PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

UNOCAL 76

UNOCAL
NORTH AMERICAN
OIL AND GAS DIVISION
WESTERN REGION
VENTURA DISTRICT

PLATFORM GINA
POINT HUENEME UNIT
(WEST HUENEME FIELD)

PROPOSED DEVELOPMENT
AND PRODUCTION PLAN (DPP)

Revision
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Submitted By:

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1. INTRODUCTION

UNOCAL has prepared a revised Development and Production Plan (DPP) for the production of West Hueneme Field gas from Platform Gina. This revised plan was prepared in order to address specific comments raised by the Minerals Management Service (MMS) in a letter to UNOCAL dated 7/19/90 and to meet DPP requirements under 30 CFR § 250.34.

The City of Oxnard has prepared and circulated their document entitled *Platform Gina Proposed Return Water Line Replacement and Conversion To Produced Gas*, May, 1990, and has reviewed and incorporated responses from all agencies. Based upon the City's review, the project description was modified to provide clarification and make possible the adoption of a negative declaration. This document is included in Appendix Volume 3.

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2. PROJECT DESCRIPTION

2.1 Overview

Platform Gina is located 6 miles southwest of Oxnard, California within OCS P-0202 in Federal waters (see Appendix Volume 6 for location map). The specific location of Platform Gina as expressed in State Plane Coordinates (Lambert Zone 6) are N 723,137, E 1,084,122. Latitude and longitude may be expressed as 34° 7' 2.99" North Latitude and 119° 16' 34.53" West Longitude. Platform Gina is in 95 feet of water and has been in production in the Hueneme and Sespe Zones since 1982. The existing well production is transferred by electric submersible pump systems through a 10 5/8 inch pipeline to the Mandalay onshore processing facility, located in the City of Oxnard. There are 15 total well slots on Platform Gina: 6 oil producing wells, 5 water injection wells, 1 exploration well (H-14), and 3 unused slots. Oil and water separation and treatment are conducted at the Mandalay facility. Since the existing operation will remain the same, the Hueneme Zone will not be discussed any further. This document will focus on the proposed development activities.

Originally, produced water was returned to Platform Gina through a 6 5/8 inch pipeline for disposal. The 10 5/8 inch and the 6 5/8 inch pipelines are the only pipelines between Platform Gina and the Mandalay facility. The 6 5/8 inch pipeline has not been in service since October, 1988, when a leak was detected in the produced water pipeline near the Mandalay facility.

UNOCAL proposes to repair the 6 5/8 inch pipeline from Platform Gina to the Mandalay facility and then convert the pipeline from water return service to gas sales service. This will allow production and evaluation of the H-14 exploratory well and initiate long term development of the West Hueneme Field. The phases of the project required to develop the West

Hueneme Field will include the recompletion of well H-14 to produce from the Monterey Zone (H-14 presently produces only from the Sespe Reservoir Zone), the proposed drilling of seven additional wells, and recompletion of two existing wells in the Hueneme field. Three of the seven wells will be drilled deep enough to produce, at a later date, from the deeper Sespe Zone following depletion of the Monterey reserves in these wells. In order to process the gas produced from Platform Gina, it will be necessary to provide for the installation of gas processing equipment on Platform Gina, minor modification of piping at the Mandalay facility, the installation of temporary facilities for hydrogen sulfide removal from the product gas stream, and permanent hydrogen sulfide monitoring equipment. As the production phase proceeds to full field development with the planned drilling of seven additional wells, a permanent gas sweetening unit will be installed. The addition of wells, processing, and environmental equipment necessitates a review of the design structural capabilities of the platform. Modifications are required to provide for expanded space requirements and anticipated loads. Additional information for each of these proposed modifications is contained herein. All phases of the project will be consistent with industry standards regarding engineering, safety, and environmental concerns.

The project is consistent with the requirements of 49 CFR Section 190-195 (Department of Transportation Regulations), and 30 CFR Section 250 (Department of Interior and Minerals Management Service (MMS) Regulations governing offshore platforms). EIR 78-19 provides background consistent with using the platform and the Mandalay onshore facility to produce, process, and transport gas to shore via the pipeline. The 6 5/8 inch pipeline was originally described as a water pipeline although it was designed to standards in order to accommodate the conversion to gas service.

UNOCAL foresees no significant space use conflicts. Pipeline repairs will be swiftly executed involving only a minimum number of vessels working along the Oxnard shoreline for 3 weeks. During drilling, testing, and production of the Monterey wells, one crew boat will be chartered to shuttle personnel and supplies from Port Hueneme to Platform Gina. This is no change from the current practice. One work boat may be chartered during this period to handle heavier items, as is currently being done.

2.2 Environmental Synopsis

Environmental impacts associated with this project are minimal. An environmental assessment and beach vegetative study (see Appendix Volume 1, Item E) reveals that impacts to fish and vegetation are minimal and will not pose any long-term consequences. A separate emissions study addressing impacts upon air quality was prepared and approved by the Ventura County Air Pollution Control District (see Appendix Volume 3).

This project, if successful, will provide a new source of natural gas fuel for the surrounding community. When compared to alternate fuels such as fuel oil, natural gas burns cleaner, resulting in less emissions. Section 13 suggests that if the maximum gas rate from Platform Gina (18 million standard cubic feet per day, or 18 MMSCFD) was to be consumed at the Southern California Edison Mandalay electrical generating station (located immediately adjacent to the UNOCAL Mandalay onshore facility) in lieu of fuel oil, there would be a net annual <u>savings</u> of over 34,000 lbs/year of carbon monoxide, 1,707,000 lbs/year of sulfur dioxide, and 105,700 lbs/year of total organic carbon.

2.3 Existing Platform Gina

Summary information for Platform Gina is as follows:

- Facts:
  - Unit Operator: UNOCAL
  - Working Interest: 100%
  - Federal Government Royalty: 16.66%
  - Surface Acreage:
    - P-0202: 2824 acres
    - P-0203: 5760 acres
  - Water Depth: 95' at Platform Gina

- History/Highlights
  - Federal lease acquired in 1968
  - 11 exploratory wells from 1969 to 1981
    - 6 on OCS P-0202
    - 5 on OCS P-0203
  - 6 production and 5 injection wells on Platform Gina to develop the Hueneme Field (OCS P-0202)
  - Exploratory wells P-0203 #5 and #6 drilled in 1985
  - Exploratory well P-0203 H-13 drilled in 1988 and redrilled as H-14 in 1988
  - Cumulative production 7.03 million standard barrels (MMSTB) of oil and 1.85 billion cubic feet (BCF) of gas through July, 1990

2.4 Current Status of Facilities

Before the drilling of wells H-13 and H-14 took place from Platform Gina in 1988, three projects were undertaken to facilitate testing and potential new field development.

The first project was minor structural modification of the platform drilling deck to allow for higher hook loads during the drilling of H-13 and H-14. Higher hook loads are the result of the greater measured well depths to reach the prospective Monterey Zone areas.

The second project was construction of a 23 foot by 40 foot production deck extension on the west side of the platform to provide room for temporary test equipment. A temporary flare stack was installed. The deck extension space will be utilized for the temporary well testing equipment, and will also be available for some of the permanent facilities. The temporary test equipment which will be utilized is described in Section 6 of this report. The Monterey Zone gas from well H-14 is expected to be sour (estimated to be 2,000 ppm), but has not yet been tested. H_2S removal by gas sweetening processes is planned. The gas produced from the Sespe Zone in well H-14 does not contain H_2S, allowing production to occur with the current facilities.

The third project completed was installation of a complete ambient hydrogen sulfide monitoring system on Platform Gina as a safety precaution. This system consists of eight monitors at various locations around the platform which monitor the air for hydrogen sulfide (H_2S). This system is wired into the platform's control logic system to completely shut down the platform if a dangerous level of H_2S is encountered. In addition, a hydrogen sulfide contingency plan was developed for Platform Gina. The deck layout plan for the ambient air hydrogen sulfide monitors is included with the Platform

Gina–Ambient Air H_2S Monitor Locations (Fire and Safety Equipment Arrangement) Drawing in Appendix Volume 6. The approved H_2S contingency plan, dated June 1, 1990, is on file at the platform and at the Minerals Management Service Ventura District Office. Both of these measures are industry safety standards and conform to 30 CFR Part 250 of the Department of Interior regulations for offshore platforms.

Wells H-13 and H-14 were drilled after completion of the first two projects described above. Well H-13 was a dry hole, and only limited drill stem testing was conducted. H-14 was drill stem and production tested in the Sespe interval, with production testing performed by blending the production directly into the 10 5/8 inch pipeline with the current Hueneme Field production. Existing equipment at the Mandalay facility separated, treated, and prepared the gas for sale. The sale of the tested gas and production from well H-14 is ongoing because the gas does not contain H_2S.

A permanent flaring system was completed in December 1989 to provide for future well testing and permanent processing of the production at Gina. This system is designed for a maximum throughput rate of 18 MMSCFD rate. This flare boom system provides a flare scrubber, seal drum, smokeless burner, and a flame extinguishing system. The smokeless burner is a state-of-the-art design to minimize emissions. This system conforms to regulations 30 CFR 250 and to API 521 governing offshore flaring installations. A schematic diagram of the system is in Appendix Volume 6, Platform Gina–Permanent Flare Boom Schematic.

To provide application per 30 CFR 250.122, in May 1990, a certified Piping and Instrumentation Diagram (P&ID) and Safety Analysis Function Evaluation (SAFE) chart has been provided to the MMS Ventura District Office for the proposed gas processing and testing facilities. A copy has been reproduced in Appendix Volume 6. In addition, the current facility

P&ID and SAFE chart were updated in 1989 and provided to the MMS Ventura District for analysis.

3. GEOLOGICAL DATA

3.1 General

Lease OCS P-0203, West Hueneme Field, is located offshore in Federal waters approximately six miles from Oxnard, California. The West Hueneme Field lies within the boundaries of the Point Hueneme Unit and was previously referred to as the West Hueneme Prospect/Field.

Productive reservoirs in the West Hueneme Field are in the Oligocene Sespe and the Miocene Monterey Formations. Potentially productive depths are from -3700' ss to -5100' ss. The trapping structure for these reservoirs is a northeast-southwest trending anticline bounded on the southeast by the Hueneme and Gina reverse fault systems. Geologic contour and cross-section maps are shown in Figure Nos. 1 through 10, Appendix Volume 7.

Development of the West Hueneme field is from Platform Gina. To date, only one exploratory well, OCS P-0203 No. H-14, has been completed in this field. This well, although not yet completed in the Monterey, was drilled from Platform Gina as a confirmation of exploratory well OCS P-0203 #6. Future development wells are planned starting in 1992, if well H-14 tests at commercial rates in the Monterey. Detailed discussion of each productive horizon follows.

Information Redaction Statement

Pursuant to the Freedom of Information Act (5 U.S.C. 552) and its implementing regulations (43 CFR Part 2) and as provided in 30 CFR 550.199(b), some information has been redacted from this document and was deleted from the public information copy of this submission.

Proprietary Information Redacted

Not for Public Release

4. DEVELOPMENT PLAN, SCHEDULE, AND PROPOSED DRILLING AND COMPLETION PROGRAM

4.1 Sespe Formation Development

Future development of the Sespe will be coordinated with the development of the significantly larger reserves in the Monterey formation. Three future Monterey development wells (No. 1, No. 4, and No. 6 shown in Figure Nos. 2, 3, 6 and 8 in Appendix Volume 7) will be drilled deep enough to fully penetrate the productive portion of the Sespe. These wells will be recompleted in the Sespe in the future following the depletion of Monterey reserves in these wells. This plan will provide the best economic opportunity for the exploitation of the West Hueneme field.

Well No. H-14 will continue to produce from the Sespe until the planned recompletion in the Monterey Formation is accomplished. **The actual Monterey recompletion date will be defined by the pipeline conversion permitting process.**

It should be noted that the Miocene Hueneme sand, which is currently being produced from Platform Gina, is apparently not present in the West Hueneme structure.

4.2 Monterey Formation Development

It is planned to recomplete Well No. H-14 in the Monterey carbonate and chert sections by temporarily abandoning the Sespe completion. Drill stem tests will be performed in at least two prospective Monterey sections prior to running the completion tubing string to evaluate productivity of each zone. This recompletion and testing program will be completed immediately after the pipeline from Platform Gina to the Mandalay onshore facility has been converted from water return to gas service. **The exact schedule will be contingent upon permit approval.** Initial production of Monterey gas from Well No. H-14 will be through this converted pipeline using temporary gas-sweetening facilities which will be installed on Platform Gina. The initial production rate from Well No. H-14 will be limited to the capacity of the temporary gas-sweetening facility estimated at 3 million cubic feet per day (MMCFD), based upon 2,000 ppm H_2S concentration. Once the productivity of the Monterey carbonate and chert sections is confirmed by the recompletion of Well No. H-14, a larger capacity permanent gas-sweetening facility will be designed and installed on the platform. A description of this equipment is described in Section 7. This facility is expected to be in service 22 months after H-14 completion or gas line conversion. At that time, gas rates up to 18 MMCFD can be processed after completion of up to seven additional wells in the West Hueneme Field and recompletion of two existing wells in the Monterey Formation (#H-9 and H-10) in the Hueneme Field.

A proposed timeline for the complete development of the Monterey is presented in Table No. 1. A drilling program for the development of seven wells is proposed to fully develop the proven Monterey gas reserves in the West Hueneme field. Also, the extent of the additional potential Monterey reserves in the field will be determined during this development drilling phase.

Reference is made to Appendix Volume 7, Figure No. 1, a structural map on the top of the Monterey Chert section, Point Hueneme Unit. A total of eight development wells, including Well No. H-14, are shown. It is anticipated that development drilling will extend over a 3 to 4-year period starting 22 months after the permit to repair the pipeline is received.

Development and Production Plan Timeline	
Month	**Action**
0	Obtain the permit to repair the pipeline.
1	Mobilize construction equipment to repair line.
2	Repair pipeline. Mobilize rig on Platform Gina.
3	Test and complete Well No. H-14 in Monterey. Install temporary facilities to sweeten gas on Platform Gina.
4	Place Well No. H-14 on production at an estimated 3 MMCFD rate.
5	Evaluate Well No. H-14 performance.
6	Initiate permanent facility design.
8	Formalize cantilever size for additional processing equipment.
9	Begin third-party verification for cantilever design and slot addition.
10	Submit structural modifications to MMS.
11	Finalize permanent sweetening facility design.
12	Complete specifications for permanent sweetening facility.
13	Issue bid packages for facility.
14	Order equipment for permanent facility.
20-22	Install permanent sweetening facility.
22	Mobilize drilling rig.
23-25	Drill Well 1.
26-28	Drill Well 4.
29-31	Drill Well 7.
32-44	Monitor Monterey performance from Wells H-14, 1, 4, and 7.
45-47	Drill Well 2.
48-50	Drill Well 6.
51-53	Drill Well 5.
54-56	Drill Well 3.
57	Recomplete Well H-9 in Monterey.
58	Recomplete Well H-10 in Monterey.
?	Recomplete Wells H-14, 1, 4, and 6 in Sespe when Monterey is depleted in each individual well.

Information Redaction Statement

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Proprietary Information Redacted

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5. 6 5/8 INCH PIPELINE REPAIR

5.1 General

This section summarizes the repair of the 6 5/8 inch pipeline between the Mandalay facility and Platform Gina. This repair will be completed prior to converting the line to gas service, and will replace 3,000 feet of the pipeline from the Mandalay facility wall [about 600 feet above the Mean High Tide Line (MHTL) landward toward the Mandalay facility] to a point 2,300 feet from the MHTL seaward toward Platform Gina. Excavation, installation, and restoration required for the pipeline repair will be explained in the following sections of this project description. Once work begins, the repair of the pipeline will take 3 weeks.

5.2 Overview of Pipeline

The subject pipeline is a 6 5/8 inch line, 32,576 feet in length, running between the Mandalay treating facility in Oxnard, California and Platform Gina within OCS P-0202. The 6 5/8 inch pipeline runs from the Mandalay facility southwest beneath the sand dunes that are northeast from the beach. Beneath the sand dune, the line is inside a 10 inch protective conduit. Once the line leaves the conduit, a long radius bend turns the pipeline to approximately 15° west of south, and from this point the line proceeds directly toward Platform Gina.

The pipeline was installed in September of 1981, and was pressure tested to 2,190 psi for 25 hours. Originally, pipeline burial was performed by natural surf conditions in the surf zone. Subsequent surveys have shown that the line has remained buried since installation in the surf zone.

The pipeline has been in service carrying produced water to Platform Gina for offshore disposal since 1982. In 1985, a 650 foot portion of the pipeline was replaced from the Mandalay facility seaward towards the surf zone. This replacement was from the wall of the Mandalay facility to the MHTL.

Original pipeline documentation, such as EIR 78-19, and the original pipeline design (Appendix Volume 1, Item D) refers to the 6 5/8 inch pipeline as a "water pipeline." The pipeline was built to the same standards as the adjacent 10 5/8 inch oil pipeline, and the three Gilda pipelines, one of which is a gas pipeline. The proposed change to gas service is consistent with the original design.

The pipeline condition has been surveyed annually since the original installation. This is done by either a Side-Scan Sonar survey or a Linalog survey each year. The Side-Scan Sonar survey is an external survey and verifies pipeline burial and external damage. The Linalog survey determines internal and external damage of the pipeline, but does not delineate burial conditions. The results of these surveys are presented in Appendix Volume 2. The survey results are submitted to the MMS annually.

5.3 Pipeline Repair Procedure

The first step of the pipeline repair was to locate the pipeline in reference to the beach and ocean floor in the repair area. This has been completed. All surveys conducted on the line since it was installed have shown that the pipeline is buried in the repair area. It was necessary to determine the depth of cover to obtain data on the required excavation and offshore tie-in. A drawing was made to show the pipeline route, contour of the beach and ocean floor, the depth of pipeline cover, and the proposed onshore and offshore tie-in points (see Appendix Volume 2, Drawing 7). The pipeline has approximately 4 feet of sand coverage throughout the repair area.

The second stage of the repair will be to cut the pipe at the offshore tie-in point, which is 2,300 feet from the MHTL. A subsea connector and a pipe flange with a blind flange attached will be installed on the pipe from Platform Gina.

After this second step in the repair operation, the pipeline from the offshore tie-in point to Platform Gina will be pressure tested to 900 psi. This test will ensure integrity of the subsea connector and the remaining pipeline toward Platform Gina. Once the test is successful, the project will proceed to step three. If the pressure test is not successful, the cause will be determined, necessary repairs will be made, and the pressure test will be repeated.

Step three will be to weld together 2,700 feet of the replacement pipe on the beach. The welding will be performed in accordance with the procedure detailed in this repair plan. The City of Oxnard has approved the welding of the pipe on the beach and an encroachment permit was approved for beach access.

The fourth step of the pipeline repair procedure will be to pull the replacement pipe to the offshore tie-in point and perform the tie-in. Once the pipe is pulled to this point, it will be flange connected to the existing pipeline from Platform Gina using the fittings installed in Step 2. This will leave 400 feet of replacement pipe on the beach which will be run in the right of way and at the same level as the existing pipeline.

The final step will be to weld the additional 300 feet of pipe from the Mandalay facility to the point where the offshore pull of the pipe terminates. The beach work will be conducted with conventional equipment. The pipe will be pulled through the 10 inch conduit that runs underneath the sand dune to prevent any alteration of the dune area.

The surf zone and offshore burial will be accomplished by conventional equipment as far as practical. Hydraulic jetting will be limited to areas in which the surf zone energy is not sufficient to bury the line. This area will extend approximately from the low water mark to as far out from shore as practical using conventional equipment. The remaining line will bury itself by the natural wave energy. The pipe will obtain burial to the same depth as the current line (4 feet) in a short period of time induced by the natural surf conditions. This is described in detail in the Evaluation of the Potential for Self-Burial of the Proposed UNOCAL Gina Pipeline study completed by the University of California, Berkeley, in May of 1989 (see Appendix Volume 4). The onshore section will be buried mechanically with conventional equipment.

5.4 Pipeline Description and Design

The original pipeline installation was designed in accordance with standards found in Title 49 CFR Part 192 from the Code of the U.S. Department of Transportation Regulations and the Minerals Management Service O.C.S. Order #9. These are the standards which apply to the transmission of gas through pipelines. The 1985 repair was conducted to these standards, and the proposed repair and conversion plan is designed to meet these same standards.

The new pipeline will be identical in size to the original pipeline. Minor coating differences will be described below. The original pipeline design was done using engineering analysis methods by a consultant, PMB Systems Engineering, and this detailed information is contained in Appendix Volume 1, Item D. This study addressed sea currents, pipeline cathodic protection, pipeline coatings, and other pertinent design information. Any deviations from this study are explained herein.

5.5 Pipeline Material Specification

Pipe:	6 5/8" O.D. Seamless (original was ERW)
Schedule:	SCH 40 (.280" wall thickness)
Weight:	18.97 pounds per foot
Grade:	A106 Grade B
SYMS:	43,700 psi, SMLS (original was 35,000 psi, ERW)
Maximum Allowable Operating Pressure (MAOP):	1,440 psig
Normal Operating Pressure:	500 psig
Maximum Operating Pressure:	600 psig
External Coating:	X-Tru Coat polypropylene (original was Pritec)
Field Joint Material:	Thermofit WPC wraparound sleeves
Length:	3,000 feet
Concrete Coating:	1.00 inch (original was 1.75 inch)
Concrete Weight:	25.36 pounds per foot
Corrosion Anodes:	300 feet apart

Anode Material:	Sea-Alloy 150 (original was Galvalum III)
Anode Type:	1/2 shell bracelet

5.6 External Coatings

The polypropylene coating was chosen because it will provide suitable protection for the pipeline, and it was readily available at the time the pipe was obtained. A letter from the UNOCAL Science and Technology Division is provided as a supporting recommendation for this choice of coating (see Appendix Volume 1, Item D).

5.7 Cathodic Protection

The original pipeline cathodic protection system was designed for a 20 year life. This original design is described in Appendix Volume 1, Item D, in the PMB Systems Engineering report of May 1981. The original design called for 88 pounds of anode per 1,000 feet of pipeline, and the repair plan will result in 190 pounds of anode per 1,000 feet of pipeline.

The line has been surveyed twice since its original installation for cathodic protection. The first survey by Harco Corporation in January 1984 indicated the only problem to be a short across an insulating flange located at the Mandalay facility, which was corrected. The UNOCAL Science and Technology Division now tests the performance of all such flanges annually to verify their proper operation. The second survey was conducted by Corrpro in February 1989, and the results of that survey indicate that adequate cathodic protection exists for the 6 5/8 inch pipeline. The complete third party survey results are in Appendix Volume 2.

5.8 Concrete Coating

The difference in the concrete coating thickness of the replacement pipe has been addressed in a burial study conducted by the Ocean Engineering Department at the University of California at Berkeley. This study, Evaluation of the Potential for Self-Burial of the Proposed UNOCAL Gina Pipeline, May 1989, is provided in Appendix Volume 4.

5.9 Specific Gravity of Pipeline

The following table summarizes the net buoyancy of the replacement pipe section of the 6 5/8 inch pipeline:

TABLE 6
Comparison of Pipeline Specific Gravity

	Surf Zone w/Concrete		Offshore w/Concrete	
	Negative Buoyancy (lbs/ft)	Specific Gravity (water=1)	Negative Buoyancy (lbs/ft)	Specific Gravity (water=1)
Pipeline Empty	43.06	2.36	18.49	2.09
Pipeline Full	55.83	2.51	31.26	2.22

5.10 Connecting Spool Piece

One connecting spool piece will be required to perform the repair of the 6 5/8 inch pipeline. This connecting spool will be located at the offshore tie-in point, 2,300 feet from the MHTL.

The connection spool piece will join the replacement pipe to the existing line using standard pipe flange connections. The spool is necessary to provide the needed fit between the existing and replacement pipe sections. The actual length and configuration of the connecting spool piece will be determined after the replacement pipe pull using actual field measurements.

5.11 Inspection and Testing Requirements

All welds will be made in accordance with UNOCAL's Western Region welding policy. Sample procedures are in Appendix Volume 1, Item E. All welds will be radiographically inspected. The standard for acceptability shall be API Standard 1104, Standard for Welding Pipelines and Related Facilities, as directed by Title 49 CFR Part 192 (gas pipelines) of the Minimum Federal Safety Standards. All welders will be certified to this standard before work on the project commences.

Once the pipeline tie-ins are made, a pressure test will be conducted. This test will be conducted at 900 psi, and will test the entire pipeline from the Mandalay facility to Platform Gina. The test will be held for a minimum of 8 hours, and witnessed by the Minerals Management Service, State Lands Commission, and a UNOCAL representative.

Prior to covering the pipe, the location of the line will be surveyed for the permanent records. The installation contractor will provide the surveyor with assistance, as required, for both the onshore and offshore sections of the survey.

Before covering the pipeline and during the pipeline pull, the replacement pipe will be inspected for coating flaws. All flaws will be repaired before the pull operation continues, or before the pipe is buried. Repairs will be performed in accordance with the pipeline coating manufacturer's recommendations.

5.12 Pipe Welding and Pulling Requirements

The replacement pipe will be welded according to UNOCAL's Western Region welding policy (Appendix Volume 1, Item E), and will be welded in the onshore staging area in a series of three to six side-by-side strings. The first joint of pipe will have a 6 inch flange installed which will connect the replacement pipe to the subsea connector at the offshore tie-in location.

Replacement pipe sections with cathodic protection anodes will be installed approximately 300 feet apart. The first anode equipped section will be the first full pipe section of the pull.

Each weld joint on the pipe will be equipped with protective sleeves installed according to manufacturer's specifications. Before and during the pulling operations, efforts will be made to ensure that the external coatings are not damaged. Additionally, the replacement pipe coatings and anodes will be inspected and repaired, if needed, both prior to and during pulling operations.

The pulling of the pipe will be conducted in a manner which will not compromise the external coatings nor overstress the pipe or its concrete coating.

5.13 Tie-In Procedure

The offshore tie-in location will be 2,300 feet from the MHTL. After excavating small holes for access, the pipeline will be cut at the tie-in point and again some 40 feet landward. The resulting 40 foot section of pipe will be removed providing room for the replacement pipe to be connected to the existing pipeline.

The subsea connector and a pipe flange with a blind flange attached will be installed by divers. Then, an underwater habitat will be installed at the tie-in point so that a dry welding environment can be obtained. After the habitat is installed, it will be filled with an inert gas, and the subsea connector will be welded with a pipeline quality seal weld.

The pipeline will then be pressure tested to 900 psi between Platform Gina and the tie-in point. This test will ensure integrity of the subsea connector and the remaining pipeline. Once the pressure test is complete, the replacement pipe on the beach can be made up in accordance with the previously outlined procedures.

Once the replacement pipe has been fabricated on the beach, a blind flange with a pulling head will be installed on the first joint of pipe. Then the replacement pipe will be pulled to the offshore tie-in location. The pipe will be pulled from the onshore fabrication area in a continuous manner, stopping only for connection of the individual strings. The pull will be achieved by the use of both a pulling winch mounted on the support vessel and that vessel's mooring anchors, and will require approximately 18 hours to complete.

The pull will be complete when the replacement pipe is about 20 feet short of the offshore tie-in point. Upon completion of the pull, the replacement pipe will be filled with water to increase its weight and resist lateral movement. This will effectively put the pipe into position on the ocean floor. Divers will then determine the size and configuration of the connecting spool piece by taking the required field measurements.

Once the connecting spool piece is complete, it will be lowered into position and installed between the replacement pipe and the subsea connector. The pipe flanges will be joined to manufacturer's specifications, and the offshore tie-in will be complete.

The onshore tie-in can be completed concurrent with the offshore tie-in and will take place 400 feet above the MHTL. The replacement pipe will be buried on the beach to the same level as the existing pipeline within the existing right of way. This work will be done with the conventional equipment listed in Appendix Volume 1, Item E.

6. TEMPORARY HYDROGEN SULFIDE SWEETENING FACILITIES

6.1 General

The initial equipment installed will include a gross separator, two batch sweeteners, two hydrogen sulfide line monitors, and a final gas scrubber. The batch sweeteners will each be capable of treating a gas volume of 3.0 MMSCFD and sweetening from a hydrogen sulfide level of 2,000 ppm to less than 4 ppm. The associated liquid production will be handled by an existing shipping tank and two pumps, each of which are capable of 2,000 barrels of liquid per day. This liquid will be shipped to Mandalay through the 10 5/8 inch pipeline.

Initially, this equipment will be utilized for only the current well H-14. All gas will be sweetened to the pipeline specification for hydrogen sulfide before it enters the 6 5/8 inch pipeline. The hydrogen sulfide pipeline monitors will verify that the gas is under the 4 ppm specification before the gas enters the pipeline. If a hydrogen sulfide level exceeding the 4 ppm specification is obtained, the monitors will automatically shut down the producing well or wells, and the pipeline shutdown valve will be closed. In addition, the Southern California Gas Company has a monitor on the sales gas meter at the Mandalay facility. Flow schematics for the temporary gas processing system may be found in the Appendix Volume 6.

6.2 Batch H_2S Removal System

For the estimated 3 MMSCFD well H-14 production, a non-regenerative batch type H_2S chemical removal system is planned. The batch sweetener will treat the gas volume of 3 MMSCFD reducing the H_2S level from 2,000 PPM to less than 4 PPM. If an H_2S level exceeding the 4 PPM specification is experienced, monitors will automatically shut down the producing well(s), and the pipeline shutdown valve will be closed. Removal of H_2S will be by direct contact of the gas stream with the H_2S scavenging medium. The sweetener system is designed for a 24 hour continuous duty cycle with redundant equipment for alternate operation and chemical recharging. When the sweetener chemical is depleted, operation is transferred to the redundant equipment train.

Referring to Drawing 90-1380 in Appendix Volume 6, a proposed H_2S removal system is shown and operation discussed as follows: At the time of actual installation, the actual design and equipment used may be adjusted to reflect best available and safest technology.

6.2.1 Major Equipment

The H_2S removal system consists of the following basic components:

(a) Gross Separator
(b) Dual Batch Sweeteners
(c) Sweetener Carryover Scrubber
(d) Sweetener Chemical Pumps
(e) Sweetener Chemical Tanks
(f) H_2S Monitors

6.2.2 Operating Elements

The inlet gas stream is introduced into an inlet gross separator equipped with a tangential inlet nozzle/diverter and a final mist eliminator. Entrained liquids, either water and/or liquid hydrocarbons, are removed from the inlet gas stream via a two-phase scrubbing action. Liquid drainage is effected by a level controlled drain valve directing the separated portion to the existing MBJ-F1 liquid shipping tank. Shipping pumps P9 and P10 transport this production into the oil pipeline to Mandalay.

After passing through the inlet separator, the inlet gas is directed into the batch sweetening towers. Operating singly, each tower is filled approximately half full of the sweetening chemical mixture. The inlet gas is directed through sparging nozzles which disperse the flow keeping the chemical solution agitated and in intimate contact with the gas stream. Within the sweetening towers, the H_2S reacts with the highly reactive chemical solution to remove the H_2S from the inlet gas stream. The treated gas passes out of the top of the sweetening tower and is directed into a carryover scrubber which is similar in construction to the inlet gross separator.

The outlet scrubber is provided to prevent any carryover of chemical solution from the sweetening towers into the gas pipeline due to unforeseen process upsets. The scrubbed gas stream exits from the top of the carryover scrubber, leaves the H_2S removal system, and is directed into the gas pipeline. The exit gas stream is monitored for residual H_2S content with two redundant level annunciators providing alarm annunciation at 2 ppm H_2S and shutdown at 4 ppm H_2S.

Gas flow is monitored by a meter run with a flow recorder. In addition, gas pressure is also monitored and controlled by pressure regulator PCV21.

The sweetener chemical mixture is supplied to the batch sweetening towers by two chemical pumps P32 and P33 which take their suction from chemical tanks TK20 and TK21. These two 600 gallons tanks are sized to accept a batch chemical mixture capable of handling a total of 24 hours of continuous operation, with one tank in operation while the other is replenished. The depleted chemical solution is transported for offsite disposal or recycling by the temporary system supplier. Chemical solution mixing for recharging the system is accomplished manually at each chemical tank.

The proposed batch H_2S removal system has provisions for the future addition of a test header, separator, and terminal gas dehydration. Additionally, a connection is provided for methanol injection which will be used for initial dehydration.

6.3 Proposed Deck Layout of Temporary Facilities

The deck space allotment for the temporary gas sweetening equipment has been designed. Appendix Volume 6 displays a proposed plot plan for installation of temporary gas sweetening equipment.

7. PERMANENT HYDROGEN SULFIDE SWEETENING FACILITIES

7.1 General

As the production phase proceeds to full field development, additional facilities and equipment will be needed. This could include the installation of additional deck space along the south side of Platform Gina to allow for some of the equipment. The additional equipment could include a standard production and test header system, a test separator, a gas dehydration unit, a permanent sweetening plant, and gas compressors. The actual equipment needed would be based on future well test results and detailed reservoir evaluation.

One method of sweetening under serious consideration involves two process units. The first unit, the sweetening operation, is an amine treater unit consisting of a high pressure H_2S removal stage and low pressure amine solution regeneration stage. The second unit is a recycle sulfur recovery unit for removing the sulfur from the amine unit discharge acid gas stream employing the Claus process.

Note: The following sections and descriptions of proposed equipment to be installed are based upon UNOCAL's best estimates of what will be required and experience in similar situations. As information from Well H-14 becomes available, the proposed design of the permanent hydrogen sulfide sweetening facilities will be checked and modified, as necessary, to suit actual conditions.

7.2 Permanent Gas Treatment System

After testing of the exploratory well H-14 is complete, gas production is contemplated. The gas stream will be processed by the temporary system until permanent gas treatment system design and installation is complete. This unit will remove H_2S and dehydrate the gas to pipeline quality levels. Final design of the permanent gas treatment system cannot be completed until testing of H-14 is complete. The proposed permanent gas treatment system will consist of the following subsystems:

(1) An Amine Gas Processing Unit
(2) A Recycle Sulfur Recovery Unit
(3) A Gas Compressor Station (may be added later)
(4) A Glycol Dehydration Unit

Refer to Appendix Volume 6 for process flow diagrams. Sections 7.2.1 through 7.2.4 generically describe the basic system components and their operation rationale.

7.2.1 Amine/Recycle Sulfur Recovery Gas Treatment

These two systems are connected in series, with the amine treatment unit the first element in the system.

Referring to Drawing 557-F-001 in Appendix Volume 6, the amine treatment system operates as described in the following process description.

7.2.1.1 Major Equipment

The amine treatment system has a high pressure train and a low pressure train consisting of the following basic components:

A. High Pressure Train

(1) Inlet Scrubber
(2) Amine Contactor
(3) Outlet Scrubber and Flash Tank

B. Low Pressure Train

(1) Carbon Filter
(2) Still
(3) Reflux Accumulator
(4) Reboiler
(5) Surge Tank
(6) Booster Pumps
(7) Solution Pumps
(8) Reflux Pumps
(9) Lean/Rich Exchange
(10) Solution Cooler
(11) Reflux Condenser

Sour gas enters the process through an inlet scrubber where entrained hydrocarbons and other liquids are removed. The separated gas stream then passes through the top of the scrubber through a high-efficiency stainless steel mist eliminator, which allows vapor passage with no entrained liquid carry over. The separated liquids are drained through a level-controlled drain valve into the shipping tank for shipment through the oil pipeline.

The scrubbed sour gas then flows to the bottom of the amine contactor column. The column contains a series of trays to provide countercurrent flow between the lean amine and the gas stream. Intimate contact between the amine and gas occurs on the surface of each tray allowing for the absorption of the acid gas. A level-controlled valve at the bottom of the contactor returns the rich amine to the low pressure train via a flash tank. Acid gas is directed out of the contactor column, flowing to the recycle sulfur recovery unit.

The flash tank includes a 3-phase separator which separates the gases released when the operating pressure is reduced. The flash tank also removes entrained gas liquids to prevent foaming. The released gas is recycled back to the unit inlet. A level control valve returns the solution to the low pressure train.

The rich amine from the flash tank enters the top of the carbon filter and flows downward through the bed. Iron sulfide, entrained hydrocarbons, and other unusable materials are removed by the activated carbon in the filter. The rich amine stream from the carbon filter enters a full stream sock filter for the removal of solid particles larger than 5 microns.

The filtered rich amine flows next to the tube side of the lean/rich exchanger, and is heated by transferring heat from the lean amine. The heated rich amine is then fed to the top of the still above the top tray, and flows downward through the still where it is contacted counter-currently with stripping steam generated in the reboiler. The stripping steam partially condenses into the solution, and provides the heat of reaction required to strip the acid gas from the rich amine.

The acid gas and uncondensed steam are removed from the top of the still and are then cooled in the reflux condenser. The cooling condenses the steam, and the resulting acid gas and water stream flows into the reflux accumulator located in the bottom of the still. The water is pumped from the reflux accumulator by the reflux pump into the rich solution being fed to the still.

By reinjection of the reflux water, water loss from the amine unit is minimized. The acid gas flowing from the top of the reflux is collected by the vapor recovery system. A backpressure controller and valve on this discharge line maintains the pressure on the amine regeneration system.

Stripped amine solution flows into the reboiler, heating the solution to provide the stripping steam. The lean amine solution flows over a weir plate and into the surge chamber in the reboiler. Lean amine flows from the surge chamber to the shell side of the lean/rich heat exchanger. Amine exits the exchanger and then flows to the booster pump suction. The booster pump circulates fluid through the solution cooler to the suction of the solution pump which pumps the lean amine back to the contactor column, completing the flow cycle.

7.2.2 Recycle Sulfur Removal

The sulfur removal system is the second gas treatment unit located downstream of the amine treatment system. It consists of a 2 long tons per day (LTD) sulfur recovery unit capable of removing over 98.5% of the sulfur content of the gas stream.

The recycle sulfur removal process is based on an extremely active catalyst patented by UNOCAL that has been specially developed for sulfur recovery from gas streams containing H_2S. This catalyst selectively oxidizes H_2S to sulfur at relatively low temperatures without forming SO_3, or oxidizing light hydrocarbons. It is highly active and stable retaining its activity over long periods of time without regeneration. Typically, the catalyst should operate for at least 3 years before requiring replacement. The process is entirely catalytic, eliminating the need for a thermal reaction furnace which results in a simplified Claus process.

Approximately one-third of the H_2S in the feed gas is oxidized catalytically with air to form SO_2, which then reacts with the remaining H_2S to form elemental sulfur, according to the principal Claus reactions:

$$H_2S + 3/2\ O_2 \rightarrow SO_2 + H_2O$$
$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

Referring to Drawing 557-F-002 in Appendix Volume 6, the sulfur removal system operates as described in the following process description.

7.2.2.1 Description

The recycle sulfur recovery unit proposed has been designed to operate on acid gas with H_2S concentrations ranging from 7.10 to 17.0 volume per cent. Relating these rates to sulfur contained in the feed gas stream, these concentrations are equivalent to 0.13-2.00 LTD of sulfur. A long ton of sulfur equals approximately 150 gallons.

The concentrated sour gas exiting the amine unit enters the sulfur recovery unit through the knock-out drum/ filter separator. This protects the catalyst from water, hydrocarbons, or amine carryover should any process upsets occur upstream. The condensate from the knock-out drum/filter separator is pumped out on level control by the low water pump into the shipping tank.

Then, the feed gas stream is heated electrically in the preheater before being combined with the recycle gas from Sulfur Condenser No. 1, and is further heated to an initial reaction temperature of 390°F in Reheater No. 1.

A controlled quantity of air is added by modulating the air flow rate with the acid gas feed flow rate. The air flow is controlled by the output signal from a tail gas analyzer on the stream from Sulfur Condenser No. 3 to maintain the desired H_2S/SO_2 ratio for optimum sulfur recovery. This system can automatically compensate for changes in the acid feed gas composition, or errors in flow measurement due to changes in flowing conditions.

The combined acid gas feed plus recycle enters the converter. The Claus reaction to form elemental sulfur proceeds as the H_2S is selectively oxidized to form SO_2.

Then the converter effluent is cooled in Sulfur Condenser No. 1. The condensed sulfur is separated from the gas and stored in a sulfur storage tank.

A portion of the effluent from Sulfur Condenser No. 1 is recycled back to the converter with the recycle blower. The remainder is heated to reaction temperature in Reheater No. 2 before entering the first Claus converter, which contains a conventional alumina Claus catalyst. Sulfur is formed and the exothermic reaction creates a temperature rise across the bed. The converter effluent is cooled in Sulfur Condenser No. 2, and the condensed sulfur flows to the sulfur storage tank.

Similarly, for the third stage, the gas from the condenser is reheated, sulfur is formed in the converter, the converter effluent is cooled in Condenser No. 3, and the condensed sulfur drains to the sulfur storage tank.

The tail gas from Sulfur Condenser No. 3 is reheated, mixed with excess air, and enters the catalytic incinerator to oxidize the residual sulfur compounds. Then, the catalytic incinerator effluent is vented to the vapor recovery system. A minimum catalytic incinerator outlet temperature of 540°F is maintained to ensure complete oxidation of the residual H_2S to SO_2. A high and low temperature alarm and high temperature shut-down are provided to alert the operator and safely shut down the plant.

7.2.3 Gas Compressor Station

Referring to Drawing 557-F-004 in Appendix Volume 6, the gas compressor station will consist of three multi-stage compressors driven by electric motor/gearbox drive packages. The gas flow rate is planned to increase incrementally to a total of 18 MMSCFD. It is proposed to design each compression module to consist of an approximately 1200 HP centrifugal compressor sized to compress 6 MMSCFD of gas from 50 psig to 500 psig. Compressors will be added to the station as gas production increases. Initially, there may be no gas compressors required.

7.2.3.1 Process Description

Inlet gas from the amine treatment unit will enter a suction scrubber. Separated condensate will be drained into shipping tank MBJ-F1 by a level-controlled drain valve for offsite transmission through the oil pipeline.

The separated gas will flow into a distributor manifold serving the suction of the three compressors. Isolation valves allow the selection and addition of compressor units.

Each compressor will be driven by a 4160V, 1200 HP explosion-proof electric motor driver. A motor control center served by a new transformer installation will be added to handle the compressor, air cooler, and oil pump motor loads. The compressor will be equipped with appropriate alarms and shutdowns per 30 CFR §250.

Gas discharge from the compressors will enter an air-cooled heat exchanger to cool gas before dehydration.

7.2.4 Gas Chiller/Dehydration

The final process unit in the gas treatment system is a gas chiller. The gas chiller uses a refrigerant pump and heat exchanger to lower the temperature of the gas below the dewpoint (estimated to be 45°F) in order to reduce the formation of gas hydrates and condensation, which could cause corrosion in the gas pipeline. The gas chiller would consist of a single packaged skid, be electrically driven, and produce no emissions.

In some situations, depending upon the specific properties of the gas, other treatment will be required. If, after gas testing, it is determined that a gas chiller will not be adequate, then a glycol dehydration system will be installed.

Ethylene glycol has a high affinity for the water vapor entrained in the gas stream. It is non-corrosive, regenerates readily, and possesses low chemical losses.

The following paragraphs describe the operation of a generic glycol dehydration system. Note that a glycol dehydration system will be utilized only if gas testing determines that a gas chiller would be inappropriate. Gas testing cannot be performed until well testing is performed.

If utilized, the glycol dehydration will be located downstream of the compressor station. Referring to process diagram 557-F-004 in Appendix Volume 6, the gas stream enters the system through the inlet scrubber. Separated condensate and liquids are drained into shipping tank MBJ-F1 for transport through the oil pipeline.

Scrubbed gas passes from the inlet scrubber into the vertical glycol-gas contactor column containing either trays or packing. The gas enters the bottom of the contactor and flows upward through the packing or trays countercurrent to the glycol flow. At the upper end of the contactor is an open space for entrainment settling. In this open space, most of the entrained glycol particles in the gas stream settle out. Any glycol not settling out will be removed by a high-efficiency mist eliminator at the top of the contactor column.

The dried gas stream flows downward from the top of the contactor column through an external glycol-gas heat exchanger. The incoming dry glycol from the surge tank is cooled in this heat exchanger before it enters the contactor column for maximum contacting efficiency.

Dry concentrated glycol is picked up from the surge tank and pumped through the glycol-gas heat exchanger to the top of the contactor column. The dry glycol enters the contactor at the top tray or top of the packing. The dry glycol flows downward through the column trays or packing. By the countercurrent flow of gas and glycol, the driest incoming glycol on the top is in contact with the driest outgoing gas for maximum dehydration of the gas stream.

The wet glycol, which has absorbed the water vapor from the gas stream, leaves the bottom of the glycol-gas contactor column, filters, and pumps through a coil in the combined heat exchanger-surge tank. In the combined heat exchanger-surge tank, it is preheated by exchanging heat with the lean glycol coming from the reboiler.

The warm wet glycol stream flows from the heat exchange coil to a low pressure flash separator which allows for the release of the entrained solution gas. The gas separated in the flash separator leaves the top of the vessel for use as a supplement to the shipping gas.

Then the glycol enters the stripping still column where it flows downward toward the reboiler, contacting hot rising glycol vapor, water vapor, and stripping gas. The water vapor has a lower boiling point than glycol; therefore, any rising glycol vapors will be condensed in the stripping still and returned to the reboiler. In the reboiler, the glycol is heated to between 350°F to 400°F to remove enough water vapor to reconstitute it to 99.5%, or greater.

The reboiler is supplied with heated heat transfer medium from the amine unit, in contrast to the direct-fired heaters typically supplied with these units.

The reconcentrated glycol leaves the reboiler through an overflow pipe and passes to a surge tank.

7.3 Proposed Deck Layout of Permanent Gas Sweetening Facilities

Proposed deck space allotment for the permanent gas sweetening system has been designed. Note that to accommodate this equipment, an extension of the production deck will be required prior to setting of equipment. More information on the structural modifications required to accommodate this type of equipment may be found in Appendix Volume 5. Appendix Volume 6 provides a proposed plot plan for installation of permanent gas sweetening equipment.

7.4 Byproducts Resulting from Temporary and Permanent Gas Sweetening Processes

The gas processing and distribution systems will produce minimal quantities of gaseous, liquid, and chemical byproducts. The majority of these effluents will be transported onshore for final disposal or recycling. All byproducts, except for relief valve discharges will be kept isolated from the environment and transported in closed systems.

7.4.1 Temporary Batch Sweetening Process

The temporary batch sweetening process system has three basic byproducts resulting from its operation:

(1) Liquid Drains
(2) Gaseous Vents
(3) Expended Chemicals

Following are estimates of production and projected disposal provisions. Since precise system design parameters have not as yet been developed, the values listed represent conservative estimates.

The final designs may have varying performance, but should produce no additional quantities beyond those listed herein.

7.4.2 Liquid Drains

The two sources of liquid byproducts are the condensate drains of the initial and final separator scrubber units. The initial gross separator will have the largest liquid removal duty. Typically, the liquid drain stream will contain separated water/condensate and unspecified hydrocarbon liquids. Operating at a capacity of 3 MMSCFD, it is estimated that approximately 1700 gallons/day of entrained liquid will be removed by the gross separator. This will be drained to the shipping tank for shipment onshore.

The remaining source of liquid byproducts will be the drain coming from the sweetener carryover scrubber. This component removes the trace vapor carryover from the direct contact sweetening process. The influent will result from process upsets and transients which will produce a minimal contribution to the liquid drains. Operating at design capacity, it is estimated that approximately 500 gallons/day of water and trace sweetener chemicals will be removed by the carryover scrubber. This will also be transported onshore, pumped from the shipping tank through the 10 5/8" oil pipeline.

7.4.3 Gaseous Vents

The only gaseous vents will come from the safety relief valves installed on the gross separator, the two sweetener tanks, and the carryover separator. Since only one sweetener tank is in operation at any time, a total of three relief valve vents require consideration. The relief valves only open during a process upset. Thus, the gaseous venting is an infrequent process. The relief valve outlets are manifolded and vented to the flare for safety reasons.

7.4.4 Expended Sweetening Chemicals

The third and final category of byproducts resulting from the temporary gas sweetening process is a small quantity of expended sweetening chemicals mixed with water. With only one sweetening tank operating while the other is being regenerated, a total 300-450 gallons of expended chemical sweetener is projected to be produced each operating day.

The expended chemical sweetener will be transported onshore for permanent onshore disposal, or recycling by the batch sweetener supplier.

The permanent gas sweetening process consists of two basic systems:

(1) An Amine Unit
(2) A Sulfur Recovery Unit

Although consisting of numerous process vessels, these two systems only produce two byproducts:

(1) Gaseous Vents
(2) Liquid Drains

Considering each process unit individually, following are byproducts production rates and disposal methods.

7.4.5 Amine Unit

All process vessels in this system will be equipped with a gas blanketing subsystem keeping these components under positive pressure during both normal operation and shutdown. All process gaseous vents will be connected to a closed vapor recovery subsystem, ultimately discharging into the gas compressor suction header, after H_2S removal. All sweetened offgassing will be collected by this system and disposed of by blending with the shipping gas stream transported onshore. The total gaseous volume discharged into vapor recovery from the amine system is projected to be approximately 15 MCFD or approximately 1/2 of 1% of the normal initial gas flow rate.

The amine unit will include several sour water drains primarily from the two scrubbers and the feed gas filter/separator. Additional liquid drain sources include the carbon and sock filters and the various process receiver vessels. The liquid drains will be manifolded for drainage into the MBJ-F1 shipping tank. Collected drain liquids will be pumped onshore by the shipping pumps through the 10 5/8" oil pipeline. It is estimated that a maximum of 2000 gallons of liquid effluent will be transported onshore per day.

7.4.6 Sulfur Recovery Unit

Next, the acid gas exiting the amine unit is processed by the sulfur recovery unit. This unit produces only gaseous vent byproducts.

All process vessels will be equipped with a gas blanketing system, with process vents being stripped by the vapor recovery system. The recovered vapor will be returned to the amine plant inlet for sweetening. The total gaseous discharge under vapor recovery is estimated to be an expected maximum 3/4 of 1% of the normal initial gas flow rate, or approximately 22.5 MCFD.

The primary liquid drain source in the sulfur recovery unit is the initial acid gas knock-out drum. Since the gas has already been scrubbed several times, a small quantity of removed condensate is expected.

Approximately 600 gallons per day of drain liquid is expected for shipment onshore via the 10 5/8" oil pipeline. A small additional liquid drain contribution is projected for the balance of the process vessels for an estimated maximum total of 100 gallons a day.

7.4.7 Glycol Dehydration Unit

The final gas processing system is the glycol dehydration unit. Only gaseous and liquid drain byproducts are expected. The vessels will be equipped with gas blanketing and vapor recovery. The recovered vapor will be blended with the shipping gas for transport onshore. It is estimated that a maximum 1/4 of 1% of normal initial flowrate, or approximately 7.5 MCFD of recovered vapor, will result.

Liquid drains for the dehydration unit consist primarily of the inlet gas scrubber. The inlet gas has previously been scrubbed in both the amine and sulfur recovery unit, and thus is essentially free of entrained moisture when it enters this unit. It is estimated that a maximum of 150 gallons of drain liquid is expected per day for collection in the shipping tank and transport onshore through the oil pipeline.

7.4.8 Gas Compressor System

Although not strictly a gas processing unit, the gas compressor system also produces both liquid drains and gaseous byproducts. Condensate is produced by the inter and aftercoolers. An estimated maximum of 800 gallons per day of liquid condensate is expected, with collection in the shipping tank for onshore shipment. Each compressor is protected by a safety relief valve, open only during major system upsets. In the unlikely event of a major system upset, it is expected that the relief valve would be open for a maximum of 3 minutes, resulting in a total of 15 MCFD of gas to be vented by all three compressors to the flare stack. This also assumes the further conservative assumption that all valves would be open simultaneously.

The preceding information constitutes all of the byproducts expected to be produced by the temporary and permanent gas sweetening systems. All values noted represent very conservative estimates. Final values may differ, but are not expected to exceed the estimates listed. The majority of the byproducts will be processed by other platform systems and will not affect the environment.

UNOCAL has, by regulation, an existing NPDES permit for the discharge of wastewater.

A copy of the General NPDES Permit for water discharge, granted to UNOCAL, can be found on Page 55037 of the Federal Register, Vol. 48, No. 237, published Thursday, December 8, 1983.

8. INSTRUMENTATION

8.1 General

Additional instrumentation, pneumatic and/or electronic, will be required for control and monitoring of the additional process units and equipment. A portion of the additional instrumentation will be furnished by vendors as part of packaged units (i.e., the unit for sulfur recovery). Control of the packaged units will be provided for by unit local panels. The existing computerized control system on Platform Gina is not currently capable of handling the increased load and thus will require modification and expansion.

Control for the packaged process units will be provided by the manufacturer's furnished local control panel(s). All furnished control panels will be UL approved for use in Class I, Division I or II hazardous areas, Group D, as applicable. In addition, all furnished controls will be provided with hermetically sealed components or enclosures designed to prevent premature failure due to the salt-laden, high humidity environment. All shutdown and alarm circuits will be designed fail-safe.

Supervisory control and data acquisition (SCADA) will be provided to the existing platform programmable logic controller (PLC) from the furnished local control panels. This information will then be available for display on a CRT based operator interface (OIT).

The existing PLC will be expanded to accommodate the additional inputs/outputs that will be required for the new gas handling equipment. The central processor currently has sufficient memory to serve all the new I/O.

8.2 H_2S Detection

As part of the temporary and permanent installation of facilities on Platform Gina to remove the hydrogen sulfide gas, a redundant H_2S monitoring, detection, shutdown, and alarm system will be installed to monitor the H_2S concentration in the product gas. The redundant system will include three separate H_2S monitors. Two will be installed at Gina, and the third at the Southern California Gas Company facility inside Mandalay. The redundancy of the monitoring is such that the gas from Gina will be verified for H_2S concentration twice before it leaves Platform Gina, and an additional time before sales are made at the Southern California Gas Company meter at Mandalay. UNOCAL considers this system to be more than adequate to insure that H_2S gas does not enter the natural gas distribution system. The reliability of this system has been more fully discussed in the risk assessment study prepared entitled "Platform Gina Gas Production and Pipeline Mandalay Onshore Receiving" dated November 21, 1989, Appendix Volume 3.

The H_2S monitors operate by being sensitive to hydrogen sulfide and sensing the rate of lead formation on a lead acetate-coated paper by use of a photocell and a light source. This type of monitor has proven to be reliable and is extensively used in the industry by gas transmission companies including Southern California Gas Company. The continuous monitors are designed to activate an alarm should a treating system upset occur that results in a hydrogen sulfide concentration of 2 ppm in the gas stream. The continuous monitors will activate shutdown of the gas producing well, or wells, should the hydrogen sulfide concentration reach 4 ppm. The alarm and shutdown features are fully automatic, and the monitors themselves are regularly calibrated with the results reviewed by the Minerals Management Service.

Regarding the timing of the H_2S monitor installations at Gina, the new H_2S monitors at Gina will be installed prior to the initiation of gas sales from Gina via the 6 5/8 inch pipeline and after the permit is obtained.

The following pages show a table of the H_2S monitors and a simplified schematic of the locations of the monitors for Platform Gina. This will identify the function of each monitor in detail.

TABLE 7

H_2S Redundant/Monitoring/Detection/Shutdown/Alarm Systems

<u>Platform Gina</u> — Proposed Monitor-Monitor A

1. Monitor: Gas stream on Gina
2. Detection: H_2S content
3. Shutdown: 4 ppm H_2S
4. Alarm: 2 ppm H_2S
5. Install: During the facility installation at Gina and before sales commence

Proposed Monitor-Monitor B (Redundant Monitor)

1. Monitor: Gas stream on Gina downstream of Monitor A
2. Detection: H_2S content
3. Shutdown: 4 ppm H_2S
4. Alarm: 2 ppm H_2S
5. Install: During the facility installation at Gina and before sales commence

Additional Redundancy: Gas is monitored in the same manner by the existing Southern California Gas Company Monitor C at the Mandalay facility sales meter.

9. ELECTRICAL

Revisions and additions will be required to handle the electrical loads of the additional equipment. These will include expansion of the Motor Control Center (MCC) capabilities.

Electrical power available to Platform Gina is via a 16.5KV submarine cable which originates at UNOCAL's Mandalay Facility. The conductors are considerably oversized in order to allow for future expansions and possibly a future platform. Therefore, incoming power to the platform at 16.5KV will be more than adequate for the proposed expansion.

Detailed investigation of existing platform electrical service at 480 volts will be performed to determine the extent of available 480 volt power for the gas equipment expansion. At this time, it is anticipated that the existing 16.5KV - 480 volt transformer will be adequate to serve the expected new load. If further investigation shows that the existing transformer does not have this spare capacity, a new 1000KVA transformer will be installed.

In addition to the 480 volt loads associated with the new proposed gas handling equipment, there will be a requirement for 2300 or 4160 volt power (medium voltage). Currently, there is no medium voltage source on the platform. Therefore, installation of a new 16.5KV - 2300 or 4160 volt transformer will be required. Initial size of this transformer is estimated at 3000/3750KVA OA/FA (fan cooled).

The existing powerhouse on the platform does not have sufficient spare space for the starters, switchgear, and circuit breakers required for the proposed gas processing equipment. A new powerhouse is proposed for this additional electrical equipment. The new powerhouse will be of a similar design as the existing powerhouse, i.e., pressurized, equipped with an automatic fire protection system, and built to NEMA standards.

The new medium voltage system will utilize solid grounding for personnel safety and reliability. This is consistent with the existing 480 volt system on the platform and medium voltage systems on Platform Gilda.

All new and revised electrical equipment will be designed in accordance with 30 CFR §250.53. In addition, the design will follow guidelines as established by the National Electric Code (NEC), API RP 14F, *Design and Installation of Electrical Systems for Offshore Production Platforms*, and API RP 500B, *Classification of Areas for Electrical Installations at Drilling Rigs and Production Facilities on Land and on Marine Fixed and Mobil Platforms.*

10. STRUCTURAL CONSIDERATIONS

10.1 Platform Modifications

10.1.1 Additional Production Well Slots

Providing that preliminary well testing data supports reservoir development, it will be necessary to install additional well slots to accommodate new production wells. A preliminary structural review of the platform has been completed, and it is proposed to install up to eight new well slots just immediately north of the existing well room area. (Please refer to Drawing 557-T-007, Appendix Volume 6 for a schematic plot plan representation.)

Detail design of the additional well slots cannot be completed until further development is performed. At that time, detail engineering and design will be performed and structural information regarding well slots provided to MMS for approval. Engineering and design of the well slots will follow API RP2A, *Planning, Designing, and Constructing Fixed Offshore Platforms* and API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*, latest edition. Preliminary design information may be found in Appendix Volume 5.

10.1.2 Deck Extension

If well testing supports reservoir development, it will be necessary to increase the available platform space in order to accommodate the gas processing equipment. It is proposed to install a 25' deck extension along the west side of the production deck. A preliminary review of the proposed equipment weights has been performed, and this information was considered in assembling a proposed equipment layout. (Please refer to Drawing 557-T-007, Appendix Volume 6, for a schematic plot plan representation.)

Detail design of the deck extension cannot be completed until process design is finalized. When this is completed, detail engineering and design will be performed, and proposed structural changes will be submitted to the MMS for approval. Engineering and design of the deck extension will follow API RP2A, *Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms*, and API RP 2G, *Recommended Practice for Production Facilities on Offshore Structures*, latest editions.

10.2 Structural Design

Two aspects of Platform Gina's structural framing that are related to the proposed development work have been examined and documented.

One aspect is a localized analysis that pertains to the ability of the existing westside production deck cantilever to safely carry the temporary equipment necessary to process the H-14 sour gas.

The second aspect is an analysis of the global platform system. This analysis establishes the performance of the decks, jacket, and piles under gravity loads–including deep well rig loads and loads from a permanent batch sweetening facility located in part on a new southside production deck cantilever–and extreme environmental (storm and seismic) loads.

10.2.1 Westside Cantilever - Temporary Loading

For the layout and loads assumed, the existing framing under the westside production deck cantilever can safely carry the proposed (temporary) loads. Static and seismic responses were analyzed.

Part A of Appendix Volume 5 provides details of the analysis methods and results.

10.2.2 Platform System - Long Term Loading

Extreme storm and seismic criteria at the site were developed per current procedures (API RP 2A, 18th ed.).

Gravity loads were developed using a deep well rig package as a basis, and equipment loads for a permanent sweetening facility.

Pile capacities and soil-pile interaction were defined using original soil sample data and pile driving data recorded during installation.

For the loads and capacities used, the platform's piled foundation is able to support gravity, storm, and seismic loading with adequate margins of safety. The jacket also appears able to support the assumed loading with adequate safety factors.

More detailed localized analysis will be necessary prior to actual execution of the drilling and production operations.

The details of this global analysis can be found in Part B of Appendix Volume 5.

11. COASTAL ZONE CONSISTENCY

The California Coastal Commission (CCC) has not completed review of the project for coastal zone consistency. UNOCAL has been advised that the CCC must obtain consistency information from the MMS prior to making this determination. As stated in the MMS letter of March 8, 1990, the MMS will notify the CCC of proposed modifications after the revised DPP has been submitted and reviewed.

12. FACILITY PERMIT

The temporary facilities for the project are currently under review by the district MMS office in accordance with 30 CFR 250.122. A certified P&ID and a SAFE chart were submitted in May 1990.

13. ENVIRONMENTAL

13.1 Existing Environment

A narrative description of the environment has been addressed in Section 12, Volume II of EIR/EA 78-19. A significant amount of pertinent environmental information was provided by this report.

13.2 Air Quality

An air quality report was provided to the city of Oxnard and the Ventura County APCD. This information has been incorporated into the report "Emission Data for Platform Gina Pipeline Repair and Conversion Project". This information may be found in Appendix Volume 3. Also contained in this Appendix is the VC-APCD's letter dated April 9, 1990, deeming the project insignificant to overall air quality.

The introduction of new sources of natural gas fuel, as proposed aboard Platform Gina, represents a viable and positive contribution to local air quality emissions. When compared to alternate fuels, such as fuel oil, natural gas burns cleaner, natural gas fuel results in less emissions. For example, it is quite possible that the natural gas produced by Platform Gina will be consumed in lieu of fuel oil by the existing Southern California Edison (SCE) electrical power station located at Mandalay (either through the existing Southern California Gas Company connection or through a dedicated connection). Natural gas is much preferred by the operations of this plant because it burns cleaner. However, there is the possibility of curtailments (due to limited supply) from the Southern California Gas Company, which would force the burning of alternate fuel sources, such as fuel oil. Historically, the SCE plant at Mandalay has burned fuel oil and currently maintains an offshore loading terminal and several bulk storage tanks for fuel oil handling.

The energy equivalent of 18 MMSCFD natural gas is approximately 18,900 MMBTUD (based upon 1050 BTU/SCF). This is equivalent to 1,021,621 lbs of No. 6 fuel oil (based upon 18,500 BTU/LB) or 127,702 gallons of No. 6 fuel oil (based upon a specific density of 8 lbs/gallon). The following tables demonstrate the possible emissions reduction which would be available should the gas from Platform Gina be used in lieu of fuel oil at the Edison Power Plant. The emission factors used in the development of this table are from the Ventura County APCD table of emission factors.

TABLE 8
VAPCD Emission Factors[4]
Fuel Oil vs. Natural Gas

Source	SCC #	Reactivity	TOC	TSP	SO_2	CO	Rate
Natural Gas	1-01-006-01	0.440	2.50	8.83	0.83	15.00	Per/-MMCF
Fuel #6	1-01-004-01	1.000	2.62	3.57	36.75	2.86	Per/Mgal

[4]Table based upon Ventura County Air Pollution Control District emission factors for electric power plants. NO_X emission factor is not published for this classification.

TABLE 9 Emission Rate Comparison Fuel Oil vs. Natural Gas[5], Lbs/Day						
Source	**ROC**	**TOC**	**TSP**	**SO_2**	**CO**	**Emission Rate**
Natural Gas	19.8	45.00	158.94	14.94	270	lbs/d
Fuel #6	334.6	334.6	455.9	4,693	365	lbs/d
Annual Savings	114,902	105,704	108,390	1,707,492	34,675	lbs/yr

It is estimated that the use of natural gas in lieu of fuel oil at the SCE power plant would nullify projected project emissions[6] in less than 10 days.

13.3 Projected Air Quality Emissions

Projected air quality emissions generated as a result of this project are provided in the above-referenced emission data report, Appendix Volume 3.

13.4 Environmental Effect Assessment

The effects on the environment as a result of the implementation of the plan are addressed in the Draft Initial Study for Platform Gina Proposed Return Water Line Replacement and Conversion to Produced Gas dated May 1990, a copy of which was sent to the MMS regional office May 14, 1990, by the city of Oxnard. An additional copy is in Appendix Volume 3. Other pertinent information is detailed in the project description already provided to the Minerals Management Service.

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[5]Assumes no emission abatement equipment.

[6]Based upon normal platform operations. Ref: Table 3.3, Appendix Volume 3. Comparison based upon worst case comparison of fuel oil and natural gas emissions.

An environmental assessment and beach vegetation study (see Appendix Volume 1, Item C) reveals that impacts to fish and vegetation are minimal and will not pose any long-term consequences.

13.5 Environmental Safeguards

13.5.1 General

13.5.1.1 Precautionary Measures

UNOCAL utilizes a multitude of safety and environmental measures in operations. These include:

1. SPCC Plan updated October 1989
2. Hydrogen Sulfide Contingency Plan updated May 1990
3. Monthly safety meetings and hydrogen sulfide certification of employees and contractors
4. MMS certification of operators
5. First aid training and CPR training
6. International Loss Control Institute (ILCI) audits
7. Regular ILCI planned inspections
8. Regular fire drills

9. Regular hydrogen sulfide drills

10. Regular oil spill drills

11. Regular abandon platform drills

12. Implementation of hazard and operational studies of new facility installations (HAZOP)

13.5.1.2 Pipeline Construction Specific Constraints

UNOCAL realizes that the range of the pipeline repair includes public areas, and the guidelines listed below will be strictly enforced during the construction period.

1. All vehicular access will be from Fifth Street in the City of Oxnard. This will require grading a small portion of sand entering the beach and the installation of a temporary gate. A guard will be posted during the construction period to protect and inform the public. Once the project is complete, removal of all equipment from the beach will be done as soon as possible. The beach and access area will be regraded to its original level.

2. The pipe staging and welding area will be north of the original pipeline towards the Edison outfall canal.

3. When equipment is on the beach, vehicular traffic will be kept to a minimum. Equipment will be

left on the site whenever possible rather than removed and returned to the site. Crew transport in and out of the facility will involve crews walking over the sand dune adjacent to the project area east of the Mandalay facility. This foot traffic through the sand dune area will be minimized and will be restricted to a designated area.

4. The sand dune area is strictly off limits except for the designated area. A temporary fence will be constructed between the sand dune and the job site to prevent any unauthorized vehicles or personnel from entering the area. This fence will be removed upon project completion.

5. Good housekeeping policies will be strictly enforced. UNOCAL and the contractor will exercise diligence to conduct all operations in a manner that will prevent pollution and will comply with all applicable laws, ordinances, rules, regulations, leases, or provisions regarding all forms of pollution. No garbage, trash, waste, or other pollutants will be discarded or discharged on the beach or in the Santa Barbara Channel. UNOCAL and the contractor will be responsible for all trash, surplus tools, and other equipment removal during the project.

6. The project area has occasional pedestrian traffic. The time that a trench is open will be minimized,

and the trench area will be barricaded with warning lights and a guard at night.

7. UNOCAL will provide a 24 hour guard for purposes of informing the public, security of the area, and prevention of unauthorized access to the beach. The guard will be at the Fifth Street access during operating times, and will be at the job site the remainder of the time. The guard will be present from the project startup to completion and will be equipped with a 4-wheel drive vehicle and radio communications.

8. Once the project is completed, UNOCAL and the contractor will be responsible for removal of the fence between the sand dune and the beach area, and for the cleanup of all material that remains on the beach. All equipment utilized for the project will be removed from the beach promptly upon project completion.

9. The beach sand will be graded to the same contour as before the project commenced. Removal of the gate at the access area and the regrading of this area will be completed by the contractor.

10. The pedestrian walk area in the sand dune area will be the responsibility of UNOCAL and the contractor. Any areas disturbed will be recontoured and revegetated. Watering of this

area will be done until the vegetation is properly established.

13.5.1.3 Produced Water Disposition

The produced water that was returned to Platform Gina from the Mandalay facility for disposal by NPDES permit is currently being returned to Platform Gilda via a 6 5/8" pipeline for disposal. The NPDES permit applies at both platforms. A copy of the NPDES permit may be found on Page 55037 of the Federal Register, Vol. 48, No. 237, published Thursday, December 8, 1983.

13.6 H_2S Removal

13.6.1 General

The basis for determination that the Monterey Zone gas may contain hydrogen sulfide is the gas analysis from drill stem test 2A of well OCS P-0203 #6, which was drilled in 1985. Of several drill stem tests conducted on this well, only test 2A encountered hydrogen sulfide which was present at a level of 2,000 ppm. All drill stem tests on Wells H-13 and H-14 performed to date have not encountered sour gas.

The exact concentration of hydrogen sulfide which the Monterey Zone will have is not currently known. Based on experience in the Santa Barbara Channel and results obtained in pertinent drill stem tests, it is assumed that the gas will be similar to the gas encountered in well OCS P-0203 #6. This is the closest Monterey Zone well to Platform Gina which has encountered sour gas.

Regardless of the concentration of the hydrogen sulfide in the produced gas, the gas will not be sent to the Mandalay facility until it is sweetened offshore to conform to the gas sales specification. The gas sales specification is 0.3 grains per 100 standard cubic feet or 4 ppm. The sales specification is more stringent than the OSHA-PEL standard of 10 ppm and the American Conference of Governmental Industrial Hygienists (ACGIH) standard of 10 ppm.

There are several methods available for treating the gas to remove the H_2S. These methods range from chemical scavenging with a variety of chemicals to large scale treatment plants. UNOCAL has experience in the production and treating of sour gas produced from both onshore and offshore reservoirs. This experience includes offshore treatment to prevent the shipment of sour gas to onshore facilities, and also includes use of both chemical scavenging and treatment plant technologies. See Sections 6 and 7 for a discussion of the temporary and permanent hydrogen sulfide sweetening facilities.

14. ALTERNATE DESIGN EVALUATION

There were several other alternatives considered for this project.

1. Lay a pipeline and transport sour gas to Platform Gilda for processing with an existing amine plant.

2. Transport the sour gas to Mandalay in the converted pipeline and sweeten the gas for sales at Mandalay.

3. Build a separate satellite platform next to Platform Gina for the processing facilities.

All three of these options are possible from a sound engineering, safety, and environmental position. UNOCAL eliminated these possibilities due to the adverse political climate concerning offshore development. UNOCAL deemed the chance of obtaining permits for any of these three options as being unlikely, if not impossible. Additionally, the environmental report from the City of Oxnard has concluded that this project will have no significant impacts on the environment and, therefore, making adoption of A NEGATIVE DECLARATION possible.

PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

APPENDIX VOLUME 1

UNOCAL 76

APPENDIX VOLUME 1
ITEM A

Gas Analysis

APPENDIX VOLUME 1
ITEM A

Gas Analysis

Page	Description
A-1 thru A-8	MCE Analysis of H-14 Gas (11/21 to 12/3/88)
A-6 thru A-28	Southern California Gas Sales Contract
A-29 thru A--32	MCE Analysis of OCS P-0203 #6 Drill Stem Test 2A (1/15 to 1/16/85)
A-33 thru A-34	Atmospheric Hydrogen Sulfide Standards

MCE TEST REPORT

COMPANY: UNOCAL

LOCATION: PLATFORM GINA

WELL NO.: H-14

DATE: NOVEMBER 21, 1988 - December 3, 1988

MEASUREMENT AND CONTROL ENGINEERING

P. O. Box 987 Ventura, California 93002

Phone (805) 650-9100

Woodland, Calif. (916) 662-2226 Bakersfield, Calif. (805) 327-2394

Information Redaction Statement

Pursuant to the Freedom of Information Act (5 U.S.C. 552) and its implementing regulations (43 CFR Part 2) and as provided in 30 CFR 550.199(b), some information has been redacted from this document and was deleted from the public information copy of this submission.

Proprietary Information Redacted

Not for Public Release

GAS SALES AND PURCHASE AGREEMENT

This expresses the agreement entered into and effective this thirty-first day of August, 1981, by and between UNION OIL COMPANY OF CALIFORNIA (hereinafter referred to as "Seller"), and PACIFIC LIGHTING GAS SUPPLY COMPANY (hereinafter referred to as "Buyer").

W I T N E S S E T H :

WHEREAS, Seller presently owns an interest in certain oil and natural gas to be produced from Federal Leases #OCS-P-0216, #OCS-P-0202 and #OCS-P-0203 located on federal submerged lands offshore the State of California, such leases hereinafter called "Said Leases"; and

WHEREAS, Seller will gather natural gas produced from Said Leases to an oil and gas treating facility located onshore Ventura County, California; and

WHEREAS, Seller desires to sell to Buyer such natural gas that is surplus to Seller's own needs from time to time and Buyer desires to purchase same from Seller, subject to the terms, conditions and limitations set forth herein; and

WHEREAS, it will be necessary for Buyer to install or cause to be installed certain pipeline and related facilities to receive gas hereunder for redelivery into the facilities of its affiliate, the Southern California Gas Company ("SoCal") and SoCal intends to install certain facilities to provide additional gas service to the Southern California Edison Company ("Edison") at its Mandalay power generating plant:

NOW THEREFORE, the parties hereto agree as follows:

I.

TERM

1.1 This agreement shall be effective from the date hereof and shall continue and remain in effect for fifteen (15) years, at which time it shall terminate.

1.2 This agreement is conditioned upon Seller receiving from the Federal Energy Regulatory Commission a producer's certificate which is, in the sole discretion of Seller, acceptable and the receipt of all permits necessary for the aforementioned facilities to be installed by Buyer and SoCal on terms acceptable to Buyer.

II

DEFINITIONS

Except where the context indicates another or different meaning or intent, the following terms as used herein shall be construed to have the following meanings:

2.1 "day" shall mean the period beginning at 7:00 a.m. local time and ending at 7:00 a.m. local time the following day. Such period shall be twenty-four (24) consecutive hours except on the days when changing to or from Daylight Savings Time.

2.2 "month" shall mean a period beginning at 7:00 a.m. on the first day of a calendar month and ending at 7:00 a.m. on the first day of the next succeeding calendar month.

2.3 "cubic foot" shall mean the volume of gas which occupies one cubic foot of space measured at fourteen and seventy-three one hundredths pounds per square inch absolute (14.73 psia) at a temperature of sixty degrees (60°) Fahrenheit.

2.4 "Mcf" shall mean one thousand (1000) cubic feet of gas.

2.5 "Btu" shall mean one (1) British thermal unit, and is defined as the amount of heat required to raise the temperature of one (1) pound of water from fifty-eight and one-half degrees (58.5°) Fahrenheit to fifty-nine and one-half degrees (59.5°) Fahrenheit at a standard pressure of fourteen and seventy-three one hundredths pounds per square inch absolute (14.73 psia).

2.6 "decatherm" shall mean one million (1,000,000) Btu's.

2.7 "heating value" shall mean the gross heating value of waterfree gas determined as the quantity of heat in Btu's liberated by the complete combustion, at constant pressure, of one (1) cubic foot of gas with air at a temperature of sixty degrees (60°) Fahrenheit, and at an absolute pressure equivalent to thirty (30) inches of mercury at thirty-two degrees (32°) Fahrenheit and shall include the heat of condensation of the water formed by combustion.

2.8 "FO Indicator" shall mean that value calculated from the number six (6) fuel oil cost as reported by Southern California Edison Company and San Diego Gas and Electric Company on the Federal Energy Regulatory Commission's Form No. 423 (Monthly Report of Cost and Quality of Fuels for Electric Plants) as converted using the Btu content of such oil to obtain cents per decatherm. The cents per decatherm for each applicable cost listed in Column eleven (11) of Form No. 423 will be weighted by the oil volume associated with that cost, shown in Column seven (7) of Form No. 423, in order to calculate the FO Indicator as the weighted average cost on a monthly basis in cents per decatherm.

III

DELIVERY CONDITIONS

3.1 Effective with the completion and testing of all pipelines and facilities required hereunder, Seller shall commence delivery of and sell and Buyer agrees to take delivery of and purchase on a daily basis all gas available from Seller in excess of Seller's current requirements up to a maximum of fifteen thousand (15,000) Mcf per day or such greater volumes as Buyer is able to take into its facilities, subject to the following:

(a) In order to effectuate the earliest possible delivery and receipt of gas hereunder Buyer intends to install, or cause to be installed, the necessary facilities to take such gas in two phases: The first phase to consist of a pipeline between the point of delivery hereunder and a point within or in close proximity to Edison's Mandalay plant where SoCal will provide Edison with gas service; the second phase to consist of a pipeline and related facilities, including compression necessary to connect with existing facilities of SoCal.

(b) Buyer will use its best efforts to complete the first phase so that delivery may be commenced hereunder by November 1, 1981 and to complete the second phase by January 1, 1982. Until completion of the second phase, Buyer's obligation to take and purchase gas hereunder shall be limited to those volumes Edison is willing and able to purchase from SoCal at its Mandalay plant.

3.2 It is recognized that Seller's delivery rate will vary or may change from time to time and Seller will inform Buyer within a reasonable time prior to any significant change in delivery rate that Seller has planned or has knowledge of.

3.3 For gas sold by Seller to Buyer hereunder the delivery point shall be a mutually agreed point at Seller's onshore treating facility.

3.4 Seller shall deliver gas to Buyer at the delivery point at the pressure existing in Buyer's pipeline up to a maximum of seventy-five (75) pounds per square inch; provided, however, if Edison is unable to accept such gas or if SoCal has a special need in their higher pressure distribution system, Seller will deliver the gas at sufficient pressure, up to a maximum of two hundred (200) pounds per square inch, so that Buyer using a compression ratio of three to one (3:1) can deliver such gas at the pressure required by SoCal. Buyer will inform Seller within a reasonable time prior to any significant changes in delivery pressure that Buyer has knowledge of.

3.5 Title to and ownership of gas shall pass to and absolutely vest in Buyer at the point of delivery and the risk of loss shall follow title.

IV

PRICE

4.1 (a) Subject to the other provisions hereof, Buyer shall pay Seller monthly for each decatherm delivered hereunder, a price, rounded to the nearest one tenth (0.1) of a cent, equal to the highest of the following prices:

(i) Eighty-five percent (85%) of the FO Indicator for that month.

(ii) The average of the two highest prices being paid in a first sale for gas (except under Buyer's so-called "Long Term Border Price" agreements or the ARCO Oil and Gas Company sale to Edison at its Mandalay power generating plant) by any company, except Seller or its majority owned subsidiaries but including Buyer and its affiliates, purchasing gas in the "Santa Barbara Channel Area", as shown within the dashed line on Exhibit A, attached hereto and made a part hereof. Such price shall be appropriately adjusted to reflect delivery conditions and Seller's point of delivery to Buyer's onshore pipeline system or the pipeline system of Buyer's affiliate. If Buyer and Seller are unable to agree upon the amount of such price adjustment, then either party may request arbitration and said adjustment shall be determined by arbitration in accordance with the provisions of Article XII hereof.

(iii) Where neither (i) nor (ii) above is applicable or allowable, five dollars ($5.00) per decatherm. Commencing on July 1, 1981, and on the first day of each succeeding calendar quarter during the term or any extensions thereof, of this agreement, the price under this subparagraph (iii) shall be increased by an amount equal to one and one-half percent (1 1/2%) above the price then in effect.

(b) The FO Indicator for each month shall be calculated using the data recorded for that month. It is recognized there may be a delay in obtaining the data for the computation of the current month's FO Indicator. Therefore, until the data has been obtained and the FO Indicator has been determined for the current month, Buyer shall pay Seller at a price equal to eighty-five percent (85%) of the most recently determined FO Indicator. When the FO Indicator for such month is determined, as herein provided, Seller will adjust the current month's invoice to effect a retroactive price adjustment equal to the difference, if any, in the price previously paid for gas for such month and the price payable based upon the then determined FO Indicator for such month. Seller shall assemble the data, make the determination, and advise Buyer of each month's FO Indicator not later than fifteen (15) days following the receipt by Seller of the data required for such determination. All data used in making such determination shall be available to Buyer, upon Buyer's request. If in any month there is no number six (6) fuel oil used by either of the companies listed in the definition of FO Indicator under Section 2.8 the price for the latest month where number six (6) fuel oil was used shall be the price for such month, as adjusted for the delay in data as provided in this Subsection 4.1(b).

If required data for the determination of the FO Indicator ceases to be published, Buyer and Seller shall choose by mutual agreement a new index or new indices which most nearly approximates the prior index in terms of content and operation. In the event the parties are unable to so agree, then either party may request that a new index or indices be determined by arbitration and said new index shall be determined by arbitration in accordance with the provisions of Article XII hereof.

(c) The price of all or a part of the gas sold hereunder may be subject to a maximum lawful price under the Natural Gas Policy Act of 1978 or under amendatory or superceding laws (the "Act"). In such event, and for so long as the Act so controls the price of all or a portion of the gas sold hereunder, the price paid for such controlled portion shall be the maximum lawful price, plus all escalations and allowances permitted under the Act.

In the event any gas sold hereunder qualifies for incentive or adjusted price treatment under Section 107 of the Act, Buyer agrees to purchase such gas at the maximum prices allowed under the incentive pricing system established by the Federal Energy Regulatory Commission or other governmental entity under the authority granted by said Section 107 of the Act.

(d) If at any time when maximum lawful prices are being paid under Subsection 4.1(c) above, the Federal Energy Regulatory Commission, or any successor governmental authority, including the U.S. Congress, or any other governmental authority having jurisdiction over the sales price hereunder shall permit, authorize or prescribe, or allow to be collected, even though subject to refund, a higher applicable price for the purchase of gas to be delivered hereunder, or applicable to other similar gas in the same area, then the price to be paid by Buyer to Seller for gas sold under the provisions of this Agreement shall be increased, as of the date such higher price if effective, to equal such higher price, including all subsequent price adjustments authorized, prescribed or allowed by such authority.

(e) The production-related amounts, allocations, costs, or add-ons assigned or designated to be collected by Seller by the Federal Energy Regulatory Commission or any other government, regulatory, admininistrative, legislative, executive agency or body, authorize to so establish relevant costs, allowances and add-ons shall be in addition to the maximum lawful price provided under Subsections 4.1(c) or (d) herein. These allowances, allocations and add-ons for production related costs shall include but not be limited to costs incurred for compression and gathering, established pursuant to Section 110 of the Act or any subsequent or additional enabling law, regulation, order or similar authority, as well as all price adjustments deemed just and reasonable, established pursuant to the Act or any subsequent or additional enabling law, regulation, order or similar authority. All applicable allowances and adjustments as stipulated above shall be payable as of the effective date of the law, regulation or order establishing the allowance.

(f) Anything in Subsections 4.1(c), (d) and (e) notwithstanding, Buyer and Seller each reserve the right, at its option, to intervene in any area, national or other rate proceeding held to give consideration to any rate, price or allowance that may be applicable to the gas sold hereunder, to fully participate in any such proceeding and to seek relief therefrom in any regulatory agency or court having jurisdiction.

(g) If at any time, when the gas committed under the Agreement is not subject to regulation and a maximum lawful price, Buyer determines in good faith using prudent business judgment that the price payable for gas under Subsection 4.1(a) hereunder renders such gas unmarketable in the market area of Buyer or SoCal, then Buyer may notify Seller in writing of such determination and stipulate the maximum price payable by Buyer hereunder, called the "Alternate Price", which would allow such gas to be marketed by Buyer or SoCal. Such Alternate Price shall apply to the continued sale and purchase of such gas by Buyer hereunder for one year commencing on the date Buyer's notice of such alternate price was received by Seller. Buyer will provide to Seller, prior to the time such notice is given, any data, information and analysis used by Buyer to determine such Alternate Price.

If the Alternate Price stipulated in Buyer's notice is not acceptable to Seller, Seller shall have the right at any time, within a period of one hundred eighty (180) days following receipt of Buyer's notice, to terminate this Agreement by giving Buyer thirty (30) days prior written notice and deliveries of gas hereunder shall cease upon such termination date. In the event the Agreement is so terminated by Seller, Buyer shall make payment to Seller for all gas delivered during the period from receipt of Buyer's notification until the effective termination date at the Alternate Price. Buyer shall apply for and support any authorization or abandonment procedures that may be necessary for the release of gas sales under this agreement.

In the event Seller does not terminate this Agreement as provided herein within said one hundred eighty (180) day period, this Agreement shall continue and remain in full force and effect with all the terms hereof except that the price payable hereunder shall be the Alternate Price during the one year alternate price period, whereupon the price will again be as provided under this Article IV.

V

TAXES

5.1 In the event any taxes are lawfully imposed on and paid by Seller with respect to the gas sold to Buyer, Buyer shall reimburse Seller a sum sufficient to cover one hundred percent (100%)

of any such taxes paid by Seller irrespective of the mode of imposition. As used herein the term "taxes" shall mean (1) any production-related tax (other than income, sales, real property, capital stock, or franchise taxes) or (2) similar charges now and hereafter levied, assessed or made by any governmental authority on the gas itself or on the act, right or privilege of production, severance, gathering, transportation or delivery of gas which is measured by the volume, value, or sales price to Buyer of the gas in question; provided, however, that Buyer's obligation to reimburse Seller for such taxes is subject to the ability of Buyer or its affiliates to recover tax reimbursement costs in their rates in any contract entered into by Buyer or its affiliates after January 1, 1981.

VI

QUALITY

6.1 All gas delivered hereunder shall be free of sand, water, and liquid hydrocarbons, shall have a minimum heating value of eight hundred fifty (850) Btu's per cubic foot, shall not contain more than three tenths (0.3) grains per one hundred (100) cubic feet of hydrogen sulfide and shall not have a water dew-point of more than forty-five degrees (45°) Fahrenheit at the delivery pressure provided herein; provided, however, if Edison is unable to accept redelivery of the gas hereunder by SoCal the following specifications shall apply for gas delivered to Buyer for SoCal's higher pressure distribution system:

(a) Have a total heating value of not less than one thousand (1000) Btu's per cubic foot nor more than twelve hundred fifty (1250) Btu's per cubic foot.

(b) Not contain more than three-tenths (0.3) grain of hydrogen sulfide per one hundred (100) cubic feet.

(c) Not contain more than three-tenths (0.3) grain per one hundred (100) cubic feet of organic sulfur.

(d) Not contain more than one (1.0) grain per one hundred (100) cubic feet total of all sulfur compounds.

(e) Not contain more than three precent (3%) by volume of carbon dioxide, and not more than four percent (4%) by volume total nitrogen and carbon dioxide; provided, however, if the heating value of the gas is one thousand fifty (1050) Btu's or over the volume of carbon dioxide my be four percent (4%) and the total volume of nitrogen and carbon dioxide may be six percent (6%).

(f) Be as free of oxygen as Seller can keep it through the exercise of all reasonable precautions, and shall not in any event contain more than two-tenths of one percent (0.2%) by volume of oxygen.

(g) Not exceed one hundred degrees (100°) Fahrenheit nor be less than forty degrees (40°) Fahrenheit in temperature at the point of delivery.

(h) Not have a water dew-point of more than forty-five degrees (45°) Fahrenheit at the delivery pressure provided herein.

(i) Not contain solid matter, sand, dust, gums, liquid hydrocarbons or other liquid or solid impurities which might be injurious to Buyer's pipeline.

(j) Buyer shall not be obligated to accept delivery of any gas under Subsections 6.1(a) through (i) hereunder which does not meet the specifications set out above, but may do so without prejudice to its rights hereunder.

VII

RESERVATIONS OF SELLER

7.1 Seller reserves the following prior rights and sufficient gas to satisfy such rights:

(a) To operate its property free from any control by Buyer in such a manner as Seller, in its sole discretion, may deem advisable.

(b) To use gas produced from Said Leases, for repressuring, pressure maintenance or cycling operations.

(c) To process or cause to be processed all or any portion of the gas, before delivery to Buyer hereunder, for the extraction of liquid hydrocarbons and any other constituents of the raw gas stream.

(d) To use gas produced from Said Leases which Seller shall from time to time require and take for its own use, inclusive of but not limited to, use by Seller's subsidiaries and affiliates and in joint operations in which Seller has an interest with others.

(e) To unitize its leases with other properties of Seller and of others in the same field.

(f) To deliver to Seller's lessor such quantities of Seller's gas as the lessor may be entitled and requests to take in kind pursuant to the provisions of Seller's leases.

VIII

MEASUREMENT

8.1 Buyer shall install and maintain at its own cost and expense a suitable meter for the purpose of measuring the volume of all gas delivered by Seller to Buyer hereunder.

8.2 All measurements of gas shall be corrected from the observed pressures and temperatures to a pressure of fourteen and seventy-three one-hundredths pounds per square inch absolute (14.73 psia), and a temperature of sixty degrees (60°) Fahrenheit, and shall be computed in accordance with the Pacific Energy Association's Bulletin's No. TS-461, No. TS-561 and TS-661-77 as revised from time to time.

8.3 Buyer shall calibrate such meter each month and Seller may have its representative present at such calibration. In the event a calibration of the meter does not register within one percent (1%) accuracy, the amount of gas measured by such meter shall be properly corrected, but no correction shall be made for any period preceding the current calendar month. Seller shall have the right to request calibration of such meter at any reasonable time; however, if any such requested calibration shows that the meter was registering within one percent (1%) accuracy, then the cost of such requested calibration shall be borne by Seller.

8.4 Buyer shall take spot samples and determine the heating value of all gas delivered in accordance with generally accepted practices in the industry. Seller shall have the right to request

Buyer to take additional samples for redetermination of such heating value at any reasonable time. However, if any such requested redetermination shows that the heating value so determined is within one percent (1%) of the heating value then being reported by Buyer, then the cost of such requested sampling and redetermination of heating heating value shall be borne by Seller.

IX

PAYMENT

9.1 On or before the fifth (5th) working day of each month Buyer will furnish Seller a statement for the preceding month showing the volume of gas, heating value and decatherms delivered hereunder. On or before the tenth (10th) day of the month, Seller shall render an invoice to Buyer showing the amount due therefore. Payment by Buyer to Seller for the invoiced amount shall be made by deposit in the United States Post Office to arrive at Seller's office by the twentieth (20th) day of such month, or as to invoices rendered after the tenth (10th) day of such month, within ten (10) days.

X

EXCESS ROYALTIES

10.1 Buyer agrees to reimburse Seller for all "excess royalty payments" which Seller shall be lawfully required to pay under the terms of Said Leases with repsect to gas sold and delivered to Buyer hereunder. The term "excess royalty payments" as used herein is defined as the amount by which actual payments by Seller to the United States government or other government authority as Lessor of the respective oil and gas leases subject to this Agreement, exceed the amount such payment would have been if the royalty value thereunder had been calculated upon the price received by Seller as provided for in Article IV of this Agreement.

XI

NON-UTILITY STATUS

11.1 Seller's agreement to sell gas upon the terms and conditions herein contained shall be its sole undertaking and it is mutually understood that Seller is not a public utility and that no lands or properties in which it may have an interest of any nature, is or are sold or offered for sale by Seller to the public or dedicated to public uses or purposes. Neither this Agreement nor service by Seller shall be deemed to create, by implication or otherwise, any obligation or duty to continue or to reinstate gas service upon the expiration of this Agreement.

11.2 If any court or regulatory body enters a final and legally binding order that Seller as a result of the sale of gas hereunder, is a public utility or subject to regulation as such, or that such regulatory body may prevent Buyer from complying with this Agreement in any respect then by thirty (30) days written notice to Buyer from Seller this Agreement may be terminated by Seller.

XII

ARBITRATION

Any controversy arising under those terms providing for arbitration in Section 4.1 of this Agreement which is not resolved by mutual agreement of the parties shall be determined by a board of arbitration upon notice of submission given either by Buyer or Seller, which request shall also name one (1) arbitrator. The party receiving such notice, shall, within thirty (30) days thereafter, by notice to the other, name the second arbitrator, or failing to do so, the party giving notice of submission shall name the second. The two (2) arbitrators so appointed shall name the third, or failing to do so within thirty (30) days, the third arbitrator shall be appointed by the person who is at the time the Senior (in service) Judge of the Federal District Court having jurisdiction over the area in which the property covered by this Agreement is situated.

The arbitrators selected to act hereunder shall be qualified by education, experience and training to pass upon the issue in question.

The arbitrators so appointed shall promptly hear and determine (after giving the parties due notice of hearing and a reasonable opportunity to be heard) the question submitted and shall render their decision within sixty (60) days after appointment of the third arbitrator. If within said period a decision is not rendered by a majority of the board, Buyer and Seller shall name new arbitrators who shall act hereunder in like manner as if none had been previously named.

The decision of a majority of the arbitrators, made in writing, shall be final and binding upon the parties hereto as to the questions submitted, and the parties will abide by and comply with such decision. Each party shall bear the expenses of its arbitrator, and the expenses of the third arbitrator shall be borne equally by Buyer and Seller, except that each party shall bear the compensation and expense of its counsel, witnesses and employees.

XIII

INDEMNIFICATION

13.1 Each of the parties hereto indemnifies and saves harmless the other party from any and all liability and expense on account of all damages, claims or actions, including damages to deaths of persons, arising from any act or accident, including an omission to act, in connection with the installation, maintenance and operation of the property, equipment, and facilities of the indemnifying party.

XIV

EXCUSABLE NON-PERFORMANCE

14.1 Except for the payment hereunder of money due, the non-performance of any of the obligations of the parties hereto shall be deemed excused if and to the extent that such nonperformance is caused by any act of God, unavoidable accident, labor disturbances, interference by governmental authority or any other cause whether or not similar to the foregoing, beyond the reasonable control of the party so unable to perform.

XV

ASSIGNMENT

15.1 All of the provisions, covenants, agreements and stipulations contained herein by which either of the parties hereto is bound shall in like manner be binding upon the successors and assigns of the parties so bound, and those which are for the benefit of either of the parties hereto shall in like manner inure to the benefit of the successors and assigns of the parties so benefited; provided, however, that neither party hereto shall assign this agreement nor any interest herein without first obtaining the written consent of the other party hereto, which consent shall not be unreasonably withheld.

XVI

CONFORMITY WITH LAWS

Both parties shall observe and comply with all applicable laws, rules, orders, ordinances, codes and regulations of governmental agencies, including federal, state, municipal and local government and judicial bodies, having jurisdiction over this Agreement.

XVII

NOTICES

17.1 Any notice to be given hereunder by either Buyer or Seller to the other shall be deemed received by the other on the second business day following the date of deposit thereof in a United States Post Office enclosed in a sealed envelope, with requisite postage thereon respectively addressed as follows:

If to Buyer:

Pacific Lighting Gas Supply Company
Attn: Contract Administrator
720 W. Eight Street
Los Angeles, California 90017

If to Seller:

Union Oil Company of California
Attn: Regional Gas Manager
Western Region
P. O. Box 7600
Los Angeles, California 90051

unless and until either party shall change the place of notice by written communication sent to the other by mail.

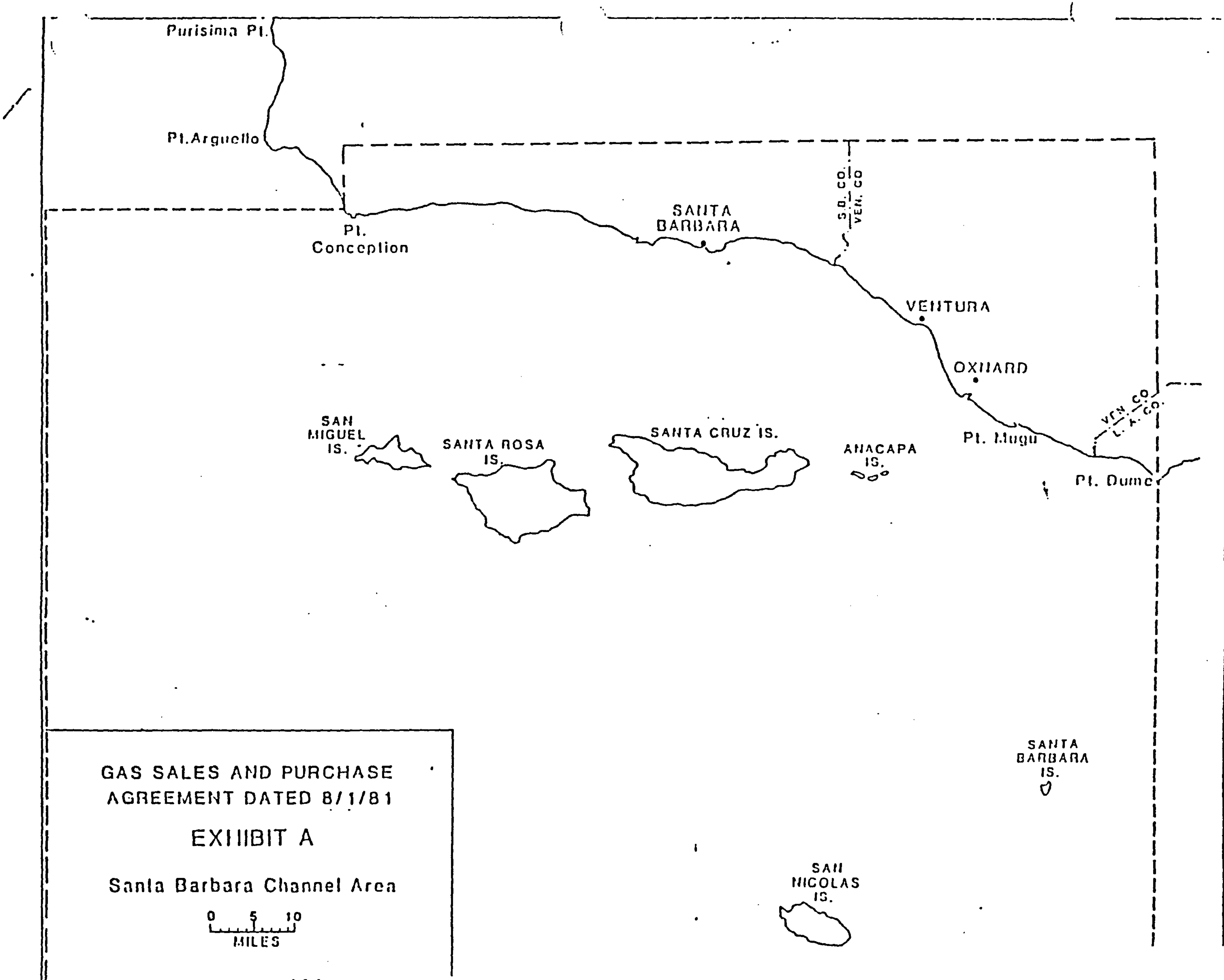
IN WITNESS WHEREOF, the parties hereto have executed this agreement as of the date first hereinabove written.

UNION OIL COMPANY OF CALIFORNIA

By ______________________________
Charles M. Schwartz, Vice President

PACIFIC LIGHTING GAS SUPPLY COMPANY

By ______________________________
William H. Owens, Vice President



Purisima Pt.
Pt. Arguello
Pt. Conception
SANTA BARBARA
S.B. CO.
VEN. CO
VENTURA
OXNARD
VEN. CO.
L. A. CO.
Pt. Mugu
Pt. Dume
SAN MIGUEL IS.
SANTA ROSA IS.
SANTA CRUZ IS.
ANACAPA IS.
SANTA BARBARA IS.
SAN NICOLAS IS.
GAS SALES AND PURCHASE AGREEMENT DATED 8/1/81
EXHIBIT A
Santa Barbara Channel Area
0 5 10
MILES

MCE TEST REPORT

COMPANY: Union Oil

LOCATION: Giant Beaver Prospect

WELL NO.: OCS-P-0203 #6 DST 2A

DATE: January 15 thru January 16, 1985

MEASUREMENT AND CONTROL ENGINEERING

P. O. Box 987 Ventura, California 93002

Phone: (805) 653-7282

Bakersfield, Calif. (805) 327-2394

Information Redaction Statement

Pursuant to the Freedom of Information Act (5 U.S.C. 552) and its implementing regulations (43 CFR Part 2) and as provided in 30 CFR 550.199(b), some information has been redacted from this document and was deleted from the public information copy of this submission.

Proprietary Information Redacted

Not for Public Release

Memorandum

UNOCAL 76

G. LEYENDECKER
MAR - 9 1989

March 3, 1989

TO: Greg Leyendecker

FROM: Jill E. Ryer-Powder JERP

SUBJECT: Hydrogen Sulfide

This memo is written in response to a request for information regarding hydrogen sulfide.

The following information concerns the most current standards for air levels in the workplace.

ACGIH

- TLV-TWA = 10ppm
- TLV-STEL = 15ppm

OSHA PEL

- Acceptable ceiling concentration = 20ppm
- Acceptable maximum peak above the acceptable ceiling concentration for an 8 hour shift = 50ppm for 10 minutes once only if no other measureable exposure occurs.

NIOSH

- 10ppm 10 minute ceiling

The IDLH (Immediately Dangerous to Life and Health) (This level represents the maximum concentration from which one can escape within 30 minutes any escape imparing symptoms or any irreversible health effects) is equal to 300ppm.

3M 1-0C03 (REV 8-85) PRINTED IN U.S.A.

The following table represents physicological effects of hydrogen sulfide through a range of doses.

HYDROGEN SULFIDE (ppm)	EFFECT
Approximately 0.2	Detectable order
Approximately 50	Eye irritation, respiratory tract irritation, headache, nausea, and signs of central nervous system depression (e.g. drowsiness, dizziness, loss of coordination and fatigue).
Approximately 150	Paralysis of sense of smell
Approximately 250	Pulmary edema (accumulation of fluid in the lungs), Gastro-intestinal distrubances, bronchial pneumonia.
Approximately 500-1000	Unconciousness and death through respiratory paralysis
Approximately 5000	Immediate death

References

1. Federal Register/Volume 54, No.12 Jan 19,1989 p 2959
2. ACGIH Documentation of the TLV's 1986 p 318
3. U.S. Dept of Health and Human Services NIOSH Recommendations for Occupational Safety and Health Standards 1988
4. Chemical Hazards of the Workplace. Proctor, Hughes, and Fischman 2nd Edition 1988 p283-284
5. Hamilton and Hardy's Industrial Toxicology 4th Edition AJ Finkel 1983 p 191

JRP/qat
0044J

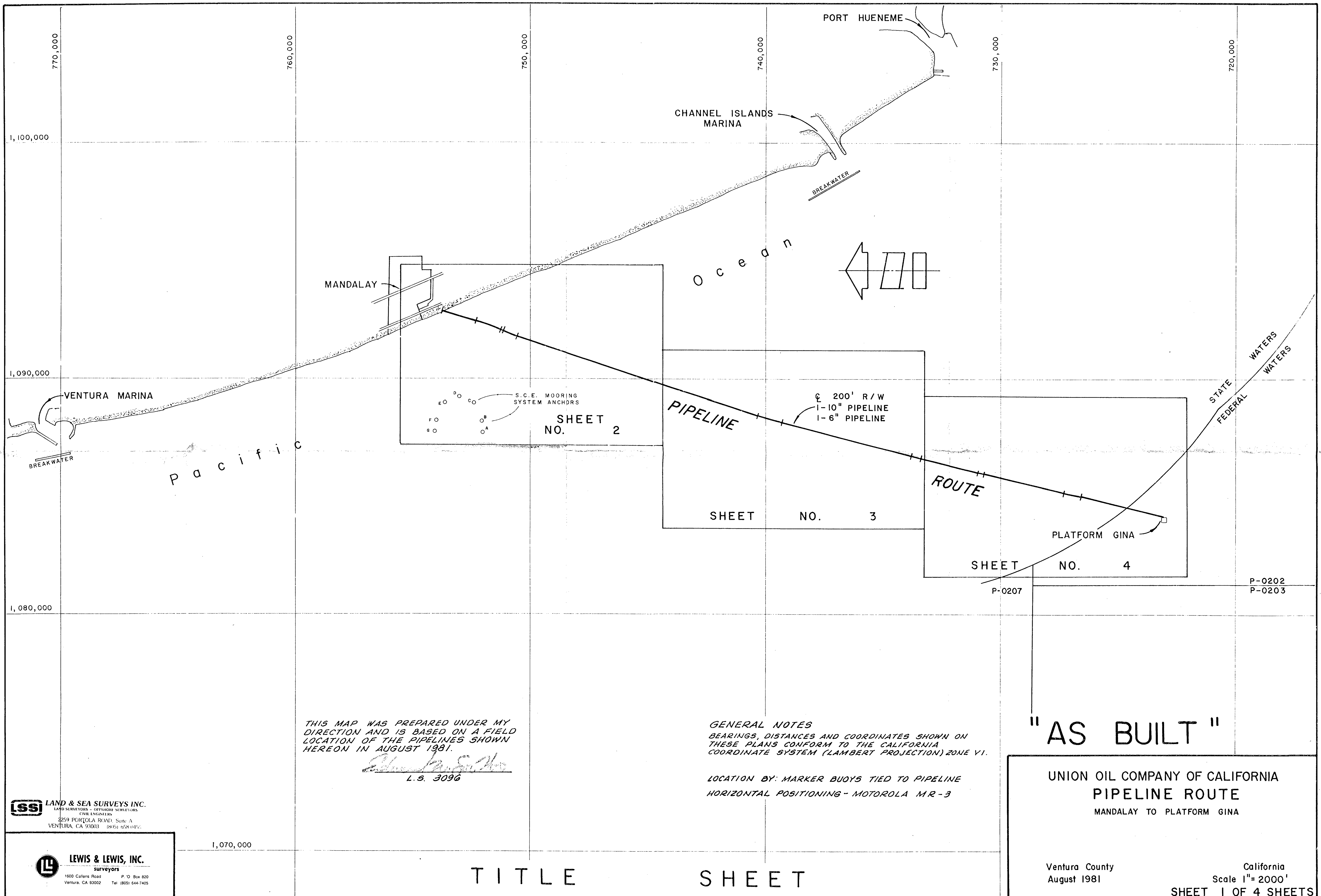
APPENDIX VOLUME 1
ITEM B

Pipeline Drawings

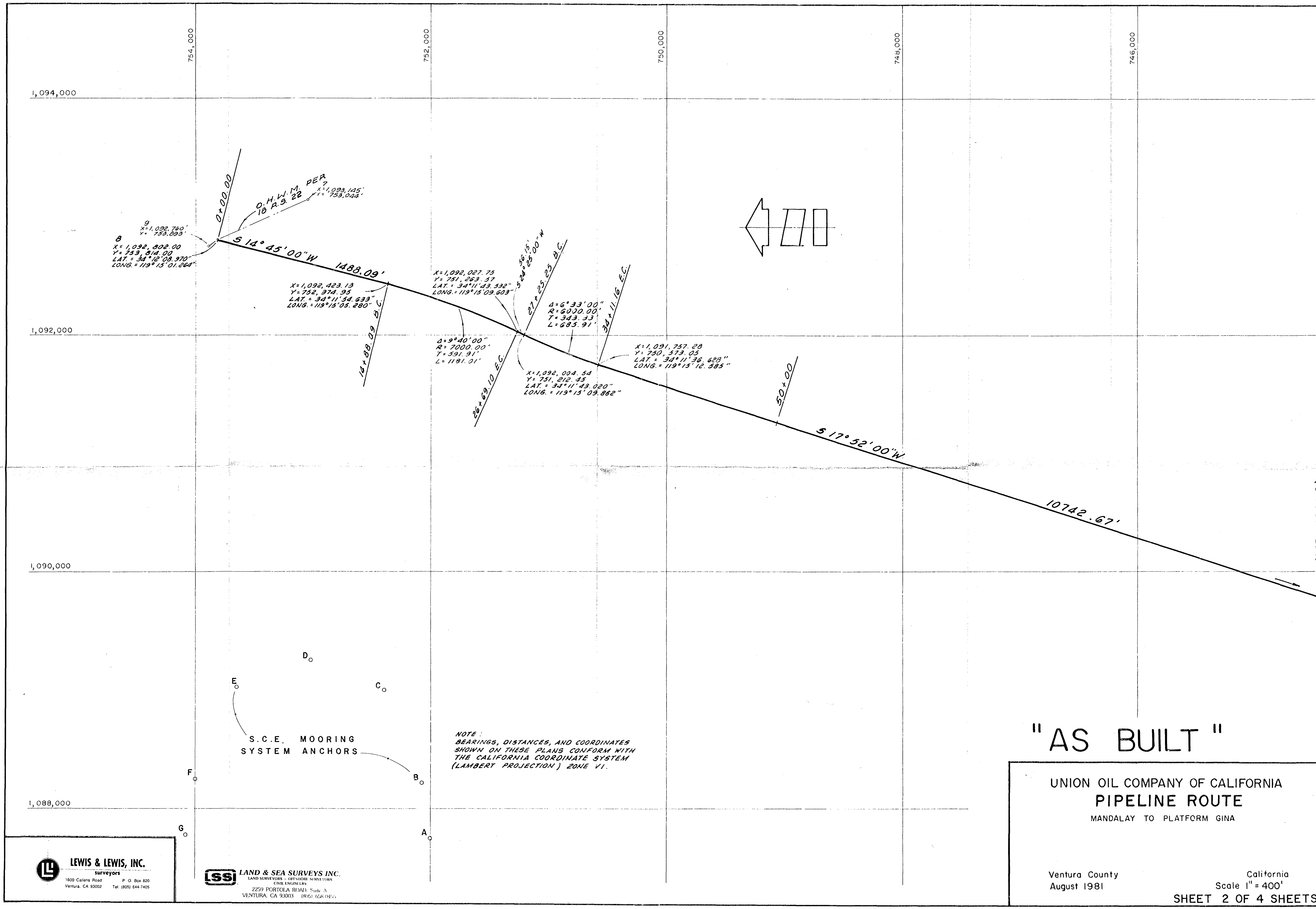
APPENDIX VOLUME 1
ITEM B

Pipeline Drawings

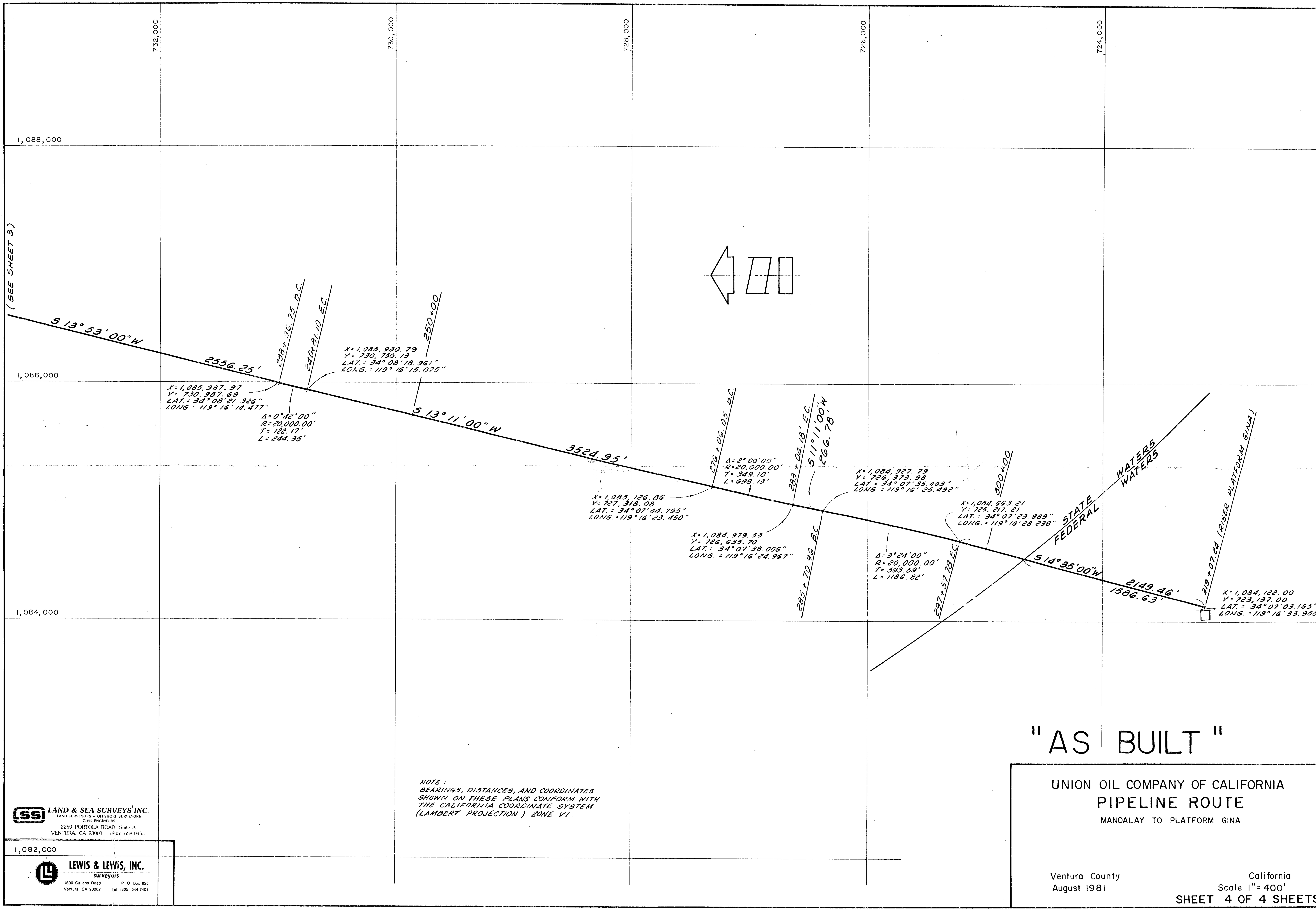
Drawing	Description	Date
1	Sheet 1 of 4 Pipeline As-Built	August 1981
2	Sheet 2 of 4 Pipeline As-Built	August 1981
3	Sheet 3 of 4 Pipeline As-Built	August 1981
4	Sheet 4 of 4 Pipeline As-Built	August 1981
5	Onshore Pipeline As-Built	October 1981
6	1985 Repair, As-Built Drawing	December 1985
7	Beach and Onshore Pipeline Profile	December 1988
8	Pipeline Staging and Tie-In Location Plan	October 1990



770,000
760,000
750,000
740,000
730,000
720,000
1,100,000
1,090,000
1,080,000
1,070,000
PORT HUENEME
CHANNEL ISLANDS MARINA
BREAKWATER
MANDALAY
VENTURA MARINA
BREAKWATER
Pacific Ocean
S.C.E. MOORING SYSTEM ANCHORS
A B C D E F G
SHEET NO. 2
PIPELINE ROUTE
℄ 200' R/W
1-10" PIPELINE
1-6" PIPELINE
SHEET NO. 3
STATE WATERS
FEDERAL WATERS
PLATFORM GINA
SHEET NO. 4
P-0202
P-0203
P-0207
THIS MAP WAS PREPARED UNDER MY DIRECTION AND IS BASED ON A FIELD LOCATION OF THE PIPELINES SHOWN HEREON IN AUGUST 1981.
L.S. 3096
GENERAL NOTES
BEARINGS, DISTANCES AND COORDINATES SHOWN ON THESE PLANS CONFORM TO THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE VI.
LOCATION BY: MARKER BUOYS TIED TO PIPELINE
HORIZONTAL POSITIONING - MOTOROLA MR-3
"AS BUILT"
UNION OIL COMPANY OF CALIFORNIA
PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
Ventura County
August 1981
California
Scale 1"= 2000'
SHEET 1 OF 4 SHEETS
LSI LAND & SEA SURVEYS INC.
LAND SURVEYORS - OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CA 93003
LEWIS & LEWIS, INC.
surveyors
1600 Callens Road
Ventura, CA 93002
P.O. Box 820
Tel (805) 644-7405
TITLE SHEET


754,000
752,000
750,000
748,000
746,000
1,094,000
1,092,000
1,090,000
1,088,000
0+00.00
O.H.W.M. PER 18 R.S. 22
7
X=1,093,145'
Y= 753,044'
9
X=1,092,760'
Y= 753,893'
8
X= 1,092, 802.00
Y= 753, 814.00
LAT. = 34°12'08.970"
LONG. = 119°15'01.264"
S 14° 45' 00" W
1488.09'
X=1,092,423.13
Y=752,374.95
LAT. = 34°11'54.633"
LONG. = 119°15'05.280"
14+88.09 B.C.
X=1,092,027.75
Y=751,263.57
LAT. = 34°11'43.532"
LONG. = 119°15'09.603"
56.15'
S 24° 25' 00" W
27+25.25 B.C.
Δ=9°40'00"
R= 7000.00'
T= 591.91'
L= 1181.01'
26+69.10 E.C.
X=1,092,004.54
Y= 751,212.45
LAT. = 34°11'43.020"
LONG. = 119°15'09.862"
Δ=6°33'00"
R=6000.00'
T= 343.33'
L=685.91'
34+11.16 E.C.
X=1,091,757.28
Y=750,573.05
LAT. = 34°11'36.628"
LONG. = 119°15'12.585"
50+00
S 17° 52' 00" W
10742.67'
(SEE SHEET 3)
D
E
C
F
B
G
A
S.C.E. MOORING SYSTEM ANCHORS
NOTE:
BEARINGS, DISTANCES, AND COORDINATES SHOWN ON THESE PLANS CONFORM WITH THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE VI.
"AS BUILT"
UNION OIL COMPANY OF CALIFORNIA
PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
Ventura County
August 1981
California
Scale 1" = 400'
SHEET 2 OF 4 SHEETS
LEWIS & LEWIS, INC.
surveyors
1600 Callens Road
Ventura, CA 93002
P.O. Box 820
Tel. (805) 644-7405
LAND & SEA SURVEYS INC.
LAND SURVEYORS - OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CA 93003


744,000
742,000
740,000
738,000
736,000
734,000
1,090,000
1,088,000
1,086,000
1,084,000
(SEE SHEET 2)
100+00
S 17° 52' 00" W
10742.67'
141+53.83 B.C.
X=1,088,461.40
Y=740,348.46
LAT.=34°09'54.590"
LONG.=119°15'48.283"
Δ=2°55'00"
R=20,000.00'
T=509.16'
L=1018.11'
150+00
151+71.94 E.C.
X=1,088,173.83
Y=739,371.93
LAT.=34°09'44.853"
LONG.=119°15'51.368"
S 14° 57' 00" W
200+00
5736.22'
X=1,086,694.03
Y=733,829.87
LAT.=34°08'49.631"
LONG.=119°16'07.060"
209+08.16 B.C.
Δ=1°04'00"
R=20,000.00'
T=186.17'
L=372.34'
212+80.50 E.C.
X=1,086,601.33
Y=733,463.27
LAT.=34°08'46.039"
LONG.=119°16'08.038"
2556.25'
S 13°53'00" W
(SEE SHEET 4)
NOTE:
BEARINGS, DISTANCES, AND COORDINATES SHOWN ON THESE PLANS CONFORM WITH THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE VI.
"AS BUILT"
UNION OIL COMPANY OF CALIFORNIA
PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
Ventura County
August 1981
California
Scale 1" = 400'
SHEET 3 OF 4 SHEETS
LEWIS & LEWIS, INC.
surveyors
1600 Callens Road
Ventura, CA 93002
P.O. Box 820
Tel (805) 644-7405
LAND & SEA SURVEYS INC
LAND SURVEYORS - OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD
VENTURA, CA 93003



LSSI LAND & SEA SURVEYS INC.
LAND SURVEYORS – OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CA 93003 (805) 658-0155

LEWIS & LEWIS, INC.
surveyors
1600 Callens Road, Ventura, CA 93003 · P.O. Box 820 · Tel (805) 644-7405

"AS BUILT"

UNION OIL COMPANY OF CALIFORNIA

PIPELINE ROUTE

MANDALAY TO PLATFORM GINA

Ventura County — California
August 1981 — Scale 1" = 400'

SHEET 4 OF 4 SHEETS

LEWIS & LEWIS, INC.
surveyors
1600 Callens Road, Ventura, CA 93002
P. O. Box 820, Tel. (805) 644-7405

LAND & SEA SURVEYS INC.
LAND SURVEYORS – OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CA 93003 (805) 658-0455
TLX 757447

NOTE: BEARINGS, DISTANCES, AND COORDINATES SHOWN ON THIS MAP CONFORM WITH THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE VI.

ALL ELEVATIONS SHOWN ARE TOP OF PIPE BASED FROM MEAN SEA LEVEL DATUM 1929.

"AS BUILT"

UNION OIL COMPANY

SKETCH SHOWING

PIPELINE ROUTES

ORDINARY HIGH WATER MARK TO MANDALAY ONSHORE RECEIVING FACIL

VENTURA COUNTY CALIFORNIA

OCTOBER 1981 SCALE: 1" = 20'

754,100
1,092,600
754,200
1,092,700
754,300
1,092,800
754,400
1,092,900
754,500
1,093,000
754,000
753,900
N82°49'54"W 410.00
CABLE
6" WATER LINE
6"
10"
12"
10"
6" WATER LINE
8"
CABLE
SECTION "A-A"
(NO SCALE)
7.28
7.86
8.93
ANODE
12.78
END 10" CASING
7.26
7.76
6.90
10.10
ANODE
6.62
12.90
END 10" CASING
11.95
BEGIN 10" CASING
10.04
10.08
10.39 ANODE
10.21
10.35
MANDALAY ONSHORE
RECEIVING FACILITY
9.97
15.54
18.35
18.25
FLANGE
18.16
15.40
END 6" PIPE
(NOT COMPLETED)
BEGIN 10" CASING
11.94
11.57
10.82
ANODE
10.77
10.26
11.92
S67°10'06"W
105.24'
A
A
5.8
ANODE
5.6
ANODE
5.74
END 6" PIPELINE
X=1092834
Y=754022
5.66
END 6" PIPELINE
X=1092848
Y=753996
VICINITY MAP
(NO SCALE)
FIFTH ST
SITE
LSSI
LAND & SEA SURVEYS INC.
LAND SURVEYORS – OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CALIFORNIA 93003
NOTE: BEARINGS, DISTANCES AND COORDINATES SHOWN ON THIS MAP CONFORM WITH THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE VI.
ALL ELEVATIONS SHOWN ARE TOP OF PIPE BASED FROM MEAN SEA LEVEL DATUM 1929.
UNION OIL COMPANY
SKETCH SHOWING
"AS BUILT" SURVEY OF
2 SIX-INCH WATER LINES
AT
MANDALAY ONSHORE
RECEIVING STATION
VENTURA COUNTY
CALIFORNIA
DECEMBER 1985
SCALE: 1"=20'

LAND & SEA SURVEYS INC.
LAND SURVEYORS – OFFSHORE SURVEYORS
CIVIL ENGINEERS
2259 PORTOLA ROAD, Suite A
VENTURA, CA 93003 (805) 658-0455

COORDINATES SHOWN CONFORM WITH THE CALIFORNIA COORDINATE SYSTEM (LAMBERT PROJECTION) ZONE 6 IN FEET.

NOTE: ELEVATIONS SHOWN ARE MEAN LOWER LOW WATER.

UNOCAL

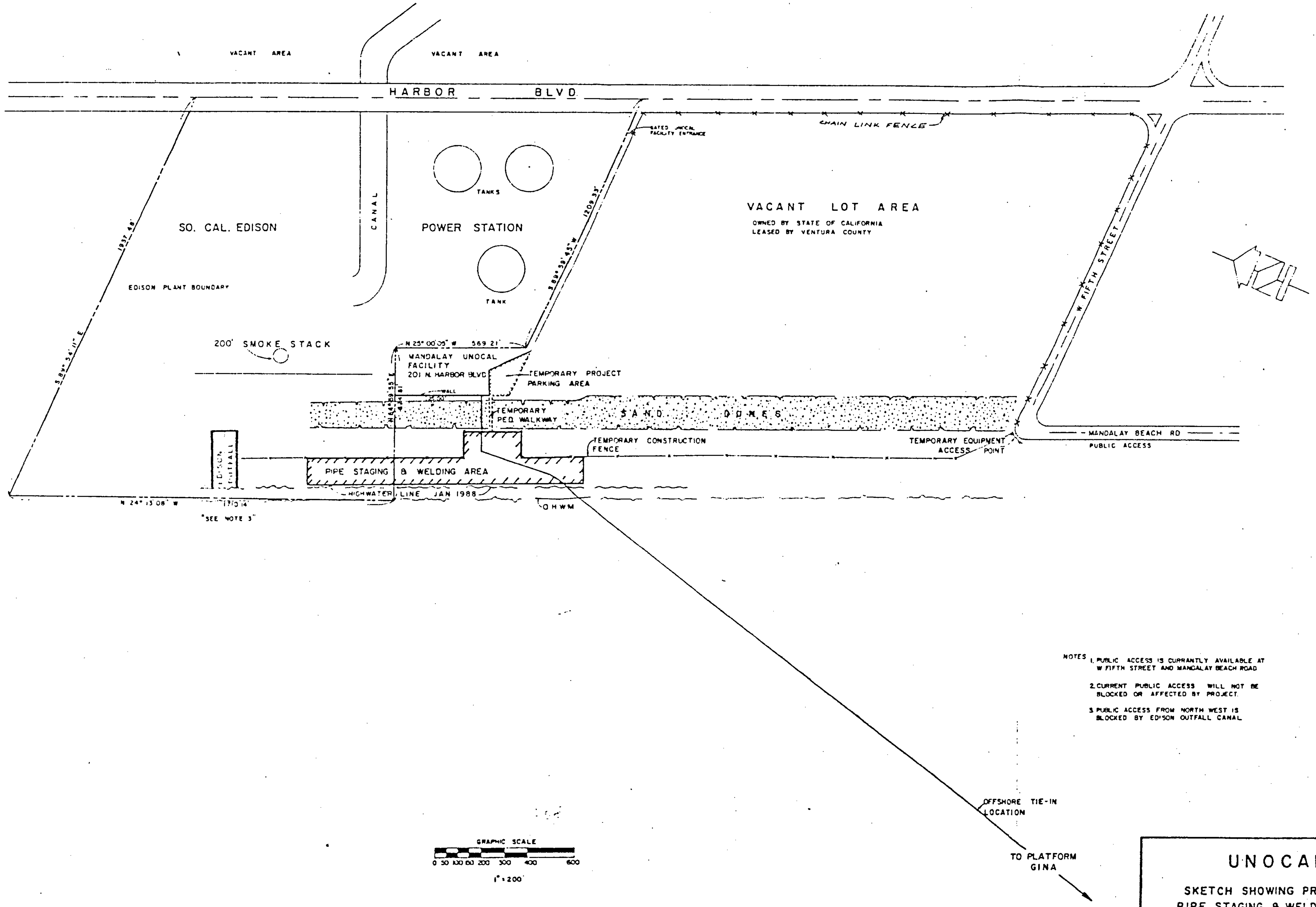
SKETCH SHOWING
BEACH PROFILE FROM SHORE TO MINUS 29 FEET OVER EXISTING PIPELINE ROUTE TO

PLATFORM GINA

VENTURA COUNTY CALIFORNIA
DECEMBER, 1988 (REVISED 12-19-88) SCALE: 1"=100'

W.O. 3376

183-D1



LSSI LAND & SEA SURVEYS INC.
2254 PORTOLA ROAD, Suite A
VENTURA, CA 93003

NOTE: BOUNDARY PER 20RS32

UNOCAL

SKETCH SHOWING PROPOSED PIPE STAGING & WELDING AREA AND MANDALAY FACILITIES

VENTURA, COUNTY — CALIFORNIA
OCTOBER 1990 — SCALE: 1" = 200'

APPENDIX VOLUME 1
ITEM C

Environmental Assessment

ENVIRONMENTAL ASSESSMENT AND BEACH VEGETATION STUDY FOR PROPOSED PLATFORM GINA PIPELINE REPLACEMENT MANDALAY BEACH, VENTURA COUNTY, CALIFORNIA

16 August 1990

Prepared for Unocal Corporation
Unocal Oil & Gas Division
Ventura, California

Prepared by MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, California 92627

ENVIRONMENTAL ASSESSMENT AND BEACH VEGETATION STUDY FOR PROPOSED PLATFORM GINA PIPELINE REPLACEMENT MANDALAY BEACH, VENTURA COUNTY, CALIFORNIA

16 August 1990

INTRODUCTION

Unocal has proposed to replace 3,000 ft of $6^5/_8$ inch pipeline previously used to return water from the Mandalay oil separator facility to Platform Gina. A new pipeline would be converted to transport produced natural gas from Gina to the Mandalay facility.

Of the 3,000 ft of pipeline to be replaced, 700 ft are onshore above the Mean High Tide Line (MHTL) and the remaining 2,300 ft are offshore, in the intertidal surf and subtidal zones (Figure 1). The onshore section of the old pipeline will be uncovered, removed and replaced with new pipeline using conventional equipment. Offshore, Unocal proposes to lay a new pipeline parallel to the old one and to allow it to bury itself by the forces of gravity and hydraulic action. Hydraulic jetting would be limited to nearshore areas where the surf zone energy is not sufficient to bury the new pipeline. Time required to complete the task once work has begun has been estimated to be three (3) weeks.

Questions have been raised regarding several environmental aspects of the intended work:

1. Unocal proposes to allow the offshore portion of the new pipeline to settle into place by gravity and to be covered gradually by sediments. The alternative suggestion has been to jet in the new pipeline to assure immediate placement. What would be the relative impact of each scenario on the benthic and epibenthic fauna?

2. Unocal proposes to leave the old offshore pipeline in place and run the new pipeline parallel to it. The alternative is to jet a trench for the removal of the old pipeline. What would be the impact of each case?

3. Unocal will jet in the new pipeline in the intertidal zone, but proposes to leave the old pipeline in place instead of removing it by jetting a working trench. What would be the impacts of leaving it in place versus jetting to remove it in the intertidal zone?

4. What would be the impact of the project on sport and commercial fishing in the offshore area?

5. What is the likelihood or magnitude of impacts on gray whales (*Eschrichtius robustus*) during their migrations along the California coast?

6. What is the nature of the vegetation of the dunes and the adjacent beach in front of the Unocal Mandalay facility?

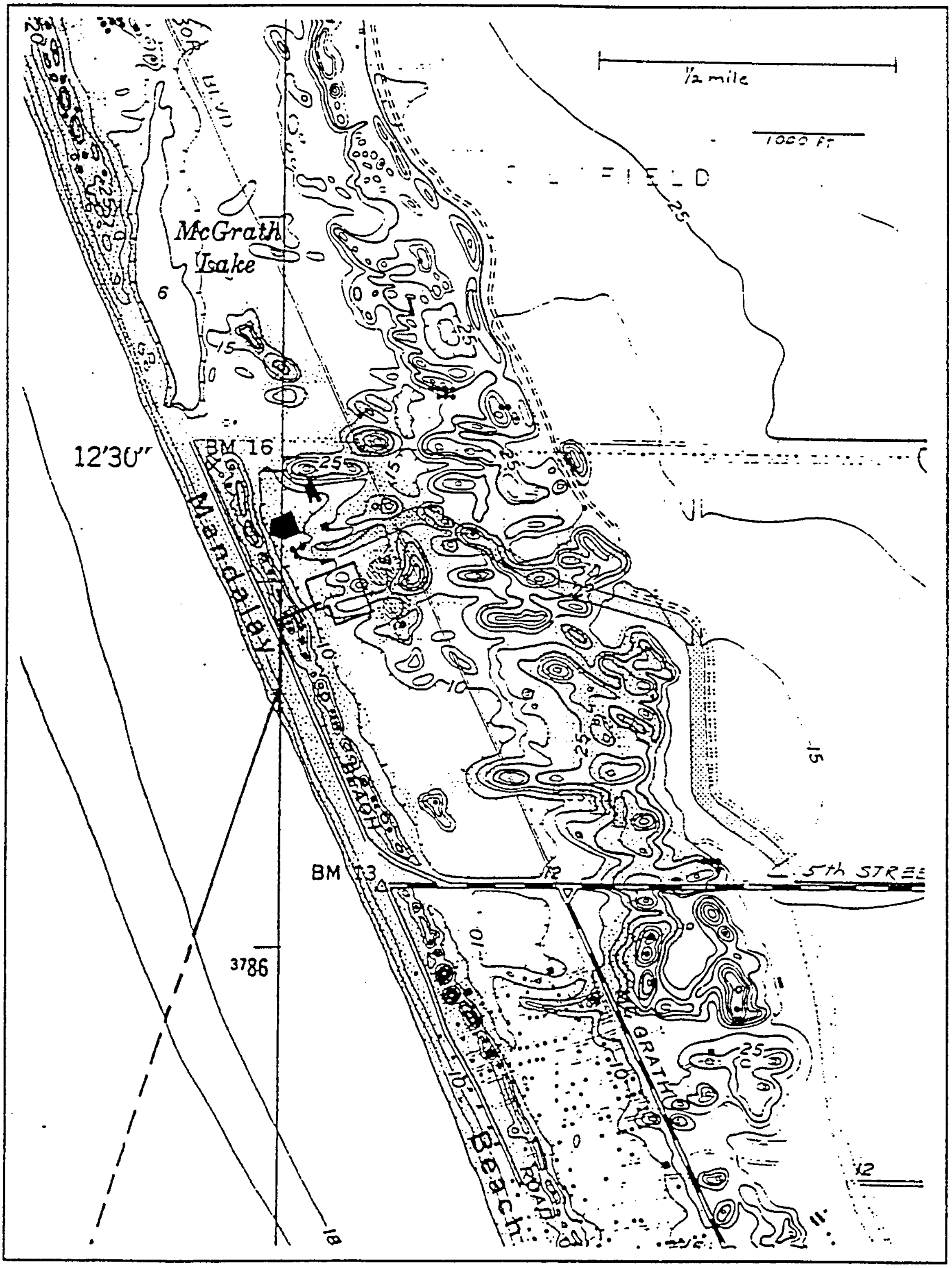


Figure 1. Map of Mandalay Beach, showing orientation of pipeline from the Unocal facility to Platform Gina.

DISCUSSION OF ENVIRONMENTAL ASSESSMENT

1. Self-burial Versus Jetting in the New Pipeline

Setting:

The $6^5/8$ inch replacement pipeline to be laid offshore, exclusive of the intertidal zone, will run from a water depth of about 7 ft (MHTL) to about 26 ft, a distance of about 1,700 ft. Benthic infauna studies in the area immediately offshore from the Unocal Mandalay facility indicate that at depths of approximately 20 ft, the number of organisms in the sediments is extremely variable, especially seasonally. In 1986, the mean abundance ranged from 3 individuals/0.01 m^2 in the winter to 31/0.01 m^2 in the summer, and in 1988, from 5 individuals/0.01 m^2 in the winter to 52/0.01 m^2 in the summer. The number of species also varied by season. In 1986, number of species increased from 2 in winter to 14 in summer, while in 1988, it increased from 4 in winter to 17 in summer (MBC Mandalay 1986, 1988).

Biomass of infaunal organisms ranged from 85 g/m^2 in winter to 444 g/m^2 in summer in 1988. Station values varied from 8 g/m^2 to 1016 g/m^2, due to the patchy distribution of Pacific sand dollars (*Dendraster excentricus*) (MBC 1988). Since the offshore slope in the Mandalay area has a gentle gradient, it would be expected that the subtidal infaunal community would be similar over short distances.

Data from otter trawls along the 20-ft isobath in the study area indicate that there are at least 24 species of fish and 18 species of macroinvertebrates in the area. The most abundant species of fish in surveys conducted from 1978 to 1988 were white croaker (*Genyonemus lineatus*), queenfish (*Seriphus politus*) and barred surfperch (*Amphistichus argenteus*). The most common invertebrate species were Pacific sand dollar (*Dendraster excentricus*) and spotted bay shrimp (*Crangon nigromaculata*). As with the infauna, numbers of individuals and species were greater in summer than in winter (MBC 1988).

Project:

Unocal proposes to lay the new pipeline on the surface of the sediment and allow it to gradually settle into place by gravity. The current pipeline has settled to a depth of four ft. In order to uncover the offshore tie-in to the old section, a 15-ft-wide, 40-ft-long trench will have to be jetted at the offshore tie-in location, 2,300 ft offshore from the high tide mark. Alternatively, the new pipeline would be jetted in to the desired depth. The area of disturbance would be about 15 ft wide by 1,700 ft long in the shallow subtidal zone.

Impacts:

Allowing the pipeline to settle by gravity would have some impact on the infaunal organisms in the immediate path of the settling pipeline. The maximum impact (assuming a 8-inch path of disturbance) would be 540,800 individuals with a biomass of 101 lb (46 kg) being displaced. However, the magnitude of the disruption would be small in both areal extent (limited to a narrow zone around the $6^5/8$ inch pipeline) and severity (organisms would not be separated from their sediment substrate) and would occur gradually over a long period of time. Most soft bottom organisms are mobile and would be able to readjust position from such gradual pressure. Until the new pipeline has buried itself, it may block longshore movement of motile epifaunal species, but would not affect fish or other swimming species.

The area which would be disturbed by jetting along the entire subtidal in order to replace the pipeline would be approximately 25,500 ft² (2,383 m²). At maximum impact, approximately 12 million infaunal organisms weighing 2,328 lb (1,058 kg) would be displaced. During the jetting procedure, organisms would be suspended in the water column, exposing them to predation by fish and epibenthic invertebrates. It is assumed that there would be 100% mortality of any organisms suspended during the jetting procedure.

In addition to the direct effects of disturbance by jetting, there would be a zone of sediment redeposition beyond the sides of the trench, which would smother any organisms which were not able to move rapidly enough to the sediment surface to maintain their suitable orientation and depth. The extent of mortality would depend on the volume of material removed, and the local current velocity and direction during the procedure. Therefore, there would be an area of unknown extent with less than 100% mortality of infauna; if the area impacted is twice that of the trench and the mortality is 50%, another 12,000,000 organisms or 2,328 lb would be lost.

In either case, in order to uncover the section of pipeline where the new pipeline will tie into the old section to the Platform, a 40-ft-long trench will have to be jetted. This will disturb about 600 ft² (56 m²) of substrate and will suspend, at most, 291,200 organisms, weighing about 55 lb (25 kg) (MBC 1988). The extent of adjacent redeposition of sediment will be small, and the period of time involved in the tie-in procedure will be short.

Mitigation:

There will be some loss of infaunal organisms involved in either method of pipeline placement. The jetted trench would have a much greater immediate impact on the infaunal community in and near the trench. However, most benthic infaunal organisms are short-lived species which reproduce annually. It would be expected, therefore, that the disturbed areas would be repopulated from the surrounding sediments within two years.

2. Removal of Old Pipeline by Jetting in the Subtidal Zone Versus Leaving in Place

Setting:

The setting is the same as that for jetting in 1,700 ft of new pipeline in the subtidal zone.

Project:

Unocal proposes to leave the old pipeline in place, under approximately 4 ft of sediment. The alternative would be to jet a trench 15 ft wide and 1,700 ft long for removal of the old pipeline.

Impact:

Jetting in a trench to expose and remove the old pipeline would disturb an area of approximately 25,500 ft² (2,383 m²), with a possible impact on 12 million benthic infaunal organisms weighing 2,328 lb (1,058 kg). Considering that the trench would have to be kept open for a much longer period of time than required for jetting in the new pipeline, the impacts would be even greater, as the trench would continue to fill in, due to downcurrent sand transport. The zone of redeposition and smothering would be greater the longer the trench has to be kept open. Therefore, the effect of removing the old pipeline and jetting in the new pipeline would be at least twice that for jetting in the new pipeline alone.

Mitigation:

The impact of removing the old pipeline would be considerable. Leaving the pipeline buried under 4 ft of sediment would have no impact on the infaunal organisms.

3. **Removal of Old Pipeline by Jetting in the Surf Zone**

Setting:

The intertidal zone, for the purposes of this study, is considered to run from the high tide mark to 7 ft below the high tide mark. It is a zone of high wave impact and is, therefore, a difficult environment to adapt to. Relatively few species of invertebrates inhabit the sandy intertidal habitat and most are very small and easily overlooked. However, there are three species which may be of concern, either because they are taken by commercial or sport fishermen or are an important prey source for local fish species.

Recent beach surveys by California Department of Fish and Game (CDF&G) found that Pismo clams (*Tivela stultorum*), bean clams (*Donax gouldi*) and sand crabs (*Emerita analoga*) occur on Mandalay Beach (Togstad and Haaker 1990). Sand crabs were also found by MBC biologists during a cursory survey of the beach on 16 August 1990.

Pismo clams live near the surface (8 to 12 inches deep), but are not rapid burrowers. Pismos have cyclical population densities: major storms, such as those of the winter of 1982-83, may cause dramatic population declines. There may also be several years of poor recruitment so that the clam population takes many years to return to its former level. Pismos grow slowly, approximately 20 mm per year during their first three to four years (Coe 1947) and take several years to reach the legal size of 4 inches.

On 25 July 1990, CDF&G conducted a survey for Pismo clams at three locations along the Ventura County coastline. One mile southeast of the Unocal Mandalay facility, CDF&G biologists found abundances averaging 13 clams/m^2 and ranging from 4 to 32/m^2. The mean shell length was 52 mm (2 in) and most of the clams were only two to three years old, indicating that 1987 and 1988 were good recruitment years. Few newly recruited (1990) clams were found (Togstad and Haaker 1990).

Bean clams live close to the sediment surface and require good aeration. CDF&G biologists also found bean clams during the Pismo clam survey, but they were not as abundant as the Pismo clams (David O. Parker, CDF&G, pers. comm.).

Sand crabs are found in the middle intertidal zone and also require good aeration. During a cursory examination on 16 August 1990, MBC scientists found sand crabs on the beach immediately in front of the Unocal Mandalay facility. There appeared to be two age cohorts: larger crabs in the size range 25 to 30 mm (carapace length), at a density of 2 to 3/m^2, and smaller crabs less than 20 mm, at a density of about 25/m^2.

During intertidal studies at the Mandalay Generating Station in 1971, MBC biologists found sand crabs at an average density of 19/m^2 (IRC and MBC 1972a). In other intertidal studies conducted at Ormond Beach, south of Mandalay Beach, investigators in 1972 found sand crabs at densities of 7/m^2, bean clams at densities of 6/m^2, and Pismo clams at 4.5/m^2 (IRC and MBC 1972b). Another intertidal study in 1974 at Ormond Beach found sand crabs in abundances of 4/m^2 and bean clams, which were patchy in distribution and occurred at only two of the five study sites, were found in numbers of 42/m^2 (MBC 1974). A study in 1975 at Ormond Beach found sand crabs in concentrations of 16/m^2, bean clams at 2.5/m^2 and Pismo clams at 1/m^2 (MBC 1975). Sand crabs are extremely mobile, rapid burrowers, and may quickly recolonize a disturbed area of beach.

No data are available on biomass of intertidal organisms in the above studies.

Project:

Due to the difficulty of working in the surf zone, Unocal proposes to leave the old pipeline in place. The alternative would be to remove of the old pipeline by jetting. Jetting will create a disturbed zone about 15 ft wide and 600 ft long (9,000 ft^2 or 842 m^2) through the intertidal at about a 45° angle to the shoreline, to a water depth of about 7 ft below the high tide mark.

Impacts:

The intertidal zone is subject to variable wave action, to water depths of about 7 ft below the high tide mark. This area could possibly contain up to 25 sand crabs/m^2 in the upper intertidal zone and as many as 42 bean clams/m^2 and 13 Pismo clams/m^2 in the lower intertidal zone. The jetting in of the new pipeline may disturb about 10,500 sand crabs, along with 17,680 bean and 11,000 Pismo clams. Additional jetting to create a trench for removal of the old pipeline would create at least twice the disturbed area and disrupt as many as 21,000 sand crabs and 35,000 bean and 22,000 Pismo clams. Most sand crabs will probably reburrow immediately when dislodged. However, if covered by too much sand, they may not be able to dig to the sediment surface and would soon suffocate. The bean and Pismo clams also require good aeration, but are not capable of burrowing as rapidly. Therefore, unless the clams are collected and carefully replaced at a suitable depth in stable sand, they would probably not survive the jetting procedure. The longer the zone is kept open to provide a working trench, the more severe the problem will be. Jetting to set the new pipeline would not involve as wide an area of disturbance as the working trench.

Repopulation of the disturbed zone by sand crabs will be rapid, but may require a much longer time for the two clam species. Pismos, especially, will probably not recruit as adults from the surrounding undisturbed zones, but will depend on good recruitment of juveniles during the next reproductive cycle. Transplanting of disturbed Pismo clams is not particularly effective, and the longer the clams are removed from the substrate, the greater the mortality (Togstad 1989). Smaller species of intertidal fauna are mostly short-lived and reproduce annually. It is expected that they will repopulated the disturbed area within a year.

Mitigation:

The least amount of disturbance possible would be advisable in the intertidal zone to prevent loss of bean and Pismo clams. Any clams found on the surface of the sand during the jetting in operation should be relocated and replaced in the sand as soon as possible. The clams should be placed lengthwise into the sand with the ligament end up, at a depth sufficient to completely cover the clam.

Table 1 is a summary of losses for the above three questions, with proposed and alternative scenarios:

Table 1.

Scenario	No. of Individuals Lost	Biomass Lost
Gravity settling offshore	<540,800	<101 lb
Jetting for offshore tie-in	>291,200	>55 lb
Jetting in new pipeline offshore	>12,000,000	>2,328 lb
Jetting trench for pipeline removal offshore	>12,000,000	>2,328 lb
Jetting in new pipeline in intertidal	<10,500 sand crabs >17,680 bean clams >11,000 Pismo clams	- - -
Jetting trench for pipeline removal intertidal	<10,500 sand crabs >17,680 bean clams >11,000 Pismo clams	- - -

- = no data

4. Commercial and Sport Fishing

Setting:

Commercial and sport fishing are limited in the Mandalay Beach vicinity due to the type of offshore habitat. Commercial fishing for California halibut (*Paralichthys californicus*) is conducted greater than one nautical mile offshore, for Dover sole (*Microstomus pacificus*) in at least 1800 ft (548 m) of water, for rockfish (*Sebastes* spp.) in greater than 180 ft (55 m) of water, and miscellaneous marketfish (including English and Rex sole, *Parophrys vetulus* and *Glyptocephalus zachirus*, respectively) in at least 600 ft (183 m) of water. Fishing for commercial invertebrates includes ridgeback shrimp (*Sicyonia ingentis*) and spot prawns (*Pandalus platyceros*)in greater than 180 ft (55 m) of water, crabs (*Cancer* spp.)in 60 to 240 ft (18 to 73 m) of water, lobsters (*Panulirus interruptus*) near rocky areas in 18-120 ft (6-37 m) of water, and urchins (*Strongylocentrotus* spp.) on shallow subtidal rocky reefs (MBC 1989). There is no commercial fishery for Pismo or bean clams in the area (David O. Parker, CDF&G, pers. comm.).

Nearshore sport fishing in the area is limited to kelp beds near the mouth of Channel Islands Harbor (Dave Parker, CDF&G, pers. comm.) and surf fishing from sand beaches. Fish species taken by surf anglers at Mandalay Beach include silver surfperch (*Hyperprosopon ellipticum*), barred surfperch (*Amphistichus argenteus*), yellowfin croaker (*Umbrina roncador*), and California corbina (*Menticirrhus undulatus*). California grunion (*Leuresthes tenuis*) may be taken (by hand only) on sandy beaches between June and March (grunion spawning or "runs" occur from March through September). (CDF&G et al. 1987). Barred surfperch, yellowfin croaker and California corbina feed largely on sand crabs (*Emerita analoga*) and bean clams (*Donax gouldi*) occurring in the intertidal zone (Fitch and Lavenberg 1971). Sand crabs are often used by surf fishermen as bait. There is probably very little clamming for Pismo clams at Mandalay Beach, as CDF&G did not find any Pismos of legal size (Togstad and Haaker 1990).

Project:

The construction phase of the pipeline replacement is projected to take three weeks. The offshore tie-in point is in about 26 ft of water. Jetting for the offshore tie-in, possible old pipeline removal and new pipeline replacement will produce some noise and activity disturbance, and turbidity in the water column in and near the construction site. In addition, there will be vessel traffic between the site and the local harbors, most probably Channel Islands Harbor.

Impacts:

The turbidity produced as a result of the jetting procedure may be a problem for fish, as they have been shown to suffer some mortality and sublethal stress due to turbidity (Soule and Oguri 1976). However, the due to increased boat activity and the noise expected to accompany the jetting, the fish will probably vacate temporarily the vicinity of the work and not be subjected to the suspended sediments. Fish have been shown to avoid noise (Suzuki et al. 1980). Furthermore, the sediments in the area are relatively coarse and will settle within a short period of time; the period of turbidity would not be long, and, therefore the downcurrent region affected by the suspended sediments would not be extensive.

The effects on the commercial fishing industry are not expected to be significant, as most fishing in the area is conducted in much deeper water. Sport surf fishing and taking of California grunion will be temporarily curtailed in the immediate vicinity of the pipeline work in the intertidal zone, due to disruption of the beach by the jetting in of the new pipeline and restricted beach access to the public by fencing around the construction site. Jetting in of the new pipeline will reduce the amount of sand crabs and bean clams available to the surf zone fish by 10,500 crabs and 17,680 clams. Jetting for removal of the old pipeline will double these numbers.

Mitigation:

Avoiding interference with commercial fishing will not be required. Adequate marking of all equipment and the exposed pipeline until it is buried should preclude snagging by errant trawl or purse seine nets. Intertidal work should be avoided during California grunion spawning (March through September).

5. Grey Whales

Setting:

Gray whales migrate along the entire California coast, from their feeding grounds in the Bering Sea to their calving and breeding areas in the lagoons of Baja California. In general, the southbound phase of the migration occurs from November through January. Off central California, the whales begin passing along the shore in late December (Dohl et al. 1982). Between Alaska and Point Conception, 95% of the whales travel within 1.2 mi (2 km) of shore (Rice and Wolman 1979), although at indentations in the coastline, they may follow a shorter path from headland to headland. Once southbound gray whales reach the Channel Islands, however, they follow a more offshore path around the islands, until they reach the southernmost of the islands, where they once again head towards the mainland (Leatherwood 1974). In aerial surveys conducted between Point Conception and the Mexican border from 1975 to 1978, 60% of the whales were sighted more than 5 mi (8 km) from shore (Dohl and Guess 1981). The northbound migration begins in February and continues through May (Poole 1981). The majority of the whales retrace their southward migration path around the Channel Islands until they reach Point Conception, where they resume a nearshore path (Leatherwood 1974).

Numerous studies have shown that migrating whales actively avoid areas of high turbidity and noise (Dohl et al. 1982). Thus, any strays which did approach the area during construction would circumnavigate the disturbance and thus avoid possible contact with vessels.

Project:

The pipeline installation and removal would involve increased activity, boat traffic and noise in an area offshore in about 26 ft of water during a three-week period.

Impacts:

The proposed pipeline work is unlikely to have any affect on California gray whales, as their migration routes are quite distant from the work location. In general, their bypassing of coastal indentations would make it extremely unlikely that any individuals would possibly stray near the shoreline of the Venture Basin.

Mitigation:

No mitigation efforts are considered to be necessary. Any whales which might possibly stray off coarse would avoid the work area where there is any activity or noise.

6. Dune and Beach Vegetation

Setting:

On 16 August 1990 MBC scientists inspected the beach in front of the Unocal facility where the pipeline replacement is to take place. Biologists identified, photographed and mapped the plant species on the sand dune and beach. During the survey the intertidal sand was examined for the presence of sand crabs, bean clams and Pismo clams.

The beach is composed of a narrow row of tall dunes (Plate 1) in front of the Unocal facility, separated from the facility wall by a 20-ft wide service road, a wide, flat beach sloping gradually up to the dunes (Plate 2), and a wide intertidal beach (Plate 3). There is a narrow footpath up the back slope of the dune and across the top of the dune near the south comer of the facility (Plate 4).

The vegetation is dependent on the beach topography, with beach grass (*Ammophile arenaria*), silver beachweed (*Ambrosia* [formerly *Franseria*] *chamissonia*)and sea fig (*Mesembryanthemum chilensis*) on the dunes (Plate 5), and scattered sea rocket (*Cakile maritima*) and heliotrope (*Heliotropium carassavicum*) on the beach sloping up to the dunes (Plate 6). There is no vegetation on the lower part of the beach between the beginning of the slope and the berm. A vegetation map and beach profile are shown in Figure 2. This same beach topography and vegetation is apparent southeast along Mandalay Beach to the housing development at 5th Street (Plate 7), and northwest to the discharge canal at the Mandalay Generating Station (Plate 8). The beach at the study site has some public use (surf fishing, sunbathing, jogging, bird watching, etc.) but this is limited, as beach access and the nearest public parking are about one-half mile southeast at 5th Street. A public county park is planned for the property southeast of the Unocal facility, between the dunes and Harbor Boulevard (Plate 9).

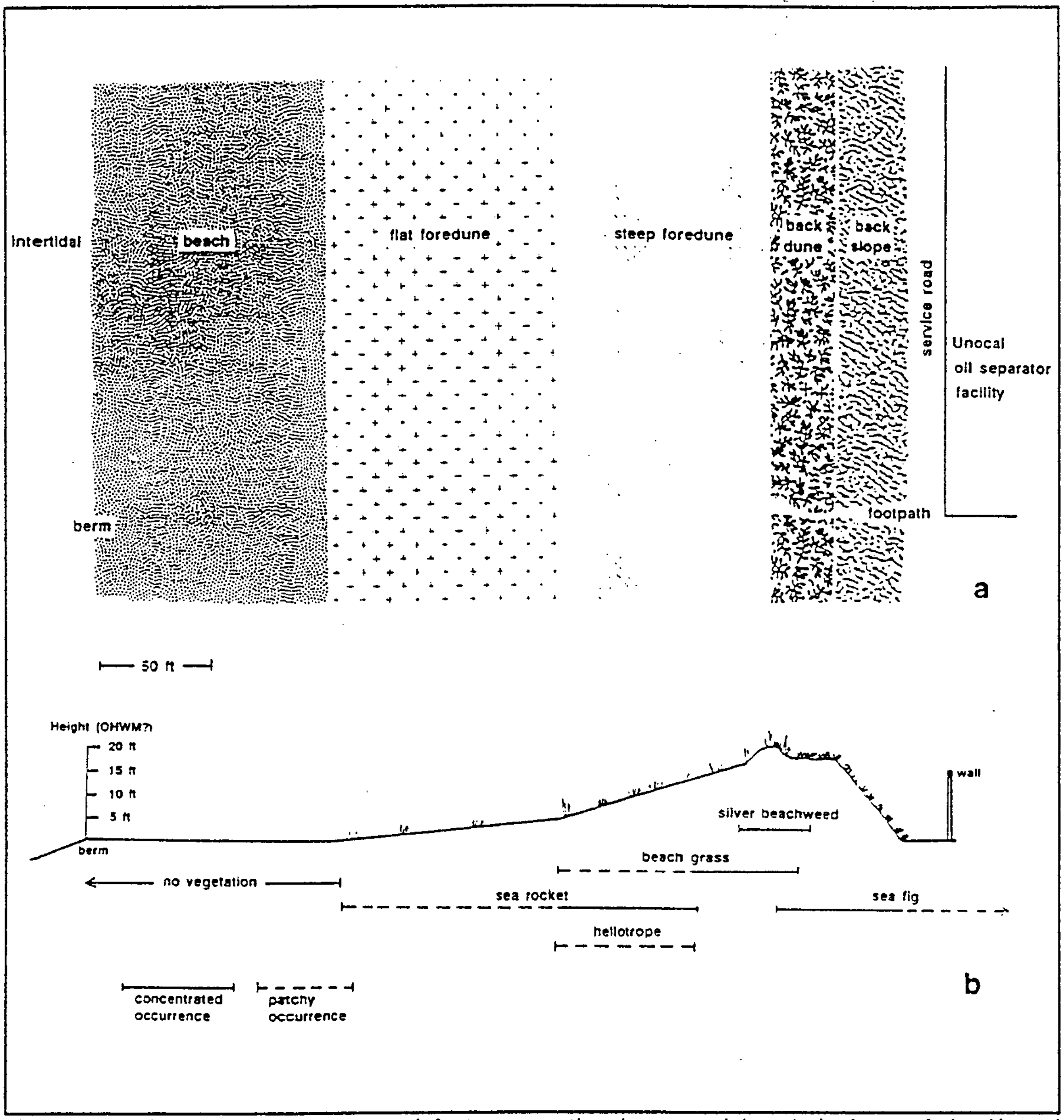


Figure 2. a) Vegetation zone map and features on the dunes and beach in front of the Unocal Mandalay facility, and b) beach profile of the dunes and beach at the southwest corner of the facility.

Of the five plant species observed on the beach and dunes, only silver beachweed and heliotrope are native to California (Munz 1973). Neither is considered to be rare, endangered or threatened (California Native Plant Society 1988). However, with continued destruction of natural beach and dune habitats, they could soon be so, at least locally.

- Silver beachweed is a low-growing, gray-green species, with inconspicuous flowers which become spiny seed pods (Figure 3, Plate 10).

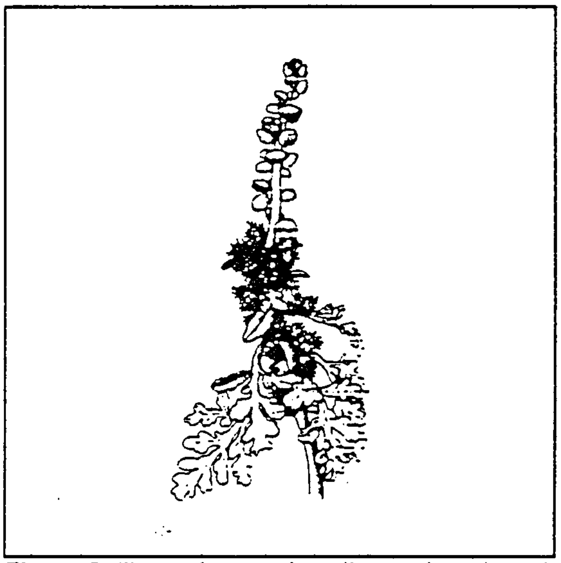


Figure 3. Illustration of silver beachweek (*Ambrosia chamissonia*). (Source: Dawson and Foster 1982.

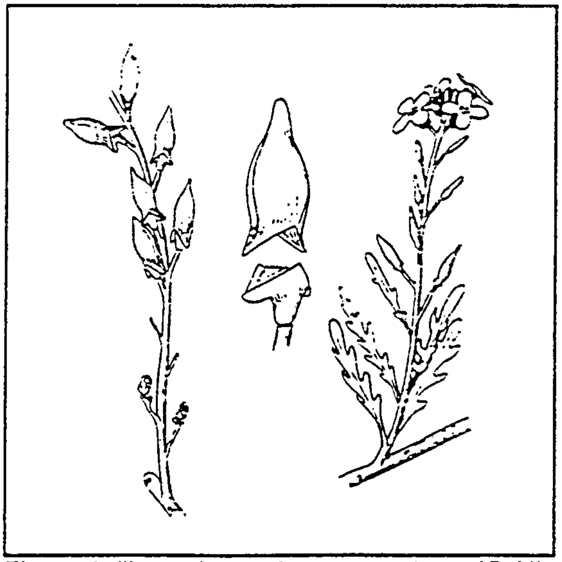


Figure 4. Illustration of sea rocket (*Cakile maritima*), showing flowering branch (right), mature seed pods on branch (left) and seed pod detached from its peduncle (center). (Source: Dawson and Foster 1982)

It was uncommon and patchy in the study area.

- Sea rocket was introduced to the West Coast from Europe in the 1930s (Dawson and Foster 1982) and has become established on beaches from Mendocino to Los Angeles County (Munz 1964). It is another spreading species in the mustard family, with small clusters of lavender flowers (Plate 12). It has large, pointed, single-seeded seed pods shaped like rockets (Figure 4). Rabbit scat on the sand near some of the sea rocket plants indicates that this species may be an important food source for rodents (Plate 13).

- Sea fig is an iceplant with large magenta flowers (Plate 14). It is native to South America and has become "naturalized" in many places in California (Dawson and Foster 1982).

- Beach grass (or marram grass) is a densely growing, tall (3 ft or 1 m), slender-leaved grass, scarcely branching, with long (4 to 12 inches or 10 to 30 cm) flower panicles (Plate 15). It is native to Europe, and has been used in many areas for stabilizing dunes (Dawson and Foster 1982). The beach grass on the dunes in front of the Unocal facility was brought from a site in Oregon in the recent past, presumably to help stabilize the dunes (Chris Culver, Unocal, pers. comm.).

Project:

There is a 10-inch conduit running under the sand dune, through which the old pipeline will be removed and the new pipeline replaced from inside of the Unocal facility. The beach end of the conduit opens on the gradual slope (Plate 16), at a depth of about 4 ft below the surface. From the base of the front of the dune to the water's edge, conventional excavation equipment would be used to expose the old pipeline so that it can be removed and the new pipeline placed and tied in. The old pipeline will be removed as far offshore in the intertidal zone as conventional excavation equipment can safely be used.

Impacts:

The use of excavation equipment and vehicle and foot traffic on the beach and dunes could have considerable impact on the dune plants and stability of the dunes. Since the conduit beneath the dunes eliminates the need to excavate through the dunes, there should be minimal effects except from foot traffic or inadvertent vehicle intrusion. The only vegetation expected to be affected by the excavation work will be that on the small area on the foredune at the conduit opening. The excavation area between the foredune and the seaward end of the excavation has no vegetation. The species expected to be affected by this limited disturbance are sea rocket and heliotrope. Excavation and temporary deposition of excavated material will eliminate these species from the disturbed areas and vehicle traffic will do additional damage. Although beach contours will be restored to the present topography, it is uncertain how quickly these two species would re-establish in the disturbed area once construction has been completed and the beach restored.

During the construction period, public use of the beach will be interrupted briefly.

Mitigation:

There will be severe depletion of the vegetation in the area directly disturbed. This area can be restricted to the immediate vicinity of the excavation by adequate fencing, both toward the dunes and to the northwest and southeast along the beach. Fencing along the beach, from the access point at 5th Street and some distance to the north where materials are expected to be stored, at the seaward edge of the sea rocket-heliotrope vegetation zone will prevent equipment and vehicle traffic from disturbing those species unnecessarily. An inset fencing configuration at the conduit opening area would limit vehicle movement to a relatively small area (Figure 5). A wooden staircase on the steep slope of the back dune would help prevent erosion due to the expected increased foot traffic across the dunes. Fencing or signing would also help to limit damage to the vegetation on the top of the dunes.

After work is completed and the beach contours restored, it could take several years for sea rocket to re-establish on the restored sand. Collection of seeds from those plants expected to be eliminated during the work and sowing of those seeds after the beach is stabilized, preferably just before or during the rainy season, would be expected to accelerate the re-establishment process.

Disruption of public access to the beach will be minimal, with the least effect occurring during the winter months when there are fewer beach visitors.

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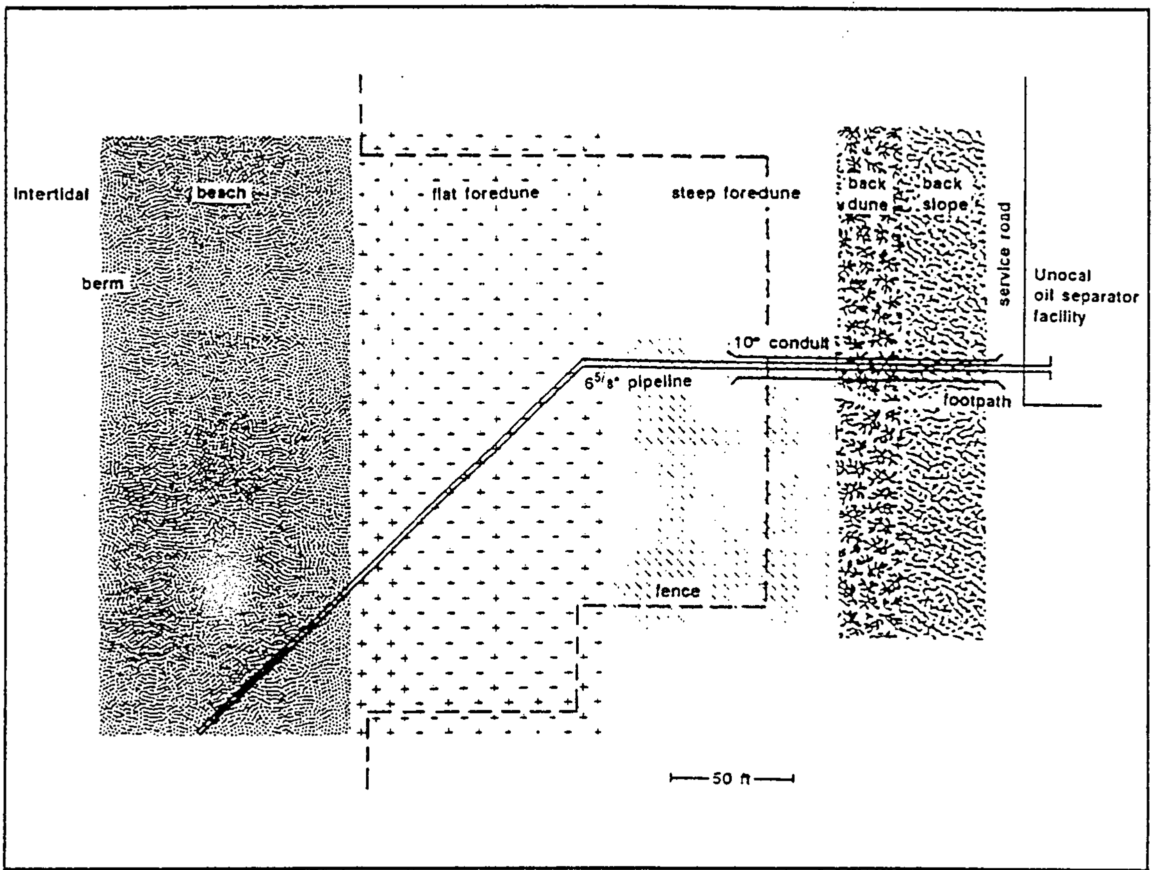

Figure 5. Suggested fencing configuration to reduce damage to the foredune vegetation.

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ENVIRONMENTAL ASSESSMENT AND BEACH VEGETATION STUDY FOR PROPOSED PLATFORM GINA PIPELINE REPLACEMENT MANDALAY BEACH, VENTURA COUNTY, CALIFORNIA

16 August 1990

Prepared for Unocal Corporation
Unocal Oil & Gas Division
Ventura, California

Prepared by MBC Applied Environmental Sciences
947 Newhall Street
Costa Mesa, California 92627

Plate 1. Top of the dunes in front of the Unocal Mandalay facility, looking northwest.

Plate 2. Beach and foredunes in front of the Unocal Mandalay facility.

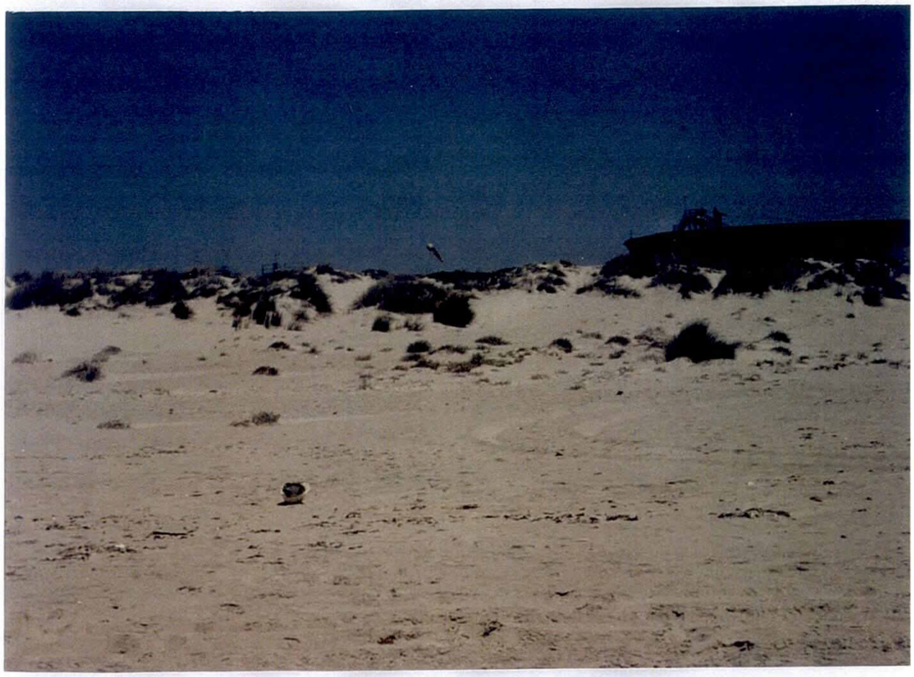

Plate 3. Upper intertidal beach in front of the Unocal Mandalay facility, looking northwest.

Plate 4. Back slope of the dunes in front of the Unocal Mandalay facility, showing the southwest wall of facility, the service road between the wall and the dunes, and the footpath leading up the back slope of the dunes.

Plate 5. Vegetation on the top of the dunes, consisting of beach grass(*Ammophile arenaria*), silver beachweed (*Ambrosia chamissonia*) and sea fig (*Mesembryanthemum chilensis*).

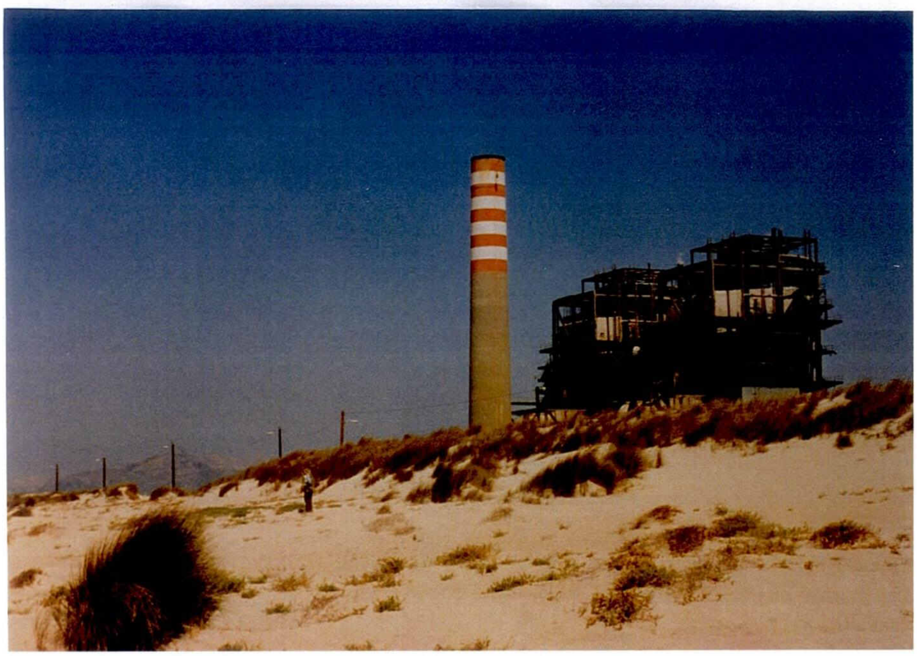

Plate 6. Vegetation on the foredune and upper beach, consisting of sea rocket (*Cakile maritima*) and heliotrope (*Heliotropium carassavicum*).

Plate 7. Dunes and beach to the southeast of the Unocal Mandalay facility.

Plate 8. Dunes and beach to the northwest of the Unocal Mandalay facility, Mandalay Generating Station discharge canal in background.

Plate 9. Site of future public park south of the Unocal Mandalay facility between the dunes and Harbor Boulevard, showing extensive coverage by sea fig.

Plate 10. Silver beachweed (*Ambrosia chamissonia*).

Plate 11. Heliotrope (*Heliotropium carassavicum*).

Plate 12. Sea rocket (*Cakile maritima*).

Plate 13. Rabbit scat on sand next to sea rocket.

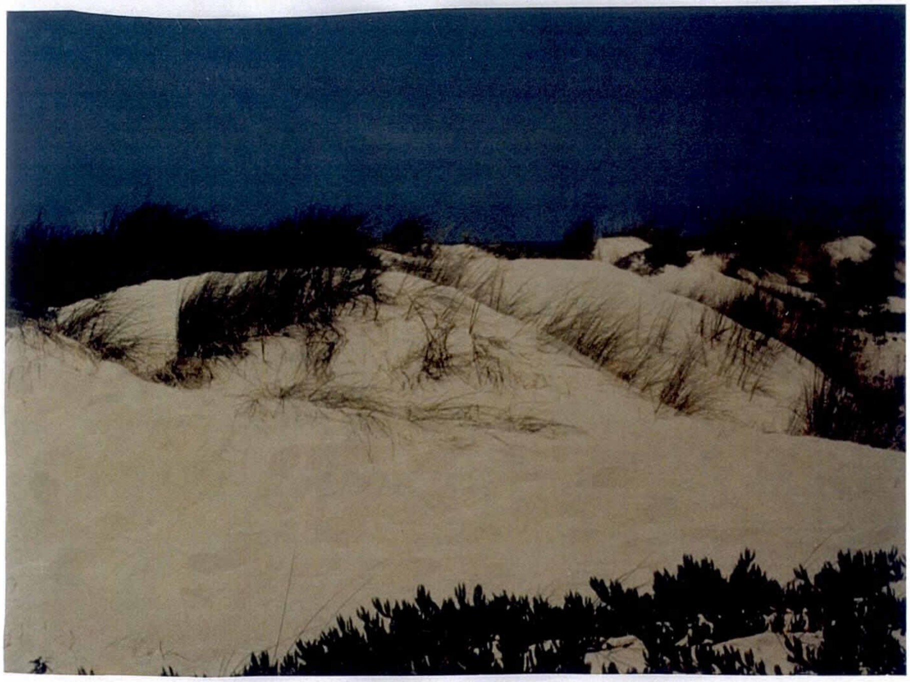

Plate 14. Sea fig (*Mesembryanthemum chilensis*) in foreground.

Plate 15. Beach grass, or marram grass (*Ammophile arenaria*).

Plate 16. Site of seaward end of conduit under the dunes (Chris Culver in background) and onshore tie-in point (MBC biologist in foreground).

APPENDIX VOLUME 1
ITEM C

Environmental Assessment

MBC

ENVIRONMENTAL ASSESSMENT AND BEACH VEGETATION STUDY FOR PROPOSED PLATFORM GINA PIPELINE REPLACEMENT MANDALAY BEACH, VENTURA COUNTY, CALIFORNIA

16 August 1990

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16 August 1990

INTRODUCTION

Unocal has proposed to replace 3,000 ft of $6^5/8$ inch pipeline previously used to return water from the Mandalay oil separator facility to Platform Gina. A new pipeline would be converted to transport produced natural gas from Gina to the Mandalay facility.

Of the 3,000 ft of pipeline to be replaced, 700 ft are onshore above the Mean High Tide Line (MHTL) and the remaining 2,300 ft are offshore, in the intertidal surf and subtidal zones (Figure 1). The onshore section of the old pipeline will be uncovered, removed and replaced with new pipeline using conventional equipment. Offshore, Unocal proposes to lay a new pipeline parallel to the old one and to allow it to bury itself by the forces of gravity and hydraulic action. Hydraulic jetting would be limited to nearshore areas where the surf zone energy is not sufficient to bury the new pipeline. Time required to complete the task once work has begun has been estimated to be three (3) weeks.

Questions have been raised regarding several environmental aspects of the intended work:

1. Unocal proposes to allow the offshore portion of the new pipeline to settle into place by gravity and to be covered gradually by sediments. The alternative suggestion has been to jet in the new pipeline to assure immediate placement. What would be the relative impact of each scenario on the benthic and epibenthic fauna?

2. Unocal proposes to leave the old offshore pipeline in place and run the new pipeline parallel to it. The alternative is to jet a trench for the removal of the old pipeline. What would be the impact of each case?

3. Unocal will jet in the new pipeline in the intertidal zone, but proposes to leave the old pipeline in place instead of removing it by jetting a working trench. What would be the impacts of leaving it in place versus jetting to remove it in the intertidal zone?

4. What would be the impact of the project on sport and commercial fishing in the offshore area?

5. What is the likelihood or magnitude of impacts on gray whales (*Eschrichtius robustus*) during their migrations along the California coast?

6. What is the nature of the vegetation of the dunes and the adjacent beach in front of the Unocal Mandalay facility?

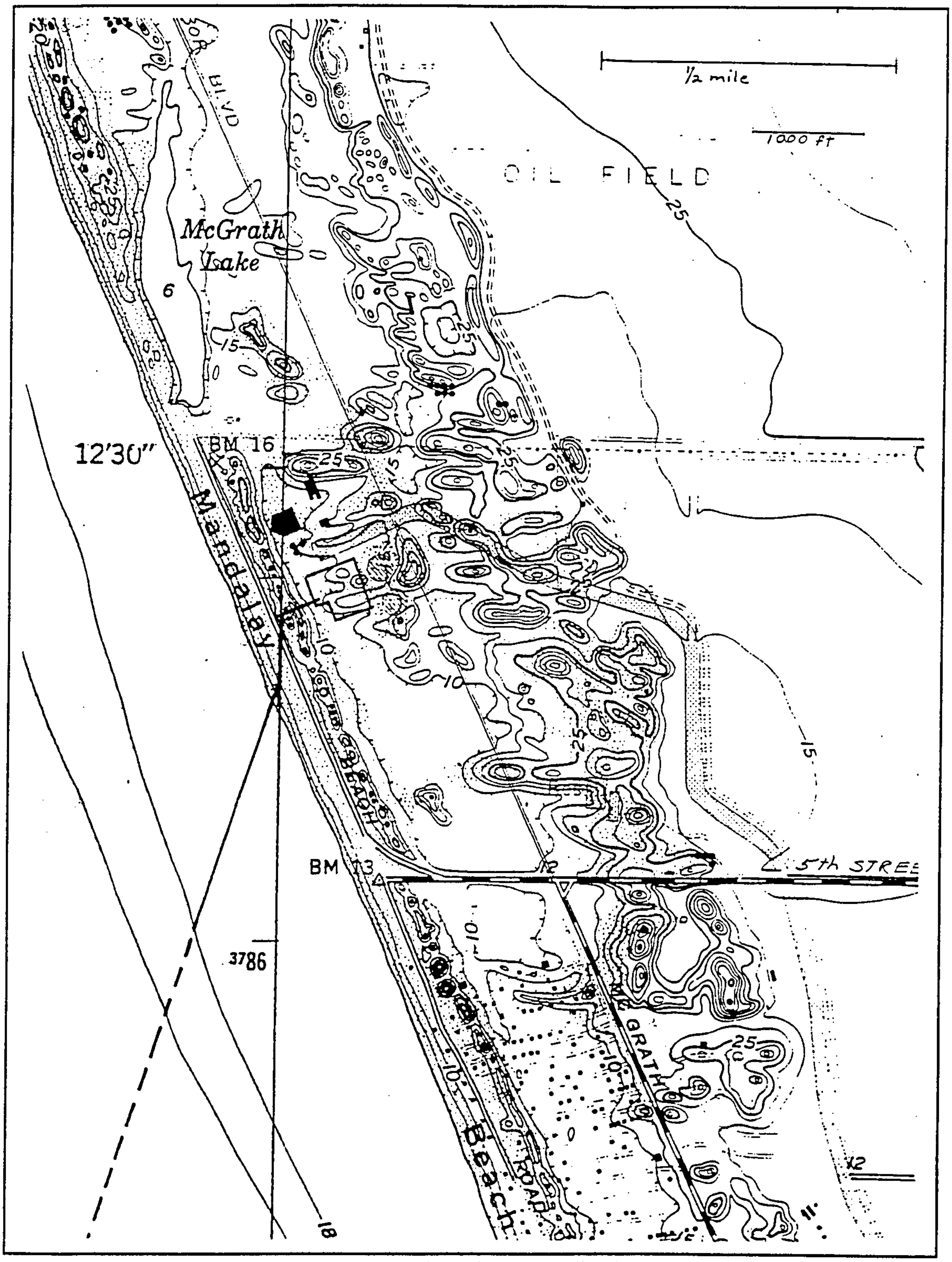

Figure 1. Map of Mandalay Beach, showing orientation of pipeline from the Unocal facility to Platform Gina.

DISCUSSION OF ENVIRONMENTAL ASSESSMENT

1. Self-burial Versus Jetting in the New Pipeline

Setting:

The $6^{5}/8$ inch replacement pipeline to be laid offshore, exclusive of the intertidal zone, will run from a water depth of about 7 ft (MHTL) to about 26 ft, a distance of about 1,700 ft. Benthic infauna studies in the area immediately offshore from the Unocal Mandalay facility indicate that at depths of approximately 20 ft, the number of organisms in the sediments is extremely variable, especially seasonally. In 1986, the mean abundance ranged from 3 individuals/0.01 m^2 in the winter to 31/0.01 m^2 in the summer, and in 1988, from 5 individuals/0.01 m^2 in the winter to 52/0.01 m^2 in the summer. The number of species also varied by season. In 1986, number of species increased from 2 in winter to 14 in summer, while in 1988, it increased from 4 in winter to 17 in summer (MBC Mandalay 1986, 1988).

Biomass of infaunal organisms ranged from 85 g/m^2 in winter to 444 g/m^2 in summer in 1988. Station values varied from 8 g/m^2 to 1016 g/m^2, due to the patchy distribution of Pacific sand dollars (*Dendraster excentricus*) (MBC 1988). Since the offshore slope in the Mandalay area has a gentle gradient, it would be expected that the subtidal infaunal community would be similar over short distances.

Data from otter trawls along the 20-ft isobath in the study area indicate that there are at least 24 species of fish and 18 species of macroinvertebrates in the area. The most abundant species of fish in surveys conducted from 1978 to 1988 were white croaker (*Genyonemus lineatus*), queenfish (*Seriphus politus*) and barred surfperch (*Amphistichus argenteus*). The most common invertebrate species were Pacific sand dollar (*Dendraster excentricus*) and spotted bay shrimp (*Crangon nigromaculata*). As with the infauna, numbers of individuals and species were greater in summer than in winter (MBC 1988).

Project:

Unocal proposes to lay the new pipeline on the surface of the sediment and allow it to gradually settle into place by gravity. The current pipeline has settled to a depth of four ft. In order to uncover the offshore tie-in to the old section, a 15-ft-wide, 40-ft-long trench will have to be jetted at the offshore tie-in location, 2,300 ft offshore from the high tide mark. Alternatively, the new pipeline would be jetted in to the desired depth. The area of disturbance would be about 15 ft wide by 1,700 ft long in the shallow subtidal zone.

Impacts:

Allowing the pipeline to settle by gravity would have some impact on the infaunal organisms in the immediate path of the settling pipeline. The maximum impact (assuming a 8-inch path of disturbance) would be 540,800 individuals with a biomass of 101 lb (46 kg) being displaced. However, the magnitude of the disruption would be small in both areal extent (limited to a narrow zone around the $6^{5}/8$ inch pipeline) and severity (organisms would not be separated from their sediment substrate) and would occur gradually over a long period of time. Most soft bottom organisms are mobile and would be able to readjust position from such gradual pressure. Until the new pipeline has buried itself, it may block longshore movement of motile epifaunal species, but would not affect fish or other swimming species.

The area which would be disturbed by jetting along the entire subtidal in order to replace the pipeline would be approximately 25,500 ft^2 (2,383 m^2). At maximum impact, approximately 12 million infaunal organisms weighing 2,328 lb (1,058 kg) would be displaced. During the jetting procedure, organisms would be suspended in the water column, exposing them to predation by fish and epibenthic invertebrates. It is assumed that there would be 100% mortality of any organisms suspended during the jetting procedure.

In addition to the direct effects of disturbance by jetting, there would be a zone of sediment redeposition beyond the sides of the trench, which would smother any organisms which were not able to move rapidly enough to the sediment surface to maintain their suitable orientation and depth. The extent of mortality would depend on the volume of material removed, and the local current velocity and direction during the procedure. Therefore, there would be an area of unknown extent with less than 100% mortality of infauna; if the area impacted is twice that of the trench and the mortality is 50%, another 12,000,000 organisms or 2,328 lb would be lost.

In either case, in order to uncover the section of pipeline where the new pipeline will tie into the old section to the Platform, a 40-ft-long trench will have to be jetted. This will disturb about 600 ft^2 (56 m^2) of substrate and will suspend, at most, 291,200 organisms, weighing about 55 lb (25 kg) (MBC 1988). The extent of adjacent redeposition of sediment will be small, and the period of time involved in the tie-in procedure will be short.

Mitigation:

There will be some loss of infaunal organisms involved in either method of pipeline placement. The jetted trench would have a much greater immediate impact on the infaunal community in and near the trench. However, most benthic infaunal organisms are short-lived species which reproduce annually. It would be expected, therefore, that the disturbed areas would be repopulated from the surrounding sediments within two years.

2. Removal of Old Pipeline by Jetting in the Subtidal Zone Versus Leaving in Place

Setting:

The setting is the same as that for jetting in 1,700 ft of new pipeline in the subtidal zone.

Project:

Unocal proposes to leave the old pipeline in place, under approximately 4 ft of sediment. The alternative would be to jet a trench 15 ft wide and 1,700 ft long for removal of the old pipeline.

Impact:

Jetting in a trench to expose and remove the old pipeline would disturb an area of approximately 25,500 ft^2 (2,383 m^2), with a possible impact on 12 million benthic infaunal organisms weighing 2,328 lb (1,058 kg). Considering that the trench would have to be kept open for a much longer period of time than required for jetting in the new pipeline, the impacts would be even greater, as the trench would continue to fill in, due to downcurrent sand transport. The zone of redeposition and smothering would be greater the longer the trench has to be kept open. Therefore, the effect of removing the old pipeline and jetting in the new pipeline would be at least twice that for jetting in the new pipeline alone.

Mitigation:

The impact of removing the old pipeline would be considerable. Leaving the pipeline buried under 4 ft of sediment would have no impact on the infaunal organisms.

3. Removal of Old Pipeline by Jetting in the Surf Zone

Setting:

The intertidal zone, for the purposes of this study, is considered to run from the high tide mark to 7 ft below the high tide mark. It is a zone of high wave impact and is, therefore, a difficult environment to adapt to. Relatively few species of invertebrates inhabit the sandy intertidal habitat and most are very small and easily overlooked. However, there are three species which may be of concern, either because they are taken by commercial or sport fishermen or are an important prey source for local fish species.

Recent beach surveys by California Department of Fish and Game (CDF&G) found that Pismo clams (*Tivela stultorum*), bean clams (*Donax gouldi*) and sand crabs (*Emerita analoga*) occur on Mandalay Beach (Togstad and Haaker 1990). Sand crabs were also found by MBC biologists during a cursory survey of the beach on 16 August 1990.

Pismo clams live near the surface (8 to 12 inches deep), but are not rapid burrowers. Pismos have cyclical population densities: major storms, such as those of the winter of 1982-83, may cause dramatic population declines. There may also be several years of poor recruitment so that the clam population takes many years to return to its former level. Pismos grow slowly, approximately 20 mm per year during their first three to four years (Coe 1947) and take several years to reach the legal size of 4 inches.

On 25 July 1990, CDF&G conducted a survey for Pismo clams at three locations along the Ventura County coastline. One mile southeast of the Unocal Mandalay facility, CDF&G biologists found abundances averaging 13 clams/m^2 and ranging from 4 to 32/m^2. The mean shell length was 52 mm (2 in) and most of the clams were only two to three years old, indicating that 1987 and 1988 were good recruitment years. Few newly recruited (1990) clams were found (Togstad and Haaker 1990).

Bean clams live close to the sediment surface and require good aeration. CDF&G biologists also found bean clams during the Pismo clam survey, but they were not as abundant as the Pismo clams (David O. Parker, CDF&G, pers. comm.).

Sand crabs are found in the middle intertidal zone and also require good aeration. During a cursory examination on 16 August 1990, MBC scientists found sand crabs on the beach immediately in front of the Unocal Mandalay facility. There appeared to be two age cohorts: larger crabs in the size range 25 to 30 mm (carapace length), at a density of 2 to 3/m^2, and smaller crabs less than 20 mm, at a density of about 25/m^2.

During intertidal studies at the Mandalay Generating Station in 1971, MBC biologists found sand crabs at an average density of 19/m^2 (IRC and MBC 1972a). In other intertidal studies conducted at Ormond Beach, south of Mandalay Beach, investigators in 1972 found sand crabs at densities of 7/m^2, bean clams at densities of 6/m^2, and Pismo clams at 4.5/m^2 (IRC and MBC 1972b). Another intertidal study in 1974 at Ormond Beach found sand crabs in abundances of 4/m^2 and bean clams, which were patchy in distribution and occurred at only two of the five study sites, were found in numbers of 42/m^2 (MBC 1974). A study in 1975 at Ormond Beach found sand crabs in concentrations of 16/m^2, bean clams at 2.5/m^2 and Pismo clams at 1/m^2 (MBC 1975). Sand crabs are extremely mobile, rapid burrowers, and may quickly recolonize a disturbed area of beach.

No data are available on biomass of intertidal organisms in the above studies.

Project:

Due to the difficulty of working in the surf zone, Unocal proposes to leave the old pipeline in place. The alternative would be to remove of the old pipeline by jetting. Jetting will create a disturbed zone about 15 ft wide and 600 ft long (9,000 ft^2 or 842 m^2) through the intertidal at about a 45° angle to the shoreline, to a water depth of about 7 ft below the high tide mark.

Impacts:

The intertidal zone is subject to variable wave action, to water depths of about 7 ft below the high tide mark. This area could possibly contain up to 25 sand crabs/m^2 in the upper intertidal zone and as many as 42 bean clams/m^2 and 13 Pismo clams/m^2 in the lower intertidal zone. The jetting in of the new pipeline may disturb about 10,500 sand crabs, along with 17,680 bean and 11,000 Pismo clams. Additional jetting to create a trench for removal of the old pipeline would create at least twice the disturbed area and disrupt as many as 21,000 sand crabs and 35,000 bean and 22,000 Pismo clams. Most sand crabs will probably reburrow immediately when dislodged. However, if covered by too much sand, they may not be able to dig to the sediment surface and would soon suffocate. The bean and Pismo clams also require good aeration, but are not capable of burrowing as rapidly. Therefore, unless the clams are collected and carefully replaced at a suitable depth in stable sand, they would probably not survive the jetting procedure. The longer the zone is kept open to provide a working trench, the more severe the problem will be. Jetting to set the new pipeline would not involve as wide an area of disturbance as the working trench.

Repopulation of the disturbed zone by sand crabs will be rapid, but may require a much longer time for the two clam species. Pismos, especially, will probably not recruit as adults from the surrounding undisturbed zones, but will depend on good recruitment of juveniles during the next reproductive cycle. Transplanting of disturbed Pismo clams is not particularly effective, and the longer the clams are removed from the substrate, the greater the mortality (Togstad 1989). Smaller species of intertidal fauna are mostly short-lived and reproduce annually. It is expected that they will repopulated the disturbed area within a year.

Mitigation:

The least amount of disturbance possible would be advisable in the intertidal zone to prevent loss of bean and Pismo clams. Any clams found on the surface of the sand during the jetting in operation should be relocated and replaced in the sand as soon as possible. The clams should be placed lengthwise into the sand with the ligament end up, at a depth sufficient to completely cover the clam.

Table 1 is a summary of losses for the above three questions, with proposed and alternative scenarios:

Table 1.

Scenario	No. of Individuals Lost	Biomass Lost
Gravity settling offshore	<540,800	<101 lb
Jetting for offshore tie-in	>291,200	>55 lb
Jetting in new pipeline offshore	>12,000,000	>2,328 lb
Jetting trench for pipeline removal offshore	>12,000,000	>2,328 lb
Jetting in new pipeline in intertidal	<10,500 sand crabs >17,680 bean clams >11,000 Pismo clams	- - -
Jetting trench for pipeline removal intertidal	<10,500 sand crabs >17,680 bean clams >11,000 Pismo clams	- - -

- = no data

4. Commercial and Spcrt Fishing

Setting:

Commercial and sport fishing are limited in the Mandalay Beach vicinity due to the type of offshore habitat. Commercial fishing for California halibut (*Paralichthys californicus*) is conducted greater than one nautical mile offshore, for Dover sole (*Microstomus pacificus*) in at least 1800 ft (548 m) of water, for rockfish (*Sebastes* spp.) in greater than 180 ft (55 m) of water, and miscellaneous marketfish (including English and Rex sole, *Parophrys vetulus* and *Glyptocephalus zachirus*, respectively) in at least 600 ft (183 m) of water. Fishing for commercial invertebrates includes ridgeback shrimp (*Sicyonia ingentis*) and spot prawns (*Pandalus platyceros*)in greater than 180 ft (55 m) of water, crabs (*Cancer* spp.)in 60 to 240 ft (18 to 73 m) of water, lobsters (*Panulirus interruptus*) near rocky areas in 18-120 ft (6-37 m) of water, and urchins (*Strongylocentrotus* spp.) on shallow subtidal rocky reefs (MBC 1989). There is no commercial fishery for Pismo or bean clams in the area (David O. Parker, CDF&G, pers. comm.).

Nearshore sport fishing in the area is limited to kelp beds near the mouth of Channel Islands Harbor (Dave Parker, CDF&G, pers. comm.) and surf fishing from sand beaches. Fish species taken by surf anglers at Mandalay Beach include silver surfperch (*Hyperprosopon ellipticum*), barred surfperch (*Amphistichus argenteus*), yellowfin croaker (*Umbrina roncador*), and California corbina (*Menticirrhus undulatus*). California grunion (*Leuresthes tenuis*) may be taken (by hand only) on sandy beaches between June and March (grunion spawning or "runs" occur from March through September). (CDF&G et al. 1987). Barred surfperch, yellowfin croaker and California corbina feed largely on sand crabs (*Emerita analoga*) and bean clams (*Donax gouldi*) occurring in the intertidal zone (Fitch and Lavenberg 1971). Sand crabs are often used by surf fishermen as bait. There is probably very little clamming for Pismo clams at Mandalay Beach, as CDF&G did not find any Pismos of legal size (Togstad and Haaker 1990).

Project:

The construction phase of the pipeline replacement is projected to take three weeks. The offshore tie-in point is in about 26 ft of water. Jetting for the offshore tie-in, possible old pipeline removal and new pipeline replacement will produce some noise and activity disturbance, and turbidity in the water column in and near the construction site. In addition, there will be vessel traffic between the site and the local harbors, most probably Channel Islands Harbor.

Impacts:

The turbidity produced as a result of the jetting procedure may be a problem for fish, as they have been shown to suffer some mortality and sublethal stress due to turbidity (Soule and Oguri 1976). However, the due to increased boat activity and the noise expected to accompany the jetting, the fish will probably vacate temporarily the vicinity of the work and not be subjected to the suspended sediments. Fish have been shown to avoid noise (Suzuki et al. 1980). Furthermore, the sediments in the area are relatively coarse and will settle within a short period of time; the period of turbidity would not be long, and, therefore the downcurrent region affected by the suspended sediments would not be extensive.

The effects on the commercial fishing industry are not expected to be significant, as most fishing in the area is conducted in much deeper water. Sport surf fishing and taking of California grunion will be temporarily curtailed in the immediate vicinity of the pipeline work in the intertidal zone, due to disruption of the beach by the jetting in of the new pipeline and restricted beach access to the public by fencing around the construction site. Jetting in of the new pipeline will reduce the amount of sand crabs and bean clams available to the surf zone fish by 10,500 crabs and 17,680 clams. Jetting for removal of the old pipeline will double these numbers.

Mitigation:

Avoiding interference with commercial fishing will not be required. Adequate marking of all equipment and the exposed pipeline until it is buried should preclude snagging by errant trawl or purse seine nets. Intertidal work should be avoided during California grunion spawning (March through September).

5. Grey Whales

Setting:

Gray whales migrate along the entire California coast, from their feeding grounds in the Bering Sea to their calving and breeding areas in the lagoons of Baja California. In general, the southbound phase of the migration occurs from November through January. Off central California, the whales begin passing along the shore in late December (Dohl et al. 1982). Between Alaska and Point Conception, 95% of the whales travel within 1.2 mi (2 km) of shore (Rice and Wolman 1979), although at indentations in the coastline, they may follow a shorter path from headland to headland. Once southbound gray whales reach the Channel Islands, however, they follow a more offshore path around the islands, until they reach the southernmost of the islands, where they once again head towards the mainland (Leatherwood 1974). In aerial surveys conducted between Point Conception and the Mexican border from 1975 to 1978, 60% of the whales were sighted more than 5 mi (8 km) from shore (Dohl and Guess 1981). The northbound migration begins in February and continues through May (Poole 1981). The majority of the whales retrace their southward migration path around the Channel Islands until they reach Point Conception, where they resume a nearshore path (Leatherwood 1974).

Numerous studies have shown that migrating whales actively avoid areas of high turbidity and noise (Dohl et al. 1982). Thus, any strays which did approach the area during construction would circumnavigate the disturbance and thus avoid possible contact with vessels.

Project:

The pipeline installation and removal would involve increased activity, boat traffic and noise in an area offshore in about 26 ft of water during a three-week period.

Impacts:

The proposed pipeline work is unlikely to have any affect on California gray whales, as their migration routes are quite distant from the work location. In general, their bypassing of coastal indentations would make it extremely unlikely that any individuals would possibly stray near the shoreline of the Venture Basin.

Mitigation:

No mitigation efforts are considered to be necessary. Any whales which might possibly stray off coarse would avoid the work area where there is any activity or noise.

6. Dune and Beach Vegetation

Setting:

On 16 August 1990 MBC scientists inspected the beach in front of the Unocal facility where the pipeline replacement is to take place. Biologists identified, photographed and mapped the plant species on the sand dune and beach. During the survey the intertidal sand was examined for the presence of sand crabs, bean clams and Pismo clams.

The beach is composed of a narrow row of tall dunes (Plate 1) in front of the Unocal facility, separated from the facility wall by a 20-ft wide service road, a wide, flat beach sloping gradually up to the dunes (Plate 2), and a wide intertidal beach (Plate 3). There is a narrow footpath up the back slope of the dune and across the top of the dune near the south corner of the facility (Plate 4).

The vegetation is dependent on the beach topography, with beach grass (*Ammophile arenaria*), silver beachweed (*Ambrosia* [formerly *Franseria*] *chamissonia*)and sea fig (*Mesembryanthemum chilensis*) on the dunes (Plate 5), and scattered sea rocket (*Cakile maritima*) and heliotrope (*Heliotropium carassavicum*) on the beach sloping up to the dunes (Plate 6). There is no vegetation on the lower part of the beach between the beginning of the slope and the berm. A vegetation map and beach profile are shown in Figure 2. This same beach topography and vegetation is apparent southeast along Mandalay Beach to the housing development at 5th Street (Plate 7), and northwest to the discharge canal at the Mandalay Generating Station (Plate 8). The beach at the study site has some public use (surf fishing, sunbathing, jogging, bird watching, etc.) but this is limited, as beach access and the nearest public parking are about one-half mile southeast at 5th Street. A public county park is planned for the property southeast of the Unocal facility, between the dunes and Harbor Boulevard (Plate 9).

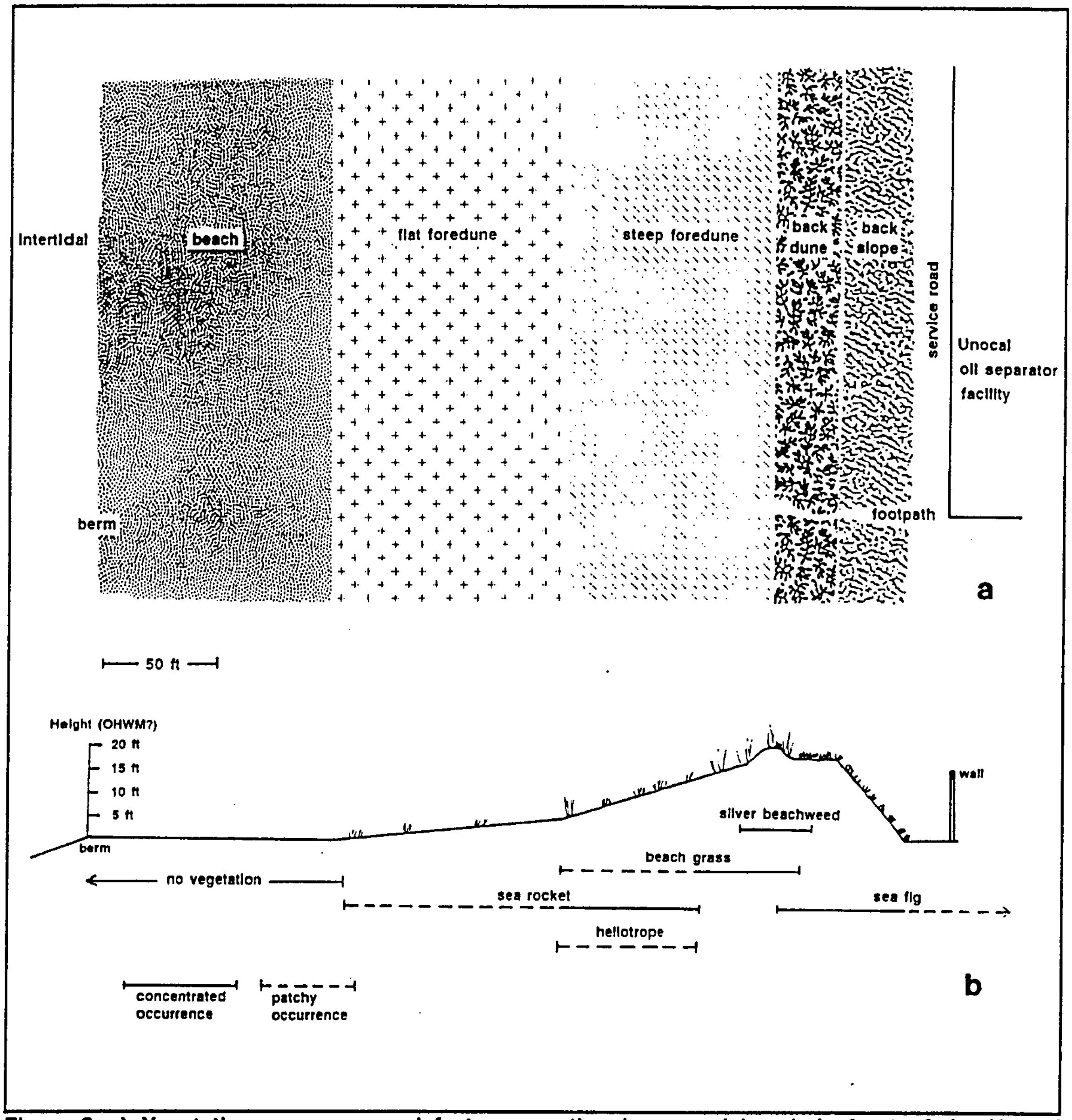

Figure 2. a) Vegetation zone map and features on the dunes and beach in front of the Unocal Mandalay facility, and b) beach profile of the dunes and beach at the southwest corner of the facility.

Of the five plant species observed on the beach and dunes, only silver beachweed and heliotrope are native to California (Munz 1973). Neither is considered to be rare, endangered or threatened (California Native Plant Society 1988). However, with continued destruction of natural beach and dune habitats, they could soon be so, at least locally.

- Silver beachweed is a low-growing, gray-green species, with inconspicuous flowers which become spiny seed pods (Figure 3, Plate 10).

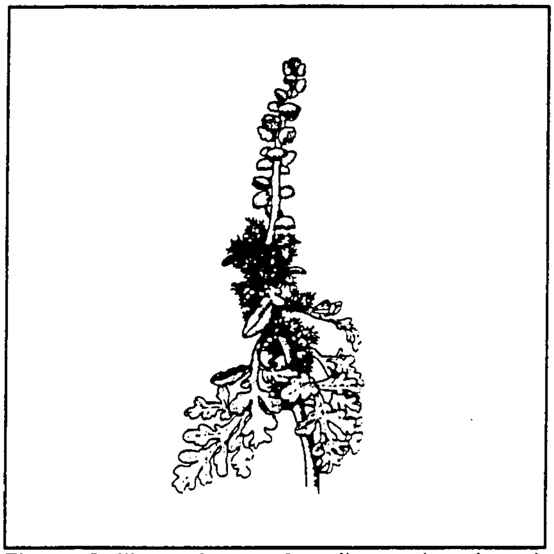

Figure 3. Illustration of silver beachweek (*Ambrosia chamissonia*). (Source: Dawson and Foster 1982.

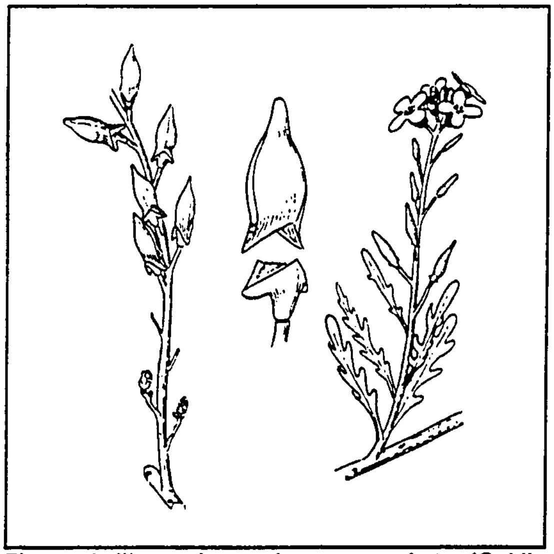

Figure 4. Illustration of sea rocket (*Cakile maritima*), showing flowering branch (right), mature seed pods on branch (left) and seed pod detached from its peduncle (center). (Source: Dawson and Foster 1982)

It was uncommon and patchy in the study area.

- Sea rocket was introduced to the West Coast from Europe in the 1930s (Dawson and Foster 1982) and has become established on beaches from Mendocino to Los Angeles County (Munz 1964). It is another spreading species in the mustard family, with small clusters of lavender flowers (Plate 12). It has large, pointed, single-seeded seed pods shaped like rockets (Figure 4). Rabbit scat on the sand near some of the sea rocket plants indicates that this species may be an important food source for rodents (Plate 13).

- Sea fig is an iceplant with large magenta flowers (Plate 14). It is native to South America and has become "naturalized" in many places in California (Dawson and Foster 1982).

- Beach grass (or marram grass) is a densely growing, tall (3 ft or 1 m), slender-leaved grass, scarcely branching, with long (4 to 12 inches or 10 to 30 cm) flower panicles (Plate 15). It is native to Europe, and has been used in many areas for stabilizing dunes (Dawson and Foster 1982). The beach grass on the dunes in front of the Unocal facility was brought from a site in Oregon in the recent past, presumably to help stabilize the dunes (Chris Culver, Unocal, pers. comm.).

Project:

There is a 10-inch conduit running under the sand dune, through which the old pipeline will be removed and the new pipeline replaced from inside of the Unocal facility. The beach end of the conduit opens on the gradual slope (Plate 16), at a depth of about 4 ft below the surface. From the base of the front of the dune to the water's edge, conventional excavation equipment would be used to expose the old pipeline so that it can be removed and the new pipeline placed and tied in. The old pipeline will be removed as far offshore in the intertidal zone as conventional excavation equipment can safely be used.

Impacts:

The use of excavation equipment and vehicle and foot traffic on the beach and dunes could have considerable impact on the dune plants and stability of the dunes. Since the conduit beneath the dunes eliminates the need to excavate through the dunes, there should be minimal effects except from foot traffic or inadvertent vehicle intrusion. The only vegetation expected to be affected by the excavation work will be that on the small area on the foredune at the conduit opening. The excavation area between the foredune and the seaward end of the excavation has no vegetation. The species expected to be affected by this limited disturbance are sea rocket and heliotrope. Excavation and temporary deposition of excavated material will eliminate these species from the disturbed areas and vehicle traffic will do additional damage. Although beach contours will be restored to the present topography, it is uncertain how quickly these two species would re-establish in the disturbed area once construction has been completed and the beach restored.

During the construction period, public use of the beach will be interrupted briefly.

Mitigation:

There will be severe depletion of the vegetation in the area directly disturbed. This area can be restricted to the immediate vicinity of the excavation by adequate fencing, both toward the dunes and to the northwest and southeast along the beach. Fencing along the beach, from the access point at 5th Street and some distance to the north where materials are expected to be stored, at the seaward edge of the sea rocket-heliotrope vegetation zone will prevent equipment and vehicle traffic from disturbing those species unnecessarily. An inset fencing configuration at the conduit opening area would limit vehicle movement to a relatively small area (Figure 5). A wooden staircase on the steep slope of the back dune would help prevent erosion due to the expected increased foot traffic across the dunes. Fencing or signing would also help to limit damage to the vegetation on the top of the dunes.

After work is completed and the beach contours restored, it could take several years for sea rocket to re-establish on the restored sand. Collection of seeds from those plants expected to be eliminated during the work and sowing of those seeds after the beach is stabilized, preferably just before or during the rainy season, would be expected to accelerate the re-establishment process.

Disruption of public access to the beach will be minimal, with the least effect occurring during the winter months when there are fewer beach visitors.

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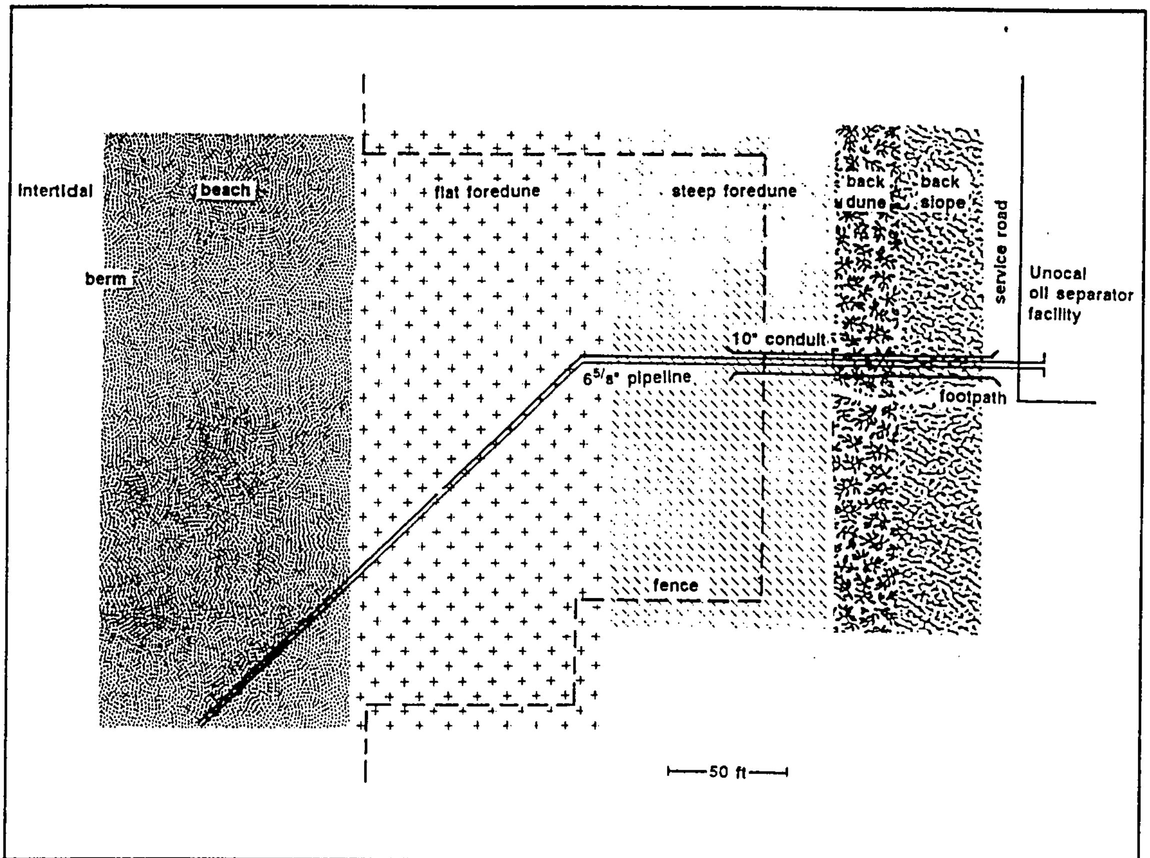

Figure 5. Suggested fencing configuration to reduce damage to the foredune vegetation.

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APPENDIX VOLUME 1
ITEM D

Pipeline Design

APPENDIX VOLUME 1
ITEM D

Pipeline Design

DESIGN SUMMARY

PROPOSED GINA & GILDA PIPELINES

FOR

UNION OIL COMPANY OF CALIFORNIA

SOUTHERN CALIFORNIA DISTRICT

MAY, 1981

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO

APPENDIX III

UNDERWATER INVESTIGATION OF NEARSHORE GEOLOGY ALONG PROPOSED AND ALTERNATIVE PIPELINE CORRIDORS

APPENDIX III

UNDERWATER INVESTIGATION OF NEARSHORE GEOLOGY ALONG PROPOSED AND ALTERNATIVE PIPELINE CORRIDORS

In response to a State Lands Commission request, Dames & Moore conducted a marine geological reconnaissance of the nearshore seafloor of the proposed Mandalay and alternative Ormond Beach pipeline corridors. The purpose of this survey was to provide geological observations in the nearshore zone beyond the shallow-water limits of the geophysical surveying.

METHOD

Marine geologists observed seafloor conditions within the two pipeline corridors continuously from about 40 feet (12 m) to the surf zone. This was accomplished using SCUBA and a combination of slow towsled (boat pull), Farallon (self-powered sled), and swimming, depending on the time and visibility conditions.

Work was conducted in association with the marine biology field investigations, with a biologist acting as safety diver for a marine geologist. The pipeline corridors were also directly observed by the team of diving marine biologists from the platform site depth of 100 feet (30 m) to the beach, and these data were also reviewed by the marine geologist and geophysicist. The work was completed as summarized below:

Corridor	Date (1979)	Visibility	Propulsion
Mandalay	August 3	2 m	Swim (13 m to surf)
Ormond Beach	July 30	5 m	Boat tow (12 - 7 m) and Farallon (7 m to surf)

RESULTS

Both corridors exhibited firm sandy seafloor and no outcrops were observed. Gentle gradients occurred over the lengths inspected, with seafloor steepening starting at about 10- to 13-foot (3- to 4-m) water depth into shore. The seafloor was generally uniform and featureless, and microrelief was limited to minor depressions and ripple marks. No fresh water springs or gas bubbles were observed.

The proposed Mandalay corridor seafloor consisted of dense sand with some small patches of pebbles. The sand was well-sorted, and graded from medium fine into coarse at the inshore end. Between 6- to 23-foot (5- to 7-m) water depth was a zone of ripples 1 - 2 inches (2 - 5 cm) high and occasional 1.5-foot (0.5-m) deep depressions, probably of biological origin.

The alternative Ormond Beach corridor seafloor exhibited dense, medium sand with ripple marks up to 2 inches (5 cm) high, grading into coarse, well-sorted sand at the inshore end. The nearshore portion above the 10-foot (3-m) depth steepens more than at the proposed Mandalay corridor. Some shell debris was present over the nearshore portion.

CONCLUSIONS

Representative geological reconnaissance traverses were swum near the centerline of each corridor, inshore of the 40-foot (12-m) water depth. There were no obstructions or outcrops observed and the seafloor is composed of dense sands. The primary distinctions between the two corridors were some minor depressions (probable biological origin) along the proposed Mandalay and a steeper nearshore slope for the Ormond Beach alternative.

None of the features observed represent any geological hazards to the pipeline. The primary potential geological hazard to a pipeline is the possibility for erosion and scour of the beach sands at the pipeline surf crossing. This could expose a pipeline to storm wave conditions. Such an event is only hyopthesized and is not necessarily predicted from the reconnaissance diving observations. This potential geological problem is generally anticipated for all beach crossings. Consequently, the problem is commonly resolved by appropriate design considerations for that section of the pipeline.

APPENDIX IV

SUMMARY OF DIVING INVESTIGATION FOR NEARSHORE GEOLOGY ALONG INSHORE PORTION OF GILDA PIPELINE ROUTE

APPENDIX IV

SUMMARY OF DIVING INVESTIGATION FOR NEARSHORE GEOLOGY ALONG INSHORE PORTION OF GILDA PIPELINE ROUTE

In response to a State Lands Commission recommendation, Dames & Moore conducted a marine geological reconnaissance survey of the nearshore seafloor of the Platform Gilda pipeline route. The purpose of this survey was to provide geological observations in the nearshore zone beyond the shallow-water limits of the geophysical surveying (from about 50 feet (15 m) to the surf zone).

METHOD

A marine geologist observed seafloor conditions within the pipeline corridor continuously from about 45 feet (14 m) to the surf zone. This was accomplished using SCUBA and swimming on a compass course.

Work was conducted in association with marine biology field investigations, with a biologist acting as safety diver for the marine geologist. The pipeline route was directly observed by the team of diving marine biologists from a depth of 105 feet (32 m) to the beach. These data were also reviewed by the marine geologist and geophysicist. The work was done on 3 August 1979. Visibility was 8 feet (2.5 m).

RESULTS

The route seafloor consisted of dense sand with some small patches of pebbles. The sand was well-sorted, and graded from medium fine into coarse at the inshore end. Between 16-23 feet (5 - 7 m) depth was a zone of ripples 1 - 2 inches (2 - 5 cm) high and occasional 1.5-foot (0.5-m) deep depressions, probably of biological origin.

No outcrops were observed. Gentle gradients occurred over the length inspected, with slight seafloor steepening starting at about 10- to 13-foot (3- to 4-m) depth into shore. The seafloor was generally uniform and featureless, and microrelief was limited to minor depressions and ripple marks. No freshwater springs or gas bubbles were observed.

CONCLUSIONS

There were no obstructions or outcrops observed and the seafloor is comprised of dense sands. None of the features observed represent any geological hazards to the pipelines. A potential geological hazard to the pipelines is the possibility for erosion and scour of the beach sands where the pipelines cross the beach. This could expose the pipelines to the effects of storm wave conditions. Such an event is only hypothesized and is not necessarily predicted from the reconnaissance diving observations. This potential geological problem is generally anticipated for all beach crossings. Consequently, the problem is commonly resolved by appropriate design considerations for that section of the pipeline route.

Design Summary

This document summarizes the design of the proposed offshore pipelines that will provide service for the Gina and Gilda Platforms, Tracts OCS P-0202 and OCS P-0216, offshore Southern California. The work included:

(1) the design of the pipeline from the riser flanges on both platforms to a termination point on Mandalay Beach
(2) the preparation of the "Instructions to Bidders" and "Specifications for Installation"

The work was done for the UNION OIL COMPANY OF CALIFORNIA, Southern California Division by PMB Systems Engineering, San Francisco.

The pipeline designs were prepared in accordance with A.N.S.I B31.4-1974 and A.N.S.I. B31.8-1975 Specifications, and confirm to the U.S. Department of Transportation Regulations, Parts 191, 192 and 195, Title 49 of the Code of Federal Regulations.

The following tables summarize the design parameters and final design specifications.

DESIGN PARAMETERS

PIPELINES

SERVICE (BY UNION OIL)		RATING (BY UNION OIL)
GILDA	OIL - 12.750" O.D.	2160 PSI
	GAS - 10.750" O.D.	2160 PSI
	WATER - 6.625" O.D.	1440 PSI
GINA	OIL - 10.750" O.D.	3600 PSI
	WATER - 6.625" O.D.	1440 PSI

DESIGN TEMPERATURE = 140° F (MAX.)

DESIGN CURRENT

5.0 FPS - SURF ZONE (BY PMB & UNION OIL)

3.3 FPS - REMAINDER (FROM "DESIGN AND SEASONAL WAVES, CURRENTS AND WEATHER CONDITIONS FOR OCS P-0216 SANTA BARBARA CHANNEL", INTERSEA RESEARCH CORPORATION, JUNE 11, 1979.)

SAFETY FACTORS AGAINST TRANSLATION (BY UNION OIL)

S.F. = 1.5 FOR WATER LINES, 2.0 FOR REMAINDER

WHERE $S.F. = \frac{\mu\left[(\text{SUB. WEIGHT OF PIPE, FULL}) - (\text{LIFT FORCE})\right]}{(\text{DRAG FORCE})}$

DESIGN ASSUMPTIONS

- MAXIMUM CURRENT ACTS. NORMAL TO PIPELINE
- SpG OF OIL = .95 (BY UNION OIL)
- DRAG AND LIFT FORCE BASED ON COMPLETELY EXPOSED PIPE.
- THE FOLLOWING COEFFECIENTS ARE APPROPRIATE:

μ (COEFFECIENT OF LATERAL SOIL RESISTANCE) = 1.0
f_s (" " LONGITUDINAL SKIN FRICTION) = .45

SUMMARY TABLE

Service	Size O.D. (in.)	Nominal Wall Thickness (in.) Pipe Grade (ksi)	Surf Zone (1) Concrete Thickness (in.)	Surf Zone (2) Safety Factor	Surf Zone (3) Net Weight During Installation (#/ft)	Offshore (1) Concrete Thickness (in.)	Offshore (2) Safety Factor	Offshore (3) Net Weight During Installation (#/ft)
Gilda Oil	12.750	.500/42	1.50	2.29	65.18	0	4.66	8.67
Gas	10.750	.365/46	3.25	2.26	120.44	1.25	2.91	~~39.80~~
Water	6.625	.280/35	1.75	1.58	42.40	0	2.20	3.65
Gina Oil	10.750	.500/56	1.50	2.21	62.98	0	4.66	14.40
Water	6.625	.280/35	1.75	1.58	42.40	0	2.20	3.65

CORRECT VALUES ON TABLE 1

(1) Based on 190 pcf concrete.

(2) Safety factor against lateral translation = $\frac{\mu\ [(\text{Submerged Weight of Pipe, Full}) - (\text{Lift Force})]}{\text{Drag Force}}$

Where μ = Coefficient of lateral friction

(3) Submerged weight of pipe (empty) plus concrete coating (if any).

SUMMARY TABLE - OFFSHORE PORTION

Service		Size O.D.(in)	Flange Rating (#)	Design Pressure (psi)	Design Temperature (°F)	Minimum Wall Thickness for Pressure (in)/ Pipe Grade (ksi)	Minimum Wall Thickness for Stability (in)	Recommended Nominal Wall Thickness (in)/ Pipe Grade (ksi)
Gilda	Oil	12.750	900	2160	200	.546/35 .455/42 .416/46	.46	.500/42
	Gas	10.750	900	2160	250	.461/35 .384/42 .351/46	.66	.688/35
	Water	6.625	600	1440	200	.189/35 .158/42 .144/46	.28	.280/35 (2)
Gina	Oil	10.750	1500	3600	200	.768/35 .640/42 .584/46 .517/52 .500/56	.39	.812/35 (1) .688/42 .594/46 .562/52 .500/56
	Water	6.625	600	1440	200	.189/35 .158/42 .144/46	.28	.280/35 (2)

(1) Choice depends on current cost and availability
(2) Wall thickness is adequate for a 900 pound system if desired.

Service	Surf Zone		Offshore	
	Negative Buoyancy (lbs./ft.)	Specific Gravity	Negative Buoyancy (lbs./ft.)	Specific Gravity
Gilda				
12-3/4" diam. .500	64.49	1.73	8.67	1.15
10-3/4" diam. .365"	118.97	2.12	39.32	1.62
6-5/8" diam. .280"	41.93	2.14	3.65	1.24
Gina				
10-3/4" diam. .500"	62.38	1.93	14.40	1.36
6-5/8" diam. .280"	41.93	2.14	3.65	1.24

Table 1

Negative Buoyancy and Specific Gravity

For Lines Empty

Service	Surf Zone		Offshore	
	Negative Buoyancy (lbs./ft.)	Specific Gravity	Negative Buoyancy (lbs./ft.)	Specific Gravity
Gilda				
12-3/4" diam. .500	109.13	2.24	53.31	1.94
10-3/4" diam. .365"	118.97	2.12	39.32	1.62
6-5/8" diam. .280"	54.45	2.49	16.17	2.06
Gina				
10-3/4" diam. .500"	93.12	2.39	45.13	2.12
6-5/8" diam. .280"	54.45	2.49	16.17	2.06

Table 2

Negative Buoyancy and Specific Gravity

For Lines Full

TECHNICAL DISCUSSION

The following discussion summarizes the technical bases for designing the Gina and Gilda pipelines. Included are:

1. A brief review of the technique used to determine the pipe nominal wall thickness in accordance with ANSI B31.4-1974 and ANSI B31.8-1975 specifications.
2. The assumptions and coefficients used for the design.
3. A table summarizing the design parameters of the pipeline designed for internal pressure only and for on-bottom stability given the design wave and currents.
4. A list of related references.

Pipeline design in accordance with ANSI specifications is straightforward and requires little judgment on the part of the designer; however, the reverse is true for designing a pipeline to withstand induced forces from waves and currents. Little is quantitatively known about the interaction between a pipeline and the surrounding water. As a result, we have used assumptions and coefficients to reflect the uncertainty associated with a design of this nature.

Design Review

- The design nominal wall thickness was determined from ANSI 404.1.2 with a design factor of .72 and a weld joint factor of 1.00 (for seamless or ERW pipe).

- The submerged-empty and submerged-full weights per foot of pipe were determined assuming a specific gravity of .95 for oil, where applicable. Using the submerged-full weight, a friction force between the soil and the pipe was determined by applying a friction factor of .45. Terzaghi and Peck (1967) give friction factors of .55 for coarse sand and .45 for silty sand, regardless of the presence of water. A friction factor of .45 was chosen corresponding to the sea floor soil type specified by Dames and Moore (1980).

- The maximum possible thermal induced stresses were determined from the design temperatures supplied by Jim Buckingham, using a coefficient of thermal expansion of 6.5×10^{-6} in/in/°F. A length of pipe necessary to supply a sufficient friction force to restrain the thermal expansion was determined and compared with the available length of pipe. If a sufficient length of pipe was available, the pipe was considered "restrained" as defined in ANSI 419.6.4 and the "net longitudinal compressive stresses" were checked. If an insufficient length of pipe was available, it was assumed that additional longitudinal restraint would be used.

- The drag and inertial forces imposed on the pipeline were calculated using the Morison equation

$$f_{D+I} = \frac{1}{2} \rho C_D D |U_e| U_e + \rho C_M \left(\frac{\pi d^2}{4}\right) \dot{U}$$

and the lift force was calculated by using

$$f_L = \frac{1}{2} \rho C_L D U_e^2 .$$

where D is the pipeline diameter, ρ is the density of sea water, U_e is the effective velocity acting on the pipeline, and $\dot{U}$ is the local water particle acceleration.

- The values of U_e and $\dot{U}$ near the sea floor were obtained from the Intersea report (1979) using a design wave height of 30 feet, a .8 knot current and a water depth of 213 feet. Although the Intersea report specifies the direction of the highest waves as from 150° - 138°, the data on page 4 shows significant waves approaching from 158° to 265°, a range encompassing the directions perpendicular to both Gilda and Gina pipelines. The current direction is also specified as being generally upcoast; however, the local current direction is more a function of the local bathymetry and can deviate significantly from the general direction. As a result, the design wave and current were applied simultaneously and in a direction normal to the pipeline in each case.

- The values used for C_L = .75 (CONCRETE) & 1.00 (STEEL) AND C_D = .90 (CONCRETE) & .80 (STEEL). ~~C_D, C_M and C_L were 1.0, 2.5 and 2.0, respectively~~. These were obtained by reviewing past research on pipelines subject to wave and current induced forces and choosing coefficients corresponding to a Reynolds number similar to that associated with this design (see references OTC 2496 and 2598). These values are larger than those generally used for platform design because of the effect of the bottom on the drag, inertial and lift forces and because the Reynolds number associated with pipelines is significantly smaller than that associated with platforms.

- The weight per foot of pipe necessary for on-bottom stability was determined by multiplying the ~~a~~ factor of safety ~~of two times~~ the drag plus inertial forces. This result was divided by a coefficient for lateral restraint for a pipe laying in sand of 1.0 to yield the necessary net downward force. The lift force was then added to the net downward force to yield the necessary weight per foot of pipe. It was assumed that the liquid lines will be full at the time the design wave passes over.

- The coefficient for lateral restraint of 1.0 was suggested by Jones (1976, reference OTC 2598) and is conservative. Other authors have suggested coefficients as high as 1.9.

The enclosed tables summarize the pipeline design parameters developed using the outlined procedure and assumptions. It will be necessary to check the proposed pipeline designed for on-bottom stability with any additional current and wave data developed closer to shore, as these conditions may impose larger forces on the pipelines.

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1. Terzahi, Karl and Peck, Ralph B., Soil Mechanics In Engineering Practice, John Wiley and Sons, Inc., N. Y., 1967.

2. Dames and Moore, "Report-Shallow Hazards/Cultural Resources Survey--Platform Gilda and Associated Pipelines--Oxnard, California--for the City of Oxnard," 1980.

3. Intersea Research Corporation, "Design and Seasonal Waves, Currents and Weather Conditions for OCS P-0216 Santa Barbara Channel, California," 1979.

4. Jones, Warren T., "On-Bottom Pipeline Stability in Steady Water Currents," OTC Paper No. 2598, 1976.

5. Nath, John H., Yamamoto, Tokuo, and Wright, James C., "Wave Forces on Pipes Near the Ocean Bottom," OTC Paper No. 2496, 1976.

INSTRUCTIONS TO BIDDERS

1. The fabrication and installation of Platform Gina with risers should be completed by November 15, 1980. The fabrication and installation of Platform Gilda with risers should be completed by December 31, 1980. The CONTRACTOR shall have 30 days prior notice of any change to this schedule.

2. The construction of the pipelines shall begin as soon as possible after November 1, 1980 such that the field connection of the pipelines to the platform risers can be made without delay. The CONTRACTOR should attempt to lay and bury the pipelines from shore to 3700' offshore during the month of February (the month of minimum beach elevation). The CONTRACTOR may assume that all materials to be supplied by the Union Oil Company, hereinafter referred to as the "COMPANY", will be available at his convenience.

3. The Instructions to Bidders will become the Instructions to Contractors when the Contract is formalized. Any revisions or qualifications made by the bidder and accepted by the COMPANY shall be included either in the Instructions to Contractor or the Contract Award Letter.

4. The CONTRACTOR shall provide the COMPANY and PMB Systems Engineering Inc., hereinafter referred to as the "ENGINEER", with a description of all equipment, methods, facilities and items that will be used in construction. This will be reviewed to determine its structural suitability and adequacy.

5. The CONTRACTOR will furnish all materials to be incorporated into the pipelines, but will not furnish any items of a consumable nature including

fuel, oil and gas. The CONTRACTOR shall include a preliminary list of materials to be supplied by the COMPANY with associated costs. Before construction, the CONTRACTOR shall supply to the COMPANY a revised list of materials, such that the COMPANY has sufficient time to purchase said materials without causing delays to the CONTRACTOR'S schedule. The list shall include those items needed for construction and shall include recommended allowances for "extras". The COMPANY shall furnish the materials according to the list and shall include allowances for "extras." The CONTRACTOR shall then be responsible for materials and shall hold the COMPANY harmless for any delays or other hardships caused by defective or short materials. The CONTRACTOR shall be responsible for providing at his expense any materials other than those specified in the list.

6. The CONTRACTOR shall submit a lump sum price which includes all weather delays. As an alternate, the CONTRACTOR shall submit a lump sum price wherein the COMPANY will pay the CONTRACTOR, at his specified standby rates, for all weather delays beyond 12 hrs./week.

7. Each bidder shall include with his bid a copy of his current insurance certificate, which shall be considered to be in effect during the course of this job. Anticipated changes in the coverage that could occur prior to Contract Award shall be attached in writing to the insurance certificate submitted.

8. At the time of award, "Approved for Construction" drawings will be issued.

9. The COMPANY shall supply the CONTRACTOR with all permits and licenses needed for the completion of the work.

10. A pre-bid meeting at the Mandalay Beach job site shall be held for all prospective bidders. The CONTRACTOR may assume that a 150' by 600' work area (the 600' boundary runs perpendicular to the beach) shall be available at the job site, unless otherwise specified. The details and location of the on-shore termination point for the five proposed pipelines will be identified at the pre-bid meeting.

11. All staking of boundaries and right of ways at the Mandalay Beach job site shall be done by the COMPANY.

12. The CONTRACTOR shall investigate the conditions of existing public and private roads and of clearances, restrictions and other limitations affecting transportation entering the job site and at the job site. The COMPANY shall not be responsible in any way for hardships or delays resulting from the limitations of transportation facilities.

13. The CONTRACTOR shall take delivery of all coated pipe at the AMERON PRICE plant in Fontana, California. The CONTRACTOR shall be responsible for the transportation of all pipe from Fontana to the Mandalay Beach job site, shall exercise due diligence so as to not damage the pipe or its coating during loading, transportation and unloading, and shall replace or repair any pipe damaged during the transportation operation at the CONTRACTOR'S expense. Any repairs made to damaged pipe shall be subject to the COMPANY'S approval. The CONTRACTOR shall include as a separate item in his bid the expense of transporting the pipe as stated herein. If the coated pipe is supplied at some location other than Fontana, the CONTRACTOR and the COMPANY shall negotiate any changes in the cost of transportation.

14. The COMPANY shall deliver the anodes to the Mandalay Beach job site or to the CONTRACTOR'S designated shipping address.

15. The CONTRACTOR shall, at all times, keep the job site at Mandalay Beach free from accumulations of waste material or rubbish caused by CONTRACTOR'S employees or work. At the completion of the work, the CONTRACTOR shall remove all rubbish, surplus tools and material from the job site and shall leave the area clean, unless otherwise specified.

16. The CONTRACTOR shall exercise all reasonable diligence to conduct his operations in a matter that will prevent pollution. He shall comply with all applicable laws, ordinances, rules, regulations and lease or contract provisions regarding pollution, including those of the U.S. Geological Survey and the U.S. Department of Interior. No garbage, trash, waste oil, bilge, waste, or other pollutants shall be discharged or allowed to escape into the Santa Barbara Channel. The CONTRACTOR shall take all reasonable measures to instruct his personnel in such matters and will clean up any pollution occurring during the course of the pipelines installation and related field operations.

17. The CONTRACTOR will be permitted to use his presently qualified welders and procedures, as long as his welders are qualified in accordance with ANSI B31.4 for Piping and API Standard 1104. The COMPANY and the ENGINEER reserve the right to review welding procedures, the test results of these procedures and test results of the welders. If these results prove to be substandard, the welders shall be qualified in accordance with the stated codes at the CONTRACTOR'S expense.

18. The risers on both platforms shall be bolted in place by the platform fabricator. The field connection between each riser and pipeline shall be either a bolted flange (as shown on drawing nos. 1703-106 and 107) or a welded connection. The CONTRACTOR may have the use of the platform cranes for the field connection.

19. The CONTRACTOR should note that the Design and Installation Specifications are prepared for the lay-barge construction method. The CONTRACTOR may choose another method, but he must describe the alternative construction method fully with the submission of the bid.

20. The CONTRACTOR shall hydrostatically test the completed lines and risers to the following pressures:

Service	Hydrostatic Test Pressure (psi)
Gilda - 12-3/4" diam.	3240
10-3/4" diam.	3240
6-5//8 diam.	2160
Gina - 10-3/4" diam.	5400
6-5/8" diam.	2160

21. In the event of conflict between the instructions contained herein and the Installation Specifications or the drawings or the standard specifications referred to in the text of these documents, the instructions contained herein shall prevail.

22. On completion of work, the point of delivery for all excessive COMPANY material and equipment shall be Port Hueneme.

UNION OIL COMPANY OF CALIFORNIA

OIL AND GAS DIVISION: WESTERN REGION

MAY 30, 1980

SPECIFICATIONS FOR

"INSTALLATION OF OFFSHORE PIPELINES FROM MANDALAY BEACH TO OCS 0202 AND OCS 0216"

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO, CALIFORNIA

1.0 GENERAL REQUIREMENTS

1.1 Scope of Work

CONTRACTOR shall provide all utilities, tools, installation equipment, supervision, nondestructive testing, and all items of a consumable nature that are required for installation of the 6-5/8", 10-3/4" and 12-3/4" OD Gilda pipelines and the 6-5/8" and 10-3/4" OD Gina pipelines for the Union Oil Company of California, Santa Barbara Channel, O.C.S. plots 0202 and 0216, as detailed in the project drawings and these specifications.

The work includes but is not limited to:

1. Lay and bury all lines as specified.
2. Connect flow lines to appropriate risers.
3. Apply field joint material to weld zones as specified (CONTRACTOR to furnish material).
4. Install anodes as specified on drawing nos. 1703-102 and 103 (CONTRACTOR shall furnish "cadweld" cartridges, if necessary).
5. Repair and apply field patch material to areas of pipe which contain damaged coating.
6. Pig and hydrostatic test all lines.
7. Perform the specified nondestructive testing.

1.2 Materials and Services as Furnished by COMPANY

1. All line pipe, including:

   _______ ft. 6-5/8" OD, .280" W.T., API 5L grade B seamless line pipe.

   _______ ft. 10-3/4" OD, .365" W.T., API 5LX 46 seamless line pipe.

   _______ ft. 10-3/4" OD, .500" W.T., API 5LX 56 seamless line pipe.

   _______ ft. 12-3/4" OD, .500" W.T., API 5LX 42 seamless line pipe.

All line pipe will be plain end beveled, 38' to 42' in length with PRITEC (or API equivalent) coating and HEVICOTE (or API equivalent) concrete coating, where applicable. Anodes will be attached on all concrete covered pipe sections.

2. Three risers located at the Gilda platform (12-3/4" OD, .500 W.T., API 5L X 52, 10-3/4" OD, .500", W.T. API 5LX 52, 6-5/8" OD, .500" W.T. API 5LX 42) and two risers located at the Gina platform (10-3/4" OD, .562 W.T., API 5L X 60, 6-5/8" OD, .280" W.T. API 5LX 42).
3. All flanges, fittings, studs, nuts, gaskets, clamps, and insulation kits, as specified by CONTRACTOR.
4. All aluminum alloy or zinc anodes.
5. All prefabricated bends for field connections.
6. Proposed routes will be marked with buoys.

1.3 Pipeline Data and Field Location

1. Pipe

6-5/8" OD, .280" W.T., API 5L grade B seamless line pipe.

10-3/4" OD, .365" W.T., API 5LX 46 seamless line pipe.

10-3/4" OD, .500" W.T., API 5LX 56 seamless line pipe.

12-3/4" OD, .500" W.T., API 5LX 42 seamless line pipe.

Risers

Gilda Platform

12-3/4" OD, .500" W.T. API 5LX 52 Grade

10-3/4" OD, .500" W.T. API 5LX 52 Grade

6-5/8" OD, .500" W.T. API 5LX 42 Grade

Gina Platform

10-3/4" OD, .562" W.T. API 5LX 60 Grade

6-5/8" OD, .280" W.T. API 5LX 42 Grade

2. Field Location

Gilda Pipelines

Santa Clara Unit, OCS lease P-0216 to Mandalay Beach.

Gina Pipelines

Santa Clara Unit, OCS lease P-0202 to Mandalay Beach.

Refer to drawing no. 1703-101 for identification of subject work area.

3. Corrosion Protection

Zinc or aluminum alloy bracelet anodes, spaced as follows:

Service	Shore to 3400'	3400' to 3700'	3700' to Platform
Gilda			
12-3/4" diam. .500"	3-170# anodes @ 850' centers	1-170# anode @ 150' center	50-170# anodes @ 990' centers
10-3/4" diam. .365"	4-120# anodes @ 680' centers	49-120# anodes @ 1020' centers (3400' to platform)	
6-5/8" diam. .280"	4-70# anodes @ 680' centers	1-70# anode @ 150' center	97-45# anodes @ 515' centers
Gina			
10-3/4" diam. .500"	4-120# anodes @ 680' centers	1-120# anode @ 150' center	40-105# anodes @ 710' centers
6-5/8" diam. .280"	4-70# anodes @ 680' centers	1-70# anode @ 150' center	56-45# anodes @ 510' centers

4. Water Depths

Ranges from 0 to 215' (MLLW datum) - Gilda
0 to 95' (MLLW datum) - Gina

5. Type of Coating

<u>Pipe</u>

PRITEC (or API equivalent), 15 mils butyl adhesive, 60 mils polyethylene outer wrap.

HEVICOTE (or API equivalent), reinforced concrete coating.

For coating schedule, refer to drawing nos. 1703-102 and 103.

<u>Riser</u> (coating applied by OTHERS in fabrication yard)

200 mils Ameron TIDEGUARD (only in splash zone).

6. Field Joint Material

Thermofit WPC wraparound sleeves (or API equivalent).

CSI 7900 Joint Fill.

7. Coating Damage Repair

Tapecoat 10/40W.

1.4 Intent of Work

The work shall be performed in accordance with generally accepted, current good practices of the several trades involved and the detailed requirements of this specification. Contractor shall be ready to operate in the manner expressed or implied herein, regardless of whether or not full details of such completeness or practices are contained herein.

1.5 Completeness

These specifications and drawings are believed to be complete in every detail but, when this proves not to be the case, CONTRACTOR shall comply with its true intent taken as a whole, and shall not avail himself or herself of any errors or omissions to the detriment of the work. Should any error, omission or discrepancy appear in the drawings, specifications or instructions, CONTRACTOR shall notify COMPANY at once, and COMPANY will issue instructions to be followed.

1.6 Precedence

In the event of a conflict between any of the following items, they shall take precedence in the order listed:

a. Instructions to bidders.
b. The text of this specification.
c. Installation and construction drawings incorporated into this specification.
d. Standard specifications incorporated into this specification.

1.7 Field Representatives

1.7.1 COMPANY's Construction Representative

COMPANY will maintain a Construction Representative in the field who will be the only COMPANY employee in the field authorized to represent COMPANY with respect to the work.

Examples of his function are to:

a. Establish and maintain field liaison between CONTRACTOR's Construction Representative and COMPANY.
b. Review CONTRACTOR's construction schedule and progress.
c. Provide drawings and other detailed information as required.

d. Explain drawings and specifications as required.

e. Direct such inspections as COMPANY may desire in order to check the quality and progress of the work.

f. Order work to be stopped in the event the work does not comply with the requirements of the approved plans and specifications.

1.7.2 CONTRACTOR's Construction Representative

CONTRACTOR shall maintain a Construction Representative in the field at all times, who shall act in full charge of CONTRACTOR's work and maintain field liaison between CONTRACTOR and COMPANY's Construction Representative. Examples of his functions are to:

a. Represent CONTRACTOR in matters pertaining to construction quality, performance schedule and accounting practice.

b. Represent CONTRACTOR during tests, including but not limited to all tests related to acceptance of the project.

1.8 Other Contracts

COMPANY reserves the right to let other contracts or perform other services in connection with CONTRACTOR's work hereunder.

1.9 Schedule and Cost Breakdown

CONTRACTOR shall maintain a detailed construction schedule for all phases of the work.

1.9.1 The construction schedule shall indicate, for each portion of the facility, the date of the start of the work thereon, job progress and completion date.

1.9.2 COMPANY's Construction Representative will review the schedule with CONTRACTOR's Construction Representative at periodic intervals to verify that the facility is progressing as scheduled. Modifications to the schedule which affect the completion dates established in the schedule must be approved in writing by both CONTRACTOR and COMPANY.

1.9.3 When applicable, CONTRACTOR shall provide COMPANY a breakdown of the compensation. Material cost, labor cost, and subcontractor shall be shown separately. Daily time sheets, signed by the COMPANY's Construction Representative, must be provided along with invoices.

1.10 Inspection and Testing

CONTRACTOR shall be responsible for thorough craft inspection during construction and for the quality of the work. CONTRACTOR shall provide all diving inspection needed for construction and all X-ray services, including all necessary operators, needed for inspecting the weld areas. The COMPANY'S Construction Representative will select location and actual quantity of testing in order to check the progress and quality of the work, to see that CONTRACTOR's employees are properly qualified in their respective crafts, that workmanship is of an acceptable grade, and that requirements of this specification are being met. In addition, COMPANY reserves the right to inspect, at COMPANY'S expense, any or all welds, materials and workmanship. Any welds or materials found by COMPANY not to meet COMPANY'S standards shall be repaired or replaced to COMPANY'S satisfaction by CONTRACTOR at CONTRACTOR'S expense. Such inspection or any other inspection or testing of COMPANY shall in no way relieve CONTRACTOR of full responsibility for the work hereunder.

1.11 Guarantee

Irrespective of whether designs, data or information have been provided, reviewed or approved by COMPANY, CONTRACTOR guarantees that the materials and workmanship provided by CONTRACTOR meet the requirements of this agreement and are free of defects or faults for a period of one year after the date such work or parts of such work are originally placed in operation.

1.12 Access

COMPANY personnel shall have access to construction areas at all times during the progress of the work to ensure that the desired quality of workmanship is obtained.

1.13 Quarters

CONTRACTOR shall furnish suitable living facilities, food, transportation to and from the site of the work for COMPANY's representatives and inspectors as may be required. The CONTRACTOR's normal AM and FM communications equipment shall be aboard all equipment and boats used by the CONTRACTOR on this work and will be available for use by COMPANY and his representative.

2.0 CONSTRUCTION REQUIREMENTS

2.1 Hauling and Storage of Materials

CONTRACTOR shall be responsible for transportation of all pipe from the concrete coating plant to the job site and from the polyethelene coating plant to the job site. Any material furnished by COMPANY shall be shipped either to the job site or to CONTRACTOR's designated shipping address. CONTRACTOR shall haul pipe and said material, in accordance with manufacturers specifications, if any, to job site as required and shall exercise due diligence in such work so as to not damage the materials handled.

CONTRACTOR shall indemnify COMPANY against any charge of detainment which may arise out of CONTRACTOR's delay of or failure to promptly unload or load materials when unloading or loading service is to be performed by CONTRACTOR.

If CONTRACTOR finds it necessary to rack pipe, he shall do so at his expense and in such a manner as to not cause damage to the pipe or its coating. CONTRACTOR shall be responsible for repairing all COMPANY property damaged by him throughout the course of the project.

CONTRACTOR at his own expense, shall clean up all storage areas where pipe or other materials used for the project have been stored.

On completion of the work, the CONTRACTOR shall return all of COMPANY's excess material and equipment to COMPANY. The CONTRACTOR will provide the necessary equipment and personnel to offload from the CONTRACTOR's barges within 24 hours after arrival at CONTRACTOR's yard or base at published rental rates.

2.2 Right-of-Way

COMPANY shall provide CONTRACTOR with general plans and drawings of the construction area where pipelines will be laid. CONTRACTOR shall be held responsible for locating all pipelines and existing structures and for any damage to said structures. CONTRACTOR shall be solely responsible for repairing or paying for the cost of repairing any damage he may cause to existing structures during the course of his work. COMPANY shall provide all state permits and right-of-way permits for the construction of the pipelines. However, CONTRACTOR shall be responsible for complying with the content of each permit.

2.3 Defective or Damaged Pipe

Any pipe found to have laminated or split ends shall not be laid. If ends of pipe are damaged to the extent that satisfactory welding contact cannot be made, the pipe shall be cut and appropriately beveled to the standard 30° angle with a company-approved beveling machine. The cost for beveling and cutting any joint shall be the CONTRACTOR's unless it is determined that the pipe was damaged before the CONTRACTOR took custody of said pipe. All line pipe cuts shall be done with a beveling machine.

2.4 Line Pipe Joint Coating

CONTRACTOR shall apply heat shrink sleeves per manufacturer's specifications. CONTRACTOR shall remove all dirt, scale and other loose or foreign materials from surface to be covered and shall heat surface to hand warm (120° - 140° F) with a torch. The sleeve shall be wrapped snugly around the joint area so that end overlap three inches minimum, six inches nominal. A closure shall be centered on the overlap, pressed in place and heated with a torch providing a 24-inch bushy yellow flame. The sleeve shall be heated starting from the center and worked toward the edges. The sleeve shall cool to ambient or below 100°F before handling of pipe.

CONTRACTOR shall apply, per manufacturer's specifications, CSI 7900 joint fill to all joint areas of pipes that have been concrete covered. Sheet steel cans shall be prefabricated to fit over concrete covering and shall have a one 1-inch diameter hole in each to accept the nozzle of the CSI IFJ 100 applicator. The cans shall be held in place by four steel bands, two per end. CONTRACTOR shall apply sufficient CSI 7900 to completely fill the area enclosed between the pipe and sheet steel can, and shall allow foam CSI 7900 to harden completely before pipe is advanced.

2.5 Coating Inspection of Damage Repairs

CONTRACTOR shall examine polyethelene pipe coating with an approved holiday detector prior to laying pipe. CONTRACTOR shall repair all coating damage with Tapecoat 10/40W tape per manufacturer's specifications. Where damage is found, CONTRACTOR shall roughen area with emery cloth and shall coat area with Tapecoat TC Coldprime. After allowing primer to dry to a tacky consistency, CONTRACTOR shall apply Tapecoat 10/40W patch to this area. A spiral wrap shall be used, where successive winds shall be 25 percent overlapped. All repair must meet COMPANY inspector's approval.

2.6 Anodes

CONTRACTOR shall apply anodes per manufacturer's specifications at the appropriate locations as stated within this document. If the anode application does not meet with COMPANY'S approval, the CONTRACTOR shall repair or replace the necessary materials or workmanship, at his own expense, to meet with COMPANY'S approval.

2.7 Bury

All pipelines shall be buried to their appropriate depths according to the schedule shown on drawing nos. 1703-102 and 103. CONTRACTOR shall not damage pipe being buried or any other nearby flow lines. CONTRACTOR shall replace or repair, at no additional cost to COMPANY, all damaged lines.

2.8 Placement of Pipe

CONTRACTOR may use any acceptable means of placing pipe so long as it does not cause damage to pipe or coating. All pipe or coating damaged shall be replaced or repaired to COMPANY's satisfaction by CONTRACTOR at CONTRACTOR's expense.

CONTRACTOR shall terminate all five lines on the beach as shown on drawing no. 1703-107. CONTRACTOR shall place all buried lines offshore within a corridor defined by boundaries 100 feet either side of the surveyed centerline. Lines may lie adjacent to each other, but at no point shall any line cross any other line. CONTRACTOR shall place all lines within the transition zone such that at no point shall any line cross any other line. CONTRACTOR shall place remainder of lines within a corridor defined by boundaries 200' either side of the surveyed centerline. Adjacent lines must lie no closer than 10 feet, except at the platforms, and at no point shall any line cross any other line.

2.9 Riser Removal and Replacement

If CONTRACTOR chooses to use a welded pipeline to riser field connection, CONTRACTOR may remove the riser if it is deemed necessary. CONTRACTOR shall replace the riser to its original position and shall bear the cost of repairing any workmanship or material necessary to restore the riser and riser clamps to their original condition.

2.10 Hydrostatic Testing

Upon completion but before burial, the lines will be hydrostatically tested with sea water. CONTRACTOR shall run a scraper with an 80 percent gauging plate through the line before any hydrostatic tests. CONTRACTOR shall furnish the necessary T-52 corrosion inhibitor to be added to the sea water at 250 parts per million (ppm). CONTRACTOR shall furnish all necessary equipment for pigging and testing the line and shall be responsible for said equipment being in proper working condition. COMPANY representative must inspect and approve all said equipment before any tests begin. CONTRACTOR shall observe adequate safety procedures throughout duration of tests. The completed lines, including risers will be hydrostatically tested to the pressures stated in the Instructions to Bidders, held for 8 hours and so recorded. All hydrotesting shall be witnessed by the COMPANY representative.

All testing equipment shall be in good working condition. Pressure gauges shall be attached at each end of the line being tested and the pressure recorded on line at all times during the eight-hour test. A dead weight test shall be used at the beginning and end of each test. Any decrease in pressure reading shall be construed as a leak unless a significant temperature drop can be identified. CONTRACTOR shall leave test fluid pressurized to 50 psi in line at the conclusion of the test.

Any leaks found due to faulty material furnished by COMPANY will be repaired by CONTRACTOR at his published rates. Any leaks or damage found due to faulty workmanship shall be repaired by CONTRACTOR at no additional cost to COMPANY. When leaks do occur and repair work is necessary the subject line must be retested to the above specifications.

2.11 Welding

Welding shall conform to the requirements of the latest edition of the "API Standard for Welding Pipelines and Related Facilities," API Standard 1104. It shall be the CONTRACTOR's responsibility to be sure that all workmanship and material comply with code requirements. CONTRACTOR shall furnish all labor, equipment, tools, welding rods and supplies. The pipe shall be welded by the electric shield arc process using electrodes in accordance with AWS-ASTM specifications for pipe. Rods shall be of a make acceptable to COMPANY and as specified by the manufacturer of the welding machine. Size of electrode for each pass shall be that which gives the best results in the opinion of the COMPANY's inspector and the amperage shall be within the range specified by the manufacturer of the rod being used. All welds to be 100 percent full penetration without allowing excessive metal to run inside the pipe. In addition, all welds on API 5LX 42 or higher strength shall have a root pass 100 percent free of defects. Each bead shall be applied completely around the circumference of the pipe. External line-up clamps shall be used. The clamps shall not be removed until 100 percent of the stringer pass, uniformly distributed about the circumference of the pipe, is completed. Pipe coating adjacent to the weld area shall be protected by fireproof blankets during all welding. Where heavier wall pipe joins thinner wall pipe and the difference in wall thickness exceeds 3/32 inch, contractor may taper grind the heavier wall to the same thickness as the thinner wall pipe. The type shall be not less than 1:4 or more than 1:2.

When required in the field, pipe ends should be beveled either by machine cutting or oxygen torch cutting. Manual oxygen cutting may be used if authorized by the COMPANY inspector. Beveled ends shall be within the tolerances tested in the specification and shall be smooth and uniform enough to facilitate defect free welding. After the proper bevel has been made all rust, scale, oil, paint, and slag shall be removed from the weld area. Hand chisels, power chisels, grinders and slag hammers may be used to clean the surface. Each pass shall be cleaned as described above before the succeeding pass is made. No uncompleted weld shall be left at the end of a day's work.

No welding shall be done if, in the opinion of the COMPANY's inspector, high winds, rain, or other environmental conditions exist so as to prevent satisfactory welding. Suitable wind guards shall be provided by CONTRACTOR in windy weather.

Striking the arc on the pipe at any point other than the welding groove shall not be permitted. A ground may not be welded to the pipe or fitting that is being welded. Support ties may not be directly welded to the pipe. Any section of pipe or line fitting which has been arc burned shall be cut out and replaced at CONTRACTOR's expense. After the weld is completed, the finished weld shall be cleaned of slag. Protrusions of the weld metal more than 1/16" beyond the outer surface of the pipe shall not be permitted.

All welds shall contain a minimum of three beads or passes. Additional beads or portions thereof shall be added at CONTRACTOR's expense where the COMPANY inspector determines this necessary due to lack of reinforcement, pinholes or other defect.

2.12 Qualification of Welders

CONTRACTOR shall employ only competent, skilled and qualified welders who have been qualified in accordance with the procedure specified in the latest edition of API Standard 1104. COMPANY's inspector or qualified representative shall witness weld test and judge the specimens. A complete test form will be completed for each welder tested and submitted to COMPANY's inspector. Any welder failing to pass the test to the satisfaction of COMPANY's inspector shall not be permitted to perform any welding on the project. COMPANY shall be privileged to have removed from the job any welder who in the judgment of the COMPANY's inspector is responsible for an excessive number of defective welds detected either by radiography tests, or other tests set out in API Standard 1104, even though said welder may have satisfactorily passed the qualifying welding tests. Each welder shall be assigned an identifying number and shall identify each weld made by him by marking this number, using non-oil base chalk or crayon, adjacent to the weld.

2.13 Inspection and Testing of Pipe Welds

The COMPANY retains the right to nondestructively test any or all girth welds and to review any or all results from the X-ray inspection. Welds that provde to be defective will be replaced or repaired, whichever is approved by COMPANY's inspector, at the CONTRACTOR's expense. CONTRACTOR will be reimbursed for extra welds at his standard rates, which shall be included in the contract as a separate item. Reimbursement shall be covered by work orders which show the location of the extra welds. Work orders shall be signed by the COMPANY's representative and the CONTRACTOR's representative in the field on the day the work is done. No reimbursement will be made for extra welds not covered by work orders as stated herein.

Should two or more welders participate in making the weld, the welding foreman and COMPANY inspector shall decide which welder is responsible for the defective work.

PIPELINE DESIGN

6.625" O.D. WATER LINE

ALLOWABLE STRESS -

$S = 0.72 \times E \times F_y$

E = WELD JOINT FACTOR = 1.00 FOR H.S. SEAMLESS OR H.S E.R.W
F_y = 35 KSI (ASSUME)

$S = 0.72 \times 1.00 \times 35$
$= \underline{25.2 \text{ KSI}}$

REQUIRED THICKNESS (INTERNAL PRESSURE ONLY) -

$$t = \frac{P_iD}{2S} = \frac{1440 \text{PSI}(6.625 \text{IN})}{2(25.2 \text{KSI})(10^3)} = \underline{.189 \text{IN.}}$$

TRY: 6.625" ϕ SCH. 40
W.T. = .280"

THERMAL EXPANSION -

$\Delta T\,(°F) = 200° - 50°$ (ASSUMED AMBIENT) $= 150°F$
$\Delta L = 6.5 \times 10^{-6}$ IN./IN./°F $\times 150° = .00098$ IN/IN.
$P_{EQUIVALENT} = \Delta AE = .00098 \times 5.581 \text{ IN.}^2 \times 29{,}000 \text{ KSI} = 157.8^K$

LENGTH OF PIPE FOR AXIAL RESTRAINT $= \dfrac{P_{EQ.}}{f_s \times (\text{SUB. WEIGHT OF PIPE, FULL})}$

$$\text{SUB WT.} = 18.974^{\#}/\text{FT.} - \left(\frac{5.581 \text{ IN.}^2}{144 \text{ IN}^2/\text{FT}^2} \times 64^{\#}/\text{FT}^3\right)$$
$$= 16.49^{\#}/\text{FT.}$$

$$\frac{P_{EQ.}}{f_s \times (\text{SUB.WT.})} = \frac{157.8^K\,(10^3\,^{\#}/K)}{.45^{(1)} \times 16.49^{\#}/\text{FT.}} \simeq 21{,}000 \text{ FT.}$$

NEAREST PLATFORM STA. IS 327+23 ≃ 33,000 FT. > 21,000 FT.
SO LINE IS <u>RESTRAINED</u>.

(1) SEE NOTE, PAGE 2

LONGITUDINAL STRESS DUE TO THERMAL EXPANSION —

$$S_L = E\alpha(\Delta T) - \nu S_H$$

$$= (29{,}000\text{KSI} \times 6.5 \times 10^{-6} \times 150°F) - 0.30\ \frac{(1.44\text{ KSI} - .089\text{ KSI})\ 6.625\text{ IN.}}{2\ (.280\text{ IN.})}$$

WHERE .089 KSI = HYDROSTATIC PRESSURE @ EL.(-) 200'-0'

$$= 23.5\text{ KSI} < .9\,(36\text{ KSI})$$ SO <u>O.K.</u>

REQUIRED THICKNESS FOR HYDROSTATIC COLLAPSE (EMPTY) -

$$t = \frac{P_H D}{2S} = \frac{.089\text{ KSI} \times 6.625\text{ IN}}{2 \times 25.2\text{ KSI}} = .012''$$ SO <u>O.K.</u>

(1) NOTE - • SOIL CONSISTS OF DENSE SAND W/SOME SMALL PATCHES OF PEBBLES (FOR MANDALAY PIPE ROUTE) - FROM DIVERS SURVEY, III-2, DAMES & MOORE REPORT. SOIL NEARBY PLATFORM IS SANDY SILT AND SILTY SAND - FROM GEOTECHNICAL CONSULTANTS, INC. "GEOTECHNICAL INVESTIGATIONS - PROPOSED HUENEME OFFSHORE PLATFORM", 3/26/76

• f_s (COEFFECIENT OF FRICTION) FOR A ROUGH BASE, SUCH AS CONCRETE OR COATED STEEL, IS .55 FOR A COARSE GRAINED SAND CONTAINING NO SILT OR CLAY, AND IS .45 FOR A COARSE GRAINED SOIL CONTAINING SILT. THE PRESENCE OF WATER DOES NOT CHANGE THE FRICTION FACTOR AS THE RESISTANCE TO SHEAR FROM THE SOIL IS A FUNCTION OF THE INTERLOCKING GRANULAR STRUCTURE.

THE FOLLOWING TABLE SUMMARIZES THE DESIGN PARAMETERS FOR THE REMAINING LINES-

SERVICE	GINA OIL - 10.75" O.D.	GILDA GAS - 10.75" O.D.	GILDA OIL - 12.75" O.D.
YIELD STRENGTH (KSI)	56	46	42
ALLOWABLE STRESS (KSI)	40.3	33.1	30.2
REQ'D t (INT. PRESS.) (IN.)	.480	.351	.456
PRELIMINARY DESIGN	10.75" ϕ .500" W.T.	10.75" ϕ .365" W.T.	12.75" ϕ .500" W.T.
$P_{RQ.}$ (KIPS)	457.6	338.4	546.9
SUB. WT., FULL (K/FT.)	45.13	N/A, NEEDS CONCRETE COVER	53.31
LENGTH FOR RESTRAINT (FT.)	22,500 (O.K.)	N/A	22,800 (O.K.)
LONGITUDINAL STRESS DUE TO THERMAL EXP.	17.0 (<.9×56 so O.K.)	19.1 (<.9×46 so O.K.)	20.4 (<.9×42 so O.K.)
REQ'D t (HYDRO.) (IN.)	.012	.014	.019

PRELIMINARY DESIGNS O.K.

CALCULATION OF BREAKER POINT

USING SPM -

$H_o = 8'$, $T = 7s$, $K_R = .6$

$\frac{H_o'}{H_o} = .6 \Rightarrow H_o' = 4.8'$

$\frac{H_o'}{L_o} = \frac{4.8'}{5.12(7)^2} = .020$

ASSUME $X_o = 400' \Rightarrow m = .0190$ (SEE XEROX FIG. 1 - INTERSEA)

FROM FIG. 2-65 (XEROX, SPM) $\frac{H_b}{H_o'} \sim 1.20 \Rightarrow$

$H_b = 4.8(1.2) = 5.8'$

$\frac{H_b}{gT^2} = \frac{5.8}{32.2(49)} = .0037$

FROM FIG. 2-66 (XEROX, SPM) $\frac{d_b}{H_b} \sim 1.14 \Rightarrow d_b = 6.61'$.

$\Rightarrow X_b \approx 375'$ FROM FIG. 1 $\Rightarrow$ O.K. —

PROJECT______ PAGE______
BY______ DATE______
PMB SYSTEMS ENGINEERING, INC.
SAN FRANCISCO

CALCULATION OF BREAKER POINT FOR 50-100 YR STORM

$H_o = 33.3'$ $T = 15s$ $K_r = .75$

$H_o' = .75(33.3) = 24.98'$

$$\frac{H_o'}{L_o} = \frac{24.95}{5.12(15^2)} = .022$$

ASSUME $X_b = 2000' \Longrightarrow m = .015$

$$\frac{H_b}{H_o'} = 1.21 \quad \text{so}$$

$H_b = 30.2'$

$$\frac{H_b}{gT^2} = \frac{30.2'}{32.2(15^2)} = .0042$$

$$\frac{d_b}{H_b} = 1.13 \longrightarrow d_b = 34.13$$

$X_b \sim 2300'$

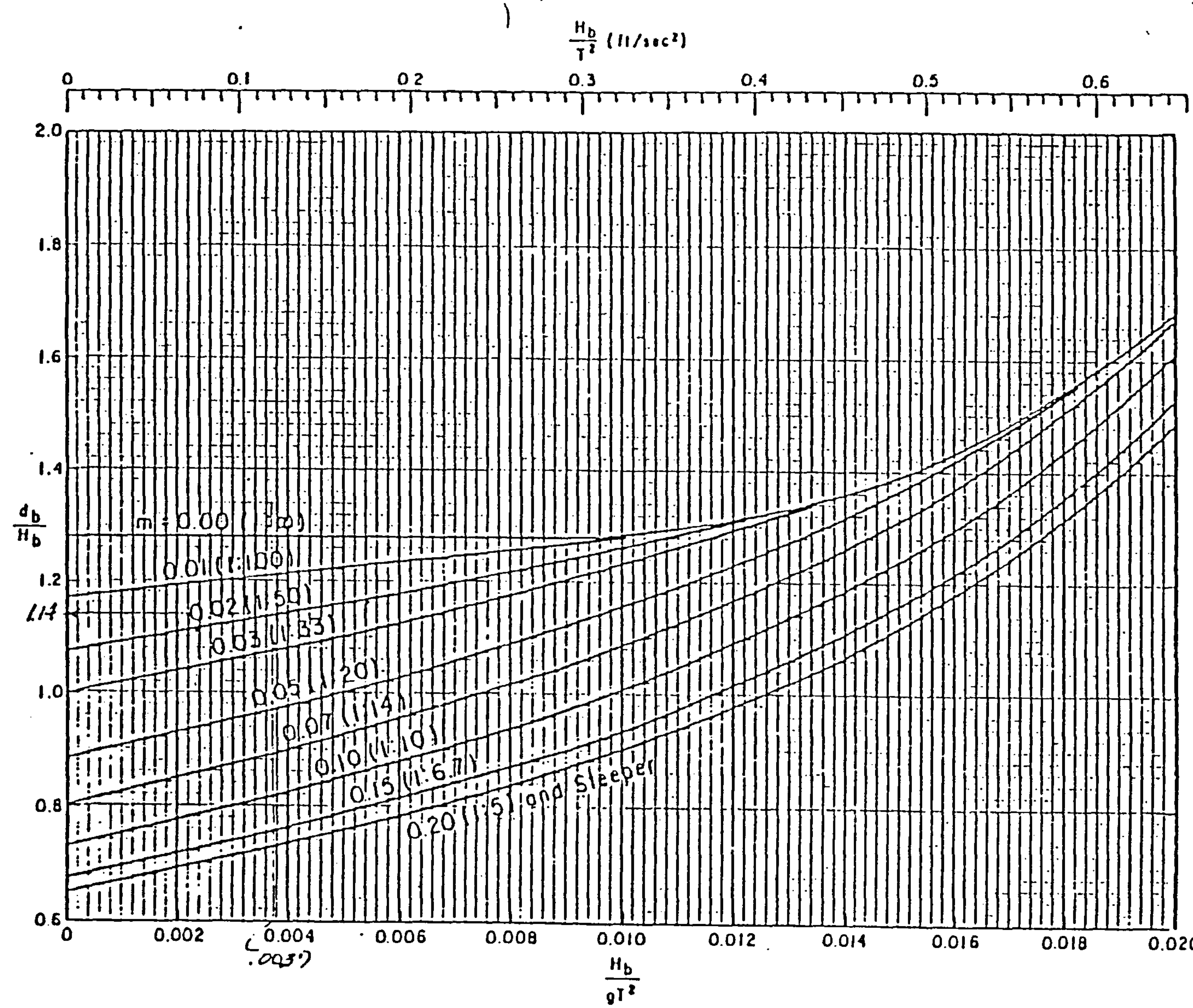

Figure 2-66. Dimensionless Depth at Breaking Versus Breaker Steepness

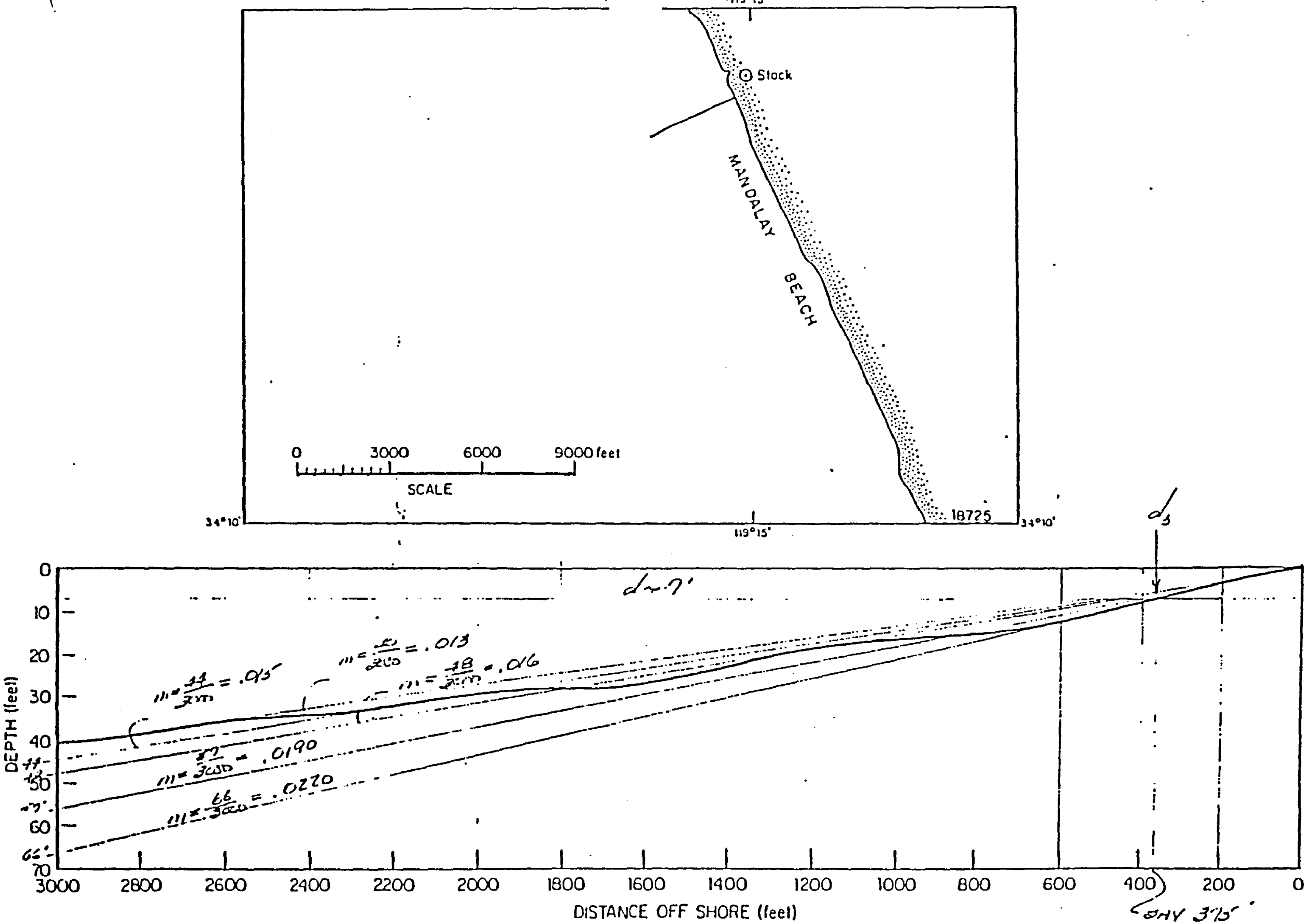

Figure 1.

Proposed pipeline location and an offshore profile.

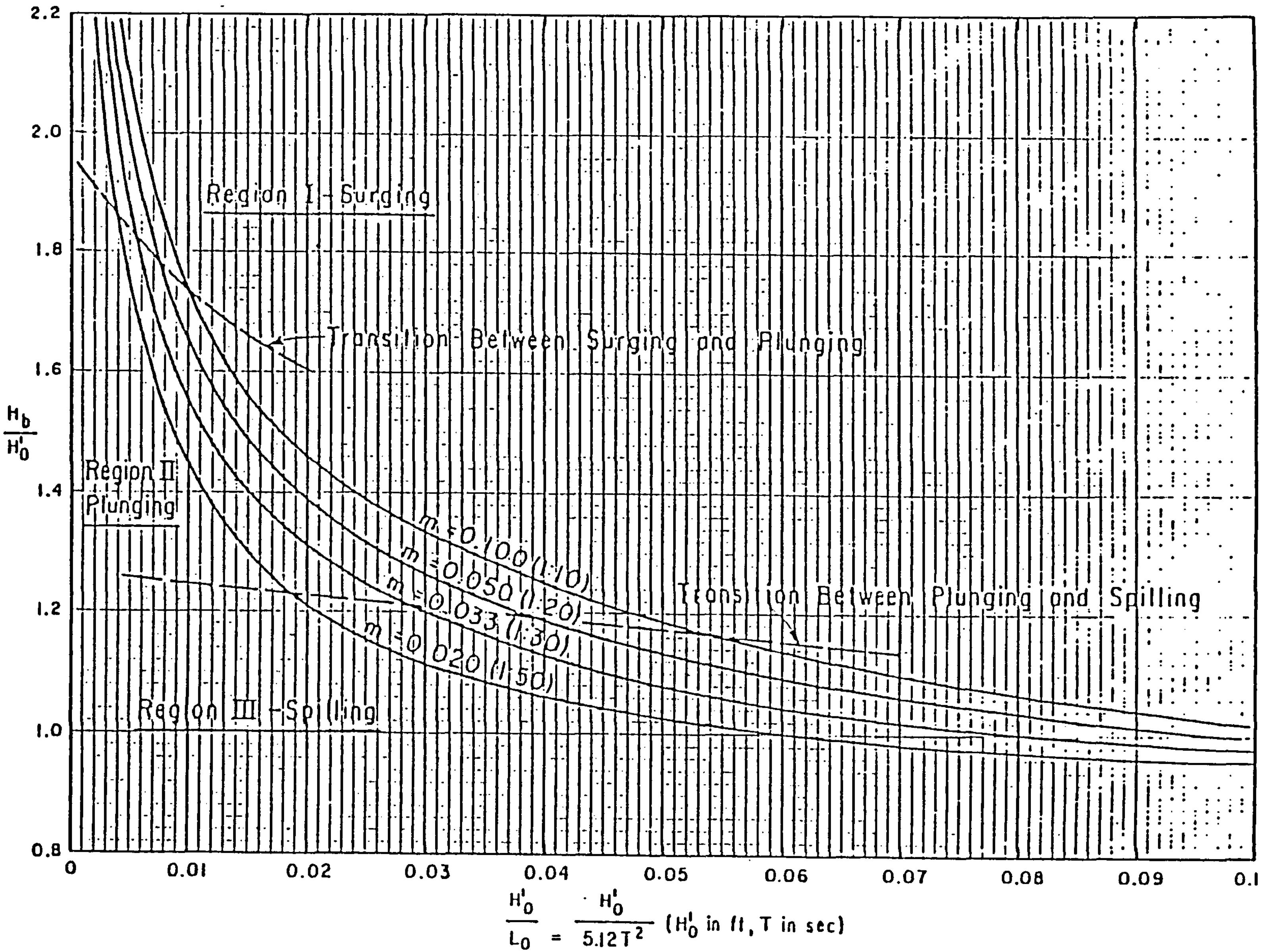

Figure 2-65. Breaker Height Index Versus Deep Water Wave Steepness

PROJECT________ PAGE 1
BY________ DATE 5/22/90
PMB SYSTEMS ENGINEERING, INC.
SAN FRANCISCO

- Cathodic protection

Assume 2% exposure, design for 20 years, $T_{operation} \le 140°F$

for #anode material/1000' of pipe, use...

$$\frac{\pi D (.02)}{12} \times \frac{5 \text{ miliamps}}{ft^2} \times \frac{25 \# \text{ zinc}}{\text{amp yr.}} \times \frac{1 \text{ amp}}{1000 \text{ miliamps}} \times 1000' \times 20 \text{ years}$$

- note this yields an average value for the pipeline. Local #/1000 may be greater or less than above.

- max. spacing of anodes for efficiency...

12" Ø or greater	~1000'
less than 12" Ø	500' ~ 700'

- anode material for pipelines...

12.75" Ø	~166.9 #/1000'
10.75" Ø	~140.7 #/1000'
6.675" Ø	~ 86.7 #/1000'

ANODE SPECIFICATIONS

12" GILDA SURF ZONE (1.5" CONCRETE)
S-619 TYPE B 112# EA. (NET)
LBS. NEEDED = 18575 (3400/54256) = 1164
ANODES NEEDED = 1164/112 = 10.4, SAY 11 @ 300' CNTR.

OFFSHORE (BARE)
S-620 TYPE 171# EA.
LBS. NEEDED = 18575 - (11)(112) = 17343
ANODES NEEDED = 17343/171 = 101.4, SAY 101 @ 505'

10" GILDA SURF ZONE (3.25" CONCRETE)
S-619 TYPE C 64# EA.
LBS. NEEDED = 6192 (3400/54256) = 388
ANODES NEEDED = 388/64 = 6.1, SAY 6 @ 550'

OFFSHORE (1.5" CONCRETE)
S-619 TYPE A 104# EA
LBS. NEEDED = 6192 - (6)(64) = 5808
ANODES NEEDED = 5808/104 = 55.8, SAY 56 @ 900'

6" GILDA SURF ZONE (1.75" CONCRETE)
S-619 TYPE "A" 41# EA
LBS. NEEDED = 3904 (3400/54256) = 244.6
ANODES NEEDED = 244.6/41 = 6 @ 550'

OFFSHORE (BARE)
S-620 32# EA.
LBS. NEEDED = 3904 - 244.6 = 3659
ANODES NEEDED = 3659/32 = 115 @ 445'

PROJECT________ PAGE________
BY________ DATE________
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10" GINA SURF ZONE (1.50" CONCRETE)

5-619 TYPE A 104 # EA.

LBS. NEEDED = 9317 (340/32723) = 968

ANODES NEEDED = 968/104 = 9.3 SAY 9 @ 380'

OFFSHORE (BARE)

3-620 142# EA

LBS. NEEDED = 9317 - 9 (104) = 8381

ANODES NEEDED = 8381/142 = 59 @ 500'

6" GINA SURF ZONE (1.75" CONCRETE)

3-619 41 # EA.

LBS. NEEDED = 2350 (3400/32723) = 244.2

ANODES NEEDED = 244.2/41 = 6 @ 550'

OFFSHORE (BARE)

3-620 82 # EA.

LBS. NEEDED = 2350 - 6 (41) = 2104

ANODES NEEDED = 2104/82 = 26 @ 445'

PROJECT______ PAGE______
BY______ DATE______
PMB SYSTEMS ENGINEERING, INC.
SAN FRANCISCO

ANODE DESIGN (REDONE)

$$\frac{\pi D \times .02}{12} \times 5 \frac{\text{mil amps}}{ft^2} \times 25 \frac{\#\,\text{zinc}}{\text{amp. yr.}} \times \frac{1\,\text{amp}}{1000\,\text{mil. amps}} \times 1000' \times 20\ \text{years} =$$

for 12¾ φ - 167#/1000'

10¾ φ - 141#/1000' use 71#/500'

6⅝ φ - 87#/1000' use 44#/500'

Cathodic Protection Services, Inc.
P.O. BOX 4378 • HOUSTON, TEXAS 77210 • 7077 PERIMETER PARK DRIVE • HOUSTON, TEXAS 77041
TELEPHONE 713/466-6400 • TELEX: 79-2345, 79-2344

June 16, 1980

P.M.B. Systems Engineering
500 Sansome
San Francisco, California 94111

Attention: Mr. Tom Coull

REFERENCE: CATHODIC PROTECTION DESIGN FOR HOT OIL, GAS AND WATER PIPELINES

Gentlemen:

This letter is to present our revised designs for the referenced structures. Our recommended parameters for pipelines carrying 90°F product and laying on the ocean floor are as follows:

12 in. Pipeline	54,384 ft; Operating Temperature 32.2°C
Surface Area	181,530.64 sq. ft.
Coating Factor	5% Bare
Current Density	10.67 mA/sq. ft.
Exposed Surface Area	9,076.53
Current Required	96.85 Amps
Anode Current Capacity	925 Amp-hrs/lb
Design Life	20 years
Lbs. GALVALUM III Required	18,353 lbs.
Recommended Anode	12.72 in. Tapered Anode per P-578 @ 171 lbs. each
Number of Anodes Required	109
Spacing	500' center to center

10 in. Pipeline	54,384 ft; Operating Temperature 32.2°C
Surface Area	153,055.25 sq. ft.
Coating Factor	2% Bare
Current Density	10.67 mA/sq. ft.
Exposed Surface Area	3,061.10
Current Required	32.69 Amps
Anode Current Capacity	925 Amp-hrs/lb
Design Life	20 years
Lbs. GALVALUM III Required	6,192 lbs.
Recommended Anode	"A" 10.75 in Bracelet Anode per S-619 @ 104 lbs. each
Number of Anodes Required	60
Spacing	906' center to center

6 in. Pipeline	54,384 ft; Operating Temperature: Ambient
Surface Area	94,324.74 sq. ft.
Coating Factor	5% Bare
Current Density	6 mA/sq. ft.
Exposed Surface Area	4,716.23 sq. ft.
Current Required	28.29 Amps
Anode Current Capacity	1,150 Amp-hrs/lb
Design Life	20 years
Lbs. GALVALUM III Required	4,311.05 lbs
Recommended Anode	6.625" Tapered Anode per S-620 @ 32 lbs. each
Number of Anodes Required	134
Spacing	406' center to center

10 in. Pipeline	32,736 ft; Operating Temperature 32.2°C
Surface Area	92,130.34 sq. ft.
Coating Factor	5% Bare
Current Density	10.67 mA/sq. ft.
Exposed Surface Area	46,065 sq. ft.
Current Required	49.19 Amps
Anode Current Capacity	925 Amp-hrs/lb
Design Life	20 years
Lbs. GALVALUM III Required	9,317 lbs
Recommended Anode	10.75 " Tapered Anode per P-578 @ 142 lbs. each
Number of Anodes Required	66
Spacing	500' center to center

6 in. Pipeline	32,736 ft; Operating Temperature: Ambient
Surface Area	51,421.5 sq. ft.
Coating Factor	5% Bare
Current Density	6 mA/sq. ft.
Exposed Surface Area	2,571 sq. ft.
Current Required	15.43 Amps
Anode Current Capacity	1,150 Amp-hrs/lb
Design Life	20 years
Lbs. GALVALUM III Required	2,350 lbs.
Recommended Anode	6.625" Tapered Anode per S-620 @ 32 lbs. each
Number of Anodes Required	74
Spacing	442' center to center

The designs presented in this letter are based on hot oil pipeline laboratory and field experiments under North Sea conditions. Conservative approximations are made to correlate cathodic protection parameters for varying conditions and the result is a higher current requirement for an elevated pipeline temperature. Cathodic Protection Services, Inc. is monitoring several hot product pipeline experiments and will continue designing with conservative parameters.

Cathodic Protection Services, Inc. proposes to furnish the following materials:

Item	Quantity	Description	Price
1.	109	12.75" Bracelet Anode per P-578	$423.21 each
2.	60	10.75" Bracelet Anode per S-619	$199.75
3.	197	6.625" Bracelet Anode per S-620	$ 89.02
4.	66	10.75" Bracelet Anode per P-578	$421.14 each

Any purchase order resulting from this proposal will be subject to the following terms and conditions:

1. Materials: F.O.B. Port Arthur, Texas.
2. Anode prices are based upon $0.76/# aluminum and current foundry costs and are subject to adjustment commensurate with changes in actual costs experienced from the date of this quotation to the date of shipment.
3. Delivery: 10 weeks
4. Terms: Net cash upon receipt of Invoice.

We appreciate this opportunity to be of service to you and if we may be of any further assistance, please do not hesitate to call.

Very truly yours,

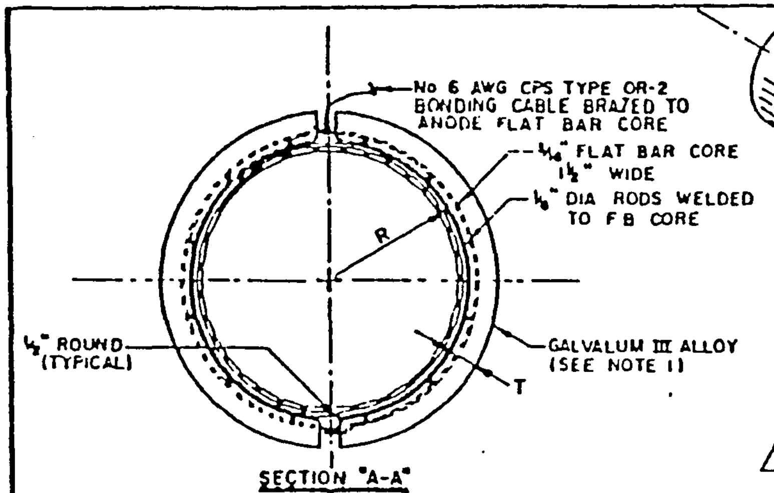
CATHODIC PROTECTION SERVICES, INC.

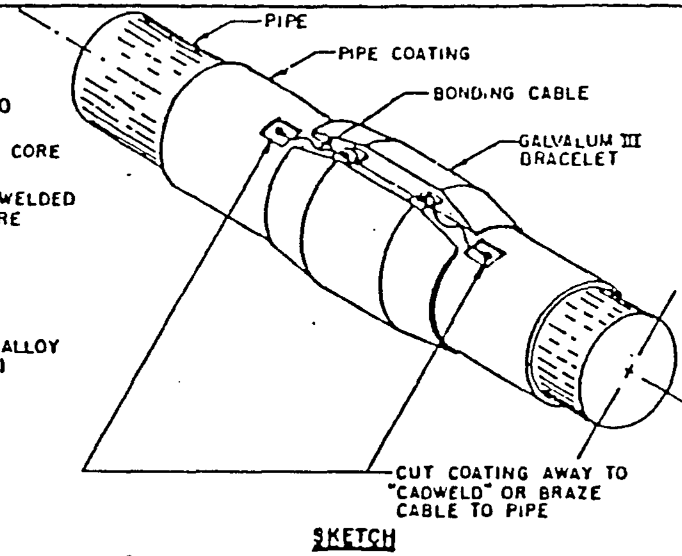
Peter Hanson

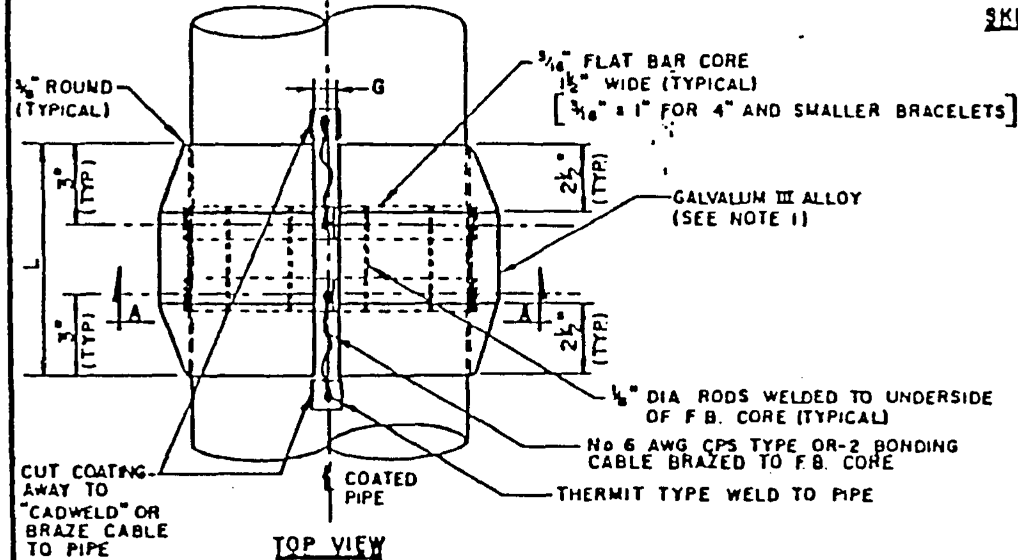
Peter Hanson

PH/bm

Enclosures: S-619; S-620; P-578







PIPE SIZE (O D)	THICKNESS OF COATING	DIMENSIONS R	T	L	G	NET WEIGHT (LBS)	GROSS WEIGHT (LBS)
12 3/4"	0 500"	6 7/8"	1 1/4"	16 3/4"	1 1/2"	88	101
12 3/4"	0 156	6 [illegible]/32"	1 1/2"	16 3/4"	1 1/2"	104	117
10 3/4"	0 125"	5 1/2"	1 1/2"	11 1/2"	1 1/2"	50	57
8 5/8"	0 040"	4 5/16"	1 1/2"	11 1/4"	1 1/2"	39	44
6 5/8"	0 040"	3 5/16"	1 1/2"	11 1/4"	1 1/4"	32	36
4 1/2"	0 040"	2 1/4"	1 1/2"	12"	1 1/4"	23	25
3 1/2"	0 040"	1 3/4"	1 1/4"	12"	1"	15	17
2 7/8"	0 040"	1 1/4"	1 1/4"	12"	1"	11	13

NOTES:

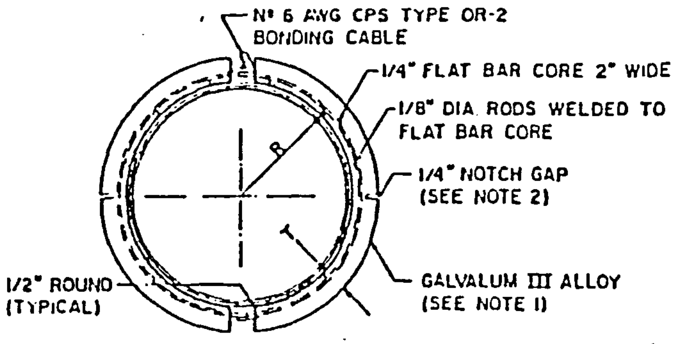
1. NOMINAL COMPOSITION OF GALVALUM III ALLOY: Al + 0.015% In + 3 0% Zn + 0.1% Si
2. NET WEIGHT REFERS TO TOTAL GALVALUM III ALLOY WEIGHT
3. GROSS WEIGHT REFERS TO TOTAL GALVALUM III ALLOY WEIGHT AND TOTAL STEEL CORE WEIGHT.

CATHODIC PROTECTION SERVICE
CORROSION ENGINEERS
HOUSTON, TEXAS

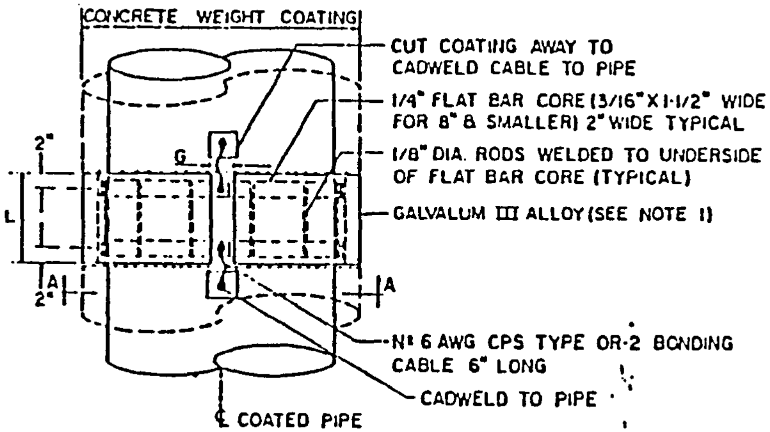
TAPERED SEMI-CYLINDRICAL[1]
GALVALUM® III[2] BRACELET ANODE

1 U S. PATENT RE 27,529
2 U S. PATENT 3,974,055
® REG T M DOW CHEMICAL CO.

MP	CPS	
NONE	9-20-76	S-820



SECTION "A-A"



TOP VIEW

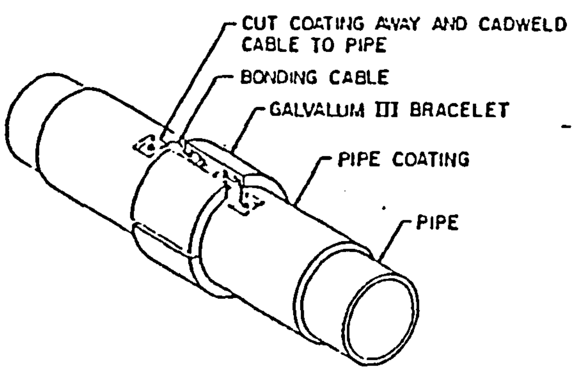
D-60

CODE	PIPE SIZE (OD)	TH.	DIMENSIONS (INCHES) R	T	L	G	NET WT. (LBS)	GR. WT. (LBS)
A	42"	5/32	21 5/32	3 1/2	9	2 1/2	441	480
A	36"	5/8	18 5/8	2 1/4	14 3/8	2 1/2	383	418
B	36"	5/8	18 5/8	3 1/2	7 3/4	2 3/4	340	375
C	36"	3/16	18 3/16	2 11/16	14 3/8	2 1/2	454	489
D	36"	3/16	18 3/16	3 15/16	7 3/4	2 3/4	367	402
E	36"	1/64	18 1/64	4 1/8	7 3/4	2 3/4	383	418
A	30"	5/8	15 5/8	2 1/4	14 1/2	2 3/4	323	353
B	30"	5/8	15 5/8	2	12 1/4	2 3/4	233	263
A	26"	5/32	13 5/32	2 7/16	10 1/2	2 1/2	215	240
A	24"	5/8	12 5/8	2 1/16	11 3/4	2 1/2	193	216
B	24"	5/32	12 5/32	2 1/16	11 3/4	2 1/2	186	209
*C	24"	5/32	12 5/32	3 3/4	6	2 1/2	188	200
D	24"	1/64	12 1/64	2	11 3/4	2 1/2	177	200
A	20"	5/8	10 5/8	1 5/8	14 1/4	1 1/2	157	176
B	20"	1/4	10 1/4	1 3/4	14 1/4	1 1/2	164	183
C	20"	5/32	10 5/32	1 5/8	14 1/4	1 1/2	150	169
D	20"	5/32	10 5/32	2 1/2	12 1/4	2	206	225
E	20"	1/64	10 1/64	1 3/4	14 1/4	1 1/2	161	180

CODE	PIPE SIZE (OD)	COATING TH.	DIMENSION (INCHES) R	T	L	G	NET WT. (LBS)	GR. WT (LBS)
F	20"	5/32	10 5/32	2	12	2	185	204
A	18"	5/32	9 5/32	2	15 1/2	1 1/2	188	205
A	16"	9/16	8 9/16	2 1/4	12	1 1/2	155	171
B	16"	9/16	8 9/16	2	11	1 1/2	123	139
C	16"	5/32	8 5/32	2 3/16	13	1 1/2	158	174
D	16"	1/64	8 1/64	2 3/8	13	1 1/2	170	186
E	16"	3/16	8 3/16	1 3/8	20	1 1/2	143	161
A	14"	5/32	7 5/32	1 1/4	16 3/4	2	92	106
B	14"	1/64	7 1/64	1 1/8	16 3/4	1 1/2	82	96
A	12 3/4"	1/2	6 7/8	1 1/8	16 3/4	1 1/2	96	109
B	12 3/4"	5/32	6 17/32	1 1/2	16 3/4	1 1/2	112	125
C	12 3/4"	1/64	6 13/32	1 23/32	16 3/4	1 1/2	122	134
A	10 3/4"	5/32	5 17/32	1 1/2	18 1/2	1 1/2	104	115
B	10 3/4"	1/8	5 1/2	1 1/2	11 1/2	1 1/2	64	75
*C	10 3/4"	1/8	5 1/2	3 1/2	4 7/32	1 1/2	64	70
A	8 5/8"	3/32	4 13/32	1 1/2	11 1/4	1 1/4	50	55
A	6 5/8"	3/32	3 13/32	1 1/2	11 1/4	1 1/4	41	45

* SINGLE FLAT BAR CORE (THIS ANODE ONLY)

ALL WEIGHTS ARE NOMINAL



SKETCH

NOTES:

1. NOMINAL COMPOSITION OF GALVALUM III ALLOY: Al + 0.015% In + 3.0% Zn + 0.1% Si
2. NOTCH GAP IS UTILIZED TO COMPENSATE FOR VARIATIONS IN COATING THICKNESS.
3. INSIDE FACE AND EDGES OF BRACELETS COATED WITH COAL TAR EPOXY.
4. NET WEIGHT REFERS TO TOTAL GALVALUM III ALLOY WEIGHT.
5. GROSS WEIGHT REFERS TO TOTAL GALVALUM III ALLOY WEIGHT AND TOTAL STEEL CORE WEIGHT.
6. WHEN ORDERING, USE DWG Nº, CODE LETTER & NOM. PIPE SIZE.

CATHODIC PROTECTION SERVICE

CORROSION ENGINEERS

HOUSTON, TEXAS

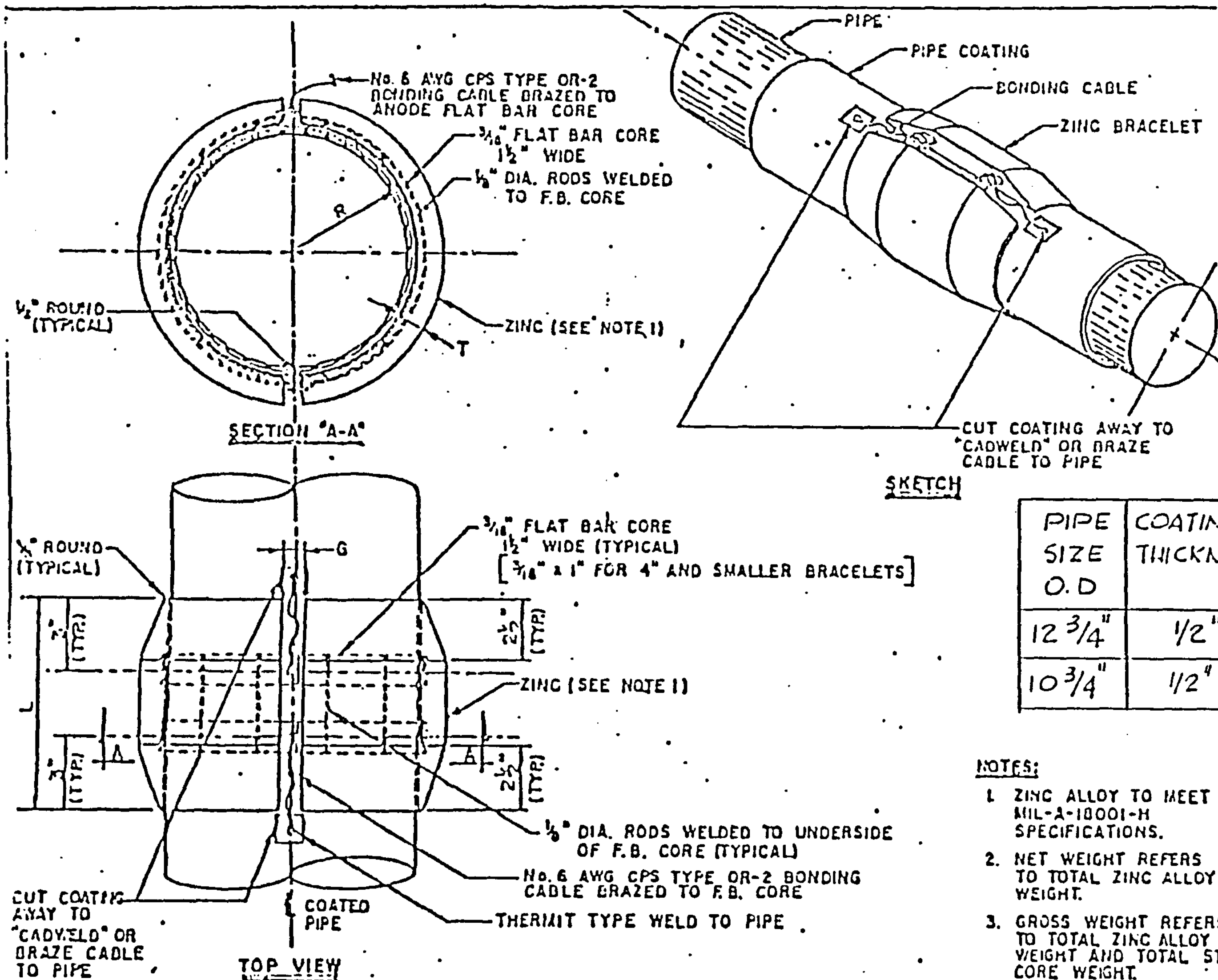
SEMI-CYLINDRICAL(1)
GALVALUM(R) III(2) BRACELET ANODE

(1) U.S. PATENT RE 27,529
(2) U.S. PATENT 3,974,055
(R) REG. T.M. DOW CHEMICAL CO.

JB

SCALE NONE

S-619



PIPE SIZE O.D	COATING THICKNESS	DIMENSIONS				NET WEIGHT LBS	GR. WEIGHT LBS
		R	T	L	G		
12 3/4"	1/2"	6.875"	2"	20 1/4"	1 1/2"	171	184
10 3/4"	1/2"	5.875"	2 1/2"	16"	1 1/2"	142	155

NOTES:

1. ZINC ALLOY TO MEET MIL-A-18001-H SPECIFICATIONS.
2. NET WEIGHT REFERS TO TOTAL ZINC ALLOY WEIGHT.
3. GROSS WEIGHT REFERS TO TOTAL ZINC ALLOY WEIGHT AND TOTAL STEEL CORE WEIGHT.

CATHODIC PROTECTION SERVICE
CORROSION ENGINEERS
HOUSTON, TEXAS

TAPERED CYLINDRICAL TYPE ZINC BRACELET ANODE

(U.S. PATENT ------ RE 27,529)

M.P.		
NONE	6-11-85	P-578

CALCULATION OF LIFT & DRAG COEFFICIENTS USING VARIABLE R_e

CURRENT VELOCITY = 2.5 FPS

R_e 6.625"Ø + 3" CONC = $\frac{10.625 (2.5)}{12.00 (1.4 \times 10^{-5})}$ = 2.5×10^5

R_e 10.75"Ø + 3" CONC. = $\frac{16.750 (2.5)}{12.00 (1.4 \times 10^{-5})}$ = 2.5×10^5

R_e 12.75"Ø + 3" CONC. = 2.5×10^5

THE VARIATION OF R_e IN THIS RANGE IS SMALL SO USE..

STEEL	$C_L = 1.00$	$C_D = .83$
CONC.	$C_L = .75$	$C_D = .90$

HP-27 program for safety factor of pipeline against translation

Let d_2 = dia. pipe + conc.
d_1 = dia. pipe
v = velocity of current due to waves (applied normally)
C_L = lift coefficient
C_D = drag coefficient
ρ = density of water (sea) = 1.99 slugs/ft^3
W_t = weight of pipe + fluid (if any) in air (#/ft)
P = weight/ft^3 of concrete = 190 pcf

sto	d_1	d_2	v	C_L	C_D	1.99	W_t	V	190	64		
Reg.	1	2	3	4	5	6	7	8	9	0		

Calc. pipe volume (Subroutine)

```
LBL 2
3
8
π
x
4
÷
RCL 2
x²
x
RCL 1
x²
π
x
2
÷
+
STO 8
RTN
```

Calc. weight in air (Subroutine)

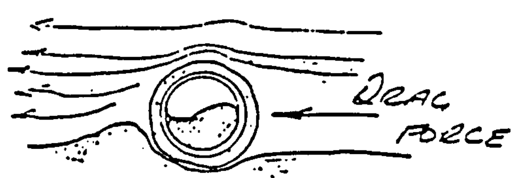
```
LBL 3
4
0
RCL 7
x
3
8
RCL 9
x
π
x
4
÷
RCL 2
x²
RCL 1
x²
−
x
+
RTN
```

HP-29 program

Calc. lift & drag force (Subroutine) - need C_L & C_D a-priori

($C_L = C_D$)
LBL 4
RCL 6
×
2
÷
RCL 2
×
RCL 3
x^2
×
RTN

Assume coefficient of lateral friction = 1.0 conservative



HP-29 program

Program

LBL1
Input dr → R/S
STO2
GSB2
GSB3
RCL8
RCL0
×
−
4
0
÷
STO.1
RCL4
GSB4
RCL.1
−
CHS
STO.1
RCL5
GSB4
RCL.1
÷
1/x
GTO1

Check calculation:-

12.750 Φ .500 oil, 1½ in. concrete, 3.5 FPS current

pipe volume = 53.19 ft³ (see "Sp. G. Calcs.")

weight in air = 7768.9# (")

submerged weight =

$7768.9\# - 64(53.19) = 4365\# =$

$4365\#/40' = 109.12\#/'$

lift force ...

$\frac{1}{2}\rho C_L D V^2 = \frac{1}{2}(1.99)(.75)\left(\frac{15.25}{12.0}\right)(3.5)^2 = 29.63\#/'$

drag force ...

$29.63\,\frac{.90}{.75} = 35.55$

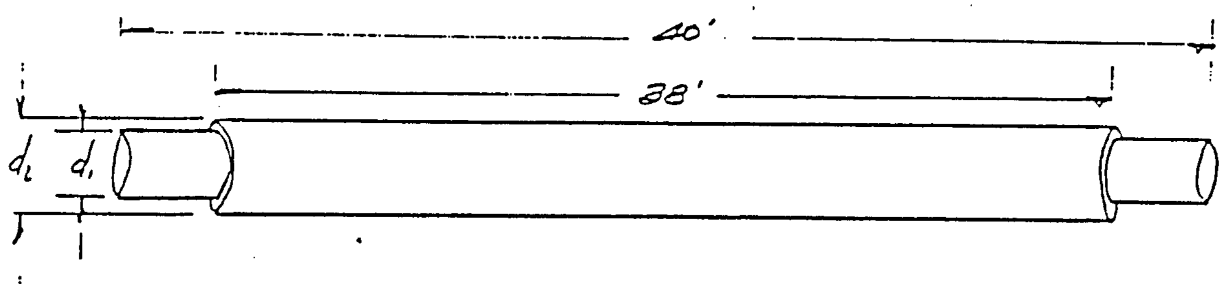
S.F.

$\frac{109.12 - 29.63}{35.55} = \underline{\underline{2.24}}$

from program ... SF = 2.29 so O.K.

Calculation of Average Specific Gravity for Conc. Coated Pipe

Assume - 12" cut back on concrete coating - double random pipe length - joint material has sp.g. = 1.00



let w_f = weight of pipe plus fluid, if any (#/')

ρ = density of concrete (#/ft³)

volume of pipe + coating...

$$V = 38\left(\frac{\pi d_2^2}{4}\right) + 2\left(\frac{\pi d_1^2}{4}\right)$$

weight (total) in air...

$$40 w_f + \rho(38)\left[\frac{\pi(d_2^2 - d_1^2)}{4}\right]$$

buoyant force...

$$64 (\#/ft^3) V$$

Sp. G Calc.

Sample ... 12.75 O.500 oil (sp.g. = .95), try 1.5" concrete coating 190 pcf

$W_f = 65.416 \#/' + .95(46.988 \#/') = 110.05 \#/'$

$V = 38 \left[\frac{\pi(12.75+3.0)^2}{4(144)}\right] + 2\left[\frac{\pi(12.75)^2}{4(144)}\right] = 53.19\ ft^3$

weight in air...

$40(110.05 \#/') + 190(38)\left[\frac{\pi(15.75^2 - 12.75^2)}{4(144)}\right] = 7768.9\#$

average specific gravity...

$\frac{7768.9\#}{53.19\ ft^3} \times \frac{1}{64.0} = \underline{\underline{2.28}}$ (based on sea water)

Remaining sp.g's were calculated by HP-29C programmable calculator, to yield values on following pages.

Sp. G. Calcs

Service	Sp. G. (lines full)		Sp.G. (lines empty)	
	Surf Zone	Offshore	Surf Zone	Offshore
Hilda				
12.75Ø .500 oil	2.24	1.94	1.73	1.15
10.75Ø .365 gas	2.12	1.62	2.12	1.62
6.625Ø .280 water	2.49	2.06	2.14	1.24
Gina				
10.75Ø .500 oil	2.39	2.12	1.93	1.36
6.625Ø .280 water	2.49	2.06	2.14	1.24

Calculation of neg. buoy. & sp. g. for 40' length, 1' cut back of laminate (198 pcf).

Service (Empty)		Surf Zone neg. buo.	sp. g	Offshore neg. buoy.	sp. g.
Glide	oil	64.49#	1.73	8.67#	1.15
	gas	118.97#	2.12	39.32#	1.62
	water	41.93#	2.14	3.65#	1.24
Gin	oil.	62.38#	1.93	14.40#	1.36
	water	41.93#	2.14	3.65#	1.24

Service (Full).		neg. buo.	sp. g	neg. buoy.	sp. g.
Glide	oil (.95)	109.73#	2.24	53.36	1.94
	gas	same		same	
	water	54.45#	2.49	16.17#	2.06
Gin	oil (.95)	93.12#	2.39	45.13#	2.12
	water	54.45#	2.49	16.17#	2.06

OTC 3072

DRAG AND INERTIA COEFFICIENTS FOR PARTIALLY-BURIED OFFSHORE PIPELINES

by Michael E. Parker, Texas A & M University, Exxon Co. U.S.A.; and John B. Herbich, Texas A & M University

ABSTRACT

This model study was designed to simulate more accurately the actual design conditions for most offshore pipelines. The data were analyzed by two approaches: (1) presentation of results in terms of a dimensionless force that can be used to give a prototype force estimation without requiring the calculation of the wave kinematics, and (2) presentation of drag, lift, and inertia coefficients that can be used in the Morison equation in combination with Stokes' third-order wave theory.

All results have been presented in a dimensionless form. Assuming that the laws of hydraulic modeling are followed and that there are no scale effects, these results can be used for determining the wave-induced forces on a partially buried pipeline.

INTRODUCTION

Since the late 19th century, men have been constructing various types of pipelines in the oceans. The first constructed were the submarine sewage outfalls, which provided a simple "out of sight, out of mind" solution to a sewage disposal problem. Until World War II, this was the extent of submarine pipeline engineering. During the Second World War, after the Normandy Invasion, twenty 3-in. (7.6 cm) submarine pipelines were laid to provide the Allied forces with fuel. Since World War II, there have been great strides made by the offshore petroleum industry and others in the commercial uses of the sea. The submarine pipeline has proved itself to be an economical and safe method of transportation of fluids from offshore locations. The petroleum industry uses pipelines for the transportation of crude oil and natural gas, utilities for extraction of cooling or hot water, and factories and cities for dumping wastes though under strict environmental control.

Since all structures placed in the ocean are subject to wave and current forces, it has always been important to estimate wave forces adequately. Until a theoretical method for calculation of such forces is developed, designers are forced to rely on experimental methods for force determination. These experimental methods may be either model studies or full-scale studies. Model studies are the most common method since full-scale studies are prohibitively expensive. Model studies also are convenient since nearly every design condition has its own peculiarities; i.e., mass production of offshore structures is not feasible.

When a pipeline is laid in an underwater environment, there will be some immediate settlement of the pipeline. The degree of this settlement depends on the bearing capacity of the sediments beneath the pipeline. If the pipe subsequently is buried, the wave forces are reduced to those caused by pore-water pressure variations. If the pipeline remains exposed to any degree, it is subject to forces caused by waves and currents. The amount of the pipe exposed can range from a fully exposed section such as a pipeline spanning between two points to having only a fraction of the diameter exposed due to settlement and sedimentation. There is no accurate way to predict the degree of settlement in other than very general terms.

THEORETICAL CONSIDERATIONS

Dimensionless Forces

The measured wave forces were converted to a dimensionless form by a method first proposed by Dean and Dalrymple[3] and later modified by Versowsky and Herbich.[10] These dimensionless forces are a desirable method for estimation of wave forces because they require no information on the wave kinematics, only the wave characteristics.

$$Fdim = \frac{Fmax}{\gamma \frac{H}{L} V \cdot SHL3 \cdot SL1} \quad (1)$$

$$SHL3 = \frac{\sinh(kl_3/2)}{kl_3/2} \quad (2)$$

$$SL1 = \frac{\sin(kl_1/2)}{kl_1/2} \quad (3)$$

References and illustrations at end of paper.

where Fdim = dimensionless force
Fmax = maximum measured force
γ = specific weight of water
H = wave height
L = wave length
V = volume of model (total) per unit length
k = wave number = $2\pi/L$
l_1 = model length in direction of wave propagation
l_3 = model height

The principal advantage of the dimensionless force method is that it does not require the water-particle velocities and accelerations. The only wave data needs are the height and length along with the prototype dimensions. This method requires that the following ratios be relatively close between the model and prototype: d/L, H/L, l_1/L, and l_3/L.

Wave Theory

The selection of a wave theory for use in the data reduction was of crucial importance. The theory selected should be easy to use, give a reasonable prediction of the wave kinematics, and be economical in terms of both time and money. First, Airy wave theory was considered, then rejected, because very few of the waves had a sinusoidal shape and also because of the errors in the prediction of accelerations by this theory in shallow water. Stokes' third-order wave theory then was considered and it proved to be adequate, especially since only minor modifications to an existing computer program were required. Stokes' fifth-order wave theory also was considered. This theory was rejected on the basis of some initial calculations that gave evidence that very few of the waves to be used in the model study would fall into the range of applicability of this theory. For the final results, Stokes' third-order wave theory as presented by Skjebreia[8] was used. Since computer programs generally are available, the use of a relatively complex wave theory, such as Stokes' third-order wave theory, is recommended.

Morison Equation

As it was first proposed, the Morison equation was intended for use with unbroken surface waves acting on a vertical circular pile extending from the bottom upward past the wave crest. The total wave-induced force computed is made up of two components, a velocity-dependent component (drag) and an acceleration-dependent component (inertia):

$$dF_T = dF_D + dF_I \quad (4)$$
$$dF_D = \tfrac{1}{2} C_D \rho A u|u| \quad (5)$$
$$dF_I = C_M \rho V \dot{u} \quad (6)$$

where dF_T = total force per unit length
dF_D = drag force per unit length
dF_I = inertia force per unit length
C_D = drag coefficient
C_M = inertia coefficient
ρ = fluid density
A = area per unit length
u = water-particle velocity (horizontal)
$\dot{u}$ = water-particle acceleration (horizontal)

This is the original form of the Morison equation, which relates the horizontal force of a submerged object to the water-particle kinematics. For this study, the Morison equation was extended for use on a horizontal cylinder partially embedded in the sea bed.

Ideally, in calculating the force on the model, the Morison equation should be integrated over the height of the model in a manner similar to that done by Versowsky and Herbich.[10] Because of the complexity of integrating the equations of Stokes' third-order wave theory, this was not done. It was felt that accurate results could be obtained by using the "centerline" velocity; that is, the velocity at the middle of the exposed height of the model. A justification for this decision has been presented by Parker.[9]

EXPERIMENTAL FACILITY, METHOD AND RESULTS

Facility

This model study was conducted in a two-dimensional wave tank of the Coastal, Hydraulic, and Ocean Engineering Group at Texas A&M U. The overall dimensions of the wave tank are 120 ft x 2 ft x 3 ft (36.6 m x 0.6 m x 0.9 m, length x width x depth) with a wave generator at one end and a variable slope beach at the other. The model was placed about 30 ft (9.1 m) from the wave generator. The model was a 2-ft (0.6-m) long section of 4.5-in. (11.4-cm) diameter aluminum pipe with a wall thickness of 0.25-in. (0.64 cm) (Fig. 1).

Since the strain-gauge load cells require that there be some displacement of the model in order to measure any forces, the model had to be suspended freely. This was accomplished by hanging the model with fine stainless steel wires attached to the strain gauges (Fig. 1).

The vertical forces were measured by two load cells connected in series. The model was connected by thin wires to a long-threaded bolt. The submerged weight of the model was sufficient to provide the pretension load required in the vertical direction except in the most severe cases. The horizontal forces were measured also by two strain gauges connected in series. Since the load cells could not be submerged, some method of converting the horizontal motion into vertical motion was required. This was accomplished with a pulley fabricated from plexiglass. The frictional through-the-pulley losses were minor, approximately 5 to 10 percent, depending on the magnitude of the load. To pretension the load cells in the horizontal direction, a spring was attached to the model on the side of the model opposite the leads for the horizontal force measurement.

Method

The experiments were made in water depths of 15 in. (38.1 cm), 18 in. (45.7 cm) and 21 in. (53.3 cm) with model exposures of ¼, ½, 3/4 for each water depth. For each combination of water depth and model exposure, 81 different waves were tried. This resulted in over 700 trials, of which about 550 runs gave usable data.

For any particular experimental run, the procedure was as follows. Assuming a run had just been completed, the motor speed was turned up to the next increment. After the water surface became calm, the instruments were set to the zero mark. The wave generator then was turned on and a wave train was allowed to become established. Once the waves were well established, a force record was taken, generally for about 30 seconds. In addition to the normal force records, high-speed records also were made for every third trial. The force records were digitized then and analyzed by an Amdahl 470/V6 computer.

To change the exposure of the model, the threaded connections were adjusted to give the desired exposure. For the one-fourth exposure, some additional modifications were required to prevent rocking of the model. For this case the horizontal wires had to be run under the false bottom. This modification required that several holes be drilled in the sealing apparatus around the model. These holes then were sealed with thin rubber membranes in an attempt to minimize any circulation around the model.

Results

Several generalized assumptions were required in the data analysis. (1) The wave reflections from the model and wave tank beach were assumed to be negligible. (2) Stokes' third-order wave theory was assumed applicable for all waves used. Additional assumptions were made for various methods of analysis as described below.

The dimensionless force analysis required no additional assumptions. With this analysis there is no problem with separation of inertia or drag components of the forces. The total vertical and total horizontal forces each are expressed in terms of a single value of dimensionless force. Plotting these dimensionless forces in groups of constant d/L vs H/L resulted in some composite plots, which were then smoothed out to give the idealized curves presented here. Figs. 2, 4, and 6 show the idealized horizontal dimensionless force for $\frac{1}{4}$, $\frac{1}{2}$, and 3/4 model exposure, respectively, while Figs. 3, 4, and 7 show the idealized vertical dimensionless force for $\frac{1}{4}$, $\frac{1}{2}$, and 3/4 model exposure, respectively.

Several interesting characteristics can be noted from these curves. First, the magnitude of the dimensionless force is increasing with increasing pipe exposure, which is to be expected as more pipe area is exposed to the moving water. The dimensionless force decreases with an increasing d/L. This is due to the fact that as the waves approach the deep water condition ($d/L > 0.5$), the water-particle kinematics near the bottom diminish. The dependence of the dimensionless force on H/L and d/L can be explained by the fact that the dimensionless force equation (Eq. 1) includes an H/d term. The effects of changing the water depth cannot be observed from plots in this form. It is felt that these effects are covered by the d/L term, which would tend to put water depth on a common base.

The Morison equation probably has become the most common method of estimating wave forces on a structure. For the first analysis of the wave forces by this method, it was assumed (because of the size of the model with respect to the wave lengths and water depths) that the forces were totally inertia-dependent, both in the horizontal and vertical directions. The equation used was of the form

$$C_M = \frac{F_{max}}{\rho \, V \, \dot{u}} \quad , \ldots \ldots \ldots \ldots (7)$$

where $\dot{u}$ = maximum water-particle acceleration in the direction of interest.

For these and all other inertia coefficient calculations, the total volume of the model was used. This was done since the model was a whole section of pipe rather than a cut section of pipe. When a wave passed over the model, the whole model was in motion, not just the exposed part.

Results for this analysis are shown in Figs. 8, 9, and 10 for $\frac{1}{4}$, $\frac{1}{2}$, and 3/4 model exposure, respectively, for the horizontal inertia coefficient. As can be seen from the data points, there is a great deal of scatter. However, each pipe exposure did appear to have a limiting value that C_M did not exceed. There was a slight trend for the value of C_M to decrease with an increasing H/L. The analysis of the vertical forces by this method gave very high values, which indicated that the assumption of the maximum vertical forces (being predominantly due to the inertial component of the Morison equation) was not valid. For this reason another method of analysis was selected.

This method of analysis was proposed by Grace[4-6] for the vertical forces. He suggested that the vertical forces can be expressed as a function of the horizontal water-particle kinematics. The equations used were of the form

$$C_L = \frac{F(\theta)}{1/2 \, \rho \, A \, u^2} \quad \ldots \ldots \ldots \ldots (8)$$

$$C_M = \frac{F(\theta)}{\rho \, V \, \dot{u}} \quad , \ldots \ldots \ldots \ldots (9)$$

where $F(\theta)$ = force at phase angle where either u or $\dot{u}$ is maximum as applicable, and

C_L = lift coefficient.

Grace makes these assumptions based on the fact that the vertical water-particle accelerations are very small near the bottom and openly admits that there is no justification in theory for this assumption. The lift-coefficient equation is based on potential flow theory, which predicts a vertical force based on the horizontal velocity.

The results for the vertical inertia coefficient are shown in Fig. 11. As with the first method of analysis, there is a slight trend for the inertia coefficient to decrease with increasing values of d/L. There also appears to be some critical value of d/L where a drastic change in slopes for the best-fit curves of d/L occurs. This value appears to be around $d/L \simeq 0.100$. The results for the lift coefficient are shown in Fig. 12. It is felt that the low values for the Reynolds number observed (10^4) in this study produced results of only peripheral value under most prototype conditions (Reynolds number = 10^6).

For the horizontal drag coefficient, the Morison equation (drag component) as shown in Eq. 10 was used. No additional assumptions were required for this analysis.

$$C_d = \frac{F(\theta)}{1/2 \, \rho \, A \, u^2} \quad \ldots \ldots \ldots \ldots (10)$$

The results for the horizontal drag coefficient are presented in Fig. 13. As with the lift coefficient, it is felt that these results are of only peripheral value under most prototype conditions.

CONCLUSIONS

The data and results presented were based on original data taken by the authors. It was felt that a need existed for a model study to represent accurately the actual design situation for offshore pipelines. Results from the model study were analyzed using a dimensionless force approach and a form of the Morison equation. The results have been presented in the form of dimensionless plots. The range of values for d/L observed were from about 0.050 to 0.600 and for H/L from about 0.001 to 0.070. All the experiments were conducted in the two-dimensional wave tank at Texas A&M U. The conclusions are as follows.

1. The dimensionless force as computed here shows a very good relationship with the wave parameters d/L and H/L.

2. The inertia coefficients calculated by the assumption of totally inertia-dependent forces were quite good for the horizontal forces. The vertical forces gave results that were not usable, and it may be concluded that the vertical forces could not be said to be totally inertia dependent.

3. The assumption proposed by Grace[4-6] gives reasonable results, even though it has no basis in theory.

4. As with any model study, it is recommended that full-scale studies be conducted. Accurate values for the drag and lift coefficients are desired. These values should be obtained at Reynolds numbers, which more closely approximate those of the prototype situation.

NOMENCLATURE

- A = projected area of model
- C_d = drag coefficient
- C_L = lift coefficient
- C_M = inertia coefficient
- d = water depth
- dF_D = drag force per unit length
- dF_I = inertia force per unit length
- dF_T = total force per unit length
- F_{dim} = dimensionless force
- F_{max} = maximum measured force
- H = wave height
- k = wave number
- L = wave length
- l_1 = model length
- l_3 = model height
- T = wave period
- u = horizontal water-particle velocity
- $\dot{u}$ = horizontal water-particle acceleration
- V = total volume of model
- γ = fluid specific weight
- ρ = fluid density

ACKNOWLEDGMENTS

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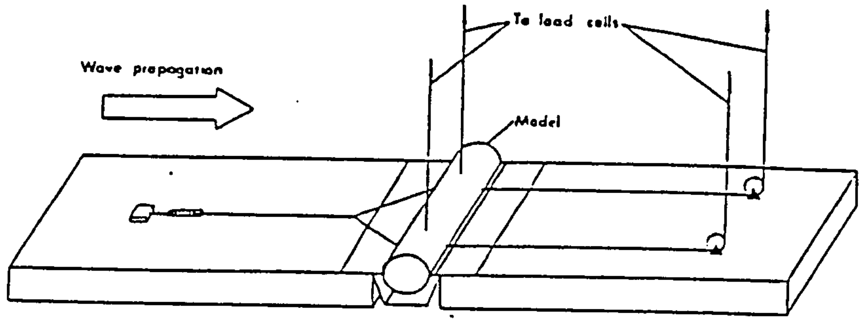

FIG. 1 - EXPERIMENTAL SET-UP.

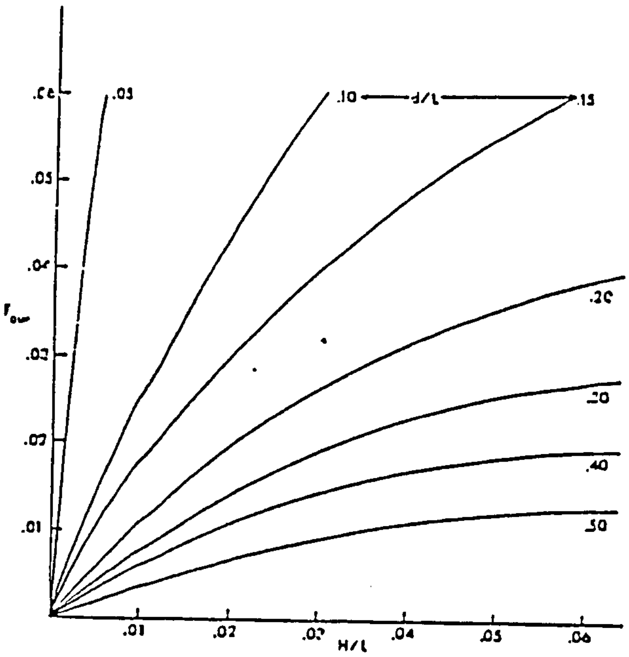

FIG. 2 - IDEALIZED HORIZONTAL DIMENSIONLESS FORCES FOR 1/4 PIPE EXPOSURE.

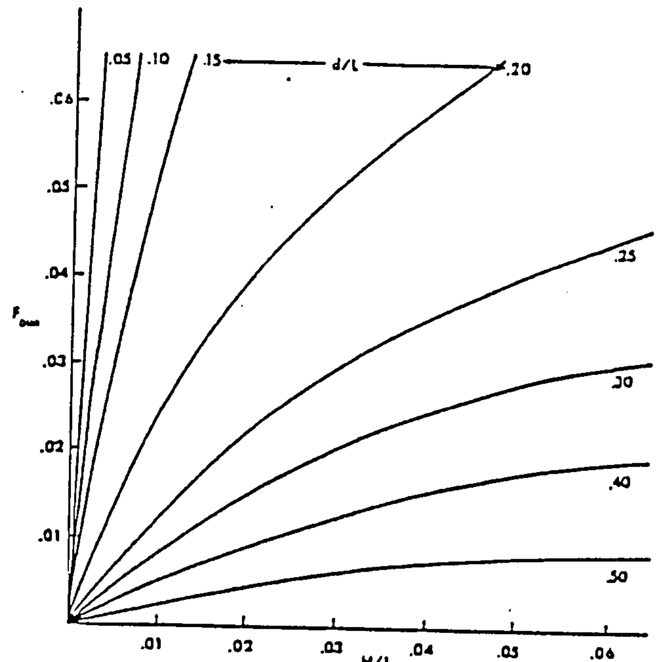

FIG. 3 - IDEALIZED VERTICAL DIMENSIONLESS FORCES FOR 1/4 PIPE EXPOSURE.

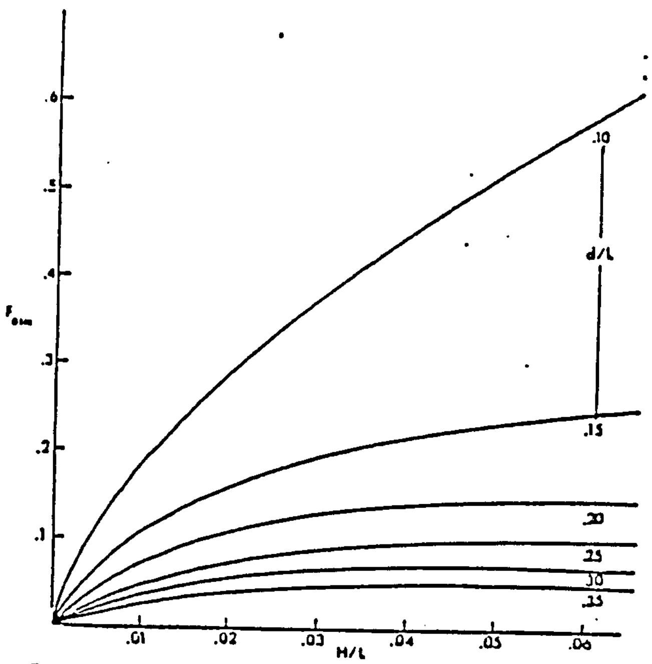

FIG. 4 - IDEALIZED HORIZONTAL DIMENSIONLESS FORCES FOR 1/2 PIPE EXPOSURE.

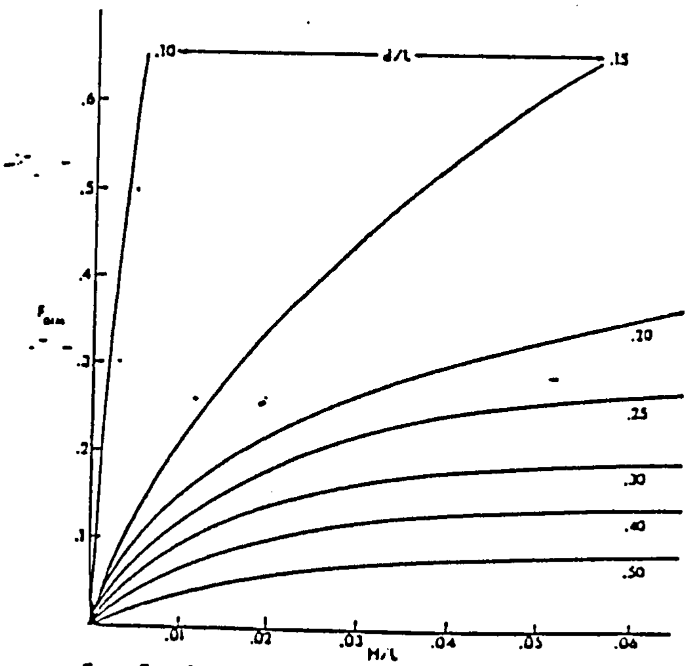

FIG. 5 - IDEALIZED VERTICAL DIMENSIONLESS FORCES FOR 1/2 PIPE EXPOSURE.

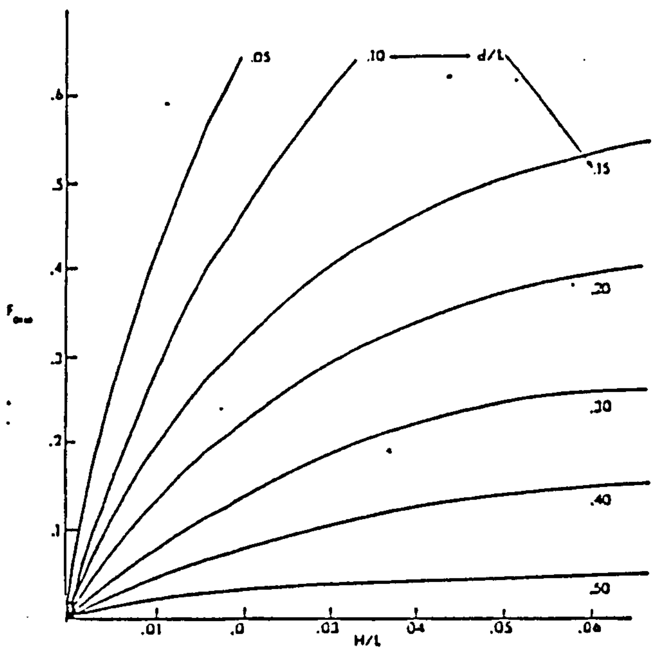

Fig. 6 - Idealized horizontal dimensionless forces for 3/4 pipe exposure.

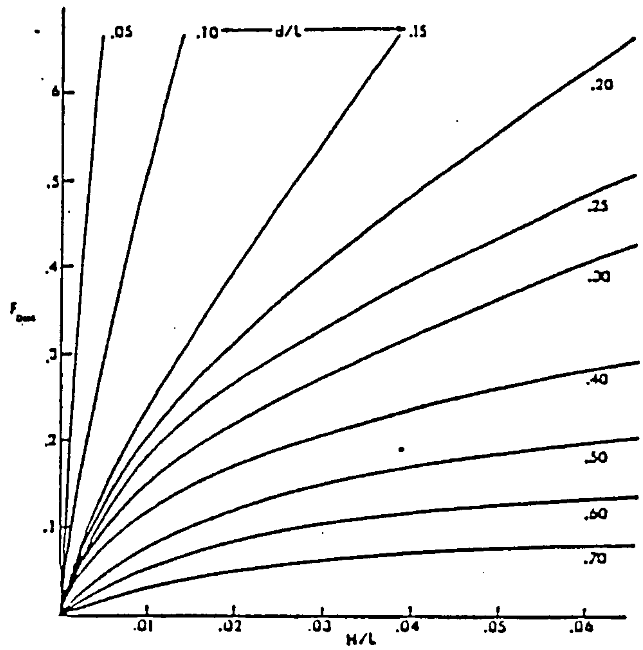

Fig. 7 - Idealized vertical dimensionless forces for 3/4 pipe exposure.

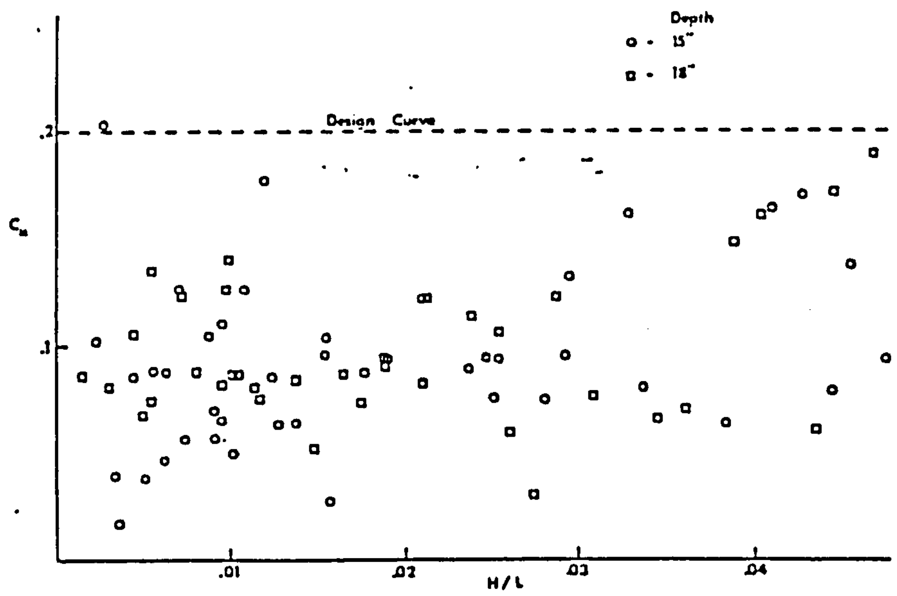

Fig. 8 - Horizontal inertia coefficient for 3/4 pipe exposure.

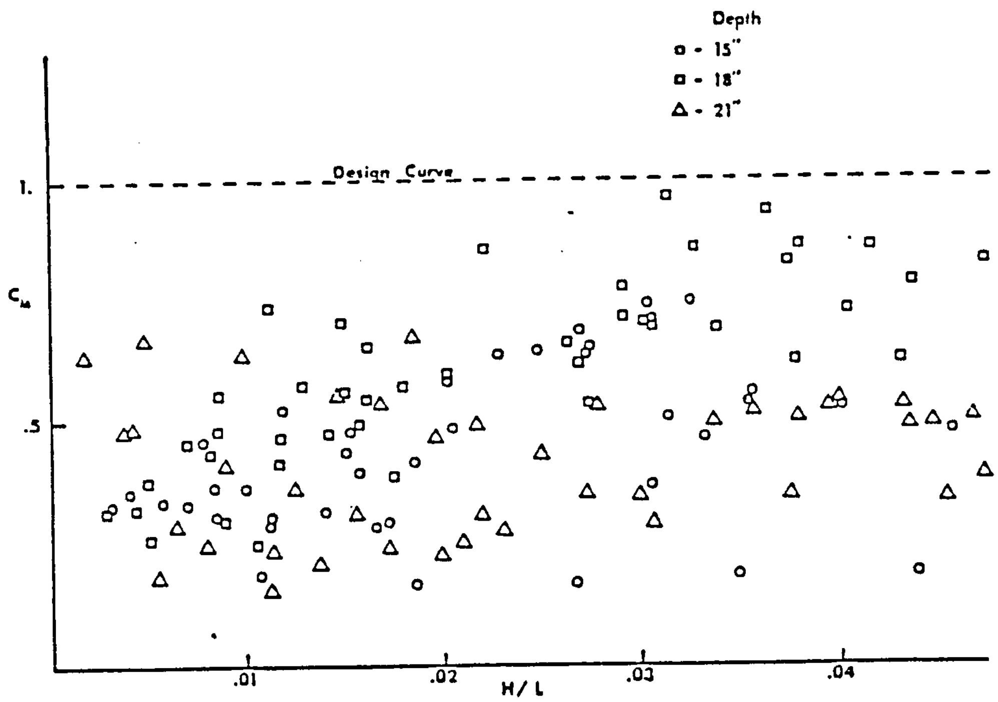

FIG. 9 - HORIZONTAL INERTIA COEFFICIENT FOR 1/2 PIPE EXPOSURE.

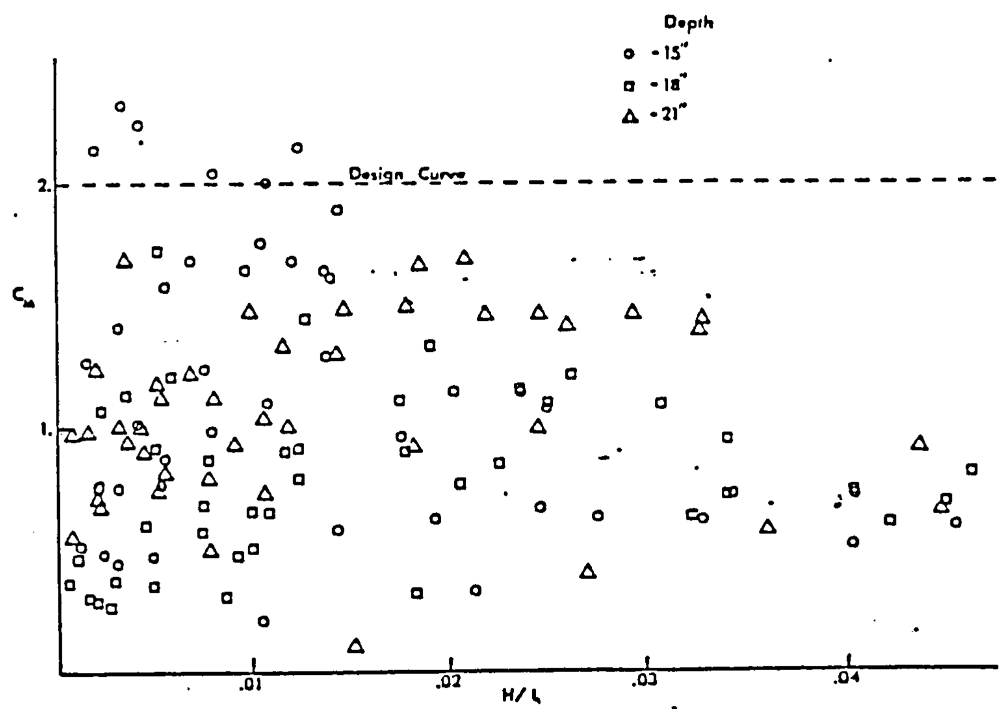

FIG. 10 - HORIZONTAL INERTIA COEFFICIENT FOR 3/4 PIPE EXPOSURE.

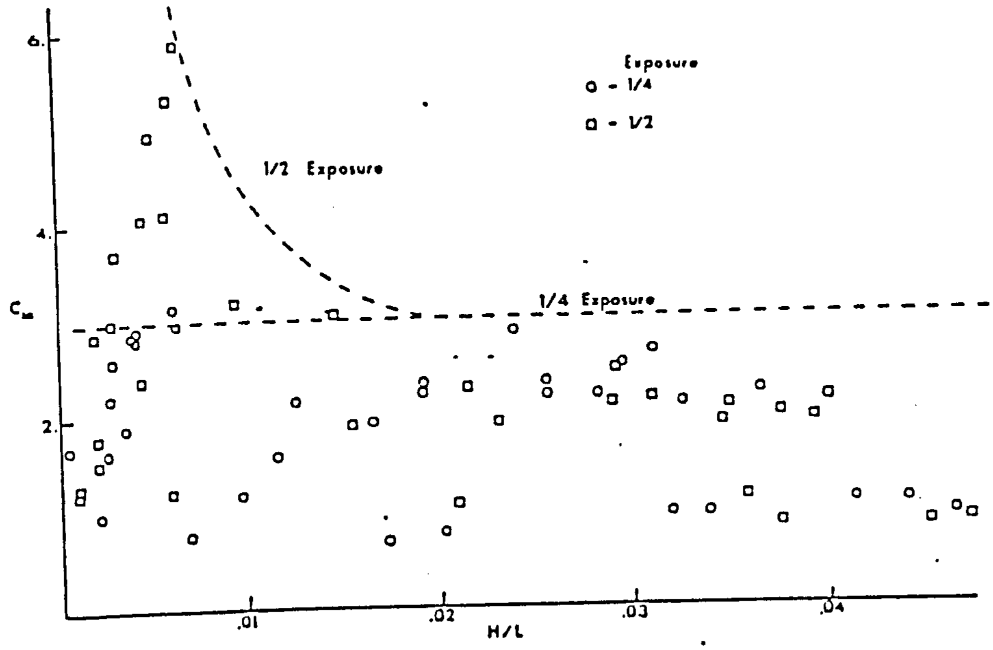

FIG. 11 - VERTICAL INERTIA COEFFICIENT.

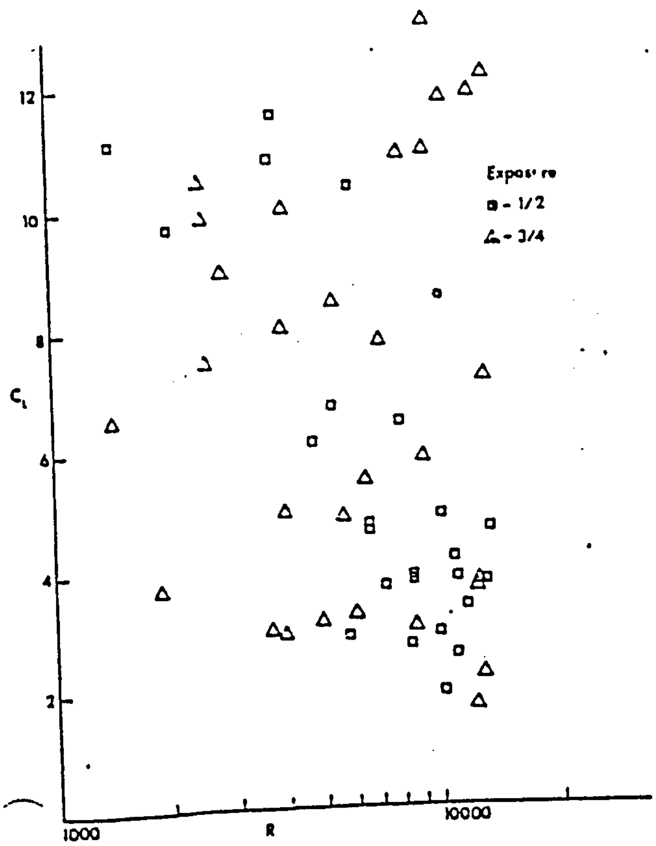

FIG. 12 - LIFT COEFFICIENT.

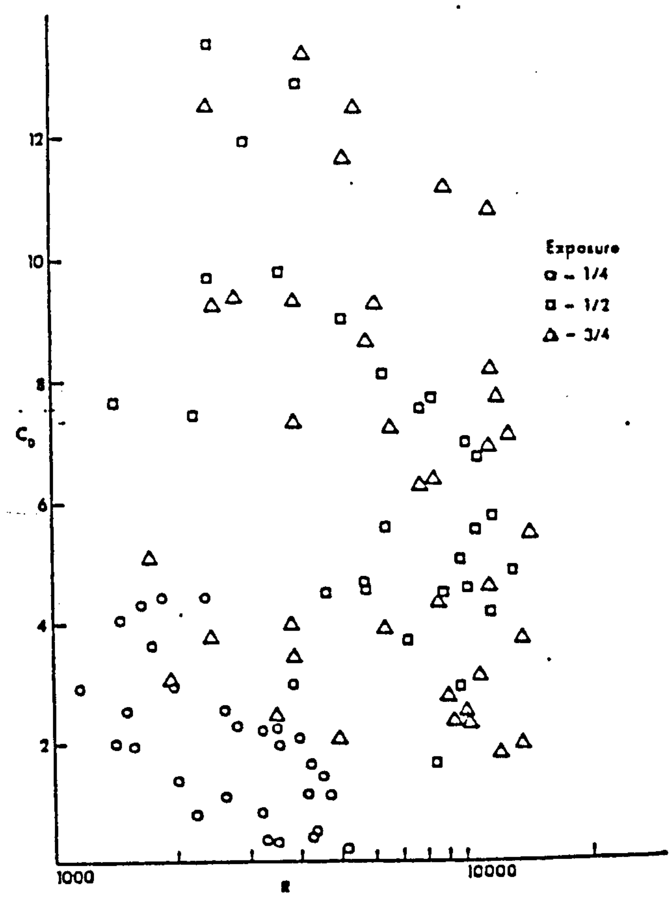

FIG. 13 - DRAG COEFFICIENT.

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On-Bottom Pipeline Stability in Steady Water Currents

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ABSTRACT

A recommended practice is established for the on-bottom stability design of a pipeline subjected to steady water currents. The analysis leading to the recommended design procedure recognizes that the water velocity decreases as the bottom is approached due to the boundary layer effect and that the magnitude of the hydrodynamic forces on the pipe will be a function of the shape of this velocity profile. The analysis also assumes that the lateral resistance to movement provided by the bottom soil is proportional to the net vertical resultant force acting on the bottom. Equilibrium, or stability, occurs when the lateral resistance is just equal to the forces exerted on the pipeline by the steady current. The resulting design equation for the required pipeline weight contains several parameters whose numerical value depends on the pipe, seawater, and soil properties. A nominal set of these values is chosen and a parametric study is made of their effect on the required pipeline weight. Design curves are generated based on the chosen parameter values, and procedures for their use are recommended. The parametric study demonstrates that the minimum specific gravity required for equilibrium is relatively insensitive to large variations in the value of most of the parameters in the design equation. It also demonstrates that the selection of the design current velocity is the most significant factor in the stability analysis. Hence, further research on stability can most profitably be aimed at developing better methods of determining the design velocity for a particular location in the ocean.

References and illustration at end of paper.

INTRODUCTION

The design of an offshore pipeline system must give due consideration to each of the following factors. The operating requirements - internal pressure, throughput, etc. - have a large influence on the design. At the same time the design must provide for the safety and integrity of the line in the face of external and environmental factors over the expected lifetime of the system. Factors influencing the selection, design, and efficiency of the construction system must also be included in the overall consideration of the design.

The specifications for the line pipe and t[illegible] pipe coating system must not exceed those required to ensure adequate operating performance and long-term safety of the line. Unnecessary pipe weight and too-stringent pipe handling criteria impose undue operating limits on present construction systems even in moderate water depths. In deeper water they may impose impractical requirements on the construction system. The selection of the pipe and specifications for the coating system are directly affected by the criteria established for the maximum environmental conditions expected over the life of the pipeline. Therefore, the environment of the operating pipeline is the basic starting point for the design.

A complete discussion of the environment near the seawater - soil interface is beyond the scope of this paper. Suffice it to say that certain environmental situations must be avoided by careful route study and selection because there is no known method to ensure pipeline stability and integrity in the face of gross instability of the sea bottom. Thus, route selection is the first and most important step in stability design. Mes[1] gives a general discussion of what needs to be known about the ocean bottom for design purposes and methods of obtaining the necessary data. Bea et al[2] in their discussion of bottom movements in the Mississippi Delta present an excellent example of the correlation of bathemetric surveys, soil borings, sparker data, and a general geologic knowledge of a given area. Such study of available data is a necessary prerequisite to rational route selection.

Once a route has been selected to avoid the hazardous environmental factors, the designer then begins to investigate the local rather than the large scale environment of the line. One of the first questions is whether the bottom is locally stable, i.e., will scour occur? This is an important question which will not be considered in this paper. Townsend and Farley[3] conducted scour tests in cohesionless soils and concluded that the pipeline would settle and stay in contact with the sand bottom as the bottom eroded. The same conclusion was reached from earlier, unpublished tests conducted by the Shell Pipeline Research and Development Laboratory. Of course if portions of the line are laid on harder or non-scouring materials, then a span could be left suspended over other portions of bottom which do scour.

Another question which will not be considered in this paper concerns the magnitude of the hydrodynamic forces exerted on the pipeline by surface waves. Grace[4] has summarized available wave force data for submarine pipelines through 1973. However, the present paper is concerned only with the hydrodynamic forces exerted by steady currents.

The discussion to this point has attempted to give a broad perspective of the complete on-bottom stability problem. With this in mind, we turn now to a specific part of the overall problem. Consider a pipeline lying exposed on the ocean bottom along a route which has been carefully chosen to avoid the hazardous environmental factors. In addition the bottom is locally stable, i.e., significant scour is not likely to occur. Only hydrodynamic forces due to steady currents are considered. Based on these assumptions, the next section presents a stability analysis in which the basic equations are derived and numerical values are recommended for the various parameters. The succeeding section is a study of the effect of the numerical values assigned to the parameters on the resulting weight of the pipeline. Design procedures, graphs, and tables are presented in the last section.

STABILITY ANALYSIS

Equilibrium Equations

The stability analysis is based on the following premise: the pipe rests on a stable bottom of slight slope and is exposed to a steady current. Soil properties are similar to those typical of the continental shelf soils, and water temperatures are between 2 and 15°C.

As the pipe comes to rest on bottom during the laying process, its weight deforms the bottom surface and the pipe settles into the soil. As the steady current tries to move the pipe, the soil provides a resisting force. The resisting force is taken to be proportional to the net effective weight on bottom. The resisting force includes not only a frictional component but also an additional reaction which stems from the sides of the groove that the pipe makes in soft bottom materials - or for hard bottom surfaces, from the projections of the irregular bottom surface. The net reaction however is expressed mathematically through a coefficient of "friction". The soil force is assumed to be a constant, μ, times the normal force exerted on the soil.

On this basis, the forces acting on a pipe resting on a bottom with a slight slope are as shown in Figure 1(a). A steady current $V(y)$, which varies with height above bottom, y, approaches the pipe in the direction shown. The slope angle, α, is taken to have directional properties as indicated. A horizontal bottom is given by $\alpha = 0$. A positive value of α gives a current flow up slope. A negative value of α gives a current flow downslope as shown in Figure 1(b). The hydrodynamic force exerted by the current on the pipeline is resolved into components parallel and perpendicular to the bottom. These components are called the drag force, F_D, and the lift force, F_L, respectively. The normal and tangential soil reaction forces are q_n and q_t, respectively. Equilibrium equations for the pipe are given by:

$$q_n = w \cos \alpha - F_L \qquad (1)$$

$$q_t = F_D - w \sin \alpha \qquad (2)$$

$$M = F_D d - 1/2\, Dw \sin \alpha \qquad (3)$$

where w is the submerged weight per foot of the pipeline including any internal fluids, D is the pipeline diameter, M is the moment about the point at which the pipe touches the soil, and d is the distance from that point to the line of action of the drag force. The moment M is resisted by the section of pipe adjacent to the plane of the figure and is not considered further. The lateral resisting force of the bottom contact is:

$$q_t = \mu q_n \qquad (4)$$

Substituting Equations (1) and (2) into (4) and rearranging gives

$$w = \frac{F_D + \mu F_L}{\mu \cos \alpha + \sin \alpha} \qquad (5)$$

The lift and drag forces have been experimentally determined at the Shell Pipeline Research and Development Laboratory. As shown in Reference 5, the lift and drag forces may be expressed in terms of the OD of the pipe, D, the mass density of the fluid, ρ, and coefficients C_D and C_L as:

$$F_D = \frac{1}{2}\rho C_D D V_e^2 \qquad (6)$$

$$F_L = \frac{1}{2}\rho C_L D V_e^2 \qquad (7)$$

where the effective velocity acting on the pipeline, V_e, is defined as:

$$V_e^2 = \frac{1}{D}\int_o^D V^2(y)\, dy \qquad (8)$$

The equilibrium equation then becomes

$$w = \frac{\frac{1}{2}\rho D V_e^2 (C_D + \mu C_L)}{\mu \cos \alpha + \sin \alpha} \qquad (9)$$

The specific gravity of the pipeline is defined as the total weight of the pipeline including the weight of the internal fluids divided by the weight of the displaced standard seawater of mass density $\rho_s = 64.0/32.2$ lb-sec^2/ft^4, or

$$SG = \frac{\rho}{\rho_s} + \frac{4w}{32.2\rho_s \pi D^2} \qquad (10)$$

Equations (3), (9), and (10) are the basic design equations which give the submerged weight of the pipeline required for equilibrium as a function of water velocity.

Parameter Values

Values of the drag and lift coefficients, C_D and C_L, will depend on the Reynolds number of the flow and on the surface roughness, k, of the pipeline. In Reference 5 experiments to determine the values of C_D and C_L are described. It is shown there that if the effective velocity is used in the definition of the coefficients and Reynolds number, then the data obtained with different boundary layer profiles collapses onto a single curve. Only recently it was discovered that the Reynolds number axis was incorrectly shifted on some of the curves recommended for design use in Figures 17 and 18 of Reference 5. The corrected recommended design curves and the data are shown here in Figures 2 and 3.

In Reference 5 a 1/7th power law representation for the boundary layer velocity profile is recommended and data is presented showing the applicability of this form. Using this profile, the definition of the equivalent velocity becomes

$$V_e^2 = 0.778U^2 \left(\frac{D}{h}\right)^{0.286} \qquad (11)$$

where U is the velocity at the height h above bottom. The principal advantage of this representation is that only one point on the velocity profile is needed to specify the equivalent velocity.

The only remaining undetermined item on the right hand side of Equation (9) is the coefficient of bottom friction, μ. A value of 1.0 is recommended for general use. Some of the data obtained in the laboratory by Lyons[6] indicates a value lower than 1.0 might be more appropriate. However, these data were obtained by carefully placing the pipe on a submerged bed of sand or clay and applying loads to simulate the hydrodynamic loads. In the ocean, the pipe is laid on the bottom by lowering from a barge on the water surface. A mathematical analysis of the suspended span of pipe shows that a concentrated vertical shear force exists at the point where the span touches bottom. In actuality this concentrated shear force is distributed over some finite length of pipe touching bottom. A rational analysis of the magnitude of this force indicates the maximum distributed force per unit length is of the same order of magnitude as the weight of water contained in the pipe during hydrostatic testing of the pipeline system. As a result of this ...racted shear force the pipe is pushed ...ard into the soil as it is lowered to the bottom. During hydrostatic testing of the completed pipe line, the soil loading is increased again and the pipe settles further into its groove". Lyons's data[6] demonstrated that pipe filled with water as during hydrostatic testing develops a 1.9 "coefficient of friction" (in the groove) to resist lateral movement. Lyons correctly attributes the large increase in "μ" to the additional settlement of the pipe into the soil. Based on these studies, it is felt that the combination of shear force during laying and loading during hydrostatic testing result in an effective "μ" greater than 1.0 in most sea bottom soils. This agrees with the value chosen by Ells[7] from experiments to determine the "coefficient of resistance" for a line in the North Sea and is recommended as a design factor for most stability analyses.

Effect of Slope Angle

Consider a pipe resting on a horizontal bottom and define w_o as the submerged weight calculated for this case using Equation (9). Then for a value of μ = 1.0 and any other slope angle, α,

$$\left(\frac{1}{\cos\alpha + \sin\alpha}\right) w_o \quad \ldots\ldots(12)$$

The factor in parenthesis is called the Slope Factor and is tabulated in Table I for values of α from -10° + 10°.

This form shows that the overall effects of slight bottom slopes on the minimum required submerged weight can be taken into account by using a "weighted" design weight. The "weighted" design weight is obtained by multiplying the design weight for a horizontal bottom by the appropriate Slope Factor from Table I. For example, a negative slope of 10 degrees requires a "weighted" design weight 1.23 times that required on a horizontal bottom.

Table I shows that for up to 10° slopes, the maximum variation in design weight from that required for a horizontal bottom is on the order of 20%. Therefore further discussion of submerged weight on bottom will consider only a horizontal ocean bottom. Values of submerged weight as obtained later can be converted to submerged weight corresponding to a slope α by multiplying by the appropriate Slope Factor from Table I.

...puter Program

The following procedure is followed to ...alculate an equilibrium submerged weight. The design velocity U and a height off bottom h are used in Equation (11) to calculate an equivalent velocity V_e. The temperature of the ocean water is used with an appropriate table to determine the kinematic viscosity of seawater, ν. The equivalent Reynolds number is then calculated from

$$Ree = \frac{V_e D}{\nu} \quad \ldots\ldots(13)$$

The surface roughness height, k, of the outermost surface of the pipeline is used with the OD of this outermost surface to calculate the k/D ratio. This ratio and the equivalent Reynolds number are then used to enter Figures 2 and 3 and read off values of C_D and C_L. These values are substituted into Equation (9) along with values of μ and α to calculate the required submerged weight. The pipeline specific gravity is obtained from Equation (10).

The above procedure is straightforward, but the use of tables and graphs makes it cumbersome and time consuming. Therefore, a computer program was written in Fortran V for the Univac 1110 computer. The program, named Equilibrium Submerged Weight (ESWT), follows precisely the above procedure except all the necessary tables and graphs are stored internally. Sample output data from the program is shown in Appendix II.

PARAMETRIC STUDY

The heading on the tables of Appendix II indicates the values of parameters used as input to the program. These are a "nominal" set of values which should apply to most pipeline design situations. However, it is of interest to study the effects of variations in each of these parameters on the resulting stability design requirements.

The equations necessary to evaluate the sensitivity of the design to each parameter are derived in Appendix I. The "nominal" values and submerged weight calculated from them are represented by a subscript "0". One of the parameter values is changed to form a "new" or "different" set of input which is given the subscript "1". The percentage change in a general variable x is defined as

$$\delta x = \frac{x_1 - x_0}{x_0} \quad \ldots\ldots(14)$$

Then the percentage change in submerged weight, δw, is expressed in terms of the percentage change in the variable in question, e.g., $\delta\rho$, δh, δU etc.

The resulting equations are mathematically correct for any percentage change of the variable in question. However, there are realistic limits on the amount of change possible in each of the parameters. As an example, consider the density of sea water which varies with salinity and temperature. The major variation for pipeline design, however, is the increase in fluid density due to sediments suspended in the bottom flow. An upper limit on this increase is provided by the density of a fully developed turbidity current which is about 10% greater than normal sea water. The lower limit is provided by the density of fresh water. Similar considerations are used to fix the practical limits on the variations of each of the parameters.

The resulting equations are plotted in Figure 4 for effective Reynolds numbers greater than about 5×10^5. In this region δC_D and δC_L are zero and the equations are considerably simplified. The shape and magnitude of the curves at lower Reynolds numbers would be similar. The solid lines represent the variation in submerged weight within the practical limits of each parameter. The dashed lines are included only to indicate the general shape of the mathematical curve.

The variation due to changes in surface roughness height, k, and water temperature, T, are not shown in Figure 4. Rather than evaluate Equation (I-26), an easier brute force method was adopted. ESWT was run for the limiting values of k and T and various combinations of velocity and diameter. The results in Table II show that all variations in calculated submerged weight are less than 10% over the full range of feasible k and T values.

The solid curves in Figure 4 show that variations in submerged weight due to $\delta\rho$, δh and δC have a maximum value of about 15-20%. However these are really upper limits and the variation in any actual pipeline situation is probably much less. Figure 4 shows that the variation in calculated design weight due to $\delta\mu$ and δU can be much larger than any of the above.

These large variations due to $\delta\mu$ and δU can be mitigated by expressing the results of the stability calculation in terms of specific gravity. Equation (I-35) shows that the variation in specific gravity is always less than the variation in submerged weight. As an example consider the case of a calculated "nominal" specific gravity of $SC_o = 1.3$. Now suppose $\delta\mu$ has the maximum realistic reduction of 50%; Figure 4 indicates a δw on the order of 50%. But Equation (I-35) gives a variation in specific gravity of only $.3 \times 50/1.3 = 11.5\%$. Even this extreme example gives results within usually accepted bounds of engineering accuracy. Variations in calculated specific gravity due to the maximum $\delta\rho$, δC, δh, δk, or δT are very small in this example, only 2 to 4%. However the maximum variation in calculated specific gravity due to δU is 23%, a still sizeable figure.

DESIGN PROCEDURE

The minimum pipeline specific gravity required for equilibrium as calculated by ESWT for the "nominal" input parameters is shown in Figure 5. The "Pipeline OD" shown is the overall diameter including the outermost coating on the steel line pipe. Since specific gravity is relatively insensitive to the numerical values of the various input parameters, this figure can be used as a general design chart for most situations.

Since the line pipe diameter is known at the start rather than the pipeline OD, a trial-and-error method is required to arrive at a design specific gravity and the resulting diameter. Trial and error solutions are not difficult since the curves in Figure 5 are relatively close together. The design velocity and an estimated OD are used to enter Figure 5 and determine a required specific gravity. A coating schedule is then designed to give this value of specific gravity. If the OD of the resulting pipeline is different from that originally assumed, Figure 5 is re-entered with the new OD and the process is repeated until the new and old OD agree.

Another possible trial-and-error scheme starts with the specification of a coating system. The resulting pipeline specific gravity and OD are calculated. Figure 5 is then entered and the equilibrium velocity is read and compared with the design velocity. The coating schedule is then adjusted accordingly.

The design chart of Figure 5 gives the specific gravity required for equilibrium in the face of a given design current. This means the pipe is just on the verge of moving. Therefore, the designer will want to include a factor of safety in his calculations. The appropriate factor of safety is a matter of engineering judgement. Its value will depend greatly on the confidence of the designer in the numbers chosen to represent "design conditions" - particularly design velocity. It will also depend on the tolerances of the weight coat application system. Small variations from the specified value of specific gravity can result in large variations in submerged weight, particularly with large pipelines. Only the designer of a particular project will have the information necessary to make these engineering judgements, so no value for the factor of safety is recommended here.

Figure 6 shows the submerged pipeline weight required for equilibrium as a function of water velocity and pipeline OD. The curves in this figure are similar to the specific gravity curves of Figure 5 with one exception. As the pipeline OD increases, the equilibrium submerged weight increases while the equilibrium specific gravity decreases. The reason for this can be seen in Equations (9) and (10). As the diameter D increases, the submerged weight goes up in direct proportion to D. The specific gravity in contrast is a function of w/D^2 or $1/D$.

Figure 6 could be used as a design chart in the same manner as Figure 5 to arrive at an equilibrium submerged weight. Because of the relative insensitivity of the specific gravity to the input parameter values, Figure 5 is recommended for coating design. Ultimately for laying system analysis, the designer will be interested in the submerged weight. Therefore, Figure 6 has been included. In addition, the output from the ESWT program for a variety of pipeline diameters and water velocities is shown in tabular form in Appendix II.

CONCLUSIONS

Route selection is the first and most important step in providing on-bottom stability and integrity. Route selection should be based on correlation of data from bathymetric surveys, sub-bottom profiles, side scan sonar, cores and bottom samples, bottom photographs, undersea cable history in the area, or from any other source which could provide information about the ocean bottom.

The on-bottom stability analysis in the face of steady currents assumes that the pipeline route has been carefully selected to avoid the environmental hazards such as gross bottom movement, turbidity currents, etc. It also assumes that a near-bottom "design" current has been established for the chosen route. The analysis recognizes that the water velocity decreases as the bottom is approached due to the boundary layer effect. The flow over the exposed pipeline in this boundary layer results in a lift force which decreases the net weight of the pipeline on bottom and a drag force which tends to displace the pipe horizontally in the downstream direction. This tendency is opposed by the passive resistance of the soil. This resistance is taken to be proportional to the net weight of the pipeline resting on the bottom. The equilibrium equations for this balance of forces determine the minimum submerged pipeline weight required for the line to be stable, i.e., just on the verge of moving. This weight can also be expressed in terms of the displaced sea water as specific gravity.

A parametric study shows that the minimum specific gravity required for equilibrium is relatively insensitive to large variations in all of the parameters appearing in the stability analysis except the "design" velocity. Therefore, a "nominal" set of numerical values of these parameters is chosen which will apply to most design situations.

The parametric study demonstrates that the selection of the "design" velocity is by far the most significant factor in the stability analysis. For providing long term stability and integrity on the ocean bottom, it is second only to the proper selection of the pipeline route to avoid hazardous bottom conditions. Hence, further research on stability analysis can most profitably be aimed at developing better methods of establishing the design velocity for a particular location in the ocean.

NOMENCLATURE

C	Coefficient representing C_D or C_L or both - Equation (I-30)
C_D	Drag coefficient
C_L	Lift coefficient
D	O.D. of pipeline
d	Distance from line of action of drag force to soil
F_D	Drag force per unit length
F_L	Lift force per unit length
h	Height above bottom of design velocity
k	Pipeline surface roughness height
M	Moment about point at which pipe touches soil
q_n	Normal soil reaction force per unit length
q_t	Tangential soil reaction force per unit length
Ree	Effective Reynolds number - Equation (13)
SG	Pipeline specific gravity
T	Sea water temperature
U	Velocity at a height h above bottom
V_e	Effective velocity - Equation (8)
$V(y)$	Velocity as a function of height above bottom
w	Submerged weight per unit length of pipeline
x	General variable - Equation (14)
y	Height above bottom
α	Slope angle
$\delta(\ )$	Percentage change in ( ) - Equation (14)
κ	Ratio defined by Equation (I-13)
μ	Coefficient of bottom "friction"
ν	Kinematic viscosity of fluid
ρ	Mass density of fluid
ρ_s	Mass density of standard sea water

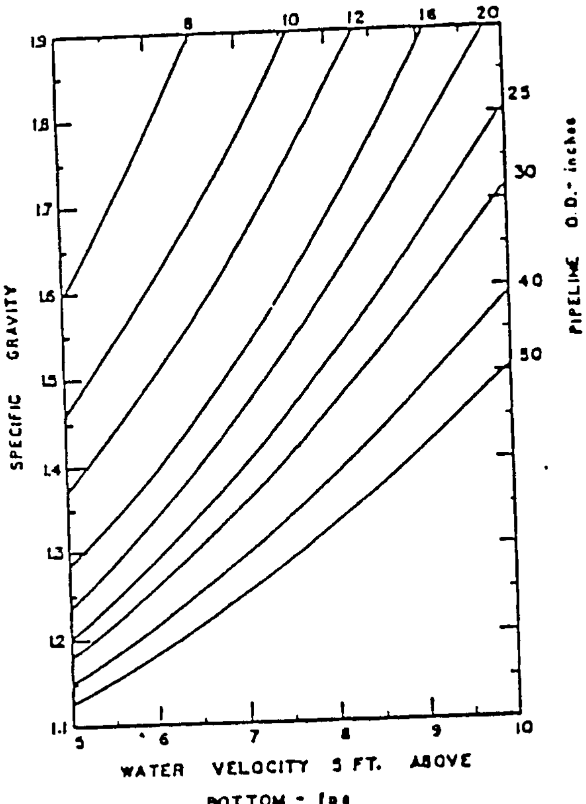


Fig. 5 - (a) Stability design chart.

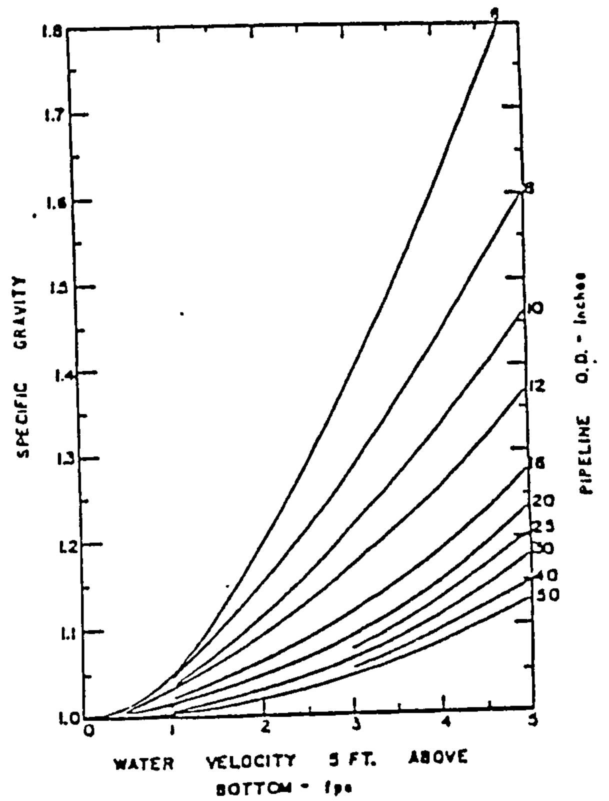


Fig. 5 - (b) Stability design chart.

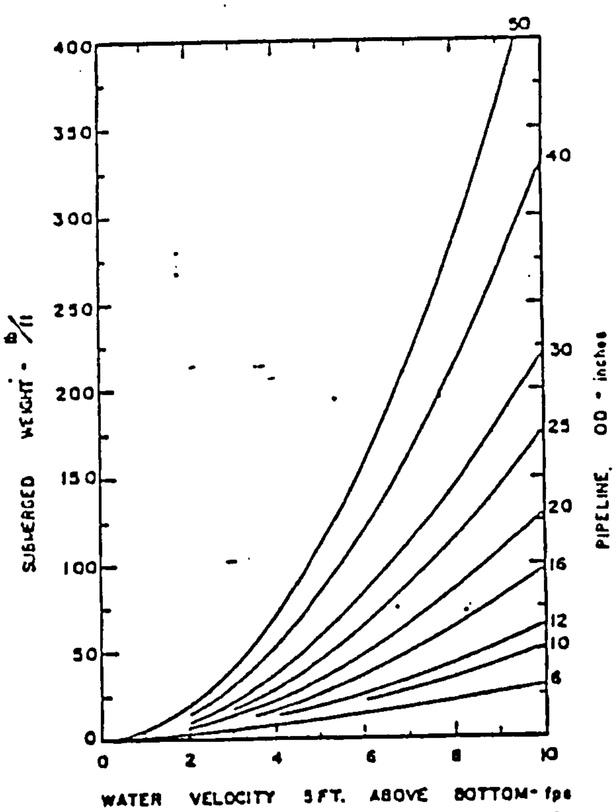


Fig. 6 - Submerged weight required for equilibrium.

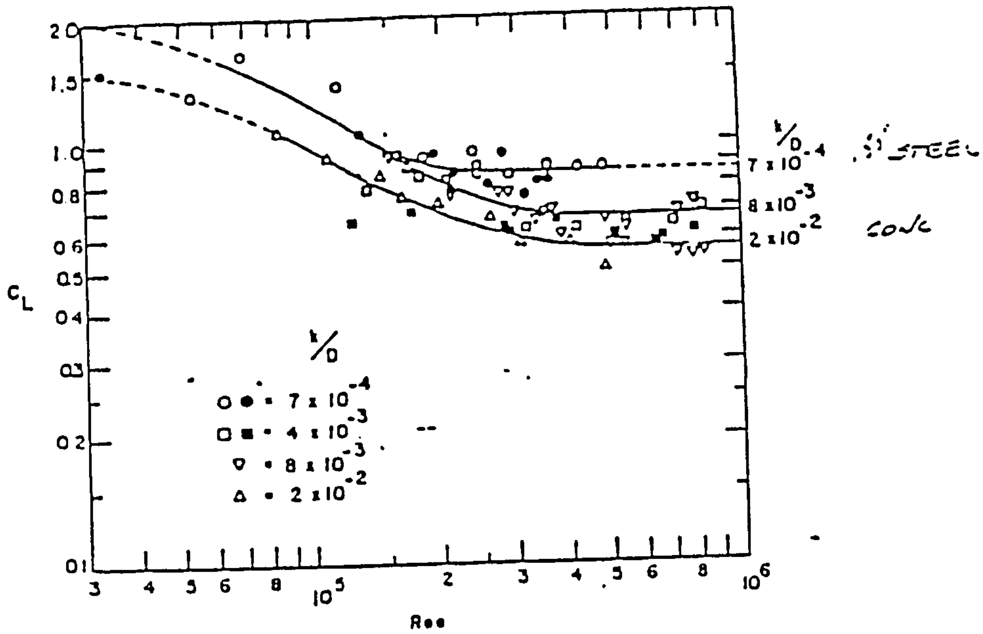


Fig. 3 - Recommended effective lift coefficient for design of a pipe resting on bottom.

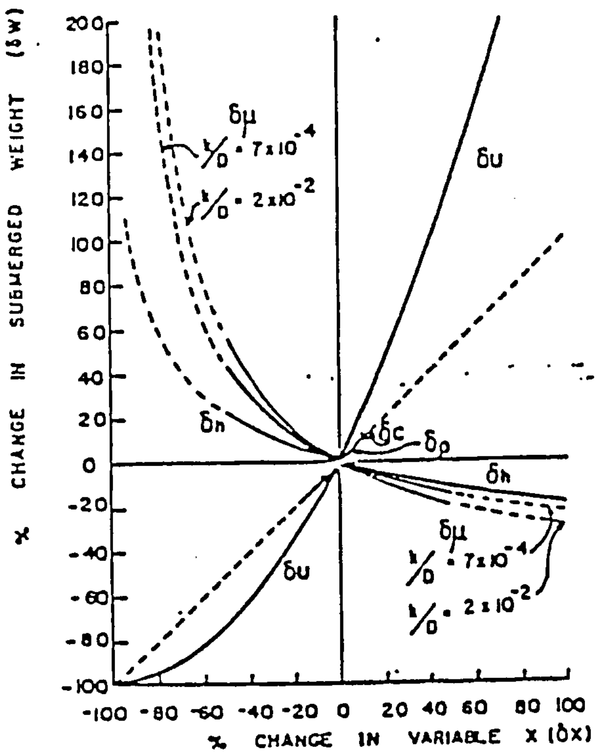
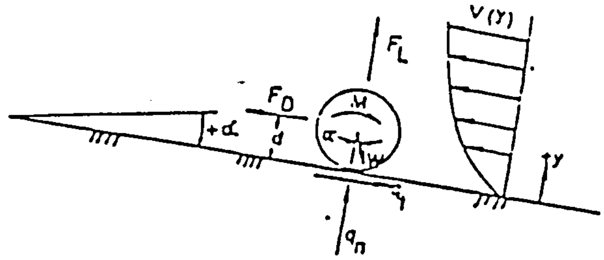
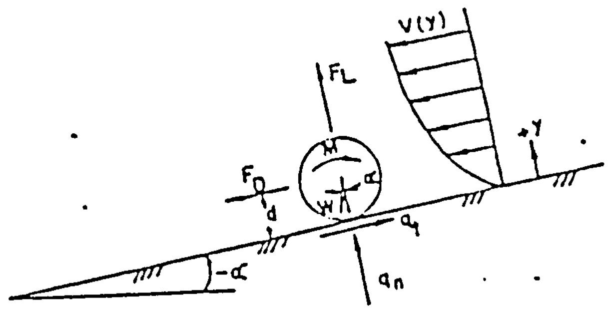


Fig. 4 - Percent change in calculated weight due to a change in parameters in the stability equation for $Ree > 5 \times 10^5$.



(a) UP SLOPE VELOCITY



(b) DOWN SLOPE VELOCITY

Fig. 1 - Equilibrium of a pipe exposed to a steady current.

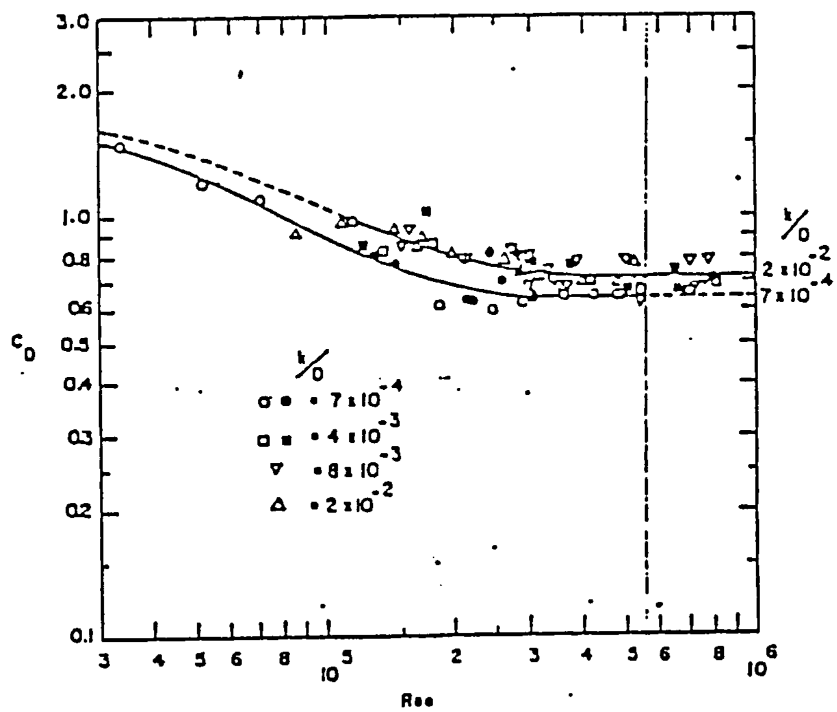


Fig. 2 - Recommended effective drag coefficient for design of a pipe resting on bottom.

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Wave Forces on Pipes Near the Ocean Bottom

By

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ABSTRACT

Where wake effects are negligible, potential flow calculations predict well the lift and added mass forces acting on pipelines near the ocean floor when subjected to time dependent flows. Wake effects have a significant influence on the flow conditions and measured frequencies of vortex shedding can predict the drag force acting on the cylinder. The Strouhal number is a function of the gap below the cylinder. The added mass coefficient is much larger when the cylinder is near the boundary than when it is a free stream.

INTRODUCTION

Vertical and horizontal hydrodynamic forces on pipes near the ocean bottom are influenced by pipe roughness, ambient turbulence, angle of skew, number and grouping of pipes, formation and collapse of the wake, the proximity of the free surface and the proximity of the bottom. Most of these topics have received little attention as to quantifying their effects for engineering purposes. However, a fund of knowledge is growing for smooth circular cylinders near the bottom away from the influence of the free surface.

Let the non-dimensional gap below the cylinder be designated as ξ, shown in Fig. 1. We consider waves with crests parallel to the cylinder center line. The free surface does no[t] influence the forces acting on the cylinder if $\delta > 4$, (3). The importance of ξ on the lift force is treated analytically in (2, 3, 7, 8, 9, 10, 11) for potential flow calculations, substantiated with laboratory results. Some influences from the free surface was presented by Chakraborti and Cotter (9), and Grace discussed the importance of the period parameter (9). The influence of groups of nearby cylinders has als[o] been treated analytically (11). The wake, however, exerts a significant modification to th[e] hydrodynamic forces (1, 2, 3, 4, 5, 6, 7).

This paper focuses on the importance of wa[ke] modifications for time varying flows. The cond[i]tions when potential flow theory can be used wi[th] be indicated. In general the wake formation is not in phase with the ambient fluid velocities, and therefore the drag force is not in phase wi[th] the ambient velocity. This can influence the value of added mass coefficients derived from laboratory data, which are ordinarily determine[d] at a time in the records when the ambient velocity is presumed to be zero.

References and illustrations at end of paper.

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LABORATORY EXPERIMENTATION

A schematic of the general laboratory layout is shown in Fig. 2. The wave channel is 104m long by 3.7m wide by 4.6m deep in the working section. It can produce incipiently breaking waves 1.5m high in deep water. For this work a false bottom was installed in order to produce a water depth of from 0.7 to 2.4m.

Two rigid smooth test cylinders were used. The first was .3m in diameter and was mounted as shown in Figs. 3 and 4. The second was mounted in much the same way but the cylinder diameter was 0.076m. Vertical and horizontal wave forces were measured on both cylinders by means of strain gage force dynamometers that supported the central test sections.

The variables in the experimentation was conducted in a flow visualization water flume (2) where the Strouhal number was calculated as a function of ξ by measuring the vortex shedding frequency with movies. Drag coefficients calculated therefrom (5) were compared with wind tunnel measurements and wave measurements in (7).

RESULTS

Theory shows that the inertia coefficient, C_I, or $(1 + C_m)$ should be the same either parallel to or perpendicular to a nearby wall for a circular cylinder (3, 8, 9). Figures 5 and 6 compare results from theory with measurements for this investigation and others when a/D is small enough so that wake effects are small.

The results for the "lift" coefficient are shown in Fig. 7. The positive values from laboratory measurements are for pronounced wake effects when $0 < \xi < 1$.

For small ξ, large a/D, one run is shown in Fig. 8. It shows a case where the lift force is due almost entirely to the ambient horizontal velocity, which is true because the two negative forces are about equal and they occur at phases of the wave where vertical accelerations are in opposing directions. The two fairly large negative forces occur because the wake has "collapsed" at that time. Note that for maximum positive and negative horizontal velocities that the vertical forces are upward, or in the positive direction, indicating strong wake effects.

The total horizontal force was determined for various phases in some waves as a function of wave height. That is, for various waves of the same period, the horizontal force was noted for a given phase and given wave height. For the same phase, the increase in horizontal force was noted as the wave height was increased. Given that the increase in force is nonlinearly related to wave height, a significant "drag" component (wake effect) exists. However, if a phase can be found where the total horizontal force is linearly related to wave height, then that must be the phase angle where the force is due completely to acceleration. Potential flow effects predominate and the drag or wake effects are zero.

Some preliminary results are shown in Fig. 9. They indicate that at a phase angle of about $\pi/6$ the wake effects are very small. However, at the node of the wave (where the phase changes as H is increased) and at a phase angle of $\pi/4$ (where the node exits for small wave heights) the horizontal force is non-linearly related to wave height. Thus, the "drag" or wake effect still exists when mathematical wave theories show the ambient velocity to be zero. This is due to the phase shift between the formation of the wake and the oscillating ambient velocities (7).

We ask the question "should C_I be determined from laboratory experimentation by determining where the drag component is zero, rather than where the ambient velocities are zero?"

Flow visualization studies showed that the Strouhal number is related to ξ as shown in Fig. 10 for Reynold's number of 5800. The drag force was calculated from the Strouhal number (2) and compared to wind tunnel measurements and measurements of others as shown in Fig. 11. An approximate agreement is seen.

CONCLUSIONS

A few interesting ramifications of hydrodynamic forces on pipelines has been presented. It is shown that vertical forces on pipelines near and above the bottom can have frequencies that are twice the frequency of the ambient wave.

The added mass coefficient is drastically increased for pipes near a boundary from the condition in an unrestrained flow.

The wake conditions from the flow have a significant influence on the forces that act both parallel to and perpendicular to the nearby boundary.

ACKNOWLEDGEMENTS

The use of Figs. 10 and part of 11 from Hafen (2) is gratefully acknowledged. This work was supported by the NOAA Institutional Sea Grant Contract 2-35187 at Oregon State University.

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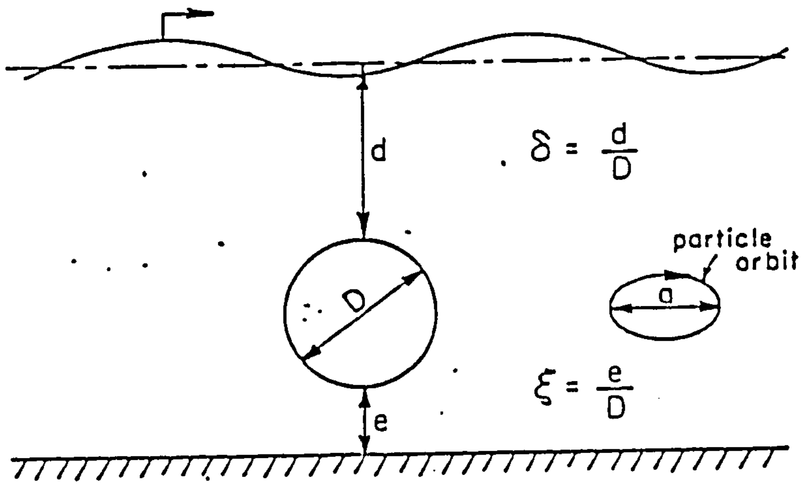


Fig. 1 - Cylinder nomenclature.

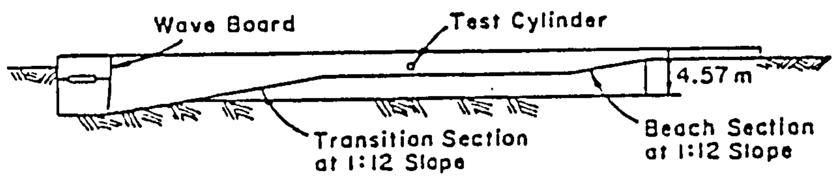


Fig. 2 -OSU wave research facility with test cylinder.

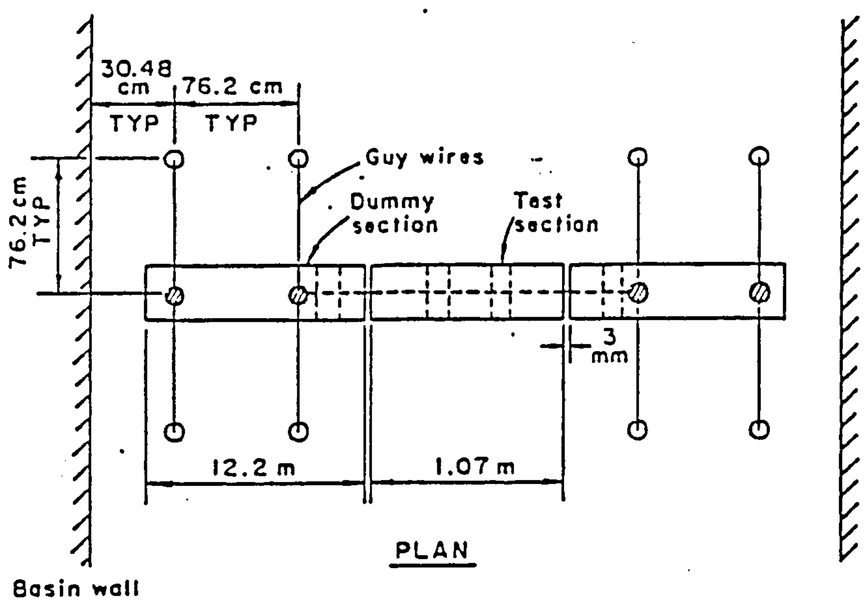


Fig. 3 - Test cylinder detail.

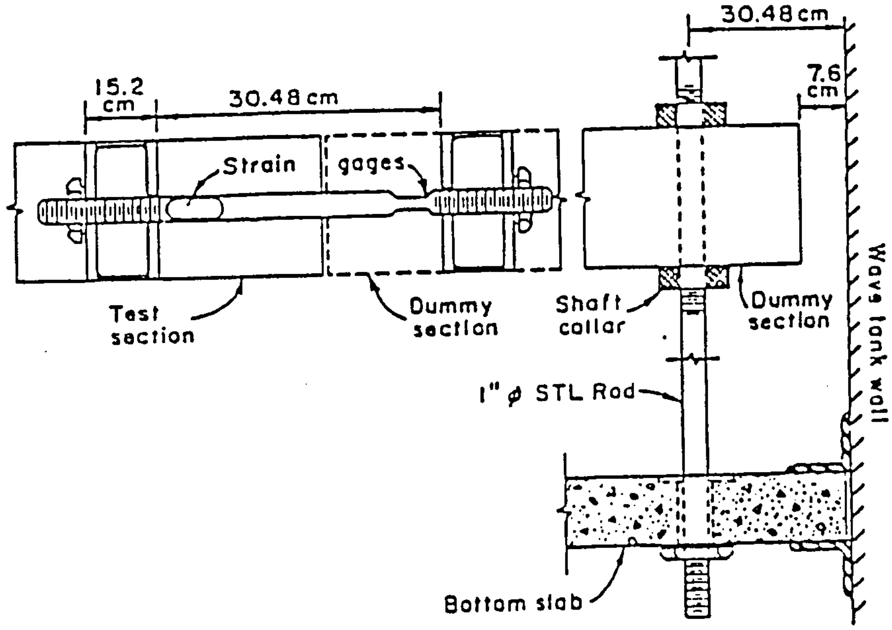


Fig. 4 - Force dynamometer and cylinder support.

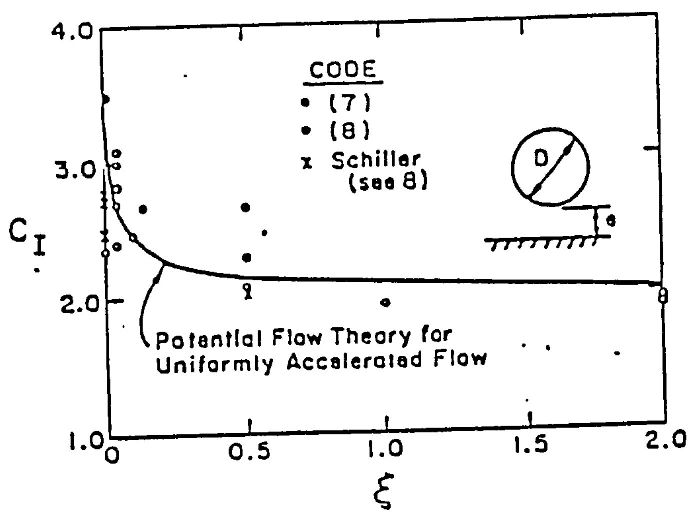


Fig. 5 - Vertical inertia coefficient near a plane boundry.

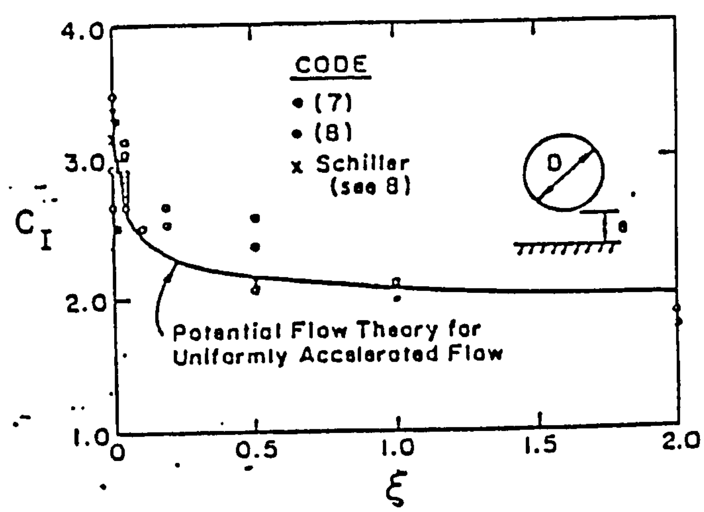


Fig. 6 - Horizontal inertia coefficient near a plane boundry.

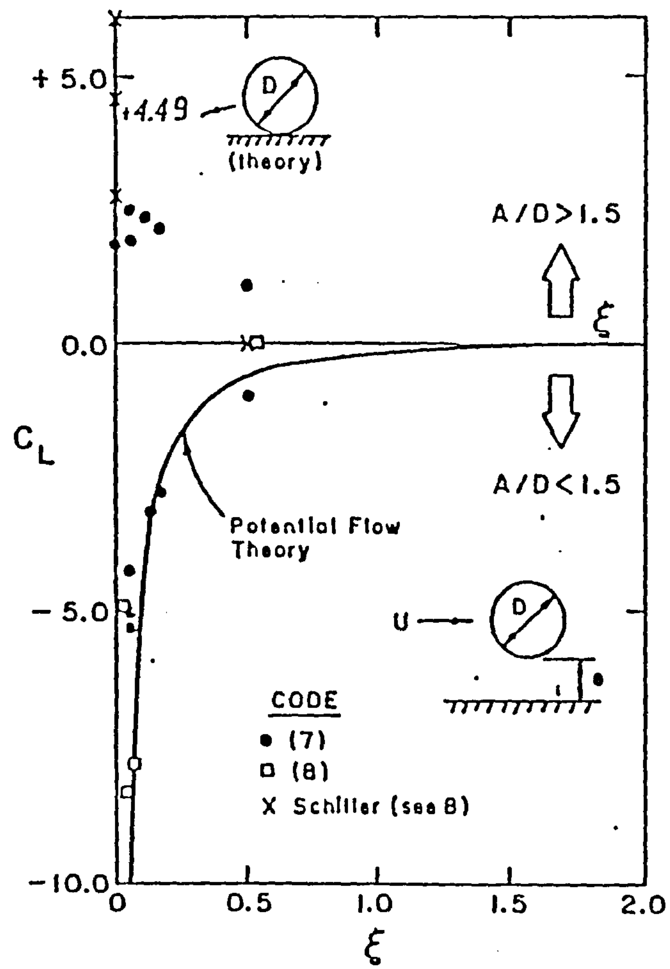


Fig. 7 - Lift coefficient near a plane boundary.

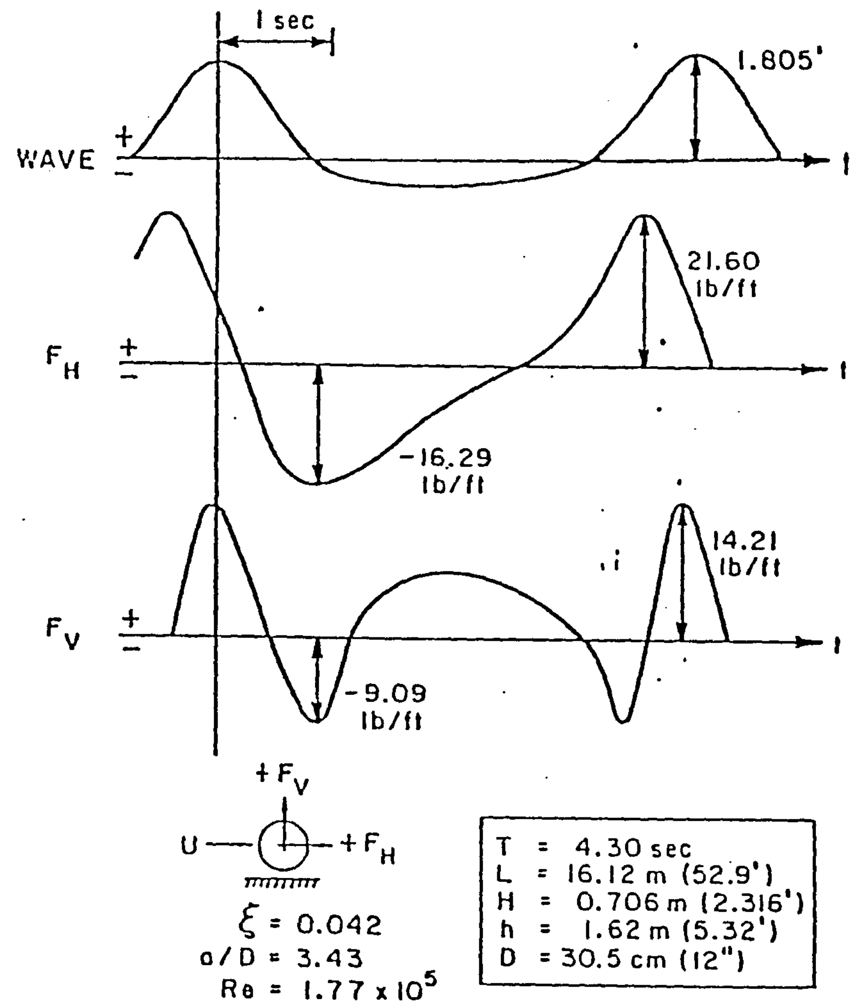


Fig. 8 - Horizontal and vertical forces for ξ =0.042.

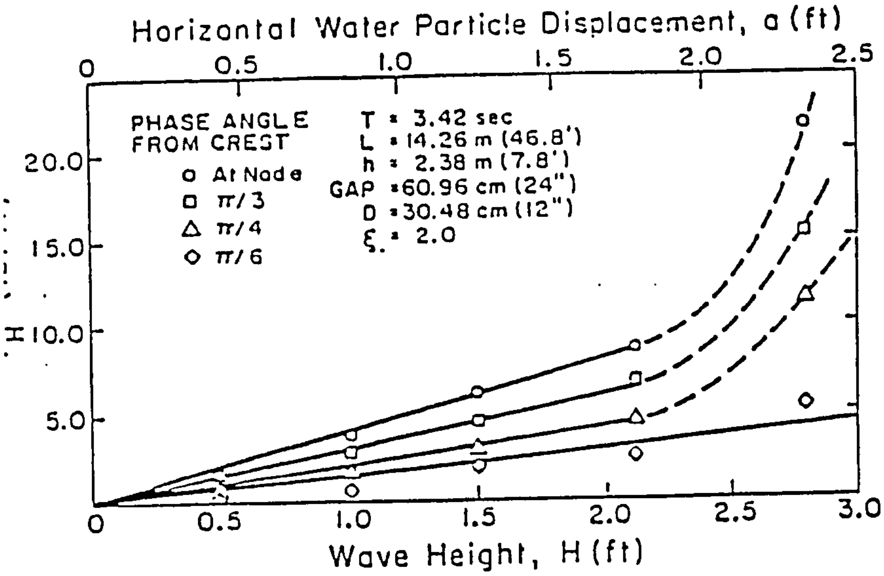
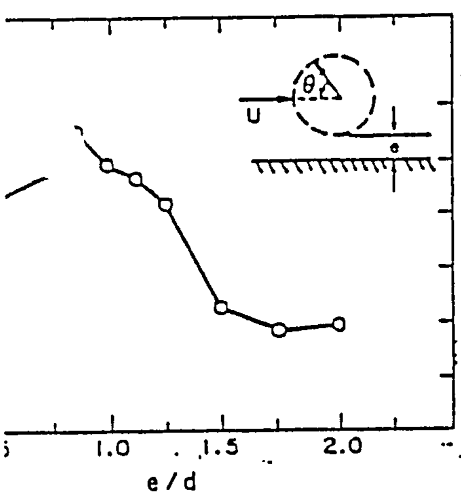


Fig. 9 - Horizontal force vs wave height for various wave phases.



- Strouhal number

R_e = 5800.

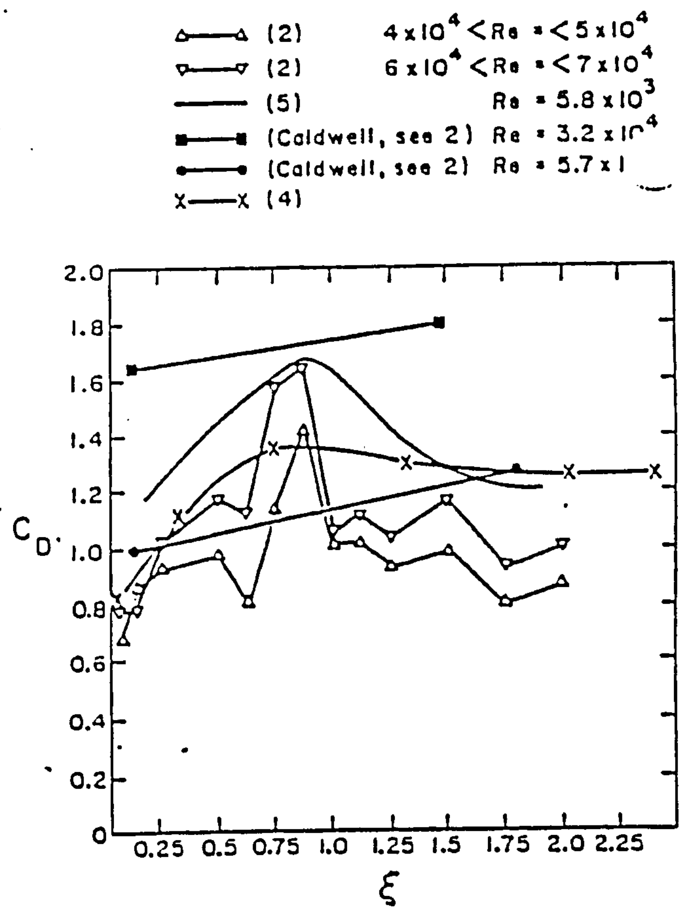


Fig. 11 - Drag coefficient vs ξ.

:RMINATION OF THERMAL CONDUCTIVITY OF SOILS: A NEED COMPUTING HEAT LOSS THROUGH BURIED SUBMARINE PIPELINES

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aper was presented at the 11th Annual OTC in Houston, Tex., April 30-May 3, 1979. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

ABSTRACT

An important parameter required for computing heat loss through buried submarine pipelines transporting crude oil is the thermal conductivity of soils. This paper describes an apparatus designed for determination of the thermal conductivity of soils at the desired moisture-density condition in the laboratory under steady state conditions. Experimental results on the three ... studied show that the thermal conductivity ...ses as dry density increases at a constant ... ure content and that it increases as water content increases at constant dry density. These results confirm the trends isolated earlier by Kersten. Further the experimental results are compared with the available empirical relationships. Kersten's relation is observed to reasonably predict the thermal conductivity of these soils. The predictions by Makowski and Mochlinski's relation are not good but improve if the sum of silt and clay fractions is treated as clay fraction in the computation.

INTRODUCTION

Submarine pipelines are extensively used for transporting crude oil from a location offshore to others offshore or onshore. These pipelines are normally steel pipes covered with a coating of concrete. They are often buried some depth below the mud-line. The rheological properties of different crude oils vary. The viscosity of all of them increases upon a decrease in temperature. Below some temperature the liquid oil tends to gel. For efficient transportation it is necessary, therefore, that the crude be at a relatively high temperature so that it has a low viscosity. The temperature of the soil-water system surrounding a submarine pipeline is usually lower than the temperature of oil. This temperature difference ...duces heat to flow from the oil to the environment and the temperature of the oil reduces as it travels along the length of the pipeline. One must ensure that this temperature reduction does not exceed desirable limits dictated by the rheological properties of oil and the imperatives of efficient economic transportation. The analytical aspect of this engineering problem is thus one of being able to predict the temperature of crude in the pipeline some distance away from the input station. In order to do so one requires knowledge of the overall heat transfer coefficient for the pipeline. For which, in turn, it is necessary to know the thermal conductivities of the oil, the pipeline materials and its coating and the soil. This paper presents thermal conductivities of soils determined in the laboratory under steady state conditions and also presents a comparison of the test results on three soils with values determined using existing empirical relationships.

LITERATURE REVIEW

Heat moves spontaneously from higher to lower temperature. In a perfectly dry porous body, transmission of heat can take place not only by conduction through the solid framework of the body and the air in the pores but also by convection and radiation between the walls of a pore as also by macro and micro-distillation. In soils, however, it can be ascribed essentially to conduction, a molecular phenomenon, which can be expressed in terms of experimentally determined coefficients of conductivity or resistivity, although these may actually include contributions from micro-distillative and other mechanisms (Winterkorn, 1960).

Heat Conduction Equation

The heat conduction in soil can be described for the one dimensional case by the Fourier equation (Kezdi, 1974):

...ences and illustrations at end of paper.

$$k \frac{\partial^2 T}{\partial z^2} = c\gamma \frac{\partial T}{\partial t} \qquad (1)$$

in which

- T = temperature at time t and at depth z in °C
- k = thermal conductivity, i.e. the amount of heat that flows under a temperature gradient $\frac{\partial T}{\partial z}$ = 1 in unit time through unit cross-sectional area, in cal per hour per cm per °C
- c = specific heat of soil
- γ = density of soil

It is important to note that the specific heat of particles of sand and clay is only one fifth of that of water. It is, therefore, largely on account of the presence of moisture that the soil is capable of storing heat.

Factors affecting thermal conductivity

The thermal conductivity of a soil depends on grain-size distribution, dry density, moisture content and mineral composition. The results of extensive studies of the thermal properties of soils by Kersten (1949) and Winterkorn (1960) indicate the following:

(a) Density:

At constant moisture content, an increase in density results in an increase in conductivity. The rate of increase is about the same at all moisture contents.

(b) Moisture Content:

At constant density, an increase in moisture content causes an increase in conductivity which is true upto the point of saturation.

(c) Texture:

Thermal conductivity in general varies with the texture of soils. At a given density and moisture content, the conductivity is relatively high in coarse textured soils such as gravel or sand, somewhat lower in sandy loam soils, and lowest in fine textured soils such as silty loam or clay.

(d) Mineral Composition:

Sands with a high quartz content have greater conductivity than sands with high contents of such minerals as plagio-clase feldspar and pyroxene. Soils with relatively high contents of kaolinite have relatively low conductivities.

Heat Transfer Mechanisms in Soils

McGaw (1969) hypothesized that there are only two paths for heat flow through saturated granular materials: a series path through the granular network, aided by a portion of the pore fluid that acts to transfer heat from grain to grain, and a continuous path through the remainder of the fluid. A third path through continuous solid material connected at grain contact points is considered to be generally non-existent.

Kolyasev and Gupelo (1958) suggested the following thermal transfer mechanisms which come into play with increasing moisture content:

(a) In the absolutely dry state through particle contacts.

(b) For water contents less than 10 percent through contacts aided by the presence of water at contacts.

(c) In the water content range between 10 - 20 percent by water movement in the film phase, when water films surround the soil particles and form a continuous phase.

(d) At about 20 percent moisture content, the film mechanism of water movement changes into the capillary mechanism but heat transmission through the solid phase still dominates.

(e) Beyond 25 percent, the capillary mechanism takes over and eventually the thermal conductivity of the soil-water system approaches the thermal conductivity of water.

DETERMINATION OF THERMAL CONDUCTIVITY

Empirical Formulae/Relationships:

To predict thermal conductivity of soils the following empirical formulae/relationships have been suggested by various investigators:

Kersten (1949)

(a) For silts and clayey soils

$$k = \left[0.9 \log (w) - 0.2\right] \times 10^{0.01\gamma_d} \qquad (2)$$

(b) For sandy soils

$$k = \left[0.7 \log (w) + 0.4\right] \times 10^{0.01\gamma_d} \qquad (3)$$

where

- k = thermal conductivity in BTU per square foot per inch per hour per degree Fahrenheit.
- w = moisture content in percent of the dry soil weight.
- γ_d = dry density in pounds per cubic foot.

The maximum error involved in these formulae is 25 percent.

Makowski and Mochlinski (quoted by Szilas, 1975)

$$k = (A \log w + B) \times 10^{C}$$

in which

- k = thermal conductivity of soil in W/(mk)
- $A = 0.1424 - 0.000465\ S_c$
- $B = 0.0419 - 0.000313\ S_c$

$C = 6.2 \times 10^{-4} \gamma_d$

S_c = weight percent of clay (less than 0.002 mm particle size) referred to the total weight of the dry soil.

w = water content of the soil in percent.

γ_d = dry density of soil in kg/m³.

Kezdi (1974) has given a triangular chart for determining the thermal conductivity of a soil as a function of the phase composition: soil solids, air and water. His method does not take into account the soil type.

McCaw (1969) has suggested the following expression for thermal conductivity of a saturated granular material:

$$k = (n - n_c)\, k_f + (\lambda + n_c)\, \frac{\epsilon\, k_s(\lambda + n_c)}{\lambda + \sigma n_c} \qquad (5)$$

in which

k_f = bulk conductivity of a continuous liquid phase.

k_s = bulk conductivity of a dispersed granular phase.

$\sigma = \frac{k_s}{k_f}$

n = porosity

$\lambda = (1 - n)$ = volume fraction of solids.

n_c = volume of fluid

This expression requires knowledge of the thermal conductivity of the granular material in dry state and that of the liquid in the pore space.

Laboratory Methods:

Existing methods of determining the thermal properties of moist capillary-porous bodies like soils, can be separated into two groups: methods of steady and non-steady heat flows. In the first group, the flow of heat passing through the body or system of bodies remains constant in magnitude and direction and the temperature field is stationary. Methods of the other group which are commonly known as "regular regime methods" are based on certain laws of the non-stationary temperature field, with cooling at the regular regime stage. Though these methods are more in vogue than those of the first group, a steady state method (belonging to the first group) viz. based primarily on Lee's disc method has been used in this investigation because:

i. it is simple in concept and in operation,

ii. it does not disturb the sample, and

iii. it allows easy placement of the sample at the desired density and moisture content.

The basic draw-back of such a steady state method is the long duration of the experiment. Further there is possibility of moisture migration due to the temperature differences created (Luikov (1966)

EXPERIMENTAL TECHNIQUE USED

Description of Apparatus:

For determining the thermal conductivity of soils, an experimental apparatus was developed which enabled determination of this property from unidirectional heat flow under steady state conditions. For such conditions the rate of heat flow can be expressed as:

$$\frac{dQ}{dt} = -k\ A\ \frac{dT}{dz} \qquad (6)$$

where

A is the cross sectional area of the soil through which heat is flowing.

Fig. 1 shows a schematic sketch of the set-up used.

Fig. 2 gives a more detailed drawing of the specimen cell assembly. A more complete description of this apparatus and the test procedure adopted is reported in IIT Delhi Report, 1978.

Soils used:

Three soils were used in this study. Their index properties and grain size distribution are given in Table 1.

Test programme:

Tests were conducted on all the three soils at widely different moisture contents ranging from d to fully saturated and for each moisture content different densities.

TEST RESULTS AND DISCUSSION

Results:

Results of experiments on soil type 1 are presented in Figure 3 for saturated specimens and in Figure 4 for different degrees of saturation. Figures 5 and 6 present the results of soils 2 and 3 respectively.

Discussion:

From Figures 3 to 6 it is generally apparent that k, the thermal conductivity of soils studied increases as dry density increases at a constant water content and that it increases as water content increases at a constant dry density. These results indicate that the trends isolated earlier by Kersten with regard to water content and density for other soils, also characterize the soils under study.

Tests on soil type 1 (Fig. 3) in the saturated state corroborate the view expressed by Kolyasev and Cupelo (1958) that with increase in water content the thermal conductivity of the soil-water system reduces and tends to approach the value of the thermal conductivity of water.

Also consistent with the observation repor in the literature is the result reported herein ...t the magnitude of thermal conductivity is greater for coarse grained material in relation to fine grained material.

Using equations 2, 3 and 4, thermal conductivities of the soils tested have been calculated at the moisture-density conditions used for testing. These values have been plotted against the experimental values and shown in Figures 7 and 8 for Kersten's relations, and Makowski and Mochlinski's relation respectively. These figures show that Kersten's relation predicts the values reasonably well, whereas Makowski and Mochlinski's predictions are always on the higher side.

By treating the percentage silt + clay as clay content, the thermal conductivities have been computed again using Makowski and Mochlinski's relation and plotted in Figure 9 against the experimental values. This figure shows that the predictions improve with such a procedure.

Another salient feature of these two relations is that, for a given moisture-density of a soil, both relations yield values which are either on the higher or the lower side of the experimental value.

CONCLUSIONS

An apparatus simple in design and operation, based on steady state heat flow conditions, has been designed for determination of thermal conductivity of soils at desired moisture-density conditions.

The experimental results on the three soils studied show that the thermal conductivity increases as dry density.

Kersten's relation makes reasonably good predictions of the thermal conductivity of soils. The prediction of Makowski and Mochlinski's relationships improves if the sum of silt and clay fractions is treated as clay fraction in the computation. Nevertheless the predictions by Kersten's method are more realistic.

ACKNOWLEDGEMENT

The authors are grateful to Dr. H.K. Sehgal and Dr. T.C. Goel of the Physics Department at IIT Delhi for their assistance in the development of the apparatus used.

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TABLE 1

SOIL PROPERTIES

Soil	% Sand	% Silt	% Clay	LL %	PL %	PI %
Type 1	9	45	46	92	24	68
Type 2	34	36	30	45	18	27
Type 3	78	22	-	-	-	-

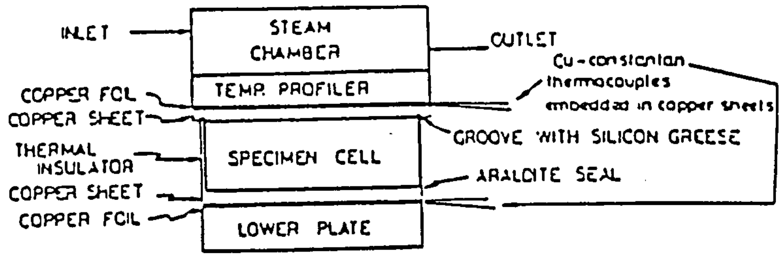

Fig. 1 - General layout of apparatus.

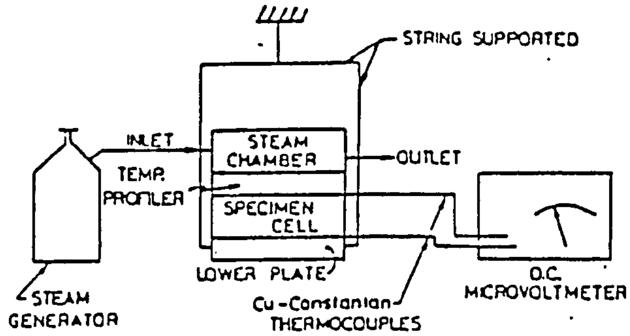

Fig. 2 - Specimen cell assembly.

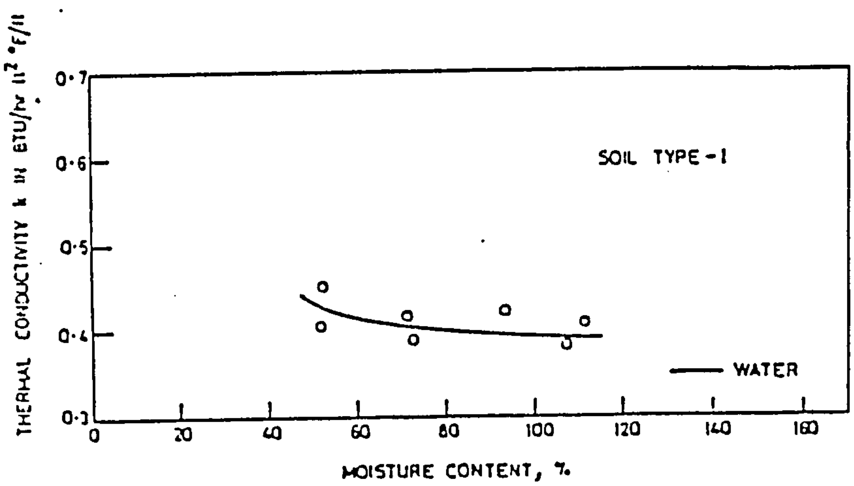

Fig. 3 - Experimental thermal conductivity values for saturated samples of soil Type 1 with increasing moisture content.

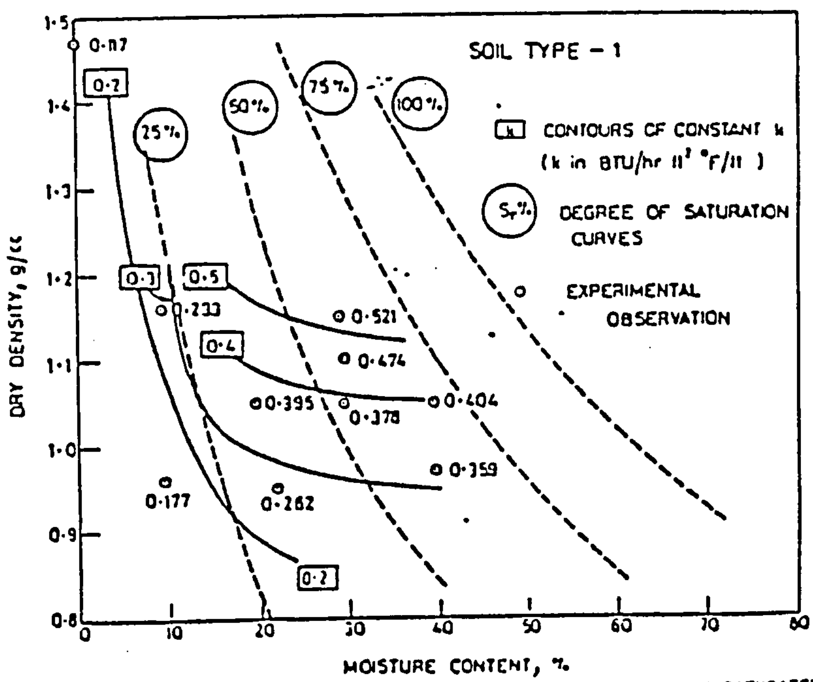

Fig. 4 - Experimental thermal conductivity values of partially saturated samples of soil Type 1.

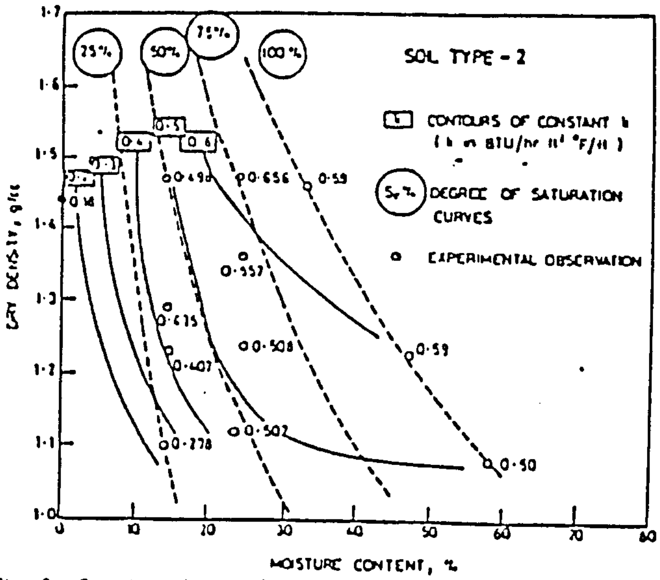

Fig. 5 - Experimental thermal conductivity values of partially saturated samples of soil Type 1 with increasing moisture content.

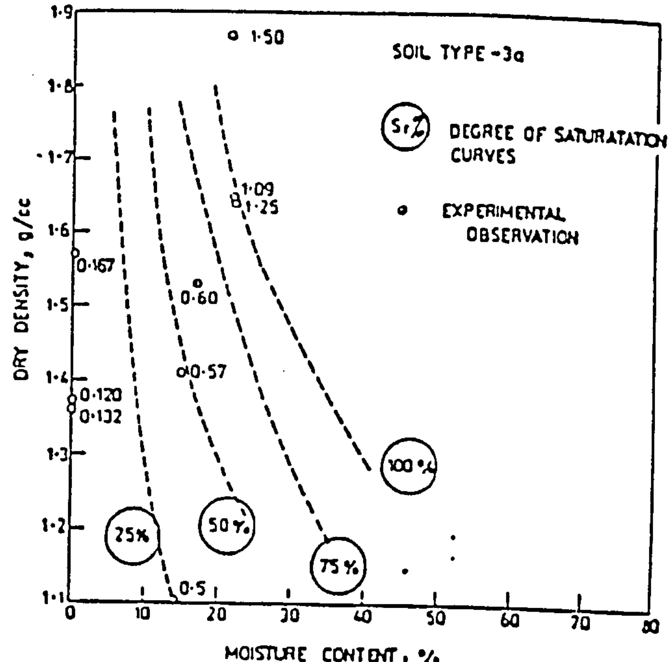

Fig. 6 - Experimental thermal conductivity values of partially saturated samples of soil Type 3.

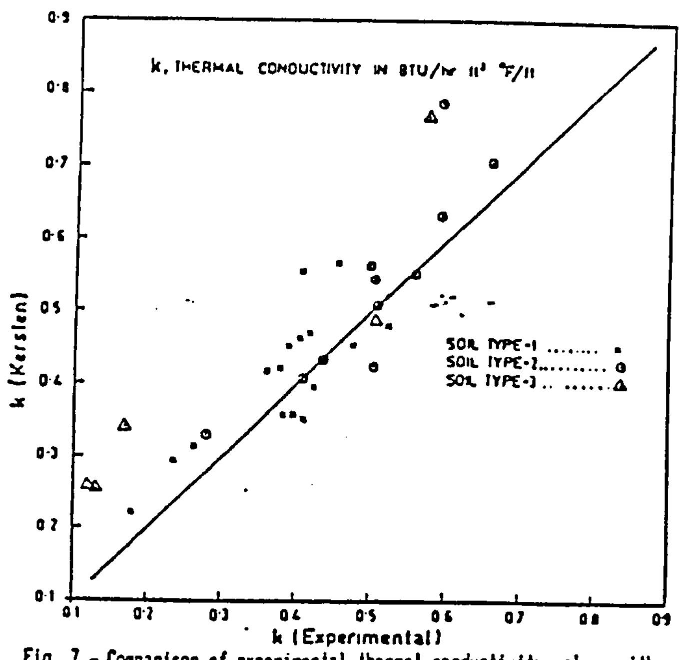

Fig. 7 - Comparison of experimental thermal conductivity values with Kersten's predictions.

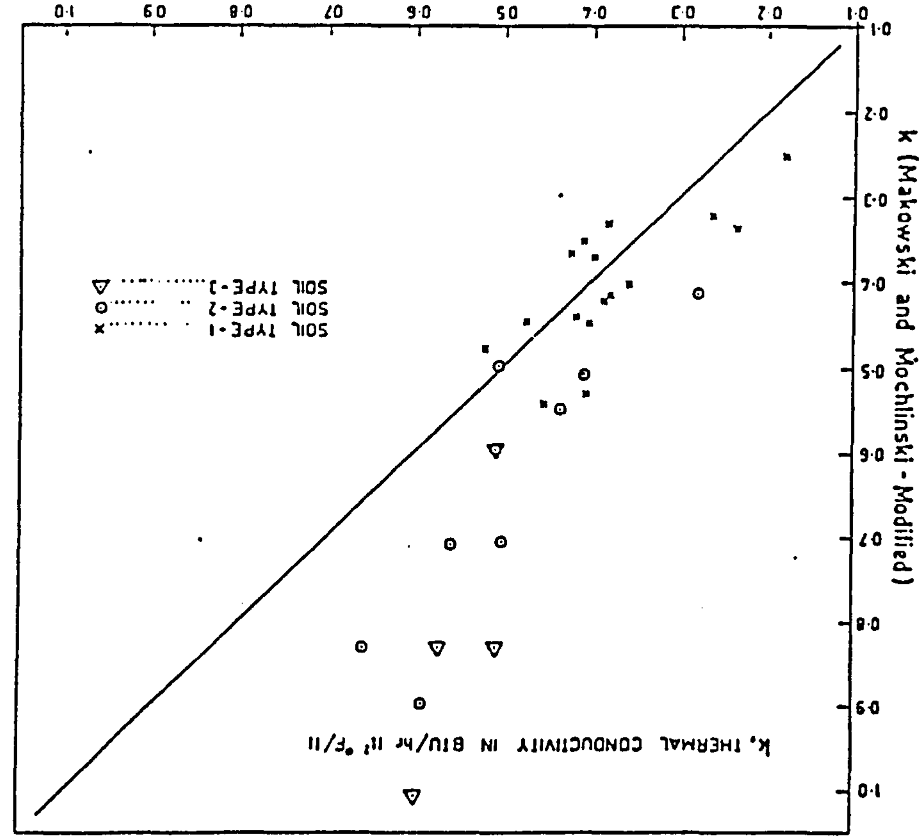

FIG. 8 - COMPARISON OF EXPERIMENTAL THERMAL CONDUCTIVITY VALUES WITH MAKOWSKI AND MOCHLINSKI'S PREDICTIONS.

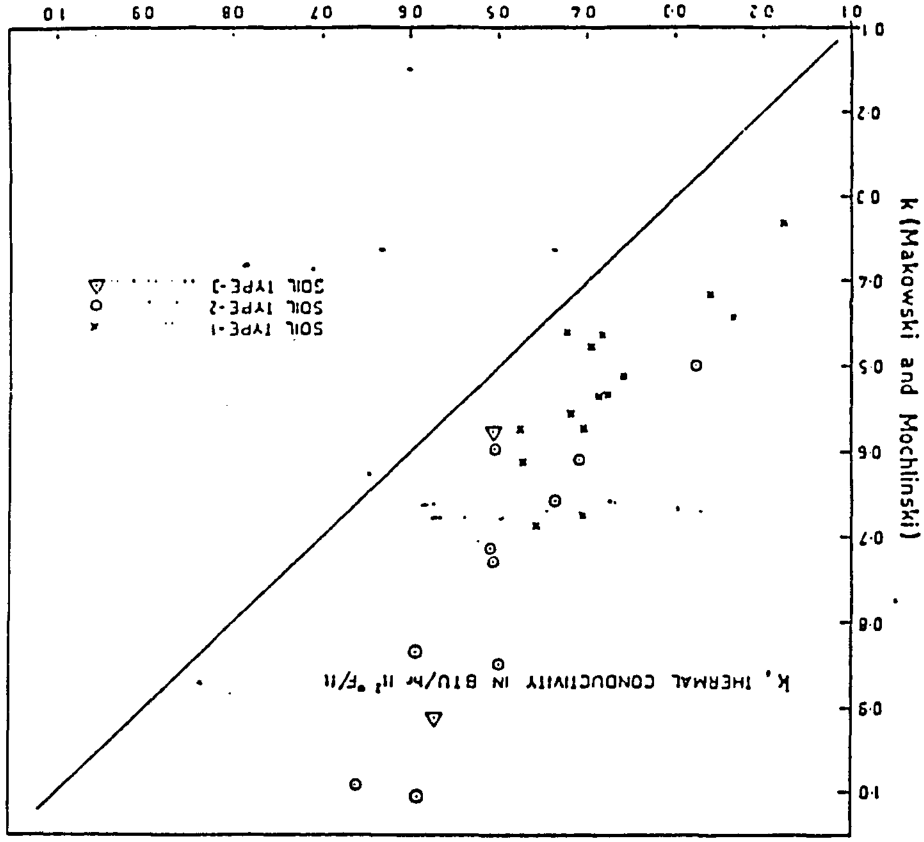

FIG. 9 - COMPARISON OF EXPERIMENTAL THERMAL CONDUCTIVITY VALUES WITH MAKOWSKI AND MOCHLINSKI'S PREDICTIONS (MODIFIED).

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NEW TECHNOLOGY IN INSULATED OFFSHORE PIPELINES - DESIGN AND INSTALLATION

by W.W. Morris, K.B. Kaplan, Brown & Root, Inc.; and S.H. Muhs

ABSTRACT

A new insulation system for offshore pipelines has been designed and installed as part of a new field located in the Arabian Gulf. This system of insulation will be used to prevent the formation of hydrates in dual flowlines transporting high temperature crude oil between six wells and a central production platform. The insulated pipeline system, designed and installed as described in this paper, is applicable to future design of insulated offshore pipelines.

The system is designed to operate at a constant temperature of 200-deg F with excursions to 225-deg F at a water depth of 50-ft. Over a period of two years, 4-in., 6-in., and 8-in. pipelines were designed through analysis and testing. The testing included field joint feasibility and reliability, flexure of insulated pipe joints at midspan and field joints, and full scale laybarge tension loading of insulated pipe joints. From this design program an insulation system consisting of polyurethane foam, polyethylene jacket, heat shrinkable polymer waterstops and field joint materials, and weight coating was developed. The insulated pipelines were installed by the laybarge method in the Fall of 1978.

In this paper the development and installation of the insulated pipeline system are described. General results and descriptions of the field joint, flexure and tension testing programs are given. A description of the method of installation, and its analysis and the actual field installation are also included.

INTRODUCTION

As the development of the field was being studied, a system of satellite wells connected to a central production facility was determined to be optimum. The possibility of hydrates forming in the crude oil in the flowlines before the oil was processed loomed as a major question to the development plan. Providing two insulated flowlines to each well, one for production flow and the other for startup circulation, to maintain the high crude oil temperatures was the answer to the process scheme for the field. The ability to safely install an insulated pipeline system in a 50-ft water depth became a key to field development.

Table 1 lists the pipeline requirements that are the basis of the insulated pipeline design. The pipe diameters were determined by flow requirements and the wall thickness by a shut-in pressure of 3,000 psi and corrosion allowances. The crude oil to be transported contains a high concentration of hydrogen sulfide which dictated the metallurgy, material grade and corrosion allowance for the pipe. Insulation requirements determined by the process scheme are 3-in. of polyurethane foam with a maximum thermal conductivity of 0.20 (BTU-in)/(ft^2-hr-deg F). Maximum design operating temperature for the pipeline system was established as 200-deg F with excursions to 225-deg F.

Also included in Table 1 are the on-bottom stability concrete coating requirements which were determined from 100-year storm conditions acting on the pipelines, coated with 3-in. of polyurethane foam, resting on the sea floor. As can be seen from the table, the concrete requirements were large to compensate for the buoyant effect of the insulation.

From these basic design parameters an insulation system was developed through design and testing. The major areas of design effort were:

1. Development of a water barrier for the insulation which could sustain pipeline installation loadings.

2. Development of a field joint system that provided a water barrier for the insulation and could be installed on a laybarge.

Illustrations at end of paper.

3. Development of a mechanism whereby the concrete coating could be bonded to the insulation water barrier to sustain pipelay tension loads.

4. Determine the effect of the composite insulated pipeline section on the flexural rigidity of the pipeline during installation.

5. Develop procedures and any necessary equipment to safely install the insulated pipelines.

INSULATION SYSTEM

The thermal insulation system for the pipelines consisted of approximately 3 inches of polyurethane foam surrounded by an outer jacket of preformed high density polyethylene as shown in Figure 1. The polyurethane foam insulation had a minimum core density of 6 pcf and a minimum compressive strength of 120 psi which resulted in an aged thermal conductivity value of 0.13 (BTU-in)/(ft^2-hr-deg F). By specifying this combination of parameters the required insulating properties could be obtained while providing sufficient foam strength to resist the crushing and bending loads of installation. Also, this strength foam would not collapse under the hydrostatic load of the sea pressure.

The application process chosen for the foam was the puller tape method. In this method, the pipe is inserted into the preformed polyethylene jacket and placed on a foaming line designed to hold the jacket concentric with the pipe. A steel puller tape attached to a roll of paper is fed through the annulus formed. The foam mixing and dispensing machine is positioned over the paper. The tape puller and the foam dispensing nozzle start simultaneously, thereby dispensing the mixed creamed polyurethane components onto the moving paper as shown in Figure 2. When the creamed components are distributed throughout the annulus of the pipe and jacket, the puller tape and the foam dispensing unit will stop, temporary steel end caps will be placed on the pipe, and the polyurethane will rise and fill the annular space between the pipe and jacket.

This method was chosen over other application procedures, such as spraying the foam on, because it was compatible with the preformed jacket system used. Different jacketing systems were investigated, but the preformed ultrahigh molecular weight polyethylene jacket system was chosen rather than other jackets, such as spiral crimped steel, extruded polyethylene, or a steel pipe, because polyethylene is extremely resistant to passage of water vapor and has the best water resistance of any readily available organic polymer. This is important, because one of the key design parameters was that no water shall be able to penetrate to the foam over the design life of the project. If the foam were to get wet, it would readily degrade and lose its insulting properties. The ultrahigh molecular weight designation means that the molecules of the material are very large which improves all mechanical properties of parts molded from it.

Some of the mechanical properties improved over normal molecular weight polyethylene are abrasion resistance, impact resistance, tear strength and overall physical strength. Another advantage of the polyethylene over steel jackets is that polyethylene would not interfere with the cathodic protection system on the pipe.

One possible problem in using a preformed jacket was the inspection of the foam after it was applied to the pipe to check for voids. An infrared heat detection unit solved the problem by sensing any cold spots or voids in the polyurethane immediately after application. It might be noted, however, that few voids in the foam were encountered during the production run of the pipeline. This was verified by periodic stripping of insulating joints each day of production as part of the quality control program.

Upon completion of the foaming process, heat shrinkable polymer waterstops were applied to both ends of the joint. By this means the insulation on each 40-ft pipe joint was encapsuled so that the failure of one joint or field joint would not effect the entire pipeline. The waterstops also protected the foam from moisture during shipping.

Another unique problem encountered was to cathodically protect the pipeline without penetrating the polyethylene jacket water barrier. This was solved by placing the anode on the outside of the polyethylene jacket and running a cable from the anode to the field joint area where it was exothermically welded to the pipe. The cable was on top of the jacket but was covered with the concrete weight coating.

The insulation system was applied over a thin film fusion bonded epoxy. This corrosion coating was chosen over an ordinary coat and wrap system because of the high operating temperature. The foam insulation adhered excellently to the fusion bonded epoxy as was demonstrated in tension tests.

FIELD JOINTS

The field joints were designed with three major considerations in mind. First of all, the field joint was to be insulated. Secondly, no water was to be able to penetrate to the field joint nor the 40-ft long insulated joint. Thirdly, the field joint system must be capable of being installed in a reasonable amount of time so that production on the laybarge would not be impeded. The field joint was designed so that there would be several levels of protection each acting independently of the others to prevent the foam insulation from becoming wet and furthermore to prevent corrosion of the pipe.

Different types of corrosion coatings were tried to protect the pipe in the weld area. A field applied epoxy was contemplated, but it was found to be too dependent upon surface preparation, which was time consuming. The corrosion coating decided upon was a heat shrinkable polymer sleeve with a stainless steel channel. The channel was installed onto molded ridges to secure the split sleeve into a cylinder. An advantage of the sleeve is that it would require no surface preparation of the pipe, other than to remove any welding slag or sharp edges of weld metal.

Another advantage of the sleeve was that it would extend between the faces of the waterstops giving added protection against water instrusion into the 40-ft joint of pipe. For added protection, heat shrink polymer collars were placed over the small end of the waterstop after it was shrunk in place. This collar would extend the length of the small end of the waterstop to ensure that the field applied inner corrosion sleeve would cover the small end of the waterstop.

When the sleeve was shrunk into place, 3-in. of polyurethane foam was injected into a mold over the sleeve to provide the insulation for the field joint area. On top of the foam insulation, another polymer split sleeve was shrunk into place to keep the insulation dry. The sleeve extended from the large end of one waterstop to the large end of the other in the field joint area. Again for added protection, a heat shrinkable collar was placed over the large end of the waterstop to extend its length to ensure that the large end would be covered.

Various materials were considered for the filler area over the outer shrink sleeve. The only filler requirement was that the material provide mechanical protection to the shrink sleeve as the pipe went over the pontoon rollers. A mastic filler was examined, but it was found to be too hot as it would melt the outer shrink sleeve. A quick-set concrete filler material was considered but was found too awkward because of problems of completely filling the area without voids. Polyurethane foam was found to be an excellent outer filler material since it provided good mechanical strength. A clear advantage of polyurethane foam as a filler material was that the foam equipment would already be available on the laybarge.

The entire field joint design and application procedure was developed with a comprehensive testing program. The field joint testing program tested all of the materials and procedures mentioned above to find out which one was best suited for the pipeline. The program verified that each of the various pieces in the field joint (i.e., inner and outer split sleeves and collars, waterstops) would act independently of each other to provide the watertight protection which was required. Each of the heat shrink pieces was tested for all three sizes of pipeline.

In addition, the testing program was used to find the best adhesives to use on each of the heat shrinkable polymer pieces under operating conditions. The setup for the test program as shown in Figure 3, consisted of 5-ft joints of pipe welded together with the resulting field joint areas. When the field joints were completed, they were submerged in a water bath for 24 hours. During the entire 24 hour test period, steam was run through the inside of the test pieces to simulate the temperature of the hot crude oil and the water bath was chilled to keep its temperature down to simulate the temperature of the sea water. This was deemed an important part of the testing program, because it was run as close as possible to the operating and environmental conditions of the pipeline. Figure 4 shows a field joint being examined after removal from the water bath.

Another phase of the field joint testing program was timing the application of the various schemes to see if production aboard the laybarge would be hampered. Some of the testing was done with laybarge supervisory personnel. Their knowledge of the actual field conditions proved invaluable in designing the field joint configuration as to what could and could not be done aboard a laybarge.

TENSION TESTING

With the selection of the polyethylene jacket insulation system, consideration was given to bonding the concrete weight coating to the insulated pipe. Problems with application of the concrete weight coating were anticipated because of the slick surface of the polyethylene jacket. A two part testing program was devised to define the bonding problem and to devise a practical means of improving the polyethylene/concrete bond within the time frame of the project. The first stage of the testing program was to test a number of alternate bonding methods under controlled conditions. Then in the second phase of the testing, full scale tests in a laybarge pipe tensioner would be conducted using insulated pipe weight coated with the optimal bonding method selected in the first phase.

Test samples for the first testing phase were prepared by taking two 40-ft joints of 4-in. pipe and insulating them in the coating plant as part of a normal production run. Eight different bonding means, including smooth polyethylene, were applied to different sections of the insulated pipe joints which were then concrete coated using the impact method. After concrete curing, the pipe joints were cut into 5-ft specimen lengths and the concrete coating on each specimen cut into 12-in. lengths for testing.

Table 2 lists each of the methods investigated in a descending order of average yield shear stress. The testing showed that untreated, smooth, polyethylene jacket has a low shear strength and that the polyethylene/concrete bond did need to be improved. Of the other methods tested, the method of lightly abrading the polyethylene jacket with a wire brush proved to be the most effective. This method was recommended for full-scale testing with the reservation that stringent quality control be employed to insure that the jacket not be deeply scratched and jeopardize its integrity.

Accordingly, full 40-ft pipe joints, six 4-in. and two 8-in. diameter, were coated for the test. As in phase 1 the pipe joints were insulated in the coating plant during production. Based on the results of the controlled testing, the pipe joints were abraded, but a grit blaster was used instead of a wire brush. By using the grit blaster it was felt the same rough texture of the polyethylene jacket could be achieved on a more productive basis with less risk of ing the polyethylene jacket. After shot ding, the pipe joints were concrete coated using the impact method and allowed to cure.

To most accurately simulate the actual installation conditions, one of the two wheel type pipe tensioners on Brown & Root's Laybarge BAR-289 was used. The testing configuration is shown in Figure 5. The pipe tensioner and cable winch are coordinated so the winch pulls the pipe out of the tensioner to determine payout tension and the tensioner pulls the pipe from the winch to determine pay in tension. This is the same procedure used in calibrating this type of tensioner and the tensioner was calibrated immediately prior to testing.

Figure 6 shows the first results of the laybarge testing. The 4-in. and 8-in. pipe joints failed at an average shear stress of 8-psi, the same as smooth polyethylene in the controlled testing. From these tests the following conclusions were reached.

1. The polyethylene jacket recovered from the roughening effect of the shot blast. The difference from the wire brush is that the polyethylene is not cut and a nap of fibers raised.

2. The 17 gauge wire reinforcing did not ribute the tension over the entire joint h since the coating repeatedly failed in last 8-ft to 10-ft of each joint.

3. The center patches in the concrete coating of the 4-in. pipe joints failed because the wire reinforcing was not continuous through them.

After testing all of the coated pipe joints, they were stripped of their concrete coating and prepared again for testing. The polyethylene jacket was abraded with a wire brush either continuously or in a close spiral to determine how much abrasion was required. Two types of heavier reinforcing, S-6 17 gauge wire with more wire strands than normal and 14 gauge wire, were used. A concrete coating was reapplied using the impact method and allowed to cure. The reinforcing wires were connected continuously through the center patches for the 4-in. joints and the patches installed separately.

Table 3 shows the results of all the laybarge testing. The use of wire brush abrasion and 14 gauge wire reinforcing proved effective because the tests for those pipe joints were carried out to either the maximum tension capacity of the tensioner or the tensioner tires slipped along the pipe. From these tests it was recommended that each pipe joint be ontinuously abraded to form a nap of lyethylene fibers, 14 gauge wire reinforcement sed, and the reinforcing wires should be inuous through the center patch on the 4-in. diameter pipe.

FLEXURAL TESTING

Concurrent with the tension testing program, a series of flexural tests were conducted to determine the bending response of the insulated pipe during installation. To achieve this goal the testing was conducted with two objectives.

- To determine the flexural rigidity of the composite insulated pipe section.
- To determine the stress concentration effect of field joints.

Seven 4-in. diameter test specimens, each 20-ft long, were prepared for testing. Weldable strain gages were attached to the pipes before the polyurethane insulation and polyethylene jacket were applied at the coating yard where the concrete coating was also applied by the impact method. One of the 4-in. pipe specimens was not insulated but only concrete coated to serve as a base for the testing. Of the remaining six 4-in. specimens, three were continuously coated with insulation and concrete while a simulated field joint was created in the center of three by removing the insulation and concrete coating. A continuously coated specimen and a field joint specimen were prepared using 8-in. pipe.

After the concrete coating had cured, concrete strain gages were attached to the compression side of each test specimen. Rods were attached to pipe through holes drilled in the concrete and insulation. In conjunction with a stationary line stretched across the test fixture, deflections of the pipe specimens were measured. Figure 7 shows the test fixture with a 4-in. pipe specimen in it. The frame supported the pipe on two saddles, 10-ft apart, equally spaced along the pipe. Two cylinders at either end of the pipe joint applied concentrated loads. By this means a constant flexural moment was obtained in the center 10-ft span of the pipe.

Each pipe specimen was loaded in incremental steps. At each loading step the load, strain in both the steel and concrete gages, and deflection along the pipe were recorded. Five of the 4-in. specimens were loaded until yielding was recorded at one or more points along the pipe. Two field joint specimens, one 4-in. and one 8-in., were loaded to 85 per cent of the specified material yield stress and cycled ten times from zero to the 85 per cent stress level. One continuously coated specimen of each size was loaded to failure then rotated 180-deg. and again incrementally loaded to failure in reverse bending.

Before the testing began a number of circumferential cracks were noted in the concrete coating and were probably due to shipping and handling. During testing cracks first appeared over the saddles and then appeared in the middle span approximately one diameter apart as the load increased. Although some of the cracks, particularly at the saddles, became as much as 1.875-in. wide, there was little spalling of the concrete coating. After testing, the concrete was removed at the location of some of the worst cracks and no damage to the polyethylene jacket or polyurethane foam was detected.

Figure 8 shows the flexural rigidity of the 4-in. and 8-in. composite pipe sections. The flexural rigidity of the 4-in. pipe decreases after it has sustained reverse bending. This indicates that the concrete coating contributes to the composite pipe strength and this contribution is reduced after the concrete has been cracked in tension. The flexural rigidity plot for the 8-in. pipe is the same for bending and reverse bending indicating a less substantial rigidity contribution of the concrete coating. As expected from this data, stress concentration factors for the field joints vary from 2.5 for initial bending to 1.6 for reverse bending of the 4-in. pipe while the 8-in. pipe stress concentration factor is 1.4 for both cases.

INSTALLATION

Upon completion of the tension and flexural bending testing programs, the design phase for the insulated pipeline system was completed. The focus shifted to installation of the insulated offshore pipelines and associated risers. Preparation for installation began with preparation of installation procedures and methods. Modifications to pipelay equipment because of the special requirements of the insulated pipelines were designed and effected. All of the advance preparations were compensated in the smooth installation of the insulated offshore pipelines.

One of the first steps in preparation for pipeline installation was the development of installation procedures. Each pipe size, 4-in., 6-in., and 8-in., was analyzed and a procedure developed for pipelay startup, normal pipelay, pipeline abandonment/recovery, and riser installation. For each case the pipeline tension was minimized. The 4-in. pipe was analyzed using a weighted average of the flexural rigidity for reverse bending over the length of a pipe joint and the field joint stress intensification factor for single bending to be conservative. The 6-in. pipe was analyzed with the more conservative assumption that it behaved like the 4-in. pipe. Analysis of the 8-in. pipe was performed directly from the flexural test data.

Normally a straight type pontoon is used for pipeline installation in 50-ft water depths. However, due to the low flexural rigidity to weight ratio for the 4-in. pipe, this method of installation was impractical. Installation stress analysis showed that the pipelines could be laid by means of axial tension and a curved pipelay pontoon. A tension level of 31,000-lbs was required for the 4-in. pipelines and 40,000-lbs was required for the 8-in. line. The optimum design of the pipelay pontoon for all the pipe sizes was determined to be a curved pontoon approximately 140-ft long with a radius of curvature of 750-ft. Since no pontoon of this type was available in the Middle East, a straight pontoon was modified by reducing its length and remounting the pipe support rollers to a 750-ft radius.

During the pipeline design and testing, modifications to the pipelay barge, BAR-207, had been determined to be required. Analysis of the 4-in. pipe indicated that it would be overstressed under its own weight if it spanned the normal 40-ft between pipe supports on the lay-barge. Accordingly, temporary roller supports were placed on the ramp of the barge so that no span was greater than 20-ft. The pipe handling crane was equipped with a spreader bar so that the 4-in. pipe would be lifted at least 6-ft from the ends of the joints. Extra lifting points were installed between the existing pipe davits to assist in lifting the pipe during riser installation. BAR-207 was also modified to accept the polyurethane injection equipment required for the field joints.

At the time that pipelay began, all of the jackets for the well tripods and the production platform were in place but none of the decks had been set. Each flowline was installed by starting at the production platform and laying away to the appropriate well tripod. After both flowlines to a well tripod had been laid, the risers at that well were installed. The risers at the central facility were installed after all the flowlines had been laid and the risers at the tripods set.

On the laybarge two work stations were used for welding, one was used for radiographic inspection, and two for field joints during pipelay operations for the 4-in. pipe. Three welding stations were used for the 6-in. and 8-in. pipe. All of the welding was done manually using external line up clamps. Concentricity of the pipe within the concrete and insulation coatings presented minor problems in welding line up but did not effect the overall installation.

Figure 9 shows the insulated pipe entering the pipe tensioner. Side rollers were mounted on the side of the tensioner to keep the pipe in because eccentricity of the pipe in the coatings would occasionally cause it to move laterally. The pipe welds were radiographically inspected immediately aft of the tensioner. At the beginning of pipelay, inspection was done by x-ray but this was later changed to gamma-ray to keep pace with the pipelay rate.

The field joints were installed using the procedures developed in testing. Figure 10 shows a shrink sleeve being installed over the weld area. Application of the inner layer of polyurethane insulation presented a number of problems during the early stages of pipelay. If the amount of foam injected into the removable mold was not carefully monitored, the amount varied with the heat of the day and the insulation would crack open after the mold was removed. After a number of interim solutions, the problem was solved by using disposable molds which were left in place. Figure 11 shows an outer shrink sleeve installed over the insulation layer. The outer layer of foam for mechanical protection was installed, as in Figure 12, immediately before the pipe was laid from the barge into the water.

Installation of the risers went as smoothly as the pipelay. In each case riser installation

·line on the sea
·cluding the existing
attached to the
o th· surface in
e · depth was
stacked onto the
e welded joint
e and riser were
d into place.

imes required for
lines and the
ulation related
that little time
elay effort due to
rements. Due to
rations, the
d offshore pipelines
difficulties than
e pipelay operations.

·lines have been
ore after two years
·ations. Many of
n features developed
icable to future
. The more signifi-
nclude.

·thane foam insulation
been developed.
larger diameter

pipelines or in deeper water depending upon the crushing strength of the insulation.

2. A system of installing insulated field joints on a laybarge has been developed. Again this system may be used for larger diameter pipelines or in deeper water depending upon the crushing strength of the foam insulation.

3. Tension testing performed as part of this project showed that an abraded polyethylene jacket could sustain tension loadings of 60,000-lbs in magnitude. Further testing would be required for tension requirements greater than this.

4. The concrete coated insulated pipeline does behave as a composite section under flexural loading. This phenomena is more pronounced with small diameter pipe and becomes less significant as the pipe diameter increases.

ACKNOWLEDGEMENTS

This paper is based upon design and testing which lasted over a period more than 2 years. During that time, H. H. Baker, R. E. Cain, R. L. Fearon, J. D. Touchet, and others have been involved in the engineering design, testing and critique that form this paper. The authors wish to thank them for their efforts which have made this paper possible. The authors also wish to thank Brown & Root, Inc. for permission to publish this paper.

TABLE 1

PIPELINE PARAMETERS

Wall Thickness (in)	Material Grade	Insulation Thickness (in)	Concrete Thickness (in)
0.531	API 5LX-42	3.06	3-140 PCF
0.719	API 5LX-42	3.25	3-140 PCF
0.719	API 5LX-42	3.19	2.75-140 PCF

Ship to Unocal

Attn of • *See below

• Your truck

• March Pipe
P.O. Box 1130
Azusa, CA 91702

• Attn: Randy Uchida

UNOCAL 76

Purchase Order
Unocal Oil & Gas Division

APPEAR ON ALL DOCUMENTS & PACKAGES	471238-A
DATE DUE DESTINATION	10/31/88
REQUISITION NO.	
PURCHASE ORDER DATE	10/28/88
PROJECT	W/O 886021
TERMS	Net 30 days
F.O.B. POINT	Delivered

MAIL INVOICE IN QUADRUPLICATE TO
Unocal O&G Division
P.O. Box 6176
Ventura, CA 93006

Attn: Chris Culver

WHEN INVOICE COVERS PREPAID TRANSPORTATION CHARGES ALWAYS ATTACH ORIGINAL RECEIPTED TRANSPORTATION BILL.

QUANTITY	UNIT	UNIT PRICE	DESCRIPTION
			CONFIRMING
3,040	FT	$ 8.07	6" .280 wall 18.97# A106 grade B, seamless, BE, 40' length line pipe coated with 40 mil thickness of orange polypropolene XTRU coat. MTR's required (Sumitomo - 28.8 Tons)
10 3)	EA	7.80	6" Wrap around heat shrink sleeves
			Delivery - 3000' to Plexco Fontana, CA
			40' to Advance Pipe Bending 2020 E. Slauson Ave Huntington Park, CA 90255 Attn: Gary McCray
		$ 25,156.80	Subtotal
		1,509.41	6% sales tax
		$ 26,666.21	TOTAL

PU... ORDER IS SUBJECT TO ALL OF THE ...IS AND CONDITIONS SET FORTH ON THE REVERSE AND ACCEPTANCE MAY BE MADE ONLY ON THE ...IS OF THIS OFFER.

2 - REQUISITIONER

UNION OIL COMPANY OF CALIFORNIA, DBA UNOCAL
BY David B. Harben

...803 (REV. 5/88) PRINTED IN U.S.A.

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Purchase Order
Unocal Oil & Gas Division

UNOCAL 76

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471230-B

to Unocal

of *See below

Westar Transport

West Coast Pipe Linings, Inc.
P.O. Box 476
Etiwanda, CA 91739

Attn: Dana Bergman
714/822-1133

DATE DUE DESTINATION	REQUISITION NO.	PURCHASE ORDER DATE
11/17/88		10/28/88

PROJECT: W/O 886021

TERMS: Net 30 days

F.O.B. POINT: Fontana

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Unocal O&G Division
P.O. Box 6176
Ventura, CA 93006

Attn: Chris Culver

WHEN INVOICE COVERS PREPAID TRANSPORTATION CHARGES ALWAYS ATTACH ORIGINAL RECEIPTED TRANSPORTATION BILL.

QUANTITY	UNIT	UNIT PRICE	DESCRIPTION
			CONFIRMING
2,700	FT	$ 3.29	to 6" sch 40 A106 grade B, seamless, 40 length line pipe coated with polypropolene XTRU coat with 1 inch thick coated of concrete weighing 25.36#/ft.
			Note: Nine joints will have anodes attached. W.C. P/L with provide installation of these anodes at $37. per unit. Farwest Corrosion will provie initial supervision of installation. Anodes are not to be coated with cement coating
		$ 8,883.00	Coating
		333.00	Anode installation
		$ 9,216.00	TOTAL

1

THIS PURCHASE ORDER IS SUBJECT TO ALL OF THE TERMS AND CONDITIONS SET FORTH ON THE REVERSE SIDE, AND ACCEPTANCE MAY BE MADE ONLY ON THE TERMS OF THIS OFFER.

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BY David B. Harbur

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Purchase Order
Unocal Oil & Gas Division

UNOCAL 76

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471238-C

DATE DUE DESTINATION	REQUISITION NO.	PURCHASE ORDER DATE
10/29/88		10/27/88

PROJECT: W/O 886021

TERMS: Net 30 days

F.O.B. POINT: Azusa

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Unocal O&G Division
P.O. Box 6176
Ventura, CA 93006

Attn: Chris Culver

WHEN INVOICE COVERS PREPAID TRANSPORTATION CHARGES ALWAYS ATTACH ORIGINAL RECEIPTED TRANSPORTATION BILL.

Ship to: Unocal

Attn of:

Via:

To:
AMF Tuboscope Inc.
P.O. Box 80238
Bakersfield, CA 93386

Attn: Earl Tiffin
800/345-7651

QUANTITY	UNIT	UNIT PRICE	DESCRIPTION
			CONFIRMING
		$ .69	to provide Amolog 4 inspection and reports on 3080 ft of 6" sch 40, A106 grade B, seamless pipe, 40' length, made by Sumitomo. Inspection is to report all defects that deviate from perfect pipe
		2,125.20	Subtotal
			Mail report to:
			Union Oil Company 225 So. Lake Ave., Suite 900 Pasadena, CA 91101 Attn: David B. Harbur
			Pipe is located at Marck Pipe in Azusa

"/mml

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Unocal Oil & Gas Division

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471238-D

Attn of: West Coast Pipe Lining
8621 Beech Ave
Fontana, CA 92335

Via: Lynden Air Freight
Kevin Eades
213/776-3142

To: Farwest Corrosion
17311 So. Main St.
Gardena, CA 90248

Attn: Jim Flake
Phone: 213/532-9524
FAX: 213/532-3934

DATE DUE DESTINATION	REQUISITION NO.	PURCHASE ORDER DATE
11/9/88		10/28/88

PROJECT: W/O 886021

TERMS: Net 30 days

F.O.B. POINT: Tulsa, OK

MAIL INVOICE IN QUADRUPLICATE TO:
Unocal O&G Division
P.O. Box 6176
Ventura, CA 93006

Attn: Chris Culver

WHEN INVOICE COVERS PREPAID TRANSPORTATION CHARGES ALWAYS ATTACH ORIGINAL RECEIPTED TRANSPORTATION BILL.

QUANTITY	UNIT	UNIT PRICE	DESCRIPTION
			CONFIRMING
9	EA	$ 279.15	C alloy 150 sacrificial anode and mounting braclet for 6" pipe dimensions - 21" long X 1-1/2" thick weight - 57# Shipping weight - 620# total
		$ 2,512.35	Subtotal
			Lynden Air Freight will pick up these anodes at Kaiser Chemicals 7311 E. 41st Street Tulsa, OK 74147 Contact Tom Brennen Phone: 918/627-0100
			and ship these to Farwest Corrosion Gardena, CA Attn: Jim Flake
			Farwest will provide delivery to West Coast Piping Lining and offer initial installation supervision of anodes onto pipe prior to cement coating.

/ml

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BY David D. Harbin

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DATE DUE DESTINATION	REQUISITION NO.	PURCHASE ORDER DATE
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PROJECT
W/O 886021

TERMS
Net 30 days

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Tulsa, OK

MAIL INVOICE IN QUADRUPLICATE TO:
Unocal O&G Division
P.O. Box 6176
Ventura, CA 93006

Attn: Chris Culver

WHEN INVOICE COVERS PREPAID TRANSPORTATION CHARGES ALWAYS ATTACH ORIGINAL RECEIPTED TRANSPORTATION BILL.

vised

Pipe Bending
Slauson Ave
on Park, CA 90255

ary McCray
213/581-0288
213/581-0712

UNIT PRICE	DESCRIPTION
	CONFIRMING
265.00	6" .280 wall 10D radius 90° pipe bend with 18" tangents. Pipe to be provided by Union Oil Company as one 40' joint. Advance will cut as needed and provide bevels at each end.

UBJECT TO ALL OF THE FORTH ON THE REVERSE BE MADE ONLY ON THE

2 - REQUISTIONER

UNION OIL COMPANY OF CALIFORNIA, DBA UNOCAL

BY David B. Harbur

D-112

.S.A.

IESS ALL CORRESPONDENCE AND ACKNOWLEDGMENTS TO THE WRITER'S ATTENTION

November 1, 1988

UNION OIL COMPANY

NEW LINE PIPE: AMALOG IV

471238 -B

198032

AMF

Tuboscope

Report of Inspection Services

TUBOSCOPE

PAGE ____ OF ____

CUSTOMER NAME & BILLING ADDRESS

UNION OIL COMPANY

P. O. BOX 6176

Ventura, California 93006

LOCATION WHERE WORK IS TO BE PERFORMED

UNION OIL COMPANY

MARCH PIPE

Azusa, California

CUSTOMER WELL NAME AND NUMBER OR SHIPPED TO

JOB BEGIN 10/28/88

JOB END 10/29/88

David B. Harbur

SIGNATURE OF CUSTOMER OR AUTHORIZED REP

LOCATION CODE	CUSTOMER NUMBER	W/O DATE	WORK ORDER NO.	INVOICE NUMBER	CUSTOMER P.O.
3 1 0 0 3 4 1		10/31/88	198032		471235-B

	SERVICE CODE / OD SIZE / WEIGHT	DESCRIPTION	LOCATION / UNITS / AMOUNT
X	SERVICE CODE; OD SIZE; WEIGHT	PO Y/N; LIST PRICE; PER; F/U; FEET; WALL THICKNESS; RANGE; GRADE; CONN.; T. JOINTER; MANUFACTURER	LOCATION; UNITS; $ AMOUNT
1	141-002; 6"	NEW LINE PIPE: AMALOG IV INSPECTION; N; .69; foot; 4,200'; .280; III; A106 SCH40; Plain End; SUMITOMO	01-00-34; 105; 2,898.00
2			
3			
4			

D-114

TUBOSCOPE INC.
P O BOX 808 • HOUSTON, TX 77001

TUBOSCOPE

REPORT PREPARED BY:
BAKERSFIELD INSPECTION DIV.

PRELIMINARY INSPECTION REPORT OF NEW TUBULAR GOODS

OWNER: UNION OIL COMPANY — DATE: OCTOBER 29, 1988

LOCATION: MARCH PIPE, AZUSA, CALIFORNIA — WORK ORDER NO.: 198032

WELL NAME & NUMBER: — CUSTOMER ORDER NO.: 471238-B

TYPE OF INSPECTION: AMALOG IV INSPECTION

TUBULAR GOODS DESCRIPTION AS REPRESENTED BY CUSTOMER:

Lengths	Size	Type of Pipe	Range	Manufacturer
105	6"	LINE PIPE	III	SUMITOMO

Weight	Wall	Grade	Connections	Welded/Seamless
	.280"	A106 SCH 40	Plain end	seamless

[X] Customer Specifications:

[X] Appropriate dimensions per API Standard 5CT
5% of the specified wall thickness for this pipe is .014"
12.5% of the specified wall thickness for this pipe is .035"
87.5% of the specified wall thickness for this pipe is .245"
Drift Mandrel: Diameter N/A Length N/A

SUMMARY OF RESULTS

77 Lengths did not indicate imperfections exceeding 12.5 % of the specified wall thickness and comply with above drift specifications, where applicable (Identified by a white band and AMALOG IV stenciled in white on the pipe body near the coupling or box end.) .... Footage 3,800.0'

A Lengths did not indicate imperfections exceeding 12.5% of the specified wall thickness but have rejectable pins and/or couplings. (Identified with a white paint band on the pipe body near the coupling or box end and a red paint band around the rejectable connection). .... Footage ______
______ Pins ______ Couplings ______ Both Pin and Coupling found rejectable.

27 *Lengths were found to have indications of imperfections exceeding 5% but not exceeding 12.5% of the specified wall thickness.
Imperfections not removed ~~(identified by a yellow paint band)~~ .... Footage 1,080.0'
Imperfections removed by grinding (identified by a white paint band) .... Footage -0-

N/A *Lengths found to have indications of imperfections exceeding 5% but not exceeding 12.5% of specified wall thickness and have rejectable pins and/or couplings. (Identified with a red paint band around the defective connection)..... Footage ______
______ Pins ______ Couplings ______ Both Pin and Coupling found rejectable.

0 Lengths were found to have inside imperfections which could not be measured. (Identified by a blue paint band) .... Footage ______

1 Lengths were found to be rejectable or would not pass the above drift specifications (Identified by a red paint band) .... Footage 40.0

SPECIAL COMMENTS: 27 LENGTHS MET API SPECIFICATIONS AS TO 87½% REMAINING BODY WALL BUT WERE NOT ACCEPTABLE TO CUSTOMER AND THEREFORE SET ASIDE NOT COLOR CODED RED OR WHITE

*This section does not apply when inspection is done to API 5A or 5AC imperfection tolerances.

Serviced By: MANUEL AGUILAR

TUBOSCOPE INC.
P.O. BOX 808 • HOUSTON, TX 77001

PAGE ______ OF ______

REPORT PREPARED BY:
BAKERSFIELD INSPECTION DIVISIO[illegible]

TUBOSCOPE

SUPPLEMENT TO INSPECTION REPORT OF NEW TUBULAR GOODS

TOMER UNION OIL COMPANY

DATE October 29, 1988

LOCATION MARCH PIPE, AZUSA, CALIFORNIA

WORK ORDER NO. 198032

CUSTOMER ORDER NO. 471238-B

WELL NAME & NUMBER

6" A106 SCH 40
PLAIN END

DESCRIPTION AND LOCATION OF IMPERFECTIONS

MFG: SUMITOMO

LENGTH NO	TYPE OF IMPERFECTION	DEPTH	REMAINING WALL THICKNESS		IDENTIFYING COLOR Red	Blu	Yel	N/A	LOCATION OF IMPERFECTIONS FROM COUPLING OR IDENTIFIED END	TALLY LENGTH
5	EXTERNAL SLUG	.078"	.202"		x				15'	40.00'
2	EXTERNAL CUTS	LESS .035"	MORE .245"					X	VARIOUS	40.00'
7	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
9	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
12	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
16	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
18	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
22	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
24	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
26	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
28	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
32	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
34	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
37	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
41	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
43	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
45	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'
47	EXTERNAL CUTS	.035"	.245"					X	VARIOUS"	40.00'
49	EXTERNAL CUTS	.035"	.245"					X	VARIOUS	40.00'

52

Form 102A (Rev. [illegible])

PRINTED IN U.S.A.

TUBOSCOPE INC.
P.O. BOX 808 • HOUSTON, TX 77001

TUBOSCOPE

PAGE ______ OF ______

REPORT PREPARED BY:
BAKERSFIELD DIVISON

SUPPLEMENT TO INSPECTION REPORT OF NEW TUBULAR GOODS

CUSTOMER UNION OIL

DATE October 29, 1988

LOCATION MARCH PIPE, AZUSA, CALIFORNIA

WORK ORDER NO. 198032

WELL NAME & NUMBER

CUSTOMER ORDER NO. 471238-B

6" A106 SCH 40
PLAIN END

DESCRIPTION AND LOCATION OF IMPERFECTIONS

MFG: sumitomo

LENGTH NO.	TYPE OF IMPERFECTION	DEPTH	REMAINING WALL THICKNESS		IDENTIFYING COLOR Red	Blue	Yel	N/A	LOCATION OF IMPERFECTIONS FROM COUPLING OR IDENTIFIED END	TALLY LENGTH
52	EXTERNAL CUTS	LESS .035"	MORE .245"					x	VARIOUS	40.00'
53	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
57	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
59	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
62	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
64	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
67	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
69	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
72	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'
101	EXTERNAL CUTS	.035"	.245"					x	VARIOUS	40.00'

Form 102A (Rev 3-87)

Unocal Science & Technology Division
Unocal Corporation
376 South Valencia Avenue, P.O. Box 76
Brea, California 92621
Telephone (714) 528-7201

UNOCAL 76

January 16, 1989

CORR 89-003

C. R. Culver
UNOCAL OIL & GAS DIVISION
Ventura, California

EXTERIOR COATING OF
GINA 6-INCH WATERLINE

Approximately 2700 feet of the 6-inch water return line from Mandalay to Platform Gina will be replaced. This section of the line has been corroded internally.

The Plexco X-Tru coat polypropylene coating system at 40 mils thickness, covered additionally by approximately one inch thickness of concrete "Hevicote" is a good exterior coating system for a subsea pipeline. The polypropylene will provide corrosion protection comparable to the Pritec polyethylene system that was used on the remainder of the line.

,propylene is similar to high density polyethylene in most respects. The differences between the Pritec and the X-Tru Coat systems are in the nature of the primers and the method of coating application. For your use, the principal advantage of polypropylene is its' better strength, rigidity, and toughness. The principal advantage to the X-Tru Coat system is that it provides a seamless coating. This, however, provides a built-in hoop stress in the plastic, which if severely damaged, may pull away from the asphaltic primer.

The principal advantage of the Pritec polyethylene coating system is the use of a softer, tackier, butyl rubber adhesive, and a helical wrap application that minimizes the hoop stress in the plastic coating. If the polyethylene is severely damaged, there may be less of a tendency for the wound to open and there is a possibility that the butyl rubber primer will remain flowable and provide a limited "self-healing" quality.

In my opinion, these differences between the Plexco X-Tru Coat polypropylene coating system and the Pritec polyethylene coating system are not important when the coating is additionally protected by a concrete, negative buoyancy coating. I recommend that you supplement the coating protection with cathodic protection, using the original number, size and distribution of bracelet anodes for this section of the line.

Mark Schilling
M. S. Schilling
Research Chemist

MSS/kb
cc: J. H. Duir
W. R. Coyle, B
C. J. Cron
R. J. Geving, B
K. E. Whitehead

Memorandum

UNOCAL 76

January 9, 1989 CORR-89-004

To: C. R. Culver, Ventura

From: R. E. Palmer

RE: USE SEALLOY 150 ANODES ON THE GINA 6" H_2O PIPELINE

You recently requested a written confirmation of my advisement to use Kaiser Sealloy 150 anodes instead of DOW Galvalum III anodes on the Gina 6" onshore water line.

Both anodes are made from a mercury-free aluminum containing indium. And both are recommended for use in high temperature, saline mud environments. However, the laboratory tests conducted at Research indicate the efficiency of Sealloy 150 in mud is over 25% greater than that of Galvalum III (84.4% versus 59%, see CORR 84-143M). As a result, I feel the use of Sealloy 150 anodes on the Gina 6" water line would be more cost effective than using Galvalum III.

If you have any questions or require any further information, please give me a call.

Yours very truly,

Bob Palmer

R. E. Palmer
Senior Engineer

REP(mlb)

cc: C. J. Cron
K. E. Whitehead

APPENDIX VOLUME 1
ITEM E

Repair Procedures

APPENDIX VOLUME 1
ITEM E

Repair Procedures

HOOD CORPORATION

PIPELINES • PLANT PIPING • CONDUIT CONSTRUCTION • INTERNAL PIPE CLEANING

CALIFORNIA STATE LICENSE NO. 186761 A

P. O. BOX 4368 • 8201 SO. SORENSEN AVE. • WHITTIER, CALIFORNIA 90607

(213) 685-5640 • (213) 945-1411 • (714) 523-9532

TELEX 67-7664 FAX (213) 945-6532

November 14, 1988

Union Oil Company
271 Market Street #12
Port Hueneme, CA 93041
Attn: Mr. John Cronk

NOV [illegible], 1988

Re: Installation of 2,700'-6" Offshore Pipeline.
Welding Procedure & Anticipated Equipment.

Dear Mr. Cronk:

Attached please find a copy of our Weld Procedure Number HC-1 which we have previously set. We have been using this procedure on a project we are working on at this time.

I am also listing the following equipment that we anticipate using on this project:

2 - Cat 561 Pipelayer (1 additional during pull)
1 - 5th Wheel Dolly
1 - John Deere 450 Combination
1 - 4x4 Pickup
1 - Equipment Van
2 - Welding Rigs
4 - Light Towers (as needed during pull)
1 - John Deere 690 Backhoe (determined by depth)
or
1 - John Deere 500C Backhoe (determined by depth)

Please feel free to contact me if you need any further information.

Very truly yours,
HOOD CORPORATION

J.M. Hagelstein
General Superintendent

HOOD CORPORATION

API STANDARD 1104

PROCEDURE NUMBER HC-1

Ref. Par. 22 API Standard 1104

STANDARD PROCEDURE SPECIFICATION

A. Process: SMAW

B. Material: API-5L GRADE B

C. Diameter and Wall Thickness: 12.750" x .375 WT.

D. Joint Design: Standard V Bevel - Open Butt

E. Filler Metal and Number of Beads: E6010/E7010

F. Electrical or Flame Characteristics: D.C. - Reverse

G. Position: 6G Stationary Axis Horizontal

H. Direction of Welding: 45° Downhill

I. Number of Welders: One

J. Time Lapse between Passes: Hot Pass within 5 Minutes

K. Type of Line-up Clamp: Internal or External

L. Removal of Line-up Clamp: Bead 50% Complete

M. Cleaning: Power grind first pass-Brush subsequent passes

N. Preheat, Stress Relief: None

O. Shielding Gas and Flow Rate: N/A

P. Shielding Flux: N/A

Q. Speed of Travel: See Attached

R.: Sketches and Tabulations (to be attached)

Tested: ACCURATE WELD TESTING Welder: BILL TIPTON

Approved: SEE ATTACHED Welding Sup.: O. D. McKINNIS

Adopted:

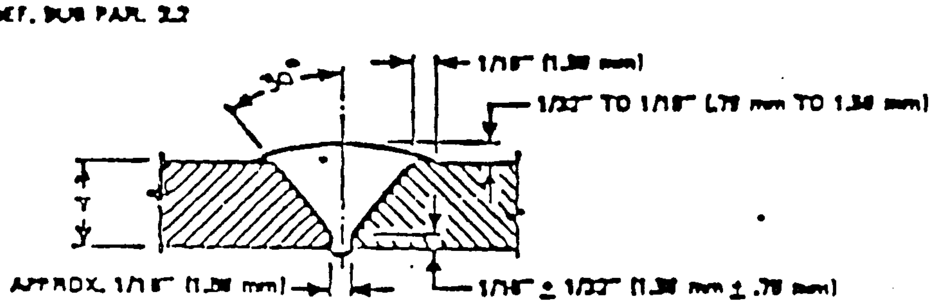
AWS QC-1 MICH... E EWING 83... 11 CWI

HOOD CORPORATION

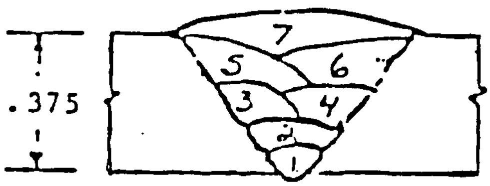
PROCEDURE NUMBER HC-1

API STANDARD 1104

rial Used for Procedure	Material Qualified	
" API 5L Grade B .375W.T.	Diameter	2" thru 12"
	SMYS	Less than 42,000
	W.T	.1875 thru .750



STANDARD "V" BEVEL BUTT JOINT



SEQUENCE OF BEADS

ELECTRODE SIZE & NUMBERS OF BEADS

NUMBER OF BEADS

BEAD #	ELECTRODE	IPM	BEAD #	ELECTRODE	IPM
1.	5/32 5P+	8-12	7.	3/16 HYP	8-12
2.	5/32 HYP	12-14	8.		
3.	3/16 HYP	8-12	9.		
4.	3/16 HYP	8-12	10.		
5.	3/16 HYP	8-12			
6.	3/16 HYP	8-12			

NOTE. FIRST PASS ONLY 5/32" Fleetweld 5P+

REMAINING PASSES USE 5/32" or 3/16" Shieldarc Hyp

COVER BEAD MAY BE MADE WITH N/A

VOLTAGE & AMPERAGE RANGE

ELECTRODE DIAMETER	AMPERAGE	ARC VOLTS
1. 5/32	130-160	24
2. 5/32	140-180	24
3. 3/16	140-190	24

ACCURATE WELD TESTING LAB

5223 TWEEDY BOULEVARD SOUTH GATE, CALIFORNIA 90280 564-5879 • 564-5870

LAB CONTROL # 151

COUPON TEST REPORT

PROCEDURE NUMBER HC-1

Test No. 151

Location UNION PACIFIC RESOURCES WILMINGTON, CA

Date 8/22/88 State CA Roll Weld .... Fixed position Weld 6G

Welder BILL TIPTON Mark ....

Welding time 1 Hour Time of day A.M. M. Temperature 75 F.

Weather condition CLEAR & SUNNY

Wind break used NO voltage SEE ATTACHED amperage SEE ATTACHED

Type of welding machine LINCOLN 250 Size 250

Filler metal SEE ATTACHED

Size of reinforcement ....

Pipe Kind and Grade API 5L GRADE B

Wall thickness .375 Dia. O.D. 12.75"

	1	2	3	4	5	6	7
Bead No.							
Size of Electrode							
No. of Electrode							

	1	2	3	4	5	6	7
Coupon stenciled / Original Dimension: of plate	1.240 x.381	1.140 x.378	1.077 x.377	1.125 x.372			
Orig. area of plate in²	.4724	.4309	.4060	.4185			
Maximum load	32 K.	30 K.	29 K.	29 K			
Tensile S/in. plate area	68 K	70 K	73 K	69 K			
Fracture location	P.M.	P.M.	P.M.	P.M.			

☒ Procedure ☐ Welder ☒ Qualifying Test ☐ Line Test ☒ Qualified ☐ Disqualified

Max. tensile 73,399 Min. tensile 68,586 Avg. tensile 70,342

Remarks on tensile

1 SATISFACTORY
2 SATISFACTORY
3 SATISFACTORY
4 SATISFACTORY

Remarks on Bend Tests

1 FACE BEND - SATISFACTORY / ROOT BEND - SATISFACTORY
2 FACE BEND - SATISFACTORY / ROOT BEND - STAISFACTORY
3 FACE BEND - SATISFACTORY / ROOT BEND - SATISFACTORY
4 FACE BEND - SATISFACTORY / ROOT BEND - SATISFACTORY

Remarks on Nick Tests

1 SATISFACTORY
2 SATISFACTORY
3 SATISFACTORY
4 SATISFACTORY

Test made at ACCURATE WELD TESTING Date 8/24/88 O. D. McKinnis

Tested by RONALD S. MOBLEY Supervised by ....

(Use back for additional remarks.)

TEST CONDUCTED BY ACCURATE WELD TESTING LAB

ER RONALD S. MOBLEY DATE 8/24 19 88

Ronald S. Mobley

Laboratory Manager

UNION OIL COMPANY OF CALIFORNIA
OIL AND GAS DIVISION
WESTERN REGION OPERATIONS - CONSTRUCTION
PIPELINE WELDING SPECIFICATION

1.0 SCOPE

1.1 The following paragraphs detail the requirements for field welding of line pipe, fittings, and related equipment in the construction of liquid and gas transmission systems.

2.0 CONTRACTOR'S RESPONSIBILITIES

2.1 The Contractor shall provide all supervision, labor, equipment, and welding materials for the fabrication or assembly by welding of the pipeline, facilities, and other associated piping described in the contract documents.

3.0 WELDING PROCESSES

3.1 All welding shall be accomplished by the shielded metal arc welding (SMAW) and/or submerged arc welding (SAW) processes. Permitted use of alternate processes may be considered upon receipt of complete details outlining the operating characteristics of the process, the extent of desired application, and actual test results indicating the requirements stated herein can be achieved by the alternate.

4.0 MATERIALS

4.1 Line Pipe - Transmission line pipe shall conform to the requirements of API Specification 5L and the additional requirements stipulated in the line pipe procurement documents attached hereto. Specific grades of pipe for the various facilities shall be as indicated in the contract documents.

4.2 <u>Welding Consumables</u> - All welding consumables shall conform to the requirements of the American Welding Society Specification A5.1, Class E6010 (Lincoln Fleetweld 5P or equivalent) and/or A 5.5, Class E7010-A1 (Lincoln Shieldarc 85/85P or equivalent) or Class E7010-G (Lincoln Shieldarc HYP) or equivalent.

5.0 QUALIFICATIONS

5.1 <u>Qualification Materials</u> - The Company shall provide pipe necessary for procedure and welder qualification tests. The Contractor shall provide all other materials necessary to perform the required tests. All completed weld test coupons shall become the property of the Company and shall be retained by the Contractor until Company advises of the means of disposal.

5.2 <u>Procedures</u> - All procedures for welding to be performed in execution of this contract shall be qualified in accordance with the provisions of the American Petroleum Institute Standard for Welding of Pipelines and Related Facilities, API Std. 1104. The Contractor shall furnish written guidelines to be employed in the testing, qualify the actual job procedures using these guidelines, and submit final documentation indicating the actual welding parameters employed in the qualifications.

5.3 <u>Performance Qualifications</u> - The performance of all welders shall also be qualified in accordance with the provisions of API Std. 1104. The Company may exercise the option to qualify welders by use of radiographic nondestructive examination.

6.0 CLEANING

6.1 Precleaning - Prior to fitup, each pipe shall be thoroughly cleaned of internal debris, dirt, scale, and rust. The beveled end areas shall be wire brushed to clean metal and the area of coating cutback shall be cleaned of all loose scale, dirt, and other foreign materials.

6.2 Weld Cleaning - The root pass of all groove welds shall be ground with power disc grinders to remove all side wall undercut prior to deposition of the second or hot pass. All subsequent beads, including the cover pass, shall be cleaned of all slag using power driven wire brushes.

7.0 ALIGNMENT

7.1 The alignment of abutting bevel preparations shall be accomplished with line-up clamps approved by the Company. For welding of pipe 16" and larger diameters, internal power line-up clamps shall be employed. For smaller diameters, selection of clamp type is the Contractor's option. The pipe shall remain in a totally static condition and the alignment clamp shall remain in place until as much of the root pass as can be completed has been deposited. When external line-up clamps are employed, a minimum of fifty percent (50%) of the root pass shall be deposited in segments equally spaced around the circumference before releasing the clamp.

7.2 Radial Mismatch - Radial mismatch or high-low shall be equally divided around the circumference of the pipe. Spacing tools shall be employed to insure a uniform root opening conforming to the procedure qualification requirements. All transitions in wall thickness shall be ground to a four-to-one taper to achieve equal internal diameters at the weld edge.

7.3 Offset of Longitudinal Seams - If the pipe is longitudinally welded (e.g. ERW pipe), the weld seams of abutting joints shall be offset not less than ten degrees (10^{o}) nor more than forty-five degrees (45^{o}) on the circumference. Weld seam alignment in the ditch shall be in the top quadrant of the pipe circumference.

8.0 HAMMERING

8.1 Any hammering of pipe to obtain alignment shall be accomplished only with smooth-faced hammers overlayed with a material softer than the line pipe. Dents, scratches, or any other damage caused from hammering shall be removed by grinding. If grinding reduces the pipe wall thickness below the minimum specified wall thickness, the affected areas shall be completely removed as a cylinder and the joint shall be rewelded.

9.0 GROUNDING AND INADVERTENT ARC STRIKES

9.1 Grounding of welding machines shall be accomplished to prevent arcing of the pipe body wall at the point of ground attachment. Grounding shall preferably be accomplished on surfaces which are to receive subsequent weld metal deposition; i.e., on bevel faces or on the face of fill passes. Any arc burns occuring on the surface of the pipe, regardless of cause, shall be eliminated by removing a cylinder containing the arc strike from the line and rewelding. The Contractor shall be responsible for all costs associated with removal and rewelding pipe affected by arc burns.

10.0 MARKING AND IDENTIFICATION

10.1 Each qualified welder shall be assigned a unique and unduplicated symbol or number. This identification shall be applied with waterproof crayon or paint in characters at least two inches high and shall be affixed to the pipe in the vicinity of each weld deposited. All marking shall be on the pipe between the weld and coating cutback.

10.2 Each identifying mark shall be employed exclusively by an individual welder. In the event a welder is terminated or leaves before completion of the project, his identifying mark shall be retired and shall not be reassigned to another welder.

11.0 NOTIFICATION

11.1 The Contractor shall notify the Company at least 3 days before commencement of work of: (1) the number of welders anticipated to be tested, (2) the number of procedures to be qualified, and (3) the amount of pipe required for the qualification tests.

12.0 RECORDS

12.1 Procedures - The Contractor shall prepare the final detailed written welding procedures in accordance with and on the forms indicated in API Std. 1104. The procedures and certified test results shall be submitted to the Company for approval before commencement of work.

12.2 Qualifications - The Contractor shall prepare written welder qualification test reports in accordance with and on the forms indicated in API Std. 1104. If welders are qualified by radiography, the film shall be submitted to the Company together with one copy of the qualification test report.

12.3 Retention - One copy of all procedures and qualification records shall be retained by the Contractor at the job site and shall be made available to the Company upon request.

13.0 REPAIR WELDING

13.1 Repair of defective welds shall be subject to the approval of the Company and the provisions of API Std. 1104.

13.2 Defect Removal - Removal of all defects shall be accomplished by power disc grinding. When an area containing defects is to be repaired, the entire length of continuous defect, and any interrupted length of defect of the same type or category, shall be entirely removed prior to commencement of the repair.

13.3 Re-deposition - The re-deposition of weld metal shall be accomplished by the approved welding procudures and qualified welders using the same consumables, in the same sequence, as employed in the original welding.

13.4 Restrictions on Repair - Welds with defects whose repair would require removal of ninety degrees (90^o) or more of the weld circumference, any cracked weld, or any weld on which a previous repair has been attempted shall be completely cut out, the pipe rebeveled, and a new weld installed.

13.5 Beveling - Pipe ends to be butt welded shall be beveled by machine tool or machine oxygen cutting. Manual oxygen beveling is not allowed.

14.0 INSPECTION

14.1 All work shall be subject to inspection by the Company or its designated representative to insure compliance with the requirements of API Std. 1104 and the requirements herein. Inspection may employ any tool or instrument deemed necessary to assure the provisions of this contract have been fulfilled.

14.2 Right of Access - The Company or its designated representatives shall have full access and the right to inspect all equipment, materials, and workmanship on this project. Any inspected item found to be inadequate to these requirements shall be subject to removal and replacement at the Contractor's sole expense.

15.0 NONDESTRUCTIVE EXAMINATION

15.1 All production welding shall be subject to radiographic inspection by a nondestructive examination contractor approved and supervised by the Company. The Company will make every effort to direct and conduct the radiographic inspections to avoid any delays to Contractor's operations; however, the Company will not compensate Contractor for any lost time resulting from the inspection or for repair of welding found to be noncompliant.

15.2 Contractor's Responsibility - The Contractor shall cooperate fully with the radiographic inspection agency to insure timely and adequate inspection of all welding. The Contractor is expected to furnish towing to free radiographer's vehicles from disabling conditions of terrain or weather at no cost to the Company or the inspection agency.

0001d

PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

APPENDIX VOLUME 2

UNOCAL 76

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Intersea Research - Side Scan Sonar Survey (12/31/82)
Pelagos - Compilation of 4 Side Scan Sonar Surveys (1/89)
Pelagos - Side Scan Sonar Survey (9/89)
Linalog Survey (2/8/85)
Linalog Survey (9/2/86)
Linalog Survey (10/5/87)
Harco Cathodic Protection Survey (1/84)
Corrpro Cathodic Protection Survey (2/89)

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Page	Description
C-1 thru C-10	Intersea Research - Side Scan Sonar Survey (12/31/82)
C-11 thru C-28	Pelagos - Compilation of 4 Side Scan Sonar Surveys (1/89)
C-29 thru C-31	McClelland As-Built, Redigitized by Pelagos for Reference (Plates 1A, 1B, and 1C)
C-32 thru C-34	Side Scan (Plates 2A, 2B, and 2C) (1/9/84)
C-35 thru C-37	Side Scan (Plates 3A, 3B, and 3C) (1/7 to 1/8/86)
C-38 thru C-40	Side Scan (Plates 4A, 4B, and 4C) (11/11/86)
C-41 thru C-43	Side Scan (Plates 5A, 5B, and 5C) (8/1/88)
C-44	Not Used
C-45 thru C-61	Pelagos - Side Scan Sonar Survey (9/89)
C-62	Not Used
6-63 thru C-66	Pelagos - Navigation Plot, Seafloor Features
C-67	Not Used
C-68 thru C-119	Linalog Survey (2/8/85)
C-120 thru C-173	Linalog Survey (9/2/86)
C-174 thru C-220	Linalog Survey (10/2/87)
C-221 thru C-269	Harco Cathodic Protection Survey (1/84)
C-270 thru C-305	Corrpro Cathodic Protection Survey (2/89)

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Intersea Research - Side Scan Sonar Survey (12/31/82)

SIDE SCAN SONAR SURVEY
SANTA BARBARA CHANNEL
PIPELINES: DOS CUADRAS,
SANTA CLARA AND HUENEME

(IRC Report #1382)

Prepared for:

Union Oil & Gas Division
Western Region
Union Oil Co. of CA
1003 Main Street
Santa Paula, CA 93060

December 31, 1982

INTERSEA RESEARCH CORPORATION
11760 Sorrento Valley Rd., San Diego, Ca. 92121 • Telephone: (619) 453-5200 • Cable: INTERSEA SAN DIEGO • Telex: 69-7901
A Subsidiary of TRITRONICS, INC.

December 31, 1982

Union Oil & Gas Division
Western Region
Union Oil Company of California
1003 Main Street
Santa Paula, California 93060

RE: Side Scan Survey
Santa Barbara Channel
Pipelines: Dos Cuadras, Santa Clara & Hueneme

Sirs:

In accordance with your request, Intersea Research has conducted a pipeline surveillance of three submarine pipelines located in the Santa Barbara Channel. The purpose of the survey was to identify possible pipeline hazards, especially portions of the lines that may be suspended.

The three subject pipeline bundles surveyed included: (1) the Dos Cuadras Pipeline Bundle (2-12" and 1-6" from Platform C to Rincon; 64,000 ft.), (2) the Santa Clara Pipeline Bundle (1-12", 1-10", and 1-6" from Platform Gilda to Mandalay Site; 53,000 ft.), and (3) the Hueneme Pipeline Bundle (1-10" and 1-6" from Platform Gina to Mandalay Site; 33,000 ft.).

Instrumentation used to survey the pipeline included a Motorola Mini-Ranger IV System (operated by Lewis and Lewis Surveyors), a Raytheon DE-719 recording echo sounder, and a Klein Model 402 side scan sonar system. Sea conditions during the survey were breezy with choppy, 1 to 3 foot swells.

Coverage of the pipelines exceeded 99% on all routes. Two separate 70 m sections of the route along the Dos Cuadras Bundle were destroyed by a recording event marker failure, but adjacent side scan coverage shows no significant bottom/pipeline variances. Pipeline conditions varied from complete burial to complete exposure, although no portions were observed to be suspended. Noted bottom characteristics include drag marks, other pipeline crossings, debris near platforms, and possible sand ridges that have drifted over the bundle.

A brief report covering field operations and findings from this survey is attached. We appreciate the opportunity to be of service to Union, and look forward to working with you again.

Very truly yours,

INTERSEA RESEARCH CORPORATION

George R. Downs
Vice-President

GRD/pw
Encl.

CONTENTS

SUMMARY OF FIELD OPERATIONS

On 28 December 1982, the N/V Western Warrior was mobilized with navigation and surveying instruments. Positioning for the survey was controlled by Lewis and Lewis surveyors (Ventura, CA) using a Motorola Mini-Ranger IV System. This system determines position with respect to radar transponder reference stations located at known fixed points. The elapsed time between the transmitted interrogation produced by the transmitter (aboard the survey vessel) and the reply received from each appropriate transponder is used as the basis for determining the range to each transponder. Accuracy of this system is within 3 meters at a range of 35 kilometers. This range-range information, combined with the known location of each transponder, is then trilaterated to provide a position fix in the appropriate X-Y coordinate system. The survey vessel's distance from the pipe routes varied between 50 and 200 feet. Event marks were placed on records at each fix location along survey lines.

On 29 December 1982, at 0430 hours, the survey vessel left the Channel Islands Marina underway for Platform C. By 0800, the vessel was on site and instruments were operating. A Raytheon DE 719 recording echo sounder was used for all sounding operations. (It had been depth calibrated back at the marina.) This system has an operating frequency of 200 KHz with a beam width of approximately 5 degrees. Operating on 0-110 and 100-210 foot scales, the accuracy of readings is within 0.5% of actual depth.

A Klein Associates side scan sonar system was used to acoustically sweep the pipelines and surrounding seafloor. The 50 KHz, two-channel Model 402 towfish emits fan-patterned acoustic beams from transducers located on both of its sides. The beams are focused normal to the vessel heading and are broad enough in the vertical plane to scan continuously from directly below the fish to the full range of the system (operated on the 150 m scale for this survey). Echoes returned from targets are received by the towfish, processed and displayed on a Klein Model 401T recorder. This creates a permanent, continuous graphic record of a path along the seafloor in which the echoes are placed side-by-side such that the record resembles an aerial photograph.

The fish was towed at variable distances behind the vessel. Notes of tow cable deployment were maintained on the record to provide set-back information. The fish was towed at heights above the seafloor that would provide the best shawdow characteristics for observing possible pipeline hazards.

Minimal difficulties were encountered during data acquisition. Pipeline Surveillance Records (pages 5 through 7 of this report) detail observations made from the side scan sonar records. All locations are corrected for set-back distances. The three lines were completed by 1440, and the M/V Western Warrior went underway back to the marina.

FINDINGS

Coverage of the pipelines exceeded 99% on all three lines. Two separate 70 meter sections of the route along the Dos Cuadras Bundle were destroyed by a recording event marker failure, but adjacent side scan coverage showed no significant bottom/pipeline variances.

On all records, pipelines were observed to lie on or below the sea-floor. No locations along the lines were seen to be suspended or under-mined. At 588 + 20 (on the Dos Cuadras line), the bundle is split and all 3 lines are separate and clearly visible on the side scan record. Drag marks from anchors and/or fishing devices are visible on many portions of the records. Also, another pipeline crosses the Dos Cuadras line near 328 + 80. Other bottom characteristics of mention are the debris piles near platforms, and migrating sand ridges at 225 + 09 and 268 + 86 along the Hueneme Bundle. The Pipeline Surveillance Records on pages 5 to 7 document the observations seen on side scan records.

PIPELINE SURVEILLANCE RECORD

Platform C to Rincon 65,121 feet

Location (ft)	Depth (ft)	Side Scan Sonar Observations
651 + 21	194	platform w/ debris
635 + 01	193	230'/70 m section of record destroyed by recording event marker failure
624 + 51	193	230'/70 m section of record destroyed by recording event marker failure
624 + 51	193	platform w/ debris
593 + 03	193	platform w/ debris
588 + 20 to 574 + 01	193 to 194	bundle split, 2-12" and 1-6" pipes clear on record
572 + 95	195	bundle exposed, no suspension
451 + 98	192	paper advanced to eliminate cutting, no appreciable data loss
400 + 05	182	survey vessel crossed pipeline
391 + 57	182	survey vessel crossed pipeline
376 + 01	180	pre-pipe (?) drag marks/anchor scars
328 + 80	167	pipeline crossing under (?) subject Union line
318 + 63	164	lose coverage
305 + 15	159	regain coverage; missing gap too large
301 + 75	158	abort and reshoot
322 + 20	163	partially exposed
274 + 60	150	pre-pipe (?) drag marks
235 + 10 to 148 + 19	135 to 106	165-250 feet (50-75 m) sections intermittantly exposed and buried
188 + 29	118	100-165 feet (30-50 m) buried
172 + 93	113	2 additional pipes to north
151 + 39	108	all pipes buried
147 + 13	106	all 3 pipes exposed
107 + 71 to 96 + 08	90 to 82	1 additional pipe, 4 total, all exposed
82 + 51 to 37 + 95	73 to 42	intermittent burial of all 4 lines
37 + 95 to 12 + 08	25	100% burial all lines, much kelp present

PIPELINE SURVEILLANCE RECORD

Platform Gilda to Mandalay 52,540 feet

Location (ft)	Depth (ft)	Side Scan Sonar Observations
520 + 30	202	platform w/ debris; begin bundle from
517 + 88	201	platform w/ minor string 30 m north; all slightly exposed on surface
508 + 53	190	1 additional line from north
499 + 81	183	1 additional line from north, total spread 45 m
423 + 21 to 404 + 40	123 to 113	faint indications of additional lines; subject bundle slightly exposed on surface
359 + 01	96	2 bundles, 3 and 4 pipes
336 + 79	90	2 bundles, 4 and 4 pipes
284 + 84 to 263 + 24	79 to 74	north bundle intermittantly buried
268 + 24	74	north bundle buried 100%
214 + 58	66	south bundle intermittently buried in 10-15 m sections
193 + 63	63	north and south bundles intermittantly slightly exposed
146 + 08	57	all lines, both bundles buried 100%
137 + 28 to 134 + 04	57 to 56	partial exposure
134 + 04	56	all lines 100% buried
73 + 25	50	buoy markers
59 + 70	47	buoy markers

PIPELINE SURVEILLANCE RECORD

Platform Gina to Mandalay 32,860 feet

Location (ft)	Depth (ft)	Side Scan Sonar Observations
28 + 43 to 230 + 53	30 to 64	no evidence of pipe exposed
167 + 42 to 209 + 09	55 to 61	seafloor irregularities
230 + 53	65	pipe exposed w/ sand accumulation on east side of line; 3 distinct lines, 1 primary, 2 minor
225 + 09	69	sand ridges cross over pipes
268 + 86	72	sand ridges cross over pipes
258 + 17 to 277 + 12	70 to 74	evidence of 6 minor lines
316 + 48	92	backwash from work boat at platform

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Pelagos - Compilation of 4 Side Scan Sonar Surveys (1/89)

PELAGOS CORP.

A COMPILATION OF FOUR ANNUAL SIDESCAN SONAR SURVEYS (1984-1988) - SUBMARINE PIPELINE PLATFORM GINA TO MANDALAY BEACH VENTURA COUNTY, CALIFORNIA

FOR
UNOCAL
VENTURA, CALIFORNIA

BY
PELAGOS CORPORATION
SAN DIEGO, CALIFORNIA
JANUARY 1989

PELAGOS CORPORATION 9173 Chesapeake Drive San Diego, California 92123
Telephone: (619) 292-8922 Telex: 295 468 PLGS UR FAX: 619 292 5308

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INTRODUCTION

Pelagos Corporation has performed a series of four annual inspections along a submarine pipeline route for UNOCAL. A pipeline bundle (one 10-inch pipe and one 6-inch pipe) and a power cable occupy the route originating at Platform Gina and terminating at a landfall near Mandalay Beach in Ventura County, California (Figure 1). In each survey, a sidescan sonar system was operated along this route.

This report describes the instruments and methods employed during the survey operations, discusses interpretation techniques, and presents results of each survey. Table 1 summarizes the pertinent facts of each survey including date, vessel, equipment and horizontal control. Supplementary details such as the personnel involved in the various field operations and office analysis tasks, survey vessel specifications, and daily operator logs are available in the original reports listed in the references.

The results of each survey include a series of three plates showing significant seafloor features and a discussion of any prominent changes in seafloor conditions from previous surveys. The first three plates (1A,1B,1C) indicate the "as-built" pipeline location based on the August 1981 McClelland Engineers survey. These serve as a common reference for all later data presentations.

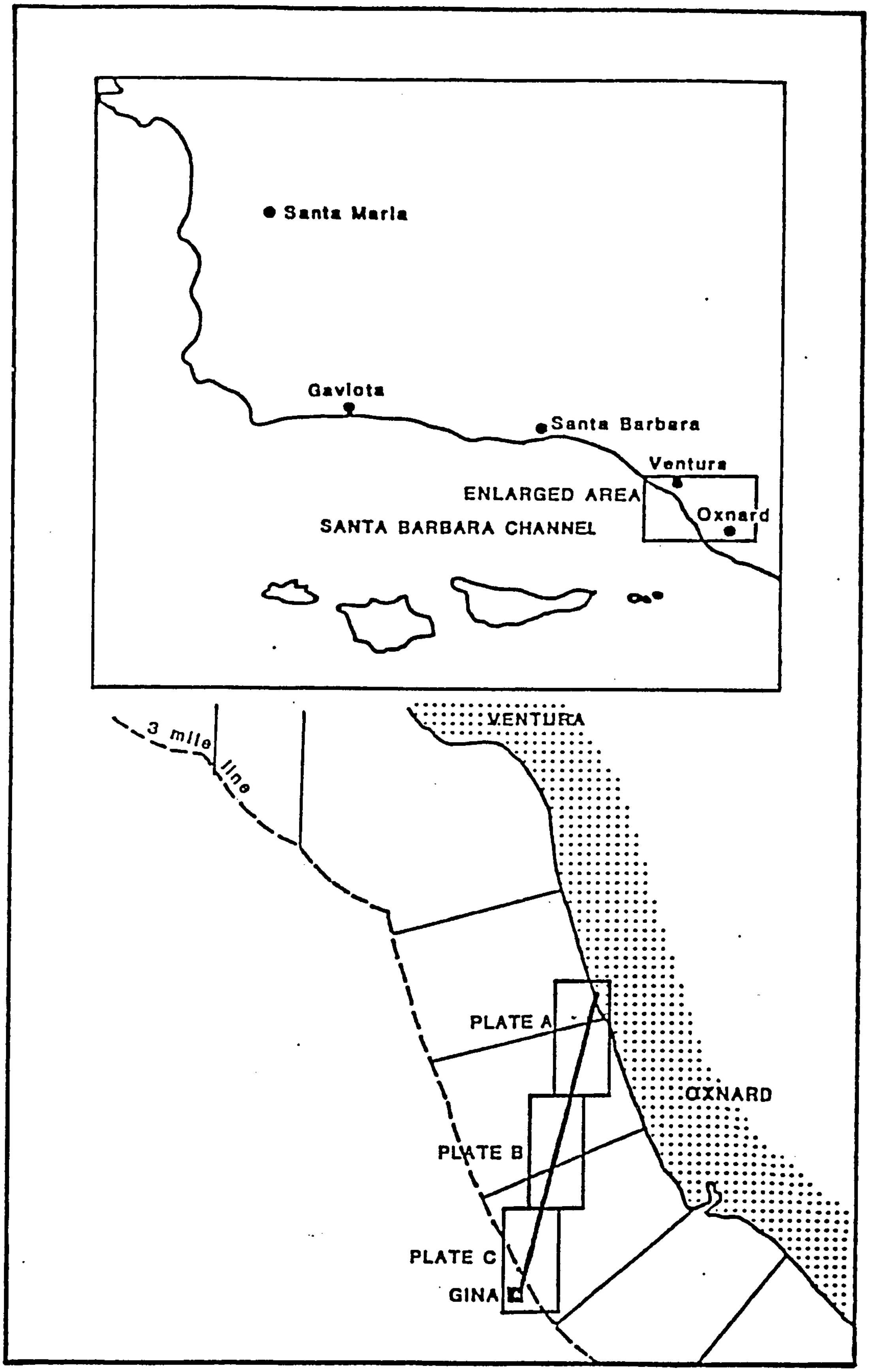

Figure 1. Location Map.

Table 1

Previous Pelagos Surveys

Survey Date	Vessel	Equipment	USC&GS Horizontal Control Stations
9 Jan 1984	WESTERN WARRIOR	MRS III w/SCOPE 85 ORE Multiscan Sidescan Sonar System Ross 801 Echo Sounder	MART 3 SEACLIFF SPRINGVILLE
7-8 Jan 1986	WESTERN WARRIOR	MRS III w/PHROGNAV ORE Multiscan Sidescan Sonar System Si-Tex HE30 Echo Sounder	MART 3 SEACLIFF SPRINGVILLE
11 Nov 1986	WESTWIND	MRS III w/PHROGNAV ORE Multiscan Sidescan Sonar System Raytheon DE-731 Echo Sounder	MART 3 SEACLIFF SPRINGVILLE
1 Aug 1988	SEA WATCH	MRS III w/PHROGNAV EG&G Model 260 Sidescan Sonar System Furuno Echo Sounder	CASA LOON MART 3 SEACLIFF

DATA ACQUISITION

A brief description of instruments utilized for these surveys is presented below and summarized in Table 1. The survey systems used to collect data for the pipeline inspection were operated simultaneously over predetermined survey lines. Figure 2 illustrates the typical towing geometry relative to the survey vessel. Echo sounder transducer location was vessel dependent. Vessel speed was approximately four knots throughout the survey. Pelagos Corporation was responsible for data acquisition, navigation, data reduction, and interpretation during each survey project.

Navigation and Positioning

A Motorola Mini-Ranger III position system was used to insure highly accurate and repeatable positioning during the survey. This is a microwave, pulse positioning system which utilizes a mobile interrogator and two or more base station transponders located at survey control points on shore. Once per second, the distance in meters to each transponder is displayed onboard the vessel where the system automatically records the ranges at selected locations or time intervals. The Mini-Ranger is an accurate line-of-sight system which is not subject to ionospheric disturbances and has a position accuracy of better than three meters.

On the January 1984 survey, a SCOPE-85 microprocessor system was operated aboard the vessel to provide real-time positioning solutions and vessel tracking. The system interfaces the Mini-Ranger to a Hewlett-Packard Series 85 computer, a 9872A plotter and video monitors. Continuous position fixes were taken at 500-foot intervals along pre-plotted lines. Preplots of vessel tracks in the area of interest were used by the navigator to direct the vessel along the desired course and to ensure compliance with the survey specifications. At every position fix, ranges and times were logged, and all recording charts were marked simultaneously to permit easy correlation between systems.

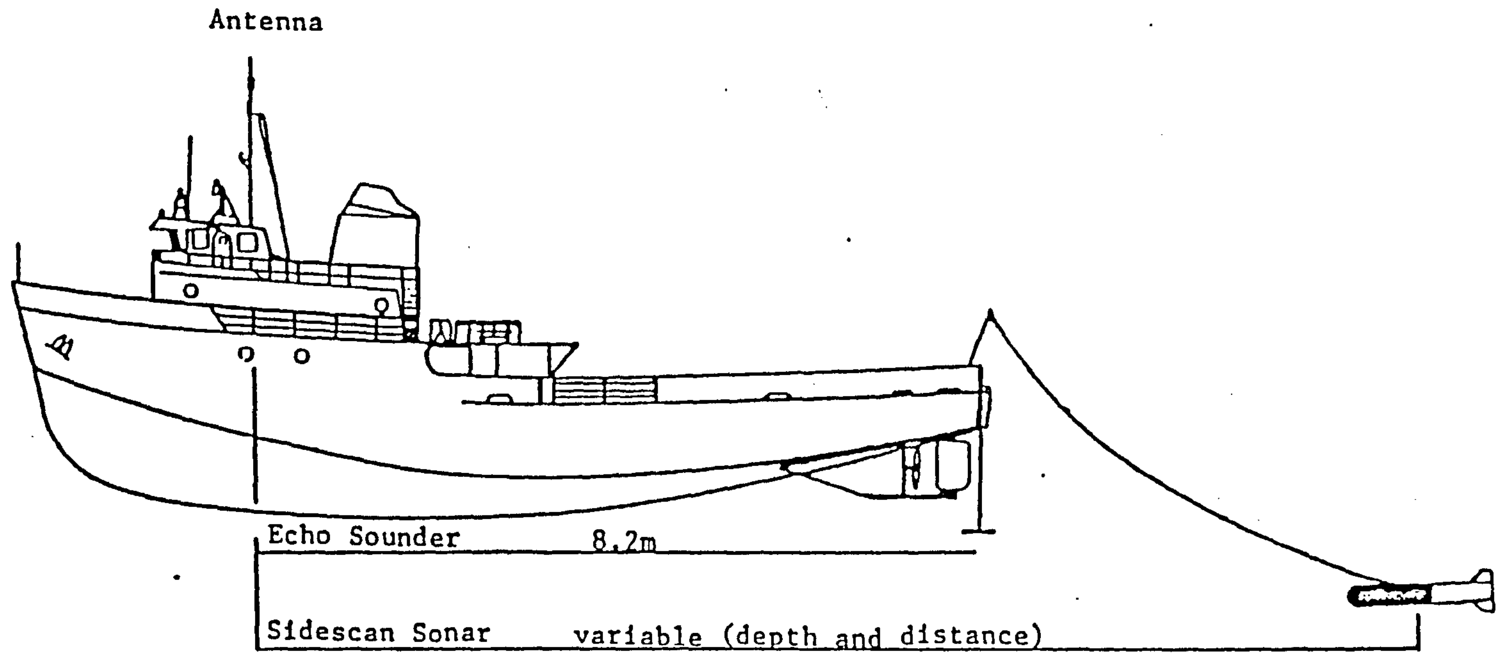

Figure 2. Typical Towing Geometry.

On all later surveys, PHROGNAV, a microcomputer-based Pelagos software system was operated aboard the vessel to provide real-time position solutions and vessel tracking from range information. The software interfaces the Mini-Ranger to an HP 9826 computer, a printer, plotter, and video monitors. Navigation fixes were logged at 60-second intervals along pre-computed survey lines and external event marks were registered and annotated simultaneously on all recordings. Field preplots and postplots were generated using the onboard computer and plotter.

Key features of both processing systems include: vessel track display on the video monitor; continuous least-squares solutions of 3-way fixes; and, a video monitor to aid the helmsman in steering accurate, straight survey lines.

Shore-based transponders for the navigation system were located at previously recovered horizontal and vertical control points; these points were selected to provide favorable shore station geometry. Horizontal angles of 30° to 150° between shore station transponders insures good trilateration solutions of three-range position information.

Transponders were placed at the well-documented U.S. Coast and Geodetic Survey triangulation stations listed below:

	Lambert Zone 6		NAD 1927	
	North	East	Latitude	Longitude
CASA	819,992.5	1,025,206.3	34°22'43.29"	119°28'49.98"
LOON	833,391.7	996,545.9	34°24'46.84"	119°34'36.79"
MART 3	788,126.1	1,087,083.6	34°17'46.59"	119°16'21.15"
SEACLIFF	806,827.4	1,046,973.3	34°20'39.73"	119°24'25.69"
SPRINGVILLE	761,601.0	1,139,998.5	34°13'39.05"	119°05'42.15"
TEAL 2	752,726.2	1,093,737.5	34°11'58.48"	119°14'49.76"

The coordinates (feet) listed above are in Zone 6 of the California Lambert Grid along with the corresponding geographic coordinate values. The spheroid used was Clarke 1866. Offsets from the USC&GS triangulation stations were used for reasons of expediency, security, and logistic support.

Seafloor Imaging

An O.R.E. Multi-scan sonar system was used on the first three surveys to sweep the seafloor within the survey area. This two-channel sidescan system emits horizontal, fan-shaped, 100-kHz beams from each side of the towed sensor (fish). Acoustic echoes returned from targets found within the beam paths from the sea surface to the seafloor are then received by the fish and displayed on an EPC 3200S recorder. This creates a permanent continuous graphic record of a path along the seafloor in which the echoes are placed side by side so that the record resembles an aerial photograph. On the August 1988 survey, an EG&G Model 260 two-channel, 100-kHz sonar system with integrated graphic recorder/display was similarly used.

Both systems were operated at a scale of 150 meters per channel on the survey lines. The depth of the towed fish was maintained at an appropriate height above the bottom in order to insure optimum coverage. An echo sounder was operated to display general bathymetric profiles and as an aid in maintaining the proper altitude of the sidescan sonar tow fish.

DATA PROCESSING

Navigation

A VAX-11/780 VMS mini-computer was used to process navigation data returned from the field. Coordinates of navigation fixes were recomputed from raw range data and were reviewed for inconsistencies and errors. Edited navigation positions were plotted on a 34-inch Zeta 3653 plotter at the desired scale. A postplot (set of three plates) was drawn for each of the survey routes at a scale of 1:4800 or one inch equals 400 feet and was used as a base map for seafloor features interpretation. The coordinates are California Lambert Zone 6 (feet) and geodetic (latitude/longitude) on the Clarke 1866 ellipsoid.

Seafloor Imaging

Conventional sidescan sonar data presentation is subject to inherent geometric distortions. The basic causes of distortion in a standard sidescan record are: presence of the water column; differences between ship speed vs recorder speed; and slant-range distortion.

An ORE Model 158A graphic processor was interfaced into the ORE multiscan sidescan sonar system to enhance the records and correct for distortion. The EG&G Model 260 also has the ability to compensate for geometric distortion. In both systems, the distortion problem is eliminated in the following manner: all data are converted to digital form; a bottom-tracker gates out the water column; ship velocity is used to control recorder paper-feed and stylus speed; and output data are "shifted" to eliminate slant-range error. The result is a record in which X and Y scales are equal. This output can then be combined with records taken from parallel tracks to create mosaics of the seafloor.

RESULTS

Sidescan sonar data collected along the pipeline route between Platform Gina and a point located a few hundred meters off the Mandalay Beach landfall were examined. The data were reviewed for evidence of possible damage to the pipelines, indications of unsupported spans, recognizable changes to general seafloor conditions as mapped by previous surveys, and anomalous sonar targets. The location of the pipeline, where exposed, was found to be in agreement with "as-built" data provided by UNOCAL. Distance along the line was accurately controlled through logging of cable out, water depth and tow fish height. Hence, targets shown (on the accompanying plates) relative to the pipe as seen on the sidescan record are accepted as the true location based on the previous "as-built" data.

The discussion of results and the corresponding set of three seafloor features plates (scale 1:4800) are reproduced from each original Pelagos report. The "as-built" series of plates (scale 1:4800) based on the McClelland Engineers August 1981 survey is also included.

9 January 1984 Survey (Plates 2A, 2B, 2C)

The pipeline is continuously exposed from the platform to a point approximately 9000 feet (2740 m) north where it becomes completely buried. From this location, the pipeline is buried throughout the remainder of the route shoreward. The only exception is a 50-foot (15 m) segment of the pipeline exposed approximately 26,800 feet (8170 m) north of Platform Gina.

From the platform to a point approximately 4000 feet (1220 m) north, a power cable is partially exposed. Over the next 2200 feet (670 m) northward, the power cable and its associated trench are well exposed (Plate 2C). From this point northward to shore the power cable is completely buried.

Near Platform Gina, approximately 250 feet (80 m) west of the pipe, there is an apparent accumulation of scars and debris (Plate 2C). In addition, three unidentified sonar targets are located approximately 7,700 feet (2350 m) north of Platform Gina and 60 feet (18 m) west of the Pipeline (Plate 2C).

A large swath, exhibiting an apparent change in sediment texture, begins about 12,000 feet (3660 m) north of Platform Gina and persists for approximately 3600 feet (1100 m) along the route. This zone suggests a change in acoustic scattering properties which may be caused by only a very subtle sediment facies change, but it is seen on both sides of the pipeline out to the limits of the sonograph. The pipeline is alternately covered and exposed along a 2000-foot-long (610 m) sector in this zone (Plate 2B).

Positioning solutions proved to be well within the accuracy of the Mini-Ranger system. This was done continuously by the least-squares solution method employed by the micro-processor. In addition, known positions of platform structures were calibrated within this navigation net via the transit fix method of the software.

<u>7-8 January 1986 Survey (Plates 3A,3B,3C)</u>

Along the pipeline route north from Platform Gina, the pipe bundle is exposed for a distance of approximately 9000 feet (2740 m). Thence, the pipeline is buried along the remainder of the route toward shore. Two notable exceptions include: a 2000-foot (610 m) length of pipe intermittently or partially exposed between 12,000 (3660 m) and 14,000 (4270 m) feet north of Gina along the route, and a second 50-foot (15 m) length of pipeline exposed 4700 feet (1430 m) from the landfall.

From a point approximately 2000 feet (610 m) north of the platform to nearly 6000 feet (1830 m) north, a power cable is exposed on the seafloor and lies parallel to and on the east side of the pipeline. Further north, along the route, the power cable is only locally exposed to a point about 8000 feet (2440 m) north of Gina. Beyond this point, the cable remains completely buried (Plate 3C).

A zone of numerous small sonar targets was mapped along the pipeline route from 12,000 (3660 m) to approximately 15,000 feet (4570 m) north of Platform Gina. This zone may represent the acoustic return from a hard substrate laying beneath a thin veneer of softer surficial sediments. The area was previously mapped as a "cluster of possible objects" by McClelland Engineers (1981) for the "as-built" survey and by Pelagos Corporation in 1984 as an apparent change in sediment texture. The pipeline is alternately covered and exposed along this 3000-foot (910 m) section of pipeline route (Plate 3B).

11 November 1986 Survey (Plates 4A,4B,4C)

The pipeline bundle occupying the route from Platform Gina to Mandalay Beach is exposed on the seafloor from Platform Gina north for a distance of approximately 9000 feet (2740 m). Shoreward, the pipeline is buried and not seen on the sonographs. One possible exception is an isolated 60-foot (18 m) segment of pipeline partially exposed 13,100 feet (4000 m) north of Gina within a zone of numerous small sonar targets. Previous surveys (McClelland Engineers, 1981; Pelagos Corp., 1984 and 1986) have mapped and reported more extensive pipeline exposure within this zone.

The zone most likely represents hard substrate lying beneath a thickening veneer of softer surficial sediments. Continued slow deposition, cross-shelf sediment transport or settlement of the pipe bundle have contributed to the gradual burial of the pipeline.

Further evidence of this is documented by the complete disappearance of a power cable, mapped just north of Platform Gina and paralleling the pipeline to the east (Pelagos Corp., 1984 and 1986).

1 August 1988 Survey (Plates 5A,5B,5C)

The pipeline bundle occupying the route from Platform Gina to Mandalay Beach is exposed or partially buried beneath the seafloor from Platform Gina north for a distance of approximately 8000 feet (2440 m). Shoreward, the pipeline is completely buried and not seen on the sonographs. Previous surveys (McClelland Engineers, 1981; Pelagos Corp., 1984 and 1986) have mapped and reported more extensive pipeline exposure indicating that the pipeline is being slowly buried by sedimentary action. Continued slow deposition, cross-shelf sediment transport or settlement of the pipe bundle have contributed to this gradual burial of the pipeline. Further evidence of this is documented by the complete disappearance of a power cable, mapped just north of Platform Gina and paralleling the pipeline to the east (Pelagos Corporation 1984 and 1986).

No evidence of damage or impingement by commercial fishing gear was seen on the most recently collected sonar records. Along the exposed segment of pipeline, near Platform Gina, no indication of unsupported spans was observed.

CONCLUSIONS

Based on the interpretation of these four sidescan sonar surveys, there was no evidence of possible damage to the pipeline, unsupported spans, or significant sonar targets along the pipeline route. Since the 1984 survey, there has been a gradual burial of the pipelines and power cable due to slow deposition, cross-shelf sediment transport and settlement of the pipe bundle. In 1984 the pipeline was exposed from Platform Gina for a length of approximately 9000 feet northward with several other partially exposed segments. By 1988, the pipeline was exposed or partially buried for a distance of approximately 8000 feet from Platform Gina and completely buried from this point shoreward. The power cable which was at least partially exposed over the first 6200 feet north of Gina in 1984, was completely buried by 1988.

REFERENCES

McClelland Engineers, August 1981. Pipeline Route, Mandalay To Platform Gina, "As-Built" Survey.

Pelagos Corporation, February 1984. Sidescan Sonar Survey, Submarine Pipeline, Platform Gina to Facilities At Mandalay Beach, Oxnard, California, for UNOCAL.

Pelagos Corporation, February 1986. Sidescan Sonar Survey, Submarine Pipeline, Platform Gina to Facilities At Mandalay Beach, Oxnard, California, for UNOCAL.

Pelagos Corporation, November 1986. Sidescan Sonar Survey, Submarine Pipeline, Platform Gina to Facilities At Mandalay Beach, Oxnard, California, for UNOCAL.

Pelagos Corporation, September 1988. Sidescan Sonar Survey, Submarine Pipeline, Platform Gina to Facilities At Mandalay Beach, Oxnard, California, for UNOCAL.

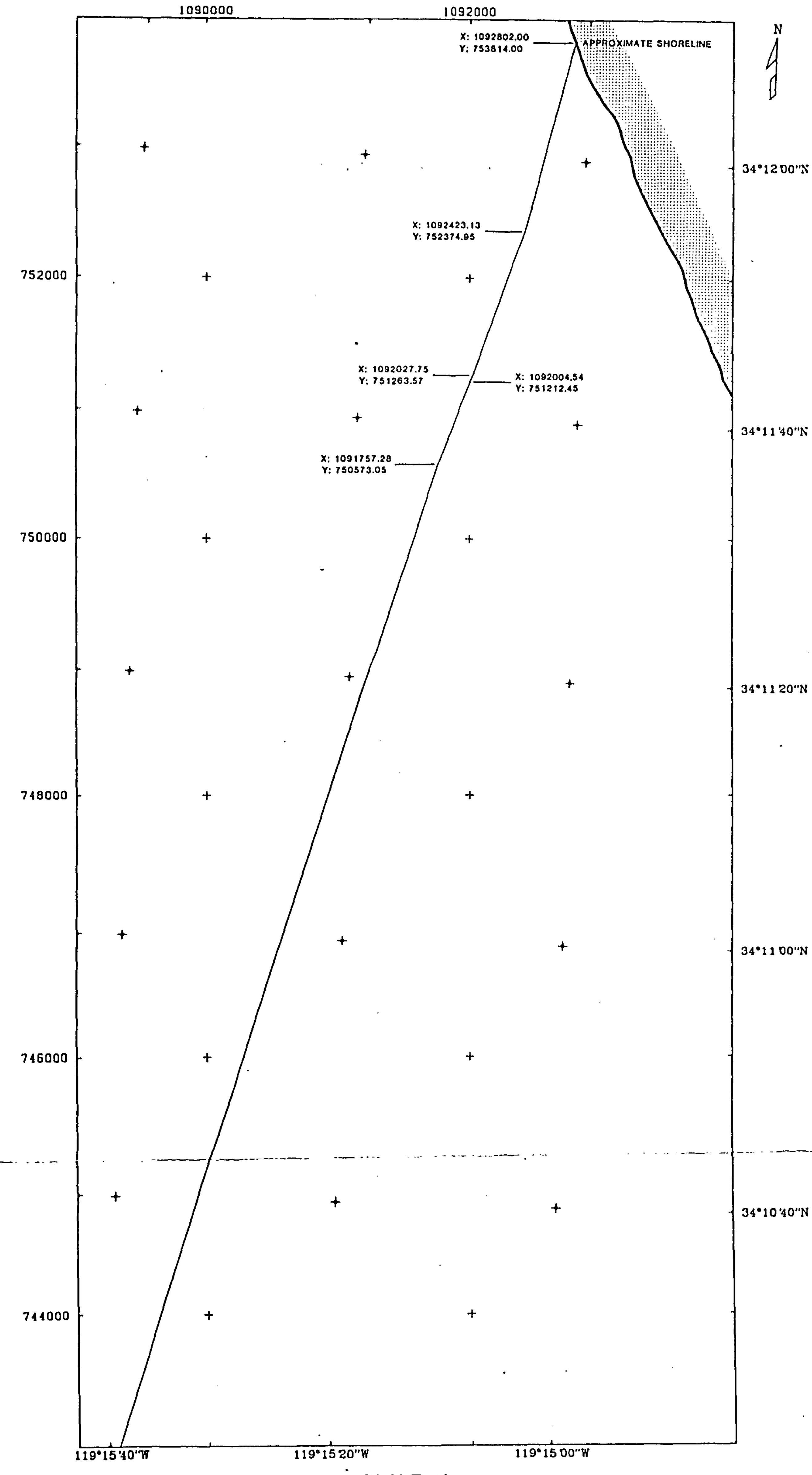

PLATE 1A

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

AS BUILT

PLATE	1A	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1981	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

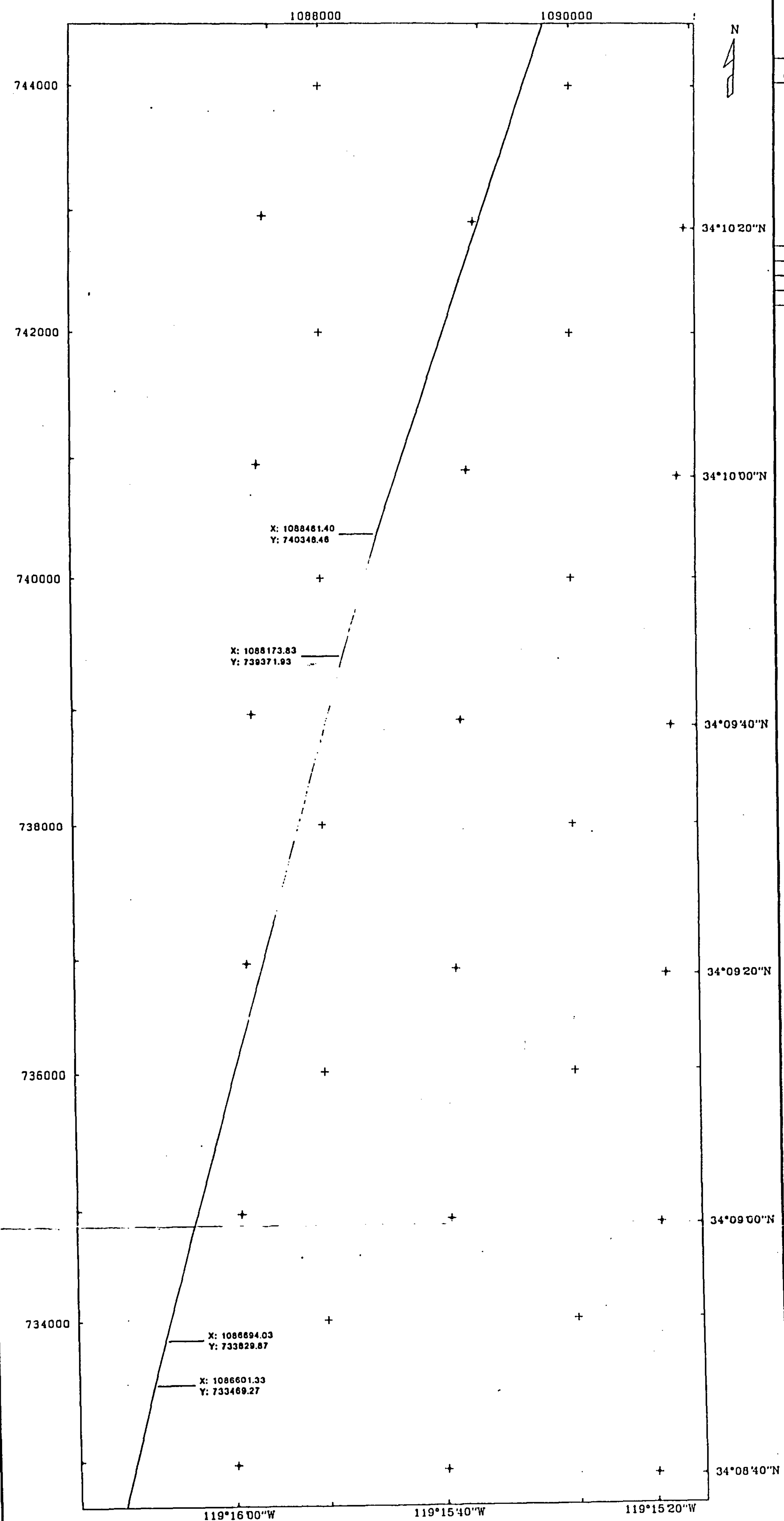

PLATE 1B

PELAGOS CORP.

SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE

MANDALAY TO PLATFORM GINA

AS BUILT

PLATE	1B	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1981	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

NOTE:
IF COPY HAS BEEN REDUCED,
CORRESPONDING SCALE WILL BE LESS
THAN ONE INCH.

35

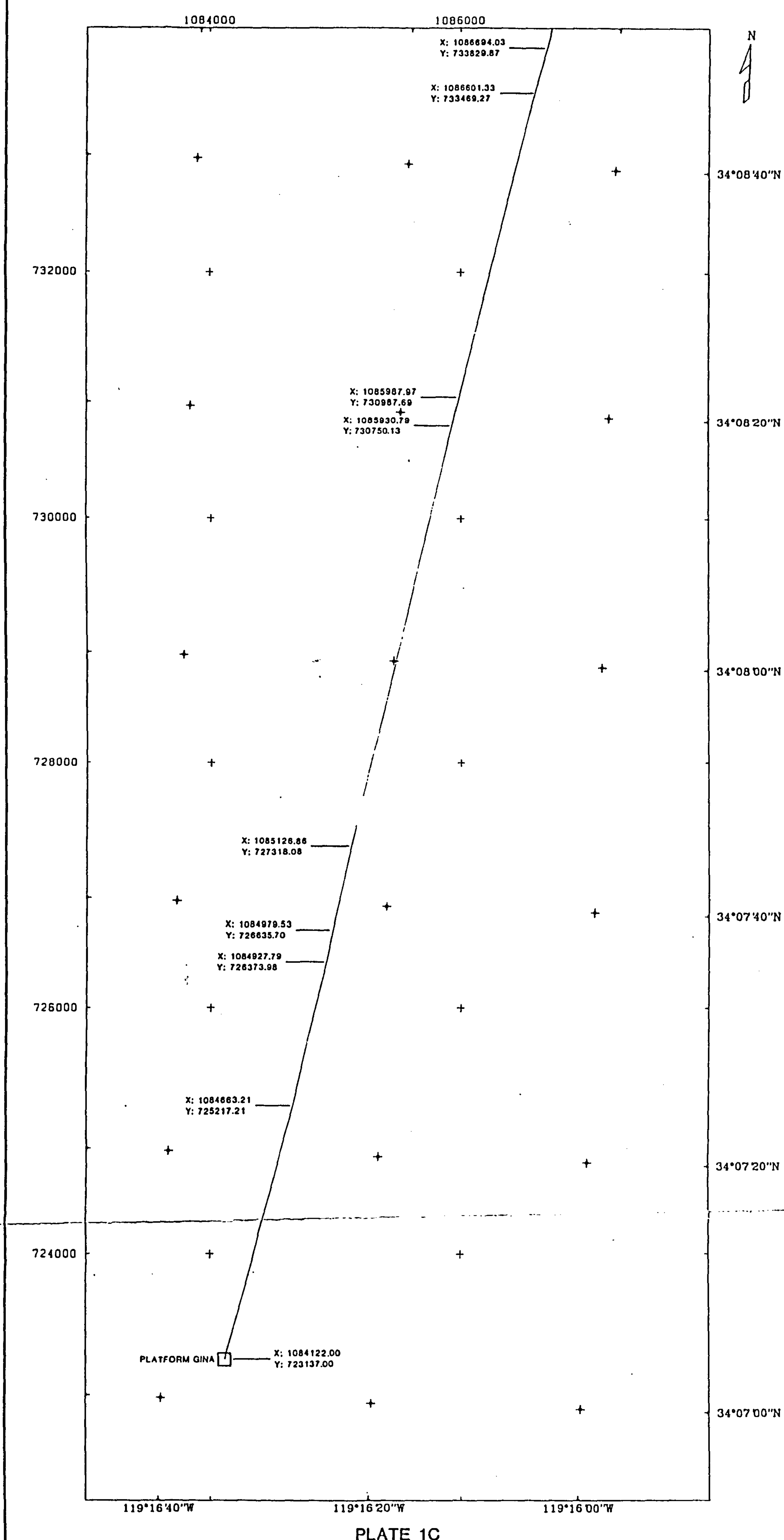

PLATE 1C

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT: UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

AS BUILT

PLATE	1C	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1981	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

NOTE:
IF COPY HAS BEEN REDUCED,
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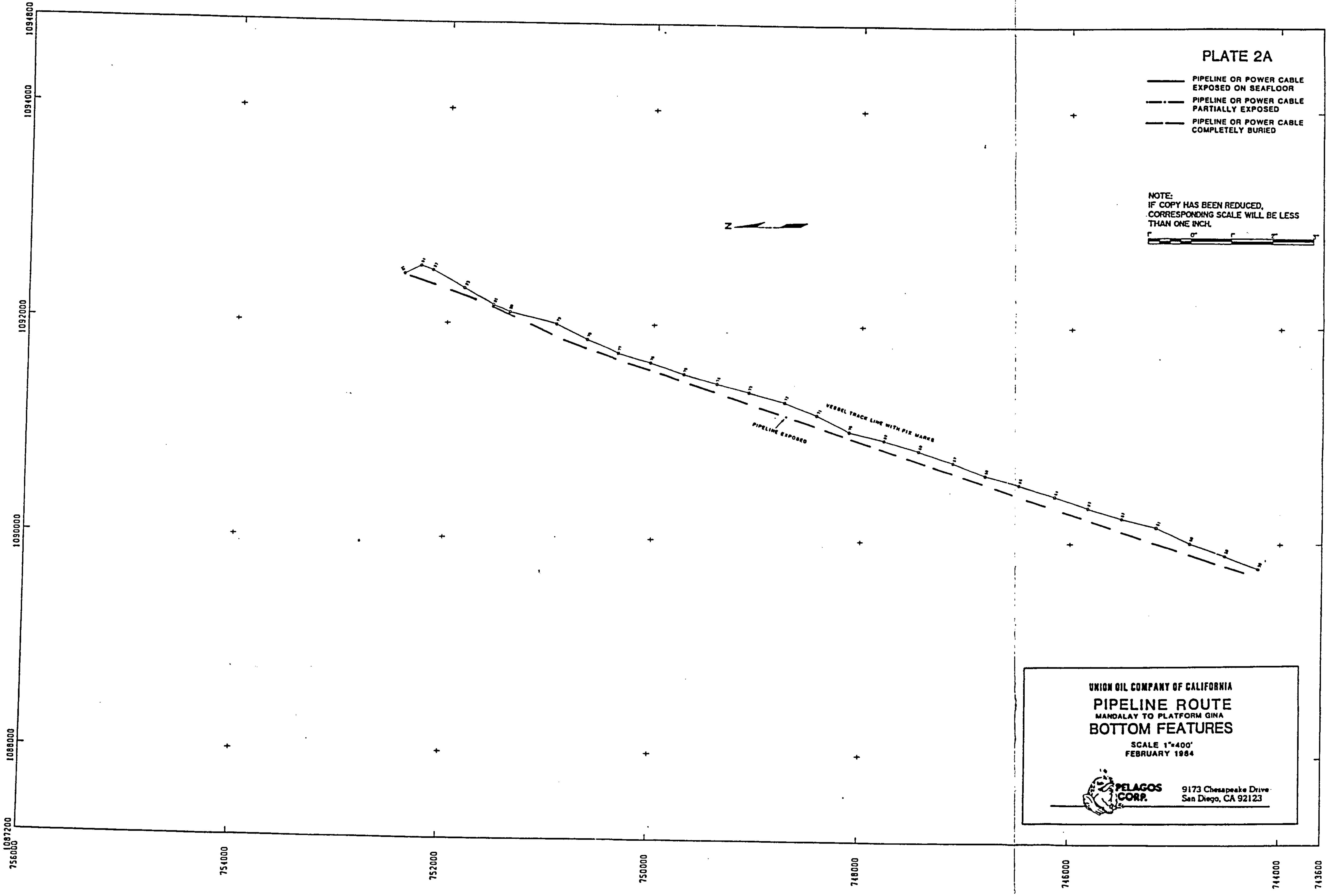
THAN ONE INCH.



MANDALAY TO PLATFORM GINA SCALE 1"=400' LAMBERT ZONE 6 SHEET 2A

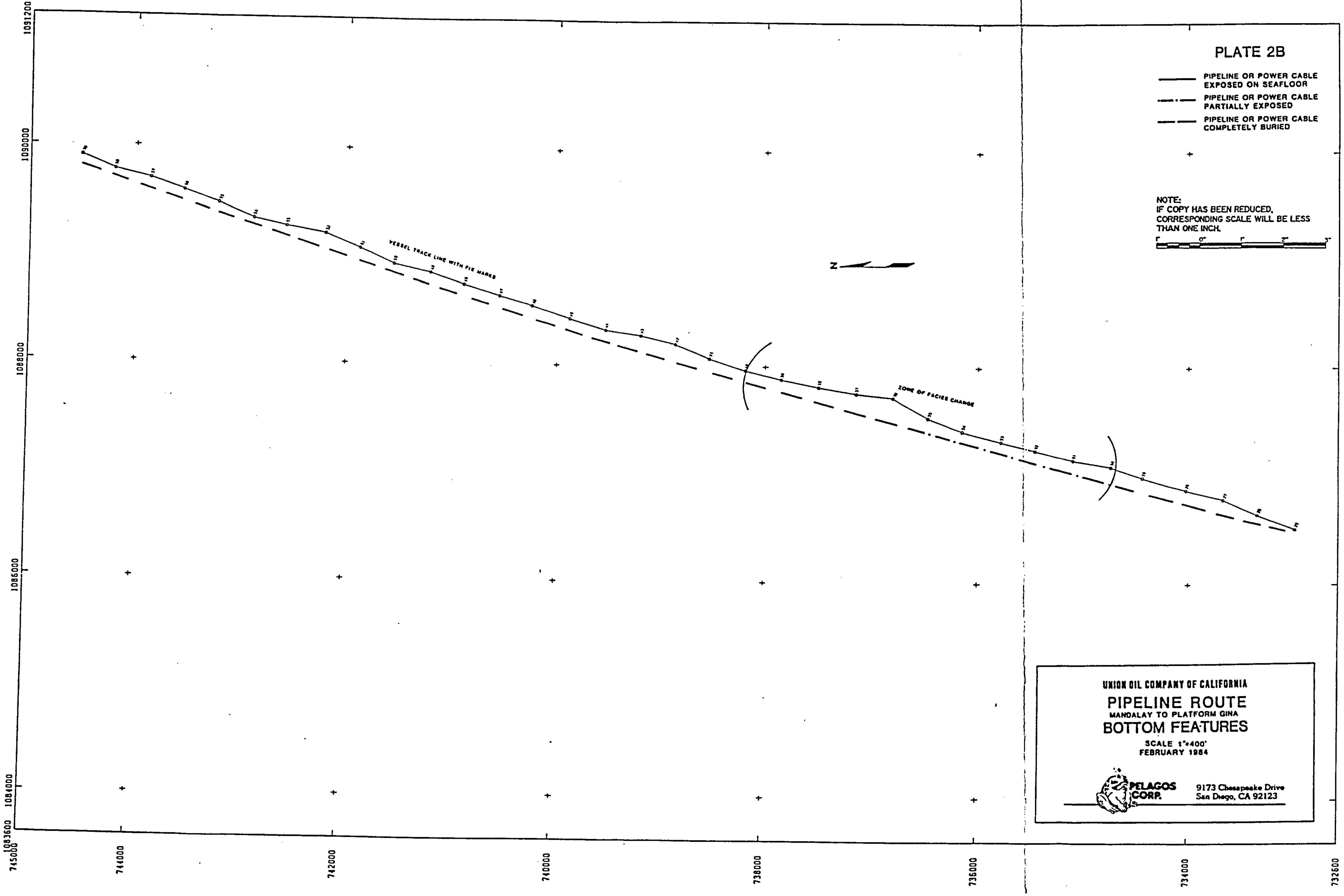
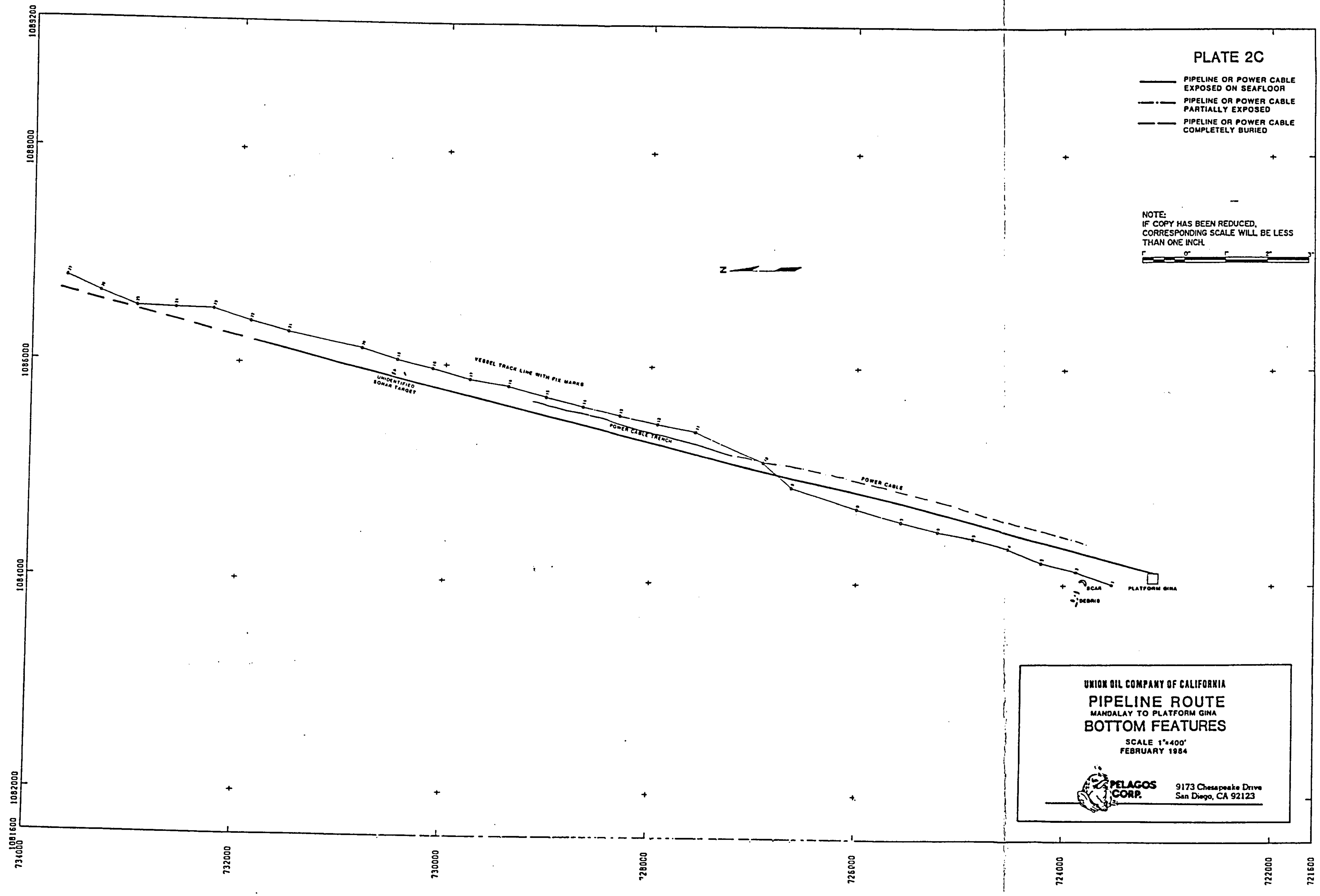


PLATE 2B
PIPELINE OR POWER CABLE EXPOSED ON SEAFLOOR
PIPELINE OR POWER CABLE PARTIALLY EXPOSED
PIPELINE OR POWER CABLE COMPLETELY BURIED
NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.
VESSEL TRACK LINE WITH FIX MARKS
ZONE OF FACIES CHANGE
N
1091200
1090000
1088000
1086000
1084000
1083600
745000
744000
742000
740000
738000
736000
734000
732600
UNION OIL COMPANY OF CALIFORNIA
PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
BOTTOM FEATURES
SCALE 1"=400'
FEBRUARY 1984
PELAGOS CORP.
9173 Chesapeake Drive
San Diego, CA 92123
MANDALAY TO PLATFORM GINA SCALE 1"=400' LAMBERT ZONE 6 SHEET 2B



MANDALAY TO PLATFORM GINA SCALE 1"=400' LAMBERT ZONE 6 SHEET 2C

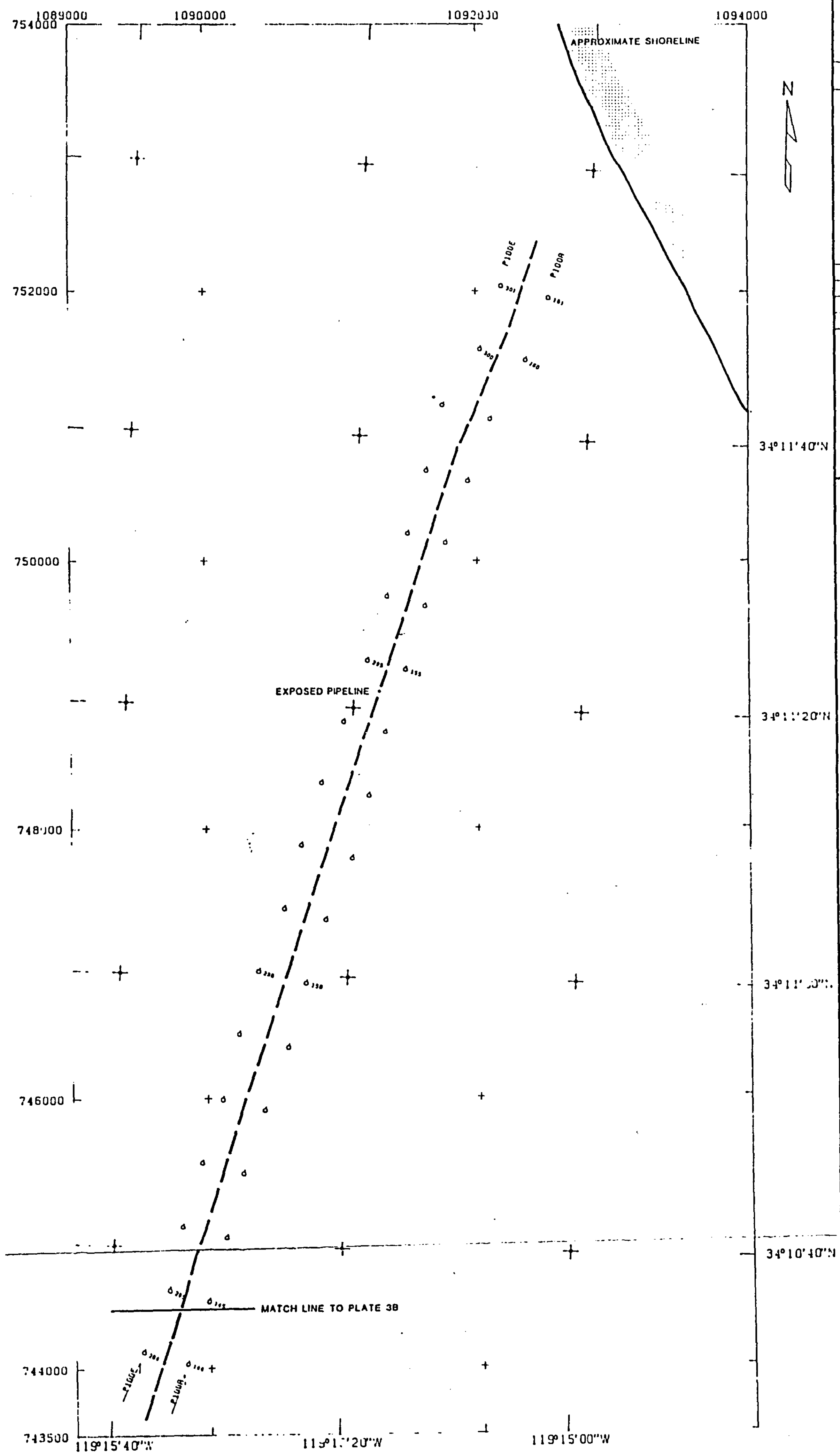


PLATE 3A

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNION OIL OF CALIFORNIA

PIPELINE ROUTE

MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	3A	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JANUARY 1986	DATUM	NAD 1927

0 400 800 1200 1600
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline or Power Cable Partially Exposed

Pipeline or Power Cable Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

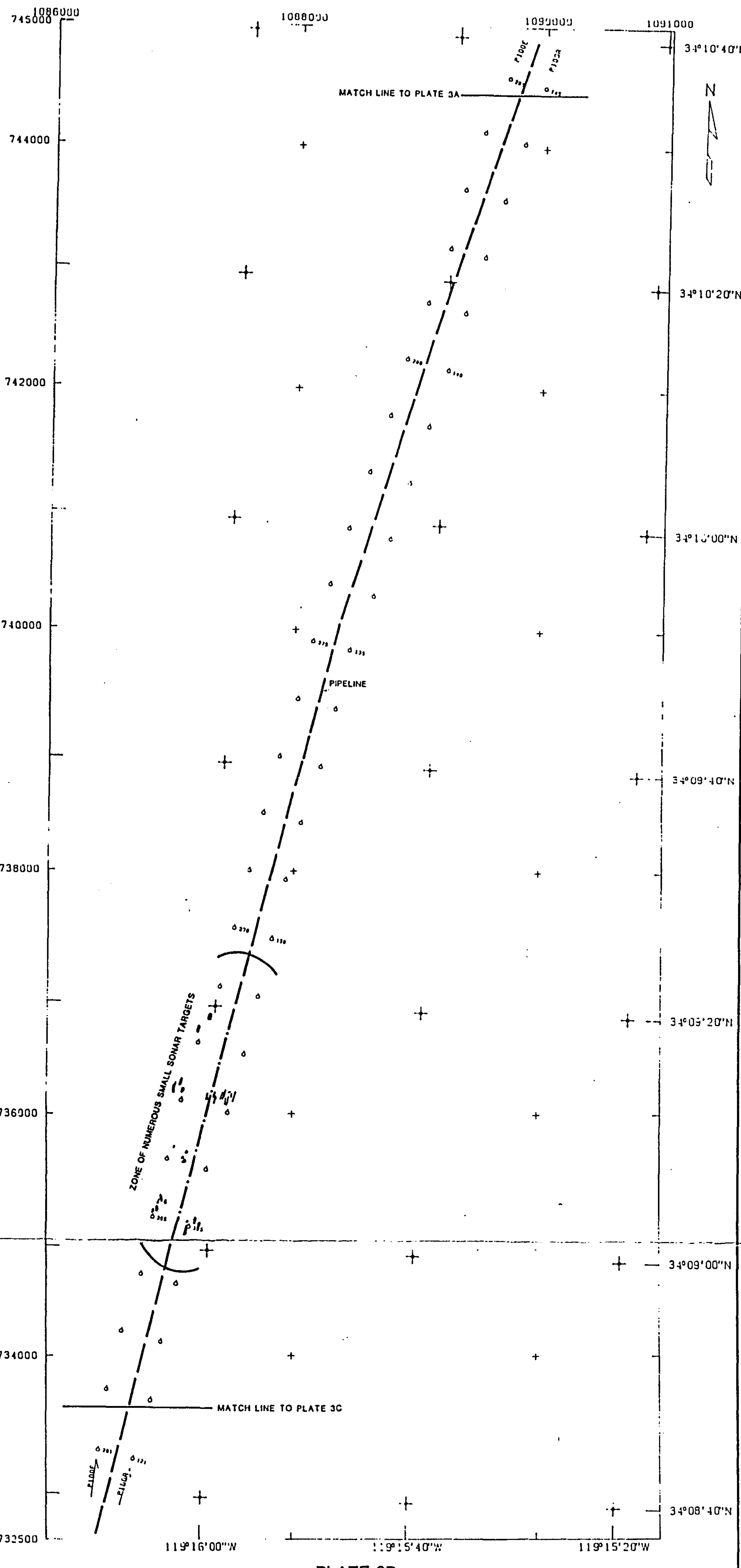


PLATE 3B

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT: UNION OIL OF CALIFORNIA

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
SEAFLOOR FEATURES

PLATE	3B	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JANUARY 1986	DATUM	NAD 1927

0 400 800 1200 1600
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline or Power Cable Partially Exposed

Pipeline or Power Cable Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

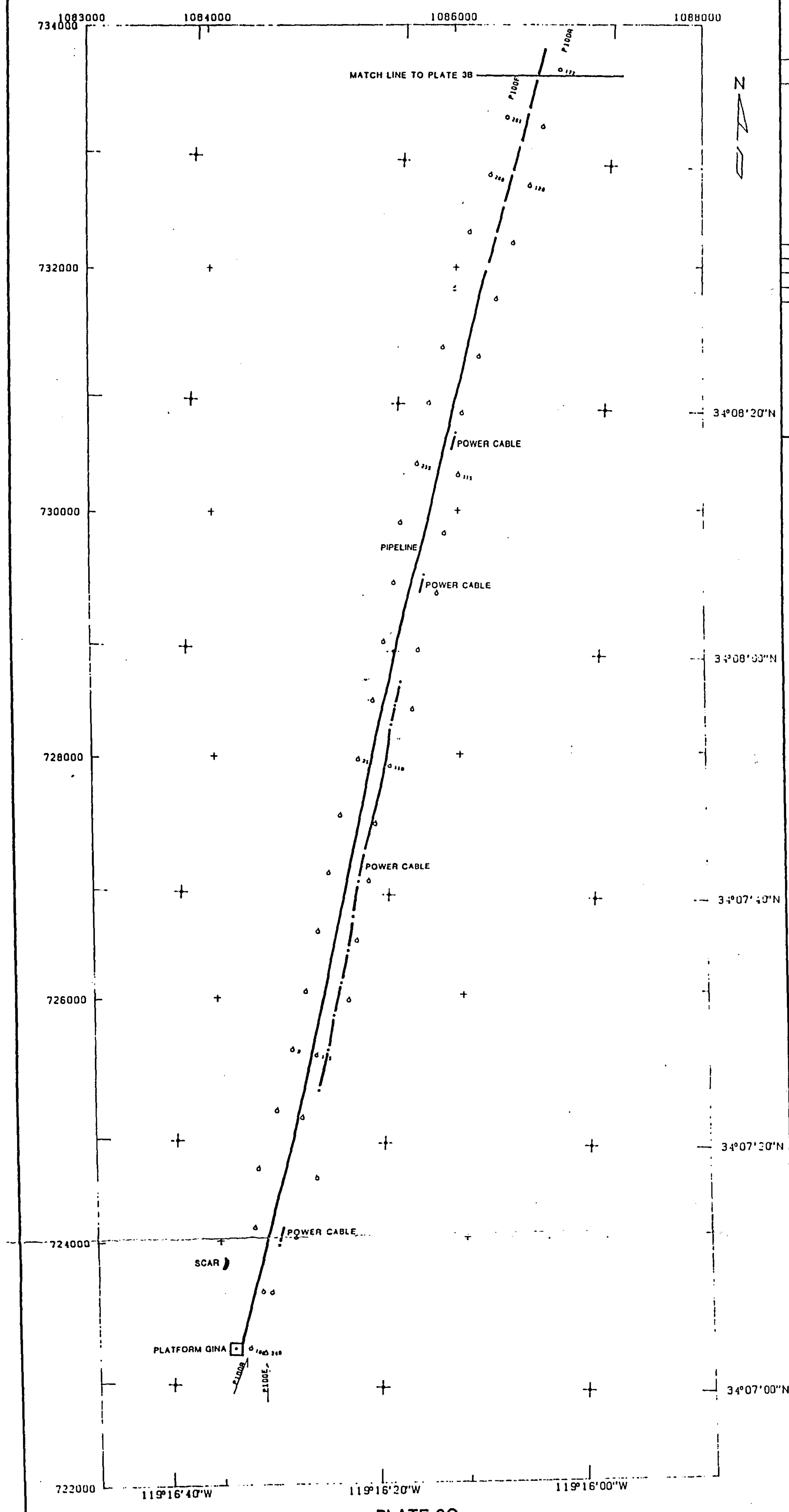


PLATE 3C

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNION OIL OF CALIFORNIA

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	3C	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JANUARY 1986	DATUM	NAD 1927

0 400 800 1200 1600
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline or Power Cable Exposed on the Seafloor

Pipeline or Power Cable Partially Exposed

Pipeline or Power Cable Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

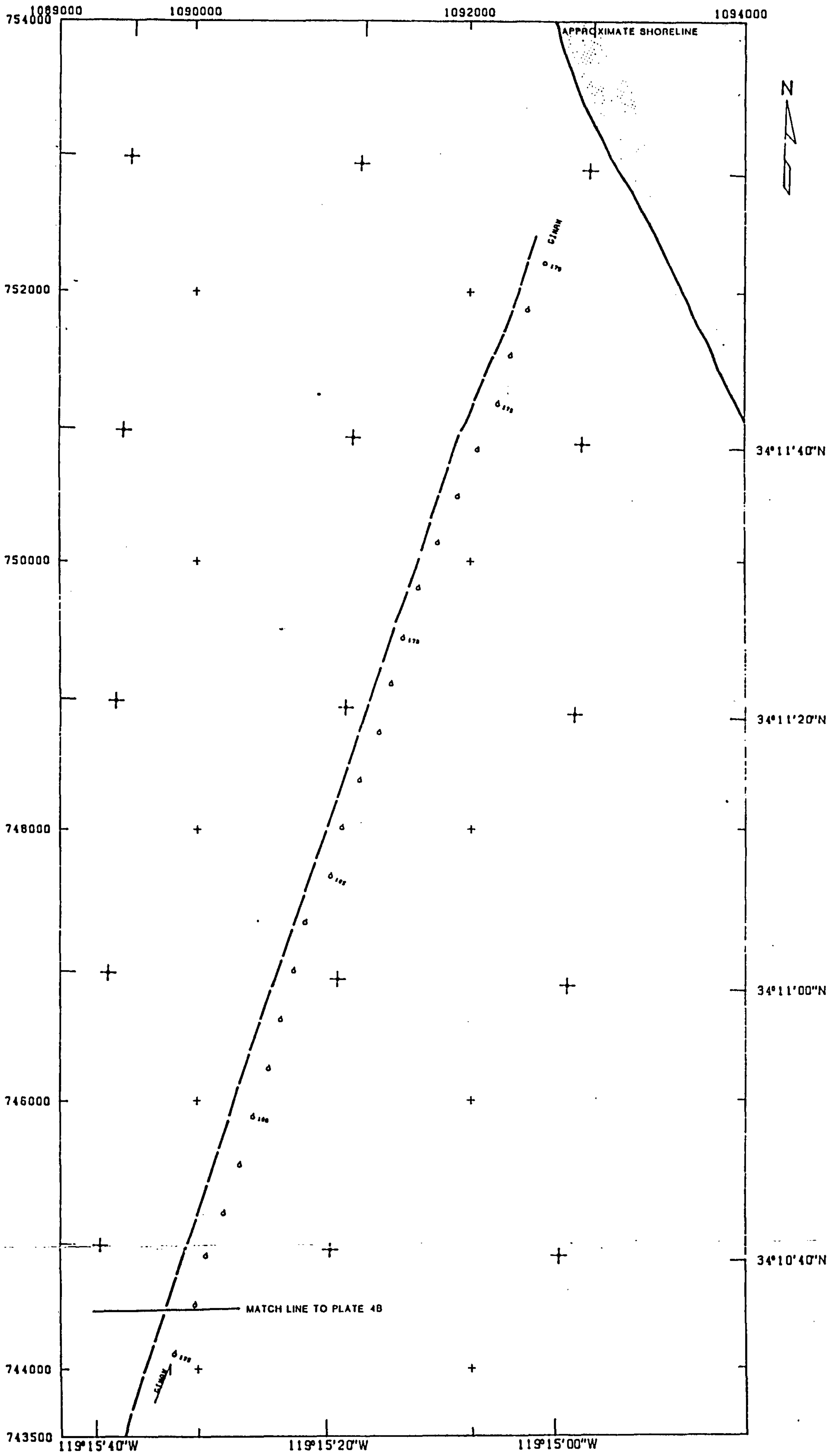


PLATE 4A

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT: UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA
SEAFLOOR FEATURES

PLATE	4A	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	NOVEMBER 1986	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

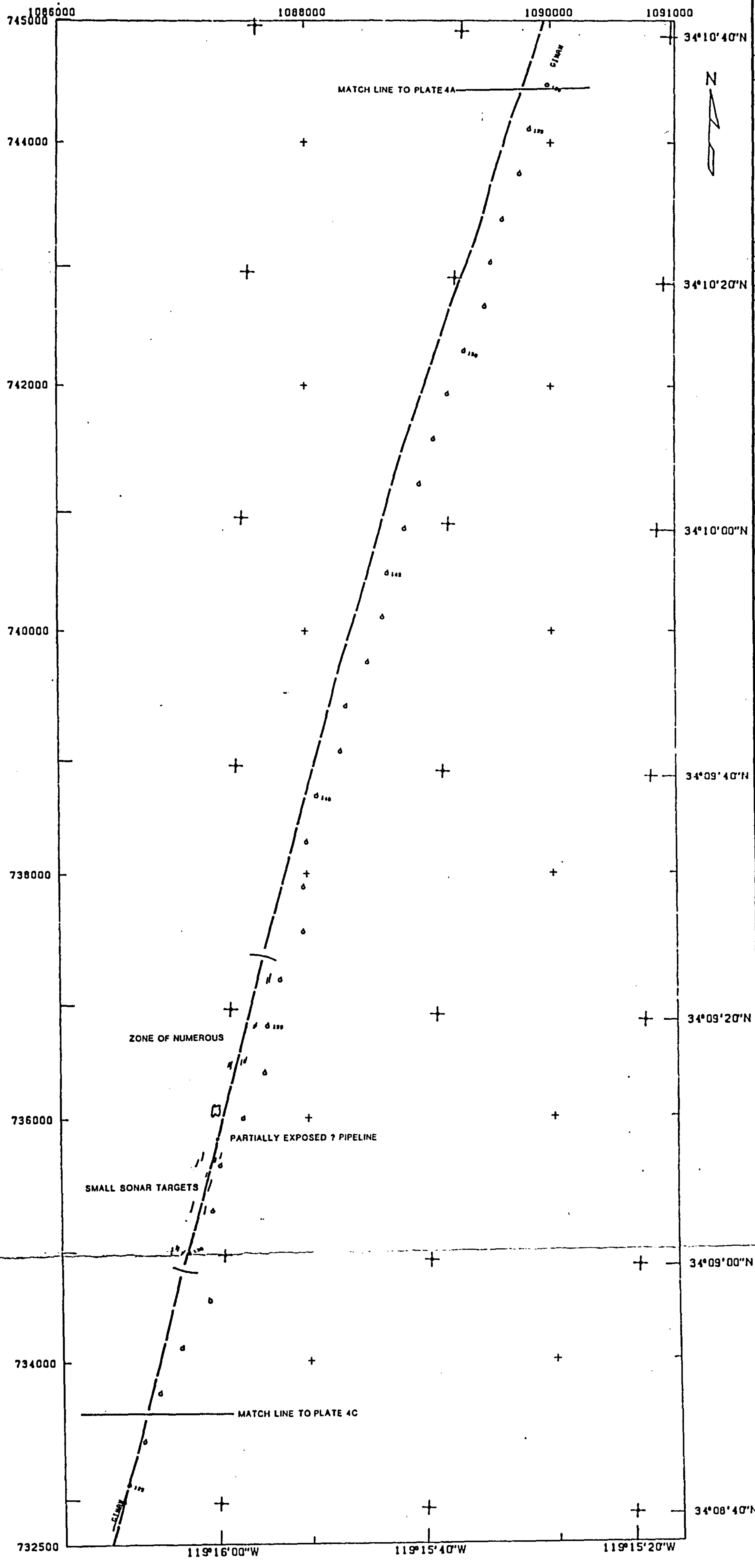


PLATE 4B

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	4B	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	NOVEMBER 1986	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Partially Exposed

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

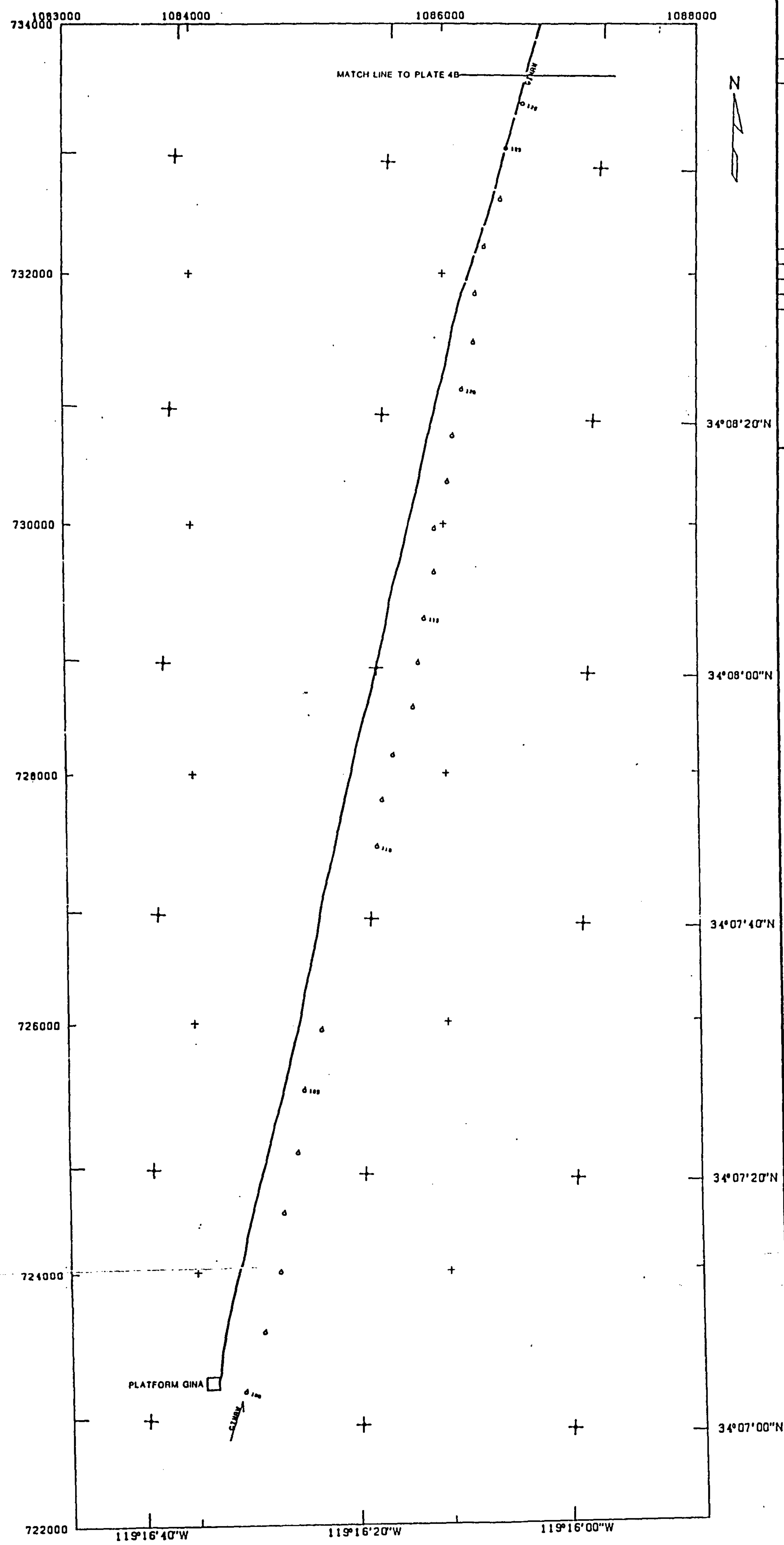


PLATE 4C

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	4C	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	NOVEMBER 1986	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Exposed on the Seafloor

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

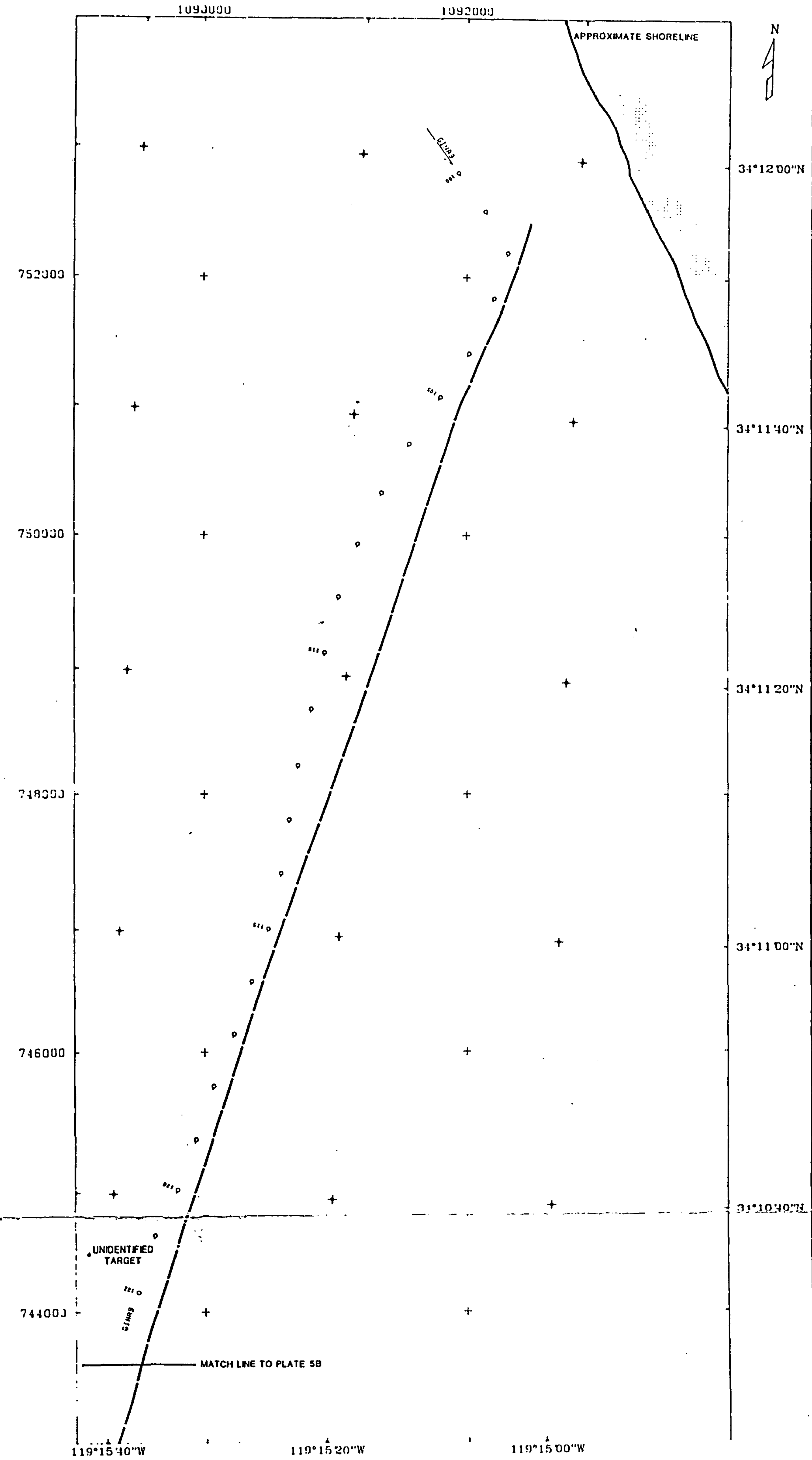


PLATE 5A

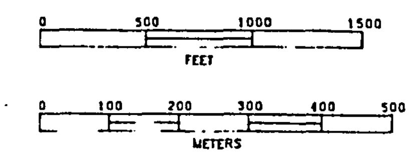
PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	5A	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1988	DATUM	NAD 1927



LEGEND and NOTES

Pipeline Partially Exposed on the Seafloor

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

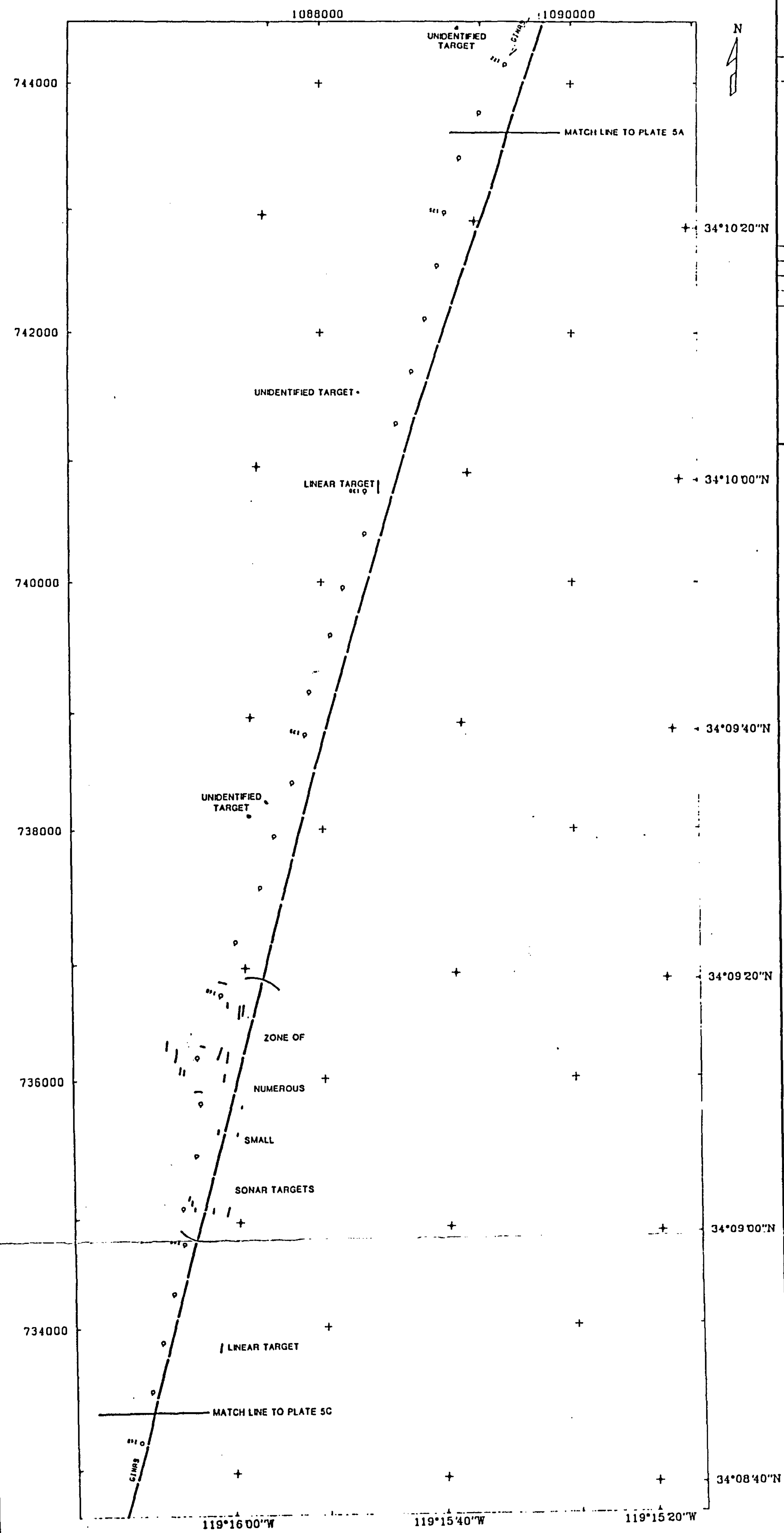


PLATE 5B

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	5B	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1988	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

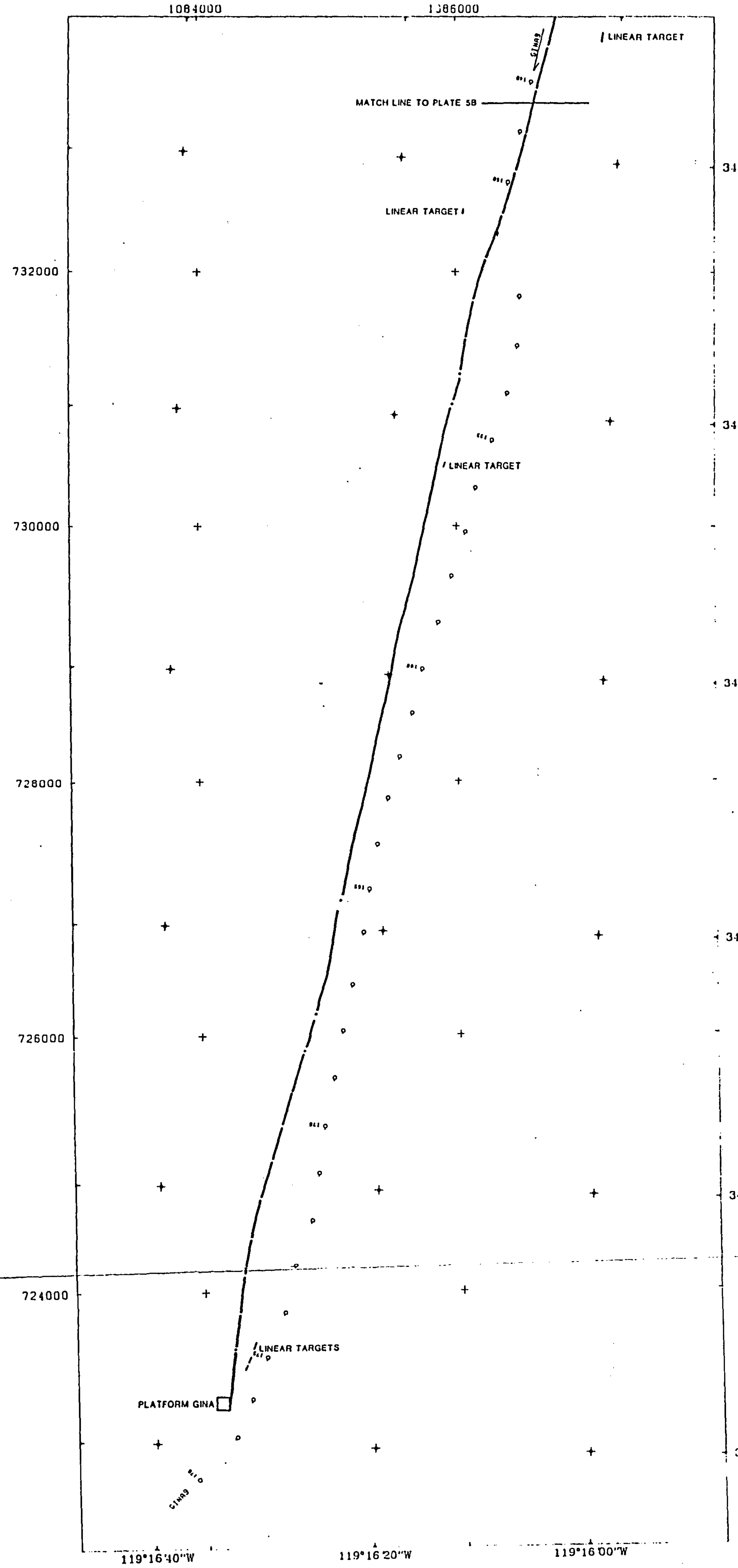


PLATE 5C

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT: UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	5C	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	AUGUST 1988	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Exposed on the Seafloor

Pipeline Partially Exposed

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
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APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Pelagos - Side Scan Sonar Survey (9/89)

PELAGOS CORP.

SIDESCAN SONAR SURVEY-SUBMARINE PIPELINES
PLATFORMS GINA AND GILDA TO MANDALAY BEACH
VENTURA COUNTY, CALIFORNIA

FOR
UNOCAL
PT. HUENEME, CALIFORNIA

BY
PELAGOS CORPORATION
SAN DIEGO, CALIFORNIA
SEPTEMBER 1989

PELAGOS CORPORATION 9173 Chesapeake Drive San Diego, California 92123
Telephone: (619) 292-8922 Telex: 295 468 PLGS UR FAX: 619 292 5308

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INTRODUCTION

Pelagos Corporation performed an annual pipeline inspection along two submarine pipeline routes for UNOCAL during 21-22 July 1989. A pipeline bundle (one 10-inch pipe and one 6-inch pipe) and a power cable occupies the route originating at Platform GINA and terminates at a landfall near Mandalay Beach in Ventura County, California. A second pipeline bundle (a 12-inch pipe, a 10-inch pipe and a 6-inch pipe) and a power cable trace a route east from Platform GILDA to the same Mandalay Beach terminus (Figure 1).

This report describes the instruments and methods employed during the survey operations, defines seafloor conditions along the pipeline routes and discusses significant changes in these conditions from previous surveys.

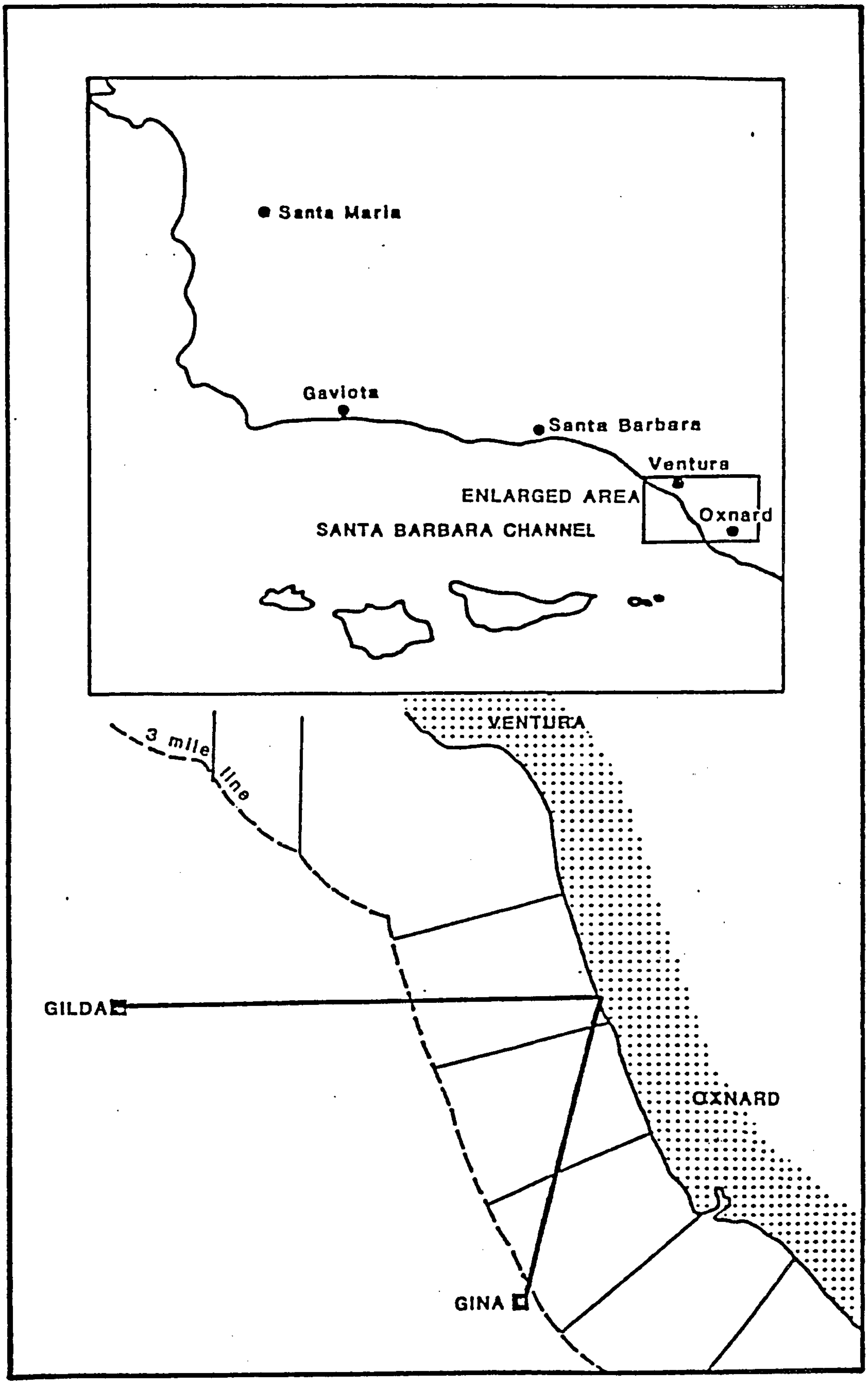


Figure 1. Location Map.

DATA ACQUISITION

A brief description of instruments utilized for this survey is presented below and summarized in Table 1. The survey systems used to collect the necessary data for the pipeline inspection were operated simultaneously over predetermined survey lines. Figure 2 illustrates the towing geometry of the various instrument sensors relative to the survey vessel. Vessel speed was approximately 4.0 knots throughout the survey. Pelagos Corporation was responsible for data acquisition, navigation, data reduction, and interpretation during the project. A list of all personnel and their responsibilities is presented in Table 2. The Daily Survey Log is included in the Appendix.

Vessel

The navigation and survey equipment were installed aboard the R/V WESTWIND, a 50-foot research vessel rigged for light oceanographic and geophysical surveying.

Navigation and Positioning

A Motorola Mini-Ranger III Position system was used to insure highly accurate and repeatable positioning during the survey. This is a microwave, pulse positioning system which utilizes a mobile interrogator and two or more base station transponders located at survey control points on shore. Once per second, the distance in meters to each transponder is displayed onboard the vessel where the system automatically records the ranges at selected locations or time intervals. The Mini-Ranger is an accurate line-of-sight system which is not subject to ionospheric disturbances and has a range-measurement accuracy of better than two meters.

PHROGNAV, a microcomputer-based software system was operated aboard the vessel to provide real-time position solutions and vessel tracking from range information. The software interfaces the Mini-Ranger to an HP 9826 computer,

Table 1

Equipment List

A. Navigation

Motorola Mini-Ranger III System including:

Range Console
Multi-user option
4 Reference station transponders
1 Receivers/Transmitters

Microprocessor Survey Package including:

HP9826 microcomputer
HP Thinkjet printer
HP7475A plotter
HP59306A relay actuator
HP color video monitor
Pelagos Corporation PHROGNAV Software

B. Survey Systems

EG&G Sidescan Sonar System including:

M260 transceiver
M272 towfish
M116A electric winch w/3000-foot cable and sliprings
HP3968A analog magnetic tape recorder

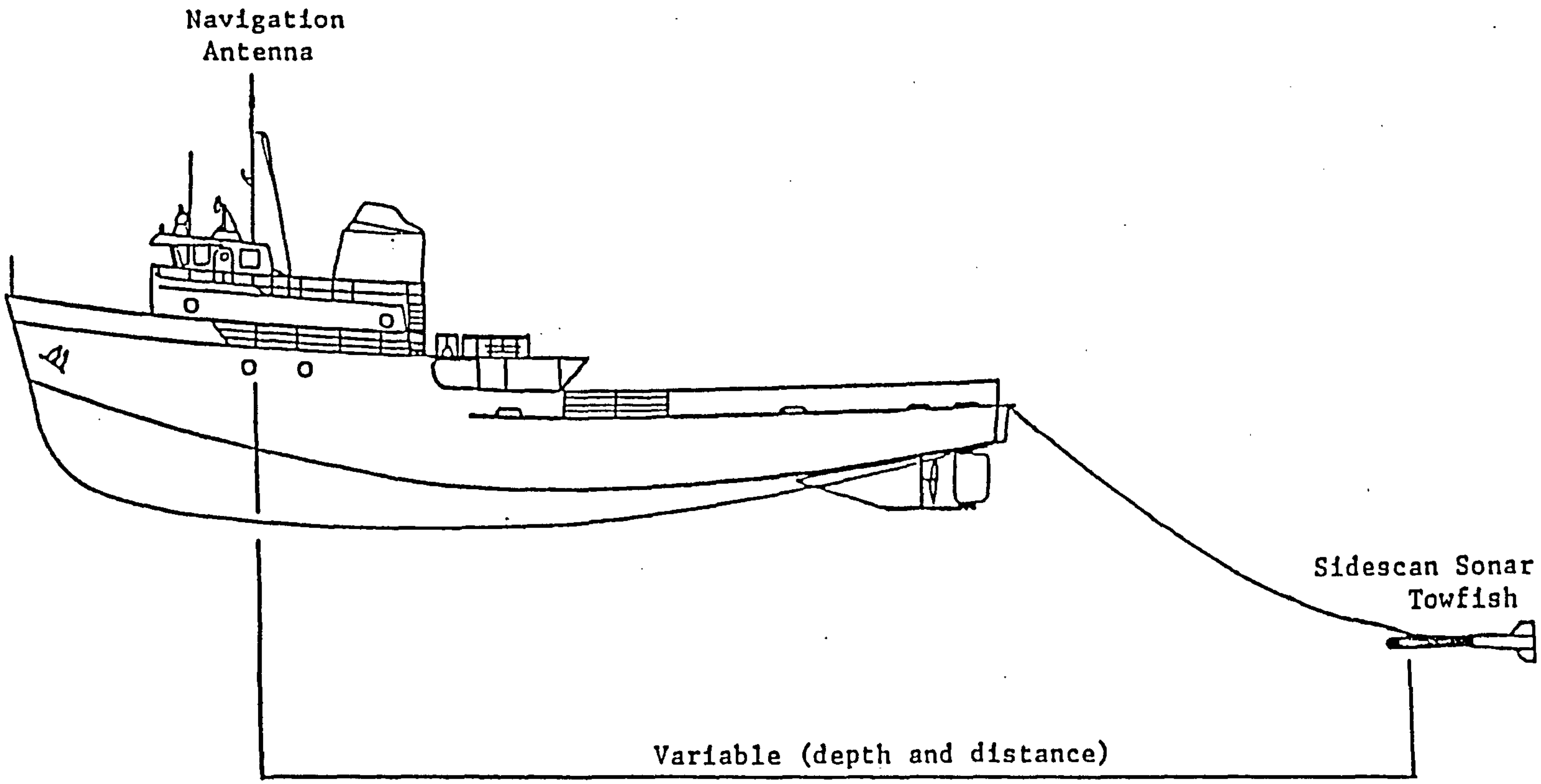


Figure 2. Typical towing geometry.

Table 2

Personnel Listing

FIELD OPERATIONS		
Shore		
Logistic Support	J. Lorenz	Pelagos Corp.
Vessel		
Party Chief/Navigator	W. Speidel	Pelagos Corp.
Sonar Operator	B. Eastman	Pelagos Corp.
OFFICE ANALYSIS		
Interpretation	R. Ashley	Pelagos Corp.
	E. King	Pelagos Corp.
	R. Hanson	Pelagos Corp.
Report	W. Speidel	Pelagos Corp.
	R. Ashley	Pelagos Corp.
	E. King	Pelagos Corp.
Drafting	K.P. Day	Pelagos Corp.

a printer, plotter, and video monitors. Key features include: a vessel track display on the video monitor; continuous least-squares solutions of multiple-range fixes; and, a video monitor to aid the helmsman in steering accurate, straight survey lines.

Shore-based transponders for the navigational system were located at previously recovered horizontal and vertical control points; these points were selected to provide favorable shore station geometry. Horizontal angles of 30° to 150° between shore station transponders insures good trilateration solutions of three-range position information.

Transponders were placed at the well-documented U.S. Coast and Geodetic triangulation stations listed below:

PLATFORM GINA TO MANDALAY BEACH PIPELINE ROUTE

	UTM ZONE 11		NAD 1927	
	NORTH	EAST	LATITUDE	LONGITUDE
SEACLIFF	3,802,763.7	278,575.6	34°20'39.54"	119°24'25.79"
SPRINGVILLE	3,789,172.5	307,024.4	34°13'39.05"	119°05'42.15"
HUENEME LIGHT	3,780,260.6	296,323.2	34°08'42.57"	119°12'32.58"

The coordinates listed above are in Zone 11 of the Universal Transverse Mercator Grid (meters) along with the corresponding geographic coordinate values. The spheroid used was Clarke 1866. Offsets from the USC&GS triangulation stations were used for reasons of expediency, security, and logistic support.

Navigation fixes were logged at 100-meter intervals along pre-computed survey lines and external event marks were registered and annotated simultaneously on all recordings. Field preplots and postplots were generated using the onboard computer and plotter.

Seafloor Imaging

An EG&G Model 260 sonar system was used to sweep the seafloor within the survey area. This two-channel sidescan system emits horizontal, fan-shaped, 100-kHz beams from each side of the towed sensor (fish). Acoustic echoes returned from targets found within the beam paths from the sea surface to the seafloor are then received by the fish and displayed on the systems graphic recorder. This creates a permanent continuous graphic record of a path along the seafloor in which the echoes are placed side by side so that the record resembles an aerial photograph.

The system was operated at scales of 100 and 150 meters per channel on the survey lines. The depth of the towed fish was maintained at an appropriate height above the bottom in order to insure optimum coverage.

DATA PROCESSING

Navigation

A VAX-11/780 VMS mini-computer was used to process navigation data returned from the field. Coordinates of navigation fixes were recomputed from raw range data and were reviewed for inconsistencies and errors. Edited navigation positions were plotted on 34-inch Zeta 3653 plotter at the desired scale. A postplot was drawn for each of the pipeline routes at a scale of 1:48,000 (one inch equals 400 feet) (Plate(s) 1 in jacket).

Sonar Imagery

An EG&G Model 260 was used to acquire the seafloor sonographs because of its ability to correct geometric distortions inherent in a conventional sidescan sonar presentation. The basic causes of distortion in a standard sidescan record are: presence of the water column; differences between ship speed and recorder speed; and, slant-range distortion. The Model 260 eliminates these problems in the following manner: all data are converted to digital form; a bottom-tracker gates out the water column; ship velocity is used to control recorder paper-feed and stylus speed; and output data are "shifted" to eliminate slant-range error. The result is a record in which X equals Y; this output can then be used with records taken from parallel tracks to create mosaics of the seafloor.

RESULTS

Positioning

The location of the pipelines, where exposed, was found to be in excellent agreement with "as-built" data provided by UNOCAL. When operating without a positioning system on the towfish, the towfish position is assumed to be directly behind the vessel. In the deeper water areas of the survey, transverse currents may cause lateral displacement of the towfish from the vessel trackline. Distance along the lines is accurately controlled through logging of cable out, water depth and fish height. Hence, targets shown on the accompanying plot were located relative to the pipes as seen on the sidescan record.

Sonar Sweeping

Sidescan sonar data collected along the pipeline routes between Platforms GINA and GILDA and the Mandalay Beach landfall were examined. The data were reviewed for evidence of possible damage to the pipelines, indications of unsupported spans and recognizable changes to adjacent seafloor conditions as mapped on previous surveys.

Platform GINA to Mandalay Beach

Sonar targets detected along the pipeline route between Platform GINA and the closest safe vessel approach off the Mandalay Beach landfall were plotted (Plates 2-4).

The pipeline bundle is exposed or partially buried beneath the seafloor from GINA north for a distance of approximately 8200 feet (2500 meters). Shoreward from this point, the pipeline is completely buried and no trace is seen on the sonographs, with the exception of an isolated 40-foot segment of the pipeline partially exposed 9480 feet (2890 meters) from the landfall terminus. Previous surveys (McClelland Engineers, 1981; Pelagos Corporation 1984 and 1986) have mapped and reported more extensive pipeline exposure indicating that the pipeline is being slowly buried by sedimentary action.

The 1988 Pelagos Corporation survey mapped approximately the same amount of pipeline exposure as seen in this current survey. However, slow sediment deposition, cross-shelf sediment transport or settlement of the pipe bundle is likely to continue contributing to this gradual burial of the pipeline. Further evidence of this is documented by the complete disappearance of a power cable, mapped just north of Platform GINA and paralleling the pipeline to the east (Pelagos Corporation 1984 and 1986).

A zone of numerous small targets was mapped 10200 feet (3110 meters) north of Platform GINA. The sonar targets are generally less than 16 feet (5 meters) in length and do not appear to have any impact on the pipeline.

No evidence of damage or impingement by commercial fishing gear was seen on the most recently collected sonar records. Along the exposed segment of pipeline, near Platform GINA, no indication of unsupported spans was observed.

Platfrom GILDA to Mandalay Beach

The pipeline route was surveyed from Platform GILDA eastward toward its Mandalay Beach landfall and anomalous features were mapped (Plate 2-6) along the route.

The pipeline bundle is fully exposed from GILDA east for approximately 21120 feet (6439 meters). Along the next 7400 feet (2256 meters) east, the pipeline is only partially exposed. At a distance of approximately 28500 feet (8689 meters) east of Platform GILDA, the pipeline is completely buried. From this location, the pipeline is buried throughout the remainder of the route shoreward; the only exceptions being isolated short lengths of pipeline exposed in the shallow water-portions of the route (Plates 2 and 3).

Drag scars previously mapped and reported (McClelland, 1981 and Pelagos Corp., 1984) were not seen on these data. The unidentified and linear targets mapped from the previous survey (Pelagos, 1988) were not observed. However, several other unidentified targets were observed during the latest survey. These targets were mapped adjacent to the pipeline, but do not appear to have any impact on the pipeline. Directly south of GILDA ground tackle for a mooring buoy was observed on the sonar record. A depression previously mapped (Pelagos Corp., 1986 and 1988) just south of GILDA was not seen on the current sonar data.

Beginning 2200 feet (671 meters) east of the platform, a power cable can be observed (Plate 6). The cable lies parallel to the pipeline and is well exposed until a point about 4600 feet (1402 meters) east of Platform GILDA. Beyond this point, the cable is completely buried, except for a 700-foot segment that is partially exposed 7600 feet (2317 meters) east of GILDA (Plate 5).

North of the pipeline route near its landfall terminus, two marker buoys were plotted from the sonar data. The well location observed on the previous surveys (Pelagos Corporation, 1986 and 1988) was not observed on the current survey because it was out of range of the sidescan sonar on this pass.

An old reported drag scar (Pelagos Corporation, 1986) near Platform GILDA that appears to impinge on the pipeline, was not recognized in this most recent data set, suggesting burial by shelf sedimentation processes.

No unsupported spans were observed along any of the exposed pipeline segments. Nor was there evidence of damage or impingement by commercial fishing gear seen in the most recent collected sonar records.

PELAGOS CORP.

Client UNOCAL

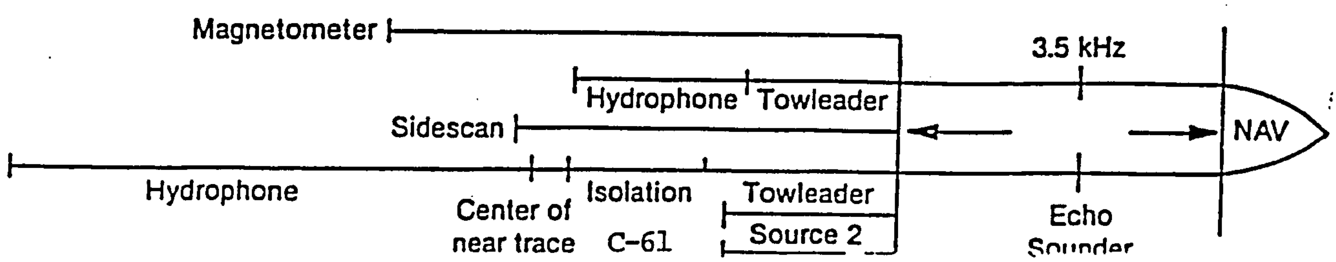
Vessel R/V WESTWIND

Daily Survey Log

Date 21 July 1989

Time	Log Entry
	Captain Larry Nufer Pelagos: Ben Eastman
	Boat length: 16m William Speidel
	Ant-Stern: 8m
1600	Under-way to survey site
1630	Deploy gear
1700	BOL GINA E N, FSP 100
1819	EOL GINA E N, LSP 192
1821	Retrieve gear
1823	Under-way to dock
1900	Arrive at dock (Channel Islands)
	22 July 1989
0600	Under-way to survey site
0720	Arrive at site, deploy gear
0744	BOL GILDA S, FSP 100 E
0953	EOL GILDA S E, LSP 254 E
0958	Retrieve gear
1000	Under-way to dock
1030	Arrive at dock (Channel Islands)

10/81



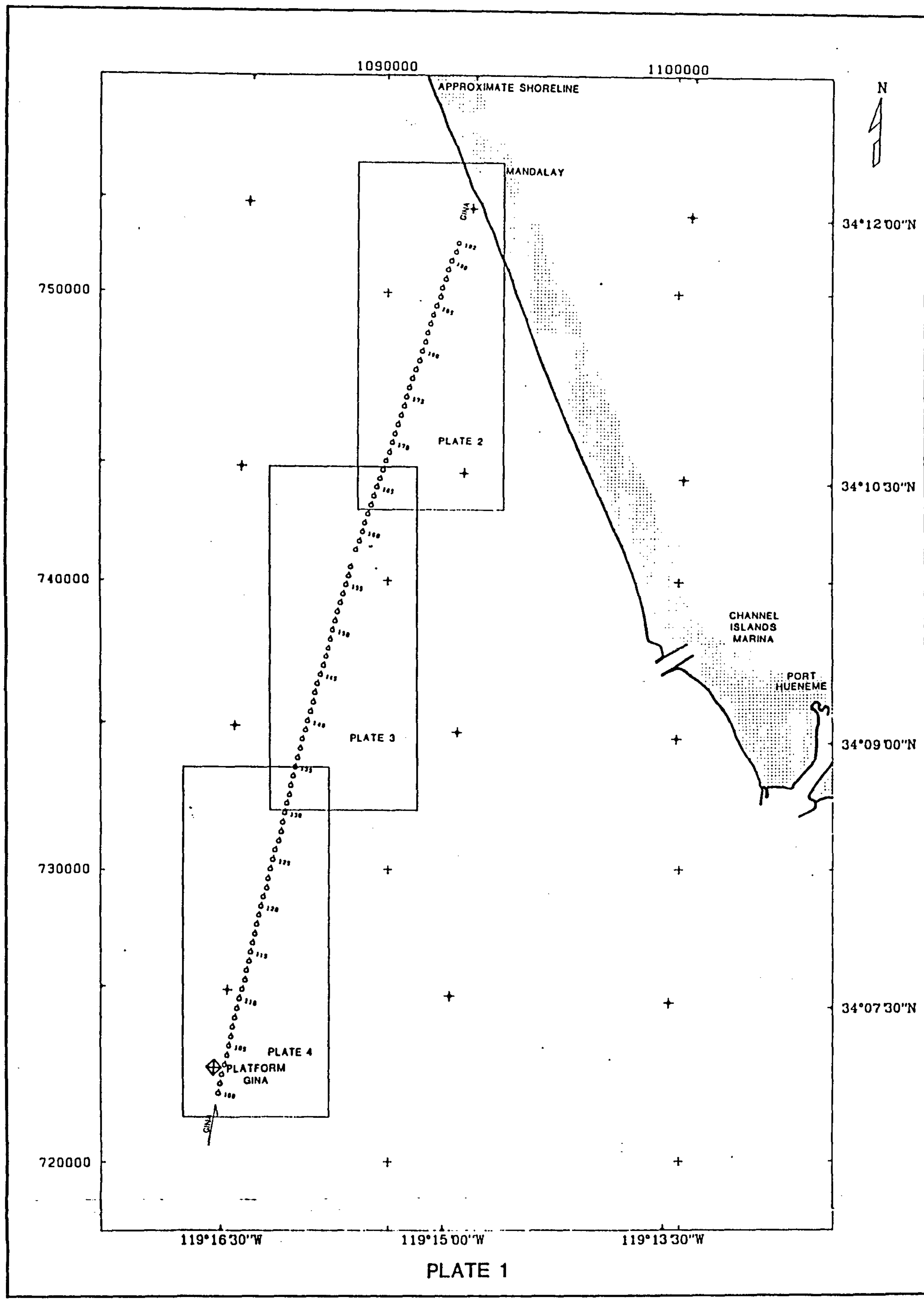


PLATE 1

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

NAVIGATION POSTPLOT

PLATE	1 OF 4	PROJECTION	CALIF. LAMBERT
SCALE	1 : 24000	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JULY 1989	DATUM	NAD 1927

0 2000 4000 6000 8000
FEET

0 500 1000 1500 2000 2500
METERS

LEGEND and NOTES

GINA — Survey Line and Direction

Fix Point, Showing Direction of Survey Lines

NOTE:
IF COPY HAS BEEN REDUCED, CORRESPONDING SCALE WILL BE LESS THAN ONE INCH.

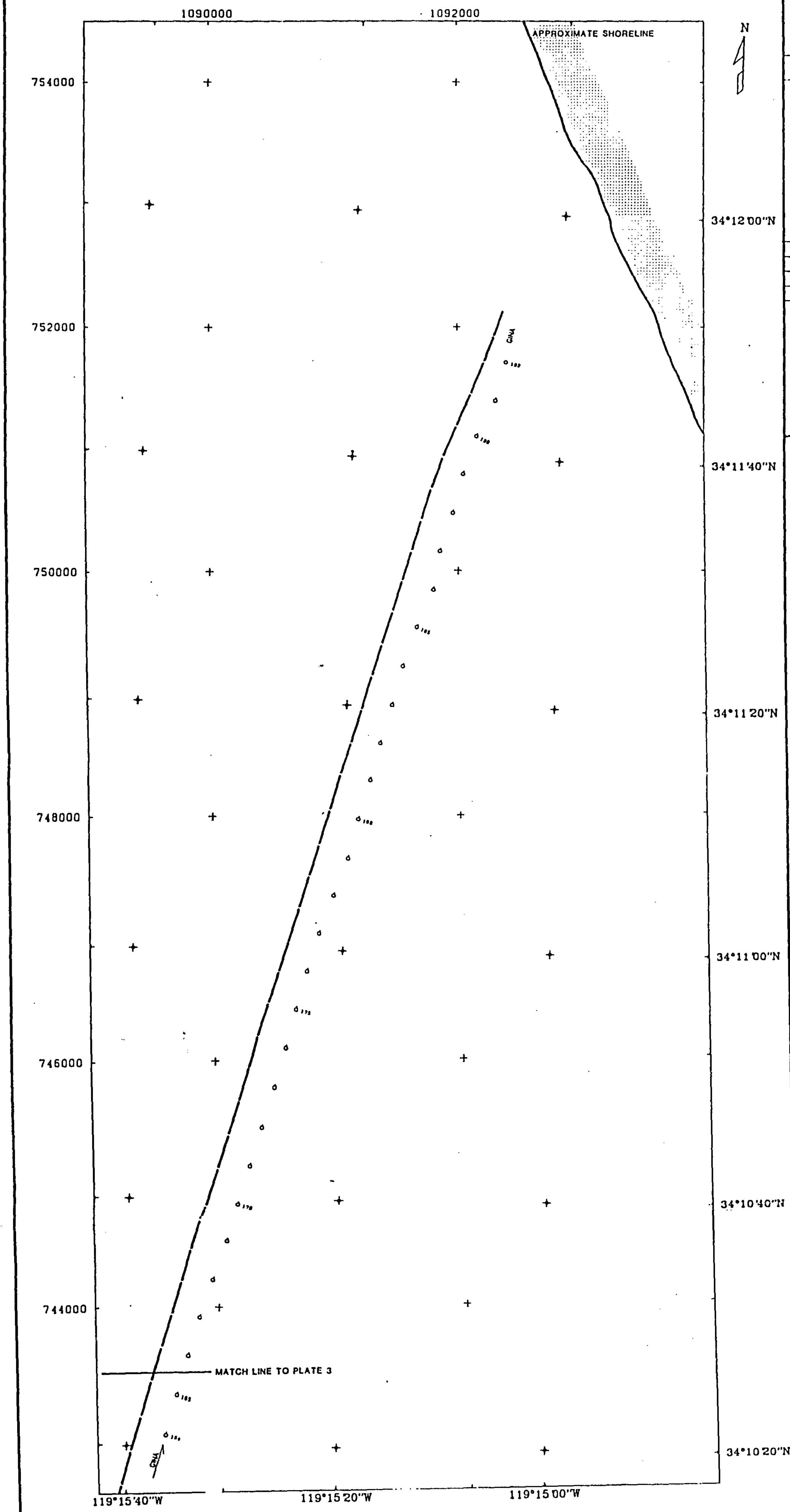


PLATE 2

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	2 of 4	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JULY 1989	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Partially Exposed on the Seafloor

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
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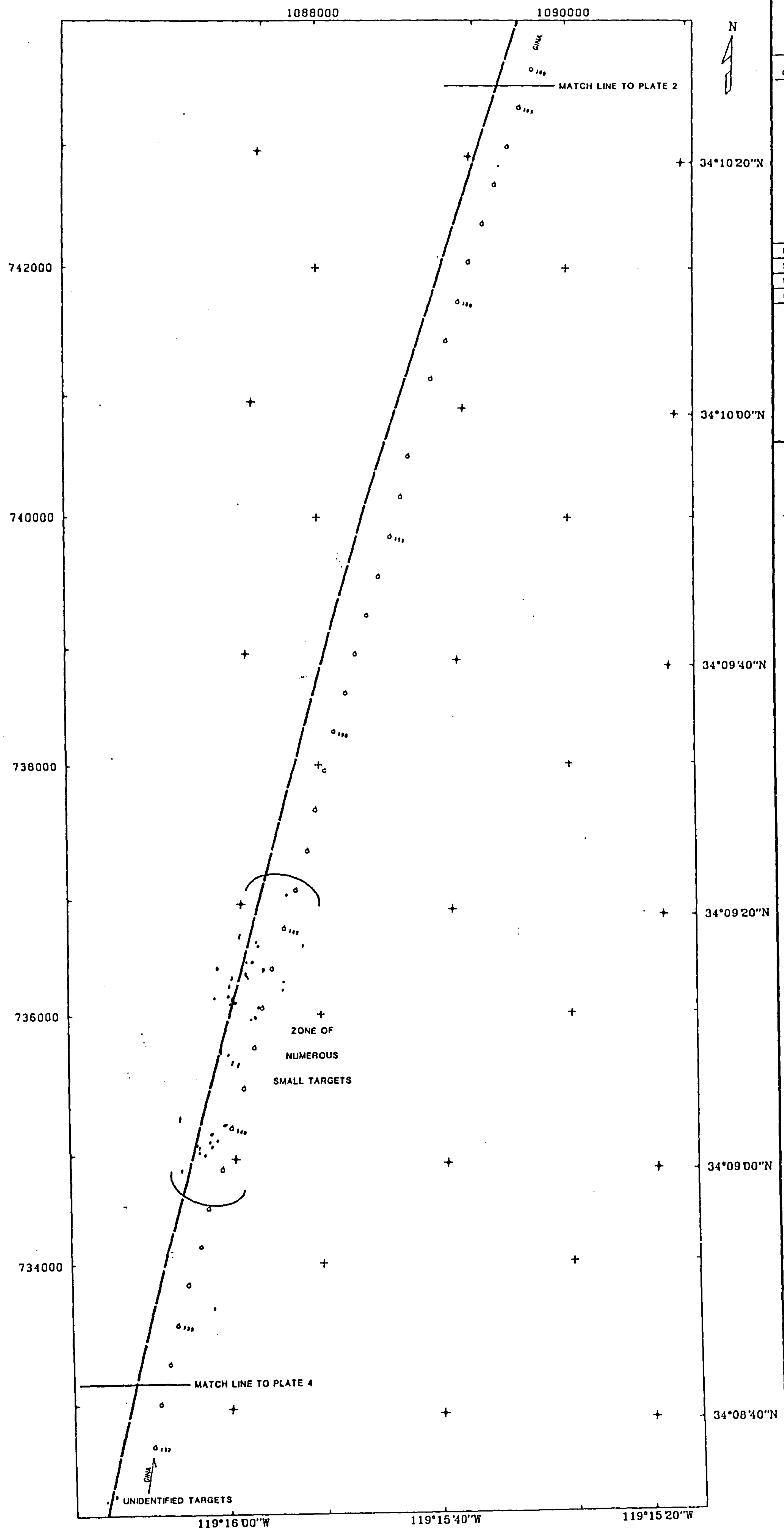

PLATE 3

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	3 of 4	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JULY 1989	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
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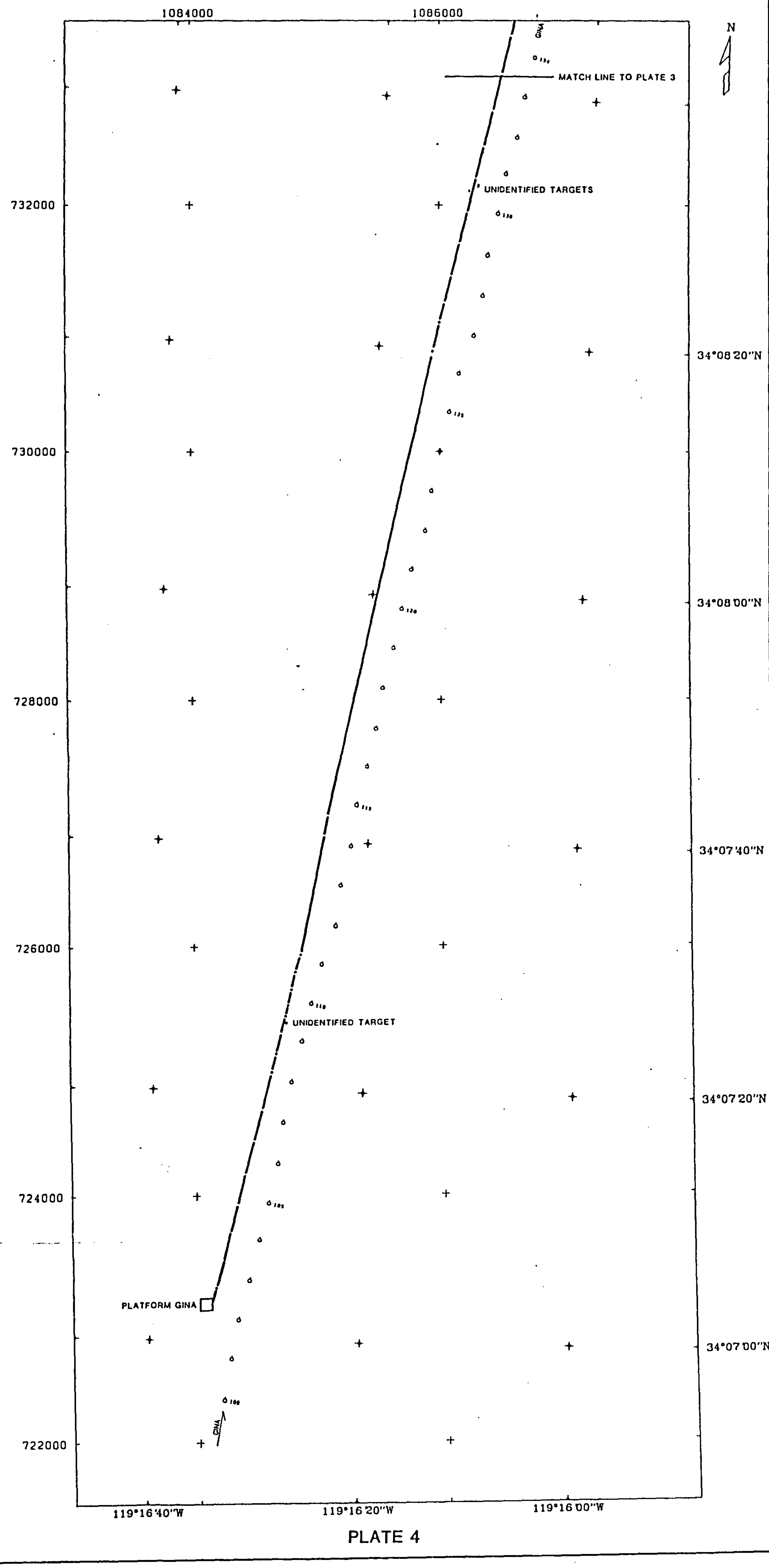

PLATE 4

PELAGOS CORP.
SAN DIEGO, CALIFORNIA

CLIENT UNOCAL

PIPELINE ROUTE
MANDALAY TO PLATFORM GINA

SEAFLOOR FEATURES

PLATE	4 of 4	PROJECTION	CALIF. LAMBERT
SCALE	1 : 4800	ZONE	6
UNITS	FEET	SPHEROID	CLARKE 1866
DATE	JULY 1989	DATUM	NAD 1927

0 500 1000 1500
FEET

0 100 200 300 400 500
METERS

LEGEND and NOTES

Pipeline Exposed on the Seafloor

Pipeline Partially Exposed on the Seafloor

Pipeline Completely Buried (Location Mapped from "As Built" Survey)

NOTE:
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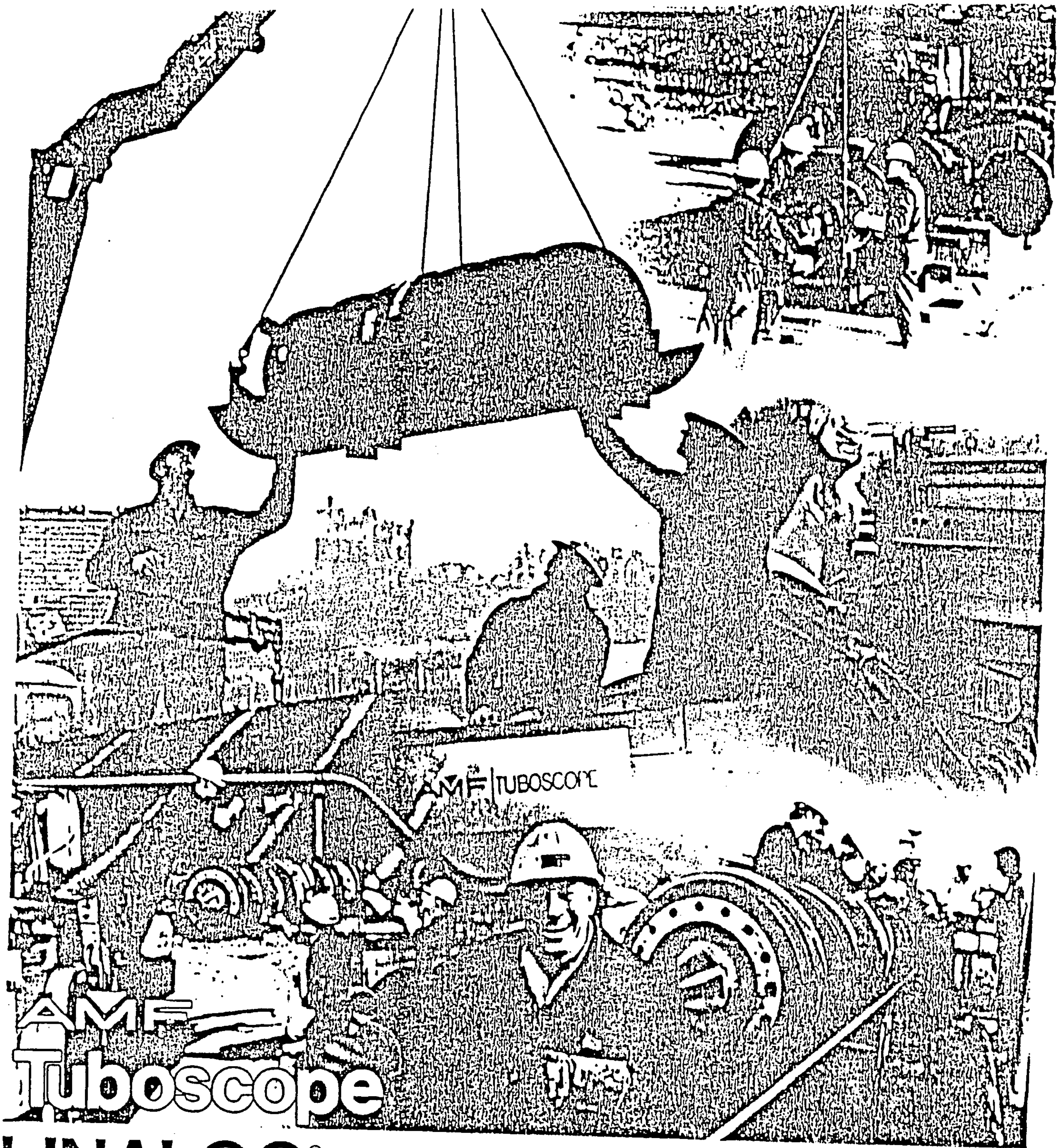
APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Linalog Survey (2/8/85)



LINALOG®
Inspection Survey Report

for
UNION OIL OF CALIFORNIA

date
FEBRUARY 8, 1985

LINALOG® CORROSION SURVEY

OF

OFFSHORE PIPELINES

FROM

6 INCH: PLATFORM GINA TO MANDALAY
10 INCH: PLATFORM GINA TO MANDALAY
12 INCH: PLATFORM GILDA TO MANDALAY

JOB NO. 1551

PREPARED

FOR

UNION OIL COMPANY OF CALIFORNIA

BY

JAIME SLIGHT

AMF TUBOSCOPE, INC.

HOUSTON LINALOG® DIVISION

FEBRUARY 8, 1985

CONTENTS

INTRODUCTION

The following offshore pipelines were surveyed by Linalog® in January 1985. The set-up location used for each survey was Ventura, California.

1. The 6 inch diameter pipeline PLATFORM GINA to MANDALAY: Length, approximately 6.2 miles. The pipe is reported to be .280" nominal wall Grade "B" ERW. One successful instrumented survey run was made January 14, 1985. Running time was 5 hours 45 minutes, resulting in an average tool velocity of approximately 1.1 miles per hour.

2. The 10 inch diameter pipeline PLATFORM GINA to MANDALAY: Length, approximately 6.2 miles. The pipe is reported to be .500" and .562" nominal wall Grade X-56 ERW. One successful instrumented survey run was made January 12, 1985. Running time was 6 hours 14 minutes, resulting in an average tool velocity of approximately 1 mile an hour.

3. The 12 inch diameter pipeline PLATFORM GILDA to MANDALAY: Length, approximatley 10.1 miles. The pipe is reported to be .500" nominal wall Grade X-42 ERW. One successful instrumented survey run was made January 9-10 1985. Running time was 8 hours 46 minutes, resulting in an average tool velocity of approximately 1.1 miles per hour.

A survey consists of passing a self-contained instrumented pipeline pig, known as the Linalog® Tool, through a pipeline. The Linalog® Tool records magnetic anomalies existing in the body wall of the pipe.

A "Dummy" Linalog® Tool was run through each pipeline, before running the instrumented tool, to check for obstructions which could interfere with the instrument's passage.

The survey showed the existence of magnetic anomalies in each pipeline. Each joint of pipe containing significant anomalies has been indicated by a grade stamped along the top of the log. These grades are tabulated by grade classification between pipeline reference markers in the "RESULTS" section of this report.

LINALOG SURVEY EQUIPMENT

THE "DUMMY" TOOL

A sizing tool, known as a "Dummy Tool", is run through the pipeline prior to running the Linalog® Survey Tool. The "Dummy Tool" is used as a gauge to check the pipeline for any restrictions which could impede the movement of, or severely damage, the Linalog® Survey Tool. The Dummy is similar in appearance to the Linalog® Survey Tool but contains no instrumentation.

MAGNETS

Prior to running the Linalog® Survey Tool, the pipeline is usually marked at convenient intervals. The suggested interval is approximately 1 mile. The actual interval used will depend upon land topography and ease of access to the pipeline Right of Way. This marking is done by placing a pair of permanent magnets on the pipeline at desired locations as shown on Figure 2. When the Linalog® Survey Tool is run, the flux field from these magnets is detected and recorded along with the other data. These "Marks" then become above ground reference points from which areas of corrosion can be located. The location of reference markers, used on a previous survey, can be transferred from the previous survey log to the current one if applicable. Natural features of the pipeline, that can be identified from the surface above the pipeline, and that can be recognized on the log, make excellent "Marks" and should be used, along with the magnets, whenever possible. Valves, flanges, taps, tees, and stopple fittings are typical examples of these natural features.

LINALOG® SURVEY TOOLS

The Linalog® Survey Tool is a self-contained unit that is inserted into, propelled through, and extracted from the pipeline in the same manner as a conventional cleaning pig. The 6 inch diameter Type 3 Linalog® Tool, used during this survey, was approximately 8 feet in length. The 10 and 12 inch diameter Type 3 Linalog® Tools were approximately 10 feet in length. Each tool is made in five sections, which are connected by universal joints ("U" joints), so they can pass through bends in the pipeline (See Figure 1).

The first section is the "Drive Section". It is supported in the pipeline by scraper cups, which provide a tight seal inside the pipe, so the pipeline throughput can propel the inspection tool. A marker detecting device is mounted between the cups. Its function is explained in the "LINALOG® SURVEY RECORD" section of this report.

The second section is the "Magnetizer Section" which magnetizes the pipe and supports the survey shoes. The magnetizer is supported in the pipeline by a set of steel brushes at each end. These brushes also provide a path for the magnetic lines of flux to enter the pipe wall. The survey shoes contain the corrosion survey sensors. These shoes, and the sensors in them, overlap one another to provide complete 360° coverage of the pipe wall. Information signals from the survey sensors are recorded on the survey channels. The function of the survey channels is explained in the "LINALOG® SURVEY RECORD" section of this report.

The third section is the "Distance Measuring Section". It is centralized in the pipeline by scraper cups mounted at each end. The distance measuring wheel is mounted between the scraper cups. Its function is explained in the "LINALOG® SURVEY RECORD" section of this report.

The fourth section is the "Battery Section". This furnishes electrical power to operate the Linalog® Tool. A scraper cup on the rear end supports and centralizes this section in the pipeline.

The fifth section is the "Recorder Section". It is supported in the pipeline by a scraper cup mounted on the rear end. The recorder section houses the magnetic tape recorder and the electronic circuits. The recorder and the electronic circuits process the data from the various sensors and record it on magnetic tape. The 10 and 12 inch recorders were equipped with "Speed Gain Control" (SGC) which automatically adjusts the the sensitivity of the survey electronics to compensate for tool speed variations.

OPERATING PRINCIPLE

The Linalog® Tool operates on the flux-leakage principle. A magnetic field is induced into the pipe wall by the magnetizer section as it moves through the pipeline. This magnetic field travels with the tool. When an anomaly is encountered in the pipe wall, the magnetic flux is forced out of the pipe at the anomaly (See Figure 3). This is called flux-leakage. The Linalog® Tool detects this flux-leakage and records a corresponding signal on magnetic tape. Line pipe usually contains small imperfections, so some amount of background signals can be expected.

We can generalize and say that the amplitude of a corrosion pitting signal, generated by the flux leakage at corrosion pitting, is proportional to the depth of the pitting. This is the basis for the grade classifications used to evaluate the condition of the pipeline. For more detailed information, refer to the "GRADING SYSTEM" section of this report.

PLAYBACK SYSTEM

After the Linalog® Survey Tool is removed from the pipeline, the magnetic tape, containing the recorded data, is removed from the recorder and placed on a machine known as the "Playback System". The Playback System "reads" the data on the magnetic tape and makes a paper graph called the "Linalog® Survey Field Log". The field log is then interpreted by the field inspector to verify that the tool has performed satisfactorily. If a verification dig is to be made, the field log is used to locate a suitable area.

When the magnetic tape is returned to the Linalog® Division Office, it is played back again to make a permanent paper graph called the "Linalog® Survey Record" or "Log".

LINALOG® SURVEY RECORD

The Linalog® Survey Record, normally called the "Log", consists of multiple channels of information. Logs of 6 inch diameter pipelines have 10 channels of information consisting of a marker channel, 8 survey channels, and a combination distance/orientation channel (See Figure 4). Logs of 10 and 12 inch diameter pipelines have 14 channels of information consisting of a marker channel, 12 survey channels and a combination distance/orientation channel (See Figure 5).

MARKER CHANNEL

The Marker channel is used as an aid in recognizing girth welds and helps identify magnets when placed on the pipeline to serve as reference markers. Since it is not practical to put magnets on offshore lines, except to locate areas for repair; magnets were not used on these pipelines. Natural features on the pipeline, such as valves, flanges, sleeves, and tie-in connections, are also recorded, and could be used as reference markers when applicable. These reference markers are used as a starting point for locating corrosion and other features of interest on the pipeline that are indicated by the log. Refer to the section of this report on "USING THE RECORD".

SURVEY CHANNELS

The survey channels show the anomalies, encountered in the body wall of a pipeline, such as corrosion, girth welds, magnets, valves, flanges, taps, saddles, anchors, patches, clamps, and manufacturing irregularities. These anomalies are detected by the survey shoes.

When the log is interpreted, each joint of pipe in the pipeline is examined, and a grade is assigned to those joints which contain anomaly indications of sufficient magnitude to be classified in one of the grading categories. Refer to the "GRADING SYSTEM" section.

Examples of anomaly classification and grading are shown on Figures 4-9.

Figures 4 and 5 show the format of the survey logs and identifies the various information channels on them.

Typical examples of corrosion anomaly grading are shown on Figures 6 and 7.

Figure 8 shows a typical unclassified anomaly indication graded "U". The majority of the class "U" grades were found to be on the 12 inch pipeline PLATFORM GILDA to MANDALAY.

The orientation channel showed these indications to fall mainly in the areas between 10 and 2 o'clock on the pipeline.

It was noted on the 6 inch survey PLATFORM GINA to MANDALAY that survey channels 2,4,6, and 8 appeared to be a little more sensitive than the other channels. This can be seen starting at approximately wheel count 7,700 and continuing throughout the survey (See Figure 9). As the tool rotated, the noise remained on the same channels; For this reason possible corrosion was not considered. At approximately 20,452 feet, a definite rotation pattern could be seen for the remainder of the survey. At this point, corrosion grades were marked on the log, as were noted on Figures 6 and 7.

DISTANCE MEASURING/ORIENTATION CHANNEL

This channel displays the distance measurement the tool recorded as it traveled through the pipeline as well as the orientation of the tool at any given point on the log. An individual mark for each one foot of pipeline length is displayed. These unit "Wheel Counts" are recorded in multiples of one, ten, one hundred, and one thousand. An amplitude differentiated signal is recorded on the log for each multiple (See Figure 10). Each thousand count is marked cumulatively throughout the log.

The total "Wheel Count" is shown on the log at each pipeline reference mark. (See Figures 4 and 5). This is read directly from the distance channel. The "Map Station" number is also shown on the log at each reference mark when it is furnished. This information comes from pipeline maps or a station number list provided by the pipeline company. No station numbers were provided for these sections. Refer to "USING THE RECORD" section of this report.

The length of the pipeline from the launch to any point of interest (reference marker, anomaly indication, etc.) is the wheel count at the point of interest minus the wheel count at the launch. This calculation is necessary because the distance wheel circuitry cannot be made to start a zero count at the launch valve.

The distance channel also indicates whether or not the Linalog® Tool traveled at a uniform velocity. Uniform spacing indicates that a steady velocity was maintained during the survey. Variable spacing between wheel counts indicates a changing velocity. As tool speed decreases, this spacing increases; as tool speed increases, this spacing decreases.

The orientation of the tool is displayed by the distance channel. The orientation channel records the rotation of the inspection tool as it moves through the pipeline. The tool is designed to rotate so that wear on the scraper cups, brushes, detectors (shoes), etc. is more uniformly distributed thus improving the quality of the survey log.

As the tool rotates, the individual footage pulses steadily begin to decrease or increase, depending on the direction of tool rotation, until the tool has completed a 360 degree revolution. At this time the individual footage pulses again return to their preset maximum or minimum height, again depending on the direction of tool rotation. (See Figure 11). The top of the pipe is being recorded on the first survey channel when the individual footage pulses are at their maximum height and the last survey channel is recording the top of the pipe when the individual footage pulses are at their minimum height.

The top of the pipe (12 o'clock position) can be plotted on the log for each rotation cycle by drawing a diagonal line from left to right starting with the survey channel recording the top of the pipe at the beginning of the rotation cycle to the survey channel recording the top of the pipe at the end of the rotation cycle. The bottom of the pipe (6 o'clock position) follows a parallel diagonal path across the log that is half way around the top of the pipe. This is shown on Figure 11.

The approximate o'clock position of the anomaly on the pipe can be determined from the log in the following manner. Refer to Figure 11.

1. Locate the top of the pipe in the joint of pipe containing the anomaly indication.

2. Assume you are standing on the top of the pipe (12 o'clock position) on the joint containing the anomaly indication and looking downstream toward the receiving trap. Turn the log viewer so you are looking downstream toward the receiving trap on the log.

3. The 3 o'clock position is to the right of the 12 o'clock position mid-way between 12 and 6 o'clock.

4. The 9 o'clock position is to the left of the 12 o'clock position mid-way between 12 and 6 o'clock.

5. The other o'clock positions are located in a similar manner between positions.

The orientation channel is intended to locate the quadrant of the pipe where the anomaly can be found. It is not intended to locate the anomaly as being a specified number of degrees off of the top dead center position on the pipe.

Figure 11 is a typical example illustrating how to interpret the orientation channel. It was not taken from the logs covered by this report.

SCALE SHEET

A scale sheet accompanies each log. It lists the markers used on a pipeline and shows their location on both the pipeline and the log (See Figures 12-14). The "Line Marks" column is the type of reference marker on the pipeline. The "Map Station" column is the station number of the reference marker, expressed in feet, and taken from information supplied by the customer. The "Map Distance" column is the distance in feet from the preceding reference marker, derived from the station numbers. The "Wheel Count" column is the reading of the Linalog® Distance Measuring Channel, expressed in feet, at each reference marker. The "Wheel Distance" column is the distance from the preceding reference marker to this one, derived from the wheel count.

The "Map Station" and "Map Distance" columns are blank when stations numbers are either unavailable or not furnished by the pipeline company.

GRADING SYSTEM

PREFACE

The Linalog® Tool operates on the flux-leakage principle. Flux-leakage is an indirect method of finding and evaluating anomalies in pipe. Probably this can be understood best by first defining direct evaluation. Direct evaluation would be to actually see and measure each anomaly as you would if the joint of pipe was on a pipe rack. You could then see and examine both the inside and the outside surfaces. This is not practical in a pipeline so we must resort to indirect methods to inspect it. Flux-leakage is one of these methods. A magnetic field is induced into the pipe. The amount of distortion in the magnetic field, caused by an anomaly in the pipewall, is detected, measured, and evaluated.

TYPES OF ANOMALY

Linalog® detects anomalies that produce a disturbance in the magnetic field that has been induced into the pipe wall by the inspection tool. These include a wide range of service related environmental anomalies, mill or manufacturing anomalies, and anomalies put in the pipe during handling, transportation, and construction. They can be on the external or internal surface. Typical examples are corrosion pits;

seams; overlaps; slugs; slivers; scratches; grinding marks; inclusions or laminations that break the surface; uneven or high trim of longitudinal weld seams; mis-matched plate edge at the longitudinal weld seams; gouges; welding marks and hard spots.

INTERPRETING THE LOG

Each joint of pipe is evaluated individually. Due consideration is given to the joints on either side to maintain continuity and perspective. The grade assigned to the joint of pipe is the grade that applies to the highest amplitude corrosion anomaly indication in that joint of pipe. Each individual anomaly indication is not graded in the joint of pipe. Once the grade for a joint has been determined, that grade is stamped at the top of the log as follows:

> Grade 1 is assigned to anomaly indications which, we believe, indicate more than 15% but less than 30% body wall penetration.
>
> Grade 2 is assigned to anomaly indications which, we believe, indicate more than 30% but less than 50% body wall penetration.
>
> Grade 3 is assigned to anomaly indications which, we believe, indicate 50% or more body wall penetration.
>
> Grade "U" means unclassified anomaly. This grade is assigned to anomaly indications which, we believe, are not associated with significant deterioration of the pipe wall. They may be caused by manufacturing irregularities in the pipe wall, which existed before the pipeline was put into service, or by something

attached to the pipeline. Unclassified anomalies show on the log in a wide range of shapes, patterns, and amplitudes depending on the nature of the anomaly.

No grade classification is assigned to anomaly indications which, we believe, indicate 15% or less body wall penetration.

If there is doubt as to the cause of the anomaly indication, it is classified as corrosion.

The number of survey channels on the log, on which an anomaly indication appears, indicates approximately how far around the pipe the actual anomaly extends. For example, an anomaly indication that shows on half of the survey channels on the log will extend about half way around the pipe. "Half-sole" patches are a good example of this. Likewise, an anomaly indication that shows on all the survey channels on the log will extend completely around the pipe. Girth welds are a good example of this. Following this line of reasoning, we would normally expect a single small area (for example, 1/2" dia.) isolated pit on the pipe to show on only one survey channel on the log. However, it can, and sometimes does, show on two adjacent survey channels. The explanation of this is that when the middle of the detector (shoe) passes over the pit, the indication will be on one survey channel on the log, and when the overlapping edge of two adjacent detectors passes over the pit, the indication will be on two adjacent survey channels. The overlapping of the detectors is necessary to ensure a complete 360 degree inspection of the pipeline. Since we cannot control whether the center of one detector, or the overlapping edge of two adjacent detectors, passes over the pit, we must consider and recognize this when interpreting the log.

The extent of an anomaly indication on the log, in the longitudinal direction of the log, indicates how far the actual anomaly on the pipe extends along the length of the joint of pipe. Suppose there is an isolated area of pitting, about one foot in length, near the middle of the joint of pipe. This would show on the log as an isolated group of indications, about one foot in length, according to the distance measuring channel on the log. However, suppose the pitted area on the pipe started near the middle of the joint and extended to the downstream girth weld. In this case, the log would show a group of anomaly indications on the survey channels beginning near the middle of the joint of pipe and extending to the girth weld at the downstream end of the joint.

It is therefore possible to determine the approximate size of the pitted area, or other anomaly, on the pipe by observing (a) the number of survey channels on the log on which the anomaly indications appear, and (b) how far along the longitudinal direction of the log -- between two girth welds -- the group of anomaly indications extend.

Many of the mill or manufacturing anomalies, such as seams and overlaps, slugs, slivers, circumferential cracks and scratches, grinding marks, inclusions or laminations that break the surface, etc., often produce a higher amplitude indication on the log than their depth justifies. These anomalies are included in the "U" (unclassified anomaly) classification because their higher amplitude signals are uniquely different from normal low amplitude signals which are characteristic of pipeline corrosion. Many of the class "U" indications are on the inside of the pipe, and consequently, could not be easily seen by external visual inspection when the pipe was made. They are difficult to find and evaluate by ultrasonics and radiography due to the small area and shallow penetration many of them have. However, these anomalies disturb the magnetic field in the pipe and Linalog® detects them. Many of these anomalies, such as seams and overlaps, slivers, and laminations that break the surface, introduce two factors which occur simultaneously to make the anomaly indication we see on the log. First, there is the disturbance in the magnetic field. Second, these anomalies sometimes have a thin edge, projecting into the inside of the pipe, that is turned up by the drive cups on the tool before the detectors in the magnetizer section pass over them. The detector bounces as it goes over this turned up edge. The detector receives the signal, caused by the bounce, at the same time it receives the signal, caused by the disturbance in the magnetic field. These two simultaneous signals add together and appear as a single indication on the log with a much greater amplitude than the depth of the anomaly justifies. This has been verified numerous times when we were able to examine the pipe in detail and compare it to the log.

While debris and foreign material (gravel, welding rods, etc.) inside the pipeline are not anomalies in the usual sense, they make similar indications on the log. They disturb the flux field and/or cause the detector to bounce as it passes over them. They do not have a unique signature and are sometimes interpreted as corrosion. Verifying them is difficult because, by the time the joint of pipe can be examined, the piece of debris has usually been moved along in the joint of pipe, or even moved to another joint of pipe downstream, by either the inspection tool or by normal pipeline throughput.

GRADE TOLERANCES

It must be recognized that there is a tolerance in the grade classification assigned to anomaly indications on the log. Consider the following:

1. Anomalies are detected by an indirect method, not by measuring and recording the anomalies themselves, but by observing their effect on a magnetic field induced in the pipe.

2. Several variables, which cannot be anticipated and compensated for, affect the signals the Linalog® Tool records. These are (a) the configuration of the defect (sharp or sloping edges, width to depth ratio); (b) variations in the magnetic permeability of the pipe; (c) the detector to defect incidence (whether the defect passes across the middle of the detector or the overlapping edge of two adjacent detectors); and (d) variations in tool speed which are beyond the capability of the velocity compensation circuits.

Due to these variables, a tolerance of ± 10% applies to the boundary line between each corrosion grade classification. This variation, between the assigned grade classification and the actual condition of the pipe, is minimized when the log is compared to the pipeline, at one or more locations, before the log is graded.

IMPORTANCE OF VERIFYING THE LOG

Comparing the log to the pipeline, at one or more locations, before the log is graded, improves grading accuracy. This comparison is made by excavating and examining the condition of the pipeline at specific locations, where the log shows significant anomaly indications, and then comparing the conditions found in the pipeline with the conditions indicated on the log. In doing this, actual pits in the pipe are identified on the log, and the measured pit depth is correlated to the amplitude of the corresponding indication on the log.

This procedure helps to "fine tune" the entire Linalog® system and establishes the actual relationship between pit depths in the pipe, and signal amplitude at the same locations on the log.

RESULTS

The Linalog® survey showed magnetic anomaly indications in each pipeline as marked on the logs. The tabulation below shows the number of joints of pipe assigned to the various amomaly grade classifications between pipeline reference markers for each section surveyed.

WHEEL COUNT	GRADE CLASSIFICATION 1	2	3	U
6" PLATFORM GINA TO MANDALAY				
ROLL NO. 1				
37	-	-	-	-
10,000	-	-	-	3
20,000	1	-	-	-
30,000	82	-	-	-
32,830	32	10	5	-
TOTAL OF PIPELINE	115	10	5	3
10" PLATFORM GINA TO MANDALAY				
ROLL NO. 1				
622	-	-	-	-
10,000	-	-	-	2
20,000	-	-	-	-
30,000	-	-	-	-
33,492	-	-	-	-
TOTAL OF PIPELINE	-	-	-	2

WHEEL COUNT	GRADE CLASSIFICATION 1	2	3	U
12" PLATFORM GILDA TO MANDALAY				
ROLL NO. 1				
57	-	-	-	-
10,000	-	-	-	11
20,000	-	-	-	9
30,000	-	-	-	3
40,000	-	-	-	1
50,000	-	-	-	-
53,549	-	-	-	2
TOTAL OF PIPELINE	-	-	-	26

Each section surveyed has been reported to be in existence for approximately 3 years. The absence of corrosion grades, with the exception of the 6 inch pipeline, reflects the new condition of these pipelines. For this reason, these surveys are considered "BASELINE" surveys. Any subsequent surveys or inspections can be compared to these "BASELINE" surveys; thus any change or deterioration in the pipelines can be clearly detected.

REVIEW OF GRADING SYSTEM

No grade classification is assigned to anomaly indications which, we believe, indicate 15% or less body wall penetration. If there is doubt as to the cause of an anomaly indication, it is classified as corrosion.

Grade No. 1 is assigned to anomaly indications which, we believe, indicate more than 15% but less than 30% body wall penetration.

Grade No. 2 is assigned to anomaly indications which, we believe, indicate more than 30% but less than 50% body wall penetration.

Grade No. 3 is assigned to anomaly indications which, we believe, indicate 50% or more body wall penetration.

Some tolerance in these grade classifications must be recognized because:

1. Anomalies are detected, and their depth of penetration into the pipe wall is evaluated, indirectly by observing their effect on a magnetic field induced in the pipe, not by measuring and recording the actual anomalies.

2. Several variables, which cannot be anticipated and compensated for, affect the signals the Linalog® Tool records. These are (a) the configuration of the defect (sharp or sloping edges; width to depth ratio); (b) variations in the magnetic permeability of the pipe; (c) the detector to defect incidence (whether the defect passes across the middle of the detector or the overlapping edge of two adjacent detectors); and (d) variations in the tool speed which are beyond the capacity of the velocity compensation circuits.

A tolerance of ± 10% applies to the boundary line between each corrosion grade classification because of these variables. This variation, between the assigned grade classification and the actual condition of the pipe, is minimized when the log is compared to the pipeline, at one or more locations, before the log is graded.

Grade "U" means unclassified anomaly. This grade is assigned to anomaly indications which, we believe, are not associated with significant deterioration of the pipe wall. See the "GRADING SYSTEM" section of this report.

USING THE LOG TO FIND ANOMALIES

Areas of interest on the pipeline can be located accurately from the log by using the distance channel. The point of interest to be found should be referenced to the nearest line marker, such as a magnet, valve, etc., recorded on the log. First, determine the wheel count reading for the anomaly you are trying to find. Next, determine the wheel count reading for the nearest line marker. Wheel count readings are read directly from the distance channel. The difference between these wheel count readings is the distance in feet from the line marker on the pipeline to the anomaly in the pipeline. Care must be taken to insure that the pipeline measurement is always in the same direction (upstream or downstream) from the reference marker as the log measurement, and that you measure from the same reference location on the pipeline that you figured from on the log.

DIGGING ON THE PIPELINE

When digging on the pipeline to find anomalies, it is advisable to measure to a girth weld at one end of the joint of pipe in question rather than measuring directly to the anomaly. Dig down to the top of the pipeline and locate the girth weld. If the measurement places you close to a girth weld, you can be confident that the measurement is correct and that the desired girth weld has been found.

Next, determine the distance from the girth weld which was just found to the anomaly by referring to the distance measuring channel on the log. Finally, measure that distance from the girth weld, and examine the pipe to find the anomaly. Since the log shows the length of each joint of pipe in the pipeline, measuring the length of an actual joint of pipe in the ground and comparing it to the log is a good way to verify correct location. This is especially true if the joint of pipe is very short compared to those on either side of it.

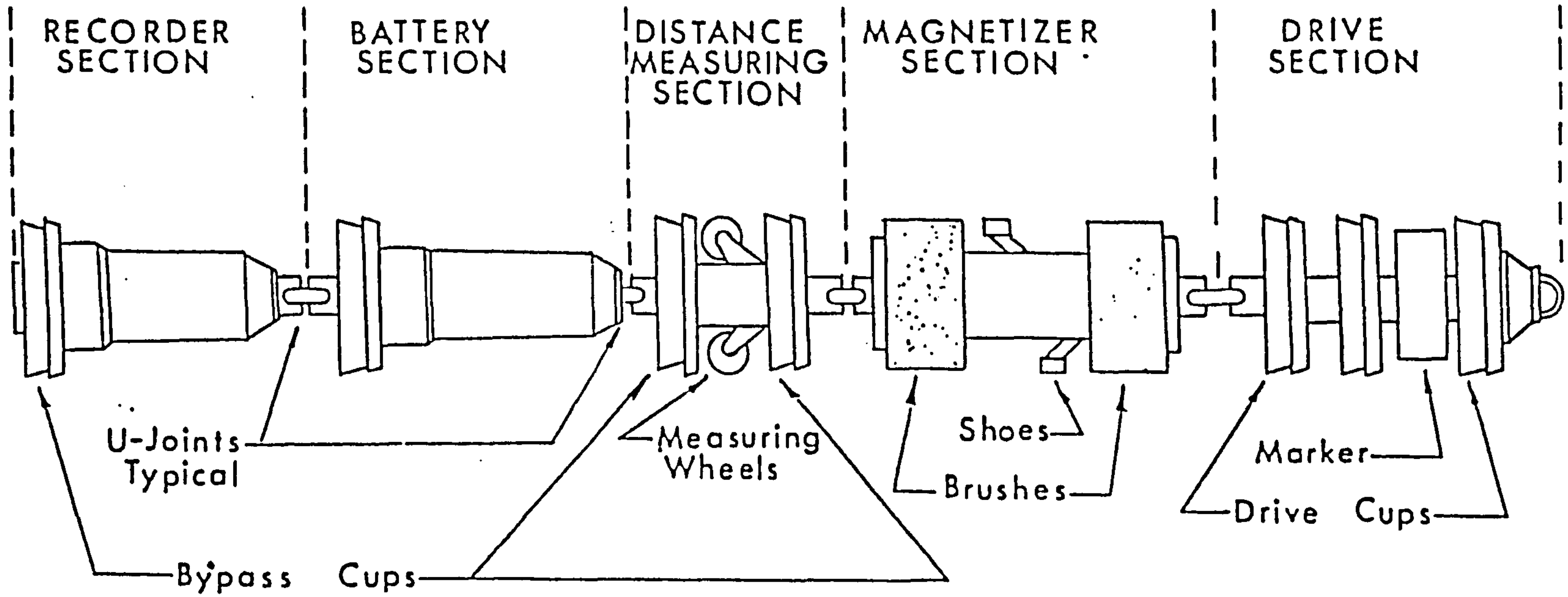
CONCLUSION

The survey showed magnetic anomalies in each pipeline as marked on the logs and listed in the Results Section of this report.

The grading on these logs is our "good faith opinion" about the condition of the pipelines at the time they were surveyed.

The survey was completed with the pipelines in place delivering the throughput desired. It is considered to be successful. The logs have been prepared and graded, scale sheets have been provided, and this report has been written. The survey is considered to be complete.

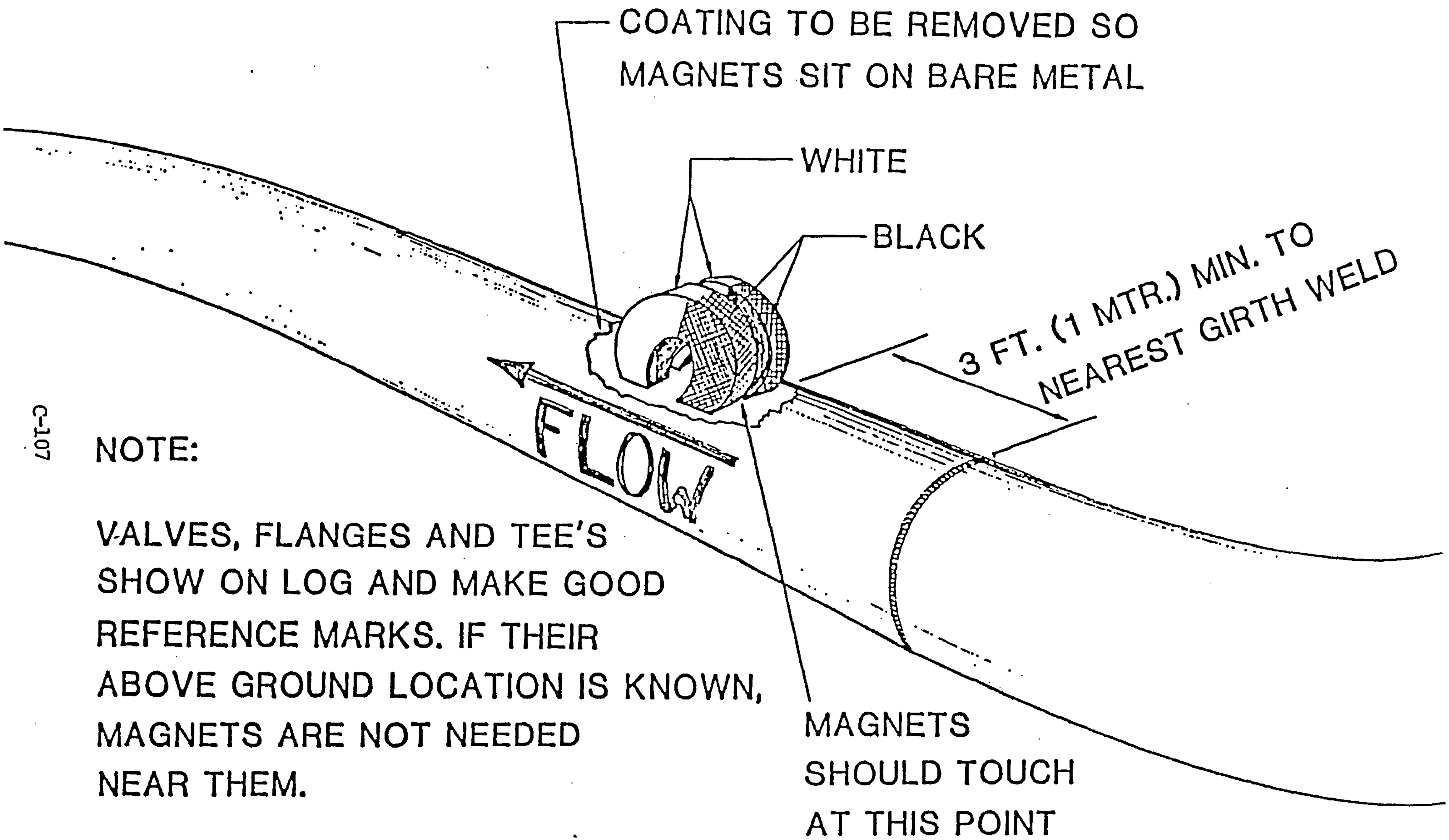
FIGURES AND EXAMPLES



6,10 & 12 INCH LINALOG TOOL

C-106

FIG 1



NOTE:

VALVES, FLANGES AND TEE'S SHOW ON LOG AND MAKE GOOD REFERENCE MARKS. IF THEIR ABOVE GROUND LOCATION IS KNOWN, MAGNETS ARE NOT NEEDED NEAR THEM.

FIG 2

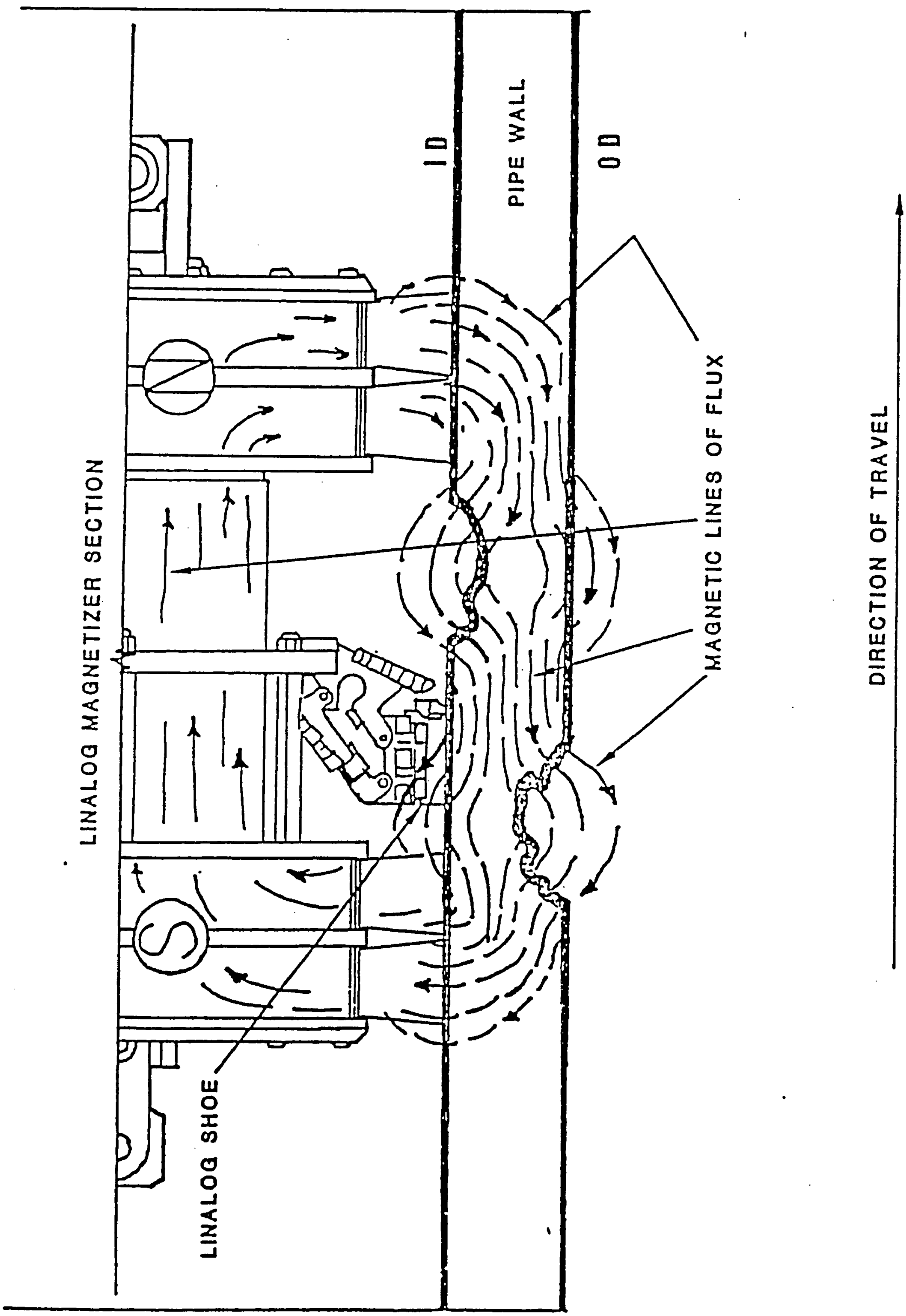
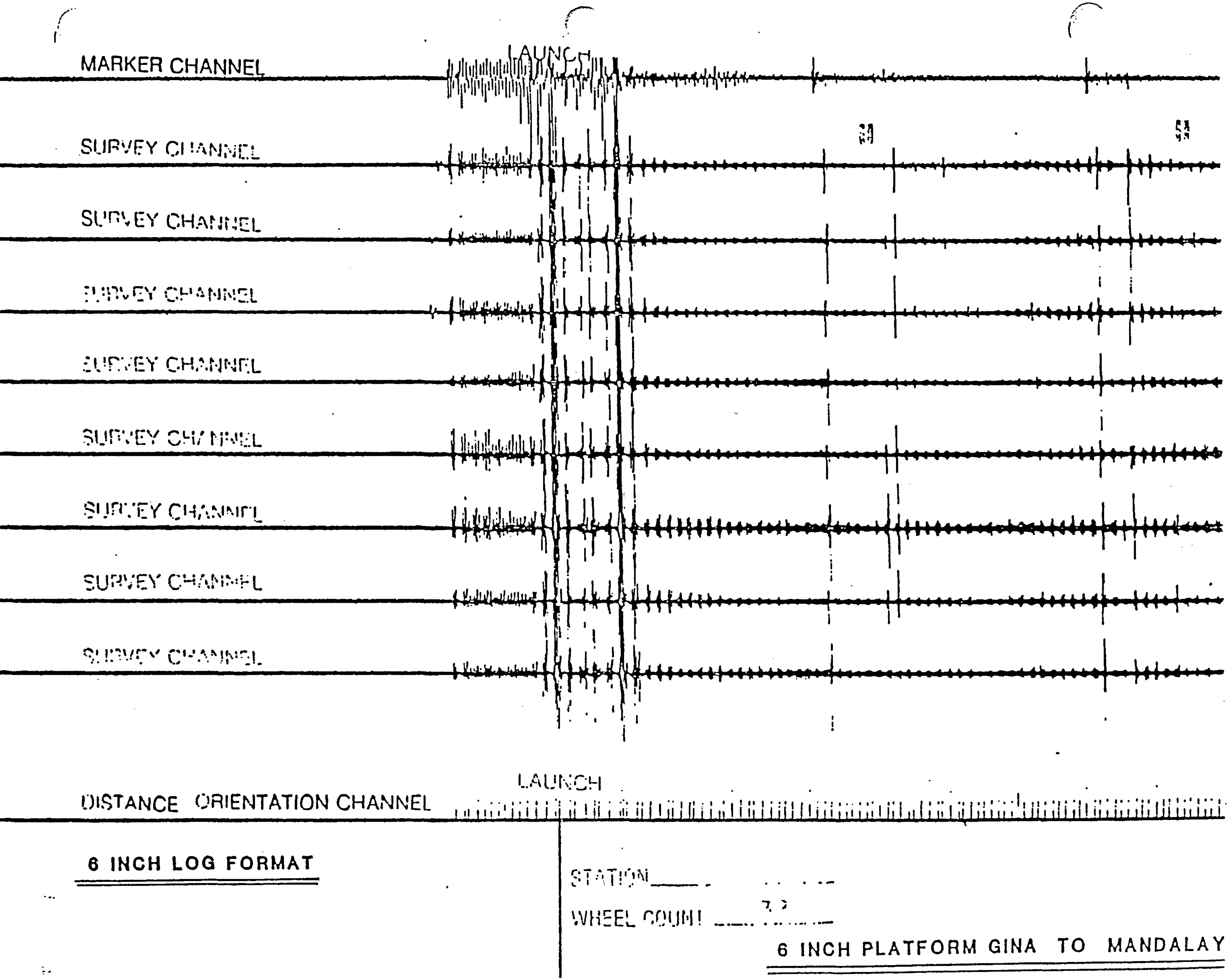

LINALOG MAGNETIZER SECTION
LINALOG SHOE
ID
PIPE WALL
OD
MAGNETIC LINES OF FLUX
DIRECTION OF TRAVEL

FIG 3

C-109



MARKER CHANNEL
LAUNCH
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
SURVEY CHANNEL
LAUNCH
DISTANCE ORIENTATION CHANNEL
6 INCH LOG FORMAT
STATION
WHEEL COUNT
6 INCH PLATFORM GINA TO MANDALAY

FIG 4

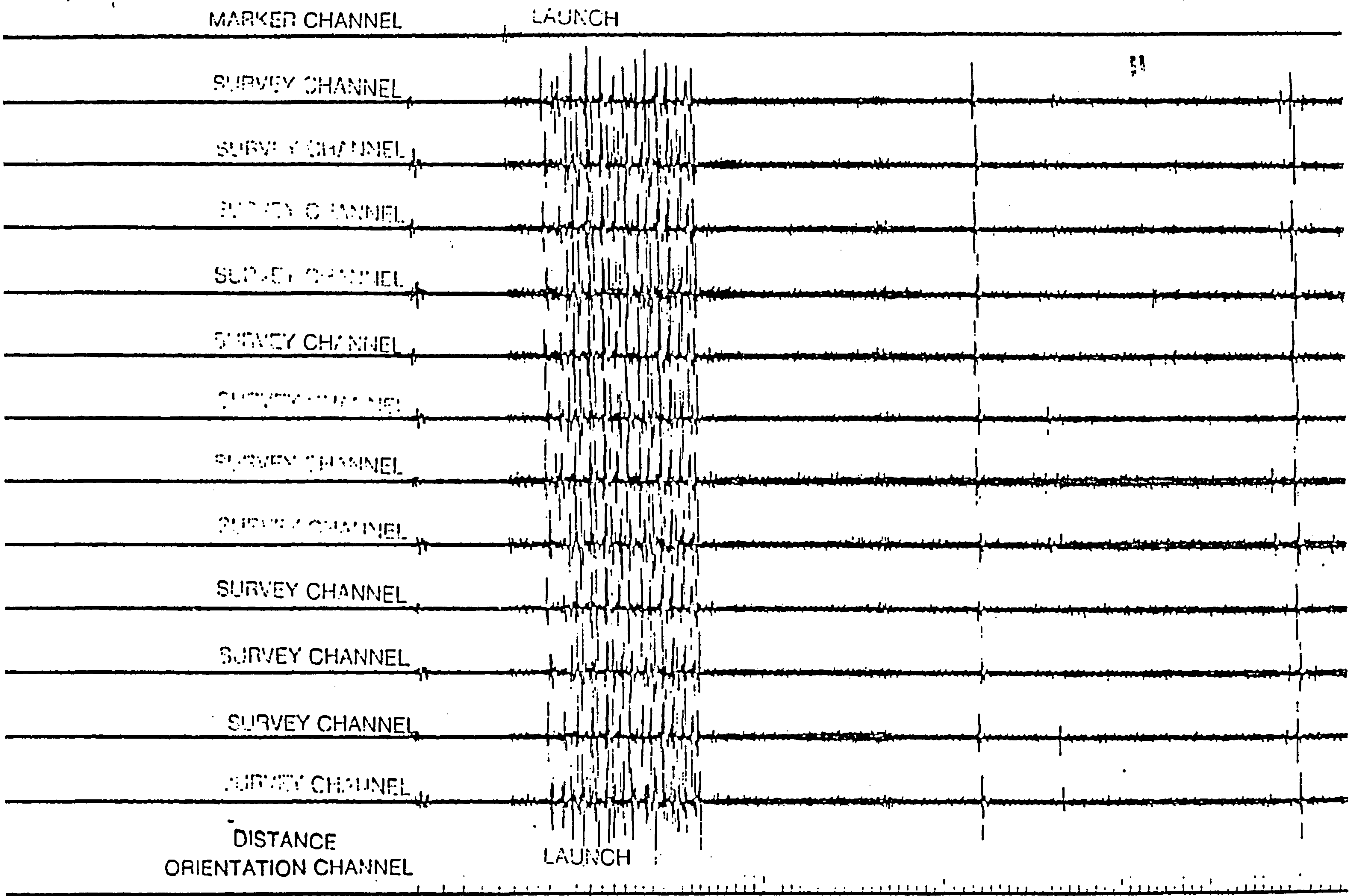
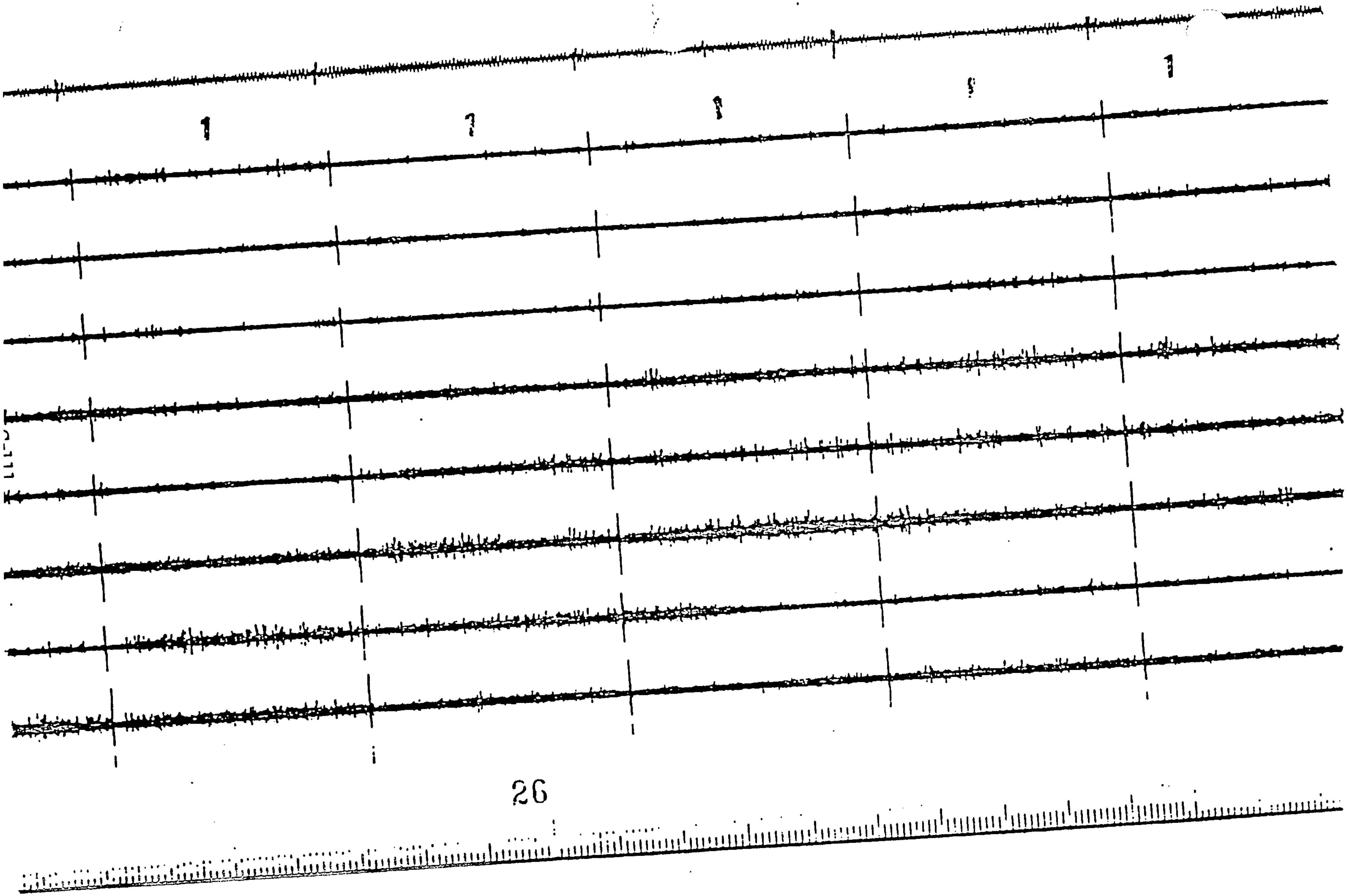


FIG 5

10 & 12 INCH LOG FORMAT

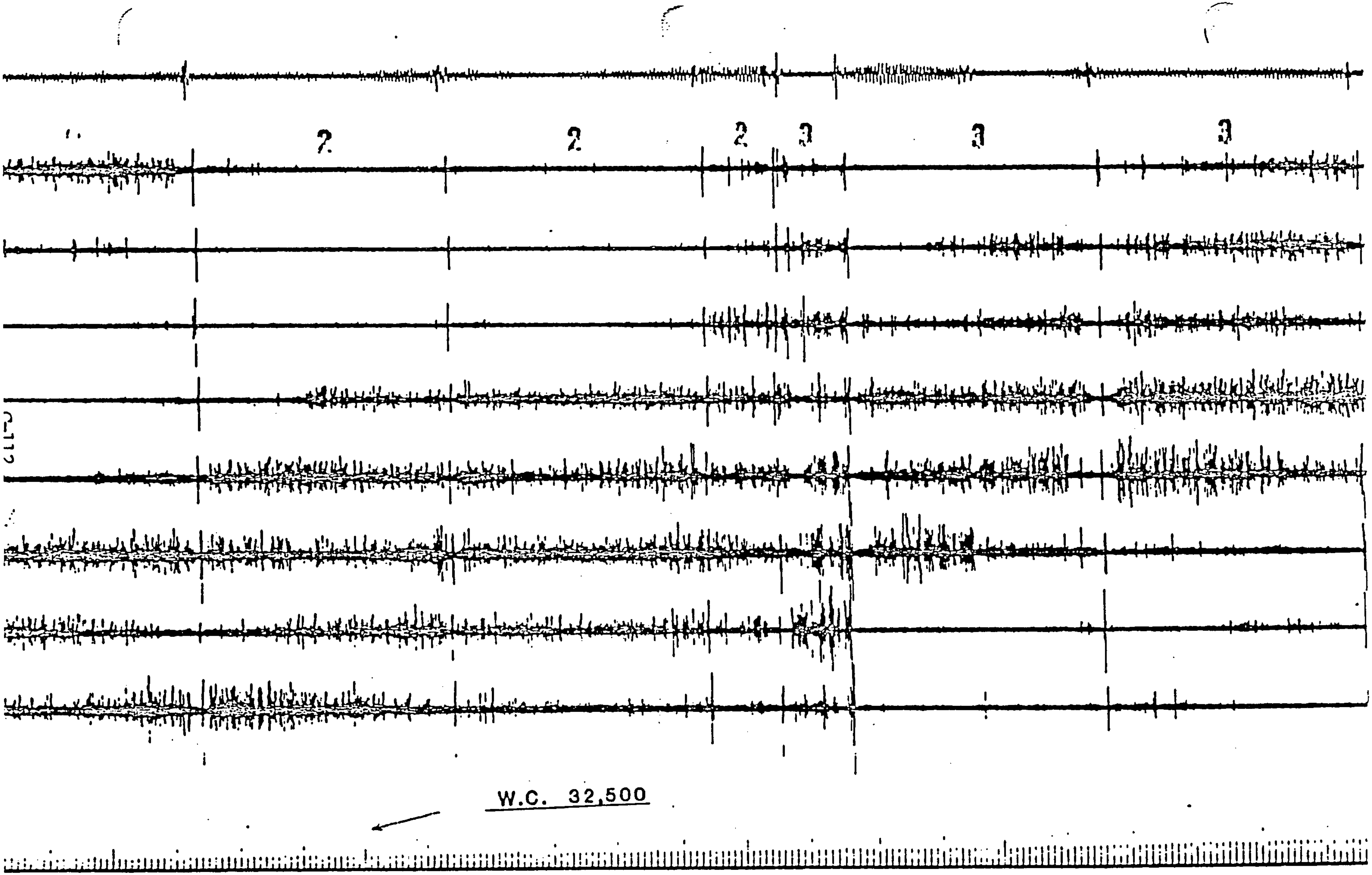
STATION ______ 10 INCH PLATFORM GINA TO MANDALAY

WHEEL COUNT ______



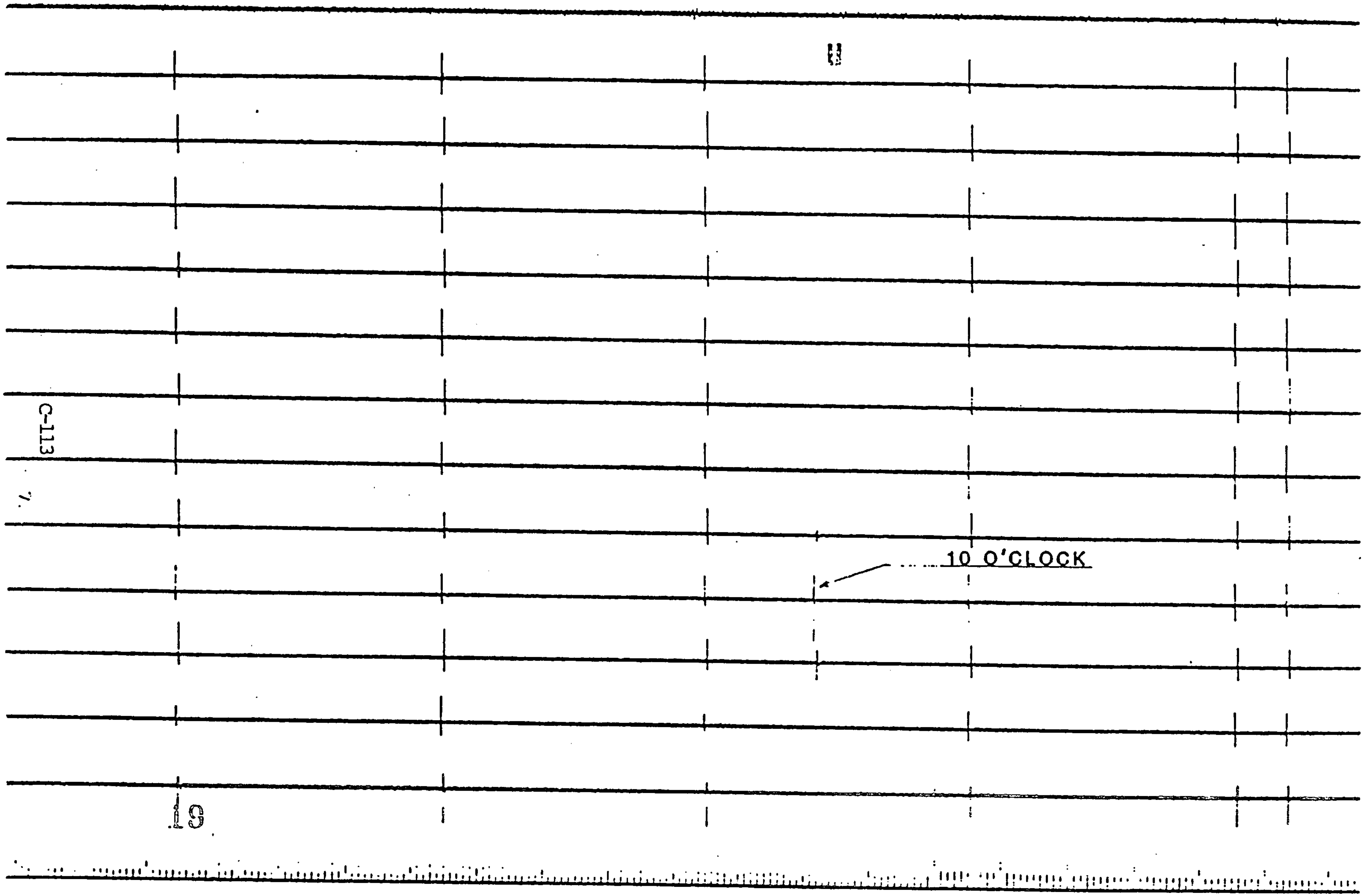
6 INCH PLATFORM GINA TO MANDA

FIG 6



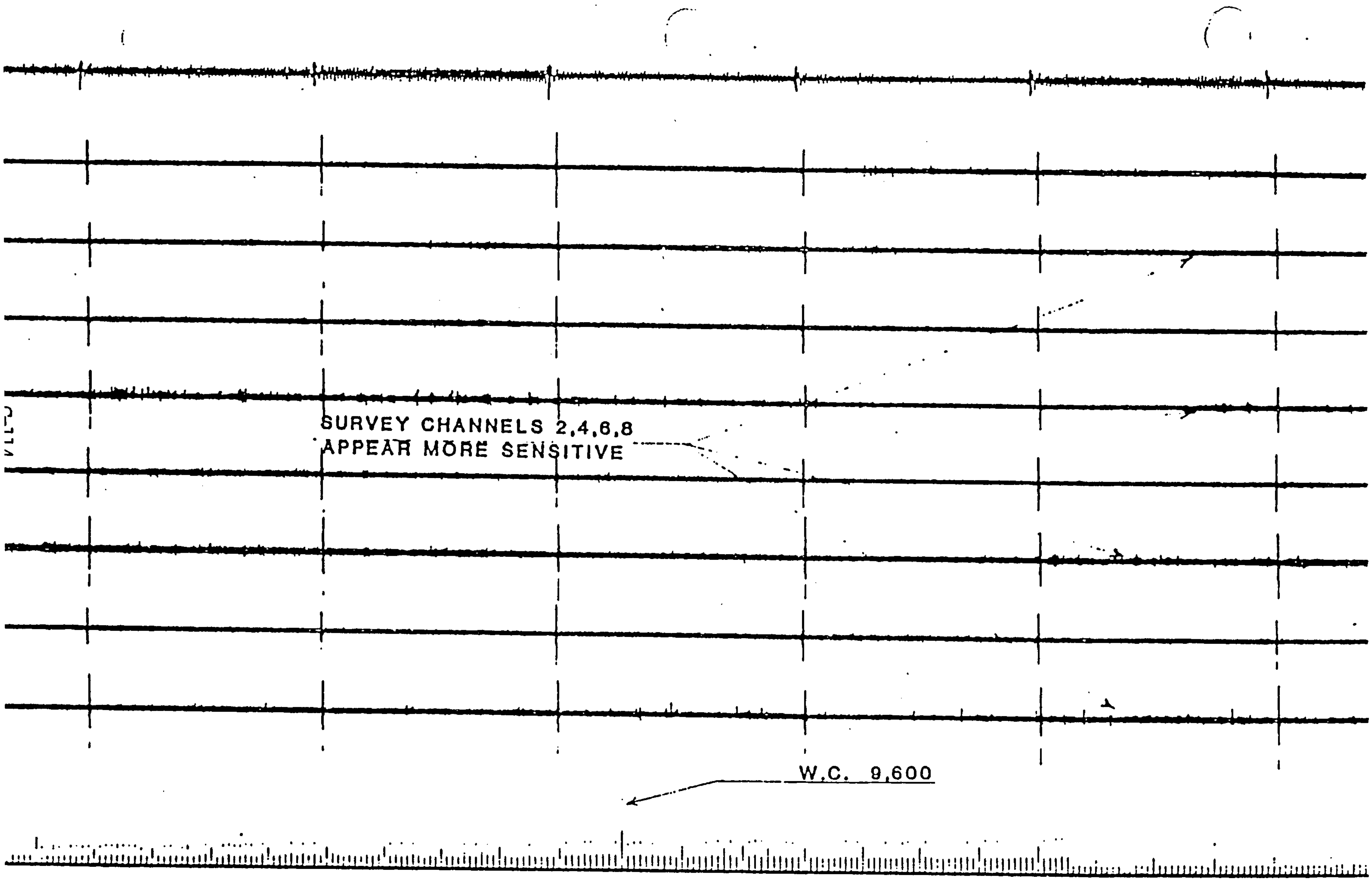
6 INCH PLATFORM GINA TO MANDALAY

FIG 7



12 INCH PLATFORM GILDA TO MANDAL/

FIG 8



6 INCH PLATFORM GINA TO MANDALAY

FIG 9

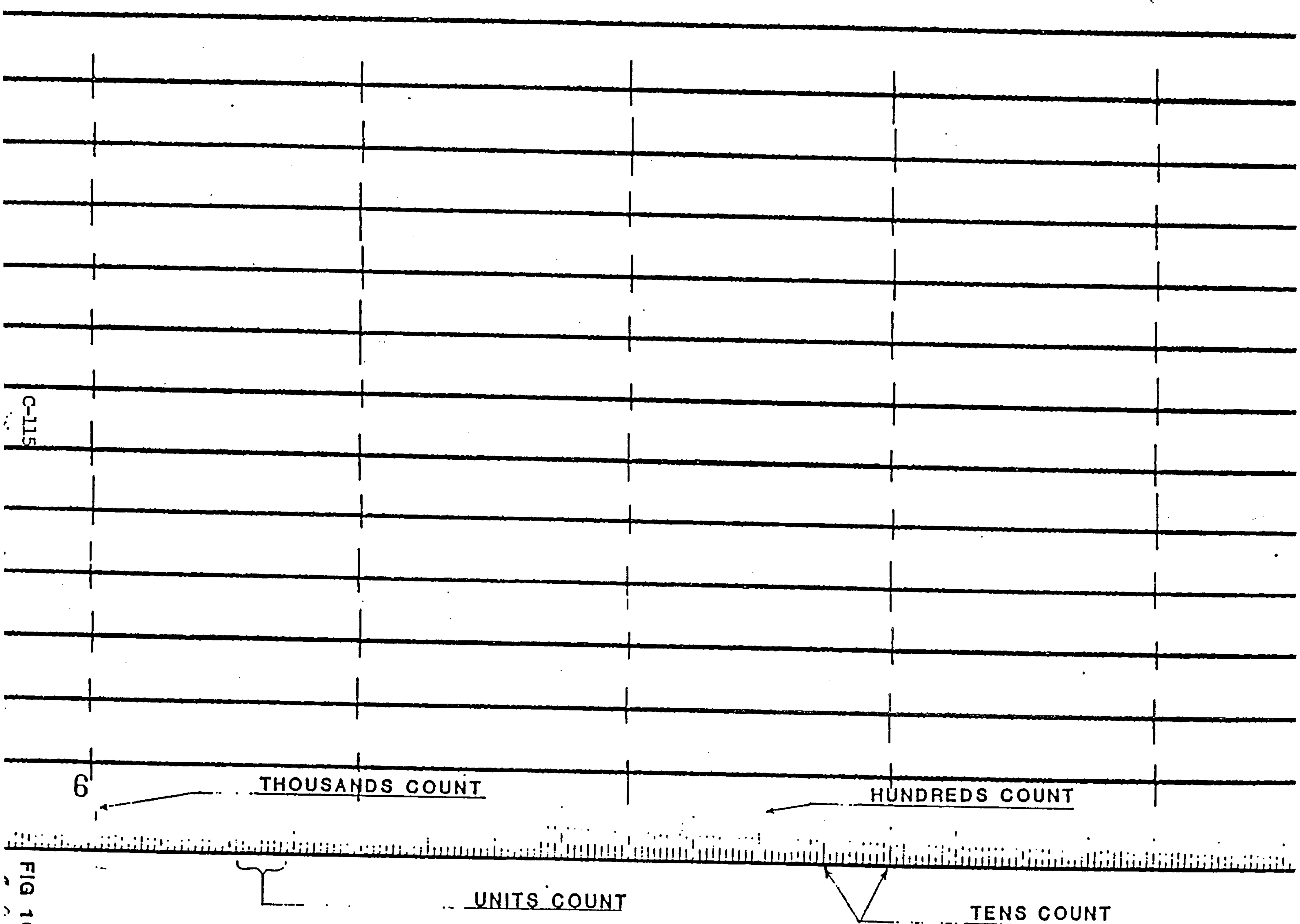
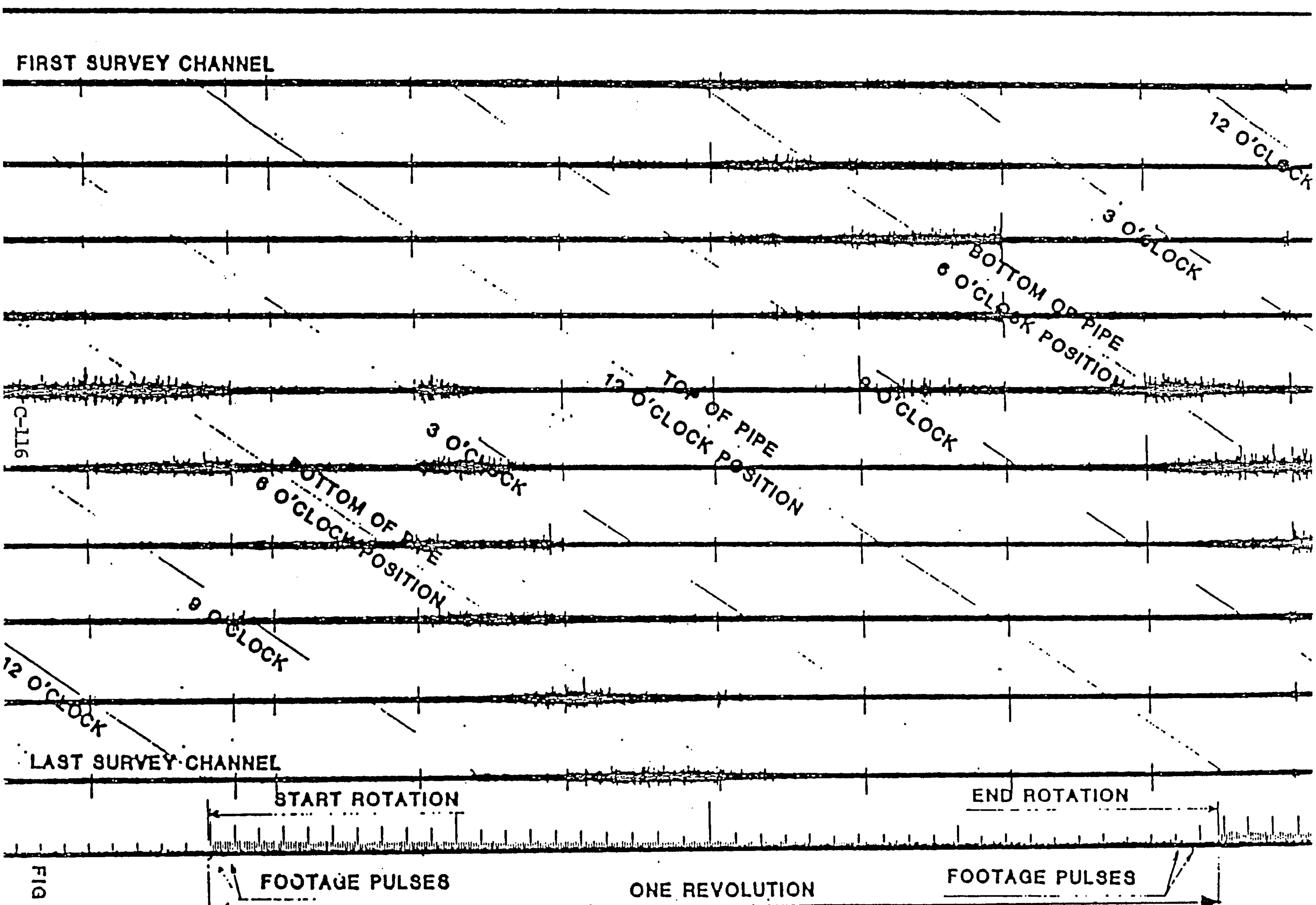


FIG 10



EXPLANATION OF ORIENTATION

FIG 11

UNION OIL OF CALIFORNIA
PLATFORM GINA TO MANDALAY
6" - CORROSION
RUN 1 - JOB 1551
JANUARY 14, 1985

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
LAUNCH			37	0
TRAP			32,830	32793

FEET OF LINE = 32793

MILES OF LINE = 6.21

FIG 12

UNION OIL OF CALIFORNIA
PLATFORM GINA TO MANDALAY
10" - CORROSION
RUN 1 - JOB 1551
JANUARY 12, 1985

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
LAUNCH			622	0
TRAP			33,492	32870

FEET OF LINE = 32870

MILES OF LINE = 6.23

FIG 1:

UNION OIL OF CALIFORNIA
PLATFORM GILDA TO MANDALAY
12" - CORROSION
RUN 1 - JOB 1551
JANUARY 9, 1985

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
LAUNCH			57	0
TRAP			53,549	53492

FEET OF LINE = 53492

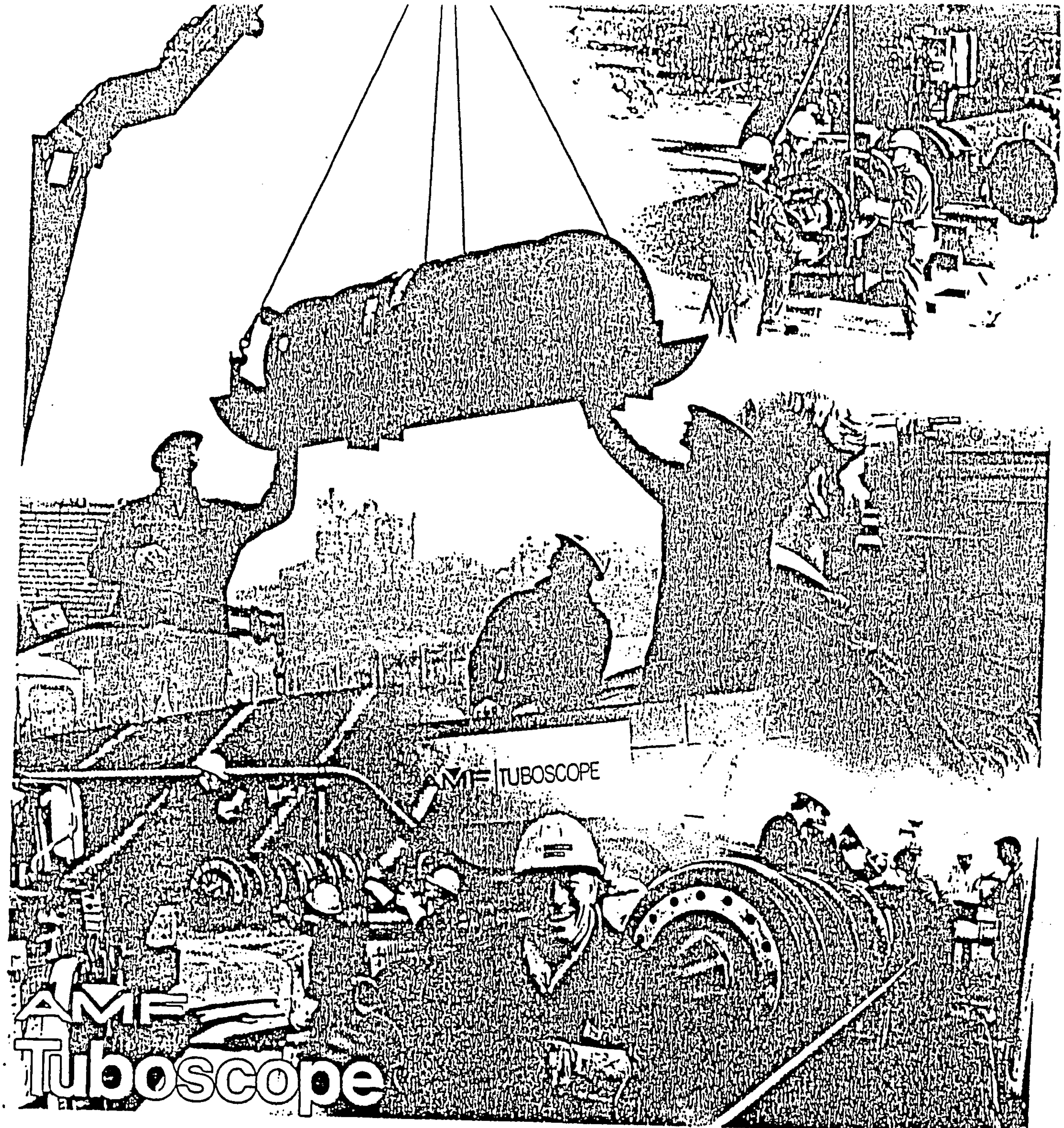
MILES OF LINE = 10.13

FIG 14

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Linalog Survey (9/2/86)



LINALOG®

for

UNION OIL COMPANY OF CALIFORNIA

date

SEPTEMBER 2, 1986

LINALOG® CORROSION SURVEY

OF

6 INCH AND 10 INCH DIAMETER PIPELINES

FROM

MANDALAY TO PLATFORM GINA

AND

PLATFORM GILDA TO MANDALAY

JOB NO. 1626

PREPARED

FOR

UNION OIL COMPANY OF CALIFORNIA

BY

ROBERT HATHAWAY

AMF TUBOSCOPE, INC.

HOUSTON LINALOG® DIVISION

SEPTEMBER 2, 1986

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INTRODUCTION

The following offshore pipelines were successfully run by Linalog® in June, 1986.

1. <u>6 Inch - Mandalay to Platform Gina</u> - Length, approximately 6.26 miles. The pipe is reported to be .280" nominal wall grade B ERW. One successful instrumented survey run was made June 29, 1986. Actual run time was 3 hours, 35 minutes, resulting in an average tool velocity of 1.74 miles per hour. Due to the distance wheel failure at 32,540 feet, 516 feet have been added using the 1985 survey as reference. No survey channel data was lost, only distance.

2. <u>10 Inch - Platform Gilda to Mandalay</u> - Length, approximately 10.1 miles. The pipe is reported to be, mainly, .365" nominal wall ERW, But contains some .500" wall. One successful instrumented survey run was made June 30, 1986. Actual run time was 6 hours, 50 minutes, resulting in an average tool velocity of 1.47 miles per hour.

Because these are offshore lines, no magnets were used as reference markers and no verification digs were made. "Dummy" runs were made on both pipelines, by Union Oil personnel, to check them for obstructions which could damage or impede the throughput of the "Live" tool. The "Dummy" runs were reported as successful by the customer.

The actual surveys consisted of passing a self-contained instrumented pipeline pig, known as the Linalog® Survey Tool, through each pipeline. This tool records magnetic anomalies which are in or on the body wall of the pipe.

The surveys showed the existence of magnetic anomalies in each pipeline. Each joint of pipe containing anomalies of significant magnitude has been indicated by a stamped numerical or letter grade along the top of the survey log, centered in each joint. These grades have been tabulated by grade classification between pipeline reference markers in the "RESULTS" section of this report.

The 6 inch pipeline from Mandalay to Platform Gina was previously run by Linalog® in January, 1985, job number 1551. A comparison was done between the 1985 survey and the 1986 survey of this pipeline. Refer to the "COMPARISON" section of this report.

This was the initial or baseline survey of the 10 inch pipeline from Platform Gilda to Mandalay, conducted by Linalog®.

LINALOG SURVEY EQUIPMENT

THE "DUMMY" TOOL

A sizing tool, known as a "Dummy Tool", is run through the pipeline prior to running the Linalog® Survey Tool. The "Dummy Tool" is used as a gauge to check the pipeline for any restrictions which could impede the movement of, or severely damage, the Linalog® Survey Tool. The Dummy is similar in appearance to the Linalog® Survey Tool but contains no instrumentation.

LINALOG® SURVEY TOOL

The Linalog® Survey Tool is a self-contained unit that is inserted into, propelled through, and extracted from the pipeline in the same manner as a conventional cleaning pig.

The lengths of the different size tools used on this survey include:

SIZE	TYPE	LENGTH
6"	3 SGL	7' 11"
10"	3 SGL	9' 11"

Each tool is made in five sections, which are connected by universal joints ("U" joints). The "U" joints allow the Linalog® Tool to negotiate the bends in a pipeline (See Figure 1).

The first section is the "Drive Section". It is supported in the pipeline by scraper cups, which provide a tight seal inside the pipe. This allows the pipeline throughput to propel the inspection tool. A marker detecting device is mounted between the cups. Its function is explained in the "LINALOG® SURVEY RECORD" section of this report.

The second section is the "Magnetizer Section" which magnetizes the pipe and supports the survey shoes. The magnetizer is supported in the pipeline by a set of steel brushes at each end. These brushes provide a path for the magnetic lines of flux to enter the pipe wall. The survey shoes contain the corrosion survey sensors. These shoes, and the sensors in them, overlap one another to provide complete 360° coverage of the pipe wall.

Information signals from the survey sensors are recorded on the survey channels. The function of the survey channels is explained in the "LINALOG® SURVEY RECORD" section of this report.

The third section is the "Distance Measuring Section". It is centralized in the pipeline by scraper cups mounted at each end. The distance measuring wheel is mounted between the scraper cups. Its function is explained in the "LINALOG® SURVEY RECORD" section of this report.

The fourth section is the "Battery Section". The batteries furnish the electrical power needed to operate the Linalog® Tool. A scraper cup on the rear end supports and centralizes this section in the pipeline.

The fifth section is the "Recorder Section". It is supported in the pipeline by a scraper cup mounted on the rear end. The recorder section houses the magnetic tape recorder and the electronic circuits. The recorder and the electronic circuits process the data from the various sensors and a recording is made on magnetic tape. The recorder was equipped with "Speed Gain Compensation" (SGC) which automatically adjusts the sensitivity of the survey electronics to compensate for tool speed variations.

OPERATING PRINCIPLE

The Linalog® Tool operates on the flux-leakage principle. A magnetic field is induced into the pipe wall by the magnetizer section as it moves through the pipeline. This magnetic field travels with the tool. When an anomaly is encountered in the pipe wall, the magnetic flux is forced out of the pipe at the anomaly (See Figure 2). This is called flux-leakage. The Linalog® Tool detects this flux-leakage and records a corresponding signal on magnetic tape. Line pipe usually contains small manufacturing imperfections, so some amount of background signals can be expected.

We can generalize and say that the amplitude of a corrosion pitting signal on the log is proportional to the depth of the pitting on the pipeline. This is the basis for the grade classifications used to evaluate the condition of the pipeline. For more detailed information, refer to the "GRADING SYSTEM" section of this report.

PLAYBACK SYSTEM

After the Linalog® Survey Tool is removed from the pipeline, the magnetic tape which contains the recorded data is removed from the recorder and placed on the "Playback System". The Playback System converts the recorded data into a temporary paper graph known as the "Field Log". The field log is then interpreted by the field inspector to verify that the tool has performed satisfactorily. If a verification dig is to be made, the field log is used to locate a suitable area.

When the magnetic tape is returned to the Linalog® Division Office, it is played back again to make a permanent paper graph called the "Linalog® Survey Record" or "Master Log".

LINALOG® SURVEY RECORD

The Linalog® Survey Record, referred to as the "Log", consists of multiple channels of information. Logs of 6 inch diameter pipelines have 10 channels of information consisting of a marker channel, 8 survey channels, and a combination distance/orientation channel (See Figure 5). Logs of 10 inch diameter pipelines have the same channels which are common to the 6 inch log with the exception of four additional survey channels (See Figure 9).

MARKER CHANNEL

The Marker channel is used as an aid in recognizing girth welds and helps identify magnets when placed on the pipeline to serve as reference markers. Natural pipeline features such as valves, flanges and sleeves, are also recorded on the marker channel. They too are used as reference markers. These reference markers are used as a starting point for locating corrosion and other features of interest by the pipeline that are indicated on the log. Refer to the section of this report on "USING THE RECORD". *Anodes were used as reference markers on the 10 inch pipeline (See Figure 10).

SURVEY CHANNELS

The survey channels show the anomalies, encountered in the body wall of the pipeline. These anomalies include corrosion, girth welds, magnets, valves, flanges, taps, saddles, anchors, patches, clamps and manufacturing irregularities. These anomalies are detected by the survey shoes.

When the log is interpreted, each joint of pipe in the pipeline is examined, and a numerical or letter grade is assigned to those joints which contain anomaly indications of sufficient magnitude to be classified in one of the grading categories. Refer to the "GRADING SYSTEM" section.

Examples of anomaly classification and grading are shown on Figures 9 and 11.

Survey channel 8, on the 6 inch Mandalay to Platform Gina survey, was dead at the launch (See Figure 5). Channel 2 began to fail at wheel count 565 (See Figure 6). On the 10 inch Platform Gilda to Mandalay survey, channel 6 was damaged at approximately 44145 feet (See Figure 12). It became progressively worse (See Figure 13) and eventually failed (See Figure 14 and 15).

DISTANCE MEASURING/ORIENTATION CHANNEL

This channel displays the distance measurement the tool recorded as it traveled through the pipeline as well as the orientation of the tool at any given point on the log. An individual mark for each one foot of pipeline length is displayed. These unit "Wheel Counts" are recorded in multiples of one, ten, one hundred and one thousand. An amplitude differentiated signal is recorded on the log for each multiple (See Figure 3). Each thousand count is marked cumulatively throughout the log.

The total "Wheel Count" is shown on the log at each pipeline reference mark. (See Figures 5 and 9). This is read directly from the distance channel.

The length of the pipeline from the launch to any point of interest (reference marker, anomaly indication, etc.) is the wheel count at the point of interest minus the wheel count at the launch. This calculation is necessary since the distance wheel circuitry cannot be made to start a zero count at the launch valve.

The distance channel also indicates whether or not the Linalog® Tool traveled at a uniform velocity. Uniform spacing indicates that a steady velocity was maintained during the survey. Variable spacing between wheel counts indicates a changing velocity. As tool speed decreases, this spacing increases; as tool speed increases, this spacing decreases.

The orientation of the tool is also displayed by the distance channel. The orientation channel records the rotation of the inspection tool as it moves through the pipeline. The tool is designed to rotate so that wear on the scraper cups, brushes, detectors (shoes), etc. is more uniformly distributed.

As the tool rotates, the individual footage pulses steadily begin to decrease until the tool has completed a 360 degree revoulution. At this time the individual footage pulses again return to their preset maximum height to indicate the next rotation sequence (See Figure 4). The top of the pipe is being recorded on the first survey channel when the individual footage pulses are at their maximum height and the last survey channel is recording the top of the pipe when the individual footage pulses are at their minimum height.

The top of the pipe (12 o'clock position) can be plotted on the log for each rotation cycle by drawing a diagonal line from left to right starting with the survey channel recording the top of the pipe at the beginning of the rotation cycle to the survey channel recording the top of the pipe at the end of the rotation cycle. The bottom of the pipe (6 o'clock position) follows a parallel diagonal path across the log that is half way around the top of the pipe. This is shown on Figure 4.

The approximate o'clock position of the anomaly on the pipe can be determined from the log in the following manner. (See Figure 4).

1. Locate the top of the pipe in the joint of pipe containing the anomaly indication.

2. Assume you are standing on the top of the pipe (12 o'clock position) on the joint containing the anomaly indication and looking downstream toward the receiving trap. Turn the log viewer so you are looking downstream toward the receiving trap on the log.

3. The 3 o'clock position is to the right of the 12 o'clock position mid-way between 12 and 6 o'clock.

4. The 9 o'clock position is to the left of the 12 o'clock position mid-way between 12 and 6 o'clock.

5. The other o'clock positions are located in a similar manner between positions.

The orientation channel is intended to locate the quadrant of the pipe where the anomaly can be found. It is not intended to locate the anomaly as being a specified number of degrees off the top dead center position on the pipe.

Figure 4 is a typical example illustrating how to interpret the orientation channel. It was not taken from the logs covered by this report.

SCALE SHEET

A scale sheet accompanies each log. It lists the markers used on the pipeline and shows their location on both the pipeline and the log (See Figures 16-20). The "Line Marks" column is the type of reference marker on the pipeline. The "Map Station" column is the station number of the reference marker, expressed in feet, and taken from information supplied by the customer. The "Map Distance" column is the distance in feet from the preceding reference marker, derived from the station numbers. The "Wheel Count" column is the reading of the Linalog® Distance Measuring Channel, expressed in feet, at each reference marker. The "Wheel Distance" column is the distance from the preceding reference marker to this one, derived from the wheel count.

The "Map Station" and "Map Distance" columns are blank when station numbers are unavailable.

GRADING SYSTEM

PREFACE

The Linalog® Tool operates on the flux-leakage principle. Flux-leakage is an indirect method of finding and evaluating anomalies in pipe. This can be understood best by first defining direct evaluation. Direct evaluation would be to actually see and measure each anomaly as you would if the joint of pipe was on a pipe rack. You could then see and examine both the inside and the outside surfaces. This is not practical in a pipeline so we must resort to indirect methods to inspect it. Flux-leakage is one of these methods. A magnetic field is induced into the pipe. The amount of distortion in the magnetic field, caused by an anomaly in the pipewall, is detected, measured, and evaluated.

TYPES OF ANOMALY

Linalog® detects anomalies that produce a disturbance in the magnetic field that has been induced into the pipe wall by the inspection tool. These include a wide range of service related enviromental anomalies, mill or manufacturing anomalies and anomalies put in the pipe during handling, transportation and construction. They can be on the external or internal surface. Typical examples are corrosion pits, seams, overlaps, slugs, slivers, scratches, grinding marks, inclusions or laminations that break the surface, uneven or high trim of longitudinal weld seams, mis-matched plate edge at the longitudinal weld seams, gouges, welding marks and some hard spots.

INTERPRETING THE LOG

Each joint of pipe is evaluated individually. Due consideration is given to the joints on either side to maintain continuity and perspective. The grade assigned to the joint of pipe is the grade that applies to the highest amplitude corrosion anomaly indication in that joint of pipe. Each individual anomaly indication is not graded in the joint of pipe. Once the grade for a joint has been determined, that grade is stamped at the top of the log as follows:

Grade 1 is assigned to anomaly indications which, we beleive, indicate more than 15% but less than 30% body wall penetration.

Grade 2 is assigned to anomaly indications which, we believe, indicate more than 30% but less than 50% body wall penetration.

Grade 3 is assigned to anomaly indications which, we believe, indicate 50% or more body wall penetration.

Grade "U" means unclassified anomaly. This grade is assigned to anomaly indications which, we believe, are not associated with significant deterioration of the pipe wall. They may be caused by manufacturing irregularities in the pipe wall, which existed before the pipeline was put into service, or by something attached to the pipeline. Unclassified anomalies show on the log in a wide range of shapes, patterns, and amplitudes depending on the nature of the anomaly.

No grade classification is assigned to anomaly indications which, we believe, indicate 15% or less body wall penetration.

If there is doubt as to the cause of the anomaly indication, it is classified as corrosion.

The number of survey channels on the log, on which an anomaly indication appears, indicates approximately how far around the pipe the actual anomaly extends. For example, an anomaly indication that shows on half of the survey channels on the log will extend about half way around the pipe. "Half-sole" patches are a good example of this. Likewise, an anomaly indication that shows on all the survey channels on the log will extend completely around the pipe. Girth welds are a good example of this. Following this line of reasoning, we would normally expect a single small area (for example, 1/2" dia.) isolated pit on the pipe to show on only one survey channel on the log. However, it can, and sometimes does, show on two adjacent survey channels. The explanation of this is that when the middle of the detector (shoe) passes over the pit, the indication will be on one survey channel on the log, and when the overlapping edge of two adjacent detectors passes over the pit, the indication will be on two adjacent survey channels. The overlapping of the detectors is necessary to ensure a complete 360 degree inspection of the pipeline. Since we cannot control whether the center of one detector, or the overlapping edge of two adjacent detectors, passes over the pit, we must consider and recognize this when interpreting the log.

The extent of an anomaly indication on the log, in the longitudinal direction of the log, indicates how far the actual anomaly on the pipe extends along the length of the joint of pipe. Suppose there is an isolated area of pitting, about one foot in length, near the middle of the joint of pipe. This would show on the log as an isolated group of indications, about one foot in length, according to the distance measuring channel on the log. However, suppose the pitted area on the pipe started near the middle of the joint and extended to the downstream girth weld. In this case, the log would show a group of anomaly indications on the survey channels beginning near the middle of the joint of pipe and extending to the girth weld at the downstream end of the joint.

It is therefore possible to determine the approximate size of the pitted area, or other anomaly, on the pipe by observing (a) the number of survey channels on the log on which the anomaly indications appear, and (b) how far along the longitudinal direction of the log the group of anomaly indications extend.

Many of the mill or manufacturing anomalies, such as seams and overlaps, slugs, slivers, circumferential cracks and scratches, grinding marks, inclusions or laminations that break the surface, etc., often produce a higher amplitude indication on the log than their depth justifies. These anomalies are included in the "U" (unclassified anomaly) classification because their higher amplitude signals are uniquely different from normal low amplitude signals which are characteristic of pipeline corrosion. Many of the class "U" indications are on the inside of the pipe, and consequently, could not be easily seen by external visual inspection when the pipe was made. They are difficult to find and evaluate by ultrasonics and radiography due to the small area and shallow penetration many of them have. However, these anomalies disturb the magnetic field in the pipe and Linalog® detects them. Many of these anomalies that break the surface introduce two factors which occur simultaneously to make the anomaly indication we see on the log. First, there is the disturbance in the magnetic field. Second, these anomalies sometimes have a thin edge, projecting into the inside of the pipe, that is turned up by the drive cups on the tool before the detectors in the magnetizer section passes over them. The detector bounces as it goes over this turned up edge. The detector receives the signal, caused by the bounce, at the same time it receives the signal, caused by the disturbance in the magnetic field. These two simultaneous signals combine and

USING THE RECORD

LOCATING AND UNCOVERING ANOMALIES

By using the distance channel on the log, desired areas can be located accurately in the following manner:

1. Choose an area of interest on the log.

2. Find the nearest reference marker (Magnet, Flange, Valve, etc.) and note its location on the log by using the wheel count from the distance channel.

3. Determine the girth weld closest to the anomaly of concern (upstream or downstream) and mark the girth weld location by using the wheel count from the distance channel.

4. The difference between the reference marker wheel count and the girth weld wheel count will yield the distance measurement, in feet, needed for the dig location of the chosen girth weld. (Upon digging, if the measurement is reasonably close to a girth weld, you can be confident that the measurement is correct and that the desired girth weld has been found).

5. Determine the location of the anomaly of concern by using the wheel count from the distance channel on the log.

6. The difference between the chosen girth weld wheel count and the anomaly wheel count will yield the distance measurement, in feet, needed to uncover the anomaly.

7. By using the orientation channel on the log an approximate o'clock position of the anomaly can be determined.

Since the log shows the length of each joint of pipe in the pipeline, measuring an actual joint of pipe in the ground and comparing it to the log measurement is a good way to verify correct location. This is especially true if the joint of pipe is shorter than those on either side.

Note: When measuring distances, be sure to signify whether the measurement is to be made upstream or downstream. (Reference marks, Girth welds, Anomalies). Record as such for accuracy.

RESULTS

The tabulation below shows the number of anodes assigned to the various anomaly grade classifications between pipeline reference markers for each pipeline.

WHEEL COUNT		GRADE CLASSIFICATION 1	2	3	U
6" MANDALAY TO PLATFORM GINA					
ROLL NO. 1					
17	LAUNCH	-	-	-	-
32,540	DIST CH. QUIT (TRAP)	90	15	2	-
TOTAL OF PIPELINE		90	15	2	-

WHEEL COUNT		GRADE CLASSIFICATION 1	2	3	U
10" PLATFORM GILDA TO MANDALAY					
ROLL NO. 1					
70	LAUNCH	-	-	-	-
960	ANODE	3	-	-	-
1523	ANODE	-	-	-	-
2126	ANODE	-	-	-	-
2730	ANODE	-	-	-	-
3333	ANODE	-	-	-	-
3936	ANODE	-	-	-	-
4539	ANODE	-	-	-	-
5142	ANODE	-	-	-	-
5745	ANODE	-	-	-	-
6349	ANODE	-	-	-	-
6953	ANODE	-	-	-	-
7555	ANODE	-	-	-	-
8159	ANODE	-	-	-	-
8762	ANODE	-	-	-	-
9365	ANODE	-	-	-	1
9969	ANODE	-	-	-	-
10572	ANODE	-	-	-	-
11176	ANODE	-	-	-	-

11779	ANODE	-	-	-	-
12383	ANODE	-	-	-	-
12984	ANODE	-	-	-	-
13590	ANODE	-	-	-	-
14193	ANODE	-	-	-	-
14796	ANODE	-	-	-	-
15400	ANODE	-	-	-	-
16003	ANODE	-	-	-	-
16607	ANODE	-	-	-	-
17210	ANODE	-	-	-	-
17813	ANODE	-	-	-	-
18417	ANODE	-	-	-	-
19020	ANODE	-	-	-	-
19624	ANODE	-	-	-	-
20217	ANODE	-	-	-	-
20831	ANODE	-	-	-	-
21434	ANODE	-	-	-	-
22038	ANODE	-	-	-	-
22640	ANODE	-	-	-	-
23244	ANODE	-	-	-	-
23846	ANODE	-	-	-	-
24449	ANODE	-	-	-	-
25053	ANODE	-	-	-	-
25656	ANODE	-	-	-	-
26259	ANODE	-	-	-	-
26863	ANODE	-	-	-	-
27466	ANODE	-	-	-	-
28070	ANODE	-	-	-	-
28674	ANODE	-	-	-	-
29278	ANODE	-	-	-	-
29881	ANODE	-	-	-	-
30484	ANODE	-	-	-	-
31088	ANODE	-	-	-	-
31691	ANODE	-	-	-	-
32295	ANODE	-	-	-	-
32898	ANODE	-	-	-	-
33502	ANODE	-	-	-	-
34105	ANODE	-	-	-	-
34709	ANODE	-	-	-	-
35312	ANODE	-	-	-	-
35916	ANODE	-	-	-	-

WHEEL COUNT		GRADE CLASSIFICATION 1	2	3	U
10" PLATFORM GILDA TO MANDALAY					
ROLL NO. 1 (CONT.)					
36519	ANODE	-	-	-	-
37123	ANODE	-	-	-	-
37727	ANODE	-	-	-	-
38330	ANODE	-	-	-	-
38933	ANODE	-	-	-	-
39537	ANODE	-	-	-	-
40140	ANODE	-	-	-	-
40744	ANODE	-	-	-	-
41347	ANODE	-	-	-	-
41951	ANODE	-	-	-	-
42554	ANODE	-	-	-	-
43158	ANODE	-	-	-	-
43761	ANODE	-	-	-	1
44365	ANODE	-	-	-	-
44968	ANODE	-	-	-	-
45571	ANODE	-	-	-	-
46175	ANODE	-	-	-	-
46778	ANODE	-	-	-	-
47382	ANODE	-	-	-	-
47985	ANODE	-	-	-	-
48589	ANODE	-	-	-	-
49192	ANODE	-	-	-	-
49795	ANODE	-	-	-	-
49836	ANODE	-	-	-	-
50198	ANODE	-	-	-	-
50560	ANODE	-	-	-	-
50922	ANODE	-	-	-	-
51284	ANODE	-	1	-	-
51646	ANODE	-	-	-	-
52008	ANODE	-	1	-	-
52370	ANODE	-	-	-	-
52732	ANODE	1	-	-	-
53191	ANODE	-	-	-	-
53424	TRAP	-	-	-	2
		-	-	-	-
TOTAL OF PIPELINE		4	2	-	4

Corrosion control programs reduce the rate of deterioration and stabilize the condition of a pipeline. Result: some anomaly indications remain virtually unchanged from one survey to the next.

Some anomaly indications on the log may have been up-graded from the previous grade to the current one, i.e. from "no grade" to "Grade 1" to "Grade 2" or from "Grade 2" to "Grade 3". This normally indicates a growth in corrosion. However, it can sometimes be attributed to normal tolerances and variations in detector to defect incidence (whether the defect passes across the middle of the detector or acrss the overlapping edge of two adjacent detectors) that normally occur from run to run. Also, it is our policy to grade anomaly indications as corrosion if there is doubt about what the anomaly is.

Some anomaly indications, that showed on the previous log, may be "down-graded" to a less severe grade classification (from "Grade 3" to "Grade 2", etc.) on the current log. Reason: the amplitude of the indication is lower on the current log than on the previous one. This is caused by normal variations between runs, such as detector to defect incidence, which was discussed previously.

Some anomaly indications, graded on the previous log, may not be graded on the current log for several reason as:

1. The pipe has been repaired or replaced since the last survey. These areas are marked on the log where indentifiable.

2. The indications were caused by loose debris (dirt, welding rods, etc.) which has been swept away since the previous survey. In this case, the anomaly indication disappears from the joint of pipe.

3. One or more shoes were prevented from touching the pipe properly by excessive amounts of paraffin or other foreign material in the pipeline. Result: the anomaly in the pipe is not detected.

4. The amplitude of the indication is below the minimum grading level. Here, the anomaly indication may still show on the log, but its amplitude is too low to justify a grade classification. This is also caused by normal variations between runs, such as detector to defect incidence, which was discussed previously.

CONCLUSION

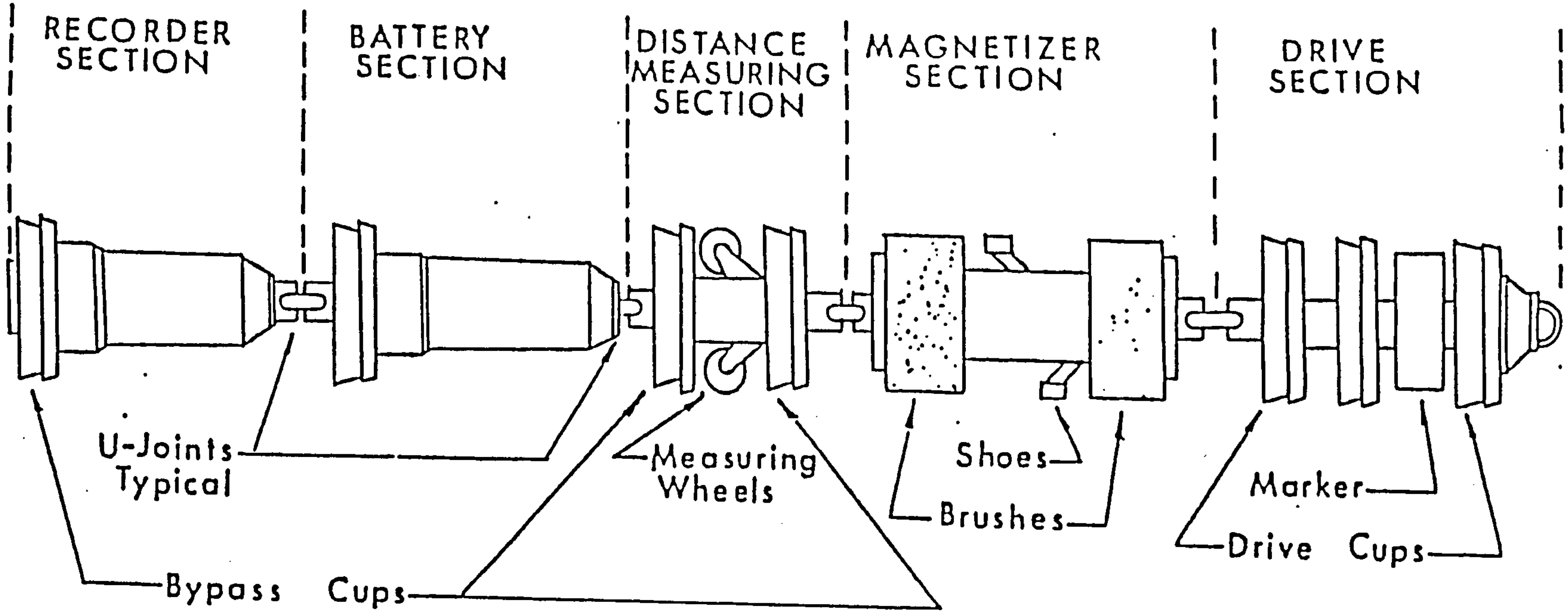
The corrosion survey showed the existence of magnetic anomalies in each pipeline as listed in the "RESULTS" section of this report.

The grading of the logs is our "good faith opinion" about the condition of the pipelines at the time they were surveyed.

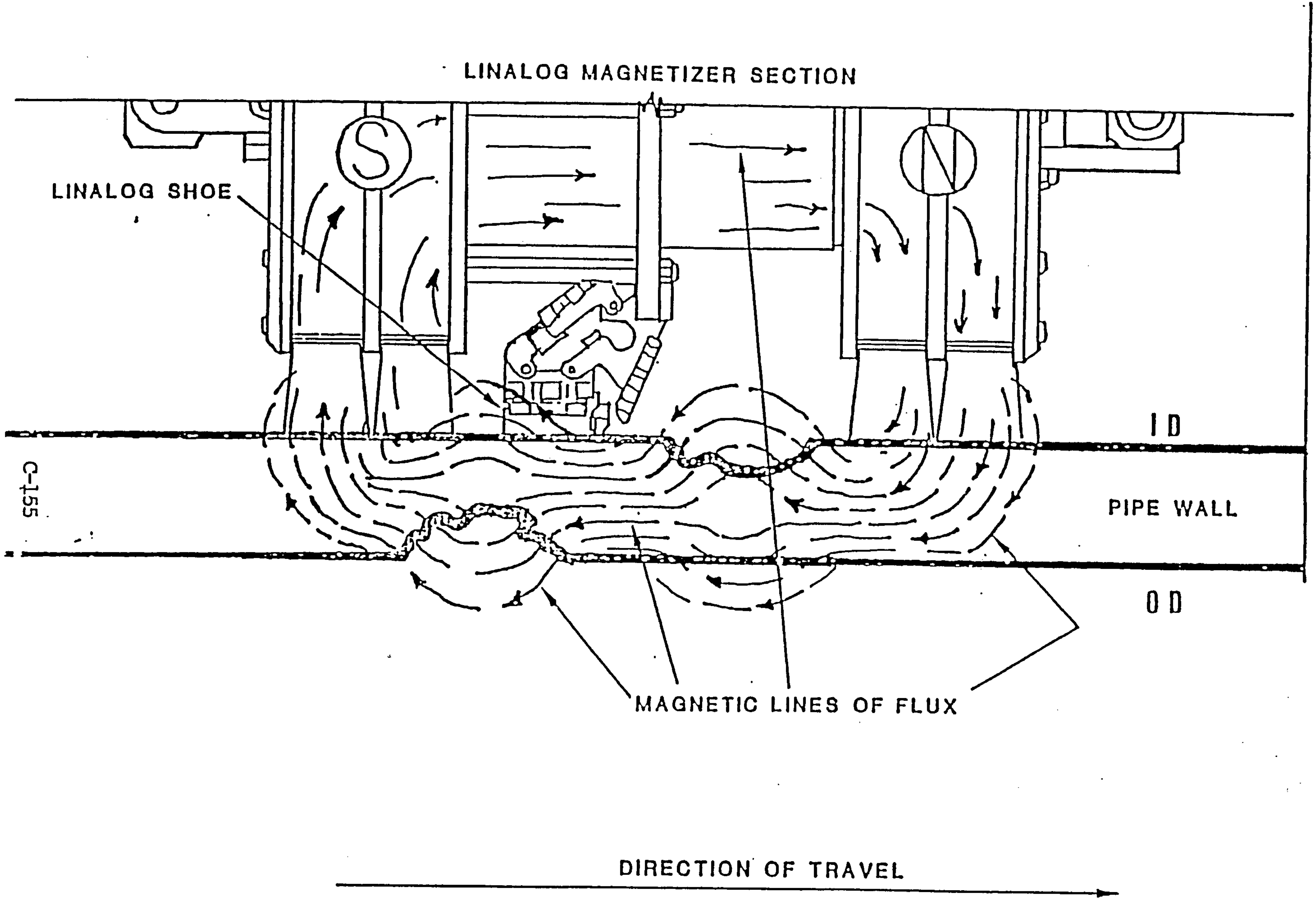
The survey was completed with the pipelines in place, delivering the throughput desired. The logs have been analyzed and graded, scale sheets have been provided and the survey report has been written. The survey of these sections is considered to be successful and complete.

Thank you for your confidence and trust in AMF Tuboscope. We sincerely hope you will continue to use our services in the future. If we can be any further assistance to you, please contact our office.

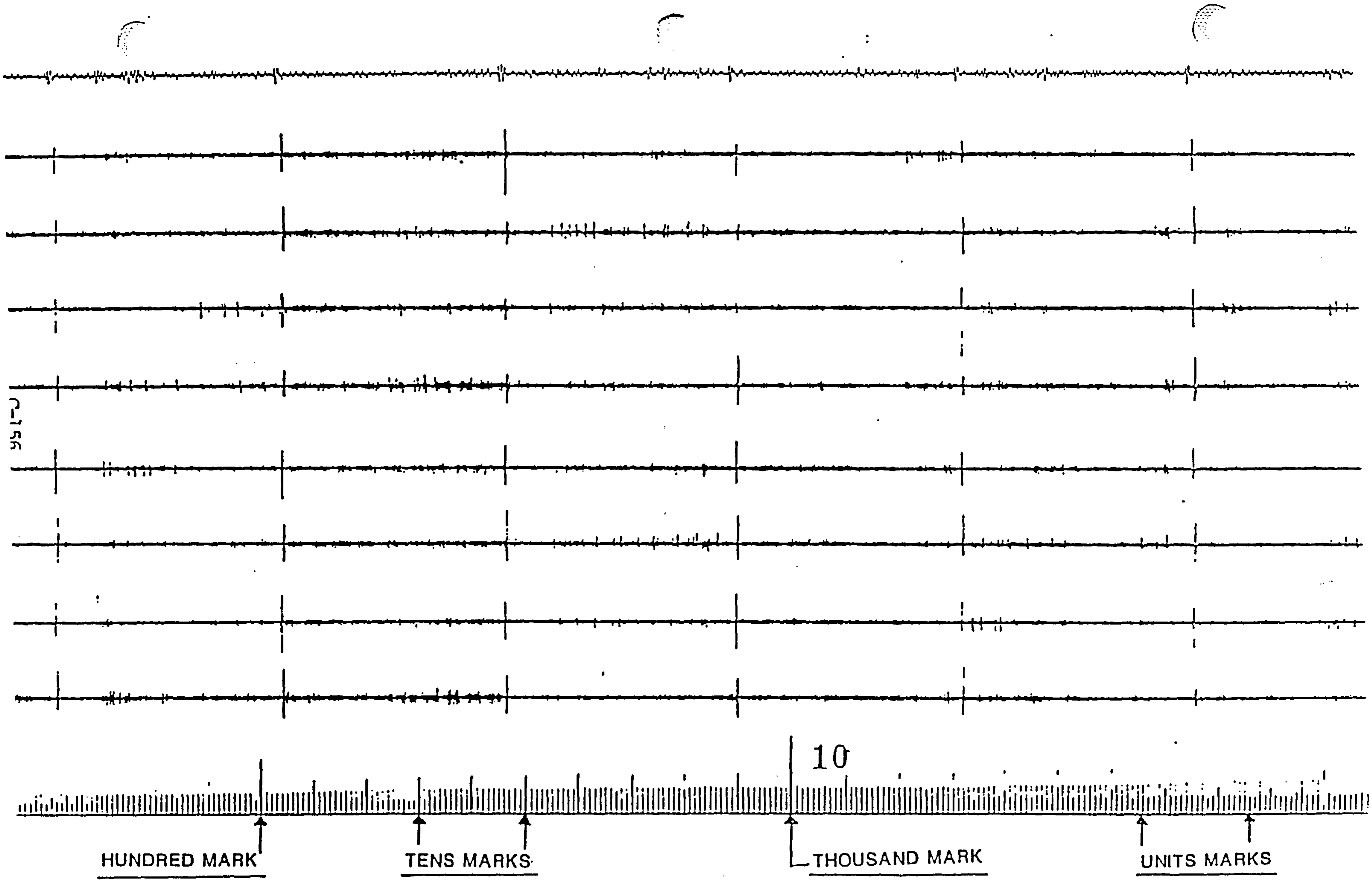
FIGURES AND EXAMPLES



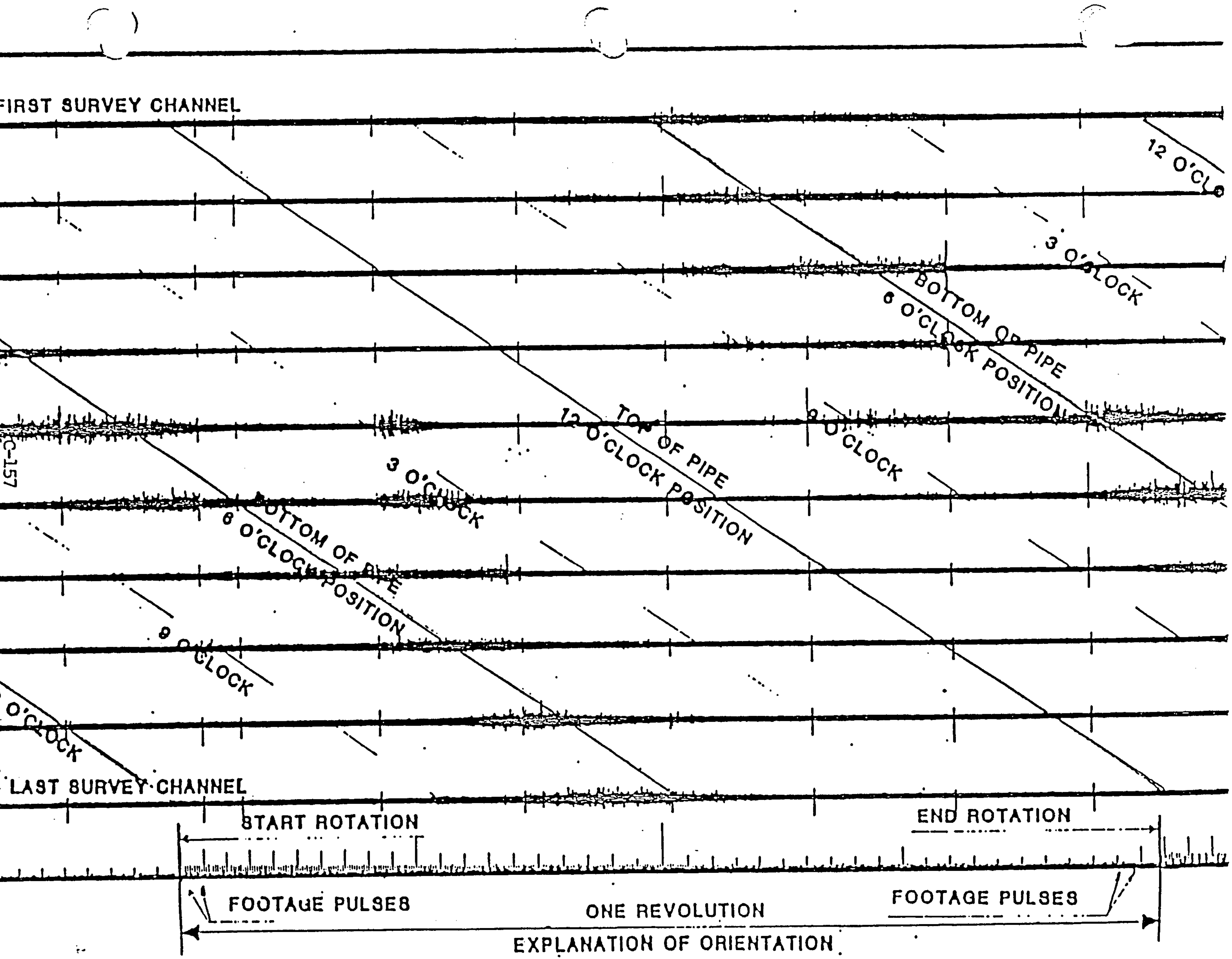
6" AND 10" LINALOG SURVEY TOOL



FLUX-LEAKAGE EXAMPLE

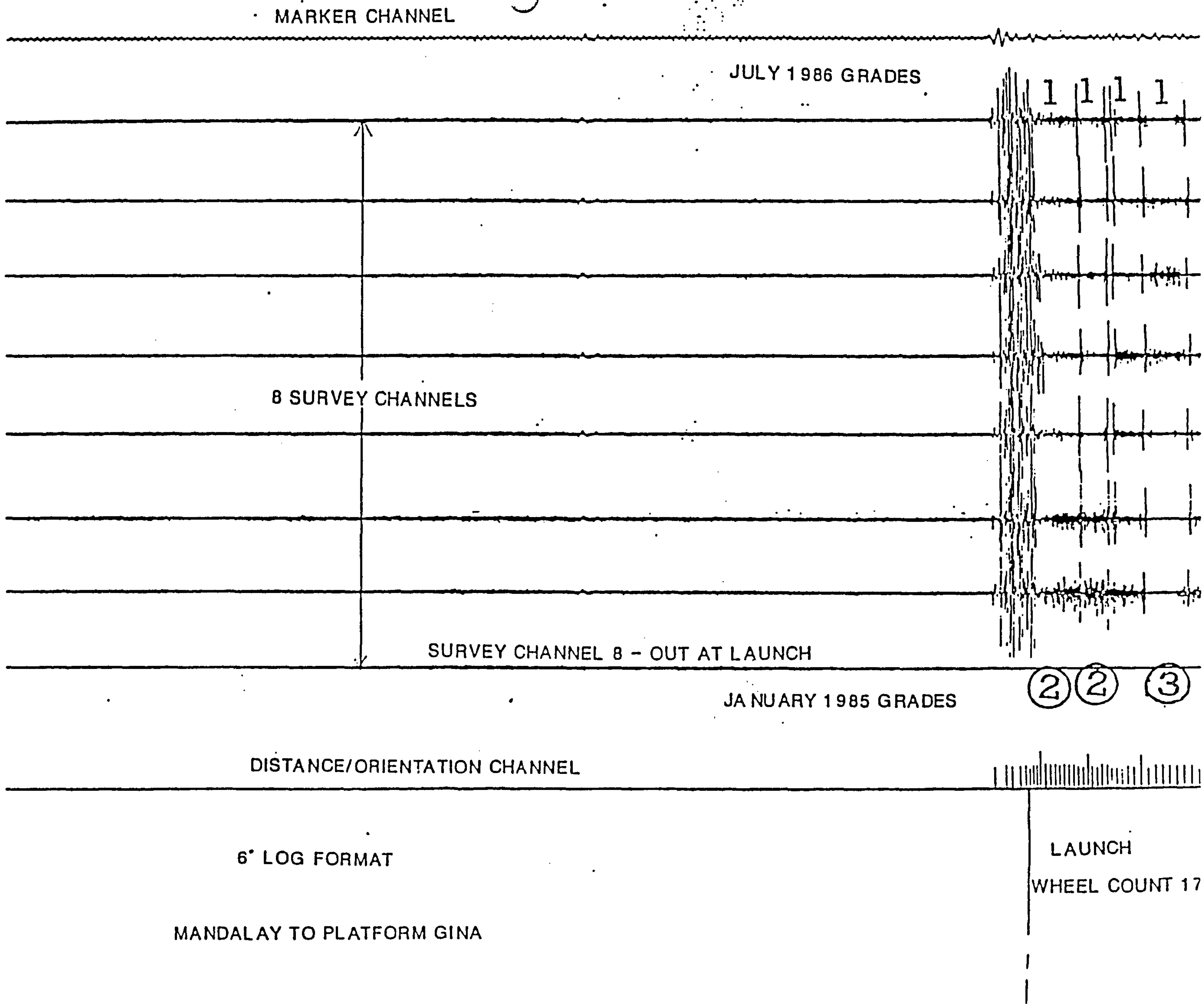


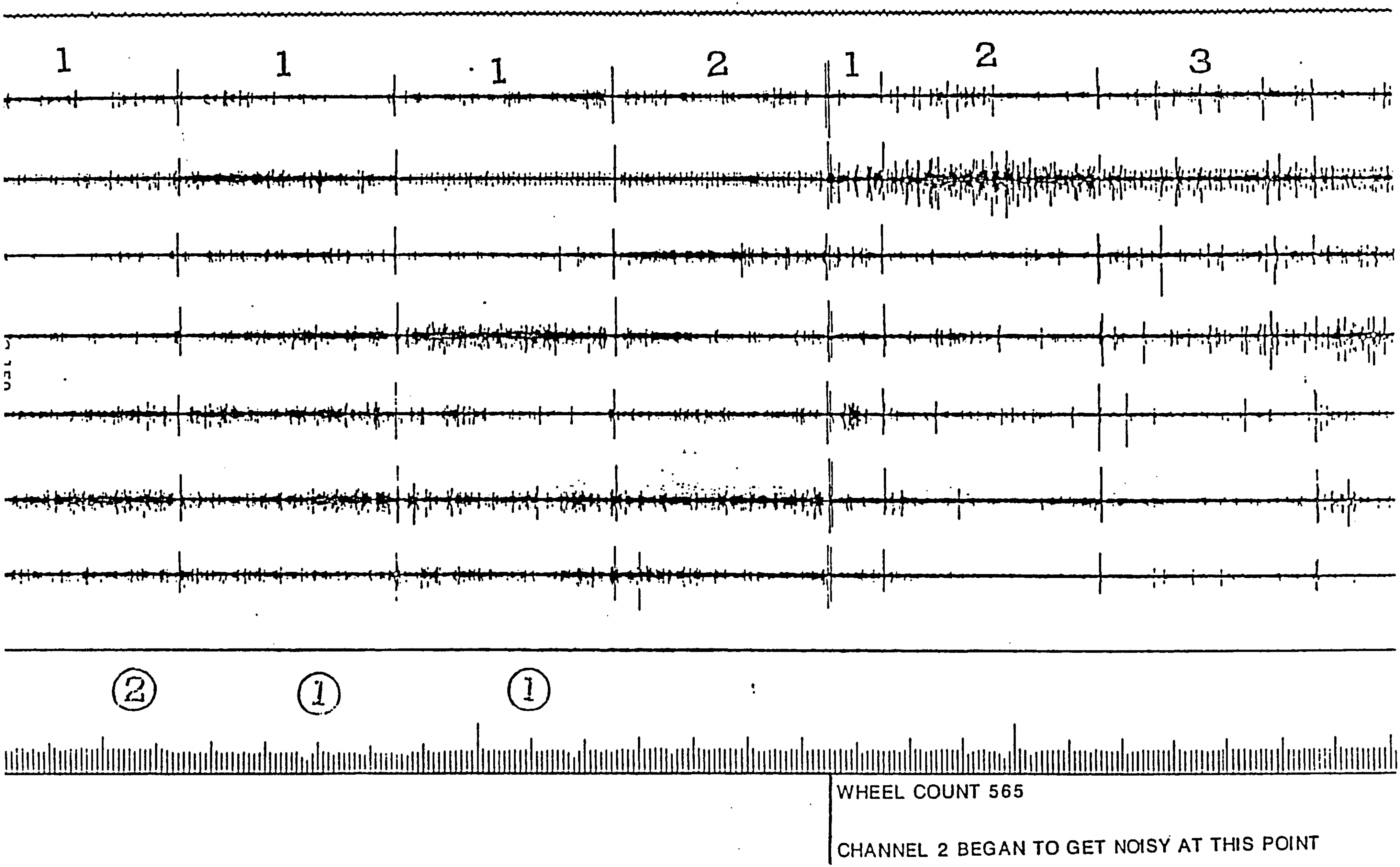
DISTANCE CHANNEL EXAMPLE *NOT TAKEN FROM THIS SURVEY



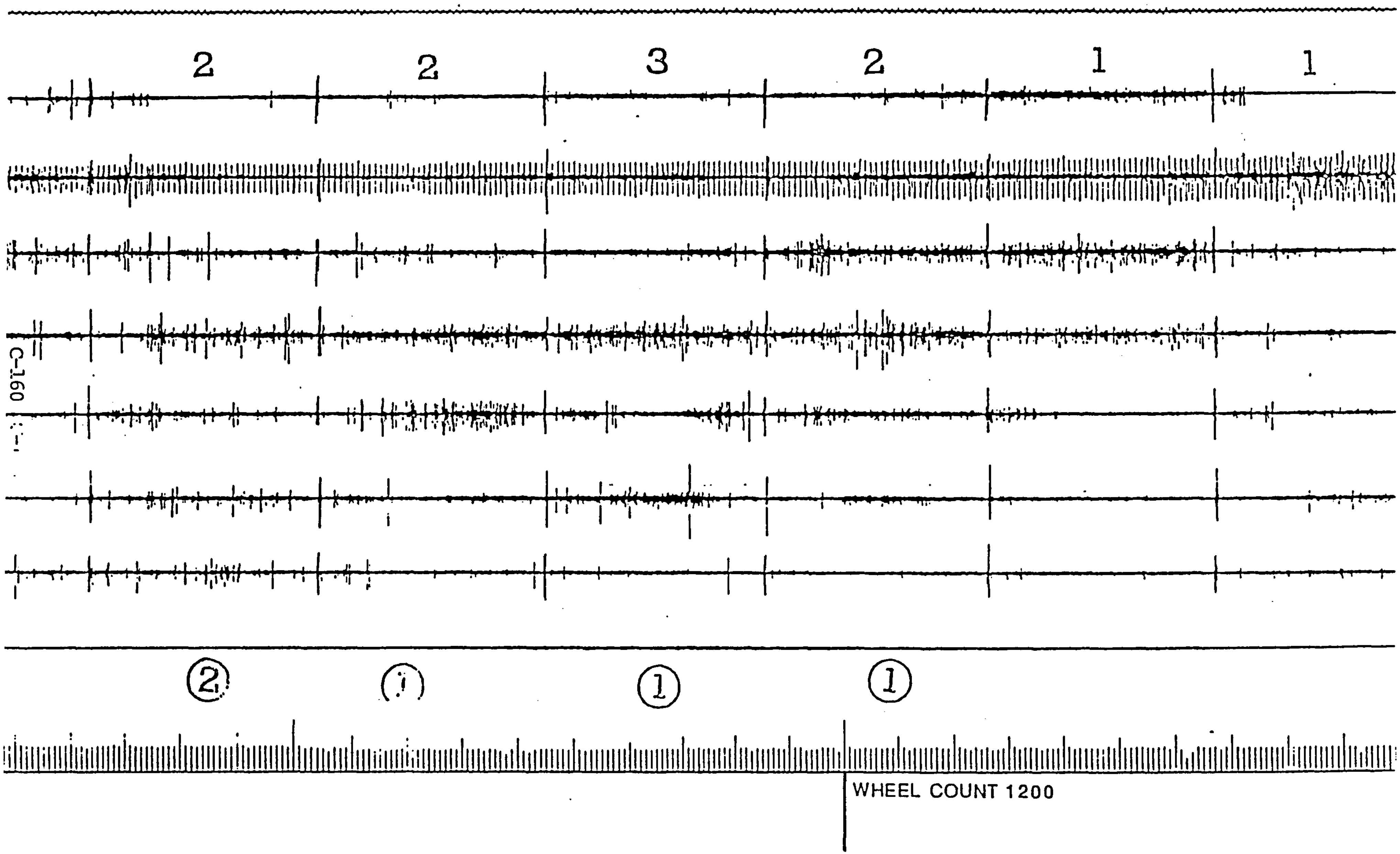
FIRST SURVEY CHANNEL
12 O'CLO
3 O'CLOCK
BOTTOM OF PIPE
6 O'CLOCK POSITION
9 O'CLOCK
TOP OF PIPE
12 O'CLOCK POSITION
3 O'CLOCK
BOTTOM OF PIPE
6 O'CLOCK POSITION
9 O'CLOCK
2 O'CLOCK
LAST SURVEY CHANNEL
START ROTATION
END ROTATION
FOOTAGE PULSES
ONE REVOLUTION
FOOTAGE PULSES
EXPLANATION OF ORIENTATION

FIG. 4


MARKER CHANNEL
JULY 1986 GRADES
1 1 1 1
8 SURVEY CHANNELS
SURVEY CHANNEL 8 - OUT AT LAUNCH
2 2 3
JANUARY 1985 GRADES
DISTANCE/ORIENTATION CHANNEL
6" LOG FORMAT
LAUNCH
WHEEL COUNT 17
MANDALAY TO PLATFORM GINA



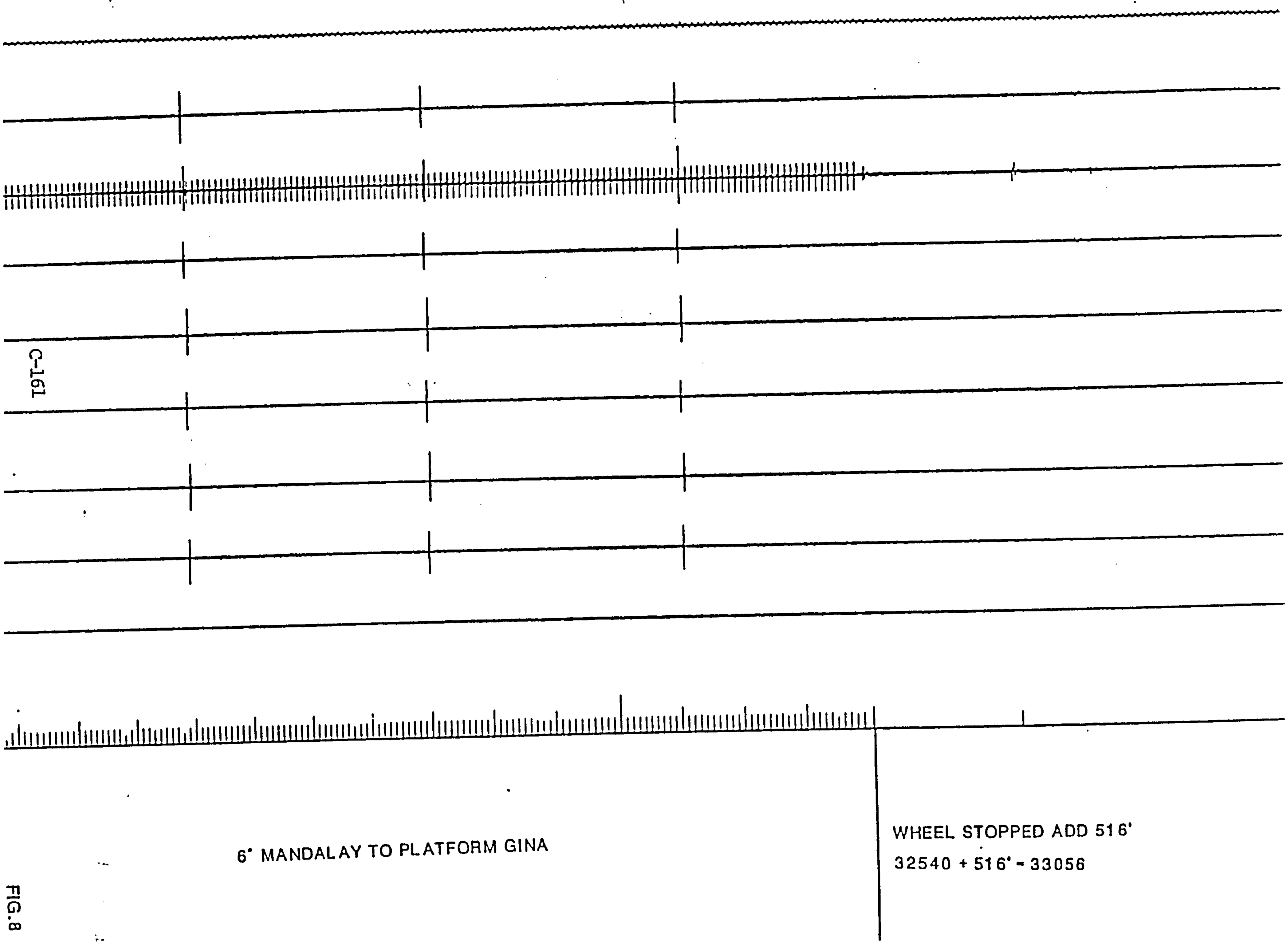
6" MANDALAY TO PLATFORM GINA



GRADE 1,2,3 ANOMALIES

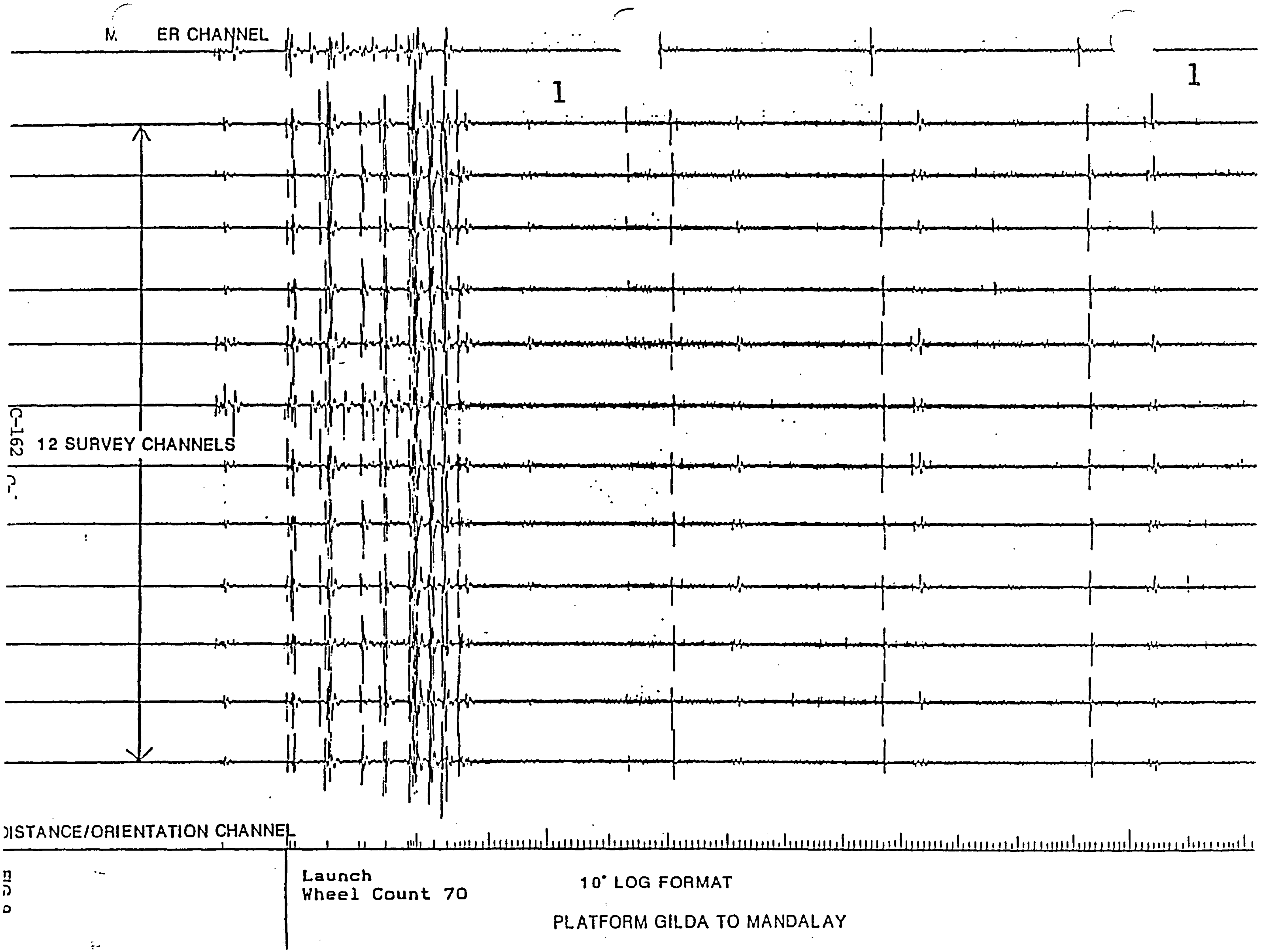
6" MANDALAY TO PLATFORM GINA

FIG.7

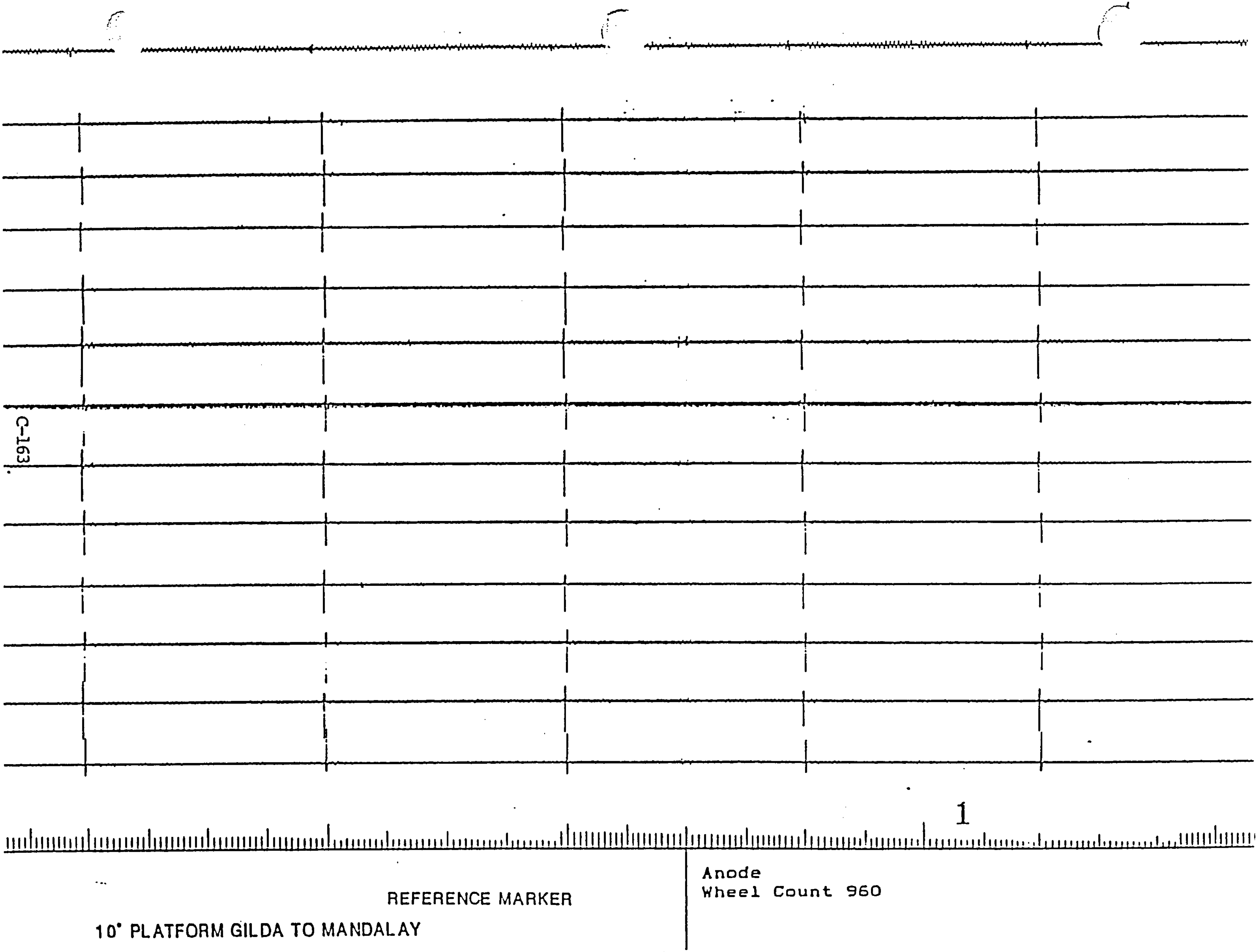


6" MANDALAY TO PLATFORM GINA
WHEEL STOPPED ADD 516'
32540 + 516' = 33056

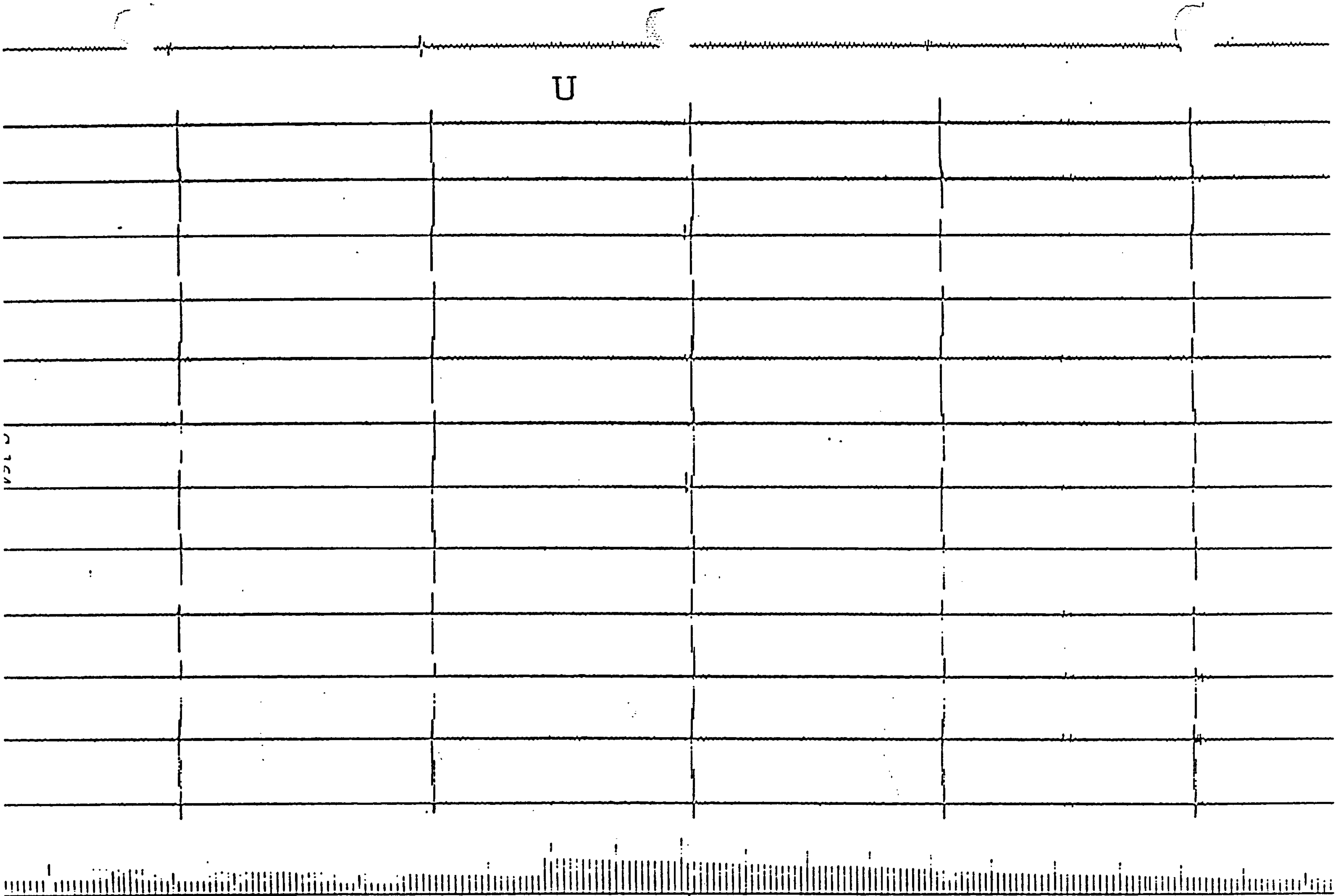
FIG.8


M ER CHANNEL
1
1
12 SURVEY CHANNELS
DISTANCE/ORIENTATION CHANNEL
Launch
Wheel Count 70
10" LOG FORMAT
PLATFORM GILDA TO MANDALAY

C-162



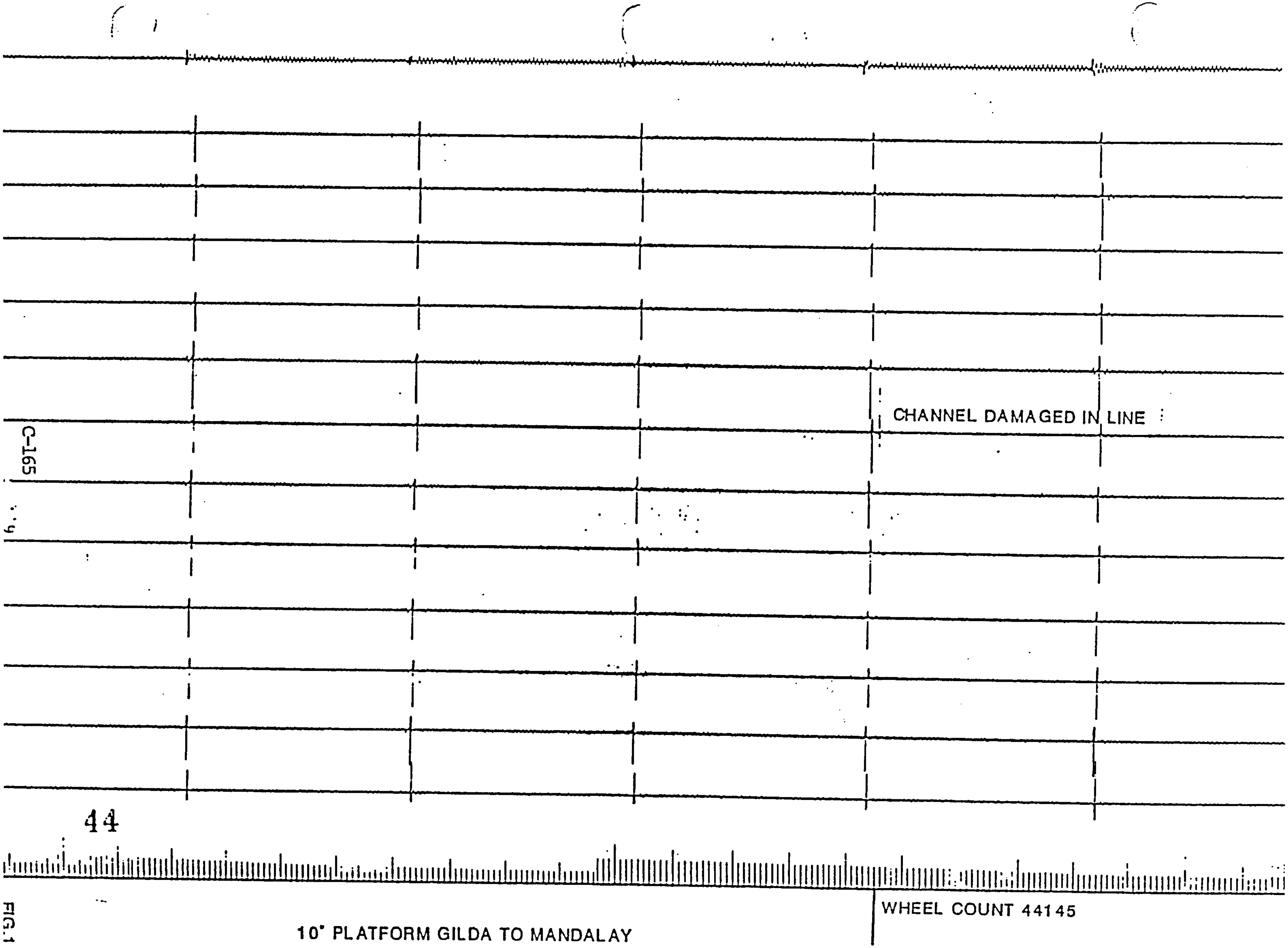
10' PLATFORM GILDA TO MANDALAY



UNCLASSIFIED ANOMALY

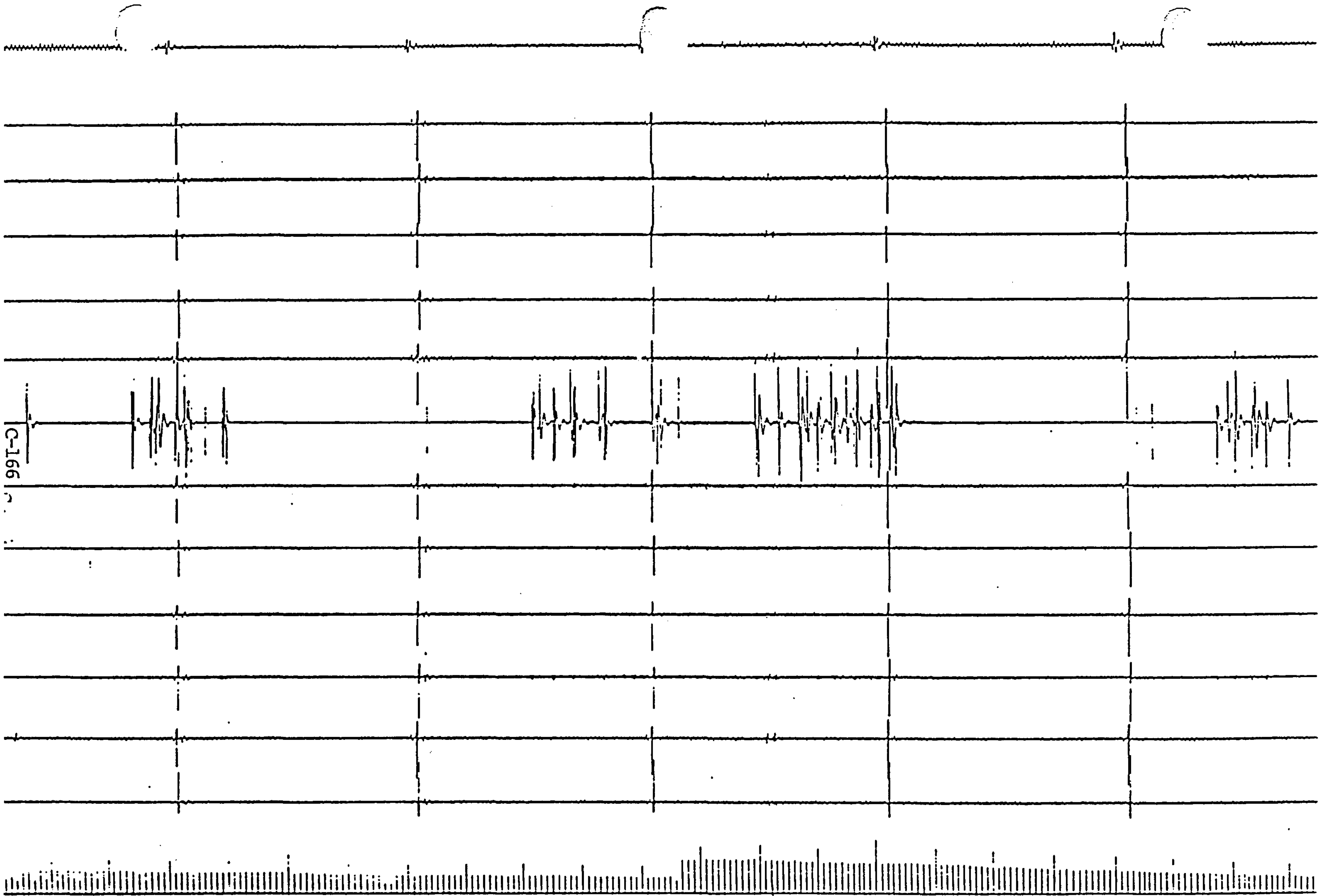
10" PLATFORM GILDA TO MANDALAY

Anode
Wheel Count 8762



CHANNEL DAMAGED IN LINE
44
WHEEL COUNT 44145
10" PLATFORM GILDA TO MANDALAY

FIG.12



CHANNEL 6 VERY NOISY

Anode
Wheel Count 47382

10' PLATFORM GILDA TO MANDALAY

FIG. 13

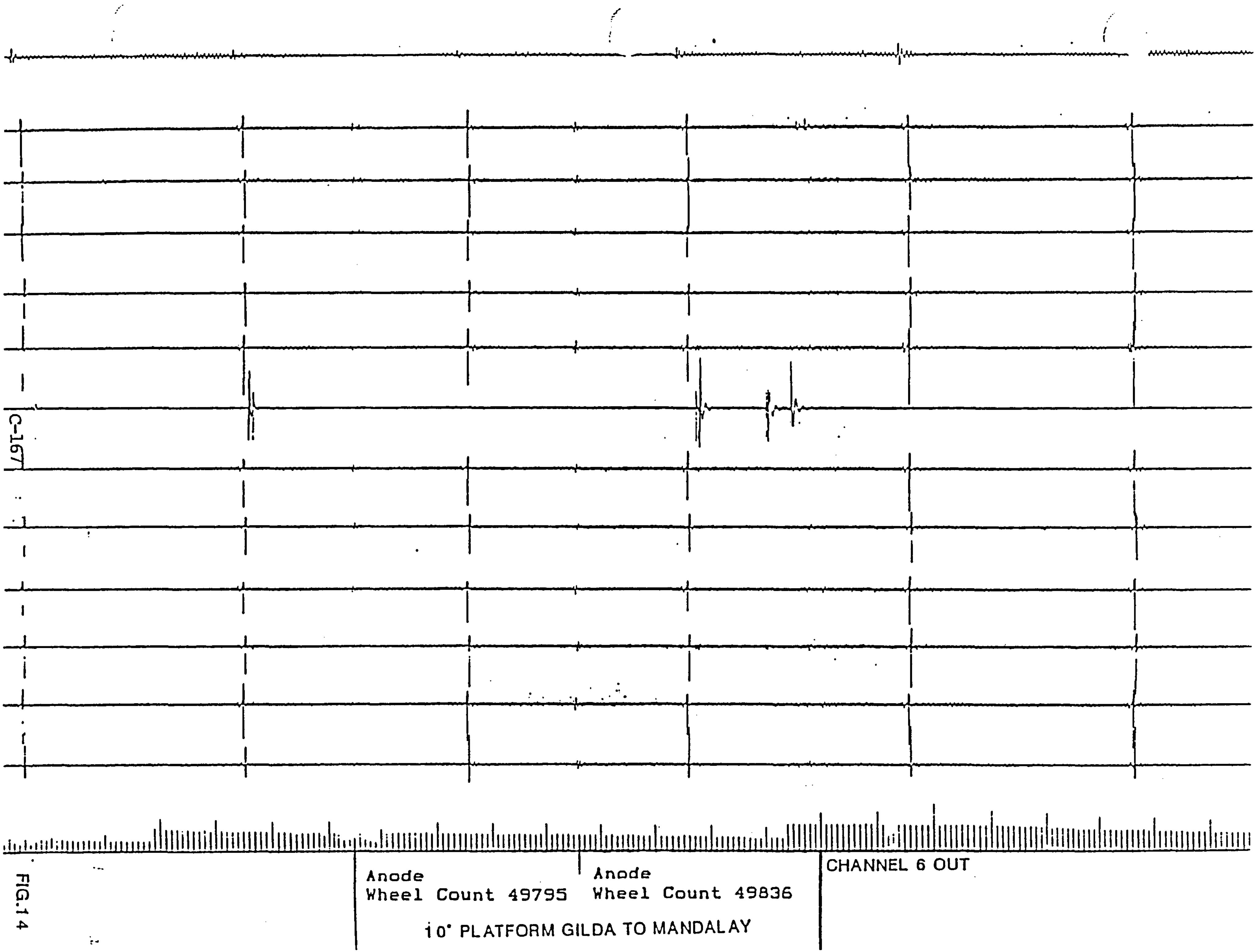

C-167
Anode
Wheel Count 49795
Anode
Wheel Count 49836
10' PLATFORM GILDA TO MANDALAY
CHANNEL 6 OUT

FIG.14

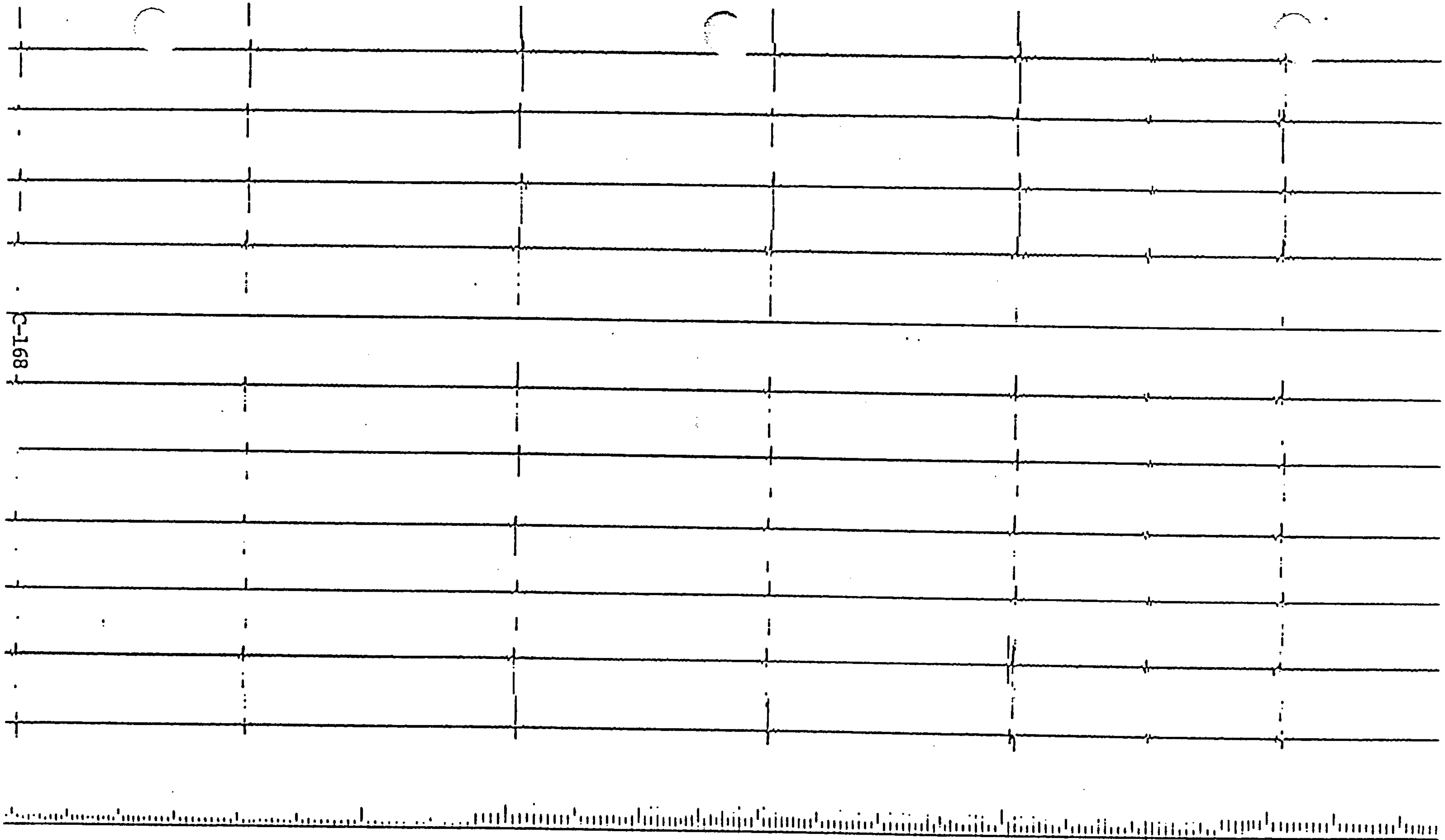


FIG.15 10° PLATFORM GILDA TO MANDALAY

ˉION OIL COMPANY OF CALIFORNIA
.NDALAY TO PLATFORM GINA
ᴗ' - CORROSION
RUN #1 - JOB #1626
JUNE 29, 1986

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
LAUNCH			17	0
TRAP			33056	33039

FEET OF LINE = 33039

MILES OF LINE = 6.25

* WHEEL STOPPED ADD 516'
32540 + 516' = 33056

FIG 16

UNION OIL COMPANY OF CALIFORNIA
GILDA TO MANDALAY
10" - CORROSION
RUN #1 - JOB #1626
JUNE 30, 1986

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
LAUNCH			70	0
ANODE			960	890
ANODE			1523	563
ANODE			2126	603
ANODE			2730	604
ANODE			3333	603
ANODE			3936	603
ANODE			4539	603
ANODE			5142	603
ANODE			5745	603
ANODE			6349	604
ANODE			6953	604
ANODE			7555	602
ANODE			8159	604
ANODE			8762	603
ANODE			9365	603
ANODE			9969	604
ANODE			10572	603
ANODE			11176	604
ANODE			11779	603
ANODE			12383	604
ANODE			12984	601
ANODE			13590	606
ANODE			14193	603
ANODE			14796	603
ANODE			15400	604

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
ANODE			16003	603
ANODE			16607	604
ANODE			17210	603
ANODE			17813	603
ANODE			18417	604
ANODE			19020	603
ANODE			19624	604
ANODE			20219	595
ANODE			20831	612
ANODE			21434	603
ANODE			22038	604
ANODE			22640	602
ANODE			23244	604
ANODE			23846	602
ANODE			24449	603
ANODE			25053	604
ANODE			25656	603
ANODE			26259	603
ANODE			26863	604
ANODE			27466	603
ANODE			28070	604
ANODE			28674	604
ANODE			29278	604
ANODE			29881	603
ANODE			30484	603
ANODE			31088	604
ANODE			31691	603
ANODE			32295	604

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
ANODE			32898	603
ANODE			33502	604
ANODE			34105	603
ANODE			34709	604
ANODE			35312	603
ANODE			35916	604
ANODE			36519	603
ANODE			37123	604
ANODE			37727	604
ANODE			38330	603
ANODE			38933	603
ANODE			39537	604
ANODE			40140	603
ANODE			40744	604
ANODE			41347	603
ANODE			41951	604
ANODE			42554	603
ANODE			43158	604
ANODE			43761	603
ANODE			44365	604
ANODE			44968	603
ANODE			45571	603
ANODE			46175	604
ANODE			46778	603
ANODE			47382	604
ANODE			47985	603
ANODE			48589	604
ANODE			49192	603

LINE MARKS	MAP STATION	MAP DISTANCE	WHEEL COUNT	WHEEL DISTANCE
ANODE			49795	603
ANODE			49836	41
ANODE			50198	362
ANODE			50560	362
ANODE			50922	362
ANODE			51284	362
ANODE			51646	362
ANODE			52008	362
ANODE			52370	362
ANODE			52732	362
ANODE			53191	459
TRAP			53424	233

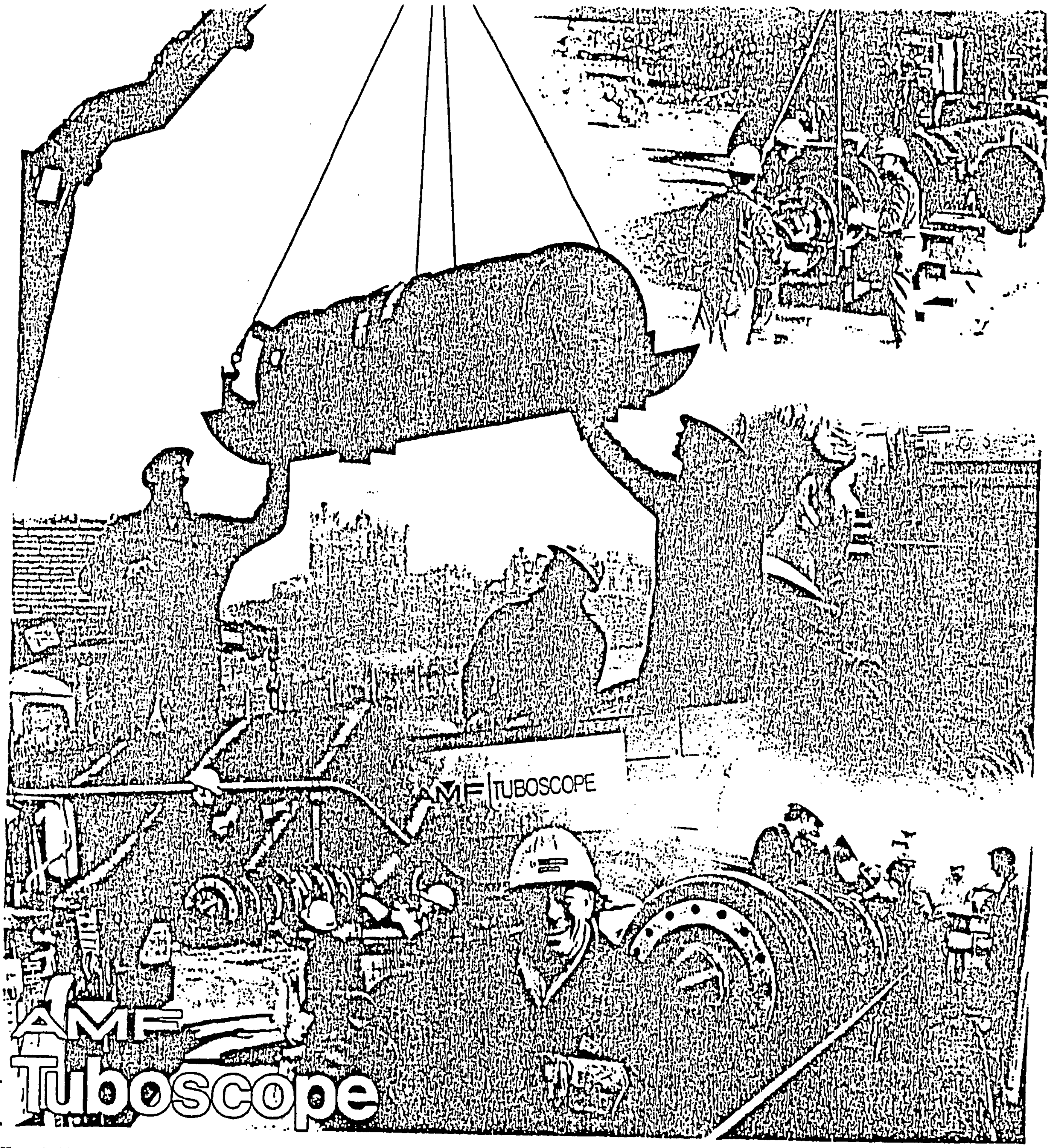
FEET OF LINE = 53354

MILES OF LINE = 10.10

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Linalog Survey (10/5/87)



LINALOG®

for

UNOCAL

date

OCTOBER 5, 1987

C-174

LINALOG CORROSION SURVEY REPORT

6, 10 AND 12 INCH DIAMETER PIPELINES:

* 6" MANDALAY TO PLATFORM GINA

* 10" PLATFORM GINA TO MANDALAY

* 12" PLATFORM GILDA TO MANDALAY

JOB # 1855

PREPARED
FOR

UNOCAL PIPELINE COMPANY

BY
ROB HATHAWAY

TUBOSCOPE INC.
HOUSTON LINALOG DIVISION

OCTOBER 5, 1987

CONTENTS

INTRODUCTION

The following three sections of offshore pipeline were corrosion surveyed by Linalog in August 1987. Since all three lines have been corrosion surveyed by Linalog in the past, a comparison is made between the previous survey and the most recent 1987 corrosion survey in the "COMPARISON" section of this report.

6" MANDALAY TO PLATFORM GINA

The length of this section of pipeline is approximately 6.2 miles. Pipe composition is reported as being .280" nominal wall Grade B ERW.

Two instrumented survey run were required on this section of pipeline. Survey run 1 failed due to tool electrical problems. Survey run 2 was launched on August 28, 1987. The actual run time was 3 hours 7 minutes, resulting in an average tool speed of 1.96 miles per hour. No major problems were reported regarding survey run 2, however, the wrong type distance measuring wheel was used for this tool. Normally, a single magnet wheel is used to produce one pulse per one rotation of the wheel. This constitutes one foot of pipeline. In this case, a four magnet wheel was used. This produced four pulses per rotation or four pulses to one foot of pipeline. All distance measurements should be divided by four to produce the correct measurement.

This section of pipeline was previously corrosion surveyed by Linalog in June 1986, Job #1626.

10" PLATFORM GINA TO MANDALAY

The length of this section of pipeline is approximately 6.2 miles. Pipe composition is reported as being predominantly .500" nominal wall Grade X-56 ERW with .562" nominal wall pipe at the risers.

One instrumented survey run was launched on August 21, 1987. The actual run time was 5 hours 9 minutes, resulting in an average tool speed of 1.2 miles per hour. No major problems concerning the survey run were reported.

This section of pipeline was previously corrosion surveyed by Linalog in January 1985, Job #1551.

12" PLATFORM GILDA TO MANDALAY

The length of this section of pipeline is approximately 10.1 miles. Pipe composition is reported as being .500" nominal wall Grade X-42 ERW.

One instrumented survey run was launched on August 26, 1987. The actual run time was 8 hours 21 minutes, resulting in an average tool speed of 1.2 miles per hour. No major problems were reported regarding the survey run.

This section of pipeline was previously corrosion surveyed by Linalog in January 1985, Job #1551.

Each corrosion survey consisted of passing a self-contained instrumented pipeline pig, known as the Linalog Tool, through the pipeline, using pipeline product as its propellant. The Linalog Tool records magnetic anomalies in and on the body wall of the pipe.

Each joint of pipe containing at least one anomaly of significant amplitude has been indicated by a stamped numerical or letter grade along the top of the survey log, centered in the joint. These grades have been tabulated by grade classification, between pipeline reference markers, in the "TOTALS" section at the end of this report.

LINALOG SURVEY EQUIPMENT

"DUMMY" TOOL

A sizing tool, known as a "Dummy Tool" is run through the pipeline before running the Linalog Survey Tool. The "Dummy Tool" is used as a gauge to check the pipeline for any restrictions which could impede the movement of or damage the Linalog Survey Tool. The Dummy is similar in appearance to the Linalog Survey Tool, but contains no instrumentation.

LINALOG SURVEY TOOL

The Linalog Survey Tool is a self-contained unit that is inserted into, propelled through, and extracted from the pipeline in the same manner as a conventional cleaning pig.

The various tools used were:

* 6 inch diameter Type 3 SGL - 7 feet 6 inches in length

* 10 inch diameter Type 3 SGL - 9 feet 8 inches in length

* 12 inch diameter Type 3 SGL - 9 feet 9 inches in length

Each tool is made in five sections which are connected by universal joints ("U" Joints). The "U" joints allow the Linalog Tool some degree of flexibility in order to negotiate bends in the pipeline (See Figure 1).

The first section is the "Drive Section". This section is supported in the pipeline by scraper cups which provide a tight seal inside the pipe. This seal allows the pipeline throughput to propel the inspection tool. A marker detecting device is usually mounted between the cups. The function of the marker detecting device is explained in the "LINALOG SURVEY RECORD" section of this report.

The second section is the "Magnetizer Section" which magnetizes the pipe and supports the survey shoes. This section is supported in the pipeline by steel brushes at each end. The brushes also provide a path for the magnetic lines of flux to enter the pipe wall. The survey shoes contain the corrosion survey sensors. The shoes, and the sensors in them, overlap one another to provide complete 360 degree coverage of the pipe wall. Information signals from the survey sensors are recorded on the survey channels. Survey channels are explained later in this report.

The third section is the "Distance Measuring Section". It is centered in the pipeline by scraper cups mounted at each end. The distance measuring wheel is mounted between the scraper cups. The function of the distance measuring wheel is explained later in this report.

The fourth section is the "Battery Section". The batteries furnish the electrical power needed to operate the Linalog Tool. A scraper cup on the rear end supports and centralizes this section in the pipeline.

The fifth section is the "Recorder Section". The recorder section houses the magnetic tape recorder and the electronic circuits. The recorder and the electronic circuits process the data from the various sensors and record it on magnetic tape. On the 10" and 12" diameter tools, the recorder was equipped with "Speed Gain Compensation" (SGC) which automatically adjusts the sensitivity of the electronics to compensate for tool speed variations within a prescribed range. The 6" diameter tool does not have the SGC.

OPERATING PRINCIPLE

The Linalog Tool operates on the flux-leakage principle. A magnetic field is induced into the pipe wall by the magnetizer section as it moves through the pipeline. This magnetic field travels with the tool. When an anomaly is encountered in the pipe wall, the magnetic flux is forced out of the pipe at the anomaly (See Figure 2). This is called flux-leakage. The Linalog Tool detects this magnetic distortion and records a corresponding signal on magnetic tape. Line pipe usually contains some manufacturing flaws, so some amount of background signals can be expected. We can generalize and say that the amplitude of a corrosion pitting signal, generated by the flux-leakage at corrosion pitting, is proportional to the depth of the pitting. This is the basis for the grade classifications used to evaluate the condition of the pipeline.

PLAYBACK SYSTEM

After the Linalog Survey Tool is removed from the pipeline, the magnetic tape which contains the recorded data is removed from the recorder and placed on the "playback system". The playback system converts the recorded data into a temporary paper graph known as the "field log". The field log is then interpreted by the inspector to confirm that the tool has performed satisfactorily. If verification digs are to be made, the field log is used to locate suitable areas. When the magnetic tape is returned to the Linalog Division Office, it is played back again to make a permanent paper graph called the "Linalog Survey Record" or "Master Log".

LINALOG SURVEY RECORD

The Linalog Survey Record, referred to as the "Log", consists of several channels of information. Refer to Figure 3 for the 6 inch log format, Figure 6 for the 10 inch log format and Figure 8 for the 12 inch log format.

SURVEY CHANNELS

The survey channels show the magnetic anomalies encountered in the pipeline. These anomalies include corrosion, girth welds, magnets, valves, taps, saddles, anchors, patches, clamps, and manufacturing irregularities. These anomalies are detected by sensing coils in the survey shoes.

When the log is interpreted, each joint of pipe in the pipeline is examined, and a numerical or letter grade is assigned to those joints which contain anomaly indications of sufficient amplitude to be classified in one of the grading categories. Refer to the "GRADING SYSTEM" section for more detailed information.

Examples of anomaly classification and grading are shown on Figures 4 and 5.

Figures 7 and 10 are examples of "Unclassified" anomalies. See the "Grading System" section for details.

DISTANCE MEASURING/ORIENTATION CHANNEL

This channel displays the distance measurement the tool recorded as it traveled through the pipeline as well as the orientation of the tool at any given point on the log. An individual mark for each one foot of pipeline length is displayed. These unit "Wheel Counts" are recorded in multiples of one, ten, one hundred, and one thousand. An amplitude differentiated signal is recorded on the log for each multiple (See Figure 11). Each thousand count is marked cumulatively throughout the log. *Note: Remember to divide by four when using the 6 inch diameter log.

The total "Wheel Count" is shown on the log at each pipeline reference marker (See Figure 9). The length of the pipeline from the launch to any point of interest (reference marker, anomaly indication, etc.) is the wheel count at the point of interest minus the wheel count at the launch. This calculation is necessary since the distance wheel circuitry cannot be made to reset to zero at the launch valve (See Figures 3,6 and 8).

The distance channel also indicates whether or not the Linalog Tool traveled at a uniform speed. Uniform spacing between wheel counts indicates that a steady speed was maintained during the survey. Variable spacing between wheel counts indicates a changing velocity. As the tool speed decreases, this spacing increases; as the tool speed increases, this spacing decreases.

The orientation of the tool is also displayed on the distance channel. The orientation channel records the rotation of the tool as it moves through the pipeline. The tool is designed to rotate so that wear on the equipment is uniformly distributed. Refer to Figure 12.

As the tool rotates, the individual distance pulses steadily decrease or increase, depending on the direction of tool rotation, until the tool has completed a 360 degree revolution. At this time, the distance pulses return to their preset maximum or minimum height, again depending on the direction of tool rotation, to indicate the next revolution. The top of the pipe is being recorded on the top survey channel when the orientation signal is at its maximum height. The bottom survey channel is recording the top of the pipe when the orientation signal is at its minimum height.

The top of the pipe (12 o'clock position) can be plotted on the log for each rotation cycle by drawing a diagonal line starting with the survey channel recording the top of the pipe at the beginning of the rotation cycle to the survey channel recording the top of the pipe at the end of the rotation cycle. The bottom of the pipe (6 o'clock position) follows a parallel diagonal path across the log that is halfway around from the top of the pipe (See Figure 12).

The approximate o'clock position of the anomaly on the pipe can be determined from the log in the following manner:

1. Locate the top of the pipe in the joint of pipe containing the anomaly indication.

2. Assume you are standing on top of the pipe (12 o'clock position) on the joint containing the anomaly indication and looking downstream toward the receiving trap. Turn the log viewer so you are looking downstream toward the receiving trap on the log.

3. The 3 o'clock position is to the right of the 12 o'clock position midway between 12 and 6 o'clock.

4. The 9 o'clock position is to the left of the 12 o'clock position midway between 12 and 6 o'clock.

5. The other o'clock positions are located in a similar manner.

The orientation channel is intended to locate the QUADRANT of the pipe where the anomaly can be found. This channel is not intended to locate the anomaly as being a specified number of degrees from the top center position on the pipe.

Figures 11 and 12 are examples used only to illustrate how to interpret the distance/orientation channel. These examples were not taken from the logs discussed in this report.

GRADING SYSTEM

PREFACE

The Linalog Tool operates on the flux-leakage principle. Flux-leakage is an indirect method of finding and evaluating anomalies in pipe. This can be understood best by first defining direct evaluation. Direct evaluation would be to actually see and measure each anomaly as you would if the joint of pipe was on a pipe rack. You could then examine both the inside and outside surfaces. This is not practical in a pipeline, so we must resort to indirect methods to inspect it. Flux-leakage is one of these methods. A magnetic field is induced into the pipe. The amount of distortion in the magnetic field, caused by an anomaly in the pipe, is detected, measured and evaluated.

TYPES OF ANOMALIES

Linalog detects anomalies that produce a disturbance in the magnetic field which has been induced into the pipe wall by the inspection tool. These include a wide range of service related environmental anomalies, manufacturing anomalies, and anomalies caused during handling, transportation and construction. They may be external or internal. Some examples include corrosion pitting, seams, overlaps, slugs, slivers, scratches, grinding marks, inclusions or laminations that break the surface, uneven or high trim of the longitudinal weld seams, mismatched plate edge at the longitudinal weld seams, gouges, welding marks and some hard spots.

INTERPRETING THE LOG

Each joint of pipe is evaluated individually. Consideration is given to the joints on either side to maintain continuity and perspective. The grade assigned to the joint of pipe is the grade that applies to the highest amplitude anomaly indication in that joint of pipe. Each individual anomaly indication in the joint of pipe is not graded. Once the grade for a joint has been determined, that grade is stamped at the top of the log, centered in the joint as follows:

> Grade U is an "Unclassified" anomaly. This grade is assigned to anomaly indications which, we believe, are not associated with significant deterioration of the pipe wall. They may be caused by manufacturing irregularities in the pipe which existed before the pipeline was put into service. Depending upon its nature, an unclassified anomaly can assume a wide range of shapes and patterns on the log.

Grade 1 is assigned to anomaly indications which, we believe, indicate more than 15% but less than 30% body wall penetration.

Grade 2 is assigned to anomaly indications which, we believe, indicate more than 30% but less than 50% body wall penetration.

Grade 3 is assigned to anomaly indications which, we believe, indicate 50% or more body wall penetration.

Grade classifications are not assigned to anomaly indications which, we believe, indicate 15% or less body wall penetration.

If there is doubt as to the nature of an anomaly indication, the anomaly will be classified as corrosion.

The number of survey channels that the anomaly indication appears on indicates approximately how far circumferentially the actual anomaly extends. For example, an anomaly indication that appears on half of the survey channels on the log will extend about halfway around the pipe. "Half-sole" patches are a good example of this. Likewise, an anomaly indication that shows on all the survey channels on the log will extend completely around the pipe. Girth welds are a good example. Following this line of reasoning, we would normally expect a single small area (for example, 1/2" dia.) isolated pit on the pipe to show on only one survey channel on the log. However, it can, and sometimes does, show on two adjacent survey channels. The explanation is that when the middle of the detector (shoe) passes over the pit, the indication will appear on one survey channel on the log. When the overlapping edge of two adjacent detectors passes over the pit, the indication will appear on two adjacent survey channels. The overlapping of the detectors is necessary to ensure a complete 360 degree inspection of the pipeline. Since we cannot control whether the center of one detector, or the overlapping edge of two adjacent detectors, passes over the pit, we must consider and recognize this when interpreting the log.

The approximate size of the pitted area, or other anomaly on the pipe, can be determined by observing:

(A). Width - The number of survey channels on the log which contain the anomaly indications:

(B). Length - The longitudinal distance on the log the group of anomaly indications extend.

Many of the mill or manufacturing anomalies, such as seams and overlaps, slugs, slivers, circumferential cracks and scratches, grinding marks, inclusions or laminations that break the surface, etc., often produce a higher amplitude indication on the log than their depth justifies. These anomalies are sometimes included in the "U" (unclassified anomaly) classification because their higher amplitude signals are uniquely different from the normal low amplitude signals which are characteristic of pipeline corrosion. Many of the class "U" indications are internal, so they were not easily seen by visual inspection when the pipe was made. These internal defects are difficult to find and evaluate using ultrasonics and radiography due to the small area and shallow penetration many of them have. However, these anomalies disturb the magnetic field in the pipe and Linalog detects them. Many anomalies of this type introduce two factors which occur simultaneously to make the anomaly indication we see on the log. First, there is a disturbance in the magnetic field. Second, these anomalies sometimes have a thin edge, projecting into the inside of the pipe, that is turned up by the drive cups on the tool before the magnetizer section passes over them. The detector bounces as it travels over this turned up edge. The detector receives the signal caused by the bounce at the same time it receives the signal caused by the disturbance in the magnetic field. These two simultaneous signals combine and appear as a single indication on the log with a much greater amplitude than the depth of the anomaly justifies. This has been confirmed many times when we were able to examine the pipe in detail and compare it to the log.

While debris and foreign material (gravel, welding rods, etc.) inside the pipeline are not anomalies in the usual sense, they produce similar indications on the log. The metallic debris will disturb the flux field and any type of debris can cause the detector to bounce as it passes over it. Debris does not have a unique signature and is sometimes interpreted as corrosion. Confirming this is difficult because by the time the joint of pipe can be examined, the debris has usually been moved by the inspection tool or by normal pipeline throughput.

GRADE TOLERANCE

There is a tolerance in the grade classification boundaries assigned to the anomaly indications on the log.

Consider the following:

1. Anomalies are detected by an indirect method, not by measuring and recording the anomalies themselves, but by observing their effect on a magnetic field induced into the pipe.

2. Several variables, which cannot be anticipated and compensated for, affect the signals the Linalog Tool records. These include (a) the configuration of the defect (sharp or sloping edges, width to depth ratio); (b) variations in the magnetic permeability of the pipe; (c) the detector to defect incidence (whether the defect passes across the middle of the detector or the overlapping edge of two adjacent detectors); and (d) variations in tool speed which are beyond the capability of the velocity compensation circuits.

Due to these variables, a tolerance of plus or minus 10% applies to the boundary line between each corrosion grade classification. This variation, between the assigned grade classification and the actual condition of the pipe, is minimized when the log is compared to the pipeline before the log is graded.

IMPORTANCE OF VERIFYING THE LOG

Comparing the log to the pipeline improves grading accuracy. This comparison is made by excavating and examining the condition of the pipeline at locations where the log shows significant anomaly indications. The conditions found in the pipeline are compared with the conditions indicated on the log. In doing this, actual pits in the pipe are identified on the log. The measured pit depth can then be correlated to the amplitude of the corresponding indication on the log.

RESULTS

The Linalog survey showed magnetic anomaly indications in the pipeline as marked on the survey log. The tabulation below shows the number of joints of pipe assigned the various grade classifications.

6" MANDALAY TO PLATFORM GINA

	U	1	2	3
TOTAL OF PIPELINE	0	161	38	1

10" PLATFORM GINA TO MANDALAY

	U	1	2	3
TOTAL OF PIPELINE	2	0	0	0

12" PLATFORM GILDA TO MANDALAY

	U	1	2	3
TOTAL OF PIPELINE	31	0	0	0

For a complete listing of grades between pipeline reference markers, refer to the "TOTALS" section at the end of this report.

GRADING SYSTEM REVIEW

GRADE U indicates "Unclassified" anomalies.

GRADE 1 indicates anomalies with 15%-30% bodv wall penetration.

GRADE 2 indicates anomalies with 30%-50% bodv wall penetration.

GRADE 3 indicates anomalies with 50% or greater body wall penetration.

Grade classifications are not assigned to anomaly indications which, we believe, reflect less than 15% body wall penetration.

If there is doubt as to the nature of an anomaly indication, it is classified as corrosion.

COMPARISON

The current 1987 survey grades have been compared with the previous survey grades below:

SECTION	U	1	2	3
6" MANDALAY TO PLATFORM GINA				
1987	0	161	38	1
1986	0	90	15	2
10 " PLATFORM GINA TO MANDALAY				
1987	2	0	0	0
1985	2	0	0	0
12" PLATFORM GILDA TO MANDALAY				
1987	31	0	0	0
1985	26	0	0	0

These figures show the composite change in the number of gradable anomalies recorded in the pipeline during the 1981 corrosion survey by Linalog, as compared to the most recent 1987 survey. Composite change is affected by several factors such as: deterioration of the pipe due to environment and pipeline products, repairs and replacements made between surveys, grade reclassification due to corrosion growth or "Unclassified" category changes, and normal variations that occur from one survey to the next, i.e. human factors, tool variations, etc.

To assist the customer with his comparison, the grades from the 1981 surveys have been stamped along the bottom of the survey log, just above the marker channels. These grades are enclosed with circles to denote their previous status and centered in the joint. Refer to Figure 6.

Keep in mind, this is only an overall comparison of total grade classifications between surveys. Even if the totals remain virtually unchanged, this does not mean the pipeline remained static also. Some anomalies may have been upgraded in classification and an equal number downgraded or removed due to repairs. Though changes may have occurred, they will not be reflected in the totals.

Some anomaly indications which were graded on the previous corrosion survey, may not be graded on the current survey due to such reasons as:

1) The joint of pipe has been repaired or replaced since the previous survey.

2) Previous indications may have been caused by debris in the pipeline such as welding rods or gravei and have since been moved by the inspection tool or normal product movement.

3) One or more survey shoes on the inspection tool may have been prevented from touching the pipe wall due to paraffin or other build-up around the spring loaded shoe assembly. Result: Limited or no anomaly detection capability.

* To make the most accurate comparison between the corrosion surveys, the current log must be compared to the previous log. This should be done by a joint to joint comparison in order to see what actually transpired between the surveys.

LOCATING AND UNCOVERING ANOMALIES

By using the distance channel on the log, desired areas can be accurately located in the following manner:

1. Choose an area of interest on the log.
2. Find the nearest reference marker (Magnet, Valve, Flange, etc.) and note its location on the log by using the wheel count from the distance channel.
3. Determine the girth weld closest to the anomaly of concern (upstream or downstream) and mark the girth weld location by using the wheel count from the distance channel.
4. The difference between the reference marker wheel count and the girth weld wheel count will yield the distance measurement, in feet, needed for the dig location of the chosen girth weld. Upon digging, if the measurement is reasonably close to a girth weld, you can be confident that the measurement is correct and that the desired girth weld has been found.
5. Determine the location of the anomaly of concern by using the wheel count from the distance channel on the log.
6. The difference between the chosen girth weld wheel count and the anomaly wheel count will yield the distance measurement, in feet, needed to uncover the anomaly.
7. By using the orientation channel on the log, an approximate o'clock position of the anomaly can be determined.

Since the log shows the length of each joint of pipe in the pipeline, measuring an actual joint of pipe in the ground and comparing it to the log measurement is a good way to verify correct location. This applies only if the joint of pipe is unequal to those on either side.

* NOTE: When measuring distances, be sure to specify whether the measurement is to be made upstream or downstream from specified reference markers. Record as such for accuracy.

CONCLUSION

The corrosion survey revealed magnetic anomalies in each pipeline as marked on the logs and listed in the "RESULTS" section. It is not the purpose of Linalog to list the causes of corrosion or to give repair or replacement advice. Our sole function is to locate and evaluate probable defects on the pipeline.

The grading of the log is our most knowledgeable assessment of the condition of the pipeline at the time it was corrosion surveyed by Linalog. We welcome the opportunity to discuss with you any details of the corrosion survey which are still unclear, after having read this report.

Each survey was completed with the pipeline in place delivering the throughput desired. The logs have been analyzed and graded. A photocopy of the survey logs have been provided, and the report concerning the corrosion surveys has been submitted. The corrosion surveys are considered to be successful and complete.

Thank you for your confidence and trust in TUBOSCOPE INC. We sincerely hope you will continue to use our services in the future. If you wish to make any comments, or if we can be of any further assistance to you, please contact our office.

FIGURES AND EXAMPLES

Pipeline Feature	Map Station	Map Distance	Wheel Count	Wheel Distance	Distance to Nearest * Marker Upstream	Downstream	1987 Grade	Distance from Upstream Weld	O'clk	Comments	Grade Tabulation U	1	2	3
Launch *	32602	0	42	0	0	4220								
Grade U Joint	32892	290	331	289	289	3931	U	16	12.00	Possible Wrinkle				
Grade 1 Joint	32983	91	422	91	380	3840	1	19	3.00					
Grade 1 Joint	36002	3019	3434	3012	3392	828	1	29	11.00		1	2	0	0
Abv Gn Mark *	36832	830	4262	828	4220	2640								
Grade 3 Joint	37337	505	4771	509	509	2131	3	18	6.00					
Begin Hvy Wall	37418	81	4853	82	591	2049								
End Hvy Wall	37667	249	5104	251	842	1798					0	0	0	1
Magnet *	39451	1784	6902	1798	2640	26								
Begin Hvy Wall			6906	4	4	22					0	0	0	0
Magnet *			6928	22	26	35								
Equation *	39501	39501	6963	35	35	0								
Equation *	0	0	6963	0	0	52								
End Hvy Wall			6991	28	28	24					0	0	0	0
Magnet *			7015	24	52	4588								
Grade 2 Joint			7345	330	330	4258	2	29	8.00	Cor n Csng				
Begin Casing			7351	6	336	4252								
Grade 1 Joint			7375	24	360	4228	1	3	6.00	Cor n Csng				
Grade U Joint			7382	7	367	4221	U	3	12.00	Possible Test Lead				
End Casing			7382	0	367	4221								
Grade 2 Joint			7388	6	373	4215	2	24	5.00					
Grade 2 Joint			8011	623	996	3592	2	8	6.00		1	1	3	0
Abv Gn Mark *	4640		11603	3592	4588	5918								
Grade 1 Joint	4819	179	11782	179	179	5739	1	19	7.00					
Grade 2 Joint	5383	564	12346	564	743	5175	2	4	6.00					
Grade 1 Joint	6254	871	13216	870	1613	4305	1	1	11.00					
Grade U Joint	6457	203	13419	203	1816	4102	U	10	3.00	Possible Wrinkle				
Grade 1 Joint	6725	268	13687	268	2084	3834	1	37	2.00					
Grade 1 Joint	7729	1004	14690	1003	3087	2831	1	40	6.00					
Begin Hvy Wall	8460	731	15421	731	3818	2100								
End Hvy Wall	8916	456	15877	456	4274	1644								
Grade 1 Joint	9096	180	16057	180	4454	1464	1	7	7.00					
Begin Hvy Wall	9117	21	16078	21	4475	1443								
Begin Casing	9152	35	16113	35	4510	1408								
End Hvy Wall	9155	3	16116	3	4513	1405								
End Casing	9273	118	16234	118	4631	1287								
Grade 1 Joint	9412	139	16373	139	4770	1148	1	18	6.00					
Grade 1 Joint	9457	45	16418	45	4815	1103	1	2	6.00					
Grade 1 Joint	10403	946	17363	945	5760	158	1	11	6.00		1	8	1	0
Abv Gn Mark *	10561	158	17521	158	5918	4396								
Grade 1 Joint	10646	85	17606	85	85	4311	1	2	6.00					
Grade 1 Joint	10714	68	17675	69	154	4242	1	3	4.00					
Grade 2 Joint	10897	183	17858	183	337	4059	2	2	10.00					
Grade U Joint	11156	259	18119	261	598	3798	U	17	6.00					
Grade 1 Joint	11456	300	18420	301	899	3497	1	5	6.00					
Grade 2 Joint	12215	759	19182	762	1661	2735	2	14	6.00					
Grade 2 Joint	12946	731	19916	734	2395	2001	2	27	6.00					

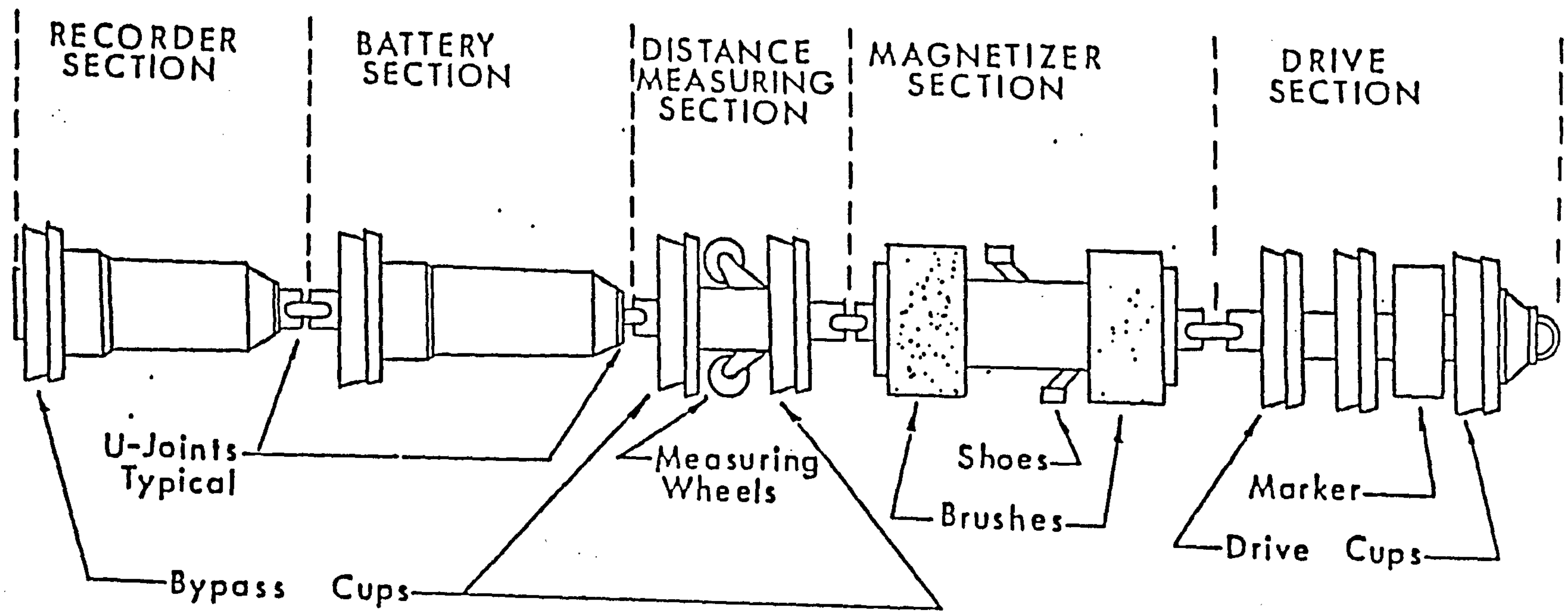
Pipeline Feature	Map Station	Map Distance	Wheel Count	Wheel Distance	Distance to Nearest Upstream	# Marker Downstream	1987 Grade	Distance from Upstream Weld	O'clk	Comments	Grade Tabulation U	1	2	3
Grade 1 Joint	13113	167	20084	168	2563	1833	1	11	6.00					
Grade 1 Joint	13690	577	20664	580	3143	1253	1	0	6.00					
Grade 2 Joint	14080	390	21055	391	3534	862	2	7	5.00					
Grade 2 Joint	14087	7	21062	7	3541	855	2	1	5.00		2	4	5	0
Abv Gn Mark #	14938	851	21917	855	4396	2826								
Grade 1 Joint	15000	62	21979	62	62	2764	1	1	3.00					
Grade 1 Joint	15074	74	22052	73	135	2691	1	31	6.00					
Begin Casing	15117	43	22095	43	178	2648								
Grade 1 Joint	15134	17	22112	17	195	2631	1	17	6.00	Cor n Csng				
End Casing	15157	23	22135	23	218	2608								
Grade 1 Joint	15671	514	22646	511	729	2097	1	30	8.00					
Grade 1 Joint	15701	30	22676	30	759	2067	1	27	5.00					
Grade 3 Joint	15793	92	22767	91	850	1976	3	7	6.00					
Grade 1 Joint	16008	215	22981	214	1064	1762	1	7	4.00					
Grade 1 Joint	16162	154	23134	153	1217	1609	1	25	2.00		0	7	0	1
Abv Gn Mark #	17780	1618	24743	1609	2826	3221								
Grade 2 Joint	18156	376	25119	376	376	2845	2	5	6.00					
Grade 2 Joint	18903	747	25866	747	1123	2098	2	7	6.00	In Wrinkle				
Grade 1 Joint	19485	582	26449	583	1706	1515	1	0	10.00					
Grade 1 Joint	20717	1232	27681	1232	2938	283	1	9	6.00	In Wrinkle	0	2	2	0
Abv Gn Mark #	21000	283	27964	283	3221	5243								
Grade U Joint	22446	1446	29413	1449	1449	3794	U	15	10.00					
Grade 1 Joint	23684	1238	30654	1241	2690	2553	1	9	6.00					
Grade 1 Joint	24181	497	31152	498	3188	2055	1	7	6.00					
Grade 1 Joint	24691	510	31663	511	3699	1544	1	28	5.00					
Grade 1 Joint	24812	121	31784	121	3820	1423	1	7	3.00					
Grade 1 Joint	25239	427	32212	428	4248	995	1	30	4.00					
Grade 1 Joint	25632	393	32606	394	4642	601	1	16	5.00					
Grade 2 Joint	25937	305	32911	305	4947	296	2	22	7.00	Dig Area				
Grade 1 Joint	25967	30	32941	30	4977	266	1	9	5.00	Dig Area				
Grade U Joint	26053	86	33028	87	5064	179	U	14	12.00	Possible Test Lead				
Grade 1 Joint	26098	45	33073	45	5109	134	1	25	6.00					
Grade 1 Joint	26158	60	33133	60	5169	74	1	11	6.00					
Grade 1 Joint	26188	30	33163	30	5199	44	1	22	4.00		2	10	1	0
Abv Gn Mark #	26232	44	33207	44	5243	5890								
Grade 1 Joint	26419	187	33394	187	187	5703	1	9	6.00					
Grade 1 Joint	26631	212	33606	212	399	5491	1	7	5.00	In Wrinkle				
Grade 1 Joint	26721	90	33696	90	489	5401	1	15	6.00					
Grade 1 Joint	27222	501	34198	502	991	4899	1	2	6.00					
Grade 1 Joint	27259	37	34235	37	1028	4862	1	3	6.00					
Grade 1 Joint	28451	1192	35428	1193	2221	3669	1	19	6.00					
Grade 1 Joint	29025	574	36002	574	2795	3095	1	12	6.00					
Begin Hvy Wall	29054	29	36031	29	2824	3066								
End Hvy Wall	29064	10	36041	10	2834	3056								
Grade 1 Joint	29205	141	36183	142	2976	2914	1	30	3.00					
Grade U Joint	31976	2771	38956	2773	5749	141	U	14	6.00	Poss Wrinkle	1	8	0	0
Abv Gn Mark #	32117	141	39097	141	5890	1942								
Grade 2 Joint	32190	73	39170	73	73	1869	2	10	6.00					

Pipeline Feature	Map Station	Map Distance	Wheel Count	Wheel Distance	Distance to Nearest * Marker Upstream	Distance to Nearest * Marker Downstream	1987 Grade	Distance from Upstream Weld	O'clk	Comments	Grade Tabulation U	1	2	3
Grade 3 Joint	32221	31	39201	31	104	1838	3	2	6.00					
Begin Hvy Wall	32224	3	39204	3	107	1835								
Begin Casing	32225	1	39205	1	108	1834								
End Casing	32257	32	39237	32	140	1802								
Grade 1 Joint	32303	46	39283	46	186	1756	1	0	4.00					
End Hvy Wall	32369	66	39350	67	253	1689								
Grade 1 Joint	33797	1428	40780	1430	1683	259	1	14	6.00					
Grade 2 Joint	33812	15	40795	15	1698	244	2	1	6.00					
Grade 2 Joint	33842	30	40826	31	1729	213	2	11	6.00	Cor n Csng				
Degin Casing	33853	11	40837	11	1740	202								
Grade 3 Joint	33873	20	40857	20	1760	182	3	24	10.00	Cor n Csng				
End Casing	33897	24	40881	24	1784	158								
Grade U Joint	33897	0	40881	0	1784	158	U	3	12.00	Possible Test Lead				
Grade 3 Joint	33933	36	40917	36	1820	122	3	30	5.00					
Grade 1 Joint	33934	1	40918	1	1821	121	1	9	6.00		1	3	3	3
Abv Gn Mark *	34055	121	41039	121	1942	5080								
Grade 1 Joint	34227	172	41211	172	172	4908	1	26	4.00					
Grade 1 Joint	35624	1397	42604	1393	1565	3515	1	13	6.00					
Grade 1 Joint	35749	125	42728	124	1689	3391	1	26	3.00					
Grade 1 Joint	35873	124	42852	124	1813	3267	1	23	6.00					
Grade 1 Joint	35934	61	42913	61	1874	3206	1	23	12.00					
Grade 3 Joint	35965	31	42944	31	1905	3175	3	11	6.00					
Grade 3 Joint	36091	126	43069	125	2030	3050	3	15	6.00					
Grade 1 Joint	36554	463	43531	462	2492	2588	1	30	6.00					
Grade 1 Joint	36646	92	43623	92	2584	2496	1	24	6.00					
Grade 1 Joint	36677	31	43654	31	2615	2465	1	3	6.00					
Grade 1 Joint	36698	21	43675	21	2636	2444	1	22	6.00					
Grade U Joint	36727	29	43704	29	2665	2415	U	26	6.00	In Wrinkle				
Grade 2 Joint	36849	122	43825	121	2786	2294	2	27	5.00					
Grade 2 Joint	36879	30	43855	30	2816	2264	2	0	5.00					
Grade 1 Joint	37645	766	44619	764	3580	1500	1	23	4.00					
Grade 1 Joint	37824	179	44798	179	3759	1321	1	21	6.00					
Trap *	39149	1325	46119	1321	5080	0					1	11	2	2

Feet of Line 46077

Miles of Line 8.73

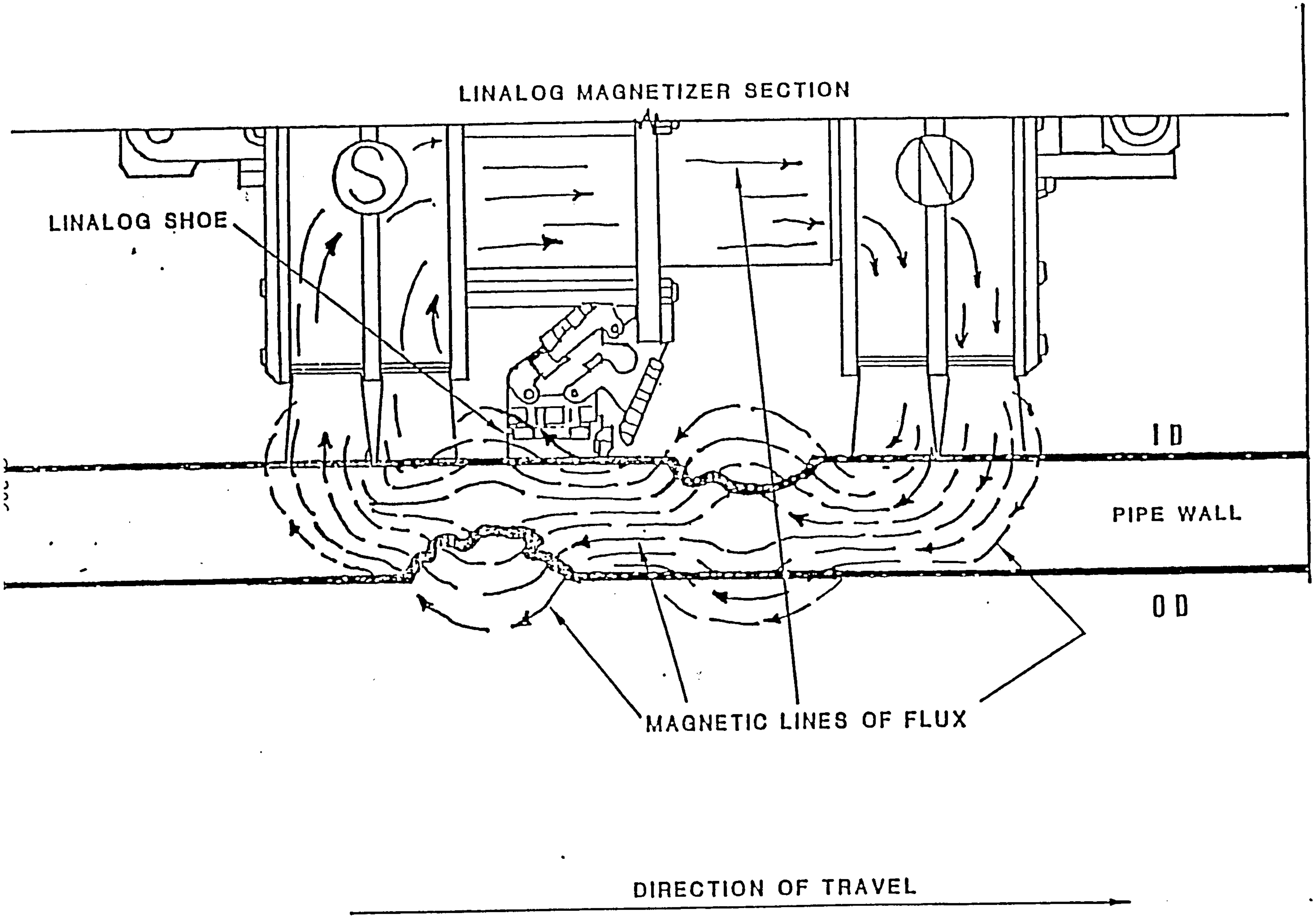
	U	1	2	3
Total for Pipeline	10	56	17	7



6, 10 AND 12 INCH LINALOG TOOL

FIG. 1

C-205



FLUX-LEAKAGE EXAMPLE

FIG. 2

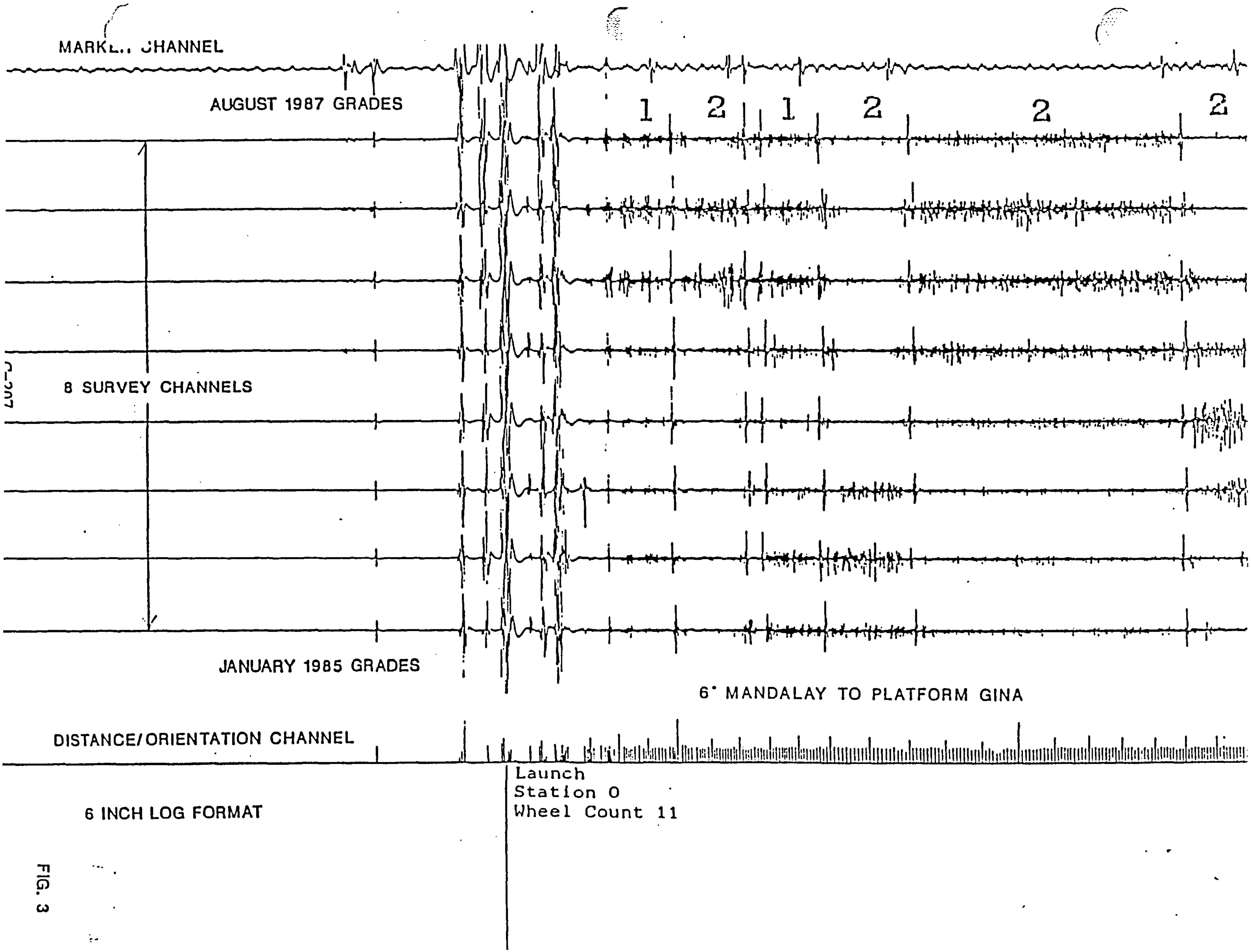
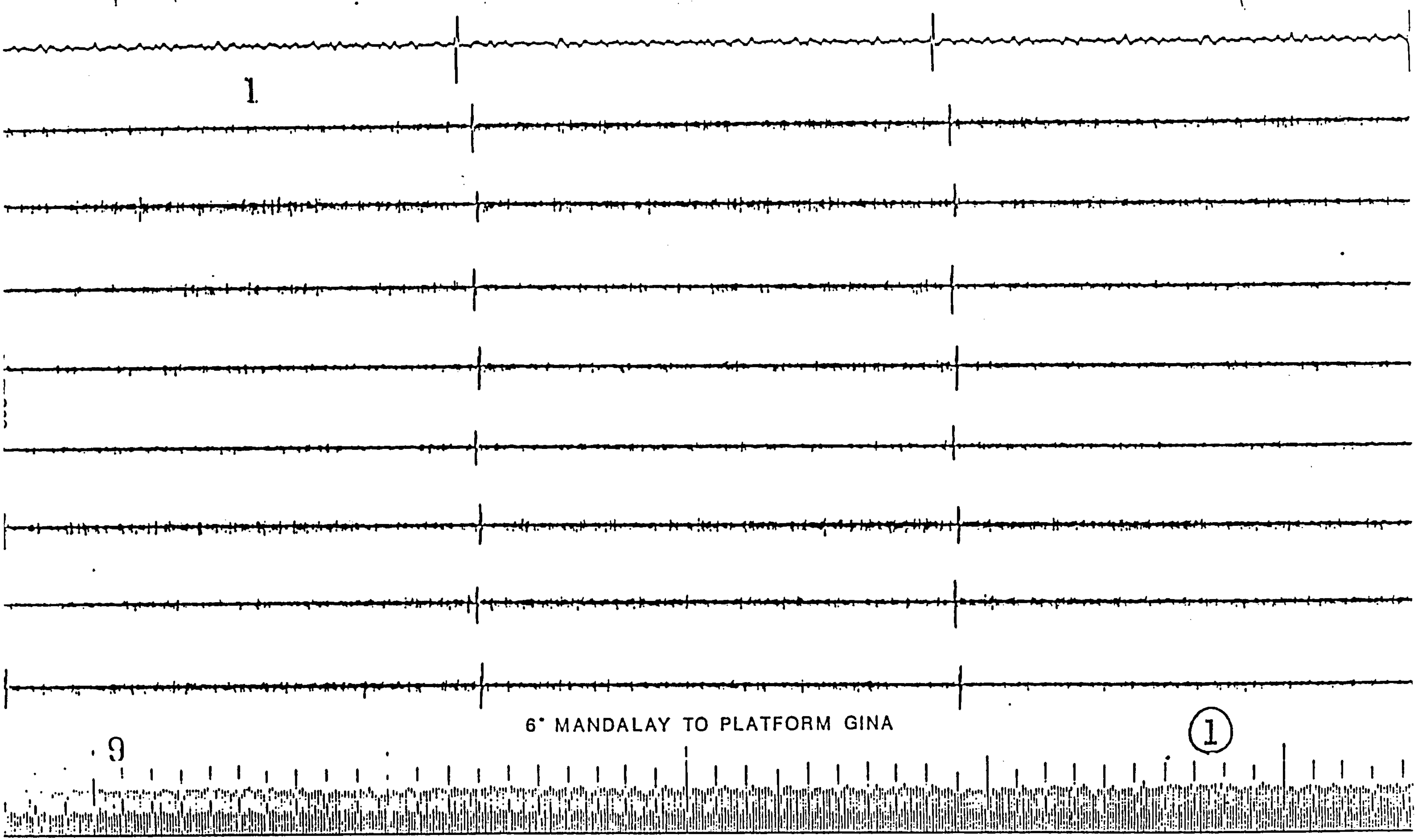
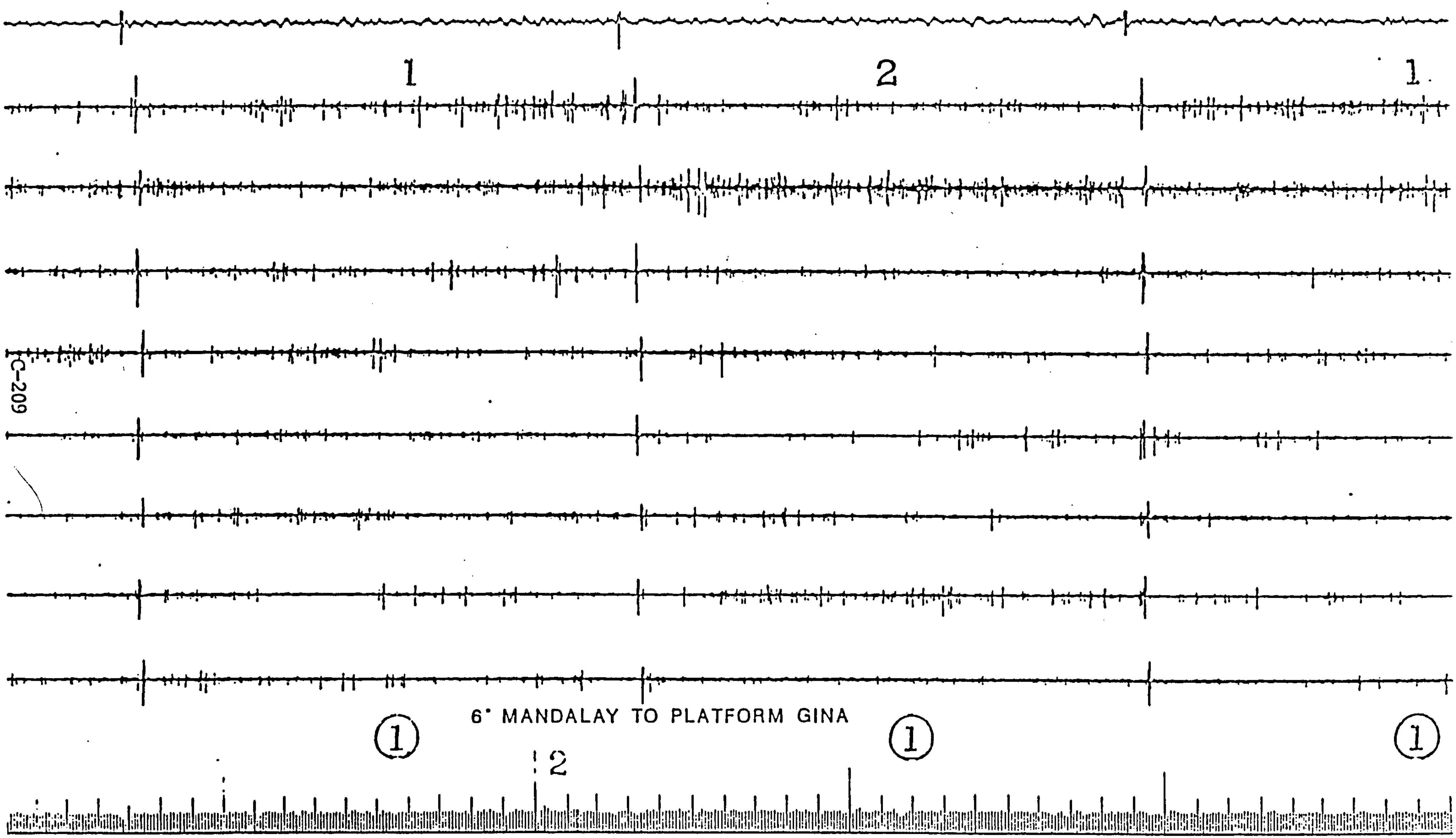

MARKER CHANNEL
AUGUST 1987 GRADES
1
2
1
2
2
2
8 SURVEY CHANNELS
JANUARY 1985 GRADES
6" MANDALAY TO PLATFORM GINA
DISTANCE/ORIENTATION CHANNEL
Launch
Station 0
Wheel Count 11
6 INCH LOG FORMAT

FIG. 3



ANOMALY GRADING

FIG. 4



ANOMALY GRADING

FIG. 5

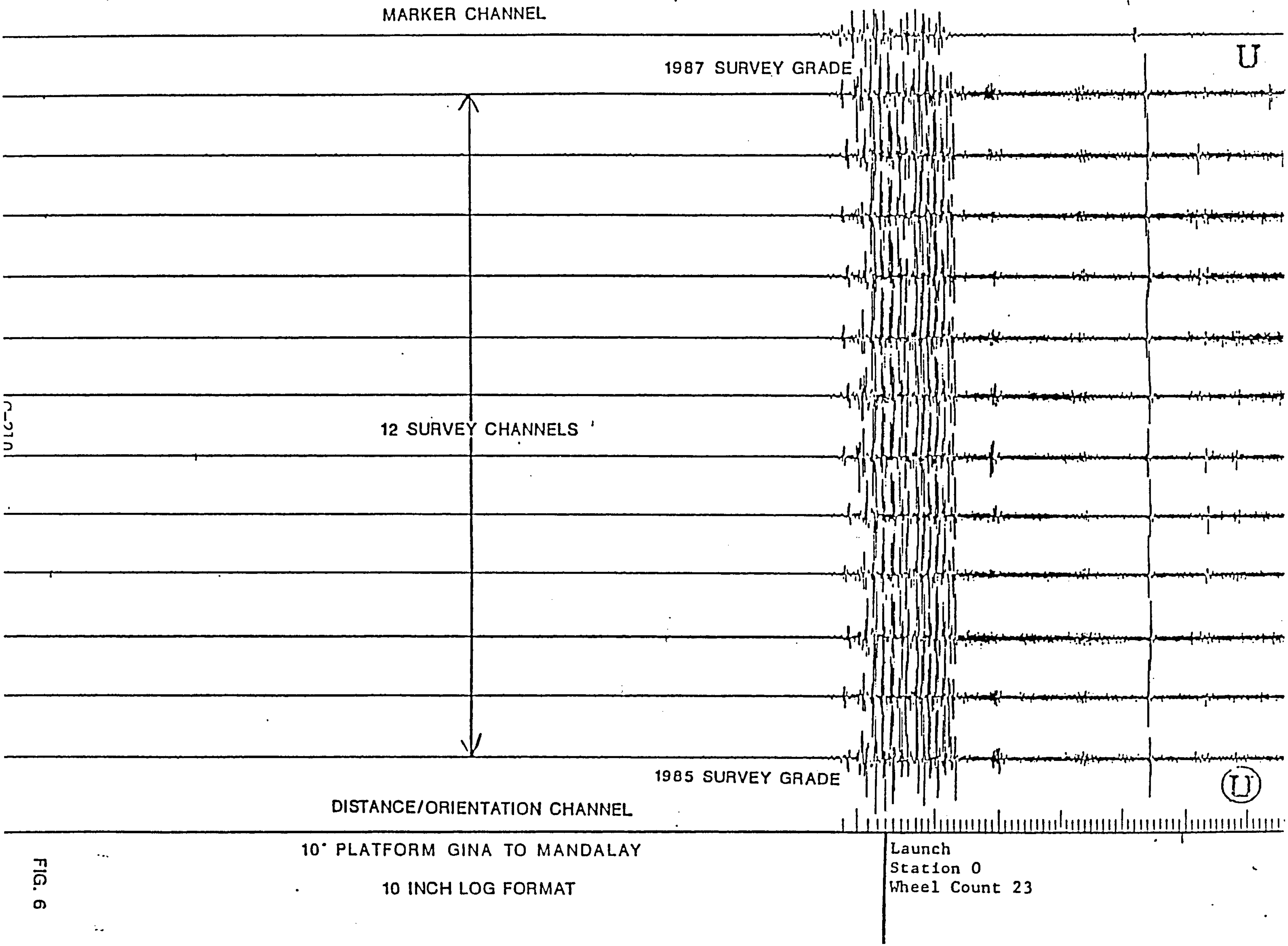
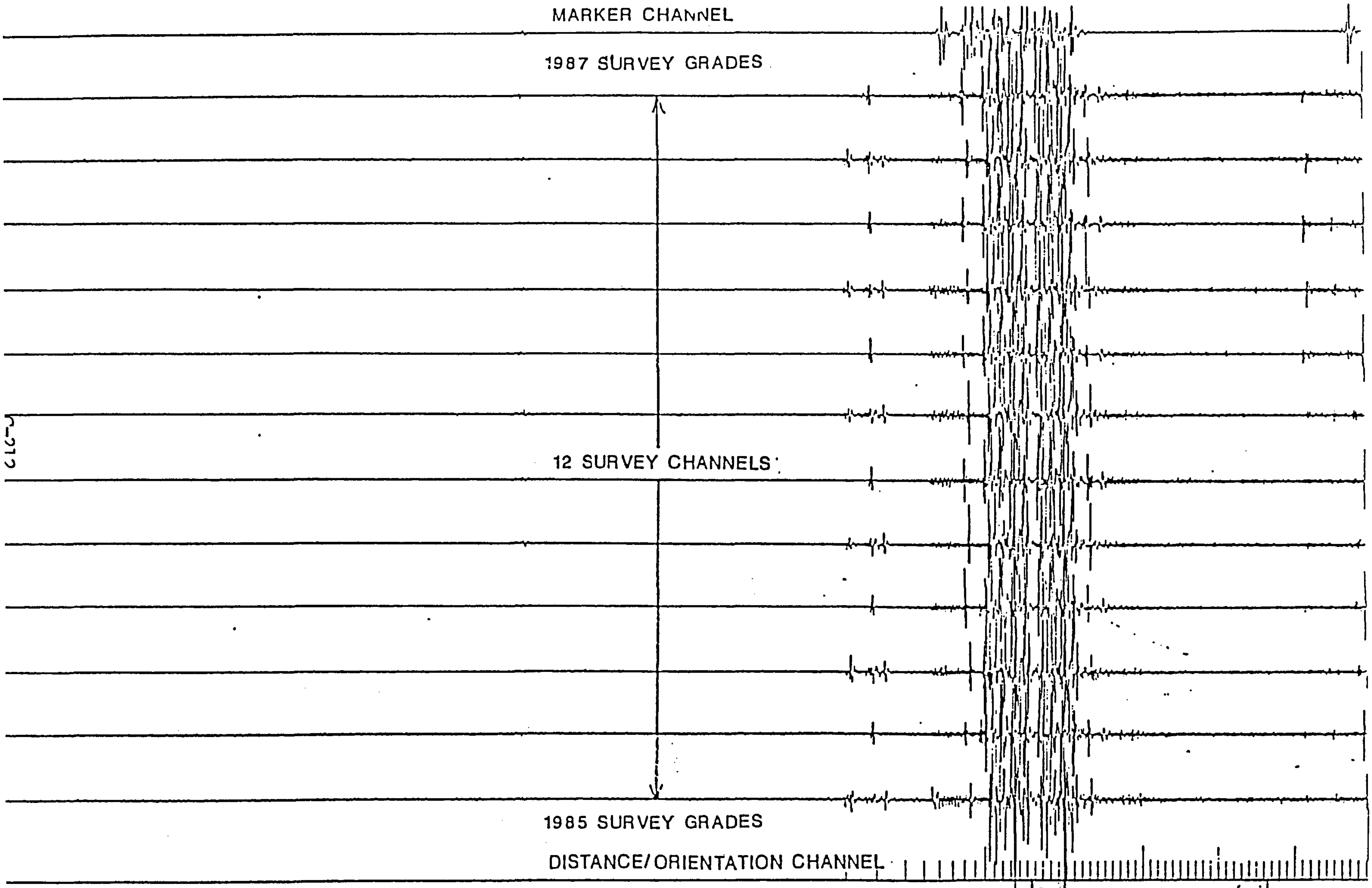

MARKER CHANNEL
1987 SURVEY GRADE
U
12 SURVEY CHANNELS
1985 SURVEY GRADE
U
DISTANCE/ORIENTATION CHANNEL
10' PLATFORM GINA TO MANDALAY
10 INCH LOG FORMAT
Launch
Station 0
Wheel Count 23

FIG. 6



Launch
Wheel Count 26

12" PLATFORM GILDA TO MANDALAY

12 INCH LOG FORMAT

FIG. 8

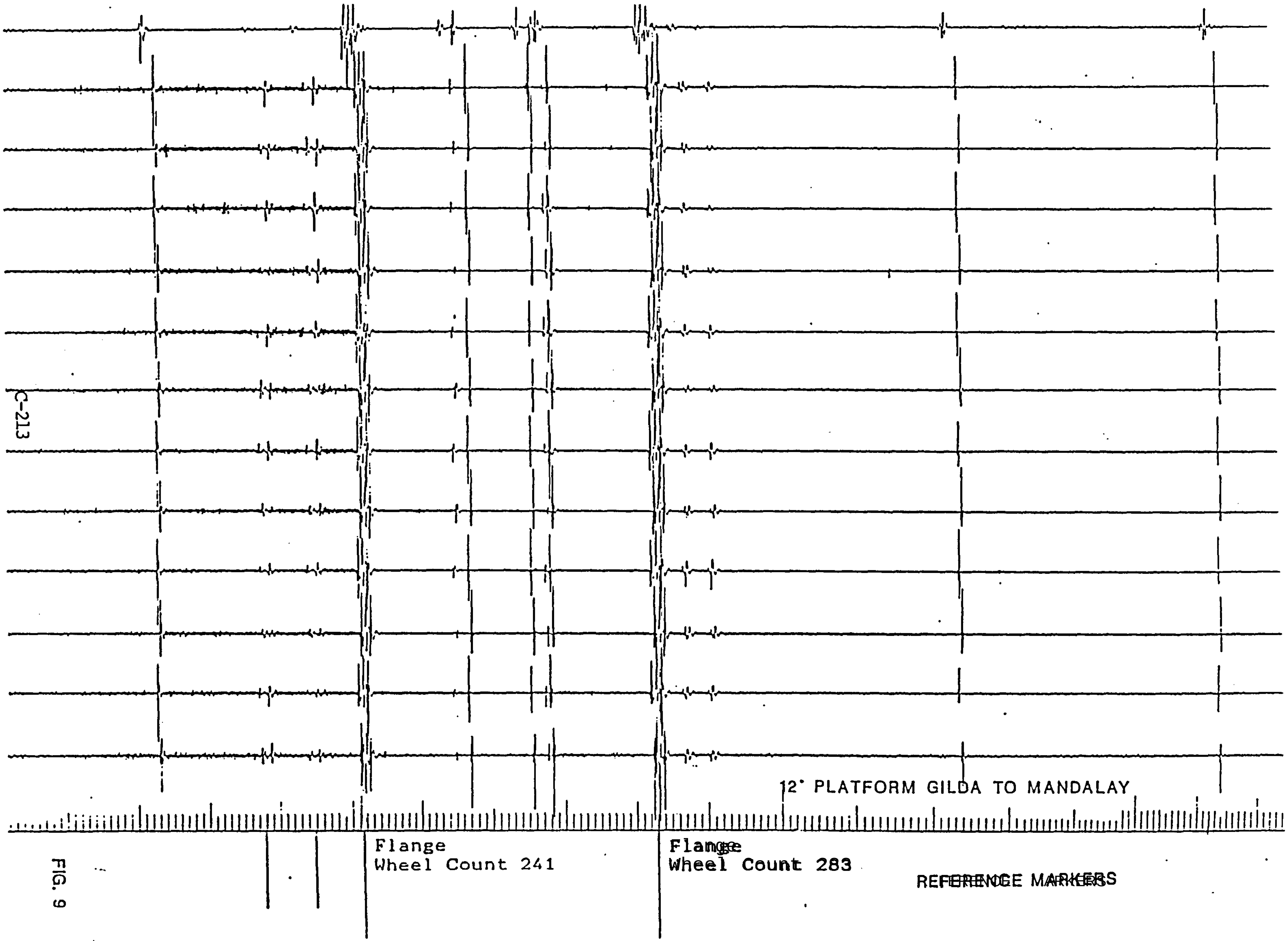
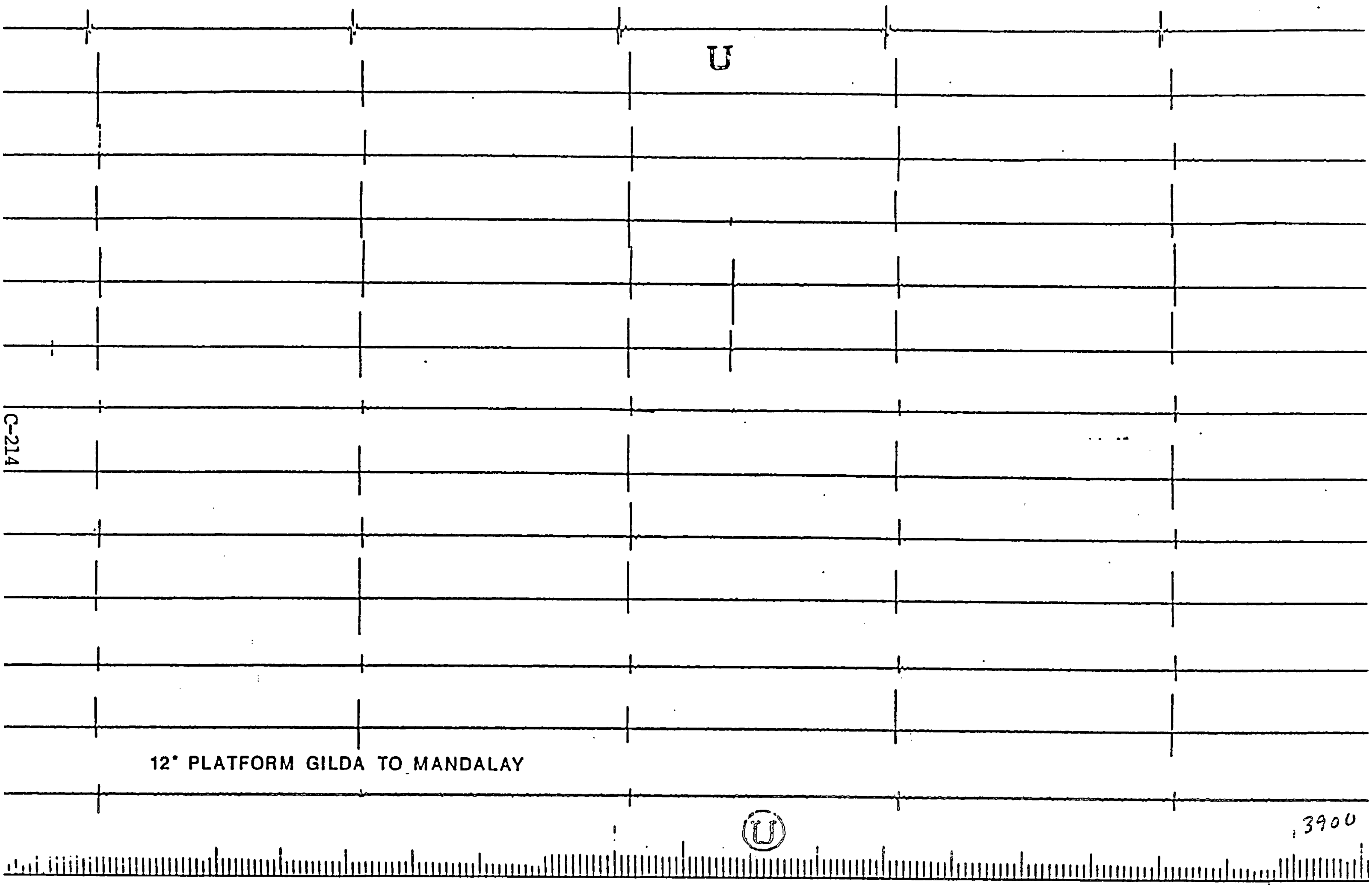

12" PLATFORM GILDA TO MANDALAY
Flange
Wheel Count 241
Flange
Wheel Count 283
REFERENCE MARKERS

FIG. 9



UNCLASSIFIED ANOMALY

FIG. 10

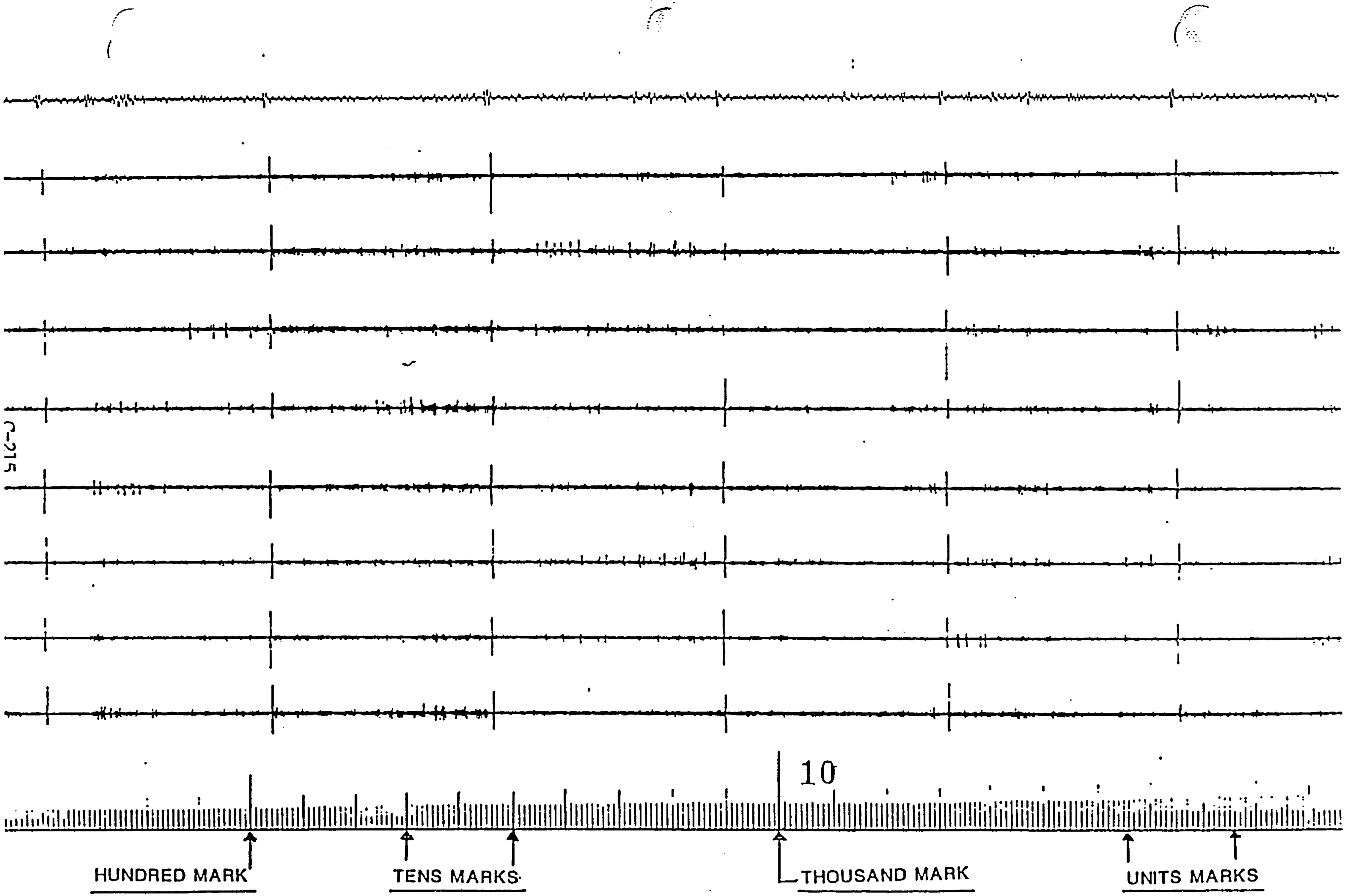
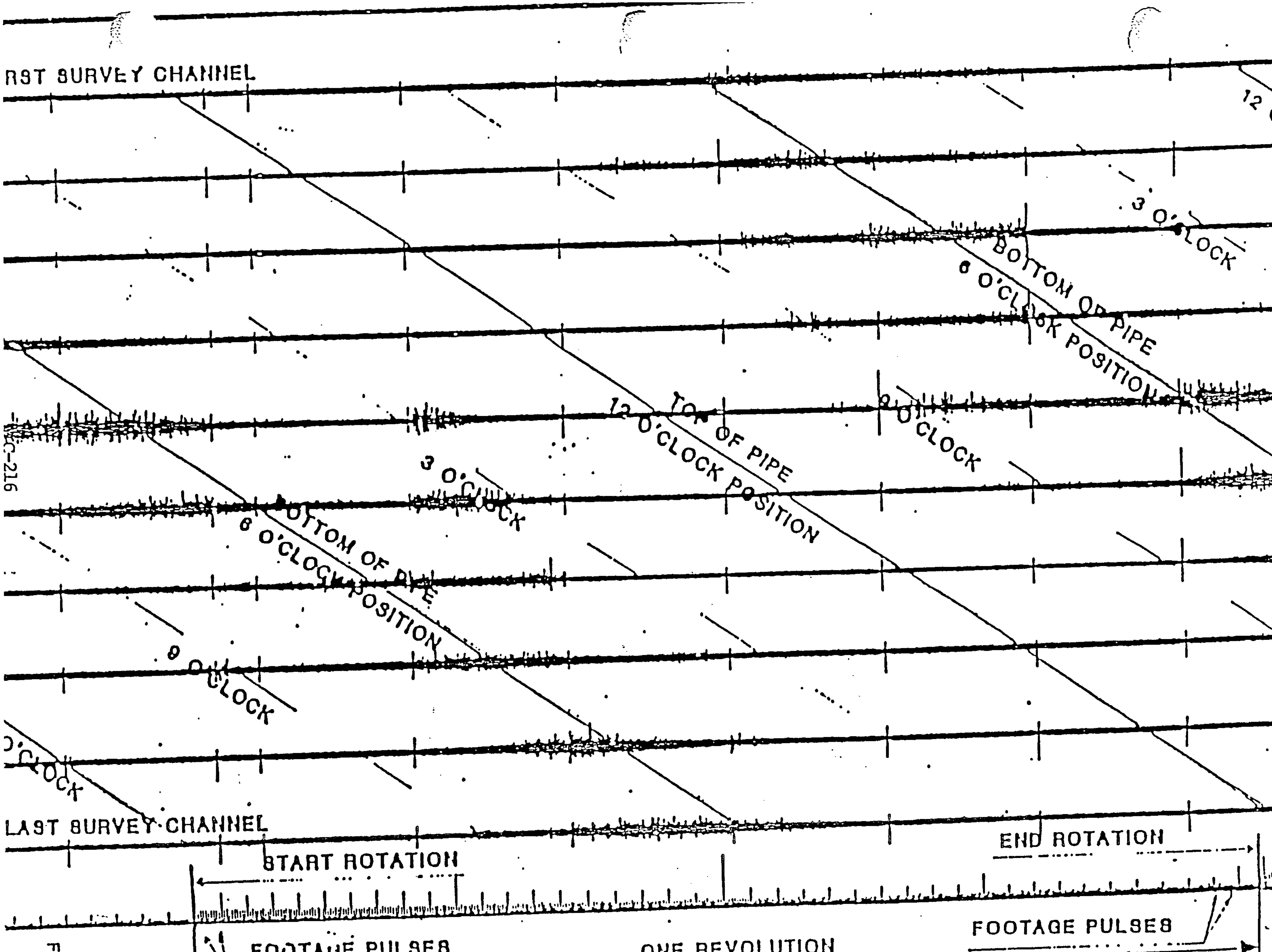


FIG. 11

DISTANCE CHANNEL EXAMPLE * EXAMPLE NOT TAKEN FROM THIS SURVEY

C-215



EXPLANATION OF ORIENTATION. * EXAMPLE NOT TAKEN FROM THIS SU

FIG. 1:

TOTALS

6" MANDALAY TO GINA

STATION NUMBER		GRADE CLASSIFICATION U	1	2	3
ROLL NO. 1					
0	LAUNCH	-	-	-	-
32792	TRAP	-	161	38	1
TOTAL OF PIPELINE		0	161	38	1

10" PLATFORM GINA TO MANDALAY

STATION NUMBER		GRADE CLASSIFICATION U	1	2	3
ROLL NO. 1					
0	LAUNCH	-	-	-	-
32961	TRAP	2	-	-	-
TOTAL OF PIPELINE		2	-	-	-

12" PLATFORM GILDA TO MANDALAY

WHEEL COUNT		GRADE CLASSIFICATION U	1	2	3
ROLL NO. 1					
26	LAUNCH	-	-	-	-
241	FLANGE	1	-	-	-
283	FLANGE	-	-	-	-
53036	TRAP	30	-	-	-
TOTAL OF PIPELINE		31	0	0	0

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Harco Cathodic Protection Survey (1/84)

ELECTRICAL POTENTIAL SURVEY
OF THE
MANDALAY AND RINCON
OFFSHORE PIPELINES
FOR
UNION OIL COMPANY OF CALIFORNIA

JANUARY, 1984

BY:
HARCO CORPORATION
HOUSTON, TEXAS
713/445-7171

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7) The electrical condition described in (6) causes the potential values recorded at Rincon to be at or below the criterion for cathodic protection.

8) A current demand is being imposed on the pipeline anodes near the Rincon shoreline and will cause these anodes to become depleted at a faster rate.

RECOMMENDATIONS

1) Install an above ground insulating flange on the 6" water line inside the Mobil Oil Facility at the location marked in Figure 1 of Appendix "A". Also install an insulating union at the location marked in Figure 1 to completely isolate the 6" water line from the Mobil Oil Facility.

2) Excavate the underground insulating flanges located outside the perimeter of the Union Oil Mandalay Facility. Conduct additional tests to determine the effectiveness of these insulating flanges.

3) Install a test station with test leads on each side of the underground insulating flanges for both the Gina and Gilda pipelines to provide for future testing of the effectiveness of the insulating flanges.

4) Conduct a re-survey of the onshore segments of the Mandalay and Rincon pipeline bundles after the insulating flange installations and repairs are complete. This will determine if the potential values are indicative of adequate cathodic protection.

5) Conduct a complete offshore survey of the Mandalay and Rincon pipeline bundles after repairs are complete. This data would provide a base line survey for comparison. Comparison of the data collected over several years will make it possible to evaluate any changes in the level of cathodic protection and thus aid in the planning of necessary corrosion control measures.

REPORT

INTRODUCTION

This report describes the work performed and the results obtained during a corrosion survey of the product and water pipelines located in the Santa Barbara Channel, California for Union Oil Company. This survey was performed by Harco Corporation on January 12-14, 1984. The survey was performed using the Harco Offshore Computerized Potential Log (CPL^{TM}) Survey Method developed specifically for obtaining continuous pipe-to-electrolyte potential measurements on offshore pipelines. The equipment and procedures used in this survey are discussed in the section of the report entitled "Test Procedures".

DESCRIPTION OF PIPELINES SURVEYED

The pipelines under consideration in this report are as follows:

A. Three (3) parallel pipelines from Platform Gilda (O.C.S. P-0216, Block 373) to Shore at Mandalay.

The three (3) pipelines in this bundle are 6", 10", and 12" in diameter. They are approximately 52,000 feet in length and were laid in August, 1981. They are coated with a Pritec type corrosion coating. In addition to the corrosion coating, an outer concrete weight coat (approx. 1" thick) exists on the gas pipeline and the shore approach sections of the water and oil pipelines. Cathodic protection for these pipelines is supplied by cast-on zinc anode bracelets. The anode sizes, net weights, and spacings are as follows:

GILDA PIPELINES

	ANODE SIZE	NET. WT. (Zn)	SPACING (# JOINTS)
12" Offshore	2" x 22"	475 lbs.	21
12" Surf Zone	1-1/2" x 16-3/4"	280 lbs.	13
10" Offshore	1-1/2" x 18-1/2"	260 lbs.	15
10" Surf Zone	3-1/2" x 4-1/4"	160 lbs.	9
6" Offshore	2" x 20"	246 lbs.	23
6" Surf Zone	1-1/2" x 11-1/4"	102 lbs.	9

All pipeline risers are electrically continuous with Platform Gilda as indicated by the data presented in Table 3 of Appendix "A".

B. Two (2) parallel pipelines from Platform Gina (O.C.S. P-0202, Block 350) to Shore at Mandalay.

The two (2) pipelines in this bundle are 6" and 10" in diameter. They are approximately 31,900 feet in length and were laid in August, 1981. These pipelines are coated with a Pritec type corrosion coating in conjunction with an outer concrete weight coat on the shore approach sections. Cathodic protection for these pipelines is supplied by cast-on zinc anode bracelets. The anode sizes, net weights, and spacings are as follows:

GINA PIPELINES

	ANODE SIZE	NET WT. (Zn)	SPACING (# JOINTS)
10" Offshore	2" x 21"	395 lbs.	22
10" Surf Zone	1-1/2" x 11-1/2"	160 lbs.	9
6" Offshore	2" x 20"	246 lbs.	23
6" Surf Zone	1-1/2" x 11-1/4"	102 lbs.	9

All pipeline risers are electrically continuous with Platform Gina as indicated by the data presented in Table 3 of Appendix "A".

C. Three (3) parallel pipelines from Platform B (O.C.S. P-0241) to Platform C (O.C.S. P-0241).

The three (3) pipelines in this bundle are 6", 12", and 12" in diameter. They are approximately 2,650 feet in length and were laid in June, 1968. They are coated with X-TRU coat with no outer concrete weight coat. Cathodic protection for these pipelines is supplied by the impressed current systems located on Platforms B and C. The operating outputs of the rectifiers located on these platforms are listed in Table 1 of Appendix "A".

All pipeline risers are electrically continuous with both Platforms B and C as indicated by the data presented in Table 3 of Appendix "A".

D. Three (3) parallel pipelines from Platform B (O.C.S. P-0241) to Shore at Rincon.

The three (3) pipelines in this bundle are 6", 12", and 12" in diameter. They are approximately 62,000 feet in length and were laid in June, 1968. They are coated with a Somastic type corrosion coating (approx. 3/4" thick) with no outer concrete weight coat. Cathodic protection for these pipelines is supplied by a combination of impressed current systems located on Platforms A and B, and sacrificial anodes installed on the length of the pipelines from Station No. 407+50 to shore. The approximate locations of the sacrificial anode stations are as follows:

ANODE STATION	WATER DEPTH (FT.)	STATION NUMBER	ANODE SPACING (FT.)
1	180	407+50	21,941 (from Platform B)
2	175	354+90	5,260
3	150	301+40	5,350
4	135	249+70	5,170
5	115	194+00	5,570
6	95	138+30	5,570
7	65	85+28	5,302
8	50	46+40	3,888
9	25	24+70	2,170

Anode Stations 1-8 consist of three (3) 450 lb. zinc anodes. Anode Station No. 9 consists of three (3) 350 lb. Galvalum anodes. The operating outputs of the rectifiers located on Platforms A and B are listed in Table 1 of Appendix "A".

All pipeline risers are electrically continuous with Platform B as indicated by the data presented in Table 3 of Appendix "A".

TEST PROCEDURES

The survey was performed using the Harco Offshore CPL^{TM} Survey Method which is designed to produce continuous pipe-to-electrolyte potential profiles along the entire length of a submerged pipeline.

The standard CPL^{TM} survey is conducted by making a test connection to the pipeline at an accessible location, such as a riser at an offshore platform or at an onshore test station. A saturated silver/silver chloride (Ag/AgCl) reference electrode is towed above the pipeline while maintaining the test connection to the pipe by spooling out a light gauge insulated wire (Litewire^{TM}) from a boat moving at approximately six (6) knots. The pipe-to-electrolyte potential is measured and recorded onboard using a Hewlett Packard data acquisition system. This system consists of a multi-channel data logger, a microcomputer equipped with appropriate interfaces, and a strip chart recorder. During the survey, the potential is displayed on the video control terminal of the computer and plotted versus real time using the strip chart recorder.

The microcomputer serves as both a controller/processor for the data logger and as a data storage device with an internal magnetic tape drive. The computer is programmed to collect potential measurements at a rate of two per second, which at a speed of six (6) knots provides potential measurements at approximately 5.0 foot intervals along the pipeline. A distance marker is embedded into the data stream at prespecified intervals, generally 1000 feet. These distance markers are later correlated with ship position coordinates to generate accurate downline distance measurements for the potential profiles.

The pipelines were tracked using the Motorola Mini-Ranger positioning system in conjunction with the coordinates used to produce as-built drawings of the pipelines. The accuracy of this system is +/-3 meters under ideal field conditions.

During the course of this work six (6) survey runs were made. These runs are listed in Table 2 of Appendix "A". In addition to the potential profiles for the offshore pipelines, potential values were measured at the platforms and risers. This data is presented in Table 3 of Appendix "A". Potential values were also measured onshore at both the Rincon and Mandalay sites. This data is presented in Table 4 of Appendix "A".

RESULTS AND ANALYSIS

The pipe-to-electrolyte potential profiles recorded on the pipelines are shown in Figures 1-4 of Appendix "B". Examination of these profiles shows that all potential values recorded are at or more negative than -800 millivolts with respect to a saturated silver/silver chloride (Ag/AgCl) reference electrode. These potential values satisfy the criterion for cathodic protection (-800 mV Ag/AgCl) as designated by the National Association of Corrosion Engineers' Standard RP-06-75, "Control of Corrosion on Offshore Steel Pipelines".

The pipe-to-electrolyte potential measurements recorded on the onshore portions of the pipelines are presented in Table 4 of Appendix "A". Examination of this data shows that all the potential values except the potential values recorded on the blue and red lead wires at the test station near the railroad crossing at Rincon do not meet the criterion for cathodic protection (-850 mV $Cu/CuSO_4$) as designated by the National Association of Corrosion Engineers' Standard RP-01-69 (1976 Revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems".

The pipe-to-electrolyte potential profile recorded on the 6", 10" and 12" pipelines from Platform Gilda to shore at Mandalay is shown in Figure 1 of Appendix "B". Since the three (3) pipelines are electrically continuous with each other, the potential values presented in Figure 1 represent the average potential level occuring on each pipeline.

Examination of Figure 1 shows a relatively flat potential profile between -850 millivolts and -825 millivolts silver/silver chloride (Ag/AgCl). The overall lower potential level which is observed near the shoreline could be due to the electrical conditions which exist between the pipeline bundle and the Mandalay Facility. This phenomenon will be discussed in further detail in the analysis of the data from the Gina pipelines.

The increase in the potential level adjacent to Platform Gilda is attributed to the effect of increased electrolyte IR drop on the potential measurement near the platform. This effect causes a more negative potential value to be measured when the reference electrode is within the current gradient field of the platform anodes. The effect of the electrolyte IR drop associated with the platform anodes decreases or increases exponentially as the reference electrode moves away from or toward the source of current. The magnitude of the electrolyte IR drop depends on several conditions, such as the size and type of platform anodes, and the electrical conditions which exist between the riser and the platform jacket.

In general the potential profile is indicative of uniform current distribution, however, the potential level is expected to be higher for pipelines of this age.

The pipe-to-electrolyte potential profile recorded on the 6" and 10" pipelines from Platform Gina to shore at Mandalay is shown in Figure 2 of Appendix "B". As previously discussed, since the two (2) pipelines are electrically continuous with each other, the potential values presented in Figure 2 represent the average potential level occuring on each pipeline.

Examination of Figure 2 shows a relatively flat potential profile at approximately -850 millivolts silver/silver chloride (Ag/AgCl).

The characteristic increase in the potential values near Platform Gina is present. This phenomenon, as previously discussed, is attributed to the effect of electrolyte IR drop on the potential measurement in the area adjacent to the platform.

Further examination of Figure 2 shows that the potential values steadily increase from a downline distance of 16,000 feet to the end of the run at 27,825 feet. This phenomenon could be due to differences in anode spacing and/or the electrical conditions which exist between the pipeline bundle and the Mandalay Facility.

The potential measurements recorded on both the Gina and Gilda pipelines (ref. Table 4, Appendix "A") indicate that the underground insulating flanges located outside the perimeter of the Mandalay Facility are not directly shorted. It does appear however that the underground insulator on the Gina water line exhibits some type of high resistance shorted condition. This phenomenon is evidenced by the relative magnitude of the potential measurements recorded on either side of the insulating flange (-589 mV. and -565 mV., respectively). This phenomenon could also be occuring to a lesser degree on the Gilda water line as evidenced by the potential measurements recorded on either side of its insulating flange, (-747 mV. and -563 mV., respectively).

Under these conditions both pipeline bundles are partially electrically continuous with the unprotected metallic piping and structures associated with the Mandalay Facility. This condition will place a current demand on the pipeline anode bracelets and can cause overall potential levels to be lower. This additional current demand will also cause the affected bracelet anodes to become depleted at a faster rate. The effective metallic resistance of the two (2) pipeline bundles also contributes to the overall electrical condition which exists between the pipeline bundles themselves and the Mandalay Facility. This could account for the increase in the potential level observed on the Gina pipeline bundle near the end of the survey run and the lower potential level observed near the end of the survey run on the Gilda pipeline bundle.

In general the potential profile recorded on the Gina pipeline bundle is indicative of uniform current distribution, however, the potential level is expected to be higher for pipelines of this age.

The pipe-to-electrolyte potential profile recorded on the 6", 12", and 12" pipelines from Platform B to Platform C is shown in Figure 3 of Appendix "B". Since the three (3) pipelines are electrically continuous with each other, the potential values presented in Figure 3 represent the average potential level occuring on each pipeline.

Examination of Figure 3 shows that current "off" potential values are more negative than -890 millivolts silver/silver chloride (Ag/AgCl), and that current "on" potential values are more negative than -910 millivolts silver/silver chloride (Ag/AgCl).

Further examination of Figure 3 shows the characteristic increase in both the current "on" and "off" potential values near the platforms. This phenomenon is again attributed to the effect of electrolyte IR drop on the potential measurement in the areas adjacent to the platforms. This effect is more pronounced at Platform B than at Platform C due to the fact that the impressed current system on Platform C was turned off during the survey run. This was done in order to record true IR free potential values.

The overall current distribution is higher on the sections of the pipelines adjacent to the platforms, and the profile in general is indicative of good coating quality and a properly functioning cathodic protection system.

The pipe-to-electrolyte potential profile recorded on the 6", 12", and 12" pipelines from Platform B to shore at Rincon is shown in Figure 4 of Appendix "B". The three (3) pipelines are electrically continuous with each other, therefore the potential values presented in Figure 4 represent the average potential level occuring on each pipeline.

Examination of Figure 4 shows several anomalies. The characteristic increase in both current "on" and "off" potential values near Platform B is observed. This is again due to the effect of electrolyte IR associated with the impressed current system on Platform B.

It is also observed in Figure 4 that after three (3) current "off" cycles of the impressed current system, the current does not return to the "on" mode. This was due to a malfunction in the individual rectifier circuit breakers. The survey was continued with the rectifier "off" until the problem was discovered and the circuit breakers reset at approximately 26,400 feet downline from Platform B. During this time the pipelines had suffered some degree of depolarization. Run #5 was terminated at 30,605 feet downline from Platform B due to a severed negative lead wire connection. Run #6 was a continuation of the survey run from Platform B to shore and was started after sufficient time had elapsed. The pipelines had therefore re-polarized which accounts for the anomaly in the potential level observed at 30,605 feet. The instant current "off" potential values between 10,000 feet and 30,605 feet downline from Platform B are expected to be on the order of -825 millivolts silver/silver chloride (Ag/AgCl).

The anomalies in the potential level observed when passing Platform A and the Hillhouse platform are due to the effect of electrolyte IR drop on the potential measurement when entering and leaving the current gradient fields associated with these platforms. Even though the impressed current systems on these platforms were turned off to provide for true IR potential measurements, the increased potential level of these platforms as compared to the pipelines does create a significant electric field. It is also indicated that supplemental cathodic protection would be provided by the impressed current systems located on Platform A and the Hillhouse platform. These platforms are electrically continuous with the pipeline bundle from Platform B to shore through other pipeline/power cable systems.

Another anomaly observed in Figure 4 is the increase in the potential level which occurs at the Pacific Interstate Pipeline Company (PAC Interstate) pipeline crossing at a downline distance of approximately 18,350 feet. It appears that supplemental current is being picked up at this location due to an electrical interference problem which exists between Platform Henry and the PAC Interstate pipeline. Another possible explanation of the observed increase in the potential level is the effect of electrolyte IR drop on the potential measurement associated with the impressed current system located on Platform Henry. In either case this anomaly is not considered significant with respect to the effectiveness of the Union Oil Company cathodic protection systems. A schematic diagram showing the layout of the various pipelines and platforms in this area is presented in Figure 2 of Appendix "A".

The last anomaly observed in Figure 4 is the increased potential level which occurs from a downline distance of 53,000 feet to the end of the survey run (approx. 1,150 feet from the shoreline at Rincon). This is due to differences in anode alloy type and/or anode spacing.

The pipe-to-electrolyte potential measurements recorded on the onshore portions of these pipelines indicates that an electrical continuity condition exists between the Union Oil Company pipeline bundle and the unprotected Mobil Oil Facility. This phenomenon occurs due to the lack of an insulating flange on the 6" water line. This condition will place a current demand on the offshore pipeline anode stations adjacent to the shoreline and can cause potential values to be below the criterion for protection.

A P P E N D I X " A "

C-240

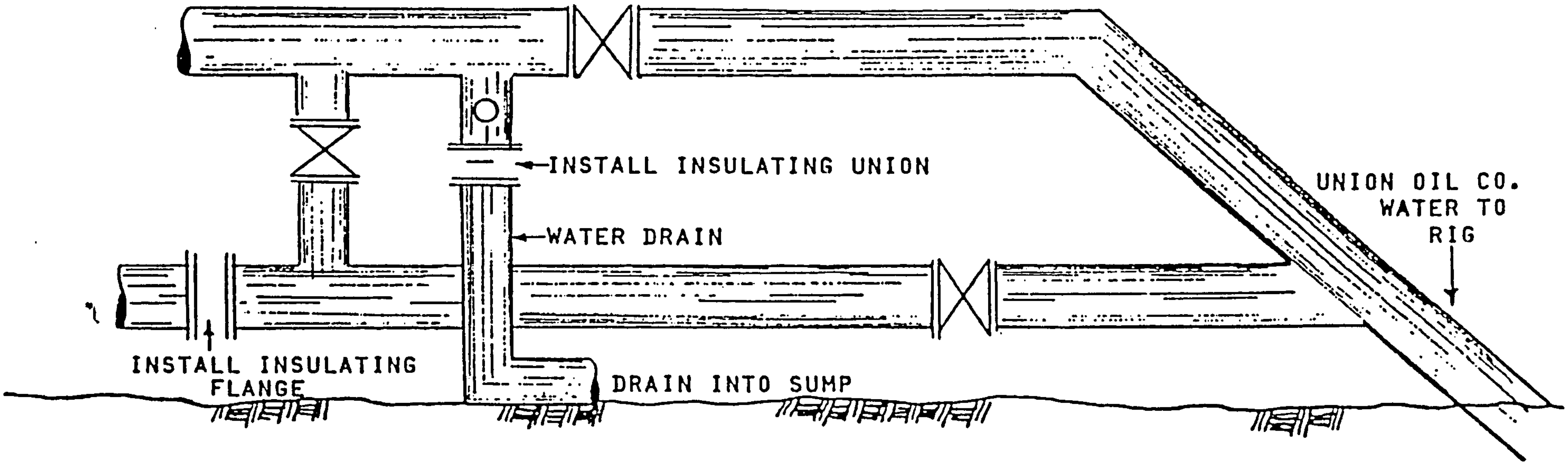

FIG. 1

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CLEVELAND · ATLANTA · CHICAGO
HOUSTON · LOS ANGELES · NEWARK

DRAWN BY:	MMH
DATE:	4-25-84
DWG. NO.	

UNION OIL CO.
WATER PIPING LAYOUT
IN MOBILE OIL PLANT
RINCON AREA

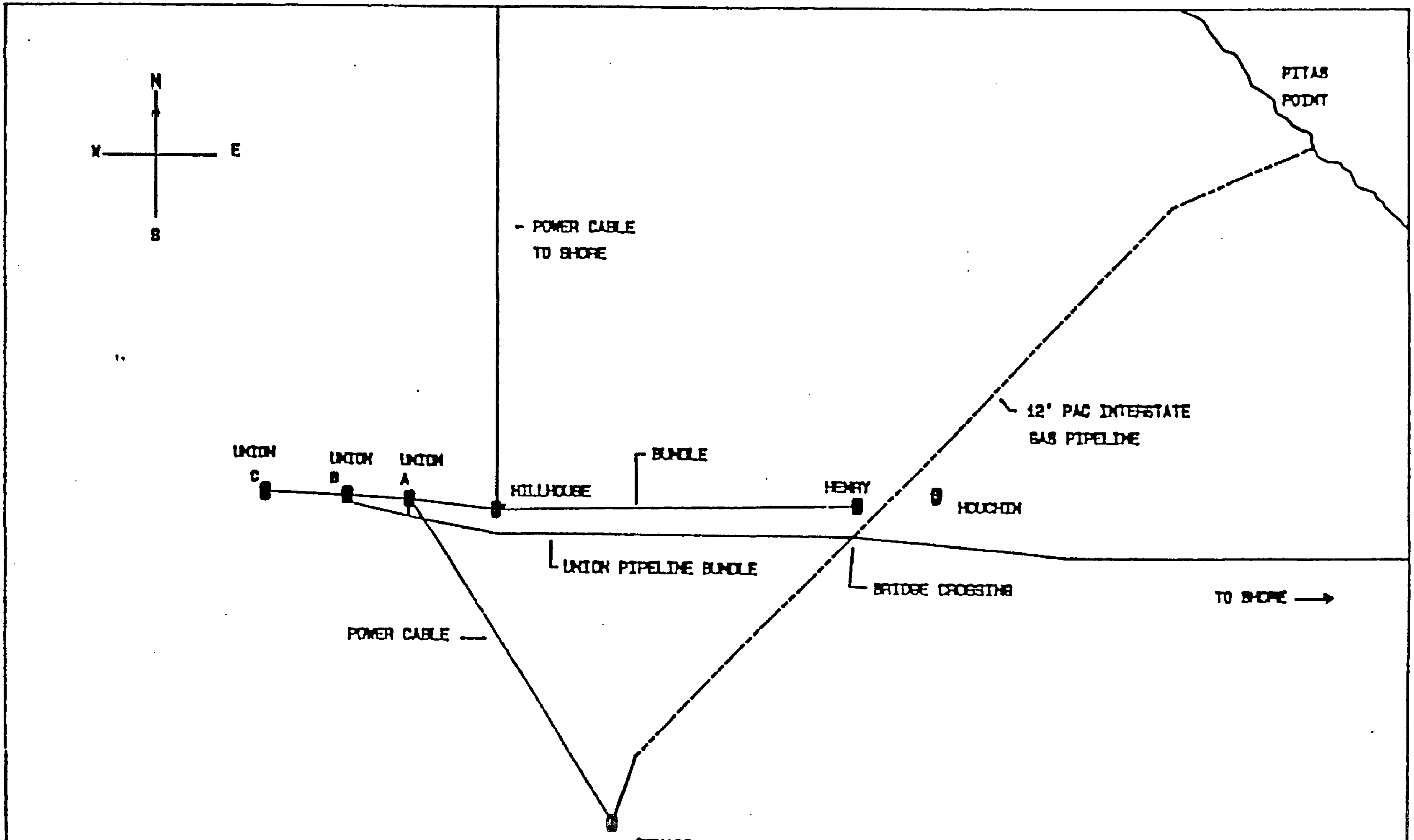

FIGURE 2
DIAGRAM OF OFFSHORE PIPELINES

TABLE 1

LOCATIONS AND OPERATING OUTPUTS OF RECTIFIERS

PLATFORM A (O.C.S. P-0241)

RECTIFIER #1	----	220 Amps @ 14.75 Volts D.C.
RECTIFIER #2	----	175 Amps @ 15.00 Volts D.C.
RECTIFIER #3	----	260 Amps @ 14.00 Volts D.C.
RECTIFIER #4	----	265 Amps @ 14.25 Volts D.C.
RECTIFIER #5	----	97 Amps @ 8.75 Volts D.C.
RECTIFIER #6	----	BACK-UP RECTIFIER

PLATFORM B (O.C.S. P-0241)

RECTIFIER #1	----	190 Amps @ 17.00 Volts D.C.
RECTIFIER #2	----	130 Amps @ 17.00 Volts D.C.
RECTIFIER #3	----	190 Amps @ 9.00 Volts D.C.
RECTIFIER #4	----	140 Amps @ 18.00 Volts D.C.
RECTIFIER #5	----	110 Amps @ 15.00 Volts D.C.
RECTIFIER #6	----	170 Amps @ 14.00 Volts D.C.

PLATFORM C (O.C.S. P-0241)

RECTIFIER #1	----	260 Amps @ 10.00 Volts D.C.
RECTIFIER #2	----	BACK-UP RECTIFIER
RECTIFIER #3	----	215 Amps @ 12.00 Volts D.C.
RECTIFIER #4	----	125 Amps @ 14.50 Volts D.C.
RECTIFIER #5	----	140 Amps @ 12.25 Volts D.C.
RECTIFIER #6	----	280 Amps @ 11.50 Volts D.C.

TABLE 2

SURVEY RUNS

Run #1	6", 10", and 12" Pipeline Bundle From Platform Gilda (O.C.S. P-0216, Block 373) Toward Shore At Mandalay. Date: 1/12/84
Run #2	6", 10", and 12" Pipeline Bundle From End of Run #1 to Shore At Mandalay. Date: 1/12/84
Run #3	6" and 10" Pipeline Bundle From Platform Gina (O.C.S. P-0202, Block 350) To Shore At Mandalay. Date: 1/12/84
Run #4	6", 12", and 12" Pipeline Bundle From Platform B (O.C.S. P-0241) To Platform C (O.C.S. P-0241). Date: 1/13/84
Run #5	6", 12", and 12" Pipeline Bundle From Platform B (O.C.S. P-0241) Toward Shore At Rincon. Date: 1/13/84
Run #6	6", 12", and 12" Pipeline Bundle From End Of Run #5 To Shore At Rincon. Date: 1/13/84

TABLE 3

OFFSHORE STRUCTURE-TO-ELECTROLYTE POTENTIAL MEASUREMENTS

STRUCTURE	POTENTIAL VS. Ag/AgCl "ON"	POTENTIAL VS. Ag/AgCl "OFF"	COMMENTS
PLATFORM A (O.C.S. P-0241)	-1154 mV.	-1110 mV.	All Risers Electrically Continuous With Platform.
6" Water Riser	-1155 mV.	---------	
12" Oil Riser	-1154 mV	---------	
12" Gas Riser	-1154 mV	---------	
PLATFORM B (O.C.S. P-0241)	-1108 mV.(*)	-1067 mV.(*)	(*) Potential Values Taken On Platform B At Risers To Platform C Location.
	-1111 mV.(**)	-1078 mV.(**)	(**) Potential Values Taken on Platform B At Risers To Rincon Location.
6" Water Riser to Platform C	-1109 mV.	---------	All Risers Electically Continuous With Platform.
12" Oil Riser to Platform C	-1108 mV.	---------	
12" Gas Riser to Platform C	-1108 mV.	---------	
PLATFORM C (O.C.S. P-0241)	-1178 mV.	-1124 mV.	All Risers Electrically Continuous With Platform.
6" Water Riser	-1180 mV.	---------	
12" Oil Riser	-1178 mV.	---------	
12" Gas Riser	-1178 mV.	---------	

STRUCTURE	POTENTIAL VS. Ag/AgCl	COMMENTS
PLATFORM GINA (O.C.S. P-0202)	-955 mV.	All Risers Electrically Continuous With Platform.
6" Water Riser	-956 mV.	
10" Oil Riser	-956 mV.	
PLATFORM GILDA (O.C.S. P-0216)	-992 mV.	All Risers Electrically Continuous With Platform.
6" Water Riser	-992 mV.	
10" Oil Riser	-992 mV.	
12" Gas Riser	-992 mV.	

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TABLE 4

STRUCTURE-TO-SOIL POTENTIAL SURVEY DATA

STRUCTURE(S) SURVEYED: SHORE SECTIONS OF GILDA AND GINA OFFSHORE PIPELINES

OWNER: UNION OIL COMPANY OF CALIFORNIA

LOCATION: MANDALAY FACILITY

SURVEYED BY: S. WOLFSON/M. McCORMICK DATE: 1-14-84

READING NUMBER	TEST LOCATION	POTENTIAL (MILLIVOLTS)		
	- TEST STATION IN UNION FACILITY -			
	(SEASIDE OF UNDERGROUND INSULATOR)			
1	GINA WATER LINE	-589 mV. $Cu/CuSO_4$		
2	GINA OIL LINE	-817 mV. $Cu/CuSO_4$		
3	GILDA OIL LINE	-828 mV. $Cu/CuSO_4$		
4	GILDA GAS LINE	-811 mV. $Cu/CuSO_4$		
5	GILDA WATER LINE	-747 mV. $Cu/CuSO_4$		
	- TEST STATION IN UNION FACILITY -			
	(FACILITY SIDE OF UNDERGROUND INSULATOR)			
6	GINA WATER LINE	-565 mV. $Cu/CuSO_4$		
7	GINA OIL LINE	-562 mV. $Cu/CuSO_4$		
8	GILDA OIL LINE	-562 mV. $Cu/CuSO_4$		
9	GILDA GAS LINE	-563 mV. $Cu/CuSO_4$		
10	GILDA WATER LINE	-563 mV. $Cu/CuSO_4$		

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TABLE 4 - CONT.

STRUCTURE-TO-SOIL POTENTIAL SURVEY DATA

STRUCTURE(S) SURVEYED: SHORE SECTIONS OF UNION ABC OFFSHORE PIPELINES

OWNER: UNION OIL COMPANY OF CALIFORNIA

LOCATION: MOBIL OIL FACILITY (RINCON) / RINCON SHORELINE

SURVEYED BY: S. WOLFSON/M. McCORMICK DATE: 1-14-84

READING NUMBER	TEST LOCATION	POTENTIAL (MILLIVOLTS)		
	- MOBIL OIL FACILITY (RINCON)			
	(UNION SIDE OF INSULATOR)			
1	12" OIL LINE	-756 mV. $Cu/CuSO_4$		
2	12" GAS LINE	-785 mV. $Cu/CuSO_4$		
	(MOBIL SIDE OF INSULATOR)			
3	12" OIL LINE	-685 mV. $Cu/CuSO_4$		
4	12" GAS LINE	-699 mV. $Cu/CuSO_4$		
	* NO INSULATING FLANGE BETWEEN UNION WATER LINE & MOBIL PLANT PIPING.			
5	6" WATER LINE	-737 mV. $Cu/CuSO_4$		
	(LINES EXITING MOBIL FACILITY)			
6	12" OIL LINE	-683 mV. $Cu/CuSO_4$		
7	12" GAS LINE	-687 mV. $Cu/CuSO_4$		
	- TEST STATION NEAR RAILROAD TRACK	(TS 1) -		
	* LEAD WIRES NOT MARKED AT T.S.			
8	BLUE WIRE	-851 mV. $Cu/CuSO_4$		
9	RED WIRE	-851 mV. $Cu/CuSO_4$		
10	BLACK WIRE	-793 mV. $Cu/CuSO_4$		

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Corrosion Engineering Division

TABLE 4 - CONT.

STRUCTURE-TO-SOIL POTENTIAL SURVEY DATA

STRUCTURE(S) SURVEYED: SHORE SECTIONS OF UNION ABC OFFSHORE PIPELINES

OWNER: UNION OIL COMPANY OF CALIFORNIA

LOCATION: MOBIL OIL FACILITY (RINCON) / RINCON SHORELINE

SURVEYED BY: S. WOLFSON/M. McCORMICK DATE: 1-14-84

READING NUMBER	TEST LOCATION	POTENTIAL (MILLIVOLTS)		
12	CASING VENT	-573 mV. Cu/$CuSO_4$		
	- TEST STATION BETWEEN OLD & NEW HIGHWAY (TS 2) -			
13	6" WATER LINE	-651 mV. Cu/$CuSO_4$		
14	12" GAS LINE	-709 mV. Cu/$CuSO_4$		
15	12" OIL LINE	-710 mV. Cu/$CuSO_4$		
	- RINCON SHORELINE -			
	* NEGATIVE CONNECTION AT TS 2			
16	6" WATER LINE	-719 mV. Ag/AgCl		
17	12" GAS LINE	-779 mV. Ag/AgCl		
18	12" OIL LINE	-779 mV. Ag/AgCl		

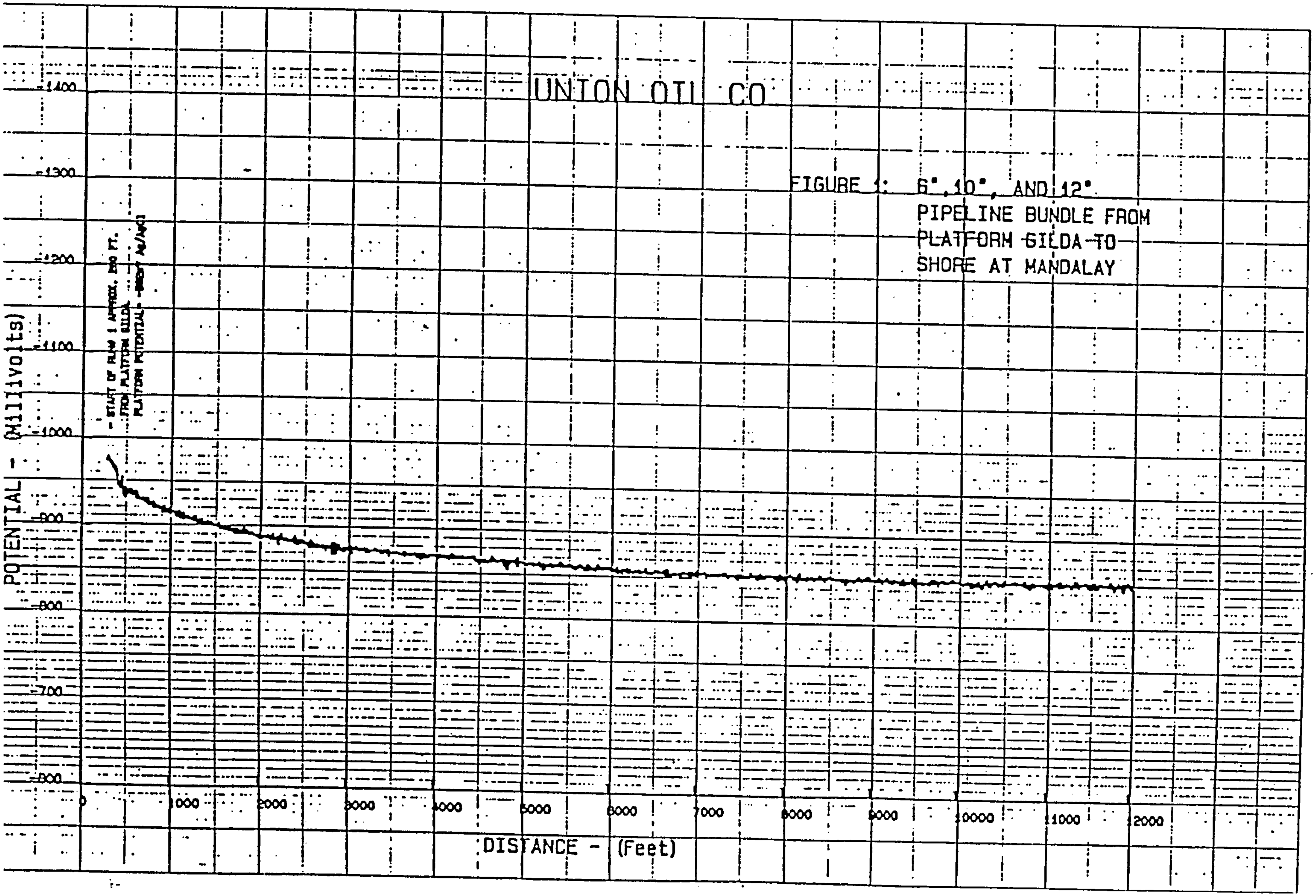
UNION OIL COMPANY
APPENDIX B
POTENTIAL PROFILES

FIGURE 1	RUN# 1	6",10", AND 12" PIPELINE BUNDLE FROM PLATFORM GILDA (O.C.S. P-0216,BLOCK 373) TOWARD SHORE AT MANDALAY.
	RUN# 2;	6",10", AND 12" PIPELINE BUNDLE FROM END OF RUN# 1 TO SHORE AT MANDALAY.
FIGURE 2	RUN# 3;	6" AND 10" PIPELINE BUNDLE FROM PLATFORM GINA (O.C.S. P-0202,BLOCK 350) TO SHORE AT MANDALAY.
FIGURE 3	RUN# 4;	6",12", AND 12" PIPELINE BUNDLE FROM PLATFORM B (O.C.S. P-0241) TO PLATFORM C (O.C.S. P-0241).
FIGURE 4	RUN# 5;	6",12", AND 12" PIPELINE BUNDLE FROM PLATFORM B (O.C.S. P-0241) TOWARD SHORE AT RINCON.
	RUN# 6;	6",12", AND 12" PIPELINE BUNDLE FROM END OF RUN# 5 TO SHORE AT RINCON.

RUNS# 1,2,3 DATE: 1/12/84

RUNS# 4,5,6 DATE: 1/13/84

FIGURE 1



UNION OIL CO
FIGURE 1: 6", 10", AND 12"
PIPELINE BUNDLE FROM
PLATFORM GILDA TO
SHORE AT MANDALAY
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
DISTANCE - (Feet)

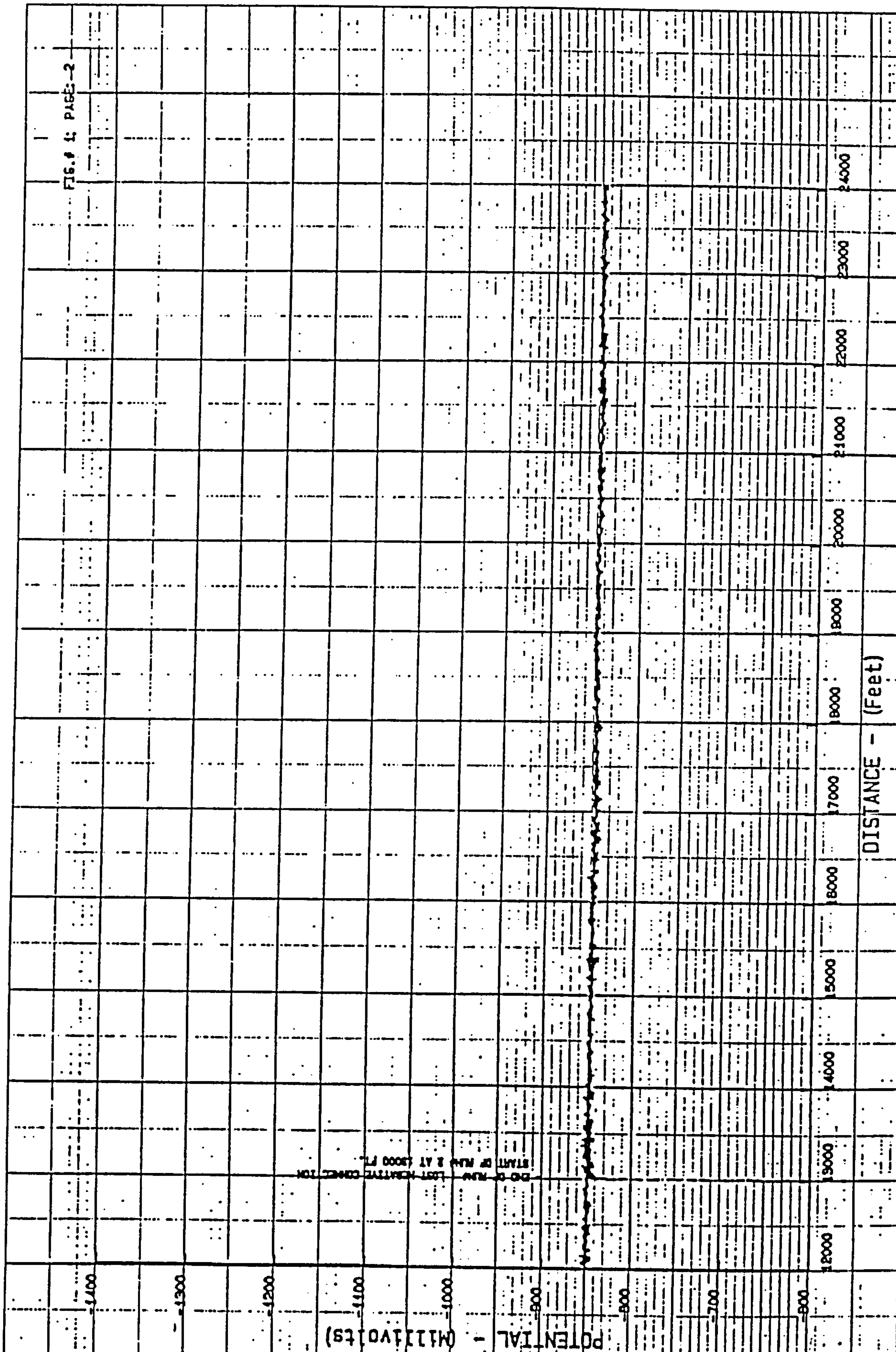


FIG.# 1: PAGE-2
DISTANCE - (Feet)
POTENTIAL - (Millivolts)
12000
13000
14000
15000
17000
20000
21000
22000
23000
24000
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
END OF RUN - LOST NEGATIVE CONNECTION
START OF RUN 2 AT 13000 FT.

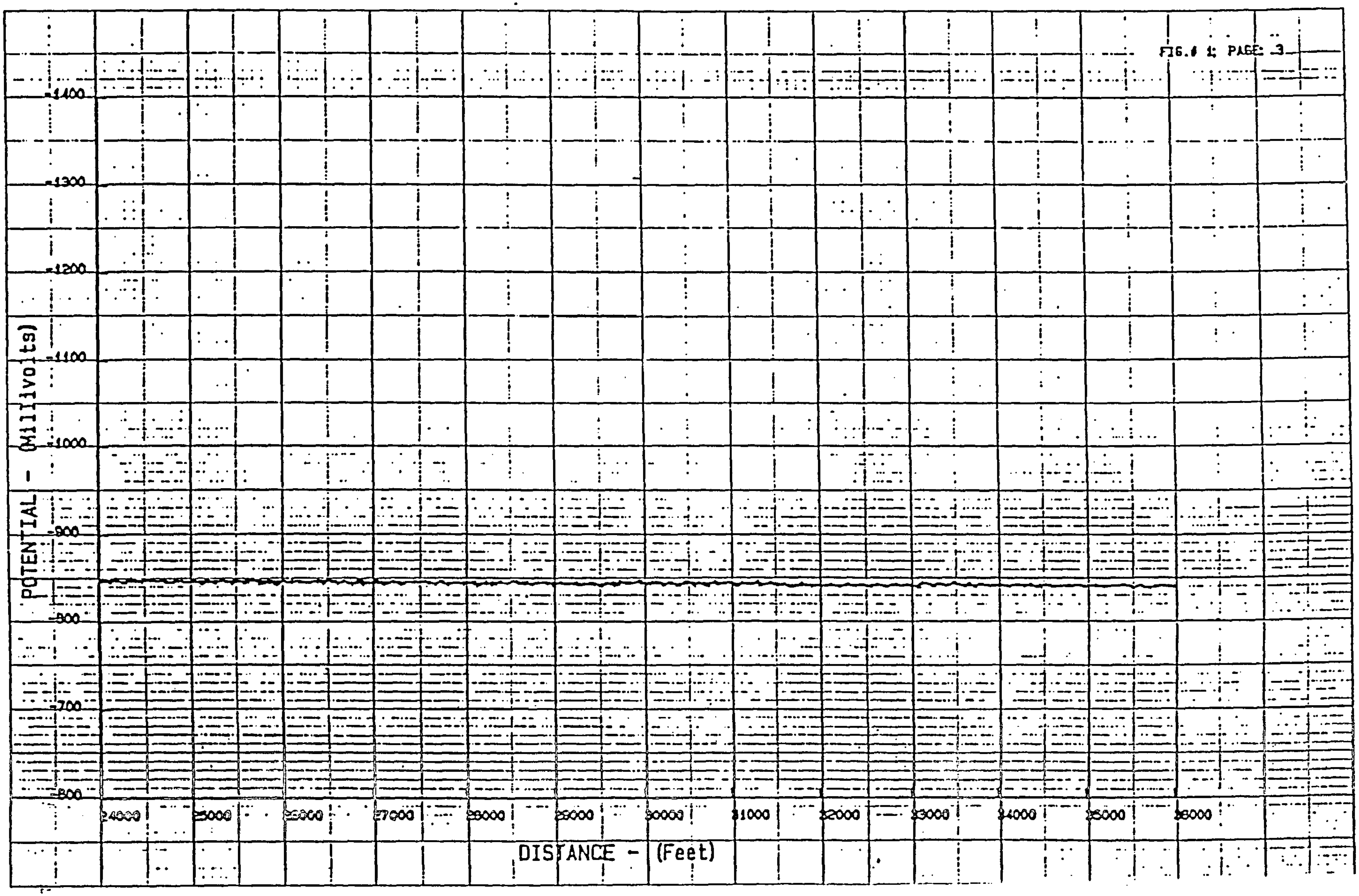
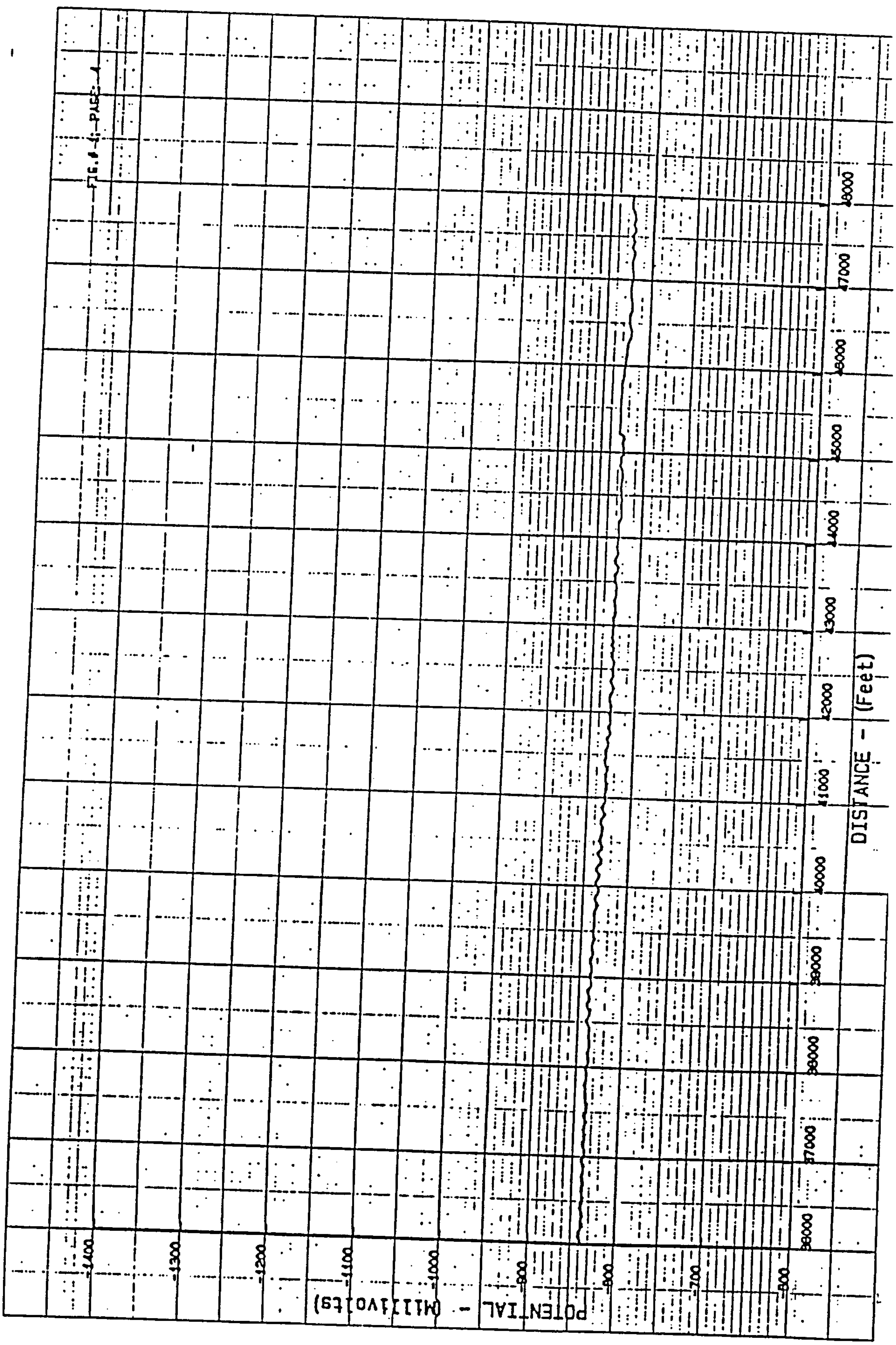


FIG.# 1: PAGE: 3
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
POTENTIAL - (Millivolts)
24000
25000
26000
27000
28000
29000
30000
31000
32000
33000
34000
35000
36000
DISTANCE - (Feet)


DISTANCE - (Feet)
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
36000
37000
38000
39000
40000
41000
42000
43000
44000
45000
46000
47000
48000

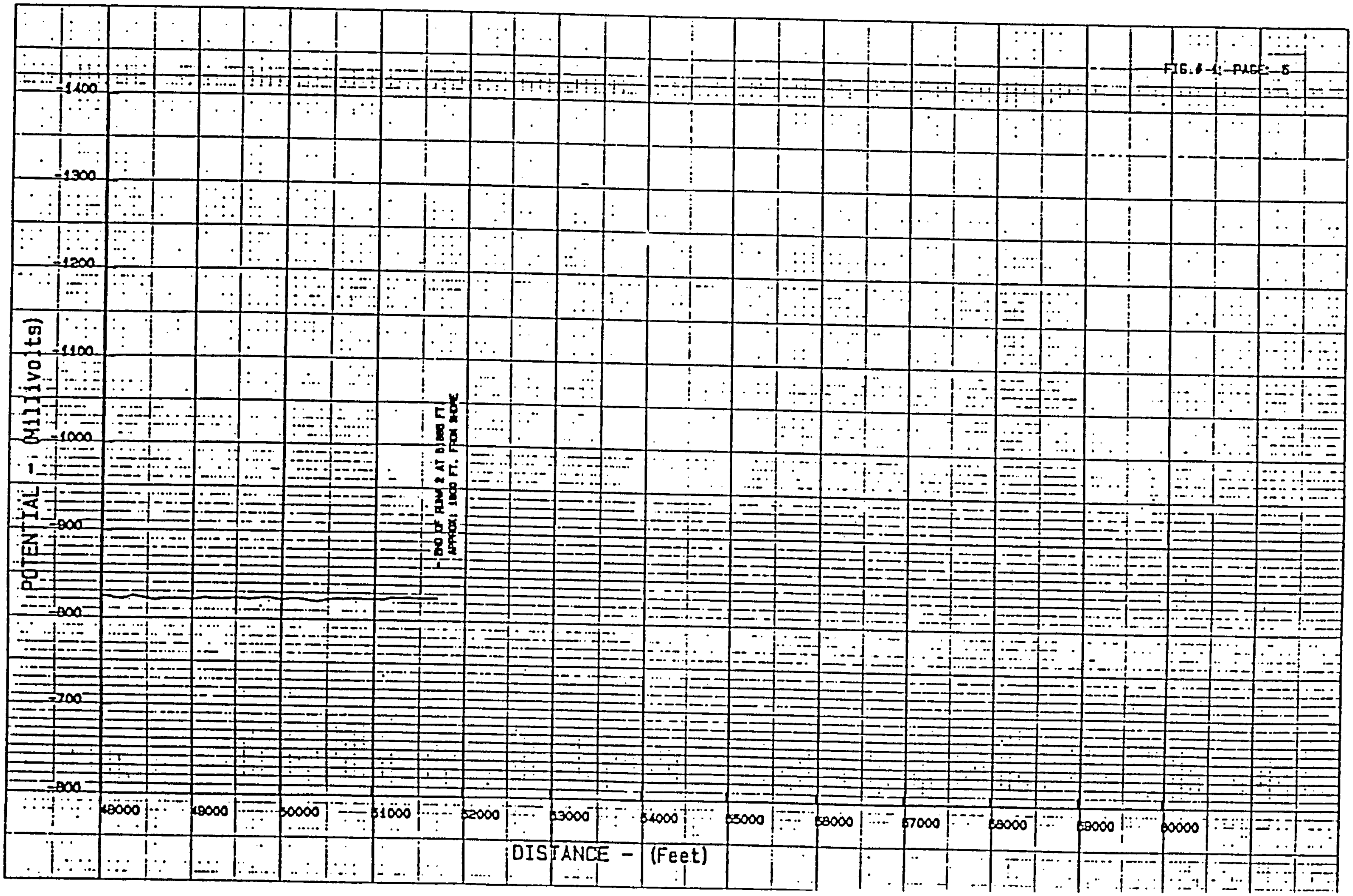
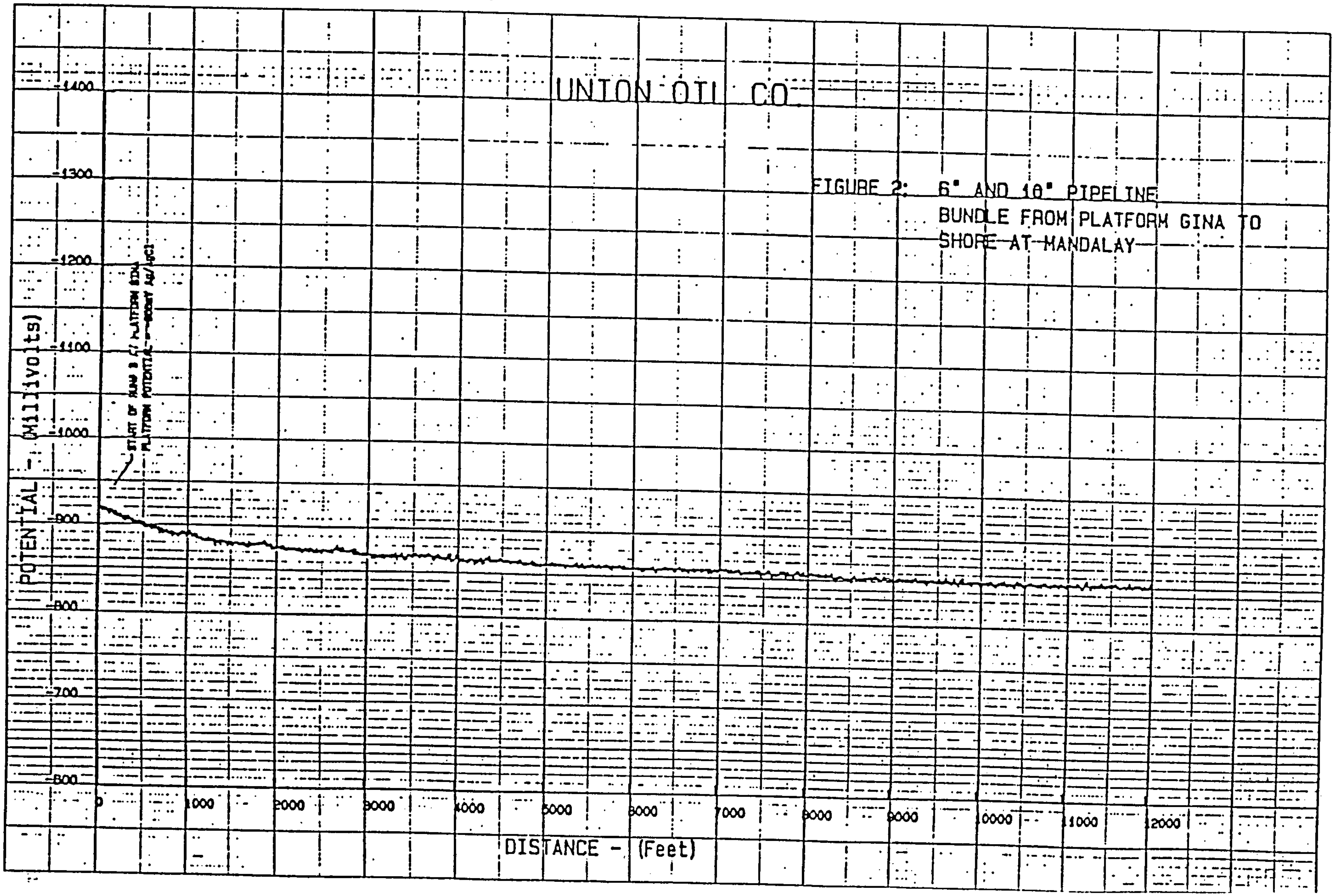


FIG. # 4 PAGE 5
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
END OF RUN 2 AT
APPROX. 1800 FT. FROM SHORE
48000
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
60000
DISTANCE - (Feet)

FIGURE 2



UNION OIL CO.
FIGURE 2: 6" AND 10" PIPELINE BUNDLE FROM PLATFORM GINA TO SHORE AT MANDALAY
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
DISTANCE - (Feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000

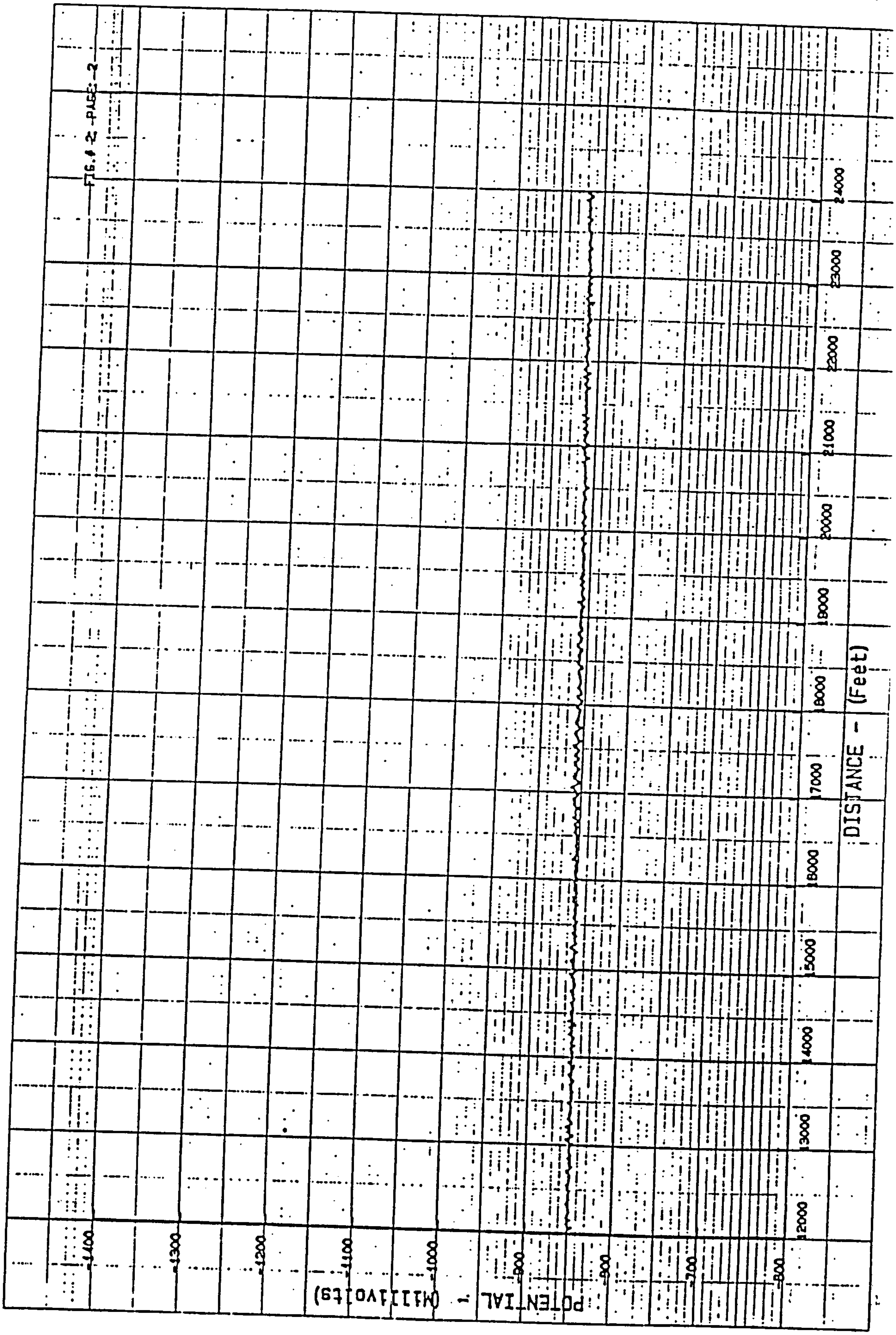


FIG. 6.4-2 PAGE 2
DISTANCE - (Feet)
POTENTIAL - (Millivolts)
12000
13000
14000
15000
16000
17000
18000
19000
20000
21000
22000
23000
24000
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600

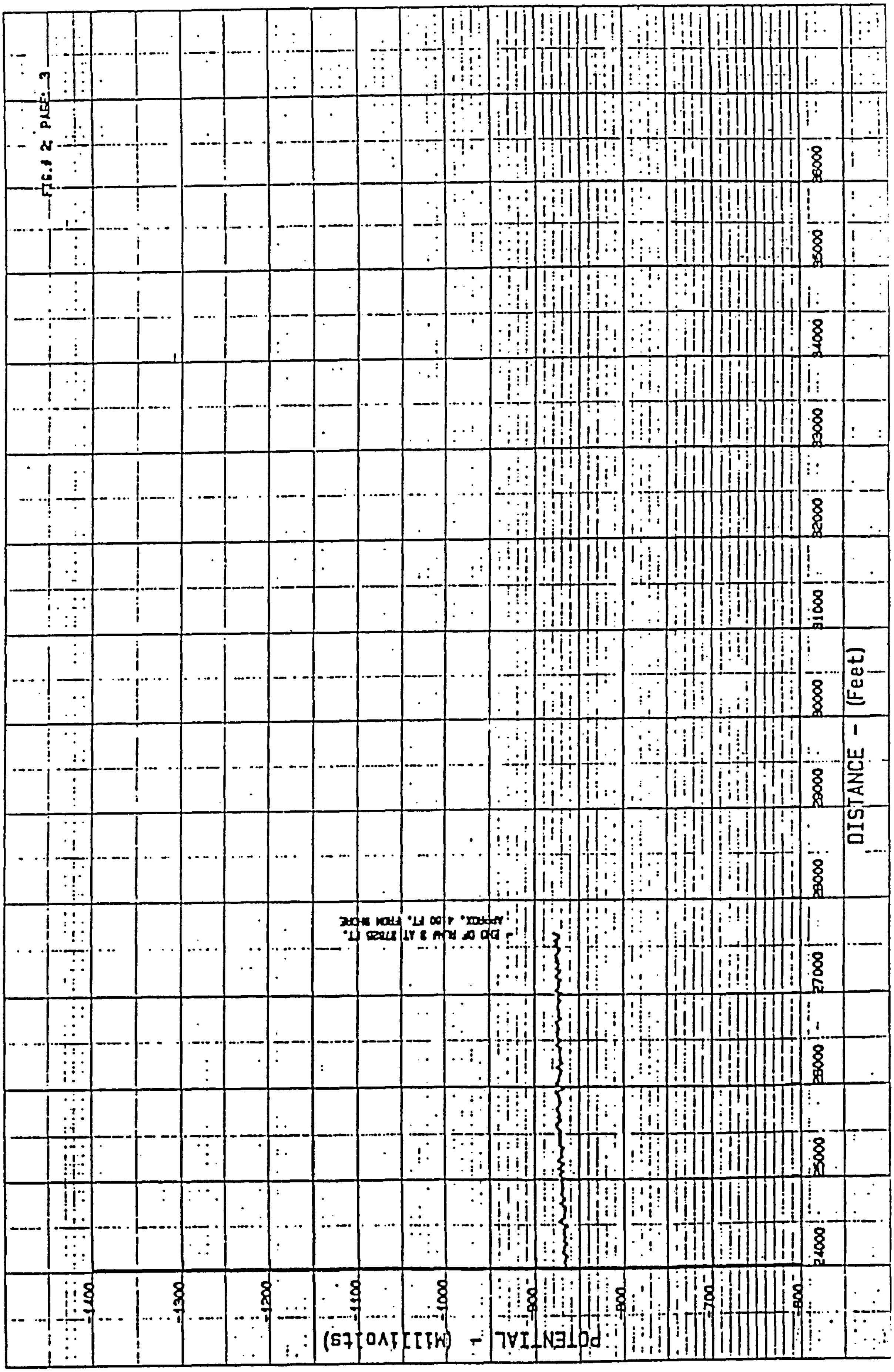


FIG.# 2 PAGE 3
END OF RUN 3 AT 27825 FT.
APPROX. 4100 FT. FROM SHORE
24000
25000
26000
27000
28000
29000
30000
31000
32000
33000
34000
35000
36000
DISTANCE - (Feet)
-1400
-1300
-1200
-1100
-1000
-900
-900
-800
-800
POTENTIAL - (Millivolts)

FIGURE 3

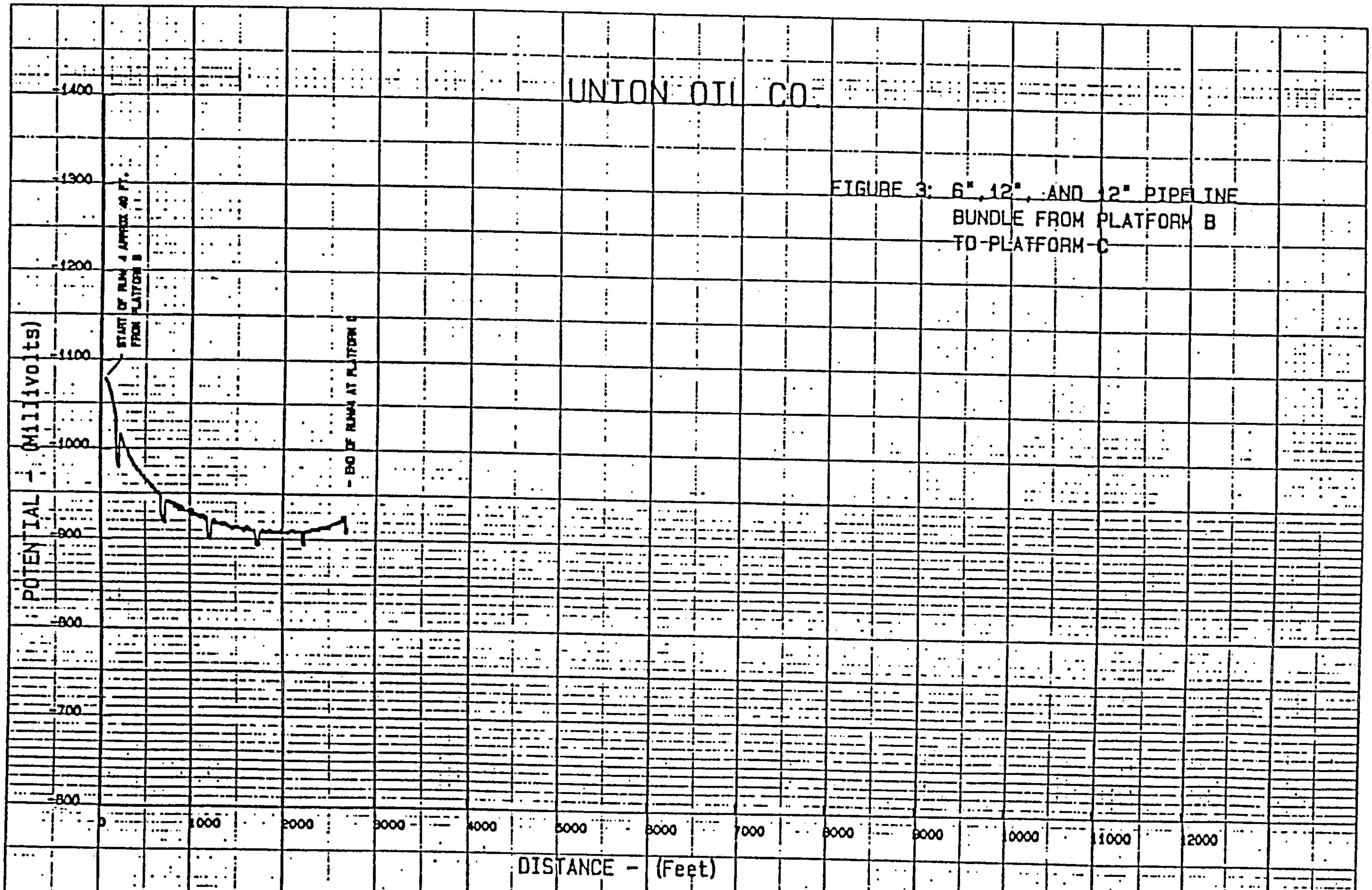
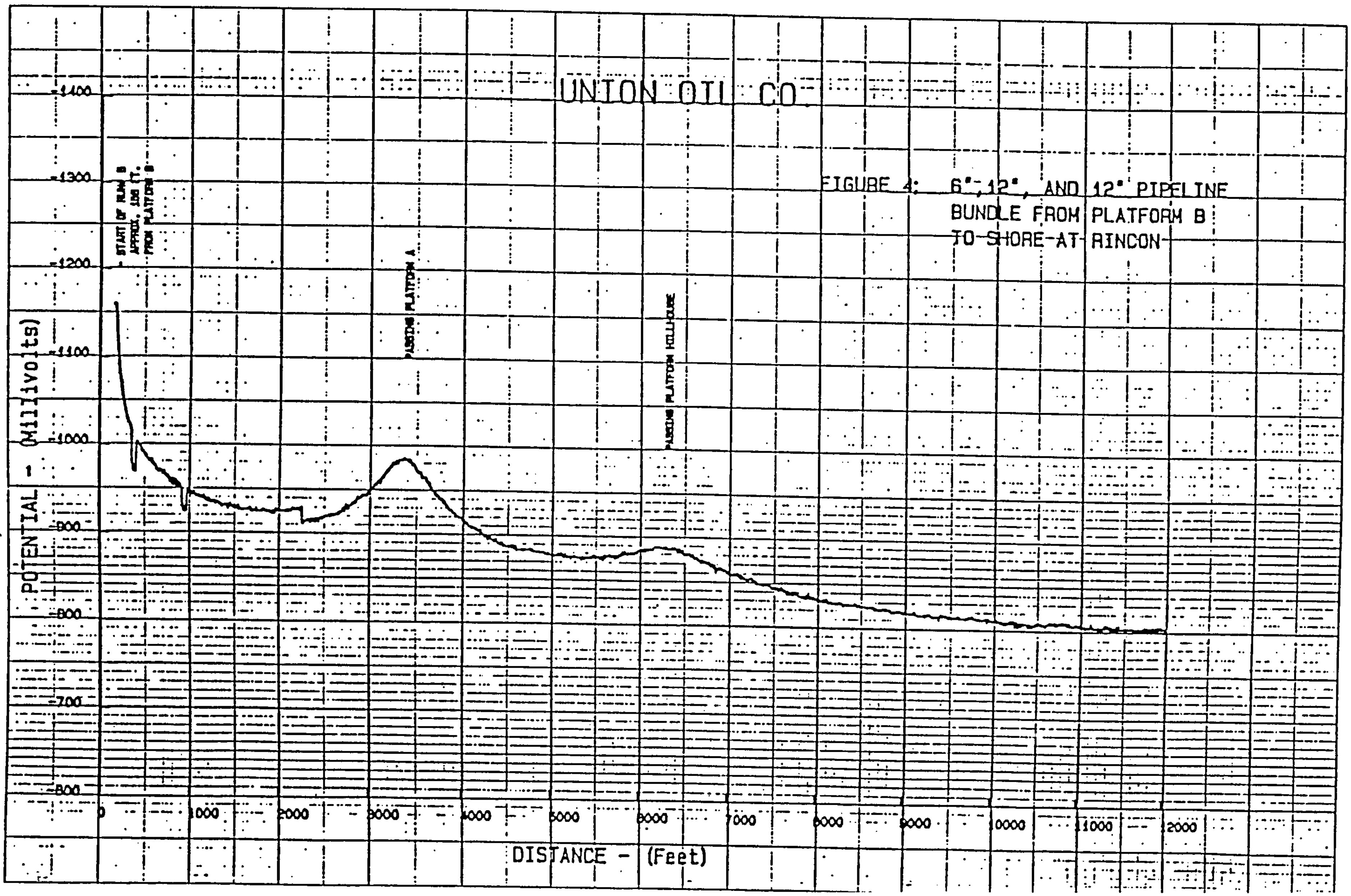
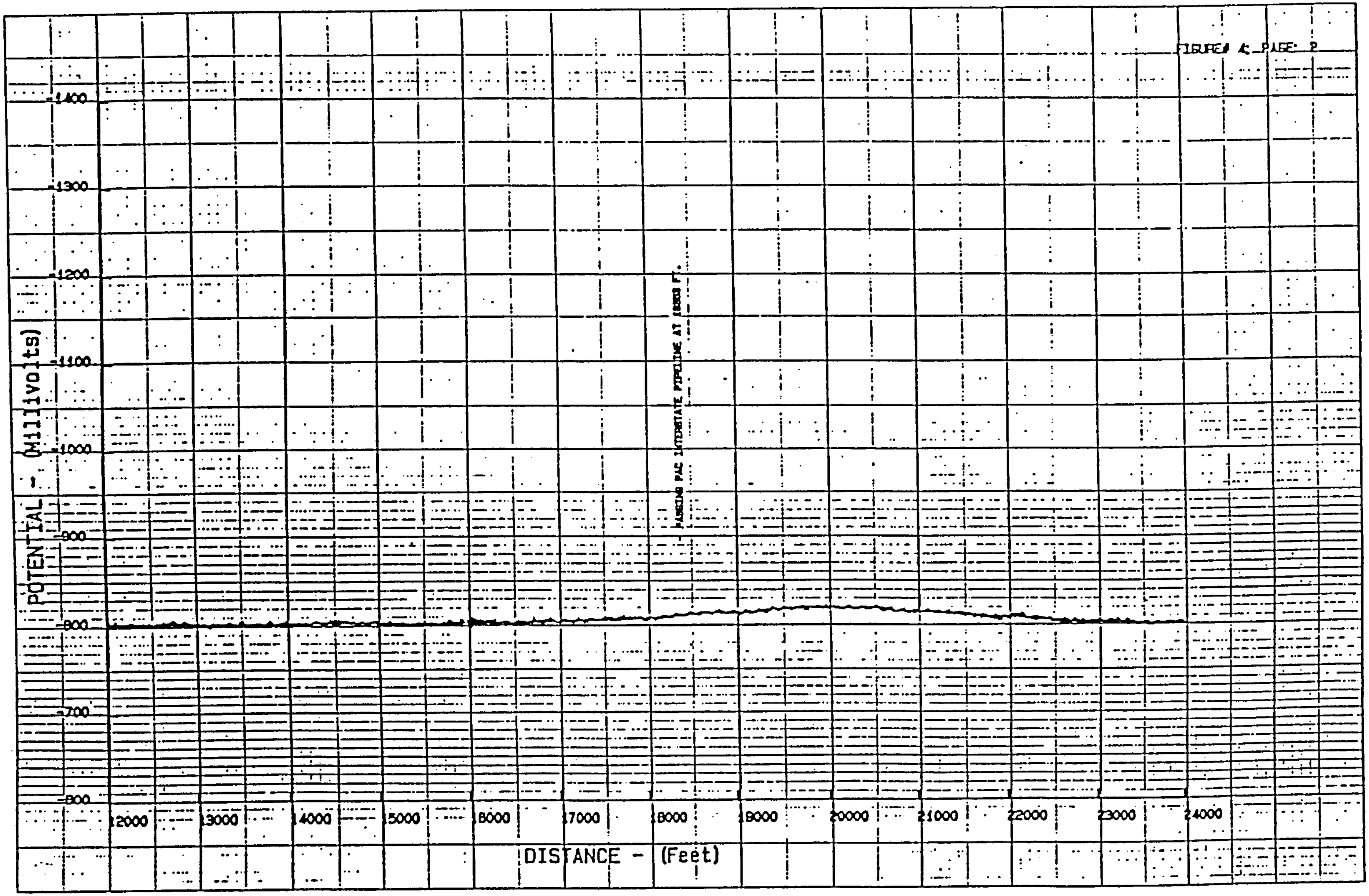
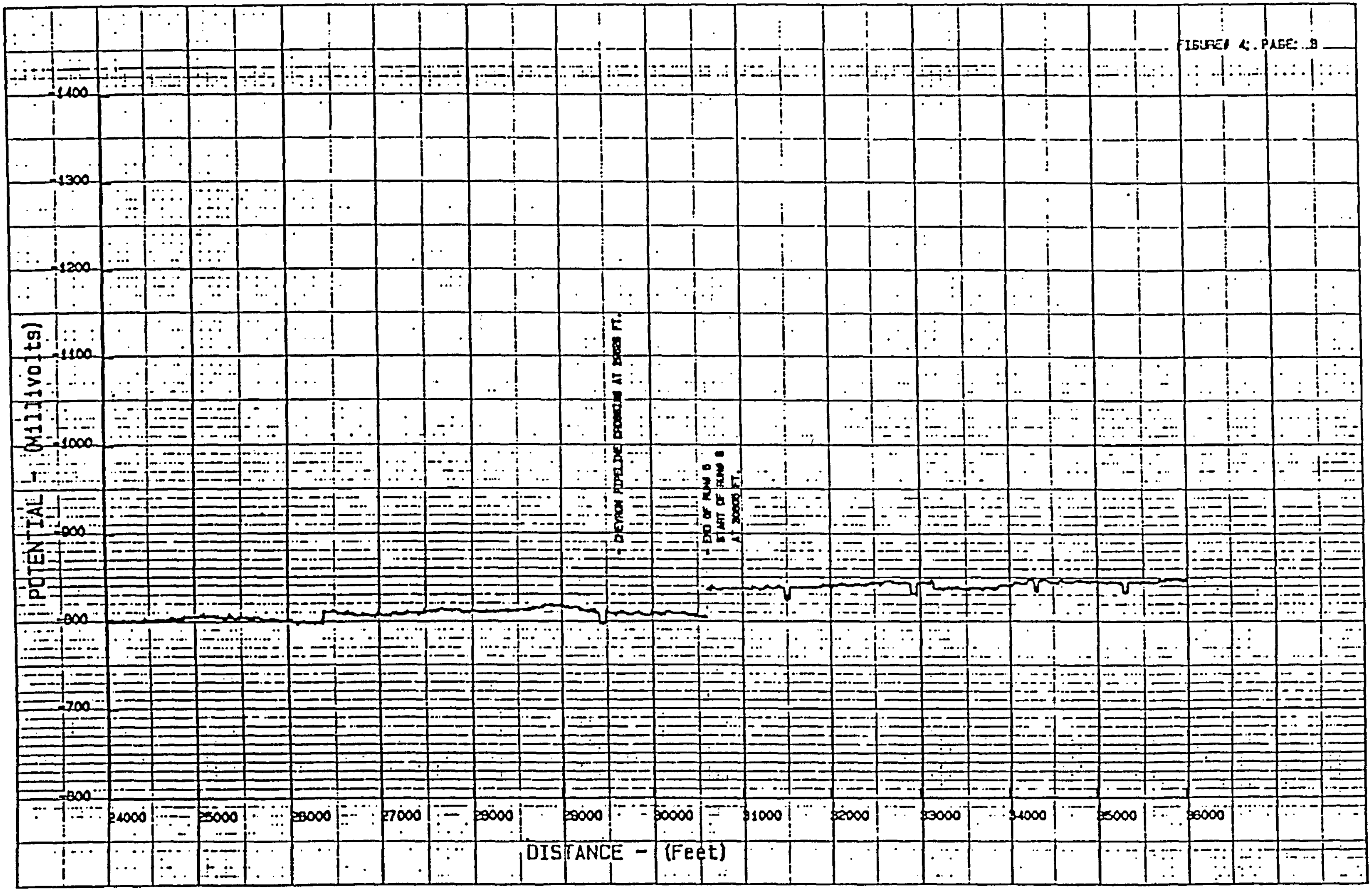
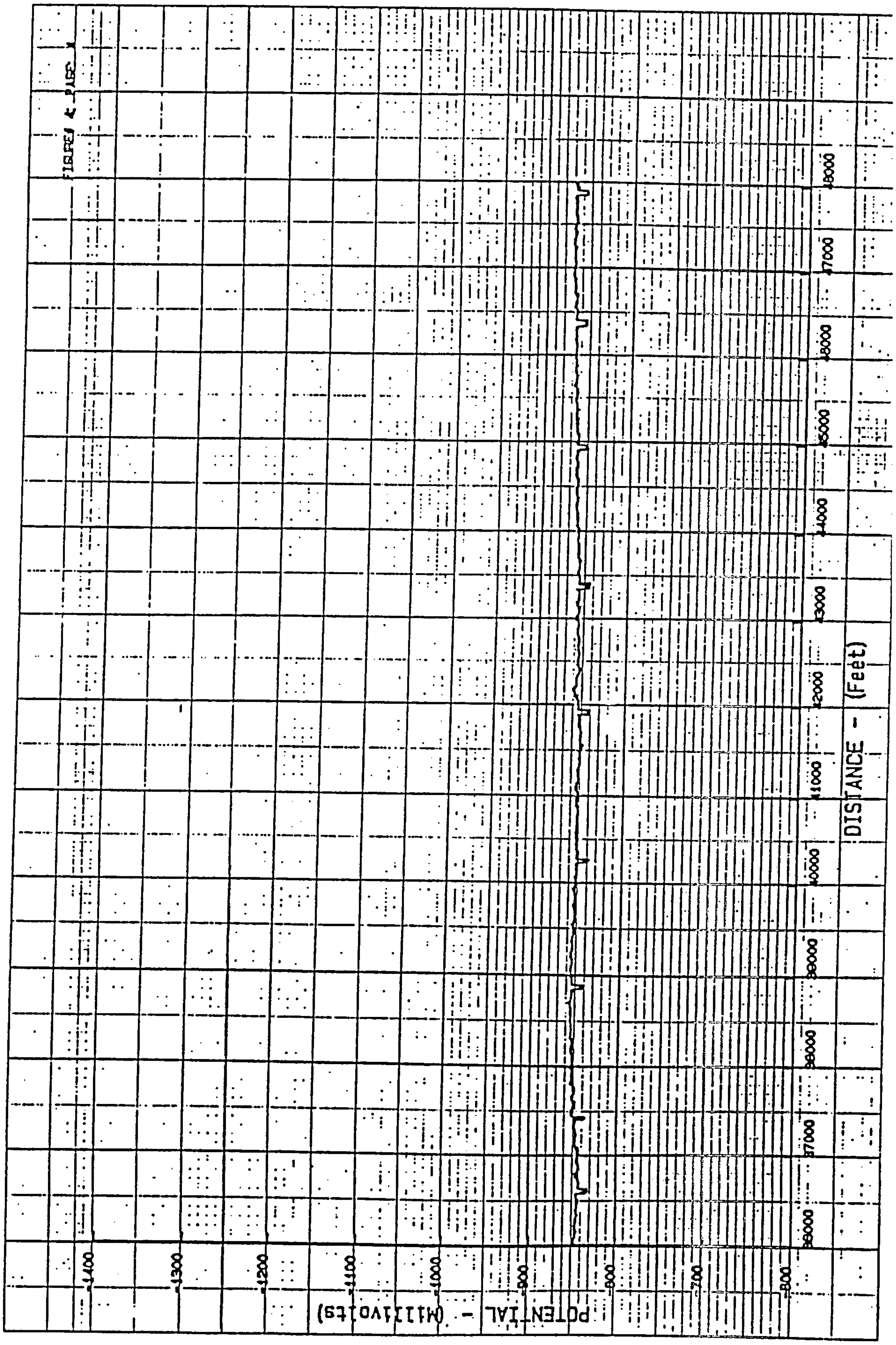

UNION OIL CO.
FIGURE 3: 6", 12", AND 12" PIPELINE
BUNDLE FROM PLATFORM B
TO PLATFORM C
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
DISTANCE - (Feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
START OF RUN 4 APPROX 40 FT. FROM PLATFORM B
END OF RUN4 AT PLATFORM C

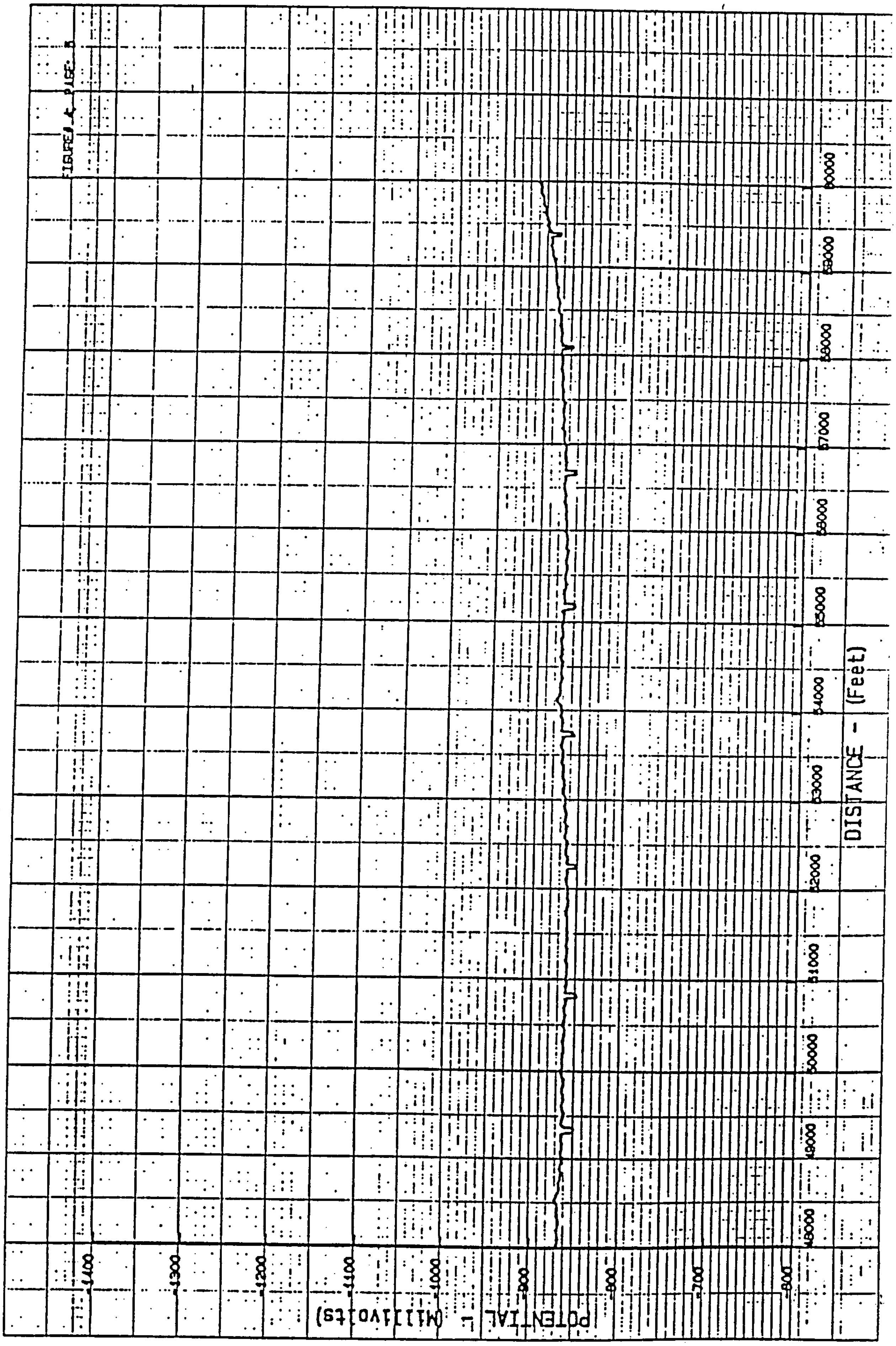
FIGURE 4

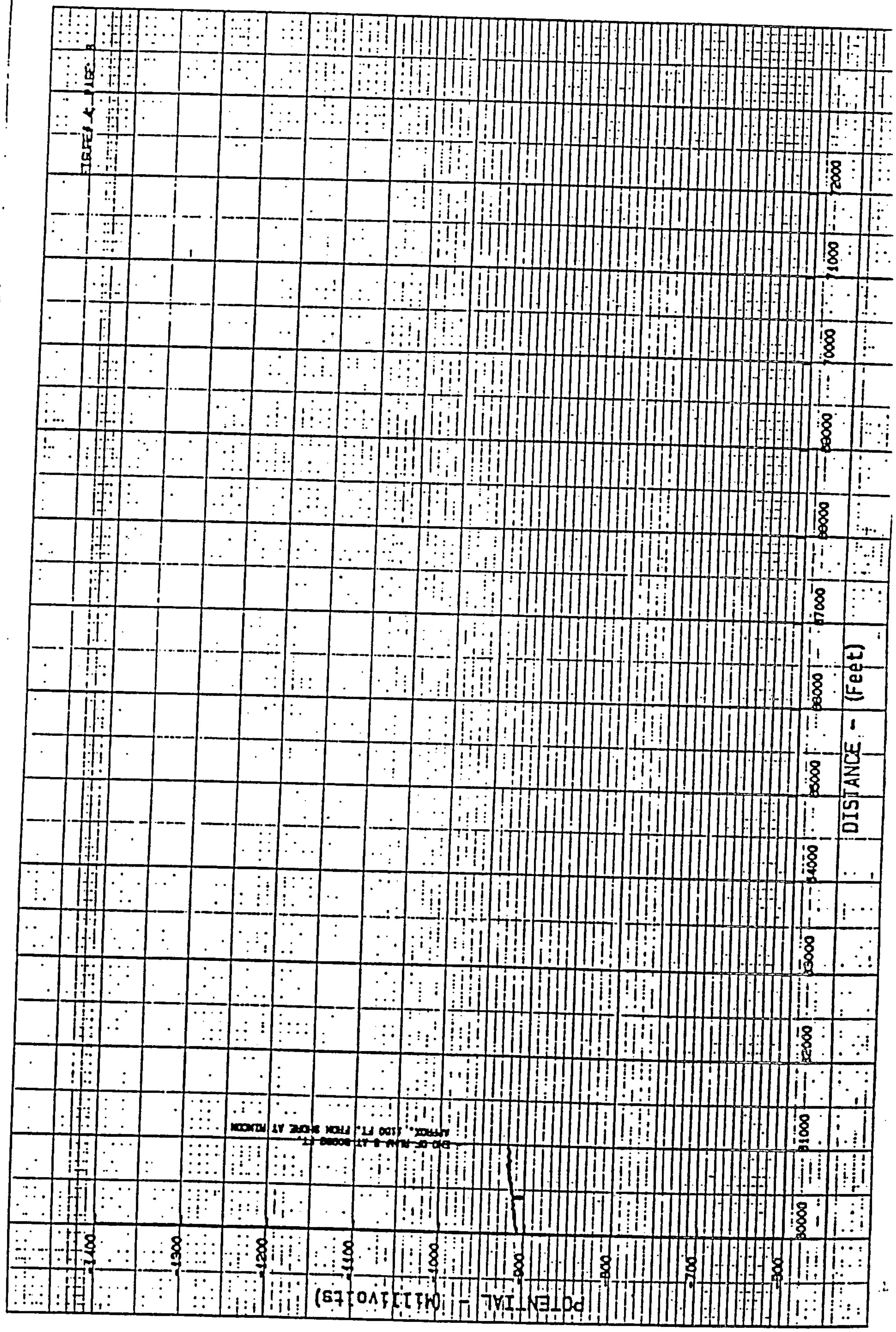

UNION OIL CO.
FIGURE 4: 6",12", AND 12" PIPELINE
BUNDLE FROM PLATFORM B
TO SHORE AT RINCON
START OF RUN B
APPROX. 100 FT.
FROM PLATFORM B
PASSING PLATFORM A
PASSING PLATFORM HILLHOUSE
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
DISTANCE - (Feet)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000


FIGURE# 4 PAGE: 2
PASSING PAC INTERSTATE PIPELINE AT FT.
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
POTENTIAL - (Millivolts)
12000
13000
14000
15000
16000
17000
18000
19000
20000
21000
22000
23000
24000
DISTANCE - (Feet)


FIGURE# 4: PAGE: 8
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600
CHEVRON PIPELINE CROSSING AT
FT.
END OF RUN# 5
START OF RUN# 6
AT 30000 FT.
24000
25000
26000
27000
28000
29000
30000
31000
32000
33000
34000
35000
36000
DISTANCE - (Feet)


POTENTIAL - (Millivolts)
DISTANCE - (Feet)


DISTANCE - (Feet)
60000
59000
58000
57000
56000
55000
54000
53000
52000
51000
50000
49000
48000
POTENTIAL - (Millivolts)
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600


POTENTIAL - (Millivolts)
DISTANCE - (Feet)

APPENDIX VOLUME 2
ITEM A

Pipeline Inspections

Corrpro Cathodic Protection Survey (2/89)

CLOSE INTERVAL

CATHODIC PROTECTION SURVEY

ON

16 MILES

OF

SUBMARINE PIPELINE

IN THE

SANTA BARBARA CHANNEL

FOR

UNOCAL CORPORATION

Prepared By:
CORRPRO COMPANIES, INC.

FEBRUARY, 1989

corrpro

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TABLE OF CONTENTS

I. INTRODUCTION

During February, 1989, Corrpro Companies, Inc., performed a close interval potential survey using the towed fish/trailing wire method on approximately 16 miles of subsea pipeline for UNOCAL Corporation. In addition, approximately 1400 feet of pipeline was surveyed onshore from the Mandalay Station wall to the water's edge. The survey was conducted on the pipeline bundles from Platforms Gina and Gilda to shore at Mandalay Station near Oxnard, California.

The survey was performed by Corrpro Companies, under direct contract to UNOCAL Corporation of Ventura, California. Electronic positioning services were provided by Land and Sea Survey of Ventura, California. The survey vessel was provided by International Diving Services of Port Hueneme, California, under contract to Corrpro Companies, Inc.

II. SUMMARY

Corrpro Companies, Inc., performed a close interval potential survey on approximately 16 miles of submarine pipeline and approximately 1400 feet of buried pipeline near Oxnard, California. The lines surveyed extended from Platforms Gina and Gilda to shore at Mandalay Beach.

Computerized close interval potential surveys are used extensively to determine the level of cathodic protection on pipelines. The principal purpose of the survey was to evaluate the effectiveness of the cathodic protection system in mitigating corrosion.

The offshore portion of the survey utilized the towed fish/trailing wire method. Onshore, a similar technique was used to record the data. Examination of the survey results indicate that all potential values recorded on the subsea portion of the pipelines were more negative than -800 mV to Ag/AgCl in accordance with

the accepted criterion for cathodic protection. Potential values recorded onshore were more negative than -850 mV to $Cu/CuSO_4$, except on the 6" Gilda to Mandalay water return pipeline, immediately adjacent to the Mandalay Station wall, where potential values decreased to near -750 mV to $Cu/CuSO_4$.

III. DESCRIPTION OF PIPELINES

A. Gilda to Mandalay

The 6", 10" and 12" pipelines from Platform Gilda to Mandalay Station near Oxnard, California are approximately 9.89 miles in length and were installed in 1982. The pipelines are reportedly equipped with a Pri-Tek corrosion control coating. The pipelines receive cathodic protection from cast-on zinc anode bracelets. These are spaced at uniform intervals from Platform Gilda to Mandalay Station except in the nearshore area where anode spacing is decreased significantly. The pipelines are electrically shorted to the Platform Gilda jacket, which is equipped with a galvanic cathodic protection system consisting of weld-on type aluminum alloy anodes. The 10" and 12" pipelines are electrically isolated from onshore piping at insulating flanges at Mandalay Beach. The 6" pipeline is electrically insulated at an above ground insulated flange at Mandalay Station.

B. Gina to Mandalay

The 6" and 10" pipelines from Platform Gina to Mandalay Station are approximately 6.04 miles in length and were installed in 1982. The pipelines are reportedly equipped with a Pri-Tek corrosion control coating. The pipelines receive cathodic protection current from cast-on zinc bracelet anodes spaced along their lengths. Anode spacing is significantly less in the nearshore zone. The lines are electrically shorted to Platform Gina and are isolated at insulated flanges at Mandalay Beach. The 6" pipeline is isolated at aboveground in Mandalay Station. Platform Gina is equipped with a galvanic cathodic protection system.

IV. SURVEY METHOD

A. Offshore Section

The survey was performed using the trailing wire/towed fish survey method which has been used extensively to determine the level of cathodic protection of subsea pipelines.

The survey was performed by first establishing an electrical connection to the pipeline at the platform riser with a clip-on connector or pipe clamp. As the survey vessel proceeded downline, an insulated light gauge wire maintained the electrical connection to the platform while a silver/silver chloride electrode, housed in a V-fin towed vehicle, was towed above the pipeline. The survey vessel moved at approximately four (4) to five (5) knots along the pipeline. The structure-to-electrolyte potential was continuously monitored and recorded on board the survey vessel.

The silver/silver chloride reference electrodes were deployed using a two foot, Endeco V-fin, which is designed to serve as a depressor, allowing the electrodes to be towed near the sea floor with a minimum layback from the survey vessel. The Ag/AgCl electrodes are attached to a 10 meter weighted line below the V-fin while being towed. This prevents electrical interference associated with metallic parts of the V-fin and allows the electrodes to be towed near the sea floor without damage to the V-fin. During the survey, two Ag/AgCl reference electrodes were towed from the V-fin. The lower of the two electrodes was the primary survey electrode, while the upper (placed approximately 3 meters above the primary) electrode was the backup electrode. The backup electrode was also used as a standard for comparison during the survey. The Ag/AgCl reference electrodes used were of the permanent saturated electrolyte type and were manufactured by G.M.C., Inc. The electrodes have a stability of ±5 millivolts with a 3 micro-ampere load.

Downline markers (navfixes) were stored in the potential data stream at approximately 100 meter intervals. To guide the survey vessel, each pipeline's "as built" coordinates were used in conjunction with a Motorola Miniranger electronic positioning system. The survey vessel operator monitored the positioning system readout and continuously updated the vessel's heading to insure that the vessel was over the pipeline.

The data acquisition system consisted of an Omnidata Polycorder and a Zenith laptop computer. The structure-to-electrolyte potential was measured by the Polycorder and electronically transferred to the computer. The Polycorder is a handheld, microprocessor controlled, high resistance voltmeter with an analog to digital converter. The computer's CRT continuously displayed the potential measurements and stored them on magnetic media. Potentials were stored at a rate of approximately one per second. At a survey speed of five knots, potentials are recorded at approximately 1.5 foot intervals.

The riser-to-electrolyte potentials were measured with a Beckman HD110 multimeter referenced to a silver/silver chloride (Ag/AgCl) reference electrode.

B. <u>Onshore Section</u>

The onshore section of the survey was conducted from the Mandalay Station Wall to the water's edge. Electrical contact was made to the 6" water return lines with a light disposable wire. The wire was spooled from an electronic distance measuring device carried by the survey operator. As the operator walked over the line, continuous contact to the soil was maintained by alternately planting two copper/copper sulphate reference electrodes, attached to poles, in the soil. As the wire was spooled out, potential measurements were recorded at 30 inch intervals by a battery powered Omnidata Polycorder datalogger carried by the operator. The voltage measurements were triggered by the distance measuring device at the specified interval. Features were entered into the data stream at the correct location using the keyboard of the Polycorder. The pipeline was located with an inductive pipe locator to ensure that all measurements were recorded directly over the pipeline. A Beckman HD110 multimeter was used to record supplemental readings and verify the Polycorder. The data was then electronically transferred to an IBM-PC computer for processing.

V. RESULTS AND ANALYSIS

Potential profiles for all survey runs are presented in Appendix "A".

Review of the potential profiles for the offshore segments of pipelines surveyed, indicates that all potential values exceed the -800 mV to Ag/AgCl criterion as established by the National Association of Corrosion Engineers' Standard RP-06-75, "Corrosion Control of Offshore Steel Pipelines".

Study of the potential profiles for the onshore line segments show potential values in excess of -850 mV to $Cu/CuSO_4$, except on the Gilda to Mandalay pipelines at the Mandalay Station wall, where potential values decrease dramatically within ten feet of the wall.

A more detailed analysis of the survey results is presented below:

A. 6", 10" and 12" Pipelines - Gilda to Shore

Examination of the potential profile for the offshore segment of the pipeline bundle shows potential values near -850 mV to Ag/AgCl at the surf zone (Station 24+70), gradually decreasing to approximately -820 mV near Station 290+00, remaining level at -820 mV to Station 450+00, then increasing gradually to -870 mV at Platform Gilda. An anomaly at Station 334+00 is due to a temporary discontinuity in the measurement circuity, and is not indicative of a true change in pipeline potential at that location.

Study of the onshore survey potential profile indicates a sharp dip in potential at the Mandalay Station Wall. Potential values from the dunes to the water's edge are between -950 and 1000 mV to $Cu/CuSO_4$ (940 mV to Ag/AgCl at the water's edge). Due to rough surf conditions, no data was collected in the surf zone.

The discrepancy in potential at the surf zone, between survey runs performed with connections at opposite ends of the pipeline, is due to metallic IR drop. This IR drop error is caused by a net current flow between Gilda and Mandalay Station toward shore. This causes potential values recorded with a connection at shore to be more negative than true IR drop free potentials. Likewise, potential values recorded with a connection at Gilda are more positive than true IR drop free potential values. The true potential values are between the two "parallel" potential profiles if the onshore profile was extended offshore, parallel to Gilda to shore profile. In this case, it appears that the onshore and nearshore anodes are providing current to the offshore segment of the pipeline bundle. The returning current causes the profile to be more negative than an IR drop free profile.

At the Platform Gilda end of the pipeline bundle, it appears that the platform cathodic protection system is providing minimal current to the pipeline bundle. This is evidenced by the significant decrease in potential recorded as the survey proceeded away from the platform. Potential values increase near shore due to the effect of decreasing spacing between anodes.

B. 6" and 10" Pipeline - Platform Gina to Mandalay Station

Study of the potential profile indicates potential levels at -850 mV near shore decreasing gradually to a low of approximately -810 mV near Station 186+00, increasing gradually to -860 mV at Station 300+00, then increasing steeply to -970 mV at the riser. Note that high frequency spikes recorded near Platform Gina are due to an external noise source and do not represent true changes in cathodic protection level.

The onshore profile shows potential values near -1050 mV to $Cu/CuSO_4$ (-990 mV to Ag/AgCl) from the water's edge to the top of the dunes then decreasing steeply to near -900 mV at the Mandalay Station Wall.

Both the onshore and offshore profiles are similar in shape and potential level to those from the Gilda to Mandalay pipeline bundle. The potential levels recorded in the onshore and offshore profile indicate a net metallic current flow toward shore similar in magnitude to that for the Gilda to Mandalay pipelines. As noted earlier, the true potential levels are between the levels shown in the onshore and offshore profiles, if the onshore profile was extended.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the close interval potential survey, the following conclusions are drawn:

1. The pipelines are receiving cathodic protection in accordance with the -800 mV to Ag/AgCl criterion along their entire nearshore and offshore lengths.

2. Onshore potential values on both of the 6" water return pipelines from Gina and Gilda are significantly depressed at the Mandalay Station wall. This condition may be due to coating damage caused by elevated temperatures on these pipelines or to unknown causes.

3. Potential values on the onshore and nearshore sections of both the Gina and Gilda pipeline bundles are significantly higher than potentials recorded further offshore, due to the effects of increased anode density (decreased spacing) in these areas. This is also causing potentials recorded with the test connection onshore to be somewhat higher than true IR drop free potentials.

4. All pipelines are electrically shorted to their respective platform jackets at the risers.

Based on the these conclusions, the following recommendations are offered:

1. Further investigate the 6" water return pipelines at the Mandalay Station wall to determine the cause of depressed potential values at that location.

2. When convenient, take direct contact pipe-to-water potential measurements on both pipeline bundles at a minimum of one location along their submerged lengths. Ideally, these locations should be on sections of line exhibiting the lowest potential values.

3. Monitor riser-to-water potentials on an annual basis to assure that potential values are maintained at or near present values. Any significant decrease in riser potential should be investigated.

4. Perform a complete close interval potential survey on the pipelines in approximately three (3) years. Comparison of potential profiles collected over the lifetime of the pipeline provides valuable information for prediction of system life, as well as for design of future cathodic protection systems.

APPENDIX A

POTENTIAL PROFILES

CLOSE INTERVAL POTENTIAL SURVEY

6" 10" AND 12" PIPELINE BUNDLE

SURF ZONE TO PLATFORM GILDA

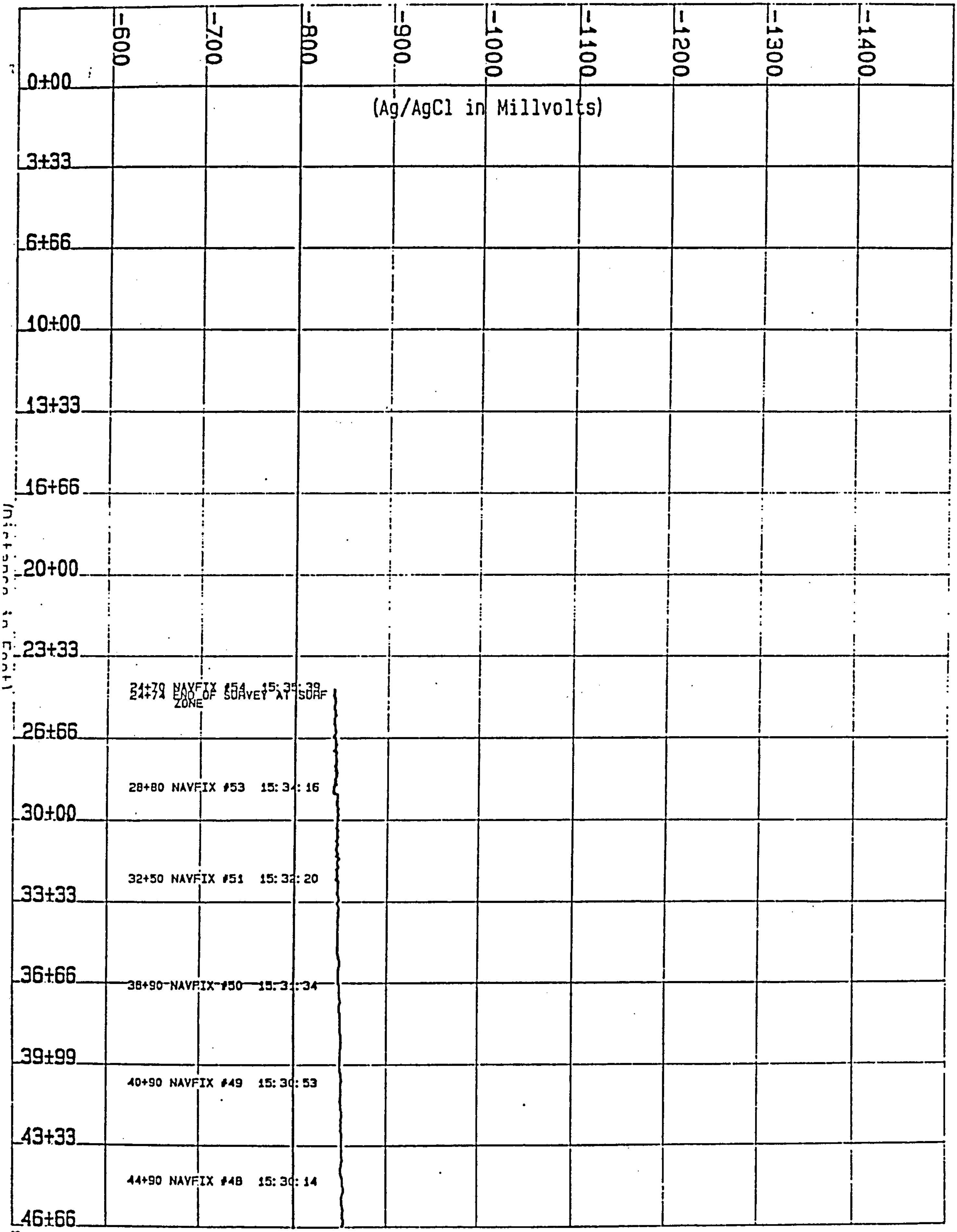
FOR

UNOCAL CORPORATION

FEBRUARY 11 1989

CORRPRO COMPANIES, INC.

C-281


-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
(Ag/AgCl in Millvolts)
0+00
3+33
6+66
10+00
13+33
16+66
20+00
23+33
26+66
30+00
33+33
36+66
39+99
43+33
46+66
24+70 NAVFIX #54 15:35:39
24+74 END OF SURVEY AT SURF ZONE
28+80 NAVFIX #53 15:34:16
32+50 NAVFIX #51 15:32:20
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40+90 NAVFIX #49 15:30:53
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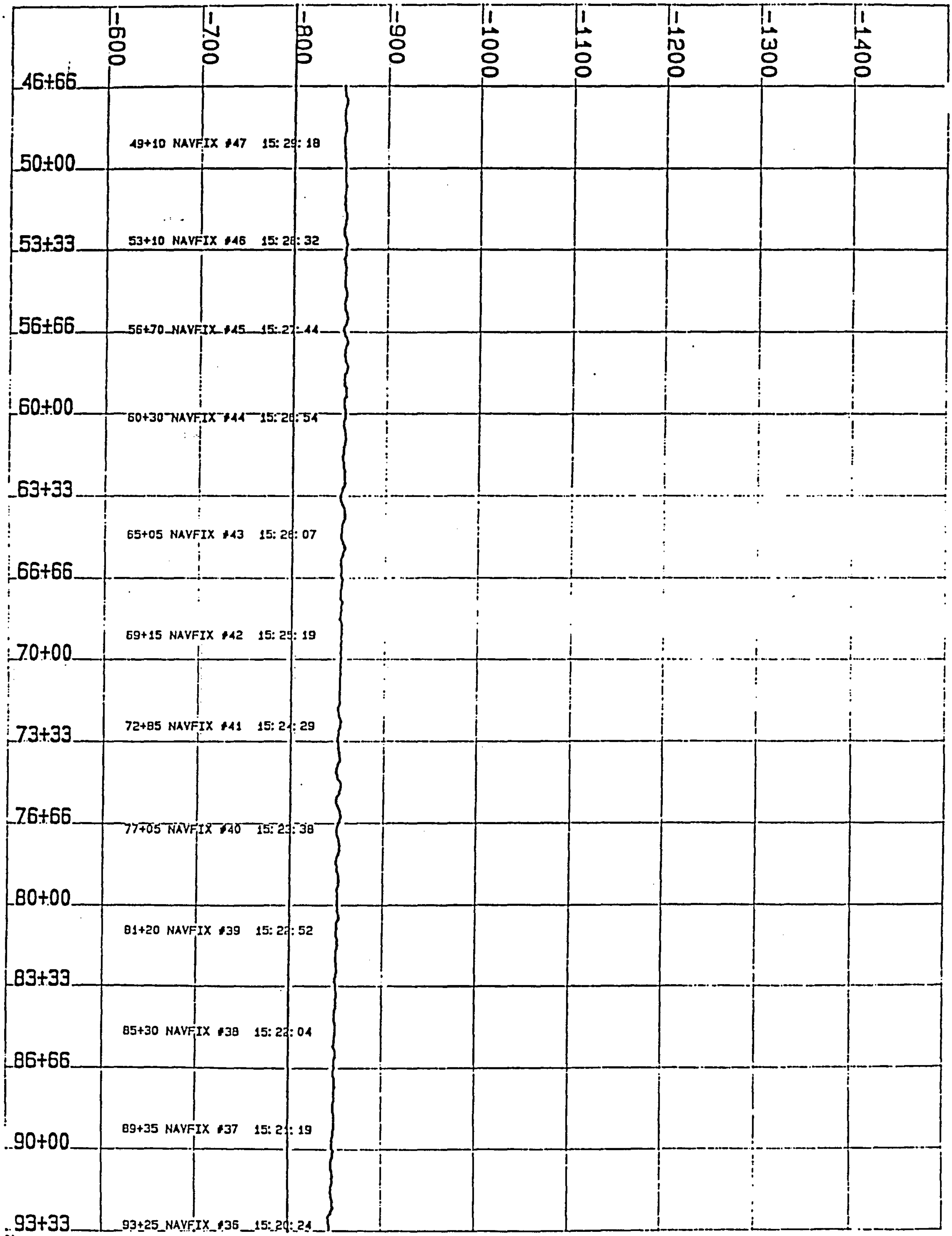
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-1200
-1300
-1400
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49+10 NAVFIX #47 15: 29: 18
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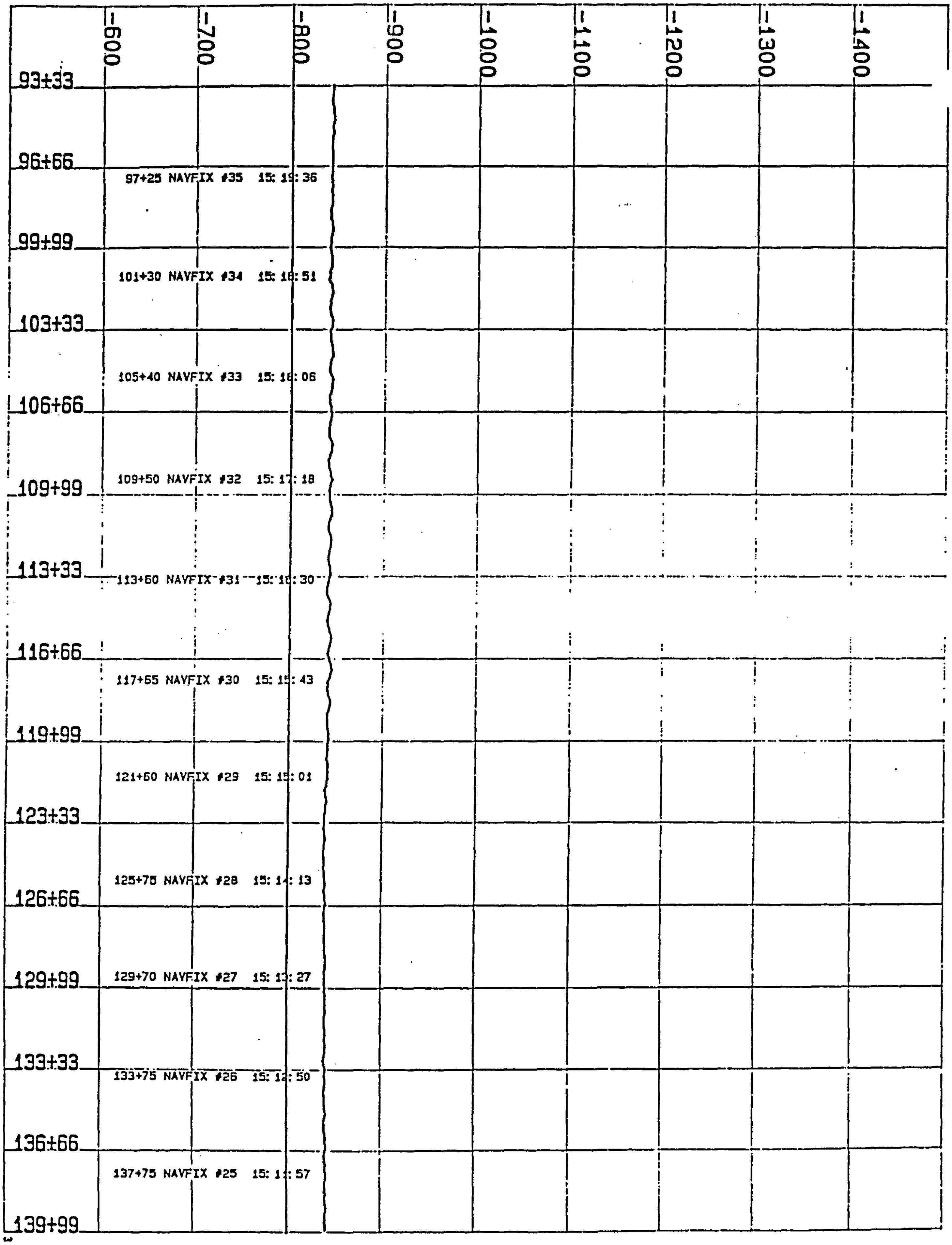
53+10 NAVFIX #46 15: 28: 32
53+33
56+66
56+70 NAVFIX #45 15: 27: 44
60+00
60+30 NAVFIX #44 15: 26: 54
63+33
65+05 NAVFIX #43 15: 26: 07
66+66
69+15 NAVFIX #42 15: 25: 19
70+00
72+85 NAVFIX #41 15: 24: 29
73+33
76+66
77+05 NAVFIX #40 15: 23: 38
80+00
81+20 NAVFIX #39 15: 22: 52
83+33
85+30 NAVFIX #38 15: 22: 04
86+66
89+35 NAVFIX #37 15: 21: 19
90+00
93+33
93+25 NAVFIX #36 15: 20: 24


-600
-700
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-900
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-1200
-1300
-1400
93+33
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97+25 NAVFIX #35 15: 19: 36
99+99
101+30 NAVFIX #34 15: 18: 51
103+33
105+40 NAVFIX #33 15: 18: 06
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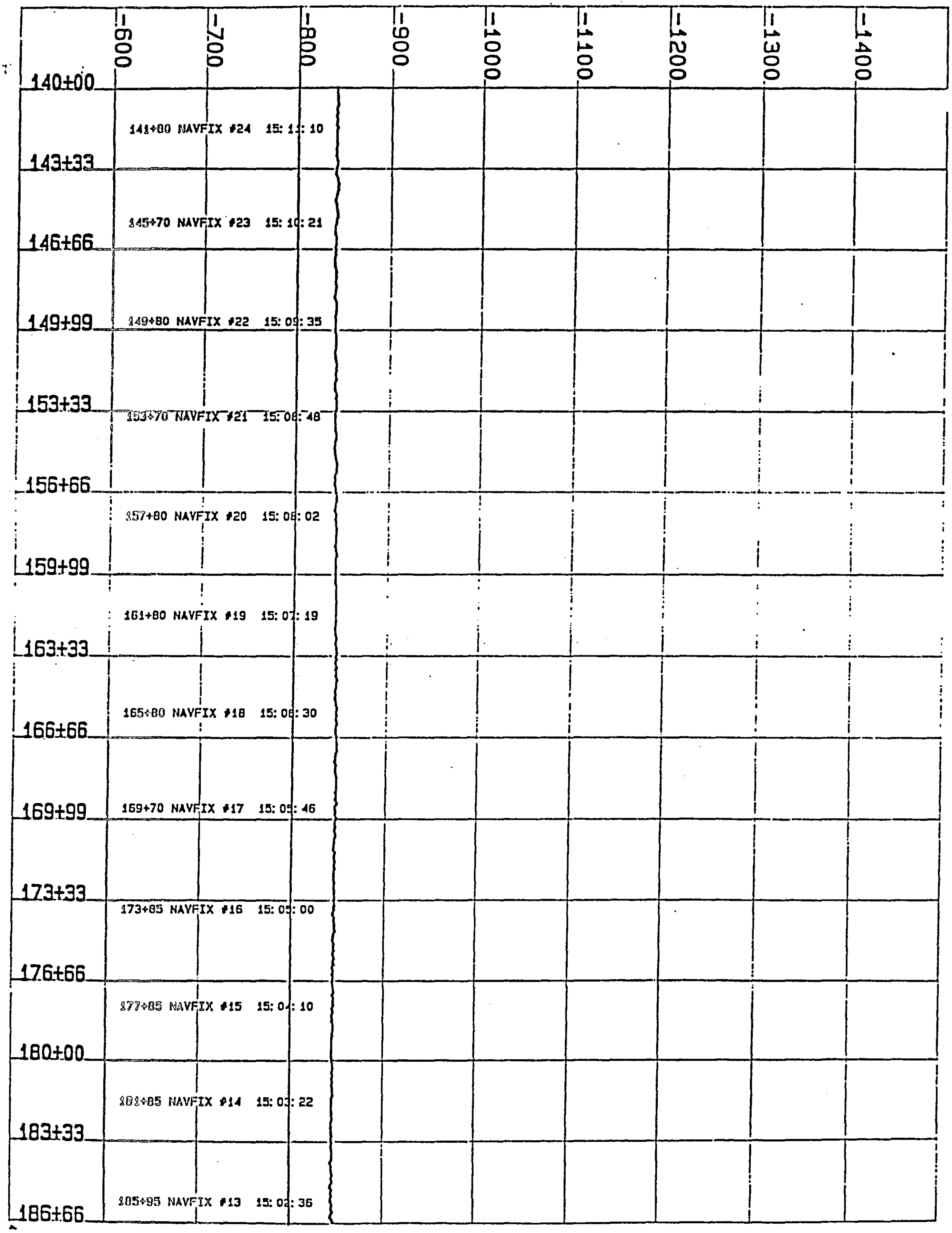
109+99
113+33
113+60 NAVFIX #31 15: 16: 30
116+66
117+65 NAVFIX #30 15: 15: 43
119+99
121+60 NAVFIX #29 15: 15: 01
123+33
125+75 NAVFIX #28 15: 14: 13
126+66
129+70 NAVFIX #27 15: 13: 27
129+99
133+33
133+75 NAVFIX #26 15: 12: 50
136+66
137+75 NAVFIX #25 15: 11: 57
139+99

C-285



-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
140+00
141+80 NAVFIX #24 15: 11: 10
143+33
145+70 NAVFIX #23 15: 10: 21
146+66
149+99
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153+33
153+70 NAVFIX #21 15: 08: 48
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157+80 NAVFIX #20 15: 08: 02
159+99
161+80 NAVFIX #19 15: 07: 19
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173+33
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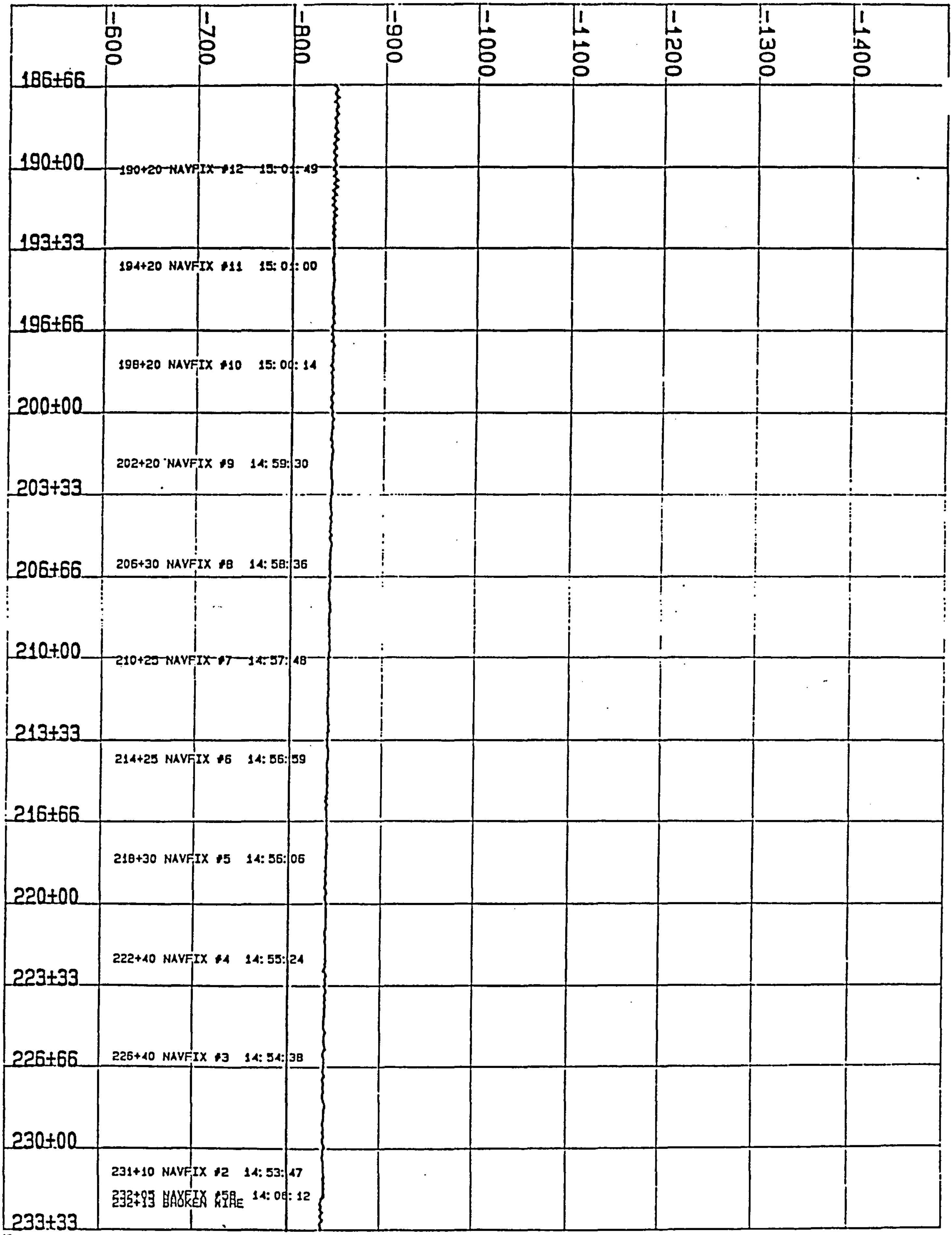
186+66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-1400
186+66
190+00
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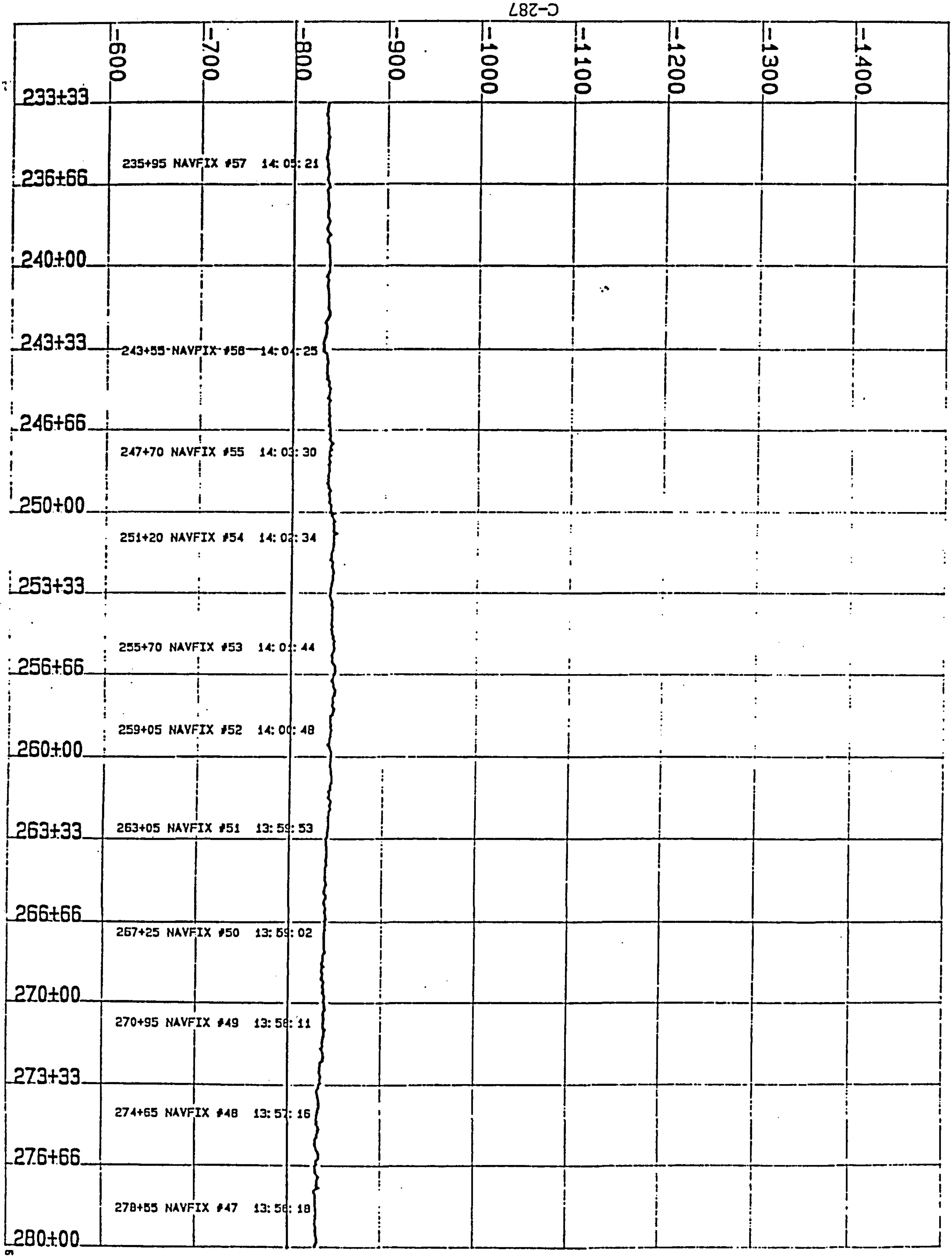
193+33
194+20 NAVFIX #11 15:01:00
196+66
198+20 NAVFIX #10 15:00:14
200+00
202+20 NAVFIX #9 14:59:30
203+33
206+30 NAVFIX #8 14:58:36
206+66
210+00
210+25 NAVFIX #7 14:57:48
213+33
214+25 NAVFIX #6 14:56:59
216+66
218+30 NAVFIX #5 14:56:06
220+00
222+40 NAVFIX #4 14:55:24
223+33
226+40 NAVFIX #3 14:54:38
226+66
230+00
231+10 NAVFIX #2 14:53:47
232+05 NAVFIX #5A 14:06:12
232+13 BROKEN WIRE
233+33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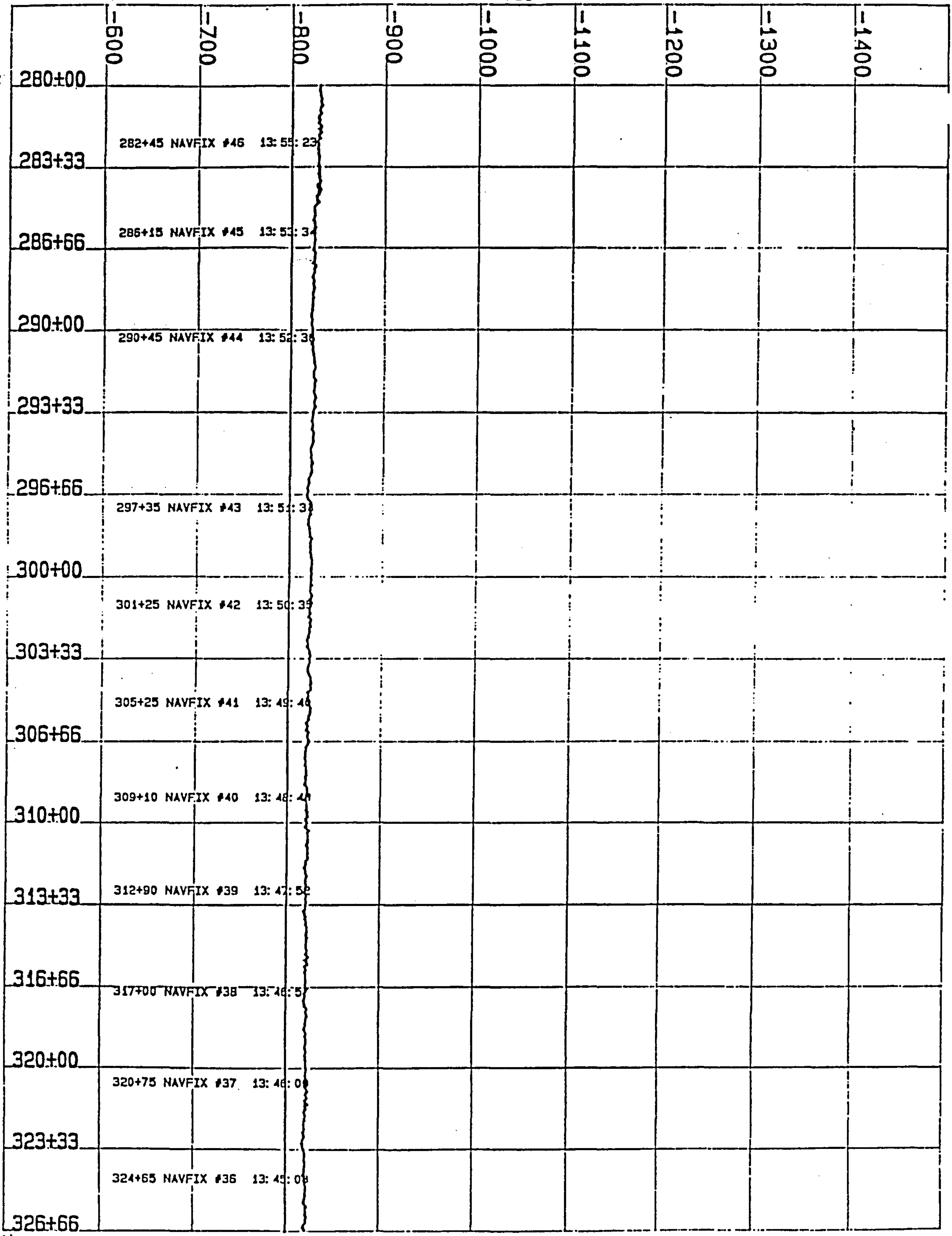
280+00


-600
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280+00
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310+00
312+90 NAVFIX #39 13:47:52
313+33
316+66
317+00 NAVFIX #38 13:46:5
320+00
320+75 NAVFIX #37 13:46:0
323+33
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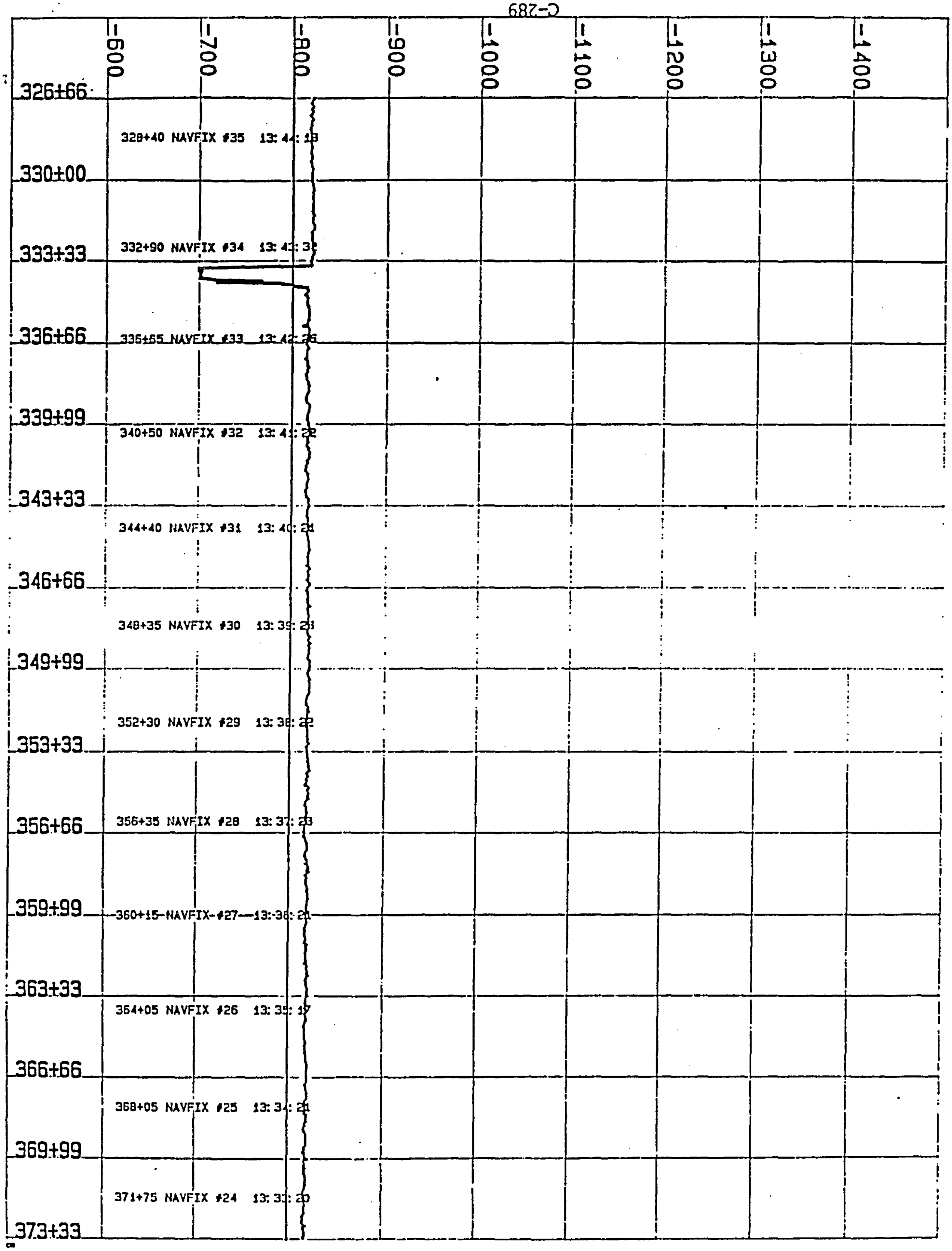
326+66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-1200
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-1400
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332+90 NAVFIX #34 13:43:32
333+33
336+66
336+65 NAVFIX #33 13:42:26
339+99
340+50 NAVFIX #32 13:41:22
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346+66
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349+99
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359+99
360+15 NAVFIX #27 13:36:21
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369+99
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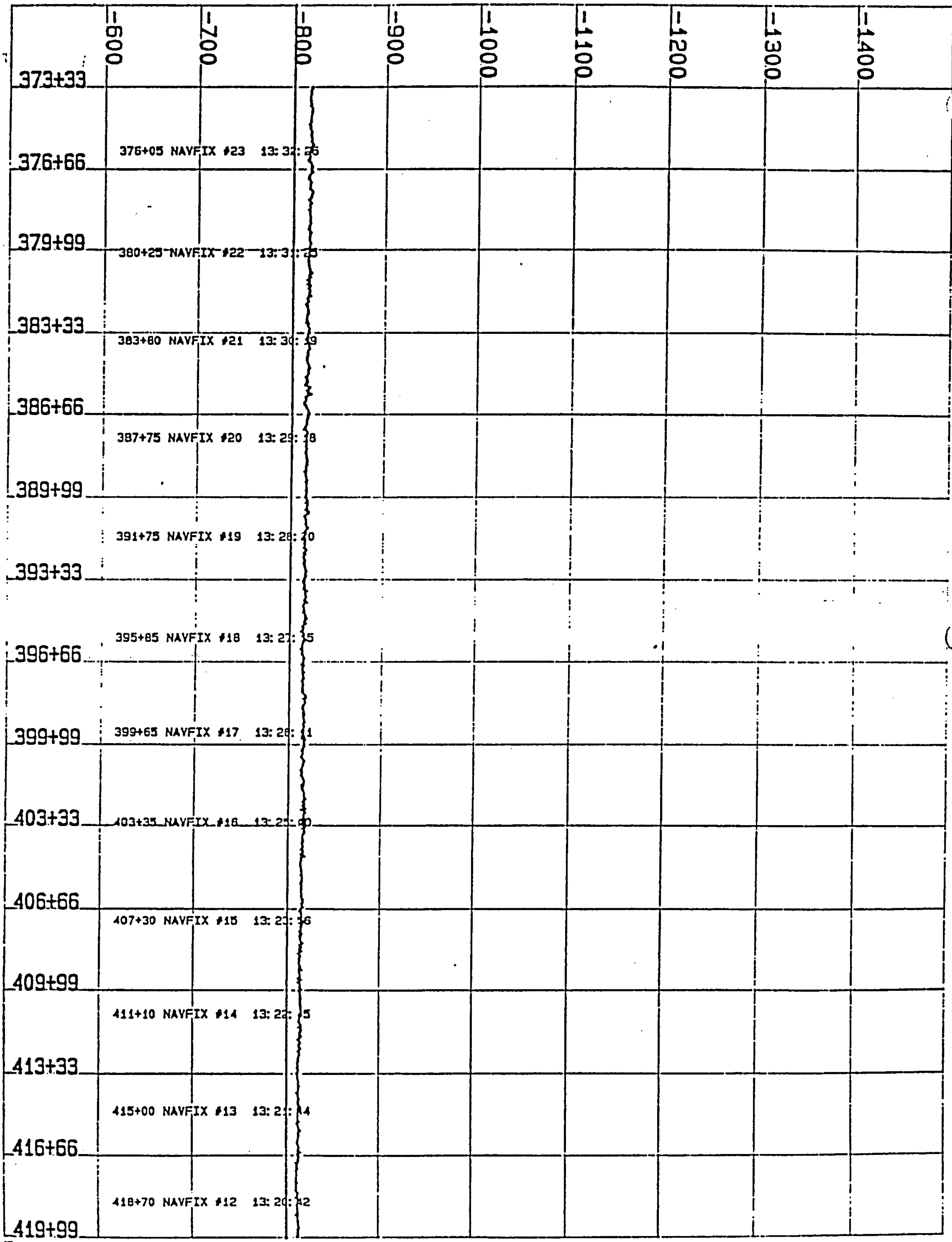
373+33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393+33
396+66
399+99
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413+33
416+66
419+99
376+05 NAVFIX #23
380+25 NAVFIX #22
383+60 NAVFIX #21
387+75 NAVFIX #20
391+75 NAVFIX #19
395+85 NAVFIX #18
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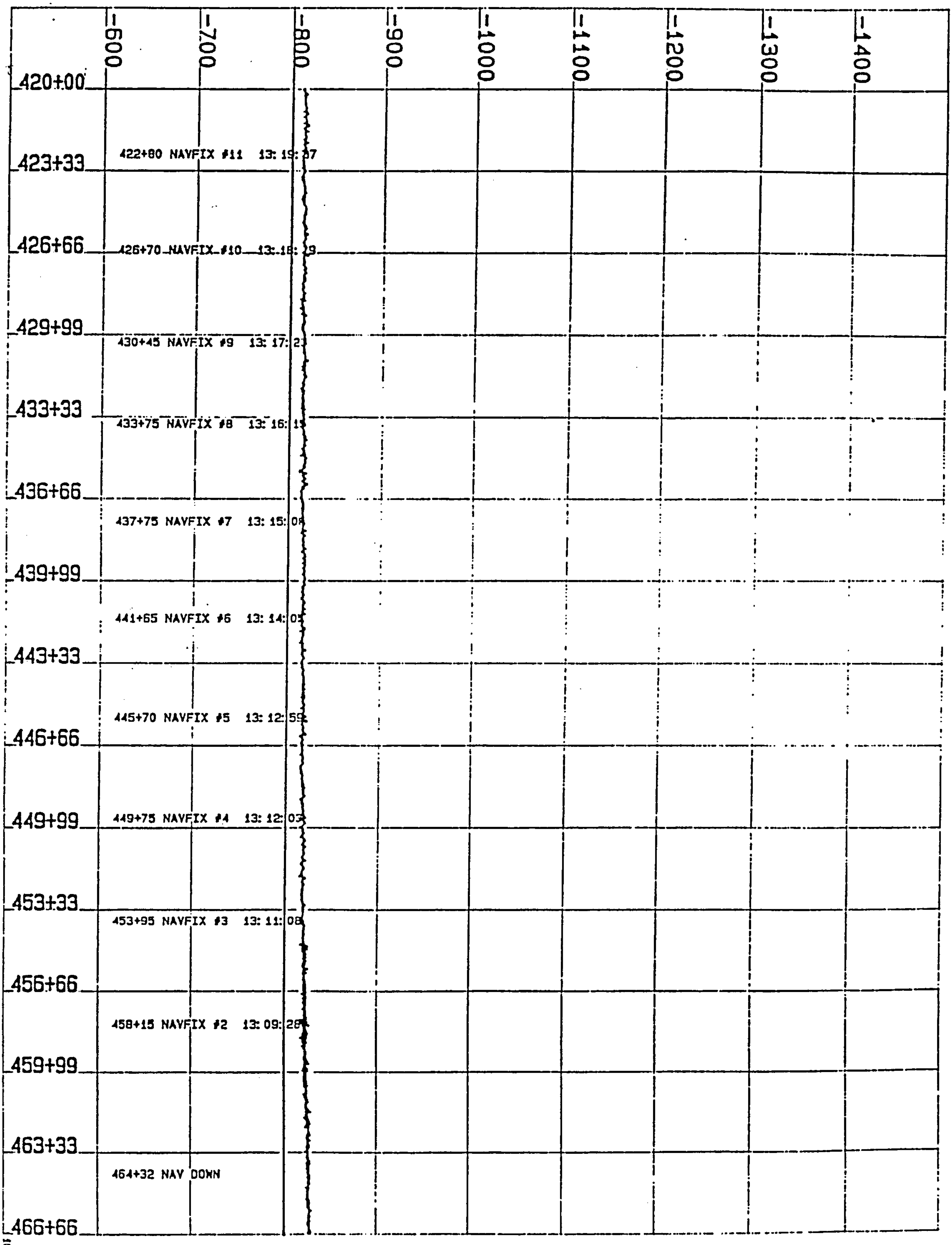

-600
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-1200
-1300
-1400
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436+66
439+99
443+33
446+66
449+99
453+33
456+66
459+99
463+33
466+66
422+80 NAVFIX #11 13: 19: 37
426+70 NAVFIX #10 13: 18: 29
430+45 NAVFIX #9 13: 17: 2
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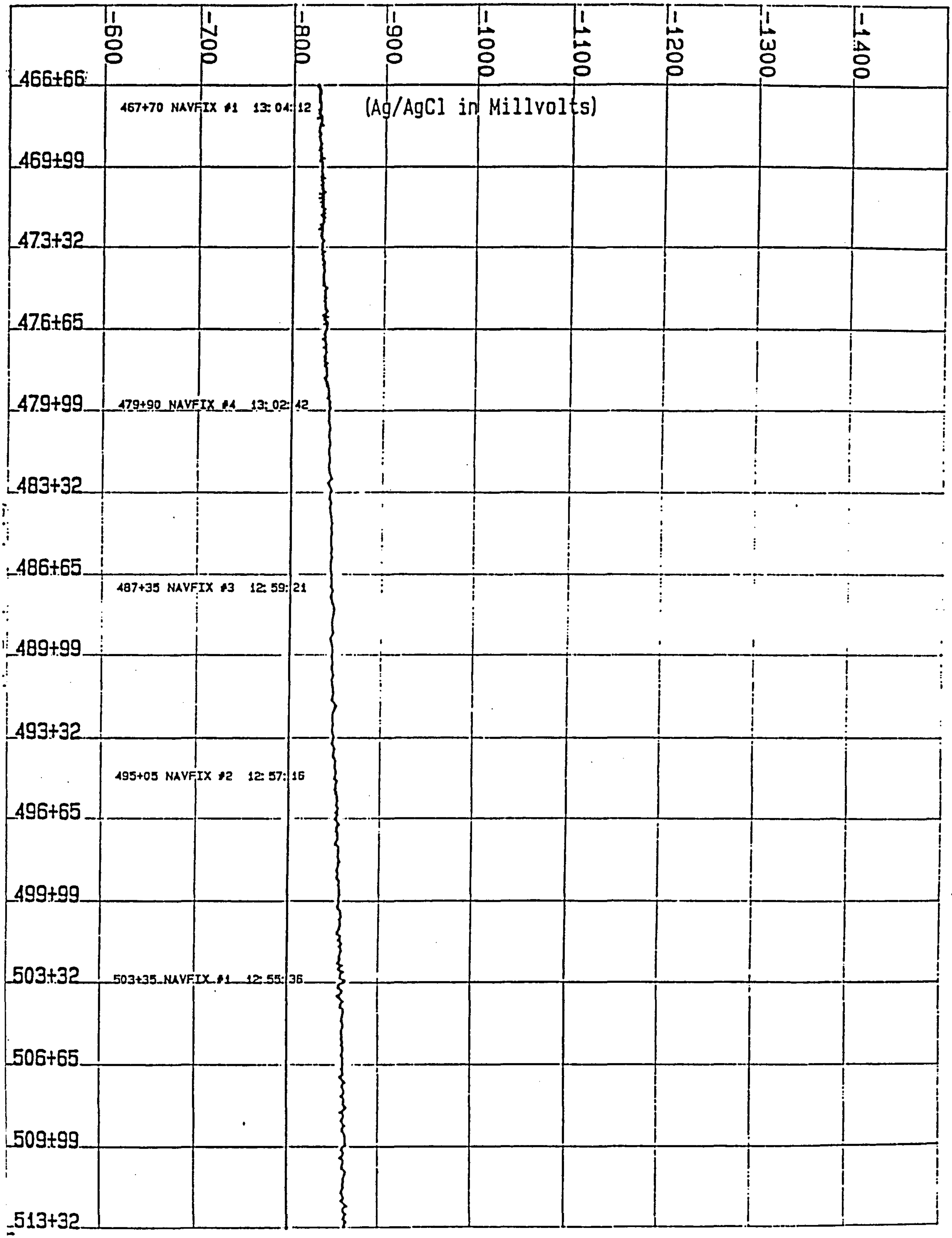
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
(Ag/AgCl in Millvolts)
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469+99
473+32
476+65
479+99
483+32
486+65
489+99
493+32
496+65
499+99
503+32
506+65
509+99
513+32
467+70 NAVFIX #1 13:04:12
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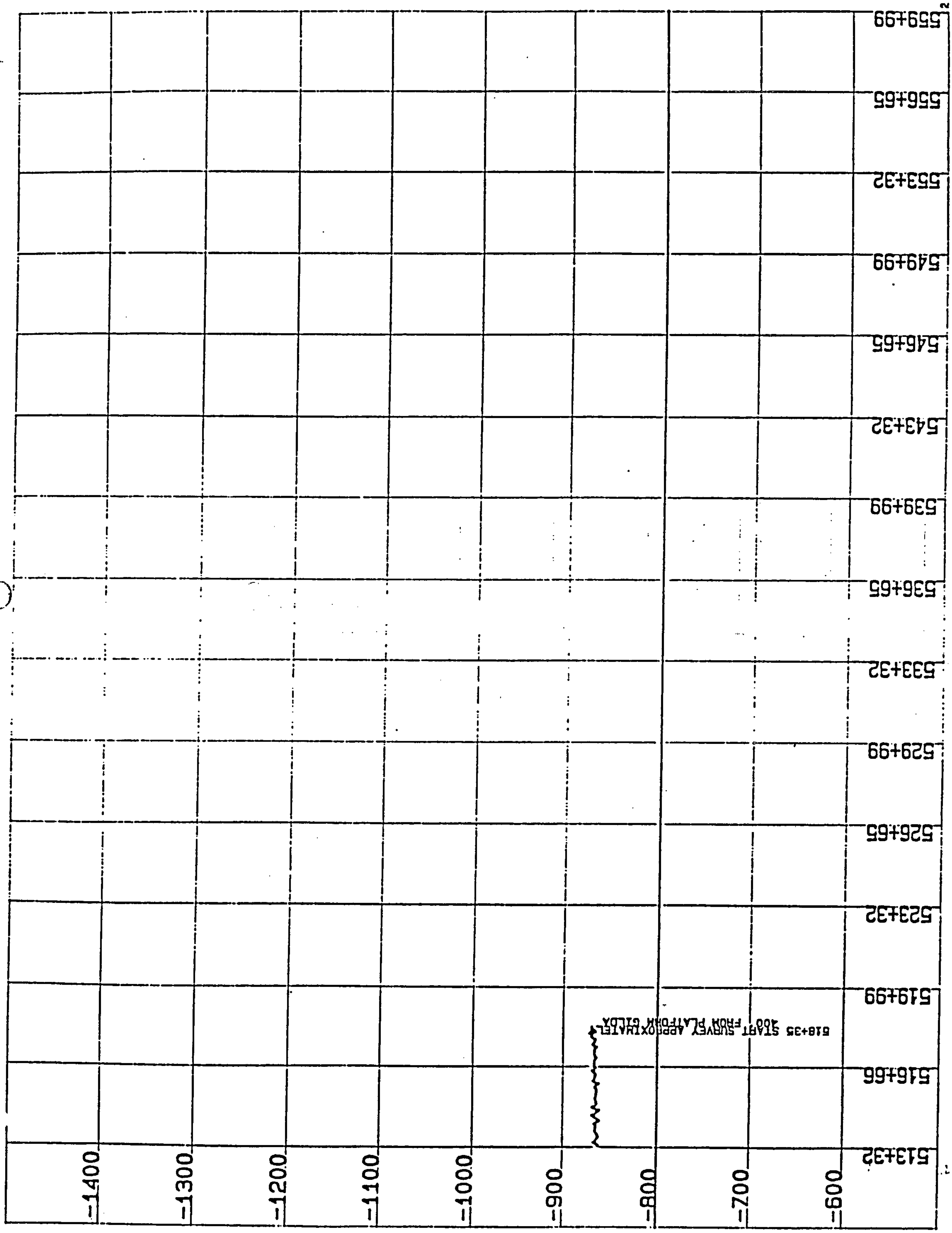
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546+65
543+32
539+99
536+65
533+32
529+99
526+65
523+32
519+99
516+66
513+32
518+35 START SURVEY APPROXIMATELY
400' FROM PLATFORM GILDA
-1400
-1300
-1200
-1100
-1000
-900
-800
-700
-600

CLOSE INTERVAL POTENTIAL SURVEY

6" AND 10" PIPELINE BUNDLE

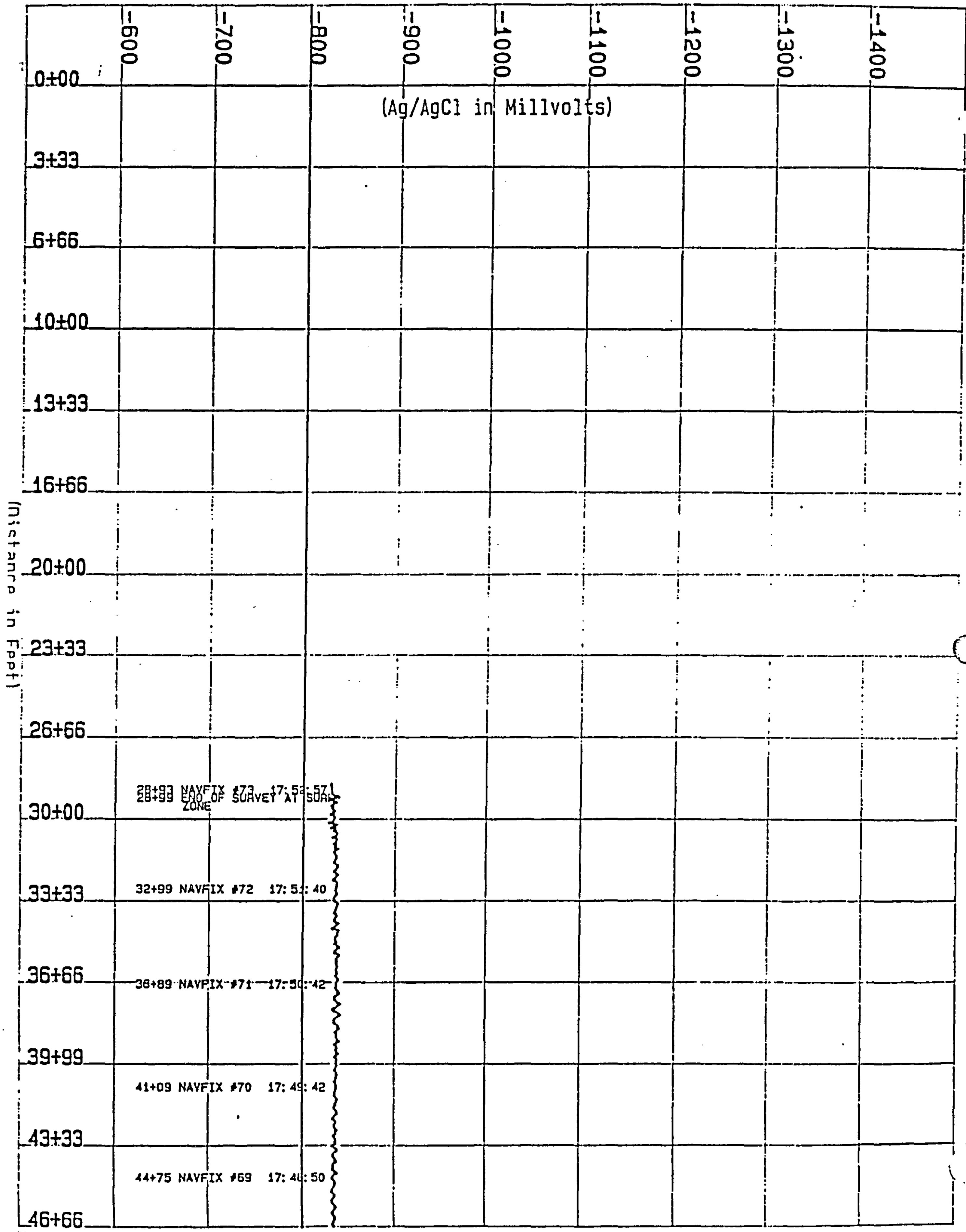
SURF ZONE TO PLATFORM GINA

FOR

UNOCAL CORPORATION

FEBRUARY 11 1989

CORRPRO COMPANIES, INC.



-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
(Ag/AgCl in Millvolts)
0±00
3±33
6+66
10±00
13+33
16+66
20±00
23+33
26+66
30±00
33±33
36+66
39+99
43±33
46+66
(Distance in Feet)
28+93 NAVFIX #73 17:52:57
28+99 END OF SURVEY AT SURF ZONE
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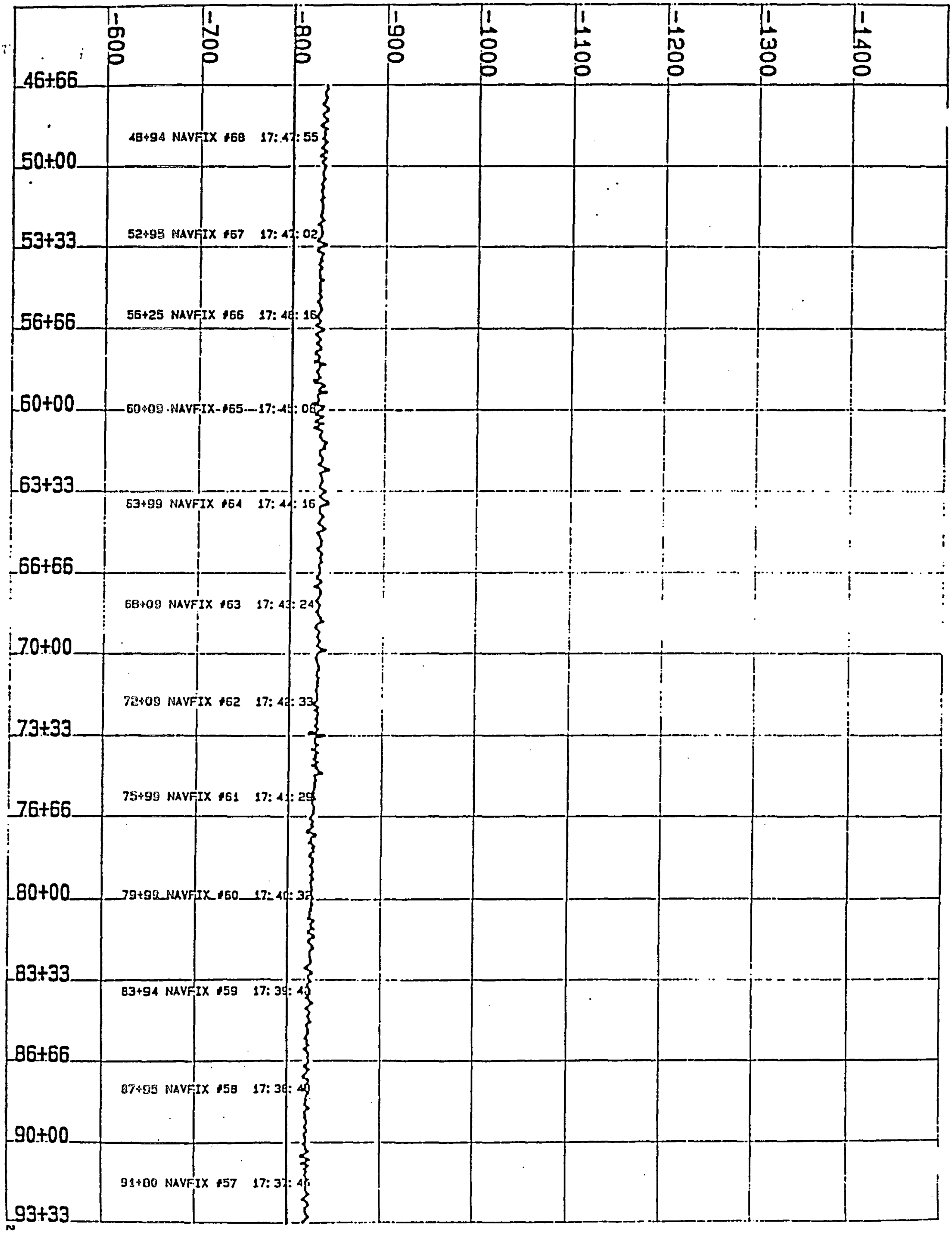
36+89 NAVFIX #71 17: 5: 42
41+09 NAVFIX #70 17: 4: 42
44+75 NAVFIX #69 17: 4: 50



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53+33
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56+66
60+00
60+09 NAVFIX #65 17:45:08
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63+99 NAVFIX #64 17:44:16
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68+09 NAVFIX #63 17:43:24
70+00
72+09 NAVFIX #62 17:42:33
73+33
75+99 NAVFIX #61 17:41:29
76+66
80+00
79+99 NAVFIX #60 17:40:32
83+33
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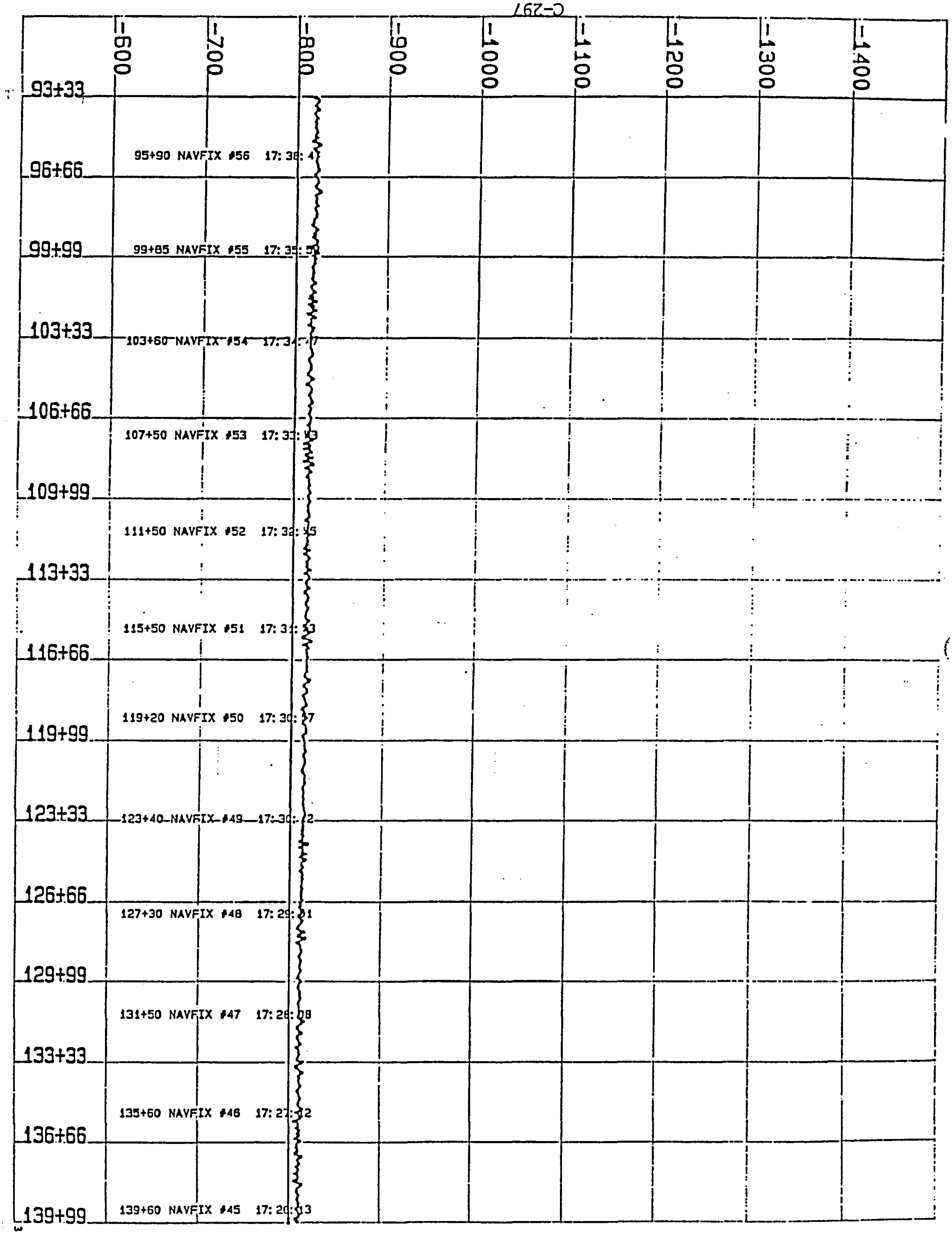
91+80 NAVFIX #57 17:37:46
93+33

C-297



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-1200
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96+66
99+99
103+33
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109+99
113+33
116+66
119+99
123+33
126+66
129+99
133+33
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111+50 NAVFIX #52
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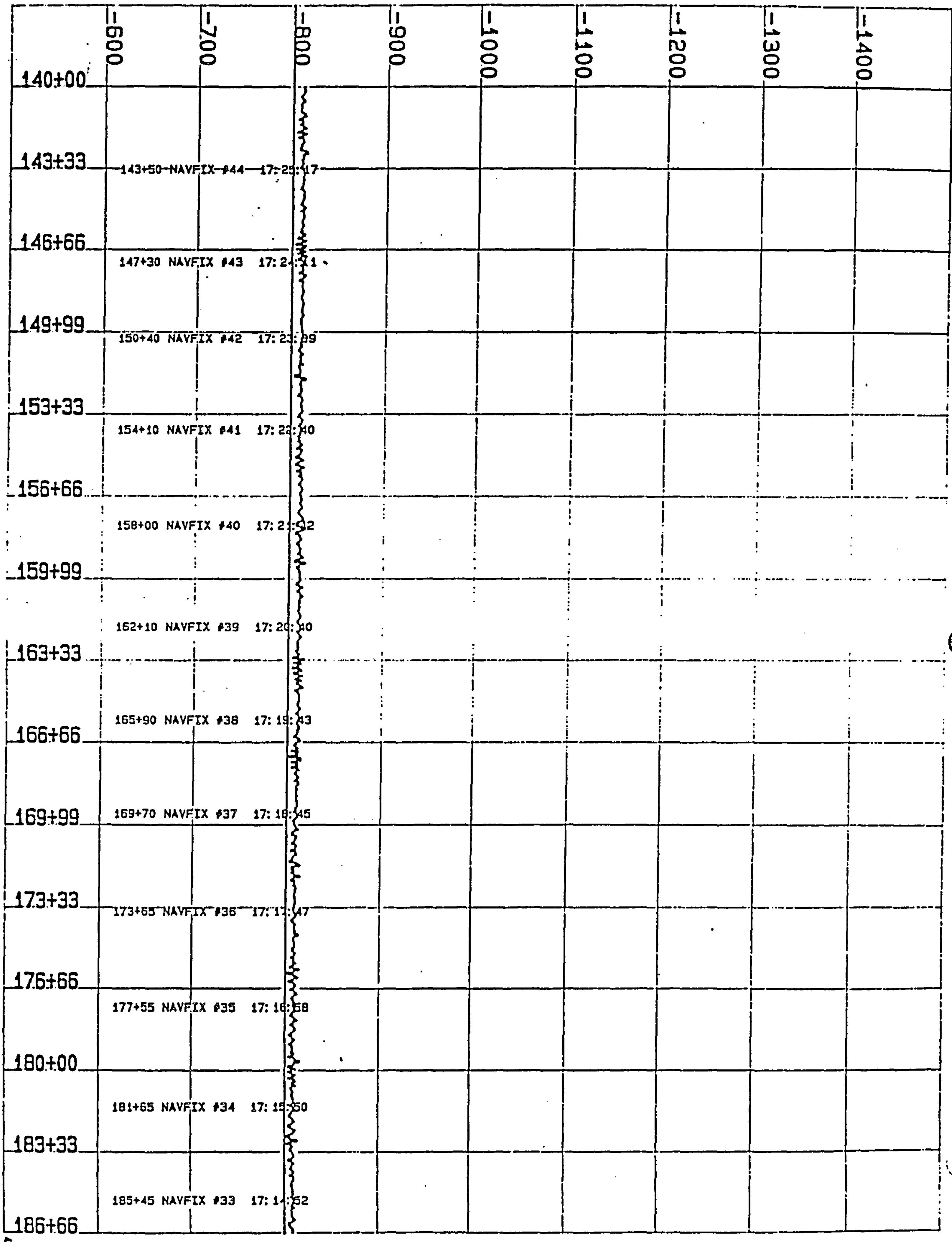

-600
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-800
-900
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-1200
-1300
-1400
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163+33
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173+33
176+66
180+00
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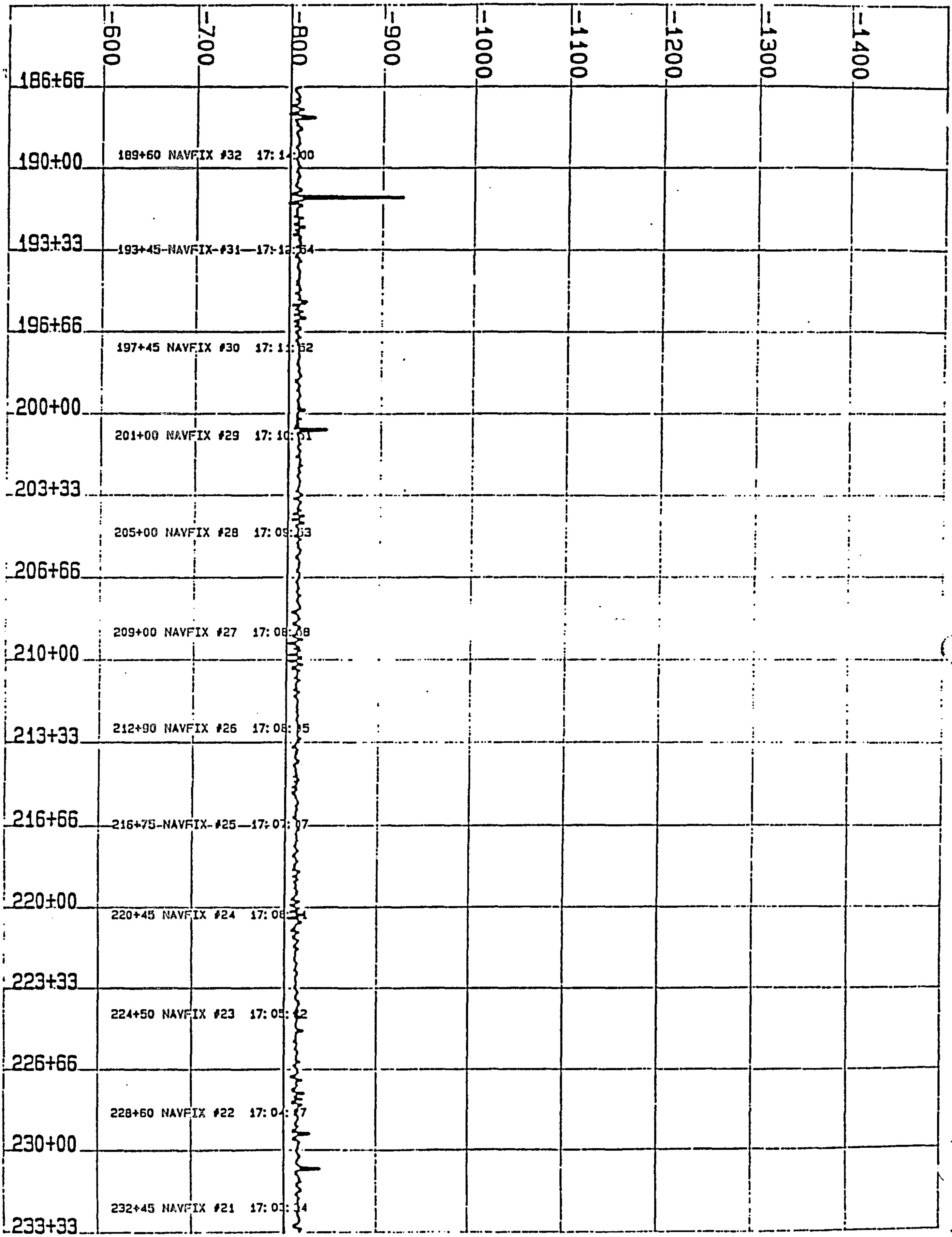
C-299



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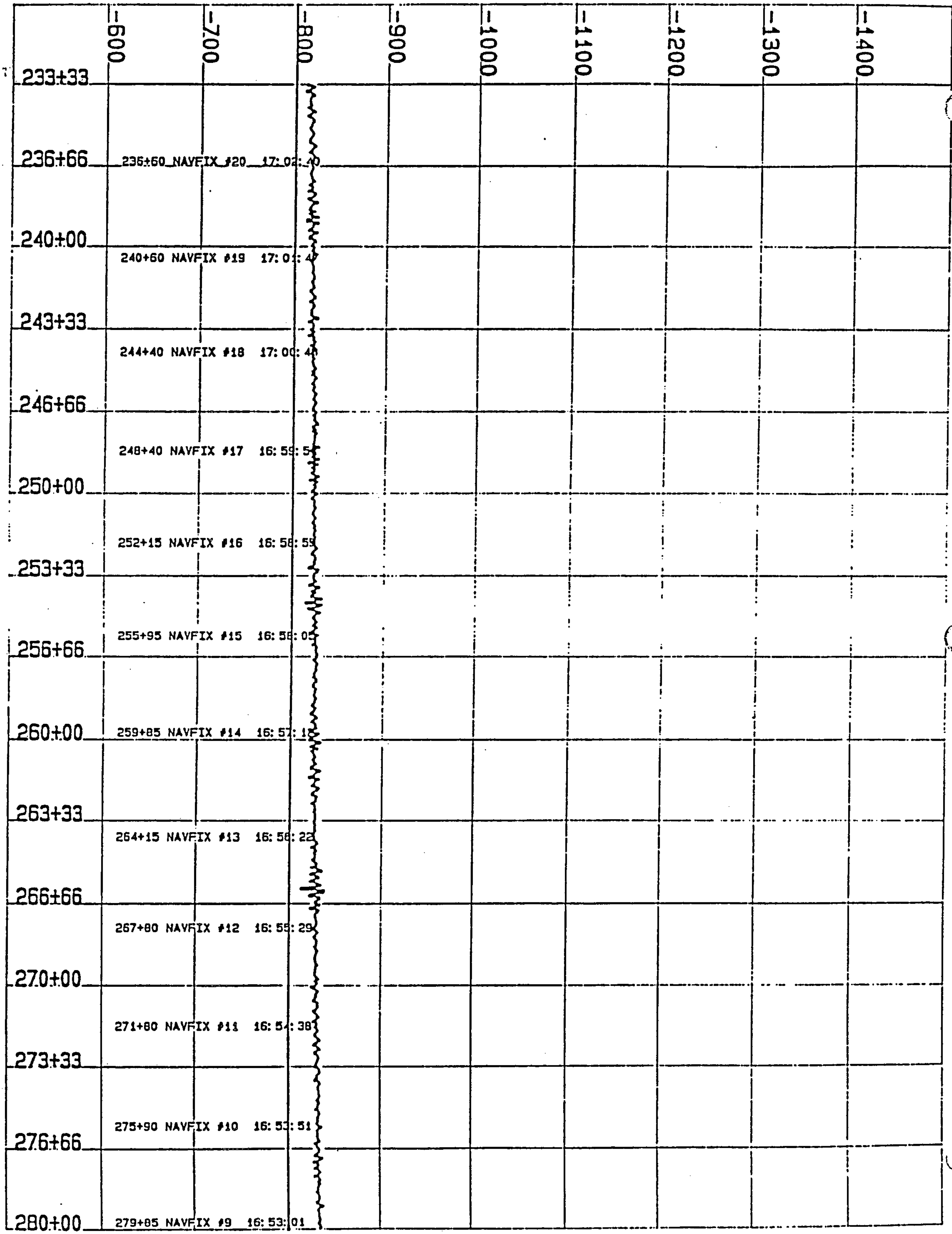
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240+60 NAVFIX #19 17:01:47
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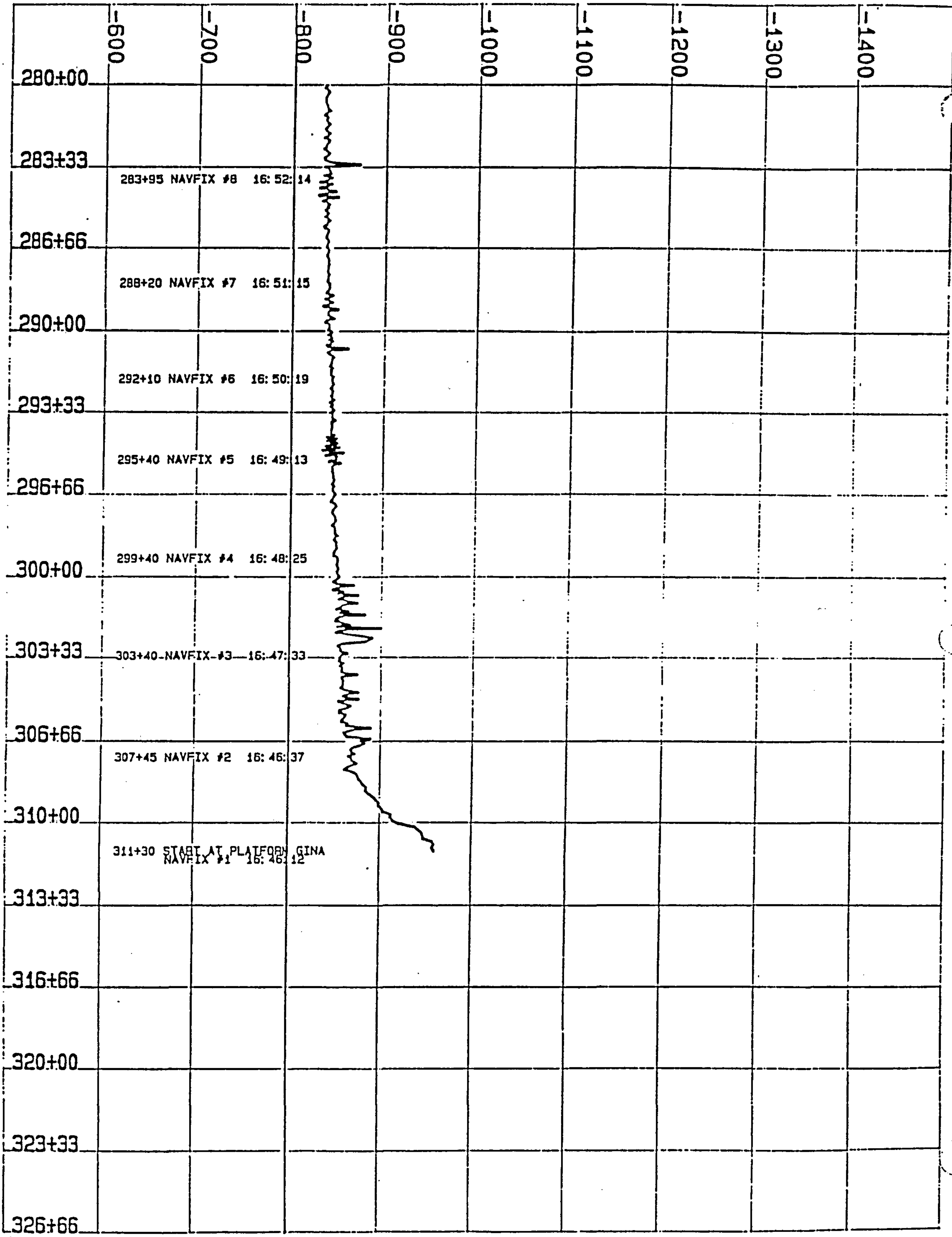
C-301



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-900
-1000
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-1200
-1300
-1400
280+00
283+33
283+95 NAVFIX #8 16: 52: 14
286+66
288+20 NAVFIX #7 16: 51: 15
290+00
292+10 NAVFIX #6 16: 50: 19
293+33
295+40 NAVFIX #5 16: 49: 13
296+66
299+40 NAVFIX #4 16: 48: 25
300+00
303+33
303+40 NAVFIX #3 16: 47: 33
306+66
307+45 NAVFIX #2 16: 46: 37
310+00
311+30 START AT PLATFORM GINA
NAVFIX #1 16: 46: 12
313+33
316+66
320+00
323+33
326+66

CLOSE INTERVAL POTENTIAL SURVEY

6" GINA WATER RETURN

MANDALAY STATION TO SHORE LINE

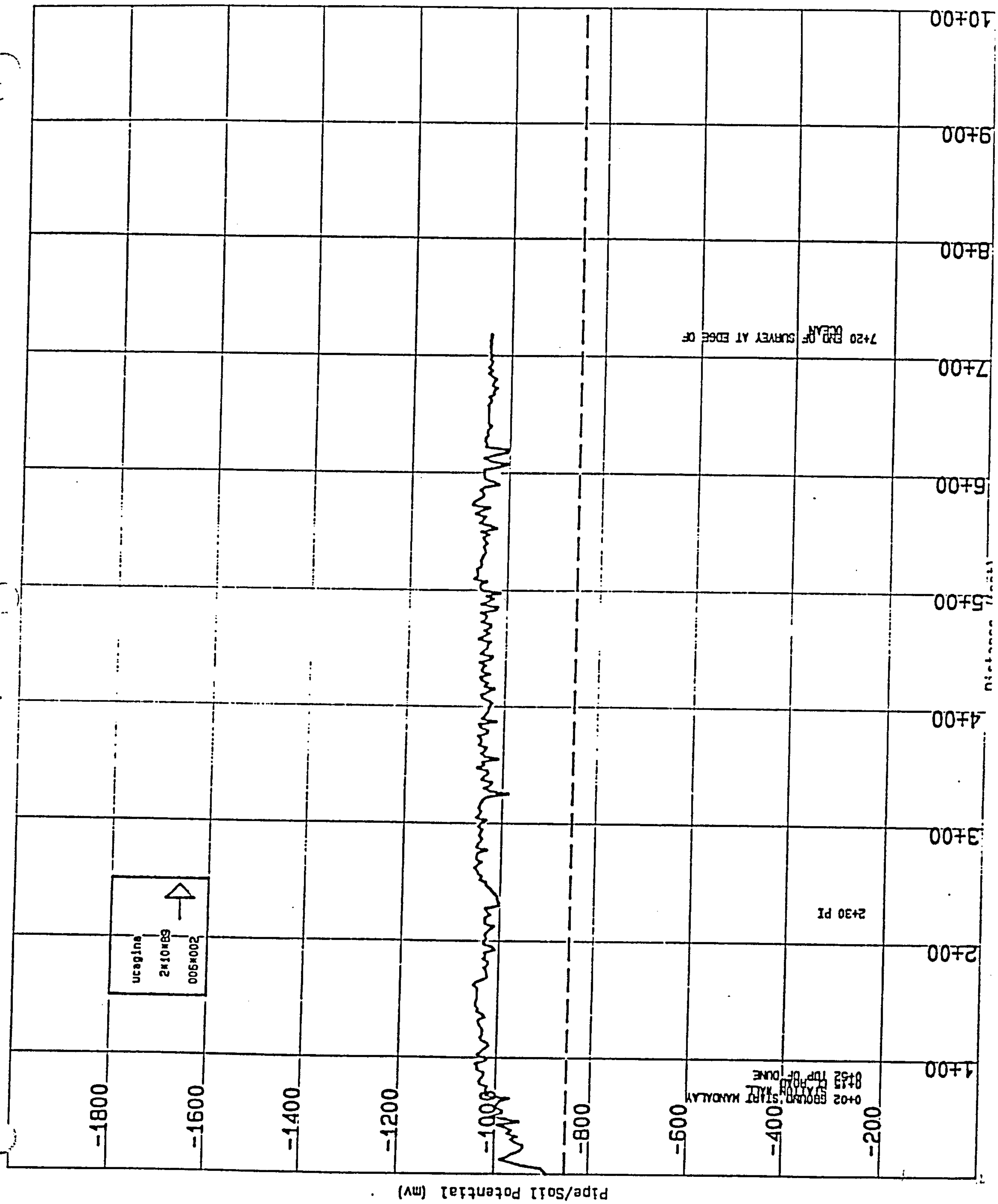
FOR

UNOCAL CORPORATION

FEBRUARY 10 1989

CORRPRO COMPANIES, INC.

C-302



1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
10+00
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
Pipe/Soil Potential (mv)
7+20 END OF SURVEY AT EDGE OF OCEAN
2+30 PI
0+02 GROUND START MANDALAY
0+52 TOP OF DUNE

CLOSE INTERVAL POTENTIAL SURVEY

6" GILDA WATER RETURN

MANDALAY STATION TO SHORE LINE

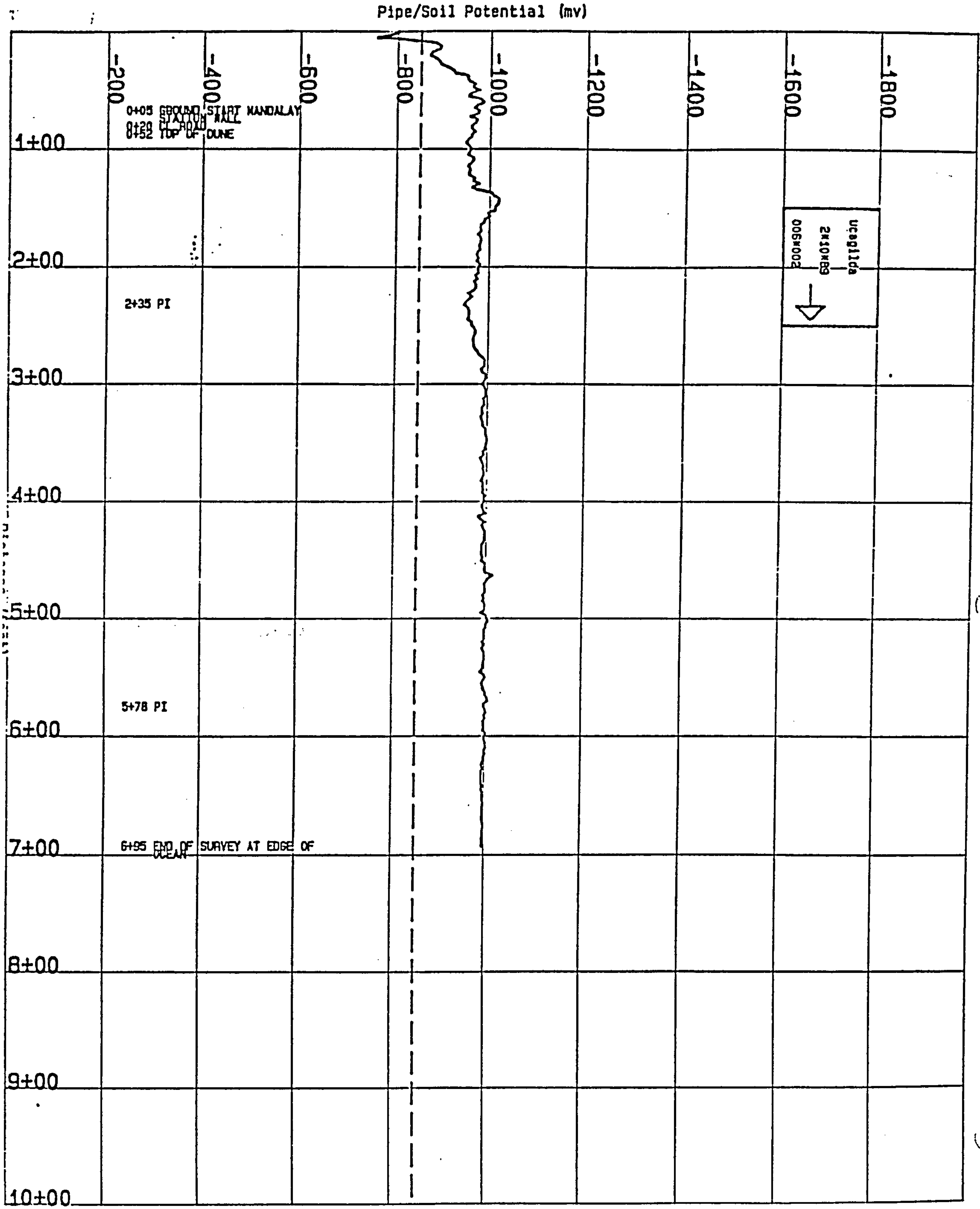
FOR

UNOCAL CORPORATION

FEBRUARY 10 1989

CORRPRO COMPANIES, INC.

C-304


Pipe/Soil Potential (mv)
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
10+00
0+05 GROUND START MANDALAY
0+20 STATION WALL
0+52 TOP OF DUNE
2+35 PI
5+78 PI
6+95 END OF SURVEY AT EDGE OF OCEAN

PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

APPENDIX VOLUME 3

UNOCAL 76

APPENDIX VOLUME 3

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APPENDIX VOLUME 3

Initial Study Component 1
Return Water Line Replacement

CITY OF
Oxnard

FINAL INITIAL STUDY

FOR

PLATFORM GINA PROPOSED RETURN WATER LINE REPLACEMENT AND CONVERSION TO PRODUCED GAS

SEPTEMBER, 1990

CAROL WALDROP & ASSOCIATES
Planning and Development Consulting

FINAL INITIAL STUDY

FOR

PLATFORM GINA PROPOSED RETURN WATER LINE REPLACEMENT AND CONVERSION TO PRODUCED GAS

Applicant

Unocal Oil and Gas Division

Prepared by

City of Oxnard Community Development Department

with the assistance of

Carol Waldrop & Associates

September, 1990

Initial Study Component 1

Return Water Line Replacement

CITY OF OXNARD

ENVIRONMENTAL CHECKLIST FORM
INITIAL STUDY
Pipeline Replacement Component

I. Project Description

A. Permit Number Modification to Special Use Permit No. 806

B. Applicant Unocal Oil and Gas Division

C. Address and Phone Number of Applicant P.O. Box 6176,

Ventura, CA 93003 (805) 656-7600

D. Name of Project, if applicable Platform Gina Return Water Line

Replacement

E. Project Description

The proposed pipeline replacement component of the project is intended to repair the 6-5/8 inch return water line from the Mandalay facility to Platform Gina. Subsequently, the pipeline will be converted from water return service to produced gas transport service to facilitate evaluating the exploratory well (H-14) and provide for long-term field development. This initial study evaluates the first component of the project which is the return water line replacement.

The 6-5/8 inch pipeline has not been in service since October 1988 when a leak was discovered near the Mandalay facility. The repair, which will be completed prior to converting the line to gas transport service, will replace 3,000 feet of the pipeline. This segment will extend from a point 700 feet above the Mean High Tide Line (MHTL) by the Mandalay facility to a point 2,300 feet from the MHTL seaward toward Platform Gina. Excavation, installation and restoration activities required for the pipeline repair are described on pages 12-24 of Exhibit A (Unocal Project Description).

The repair involves the following steps: locate the pipeline in reference to the beach and ocean floor (completed), cut the pipe at the offshore tie-in point, pressure test the pipeline to 900 psi from the cut point to Platform Gina, weld together the 2,300 feet of offshore replacement pipe on the beach, and pull the replacement pipe to the offshore tie-in point and perform the tie-in.

The final step will be to weld the additional 700' of pipe to connect from the Mandalay Facility to the point where the offshore pipeline terminates at the MHTL. Thus, there will be all new pipe from the Mandalay facility to the tie-in point offshore. The beach work will be conducted with conventional equipment within an area initially evaluated in EIR 78-19. The pipe will be pulled through the 10" conduit that runs underneath the sand dune to prevent any alteration of the dune area.

The onshore section will be buried mechanically with conventional equipment. The remaining line will be buried by the forces of gravity and hydraulic action. It is projected to attain burial to the same depth as the current pipeline (four feet) in a short period of time. Hydraulic jetting will be limited to areas near shore in which the surf zone energy is not sufficient to bury the line.*

Upon completion, Unocal and the contractor will be responsible for removal of the construction area fencing and for clean up of all material. Subsequently, any disturbed areas shall be regraded, recontoured, and revegetated to conform to original conditions.

The estimated time required for the repair of the pipeline will be three (3) weeks once work begins. In November 1988 the City of Oxnard authorized use of the staging area and activities associated with the pipeline repair. The findings and conditions of this approval which are included in the City of Oxnard's letter of November 18, 1988 and the original conditions of Resolution 6218 approving Special Use Permit No. 806 are attached as Exhibit B. Since the repair was delayed and is now being presented in conjunction with the change of use from a return water line to a produced gas line, the repair phase is being evaluated in the context of the project as a whole. Approvals granted by the City of Oxnard apply only to the portion of the pipeline within the Oxnard city limits and the construction staging area. Seaward of the MHTL, the pipeline replacement is under the jurisdiction of the State Lands Commission. The Coastal Commission has overlapping jurisdiction related to the entire pipeline replacement project area.

II. Environmental Impacts

	Yes	Maybe	No
A. Earth. Will proposal result in:			
1. Unstable earth conditions or in changes in geological substructures?			X
2. Disruptions, displacements, compaction or overcovering of the soil?		X	
3. Change in topography or ground surface relief features?			X

*See Appendix A, SLC October 18 letter of comment number 1 and Unocal October 24 letter of response number 1.

4. The destruction, covering or modification of any unique geological or physical features? ___ ___ X

5. Any increase in wind or water erosion of soils, either on or off the site? ___ ___ X

6. Changes in deposition or erosion of beach sands, or changes in situation, deposition or erosion which may modify the channel of a river or stream or the bed of the ocean or any bay, inlet or lake? ___ X ___

7. Exposure of people or property to geological hazards such as earthquakes, landslides, mudslides, ground failure, or similar hazards? ___ ___ X

Documentation: A(2,6) Disruption, displacements, or overcovering of the bottom surface may occur as a result of exposing certain sections of the installed pipeline, cutting through the pipeline, and tying in a new segment of pipeline. The environmental consequences of construction of both offshore and onshore pipelines are evaluated in EIR 78-19, pages 4.1-2 through 4.1-7. Alteration of onshore and sea floor topography is determined to be insignificant due to the minor and temporary nature of the disturbance. The onshore marshalling and fabrication area will be regraded and revegetated.

A study conducted by the University of California titled Evaluation of the Potential for Self-Burial of the Proposed Unocal Gina Pipeline (May 1989) on file in the City of Oxnard Planning Division, provides an engineering evaluation of the mechanisms contributing to the pipeline's tendency for self-burial when acted upon by wave and current forces specific to the Mandalay area. Both actual history and related studies support the conclusion that the internally corroded pipeline will remain in place and that abandoning the pipeline in place after the replacement section is tied in is desirable to minimize the disturbance of the sea floor. Please see Exhibit A, Unocal Project Description, pages 33-36, which contains a summary memorandum (June 26, 1989) and the conclusions of the evaluation study (May 1989).*,**

Mitigation: Any known or potential impacts will be mitigated to a level of insignificance by implementing the intent and requirements of the City of Oxnard's letter of authorization extending the applicability of Coastal Development Permit No. 85-5 dated November 18, 1988; the conditions included in Coastal Development Permit No. 85-5; Resolution 6218 approving Special Use Permit No. 806, plus related attachments that are cited within each of these documents (see Exhibit B).

*See Appendix A, SLC October 18 letter of comment number 2 and Unocal October 24 letter of response number 2.

**See Appendix A, SLC October 18 letter of comment number 3 and Unocal October 24 letter of response number 3.

B. Air. Will the proposal result in:

	Yes	Maybe	No
1. Substantial air emissions or deterioration of ambient air quality?	___	___	X
2. The creation of objectionable odors?	___	___	X
3. Alteration of air movement, moisture, or temperature, or any change in climate, either locally or regionally?	___	___	X

Documentation: Air pollutant emissions from onshore and offshore sources would occur as a result of the pipeline repair project. Construction emissions would be of short duration. Emission sources would include worker transportation (automobile and boat), supply boats and trucks, electric power generation, and various types of portable and stationary diesel and natural gas powered equipment. Please see Exhibit D for additional supporting information.

B(2)
Odor will occur only in the event of accidental release of gas from the pipeline which could only occur if there is catastrophic failure of the H_2S Processing Detection and Shutdown System. The Risk Assessment Study (Exhibit E) indicates that the possibility of such a failure is extremely remote and if a worst case accident were to occur the affected area would be limited to a 1,320 foot radius of the Mandalay Onshore Processing Facility. There are no residences within this distance. The closest residences are approximately 3,000 feet to the south.

B(1) and (3)
The potential impacts on air quality are discussed in the analysis in EIR 78-19 Section 4.2. In addition, Unocal has submitted a report entitled "Emission Data for Platform Gina Pipeline Repair and Conversion Project", prepared By EnerSource Engineering, February 1990 (included herein as Exhibit D). The report was acceptable to the Ventura County APCD and is included as part of Exhibit D. Construction related emissions for the entire project duration of approximately 2 weeks are 420 lbs ROC and 5197 lbs NOx. This level of emissions is well below the APCD threshold of significance of 13.7 tons per year of either reactive organic compounds (ROC) or oxides of nitrogen (NOx). Offshore generated emissions and impacts onshore are minor and of low significance (see Table 1.3 in Exhibit D). In addition the report identifies offsets available as further mitigation. At Mandalay, net reductions in emissions have been achieved as a result of on-going fuel conservation efforts. Also, the development of new sources of natural gas represents a positive contribution to local air quality.

Mitigation: The EIR recommended mitigation measures which were incorporated into the conditions of Resolution 6218 approving Special Use Permit 806 (#27 C 1-5) are applicable to the repair project.

	Yes	Maybe	No
C. Water. Will the proposal result in:			
1. Changes in currents, or the course of direction of water movements, in either marine or fresh waters?			X
2. Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff			X
3. Alterations to the course or flow of flood waters?			X
4. Change in the amount of surface water in any water body?			X
5. Discharge into surface waters, or in any alteration of surface water quality, including but not limited to temperature, dissolved oxygen or turbidity?	X		
6. Alteration of the direction or rate of flow of ground waters?			X
7. Change in the quantity of ground waters, either through direct additions or withdrawals, or through interception of an acquifer by cuts or excavations?			X
8. Substantial reduction in the amount of water otherwise available for public water supplies?			X
9. Exposure of people or property to water related hazards such as flooding or tidal waves?			X

Documentation: There are no activities involved in the pipeline repair project which would have an impact on the items in Sections C 1-4 and 6-9. See Unocal Project Description and EIR 78-19 Sections 3.0 and 4.0.

C(5)
EIR 78-19 Section 4.3.1.1.2 contains discussion of the effect of the entire Platform Gina pipeline installation on turbidity as follows:

> "The act of pulling the pipelines offshore would cause some disturbances and suspension of bottom sediments. Effects could persist slightly past the 3 week period of pipeline installation. The turbid plume could extend several to many tens of feet up or downcoast (depending on bottom sediment type, local current advection and wave mixing). However, the impact is considered to be of negligible significance in relation to natural

turbidity in the area generated periodically by the Santa Clara River outflow to the ocean or by dredging activity at Channel Islands Harbor, the Ventura Marina or Port Hueneme."

The above conclusions pertain to approximately 814,000 feet of pipeline routes analyzed for Platform Gina and Platform Gilda. The current project involves replacement of only 2,300 feet offshore. Therefore, the project has substantially less impact on water turbidity than that evaluated in the original EIR.

Section 4.3.1.1.2 of EIR 78-19 evaluates excavation activities and the effect on turbidity as follows:

> "Excavation activities would cause a temporary increase in nearshore turbidity and a minor redistribution of the sediments. The nearshore zone is a high energy environment where sediments are subject to natural movement and redistribution by active longshore transport processes. Therefore the impacts associated with the pipeline and power cable are not expected to be a significant contribution to the effects of naturally occurring processes within the nearshore zone. The affected areas would be impacted to a far greater extent by storm wave action and dumping of dredge spoil from bypassing operations at harbor entrances in the general area."

Because the project will be conducted in the high energy zone described above and to a substantially lesser extent than the original pipeline installation, the project will have only temporary and negligible effects on turbidity.

Mitigation: none required

	Yes	Maybe	No
D. Plant Life. Will the proposal result in:			
1. Change in the diversity of species, or number of any species of plants (including trees, shrubs, grass, crops and aquatic plants)?	___	___	X
2. Reduction of the numbers of any unique, rare, or endangered species of plants?	___	___	X
3. Introduction of new species of plants into an area, or in a barrier to the normal replenishment of existing species?	___	___	X
4. Reduction in acreage of any agricultural crop?	___	___	X

Documentation: EIR 78-19 pages 4.5-1 through 4.5-3 provides discussion of impacts on the fabrication and marshalling area which adequately covers any potential onshore impacts from the repair project.

Mitigation: Conditions set forth in the November 18, 1988 letter of authorization from the City of Oxnard and Special Use Permit 806 which include the EIR recommended mitigation measures, shall apply and are attached as Exhibit B.

	Yes	Maybe	No
E. Animal Life. Will the proposal result in:			
1. Change in the diversity of species, or numbers of any species of animals, (birds, land animals including reptiles, fish and shellfish, benthic organisms or insects?			X
2. Reduction of the numbers of any unique, rare or endangered species of animals?			X
3. Introduction of new species of animals into an area, or result in a barrier to the migration or movement of animals?			X
4. Deterioration to existing fish or wildlife habitat?		X	

Documentation: E (1-3) EIR 78-19 pages 4.4-1 through 4.4-6. Impacts on the marine biota that could potentially occur during installation of the offshore pipelines and power cable from Platform Gina would result from: disturbance and displacement of sedimentary substrate and associated biota during jetting, burial, and emplacement of the pipelines and cable; and, discharge of hydrostatic test water.

This would be an insignificant impact because of the paucity of the fauna found at the site, the small area disturbed (0.003 percent of the sandy beach habitat within the region), the brief duration of the disturbance, and the presence nearby of similar biotas for recolonization which should begin shortly after completion of construction operations.

The EIR also evaluated the distribution of hard bottom habitat and kelp beds. The area of the pipeline location is composed of unconsolidated sediments and not hard bottom habitats or kelp beds. A review of the area was conducted in November 1988 to update that information and to determine if any kelp beds or hard bottom habitat had been established in the area. None were found and the research is documented in correspondence on file in the Planning Division.

Mitigation: Condition 34 of Resolution 6218 approving Special Use Permit 806, restricts onshore and offshore pipeline placement activities to occur only between September and February in order to avoid interference with the Grunion migration activities.

	Yes	Maybe	No
F. Noise. Will the proposal result in:			
1. Increase in existing noise levels?	___	X	___
2. Exposure of people to severe noise levels?	___	___	X

Documentation: EIR 78-19 pages 4.2-37 to 4.2-39 provides a thorough analysis of noise impacts which adequately covers the potential noise impacts from the pipeline repair activities.

Mitigation: Condition 27d of Resolution 6218 provides mitigation of noise generated from pipeline pulling activities.

	Yes	Maybe	No
G. Light and Glare. Will the proposal produce new light or glare?	___	X	___

Documentation: On shore construction activities are conducted only during daylight hours per City of Oxnard Building and Safety Division requirements. The offshore pipeline pull and tie-in will take place over one 24-36 hour period. Please see page 21 of the Unocal Project Description attached as Exhibit A for a description of the pipeline pull operation.

Mitigation: none required

	Yes	Maybe	No
H. Land Use. Will the proposal result in a substantial alteration of the present or planned use of an area?	___	___	X

Documentation: The repair project will temporarily alter the land use of a limited area from the beach to the fabrication and marshalling area (See Unocal Project Description attached as Exhibit A). This short term use will occur over a three week period.

Mitigation: Complete restoration to original condition is required by conditions of approval included in the November 18, 1988 letter of authorization from the City of Oxnard.

	Yes	Maybe	No
I. Natural Resources. Will the proposal result in:			
1. Increase in the rate of use of any natural resources?			X
2. Substantial depletion of any nonrenewable natural resources?			X

Documentation: Short term use of fuel for construction equipment and pipeline pulling equipment. Please see discussion under Section N. Energy and the energy balance analysis in EIR 78-19 Section 4.10.3 pages 4.10-11 though 4.10-16.

Mitigation: none required

	Yes	Maybe	No
J. Population. Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?			X

Documentation: EIR 78-19 Section 4.7 pages 4.7-1 through 4.7-87

Mitigation: none required

	Yes	Maybe	No
K. Housing. Will the proposal affect:			
1. Existing housing, or create a demand for additional housing?			X
2. Existing low-moderate income or elderly housing opportunities, or create a demand for additional housing assistance?			X

Documentation: EIR 78-19 Section 4.7 pages 4.7-1 through 4.7-87

Mitigation: none required

	Yes	Maybe	No
L. Transportation/Circulation. Will the proposal result in:			
1. Generation of substantial additional vehicular movement?		X	
2. Effects on existing parking facilities or demand for new parking?		X	
3. Substantial impact upon existing transportation systems?			X

	Yes	Maybe	No
4. Alterations to present patterns of circulation or movement of people and/or goods?			X
5. Alterations to waterborne, rail or air traffic?		X	
6. Increase in traffic hazards to motor vehicles, bicyclists or pedestrians?		X	

L(1-4)
Documentation: Additional vehicular activity will occur as a part of the three week repair project. Any potential impact will be short-term in duration. All access will be from West Fifth Street. Both Fifth Street and Harbor Boulevard are designated truck routes (see description of vehicular activity and sketch of staging area pages 5-7 of Exhibit B and see Exhibit A, Unocal Project Description).

Mitigation: Truck routing and delivery schedule shall be submitted to the Community Development Director and Public Works Traffic Engineer for approval. The plan and schedule shall be designed to minimize impact on residents and City streets.

L(5)
Documentation: The replacement of 3,000 feet of the pipeline will be within 1/2 mile of the Mandalay Beach. Of the 3,000 foot section, only 2,300 feet will actually be offshore with the remaining pipe replacement confined to the beach. Since the repair work will be in close proximity to the beach and in-route boating traffic tends to stay further off shore to avoid shoaling and surf, the increased navigational hazard of the project will be small. Unocal will follow normal navigational safety practices and exercise standard courtesy to other boating traffic.

Unocal will be conducting diving, welding and pipe pulling operations for about three weeks when the project commences. Since only about 1 week of this work will actually be offshore, the risk to navigational traffic will be minimal due to the short project duration.

As the project begins, Unocal will spend 3 to 4 days in a small area 2,300 feet from the MHTL along the pipeline route. Work will then be conducted on the beach for about 2 weeks to weld the pipe together. After welding is completed the pipe will be pulled to the 2,300 foot mark from the MHTL and installed. This will require another 3 to 4 days.

This project will require 3 vessels, a 100-150 foot diving support vessel, a smaller 50-75 foot anchor setting vessel, and a smaller crew transport vessel. The diving support and anchor setting vessel will be on site for the offshore work while the crew transport vessel will transport 8-12 personnel per shift, 3 times per day to and from the site. The anchor setting vessel will be available to warn navigational traffic of any possible hazards in the area during the project, while the diving support vessel will be directly over the small work area.

Mitigation: The following measures recommended by the U.S. Coast Guard for Navigation Safety shall be implemented. Prior to beginning the in-water portion of the project, the Eleventh Coast Guard District Aids to Navigation Office will be notified of the dates of the operation and the names and radio call signs of the vessels which will be working in the area. Additionally, the Aids to Navigation Office will be notified of the radio frequency which mariners can use to contact the vessels working in the area.

L(6)
Documentation: The area of the project has occasional pedestrian traffic. The time that a trench is open will be minimized, and the trench area will be barricaded with warning lights at night.

Unocal will provide a 24 hour guard for purposes of informing the public, security of the area, and prevention of unauthorized access to the construction area. The guard will be at the Fifth Street access during operating times and will be at the job site the remainder of the time. The guard will be present from the project start up to completion and will be equipped with a 4 wheel drive vehicle and radio communications.

Mitigation: none required

	Yes	Maybe	No
M. Public Services. Will the proposal have an effect upon, or result in a need for new or altered governmental services in any of the following areas:			
1. Fire protection?			X
2. Police protection?			X
3. Schools?			X
4. Parks or other recreational facilities?			X
5. Maintenance of public facilities, including roads?			X
6. Other governmental services?			X

Documentation: EIR 78-19 Pages 4.7-1 through 4.7-87

Mitigation: none required

		Yes	Maybe	No
N.	Energy. Will the proposal result in:			
1.	Use of substantial amounts of fuel or energy?	___	___	X
2.	Substantial increase in demand upon existing sources of energy, or require the development of new sources of energy?	___	___	X

Documentation: EIR 78-19 pages 4.10-11 through 4.10-12 provides a discussion of the energy balance analysis conducted for the entire lifetime of the project and concludes that approximately 33.3 units of energy would be produced for every unit consumed. The additional energy utilized to repair the pipeline over a three week period which would result from use of diesel fuel powered equipment (trucks, boats) would not be of sufficient quantity to affect the calculated balance.

Mitigation: none required

		Yes	Maybe	No
O.	Utilities. Will the proposal result in a need for new systems, or substantial alterations to the following utilities?			
1.	Power or natural gas?	___	___	X
2.	Communications systems?	___	___	X
3.	Water?	___	___	X
4.	Sewer or septic tanks?	___	___	X
5.	Storm water drainage?	___	___	X
6.	Solid waste disposal?	___	___	X

Documentation: EIR 78-19 Pages 4.7-1 through 4.7-87

Mitigation: none required

P. RISK/HUMAN HEALTH	Yes	Maybe	No
1. Risk or Upset. Will the proposal result in:			
a. A risk of an explosion or the release of hazardous substances (including but not limited to, oil, pesticides, chemicals or radiation) in the event of an accident or upset conditions?		X	
b. Possible interference with an emergency response plan or an emergency evacuation plan?			X
2. Human Health. Will the proposal result in:			
a. Creation of any health hazard or potential health hazard (excluding mental health)?		X	
b. Exposure of people to potential health hazards?		X	

Exhibit E includes the document titled Risk Assessment Study, Platform Gina Gas Production and Pipeline, Mandalay Onshore Receiving, prepared by EnerSource Engineering, November 21, 1989. The report specifically addresses the risk assessment and design of the pipeline, gas processing, H_2S detection, monitoring, shutdown, and alarm systems at both Platform Gina and Mandalay. This study is discussed further in the Initial Study Component 2 - Conversion to Produced Gas.*

Related to the pipeline repair project which is the subject of this Initial Study, the Risk Assessment Study evaluated the design of the current pipeline, the proposed replacement pipeline and minor piping changes needed at the Mandalay facility. Design drawings and proposed conceptual changes were reviewed for conformance to applicable codes and local industry standards. Where critical systems were proposed which tied into existing production process or safety systems, the existing systems were reviewed for compatibility with current codes and practices and no serious design deficiencies were found in the proposed designs.**

In addition to the information in the risk assessment study, the Unocal Project Description (Exhibit A) contains a complete list of all equipment, methods, facilities and items to be used during the project provided by the contractor (Hood Corporation). The following summarizes the inspection and testing procedures.***

*See Appendix A, SLC October 18 letter of comment number 6 and Unocal October 24 letter of response number 6.

**See Appendix A, SLC October 18 letter of comment number 5 and Unocal October 24 letter of response number 5.

***See Appendix A, SLC October 18 letter of comment number 4 and Unocal October 24 letter of response number 4.

All welds will be made in accordance with Unocal's welding procedure and will be radiographically inspected. The standard for acceptability shall be API Standard 1104 "Standard for Welding Pipelines and Related Facilities", as directed by Title 49 CFR Part 192 (gas pipelines) of the Minimum Federal Safety Standards. All welders will be certified for this standard before work on the project commences.

Once the pipeline tie-ins are made, a pressure test will be conducted. This test will be conducted at 900 psi and will test the entire pipeline from the Mandalay facility to Platform Gina. The test will be held for a minimum of 4 hours and witnessed by the Minerals Management Service and a Unocal representative.

Prior to covering the pipe, the location of the line will be surveyed for the permanent records. The installation contractor will provide the surveyor with assistance as required for both the onshore and offshore sections of the survey.

Before covering the pipeline and during the pipeline pull, the replacement pipe will be inspected for coating flaws. All flaws will be repaired before the pull operation continues, or before the pipe is buried. Repairs will be performed in accordance with the pipeline coating manufacturer's recommendations.

Mitigation: none required

	Yes	Maybe	No
Q. Aesthetics. Will the proposal result in the obstruction of any scenic vista or view open to the public, or will the proposal result in the creation of an aesthetically offensive site open to the public?	___	X	___

Documentation: At the construction staging area there will be a temporary disruption in the aesthetics of the area by the presence of construction equipment (3 weeks). The area will be completely restored at project completion.

Mitigation: Comply with conditions of the November 18, 1988 letter of authorization from the City of Oxnard and Special Use Permit No. 806 which includes the mitigation measures recommended in the EIR.

	Yes	Maybe	No
R. Recreation. Will the proposal result in an impact upon the quality or quantity of existing recreational opportunities?		X	

Documentation: The disruption of use of a limited portion of the beach and dune area is short term (3 weeks). The area will be completely restored at project completion.

Mitigation: Comply with conditions of November 18, 1988 letter of authorization from the City of Oxnard and Special Use Permit No. 806 which includes mitigation measures recommended in the EIR.

	Yes	Maybe	No
S. Cultural Resources.			
1. Will the proposal result in the alteration of or the destruction of a pre-historic or historic archaeological site?			X
2. Will the proposal result in adverse physical or aesthetic effects to a pre-historic or historic building, structure, or object?			X
3. Does the proposal have the potential to cause a physical change which would affect unique ethnic cultural values?			X
4. Will the proposal restrict existing religious or sacred uses within the potential impact area?			X

Documentation: It is not anticipated that the proposed pipeline conversion project would have any impact on cultural resources. The route of the pipeline in unchanged and no cultural resources were identified for the route in the EIR.

EIR 78-19 Section 4.8.2.1.2 states:

> "No adverse impacts on such potential sites are expected to occur as a result of pipeline and power cable construction activities. This was due to the fact that literature analysis and evaluation of marine geophysical survey records revealed no evidence of features indicative of former environments favorable for aboriginal habitation within the zone of potential impact for the Platform Gina Offshore Mandalay pipeline corridor. Furthermore, the area in which pipeline and power cable construction activities would occur would involve; (1) the surf zone where the pipeline would be buried below the depth of scour (i.e. where sediments above the depth of burial would be in a zone of active sediment movement where no intact aboriginal sites would be expected to occur; below this zone, it is expected that marine sediments would be encountered where aboriginal sites are not expected to occur); and, (2) the area beyond the surf zone, where aboriginal resources would be expected to occur at a greater sediment depth than could be affected by a pipeline or power cable laid on the surface of the sea floor or by vessel anchors."

Since the original EIR 78-19 study is for the entire 84,000 feet of pipeline routes and the current repair will extend only 2,300 feet offshore, it is concluded that no adverse impacts will occur to cultural resources. As a further measure to ensure no impact, the EIR required that when the Gina, Gilda and Mandalay operations are complete and the platforms removed the pipelines would not be removed. Consistent with this requirement, the current offshore pipeline to be repaired/replaced will be purged and left in place. Liquids used to purge the pipeline will be cleaned at Mandalay and then sent via the return water line to Platform Gilda for disposal either by injection or in a manner consistent with the approved NPDES permit.

Mitigation: The project must comply with mitigation measures of EIR 78-19 as stated in Resolution 6218 approving Special Use Permit 806 No. (Condition 27g). No additional mitigation is required for the proposed project.

III. Mandatory Findings of Significance.

	Yes	Maybe	No
A. Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife to population to drop below self sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	___	___	X
B. Does the project have the potential to create short-term impact, to the disadvantage of long-term environmental goals? (A short-term impact on the environment is one which occurs in a relatively brief, definitive period of time while long-term impacts will endure well into the future.)	___	___	X
C. Does the project have impacts which are individually limited, but cumulatively considerable? (A project may impact on two or more separate resources where the impact on each resource is relatively small, but where the effect of the total of those impacts on the environment is significant).	___	___	X
D. Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	___	___	X

IV. Determination
(To be completed by the Lead Agency)

On the basis of this initial evaluation:

The proposed project WILL NOT have a significant effect on the environment. A NEGATIVE DECLARATION will be prepared. X

The proposed project COULD have a significant effect on the the environment; however, there will not be a significant effect because the mitigation measures described on a attached MITIGATED NEGATIVE DECLARATION will be incorporated into the project. A MITIGATED NEGATIVE DECLARATION WILL BE PREPARED ___

I find the proposed project MAY have a significant effect on the environment, specifically on the impacts identified below, and an ENVIRONMENTAL IMPACT REPORT is required. ___

Prepared By:

Carol Waldrop/Ralph Steele DST

Date: May 1, 1990

Matthew G. Winegar, City Planner
For: Richard J. Maggio, Director
Community Development Department

REV. 4/28/90 MGW

APPENDIX VOLUME 3

Initial Study Component 2
Conversion to Produced Gas

CITY OF OXNARD

ENVIRONMENTAL CHECKLIST FORM
INITIAL STUDY
Pipeline Conversion Component

I. Project Description

A. Permit Number Modification to Special Use Permit No. 806

B. Applicant Unocal Oil and Gas Division

C. Address and Phone Number of Applicant P.O. Box 6176,

Ventura, CA 93003 (805) 656-7600

D. Name of Project, if applicable Platform Gina Return Water Line - Conversion to Produced Gas Line

E. Project Description

The purpose of the project is to repair and then convert the 6 5/8 pipeline from return water service to produced gas transport service to facilitate evaluating the final exploratory well and provide for long term field development. Once conversion is complete, more extensive testing will be conducted to determine the size and extent of the gas reserves underlying OCS leases P-0202 and P-0203. This Initial Study evaluates the Pipeline conversion component of the proposal.

The stages of the project required to test and evaluate the exploratory well (H-14) will include the installation of gas processing equipment on Platform Gina, conversion of the 6 5/8 inch pipeline to gas transport service, and the modification of piping at the Mandalay facility.

Unocal has provided a project description which is included as Exhibit A in the Initial Study. Section I of the project description identifies current development plans; Section II explains the repair of the pipeline and its conversion to gas transport service; and Section III identifies the equipment changes necessary on Platform Gina and at the Mandalay facility to provide for gas transport and sale.

In addition, a risk assessment study has been completed for the project and is included as Exhibit E. The study includes a review of the following:

- o Overall project design.
- o Hydrogen sulfide monitoring and shutdown system and the probability of H_2S gas leaving the platform and being released to the atmosphere.
- o Comparison of the proposed design to industry standards, MMS standards, DOT pipeline standards, and other standards where applicable.

The current exploratory well, H-14, was drilled from Platform Gina in the last half of 1988 and is currently completed in the Sespe zone. The tested Sespe gas does not contain any hydrogen sulfide and conforms to all gas sales specifications required by Southern California Gas Company.

The Monterey zone is potentially productive in well H-14, and it is planned to complete and test this zone. The zone may be a sour gas (hydrogen sulfide) zone, in which case all gas will be sweetened offshore prior to either temporary flaring or transportation through the pipelines to shore for long term testing or gas sales.

No gas will be sent through either the existing or proposed converted pipeline to the Mandalay facility until sweetened offshore to conform to the gas sales specification of 0.3 grains per 100 standard cubic feet or 4 ppm, which is more stringent than the OSHA-PEL standard of 20 ppm. Exhibit A contains the full text of the Unocal Project Description.

There are several methods available for treating the gas to remove hydrogen sulfide (H_2S). Unocal proposes offshore treatment, including use of both chemical scavenging and treatment plant technologies, to prevent the shipment of sour gas to onshore facilities. Continuous monitors will be located on Platform Gina and at the Mandalay facility. They will be designed to activate an alarm should a treating system upset occur that results in a hydrogen sulfide concentration of 2 ppm in the gas stream. The monitors will activate shutdown of the gas producing well or wells should the hydrogen sulfide concentration reach 4 ppm. Explanation of gas processing is provided in Section III of Unocal's Project Description included herein as Exhibit A.

In order to process the gas produced from Platform Gina, equipment will be installed on Platform Gina and some piping modifications will be made at the Mandalay facility. The proposed processing method is to install the necessary equipment to separate and treat gas on Platform Gina once the pipeline repair is complete. The initial equipment installed will include a gross separator, two batch sweeteners, a flare scrubber, a hydrogen sulfide line monitor, and a final gas scrubber. The batch sweeteners will each be capable of treating a gas volume of 3.0 MM SCF/day and sweetening from a hydrogen sulfide level of

2,000 ppm to less than 4 ppm. The associated liquid production will be handled by an existing shipping tank with two triplex pumps, each of which is capable of pumping 2,000 barrels of liquid per day. This liquid will be shipped to Mandalay through the 10-3/4 inch pipeline. Flow schedules for all the equipment can be found in the Unocal Project Description attached as (Exhibit A).

As the production phase proceeds to full field development, additional facilities and equipment will be needed. This could include the installation of additional deck space along the south side of Platform Gina to allow for some of the equipment. The additional equipment could include a standard production and test header system, a test separator, a gas dehydration unit, a permanent sweetening plant, and gas compressors. The actual equipment needed would be based on future well test results and detailed reservoir evaluation. Any proposed changes to the platform, wells, or pipelines located in Federal waters would have to be approved by the Minerals Management Service.

As part of both the temporary and permanent installation of facilities on Platform Gina, a redundant H_2S monitoring, detection, shutdown, and alarm system will be installed to monitor the H_2S concentration in the gas before it enters the gas pipeline leaving Platform Gina. This will provide two separate verifications of the H_2S concentration before the gas leaves the platform. This will insure excessive H_2S gas does not leave the platform via the pipeline. The gas will be monitored one more time before sales, transfer is made at the Southern California Gas Company facility located at Mandalay. The reliability of this system has been evaluated in the Risk Assessment Study (Exhibit E).

II. Environmental Impacts

A. Earth. Will proposal result in:

		Yes	Maybe	No
1.	Unstable earth conditions or in changes in geological substructures?			X
2.	Disruptions, displacements, compaction or overcovering of the soil?			X
3.	Change in topography or ground surface relief features?			X
4.	The destruction, covering or modification of any unique geological or physical features?			X
5.	Any increase in wind or water erosion of soils, either on or off the site?			X
6.	Changes in deposition or erosion of beach sands, or changes in situation, deposition or erosion which may modify the channel of a river or stream or the bed of the ocean or any bay, inlet or lake?			X
7.	Exposure of people or property to geological hazards such as earthquakes, landslides, mudslides, ground failure, or similar hazards?			X

Documentation: EIR 78-19 Pages 4.1-1 through 4.1-21

Mitigation: none required

B. Air Quality. Will the proposal result in:

		Yes	Maybe	No
1.	Substantial air emissions or deterioration of ambient air quality?			X
2.	The creation of objectionable odors?		X	
3.	Alteration of air movement, moisture, or temperature, or any change in climate, either locally or regionally?			X

Documentation: B(1,3) EIR 78-19 Pages 4.2 through 4.2-59
B(2) In the event of a leak of H_2S below 150 ppm concentration, an odor similar to rotten eggs may be detected by human receptors. See page 43 of Exhibit A, Unocal Project Description Platform Gilda Contingency Plan. Odor will occur only in the event of accidental release of gas from the pipeline. It is projected that an accidental release would occur only in the event of a catastrophe. The Risk Assessment Study (Exhibit E) indicates that the possibility of such a failure as extremely remote and projects that if a worst case accident were to occur, the affected area would be limited to a 1,320 foot radius of the Mandalay Onshore Processing Facility. There are no residences within this area.

Mitigation: B(1,3) none required.
B(2) see discussion of H_2S monitoring and shut down equipment and H_2S contingency plan under Section P of this Initial Study.

	Yes	Maybe	No
C. Water. Will the proposal result in:			
1. Changes in currents, or the course of direction of water movements, in either marine or fresh waters?	___	___	X
2. Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff	___	___	X
3. Alterations to the course or flow of flood waters?	___	___	X
4. Change in the amount of surface water in any water body?	___	___	X
5. Discharge into surface waters, or in any alteration of surface water quality, including but not limited to temperature, dissolved oxygen or turbidity?	___	___	X
6. Alteration of the direction or rate of flow of ground waters?	___	___	X
7. Change in the quantity of ground waters, either through direct additions or withdrawals, or through interception of an acquifer by cuts or excavations?	___	___	X
8. Substantial reduction in the amount of water otherwise available for public water supplies?	___	___	X

	Yes	Maybe	No
9. Exposure of people or property to water related hazards such as flooding or tidal waves?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in an impact on water.

Mitigation: none required

D. Plant Life. Will the proposal result in:

	Yes	Maybe	No
1. Change in the diversity of species, or number of any species of plants (including trees, shrubs, grass, crops and aquatic plants)?	___	___	X
2. Reduction of the numbers of any unique, rare, or endangered species of plants?	___	___	X
3. Introduction of new species of plants into an area, or in a barrier to the normal replenishment of existing species?	___	___	X
4. Reduction in acreage of any agricultural crop?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in an impact on plant life.

Mitigation: none required

E. Animal Life. Will the proposal result in:

	Yes	Maybe	No
1. Change in the diversity of species, or numbers of any species of animals, (birds, land animals including reptiles, fish and shellfish, benthic organisms or insects?	___	___	X
2. Reduction of the numbers of any unique, rare or endangered species of animals?	___	___	X
3. Introduction of new species of animals into an area, or result in a barrier to the migration or movement of animals?	___	___	X

	Yes	Maybe	No
4. Deterioration to existing fish or life habitat?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in an impact on animal life.

Mitigation: none required

F. Noise. Will the proposal result in:

	Yes	Maybe	No
1. Increase in existing noise levels?	___	___	X
2. Exposure of people to severe noise levels?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in changing noise levels.

Mitigation: none required

	Yes	Maybe	No
G. Light and Glare. Will the proposal produce new light or glare?	___	___	X

Documentation: Project Description and EIR 78-19 pages 4.7-1 through 4.7-87. No additional lighting is planned to be installed on the platform in connection with this project. Flaring of natural gas will only be necessary during times of mechanical equipment breakdown, processing upsets, or processing system startup and shutdown. Flaring during these instances is permitted subject to Minerals Management Service regulations.

To reduce the impact of glare and emissions, Unocal has installed a Mardair flare burner. This type of burner improves mixing for more complete combustion and also provides reduced illumination from flaring. Luminosity will be reduced by one third and the flame length will be reduced nearly one half that of a standard pipe flare.

Mitigation: none required

	Yes	Maybe	No
H. Land Use. Will the proposal result in a substantial alteration of the present or planned use of an area?	___	___	X

Documentation: Project description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in an impact on land use.

Mitigation: none required

	Yes	Maybe	No
I. Natural Resources. Will the proposal result in:			
1. Increase in the rate of use of any natural resources?	___	___	X
2. Substantial depletion of any nonrenewable natural resources?	___	X	___

Documentation: EIR 78-19 Pages 1-9 through 4.1-14 provides discussion of depletion of non-renewable mineral resources.

Mitigation: none required

	Yes	Maybe	No
J. Population. Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?	___	___	X

Documentation: Project Description and EIR 78-19 Pages 4.7-1 through 4.7-87. There are no activities involved in changing the use from a water return line to produced gas transport service or in installing additional equipment on Platform Gina which would have an impact on population.

Mitigation: none required

	Yes	Maybe	No
K. Housing. Will the proposal affect:			
1. Existing housing, or create a demand for additional housing?	___	___	X
2. Existing low-moderate income or elderly housing opportunities, or create a demand for additional housing assistance?	___	___	X

Documentation: Project Description and EIR 78-19 Pages 4.7-1 through 4.7-87. There are no activities involved in changing the use from a water return line to produced gas transport service or in installing additional equipment on Platform Gina which would have an impact on population.

Mitigation: none required

	Yes	Maybe	No
L. Transportation/Circulation. Will the proposal result in:			
1. Generation of substantial additional vehicular movement?			X
2. Effects on existing parking facilities or demand for new parking?			X
3. Substantial impact upon existing transportation systems?			X
4. Alterations to present patterns of circulation or movement of people and/or goods?			X
5. Alterations to waterborne, rail or air traffic?		X	
6. Increase in traffic hazards to motor vehicles, bicyclists or pedestrians?			X

Documentation: Project Description and EIR 78-19 Pages 4.7-1 through 4.7-87. L.(5). The installation of additional equipment on Platform Gina may increase temporarily the number of crew and supply boat trips and may temporarily interfere with commercial and recreational vessel movements in the area.

Mitigation: Measures recommended by the U.S. Coast Guard for Navigation Safety shall be implemented.

	Yes	Maybe	No
M. Public Services. Will the proposal have an effect upon, or result in a need for new or altered governmental services in any of the following areas:			
1. Fire protection?			X
2. Police protection?			X
3. Schools?			X
4. Parks or other recreational facilities?			X
5. Maintenance of public facilities, including roads?			X

	Yes	Maybe	No
6. Other governmental services?			X

Documentation: Project Description and EIR 78-19 pp 4.7-1 through 4.7-87. There are no activities involved in the process of changing the use from water return line to produced gas transport service and installing additional equipment on Platform Gina which would have an effect upon or result in the need for new or altered governmental services.

Mitigation: none required

	Yes	Maybe	No
N. Energy. Will the proposal result in:			
1. Use of substantial amounts of fuel or energy?			X
2. Substantial increase in demand upon existing sources of energy, or require the development of new sources of energy?			X

Documentation: EIR 78-19 pages 4.10-11 through 4.10-12 (Provides discussion of energy use and an Energy Balance Analysis). The amount of fuel required for equipment and supply transport for the conversion project is a minimal incremental addition to the original amounts estimated and will be offset substantially by the future production of natural gas.

Mitigation: none required

	Yes	Maybe	No
O. Utilities. Will the proposal result in a need for new systems, or substantial alterations to the following utilities?			
1. Power or natural gas?			X
2. Communications systems?			X
3. Water?			X
4. Sewer or septic tanks?			X
5. Storm water drainage?			X
6. Solid waste disposal?			X

Documentation: EIR 78-19 Pages 4.7-1 through 4.7-87. Project Description. There are no activities involved in the process of changing the use of the water return line to produced gas transport service or in installing additional equipment on Platform Gina that would result in the need for new utilities systems or alterations thereto.

Mitigation: none required

P. RISK/HUMAN HEALTH. Will the proposal result in:

1. Creation of any health hazard or potential health hazard (excluding mental health)?	___	X	___
2. Exposure of people to potential health hazards?	___	X	___
3. A risk of an explosion or the release of hazardous substances (including but not limited to, oil, pesticides, chemicals or radiation) in the event of an accident or upset condition?	___	X	___
4. Possible interference with an emergency response plan or an emergency evacuation plan?	___	X	___

Documentation: P(1,2) EIR 78-19 pages 3.5-1 through 3.5-13 and 4.9-1 through 4.9-29 provide an analysis of risk over the lifetime of the original project which included produced gas piped from Platform Gilda which is felt to be directly applicable to Platform Gina characteristics. There is always a possibility that a leak will develop in the produced gas line going to the H_2S scrubber equipment or from the equipment to the atmosphere. Also there is a possibility that excess amounts of H_2S may enter the pipeline from Platform Gina and travel to the Mandalay facility. In response to this possibility, the applicant has proposed to install redundant H_2S monitoring and system shutdown equipment on Platform Gina and at the Mandalay facility. It is intended that if certain pre-determined thresholds of H_2S are exceeded at established monitoring points, the well will be shut down and the pipeline closed at both ends. Please see Exhibit A, Unocal Project Description for a description of the redundant monitoring/detection/shut down/alarm systems. To further verify these systems, the applicant, at the City's request, engaged a qualified Risk Assessment Engineering firm to conduct a verification review of the proposed and alternative systems designs related to the monitoring/ detection/shut down/alarm functions (Exhibit E).

As a conclusion to the review, no serious design deficiencies were found in the proposed system design. It was also concluded that the proposed project is safe with chance of accidental release of gas near Mandalay containing greater than 4 ppm hydrogen sulfide estimated to be 2.7 in 1,000,000. Expressed another way, this is the equivalent of an accidental release of H_2S greater than 4ppm of once in 1,014 years. In the remote chance that an accidental release of gas should occur, it was determined that the radius of dangerous exposure would be 1,320 feet, based upon accidental full flow release of gas containing 7,000 ppm H_2S which is 3-1/2 times greater than the worst case gas expected to be produced. Since the nearest residences are located nearly 3000 feet to the south, or over 2-1/4 times the dangerous exposure radius, it is felt that there would not be any significant impact to residents in the surrounding area.*

*See Appendix A, SLC October 18 letter of comment number 6 and Unocal October 24 letter of response number 6.

P(4) Since H_2S is a potentially lethal gas, this characteristic has to be taken into account when developing and implementing emergency response and evacuation plans.

In response, Unocal has prepared an emergency response and evacuation plan for on-site personnel taking into account aspects of H_2S for Platform Gina and Platform Gilda and the Mandalay separation facility. See Exhibit A, Unocal Project Description, pages 37 - 58 which contain the Contingency Plan for Platform Gina and Platform Gilda.

Mitigation: Comply with provisions of Emergency Response - Evacuation Plan

	Yes	Maybe	No
Q. Aesthetics. Will the proposal result in the obstruction of any scenic vista or view open to the public, or will the proposal result in the creation of an aesthetically offensive site open to the public?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on Platform Gina which would result in an impact on aesthetics.

Mitigation: none required

	Yes	Maybe	No
R. Recreation. Will the proposal result in an impact upon the quality or quantity of existing recreational opportunities?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on the Platform Gina which would result in an impact on recreation.

Mitigation: none required

S. Cultural Resources.

	Yes	Maybe	No
1. Will the proposal result in the alteration of or the destruction of a pre-historic or historic archaeological site?	___	___	X
2. Will the proposal result in adverse physical or aesthetic effects to a pre-historic or historic building, structure, or object?	___	___	X
3. Does the proposal have the potential to cause a physical change which would affect unique ethnic cultural values?	___	___	X

	Yes	Maybe	No
4. Will the proposal restrict existing religious or sacred uses within the potential impact area?	___	___	X

Documentation: Project Description. There are no activities involved in the process of changing the use from water return service to produced gas transport service and installing additional equipment on the Platform Gina which would result in an impact on cultural resources.

Mitigation: none required

III Mandatory Findings of Significance.

	Yes	Maybe	No
A. Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife to population to drop below self sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	___	___	X
B. Does the project have the potential to create short-term impact, to the disadvantage of long-term environmental goals? (A short-term impact on the environment is one which occurs in a relatively brief, definitive period of time while long-term impacts will endure well into the future.)	___	___	X
C. Does the project have impacts which are individually limited, but cumulatively considerable? (A project may impact on two or more separate resources where the impact on each resource is relatively small, but where the effect of the total of those impacts on the environment is significant).	___	___	X
D. Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	___	___	X

IV. Determination
(To be completed by the Lead Agency)

On the basis of this initial evaluation:

The proposed project WILL NOT have a significant effect on the environment. A NEGATIVE DECLARATION will be prepared. X

The proposed project COULD have a significant effect on the the environment; however, there will not be a significant effect because the mitigation measures described on a attached MITIGATED NEGATIVE DECLARATION will be incorporated into the project. A MITIGATED NEGATIVE DECLARATION WILL BE PREPARED ___

I find the proposed project MAY have a significant effect on the environment, specifically on the impacts identified below, and an ENVIRONMENTAL IMPACT REPORT is required. ___

Prepared By:

Carol Waldrop/Ralph Steele

Date: May 1, 1990

Matthew G. Winegar, City Planner

For: Richard J. Maggio, Director
Community Development Department

REV. 4/28/90 MGW

APPENDIX VOLUME 3

Comments Received on May 1990 Draft Initial Study

Comments and Responses

Letter of Comment from the United States Department of the Interior, Minerals Management Service, June 20, 1990

Letter of Response from Unocal to Minerals Management Service

Letter of Comment from the State of California, State Lands Commission, June 18, 1990

Letter of Response from Unocal to the State Lands Commission

Letter of Comment from the California Coastal Commission, June 14, 1990

Letter of Response from Unocal to the California Coastal Commission

Letter from the United States Coast Guard, May 22, 1990 indicating no further comment

Letter from the Office of Planning and Research, June 13, 1990 indicating no comments received

Letter from the California Regional Water Quality Control Board, Los Angeles Region, May 30, 1990 indicating no comment

Letter from the State of California Department of Transportation, June 14, 1990 indicating no comment

United States Department of the Interior

MINERALS MANAGEMENT SERVICE
PACIFIC OCS REGION
1340 WEST SIXTH STREET
LOS ANGELES, CALIFORNIA 90017

TAKE PRIDE IN AMERICA

In Reply Refer To:
MMS—Mail Stop 7200

June 18, 1990

Mr. Ralph J. Steele
City of Oxnard
Community Development Department
305 W. Third Street
Oxnard, CA 93030

Re: Platform Gina Gas Production

Dear Mr. Steele:

Thank you for the opportunity to review and comment on the May 1990 Final Draft Initial Study for Platform Gina Proposed Return Water Line Replacement and Conversion to Produced Gas. It is apparent from the document that the City of Oxnard has performed a careful and thorough review of the onshore components of the project. We do have some comments pertaining to the air quality analysis:

Comment #

1. (1) Page 5, Section 2, Construction Related Emissions: It is not stated whether the construction and the drilling and testing of wells is expected to cause an increase in support vessel visits to the platform. If this is the case, estimates of the increase in emissions should be presented.

2. (2) Page 9, Table 2.5 and Table 2.6: The "Lb/1000 Gal" after the reactivity figure should be deleted.

3. (3) Page 14, 1st paragraph, 2nd sentence: The sentence is incomplete. The word "either" implies that there is another possible means of distribution besides the Southern California Gas Company.

4. (4) Page 14, Section 3.2, Preliminary Modeling: While MMS does not have any specific requirements for modeling emissions resulting from modification of existing facilities not on Lease Sale 73 or 80 leases, the air quality analysis would have been enhanced by using a model that incorporates coastal fumigation and/or applying a model that accounts for overwater dispersion. The California Air Resources Board Coastal Fumigation Model (CCFM) is a simple screening model that calculates maximum onshore concentrations during fumigation conditions. Application of the MMS Offshore & Coastal Dispersion (OCD) model for selected wind and stability categories would be more appropriate than using either the PTPLU2 or ISCST models as the former simulates overwater and coastal dispersion.

5. (5) Page 15, 1st full paragraph, 8th line: It is unclear how default values for wind speed are used in the PTPLU2 and ISCST models.

6. (6) Page 16, 1st full paragraph, 10th line: It should be noted that the results in Table 3.5 do not account for limited mixing as described.

7 (7) Page 17, Table 3.2: The factor for calculating SO2 emissions for the flare is applied incorrectly. This factor is 950 x percent sulfur in fuel. Furthermore, since the sulfur content is presented in terms of H2S, and the emission factor is for SO2, an additional multiplication factor of 1.88 should be applied (the ratio of the molecular weights). Therefore, for gas with an H2S content of 2,000 ppm, the correct SO2 emission factor should be 0.2 x 950 x 1.88 = 357.2 lb/MMscf.

Since the assumed NO_x emission factor of 51.5 lb/MMscf is based on measured emissions, rather than emissions factors commonly used by the regulatory agencies, MMS would like to review the documentation on that emission factor.

8. (8) Page 19, Table 3.4: The wind speeds assumed under stability categories C and D are unrealistically high.

The Minerals Management Service is in the process of reviewing the Development and Production Plan revision, the pipeline permit change application, and other related applications filed by Unocal Corporation. As we progress through our environmental and technical reviews of the project components in Federal waters, we will keep you and other involved agencies informed of their status.

If you have any questions, please call Mr. Ed Lee at (213) 894-5114.

Sincerely,

Thomas W. Dunaway
Regional Supervisor
Office of Field Operations

Unocal Oil & Gas Division
Unocal Corporation
2323 Knoll Drive, P.O. Box 6176
Ventura, California 93006
Telephone (805) 656-7600

UNOCAL 76

August 9, 1990

Western Region

Mr. Thomas W. Dunaway
Minerals Management Service
1340 West Sixth Street
Los Angeles, CA 90017

RE: Platform Gina/Mandalay Facility
<u>Offshore/Ventura County, Calif.</u>
Pipeline Gas Production

Dear Mr. Dunaway:

Unocal is proposing to repair the existing Platform Gina water line and convert it to gas service. By letter dated June 18, 1990, the U.S. Department of the Interior - Minerals Management Service (USDI-MMS) commented on the May 1990 Final Draft Initial Study for Platform Gina Proposed Return Water Line Replacement and Conversion to Produced Gas. The comments pertained to the air quality analysis section of the report. The responses to the specific comments of the USDI-MMS are provided below:

1. <u>Comment On Boat Traffic</u>: Page 5, Section 2, Construction Related Emissions.

   Estimated increases in emissions due to an increase of boat traffic were calculated only for work crews stationed immediately offshore and did not include additional transport to the platforms as pointed out by the reviewer. Boat traffic to the platforms to support facility construction is estimated to increase by an additional ten (10) boat trips during the project. Boat traffic for the regular platform crew will not increase during the project. The revised total emissions for the project with the additional ten (10) boat trips are given below:

TABLE 1
Construction Emissions, Total for Project, Lbs

	Gal.	TOC	ROC	NO_x	TSP	SO_2	CO
Total Emissions	11,384	473	420	5,197	371	344	2,656
Additional Boat Trips	3,000	113	101	1,406	100	94	305
Revised Total Emissions	14,384	586	521	6,603	471	438	2,961

2. Comment: Page 9, Table 2.5 and Table 2.6.

   Comment noted and correction(s) made.

3. Comment: Page 14, 1st paragraph, 2nd sentence.

   Comment noted and correction(s) made. There is some consideration towards construction of a direct tie-in to the Southern California Edison power station located at Mandalay. It is therefore conceivable that gas from Platform Gina could then be directed to either the main distribution system or to the possible tie-in at the Mandalay.

4. Comment On the Selection of an Air Dispersion Model: Page 14, Section 3.2, Preliminary Modeling.

   The OCD model was considered for the air quality analysis and it is agreed that the OCD model would have been more appropriate since it models the surface boundary layer structure using a modified algorithm to account for the behavior of plumes over water. However, the purpose of this air quality analysis was to provide preliminary screening results and not a refined modeling evaluation, and the use of the OCD model requires on-site wind turbulence measurements which were not available for this study. As such, the PTPLU2 and ISCST models were selected for the analysis expecting they would provide the best screening assessment possible from the information available.

   Concerning fumigation modeling, California Air Resources Board (CARB) - Technical Support Division - Air Quality Modeling Section was contacted and it was discovered that the over-water coastal fumigation version of PTFUM (referred to as PTFUM-OW) was not available in runable format for IBM PCs (FORTRAN source code only). CARB staff recommended examining the possibility of using the EPA

SCREEN model which includes a shoreline fumigation option. However, it was discovered that the shoreline fumigation option of the EPA SCREEN modeling program considers land-based sources only and cannot estimate fumigation concentration for sources located offshore. Nevertheless, based on a review of the procedures and technical description of the SCREEN model (EPA User's Guide for Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, 1988, pp. 4-31f., A-39f. [EPA-450/4-88-010]), it was determined that the method used for coastal fumigation calculations of land-based sources could be adapted for estimating offshore sources.

The calculations used in SCREEN are based on the 1987 EPA study, Analysis and Evaluation of Statistical Coastal Fumigation Models (EPA-450/4-87-002) which recommends the worst-case meteorological conditions of F-stability and 2.5 meter per second wind speed for coastal fumigation screening. Based on the results of coastal air studies, inland distances can be estimated at which the aloft stable plume intercepts the thermal internal boundary layer (TIBL) thereby causing the fumigation phenomenon. Then using Turner's equation for calculating fumigation concentrations (Turner, Workbook of Atmospheric Dispersion Estimates, 1970, p. 35), the maximum ground-level concentration resulting from fumigation can be estimated. One assumption made in adapting this method to sources located offshore is that the stack height (a parameter needed to determine inland interception distance) can be approximated as equal to the plume height by the time the plume reaches the shoreline. A value for the stack height must be assumed in order to estimate the distance inland at which the plume intercepts the TIBL and fumigation occurs.

The results of the calculations indicate an estimated maximum concentration of 2.91 micrograms NO_2 per cubic meter (.0015 ppm NO_2) occurring at an inland distance of 350 meters, or 7.35 kilometers from the offshore platform (See Attachment 1 for calculation). This estimated concentration for coastal fumigation is greater than the earlier predicted maximum concentration at shoreline distance obtained by the PTPLU2 and ISCST modeling (1.182 micrograms NO_2 per cubic meter). Therefore the coastal fumigation concentration should be used in assessing shoreline impact of well-testing operations on Platform Gina. These conditions are not expected to last more than two (2) days for any single well-testing operation.

5. Comment: Page 15, 1st full paragraph, 8th line.

PTPLU2 uses a specified number of default combinations of stability categories and wind speed to analyze for occurrences of maximum concentrations (e.g., stability C and 1, 3, 5, etc. m/s wind speeds). The ISCST model can reproduce the PTPLU2 default combinations via discrete hour-long periods (e.g., hour 1 is stability C, 1 m/s; hour 2 is stability C, 3 m/s, etc.). In the report, the term "default values" in reference to wind speed means that the same range of wind speeds covered by PTPLU2 "default" stability-windspeed combinations is also utilized during the ISCST runs.

6. Comment: Page 16, 1st paragraph, 10th line.

Comment noted and correction(s) made.

7. Comment: Page 17, Table 3.2.

Comment noted and correction(s) made. The study from which the flare emission factor of NO_x was derived is the 1982 EPA Flare Efficiency Study (EPA-600/2-83-052) (See Attachment 2 for documentation).

8. Comment: Page 19, Table 3.4.

These high wind speeds (16.74 and 23.57 m/s) were reported by the PTPLU2 program only because maximum concentrations happen to occur at these values. Lower windspeeds were also tested by the PTPLU2 program but did not give results higher than the ones obtained at these high windspeeds. The reviewer is correct in describing these values as 'unrealistically high'.

Very truly yours,

UNION OIL COMPANY OF CALIFORNIA

William W. Weldon

William W. Weldon
Landman

WWW:ka
Attachments

ATTACHMENT 1
CALCULATIONS FOR COASTAL FUMIGATION BY OFFSHORE STATIONARY SOURCES

CALCULATION OF MAXIMUM CONCENTRATION
FROM COASTAL FUMIGATION - OFFSHORE SOURCE

(Reference: EPA 1988 *User's Guide for Screening Procedures for Estimating the Air Quality Impact of Stationary Sources,* Pp. 4.31f., A.39f. [EPA-450/4-88-010])

(1) The SCREEN dispersion model was run using the source parameters of Platform Gina - well testing conditions for NO_x and the meteorological conditions: stability F, 2.5 meters per second windspeed (see the enclosed computer results).

(2) Plume height (h_e) was obtained from the results of the SCREEN run. At shoreline distance, 7000 meters,

$$h_e = 109 \text{ meters}$$

and

$$\sigma_y = 198\ m$$
$$\sigma_z = 44.8\ m$$

(3) Calculation of the inland distance (x) at which the thermal internal boundary layer (TIBL) height (h_T) intersects with the plume centerline (h^e) was accomplished using Table 4-5 of *EPA 1988* and assuming that stack height (h_s) is equivalent to h_e (see narrative discussion). The value for inland distance at which fumigation occurs was determined to be:

$$x = 350 \text{ meters}$$

(4) As a double check on the downwind distance, x, this value was substituted into the TIBL coastal height equation,

$$h_T = A\,(x)^{1/2}$$ equation A.15 in *EPA 1988*

where,

$A = 6\ m^2$
$x =$ inland distance to point of coastal fumigation

to see if the TIBL height corresponds with the predicted plume height calculated by SCREEN ($h_e = 109$ m). Substituting x = 350 meters into the equation,

$$h_T = 6\,(350)^{1/2}$$
$$= \underline{112\ m}$$

This value corresponds relatively close to the calculated plume height of 109 meters.

(5) Calculation of maximum ground-level concentration for NO_x from fumigation is accomplished by Turner's fumigation equation:

$$X_f = \frac{Q}{\sqrt{2\pi}\ u\ (\sigma_y' + \frac{h_e}{8})\ (h_e + 2\sigma_z')}$$

Where,

$Q = 0.811\ g/s$

$u = 2.5\ m/s$

$h_e = h_s + \Delta h$

$= 29.93 + 79 = 109\ m$

and,

$$\sigma_y' = [\sigma_y^2 + (\frac{\Delta h}{3.5})^2]^{1/2}$$

$$= [(198)^2 + (\frac{79}{3.5})^2]^{1/2}$$

$$= 199\ m$$

$$\sigma_z' = [\sigma_z^2 + (\frac{\Delta h}{3.5})^2]^{1/2}$$

$$= 50\ m$$

Then,

$$X_f = \frac{0.811}{\sqrt{2\pi}(2.5)(199 + \frac{109}{8})(109 + 2(50))}$$

$$= 2.912\ x\ 10^{-6}\ \ g/m^3$$

Converting to ppm units,

$$ppm = 2.912x10^{-6}(1000)(\frac{24.5}{MW})$$

$$= .0015 \quad ppm\ NO_2$$

The California Ambient Air Quality Standard for NO_2 is 0.25 ppm, 1-hour average.

EPA SCREEN - VERSION 1.1 (DATED 88300)

IBM-PC VERSION (1.01)

NSC15010 PLATFORM GINA FLARE EMISSIONS - F, 2.5 m/s

SIMPLE TERRAIN INPUTS:

SOURCE TYPE	=	FLARE
EMISSION RATE (G/S)	=	.8110
FLARE STACK HEIGHT (M)	=	29.93
TOT HEAT RLS (CAL/S)	=	.7347E+07
RECEPTOR HEIGHT (M)	=	.00
IOPT (1=URB,2=RUR)	=	2
EFF RELEASE HEIGHT (M)	=	38.66
BUILDING HEIGHT (M)	=	.00
MIN HORIZ BLDG DIM (M)	=	.00
MAX HORIZ BLDG DIM (M)	=	.00

BUOY. FLUX = 121.81 M**4/S**3; MOM. FLUX = 74.28 M**4/S**2.

*** STABILITY CLASS 6 ONLY ***
*** 10-METER WIND SPEED OF 2.5 M/S ONLY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
100.	.0000	0	.0	.0	.0	.0	.0	.0	
200.	.1828E-08	6	2.5	5.3	5000.0	109.0	16.6	15.3	NO
300.	.4616E-04	6	2.5	5.3	5000.0	109.0	22.3	20.1	NO
400.	.1897E-03	6	2.5	5.3	5000.0	109.0	24.9	21.3	NO
500.	.3041E-03	6	2.5	5.3	5000.0	109.0	26.9	21.8	NO
600.	.4925E-03	6	2.5	5.3	5000.0	109.0	29.2	22.3	NO
700.	.7967E-03	6	2.5	5.3	5000.0	109.0	31.6	22.9	NO
800.	.1187E-02	6	2.5	5.3	5000.0	109.0	34.2	23.4	NO
900.	.1737E-02	6	2.5	5.3	5000.0	109.0	36.8	23.9	NO
1000.	.2495E-02	6	2.5	5.3	5000.0	109.0	39.4	24.5	NO
1100.	.3405E-02	6	2.5	5.3	5000.0	109.0	42.1	25.0	NO
1200.	.4563E-02	6	2.5	5.3	5000.0	109.0	44.8	25.5	NO
1300.	.6009E-02	6	2.5	5.3	5000.0	109.0	47.5	26.0	NO
1400.	.7784E-02	6	2.5	5.3	5000.0	109.0	50.2	26.5	NO
1500.	.9928E-02	6	2.5	5.3	5000.0	109.0	53.0	27.0	NO
1600.	.1248E-01	6	2.5	5.3	5000.0	109.0	55.7	27.5	NO
1700.	.1547E-01	6	2.5	5.3	5000.0	109.0	58.5	28.0	NO
1800.	.1893E-01	6	2.5	5.3	5000.0	109.0	61.3	28.5	NO
1900.	.2288E-01	6	2.5	5.3	5000.0	109.0	64.0	29.0	NO
2000.	.2735E-01	6	2.5	5.3	5000.0	109.0	66.8	29.5	NO
2100.	.3144E-01	6	2.5	5.3	5000.0	109.0	69.5	29.9	NO
2200.	.3585E-01	6	2.5	5.3	5000.0	109.0	72.3	30.4	NO
2300.	.4058E-01	6	2.5	5.3	5000.0	109.0	75.0	30.8	NO
2400.	.4561E-01	6	2.5	5.3	5000.0	109.0	77.8	31.2	NO
2500.	.5094E-01	6	2.5	5.3	5000.0	109.0	80.5	31.6	NO
2600.	.5655E-01	6	2.5	5.3	5000.0	109.0	83.2	32.0	NO
2700.	.6243E-01	6	2.5	5.3	5000.0	109.0	86.0	32.4	NO
2800.	.6857E-01	6	2.5	5.3	5000.0	109.0	88.7	32.8	NO
2900.	.7495E-01	6	2.5	5.3	5000.0	109.0	91.4	33.2	NO
3000.	.8155E-01	6	2.5	5.3	5000.0	109.0	94.1	33.6	NO
3500.	.1092	6	2.5	5.3	5000.0	109.0	107.5	35.3	NO
4000.	.1378	6	2.5	5.3	5000.0	109.0	120.9	36.8	NO
4500.	.1661	6	2.5	5.3	5000.0	109.0	134.0	38.3	NO
5000.	.1935	6	2.5	5.3	5000.0	109.0	147.0	39.7	NO
5500.	.2194	6	2.5	5.3	5000.0	109.0	160.0	41.0	NO
6000.	.2435	6	2.5	5.3	5000.0	109.0	172.8	42.3	NO
6500.	.2658	6	2.5	5.3	5000.0	109.0	185.4	43.6	NO
7000.	.2861	6	2.5	5.3	5000.0	109.0	198.0	44.8	NO
7500.	.3005	6	2.5	5.3	5000.0	109.0	210.5	45.8	NO
8000.	.3132	6	2.5	5.3	5000.0	109.0	222.9	46.8	NO
8500.	.3244	6	2.5	5.3	5000.0	109.0	235.2	47.8	NO
9000.	.3342	6	2.5	5.3	5000.0	109.0	247.4	48.7	NO

9500.	.3427	6	2.5	5.3	5000.0	109.0	259.6	49.7	NO
10000.	.3500	6	2.5	5.3	5000.0	109.0	271.6	50.5	NO
15000.	.3797	6	2.5	5.3	5000.0	109.0	388.9	58.4	NO

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 100. M:

14999.	.3798	6	2.5	5.3	5000.0	109.0	388.9	58.4	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SCREEN DISCRETE DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
7000.	.2861	6	2.5	5.3	5000.0	109.0	198.0	44.8	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	.3798	14999.	0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

RUN ENDED ON 90/07/18 AT 12:47:57

ATTACHMENT 2
DOCUMENTATION OF NO_x EMISSION FACTOR

KALDAIR INCORPORATED

FILE COPY

KALDAIR

15835 Park Ten Place
Suite 115, Houston, Texas 77084 USA
☎ (713) 492-2252 Fax: (713) 492-2399

February 5, 1990

Unocal
P.O. Box 6176
Ventura, Ca 93006

Attn: Chris R. Culver

Dear Mr. Culver:

It is, at best, difficult to measure the emissions from an open flame flare tip. Any attempt at enclosing the flame (required for accurate plume testing) greatly changes the combustion characteristics of any flare. It is impossible to place a probe at every possible location and get the exact plume sample.

Due to the inherent difficulties in measuring the emissions from an open flare, very little information is available. While new technologies are being developed to measure the full spectrum of emissions (using light detection and ranging devices) they are not currently available for use on flares. Our only reference for accepted calculated levels of emissions are in the EPA - Flare Efficiency Study of 1982. Obviously they could not conduct testing for every type of flare.

In reference to the type of combustion achieved by the Coanda flares and NOx formation, we feel the Coanda flares should out-perform the flares used in the EPA study. The reasons for this are as follows:

Basically, all of our flares produce a gas rich flame. The flame from our Coanda type flares is highly turbulent. The gas passes through the lower portion of the flame at high velocity (low resonance time). The upper portion of the flame is cooled by the high turbulence, recirculation, and air entrainment. These occurances tend to lead to lower NOx formation.

Although we anticipate a lower NOx production, we state the production rate as estimated by the EPA of approximately 0.049 lbs/MMBTU.

KALDAIR

If you require further assistance, please do not hesitate to contact our office or your local representative, Don Boling of Northpoint Industries.

Sincerely,

Bernard Bolanowski
Combustion Engineer

BB/bf

KALDAIR INCORPORATED

COPY

KALDAIR

15835 Park Ten Place
Suite 115, Houston, Texas 77084 USA
☎ (713) 492-2262 Fax: (713) 492-2399

July 17, 1990

Environmental Management
405 S. State College Blvd. # 211
Brea, CA 92621

Attn: Scott Nikaido

Ref: P-361
Unocal - Gina Platform

Dear Mr. Nikaido,

The following is in response to our request for technical assistance pertaining to the Unocal - Gina Platform.

In the 1982 EPA study, a wide variety of studies were conducted. Because no testing was conducted on the Kaldair Coanda flares, we must pick tests which most closely simulate our flares. We have not used the air assist flares because the flame produced by the low velocity air flare, does not compare to the highly turbulent, high velocity Coanda flare flame. The Coanda flare flames are most closely likened to the high steam rate, steam flares. While the Coanda flares do not inject steam to cool the flame, the turbulence created does ensure a constant supply of cool air. These are test numbers 7, 5, 17, 50 and 56. The highest value is 0.48 lbs/MMBTU.

In our estimate, we used a conservative rate of 0.49 lbs/MMBTU. And, as stated in our letter, we anticipate the actual NO_x formation will be less.

Hopefully this information will assist you in your evaluation. If you have any questions, please call.

Sincerely,

Bernard Bolanowski
Sr. Application Engineer

BB/ki

TABLE 6. FLARE NO_x RESULTS

		Test No.	NO_x* Concentration (PPMv)	CO_2* Concentration (PPMv)	NO_x Mass Emission (lbs/10^6 BTU)
Steam-Assisted Flare	High Btu Content	1	3.09	7,052	0.068
		2	2.16	4,719	0.071
		3	1.54	2,496	0.095
		4	1.36	6,616	0.046
		8	1.45	5,400	0.042
		7	1.62	5,224	0.049
		5	2.09	7,052	0.046
		67	3.77	N/A	N/A
		17	1.00	3,499	0.044
		50	0.50	4,220	0.018
		56	0.58	3,120	0.029
		61	1.32	6,273	0.033
		55	0.38	2,012	0.029
	Low Btu Content	57	2.68	6,945	0.060
		11	3.69	5,269	0.109
		59	1.41	5,413	0.040
		60	0.39	3,685	0.047
		51	0.57	3,347	0.026
		16	1.87	4,059	0.071
		54	5.00	7,115	0.109
		23	5.90	8,465	0.108
		52	0.68	2,572	0.040
		53	2.83	5,741	0.076
Air-Assisted Flare	High Btu Content	26	5.34	6,270	0.132
		65	2.40	4,378	0.076
		28	8.16	6,076	0.208
		31	4.02	4,568	0.136
	Low Btu Content	66	0.97	2,432	0.062
		29	1.06	2,179	0.075
		64	1.24	3,282	0.058
		62	0.60	3,076	0.030
		63	1.57	4,184	0.058
		33	0.74	1,957	0.061
		32	1.75	3,702	0.073

* Corrected for background.

JUL 17 '90 15:34 KALDAIR INC. HOUSTON TX P.3

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, *Governor*

STATE LANDS COMMISSION

LEO T. McCARTHY, *Lieutenant Governor*
GRAY DAVIS, *Controller*
JESSE R. HUFF, *Director of Finance*

EXECUTIVE OFFICE
1807 - 13th Street
Sacramento, CA 95814

CHARLES WARREN
Executive Officer

June 18, 1990

RECEIVED

JUN 2 1 1990

CITY OF OXNARD
COMMUNITY DEVELOPMENT

Mr. Ralph Steele
City of Oxnard
305 West 3rd Street
Oxnard, California 93030

Dear Ralph:

The staff of the State Lands Commission has reviewed the "Draft Initial Study for Platform Gina Proposed Return Line Replacement and Conversion to Produced Gas," dated May 1990. In general, we found it to be fairly comprehensive and thorough. We would, however, like to offer the following comments:

Initial Study Component 1 - Return Water Line Replacement:

Comment #

1. p.2. Unocal expects the replacement pipeline to bury itself by gravity and natural hydraulic action of ocean movement as did the original water line.

We question whether the lighter gas filled line will bury itself in a manner similar to the original water filled line. Therefore, we recommend that Unocal's Project Description be amended to provide for monitoring the position of the line and agree that if it has not buried itself to the required depth within 2-years, Unocal will take positive measures, such as jetting, to achieve proper burial.

2. p.3. Unocal proposes to leave the old corroded pipeline in place for its 2,700 ft. length along the seafloor and across the beach after construction of the new line.

We are concerned that this line could become exposed at some time in the future and pose a hazard to public safety. Therefore, Unocal should amend its Project Description to provide, as mitigation, for the complete removal of the old pipeline to its offshore connection point.

3. p.10. The bottom paragraph states that a diving support vessel, an anchor setting vessel and a crew transport vessel will be used in the project. The Project Description should specify what vessel will be used for pipe pulling.

4. p.13. Section P. RISK/HUMAN HEALTH of the Environmental Checklist is checked to indicate no potential adverse impacts. Since there is the possibility of pipeline rupture in shallow water, nearshore, or on the beach, combined with a failure of the gas sweetening systems on the platform, the "Maybe" or "Yes" columns should be checked and the potential public safety and human health concerns evaluated.

5. p.14. The Initial Study states that the pipeline pressure tests will be witnessed by MMS and Unocal. The State Lands Commission should also be included. Mr. Pete Johnson, Chief Petroleum Engineer in our Long Beach office, should be given reasonable advanced notice of when these tests are scheduled. He may be contacted at (213) 590-5229. Also, information relative to the design and operating pressures of the pipeline should be included in the Initial Study.

<u>Initial Study Component 2 - Conversion to Produced Gas:</u>

6. p.3. The Initial Study acknowledges that if and as the gas production phase proceeds to full field development, additional facilities and equipment will be necessary, and that actual equipment needed would be based on future well test results and detailed reservoir evaluation. It states that any changes to the platform, wells of pipelines would have to be approved by the Minerals Management Service.

All safety systems on the platform which govern the transportation of gas through State waters should be examined under CEQA and submitted also to the staff of the Commission for its review.

7. p.11. As is the case in Component 1 of the Initial Study, Section P. RISK/HUMAN HEALTH of the Environmental Checklist is checked to indicate no potential adverse impacts. Since there is the possibility of pipeline rupture in shallow water, nearshore, or on the beach, combined with a failure of the gas sweetening systems on the platform, the "Maybe" or "Yes" columns should be checked and the potential public safety and human health concerns evaluated.

We appreciate the opportunity to review the draft Initial Study and look forward to working with you to answer any questions you may have. Since Dan Gorfain will be on vacation from June 25 to July 20, please contact me directly, if necessary, at (916) 322-7827, Debbie Townsend at (916) 322-7803, or Pete Johnson at (213) 590-5229.

Sincerely,

Dwight E. Sanders

DWIGHT E. SANDERS, Chief
Division of Research
and Planning

DES:maa

cc: Dr. Gordon Snow, State Projects Coordinator, The Resources Agency
Office of Planning and Research
Debbie Townsend
Pete Johnson
Daniel Gorfain

Unocal Oil & Gas Division
Unocal Corporation
2323 Knoll Drive, P.O. Box 6176
Ventura, California 93006
Telephone (805) 656-7600

UNOCAL 76

August 10, 1990

Western Region

Mr. Dwight E. Sanders
State Lands Commission
1807 13th Street
Sacramento, CA 95814

RE: PLATFORM GINA/MANDALAY
Offshore/Ventura County, CA
Pipeline Conversion & Repair

Dear Mr. Sanders:

By letter dated June 18, 1990 the State Lands Commission commented on the City of Oxnard's Initial Study. The subject of this letter is to address the Commission's comments.

Initial Study Component 1 - Return Water Line Replacement

1. (P.2) Union Oil is confident the line will self bury. The subject line is made of steel 6-5/8" in diameter with 1" of concrete coating and weighs 44.33 lbs per foot dry. Please refer to page 71 of the Burial Study for additional information.

   Union would prefer not to amend its Project Description as we would have to re-submit to all other agencies. Please be advised that under the terms of our lease Union is already required to monitor the pipeline. Should the pipeline have failed to reach two feet of burial at the end of two years Union will bury the line with hydraulic jetting to between two to four feet below the sand bottom.

2. (P.3) Union will remove the old line to the MLLW water line. This will result in the remaining 2300' to be abandoned in place.

   Union believes the removal of this entire replacement section of the line could have adverse affects on turbidity, fish propagation and recreation.

The abandoned line will not become exposed and corroded for several reasons:

A. The abandoned line will remain full of water and is subject to conditions of burial equal to or greater than the gas line described in the burial study.

B. During the original pipeline pull of the 6-5/8" water and 10-5/8" oil pipeline, the 6-5/8" water line was secured to the 10-5/8" oil pipeline. Positive buoyancy was attached to both lines during the pull. When the buoyancy was removed the lines were left secured to each other. Thus the 6-5/8" line remains secured to the 10" line which is in place.

C. The abandoned line will be protected cathodically preventing corrosion. The subject line will retain the original anodes and be protected further by the 10-5/8" line to which it is secured, creating electrical continuity. Since continuity will exist the line will be protected cathodically. Should problems develop they will be detected by the cathodic protection surveys that are done annually at Mandalay and every 5 years for the entire line. Should additional protection be required for the replacement 6-5/8" line or the existing 10-5/8" in the future this protection will also protect the abandoned 6-5/8".

D. The line is currently buried and has continued to show more burial throughout it's life of almost 10 years. The Side Scan sonar surveys have consistently shown an increase in burial.

Reasons Unocal wishes not to remove the line:

A. Minimize environmental disturbance. This position will be supported by an environmental biologist and the Department of Fish & Game. A copy of their comments will be forwarded to the Commission.

B. Minimize project time and inconvenience to the public. Pipe removal would require restricting access to the affected portion of the water and bench while removal work is conducted.

C. Since line is secured to the 10-5/8" oil line, removal of this line presents some risk to the 10-5/8" oil pipeline.

D. Due to the high turbulence of the surf zone it will be logistically very difficult to remove this pipe. The excavation will fill as fast as it is opened. With the pipe secured to the 10-5/8" line, it cannot simply be pulled out.

3. (P.10) A vessel has not been selected at this time due to the unknown completion date of the permitting process.

4. (P.13) The potential of those two occurrences is remote. We refer you to page 1 and pages 29-57 of the Risk Assessment Study for further detail. Union's consultant has indicated she will amend the check list to indicate "maybe" and will add an explanatory note to the text of the Initial Study to reference subsequent documentation.

5. (P.14) Pete Johnson has been contacted personally by Union and will be notified of the pressure test.

   The design and operating pressures for the pipeline are included in the Initial Study under Union's Project Description. Section II.2.0 (pg. 15) through II.2.6 (pg. 17) describes line design. The design pressure of 1440 PSI and the operating pressure of 500 PSI can be found on page 15 of the Project Description.

<u>Initial Study Component 2 - Conversion to Produced Gas</u>

6. (P.3) The safety systems on the platform that govern the transportation of the gas through State Waters will all be in place at the completion of this project. The changes anticipated in the future are in the process themselves, i.e., a permanent sweetening plant, gas compression, etc. These changes will not modify the safety systems on the platform which govern the transportation of gas through State Waters. A special study related to systems was completed for the proposed pipeline conversion project and it is included in the initial study as Exhibit "E.

7. (P.11) The potential of those two occurrences is remote. We would refer you to the Risk Assessment Study for further detail. Same response as Item #4.

Very truly yours,

UNION OIL COMPANY OF CALIFORNIA

William W. Weldon
Landman

WWW:ka

APPENDIX VOLUME 3

Response to Comments

STATE OF CALIFORNIA—THE RESOURCES AGENCY GEORGE DEUKMEJIAN, *Governor*

CALIFORNIA COASTAL COMMISSION
631 HOWARD STREET, 4TH FLOOR
SAN FRANCISCO, CA 94105-3973
(415) 543-8555
Hearing Impaired/TDD (415) 896-1825

June 14, 1990

Mr. Ralph J. Steele
City of Oxnard
Community Development Department
305 W. Third Street
Oxnard, CA 93030

Dear Mr. Steele:

Comment #

Thank you for this opportunity to comment on the City of Oxnard's Draft Initial Study for Platform Gina Proposed Return Water Line Replacement and Conversion to Produced Gas. We appreciate the work done by the City of Oxnard and Unocal since the Preliminary Draft was published last fall. However, as we stated in our October 30, 1989, comment letter on the Preliminary Draft, the Commission has found that it is very important to look at a project in its entirety. Permitting agencies need a complete project description and data on the effects of proposed activities in federal and state waters, on the platform, at pipeline landfall, and in the Mandalay facility. It is unclear exactly what aspects of the project this Draft Initial Study (DIS) covers.

SCOPE OF PROJECT

The document states "The first initial study evaluates the first component of the project which is the return water line replacement" and later says "...the repair phase is being evaluated in the context of the project as a whole." The second Initial Study states: "As the production phase proceeds to full field development, additional facilities and equipment will be needed. This could include the installation of additional deck space along the south side of Platform Gina to allow for some of the equipment." Page 28 of Exhibit A refers to "Permanent Hydrogen Sulfide Sweetening Facilities" which will be
1. needed. It must be made very clear what is and what is not included in this project proposal. Those items that are included in the present proposal must be throughly covered in the environmental document.

City of Oxnard Resolution No. 6218 states that "no significant unavoidable adverse impacts are expected to occur within the jurisdiction of the City of Oxnard." Is this current Initial Study limiting itself to determining impacts
2. only in the jurisdiction of the City?

Page 14 of Exhibit A states that "[I]f the pressure test from the tie-in out
3. to Platform Gina is not successful, the cause will be determined, necessary repairs will be made accordingly, and the pressure test will be repeated." Does this mean that some (or much) of the line from 2,300' out to the platform may be replaced? As part of this project? The document should so specify.

LANDFALL AND ONSHORE INFORMATION

There is not enough information as to what is the present state of the onshore area. It is stated that disturbed areas shall be "revegetated" to conform to
4a. original conditions. The reader is not informed as to what type of vegetation is presently there. Some detailed maps of the onshore area, showing existing flora and public access areas for instance, are necessary in order to properly analyze the project impacts. (The hand-drawn map attached to the Unocal letter of 10/28/88 is the most useful one in the document, but is obviously not adequate to analyze environmental, safety, and public access issues.) How
4b. much of the pipeline onshore will NOT be in the 10" conduit? It is unclear from the document what effect the project will have on public access - and what public access currently is available and used. The reader is told that a worst case accident would affect an area limited to a 1,320 foot radius of the Mandalay Onshore Processing Facility. One can not tell from the text or maps whether there is existing public access or public roads included within that radius. The document does state that there are pedestrians within this radius at times. There is no mention of a Emergency Response - Evacuation Plan for
4c. these pedestrians. Such a plan is essential for public safety.

Page 4 of Resolution No. 6218 discusses lighting, stating that the project should not "... direct light onto the adjacent park area." This is the first, and only, time in the document that a park is mentioned. Is there a park, or
4d. is "parking area" what is meant?

Exhibit A, Pg. 20, discusses "prevention of unauthorized access to the
4e. beach." Because the project site has not been adequately described, we do not know if this is a public beach. If so, what is "unauthorized access"?

The second page of the first Initial Study (It would be helpful if pages were
4f. numbered.), in a paragraph dealing with the offshore pipeline, states that "The onshore section will be buried mechanically with conventional equipment." What sections of the onshore line? Is the author referring to the offshore section?

OFFSHORE TRANSPORTATION

OCS P-0202 and P-0203 are near or in the Santa Barbara Channel Vessel Traffic
5. Lanes. Such a location makes it essential that workboats associated with future construction on Platform Gina use a marshalling or waiting area away from the vessel lanes or any approaches to ports or marine terminals.

The Initial Study L. Transportation/Circulation 5. describes mitigation as notifying the Coast Guard of the dates of the operation and the names and radio call signs of the vessels working in the area, along with the radio frequency which mariners can use to contact these vessels. What is to be done with this information? We believe that it should not only be published in the Local Notice to Mariners, but in the advisory newsletter published by Sea Grant for the fishermen in southern California. The second Initial Study simply states, in response to L.5, "Measures recommended by the U.S. Coast Guard for Navigation Safety shall be implemented." What measures?

SYSTEMS SAFETY ANALYSIS

The second Initial Study states that "...the applicant has proposed to install redundant H_2S monitoring and system shutdown equipment on Platform Gina and at the Mandalay facility." Will there be redundant monitoring, alarm, and
6a. shutdown systems at the Mandalay facility? We would agree that this is an excellent idea, just as we believe the plan to have redundant systems on the platform is essential for the safety of the project.

"The project was deemed to meet or exceed CEQA Guidelines for Environmental Protection." (Pg. 10) How? By whom? Exhibit A, Pg. 25, states that the equipment installed on Platform Gina will conform with provisions of CEQA.
6b. Please explain.

One of the "Premises for Basic Analysis and Design" states that the two levels of protection that should be provided by the safety system should be functionally different types of safety devices for a wider spectrum of coverage. "Two identical devices would have the same characteristics and might have the same inherent weaknesses." (Pg. 12) On page 27, it is stated
6c. that the redundant H_2S systems are the same. Please explain.

"For the purpose of this analysis, it is assumed the concentration of H_2S will be approximately 2000 ppm at the well head." (Pg. 30) Is the amount of
6d. H_2S expected to be encountered all based on results from the testing of one well? Might 2000 ppm be low?

Page 17 states that the batch sweeteners will be capable of sweetening the gas from a level of 2,000 ppm to a level of 4 ppm. As the system is designed to
6e. sound alarms at 2 ppm, wouldn't they sweeten the gas to 2 ppm instead of 4 ppm, at which point the system closes down?

On page 50, there is a discussion of the IDLH concentration level zone, in which 50% of the population are assumed to die and "The remaining 50 percent of the population exposed within this zone was assumed to be seriously injured. The population beyond the IDLH concentration level may suffer minor but not irreversible health effects; therefore they were not considered in the risk analysis." If 50% die in the "fatality zone" then it would seem that 25% (or 37% or 9%) may die in the area next to this zone. It does not therefore seem correct to state, as is done on page 54, that "the only area which hydrogen sulfide would adversely affect the public would be within the
6f. envelope 1,320 feet downwind." Please explain.

6g. The Risk Assessment Study seems to be quite preliminary in terms of design review. ("As much of the design for the proposed gas sweetening system is not complete at this time, a complete safety analysis could not be performed." (Pg. 12) "At this time, the final design has not been completed." (Pg.14) "The actual equipment to be used will be based upon future test well test results and a detailed reservoir analysis." (Pg. 17) "As the piping and electrical design for the Platform Gina gas tie-in is not completed, this could not be reviewed at this time." (Pg. 25) "Because the P&IDs for this project are still preliminary, such a detailed review would not be appropriate at this stage." (Pg. 32)) Yet it determines that the proposed project "is very safe" (Pg. 1), and several sections conclude "no problems were identified" or "no problems have occurred or are expected" or "no problems have been reported" (Pg. 22) or "The survey report was reviewed for deficiencies, and none were found." (Pg. 23)

OTHER COMMENTS

7. The document does not cover specifics of the effects of anchoring the barge on fishing grounds, if any. Please discuss.

8. There has been concern over entangling of grey whales in anchor lines from pipelaying barges. Please discuss this possible impact to migrating grey whales.

9. The State Lands Commission pointed out in its 10/23/89 comments that Initial Study C. Water 5., in reference to turbidity, should be answered "yes". Despite the explanation in the current Initial Study, it appears that the answer should still be "yes". While the turbidity may be less than that caused by the Santa Clara River outflow or by dredging activity at nearby harbors, it is still turbidity.

Again, we wish to express our appreciation for the efforts by the City of Oxnard and Unocal in attempting to meet the concerns expressed in comments on the Preliminary Draft Initial Study. With the cooperation of responsible federal and state agencies, we believe the review and permitting process for the Platform Gina conversion project should proceed in a timely fashion. The Coastal Commission staff will work closely with all the responsible agencies to make the process work as smoothly as possible.

Sincerely,

Suzanne Rogalin

Suzanne Rogalin
Energy Analyst

cc:SLC
MMS
Santa Barbara District, CCC

3514N

Unocal North American
Oil & Gas Division
Unocal Corporation
2323 Knoll Drive, P.O. Box 6176
Ventura, California 93006
Telephone (805) 650-4505

UNOCAL 76

Hugh H. Herndon
District Land Manager

August 11, 1990

Mrs. Suzanne Rogalin
California Coastal Commission
631 Howard Street, Fourth Floor
San Francisco, CA 94105-3973

RE: PLATFORM GINA/MANDALAY FACILITY
Offshore/Ventura County, CA
Pipeline Conversion

Dear Mrs. Rogalin:

Reference is made to the California Coastal Commission letter dated June 14, 1990. Union has addressed your comments in the same sequence as in your letter.

1) The Draft Initial Study is intended to review the impacts associated with the pipeline replacement and pipeline use conversion aspects of the project. In addition it includes information pertaining to risk and hazards associated with the transport of gas from Platform Gina and Platform Gilda to the Mandalay Separation Facility. This evaluation covers the effects of proposed activities in Federal and State waters, on the platform, at pipeline landfall, and in the Mandalay Facility.

   This Initial Study does not evaluate additional facilities and equipment such as the installation of deck space, or the permanent hydrogen sulfide sweetening facilities which may be needed in the future.

2) The City of Oxnard prepared the Initial Study with the assistance and cooperation of other responsible and interested agencies. The Initial Study does evaluate the effects of the proposed activities in Federal and State waters, on the Platform, at the pipeline landfall and at the Mandalay Facility. This initial study has concluded in a negative declaration.

3) The intent of the comments were that Unocal as a prudent operator will take the measures necessary to obtain quality assurance of the repairs. Unocal accepts its role in this project to obtain pipeline integrity and will take such measures.

The last internal survey of the pipeline was conducted in August 1987 prior to removing the line from service in October of 1988. A subsequent survey cannot be conducted until the line is repaired. It is possible that additional pipe past the 2,300' offshore point may need to be replaced, but it is considered very unlikely. The survey data indicates the repair described in the project description is the most prudent means to insure pipeline integrity and minimize environmental concerns as well as the length of the project.

4) a) Attached you will find photographs showing existing rural and public access areas. A rural park exists adjacent to the facility and has public access as shown. The City of Oxnard dealt with these issues by letter dated November 18, 1988, a copy of which is enclosed.

b) The segment of the onshore pipeline from the MLLW to the 10" conduit will be buried mechanically and is approximately 500 feet long.

c) There is no plan due to remoteness of the occurrence cited in the Risk assessment "Platform Gina Gas Production and Pipeline Mandalay Onshore Receiving" page 1 at, 2.7 x 10-6 per year. <u>One could be adapted if desired</u>.

d) Please see the exhibits to 4.a.

e) Union Oil will prohibit access in and to the staging and repair area during construction which will be three weeks in duration. This has also been addressed by the City of Oxnard's letter, November 18, 1988.

f) The line will be buried from the Mandalay wall to the MLLW. This information is addressed on page 14 of the prospect description.

5) In their letter of January 19, 1990, the U.S. Coast Guard stated the following requirement:

"Prior to the beginning the in-water portion of the project, I request that you notify the Eleventh Coast Guard District Aids to Navigation Office of the dates of the operation and the names and radio call signs of the vessels which will be working in the area. Additionally, the Aids to Navigation Office should be notified of the radio frequency which mariners can use to contact your vessels. All of this information will be used to notify the Southern California mariners of the project and its potential impact on vessel navigation."

Following their review of the subsequent initial study, the U.S. Coast Guard stated in a letter of May 22, 1990 that their concern in the area of impacts to waterborne transportation had been fully identified and adequately addressed.

6) Systems Safety Analysis

a) No, there will not be redundant monitors at Mandalay. The risk assessment, page 43 shows the failure tree of the monitor. With two on the platform and one at the facility, there is no reason to install additional monitors. For reference, redundant monitors including detection, alarm and shutdown equipment are installed on Platform Gina.

b) Incorrect statement should be deleted.

c) We agree that there appears to be an apparent incongruity with regards to the use of two identical monitors for providing redundant detection of Hydrogen Sulfide (H_2S) gas. However, the market selection of monitors for this type of application is limited. The Del-Mar monitors are an industry standard, and it was determined that there were no other monitors available which were as reliable and that would provide the desired benefits. Hence, the Del-Mar monitors were selected for use as both the primary and back-up H_2S detectors. Also, the fault tree analysis starting on page 42 indicates that a sequence of four events must occur simultaneously (see page 43, Fig. 2) for the gas to leave the platform by monitor failure. This chance is 4 x 10-11 per year. Note that this figure is based upon the occurrence of an upset condition that would not otherwise trigger a shutdown via other safety instrumentation, such as high pressure switches or high level. The fault tree analysis has indicated that the chance of failure is so remote that the addition of subsequent monitors (two on the platform and one at the facility) would provide no additional benefit.

d) Yes, only one well has been tested. It is possible hydrogen sulfide concentration could be higher. Should the hydrogen sulfide concentration be higher than estimated, Union will still sweeten the gas to pipeline quality before transport from Platform Gina. The gas transported to shore will be pipeline quality regardless of the hydrogen sulfide concentration. It should be noted that the Risk Assessment used a 7,000 PPM case for analysis to model a worst case scenario.

e) An error has been made in this statement. The gas leaving the batch sweeteners will be lower in concentration than 2 PPM and usually between 0 and 1 PPM. The system will be designed as described to alarm at 2 PPM and shut down at 4 PPM.

f) Comment Regarding IDLH Concentration: Page 3, Paragraph 6:

While it is true the fatality rate does not go from 50% to 0% at one particular point, the number of fatalities will go from 0% at 1,320 feet downwind to 100% at the source of release. In the zone, from the point of release to 1,320 feet downwind, 50% of those present are assumed to be seriously injured. This is a very conservative estimate and it is certainly unlikely that at least some of the people 1,319 feet downwind could not evacuate the necessary one foot defined by OSHA/NIOSH to a safer zone. However, in this Risk Analysis it was assumed they could not.

The immediately dangerous to life and health (IDLH) levels are prescribed by OSHA/NIOSH. Concentrations of hydrogen sulfide at these levels, if one escapes this zone within 30 minutes, do not .produce irreversible health effects.

The 1,320 feet downwind figure is based on the vapor cloud dispersion model. At this point, the concentration of hydrogen sulfide was at the IDLH. A person at this point has 30 minutes to take a few steps to evacuate the area and avoid irreversible health effects.

Perhaps another approach to this point is that a total release would only affect people within a certain envelope (see Page 52). A total release offshore could not affect people at all if they were over a certain distance away from the platform. The hazard is from a release at Mandalay and for the first 1,320 feet of the pipeline offshore. The gas is monitored with a redundant system before it leaves the platform. Both monitors must fail at the same time the process fails in order to ship sour gas to shore. This still does not present a problem unless there is a simultaneous accident at the shore facility. As noted in Figures 2 and 3, this probability is 2,700,000 to 1.

g) Comment Regarding Preliminary Nature of Report: Page 3, Paragraph 7:

In determining the relative safety of the proposed project, Unocal's proposed design was compared to other gas sweetening systems which have been constructed and are now in operation. This included systems which are currently operating on offshore platforms, including one which is operated by Unocal. It was noted that the proposed process to be used for gas sweetening is an industry standard. Unocal has also indicated that the detail design of the gas sweetening system will also follow API 14C and API RP 2G, and applicable MMS standards, which will provide for a pre-determined level of protection. Unocal has indicated the final design drawings will be reviewed for compliance with these standards when they are completed. Unocal has also indicated a S.A.F.E. (Safety Analysis Function Evaluation) chart review of the proposed gas sweetening system will be prepared for MMS review; this will help to assure a safe design.

7) The commercial fishing activit s which occur in the area can be identified in Append x "A" of "A Manual for Geophysical Operations in Fishing Areas of South/Central California". This report and Union's conversation with Dr. Craig Fusaro of Joint Oil/Fisheries Offices indicates the potential of gill netting and trapping in the general area. Union would refer you to the Seasons Peak Activity Chart, of the subject manual, for detailed time periods. It is important to note that Union's repair will be in less than 30 feet of water and no more than 1,500 feet from the MLLW, therefore limiting the amount of interference with fishing activity.

The Coast Guard has stated that upon Union's notification of the dates of operating they will notify Southern California mariners of the project and its impact on vessel navigation. Also, Union's anchor mooring vessel will be on site to warn any potential traffic.

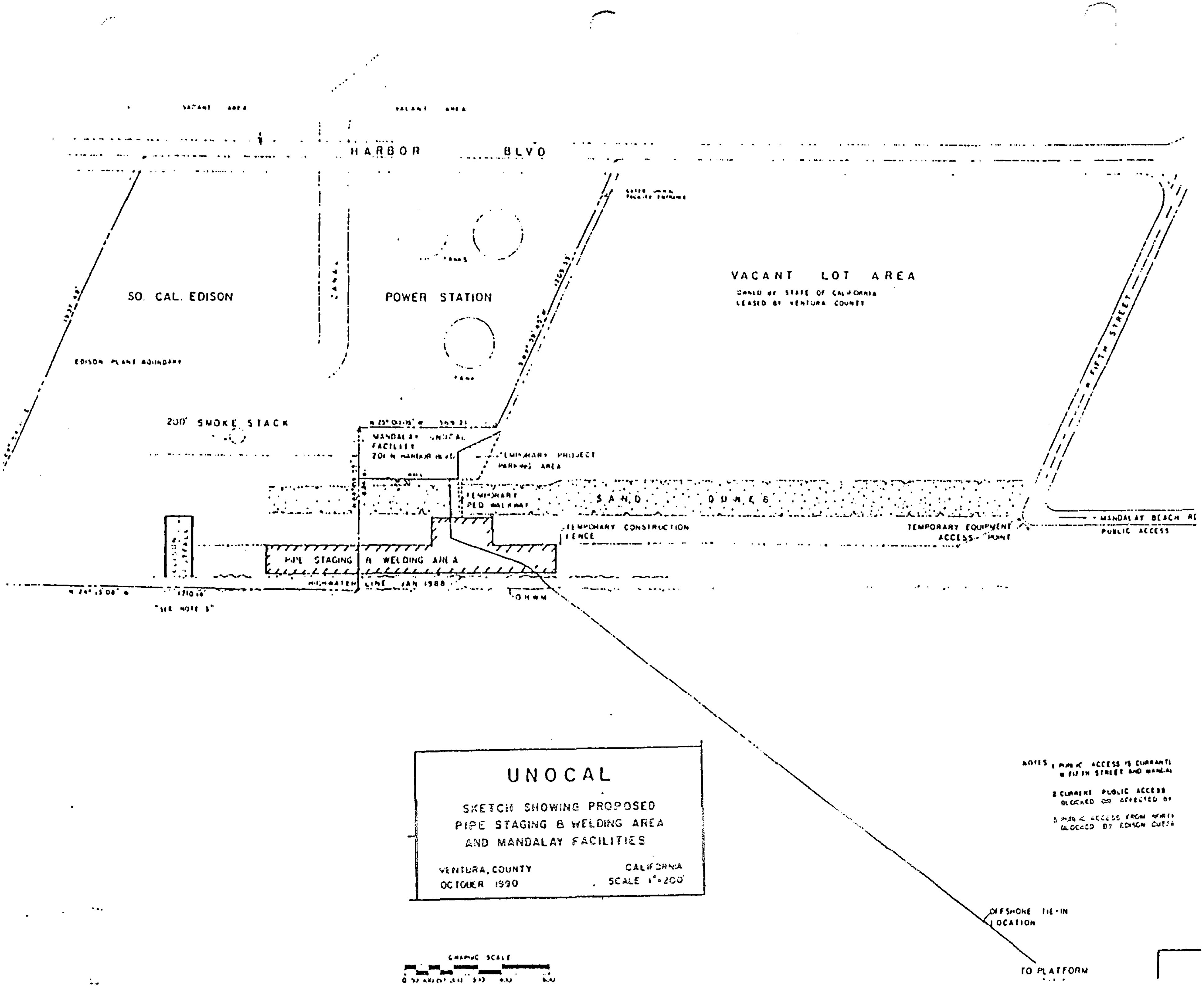
8) It is important to note that this project at the deepest level only takes place in 30' of water and will be for a minimal time period of less than three weeks. Union has contacted Mr. Peter Howorth of Howorth & Associates and who is a Director of the Marine Mammal Center in Santa Barbara for comments on the grey whale. Mr. Howorth states that near shore migrations take place from February - April. He says temporary disruption could be possible on occasion however he believes there will be no significant long term negative impact on grey whale migration based on his observations made to date. Most of these mammals migrate much further offshore.

9) You are correct that turbidity will be caused, however, it will be negligible.

Very truly yours,

William W. Weldon
Landman

WWW:ka



UNOCAL
SKETCH SHOWING PROPOSED
PIPE STAGING & WELDING AREA
AND MANDALAY FACILITIES
VENTURA, COUNTY
OCTOBER 1990
CALIFORNIA
SCALE 1"=200'
HARBOR BLVD
VACANT AREA
VACANT AREA
SO. CAL. EDISON
POWER STATION
EDISON PLANT BOUNDARY
200' SMOKE STACK
VACANT LOT AREA
OWNED BY STATE OF CALIFORNIA
LEASED BY VENTURA COUNTY
FIFTH STREET
MANDALAY UNOCAL
FACILITY
201 N HARBOR BLVD
TEMPORARY PROJECT
PARKING AREA
TEMPORARY
PED WALKWAY
SAND DUNES
TEMPORARY CONSTRUCTION
FENCE
PIPE STAGING & WELDING AREA
HIGHWATER LINE JAN 1988
OHWM
TEMPORARY EQUIPMENT
ACCESS POINT
MANDALAY BEACH
PUBLIC ACCESS
"SEE NOTE 3"
OFFSHORE TIE-IN
LOCATION
TO PLATFORM
GRAPHIC SCALE

See Volume #1, Item C, for Environmental Assessment and Beach Vegetation Study for proposed Platform Gina Pipeline Replacement. Mandalay Beach, Ventura County, Ca.

U.S. Department of Transportation
United States Coast Guard

Commander
Eleventh Coast Guard District

Union Bank Bldg
400 Oceangate
Long Beach, CA
90822-5399
Staff Symbol: (m)
(213) 499-5330

16475/0175

Mr. Ralph J. Steele
City of Oxnard
Community Development Department
305 W. Third Street
Oxnard, CA 93030

Dear Mr. Steele,

Thank you for the opportunity to review the Final Draft Initial Study for the Platform Gina Return Water Line Replacement and Conversion Project.

As discussed in our comments on the preliminary draft, the Coast Guard's primary interest in this project involves impacts to waterborne transportation. Our concern in this area has been fully identified and adequately addressed in the final draft and its accompanying environmental analysis. As a consequence, we have no objection to the issuance of a Negative Declaration.

If you have any questions about this issue, please feel free to contact me at the number shown above.

Sincerely,

N. S. PORTER
Commander, U.S. Coast Guard
Chief, Marine Safety Planning and
Administration Branch
By direction of the District Commander

RECEIVED
MAY 25 1990
CITY OF OXNARD
COMMUNITY DEVELOPMENT

STATE OF CALIFORNIA—OFFICE OF THE GOVERNOR

GEORGE DEUKMEJIAN, Governor

OFFICE OF PLANNING AND RESEARCH
1400 TENTH STREET
SACRAMENTO, CA 95814

June 13, 1990

Ralph Steele
City of Oxnard
305 W. Third Street
Oxnard, CA 93030

Subject: Platform Gina Proposed Return Water Line Replacement, SCH# 90010478

Dear Mr. Steele:

The State Clearinghouse submitted the above named environmental document to selected state agencies for review. The review period is closed and none of the state agencies have comments. This letter acknowledges that you have complied with the State Clearinghouse review requirements for draft environmental documents, pursuant to the California Environmental Quality Act.

Please call Nancy Mitchell at (916) 445-0613 if you have any questions regarding the environmental review process. When contacting the Clearinghouse in this matter, please use the eight-digit State Clearinghouse number so that we may respond promptly.

Sincerely,

David C. Nunenkamp
Deputy Director, Permit Assistance

RECEIVED
JUN 15 1990
CITY OF OXNARD
COMMUNITY DEVELOPMENT

STATE OF CALIFORNIA GEORGE DEUKMEJIAN, Governor

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD—
LOS ANGELES REGION
101 CENTRE PLAZA DRIVE
MONTEREY PARK, CALIFORNIA 91754-2156
(213) 266-7500

May 30, 1990

File: 700.513

Ralph Steele
City of Oxnard
305 W. Third Street
Oxnard, CA 93030

DRAFT INITIAL STUDY - REPLACE 3,000 FEET OF RETURN WASTEWATER LINE AT BEACH, PLATFORM GINA. SCH#90010478: CITY OF OXNARD

We have reviewed the subject document regarding the proposed project, and have the following comments:

Based on the information provided, we recommend the following:

- [X] We have no further comments at this time.
- [ ] The proposed project should address the attached comments.

Thank you for this opportunity to review your document. If you have any questions, please contact Eugene C. Ramstedt at (213) 266-7553.

John L Lewis

JOHN L. LEWIS, Unit Chief
Technical Support Unit

cc: Garrett Ashley, State Clearinghouse

RECEIVED
JUN 05 1990
CITY OF OXNARD
COMMUNITY DEVELOPMENT

(07-13-89)

State of California | Business, Transportation and Housing Agency

Memorandum

To : Mr. Barnara Ceran
State Clearinghouse
1400 Tenth Street, Room 121
Sacramento, Ca. 95814

Date : June 14, 1990

File : IGR/CEQA
City of Oxnard
NEGDEC; Water
Line Replacement
and Conversion to
Produced Gas
Vic.VEN-1-R19.62

From : Gary McSweeney - District 7
DEPARTMENT OF TRANSPORTATION

Subject: Project Review Comments

SCH No. 90010478

Caltrans has reviewed the above-referenced document. Based on the information recieved we find no apparent impact on the operation of the State transportation system.

If you have any questions regarding this response, please call Wilford Melton at (213)620-6160.

Original signed by

Gary McSweeney
IGR/CEQA Coordinator
Transportation Planning and
Analysis Branch

cc: Mr. Ralph Steele
City of Oxnard

RECEIVED
JUN 22 1990
CITY OF OXNARD
COMMUNITY DEVELOPMENT

APPENDIX VOLUME 3

Exhibit A

EXHIBIT A

UNOCAL OIL AND GAS DIVISION

Platform Gina To The Mandalay Facility

6-5/8" Pipeline Repair And Conversion

Revision 1

December, 1989

Prepared by: Unocal Oil & Gas Division
P.O. Box 6176
Ventura, California 93003
805/656-7600

January 29, 1990

Outline of Unocal project description for "Platform Gina Pipeline Line Repair and Conversion Project".

I. Platform Gina

A. Located 6 miles SW of Oxnard

B. OCS P-0202

C. Existing platform on production since 1982

D. Pipeline length is 6.2 miles between Gina and Mandalay

E. New facilities are consistent with approved EIR 78-19 concerning original installation of Gilda, Gina, and Mandalay

II. Monterey Development

A. 4 exploratory wells have been drilled

1. Exploration completed with well H-14 in 1988

2. Development beginning with pipeline repair and conversion

B. Gas zone with H_2S present

1. H_2S to be processed on Gina

a) State-of-the-art <u>redundant</u> Monitoring/Detection/Alarm/Shutdown system for H_2S

2. Risk assessment study has determined project is very safe and represents a minimal risk to public health or the environment.

a) 2.7 in 1,000,000 annual chance of a release of 4 ppm H_2S concentration near Mandalay

III. Pipeline Repair

A. 3,000′ of 32,000′+ route for 6-5/8" pipeline

1. 2,300′ offshore (Mean High Tide Line (MHTL) to 2,300′)

2. 700′ onshore (Mandalay facility to MHTL)

B. Limited Excavation

1. 40′ in length and 4′ in depth of excavation at offshore tie-in location

2. Other excavation above mean low tide line (MLTL)

3. No sand dune excavation

4. Self-Burial Study and EIR 78-19

a) Minimal turbidity

b) No hard bottom habitats or kelp beds in area

C. 3 week project duration

IV. Platform Gina Modifications

A. H_2S Monitors

1. Ambient air monitors (installed)

2. 2 state-of-the-art pipeline monitors to prevent H_2S gas from leaving the platform

a) Redundant monitoring

b). Redundant detection

c). Redundant alarm

d) Redundant shutdown

B. Separation Equipment

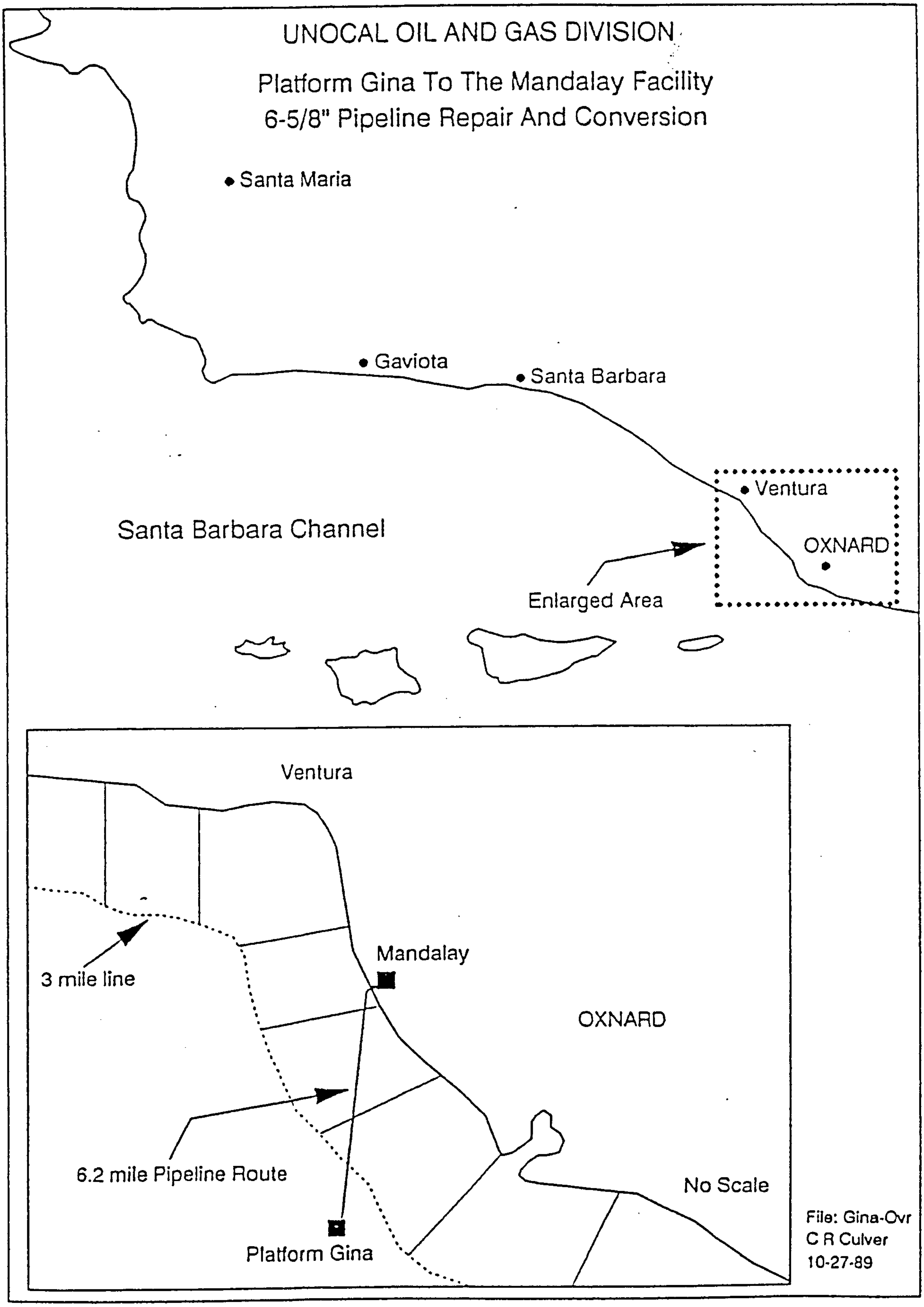
C. H_2S Removal

1. Temporary Sweeteners (initial)

2. Permanent Plant (design from initial production information)

D. Water Dehydration (either Gina or Mandalay)

E. Electric Driven Gas Compression (may be required)


UNOCAL OIL AND GAS DIVISION
Platform Gina To The Mandalay Facility
6-5/8" Pipeline Repair And Conversion
Santa Maria
Gaviota
Santa Barbara
Ventura
Santa Barbara Channel
OXNARD
Enlarged Area
Ventura
3 mile line
Mandalay
OXNARD
6.2 mile Pipeline Route
Platform Gina
No Scale
File: Gina-Ovr
C R Culver
10-27-89

December 8, 1989

INTRODUCTION

Unocal initiated this project, Platform Gina To The Mandalay Facility 6-5/8" Pipeline Repair And Conversion in late 1988. After completion of the design of the project a project description was prepared in March of 1989. This preliminary project description was provided to the City of Oxnard for review and comment in order to address as many public agency concerns as possible prior to formal submission to all the juristictional agencies.

During the period between submittal of the preliminary project description and the present the City conducted an extensive review of the project. This review has resulted in the City issuing studies of the project and soliciting comments from the other juristictional agencies. Unocal has completed other studies and background work to more fully describe the project.

At this time Unocal has published a second project description entitled "Platform Gina To The Mandalay Facility 6-5/8" Pipeline Repair And Conversion Project--Revision 1" dated December 1989. This document incorporates the new studies, is an expansion of the description to address certain areas, and provides other information assembled since the original description. This revision is designed to provide an updated and complete description of the project as the project undergoes the formal review process by the jurisdictional agencies.

At this time Unocal would like to thank the City of Oxnard for the work to date on Unocal's behalf and the ongoing coorperation. Unocal also would like to stress it's intent to work closely and cooperatively with all responsble agencies with this and other projects.

TABLE OF CONTENTS

PROJECT DESCRIPTION: OVERVIEW

Platform Gina is located 6 miles southwest of Oxnard, California within OCS P-0202 in federal waters. Platform Gina is in 95 feet of water and has been on production in the Hueneme zone since 1982. The existing wells are produced by electric submersible pump systems to the Mandalay onshore processing facility, located in the City of Oxnard, through a 10-3/4 inch pipeline. There are 15 total well slots on Platform Gina, 6 oil producing wells, 5 water injection wells, 1 exploratory well (H-14), and 3 unused slots.

Oil and water separation and treating are conducted at the Mandalay facility. The produced water was returned to Platform Gina through a 6-5/8 inch pipeline for disposal. The 10-3/4 inch and the 6-5/8 inch pipelines are the only pipelines between Platform Gina and the Mandalay facility. The 6-5/8 inch pipeline has not been in service since October, 1988 when a leak was detected in the pipeline near the Mandalay facility.

The final exploratory well, H-14, is now being tested in the Sespe zone in an effort to determine the size and extent of reserves which underlie both OCS P-0202 and the adjacent tract OCS P-0203. It is proposed to repair and then convert the 6-5/8 inch pipeline from Platform Gina to the Mandalay facility from water return service to gas sales service to evaluate the final exploratory well, and provide for long term field development.

The phases of the project required to develop exploratory well (H-14) will include the installation of gas processing equipment on Platform Gina, conversion of the 6-5/8 inch pipeline to gas sales service, and the modification of piping at the Mandalay facility. All phases of the project will be consistent with the highest industry standards with regard to engineering, safety, and environmental concerns. The project is consistent with the requirements of CFR 49 section 190-195 (Department of Transportation Regulations), CFR 30 (Department of Interior and Minerals Management Service Orders governing offshore platforms), and provisions of CEQA (California Enviromental Quality Act).

Since the change in service of the 6-5/8 inch pipeline is the main deviation from current permits and operating plans, this is the phase of the project which will be explained in detail in the remainder of this project description. EIR 78-19 provides background consistent with using the platform to produce, process and transport gas to shore via the pipeline. The 6-5/8" pipeline was originally described as a water pipeline although it was designed to standards to accomodate the conversion to gas service. Another purpose of this project description is to summarize the possibilities of development known at this time and explain the options which will be pursued prior to long term field development.

The project description will be divided into three separate sections. Section I will identify current development plans, Section II will explain the repair of the pipeline and its conversion to gas sales service, and Section III will identify the equipment changes necessary on Platform Gina and at the Mandalay facility to provide for gas sales.

To provide background for the project and support the original EIR 78-19 a risk assessment study has been completed to quantify the risks associated with the project. The risk assessment study has reviewed the following:

1. The overall project design.

2. The hydrogen sulfide (H_2S) monitoring and shutdown system and the probability of H_2S gas leaving the platform and being released to the atmosphere posing a public concern.

3. Comparison of design to industry standards, MMS standards, DOT pipeline standards, and other standards where applicable.

4. Any other project areas that represent significant risk.

The following page provides some historical highlights of the Hueneme Field and Platform Gina to date, for general information.

PT. HUENEME UNIT
OCS P-0202 & P-0203

BRIEF SUMMARY

- Unit Operator: Unocal
- Unocal's Working Interest: 100%
- Federal Government Royalty: 16.66%
- Surface Acreage: 2824 acres P-0202

  5760 acres P-0203
- Water Depth: 95' at Platform Gina

HISTORY/HIGHLIGHTS

- Federal Lease Aquired in 1968
- 11 Exploratory Wells from 1969 to 1981
  - 6 on OCS P-0202 and 5 on OCS P-0203
- 6 Production and 5 Injection Wells on Gina
- Exploratory Wells P-0203 #5 and #6 drilled in 1985
- Exploratory Wells P-0203 H-13 and H-14 drilled in 1988
- Cumulative Production 6.36 MMSTB of Oil and 1.65 BCF of Gas to January, 1989

SECTION I

I.1.0 CURRENT DEVELOPMENT PLANS

It is known that gas reserves underlie Platform Gina in OCS tracts P-0202 and P-0203 in the Sespe and Monterey zones. The size and extent of these reserves will be determined by development drilling and prodcution testing. The first well drilled to explore the Monterey zone gas was drilled in 1985 from a mobile drilling rig. This well, OCS P-0203 # 5, was plugged after testing, but provided data that warranted further exploration. A second well OCS P-0203 # 6 was also drilled in 1985.

Two wells were drilled in 1988 from Platform Gina. The first well, H-13, was drilled and tested in the Monterey zone but has been plugged and abandoned as a dry hole. The second well, H-14, is currently completed in and is testing the Sespe zone that underlies the Monterey zone. The Monterey zone in well H-14 is potentially productive, based on analysis of information gained during the drilling process.

I.1.1 CURRENT EXPLORATORY WELL - H-14 (Drilled in 1988)

The current exploratory well, H-14, was drilled from Platform Gina in the last half of 1988 and is currently completed in the Sespe zone. Some drill stem and production testing have been done. The tested Sespe gas does not contain any hydrogen sulfide and conforms to all gas sales specification required by Southern California Gas Company. The H-14 gas analysis and gas sales specifications can be found in Appendix A.

Oil and gas has been tested from the H-14 well by producing directly into the 10-3/4 inch pipeline and using the separation and treating equipment at the Mandalay facility. The well is producing currently with a submersible pump from the Sespe zone. This is the method used for the Hueneme zone wells which are currently produced.

The Monterey zone is potentially productive in well H-14, and it is planned to complete and test this zone when the testing of the current zone is complete. The Monterey zone is possibly a sour gas (hydrogen sulfide (H_2S)) zone. If this is the case, all gas will be sweetened offshore prior to either flaring for short term testing or transportation through either of the pipelines to shore for long term testing or gas sales. Hydrogen sulfide (H_2S) gas will not be transported to the Mandalay facility through either pipeline. In section III a further explanation of the gas processing equipment will be provided.

The basis for determination that the Monterey zone gas may contain hydrogen sulfide is the gas analysis from drill stem test 2A of well OCS P-0203 #6, which again was drilled in 1985. Of several drill stem tests conducted on this well, only test 2A encountered hydrogen sulfide, which was present at a level of 2,000 ppm. The gas analysis of this drill stem test is also found in Appendix A. All drill stem tests on wells H-13 and H-14 performed to date have not encountered sour gas.

I.1.2 RESERVOIR DEVELOPMENT

Although it is difficult to determine the exact development size of gas reserves under Platform Gina in OCS tracts P-0202 and P-0203 until further drilling and testing are completed, some assumptions have been made and will be presented. Current drilling and geologic boundaries have determined that the gas reservoir could require eight wells for full development.

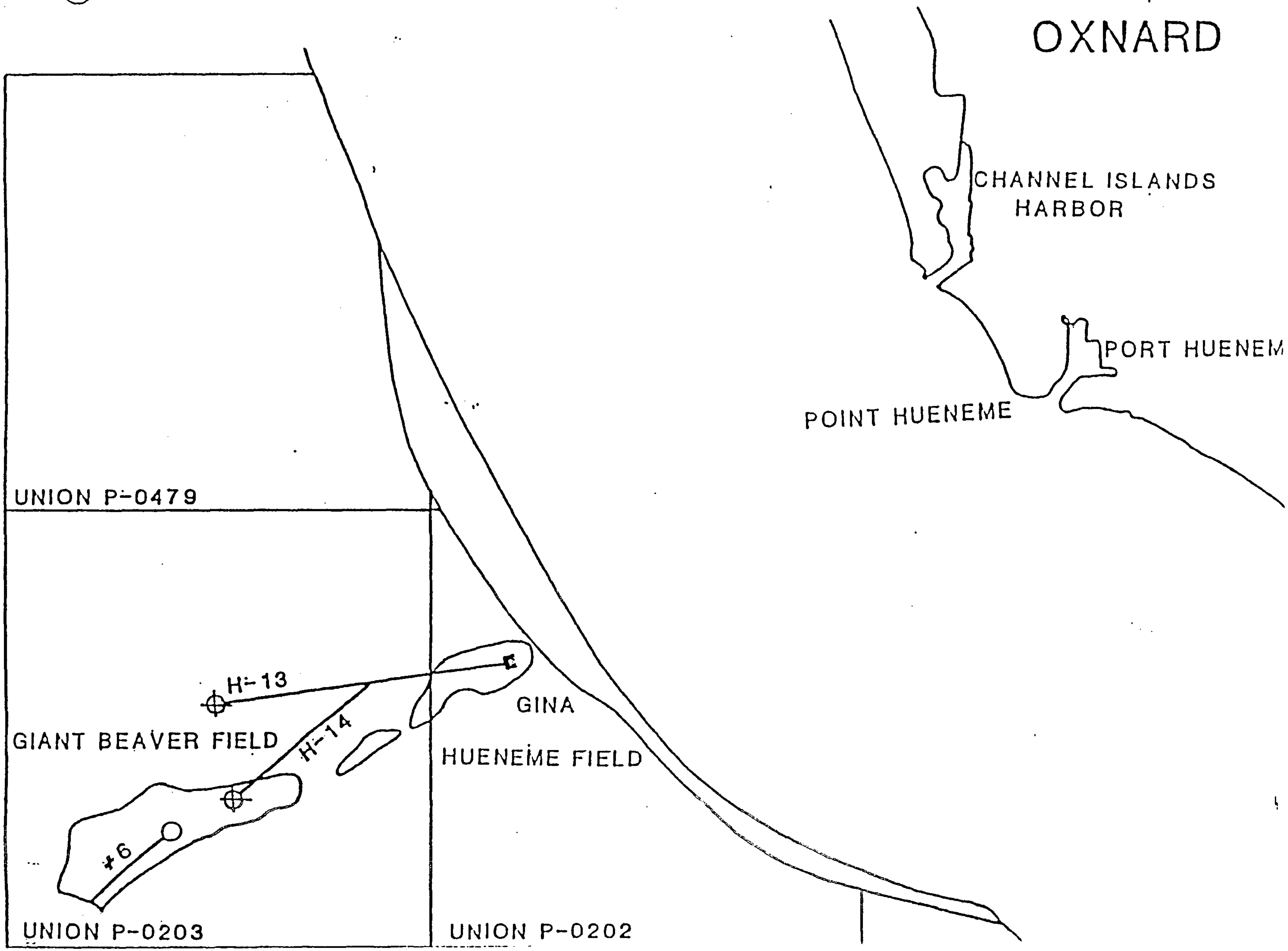
The major reservoir to be developed is the Monterey zone. Current information about the reservoir indicates potential reserves of 33 billion cubic feet, producing at a maximum 18 MMSCF/Day rate after all the wells are on production. A twelve year life is estimated, and project timing is based upon drilling the second developement well in 1990, three additional wells in 1991, and the final three wells in 1992.

I.1.3 HYDROGEN SULFIDE TREATING

The exact concentration of hydrogen sulfide which the Monterey zone will have is not known currently. Based on experience in the Santa Barbara Channel and results obtained in pertinent drill stem tests, it is assumed that the gas will be similar to gas encountered in well OCS P-0203 #6. This is the closest Monterey zone well to Platform Gina which has encountered sour gas.

Regardless of the concentration of the hydrogen sulfide in the produced gas, the gas will not be sent to the Mandalay facility until it is sweetened offshore to conform to the gas sales specification. The gas sales specification is 0.3 grains per 100 standard cubic feet or 4 ppm (the gas sales contract and its specifications are in Appendix A). The sales specification is more stringent than the OSHA-PEL standard of 20 ppm, and the American Conference of Governmental Industrial Hygienists (ACGIH) standard of 10 ppm. Additional detail on these standards is located in Appendix A.

There are several methods available for treating the gas to remove the hydrogen sulfide (H_2S). These methods range from chemical scavenging with a variety of chemicals to large scale treatment plants. Unocal has experience in the production and treating of sour gas produced from both onshore and offshore reservoirs. This experience includes offshore treatment to prevent the shipment of sour gas to onshore facilities, and also includes use of both chemical scavenging and treatment plant technologies. Further explanation of gas processing will be provided in Section III.


OXNARD
CHANNEL ISLANDS
HARBOR
PORT HUENEM
POINT HUENEME
UNION P-0479
H-13
GINA
H-14
GIANT BEAVER FIELD
HUENEME FIELD
+6
UNION P-0203
UNION P-0202

SECTION II

II.1.0 6-5/8 INCH PIPELINE REPAIR- DESCRIPTION

This section of the project description summarizes the repair of the 6-5/8 inch pipeline between the Mandalay facility and Platform Gina. This repair will be completed prior to converting the line to gas service, and will replace 3,000 feet of the pipeline from the Mandalay Facility wall (about 600 feet above the Mean High Tide Line (MHTL) landward towards the Mandalay facility), to a point 2,300 feet from the MHTL seaward toward Platform Gina. Excavation, installation, and restoration required for the pipeline repair will be explained in the following sections of this project description. The time required for the repair of the pipeline will be 3 weeks once work begins.

II.1.1 OVERVIEW OF PIPELINE

The subject pipeline is a 6-5/8 inch line 32,576 feet in length between the Mandalay treating facility in Oxnard, California and Platform Gina within OCS P-0202. The 6-5/8 inch pipeline runs from the Mandalay facility southwest beneath the sand dunes that are northeast from the beach. Beneath the sand dune the line is inside a 10 inch protective conduit. Once the line leaves the conduit, a long radius bend turns the pipeline to 14° west of south and from this point the line proceeds directly towards Platform Gina. The as-built pipeline drawings can be found in Appendix B.

The pipeline was installed in September of 1981 and was pressure tested to 2190 psi for 25 hours. Originally, pipeline burial was performed by natural surf conditions in the surf zone. Subsequent surveys have shown that the line has remained buried since installation in the surf zone.

The pipeline has been in service carrying produced water to Platform Gina for offshore disposal since 1982. In 1985, a 650 foot portion of the pipeline was replaced from the Mandalay facility seaward towards the surf zone. This replacement was from the wall of the Mandalay facility to the MHTL (see 1985 Repair, as-built drawing in Appendix B).

Original documentation for the pipeline such as EIR 78-19 and the pipeline design conducted by PMB Engineering (in Appendix A) refer the 6-5/8 inch pipeline as a "water pipeline". The pipeline was built to the same standards as the adjacent 10-3/4 inch oil pipeline and the three Gilda pipelines of which one of which is a gas pipeline. The proposed change to gas service is consistent with the original design.

The condition of the pipeline has been surveyed annually since the original installation. This is done by alternating a Side-Scan Sonar survey and a Linalog survey each year. The Side-Scan Sonar survey is an external survey and verifies pipeline burial and external damage; the Linalog survey determines internal and external damage of the pipeline, but does not delineate burial conditions. The results of these surveys are presented in Appendix C. The survey results are reviewed by the Minerals Management Service annually.

II.1.2 PIPELINE REPAIR PROCEDURE

The first step of the pipeline repair, which has been completed, was to locate the pipeline in reference to the beach and ocean floor in the area of the repair. All surveys conducted of the line since it was installed have shown that the pipeline is buried in the repair area. It was also necessary to determine the depth of cover to obtain data on the required excavation and offshore tie-in. A drawing was made to show the pipeline route, contour of the beach and ocean floor, the depth of pipeline cover, and the proposed onshore and offshore tie-in points (see Appendix B, drawing 7). The pipeline has 4 feet of sand coverage throughout the repair area.

The second stage of the repair will be to cut the pipe at the offshore tie-in point, which is 2,300 feet from the MHTL. Once the pipe is cut, a small section will be removed for inspection purposes and to allow room for the tie-in. A subsea connector and a pipe flange with a blind flange attached will be installed.

After this second step in the repair operation, the pipeline from this point to Platform Gina will be pressure tested to 900 psi. This test will ensure integrity of the subsea connector and the remaining pipeline toward Platform Gina. Once the test is successful the project will proceed to step three. If the pressure test is not successful, the cause will be determined, necessary repairs will be made accordingly, and the pressure test will be repeated.

Step three will to weld together 2,700 feet of the replacement pipe on the beach. This will be performed in accordance with the procedure detailed later in this repair plan. The City of Oxnard has approved the welding of the pipe on the beach and an encroachment permit was approved for beach access.

The fourth step of the pipeline repair procedure will be to pull the replacement pipe to the offshore tie-in point and perform the tie-in. Once the pipe is pulled to this point, it will be flange connected to the existing pipeline from Platform Gina using the fittings installed in step two. This will leave 400 feet of replacement pipe on the beach which will be run in the right of way and at the same level as the existing pipeline.

The final step will be to weld the additional 300' of pipe to get from the Mandalay Facility to the point where the offshore pull of the pipe terminates. The beach work will be conducted with conventional equipment. The pipe will be pulled through the 10" conduit that runs underneath the sand dune to prevent any alteration of the dune area.

The surf zone and offshore burial will be accomplished by conventional equipement as far as practical. Hydraulic jetting will be limited to areas in which the surf zone energy is not sufficient to bury the line. The remaining line will bury itself by the natural wave energy. This is described in detail in the "Evaluation of the Potential for Self-Burial of the Proposed Unocal Gina Pipeline" study completed by the University of California, Berkeley in May of 1989. The pipe will obtain burial to the same depth as the current line (4 feet) in a short period of time induced by the natural surf conditions. The onshore section will be buried mechanically with conventional equipment.

II.2.0 PIPELINE DESCRIPTION AND DESIGN

The original pipeline installation was designed in accordance with standards found in Title 49 CFR Part 192 from the Code of the U.S. Department of Transportation Regulations, and the Minerals Management Service O.C.S. Order #9. These are the standards which apply to the transmission of gas through pipelines. The 1985 repair was conducted to these standards and the proposed repair and conversion plan is designed to meet these same standards.

The new pipeline will be identical in size to the original pipeline; minor coating differences will be described below. The original pipeline design was done using engineering analysis methods by a consultant, PMB Systems Engineering, and this detailed information is contained in Appendix D. This study addressed sea currents, pipeline cathodic protection, pipeline coatings, and other pertinent design information. Any deviations from this study are explained in the next section.

II.2.1 MATERIAL SPECIFICATION

Pipe:	6-5/8" O. D. Seamless (original was ERW)
Schedule:	SCH 40 (.280" wall thickness)
Weight:	18.97 pounds per foot
Grade:	A106 grade B
SMYS:	35,000 psi
Design Pressure:	1440 psi
Operating Pressure:	500 psi
Maximum Operating Pressure:	600 psi
External Coating:	X-Tru Coat polypropylene (original was Pritec)
Field Joint Material:	Thermofit WPC wraparound sleeves
Length:	3,000 feet
Concrete Coating:	1.00 inch (original was 1.75 inch)
Concrete Weight:	25.36 pounds per foot
Corrosion Anodes:	300 feet apart
Anode Material:	Sea-alloy 150 (original was Galvalum III)
Anode type:	1/2 shell bracelet

This material to complete the line repair has been obtained and the purchase orders, pipe inspection data, and other information for the material can be found in Appendix D.

II.2.2 EXTERNAL COATINGS

The polypropylene coating was chosen because it will provide suitable protection for the pipeline and it was readily available at the time the pipe was obtained. A letter from the Unocal Science and Technology Division is provided as a supporting recommendation for this choice of coating (see Appendix D).

II.2.3 CATHODIC PROTECTION

The original pipeline cathodic protection system was designed for a 20 year life. This original design is in Appendix D in the PMB Systems Engineering report of May 1981. The original design called for 88 pounds of anode per 1,000 feet of pipeline, and the repair plan will result in 190 pounds of anode per 1,000 feet of pipeline.

The line has been surveyed twice since its original installation for cathodic protection. The first by Harco Corporation in January, 1984 indicated the only problem to be a short across an insulating flange located at the Mandalay facility, which was corrected. The Unocal Science and Technology Division now tests the performance of all such flanges annually to verify their proper operation. The second survey was conducted by Corrpro in February, 1989 and the results of that survey indicate that adequate cathodic protection is being given to the 6-5/8 inch pipeline. The complete survey results are in Appendix C.

II.2.4 CONCRETE COATING

The difference in the concrete coating thickness of the replacement pipe has been addressed in a burial study conducted by the Ocean Engineering Departmant at the University of California at Berkeley. This study, Evaluation of the Potential for Self-Burial of the Proposed Unocal Gina Pipeline, May 1989 is provided under separate cover.

II.2.5 SPECIFIC GRAVITY OF PIPELINE

The following table summarizes the net buoyancy of the replacement pipe section of the 6-5/8 inch pipeline:

	SURF ZONE W/CONCRETE		OFFSHORE W/CONCRETE	
	Negative Buoyancy (lbs/ft)	Specific Gravity (water=1)	Negative Buoyancy (lbs/ft)	Specific Gravity (water=1)
Pipeline Empty	43.06	2.36	18.49	2.09
Pipeline Full	55.83	2.51	31.26	2.22

II.2.6 CONNECTING SPOOL PIECE

One connecting spool piece will be required to perform the repair of the 6-5/8 inch pipeline. This connecting spool will be located at the offshore tie-in point, 2,300 feet from the MHTL.

The connecting spool piece will join the replacement pipe to the existing line, using standard pipe flange connections. The spool is necessary to provide the needed fit between the existing and replacement pipe sections. The actual length and configuration of the connecting spool piece will be determined after the replacement pipe pull using actual field measurements.

II.3.0 PROJECT CONSTRAINTS

All construction projects of this type are conducted in a professional manner, stressing safety and environmental protection equally with other measures of job performance. Unocal realizes that the range of the project includes public areas, and the guidelines listed below will be strictly enforced during the construction period.

1. All vehicular access will be from Fifth Street in the City of Oxnard. This will require grading a small portion of sand entering the beach and the installation of a temporary gate. A guard will be posted during the construction period in order to protect and inform the public. Once the project is complete, removal of all equipment from the beach will be done as soon as possible. The beach and access area will be regraded to its original level.

2. The pipe staging and welding area will be north of the original pipeline, towards the Edison outfall canal.

3. When equipment is on the beach, vehicular traffic will be kept to a minimum. Equipment will be left on the site whenever possible rather than removed and returned to the site. Crew transport in and out of the facility will involve crews walking over the sand dune adjacent to the project area, east of the Mandalay Facility. This foot traffic through the sand dune area will be minimized and will be restricted to a designated area.

4. The sand dune area is strictly off limits except for the designated area. A temporary fence will be constructed between the sand dune and the job site to prevent any unauthorized vehicles or personnel from entering the area. This fence will be removed upon project completion.

5. Good housekeeping policies will be strictly enforced. Unocal and the contractor will exercise diligence to conduct all operations in a manner that will prevent pollution, and will comply with all applicable laws, ordinances, rules, regulations, leases, or provisions regarding all forms of pollution. No garbage, trash, waste, or other pollutants will be discarded or discharged on the beach or in the Santa Barbara Channel. Unocal and the contractor will be responsible for all trash, surplus tools, and other equipment removal during the project.

6. The area of the project has occasional pedestrian traffic. The time that a trench is open will be minimized, and the trench area will be barricaded with warning lights and a guard at night.

7. Unocal will provide a 24 hour guard for purposes of informing the public, security of the area, and prevention of unauthorized access to the beach. The guard will be at the Fifth Street access during operating times and will be at the job site the remainder of the time. The guard will be present from the project start up to completion and will be equipped with a 4 wheel drive vehicle and radio communications.

II.3.1 GENERAL PROJECT REQUIREMENTS

The contractor (Hood Corporation) has provided Unocal a complete list of all equipment, methods, facilities and items to be used during the project (See Appendix E).

The contractor will be required to transport the pipe and material from the access area at Fifth Street to the job site and will provide suitable equipment for this work. At completion of the project, Unocal and the contractor will be responsible for removal of all unneeded material from the job site to appropriate storage yards.

II.4.0 INSPECTION AND TESTING REQUIREMENTS

All welds will be made in accordance with Unocal's welding procedure (see Appendix E) and will be radiographically inspected. The standard for acceptability shall be API Standard 1104 "Standard for Welding Pipelines and Related Facilities", as directed by Title 49 CFR Part 192 (gas pipelines) of the Minimum Federal Safety Standards. All welders will be certified to this standard before work on the project commences.

Once the pipeline tie-ins are made, a pressure test will be conducted. This test will be conducted at 900 psi and will test the entire pipeline from the Mandalay facility to Platform Gina. The test will be held for a minimum of 4 hours and witnessed by the Minerals Management Service and a Unocal representative.

Prior to covering the pipe, the location of the line will be surveyed for the permanent records. The installation contractor will provide the surveyor with assistance as required for both the onshore and offshore sections of the survey.

Before covering the pipeline and during the pipeline pull, the replacement pipe will be inspected for coating flaws. All flaws will be repaired before the pull operation continues, or before the pipe is buried. Repairs will be performed in accordance with the pipeline coating manufacturer's recommendations.

II.5.0 PIPE WELDING AND PULLING REQUIREMENTS

The replacement pipe will be welded according to Unocal's welding procedure (Appendix E) and will be welded in the onshore staging area in a series of three to six side-by-side strings. The first joint of pipe will have a 6 inch flange installed, which will connect the replacement pipe to the subsea connector at the offshore tie-in location.

Replacement pipe sections with cathodic protection anodes will be installed approximately 300 feet apart. The first anode equipped section will be the first full pipe section of the pull.

Each weld joint on the pipe will be equipped with protective sleeves installed according to manufacturer's specifications. Before and during the pulling operations, efforts will be made to insure that the external coatings are not damaged. Additionally, the replacement pipe coatings and anodes will be inspected and repaired, if needed, both prior to and during pulling operations.

The pulling of the pipe will be conducted in a manner which will not compromise the external coatings nor overstress the pipe or its concrete coating.

II.5.1 TIE-IN PROCEDURE

The offshore tie-in location will be 2,300 feet from the Mean High Tide Line (MHTL). After excavating small holes for access, the pipeline will be cut at the tie-in point and again some 40 feet landward. The resulting 40 foot section of pipe will be removed, providing room for the replacement pipe to be connected to the existing pipeline.

The subsea connector and a pipe flange with a blind flange attached will be installed by divers. An underwater habitat will then be installed at the tie-in point so that a dry welding environment can be obtained. After the habitat is installed it will be filled with an inert gas and the subsea connector will be welded with a pipeline quality seal weld.

The pipeline will then be pressure tested to 900 psi between Platform Gina and the tie-in point. This test will ensure integrity of the subsea connector and the remaining pipeline. Once the pressure test is complete, the replacement pipe on the beach can be made up in accordance with the previously outlined procedures (sections II.3.0 through II.5.0).

II.6.0 MATERIAL PROVIDED BY UNOCAL

1. 3,000 feet of 6-5/8 inch diameter schedule 40 pipe, externally and concrete coated.

2. 9 pipe sections equipped with cathodic protection anodes.

3. Protective sleeves.

4. Six - 6 inch nominal 600 series RTJ weld neck flanges with rings, studs, and nuts (only 4 should be required).

5. Two - 6 inch nominal 600 series blind flanges (for testing purposes and pipeline pull).

6. Two - 6 inch 10 diameter sweep bends (none should be required).

7. Fencing for the sand dune area (work will be done prior to project start after permits are approved).

II.6.1 MATERIAL PROVIDED BY CONTRACTOR

All equipment and consumables necessary for project completion not provided by Unocal will be provided by the contractor. These include, but are not limited to, welding materials, excavation equipment, buoys for line buoyancy, marker buoys for post line replacement survey, fittings for pressure testing, and coating repair material.

The contractor will provide equipment designed to minimize the total equipment needed to complete the project. Equipment which can serve dual roles will be used whenever possible.

II.7.0 POST LINE REPAIR REQUIREMENTS

Once the project is completed, Unocal and the contractor will be responsible for removal of the fence between the sand dune and the beach area, and for the clean up of all material that remains on the beach. All equipment utilized for the project will be removed from the beach promptly upon project completion.

The beach sand will be graded to the same contour as before the project commenced. Removal of the gate at the access area, and the regrading of this area, will be completed by the contractor.

The pedestrian walk area in the sand dune area will be the responsibility of Unocal and the contractor. Any areas disturbed will be recontoured and revegetated. Watering of this area will be done until the vegetation is properly established.

SECTION III

III.1.0 PLATFORM GINA AND THE MANDALAY FACILITY EQUIPMENT

In order to process the gas produced from Platform Gina, equipment will be installed on Platform Gina and some piping modifications will be made at the Mandalay facility. The current processing method has been to produce the current exploratory well (H-14) through to the Mandalay facility using the 10-3/4 inch oil pipeline, with gas separation and treating performed onshore as previously mentioned. The H-14 well is currently on production in the Sespe zone with a submersible pump producing the oil and associated gas.

The proposed processing method is to install the necessary equipment to separate and treat gas on Platform Gina once the pipeline repair is complete. All modifications performed or equipment installed at the Mandalay facility or on Platform Gina will be designed, installed, and operated in accordance with all applicable standards regarding safety and environmental concerns.

The equipment installed on Platform Gina will conform to the highest industry standards and Title 30 CFR Part 250 of the Department of Interior regulations governing offshore platforms, and provisions of CEQA (California Environmental Quality Act). All equipment modifications at the Mandalay facility will be permitted with the City of Oxnard before they are installed.

III.1.1 CURRENT STATUS OF FACILITIES

Before the drilling of wells H-13 and H-14 took place from Platform Gina in 1988, three projects were completed to facilitate testing and potential new field development. One project was the structural modification of the platform drilling deck to allow for higher hook loads during the drilling operations. Higher hook loads are the result of the greater measured well depths to reach the prospective Monterey zone areas. This work will allow drilling the remaining 3 slots on Platform Gina, and additional slots can be added in the future as needed, with other structural modifications.

A second project was to construct a 23 foot by 40 foot production deck extension on the west side of the platform to provide room for test equipment and a temporary flare stack was installed to test the wells. The deck extension space was utilized for the temporary well testing equipment and will also be available for some of the permanent facilities. The temporary test equipment consisted of a test separator, 2 temporary sweeteners, and a flare scrubber. The flow schematic is in Appendix F. The 2 temporary sweeteners were not used as the gas encountered during the H-13 and H-14 drill stem tests of the Sespe zone has been sweet. The Monterey zone gas from well H-14 is expected to be sour, but has not yet been tested.

The third project which took place was to install a complete ambient hydrogen sulfide monitoring system on Platform Gina as a safety precaution. This system consists of eight monitors at various locations around the platform to monitor the air for hydrogen sulfide (H_2S). This system has been wired into the platform's control logic system to effect complete platform shutdown should a dangerous level of hydrogen sulfide (H_2S) be encountered. In addition, a hydrogen sulfide contingency plan was developed for Platform Gina. The deck layout plan for the ambient air hydrogen sulfide monitors is included with the Fire and Safety Equipment Arrangement Drawing in Appendix F. The H_2S contingency plan is on file at the platform and at the Minerals Management Service. Both of these measures are industry safety standards and conform to 30 CFR Part 250 of the Department of Interior regulations for offshore platforms.

Wells H-13 and H-14 were drilled after completion of the three projects described above. Well H-13 was a dry hole, and only limited drill stem testing was conducted. H-14 was drill stem and production tested in the Sespe interval, with production testing performed by blending the production directly into the 10-3/4 inch pipeline with the current Hueneme zone production. Existing equipment at the Mandalay facility separated, treated, and prepared the gas for sale. The sale of the tested gas and production of H-14 is ongoing because the gas does not contain any hydrogen sulfide (H_2S). The flow schematics for this testing equipment used prior to installation of the submersible pump are presented in Appendix F.

A current project underway to provide for future well testing and permanent processing of the production at Gina is a permanent flaring system. This system will be designed for a maximum throughput of 18 MMSCFD rate and will be complete by the end of 1989. This flare boom system will provide a flare scrubber, seal drum, smokeless burner design, and a flame extinguishing system. This system will conform to regulations 30 CFR 250 and to API 521, governing offshore flaring installations. A schematic diagram of the system is in Appendix F.

III.2.1 MONTEREY PRODUCTION FACILITIES

In order to produce the prospective Monterey interval in well H-14 once the pipeline is repaired, a separation system and treating system will be installed on Platform Gina. The flow schematics for this equipment are presented in Appendix F. Initially, temporary equipment will be used to provide flexibility for the test volumes and hydrogen sulfide (H_2S) concentrations of the gas. As development with additional wells takes place, permanent facilities will be designed and installed.

III.2.2 TEMPORARY HYDROGEN SULFIDE SWEETENING FACILITIES

The initial equipment installed will include a gross separator, two batch sweeteners, two hydrogen sulfide line monitor, and a final gas scrubber. The batch sweeteners will each be capable of treating a gas volume of 3.0 MMSCF/Day and sweetening from a hydrogen sulfide level of 2,000 ppm to less than 4 ppm. The associated liquid production will be handled by an existing shipping tank with two triplex pumps, each of which are capable of 2,000 barrels of liquid per day. This liquid will be shipped to Mandalay through the 10-3/4 inch pipeline.

Initially, this equipment will be utilized for only the current well H-14. All gas will be sweetened to the pipeline specification for hydrogen sulfide before it enters the 6-5/8 inch pipeline. The hydrogen sulfide pipeline monitors will verify that the gas is under the 4 ppm specification before the gas enters the pipeline. If a hydrogen sulfide level exceeding the 4 ppm specification is obtained, the monitors will automatically shut down the producing well or wells and the pipeline shutdown valve will be closed. Southern California Gas Company has a monitor as well at the Mandalay Facility on the sales gas meter. The flow schematics of all the equipment can be found in Appendix F.

III.2.3 PERMANENT HYDROGEN SULFIDE SWEETENING FACILIT

As the production phase proceeds to full field developme additional facilities and equipment will be needed. This could include the installation of additional deck space along the south side of Platform Gina to allow for some of the equipment. The additional equipment could include a standard production and test header system, a test separator, a gas dehydration unit, a permanent sweetening plant, and gas compressors. The actual equipment needed would be based on future well test results and detailed reservoir evaluation.

III.3.0 HYDROGEN SULFIDE REDUNDANT MONITORING, DETECTION, SHUTDOWN, AND ALARM SYSTEM

As part of the temporary and permanent installation of facilities on Platform Gina to produce the hydrogen sulfide gas a redundant H_2S monitoring, detection, shutdown, and alarm system will be installed to monitor the H_2S concentration in the gas before it enters the gas pipeline leaving Platform Gina. This will provide two separate verifications of the H_2S concentration before the gas leaves the platform. This will insure H_2S gas does not leave the platform via the pipeline.

The redundant monitoring, detection, shutdown, and alarm system for the H_2S in the gas stream at Platform Gina will be accomplished by 3 separate H_2S monitors. These monitors will be 2 at Gina, and the 3rd monitor will be the Southern California Gas Company monitor at Mandalay. The redundancy of the monitoring is that the gas from Gina will be verified for H_2S concentration 2 times before it leaves Platform Gina and one more time before sales are made at the Southern California Gas Company meter at Mandalay. This system is considered by Unocal to be more than adaquate to insure that H_2S gas does not leave either platform. The relibility of this system has been more fully discussed in the risk assessment study prepared entitled "Platform Gina Gas Production And Pipeline Mandalay Onshore Receiving" dated November 21, 1989.

The monitors operate by being sensitive to hydrogen sulfide and sensing the rate of lead formation on a lead acetate coated paper by use of a photo-cell and a light source. This type of monitor has proven to be reliable and is extensively used in the industry by gas transmission companies like Southern California Gas Company. The continuous monitors are designed to activate an alarm should a treating system upset occur that results in a hydrogen sulfide concentration of 2 ppm in the gas stream. The continuous monitors will activate shutdown of the gas producing well or wells should the hydrogen sulfide concentration reach 4 ppm. The alarm and shutdown features are fully automatic, and the monitors themselves are regularly calibrated, with the results reviewed by the Minerals Management Service.

With regard to the timing of the H_2S monitor installations at Gina, the new H_2S monitors at Gina will be installed prior to the initiation of gas sales from Gina via the 6-5/8" pipeline and after the permit is obtained.

The following pages show a table of the H_2S monitors and a simplified schematic of the locations of the monitors for Platform Gina. This will identify the function of each monitor in detail.

H_2S Redundant/Monitoring/Detection/Shutdown/Alarm Systems

Platform Gina

Proposed Monitor-Monitor A

1. Monitor: Gas stream on Gina
2. Detection: H_2S content
3. Shutdown: 4 ppm H_2S
4. Alarm: 2 ppm H_2S
5. Install: During the facility installation at Gina and before sales commence.

Proposed Monitor-Monitor B (Redundant Monitor)

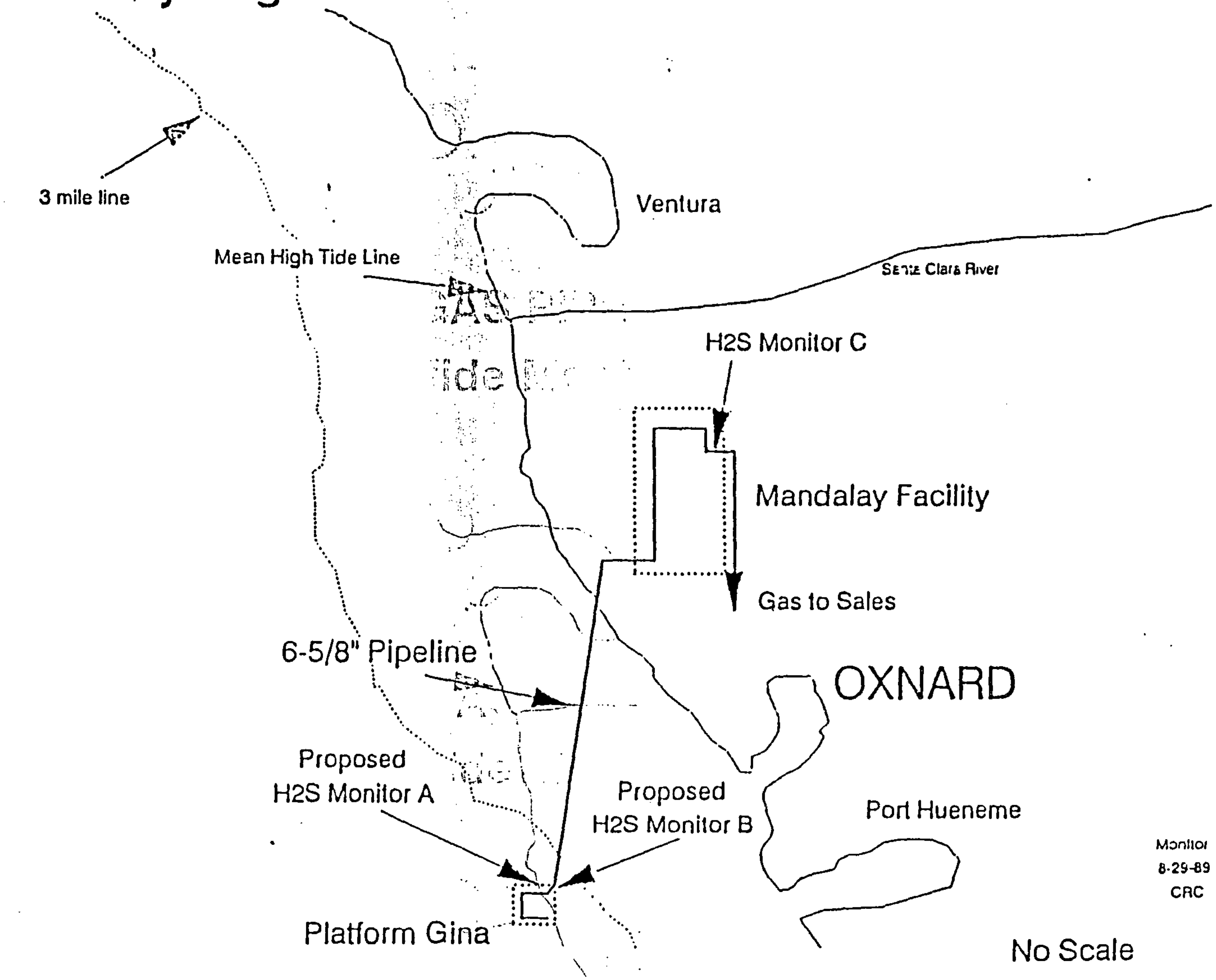
1. Monitor: Gas stream on Gina downstream of monitor A
2. Detection: H_2S content
3. Shutdown: 4 ppm H_2S
4. Alarm: 2 ppm H_2S
5. Install: During the facility installation at Gina and before sales commence.

Additional Redundancy: Gas is monitored in the same manner by the Southern California Gas Company (monitor C) monitor at the sales meter at the Mandalay Facility.

Mandalay Facility	Current Monitor-Monitor C		
	1.	Monitor:	Gas stream of Gilda (currently) and Gina (when sales begin) at gas sales meter
	2.	Detection:	H_2S content
	3.	Shutdown:	4 ppm H_2S
	4.	Alarm:	2 ppm H_2S
	5.	Owner:	Southern California Gas Company

PLATFORM GINA GAS PIPELINE CONVERSION

Hydrogen Sulfide Monitor Locations



Memorandum

UNOCAL 76

Copy: 6/28/89 DR
Ralph Steele

June 26, 1989

TO: Bill Weldon

FROM: Chris Culver CRC

RE: Abandonment of 6-5/8" Gina Pipeline Section

To confirm and support the conversation of the question of how the 2700' section of pipeline should be abandoned review has been conducted of the surveys and studies conducted on the 6-5/8" pipeline between Platform Gina and Mandalay. Abandonment of the pipeline in place is acceptable due to the heavy specific weight of the pipeline, the wave current climate, and the local geology of the Mandalay Beach Area. History and study, of the pipeline, support that the abandoned line will remain in place. A secondary intent of abandoning the pipeline in place is to minimize the disturbance of the seafloor. If desired, the pipeline section cut and abandoned can be attached to the 10" pipeline adjacent to it, jetted deeper and sand bagged, or anchored in place in some other manner, but this is not deemed necessary to keep the line in place.

A study conducted by the University of California titled; Evaluation Of The Potential For Self-Burial Of The Proposed Unocal Gina Pipeline is specific to the 6-5/8" pipeline in the Mandalay location. This study is dated May 1989 and was conducted by leading authorities on the subject. This study is an engineering evaluation of the mechanisms behind the pipelines tendency for self-burial when acted upon by the natural forces specific to the Mandalay area. The conclusion of the study page 71 and 72 is attached for reference. Since the abandoned section of pipeline will be in the same condition as the pipeline modeled in the study the same conclusions will be applicable.

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Basically the study indicates that if the pipeline should be acted on by a storm condition which should remove the cover on the pipeline, the line will be acted upon by self-burial mechanisms. Since the pipeline has a greater density than the supporting media in the area burial will occur. The geology of the area indicates that the area is composed of unconsolidated sediments. The original pipeline design more fully describes the geology of the area in Appendix D of the Project Description.

Additional information in Appendix C of the Pipeline Description will support the self-burial of the pipeline. In this appendix are the Side Scan Sonar studies that show the pipeline to have been buried in the area of interest since original installation.

An additional piece of information as to the depth the line is currently buried can be found in the drawing appendix of the Project Description, Appendix B, Drawing 7. This drawing shows the points offshore where the line was physically located by jetting the sand and locating the pipe. These points are delineated by the small circles on the line representing the pipeline. Each of these locations has shown the line to have at least 4 feet of sand cover currently. The onshore depth of the line was determined using a pipeline locator and the line was not physically located. The onshore depths are also indicated by circles on the pipeline in Drawing 7.

If there are any further questions regarding the abandonment of the 2700' section or other assistance is needed regarding the project please contact me.

cc: Greg Leyendecker

For the study area of Mandalay Beach, sidescan sonar studies of the previous pipeline between Gina platform and the Mandalay Beach Power Station by Pelagos Corp. (Jan. 1984, Jan. 1986, Nov. 1986, and August 1988) and Intersea Research Corp. (Dec. 1982) indicated 99% burial of the pipeline along its entire length especially in the 3000 foot zone in question. The surveys between 1984 and 1988 indicated an extension of the burial length of 1000 feet near platform Gina while the power cable laid at the same time showed complete burial for 6200 feet in the similar area. At no time were unsupported spans identified.

These field observations tend to confirm the ranges of self-burial depths and rates projected for the Gina Pipeline.

Conclusions:

The pipeline under study has a high potential for rapid self-burial from the MLLW line to 3000 feet offshore. The self-burial of the pipeline is due in part to the heavy specific weight of the pipeline, the wave-current climate, and the local geology and sedimentology of the Mandalay Beach area. Offshore migration of sediment shows a steadily increasing bed level in the area. Therefore, the depth of burial expected over the next one to ten years is between 2 and 4 feet. Eventual breakout of the pipeline is unlikely since there is an annual increase in bed level elevation.

Memorandum

UNOCAL 76

July 18, 1989

To: Bill Weldon

From: Chris Culver

Subject: Equipment Description of 6-5/8" Pipeline Project

This letter is to provide further information as to the estimated total vehicle trips per day and the suggested truck route of the equipment used for the pipeline repair project as requested in the letter to you from the City of Oxnard dated July 6, 1989.

First of all it is anticipated there will be six loads of equipment and 3 or 4 loads of pipe that will be transported to the site at the start of the project. This equipment will remain on the project site during the entire project. This heavy truck traffic will exit the 101 Freeway at Victoria, travel south on Victoria, to Gonzalez, west on Gonzalez to Harbor, south on Harbor to Fifth, and west on Fifth one block to the temporary access at the west terminus of Fifth street at the beach. Trucks may also stay south on Victoria to Fifth, and then west on Fifth to the west terminus of the street. These are the two routes which will be used. After the project is complete there will be six loads of equipment to leave the site reversing these routes. The equipment to be used has been described in the Hood letter dated November 14, 1989 and appears in Appendix E of the Project Description (a copy is also attached). The pipe will only be transported one way.

In addition to this equipment some miscellaneous lighter equipment will be needed. This equipment will be a 2 ton truck or smaller and is described below by type, number of trips required, and when the trips are required:

Type	Number of Trips	When needed
Backhoe, small	2	Start and end
4WD pickup	8	various
X-ray truck	1	middle
Pressure test truck	1	3rd week

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Daily project requirements will include 2 to 3 automobiles for Unocal supervising personnel, 1 automobile for a Hood Corporation supervising personnel, 3 to 4 automobile or pickup trucks for transport of Hood Corporation pipeline welding crew. Each of these vehicles will be parked at the Mandalay Facility in the area south of the facility outside the fence. Most of these vehicles will make only one trip in and one trip out per day however a couple vehicles may make more trips.

Two trips to the Fifth street access area will be made for the security guards to switch out and the security guard will have a 4WD vehicle which could be at the Fifth street access or at the welding area. This 4WD vehicle will be in the area during the entire project.

UNOCAL

PLATFORM GINA

CONTINGENCY PLAN

FOR

HYDROGEN SULFIDE

AND

SULFUR DIOXIDE

Revised from 4/13/88

CONTINGENCY PLAN FOR H2S and SO2

The following plan is prepared to establish procedures for safe operations on Platform Gina while producing and handling fluids containing Hydrogen Sulfide and Sulfur Dioxide. All personnel should be acquainted with this plan, whether they are regular employees, contract service personnel or visitors.

This plan deals with hydrogen sulfide, since the only likely presence of sulfur dioxide would come from burning of gas with fractional concentrations of hydrogen sulfide. To avoid problems with SO2, any intentional burning of formation gas will be done from the top of a flare boom. In the event of an unintentional fire, there will be more important problems than sulfur dioxide to contend with, and all personnel will, for obvious reasons, work upwind of of the fire source in an effort to contain and extinguish it.

I GENERAL

H2S is a poisonous gas. The degree of danger depends upon the concentrations in the air breathed. It should be remembered that changes in atmospheric conditions, wind, composition of a gas, etc., can quickly increase the concentration many times. Poor ventilation in enclosed spaces or buildings where gas may be leaking can cause the accumulation of dangerous concentrations of H2S. H2S is colorless and 18% heavier than air and tends to accumulate close to the floor or ground in depressions, inside of firewalls, in manifold pits, in sumps, and above the roofs of floating roof tanks below the upper rim of the tank sides, or other unventilated and protected areas. It is also possible if H2S is present, combustible gases could be present.

II TOXIC EFFECTS & PHYSIOLOGICAL RESPONSE

The serious and acute effects of hydrogen sulfide occur in the higher ranges of concentrations: 500 or more ppm. Breathing in this atmosphere results very quickly in unconsciousness and stoppage of respiration. If this occurs, artificial respiration will be required (in a fresh air area) within a very few minutes to preserve life. If respiration is restored promptly, no serious after-effects are expected from such an exposure. This points out the absolute necessity of having at least two people present where hydrogen sulfide is a possible contaminant.

Toxic Effects of H2S

Concentration in PPM	Effect
0.1	Approximate odor threshold. Air pollution measurements require detection below this level.
10	Threehold Limit Value (TLV) recommend maximum safe level for 8-hour exposure.
20	Current OSHA "ceiling" concentration. Respiratory irritation after long exposures. Possible eye irritation.
50	Current maximum allowable by OSHA up to 10 minutes per day if no other exposure exists. Respiratory protective equipment required at higher levels.
100	Coughing, loss of sense of smell, serious respiratory irritation if exposure is prolonged.
500	Unconsciousness within 2 minutes. Respiratory failure within 15 minutes.
1000	Immediately hazardous to life.

Effects from exposures to concentrations in the range of 50 to 450 ppm are irritation of mucous membranes, eyes, and the respiratory tract. Although hydrogen sulfide can be detected by smell in concentrations of less than 1 ppm, exposure to 100 ppm for two to fifteen minutes and much shorter exposures at higher concentrations will deaden the olfactory nerves to the extent that hydrogen sulfide cannot be smelled at any concentration.

These effects are sufficiently uncomfortable (coughing, eye burn, throat irritation) that personnel familiar with the physiological response can recognize the symptoms and remove themselves from the area of contamination. The maximum concentration in which an employee should work for a period of eight hours a day without respiratory protection is 10 ppm (OSHA Rules and Regulations Federal Register 10-18-72).

III <u>PERSONNEL SAFETY</u>

There will be sensors with alarms placed in potential areas of H2S release and on purge and ventilation intakes. In the event of H2S release, the sensors will activate a visible alarm on its meter and an audible alarm when the concentration reaches 10 ppm. At 20 ppm, a visible alarm (flashing red light) in addition to the audible alarm will be activated. Personnel not actively involved in controlling the situation shall proceed to a safe briefing area when a H2S level of 20 ppm+ is detected in their working area.

Work & escape SCBA's will be available at various places on the platform for personnel engaged in control of an H2S release. Locations of these units and their respective stored air systems may be found at the end of Section IX entitled 'EQUIPMENT LIST'.

Self-contained, pressure-demand breathing apparatus are available for members of the working crew and supervisors so that an unexpected contamination of dangerous quantities of hydrogen sulfide can be corrected and placed under control by the crew in complete safety.

These units will be equipped with 30-minute cylinders. Fifteen minute air masks are available to equip non-essential and transient personnel and visitors to protect themselves whil leaving the premises. The escape capsules are not to be used for entering H2S-contaminated areas; they are supplied for escape purposes only.

Resuscitators with mask, oxygen bottle and spare oxygen bottle will be located in the drilling office and production control room.

There will also be one movable blower on the platform of sufficient size to enable the crews to create their own breeze and up-wind areas in the event of H2S release during a dead calm.

Ropes with safety harnesses to retrieve incapacitated personnel from contaminated areas, and a Stokes litter or equivalent, will be available for use on the platform.

Portable hydrogen sulfide detectors will be placed on board and distributed to areas where it may become necessary to determine the ambient concentrations of hydrogen sulfide at any time. In the event of an alarm from any source, men wearing self-contained breathing equipment will work in teams monitoring the hazardous areas with portable hydrogen sulfide detectors, and only when the monitoring equipment indicates safe levels of this gas may personnel remove breathing apparatus, or personel without breathing apparatus, move into these areas once again.

IV TRAINING

A training program for all working personnel and supervisors will be conducted. Regular operating personnel will receive annual refresher instruction. First-time visitors/workers will receive training immediately upon their arrival to Platform Gina. This program will assure that all workers will be familiar with the location and use of available equipment and understand the physiological effects of hydrogen sulfide. They will also be informed of the safety and alarm features on the platform and will be instructed in procedures that must be taken in the event of an emergency. This instruction will include the proper use of personnel safety equipment, the use of mechanical ventilation equipment, the location of briefing areas, identification of evacuation routes, and will also include the rapid instruction of outsiders (who could be present in an emergency) in the use of the breathing equipment for their protection. Instruction will also include familiarization with Station Bills and Unocal's beard and contact lens policy.

All personnel in the working crew will be trained in basic first aid. Weekly H2S drills will be conducted during training sessions and drills, emphasis will be placed upon rescue and first aid for H2S victims. The working crew will be trained in the use of the first aid equipment on board.

V <u>OPERATING PROCEDURE</u>:

Essential operating personnel are defined as the Production Foreman, M.O. #1's, M.O. #2's, M.O. #3's and others as designated by the supervisor.

All other company and contractor personnel and visitors are defined as nonessential for the purpose of controlling an H2S release.

In the event of an H2S alarm, the following procedures will be followed:

<u>WHEN ANY SENSOR READS 10 PPM H2S:</u>

--There will be an audible alarm - <u>W H O O P</u>

--All personnel continue your normal work or activity, but be alert.

<u>NOTE:</u> This is a very low concentration of H2S in which a person can safely work for 8 hours.

--During an H2S alarm, all Hot Work throughout the platform should be stopped.

--All smoking (which is normally confined to safe areas) should be stopped. Only when the <u>Return to Work</u> signal is given can Hot Work or smoking be resumed (only in designated areas).

--<u>Return to Work</u> will be explained in more detail on the following page.

The production supervisor will direct efforts to determine the source of the alarm and corretive actions required.

<u>IF THE PROBLEM GETS WORSE, WHEN THE SENSOR READS 20 PPM H2S:</u>

--The audible alarm will start again and there will also be a <u>FLASHING RED LIGHT.</u>

--Essential personnel will take instructions from the production supervisor regarding the steps to be taken to guarantee safety and deal with the problem.

--All Hot Work and smoking shall immediately cease until further notice.

--Nonessential personnel immediately go to the safe briefing area on the 12' level.

--Remain in that area until you are given one of the following instructions:

--<u>Return to work</u> - because it has been determined by the Production Foreman or the H2S specialist that it is safe to do so.

--<u>Prepare to be evacuated</u> from the Platform, because the H2S concentration has increased to the 10 minute allowable of 50 ppm.

<u>NOTE:</u> 20 ppm is also a low H2S concentration, in which a person can safely work for a number of hours without any danger to his health, although there may be some discomfort.

Extreme Danger (Over 20 ppm H2S)

Operational danger signs (8' x 4') indication "DANGER HYDROGEN SULFIDE H2S" will be displayed on each side of the platform, and a number of warning flags shall be hoisted in a manner visible to any water craft or aircraft that may be in the area.

VI EVACUATION PLAN

If it appears the concentration will spread to working or living areas, all non-essential personnel will evacuate the facility. Radio communication shall be used to alert helicopter and water craft in the immediate vicinity of the condition, and agencies listed in Section X.

Two briefing areas have been designated. They are located at the

HELIPORT

12 FOOT LEVEL

If there is a steady breeze, the upwind area shall be the safe briefing area at any time. If there is no wind blowing, the movable blower will be available to establish an upwind briefing area where necessary.

Under normal conditions, each operating crew should undergo a hydrogen sulfide drill each week, in conjunction with other drills required in offshore operations. Drills should acquaint personnel with the problem of putting on a self-contained breathing apparatus or an escape capsule, the use of movable blowers and the best approaches to their briefing areas, and how to abandon platform stations. Records of attendance will be maintained aboard the platform.

At a fixed time each day, one member of the crew will check the alarm systems to see that they are functoning.

The evacuation of personnel will follow the procedures set forth in the Coast Guard Station Bill.

When the level reaches 50 ppm H2S in the working or living areas, all nonessential personnel will be evacuated as soon as possible, and all working people will put self-contained breathing apparatus on and move to the upwind briefing area for instructions. The movable blower will be started, if required to establish an ample area of safety upwind of the source. Men with self-contained breathing apparatus on and functioning will survey the various working areas with H2S detectors and report to the man in charge of conditions throughout the platform. The man in charge will then make the decision whether to set the crew to immediate corrective action with self-contained breathing apparatus on and functioning, or to evacuate as soon as possible. The Production Supervisor will be contacted to assist with calling for outside assistance, corrective action or platform evacuation.

ALL PERSONNEL WORKING IN H2S WILL USE THE BUDDY SYSTEM.

VII FIRST AID

In case a man is overcome, summon the nearest help, put on self-contained breathing equipment, then immediately get the victim into the fresh air and proceed as follows:

A. Apply mouth-to-mouth artificial respiration, without interruption, until the resuscitator is available. Use the resuscitator until normal breathing is restored. Symptoms may pass off rapidly; however, keep the victim warm, even during artificial respiration.

B. Summon a doctor as soon as possible.

C. Summon transportation if required by doctor. When the patient has recovered and can be safely moved, he must be sent to the hospital and never allowed to stand until released by the doctor.

NOTE: The man in charge of the working crew shall be in full charge of safety precautions and shall direct operations necessary to the safety and health of all people on the platform.

VIII RESPONSIBILITIES OF PERSONNEL

The person in charge of production operations at any time will also supervise the action to be taken in an H2S emergency. An H2S consultant will be on board Platform Gina 2 days/week. The consultant will maintain all H2S-related equipment, ensure its function and testing, supervise proper use sessions and train any new personnel on board the platform. The production operator should be fully acquainted with detector operation and be prepared to be one of the front-line men in putting on his self-contained breathing apparatus and testing the atmosphere at points directed by the Supervisor. (con't)

One man shall also be designated in each crew to take over the Supervisor's position immediately, if the Supervisor should become incapacitated by hydrogen sulfide inhalation.

IX BEARDS AND CONTACT LENSES

EFFECTIVE, JANUARY 1, 1988, ALL PERSONNEL BOARDING PLATFORM GINA MUST NOT HAVE BEARDS OR FACIAL HAIR THAT WOULD INTERFERE WITH FACE-MASK SEALING.

Essential operating personnel (defined in Sec V) are not allowed to wear contact lenses while on duty.

These requirements are necessary for you, who may await evacuation or who may be asked to stay on the Platform and deal with a problem that requires the use of fresh air breathing equipment.

X AGENCY NOTIFICATION

The following agency shall be immediately notified if hydrogen sulfide concentrations reach 10 ppm or above:

MINERALS MANAGEMENT SERVICE (call one)

First	Bill Kohut	Office 805/648-5131 - Home [redacted]
Second	C. Dennis Rau	Office 805/648-5131 - Home [redacted]
Third	Rishi Tyagi	Office 805/648-5131
Fourth	Tom Dunaway	Office 213/688-2846 - Home [redacted]

XI. H2S CONSULTANT DUTIES & RESPONSIBILITIES ON PLATFORM GINA

The duties listed below are not intended to cover all situations which may occur on the platform. It is intended as a basic quideline for H2S operations. The consultant will be under the direct supervision of the Unocal's Production Foreman and will, as much as physically possible, comply with the requests of the Production Foreman.

Weekly:

1. Check SCBA equipment for cleanliness, full preassure, and proper location.

2. Repair, refill, and relocate equipment as necessary.

3. Drill Gina hands in proper use of H2S safety equipment.

4. Test H2S alarm system by gasing a sensor setting off lights and audible alarms.

5. Send to appropriate office a sample of breathing air from compressor for analyzation (post weekly Air Certificate).

6. Calibrate H2S monitor system and log results in Tester's log book.

Monthly:

1. Full function check of all H2S safety equipment on board platform and log in Testers Log.

XII APPENDIX

A. LISTING OF MEDICAL PERSONNEL AND FACILITIES

HOSPITAL

Community Memorial Hospital (805) 648-3201
of San Buenaventura
2800 Loma Vista Road
Ventura, California

St. John's Hospital (805) 483-1141
333 North "F" Street
Oxnard, California

DOCTORS

Ventura Medical Group (805) 643-2161
3003 Loma Vista Road
Ventura, California

D[redacted] [redacted]
1[redacted] R[redacted]
O[redacted] C[redacted]

AMBULANCE

Courtesy-Ventura 3110 Loma Vista Road Ventura, California	(805) 643-5496
Oxnard Ambulance Service 321 South "C" Street Oxnard, California	(805) 486-6333

FIRE DEPARTMENTS

Ventura City	(805) 643-6121
Oxnard City	(805) 483-2211

POLICE DEPARTMENTS

Highway Patrol	ZEnith 12000
Ventura County Sheriff	(805) 648-3311
Oxnard Police	(805) 486-1663

HARBOR MASTER

Ventura	(805) 642-8538
Oxnard	(805) 487-5511
Hueneme	(805) 488-4615

U. S. COAST GUARD (Channel Islands)	(805) 985-9822

HELICOPTERS

Aspen	(805) 985-5416
ERA	(805) 922-1424

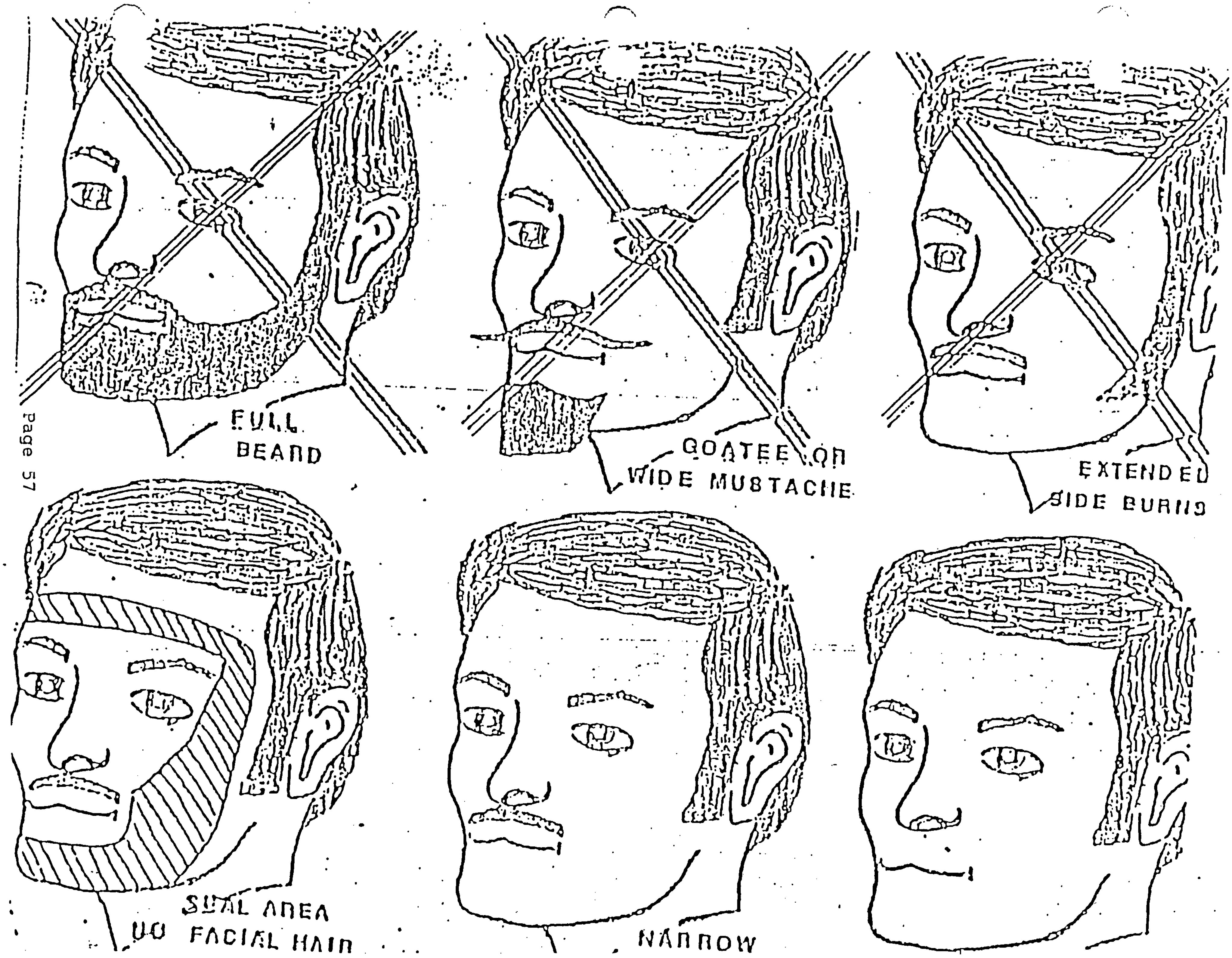
U. S. COAST GUARD (Channel Islands)	(805) 985-9822

HELICOPTERS

Aspen	(805) 985-5416
ERA	(805) 922-1424

B. GROOMING STANDARDS

(see illustration)


FULL
BEARD
GOATEE OR
WIDE MUSTACHE
EXTENDED
SIDE BURNS
SEAL AREA
NO FACIAL HAIR
NARROW

C.

PLATFORM GINA

H2S EQUIPMENT LIST

ITEM #	QUANTITY	DISCRIPTION/LOCATION
1	1	Eight bottle cascade complete with dual regulators
2	7	5 man manifolds located at North and South boat landings, sub deck, well room, production area, quarters mezannine
3	1	8 channel ambient H2S monitor with sensors located on sub deck, well room (2), Production area, purge air intake, crew quarters
4	20	50 foot breathing air hoses complete with stainless coupling and dust caps
5	12	6 foot breathing air hoses complete with stainless couplings and dust caps
6	1	Hand held portable H2S detector
7	4	High visability warning flags
8	12	Model 502 work line/escape fresh air breathing units

NOTE: This inventory will be augmented with additional equipment whenever necessary due to platform activity level, (construction, work-overs, etc).

APPENDIX VOLUME 3

Exhibit B

City of Oxnard letter of November 18, 1988 granting approval of pipeline replacement and staging area pursuant to Coastal Development Permit No. 85-5 and Resolution 6218 approving Special Use Permit No. 806

CITY OF
Oxnard

COMMUNITY DEVELOPMENT DEPARTMENT • 305 W. THIRD ST. • OXNARD, CA 93030 • (805) 984-4657

RICHARD J. MAGGIO, DIRECTOR

November 18, 1988

Mr. J. S. Attebery
California District Land Manager
Union Oil Company of California
2323 Knoll Drive
Post Office Box 6176
Ventura, California 93006

Dear Mr. Attebery:

Subject: Proposed Replacement of Leaking Return Water Line to Platform Gina - Coastal Development Permit No. 85-5

After reviewing the description of the problem section of pipeline (letter from J. A. Cronk, October 21, attached) and the proposed repair project (letter from C.R. Culver, October 28, attached), steps were taken to formally notify the Coastal Commission (letter of November 4, attached) of our findings and recommendations concerning the proposed pipeline repair. Having received no objections from the Coastal Commission as of this date and being cognizant of the difficulty of scheduling repairs now that winter storms have commenced it has been determined that:

1. The proposed repair project can be considered as a continuation of the repair project authorized in Coastal Development Permit No. 85-5 since there would not be any deviation from the previously approved pipeline route.

2. The proposed repair project will not have any significant impacts on the coastal environment because the construction activity can be limited to the dry sand area on the ocean side of the sand dune and will be for a brief period of time (e.g., two weeks), and any disturbance of the dry or wet sand area can be readily corrected.

Continuation of the repair work originally authorized under Coastal Development Permit No. 85-5 may be continued as described in your company's letter of October 28, including the attached map subject to provisions and conditions as follows:

1. The intent of all applicable provisions of Special Use Permit No. 806 and Coastal Development No. 85-5 shall be met.

2. The boundaries of the access route along the dry sand portion of Mandalay Beach from the westerly terminus of West Fifth Street shall be flagged to avoid encroaching on the sand dunes.

3. The boundaries of the construction area shall be flagged to prevent encroaching on the sand dunes.

4. A guard shall be maintained at the westerly end of Fifth Street to direct traffic and advise beach users of the construction activity.

5. Immediately after the construction activity is completed and the new return water line is tested and deemed satisfactory all areas of disturbance shall be cleaned and returned to their original condition.

6. The Public Works Department shall be contacted to determine whether or not an encroachment permit is needed to move equipment and supplies over the westerly terminus of Fifth Street.

7. Any damage to public or private property stemming from the repair project shall be repaired at the sole expense of Union to the reasonable satisfaction of the property owner.

8. Union is solely responsible for obtaining any permits or approvals needed from other governmental agencies.

9. The hours of operation of the proposed repair are not restricted. However, if complaints are received from adjacent residents the hours may be restricted.

10. The Planning Division shall be notified when all the repair work has been completed and the site restored to its original condition. In the event that the site is not restored to its original condition within 30 days after completion of the work or December 31, 1988, whichever is later, Union will pay the City of Oxnard to restore the site to its original condition according to contracting procurement procedures currently in effect as would be applied in a reasonable manner.

11. If during the pipeline repair project a condition(s) is discovered that is hazardous to surrounding residents or passersby, the work shall be stopped and all appropriate measures taken expeditiously to protect life and safety. In the event this type of situation occurs the Oxnard Fire Department and Police Department shall be notified by phone by calling 911 and a written report of the situation and corrective actions taken provided within 24 hours to the Fire Chief.

12. A copy of this approval shall be maintained at the construction supervisors location on the site and another copy shall be maintained within the control room of the Mandalay Separation Facility. Please sign below indicating your acceptance, without reservation, of these conditions of approval.

Sincerely,

Matthew G. Winegar
City Planner

MGW:RJS:nr

cc: Building and Safety
Fire Department
Police Department
Public Works Department
County of Ventura
Coastal Commission
State Lands Commission
Department of the Army, Corps. of Engineers

Accepted and agreed to this 19th day of November, 1988.

J. S. Attebery

Mr. J. S. Attebery

Unocal Oil & Gas Division
Unocal Corporation
271 Market Street
Port Hueneme, California 93041

UNOCAL 76

October 21, 1988

Southern California District

Mr. Ralph Steele
Community Planning Department
City of Oxnard
305 W. 3rd. Street
Oxnard, Ca. 93030

Mr. Steele:

Unocal wishes to advise the City that a 6" water pipeline running from Platform Gina to our Mandalay onshore facility did not pass a recent hydrotest. A leak was located on October 20, approximately 150 ft offshore, in four feet of water. The line is buried an additional 4 feet at the location. The line was removed from service prior to the hydrotest, and remains so.

Unocal will contact the California Coastal Commission and State Lands Commission regarding this matter. Our management is currently evaluating repair/replacement of this section of pipeline.

We respectfully request information from the City of Oxnard regarding permits that may be required for the repair. I may be reached at 986-3876 if questions arise. Thank you for your assistance.

Very truly yours,

Jon A. Cronk
Jon A. Cronk
Field Superintendent

JAC:ls

PHJC0357

Unocal Oil & Gas Division
Unocal Corporation
1003 Main Street
Santa Paula, California 93060
Telephone (805) 525-6672

UNOCAL 76

October 28, 1988

Ralph J. Steele
City of Oxnard

The 6 5/8 inch pipeline which carries produced water from the Mandalay Facility, on Harbor Blvd, to Platform Gina is in need of repair and the line has been removed from service. The water pipeline is critical to our operation as our only other means for produced water disposal is through a similar pipeline to Platform Gilda. Our production operation can be jeopardized and this repair is of an emergency nature. It is desireable to commence this repair project as soon as possible. We are in the process of obtaining the pipe to complete the work and would like to begin repairs as soon as the material arrives, which is estimated to be in about two to three weeks. It is anticipated that the project can be completed in two weeks from the time work commmences assuming good weather conditions.

It will be necessary to replace 2700 feet of 6 5/8 inch pipeline between Mandalay and the platform. The portion of pipe to be replaced is from about 400 feet above the ordinary high water mark toward the Mandalay facility to 2300 feet from the ordinary high water mark toward the platform. The plan as outlined below has been selected to effectively repair the pipeline and at the same time minimize environmental concerns. The plan will require the minimum amount of time to complete the project, minimize beach disturbance and will not require sand dune disturbance.

The first phase of the project will require a staging and onshore fabrication area. Please refer to the attached sketch for the detail of the area. The area required for this will be on the beach from the Mandalay facility to the Edison canal outfall to the north. This area will be utilized for a period of one week to prepare pipe and one week to aid the remainder of the project. All equipment will access the beach from the south using Fifth Street. The equipment required will be a pipe transport vehicle, a fork lift type vehicle, an x-ray truck, and three welding rigs. This will allow the pipe to be welded together and prepared for movement to the replacement area to the south.

The second phase of the project will be to survey the pipeline from Mandalay to the endpoint of the replacement section. This will enable locating the oil pipeline, power cable, and water pipeline to insure proper location and expedite completion of the tie-in when the replacement pipe is moved to the replacemant area. A small vessel with divers will be used for this survey. Once the survey is complete, an offshore diving support vessel can begin exposing the current pipeline at the offshore tie-in point, anchor the vessel properly to pull the replacement pipe in place, and prepare for the pull of the pipe. This will be done concurrently with the onshore phase (phase one) and will require a vessel offshore as well as a survey crew on the beach and is estimated to take one week. This offshore work will not require additional vehicular beach traffic.

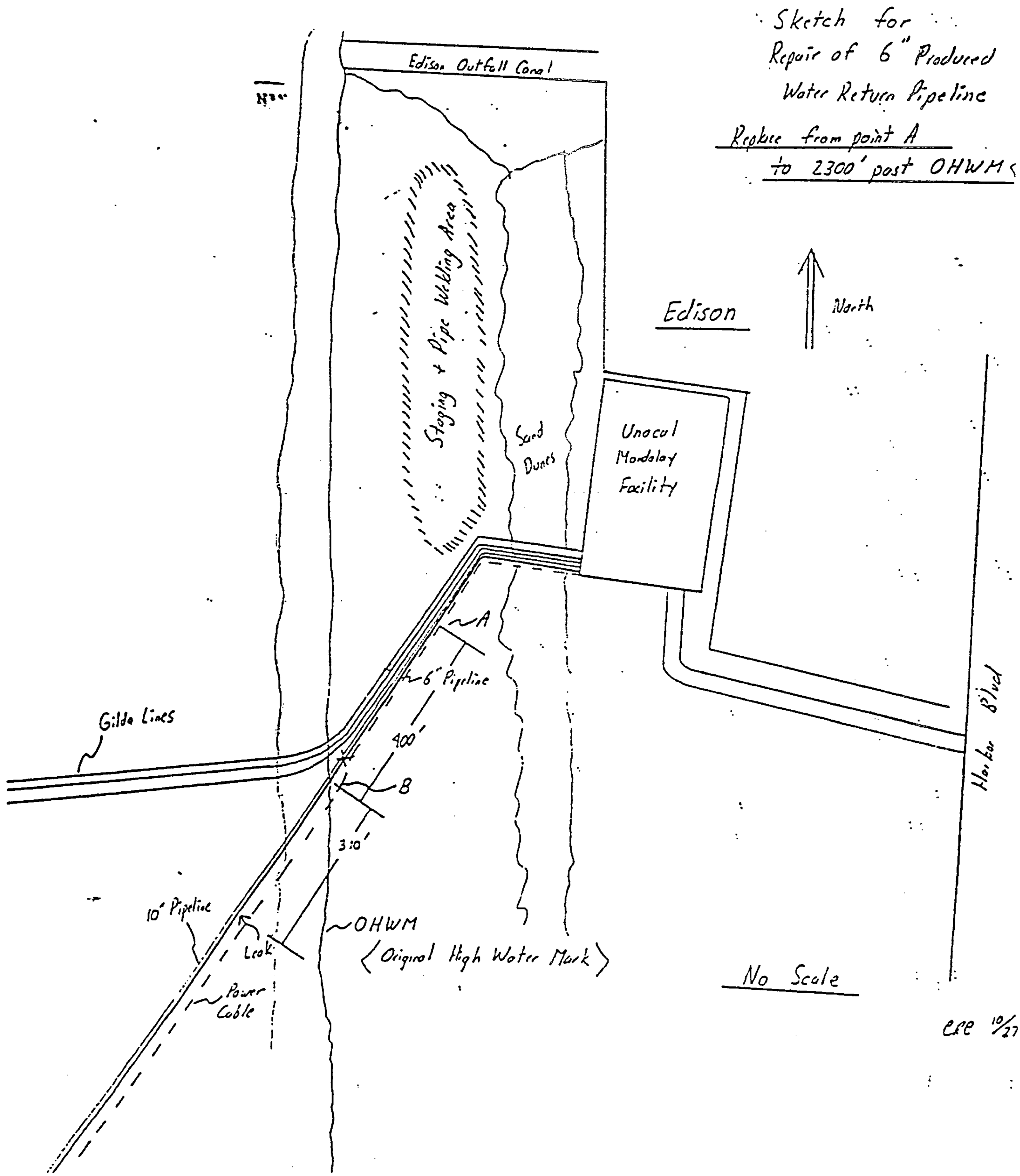
The third phase of the project will be to move the pipe from the onshore location to the beach, pull the pipe to the offshore tie in point, make the underwater tie-in, and make the onshore tie-in. This phase of the project will require a backhoe to dig the onshore tie-in point, a welding rig, a support vehicle with tools, an x-ray vehicle, pressure testing equipment, and a tractor to recontour the sand. Not all this equipment will be required at the same time. The time required for this portion of the project is about 1 week, depending on weather conditions.

The project will be complete at this point in an overall time of two weeks. All vehicular access to this area will be from west end of Fifth street. This program is designed to minimize disturbance to the environment as well as time required to complete the project.

cc: J. Grimes
J. Cronk
R. Hoover

Chris R. Culver

C.R. Culver



Sketch for
Repair of 6" Produced
Water Return Pipeline
Replace from point A
to 2300' post OHWM
Edison Outfall Canal
Staging + Pipe Welding Area
Sand Dunes
Edison
North
Unocal
Mondaloy
Facility
A
6" Pipeline
400'
B
310'
Gilda Lines
Harbor Blvd
10" Pipeline
Leak
Power
Cable
OHWM
(Original High Water Mark)
No Scale
ere 10/27

CITY OF Oxnard

COMMUNITY DEVELOPMENT DEPARTMENT • 305 W. THIRD ST. • OXNARD, CA 93030 • (805) 984-4657

RICHARD J. MAGGIO, DIRECTOR

October 3, 1985

Mr. Michael T. Bridges
Union Oil Company
2323 Knoll Drive
P.O. Box 6176
Ventura, CA 93006

Dear Mr. Bridges:

Re: Development Review Permit No. 85-5

The City of Oxnard Planning Division staff has reviewed your application for Development Review Permit No. 85-5.

The purpose of the project is to replace approximately 600 ft. (linear distance) of two 6.625 inch return water lines between your company's separation facility at Mandalay Beach and the mean high tide line--the lines return produced water to Platforms Gina and Gilda.

Prior to approving your company's request, findings were made as follows:

1. The proposed use is one permitted within the subject sub-zone and complies with all of the applicable provisions of this Chapter;

2. The proposed use would not impair the integrity and character of the sub-zone in which it would be located;

3. The subject site would be physically suitable for the land use being proposed and the proposed use will protect and maintain coastal resources including environmentally sensitive areas, adjacent to the project site; and

4. The proposed use would be consistent with all policies of the Oxnard Coastal Land Use Plan.

Based upon the above findings, Development Review Permit No. 85-5 is hereby approved subject to the following conditions:

1. The intent of all conditions set forth in Resolution No. 6218, approving Special Use Permit No. 806 to permit an onshore treating facility, associated pipelines, and a pipe fabrication area shall be met. For reference, emphasis should be placed on the requirements set forth in

CITY OF
Oxnard

COMMUNITY DEVELOPMENT DEPARTMENT • 305 W. THIRD ST. • OXNARD, CA 93030 • (805) 984-4657
RICHARD J. MAGGIO, DIRECTOR

October 3, 1985

Mr. Michael T. Bridges
Union Oil Company
2323 Knoll Drive
P.O. Box 6176
Ventura, CA 93006

Dear Mr. Bridges:

Re: Development Review Permit No. 85-5

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The purpose of the project is to replace approximately 600 ft. (linear distance) of two 6.625 inch return water lines between your company's separation facility at Mandalay Beach and the mean high tide line--the lines return produced water to Platforms Gina and Gilda.

Prior to approving your company's request, findings were made as follows:

1. The proposed use is one permitted within the subject sub-zone and complies with all of the applicable provisions of this Chapter;
2. The proposed use would not impair the integrity and character of the sub-zone in which it would be located;
3. The subject site would be physically suitable for the land use being proposed and the proposed use will protect and maintain coastal resources including environmentally sensitive areas, adjacent to the project site; and
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Based upon the above findings, Development Review Permit No. 85-5 is hereby approved subject to the following conditions:

1. The intent of all conditions set forth in Resolution No. 6218, approving Special Use Permit No. 806 to permit an onshore treating facility, associated pipelines, and a pipe fabrication area shall be met. For reference, emphasis should be placed on the requirements set forth in

conditions numbers 27 "e" (introductory paragraph) 1, 3, and 5; "g" 1, 2 (deleted), 3, 4, and 5; and 34; and 36 (the report previously prepared by Intersea Research may be utilized for the intended purpose, if upgraded and approved by both the Parks and Community Development Directors).

2. Alternative number 6 (Bore Casing through Dune, conventionally replace remaining sections of pipelines) as described in the Engineering Study and Report--Mandalay Facility-- 6 in. Water Return Pipelines (July 1985) is approved.

3. A copy of this Development Review Permit and Resolution No. 6218 must be posted at the construction site or on an interior wall of the control room at the Mandalay Separation Facility.

Building permits and authorizations for any improvements requiring approval by the Building Division must be pursued separately. Should you have any questions regarding this permit, please call Ralph J. Steele-Planner of this office at (805) 984-4657.

Very truly yours

Richard J. Maggio, Director
Community Development Department

RJS:mcd

cc: Coastal Commission

Enclosure

RESOLUTION NO. 6218

A RESOLUTION OF THE PLANNING COMMISSION OF THE CITY OF OXNARD APPROVING SPECIAL USE PERMIT NO. 806, APPLIED FOR BY UNION OIL COMPANY OF CALIFORNIA, TO PERMIT AN ONSHORE TREATING FACILITY, ASSOCIATED PIPELINES, AND A PIPE FABRICATION AREA, SUBJECT TO CERTAIN CONDITIONS.

WHEREAS, the Planning Commission of the City of Oxnard has considered an application for an onshore treating facility, associated pipelines, and a pipe fabricating area, filed by Union Oil Company, in accordance with Section 34-146 through 34-157.1 of the Oxnard City Code; and

WHEREAS, the Planning Commission, having previously considered the Environmental Impact Report (E-78-19) prepared for the project, has found it adequate; and

WHEREAS, the Commission finds that, after due study, deliberation and public hearing, the following circumstances exist:

1. The proposed use is in conformance with the General Plan, Local Coastal Plan (including Policy 40, which provides that the facility may be located in the least environmentaly damaging site of the three alternative sites evaluated in the EIR), and other adopted standards of the City of Oxnard.

2. Applicable mitigation measures that are recommended in Section 5 of the EIR have been attached to this permit to reduce the potential for adverse impacts during construction and operation. Therefore, no significant unavoidable adverse impacts are expected to occur within the jurisdiction of the City of Oxnard.

3. The proposed use will not adversely affect or be materially detrimental to the adjacent uses, buildings or structures or to the public health, safety or general welfare.

4. The site for the proposed use is adequate in size and shape to accommodate the yards, walls, fences, parking and loading facilities, landscaping and other items as required.

5. The site for the proposed use will be served by streets and highways adequate in width and structure to carry the kind and quantity of traffic such use will generate.

6. The site for the proposed use will be provided with adequate sewerage, water, fire protection and storm drainage facilities.

NOW, THEREFORE, BE IT RESOLVED that the Planning Commission of the City of Oxnard hereby approves said special use permit, subject to the following conditions. The decision of the Planning Commission is final unless appealed in accordance with the provisions of Section 34-155 of the Oxnard City Code.

GENERAL CONDITIONS

1. The special use permit is granted for the land as described in the application, shown as Exhibit "A" (Tentative Parcel Map), and including Exhibits "B" (Proposed Lease Parcel), "C" (Plot Plan), "D" (Elevations), "E" (Signing), and "F" (Materials Board), and shall not be transferable from one property to another.

2. The special use permit shall become null and void within twelve months from the date of its issuance, unless the proposed development or use has been diligently pursued. The issuance of a grading, foundation, or building permit for structural construction shall be the minimum requirement for evidence of diligent pursuit.

3. The special use permit is granted subject to the approval of a zone change application.

4. The special use permit shall be granted subject to the approval of a tentative and final parcel map and recordation of said map. Building permits shall be issued only after map recordation. All conditions of the required parcel map shall be complied with prior to occupancy of the use applied for in this permit.

5. Any covenants, conditions and restrictions shall be subject to the review and approval of the City Attorney and the Planning Director.

6. All conditions of this special use permit shall be complied with prior to the approval of occupancy, unless occupancy is approved by the Planning Director or Planning Commission.

7. As a condition of approval of this permit, the developer agrees to defend, at his sole expense, any action brought against the City based upon approval or use of this permit or, in the alternative, to relinquish this permit. The developer shall reimburse the City for any court costs and attorney's fees which the City may be required to pay as a result of any such action. The City may, at its sole discretion, participate in the defense of any such action, but such participation shall not relieve the permittee of the obligations under this condition.

   Commencement of construction of operations under this permit shall be deemed to be acceptance by the developer of all the conditions of this permit.

8. As a condition precedent to any building permit being issued by the City, the developer shall file for, or cause to be filed, an annexation of the subject 1.8 acre parcel to the Calleguas Municipal Water District and the Metropolitan Water District.

9. The location of buildings and structures shall conform substantially to the plot plan submitted, labeled Exhibit "C", except as amended at the time of approval.

10. The elevations of all buildings shall be substantially in conformance with the elevation plan submitted as part of Exhibit "D", except as amended at the time of approval.

11. The final design of buildings and masonry walls, including materials and colors, shown in Exhibits "D", "E" and "F", is subject to the approval of the Planning Director.

12. Any minor changes or minor increase in the extent of use or size of structures may be approved by the Planning Director, but any substantial change or increase will require the filing and approval of a major modification or an amended special use permit by the Planning Commission. Any request for minor modification shall be made to the Planning Director in writing and shall be accompanied by three copies of any plans reflecting the requested modification. Any subsequent modification of the development plans initially approved by the Planning Commission shall be designed to minimize impacts on the visual resources of the area. (LCP, #15)

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UTILITIES

13. No exterior refuse storage or pick-up facilities are permitted.

14. On-site and adjacent offsite utility service shall be installed underground in accordance with adopted City Council Ordinance and Policies.

PARKING AND ACCESS

15. Offstreet parking, including number of spaces, stall size, paving, striping, location and access, shall comply with Sections 34-5 and 34-6 of the Oxnard City Code.

SIGNS AND APPURTENANT STRUCTURES

16. Building signs corresponding to Exhibit "E" may be approved by the Planning Department. Sign area, size and location shall be in accordance with sign regulations of the M-2 zone, as established by the Oxnard City Code. The applicant shall submit color scheme information with any request for change of copy.

17. On-site lighting, if provided, shall be shielded from abutting properties so as to produce no nuisance or annoyance. No lighting shall be of the type or in a location such that it constitutes a hazard to vehicular traffic, either on private property or on abutting streets. The spacing and height of the standards and luminars shall be such that a maximum of seven foot candles and a minimum of one foot candle of illumination are obtained on all vehicle access ways and parking areas. The height of light standards shall not exceed twenty feet above the finished interior base pad elevation. To prevent damage from automobiles, standards shall be mounted on reinforced concrete pedestals or otherwise protected. Lighting elements shall be placed in such a manner as not to direct light onto the adjacent park area.

18. All open storage of materials shall be located as shown in Exhibit "C". Open storage areas shall be screened from adjacent properties and streets by construction of a wall, fencing or screening. All fence or wall materials shall match major design and materials elements of the main structure.

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FIRE SAFETY CONDITIONS

19. Onsite and/or boundary water mains, fire hydrants, and services shall be designed and installed to Fire Department and Water Service Division specifications.

20. Adequate fire protection, as determined by the Fire Chief, shall be available prior to the issuance of any building permit. The developer, prior to the start of construction, shall present a plan to the Fire Chief designed to insure the integrity of providing both fire equipment access and water for fire combat operations to all areas of captioned property. Such plan shall meet the approval of the Fire Chief. All vehicle access driveways will be 25 feet in width, and will be striped and signed to Fire Lane Standards.

21. A comprehensive plan pertaining to the treatment facility and associated pipelines within the City for fire suppression, prevention of explosion, and prevention of the escape of hazardous gases (i.e., hydrogen sulfide, etc.) shall be submitted to and approved by the Fire Chief prior to starting construction of either the treatment facility or pipeline. A comprehensive plan of the onsite fire suppression system shall be designed by a qualified fire prevention engineering firm or engineer.

22. No burning of combustible refuse on the subject property is permitted.

23. A permit shall be obtained from the Oxnard Fire Department for the handling, storage and use of all flammable, combustible and hazardous materials.

24. All flammable liquid installations shall be in conformance with Standard No. 30, "Flammable and Combustible Liquids Code", 1979 edition, of the National Fire Protection Association.

25. Three copies of prints showing the proposed equipment and material delivery routes shall be approved, and a moving permit issued by the City Traffic Engineer, prior to any equipment or material deliveries to the site. The developer shall be responsible for the design and construction of any improvements necessary for the safe and orderly movement of traffic.

26. Oil transmission pipelines will not be allowed to be suspended or in any other way connected to the existing brackets now supporting the City water main on the west side of the Harbor Boulevard bridge at the Edison Canal bridge. The developer shall use alternate means, such as the east side or underside of the bridge. Alternate plans shall be subject to and have prior approval of the Public Works Director.

27. Conditions 27a through 27g are based upon mitigating measures recommended in E-78-19. The numbers in parentheses refer to sections in Volume I of E-89-19. The conditions are as follows:

    a. Mitigation of Potential Effects of Geologic and Hydrologic Phenomena (5.1.1)

       A qualified engineer, licensed in the State of California, shall review all project elements (treatment facility and pipeline) proposed for installation, construction, and operation within the City for adequacy of their design related to: maximum creditable earthquake ground motion, liquefaction potential, differential settlement, and erosion. The certification must be submitted to the Department of Building and Safety for review prior to the issuance of a grading or building permit.

    b. Mitigation of Potential Effects on Soil and Water (5.1.2)

       1. Wherever disturbance of agricultural or productive soils is necessary, they should be stockpiled and replaced in a manner such that resulting profiles are as similar as is practicable to those which existed prior to the disturbance.

       2. Consumptive use of fresh water during hydrostatic testing of onshore pipelines should be minimized by testing the pipelines in sections, if practicable.

    c. Mitigation of Potential Effects on Air Quality (5.2)

       1. Water sprays should be used during construction to minimize fugitive dust.

2. The applicant shall certify that the burners specified for installation on the heater treaters are designed to reduce NO emissions to the lowest level practical, and are acceptable to the Ventura County Air Pollution Control District (APCD).

3. Total hydrocarbon (THC) emissions from all vessels shall be controlled by using a vapor recovery and compression system that is not vented to the ambient air.

4. The applicant shall develop, maintain, and implement a program of regular maintenance and inspection of all valves, flanges, and pump and compressor seals to reduce THC emissions to a level that is acceptable to the Ventura County APCD.

5. The applicant shall comply with all conditions and permits issued by the Ventura County APCD.

d. Mitigation of Ambient Noise Levels (5.2.2)

Offshore pipeline-pulling activities should be initiated at 7:00 a.m. early in the week, so that tug and barge operations will be further from shore during the first and subsequent nights and the weekend.

e. Mitigation of Potential Effects on Terrestrial Biology (5.5)

Revegetation associated with restoration of surface conditions after construction activities at the offshore pipeline marshalling and fabrication areas and along the onshore pipeline systems, as well as the onshore treating facility after project termination, shall be dictated by the type and nature of the adjacent vegetation as follows:

1. Fore-dunes and dune scrub habitat should be revegetated with native species or introduced dune stabilizers presently dominating many areas, or left without vegetation on flat strand used intensively for recreation.

2. Agricultural and urban habitat should be revegetated with the appropriate crops or landscape species.

3. Ruderal habitat should be revegetated with annual or perennial grass or other appropriate cover.

4. Riparian habitat in the vicinity of the Santa Clara River should be allowed to revegetate naturally.

5. For projects where a revegetation plan and/or habitat restoration plan has been required, the area crossed by the pipeline shall be resurveyed one year after the completion of construction to determine the effectiveness of the plan. This survey shall continue, on an annual basis, to monitor progress in returning the site to preconstruction conditions until the City has determined that the vegetation restoration is complete.

6. Herbicides shall not be used during pipeline construction. The sidecasting of soil may be restricted, where the City deems necessary, by removal of excess soil to an approved dumping site after the excavation has been backfilled and compacted. The City may require that the trenches be filled by replacing the soil horizons in sequence.

f. Mitigation of Potential Effects on Surrounding Land Uses (5.6)

1. Detour lane recommendations listed in Table 5.0-1 of E-78-19 are subject to the review and approval of the Public Works Director before implementation.

2. The block wall surrounding the treating facility shall be beige, or a color that is compatible with the natural surroundings. The wall shall be regularly maintained to remove graffitti and repair the effects of vandalism. No ornamental landscaping should be introduced on the exterior of the wall, as it would highlight the facility against the natural color of the surrounding dunes.

g. Mitigation of Potential Effects on Cultural Resources (5.8)

1. Avoidance is the preferred mitigation in all cases where a proposed project element would intrude on the known location of a cultural resource.

2. A qualified archaeologist shall be present to monitor all subsurface work during treatment facility and onshore pipeline construction.

3. Should any object of potential cultural significance be encountered during construction of offshore and onshore facilities, a qualified cultural resources consultant should evaluate the find and recommend any further mitigation measures needed to the Planning Director. Upon receipt of this recommendation, the Planning Director may require that subsurface work be stopped in the affected area until a mitigation plan is prepared that is acceptable to the City.

4. Any buried sites discovered during onshore construction should be excavated by a qualified archaeologist, using professionally accepted methods and techniques, in accordance with an acceptable research design. During such site excavation, a qualified representative of the local descendants of the Chumash Indians should be employed to assist in the study, ensure proper handling of cultural materials, and ensure proper curation or reburial of finds of religious importance or sacred meaning.

5. Access to permanent facilities construction areas and the offshore pipeline fabrication/marshalling area near the SCE Mandalay Generating Station should be strictly controlled during construction and operation to avoid encroachment on the basket material site located to the southeast.

28. Conditions 28a through 28d are based upon policy recommendations included within the adopted City of Oxnard Local Coastal Plan (LCP). The numbers in parentheses refer to policy sections in the LCP.

a. Any person developing property within the 100-year flood line shall agree to indemnify, and hold the City harmless, from any liability or damages resulting from the construction of his development. (18)

b. Because it is not possible to route pipelines around coastal resource areas (extending from the mean high tide line to Harbor Boulevard and designated as habitat, recreational and possibly subsequent archaeological areas), they shall be permitted to cross the areas with the following conditions: (33)

1. In case of a break, pipeline segments, except for natural gas pipelines, shall be isolated by automatic shut-off valves or with other safety techniques approved by the City, Department of Transportation (DOT), or other appropriate agency. An automatic shutoff valve will be required at the point where the DOT pipeline intersects the Harbor Boulevard right-of-way. If the City determines it is necessary, the valves may be located at intervals less than the maximum required by the DOT.

2. Any routing of pipelines, other than natural gas pipelines, through resources areas shall be designed to minimize the impacts of a spill, should it occur, by considering spill volumes, durations, and trajectories. Plans for appropriate measures for clean-up shall be submitted with the franchise applications for all pipeline project proposals. This shall include a risk management plan, including oil spill prevention measures and contingency plans, which shall be developed and placed on file with the Public Works, Fire and Police Departments.

3. All alarm malfunction systems for pipeline pressure drops, breaks, etc., shall be supervised twenty-four hours a day.

4. Certification shall be presented to the Oxnard Fire Department yearly by an outside, widely recognized testing agency. This certificate will attest to the condition of all lines. valves, storage containers and pressure systems.

5. The portions of the oil and gas pipeline systems that are within the City shall be designed, installed, and operated in accordance with DOT standards, as if the pipelines were under the jurisdiction of the DOT.

c. Oil processing and shipping facilities shall be consolidated to the maximum extent feasible, as determined by the City. Union Oil shall make space or treatment capacity available to other companies if it is technically feasible to do so after taking into account Union Oil's short and long term needs for the facility. (42)

d. Pipelines shall be used to transport all petroleum products produced in the City's Coastal Zone to other areas for further processing. Existing pipelines shall be used, including multi-company use, wherever possible. (43)

29. Upon completion of production, the oil and gas separation facility area shall be restored to a state approximating its original condition, with respect to topography and vegetation.

30. Sanitary wastes generated during the onshore treatment facility construction, operation and power cable and pipeline installation will be collected in portable chemical toilets. At regular intervals, the contents shall be emptied and trucked to an approved offsite disposal facility by a licensed contractor, and disposed of by methods approved by local regulatory agencies.

31. Any agreement entered into between Union Oil Company and the County of Ventura related to the use of or access to the subject property shall be subject to review and approval by the Oxnard City Council. Union shall request a review of any agreements in effect at the time this permit is issued within thirty days of the date of final approval and, subsequently, thirty days prior to changing any existing agreement or entering into a new agreement.

32. The pipeline fabrication shown in Exhibit "B" and all access routes must be restored to conditions existing before the disturbance (or better) after construction of the pipeline and laying of the pipelines and cables are completed.

33. Permanent surface access to the treatment facility is to be provided by an easement that is contiguous with and parallels the southerly boundary of the generating facility and shall cross the area indicated on Exhibit "A" (tentative parcel map) as Drill Site No. 1, unless this is proven infeasible to the satisfaction of the Planning and Public Works Directors and an acceptable alternative is presented for their approval. No departure from the concept of contiguity is permitted without review and report by the Recreation Director and approval by the Planning Commission.

34. The applicant shall follow the recommendation of the California Department of Fish and Game (E-78-19, Vol. III, P. 22-1), which states: "Onshore and offshore pipeline and power cable placement activities [shall only] be conducted from September through February." This construction timing limitation shall be reflected in any franchise agreement requested by the applicant of the City and adhered to unless the recommendation by the Department of Fish and Game is modified by a written report and approved by the Planning Director.

35. The 1.8 acre treatment facility design pad elevation shall be designed to provide flood proofing from a 100-year level of wave runup.

36. The interrelationships of the sand dune system, beach aggradation and degradation, and the facility, shall be evaluated by a qualified consultant. The findings, conclusions, and recommendations shall be taken into account during the development of the final design specifications for the treatment facility before the final specifications are submitted to the Building and Safety Department for review and approval. A plan for restructuring and revegetating the sand dunes to the west of the facility after completion of construction shall be submitted to the Parks Director for review and approval prior to the Building and Safety Department issuing a building permit for the 1.8 acre treatment facility.

37. A plan for perimeter and internal security shall be developed and submitted to the Police Department for review and approval prior to obtaining an electrical permit from the Building and Safety Department.

PASSED AND ADOPTED by the Planning Commission of the City of Oxnard on this 18th of December, 1980, by the following vote:

AYES:	Commissioners:	Dressler, Duff, Flores, Stoll, O'Connell
NOES:	Commissioners:	None
ABSENT:	Commissioners:	Lopez

Hugh [illegible]. O'Connell, Jr., Chairman

ATTEST:

Gene L. Hosford, Secretary

APPENDIX VOLUME 3

Exhibit C

Original Project Description evaluated in EIR/EA 78-19

EXHIBIT C

Original Project Description Evaluated in EIR/EA 78-19

The following summarizes the original project description and identifies sections and pages of EIR 78-19 where fuller elaboration is found. The proposed project may be compared to the original project to determine what aspects of the proposed project, if any, may raise new significant impacts, not previously evaluated.

In the original project Union Oil Company of California proposed to develop Outer Continental Shelf oil and gas leases OCS P-0202, OCS P-0203 and P-0216 in the eastern Santa Barbara Channel, offshore California. The major elements of the project were:

- o Two offshore drilling and production platforms, named Gina and Gilda, located approximately 4.5 miles (7.2 km) west-southwest of Port Hueneme and 10 miles (16 km) west of Oxnard, California, respectively.

- o Two offshore pipeline systems (one for each platform) to convey produced crude oil/water/natural gas to an on-shore treating facility, and to return produced water to the platforms for injection.

- o An on-shore treating facility which would separate the produced water and natural gas from the crude oil.

- o An on-shore pipeline system which would convey the product crude oil and product natural gas to existing oil and gas distribution systems within the Oxnard/Ventura area.

The on-shore treating facility is located on a 1.8 acre parcel of land located immediately south of and adjacent to the existing Southern California Edison Company (SCE) Mandalay Generating Station in Oxnard.

The City of Oxnard had required that Union's project and the three primary alternative configurations be addressed at an equivalent level of detail in the EIR/EA. In addition, the U.S. Geological Survey required that Platform Gina and Platform Gilda portions of the project be addressed separately. For these reasons, the project description was organized to facilitate an understanding of the individual project elements (platforms, offshore pipelines, on-shore treating facility, and on-shore pipelines).

Project Facilities

Platforms

Platform Gina consisted of a six pile steel structure designed for the following:

- o Drill the required production and injection wells, test and measure the produced fluids and pump them to shore.

- o Inject produced water and or cleaned treated seawater into the producing formations for reservoir pressure maintenance.

Platform Gilda consists of a 12 leg template type steel structure designed for the following:

- o Drill the required production and injection wells to develop the Repetto formation.
- o Drill test wells to evaluate the quantities and properties of natural gas and oil within the Monterey formation.
- o Drill the required production and injection wells to develop the Monterey formation if commercially feasible production rates are indicated by the test drilling program.
- o Separate the produced natural gas from the produced crude oil and water.
- o Test, measure and transport the produced crude oil, water and natural gas on-shore.
- o Separate the water from the produced fluids if required.
- o Measure and inject produced water in to the producing formations if required.
- o Remove hydrogen sulfide (H2S) present in produced natural gas from the Monterey Formation if required.
- o Measure and inject natural gas produced from the Monterey Formation.
- o Produce the injected gas after liquid production is depleted.

Differences Between Facilities

The major differences between the two facilities are:

- o Platform Gilda is physically larger than Platform Gina.
- o Natural gas would be separated from the produced fluids on Platform Gilda. This separation would not occur on Platform Gina.
- o Platform Gilda may have facilities to accomplish the following tasks:
  - -- separate the water from the produced fluids if required as a result of the increased water content of the produced fluid during the project lifetime.
  - -- remove the H2S that may be present in the natural gas produced from the Monterey Formation.
  - -- inject the treated natural gas back into the Monterey Formation.
  - -- produce the injected gas after liquid production is depleted.

On-shore Pipelines

The following on-shore pipe lines were listed as required for the proposed project:

Group 1:

- one oil/water/natural gas mixture pipeline from Platform Gina.
- one return water pipeline to Platform Gina.
- one oil/water mixture pipeline from Platform Gilda.
- one natural gas pipeline from Platform Gilda.
- one return water pipeline to Platform Gilda.

Group 2:

- one product crude oil pipeline from the Mandalay Facility to a Unocal main transmission line.
- one product natural gas pipeline from the Mandalay Facility to a Southern California Gas Company line.

Drilling

This section describes the drilling program and procedure for both Platforms Gina and Gilda.

Platform Gina-- Union planned to recover hydrocarbon fluids from the Hueneme sand (of the Miocene Rincon Formation) and the Oligocene Sespe Formation. Drilling procedures would be in accordance with all applicable requirements, including the code of Federal Regulations and OCS Orders 2,5, and 6. Union was required to submit final detailed plans to the U.S. Geological Survey for approval prior to commencing drilling operations.

Platform Gilda-- Union planned to recover hydrocarbon fluids from the Pliocene Repetto and the Miocene Monterey formations. Hydrocarbon accumulations in these two formations would be recovered through separate drilling programs. Section 3.4.1.2.1 of the EIR describes the Drilling Procedures for the Repetto Formation.

Drilling Procedures for the Monterey Formation are described in EIR Sections 3.4.1.2.2. Fractured zones within the Monterey Formation on lease OCS P-0216 have yielded measurable qualities of hydrocarbon fluids during limited testing. Since currently available data was limited, no significant determination of reservoir characteristics and performance had been made. For this reason, further test drilling from Platform Gilda would be required to evaluate and optimize development of this formation. Test drilling of the Monterey Formation would be performed as an extension of the Repetto Formation production well drilling program. The same work force, equipment, support facilities, and drilling procedures would be used as for the Repetto formation drilling. (EIR page 3.4-8)

Production

Platform Gina

The analysis of production on Platform Gina was based the following general characteristics: Union proposed to develop oil and gas from the Hueneme sand and Sespe Formation underlying leases OCS P-0202 and P-0203 using six production and six injection wells drilled from Platform Gina and assumed production of 15.5^{o} of API crude oil with a gas: oil ratio of approximately 200 standard cubic feet per barrel (SCF/bbl). (page 3.5-1)

Platform Gilda

Union proposed to develop oil and gas from the Repetto Formation and, potentially, the Monterey Formation underlying lease OCS P-0216.

The combined oil, gas and water production rates from both Platforms Gina and Gilda are shown on EIR Figure 3.5-3. Peak oil recovery rates from the Monterey Formation were estimated in the EIR by Union to be approximately 8,000 bbl/day (2,280 m3/day) with a gas: oil ratio of approximately 1,000SCF/bbl. Ultimate oil and natural gas recovery estimates from the Monterey Formation had not been made. (EIR p.3-5-8) Under the section describing process flow for Platform Gilda a description of the crude oil/water/natural gas fluid from the Monterey formation is included. This would be treated in a separate gas separation unit. (EIR Appendix A Figure A-12)

The natural gas produced at the platform would be dehydrated and then sent to the on-shore treating facility. The gas would flow from the various well annuli and from the test separator, gross separator, and shipping tank. The collected gas would then be compressed and dehydrated. The gas treatment would be accomplished using a gas scrubber and a refrigeration-type dehydration unit. The processed gas would then be transmitted to the on-shore facility. Additional processing of the produced natural gas would be required if hydrogen sulfide (H2S) is present. Tests of Monterey Formation natural gas from an adjacent OCS lease show H2S concentrations varying from 0 to 3,000ppmc. If present, H2S would be removed using the Stretford process. This process produces a high purity elemental sulfur product. Sulfur produced on Platform Gilda would be transported to shore by boat for sale. A process flow diagram of the Stretford process is shown in EIR Appendix A, Figure 1-13.

The major difference between the process flow on Platform Gilda and that on Platform Gina is the natural gas separation on Platform Gilda. The natural gas is not separated on Platform Gina because its presence greatly reduces the fluid viscosity and, therefore, greatly reduces the power required to pump the Gina fluid to the on-shore site. The produced fluid at Platform Gilda has lower viscosity than the Platform Gina fluid and therefore requires less pumping pressure. The separated natural gas and resulting oil/water stream would flow to the on-shore treating facility in separate pipelines from Platform Gilda.

Safety procedures and practices

The text under EIR Section 3.6 describes the safety procedures and practices for process control, direct protection, hydrogen sulfide exposure, oil spills, navigation aids, blowout prevention, and personnel safety. Under process control, in addition to the valves sensors, alarms and shutdown equipment listed, Platform Gilda would be equipped with an emergency vent system consisting of a gas scrubber and vent stack.

Blowout prevention systems for both platforms include:

1. An hydraulic actuating system that provides sufficient accumulator capacity to repeatedly operate the blowout preventors.

2. Side outlets to provide for kill and choke lines.

3. Choke and kill lines, a choke manifold, and a fill-up line.

4. A top kelly cock installed below the swivel, and another at the bottom of kelly that can be run through the blowout preventors.

5. An inside blowout preventor and a full opening drill string safety valve in the open position, which would be maintained on the rig floor at all times while drilling is being conducted.

The Union H_2S Contingency Plan provides for the safety of personnel who may be exposed to harmful concentrations of this gas. The key elements of this plan are similar in nature to those described for oil spills. Response procedures are described and personnel are trained in the proper use of protective equipment. This plan also has been reviewed by the USGS for adequacy and completeness. Other regional and local plans would supplement this one as in the case of an oil spill.

The attached Initial Study includes the full text of the proposed pipeline conversion project and its Appendices as Exhibit A. Exhibit B to the Initial Study is the Approval of Minor Modification to Special Use Permit 806 and Resolution 6218 approving SUP 806 which contains the conditions which implement the mitigation measures of EIR 78-19. Exhibit C to the Initial Study provides copies of the pages from the EIR which are referenced in the Initial Study. The discussion attached to the Initial Study reviews the impacts associated with the original project, their applicability of that evaluation and related mitigation measures to the proposed pipeline conversion project, and provides further technical analysis of any aspects of the proposal not covered by EIR/EA 78-19.

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APPENDIX VOLUME 3

Exhibit D

Emission Data for Platform Gina Pipeline Repair and Conversion Project, February 1990

Letter of April 9, 1990 from the Ventura County Air Pollution Control District concerning the proposed project

Emission Data

for

Platform Gina

Pipeline Repair and Conversion Project

Prepared By:

EnerSource Engineering
17280 Newhope St., Ste. 20
Fountain Valley, CA 92708

February 28, 1990

⚠ Revised July 20, 1990 per MMS Comments

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TABLE OF ATTACHMENTS

1. INTRODUCTION AND SYNOPSIS

UNOCAL is proposing to repair the existing Platform Gina water line and convert it to gas service. A complete description of this project may be found in the published project description entitled *Platform Gina to the Mandalay Facility 6-5/8" Pipeline Repair And Conversion Project--Revision 1*, dated December 1989. This report was prepared in response to specific comments received from Mr. Chuck Thomas, Ventura County APCD, in his memorandum of October 16, 1989.

Specific responses to comments are as follows:

Comment 1, Construction-Related Emissions:

Section 2 of this report, entitled "Construction Related Emissions" addresses estimated construction related emissions. In addition, a copy of EIR 78-19 has been forwarded separately as requested. Section 4.2 of the EIR contains the requested atmospheric air quality information.

Comment 2, Air Emissions:

As requested, the EIR has been supplied to substantiate Item B.1 of the subject initial study.

Comment 2, Odor:

Odor will occur only in the event of accidental release of gas from pipeline. This can occur only if there is a catastrophic failure of the H_2S Processing Detection and Shutdown System. Please see next comment response.

Comment 2, Failure of H_2S Processing, Detection, and Shutdown System:

Union has contracted with an outside consultant to prepare a risk assessment study addressing catastrophic failure of the proposed Hydrogen Sulfide Processing Detection, and Shutdown System. This report shows the possibility of such a failure is extremely remote and does not pose a threat. A copy of this report has been forwarded separately for your review. The report shows that if a worst-case accident were to occur, the affected area would be limited to a 1,320 foot radius of the Mandalay Onshore Processing Facility, within which there are no public residences.

Comment 3, Onshore Impacts Associated with Processing of Gas on Platform Gina:

Gas which is produced on Platform Gina is essentially "sales ready," and no further processing will need to take place onshore before transmission into the Southern California Gas Company Pipeline/Distribution System. Offshore generated emissions and impacts to onshore are summarized in Section 3 of this report, entitled "Onshore Impacts Associated With This Project."

Synopsis:

For clarity, this report is segregated into three areas:

1) Estimated construction related emissions associated with the project
2) Estimated onshore impacts resulting from the project
3) Potential offsets available to support project

1.1 Construction Related Emissions

Construction-related emission sources for this project were identified and daily and total emissions were calculated. Emission factors used were based upon those published by the Ventura County APCD.

The following table summarizes the total construction related emission impacts:

TABLE 1.1
Total Construction Emissions, Lbs

	TOC	ROC	NO_X	TSP	SO_2	CO
Total Construction Emissions	473	420	5,197	371	344	2,656

These construction emission figures represent the "one-time" total emissions directly generated as a result of the construction. The emissions would be generated over the construction time table period, expected to take approximately 2 weeks. Daily emission estimates for the various equipment items expected to be used may be found in Section 2.

1.2 Onshore Impacts

The development of offshore gas sources will result in increased flaring aboard Platform Gina. Flaring will be done at low rates during normal production periods and higher rates during well testing. In order to ascertain the emissions impact onshore, computer dispersion modeling was performed for the expected flare emission. It was found that the onshore impact resulting from normal production operations was very small, and thus it was modeled. Flaring emissions were then examined during periods of higher flow rates expected during well testing. Well testing is expected to occur for a maximum of two days for each new well that is to be developed. The expected days of well testing for the next 3 years is as follows:

TABLE 1.2 Number Days of Well Testing			
	1990	1991	1992
Days	4	6	6

The onshore average incremental pollution increase, during the few days each year that well testing is occurring, was calculated and found to be only:

TABLE 1.3
24 Hour Average Incremental Pollutant Concentration at Shore, $\mu g/m^3$

	TOC	ROC	NO_X	TSP	SO_2	CO
24 Hour	0.0532	0.0256	0.472	0.0276	0.0176	0.322

A complete discussion of the emission factors used in this model are in Section 3.

1.3 Potential Offsets

Should mitigation of either the short term construction-related emissions or operating/well testing flaring emissions be required, UNOCAL has offsets available to help support this project. At Mandalay, an on-going fuel conservation effort has identified several areas of improvement, all which will soon come on-line, which will provide the following net reduction in emissions:

TABLE 1.4
Annual Emissions Reduction Available, At Mandalay, From Fuel Conservation (Lbs)

	TOC	ROC	NO_X	TSP	SO_2	CO
Fuel Saved (127MCF/D)	372	248	4,636	139	29.2	927

In addition, the introduction of new sources of natural gas, such as is what is proposed aboard Platform Gina, represents a viable and positive contribution to local air quality. When compared to alternative fuels, such as fuel oil, natural gas burns cleaner, resulting in less emissions. For example, if the gas produced aboard Platform Gina were to be utilized by the Mandalay SCE electrical power generation station, in lieu of fuel oil, the following net reduction in air emissions would be realized:

TABLE 1.5[1]
Annual Emissions Reduction Available at the Mandalay Generating Station, Using Gas From Platform Gina In Lieu of Fuel Oil No. 6 (Lbs)

	TOC	ROC	TSP	SO_2	CO
Emissions, Lb/Day	28,722	26,422	27,105	427,147	8,687

[1]Table based upon Ventura County APCD emission factors for power plants (see Section 4). NO_X emission factor is not published for this classification.

2. CONSTRUCTION RELATED EMISSIONS

A potential construction-related air emission analysis was performed by evaluating the offshore emissions related to the repair of the Gina pipeline. Emission sources for the project include a working vessel (Equipment Group 1), three (3) transportation vessels (Equipment Group 2), a generator set (Equipment Group 3), and an onshore spread (Equipment Group 4). Emission sources are diesel or gas powered, and the emissions last from a few minutes to 24 hours, depending upon their function. Based upon estimates of equipment usage and fuel consumption at various stages of the project (provided by International Diving Services and Hood Corporation), daily emissions and total emissions for the project were calculated using emission factors published by the Ventura County APCD.

2.1 Description of Emission Sources

Emission sources for this project were identified and are arranged into the following groups for ease of tabulation:

1) Equipment Group 1 - Offshore Working Vessel and Equipment
2) Equipment Group 2 - Offshore Transportation Vessels
3) Equipment Group 3 - Generators
4) Equipment Group 4 - Onshore Construction Equipment

2.1.1 Equipment Group 1, Offshore Working Vessel and Equipment

Equipment Group 1 represents a working pipe-lay vessel, which will be involved in most of the work. It will be anchored offshore for most of the project. During this time, there will be no emissions from the marine gear; movement is accomplished by means of anchor cables and winch.

TABLE 2.1 Equipment Group 1, Offshore Working Vessel and Equipment			
Make/Model	**Rated RPM**	**Rated HP**	**Driving**
Cat 398 TA	950	850	Marine Gear
Cat 398 TA	950	850	Marine Gear
GM V671	1800	180	RB-90 Winch
GM V671	1800	180	RB-90 Winch
GM V671	1800	180	RB-90 Winch
GM V653	1800	180	40 T Crane
GM 671	1200	135	Jet Pump
GM 671	1200	135	Air Comp.
Total		2690	

2.1.2 Equipment Group 2, Offshore Transportation Vessel

Equipment Group 2 represents three (3) transportation vessels which would be used for this project, and consists of the following emission sources:

TABLE 2.2 Equipment Group 2, Offshore Transportation Vessel			
Make/Model	**Rated RPM**	**Rated HP**	**Driving**
Cat 343 TA	1650	350	Marine Gear
Cat 343 TA	1650	350	Marine Gear
Cat 343 TA	1650	350	Marine Gear
Cat 343 TA	1650	350	Marine Gear
Cat 343 TA	1650	350	Marine Gear
Cat 343 TA	1650	350	Marine Gear
Total		2100	

2.1.3 Equipment Group 3, Generators

Equipment Group 3 consists of two generators, as follows:

TABLE 2.3
Equipment Group 3, Generator Sets

Make/Model	Rated RPM	Rated HP	Driving
GM 671	1200	135	60 kW Gen
GM 671	1200	135	60 kW Gen
Total		270	

2.1.4 Equipment Group 4, Onshore Construction Equipment

Equipment Group 4 consists of shore-side equipment which will be used in construction. Both gasoline and diesel engines are present.

TABLE 2.4 Equipment Group 4, Onshore Equipment			
Make/Model	**Horsepower**	**GPD[2]**	**Driving**
CAT 561	105	40	Side Boom
CAT 561	105	40	Side Boom
JD 450	70	18	Dozer
JD 710	105	27	Backhoe
Welding Rig	60	8[3]	Welding Machine
Welding Rig	60	8[3]	Welding Machine
3 Ton Crew Truck	210	40[3]	--
Equipment Van	210	40[3]	--

2.2 Emission Factors

The following emission factors were used in calculations. The factors are from the Ventura County APCD internal combustion table, sub-category 1 = industrial, sub-category 2 = diesel, sub-category 3 = recipicating, SCC Code = 2-02-001-02. These factors were found to be conservative and in excess of published engine manufacturer's guidelines.

[2]Figures corrected for estimated hours of operation.

[3]Gasoline fueled.

TABLE 2.5 Emission Factors (Diesel)	
Reactivity	0.884
TOC	37.5 Lb/1000 Gal
NO_x	469.0 Lb/1000 Gal
TSP	33.5 Lb/1000 Gal
SO_2	31.2 Lb/1000 Gal
CO	102.0 Lb/1000 Gal

Similarly, the following factors were used for gasoline powered equipment. The factors are from the Ventura County APCD internal combustion table, subcategory 1 = industrial, subcategory 2 = gasoline, subcategory 3 = recipicating, SCC Code = 2-02-003-01.

TABLE 2.6 Emission Factors (Gasoline)	
Reactivity	.908
TOC	161.0 Lb/1000 Gal
NO_x	102.0 Lb/1000 Gal
TSP	6.47 Lb/1000 Gal
SO_2	5.31 Lb/1000 Gal
CO	3990.0 Lb/1000 Gal

2.3 Construction Emissions

The following tables were created to show emissions for each phase of the construction. The gallons per day figures were based upon discussions with contractors and run-time estimates for the various pieces of equipment.

TABLE 2.7 Construction Emissions, Offshore Mobilization (1 Day Working) Emissions, Lbs/Day								
	GPD	Rx	TOC	ROC	NO_x	TSP	SO_2	CO
Equip Group 1	1200	0.884	45.00	39.78	562.8	40.20	37.44	122.40
Equip Group 2	900	0.884	33.75	29.85	422.10	30.15	28.08	91.80
Daily Total	2100		79	70	985	70	66	214

TABLE 2.8 Construction Emissions, Jetting Spread (2 Days Working) Emissions, Lbs/Day								
	GPD	Rx	TOC	ROC	NO_x	TSP	SO_2	CO
Working Equip Group 1	300	0.884	11.25	69.95	140.70	10.05	9.36	30.60
Working Equip Group 2	300	0.884	11.25	69.95	140.70	10.05	9.36	30.60
Working Gen Set	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Standby Equip Group 1	200	0.884	7.50	6.63	93.80	6.70	6.24	20.40
Standby Equip Group 2	150	0.884	5.63	4.97	70.35	5.03	4.68	15.30
Standby Gen Set	255	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Daily Total	1400		52	46	656	47	43	143
2 Day Total	2800		104	92	1312	94	86	286

TABLE 2.9
Construction Emissions,
Working Spread (2 Days Working) Emissions, Lbs/Day

	GPD	Rx	TOC	ROC	NO_x	TSP	SO_2	CO
Working Equip Group 1	300	0.884	11.25	9.95	140.70	10.05	9.36	30.60
Working Equip Group 2	900	0.884	33.75	29.85	422.10	30.15	28.08	91.80
Working Gen Set	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Standby Equip Group 1	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Standby Equip Group 2	150	0.884	5.63	4.97	70.35	5.03	4.68	15.30
Standby Gen Set	225	0.884	7.46	7.46	105.53	7.54	7.02	22.95
Daily Total	2025		75	67	949	68	63	207
2 Day Total	4050		150	134	1898	136	126	414

TABLE 2.10
Construction Emissions,
Tie-In Spread (2 Days Working) Emissions, Lbs/Day

	GPD	Rx	TOC	ROC	NO_X	TSP	SO_2	CO
Working Equip Group 1	500	0.884	18.75	16.58	234.50	16.75	15.60	51.00
Working Equip Group 2	900	0.884	33.75	29.85	422.10	30.15	28.08	91.80
Working Gen Set	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Standby Equip Group 1	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Standby Equip Group 2	200	0.884	7.50	6.63	93.80	6.70	6.24	20.40
Standby Gen Set	225	0.884	8.44	7.46	105.53	7.54	7.02	22.95
Daily Total	2275		86	76	1067	76	71	232
2 Day Total	4550		172	152	2134	152	142	464

TABLE 2.11
Construction Emissions,
Onshore Spread (4 Days Working) Emissions, Lbs/Day

	GPD	Rx	TOC	ROC	NO_X	TSP	SO_2	CO
Equip Group 4 (Diesel)	125	.884	4.69	4.15	58.63	4.19	3.90	12.75
Equip Group 4 (Gasoline)	96	.908	15.46	14.03	9.79	0.62	0.51	383.04
Daily Total	221		20.15	18.18	68.42	4.81	4.41	395.8
4 Day Total	884		80.60	72.72	273.68	19.24	17.64	1583.2

2.4 Summary of Total Construction Emissions

The overall total construction emissions for the project are thus summarized as follows:

TABLE 2.12
Construction Emissions, Total for Project, Lbs

	Gal	TOC	ROC	NO_X	TSP	SO_2	CO
Total Emissions	14,384	586	521	6,603	471	438	2,961

3. ON-SHORE IMPACTS ASSOCIATED WITH THE PROJECT

The potential on-shore impacts resulting from the proposed project would occur primarily as a direct result of flaring aboard Platform Gina. After gas is processed aboard Platform Gina, it is ready for direct transfer to the Southern California Gas Company distribution system. However, there is some consideration of a direct tie-in to the Southern California Edison power station at Mandalay, in which case gas from the platform may be directed either to the main distribution system or the Mandalay power station. After being shipped to shore, it will pass through the Mandalay facility with no further processing. There are no new emission sources associated with this project at the Mandalay facility.

Aboard Platform Gina, the equipment used to produce, process, and ship the gas will be all electric. All drilling will be (as is currently) performed by an all-electric drilling rig. The number of personnel and transportation requirements will remain the same. Thus, there will be no new sources of emissions directly related to these operations. However, there will be some residual waste or "tail-gas" generated by the gas sweetening process, and this gas will be burned using a flare. In addition, the flare will also be used to dispose of gas generated by well testing operations and by upset process conditions.

3.1 Determination of Emission Rates

The projected flow rates for Platform Gina under normal operations and during well-testing operations are summarized in Table 3.1. The emission factors used to calculate the concentration of products from the combustion of flare gas are listed in Table 3.2. Since the emission factors for every product of the combustion were not available from Kaldair (the manufacturer of the Coanda flare nozzle to be used on Platform Gina) conservative emission factors for TOC, ROC, TSP, NO_x, SO2, and CO were taken from published tables of the Ventura County Air Pollution Control District (VAPCD) and California Air Resources Board (CARB).

A high and low estimate of emission rates were determined by using the highest and lowest values of the derived emission factors, respectively (see Table 3.3).

3.2 Preliminary Modeling of Air Quality Impacts from Flare Emissions

To facilitate the evaluation of potential air quality impacts from Platform Gina operations, a preliminary air dispersion modeling study was undertaken using the emission data developed above. In order to estimate the air dispersion behavior of an open flare, parameters were needed which would allow the flare to be modeled as a stack emission. Since the plume rise of the flare is dominated by the heat induced buoyancy effect resulting from the combustion of gas (with a heat value of 1050 Btu per cubic feet), the value for stack diameter was determined by calculating the net heat released and solving for stack diameter using the Buoyancy Flux Equation (see Attachment 1). Ambient air temperature was set at 293° Kelvin and exit gas velocity at 10 meters per second.

Two established computer models, PTPLU2 and ISCST, were utilized in this investigation to provide a preliminary survey of the expected impact from flare emissions during conditions of expected highest release (i.e. during well-testing operations). The study used the emission rates provided in Table 3.3 and employed estimated values for stack diameter, stack velocity, and exiting temperature of the gas derived on Attachment 1. The rural diffusion coefficients (Pasquill-Gifford) and the options for stack tip downwash and buoyancy induced dispersion were used in both models. Default values for wind speed and the wind profile exponent were used to coincide with the stability categories of Pasquill. The possibility of limited mixing conditions at the stable-unstable interface was considered by setting the mixing height at 5,000 meters and then doubling the concentrations that occur under stability classes A through D.

The PTPLU2 run gave a maximum concentration under stability class C (Table 3.4). The ISCST model was run under the stability classes B, C, and D with seven discrete receptor points (see Attachments 2 and 3, respectively). The concentrations at a receptor point approximately seven (7) kilometers from the source are provided and represent the distance from Platform Gina to the nearest shoreline. The maximum projected concentration of NO_X at the shoreline receptor point was 1.182 micrograms per cubic meter (see Table 3.5), and the maximum ISCST one-hour average concentrations for all relevant flare emissions is summarized in Table 3.6.

Since both the PTPLU2 and ISCST models only derive 1-hour average concentrations, we also calculated less conservative 3-hour, 8-hour, and 24-hour average concentrations from the modeling results based on standard multiplying factors recommended by the EPA (see Table 3.7).[4]

[4]U. S. Environmental Protection Agency. Guidelines for Air Quality Maintenance Planning and Analysis. Volume 10 (revised), October 1977.

TABLE 3.1 Projected Gas Flare Rates - Platform Gina			
	1990	1991	1992
Normal Operations[5]	30 Mcf/d	100 Mcf/d	180 Mcf/d
Well - Testing[6]	3,000 mcf/d for 4 days	3,000 Mcf/d for 6 days	3,000 Mcf/d for 6 days
Total Rate	22.98 MMcf/yr	54.50 MMcf/yr	83.70 MMcf/yr

[5]During normal operations, flare rate is estimated as 1% of production rate.

[6]During well testing, the entire flow from a single well is assumed to be flared during the test period. Production flow tests are assumed to last up to two (2) days per well test, and only one well is assumed to be tested at any given time.

TABLE 3.2
EMISSION FACTORS FOR COMBUSTION OF NATURAL GAS (lbs/MMcf)
(Note - Factors Believed to Best Represent the Conditions on Platform Gina are Marked with an Asterisk)

Source	SubCategory	Reactivity	TOC	NO_x	TSP	SO_2	CO
From VAPCD:[7]							
SCC # 1-02-006-01	> 100 MM Btu/hr	0.824	1.70	550	3.00	0.60	40
SCC # 1-02-006-02	10 - 100 MM Btu/hr	0.483*	5.80*	140	3.00*	0.60	35*
SCC # 1-02-006-03	< 100 MM Btu/hr	0.663	8.00	100	3.00	0.60	35
SCC # 1-02-007-01	Process Gas	0.924	3.00	140	3.00	357*[8]	35
From CARB:[9]							
SCC # 3-10-002-05	Gas Flare[10]	-	5.60	-	-	-	-
Kaldair Inc.:	COANDA-Type Flare[11]	-	-	51.5*	-	-	-
UNOCAL Quarterly Report:	Selected VAPCD Factors	-	5.8	140	3.00	0.60	35

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[7]Ventura Air Pollution Control District Emission Factors and Calculation Procedures (July 1985), page 3-2. Ext. Combustion Boiler, Industrial, Natural Gas.

[8]Calculated as 950 x percent sulfur in fuel (assumed 2,000 ppm H_2S) per Ventura Air Pollution Control District Emission Factors and Calculation Procedures (July 1985).

[9]California Air Resources Board. Personal conversation with Ventura Air Pollution Control District.

[10]Emissions from a Natural Gas Production Flare

[11]NO_X emission factor developed from measured emissions of a representative natural gas flare. Personal correspondence Kaldair, Inc.

TABLE 3.3
PROJECTED EMISSION RATES DURING NORMAL OPERATIONS AND WELL-TESTING OPERATIONS ON PLATFORM GINA

Conditions	Units	TOC	ROC	NO_x	TSP	SO_2	CO
(A) Normal Platform Operations:[12]	lbs/hr	0.0073	0.0035	0.064	0.0038	0.451	0.044
(B) Well-Testing Operations:[13]							
• Highest Estimate[14]	lbs/hr	1.00	0.924	68.75	0.375	44.74	5.00
• Lowest Estimate[15]	lbs/hr	0.213	0.103	6.44	0.375	14.10	2.50
• Most Probable Estimate[16]	lbs/hr	0.725	0.350	6.44	0.375	44.74	4.38
	g/s	0.0915	0.0442	0.8114	0.0473	5.66	0.552

[12]Flare emissions from Platform Gina under normal operating conditions are assumed to be one (1) percent of the 1990 production flow rate (see Table 3.1).

[13]Well-testing conditions assumes an unabated emission of natural gas at 3,000 Mcf/d.

[14]Calculated using the highest documented emission factors provided in Table 3.2.

[15]Calculated using the lowest documented emissions factors provided in Table 3.2.

[16]Calculated using emission factors which are believed to best represent the conditions on Platform Gina (see Table 3.2).

TABLE 3.4
PTPLU MAXIMUM CONCENTRATION (X) OF NO_X[17]

X Maximum $\mu g/m^3$ [18]	u Wind (m/s)	Air Stability	Distance (km)
3.82	3.24	A	0.584
3.38	5.40	B	0.789
4.44	16.74	C	0.600
3.60	23.57	D	0.957
2.26	2.94	E	6.03
1.70	3.66	F	10.66

[17] Uses the most probable emission rates for NO_X (see Table 3.3).

[18] Stability Class C gives highest 1 Hr. avg. concentrations. Concentrations are doubled to account for limited mixing conditions (see narrative discussion).

TABLE 3.5
ISCST MAXIMUM CONCENTRATION (X) OF NO_X[19,20,21]

X Maximum ($\mu g/m^3$)[20]	u Wind (m/S)	Air Stability	Distance (km)	(x,y) Location
3.212	15	D	1.41	1,1
2.200	7	D	2.83	2,2
1.702	7	D	4.24	3,3
1.414	5	D	5.66	4,4
1.182	3	D	7.07	5,5
1.030	3	D	8.49	6,6
0.942	3	D	9.90	7,7

[19]Uses the most probable emission rates for NO_X (see Table 3.3).

[20]Stability Class D gives highest concentration at all receptor points. Concentrations are doubled to account for limited mixing conditions (see narrative discussion).

[21]Nearest distance from Platform Gina to shore is approximately 7.2 km (4.5 miles).

TABLE 3.6
CALCULATED ISCST MAXIMUM ONE-HOUR AVERAGE INCREMENTAL POLLUTANT CONCENTRATIONS DURING WELL-TESTING OPERATIONS AT SHORE[22,23]

(Maximum 1-Hour Average Concentrations at Shore $\mu g/m^3$)

Modeling Conditions	TOC	ROC	NO_X	TSP	SO_2	CO
Highest Emission Rates	1.836	0.1218	12.62	0.0688	8.23	0.9180
Lowest Emission Rates	0.0390	0.0322	1.182	0.0688	2.59	0.4580
Most Probable Emission Rates	0.1330	0.0642	1.182	0.0688	8.23	0.804

TABLE 3.7
ESTIMATION OF 3-, 8-, AND 24-HOUR AVERAGE INCREMENTAL POLLUTANT CONCENTRATIONS AT SHORE ($\mu g/m^3$)

Averaging Period	TOC	ROC	NO_X	TSP	SO_2	CO
1-hour	0.1330	0.0642	1.182	0.0688	8.23	0.804
3-hour[24]	0.1198	0.0578	1.064	0.0620	7.40	0.724
8-hour[25]	0.0932	0.0450	0.828	0.0482	5.75	0.562
24-hour[26]	0.0532	0.0256	0.472	0.0276	3.30	0.322

[22]At 7.07 Km from platform (shoreline), with a wind speed of 5 meters per second and stability Class D.

[23]Concentrations are doubled to account for limited mixing conditions (see narrative discussion).

[24]3-hour Peak-to-Mean Factor = 0.9

[25]8-hour Peak-to-Mean Factor = 0.7

[26]24-hour Peak-to-Mean Factor = 0.4

4. POTENTIAL OFFSETS AVAILABLE

Should it become necessary to offset emissions related to this project, there are potential offsets at the Mandalay onshore facility which could be used. Also, it is possible that an offset would be available from the Southern California Edison Electric Company. These potential offsets are described as follows:

4.1 Potential Mandalay Offsets

During 1989 there were five test projects conducted at the Mandalay facility to identify ways to reduce fuel gas usage and emissions at the facility. These projects could provide a considerable emissions offset to the pipeline repair project. In order to quantify the potential emissions savings, the projects were subjected to extensive in-place testing and evaluation between May and December 1989. The long-term testing was requested in order to optimize heat settings and throughput rates on various pieces of equipment. The projects are identified as follows:

Fuel and Emissions Reduction Project	Date Testing Started
Installation of 3rd Heat Exchanger	May 1989
Insulation of Hot Oil Piping Upstream of All 3 Heat Exchangers	July 1989
Insulation of Hot Emulsion Piping Downstream of All 3 Heat Exchangers	August 1989
Installation of Additional Heat Exchange Plates in 3rd Heat Exchanger	October 1989
Revision of FWKO Internals to Reduce Heater Treater Requirements	December 1989

Since the projects all had some effect on the reduction in fuel gas, below is provided the fuel gas and throughput volumes prior to May, the numbers after May to December, and the numbers to date for 1990. The 1990 numbers reflect the fuel gas usage expected to occur with all five emission-reduction projects on-line. It is also important to consider that throughput volume increased during the period of these projects. A comparison with throughput factored in has resulted in a 36.1% reduction in fuel gas usage. If throughput were held constant, current usage would be 247 MCF/D compared to 386 MCF/D prior for a reduction of 139 MCF/D.

TABLE 4.1 Fuel Conservation Savings					
Date	Average Fuel (MCF/D)	Volume Thru (Bbl/D)	Fuel Divide By Volume	Percentage Reduction	
				by MCF	by MCF/Vol
Jan-May 1989	386	18,865	.0205		
May-Dec 1989	289	20,956	.0138	25.0%	32.7%
Jan-Feb 1990	259	19,735	.0131	32.9%	36.1%

Based upon test results, there is available a net reduction of 127 MCF/D in terms of fuel gas. Assuming that all of this gas is consumed in gas-fired equipment (such as heater treaters); this translates into a net reduction of emissions as follows:

TABLE 4.2 Annual Emission Reduction at Mandalay[27] Due to Fuel Conservation (Lbs/Day)						
Fuel Saved (MCF/D)	TOC	ROC	NO_x	TSP	SO_2	CO
127	372	248	4,636	139	29.2	927

4.2 Potential SCE Offsets

The introduction of new sources of natural gas fuel, such as is proposed aboard Platform Gina, represents a viable and positive contribution to local air quality emissions. When compared to alternate fuels, such as fuel oil, natural gas burns cleaner, resulting in less emissions. For example, it is quite possible that the natural gas produced by Platform Gina will be consumed in lieu of fuel

[27] Emission factors based upon Ventura County Air Pollution Control District factors for draft fired equipment.

oil by the existing Southern California Edison electrical power station, located at Mandalay (either through the existing Southern California Gas Company connection or through a dedicated connection). Natural gas is much preferred by the operations of this plant, as it burns cleaner. However, there is the possibility of curtailments (due to limited supply) from the Southern California Gas Company, which would force the burning of alternate fuel sources, such as fuel oil.

The energy equivalent of 4.5 MMSCF/D natural gas is approximately 4,725 MMBTU/D (based upon 1050 BTU/SCF). This is equivalent to 255,405 lbs of No. 6 fuel oil (based upon 18,500 BTU/LB) or 31,925 gallons of No. 6 fuel oil (based upon a specific density of 8 lbs/gallon). The following tables demonstrate the possible emissions reduction which would be available should the gas from Platform Gina be used in lieu of fuel oil at the Edison Power Plant. The emission factors used in the development of this table are from the Ventura County APCD table of emission factors.

TABLE 4.3
VAPCD Emission Factors[28]
Fuel Oil vs. Natural Gas

Source	SCC #	Reactivity	TOC	TSP	SO_2	CO	Rate
Natural Gas	1-01-006-01	0.440	2.50	8.83	0.83	15.00	Per/MMCF
Fuel #6	1-01-004-01	1.000	2.62	3.57	36.75	2.86	Per/Mgal

[28]Table based upon Ventura County Air Pollution Control District emission factors for electric power plants. NO_X emission factor is not published for this classification.

TABLE 4.4
Emission Rate Comparison
Fuel Oil vs. Natural Gas[29], Lbs/Day

Source	ROC	TOC	TSP	SO_2	CO	Emission Rate
Natural Gas	4.95	11.25	39.74	3.735	67.5	lbs/d
Fuel #6	83.64	83.64	114.0	1,174	91.3	lbs/d
Annual Savings	28,722	26,422	27,105	427,147	8,687	lbs/d

[29]Assumes no emission abatement equipment.

ATTACHMENT 1

SUPPLEMENTAL DATA AND CALCULATIONS FOR MODELING PLATFORM GINA FLARE EMISSIONS DURING WELL-TESTING OPERATIONS[1]

Given the following conditions:

Gas Flow Rate (Q): Q = 3,000 Mcf/d or 0.125MMcf/hr

Stack Height (h): h = 98.2 ft or 29.9 m

Emission Factor:	NO_x	SO_2	CO_2	TOC	TSP
(lbs/MMcf)	51.5	1.90	35	5.8	3.0

where;

- Emission factors were taken from Table 2;
- The emission factor for SO_2 was calculated as follows:

$$SO_2 = 950 \times (\%\ \text{sulfur content})\ (\text{mW, } SO_2 \div \text{mW, } H_2S)$$
$$= 950 \times (2{,}000 \times 10^{-6} \times 10^2)\ (64 \div 34)$$
$$= 357.2\ \text{lbs/MMcf}$$

and;

- The NO_x emission factor was supplied by Kaldair, Inc. (0.49 lbs/MMbtu.)

Assume the following values:

Ambient Temperature (T_a):	T_a	=	20°C or 293°K
Exiting Gas Temperature (T_o):	T_o	=	1,000°K
Exiting Stack Velocity (v):	v	=	10 m/s

Then calculate the Heat Released by Combustion (Q_H);[2]

$$Q_H = (0.125\ \text{MMcf/hr})(1{,}050\ \text{MMbtu/MMcf})(0.80)$$
$$= 105\ \text{MMbtu/hr}$$

[1]The values derived were used to run the impact modeling studies for emissions from flaring during well-testing conditions offshore (see Attachments 2 and 3).

[2]Assumes 99.9% methane and 2,000 ppm H_2S; with 20% heat loss to radiation and heating.

Determine the Stack Diameter using the Buoyancy Flux Equation;

where; Volumetric Flow Rate ≡ (V_o), and

$$V_o = 3.7 \times 10^{-5}(Q_H)$$

$$= (3.7 \times 15^5 \text{ m}^3\text{cal})(105 \text{ MMBtu/hr})(252 \text{ cal-hr/3,600 MMBtu-sec})$$

$$= 122.75 \text{ m}^3/\text{s}$$

and; where

Stack Diameter ≡ (d):

$$d = ((4\,V_o)/\pi v)^{\frac{1}{2}}$$

$$= 1.98 \text{ m}$$

ATTACHMENT 2

PTPLU - SCREENING OF NO_x FLARE EMISSIONS FROM GINA PLATFORM (RUN - February 15, 1990)

```
PTPLU-2.0  (DATED 86196)
AN AIR QUALITY DISPERSION MODEL IN
SECTION 3. NON-GUIDELINE MODELS.
IN UNAMAP (VERSION 6) JUL 86
SOURCE: FILE 21 ON UNAMAP MAGNETIC TAPE FROM NTIS.

IBM-PC VERSION 1.20
(C) COPYRIGHT 1986, TRINITY CONSULTANTS, INC.
SERIAL NUMBER    0 SOLD TO TRINITY CONSULTANTS, INC.
RUN BEGAN ON 02-15-90 AT 13:32:46

                                 >>>INPUT PARAMETERS<<<
*** TITLE***  FLARE UPSET  H=29.9

***OPTIONS***                        ***METEOROLOGY***                                     ***SOURCE***
IF = 1, USE OPTION                   AMBIENT AIR TEMPERATURE =  293.00 (K)                 EMISSION RATE =      .81 (G/SEC)
IF = 0, IGNORE OPTION                MIXING HEIGHT           = 5000.00 (M)                 STACK HEIGHT  =    29.93 (M)
IOPT(1) = 0 (GRAD PLUME RISE)        ANEMOMETER HEIGHT       =   10.00 (M)                 EXIT TEMP.    =  1000.00 (K)
IOPT(2) = 1 (STACK DOWNWASH)         WIND PROFILE EXPONENTS  = A: .07, B: .07, C: .10      EXIT VELOCITY =    10.00 (M/SEC)
IOPT(3) = 1 (BUOY. INDUCED DISP.)                              D: .15, E: .35, F: .55      STACK DIAM.   =     1.98 (M)
IDFLT   = 1 (1 = USE DEFAULT, 0 = NOT USE DEFAULT)
MUOR    = 2 (1 = URBAN, 2 = RURAL)
***RECEPTOR HEIGHT*** =      .00 (M)

                                 >>>CALCULATED PARAMETERS<<<
VOLUMETRIC FLOW =    30.79 (M**3/SEC)          BUOYANCY FLUX PARAMETER =    67.95 (M**4/SEC**3)
```

FLARE UPSET H=29.9

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
1	.50	.79	1.355	1003.1(2)	.54	.84	1.305	931.2(2)
1	.80	1.07	1.081	638.1(2)	.86	1.11	1.042	593.2(2)
1	1.00	1.20	.973	516.5(2)	1.08	1.25	.939	480.5(2)
1	1.50	1.46	.809	354.3(2)	1.62	1.51	.782	330.3(2)
1	2.00	1.64	.713	273.2(2)	2.16	1.69	.690	255.2(2)
1	2.50	1.77	.649	224.6(2)	2.70	1.81	.626	210.2(2)
1	3.00	1.87	.601	192.1	3.24	1.91	.584	180.1

PTPLU - Screening of NO_x Flare Emissions from Gina Platform

Attachment 2

Run: February 15, 1990

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
2	.50	.38	5.398	1003.1(2)	.54	.40	5.041	931.2(2)
2	.80	.54	3.560	638.1(2)	.86	.57	3.329	593.2(2)
2	1.00	.64	2.933	516.5(2)	1.08	.67	2.745	480.5(2)
2	1.50	.85	2.079	354.3(2)	1.62	.89	1.952	330.3(2)
2	2.00	1.02	1.643	273.2(2)	2.16	1.07	1.545	255.2(2)
2	2.50	1.17	1.377	224.6(2)	2.70	1.22	1.298	210.2(2)
2	3.00	1.29	1.197	192.1	3.24	1.34	1.130	180.1
2	4.00	1.49	.969	151.6	4.32	1.54	.918	142.6
2	5.00	1.64	.830	127.2	5.40	1.69	.789	120.1

	****WINDS CONSTANT WITH HEIGHT****				****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)****			
STABILITY	WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
3	2.00	.80	3.184	273.2(2)	2.23	.87	2.871	247.9(2)
3	2.50	.94	2.584	224.6(2)	2.79	1.01	2.337	204.3(2)
3	3.00	1.07	2.189	192.1	3.35	1.14	1.986	175.3
3	4.00	1.28	1.704	151.6	4.46	1.36	1.556	138.9
3	5.00	1.44	1.419	127.2	5.58	1.52	1.301	117.1
3	7.00	1.68	1.093	99.2	7.81	1.77	1.003	91.4
3	10.00	1.96	.834	76.6	11.16	2.03	.772	71.1
3	12.00	2.08	.734	67.8	13.39	2.14	.683	63.3
3	15.00	2.19	.640	59.1	16.74	2.22	.600	55.4

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
4	.50	9999.99	999.999(3)	1003.1(2)	.59	.05	80.020	855.5(2)
4	.80	.09	45.460	638.1(2)	.94	.11	33.723	545.9(2)
4	1.00	.12	30.331	516.5(2)	1.18	.16	25.571	442.7(2)
4	1.50	.21	17.470	354.3(2)	1.77	.26	13.561	305.1(2)
4	2.00	.31	11.251	273.2(2)	2.36	.38	9.352	236.3(2)
4	2.50	.40	8.630	224.6(2)	2.95	.48	6.937	195.0
4	3.00	.49	6.780	192.1	3.54	.58	5.478	167.5
4	4.00	.65	4.697	151.6	4.71	.76	3.849	133.1
4	5.00	.80	3.589	127.2	5.89	.91	3.000	112.5
4	7.00	1.03	2.573	99.2	8.25	1.16	2.152	87.8
4	10.00	1.32	1.765	76.6	11.79	1.45	1.505	68.6
4	12.00	1.47	1.479	67.8	14.14	1.59	1.274	61.2
4	15.00	1.62	1.211	59.1	17.68	1.72	1.056	53.7
4	20.00	1.78	1.000	50.3	23.57	1.80	.957	46.3

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
5	2.00	1.28	7.163	126.2	2.94	1.13	6.028	114.6
5	2.50	1.19	6.475	119.3	3.67	1.04	5.472	108.6
5	3.00	1.12	5.972	114.0	4.40	.98	5.061	103.9
5	4.00	1.01	5.269	106.3	5.87	.88	4.490	97.2
5	5.00	.93	4.796	100.9	7.34	.82	4.040	91.8

STABILITY	****WINDS CONSTANT WITH HEIGHT**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)	****STACK TOP WINDS (EXTRAPOLATED FROM 10.0 METERS)**** WIND SPEED (M/SEC)	MAX CONC (UG/CU M)	DIST OF MAX (KM)	PLUME HT (M)
6	2.00	1.01	14.421	109.8	3.66	.85	10.660	95.3
6	2.50	.95	12.870	104.1	4.57	.79	9.590	90.6
6	3.00	.90	11.740	99.7	5.48	.74	8.811	87.0
6	4.00	.82	10.220	93.3	7.31	.68	7.599	81.3
6	5.00	.77	9.194	88.8	9.14	.66	7.000	76.5

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME IS CALCULATED TO BE AT A HEIGHT WHERE CARE SHOULD BE USED IN INTERPRETING THE COMPUTATION.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE.

RUN ENDED ON 02-15-90 AT 13:33:02

ATTACHMENT 3

ISCSG - SCREENING NO_x FLARE EMISSIONS FROM GINA PLATFORM
(RUN - February 16, 1990)

```
ISCST - VERSION 3.4 (DATED 88348)

IBM-PC VERSION (1.64)
(C) COPYRIGHT 1988, TRINITY CONSULTANTS, INC.
SERIAL NUMBER    0 SOLD TO Trinity Consultants, Inc.
RUN BEGAN ON 02-16-90 AT 15:36:01


          *** ISCSG - SCREENING GINA FLARE, D=1.98                         ***

CALCULATE (CONCENTRATION=1,DEPOSITION=2)                                 ISW(1) =   1
RECEPTOR GRID SYSTEM (RECTANGULAR=1 OR 3, POLAR=2 OR 4)                  ISW(2) =   3
DISCRETE RECEPTOR SYSTEM (RECTANGULAR=1,POLAR=2)                         ISW(3) =   1
TERRAIN ELEVATIONS ARE READ (YES=1,NO=0)                                 ISW(4) =   0
CALCULATIONS ARE WRITTEN TO TAPE (YES=1,NO=0)                            ISW(5) =   0
LIST ALL INPUT DATA (NO=0,YES=1,MET DATA ALSO=2)                         ISW(6) =   2

COMPUTE AVERAGE CONCENTRATION (OR TOTAL DEPOSITION)
WITH THE FOLLOWING TIME PERIODS:
  HOURLY (YES=1,NO=0)                                                    ISW(7) =   1
  2-HOUR (YES=1,NO=0)                                                    ISW(8) =   0
  3-HOUR (YES=1,NO=0)                                                    ISW(9) =   0
  4-HOUR (YES=1,NO=0)                                                   ISW(10) =   0
  6-HOUR (YES=1,NO=0)                                                   ISW(11) =   0
  8-HOUR (YES=1,NO=0)                                                   ISW(12) =   0
  12-HOUR (YES=1,NO=0)                                                  ISW(13) =   0
  24-HOUR (YES=1,NO=0)                                                  ISW(14) =   0
PRINT 'N'-DAY TABLE(S) (YES=1,NO=0)                                     ISW(15) =   0

PRINT THE FOLLOWING TYPES OF TABLES WHOSE TIME PERIODS ARE
SPECIFIED BY ISW(7) THROUGH ISW(14):
  DAILY TABLES (YES=1,NO=0)                                             ISW(16) =   0
  HIGHEST & SECOND HIGHEST TABLES (YES=1,NO=0)                          ISW(17) =   1
  MAXIMUM 50 TABLES (YES=1,NO=0)                                        ISW(18) =   1
METEOROLOGICAL DATA INPUT METHOD (PRE-PROCESSED=1,CARD=2)               ISW(19) =   2
RURAL-URBAN OPTION (RU.=0,UR. MODE 1=1,UR. MODE 2=2,UR. MODE 3=3)       ISW(20) =   0
WIND PROFILE EXPONENT VALUES (DEFAULTS=1,USER ENTERS=2,3)               ISW(21) =   1
VERTICAL POT. TEMP. GRADIENT VALUES (DEFAULTS=1,USER ENTERS=2,3)        ISW(22) =   1
SCALE EMISSION RATES FOR ALL SOURCES (NO=0,YES>0)                       ISW(23) =   0
PROGRAM CALCULATES FINAL PLUME RISE ONLY (YES=1,NO=2)                   ISW(24) =   1
PROGRAM ADJUSTS ALL STACK HEIGHTS FOR DOWNWASH (YES=2,NO=1)             ISW(25) =   2
PROGRAM USES BUOYANCY INDUCED DISPERSION (YES=1,NO=2)                   ISW(26) =   1
CONCENTRATIONS DURING CALM PERIODS SET = 0 (YES=1,NO=2)                 ISW(27) =   2
REG. DEFAULT OPTION CHOSEN (YES=1,NO=2)                                 ISW(28) =   2
TYPE OF POLLUTANT TO BE MODELLED (1=SO2,2=OTHER)                        ISW(29) =   2
DEBUG OPTION CHOSEN (YES=1,NO=2)                                        ISW(30) =   2
ABOVE GROUND (FLAGPOLE) RECEPTORS USED (YES=1,NO=0)                     ISW(31) =   0
```

```
NUMBER OF INPUT SOURCES                                      NSOURC =   1
NUMBER OF SOURCE GROUPS (=0,ALL SOURCES)                     NGROUP =   0
TIME PERIOD INTERVAL TO BE PRINTED (=0,ALL INTERVALS)         IPERD =   0
NUMBER OF X (RANGE) GRID VALUES                              NXPNTS =   0
NUMBER OF Y (THETA) GRID VALUES                              NYPNTS =   0
NUMBER OF DISCRETE RECEPTORS                                 NXWYPT =   7
NUMBER OF HOURS PER DAY IN METEOROLOGICAL DATA               NHOURS =  16
NUMBER OF DAYS OF METEOROLOGICAL DATA                         NDAYS =   1
SOURCE EMISSION RATE UNITS CONVERSION FACTOR                     TK =.10000E+07
HEIGHT ABOVE GROUND AT WHICH WIND SPEED WAS MEASURED             ZR =  10.00  METERS
LOGICAL UNIT NUMBER OF METEOROLOGICAL DATA                     IMET =   5
ALLOCATED DATA STORAGE                                        LIMIT = 43500 WORDS
REQUIRED DATA STORAGE FOR THIS PROBLEM RUN                    MIMIT =   551 WORDS

             *** ISCSG - SCREENING GINA FLARE, D=1.98                    ***


             *** UPPER BOUND OF FIRST THROUGH FIFTH WIND SPEED CATEGORIES ***
                                      (METERS/SEC)

                          1.54,   3.09,   5.14,   8.23,  10.80,


                         *** X,Y COORDINATES OF DISCRETE RECEPTORS ***
                                        (METERS)

(   1000.0,   1000.0), (   2000.0,   2000.0), (   3000.0,   3000.0), (   4000.0,   4000.0), (   5000.0,   5000.0),
(   6000.0,   6000.0), (   7000.0,   7000.0), (
```

*** ISCSG - SCREENING GINA. FLARE, D=1.98 ***

*** SOURCE DATA ***

SOURCE NUMBER	TYPE	WAKE	NUMBER PART. CATS.	EMISSION RATE TYPE=0,1 (GRAMS/SEC) TYPE=2 (GRAMS/SEC) *PER METER**2	X (METERS)	Y (METERS)	BASE ELEV. (METERS)	HEIGHT (METERS)	TEMP. TYPE=0 (DEG.K); VERT.DIM TYPE=1 (METERS)	EXIT VEL. TYPE=0 (M/SEC); HORZ.DIM TYPE=1,2 (METERS)	DIAMETER TYPE=0 (METERS)	BLDG. HEIGHT TYPE=0 (METERS)	BLDG. LENGTH TYPE=0 (METERS)	BLDG. WIDTH TYPE=0 (METERS)
1	0	0	0	.81143E+00	.0	.0	.0	29.93	1000.00	10.00	1.98	.00	.00	.00

MET. DATA
DAY 100

*** ISCSG - SCREENING GINA FLARE, D=1.98 ***

* METEOROLOGICAL DATA FOR DAY 100 *

HOUR	FLOW VECTOR (DEGREES)	WIND SPEED (MPS)	MIXING HEIGHT (METERS)	TEMP. (DEG. K)	POT. TEMP. GRADIENT (DEG. K PER METER)	STABILITY CATEGORY	WIND PROFILE EXPONENT	DECAY COEFFICIENT (PER SEC)
1	45.0	1.00	5000.0	293.0	.0000	2	.0700	.000000E+00
2	45.0	3.00	5000.0	293.0	.0000	2	.0700	.000000E+00
3	45.0	5.00	5000.0	293.0	.0000	2	.0700	.000000E+00
4	45.0	1.00	5000.0	293.0	.0000	3	.1000	.000000E+00
5	45.0	3.00	5000.0	293.0	.0000	3	.1000	.000000E+00
6	45.0	5.00	5000.0	293.0	.0000	3	.1000	.000000E+00
7	45.0	7.00	5000.0	293.0	.0000	3	.1000	.000000E+00
8	45.0	10.00	5000.0	293.0	.0000	3	.1000	.000000E+00
9	45.0	15.00	5000.0	293.0	.0000	3	.1000	.000000E+00
10	45.0	1.00	5000.0	293.0	.0000	4	.1500	.000000E+00
11	45.0	3.00	5000.0	293.0	.0000	4	.1500	.000000E+00
12	45.0	5.00	5000.0	293.0	.0000	4	.1500	.000000E+00
13	45.0	7.00	5000.0	293.0	.0000	4	.1500	.000000E+00
14	45.0	10.00	5000.0	293.0	.0000	4	.1500	.000000E+00
15	45.0	15.00	5000.0	293.0	.0000	4	.1500	.000000E+00
16	45.0	20.00	5000.0	293.0	.0000	4	.1500	.000000E+00

HIGH
1-HR
SGROUP# 1

*** ISCSG - SCREENING GINA FLARE, D=1.98 ***

* HIGHEST 1-HOUR AVERAGE CONCENTRATION (MICROGRAMS/CUBIC METER) *
* FROM ALL SOURCES *

* FOR THE DISCRETE RECEPTOR POINTS *

- X -	- Y -	CON.	(DAY,HOUR)	- X -	- Y -	CON.	(DAY,HOUR)
1000.0	1000.0	1.60627	(100,15)	2000.0	2000.0	1.09945	(100,13)
3000.0	3000.0	.85146	(100,13)	4000.0	4000.0	.70743	(100,12)
5000.0	5000.0	.59119	(100,12)	6000.0	6000.0	.51511	(100,11)
7000.0	7000.0	.47161	(100,11)				

2ND HIGH
1-HR
SGROUP# 1

*** ISCSG - SCREENING GINA FLARE, D=1.98 ***

* SECOND HIGHEST 1-HOUR AVERAGE CONCENTRATION (MICROGRAMS/CUBIC METER) *
* FROM ALL SOURCES *
* FOR THE DISCRETE RECEPTOR POINTS *

- X -	- Y -	CON.	(DAY,HOUR)	- X -	- Y -	CON.	(DAY,HOUR)
1000.0	1000.0	1.53534	(100, 7)	2000.0	2000.0	1.09749	(100,14)
3000.0	3000.0	.83737	(100,12)	4000.0	4000.0	.65506	(100,13)
5000.0	5000.0	.55471	(100,11)	6000.0	6000.0	.49786	(100,12)
7000.0	7000.0	.42433	(100,12)				

MAX 50
1-HR
SGROUP# 1

*** ISCSG - SCREENING GINA FLARE, D=1.98 ***

* 50 MAXIMUM 1-HOUR AVERAGE CONCENTRATION (MICROGRAMS/CUBIC METER) *

* FROM ALL SOURCES *

RANK	CON.	HOUR	DAY	X OR RANGE (METERS)	Y(METERS) OR DIRECTION (DEGREES)	RANK	CON.	HOUR	DAY	X OR RANGE (METERS)	Y(METERS) OR DIRECTION (DEGREES)
1	1.60627	15	100	1000.0	1000.0	26	.65088	5	100	3000.0	3000.0
2	1.53534	7	100	1000.0	1000.0	27	.59119	12	100	5000.0	5000.0
3	1.50599	6	100	1000.0	1000.0	28	.57718	11	100	4000.0	4000.0
4	1.50392	16	100	1000.0	1000.0	29	.57446	15	100	3000.0	3000.0
5	1.44764	14	100	1000.0	1000.0	30	.55471	11	100	5000.0	5000.0
6	1.35313	8	100	1000.0	1000.0	31	.55293	11	100	3000.0	3000.0
7	1.24314	2	100	1000.0	1000.0	32	.53993	14	100	4000.0	4000.0
8	1.09945	13	100	2000.0	2000.0	33	.52665	12	100	1000.0	1000.0
9	1.09749	14	100	2000.0	2000.0	34	.52111	1	100	3000.0	3000.0
10	1.06090	3	100	1000.0	1000.0	35	.51721	13	100	5000.0	5000.0
11	1.04149	9	100	1000.0	1000.0	36	.51635	2	100	2000.0	2000.0
12	.99200	5	100	2000.0	2000.0	37	.51511	11	100	6000.0	6000.0
13	.99169	13	100	1000.0	1000.0	38	.49804	4	100	4000.0	4000.0
14	.97086	5	100	1000.0	1000.0	39	.49793	8	100	2000.0	2000.0
15	.91875	15	100	2000.0	2000.0	40	.49786	12	100	6000.0	6000.0
16	.90416	12	100	2000.0	2000.0	41	.47161	11	100	7000.0	7000.0
17	.85146	13	100	3000.0	3000.0	42	.47083	4	100	5000.0	5000.0
18	.83737	12	100	3000.0	3000.0	43	.46195	6	100	3000.0	3000.0
19	.83235	6	100	2000.0	2000.0	44	.45692	16	100	3000.0	3000.0
20	.75791	16	100	2000.0	2000.0	45	.44923	4	100	3000.0	3000.0
21	.74754	14	100	3000.0	3000.0	46	.43688	5	100	4000.0	4000.0
22	.70743	12	100	4000.0	4000.0	47	.42433	12	100	7000.0	7000.0
23	.67370	1	100	2000.0	2000.0	48	.42417	11	100	2000.0	2000.0
24	.66427	7	100	2000.0	2000.0	49	.41944	13	100	6000.0	6000.0
25	.65506	13	100	4000.0	4000.0	50	.41825	4	100	6000.0	6000.0

RUN ENDED ON 02-16-90 AT 15:36:05

Attachment 4

RESPONSE TO USDI-MMS COMMENTS ON THE AIR QUALITY ANALYSIS FOR THE PLATFORM GINA PROJECT

UNOCAL is proposing to repair the existing Platform Gina water line and convert it to gas service. In a letter dated June 18, 1990, the U.S. Department of the Interior Minerals Management Service (USDI-MMS) commented on the May 1990 Final Draft Initial Study for Platform Gina Proposed Return Water Line Replacement and Conversion to Produced Gas. The comments pertained to the air quality analysis section of the report. The responses to the specific comments of the USDI-MMS are provided below:

(1) Comment On Boat Traffic: "Page 5, Section 2, Construction Related Emissions: It is not stated whether the construction and the drilling and testing of wells is expected to cause an increase in support vessel visits to the platform. If this is the case, estimates of the increase in emissions should be presented."

Response: Estimated increases in emissions due to an increase of boat traffic were calculated only for work crews stationed immediately offshore and did not include additional transport to the platforms as pointed out by the reviewer. Boat traffic to the platforms to support facility construction is estimated to increase by an additional ten (10) boat trips during the project. Boat traffic for the regular platform crew will not increase during the project. The revised total emissions for the project with the additional ten (10) boat trips are given below:

TABLE 1
Construction Emissions, Total for Project, Lbs

	Gal	*TOC*	*ROC*	*NO_X*	*TSP*	*SO_2*	*CO*
Total Emissions	*1,384*	*473*	*420*	*5,197*	*371*	*344*	*2,656*
Additional Boat Trips	*3,000*	*113*	*101*	*1,406*	*100*	*94*	*305*
Revised Total Emissions	*14,384*	*586*	*521*	*6,603*	*471*	*438*	*2,961*

(2) Comment: "Page 9, Table 2.5 and Table 2.6: The 'Lb/1000 Gal' after the reactivity figure should be deleted."

Response: Comment noted and correction(s) made.

(3) Comment: "Page 14, 1st paragraph, 2nd sentence: The sentence is incomplete. The word 'either' implies that there is another possible means of distribution besides the Southern California Gas Company."

Response: Comment noted and correction(s) made. There is some consideration towards construction of a direct tie-in to the Southern California Edison power station located at Mandalay. It is therefore conceivable that gas from Platform Gina could then be directed to either the main distribution system or to the possible tie-in at the Mandalay.

(4) Comment on the Selection of an Air Dispersion Model: "Page 14, Section 3.2, Preliminary Modeling: While MMS does not have any specific requirements for modeling emissions resulting from modification of existing facilities not on Lease Sale 73 or 80 leases, the air quality analysis would have been enhanced by using a model that incorporates coastal fumigation and/or applying a model that accounts for overwater dispersion. The California Air Resources Board Coastal Fumigation Model (CCFM) is a simple screening model that calculates maximum onshore concentrations during fumigation conditions. Application of the MMS Offshore and Coastal Dispersion (OCD) model for selected wind and stability categories would be more appropriate than using either the PTPLU2 or ISCST models as the former simulates overwater and coastal dispersion."

Response: The OCD model was considered for the air quality analysis and it is agreed that the OCD model would have been more appropriate since it models the surface boundary layer structure using a modified algorithm to account for the behavior of plumes over water. However, the purpose of this air quality analysis was to provide preliminary screening results and not a refined modeling evaluation, and the use of the OCD model requires on-site wind turbulence measurements which were not available for this study. As such, the PTPLU2 and ISCST models were selected for the analysis expecting they would provide the best screening assessment possible from the information available.

Concerning fumigation modeling, California Air Resources Board (CARB)-Technical Support Division-Air Quality Modeling Section was contacted, and it was discovered that the over-water coastal fumigation version of PTFUM (referred to as PTFUM-OW) was not available in runnable format for IBM PCs (FORTRAN source code only). CARB staff recommended examining the possibility of using the EPA SCREEN model which includes a shoreline fumigation option. However, it was discovered that the shoreline fumigation option of the EPA SCREEN modeling program considers land-based sources only and cannot estimate fumigation concentration for sources located offshore. Nevertheless, based on a review of the procedures and technical description of the SCREEN model (EPA User's Guide for

Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, 1988, Pp. 4-31f., A-39f. [EPA-450/4-88-010]), it was determined that the method used for coastal fumigation calculations of land-based sources could be adapted for estimating offshore sources.

The calculations used in SCREEN are based on the 1987 EPA study, Analysis and Evaluation of Statistical Coastal Fumigation Models (EPA-450/4-87-002) which recommends the worst-case meteorological conditions of F-stability and 2.5 meter per second wind speed for coastal fumigation screening. Based on the results of coastal air studies, inland distances can be estimated at which the aloft stable plume intercepts the thermal internal boundary layer (TIBL) thereby causing the fumigation phenomenon. Then using Turner's equation for calculating fumigation concentrations (Turner, Workbook of Atmospheric Dispersion Estimates, 1970, p. 35), the maximum ground-level concentration resulting from fumigation can be estimated. One assumption made in adapting this method to sources located offshore is that the stack height (a parameter needed to determine inland interception distance) can be approximated as equal to the plume height by the time the plume reaches the shoreline. A value for the stack height must be assumed in order to estimate the distance inland at which the plume intercepts the TIBL and fumigation occurs.

The results of the calculations indicate an estimated maximum concentration of 2.91 micrograms NO_2 cubic meter (.0015 ppm NO_2) occurring at an inland distance of 350 meters, or 7.35 kilometers from the offshore platform (see Attachment 1 for calculation). This estimated concentration for coastal fumigation is greater than the earlier predicted maximum concentration at shoreline distance obtained by the PTPLU2 and ISCST modeling (1.182 micrograms NO_2 per cubic meter). Therefore the coastal fumigation concentration should be used in assessing shoreline impact of well-testing operations on Platform Gina. These conditions are not expected to last more than two (2) days for any single well-testing operation.

(5) Comment: "Page 15, 1st full paragraph, 8th line: It is unclear how default values for wind speed are used in the PTPLU2 and ISCST models."

Response: PTPLU2 uses a specified number of default combinations of stability categories and wind speed to analyze for occurrences of maximum concentrations (e.g., stability C and 1, 3, 5, etc. m/s wind speeds). The ISCST model can reproduce the PTPLU2 default combinations via discrete hour-long periods (e.g., hour 1 is stability C, 1 m/s; hour 2 is stability C, 3 m/s, etc.). In the report, the term "default values" in reference to wind speed means that the same range of wind speeds covered by PTPLU2 "default" stability-windspeed combinations is also utilized during the ISCST runs.

(6) Comment: "Page 16, 1st paragraph, 10th line: It should be noted that the results in Table 3.5 do not account for limited mixing as described."

Response: Comment noted and correction(s) made.

(7) Comment: "Page 17, Table 3.2: The factor for calculating SO_2 emissions for the flare is applied incorrectly. This factor is 950 x percent sulfur in fuel. Furthermore, since the sulfur content is presented in terms of H_2S, and the emission factor is for SO_2, an additional multiplication factor of 1.88 should be applied (the ratio of the molecular weights). Therefore, for gas with an H_2S content of 2,000 ppm, the correct SO_2 emission factor should be 0.2 x 950 x 1.88 = 357.2 lb/MMscf.

Since the assumed NO_X emission factor of 51.5 lb/MMscf is based on measured emissions, rather than emissions factors commonly used by the regulatory agencies, MMS would like to review the documentation on that emission factor."

Response: Comment noted and correction(s) made. The study from which the flare emission factor for NO_X was derived is the 1982 EPA Flare Efficiency Study (EPA-600/2-83-052) (see Attachment 2 for documentation).

(8) Comment: "Page 19, Table 3.4: The wind speeds assumed under stability Categories C and D are unrealistically high."

Response: These high wind speeds (16.74 and 23.57 m/s) were reported by the PTPLU2 program only because maximum concentrations happen to occur at these values. Lower windspeeds were also tested by the PTPLU2 program but did not give results higher than the ones obtained at these high windspeeds. The reviewer is correct in describing these values as 'unrealistically high.'

(9) Comment: "The units of annual emissions should be indicated. What emission factors were used?"

Response: Comment noted and corrections made.

(10) Comment: "Attachment 1: The calculation of the effective stack diameter is in error, as a result of using the wrong formula to calculate V°."

Response: The reviewers calculations are correct and stack diameter of 3.96M is correct. However, this correction is insignificant in that fumigation calculations, which used the internal algorithm of the SCREEN modeling program replaced the manual determination of stack diameter (d).

Attachment 5

CALCULATIONS FOR COASTAL FUMIGATION BY OFFSHORE STATIONARY SOURCES

CALCULATION OF MAXIMUM CONCENTRATION FROM COASTAL FUMIGATION - OFFSHORE SOURCE

(Reference: EPA 1988 *User's Guide for Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Pp. 4.31f., A.39f. [EPA-450/4-88-010])*

(1) The SCREEN dispersion model was run using the source parameters of Platform Gina - well testing conditions for NO_X and the meteorological conditions: stability F, 2.5 meters per second windspeed (see the enclosed computer results).

(2) Plume height (h_e) was obtained from the results of the SCREEN run. At shoreline distance, 7000 meters,

$$h_e = 109 \text{ meters}$$

and

$$\sigma_y = 198\ m$$
$$\sigma_z = 44.8\ m$$

(3) Calculation of the inland distance (x) at which the thermal internal boundary layer (TIBL) height (h_T) intersects with the plume centerline (h^e) was accomplished using Table 4-5 of *EPA 1988* and assuming that stack height (h_s) is equivalent to h_e (see narrative discussion). The value for inland distance at which fumigation occurs was determined to be:

$$x = 350 \text{ meters}$$

(4) As a double check on the downwind distance, x, this value was substituted into the TIBL coastal height equation,

$$h_T = A\,(x)^{1/2}$$ equation A.15 in *EPA 1988*

where,

$A = 6\ m^2$
x = inland distance to point of coastal fumigation

to see if the TIBL height corresponds with the predicted plume height calculated by SCREEN (h_e = 109 m). Substituting x = 350 meters into the equation,

$$h_T = 6\,(350)^{1/2}$$
$$= \underline{112\ m}$$

This value corresponds relatively close to the calculated plume height of 109 meters.

(5) Calculation of maximum ground-level concentration for NO_X from fumigation is accomplished by Turner's fumigation equation:

$$X_f = \frac{Q}{\sqrt{2\Pi}\, u\, (\sigma_y' + \frac{h_e}{8})\, (h_e + 2\sigma_z')}$$

Where,

$Q = 0.811\ g/s$

$u = 2.5\ m/s$

$h_e = h_s + \Delta h$

$= 29.93 + 79 = 109\ m$

and,

$$\sigma_y' = [\sigma_y^2 + (\frac{\Delta h}{3.5})^2]^{1/2}$$

$$= [(198)^2 + (\frac{79}{3.5})^2]^{1/2}$$

$$= 199\ m$$

$$\sigma_z' = [\sigma_z^2 + (\frac{\Delta h}{3.5})^2]^{1/2}$$

$$= 50\ m$$

Then,

$$X_f = \frac{0.811}{\sqrt{2\Pi}(2.5)(199 + \frac{109}{8})(109 + 2(50))}$$

$$= 2.912\ x\ 10^{-6}\ g/m^3$$

Converting to ppm units,

$$ppm\ =\ 2.912x10^{-6}(1000)(\frac{24.5}{MW})$$

$$=\ .0015\ ppm\ NO1_2$$

The California Ambient Air Quality Standard NO_2 is 0.25 ppm, 1-hour average.

1 EPA SCREEN - VERSION 1.1 (DATED 88300)

IBM-PC VERSION (1.01)

NSC1501D PLATFORM GINA FLARE EMISSIONS - F, 2.5 m/s

SIMPLE TERRAIN INPUTS:

SOURCE TYPE	=	FLARE
EMISSION RATE (G/S)	=	.8110
FLARE STACK HEIGHT (M)	=	29.93
TOT HEAT RLS (CAL/S)	=	.7347E+07
RECEPTOR HEIGHT (M)	=	.00
IOPT (1=URB,2=RUR)	=	2
EFF RELEASE HEIGHT (M)	=	38.66
BUILDING HEIGHT (M)	=	.00
MIN HORIZ BLDG DIM (M)	=	.00
MAX HORIZ BLDG DIM (M)	=	.00

BUOY. FLUX = 121.81 M**4/S**3; MOM. FLUX = 74.28 M**4/S**2.

*** STABILITY CLASS 6 ONLY ***
*** 10-METER WIND SPEED OF 2.5 M/S ONLY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
100.	.0000	0	.0	.0	.0	.0	.0	.0	
200.	.1828E-08	6	2.5	5.3	5000.0	109.0	16.6	15.3	NO
300.	.4616E-04	6	2.5	5.3	5000.0	109.0	22.3	20.1	NO
400.	.1897E-03	6	2.5	5.3	5000.0	109.0	24.9	21.3	NO
500.	.3041E-03	6	2.5	5.3	5000.0	109.0	26.9	21.8	NO
600.	.4925E-03	6	2.5	5.3	5000.0	109.0	29.2	22.3	NO
700.	.7967E-03	6	2.5	5.3	5000.0	109.0	31.6	22.9	NO
800.	.1187E-02	6	2.5	5.3	5000.0	109.0	34.2	23.4	NO
900.	.1737E-02	6	2.5	5.3	5000.0	109.0	36.8	23.9	NO
1000.	.2495E-02	6	2.5	5.3	5000.0	109.0	39.4	24.5	NO
1100.	.3405E-02	6	2.5	5.3	5000.0	109.0	42.1	25.0	NO
1200.	.4563E-02	6	2.5	5.3	5000.0	109.0	44.8	25.5	NO
1300.	.6009E-02	6	2.5	5.3	5000.0	109.0	47.5	26.0	NO
1400.	.7784E-02	6	2.5	5.3	5000.0	109.0	50.2	26.5	NO
1500.	.9928E-02	6	2.5	5.3	5000.0	109.0	53.0	27.0	NO
1600.	.1248E-01	6	2.5	5.3	5000.0	109.0	55.7	27.5	NO
1700.	.1547E-01	6	2.5	5.3	5000.0	109.0	58.5	28.0	NO
1800.	.1893E-01	6	2.5	5.3	5000.0	109.0	61.3	28.5	NO
1900.	.2288E-01	6	2.5	5.3	5000.0	109.0	64.0	29.0	NO
2000.	.2735E-01	6	2.5	5.3	5000.0	109.0	66.8	29.5	NO
2100.	.3144E-01	6	2.5	5.3	5000.0	109.0	69.5	29.9	NO
2200.	.3585E-01	6	2.5	5.3	5000.0	109.0	72.3	30.4	NO
2300.	.4058E-01	6	2.5	5.3	5000.0	109.0	75.0	30.8	NO
2400.	.4561E-01	6	2.5	5.3	5000.0	109.0	77.8	31.2	NO
2500.	.5094E-01	6	2.5	5.3	5000.0	109.0	80.5	31.6	NO
2600.	.5655E-01	6	2.5	5.3	5000.0	109.0	83.2	32.0	NO
2700.	.6243E-01	6	2.5	5.3	5000.0	109.0	86.0	32.4	NO
2800.	.6857E-01	6	2.5	5.3	5000.0	109.0	88.7	32.8	NO
2900.	.7495E-01	6	2.5	5.3	5000.0	109.0	91.4	33.2	NO
3000.	.8155E-01	6	2.5	5.3	5000.0	109.0	94.1	33.6	NO
3500.	.1092	6	2.5	5.3	5000.0	109.0	107.5	35.3	NO
4000.	.1378	6	2.5	5.3	5000.0	109.0	120.9	36.8	NO
4500.	.1661	6	2.5	5.3	5000.0	109.0	134.0	38.3	NO
5000.	.1935	6	2.5	5.3	5000.0	109.0	147.0	39.7	NO
5500.	.2194	6	2.5	5.3	5000.0	109.0	160.0	41.0	NO
6000.	.2435	6	2.5	5.3	5000.0	109.0	172.8	42.3	NO
6500.	.2658	6	2.5	5.3	5000.0	109.0	185.4	43.6	NO
7000.	.2861	6	2.5	5.3	5000.0	109.0	198.0	44.8	NO
7500.	.3005	6	2.5	5.3	5000.0	109.0	210.5	45.8	NO
8000.	.3132	6	2.5	5.3	5000.0	109.0	222.9	46.8	NO
8500.	.3244	6	2.5	5.3	5000.0	109.0	235.2	47.8	NO
9000.	.3342	6	2.5	5.3	5000.0	109.0	247.4	48.7	NO

9500.	.3427	6	2.5	5.3	5000.0	109.0	259.6	49.7	NO
10000.	.3500	6	2.5	5.3	5000.0	109.0	271.6	50.5	NO
15000.	.3797	6	2.5	5.3	5000.0	109.0	388.9	58.4	NO

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 100. M:

14999.	.3798	6	2.5	5.3	5000.0	109.0	388.9	58.4	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SCREEN DISCRETE DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
7000.	.2861	6	2.5	5.3	5000.0	109.0	198.0	44.8	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	.3798	14999.	0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

RUN ENDED ON 90/07/18 AT 12:47:57

Attachment 6

DOCUMENTATION OF NO_X EMISSION FACTOR

KALDAIR INCORPORATED

FILE COPY

KALDAIR

15835 Park Ten Place
Suite 115, Houston, Texas 77084 USA
(713) 492-2262 Fax: (713) 492-2399

February 5, 1990

Unocal
P.O. Box 6176
Ventura, Ca 93006

Attn: Chris R. Culver

Dear Mr. Culver:

It is, at best, difficult to measure the emissions from an open flame flare tip. Any attempt at enclosing the flame (required for accurate plume testing) greatly changes the combustion characteristics of any flare. It is impossible to place a probe at every possible location and get the exact plume sample.

Due to the inherent difficulties in measuring the emissions from an open flare, very little information is available. While new technologies are being developed to measure the full spectrum of emissions (using light detection and ranging devices) they are not currently available for use on flares. Our only reference for accepted calculated levels of emissions are in the EPA - Flare Efficiency Study of 1982. Obviously they could not conduct testing for every type of flare.

In reference to the type of combustion achieved by the Coanda flares and NOx formation, we feel the Coanda flares should out-perform the flares used in the EPA study. The reasons for this are as follows:

Basically, all of our flares produce a gas rich flame. The flame from our Coanda type flares is highly turbulent. The gas passes through the lower portion of the flame at high velocity (low resonance time). The upper portion of the flame is cooled by the high turbulence, recirculation, and air entrainment. These occurances tend to lead to lower NOx formation.

Although we anticipate a lower NOx production, we state the production rate as estimated by the EPA of approximately 0.049 lbs/MMBTU.

$0.049 \frac{lbs}{MMBTU} \times 1050 \frac{MMBTU}{MMCF} = 51.45 \frac{lbs}{MMCF}$

KALDAIR

If you require further assistance, please do not hesitate to contact our office or your local representative, Don Boling of Northpoint Industries.

Sincerely,

Bernard Bolanowski
Combustion Engineer

BB/bf

KALDAIR INCORPORATED

COPY

KALDAIR

15835 Park Ten Place
Suite 115, Houston, Texas 77084 USA
☎ (713) 492-2262 Fax: (713) 492-2399

July 17, 1990

Environmental Management
405 S. State College Blvd. # 211
Brea, CA 92621

Attn: Scott Nikaido

Ref: P-361
Unocal - Gina Platform

Dear Mr. Nikaido,

The following is in response to our request for technical assistance pertaining to the Unocal - Gina Platform.

In the 1982 EPA study, a wide variety of studies were conducted. Because no testing was conducted on the Kaldair Coanda flares, we must pick tests which most closely simulate our flares. We have not used the air assist flares because the flame produced by the low velocity air flare, does not compare to the highly turbulent, high velocity Coanda flare flame. The Coanda flare flames are most closely likened to the high steam rate, steam flares. While the Coanda flares do not inject steam to cool the flame, the turbulence created does ensure a constant supply of cool air. These are test numbers 7, 5, 17, 50 and 56. The highest value is 0.48 lbs/MMBTU.

In our estimate, we used a conservative rate of 0.49 lbs/MMBTU. And, as stated in our letter, we anticipate the actual NO_x formation will be less.

Hopefully this information will assist you in your evaluation. If you have any questions, please call.

Sincerely,

Bernard Bolanowski
Sr. Application Engineer

BB/ki

TABLE 6. FLARE NO_x RESULTS

Flare	Btu Content	Test No.	NO_x* Concentration (PPMv)	CO_2* Concentration (PPMv)	NO_x Mass Emission (lbs/10^6 BTU)
Steam-Assisted Flare	High Btu Content	1	3.09	7,052	0.068
		2	2.16	4,719	0.071
		3	1.54	7,496	0.095
		4	1.96	6,616	0.046
		8	1.45	5,400	0.042
		7	1.62	5,224	0.048
		5	2.09	7,052	0.046
		67	3.77	N/A	N/A
		17	1.00	3,499	0.044
		50	0.50	4,220	0.018
		56	0.58	3,120	0.029
		61	1.27	6,273	0.033
		55	0.38	2,012	0.029
	Low Btu Content	57	2.68	6,945	0.060
		11	3.69	5,269	0.108
		59	1.41	5,413	0.040
		60	0.99	3,685	0.047
		51	0.57	3,347	0.026
		16	1.87	4,059	0.071
		54	5.00	7,115	0.109
		23	5.90	8,465	0.108
		52	0.68	2,627	0.040
		53	2.83	5,741	0.076
Air-Assisted Flare	High Btu Content	26	5.34	6,270	0.132
		65	2.40	4,878	0.076
		28	8.16	6,076	0.208
		31	4.02	4,568	0.136
	Low Btu Content	66	0.97	2,432	0.062
		29	1.06	2,179	0.075
		64	1.24	3,282	0.058
		62	0.60	3,076	0.030
		63	1.57	4,184	0.058
		33	0.74	1,857	0.061
		32	1.75	3,702	0.073

* Corrected for background.

JUL 17 '90 15:34 KALDAIR INC. HOUSTON TX P.3

RESOURCE MANAGEMENT AGENCY

county of ventura

Air Pollution
Control District

Richard H. Baldwin
Air Pollution Control Officer

W. W. WELDON

APR 16 1990

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H.H. P.M. W.W.
APR 16 1990
J.D. K.A.

April 9, 1990

Mr. Ralph Steele
City of Oxnard
Department of Planning and Community Development
305 West Third Street
Oxnard, CA 93030

Dear Mr. Steele:

Air Pollution Control District (APCD) staff has reviewed EIR 78-10 (Platform Gina and Platform Gilda Project), and the emission data and hydrogen sulfide risk studies submitted by Unocal in response to APCD's comments on the initial study for the Platform Gina Pipeline and Conversion Project.

The hydrogen sulfide risk study indicates that the chance of an accidental release of hydrogen sulfide gas greater than 4 parts per million to be 2.7 x 10^{6}/year (annual chance of occurrence of 2.7 in 1,000,000). This compares with an estimated annual chance of occurrence of 7.9 in 100,000 for a direct impact by an aircraft, or an estimated annual chance of occurrence of a traffic accident at the corner of Harbor and Fifth Street for local residents of 5.5 in 1,000. Furthermore, the risk study did not find any serious system design deficiencies. The risk study therefore concluded that the proposed project will be very safe with respect to accidental releases of hydrogen sulfide gas. If an accidental release of hydrogen sulfide gas should occur, the risk study determined that the radius of dangerous exposure would be 1,320 feet.

The emission data study indicates that reactive organic compound and nitrogen oxide emissions associated with the project will be substantial. The 1989 edition of Ventura County's *Guidelines for the Preparation of Air Quality Impact Analyses* (*Guidelines*), which was adopted by the Ventura County Air Pollution Control Board on October 24, 1989, specifically states that construction-related reactive organic compounds and nitrogen oxides emissions are not counted towards the air quality impact significance thresholds contained in the *Guidelines*, since such emissions are only temporary. However, according to the Guidelines, if such emissions from heavy-duty construction equipment anticipated to be used for a particular project exceed the specified significance thresholds, appropriate mitigation measures should be identified. The 1983 edition of the *Guidelines* does not address construction-related emissions at all.

The emission data study also addressed the project's potential to cause objectionable odors. The study concluded that objectionable odors will only occur if there is a catastrophic failure of the Hydrogen Sulfide Processing and Detection Systems, a possibility that the risk study determined to be remote.

An air quality modeling study was conducted to estimate the onshore air quality impacts that would result from flaring on Platform Gina. The modeling study utilized two models, PTPLU2 and ISCST. The modeling study indicated that the onshore air quality impacts resulting from flaring during well-testing operations would be negligible. Furthermore, the study stated that well-testing operations on Platform Gina would occur only four times in 1990, and six times in 1991 and 1992.

It should be noted, however, that the air quality modeling study utilized models and model inputs which may not be entirely appropriate for a marine environment. However, given the nature of the project, APCD staff believes that the emission information is sufficient. If further modeling is deemed necessary by the city, the applicants should contact the APCD for recommendations regarding appropriate models and model inputs.

The modeling study did not look at the possible effect of well-testing operations on ambient ozone concentrations. To do so would require the use of a photochemical model. The California Air Resources Board and the APCD do not approve of the use of photochemical modeling for assessment of source specific impacts. This is due to the great uncertainty in emission transport patterns which cause errors in site specific ozone predications. Even if such a study is conducted, it is doubtful that the model would be able to detect an incremental increase in onshore ambient ozone concentrations given the amounts of emissions associated with the project.

APCD staff would like to thank Unocal for its thorough response to APCD comments on the initial study for the project. If you have any questions, please contact me at (805) 654-2798.

Sincerely,

Chuck Thomas for

Bill Mount, Manager
Planning and Evaluation Section

cc: Bill Weldon, Unocal

APPENDIX VOLUME 3

Exhibit E

Risk Assessment Study, Platform Gina Gas Production and Pipeline, Mandalay Onshore Receiving, November 1989

UNOCAL

RISK ASSESSMENT STUDY

PLATFORM GINA GAS PRODUCTION AND PIPELINE
MANDALAY ONSHORE RECEIVING

Prepared by

EnerSource Engineering
17280 Newhope Street, Suite 20
Fountain Valley, CA 92708

November 21, 1989

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I. PREFACE AND SYNOPSIS

A design review and risk assessment study of a proposed project to produce and transport gas from Platform Gina to the Mandalay onshore facility was performed. No serious design deficiencies were found in the proposed designs, which are currently at concept level. The risk study indicated that the proposed project is very safe, with chance of accidental release of gas near Mandalay containing greater than 4 ppm hydrogen sulfide estimated to be 2.7×10^{-6}/year. (Annual chance of occurrence of 2.7 in 1,000,000.) This compares with an estimated chance of occurrence 7.9×10^{-5}/year (annual chance of occurrence 7.9 in 100,000) for direct impact by aircraft, or an estimated chance of occurrence of traffic accident at the corner of Harbor and 5th Street for local residents estimated to be 5.5×10^{-3}/year (annual chance of occurrence 5.5 in 1000).

In the remote chance that an accidental release of gas should occur, it was determined that the radius of dangerous exposure would be 1,320 feet. This was based upon accidental full flow release of gas containing 7,000 ppm H_2S, which is 3-1/2 times greater than the worst case gas expected to be produced.

II. PROJECT OVERVIEW

A. Description

Platform Gina is located 6 miles southwest of Oxnard, California within Tract OCS P-0202 in Federal waters. Platform Gina is in 95 feet of water and has been on production in the Hueneme zone since 1982. The existing wells are produced by electric submersible pump systems to the Mandalay onshore processing facility, located in the City of Oxnard, through a 10-3/4 inch pipeline. There are currently 15 total well slots on Platform Gina, 6 oil producing wells, 5 water injection wells, 1 exploratory well (H-14), and 3 unused slots.

Oil and water separation and treating are conducted at the Mandalay facility. Formerly, produced water was returned to Platform Gina from Mandalay through a 6-5/8 inch pipeline for disposal. The 10-3/4 inch and the 6-5/8 inch pipelines are the only pipelines between Platform Gina and the Mandalay facility. The 6-5/8 inch pipeline has not been in service since October, 1988.

An exploratory well is now being tested in an effort to determine the size and extent of gas reserves which underlie tracts OCS P-0202 and the adjacent tract OCS P-0203. It is proposed to convert the 6-5/8 inch pipeline from Platform Gina to the Mandalay facility from water return service to gas sales service to evaluate the exploratory well and provide for long term field development.

The phases of the project required to test and evaluate the exploratory well (H-14) will include the installation of gas processing equipment on Platform Gina, conversion of the 6-5/8 inch pipeline to gas sales service, and the modification of piping at the Mandalay facility.

This report specifically addresses the risk assessment and design of the pipeline, gas processing, H_2S detection, monitoring, shutdown, and alarm systems at both Platform Gina and Mandalay.

B. Platform Gina

1. Description

Platform Gina was set on OCS Tract P-0202 in 1981. Six production wells and five injection wells were completed from 1981 to 1983. Exploratory wells Nos. 5 and 6 were drilled in 1985, and H-13 and H-14 were drilled in 1988. The platform is set in 95 feet of water in Federal waters off of Oxnard (see map, Figure 1).

2. Development Plans

It is known that gas reserves underlie Platform Gina in OCS Tracts P-0202 and P-0203 in the Sespe and Monterey zones. The size and extent of these reserves are currently being determined by exploratory drilling and drill stem testing. The first well

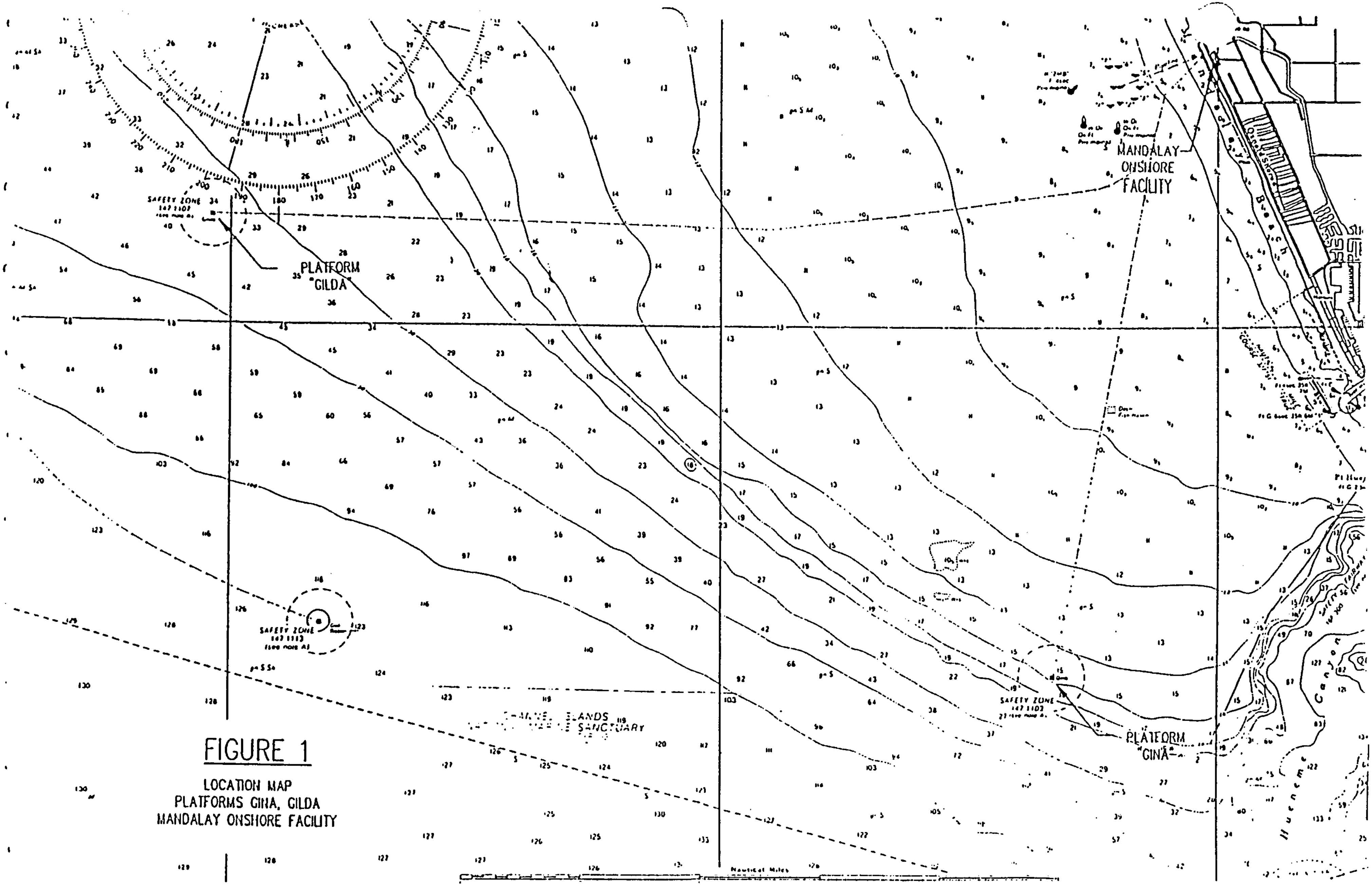


FIGURE 1

LOCATION MAP
PLATFORMS GINA, GILDA
MANDALAY ONSHORE FACILITY

drilled to explore the Monterey zone gas was drilled in 1985 from a mobile drilling rig. This well, OCS P-0203 #6, was plugged after testing, but provided data that warranted further exploration.

Two exploratory wells were drilled in 1988. The first well, H-13, was drilled and tested in the Monterey zone but has been plugged and abandoned as a dry hole. The second well, H-14, was completed in the latter half of 1988 and is completed in the Sespe zone that underlies the Monterey zone. The Monterey zone in Well H-14 is potentially productive, based on analysis of information gained during the drilling process.

3. Exploratory Well H-14

Some drill stem production testing of Well H-14 has been done. The tested gas does not contain any hydrogen sulfide and conforms to all gas sales specifications required by Southern California Gas Company.

Gas has been tested from the H-14 well by producing directly into the 10-3/4 inch pipeline and using the separation and treating equipment at the Mandalay facility. The well is not now continuously producing due to fluid loading caused by high liquid production rates.

The Monterey zone is potentially productive in Well H-14, and it is planned to complete and test this zone when the testing of the current zone is complete. This Monterey zone is possibly a sour gas (hydrogen sulfide) zone. If this is the case, all gas will have hydrogen sulfide removed (sweetened) offshore prior to either flaring for short term testing or transportation through either of the pipelines to shore for long term testing or gas sales. No hydrogen sulfide gas will be transported to the Mandalay facility through either pipeline.

The basis for determination that the Monterey zone gas may contain hydrogen sulfide is the gas analysis from drill stem Test 2A of Well OCS P-0203 #6, which again was drilled in 1985. Of several drill stem tests conducted on this well, only Test 2A encountered hydrogen sulfide, which was present at a level of 2000 ppm. All drill stem test on Wells H-13 and H-14 performed to date have not encountered sour gas.

4. Reservoir Development

Until further drilling and testing are completed, it will be difficult to determine the development of gas reserves under Platform Gina in OCS Tracts P-0202 and P-0203. Some assumptions have been made by UNOCAL as follows: The major reservoir to be developed is the Monterey zone. Current information about the reservoir indicates potential reserves of 33 billion cubic feet, producing at a maximum 18 MMSCF/day rate after all the wells are on production. A 12 year life is estimated, and project timing is based upon drilling the second well in 1989, three additional wells in 1990, and the final three wells in 1991.

5. Hydrogen Sulfide Treating

The exact concentration of hydrogen sulfide which the Monterey zone will have is currently not known. Based on experience in the Santa Barbara Channel and results obtained in pertinent drill stem tests, UNOCAL has assumed that the gas will be similar to gas encountered in Well OCS P-0203 #6. This is the closest Monterey zone well to Platform Gina which has encountered sour gas.

Regardless of the concentration of the hydrogen sulfide in the produced gas, the gas will not be sent to the Mandalay facility until it is sweetened offshore to conform to the gas sales specification. The gas sales specification is 0.3 grains per 100 standard cubic feet, or 4 ppm. The sales specification is more stringent than the OSHA-PEL standard of 20 ppm and is more stringent than the American Conference of Governmental Industrial Hygienists (ACGIH) standard of 10 ppm.

There are several methods available for treating the gas to remove the hydrogen sulfide. These methods range from chemical scavenging with a variety of chemicals to large scale treatment plants. UNOCAL has experience in the production and treating of sour gas produced from both onshore and offshore reservoirs. UNOCAL will be treating the gas offshore to prevent transmission of hydrogen sulfide gas to the onshore facility.

A redundant detection, monitoring, shutdown, and alarm system will be installed to prevent the release of hydrogen sulfide gas into the pipeline.

C. Pipeline

1. Description

The subject pipeline is a 6-5/8 inch line 32,576 feet in length between the Mandalay treating facility in Oxnard, California, and Platform Gina within OCS P-0202. The 6-5/8 inch pipeline runs from the Mandalay facility southwest beneath the sand dunes that are northeast from the beach. Beneath the sand dunes, the line is inside a 10 inch protective conduit. Once the line leaves the conduit, a long radius bend turns the pipeline to 14° west of south, and from this point, the line proceeds directly towards Platform Gina. The approximate pipeline route may be seen in Figure 1.

The pipeline was installed in September of 1981 and was pressure tested to 2190 psi for 25 hours. Originally, pipeline burial was performed by natural surf conditions in the surf zone.

Subsequent surveys have shown that the line has remained buried since installation in the surf zone.

The pipeline has been in service carrying produced water to Platform Gina for offshore disposal since 1982. In 1985, a 650 foot portion of the pipeline was replaced from the Mandalay facility seaward towards the surf zone. This replacement was from the wall of the Mandalay facility to the mean high tide line.

The condition of the pipeline has been surveyed annually since the original installation. This is done by alternating a Side-Scan Sonar survey and a Linalog survey each year. The Side-Scan Sonar survey is an external survey and verifies pipeline burial and external damage; the Linalog survey determines internal and external damage of the pipeline, but does not delineate burial conditions. The survey results are reviewed by the Minerals Management Service annually.

As part of this project, this pipeline will be converted to gas service.

D. Mandalay Onshore Facility

1. Description

Produced oil, gas, and water from Platform Gina is currently being produced at the Mandalay Beach onshore facility. Here, gas, oil, and water are separated and made ready for shipping. In order to properly distribute the incoming gas from Platform Gina (via the converted existing water line), it will be necessary to perform minor piping changes at this facility. Gas will be tied directly into a Southern California Gas Company connection.

III. DESIGN REVIEW

A. Description

A design review of the proposed project was conducted in conjunction with the risk assessment study. In areas where completed design drawings were not available, proposed concept-level intentions were reviewed for conformance to applicable codes and to local industry standards. Where critical systems were proposed which tied into existing production process or safety systems, the existing systems were reviewed for local compatibility with current codes and practices. The project was deemed to meet or exceed CEQA Guidelines for Environmental Protection.

1. Applicable Codes and Standards

Where applicable, the following codes and standards were referenced during the course of the design review:

API 14C

ANSI 31.3

ANSI 31.4

ANI 31.8

30 CFR Pt. 250, 256 (MMS Orders)

33 CFR Pt. 126, 143, 147, 151-157

49 CFR Pt. 190-195

2. Safety Analysis

a. Purpose and Objectives

The purpose of a production platform surface safety system is to protect personnel, the environment, and the facility from threats to safety caused by the production process. The purpose of a safety analysis is to identify undesirable events that might pose a threat to safety and define reliable protective measures that will prevent such events or minimize their effects if the occur. Potential threats to safety are identified through the use of proven systems analysis techniques with have been adapted to the production process.

Recommended protective measures are common industry practices proven through long experience.

As much of the design for the proposed gas sweetening system is not complete at this time, a complete safety analysis could not be performed. However, a safety analysis of the existing pipeline system and applicable portions of the Mandalay onshore gas facility was performed using the following methodology:

b. Premises for Basic Analysis and Design

The recommended analysis and design procedures for a platform safety system are based on the following premises:

(1) The process facility will be designed for safe operation in accordance with good engineering practices.

(2) The safety system should provide two levels of protection to prevent or minimize the effects of an equipment failure within the process. The two levels of protection should be independent of and in addition to the control devices used in normal process operation. In general, the two levels should be provided by functionally different types of safety devices for a wider spectrum of coverage. Two identical devices would

have the same characteristics and might have the same inherent weaknesses.

(3) The two levels of protection should be the highest order (primary) and next highest order (secondary) available. Judgment is required to determine these two highest orders for a given situation. As an example, two levels of protection from a rupture due to overpressure might be provided by pressure switch high (PSH) and a pressure switch low (PSL). The PSH prevents the rupture by shutting in affected equipment before pressure becomes excessive, and the PSL shuts in affected equipment after the rupture occurs. However, a pressure safety valve (PSV) is selected in lieu of the PSL because it prevents the rupture by relieving excess volumes to a safe location. Moreover, its fast response could prevent a rupture in situations where the PSH might not effect corrective action fast enough.

(4) The use of proven systems analysis techniques, adapted to the production process, will determine the minimum safety requirements for a process component. If such an analysis is applied to the component as an independent unit, assuming worst case conditions of input and output, the analysis will be valid for that component in any process configuration.

(5) All process components on a production platform comprise the entire process from the wellhead to the most downstream discharge point; thus, all process equipment and functions are incorporated into the safety system.

(6) When fully protected process components are combined into a facility, no additional threats to safety are created. Therefore, if all process component safety devices are logically integrated into a safety system, the entire facility will be protected.

B. Platform Gina Process Equipment

1. Background

Before gas can be produced on Platform Gina, it will be necessary to install and configure processing equipment to sweeten, or remove hydrogen sulfide H_2S from the gas, then transfer it to the pipeline, and then send it to the Mandalay on-shore production facility. At this time, the final design has not been completed. Design review has been limited to existing equipment which has been installed or to concept-level review of proposed process facilities.

UNOCAL has indicated that should industry or regulatory standards change before actual design of the Gina gas processing starts, then the design will be modified accordingly to reflect the latest standards and practices.

Before drilling of the exploratory Wells H-13 and H-14 on Platform Gina in 1988, three related projects were completed to allow for exploratory drilling to proceed.

One project involved structural modifications to the platform to allow for higher hook loads during the drilling operation. The higher hook loads came about because of the deeper depth of the Monterey formations. This project met all applicable MMS structural requirements.

Another project involved the construction of a 23'x40' production deck extension on the west side of the platform to provide room for test equipment and installation of a flare stack to allow for testing of the wells. As with the other structural modifications, this project was completed and the design met all applicable MMS codes.

A third project which was completed before the exploratory drilling involved the installation of ambient hydrogen sulfide monitors at various locations around the platform to warn of any hydrogen sulfide release. The monitors are manufactured by General Monitors and are tied into the platform programmable logic controller (PLC) to effect a complete platform shutdown should dangerous levels of hydrogen sulfide be detected. In addition, early warning alarms were installed, and a hydrogen sulfide contingency plan was developed which included operator training and safety and evacuation plans. The existing contingency plans were reviewed and found to be in conformance with 30 CFR Part 250 (MMS Orders) regulations.

Exploratory Wells H-13 and H-14 were drilled after the above projects were completed. Well H-13 was a dry hole, and only limited drill stem testing was completed. Well H-14 had its production blended into the existing 10-3/4" production pipeline, and testing of the gas was performed at Mandalay. The shipping of the gas to Mandalay was possible because the gas did not contain hydrogen sulfide.

2. Proposed Process Description

In order to allow for testing and sweetening of gas offshore before shipment to Mandalay, it will be necessary to install gas separation and treating systems. For initial testing, UNOCAL proposes to utilize temporary batch sweeteners in order to provide flexibility for the test volumes and ability to handle the gas concentrations which will be found. As development proceeds, permanent equipment, optimally designed to match encountered conditions, will be installed.

UNOCAL proposes to install a gross separator, two batch sweeteners, a flare scrubber, an H_2S monitor, and a final gas scrubber. The batch sweeteners will each be capable of treating a gas volume of 3 million scf/day and sweetening from a level of 2,000 ppm to a level of 4 ppm. The associated liquid production will be pumped to shore using two triplex plunger pumps, each capable of handling 2,000 Bbl/day. A fully redundant hydrogen sulfide gas monitoring, detection, alarm, and shutdown system will be installed to protect the pipeline against hydrogen sulfide concentrations greater than 4 ppm and to protect platform personnel (see Section E). The monitoring, detection, alarm, and shutdown systems will be tied into the platform's PLC system to activate alarms and effect platform shutdown in the event that hazardous concentrations of H_2S are detected.

The initial plan is to dedicate all of this equipment to Well H-14. After well testing is completed, additional wells will then be brought on one at a time. As additional wells are brought on, additional equipment may need to be added to accommodate production. This additional equipment could include test separators, gas dehydration unit, and gas compression equipment. The actual equipment to be used will be based upon future test well test results and a detailed reservoir analysis. The design of the proposed gas production system was reviewed and found to be in accordance with modern and standard industry operating practices and current codes and regulations.

C. Pipeline

1. Description

The original 6-5/8" pipeline from Gina to Mandalay was designed as an ANSI 600# rated pipeline. For an ANSI 600 # class piping system, the design pressure rating is 1480 psig at temperatures up to 100 °F (Ref. ANSI B-16.5). Original design of the pipeline and risers met applicable portions of the OCS Orders, ANSI B-31.4, and 49 CFR Part 195 standards related to the transportation of hazardous liquids by pipeline. In general, the original design also met applicable portions of the OCS Orders, ANSI B31.8, and 49 CFR Part 192 standards relating to transportation of gas by pipeline. Since the original installation, the 6-5/8" pipeline has had a 650 foot portion replaced near Mandalay, and there is a proposed repair involving replacement of approximately 3000 feet of pipeline.

2. Design Review

a. Pipeline Material

According to available records, the existing pipeline material is 6-5/8" OD x 0.280 ERW API 5L Grade B pipe. The proposed replacement pipe to be used in the repair is 6-5/8" OD x 0.280 Seamless A106 Grade B pipe. The planned operating pressure is 500 psig, and the maximum allowable operating pressure will be 600 psig.

The maximum concentration of 4 ppm H_2S presents no unusual corrosion hazards for this grade pipe.

In accordance with 49 CFR Part 192, Minimum Federal Safety Standards for Gas Pipelines, the original pipe selection was checked for pressure handling limitations. Although offshore locations typically qualify as Class 1 locations, and hence are subjected to a lessor safety factor, it was decided to use a more conservative safety factor based upon a Class 3 location, which is more representative of the onshore environment around the Mandalay onshore facility:

$$P = (2\ St/D) * F * E * T \qquad \text{(49 CFR Pt. 192)}$$

P = Design Pressure in psig

S = Yield Strength

= 35,000 psi per API Spec 5L

t = Wall Thickness

= .280

D = Outside Diameter

= 6.625

F = Design Factor

Assume Class 3 Location, Type 3 Construction

= .50

E - Longitudinal Joint Factor

- 1.00 Per 49 CFR Pt. 192.113

T - Temperature Derating Factor

- 1.00 Per 49 CFR Pt. 192.115

P - 1,480 psig

Maximum Allowable Operating Pressure - 600 psig

Safety Factor - 2.5 minimum

Likewise, the proposed replacement pipe was also checked:

P - (2 St/D) * F * E * T (49 CFR Pt. 192)

P - Design Pressure in psig

S - Yield Strength

- 35,000 psi min per mill test certificates (actual test values - 43,700 psi)

t - Wall Thickness

- .280

D - Outside Diameter

- 6.625

F - Design Factor

Assume Class 3 Location, Type 3 Construction

- .50

E - Longitudinal Joint Factor

- 1.00 Per 49 CFR Pt. 192.113

T - Temperature Derating Factor

- 1.00 Per 49 CFR Pt. 192.115

P - 1,480 psig

Maximum Allowable Operating Pressure - 600 psig

Safety Factor - 2.5 minimum

b. Pipeline Riser

The pipeline riser at Platform Gina is constructed from API 5LX42 ERW pipe. By code, pipeline risers must be subject to a design factor of .50 or less:

P - (2 St 10) * F * E * T (49 CFR Pt. 192)

P - Design Pressure in psig

- 1,440 psig min

S - Yield Strength

- 42,000 psi

t - .280

D - 6.625

F - .50

E - 1.00

T - 1.00

P - 1,775 psig

Maximum Allowable Operating Pressure = 600 psig

Safety Factor = 2.96

The pipe is considered to be acceptable for maximum operating pressure of 600 psig. As actual operating pressures will be less, the safety factors will increase.

c. Pipeline Fittings

All new and existing pipeline fittings are proposed to be ANSI class 600# RF components. This class is good for pressures up to 1,480 psig at 100°F. A review of existing pipeline fittings, valves, and instrumentation was held, and no problems were identified.

d. Coatings

The existing coating at the splash zone is Ameron Tideguard 171. This product has been used in many similar applications, and no problems have occurred or are expected. The existing pipeline coating is Ameron PRITEC, and no problems have been reported. The coating for the new section of pipe is to be polypropylene. This material is desirable as it will be shop applied and will protect the pipeline through shipping and fabrication. Field joints will be wrapped at the time of welding using a suitable coating compatible with the polypropylene.

e. Cathodic Protection

The original cathodic protection system was designed for a 20 year life. The original design called out for 88 pounds of anode per 1,000 feet of pipeline, and the proposed repair will have installed approximately 190 pounds per 1,000 feet of pipeline. The pipeline was recently surveyed in February, 1989. The survey report was reviewed for deficiencies, and none were found.

f. Concrete Coating

The original pipeline was coated with a nominal thickness of 1.75 inches of concrete throughout the surf zone. UNOCAL proposes to supply a 1" thickness of coating for the replacement section of pipe which crosses through the surf zone. A comprehensive design review of burial characteristics and resistance to surf conditions of the original pipe was performed. After reviewing this and the selection of newer coatings available, it was determined that a 1" coating will provide ample pipeline protection.

D. Mandalay Onshore Facility

1. Description

The Mandalay onshore facility currently receives dry gas from Platform Gilda and also separates and processes gas from the Platform Gilda and Platform Gina processing trains for ultimate sale to the Southern California Gas Company. As designed, the facility has the capability to handle up to 9 MMSCFD from Platform Gilda and also can process up to an additional 2,000 MSCFD through local vapor recovery compression and dehydration equipment. As gas entering from Platform Gina will be sweetened offshore, there will be very little processing modifications required at Mandalay. A pipeline tie-in connecting the to-be-converted water line to the existing gas line is the only major modification which will need to be constructed.

2. Design Review

A design review of the existing pipeline sales gas system at Mandalay was conducted. In conjunction with this review, a Safety Analysis Function Evaluation (SAFE) Chart was prepared, which identifies critical safety functions and checks for code compliance. The existing Piping and Instrumentation Diagrams (P&IDs) for the pipeline gas handling system were reviewed and minor drawing corrections were made. It was recommended that UNOCAL install one additional flow safety valve and pressure switch. UNOCAL has agreed to perform this work. As the piping and electrical design for the Platform Gina gas tie-in is not completed, this could not be reviewed at this time. The design review did not encompass existing up-stream vapor recovery and gas separation systems, as they function independently of the proposed Gina gas processing systems and were known to be in full code compliance at the time of construction, in 1981.

Major equipment and physical layout of the existing gas processing equipment at Mandalay was checked and no problems relating to the existing gas processing system were observed.

Control at Mandalay is effected by a PLC located at the control room. All of the electrical logic operates in a fail-safe mode.

E. Hydrogen Sulfide Redundant Monitoring, Detection, Shutdown, and Alarm System

1. Description

In order to guard against the accidental transmission of H_2S gas to shore, Platform Gina will have redundant H_2S monitors installed on the departing gas pipeline. The monitors are designed to continuously monitor the flowing gas stream, and will alarm immediately if the H_2S concentration reaches a level of 2 ppm. This early warning alarm gives the platform operators an opportunity to check and adjust the gas sweetening equipment to reduce the H_2S concentration. If, for any reason, the H_2S level is not controlled properly and the concentration reaches 4 ppm, the H_2S monitors then trigger a shutdown of the gas processing system and gas delivery to Mandalay will cease.

A similar monitor is also installed at the Southern California Gas Company pipeline tie-in at Mandalay to provide independent and triple redundant back-up to the platform safety systems. Should this monitor detect H_2S, an emergency alarm signal is generated which will cause shutdown of the sales gas pipeline, which will then force a shutdown of gas shipping from the platform.

In addition to the gas pipeline monitoring, UNOCAL also has installed a number of atmospheric gas monitors aboard the platform to protect employees and visitors against any leaks which could release H_2S gas into the working environment. Should these detectors detect H_2S gas, an alarm is sounded and the location of the leak indicated to the platform operators in the control room. If the concentration approaches potentially harmful concentrations (20 ppm), the control panel logic will effect an immediate shutdown of the gas processing systems and gas wells. The entire system is calibrated monthly and results reviewed by the Minerals Management Service.

UNOCAL has also prepared a detailed H_2S contingency plan, which documents and provides all employees and platform visitors specific instructions and procedures to be followed in the event of an H_2S alarm.

2. Design Review

a. Platform Gina

Pipeline Gas Monitors: The redundant H_2S gas monitoring, detection, shutdown, and alarm systems utilize Del Mar Series DM-EXMR hydrogen sulfide monitors for detection. This monitor uses a continuously moving tape, specially coated with lead acetate, which is exposed to the flowing gas stream. When the tape comes into contact with H_2S, a chemical reaction occurs which changes the lead acetate into lead sulfide. An optical sensor and reference circuitry convert the resulting color change of the tape into a numerical value, which corresponds to actual ppm of H_2S present in the gas stream. The system self-calibrates and recalculates approximately every 30 seconds. The monitors will be adjusted to provide an alarm signal at 2 ppm, and a shutdown signal at 4 ppm. This type of monitor is currently an industry standard and is also used by the Southern California Gas Company to protect their system in several locations against accidental H_2S contamination. This particular sensor is a state-of-the-art device and is well-suited for this type of application.

The outputs from the monitors are to be wired in a fail-safe manner into the PLC in the control room. The PLC logic operates the alarms and effects shutdown of the gas system. The PLC operates in a fail-safe mode, continuously checking sensors and sensor circuits. Upon any faults, the PLC automatically initiates a system shutdown and alarm. There have been no incidents of PLC failure of any kind aboard Gina or at Mandalay since start-up in 1982.

In the event H_2S concentration is detected in excess of 4 ppm, the PLC will automatically shut down the Amine gas plant, stop gas production, and divert gas blow-down to the flare, where it may be safely burned off. The sequence is fully automatic and does not require operator intervention. The control logic is such that the cause of the problem must be identified and corrected before start-up can occur.

UNOCAL has expressed intentions to update some of their platform control as part of this project. Part of these modifications will involve converting some of the existing pneumatic controls (e.g., pressure transmitters, valve actuators, flow controllers) aboard Gina to electronic controls. The availability and reliability of these controls is now greater than what was originally available at the time of the original platform design. In general, this will provide increased system reliability and reduce the amount of field upkeep required for these controls. The existing PLC should be able to handle the increased logic demands which will be required. However, more physical alarm annunciators or a different means of operator interface will have to be added to the existing control panel.

Atmospheric Monitoring: Atmospheric monitoring is accomplished through the use of 8 monitors spread around the platform which continuously sniff the air for any traces of H_2S gas. The system is designed to detect any gas leaks which could threaten platform personnel. The signals from the detectors are received by a dedicated control panel in the control room, which will indicate where on the platform H_2S is detected and whether the amount is 10 or 20 ppm. In addition, the outputs from this panel are also wired into the PLC and will effect a gas well and amine plant shutdown should H_2S gas at 20 ppm be detected. Audible alarms are provided at both 10 ppm and 20 ppm. The monitors in use are manufactured by General Monitors and reflect current state-of-the-art design for this application.

IV. RISK ANALYSIS

A. Methodology

The purpose of the safety assessment was to quantify the risks of a hydrogen sulfide (H_2S) release arising from the proposed 6-5/8" pipeline conversion project. In this context, "risk" is defined as "the potential" for realization of undesirable consequences arising from an event of activity; as such, it has both a probabilistic component (the probability of the event occurring) and a deterministic component (the consequences of the event).

The potentially harmful material which will be handled by the project will be natural gas with an undetermined concentration of hydrogen sulfide (H_2S). For the purpose of this analysis, it is assumed the concentration of H_2S will be approximately 2000 ppm at the well head. Although safety considerations during the design stage can serve to reduce process-related risks to very low levels, risk can never be eliminated. Therefore, the assessment focused on potential releases of hazardous gases which, in turn, might affect the safety of the general public and surrounding community.

The methodology for safety assessments for this project consisted of a number of steps which are briefly described below:

In the first step, preliminary design information was reviewed with the objective of identifying the events that might lead to a release of hazardous material.

The second step in the safety assessment was to determine the likelihood of these types of failure events using fault tree analysis.

The third step was to assess the frequency of system failures and accidental events that could cause releases.

The fourth step was to calculate the magnitude of releases caused by accidents or the rate at which materials would be released from equipment, pipes, etc., if the events postulated in the fault tree analysis were to occur.

In the fifth step, the possible consequences of the releases postulated above were estimated. For toxic materials, the consequences involve the dispersion of a toxic vapor cloud.

Finally, in the sixth step, the frequencies associated with particular events and the consequences of those events were combined to produce risk profiles in order to display both the probabilistic and deterministic elements of risk. Impact summary tables were also used to present a concise description of these results and key safety issues.

1. Assessment of System Failures and Accidental Events

This consisted of four steps:

- hazard identification
- fault tree analysis
- assessment of frequency of system failures
- assessment of frequency of accidental events

a. Hazard Identification

An accepted technique for hazard identification is the hazard and operability study. This technique requires careful review of the project P&IDs by a team of engineers and designers. Because the P&IDs for this project are still preliminary, such a detailed review would not be appropriate at this stage. Therefore, the identification of events or system failures that could lead to releases with potentially harmful consequences for the public was accomplished by a critical examination of the preliminary P&IDs, layouts, and process drawings.

In addition to the concerns of system failures raised in the review of these preliminary drawings, there were also some failure modes with large consequences associated with externally induced events (e.g., earthquakes) and frequent hazards of small consequences associated with procedural errors. All such events with the potential for negative impact, either directly or through a chain of events, were examined further, whether induced by system failures, external event, or improper procedure.

b. Fault tree Analysis

Fault tree analysis is used to identify the sequence of failures leading to an unwanted failure event and to estimate the likelihood of occurrence of that event. This technique starts with a particular top event, such as a hydrocarbon release from a particular system. It then breaks down the causes of such an accident into all the identifiable contributing sequences, and each sequence is separated into all of its necessary components or events. The presentation of all this information is facilitated by the use of a logic diagram, or "fault tree."

The sequence of events forms pathways, along which are found logical "AND" and "OR" gates. These gates connect the basic initiating and contributing events to the higher order events. When the occurrence of all of a set of lower order events is necessary for the next higher order event to occur, they are joined by an "AND" gate. By multiplying together the probabilities of each event in the set, the probability of the next higher event is obtained. When the occurrence of any one of the set of lower order events is sufficient for the next higher order event to take place, the events in the set are joined by an "OR" gate, and their probabilities are added. These rules are valid for independent events and events with very low probabilities. Probabilities of the top events are expressed as a yearly rate -- e.g., 10^{-4} chance of occurrence per year. (This event would be expected to have an annual chance of occurrence of 1 in 10,000.)

Since the probability of each top event (accident scenario) is to be expressed as a yearly rate, no more than one event leading into an "AND" gate can have a likelihood expressed as a frequency. Otherwise, the overall rates will be in terms of something similar to "occurrence rate per year squared" -- a meaningless concept. Thus, at most, one lower event leading into an "AND" gate can be expressed as a frequency; the remaining events are expressed as conditional probabilities, or probabilities per demand. These are dimensionless and can then be multiplied by a frequency to yield a conditional frequency.

At "OR" gates, it is essential that all the events entering the gate be quantified in the same units -- either frequencies or probabilities -- since they are to be added. The next higher order event will be in the same units as the events immediately preceding it.

For this study, fault trees were constructed for failure events related to platform operations, the pipelines, and the onshore facilities operations.

c. Assessment of Frequency of System Failures

Once the fault trees for the release of hazardous gases were developed, the likelihood of such events occurring was estimated by assigning probabilities and frequencies to each event or failure in a particular fault tree. The frequency rates for human errors and equipment failure that were used in this study are based either on information reported in the literature, or on estimates that combine information supplied by the operator with information from other sources. The failure rates and probabilities given by this report are based on information from operating industrial facilities, such as chemical plants, refineries, power plants and manufacturing facilities.

Additional failure rate data sources for pipelines and offshore facilities include: U.S. Department of Transportation, Research and Special Programs Administration, Annual Report on Pipeline Safety; U.S. Department of Transportation, Research and Special Programs Administration, Transportation Safety Information Report; U.S. Environmental Protection Agency, Petroleum Pipeline Leak Detection Study.

Probabilities were obtained from these sources and, if appropriate, were modified on the basis of engineering judgment and the specific features of this particular project. By multiplying or adding the probabilities as described above, the likelihood of the top event occurring can be estimated.

d. Assessment of Frequency of Accidental Events

The frequency of occurrence of certain types of accidental events was estimated using historical data. It is important to recognize that the use of historical data inherently implies that certain assumptions are being made. These assumptions include:

- Past experience is a reliable indicator of future experience.

- Accident causes will be the same in the future as they have been in the past.

- Accident rates will not be affected by improved technology or regulations.

- Accidents at the location where these data are being applied will be similar to those where the data were collected.

- The accident performance for any one facility will be average or typical of the entire industry.

Some of these assumptions are simplistic and may not reflect conditions that in reality bear upon the facility being evaluated; for example, improved technology in system operations in accordance with the Best Available and Safest Technologies (BAST) policy of the Minerals Management Service (1980) can reduce accident rates and associated levels of risk. Because of this, historical data was carefully examined to ascertain how applicable it is to the scenario. If necessary, adjustments were introduced where supportable with specific information or independent analysis.

2. Assessment of the Magnitude of Releases

Having postulated various events that could result in the release of a hazardous material, it was necessary to calculate the quantities that would be released in specific circumstances.

Two approaches were applied to quantify release amounts and to ensure their validity for the particular facilities of concern:

- Analysis of historical data via review of prior studies in the topical areas of interest, and

- Engineering analysis based on the specific capacities and characteristics of project-related systems.

Historical data have advantages for use where the physics of the discharge phenomena is poorly understood and/or where an engineering analysis requires data that are not readily available and cannot be estimated without an extreme degree of uncertainty. Historical data may also be used to confirm that the results of engineering analysis or estimates are credible from a historical perspective. Analysis of historical accident records, where available, typically provided release-size distributions giving the conditional probabilities associated with various ranges of release volume, i.e., the probability that a release will be of a particular size range, given that a release has occurred. They served to confirm the reasonableness of engineering estimates of release volumes resulting from non-blowout-related accidents involving pipelines.

Engineering analysis, where possible, permits consideration of the key features and characteristics of proposed systems and may provide more accurate assessments of release volumes or discharge rates. In the majority of cases for this particular study, efforts were made to compute typical release volumes or discharge rates resulting from specific sequences of events identified in the fault-tree analysis. However, since such engineering evaluations are deterministic in nature, it often became necessary to develop worst-case estimates in conjunction with estimates for more typical incidents. These efforts were coordinated with the frequency assessment for system failures and accidental events to take best advantage of available data.

Uncertainties and/or unknowns were addressed by assumptions tending to err on the conservative side, i.e., tending to over predict release volumes or discharge rates.

3. Major Hazards and Consequences

a. Releases of Hazardous Materials

The major hazards resulting from accidental releases are those associated with toxic substances (such as hydrogen sulfide). For toxic substances, the dispersion of toxic vapors is the main concern.

b. Vapor Dispersion Hazards

A vapor cloud may be formed as a result of a release of gas. The vapor cloud will travel downwind and will disperse owing to jet mixing (if it is from a pressurized release), gravity spreading (heavy as releases), and/or turbulence in the atmosphere.

For toxic releases, the immediately dangerous to life or healthy (IDLH) value defined by NIOSH/OSHA was used to determine the toxic vapor dispersion zone.

4. Risk Profiles and Risk Consequences

A risk profile is a graphical representation of the probability with which various levels of unwanted impacts will be exceeded.

For release of hazardous gas, the results of fault tree analysis and consequence analysis are combined with population distributions to develop risk profiles. It is also necessary to estimate the likelihood of occurrence of conditional events (e.g., the probability of wind velocity and direction to carry the vapor clouds over populated areas) and the degree of impact to personnel in the event a toxic release does indeed take place.

For a toxic release, it is simply necessary to determine the probability of a release occurring and the cloud moving into a particular geographic sector.

Gas dispersion models can be used to develop conditional risk profiles. These profiles are conditional on the location and amount of material released, the type of hazard experienced, and on the weather conditions at the time of the release. By combining the likelihoods of specific weather conditions, hazard types, and release scenarios with the potential impacts of these conditions, overall risk profiles for these operations can be developed.

B. Assessment of System Failures and Accidental Events

This section considers system failures and accidental events that may occur in the various components of the project. It identifies failures and accidental events that may lead to adverse impacts on the public or the environment from the toxic effects of a potential gas release. In addition, there may be a number of events with more limited consequences that might adversely affect the project employees or facilities, but not the public or the environment. Unless such events could escalate into a more serious situation, they are not a part of this assessment.

1. Platform Gina Failure Modes

Because platform Gina is located more than 3 miles offshore, toxic releases occurring at the platform will not have the potential to affect the public onshore directly. Nevertheless, it is noted that Unocal proposes to set up comprehensive contingency plans to deal with the release of gas, which may contain hydrogen sulfide and could present a toxic hazard to the platform crew. These contingency plans provide for an orderly platform shutdown in the event of a major gas release.

Redundant hydrogen sulfide detection, monitoring, shutdown, and alarm systems will be installed to prevent gas containing hydrogen sulfide in concentrations greater than 4 ppm from entering the pipeline to Mandalay. When hydrogen sulfide concentrations greater than 4 ppm are detected in the gas stream the monitor will send a signal to the platform programmable logic controller (PLC) to effect immediate shut down of the pipeline shut down valve and the surface safety valve at the wellhead. During the initial stages of well testing the valve to the flare will be manually opened and the operator will back flow the pipeline until the hydrogen sulfide concentrations are below the 4 ppm level. This will be confirmed by both the redundant hydrogen sulfide monitors and by manually testing samples taken from the pipeline before production can continue.

Figure 2 summarizes the frequencies that would result in gas leaving the platform with a hydrogen sulfide concentration of greater than 4 ppm.

2. Pipeline Failure Modes

Failure modes for both the onshore and offshore lines include:

- Internal corrosion - especially on two phase flow lines and in sour service;

- External corrosion - from faults in protective systems, in splash zones offshore, or in cased crossings beneath roads and railway lines;

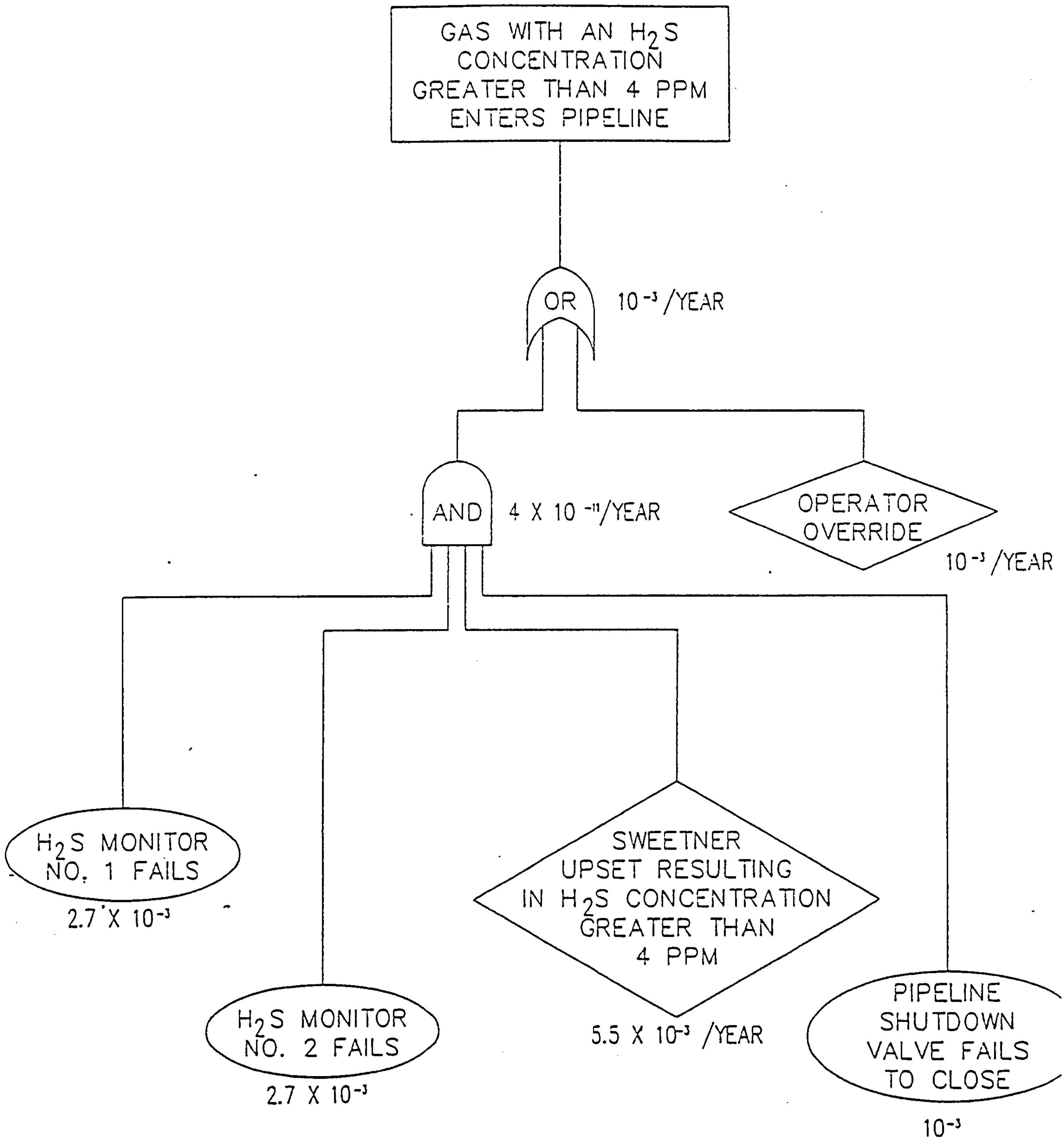

GAS WITH AN H2S CONCENTRATION GREATER THAN 4 PPM ENTERS PIPELINE
OR
10⁻³ /YEAR
AND
4 X 10⁻¹¹/YEAR
OPERATOR OVERRIDE
10⁻³ /YEAR
H2S MONITOR NO. 1 FAILS
2.7 X 10⁻³
H2S MONITOR NO. 2 FAILS
2.7 X 10⁻³
SWEETNER UPSET RESULTING IN H2S CONCENTRATION GREATER THAN 4 PPM
5.5 X 10⁻³ /YEAR
PIPELINE SHUTDOWN VALVE FAILS TO CLOSE
10⁻³

FIGURE 2

- External impact - dropped equipment (cranes, booms, drill collars) near platforms, anchor dragging, marine traffic impact (to risers), or farm or construction machinery;

- Structural failures or mechanical defects - defective seams or welds;

- Natural hazards - seismic events, subsistence, etc.

Operating errors and construction defects are also potential causes of pipeline incidents. The onshore pipelines will also have block valves which might yield leaks at connections.

While there are numerous ways in which a pipeline may fail, the most significant failures modes are external impact, corrosion (mostly external), and mechanical failures. The relative contribution of each mode varies slightly for different pipeline systems, but is remarkably consistent despite different operating environments.

The Futures Group (1982) gives an overall failure rate of 1.7 x 10^{-3}/km-yr for gas lines of 6- to 10-inch diameter. They also state that these rates may be overstated because only Texas and Louisiana total lengths have been used in the denominator. This translates to a failure rate of 2.7 x 10^{-3}/mile-yr.

When considering the offshore platforms, it was possible to discount toxic releases from consideration because the separation distances ruled out any adverse public impact. In the case of the pipeline, the first mile extending from Mandalay offshore necessitates consideration because members of the public could be in much closer proximity to possible failures and accidental events that may lead to toxic effects.

The resulting frequency for a failure of the pipeline within one mile of the Mandalay facility which will produce a release of gas with a concentration greater than 4 ppm hydrogen sulfide is shown in Figure 3.

3. Mandalay Facility

The gas pipeline from Gina to Mandalay will enter the facility, where the first item of equipment will be a pig receiver. It is currently estimated that it will be necessary to pig the pipeline up to once a week.

If a major gasket leak were to develop while the receiver was under full line pressure, a limited release of gas could occur. It is also possible that a mechanical defect or operator error could occur and yield a full gas release from the main inlet line. Full gas releases have been estimated at 5.7×10^{-4} per year. The resulting frequency of a full gas release with a

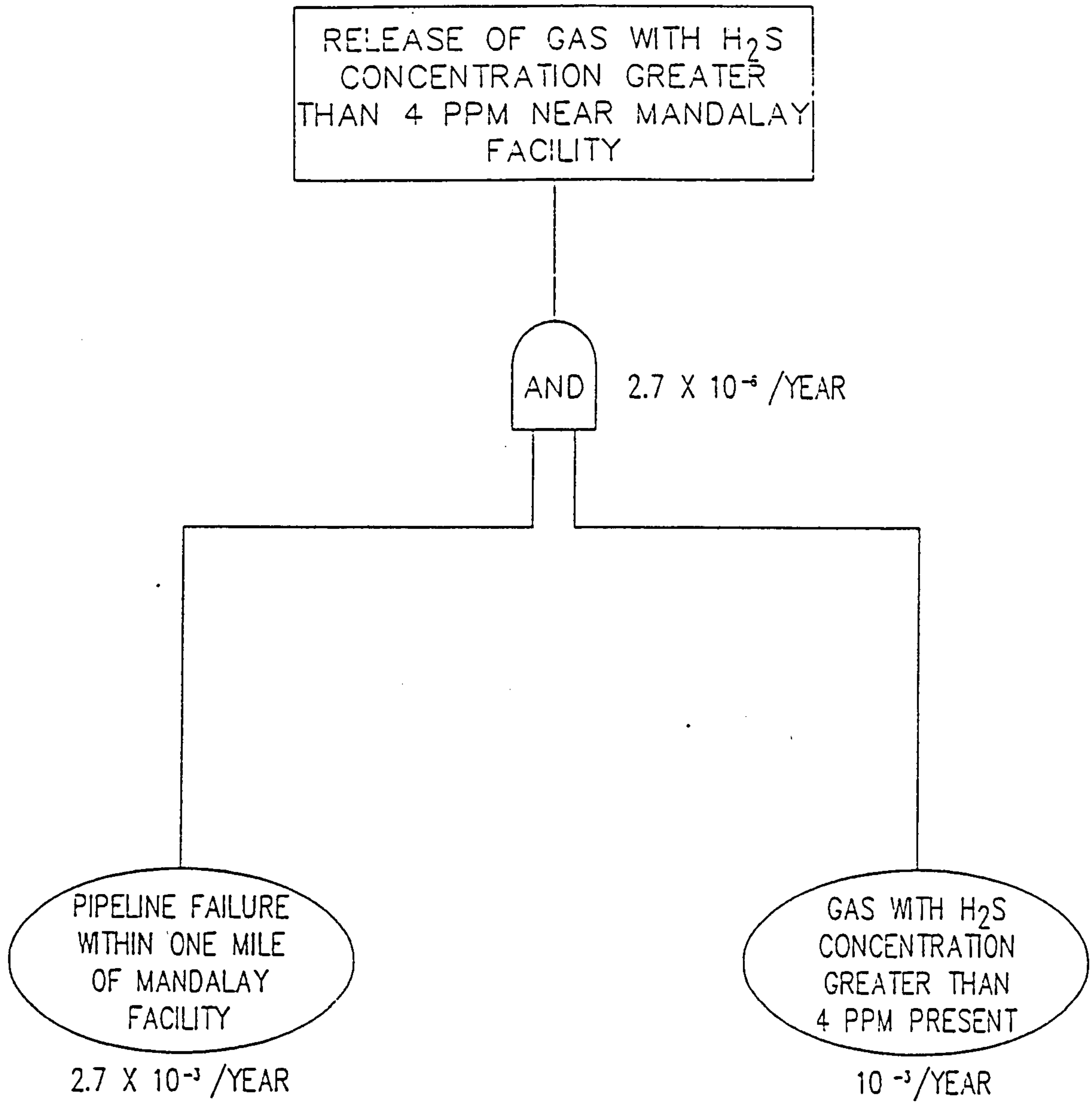

RELEASE OF GAS WITH H_2S CONCENTRATION GREATER THAN 4 PPM NEAR MANDALAY FACILITY
AND
2.7 X 10^{-6} /YEAR
PIPELINE FAILURE WITHIN ONE MILE OF MANDALAY FACILITY
2.7 X 10^{-3} /YEAR
GAS WITH H_2S CONCENTRATION GREATER THAN 4 PPM PRESENT
10^{-3}/YEAR

FIGURE 3

greater than 4 PPM hydrogen sulfide concentration is shown in Figure 4.

Another item necessitating consideration, due to the proximity of the Mandalay facility to the Oxnard Airport, is the frequency of external impact from aircraft. Arthur D. Little, Inc. (1976) estimated the probability of an aircraft impacting a proposed LNG storage tank located between three major New York airports -- LaGuardia, JFK, and Newark. The result was a total probability of 7.9×10^{-5}/yr. when the target area of concern was 0.023 square mile. The authors used aircraft accident data for the years 1964-72.

The U.S. Department of Transportation, Research and Special Programs Administration, Transportation Safety Information Report, 1987 Annual Summary, indicated both the number and rate (accidents per 100,000 hours flown) of accidents for General Aviation have decreased from 1982 to the end of the reporting period in 1987.

Based on a generally conservative order-of-magnitude analysis, it is concluded that the risk associated with aircraft crashes into vulnerable facilities which would result in a release of gas with toxic concentrations is negligible compared to those associated with other hazards.

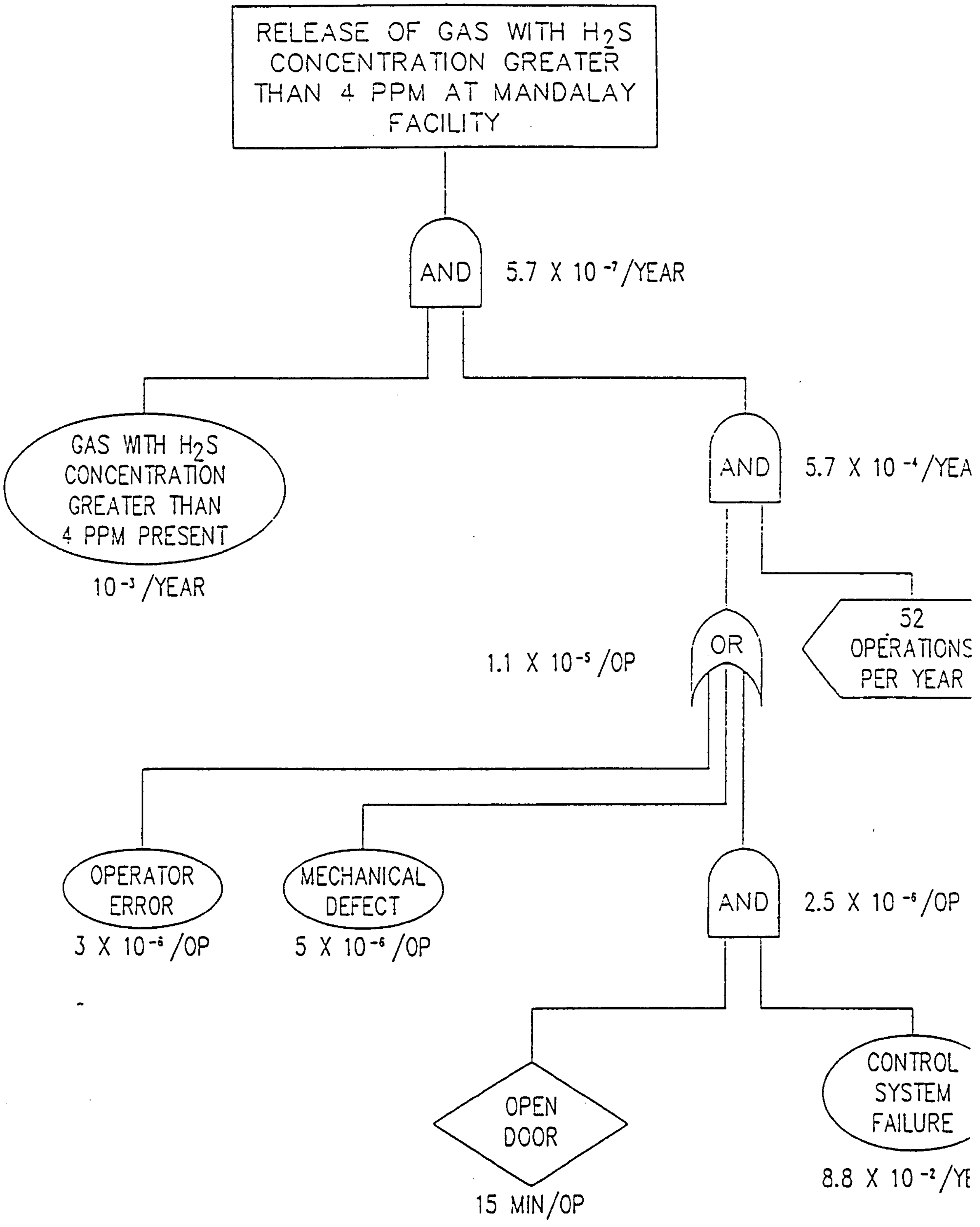

RELEASE OF GAS WITH H2S CONCENTRATION GREATER THAN 4 PPM AT MANDALAY FACILITY
AND
5.7 X 10 -7/YEAR
GAS WITH H2S CONCENTRATION GREATER THAN 4 PPM PRESENT
10 -3 /YEAR
AND
5.7 X 10 -4/YEA
OR
1.1 X 10 -5 /OP
52 OPERATIONS PER YEAR
OPERATOR ERROR
3 X 10 -6 /OP
MECHANICAL DEFECT
5 X 10 -6 /OP
AND
2.5 X 10 -6 /OP
OPEN DOOR
15 MIN/OP
CONTROL SYSTEM FAILURE
8.8 X 10 -2 /YE

FIGURE 4

C. Major Hazards and Consequences

An accidental release of gas with low concentrations of hydrogen sulfide will form a vapor cloud. The dispersion of the cloud is determined by its own physical characteristics and the characteristics of the prevailing atmospheric conditions. For pure hydrogen sulfide releases, the mean density of the cloud is greater than the air density. Therefore, low clouds may form and spread close to the ground due to the effects of gravity, and then disperse in the atmosphere due to turbulence. For low concentrations of hydrogen sulfide in other hydrocarbons (like natural gas in Santa Barbara region with 6,000 to 7,000 ppm of hydrogen sulfide), Arthur D. Little, Inc. determined the dispersion to be largely governed by the behavior of the hydrocarbon. The vapor concentration in the cloud decreased because of the entrainment of ambient air.

Although H_2S has an obnoxious odor of bad eggs at concentrations of a few ppm, at higher concentrations -- 100 ppm upwards -- the sense of smell is lost and fatalities can occur without the warning provided by the H_2S odor. Another significant hazard of hydrogen sulfide is that the odor can be masked by the presence of other chemicals. Experiments have indicated that as low as 1 ppm could be detected by odor in the air, but in the presence of propane and butane, even 5-10 ppm could not be smelled.

A vapor cloud will travel downwind and disperse, owing to jet mixing (if it is from a pressurized release), gravity spreading (heavier than air releases), and/or turbulence in the atmosphere.

The toxic vapor cloud dispersion hazard was determined by using the immediately dangerous to life and health (IDLH) levels prescribed by OSHA/NIOSH. This concentration represents a maximum level from which one could escape within 30 minutes without any escape impairing symptoms or any irreversible health effects. Therefore, these concentrations represent a possible boundary between "serious injuries" and "recoverable health effects." However, the toxic concentration within the vapor cloud is fluctuating and increases as one moves toward the source of release. Therefore, it was assumed that the toxic vapor dispersion hazard zones calculated using dispersion models represent a 50 percent fatality zone (due to increase in concentration). The remaining 50 percent of the population exposed within this zone was assumed to be seriously injured. The population beyond the IDLH concentration level may suffer minor but not irreversible health effects; therefore they were not considered in the risk analysis.

The dispersion hazard zones are generally calculated for two atmospheric conditions:

- D-Stability (neutral) with a wind velocity of 5 m/s (11 mph) representing the most likely weather condition;

- F-Stability (stable) with a wind velocity of 2 m/s (4.5 mph) representing a worst case dispersion hazard.

The increased atmospheric stability associated with Pasquill-Gifford Category F, along with the low wind speed, provides conditions in which a release can travel long distances downwind before dispersing below the specified concentration limit.

Arthur D. Little, Inc. (1984) conducted a hydrogen sulfide dispersion analysis using natural gas with 0.7% (7000 ppm) H_2S in the gas at the source. The results are shown in Table 1 and Figure 5. Using this data, it can be seen that the maximum anticipated production rate of 18 MMSCF/D, if completely released to the atmosphere, would achieve only about a 15 ppm concentration in air, approximately 1/2 mile from the point of release, if the H_2S concentration in the gas stream at the point of release was 7000 ppm. It should be noted that the concentration of hydrogen sulfide in this model is much higher (3 1/2 times) than the highest concentration found in the gas analysis of drill stem test 2H of the Well OCS P-0203 #6.

D. Assessment of Risk

This section combines the frequency of system failures and accidental events developed in Section B and their subsequent hazards and consequences developed in Section C. From this, the overall risk profile associated with the proposed project was developed.

TABLE 1

H_2S DISPERSION ANALYSIS

Distance Downwind (miles)	Estimated Gas Flow Required to Achieve 10 ppm Concentration in Air (MMCFD)*
10	937
9	818
8	705
7	606
6	477
5	377
4	280
3	184
2	104
1	39

*Assumptions:

1. Atmospheric condition F
2. Wind velocity of 2 m/s (4.47 mph)
3. 0.7 (7000 ppm) H_2S in gas at source

Notes:

1. Based on point source Gaussian dispersion model for ground-level continuous emission.

2. Concentration of 15 ppm is the 1983-84 short-term exposure limit (STEL) suggested for H_2S by the American Conference of Governmental Industrial Hygienists (ACGIH).

HYDROGEN SULFIDE DISPERSION ANALYSIS

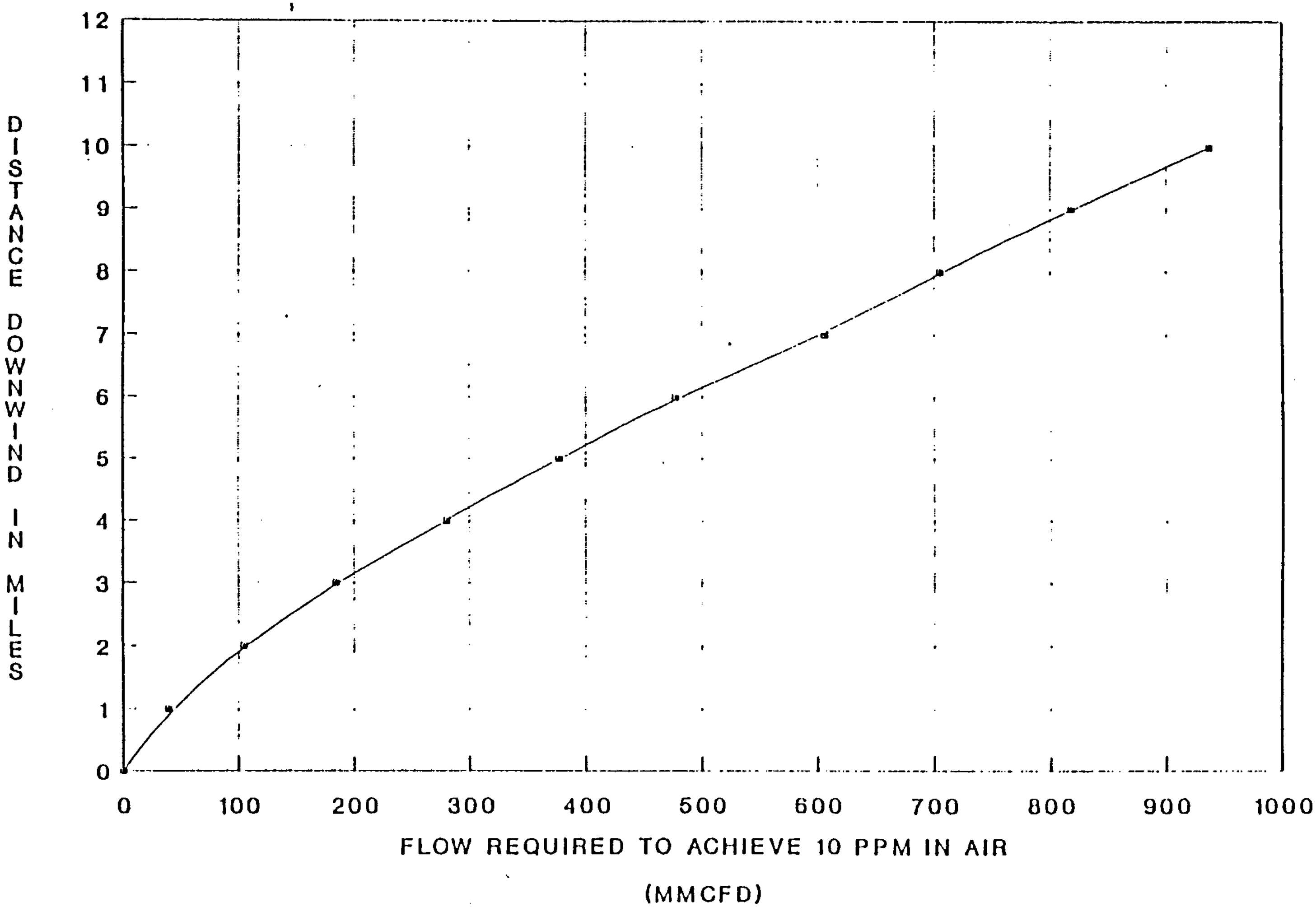


FIGURE 5

Due to the low concentrations of hydrogen sulfide (2000 ppm) in the gas stream, this risk analysis employs the following worst case assumptions.

1. Anytime gas entered the pipeline from Platform Gina above 4 PPM hydrogen sulfide we considered the concentration to be 2000 ppm.

2. All system failure and accidental events were considered full pipeline breaks.

3. The gas released was at the maximum anticipated production rate of 18 MMSCF/D.

From an evaluation of Section C it can be estimated that with a full release, the only area which hydrogen sulfide would adversely affect the public would be within the envelope 1,320 feet downwind.

No historical data was available relating the distribution of people along the beach where the pipeline comes ashore related to time. This distribution was estimated to be as given in Table 2.

The toxic vapor cloud dispersion hazard was estimated by using the immediately dangerous to life and health (IDLH) levels prescribed by OSHA/NIOSH. This concentration represents a maximum level from which one could escape within 30 minutes without any escape impairing symptoms or any irreversible health effects.

TABLE 2

ESTIMATED BEACH CROWD DISPERSION
WITHIN 1,320 FEET DOWNWIND OF PIPELINE

1 person	175 days	1400 hours
5 people	60 days	480 hours
10 people	30 days	240 hours
25 people	10 days	80 hours
50 people	4 days	32 hours
100 people	1 day	8 hours

The described risk profile is shown in Figure 6.

HYDROGEN SULFIDE RELEASE RISK PROFILE

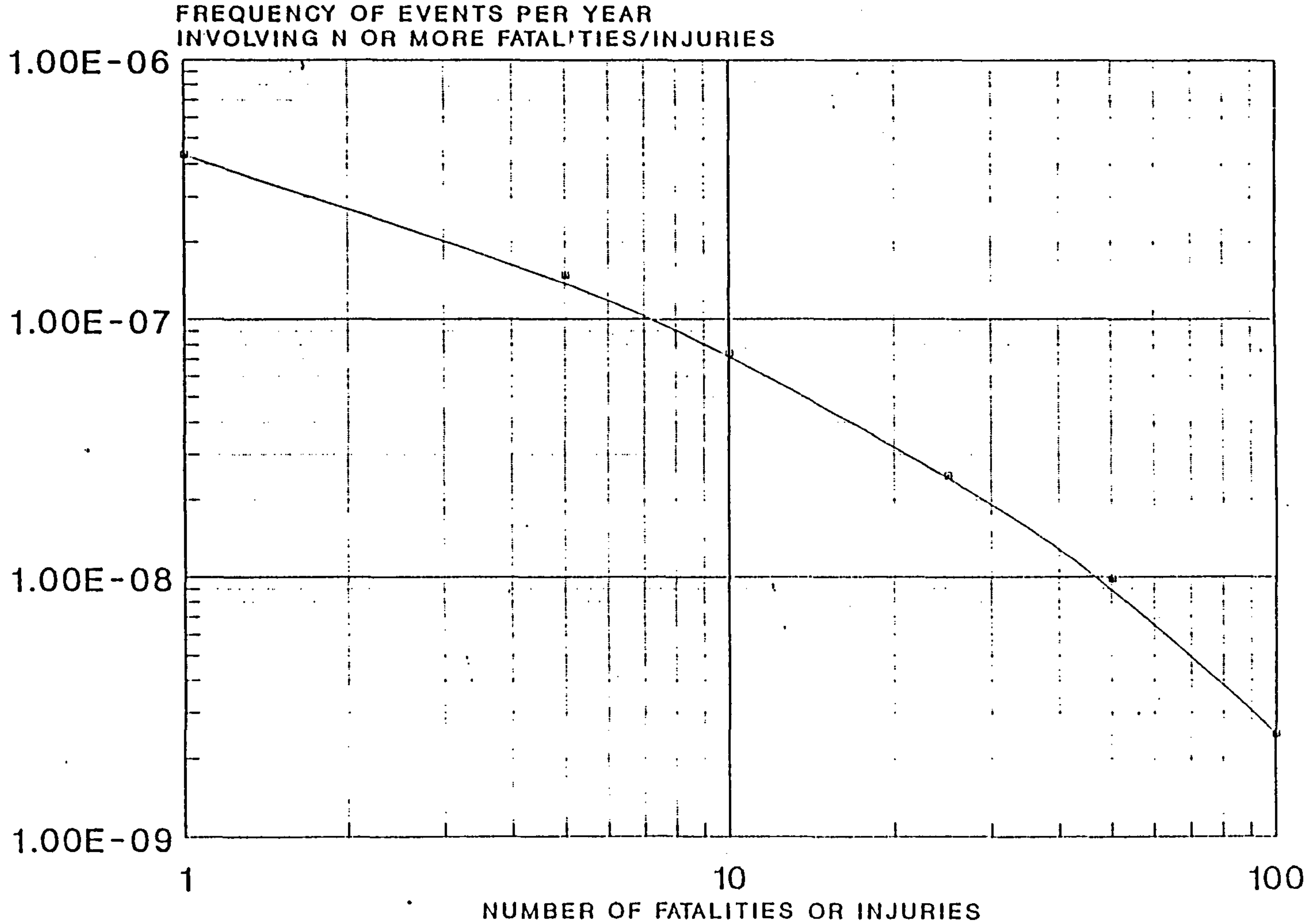
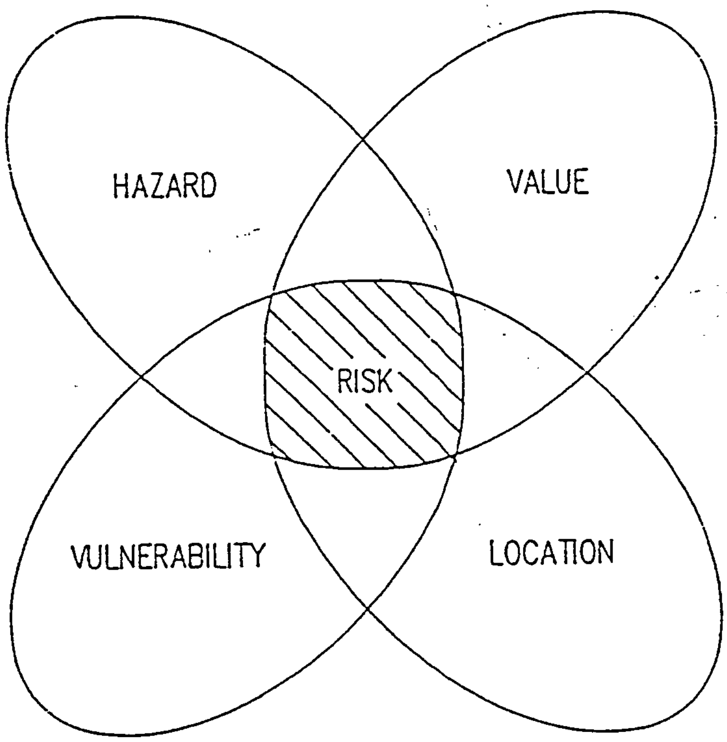


FIGURE 6

WHAT ARE THE INGREDIENTS OF RISK?



PHYSICAL PROPERTIES OF HYDROGEN SULFIDE

Chemical Formula:	H_2S
State at 15 degrees C and 1 atm:	Gas
Molecular Weight:	34.08
Specific Gravity of Gas (air=1):	1.1985 @ 15 degrees C
Boiling Point:	-59.6 degrees C.
Density of Liquid at Boiling Point:	993 kg/m^3
Density of Gas at 0 degrees C:	1.538 kg/m^3
Specific Heat Ratio at 20 degrees C:	1.32
Flammable Limits in Air:	4.3-45% (volume)
Auto-ignition Temperature:	260 degrees C
Odor:	Smell of rotten eggs

LIMITING CONCENTRATIONS FOR H_2S EXPOSURE SUGGESTED BY REGULATORY AUTHORITIES

1.	NIOSH - Industrial standard for 10-minute exposure	10 ppm
2.	Threshold Limit Values, Germany and Sweden	10 ppm
3.	American Standards Association -	
	• maximum concentration for prolonged exposure	20 ppm
	• 1-hour exposure with no serious consequence	170-300 ppm
	• dangerous after 0.5 to 1.0 hr exposure	400-700 ppm
4.	NIOSH/OSHA immediately dangerous to life and health (0.5-hour exposure)	300 ppm

VAPOR DISPERSION HAZARD ZONE CRITERIA

	Flammable Concentration (Volume %)	Toxic Concentration (ppm)
1. Methane (natural gas)	2.50	N/A
2. Propane	1.05	20,000
3. Butane (normal and Iso)	0.95	10,000
4. Hydrogen Sulfide	2.15	300
5. Sulfur Dioxide	-	100

TOXIC EFFECTS OF H_2S

Concentration in PPM	Effect
0.1	Approximate odor threshold. Air pollution measurements require detection below this level
10	Threshold limit value (TLV) recommend maximum safe level for 8 hour exposure
20	Current OSHA "ceiling" concentration. Respiratory irritation after long exposures. Possible eye irritation.
50	Current maximum allowable by OSHA up to 10 minutes per day if no other exposure exists. Respiratory protective equipment required at higher levels.
100	Coughing, loss of sense of smell, serious respiratory irritation if exposure is prolonged.
500	Unconsciousness within 2 minutes. Respiratory failure within 15 minutes.
1000	Immediately hazardous to life.

Effects from exposures to concentrations in the range of 50 to 450 ppm are irritation of mucous membranes, eyes, and the respiratory tract. Although hydrogen sulfide can be detected by smell in concentrations of less than 1 ppm, exposure to 100 ppm for 2 to 15 minutes and much shorter exposures at higher concentrations will deaden the olfactory nerves to the extent that hydrogen sulfide cannot be smelled at any concentration.

RISK OF CROSSING HARBOR AT 5TH

Based on 1987 and 1988 accident reports

10	accidents per year
0.5	serious injuries per year
2.5	moderate injuries per year
6	minor injuries per year

7000 vehicles on 5th crossing Harbor/day

Risk of accident	3.8x10-6/crossing
Risk of minor injury	2.3x10-6/crossing
Risk of moderate injury	10-6/crossing
Risk of serious injury	1.9x10-7/crossing

Assume the average person will go somewhere twice per day which takes them across Harbor on 5th. This results in 1460 crossings per year.

Risk of accident	5.5x10-3/year
Risk of minor injury	3.4x10-3/year
Risk of moderate injury	1.5x10-3/year
Risk of serious injury	2.8x10-4/year

APPENDIX VOLUME 3

Appendix A

Subsequent State Lands Commission October 18, 1990 letter of comment

Subsequent UNOCAL October 24, 1990 letter of response

STATE OF CALIFORNIA

GEORGE DEUKMEJIAN, *Governor*

STATE LANDS COMMISSION

LEO T. McCARTHY, *Lieutenant Governor*
GRAY DAVIS, *Controller*
JESSE R. HUFF, *Director of Finance*

EXECUTIVE OFFICE
1807 - 13th Street
Sacramento, CA 95814

CHARLES WARREN
Executive Officer

October 18, 1990

RECEIVED
OCT 22 1990
CITY OF OXNARD
COMMUNITY DEVELOPMENT

Mr. Ralph Steele
City of Oxnard
305 West Third Street
Oxnard, California 93030

RE: PLATFORM GINA/MANDALAY

Dear Ralph:

On September 27, 1990, we received a copy of William W. Weldon's August 10, 1990 letter to Dwight E. Sanders. Mr Weldon was responding to the State Lands Commission's comments on the "Draft Initial Study for Platform Gina Proposed Return Line Replacement and Conversion to Produced Gas." As we understand the circumstances, the letter was sent to you, by Union, on August 10, 1990, for inclusion and response in the City's proposed Negative Declaration (ND) for the project.

Staff has reviewed the letter and offers the following comments to you and Union, as you finalize the ND:

1. Union's comment #1 addresses self burial of the new line and states: "Should the pipeline have failed to reach two feet of burial at the end of two years Union will bury the line with hydraulic jetting to between two to four feet below the sand bottom."

   We believe that the new line should bury itself or be buried to a minimum of 3 feet within 2 years of completion of construction. Union's Project Description should be revised to reflect this requirement.

2. The Commission originally asked that the abandoned line be filled with concrete and cut off at 15 feet MLLW.

   The State Department of Fish and Game has expressed concern over the potential adverse effects to the sea bottom which could result if the line was removed. Staff therefore concurs with Union's proposal to cut the line off at MLLW provided that:

a) The abandoned line is pumped full of concrete for its entire 2,300 foot length to stabilize it in a buried condition; and

b) Union agrees that this abandonment does not constitute permanent abandonment of the old water line, and understands that the removal of this water line may be required when the 10 5/8" line is taken out of service.

3. Unocal's pipeline "as built" survey drawings prepared by Land and Sea Surveys, Inc. (October 1981), shows an average horizontal separation of over 3 feet between the existing oil and water lines. Union should confirms that this line is indeed tied to the adjoining 10 5/8" oil line and whether that separation exists. Also, is there continuity of cathodic protection between these lines at this time?

4. Unocal should be required to inform the Commission of what construction vessel is selected and submit a complete pipeline pulling operations plan for its approval prior to the start of construction;

5. Unocal should be required to submit complete set of construction contract documents, including engineering design, construction drawings and execution plan specifications to the Commission prior to the start of construction. A complete list of the required documentation, provided to Unocal earlier, is attached ("Lease Amendment Conditions Pertinent to Unocal's 6-5/8" Pipeline Repair and Conversion").

6. Finally, we are concerned that actual production parameters may require changes to the proposed safety systems governing the pipelines, including those to processing facilities on the platform (Item 6, page 3). For example, larger compressors may be installed to increase the gas pressure in the pipeline, or additional sweetening equipment may be required to handle higher than expected H_2S concentrations. Therefore, the Commission will need to review all future modifications to any safety systems.

We hope these comments are helpful in the finalization of the ND for this project. If you have any questions, please contact me at (916) 322-7829.

Very truly yours,

DANIEL GORFAIN
Division of Research
and Planning

Enclosure

cc: William W.Weldon, UNOCAL
Chris Culver, UNOCAL

LEASE AMENDMENT CONDITIONS PERTINENT TO UNOCAL'S 6-5/8 INCH PIPELINE REPAIR AND CONVERSION

1. LESSEE shall allow LESSOR's staff and/or LESSOR's consultant open and nondiscriminatory access to the pipeline repair and conversion project for the purposes of monitoring and inspection of the construction and related operations. LESSEE agrees to compensate LESSOR for all of LESSOR's staff and/or consultant costs associated with the engineering review, monitoring and inspection of the subject project. LESSOR shall bill LESSEE for such staff costs quarterly; the costs shall be paid within sixty (60) days after the billing date. LESSEE shall be entitled to audit LESSOR's records for such costs subject to providing a written request to audit with reasonable advance notice.

2. LESSEE shall provide temporary field office space on or in close proximity to the project construction site for LESSOR's staff use during the period of the project. The office shall be furnished for staff use and shall be supplied with electric power, light and telephone service. All costs associated with the provision of such field office shall be borne by LESSEE.

3. LESSEE shall provide LESSOR with copies of certified reports of all tests conducted by LESSEE or his appointed agent that verify the structural integrity and safety of all elements of the construction.

   Such reports shall be provided to LESSOR promptly as they become available to LESSEE during the course of the project and they shall include but not be limited to:

   a. pipe manufacturer's mill tests to certify that the pipe supplied meets the project's structural and dimensional specifications.

   b. tests qualifying the application of the XTRU polypropylene corrosion coating, the concrete weight coating and the cathodic protection anodes, including their attachment to the pipe.

   c. test results qualifying the pipe welding procedure.

   d. test results qualifying project pipeline welders.

   e. non destructive examination results of all welds, weld repairs and cut-out rewelds made on the pipeline including appurtenances (flanges, fittings, connectors etc.). LESSOR's staff shall be provided timely and unrestricted access to review all pipeline weld radiographic examinations.

   f. manufacturer's report certifying the PLIDCO subsea fitting to be used on the project.

g. results of all hydrotesting or other pressure testing procedures conducted on the pipeline together with a certified analysis of each test's results.

h. any other reports or information requested by LESSOR related to the project when requested by LESSOR.

4. LESSEE shall provide LESSOR with written notice at least five (5) days in advance of any pressure test to be conducted on the pipeline.

5. The replacement pipeline shall be buried under a minimum four (4) feet of sand cover across the beach area and seaward to where the water depth is at least minus fifteen (-15) feet below mean lower low water (MLLW).

   The replacement pipeline shall be placed so that a lateral separation of at least three (3) feet is maintained from any portion of the original (replaced) pipeline that may be left in place.

6. In the event that LESSOR's staff determines that the work being performed is not in conformance with the project plans and specifications, with LESSOR's rules and regulations and generally accepted industry codes and standards governing the integrity and safety of the construction, or with any of the conditions set forth in this lease amendment, LESSOR's staff may immediately order, either orally or in writing, a redirection or suspension of a specific activity until LESSOR is assured that the non-conformance issue is resolved. If such redirection or suspension can be shown by LESSEE to be potentially threatening to life, health or safety, the required corrective action may be temporarily deferred but shall be implemented as soon as the potential threat is past.

7. LESSEE shall submit for LESSOR's review and approval all contract changes affecting the design and/or construction of the project before such changes are implemented.

8. LESSEE shall make both an internal and external inspection of that portion of the pipeline on STATE tide and submerged lands at least once a year following the completion of the pipeline repair project. The internal inspection shall include running an inspection tool through the pipeline. The external inspection shall be by side scan sonar or other technique acceptable to LESSOR to identify all exposed portions of the pipeline. Should the external inspection show any signs of excessive free-spanning or other potential hazard to the pipeline as determined by LESSOR, further detailed inspection of the pipeline shall be made by LESSEE and any needed corrective action shall be taken as expeditiously as possible.

LESSEE shall make additional internal or external inspections if so directed by LESSOR whenever LESSOR determines that such inspections are warranted by any unsafe or emergency conditions.

Copies of the results of all internal and external inspections including reports, analyses and recommendations prepared by or for LESSEE shall be submitted promptly to LESSOR.

9. LESSEE shall monitor the corrosion control cathodic protection system of the pipeline as follows:

   (a) the entire system shall be tested at least once a year to determine that the system meets its designed protection criteria and the cathodic protection requirements of Title 49 CFR, Part 192, Section I - Requirements for Corrosion Control.

   (b) each cathodic protection rectifier or other power source shall be inspected at two (2) monthly intervals to ensure that it is operating satisfactorily.

   (c) LESSOR shall be promptly notified of any deficiencies indicated by the monitoring and any needed remedial action shall be taken as expeditiously as possible.

10. LESSEE shall conduct semi-annual maintenance inspections to test the satisfactory operating condition of each pipeline valve that might be required during any emergency condition. Any deficiencies discovered during such semi-annual inspections shall be corrected as expeditiously as possible. LESSEE shall provide LESSOR with a written report of each semi-annual inspection. The report shall describe any deficiencies discovered and the remedial action taken.

11. LESSEE shall provide LESSOR an "as-built" report within one hundred and twenty (120) days after completion of construction. This report shall include the results of a survey of the route of the pipeline and pertinent maps and text indicating any debris, potential hazards or changes to the seafloor that may have occurred during installation. Hazardous debris shall be removed and other concerns shall be mitigated as specified by LESSOR's staff. Such "as-built" report shall consist of map(s) with grid references (Lambert and Latitude-Longitude coordinates) for all turning points in the line, beginning and end points, and other pertinent data as may be required by LESSOR's staff. LESSEE shall submit a certified declaration by a licensed engineer or licensed surveyor indicating that the improvements are accurately located and depicted on the map(s).

12. With respect to the three thousand (3,000) feet of the original 6 5/8 inch pipeline that is to be replaced, LESSEE shall have the option of:

(a) removing the entire 3,000 feet of the original pipeline, following which the beach and seafloor areas in which the pipeline lay shall be restored as nearly as possible to their original condition; or

(b) the portion of the original pipeline to be replaced shall be removed from its onshore end to a depth of minus fifteen (-15) feet below mean lower low water (MLLW) and the remaining portion of the original pipeline left in place shall be filled with concrete for its entire length and it shall be capped with one quarter (1/4) inch steel cover plates welded onto each end.

13. LESSEE shall furnish LESSOR a yearly report detailing the volume of gas or other fluid transported through the pipeline and an analysis of the gas or fluid content, especially the presence and concentration of any corrosive elements such as hydrogen sulfide (H_2S).

14. LESSEE shall assume full responsibility for keeping informed of and being in compliance with all Federal, State, and local laws, ordinances and regulations which in any way govern the execution of the project. LESSEE shall ensure that LESSEE's employees and LESSEE's agents and their employees shall observe and comply with all such regulations.

LESSEE shall protect, indemnify and in all respects hold harmless LESSOR and all LESSOR's staff and/or consultants against any claim or liability from any source or cause whatsoever arising from the execution of the project.

Unocal North American
Oil & Gas Division
Unocal Corporation
2323 Knoll Drive, P.O. Box 6176
Ventura, California 93006
Telephone (805) 650-4505

UNOCAL 76

Hugh H. Herndon
District Land Manager

October 24, 1990

Mr. Daniel Gorfain
State Lands Commission
1807 13th Street
Sacramento, CA 95814

RE: PLATFORM GINA/MANDALAY
Offshore/Ventura Co., Calif.
Pipeline Conversion and
Repair (3246)

Dear Mr. Gorfain:

Reference is made to your letter dated October 18, 1990 and our subsequent phone conversations whereby the State Lands Commission offered certain comments to the City of Oxnard's proposed negative declaration. Although the comments were received after the close of the comment period on the draft negative declaration, we are comfortable and willing to address the comments at this time. The purpose of this letter is to serve as clarification to your written comments and will be included in the Initial Study as a part of the appendix. The comments below are in the same order as your October 18, 1990 letter.

1) Union will bury the new line to a depth of three feet after two years from the completion of construction should the line fail to do so, during that period under natural conditions.

2) Union agrees to pump the abandoned section of the line with concrete and understands that the line may potentially have to be removed, when the 10-5/8" line is removed from service. You should note that under EIR 78-19 the lines were to be abandoned in place.

3) As a point of clarification the October 1981 "As Built" Survey prepared by Land & Sea Surveys is correct. This survey covers the pipeline from the Mandalay wall to the present high water mark. The lines are banded together from the mean high tide line to Gina and not in the section covered by the October

1981 survey. The 6-5/8" line was repaired in 1985 and the "As Built" Survey dated December 1985 by Land & Sea Surveys shows the current location of the pipelines above the current high water mark.

4) This request is acknowledged and should be a condition of approval. Obviously at this time Union has not arranged for a construction vessel.

5) This request is acknowledged and should be a condition of approval. Contractual construction documents, etc. have not been created as of the date of this letter.

6) To clarify the statements made in my letter dated August 10, 1990 to Dwight Sanders, the pipeline safety systems will not change in later years.

Gas compression will be used to maintain pressure and volume at the level previously described and not to increase pressure. Operating pressure is expected to be 500 psi, and maximum allowable operating pressure will be 600 psi. This is listed on page 15 of the "Unocal, Platform Gina to Mandalay Facility 6-5/8" Pipeline Repair & Conversion - Revision 1" dated December 1989. Should pressure and line volume decrease from the operating pressure due to well depletion, compression may be used at that time to boost pressure to the original 500 psi operating pressure.

Regarding H_2S concentrations, Union will sweeten the gas to sales quality of less than 4 ppm H_2S at the platform prior to entering the line. The pipeline condition regarding H_2S concentration will remain at less than 4 ppm throughout the project. Please remember that there are two monitors prior to the gas entering the line and one at the facility that are set to shut down for any H_2S concentration greater than 4 ppm. Therefore, conditions of pipeline pressure and pipeline H_2S concentration will remain constant, not requiring a change in the safety systems.

Very truly yours,

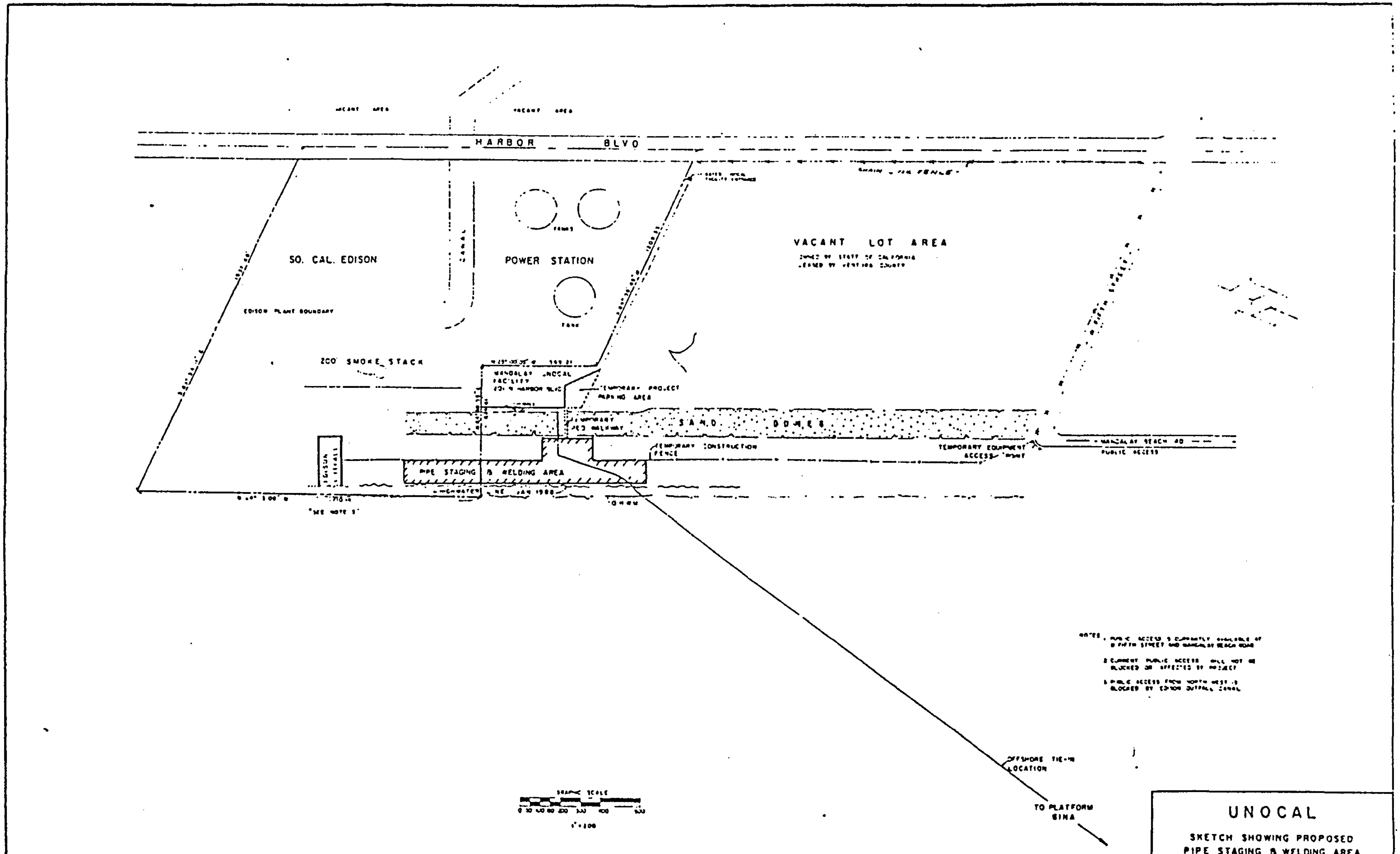
UNION OIL COMPANY OF CALIFORNIA

William W. Weldon

William W. Weldon
Landman

WWW:ka

cc: Ralph Steele, City of Oxnard
Carol Waldrop



LAND & SEA SURVEYS INC.

UNOCAL

SKETCH SHOWING PROPOSED PIPE STAGING & WELDING AREA AND MANDALAY FACILITIES

VENTURA, COUNTY CALIFORNIA

OCTOBER 1990 SCALE 1"=200'

PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

APPENDIX VOLUME 4

UNOCAL 76

APPENDIX VOLUME 4
ITEM A

Self-Burial Study

MINERALS MANAGEMENT SERVICE
PACIFIC OCS REGION
RECEIVED
FIELD OPERATIONS
LOS ANGELES

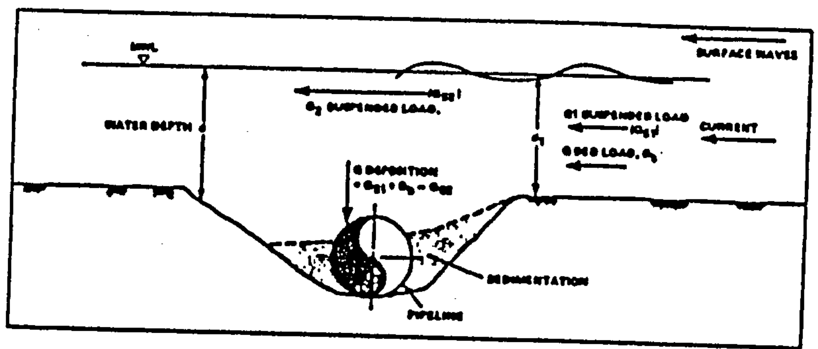
APPENDIX VOLUME 4
ITEM A

Not Proprietary

Self-Burial Study

Section

EVALUATION OF THE POTENTIAL FOR SELF-BURIAL OF THE PROPOSED UNOCAL GINA PIPELINE



* NATURAL BACKFILLING AT A PRE-DREDGED PIPELINE TRENCH

BY

JOEL B. FARRIER

MOSTAFA A. FODA

ROBERT G. BEA

HYDRAULIC AND COASTAL ENGINEERING DIVISION
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY

MAY 1989

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Executive Summary:

The problem of pipeline self-burial in cohesionless soils under steady and unsteady flow conditions is complex. The quantifiable interactions between structures, soils, and hydrodynamics in the ocean are difficult to calculate. The purpose of this report is to analyze these relationships for a 6-5/8-inch diameter pipeline to be laid off of Mandalay Beach, Ventura County (from Mandalay power station to platform Gina) for Unocal, Inc. Specifically of interest is the evaluation of how the pipeline will bury itself (hereafter, termed "self-burial") in the sandy bottom from the surf zone to a distance of 3000 feet offshore (~40 feet water depth).

Pipeline self-burial is composed of three important components: localized scour and deposition, regional scour and deposition, and soil liquefaction. Localized scour occurs through the hydrodynamic interaction of waves, currents, and soil due to the disturbance of flow by a pipeline. Regional scour occurs independent of the pipeline and is a function of the regional geography and the wave-current climate. Soil liquefaction is a special condition resulting from the interaction of waves and cohesionless soils and to a minor extent, the pipeline.

Since the purpose of this study is to determine the mechanism as well as the possibility of self-burial in the study

area, an annual storm is used to model design conditions. The currents and bottom velocities generated by the annual storm form a scour trench by localized scour mechanisms. This activity is followed by a period of calm whereupon the trench will fill by regional scour mechanisms. Regional deposition can bury the pipeline through bed level elevation increases. The arrival of an extreme event storm can cause sufficient liquefaction beneath the already buried pipeline to cause further settlement of the pipeline.

Localized scour is modelled based on work by Kjeldson (1973), Chao and Hennessy (1972), Herbich (1984), Bijker (1976), and Mao (1986). The possibility of regional offshore burial of the pipeline is explored by analyzing the historical records and applying appropriate predictions. Finally, soil liquefaction is explored as a potential mechanism for pipeline self-burial by analyzing the work of Bea (1981), Luque (1973), Yamamoto (1978), and Reddy (unpublished).

The results of the study show that the pipeline will probably bury initially from 1 to 1.75 pipe diameters within one week of the first annual storm following construction. Regional deposition will further bury the pipe due to the annual erosion of the beaches in the area and transport of the material offshore up to 0.2 feet in the first year. After an extreme storm, soil liquefaction can cause settlement of the pipeline up to a theoretical final depth of 10 to 15 feet, but will probably cause settlement to 2-4 feet within one to ten years.

This study was directed by Mr. Mike Craig, Senior Project Engineer, UNOCAL, Inc., Ventura, California. Data on pipeline self-burial experiments was provided by Dr. Vagner Jacobsen of the Danish Hydraulic Institute, Copenhagen, Denmark. Data on historic beach and offshore profiles for the Mandalay Beach area was provided by the Los Angeles District U.S. Army Corps of Engineers. Data on recent beach and offshore profiles was provided by Nobel Consultants, Inc. of Irvine, CA. Data on sidescan sonar surveys and the present pipeline location was provided by UNOCAL, Inc. These contributions to this study are gratefully acknowledged.

Introduction:

This report concerns the prediction of pipeline self-burial for a pipeline to extend from Mandalay Beach, Ventura County to Gina Platform in the Santa Barbara Channel. This study focuses on the possible mechanisms for the rate of burial and the final depth of burial for this pipeline. The gas pipe will replace an old water line which has undergone significant self-burial throughout its length.

Figure 1 is a location map of the old pipeline route. Figure 2 is a plan of the proposed new pipeline and an offshore bed profile of the study area.

This study included a comprehensive review of published and proprietary existing literature concerning self-burial of pipelines. The study also included a pipeline-seafloor-wave and current model study. This background was integrated into a final formulation and calculation of the depth of burial, with an estimation of the rate of burial.

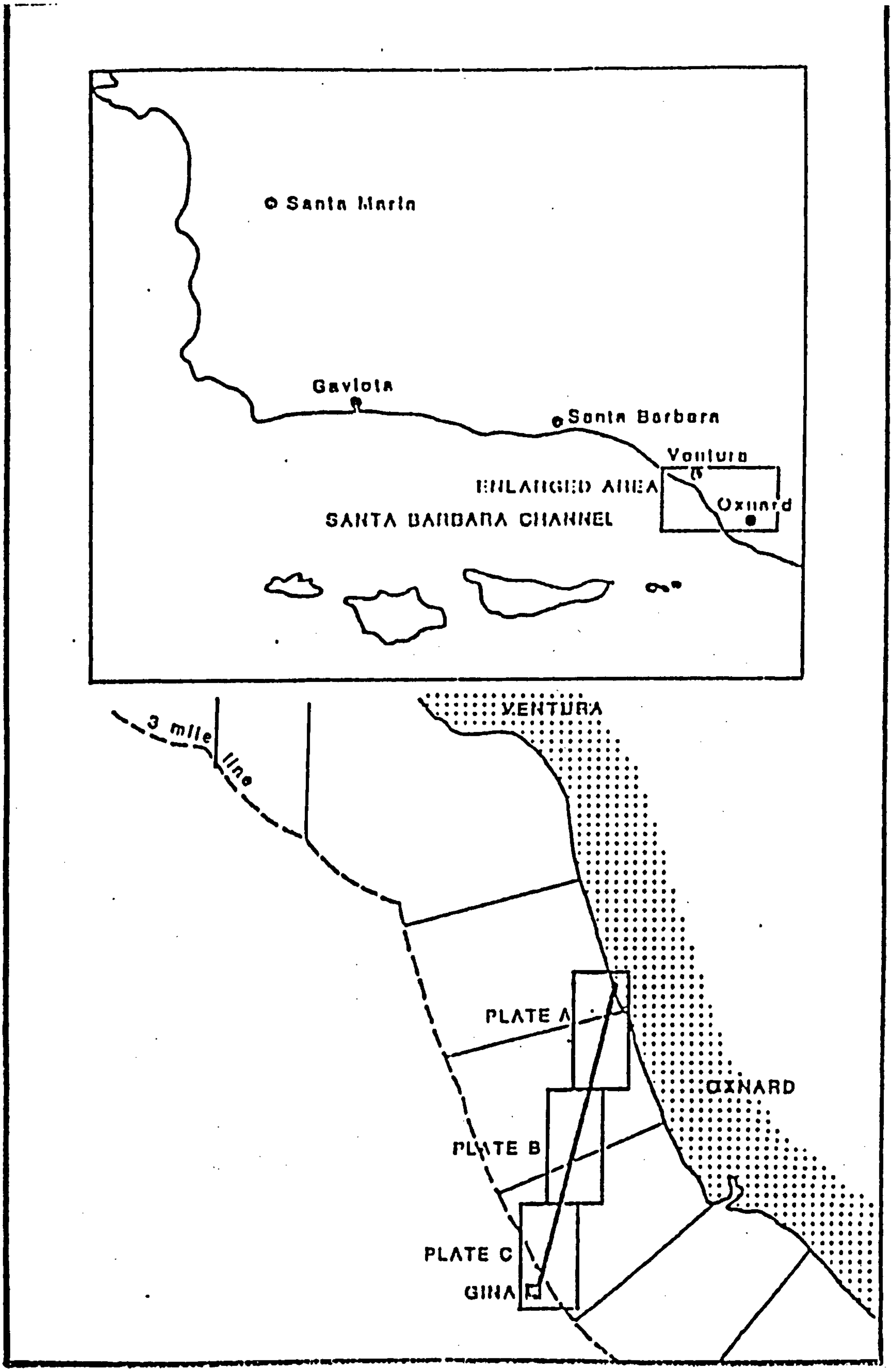


Figure 1: Location map and plan of old water pipeline.

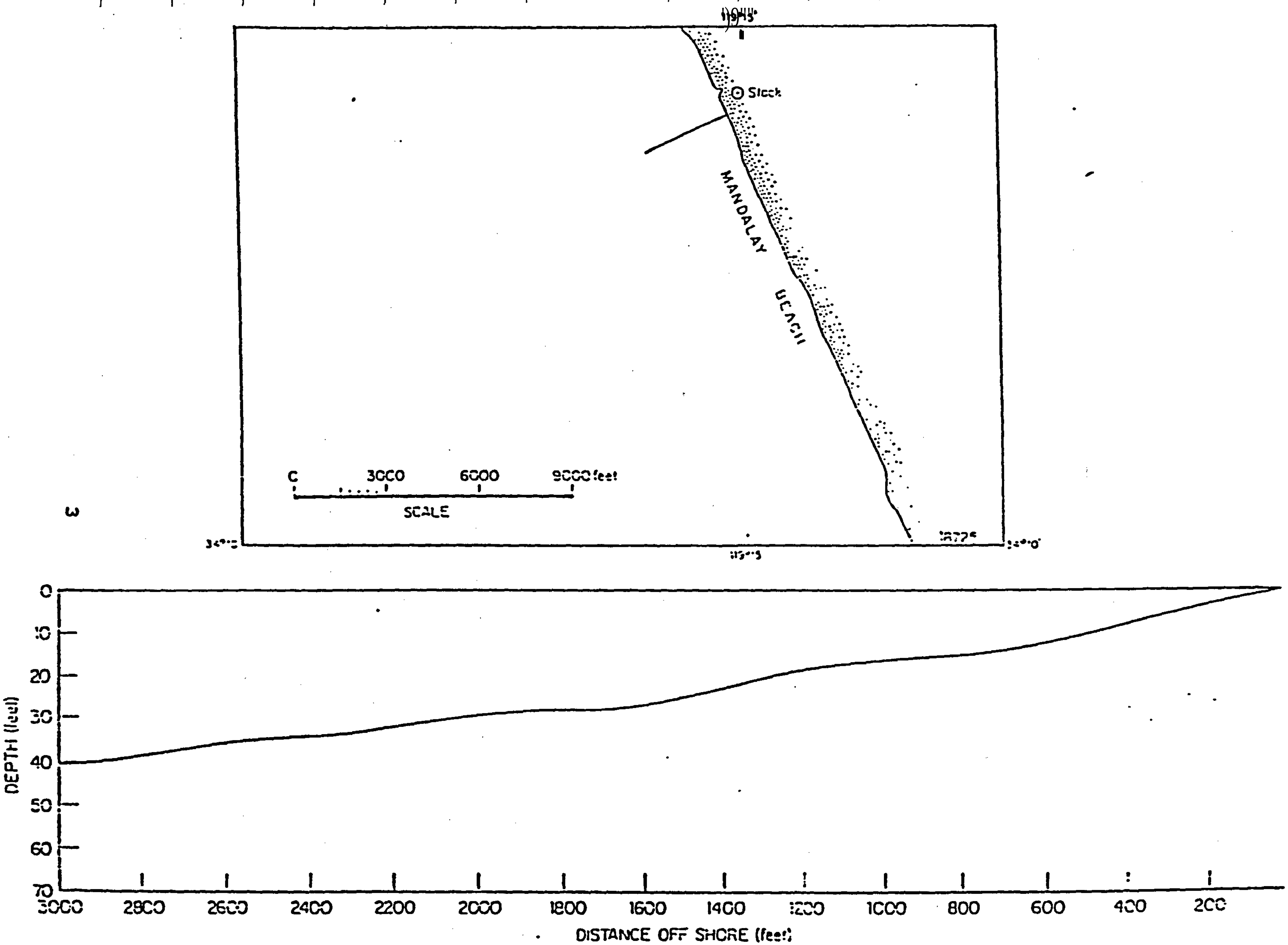


**Figure 2: Proposed pipeline location and an offshore profile.
(From Intersea Research Corp., 1980.)**

Literature Review:

The problem of pipeline self-burial is complex and not well understood. For the purposes of this study, self-burial can be attributed to three mechanisms that may account for burial separately or in combination. The first mechanism is localized scour and deposition which may be considered the initial phase. The second mechanism is regional scour and deposition. The third is soil liquefaction.

A. Localized Scour

1. Scour Due to Currents Only

(a) Pipeline on Surface of Bed

Localized scour is caused by the interaction of pipeline, waves and current, and cohesionless soils. The pipeline causes disturbances in flow which induce vortex shedding and increased flow areas that induce sediment particle lift and transport apart from normal regional movement of sediment particles.

Model experiments performed for this study at the University of California have shown that the initial stage of flow disturbance causes scour trench development on the wave-ward edge of the pipeline (see the beginning diagram of Figure 3). The wave-ward edge corresponds to the upstream of the current.

Researchers have generally agreed that a "tunnel-erosion" effect is induced after the initial trench formation. A gap is formed between the pipeline and the bed at various points along the pipeline length. Figure 3 demonstrates the formation of the gap and eventual sagging of the pipeline between sag spans into the scour hole. It is reasonable to assume the pipe will then become buried after sagging under a reduced wave climate. The following models assume an initial gap formation.

An analytical approach for estimating the scour around pipelines due to currents only has been developed by Chao and Hennessy (1972). The velocity field in the gap between a pipe and a solid boundary is derived from potential flow theory. The discharge through the scour hole is determined, and is combined with the friction factor for flat bed sand channels to calculate the boundary shear stress in the scour hole. Since the average jet velocity and boundary shear stress tend to decrease as the scour hole deepens, the maximum scour depth under the pipeline is obtained by

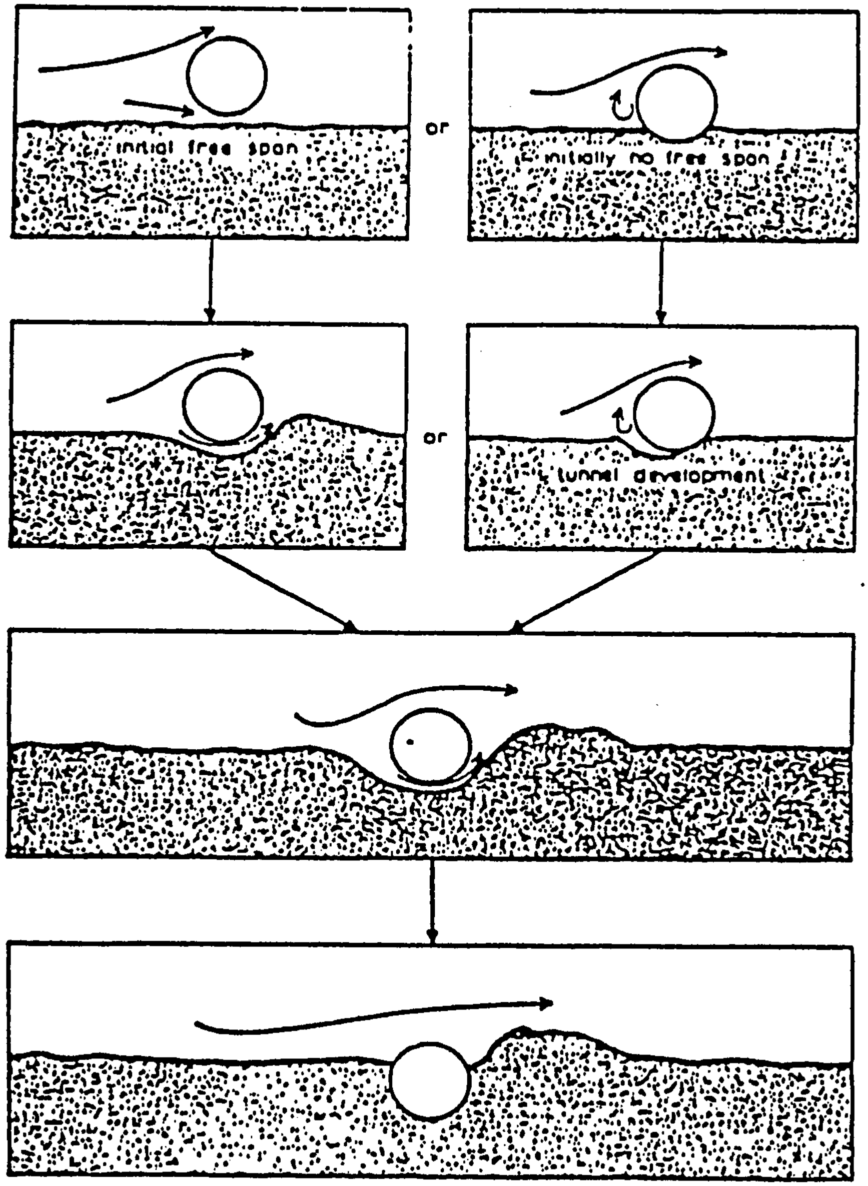


Figure 3: Schematic representation of tunnel-erosion.
(From Hulsbergen, 1984)

matching the calculated boundary shear stress with the critical tractive stress corresponding to the grain size of the seafloor sediments.

Herbich (1984) used the approach in a practical and simple method for scour prediction. Figure 4 gives the graphical component of this method. Figure 4a gives the bed friction factor versus Reynold's number and bed roughness. Figure 4b gives the critical bed shear stress versus sieve size through which 50% of the sand grains pass (hereafter referred to as the grain diameter).

(b) Partially Buried or Buried Pipelines

"Breakout" of buried or partially buried pipelines is a phenomenon where the pipe is scoured to the point that it appears to move rapidly from the sandbed. Analysis of this phenomenon is necessary for the present study to determine the potential for uncovering of the pipeline once it is already buried.

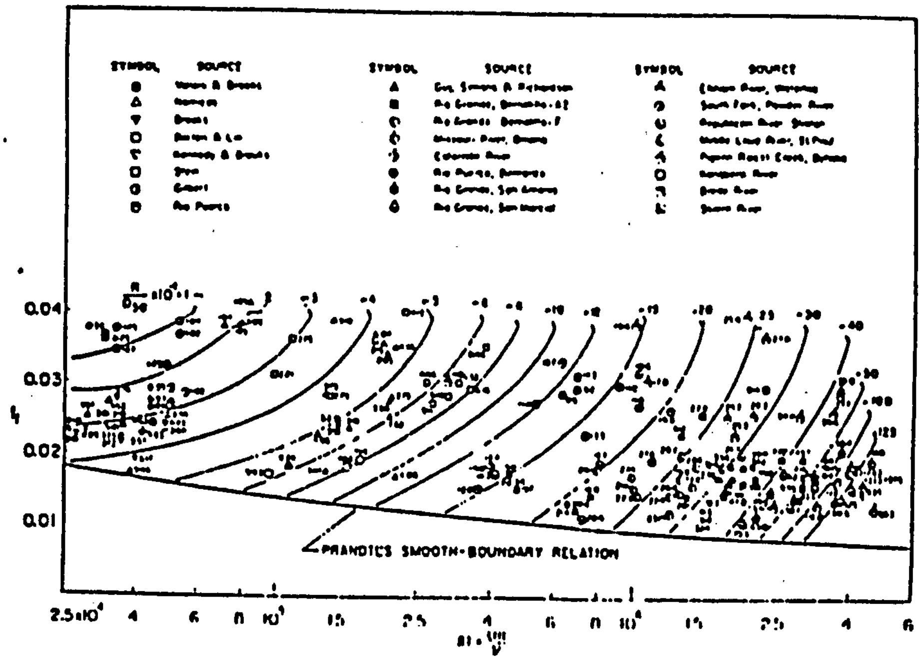


Figure 4a: Friction factor predictor for flat-bed flows in alluvial channels. (From Lovera and Kennedy, 1969.)

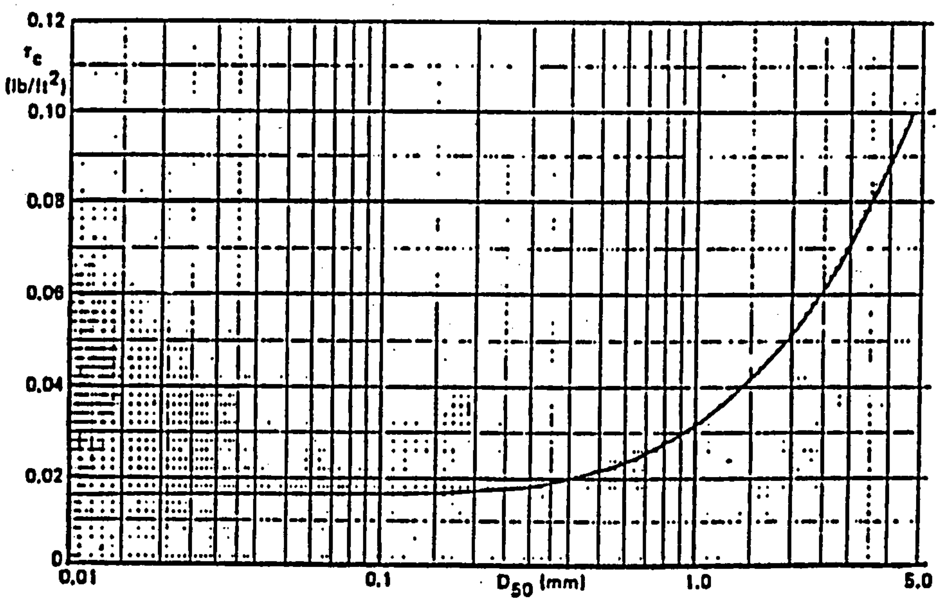
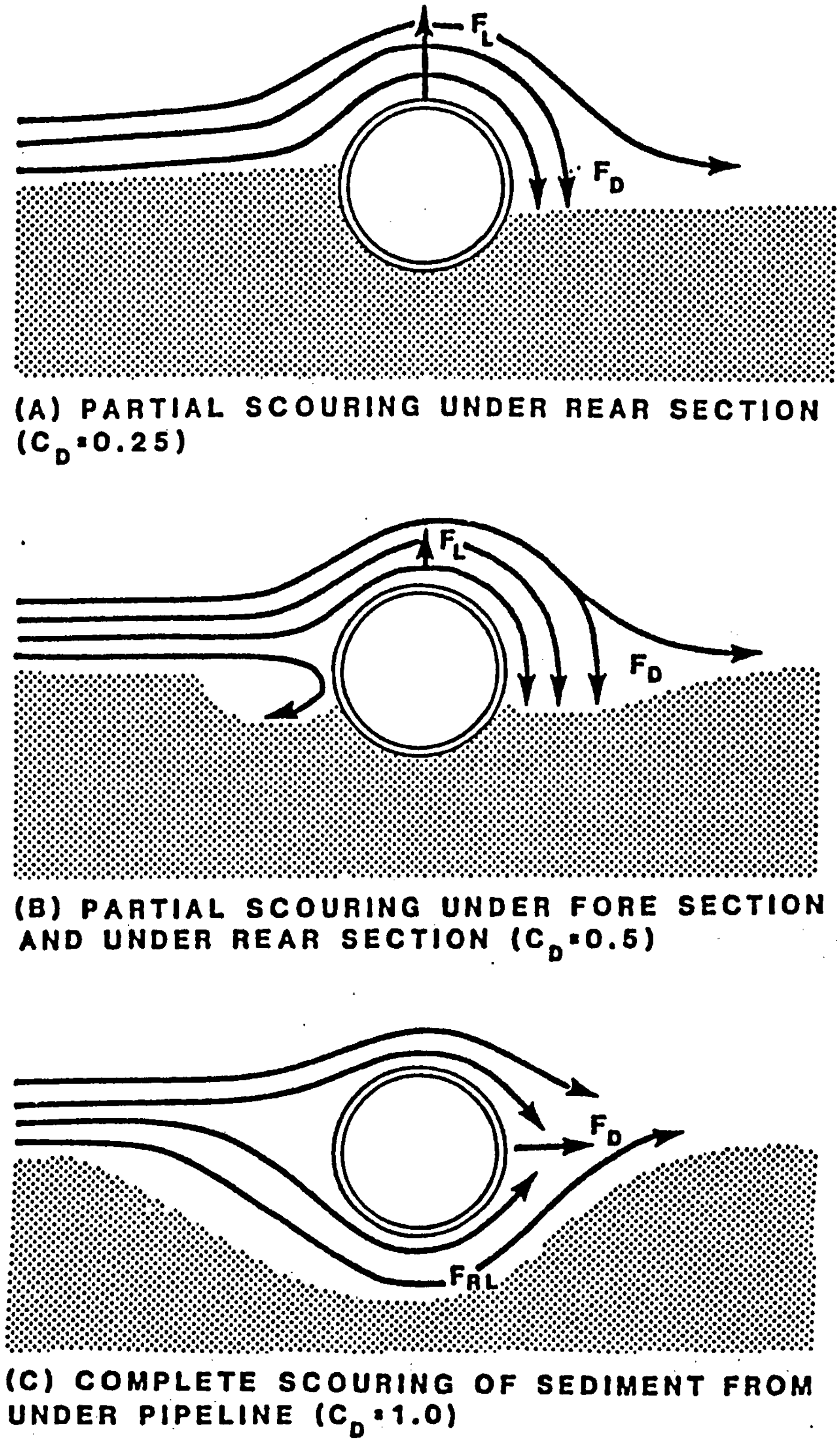


Figure 4b: Critical tractive stress versus grain size. (From Herbich, 1981.)

Townsend and Farley (1973) reported that the rate of scour around a buried pipeline increased locally after the bed had been eroded to the top of the pipe, and that scour would occur on both sides of the pipe. It was reported that the material under the pipe was suddently washed out when the bed level was scoured below the top of the pipe (Hjorth, 1975).

Blumberg (1966) suggests that the fluid velocity increases as the streamlines pass over the mound created by a partially exposed pipeline. The pressure reduction associated with the increased velocity of the water particles produces a lift force on the cylinder, while the direct pressure on the upstream side of the pipe and the pressure reduction on the rear side produce a drag force in the direction of the fluid flow. As the streamlines close behind the pipe, turbulence is generated at the fluid-seabed interface and scouring of the sediment occurs at the rear of the pipe, as illustrated in Figure 5a.

As turbulent flow begins occurring on the forward side of the pipe, partial scouring takes place both in front of and behind the pipeline, as shown in Figure 5b. The increase in projected area and drag coefficient associated with the shape



LEGEND:
F_L - LIFT FORCE
F_D - DRAG FORCE
F_{RL} - SOIL RESISTIVE FORCE
C_D - DRAG COEFFICIENT

Figure 5: Development of scour around partially buried pipeline. (From Blumberg, 1966)

produces an increased drag force. The lift forces are still generated and may pull the pipeline up from the sediment, if it is not sufficiently weighted.

If erosion around the pipeline continues, complete scouring of sediment from under the pipe will occur due to piping, at least in a local area, as shown in Figure 5c. When only a small amount of sediment is eroded from under the pipe, a reverse lift force will be developed, tending to pull the pipeline downwards. However, the development of a vortex trail behind the cylinder will probably prevent any stable downward forces due to the vortices being shed alternatively from each side of the cylinder.

Kjeldsen et al. (1974) examined scour patterns around pipes resting on the seabed or partly embedded in it. The generalized scour profiles near pipelines are summarized in Figure 6 for a completely buried pipe, two partially buried pipes and an unburied pipe. It was suggested that the local flow pattern and local turbulence are mainly responsible for the scour. The relative grain size was reported to have no influence, although the sediment used in the tests was limited to fine grain sizes. The equilibrium scour depth was found to depend primarily on the geometry of the structure

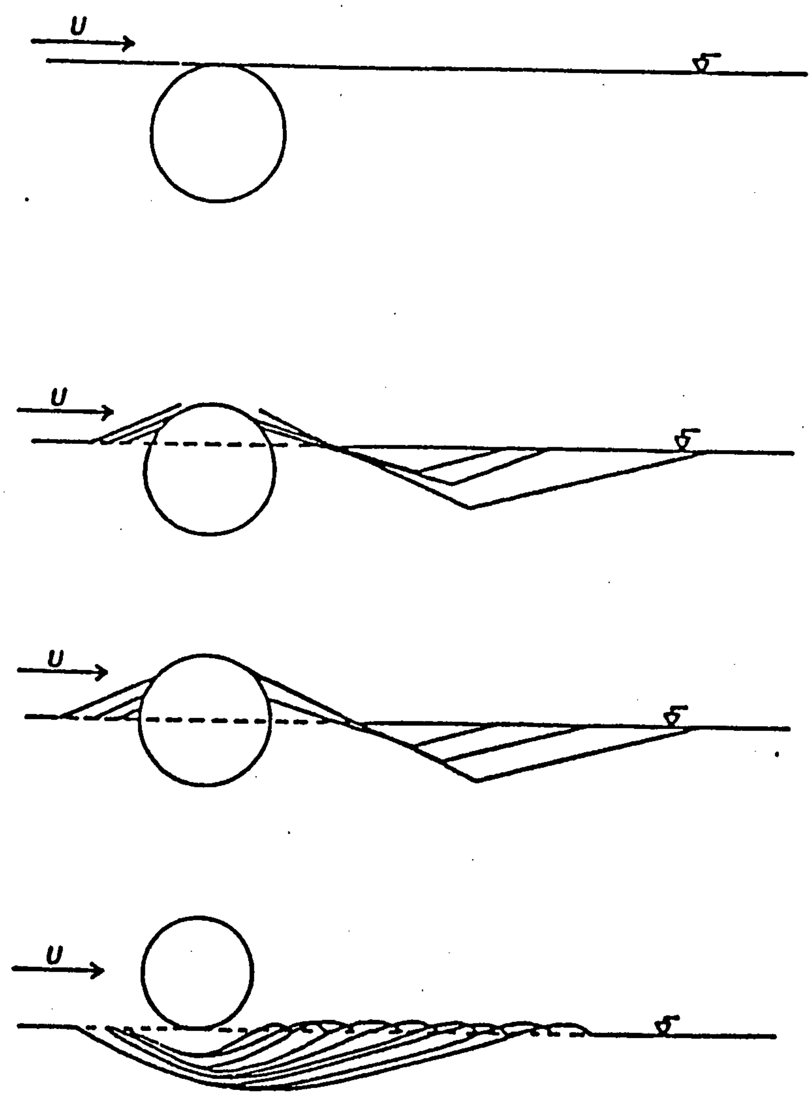


Figure 6: Generalized scour profiles near pipelines. (From Kjeldson, 1974.)

and to a small extent on the flow velocity. The risk of undercutting was small, if the pipe was initially embedded at least halfway in the sand.

Hjorth (1975) presented a theoretical analysis involving vorticity considerations and gave qualitative conclusions concerning the mean boundary shear for a partially exposed pipe. Since an analytical solution could not be derived, laboratory measurements were performed to examine the velocity and pressure distributions within the flow over the pipe. The results indicated that the initial undermining of a pipeline is caused by pressure gradients in the bed set up by the pressure difference between the stagnation zone upstream and the wake region downstream. The secondary flows cause a pressure increase upstream and a pressure decrease downstream. If the length of the pipe wall in contact with the bed is small, the pressure gradients may cause piping or severely reduce the bed resistance to other fluid forces.

The fact that the references concerning scour around a pipeline due to currents alone are nine years old or more indicates that the effect of currents was the primary concern in the earlier studies. More recent work, such as that by

Herbich (1977, 1981), and Mao (1986) considers the additional influence of waves on scour around the pipeline, as discussed in the following section.

2. Local Scour Due to Waves

(a) Unburied Pipelines

Scour around pipelines lying horizontally on the seabed and subjected to wave-induced oscillatory flow has received less attention than the situation of scouring due to currents. However, Carstens (1966) has examined the scour around horizontal cylinders due to oscillatory flow in a large U-shaped channel. It was found that scour always started at a point of localized scour under the pipe and extended laterally until the whole cylinder was undercut. The settlement of the cylinder into the scour hole was observed to take place in steps, as the scouring at both ends of the cylinder progressed laterally to the central support.

Contour maps of the scour holes indicated that their shapes were similar to the inverted frustum of a circular cone, with the side slopes equal to the angle of repose of the sediment. Under oscillatory flow, the net rate of sediment tranport into the scour hole is assumed to be negligible, so that the rate of change of the scour hole volume is equal to the rate of transport out of the scour hole. The actual sediment transport rate out of the scour hole was expressed in terms of the rate of change of scour hole volume based on the contour maps, and an empirical function for the sediment transport rate was derived from the experimental results in terms of the sediment number. By equating the two transport rates, an expression for the scour depth was derived in integral form and a functional relationship for the scour depth was suggested.

(b) Buried Pipelines

Herbich (1977, 1981) investigated the effect of storm waves on buried pipelines approaching the shoreline by means of laboratory measurements in a wave tank and a wave basin. It was found that the presence of the pipeline does not appreciably affect the beach profile, but in many cases, local scour occurs around the pipe due to pipe-sediment interaction. Burial of the pipe to a depth of one-half its diameter tended to produce significant scour until the pipe was uncovered, if the pipe was placed at a large angle to the wave crest.

Storm waves produce appreciable velocities at the seabed in shallow water and erosion or deposition of sediment produce changes in the beach profiles. The presence of the pipe itself triggers additional localized scour, and as the storm intensifies, the scour may progressively uncover or undermine the pipeline. Herbich (1977) suggests that buried pipelines approaching and passing through the surf zone should be located below the storm (or winter) beach profiles.

It is also suggested that no reliance should be placed on the pipeline being covered by natural processes, since the pipe may rise to the surface of the seabed, if the weight coating is not sufficient to overcome the buoyant force resulting from the dense sediment laden water which accumulates in the open trench. Instead, the trench should be backfilled with suitable material soon after the pipe has been placed in the trench. Herbich (1977) indicates that the depth of backfill should exceed the design burial depth to allow for settlement and consolidation of the backfilled material. However, this material will erode at a much faster rate than the sediment on either side of the trench if a storm should occur before the material has sufficient time to settle and consolidate.

To date, research on local scour due to waves and currents acting simultaneously on a horizontal pipeline has not been reported in the literature.

Bijker (1976) attempted a boundary layer and a potential flow explanation for his model of pipe scour in unidirectional and cyclic flows. This model assumed a velocity distribution between the bed and the pipe after the initial gap formation (see Figure 7). The flow through the gap forms a jet with a bed velocity roughly equal to the regional bed velocity. The bed velocity in the gap erodes the bed material faster than the regional bed erosion. Equilibrium is reached when the gap has expanded to the point that the bed velocity in the gap equals the regional bed velocity. Bijker included a wave and current reduction factor to account for effects of the bed form on the potential flow around the pipe.

3. Freely-Moving Pipelines

The phenomenon of pumping scour has been reported to occur for pipelines (personal communication, R.G. Bea). The scour mechanism apparently affects pipelines which are initially unburied, as well as those placed in a trench. The flow past a pipeline which has been undercut produces an oscillation of the pipe in a crossflow direction shown in Figure 8a. The upward motion of the pipe causes an inward flow beneath the pipe, and the subsequent downward motion produces an outward flow which removes sediment.

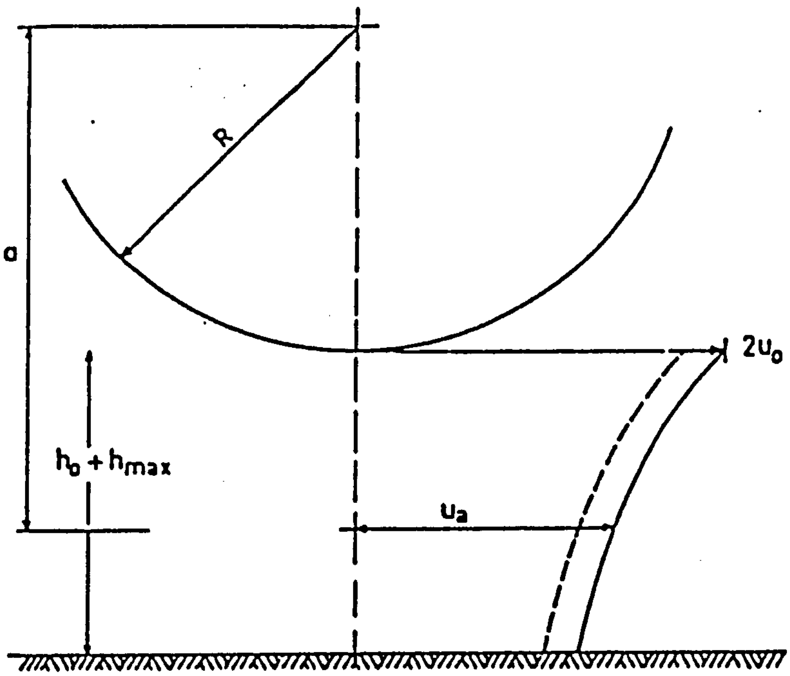


Figure 7: Velocity Distribution around a pipeline.
(From Bijker, 1976)

The resulting scour depth h_s below a pipe of diameter D varies as a function of the gap h_o between the pipe and the level of the seabed as shown in Figure 8b. The scour tends to approach zero for pipes suspended one diameter above or below the seabed and approaches a maximum for pipes laid directly on the seabed. A maximum scour depth of 2.5 pipe diameters is generally suggested for pumping scour around pipelines (personal communication, R.G. Bea).

Mao (1986) expanded the analysis to sagging and vibrating pipes. Through a series of well-documented experiments, the subcomponents of the scour process were analyzed. Mao also balanced the sediment transport into the scour trench with the sediment transport out of the trench for the determining condition of scour equilibrium. Mao used a modified bed load transport equation to account for local bedslope conditions. Appendix A contains Mao's results for a wide variety of experiments used in this report.

B. Regional Scour

Estimation of regional scour and deposition is covered extensively in the literature, but is by no means complete. Because there is a large dependence of regional scour on local geomorphology and sedimentology, historical analyses

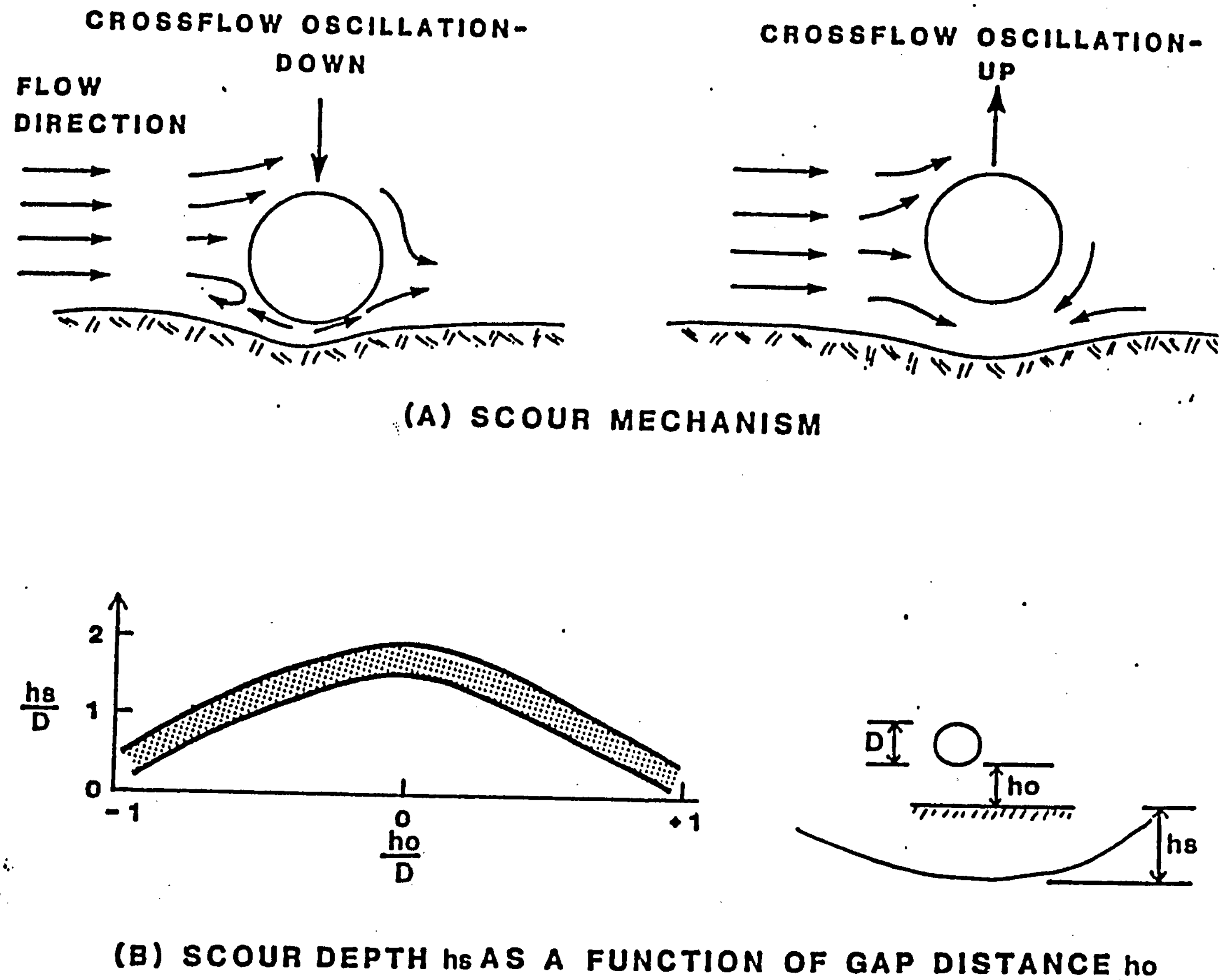


Figure 8: Pumping scour around pipelines.

are more accurate for scour prediction. Historical foreshore, nearshore, and offshore profiles of the Mandalay Beach area from the United States Army Corps of Engineers from the Ventura County BEACON study, and personal communications with Nobel Consultants, Inc. (see Appendix B) have provided the information necessary for this study.

C. Soil Liquefaction

The problem of wave-induced soil liquefaction is a relatively new field with little definitive information. However, the relation between shear strength of the soil, the wave-induced shear stresses in the soil, and the unit weight of the pipeline can be estimated to give a final burial depth for the pipeline after it has been initially covered. This estimation, however, will depend on the determination of pipeline flotation or settlement.

Bea (1981) gives a simplified method for liquefaction prediction in which the wave-induced shear stress within the soil layer is compared to the undrained shear strength distribution. Figure 9a diagrammatically shows the shape of a wave-induced shear stress distribution for a semi-infinite elastic continuum. Figure 9b shows a comparison of maximum wave-induced shear stress with soil shear strength. Above

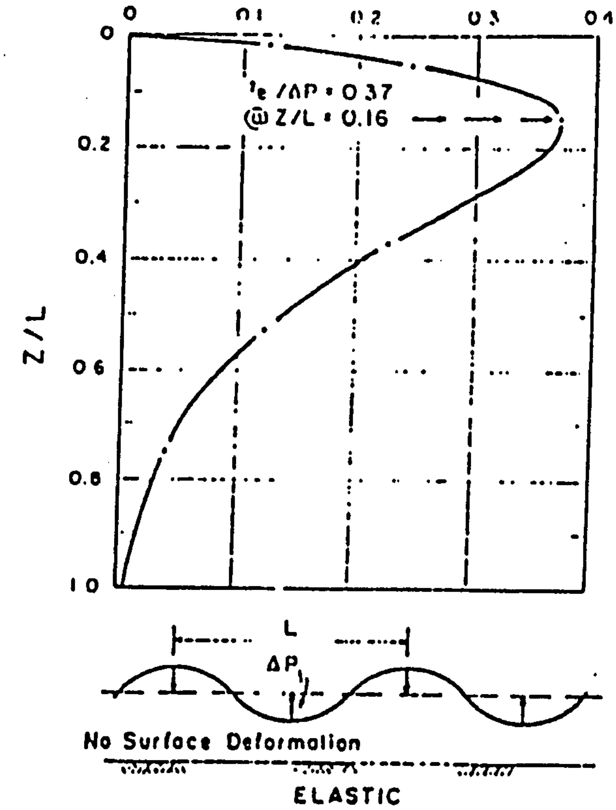


Figure 9a: Maximum shear stress versus depth for semi for semi-infinite elastic medium. (From Bea, 1981)

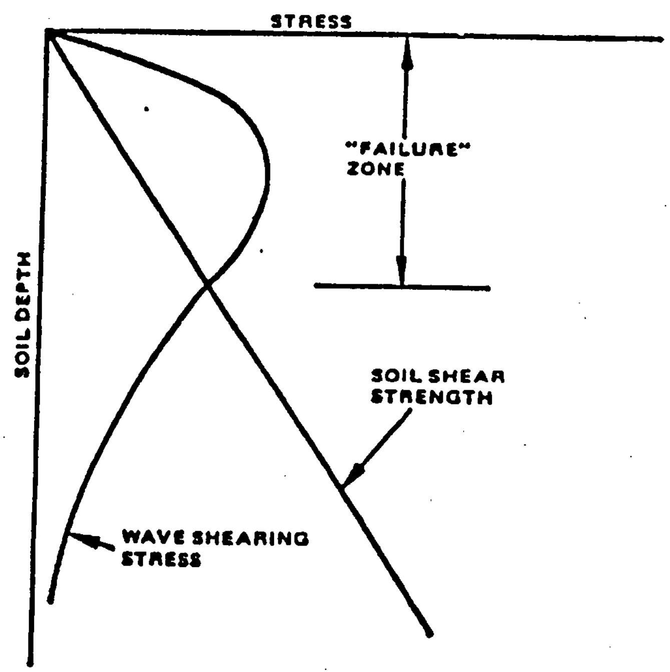


Figure 9b: Comparison of maximum wave-induced shear stress with soil shear strength. (From Doyle, 1973)

the soil depth where the shear stress exceeds the shear strength, liquefaction is essentially induced. The depth limit occurs at the intersection of the two distributions. Bea's model is extremely sensitive to the wave height and therefore accurate predictions of wave heights in the area concerned is necessary.

Yamamoto (1978) predicts smaller depths of liquefaction using a complex theory. Luque's theory, similar to Bea's method, utilizes a soil mechanics approach and predicts much larger depths of liquefaction. All models predict a similar shape to the wave-induced shear stress distribution.

Alternative Computation Methods for Scour Prediction:

A. Pipelines

1. Local Scour Due to Waves and Currents

Computational methods for estimating the scouring of pipelines by simultaneous waves and currents have not yet been reported in the literature. However, the scour depth under a pipeline subjected to waves can be estimated from 1) an empirical method presented by Carstens (1966), or 2) an analytical theory developed by Bijker (1976). The equlibrium scour depth under a pipeline subjected to currents can be estimated using 1) an analytical approach developed by Chao and Hennessy (1972) 2) an empirical formula based on laboratory tests by Kjeldsen et al. (1973), or 3) an analytic method and experimental results reported by Bijker (1976). The methods presented by Bijker (1976) are applicable to pipelines which are initially suspended, unburied or partially buried while the other techniques only consider the pipeline to be initially resting on the seafloor. The documentation of the available scour estimation methods for pipelines is presented below for the conditions of waves only and currents only, as shown in Figure 10.

B. Waves Only

1. Carstens (1966)

Localized scour around horizontal cylinders in oscillatory flow was investigated by placing three aluminum cylinders with diameters of 8.76, 4.32, and 2.54 cm (3.4, 1.7, and 1.0 in) on a bed material of 0.297 mm diameter glass beads in a large U-shaped channel. The scour depth function was related to a sediment number N_S defined as:

$$N_s = \frac{U_1}{\sqrt{(s-1)gd}}$$

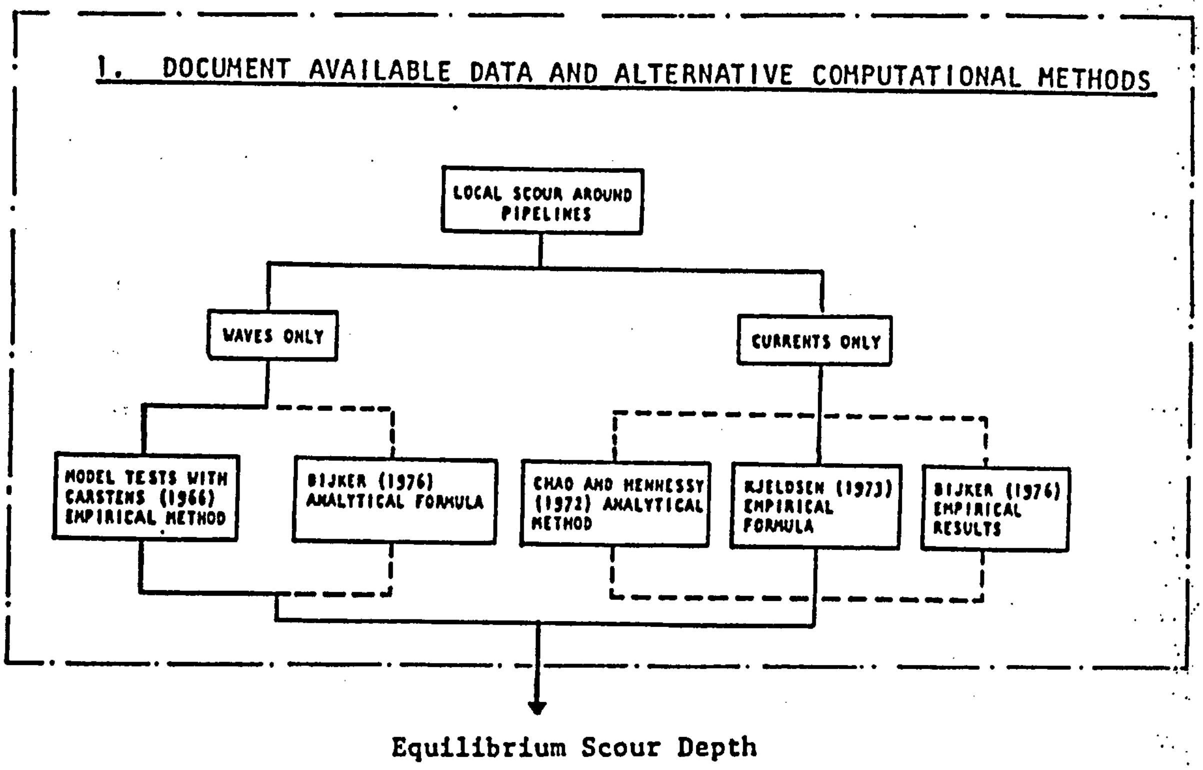


Figure 10: Alternative computational methods for local scour around pipelines.

where U_1 is the maximum velocity in the oscillating flow

s is the specific gravity of the sediment

d is the geometric mean grain diameter

The functional relationship was expressed in the form

$$\frac{S}{L_c} = f[(N_s^2 - N_{sc}^2)^{5/2} \ \frac{d}{L_c} \ \frac{U_c t}{L_c}]$$

where L_c is a characteristic length

U_c is a characteristic velocity

t is time

N_{sc} is a zero transport sediment number which must be evaluated from model tests for any given situation of localized scour.

It is not possible to quantify the sensitivity of the estimates for scour depth to variations in all parameters, since the form of this functional relationship is not yet known.

A minimum of two model tests is required to apply this similarity relationship to a given situation of localized scour. The first test is an empirical determination of the sediment number with zero transport N_{sc} and the second test is an empirical determination of the right side of the above equation.

2. Bijker (1976)

The details of this method are presented by Van Ast and De Boer (1973) in a Masters thesis (in Dutch) at Delft University of Technology. Bijker (1976) presents the results of the study with a brief outline of the approach. It is assumed that the flow approaching the pipe divides into a flow underneath and over the pipe along a line of division which lies in the middle of the portion of the pipe protruding above the seabed, as shown in Figure 10A. The velocity distribution around the pipe is expressed as:

$$U_a = U_o\left(1 + \frac{R^2}{a^2}\right)$$

where U_a is the velocity around the pipe

a is the distance from the center of the pipe

R is the radius of the pipe

U_o is the orbital at the bottom, which is approximately constant over the height of the pipe

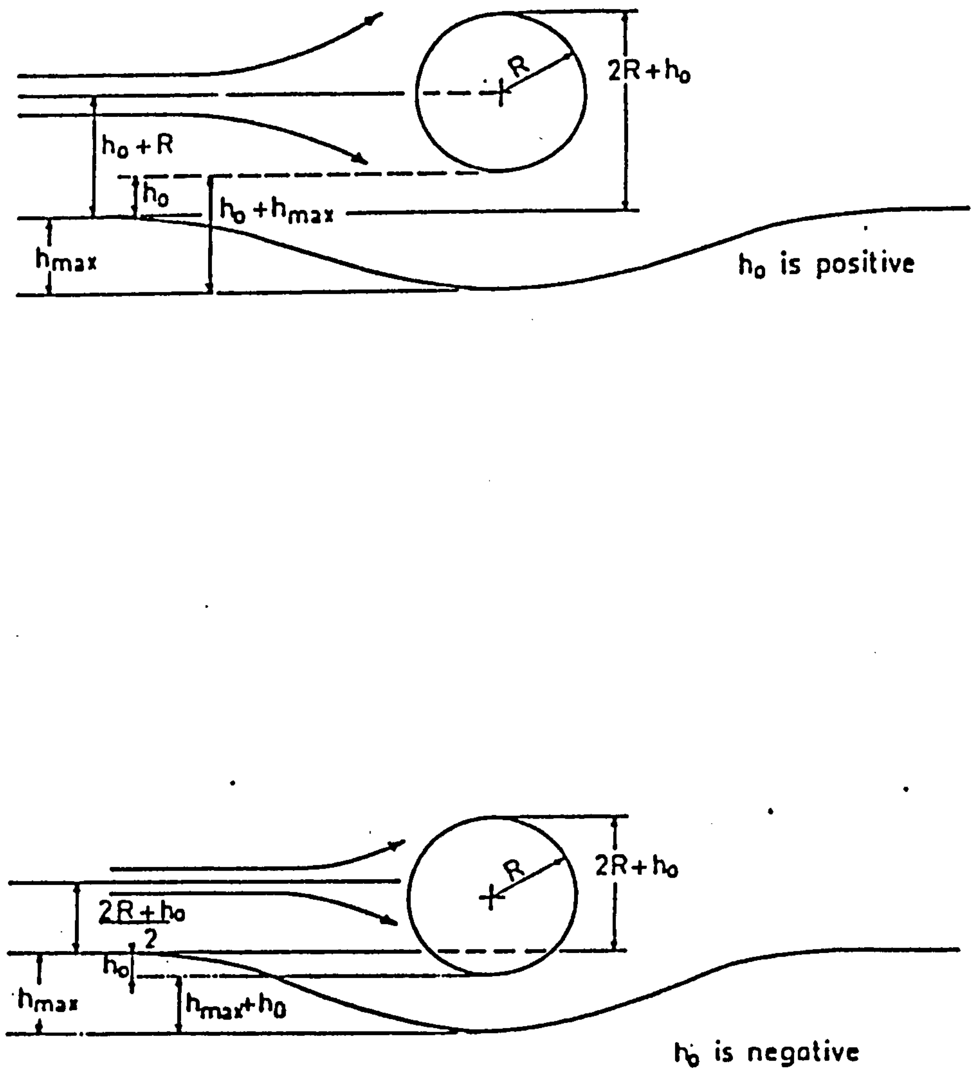


Figure 10A: Flow pattern around pipelines. (From Bijker, 1976)

For the equilibrium situation, the bed shear underneath the pipe must be equal to that outside the area influenced by the pipe. Since the boundary layer is determined by the combination of viscous, turbulent and inertia effects, it is assumed to be the same both in front of and underneath the pipeline. Based on the velocity distribution shown in Figure 7, the velocity just outside the boundary layer under the pipe is:

$$U_B = U_o\left\{1 + R^2/(h_o + h_{max} + R)^2\right\}$$

Since this velocity must be equal to U_o, the velocities under the pipeline are decreased by the value U_t, defined as:

$$U_t = U_o\left\{1 + R^2/(h_o + h_{max} + R)^2\right\} - U_o$$
$$= U_o R^2/(h_o + h_{max} + R)^2$$

Van Ast and De Boer (1973) use the assumed distribution of flow around the pipe to derive an expression for the scour depth $(h_o + h_{max})$.

By defining $(h_o + h_{max}) = S$ and $(h_o + R) = B$, the resulting expression can be written as:

$$S^3 + S^2 (3R - B) + S (R^2 - 2BR) - BR^2 = 0 \quad \text{for } H_o > 0$$

$$S^3 + 2S^2R - SR^2 - R^3 = 0 \quad \text{for } H_o = 0$$

$$S^3 + S^2 (5R - B)/2 - BRS - (R^3 + BR^2)/2 = 0 \quad \text{for } h_o < 0$$

The scour depth estimate is insensitive to soil and oceanographic conditions, and depends only on the radius of the pipeline.

The results of tests conducted at the Hydraulics Research Station and Delft University of Technology are shown in Figure 11 and compared with computations based on the above equations. A reasonable agreement is obtained between the computations and the experiments.

C. Currents Only

1. Chao and Hennessy (1972)

The analytical approach considers a steady current flowing perpendicular to the longitudinal axis of a pipeline initially resting on the seafloor. The scour hole is assumed to be two dimensional so that no end effect is imposed on the flow field. The maximum scour takes place below the centerline of the pipe, but the upstream and downstream slopes of the scour hole are so gentle that the curvature effect can be neglected. The velocity field in the scour hole below the centerline of the pipe is assumed to be horizontal.

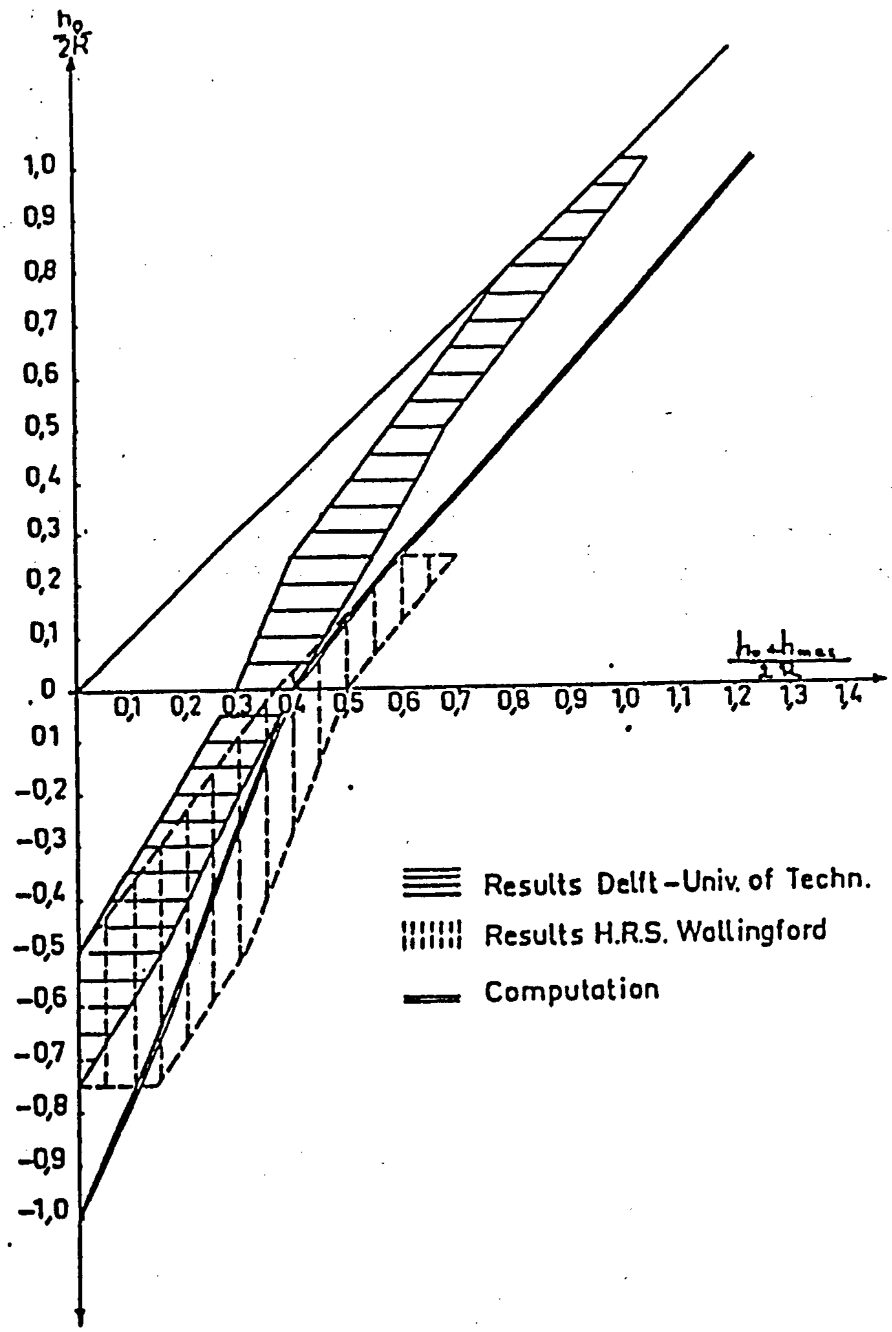


Figure 11: Pipeline Scour by waves. (From Bijker, 1976.)

The velocity field in the gap between the rigid cylinder and a solid boundary can be derived from the method of images in potential flow theory. The potential function governing the flow is

$$\phi = Ux_p + \frac{UR^2 x_p}{x_p^2 + (y_p - h_c)^2} + \frac{UR^2 x_p}{x_p^2 + (y_p + h_c)^2}$$

where

U is the undisturbed flow velocity

R is the radius of the pipe

h_c is the distance from the center of the pipe to the bottom of the scour hole

x_p is the horizontal distance from the centerline of the pipe

y_p is the vertical distance above the bottom of the scour hole

The velocity U_h in the scour hole is

$$U_h = \frac{\partial \phi}{\partial x_p} = U\{1 + \frac{R^2}{x_p^2 + (y_p - h_c)^2} - \frac{4R^2}{[x_p^2 + (y_p - h_c)^2]^2}$$

$$+ \frac{R^2}{x_p^2 + (y_p + h_c)^2} - \frac{4R^2}{[x_p^2 + (y_p + h_c)^2]^2}\}$$

and the discharge through the scour hole per unit length of pipeline is obtained by integrating the velocity from $y_p = 0$ to $y_p = (h_c-R)$ to obtain

$$q = \int_0^{h_c-R} u_h \, dy_p = U\left(h_c - \frac{R^2}{2h_c - R}\right) \quad for \;\; h_c \geq R$$

The average jet velocity U_{avg} is determined by dividing the discharge through the scour hole by the corresponding depth. If this velocity in the scour hole is greater than the free stream velocity, scouring takes place. As the scour section is enlarged, the velocity along the boundary decreases to the point at which the boundary shear stress becomes equal to the critical tractive stress of the sediment and no further sediment is transported.

The maximum boundary shear stress in the scour hole is estimated by assuming that the bottom of the scour hole is essentially flat in nature and the flow in the eroded section resembles open channel flow characteristics. The friction factor and Reynolds number relationship developed by Lovera and Kennedy (1969) can be used to estimate the friction factor, and the boundary shear stress corresponding to a given flow velocity can then be computed. The maximum scour depth under the pipeline is then determined by matching the boundary shear stress with the critical tractive stress of the sediment. The sensitivity of the scour depth estimates to variations in all parameters is difficult to quantify because the friction factor and Reynolds Number relationship of Lovera and Kennedy (1969) is presented in a graphical format. A quantitative assessment of the sensitivity requires a detailed series of computations which is not included in this report.

The analytical approach developed by Chao and Hennessy (1972) provides a simple method of estimating the maximum scour depth. However, comparisons of the scour estimates with field or laboratory measurements have not been made.

2. Kjeldsen et al. (1973)

Tests were carried out on pipes with diameters ranging from 6.0 cm (2.4 in) to 50.0 cm (19.7 in) resting on a bed material with a mean grain size of 0.074 mm. A uniform flow velocity of 25 to 50 cm/sec (0.82 to 1.64 ft/sec) was used in the tests. The following formula was proposed for estimation of the equilibrium scour depth:

$$S = 0.972\left(\frac{U^2}{g}\right)^{0.20} D_{pl}^{0.80}$$

where S is the equilibrium scour depth in mm below the bottom of the pipeline

D_{pl} is the pipe diameter in m

g is the acceleration due to gravity, 9.81 m/sec^2

U is the flow velocity in m/sec

In subsequent tests by Kjeldsen et al. (1974), reported by Hjorth (1975), the ratio of water depth to pipe diameter was found to have no influence for ratios greater than 3 to 5, and relative grain size was found to have no influence.

The sensitivity of the calculations to variations in each parameter can be investigated in terms of the partial derivatives, which indicate that a change in velocity of ΔU will produce a change in scour depth of:

$$\Delta S = \frac{0.40\,\Delta U}{U} S$$

For example, if a design velocity of U = 0.7 m/sec is being considered, then a change in the design velocity of ΔU = 10%

will change the predicted scour depth by 5.7% of S. Similarly, the change in scour depth estimate due to a change in pipeline diameter is given by

$$\Delta S = \frac{0.80 \Delta D_{pl}}{D_{pl}} S$$

For example, if a pipeline with diameter D_{pl} = 0.76 m is changed by ΔD_{pl} = 10%, then the estimate of the scour depth will change by ΔS = 10.5% of S.

3. Bijker (1976)

As in the case for waves only, the details of this method are presented by Van Ast and De Boer (1973) in a Master's thesis (in Dutch), and only the results and basic approach are presented by Bijker (1976). It is assumed that the velocity just outside the viscous sublayer U_b for the undisturbed flow is given by:

$$V_b = q\, V_r$$

where $q = 1/\ln(33\, y_h/\epsilon)$

$y_h = h_o + 2R$, with a positive or negative value of h_o

ϵ = bed roughness

V_r = mean velocity over the height of the pipe above the

seafloor

Underneath the pipe, the velocity profile will not be logarithmic since the boundary layer does not adjust itself to the higher velocity within the scour hole, but will be similar to that developed by orbital motions. The velocity just outside the viscous sublayer under the pipe is expressed as:

$$V_b = s_w V_B$$

and

$$s_w = \sqrt{f_w / 2\kappa^2}$$

where

f_w = wave friction factor

κ = von Karman's constant

V_B = velocity just outside the boundary layer under the pipe.

Based on the same velocity distribution under the pipe as in the case of waves, the velocity V_B is:

$$V_B = V_R\left[1 + R^2/(h_o + h_{max} + R)^2\right]$$

and the velocity V_b under the pipe is given by:

$$V_b = s_w V_R\left[1 + R^2/(h_o + h_{max} + R)^2\right]$$

Since this velocity must be equal to q V_R, the velocities under the pipe must be decreased by the value V_t, so that

$$q\ V_R = s_w\left\{V_R\left[1 + R^2/(h_o + h_{max} + R)^2\right] - V_t\right\}$$

or,

$$V_t = V_R\left[1 + R^2/(h_o + h_{max} + R)^2\right] - \frac{q}{s_w}\ V_R$$

This expression degenerates to the situation for waves for the case when q is equal to s_w. However, Bijker (1976) shows that normally q is greater than s_w, and the decrease in velocities under the pipe is greater for uniform flow than for waves. Due to continuity considerations, the scour depth under the pipe should be larger for uniform flow than for waves, as confirmed by tests carried out by Van Ast and De Boer (1973). The scour measured under the pipe for uniform flow is shown in Figure 12. The sensitivity of the scour measurements to variations in current velocity is difficult to evaluate because the empirical results are presented in graphical form and it was suggested that further research is required to solve this problem completely.

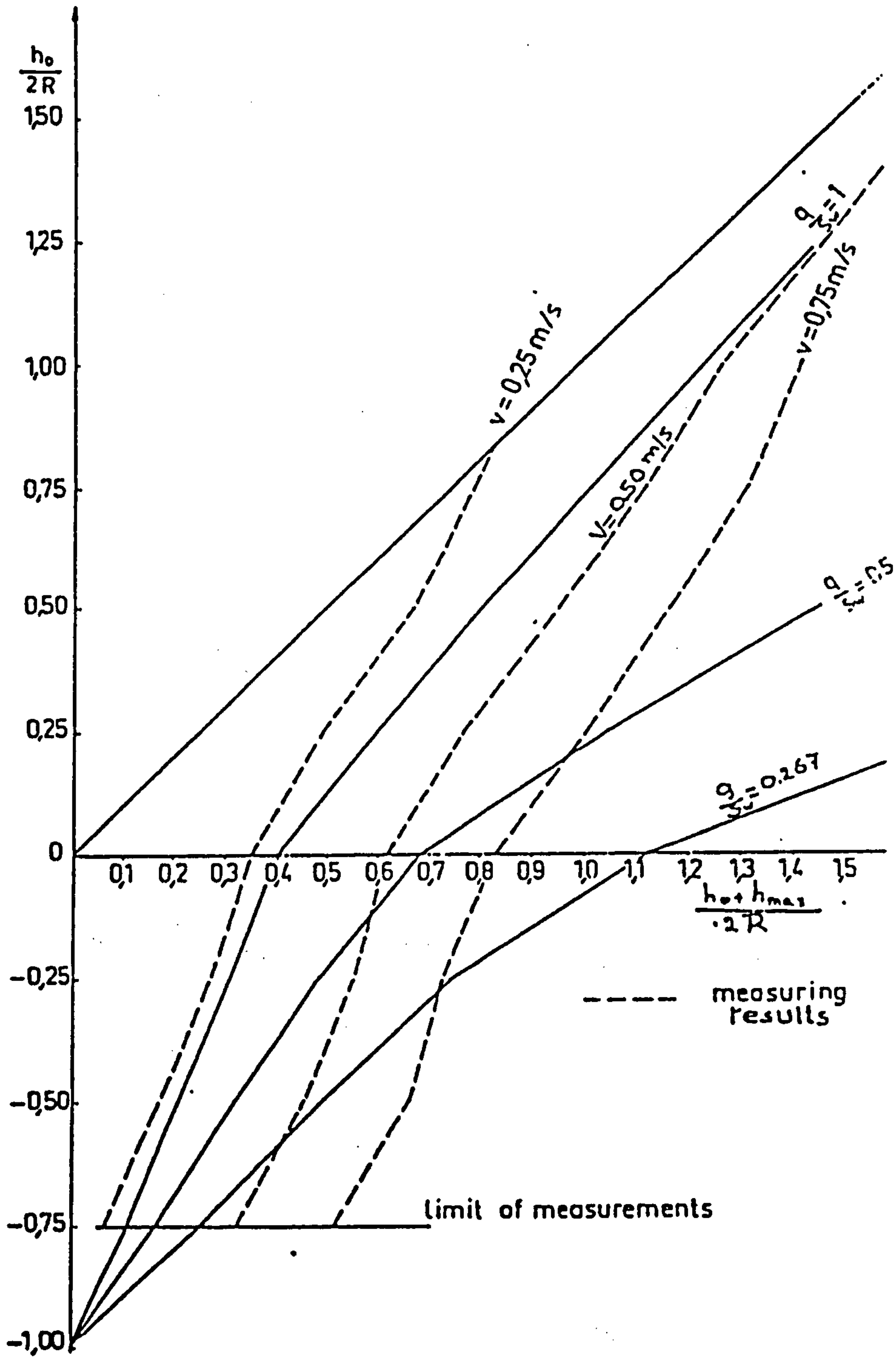


Figure 12: Pipeline scour by currents. (From Bijker, 1976)

Mao (1986) used a modified Meyer-Peter sediment transport equation to define the equilibrium scour depth. The well-known Meyer-Peter equation,

$$\Phi = 8(\theta - \theta_c)^{3/2}$$

where

Φ = dimensionless sediment transport

θ = dimensionless bed shear stress (Shield's parameter)

θ_c = Shield's parameter for incipient motion

is modified to account for local bed form such as the downward slope of the scour trench. The resulting modified Meyer-Peter equation is:

$$\Phi = 8(\theta^* - \theta_c)^{3/2}$$

where

$$\theta^* = \theta - 0.10\frac{\partial h}{\partial x}$$

$$\frac{\partial h}{\partial x} = \text{local bed slope}$$

Calculation Procedure for Pipeline Self-Burial Prediction:

A. Conditions

The Unocal pipeline to be installed is a 6-5/8 inch diameter pipe of 0.280 inch wall thickness (Sched. 40) grade B steel. A one inch thick concrete coating is applied to the outside giving a final diameter of 8-5/8 inches. With an assumed specific gravity of pipe contents to be 0.98, the final specific weight of the pipeline is 140 psf in air. The old line has similar specifications being 1-1/2 inch larger diameter and 164.8 psf in air. Based on grain size tests on Mandalay Beach sand samples provided by Unocal, the bed material is well-graded sand 50% of whose grains pass through a 0.42 mm mesh.

Using wave hindcast data from the Pacific Coast Wave Information Study No. 16 (U.S. Army Corps of Engineers, 1987), an annual storm of 48 hours duration was used to calculate the bottom velocities acting along the 3000 foot length of pipeline. This hindcast data can be misleading because it neglects subtropical and southern storms generating long period swell. For this study, however, where typical annual conditions are of interest the long period swell conditions are not a concern.

The hindcast data is divided into significant wave heights of 3-6 hour duration. An associated average wave period can be deduced from the distribution of wave heights. Wave height attenuation using Shore Protection Manual (U.S. Army Corps of Engineers, 1984) refraction and shoaling coefficients based on parallel bottom countours results in wave heights much larger than expected for the Eastern Santa Barbara channel. This discrepancy is due to the complex wave and wind interactions between the various channel Islands and the mainland. This fact suggests a significant attenuation of the deep water significant wave heights given by the Pacific Coast Wave Hindcast data.

For the purposes of understanding the burial process and for determining the probable depth of burial of the proposed pipeline, two storms are considered: a high probability local annual storm and a 25-year return period storm. The annual storm acts as the design storm, whereas the 25-year storm acts as a point of comparison. Locally, a 10-foot significant wave height is taken as the peak wave height during the annual storm. Table 1 supports this choice since a comparison of westerly swell and local westerly wind-generated waves fall in the range 10 to 13 feet. A 10 foot wave height is most likely to occur in any given year. The associated wave period is 7 seconds and the associated peak wind speed is 30 knots.

Table 1. High Wave Events (Eastern Santa Barbara Channel)

	High Westerly Swell ($H_s \geq 10$ ft)	Strong West Winds ($H_s \geq 13$ ft)
1981:	Nov 11-14, Dec 18-19	
1982:	Mar 8-9, Oct 22-23, Dec 1, Dec 16-18	Nov 30
1983:	Jan 23-25, Jan 27-30, Feb 10, Feb 13, Feb 20-21, Feb 28, Mar 1-2, Mar 4, Mar 14-15, Mar 17-18, Dec 1, Dec 9	Feb 10, Apr 2
1984:	Mar 9-10, Nov 3-4	Feb 16, Mar 31, Apr 24, Dec 12
1985:	Dec 2-3	
1986:	Jan 23, Feb 1-4, Feb 13-16, Feb 25-26, Feb 28, Mar 11-14, Mar 16-17	
1987:	Mar 5, Mar 13	
1988:	Jan 17	Apr 30, May 28

Since the 10 foot local wave height is associated with an 18-foot open ocean wave from the Hindcast data, a corresponding 25-year wave height is 26 feet. This westerly swell height will attenuate to an Eastern Santa Barbara Channel wave height of 18 feet. Therefore, the 25-year peak significant wave height is 18 feet. The associated wave period is 14 seconds from the Hindcast data. For comparison purposes, the swell is assumed to occur simultaneously as high local wind speeds similar to the annual storm.

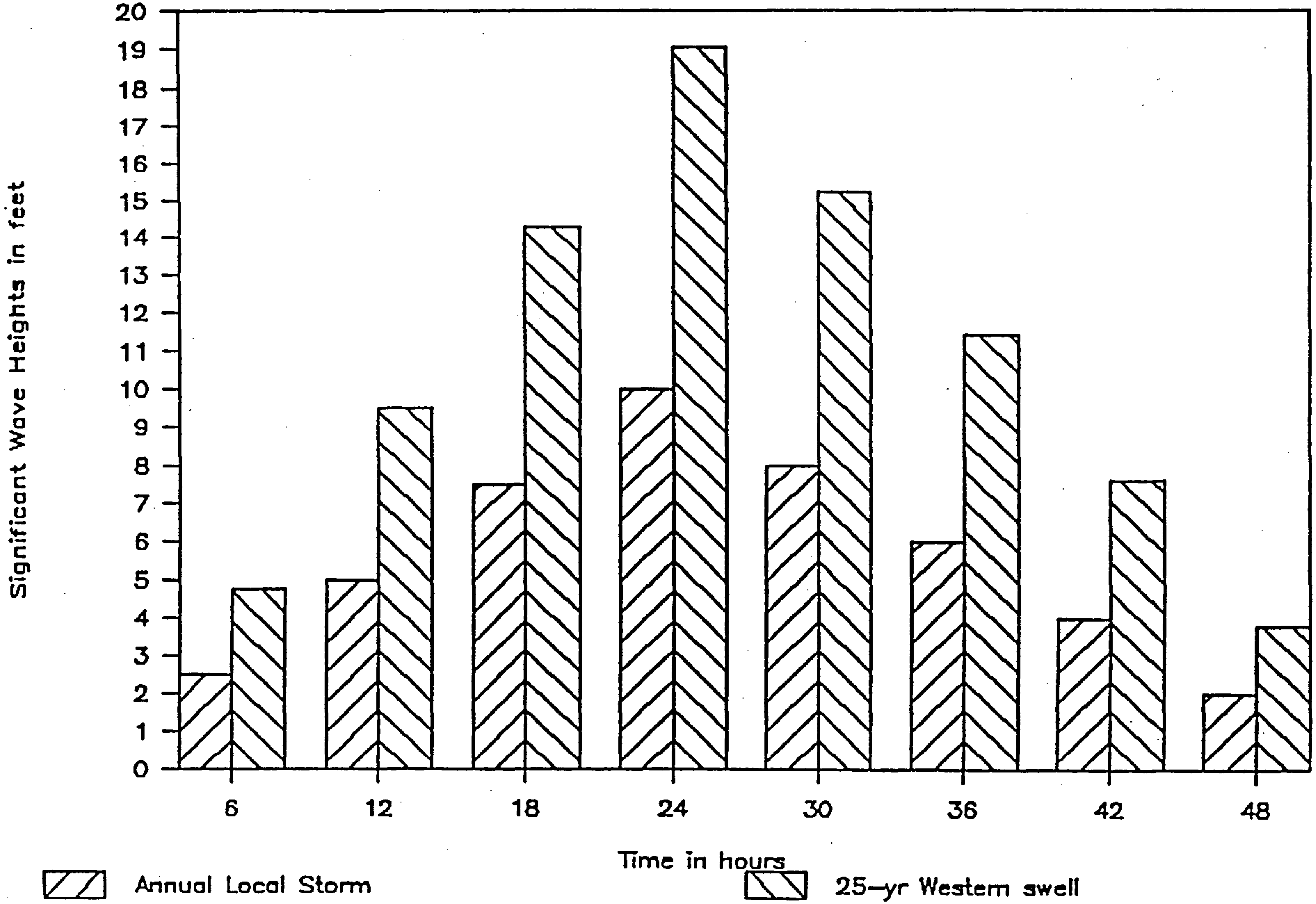
B. Localized Scour

The model used for local scour prediction and backfilling depends on calculating the bed shear stresses during the design storm. A 48-hour duration was chosen as a typical storm duration for an annual storm and a 25-year return period storm in the Santa Barbara channel. The progression of significant wave heights and periods during the storm was assumed to be linearly increasing to the maximum and then linearly decreasing to zero at a slightly slower rate (Figure 13). The final distribution was divided into eight wave groups of 6-hour duration. Wave records for the 1982 - 1983 storms in the Santa Barbara Channel suggest that this simplified model is justified (see Figures 14, 15).

Calculation of the current and wave orbital bed velocities was done previously by Intersea Research Corp.

Figure 13: Design Wave Record

48—hour Annual—Local & 25—year Storms



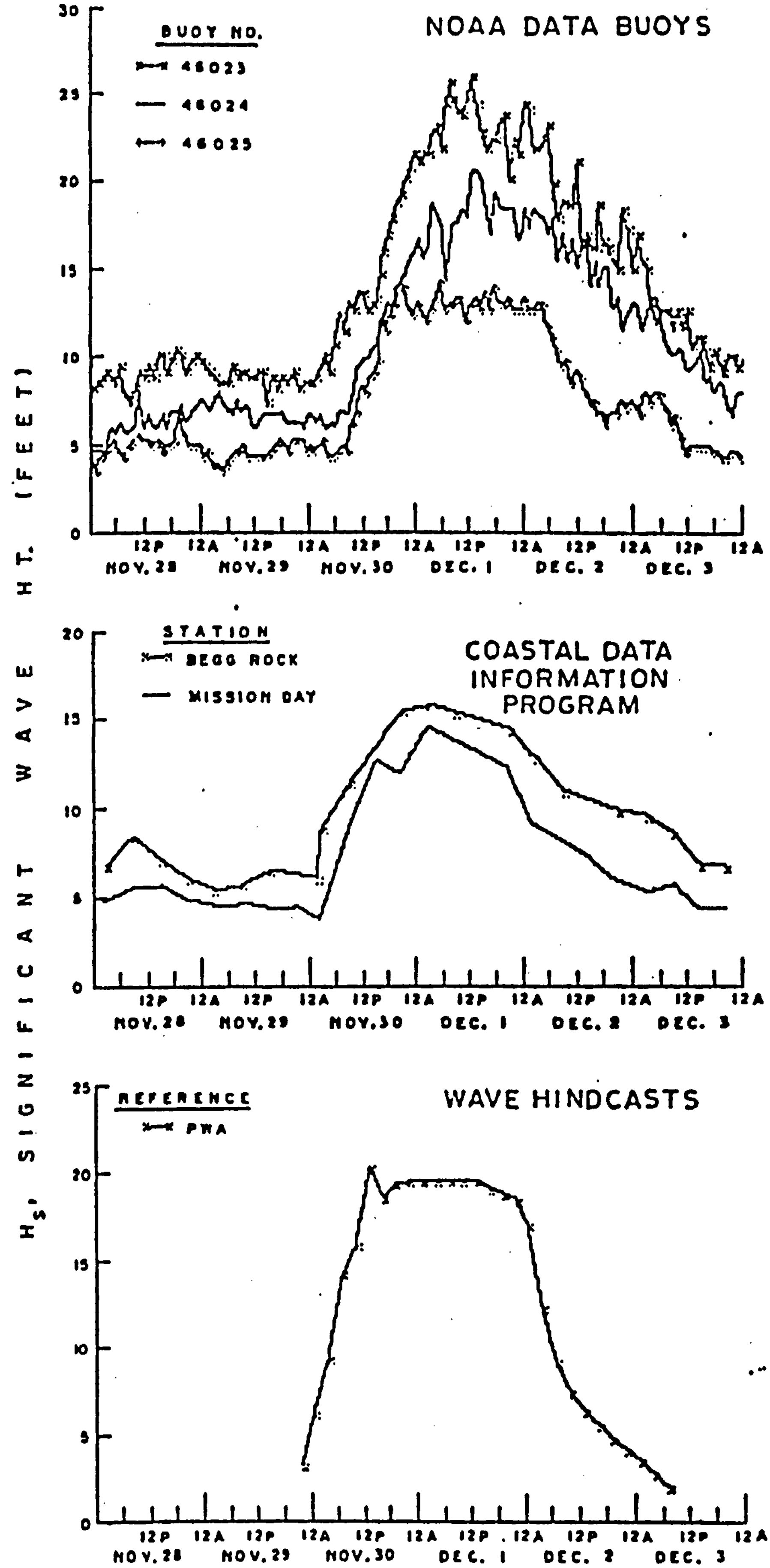


Figure 14: Deepwater significant wave heights, Nov.-Dec. 1982 storm. (From Moffat and Nichol Engineers, 1983)

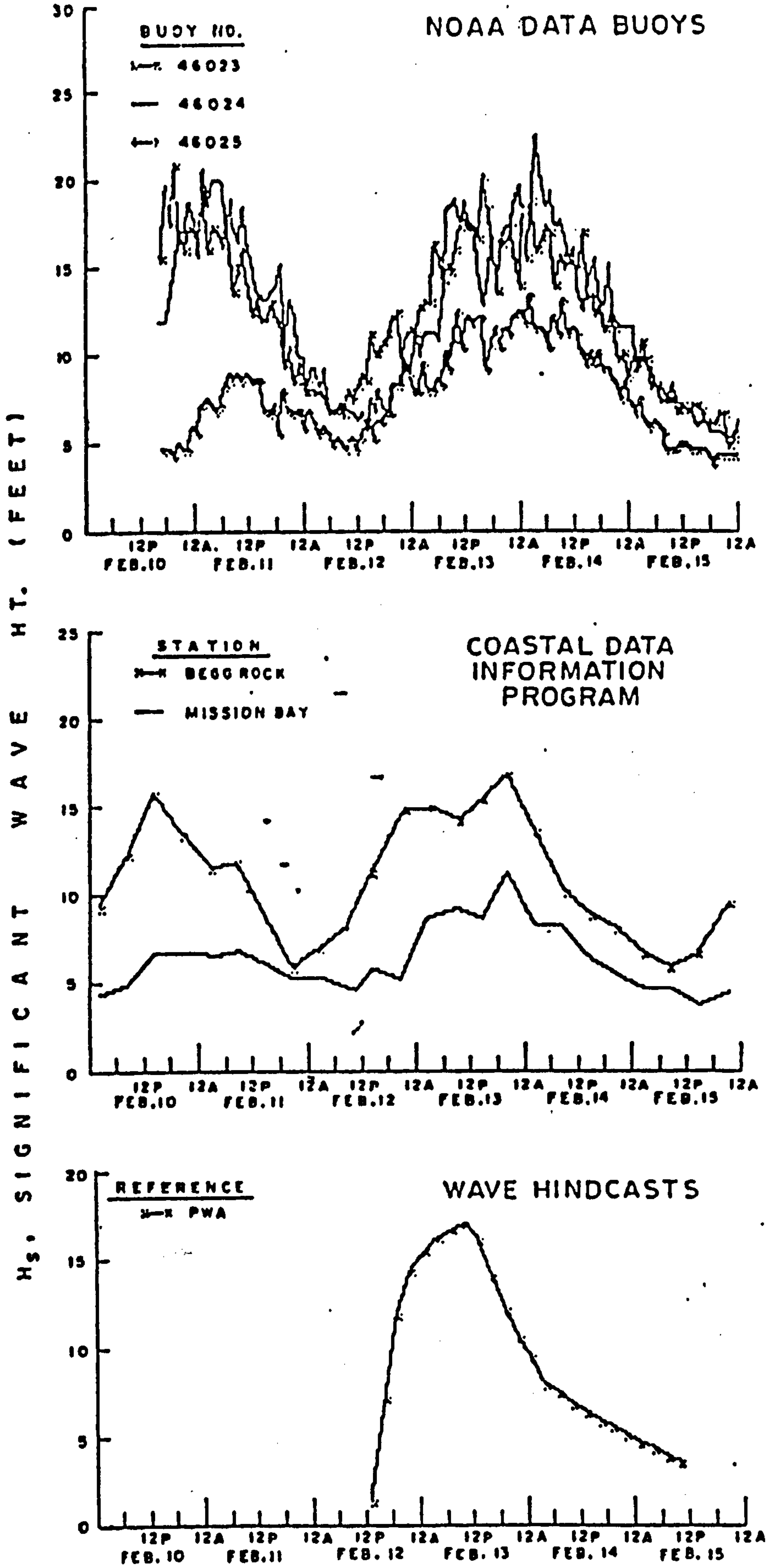


Figure 15: Deepwater significant wave heights, February 1983 storm. (From Moffat and Nichol Engineers, 1983)

(1980). Reported velocities were subdivided into tidal and wind-driven, and longshore and wave orbital velocities. The bed velocity distributions perpendicular to the pipeline are shown in Figure 16.

Since equilibrium scour depths are dependent on current bed velocities and wave orbital bed velocities additively and separately, this report subdivides the bed velocities into three groups: tidal and wind-driven, longshore current, and wave orbital. Currents due to storm surge were neglected. The vertical distribution of the unidirectional current velocities was assumed constant with depth for shallow water. Therefore, bed velocities (just above the boundary layer) are equivalent to the calculated surface velocities.

Tidal and wind-driven velocities were assumed to be an average of one-year return period peak value of 2 ft/s and a 25-year return period peak value of 3.7 ft/s (Intersea Research Corp., 1980). Since tidal currents will be independent of the storm conditions, a tidal current base velocity was chosen with linearly time-varying wind-induced bottom velocities similar to the wave height distribution (Figure 17). The distribution along the length of the pipeline is presumed nearly constant, although a sharp drop off approximately 30 feet offshore from the MLLW line is likely.

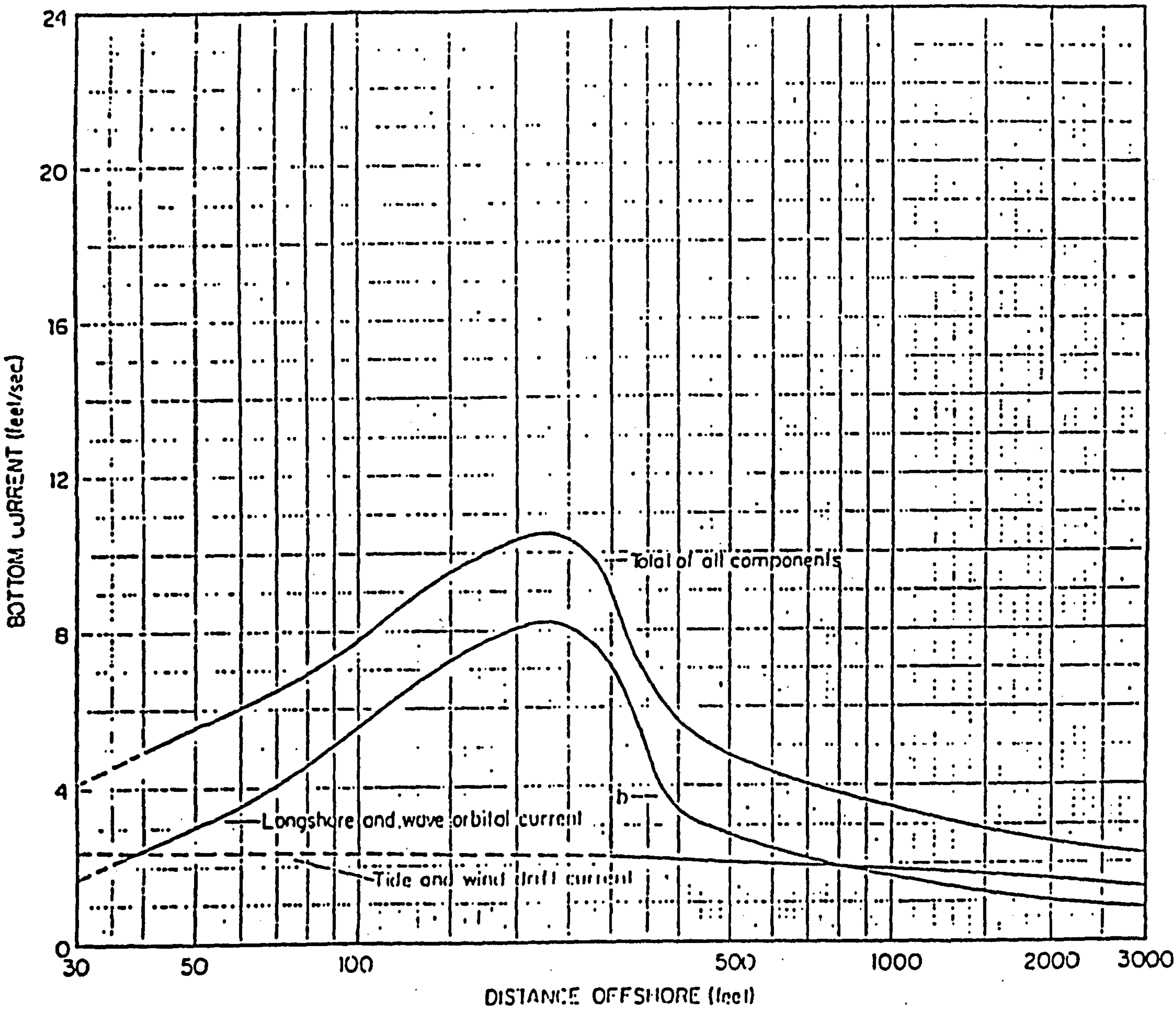
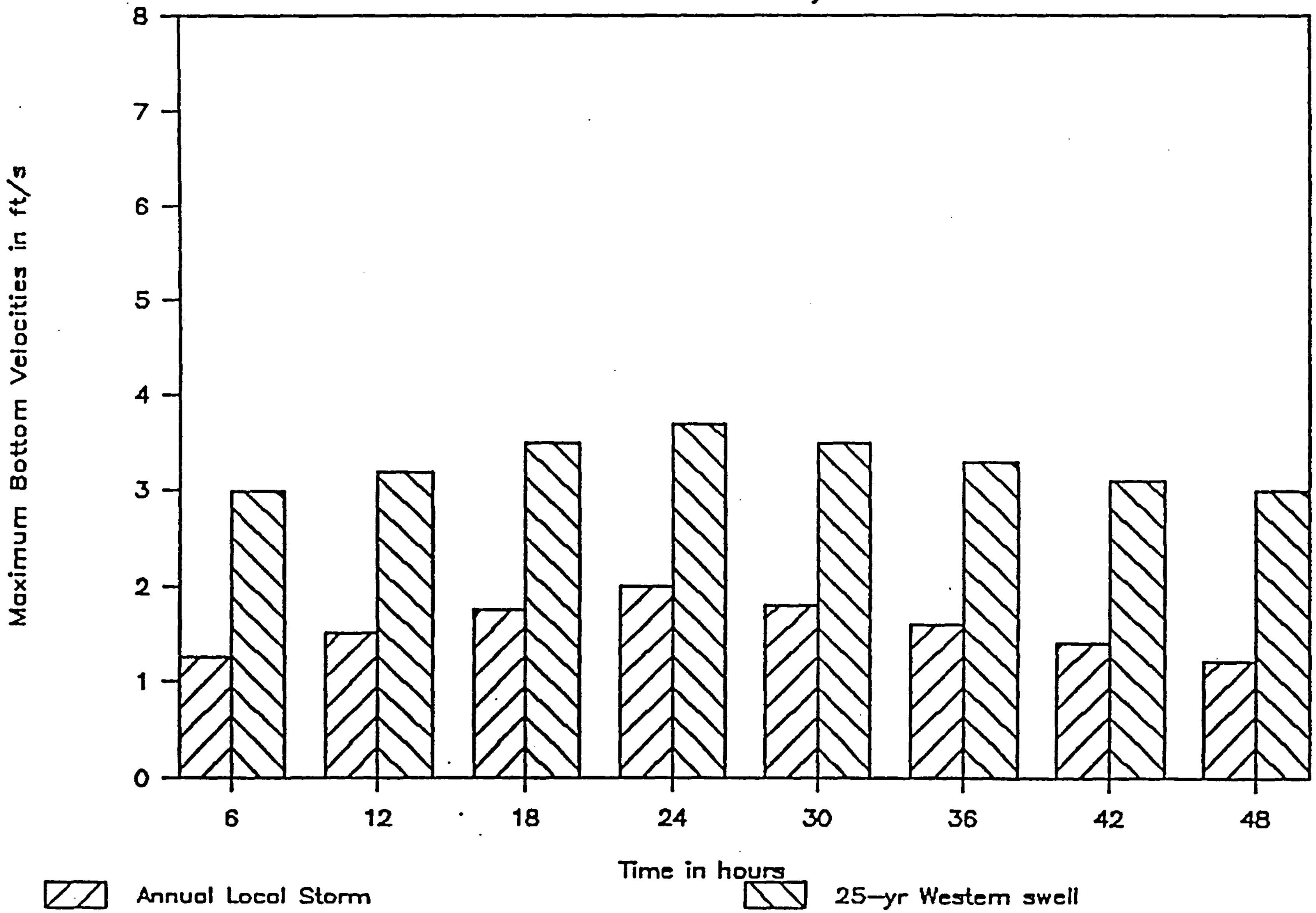


Figure 16: Calculated maximum bottom current perpendicular to the pipeline for annual winter storm (b indicates breaker location). (From Intersea Research Corp., 1980.)

Figure 17: Bottom Velocity Record

48-hour Annual-Local & 25-year Storms



For longshore current velocities, the standard Longuet-Higgins equation (Shore Protection Manual, 1984) was used for the surface velocity at the breaker line and at the point of maximum flow which occurs approximately midway between the MLLW and the breaker line. The longshore current falls off rapidly sea-ward of the breaker line. A linear approximation of the distribution used in the Intersea report was used to characterize the distribution along the pipeline.

Wave orbital bed velocities were calculated using solitary wave theory instead of the method used by Intersea Research Corp. The Intersea values based on linear Airy wave theory are higher by a factor of 100%. Linear wave theory is inappropriate for shallow water. Cnoidal theory is most appropriate for the shallow water in which the pipeline will rest, but solitary wave theory was chosen for ease of calculation and for more appropriate values.

Discrepancies between the two calculation procedures may be due to differing design conditions such as the breaker angle which is very small in the case of this report. The design conditions specified in this report are more conservative in that they allow less ability for the scour trench to refill.

The model for localized scour prediction, presented in this study, relies on the Chao and Hennessy model for low velocity regimes where the current plus wave bed shear stress does not exceed the critical stress limit for bed load initiation ("clean water" upstream flow). A FORTRAN program based on linear wave theory is presented in Appendix C that utilizes the Kjeldson and the Chao and Hennessy models (Work, 1987). For higher flow regimes, where the Chao and Hennessy model gives unreasonably high scour depths, the Bijker (1976) model is used with adjustments from Mao (1986).

Both models are compared with experimental results from Mao (1986) in Appendix A and engineering judgement. Specifically, Bijker's "q/s_w" reduction factor is found to be too high and is lowered. Unfortunately, the model is very sensitive to this factor. Using a Meyer-Peter bed load transport potential ratio equal to one gives the equilibrium scour depth by trial and error in a Lotus spreadsheet. This model has high potential for practical use and can be converted into a FORTRAN program and calibrated using further model experiments.

The sediment transport potentials into and out of the scour trench are modified using Mao's local bed form adjustment. In addition, Mao's observations on the effects of pipe sagging and vibration are incorporated into the model. The scour model agrees well with Mao's experimental work when the appropriate experimental conditions are inputted into the model. Appendix A includes bed profiles obtained in Mao's experiments.

The assumptions made in this formulation are:

(1) the formation of a gap between pipeline and bed, also known as "tunnel-erosion".

(2) a potential flow justification for the velocity distribution in the gap between pipe and bed.

(3) an adjusted Bijker gap velocity reduction factor.

(4) neglecting the effects of sand waves and other bed form artifacts.

(5) a coupling of the vector components of the wave orbital and current bed velocities normal to the pipeline.

The assumption of "tunnel-erosion" or gap formation is a reasonable one owing to the large extent of the pipeline and the existence of localized high bed velocities at certain points along the pipeline. The modified potential flow velocity distribution between the pipeline and the bed is reasonable. An unmodified approach would not take into account the effects of the bed and bed roughness as well as give infinite scour depths where the velocity under the pipe is equal to the free stream velocity. Decreasing the flow using a $q/s_W = 1$, as Bijker suggests, is unreasonable. A value of 0.08 allows the results to fit more closely Mao's experimental results. The sensitivity of the model to this factor, however, necessitates further study beyond the scope of this report.

The effects of sand waves and other bed forms can play a significant role in the scour process (Mao, 1986). The equilibrium scour depths, however, are probably not seriously affected. The bed slope modification to the Meyer-Peter equation is the only value that is significantly affected, and evaluation of this impact would require study beyond the scope of this report.

The results of these calculations are summarized in Figure 18 for the local annual storm. Figure 19 shows the results for the 25-year Westerly swell and storm. The graph represents the ratio of scour depth below the bottom of the pipeline over the pipe diameter versus the distance offshore. These are plotted for the beginning of the design storm, the peak period of the storm and near the end of the storm. The important point to note is that the pipeline will scour more than one diameter during the peak wave heights, and thereby, allow full burial of the pipe along its entire length. These values should be afforded an error of +/- 30% to allow for the uncertainties involved in the calculation. Figure 20

Figure 18: Equilibrium Scour Depth

48—hour Annual Winter Storm

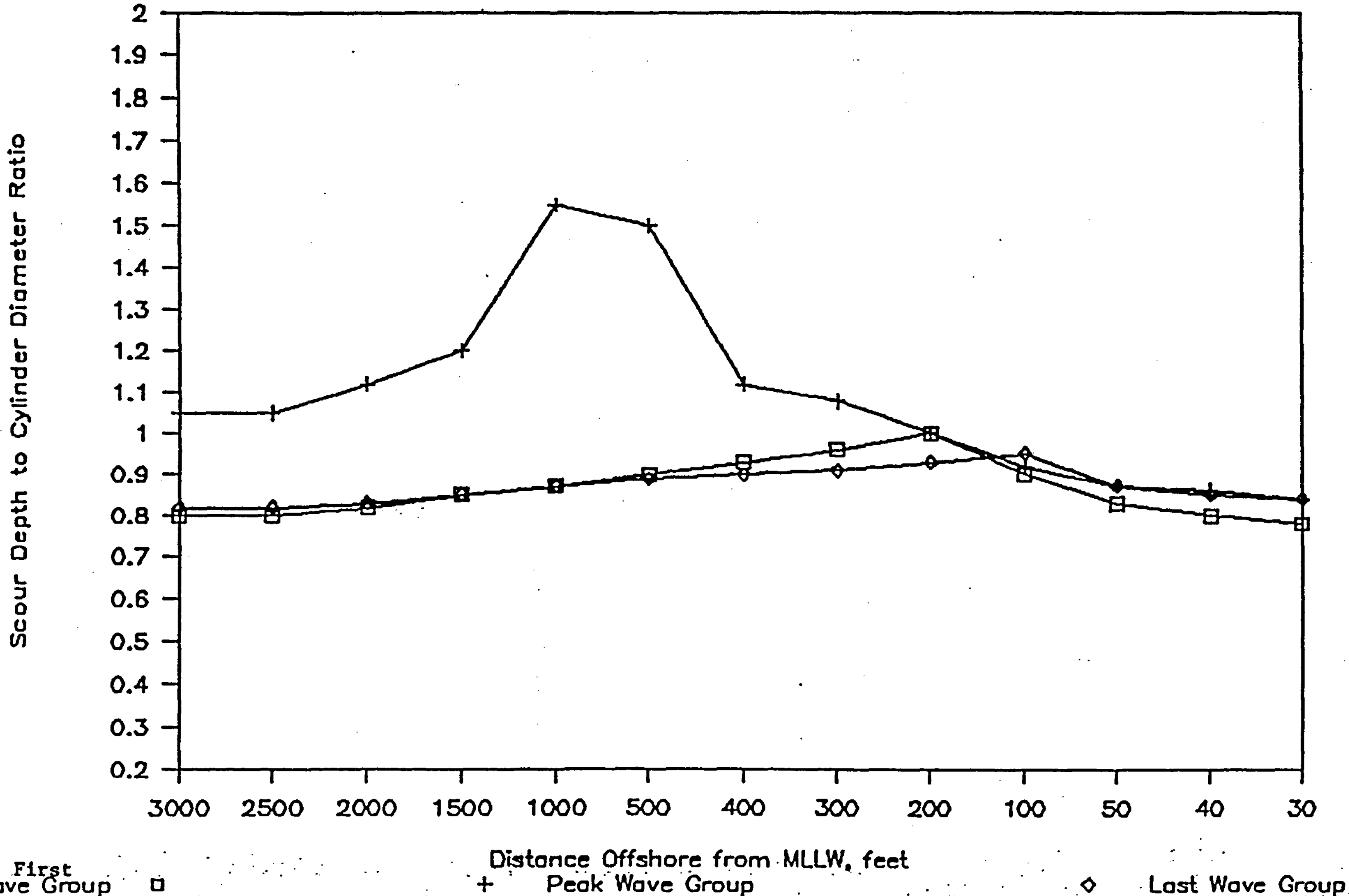


Figure 19: Equilibrium Scour Depth

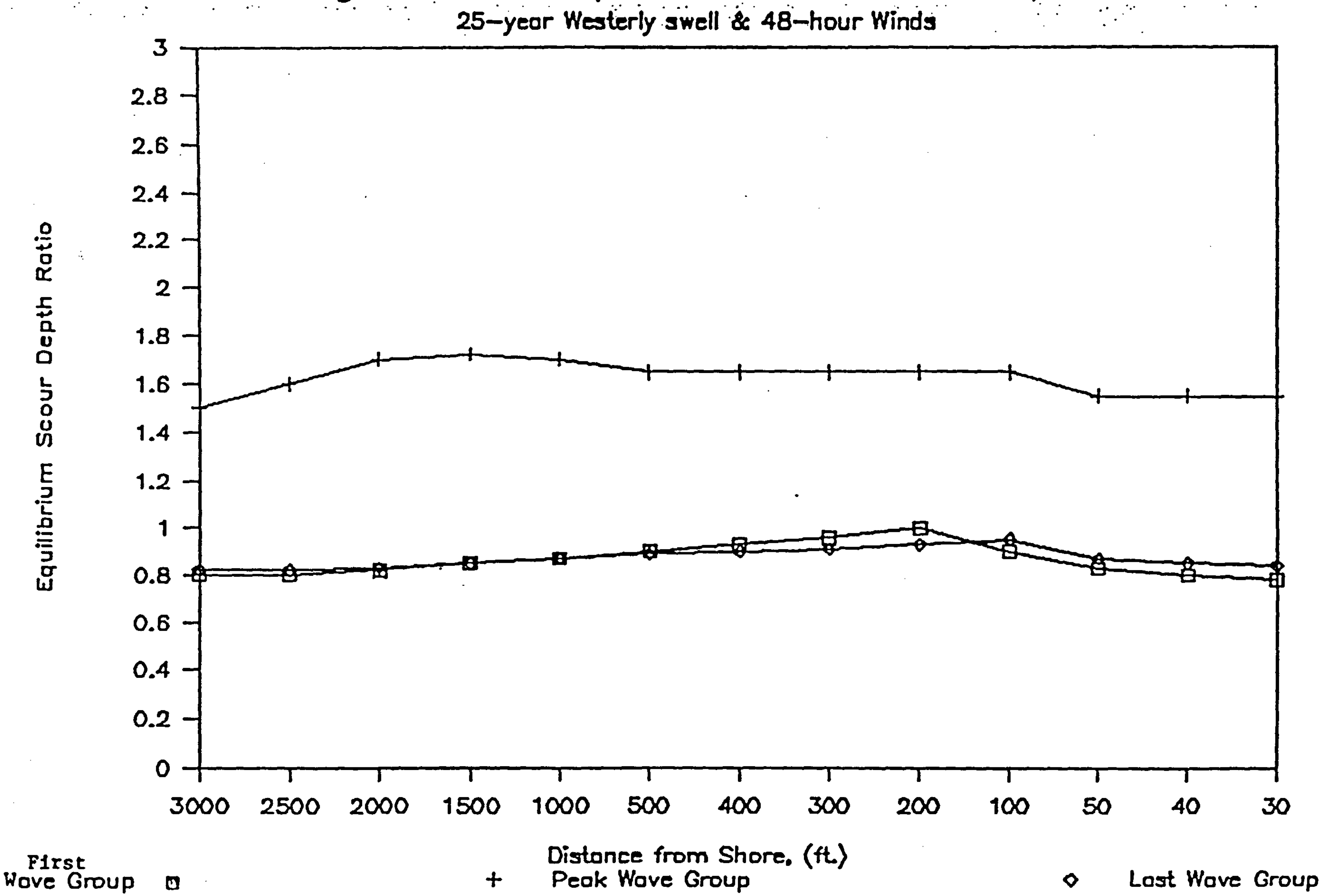
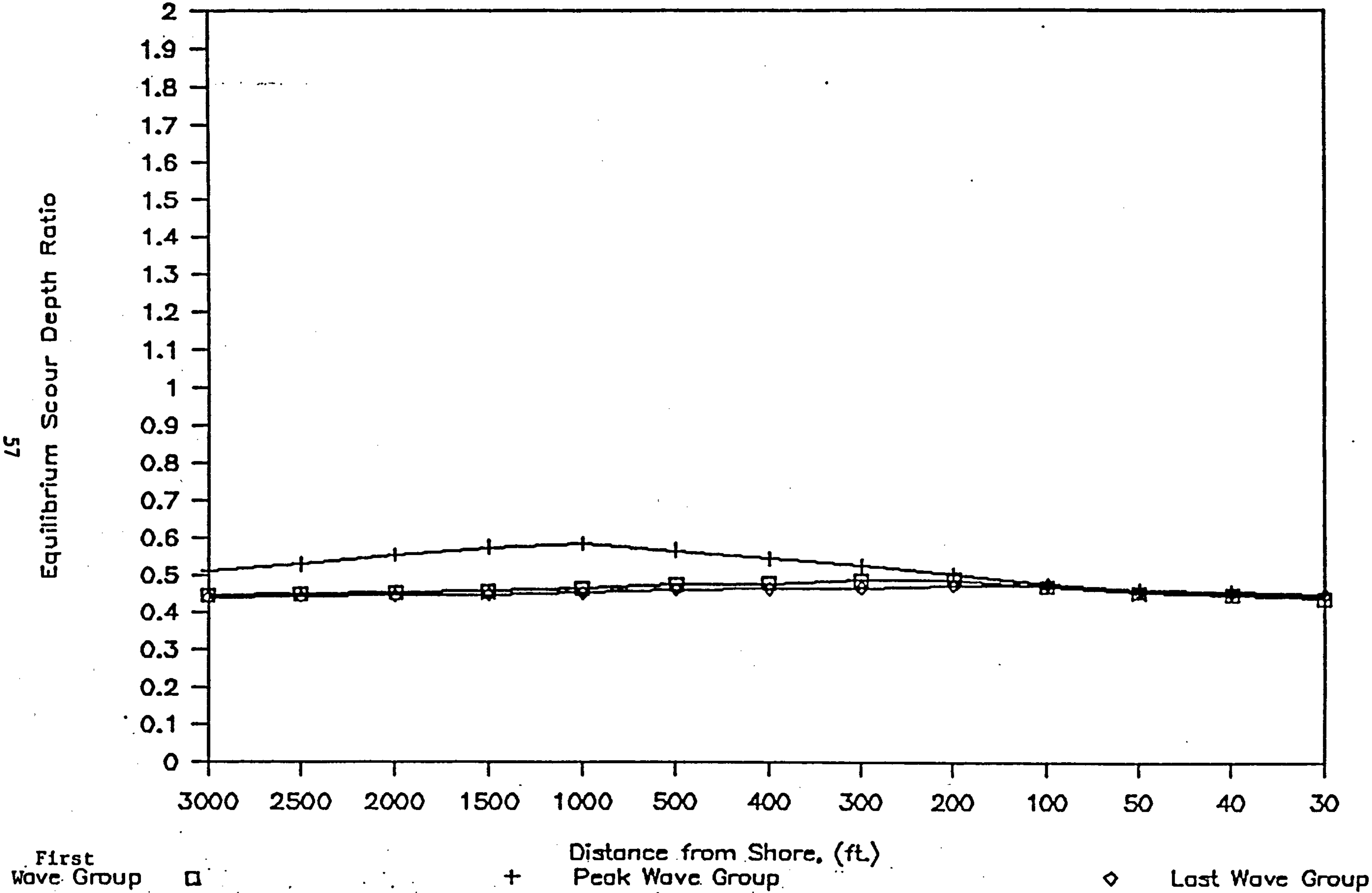


Figure 20: Kjeldson's Scour Depth

48—hour Annual Storm



shows results from Kjedlsen (1973) for the 48-hour duration annual storm. The values indicated are significantly lower than the previous model and to be reasonably expected.

Along the pipeline length, the pipeline may not completely rebury during the storm. A lengthy calm period is required after the design storm to adequately insure full burial. Once the scour trench is formed, the trench will begin to backfill under a reduced wave climate. The bed shear will decrease substantially from reduced wave heights, thereby, decreasing the equilibrium scour depth and burying the pipeline. The modified Meyer-Peter equation was used to estimate the rate of back filling. Calculations of the rate of refilling suggest that the trench will fill within 24-48 hours under very reduced conditions (critical tractive stress of surrounding bed is barely exceeded).

C. Regional Erosion and Deposition Estimation

Historical records are relied upon to calculate a reasonable value for bed level changes in the study area. Bed level fluctuations are highly dependent on regional geomorphology and wave\current climate. The profiles in Appendix B for 1938, 1948, 1959, 1966, 1977, and 1987-1988 suggest a recession of the beach of approximately five horizontal feet per 10-year period and a general increase in bed elevation of the offshore region of 2 to 4 feet over a

20-year period. It is reasonable to conclude an average increase in bed elevation of 0.1 to 0.2 feet per year. This observation is consistent with general knowledge of California's receding shoreline. Figure 21 is a location map and shoreline description of Mandalay Beach.

The recession of the shoreline and the increase in offshore bed level suggest a transference of material from the foreshore to the offshore. The reason for this observation would require further analysis of the local topography and field studies in the area. The fact that the old water line to Gina platform is undergoing burial may be due strictly to localized scour in conjunction with regional deposition in the area being studied.

Formation of large span lengths of uncovered pipelines is unlikely in the region of present interest, since the Beacon 20 profile of 1987-1988 indicates a local fluctuation in bed level elevation off of Oxnard Shores, very near the Mandalay Beach pipeline. Seasonal on-offshore migration of bed forms such as formation of offshore bars, etc., is always in a state of change. Figure 21 shows a beach behavior description supporting this notion. It is possible this environment is not condusive to open span length formation.

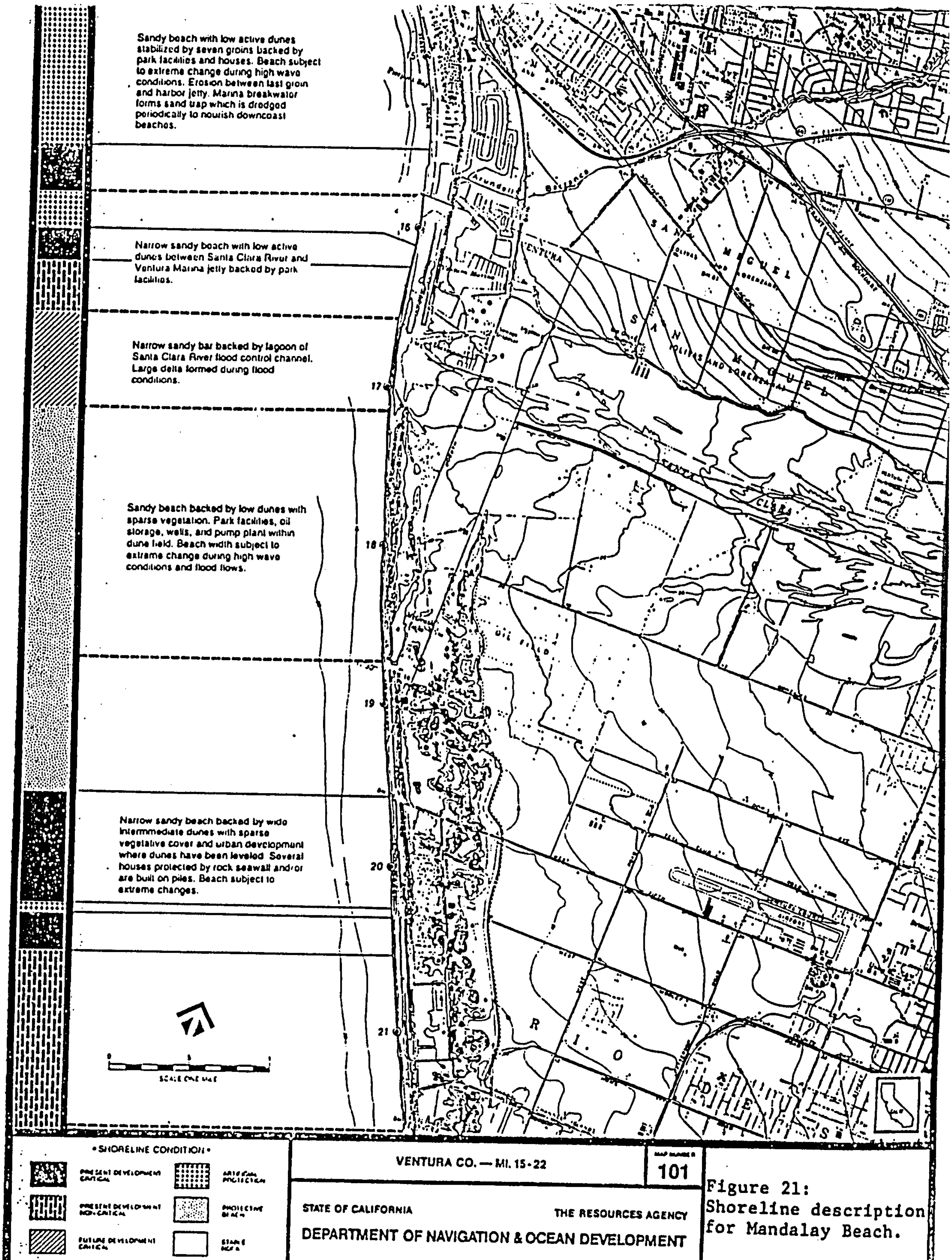


Figure 21: Shoreline description for Mandalay Beach.

Calculation of span lengths are possible using Mao (1986) and the SCOUR.EXE program, provided. This calculation was not done for this report.

D. Soil Liquefaction

Another mechanism for pipeline self-burial could be wave-induced soil liquefaction. Using Reddy's and Bea's approximation of the undrained shear strength of dense sand with depth, the final depth of burial is estimated using Bea's (1981) equation for wave-induced shear stress in a semi-infinite elastic continuum (see Figure 9a):

$$\tau_{e} = \frac{2\pi Z}{L} \exp\left[-\frac{2\pi Z}{L}\right] \cdot \Delta P$$

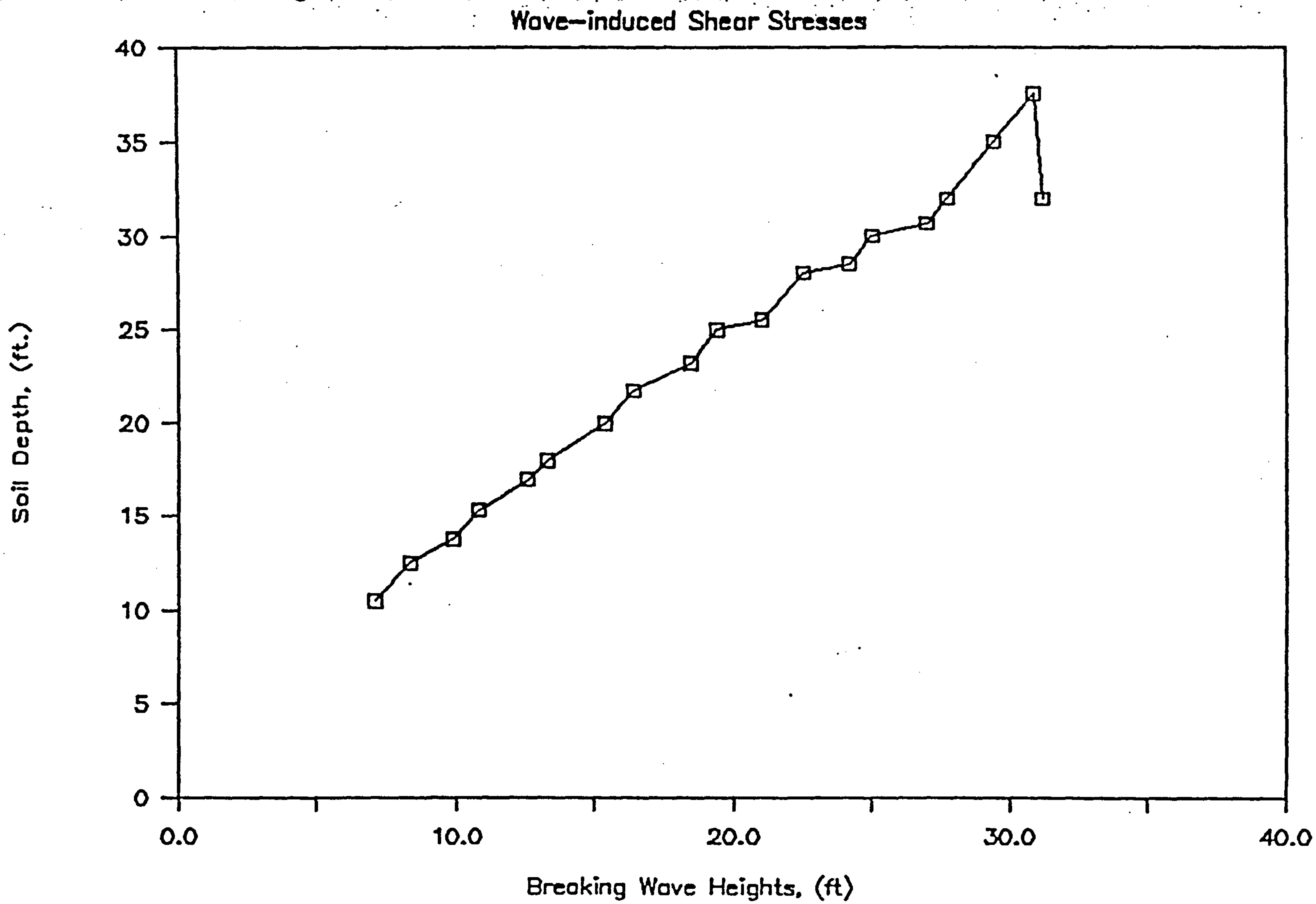
where Z = depth into soil

L = wave length

ΔP = pressure change at sea floor

the wave-induced shear stress can be compared to the distribution of undrained shear strength. The values for Luque's formation are unreasonably higher and Yamamoto's values are much more reasonable. Yamamoto's calculation procedure, however, is too complex for practical use. Figure 22 shows a nearly linear increase in final liquefaction depth with wave height.

Figure 22: Depth of Soil Liquefaction



The depth limit of liquefaction represents a possible final settlement depth for the pipeline. The criteria for settlement of the pipeline is not well-studied. The only conclusion possible within the scope of this study is to determine if the pipeline will not "float" in the liquefied sand. Comparing the specific weights of the pipeline and the liquefied sand (140 psf and 100 psf, respectively), shows that the pipeline cannot "float".

Laboratory Experiments:

Using an 8-foot wide, 5-foot deep, 180-foot long flume located at the University of California, Richmond Field Station, waves were generated of 0.5 feet in height and 3 second periods. A test section of pipe approximately 6 feet long with an air specific weight of 140 psf and a roughened exterior coating was laid on a bed of 0.3 mm grain diameter sand. Figure 23a,b shows photographs of the pipe test-section on a sandy bed. The rate of settlement was measured using a point gauge resting on the middle of the pipe at its highest point.

The results are shown in Figure 24. The small bed velocities associated with the testing procedure did not allow significant scour to occur such as tunnelling. From visual observations of the pipe behavior under waves and current, and waves only, rapid settlement (Stage 1) occurs in

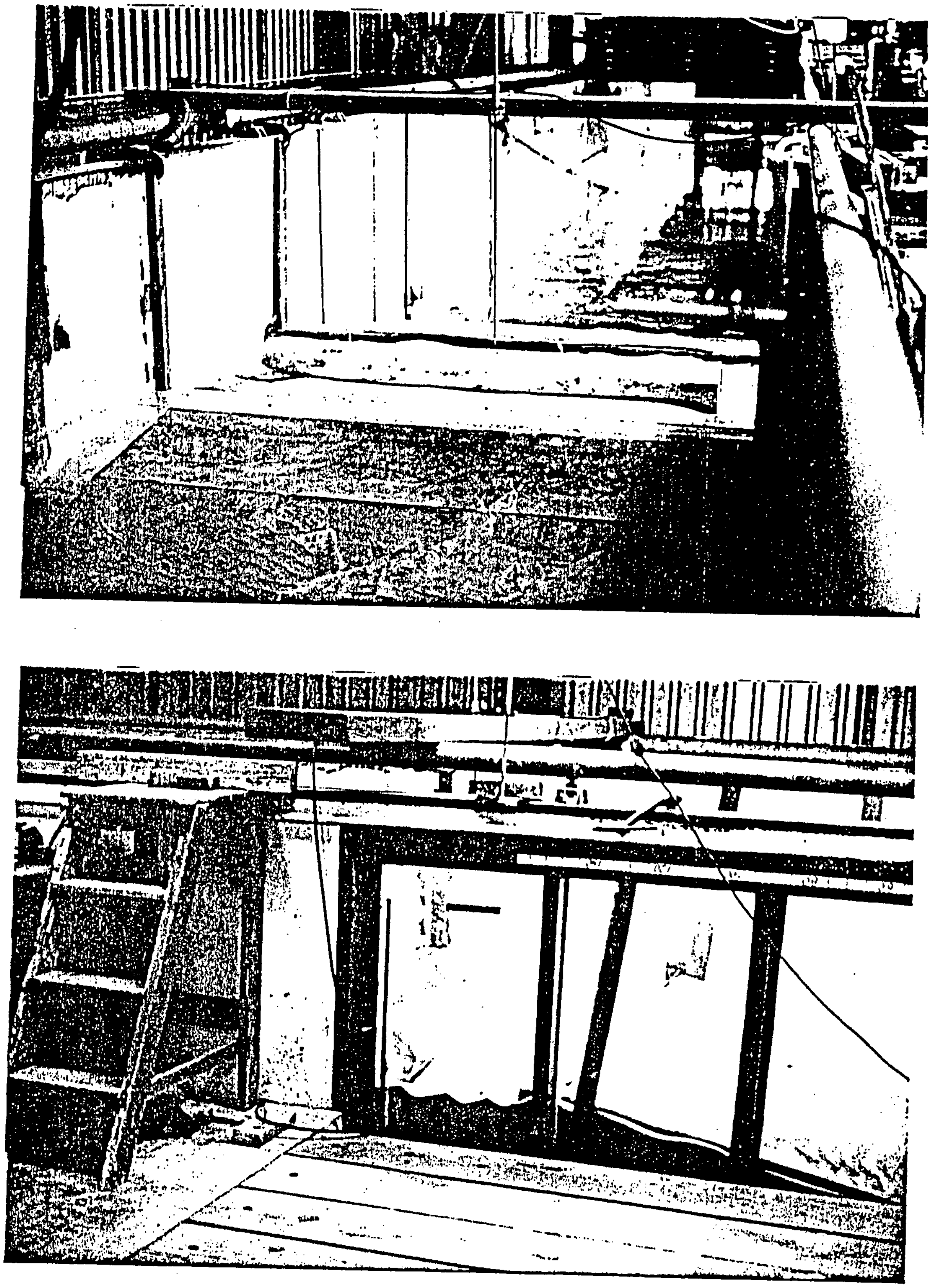


Figure 23 a,b: Photographs of Experimental set-up.

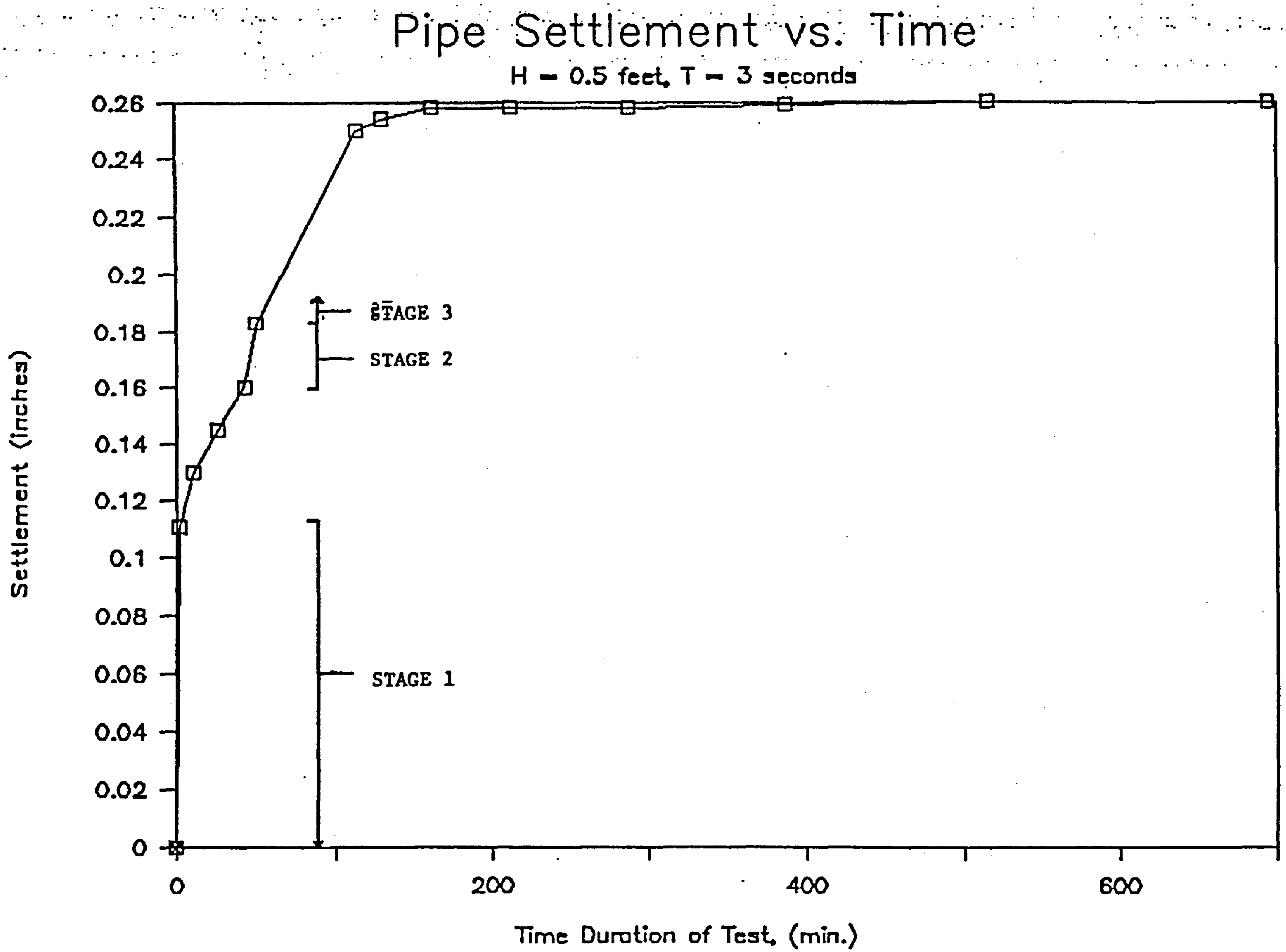


Figure 24: Pipe Settlement with time for model study.

the first two minutes of the test under waves and a limited current. Also, an initial trench forms on the upstream side of the pipe. When the initial trench is large enough a local slope failure occurs and the pipe settles another small increment (Stage 2). Stage 3 settlement was probably due to consolidation of the sediment directly below the pipe. The Stage 1 settlement was used as a determinant of the rate of settlement after soil liquefaction assuming a linearly elastic failure. Results indicate that the pipe would settle to an storm-averaged depth on the order of 24 hours after liquefaction. More comprehensive studies are required to better estimate the settlement rate.

Field Observations:

To develop further insight into the magnitude of scour and self-burial in the field, field observations are summarized for other offshore areas and the Gina pipeline study area.

The scour around pipelines lying horizontally on the seabed has received less attention than the scour around vertical structures. Previous research has been primarily directed towards determining the hydrodynamic forces on the pipe itself. The maximum length of unsupported pipeline spans is an important consideration in the structural design of the pipe, since sagging of the line could induce excessive stresses, transverse motions or galloping (personal communication, R. Bea).

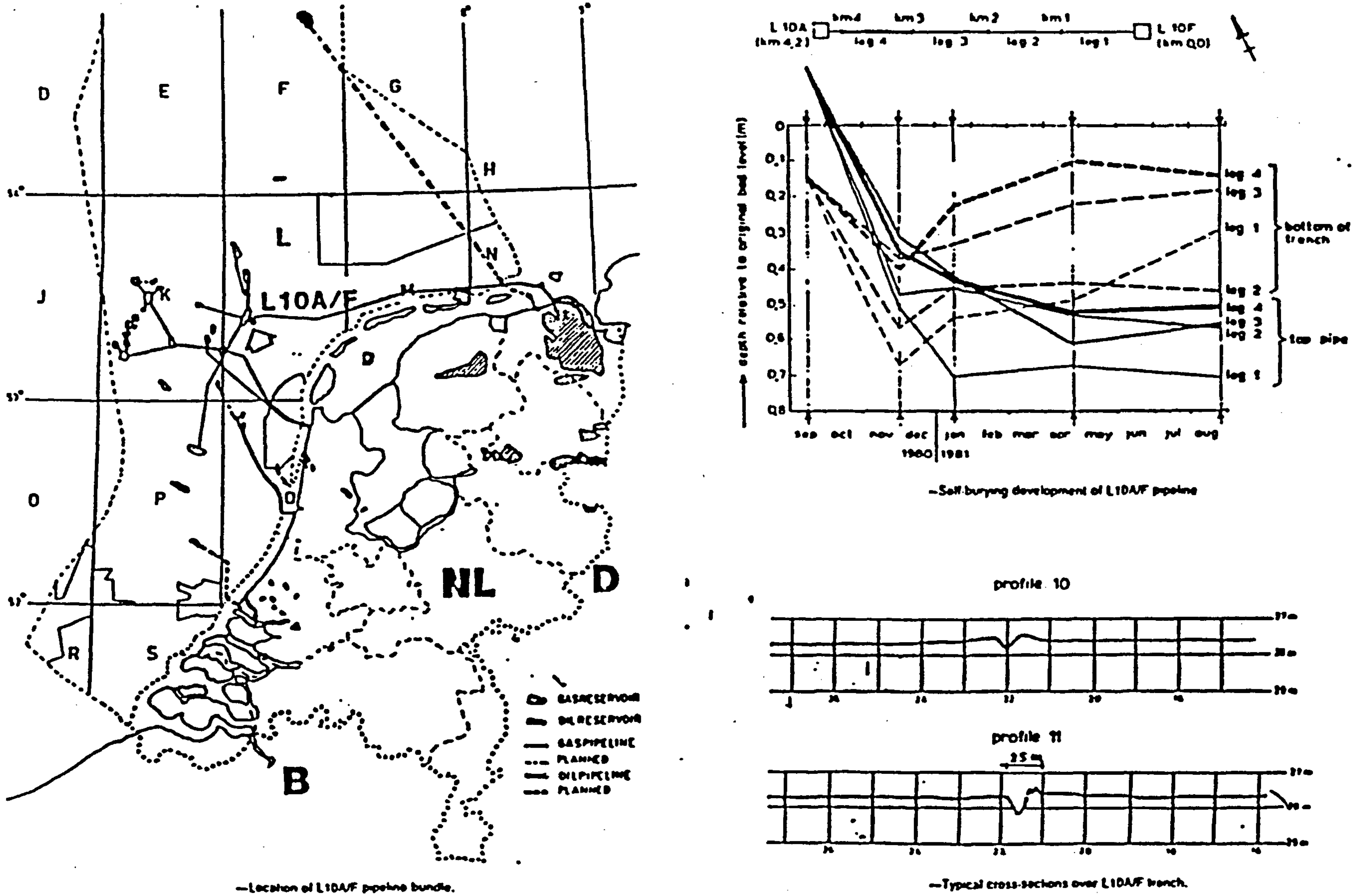
In the North Sea, a submersible survey of BP's West Sole-Wasington 40.6 cm (16 in) gas pipeline in June, 1973 indicated that a maximum span of 40 m (131 ft) with a scour depth of 12.7 to 15.2 cm (5 to 6 in) was observed, while the deepest span of 1 m (3.28 ft) has an overall length of 11 m (36 ft) (Ells, 1975). The seabed in this area was primarily sand overlaying stiff clays which contained boulders, and both scour and building of deposits at the pipeline had occurred between 1972 and 1973.

During similar surveys of BP's pipeline from the Forties Field to Cruden Bay in 1973, 38 separate spans were found in one of the sand wave areas prior to trenching of the pipe. The maximum span length was 90 m (295 ft) with a depth of 1.2 m (4 ft) and the maximum span depth was 1.3 m (4.2 ft) with a span length of 40 m (131.2 ft) (Ells, 1975). Special attention was given to these areas during the trenching operations. In 1974, submersible surveys of the pipeline before trenching indicated a large number of spans in the sandwave areas up to maximum length of 60 m (197 ft) with a depth below the pipe of 1 m (3.28 ft) (Ells, 1975). In one sandwave area, the first trenching pass had satisfactorily removed all the spans, but in the area of stones, there were minor spans, caused by the pipe having been laid over the stones, typically 9.8 m (32 ft) long and 20 cm (8 in) deep (Ells, 1975).

A field study of the behaviour of pipes laid directly on top of the sea floor by the Hydraulics Research Station (1973) found that considerable undercutting occurred over greater parts of the pipe lengths. As a result of the undercutting, the pipes rested in scour trenches and were left only supported on sand bars at regular intervals. Tests with a flexible pipe produced very little spanning, as the pipe settled gently and uniformly along its length until a stable position was obtained.

Actual measurement of pipeline self-burial in the field was accomplished by Hulsbergen (1984). Figure 25 indicates pipelines whose top-most elevations and bed level elevations were tracked for a year off of the Netherlands. Self-burial of the pipelines was evident. Figure 25b shows the progression of elevations for pipeline L10-A. Figure 26 shows that most of the pipelines in that area self-buried within 8 months. The depth of water was around 27.5 meters or 90 feet. Pipeline L10-A shows a definite eventual equilibrium depth of -0.6 meters above the top of the pipeline.

Figure 25: Self-burial of pipelines off the Netherlands. (From Hulsbergen, 1984)



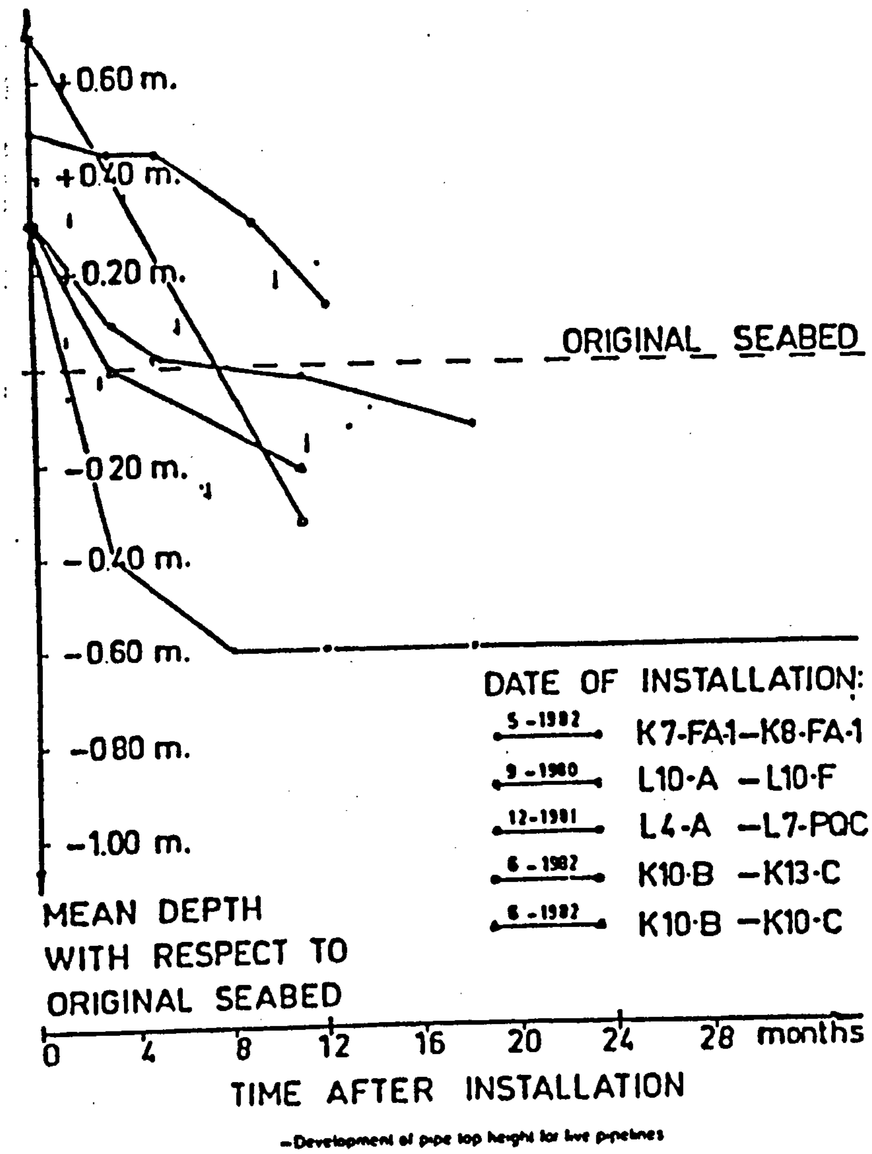


Figure 26: Time durations of self-burial in the field.
(From Hulsbergen, 1984)

For the study area of Mandalay Beach, sidescan sonar studies of the previous pipeline between Gina platform and the Mandalay Beach Power Station by Pelagos Corp. (Jan. 1984, Jan. 1986, Nov. 1986, and August 1988) and Intersea Research Corp. (Dec. 1982) indicated 99% burial of the pipeline along its entire length especially in the 3000 foot zone in question. The surveys between 1984 and 1988 indicated an extension of the burial length of 1000 feet near platform Gina while the power cable laid at the same time showed complete burial for 6200 feet in the similar area. At no time were unsupported spans identified.

These field observations tend to confirm the ranges of self-burial depths and rates projected for the Gina Pipeline.

Conclusions:

The pipeline under study has a high potential for rapid self-burial from the MLLW line to 3000 feet offshore. The self-burial of the pipeline is due in part to the heavy specific weight of the pipeline, the wave-current climate, and the local geology and sedimentology of the Mandalay Beach area. Offshore migration of sediment shows a steadily increasing bed level in the area. Therefore, the depth of burial expected over the next one to sten years is between 2 and 4 feet. Eventual breakout of the pipeline is unlikely since there is an annual increase in bed level elevation.

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Appendix A: Laboratory Experiments of Mao (1986)

[Reprinted]

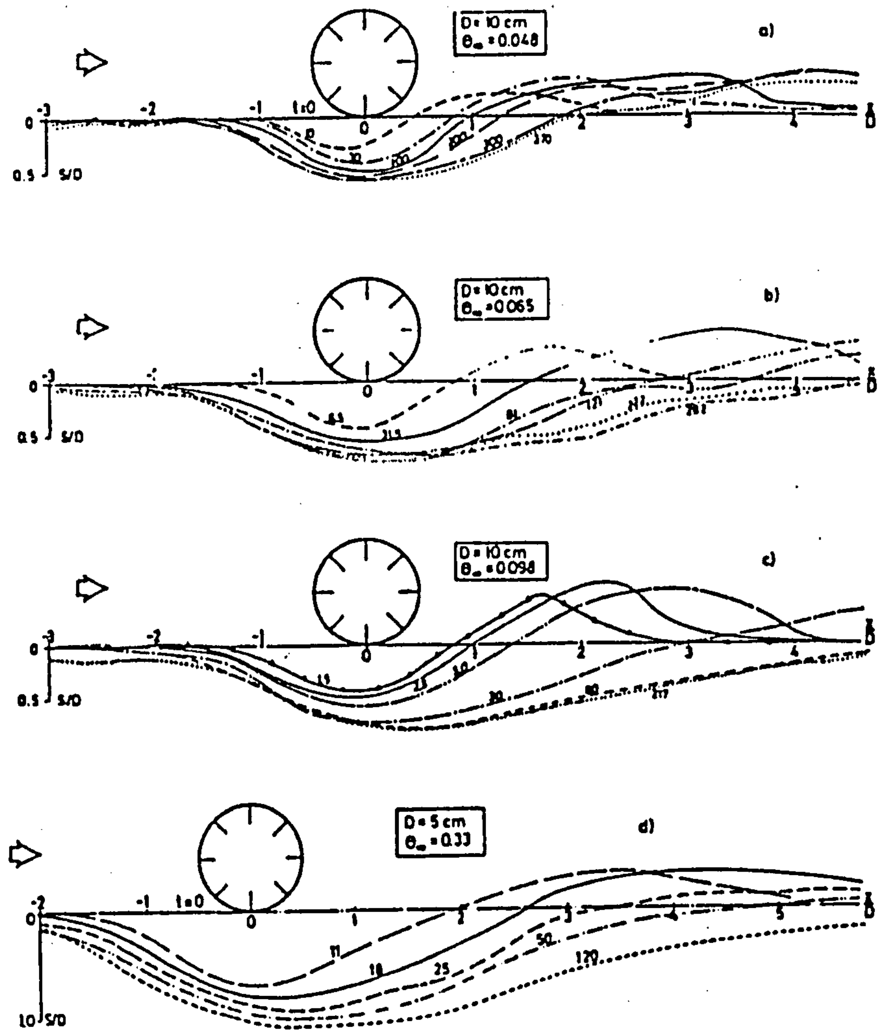


Fig. Development of bed profile with time (in min.), $e_0/D = 0$; for (a)(b)(c), $H_\infty = 0.35$ m, D = 10 cm; for (d), $H_\infty = 0.23$ m, D = 5 cm.

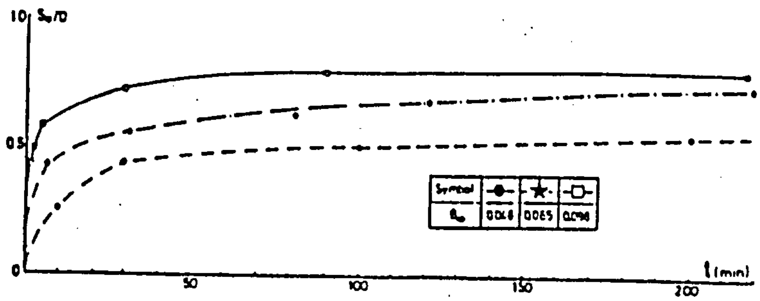


Fig. 2-31 The scour process for low θ_∞, $e_0/D = 0$, D = 10 cm.

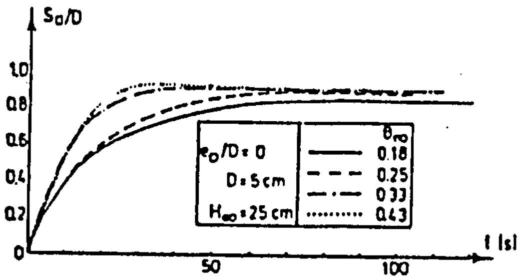


Fig. 3 The scour process for high θ_∞, $e_0/D = 0$, D = 5 cm.

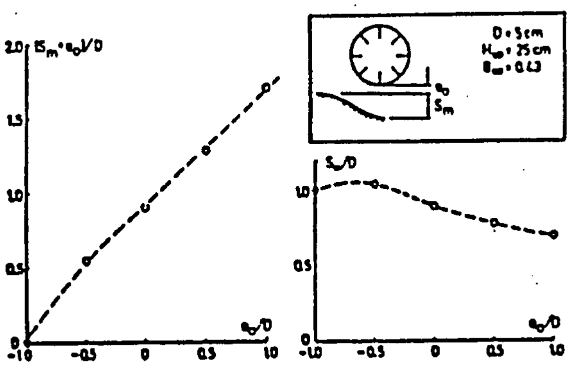


Fig. 4 ~~2-30~~ The equilibrium scour depth S_m versus the initial gap e_0, for $\theta_\infty = 0.43$, D = 5 cm.

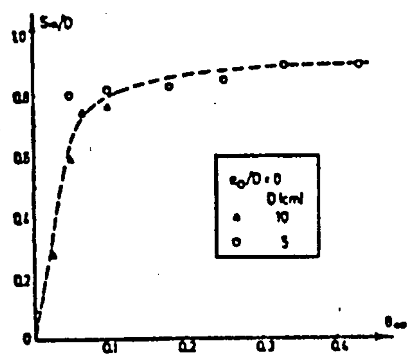


Fig. 5 The equilibrium scour depth S_m versus θ_∞, for $e_0/D = 0$.

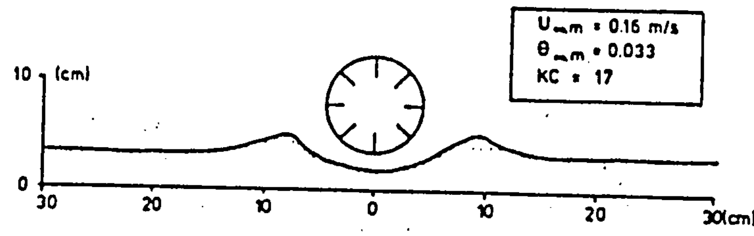


Fig. 6 Equilibrium scour bed profile for the clear-water case, D = 90 mm.

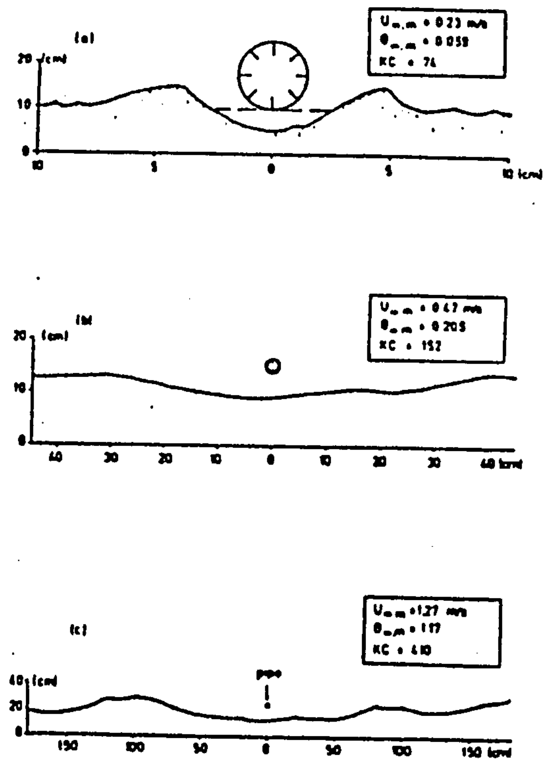
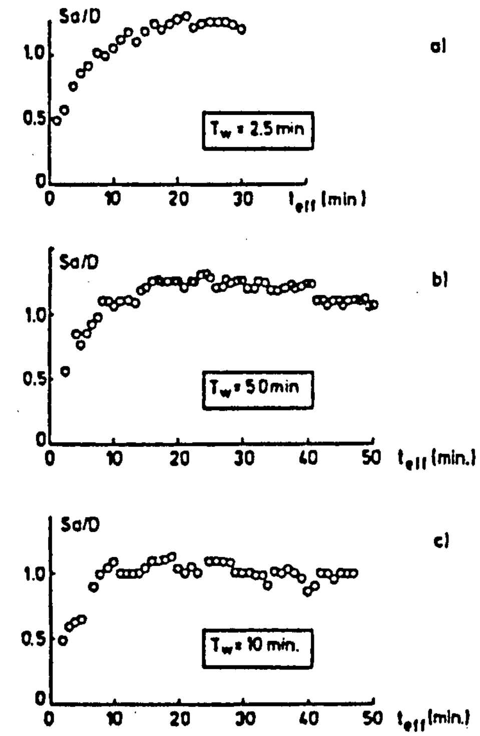
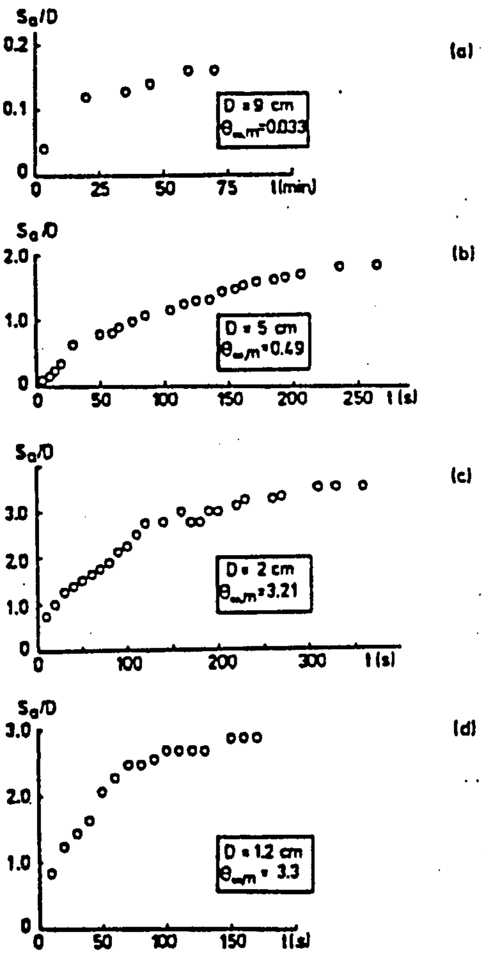


Fig. 7 Equilibrium scour bed profiles in the presence waves, D = 30 mm.



The scour processes for different T_w, when $\theta_{\infty,m}$ = 0.098, D = 5 cm, e_0/D = 0.



Scour processes for three different flow stages. (a) The clear water scour. (b) In the presence of bed waves. (c) (d) In no-bed-waves flow stage.

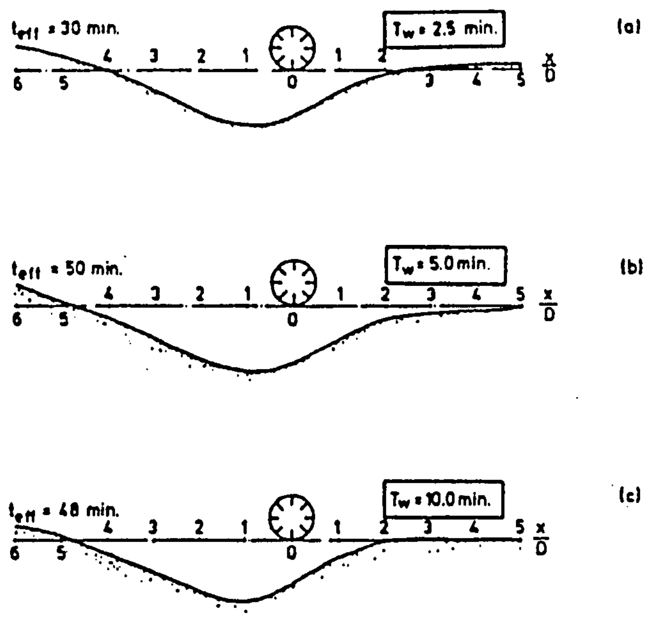


Fig. The equilibrium scour bed profiles for different T_w, when $\theta_{w,m}$ = 0.098, D = 5 cm, e_0/D = 0.

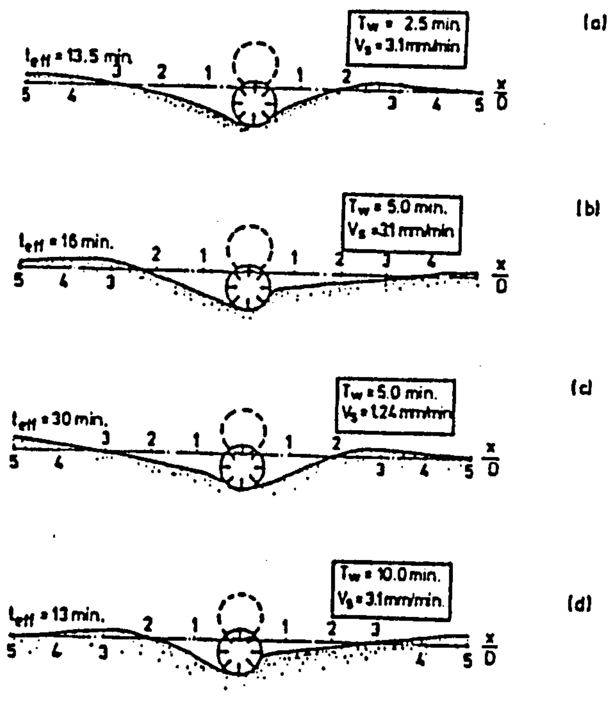


Fig. The eroded bed profiles under a sagged pipe exposed t the two-directional flow, when $\theta_{w,m}$ = 0.098, D = 5 cm, e_0/D = 0.

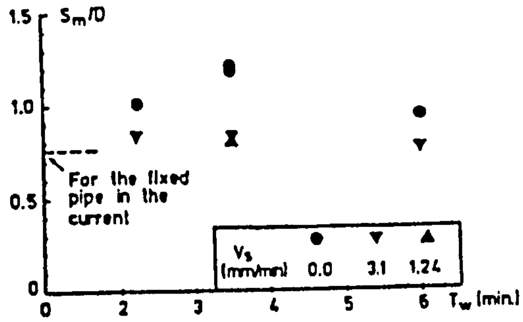


Fig.   The equilibrium scour depth versus T_w for the fixed pipe and the sagged pipe.

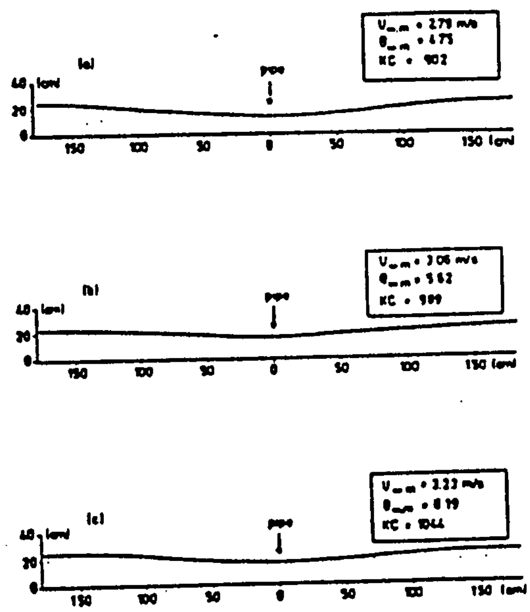


Fig.   Equilibrium scour bed profiles in the no-bed-waves flow stage, D = 30 mm.

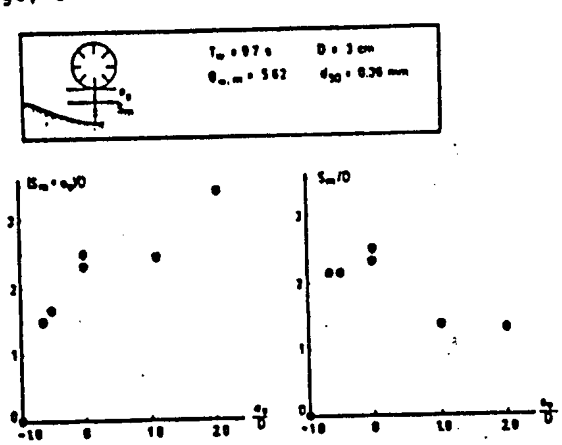


Fig.   Scour depth versus the initial gap in the no-bed-waves flow stage.

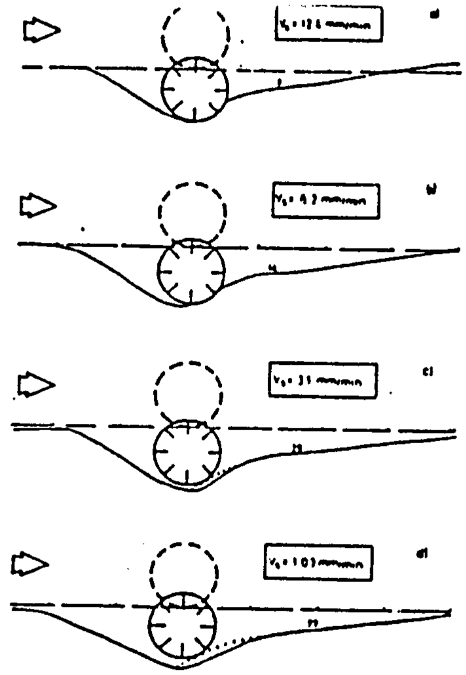


Fig. The scour bed profiles for θ_∞ = 0.15, e_0/D = 0 with boundary situation "A".
—— : the mean value;
... : the local longitudinal profile below the pipe.
(number in min.).

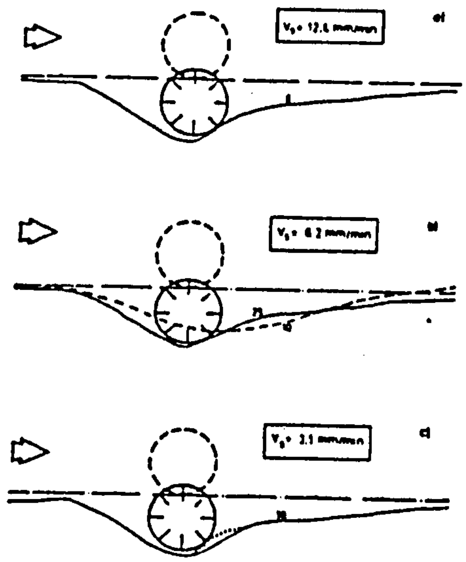


Fig. . The scour bed profiles for θ_∞ = 0.15, e_0/D = 0 with boundary situation "B".
—— : the mean value;
... : the local longitudinal profile below the pipe.
(number in min.).

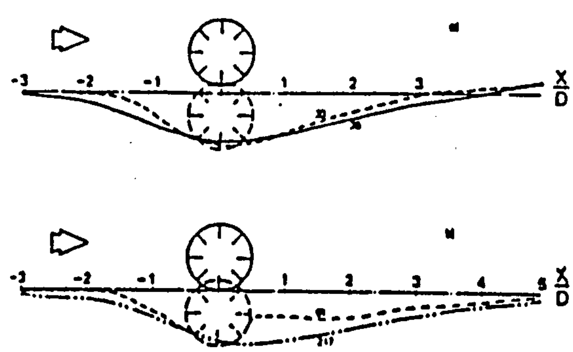


Fig. The comparison of the eroded bed profiles between the sagged-pipe case and the fixed - pipe case for θ_∞ = 0.098. (number in min.).
—— : the fixed pipe, e_0/D = 0.1;
-·-·- : fixed pipe, e_0/D = 0;
- - - - : the sagged pipe, e_0/D = 0.1,
V_s = 1.55 mm/min.

Appendix B: Bed Elevation Profiles

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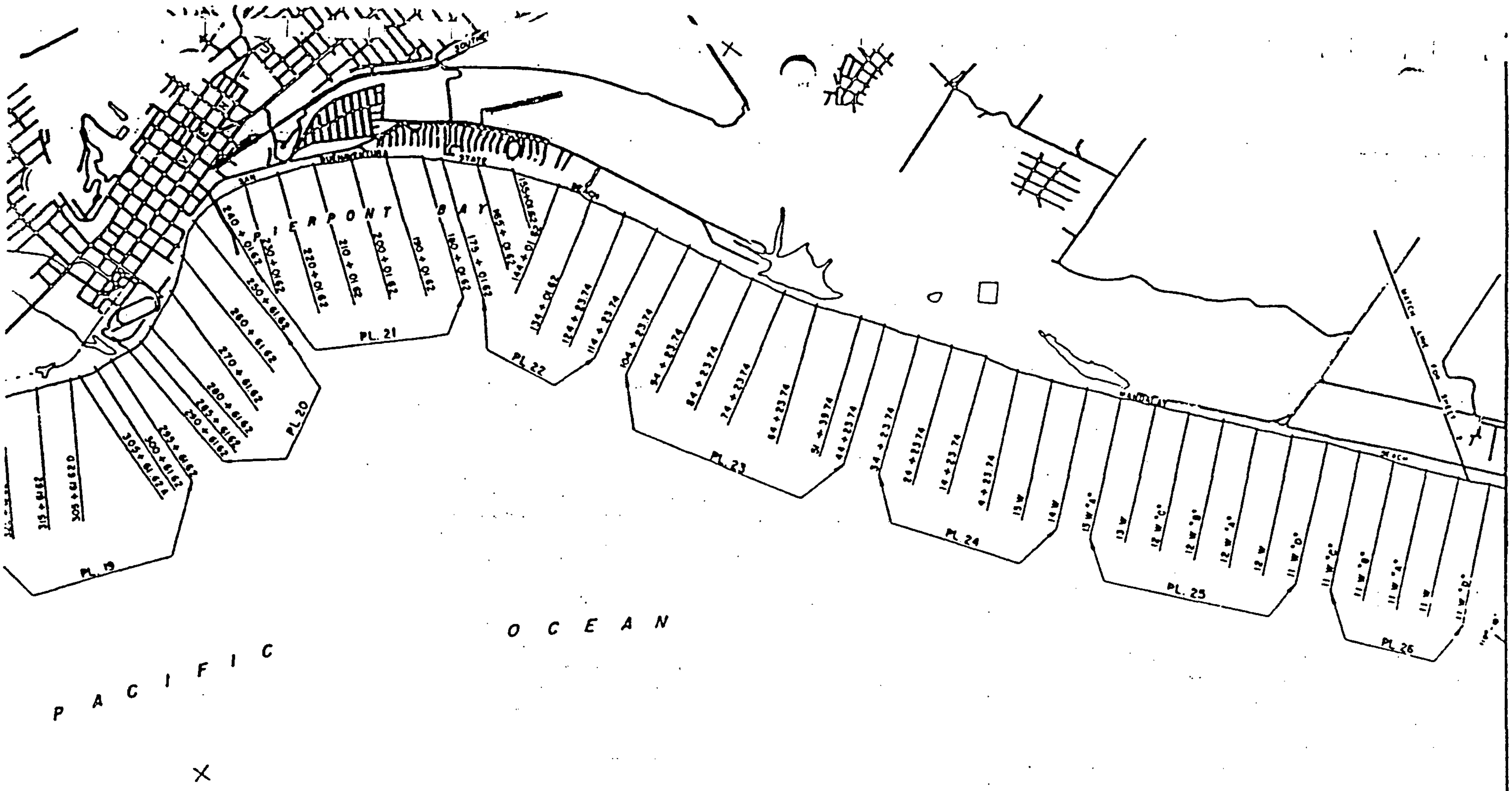


STATE OF CALIFORNIA COOPERATIVE BEACH EROSION CONTROL STUDY

APPENDIX XII

VENTURA AREA

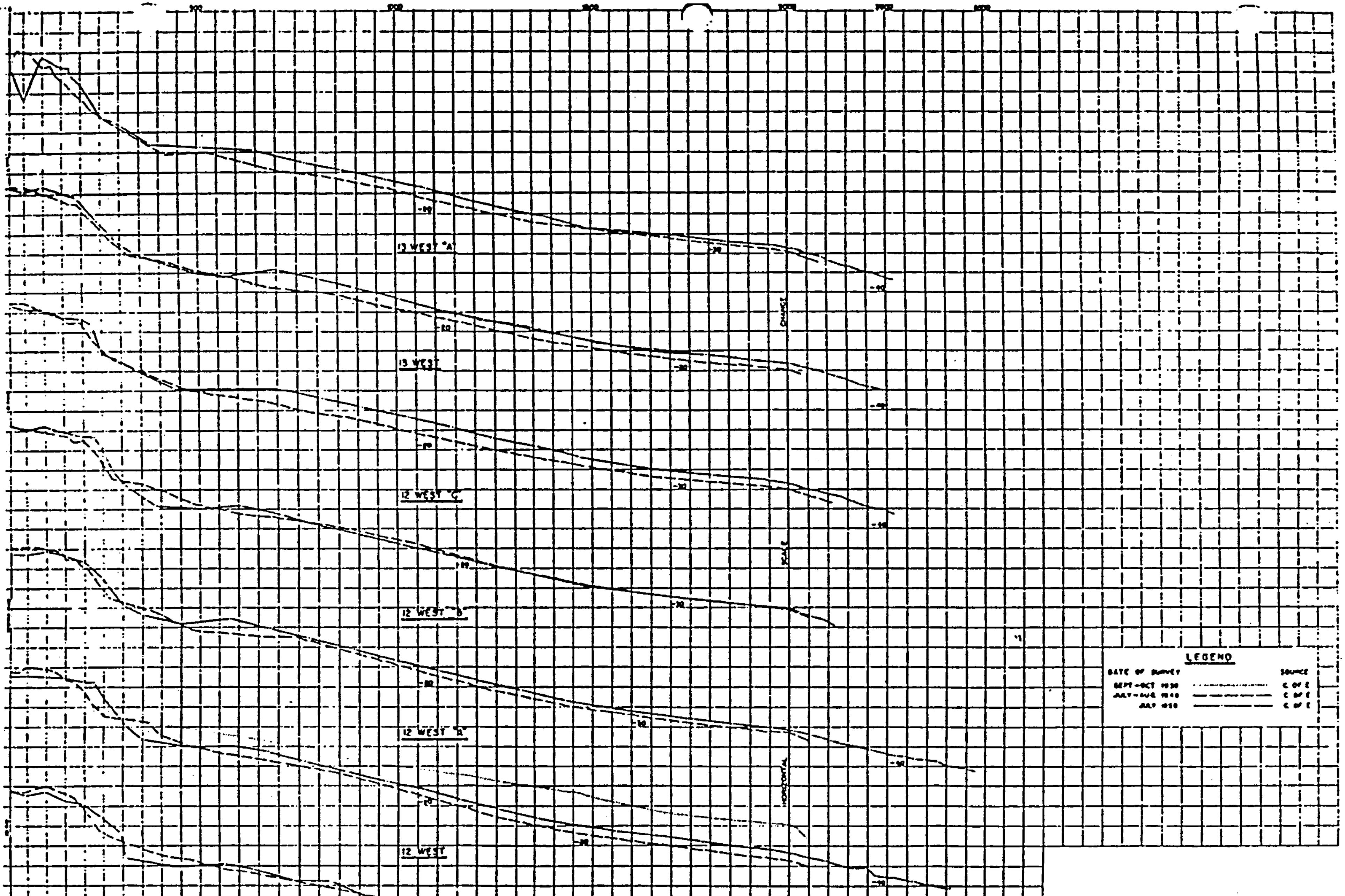
LOCATION OF PROFILES

SHEET 1 OF 2

GRAPHIC SCALE 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

OFFICE OF THE DISTRICT ENGINEER, LOS ANGELES, CALIF., JAN. 1960

PREPARED UNDER THE DIRECTION OF



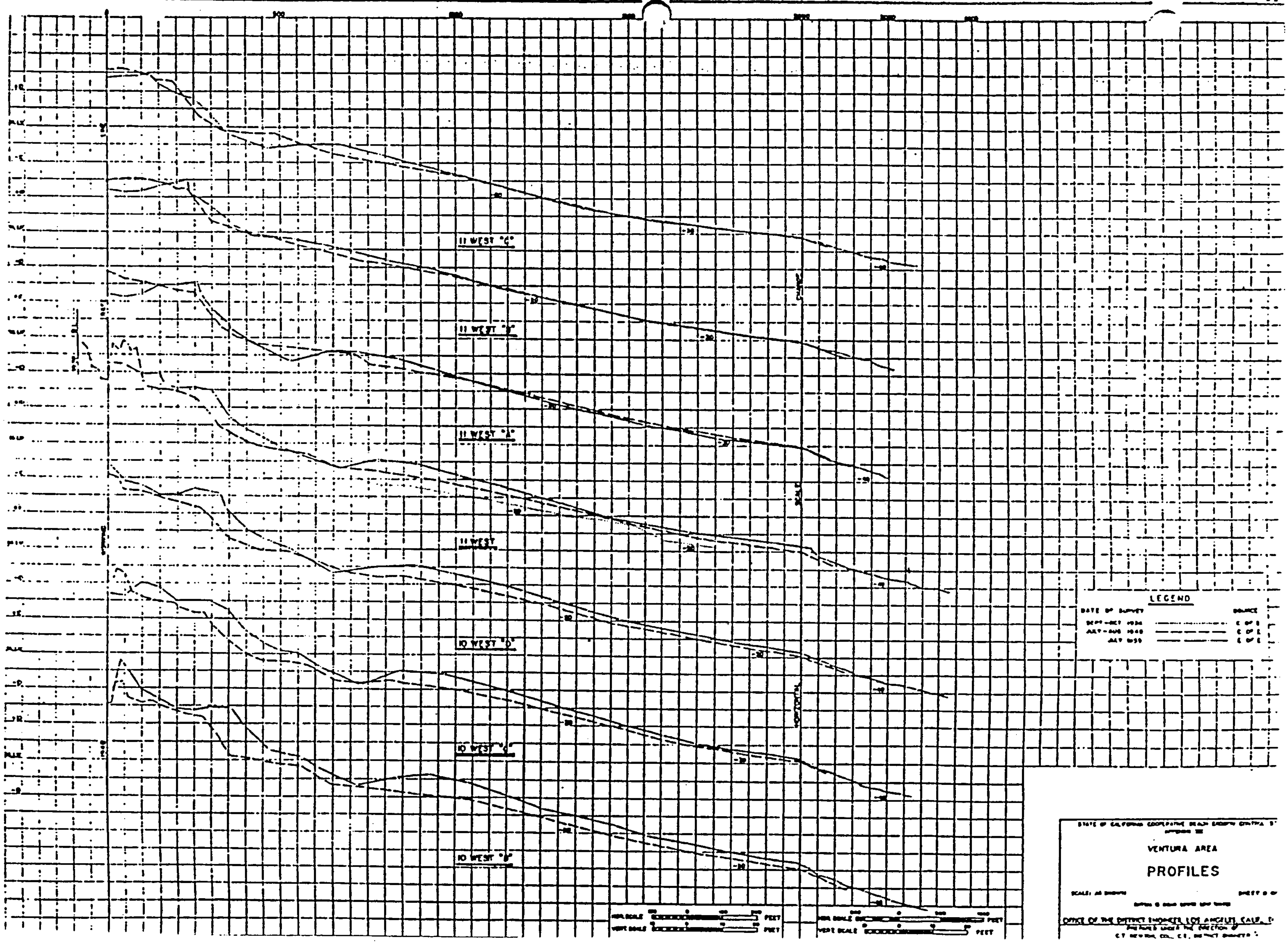
STATE OF CALIFORNIA COOPERATIVE BEACH EROSION CONTROL STUDY

VENTURA AREA

PROFILES

SCALE, AS SHOWN

OFFICE OF THE DISTRICT ENGINEER, LOS ANGELES, CALIF. DEC. 1950



STATE OF CALIFORNIA COOPERATIVE BEACH EROSION CONTROL STUDY

VENTURA AREA

PROFILES

OFFICE OF THE DISTRICT ENGINEER, LOS ANGELES, CALIF.

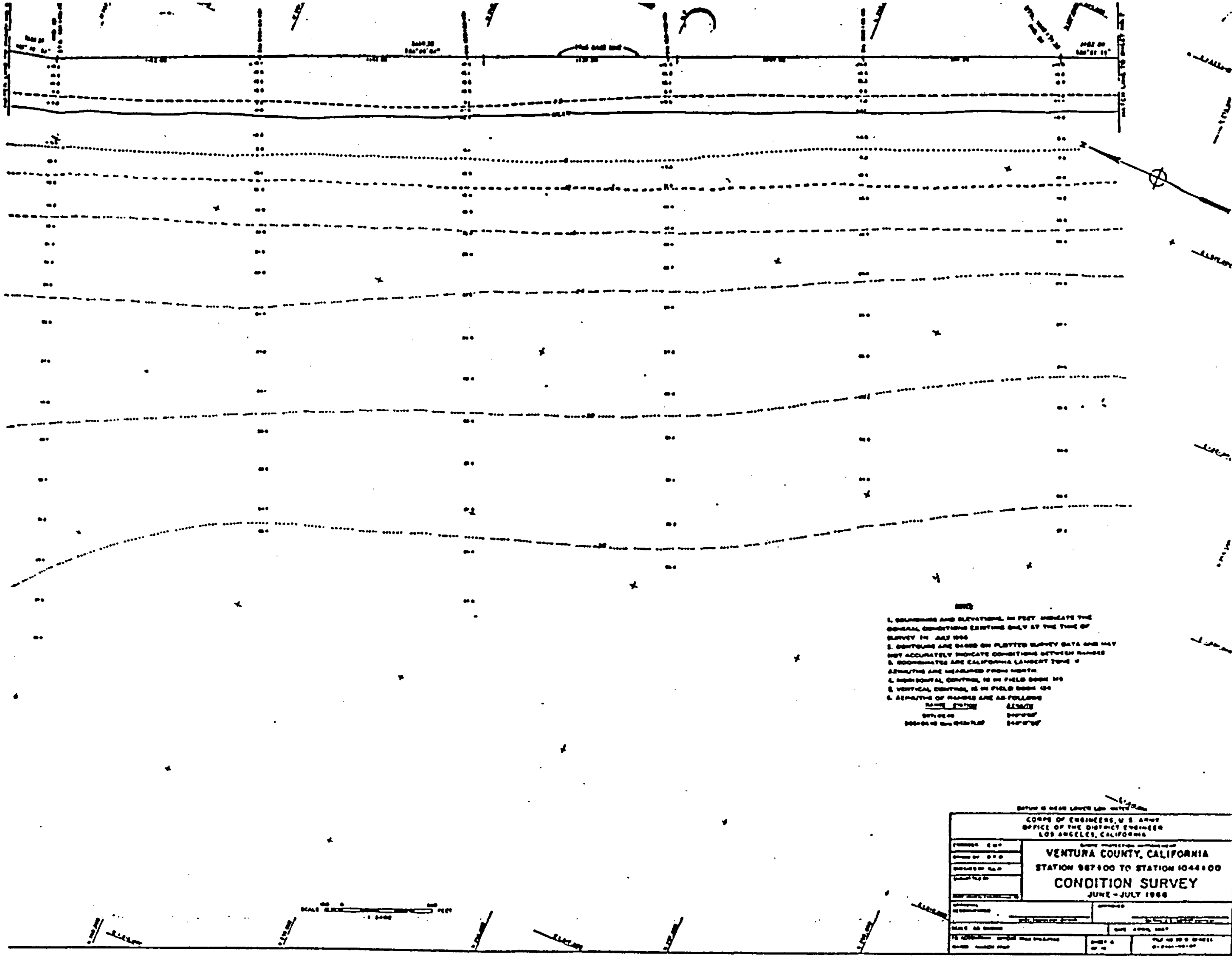

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
LOS ANGELES, CALIFORNIA
VENTURA COUNTY, CALIFORNIA
STATION 987+00 TO STATION 1044+00
CONDITION SURVEY
JUNE - JULY 1966

PLATE 19

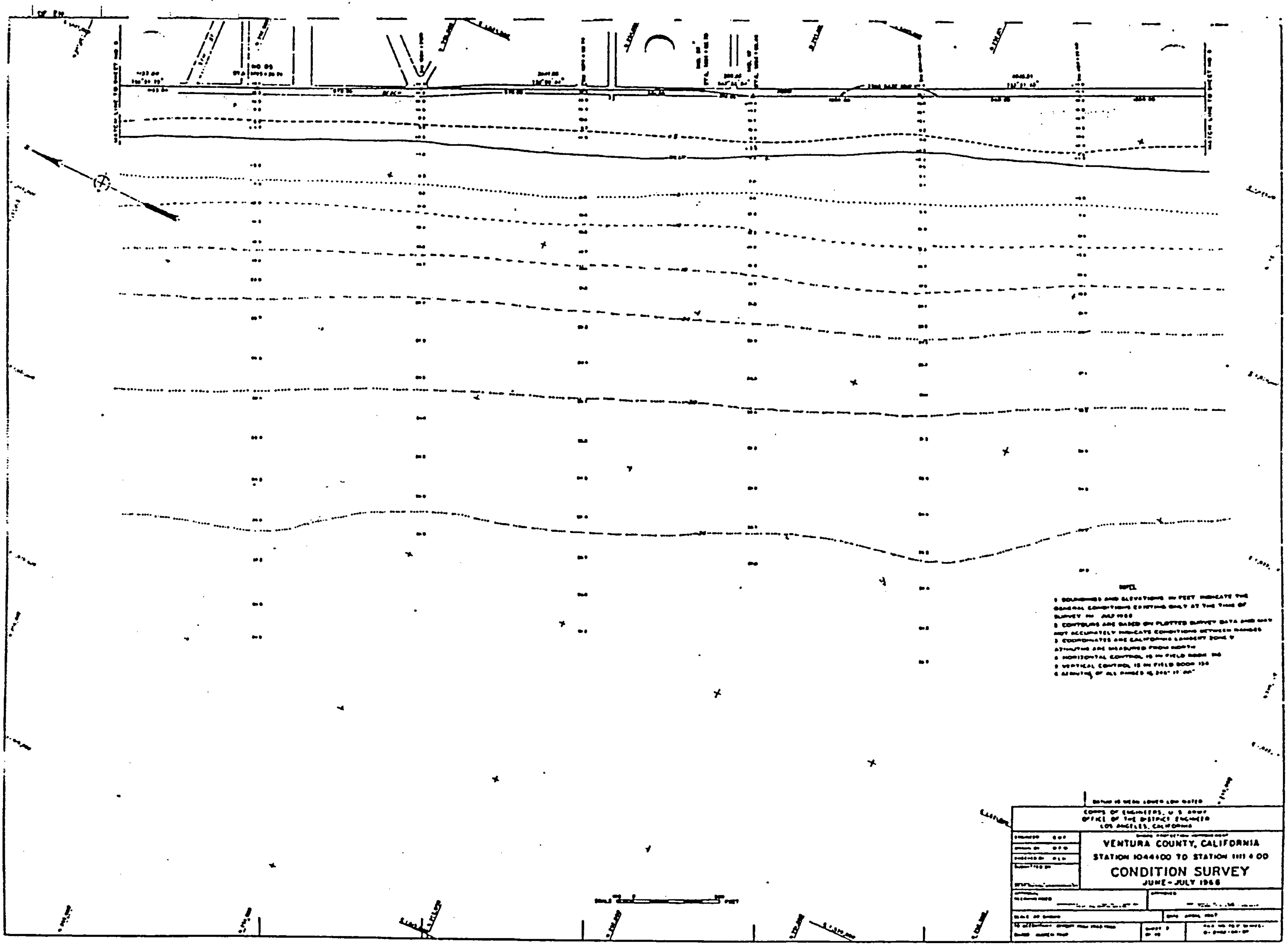
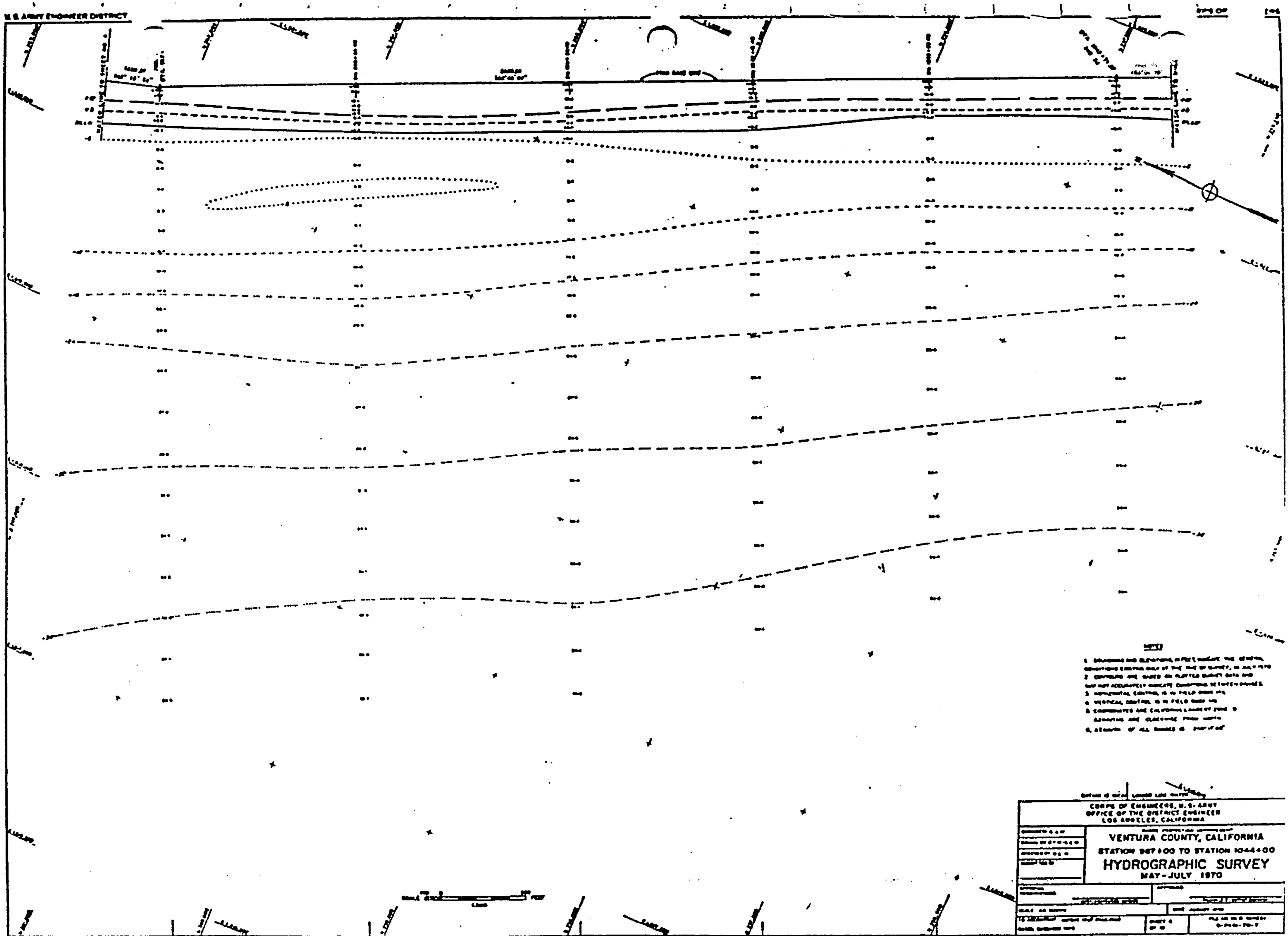
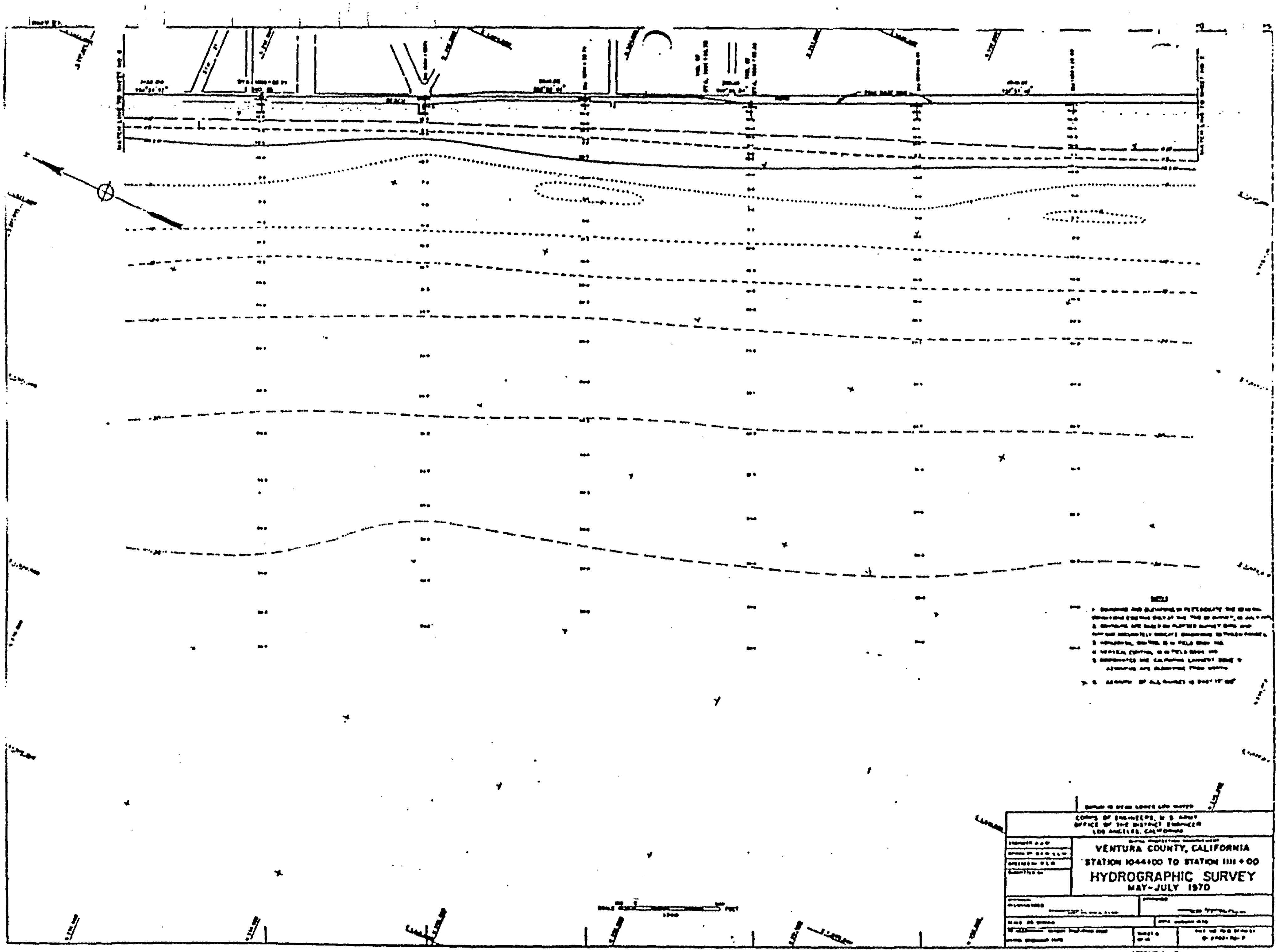

VENTURA COUNTY, CALIFORNIA
STATION 1044+00 TO STATION 1111+00
CONDITION SURVEY
JUNE - JULY

PLATE 20



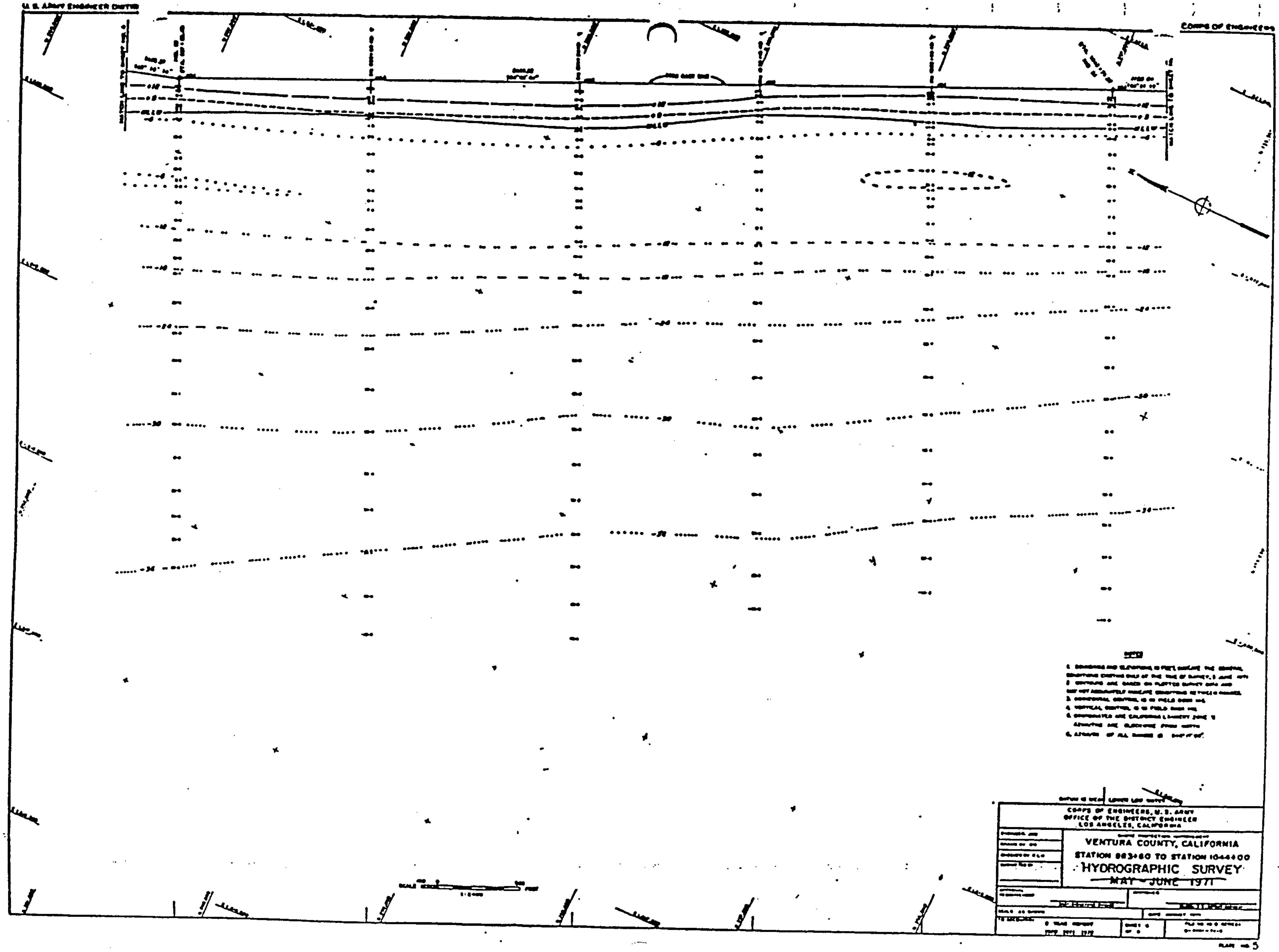
APPENDIX C

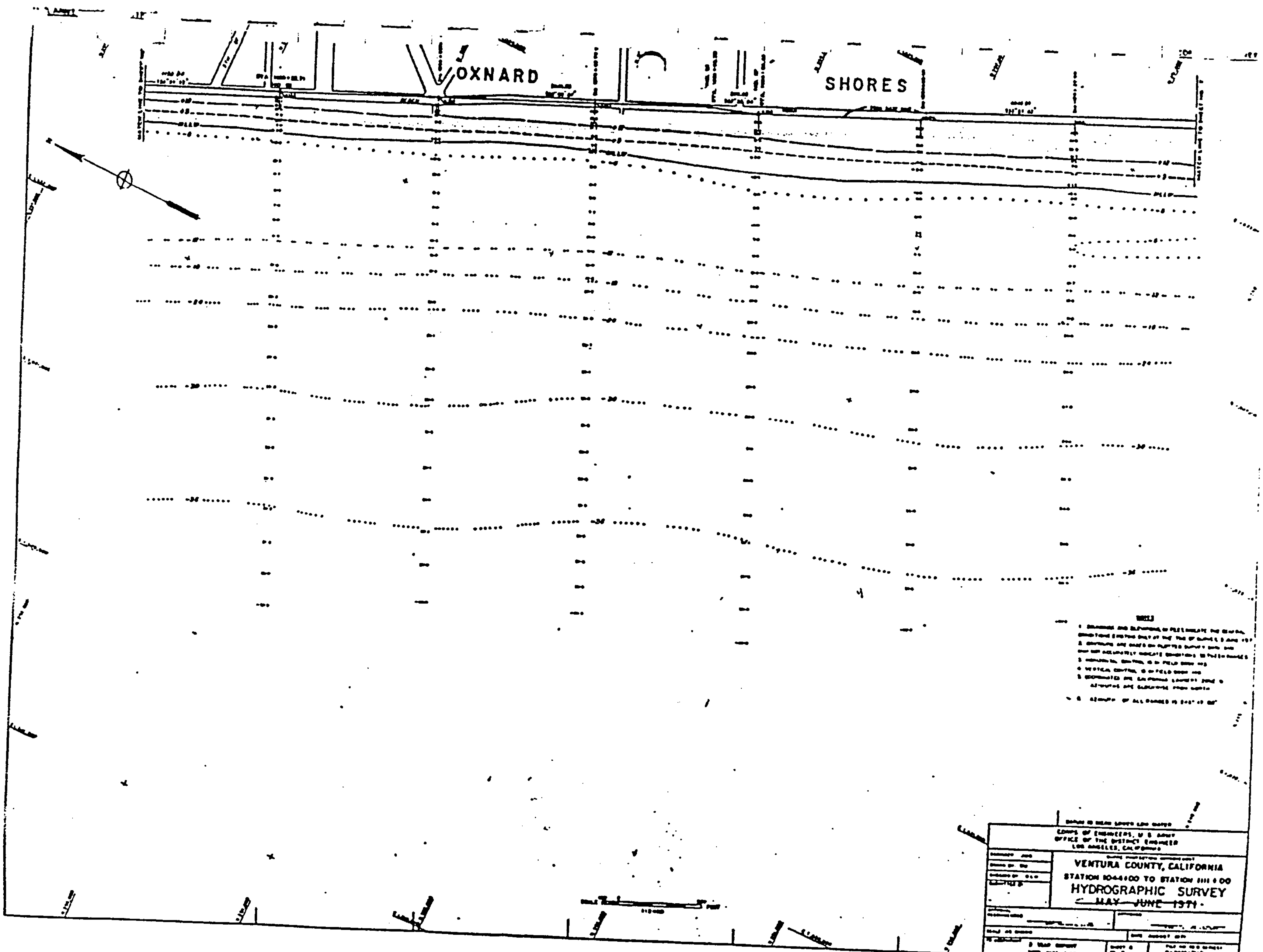
PLATE 10



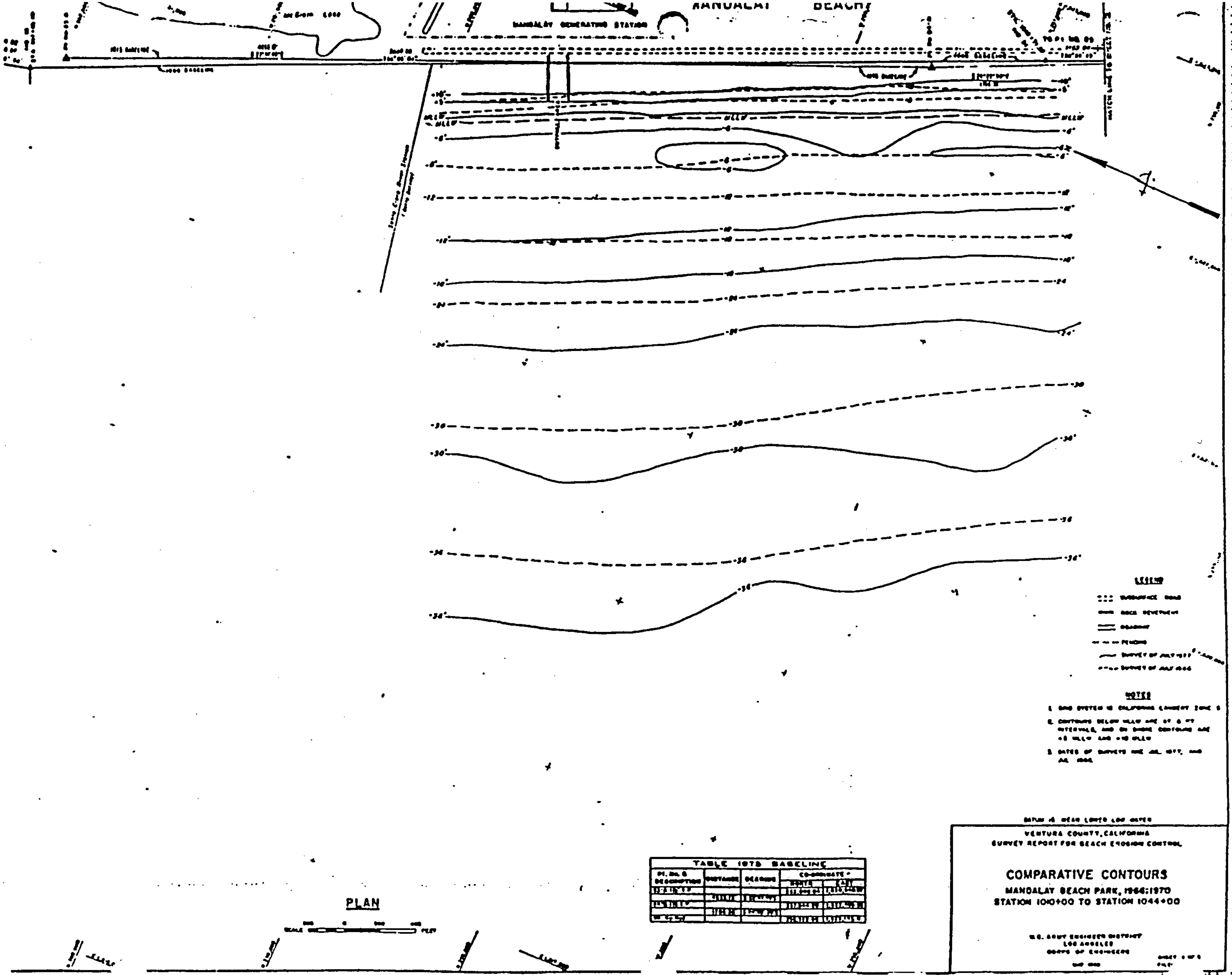
APPENDIX C

PLATE 11

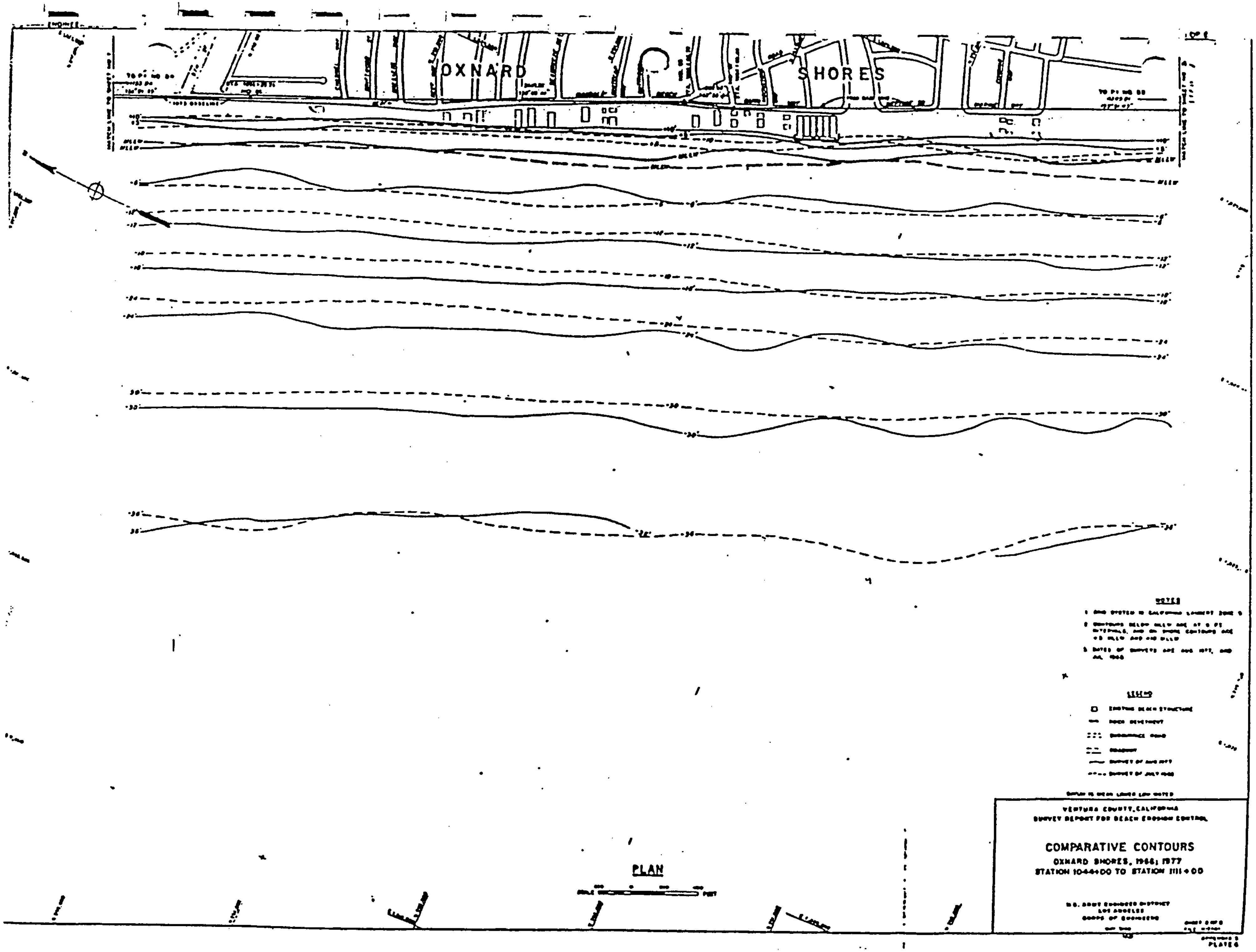

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
LOS ANGELES, CALIFORNIA
VENTURA COUNTY, CALIFORNIA
STATION 983+60 TO STATION 1044+00
HYDROGRAPHIC SURVEY
MAY - JUNE 1971
PLATE NO. 5



OXNARD
SHORES
CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
LOS ANGELES, CALIFORNIA
VENTURA COUNTY, CALIFORNIA
STATION 104+00 TO STATION 111+00
HYDROGRAPHIC SURVEY
MAY - JUNE 1971



MANDALAY BEACH
MANDALAY GENERATING STATION
PLAN
VENTURA COUNTY, CALIFORNIA
SURVEY REPORT FOR BEACH EROSION CONTROL
COMPARATIVE CONTOURS
MANDALAY BEACH PARK, 1966:1970
STATION 1010+00 TO STATION 1044+00


OXNARD
SHORES
PLAN
VENTURA COUNTY, CALIFORNIA
COMPARATIVE CONTOURS
OXNARD SHORES, 1966; 1977
STATION 1044+00 TO STATION 1111+00
PLATE 6

B.E.A.C.O.N. COASTAL SURVEY

COASTAL PROFILE MONUMENT DESCRIPTION

MONUMENT NO. 20
DESIGNATION: OXNARD SHORES
BEARING: 233° MAG.
ELEVATION: 13.701 FT (MLLW)

City: Oxnard

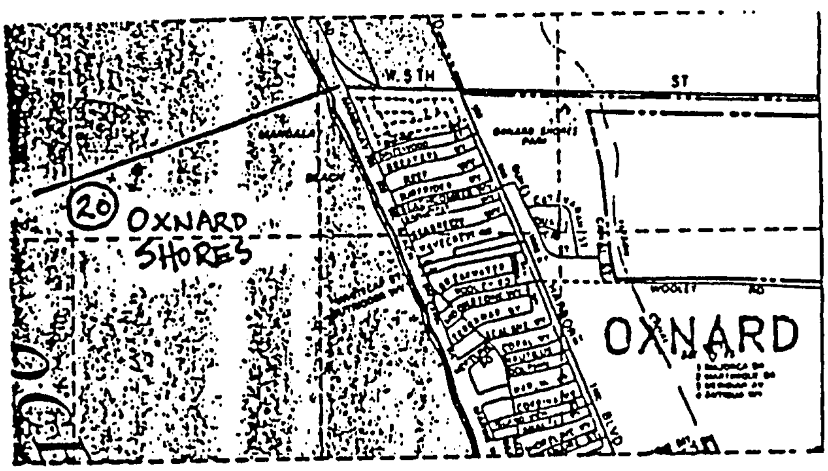
County: Ventura

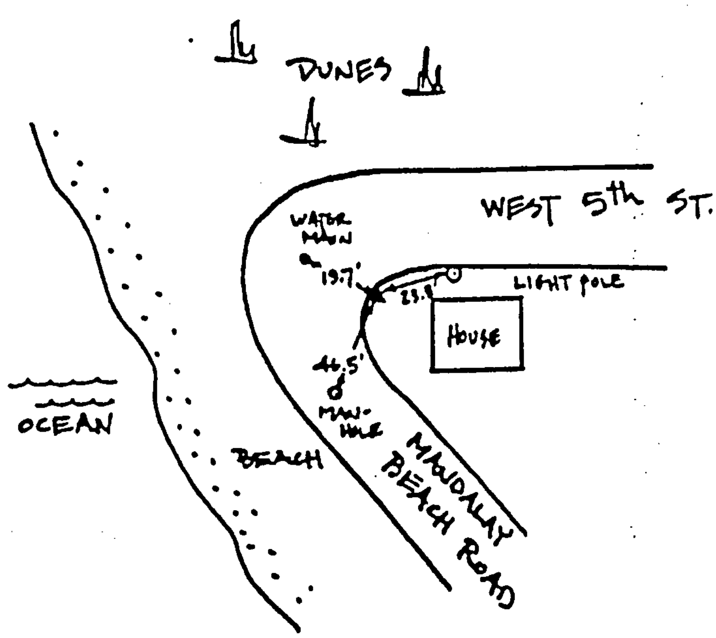
Date of Establishment: October 21, 1987

Description of Location: From Harbor Blvd., turn west on West Fifth Street and stop at junction of West Fifth Street and Mandalay Beach Road. Monument is located on sidewalk curb on southeast corner of intersection.

Description of Monument: Monument is 2.5 inch diameter brass disk set in concrete curb and stamped, "BEACON 20 1987".

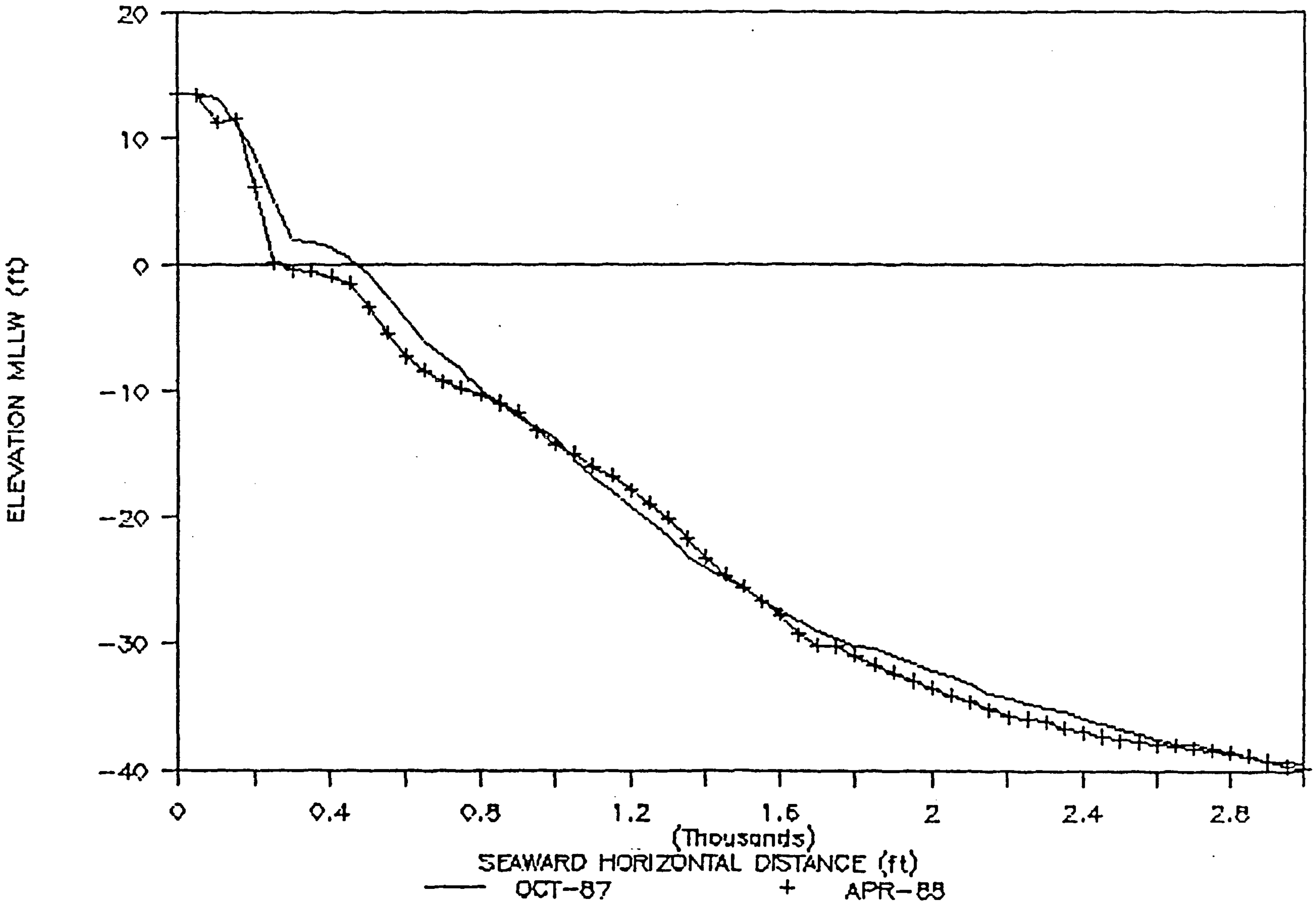
Map:

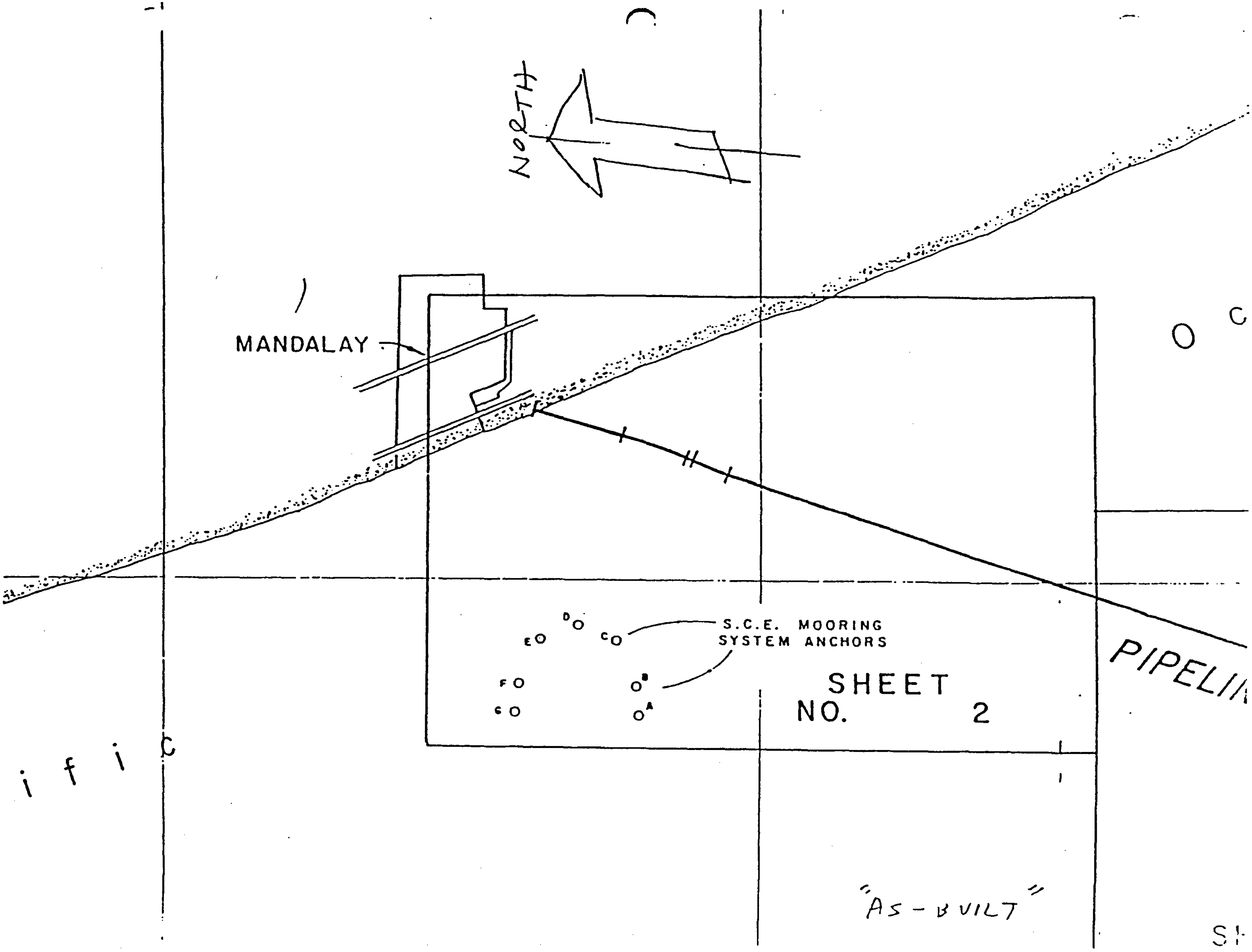


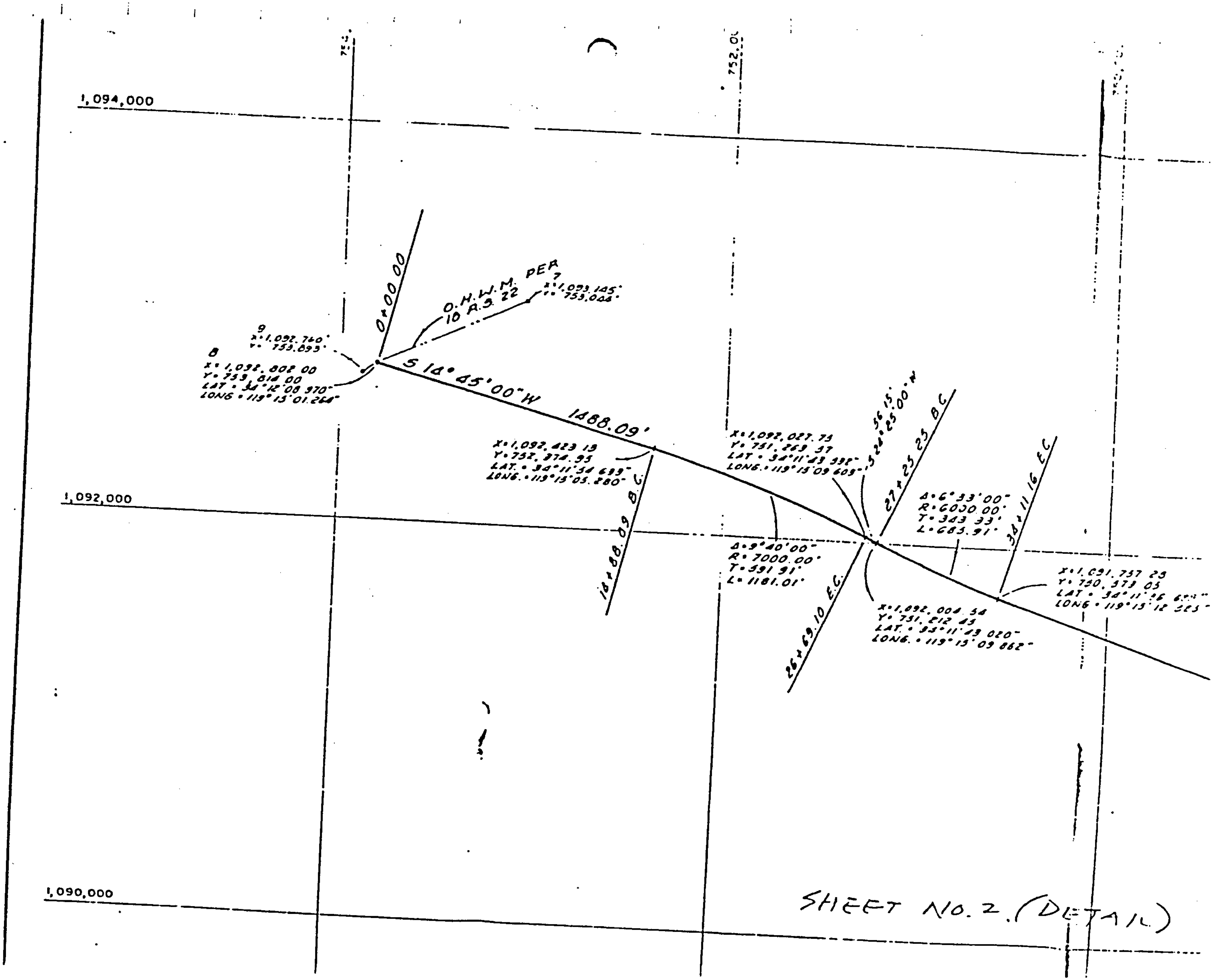


BEACON PROFILE 20

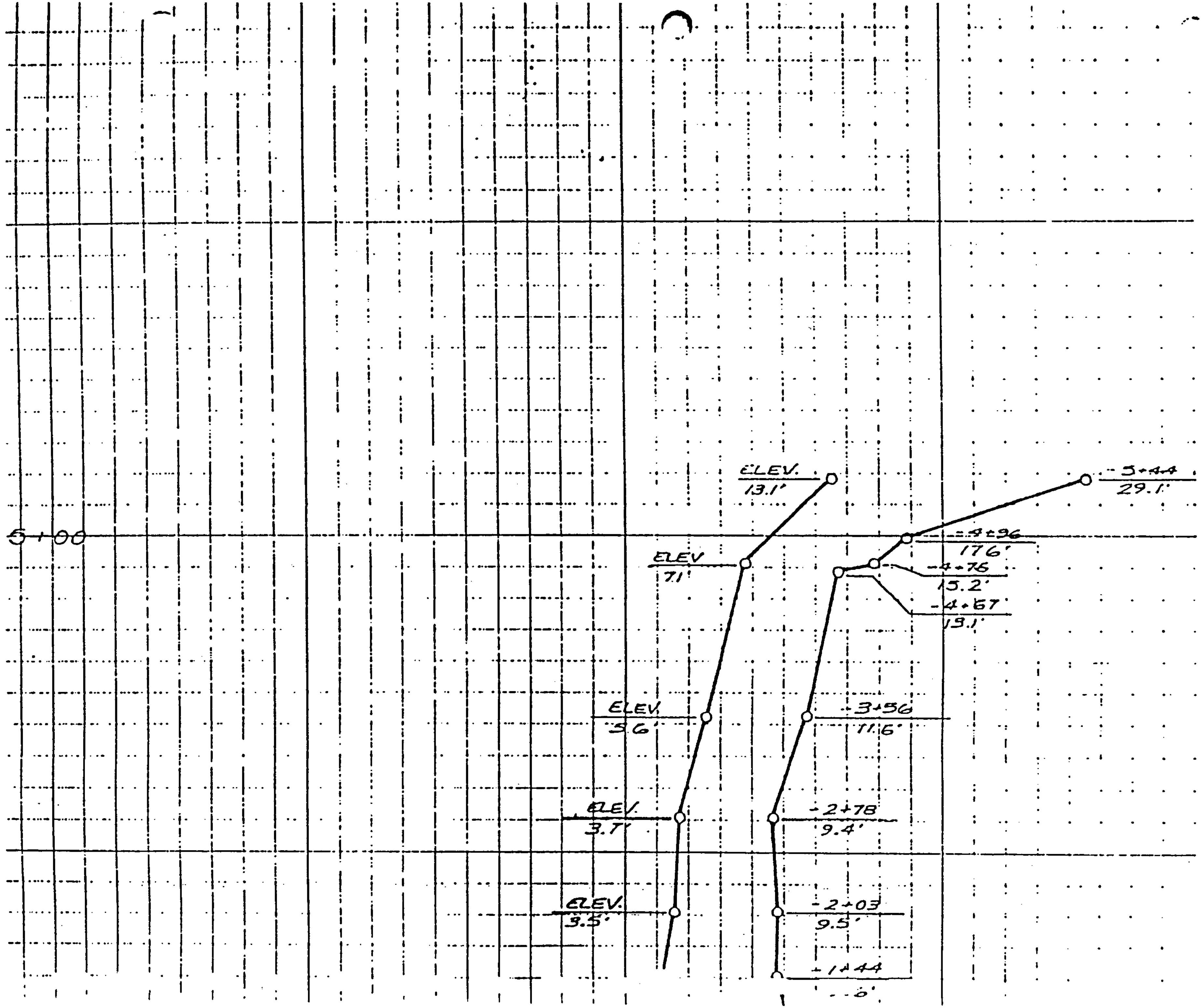
OXNARD SHORE



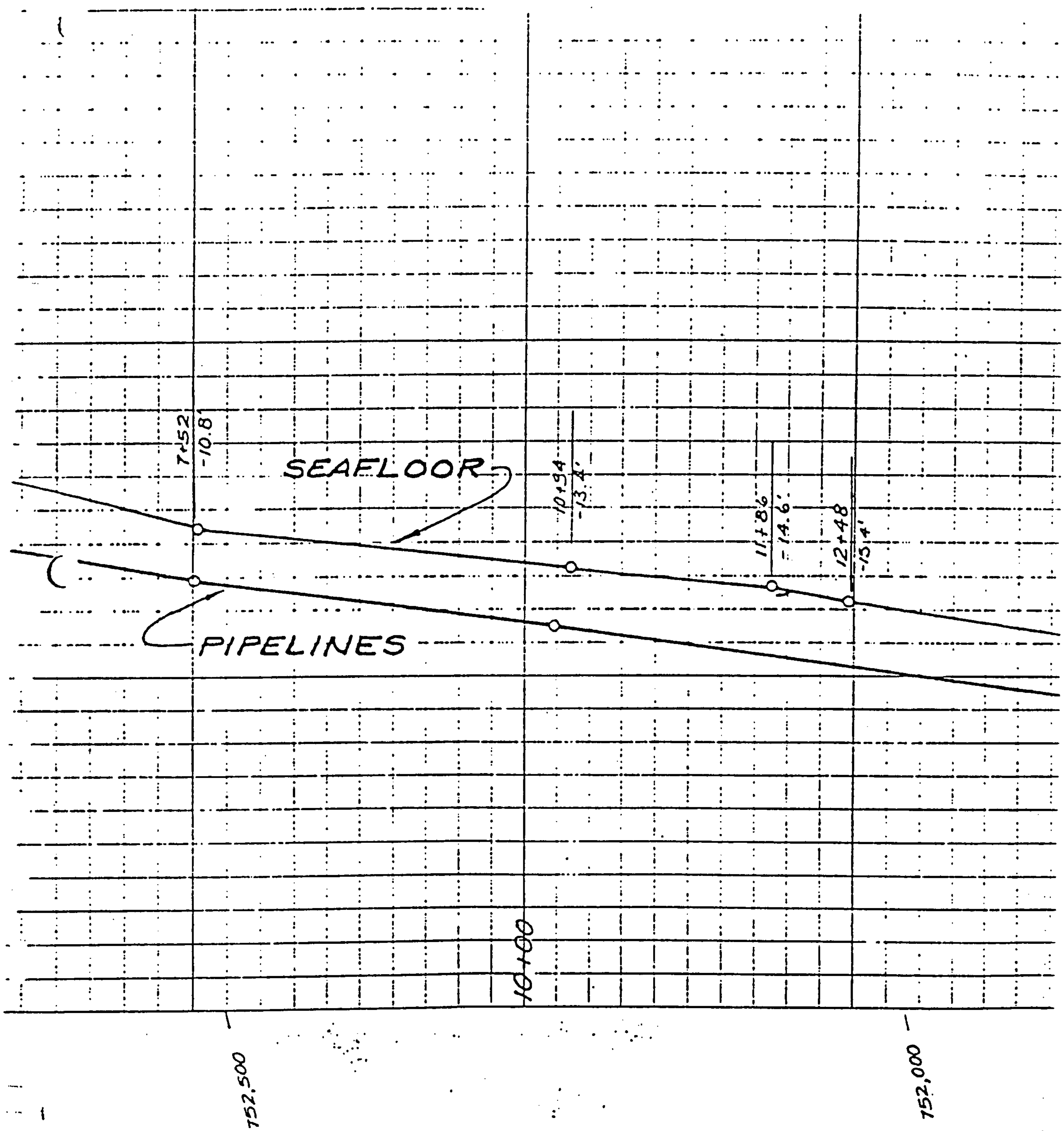

NORTH
MANDALAY
S.C.E. MOORING
SYSTEM ANCHORS
D
E
C
F
B
G
A
SHEET
NO. 2
PIPELIN
"AS-BUILT"
i f i c
O c



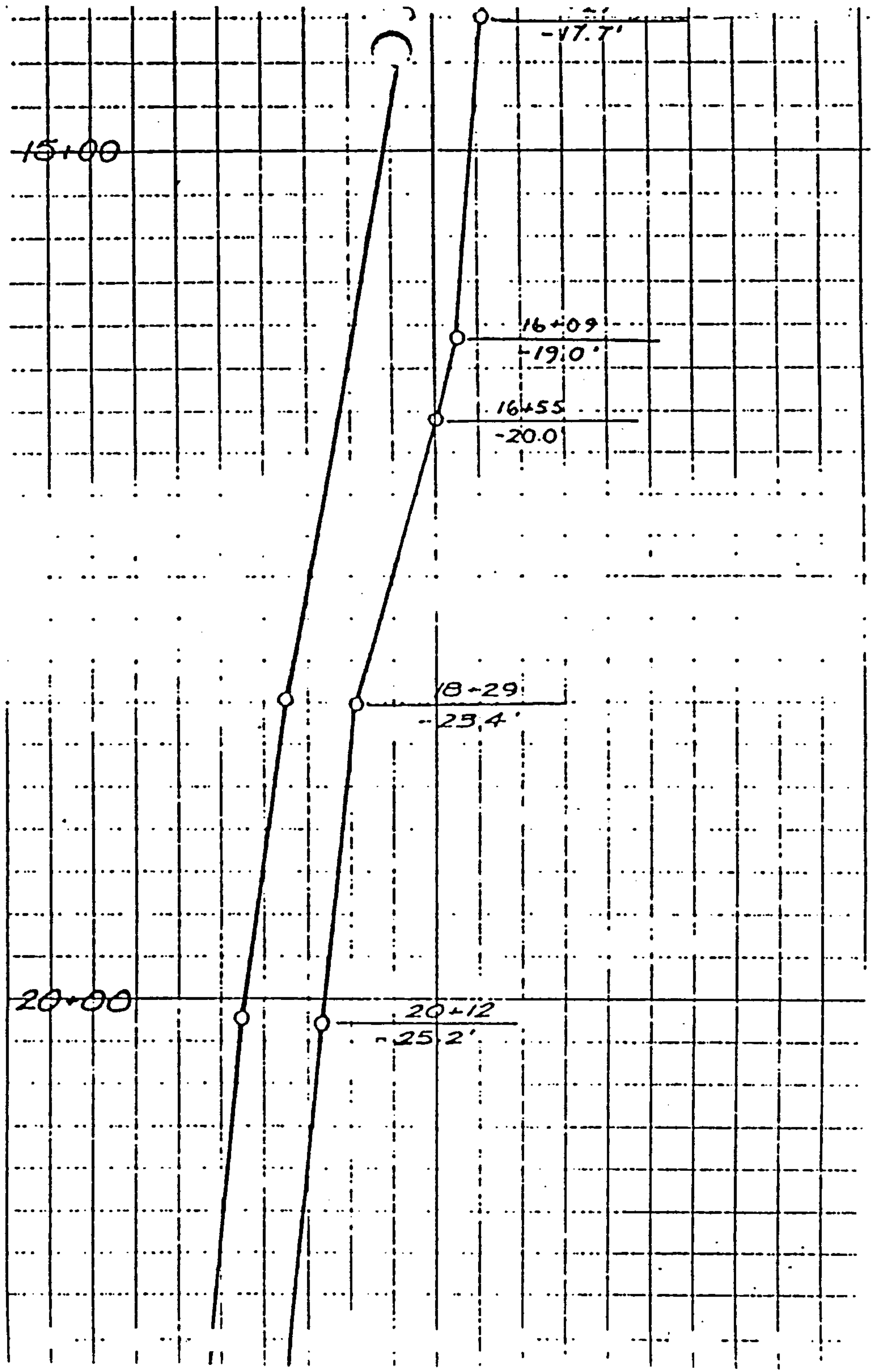
SHEET NO. 2 (DETAIL)



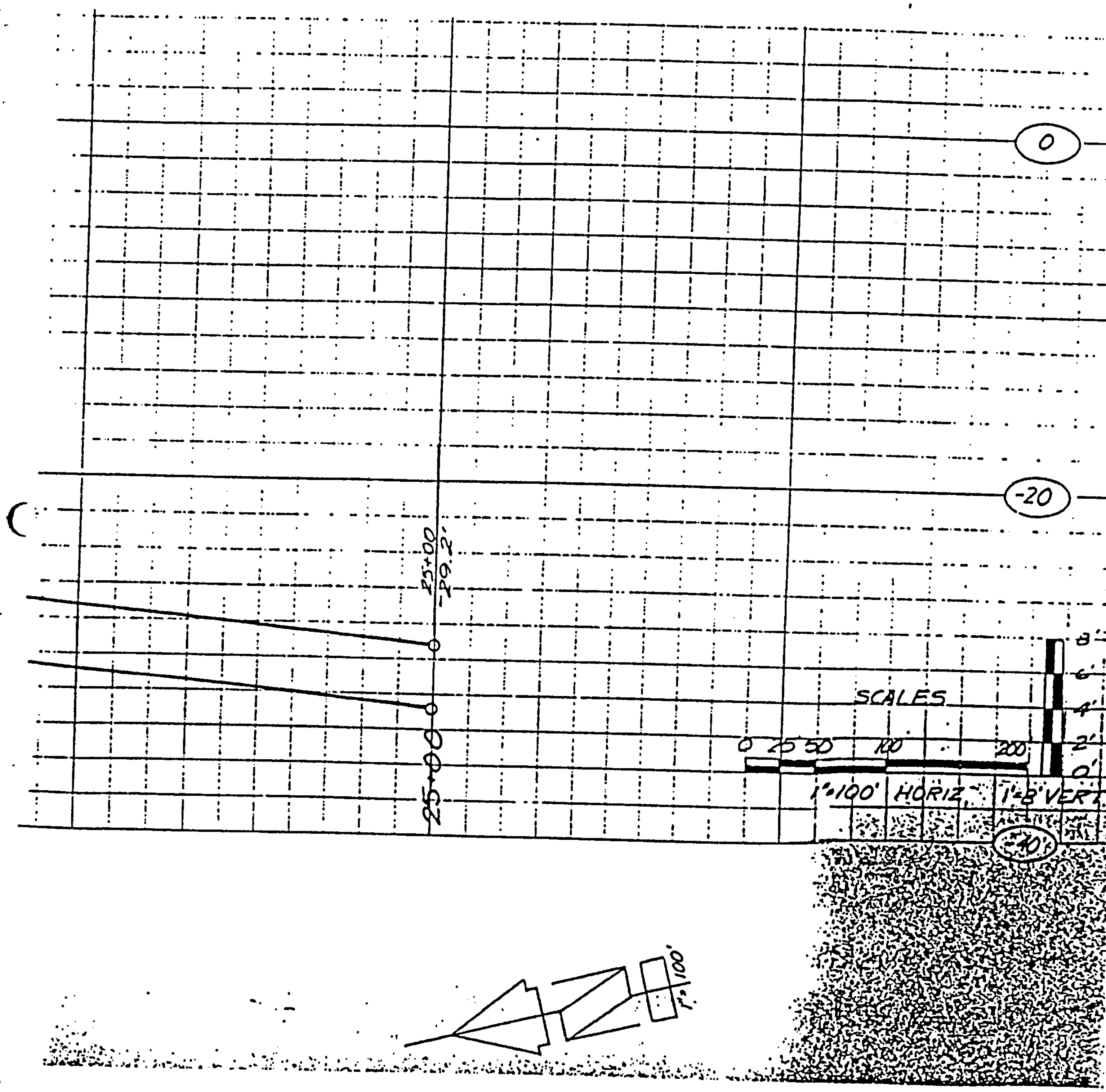
5+00
ELEV. 13.1'
ELEV 7.1'
ELEV. 5.6'
ELEV. 3.7'
ELEV. 3.5'
-5+44 29.1'
-4+96 17.6'
-4+76 15.2'
-4+67 13.1'
-3+56 11.6'
-2+78 9.4'
-2+03 9.5'
-1+44



7+52
-10.8
SEAFLOOR
10+94
-13.4'
11+86
-14.6'
12+48
-15.4'
PIPELINES
10+00
752,500
752,000



-17.7'
15+00
16+09
-19.0'
16+55
-20.0
18+29
-23.4'
20+00
20+12
-25.2'


0
-20
25+00
-29.2'
25+00
SCALES
0 25 50 100 200
1"=100' HORIZ. 1"=8' VERT.
8'
6'
4'
2'
0'
-40'
1"=100'

Appendix C: SCOUR.EXE Program

[Reprinted from Work (1987)]

SCOUR Program User Instructions

Input Requirements:

Data can be input in an interactive mode from the keyboard during program execution, or from a data file labeled SCOURIN.DAT.

To start the program, type SCOUR, followed by the <ENTER> or <RETURN> key. The program will display an introductory screen and pause, and then will prompt with:

```
Data input method:  1 = Screen input
                    2 = Data file (SCOURIN.DAT)
```

The user should enter 1 or 2 as appropriate. A second prompt will show:

```
Data units system:  1 = SI
                    2 = FPS
```

Again, enter 1 or 2 as desired.

Interactive Mode

The program will prompt for, in the following sequence:

1) Sediment D50 (mm)
2) Water density (slugs/cu. ft. or kg/ cu. m)
3) Steady current velocity (ft/s or m/s)
4) Angle between current and pipeline (degrees) (Enter the smallest angle between the current vector and the pipeline axis.)
5) Significant wave height (ft or m)
6) Wave period (seconds)
7) Mean water depth (ft or m)
8) Angle between waves and pipeline (degrees) (Enter the smallest angle between the wave orthogonals and the pipeline axis.)
9) Pipeline diameter (ft or m)

10) Pipeline modulus of elasticity (psi or N/sq m)
11) Pipeline section moment of inertia (ft^4 or m^4)
12) Submerged load on unit length of pipeline (lb/ft or N/m, including self-weight and any cargo)

At each prompt, the appropriate value should be entered, followed by the <ENTER> or <RETURN> key. Zeroes should be entered rather than entering no value.

Batch File Mode

A file should be created by line editor, etc., containing the 12 data input items listed above. The first item should start in the first column of the first line of the file. The remaining items should be put on subsequent lines with no blank lines separating them. After all numbers have been entered, the file should be saved under the name SCOURIN.DAT. It must reside on the same disk drive and directory as the SCOUR program. A sample input file is included in Section VIII of this report.

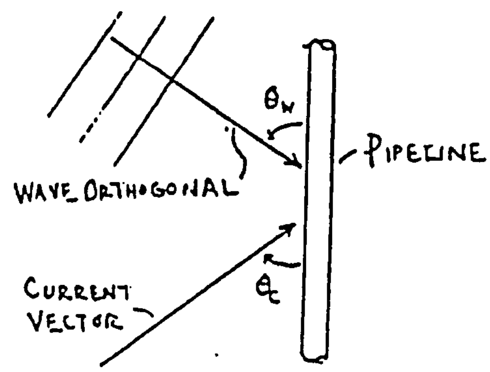


Fig. 11. Problem geometry, plan view.

Several calculation results are displayed on the screen during program execution. A complete output file is saved on the resident drive and directory under the name SCOUROUT.DAT. This data can be inspected or printed through the use of a text or line editor.

The program can handle: 1) current-only cases, and 2) waves and current combined, but has not been thoroughly tested. As explained in the body of this report, attempting to use the program for the waves-only case will yield scour depths of zero. Another problem that may develop is the condition where the bed shear stress exceeds the critical shear stress everywhere in the flow, even away from the pipeline. An equilibrium situation would exist when the bed load was the same everywhere, but the method of Chao and Hennessy (1972) does not account for this and would not yield a solution. The SCOUR program would not be able to find a solution and the result would be infinite iterations.

VIII. Sample Input and Output Files

<u>Sample Input</u>

```
1
1.94
1.0
90
5
6
100
70
2
29000000
100
```

<u>Sample Output</u> appears on the following page.

SCOUR Program: Input and Output Summary

SEDIMENT PARAMETERS:

Sediment D50 = 1.0000 mm
Sediment density, RHOS = 5.14 slugs/cu ft
Critical tractive stress, TAUC = 0.0310 lb per sq. ft
Nikuradse roughness size, KS = 0.0082 ft

WATER AND STEADY CURRENT PARAMETERS

Water density, RHO = 1.94 slugs/cu ft
Steady current velocity, UO = 1.0 ft/s
Angle between current vector and pipeline, THETAC = 90.0 degrees
Friction factor due to steady current, FC = 0.0150

WAVE PARAMETERS:

Significant wave height, HS = 5.0 ft
Wave period, T = 6.0 seconds
Mean water depth, DEPTH = 100.0 ft
Angle between wave orthogonals and pipeline, THETAW = 70.0 degrees
Deep water wavelength, LO = 184.5 ft
Wavelength at specified water depth, LCALC = 184.1 ft
Amplitude of horizontal orbital velocity, UINF = 0.1727 ft/s
Amplitude of horizontal orbital motion, A = 0.1649 ft
Friction factor due to waves, FW = 0.0478

PIPELINE PARAMETERS:

Pipeline diameter, D = 2.00 ft
Pipeline modulus of elasticity, E = 0.29E+08 psi
Pipeline section moment of inertia, I = 0.02 ft^4
Submerged load on pipeline, Q = 100.00 lb per ft

SCOUR PARAMETERS:

Total roughness coefficient, FWC = 0.0574
Angle between resultant velocity vector and wave vector, THETARW = 17.1
Method of C & H: Equilibrium scour depth, H-R = 1.51 ft
Method of Kjeldson, et al: Equilibrium scour depth, SMAX = 0.74 ft
Method of Mao: Maximum free span length, LMAX = 32.5 ft

```
      PROGRAM SCOUR
C CALCULATION OF EQUILIBRIUM SCOUR UNDER PIPELINE LAID ON SEAFLOOR
C
C SEE PAPER TITLED  SELF-BURIAL OF PIPELINES IN NON-COHESIVE SEDIMENTS
C BY PAUL WORK, FALL 1987
C COMPLETED FOR CE299, DEPARTMENT OF HYDRAULIC AND COASTAL ENGINEERING
C UNIVERSITY OF CALIFORNIA, BERKELEY
C
C
C TWO CALCULATION METHODS ARE USED TO FIND SCOUR DEPTHS
C MAXIMUM FREE SPAN LENGTH THEN PREDICTED
C
      IMPLICIT REAL*8 (A-Z)
      INTEGER MODEIN,INMODE,UNITS
      CHARACTER*3 LENGTH,FORCE
      CHARACTER*5 VELOCITY,MOI
      CHARACTER*7 MODULUS
      CHARACTER*12 DENSITY
C
C
C DATA INPUT BY USER:
C
C D50    = 50TH PERCENTILE SEDIMENT SIZE (mm)
C RHO    = WATER DENSITY (slugs/cu ft or kg/cu m)
C UO     = MAGNITUDE OF STEADY CURRENT (ft/s or m/s)
C THETAC = ANGLE BETWEEN CURRENT VECTOR AND PIPELINE (degrees)
C HS     = SIGNIFICANT WAVE HEIGHT (ft or m)
C T      = WAVE PERIOD (seconds)
C DEPTH  = MEAN WATER DEPTH (ft or m)
C THETAW = ANGLE BETWEEN WAVE ORTHOGONALS AND PIPELINE (degrees)
C D      = PIPELINE DIAMETER (ft or m)
C E      = MODULUS OF ELASTICITY OF PIPELINE (psi or N/sq m)
C I      = MOMENT OF INERTIA OF PIPELINE SECTION (ft^4 or m^4)
C Q      = UNIT WEIGHT OF SUBMERGED PIPELINE (lb/ft or N/m)
C
C
C DETERMINED BY PROGRAM:
C
C          INMODE, MODEIN DEFINE SCREEN OR FILE INPUT
C RHOS   = SEDIMENT DENSITY (slugs/cu ft or kg/cu m)
C          ASSUMED EQUAL TO 2.65*RHO
C UNITS  = DEFINES UNITS SYSTEM (SI OR FPS)
C LASS   = ASSUMED WAVELENGTH FOR CALCULATION PURPOSES (ft or m)
C LO     = DEEP WATER WAVELENGTH (ft or m)
C LCALC  = CALCULATED WAVELENGTH FOR SPECIFIED WATER DEPTH (ft or m)
C G      = GRAVITATIONAL CONSTANT (9.81 m/s^2 or 32.2 ft/s^2)
C UNIF   = MAGNITUDE OF WAVE-INDUCED VELOCITY IN DIRECTION OF WAVE
C          TRAVEL, JUST OUTSIDE BOUNDARY LAYER
C KS     = ROUGHNESS SIZE = 2.5*D50 PER FREDSOE (1979)
C A      = HORIZONTAL AMPLITUDE OF WATER PARTICLE ORBITAL DISPLACEMENT
C          JUST OUTSIDE BOUNDARY LAYER
C FW     = FRICTION FACTOR DUE TO WAVE ACTION ONLY
C FC     = FRICTION FACTOR DUE TO CURRENT ACTION ONLY
C THETARW= ANGLE BETWEEN VECTOR SUM OF WAVE AND CURRENT VELOCITIES AND
C          WAVE ORBITAL VELOCITY VECTOR
```

```
C FWC     = TOTAL FRICTION FACTOR
C H       = VERTICAL DISTANCE FROM PIPELINE CENTER TO BOTTOM OF TRENCH
C           (METHOD OF CHAO AND HENNESSY (1972)
C UAVG    = AVERAGE VELOCITY THROUGH SCOUR GAP
C TAUC    = CRITICAL TRACTIVE SHEAR STRESS
C TAUB    = BED SHEAR STRESS BELOW PIPELINE
C SMAX    = EQUILIBRIUM SCOUR DEPTH, KJELDSON'S METHOD
C LMAX    = MAXIMUM FREE SPAN LENGTH, MAO'S METHOD
C
C
C BRING UP INITIAL COMMENT SCREEN
      WRITE(6,*)  '                    S          C          O        U      U
     + RR'
      WRITE(6,*)  '                  S   S      C    C     O    O     U      U
     + R    R'
      WRITE(6,*)  '                  S          C          O    O     U      U
     + R    R'
      WRITE(6,*)  '                   S         C          O    O     U      U
     + R    R'
      WRITE(6,*)  '                    S        C          O    O     U      U
     + R R'
      WRITE(6,*)  '                     S       C          O    O     U      U
     + R R'
      WRITE(6,*)  '                      S      C          O    O     U      U
     + R    R'
      WRITE(6,*)  '                  S   S      C    C     O    O      U    U
     + R    R'
      WRITE(6,*)  '                    S          C          O          U
     + R    R'
      WRITE(6,*)  ' '
      WRITE(6,*)  ' '
      WRITE(6,*)  '              Program for Calculation of Equilibrium
     +cour Depth'
      WRITE(6,*)  '                     Below Submarine Pipeline on Sand
     +ed'
      WRITE(6,*)  ' '
      WRITE(6,*)  ' '
      WRITE(6,*)  '                                 By Paul A. Work'
      WRITE(6,*)  '                                  UC Berkeley'
      WRITE(6,*)  '                                   Fall, 1987'
      WRITE(6,*)  ' '
      WRITE(6,*)  ' '
      PAUSE '  Press ENTER to begin'
C
      OPEN(UNIT=7,FILE='SCOURIN.DAT',FORM='FORMATTED',ACCESS='SEQUENTIA
     1',STATUS='UNKNOWN')
C
      OPEN(UNIT=8,FILE='SCOUROUT.DAT',FORM='FORMATTED',ACCESS='SEQUENTI
     1L',STATUS='UNKNOWN')
C
   10 WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
```

```
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) 'Data input method:  1 = Screen input'
      WRITE(6,*) '                    2 = Data file ( SCOURIN.DAT )'
      WRITE(6,*) '     Enter 1 or 2:  '
      READ(6,*) INMODE
      IF((INMODE.NE.1).AND.(INMODE.NE.2)) GOTO 10
      IF(INMODE.EQ.1) MODEIN=6
      IF(INMODE.EQ.2) MODEIN=7
C
C DATA INPUT ROUTINE
C
   20 WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) 'Data units system:  1=SI'
      WRITE(6,*) '                    2=FPS'
      WRITE(6,*) '     Enter 1 or 2: '
      READ(6,*) UNITS
      IF((UNITS.NE.1).AND.(UNITS.NE.2)) GOTO 20
```

```
      IF(UNITS.EQ.1)THEN
      G=9.81
      LENGTH=' m '
      VELOCITY=' m/s '
      DENSITY=' kg/cu m     '
      MODULUS=' N/sq m'
      MOI=' m^4 '
      FORCE=' N '
      ELSE
      G=32.2
      LENGTH=' ft'
      VELOCITY=' ft/s'
      DENSITY=' slugs/cu ft'
      MODULUS=' psi    '
      MOI=' ft^4'
      FORCE=' lb'
      ENDIF
      PI=3.1416
C
      WRITE(6,*) ' '
      WRITE(6,*) ' '
      WRITE(6,*) 'Sediment D50 (mm): '
      READ(MODEIN,*) D50
      IF(MODEIN.EQ.7)THEN
      WRITE(6,101) D50
 101  FORMAT(1F9.6)
      ENDIF
C
      WRITE(6,140) DENSITY
 140  FORMAT(' Water Density,',A,': ')
      READ(MODEIN,*) RHO
      IF(MODEIN.EQ.7)THEN
      WRITE(6,141) RHO
 141  FORMAT(1F8.2)
      ENDIF
      RHOS=2.65*RHO
C
      WRITE(6,150) VELOCITY
 150  FORMAT(' Magnitude of Steady Current,',A,': ')
      READ(MODEIN,*) UO
      IF(MODEIN.EQ.7)THEN
      WRITE(6,151) UO
 151  FORMAT(1F7.2)
      ENDIF
C
      WRITE(6,*) 'Angle between current and pipeline (degrees):  '
      READ(MODEIN,*) THETAC
      IF(MODEIN.EQ.7)THEN
      WRITE(6,152) THETAC
 152  FORMAT(1F6.1)
      ENDIF
      THETAC=THETAC*2.0*PI/360
C
      WRITE(6,160) LENGTH
 160  FORMAT(' Significant wave height,',A,': ')
```

```
      READ(MODEIN,*) HS
      IF(MODEIN.EQ.7)THEN
      WRITE(6,161) HS
  161 FORMAT(1F6.1)
      ENDIF
C
      WRITE(6,*) 'Wave Period (seconds): '
      READ(MODEIN,*) T
      IF(MODEIN.EQ.7)THEN
      WRITE(6,162) T
  162 FORMAT(1F5.1)
      ENDIF
C
      WRITE(6,170) LENGTH
  170 FORMAT(' Mean Water Depth,',A,': ')
      READ(MODEIN,*) DEPTH
      IF(MODEIN.EQ.7)THEN
      WRITE(6,171) DEPTH
  171 FORMAT(1F6.1)
      ENDIF
C
      WRITE(6,*) 'Angle between waves and pipeline (degrees): '
      READ(MODEIN,*) THETAW
      IF(MODEIN.EQ.7)THEN
      WRITE(6,172) THETAW
  172 FORMAT(1F6.1)
      ENDIF
      THETAW=THETAW*2.0*PI/360
C
      WRITE(6,180) LENGTH
  180 FORMAT(' Pipeline Diameter,',A,': ')
      READ(MODEIN,*) D
      IF(MODEIN.EQ.7)THEN
      WRITE(6,181) D
  181 FORMAT(1F6.2)
      ENDIF
C
C
      WRITE(6,190) MODULUS
  190 FORMAT(' Pipeline modulus of elasticity,',A,': ')
      READ(MODEIN,*) E
      IF(MODEIN.EQ.7)THEN
      WRITE(6,191) E
  191 FORMAT(1E10.2E2)
      ENDIF
C
      WRITE(6,200) MOI
  200 FORMAT(' Pipeline moment of inertia,',A,': ')
      READ(MODEIN,*) I
      IF(MODEIN.EQ.7)THEN
      WRITE(6,201) I
  201 FORMAT(1F8.2)
      ENDIF
C
      WRITE(6,210) FORCE,LENGTH
```

```
  210 FORMAT(' Unit weight on submerged pipeline,',A,' per',A,': ')
      READ(MODEIN,*) Q
      IF(MODEIN.EQ.7)THEN
      WRITE(6,211) Q
  211 FORMAT(1F12.2)
      ENDIF
C
      IF(MODEIN.EQ.7)THEN
      PAUSE '  Press ENTER to continue'
      ENDIF
      WRITE(6,*) ' '
C
C FREDSOE'S EQN. FOR ROUGHNESS SIZE
      KS=2.5*D50/1000
      IF(UNITS.EQ.2)THEN
      KS=KS*3.2808
      ENDIF
      WRITE(6,212) KS,LENGTH
  212 FORMAT(' Roughness size Ks = ',1F7.4,A)
      WRITE(6,*) ' '
      R=D/2.0
C
C WAVE AND CURRENT PARAMETER CALCULATION ROUTINE
C FIRST-ORDER LINEAR (AIRY) WAVE THEORY
C
      IF((HS.GT.0).AND.(T.GT.0))THEN
      LO=(G*T**2.0)/(2.0*PI)
      LASS=LO
  300 LCALC=LO*TANH(2.0*PI*DEPTH/LASS)
      IF(DABS((LASS-LCALC)/LASS).GT.(0.001))THEN
      LASS=0.999*LASS
      GOTO 300
      ENDIF
      WRITE(UNIT=6,FMT=310) LCALC,LENGTH
  310 FORMAT(' Calculated wavelength = ',1F6.1,A)
      WRITE(6,*) ' '
      IF(DEPTH/LCALC.LT.(0.5))THEN
      WRITE(6,*) ' Warning: Shallow or Transitional Depth Specified '
      WRITE(6,*) ' '
      ENDIF
C
C CALCULATE AMPLITUDE OF HORIZONTAL COMPONENT OF VELOCITY, JUST OUTSIDE
C BOUNDARY LAYER - WAVE ACTION ONLY
C EQ. 5.15, SLEATH:
C
      UINF=(2.0*PI*HS)/(2.0*T*DSINH(2.0*PI*DEPTH/LCALC))
      WRITE(6,320) UINF,VELOCITY
  320 FORMAT(' Orbital velocity UINF = ',1F6.2,A)
      WRITE(6,*) ' '
C
C CALCULATE ORBITAL AMPLITUDE JUST OUTSIDE BOUNDARY LAYER:
C
      A=(HS)/(2.0*DSINH(2.0*PI*DEPTH/LCALC))
      WRITE(6,330) A,LENGTH
```

```
  330 FORMAT(' Orbital Amplitude A = ',1F6.2,A)
      WRITE(6,*) ' '
C
C EQ. 5.49, 5.50 SLEATH:
      IF((A/KS).GT.1.57)THEN
      FW=0.00251*EXP(5.21*((A/KS)**(-0.19)))
      ELSE
      FW=0.3
      ENDIF
      ELSE
      FW=0.0
      UINF=0.0
      ENDIF
C
      IF(UO.GT.0.0)THEN
      FC=0.015
      ELSE
      FC=0.0
      ENDIF
      IF((UINF.GT.0.0).AND.(UO.GT.0.0))THEN
      THETARW=DASIN((DABS(UINF*DSIN(THETAW))+DABS(UO*DSIN(THETAC)))/((DA
     1BS(UINF*DSIN(THETAW))+DABS(UO*DSIN(THETAC)))**2+(DABS(UINF*DCOS(TH
     1ETAW))+DABS(UO*DCOS(THETAC)))**2)**0.5)-THETAW
C
C TOTAL BED FRICTION FACTOR, PER MEI (1983)
      FWC=FW+DABS((FC-FW)*DSIN(THETARW))
      ELSE
      FWC=FC+FW
      ENDIF
C
C ROUTINE TO CALCULATE SCOUR BY METHOD OF CHAO AND HENNESSY
C
C INITIAL SCOUR HOLE SIZE
      H=1.01*R
C
C CRITICAL TRACTIVE STRESS
C
      IF((D50.GE.0.01).AND.(D50.LE.0.3))THEN
      TAUC=0.0165
      ELSEIF((D50.GT.0.3).AND.(D50.LE.1.0))THEN
      TAUC=0.017+0.02*(D50-0.3)
      ELSEIF((D50.GT.1.0).AND.(D50.LE.5.0))THEN
      TAUC=0.032+0.0183*(D50-1.0)
      ELSEIF(D50.GT.5.0)THEN
      WRITE(6,*) ' WARNING: Sediment size too large'
      H=R
      GOTO 401
      ELSEIF(D50.LT.0.01)THEN
      WRITE(6,*) ' WARNING: Sediment size too small'
      H=R
      GOTO 401
      ENDIF
      IF(UNITS.EQ.1)THEN
      TAUC=TAUC*47.84
      ENDIF
```

```
C
C HERBICH, ET AL, EQ. 6.2, P.205:
      WRITE(6,*) 'Iterating. . .'
 400  UAVG=UO*DSIN(THETAC)*(2.0*(H/R)**2.0-(H/R)-1.0)/(2.0*(H/R)**2.0-3
     10*(H/R)+1.0)
C
C HERBICH, ET AL, EQ. 6.4, P.206
      TAUB=FWC*RHO*UAVG**2.0/8.0
C
      IF(TAUB.LT.TAUC)THEN
      GOTO 401
      ENDIF
      IF(((TAUB-TAUC)/TAUC).GT.0.01)THEN
      H=H+0.01
      GOTO 400
      ENDIF
 401  WRITE(6,410) LENGTH,H-R
 410  FORMAT(' Method of Chao & Hennessy: Equilibrium Scour Depth,',A,'
     1 ',1F5.2)
C
C ROUTINE KJ FOR CALCULATION OF MAXIMUM SCOUR DEPTH BY METHOD
C OF KJELDSON, ET AL
C
      SMAX=0.972*((((UO*DSIN(THETAC))**2.0)/(2.0*G))**.20)*(D**.80)
      WRITE(6,500) LENGTH,SMAX
 500  FORMAT(' Method of Kjeldson: Equilibrium Scour Depth,',A,': ',1F5
     12)
C
C ROUTINE MAO FOR PREDICTION OF MAXIMUM FREE SPAN LENGTH
C
      LMAX=(128.0*E*I*(H-R)/Q)**.25
      WRITE(6,600) LENGTH,LMAX
 600  FORMAT(' Mao''s method: Maximum free span length,',A,': ',1F6.1)
      THETAC=THETAC*360/(2*PI)
      THETAW=THETAW*360/(2*PI)
      THETARW=THETARW*360/(2*PI)
C
C OUTPUT ROUTINE
C
      WRITE(UNIT=8,FMT=800)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=802)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=803) D50
      WRITE(UNIT=8,FMT=804) RHOS,DENSITY
      WRITE(UNIT=8,FMT=805) TAUC,FORCE,LENGTH
      WRITE(UNIT=8,FMT=806) KS,LENGTH
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=807)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=808) RHO,DENSITY
      WRITE(UNIT=8,FMT=809) UO,VELOCITY
      WRITE(UNIT=8,FMT=810) THETAC
```

```
      WRITE(UNIT=8,FMT=811) FC
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=812)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=813) HS,LENGTH
      WRITE(UNIT=8,FMT=814) T
      WRITE(UNIT=8,FMT=815) DEPTH,LENGTH
      WRITE(UNIT=8,FMT=816) THETAW
      WRITE(UNIT=8,FMT=817) LO,LENGTH
      WRITE(UNIT=8,FMT=818) LCALC,LENGTH
      WRITE(UNIT=8,FMT=819) UINF,VELOCITY
      WRITE(UNIT=8,FMT=820) A,LENGTH
      WRITE(UNIT=8,FMT=821) FW
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=822)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=823) D,LENGTH
      WRITE(UNIT=8,FMT=824) E,MODULUS
      WRITE(UNIT=8,FMT=825) I,MOI
      WRITE(UNIT=8,FMT=826) Q,FORCE,LENGTH
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=827)
      WRITE(UNIT=8,FMT=801)
      WRITE(UNIT=8,FMT=828) FWC
      WRITE(UNIT=8,FMT=829) THETARW
      WRITE(UNIT=8,FMT=830) H-R,LENGTH
      WRITE(UNIT=8,FMT=831) SMAX,LENGTH
      WRITE(UNIT=8,FMT=832) LMAX,LENGTH
      WRITE(UNIT=8,FMT=801)
C
  800 FORMAT(' SCOUR Program: Input and Output Summary')
  801 FORMAT('  ')
  802 FORMAT('SEDIMENT PARAMETERS:')
  803 FORMAT('Sediment D50 = ',1F8.4,' mm')
  804 FORMAT('Sediment density, RHOS = ',F7.2,A)
  805 FORMAT('Critical tractive stress, TAUC = ',1F8.4,A,' per sq.',A)
  806 FORMAT('Nikuradse roughness size, KS = ',1F8.4,A)
  807 FORMAT('WATER AND STEADY CURRENT PARAMETERS')
  808 FORMAT('Water density, RHO = ',1F7.2,A)
  809 FORMAT('Steady current velocity, UO = ',1F6.1,A)
  810 FORMAT('Angle between current vector and pipeline, THETAC = ',1F4.
     1l,' degrees')
  811 FORMAT('Friction factor due to steady current, FC = ',1F6.4)
  812 FORMAT('WAVE PARAMETERS:')
  813 FORMAT('Significant wave height, HS = ',1F5.1,A)
  814 FORMAT('Wave period, T = ',1F4.1,' seconds')
  815 FORMAT('Mean water depth, DEPTH = ',1F5.1,A)
  816 FORMAT('Angle between wave orthogonals and pipeline, THETAW = ',1F
     14.1,' degrees')
  817 FORMAT('Deep water wavelength, LO = ',1F6.1,A)
  818 FORMAT('Wavelength at specified water depth, LCALC = ',1F6.1,A)
  819 FORMAT('Amplitude of horizontal orbital velocity, UINF = ',1F7.4,A
```

```
     1)
 820 FORMAT('Amplitude of horizontal orbital motion, A = ',1F7.4,A)
 821 FORMAT('Friction factor due to waves, FW = ',1F8.4)
 822 FORMAT('PIPELINE PARAMETERS:')
 823 FORMAT('Pipeline diameter, D = ',F5.2,A)
 824 FORMAT('Pipeline modulus of elasticity, E = ',1E10.2E2,A)
 825 FORMAT('Pipeline section moment of inertia, I = ',1F8.2,A)
 826 FORMAT('Submerged load on pipeline, Q = ',1F8.2,A,' per',A)
 827 FORMAT('SCOUR PARAMETERS:')
 828 FORMAT('Total roughness coefficient, FWC = ',1F6.4)
 829 FORMAT('Angle between resultant velocity vector and wave vector, T
    1HETARW = ',1F4.1,' degrees')
 830 FORMAT('Method of C & H: Equilibrium scour depth, H-R = ',1F6.2,A)
 831 FORMAT('Method of Kjeldson, et al: Equilibrium scour depth, SMAX =
    1 ',1F6.2,A)
 832 FORMAT('Method of Mao: Maximum free span length, LMAX = ',1F7.1,A)
     STOP
     END
```

DEFINITION OF VARIABLES

Symbol	Computer Abbreviation	Definition
a	A	Amplitude of water particle orbits
$c(x,y,t)$		Suspended sediment concentration
C_L		Coefficient of lift
C_D		Coefficient of drag
C_M		Coefficient of virtual mass
D50	D50	50th percentile sediment size
D	D	Pipeline diameter; sediment size
d	DEPTH	Mean water depth
E	E	Pipeline modulus of elasticity
fc, f_1	FC	Friction coefficient due to current only
fwc	FWC	Total friction coefficient
fw	FW	Friction coefficient due to waves only
g	G	gravitational constant
H	H	Distance from pipe center to seafloor
Hs	HS	Significant wave height
I	I	Pipeline section moment of inertia
ks	KS	Nikuradse sand grain roughness size
L	LCALC	Wavelength at specified depth
Lmax	LMAX	Maximum free span length (Mao, 1986)
Lo	LO	Deep-water wavelength
p		Bed porosity
Q	Q	Unit loading on submerged pipeline
q		Flow through pipeline gap
R	R	Pipeline radius
R		Reynolds number
Sb		Bed load transport rate
Sm	SMAX	Equilibrium scour depth (Kjeldson, 1973)
T	T	Wave period
u		Velocity
$\dot{u}$		Acceleration
u_*	USTAR	Shear velocity
U_∞	UINF	Wave-induced orbital velocity
Uavg	UAVG	Average flow velocity through pipe gap
Uo	UO	Magnitude of steady current
U_{bed}		Velocity at bed beneath pipeline
yb		Local bed elevation
ys		Free surface elevation
ν		Kinematic viscosity of water
ρ	RHO	Water density
ρ_s	RHOS	Sediment density
θ		Dimensionless Shields parameter
θ_c		Critical Shields parameter
θ'		Modified Shields parameter
θc	THETAC	Angle between current vector and pipe;
θw	THETAW	Angle between wave orthogonals and pipe
θ_{Rw}	THETARW	Angle between resultant velocity vector and wave vector

DEFINITION OF VARIABLES, contd.

Symbol	Computer Abbreviation	Definition
ϕ		Angle of contact of sediment grains with other grains; Dimensionless sediment transport rate
γ_s		Bed slope correction factor
τ_c	TAUC	Critical tractive stress
τ_b	TAUB	Bed shear stress

Appendix D: Pertinent Literature

[Reprinted]

BOSS '76
-BEHAVIOUR OF OFF-SHORE STRUCTURES-
The Norwegian Institute of Technology

WAVE - SEABED - STRUCTURE INTERACTION

E.W. Bijker, Professor of Coastal Engineering
Delft University of Technology
The Netherlands

ABSTRACT

The interaction under influence of wave motion between a structure and the sea-bed consisting of relatively fine, non cohesive material is compared with this interaction under the influence of uniform flow and the combination of uniform flow and waves.
After the scour underneath pipes, the scour around vertical structures is discussed. It is demonstrated that in both cases the scour by uniform flow is greater than the scour by waves or by the combination of waves and uniform flow.
Finally the spanning of a pipe over a scour hole or between two ripple crests is discussed. The relations between sag and tensions with a certain pretension resulting from the laying operation are determined. For two pipes the sag and tensions for various spans are computed. This computation shows that it cannot be expected that pipelines with great diameters (> 0.70 m) will bury themselves.

Contents

1. Introduction

Scouring around structures will be discussed as the first aspect of the interaction between seabed and structures. In order to be able to use sediment transport formulae the seabed will be assumed to consist of granular non cohesive material. The scouring will be studied for waves, for uniform flow and for the combination of these.

Although at this time a new sediment transport formula will have been developed by the combined research of Dutch Public Works, the Delft Hydraulics Laboratory and the Delft University of Technology, the older formula for sediment transport by waves and current as proposed by Bijker will be used in this paper [2].

From the theory which forms the basis of this formula, it becomes clear that the gradient of the velocity very near to the sea bed, just outside the viscous sublayer, determines the rate of the sediment motion. The adjustment of this velocity gradient to altered flow conditions therefore will be a very important factor in the development of the scour around the structure.

Van Ast and de Boer [1] developed a theory which describes the adjustment and subsequent scouring underneath a pipe under influence of waves and uniform flow. Since the basis of this approach can also be used for the explanation of scouring phenomena around vertical structures, the scouring underneath pipes will be treated first.

Scouring near vertical structures will be treated only for the case in which the scouring can not extend underneath the structures; in that case, a basically different phenomena will probably occur. It is therefore assumed that slender structures (pipes) penetrate into the sea bed and bulky (gravity) structures are protected by skirts.

For both the scour around vertical piles and underneath pipelines it is assumed also that sediment transport takes place even outside the area influenced by the structure. The scouring phenomena will be determined by the equation of continuity for the sediment motion. In the case this is not so, the situation is changed in that at the places where scouring occurs this has to proceed until here the limit of sediment motion has been reached again also.

Finally the situation which develops when scouring occurs locally underneath a pipe line will be discussed.

2. Principles of sediment motion caused by uniform flow and waves.

It is assumed according to Bijker [2] that the sediment motion is determined by the bed shear.
This bed shear can be written in

$$\tau = \rho \kappa^2 y'^2 (v_b/y')^2, \qquad (1)$$

where y' = thickness of viscous sublayer
v_b, resp. u_b = velocity just outside this viscous sublayer.

When $\tau_c = \rho g\, v^2/C^2$ for uniform flow (2)

and $\tau_w = \frac{1}{2} f_w \rho\, u_o^2$ for wave motion (3) where u_o = amplitude of orbital motion just outside the boundary layer at the bottom (see figure 1), the following relations between v_b and u_b and u_o can be given.

v = mean velocity of uniform flow,

then
$$\frac{v_b}{v} = \frac{\sqrt{g}}{\kappa C} \text{ and} \qquad (4)$$

$$\frac{u_b}{u_o} = \sqrt{\frac{f_w}{2\kappa^2}} \qquad (5)$$

In this formula f_w is the wave friction factor according to Jonsson (6)
This factor is written by Swart [7] as:

$$f_w = \exp.\left[-5{,}977 + 5{,}213\ (a_o/r)^{-0.194}\right] \qquad (6)$$

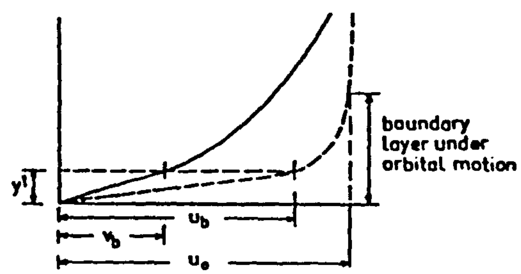


Fig.1 Velocity profile of uniform flow and orbital motion near the bed.

where a_o = amplitude of the orbital motion just outside the viscous sublayer, and

r = bed roughness.

Thus, according to this approach, the velocity at a distance y' above the bed, just outside the viscous sublayer, is considered to determine the sediment motion.

3. Scour underneath a pipe by wave motion.

Based on visual observations by Van Ast and De Boer [1] it is assumed that the water approaching the pipe is divided by the pipe into quantities flowing underneath and over it, with the line of division laying midway in that part of the pipe that protrudes above the bed (see figure 2).

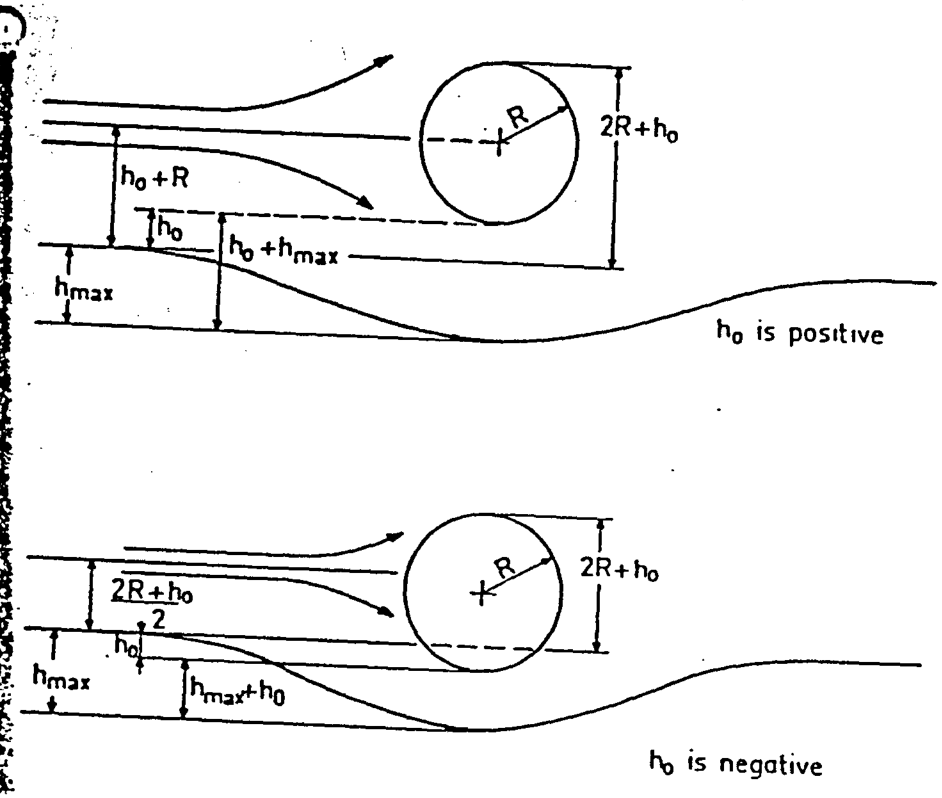


Fig. 2 Flow pattern around pipes.

The velocity distribution around the pipe as result of the disturbance of the pipe can be written as:

$$u_a = u_o\ (1 + R^2/a^2) \qquad (7)$$

where u_o = orbital velocity at the bottom, which is (with sufficient approximation) constant over the height of the pipe,

R = half of pipe diameter, and

a = distance from the center of the pipe (see figure 3).

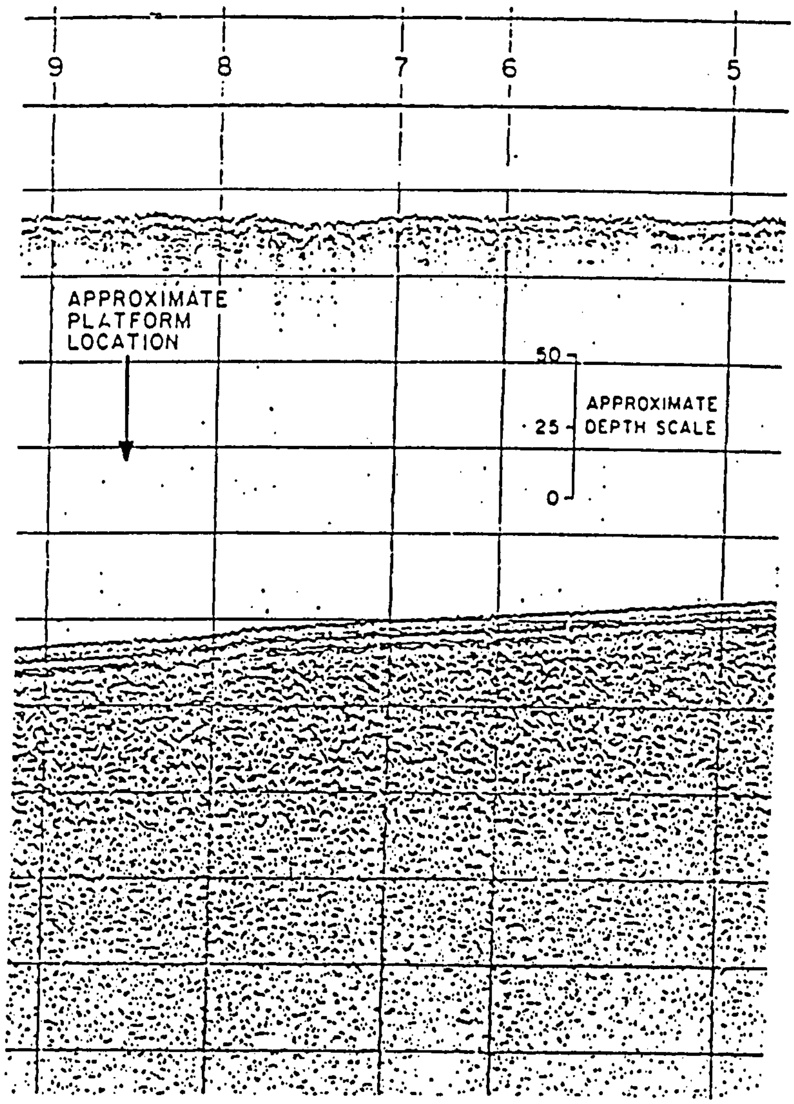


Fig. 6 - TYPICAL SHALLOW GEOPHYSICS RECORD THROUGH THE PLATFORM SITE.

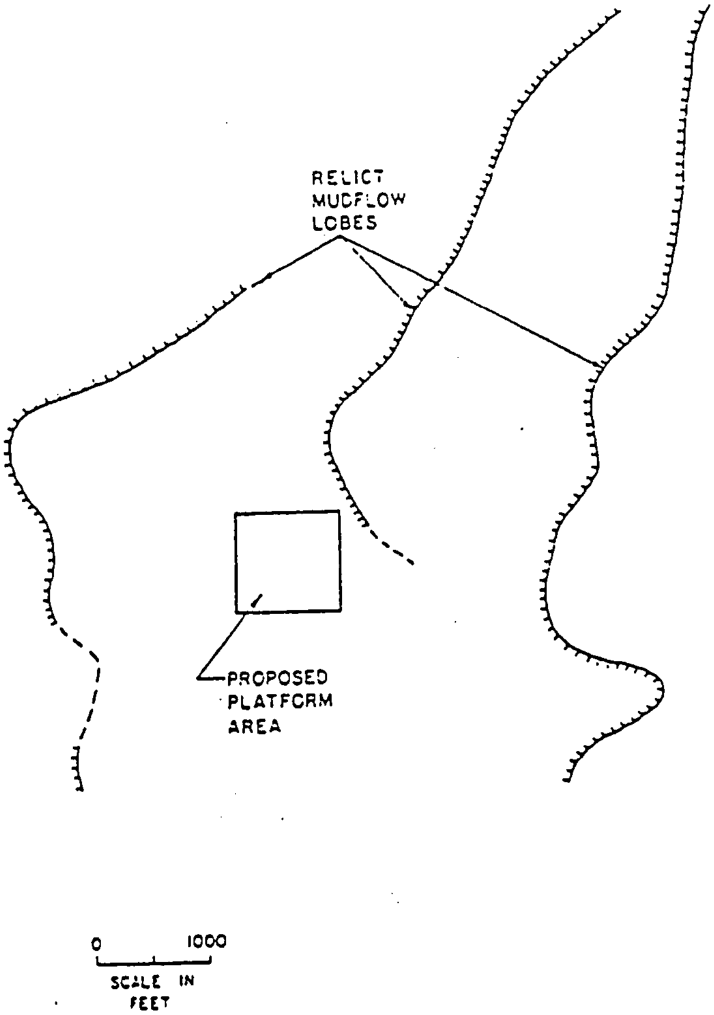


Fig. 7 - RELICT SLIDE FEATURES IN VICINITY OF PLATFORM SITE AS DETERMINED FROM SHALLOW GEOPHYSICS RECORDS.

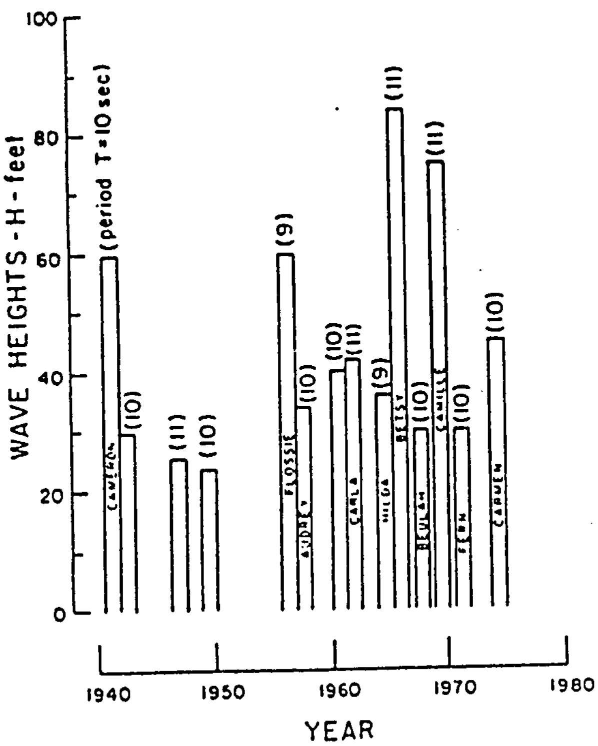


Fig. 8 - HINDCAST HURRICANE MAXIMUM WAVE HEIGHTS IN DEEP WATER, 1940 - 1980.

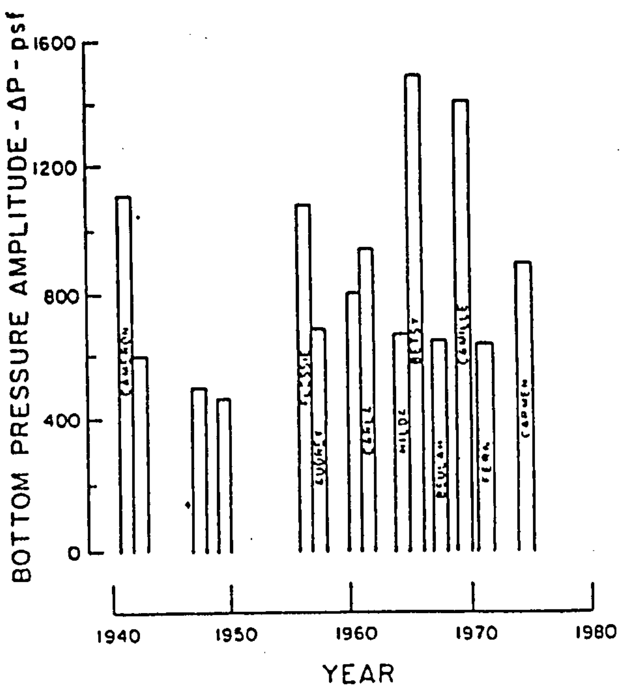


Fig. 9 - HINDCAST HURRICANE MAXIMUM BOTTOM PRESSURE AMPLITUDES IN 150 FT. WATER DEPTHS, 1940 - 1980.

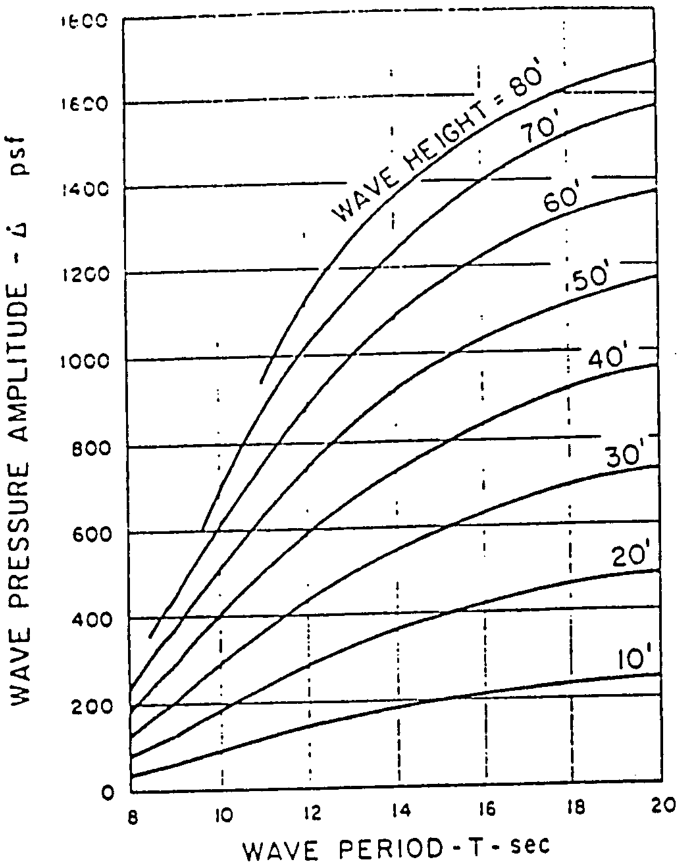


Fig. 10 - RIGID BOTTOM WAVE PRESSURE AMPLITUDES IN 150 FT. WATER DEPTHS.

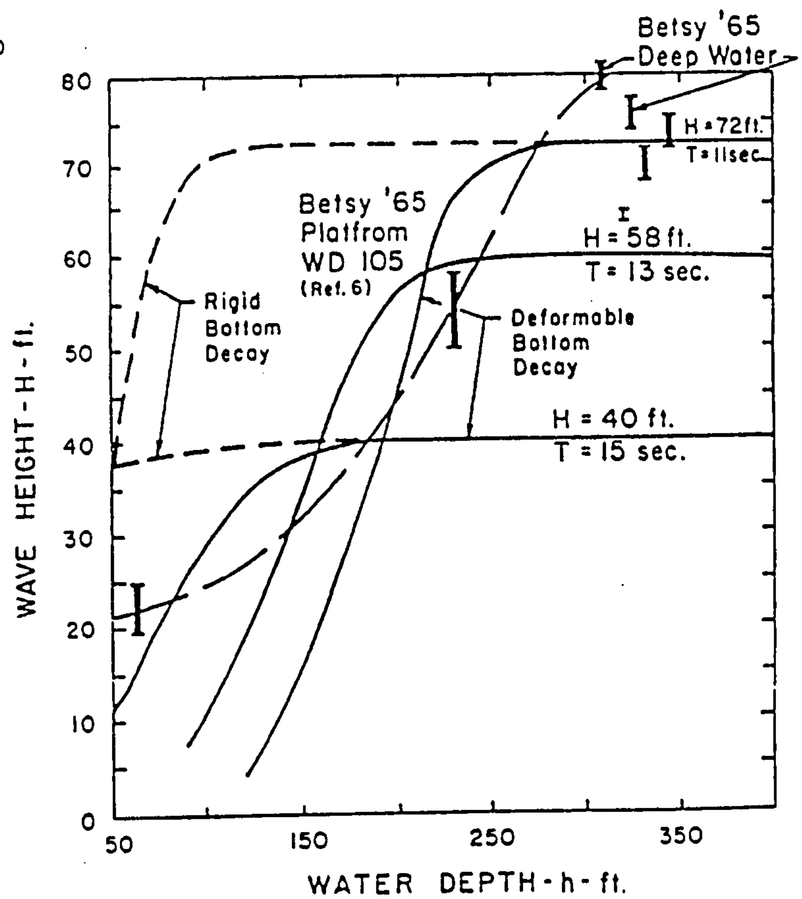
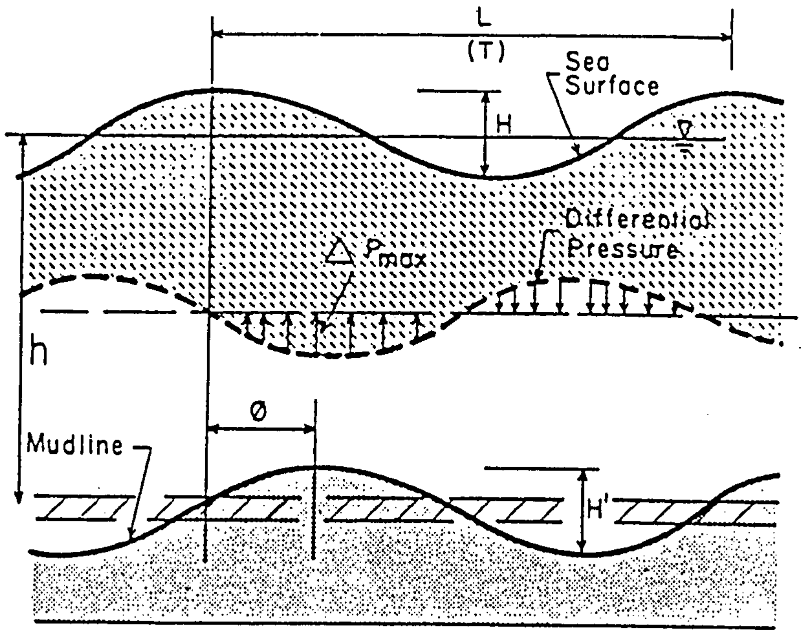


Fig. 11 - PREDICTED AND MEASURED DECAY OF HURRICANE WAVE HEIGHTS AS INFLUENCED BY BOTTOM DEFORMATION CONDITIONS.



$$\Delta P_{max} = \frac{\gamma}{2}\left[\frac{H}{\cosh Kh} - \frac{H'\omega}{gK}\cos \emptyset (\tanh Kh)\right]$$

$$K = \frac{2\pi}{L} \quad , \quad \omega = \frac{2\pi}{T}$$

Fig. 12 - FORMULATION FOR PREDICTION OF BOTTOM PRESSURE AMPLITUDES AS INFLUENCED BY BOTTOM DEFORMATION CONDITIONS.

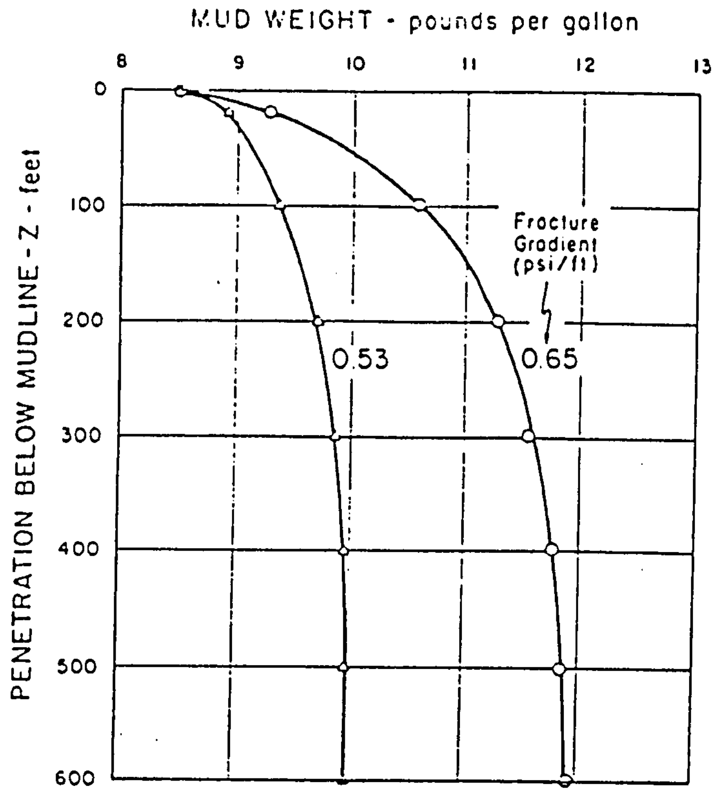


Fig. 13 - DRILLING MUD WEIGHTS REQUIRED TO MAINTAIN HOLE STABILITY IN 150 FT. WATER DEPTHS.

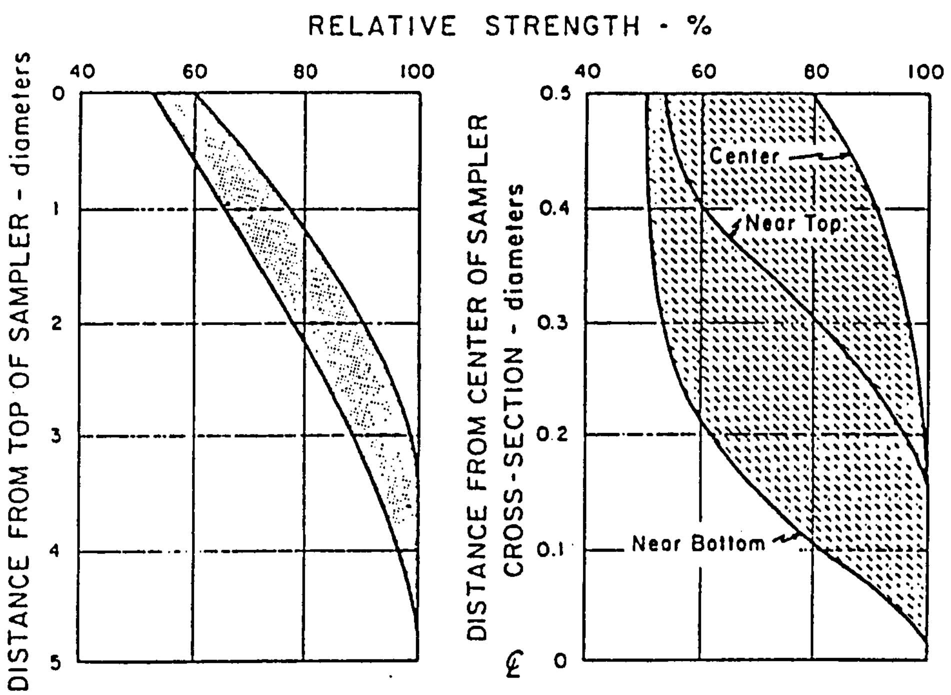


Fig. 14 - INFLUENCE OF SAMPLE LOCATION WITHIN SAMPLE TUBE ON MEASURED SOIL SHEAR STRENGTH (TOP OF SAMPLER IS DEEPEST POINT CORED).

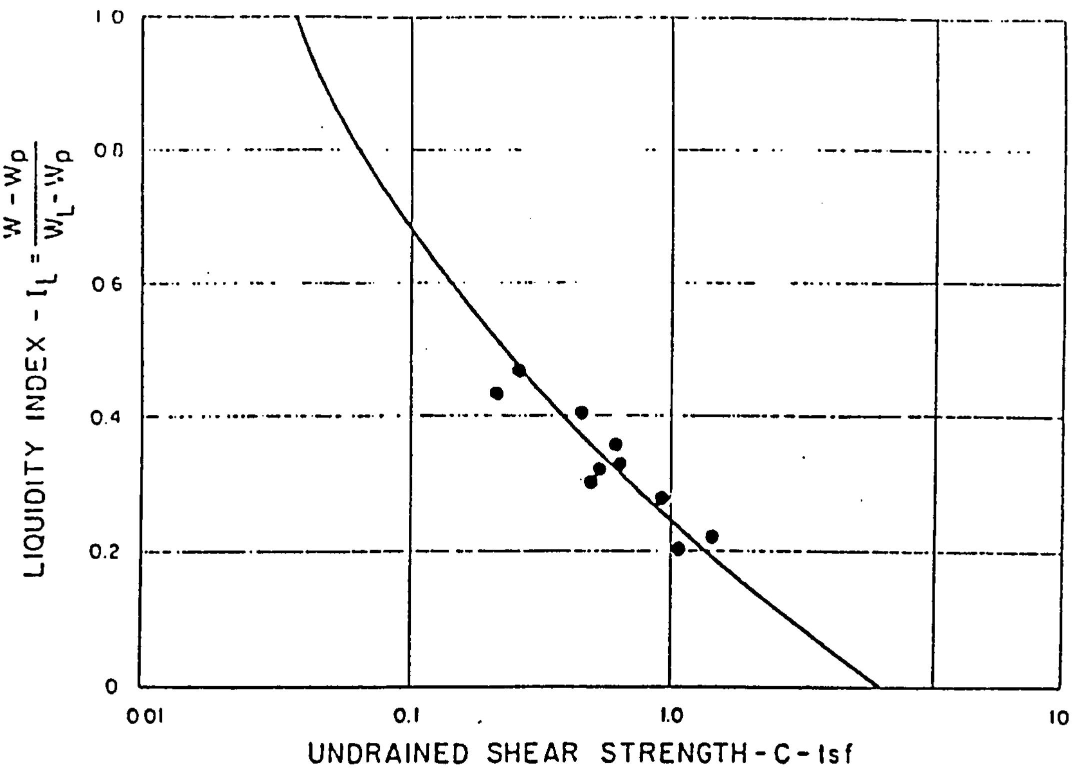


Fig. 15 - UNDRAINED SHEAR STRENGTH AS DETERMINED FROM TOTAL PRESSURE TRIAXIAL TESTS.

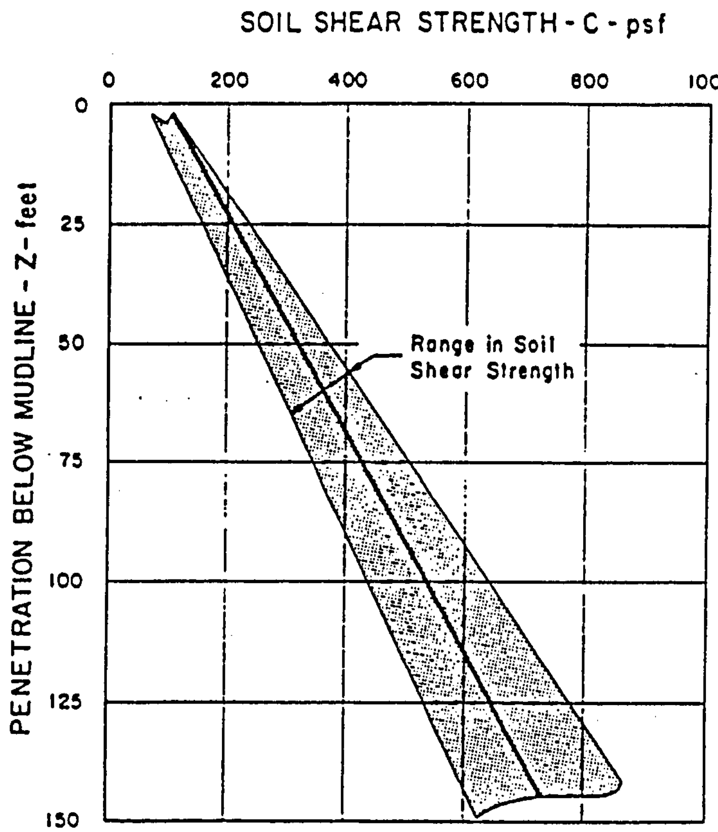


Fig. 16 - SOIL SHEAR STRENGTH FROM PERCEPTIVE ANALYSIS FOR PLATFORM SITE.

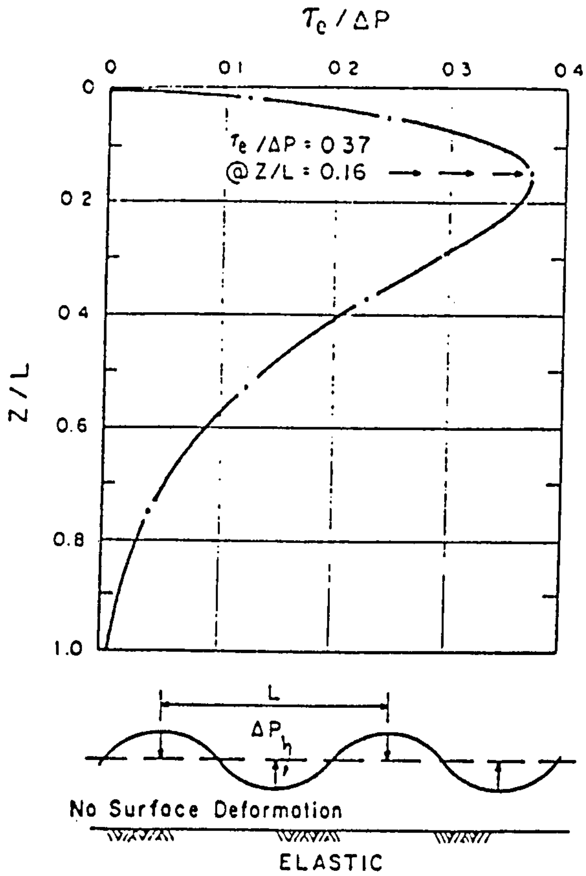


Fig. 17 - MAXIMUM SHEAR STRESS VERSUS DEPTH FOR SEMI-INFINITE ELASTIC CONTINUUM.

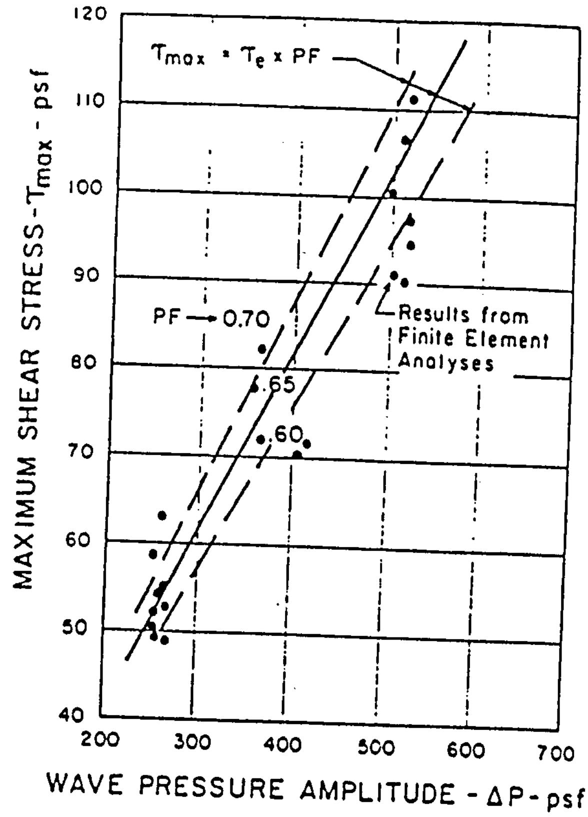


Fig. 18 - MAXIMUM SHEAR STRESS IN SOILS BASED ON RESULTS FROM FINITE ELEMENT ANALYSES.

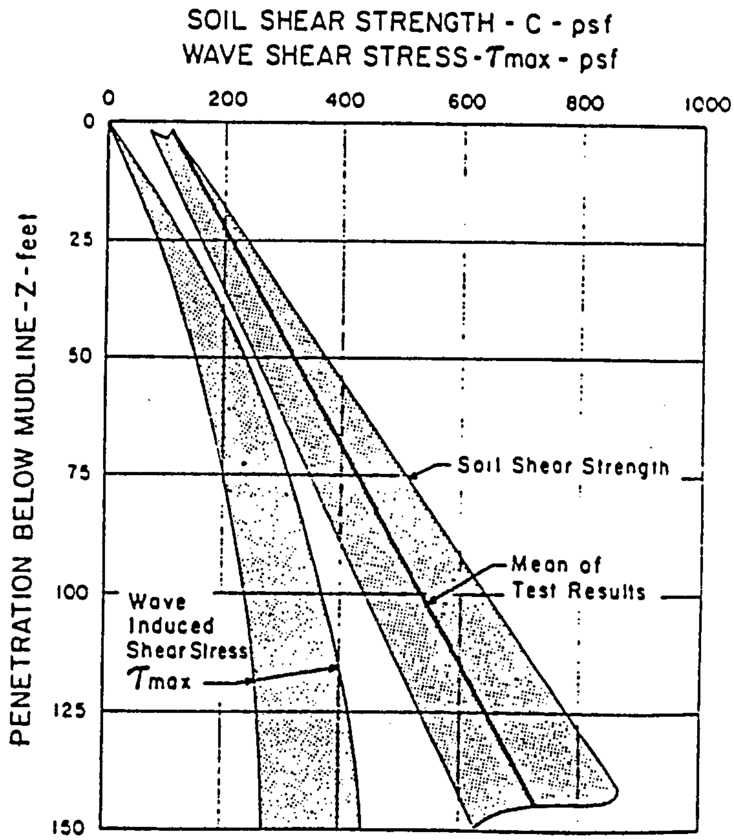


Fig. 19 - COMPARISON OF MAXIMUM WAVE INDUCED SHEAR STRESS WITH SOIL SHEAR STRENGTH.

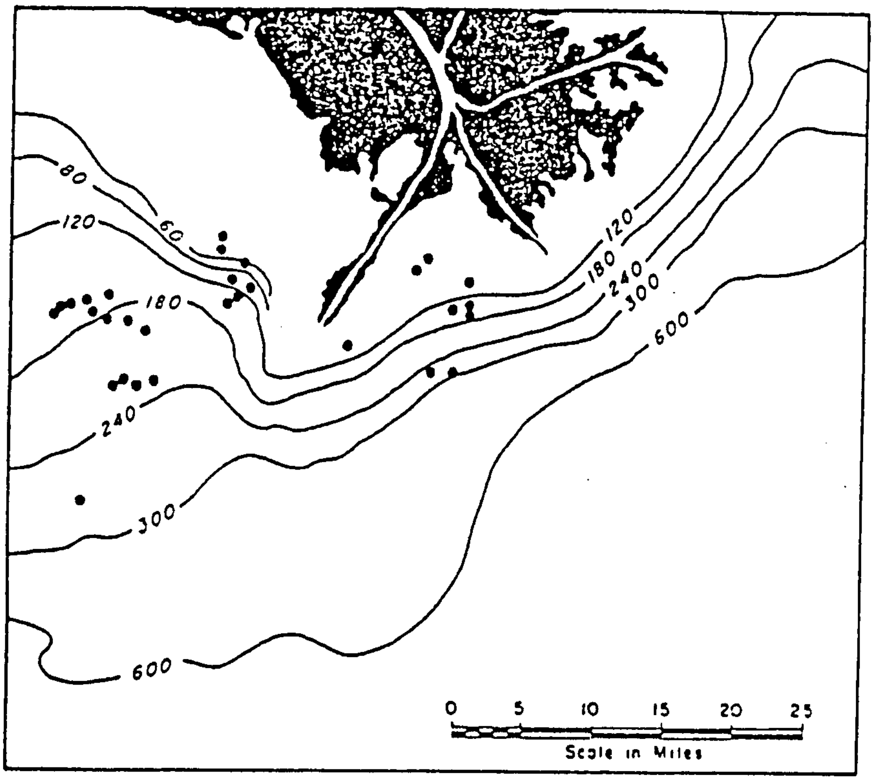


Fig. 20 - CONVENTIONAL PLATFORM LOCATIONS IN VICINITY OF SOUTHWEST PASS.

OTC 4411

Design of Pipelines in Mudslide Areas

by Robert Glenn Bea, *PBM Systems Engineering, Inc.*, and Ravi P. Aurora, *Marathon Oil U.K. Ltd.*

ABSTRACT

A design strategy is presented for routing and configuring pipelines in mudslide areas. This strategy is illustrated with a case study of a pipeline in the Mississippi River Delta. The case study focuses on the geotechnical aspects of pipeline settlement, flotation, and analysis of mudslide forces and stresses.

INTRODUCTION

It is impossible to prevent pipeline failures in an active mudslide area (5,12,18). Key strategies to design pipelines that have acceptable cost and reliability in these areas include:

- Minimum exposure to existing and potential locations of mudslides.
- Minimum lateral soil forces.
- Weighting to minimize penetration into the sea floor.
- Analysis to establish soil loadings, restraints, flexibility, and ultimate strength of the pipeline.
- Design of terminals to incorporate flexibility, repairability and control of escape of products.

DESIGN STRATEGY

The primary objective of the pipeline design process is to design a system that will reliably transport products during its lifetime at the lowest total cost.

The pipeline design process (Figure 1) must consider the constraints posed by environment, construction, operations and design. These constraints are discussed next.

[1] Ocean Engineering Division, PMB Systems Engineering, Inc., San Francisco, CA

[2] Structural Supervisor, Brae Field Development, Marathon Oil U.K., London, England

Constraints

Environmental constraints include definition of the waves, currents, mudslides, fault movements, soil profile and bathymetry that can influence the pipeline during its lifetime.

Construction constraints include the equipment used for fabrication and installation; pipeline steels, welding and quality controls, and pipeline bedding, backfill and armoring.

Operational constraints include desired tie-in points; volumes, pressures, temperature and corrosivity of fluids to be transported; pipeline maintenance, pipeline repair, fluid escape control measures, and acceptable failure incidence.

Design constraints include analysis methods to be used, routing guidelines, regulatory requirements and codes, allowable stresses and factors-of-safety.

Design constraints also include economic and impact considerations. Economic considerations include costs of construction, operation, failure and repair. Impact considerations include potential effects of the pipeline on other operations and facilities, impacts of the pipeline on the environment, and social and political effects of failures.

In view of the above constraints, the pipeline designer has to gather the data and information needed to define the constraints at the outset of the engineering process. The design process then focuses on a logical balancing of these constraints to result in an optimum pipeline design.

Of particular importance is the use of hazard mitigation techniques in the pipeline design process. Backflow valves to prevent escape of fluids; pumping or compression shutdown systems; breakaway couplings to control the points of failure; use of pipe coatings to minimize forces; and incorporation of failure detection and repair systems are examples of such techniques.

Perhaps the most important hazard mitigation technique is perceptive siting and routing of the pipeline to avoid or minimize exposure to present and future hazards (12), which are discussed next.

...iting Reconnaissance and Hazard Identification (5-7)

Perceptive routing of pipelines to avoid hazardous conditions starts with detailed surveys and geologic study of the potential routes.

Pipeline route surveys are intended to result in definition of bottom conditions including locations of faults, slumps, slump channels and other geologic features and soil conditions.

Side scan sonar, high resolution profiling, sub-bottom profiling (shallow, geophysics), soil coring and drop penetrometers provide the necessary background data.

Geology-based geotechnical studies are an essential ingredient for analyzing the route survey data to define relict conditions, initial hazards and the likely location and characteristics of future hazards. Knowledge of the underlying conditions that create the seafloor characteristics found in the surveys becomes a key factor in projecting the locations and characteristics of these or similar hazards during the pipeline lifetime.

Soil samples along the pipeline route are obtained by drop coring, by shallow seaflow sampling equipment such as vibracoring, and by deeper rotary drill and sampling from floating and fixed structures.

Laboratory tests on the cores provide indices of ...ress-strain characteristics of the soils. Due to the inevitable disturbance of the soils by coring, sampling and testing, it is important to recognize that these measured characteristics are not indicative of true in-situ characteristics. They must not be confused with the actual behavior of the soils in-situ.

In-situ tests provide other information on soil characteristics. In-situ tests are performed by a variety of techniques, including vanes and penetrometers. Again, it is important to note that all of these provide data indicative of soil characteristics. The processes associated with sensor implantation and operation and data interpretation generally do not allow direct assessment of in-situ soil properties.

The data provided by the route surveys must be combined with the overall geologic understanding of the seafloor conditions as well as the environmental constraints cited earlier in order to estimate the loads (or deformations) and restraints provided by the seafloor (5).

It is sometimes not possible, however, to avoid hazards because this would result in excessively longer routes, or simply because the hazard is one which cannot be located accurately, or one which may occur anywhere along the pipeline route (e.g., collapse depression, mudslide, faulting, mudlump). In ...n cases, it is necessary to define the extent and characteristics of the hazards which may occur along selected sections of the line, e.g., width, length and thickness of the potential mudslide. Simultaneously it is imperative to estimate the engineering properties of the soils at the location of the potential mudslide.

Analysis of the Line (8)

The pipeline and its surrounding medium (soil and water) must be idealized through a structural model for either specific design sections or for the entire line. The line is usually modeled as a simple structural member with nodal forces representing the loads from the design hazard, while discrete springs represent the restraint from the soil continuum.

Given the characteristics of the design hazards, it is then necessary to select the design algorithms with which to calculate the forces, as well as the restraints present in the soil-pipeline system.

Various State-of-the-Art computer codes are available to perform a structural analysis of the pipeline subjected to the forces and restraints determined in the previous step.

Soil-pipeline interaction is generally represented by its three components in the X, Y and Z direction. Depending on the relative motion between the soil and the pipeline, the seafloor soils may either load the pipeline or restrain it from moving. The amount of restraint or load exerted on the pipeline is a nonlinear function of the amount of relative motion between the soil and pipeline. The load/restraint-deformation relationships are denoted as t-x (axial), p-y (horizontal) and q-z (vertical) curves.

When soils restrain the line from moving, the soil continuum is generally represented by discrete springs having restraint deformation characteristics given the by t-x, p-y and q-z relationships. The line itself is modeled as a structural beam. Nodal forces (t, p and q) can be used to represent soil loads. If large relative displacements (greater than x_u, y_u and z_u) occur between soils and line, the soil loads may reach a constant ultimate value (t_u, p_u and q_u).

Axial (t-x), horizontal (p-y) and vertical (q-z) load/restraint algorithms presently available to the pipeline designer have been recently reviewed and are summarized in Table 1 (2,3).

Performance, Cost and Decision Analysis (9-10)

If the stresses in the line are below an acceptable level (ultimate strength for extreme loadings, fatigue threshold for nominal loadings), the selected configuration (line diameter, thickness, steel grades, embedment conditions) is an adequate design solution, although a more economical configuration may exist. If the stresses are too high, however, it is necessary to repeat the structural analysis with a new configuration and possibly a new routing. This may result in changing from a single large line to multiple smaller lines, or changing from crossing a mudslide at right angles to routing the line straight up the slide so as to subject the line to tension rather than bending (12). The process is repeated until a satisfactory design is obtained.

The designer can now evaluate the cost for fabricating, installing and operating (including costs of repairs and loss of production if failure occurs) the selected line configuration.

A value decision process ensues. If it is found that an inequitable balance exists between costs and risks, the entire design process must be repeated until a satisfactory design is reached.

Final Design and Installation (11-12)

Once a satisfactory design has been reached, it is finalized and submitted for approval to the regulatory bodies having jurisdiction over pipeline construction in the area considered. If revisions are required, these are implemented and a revised design submitted.

Offshore pipelines are generally installed directly on the seafloor by a lay barge and further buried to meet regulations and/or for protection against hazards such as anchors, trawler boards, scour, etc. In very soft sea bottom conditions, as encountered offshore the Mississippi Delta, self burial may occur whereby the pipeline sinks under its own weight several feet below the mudline. In more competent sea bottom conditions, the pipeline must be jetted down below the mudline using special jet sleds.

Construction methods affect the soil coming directly in contact with the pipeline inasmuch as a softer or looser backfill generally fills in the trench. The stability of the trench walls and the possibility of pipeline flotation during pipeline installation have been addressed by Yen, et al (23, 24).

Construction methods also affect the design of a particular line in that availability of equipment may preclude or impose certain installation procedures which have a direct impact on the geotechnical engineering of the line.

Also of particular importance are considerations of the construction constraints posed by necessary maintenance and repairs to the pipeline. Pipeline repairs are difficult and costly, and due to the uniqueness of the equipment required for such repairs, lost production time could be large. Thus, construction strategies which would confine pipeline breaks to a minimum and which would allow early detection and location of the breaks are desirable. The use of breakaway couplings located at strategic points and pipeline break location and retrieval systems is one of the design strategies.

Construction constraints also include tie-in points inshore or at the offshore terminals. Thus, the methods used to place the pipeline and its risers must be considered. Of particular importance is the provision of adequate flexibility and strength at these points. Too much strength and stiffness can be counterproductive in that excessive damage to the pipeline and to the platform and terminal tie-in points can result as the pipeline is subjected to excessive pulling and bending forces. Provisions for as much flexibility as is feasible are highly desirable. Thus, the use of flexible tie-ins and provision of slack in the pipeline constitute another group of suggested design strategies (9).

CASE STUDY

Constraints

A 12-inch diameter crude oil line must be installed to connect two platforms located south of the Southwest Pass of the Mississippi Delta to a tank farm on the Louisiana coastline (Figure 2). The design of the line must be such as to optimize the line's reliability over its expected lifetime (20 to 30 years).

Operational considerations call for two pipe sizes:

- 12.75 in. OD X-52 steel pipe with a wall thickness of 0.375 in. and a 1.5 in. thick concrete weight coating. The specific gravity of the empty pipe, with respect to seawater, is 1.33. This pipe will be laid in water depths less than 200 ft and buried.
- 12.75 in. OD X-42 steel pipe with a wall thickness of 0.5 in. and no weight coating. The specific gravity of the empty pipe, with respect to seawater, is 1.16. This pipe will be installed in water depths greater than 200 ft, and will be left unburied.

Route and Hazards

The present front of active mudslide features is shown in Figure 2 (6,7). Study of the historic progradation of Southwest Pass indicates that this mouth of the river is presently building seaward at the rate of 150 to 200 ft per year. With future efforts to increase the flow through Southwest Pass to decrease maintenance dredging, this rate is anticipated to increase to 200 to 300 ft per year.

With this background, the primary front of active mudslide features in 30 years has been projected in Figure 2. The pipeline route was chosen to stay outside this perimeter.

However, a study of the present front features (6,7) indicates that it might still be possible for some small flow features to reach the pipeline during its lifetime. These features are indicated to have widths of up to 500 ft and lengths of several thousands of feet.

The strategy is to route the line to minimize adverse effects of the present and anticipated future slide features; further, to define the characteristics of the future slides in a generic sense, not specific to the present locations or features. Thus, the design of the pipeline becomes based on sizing the line to resist forces from classes of anticipated slide features.

Field Reconnaissance and Soil Characterization

Given the pipeline route in Figure 2 and a general characterization of hazards along the route, a field reconnaissance effort was organized to define the soil characteristics. This effort consisted of geophysical surveys along the route. Side scan sonar, high resolution profiles and shallow geophysical surveys were made in a corridor 200 ft either side of the route. Several "probe" surveys were made into the front of the advancing delta sediments to further define their characteristics and location.

An extensive program of drop coring along the route and along the "probe" lines was performed to obtain soil samples. Coring locations were generally spaced about 2000 ft apart along the route. A large drop coring device (3.5 in. internal diameter, 20 ft barrel) with a heavy weight stand (3000 lbs) was used to obtain the samples.

Figure 3 shows the results of the soil tests on samples obtained along the southern portion of the route. The sediments were predominately clays with undrained shear strengths of 40 to 80 psf in the upper 3 to 4 ft of soil. Below about 4 ft, the soil strength began to increase with depth. Sensitivities generally ranged between 2 and 3.

Water contents of these soils ranged from 100 to 150 percent at the mudline to 50 to 100 percent at penetrations of 6 ft. Buoyant unit weights generally ranged between 25 and 35 pcf. Specific gravities ranged from 2.71 to 2.75.

In areas offshore the Mississippi Delta, the interface between the water and the seafloor is rarely sharp due to the presence of suspended sediments. Rather, there is a "layer" of suspended sediments located between the seafloor and the water column, with variable thickness and viscosity that behaves more like a fluid than a solid. As wave and current action becomes sufficiently intense to develop significant tractive stresses, soil bonds are destroyed and water content increased through the suspension of soil particles into the water column. Thus, a layer of soil and water is developed that has non-Newtonian properties. With continued and intensifying wave action, the layer becomes thicker (8).

When the wave action ceases, the sediments settle, thixotropy and consolidation start, and the sediment again assumes a solid consistency. Given sufficient time without significant agitation, the soils consolidate to less than their Liquid Limit and have engineering characteristics that are plastic in nature. The behavior of the soils within this zone has important effects on the flotation and settlement characteristics of the pipeline and on the forces exerted by the soils as they move past the pipeline.

Viscosity tests were conducted on the soils close to the mudline to gain an understanding of the behavior of these materials in a fluid-like state. Viscosities were measured using a Coutte type coaxial cylinder viscometer (16). Results of the tests are summarized in Figure 4.

Robertson and Pazwash (19,16) discuss the behavior of soft bottom materials such as are found in the Delta. They have found that the rheologic equation for Bingham plastics provides satisfactory agreement with the observed behavior of such "soils":

$$T = T_y + \mu_p \dot{x} \quad (1)$$

where T = shear stress
T_y = yield stress
$\dot{x}$ = strain rate
μ_p = plastic viscosity

The data presented in Figure 4 permits development of relationship between water content and shear stress, given a range of strain rates. These data are used subsequently to compute lateral flow slide and vertical buoyancy forces.

Settlement and Flotation

An important consideration in the design of the pipeline is the the density of the pipeline relative to the density and shear strength of the undisturbed sediment and the backfill material for buried pipes. If the weight of a buried pipeline is low, it may float out of the soil and thus be subject to current-induced forces. If the pipe plus content unit weight is less than the unit weight of seawater (64 pcf), the pipe will float to the surface.

For heavy pipelines, a soil bearing capacity failure may occur and the pipeline may have excessive burial. Since forces due to soil movement generally increase with penetration below the seafloor, while the depth of embedment increases with the unit weight of pipe plus content, the pipeline should have the minimum practical unit weight considering the full range of service conditions, in order to minimize the soil forces that may act on it when the soil mass is unstable. Both the phenomena of flotation and settlement are affected by the soil conditions near the surface. Strength and water contents along the line have been presented in Figure 3.

Computations were made for potential flotation of the buried section of the pipeline using the analytical-experimental procedure developed by Ghazzaly, Kraft and Lim (10). The results of the flotation analysis are presented in Figure 5. Shown are the computed pipe unit weights required to prevent flotation of a buried pipeline for a range of soil strength.

Soil shear strengths at the mudline would generally indicate no potential for flotation. However, these shear strengths are for undisturbed soils, whereas flotation would likely be governed by the characteristics of the disturbed mudline materials, which could be considerably weaker due to its remolded state. As indicated in Figure 5, the pipe could be barely stable if the soil shear strengths dropped to 5 psf or lower. This is quite possible for such soft soils when subjected to intense wave and current action or jet sled trenching. It may thus be surmised that the pipe is marginally stable against flotation during such conditions if empty and stable if full of water or oil.

Ghazzaly, Kraft and Lim (10) present a methodology for the computation of settlement of buried pipelines. Potential for added settlement of the buried pipe was assessed using this method. The near-surface soil properties shown in Figure 3 were used. The results of the assessment are shown in Figure 6. Figure 6 indicates that for a fully-buried pipe, as shown in the inset, the pipe will not sink even when flooded if the soil shear strength exceeds 10 psf. It may be concluded that additional significant settlements of the buried pipeline are unlikely.

The settlement problem for a pipeline placed on the seafloor is somewhat different from that of the buried pipeline. The primary settlement will occur due to bearing failure of the soil mass. The pipe will settle until it reaches a depth at which the bearing capacity of the pipe-soil system is equal to the weight of the pipe. A method for computing settlements due to the above phenomenon has been described by Small, et al. (20).

This procedure was used to evaluate the potential for settlement of a 12.75 in. OD pipe with a wall thickness of 0.5 in. and no weight coating. The computations indicated that for the softest soils (20 f) the pipe would barely settle to its springline when flooded. Since all pipes are hydrotested, it is expected that the pipe wil sink at most up to its springline. The pipe would barely sink only when laid empty on the seafloor.

Analysis - Stability Against Mud Flows

Large tensile stresses may be induced in pipelines by soil movements oblique to the longitudinal axis of the pipe. The magnitude of the stresses depends on the width of the sliding soil mass, the magnitude and direction of soil movement, the soil shear strength and depth of burial. Soil movements transverse to or slightly oblique to the direction of the pipe cause the most severe stresses.

Analyses were performed for the evaluation of tensile stresses for mudslide widths of up to 500 ft. The method used was that developed and presented by Reid (17). This procedure treats the pipeline as a loaded, flexibly supported cable. Soil forces and resistances were described using the procedures summarized in Table 1. Soil shear strengths were assumed to range from 20 to 80 psf.

Results of the analyses for a 500 ft wide slide are shown in Figure 7. Increasing stresses (tensile, flexural, shear) due to deeper burial are evident. The results indicate that the proposed pipelines should not be buried or allowed to bury across an unstable zone where the undrained shear strength is 80 psf or greater at the surface. If soil strengths in the unstable zone lie between 20 and 50 psf, the stresses induced in the line are less than the yield stress for the design depths of burial.

A second approach for evaluation of stresses generated on a pipeline crossing a mudslide or turbidity flow area was examined using the concepts of fluid dynamics in very soft Bingham materials. Pazwash and Robertson (16) report the results of drag coefficient measurements on a limited number of body shapes in clay-water mixtures which behave as Bingham fluids. The drag force, under steady flow, can be computed from the equation

$$D = \frac{1}{2} C_D \rho V^2 A \qquad (2)$$

and

$$C_D = C_{D,N} + KP \qquad (3)$$

where:

D = Drag force on body in Bingham fluid
C_D = Drag coefficient in Bingham fluid
$C_{D,N}$ = Drag coefficient in Newtonian fluid
K = Plasticity factor, function of body shape

$$P = \frac{2T_y}{\rho V^2}, \text{ plasticity number} \qquad (4)$$

and

T_y = yield stress
ρ = mass density
V = velocity of fluid

Drag forces were computed for the two pipe sizes studied. Velocities of motion were assumed to be in the range of 1 ft/sec to 4 ft/sec (21,22). For samples with water content between 120 to 160 percent, the absolute viscosity varies between 15 to 40 centipoise at shear rates of 5 to 10 sec^{-1}. However, the Newtonian drag coefficient is approximately constant for absolute viscosities between 5 to 80 centipoise. The computed pipeline stresses using the aforementioned parameters are summarized in Figure 8.

Comparison of the soil forces and generated stresses between the two different approaches indicates that the viscosity approach yields forces which are substantially lower than those obtained with the conventional method. This is a topic for further research.

Pipeline Burial Depth

Several factors dictate the selection of burial depth for an offshore pipeline. Some of these factors are listed below:

1. Regulations
2. Protection against bottom currents
3. Protection against flotation
4. Protection from dragging ship anchors
5. Availability of appropriate burial equipment

Of all these factors, it appears that the local and federal regulations have an overriding influence in dictating the burial requirements for an offshore pipeline.

The Bureau of Land Management (BLM) has primary responsibility for certifying construction permits for pipelines in the present area of interest. It is generally required by the Bureau that the pipelines be buried to have a depth of cover at least 3 ft for all areas with water depths shallower than 200 ft. For water depths greater than 200 ft, there are no burial requirements. The Corps of Engineers policy requires 10 ft of pipeline burial when pipelines cross a shipping lane in water depths less than 200 ft.

The BLM reviews any request for the waiver of burial requirement if such request is made during the application of the construction permit. The review is based on the soil conditions and geophysical data presented to BLM. A waiver can be granted if it can be shown that burial of the pipeline will be detrimental to its performance or survival.

Any burial (other than self-burial) of pipeline involves additional construction costs. The analyses for this case indicate that the pipeline will barely be buried to its springline when hydrotested. Thus, additional effort is required if the standard BLM requirement is to be met in water depths less than 200 ft.

Should such burial requirements be imposed on the pipeline, difficulty may be encountered. Due to the very soft soils in this area, it is not possible to hold a pipeline ditch open to any great depth for any substantial period of time. The soils will virtually flow back into the trench due to their very soft condition. Jet sled trenching will be required if the pipe is to be buried.

As discussed in the section on Pipeline Stability, greater burial depths increase the potential for pipeline failures when crossing mudflows. Thus, non-burial of the pipeline is desirable. However, damage due to anchors must be considered.

Presented in Figure 9 are the depths below the seafloor that various weights of conventional anchors are anticipated to penetrate. The initial depth and the maximum depth of embedment (under large sustained pulls) are shown. As indicated by Figure 9, anchors in the range of 15,000 to 45,000 pounds are anticipated to penetrate initially to depths of 40 to 50 ft. Under large pulling forces, their maximum penetrations are estimated to be in the range of 75 to 100 ft. Such penetrations have been confirmed by anchor sounding tests in this portion of the Mississippi River Delta. The results indicate that protection of a pipeline against damage due to dragging anchors is virtually impossible to obtain by burying it 10 ft.

Stability Against Bottom Currents

Ocean currents that may induce lateral and uplift forces on unburied pipelines include wind-driven, density, tidal, inertial, deep Gulf, longshore, wave-induced and riverine currents. Their cumulative effect may induce sufficient force on unburied pipelines to cause significant lateral movements.

An evaluation of the magnitude and recurrence intervals of various potential currents for the proposed route is presented in Table 2. Shown are the various peak near-bottom current velocities (combination steady and transient wave 5 ft above mudline) and corresponding recurrence intervals at different water depths along the pipeline route.

The method described by Jones (13) to evaluate the resistance of unburied pipelines to current-induced forces was used in the present study. Results of the evaluation for six different pipe sizes and coatings are presented in Table 3. Preliminary design plans are for pipe #1 (12.75 in. OD, 0.5 in w.t., X-42 steel, no weight coating) to be used in deeper water. The recurrence interval for the critical current velocity (inducing incipient instability) of 3.0 ft/sec for the empty pipe ranges from 2.2 to 3.1 years. It therefore appears that should a storm capable of generating currents equal to or larger than the critical velocity be anticipated to occur during installation, the pipe should be flooded to avoid movement.

Flotation of the pipeline can be ruled out with a slightly thicker weight coating (e.g., 2 in.). However, it is believed that successful burial can be achieved with the 1.5 in. concrete coating if care is exercised by the contractor in minimizing jetting and maximizing the eductor system action.

With time, the pipeline is expected to get buried gradually under added deposition. A small burial, coupled with the presence of much smaller current at the seafloor is expected to render the pipeline sufficiently safe against sliding failure due to bottom currents.

Stability Against Collapse Depressions

Pipelines have been shown to fail repeatedly in the zones of collapse depressions (1,4). These collapse depressions are common in the shallow water portions of the Mississippi Delta area (6). They are presumably caused by a liquefaction process associated with the escape of gas, and are characterized by a sudden loss of vertical support capacity. These features may range from circular (diameters ranging from 100 to 1500 ft) to elongated (500 ft wide by 6000 ft long). The depressions have irregular interiors with relief ranging from 1 to 5 ft (6,7).

Post-failure examination of pipelines crossing collapse depressions indicate that many of the pipelines have failed under fatigue due to a large number of cyclic loads. Proprietal studies have indicated that the fundamental frequencies of the pipeline section spanning such a zone may be very close to the wave and current vortex shedding frequencies. Thus, the fatigue failures appear to be the result of loss of support across the collapse depressions and subsequent strain cycling caused by vortex shedding.

To consider the potential for fatigue failure of the line crossing a collapse depression, sustained near-bottom current velocities in the range of 1 to 4 fps were considered. For such a range, the vortex shedding frequency would be in the range of 0.2 to 0.8 cps.

Assuming that the pipe could be required to span collapse depressions having widths up to 100 ft, the unsupported pipe span would have a natural frequency in the range of 0.7 to 1.0 cps (14).

Studies of pipe span vibrations (13,14,15) indicate that the span starts to oscillate in line with the flow when the shedding frequency is about one-third of the pipe span natural frequency. Significant oscillations occur when the vortex shedding and natural frequencies coincide.

These results indicate the potential for significant horizontal and vertical oscillations and a high potential for fatigue failure. Given that the line had to span such a feature, the cyclic stressing could only be reduced through the use of vortex spoilers or by covering the pipeline. Re-laying the line around the feature would be implied as the only practical solution.

CONCLUSIONS

This paper has described and illustrated an engineering process for design of pipelines in mudslide areas. Through a combination of routing, weighting, sizing, burying and anchoring strategies (3), a pipeline having acceptable cost and reliability can be designed.

Research is needed to reduce the existing uncertainties in identification of future mudslide hazards and the associated soil loads and restraints. More detailed information on the performance of pipelines installed in mudslide areas (12) is needed to guide further development of design and analytical procedures.

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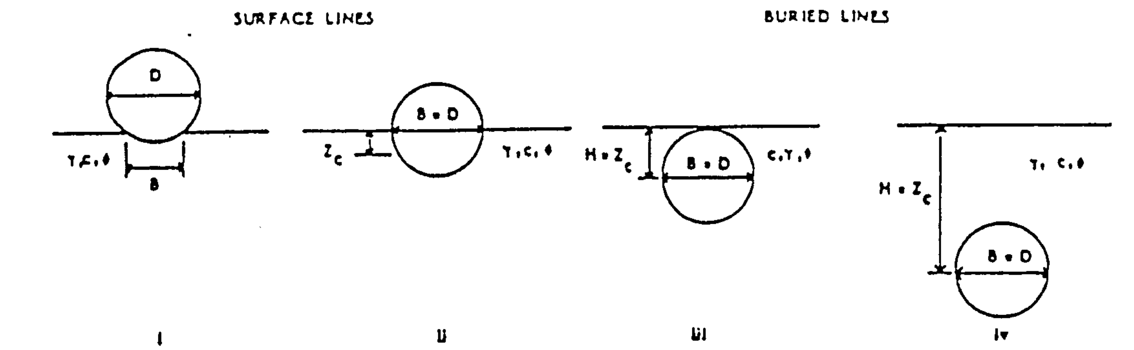
TABLE 1: SOIL LOADING AND RESTRAINT ALGORITHMS
(Adapted from Audibert, et al, 1978)

COMPONENTS AND RELATIONSHIPS	PROPOSED LOAD/RESTRAINT-DEFORMATION RELATIONSHIPS	REMARKS
Axial Component t-z Curve	$T_u = \begin{cases} \alpha C A_c & \text{for clays} \\ \iint_{A_c} \bar{\sigma}_n \tan \delta \, dA & \text{for sands} \end{cases}$ z_u = 0.1 to 0.2 inches (2.5 to 5 millimeters) where: A_c = soil-pipeline contact area/unit length C = undrained shear strength α = load transfer coefficient $\bar{\sigma}_n$ = effective normal stress at soil-pipeline interface δ = interface friction angle dA = incremental contact area	Inferred from pile shaft load-transfer technology
Horizontal Component p-y Curve	<u>Surface Lines</u> (Cases i and ii below): $p_u = F (W_b - F_v)$ $y_u = \Delta H \frac{D}{2}$ where: F = coefficient of lateral stability W_b = buoyant weight of pipeline/unit length F_v = hydrodynamic lift force/unit length ΔH = lateral displacement	After Karal (1977) (24)
	<u>Buried Lines</u> (cases iii and iv below): $p_u = \begin{cases} C N_c D & \text{for clays} \\ \bar{\gamma} Z_c N_q D & \text{for sands} \end{cases}$ $y_u = \begin{cases} 0.04 \text{ to } 0.06 \ (Z_c + D/2) & \text{in clays} \\ 0.015 \text{ to } 0.02 \ (Z_c + D/2) & \text{in sands} \end{cases}$ where: N_c, N_q = bearing capacity factors (horizontal direction) $\bar{\gamma}$ = effective soil unit weight Z_c = depth to center line of equivalent footing or anchor plate D = pipeline diameter	Inferred from footing and pull-out capacity technology of vertical anchor plates (after Audibert, et al, 1977) (5)
Vertical Component q-z Curve	<u>Downward Direction</u> $Q_u = \begin{cases} C N_c B & \text{in clays} \\ (\bar{\gamma} H N_q + \lambda \bar{\gamma} B N_\gamma) B & \text{in sands} \end{cases}$ $z_u = \begin{cases} 2 \epsilon_f B & \text{in clays} \\ 0.1 B & \text{in sands} \end{cases}$ where: N_c, N_q, N_γ = bearing capacity factors (vertical direction) H = depth of embedment of equivalent footing of width B B = width of equivalent footing $\leq$ diameter of pipeline ϵ_f = axial strain to failure in triaxial compression test	Inferred from bearing capacity technology for strip footings
	<u>Upward Direction</u> $Q_u = (c F_c + \bar{\gamma} Z_c F_q) B$ all soils $z_u = 0.04 H$ all soils where: F_c, F_q = breakthrough factors for long cylinders of diameter B	Inferred from pull-out capacity technology for horizontal anchor plates & cylinders Thomas (1978) (35)



Notes: In the above formulations, it is assumed that undrained conditions prevail in clays while drained conditions prevail in sands. T_u, P_u and Q_u are ultimate soil loads or restraints per unit length of pipelines.

TABLE 2: HURRICANE-GENERATED CURRENT VELOCITY RECURRENCE INTERVAL

PEAK WAVE AND CURRENT VELOCITY (5 ft above ML)		RECURRENCE INTERVAL (years) Water Depth (ft)			
Magnitude (ft/sec)	Direction (°magnetic)	250	300	350	400
3	290	2	3	3	3
4	295	3	3	3	4
5	296	3	4	4	4
6	297	4	4	5	5
7	298	5	5	6	6
8	299	6	7	7	7
9	300	8	8	9	9
10	300	10	10	12	14

TABLE 3: STABILITY OF PIPES AGAINST BOTTOM CURRENTS

Pipe (#)	O.D. (in)	W.T. (in)	Concrete Coating	Condition	Specific Gravity	Critical Current Velocity ft/sec	knots
1	12.75	0.5	None	Empty	1.16	3	2
1	12.75	0.5	None	Full	1.98	8	5
2	12.75	0.375	1.0 in.	Empty	1.2	4	2.5
2	12.75	0.375	1.0 in.	Full	1.85	8	5
3	12.75	0.5	1.0 in.	Empty	1.41	6	3.5
3	12.75	0.5	1.0 in.	Full	2.03	10	6

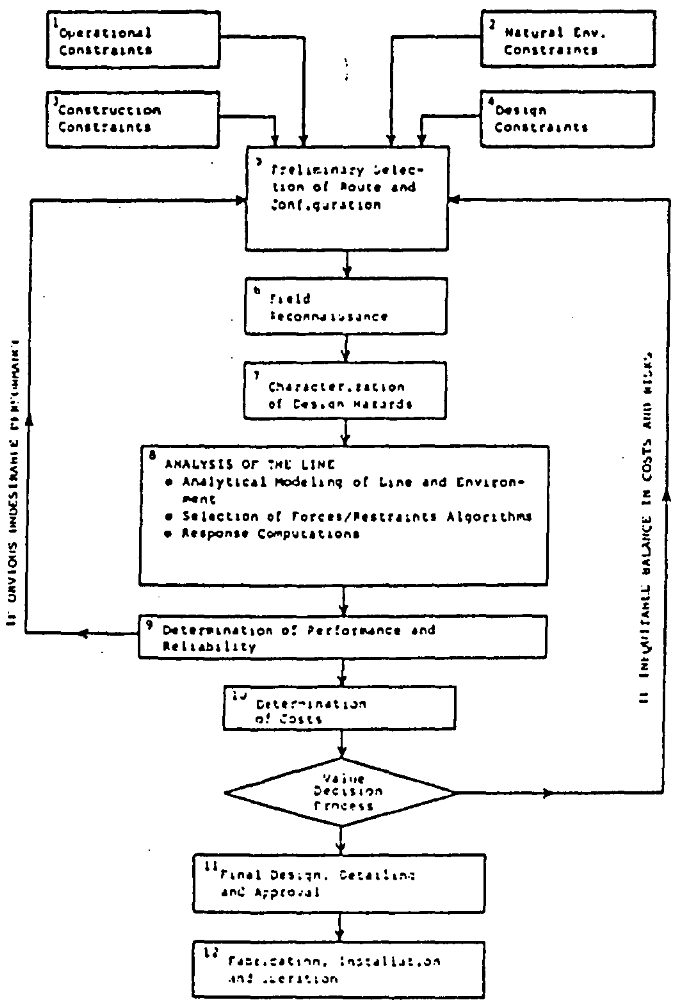


Fig. 1 — A flow diagram for the offshore pipeline design process

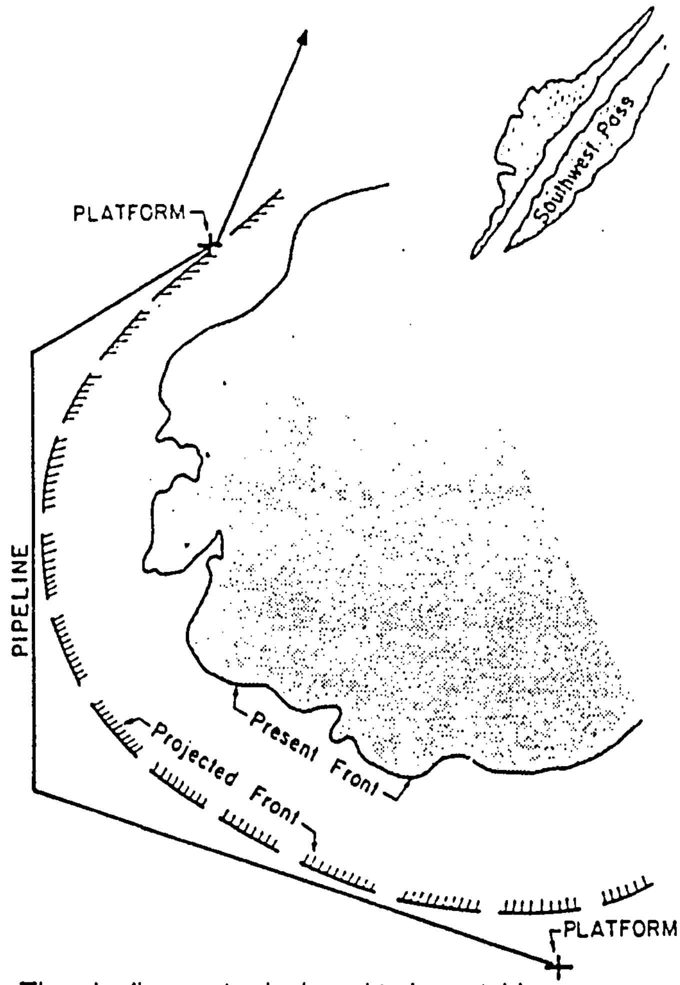


Fig. 2 — The pipeline route designed to be outside the projected front of unstable delta sediments

$sf = 47.8\ N/m^2$

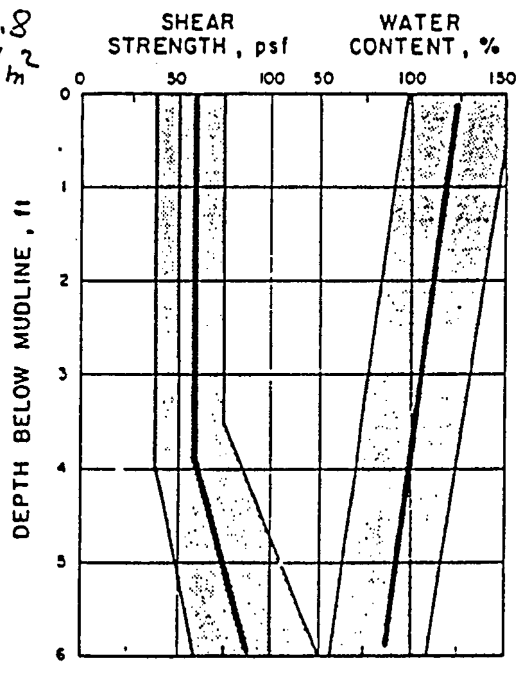


Fig. 3 — Range of undrained shear strengths and water contents of soils along pipeline route

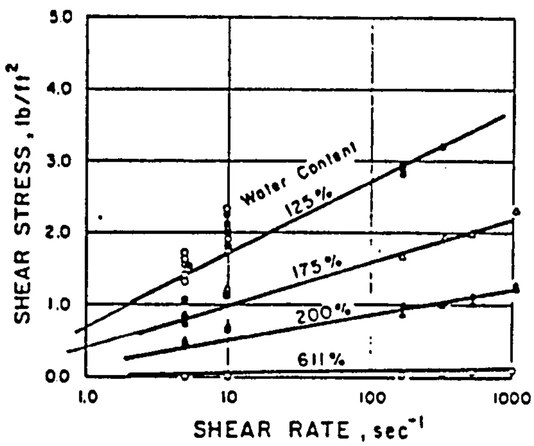


Fig. 4 — Variation of shear stress as determined by viscometer with shear rate and water content

$\tau_y \cong 0.5\ psf \cong 24\ N/m^2$

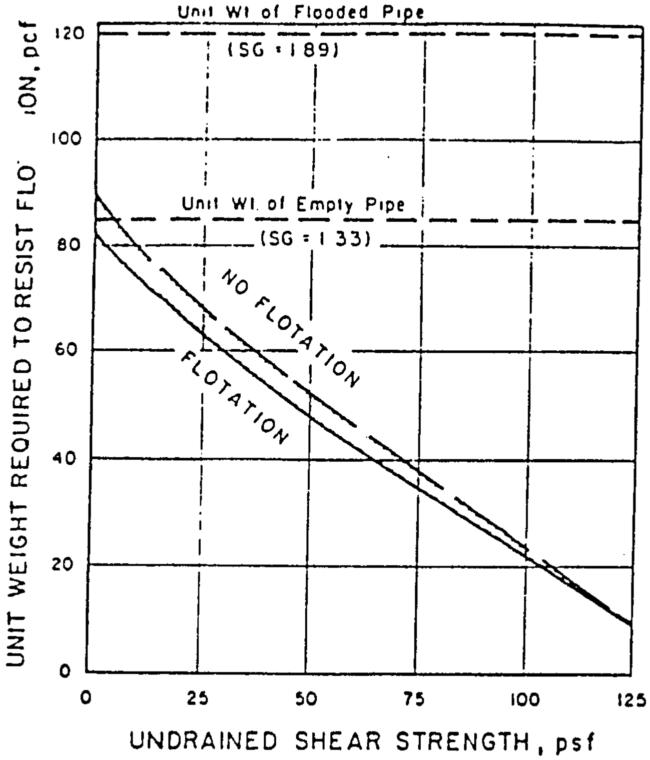


Fig. 5 — Flotation of propose D pipeline for shallow water (12.75 in. *OD*, 0.375 in WT 1.5 in WT coating)

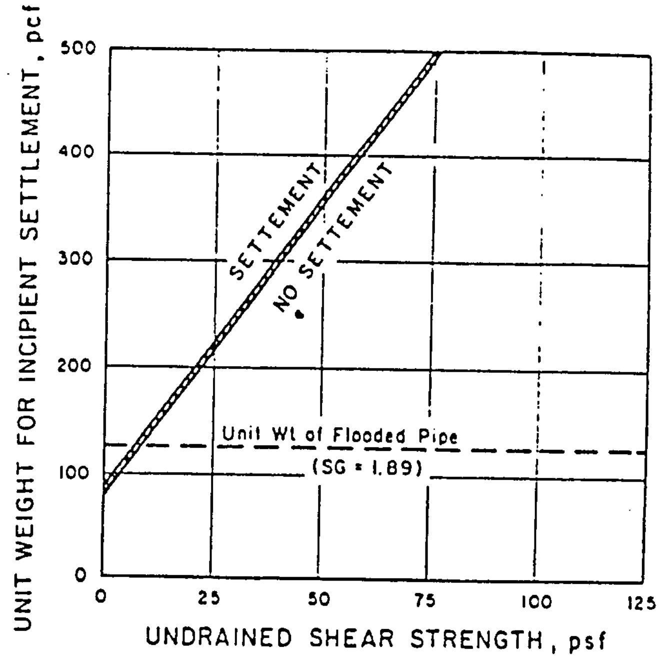


Fig. 6 — Settlement of proposed pipeline for shallow water

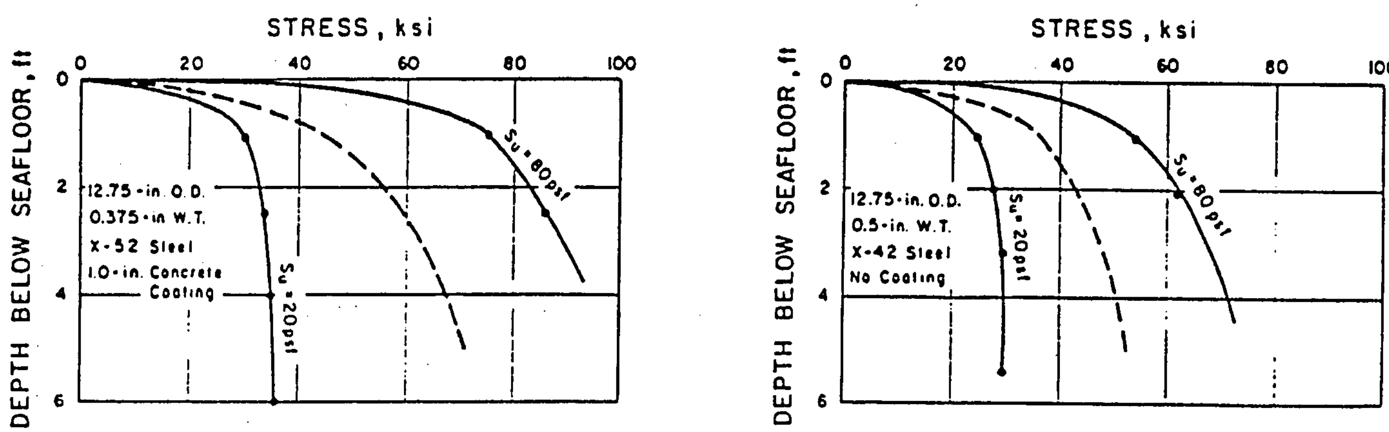


Fig. 7 — Combined tensile and flexural stresses developed in pipeline subjected to transverse 500 ft wide mudflow treating the soil as a plastic solid

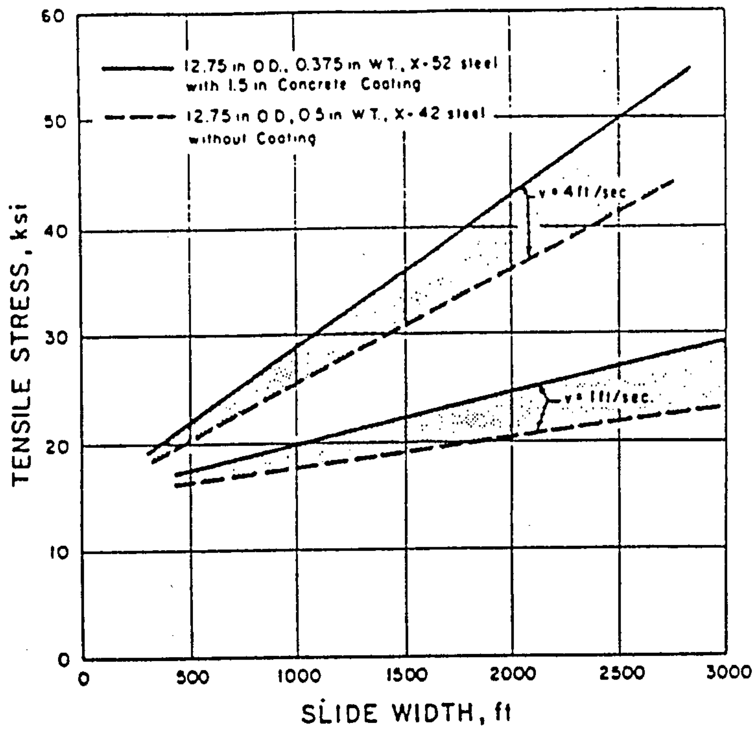


Fig. 8 — Combined tensile and flexural stresses developed in pipeline subjected to 500 ft wide mudflow treating the soil as a bingham fluid

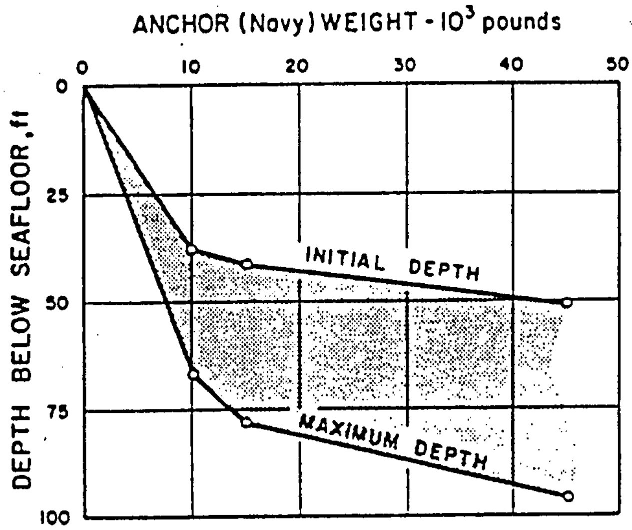


Fig. 9 — Predicted initial and maximum depth of embedment of navy type anchors in delta soils

OTC 4667

Stimulated Self-Burial of Submarine Pipelines

by C.H. Hulsbergen, *Delft Hydraulics Laboratory*

This paper was presented at the 16th Annual OTC in Houston, Texas, May 7-9, 1984. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words.

ABSTRACT

Under certain conditions submarine pipelines bury themselves down to two diameters below the original sea bed. A field example is presented, and an analysis is given of the possible mechanisms involved. Seeking a wider application of this phenomenon, a stimulated self-burial method is introduced, using fins attached to the pipe. Tentative laboratory tests show promising results.

INTRODUCTION

The answer to the question whether a specific pipeline on the seabed should be buried or not depends on a variety of arguments, stemming from corporate engineering practice, government regulations, international conventions, etc. All these arguments are somehow used in cost/risk analyses, where factors of widely different nature play a part, each with their own margin of uncertainty. The accumulated uncertainties may create such an amount of manoeuvring room that the original question may be answered either way. There are quite some uncertainties involved with a pure technical nature, including such items as:

- pipeline resistance to impacts
- pipeline/bed interaction under currents and waves
- definition of adequate pipeline stability under hydrodynamic forces and the related design criteria adopted
- last but not least the burial techniques themselves.

All items just mentioned are subject to a continuing development of theoretical, empirical and technical know-how, thereby possibly affecting the outcome of the burial question.

An interesting development in the area of pipeline burial was the recent discovery of the fact that pipelines bury themselves down to three pipe diameters under certain circumstances. A surprising example of this phenomenon in the Dutch North Sea sector will be presented hereafter.

Needless to say that this is an important asset [illegible] attempting to minimize the capital cost, especially for marginal oil and gas fields. In fact this phenomenon has recently led the Dutch authorities to relax their pipeline burial regulations. Meanwhile, specific research is being conducted in th[e] framework of MATS (Netherlands Marine Technological Research) aiming at a better understanding an[d] subsequent predictability of self-burial for specific pipelines. However, there are natural limit[s] to the self-burial potential of pipelines, depending on pipeline characteristics, hydraulic condi[tions], and the nature of the sea bed.

In order to broaden the applicability of self-burial, and to cope with conditions where plain pipelines would not or not fast enough bury themselves, the Delft Hydraulics Laboratory has investigated the feasibility of a new method (patent pending), called stimulated self-burial. The method essentially seeks to stimulate a controlle[d] local erosion by using plastic fins attached to the pipeline. Laboratory tests showed promising results so far, which may lead towards a cheap n[ew] pipeline burial method, thereby shifting the answer to the original question in positive direction.

DUTCH PIPELINE BURIAL REGULATIONS ON THE MOVE

In this context it is pertinent to briefly mention a certain development in the view of the Dutch State Supervision of Mines with respect to mandatory pipe burial. In the mid-seventies trun[k] lines had to be buried and covered by 2 m of san[d]. This rule stemmed from various arguments, among which two reasons in the background were roughly

- the wish to be on the safe side in view [of] envisaged risks.
- the availability of pipeline burial meth[-]ods which were fit for the job.

Since then, the ongoing debate [1,2] has be[en] refreshed semi-continuously by new research, wit[h] the result that the rules were adapted, i.e. relaxed. To date, certain categories of pipelines are allowed to be simply laid on top of the sand sea bed, provided that there is reasonable prospect that they will bury themselves and have a minimum sand cover of 0.2 m within one year. This last restriction mainly stems from the intense fishery with bottom gear, but this rule deliberately allows the process of self-burial to be deployed during a reasonable time span. The above mentioned evolution of pipe burial regulations illustrates the ongoing adaptation as mentioned in the introduction, and there is no reason to believe that this evolution has already come to an end.

SCOURING UNDERNEATH PLAIN PIPELINES

Perhaps induced by the concern with free spans, local erosion underneath pipelines has been dealt with largely with a view to prevent it, rather than to stimulate the erosion of the remaining supporting points. This is probably also due to a certain similarity which was attributed to local erosion near pipelines as compared to local erosion near vertical piles and piers [3]. This apparent similarity may have distracted the attention from possible attempts to stimulate the erosion near pipelines as a potential active means to control the pipe/bed behaviour in a favourable way.

Kjeldsen's laboratory experiments [4] show that underneath pipelines, fixed on the original bed level, a scour hole develops with an ultimate depth which depends on the pipe diameter and the mean current velocity according to:

$$y = 0.972\ (V^2/2g)^{0.20} * D^{0.80} \quad \ldots. \quad (1)$$

where: y = maximum depth of scour hole after establishment of equilibrium
V = mean current velocity
D = pipeline diameter
g = acceleration of gravity

In general the scour hole depth is smaller than the pipeline diameter. This would point towards the expectation that a pipeline, if free to sag, would settle somewhat in its own erosion pit down to a position where it no longer protrudes above the bed effectively enough to cause further scouring underneath. Thus the erosion would stop, leaving the top of the pipeline exposed. This is precisely what happened during laboratory experiments conducted in the Delft Hydraulics Laboratory in the framework of MATS [5].

The above mentioned local erosion process (either by currents alone or by combined waves and currents [6]) is labeled "tunnel-erosion". The tunnel erosion process may start from an existing opening underneath the pipe (e.g. because the pipeline lies on the top of ripple crests), or by the excavating work done by the strong upstream eddy. The tunnel erosion development has schematically been represented in Figure 1.

SELF-BURIAL OF PLAIN PIPELINES IN THE NORTH SEA

In September 1980, Placid Oil's 4.2 km long, 10" + 2" gas-pipeline bundle served as a pilot project and was laid on the top of the sea bed in the Dutch North Sea block L10, connecting the platforms L10/A and L10/F (Figure 2, taken from [2]). The sea bed, consisting of fine sand (D_{50} appr. 0.18 mm), is very flat and shows no distinct ripple marks. Divers report the sand to be very weak and soft. Tidal currents turn clockwise, resulting in a tidal ellipse with the main axis perpendicular to the pipe alignment. During spring tide the maximum current velocity averaged over the water depth of 26 m is appr. 0.5 m/sec. The 5-year exceedance wave condition can be characterized [7] by a significant wave height of 6 m and a mean-zero-upcrossing wave period of 8 secs.

After laying, surveys were conducted in order to follow the height of the top of the pipe and the depth of the naturally formed trench with respect to the undisturbed sea bed elevation. The result, given in Figure 3, shows that within one year the three consecutive phases of self-burial occurred, viz. the erosion phase, the conversion phase and the depositional phase. Figure 3 gives mean values over four 1 km long pipeline sections; along the pipeline sections variations occurred which are discussed in detail in ref. [5]. The main result is the fact that the top of the pipe was finally more than 2 diameters below the original sea bed level.

At first it was a puzzle what processes could have caused such a deep burial trench, in view of the rather limited scouring depths in e.g. Kjeldsen's tests [4] and in the tests with freely sagging pipes [5]. By lack of pertinent in situ observations regarding the burial process itself, refuge was taken to hints which could be used to reconstruct the possible course of events.

A clue to understand what could have happened arose from detailed cross-sections over the remainder of the trench, made on 19 May 1981 (Figure 4): the trench appeared to be more than 15 m wide, having side slopes as gentle as 1 in 15. This means that the alternating tidal current could probably follow the downward slope reasonably well, even after the pipeline, lying in the lower centre of the trench, sank lower than the surrounding sea bed. This is in contrast to the steep (appr. 1 in 2) slopes which typically appear in the tunnel erosion tests as discussed before. Seeking a reason for the formation of such gentle slopes, it was thought that it could be the result of a different erosion process, viz. erosion produced by the turbulence near the leeward reattachment point of the separated stream coming over the top of the pipeline, rather than by tunnel erosion [5].

This kind of erosion process is known from the scouring behind a sill during the construction phase of estuary closure works [8]. Such a scouring pit typically has a steep (appr. 1 in 2) downward slope immediately behind the sill, and a gentle upward slope (appr. 1 in 20). The development and the geometry of the scouring pit depend on the sediment yield from upstream, on the sediment characteristics, on the hydraulic conditions and on the geometry of the sill. Both last mentioned factors are the cause of the deviating downstream velocity field with an increased turbulence level, which on its turn causes a significant increase of the local sediment transport capacity.

A certain analogy seems to exist between this process and the trench formation downstream of a pipeline resting on or partly in the sea bed; therefore this inferred type of trench formation is labeled as "leeside-erosion". Such a leeside-erosion event was noted by Kjeldsen (Figure 6 of ref. [4]), but he did not regard it as a potential contribution to pipeline burial, probably because he considered unidirectional currents only.

However, under alternating tidal current conditions this leeside-erosion would occur on both sides of the pipeline (as long as the leeside scour from one side is stronger than the rate of filling-in due to the normal sediment yield from the opposing side), thus producing a double scour pit, with the pipeline left on an elevated position in between. This would obviously lead to an increased exposure of the pipeline which subsequently would be lowered by one or more of the following processes:

- sliding or rolling down one of the steep slopes
- collapsing of the sand ridge on which the pipe rests
- alternating unilateral undermining of the pipe by the strong upstream eddy, causing the pipe to sag in a zigzag course
- tunnel erosion with spanwise extension.

A sketch of the supposed leeside-erosion scenario is presented in Figure 5. It is believed that the self-burial of the LIOA/F pipeline is the result of the combined processes of alternating leeside-erosion (creating a rather extended depression around the pipeline) and local pipe-sagging caused by the four above mentioned processes. This seems the only explanation for such a deep burial.

After the success of the LIOA/F pipeline, more pipelines were laid on top of the sea bed. In general they started to bury themselves, but the result is not as good as with the first pipeline. Figure 6 (taken from [2]) shows the mean elevation of the top for each pipeline as compared to the original sea bed, during the first year after laying. While an analysis of this different behaviour is still going on, a method was sought to increase the self-burial potential of pipelines by means of fins.

SELF-BURIAL POTENTIAL OF PIPELINES WITH FINS

The round cross-section of pipelines is certainly logical from a fluid transport and operational point of view, but that does not imply a good self-burial performance. It is normal practice that local scour (e.g. near bridge piers, piles etc.) is minimized by limiting the size and by improving the "streamline" of the cross-section.

However, in trying to improve the self-burial capacity of pipelines the reverse should be done, viz. increasing the cross-sectional area and creating much turbulence. This may be achieved by the application of roughness elements on the pipeline, e.g. in the form of fins or spoilers. Spoilers etc. have widely been investigated, mainly in attempts to limit vortex induced forces on piles, risers and cables [9, 10]. Recent research in the Delft Hydraulics Laboratory has shown that they also can serve to increase the self-burial capacity of pipelines, both in the leeside-erosion mode (Figure 7) and in the tunnel-erosion mode (Figure 8). Both examples, which were run in a 0.3 m wide flume with unidirectional current only, had the aim to demonstrate the increased erosional power of fins, rather than to give a conclusive proof of their feasibility. The pipelines were fixed between the glass panels of the flume; subsequent experiments with freely sagging pipes and alternating current are being executed now.

In the leeside-erosion experiment (Figure 7) where sand was used with D_{50} = 0.20 mm, care was taken to prevent tunneling by applying a "keel" fin underneath the plain pipeline (Figure 7, sub 1). Care must be taken when comparing plain pipes with pipes + fins, because the application of fins has at least three simultaneous effects:

- The effective pipe diameter is increased, so a larger part of the near-bed current velocity profile is blocked. This alone would result in an increased scour according to equation (1).
- The mean flow around and behind the pipe is deviated (depending on the geometry of the spoilers).
- The turbulence characteristics around and behind the pipe are deviated (again affected by the specific form and orientation of the spoilers).

In the experiments presented here, only the second and third effect play a part, because plain pipes have been compared to pipes+spoilers of equal gross diameters. This means that the actual effect of spoilers will be larger than indicated by Figures 7 and 8.

Figure 7 shows a doubling of the rate of leeside-erosion of type III as compared to a plain pipe. The ultimate scouring depth for the plain pipe would be 0.042 m according to equation (1).

Figure 8 shows a situation where very fine sand was used with D_{50} = 0.10 mm. A plain pipeline, fixed between the flume panels and just resting on the sand (like Kjeldsen [4] did), developed in 5 hours a tunnel erosion pit with its deepest point 3.3 cm below the original bed. According to equation (1), an ultimate depth of 0.049 m would be reached. Compared to the plain pipe, the scouring pit of the pipe with two spoilers is 2.7 times as deep, and the average erosion rate is 5.0 times as large.

From the results as given in Figure 7 and 8 the provisional conclusion may be drawn that spoilers are quite effective in increasing both tunnel-erosion and leeside-erosion near pipelines. It remains to be demonstrated, however, that spoilers are also effective in the actual sagging and burying process of a freely suspended pipeline. Experiments of this type are in progress, both in the laboratory and in the field.

DISCUSSION

In between the promising experimental results and the application of fins on a routine basis for specific circumstances, some additional research is necessary with regard to questions such as:

- optimum size and arrangement of fins
- operational aspects
- adverse and favourable side effects

With respect to the optimum size, form and arrangement of the fins, a provisional conclusion from Figure 7 is that the erosion effect increases with increasing fin size. However, additional tests are necessary to show the effect of fins which actually enlarge the gross diameter of the pipeline. It is expected that fins, apart from an increased erosion in loose sediment, will also stimulate the self-burial in slightly cohesive soils (e.g. sand-clay laminations) where plain pipes would not bury themselves at all. Preliminary tests have shown that the fin effect may be increased if the fins are indented instead of straight. The arrangement of the fins around the circumference of the pipe is important for a good performance. Fins are most effective in the vertical plane, above and underneath the pipe. The pipe, however, will rotate during laying and sagging, and will take any orientation. To cope with this effect, three or more equidistant fins should be applied, depending on the ratio fin-width/pipe-diameter.

With respect to operational aspects questions arise concerning the material of the fins, the attachment to the pipe, and the laying operation. The material of the fins should be cheap and effective. Plastic or nylon etc. is stiff enough to keep its form under the hydrodynamic forces, and strong enough to stay intact if lying underneath. Moreover it is flexible enough to present no adverse effects to fishery gear. The fins may be mounted on collar pieces of limited unit lengths which are then tied around the pipe. This can be done aboard the laying barge, or afterwards by divers. If done aboard, the stinger and the fins should match in order to avoid problems. The reel-method without stinger would pose no problems in this respect.

Apart from the erosional effect, various additional effects of fins will present themselves. The drag force will obviously increase, but simultaneously the lift force may decrease [11]. More research is needed to settle the stability of pipelines with fins near the bed under the hydrodynamic forces. The same holds for flow induced vibrations in near-bed pipelines with fins which may be subject to free spans. Provisional tests have yielded indications that fins may reduce the problem of free spans by provoking an excess self-burial effect which is concentrated on those pipeline sections which are most exposed, i.e. near the supports. This points towards a favourable effect of fins, viz. that pipelines with fins will sag more evenly than plain pipes. Finally the presence of fins will increase the resistance of the pipe, once embedded, against a possible upward movement under unfavourable soil conditions such as local liquefaction.

CONCLUSIONS

1. The pipeline burial regulations for the Dutch North Sea have recently been relaxed, enabling the deployment of the self-burial process during one year after laying.
2. The 10" +2" pipeline bundle between platforms L10A and L10F buried itself within six months, leaving the top of the pipe two diameters below the origina. bed level. The open trench which existed as an intermediate phase has completely been filled in since then.
3. Attempting to explain this deep pipe burial event, it is supposed that two important processes are involved, viz. tunnel-erosion and alternating leeside-erosion.
4. Pipelines which were recently laid do in general show a tendency to sag, but some are much too slow to meet the requirements.
5. Application of spoilers or fins to pipelines cause an increase of the erosional power, both in leeside- erosion and in tunnel-erosion mode. Conservative model tests show an erosional power up to five times as large as with plain pipes.
6. The results so far are promising, because the method appears to work well and is cheap as compared to artificial burial methods. Further research therefore seems to be worth while.

ACKNOWLEDGEMENT

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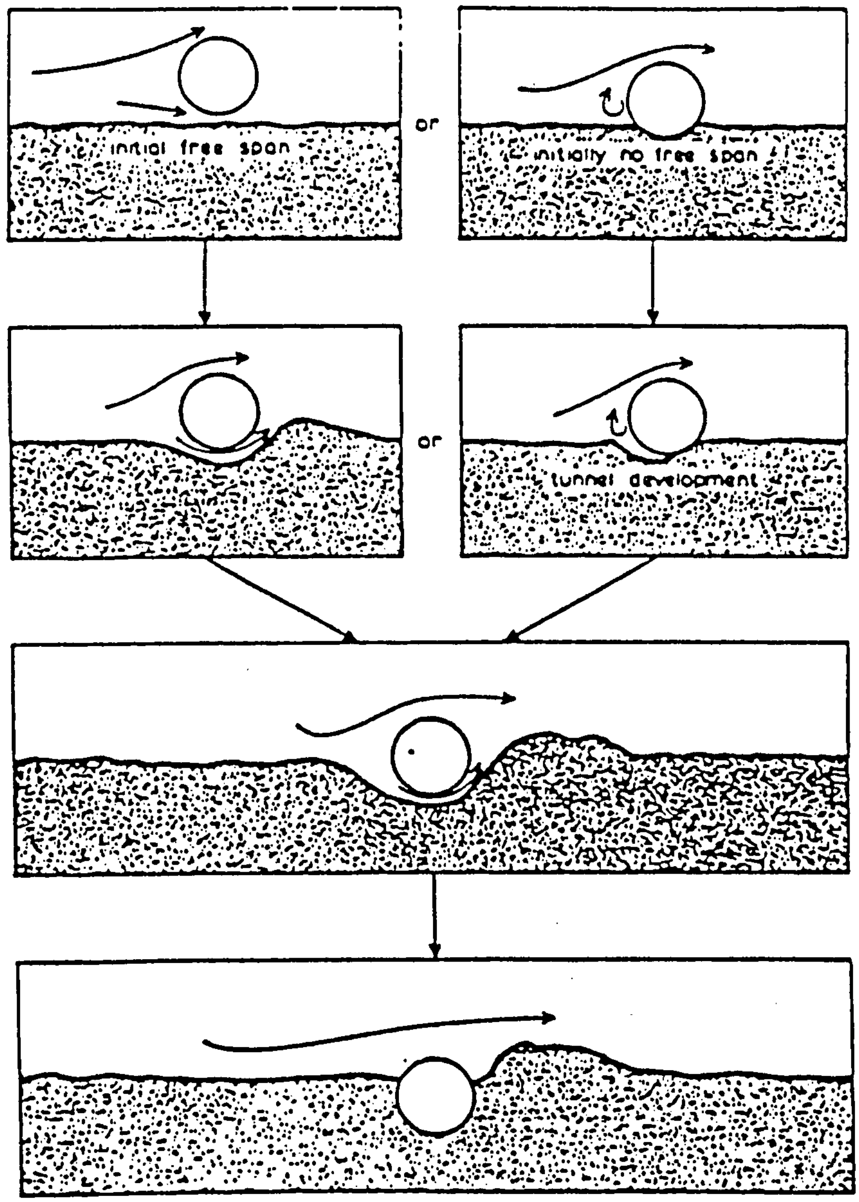

Fig. 1—Schematic representation of tunnel-erosion.

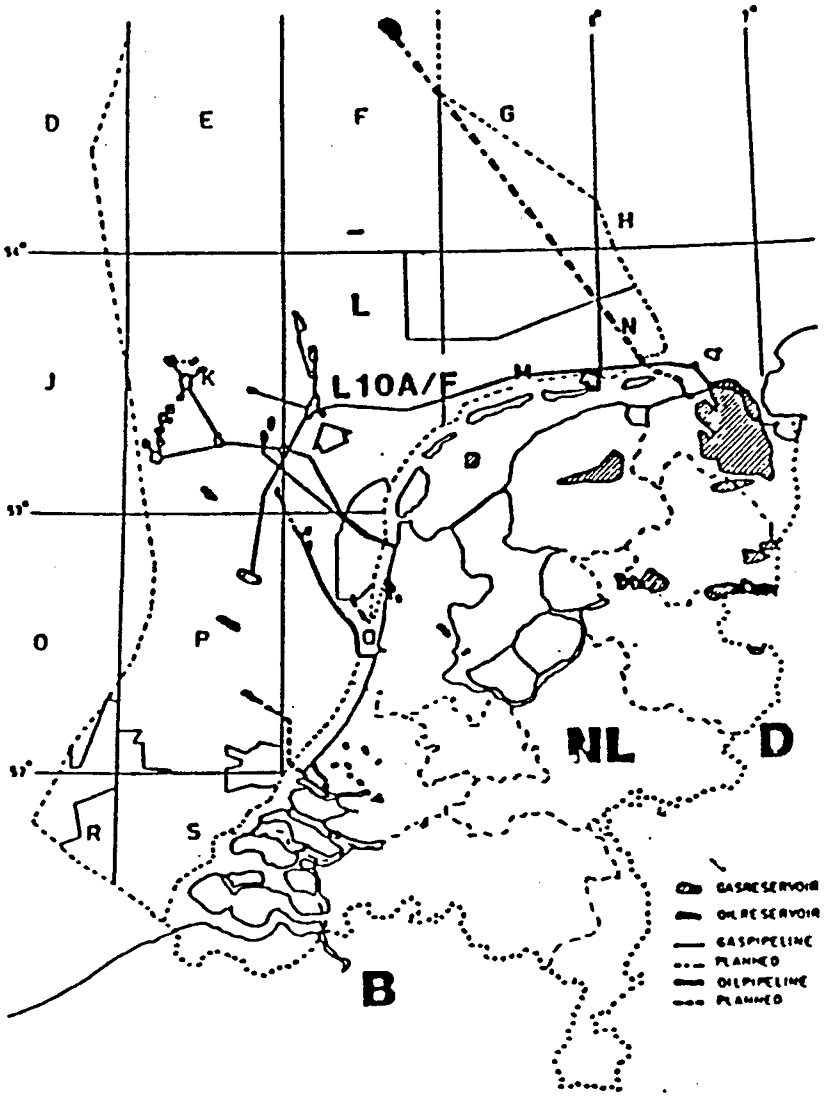

Fig. 2—Location of L10A/F pipeline bundle

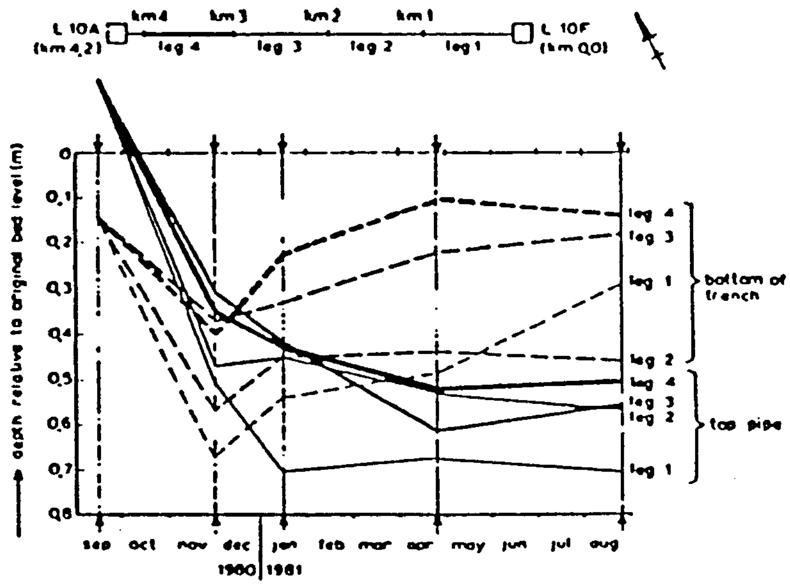

Fig. 3—Self-burying development of L10A/F pipeline

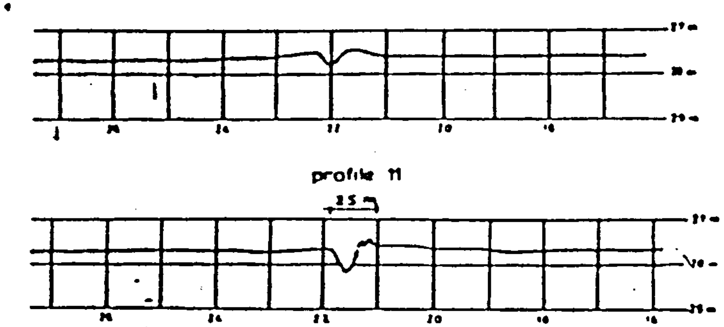

Fig. 4—Typical cross-sections over L10A/F trench

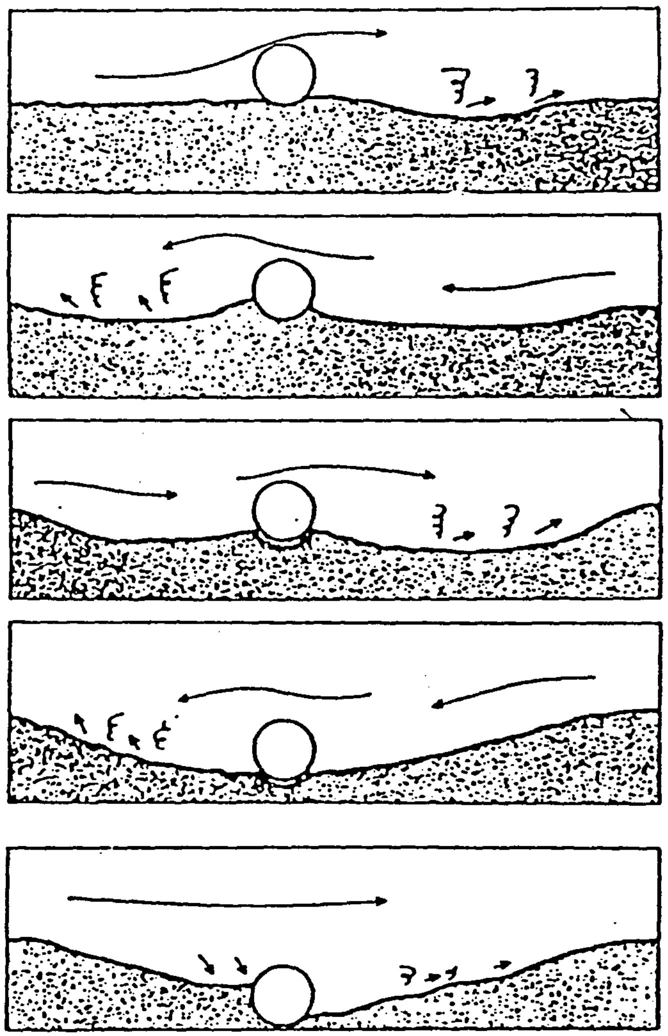

Fig. 5—Schematic representation of leeside erosion

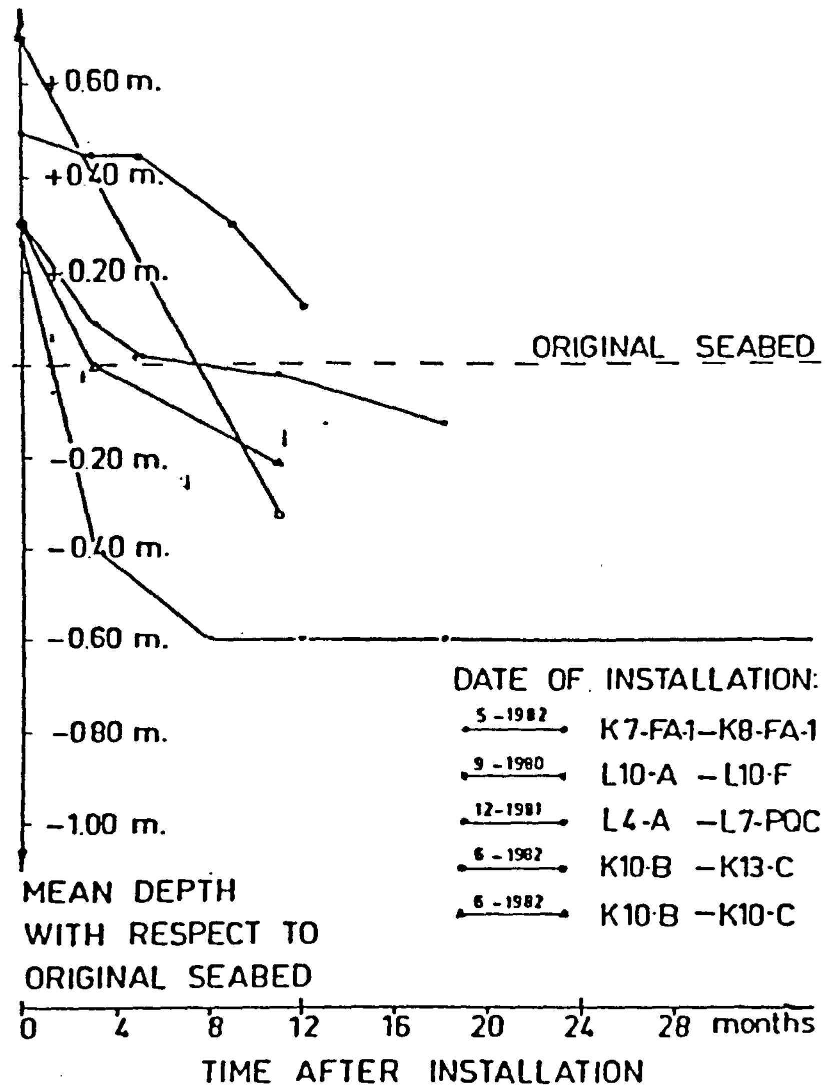

Fig. 6—Development of pipe top height for five pipelines

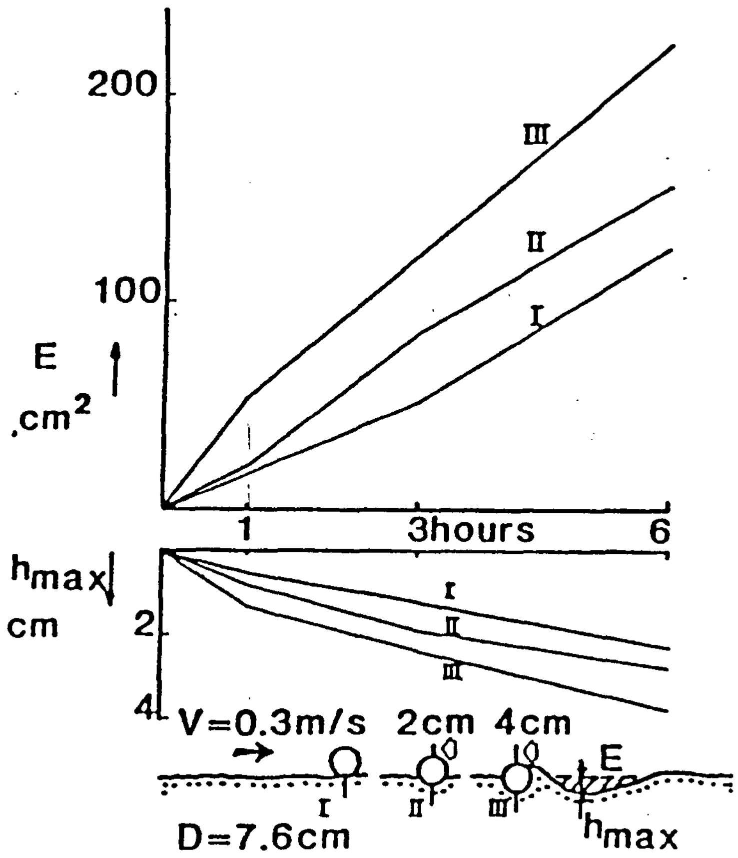

Fig 7—Effect of fins on leeside-erosion

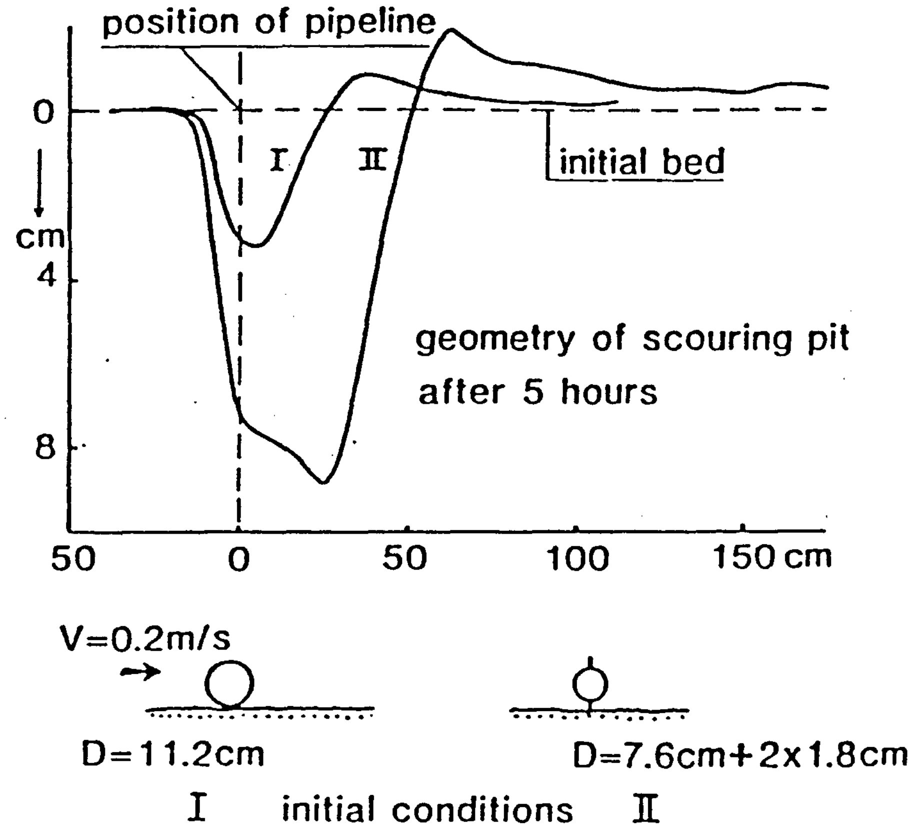

Fig. 8—Effect of fins on tunnel erosion

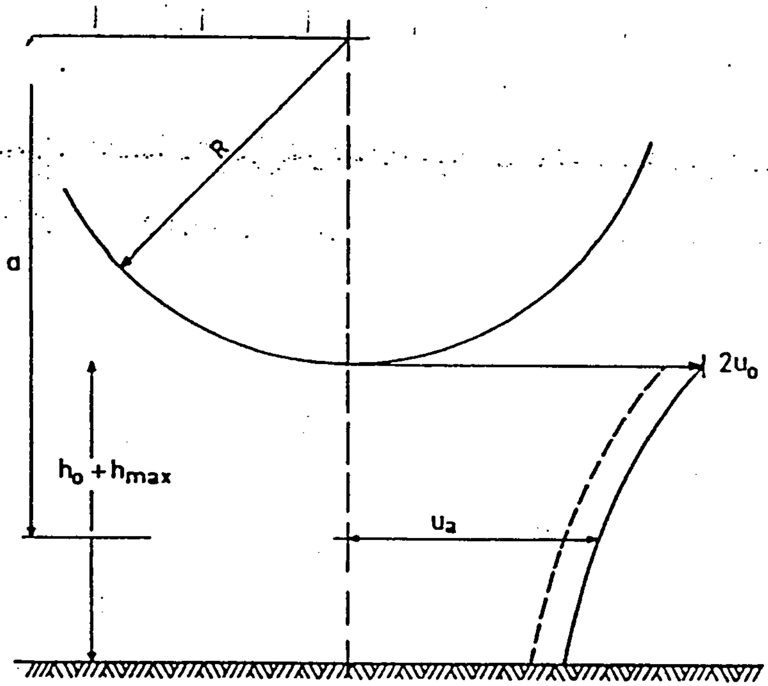

Fig.3 Velocity distribution around pipe.

Since the equilibrium situation of the sediment movement is considered, the bed shear outside the area influenced by the pipe and underneath the pipe must be equal. As the boundary layer is determined by the combination of viscous, turbulent and inertia effects, the same boundary layer is assumed in front and underneath the pipe. This leads to the conclusion that the velocity just outside the boundary layer underneath the pipeline, which is, according to the velocity distribution of figure 3,

$u_o\left[1 + R^2/(h_o + h_{max} + R)^2\right]$, must be equal to u_o.

It should be stated, however, that it is not impossible that underneath the pipeline a smaller value for r has to be used than that for the undisturbed sea bed. According to the results obtained by Van Ast and De Boer this influence will be small. Van Ast and De Boer [1] accomplished the above mentioned equality by diminishing the velocities under the pipeline with the value u_ξ.

$$u_\xi = u_o(1 + R^2/(h_o + h_{max} + R)^2) - u_o = u_o R^2/(h_o + h_{max} + R)^2 \qquad (8)$$

Together with the assumption of the distribution of the flow around the pipe, they are able to give an expression for $h_o + h_{max}$.

If $h_o + h_{max} = A$ and $h_o + R = B$,
then the expression is

for $h_o > 0$:

$$A^3 + A^2(3R-B) + A(R^2-2BR) - BR^2 = 0, \qquad (9)$$

for $h_o = 0$:

$$A^3 + 2A^2R - AR^2 - R^3 = 0, \qquad (10)$$

and

for $h_o \leqslant 0$:

$$A^3 + A^2(5R-B)/2 - BRA - (R^3 + BR^2)/2 = 0. \qquad (11)$$

The results of this equation are shown in figure 4 together with the results of tests executed at the Hydraulics Research Station at Wallingford and the laboratory of Fluid Mechanics of the Delft University of Technology. This figure indicates a reasonable agreement between computation and experiments.

4. Scour underneath a pipe by uniform flow

The two basic assumptions for the computation of the scour for waves hold good also in this case. They are:

a. A certain part of the flow is forced to flow underneath the pipe, and
b. The velocity v_b in front of the pipe should be equal to the value of v_b underneath the pipe.

A difference is, however, that in this case the ratio between v_b and the velocity of the water layer close to the bed is different for the normal undisturbed uniform flow and the flow underneath the pipe.
If the mean velocity over the height of the pipe above the undisturbed sea bed is called $\overline{v_R}$, the ratio between v_b and $\overline{v_R}$ is:

$$v_b = \overline{v_R}/\ln(33y/er) = q\,\overline{v_R} \qquad (12)$$

$y = h_o + 2R$, with a positive or negative value of h_o.

The value of q will be in the order of 0.2.

Underneath the pipe the velocity profile will not be of the normal logarithmic form since the boundary layer does not adjust itself to the higher velocity within the extent of the scour hole. The boundary layer will develop as is indicated schematically in figure 5. This situation can be compared to that for the development of the boundary layer under orbital motions.

Using the relationships between u_b and u_o, the ratio between v_b and the velocity just outside the boundary layer, v_B, can be written as:

$$v_b = v_B\sqrt{f_w/2\kappa^2} = s v_B \qquad (14)$$

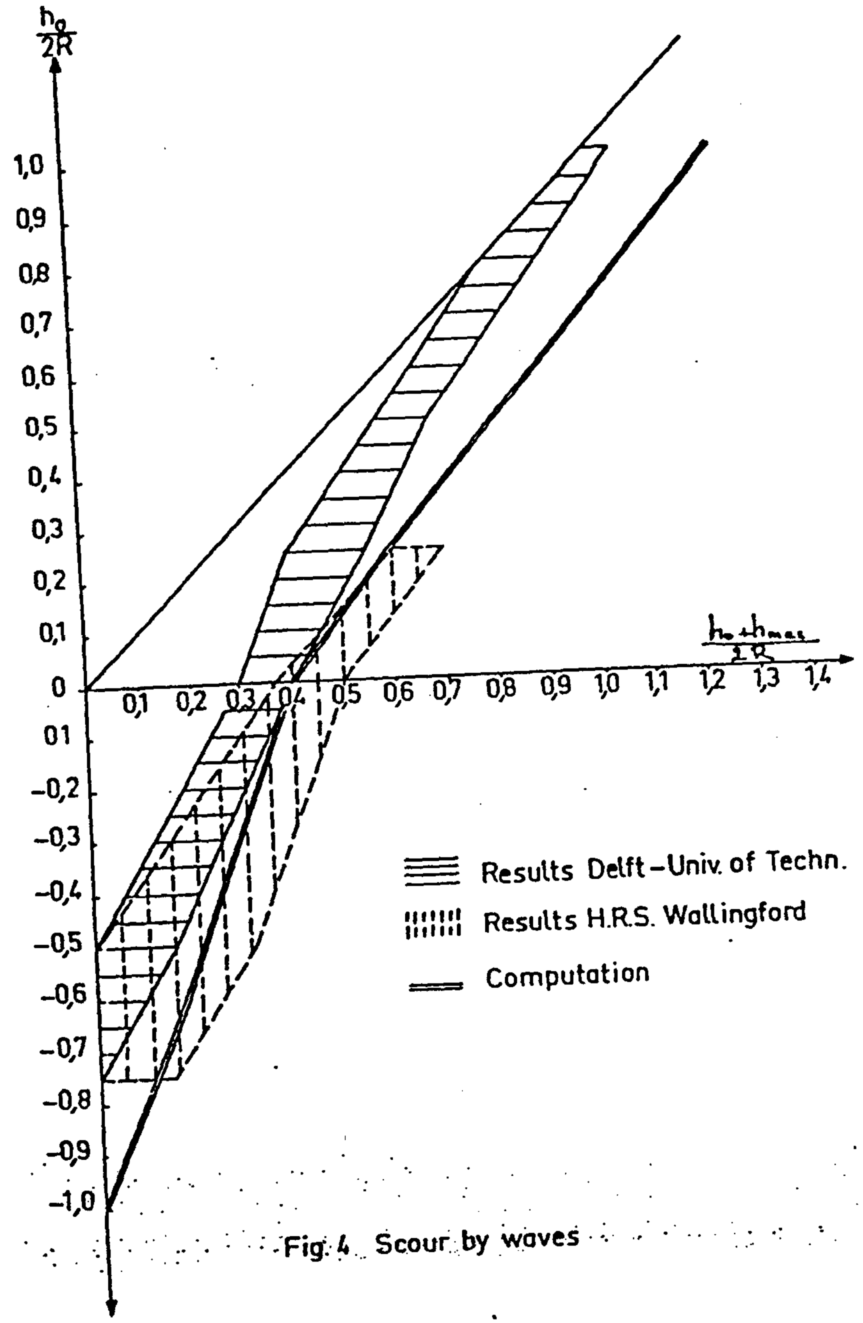

Fig. 4 Scour by waves

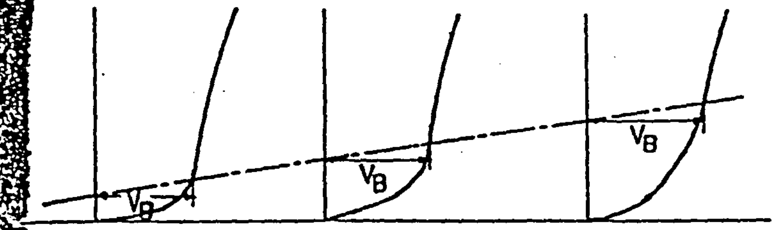

Fig. 5 Development of boundary layer.

In the case of orbital motion f_w is - according to equation(6)- determined by the ratio a_o/r. It stands to reason that a value of a_o related to the size of the scour hole, be introduced into the expression for f_w in this case, since this size determines the rate at which the boundary layer can develop.

The thickness of the boundary layer can be written as $\delta = f(x^{4/5}, v^{1/5})$. As a first approximation, the dependence upon v will be neglected and δ will be assumed to vary linearly with x. Since the velocity increases only from $\bar{v}_R$ (instead of zero). to the order of $2\bar{v}_R$, the characteristic length of the scouring hole can be compared with

$$\frac{\text{arc cos } \frac{1}{2}}{\pi/2} a_o = 0.67 a_o.$$

Thus, for the computation of f_w, a value of (1/0.67) x the characteristic scour length (in principle half the size of the scour hole) will be used.

For normal pipe diameters and related scour holes the value of s calculated via equation (14) will be then 0.3 to 0.4, which is significantly higher than the value of q for the undisturbed situation in front of the pipe.

Under the pipe the same velocity distribution as given by figure 3 and eq. (7) is assumed.

Here, $$v_B = \bar{v}_R \left[1 + R^2/(h_o + h_{max} + R)^2\right] \quad (15)$$

Since the sediment transport capacities beyond the influence of the pipe and underneath it must be equal, the following relationship must be valid:

$$q \bar{v}_R = s \bar{v}_R \left[1 + R^2/(h_o + h_{max} + R)^2\right] \quad (16)$$

According to the same procedure as described for orbital motion, this can be achieved by decreasing the whole velocity profile with v_ε. In that case equation 16 changes to:

$$q \bar{v}_R = s\left\{\bar{v}_R \left[1 + R^2/(h_o + h_{max} + R)^2\right] - v_\varepsilon\right\} \quad (17)$$

s gives:

$$\tilde{v}_R \left[1 + R^2/(h_o + h_{max} + R)^2\right] = \frac{q}{s} v_R \qquad (18)$$

For $q = s$, (18) degenerates to the situation for waves (equation 8).

Since normally $q > s$, the decrease of the velocity profile for the case of uniform flow is greater than for the case of wave motion. As also in this case the equation of continuity of the flowing water has to be met, the space underneath the pipe must be greater in the case of uniform flow than in the case of wave motion. This is confirmed by the tests executed by Van Ast and De Boer.

With increasing distance of the pipe from the original bottom, the required change in the velocity profile will be less and therefore q will be more nearly equal to s, and the difference between erosion by uniform flow and by wave motion will be less.

The erosion under a pipe for uniform flow for various distances of the pipe above the bed is given in figure 6. This figure demonstrates that for increasing value of $h_o/2R$ and constant v, the value of q/s indeed increases.

With a constant value of $h_o/2R$, an increasing value of the velocity in front of the pipe leads to lower values of q/s; this confirms the assumption that the development of the velocity profile under the pipe is also a function of the velocity. More research is required to solve this problem completely.

5. Scour around vertical structures by wave motion

In the case of erosion around vertical structures, the velocity profile will also be influenced by the structure in the way indicated in figure 3. In this case the figure represents a horizontal cross-section. Since the increase in velocity is the result of narrowing flow lines, the sand transport should also increase in order to meet the equation of continuity for the transport. Due to this effect both velocity and transport will increase with a factor $n(> 1)$. The development of the scour hole will decrease the velocity by a factor $m(< 1)$. Because in orbital motion the ratio u_b/u_o is determined by the oscillatory motion. this value will be the same for the undisturbed area as for the scour hole.
The transport function can be written in principle as:

$$S = \alpha\, u_b^{\beta} \qquad (19)$$

In the scour hole the transport equation is:

$$n\; S = \alpha (m\, n\, u_o)^{\beta} \qquad (20)$$

This leads to the following relationship between m and n,

$$m = n^{(1-\beta)/\beta} \qquad (21)$$

The value of β is not constant. It normally decreases with increasing velocity, with a tendency toward 1 for extremely high velocities.

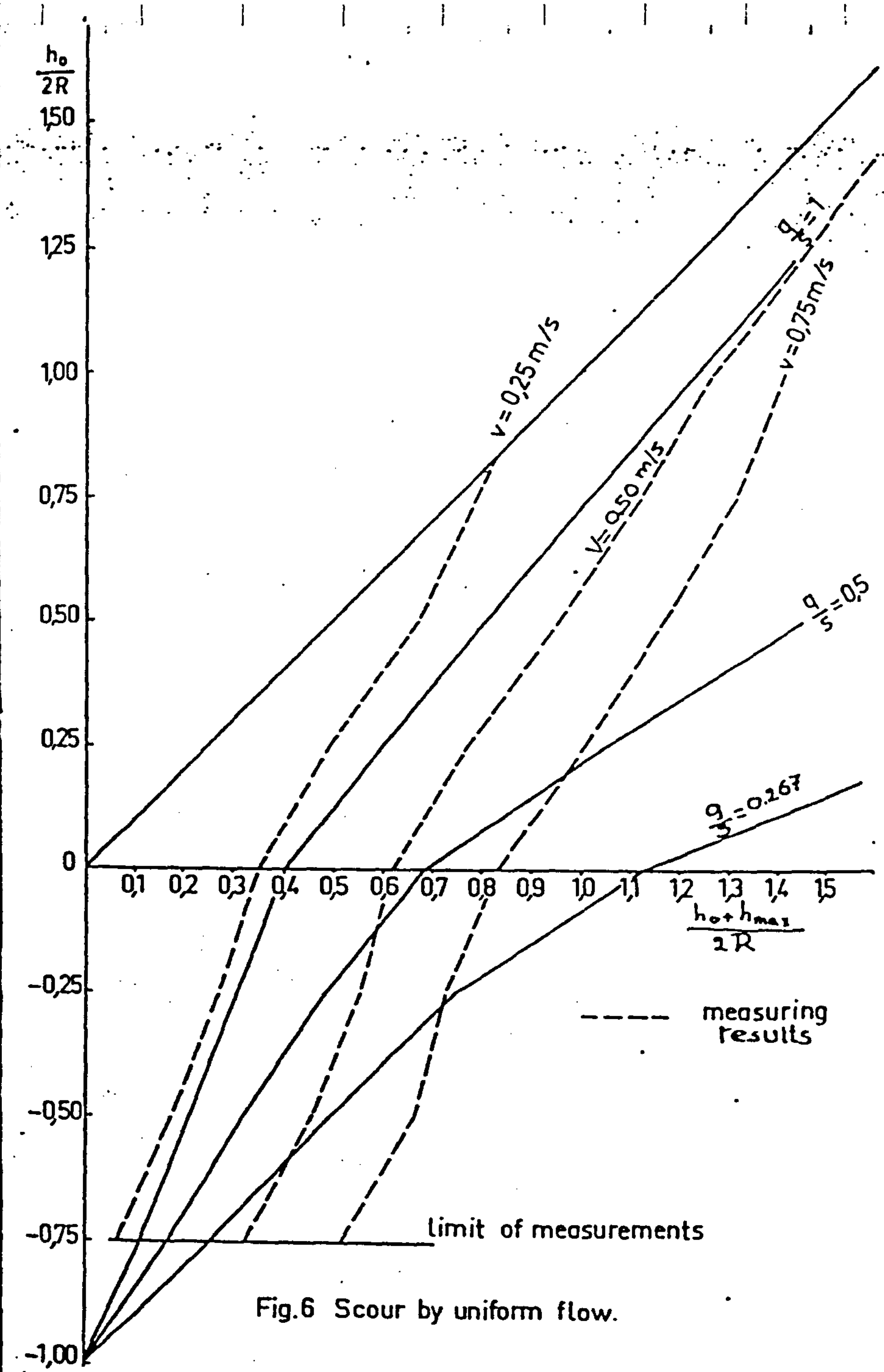

Fig.6 Scour by uniform flow.

When $\beta = 1$, $m = 1$, and no scouring will occur.
For normal conditions $\beta = 2$ to 3.
The value of m can be determined from the development of the theoretical velocity profile of figure 3. The value of the velocity should, however, not be taken at the surface of the structure because surface friction along the structure and lateral exchange of material in the scouring area distort the transport. When the distance (R - a) from the structure is held constant - in eq. (7) - the influence of the diameter of the structure is revealed. This effect is confirmed by tests. Breusers (4) reports scouring under wave motion of 1.2 x diameter. In the case of scouring by uniform flow Breusers reports scouring depth of 1.3 to 1.4 times the diameter. This increase will be discussed in the next section.

6. Scour around vertical structures by uniform flow

Fundamentally, the best procedure to calculate the scour would be to determine the velocity profiles in the scour hole by, for instance, using the method of Reichart as described by Breusers in [5]. Here, however, the same procedure as suggested by Van Ast and De Boer for scour underneath pipes is followed. By this method it is possible to explain why the scour by uniform flow is greater than by wave motion and to isolate parameters to be determined by further model tests.

The scour is determined by the velocity v_b just outside the viscous sublayer just above the bed. This velocity is computed using equation (4) for the undisturbed flow and using equation (14) for the scour area. The factor f_w in equation (14) is determined with equation (6). Analogous to the method followed for pipes, a_o in this equation is:

$$\frac{\pi/2}{\arccos(1/mn)} \times \text{(characteristic length of scour)}$$

For a vertical circular pile this characteristic length will be of the order of 2 R.

With normal values of this characteristic length, the factor $s = v_b/v$ for the scour hole will be significant higher than $q = v_b/v$ for the undisturbed area.

The two transport equations 19 and 20 are in this case

$$S = \alpha(q\ v)^{\beta} \qquad (22)$$

$$S = \alpha(m\ n\ s\ v)^{\beta} \qquad (23)$$

$$\text{and } m = \frac{q}{s}\ n^{(1-\beta)/\beta} \qquad (24)$$

Since $q/s < 1$, m for uniform flow will be smaller than for wave motion. Since m is approximately equal to the ratio of waterdepths in the undisturbed area and in the scour hole, this indicates an increased scour in the case of uniform flow. For bigger structures s will be more nearly equal to q and the difference will be less.

A different situation occurs if the structure is not penetrating into the soil. Then scour holes may develop underneath the structure which prove to be greater for wave motion than for uniform flow according to recent tests of the Delft Hydraulics Laboratory. The probable cause is the steep pressure gradients which can be built up underneath the structure by wave oscillatory motion.

7. Behaviour of pipelines over a scour hole.

A pipe spanning a scour hole will have a certain sag. When this sag is, without exceeding the tolerable tension, more then the depth of the scour hole the pipe will remain in contact with the ground. In that case it is possible or even likely that finally the pipe will be covered with sand again. The maximum depth of the scour hole below the adjacent, original, sea bed is according to figures 4 and 6, about one pipe diameter, assuming that the pipe is able to follow the scour. In order to see whether it is possible for the pipeline to follow the scour, relations between length of the pipe, sag and tensions will be developed. This computation can be made for two assumptions viz.:

a. The pipeline is computed as a girder supported and clamped at the ends.
b. The pipeline is computed as a catenary. In this case the length of the span must be so much that the bending causes only neglectable curvatures in the pipe. Only at and very near to the supports where the pipe is assumed to be clamped, are bending moments assumed.

In most circumstances the length will be too short to permit the catenary computations as has been demonstrated by Bouwmeester [3]. According to Bouwmeester the ratio between span and pipe diameter must be over 200 to allow for a computation as catenary.

In the following the pipe will be calculated, therefore, as a girder. In this case, however, the pretension as result of the laying procedure has to be taken into account. For waterdepths greater than 30 m this pretension is

$$\beta = D\ \alpha\ E/2\sigma \qquad (25)$$

in which D = pipediameter (m)
E = elasticity modulus of pipe material [N/m^2] (for steel 210 10^9 N/m^2)
σ = maximum allowable tension [N/m^2]
q = weight of pipe [N/m]
A = steel cross-section of pipe [m]
α = q/A
L = length between supports [m]

The total (horizontal) force in the pipe is

$$H = \beta . A$$

The final sag, δ, is calculated in the following way (see figure 7) (page 15)

In that case:

$$M_x = M_o + \tfrac{1}{2}\ q\ L\ x - \tfrac{1}{2}\ q\ x^2 - H\ \delta_x \qquad (26)$$

$$\frac{d^2\delta_x}{dx^2} = -\frac{M_x}{EI} \qquad (27)$$

$$\frac{d^2\delta_x}{dx^2} - \frac{H}{EI}\delta_x = \frac{1}{EI}\left[-M_o + \tfrac{1}{2} q x (L-x)\right] \qquad (28)$$

The solution of this differential equation is after writing $EI/H = \lambda^2$

$$\delta_x = \frac{q\lambda^2 L x}{2\,EI} - \frac{q\lambda^2 x^2}{2\,EI} - \frac{q\lambda^3 L}{2\,EI}\sinh\left(\frac{x}{\lambda}\right) + \frac{q\lambda^3 L}{2\,EI}\,\frac{\sinh(L/\lambda)}{1-\cosh(L/\lambda)}\left[1-\cosh\left(\frac{x}{\lambda}\right)\right] \qquad (29)$$

The maximum sag in the middle of the span is:

$$\delta_{max} = \frac{q\lambda^2 L^2}{8\,EI} - \frac{q\lambda^3 L}{2\,EI}\,\mathrm{tgh}\left(\frac{L}{4\lambda}\right)$$

The maximum moment, still occurring at the supports is

$$M_o = q\lambda^2 + \tfrac{1}{2} q\lambda L\,\frac{\sinh(L/\lambda)}{1-\cosh(L/\lambda)}$$

The maximum tension is $\sigma_b + \beta$.

For two pipes, one with a relatively large and another with a small diameter, the computation will be executed.

The bigger pipe has an outer diameter of 1.27 m, a wall thickness of 2.5 mm and a reinforced concrete cover of 65 mm, whereas the smaller has an outer diameter of 0.45 m, a wall thickness of 20 mm and a reinforced concrete cover of 50 mm. It is assumed that steel Fe 52 is used.

The various relevant values for the pipes are given in Table I.

D [m]	A [m^2]	q [N/m]	α [N/m^3]	β [N/m^2]	H [N]	λ [m]
1.27	$9.78\ 10^{-2}$	$1.42\ 10^4$	$1.45\ 10^5$	$5.37\ 10^7$	$5.25\ 10^6$	27.6
0.45	$2.70\ 10^{-2}$	$3.99\ 10^3$	$1.48\ 10^5$	$1.94\ 10^7$	$5.24\ 10^5$	15.8

TABLE I Various pipe values

L [m]	M_o [N.m]	σ_b [N/m^2]	σ_{tot} [N/m^2]	δ_{max} [m]
50	$-2.81\ 10^6$	$9.42\ 10^7$	$1.48\ 10^8$	$5.35\ 10^{-2}$
75	$-5.96\ 10^6$	$2.00\ 10^8$	$2.53\ 10^8$	$2.48\ 10^{-1}$
100	$-9.85\ 10^6$	$3.31\ 10^8$	$3.84\ 10^8$	$6.98\ 10^{-1}$

TABLE II Pipe of 1.27 m diameter

L [m]	M_o [N.m]	σ [N/m^2]	σ [N/m^2]	δ_{max} [m]
25	$-2.00\ 10^5$	$7.18\ 10^7$	$9.12\ 10^7$	$2.92\ 10^{-2}$
50	$-7.19\ 10^5$	$2.59\ 10^8$	$2.78\ 10^8$	$3.97\ 10^{-1}$
75	$-9.85\ 10^5$	$5.09\ 10^8$	$5.26\ 10^8$	1.61

TABLE III Pipe of 0.45 m diameter

In figure 8 the maximum occurring sag is plotted against the maximum tension for the two pipes. From this figure it follows that, without exceeding the allowable tension of $360\ 10^6\ N/m^2$ the sag for the pipe of 1.27 m diameter is 0.6 m and for the pipe of 0.45 m diameter is 0.86 m. This corresponds with a span of respectively 96 m and 58 m.

Since the scour underneath the original sea bed for the pipe of 1.27 m will be in the order of 1.27 m, this pipe will not be supported in the center. For the pipe of 0.45 m diameter this scour will be about 0.45 and this pipe will, therefore, remain supported in the center. Only for the smaller pipe is there, therefore, a possibility that the pipe will be finally covered with sand.

Of course this computation is a very strong simplification since no forces as result of waves and current have been taken into consideration. This can be done relatively simply by calculating stresses as result of these forces for the relevant spans, and by decreasing the allowable tension with these values. It will be recommendable in that case also to apply a more sophisticated computational procedure according to the plasticity theory. The aim of this example was only to prove that it cannot be expected that big pipe lines will bury themselves, and that laying a pipeline of 0.45 m diameter through a megaripple field with a ripple length over 60 m will also cause great difficulties.

Ackowledgements.

Prof. Dr. A. Verruyt made the computations of the sag and moments in the pipeline with pretension.

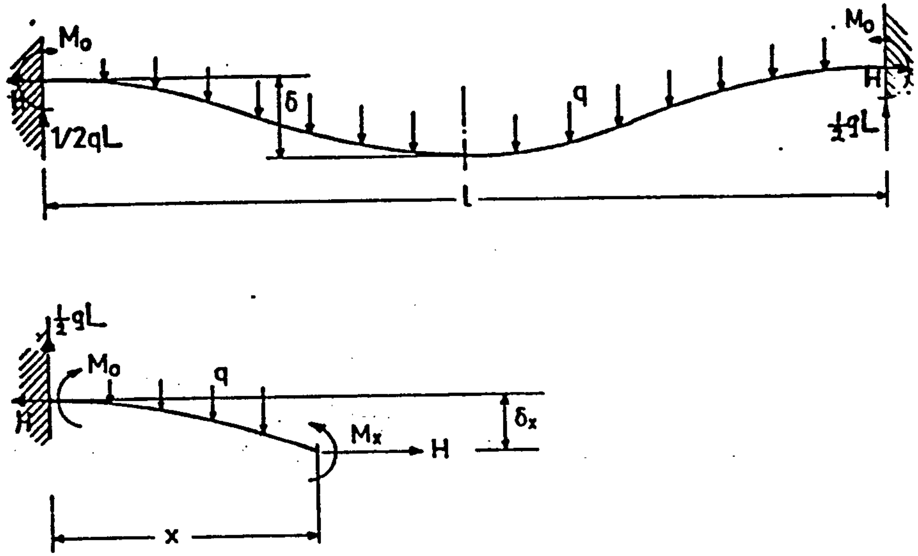

Fig.7 Computational procedure for pipeline with pretension.

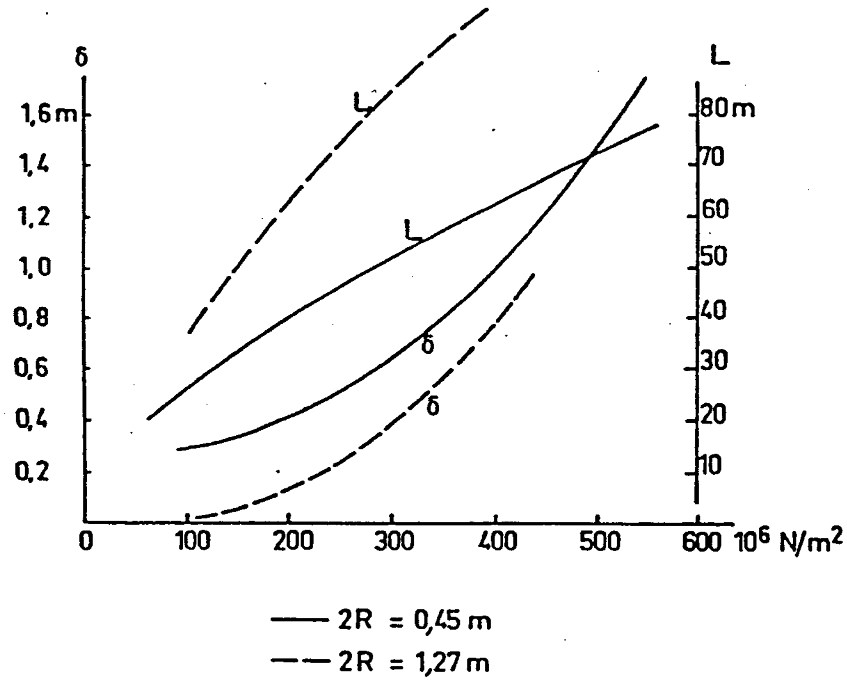

Fig.8 Sag and span versus stresses in pipes of 1.27 and 0.45 m diameter.

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6

Scour Around Pipelines

6.1 GENERAL COMMENT

Scour around pipelines may be caused by currents and/or waves and may be either long-term or short-term. Long-term changes in shallow water* involve a general erosion or accretion of sediment over decades or hundreds of years. The short-term changes are associated with a variable wave climate; the direction of sediment motion depends on the direction of wave approach angle (Herbich, 1981). If the currents near the pipeline are sufficiently strong enough to produce scour, the overburden will gradually erode as shown in Fig. 6-1.

Storm waves produce appreciable horizontal and vertical velocities in shallow water. If the ocean bed is composed of erodible materials, the dynamic equilibrium of sediment may be disturbed; then scour and deposition of sediment will occur.+ The pipe itself may trigger (or initiate) scour or cause additional local scour. Because of larger horizontal drag and inertial forces as the storm intensifies, the scour may eventually uncover and expose the pipeline. The exposed pipe may be broken

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*Shallow water by definition relates to a condition where the wave length to water depth ratio is greater than 2.

+Only granular, cohesionless sediments are considered in this chapter.

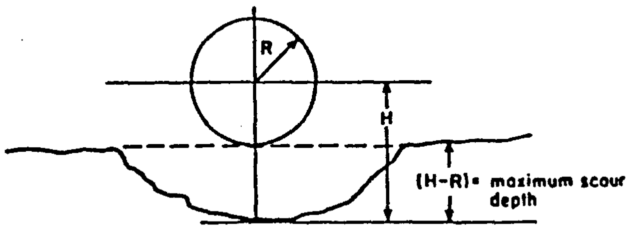

Figure 6-1. Graphic illustration of the problem of scour around a pipeline.

or damaged in such a case, since pipelines generally are not designed for this condition where spanning and vibration due to vortex shedding occurs. The subsiding storm may fill the trench, pushing the pipe upward, or closer to the ocean bottom. If the pipe were to become buried again, visual observation by a diver after the storm would not show that the pipe had moved closer to the ocean bottom, or that it had been exposed during the storm.

6.2 MAXIMUM SCOUR DEPTH

An analytical method for estimating the maximum scour depth under the offshore pipelines due to currents was developed by Chao and Hennessy (1972). This method provides an order of magnitude estimation of the possible scour hole depth.

The subsurface current is assumed to flow perpendicular to the longitudinal axis of the pipeline. Based on two-dimensional potential flow theory and the assumptions outlined by Chao and Hennessy, the discharge through the scour hole is

$$q = u_0 \left(H - \frac{R^2}{2H - R}\right) \quad \text{for} \quad H \geq R \qquad (6.1)$$

where

u_0 = undisturbed subsurface current at the top of the pipe
R = radius of the pipe
H = scour hole depth from the center of the pipe

The average jet velocity is

$$u_{avg} = \frac{q}{(H - R)} = u_0 \left[\frac{2(H/R)^2 - (H/R) - 1}{2(H/R)^2 - 3(H/R) + 1}\right] \quad \text{for} \quad H \geq R \qquad (6.2)$$

If the velocity in the scour hole is greater than the free stream velocity, erosion may take place. The limit of scour is presumably reached when, because of the enlargement of the scour section, the velocity along the boundary has decreased to the point at which the boundary shear stress τ_b becomes equal to the critical tractive stress τ_c of the sediment composing the erodible beds. The tractive stress for a given sand grain size is plotted in Fig. 6-2, and required values of τ_c were obtained as shown in Table 6.1.

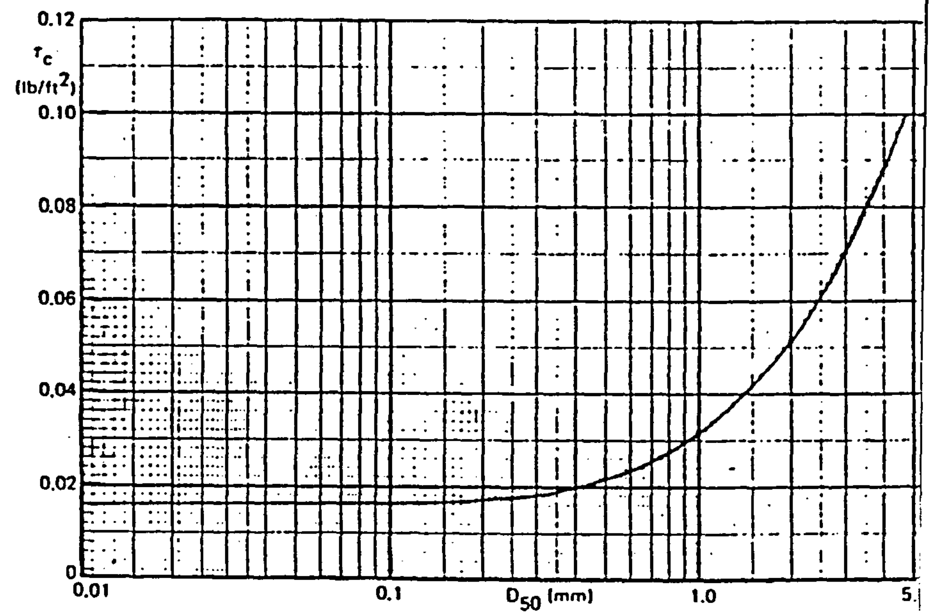

Figure 6-2. Critical tractive stress versus grain size. (From Herbich, 1981.)

TABLE 6-1. Critical Tractive Stress for Various Grain Sizes

D_{50}(mm)	τ_c(psf)
4.00	0.0890
2.00	0.0513
1.00	0.0316
0.75	0.0266
0.50	0.0215
0.25	0.0172
0.13	0.0166
0.10	0.0164
0.08	0.0162
0.05	0.0161

The boundary shear stress in the eroded channel is computed based on assumptions stated by Chao and Hennessy (1972). The friction factor f_f is estimated from the Reynolds number relationship reported by Lovera and Kennedy (1969), by using a Reynolds number defined as

$$N_R = \frac{u_{avg}(H - R)}{\nu} \qquad (6.3)$$

where ν is the kinematic viscosity of seawater. The roughness parameter is defined as $R_h/D_{50} \times 10^{-2}$, where R_h is the hydraulic radius, which is approximated as $(H - R)$. The friction factor f_f is determined from Fig. 6-3.

Once the friction factor is known, the boundary shear stress is calculated by using the following relationship (Streeter, 1971):

$$\tau_b = \frac{f_f\ \rho (U_{avg})^2}{8} \qquad (6.4)$$

where ρ is the density of seawater. The maximum scour depth

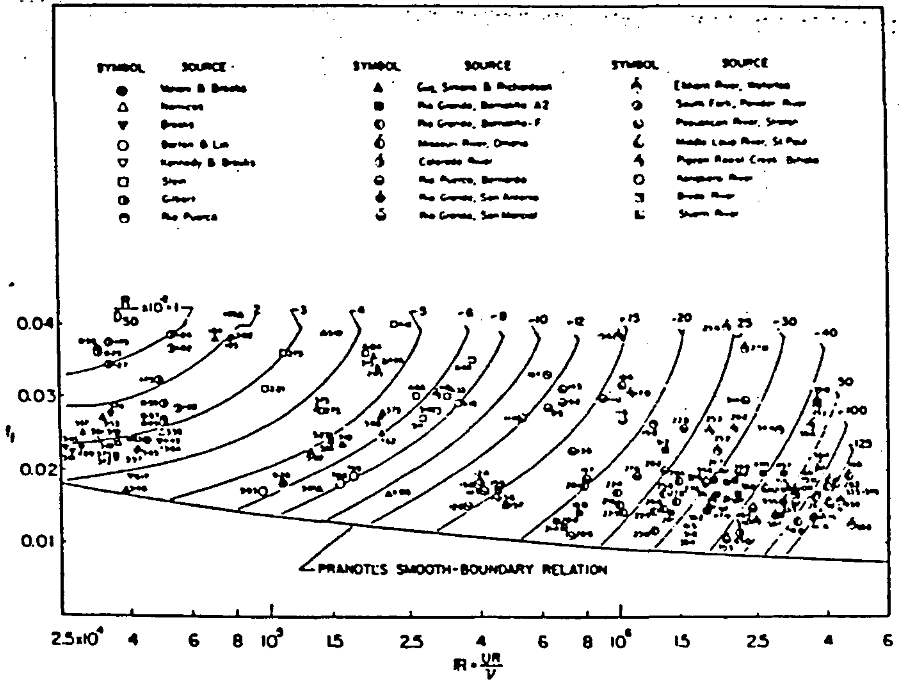

Figure 6-3. Friction factor predictor for flat-bed flows in alluvial channels. (From Lovera and Kennedy, 1969.)

under the pipeline can then be determined by matching the calculated boundary shear stress with the critical tractive stress of the size of the sand grains composing the ocean floor.

6.3 SAMPLE CALCULATION

In order to illustrate the method of estimating the maximum scour hole depth, a sample calculation is presented below:

Given: A pipeline with an outside diameter of 24 in., a sandy ocean floor with D_{50} = 0.25 mm.

Required: Find the maximum scour depth as a function of bottom current velocity.

Solution: The boundary shear stresses were calculated for a bottom free stream velocity of U_o = 2.0 ft/sec, with the scour hole depth as an independent variable, using Eqs. (6.2)-(6.4) and Fig. 6-3.

The variation of boundary shear stress with scour hole depth is shown in Fig. 6-4.

The critical tractive stress for a grain size of D_{50} = 0.25 mm is τ_c = 0.0172 psf. This value is plotted on the graph of τ_b versus H and the maximum scour depth under the pipe is determined for $\tau_b = \tau_c$. For U_o = 2 ft/sec, H = 3.50 ft and H - R = 2.50 ft. This calculation is then repeated for U_o = 1.5, 1.0, and 0.5 ft/sec; the maximum scour depth as a function of bottom current velocity is shown in Fig. 6-5.

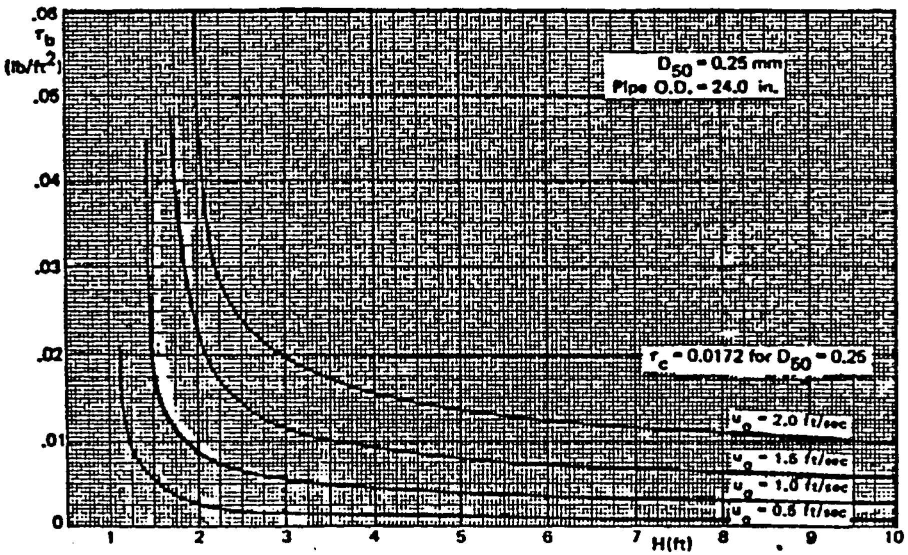

Figure 6-4. Boundary shear stress as a function of scour hole depth (D_{50} = 0.25 mm, pipe).D. = 24 in.). (From Herbich, 1981.)

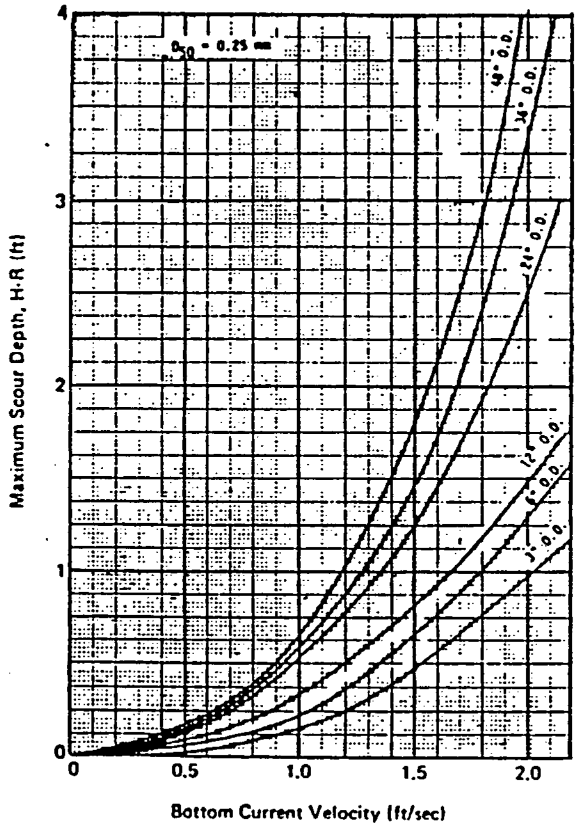

Figure 6-5. Maximum scour depth as a function of bottom current velocity (D_{50} = 0.25 mm). (From Herbich, 1981.)

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The Effect of Shallow Water Waves on Stability and Bearing Capacity of Sea Floor Beds

By

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ABSTRACT

This paper reports a theoretical and experimental investigation of the influence of shallow water waves on the bearing capacity of foundations in sea floor beds. Waves are able to generate notable shearing forces in sea-floor sediments up to a water plus soil depth of about half the length of the water waves. The propagation of pressure waves through a porous sea bed has therefore been calculated assuming plane and undrained conditions, and including the effect of dilatancy. The effective stresses thus generated could be compared with the soil stability limits. The consequences for both sand and clay deposits were considered individually.

Model experiments in a flume demonstrate how prolonged wave action results in increased density for an initially very loose sand, while an initially dense sand expands. Because small changes in void ratio have a significant effect on the bearing capacity of a sediment, the bearing capacity of a loose sand bed increases with prolonged wave action whilst that of a dense sand decreases. It was found, however, that under all circumstances the ultimate bearing capacity of a sandy sea bottom is largely sufficient for pile-foundation purposes. In fact, stormy weather tends to stabilise the bearing capacity of a sandy sea bottom.

In contrast, calculations for clay deposits show that the excess pore pressure caused by wave action on a normally consolidated clay cannot be dissipated within a practical time limit. Waves are therefore unable to compact a clay deposit.

This paper presents a method for calculating a safe depth of burial and bearing capacity for shallow foundations subject to wave action.

INTRODUCTION

Ocean waves generate significant shearing forces in sea-floor sediments up to total (water + soil) depths of approximately half the length of the waves. Waves could thus affect the end bearing capacity of shallow foundations or the lateral resistance at shallow depths of deep foundation piles. We shall first calculate the pressure fluctuations at the sea bottom due to plane irregular waves using the small-amplitude wave theory. We shall then calculate the stresses and pore pressures generated in the sea bottom by such irregular pressure fluctuations at the bed surface, assuming plane elastic soil deformation and introducing a pore-pressure parameter for the saturated soil under undrained, biaxial loading conditions. We shall compare those stresses with the soil stability limit and we shall consider soil consolidation due to wave action. Then we shall present the results of model experiments performed in a laboratory flume,

...wing that prolonged wave action increases the density of an initially very loose sand, while an initially dense sand expands. Finally, we shall present a method for calculating a safe depth of burial and bearing capacity for shallow foundations subject to wave action.

PRESSURE FLUCTUATIONS AT THE SEA BOTTOM DUE TO PLANE IRREGULAR WAVES

Let η be the surface configuration produced by n single-plane sinusoidal gravity waves of amplitude a_n, wave number k_n, angular velocity σ_n and phase δ_n (see Fig. 1):

$$\eta = \sum_n a_n \sin(k_n x + \epsilon_n) \tag{1}$$

$$\epsilon_n = -\sigma_n t + \delta_n \tag{2}$$

The magnitude of the pressure fluctuations P at the sea bottom caused by these waves may be expressed as follows using the small-amplitude wave theory[1]:

$$P = \sum_n P_n \sin(k_n x + \epsilon_n) \tag{3}$$

$$\frac{P_n}{\gamma_w} = \left(\frac{a_n}{h}\right)\left(\frac{k_n h}{\cosh k_n h}\right) \tag{4}$$

where h is the water depth and γ_w the unit weight of water.

For waves of small amplitude (compared to wave length and water depth), the wave number k_n is a function of the angular velocity σ_n:

$$k_n h \tanh k_n h = \frac{h\,\sigma_n^2}{g} \tag{5}$$

where g is the acceleration due to gravity.

PROPAGATION OF PRESSURE FLUCTUATIONS THROUGH THE SEA BOTTOM

We consider the stresses induced in a saturated sea bottom by the pressure wave (eq. 3) under undrained loading conditions:

$$P = \sum_n P_n \sin(k_n x + \epsilon_n) \tag{6}$$

A Cartesian frame [x,y,z] is chosen with the x-axis along the sea bottom in the direction of wave propagation and the z-axis normal to the sea bottom, pointing downwards (see Fig. 1). Assuming plane elastic soil deformation without dilation, the total stresses $\Delta\sigma_{ij}$ induced in the soil by such a pressure wave must satisfy the differential equation[2]:

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}\right)(\Delta\sigma_{xx} + \Delta\sigma_{zz}) = 0 \tag{7}$$

with the plane-strain condition:

$$\Delta\sigma_{yy} = \tfrac{1}{2}(\Delta\sigma_{xx} + \Delta\sigma_{zz}) \tag{8}$$

and the boundary conditions:

$$z=0 \rightarrow \Delta\sigma_{zz} = -\sum_n P_n \sin(k_n x + \epsilon_n);\ \Delta\sigma_{xz} = 0 \tag{9a}$$

$$z \rightarrow \infty \rightarrow \Delta\sigma_{zz} = \Delta\sigma_{xz} = 0 \tag{9b}$$

The stress tensor also satisfies the following equilibrium equations:

$$\frac{\partial\Delta\sigma_{xz}}{\partial x} + \frac{\partial\Delta\sigma_{xz}}{\partial z} = 0 \tag{10a}$$

$$\frac{\partial\Delta\sigma_{zx}}{\partial x} + \frac{\partial\Delta\sigma_{zz}}{\partial z} = 0 \tag{10b}$$

while in addition $\Delta\sigma_{xz} = \Delta\sigma_{zx}$.

Equations (7) and (10) satisfy the following equation, in terms of Airy's stress function[2]:

$$\frac{\partial^4\Phi}{\partial x^4} + 2\frac{\partial^4\Phi}{\partial x^2\partial z^2} + \frac{\partial^4\Phi}{\partial z^4} = 0 \tag{11}$$

when the stresses are expressed as derivatives of this stress function Φ:

$$\Delta\sigma_{ij} = \frac{\partial^2\Phi}{\partial x_i \partial x_j} \tag{12}$$

Equations (11) and (12), with the boundary conditions (9), are satisfied by the stress function:

$$\Phi = \sum_n P_n\left(\frac{1+k_n}{k_n^2}\right)\sin(k_n x + \epsilon_n)\, e^{-k_n z} \tag{13}$$

The change in total soil stresses is thus given by:

$$\Delta\sigma_{xx} = -\sum_n P_n(1-k_n z)\sin(k_n x + \epsilon_n)\, e^{-k_n z} \tag{14a}$$

$$\Delta\sigma_{zz} = -\sum_n P_n(1+k_n z)\sin(k_n x + \epsilon_n)\, e^{-k_n z} \tag{14b}$$

$$\Delta\sigma_{xz} = +\sum_n P_n k_n z\cos(k_n x + \epsilon_n)\, e^{-k_n z} \tag{14c}$$

The change in transverse stress under plane-strain conditions (eq. 8) is given by:

$$\Delta\sigma_{yy} = -\sum_n P_n \sin(k_n x + \epsilon_n)\, e^{-k_n z} \tag{14d}$$

If the stress-strain relations for the solid skeleton are elastic and isotropic, the change in pore pressure Δu under undrained loading conditions in saturated soil, is almost equal to the change in average compressive stress[6]:

$$\Delta u = -\frac{1}{3}(\Delta\sigma_{xx} + \Delta\sigma_{yy} + \Delta\sigma_{zz}) \tag{15}$$

Substitution of (14) in (15) gives the following expression for the change in pore pressure in the sea bottom under a plane pressure wave:

$$\Delta u = \sum_n P_n \sin(k_n x + \epsilon_n)\, e^{-k_n z} \tag{16}$$

Combining equations (14) and (16), we find the following expressions for the change in effective soil stresses ($\Delta\bar{\sigma}_i$) during wave action:

$$\Delta\bar{\sigma}_x = -(\Delta\sigma_{xx} + \Delta u) = -\sum_n P_n k_n z \sin(k_n x + \epsilon_n) e^{-k_n z} \tag{17a}$$

$$\Delta\bar{\sigma}_y = -(\Delta\sigma_{yy} + \Delta u) = 0 \tag{17b}$$

$$\Delta\bar{\sigma}_z = -(\Delta\sigma_{zz} + \Delta u) = +\sum_n P_n k_n z \sin(k_n x + \epsilon_n) e^{-k_n z} \tag{17c}$$

Under the crest of the pressure wave, for $x = x_o$, equations (14) reduce to:

$$\Delta\sigma_{xx} = -\sum_n P_n(1 - k_n z) \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{18a}$$

$$\Delta\sigma_{zz} = -\sum_n P_n(1 + k_n z) \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{18b}$$

$$\Delta\sigma_{yy} = -\sum_n P_n \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{18c}$$

$$\Delta\sigma_{xz} = 0 \tag{18d}$$

If the soil is dilatant and has nonisotropic stress-strain relations, the deviator stress under those conditions will give rise to an additional change in pore pressure

$$\Delta u' = A_2(\Delta\sigma_{xx} - \Delta\sigma_{zz}) = 2A_2 \sum_n P_n k_n z \sin(k_n x_o + \epsilon_n) e^{-k_n z} \tag{19}$$

where A_2 is a pore-pressure parameter for the soil under undrained loading:

$$\Delta\sigma'_{xx} = -\Delta\sigma'_{zz}; \quad \Delta\sigma'_{yy} = \Delta\sigma'_{yz} = 0 \tag{20}$$

The change in principal effective soil stresses during wave action is then given, for $x = x_o$, by:

$$\Delta\bar{\sigma}_x = -\sum_n P_n(1 + 2A_2) k_n z \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{21a}$$

$$\Delta\bar{\sigma}_z = +\sum_n P_n(1 - 2A_2) k_n z \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{21b}$$

$$\Delta\bar{\sigma}_y = -\sum_n P_n\, 2A_2 k_n z \sin(k_n x_o + \epsilon_n)\, e^{-k_n z} \tag{21c}$$

If the dilatancy is an isotropic property of the soil, the change in pore pressure under the undrained loading conditions (14) may be expressed as:

$$\Delta u = -\frac{1}{3}(\Delta\sigma_{xx} + \Delta\sigma_{yy} + \Delta\sigma_{zz}) + A_2[(\Delta\sigma_{xx} - \Delta\sigma_{zz})^2 + 4\Delta\sigma_{xz}^{\,2}]^{\frac{1}{2}} \tag{22}$$

Substitution of equations (14) in (22) gives, for a sinusoidal pressure wave of amplitude P_o:

$$\Delta u = P_o \sin(kx + \epsilon)\, e^{-kz} + P_o 2A_2 k z\, e^{-kz} \tag{23}$$

The change in principal effective soil stresses $[\Delta\bar{\sigma}_1, \Delta\bar{\sigma}_2, \Delta\bar{\sigma}_3]$ during wave action is then independent of x:

$$\Delta\bar{\sigma}_1 = P_o(1 - 2A_2)\, k z\, e^{-kz} \tag{24a}$$

$$\Delta\bar{\sigma}_2 = -P_o\, 2A_2\, k z\, e^{-kz} \tag{24b}$$

$$\Delta\bar{\sigma}_3 = -P_o(1 + 2A_2)\, k z\, e^{-kz} \tag{24c}$$

where

$$\Delta\bar{\sigma}_1 = -\tfrac{1}{2}(\Delta\sigma_{xx} + \Delta\sigma_{zz}) + \tfrac{1}{2}[(\Delta\sigma_{xx} - \Delta\sigma_{zz})^2 + 4\Delta\sigma_{xz}^{\,2}]^{\frac{1}{2}} - \Delta u \tag{25a}$$

$$\Delta\bar{\sigma}_2 = -(\Delta\sigma_{yy} + \Delta u) \tag{25b}$$

$$\Delta\bar{\sigma}_3 = -\tfrac{1}{2}(\Delta\sigma_{xx} + \Delta\sigma_{zz}) - \tfrac{1}{2}[(\Delta\sigma_{xx} - \Delta\sigma_{zz})^2 + 4\Delta\sigma_{xz}^{\,2}]^{\frac{1}{2}} - \Delta u \tag{25c}$$

4. STABILITY LIMITS

The undrained shear strength of a normally consolidated sand or clay can be expressed as:

$$s_u = \tfrac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)_f = \tfrac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3)_f \sin\bar{\phi} \qquad (26)$$

...ere $(\bar{\sigma}_1)_f$ and $(\bar{\sigma}_3)_f$ are the principal maximum and ...inimum effective soil stresses at failure ...d $\bar{\phi}$ is the friction angle of the solid skeleton.

In the absence of waves, the principal effective ...resses in an undisturbed, normally consolidated ...il are:

$$(\bar{\sigma}_1)_o = (\bar{\sigma}_z)_o = \gamma_b z \qquad (27a)$$

$$(\bar{\sigma}_3)_o = (\bar{\sigma}_x)_o = K_o \gamma_b z \qquad (27b)$$

...ere γ_b is the unit submerged weight of the soil, ... the soil depth (see Fig. 1), and K_o the ...efficient of lateral earth pressure. According to ...ky[4], K_o is a function of the friction angle $\bar{\phi}$ for ...normally consolidated sand or clay:

$$K_o = 1 - \sin\bar{\phi} \qquad (28)$$

...e maximum difference between the principal ...ective soil stresses in the sea bottom under a ...ne pressure wave (eq. 6), according to ...uations (21) and (27), is:

$$(\bar{\sigma}_1 - \bar{\sigma}_3)_{max} = \tfrac{1}{2}(1-K_o)z + \sum_n P_n k_n z \sin(k_n x_o + \epsilon_n) e^{-k_n z} \qquad (29)$$

...se stresses will thus reach the plastic yield ...it for:

$$\left[\sum_n P_n k_n \sin(k_n x_o + \epsilon_n) e^{-k_n z}\right]_f = \frac{s_u}{z} - \tfrac{1}{2}(1-K_o)\gamma_b \qquad (30)$$

... undrained shear strength s_u under these ...ing conditions, according to equations (21) and ..., is:

$$\ldots \tfrac{1}{2}(1+K_o)\gamma_b - \left[\sum_n P_n k_n 2A_2 \sin\bar{\phi} \sin(k_n x_o + \epsilon_n) e^{-k_n z}\right] \qquad (31)$$

...on of (31) in (30) gives the following ...ion for plastic failure at soil depth z, under ...crest of the pressure wave:

$$\left[\left(\frac{P_n k_n}{\gamma_w}\right) \sin(k_n x_o + \epsilon_n) e^{-k_n z}\right]_f = \tfrac{1}{2}\frac{\gamma_b}{\gamma_w}\,\frac{(1+K_o)\sin\bar{\phi} + K_o - 1}{1 + 2A_2 \sin\bar{\phi}} \qquad (32)$$

where γ_w is the unit weight of the pore water.

Equation (32) reduces for a sinusoidal pressure wave of amplitude P_o and wave length L, after substitution of $k = 2\pi/L$, to:

$$\left(\frac{P_o}{\gamma_w L}\right)_f = \frac{1}{4\pi}\,\frac{\gamma_b}{\gamma_w}\,\frac{(1+K_o)\sin\bar{\phi} + K_o - 1}{1 + 2A_2\sin\bar{\phi}}\,\exp\left(\frac{2\pi z}{L}\right) \qquad (32a)$$

This expression has a value $(P_o/\gamma_w L)_f = 0.02$ at $z \ll L$ for a normally consolidated sand or clay with a friction angle $\bar{\phi} = 32^o$, a unit submerged weight $\gamma_b = \gamma_w$, a coefficient of lateral earth pressure $K_o = 1 - \sin\bar{\phi}$ (eq. 28) and a pore pressure parameter $A_2 = 1$. This failure condition can easily be reached at shallow water depths ($h < \tfrac{1}{2}L$) during strong wave action (see eq. 4).

It seems reasonable to assume that, during prolonged wave action, the coefficient of lateral earth pressure K_o will increase as a function of z for $z \le z_f$ until the plastic yield limit is just reached by the maximum deviator stress under the crest of the pressure wave (for $x = x_o$, see eq. 32). The maximum soil depth z_f at which the soil stresses will then reach the plastic yield limit is given by equation (32) for $K_o = 1 - \sin\bar{\phi}$. For a sinusoidal pressure wave, this equation reads (see eq. 32a):

$$\frac{2\pi z_f}{L} = \ln\left[\left(\frac{P_o}{\gamma_w L}\right)_{max} \frac{\gamma_w}{\gamma_b}\,\frac{4\pi(1+2A_2\sin\bar{\phi})}{\sin\bar{\phi}(1-\sin\bar{\phi})}\right] \qquad (33)$$

According to this equation, z_f has a value of $0.064L$ for $(P_o/\gamma_w L)_{max} = 0.03$, $\gamma_b = \gamma_w$, $\bar{\phi} = 32^o$ and $A_2 = 1$.

It follows from the above that the shear stresses generated in a clay soil by shallow water waves will reach the plastic yield limit under the crest of the pressure waves up to soil depths $z = z_f$, as given by equation (32) or (33). Shallow foundations in clay with point loads exceeding the total overburden pressure $\gamma_b z + u_o$ would tend to settle during strong wave action in the plastic region $z \le z_f$ and should thus preferably be located at soil depths $z > z_f$.

Shallow waves will only generate plastic shear flow in the sea bottom under the failure condition (32) for $K_o = 1$. Under a sinusoidal pressure wave, the plastic yield limit will then be reached at $z \ll L$, over the whole area of the sea bottom simultaneously according to equation (24) (assuming that the soil's dilatancy is isotropic), for:

$$\left(\frac{P_o}{\gamma_w L}\right)_f = \frac{1}{2\pi}\,\frac{\gamma_b}{\gamma_w}\,\frac{\sin\bar\phi}{1+2A_2\sin\bar\phi} \qquad (34)$$

This failure condition will never be reached by a normally consolidated sand or clay. Under-consolidated clays and very loose sands, however, can develop large pore pressures under differential loading conditions and may therefore become unstable under strong wave action. The failure condition (34) will, for instance, be reached by a very soft clay with $\bar\phi = 24^0$, $\gamma_b = \gamma_w$ and $A_2 = 2$ for $(P_o/\gamma_w L)_f = 0.025$. Shallow foundations should preferably not be located in areas of potential plastic shear flow.

CONSOLIDATION DUE TO WAVE ACTION

During wave action, the sea bottom is subject to cyclic loading (eq. 14). If the soil has no dilatancy, the change in pore pressure during wave action (eq. 16) is as a time average equal to zero. If, however, the soil is dilatant, an excess pore pressure will be generated (eq. 19) with a positive ($A_2 > 0$) or negative ($A_2 < 0$) time-averaged value.

Under a sinusoidal pressure wave, this excess pore pressure is only a function of the soil depth z, assuming that the dilatancy is an isotropic soil property (see eq. 23):

$$\Delta u' = P_o\, 2A_2\, \frac{2\pi z}{L}\, e^{-\frac{2\pi z}{L}} \qquad (35)$$

The rate of dissipation of this excess pore pressure is governed by Terzaghi's consolidation equation[5]:

$$c_v\, \frac{\partial^2 \Delta u'}{\partial z^2} = \frac{\partial\, \Delta u'}{\partial t} \qquad (36)$$

where c_v is the coefficient of consolidation. This coefficient can vary from 4.10^3 cm²/sec for very loose sand to 20.10^3 cm²/sec for very dense sand. Clays under virgin compression have typical c_v values ranging from 2.10^{-4} to 5.10^{-3} cm²/sec.

We solved equation (36) numerically with the boundary condition:

$$\left.\begin{aligned} & t=0 \rightarrow \Delta u' = P_o 2A_2 \frac{2\pi z}{L} e^{-\frac{2\pi z}{L}} \\ & t \geq 0,\ z=0,\ z\rightarrow\infty \rightarrow \Delta u' = 0 \end{aligned}\right\} \qquad (37)$$

Figure (2) shows $U = \Delta u'/(2P_oA_2)$ as a function of $\zeta = z/L$ and $T = tc_v/L^2$. It can be seen that the average excess pore pressure is practically dissipated at $T \geq 1$. For sand, this corresponds to a consolidation time of roughly 24 hr ($c_v = 10^{+3}$ cm²/sec, L = 90 m). For clay it corresponds to 3000 yr ($c_v = 10^{-3}$ cm²/sec). We may thus entirely neglect the consolidation of a clay soil for engineering purposes.

After the primary consolidation, secondary compression or expansion will proceed very slowly in sand under cyclic loading due to wave action (eq. 14) until the soil is no longer dilatant (A_2=0). The final void ratio $e_{oo} = (V_v/V_s)_{oo}$ will be independent of the initial void ratio and can only depend on the effective overburden pressure $\gamma_b z$.

The rate of secondary compression will be a function of the peak cyclic loading $\frac{1}{2}(\Delta\sigma_{xx} - \Delta\sigma_{zz})_{max}$ divided by the ultimate load at plastic failure $\frac{1}{2}(1+K_o)\gamma_b z \sin\bar\phi$.

THE EFFECT OF WAVES ON THE BEARING CAPACITY OF THE SEA BOTTOM

The ultimate end bearing capacity Q_b of a shallow circular foundation on a sand bed under drained loading conditions can be expressed in the following dimensionless form[5]:

$$\frac{Q_b^d}{\gamma_b D^3} = \frac{\pi}{4}\left(0.3\, N_\gamma + \frac{z}{D} N_q\right) \qquad (38)$$

where N_γ and N_q are dimensionless factors that depend only on the friction angle $\bar\phi$ of the soil. D is the diameter of the footing, z the soil depth and $\gamma_b = \gamma_t - \gamma_w$ the unit submerged weight of the soil. Figure 3 shows the bearing capacity factors N_γ and N_q as a function of the friction angle $\bar\phi$, after Terzaghi[5].

The end bearing capacity of a shallow circular foundation under undrained loading conditions can, according to Terzaghi and Peck[5], be simplified to:

$$\frac{Q_b^u}{\gamma_b D^3} = \frac{\pi}{4}\left(\frac{s_u}{\gamma_b D} N_c + \frac{z}{D}\,\frac{\gamma_t}{\gamma_b}\right) \qquad (39)$$

where s_u is the undrained triaxial shear strength and γ_t the bulk unit weight of the soil. The bearing capacity factor N_c has a value of 6.2 for a circular footing.

The in-situ undrained triaxial shear strength of a soil under vertical compression, s_u, is related as follows to the drained shear strength[6]:

$$s_u = \tfrac{1}{2}(\sigma_1 - \sigma_3)_f = \bar p_o\, \frac{\sin\bar\phi\,[K_o + A(1-K_o)]}{1 + (2A-1)\sin\bar\phi} \qquad (40)$$

ere $\bar{\phi}$ is the friction angle, $\bar{p}_o$ the effective -burden pressure, K_o the coefficient of lateral .h pressure, and Λ the pore pressure parameter of the soil under triaxial loading conditions.

The friction angle $\bar{\phi}$ is a function of the void itio e_o of the soil before loading. Figure 4 shows . versus e_o for medium to fine sand, after Rowe[7]. ccording to this figure, $\bar{\phi}$ increases from 32° at void ratio of 0.75 to 38° at a void ratio of 0.55. small change in void ratio due to wave action can us have a considerable effect on the end bearing ipacity of the sea bottom. In the next section we iall discuss the results of model experiments in a boratory flume in which a sand bed was subjected prolonged wave action.

Vertical wave forces on top of a submerged undation and on the adjacent sea floor can be so rge in shallow water that they should be nsidered, in addition to horizontal wave forces, ien calculating the foundation's ultimate bearing pacity. Figure 5 shows how these forces can be corporated.

A hypothetical failure surface with circular oss-section (surface of revolution) is assumed, as ustrated in figure 5. The moment of all forces iting on the volume of soil enclosed between the -thetical failure surface and the bed surface, ding forces transmitted by the foundation, is en calculated. It is assumed that the full shear rength s_u of the soil is mobilised along the pothetical failure surface. The position of the sign wave and of the centre of revolution M of e hypothetical failure surface (see Fig. 5) should th be varied independently relative to the undation in order to calculate the ultimate bearing pacity during wave action.

ESCRIPTION OF EXPERIMENTS

Figure 6 shows the set-up used in our boratory to study, on a 1:100 length scale and :10 time scale (according to Froude), the change bearing capacity of a sand bottom due to wave tion in shallow water. The set-up consists of a m long, 1 m deep and 1 m wide tank filled with 5 m of sand (d_{65}=0.4 mm).

Waves with period T = 1.125 sec and average ngth L = 0.7 m were generated at a water depth 70 mm by a vertically oscillating drum. gure 7 shows a recording made at the sand-bed rface with an electrical pressure transducer. The erage amplitude of the bottom pressure waves ring all experiments $P_o = \frac{1}{2}(p_{max} - p_{min})/\gamma_w$ = mm. The average dimensionless pressure $/\gamma_w L$ was therefore equal to 0.025.

The (undrained) penetration resistance of the sand bed was measured before and after wave action by driving a circular disc (diameter D=24mm) into the bed at a constant speed (2.5 mm/sec) and recording the driving resistance (excluding the shaft resistance on the pipe around the driving rod) as a function of soil depth.

The bearing capacity of the sand bed under drained loading conditions was tested after wave action by loading a 50 mm diameter disc with a static load of between 1 and 5 kgf and measuring the settling of the disc.

Before subjecting the bed to wave action, the sand was vibrated in one case until it had a final void ratio of e_{oA} = 0.46. In the second case the sand was fluidised and then allowed to settle for 55 hr until it had a final void ratio of e_{oB} = 0.55. The unit submerged (buoyant) weight of the bed was $(\gamma_b)_A$ = 1130 kgf/m³ = 70.5 pcf and $(\gamma_b)_B$ = 1060 kgf/m³ = 66 pcf. The permeabilities of the sand bed were k_A = 0.19 mm/sec and k_B = 0.33 mm/sec. All experiments were carried out for the originally compacted (A) and the originally loose (B) sand beds.

RESULTS OF THE EXPERIMENTS

Figure 8 shows three independent recordings of driving resistance as a function of soil depth (in dimensionless form) for the disc penetrometer in the compacted sand bed (e_{oA} = 0.46). Figure 9 shows the three recordings of driving resistance for the loose sand bed (e_{oB}=0.55). Figures 10 and 11 show similar recordings after subjecting the bed to 175 000 pressure waves with T = 1.125 sec, L = 0.7 m and $P_o = \frac{1}{2}(\bar{p}_{max} - \bar{p}_{min})$ = 0.025 γ_wL.

Figures 12A and 12B show the average penetration resistance $\bar{F} \pm$ standard error

$$\sigma_m = \left[\frac{1}{6}\sum_{j=1}^{3}(F_j - \bar{F})^2\right]^{\frac{1}{2}}$$

derived from the above recordings (Figs. 8-11) taking the average over the three independent measurements obtained under the same conditions. These figures clearly show that the penetration resistance of the compacted sand bed decreases (Fig. 12A) and that of the loose sand bed increases, due to wave action. At z/D=3, for instance, the average reduction in penetration resistance in Figure 12A is 33%, whereas in Figure 12B the average increase is 100%.

During wave action, we measured a reduction in the void ratio of the loose sand bed from 0.55 to 0.52 approximately. The change in the void ratio of the compacted sand bed was too small to be measured with accuracy.

A disc of diameter D = 50 mm settled 7.5 mm 55 hr under a static load of 3.3 kgf on the loose d bed after wave action ceased (this value includes the settling of the sand bed in the vicinity of the footing). The compacted sand bed settled 3 mm in 65 hr under the same load.

COMPARISON WITH THEORY

All soil parameters are the same in our experiments, as in reality. Only the dimensionless group tc_v/L^2, which is a measure of the pore pressure built up in the soil, is 1000 times greater in our model than in reality. We may neglect the build-up of any time-averaged excess pore pressure in the soil for values of tc_v/L^2 larger than 1. In the model, $tc_v/L^2 = 1$ corresponds approximately to t = 0.5 sec; in reality it corresponds to t = 500 sec. Since the consolidation in our experiments took some 10^5 sec, corresponding with 10^8 sec in reality according to our time scale, we conclude that the consolidation due to waves is far too slow for any time-averaged excess pore pressure to build up, either in our model experiments or in reality. The exact magnitude of the group tc_v/L^2 is therefore irrelevant for a sandy soil. A clay, on the other hand, has such a small coefficient of consolidation (c_v=2. 10^{-4}-5. 10^3 cm^2/sec) that it would take thousands of years for an excess pore pressure caused by wave action to dissipate (tc_v/L^2=1). We can therefore neglect the consolidation of a clay soil by wave action for engineering purposes.

The final void ratio, after 50 hr of wave action of the originally loose sand bed was 0.52. A medium fine sand would then have a friction angle $\bar{\phi} = 40^o$, [fig. 4, according to Rowe] and bearing capacity factors $N_\gamma > 80$ and $N_q > 60$ [fig. 3, according to Terzaghi]. According to Terzaghi (eq. 38) a circular foundation of diameter D at a soil depth z = 0.1 D would have an end bearing capacity for $N_\gamma = 80$ and $N_q = 60$, of $Q_b^d/(\gamma_b D^3) = 24$. We tested the bearing capacity of the loose sand bed after wave action and found that a disc of 50 mm diameter carrying a load of 3.3 kgf settled 7.5 mm in 55 hr (including settling of the sand bed in the vicinity of the footing). This corresponds to $Q_d^b/(\gamma_b D^3) = 23$.

CONCLUSIONS

The shear stresses generated in a clay soil by shallow waves will reach the plastic yield limit under the crest of the pressure wave for soil depths $z = z_f$, given by equation (32) or (33). Shallow foundations in clay with point loads exceeding the total overburden pressure ($\gamma_b z + u_o$) tend to settle during wave action in the plastic region $z \leq z_f$ and should thus preferably be located at soil depths $z > z_f$.

Shallow waves will generate plastic shear flow in the sea bottom under the failure condition (32) for K_o=1, or condition (34). Shallow foundations should preferably not be located in areas of potential plastic shear flow.

The bearing capacity of a loose sand bed tends to be increased by wave action, whilst that of a dense bed tends to decrease. The ultimate bearing capacity of a sand bed after prolonged wave action is generally sufficient for foundation purposes.

Vertical wave forces on top of a submerged foundation and on the adjacent sea floor can be so large in shallow water that they should be considered, in addition to horizontal wave forces, when calculating the foundation's ultimate bearing capacity.

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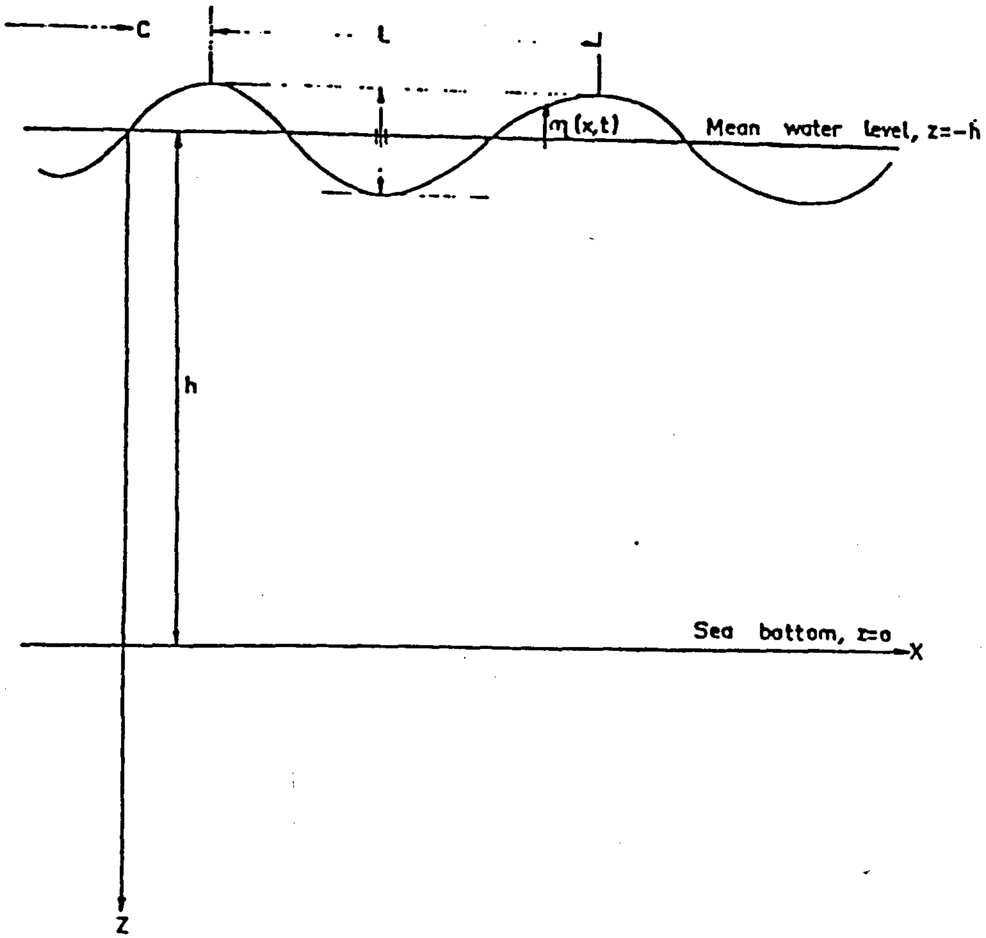


Fig. 1 - A sinusoidal wave system.

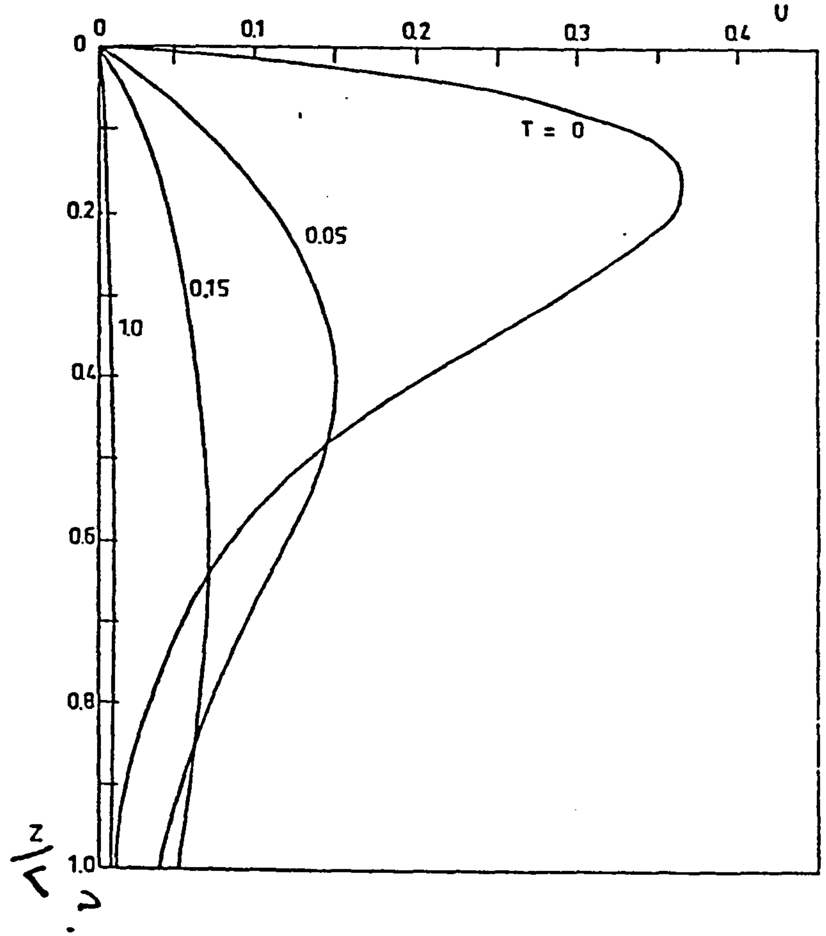


Fig. 2 - Dissipation of excess pore pressure, $U = \frac{Z - z}{L} \exp. (-\frac{Z - z}{L})$ as a function of soil depth $Z = \frac{z}{L}$ and time, $T = tc_v/L^2$.

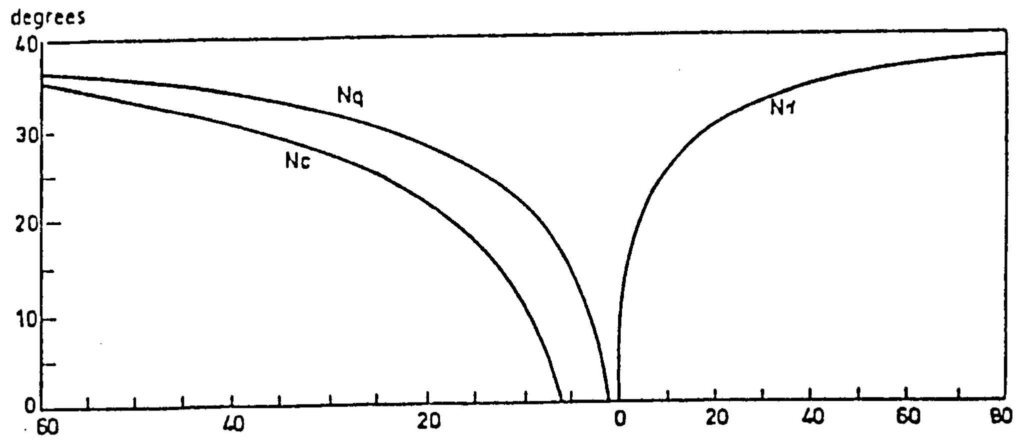
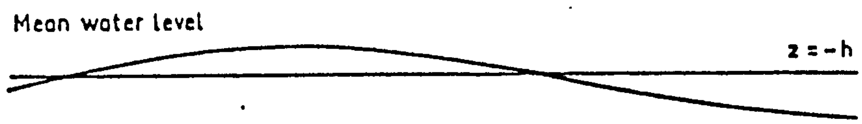


Fig. 3 - Bearing-capacity factors (after Terzaghi[5]).



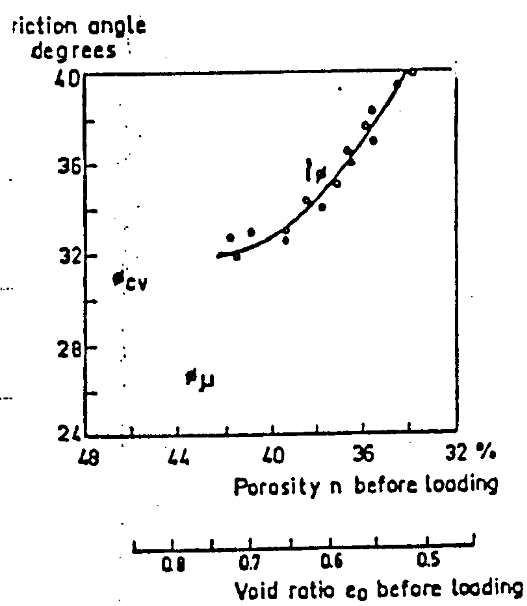


Fig. 4 - Friction angle as a function of ratio for medium fine sand (after Rowe[7]).

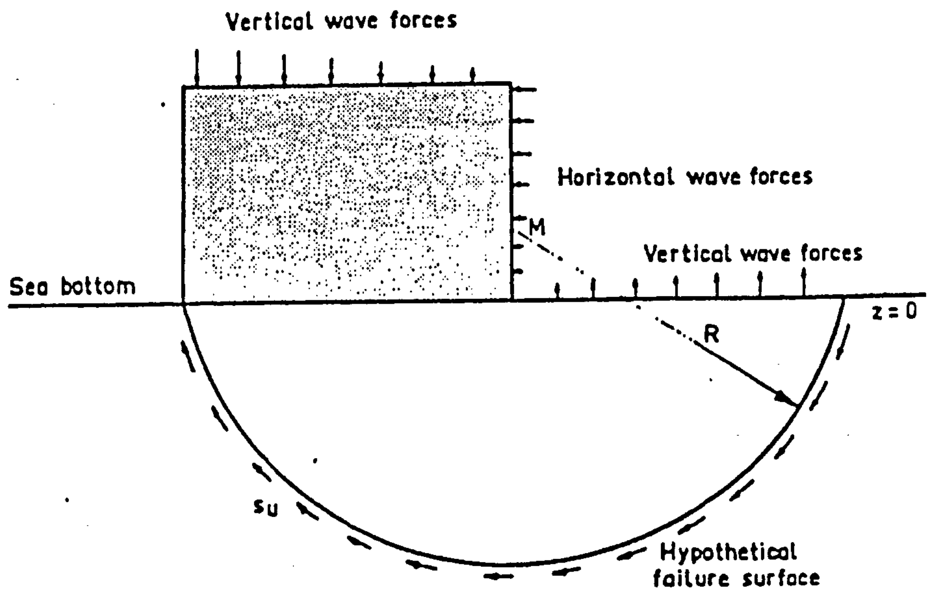


Fig. 5 - Ultimate bearing capacity of submerged foundation.

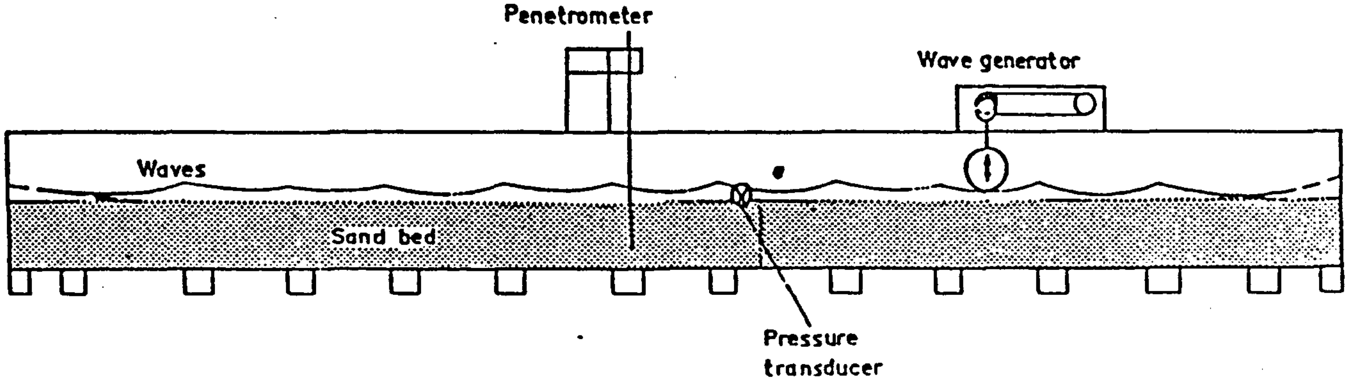


Fig. 6 - Wave tank used to measure the effect of pressure waves on the bearing capacity of a sand bed.

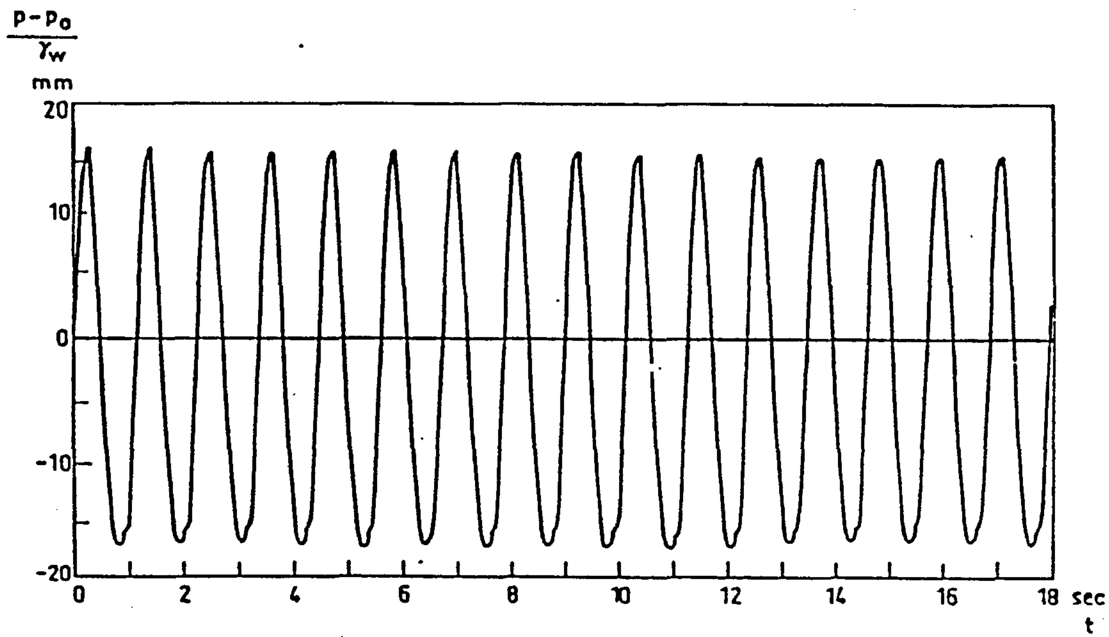


Fig. 7 - Pressure wave measured at the bed surface at water depth H = 70mm average wave length L = 700mm, average period T = 1.125 seconds $\frac{p_{max} - p_{min}}{2 \gamma_w L} = 0.025$.

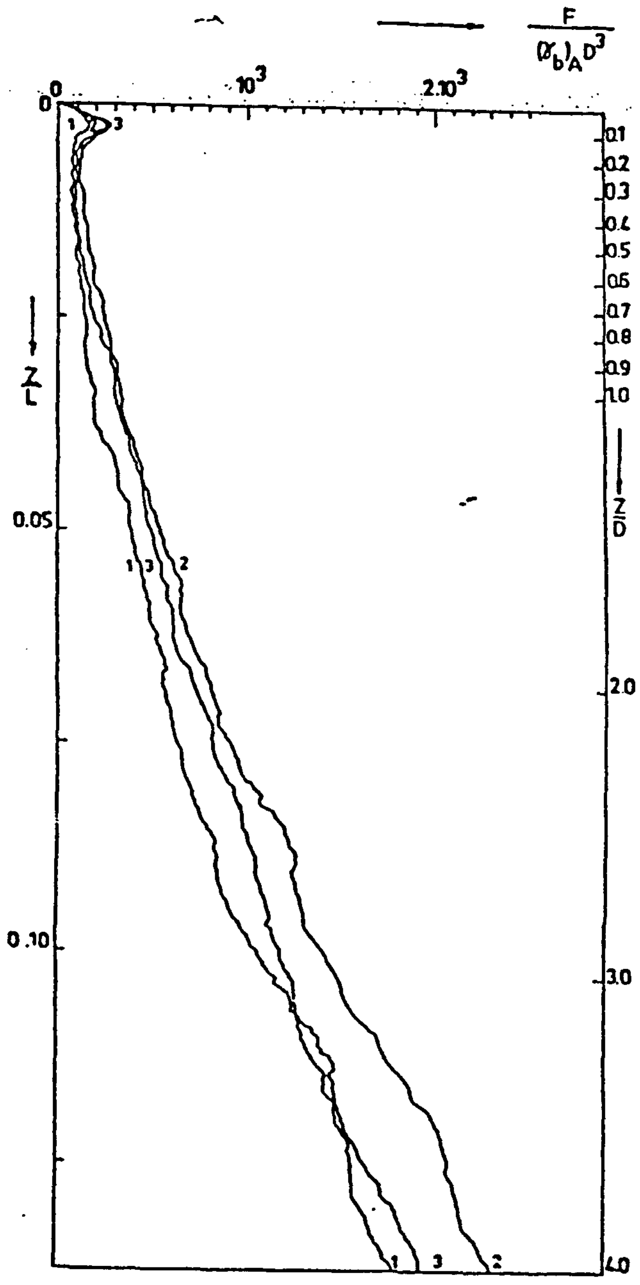


Fig. 8 - Penetration resistance of compacted sand bed of unit submerged (buoyant) weight $(\gamma_b)_A$ = 1130 kgf/m^3 = 70.5 pcf.

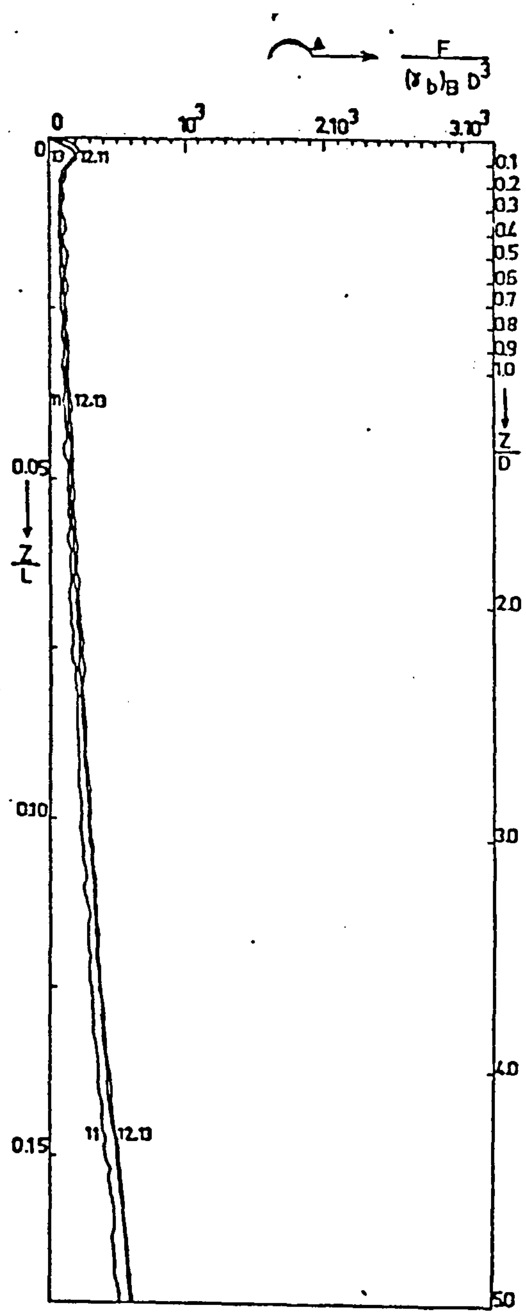


Fig. 9 - Penetration resistance of loose sand bed of unit submerged (buoyant) weight $(\gamma_b)_B$ = 1060 kgf/m^3 = 66 pcf.

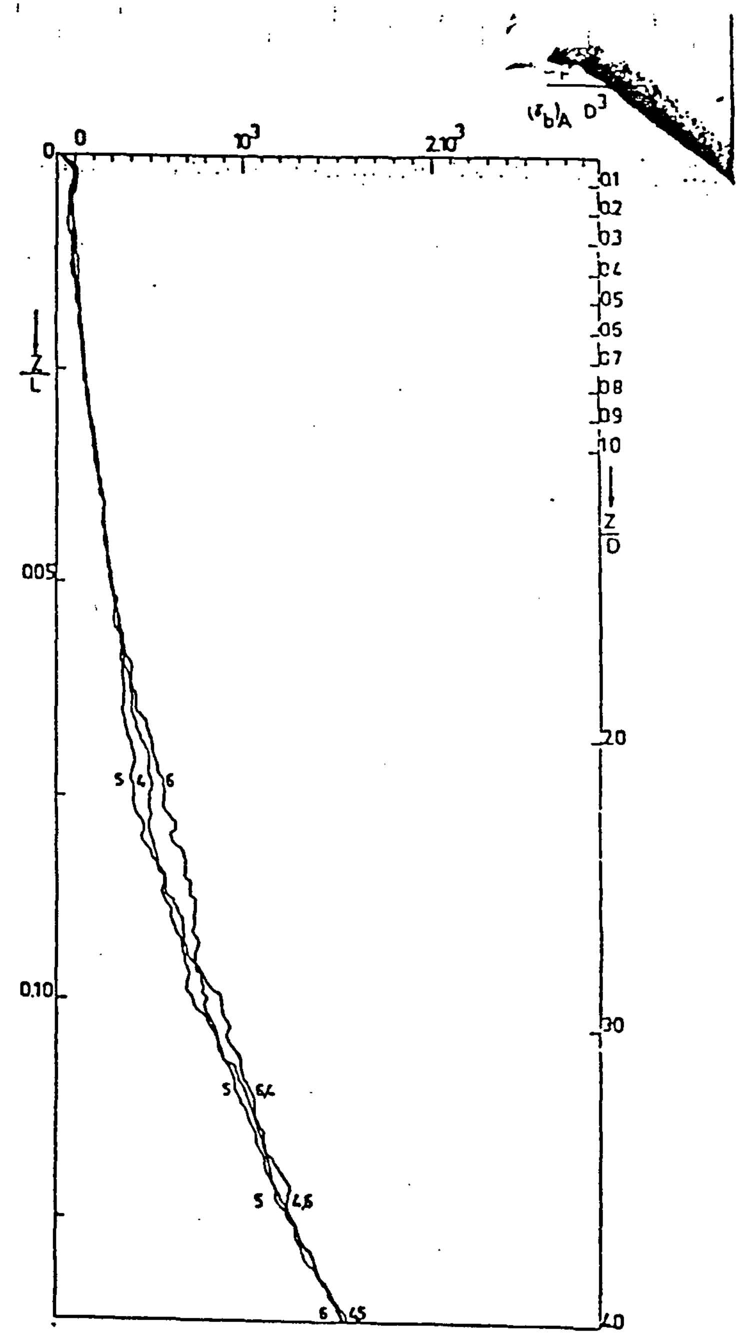


Fig. 10 - Penetration resistance of originally compacted sand bed [$(\gamma_b)_A$ = 1130 kgf/m^3 = 70.5 pcf] after subjecting bed to wave action.

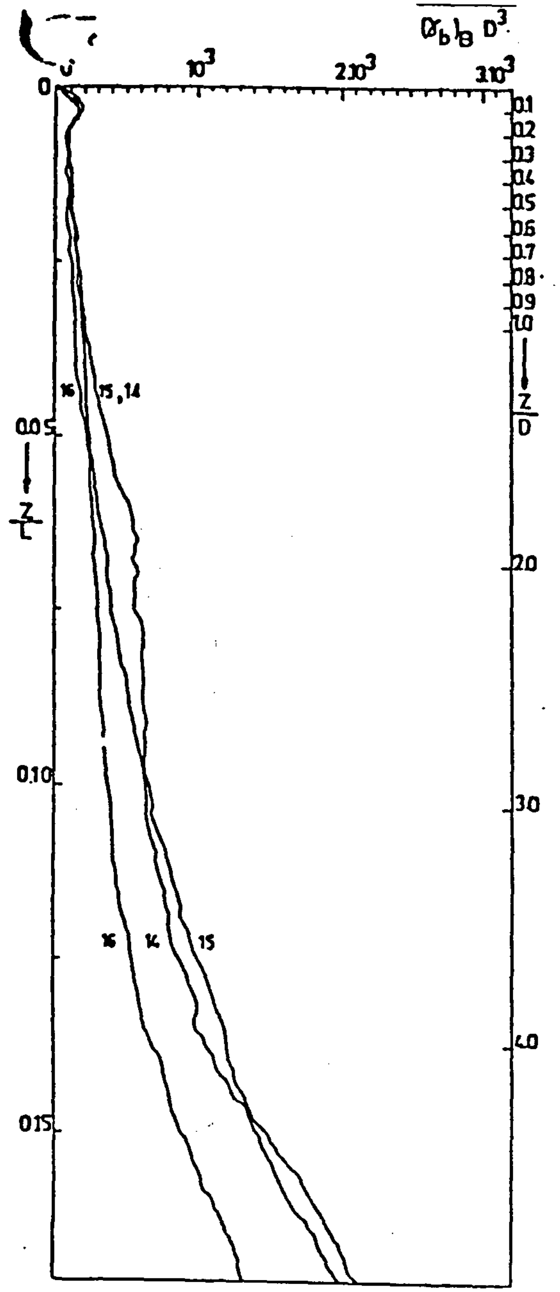


Fig. 11 - Penetration resistance of originally loose sand bed [$(\gamma_b)_B$ = 1060 kgf/m^3 = 66 pcf] after subjecting bed to wave action.

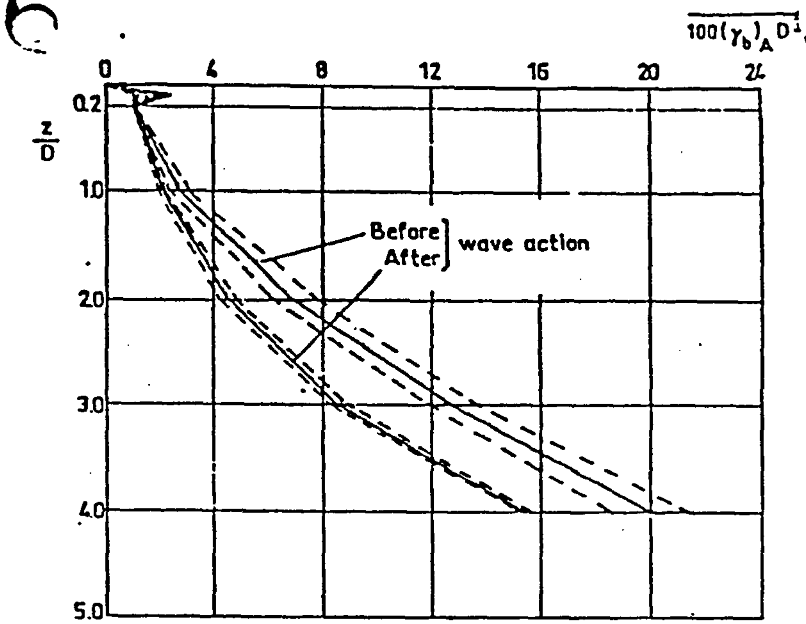


Fig. 12A - Penetration resistance of originally compacted sand ($\gamma_b)_A$ = 1130 kgf/m^3 = 70.5 pcf.

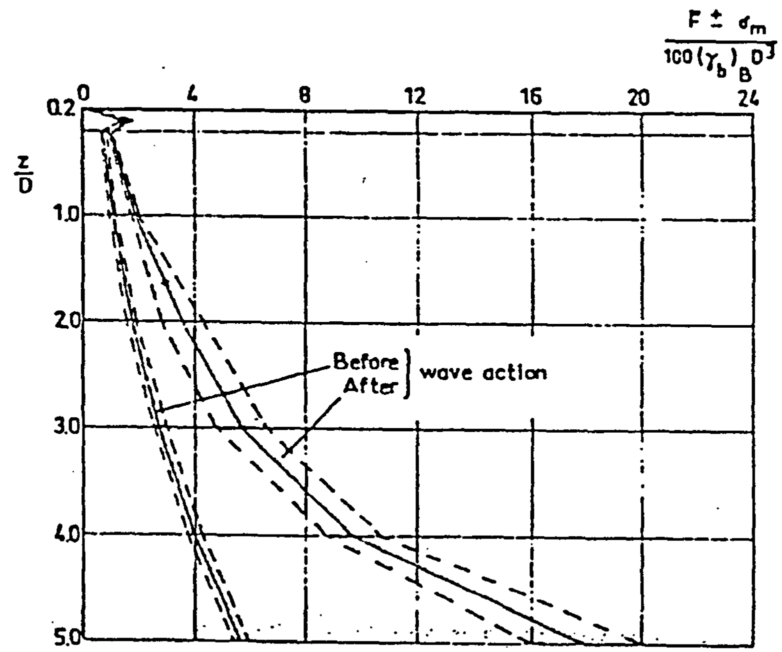


Fig. 12B - Penetration resistance of originally loose sand bed ($\gamma_b)_B$ = 1060 kgf/m = 66 pcf.

OTC 3262

SEA BED INSTABILITY FROM WAVES

by Tokuo Yamamoto, Oregon State University

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ABSTRACT

The pressures and the effective stresses in seabeds induced by waves are treated analytically based on Biot's three-dimensional consolidation theory. The wave induced pressures and stresses in a bed are strongly influenced by the permeability and the shear modulus of the soil, the compressibility of pore water, and the thickness of the bed. As a design example, a stress analysis is made for the North Sea design wave and seabed conditions. The numerical results indicate that the North Sea design waves will liquefy the top up to 2 m of the sand beds and induce the sliding failures in the top up to 8.0 m of the sand beds. The theory has been verified by a laboratory experiment for the wave induced pressures.

INTRODUCTION

The subject of wave induced pressures and stresses in seabeds is important with regard to the design of foundations for various ocean and near-shore structures, such as gravity type breakwaters, offshore oil storage tanks, and drilling rigs like EKOFISH at North Sea. The subject is also important when one considers the problems of the flotation of buried pipelines and the burial of rubble mounds, tetorapods, and other blocks by waves. However, the subject is not well understood because the dynamic behavior of soils is difficult to express mathematically.

When the water waves propagate over a porous bed such as a sand bed, the flow of fluid is induced in the porous medium and the porous medium itself is forced to deform. Thus, the bed response to water waves is actually a combination of fluid and solid mechanical effects.

There have been numerous investigations of the problem of the flow induced in a porous bed by water waves, including Liu (1973), Massel (1976), Moshagen and Tørum (1975), Nakamura, et al. (1973), Putnam (1949), Reid and Kajiura (1957), and Sleath (1970). However, they all assumed that the porous beds are rigid and nondeformable. In addition, all except Moshagen and Tørum (1975) and Nakamura, et al. (1973) assumed that the pore fluid is incompressible. The fluid motion in the porous bed is usually expressed by Darcy's law which, with the assumption of a rigid bed with isotropic permeability and incompessible water, leads to the Laplace equation for the pore-water pressure. The consequence of this theory is that the pore-water pressure response is independent of the permeability of the bed material. The approach taken by Nakamura, et al. (1973) and Moshagen and Tørum (1975) is based on the assumption that the water is compressible while the porous bed is nondeformable which leads to the heat conduction equation for the pore-water pressure. The conclusion from this assumption was that the pore-water pressure response is strongly dependent on the permeability of the bed material. This approach provides no information on the wave induced stresses in seabeds.

References and illustrations at end of paper.

On the other hand, the assumption common to the investigations concerned with the bed deformation and the stresses in the bed from water waves such as Doyle (1973), Prevost, et al. (1975), and Mallaid and Dalrymple (1976) is that the bed is an elastic continuum and no fluid flow takes place in the bed. This is a classical solid mechanical problem and the solution can be found in the text books of elasticity. Assuming that the pore-water pressure is equal to the change in the octahedral normal stresses in the elastic continuum, Prevost, et al. (1975) concluded that the pore-water pressure is the same as the one obtained from the Laplace equation and, therefore, is independent of the permeability of the soil. This approach is, however, not physically consistent.

Pore-water flow, volume change, and deformation occur simultaneously in the real soil beds. In order to take into account all of the effects, the analysis must be based on a more sophisticated mathematical model for the behavior of the fluid-porous medium complex. Biot (1941) presented the theory which takes into account the elastic deformation of porous medium, the compressibility of pore fluid, and the Darcian flow of pore fluid. Koning (1968) applied the Biot theory to the problem of the response of an inifinitely deep bed to waves in an unpublished report. The theory and some supporting experimental data are to be published by Yamamoto, Koning, Sellmeijer, and Van Hijum (1978). They concluded that the pressure and effective stress response of a saturated soil bed of infinite depth to waves is independent of the permeability of the soil. However it will be shown in this paper that this is not the case for a bed of finite thickness.

This paper considers, analytically, the wave induced behavior of soil and water in seabeds of finite thickness based on the Biot theory. The analytical results are compared with the results from a laboratory experimentation. As a practical numerical example, the stress analysis is done for a coarse sand bed and a fine sand bed which are subjected to the North Sea design wave conditions. The results, as will be shown, indicate that the response of a bed of finite thickness is strongly dependent of the permeability and the stiffness of soil and that the top part of the sand beds as much as 8.0 m can be unstabilized and even liquefied by the design waves.

THEORY

Governing Equations of Dynamic Equilibrium

The problem considered in this paper is two-dimensional. A homogeneous isotropic sediment is considered which has a constant thickness d. The x-axis is taken on the bed surface (mud line) and the positive direction of the z-axis is taken vertically downward from the bed surface. The waves travel from right to left.

Since the hydrostatic components of the pore-water pressure, stresses, and strains in the soil are trivial to the following consideration of the problem, only the incremental components of such variables will be considered unless otherwise mentioned.

The continuity equation is given as

$$\frac{k}{\gamma} \nabla^2 p = \frac{n}{K'} \frac{\partial p}{\partial t} + \frac{\partial \varepsilon}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots [1]$$

in which p is the excess pore-water pressure, ε is the volume strain of the porous medium, t is the time, k is the coefficient of permeability of the soil, γ is the unit weight of the pore-water, n is the porosity, and K' is the apparent bulk modulus of pore-water.

If the pore-water is absolutely air-free, K' is equal to the true bulk modulus of elasticity of water, K. However, if the pore-water contains even a very small amount of air, the apparent bulk modulus of elasticity of the water decreases drastically and K' is related to K as [Verruijt (1969)]

$$\frac{1}{K'} = \frac{1}{K} + \frac{1 - S_r}{P_o} \quad \ldots\ldots\ldots\ldots\ldots [2]$$

where S_r is the degree of saturation and P_o is the absolute pore-water pressure. The volume strain for the two-dimensional problem is given as

$$\varepsilon = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \quad \ldots\ldots\ldots\ldots\ldots [3]$$

where u is the x-component of soil displacement and w is the z-component of soil displacement.

From the effective stress concept and Hooke's law, the equations of equilibrium are given as,

$$G\nabla^2 u + \frac{G}{1 - 2\nu} \frac{\partial \varepsilon}{\partial x} = \frac{\partial p}{\partial x} \quad \ldots\ldots\ldots\ldots [4]$$

$$G\nabla^2 w + \frac{G}{1 - 2\nu} \frac{\partial \varepsilon}{\partial z} = \frac{\partial p}{\partial z} \quad \ldots\ldots\ldots [5]$$

where ν is Poisson's ratio of the soil, G is the shear modulus of the soil. The effective stresses are related to the strains by Hooke's law as

$$\sigma'_x = 2G \left[\frac{\partial u}{\partial x} + \frac{\nu}{1 - 2\nu} \varepsilon\right] \quad \ldots\ldots\ldots\ldots [6]$$

$$\sigma'_z = 2G \left[\frac{\partial w}{\partial z} + \frac{\nu}{1 - 2\nu} \varepsilon\right] \quad \ldots\ldots\ldots\ldots [7]$$

$$\tau'_{xz} = G \left[\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right] \quad \ldots\ldots\ldots\ldots [8]$$

wherein σ'_x is the effective normal stress in the x-direction, σ'_z is the effective normal stress in the z-direction, and τ'_{xz} is the shear stress in the z-direction on the plane perpendicular to the x-axis.

Equations [1], [4], and [5] form a system of three partial differential equations in terms of the three unknown variables, p, u, and w, to be solved for particular boundary conditions.

Boundary Value Problem

In this section, the three simultaneous partial differential equations will be solved for the case of waves propagating over a porous bed. At the top of the bed (z = 0) the pressure fluctuates due to surface waves. The pressure fluctuation attenuates as the waves travel over the bed due to the energy loss in the bed. However, the attenuation rate is usually small and may be neglected when only the region around a structure is considered. Thus the pressure at the bed surface is assumed to be periodic in this development. The value may be determined by experiment or, ignoring the damping, by higher order wave theories. In any event, the periodic signal can be expanded in a Fourier series and it is, therefore, sufficient to study a sinusoidal fluctuation.

Boundary Conditions

In order to solve the three simultaneous partial differential equations, one needs three independent conditions per boundary. At the bed surface, the boundary conditions are that the vertical effective stress is zero, that the shear stress is negligibly small, and that the sinusoidal pressure fluctuation exists, or,

$$\sigma'_z = \tau_{xz} = 0, \; p = p_o e^{i(\lambda x + \omega t)} \quad (z = 0) \quad \ldots [9]$$

where p_o is the amplitude of pressure fluctuation at the bed surface, λ is the wave number, and ω is the angular wave frequency, and only the real part is considered in the last equation.

If the seabed has an impermeable and rigid boundary at z = d, the boundary conditions are that no soil displacements at the boundary and no flow across the boundary are allowed, or,

$$u = w = \frac{\partial p}{\partial z} = 0 \quad (z = d) \quad \ldots\ldots\ldots [10]$$

Harmonic Solutions

Since the boundary conditions [9] is periodic both in time and space, it is reasonable to assume u, w, and p are also periodic in time and space,

$$u = U(z)\, e^{i(\lambda x + \omega t)} \quad [11a]$$

$$w = W(z)\, e^{i(\lambda x + \omega t)} \quad [11b]$$

$$p = P(z)\, e^{i(\lambda x + \omega t)} \quad [11c]$$

in which only the real parts are considered as before and U, W, and P are functions of z only.

Substitution of Equations [11a,b,c] into the three governing partial differential equations [1], [4], and [5] leads to the three simultaneous ordinary differential equations of second order. The differential equations are linear and homogeneous and the solutions can be found by forming the characteristic equations of the operator, $D = d/dz$. One will find the characteristic equation as,

$$(D^2 - \lambda^2)^2\, (D^2 - \lambda'^2) = 0 \quad [12]$$

where

$$\lambda' = \lambda\left(1 + i\, \frac{\omega}{c\lambda^2}\right)^{1/2} \quad [13]$$

in which c is known as the consolidation coefficient of soil and given by

$$c = \frac{k}{\gamma}\left[\frac{n}{K'} + \frac{(1 - 2\nu)}{2(1 - \nu)G}\right]^{-1} \quad [14]$$

Since the parameter ω/λ^2 may be considered as a diffusivity of surface wave, the parameter $c\lambda^2/\omega$ is the ratio of the diffusivity of water in soil to the wave diffusivity. Therefore, the general solutions may be given as:

$$U = a_1 \,\text{ch}\, \lambda z + a_2 \,\text{sh}\, \lambda z + a_3 z \,\text{ch}\, \lambda z + a_4 z \,\text{sh}\, \lambda z + a_5 \,\text{ch}\, \lambda' z + a_6 \,\text{sh}\, \lambda' z \quad [15a]$$

$$W = b_1 \,\text{ch}\, \lambda z + b_2 \,\text{sh}\, \lambda z + b_3 z \,\text{ch}\, \lambda z + b_4 z \,\text{sh}\, \lambda z + b_5 \,\text{ch}\, \lambda' z + b_6 \,\text{sh}\, \lambda' z \quad [15b]$$

$$P = c_1 \,\text{ch}\, \lambda z + c_2 \,\text{sh}\, \lambda z + c_3 z \,\text{ch}\, \lambda z + c_4 z \,\text{sh}\, \lambda z + c_5 \,\text{ch}\, \lambda' z + c_6 \,\text{sh}\, \lambda' z \quad [15c]$$

where a_n, b_n, c_n ($n = 1 \ldots 6$) are constants which have to be determined from the governing equations and the boundary conditions. The functions cosh x and sinh x are abbreviated as ch x and sh x, respectively, in this paper. It should be noted that the dispersion ratio $c\lambda^2/\omega$, the stiffness ratio G/K', and the relative bed thickness λd are the three important parameters in the dynamic response of soil to waves.

The analytical expressions become very simple if the seabed is infinitely thick. If the soil is saturated with water, then the apparent modulus of elasticity, K', is equal to the true modulus of elasticity of water, $K = 2.3 \times 10^9$ N/m². Since the value for G for soils varies from about 10^9 N/m² for very dense sand to 10^6 N/m² for silt and clay, the stiffness ratio, G/K', becomes practically zero for most soils except for dense sand.

For the limit of $\lambda d \to \infty$ and $G/K' \to 0$

$$u = -i\lambda z e^{-\lambda z} \frac{p_o}{2\lambda G}\, e^{i(\lambda x + \omega t)} \quad [16a]$$

$$w = (e^{-\lambda z} + \lambda z e^{-\lambda z}) \frac{p_o}{2\lambda G}\, e^{i(\lambda x + \omega t)} \quad [16b]$$

$$p = p_o e^{-\lambda z}\, e^{i(\lambda x + \omega t)} \quad [16c]$$

It is interesting to note that the pore-water pressure response for this case is the same as that obtained by Putnam (1949) who assumed that the soil is rigid and water is incompressible. The pressure attenuation for this case is small and independent of the permeability of soil. As can be seen from Equations [16a,b], however, such good transmission of the pressure has to be associated with the deformation of the soil. The amplitudes of the displacements and the pore-water pressure after nondimensionalizations are plotted in Figure 1. A given soil particle moves on an elliptical orbit in general. Near the bed surface the motion is only vertical. For $\lambda z > 4.0$, the orbit becomes essentially a circle. The effective stresses are given as

$$\sigma'_x = -\sigma'_z = -i\tau_{xz} = p_o\, \lambda z e^{-\lambda z}\, e^{i(\lambda x + \omega t)} \quad [17]$$

Substituting [16a,b] into [3], one finds that the volume strain, ε, is always zero for this case--no volume change. The amplitudes of the stresses given by [17] are also plotted in Figure 1. All three effective stresses increase from zero at the bed surface ($z = 0$) to the maximum value, 0.36 p_o at $\lambda z = 1$, and then gradually decrease as z is increased.

As will be demonstrated later in this paper, the response of a bed of finite thickness is strongly dependent on the permeability and the stiffness of bed soil.

Failure Analysis

So far, only the wave induced incremental changes in stresses and pressures in soils from the initial equilibrium state have been considered. In this section the failure mechanicsms of soils induced by waves are considered. From this point on the traditional sign convention for stresses in the soil mechanics will be used, i.e., a stress is positive when it acts as a compression. Although the failure analysis given herein may be extended to cohesive soils, only sands and cohesionless soils are considered in this paper.

The total effective stress, $\bar{\sigma}'_z$, in the z-direction is given as

$$\bar{\sigma}'_z = \bar{\sigma}'_{oz} - \sigma'_z \quad [18]$$

where $\bar{\sigma}'_{oz}$ is the effective normal stress in z-direction at initial equilibrium and given as

$$\bar{\sigma}'_{oz} = \gamma_b\, z = \gamma_n (G_s - 1) z \quad [19]$$

where γ_b is the buoyant unit weight of the soil and G_s is the specific gravity of soil grains. σ'_z in Eq. [18] is the incremental effective stress given by Eq. [7]. The total effective normal stress, $\bar{\sigma}'_x$, in x-direction is given by

$$\bar{\sigma}'_x = \bar{\sigma}'_{ox} - \sigma'_x \quad \ldots \quad [20]$$

where $\bar{\sigma}'_{ox}$ is the effective stress at the initial hydrostatic equilibrium and may be given as

$$\bar{\sigma}'_{ox} = K_o \, \bar{\sigma}'_{oz} = K_o \gamma_b \, z \quad \ldots \quad [21]$$

where K_o is the coefficient of earth pressure at rest and is related to the Poisson ratio, ν, as

$$K_o = \frac{\nu}{1 - \nu} \quad \ldots \quad [22]$$

The values of K_o for soils range from 0.4 to 1.0 (Scott, 1963).

Since the shear stresses on horizontal and vertical planes are zero at the initial equilibrium, the total shear stress, $\bar{\tau}_{xz}$, is related to the incremental shear stress, τ'_{xz} of Eq. [8] as

$$\bar{\tau}'_{xz} = - \tau'_{xz} \quad \ldots \quad [23]$$

Equations [18], [20], and [23] may be represented by the Mohr circles as shown in Fig. 2. The Mohr circle at a given instance is illustrated by a heavy solid circle passing through points P and Q. The point P and Q rotates on the shear ellipses shown by dashed lines at wave angular velocity, ω, as the waves progress over the seabed.

The stress state at a given location at a given instance may be conveniently expressed by the angle ϕ between the tangent from the origin to the instantaneous Mohr circle and the $\bar{\sigma}$-axis. The angle ϕ may be called the stress angle and given by,

$$\sin \phi(x,z,t) = \frac{\{(\bar{\sigma}'_z - \bar{\sigma}'_x)^2 + 4 \, \bar{\tau}'^{\,2}_{xz}\}^{1/2}}{\bar{\sigma}'_z + \bar{\sigma}'_x} \quad \ldots \quad [24]$$

Thus, the failure criteria of the soil element at a given point at a given instance may be defined as

$$\phi(x,z,t) \geq \phi_f \quad \ldots \quad [25]$$

where ϕ_f is the angle of internal friction of soil.

Numerical examples of failure analyses applied to the North Sea design conditions are given later in this paper.

VERIFICATION OF THEORY

In order to verify the present theory, the pore pressure calculated from the present theory are compared with the measured values from the laboratory experiments which are reported in Yamamoto, et al. (1978). There, the pore pressures at various depths in a 0.5 m thick sand bed were measured for 1 to 2.6 sec. waves in 0.9 m water. The comparisons between the theory and experiment for a fine sand are shown in Fig. 3 for a 2.6 sec. wave. In the calculation, the experimentally determined values of soil properties, $\nu = 0.333$, $c = 0.2$ m^2/sec, $n = 0.35$, $G = K' = 1.6 \times 10^6$ N/m^2 were used. The comparison shows a good agreement for both magnitude and phase. Although not shown here, generally good agreements were obtained for other wave periods and for coarse sand. Also compared in Fig. 3 are the calculated values from the theories given in Putnam (1949) and Moshagen and Tørum (1975).

The theory in Putnam (1949) is based in the assumption that soil is rigid and water is incompressible, i.e., the Laplace equation for pore pressure. As will be shown later, this is given as the limit of the present solution when $k \to \infty$. The theory by Moshagen and Tørum (1975) assumed that the water is compressible while the soil is rigid, i.e., the heat conduction equation of pore pressure, which is given as the limit of the present solution when $G/K' \to \infty$.

For the case shown in Fig. 3, neither of the two earlier theories agree with the experiment. This is because of the unrealistic assumption of nondeformable soil structures used in both theories.

Since no measured values for stresses or deformations are available, further verificant of the present theory cannot be made. However, the good agreements for the pressures between the present theory and the experiment support the validity of the proposed theory to some extent.

PRACTICAL EXAMPLES

As practical examples, the proposed theory is applied to North Sea design conditions. The same numerical values of physical quantities for waves and soils used in Moshagen and Tørum (1975) are used for comparisons. The design wave conditions are: $T = 15$ sec.; $L = 324$ m; wave height $H = 24$ m; water depth h 70 m; bed thickness $d = 25$ m. Thus the relative bed thickness λd is 0.46. Various sand beds are considered. Sands are assumed to be saturated ($K' = 2.3 \times 10^9$ N/m^2) and isotropic ($n = 0.3$, $\nu = 0.333$, $G_s = 2.7$). The linear wave theory was used to calculate the pressure distribution on the mud line as was used in Moshagen and Tørum (1975).

Effect of Soil Stiffness

The vertical distribution of amplitude and phase lag of the pressure in fine sand beds ($k = 10^{-4}$ m/sec) with various stiffnesses are shown in Fig. 4. For a very stiff bed like a sandstone ($G = 10^{11}$ N/m^2, $G/K' = 50$) the flow is essentially that of compressible fluid in a rigid porous material and the present solution approaches the solution by Moshagen and Tørum (1975). The pressure attenuates rapidly and has a large phase lag which nearly linearly increases with depth. As the soil stiffness gets smaller, the soil fram deforms more easily and the phase lag becomes small. For moderately packed sands, $G = 10^7$, the amplitude of pressure decreases rapidly and has a minimum at $z = 4$ m and gradually increases as the depth is increased. In the lower part of the sand bed, the relative motions between the fluid and solid is very small and the soil behaves more like an elastic continuum. The rigid bedrock restricts the free elastic deformation of the soil near the boundary and icnreases the stresses and pressure.

Effect of Permeability

The pressure distributions in the moderately packed sand beds ($G = 10^7$ N/m^2, $G/K' = .005$) with various permeabilities are shown in Fig. 5. As shown in this figure, the pressure distribution in a sand bed of

...e thickness is strongly dependent on the permeability contrary to the infinitely thick bed.

For the very coarse sand (k = 0.1 m/sec), the compressiblities of water and soil have small influence on the fluid flow and the pressure distribution approaches that of the incompressible flow in a rigid porous medium by Putnam (1949). As the permeability decreases, the solid mechanical effect becomes more important as discussed in the previous section. The pressure gradient near the mud line increases as the permeability decreases. This may indicate that the fine sand may be more easily liquefied than a coarse sand.

Complete stress analysis will be given next for a coarse sand bed and a fine sand.

Coarse Sand

The physical properties for the coarse sand used in calculations are: $k = 10^{-2}$ m/s; $G = 10^{7}$ N/m ; $n = .3$; $\nu = .333$; and $G_s = 2.7$. The consolidation coefficient is calculated by Eq. 14 and $c = 40.8$ m^2/s. For this case, the dispersion ratio is $c\lambda^2/\omega = .037$ and the stiffness ratio is $G/K = .00435$.

The vertical distributions of the vertical and horizontal displacements and the volume strain are given in Fig. 6. As can be seen, a given soil particle moves on an ellipse with its major axis in the horizontal. The amplitudes decrease with depth. The volume change is maximum at the mud line, decreases to the minimum at z = 16 m and increases near the rigid bedrock. Near the mud line the soil expands under a wave crest and contracts under a wave trough. The opposite is true near the bed rock.

Fig. 7 shows the vertical distribution of wave induced effective stresses. The shear stress linearly increases with the depth. At the mud line the vertical stress is zero and the horizontal stress is maximum. The effects of wave induced stresses on the soil instability can be more clearly illustrated by the stress angle ϕ defined by Eq. [24]. The spacial distribution of the stress angle ϕ so calculated is shown in Fig. 8. The distribution is practically symmetric about the wave crest. A "tensile" stress occurs in the shaded area near the mud line.

Of course a sand cannot withstand tension, therefore, it must be liquefied. The penetration depth of liquefied zone is maximum at a wave crest and about 2.2 m, and near the trough .2 m. Below the liquefied zone, there exists a slide-failure zone, the depth of which depends on the internal friction of the sand, ϕ_f. If $\phi_f = 30°$, the failure zone penetrates 7.5 m at the crest and 1 m at the trough.

Fine Sand

The similar calculations are made for a fine sand with $k = 10^{-4}$ m/s. The values of other physical properties are the same as for the coarse sand. The values of c, $c\lambda^2/\omega$, and G/K are .408 m^2/s, .00037, and .004, respectively. The results of calculations are shown in Figs. 9 to 11 in the same manner as for the coarse sand. As shown in Fig. 5, the pressure ...ops rapidly from 57 KN/m^2 at the mud line to ... KN/m^2, and gradually increases as the depth is increased further. Since the water cannot escape easily in a fine sand, the high pressure in the lower part of the sand bed is maintained by the elastic volumetric change of the pore water as can be seen in Fig. 9. As shown in Fig. 10, the shear stress increases linearly similar to the coarse sand. However, the normal stresses vary differently from the coarse sand. As shown in Fig. 11, although the distribution of the stress angle is slightly assymmetric about the wave crest, the overall tendency is similar to the coarse sand.

The penetration depth of liquefied zone is 2 m at the crest and 1 m at the trough which is deeper than the coarse sand. If $\phi_f = 30°$, the sliding failure zone is 6.5 m deep at the crest and 1.5 m deep at the trough.

Since the sand in the liquefied zone and the failure zone loses its strenth, the structures within or upon such soil mass will lose their supports. This may explain why submerged pipelines float and why rubble mounds and artifial blocks are buried in sand. This may also explain the foundation failures for some offshore structures.

Since the sand in the liquefied zone should behave like a fluid, it will be easily carried away by waves. This may explain why a huge amount of soil is moved by tsunamis and large storm waves. A large wave energy is consumed by fluidization of sands. This may explain why large, steep waves attenuate rapidly on sandbeds.

SUMMARY AND CONCLUSIONS

The effect of wave induced pressures and stresses on the instability in sandy seabeds of finite thickness was considered mathematically based on Biot's three-dimensional consolidation equations. The bed response to waves was found to be strongly influenced by the permeability and the stiffness of soil and the thickness of the bed.

The analytical expression for the pore pressure was verified with experimental data. An excellent agreement was obtained.

For North Sea design conditions, numerical calculations were made to analyze the stability of both a coarse sand bed and a fine sand bed. The numerical results indicated that the top portions of sand beds as thick as 2.5 m can be liquefied from the design wave and that the slide-failure zone can penetrate the sand beds even deeper, as deep as 8.0 m.

NOMENCLATURE

- c = coefficient of consolidation of soil
- d = thickness of seabed
- G = shear modulus of soil
- G_s = specific gravity of soil skelton
- K = bulk modulus of elasticity of water
- k = coefficient of permeability of soil
- K' = apparent bulk modulus of water
- K_o = coefficient of earth pressure of soil at rest
- n = porosity of soil
- P = pore pressure function
- p = incremental pore pressure
- P_o = absolute value of pore pressure
- p_o = amplitude of dynamic pressure at mud line
- S_r = degree of saturation of soil
- t = time
- U = horizontal displacement function
- u = horizontal displacement of soil

W	=	vertical displacement function
w	=	vertical displacement of soil
x	=	fixed horizontal coordinate
z	=	fixed vertical coordinate measured downward from mud line
γ	=	unit weight of water
γ_b	=	buoyant unit weight of soil
ε	=	volume strain of soil
λ	=	wave number
λ'	=	complex wave number
ν	=	Poisson ratio of soil
σ_x	=	incremental horizontal effective stress
σ_z	=	incremental vertical effective stress
$\bar{\sigma}_{ox}$	=	horizontal effective stress at rest
$\bar{\sigma}_{oz}$	=	vertical effective stress at rest
τ_{xz}	=	incremental shear stress
$\bar{\tau}_{xz}$	=	total shear stress
ϕ	=	stress angle
ϕ_f	=	angles of internal friction of soil
ω	=	angular wave frequence

ACKNOWLEDGEMENTS

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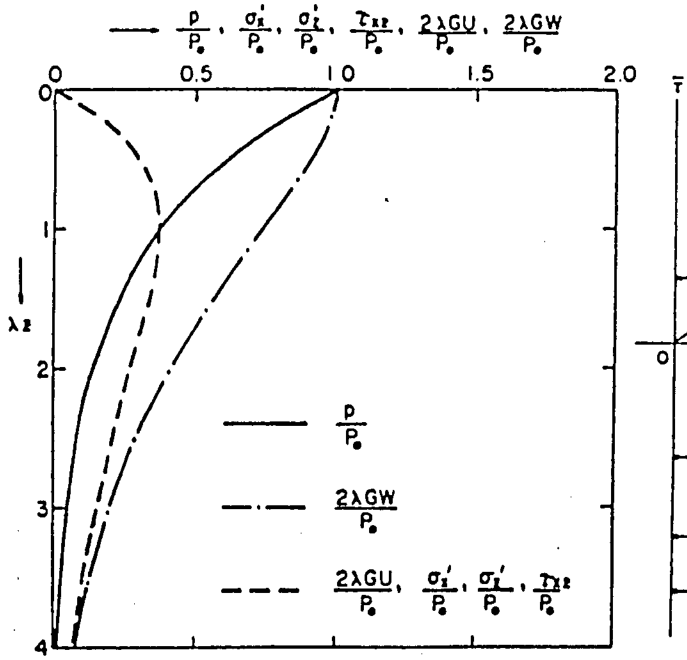

FIG. 1 - WAVE INDUCED PRESSURE, EFFECTIVE STRESSES AND DISPLACEMENTS IN A SATURATED SOIL OF FINITE THICKNESS.

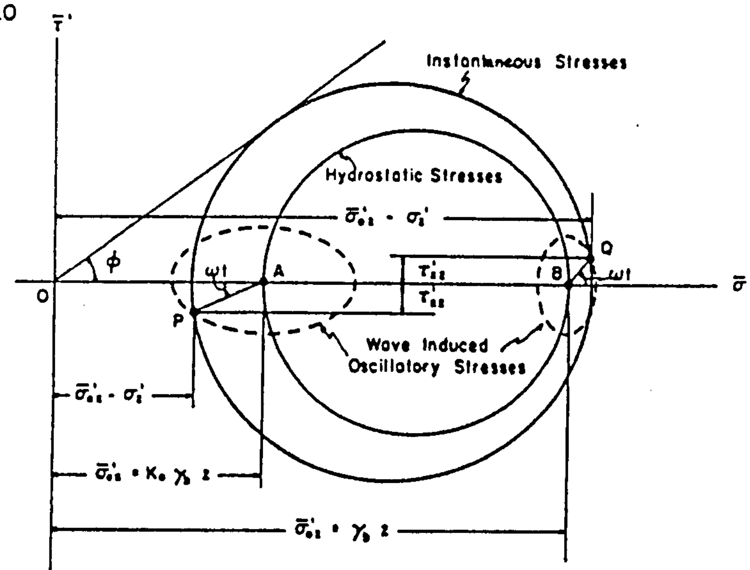

FIG. 2 - MOHR'S CIRCLE DIAGRAM OF WAVE INDUCED EFFECTIVE STRESSES.

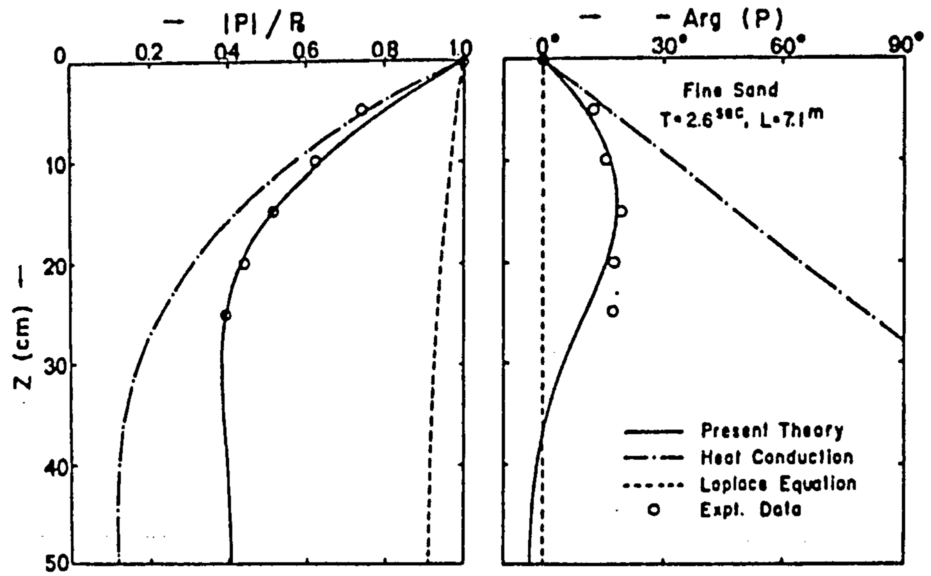

FIG. 3 - COMPARISON OF THEORIES AND EXPERIMENTS FOR WAVE INDUCED PORE PRESSURE IN A FINE SAND.

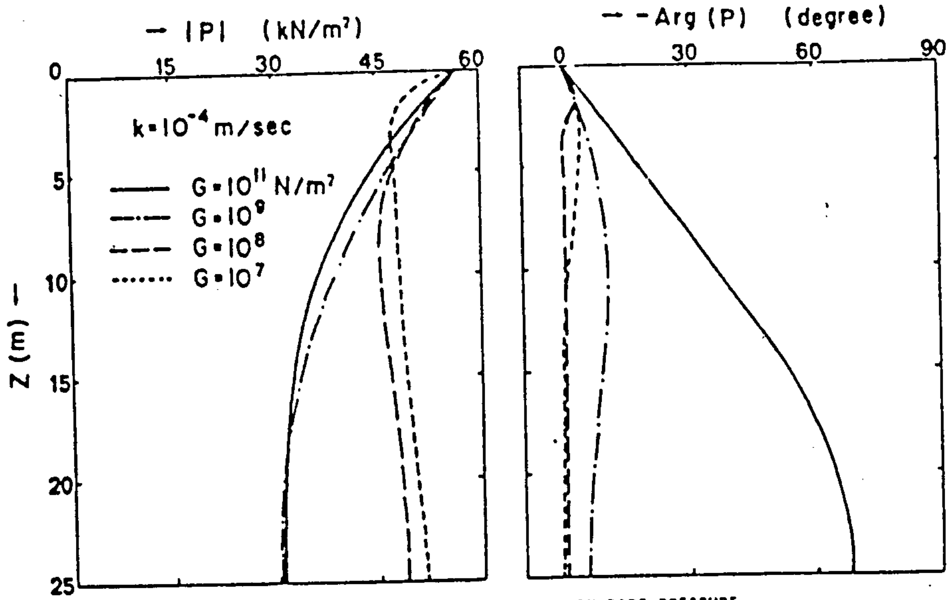

Fig. 4 - Effect of soil stiffness on pore pressure.

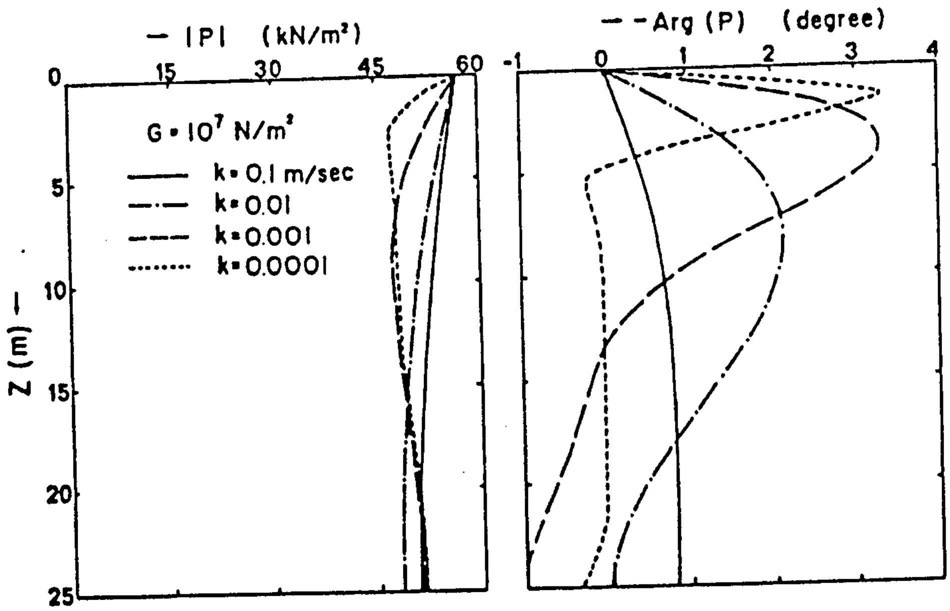

Fig. 5 - Effect of soil permeability on pore pressure.

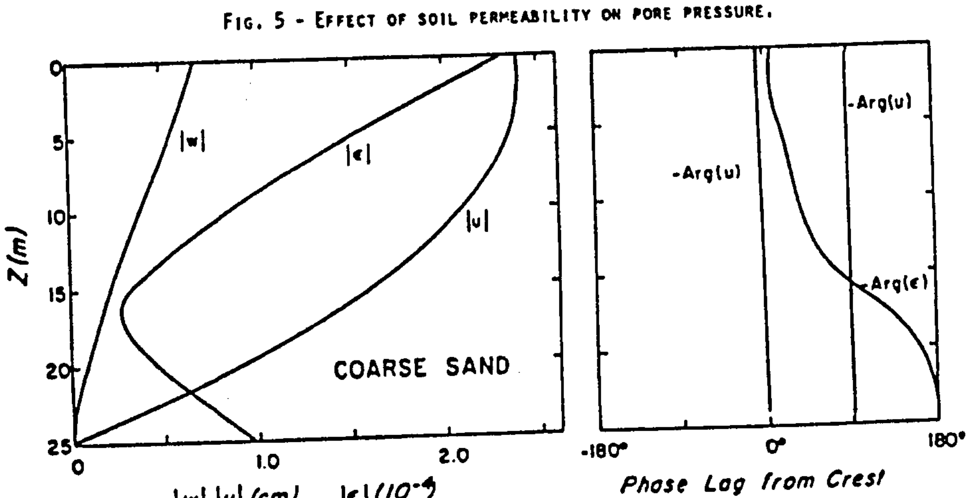

Fig. 6 - Displacements and volume strain in coarse sand, c^2/ω = 0.037, G/K' = 0.044, λD = 0.46.

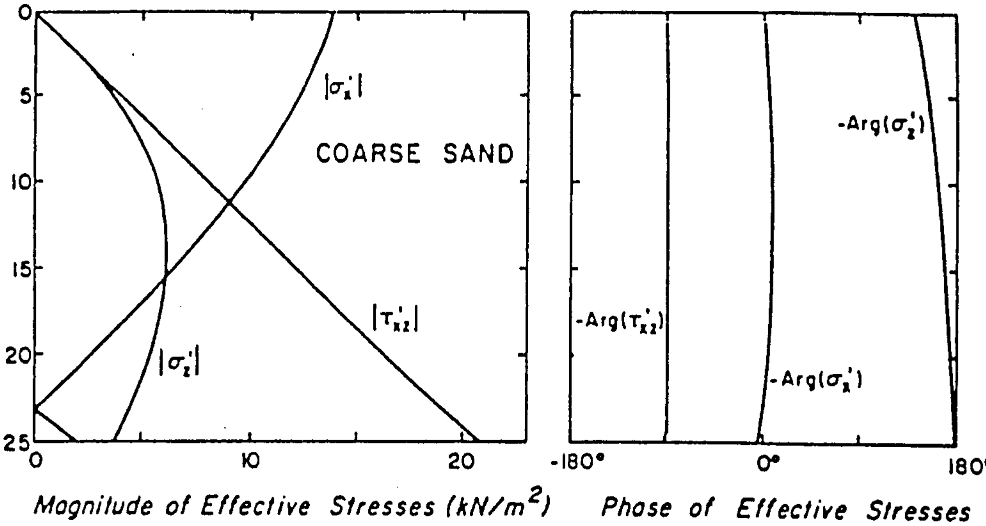

FIG. 7 - EFFECTIVE STRESSES IN COARSE SAND $c\lambda^2/\omega = 0.037$, $G/K' = 0.044$, $\lambda_D = 0.46$.

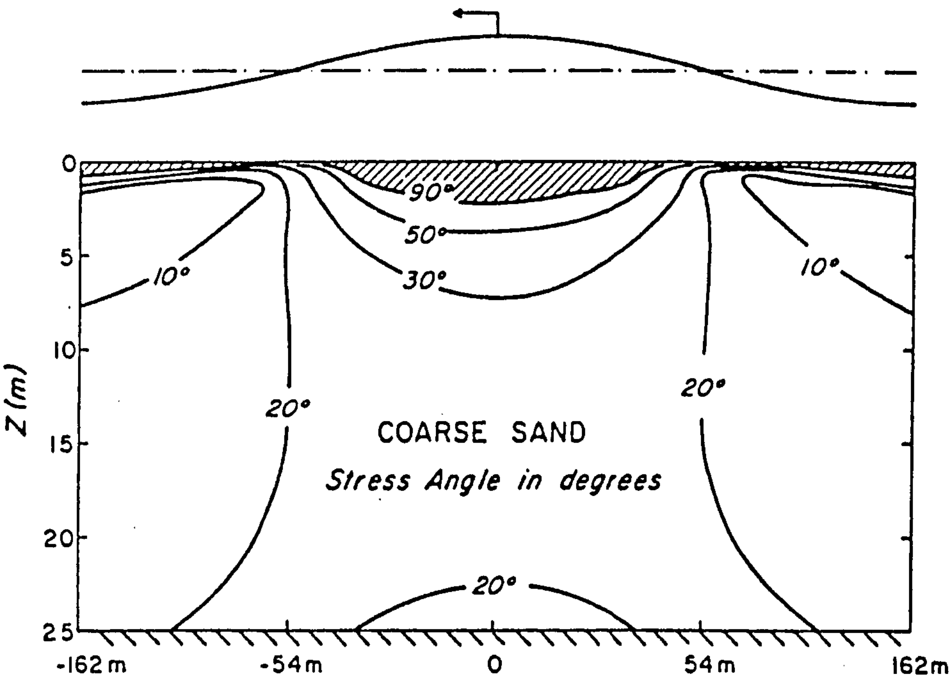

FIG. 8 - HAVE INDUCED STRESS STATE IN COARSE SAND, $c\lambda^2/\omega = 0.037$, $G/K' = 0.044$, $\lambda_D = 0.46$.

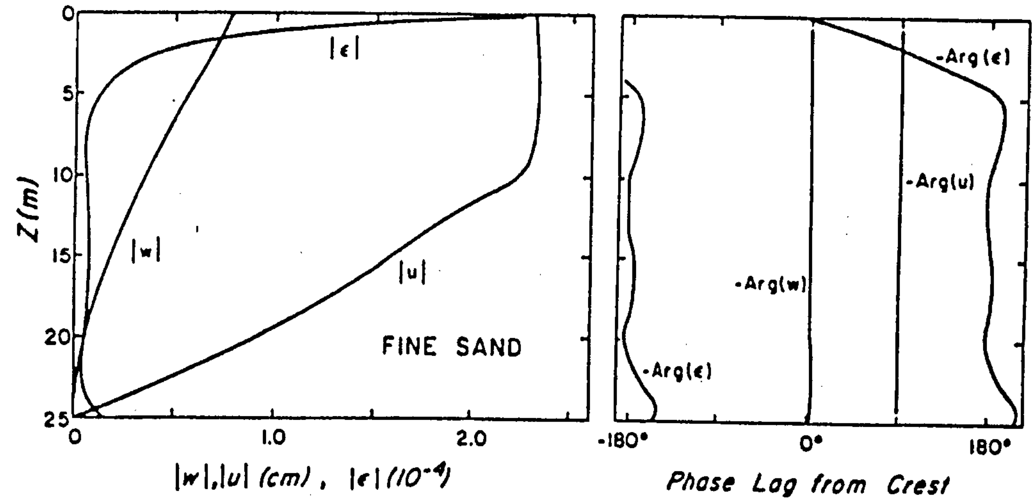

FIG. 9 - DISPLACEMENTS AND VOLUME STRAIN IN FINE SAND, $c\lambda^2/\omega = 0.00037$, $G/K' = 0.04$, $\lambda_D = 0.47$.

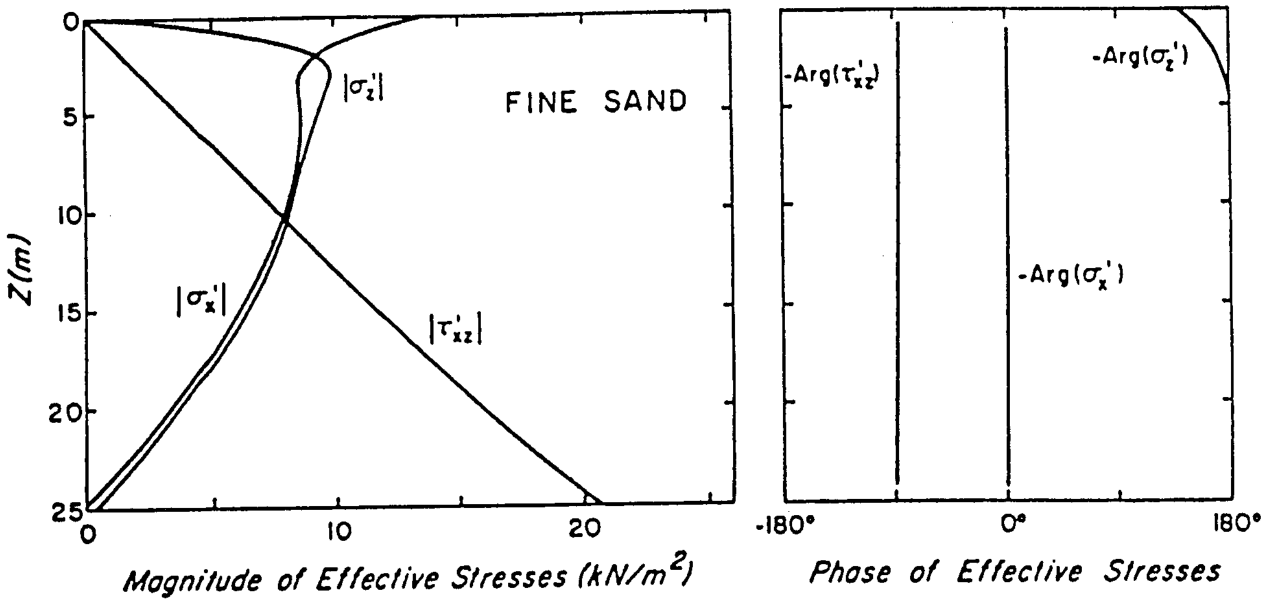

FIG. 10 - EFFECTIVE STRESSES IN FINE SAND, $c^2\lambda / \omega$ = 0.00037, G/K' = 0.044, λ_D = 0.46.

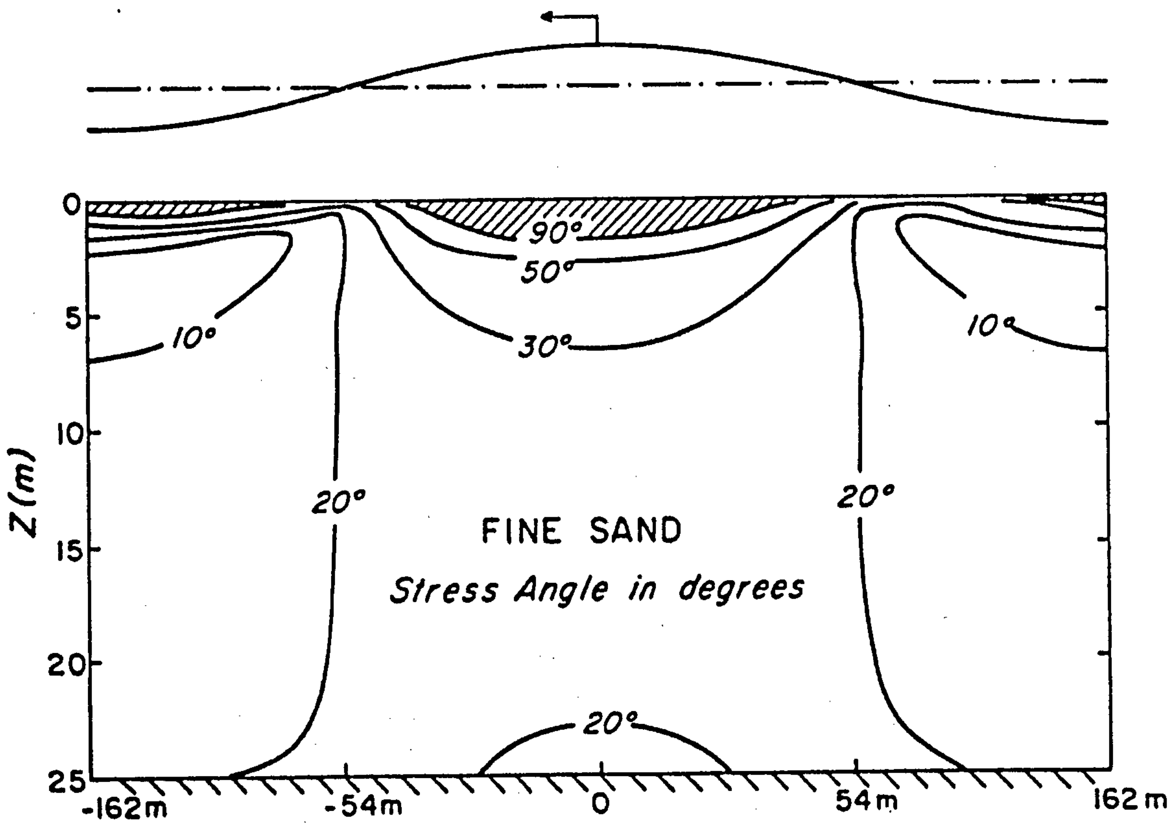

FIG. 11 - WAVE INDUCED STRESS STATE IN FINE SAND, $c^2\lambda / \omega$ = 0.00037, G/K' = 0.044, λ_D = 0.46.

_OTC 3975

A SIMPLIFIED EVALUATION OF SEAFLOOR STABILITY

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ABSTRACT

A simplified method is described for evaluation of seafloor stability. The analysis is based on an elastic continuum formulation modified by a Plasticity Factor. Two key elements of input into such an analysis are examined in detail: soil shear strength and wave-induced bottom pressures.

For the example platform location used in this paper, conventional treatment of these two input elements leads to an evaluation that the seafloor will be unstable during criteria conditions. However, when perceptive evaluations are made of drilling, sampling, and testing factors that act to lower measured shear strength, and when recognition is given to the wave attenuating effects of bottom motions, then the evaluation leads to the conclusion that the seafloor will be stable. Platform experience during past criteria conditions in the vicinity of the example location is used to justify the conclusions.

INTRODUCTION

A primary objective of an evaluation of seafloor stability is to determine if (under criteria conditions) the seafloor soils will move significantly so as to generate important forces on a structure. A simplified approach to developing such evaluations is described in this paper. The approach is illustrated with data from a fictitious platform site in the West Delta area of the Gulf of Mexico.

EVALUATION

Experience indicates that assessment of the potential for significant soil movements depends on proper analysis and integration of data and evidence from six categories of information.

1) Geologic - historic and present depositional and deformational environments, proximity to high rate deposition centers, bathymetric features and their historic changes.

2) Geophysic - high resolution geophysics and side scan sonar data to identify relict and active bottom and sub-bottom features in the vicinity of the location.

3) Geotechnic - results from closely controlled soil borings including drilling characteristics, measurements of soil shear strengths, water contents, sensitivities, gas contents and composition, and observations of the macro-structure of the soils.

4) Oceanographic - estimates of extreme tide, wave, and current conditions, bottom pressure changes caused by such conditions, and general alteration of these conditions caused by sea wave-bottom interactions.

5) Analytic - results from computational and physical models which attempt to determine the stress and strain conditions developed in the soils by geostatic (slope, regional deformation, reservoir sources) and oceanographic conditions.

6) Structure Performance - studies of platforms and pipelines located in the same or similar areas which have experienced severe oceanographic conditions and been subjected to seafloor soil movements. This frequently-ignored source of information can provide valuable data to calibrate results of the evaluation.

In an area such as that of the Mississippi River Delta, in general, it is not a question of whether or not there will be soil movements. The soils will move. It is a question of how much, how deep, how often, and with what effects (force, displacements).

The significance of the movements depend on the structure involved and the engineering strategies employed in its design. In general, the design of platforms and pipelines are such that large deformations can be tolerated without developing unacceptable performance. Failure of the soils does not constitute failure of the structural system, provided the system has been designed to maintain its integrity under the loads and imposed deformations. Assessments of the characteristics of soil response or evaluations of bottom stability must be kept within the context of the expected or desired performance of the structural system (20).

CONVENTIONAL EVALUATION

In this paper a fictitious platform site is used to illustrate application of the proposed evaluation procedure.

References and illustrations at end of paper.

Shown in Fig. 1 is the bathymetry of the Southwest Pass of the Mississippi River Delta. This is an area that is being bypassed by the rapid seaward progradation of this mouth of the river. The platform site is in a water depth (h) of 150 ft.

Based on results from a conventional soil boring at the platform site, Fig. 2 depicts the measured shear strength (field miniature vane) profile for the upper 150 ft of soil.

A conventional study of the oceanographic conditions for this area indicates a design wave height (H) of 55 ft and a wave period (T) of 16 sec. These design conditions are for 100-year return period hurricanes. Such design waves would generate a bottom pressure amplitude (ΔP) of about 1200 psf.

A conventional analytical model used to determine bottom stability is that proposed by Henkel (22). A sinusoidal bottom pressure wave is imposed at the mudline. A series of circular arcs are assumed to penetrate the soils to different depths. Soil shear strength along the perimeters of these circular arcs resist the motion-producing moments of the bottom pressures and the gravity or slope effects. Through a series of trials, the circular arc possessing the lowest factor of safety is located.

Shown in Fig. 3 are results from application of this limit equilibrium model to oceanographic and soil conditions cited. The results are presented as the depth of sliding caused by a range of bottom pressure amplitudes and wave periods. These results imply that these soils will not be in equilibrium under design wave conditions. Slide depths of 120 ft are indicated.

The initial conclusion is that a slide-resistant platform will be necessary for this location. But, is this a reasonable evaluation?

GEOLOGY

During the last decade, the geology of the Mississippi Delta has been studied extensively (8,13,14,39). Our understanding of current deformational processes and bottom morphology has increased greatly (14,32). We have come to learn that the geology of this environment is extremely complex.

The example platform site is located in the Delta Front. Shown in Fig. 4 are bottom features identified in this area (14). Collapse depressions, bottleneck slides, advancing mud fronts, and mud diapirs are present in portions of this area.

The fundamental sources of the activity are sediments deposited by Southwest Pass. Activity can be directly correlated with periods of high sediment buildup by the river, with periods of intense wave and current action, and with periods of very low tides (such as accompany hurricanes and northers) (10).

Figure 5 shows north-south and east-west bottom profiles through the platform location. The elevations of the seafloor in 1940 are compared with those in 1977. About 10 ft of buildup of the bottom occurred at the platform location during this 38-year period. Note the unusual buildup that occurred in the southern portion of the location. This is indicative of an advancing mud front. However, the platform location now appears to be located in a bypassed area where deposition rates and influxes of soils transported by sliding mechanisms are minimal (29).

GEOPHYSICS

Figure 6 shows a sample high resolution geophysics line across the platform location. Within 3000 ft of the location the geophysics data show no active bottom features. The strong reflector at a penetration of 170 ft is the contact between the Pleistocene and Recent sediments. The records imply the possible presence of small quantities of gas in the sediments above 170 ft of penetration. As shown in Fig. 7, the data outside the immediate platform area show evidence of relict mudflow lobes that are now buried below the seafloor. Similarly, side scan sonar records show no unusual bottom features in the vicinity of the platform site (14).

It is obvious that in the past this area has been subject to influxes of materials. At the present time, the area appears to be relatively quiescent. This is in general conformance with the picture of Recent geology previously described.

OCEANOGRAPHY

Since 1940, a large number of intense hurricanes have affected the West Delta area. The hindcast and measured deep water (> 300 ft) maximum wave heights and significant periods associated with each of these hurricanes are shown in Fig. 8 (7,10). Wave heights ranging from 20 to in excess of 80 ft have been generated by these storms. There have been 7 storms that produced maximum wave heights in deep water in excess of 40 ft during this 40-year period, or about one storm every six years.

Figure 9 shows estimated maximum bottom pressure amplitudes associated with the recent history of hurricanes. Bottom pressure amplitudes have been computed for a water depth of 150 ft and based on non-moving bottom theory (35,38). Note the general tendency toward more frequent occurrences of high bottom pressures than high wave heights. There were 12 occasions in the 40-year period in which computed bottom pressures exceeded 600 psf.

High wave heights are generated by near-passing hurricanes. Long waves or large wave periods can be generated by both near-passing (preceding swell) and distant storms. As shown in Fig. 10, bottom pressures are sensitive to wave periods and wave heights. Thus, the combination of high wave heights and large wave periods leads to more frequent occurrence of high bottom pressures. This can be an important factor in assessing the return periods or probabilities associated with storm wave effects on the bottom.

One of the most important oceanographic effects in the West Delta area is that of wave decay. It was pointed out in a previous study (7) that in two of the most intense storms to affect this area in recent times, recorded and observed high deep water waves did not reach shallow water as might have been expected. For example, in Hurricane Betsy (1965), deep water wave heights in the range of 75 to 80 ft were recorded and observed in the Delta area. However, in the shallow water portions of the Delta, wave heights less than 20 ft were observed. This was much greater wave decay than could be explained by conventional wave decay mechanisms. Two additional mechanisms were proposed: wave-current interaction and wave-deformable bottom interaction (7).

Recent studies (10,15,37,38,40) and recorded data (19,40,41) suggest that deformations of the seafloor in soft bottom areas have extremely important effects on wave heights in shallow water. Results from one of these studies in the West Delta area is shown in Fig. 11. Analyses have been performed on three sets of propagating waves; a wave train having deep water wave heights of 72 ft and periods of 11 sec in deep water. This wave condition was chosen from the API ideline design wave heights for the Gulf of Mexico (27). ne second and third wave trains have deep water heights of 58 and 40 ft, and periods of 13 and 15 sec, respectively.

The dashed lines show the decay of these wave trains as they propagate into the West Delta area assuming that the seafloor is rigid. The solid lines show decay of these wave trains based on results from analyses which recognize that the seafloor is deformable. Deformation characteristics of the seafloor have been based on the soil characteristics of the West Delta area (21) and results of viscoelastic continuum analyses of these soil profiles (11,33,34).

For purposes of reference, the recorded and observed wave heights during Hurricane Betsy have been shown. The data are in general agreement with the analytical results. Similar conclusions can be reached from data recently reported by Forristall, et al. (19).

The important observation is that in a water depth of 150 ft, a maximum wave height of about 40 ft with a period of 16 sec is indicated based on these results. It should be noted that other reasonable combinations of high waves and large wave periods are bracketed by these results. Higher and steeper waves are attenuated more rapidly than lower and longer waves. Also, note that in very shallow water, say less than 50 ft, these results indicate wave heights less than 10 to 15 ft are expected, even in very intense hurricanes.

Based on these findings, a criteria level wave height of 40 ft and a wave period of 16 sec were selected for use in the analytical evaluations of soil stability at the platform location.

Another potentially important effect of the deformations of the seafloor is on the effective bottom pressures. This problem has been addressed by Suhayda (37,38,40) and others (11,35). A general solution for the bottom pressure amplitude for a sinusoidal surface wave that develops a comparable seafloor deformation wave is given in Fig. 12 (38).

The first portion of this equation is that for the condition of a rigid bottom. The second portion recognizes the influence of the deformations of the seafloor on the bottom pressures. The seafloor deformations can cause either an increase or decrease in the bottom pressures depending upon the phase angle (ϕ) between the surface and bottom disturbances. For phase angles between 0 and 90 degrees and 270 and 360 degrees, the bottom motions reduce the bottom pressures. For phase angles between 90 and 270 degrees, the bottom motions increase the bottom pressures.

Analyses (11,37) and measurements (19,40,41) indicate that the phase angle is a function of the intensity of the bottom motions and the extent of plasticity or inelasticity induced in the soils. At low levels of deformation, the response is largely elastic, implicating a phase angle (ϕ) of approximately 180 degrees (28,34). For fluid-like or viscous response of the soils, at low levels of excitation, the phase angle may be in the range of 10 to 20 degrees (38). For intense bottom motions, dynamic viscoelastic continuum analyses indicate phase angles in the range of 120 to 130 degrees (11).

For the intense bottom pressures and motions of concern at the platform site, the analyses imply that bottom pressure amplitudes might be increased by 20 to 30 percent over rigid bottom pressures (11). For a 40-ft, 16-sec period design condition wave, the bottom pressure consequently is about 1000 psf.

GEOTECHNICAL

In an earlier section, the results of soil sampling and testing from a conventional boring at the platform site were described. These results incorporated three important sources of disturbance, all of which tend to lower the strength of the soil: drilling, sampling, and pressure relief (31,32).

Figure 13 shows the mud weight required to hold the drill hole at the platform site stable without allowing collapse or fracture (1,12,24,30,32). Two different fracture gradients are indicated. The gradient of 0.65 psi/ft is typical for most conditions along the Gulf Coast (1,24). The gradient of 0.53 psi/ft has been found to be characteristic of conditions in the vicinity of the Delta (23,24).

In the conventional boring discussed earlier, the driller decided to spud the hole with a drill fluid having a weight of 9.5 pounds per gallon (ppg). For normal Gulf Coast formations such a practice would be satisfactory. However, in this particular location such a practice results in overpressuring the drill hole and fracturing the formation to depths of 100 ft. Close examination of the samples to depths of 50 to 60 ft indicated the presence of drill fluid and formation squeezing (distorted soil structure). Proper control of drill mud weight and viscosity are key elements in performing soil borings that are able to result in retrieving samples that are relatively undisturbed.

A second important source of disturbance is that associated with sampling. The influence of one of the causes of sampling disturbance is illustrated in Fig. 14 (25). It is conventional practice to perform the shipboard vane shear tests in the ends of the sampling (Shelby) tubes, generally with a vane penetration of 1/4 to 1/2 inch. The data summarized in Fig. 14 indicate that the soils close to the ends of the Shelby tubes are disturbed to a much greater degree than those farther into the sampler. This is due to the sample insertion and withdrawal effects acting to distort the soils in two directions close to the end of the sample tube.

Vane shear strengths are 40 to 50 percent greater 3 to 4 sample tube diameters from the end of the tube (25). These results have been developed by utilizing a vane shear device that has a very long shaft that can be successively pushed depeer into the sample. Also, the results have been determined by successively cutting the end of the steel sampling tubes and running the vane shear tests. Similar effects take place across the cross-section of the samples as shown in Fig. 14.

Obviously, it is important to recognize how the vane shear tests have been performed, for there are large potential effects on the characterization of the inplace or in-situ strength strength of the soils.

A third important source of disturbance is that due to stress relief. This stress relief effect is due primarily to expansion or free and dissolved gases in the soils (18,42). As the samples are brought up to the sea surface, there is a substantial reduction in the effective pressure acting on the soil. Upon sample extrusion, dissolved and free gases expanc and distort the fabric of the soil. Strength reductions result.

One approach to compensate for such stress relief effects is that of high pressure triaxial testing. In such tests, high total pressures and pore water back pressures are utilized to recompress the gases to a volume about equal to that in-situ. Samples are allowed to age so that significant thixotropic effects can assist in mending the fabric bonds broken by sample retrieval, extrusion, and re-compression.

Results of such tests on Delta clays are summarized in Fig. 15 (17). Soil shear strength (C) is plotted versus the Liquidity Index (LI) of the soil. The Liquidity Index is a normalized water content (water content (W) - Plastic Limit (W_p) / Liquid Limit (W_L) - Plastic Limit). The natural water content and the Liquid and Plastic Limits are soil properties that are not sensitive to disturbance effects, even though they may contain errors due to soil inhomogeneities, porewater migration, and operator technique.

In this boring, due to disturbance of the samples in the upper 50 to 60 ft by the drilling, and gas relief effects in the deeper soils, the correlation of strength to Liquidity Index was utilized to estimate in-situ shear strength (31). Results of this estimation and results of using the vane shear strengths corrected for their location in the sample tubes are indicated in Fig. 16. The soils are inferred to be significantly stronger than originally determined from the conventional sampling and testing data.

ANALYTICAL

A large number of sophisticated analytical models have been developed to assist in evaluating seafloor stability. These models fall into three general classes: (1) Limit Equilibrium, (2) Finite Element, and (3) Layered Continua. The slip-circle analysis previously described falls into the first class. The finite element analyses developed by Wright (43,44) and others (3,6,26) fall into the second class. An example of the most recent development, layered continua analyses, has been published by Schapery and Dunlap (33,34). All three of these classes of analyses recently have been reviewed and their results compared (11).

In an early paper dealing with physical modeling of the wave-bottom interaction phenomena, Doyle (16) suggested use of an elastic continuum analysis. For a given amplitude of pressure (ΔP) at the seafloor, the maximum shear stress (τ_e) induced in the elastic medium can be computed from the following expression (16):

$$\tau_e = 2\pi\, Z/L \exp(-2\pi\, Z/L)\ \Delta P \quad \ldots\ldots\ldots\ldots (1)$$

where Z is the depth into the medium and L is the wave length.

The shear stress normalized by the pressure amplitude ($\tau_e/\Delta P$) plotted versus the depth into the medium normalized by the wave length (Z/L) is given in Fig. 17. The peak shear stress occurs at a depth equal to 16 percent of the wave length. The peak shear stress is equal to about 37 percent of the bottom pressure amplitude. For example, a wave height and period producing a bottom pressure amplitude of 1000 psf with a wave length of 1000 ft, would produce a peak shear stress in the soil of 370 psf at a depth of 160 ft.

These stress conditions are appropriate for elastic media. Under intense wave excitation, significant amounts of inelastic action develop in the soils. Such inelasticity would lead to a reduction in stresses as indicated by the elastic analyses.

To recognize the effects of inelasticity in reducing the shear stresses induced in the soils, finite element analyses (11,44) have been performed in which the constitutive relationships for the soils were determined for high strain behavior (from results of laboratory tests (3,17)). Soil response was analyzed for intense wave action, or high bottom pressures. The results of these analyses are summarized in Fig. 18.

The maximum shear stress induced in the soil (τmax) is plotted versus the wave pressure amplitude. The data points are from the finite element analyses in which different characterizations of soil strength and stiffness (recognizing dynamic and cyclic effects) were used. The inclined lines through these points are for various values of a Plasticity Factor (PF) that were used to modify computed elastic stresses so that they would approximate results from the complex inelastic finite element analyses.

The Plasticity Factors are simply empirical constants. Thus, one computes the shear stress from equation (1) and multiplies the results by Plasticity Factors in the range of 0.6 to 0.7. This enables a simple analysis of soil response that involves significant amounts of inelastic and nonlinear behavior.

The results of applying the foregoing simplified analysis to the example platform site are given in Fig. 19. The elastic stresses from Equation (1) have been modified by Plasticity Factors in the range of 0.7 to 0.6. The soils are indicated to be stable. The shear stresses induced by the criteria wave pressures are less than the in-situ soil shear strength.

STRUCTURE PERFORMANCE

Platforms and pipelines have been installed in the Mississippi River Delta since the 1950's. There are in excess of 500 platforms and many hundreds of miles of pipelines installed in this area. In general, the performance of these structures has been satisfactory (10). The soil movement associated failures that have occurred have been cases in which conventional platforms were unknowingly or inadvertently installed in the direct path of active slides or across active growth faults (5,10,11,36). Similar statements can be made concerning pipelines, with the exception that smaller features, such as collapse depressions, can lead to loss of support and subsequent fatigue failures (4,9).

Figure 20 locates 29 conventional platforms in the general vicinity of West Delta (in water depths greater than 60 ft). These platforms were installed in the West Delta area prior to Hurricane Betsy (9-9-65) and were in place during Hurricane Camille (8-17-69). Structures installed after Camille have not been shown. One platform (West Delta Block 133 A) suffered damage from a floating semisubmersible that broke its moorings in the midst of a salvage operation.

It is important to note that all of these platforms were conventional structures designed for deep water wave heights in the range of 55 to 60 ft. The deep water (>200 to 300 ft) platforms experienced wave heights of 50 to 60 ft in Betsy and 45 to 55 ft in Camille (7,27). Soil conditions in this area are generally similar (21). If the soils were going to move and exert significant forces on the platforms, then the structures would have indicated the effects. None of the platforms indicated any such effects.

These data imply that a conventionally designed platform (2) in this area has sufficient inherent strength to survive such hurricanes, even if soil movements have occurred during these events. This anomaly apparently is due to conservative wave force formulations and significant reserve strength in the platforms (7,11,27). It is likely that the 55 to 60-ft design waves cannot propagate into shallow water due to the wave-bottom interactions. Also, it is likely that the soils have moved significant amounts at least to depths of the order of 20 to 30 ft. Thus, the platforms and foundations have been designed to incorporate sufficient strength and ve been able to withstand the storm waves and bottom vements.

CONCLUSIONS

This paper has illustrated a simplified, yet realistic, method to evaluate seafloor stability. The paper has highlighted two key elements which, if treated conventionally, can lead to overconservatisms in the prediction of seafloor instabilities: evaluation of in-situ soil shear strength and evaluation of shallow water hurricane wave heights. In the example cited in this paper, the conventional treatment of these two elements leads to an evalution that the seafloor will be unstable during criteria conditions. However, when perceptive evaluations are made of the drilling, sampling, and testing factors that act to lower the measured shear strength, and when recognition is given to the wave attenuating effects of bottom motions, then the evaluation is that the seafloor will be stable during criteria level conditions. Platform and pipeline experience during criteria level conditions is used to calibrate and justify such conclusions.

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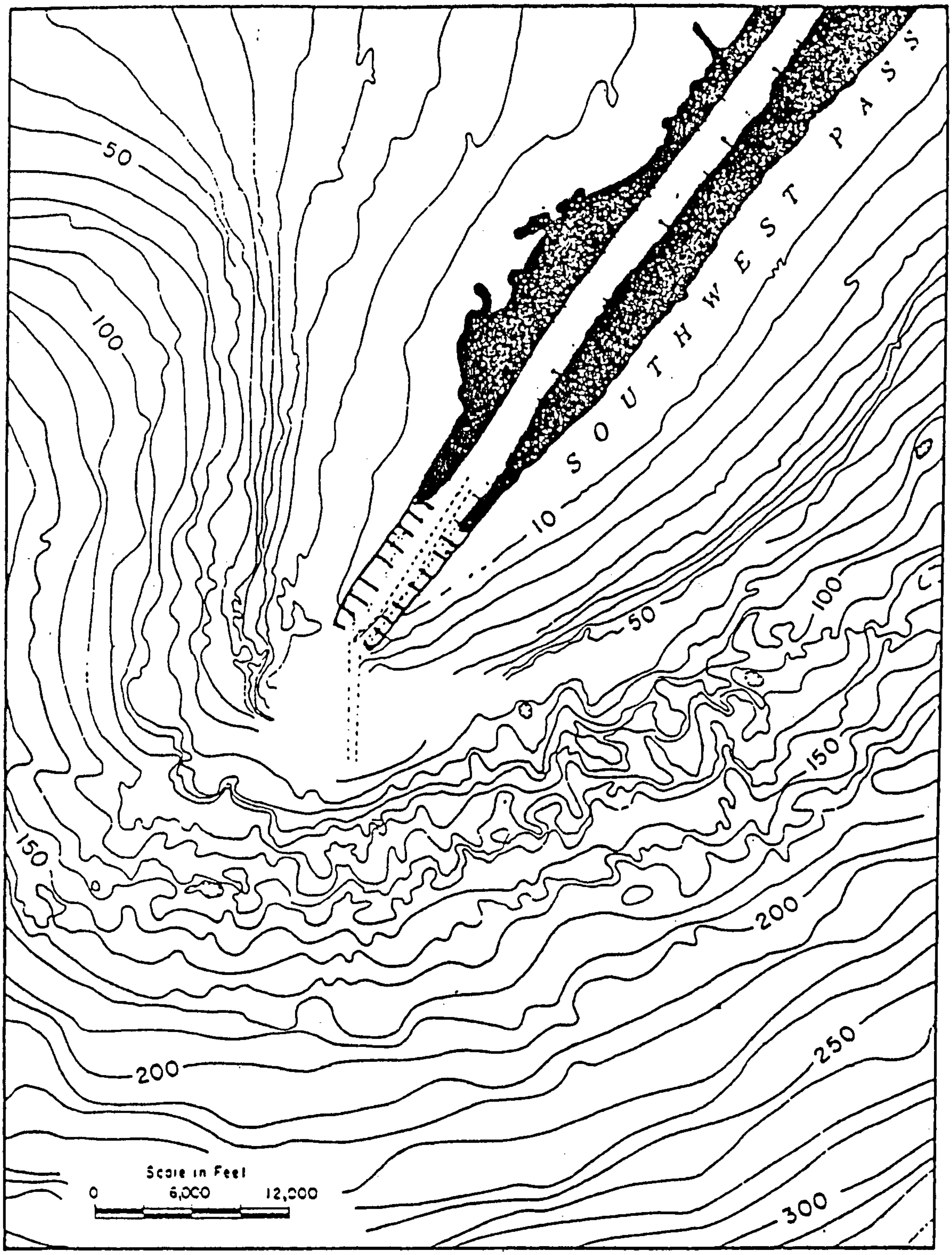

Fig. 1 - BATHYMETRY IN VICINITY OF SOUTHWEST PASS, MISSISSIPPI RIVER DELTA.

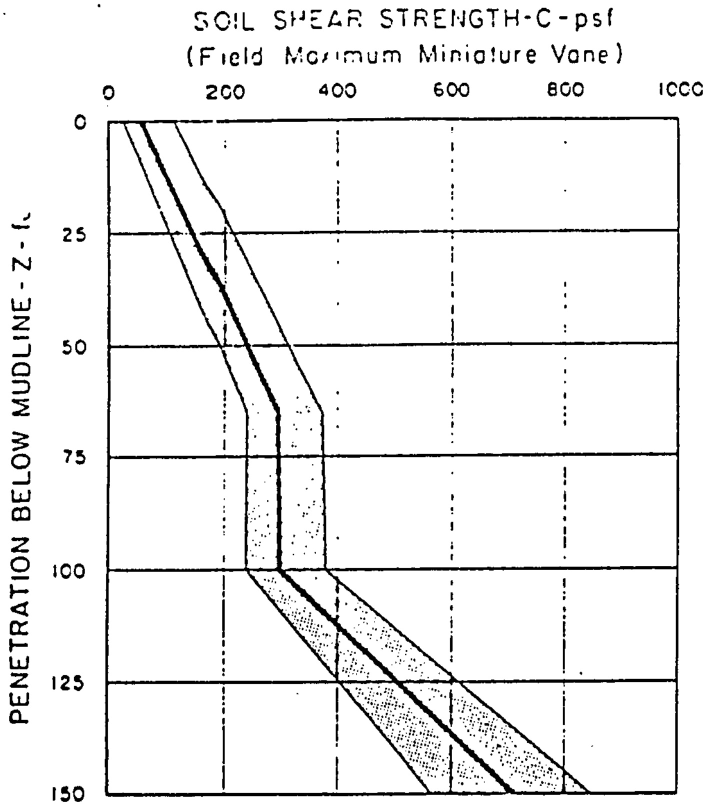

Fig. 2 - SOIL SHEAR STRENGTH FROM CONVENTIONAL ANALYSIS FOR PLATFORM SITE.

C

p↑ slide depth ↑

T↑ L↑ slide depth ↑

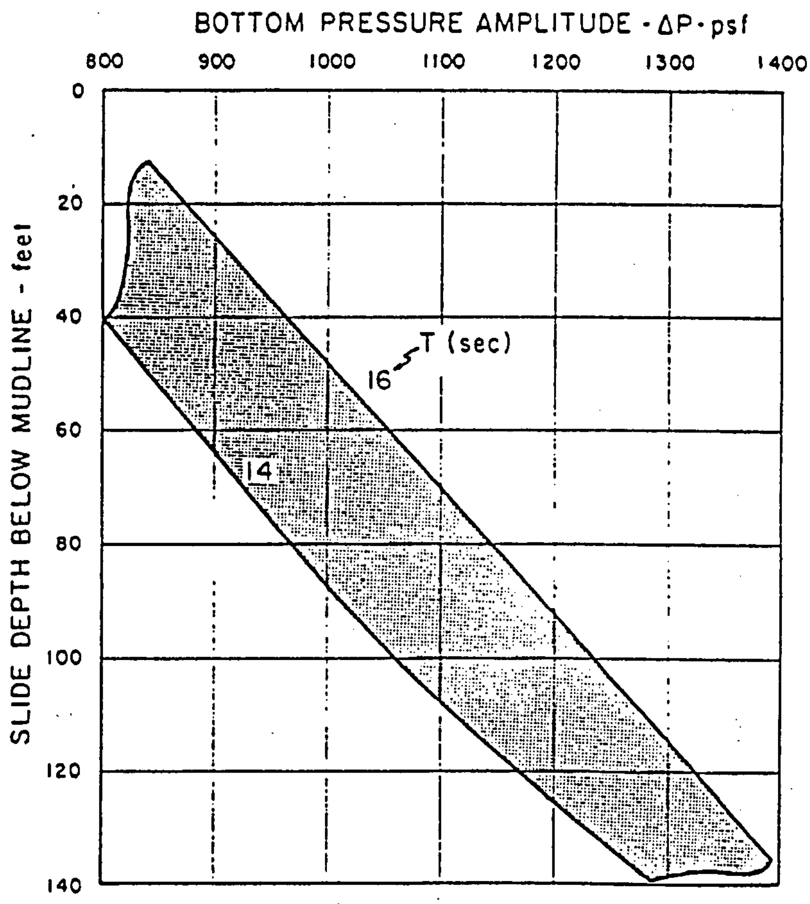

Fig. 3 - SLIDE DEPTHS DETERMINED FROM LIMIT EQUILIBRIUM ANALYSES.

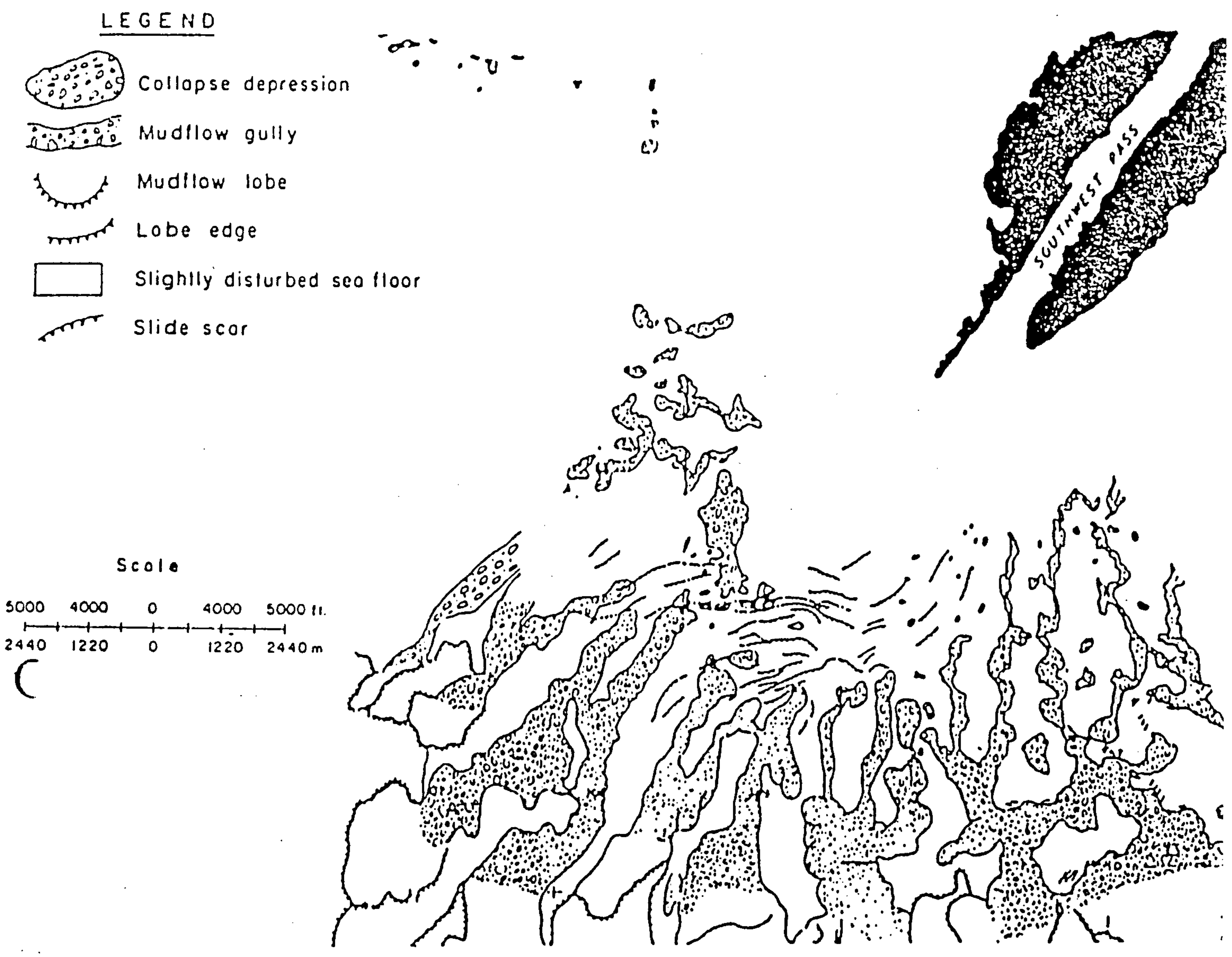

Fig. 4 - SEAFLOOR FEATURES IN VICINITY OF SOUTHWEST PASS.

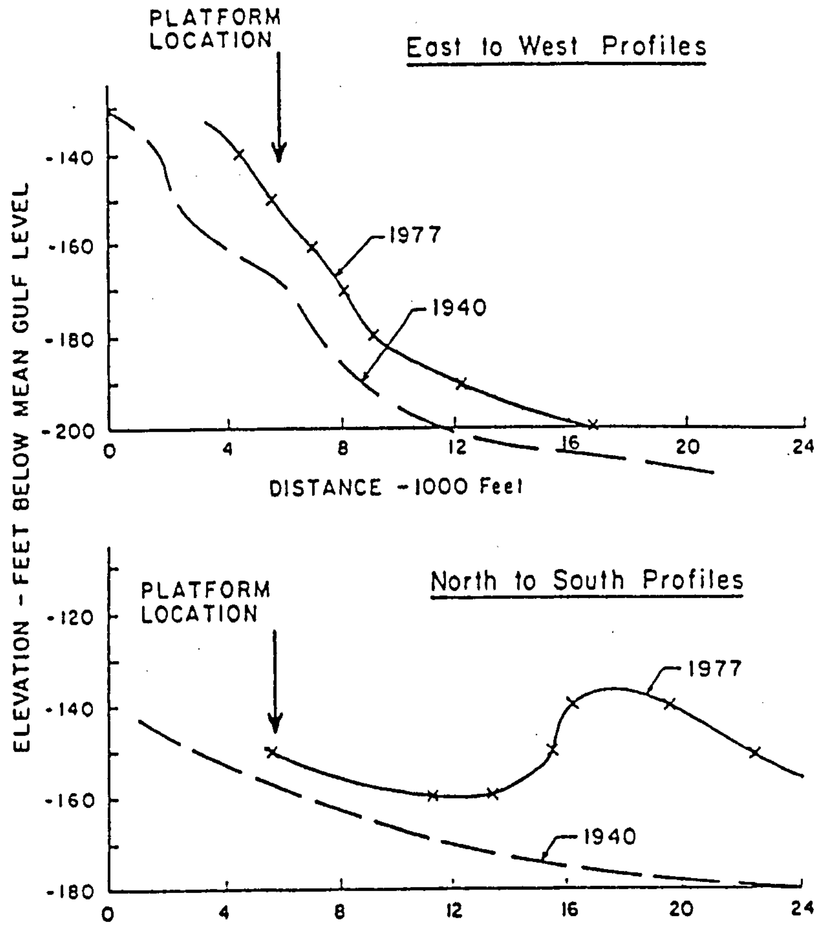

Fig. 5 - CHANGES IN IN-WATER DEPTH AT PLATFORM SITE, 1940-1977.

INSTITUTE OF HYDRODYNAMICS AND HYDRAULIC ENGINEERING
TECHNICAL UNIVERSITY OF DENMARK
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THE INTERACTION BETWEEN A PIPELINE AND AN ERODIBLE BED

by

Ye Mao

March, 1986

JJ trykteknik a-s, København

PREFACE

The present report is part of the requirements for the Degree of Licentiatus Technices according to the notice of February 18th, 1981 from the Danish Ministry of Education.

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Lyngby, March, 1986.

Ye Mao

RESUME (in Danish)

Denne afhandling omhandler vekselvirkningen mellem en rørledning og en erodérbar bund.

Først studeres erosionen under en rørledning udsat for strømmende vand i én retning. Erosionsmønstret sammenlignes med en teoretisk hydrodynamisk model, hvor strømningen beskrives ved hjælp af potentialteori. Den tidslige udvikling beregnes ved hjælp af en sedimenttransportformel kombineret med kontinuitetsligningen for sediment. Denne 2-dimensionale model udvides i kapitel 3 til også at give visse ideer om 3-dimensionale erosionshuller under rørledninger. Dette baseres kraftigt på hypotesen, at erosionen standser det dybeste sted, når rørledningen rører bunden.

Betydningen af hvirvelafløsning nedstrøms en rørledning på udstrækningen og dimensionen af erosionshullet er studeret i kapitel 4. Det vises at hvirvelafløsningen øger erosionshullets dimensioner.

I kapitel 5 studeres betydningen af, at strømningen skrifter retning med tiden (tidevand, bølger). Herved bliver erosionsdybden betydelig større end i strømtilfældet, da den store nedstrøms erosion nu finder sted på begge sider af rørledningen.

Endelig er vekselvirkningen mellem et vibrerende rør og en erodérbar bund undersøgt i kapitel 6: på grund af rørets vibrationer kan langt mere sediment nu bringes i opslemning, hvorfor erosionen øges. På den anden side vises det, at tilstedeværelsen af et erosionshul i visse tilfælde mindsker risikoen for at røret vibrerer.

ABSTRACT

The interaction between a pipeline and an erodible bed has been studied. The thesis consists of six chapters on five topics.

In chapter 2, the two-dimensional scour under a fixed pipe in current is studied. First, the on-set of the scour in the case when a fixed pipe is resting on a plane bed has been studied. Then, based on a modified potential flow theory, a mathematical model on the scour underneath pipelines has been proposed. By calculating the flow state in the scour hole and applying the sediment continuity equation, the final equilibrium bed profile in the two-dimensional flow can be calculated. The theory is confirmed by present experiments. It is found from experiments that the scour process can be split up into the jet period and the wake period. The scour rate is very high at the early stage. In the equilibrium state, the velocities along the bed surface were similar. The bigger the initial gap, the shallower the scour depth. The equilibrium scour depth is a weak function of the Shields parameter θ_∞, and it is less than the diameter of the pipe.

In chapter 3, a simplified physical model on the three-dimensional scour in a current has been proposed. The sagging of the pipeline plays the key role in the development of the three-dimensional scour. The scour depth is slightly deeper than that in the fixed-pipe case. A formula to estimate the maximum length of the span is proposed, and a numerical example is given.

In chapter 4, the role of the vortex shedding in the scour below pipelines has been investigated. It is demonstrated by experiments that the vortex shedding exists from quite early stages of the scour process, it may result in substantial scour downstream the pipe. A fluctuating velocity field is induced by the vortices shed from the lower edge of the pipe. In the near-wake bed region ($1 \lesssim x/D \lesssim 8$), the magnitude of the vortex-induced velocity remains approximately constant along the bed. A

simple model has been developed to predict the vortex-induced near-bed velocity.

In chapter 5, the scour under pipelines exposed to two-directional flow is studied. In the presence of the sand waves, the pipe fixes the trough of the sand waves in its neighbourhood. The wake-induced erosion plays a significant role in the two-directional-flow case. The scour depth is deeper than that in the current case. In the high sediment transport stage, the scour depth under the pipe may be several times the pipe diameter. The scour depth in the sagging case is shallower due to the shelter of the upstream hill and the sinking of the pipe in the scour hole.

In chapter 6, the interaction between the pipe vibration and an erodible bed is investigated. First, the influence of the pipe vibration on the scour below the pipe is studied. The influence of pipe vibration on the flow structure around the pipe is found to be significant, resulting in high scour rate and much deeper scour depth. A relatively small gap caused a relatively deep scour hole and the pipeline may impact on the scour hole. In the vicinity of an eroded bed the pipe is exposed to a negative lift force. The water body in the scour hole gives resistance to the pipe vibration. The pipe state with respect to the pipe vibration can be classified into three stages: the pre-vibration stage, the lock-in stage and the lock-out stage. The eroded bed has strong restrictive action on the pipe vibration. The problems in the two-directional flow and in the sagged-pipe case have been studied too.

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CHAPTER 1

INTRODUCTION

Pipelines play an important role in the exploitation of ocean resources, and therefore they have drawn special attention for some years. It is very convenient to transport oil, gas and granular materials by pipelines along the sea bottom. Countless pipelines have been laid on the seabed. Certainly more and more pipelines will be laid from now on.

The seabed is composed of different materials. A large part of the seabed may be covered by loose sediment, and pipelines may be exposed to unidirectional flow, to waves, tide or the combinations of them, resulting in the development of scour.

During the development of the scour hole under the pipeline, the stress inside the wall of the pipe increases due to the sagging of the pipe, and the suspended part of the pipe may vibrate seriously. Pipelines can be damaged due to overstress or fatigue. An understanding of the scour mechanism is important in relation to the self-burial of pipelines.

In short, the research concerning the pipeline - loose bed interaction is of fundamental interest as well as being important in the offshore engineering applications.

1.1 <u>Previous research on scour around pipes</u>

The scour around structures is one of the important fields in hydraulic engineering. One of the classical problems is the prediction of the scour around a vertical cylinder placed in a loose bed like a river bed. Though this problem is of extreme importance for the safety of bridges crossing the rivers, this problem is still not solved theoretically in a satisfactory way. Good reviews on the state of the art are given by Hjort [11] and Breusers et al. [4].

The reason for the problem not being solved yet is the highly complex three-dimensional turbulence flow pattern including the so-called horseshoe vortex around the cylinder just above the bed.

In 1971, Posey published "Protection of offshore structure against underscour" [19], where he tried to understand the phenomena concerned. A field study on scour under pipelines in a region dominated by tidal flow was reported by Littlejohns in 1973 [16].

Kjeldsen et al. (1973) [12] summarized their experiments with 0.5 m diameter pipe in a current giving a formula to calculate the final equilibrium scour depth S_m in the current:

$$S_m = 0.972\left(\frac{U_\infty^2}{2g}\right)^{0.20} D^{0.80} \qquad (1.1)$$

in which U_∞ is the undisturbed velocity;
D is the diameter of the pipe;
g is the acceleration of gravity.

Chao and Hennessy made an attempt to describe the scour process using the potential flow theory for a cylinder placed above a plane bed (1972) [5].

Recently, Bijker, Leeuwestein et al. tried to calculate the scour depth by application of a turbulence model [15, 16].

1.2 The related research

A related problem to the scour process is the self-burial of pipelines. This phenomenon takes place because the pipe partly or totally sags into the scour hole, whereby it will be partly or totally covered by sediment. This problem has recently been investigated in a descriptive and experimental way by Hulsbergen [12].

Some related papers which are not directly treating the scour process, but rather the flow around a pipe in the vicinity of a plane bed have recently been published [1], [7], and [8]. The flow pattern around the pipe, the lift forces and the vibration of the pipeline described in these papers shed some light on the understanding of the interaction between the pipeline and the loose bed. [illegible]

1.3 The scope of the present study

The aim of the present work is to promote the understanding of the interaction between the pipeline and the loose bed, including the scour under the pipeline and the vibration of the pipeline.

First, the scour under a pipe in unidirectional flow is studied. A mathematical model using a modified potential flow theory is presented in chapter 2. Serial experimental results are compared with the theoretical results.

In chapter 3, a simplified physical model is proposed. The sagging phenomenon is considered to be the key point of the three-dimensional scour. A method to estimate the final span length of the scour hole is proposed.

Chapter 4 concerns the effect of the lee-side wake, which is considered to be the most important factor causing the discrepancy between the tests and the potential theory.

Because a pipeline laid on a seabed may be exposed to waves and tide, the scour problem in such a two-directional-flow case is studied in chapter 5. The scour tests with a high Shields parameter's value in an oscillatory flume correspond to the situations in stormy weather. Some experiments with the sagged pipe were carried out in the two-directional flow.

Up to now, to the author's knowledge no paper exists yet about the interaction between the vibrating pipe and the scour under the pipe, so in chapter 6 the action of the vibrating pipe on the scour and the eroded bed on the behaviour of the pipe are studied respectively. Furthermore, the interaction in the sagging process is discussed too.

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CHAPTER 2

TWO-DIMENSIONAL SCOUR UNDER A FIXED PIPE IN A CURRENT

2.1 Introduction

In this chapter, the study is limited to a steady unidirectional flow, i.e. in a current. The seabed is assumed to be a loose bed. Only two-dimensional scour underneath the pipeline is discussed.

First, the onset of scour underneath a pipe resting on a plane bed is discussed. Then, a mathematical model is presented. At last the tests are analysed.

2.2 Onset of scour

If a pipe is resting on a plane bed, and there is no opening at all, will scour then take place under the pipe? The solution to the interesting problem may help us to understand the scour phenomenon.

2.2.1 The flow pattern in the surrounding of the pipe

If a pipe is resting on a plane bed, the uniformly distributed flow field is disturbed by the presence of the pipe. The flow has to adjust its state to pass the pipe.

Fig. 2.1 shows the velocity profiles in different vertical sections along the stream.

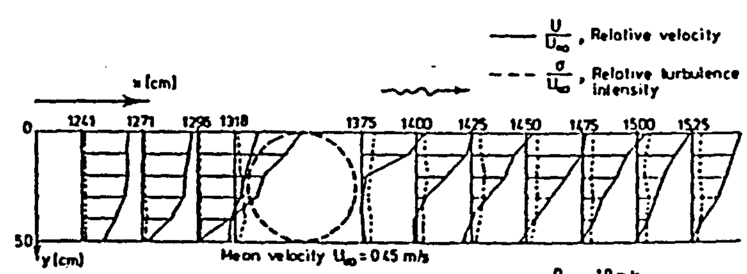

Fig. 2.1 Flow state around a pipe resting on a plane bed.

From the flow velocity distribution three vortices were found. The first vortex A was in front of the pipe and the flow close to the bed is upwards. Next, when flow passes the pipe, there was a big vortex B behind the pipe. At last, a small vortex C was at the corner downstream the pipe.

The author's observations are sketched in Fig. 2.4 (a).

2.2.2. Pressure distribution on the bed and ground water flow

Along the bed, the local pressure P at a point could be compared with the pressure on the bed far away from the pipe, P_∞, by defining the relative pressure coefficient C_p as

$$C_p = \frac{(P-P_\infty)/\gamma}{U_\infty^2/2g}, \qquad (2\text{-}1)$$

in which γ is the specific gravity of the liquid.

U_∞ is the mean velocity well upstream from the pipe.

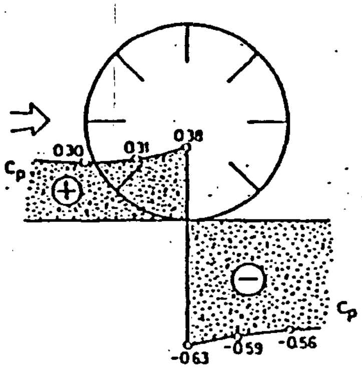

Fig. 2.2 Variation in the pressure coefficient in the neighborhood of the pipe (After ref. [1]).

Fig. 2.2 shows the distribution of C_p near the pipe, measured by Bearman and Zdravkovich [1].

It is very clear that the pipe resting on the bed almost stops the flow close to the bed. The pressure makes a big jump around the footing of the pipe, $\Delta C_p = 1$. (In the wave case, due to the reverse of the flow direction, $\Delta C_p = 3$. Cf [9]).

Because the bed is composed of loose material, the pressure difference results in ground water flow (see Fig. 2.3).

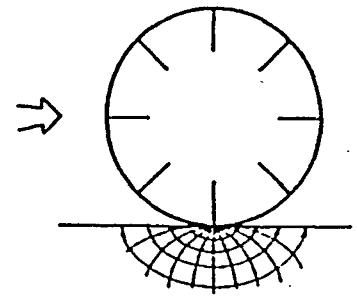

Fig. 2.3 Sketch of the ground water flow.

It is known that the velocity of ground water flow

is $$U_{under} = K\, i \qquad (2.2)$$

in which K is the permeability coefficient.

Designating ΔH as the head loss and L as the flow line length, the slope of head loss reads

$$i = \Delta H/L \qquad (2.3)$$

By inserting Eq. (2.3) into Eq. (2.2), we get

$$U_{under} = \frac{K\,\Delta H}{L}, \qquad (2.4)$$

Equation (2.4) suggests that the ground water flow has maximum velocity around the footing. But, because the permeability coefficient is rather small (for example, for fine sand $K = 10^{-3} \sim 6\times10^{-3}$ cm/s), the velocity U_{under} is generally too small to move sand particles.

Although ground water flow may not move downstream particles away directly, it gives a lift force on these particles reducing their specific density. Because the stability is reduced, those particles are easily moved away.

2.2.3 Sediment bed movement near the pipe

Along a plane bed, the Bernouilli equation reads

$$\frac{P_\infty}{\gamma} + \frac{U_\infty^2}{2g} = \frac{P}{\gamma} + \frac{U^2}{2g} \qquad (2.5)$$

By inserting Eq. (2.1). Eq. (2.5) is recast as

$$U/U_\infty = \sqrt{1-C_p} \qquad (2.6)$$

It means that in the place where $C_p < 0$, the local velocity U may be high enough to move sand particles in the potential flow region.

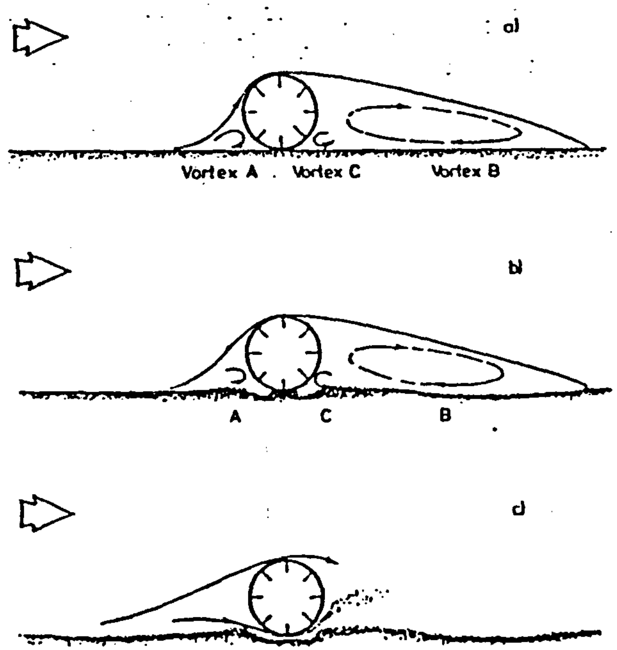

Fig. 2.4 Sketch of the onset process

As shown in Fig. 2.4 (b) the three vortices move sand particles along the bed. Both vortex A and vortex C move sand particles away from the footing area, but their directions of movement are opposite to each other. On the other hand, vortex B moves sand towards the pipe. Even though vortex B may be quite strong, its acting area is limited by the vortex C.

Due to the combined action of vortices and the underflow, a small opening is created under the pipe. This is the onset of scour (see Fig. 2.4 c).

Plate 2.1 shows the process of the onset, while θ_∞ = 0.048. When it has started, the scour develops quickly along the direction of the pipe axis.

2.2.4 Conclusions

On the basis of observation and analysis, the conclusion can be drawn as follows:

Provided that the fixed pipe is resting on the bed, and the undisturbed flow velocity is not too small, the scour underneath the pipe is inevitable.

The onset process depends on undisturbed velocity. The bigger the velocity, the quicker the onset process.

For a buried pipe, if it is not embedded too deeply, a similar onset will happen.

2.3 A mathematical model on the scour underneath pipelines

2.3.1 Introduction

The purpose of the present investigation is to develop a mathematical model for the scour process under pipelines. The idea is to apply a modified potential flow theory in order to calculate the flow state around a pipe placed near a loose bed, and using this information along with the sediment continuity equation to calculate the variation of the bed surface, and then, to get the equilibrium bed profile.

A. Background

The flow state around a pipe can be split up into two different parts: the upstream part and the downstream part (see Fig. 2.5).

In the upstream part, the viscosity of the fluid does not play an important role. On the top and bottom of the pipe there are flow separations forming a wake. The downstream flow is controlled by the wake, therefore the viscosity of fluid must be

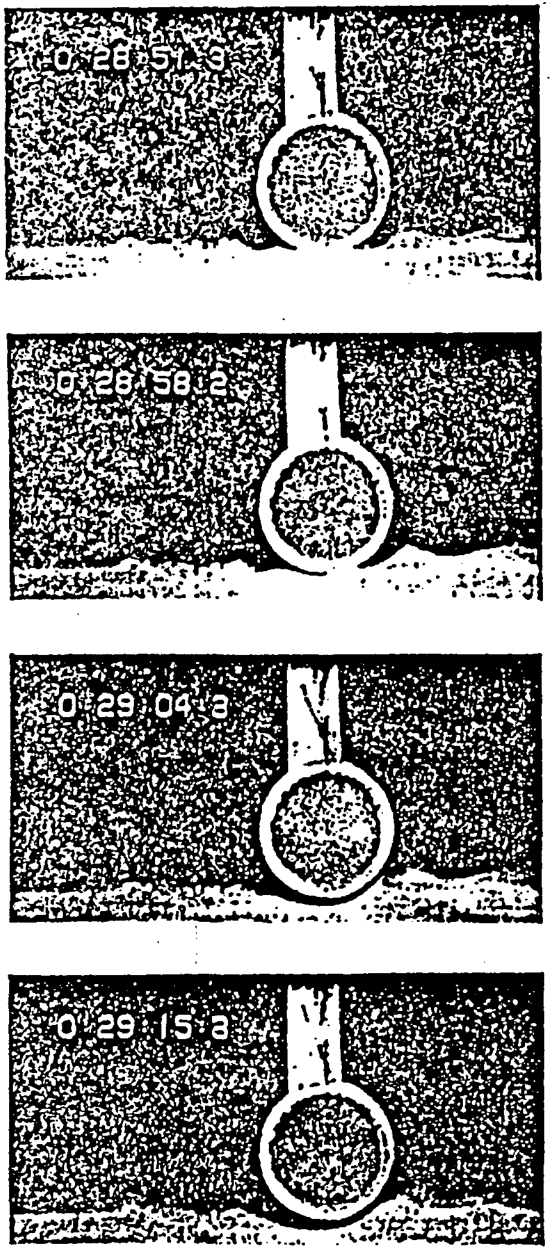

Plate 2.1 Process of onset, while $\theta_\infty = 0.048$.

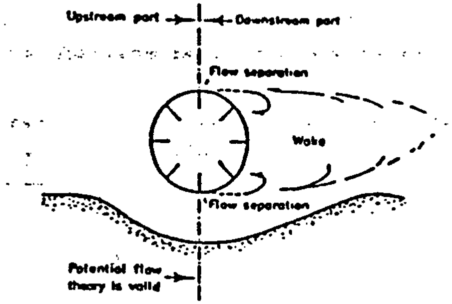

Fig. 2.5 Sketch of flow state and the valid region of potential flow theory

considered. The influence of the wake on the upstream part is rather moderate. For engineering purposes one of the major items of interest is the depth of scour just below the pipe. However, this downstream wake has only minor influence on the flow just below the pipe.

Fig. 2.6 shows the Hele-Shaw flow around a cylinder with differently eroded bed profiles. In the development of scour, while the bed profile was changing, the flow state around the pipe was varying too. Fig. 2.6 shows that the potential flow describes the upstream part satisfactorily.

B. Potential flow around a cylinder placed near a plane bed

The complex coordinate is defined as

$$z = x + iy, \tag{2-7}$$

where i is the imaginary unit.

So the complex potential ω is the function of z.

$$\omega = \omega(z) \tag{2-8}$$

ω is composed of the real part ϕ and the imaginary part ψ. Both are the function of the variables x and y:

$$\omega = \phi(x,y) + i\psi(x,y) \tag{2-9}$$

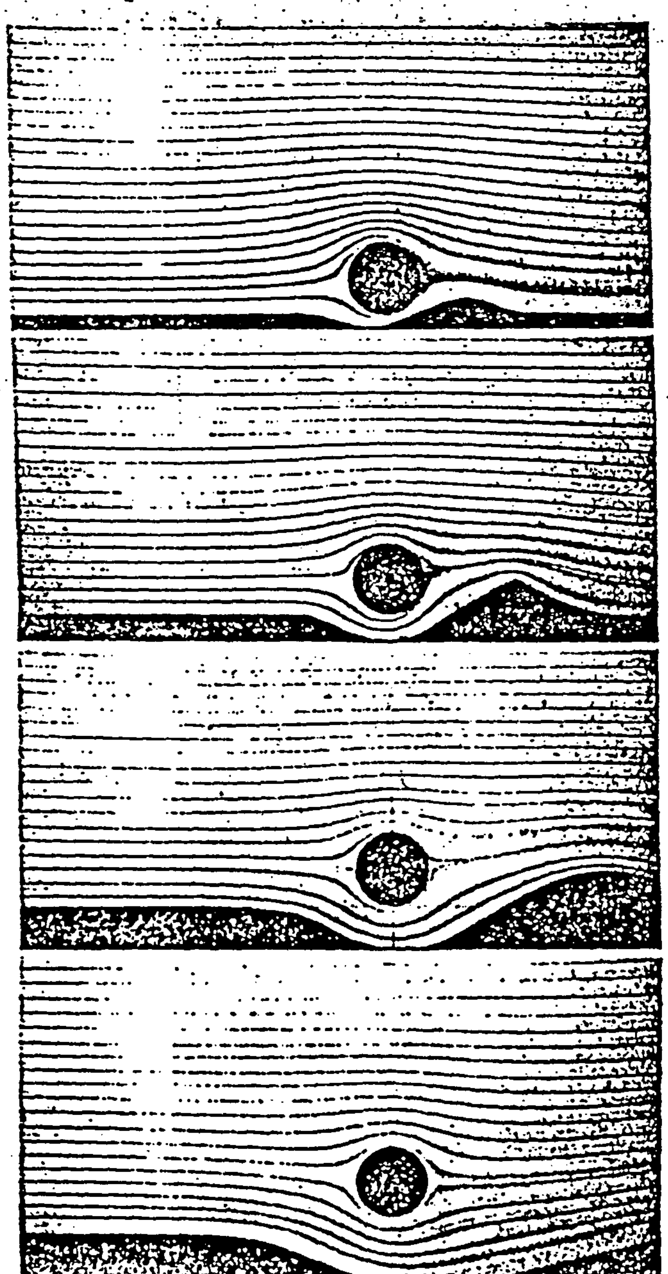

Fig. 2.6 Hele-Shaw flow past a cylinder close to an eroded bed.

The derivative of the complex potential ω is called the complex velocity, which describes the flow field.

$$\frac{d\omega}{dz} = \frac{\partial \phi}{\partial x} + i\frac{\partial \phi}{\partial x} = u - iv \tag{2.10}$$

in which u is the x-directional component of velocity; v is the y-directional component of velocity.

Suppose a pipe with a diameter D is placed close to a plane bed, the distance between the pipe centre and the plane is 'a', and the flow velocity far away from the pipe is U_∞. Von Müller (1927) [13] described the potential flow around the cylinder with dipoles. The complex potential ω_1 could be expressed as

$$\omega_1 = -U_\infty z - \sum_{j=0}^{\infty} \left(\frac{m_j}{(z-z_j)} + \frac{m_j}{(z-\bar{z}_j)}\right), \tag{2-11}$$

where

$$\left.\begin{aligned} m_0 &= U_\infty \frac{D^2}{4} \\ m_{j+1} &= m_j \frac{D^2}{4(2a-Y_j)^2}\ ; \quad Y_0 = a \\ Y_{j+1} &= a - \frac{D^2}{8(2a-Y_j)} \\ z_j &= iY_j \end{aligned}\right\} \tag{2-12}$$

The theory [11] suggested that the velocity below the pipe, U_{bottom}, (for definition, see Fig. 2.8) is predicted to be larger than the velocity above the pipe, U_{top}. Both velocities are larger than the far field flow velocity U_∞.

In real flow, separation takes place downstream the pipe, which modifies the near pipe flow pattern upstream as well as downstream the pipe. In the wake, the pressure is nearly constant, as it is experimentally verified by Bearman and Zdavkovich [1]. Because flow separation takes place close to the top (T) and the bottom (B), see Fig. 2.8, the upstream part of the flow is modified, so U_{top} and U_{bottom} become nearly the same. This is because the

The solution suggested by Von Müller has been modified by Fredsøe and Asp Hansen [5]. They superposed a vortex body on the potential flow. This modified potential solution is shown as

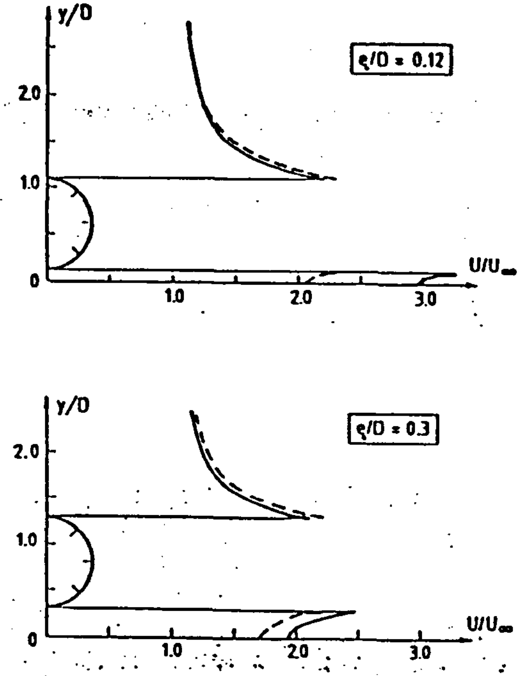

Fig. 2.7 Longitudinal flow velocity along a vertical axis through a pipe center. ——: potential theory, ref. [12]. ---: modified potential theory, ref. [5].

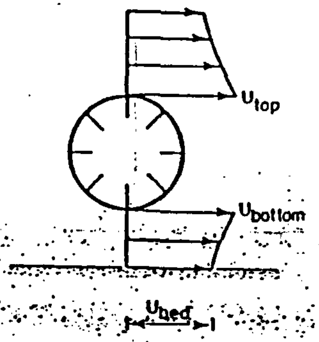

Fig. 2.8 Definition sketch of U_{top}, U_{bottom} and U_{bed}.

dashed lines in Fig. 2.7. The modification is especially significant at a small gap ratio.

Fig. 2.9 shows the variation in U_{bed}/U_∞ with the dimensionless gap ratio obtained from ref. [5]. U_{bed} is always predicted to be larger than U_∞ independent of the gap ratio. Although some sediments are supplied by the flow upstream the pipe, more sediment is moved away continuously below the pipe. It means that the scour depth will be infinite.

In this section, governing equation of the scour process and the requirement about the equilibrium state in sediment transport are discussed. The potential flow theory is improved further to suit the loose boundary.

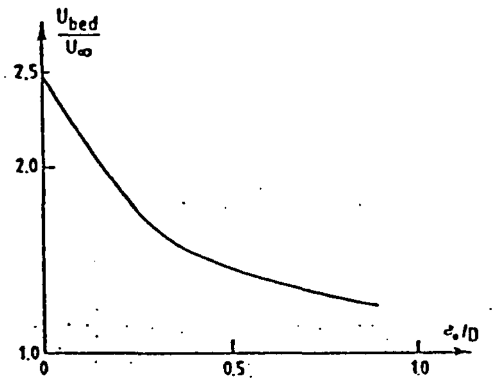

Fig. 2.9 Variation in U_{bed}/U_∞ with gap ratio for a pipe placed above a plane bed.

2.3.2 Sediment transport and scour under the pipe

A. Scour and its governing equation

In two-dimensional flow, the scour is caused by the variation in the sediment transport rate along the stream direction.

In the presence of a pipe, the flow accelerates under the pipe, enhancing its ability to move sediment away.

Especially in the clear-water-scour case, the supply rate of sediment equals zero. It means that the scour underneath the pipe is caused only by local increase of flow velocity.

After onset, the scour continues until it reaches its equilibrium state.

It is possible to get a governing equation of scour at a point. If the scour state at every point at any moment is known, the scour process of the whole bed is determined.

Fig. 2.10 is the definition sketch of the pipe position and the geometry of a scour hole. The initial gap between the pipe and the original plane bed is e_0. The elevation coordinate h originates from the horizontal x-axis.

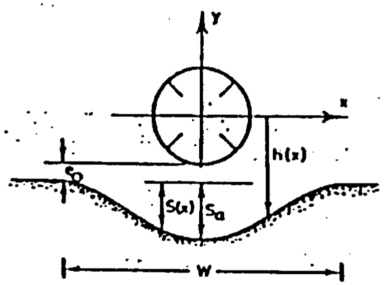

Fig. 2.10 Definition sketch of the scour hole.

The sediment continuity equation is the governing equation of scour for a point. In the case that bed load is dominant, it reads

$$\frac{\partial q}{\partial x} + (1-n)\frac{\partial h}{\partial t} = 0 \qquad (2.13)$$

where n is the porosity of sediment, n = 0.4;

t is the time;

and q is the bed load transport rate in volume.

At any moment the variation in elevation could be calculated from Eq. (2.13). It reads

$$\frac{\partial h}{\partial t} = - \frac{\partial q}{\partial x} / (1-n), \qquad (2.14)$$

In the case of scour, the erosion rate is higher than the supply rate, it is $\partial q/\partial x > 0$, so $\partial h/\partial t < 0$, which means that the bed elevation is decreasing.

In the equilibrium state, the bed level does not change,

$$\frac{\partial h}{\partial t} = 0, \qquad (2.15)$$

which suggests that the essential condition is

$$\frac{\partial q}{\partial x} = 0 \quad \text{or } q = \text{const.} \qquad (2\text{-}15)$$

B. Dimensionless form of the governing equation

The sediment continuity equation could be changed into a dimensionless form as shown in the following:

Comparing other geometrical parameters, the diameter of the pipe is more characteristic, so the geometrical properties are made dimensionless with the pipe diameter D:

$$x^* = x/D$$
$$h^* = h/D \qquad (2.16)$$

The sediment transport is non-dimensionalized with the far field rate of sediment transport q_∞

$$q^* = q/q_\infty \qquad (2.17)$$

By inserting Eqs. (2.16) and (2.17), Eq. (2-13) is recast as

$$\frac{\partial(\frac{q}{q_\infty})}{\partial(\frac{x}{D})} = - \frac{D^2}{q_\infty} \frac{(1-n)}{t_0} \frac{\partial(\frac{h}{D})}{\partial(\frac{t}{t_0})}, \qquad (2.18)$$

It is convenient to define a time parameter t_0 as

$$t_0 = \frac{D^2}{q_\infty} (1-n) \qquad (2.19)$$

whereby Eq. (2.13) can be written as

$$\frac{\partial q^*}{\partial x^*} = -\frac{\partial h^*}{\partial t^*}, \qquad (2.20)$$

where the dimensionless time t^*

$$t^* = t/t_0 \qquad (2.21)$$

C. The calculation of sediment transport rate

Generally, sediment transport loads are divided into bed load and suspended load. In the following only bed load is considered. In that case sediment particles are rolling, sliding or jumping along the bed.

The action of flow on the bed is measured by shear stress τ_b, which could be expressed as a dimensionless form. It is the so-called Shields parameter θ,

$$\theta = \frac{\tau_b}{\rho g(s-1)d_{50}} , \quad (2.22)$$

where ρ = density of water, s = relative density of sediment, d_{50} = mean grain diameter.

The value of θ at far field is called θ_∞.

The sediment transport rate q could be expressed as a dimensionless form ϕ, which is defined as

$$\phi = \frac{q}{\sqrt{g(s-1)d_{50}{}^3}} \quad (2.23)$$

The Shields parameter θ includes the action of flow, the effects of gravity and the particle size. So, the sediment transport rate is the function of θ. If θ is not too big, say $\theta < 0.25$. (When the bed behaves as a rough boundary, cf. Sumer [11]). sediment particles move as bed load. In that case, the rate of sediment transport can be calculated by a bed-load transport formula like the well-known Meyer-Peter formula [10]:

$$\phi = \phi(\theta) = 8(\theta-\theta_c)^{3/2} \quad (2.24)$$

In Eq. (2.24) θ_c stands for the critical Shields parameter, below which sediment transport does not take place. In the original Meyer-Peter formula θ_c is taken to be equal to 0.047, but it is in fact a weak function of the grain Reynolds number. See ref. [12].

The Meyer-Peter formula is developed for the bed-load transport on a nearly horizontal bottom. In a scour hole, when sediment particeles are moving along the bed, the local slope becomes partly of significance.

As shown in Fig. 2.11, sometimes the gravity is a stabilizing force (see point A). Sometimes it is an unstabilizing force (see point B).

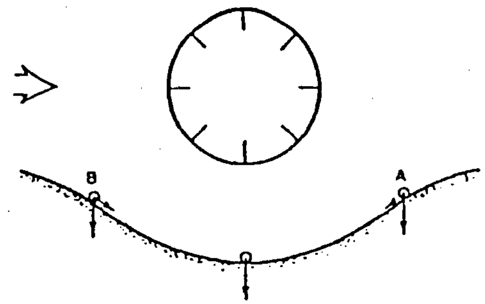

Fig. 2.11 The action of gravity on particles placed on different slopes.

The Shields parameter is modified as

$$\theta^* = \theta - 0.1 \frac{\partial h}{\partial x} , \quad (2.25)$$

which expresses the ratio between unstabilizing forces versus stabilizing forces (see Fredsøe [4]).

Then the rate of bed load could be calculated from the modified Meyer-Peter formula

$$\phi_b = \phi_b(\theta^*) = 8(\theta^*-\theta_c)^{3/2}, \quad (2.26)$$

From the knowledge of the longitudinal variation in the near bed flow, the bed shear stress τ_b is found from the relation

$$\tau_b/\rho = U_f{}^2 = U_\infty{}^2 \, f/2 \quad (2.27)$$

where U_f = friction velocity and f the Darcy-Weisbach friction factor. In open channel flow, this is determined by

$$\sqrt{\frac{2}{f}} = 6 + 2.45 \ln\left(\frac{H}{\kappa}\right) , \quad (2.28)$$

where H = flow depth and κ is the bed roughness. The variation in f due to changes in depth H and roughness κ is small because of the slowly varying logarithmic function appearing in Eq. (2.28). For this reason, f has been kept constant along the bed in the following calculations.

2.3.3 The flow around a pipe placed above a scour hole

When the flow along a bed is strong enough the bed will be eroded. On the other hand, the eroded bed brings about the change of the flow state. The modified potential flow theory could be used in the mathematical model, but some important changes in the boundary must be made. The requirements are discussed as follows:

A. The scour hole is a streamline

As shown in Fig. 2.10, a scour hole is characterized by its dimensions and its shape. Generally, the dimensions are described by the scour depth S_a directly under the pipe and the width of the scour hole W. The bed shape of the scour hole is described by

$$h = h(x) \tag{2.29}$$

the local scour depth S below the undisturbed bed could be calculated by

$$S = S(x) = h(x) - \frac{D}{2} - e_0, \tag{2.30}$$

The scour depth S_a located under the pipe is the maximum value of S at any moment.

First, suppose a free cylinder is placed in a uniformly distributed current, where no bed is present. The complex potential ω_0 is then given by

$$\omega_0 = U_\infty \left(\frac{D^2}{4z} + z\right) \tag{2.31}$$

Next, in order to fulfil the requirement that the prescribed curve h = h(x) becomes a streamline, an infinite series of pairs of dipoles are implemented.

The individual pairs of double dipoles are given by the complex potential ω_n.

$$\omega_n(z) = \frac{e_{n,1}\, M_{n,1}}{z - z_{n,1}} + \frac{e_{n,2}\, M_{n,2}}{z - z_{n,2}}\ , \tag{2.32}$$

in which $z_{n,1}$ and $z_{n,2}$ are the position of two dipoles; $M_{n,1}$ and

$M_{n,2}$ are their strengths; $e_{n,1}$ and $e_{n,2}$ are their directions.

The direction of the dipole in $z_{n,1}$ is chosen parallel to the x-axis

$$e_{n,1} = (1,0) \tag{2.33}$$

The direction of the dipole in $z_{n,2}$ will be chosen later.

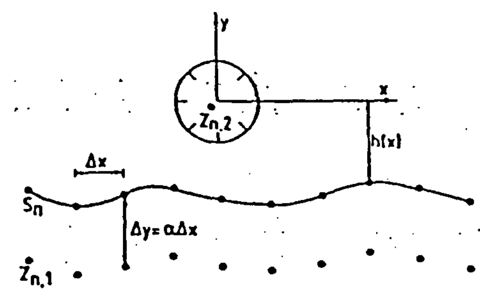

Fig. 2.12 Selected position of $z_{n,1}$ and $z_{n,2}$

As shown in Fig. 2.12, N points are chosen from the curve h(x) to describe the streamline, while the increase along x direction is Δx.

The position of one of the dipoles must be chosen. For the present it is convenient to place $z_{n,1}$ below the Nth points S_n. The distance is

$$\Delta Y = \alpha\ \Delta x \tag{2.34}$$

The position of the dipoles must always be outside the flow region in order to avoid singularities. Several values of α have been used. The calculated results indicated that 2.0 is a suitable value, but another factor than 2 would give similar results. However, if α is taken too small, the approximation of the flow between two neighbour points on h(x) does not become very smooth. On the other hand, α must not be selected too large in order to give only a local influence of the dipole close to the point S_n under consideration.

B. The contour of the cylinder is one of the streamlines

According to the requirement, the resultant action of two pairs of dipoles should form a streamline along the cylinder. As the direction of the first pair of dipoles placed at $z_{n,1}$ has been decided before, the direction and strength of the second pair of dipoles placed at $z_{n,2}$ must be related to the first pair.

The complex potential $\omega n(z)$ formed by the two pairs of dipoles is given by Eq. (2.31). By choosing

$$e_{n,2} = -\bar{e}_{n,1}\frac{z_{n,1}\bar{z}_{n,1}}{|z_{n,1}|^2} = -\bar{e}_{n,1}\frac{z_{n,1}}{\bar{z}_{n,1}}, \qquad (2.35)$$

$$M_{n,2} = M_{n,1}\frac{|r|^2}{|z_{n,1}|^2}, \qquad (2.36)$$

and

$$z_{n,2} = z_{n,1}\frac{|r|^2}{|z_{n,1}|} = \frac{r\,\bar{r}}{\bar{z}_{n,1}}, \qquad (2.37)$$

from Eq. (2.37) we obtain a cylinder, the radius of which is $|r|$ and the centre of which is at z(0,0). That the cylinder is a streamline is demonstrated by the following:

Let us consider the point r on the cylinder with radius $|r|$. The coordinate of r is given by

$$r = r_x + i\,r_y \qquad (2.38)$$

The complex potential at the cylinder is given by

$$\omega_n(r) = \frac{e_{n,1}M_{n,1}}{r - z_{n,1}} + \frac{e_{n,2}M_{n,2}}{r - z_{n,2}}, \qquad (2.39)$$

By inserting Eqs. (2.34), (2.35), (2.36) into Eq. (2.38) we obtain

$$\omega_n(r) = M_{n,1}\left[\frac{e_{n,1}}{r-z_{n,1}} + \frac{\bar{e}_{n,1}}{\bar{r}-\bar{z}_{n,1}} + \frac{\bar{e}_{n,1}}{\bar{z}_{n,1}}\right], \qquad (2.40)$$

Because the second term is the conjugate of the first term, the sum of the first two terms is real. The imaginary part comes from the third term, but the third term is constant being independent of r. It is means that the imaginary part of ω is constant along the circle with center in (0,0) and with radius $|r|$.

C. The horizontal line far above the cylinder is a streamline

It is evident that at any point far above the cylinder the flow velocity does not have a vertical component. There the flow is parallel with the undisturbed bed.

The calculation concerned has verified that the distance between the horizontal streamline and the pipe should be larger than 5 times the pipe diameter.

D. U_{top} equals U_{bottom}

In order to make U_{top} equal to U_{bottom}, a vortex body is implemented. The vortex has its centre in the centre of the cylinder with diameter D. The strength of the vortex is determined by the factor V_v.

The complex potential given by the vortex body is

$$\omega_v = V_v \ln\left(\frac{iD}{z}\right), \qquad (2.41)$$

Finally, the requirement could be expressed as

$$\left[\frac{\partial\omega_v}{\partial z}\right]_{z=i\frac{D}{2}} - \left[\frac{\partial\omega_v}{\partial z}\right]_{z=-i\frac{D}{2}} = -\sum_{n=1}^{N}\left[\frac{\partial\omega_n}{\partial z}\right]_{z=i\frac{D}{2}} - \left[\frac{\partial\omega_n}{\partial z}\right]_{z=-i\frac{D}{2}} \qquad (2.42)$$

E. The stream function ψ is constant along the scour hole

Suppose that there is a point K on the boundary h(x). The imaginary part of its complex potential could be calculated as following:

$$\psi_K = \psi_0 + \psi_v + \sum_{n=1}^{N}\psi_{n,K} \qquad (2.43)$$

where Φ_0 is the contribution from the basic solution Eq. (2.31);
Φ_v is the contribution from Eq. (2.41);
and $\Phi_{n,1}$ is obtained from Eq. (2.32).

Finally, Eq. (2.43) becomes N linear equations in the N + 1 unknown values of $M_{n,1}$ and V. Adding Eq. (2.42) the system is closed.

2.3.4 Theoretical results

Some theoretical results are given in this section. In order to focus on the more important geometrical factors W and S_a, a theoretical shape of the scour hole is used at the present. It is described by Eq. (2.44)

$$h(x) = \begin{cases} e_0 + \frac{D}{2} + \frac{S_a}{2}\left(1 + \cos\left(2\pi\frac{x}{W}\right)\right), & |x| < \frac{W}{2}, \\ e_0 + \frac{D}{2}, & |x| > \frac{W}{2}, \end{cases} \qquad (2.44)$$

In fact, the upstream parts of scour holes in nature are very similar to it.

A. Stream pattern

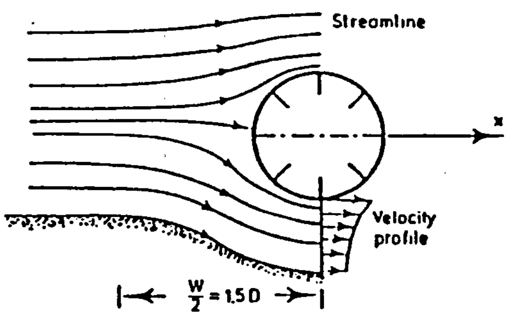

Fig. 2.13 Flow pattern around the cylinder placed above the scour hole.

Fig. 2.13 shows the calculated flow pattern around the pipe with a scour hole in the bed.

It should be mentioned that the stagnation point of stream on the cylinder is above the x-axis.

The velocity distribution underneath the pipe indicates that the velocity close to the bed is much smaller than that near the cylinder.

B. Variation in U_{bed} with e_0/D and S_a/D

There are three geometrical factors, e_0, W, S_a, they influence the velocity underneath the pipe. It is important to get their relationship.

From Fig. 2.14 and 2.15, the following conclusions can be drawn:

(i) For fixed gap ratio, U_{bed}/U_∞ decreases with increasing scour depth. In the usual range of e_0/D for marine pipelines, U_{bed}/U_∞ is larger than unity for small scour depths and smaller than unity for larger scour depth.

(ii) For a fixed value of the scour depth, the value of U_{bed}/U_∞ increases with decreasing gap ratios.

(iii) For fixed gap ratio, the state $U_{bed}/U_\infty = 1$ leads to deeper scour depth corresponding to a wider scour hole.

Comparing Figs. 2.14 and 2.15 with Fig. 2.9, we see that the conclusions drawn above are very important.

In fact, the scour below the pipelines has obtained its final stage when the sediment transport below the pipe q_{bed} equals the upstream sediment transport q_∞. Disregarding the small variations in friction factor etc., the requirement $q_{bed} = q_\infty$ becomes indentical with

$$\frac{U_{bed}}{U_\infty} = 1 \qquad (2.45$$

The requirement gives a relation between final scour depth S_0 and gap ratios as demonstrated later.

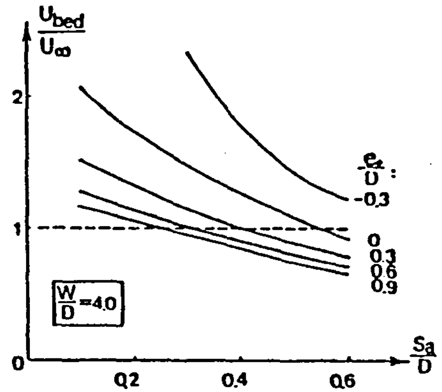

Fig. 2.14 Variation in U_{bed}/U_{∞} with scour depth at different gap ratios. The width of the scour hole is kept fixed.

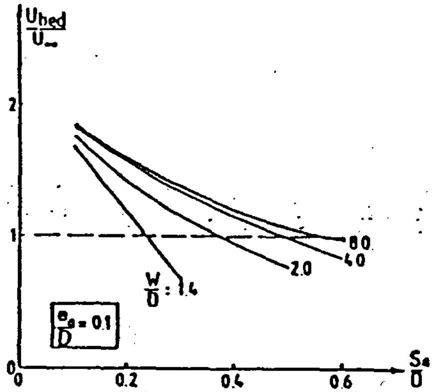

Fig. 2.15 Variation in U_{bed}/U_{∞} with scour depth at different width of the scour hole. The gap ratio is constant.

C. Spatial variation in near-bed velocity

Besides the flow velocity U_{bed} below the pipe, also the variation along the bottom is of interest in order to calculate the shape of the scour hole. Disregarding the effect of gravity on the rate of bed load transport due to longitudinal slope, the correct width of the scour hole is found when the flow velocity along the bed becomes nearly constant. Fig. 2.16 shows how the

velocity varies along the bed for different widths.

Still assuming the shape of the scour hole to be determined by Eq. (2.44), three different widths are chosen. In every case, the suitable maximum scour depth S_a is chosen to fulfil $U_{bed}/U_{\infty} = 1$ and $e_0/D = 0.1$. The calculations indicate that in the small-width case (see Fig. 2.16 (c)), the flow velocity along the bed is larger than U_{∞} in front of the pipe, while in the large-width case, the velocity along the scour hole is smaller than U_{∞} and underneath the pipe the velocity has its maximum value (See Fig. 2.16) (a)). It should be mentioned that for very large W/D (the plane bed), $U_{bed}/U_{\infty} > 1$.

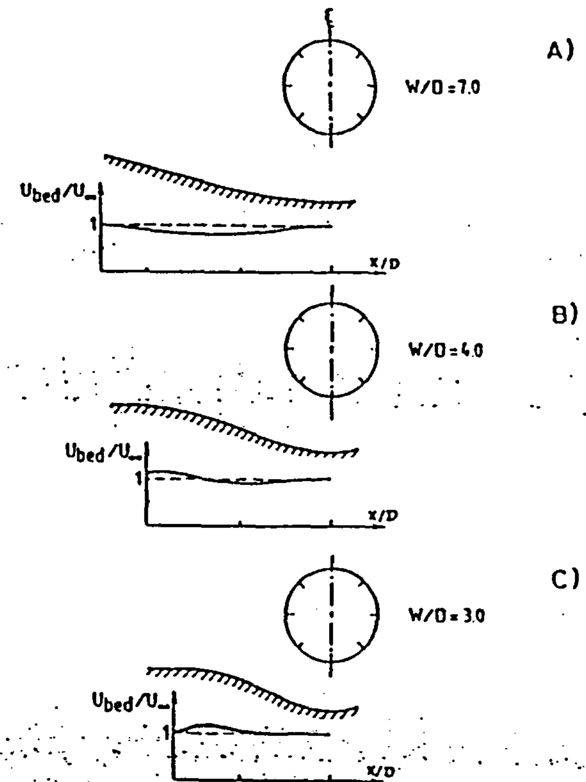

Fig. 2.16 Variation in U_{bed}/U_{∞} along the bed at different width.

2.3.5 Calculation of the scour process and the equilibrium scour profile

A. Calculation of the scour process

The calculation flow chart is shown in Fig. 2.17. Calculated examples are shown in Fig. 2.18. In Fig. 2.18 (a) the bed profile is assumed symmetrical around a vertical through the pipe center, the downstream part of the bed is sketched as a dashed line. The calculated equilibrium profile is shown as a dot-dashed line.

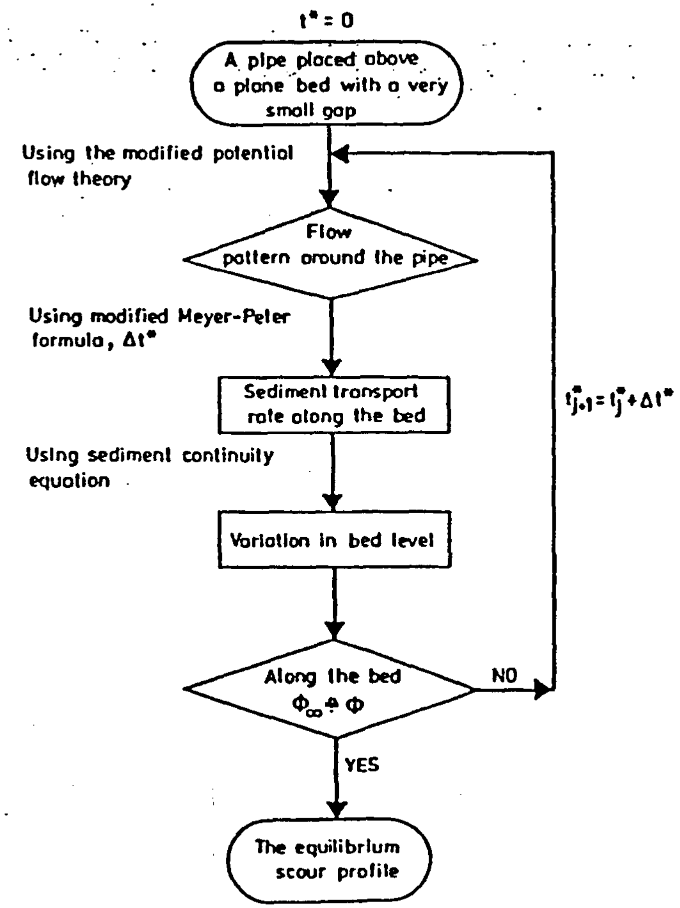

Fig. 2.17 Flow chart to calculate the equilibrium bed profile.

In Fig. 2.18 (b) the downstream part of the bed profile is assumed to be horizontal.

From Fig. 2.18 it is seen that the two extreme assumptions on the shape of the scour hole result in nearly the same calculated shape of the scour hole in front of the pipe. This is because the shape of the downstream part of the scour hole only affects the upstream potential flow description very moderately.

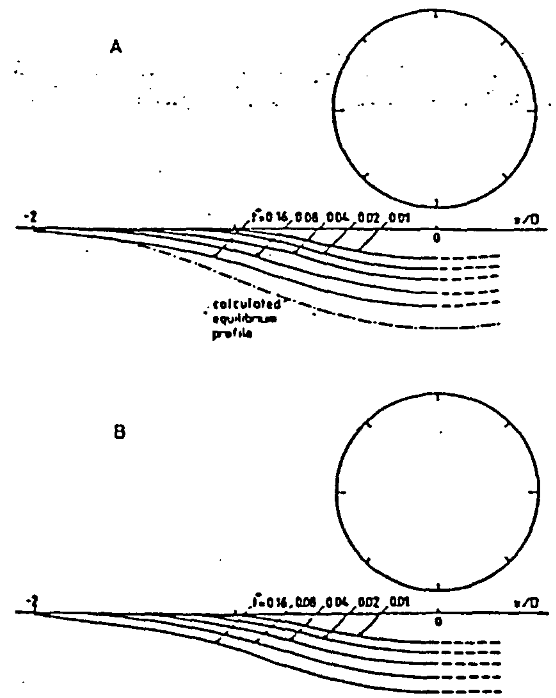

Fig. 2.18 Calculated development in scour with dimensionless time t^*, for $\theta_\infty = 0.2$, $e_0/D = 0.1$.
A: Scour hole assumed symmetrical.
B: Scour hole downstream the pipe assumed horizontal.

B. Discussion about the equilibrium state

As shown in Fig. 2.18, the final equilibrium scour profile could be calculated as shown in Fig. 2.17. But the calculations concerned are rather tedious.

For simplicity, in the following discussion the bed profiles are still assumed as the scour hole given by Eq. (2.44). In that way the useful information could be acquired by simpler calculations.

As seen from Figs. 2.14 and 2.15, it turns out that different combinations of S_a and W can fulfil the requirement that the sediment transport just below the pipe becomes equal to the undisturbed sediment transport rate.

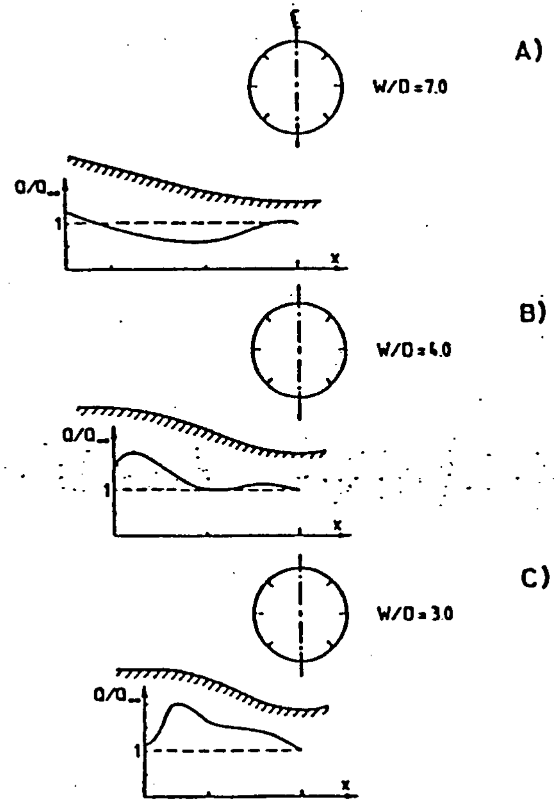

Fig. 2.19 Spatial variation in sediment transport along the scour hole at different widths $e_0/D = 0.1$.

Fig. 2.19 shows the spatial variation in sediment transport along the scour hole with application of the modified Meyer-Peter formula. As the calculations show in Fig. 2.16, the combinations of W and S_a were chosen from Fig. 2.14 and 2.15 to fulfil U_{bed}/U_∞.

Regarding the equilibrium state in scour, it is easily seen from Fig. 2.19 that some combinations describe the variation more correctly than others do. For example, Fig. 2.19 (c) describes the variation rather well except at the place around $x = -W/2$, where the shape given by Eq. (2.44) is just an approximation.

Further, the calculated equilibrium state shown in Fig. 2.19 confirmed that in the final state $W/D = 3 \sim 4$.

It can be mentioned that W is more sensitive than S_a to the correct estimate of the shape of the scour hole.

In order to choose the best combination of W and S according to the variation in sediment transport along the stretch of the scour hole, it is necessary to introduce a quantity ε, defined by

$$\varepsilon = \left\{ \int_{-L}^{0} (q_\infty - q_{calc})^2 \, dx \right\}_{L\to\infty} \qquad (2.46)$$

where q_{calc} is the calculated sediment transport rate. Then the least-square fit is used.

The variations in S_a and W at different gap ratio are shown in Fig. 2.20.

In Fig. 2.20, two different values of θ_∞ are introduced in order to show the effect of gravity (Eq. 2.25) which is most important at small Shields parameters. The effect of gravity is that the scour hole becomes deeper and wider.

However, in agreement with the experimental findings by Kjeldsen et al. for a pipe without gap, the variation in θ_∞ is small.

2.3.6 Comparison with experiments

Fig. 2.21 shows the initial development with time of the scour hole from ref. [7]. The pipe diameter was 0.5 m. The pipe

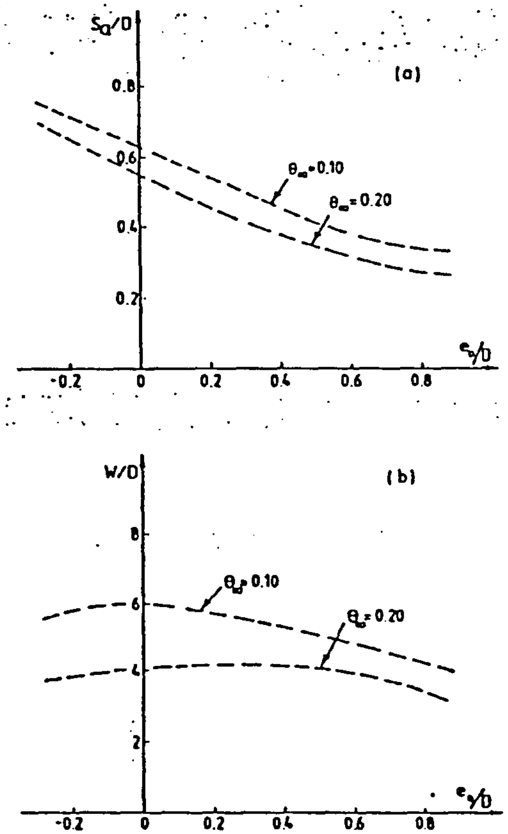

Fig. 2.20 Variation in scour depth S_a and width W at different gap ratios and Shields parameter.

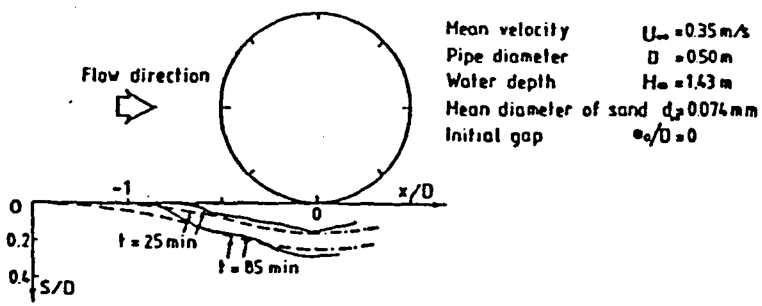

Fig. 2.21 Calculated (dashed line) and measured (fully drawn line) development in scour with time time. Measurements from [7].

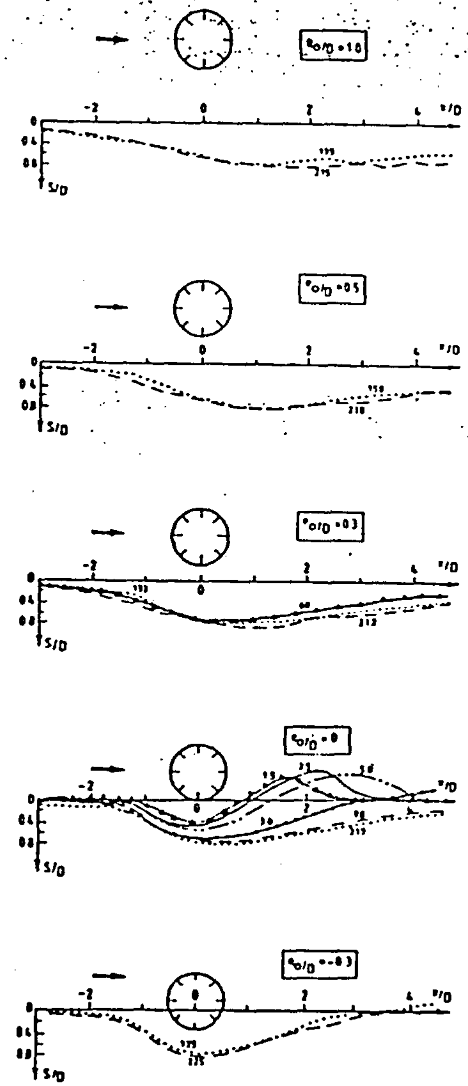

Fig. 2.22 Development of bed profile with time (in minutes) at different gap ratios, for $\theta_\infty = 0.098$, $d_{50} = 0.36$ mm, $H_\infty = 0.35$ m and $D = 0.10$ m.

was placed on the bottom without any initial gap. The experiments were carried out at different values of the ratio water depth to the pipe diameter. In accordance with the theory this seems to have no influence.

The development of the scour hole can be calculated for Eq. (2.20) and is shown in Fig. 2.21 together with the measured development. The calculated and measured development is quite similar.

The experiments carried out by the author will be described in detail later. Fig. 2.22 shows the development of the bed profile with time at different initial gap ratios e_0/D while the undisturbed Shields parameter $\theta_\infty = 0.098$. For the negative gap ratio, erosion below the pipe is initially introduced artificially.

The experiments of ref. [7] were carried out with a mean diameter $d_{50} = 0.074$ mm, while the present experiments are carried out with $d_{50} = 0.36$ mm.

The variation in fully developed scour depth S_a below the pipe with gap ratio is depicted in Fig. 2.23. It is seen that the experimental findings are in accordance with theoretical predictions (dashed lines).

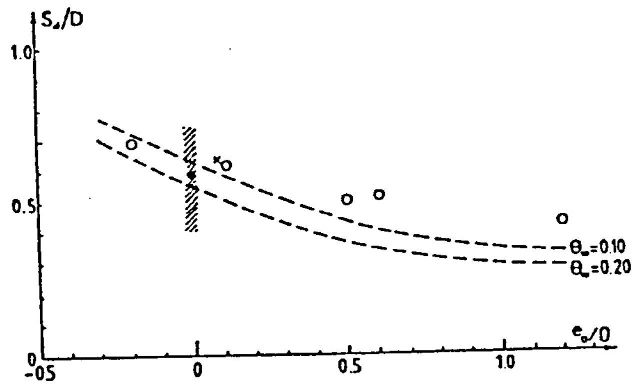

Fig. 2.23 Variation in scour depth with gap ratio.
o : present data $\theta_\infty = 0.098$
x : present data $\theta_\infty = 0.065$
● : present data $\theta_\infty = 0.048$
Hatched band: Kjeldsen et al. data [7].

2.4 Experiments

2.4.1 Experimental set-up

The tests in current were carried out in a flume 2 m wide, 23 m long and 50 cm deep. The middle part of the flume has glass side walls. (See plate 2.2).

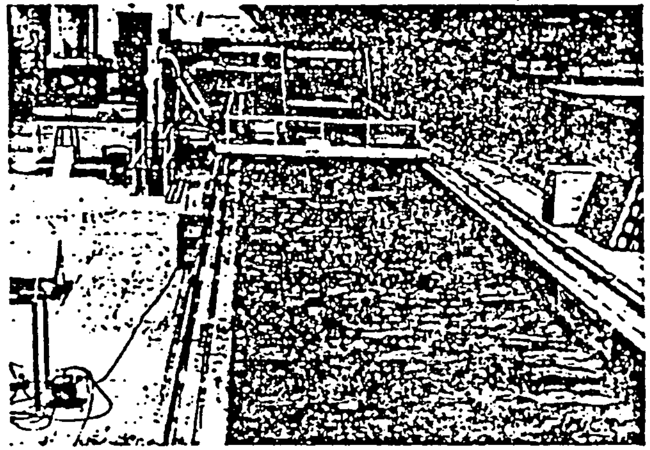

Plate 2.2 The 2 m wide flume.

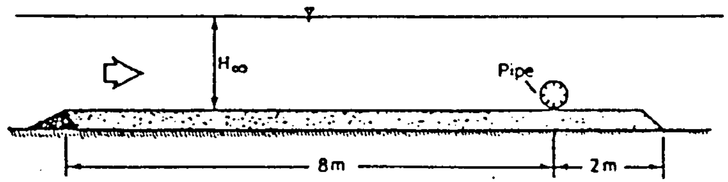

Fig. 2.24 Sketch of experimental set-up.

One kind of sand with $d_{50} = 0.36$ mm and $\sigma = \sqrt{d_{85}/d_{15}} = 1.38$ was used in the tests. The sand bed was 8 to 10 m long with the thickness of 10-15 cm. After several months, the sand became a little coarser. Two kinds of pipes were used: One with D = 10.1 cm, and the other with D = 5 cm, both 1.99 m long. The surfaces of them were hydraulically smooth.

The pipe position is shown in Fig. 2.24. It was convenient to observe the phenomenon around the pipe through the glass walls. A video camera was used to record the experiment process.

For the tests with the 10 cm pipe, the flow depth was kept at 35 cm, and for the 5 cm pipe the flow depth was around 25 cm. The blockage effect of the pipe on the flow was very limited. The measured velocity profiles agree well with the logarithmic distribution. A micropropeller was used to measure the velocity.

In order to measure bed profiles, a so-called sand bed follower was used [3]. (See plate 2.3). It could move along the rails on a carriage which could move along other rails on the top of the side walls, so the probe of the sand bed follower could move in three directions. Results were recorded on charts. The accuracy of the measured bed level was around 1 mm. The eroded bed profile was the mean value of measured bed profiles along five sections (Fig. 2.25).

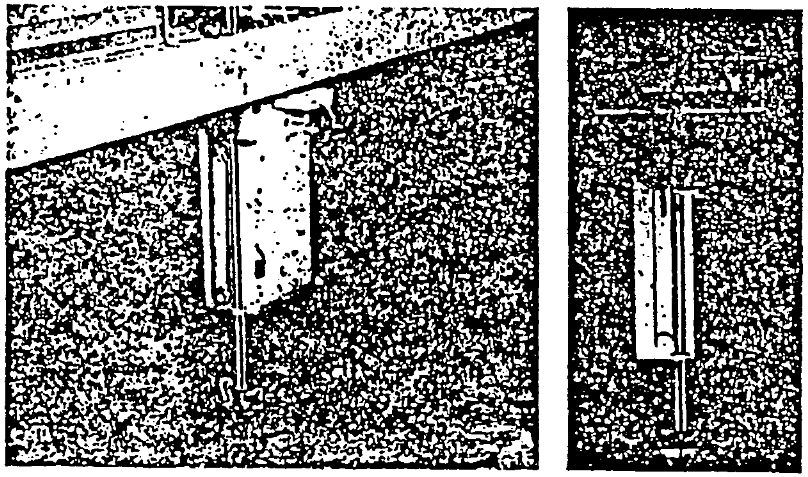

Plate 2.3 The sand bed follower.

For a pipe of 5 cm diameter, a needle with a scale is fixed on the bottom of the mid-span, so the scour depth in the process was read directly through the glass walls.

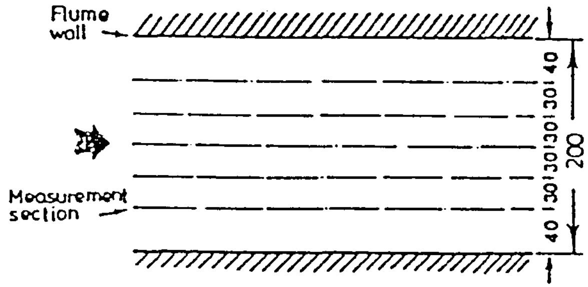

Fig. 2.25 Sketch of measurement sections. (Top view, number in cm).

2.4.2 Observation

A. Process of scour

After onset, the scour process has two different stages: the jet period and the wake period.

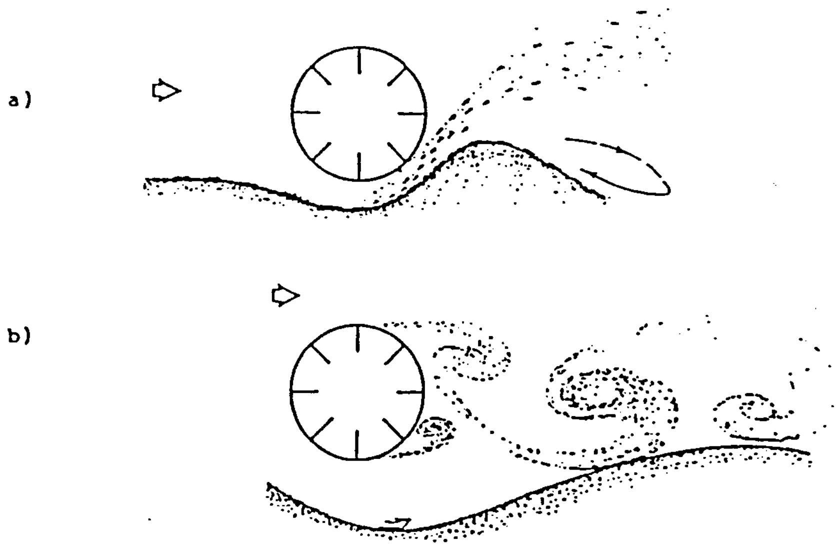

Fig. 2.26 Sketch of scour. A. The jet period. B. The wake period.

As shown in Fig. 2.26 (a), at an early stage the gap between the pipe and the scour hole is small, and the downstream hill is relatively high. The jet plays an important role. The jet rushes sand particles away. At first the scour rate was quite high. The eddy behind the hill was moving sand particles upstream, some sand particles were sliding into the scour hole. In the jet period there was generally no action of vortex shedding behind the pipe. Later on, the scour depth under the pipe was increasing slowly, and the hill was decreasing and moving away.

When the relative gap was greater than 0.3, and the downstream hill was sufficiently far from the pipe, a vortex shedding occurred. (Fig. 2.23 (b)). The vortices from the top and bottom of the pipe attack the downstream bed, but the lower eddy from the bottom of the pipe had a stronger ability to move sand away. The explanation is that when the eddy attacked the bed, it moved sand particles in the same direction as the flow direction. Plate 2.7 shows the scene where vortices were hitting the bed. Fine plastic particles were used to show the vortices.

B. Flow state

As indicated before, the flow could be divided into an upstream part and a downstream part. The upstream part was more laminar. Plate 2.4 shows that the upstream slope of the scour hole was a streamline, and there was no flow separation. It is seen from plate 2.6 that the flow stagnation point was higher than the horizontal line through the pipe centre.

C. Sand wave

In the clear-water-scour case, local scour around the pipe was observed. Upstream bed was a plane, but downstream the pipe there were sand waves.

The examples of measured bed profiles were shown in Fig. 2.27 and 2.28 for $\theta_- = 0.048$ and $\theta_- = 0.098$ respectively.

At an early stage both of them had hills downstream the pipe, but later the hill moved (for $\theta_- = 0.048$) or disappeared (for $\theta_- = 0.098$).

The scatter of curves suggests the turbulence.

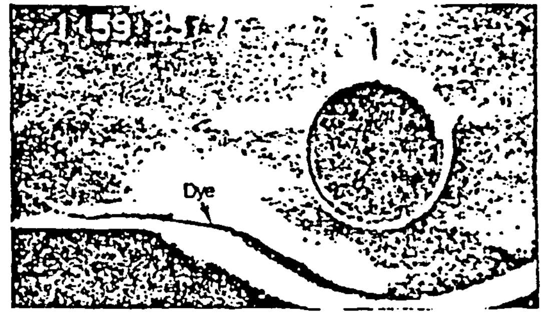

Plate 2.4
Flow state along upstream slope.

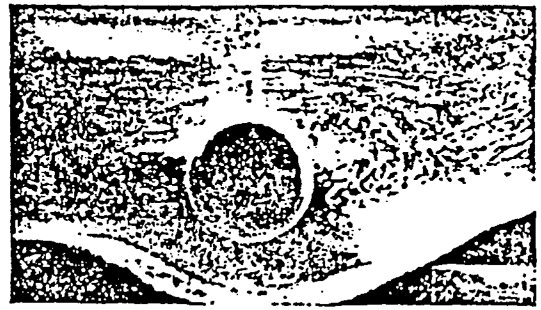

Plate 2.5
Flow state around a pipe with an eroded bed, $\theta_- = 0.048$.

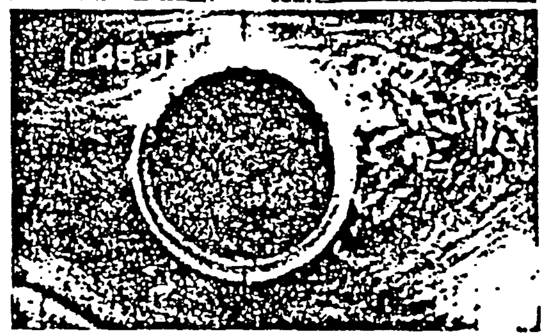

Plate 2.6
Stagnation point was on the upper part of the pipe.

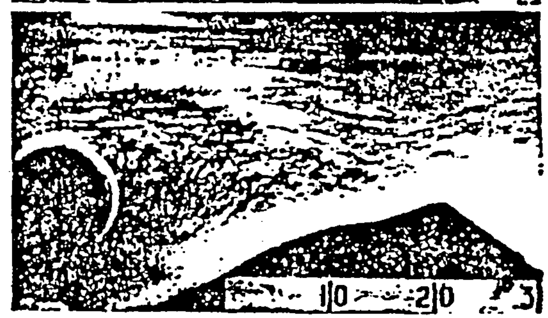

Plate 2.7
Vortices were attacking the bed downstream the pipe.

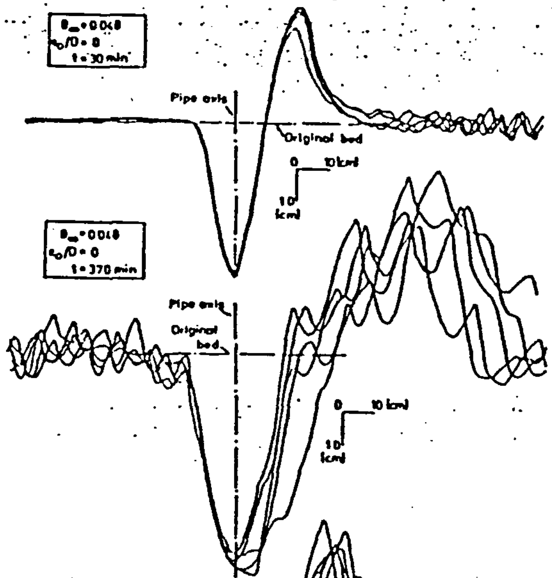

Fig. 2.27 Measured bed profiles for θ_∞ = 0.048.
(a) t = 30 min, (b) t = 370 min.

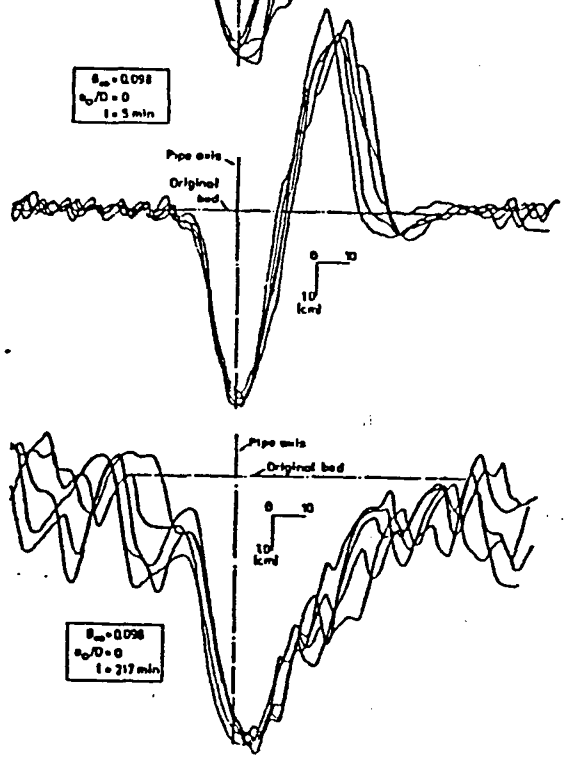

Fig. 2.28 Measured bed profiles for θ_∞ = 0.098.
(a) t = 5 min,
(b) t = 217 min.

Plate 2.8 shows the sand waves along the flow direction. The dimensions of sand waves were different upstream and downstream.

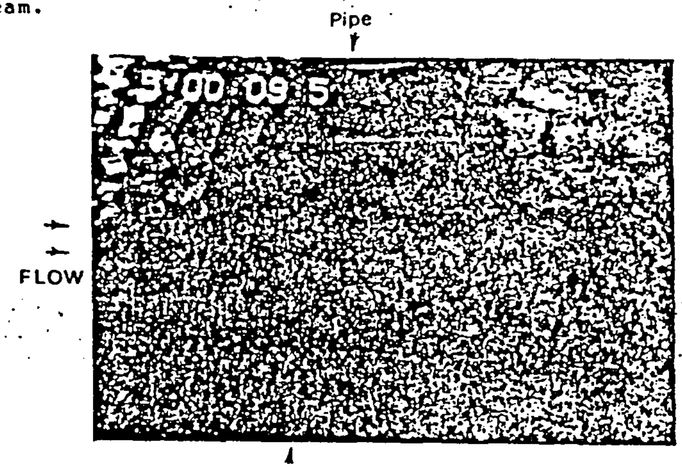

Plate 2.8 Sand waves along stream. θ_∞ = 0.048. Plate was placed along opposite arrows.

2.4.3 Experimental results and analysis

A. Velocity distribution close to the bed

The micro-propeller was 5 mm above the bed. The average value in 30 seconds was taken as the velocity at the point.

Some conclusions may be drawn from Fig. 2.29 as follows:

a) The eroded bed profile had strong influence on the velocity close to the bed. At around one diameter of the pipe, (x/D = 1), the ratio U/U_∞ was relatively high.

b) In the equilibrium state, the velocity varied little along the eroded bed.

B. Development of eroded bed profile

Fig. 2.30 shows the development of bed profiles for e_0/D = 0 and θ_∞ = 0.048 to 0.33. Similar pictures have been show in Fig. 2.22. While θ_∞ = 0.098, e_0/D = -0.3 ~ 1.0.

It is seen that the deepest position of the scour hole moved from upstream to downstream with time.

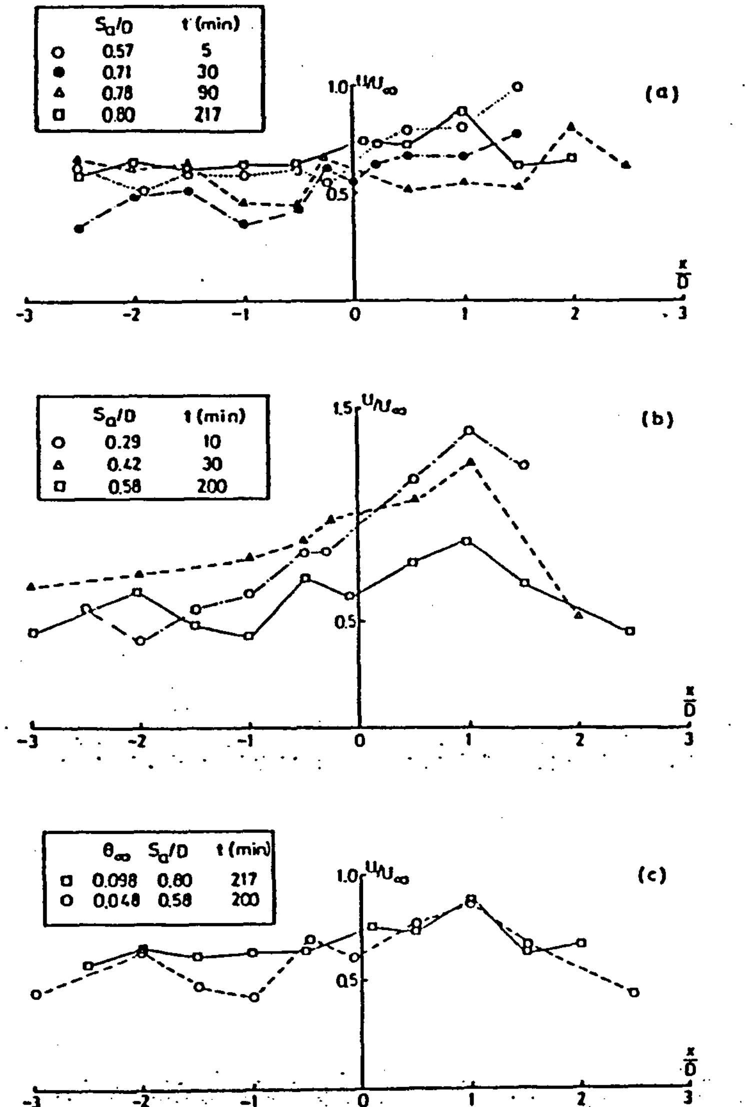

Fig. 2.29 Velocity distributions close to the eroded bed.
(a) $\theta_\infty = 0.048$, $e_0 = 0$, t = 5, 30, 90, 217 min.
(b) $\theta_\infty = 0.098$, $e_0 = 0$, t = 10, 30, 200 min.
(c) Comparison between flow velocity distributions along the nearly steady bed.

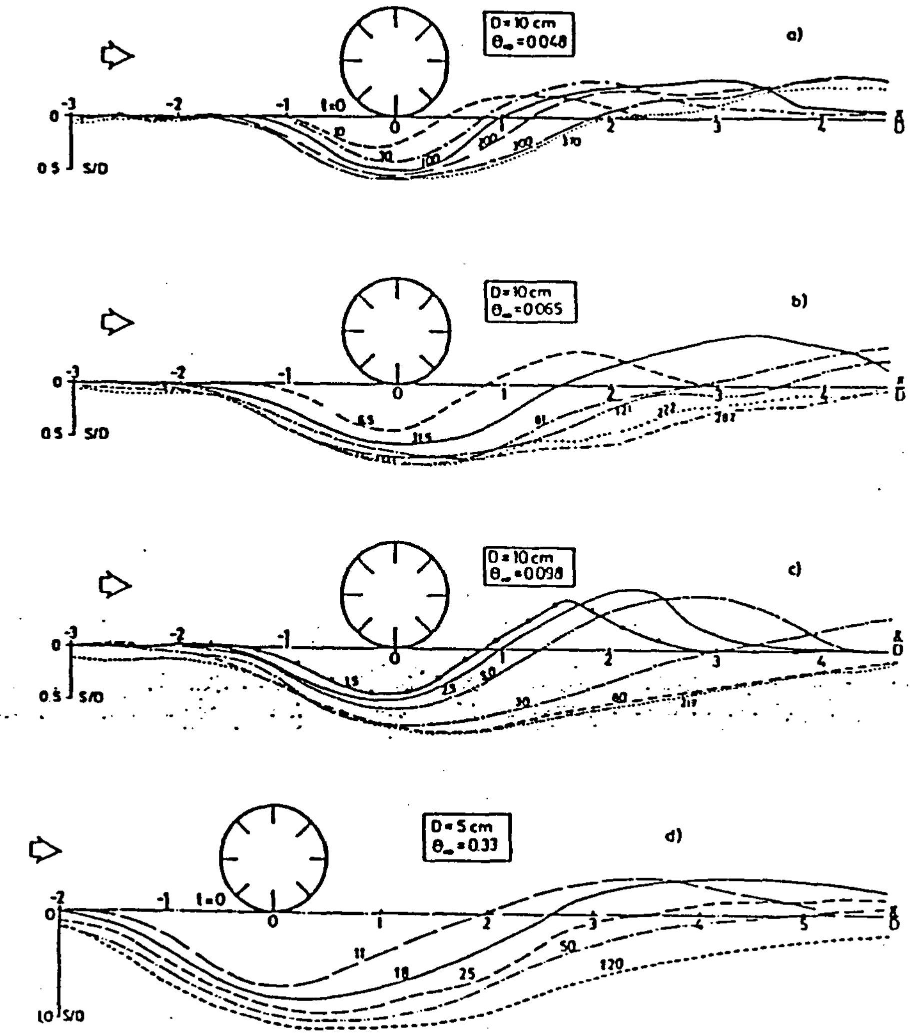

Fig. 2.30 Development of bed profile with time (in min.), $e_0/D = 0$, for (a)(b)(c), $U_\infty = 0.35$ m, D = 10 cm; for (d), $U_\infty = 0.23$ m, D = 5 cm.

C. Scour rate and its dimensionless formulation

Fig. 2.31 and Fig. 2.32 show the scour process for different values of θ_∞. The following conclusions can be drawn:

(a) The scour rate is decreasing with respect to time.

(b) The larger the value of θ_∞, the higher the scour rate at the early stage. Especially when $\theta_\infty > 0.25$, there is suspension, so the scour rate is quite high.

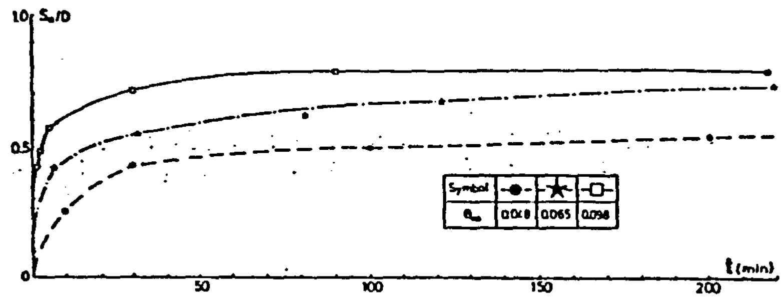

Fig. 2.31 The scour process for low θ_∞. $e_0/D = 0$, $D = 10$ cm.

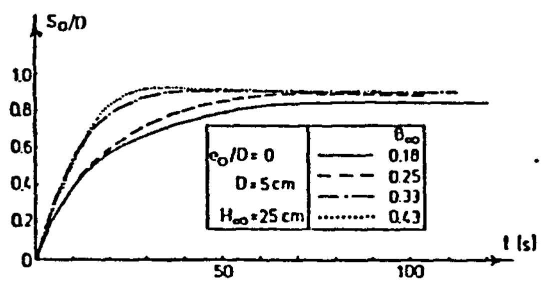

Fig. 2.32 The scour process for high θ_∞, $e_0/D = 0$, $D = 5$ cm.

In the following, the different measured scour developments are compared in the dimensionless formulation of the scour process as given by Eqs. (2.19) and (2.21).

As pointed out, the dimensionless time is given by

$$t^* = t/t_0,$$

$$\text{where } t_0 = \frac{D^2(1-n)}{q_{sediment}}, \tag{2.47}$$

Here $q_{sediment}$ is a typical scale of sediment transport rate. In the following, two different estimates of $q_{sediment}$ have been applied.

$$\text{(A) } q_{sediment} = q_\infty \tag{2.48}$$

which is the bed load rate far way from the pipe.

$$\text{(B) } q_{sediment} = q_{local,max} \tag{2.49}$$

where $q_{local,max}$ is the maximum sediment transport rate of the bed load just under the pipe. (See Fig. 2.33).

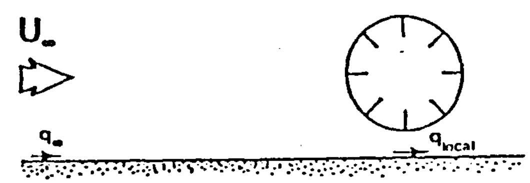

Fig. 2.33 Definition sketch of q_∞ and q_{local}.

For the early stage of the scour process, the local velocity under the pipe U_{bed} (see Fig. 2.8) is larger than the undisturbed velocity U_∞. As shown in Fig. 2.7, the modified potential flow theory suggested $U_{bed}/U_\infty = 1.65$. Therefore, using $\theta_{local} = 2.5\ \theta_\infty$, the value of q_{local} can be calculated as a bed load.

The scour processes with respect to the dimensionless time t^*_A based on q_∞ were depicted in Fig. 2.34.

As shown in Fig. 2.34, when the value of θ_∞ varies from 0.065 to 0.43, there is a systematic shift. When θ_∞ is 0.065 and 0.098, in fact, their scour processes become a single curve. With the increase of θ_∞, the equilibrium value of h^* becomes larger, and the scour rate at the early stage is changing.

The systematic shift of the scour process may be due to the effect of suspension. It was observed in the experiments that for $\theta_\infty = 0.065$, sediment moves only along the bed surface.

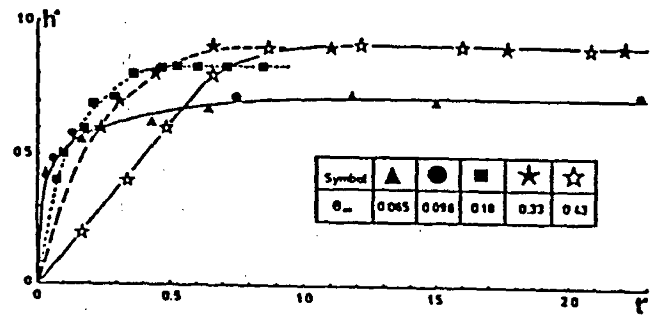

Fig. 2.34 The scour process with respect to the dimensionless time t^*_A based on q_∞.

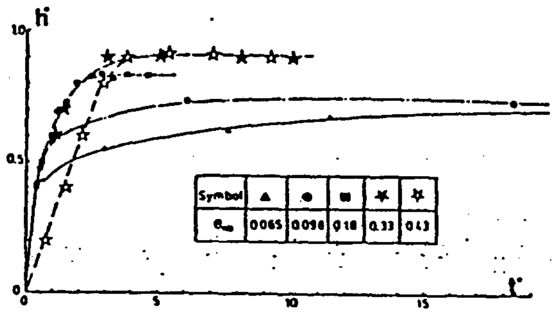

Fig. 2.35 The scour process with respect to the dimensionless time t^*_B based on $q_{local,max}$.

Owing to the increase of θ_∞, more and more sediment moved in suspension. When $\theta_\infty = 0.43$, the suspended load became quite important.

The scour process with respect to the dimensionless time t^*_B based on $q_{local,max}$ for different values of θ_∞ were plotted in Fig. 2.35. It is seen that for the early stage of the scour process, the curves overlap except for the case of $\theta_\infty = 0.43$. Here the suspended load is quite important. The curve suggested that if the bed load is dominant compared with the suspended load, the scour processes with respect to the dimensionless time t^*_B at the early stage are approximately the same due to the

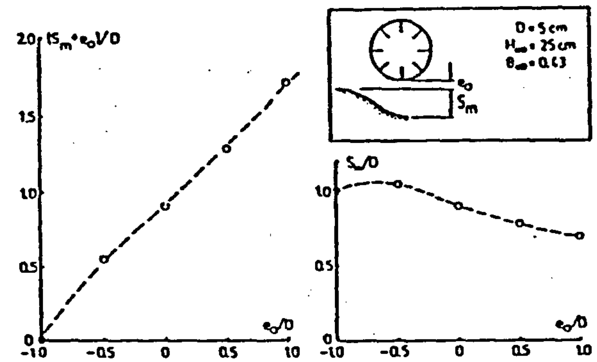

Fig. 2.36 The equilibrium scour depth S_m versus the initi[al gap] e_0, for $\theta_\infty = 0.43$, D = 5 cm.

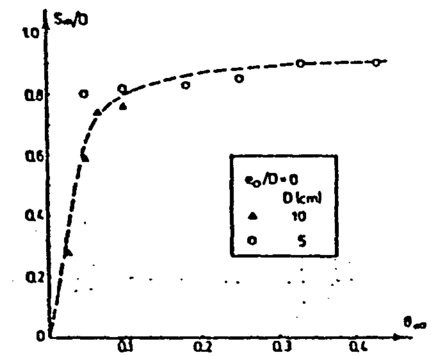

Fig. 2.37 The equilibrium scour depth S_m versus θ_∞, for $e_0/D = 0$.

local increase of the velocity under the pipe.

D. Some remarks about the influencing factors

Scour process is a complex process. There are seve[ral fac]tors influencing the equilibrium scour depth.

(a) The inital gap.

The variation in scour depth with gap ratio for θ_∞ shown in Fig. 2.23 suggested that the larger the initial [gap] the shallower the equilibrium scour depth.

In the case when the sand particles could move in suspension, the tendency was the same. (See Fig. 2.36).

(b) The movement of sand waves.

The movement of sand waves affects the supply of sediment, so the equilibrium scour depth is varying with time.

Therefore the mean value of several different sections was taken to be the representative bed profile in the experiments.

Of course, the pipe size has some influence on the accuracy of the results. The diameter of the pipe should not be too small compared to the height of the sand waves.

(c) The wake behind the pipe.

The equilibrium scour depths were plotted in Fig. 2.37. It shows that the equilibrium scour depth is a weak function of θ_∞. The scour depth is less than the diameter of the pipe.

The final scour depths were deeper than those expected by the potential flow theory which disregarded the action of vortex shedding and the suspensition of sediment particles. In fact, it is the vortex shedding that moves the hill away from the pipe and affects the scour depth underneath the pipe. So, in order to understand the scour, the effect of the lee-side wake should be paid enough attention.

2.4.4 Conclusions drawn from experiments

The scour process could be split up into two regions: the jet period and the wake period. The flow stagnation point is on the upper part of the pipe. The scour rate is very high at an early stage. Later on it decreases.

In the equilibrium state, the velocities along the bed surface were very similar.

The bigger the initial gap, the shallower the scour depth. The equilibrium scour depth is a weak function of θ_∞, the value of S_m is less than the diameter of the pipe. The final scour depth is influenced by the wake behind the pipe.

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CHAPTER 3

THREE-DIMENSIONAL SCOUR UNDER PIPELINES IN A CURRENT

3.1 Introduction

Two-dimensional scour under pipelines discussed in chapter 2 is a simplified scour model (see Fig. 3.1). In the field, as shown in Fig. 3.2, scour takes place under the pipeline forming a three-dimensional scour hole. Along the axis of the pipeline, the scour situation varies. If the pipeline is stiff enough, and the span length is not very long, the mid-span may be suspended above the scour hole. In order to get sufficient support, the pipeline is partly buried in the sustained positions.

From the engineering point of view, the dimensions of the scour hole are very important parameters. Especially the value of the span length L is needed.

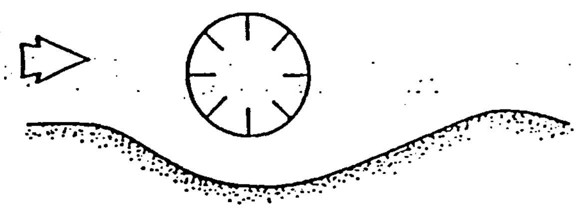

Fig. 3.1 Sketch of the two-dimensional scour.

Besides hydraulic conditions and sediment properties, the stiffness length L_s of the pipeline is the main factor influencing the length of the span. It is defined by

$$L_s = \left(\frac{EI}{q}\right)^{1/3} \tag{3.1}$$

in which E is the modulus of elasticity of the pipeline;
I is the bending moment of inertia of the cross section of the pipeline;

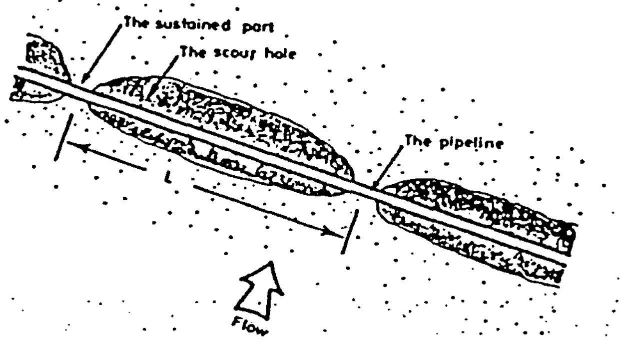

Fig. 3.2 Sketch of the three-dimensional scour.

q is the submerged load on the unit length of the pipeline, including the pipe weight and the cargo weight transported by the pipe.

The phenomena of the three-dimensional scour have been studied very little, and consequently are rather poorly understood. A method to predict the span length is urgently needed.

The scope of the present chapter is to get an insight into the three-dimensional scour in a current and to give an explanation of the maximum span length for the individual scour hole.

In this chapter, a simplified physical model on the three-dimensional scour is presented. Then the results of serial tests are analysed. At last, a method to assess the maximum span length of the scour hole is proposed.

3.2 A simplified physical model

In this section an idealized three-dimensional scour process in a current is interpreted. The flow pattern under a sagged pipe and the sustained part of the pipeline are analyzed.

3.2.1 The three-dimensional scour process

A pipeline is laid on a plane bed, the scour process is ideally shown in Fig. 3.3. After the onset of the scour (Fig. 3.3(b)), the small scour hole under the pipeline is widened and deepened by the flow. Because the pipeline is flexible to a certain extent, the pipeline starts to sag when the span length is large enough (see Fig. 3.3(c)). The pipeline continues its sagging process during the development of the scour hole, until the mid-span comes into contact with the scour hole (see Fig. 3.3(d)).

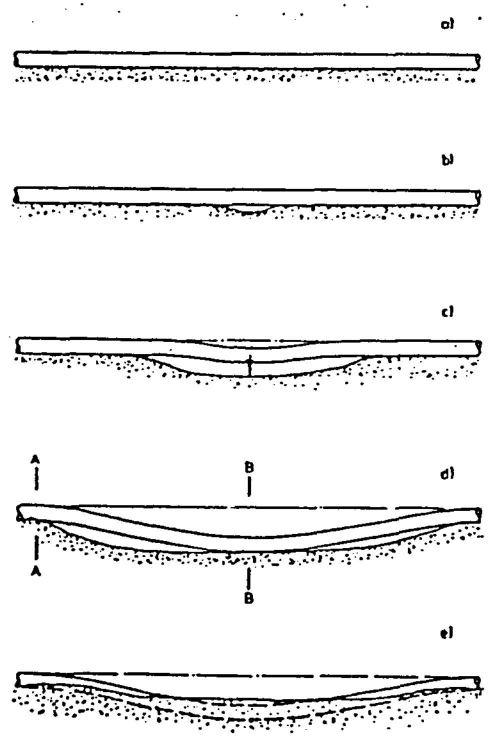

Fig. 3.3 Sketch of the three-dimensional scour process and self-burial.

As a three-dimensional phenomenon, the scour situation along the axis of the pipeline is different. It is seen clearly from Fig. 3.3, the section A-A and B-B are the typical sections. As seen in Fig. 3.4, the bed in section A-A is just slightly scoured in the process, then further erosion is prevented. The scour situation in the section B-B is quite similar to the two-dimensional scour, but in the present case the pipe is not fixed. The pipe is sagging until it contacted the bottom of the scour hole.

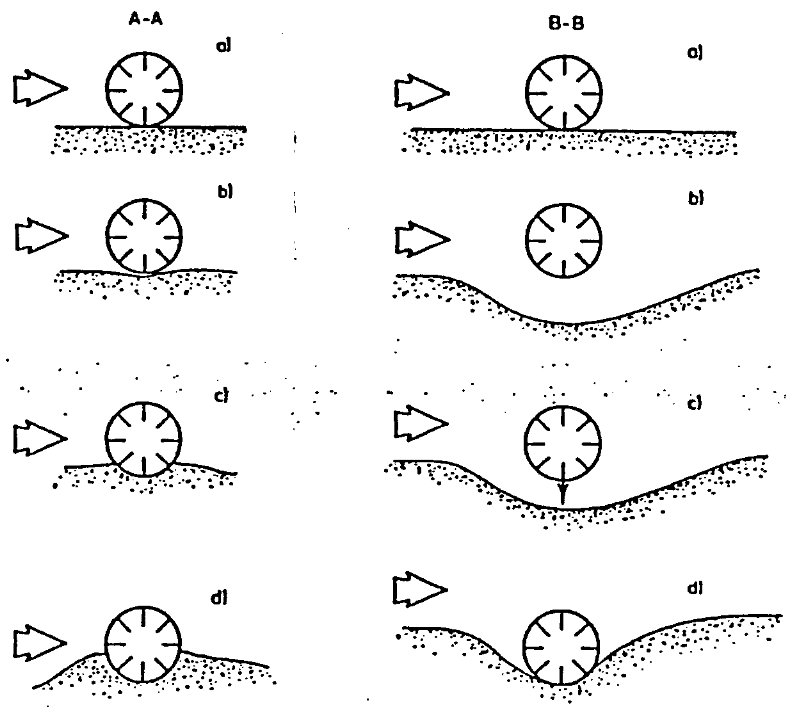

Fig. 3.4 Schematic variation in the situation of pipeline at section A-A and B-B shown in Fig. 3.3.

3.2.2 The flow pattern under a sagged pipe

The flow pattern under the pipe is determined by the shape of the scour hole and the relative position of the pipe. For the present, the bed form is assumed constant, only the sagging of the pipe is discussed.

The influence of the sagging on the flow velocity under the pipe is different in two stages.

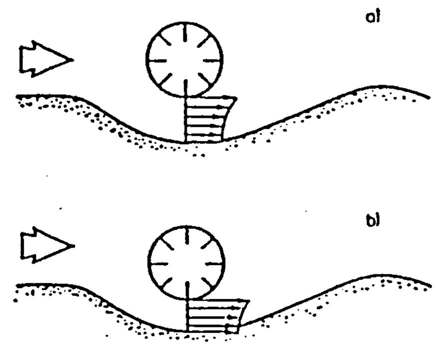

Fig. 3.5 At the early stage the sagging increases the flow velocity under the pipe.

As shown in Fig. 3.5, at the early stage, the sagging of the pipeline promotes the scour. Because the gap between the pipe and the scour hole is reduced, while the flow discharge passing from the gap is nearly the same as before, the velocity under the pipe is increased.

At the later stage, sagging into the scour hole the pipe partly becomes protected against the flow. The flow velocity in the gap is therefore reduced (see Fig. 3.6). The result is that the scour rate under the pipe is decreased.

3.2.3 The sustained situation of the pipeline

In the spreading process of the scour hole, due to the action of the flow and the gravity, the sediment particles on the

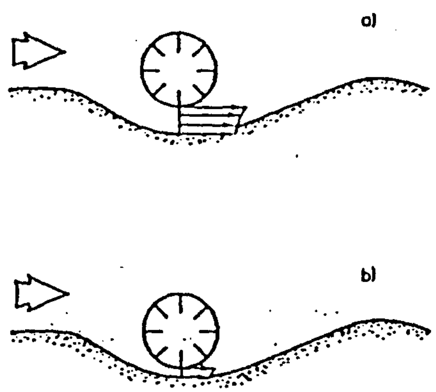

Fig. 3.6 At the later stage the sagging reduces the flow velocity under the pipe.

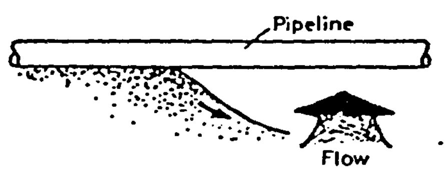

Fig. 3.7 Sketch of the slope situation of the scour hole.

slope are sliding down, widening the scour hole (see Fig. 3.7).

When the span length is longer, the pipeline gives larger pressure on the sustaining part of the bed. Consequently, the frictional forces between the sediment particles on the slope are increased. It is more and more difficult for those particles on the slope to slide down. The spread rate of the scour hole is therefore reducing with the increase of the span length.

Detailed knowledge of the sustaining part of the bed is needed. As an approximation, the sustained part of the pipeline is generally considered to be a kind of situation between the

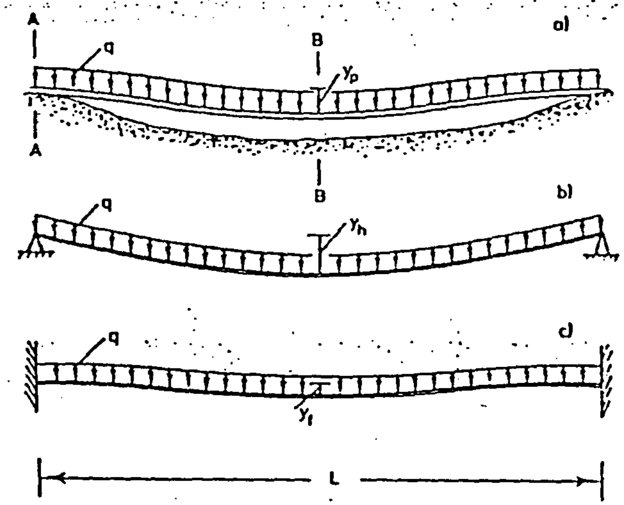

Fig. 3.8 The comparison between the pipeline and other girders.

(a) the real pipeline;

(b) the hinged-edges-girder, $y_h = \frac{5}{384}\frac{qL^4}{EI}$;

(c) the fixed-ends-girders, $y_f = \frac{1}{384}\frac{qL^4}{EI}$.

two extremes, the hinged-edges and the fixed-ends. (See Fig. 3.8). The three-dimensional scour under a pipeline stops mainly due to the continuous sagging of the mid-span.

In brief, the simplified physical model on the three-dimensional scour is the following:

To analyse the three-dimensional scour phenomenon, the pipeline could be considered a uniform girder with circular sections shown in Fig. 3.8(a). In the section A-A, the pipe is assumed not to sag at all. In the section B-B, the scour continues until the sagged pipe comes into contact with the eroded bottom.

3.3 The effect of sagging on the final scour hole

The spreading rate of the scour hole along the pipe axis may influence the dimensions of the scour hole: If the scour spreads very fast, the pipe will sag quite fast. On the other hand, if the spread occurs slowly compared with the erosion process under the mid-spand of the pipeline, the pipe will sag very slowly into the scour hole. In this case, the scour underneath the pipeline will be similar to the scour in the fixed-pipe case, as described in chapter 2.

Hence, the influence of the spreading of the scour hole along the pipe axis on the final scour can be studied by studying the effect of the sagging velocity of the pipeline V_s on the final scour depth of the two-dimensional scour at the middle of the three-dimensional scour hole (see Fig. 3.8, the cross section B-B).

This effect has been studied experimentally.

3.3.1 Experimental set-up

Some of the equipment used in the sagging experiments has been described in chapter 2. Hereafter, in the following chapters only the salient features as well as the adaption for specified tests will be briefly described.

A unit length of pipe was chosen as the model of the middle part of the pipeline. The diameter of the pipe covered with rubber was 10.1 cm. The length of the pipe was 1.99 m, which was 1 cm shorter than the width of the flume. (For details see section 2.4.1).

In order to simulate the sagging of the pipe, a long screw bolt was connected to the frame which supported the pipe (see Fig. 3.9). By turning the handle (by hand), the pipe could be moved quite smoothly up and down.

In the experiments, the following parameters have been varied:

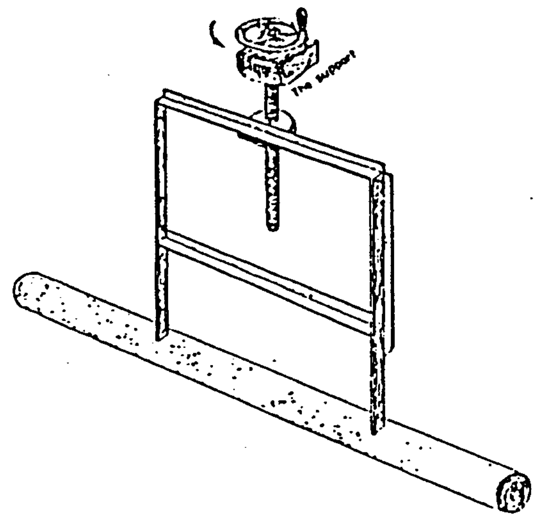

Fig. 3.9
Sketch of the sagged pipe.

1. The Shield's parameter θ_* (for the definition see Eq. (2.22)). θ_* = 0.098 and 0.15.

2. The sagging velocity of the pipe V_s. It was kept constant during each test. V_s = 0.62 to 12.4 mm/min.

3. The initial relative gap e_0/D between the pipe and the undisturbed plane bed. e_0/D = 0 and 0.1.

4. The boundary situation. Two different boundary situations were taken. This is related to the following considerations:

The necessary condition for starting the sagging is that there is a scour hole underneath the pipeline. It means that the pipeline starts sagging when there is a certain scour gap under the pipe.

In the experiments, different initial boundaries underneath the pipe correspond to different starting moments. It is known that at the early scour stage there is quite a high hill downstream the pipe in unidirectional flow (see Fig. 3.10(a)). It takes time to move the downstream hill away from the pipe, and during this period the scour depth under the pipe remains nearly constant.

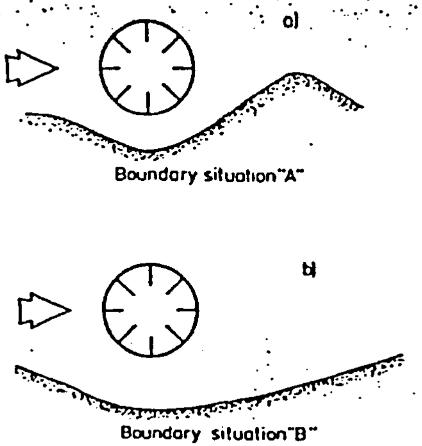

Fig. 3.10 Sketch of the boundary situation "A" and "B".

The boundary situation with the presence of the downstream hill is designated "A" (Fig. 3.10(a)). The boundary situation without the hill is designated "B" (Fig. 3.10(b)). When the pipe started to sag, the relative scour gap between the pipe and the eroded bed in the case of "A" was about 0.4, and in the case of "B" about 0.6.

The experiments carried out are listed in the table 3.1 with the circles.

Table 3.1 The summary of the test conditions

θ_∞	Boundary situation	e_0/D	V_s (mm/min)					
			12.4	6.2	3.1	1.5	1.03	0.62
0.098	A	0.1	o	o	o	o		o
	B		o	o	o		o	
0.15	A	0.	o	o	o		o	
	B		o	o	o			

3.3.2 Experimental results and analysis

Fig. 3.11 shows the variation in the final scour depth with the sagging velocity. In Fig. 3.11(a), the results correspond to the small value of θ_∞, while Fig. 3.11(b) shows the similar results for somewhat larger values of θ_∞ (the largest possible value in the present set-up for the given grain size).

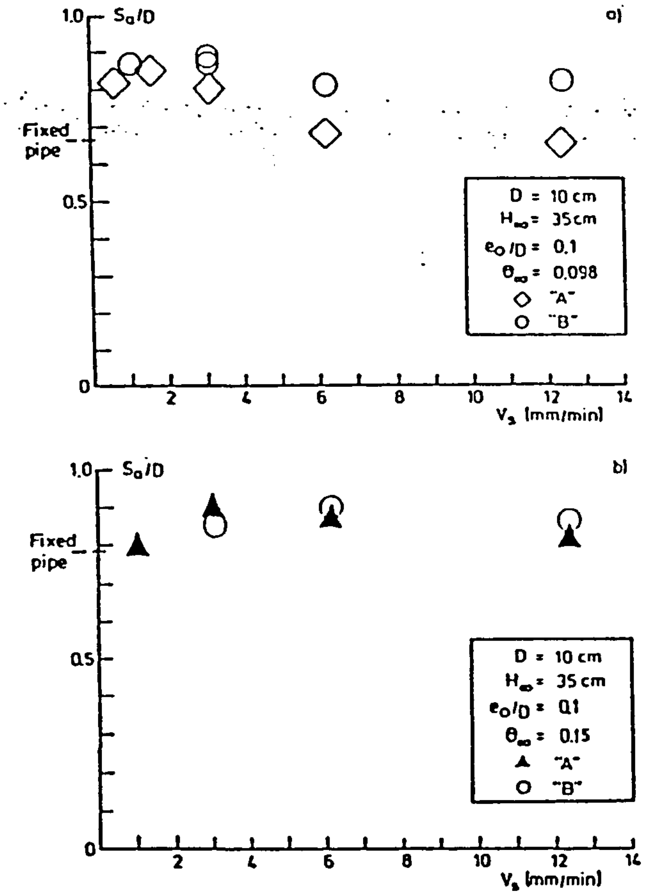

Fig. 3.11 The relative scour depths S_a/D versus sagging velocity V_s for the boundary situation "A" and "B". a) θ_∞ = 0.098. b) θ_∞ = 0.15.

It is seen that the final scour depth in the sagged-pipe case is always deeper than that in the fixed-pipe case.

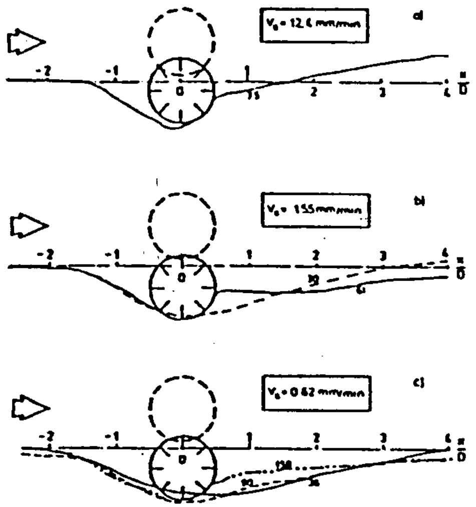

Fig. 3.12 The scour bed profile for θ_∞ = 0.098, e_0/D = 0.1 with the boundary situation "A". (number in min.).

A. The development in bed profiles

Fig. 3.12 to Fig. 3.15 show the measured longitudinal bed profiles.

In Fig. 3.12, θ_∞ = 0.098 and the relative gap between the pipe and the undisturbed bed e_0/D = 0.1, and the boundary situation is "A". It is seen that with increasing sagging velocity of the pipe the scour hole becomes deeper. The streamwise dimension of the scour hole varies with the sagging velocity in the following way: The scour hole becomes wider with the increasing sagging velocity. The downstream hill is seen in Fig. 3.12(a). In Fig. 3.12(b) and (c), the hill is seen to be moved away because the sagging velocity is relatively small (cf. the discussion above about the boundary situation "A" and "B"). It

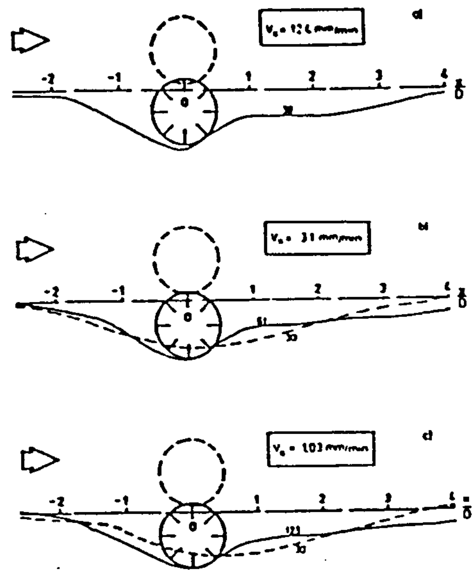

Fig. 3.13 The scour bed profiles for θ_∞ = 0.098, e_0/D = 0.1 with the boundary situation "B". (number in min.).

should be mentioned that in the sagging process of the pipe, some sediment particles are deposited on the bed just downstream the pipe (see Fig. 3.12(c). The sagging process of the pipe is stopped because of the deposition of sediment on the downstream slope so the gap is filled.

Fig. 3.13 shows the scour profiles for different sagging velocities of the pipe. The boundary situation differs from Fig. 3.12 in the way that in Fig. 3.13 the pipe does not start to sag until the flow has run for 30 min. (see Fig. 3.13(b) and (c). t = 30 min.). Hereby the hill originally formed downstream the pipe was moved away by the flow (boundary situation "B"). In this case the streamwise dimension only varies slightly with the sagging velocity. It is interesting that the final scour depths

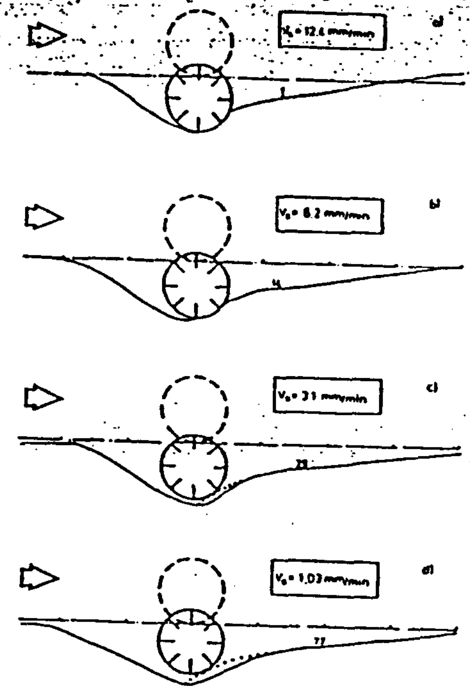

Fig. 3.14. The scour bed profiles for θ_∞ = 0.15, e_0/D = 0 with boundary situation "A".
—— : the mean value;
... : the local longitudinal profile below the pipe.
(number in min.).

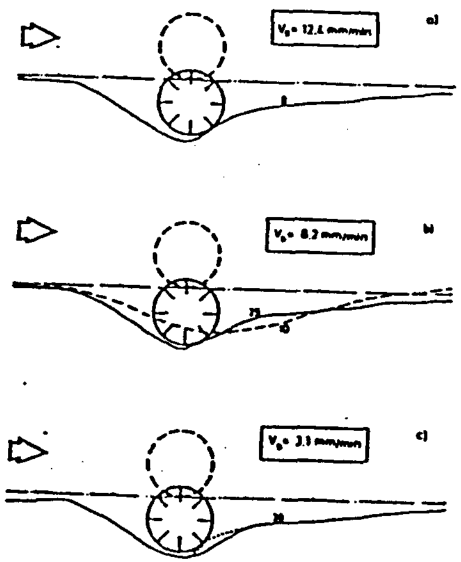

Fig. 3.15. The scour bed profiles for θ_∞ = 0.15, e_0/D = 0 with boundary situation "B".
—— : the mean value;
... : the local longitudinal profile below the pipe.
(number in min.).

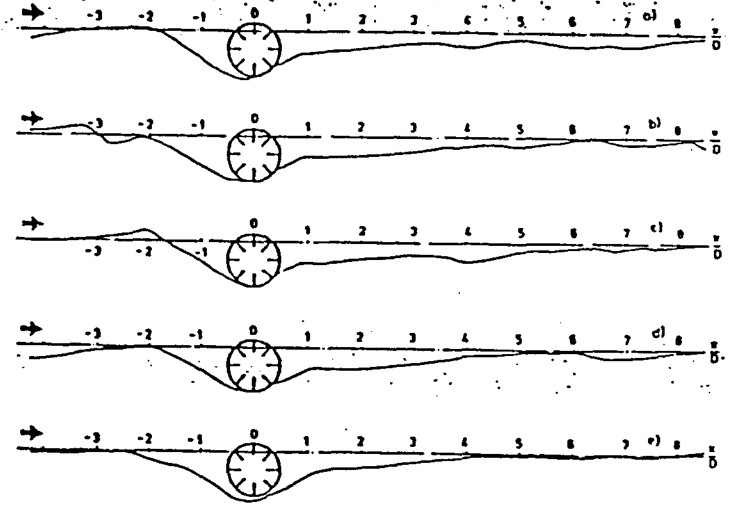

Fig. 3.16 The scour bed profiles measured in five longitudinal sections for θ_∞ = 0.098, e_0/D = 0.1, boundary situation "B" and V_s = 1.03 mm/min.

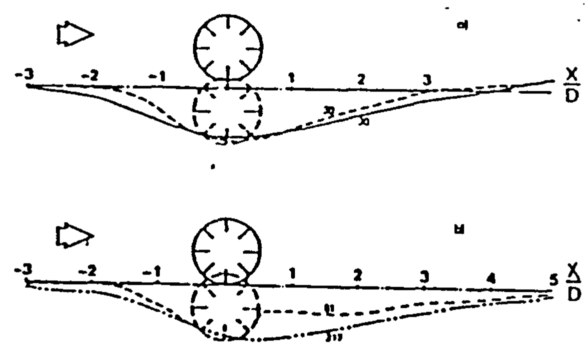

Fig. 3.17 The comparison of the eroded bed profiles between the sagged-pipe case and the fixed - pipe case for θ_∞ = 0.098. (number in min.).
—— : the fixed pipe, e_0/D = 0.1;
-·-· : fixed pipe, e_0/D = 0;
- - - - : the sagged pipe, e_0/D = 0.1, V_s = 1.55 mm/min.

are approximately the same for different sagging velocities. In all cases, boundary situation "B" always results in a deeper final scour depth than "A".

Fig. 3.14 shows the scour profiles for θ_∞ = 0.15. Here, the gap between the pipe and the undisturbed bed is zero and the boundary situation is "A". The tendency is similar to that shown in Fig. 3.12, but the final scour depth is a little deeper. This is partly because of the larger value of the Shields parameter and partly due to the smaller value of e_0/D, which both contribute to a larger scour depth (cf. chapter 2).

Fig. 3.15 shows the scour profiles for θ_∞ = 0.15 and e_0/D = 0, but with the boundary situation "B". After 10 minutes run, the pipe started to sag. The created initial boundary situation "B" is shown as a dashed line in Fig. 3.15(b). The final bed profiles are very similar independently of the sagging velocity. The final scour depth is a little deeper than that in the case of boundary situation "A".

B. The three-dimensional character of the scour holes

If the sagging velocity is rather small, the scour hole is influenced by the movement of the sand waves which are of three-dimensional character. Fig. 3.16 shows the measured bed profiles in five longitudinal sections (cf. section 2.4.1 and Fig. 2.25). The data are: θ_∞ = 0.098, e_0/D = 0.1 and V_s = 1.03 mm/min. The mean value of the five profiles is plotted in Fig. 3.13(c). It is seen that the upstream parts are different in Fig. 3.16, but the downstream parts are similar.

In the case that the Shields parameter θ_∞ is relatively higher and the sagging velocity is lower the three-dimensional character of the scour hole is clearer. The downstream part of the scour hole differs along the axis of the pipe. The dashed lines in Fig. 3.14(c), (d) and Fig. 3-15(c) show that the pipe was stopped by the local higher elevation on the downstream slope.

C. Comparing with the fixed-pipe case

The comparison of the eroded bed profiles between the sagged-pipe case and the fixed-pipe case for θ_∞ = 0.098 is shown

in Fig. 3.17. It is seen that the streamwise dimension of the scour hole becomes smaller around the sagged pipe than around the fixed pipe. Further, the scour depth directly under the pipe in the sagged-pipe case is slightly deeper than that in the fixed pipe case.

3.3.3. The conclusions drawn from the experiments

The following conclusions are made:

1. The sagging of the pipeline has essential effects on the underneath scour. In the sagged-pipe case the scour hole is slightly deeper than that in the fixed-pipe case.

2. The sagging of the pipe reduces the streamwise dimension of the scour hole. The gap will be filled just downstream the pipe due to the continuous sagging of the pipeline.

3. The final scour depth varies slightly with the sagging velocity of the pipeline. The initial scour profile before sagging only influences the final scour depth in the case where the Shields parameter is relatively small, and the sagging velocity is relatively high.

4. The maximum value of the final scour depth is approximately one diameter of the pipeline.

3.4 The estimation of the maximum span length

3.4.1 A theoretical formula

The pipeline can be considered as a uniform girder with a circular section. According to the physical model (cf. section 3.2.3), the three-dimensional scour can be simplified as the scour under the girder with two sustained ends (see Fig. 3.8(a)).

When there is no scour underneath the pipeline, the load on the pipeline is balanced by the support of the plane bed under the pipeline.

If the scour hole under the pipeline is wide enough, the pipeline sags until it reaches the scour hole. It is well known that the deflexion of a girder has its maximum value at the mid span. Because only the deflexion at the mid-span will be discussed in the following, for simplicity, it is designated to be Y with omitting "max" (see Fig. 3.8). It is evident that with the increase of the span the value of y will be larger.

In the case where the ends of the girder are the hinged edges (see Fig. 3.8(b)), the maximum deflexion Y_h reads

$$Y_h = \frac{5}{384}\frac{qL^4}{EI} \tag{3.2}$$

In the case where the ends of the girder are the fixed ends, the maximum deflexion Y_f reads

$$Y_f = \frac{1}{384}\frac{qL^4}{EI} \tag{3.3}$$

It should be mentioned that the only difference between Eq. (3.2) and (3.3) is the coefficient, which is due to the different conditions at the ends. The maximum defelxion is decreased with the reduction of the freedom at the ends.

Similarly, the maximum deflexion at the pipeline Y_{max} can be calculated by

$$Y_p = \alpha\frac{qL^4}{EI} \tag{3.4}$$

where α is a coefficient depending on the end situations. Because the end situation of the real pipeline is supposed to be the middle between the hinged edges and the fixed ends the value of α is between 1/384 and 5/384.

The sagging velocity of the pipeline is a function of the deflexion Y_p and the spread velocity of the span. The relation reads

$$V_s = \frac{dY_p}{dt} = \frac{dY_p}{dL}\ \frac{dL}{dt} \tag{3.5}$$

the sagging velocity V_s is in direct proportion to the spread velocity of the scour hole.

As soon as the values of dY_p/dt and dY/dL are known, the spread velocity of span can be calculated by

$$\frac{dL}{dt} = \frac{dY_p}{dt}\Big/\frac{dY_p}{dL} \tag{3.6}$$

By inserting Eq. (3.4), Eq. (3.6) is recast to be

$$\frac{dL}{dt} = \frac{EI}{4\alpha qL^3}\frac{dY_p}{dt} \tag{3.7}$$

Leeuwestein et al. reported that the order of the spread velocity dL/dt had the order of 10^{-2} to 10^{-1} m/h (cf. [3]). Fron the engineering point of view the length of the span is more important than the spread velocity.

Eq. (3.7) can be reformed as

$$\frac{d(L^4)}{dt} = \frac{EI}{\alpha q}\frac{dY_p}{dt} \tag{3.8}$$

Then the span length at any moment t can be calculated by integrating Eq. (3.8):

$$L = \left[\frac{EI}{\alpha q}\int_0^t \frac{dY_p}{dt}\,dt\right]^{1/4} \tag{3.9}$$

According to the simplified physical model, the scour process ends when the sagged pipe comes into contact with the scour hole. It means that the value of Y_p is equal to the scour depth under the pipeline. It reads

$$S_a = \int_0^T \frac{dY_p}{dt}\,dt \tag{3.10}$$

in which T is the total time of the sagging process of the pipeline.

The maximum length of the span corresponding to the maximum flexibility reads

$$L_{max} = \left[\frac{EI}{\alpha q}S_a\right]^{1/4} \tag{3.11}$$

As an approximation, taking

$$S_a = D \tag{3.12}$$

and $$\alpha = \frac{3}{384} \tag{3.13}$$

Eq. (3.11) has become $$L_{max} = \left[\frac{126\ EID}{q}\right]^{1/4} \tag{3.14}$$

It should be recast as a dimensionless formula

$$\frac{L_{max}}{D} = \left[\frac{126\ EI}{qD^3}\right]^{1/4} \tag{3.15}$$

The maximum span length L_{max} can be compared with the stiffness length L_s (see Eq. (3.1). By inserting Eq. (3.1), the Eq. (3.14) reads

$$L_{max} = [126 \cdot D \cdot L_s^3]^{1/4}$$
$$= 3.35\ D^{1/4}\ L_s^{3/4} \tag{3.16}$$

It means that the maximum span length is in direct proportion to the stiffness length of the pipeline.

3.4.2 A numerical example

It is well known that the safety coefficient of the pipeline decreases with the increase of the span length.

The data given by Bijker [1] were taken as the input of the numerical example.

The pipeline is supposed uniform. Fig. 3.18 shows the sketch of the cross-section. The outer diameter of the steel pipe is 1.27 m, the steel wall has the thickness of 25 mm, the reinforced concrete cover is 65 mm thick.

The elasticity modulus of steel is $E = 2.1 \times 10^{11}$ N/m². As a component pipe, because the elasticity modulus of the reinforced concrete is smaller than that of the steel, the component elasticity is smaller than the elasticity modulus of steel. From the engineering point of view, in order to get a higher safety coefficient in the calculation, the value of the elasticity modulus of steel should be taken.

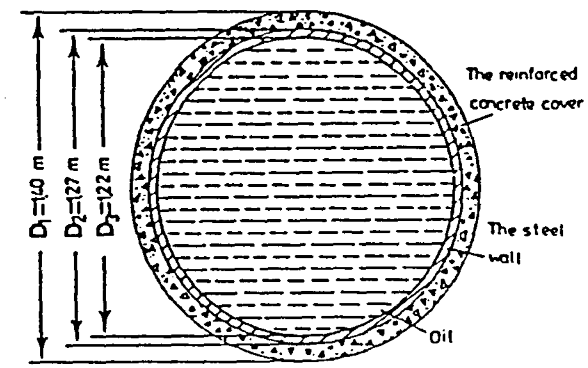

Fig. 3.18 Sketch of the cross section of the pipeline.

The bending moment relative to the central axis in the cross section of the circle can be calculated as

$$I = \frac{\pi}{64}\,(D_1^4 - D_3^4), \tag{3.17}$$

where D_1 is the outer diameter of the circle; D_3 is the internal diameter of the circle.

Here a large value of I is chosen to get a higher safety coefficient.

By inserting D_1 = 1.40 m, D_3 = 1.22 m, the bending moment of inertia is $I = 0.08\ m^4$.

Suppose that the pipeline is filled with oil. The specific weight of oil γ_{oil} is taken as 0.8, and the specific weights of steel and reinforced concrete γ_{steel}, $\gamma_{concrete}$ are taken as 7.8 and 3.0, respectively.

The unit load q of the pipeline in water could be calculated by

$$q = [\tfrac{\pi}{4}\,(D_2^2 - D_3^2)\ \gamma_{steel} + \tfrac{\pi}{4}(D_1^2 - D_2^2)\gamma_{concrete} +$$
$$+ \tfrac{\pi}{4}\,D_3^2 \times \gamma_{oil} - \tfrac{\pi}{4}\,D_1^2\ \gamma] \times 1$$

$$= (0.098 \times 7.8 + 0.273 \times 3.0 + 1.169 \times 0.8 + 1.539) \times 10^3$$

$$= 980 \text{ kg/m} = 9613.8 \text{ N/m} \qquad (3.18)$$

By inserting E, I and q into Eq. (3.1), we get the value of the stiffness length of the pipeline, $L_s = 120$ m

Then, the maximum span length is calculated by Eq. (3.16):

$$L_{max} = 133 \text{ m.}$$

The calculated result seems quite reasonable.

3.5 Summary

A simplified physical model on the three-dimensional scour in a current has been proposed. The sagging of the pipeline plays the key role in the development of the three-dimensional scour.

Experimental results indicate that the Shields parameter θ_∞, the sagging velocity of the pipe V_s and the boundary situation have some influence on the final scour depth. In general, the scour depth in the sagged-pipe case is slightly deeper than that in the fixed-pipe case. The maximum scour depth is approximately one diameter of the pipeline.

A formula to estimate the maximum length of the span is given. The numerical example shows that the calculated results are satisfactory.

3.6 References

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CHAPTER 4

THE EFFECT OF THE LEE-WAKE ON THE SCOUR BELOW PIPELINES

4.1 Introduction

In the present chapter, the effect of the lee-wake behind the pipelines on the scour is studied.

The measured equilibrium bed profiles in the two-dimensional flow (see Fig. 2.18) indicated that the downstream slope of the scour hole is quite gentle while the upstream slope is steep.

As demonstrated in chapter 2, the modified potential flow theory is able to explain the maximum scour hole under the pipe and the slope of the upstream part. But the modified potential flow theory is not suitable to explain the scour downstream the pipe.

The more gentle slope is caused by the strong turbulence formed downstream the pipe (see Fig. 2.5). In practice, the increased turbulence downstream the pipe is mainly created by the vortex shedding.

In this chapter, the conditions for the appearance of the vortex shedding in the scour process below the pipe are studied first. After that the results on the vortex shedding induced erosion are presented. Then, the experimental results for the vortex-induced velocity near the bed are introduced. A simple model for the vortex induced velocity near the bed is proposed, and the calculated results are compared with measured data. Finally the effect of the scour on the velocity field induced by the vortex shedding is presented.

4.2 Experimental set-up

The experiments were carried out partly in the 2 m wide flume with the sand bed used before (see Fig. 2.24). In the flume, two pipe models with diameters of 100 mm and 50 mm, re-

Table 4.1 Summary of the test conditions

	FLOW			PIPE MODEL			SEDIMENT		
	Flow depth H_∞ (cm)	Mean flow velocity U_∞ (cm/s)	Bed shear velocity U_f (cm/s)	Pipe diameter D (mm)	Pipe surface	Pipe Reynolds number $Re = \frac{D\,U_\infty}{\nu}$	Mean grain size d_{50} (mm)	Grain Reynolds number $\frac{d_{50}\,U_f}{\nu}$	Shields parameter $Re = \frac{U_f^2}{g(s-1)d_{50}}$
The loose-bed experiment	35	25	1.04	50	smooth	1.25×10^4	0.36	3.77	0.019
	35	25	1.04	100	smooth	2.50×10^4	0.36	3.77	0.019
The rigid-bed experiments	18	39	1.79	30	smooth	1.18×10^4			

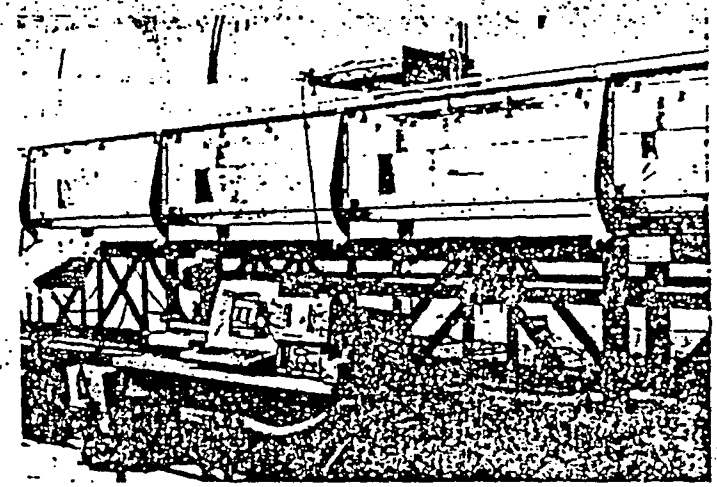

Plate 4.1 The tilting flume and the terminal of the computer SPC/1.

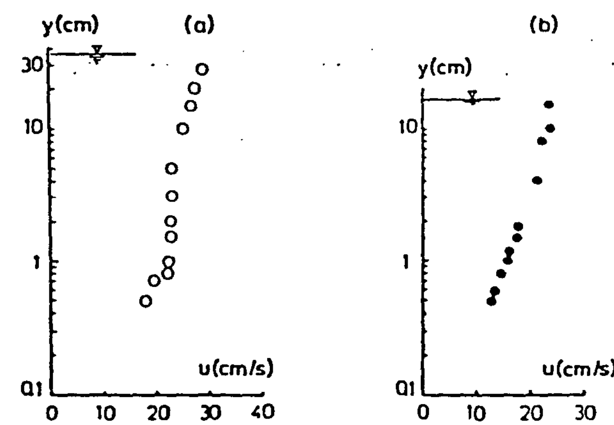

Fig. 4.1 The undisturbed velocity profiles measured far away from the pipe.
(a) In the 2 m wide flume
(b) In the 0.3 m wide flume.

spectively, have been used. The surface of them were hydraulically smooth.

Some experiments were conducted in a tilting flume with a rigid bed. (See plate 4.1) The flume dimensions were 0.3 × 0.3 × 10 m. It has a hydraulically smooth bottom and glass side walls. A plexiglass cylinder with a diameter of 30 mm was used as the pipe model. The surface of the cylinder was also smooth.

The micro-propeller with a diameter of 5 mm was used to measure the velocity. The velocity time series digitized and stored on a computer (SPC/1) were processed off-line.

The sand bed follower was used to measure the bed profiles.

Fig. 4.1 (a) and (b) show the measured velocity distributions in the vertical direction in the 2 m wide flume and in the 0.3 m wide flume respectively.

Table 4.1 is the summary of the test conditions. For the sake of clearness, the tests carried out in the 2 m wide flume are designated "the loose-bed experiments", and the tests carried out in the 0.3 m wide flume are designated "the rigid-bed experiments".

4.3 The occurrence of the vortex shedding

It is well known that the flow passing a stationary cylinder separates at the top and bottom of the cylinder, vortices are shed, forming a wake.

The Strouhal number is defined by

$$S_t = \frac{f\ D}{U_\infty} \qquad (4.1)$$

in which f is the frequency of pairs of vortices. f is the function of the Reynolds number defined by

$$Re = \frac{D\ U_\infty}{\nu} \qquad (4.2)$$

where ν is the kinematic viscosity of water. Fig. 4.2 shows that for a free cylinder in a wide range of Reynolds number $10^2 < Re < 10^5$, the Strouhal number keeps constant, St = 0.2. In fact, the Strouhal number of the vortices is effected by the roughness

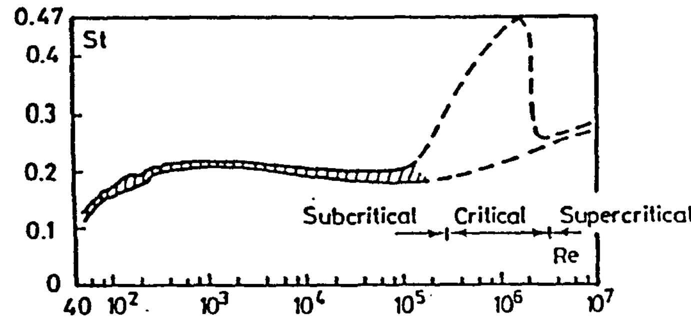

Fig. 4.2 Strouhal number vs. Re number.

of the pipe surface and the boundary close to the pipe.

Fig. 4.3 is the spectral density distribution of the velocity measured at the upper and the lower edge behind the pipe which is placed at 1.5 times the pipe diameter above a plane bed. The dominant frequency was 0.57 Hz, corresponding to St = 0.23.

When a pipe is placed close to a plane bed, as pointed out by Bearman and Zdravkovich [1], the regular vortex shedding is suppressed if the gap ratio between the pipe and the plane bed is less than 0.3.

When the undisturbed flow velocity is large enough, the bed under a pipe is eroded forming a gap. Fig. 4.4 shows the serial spectral density distribution of the streamwise component of the velocity u measured at the upper edge behind the pipe during the scour process.

The following conclusions may be drawn from the figures:

1. When the gap ratio e/D < 0.35, there is no clear regular vortex shedding. In the early stage of the scour process there is a relatively high hill downstream the pipe. Although the gap ratio is larger than 0.3, the space behind the pipe is not large enough for the vortices at the upper and lower edges to grow and to interact. The first appearance of the vortex shedding corresponded to t = 15 min, when the gap ratio is larger than 0.35. Due to the erosion of the bed below the pipe, the Strouhal number varied. At last, at t = 60 min. the vortex shedding frequency corresponded to St = 0.20.

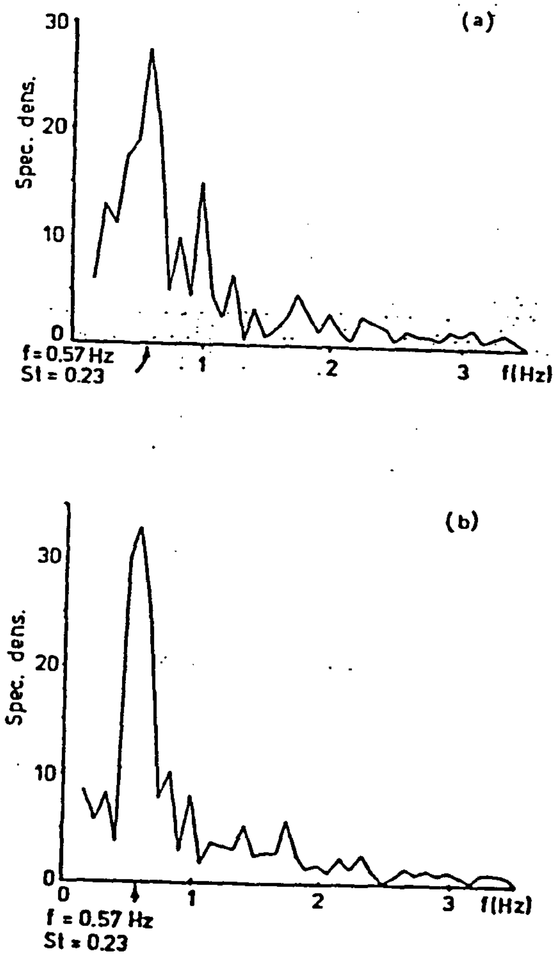

Fig. 4.3 The spectral density distribution of the velocity for $e_0/D = 1.5$, $\theta_\infty = 0.019$ with the erodible bed.
a) Measured at the upper edge behind a pipe;
b) Measured at the lower edge behind a pipe.

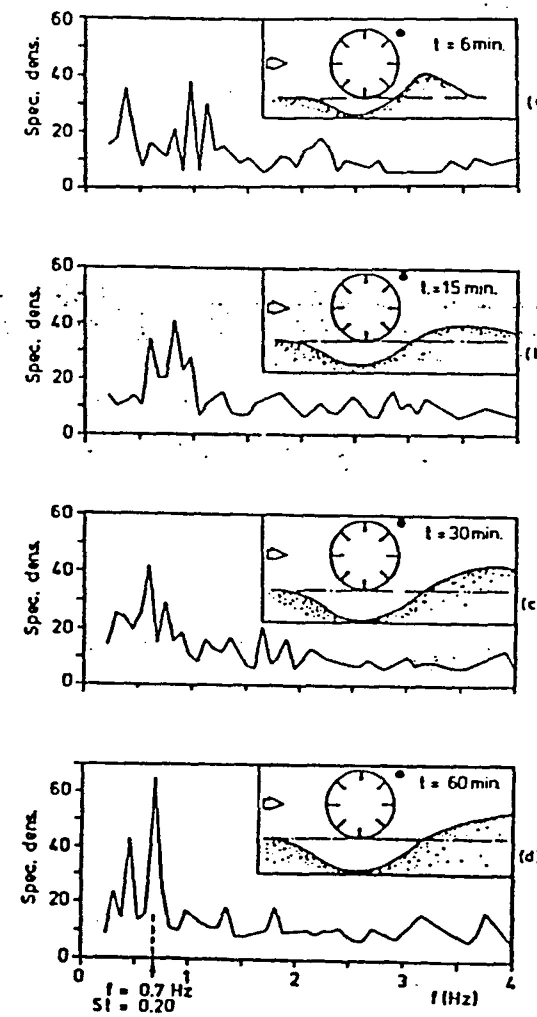

Fig. 4.4 The spectral density distributions of the velocities measured at the upper edge behind the pipe (see position •) in the scour process. Measured with a Laser Doppler Anemometer made by DANTEC.

2. Compared with the total scour process the vortex shedding appeared at rather quite early stage. Therefore the question is: what is the role of the vortex shedding in the scour below pipelines?

4.4 The vortex-induced erosion

4.4.1 The scour in the case that the sediment transport rate is very low

To investigate the effect of the vortex shedding alone in the erosion, the transport stage in the present tests is kept very low, well below the incipient sediment transport. In that way the influence of factors other than the vortex shedding can be minimized if not reduced to zero. To this end, the Shields parameter θ_{-} in the tests with the loose-bed was chosen to be 0.019.

Fig. 4.5 and Fig. 4.6 show the scour bed profiles obtained for two different pipe diameters. In the tests the initial gap between the pipe and the plan bed varied.

From the figures the following conclusions are straightforward:

1. The scour occurs downstream the pipe rather than just under it, which indicates that the erosion there is induced by the action of the leewake, namely the vortex shedding.

2. The scour depth decreases as the pipe position above the plan bed is higher, indicating that the effect of the wake decreases as the initial gap increases. Fig. 4.5 (a) and Fig. 4.6 (a) indicate that the scour ceases to exist as the gap exceeds approximately two times the pipe diameter.

4.4.2 The flow visualization study

A flow visualization study was conducted by injecting dye into the near-wake region of the pipe. The sediment motion was simultaneously observed when the flow structures marked by the dye were passing above the bed. It was very clear that in the scour region shown in Fig. 4.5 and Fig. 4.6, the sediment transport is intermittent and occurs periodically at the time when

the vortex shed from the lower edge of the pipe passes over. Meanwhile the sand particles placed directly under the pipe or placed upstream the pipe did not move. Fig. 4.7 schematically illustrates the observed phenomenon. The observed periodic sediment movement is in good agreement with the Strouhal number St = 0.2, confirming that the sediment movement is caused by the vortex shedding.

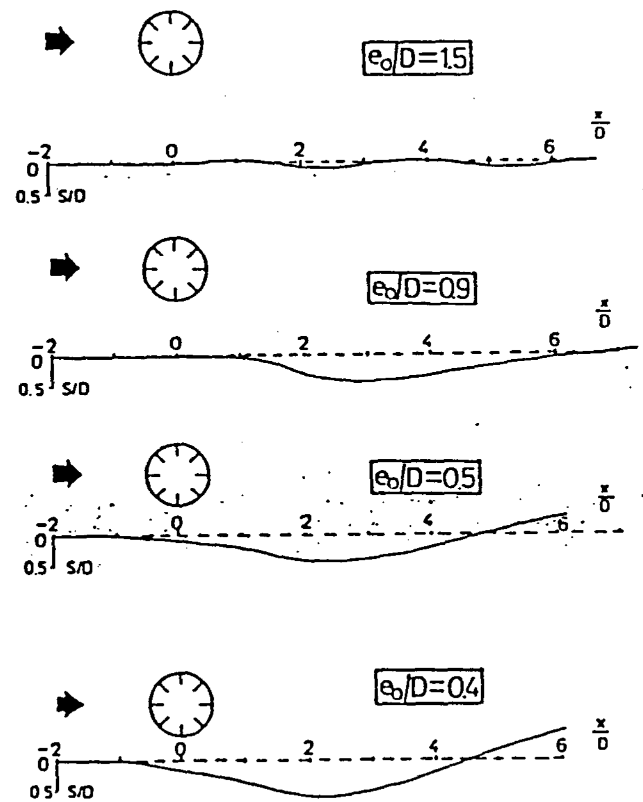

Fig. 4.5 Scour bed profiles at t = 400 min.
θ_{-} = 0.019, D = 100 mm.

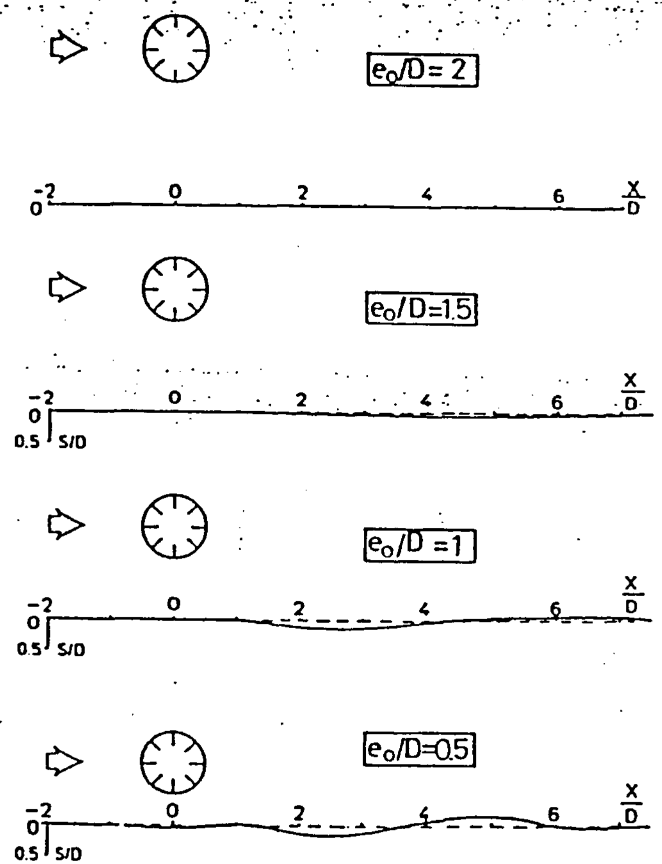

Fig. 4.6 Scour bed profiles at t = 200 min. θ_∞ = 0.019, D = 50 mm.

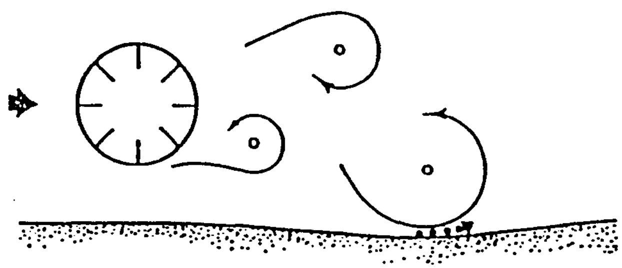

Fig. 4.7 Sediment motion caused by the vortex passing overhead.

4.4.3 The flow velocity study

To understand the role of the vortex shedding in the scour, it is necessary to study the flow velocity downstream the pipe, especially the flow field near the bed.

A. Some definitions in the analysis of velocity.

During the sampling process, the flow velocity had already been digitized. The sampling time interval as ΔT = 0.012 S, the sample size is the total sampling time $T = \Delta T \times 2047 = 24.564$ S.

The mean flow velocity at a measurement point with respect to the total sampling time T is defined by

$$\bar{u} = \left(\sum_{i=1}^{n} u_i\right)/n \tag{4.3}$$

where u_i is the digitized velocity and $n = T/\Delta T + 1$.

The fluctuation velocity u' was defined by

$$u' = u - \bar{u} \tag{4.4}$$

The root-mean-square value of u' (i.e. the r.m.s.) or the so-called flow turbulent intensity σ is defined by

$$\sigma = \sqrt{\overline{u'^2}} = \sqrt{\left(\sum_{i=1}^{n} (u_i - \bar{u})^2/n\right)} \tag{4.5}$$

B. The comparison of the velocities between the upstream and near-wake region

The flow velocity was measured along the stream at 5 mm above the bed (cf. Fig. 4.8).

Fig. 4.9 (a) and (b) show a part of two measured samples of the streamwise component of the velocity u. Fig. 4.9 (a) corresponds to the undisturbed flow velocity far upstream while (b) corresponds to the flow velocity in the section downstream the pipe with x/D = 3. Fig. 4.9 (b) clearly indicates that the sediment bed in the near-wake region is exposed to a periodic velocity field.

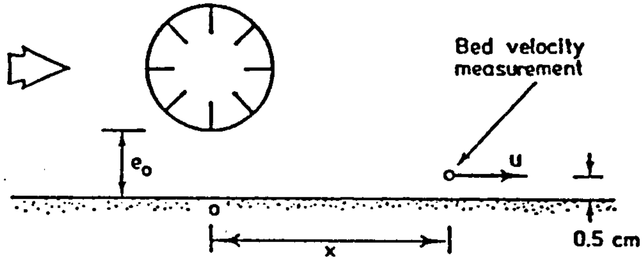

Fig. 4.8 Definition sketch for bed velocity measurement.

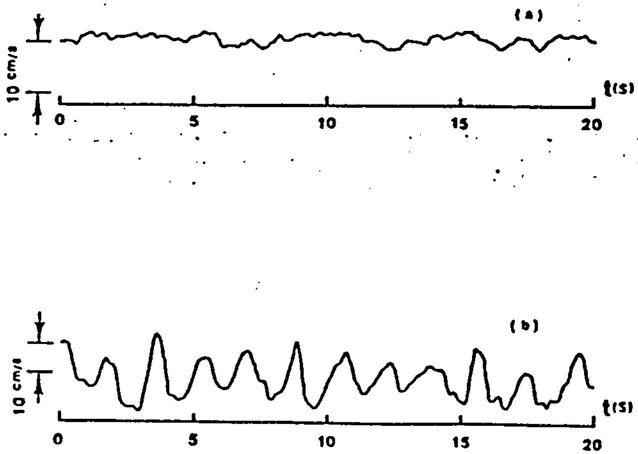

Fig. 4.9 Samples of near-bed velocity records in the loose-bed experiments. D = 100 mm. (a) Far upstream the pipe with x/D = − 15. (b) Downstream the pipe with x/D = 3, e_0/D = 1.0.

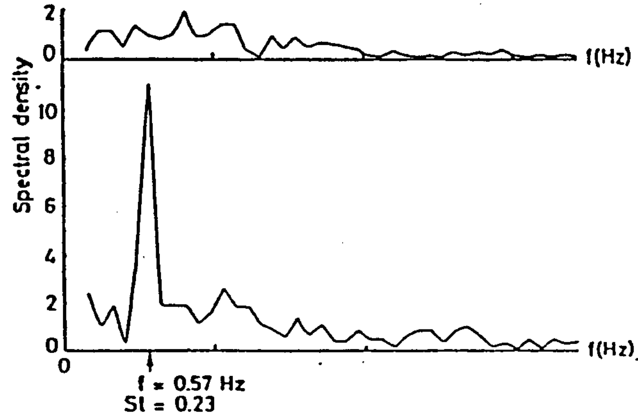

Fig. 4.10 Spectral density distribution of flow velocity measurements in Fig. 4.9.

Fig. 4.10 is the spectral density distributions of the velocity records partly depicted in Fig. 4.9. It is seen clearly that the dominant frequency of the velocity record shown in Fig. 4.9 (b) is nothing but the frequency corresponding to St = 0.23, revealing the fact that the periodic velocity field exposed by the bed in the near-wake region is created by the vortex shedding.

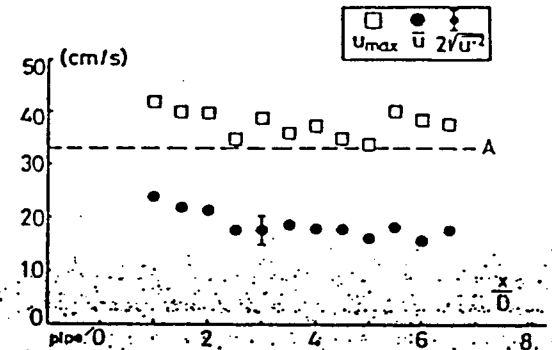

Fig. 4.11 Variation of the near-bed velocity u with respect to the downstream distance from the pipe. "A" is the threshold velocity for the sand particles used in the experiments.

C. Variation of the velocity in the near-wake region.

Fig. 4.11 shows the variation of the near-bed velocity as a function of the downstream distance from the pipe. The threshold velocity for sediment particles is plotted as a reference line in Fig. 4.11. U_{max} represents the maximum value of the near-bed velocity seen at the points on the bed when the vortex that is shed from the lower edge of the pipe passes overhead.

The figure clearly shows that the sediment transport occurs only when the shed vortex sweeps the bed. This is because only during these brief periods are the near-bed velocities large enough to move the sediment. Therefore this figure explains why the sediment transport observed in the tests was intermittent and occurred periodically.

4.4.4 A brief summary

The following conclusions can be drawn from the experimental information presented in this section:

1. In the scour below pipelines the vortex shedding is present from practically quite an early stage of the scour process. Then the near-wake bed region downstream the pipe undergoes the action of the vortex shedding.

2. The vortex shed from the lower edge of the pipe induces a fluctuating flow field in the near-wake bed region as it is convected downstream.

3. Every point of the bed downstream the pipe feels this extra velocity in the form of a periodic signal (see Fig. 4.9) with a frequency corresponding to St = 0.2.

4. This effect causes what might be termed the vortex shedding induced erosion downstream the pipe. Depending on the gap ratio the vortex shedding induced erosion may result in substantial scour as shown in Fig. 4.5 and Fig. 4.6.

4.5 The vortex-induced velocity near the bed

Now it is very clear that the vortex-induced velocity plays an important role in the scour below the pipe. In this

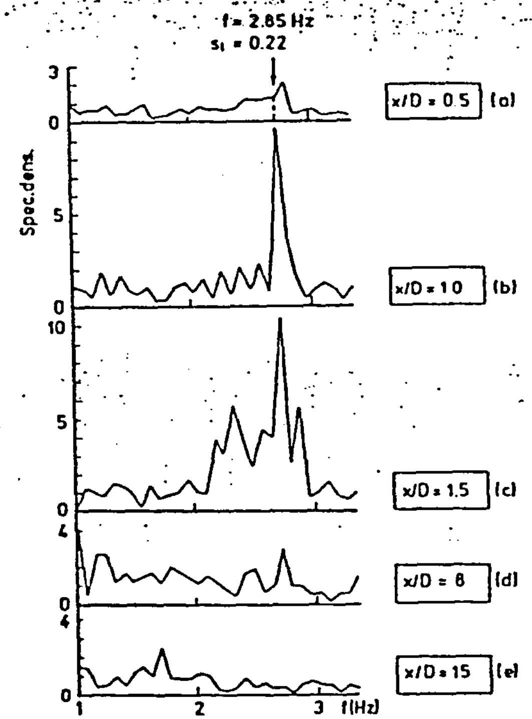

Fig. 4.12 Spectral density distributions of the near-bed velocity at various locations downstream the pipe in the rigid-bed experiment, $e_0/D = 0.6$.

section the properties of the vortex-shedding-induced velocity near the bed downstream the pipe are investigated further.

4.5.1 The vortex-shedding-influenced region along the stream

Fig. 4.12 shows the spectral density distribution of the near-bed velocity for different locations downstream the pipe. As seen from the figures, the dominant frequency of the vortex shedding was f = 2.85 Hz, which corresponded to the Strouhal number St = 0.22. The serial figures indicate that the vortex shedding-influenced region along the bed extends from x/D = 1 to x/D = 8. At the place where x/D = 0.5 ...

weakly effected by the vortex shedding (see Fig. 4.12 (a)). The spectral density distributions shown in Fig. 4.12 (b) and (c) indicate that the effect of the vortex shedding is quite strong in that region. Although the vortex shedding frequency in the spectral plot at x/D = 8 can still be detected (see Fig. 4.12 (d)), it is no longer the dominant frequency. From Fig. 4.12 (d) to (e) it is seen that the bed is not influenced by the vortex-induced velocity for the distances x/D > 8 and x/D < 1 for the present experimental conditions.

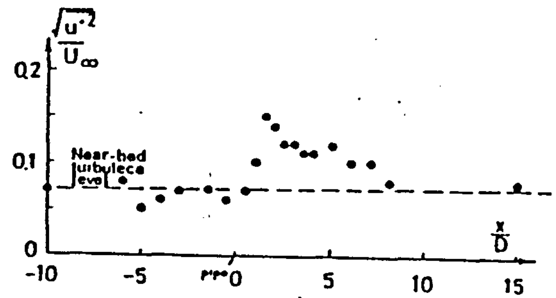

Fig. 4.13 $\frac{\sqrt{\overline{u'^2}}}{U_\infty}$ versus $\frac{x}{D}$ in the rigid-bed experiment, $\frac{e_0}{D} = 0.6$.

In Fig. 4.13, the variation of the relative r.m.s. value of the fluctuating near-bed velocity $\frac{\sqrt{\overline{u'^2}}}{U_\infty}$ with respect to the distance along the bed is plotted in comparison with the near-bed turbulent level upstream the pipe. It is seen from this figure that the excess r.m.s. velocity created by the vortex shedding ceases to exist at x/D = 8, thus confirming the analysis shown in Fig. 4.12.

Thus, one may conclude that the x-extent of the vortex-shedding-influenced region can be taken as $1 \lesssim \frac{x}{D} \lesssim 8$.

The preceding result is significant in the sense that it explains why the lee side of the scour hole below the pipe has a very gentle slope. Indeed, taking the scour depth as ~ D and the downstream extent of the vortex shedding-influenced region as ~ 8D, the lee-side slope of the scour hole is approximately 1:8, which agrees well with the values reported in the literature [6].

4.5.2. The description of the vortex-induced velocity

The vortex-shedding-induced velocity detected at the points on the bed in the wake region is schematically shown in Fig. 4.14. For the points on the bed, the velocity seen there varies periodically depending on the shedding of the vortex. The varying amplitude of the velocity is the double amplitude of the vortex-induced velocity denoted by 2 U_v.

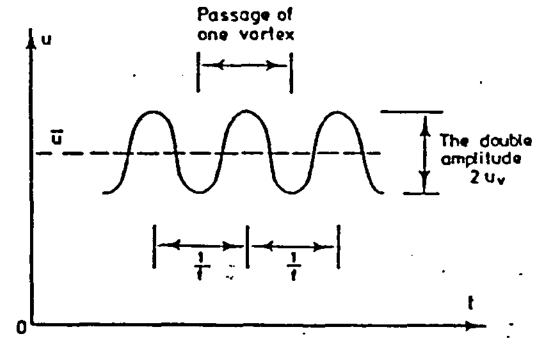

Fig. 4.14 The velocity seen at a point on the bed in the near-wake region.

Fig. 4.15 shows the variation of $2U_v$ with respect to the distance downstream the pipe in various tests of the present study. It is seen that except very close to the pipe, the double amplitude of the vortex-induced velocity remains practically constant along the bed. This implies that the vortex keeps its entity without undergoing too much change throughout its lifetime. Thus every point underneath the vortex is exposed to the same fluctuating velocity as the vortex is convected downstream.

4.6 A simple model for the vortex-induced velocity near the bed

In order to calculate the vortex shedding induced velocity near the bed in the near-wake region a simple model is proposed in this section.

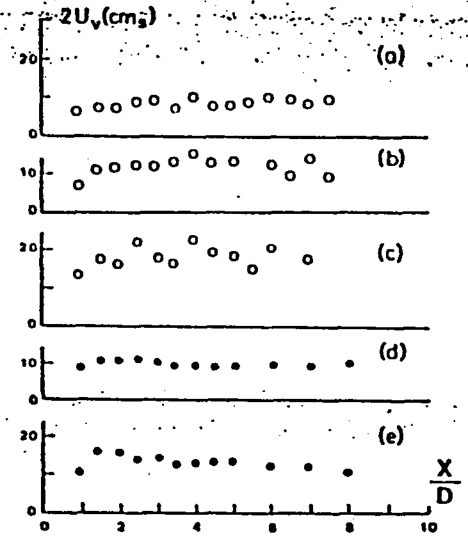

Fig. 4.15 The double amplitude of the vortex-induced near-bed velocity $2U_v$ versus x/D.
(a), (b) and (c) correspond to the loose-bed experiments with gap ratio e_0/D = 1.5, 1.0 and 0.35 respectively.
(d) and (e) correspond to the rigid-bed experiments with the gap ratio e_0/D = 1.0 and 0.6 respectively.

The definition sketch for the model is shown in Fig. 4.16. The velocity created at point A by the vortex just passing over this point is denoted by 2 U_v. This velocity can be represented by

$$2U_v = \frac{\Gamma}{2\pi \ell} \tag{4.6}$$

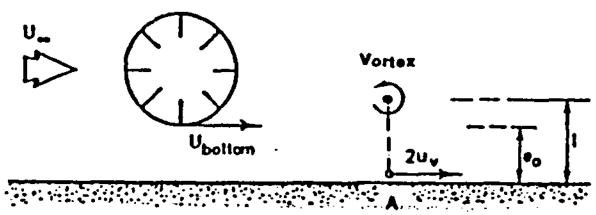

Fig. 4.16 Definition sketch for the vortex-induced velocity model.

This is actually the double amplitude of the velocity signal introduced in Fig. 4.14.

Here, Γ is the strength of the vortex and ℓ is the distance between the point A and the point where the vortex centre is located. The velocity $2U_v$ can be considered to remain approximately constant throughout the wake region along the bed ($1 \lesssim \frac{x}{D} < 8$) as shown in the previous section.

The strength of the vortex Γ can be related to the shedding of the circulation at the separation point at the lower edge of the cylinder by the following expression (see Bearman [2]):

$$\Gamma = \frac{1}{2}\,\alpha\,\frac{1}{f}\,U_{bottom}^{2}, \tag{4.7}$$

in which f is the vortex shedding frequency.

U_{bottom} is the velocity just outside the cylinder boundary layer at the lower edge of the cylinder and α is a coefficient corresponding to the fraction of the original circulation that survives the formation of the vortex.

Substituting Eq. (4.7) into Eq. (4.6) and bearing in mind that $St = Df/U_\infty$, the following Eq. can be drawn:

$$\frac{2U_v}{U_\infty} = \frac{\alpha}{4\pi St}\left(\frac{U_{bottom}}{U_\infty}\right)^2 / \left(\frac{\ell}{D}\right) \tag{4.8}$$

in which the undisturbed velocity U_∞ is introduced.

The distance ℓ can be approximated by

$$\ell = e_0 + D/4 \tag{4.9}$$

Fredsøe and Hansen (1985) presented their measurements U_{bottom}/U_∞ for a cylinder placed near a plane wall [3]:

$$U_{bottom}/U_\infty = 1.5 \tag{4.10}$$

The Eq. (4.10) is valid within a broad range of e_0/D, namely $0.1 < e_0/D < 1.3$.

Bearman [2] has summarized the previous results for the value of α. The range of α is from 0.2 to 0.6, depending on the shape of the body and the Reynolds number. According to Roshko [7], α = 0.43 and is the average value for a circular cylinder, a 90° wedge, and a fl...

bed, in the present model α is chosen to be 0.4.

The value of the Strouhal number is taken to be 0.2, neglecting the influence of the roughness of the pipe surface and the effect of the bed on the vortex shedding.

Therefore, by inserting the values of α, St and U_{bottom}/U_∞, the Eq. (4.8) can be simplified to be

$$\frac{2U_v}{U_\infty} = \frac{0.36}{\ell/D} \qquad (4.11)$$

It means that the vortex-shedding-induced velocity (i.e. the double amplitude $2U_v$) is directly proportional to the undisturbed velocity U_∞ and inversely proportionel to the distance ℓ.

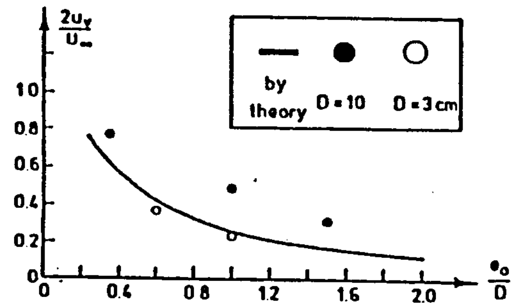

Fig. 4.17 The double amplitude of the vortex shedding induced near-bed velocity versus the gap ratio.

The value of U_v/U_∞ calculated by Eq. (4.11) is plotted in Fig. 4.17 where the present experimental results also are plotted.

When $e_0/D = 2$ it is seen from Fig. 4.17 that $2U_v/U_\infty = 0.16$. It means that the vortex shedding induced near-bed velocity is very limited. It was confirmed by experiments (see Fig. 4.5 and Fig. 4.6).

In spite of several approximations made in the model development, the theory agrees reasonably well with the experiments.

The discrepancy between the two series of experiments shown in Fig. 4.17 may be attributed to the difference in the sizes of the cylinder diameter and perhaps to the difference in the shear present in the corresponding flows.

As shown in Fig. 4.14, the vortex-shedding-induced velocity seen at a point on the bed can be assumed to be sinusoidal:

$$u_v = U_v \cdot \sin 2\pi ft \qquad (4-12)$$

In the case that the vortex-shedding induced velocity is approximately sinusoidal, the relation between the amplitude U_v and the value of σ is

$$U_v = \sqrt{2\sigma} = \sqrt{2\,\overline{u'^2}} \qquad (4.13)$$

Fig. 4.18 compares the theoretical predictions calculated by Eqs. (4.11) and (4.12) with the individual experimental mean profiles obtained according to the so-called zero-up-crossing definition.

4.7 A comparison experiment

A special comparison experiment was carried out in the 2 m wide flume. The purpose of the test is to study the effect of the bed profile on the vortex-shedding-induced near-bed velocity.

The pipe with 10 cm diameter was fixed above an erodible plane bed with gap ratio $e_0/D = 0.35$. The undisturbed flow velocity U_∞ was kept constant, $U_\infty = 25$ cm/s, corresponding to $\theta_\infty = 0.019$, for 330 min. The velocity and bed profile were measured at the initial and the final stage of the test.

Fig. 4.19 shows the eroded bed profile after 330 minutes' running. The deepest position of the scour hole was about $x/D = 2$. The streamwise dimension of the eroded part is about 5D (from $x/D = -1$ to $x/D = 4$).

Two samples for the position $x/D = 2$ were plotted in Fig. 4.20, in which Fig. (a) corresponds to the initial stage of the test, Fig. (b) corresponds to the final stage of the test.

The spectral density distributions corresponding to Fig. 4.2 were plotted in Fig. 4.21 (a) and (b) respectively.

It is seen from Fig. 4.21 (a) that in the plane-bed case the vortex shedding was not very clear. In the bed scour process, the space below the pipe was being more and more suitable

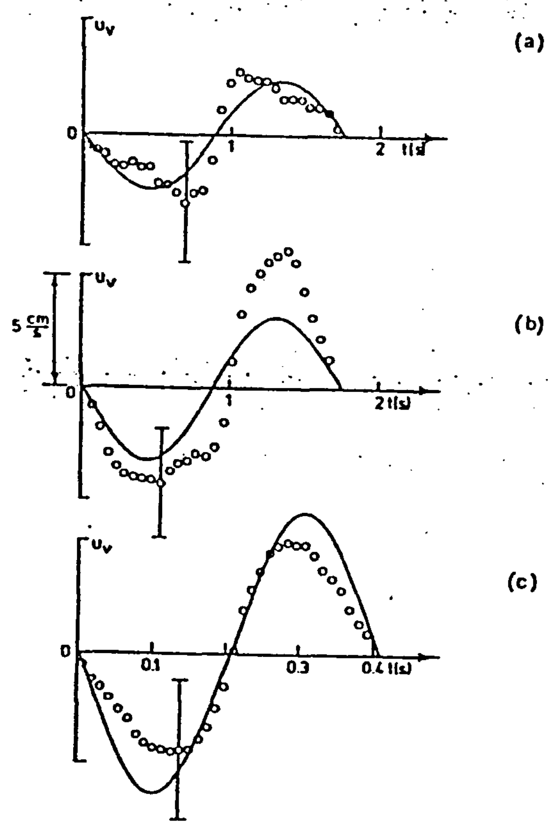

Fig. 4.18 Individual mean profiles for the vortex-shedding-induced near-bed velocity at location $x/D = 3$.
—— : by theory; I : 2σ.
(a) $e_0/D = 1.5$, $D = 100$ mm; (b) $e_0/D = 1.0$, $D = 100$ mm; (c) $e_0/D = 0.6$, $D = 30$ mm.

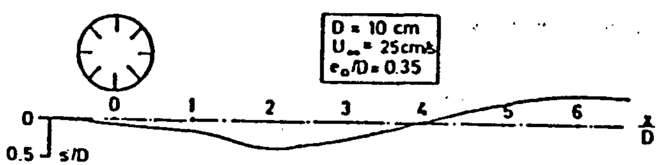

Fig. 4.19 The eroded-bed profile, measured after 330 minutes' running.

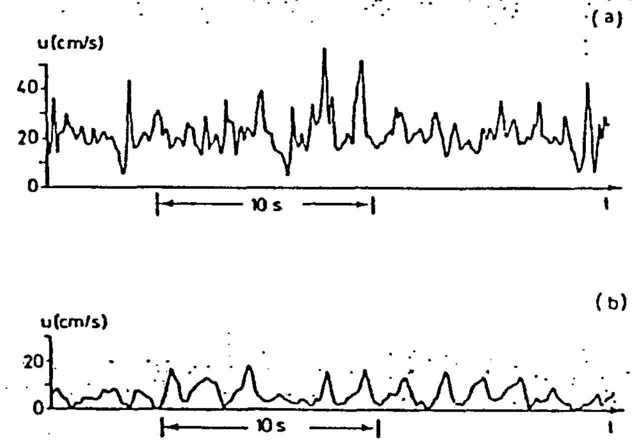

Fig. 4.20 Samples of near-bed velocity records.
(a) At the initial stage, (b) At the final stage.

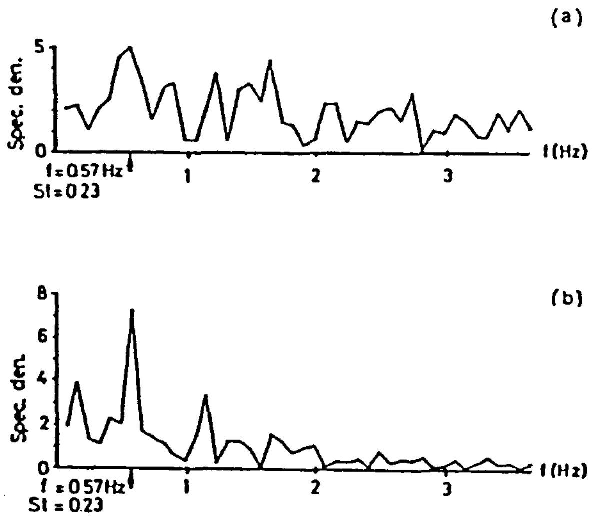

Fig. 4.21 The spectral density distributions for the records shown in Fig. 4.20.
(a) At the initial stage; (b) At the final stage.

for the vortex shedding. Therefore the peak corresponding to the vortex shedding frequency was quite high in Fig. 4.21 (b).

The variations of $\bar{u}$, $\sqrt{\overline{u'^2}}$ and U_{max} measured at the start and after 330 minutes' running are plotted in Fig. 4.22.

Fig. 4.22 (a) shows that in the eroded-bed case, the mean value of the near-bed velocity $\bar{u}$ in the place downstream the pipe was reduced due to the increase of the cross section caused by the erosion on the bed. The smallest value of $\bar{u}$ corresponded to the deepest local scour depth. Then, with the increase of x/D, $\bar{u}$ increased too.

There is a similar tendency in Fig. 4.22 (b). In general, the value of $\sqrt{\overline{u'^2}}$ became smaller when the bed was eroded, especially around the position x/D = 1.5. It could be explained that, due to the erosion, the distance between the point on the bed and the vortex centre ℓ is increased, therefore according to the simple model, the vortex-shedding-induced velocity was smaller than before.

It is interesting that at the initial stage of the test the values of U_{max} measured near the bed downstream the pipe (see Fig. 4.22 (c)) were much higher than the threshold flow velocity for the sand particles on the bed to start moving. Therefore, the vortex shedding scoured the bed. When the bed was notably eroded by the vortex shedding (see Fig. 4.19), the values of U_{max} were much smaller than the initial value. In the scour hole ($1.5 < x/D < 3.5$), U_{max} was smaller than the threshold velocity. The scour would continue for the range $x/D > 4$, because U_{max} there was still larger than the threshold velocity.

The conclusion that can be drawn from the comparison experiment is that the vortex-shedding-induced velocity near the bed downstream the pipe will be weakened by the erosion of the bed.

4.8 Conclusions

The role of the vortex shedding in the scour below pipelines has been investigated. The results can be summarized as follows:

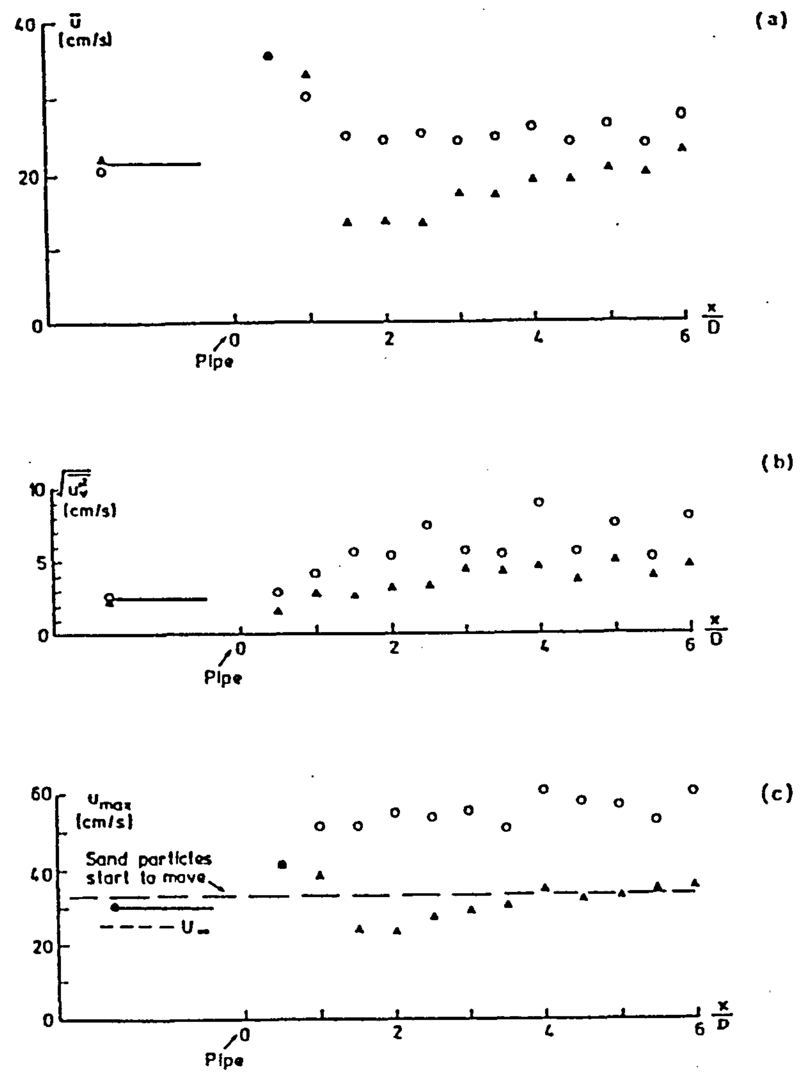

Fig. 4.22 Comparisons of $\bar{u}$, $\sqrt{\overline{u'^2}}$ and U_{max} between the initial stage and the final stage of the test.
o : measured at the start; ▲ : measured after 330 minutes' running. —— : measured at the position far away from the pipe. --- U_∞ : undisturbed velocity.
(a) $\bar{u}$; (b) $\sqrt{\overline{u'^2}}$; (c) U_{max}.

1. Experiments have demonstrated that when the gap under the pipe is larger than 0.35 and the space behind the pipe is suitable, the vortex shedding occurs. In fact, in the scour process below pipelines, the vortex shedding exists from quite early stages. Therefore the nearwake region of the bed normally undergoes changes due to the action of the vortex shedding.

2. A fluctuating velocity field is induced by the vortices shed from the lower edge of the pipe. Every point of the bed downstream the pipe feels this velocity field in the form of a periodic signal, the Strouhal number of which is approximately equal to 0.2.

It was found that the wake bed region influenced by the vortex-induced velocity field extends from $x/D = 1$ to $x/D = 8$. It was also found that in this region the magnitude of the vortex-induced velocity remains approximately constant along the bed.

3. A simple model has been developed to predict the vortex-induced near-bed velocity. The value of the vortex-shedding induced near-bed velocity is directly proportional to the undisturbed velocity, but inversely proportional to the initial gap. (See Eq. (4.11)). It was demonstrated that the model gives fairly good results.

4. It has been shown that the vortex-shedding-induced erosion may result in substantial scour downstream the pipe, and in a quite gentle downstream slope of the scour hole. On the other hand, the vortex-shedding-induced velocity field near the bed will be weakened by the erosion on the bed.

4.9 References

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CHAPTER 5

THE SCOUR BELOW PIPELINES EXPOSED TO TWO-DIRECTIONAL FLOW

5.1. Introduction

The purpose of the present chapter is to extend the investigation for the unidirectional flow presented in chapter 2 to the case where the flow direction reverses periodically, which is called the two-directional flow hereafter. Waves, tide and their combinations with current are examples of the two-directional flow.

The flow pattern undisturbed by the pipe could be expressed by

$$U_{\infty} = U_{\infty,m} \cos(\omega t) \qquad (5.1)$$

in which t is the time;

$u_{\infty,m}$ is the maximum free stream velocity;

ω is the angular wave frequency, defined by $\omega = 2\pi f$, where f is the wave frequency.

The lee-side wake plays an important role in the scour under the pipeline exposed to the two-directional flow due to the reverse of the flow direction.

Although there are some data available on the scour under pipelines exposed to the current, the data for the two-directional flow are scarce.

The main object of the present work is to obtain the experimental data to cover a reasonably broad range of sediment-transport stages and to get a better insight into the mechanism involved in the two-directional-flow-induced scour process and the self-burial of the pipeline in the two-directional flow.

5.2 Experimental set-up

The experiments were carried out partly in an oscillating water tunnel, partly in a 2 m wide flume.

5.2.1 In the oscillating water tunnel

As shown in Fig. 5.1, the oscillating water tunnel is a U-shaped tube with one closed riser and one open riser.

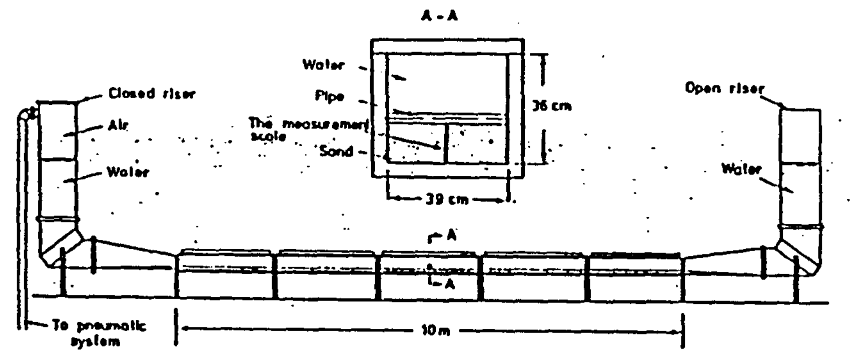

Fig. 5.1 Sketch of the oscillating water tunnel.

The compressed air supplied by pneumatic machinery is used to make the flow oscillate. The walls and the cover of the tunnel are made of plixiglass. The frequency of the oscillating flow in the tunnel was kept at the natural frequency of the tunnel f = 0.103 Hz. The horizontally working part of the tunnel is 10 metre long (For detail see [4]). The working section is 36 cm high by 39 cm wide. Plexiglass cylinders were used as the model of pipelines. The diameters of the pipe model were from 12 mm to 90 mm. Most of the experiments were made with a pipe of 30 mm diameter. The depth-to-diameter ratio for this pipe is approximately 8, indicating that there is no blockage effect. The sediment used in the experiments is the same as before. The thickness of the loose bed is 5 to 13 cm for different cylinders.

5.2.2 In the two-metre-wide flume

The flume has been described in section 2.4.1. Because the

flow direction could be reversed by changing the blade angle of the pump, the flume was used for some two-directional flow experiments.

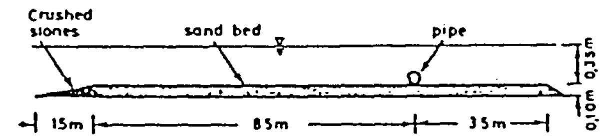

Fig. 5.2 Sketch of the experimental set-up in the 2 m wide flume.

The sand grain size was the same as in the current case. The length of the sand bed was extended to 12 m, while the thickness is 10 cm.

A metal pipe of 5 cm diameter was placed in the section with glass side-walls (see Fig. 5.2). The surface of the pipe was smooth.

For the experiments with the fixed pipe, the scour depth under the middle of the pipe was measured by a needle-shaped meter fixed on the bottom of the pipe. The final scour depth was obtained by the sand bed follower (see section 2.4.1 and Fig. 2.25).

The sagging system is the same as in the current case (see section 3.3.1).

The flow velocity in the experiments could be simplified to be the model shown in Fig. 5.3. In the experimental situation θ_c was exceeded for the mean velocity U_m larger than 0.34 m/s.

Close to the pipe, the local increase in the bed shear stress involves that the particles start moving earlier than far upstream the pipe. Therefore T_w is defined as the time interval when the mean velocity was bigger than 0.29 m/s in a period. Then, for the sake of convenience the sum of the time when θ_c was exceeded is designated t_{eff}.

Fig. 5.4 is one of the velocity records measured at 25 cm above the bed.

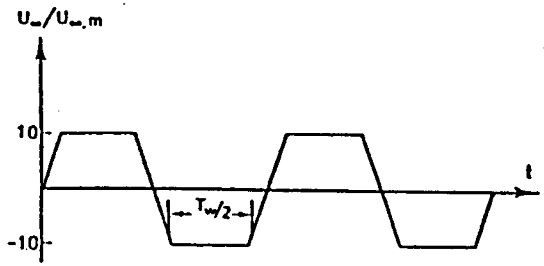

Fig. 5.3 Sketch of the flow pattern in the 2 m wide flume.

Fig. 5.4. A typical velocity record for the two-directional flow in the 2 m wide flume.

5.3 Experimental results and discussion

5.3.1 Bed waves in the oscillating flow

By the action of the two-directional flow, sediment particles move, thereby forming sand waves. It is found that the sand waves in the two-directional-flow case have strong influence on the scour under the pipe. In order to get an insight into the scour in this instance, here the sand waves with no pipe present are discussed first.

In the two-directional-flow case, the maximum undisturbed flow velocity U_∞ is taken as the reference velocity.

The maximum shear velocity $U_{f\infty,m}$ is defined by

$$U_{f\infty,m} = \sqrt{\frac{f_w}{2}}\,U_\infty \tag{5.2}$$

where f_w is the friction coefficient. When the amplitude of the free stream particle "a" and the bed roughness K_s are known, the value of f_w is calculated by Fredsøe's theory [1].

The maximum Shields parameter is defined by

$$\theta_{\infty,m} = \frac{U_{f\infty,m}^2}{(s-1)\,g\,d_{50}} \tag{5.3}$$

Fig. 5.5 shows the ranges for the sand waves observed in the oscillating water tunnel in the absence of a pipe. When the value of $\theta_{\infty,m}$ is larger than the critical value θ_c, sand particles on the bed start to move. First, particles move along the surface of the bed backwards and forwards following the oscillation of the flow. In that case some ripples are formed. With the increase of $\theta_{\infty,m}$ some particles are moving in suspension, while the dimensions of sand waves increase. When the Shields parameter is large enough, suspension dominates the sediment movement forming a plane bed.

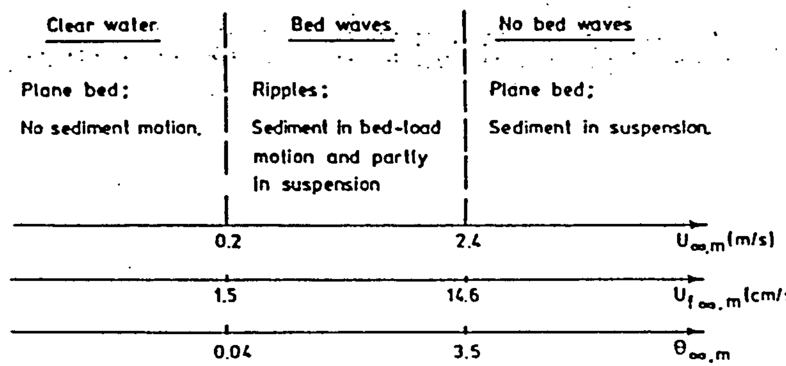

Fig. 5.5 The ranges of the bed features corresponding to the sediment transport stages.

5.3.2 The scour below the fixed pipe in the oscillating water tunnel

A. The clear-water scour

When $\theta_{\infty,m}$ is less than θ_c (in the experimental situation $\theta_c = 0.04$), there is not sediment transport at the place far away from the pipe. Due to the presence of the pipe, the velocity in the neighbourhood of the pipe is increased; therefore the local scour under the pipe may take place.

The common feature of the scour profiles in the clear-water-scour case is the appearance of the two hills around the pipe. Fig. 5.6 is one of the typical examples of the equilibrium scour bed profile. The hills are formed by the deposition of sediment particles eroded from the bed under the pipe. When the flow reverses its direction, there is always an upstream hill to force some water to pass above the top of the pipe. When the hills are high enough, the scour process is stopped.

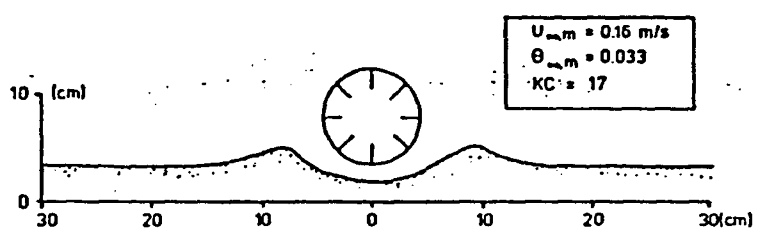

Fig. 5.6 Equilibrium scour bed profile for the clear-water case, D = 90 mm.

B. In the presence of bed waves

When the Shields parameter is larger than θ_c, the scour under the pipe is the combined result due to the presence of the pipe and the moving of the sand waves.

Fig. 5.7 shows the typical equilibrium scour bed profiles.

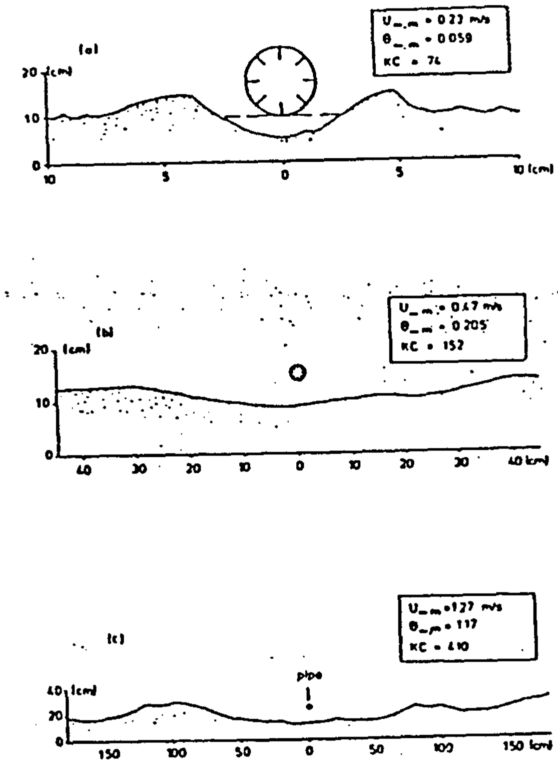

Fig. 5.7 Equilibrium scour bed profiles in the presence of bed waves, D = 30 mm.

Some conclusions can be drawn as follows:

1. The pipe is the dominating factor of the scour hole. The scour rate in the neighbourhood of the pipe is relatively high until the scour under the pipe reaches its equilibrium situation. Although in the presence of sand waves the scour rate under the pipe is affected by the moving of the sand waves, experiments indicated that the pipe determined the bed feature

in the way that the scour hole under the pipe always is the trough of the sand waves.

2. In general, the scour bed profile is symmetrical around the pipe due to the periodical reversing of the flow direction.

3. It is difficult to use the results quantitatively, because the height of the sand waves is in the same order as the pipe diameter, in some case even larger than the pipe diameter. The pipe size is limited by the space in the oscillating water tunnel.

C. In the no-bed-waves flow stage

When the Shields parameter $\theta_{\infty,m}$ is large enough, say $\theta_{\infty,m} > 3.5$, there is not the effect of the sand waves. In that case, the bed form at a position far away from the pipe is a plane bed, therefore it is called the no-bed-waves flow stage.

1. The dimensions of the scour hole.

Fig. 5.8 shows the typical results for $\theta_{\infty,m} > 4.75$.

It is seen that the scour depth is larger than the pipe diameter. On the other hand, the streamwise dimension of the scour hole is large compared to the pipe diameter.

2. The effect of the initial gap.

The scour depth obtained for various values of e_0/D is plotted in Fig. 5.9 (a) and (b) in two alternative forms. It is seen from Fig. 5.9 (b) that when the pipe is totally buried into the bed ($e_0/D = -1$), there is no scour under the pipe. When the pipe is not buried so deeply, the scour depth is deeper than two times the pipe diameter. With the increase of the initial gap, the scour depth becomes shallower.

It should be mentioned that in the no-bed-waves flow case there is a moving layer of a mixture of sand and water between water and the loose bed. If the pipe diameter is smaller than the thickness of the mixed layer, there may still be some scour around the pipe even though the pipe is buried thoroughly.

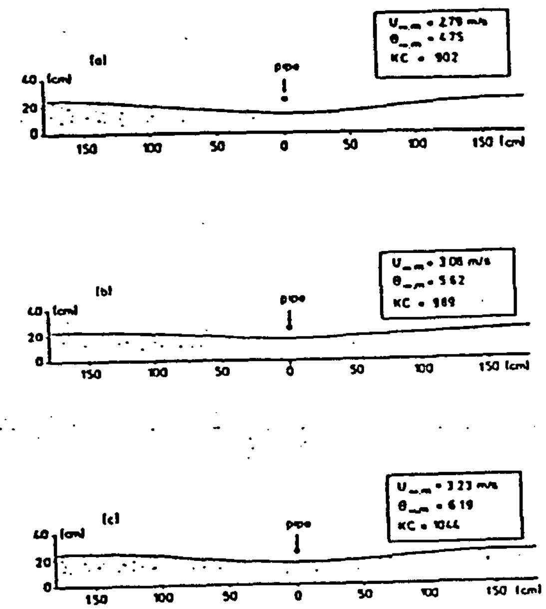

Fig. 5.8 Equilibrium scour bed profiles in the no-bed-waves flow stage, D = 30 mm.

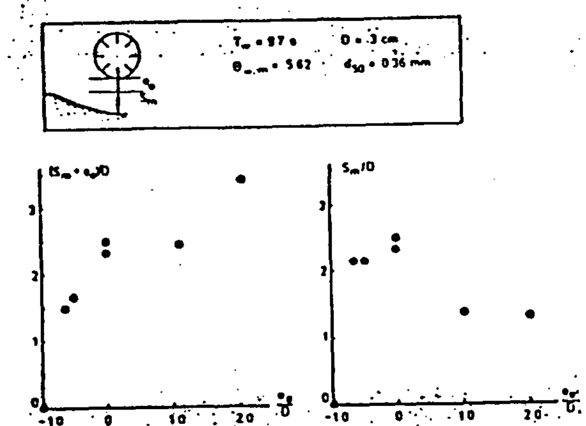

Fig. 5.9 Scour depth versus the initial gap in the no-bed-waves flow stage.

3. The meaning of the tests

It should be noted that these tests are important from the practical application point of view, since the test conditions here correspond to the most severe wave climate. The results obtained from the tests indicated that the scour depth under the pipeline may be as deep as several times the pipe diameter in stormy weather.

D. Scour development

Fig. 5.10 shows four typical scour curves which describe the time development of the scour process for three different flow stages. They are similar to the scour process in the current.

5.3.3 The scour below the fixed pipe exposed to the two-directional flow in the 2 m wide flume

A. The observation

The value of $\theta_{\infty,m}$ in the experiments was 0.098. There were some sand waves on the bed.

Fig. 5.11 shows the scour phenomenon in the second half period observed in the 2 m wide flume. When the flow direction was reversed (from Fig. 5.11 (a) to (b)), the downstream hill the upstream hill, which made the altitude of the approach flow relatively high. As shown in Fig. 5.11 (b) and (c), behind the hill the flow was separated, resulting in the formation of an eddy. This eddy reduced the effective cross section in front of the pipe, whereby the flow velocities under the pipe were increased. Therefore the sediments under the pipe were more easily picked up, so the scour hole quickly became deeper. Later on, when, owing to the decrease of the upstream hill, the upstream eddy disappeared, the scour hole under the pipe did not become deeper.

B. The scour processes and the equilibrium bed profiles

Fig. 5.12 shows the development of the scour depth under the pipe with respect to the effective time t_{eff} for three different values of T_w. It is seen that the scour depth was increasing at the early stage until it reaches its maximum value.

Later on, the scour hole was shallower, because the hills on the two sides of the pipe were smoothed out.

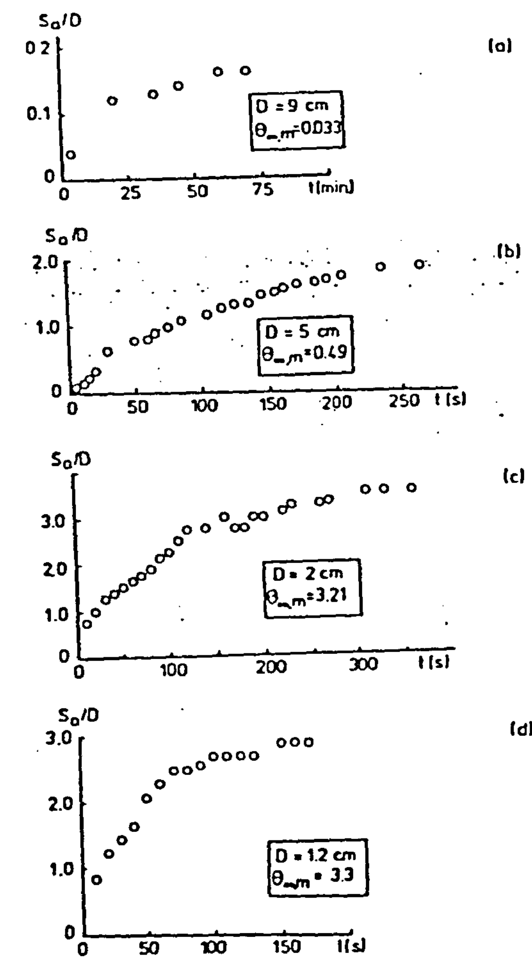

Fig. 5.10 Scour processes for three different flow stages. (a) The clear water scour. (b) In the presence of bed waves. (c) (d) In no-bed-waves flow stage.

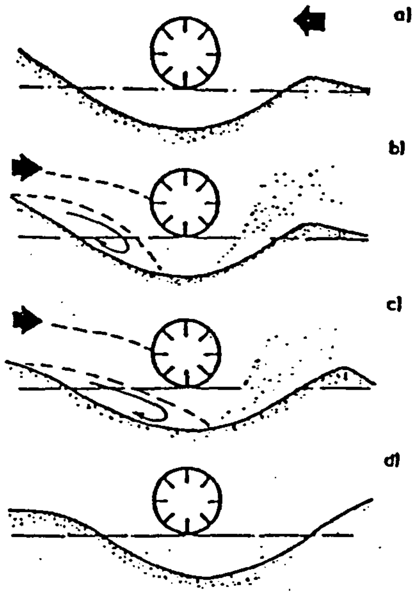

Fig. 5.11 The scour in a half period.

Fig. 5.13 shows the equilibrium bed profiles. The eroded bed profiles are not symmetrical. The reason is the following: (1) The flow direction was from the right to the left before the measurement of the bed profile; (2) The position of the pipe was not in the middle of the sand bed (see Fig. 5.2); (3) The shapes of the inlet at the two ends of the flume were not the same. Fig. 5.4 indicated that although the mean velocities for the two directions were very similar, the turbulence for the two directions was different. The more turbulent flow corresponded to the flow, the direction of which was from the right to the left in Fig. 5.13.

C. The comparison with the scour under a fixed pipe exposed to a current

It is seen from Fig. 5.14 that the equilibrium scour depth S_m/D is deeper than 0.9 for all T_w. It is deeper than the scour depth under the fixed pipe in the current.

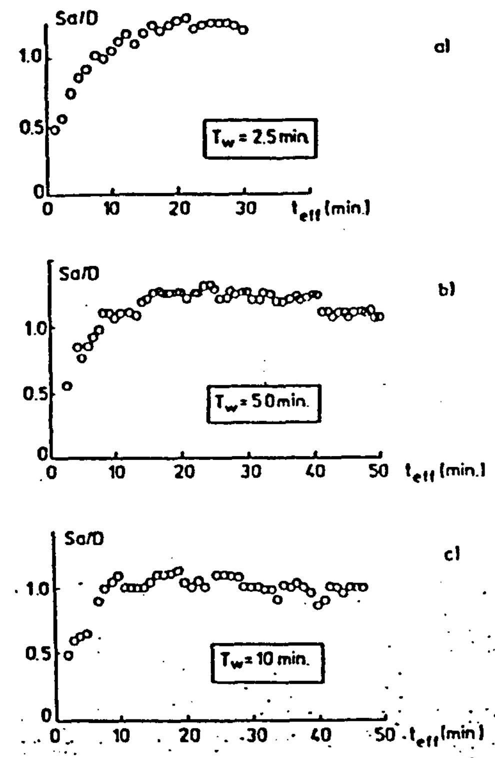

Fig. 5.12 The scour processes for different T_w, when $\theta_{-,m}$ = 0.098, D = 5 cm, e_0/D = 0.

5.3.4 The effect of the variation in the KC-number on the equilibrium scour depth below the fixed pipe

A. The definition of the KC-number and its meaning

A characteristic dimensionless parameter in the oscillating flow case is the Keulegan-Carpenter number KC, which is defined by

$$KC = \frac{U_{-,m} \times T_w}{D} \quad (5.4)$$

By inserting

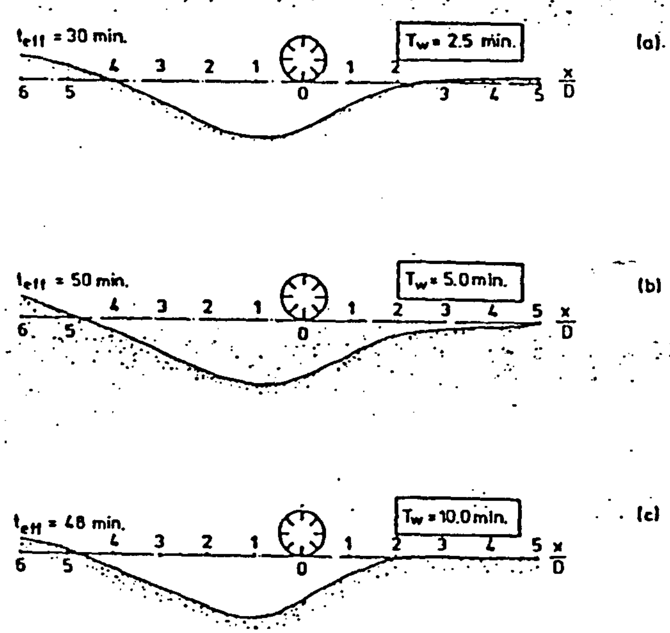

Fig. 5.13 The equilibrium scour bed profiles for different T_w, when $\theta_{\infty,m}$ = 0.098, D = 5 cm, e_0/D = 0.

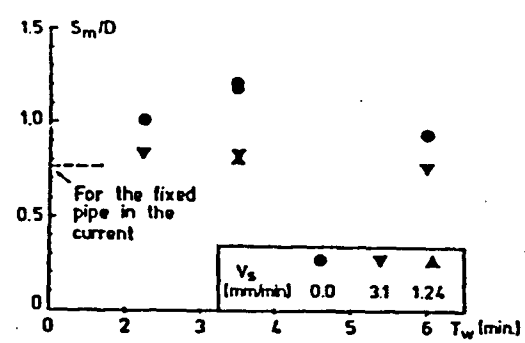

Fig. 5.14 The equilibrium scour depth versus T_w for the fixed pipe and the sagged pipe.

where $\omega = 2\pi/T_w$ (5.6)

the Eq. (5.4) is recast to be

$$KC = \frac{2\pi a}{D} \tag{5.7}$$

It means that KC is the ratio between the amplitude of the oscillating water particles a to the diameter of the pipe D.

If the value of D is kept constant, the increase in the KC-numbers means the increase in the oscillation amplitude a.

Due to the oscillation of the flow the vortex shedding reverses its shedding direction periodically. It is clear that the number of the shed vortices depends on the oscillating amplitude of the flow a. Therefore, with the increase of the KC-number, the number of the shed vortices is increased, which means that the action of the vortex shedding on the bed is enhanced.

Fig. 5.6 to Fig. 5.8 show the scour bed profiles for KC = 17.2 to 1044.4. Generally, the KC-number for the pipelines in the sea is about 5 ~ 100. Due to the small diameter of the pipe in the experiments, the KC number is quite large.

B. Why the equilibrium scour depth in the two-directional flow is deeper than that in the current

The unidirectional flow corresponds to the case where KC = ∞.

As pointed out in chapter 2 and 3, there is a wake downstream the pipe. It is the wake-induced erosion that causes the downstream part of the scour hole (= w_2) to be wider than the upstream part of the scour hole (= w_1), see Fig. 5.15 (a).

In the two-directional flow case, due to the reverse of the flow direction, the upstream part of the scour hole in the first half cycle will be the downstream part of the scour hole in the next half cycle. In that way, the width of the scour hole W is larger than that observed in the current. (See Fig. 5.15 (b)).

According to the modified potential flow theory (see Fig. 2.15), the deeper scour depth corresponds to the larger width of W. Therefore, the final equilibrium scour depth in the two-

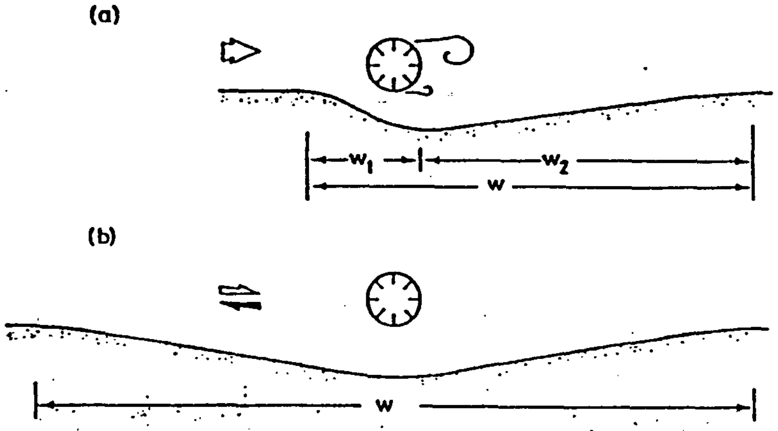

Fig. 5.15 Comparison between the scour bed profiles.
(a) In the current. (b) in the two-directional flow.

directional flow is, in fact, deeper than that in the current.

The tendency depicted in Fig. 5.6 and Fig. 5.7 shows very clearly that the scour depth will be larger with the increase of the KC-number. But it should be mentioned that, when the value of KC is large enough, the variation in KC has only very limited effect on the scour depth. It can be explained by the limit of the lifetime of the vortices shed from the pipe. It is confirmed again by the experiments carried out in the two-meter-wide flume: the results shown in Fig. 5.14 indicate that the scour depth hardly depends on the value of T_w, while the values T_w = 2.5 ~ 10.0 correspond to the values KC = 750 ~ 3000.

5.3.5 The effect of sagging on the scour

A. The observation

Generally speaking, the mechanism for the self-burial in the two-directional flow case is similar to that in the current case. When the pipe comes into contact with the scour hole, the scour process is stopped (see chapter 3).

In the experiments the pipe started its sagging process when the gap was e/D = 0.3. In most of the tests the sagging velocity of the pipe V_s was kept equal to V_s = 3.1 mm/min. In

fact, the influence of the sagging velocity V_s on the final scour depth is relatively small.

As explained in chapter 3, the scour rate was enhanced by the sagging of the pipe at the early stage. Fig. 5.16 shows the variation of the scour gap between the pipe and the eroded bed with respect to time. It is seen that the relative gap e/D increased until it obtained a value about 0.45. After that it gradually became smaller until the pipe came into contact with the bed.

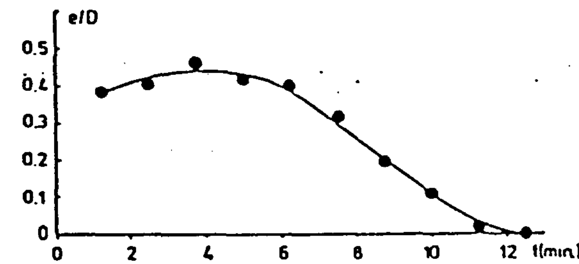

Fig. 5.16 Variation of the gap between the pipe and the eroded bed e/D versus time t.

B. The comparisons

The final scour bed profiles were plotted in Fig. 5.17.

First, as seen from Fig. 5.14, the scour hole in the case of a sagged pipe is shallower than that for a fixed pipe exposed to the two-directional flow.

Next, comparing with the scour under a sagged pipe exposed to the current (see Fig. 3.12) (b), for the boundary situation "A" and V_s = 3.1 mm/min), the scour depth in the present case is shallower.

At last, as seen from Fig. 5.14, the scour depth is a little deeper than that under the fixed pipe in the current.

It is known that the flow velocity under the pipe will decrease with the sagging of the pipe at the later stage of the sagging process. In the two-directional flow case, no matter how the flow reverses its direction, there is always a hill upstream the pipe. It is the upstream hill that plays the key role in the sagging procedure of the pipeline exposed to the two-directional

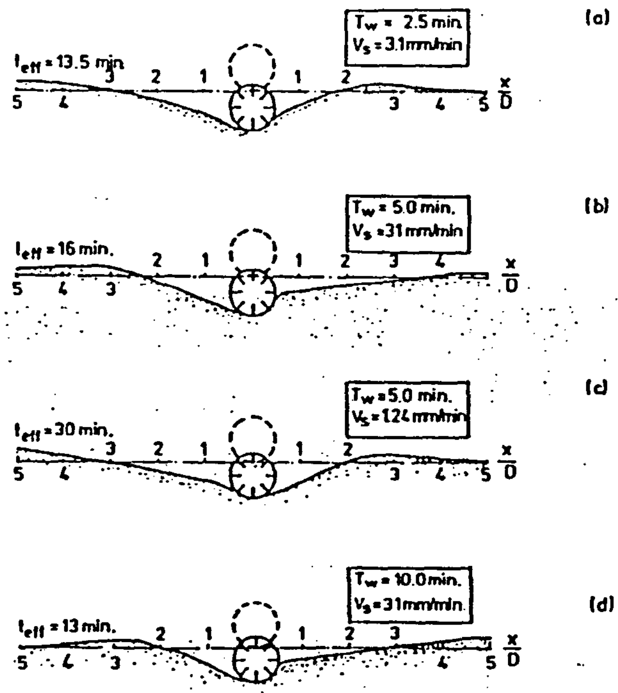

Fig. 5.17 The eroded bed profiles under a sagged pipe exposed to the two-directional flow, when $\theta_{w,m}$ = 0.098, D = 5 cm, e_0/D = 0.

flow. Because the extent of the protrusion of the pipe in the sagging case is smaller than that in the fixed-pipe case, more flow passes above the pipe. In the case when the pipe sagged in the current there was no upstream hill.

Therefore the scour depth under the sagged pipe exposed to the two-directional flow is, in fact, shallower.

It can thus be concluded that the different mechanisms are the following: in the current case the sagging makes the scour hole deeper (see Fig. 3.12), but in the two-directional-flow case the sagging makes the scour hole shallower.

The formula Eq. (3.16) proposed in section 3.4.1 is still valid when estimating the maximum span length of the scour hole in the two-directional-flow case. The safety coefficient given by the estimation in the two-directional flow is a little higher than that in the current.

5.4 Conclusions

The conclusions which can be drawn from the present work are summarized as follows:

1. In the presence of the sand waves the pipe determines the trough of the sand waves in its neighbourhood.

2. The wake-induced erosion plays a significant role in the final dimensions of the scour hole. The KC-number has some influence on the scour.

3. Except in the clear-water case, the scour depth under a fixed pipe exposed to the two-directional flow is deeper than that in the current case. It may be several times the pipe diameter for the high sediment transport stages such as no-bed-waves flow situations.

4. Due to the shelter action of the hills on the two sides of the pipe, the scour hole under the sagged pipe exposed to the two-directional flow is shallower than that under the fixed pipe in the two-directional flow and shallower than that under the sagged pipe in the current.

5. The maximum span length of the scour hole can be estimated by Eq. (3.13) in the current case and in the two-directional flow case.

5.5 References

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CHAPTER 6

THE INTERACTION BETWEEN A VIBRATING PIPE AND AN ERODIBLE BED

6.1 Introduction

One of the important problems that may result in damage of pipelines is the vibration of the pipeline. This vibration has received much attention. The boundary near the pipeline has some influence on it. If the pipeline is suspended in the water at a position far away from the seabed, the influence of the boundary can be neglected. Otherwise, the influence of it should be considered. Wilson and Caldwell [20] may be the first investigators of this problem. In recent years, Tsahalis [16-18] Jacobsen [8, 9], Fredsøe et al. [6] and Sumer et al. [15] gave some information about the problem of pipe vibration near a plane bed.

It is known that the vibration of pipelines is caused by the flow around the pipe. Meanwhile, the loose bed underneath the pipe may be eroded by the flow.

In the previous studies about the pipe vibration the pipes were placed in the vicinity of a rigid plane bed. In practice, as discussed in the previous chapters, the loose bed underneath a pipeline can be eroded by flow. As far as the author knows, no study about the vibration problem in the vicinity of an erodible bed has been published until now.

Although the scour below pipelines has been studied a lot, the scour below a vibrating pipe has not been studied yet.

The scope of the present chapter is to fill this gap in the field of the pipeline engineering. The interaction between a vibrating pipe and an erodible bed is studied. First, the action of a vibrating pipe on a loose bed is studied, then the effect of an eroded bed on the vibration of a pipe is presented.

6.2. Experimental set-up

6.2.1 The system of the set-up

The experiments were carried out in the 2 m wide flume,

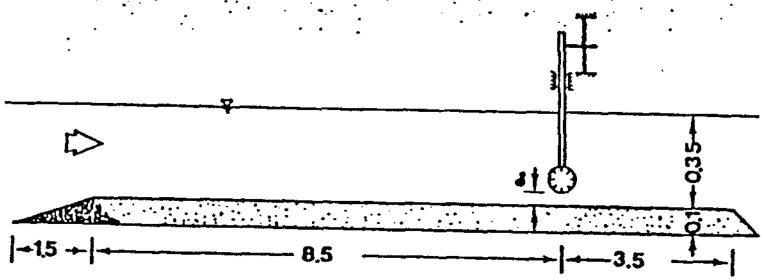

Fig. 6.1 (a) Sketch of experimental set-up. (number in metres).

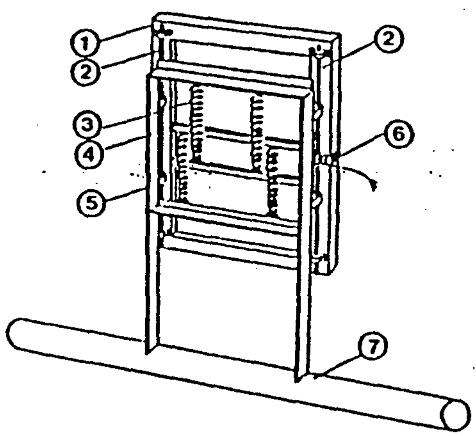

Fig. 6.1. (b) Sketch of the vibration system.
(1) The support frame; (2) The slideway;
(3) Spring; (4) The bar to adjust the equilibrium position of the pipe; 5) The holding frame;
(6) Potentiometer; (7) Pipe model.

The sand bed was the same as before (See 5.2.2 and Fig. 6.1. (a)). A pipe model covered with smooth rubber was placed at 8.5 m downstream the inlet section of the sand bed. The diameter of the pipe model was 10.1 cm, its length was 1.99 m. As shown in Fig. 6.1 (b), the pipe was connected to a frame by two holders. The holding frame could only move up and down along two slideways fixed on a supporting frame. The pipe was rigid, but it was supported by four soft springs connecting the support frame and the holding frame, so the pipe was flexibly mounted. The position of the pipe at any moment was measured by a potentiometer. A SPC-1 computer and a chart recorder were used to record the variation of the pipe position. The digitized displacements of the pipe were analyzed off-line.

The sand bed follower was used to measure the bed profile, and a micropropeller with the diameter of 5 mm was used to measure the flow velocity.

The results of Tsahalis [16] indicated that in comparison with the transverse vibration, the inline vibration was so small that it could be neglected. Therefore, the system was designed as a one-degree system, which means that the pipe is only allowed to vibrate in the transverse direction. Hereafter, only the transverse vibration is discussed.

The relative density of the pipe, $S_p = \rho_{pipe}/\rho$, was equal to 1. The spring constant per unit length of the pipe was $K = 0.336\ m^2/s^2$. The natural frequency of the system was measured in still water and had very limited variations with the change of the initial gap. Therefore, the mean value $f_n = 0.695$ Hz was taken to be the natural frequency of the vibrating system.

The mean structural damping coefficient measured in air is $\zeta_s = 0.05$. The so-called stability parameter of the pipe is defined by

$$K_s = \frac{2(m + m')\,(2\pi\zeta_s)}{\rho D^2} \tag{6.1}$$

in which m is the mass of the pipe;
m' is the hydrodynamic mass of the pipe;
ρ is the water density.

The hydrodynamic mass is defined by

$$m' = \beta \cdot \rho \cdot \frac{\pi}{4} D^2 \qquad (6.2)$$

The coefficient β is a function of the gap between the pipe bottom and the bed under the pipe. By inserting Eq. (6.2), K_s can be recast as

$$K_s = (1 + \beta)\ \pi^2 \cdot \zeta_s \qquad (6.3)$$

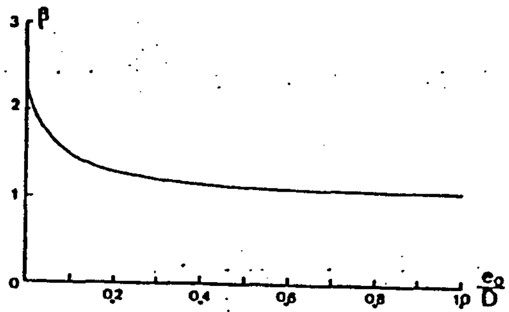

Fig. 6.2 Variation of hydrodynamic mass with gap ratio. After [19].

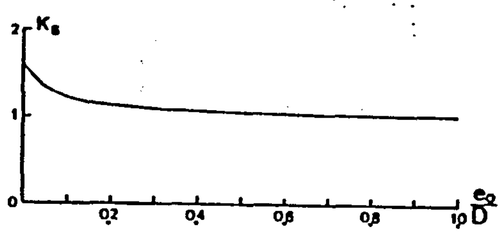

Fig. 6.3 Variation of the stability parameter with gap ratio.

Using a potential flow theory, Yamatoto et al. [19] calculated the variation of β with the initial gap ratio e_0/D in the case that the bed is plane (See Fig. 6.2.). When the bed is eroded by the flow, the value of β differs from that in the plane-bed case, especially when the gap is small. As an approximation, the calculated stability parameter of the K_s based on the result given by Yamatoto is plotted in Fig. 6.3.

6.2.2 Experimental arrangement

In the vibrating-pipe case, the reduced velocity is an important dimensionless parameter, connecting the undisturbed velocity U_∞, pipe diameter D and the natural frequency of the pipe f_n. It reads

$$V_r = \frac{U_\infty}{D\ f_n} \qquad (6.4)$$

In the experiments the range of V_r is 2.57 to 10.28.

The main purpose of the experiments summarized in Table 6.1 was to study the effect of the pipe vibration on the scour.

The experiments on the vibration of a pipe in the vicinity of an eroded bed were summarized in Table 6.2. Finally, some experiments in the two-directional flow were listed in Table 6.3.

6.3 The effect of the pipe vibration on an erodible bed

6.3.1 The scour influenced by the pipe vibration in unidirectional flow

A. The scour process for different values of θ_∞

The scour processes of a fixed pipe and a free pipe were plotted in Fig. 6.4 for $\theta_\infty = 0.048$ and $\theta_\infty = 0.098$.

The conclusion which can be drawn from the figures is that the scour depth influenced by the pipe vibration is much deeper than that in the fixed-pipe case.

It should be mentioned that the scour curves with the free pipe are quite different in Fig. 6.4 (a) and (b).

It is seen from Fig. 6.4 (a), when $\theta_\infty = 0.048$, in the early stage of the scour process (until t = 200 min) the difference between the fixed-pipe curve and the free-pipe curve was very limited. Conversely, when $\theta_\infty = 0.098$, the scour depth was much deeper than that in the fixed-pipe case from a quite early stage of the scour process.

Table 6.1. Summary of tests about scour in current.

Test name	Shield Parameter $\theta_\infty = \frac{U_f^2}{g(s-1)d_{50}}$	Reduced velocity $V_r = \frac{U_\infty}{Df_n}$	Initial gap e_0/D	Initial bed state	Pipe state	Time (min)
A1	0.048		0	plane	fixed	370
A2	0.048	5.10	0	plane	free	404
A3	0.098		0	plane	fixed	217
A4	0.098	7.19	0	plane	free	243
A5	0.063		0	The initially eroded bed	fixed	234
A6	0.063	5.65	0	The initially eroded bed	free	95

Table 6.2 Summary of tests about vibration in current.

Test name	Shield Parameter $\theta_\infty = \frac{U_f^2}{g(s-1)d_{50}}$	Reduced velocity $V_r = \frac{U_\infty}{Df_n}$	Initial gap e_0/D	Initial bed state	Pipe state	Time (min)
B1	0.015~0.221	2.57~10.28	0	The initially eroded bed	free	~ 30
B2	0.015~0.221	2.57~10.28	0.3	do	free	~ 30
B3	0.015~0.221	2.57~10.28	0.9	do	free	~ 30
B4	0.015~0.221	2.57~10.28	-0.15	do	free	~ 30
B5	0.015~0.221	2.57~10.28	-0.30	do	free	~ 30

Table 6.3 Summary of tests in two-directional flow.

Test Name	Shield Parameter $\theta_\infty = \frac{U_f^2}{g(s-1)d_{50}}$	Reduced velocity $V_r = \frac{U_{\infty max}}{Df_n}$	The period T_w (min)	Initial gap e_0/D	Initial bed state	Pipe state	Total effect time (min)
C1	0.098		4.0	0	plane	fixed	24
C2	0.098		8.0	0	plane	fixed	24
C3	0.098	7.19	2.5	0	plane	free	25
C4	0.015~0.098	2.57~7.19	6.0~20.8	0	eroded bed by two-directional	free	~ 90

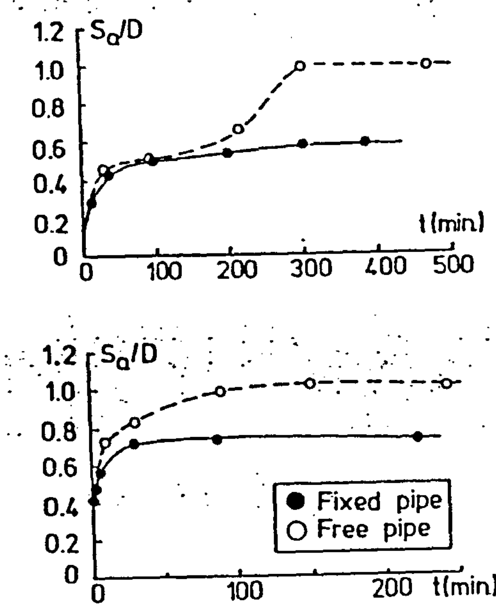

Fig. 6.4 Scour process for fixed pipe and free pipe, D = 10 cm, d_{50} = 0.36 mm. (a) θ_∞ = 0.048, V_r = 5.1; (b) θ_∞ = 0.098, V_r = 7.2.

The difference could be explained as follows:

It was the pipe vibration that made the scour hole much deeper than that in the fixed-pipe case. The vibration of the pipe is in close relation with the vortex shedding from the upper and lower edges of the pipe. If there is not enough space below the pipe, there is no regular vortex shedding. Although the gap under the pipe is larger than 0.3 [1], a suitable afterbody is necessary for the occurrence of sustained oscillations of the pipe [13]. The time needed for a flow to create a suitable space below the pipe depends on the undisturbed velocity of the flow. Because θ_∞ = 0.048 only a little larger than the critical value θ_c it took a very long time to move away the hill downstream the pipe.

Both in the case of θ_∞ = 0.048 and θ_∞ = 0.098 and when S_a/D = 0.7 the pipe started its sustained vibration with appreciable amplitude.

It is seen clearly from Fig. 6.4 that when the pipe started its large-amplitude vibration, the scour hole was eroded much quicker and deeper than before, which demonstrated that the pipe vibration has a very strong influence on the scour below the pipe.

The comparisons of scour holes between the fixed-pipe case and the free-pipe case were plotted in Fig. 6.5 and Fig. 6.6 for $\theta_\infty = 0.48$ and $\theta_\infty = 0.098$ respectively. The interesting thing is that both final equilibrium scour depths were about the diameter of the pipe in the case that $e_0/D = 0$.

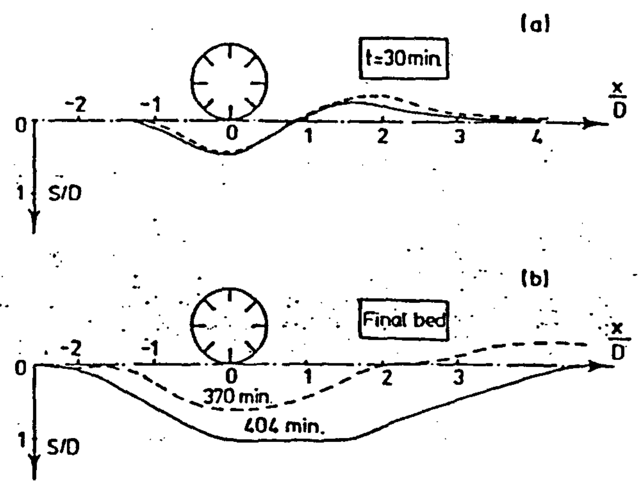

Fig. 6.5 Comparison between scour holes; $\theta_\infty = 0.048$, $V_r = 5.1$
$e_0/D = 0$. ---: fixed pipe, ——: free pipe.
(a) The early stage, t = 30 min;
(b) The equilibrium stage.

B. The pipe-vibration-induced scour

Why does the pipe vibration have so strong an effect on the bed scour?

The pipe vibration induces extra erosion. By the strong action of the oscillation of the pipe, first, as bed load the particles on the upstream slope of the scour hole are rushed

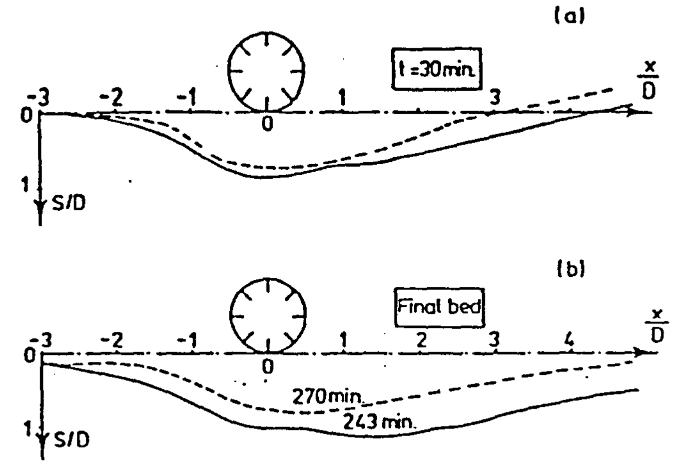

Fig. 6.6 Comparison between scour holes, $\theta_\infty = 0.098$, $V_r = 7.19$,
$e_0/D = 0$. ---: fixed pipe, ——: free pipe.
(a) The early stage, t = 30 min..
(b) The equilibrium stage.

down by the accelerated flow. Next, some sand particles directed under the pipe move out of the scour hole in suspension. Moreover, the effect of the lee-wake on the scour downstream the pipe is more violent in the vibrating-pipe case.

Fig. 6.8 shows the synchronous records of the pipe displacement and the velocity measured at the position close to the upstream slope (see Fig. 6.7). It is evident that every time when the pipe moved up the flow above the upstream slope accelerated correspondingly.

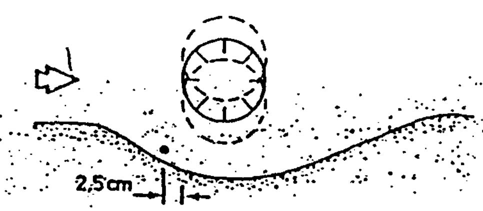

Fig. 6.7 Sketch of the synchronous-records-test, "•" is the position of the micropropeller.

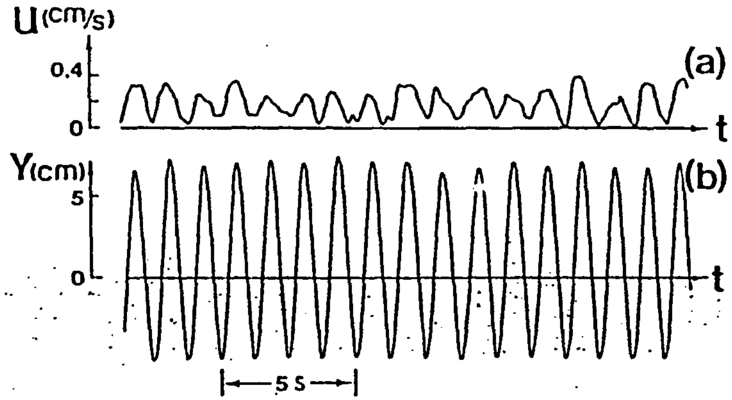

Fig. 6.8 A sample of the syncronous records.
(a) The velocity record measured at the position close to the upstream slope of the scour hole;
(b) The record of the pipe displacement, "o" corresponded to the equilibrium position of the pipe in still water.

Fig. 6.9 shows the flow pattern and the sediment movement in the scour hole following the pipe vibration. The dashed arrow drawn inside the pipe shows the moving direction of the pipe. The black arrows show the extra flow velocity induced by the pipe vibration.

The flow in the scour hole is determined by the upstream flow and the bed profile in the case of fixed pipe (see Fig. 6.9. (a)). In the vibration-pipe case, there is another dominant factor for the flow in the scour hole: the oscillation of the pipe. The action of the pipe in the scour hole is similar to that of a piston. When the pipe moves up in the scour hole, an extra water body is urgently needed. The pressure above the bottom of the scour hole is rather low, so some sand particles move in suspension. Meanwhile, some extra water rushes into the scour hole from upstream and downstream carrying some sand particles in bed load. (See Fig. 6.9 (b)).

When the pipe reaches its highest position, the flow is the same as in the fixed-pipe case with a large gap (see Fig.

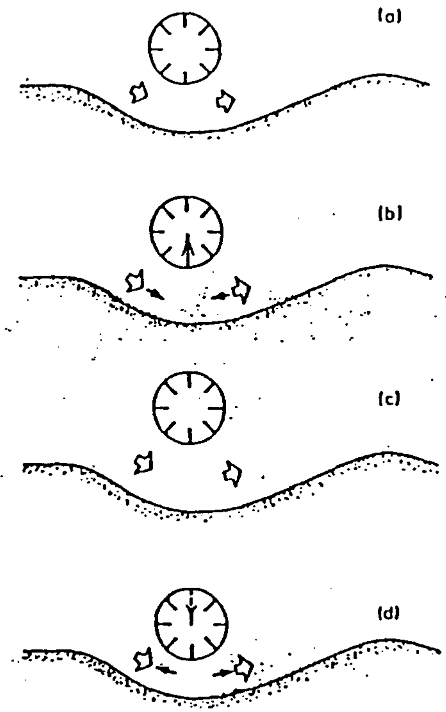

Fig. 6.9 The pattern of the flow and sediment movement in the scour hole during the oscillation process of the pipe.

6.9 (c)). The suspended particles are moved downstream by the flow.

When the pipe moves downward, some water body must be pumped out of the scour hole quickly in two directions (See Fig. 6.9 (d)). At that moment, the flow velocity above the upstream slope has its minimum value, therefore the bed load from the upstream is rather smaller than before. Meanwhile the flow above the downstream slope has much higher value. Therefore more sand particles move out of the scour hole. The result is that the bed is much eroded. Due to the reversing of the flow direction, a small ripple with a sharp crest could be observed in the downstream part of the scour hole.

The displacement of the pipe in the vertical direction can be described by

$$y = A_{max} \sin(\omega t) \quad (6.5)$$

in which A_{max} is the maximum amplitude of the pipe oscillation; ω is the angular frequency of the pipe oscillation, $\omega = 2\pi f$.

For a unit length of the scour hole along the direction of the pipe axis, the fluctuating part of the discharge in the scour hole is

$$\Delta Q = \frac{\pi}{4} D^2 \frac{dy}{dt} \quad (6.6)$$

It reads

$$\Delta Q = \frac{\pi}{4} A_{max} D^2 \omega \cos \omega t \quad (6.7)$$

The amplitude of the pipe vibration plays an important role in the scour process.

C. The pipe vibration in the scour process

The vibration problem will be discussed in detail later on. Here the analysis on the pipe vibration in the early stage of the scour process is presented for $\theta_0 = 0.098$, $V_r = 7.19$, $e_0/D = 0$.

The spectral density distribution in the first 30 minutes were plotted in Fig. 6.10.

Fig. 6.11 shows the variation of the mean amplitude and frequency response in the scour process.

It is seen that the pipe started its vibration quite early. The amplitude had a jump at t = 20 min. When t = 23 min, the mean amplitude of the pipe vibrations was 0.54 D. Meanwhile the dominant frequency increased too. In the late stage, the dominant frequency kept constant and was close to the natural frequency of the pipe f_n. $f/f_n = 1.2$

D. The effect of the initial gap on the scour.

In order to compare the influence of different initial

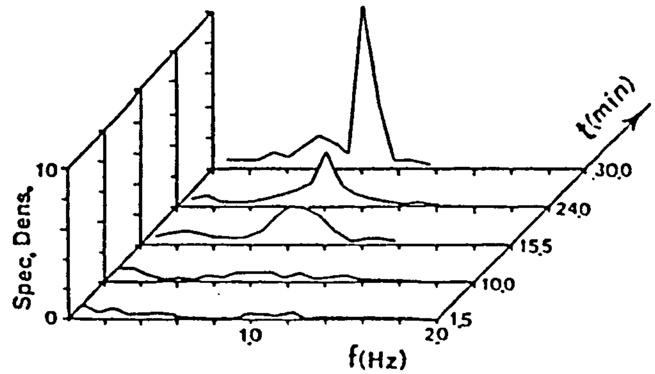

Fig. 6.10 The sprectral density distribution of the pipe vibration in the early stage of the scour process started from a plane bed, $\theta_\infty = 0.098$, $V_r = 7.19$, $e_0/D = 0$.

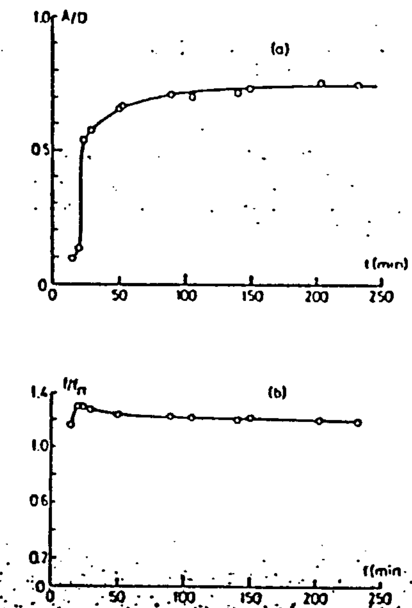

Fig. 6.11 The dominant frequency f and the mean amplitude A of the pipe vibration in the early stage of the scour process started from a plane bed, $\theta_\infty = 0.098$, $V_r = 7.19$, $e_0/D = 0$.

gaps on the scour, an initially eroded bed profile was needed. The bed profile used in the experiments was self produced in the following way: First, the pipe resting on the plane bed was fixed. Then the flume was run with a steady discharge corresponding to θ_{-} = 0.098 for 30 minutes.

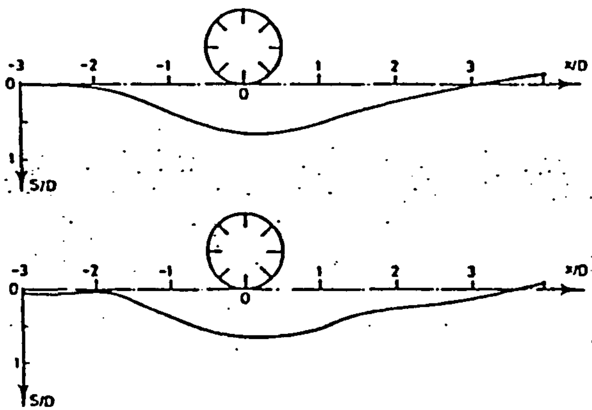

Fig. 6.12 The comparison between the self produced bed profiles in different tests.

Fig. 6.12 gives two bed profiles made in above-mentioned way illustrating that the scour hole is reproducible. Hereafter, the bed profile is designated "the initially eroded bed profile".

For the serial tests B1 to B5, every time the test started from the initially eroded bed profile, the discharge was increasing evenly step by step corresponding to the increase of V_r from 2.57 to 10.28. The total test time was around 30 min. Except the initial gap ratio, other factors were kept constant (see Table 6.2.). Therefore, the effect of the initial gap on the scour in the vibrating-pipe case can be studied.

The scour depths for the tests B1 to B5 are plotted in Fig. 6.13. It is clear that the initial gap has some appreciable influence on the scour. Fig. 6.14 (a) and (b) plot the scour bed profiles measured at the end of each test for the positive and negative gaps respectively.

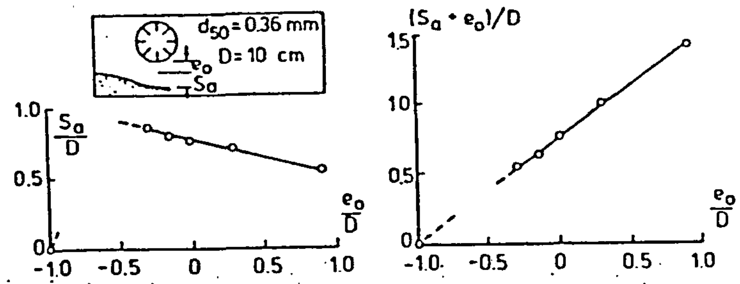

Fig. 6.13 Scour depth versus the initial gap in the serial tests B1 to B5.

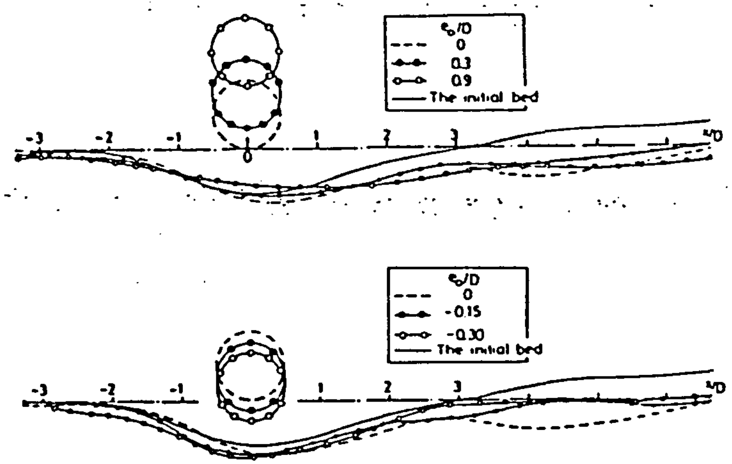

Fig. 6.14 The bed profiles for tests B1 to B5.
(a) For the positive gaps, $e_0/D > 0$;
(b) For the negative gaps, $e_0/D > 0$.

With the decrease of the gap ratio, the scour depth was larger, which is similar to the tendency in the fixed-pipe case (see Fig. 2.36).

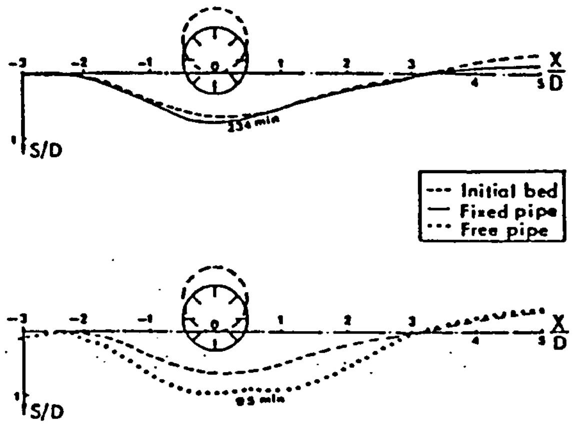

Fig. 6.15 Comparison between the eroded bed profiles which started from the same initially eroded bed profile, $\theta_{\infty} = 0.063$, $e_{\infty}/D = -0.3$. (a) For the fixed pipe (the test A5), (b) for the free pipe, $V_r = 5.65$ (the test A6).

The observation on the serial tests with the initially eroded bed profile indicated that when the initial gap e_0/D was small enough and the reduced velocity was suitable, the pipe was making an impact on the eroded bed, resulting in more serious scour.

As seen in Fig. 6.15, both the test of the fixed pipe and the free pipe started from the initially eroded bed profile. The undisturbed velocity was the same, corresponding to $V_r = 5.65$, $\theta_{\infty} = 0.063$. The test with the fixed pipe was run for 234 min, the relative scour depth directly under the pipe was 0.75 (see Fig. (a)). Although the test with the free pipe was run only 95 min. the relative scour depth concerned was as deep as 0.97 (See fig. (b)).

Fig. 6.16 is the scour process in the free-pipe case. For the sake of comparison, the scour depth corresponding to the fixed pipe case was drawn as a dashed line. Due to the impact of the pipe on the scour hole, the scour rate was so high in the free-pipe case that after 10 min. the scour depth under the pipe

was as deep as in the fixed-pipe case corresponding to 234 min. running.

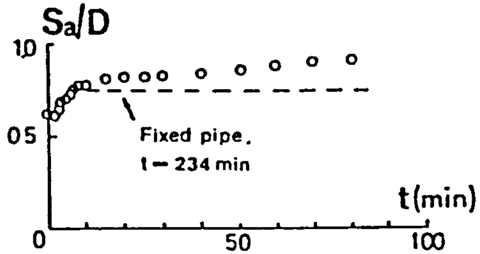

Fig. 6.16 The scour process in the test A6 with the free pipe, $e_0/D = -0.3$, started from the initially eroded bed profile.

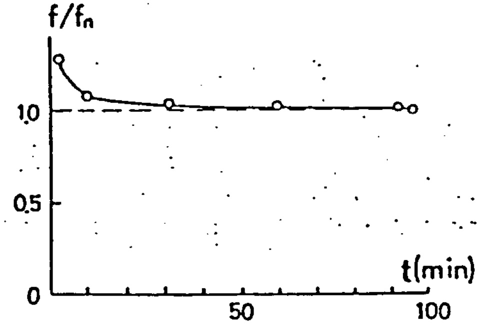

Fig. 6.17 The variation of the dominating frequency f in the test A6 with the free pipe, $e_0/D = -0.3$, started from the initially eroded bed profile.

In Fig. 6.17 the dominant frequency showed that the natural frequency of the pipe tends to incline.

In Fig. 6.18, the dimensionless scour depth S_a/D for both fixed and free pipes are plotted against the initial gap ratio for $\theta_{\infty} = 0.098$. It is clear that the initial gap ratio e_0/D and the pipe category (i.e. vibrating pipe or fixed pipe) control the final scour depth.

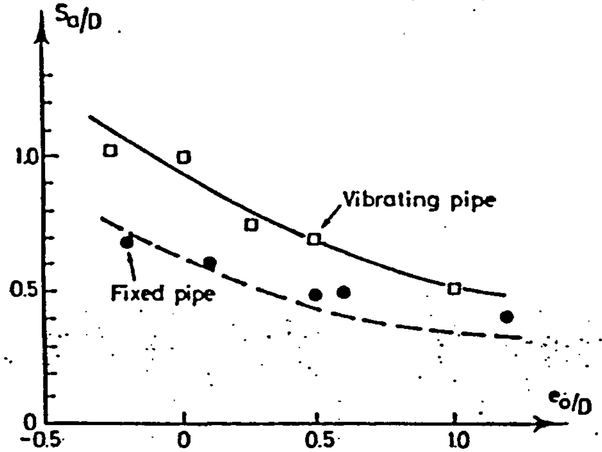

Fig. 6.18 Final scour depth versus the initial gap for θ_∞ = 0.098. V_r = 7.2. ---: The theoretical result for the fixed-pipe case for θ_∞ = 0.10. ——: The empirical result for the free-pipe case.

In the sagging process, the mid-span of the pipeline is lower than the original plane bed, which corresponds to the case that the gap is negative. The mid-span is responsive to the flow induced vibration. When the pipe vibrates, the underneath scour hole is quite deep, especially when the impact of the pipeline on the scour hole takes place. A deep scour hole helps the self-burial of the pipeline, but the vibration may cause fatigue of the pipe, and the impact may result in the break of the pipeline.

6.3.2 The scour influenced by the pipe vibration in the two-directional flow

As described in section 5.2.2 the flow direction in the 2 m wide flume can be reversed. The pattern of the two-directional flow was shown in Fig. 5.3.

The comparison shown in Fig. 6.19 (a) suggested that t_{eff} was more influential than T_w on the scour below the pipe.

Fig. 6.19 (b) indicated that when the pipe is fixed, the scour depth in the two-directional flow was deeper than that in the unidirectional flow.

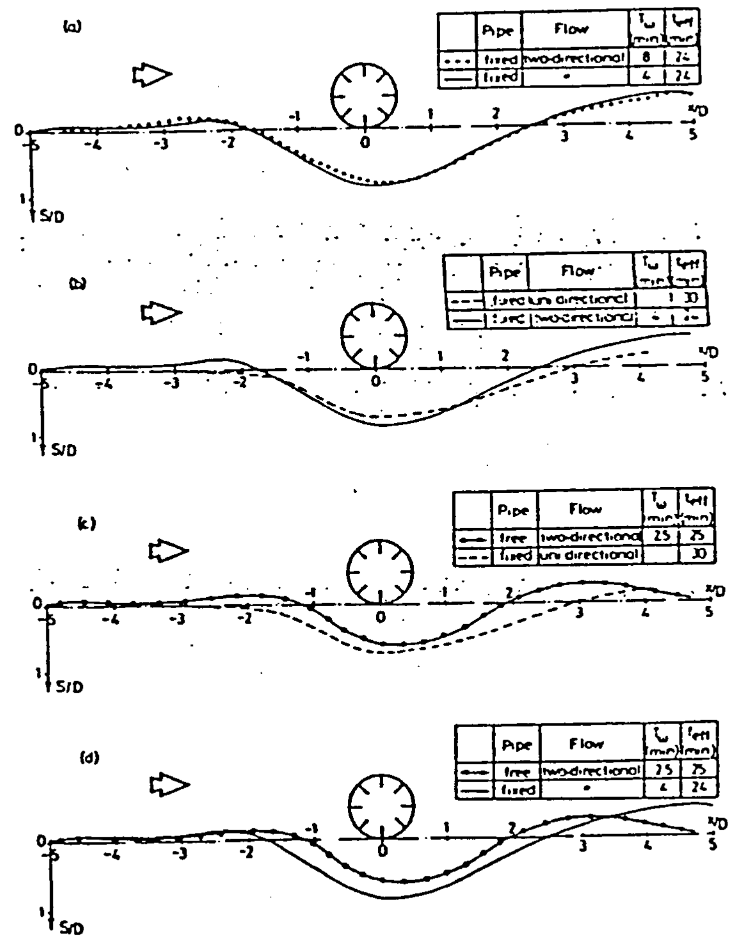

Fig. 6.19 Comparisons between scour bed profiles in unidirectional flow, two-directional flow with fixed or free pipe. D = 10 cm, e_0/D = 0, $\theta_{\infty,m}$ = 0.098, $V_{r,m}$ = 7.19.

The comparison of Fig. 6.19 (c) shows that the scour rate with the free pipe in the two-directional flow is smaller than that with the fixed pipe in the unidirectional flow.

In the two-directional flow case, as shown in Fig. 6.19 (d) the scour depth in the free-pipe case was much shallower than that in the fixed-pipe case.

The conclusion is the following: If the flow is two-directional, and the pipe is free to vibrate, the scour rate is small, and the final equilibrium scour depth is shallower than that in the unidirectional flow and that for the fixed pipe in the two-directional flow.

The explanation is the following:

1. When the flow reverses its direction, there always is an upstream hill limiting the discharge passing under the pipe.

2. Due to the sinking of the pipe, the position of the free pipe in the scour hole is rather lower than that of the fixed pipe. It makes the discharge passing under the pipe smaller.

3. Owing to the sinking into the scour hole and the effect of the hill downstream the pipe, the vortex shedding is suppressed in the two-directional flow case. Therefore the free pipe cannot continuously vibrate with appreciable amplitude resulting in deep scour.

6.4 The effect of an eroded bed on the behaviour of the pipe

6.4.1 The methodology of the tests

The séries tests B1 to B5 (see Table 6.2) were carried out with a free pipe. The scour hole used is the initially eroded bed introduced in section 6.3.1 D.

The reduced flow velocity was increased step by step from $V_r = 2.57$ to 10.28 (see Fig. 6.20). The total measurement time in a test was about 30 min.

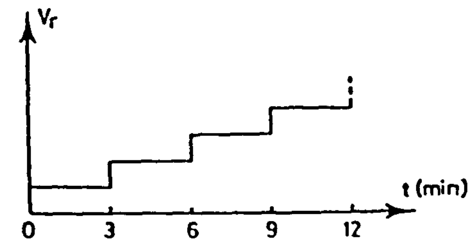

Fig. 6.20 Sketch of the flow in the series tests B1 to B5.

In Fig. 6.21 the eroded bed profiles of test B1 measured after sampling were plotted. Because it took a relatively long time to erode the bed substantially, the changes of the eroded bed profiles underneath the pipe corresponding to different values of V_r were rather limited. Obviously, well downstream the pipe, there was some change in the scour bed profiles, but this should be expected to have no influence on the pipe vibration.

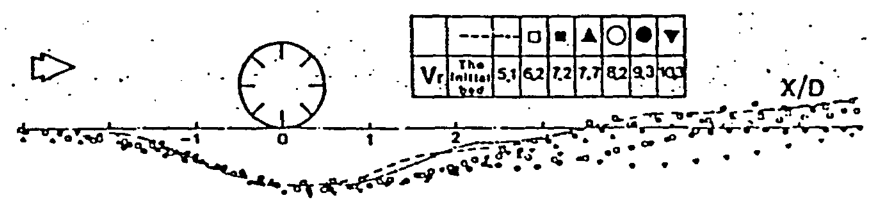

Fig. 6.21 Comparison between eroded bed profiles corresponding to different reduced velocities in test B1 started from the initially eroded bed profile.

6.4.2 The equilibrium position of the pipe

A. A negative lift force

As demonstrated by Fredsøe and Hansen [5], when a pipe is in the vicinity of a plane bed, the pipe is exposed to an upward lift force, because the stagnation point of the flow is on the lower part of the cylinder (see Fig. 6.22 (a)). Therefore, if the pipe is free, it will move upward.

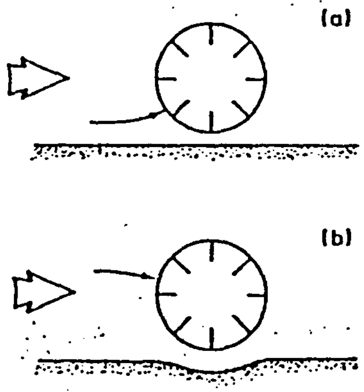

Fig. 6.22 Sketch of the stagnation point of the flow on the cylinder (a) with a plane bed; (b) with an eroded bed.

In the case that a pipe is placed in the vicinity of an eroded bed, the calculation (see Fig. 2.13) and the flow visualization experiments with dye have indicated that the stagnation point of the flow is on the upper part of the cylinder (see Fig. 6.22 (b)).

The wake behind the pipe varies with different bed forms below the pipe. It is demonstrated by tests that even though the initial gap e_0/D was 0.9, the pipe was still exposed to a negative lift force (cf. Fig. 6.25).

Owing to the negative lift force, the pipe is moving downward until it finds a new equilibrium position.

B. The equilibrium position of the pipe in the early stage of the scour process.

In the experiments where the pipe was resting on a plane bed it was observed that at the start of the tests, due to the upward lift force, the pipe moved upwards. As soon as there was a scour hole under the pipe, the pipe moved downwards due to the negative lift force. Fig. 6.23 is one of the typical records.

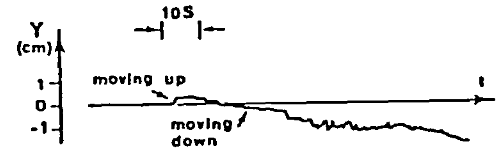

Fig. 6.23 The record of the pipe position in the early stage for $\theta_* = 0.098$, $V_r = 7.19$, $e_0/D = 0$.

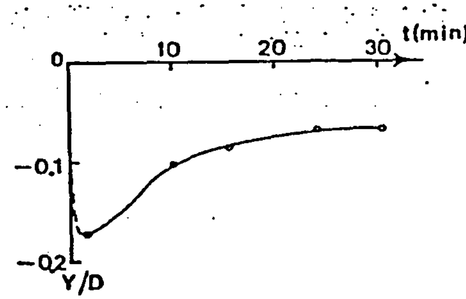

Fig. 6.24 The equilibrium position of the pipe in the early stage of the scour process $\theta_* = 0.098$, $V_r = 7.19$, $e_0/D = 0$.

Taking the pipe position in still water as the datum, the instantaneous equilibrium position of the pipe Y in flow was calculated from the amplitudes of the pipe vibration. Fig. 6.24 plotted the variation of the equilibrium position Y in the early stage of the scour process. It is seen that, due to the erosion of the bed, the equilibrium position of the pipe was varying. At first, the pipe sank as deep as 0.17 D. Later on it rose gradually, but its equilibrium position was always lower than the original equilibrium position in still water. The lowest position corresponded to the maximum downward force on the pipe in the early stage of the scour process.

C. The variation of the equilibrium position of the pipe with the initial gap and the reduced velocity in the current.

In fact, the equilibrium position of the pipe in flow not only depends on the initial equilibrium position in still water, but also on the reduced velocity.

Fig. 6.25 showed the variations of the equilibrium position with the reduced velocity for 5 different gap ratios e_0/D. It should be remembered that Y originates from the equilibrium position of the pipe in still water.

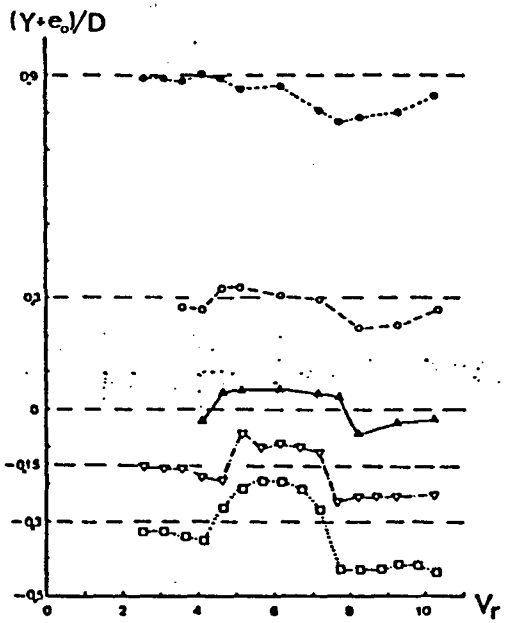

Fig. 6.25 The variation of the equilibrium position of the pipe with the reduced velocity for different initial gap ratios: 0.9, 0.3, 0, -0.15, -0.3.

It is seen that the pipe managed its equilibrium position in flow in quite different ways depending on the initial gap and the reduced velocity.

When the gap was large enough, for example $e_0/D = 0.9$, the equilibrium position was always lower than or equal to its original position in still water, which demonstrated than even though the pipe was placed quite far away from the eroded bed, it was still exposed to the negative lift force.

When the gap was not so large, sometimes the pipe moved upwards. The range of the reduced velocity V_r, in which the equilibrium position of the pipe was higher than the original position in still water, was enlarged with the decrease of the initial gap ratio e_0/D until $e_0/D = 0$.

In fact the moving upwards of the equilibrium position of the pipe corresponded to the pipe vibration with appreciable amplitude. When the reduced velocity V_r was larger than 8, the pipe vibration was limited, the equilibrium position of the pipe was much lower than the original position.

D. The explanation of the shift of the equilibrium position of the pipe in flow.

1. The formal explanation.

The instantaneous equilibrium position of the pipe was calculated as the middle of the double amplitude. Based on the equilibrium position of the pipe in still water the amplitude of the pipe vibration in flow can be split up into two parts, an upper amplitude and a lower amplitude (cf. Fig. 6.26). When the amplitude was appreciable, although the pipe was exposed to the negative lift force, because the lower amplitude was smaller than the upper amplitude, the equilibrium position of the pipe in flow was higher than the original position in still water.

Fig. 6.27 is the record of the pipe vibration for $\theta_- = 0.063$, in the case of $e_0/D = -0.3$. In the sample the lower amplitude is kept constant due to the impact on the scour hole.

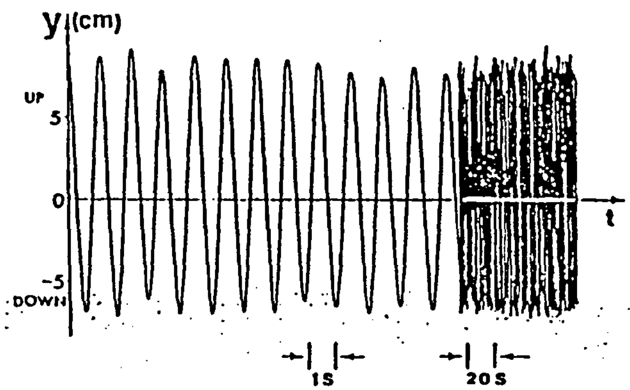

Fig. 6.26 A sample of the pipe vibration in test B1, θ_{-} = 0.098, V_r = 7.19, e_0/D = 0.

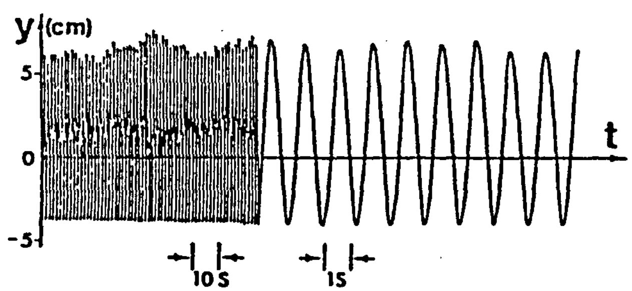

Fig. 6.27 A sample of the pipe vibration in test B5, θ_{-} = 0.063, V_r = 5.65, e_0/D = -0.3.

2. The physical explanation.

Why is the lower amplitude smaller than the upper amplitude?

The bed boundary has a strong influence on the behaviour of the vibrating pipe. Except in the impact case, generally speaking, the pipe does not contact the scour hole directly. When the pipe is moving down the pipe gives the water body around it an acceleration in the vertical direction. In turn, the accelerated water body creates an extra pressure field on the surface of the pipe to constitute an additional resistance to the body motion. The action of the water can be expressed as a so-called hydrodynamic mass timing the acceleration of the pipe. As pointed out by Yamatoto et al. [19], the hydrodynamic mass coefficient β is the function of the gap ratio in the plane bed case (see Fig. 6.2). When the gap e_0/D = 0, the maximum value of β equals 2.29. In the eroded bed case, due to the effect of the geometry of the scour hole, the value of β may be higher than that in the plane-bed case.

The serious increase of the hydrodynamic mass in close proximity to the scour hole means the increase of the resistance to the motion of the pipe. It seems that in the close proximity of the scour hole, the pipe is exposed to a lift force directed away from the scour hole. Therefore the lower amplitude is rather smaller than the upper amplitude.

E. The equilibrium position of the pipe in the two-directional flow

Due to the presence of the upstream hill, the decline of the pipe equilibrium position in two-directional flow is more serious than in the unidirectional flow. It is seen from Fig. 6.28 (a) that when there was a scour hole under the pipe, the pipe sagged quickly, and then kept the low position in the scour hole. Consequently, the vibration of the pipe is restrained a lot, resulting in a small amplitude.

Starting from an eroded bed made by the two-directional flow, test C4 was run to find the influence of the reduced velocity on the pipe. Fig. 6.29 pointed out that there was a systematic decrease of the equilibrium position with the increase of the reduced velocity $V_{r,m}$.

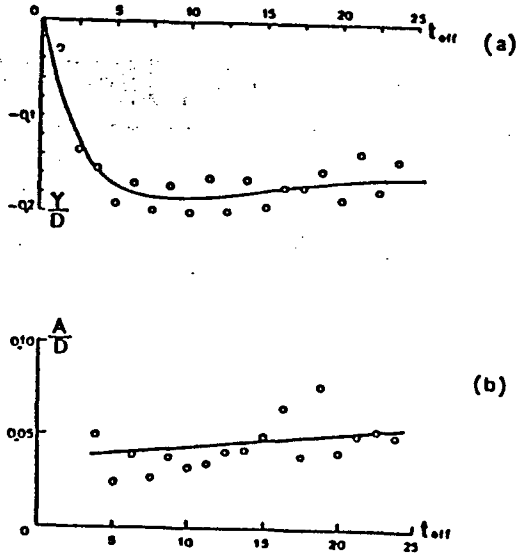

Fig. 6.28 The variation of the equilibrium position of the pipe and the amplitude in the scour process of the two-directional flow, $V_{r,m}$ = 7.19, T_w = 2.5 min, e_0/D = 0.
a) Y/D versus T_{eff}; b) A/D versus T_{eff}.

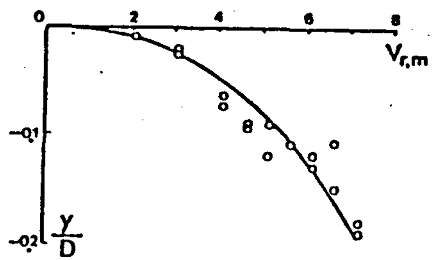

Fig. 6.29 The variation of the equilibrium position of the pipe with the reduced velocity in test C4.

6.4.3 The responses of the pipe near an eroded bed

The amplitude response of the pipe in the tests B1 to B5 was plotted in Fig. 6.30 (a) in the form of the double amplitude 2A. The frequency response was plotted in Fig. 6.30 (b). The spectral density distributions of pipe displacement corresponding to different gaps were shown in Figs. 6.31 and 6.32.

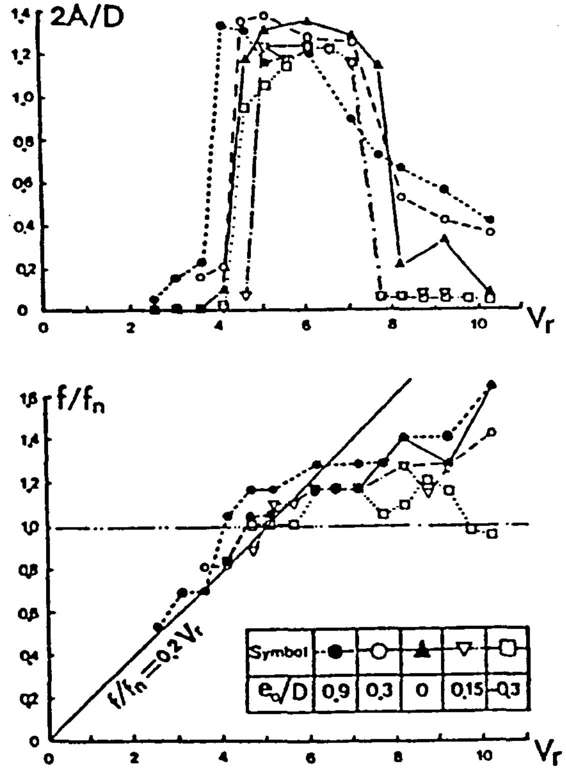

Fig. 6.30 The variation of the amplitude response and the frequency of the pipe in the reduced velocity.
(a) 2A/D versus V_r; (b) f/f_n versus V_r.

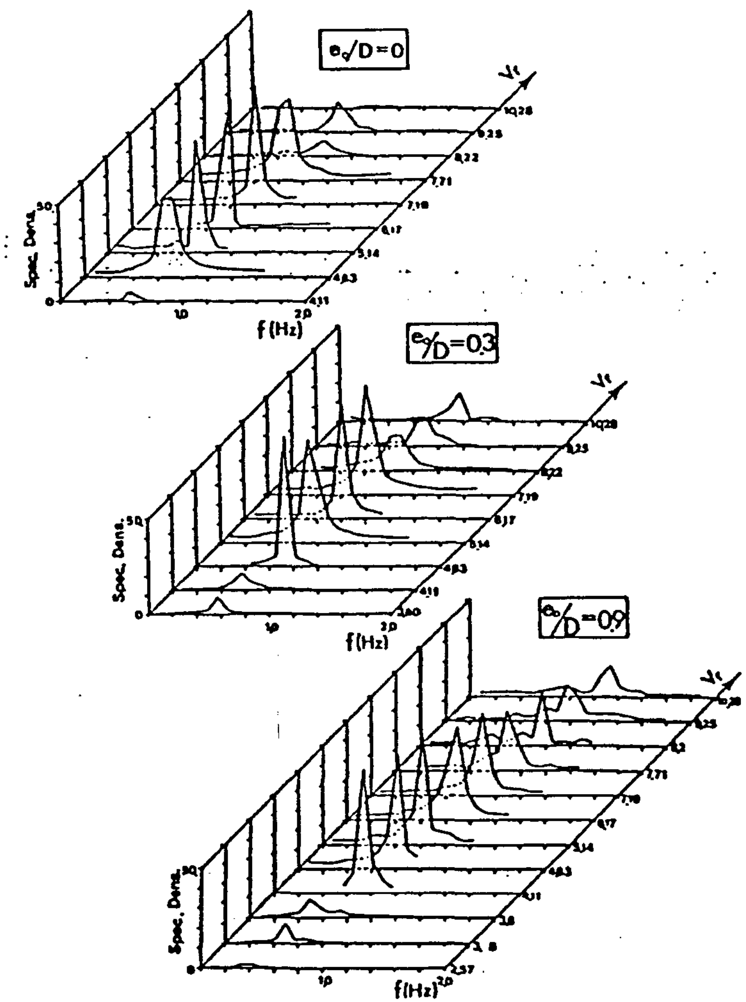

Fig. 6.31 Spectral density distribution of pipe displacement versus reduced velocity for the initial gap ratios: e_0/D = 0, 0.3, 0.9.

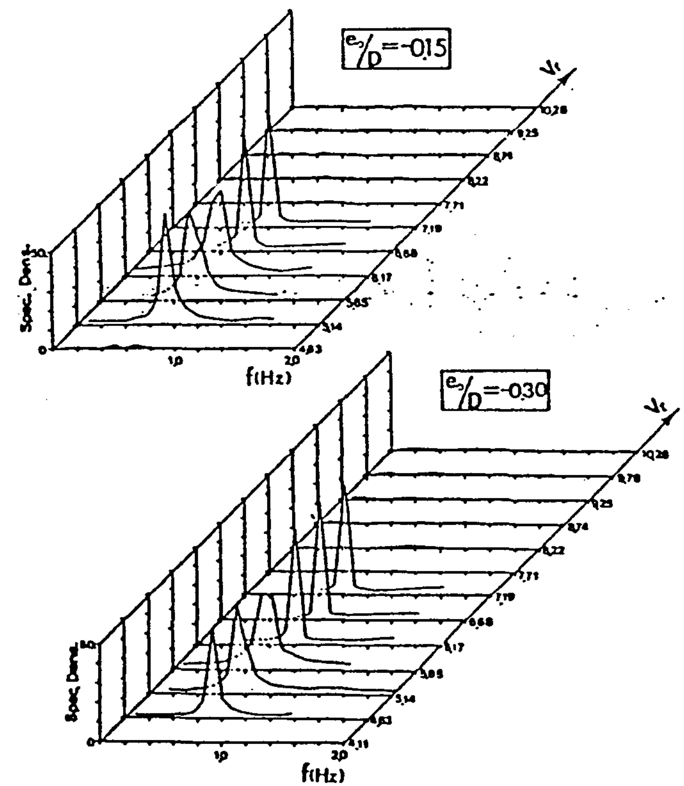

Fig. 6.32. Spectral density distribution versus reduced velocity for the initial gap ratio e_0/D = -0.15, -0.30.

<u>A. Three stages of the pipe state with respect to the pipe vibration</u>

Previous studies [13, 6] about the vibration of the pipe in close proximity to a plane bed indicated that there was a "lock-in" phenomenon where the response frequency and the vortex shedding frequency collapsed into a single frequency close to the natural frequency of the pipe.

Present tests indicated that when the pipe close to an eroded bed was vibrating, the lock-in phenomenon occurred too. When the pipe was in the lock-in state, the amplitudes were appreciable.

The reduced velocity V_r has a very important influence on the lock-in phenomenon. The general comparison shown in Fig. 6.30 indicated that the state of the pipe with respect to the pipe vibration can be classified in three stages, which is summarized in Table 6.4.

Table 6.4 The range of V_r and the amplitude response of the pipe in three stages.

The stage of the pipe vibration	The range of the reduced velocity	Relative amplitude A/D
The pre-vibration stage	0 ~ 3.5	< 0.1
The lock-in stage	4 ~ 7.8	~ 0.6
The lock-out stage	8 ~	< 0.3

B. The influence of the initial gap on the lock-in phenomenon.

As shown in Fig. 6.30, a larger gap corresponded to a wider lock-in range. When $e_0/D = 0.9$, the difference between the lock-in and the lock-out was not so clear as in the small-gap case. In that case the influence of the boundary was rather limited. When the initial gap is larger, the lock-in phenomenon corresponds to smaller reduced velocity. $e_0/D = -0.3$ is an exception due to the impact of the pipe on the scour hole.

In the lock-in region of the reduced velocity V_r, the amplitude response 2A/D varied only little with the variation of the initial gap ratio e_0/D.

On the other hand, when the pipe is not in the lock-in stage, the amplitude response of the pipe was larger with the increase of the gap.

C. The frequency response

vibration was close to the natural frequency, $f/f_n = 1.0 \sim 1.2$. Especially when $V_r < 6$, the frequency followed the equation $f/f_n = 0.2\ V_r$ quite well. Later on, with the increase of V_r, the frequency $f/f_n < 0.2\ V_r$. For different gaps, the values of f/f_n scattered. A larger gap corresponded to a higher frequency.

6.4.4 The comparison with the results in [6]

The present results with a gap ratio $e_0/D = 0.3$ and -0.3 were plotted in Fig. 6.33 and 6.34 respectively to make a comparison with the data given in [6].

It is evident that the behaviour of the pipe near an eroded bed was quite different from the behaviour of the pipe near a plane bed:

1. The pipe in the vicinity of an eroded bed had an evident lock-out state. The amplitude was smaller than that with a plane bed. When the reduced velocity is quite high, due to the effect of the scour hole, the pipe cannot vibrate with appreciable amplitude.
2. The frequency in the eroded-bed case was smaller than that with a plane bed.

The serious systematic decrease of amplitude response and frequency revealed that the eroded bed had a strong ability to restrain the vibration of the pipe.

6.5 The influence of the pipe sagging on the pipe vibration

Corresponding to the three stages of the pipe state, the reduced velocity can be split up into three different regions. The influence of the pipe sagging on the behaviour of the pipe is different in each region. The amplitude response A/D and the initial gap ratio e_0/D in Fig. 6.35 and 6.36 respectively.

If a pipe exposed to a steady unidirectional flow is sagging from gap ratio $e_0/D = 0.9$ to -0.3, its behaviour in different regions of the reduced velocity varies. In the pre-vibration region, the amplitude response decreased following the decrease of the gap until the amplitude was equal to 0. Meanwhile frequency response f/f_n decreased too.

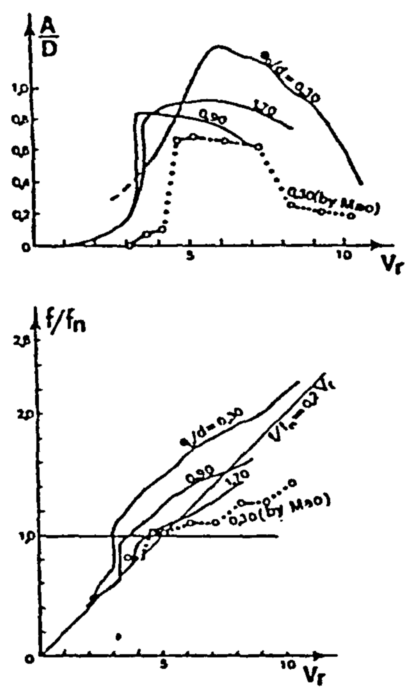

Fig. 6.33 Comparison between [6] and present test with $e_0/D = 0.3$.
a) amplitude A/D;
b) frequency f/f_n.

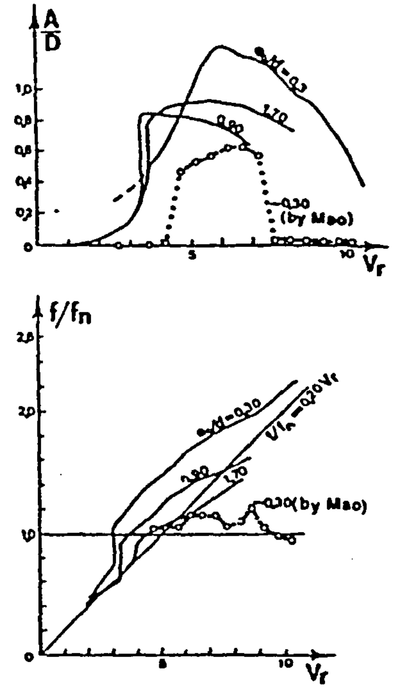

Fig. 6.34 Comparison between [6] and present test with $e_0/D = -0.30$.
a) amplitude A/D;
b) frequency f/f_n.

In the lock-out region, the phenomenon was similar to that in the pre-vibration region during the sagging process. The amplitude and frequency decreased.

The situation was very different in the lock-in region. The amplitude response and frequency response almost did not change during the sagging process. It should be mentioned that this situation is quite dangerous: when a pipe vibrating with appreciable amplitude sags deeply into a scour hole, then, due to the appreciable amplitude of the vibration, the impact of the pipe on the bed may result in the damage of the pipe.

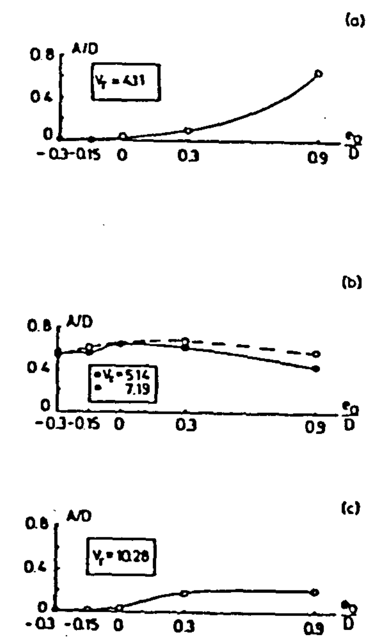

Fig. 6.35 Amplitude response A/D versus the initial gap ratio e_0/D in different regions of V_r:
a) in the pre-vibration region
b) in the lock-in region
c) in the lock-out region.

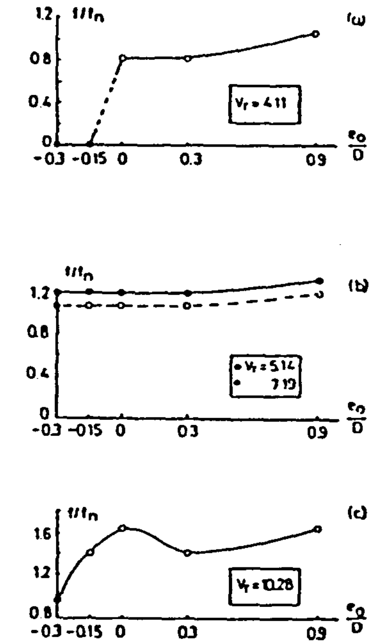

Fig. 6.36 Frequency f/f_n versus the initial gap ratio e_0/D in different regions of V_r: a) in the pre-vibration region b) in the lock-in region c) in the lock-out region.

6.6 The pipe vibration in the two-directional flow

The eroded bed used in the test C4 was in the final scour bed profile created by the two-directional flow in the test C3.

In the test C4, the value of KC was kept constant, KC = 1800.

From Eq. (5.4), KC reads

$$KC = T_w \, f_n \, V_{r,m} \qquad (6.8)$$

in which $V_{r,m}$ is the maximum value of the reduced velocity.

Corresponding to the variation of $V_{r,m}$ (2.57 ~ 7.19) the range of the period is T_w = 6.0 ~ 20.8 min.

The maximum amplitude and the frequency response were plotted in Fig. 6.37.

It is very clear that in the two-directional flow, there was a lock-in phenomenon, but the lock-in region of $V_{r,m}$ was quite narrow, and the maximum amplitude response was only about 0.1 D. Compared to the vibration of the pipe in the unidirectional flow, it is rather small.

The results suggest that in the two-directional flow the eroded bed with two hills on each side of the pipe has a very strong restrictive action on the pipe vibration.

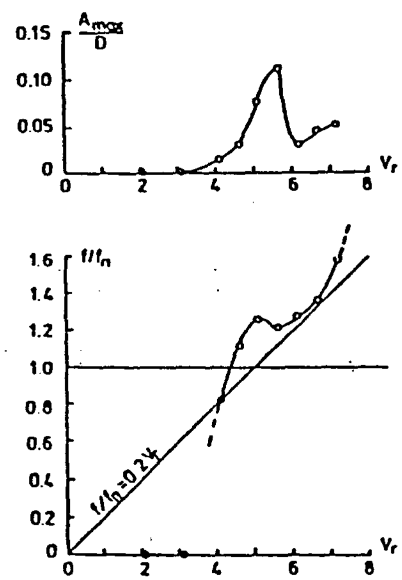

Fig. 6.37 Maximum amplitude and frequency response versus reduced velocity in test C4.

6.7 Conclusions

The transverse vibration of a pipe with appreciable amplitude controls the flow state and the sediment movement in the

In unidirectional flow, the final scour depth is about the diameter of the pipe. Because the vortex shedding and the vibration of the pipe need a certain space under and behind the pipe, the on-set of the pipe vibration and its amplitude response are influenced by the undisturbed velocity. A relatively small initial gap causes a relatively deep scour hole and may have the accompanying impact phenomenon.

In the two-directional flow, due to the shelter action of the hill upstream the pipe and the sagging forced by the flow, the scour rate is smaller than that in the unidirectional flow, and the final scour depth will be shallower.

In the vicinity of an eroded bed, the pipe is exposed to a negative lift force. When a pipe is vibrating with appreciable amplitude, the lower amplitude is much smaller than the upper amplitude, resulting in the moving up of the equilibrium position of the pipe due to the strong resistance of the water body in the scour hole.

There are three different stages of the pipe state with respect to the pipe vibration: the pre-vibration stage, the lock-in stage and the lock-out stage. The corresponding regions in the reduced velocity vary with the initial gap ratio. Compared to the vibration of the pipe near a plane bed, if the pipe is in the vicinity of an eroded bed, the pipe vibration has a narrower lock-in region of V_r, smaller amplitude response and the frequency response is close to the natural frequency of the pipe.

In short, the eroded bed has a strong restrictive action on the pipe vibration, especially in the two-directional flow.

The sagging phenomenon was analysed from the scour point of view, and the vibration characteristics in the sagging process was discussed.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	The distance between the pipe centre and the plane (2
	The amplitude of the free stream particle (5.3.4).
A	The mean amplitude of the pipe vibration (6.3).
A_{max}	The maximum amplitude of the pipe oscillation (6.3).
c_p	The relative pressure coefficient $c_p = \frac{(P-P_\infty)/\gamma}{U_\infty^2/2g}$ (2.2.
D	The diameter of a pipe (1.1).
D_1	The outer diameter of a reinforced concrete pipe (3.4.
D_2	The diameter of a steel pipe (3.4.2)
D_3	The inner diameter of a reinforced concrete pipe (3.4.
d_{50}	Mean grain diameter of sediment particles.
e	The gap betwen a pipe and a bed (2.3).
e_0	The initial gap between the pipe and the original plan bed (2.3).
$e_{n,1}$ and $e_{n,2}$	The directions of a pair of double dipoles (2.3)
E	The modulus of elasticity of a pipeline (3.1).
f	The Darcy-Weisbach friction factor (2.3.2).
	The frequency of pairs of vortices shed from a pipe (4
	The dominant frequency of the pipe vibration (6.3.1).
f_n	The natural frequency of the pipeline (6.3.1).
f_w	The friction coefficient in the wave case (5.3).
g	The acceleration of gravity (1.1).
h(x)	The local bed level (See Fig. 2.10) (2.3).
h*	The dimensionless bed level (2.3).
H_z	The unit of the frequency (4.2).
H_∞	The flow depth (2.1).
i	The slope of head loss (2.2.2)
	The imaginary unit (2.3).
I	The bending moment of the inertia of the cross section pipeline (3.1).
K	The spring constant per unit length of a pipe (6.2).
KC	The Keulegan-Carpenter number, $KC = \frac{U_{\infty,m} T_w}{D}$ (5.3.2).
K_s	The bed roughness (5.3.1).
	The stability parameter (6.2).

l The distance between the measurement point and the vortex centre (4.6).

L The length of a flow line (2.2.2)
The span length of a pipeline (3.1).

L_{max} The maximum span length of a pipeline (3.4.1).

m The mass of a pipe (6.2.1)

m' The hydrodynamic mass of a pipe (6.2.1)

$M_{n,1}$ and $M_{n,2}$ The strength of a pair of double dipoles (2.3).

n The porosity of sediment (2.3).
The number of the digitized velocity in one sample (4.4.3).

P The local pressure on a bed (2.2.2).

P_∞ The pressure on the bed far away from a pipe (2.2.2).

q The bed load transport rate in volume (2.3).
The submerged load on the unit length of a pipeline (3.1).

q^* The dimensionless bed load transport rate, $q^* = \frac{q}{q_\infty}$ (2.3).

q_{calc} The calculated sediment transport rate (2.3.5)

$q_{local,\ max}$ The maximum sediment transport rate of the bed load just under the pipe (2.4).

$q_{sediment}$ A typical scale of sediment transport rate (2.4).

q_∞ The far field rate of sediment transport (2.2).

Re The Reynolds number defined by $Re = \frac{D\,U_\infty}{\nu}$ (4.1).

S The relative density of sediment (2.3).

S_a The scour depth directly under a pipe (2.3).

S_m The final equilibrium scour depth directly under a pipe (1.1).

S_p The relative density of a pipe. $S_p = \frac{\rho_{pipe}}{\rho}$, (6.2.1).

St The Strouhal number, $St = \frac{Df}{U_\infty}$, (4.3)

$S(x)$ The local scour depth (See Fig. 2.10).

t time (2.3).

t_0 The time parameter, $t_0 = \frac{D^2(1-n)}{q_\infty}$, (2.3).

t^* The dimensionless time $t^* = t/t_0$ (2.3).

t_{eff} The sum of the time when θ_c was exceeded (5.2)

t_A^* The dimensionless time based on q_∞ (2.4).

t_B^* The dimensionless time based on q_{local} (2.4).

T The total time of the sagging process of the pipeline (3.4.1).

T_w The period of waves (5.2).

u The x-directional component of velocity (2.3).

u_i The digitized instantaneous velocity u (4.3).

u_{max} The maximum value of u in a sample (4.4.3).

u_v The instantaneous value of the vortex-shedding-induced velocity (4.6).

$\bar{u}$ mean value of u (4.3).

u' fluctuation velocity (4.3).

U_{bed} The velocity close to the bed directly under a pipe (2.

U_{bottom} The velocity in the vicinity of the lower edge of a pi (2.3.1).

U_f The friction velocity (2.3).

$U_{f\infty,m}$ The maximum shear velocity defined by $U_{f\infty,m} = \sqrt{\frac{f_w}{2}}\,U_\infty$. (5.3.1).

U_{top} The velocity in the vicinity of the upper edge of a pi (2.3.1).

U_{under} The velocity of the ground water flow (2.2.2).

U_v The amplitude of the vortex-shedding-induced velocity (4.5.2).

U_∞ The undisturbed velocity at the place well upstream a (2.1).

$U_{\infty,m}$ The maximum value of U_∞ in the two-directional flow (

V The y-directional component of velocity (2.3).

V_r The reduced velocity. $V_r = \frac{U_\infty}{Df_n}$, (6.2.2).

$V_{r,m}$ The maximum value of the reduced velocity in the two-tional flow (6.3.2).

V_v The strength factor of the vortex body.

V_s The sagging velocity of the mid-span of a pipeline.

W The width of a scour hole (2.3.2).

W_1 The upstream part of a scour hole (5.3.4).

W_2 The downstream part of a scour hole (5.3.4).
x The longitudinal coordinate.
x^* The dimensionless distance $x^* = x/D$ (2.3.2).
y The vertical coordinate.
The displacement of the pipe with respect to its initial equilibrium position in still water (6.3.1).
y_f Deflextion of the midspan of a fixed-ends-girder (3.2.3).
y_h Deflexion of the midspan of a hinged-edges-girder (3.2.3).
y_p Deflexion of the midspan of a pipeline (3.2.3).
z The complex coordinate, $z = x + iy$, (2.3).
$z_{n,1}$ and $z_{n,2}$ The position of a pair of double dipoles (2.3).

α The coefficient of distance (2.3).
The coefficient of the flexibility of a pipeline depending on the bed situation of a pipeline (3.4.1).
The coefficient corresponding to the fraction of the original circulation that survives the formation of the vortex (4.6).
β The coefficient of the hydrodynamic mass of pipe (6.2).
γ The specific gravity of water.
γ_{steel} The specific gravity of steel (3.4).
$\gamma_{concrete}$ The specific gravity of concrete (3.4).
Γ The strength of the vortex (4.6).
$\Delta *$ The increment of * (2.2.2).
ΔH The head loss (2.2).
ΔT The sampling time interval (4.4.3).
ΔY The distance (see Fig. 2.12).
ϵ The value to judge the discrepancy between q_∞ and q_{calc} along the upstream part of the scour hole. (See eq. 2.46). (2.3.5).
ζ_s The structural damping coefficient (6.2).
θ The Shields parameter, $\theta = \frac{\tau}{\rho g(s-1)d_{50}}$, (2.3).
θ_c The critical Shields parameter, below which sediment transport does not take place (2.3).

θ_{local} The local value of θ under the pipe (2.3).
θ_∞ The value of θ at the place well upstream the pipe (2.3).
$\theta_{\infty,m}$ The maximum value of θ_∞ in the two-directional flow (5.3.1).
κ The permeability coefficient of the ground material (2.2).
ν The Kinematic viscosity of the water.
ρ density of water.
ρ_{pipe} density of pipe.
σ The turbulence intensity, $\sigma = \sqrt{\overline{u'^2}}$, (4.3)
$\sum_{j=0}^{\infty}$ The summary of the elements from number j = 0 to j = ∞, (2.3).
τ_b The bed shear stress (2.3)
Φ The dimensionless sediment transport rate $\Phi = \frac{q}{\sqrt{g(s-1)d_{50}^3}}$ (2.3).
ϕ The real part of the complex potential ω (2.3).
ψ The imaginary part of the complex potential ω (2.3).
ψ_0 A part of ψ_k due to the contribution of Eq. (2.3).
ψ_k The imaginary part of the complex potential at point k on the boundary h(x) (2.3).
ψ_v A part of ψ_k due to the contribution of Eq. (2.4).
ω The complex potential (2.3).
The angular wave frequency. $\omega = 2\pi f$ (5.1).
The angular frequency of the pipe vibration (6.3).
ω_0 The complex potential in the absence of a pipe (2.3).
ω_1 The complex potential (2.3)
ω_n The complex potential induced by a pair of dipoles (2.3).
ω_v The complex potential given by a vortex body (2.3).
$\frac{d*}{dz}$ The operator (2.3).
$\frac{\partial *}{\partial x}$ The operator (2.3).
$\bar{*}$ The conjugate of * (2.3).
$|*|$ The module of * (2.3).
$\int_0^T$ The integration from t = 0 to t = T (3.4.1).

PLATFORM GINA

DEVELOPMENT AND PRODUCTION PLAN REVISION

APPENDIX VOLUME 5

UNOCAL 76

APPENDIX VOLUME 5

Structural Information

PLATFORM GINA
Structural Analysis of the Production Deck West Extension for the Temporary Batch Sweetening System

Prepared for: **Unocal Oil & Gas Division**
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Partner
Thomas & Beers

Date: Nov 20, 1990

Thomas & Beers Report Number 103
November 20, 1990

PLATFORM GINA
Structural Analysis of the Production Deck West Extension for the Temporary Batch Sweetening System

Table of Contents

THOMAS & BEERS
ENGINEERING,
ANALYSIS & DESIGN

November 19, 1990

Mr. Michael Craig
Regional Civil Engineer
Unocal Corporation
1800 30th Street, Suite 200
Bakersfield, California 93301-1921

Dear Mike:

Per your request we have performed a three dimensional structural analysis of the production deck - west extension of Platform Gina. The purpose of the analysis was to verify the structural adequacy of the west extension for supporting the batch sweetener system for operating and seismic loading.

Computer Model

Approximately half of the production deck and subdeck along with the associated kickers and columns were modeled. The platform finite element model, summarized in Appendix A, consists of beam, pipe and shell elements. The wide flange members were modeled with beam elements, and the columns and kicker braces were modeled with pipe elements. The deck plating was modeled with shell elements.

Loads

The platform loading consists of three primary loads: dead load, equipment load and live load. Structural dead load was input by accelerating the members with a 1.0g acceleration in the positive Z direction.

Equipment loads applied to the model include, but not limited to, the gross separator skid, sweetener carry over scrubber skid, batch sweetener skids, sweetener chemical tank skids, sweetener chemical pump skids, and emergency generator.

A 15 psf live load was applied to the entire west extension to account for miscellaneous piping and light traffic. Concentrated loads were applied at the north end of the extension for the stairs. One hundred percent of the drill deck stair loads and 50% of the subdeck stairs loads were input.

Seismic considerations were addressed by applying a 1.75g ($1g_{(dl+ll)} \pm 0.75g_{(seismic)}$) vertical acceleration to the dead and live loads. Results from the global response spectrum seismic analysis (Thomas and Beers Report 102) indicate that the actual vertical acceleration component is ±0.30g for a strength level earthquake and ±0.53g for a ductility level earthquake. Therefore a ± 0.75g seismic acceleration is a reasonable assumption for this temporary (one year) batch sweetener loading. Note that all masses were concentrated at the deck level, thus no rotary inertia effects of the tanks/equipment are included.

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FAX (805) 652-0170

Structural Evaluation Method
The Gina west extension was evaluated using the criteria set forth in the AISC Steel Construction Manual-Allowable Stress Design and the API RP 2A Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms. The results are expressed in terms of the AISC Interaction Ratio (IR), where the resulting ratio must be less than one. Details of the equation can be found in AISC Section H1 (9th Ed.).[1] This equation is summarized below for the general case. Modifications to this equation were made as appropriate for individual cases to adjust the allowable bending stresses or simplify the equation. Allowable stresses are increased by 70% for seismic loads. Punching shear calculations for the kicker to column connection are based on API RP 2A (18th Ed.) criteria.[2]

$$IR = \frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_x}{F'_{e_x}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_x}{F'_{e_y}}\right) F_{by}} < 1.00$$

Results and stress evaluation are presented in Appendix C.

Results

1. Operating Loads (Dead load plus Live load)

Member/Connection	IR
W12x45	0.40
W21x73	0.47
10.75ø x 1/2" Kicker	0.62
Kicker to Column	0.93
Kicker to W21 (Weld)	0.90
Kicker to W21 (Stiffener)	0.37

2. Seismic Loads (1.75g-Seismic Load)

Member	IR (1.7 Allowable Increase)
W12x45	0.41
W21x73	0.48
10.75ø x 1/2" Kicker	0.63

Connection	IR (1.7 Allowable & 1.15 Material Increase)
Kicker to Column (Comp)	0.83
Kicker to Column (Tension)	0 (No net uplift)
Kicker to W21 (Weld)	0.80
Kicker to W21 (Stiffener)	0.34

Conclusions

1. Operating Conditions: The platform extension (members and connections) is adequate for new operating loads (Batch Sweetener System).

2. Operating plus Seismic Loads: Assuming a 1.75g total vertical acceleration, the platform extension members will be adequate for operating plus seismic loads.

Recommendations

1. The tops of the 60" O.D. by 18' high (22'-6" total height) batch sweetener tanks should be secured to the drilling deck to prevent lateral motion during a seismic event. The tops of the 36" O.D. by 10' high (13'-6" total height) gross separator tank should be guyed to the production deck to prevent similar lateral motion.

Please do not hesitate to contact us if you have any questions regarding our analysis and recommendations.

Respectfully Submitted,

R J Beers Jr

Rick Beers, P.E.
Partner

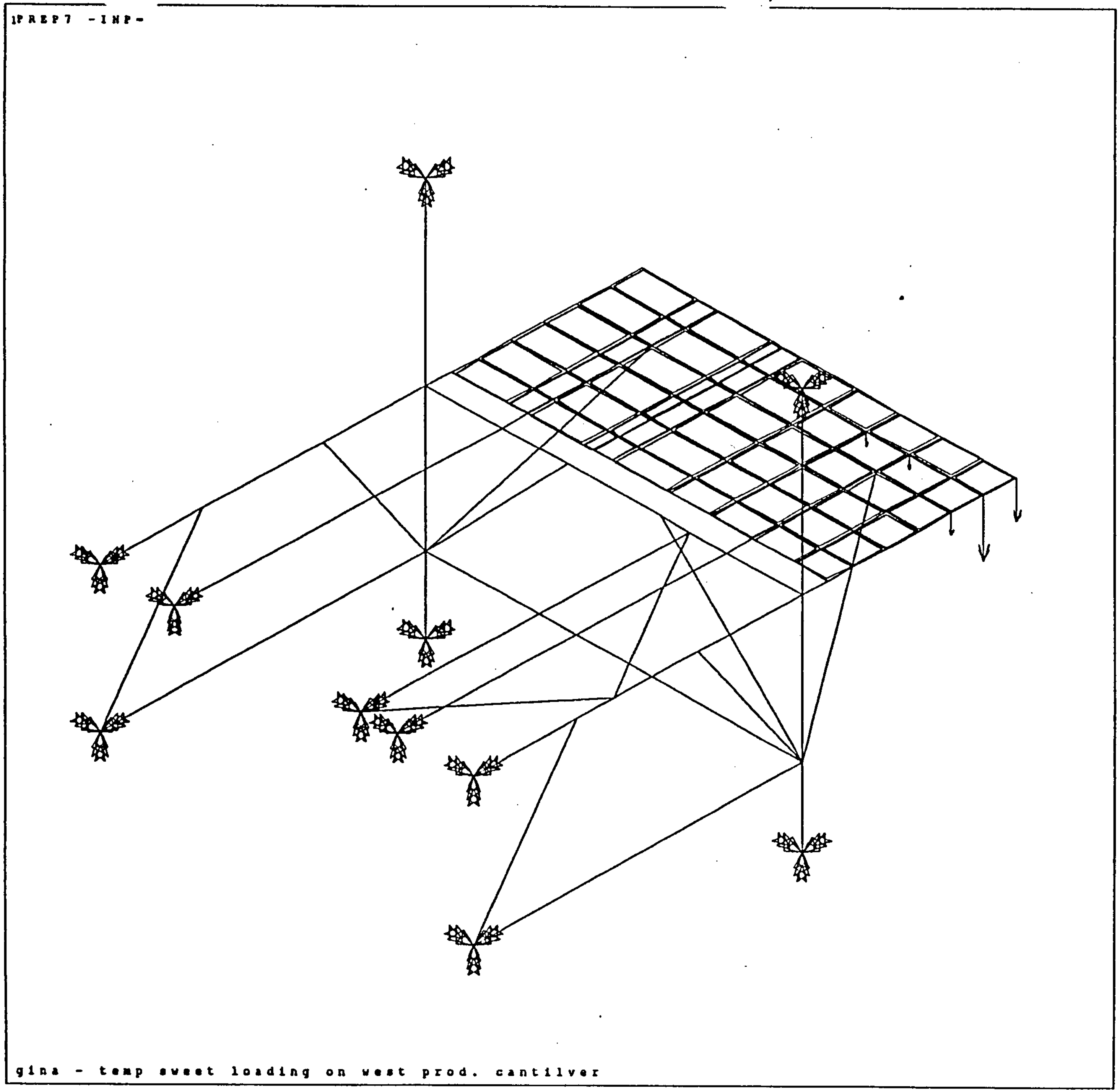
References

1. American Institute of Steel Construction, "Manual of Steel Construction, Allowable Stress Design", 9th Edition, Chicago, Illinois, 1989.

2. American Petroleum Institute, "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms", API RP 2A , 18th Edition Washington, DC, 1989.

Appendix A:

Platform Gina (West Extension) Computer Model



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COMPLETE MODEL

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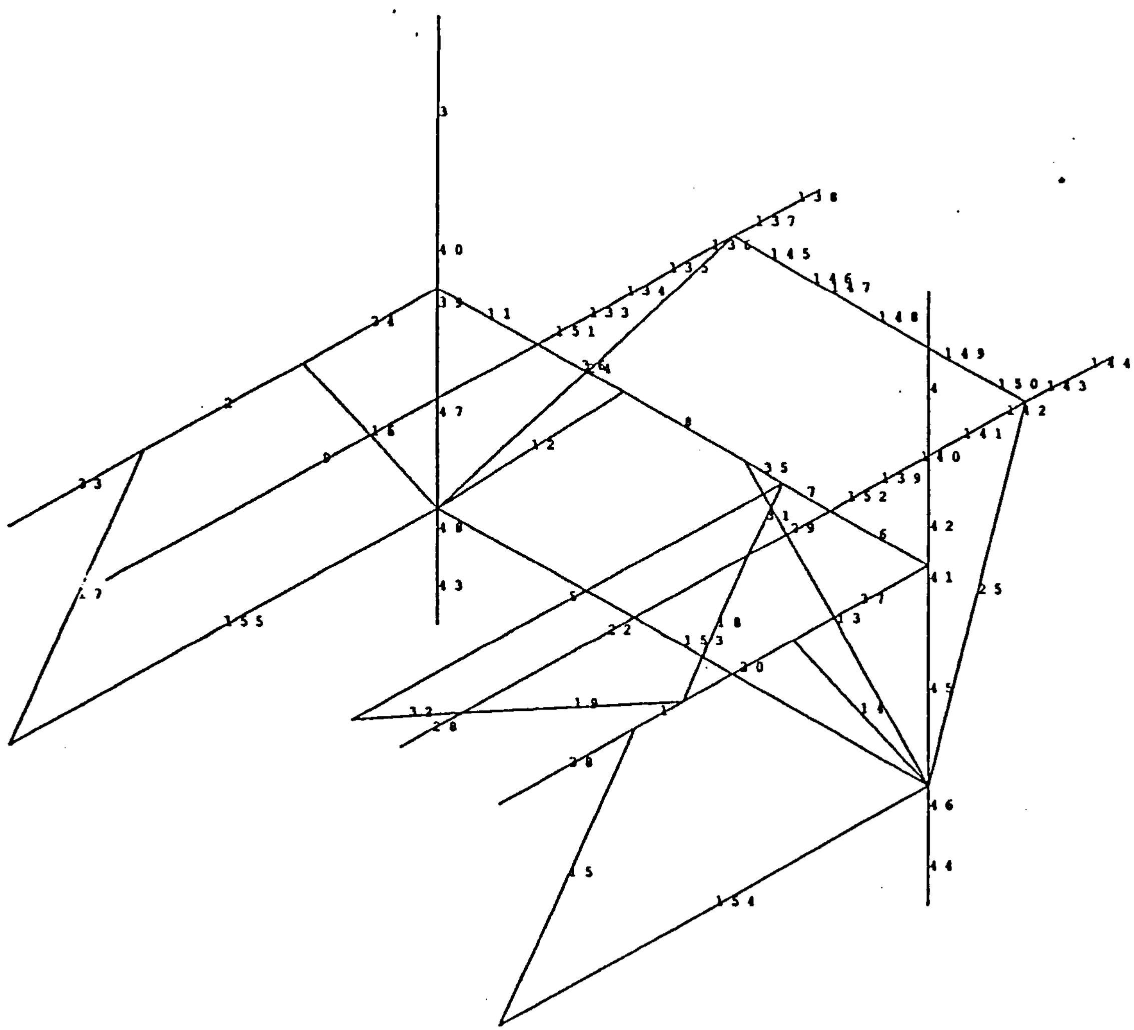

gina - temp sweet loading on west prod. cantilver

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MAIN FRAMING

ELEMENTS

A2

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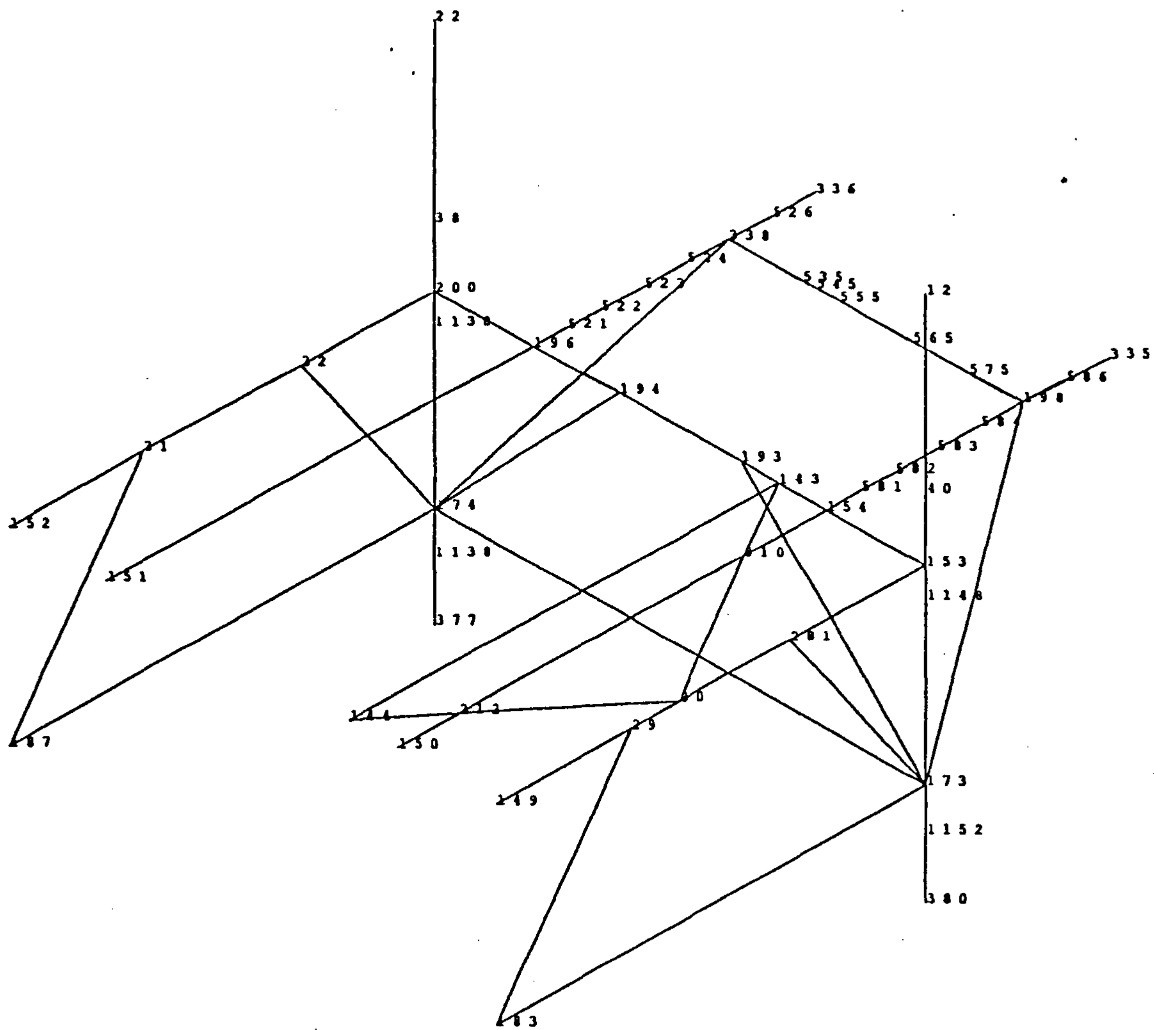

gina - temp sweet loading on west prod. cantilver

MAIN FRAMING

NODES

A3

A4

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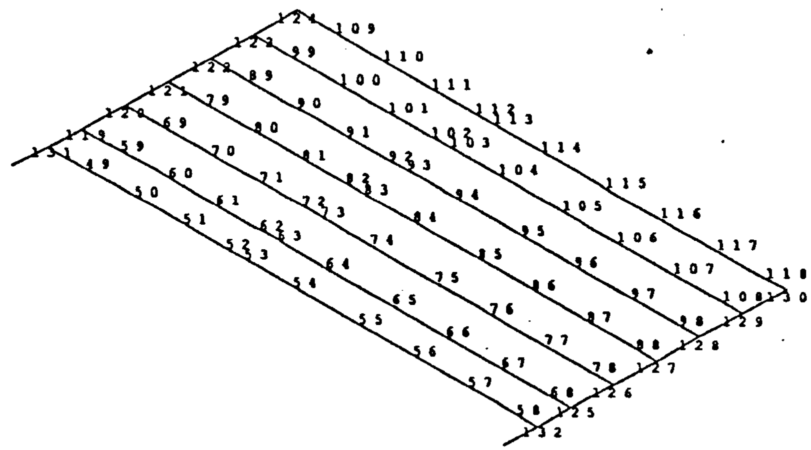

W12X45s
ELEMENTS

gina - temp sweet loading on west prod. cantilver

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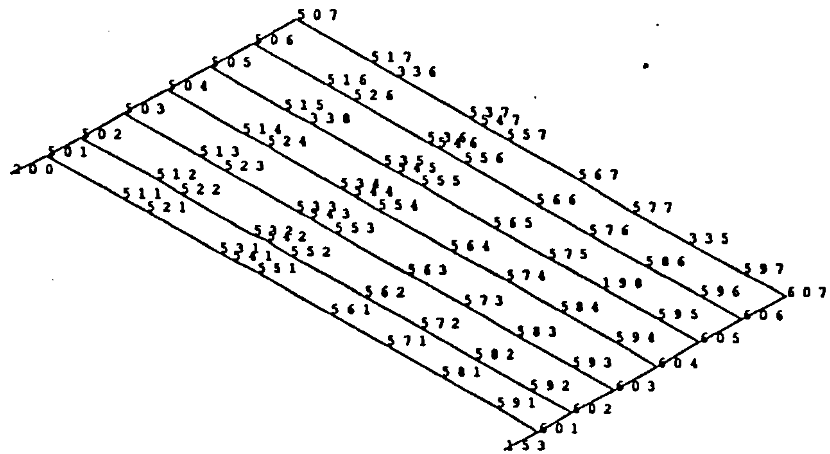

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W12X45's
NODES

A5

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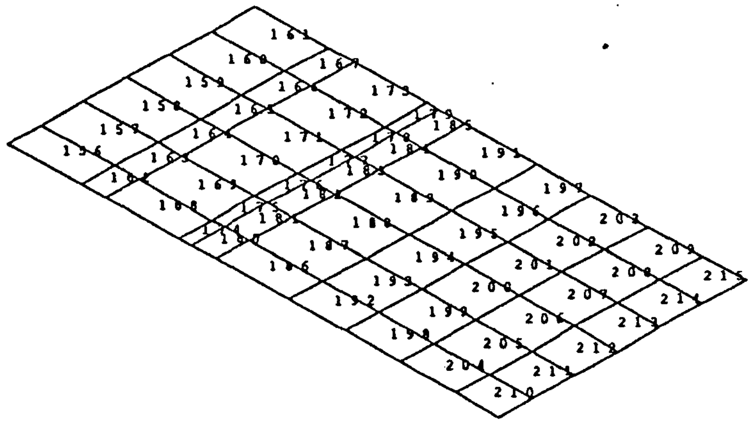

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SHELLS

ELEMENTS

gina - temp sweet loading on west prod. cantilver

PREP7 -INP-

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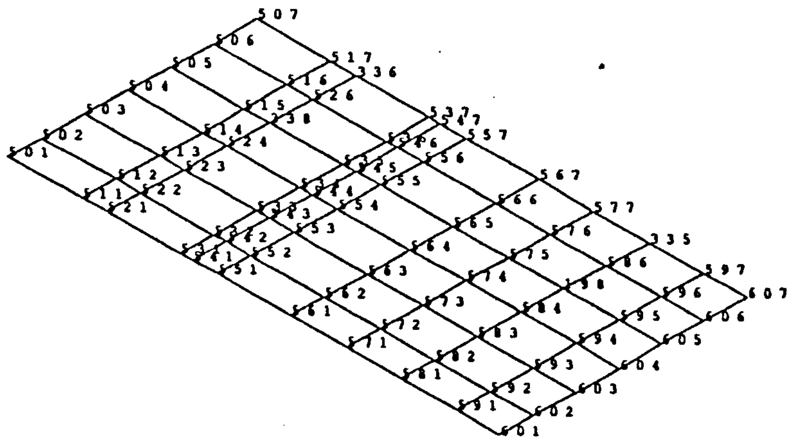


gina - temp sweet loading on west prod. cantilver

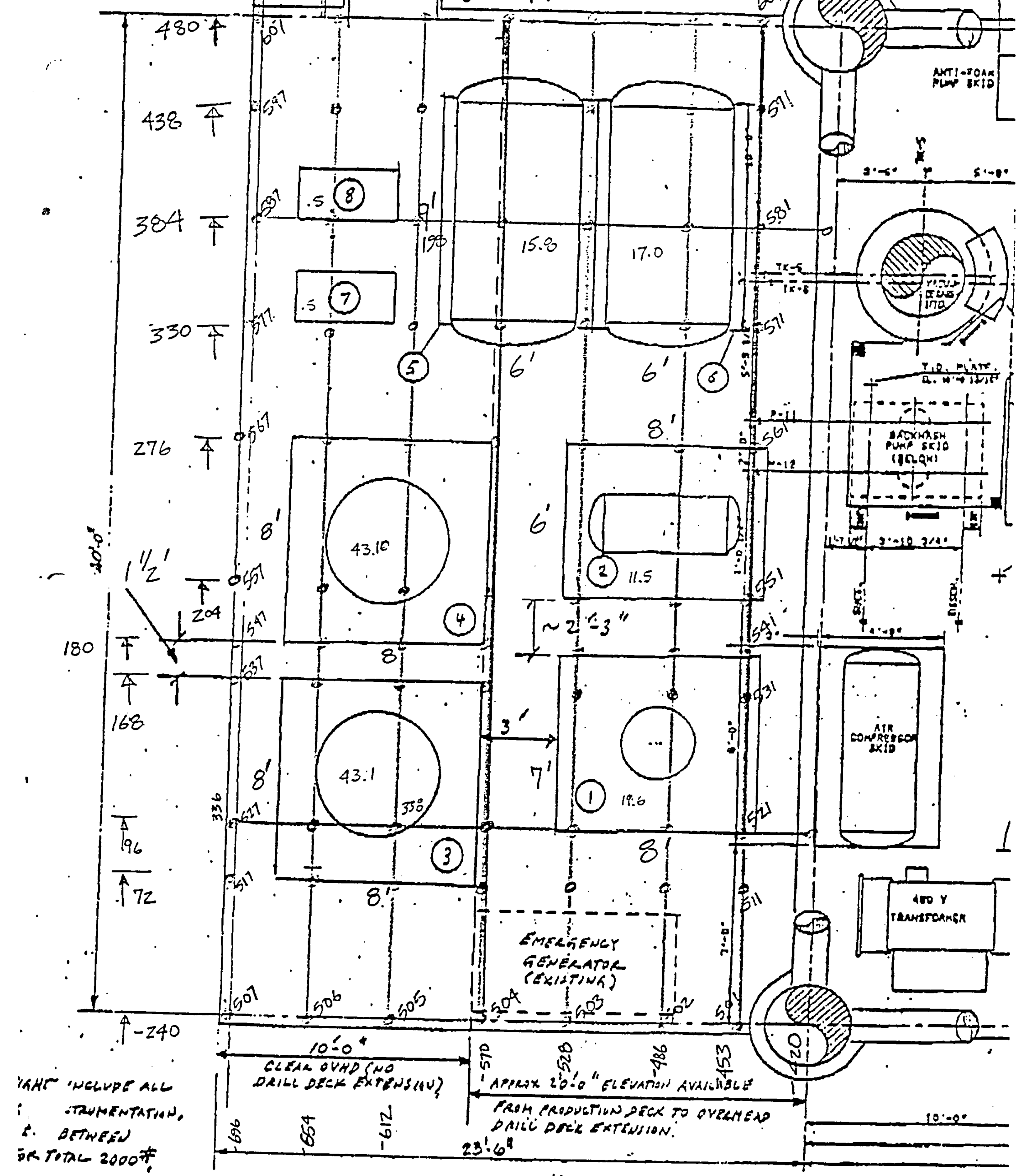
SHELLS

NODES

A7

WORKSHEET

A8

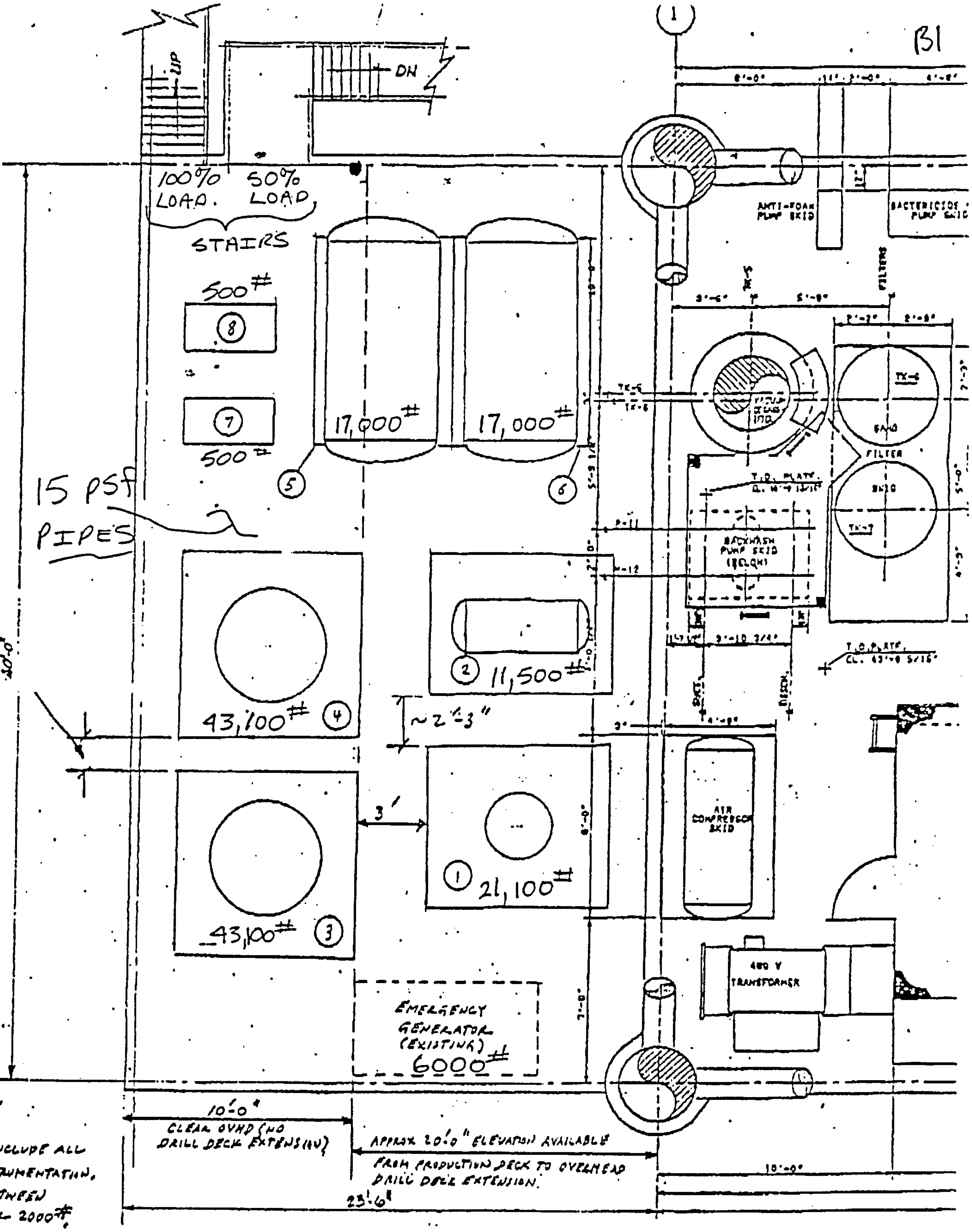


(1.) GROSS SEPARATOR SKID - 8' x 7' x 13'-6" OVERALL HEIGHT. (VESSEL - 36" O.D. x 10'-0" S-.
UNIT WT DRY = 18000#, OPERATING = 19600#

Appendix B:

Platform Gina (West Extension) Loading

B1



NOTE: WEIGHTS INCLUDE ALL SKID PIPING & INSTRUMENTATION. FOR PIPING, ETC BETWEEN SKIDS, ADD FOR TOTAL 2000#.

(1) GROSS SEPARATOR SKID = 8'x7'x13'-6" OVERALL HEIGHT. (VESSEL - 36" O.D. x 10'-0" S-S). UNIT WT DRY = 18000#, OPERATING = 19600# USE 21,100#

(2) SWEETENER CARRYOVER SCRUBBER SKID - 8'x6'x8'-0" HEIGHT (VESSEL - 30" O.D. x 5'-0" S-S) UNIT WT DRY = 10,400#, OPER = 11,500#

(3), (4) BATCH SWEETENER SKIDS - 8'x8'x22'-6" HEIGHT (VESSELS - 60" O.D. x 18'-0" S-S) EACH UNIT WT DRY = 29,000#, OPER = 43,100#

(5), (6) SWEETENER CHEMICAL TANK SKIDS - 6'x9'x6' HEIGHT (VESSELS - 60" O.D. x ~9'-0" S-S) EACH UNIT WT DRY = 3000#, OPER: TANK NO. 5 (UNUSED CHEMICAL) = 15,800#, NO. 6 (USED CHEM) = 17000#

(7) (8) SWEETENER CHEM. PUMP SKIDS - 2'x4' WEIGHT = 500# (EACH)

PROJECT: [illegible] ENGINEER: [illegible] DATE: 10/1/90

SUBJECT: WEST EXTENSION FILE NO.: 103 SHT. ___ OF ___

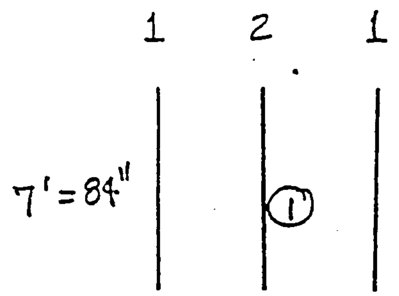
LOADS

1) PIPING & LIVE LOADS: 15 PSF = .000104 ksi

APPLY TO PLATES

2) DEAD LOAD: 1g Z

3) GROSS SEPARATOR



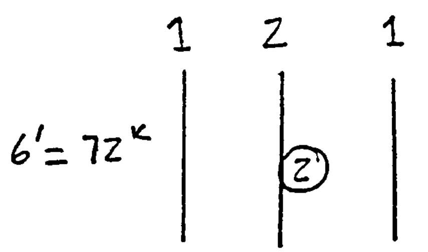
$P = 21.1^K$

$w_1 = \frac{21.1}{4(84)} = .06275^{K/"}$

$w_2 = .1255^{K/"}$

ELEM'S: 71, 72; 51, 52; 61, 62

4) SWEETNER C.O. SKID

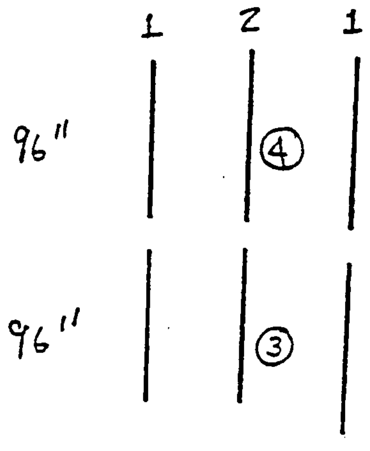


$P = 11.5^K$

$w_1 = \frac{11.5}{4(72)} = .03993^{K/"}$ — 54, 74

$w_2 = .07986^{K/"}$ — 64

5) BATCH SWEETNER



$P = 43.1$ EACH

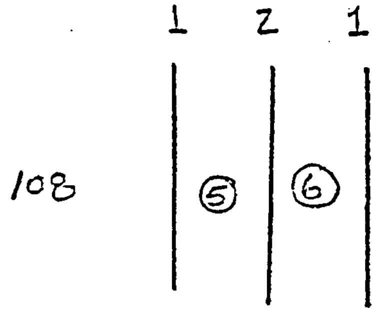
$w_1 = \frac{43.1}{4(96)} = .11224^{K/"}$ — 100, 101; 103, 104; 80, 81; 83, 84

$w_2 = .22448^{K/"}$ — 90, 91; 93, 94

PROJECT: Gina — ENGINEER: Beers — DATE: 10/1/90

SUBJECT: WEST EXTENSION — FILE NO. 103 — SHT. ____ OF ____

6) SWEETNER CHEM. TANKS



ELEM

$P = 15.8 + 17 = 32.8$

$\omega_1 = \frac{32.8}{4(108)} = .07593^{K/''}$ — 86, 87; 66, 67

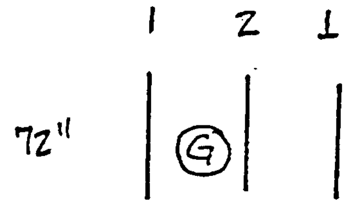
$\omega_2 = .15185^{K/''}$ — 76, 77

7) SWEETNER PUMPS

$P_1 = P_2 = .5^K$

$P_Z = -.5^K$ @ 576
$P_Z = -.5^K$ @ 586 — NODE FORCES

8) GENERATOR

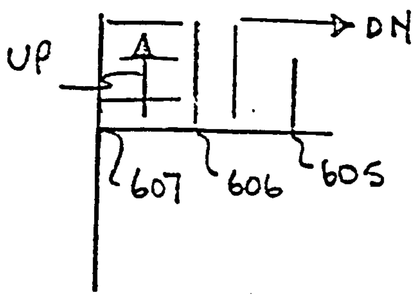


$P = 6^K$

$\omega_1 = \frac{6}{4(72)} = .020833^{K/''}$ — 59, 79

$\omega_2 = .041667^{K/''}$ — 69

9) STAIRS



UP to D.D 100% OF LOAD

$psf = 40$

$A = [(30 \text{ TREADS}) 8/12] + 5]3 = 75 \text{ ft}^2$

$P = .040 (75) = 3^K$

DN to SUB 50% OF LOAD

$psf = 40$

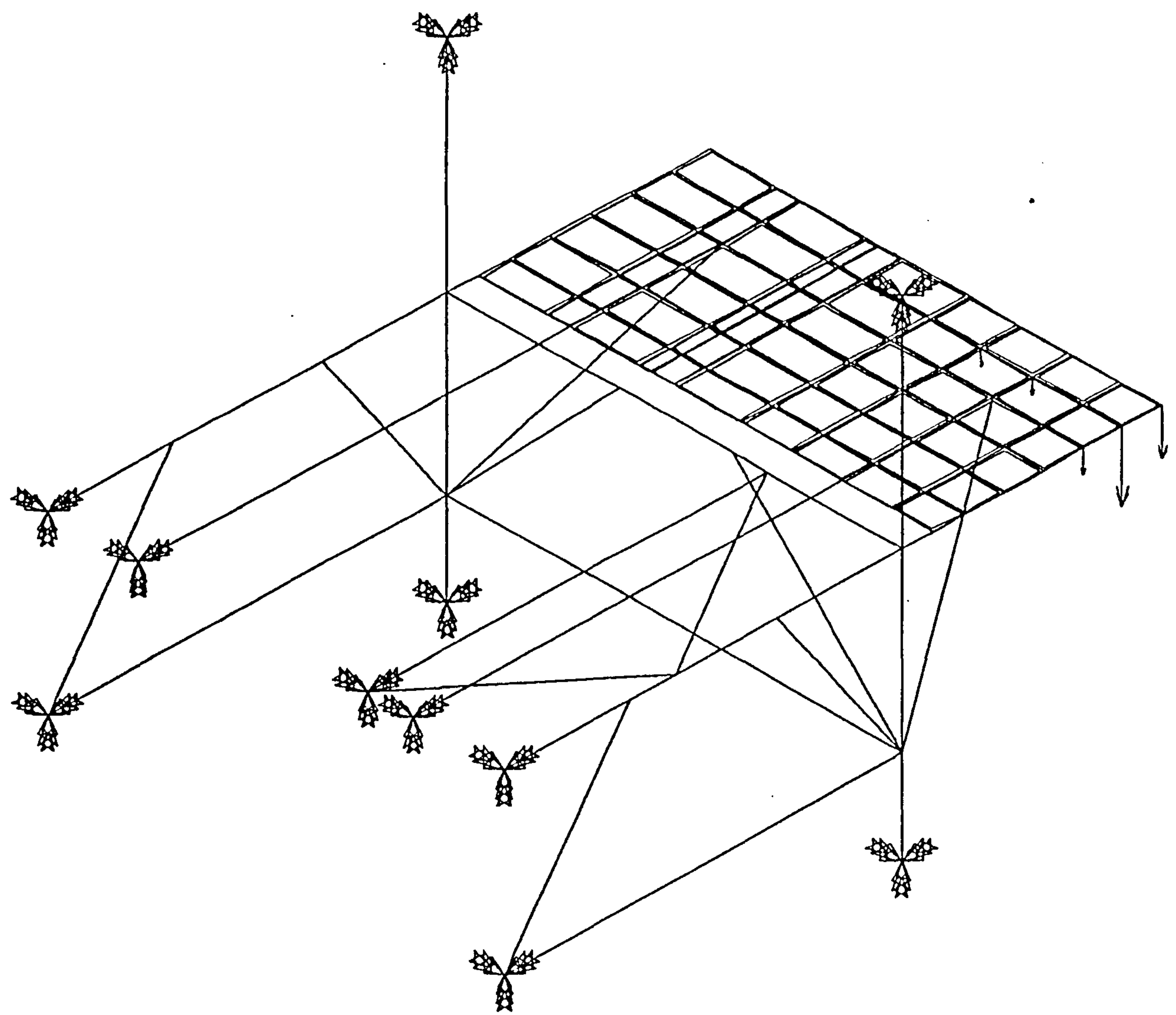
$A = [(24 \text{ TR.}) 8/12) + 8.]3 = 72 \text{ ft}^2$

$P = \frac{.04(72)}{2} = 1.44^K$

$P_{607} = -1.5_Z$

$P_{606} = -2.22_Z$

$P_{605} = -.72_Z$



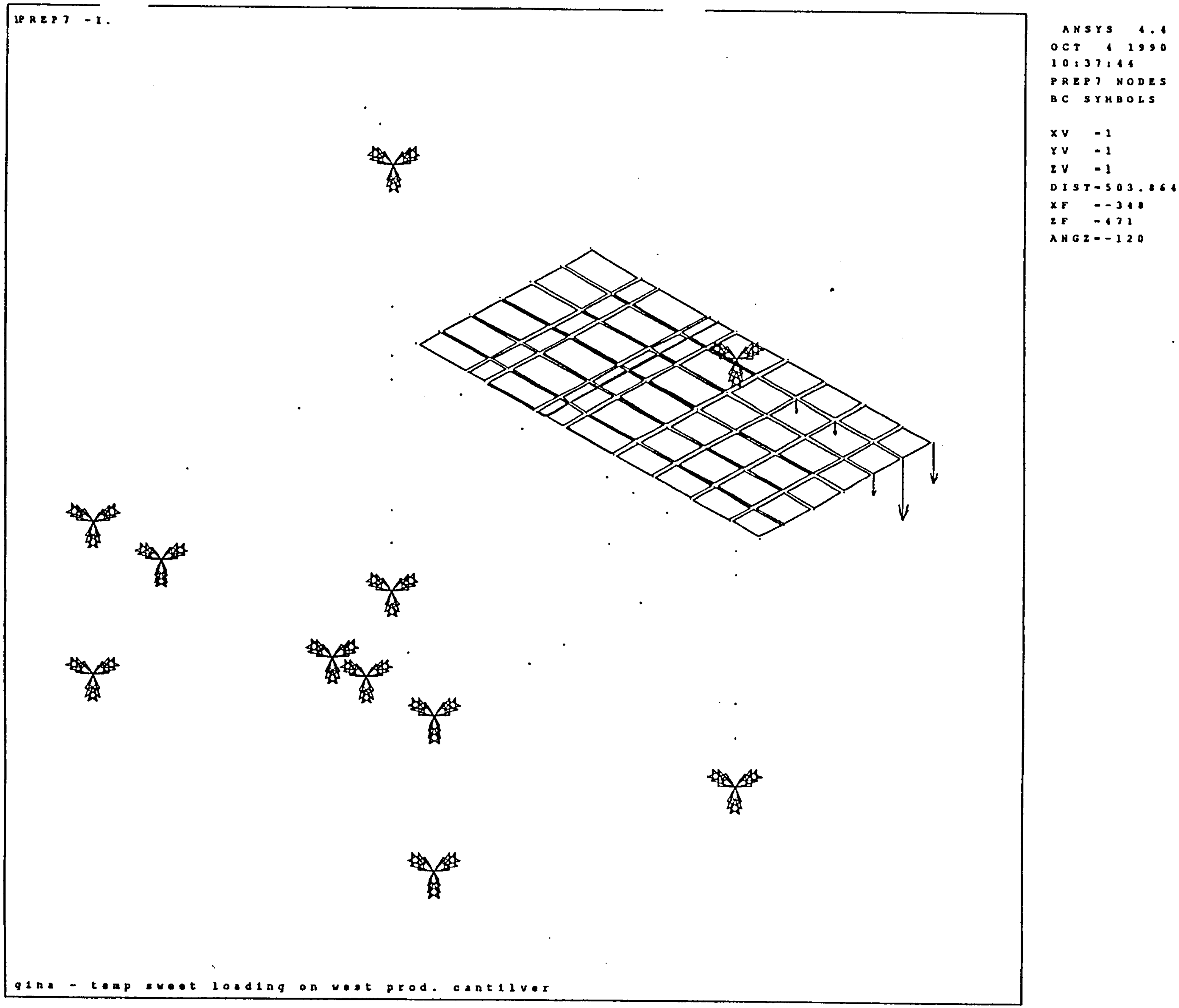
PREP7 -I.

ANSYS 4.4
OCT 4 1990
10:37:19
PREP7 ELEMENTS
TYPE NUM
BC SYMBOLS

XV =1
YV =1
ZV =1
DIST=503.864
XF =-348
ZF =471
ANGZ=-120

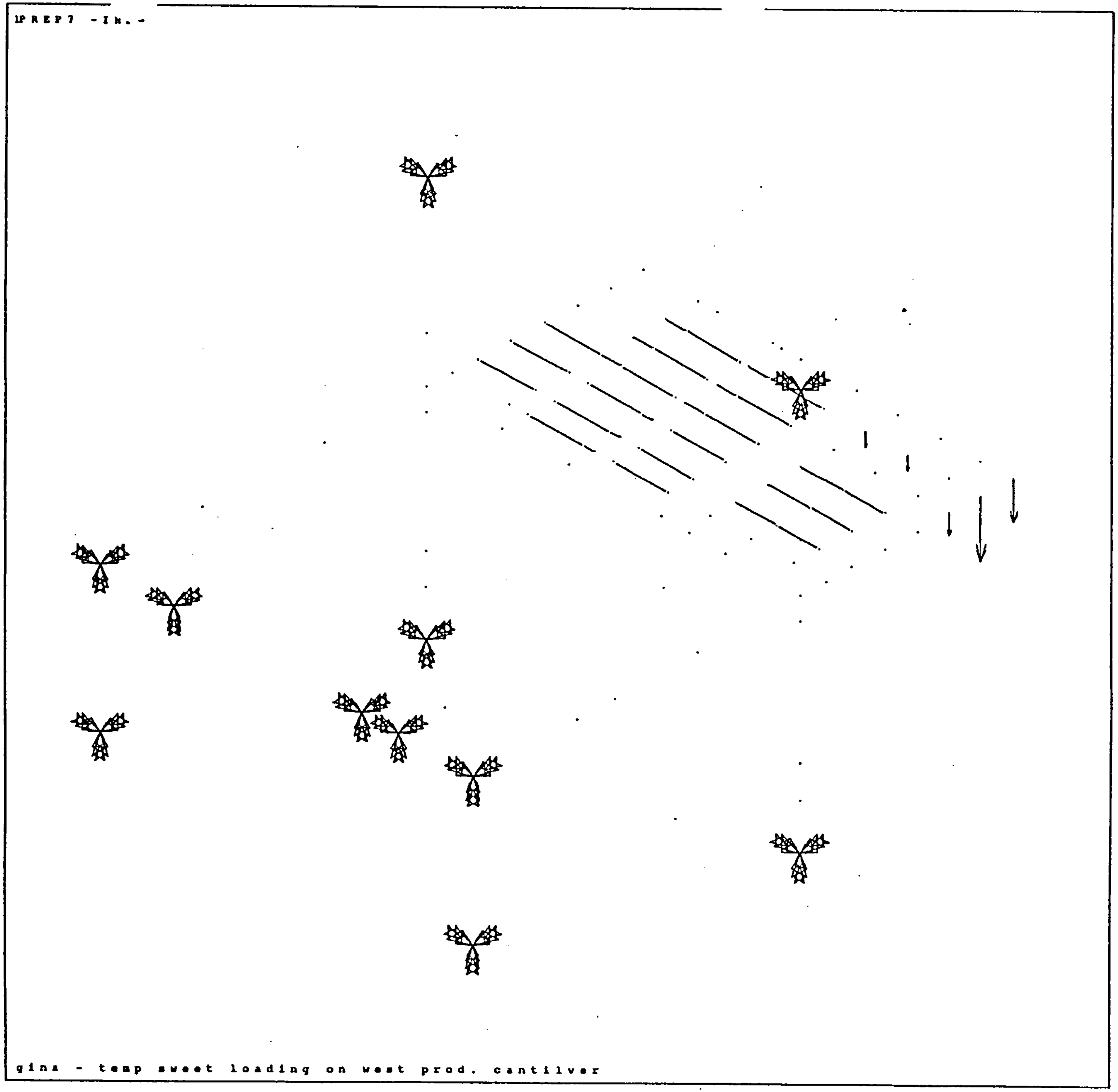
gina - temp sweet loading on west prod. cantilver

B4


1PREP7 -I.
ANSYS 4.4
OCT 4 1990
10:37:44
PREP7 NODES
BC SYMBOLS
XV =1
YV =1
ZV =1
DIST=503.864
XF =-348
ZF =471
ANGZ=-120
gina - temp sweet loading on west prod. cantilver

B5

B6



ANSYS 4.4
OCT 4 1990
10:39:29
PREP7 NODES
BC SYMBOLS

XV =1
YV =1
ZV =1
DIST=503.864
XF =-348
ZF =471
ANGZ=-120

Appendix C:

Platform Gina (West Extension) Results & Evaluation

THOMAS & BEERS

PROJECT Gina ENGINEER Beers DATE 10/9/90
SUBJECT Superliner Extension FILE NO. 103 SHT. ___ OF ___

STRESS REVIEW

W12x45's

1G: $IR = \frac{9.43}{.66(36)} = .40 < 1.0$ OKAY (DL+LL)

1.75G: $IR = \frac{9.43(1.75)}{1.7(.66)36} = .41 < 1.0$ OKAY (DL+LL+E)

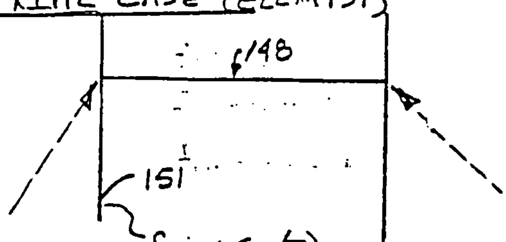
W21x73

BENDING CASE (ELEM 148)

1G: $IR = \frac{9.24}{.66(36)} = .39 < 1.0$ OKAY (DL+LL)

1.75G: $IR = \frac{9.24(1.75)}{1.7(.66)(36)} = .40 < 1.0$ OKAY (DL+LL+E)

AXIAL CASE (ELEM 151)



$f_a = 1.5$ (T)
$f_{bx} = 5.48$
$f_{by} = 4.47$

1G: $\frac{1.5}{.6(36)} + \frac{5.48}{.66(36)} + \frac{4.47}{.75(36)} = .47 < 1.0$ (DL+LL)

1.75G: $\frac{1.5(1.75)}{1.7(.6)36} + \frac{5.48(1.75)}{1.7(.66)36} + \frac{4.47(1.75)}{1.7(.75)36} = .48 < 1.0$ (DL+LL+E)

PROJECT: Gena ENGINEER: Beers DATE: 10/9/90
SUBJECT: Sweetner Extension FILE NO.: 103 SHT. ___ OF ___

10" ⌀ XS PIPE KICKER

$f_a = 8.16$

$f_b = 3.11$

$$\frac{KL}{r} = \frac{(.8)(24)(12)}{3.63} = 63.5$$

$F_a = 18.03$ $F_e' = 31.8$

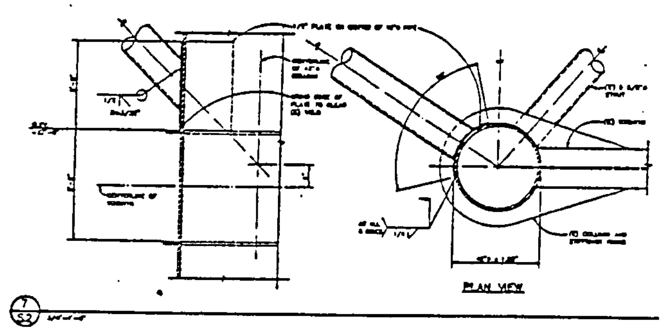
1G: $$IR = \frac{8.16}{18.03} + \frac{3.11}{\left(1 - \frac{8.16}{31.8}\right).66(36)} = .62 < 1.0 \quad (DL+LL)$$

1.75G: $$IR = \frac{8.16(1.75)}{1.7(18.03)} + \frac{3.11(1.75)}{\left(1 - \frac{8.16}{1.7(31.8)}\right)1.7(.66)36} = .63 < 1.00$$

(DL+LL+E)

PROJECT Gina	ENGINEER Beers	DATE 10/10/90
SUBJECT Sweetner Extension	FILE NO. 103	SHT. ___ OF ___

PUNCHING SHEAR



Brace: $f_a = 8.16$ ksi — 10.75" OD
$f_b = 3.11$ ksi in-plane — 1/2" WALL

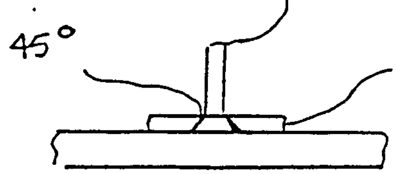
Column: f_a = ? ksi, f_b = ? ksi } ASSUME A = .70 (70% UTILITY OF COLUMN)

42" OD
1" WALL
1/2" DOUBLER

API RP 2A - 18th ED

$$V_{pa} = Q_q Q_f \frac{F_{yc}}{0.6\,\gamma}$$

COMPRESSION



FOR CALCS: ASSUME $\phi_{EQ} = 11\,3/4$ $t_{EQ} = 1\,1/2$" ON 42" x 1" PIPE

THOMAS & BEERS

PROJECT Gina-Sweetner Ext ENGINEER Beers DATE 10/10/90

SUBJECT FILE NO. SHT. OF

COMPRESSION CASE (CONT)

BRACE

$M = 122^{\text{''-K}}$

$P = 131.4^{K}$

W/ EQ. PIPE OD = 11.75" t = 1"

$$f_{a_{EQ}} = \frac{131.4}{48.3} = 2.72 \text{ ksi}$$

$$f_{b_{EQ}} = \frac{122}{110.3} = 1.11 \text{ ksi}$$

$$Q_f = 1 - \lambda \gamma A^2$$

$$\gamma = \frac{D}{2T} = \frac{42}{2(1)} = 21$$

$\lambda = .03$ (AXIAL)

$\lambda = .045$ (IN-PLANE BENDING)

$Q_f = .69$ (AXIAL)

$Q_f = .54$ (BEND)

$$\beta = \frac{d}{D} = \frac{11.75}{42} = .28$$

$$Q_Q = 1.10 + \frac{.2}{.28} = 1.81 \quad \text{(AXIAL)}$$

$$Q_Q = 3.72 + \frac{.67}{.28} = 6.11 \quad \text{(IN-PL. BEND)}$$

THOMAS & BEERS

PROJECT Gina ENGINEER Beers DATE 10/10/90
SUBJECT Sweetner Ext. FILE NO. 103 SHT. ____ OF ____

AXIAL

$$v_{pa_{ax}} = 1.81(.69)\frac{36}{.6(21)} = 3.57 \text{ ksi}$$

BENDING

$$v_{pa_{Bend}} = 6.11(.54)\frac{36}{.6(21)} = 9.43 \text{ ksi}$$

$$v_p = \tau f \sin\theta$$

$$\tau = 1.5/1.0 = 1.5$$

$$\sin\theta = \sin(48) = .74$$

$$v_{p_{axial}} = .74(1.5)\,2.72 = 3.02$$

$$v_{p\,Bend} = .74(1.5)\,1.11 = 1.23$$

$$1G: \quad IR = \left(\frac{3.02}{3.57}\right) + \frac{2}{\pi}\,\text{ARCSIN}\sqrt{\left(\frac{1.23}{9.43}\right)^2} = 0.93 < 1.0$$

(DL + LL)

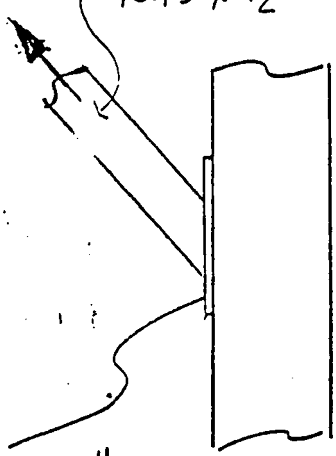
$$1.75G: \quad IR = \frac{1.75(3.02)}{(1.15)1.7(3.57)} + \frac{2}{\pi}\,\text{ARCSIN}\sqrt{\left(\frac{1.75(1.23)}{1.15(1.7)9.43}\right)^2} = 0.83 < 1.0$$

(DL + LL + E)

THOMAS & BEERS

PROJECT Gina	ENGINEER Beers	DATE 11/7/90
SUBJECT Sweetner Extension	FILE NO. 103	SHT. ' OF

TENSION CASE (SEISMIC)



ASSUME TOTAL UPLIFT FORCE = 1.0g - .75 g = .25g

(NO UPLIFT) ✓

API RP 2A - 18th

$$v_{pa} = Q_q Q_f \frac{F_y}{.6\gamma}$$

$A = 0 \quad Q_f = 1$

$$\gamma = \frac{D}{2T} = \frac{43}{2(.5)} = 43$$

$$\beta = \frac{d}{D} = \frac{10.75}{43} = .25$$

$$Q_q = 1.10 + \frac{.2}{.25} = 1.90$$

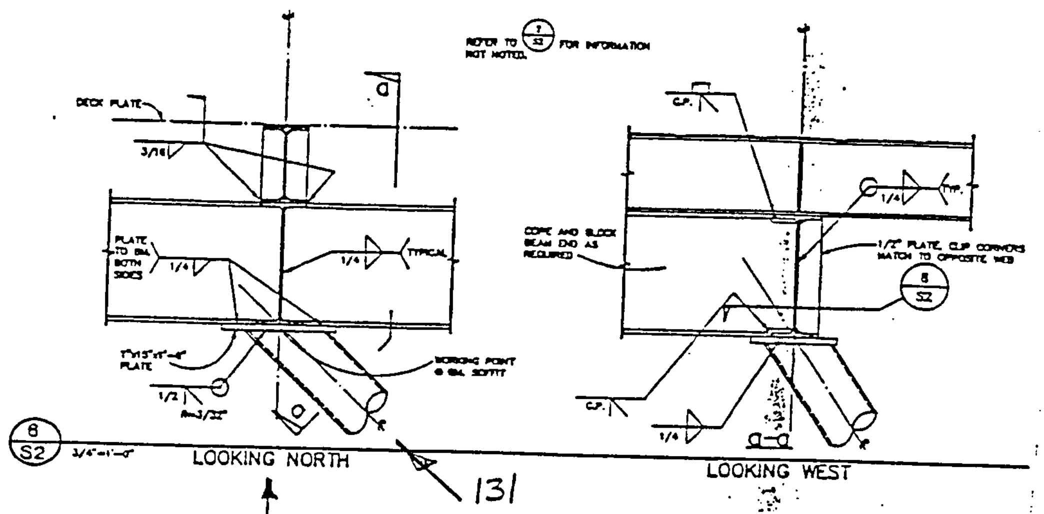
$$v_{pa} = 1.90(1)\frac{36}{.6(43)} = 2.65\,ksi \quad \text{(allowable uplift } \tau\text{)}$$

NO UPLIFT ∴ OKAY

PROJECT Gena ENGINEER Beers DATE 10/10/90

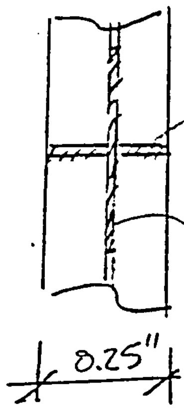
SUBJECT FILE NO. SHT. OF

TOP CONNECTION



131

$131 \sin 42 = 87^K$



$A \cong .5(8) + 15(.455)$

$A \sim 10.82$

1.75G: $\frac{87(1.75)}{10.82} = 14.7$ ksi ✓ okay $< 1.7(21)$

IR = .34

w/1.15

1/4" WELD:

$IR = \frac{100(1.75)}{15(2)(3.71)1.7(1.15)} = .80$

2 w/1.15 Material Increase

C8

****

UNOCAL GINA: WEST EXTENSION WITH SWEETNER LOADS - DEAD + LIVE LOAD

****

unocal gina west extension: real 13, w12x45 10.7808 OCT 4,1990 CP= 9.450

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
84	1.8963	-0.14366	-9.2589	-0.23323E-01	9.1386	-9.4259	-7.4268	0.22878E-02	7.2854	-7.5727
104	-0.13940E-01	0.10560E-02	-9.2087	-0.17333E-03	9.2099	-9.2078	-6.8544	0.69071E-02	6.8623	-6.8602
103	0.19165	-0.14519E-01	-7.5590	0.66006E-01	7.6105	-7.6395	-9.1887	-0.18950E-03	9.1744	-9.2034
83	1.8017	-0.13650	-7.4417	0.34577E-01	7.3398	-7.6127	-9.2395	-0.23454E-01	9.1264	-9.3994
85	1.7766	-0.13459	-7.4164	0.23109E-02	7.2841	-7.5533	-1.7183	-0.60840E-01	1.6445	-1.9137
64	5.0582	-0.38320	-6.7019	-0.33149E-01	6.3518	-7.1182	-5.4888	-0.17272E-01	5.1229	-5.8893
87	1.3937	-0.10558	6.3997	-0.52287	6.8170	-7.0282	1.7214	0.13291	1.7487	-1.9599
105	0.77868E-01	-0.58991E-02	-6.8444	0.69038E-02	6.8455	-6.8573	-0.73769	0.24148E-02	0.73420	-0.74600
81	2.0484	-0.15518	6.5349	0.12432	6.5040	-6.8144	-6.2545	-0.79084E-01	6.1784	-6.4888
107	-0.81201	0.61516E-01	6.3567	-0.27223	6.6904	-6.5674	2.5298	0.85070E-01	2.6764	-2.5534
61	4.7392	-0.35903	6.0510	-0.10595	5.7979	-6.5159	-5.0566	-0.16994E-01	4.7146	-5.4327
102	0.47276	-0.35815E-01	-6.4317	0.29422E-02	6.3988	-6.4704	-7.5579	0.66087E-01	7.5882	-7.6598
82	1.6395	-0.12420	-6.2324	-0.79430E-01	6.1877	-6.4361	-7.4409	0.34624E-01	7.3513	-7.5997
63	4.6992	-0.35600	-5.7109	-0.78622E-01	5.4335	-6.1455	-6.6824	-0.33332E-01	6.3598	-7.0718
101	-1.7241	0.13062	5.8577	-0.14909	6.1374	-5.8762	-6.4555	0.39720E-02	6.5901	-6.3289
65	4.6020	-0.34864	-5.4791	-0.17218E-01	5.1477	-5.8449	-1.3220	-0.11773	1.0911	-1.7884
74	2.3364	-0.17700	-5.4623	-0.25505E-01	5.3108	-5.6648	-5.0329	-0.19972E-01	4.8759	-5.2299
67	2.0715	-0.15693	5.2462	-0.60253E-01	5.1495	-5.4634	1.2339	-0.15810	1.2351	-1.5490
62	4.3019	-0.32590	-5.0347	-0.16813E-01	4.7256	-5.3774	-5.7096	-0.78692E-01	5.4624	-6.1142
131	-54.782	4.1502	-3.5711	-5.8700	13.591	-5.2910	-1.3131	4.6258	10.089	-1.7888
75	2.3056	-0.17467	-5.0198	-0.20010E-01	4.8652	-5.2145	-2.5767	-0.42933E-01	2.4450	-2.7943
73	2.2676	-0.17179	-4.7089	-0.20120E-01	4.5572	-4.9008	-5.4344	-0.25680E-01	5.2883	-5.6319
51	6.5616	-0.49709	3.0612	1.2071	3.7713	-4.7655	-2.7174	-0.67020	2.8905	-3.8847
92	3.3360	-0.25272	-3.8633	0.50367	4.1143	-4.6197	-4.2595	-0.88765E-01	4.0956	-4.6010
77	1.3866	-0.10505	4.3177	-0.15901	4.3716	-4.5817	-0.99609E-02	-0.10069E-01	-0.85017E-01	-0.12508
72	2.2520	-0.17061	-4.2112	-0.63108E-01	4.1037	-4.4449	-4.7057	-0.20136E-01	4.5552	-4.8964
60	1.8289	-0.13855	4.1317	-0.16558	4.1588	-4.4359	6.0446	0.22068	6.1267	-6.4038
93	2.8866	-0.21868	-4.1066	-0.88703E-01	3.9767	-4.4140	-4.6700	0.14819E-01	4.4662	-4.9035
80	2.1021	-0.15925	4.0599	0.78629E-01	3.9792	-4.2978	6.5232	-1.1593	7.5232	-7.8417
54	8.6948	-0.65870	-3:5689	-0.33391E-01	2.9436	-4.2610	-2.8249	-0.11712E-01	2.1779	-3.4953
95	3.0312	-0.22964	-3.8863	-0.86220E-01	3.7429	-4.2021	-1.6235	0.33476	1.7286	-2.1879
50	9.7311	-0.73720	2.2021	-1.1461	2.6110	-4.0854	3.0696	-1.0479	3.3803	-4.8547
52	9.1103	-0.69018	-2.7058	-0.66969	2.6853	-4.0657	-3.0606	0.17710E-01	2.3882	-3.7685
53	8.9389	-0.67719	-3.0618	0.17673E-01	2.4023	-3.7567	-3.5584	-0.33457E-01	2.9147	-4.2690
100	-1.4383	0.10896	3.7730	0.42161E-01	3.9242	-3.7062	5.8359	-0.52655	6.4715	-6.2535
94	2.5231	-0.19115	-3.4438	0.14920E-01	3.2675	-3.6498	-2.5115	-0.85859E-01	2.4062	-2.7885
55	8.8294	-0.66889	-2.8200	-0.11661E-01	2.1628	-3.5006	-0.48930	-0.10970	-0.69896E-01	-1.2679
57	4.8868	-0.37021	2.1984	0.87656	2.7047	-3.4452	0.82690	-0.77816	1.2348	-1.9753
91	5.9459	-0.45045	1.8774	-0.89208	2.3191	-3.2200	-2.4838	0.50413	2.5375	-3.4384
71	2.2147	-0.16778	2.6753	0.37118E-01	2.5447	-2.8802	-4.2415	-0.62987E-01	4.1367	-4.4723
76	2.4155	-0.18299	-2.5764	-0.43134E-01	2.4365	-2.8025	4.3104	0.31308E-01	4.1587	-4.5247
113	-2.6266	0.19899	-2.9661	-0.29639E-01	3.1947	-2.7968	-2.8499	0.21021E-01	3.0699	-2.6720
112	-3.5100	0.26591	-2.9901	0.24018E-01	3.2800	-2.7482	-2.9646	-0.29648E-01	3.2602	-2.7284
114	-1.9167	0.14521	-2.8640	0.20958E-01	3.0302	-2.7398	-2.0002	0.38298E-03	2.1458	-1.8554

1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

unocal gina west extension: real 13, w12x45 10.7808 OCT 4,1990 CP= 9.717

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
108	-0.18632	0.14115E-01	2.5365	0.84542E-01	2.6352	-2.6069	-0.15872E-01	0.76033E-01	0.10602	-0.77790E-01
111	-5.5786	0.42262	-2.7288	-0.15406	3.3055	-2.4602	-3.0054	0.24267E-01	3.4523	-2.6071
97	-4.5709	0.34628	2.5565	0.17780	3.0806	-2.3881	0.88536	0.55330E-01	1.2870	-0.59440
96	5.1279	-0.38848	-1.6233	0.33563	1.5705	-2.3474	0.81203	-0.97767	1.4012	-2.1782
49	3.2512	-0.24630	-0.11031E-01	1.9574	1.7221	-2.2147	2.2925	-1.1473	3.0934	-3.5860
86	2.0247	-0.15339	-1.7188	-0.61122E-01	1.6265	-1.9333	6.4256	0.20410	6.4763	-6.7830
58	3.3237	-0.25179	0.82913	-0.77823	1.3556	-1.8591	-0.42054E-02	0.65359	0.40600	-0.90959
88	-0.24070	0.18235E-01	1.7276	0.13173	1.8775	-1.8411	-0.10994E-01	0.21523	0.24436	-0.20789
115	-2.6178	0.19832	-1.9938	0.41476E-03	2.1926	-1.7959	-0.85033	0.21107E-02	1.0508	-0.65412
66	4.3357	-0.32846	-1.3227	-0.11814	1.1123	-1.7693	5.2663	0.18595	5.1238	-5.7807
110	-6.3913	0.48419	-2.1276	-0.14639E-01	2.6264	-1.6580	-2.6900	-0.27936	3.4536	-2.4852
70	1.7539	-0.13287	1.4018	-0.62333E-01	1.3313	-1.5970	2.7168	-0.57857	3.1625	-3.4283
119	-32.814	2.4859	-1.3260	2.6664	6.4783	-1.5065	0.13121	-0.85529	3.4724	1.4994
128	-6.5077	0.49301	1.8689	0.10101	2.4629	-1.4769	1.5141	-0.14271	2.1498	-1.1638
124	-1.2196	0.92394E-01	1.4921	0.24662E-01	1.6091	-1.4243	-0.10045E-01	0.51910E-01	0.15435	0.30439E-01
68	-0.46160	0.34970E-01	1.2393	-0.15864	1.4330	-1.3630	-0.91610E-02	0.28775	0.33188	-0.26194
129	-2.4967	0.18915	1.5166	0.29056E-02	1.7087	-1.3304	1.0798	-0.81038E-01	1.3499	-0.97164
56	7.2385	-0.54837	-0.48944	-0.10969	0.50756E-01	-1.1475	2.1978	-0.15994	1.8094	-2.9061
130	-0.73460	0.55651E-01	1.0808	-0.47976E-02	1.1412	-1.0299	-0.99782E-02	-0.44962E-01	0.11059	0.71117E-03
126	-17.356	1.3148	-0.13135E-01	0.29067	1.6186	1.0110	0.77931	-0.11252	2.2067	0.42300
122	-9.0099	0.68257	1.5520	-0.10282	2.3374	-0.97222	1.2075	0.12736	2.0175	-0.65232
132	-34.928	2.6461	-3.2829	-0.32850	6.2575	-0.96528	-1.3856	-0.32735	4.3590	0.93317
123	-3.8582	0.29229	1.2078	0.12711E-01	1.5128	-0.92824	1.4924	0.11981	1.9045	-1.3199
98	-0.92066	0.69747E-01	0.89110	0.55162E-01	1.0160	-0.87651	-0.52840E-02	0.14524	0.22027	-0.80779E-01
120	-24.065	1.8231	0.12093	-0.85179	2.7958	0.85038	0.49189	0.26876	2.5837	1.0624
106	-1.3514	0.10238	-0.73924	0.27712E-02	0.84439	-0.63963	6.3983	-0.88036E-01	6.5787	-6.3740
121	-15.813	1.1979	0.48841	-0.74328E-01	1.7607	0.63519	1.5525	0.11550	2.8660	-0.47009
117	-3.6839	0.27909	0.71572	-0.13984	1.1346	-0.57647	0.16326	0.26738E-01	0.46908	0.89087E-01
116	-4.4514	0.33723	-0.85072	0.22411E-02	1.1902	-0.51573	0.69321	-0.12667	1.1571	-0.48266
69	0.45066	-0.34141E-01	-0.17997E-01	0.34149	0.32534	-0.39362	1.3774	-0.63595E-01	1.4068	-1.4751
79	0.23489	-0.17794E-01	-0.32253E-01	0.21697	0.23143	-0.26702	4.0349	0.76958E-01	4.0940	-4.1296
109	-2.6574	0.20132	-0.83072E-02	0.51815E-01	0.26144	0.14119	-2.1396	-0.14769E-01	2.3557	-1.9531
118	-0.89021	0.67440E-01	0.16603	0.26526E-01	0.26000	-0.12512	-0.27251E-02	0.44911E-01	0.11508	0.19804E-01
89	-3.0704	0.23261	-0.19674E-01	0.11325	0.36553	0.99687E-01	-0.37561	0.22754	0.83576	-0.37054
99	-0.45029	0.34113E-01	-0.36971E-01	0.94489E-01	0.16557	-0.97347E-01	3.7479	0.41474E-01	3.8234	-3.7552

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ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
125	-23.802	1.8032	-1.3970	0.32609	3.5262	0.80121E-01	-0.40368E-02	0.27513E-02	1.8100	1.7964
59	0.62386	-0.47262E-01	-0.27310E-01	-0.19442E-02	-0.18009E-01	-0.76516E-01	4.1093	-0.16590	4.2280	-4.3225
127	-11.307	0.85658	0.77697	0.15297	1.7865	-0.73366E-01	1.8675	-0.11473	2.8388	-1.1257
90	-8.1088	0.61431	-0.35133	0.22959	1.1952	0.33382E-01	0.87160	-0.33238	1.8183	-0.59967
78	0.13557	-0.10271E-01	-0.44923E-02	-0.10863E-01	0.50845E-02	-0.25626E-01	-0.10360E-02	0.26501	0.25577	-0.27632

MINIMUMS

ELEMENT	131	50	84	131	59	84	83	80	77	83
VALUE	-54.782	-0.73720	-9.2589	-5.8700	-0.18009E-01	-9.4259	-9.2395	-1.1593	-0.85017E-01	-9.3994

MAXIMUMS

ELEMENT	50	131	81	119	131	126	80	131	131	125
VALUE	9.7311	4.1502	6.5349	2.6664	13.591	1.0110	6.5232	4.6258	10.089	1.7964

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: real 12, w21x73 10.7811 OCT 4,1990 CP= 10.250

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
148	4.1097	-0.19115	-9.0392	0.15308E-01	8.8633	-9.2456	-7.3972	-0.88089E-01	7.2941	-7.6764
151	-32.529	1.5130	5.4877	-4.4721	11.473	-8.4468	-1.1572	3.7020	6.3722	-3.3462
147	4.7016	-0.21868	-7.5630	-0.91007E-01	7.4354	-7.8727	-8.5553	0.15204E-01	8.3518	-8.7892
146	5.4336	-0.25272	-6.8049	0.51675	7.0689	-7.5744	-7.5027	-0.91071E-01	7.3411	-7.8465
149	4.9372	-0.22964	-6.8622	-0.88459E-01	6.7210	-7.1803	-2.8770	0.34345	2.9908	-3.4501
152	-31.990	1.4879	5.5766	-3.0447	10.109	-7.1334	-0.62997	1.4335	3.5514	-0.57552
141	-18.790	0.87397	-7.7387	0.90435E-01	8.7031	-6.9552	-3.8167	0.14494	4.8356	-3.0877
137	13.673	-0.63594	5.5180	-0.64765	5.5297	-6.8016	-0.19358	0.19964	-0.24272	-1.0292
143	9.8018	-0.45590	5.2187	0.69722	5.4600	-6.3718	0.76629	-0.18210	0.49249	-1.4043
135	-22.522	1.0476	-6.2581	-0.19339	7.4991	-5.4039	-3.4959	0.60454E-02	4.5495	-2.4544
134	-18.259	0.84925	-5.7188	-0.47638	7.0444	-5.3459	-6.2579	0.25412	7.3612	-5.6627
140	-16.697	0.77659	-5.7642	0.37519E-01	6.5783	-5.0252	-7.7382	-0.48031E-01	8.5628	-7.0096
150	8.3522	-0.38848	-2.8767	0.34435	2.8326	-3.6095	1.4124	-1.0031	2.0270	-2.8040
142	-25.711	1.1959	-3.8163	0.67467	5.6868	-3.2951	5.3413	-1.3890	7.9262	-5.5345
136	-33.567	1.5613	-3.4949	-0.92771	5.9838	-2.8613	5.5338	1.6086	8.7037	-5.5811
133	-20.595	0.95792	-1.1640	2.0620	4.1840	-2.2681	-5.7175	-0.71467	7.3901	-5.4742
145	9.6846	-0.45045	0.33249	-0.91525	0.79729	-1.6982	-7.3485	0.51722	7.4153	-8.3162
144	2.4098	-0.11208	0.76481	-0.47770E-01	0.70049	-0.92466	-0.14549E-01	-0.95277E-02	-0.88007E-01	-0.13616
138	3.1554	-0.14676	-0.19456	-0.74665E-01	0.12247	-0.41599	-0.15986E-01	0.90870E-01	-0.39907E-01	-0.25362
139	-19.642	0.91356	-0.63695	0.67985	2.2304	-0.40324	-5.7624	-0.14203	6.8180	-4.9909

MINIMUMS

ELEMENT	136	137	148	151	138	148	147	142	137	147
VALUE	-33.567	-0.63594	-9.0392	-4.4721	0.12247	-9.2456	-8.5553	-1.3890	-0.24272	-8.7892

MAXIMUMS

ELEMENT	137	136	152	133	151	139	136	151	136	144
VALUE	13.673	1.5613	5.5766	2.0620	11.473	-0.40324	5.5338	3.7020	8.7037	-0.13616

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: real 6, girder 3 10.7811 OCT 4,1990 CP= 10.600

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
2	-24.932	0.68307	-0.31114	-0.42523E-02	0.99847	0.36768	0.60327	0.14118E-01	1.3005	0.65683E-01
33	-23.558	0.64542	0.27514	-0.11564E-01	0.93212	0.35872	-0.32549	0.25904E-02	0.97351	0.31734
30	-15.067	0.41279	-0.78115E-01	0.47100E-01	0.53801	0.28758	0.41751	0.21674E-01	0.85198	-0.26393E-01
34	-29.438	0.80651	0.52428	-0.85397E-01	1.4162	0.19683	-0.18457	0.10401	1.0951	0.51792
37	-18.460	0.50575	0.35101	0.83606E-01	0.94037	0.71136E-01	-0.72189E-01	-0.93035E-01	0.67098	0.34053
1	-13.750	0.37671	-0.20007	-0.10850	0.68527	0.68139E-01	-0.12199	-0.20421	0.70291	0.50503E-01
38	-13.388	0.36679	0.24078	0.11372	0.72130	0.12281E-01	-0.22157	-0.96481E-01	0.68484	0.48737E-01

MINIMUMS

ELEMENT	34	38	2	1	30	38	33	1	37	30
VALUE	-29.438	0.36679	-0.31114	-0.10850	0.53801	0.12281E-01	-0.32549	-0.20421	0.67098	-0.26393E-01

MAXIMUMS

ELEMENT	38	34	34	38	34	2	2	34	2	34
VALUE	-13.388	0.80651	0.52428	0.11372	1.4162	0.36768	0.60327	0.10401	1.3005	0.51792

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: real 7, girder 2 10.7811 OCT 4,1990 CP= 10.867

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
7	-5.7034	0.11752	-1.5828	2.8707	4.5710	-4.3360	-0.59749	-1.5798	2.2948	-2.0598
6	-3.0936	0.63745E-01	2.1855	-1.6960	3.9452	-3.8177	-1.5803	2.2971	3.9412	-3.8137
11	-5.6785	0.11701	-1.6725	1.8613	3.6508	-3.4167	2.3171	-1.6492	4.0833	-3.8493

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35	-4.8258	0.99439E-01	-0.65392	-1.3598	2.1131	-1.9142	0.15856	-1.0556	1.3136	-1.1147
8	9.8125	-0.20219	0.15385	-0.93474	0.88640	-1.2908	-0.57654E-01	0.16649	0.21946E-01	-0.42634
36	-1.4604	0.30093E-01	-0.40478E-01	-0.14387	0.21444	-0.15426	-1.6753	0.78223	2.4876	-2.4274
MINIMUMS										
ELEMENT	7	8	11	6	36	7	36	11	8	11
VALUE	-5.7034	-0.20219	-1.6725	-1.6960	0.21444	-4.3360	-1.6753	-1.6492	0.21946E-01	-3.8493
MAXIMUMS										
ELEMENT	8	7	6	7	7	36	11	6	11	8
VALUE	9.8125	0.11752	2.1855	2.8707	4.5710	-0.15426	2.3171	2.2971	4.0833	-0.42634

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: real 5, w24x68 10.7814 OCT 4,1990 CP= 11.150

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FX	FAI	FBXI	FBYI	S1I	S3I	FBXJ	FBYJ	S1J	S3J
29	-22.580	1.1234	2.7663	0.78635	4.6761	-2.4293	5.3986	-0.74126	7.2632	-5.0164
28	-21.419	1.0656	-1.0849	0.35311	2.5036	-0.37239	-0.92054	-0.20000	2.1862	-0.54918E-01
9	-29.195	1.4525	-1.7434	0.11182E-01	3.2071	-0.30214	5.3236	-0.33217E-01	6.8093	-3.9044
22	-21.816	1.0854	-0.92189	-0.33538	2.3427	-0.17188	2.7683	0.38793	4.2416	-2.0708
MINIMUMS										
ELEMENT	9	28	9	22	22	29	28	29	28	29
VALUE	-29.195	1.0656	-1.7434	-0.33538	2.3427	-2.4293	-0.92054	-0.74126	2.1862	-5.0164
MAXIMUMS										
ELEMENT	28	9	29	29	29	22	29	22	29	28
VALUE	-21.419	1.4525	2.7663	0.78635	4.6761	-0.17188	5.3986	0.38793	7.2632	-0.54918E-01

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: real 70 10.75 x .50 pipe 10.7814 OCT 4,1990 CP= 11.383

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FAI	FBI	FAJ	FBJ	I	J
24	-8.1623529	3.1126983	-8.2166904	1.8402618	338	174
25	-6.2592697	1.9535010	-6.2049322	3.2269014	173	198
MINIMUMS						
ELEMENT	24	25	24	24		
VALUE	-8.1623529	1.9535010	-8.2166904	1.8402618		
MAXIMUMS						
ELEMENT	25	24	25	25		
VALUE	-6.2592697	3.1126983	-6.2049322	3.2269014		

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

unocal gina west extension: reals 21,22,31,32, 42" columns 10.7814 OCT 4,1990 CP= 11.700

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FAI	FBI	FAJ	FBJ
48	-0.85391916	1.6508209	-0.86580550	0.80469228E-01
46	-0.73220066	1.1947794	-0.74408699	0.15955522
43	-0.58432964	0.55614498E-01	-0.60131012	1.6374524
44	-0.50218217	0.11027301	-0.51916265	1.3503767
3	0.30560478	0.89298023	0.25551236	0.80547060
4	0.28168198	0.51814560	0.23158956	0.54420120
40	0.20566394	0.65608217	0.18783443	1.1435027
42	0.18640829	0.44326969	0.16857878	0.74069148
47	0.70995535E-01	0.78503460	0.25148239E-01	1.5751661
39	0.65635112E-01	0.96707452	0.57144872E-01	0.63943638
45	0.46318378E-01	0.64907654	0.47108189E-03	1.1383337
41	0.45772272E-01	0.75012360	0.37282032E-01	0.52869409
MINIMUMS				
ELEMENT	48	43	48	48
VALUE	-0.85391916	0.55614498E-01	-0.86580550	0.80469228E-01
MAXIMUMS				
ELEMENT	3	48	3	43
VALUE	0.30560478	1.6508209	0.25551236	1.6374524

PRINT ELEMENT STRESS ITEMS PER ELEMENT
1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	FAI	FBI	FAJ	FBJ
13	-1.1467623	0.91169285E-01	-1.2010998	0.69519400
12	-0.88202946	0.23311379	-0.93636700	0.80787227
16	-0.45317676	0.56091172	-0.50751430	0.20613130
14	-0.33455039	0.47208542	-0.38888792	0.12912120
17	0.17403526	0.10180461	0.11969773	0.30692976
15	0.64511448E-01	0.15283264	0.10173912E-01	0.27365341

MINIMUMS				
ELEMENT	13	13	13	14
VALUE	-1.1467623	0.91169285E-01	-1.2010998	0.12912120

MAXIMUMS				
ELEMENT	17	16	17	12
VALUE	0.17403526	0.56091172	0.11969773	0.80787227

PRINT ELEMENT STRESS ITEMS PER ELEMENT

unocal gina west extension: real 71, shells/deck plate   10.7817 OCT 4,1990 CP= 12.250

***** POST1 ELEMENT STRESS LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

ELEM	SEIT
156	3.1038146
165	2.8753950
157	2.4731091
178	2.3576108
184	2.2486420
158	2.0702852
196	2.0440718
207	1.9949326
190	1.9683667
171	1.9594287

MINIMUMS	
ELEMENT	171
VALUE	1.9594287

MAXIMUMS	
ELEMENT	156
VALUE	3.1038146

PRINT REACTION FORCES PER NODE

unocal gina west extension: Reaction forces   10.7817 OCT 4,1990 CP= 12.367

***** POST1 REACTION FORCE LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

THE FOLLOWING X,Y,Z FORCES ARE IN GLOBAL COORDINATES

NODE	FX	FY	FZ	MX	MY	MZ
12	6.3838680	4.0668978	36.282132	230.03007	-627.35057	77.703721
22	9.9225946	-7.2646713	39.363515	-578.25411	-995.86521	-33.355265
144	9.5663462	-0.76677043	2.3728795	-4.4301988	225.94361	0.67741661
149	13.387780	0.40034450E-01	2.0048081	-0.92677998E-02	90.949578	-2.8590081
150	21.419022	0.14478191	-0.25183204	0.75003725E-01	-167.32932	-5.5458426
151	29.194606	0.16602674E-02	-1.4006275	0.85026878E-02	-268.89695	-0.17561470
152	23.557995	-0.26957373E-02	2.4004799	0.97176787E-03	103.92508	0.29071495
183	-16.103546	0.80573284E-02	2.2239790	-1.4939278	179.88443	-0.46198883
187	-19.309098	0.26516826E-02	0.77922411	0.76442658E-01	181.32049	-0.49653269
377	-44.340478	24.757189	114.76109	-1579.0559	-2615.6729	-75.655808
380	-33.679090	-20.987135	99.083102	1462.6453	-2051.7086	116.84060
TOTAL	0.27000624E-12	-0.98410169E-12	297.61875	-470.40707	-5944.8004	76.962391

PRINT NODAL DISPLACEMENTS

unocal gina west extension: maximum displacements   10.7819 OCT 4,1990 CP= 13.033

***** POST1 NODAL DISPLACEMENT LISTING *****

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.00000E+00 LOAD CASE= 1

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
554	-0.24442955E-01	0.10742238E-01	-0.51618041	-0.14884642E-02	0.85762899E-03	-0.14677647E-04

C12

556	-0.24887109E-01	0.12173911E-01	-0.49860160	-0.12084136E-02	-0.42375496E-03	-0.20836441E-04
564	-0.23070138E-01	0.10397458E-01	-0.48706718	0.21756279E-02	0.94755029E-03	-0.20921972E-04
544	-0.24785458E-01	0.10851435E-01	-0.46654902	-0.26077323E-02	0.75062421E-03	-0.15778244E-04
546	-0.25439133E-01	0.12185526E-01	-0.45568304	-0.23320968E-02	-0.51815696E-03	-0.27348851E-04
566	-0.23433625E-01	0.12176445E-01	-0.45253881	0.23317637E-02	-0.16052612E-03	-0.18837536E-04
534	-0.24972782E-01	0.10901116E-01	-0.43245471	-0.30612927E-02	0.65526702E-03	-0.13561503E-04
536	-0.25794059E-01	0.12199852E-01	-0.42483887	-0.27961463E-02	-0.48520845E-03	-0.30764026E-04
553	-0.24365179E-01	0.99600025E-02	-0.39121694	-0.97715358E-03	-0.16191694E-02	-0.11700017E-04
552	-0.24372809E-01	0.94106751E-02	-0.38308477	-0.11089126E-02	-0.26919356E-02	-0.10156533E-04
563	-0.23017078E-01	0.95352039E-02	-0.38070061	0.12407915E-02	-0.14719208E-02	-0.25199684E-04
562	-0.23046164E-01	0.84910056E-02	-0.36377846	0.15647289E-02	-0.27543715E-02	-0.25123721E-04
543	-0.24589397E-01	0.10097436E-01	-0.35949354	-0.16504206E-02	-0.14975836E-02	-0.71682183E-05
555	-0.24670329E-01	0.11633258E-01	-0.35207506	-0.62656380E-03	0.18657682E-03	-0.14020230E-04
542	-0.24501558E-01	0.96954724E-02	-0.34634284	-0.19314324E-02	-0.24928087E-02	0.92120478E-06

MAXIMUMS

NODE	536	536	554	534	562	536
VALUE	-0.25794059E-01	0.12199852E-01	-0.51618041	-0.30612927E-02	-0.27543715E-02	-0.30764026E-04

***** ROUTINE COMPLETED ***** CP = 13.233

/EOF ENCOUNTERED ON FILE18

***** RUN COMPLETED ***** CP= 13.2333 TIME= 10.7819

Appendix D:

Platform Gina (West Extension) Key Computer Input

INPUT FILE


```
/prep7
/nopr
/show,4014
/title,gina - temp sweet loading on west prod.
cantilver
/view,1,1,1,1,1
/angle,1,-120
c**** set element types
et,1,4          *not used
et,2,4          *drill deck beam elements
et,3,4          *production deck beam elements
et,4,16         *production deck floor pipe braces
et,5,4          *subdeck beam elements
et,6,16         *subdeck pipe elements
et,7,16         *Elev +12' submerged pipes
et,8,16         *Elev -40' submerged pipes
et,9,16         *Elev -95' submerged pipes
et,10,16        *trusses a,b,1,2,3 pipes
et,11,16        *trusses a,b,1,2,3 submerged pipes
et,12,63        *deck shells
c**** set real constants
r,1,                                        *not used
r,2,34.2,164,4930,30.01,10.495,,            *w30x116
rmore,,6.43
r,3,29.1,128,3990,29.65,10.450,,            *w30x99
rmore,,3.77
r,4,13.1,81.3,67.2,,13.35,10.365,,          *wt8x44.5
rmore,,.5
r,5,20.1,70.4,1830,23.73,8.965,,            *w24x68
rmore,,1.87
r,6,36.5,125.7,6799,36,10,,                 * girder 3
rmore,,7.36
r,7,48.53,543,10461,36,15.5,,               * girder 2
rmore,,12.7
r,8,66.4,937,14808,36,16.5,,                * girder 1
rmore,,34.3
r,9,56.43,796,12774,36.3125,16.5,,          * girder 5
rmore,,22.8
r,10,78.64,1125,17454,36.3125,16.5,,        * girder 4
rmore,,63.3
r,11,62.00,1.25                             *62 x 1.25
pipe
r,12,21.5,70.6,1600,21.24,8.295,,           *w21x73
rmore,,3.02
r,13,13.2,50.0,350,12.06,8.085,,            *w12x45
rmore;,1.31
r,14,14,.5                                  *Pipe 14x.5
r,15,7.68,9.59,301,15.69,5.50,,             *w16x26
rmore,,.26
r,16,2.875,1.3,15.87,6,3,,                  *L5x3x.25
with plate llv
r,17,8.625,.5                               *Pipe
8.625x.5
r,18,44.2,270,9040,35.85,11.975             *w36x150
rmore,,10.1
r,19,6.61,25.0,16.6,9.8,8.05,,              *wt6x22.5
rmore,,.2
r,20,62.00,.75              *Pipe 62 x .75  awl
r,21,42.00,1.25             *Pipe 42 x 1.25 awl
r,22,42.00,1.00             *Pipe 42 x 1.00 awl
r,23,26.00,.625             *Pipe 26 x .625 awl
r,24,20.00,.625             *Pipe 20 x .625 awl
r,25,18.00,.500             *Pipe 18 x .50  awl
r,26,16.00,.375             *Pipe 16 x .375 awl
```

```
r,27,12.75,.375             *Pipe 12 x .375 awl
r,28,14.00,.375             *Pipe 14 x .375 awl
r,29,26.00,.500             *Pipe 26 x .50  awl
c*** submerged pipes above water line (awl)
r,30,48.50,1.75             *Pipe 48.50 x 1.75 awl
r,31,42.00,1.50             *Pipe 42 x 1.5  awl
r,32,42.00,1.00             *Pipe 42 x 1.0  awl
r,33,18.00,.375             *Pipe 18 x .375 awl
r,34,16.00,.375             *Pipe 16 x .375 awl
r,35,12.75,.375             *Pipe 12 x .375 awl
r,36,18.00,.500             *Pipe 18 x .50  awl
r,37,14.00,.375             *Pipe 14 x .375 awl
c*** submerged pipes below water line (bwl)
r,40,48.50,1.75             *Pipe 48.5 x 1.75 bwl
r,41,46.00,.50              *Pipe 46 x .50  bwl
r,42,36.00,.625             *Pipe 36 x .625 bwl
r,43,30.00,.75              *Pipe 30 x .75  bwl
r,44 30.00,.50              *Pipe 30 x .50  bwl
r,45,22.00,.875             *Pipe 22 x .875 bwl
r,46,22.00,.625             *Pipe 22 x .625 bwl
r,47,22.00,.375             *Pipe 22 x .375 bwl
r,48,20.00,.875             *Pipe 20 x .875 bwl
r,49,20.00,.625             *Pipe 20 x .625 bwl
r,50,20.00,.375             *Pipe 20 x .375 bwl
r,51,14.00,.375             *Pipe 14 x .375 bwl
r,52,                       *Pipe equiv. to 46.5 x
& 42 x 1.5 inside
r,53,                       *Pipe equiv. to 48.5 x
1.75 & 42 x 1.5 inside
r,54,                       *Pipe equiv. to 46.5 x
& 42 x 2 inside
r,55,                       *Pipe equiv. to 48.5 x
1.75 & 42 x 2 inside
r,56,                       *Pipe equiv. to 48.5 x
1.75 & 42 x 1.75 inside
r,57,                       *Pipe equiv. to 46.5 x
& 42 x 1.75 inside
c*** piles below mudline (bml)
r,60,42.00,2.00             *Pipe 42 x 2.0  bml
r,61,42.00,1.75             *Pipe 42 x 1.75 bml
r,62,42.00,1.50             *Pipe 42 x 1.50 bml
c*****
r,70,10.75,.5               *Pipe 10" x xs (.5)
c*****
r,71,.3125
c*** material properties
ex,1,30e3
nuxy,1.3
dens,1,7.37e-7
c****
c****
nread
eread
c****
edelete,20
,23
,21
,27
,10
,26
c****
n,501,-453,-240,498
n,502,-486,-240,498
n,503,-528,-240,498
```

D2

```
n,504,-570,-240,498
n,505,-612,-240,498
n,506,-654,-240,498
n,507,-696,-240,498
c****
ngen,2,10,501,507,1,0,72
ngen,2,20,501,507,1,0,96
ngen,2,30,501,507,1,0,168
ngen,2,40,501,507,1,0,180
ngen,2,50,501,507,1,0,204
ngen,2,60,501,507,1,0,276
ngen,2,70,501,507,1,0,330
ngen,2,80,501,507,1,0,384
ngen,2,90,501,507,1,0,438
ngen,2,100,501,507,1,0,480
c****
type,3
mat,1
real,13
e,501,511
egen,10,10,-1
egen,7,1,-10
e,501,502
egen,6,1,-1
egen,2,100,-6
e,200,501
e,153,601
c****
real,12
e,521,522
egen,6,1,-1
egen,2,60,-6
e,525,535
egen,6,10,-1
e,196,521
e,154,581
c****
real,18
type,3
e,174,173
real,2
e,173,183
e,174,187
c**** shells
type,12
real,71
mat,1
e,501,511,512,502
egen,6,1,-1
egen,10,10,-6
/gopr
nummrg,node,2
/nopr
iter,1,1,1
c**** displacements
nrsel,,187
nasel,,183
nasel,,380
nasel,,377
nasel,,22
nasel,,12
nasel,,152
nasel,,149
nasel,,150,151
nasel,,144
d,all,all
nall
c****
ersel,real,71
ep,all,2,.000104
eall
c****
acel,0,0,384
c****
ersel,,71,72
easel,,51,52
ep,all,,.06275
eall
ersel,,61,62
ep,all,,.1255
eall
c****
ersel,,54,74,20
ep,all,,.03993
eall
ersel,,64
ep,all,,.07986
eall
c***
ersel,,100,101
easel,,103,104
easel,,80,81
easel,,83,84
ep,all,,.11224
eall
ersel,,90,91
easel,,93,94
ep,all,,.22448
eall
c*****
ersel,,86,87
easel,,66,67
ep,all,,.07593
eall
ersel,,76,77
ep,all,,.15185
eall
c****
f,576,fz,-.5
f,586,fz,-.5
c***
ersel,,59,79,20
ep,all,,.020833
eall
ersel,,69
ep,all,,.041667
eall
c****
f,607,fz,-1.5
f,606,fz,-2.22
f,605,fz,-.72
afwrite,1,1
finish
/input,27
```

ELEMENTS FROM CAD

29	30	0	0	0	0	0	0	1	3	6	15	0
31	32	0	0	0	0	0	0	1	3	6	16	0
22	38	0	0	0	0	0	0	1	10	22	19	0
12	40	0	0	0	0	0	0	1	10	22	20	0
143	144	0	0	0	0	0	0	1	3	2	72	0
153	154	0	0	0	0	0	0	1	3	7	77	0
154	143	0	0	0	0	0	0	1	3	7	78	0
193	194	0	0	0	0	0	0	1	3	7	97	0
151	196	0	0	0	0	0	0	1	3	5	98	0
154	198	0	0	0	0	0	0	1	3	12	99	0
196	200	0	0	0	0	0	0	1	3	7	100	0
194	174	0	0	0	0	0	0	1	11	34	133	0
193	173	0	0	0	0	0	0	1	11	34	134	0
281	173	0	0	0	0	0	0	1	11	37	141	0
29	183	0	0	0	0	0	0	1	11	37	142	0
32	174	0	0	0	0	0	0	1	11	37	145	0
31	187	0	0	0	0	0	0	1	11	37	146	0
30	310	0	0	0	0	0	0	1	3	4	155	0
30	312	0	0	0	0	0	0	1	3	4	156	0
335	336	0	0	0	0	0	0	1	3	13	168	0
196	338	0	0	0	0	0	0	1	3	12	169	0
312	310	0	0	0	0	0	0	1	3	5	170	0
198	338	0	0	0	0	0	0	1	3	12	171	0
338	174	0	0	0	0	0	0	1	10	70	172	0
173	198	0	0	0	0	0	0	1	10	70	173	0
198	335	0	0	0	0	0	0	1	3	12	365	0
338	336	0	0	0	0	0	0	1	3	12	366	0
150	312	0	0	0	0	0	0	1	3	5	367	0
310	154	0	0	0	0	0	0	1	3	5	368	0
30	281	0	0	0	0	0	0	1	3	6	369	0
310	143	0	0	0	0	0	0	1	3	4	379	0
312	144	0	0	0	0	0	0	1	3	4	380	0
152	31	0	0	0	0	0	0	1	3	6	386	0
32	200	0	0	0	0	0	0	1	3	6	387	0
143	193	0	0	0	0	0	0	1	3	7	388	0
194	196	0	0	0	0	0	0	1	3	7	389	0
281	153	0	0	0	0	0	0	1	3	6	390	0
149	29	0	0	0	0	0	0	1	3	6	391	0
200	1130	0	0	0	0	0	0	1	10	21	565	0
38	200	0	0	0	0	0	0	1	10	21	568	0
153	1148	0	0	0	0	0	0	1	10	21	574	0
40	153	0	0	0	0	0	0	1	10	21	575	0
1138	377	0	0	0	0	0	0	1	11	31	583	0
1152	380	0	0	0	0	0	0	1	11	31	586	0
1148	173	0	0	0	0	0	0	1	11	32	598	0
173	1152	0	0	0	0	0	0	1	11	32	599	0
1130	174	0	0	0	0	0	0	1	11	32	602	0
174	1138	0	0	0	0	0	0	1	11	32	603	0

NODES FROM CAD

12	-420.000000	240.000000	738.000000	0.0000	0.0000	0.0000
22	-420.000000	-240.000000	738.000000	0.0000	0.0000	0.0000
29	-132.000000	240.000000	498.000000	0.0000	0.0000	0.0000
30	-180.000000	240.000000	498.000000	0.0000	0.0000	0.0000
31	-132.000000	-240.000000	498.000000	0.0000	0.0000	0.0000
32	-288.000000	-240.000000	498.000000	0.0000	0.0000	0.0000
38	-420.000000	-240.000000	561.000000	0.0000	0.0000	0.0000
40	-420.000000	240.000000	561.000000	0.0000	0.0000	0.0000
143	-420.000000	96.0000000	498.000000	0.0000	0.0000	0.0000
144	0.000000000E+00	96.0000000	498.000000	0.0000	0.0000	0.0000
149	0.000000000E+00	240.000000	498.000000	0.0000	0.0000	0.0000
150	0.000000000E+00	144.000000	498.000000	0.0000	0.0000	0.0000
151	0.000000000E+00	-144.000000	498.000000	0.0000	0.0000	0.0000
152	0.000000000E+00	-240.000000	498.000000	0.0000	0.0000	0.0000
153	-420.000000	240.000000	498.000000	0.0000	0.0000	0.0000
154	-420.000000	144.000000	498.000000	0.0000	0.0000	0.0000
173	-420.000000	240.000000	306.000000	0.0000	0.0000	0.0000
174	-420.000000	-240.000000	306.000000	0.0000	0.0000	0.0000
183	0.000000000E+00	240.000000	306.000000	0.0000	0.0000	0.0000
187	0.000000000E+00	-240.000000	306.000000	0.0000	0.0000	0.0000
193	-420.000000	60.0000000	498.000000	0.0000	0.0000	0.0000
194	-420.000000	-60.0000000	498.000000	0.0000	0.0000	0.0000
196	-420.000000	-144.000000	498.000000	0.0000	0.0000	0.0000
198	-612.000000	144.000000	498.000000	0.0000	0.0000	0.0000
200	-420.000000	-240.000000	498.000000	0.0000	0.0000	0.0000
281	-288.000000	240.000000	498.000000	0.0000	0.0000	0.0000
310	-340.000000	144.000000	498.000000	0.0000	0.0000	0.0000
312	-60.0000000	144.000000	498.000000	0.0000	0.0000	0.0000
335	-696.000000	144.000000	498.000000	0.0000	0.0000	0.0000
336	-696.000000	-144.000000	498.000000	0.0000	0.0000	0.0000
338	-612.000000	-144.000000	498.000000	0.0000	0.0000	0.0000
377	-420.000000	-240.000000	204.000000	0.0000	0.0000	0.0000
380	-420.000000	240.000000	204.000000	0.0000	0.0000	0.0000
1130	-420.000000	-240.000000	468.000000	0.0000	0.0000	0.0000
1138	-420.000000	-240.000000	264.000000	0.0000	0.0000	0.0000
1148	-420.000000	240.000000	468.000000	0.0000	0.0000	0.0000
1152	-420.000000	240.000000	264.000000	0.0000	0.0000	0.0000

D5

```
/post1     *post processing of unocal gina west extension
/nopr
stress,fai,4,13    *wf beams
,fbxi,4,14
,fbyi,4,15
,fbxj,4,17
,fbyj,4,18
,s1i,4,19
,s3i,4,20
,s1j,4,21
,s3j,4,22
,fx,4,1
,fai,16,13         *pipes
,fbi,16,14
,faj,16,18
,fbj,16,19
,fxi,8,1           *truss
,fa,8,3
,seit,63,73        *shells
set,1
ersel,real,13
esort,s3i,0,1
/title, unocal gina west extension: real 13, w12x45
prstrs,fx,fai,fbxi,fbyi,s1i,s3i,fbxj,fbyj,s1j,s3j
eall
ersel,real,12
esort,s3i,0,1
/title, unocal gina west extension: real 12, w21x73
prstrs,fx,fai,fbxi,fbyi,s1i,s3i,fbxj,fbyj,s1j,s3j
eall
ersel,real,6
esort,s3i,0,1
/title, unocal gina west extension: real 6, girder 3
prstrs,fx,fai,fbxi,fbyi,s1i,s3i,fbxj,fbyj,s1j,s3j
eall
ersel,real,7
esort,s3i,0,1
/title, unocal gina west extension: real 7, girder 2
prstrs,fx,fai,fbxi,fbyi,s1i,s3i,fbxj,fbyj,s1j,s3j
eall
ersel,real,5
esort,s3i,0,1
/title, unocal gina west extension: real 5, w24x68
prstrs,fx,fai,fbxi,fbyi,s1i,s3i,fbxj,fbyj,s1j,s3j
eall
ersel,real,70
esort,fai,0,1
/title, unocal gina west extension: real 70  10.75 x .50 pipe
prstrs,fai,fbi,faj,fbj
eall
ersel,real,21,22
easel,real,31,32
esort,fai,0,1
/title, unocal gina west extension: reals 21,22,31,32,   42" columns
prstrs,fai,fbi,faj,fbj
eall
ersel,real,34,37,3
esort,fai,0,1
/title, unocal gina west extension: Reals 34,37     other pipe braces
prstrs,fai,fbi,faj,fbj
eall
ersel,real,71
esort,seit,0,1,10
/title, unocal gina west extension: real 71, shells/deck plate
prstrs,seit
eall
/title, unocal gina west extension: Reaction forces
prrfor
nsort,uz,0,1,15
/title, unocal gina west extension: maximum displacements
prdisp
finish
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PLATFORM GINA

Gravity, Storm, and Seismic Performance under Anticipated West Hueneme Development Loads

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1.0 SUMMARY

This report presents the significant results of a structural evaluation of Platform Gina prepared for Unocal Oil and Gas Division. The structural evaluation was performed in order to investigate the feasibility of the platform system to support loads anticipated from higher rig loads, wave loads from additional wells, and equipment loads from new south and west cantilevers, resulting from the proposed development of the West Hueneme Gas Reservoir. The analyses were performed with the finite element method, utilizing the general purpose computer program ANSYS™. The platform was analyzed under three design load conditions—gravity, extreme storm, and seismic, developed in accordance with the latest guidelines of API RP 2A (1).

Again, the purpose of the evaluation was to determine the feasibility of new reservoir development, involving expanded drilling and production activities from Platform Gina. The main criteria in evaluating the feasibility was the ultimate safety factors of the platform piles with respect to axial capacity. The general states of stress in the structural members were also reviewed, and all of the evaluation criteria are consistent with the guidelines provided in API RP 2A.

Our preliminary structural evaluation indicates that Platform Gina has adequate structural reserve capacity to support the proposed drilling and production equipment associated with additional reservoir development. Pile safety factors were found to be within the recommended allowables, and stresses in the structural members are acceptable, based on a comparison to basic allowable stresses. It should be noted that if it is decided to proceed with the new development, additional detail design will be required to check for items such as local buckling, punching shear, etc.

Table 1.1 is a summary of the pile reactions from all of the analyses that were performed. Critical values and their corresponding factors of safety are highlighted in bold italic for easy reference. The allowable safety factors are 2.0 for maximum gravity loads, 1.5 for extreme storm and strength level seismic loading, and 1.0 for ductility level seismic loads. As seen in the table, Platform Gina has an adequate factor of safety for all of the load cases that were evaluated.

Table 1.1. **Platform Gina - Axial Pile Reactions at the Mudline in Kips (+ Compression; - Tension)**

	Pile Location					
Load Case	B1	B2	B3	A1	A2	A3
1. Maximum Gravity	1040	1296	1072	989	***1494***	1361
•Ult. Safety Factor					***3.35***	
2. Operating Gravity	926	1065	821	821	1125	944
3. Extreme Storm	-33	1565	***2400***	***-1055***	659	1961
•Ult. Safety Factor			***2.08***	***2.27***		
4. Seismic (Strength)						
— CQC "x" (E-W)	±1381	±40	±1374	±1331	±25	±1338
— CQC "y" (N-S)	±1013	±1110	±1041	±1031	±1108	±1044
— CQC "z" (vertical)	±215	±270	±207	±210	±325	±273
— SRSS Combined	±1727	±1143	±1736	±1696	±1155	±1719
— Operating + SRSS	2653	2208	2557	2517	2280	***2663***
•Ult. Safety Factor						***1.88***
— Operating - SRSS	-801	-78	***-915***	-875	-30	-775
•Ult. Safety Factor			***2.62***			
5. Seismic (Ductility)						
— CQC "x" (E-W)	±2182	±48	±2181	±2102	±39	±2121
— CQC "y" (N-S)	±1592	±1709	±1630	±1589	±1702	±1644
— CQC "z" (vertical)	±408	±503	±407	±415	±590	±503
— SRSS Combined	±2732	±1782	±2753	±2667	±1802	±2731
— Operating + SRSS	3658	2847	3574	3488	2927	***3675***
•Ult. Safety Factor						***1.36***
— Operating - SRSS	-1806	-717	***-1932***	-1846	-677	-1787
•Ult. Safety Factor			***1.24***			

2.0 INTRODUCTION

The subject of this report is the structural evaluation of a 6-pile oil drilling and production platform known as Platform Gina, O.C.S. P-0202. Gina is located offshore, near Port Hueneme, California in a water depth of 95 feet. Its orientation is shown in Figure 2.1, as are the reference numbers and letters for the main structural vertical frames.

The purpose of the Platform Gina structural evaluation was to establish the feasibility of drilling and producing several additional wells if preliminary testing data supports reservoir development. Some possible locations for the new well slots are shown in Figure 2.2, and a preliminary process equipment layout is depicted in Figure 2.3. As shown, the additional process equipment will necessitate a new production deck extension on the south side of the platform.

Structural evaluation was necessary because the drilling loads and weight of the additional process equipment for the new development are significantly higher than the original design loads. Global pile foundation safety factors were the primary criteria used in the structural evaluation.

Analyses of Platform Gina were performed with the finite element method, consistent with the requirements of API RP 2A (1), utilizing the general purpose finite element program ANSYS™. The computer model includes elements for all of the main structural components, as well as special elements at the mud-line modeling the pile/soil interface. While a secondary objective of the analytical study was a review of stress levels in the structural members, an exhaustive stress evaluation was postponed until the detail design stage. If reservoir development is justified, the detailed design will be performed in accordance with API RP 2A and API Spec 6A (1,2).

The main body of this report has three sections. Section 3 is a description of the analytical load cases, and Section 4 presents the details of the finite element models that were used in the evaluation, with explanations of the differences for each load case. The significant analytical results are discussed and summarized in Section 5, and a list of references is contained in Section 6.

Figure 2.1 Platform Gina—General elevations and orientation plan.

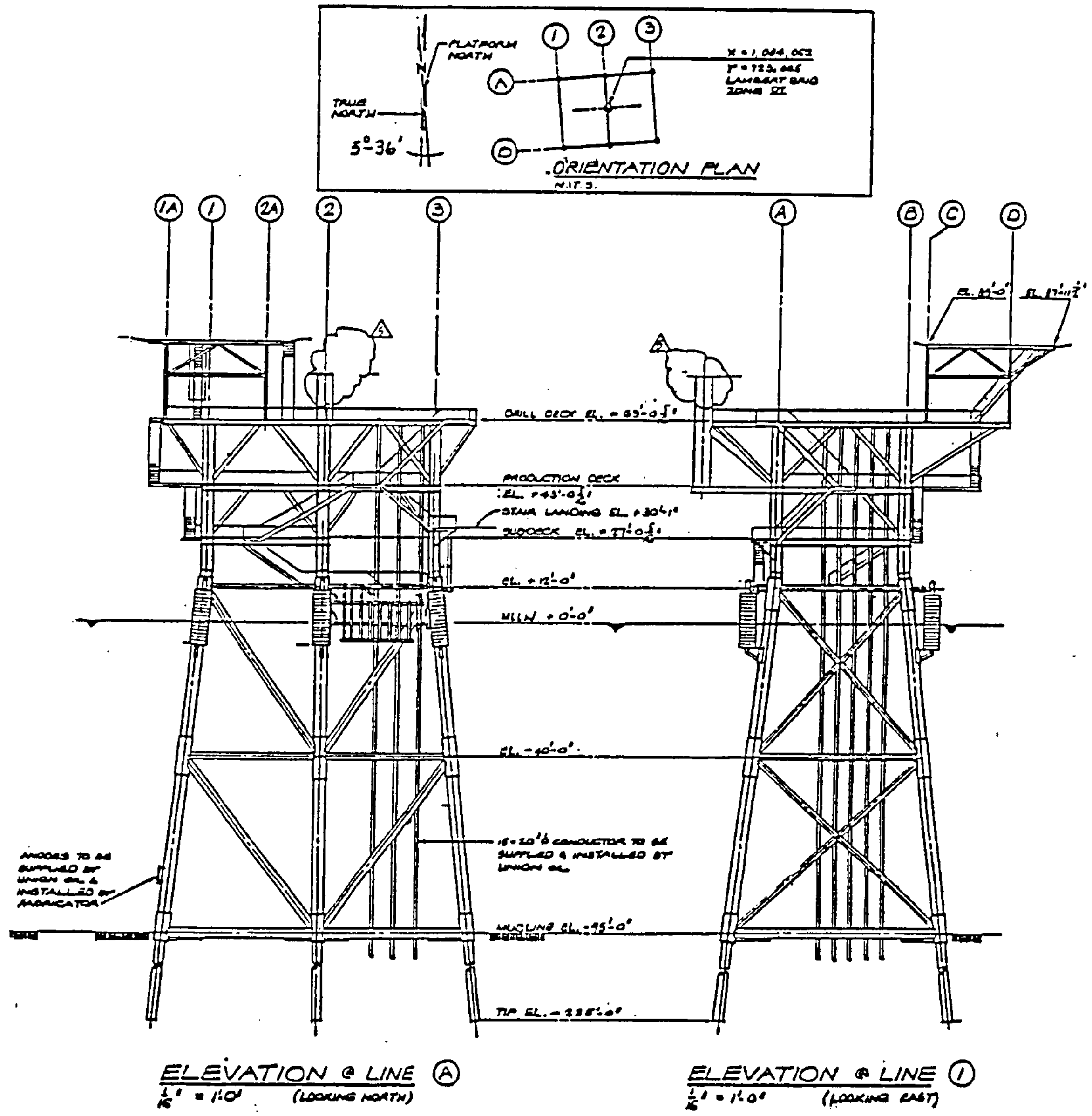


Figure 2.2 Platform Gina—Possible new well slot locations.

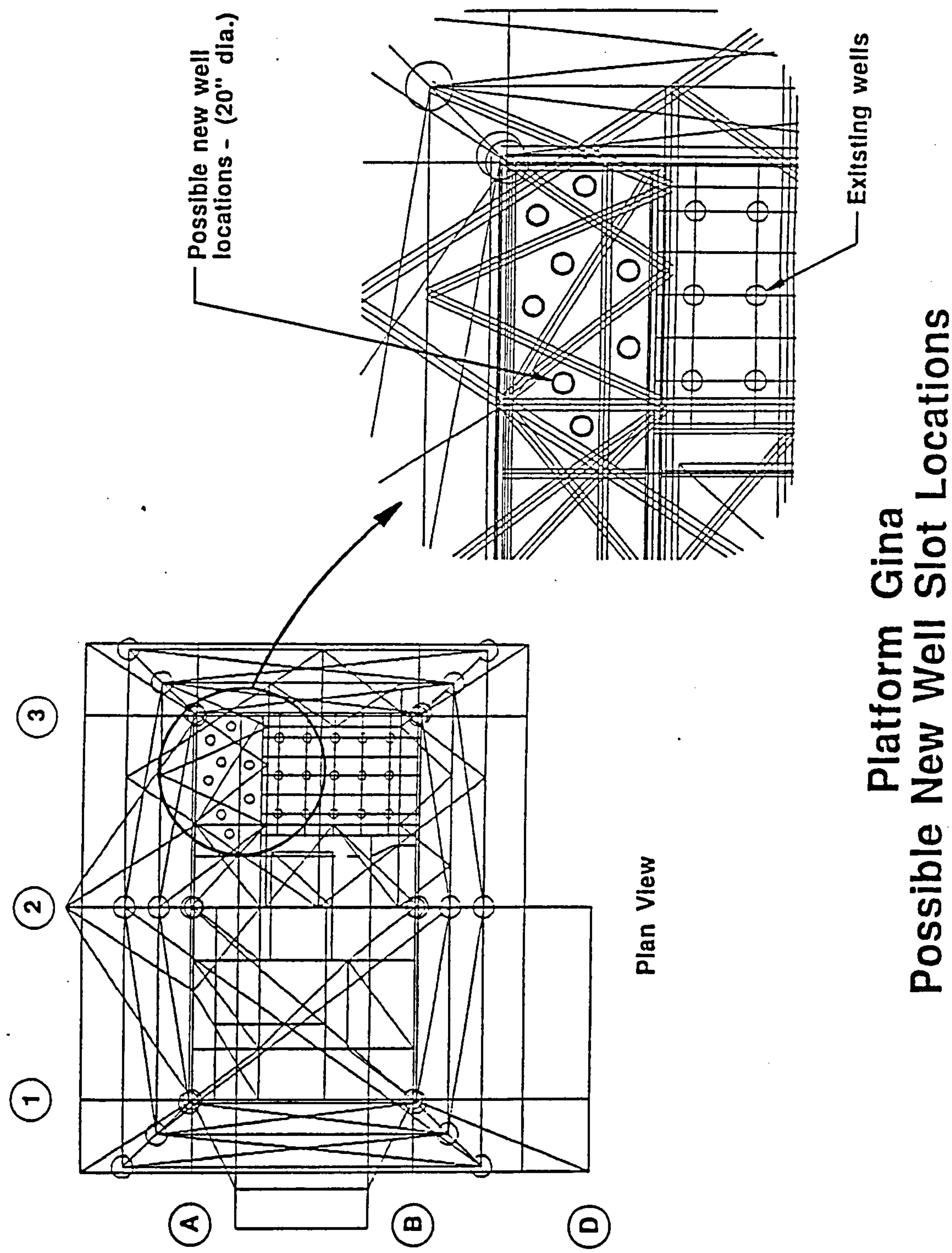
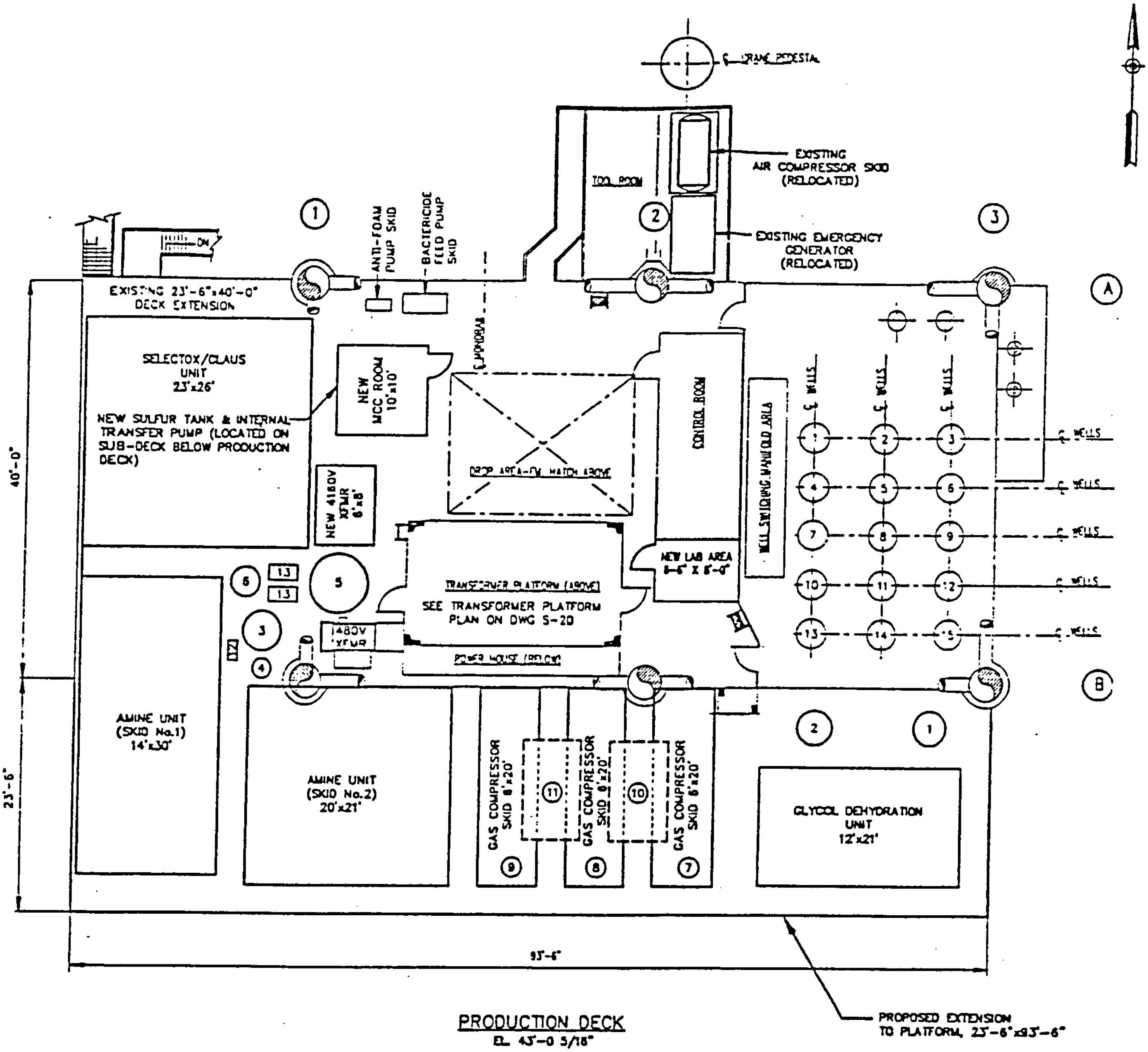


Figure 2.3 Preliminary production deck process equipment layout.



3.0 LOAD CASES

Three load conditions were considered in evaluating Platform Gina—maximum gravity loads, extreme storm loading, and seismic loads. The sections that follow provide details for each of these three load cases.

3.1 Maximum Gravity Loads

A primary component of the maximum gravity load case is simply the dead weight of the platform itself. This includes the weight of the jacket framing members, main structural members of the deck superstructures, fill beams, deck plate, and any other permanent structural component. By using the appropriate material density and element properties in the finite element model, the overall platform weight is automatically calculated by the computer program. To account for connections and miscellaneous details in the structure, the material density of the structural components was assumed to be 5 per cent above that normally used for steel. The total dry weight of the permanent structural components of the platform was calculated to be 3,544 kips.

To calculate the maximum equipment gravity loads, it was assumed that all process equipment associated with the new reservoir development had been installed, and that a full scale drilling program was in progress. Based on these assumptions, the equipment weight at each of the deck levels was calculated and included in the analysis. Conservatively, all of the equipment live loads were assumed to be at their maximum operating values.

Layouts of the equipment on the drill, production, and sub-decks are presented in Figures 3.1 and 3.2. The numbers on each piece of equipment in the figures correspond to the list of loads presented in Tables 3.1-3.3. As indicated in the tables, the total weights of the deck equipment are 4,035 kips, 811 kips, and 189 kips for the drill, production and sub-decks, respectively, giving a total equipment weight of 5,037 kips.

Besides specific equipment loads, a 20 psf uniformly distributed load was included at each of the three decks. This uniform load accounts for miscellaneous piping, equipment, people, etc. An exception is on the west and south production deck extensions, where a 5 psf uniform load was assumed. The reduced load was used because it was recognized that the equipment footprint on these extensions would not allow for much additional miscellaneous equipment.

The total mass associated with the maximum gravity load case, including the dead weight of the platform and the maximum equipment loads, was calculated to be 8,581 kips.

3.2 Extreme Storm Loads

Weather data used in the storm load analysis were taken from a report entitled *Platform Gina - Extreme Storm Criteria* (3). Weather loads consist of wave, current, and wind induced forces, associated with an extreme storm event with return period of 100 years. The analytical water depth of 98 feet includes a storm surge of 3 feet, and the design wave height is 42 feet with a period of 15 seconds. The current is assumed to be 1.5 knots at the surface, varying linearly to 0.5 knots at the sea floor, and the design one minute average wind speed is 60 knots at a reference height of 33 feet above mean sea level.

It was conservatively assumed that all the components of the weather act collinearly, i.e., the wind, wave, and current are all assumed to have the same heading with respect to the platform. The platform orientation is at 5° 36' counter-clockwise from true north as indicated in Figure 2.1, and the design weather heading is at 282° 30' clockwise from true north. This means that the design storm approaches Platform Gina at 18.1° clockwise from the west side of the platform. This orientation, as well as a general schematic of the storm loads are depicted graphically in Figures 3.3 and 3.4.

Forces exerted by the current and waves in the extreme storm were calculated using the Morison equation. This equation calculates the total force as the sum of two terms—a drag force and an inertial force. For cylindrical members, coefficients of 0.7 and 2.0 were used for the drag and inertia terms, respectively. Water particle velocities and accelerations were calculated using Stoke's fifth order wave theory.

Forces on cylindrical members of the platform caused by the water motion were automatically calculated by the finite element computer program, but the forces acting on the sub-deck as the wave passes were calculated by hand. In these calculations, the entire projected area between the sub-deck and production deck was assumed to carry load with a drag coefficient of 2.0.

A similar procedure was used to calculate forces acting above the water surface caused by wind. The technique presented in RP 2A 2.3.2 was used to calculate wind forces acting on the platform projected areas, assuming a shape coefficient of 2.0. Hand calculations of the wind and wave forces are included in Appendix A.

3.3 Seismic Loads

Seismic evaluation of Platform Gina was accomplished with the response spectrum analysis method. Which spectrum to use in evaluating the seismic response of Platform Gina was addressed by Staal, Gardner, and Dunne, Inc. in their report *Seismic Hazard Analysis—Platform Gina* (4). In that report, it was concluded that the response spectrum in Figure C2.3.6-2, from API RP 2A, for shallow strong alluvium soils (type B) could be used in the analysis. The API spectrum is given in terms of spectral accelerations that are normalized to 1.0 gravity. The values must be further modified depending upon which zone the platform is located in. Platform Gina is located in seismic zone 4 so the ordinates in Figure C2.3.6-2 were multiplied by 0.25. The resulting spectrum was used to perform the strength level seismic analysis, with an effective damping ratio of 5%.

In addition to the strength level analysis, a ductility level analysis was performed to ensure that the platform has adequate reserve capacity to prevent collapse during a rare intense earthquake. Twice the strength level earthquake loads are used in the ductility analysis with an effective damping ratio of 8%. The response spectra used in the seismic analysis of Platform Gina are presented in Figure 3.5.

Table 3.1. **Platform Gina - Drilling Deck Load Summary**

Item	(kips) Dead Load	(kips) Operating Live Load	(kips) Operating Total
1. Flare Boom	13.0	0	13.0
2. Flare Scrubber	5.0	2.4	7.4
3. Cement Pods (3)	45.0	255.0	300.0
4. Crane Pedestal	50.0	0	50.0
5. Cement Unit	6.7	38.3	45.0
6. Logging Unit	35.0	30.0	65.0
7. Emergency Generator	45.0	0	45.0
8. Pre-Hydration	15.0	85.0	100.0
9. Drill Rig	1000.0	1000.0	2000.0
10. Mud Dock	30.0	200.0	230.0
11. Active Mud	45.0	255.0	300.0
12. Pipe Rack	50.0	200.0	250.0
13. Mud Pumps (2)	22.5	127.5	150.0
14. SCR House	65.0	0	65.0
15. Reserve Mud Tanks (2)	40.5	229.5	270.0
16. Tools	7.0	0	7.0
17. Quarters (25 psf/flr)	32.0	48.0	80.0
18. Helipad	58.3	0	58.3
Totals	**1565.0**	**2470.7**	**4035.7**

Notes:

- Structure weight increased 5% to account for misc. connections and equipment.
- 20 psf uniform load

Table 3.2. **Platform Gina - Production Deck Load Summary**

Item	(kips) Dead Load	(kips) Operating Live Load	(kips) Operating Total
1. Test Separator	8.5	2.2	10.7
2. Gross Separator	8.5	2.2	10.7
3. Treated H_2O Vaporizer	1.4	5.9	7.3
4. Make-up H_2O Vaporizer	.7	1.4	2.1
5. HTM Heater	8.0	.7	8.7
6. HTM Expansion Tank	2.5	1.5	4.0
7, 8, 9. Gas Compressors (3)	75.0	0	75.0
10. Lube Oil Cooler	3.0	.3	3.3
11. Discharge Gas Cooler	5.0	0	5.0
12. Treated H_2O Transfer Pump	.5	0	.5
13. HTM Transfer Pumps (2)	2.0	0	2.0
14. Amine Unit Skid #1	80.0	46.0	126.0
15. Amine Unit Skid #2	70.0	86.0	156.0
16. Selectox/Claus Unit	160.0	0.0	160.0
17. Glycol Dehydration Unit	26.0	8.0	34.0
18. Sulfer Tank & Pump	6.0	21.0	27.0
19. MCC Room	10.0	0	10.0
20. 4160V Transformer	25.0	0	25.0
21. Lab	3.0	0	3.0
22. Emergency Generator	5.0	0	5.0
23. Air Compressor Skid	19.0	0	19.0
24. Transformer (480 V)	7.6	0	7.6
25. Electrical Gear	70.0	0	70.0
26. Office / Control Room	22.0	0	22.0
27. Shop	8.0	0	8.0
28. Well Room Manifold	10.0	0.0	10.0
Totals	**636.7**	**175.2**	**811.9**

Notes:

- Structure weight increased 5% to account for misc. connections and equipment.
- 20 psf uniform load except 5 psf on west and south extensions.

Table 3.3. **Platform Gina - Sub-Deck Load Summary**

Item	(kips) Dead Load	(kips) Operating Live Load	(kips) Operating Total
1. Chemical Tanks & Pumps	5.4	18.4	23.8
2. Storage Closet	3.0	.5	3.5
3. Triplex Pumps	10.0	0	10.0
4. Waste Water Tank	15.0	15.0	30.0
5. Shipping Tank	7.4	4.6	12.0
6. Septic Tank	2.0	4.0	6.0
7. Air Tugger	2.0	0	2.0
8. Transfer Pumps	1.0	0	1.0
9. Chemical Tank	0	1.3	1.3
10. Belly Tank	20.0	40.0	60.0
11.* Boat Landings (2)	40.0	0	40.0
Totals	**105.8**	**83.8**	**189.6**

Notes:

- Structure weight increased 5% to account for misc. connections and equipment.
- 20 psf uniform load

* Boat Landings are located at MWL

Figure 3.1 Drill deck equipment layout for maximum gravity loads.

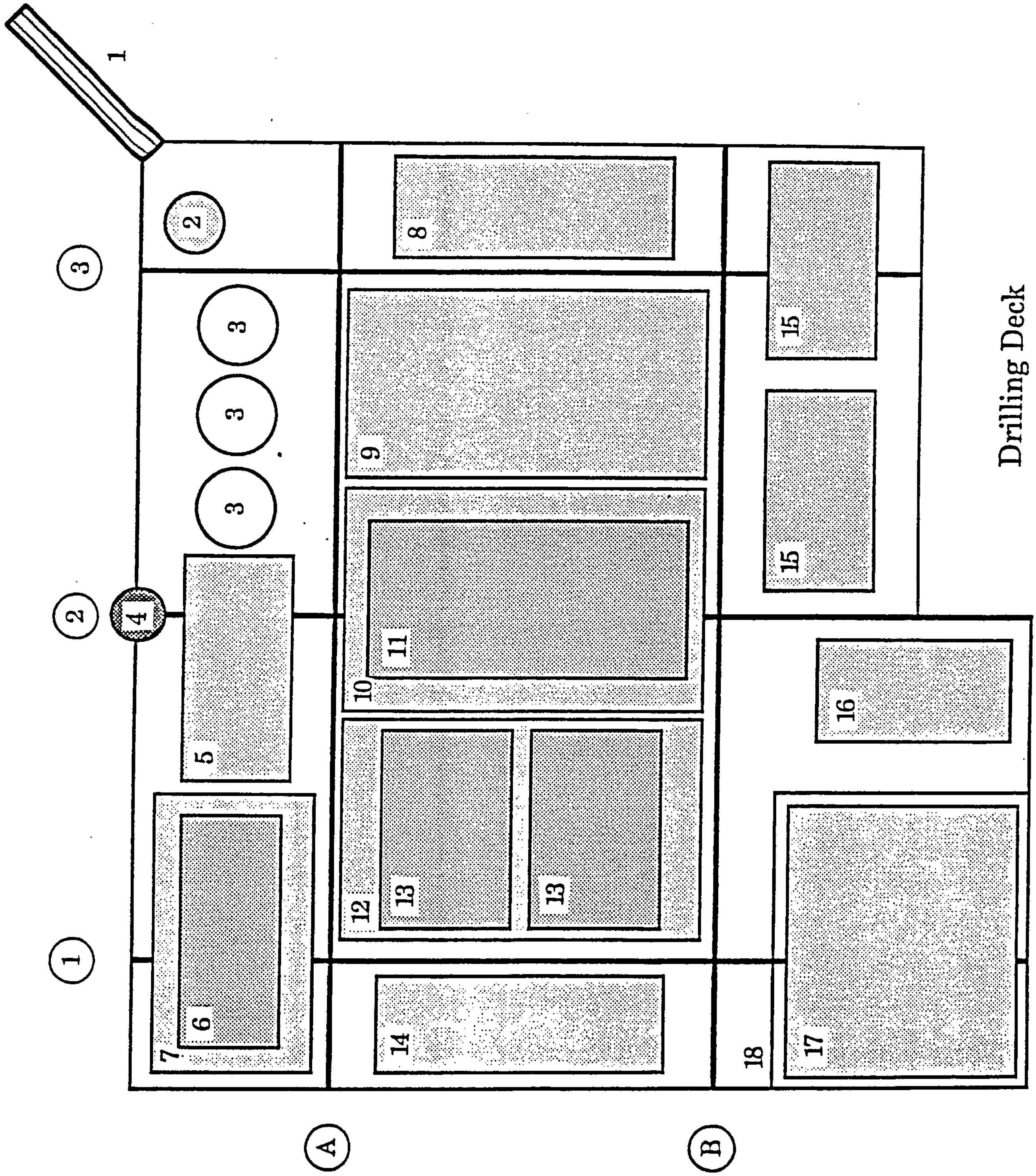


Figure 3.2 Production and sub-deck equipment layout for maximum gravity loads.

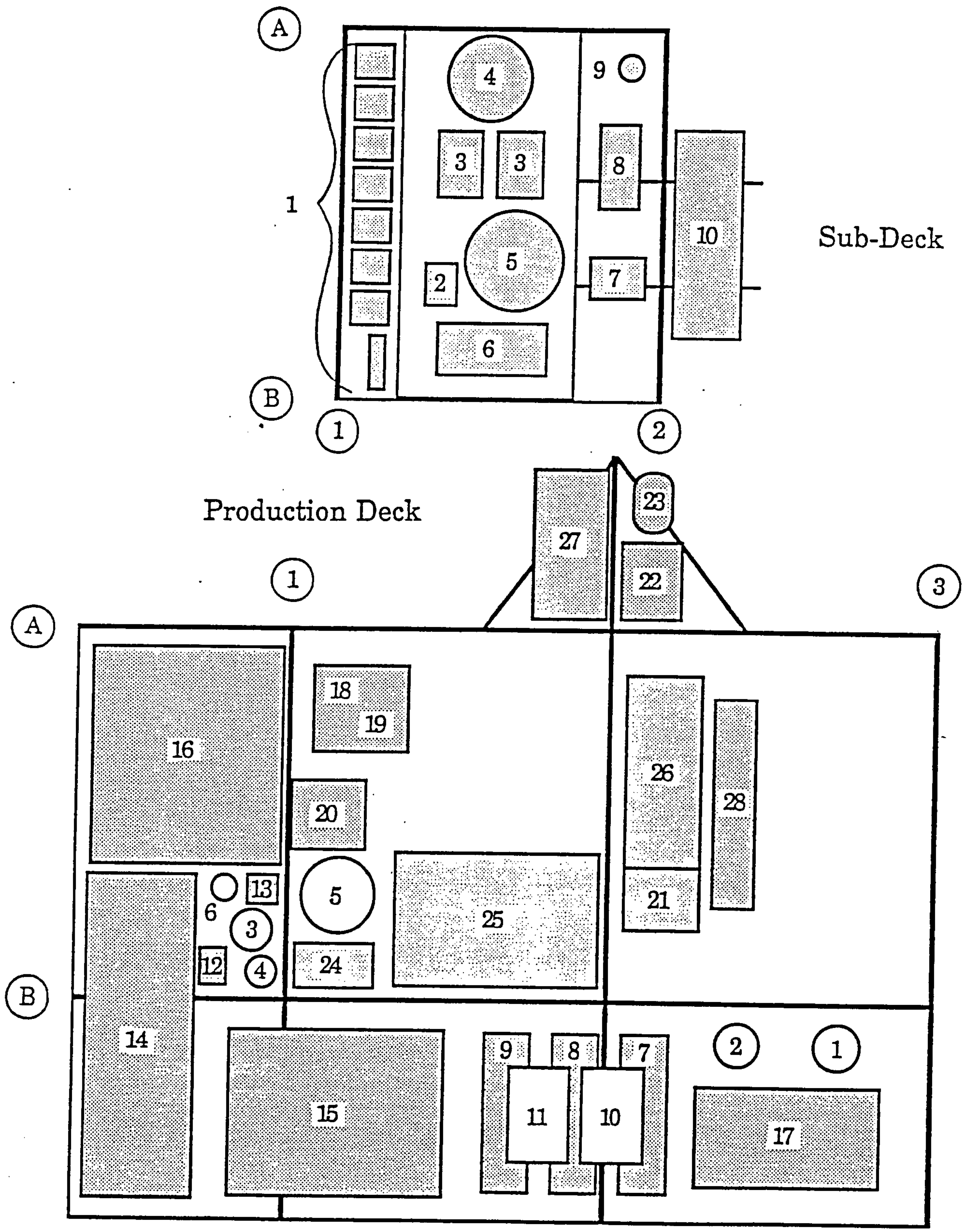


Figure 3.3 Extreme storm analysis weather heading orientation.

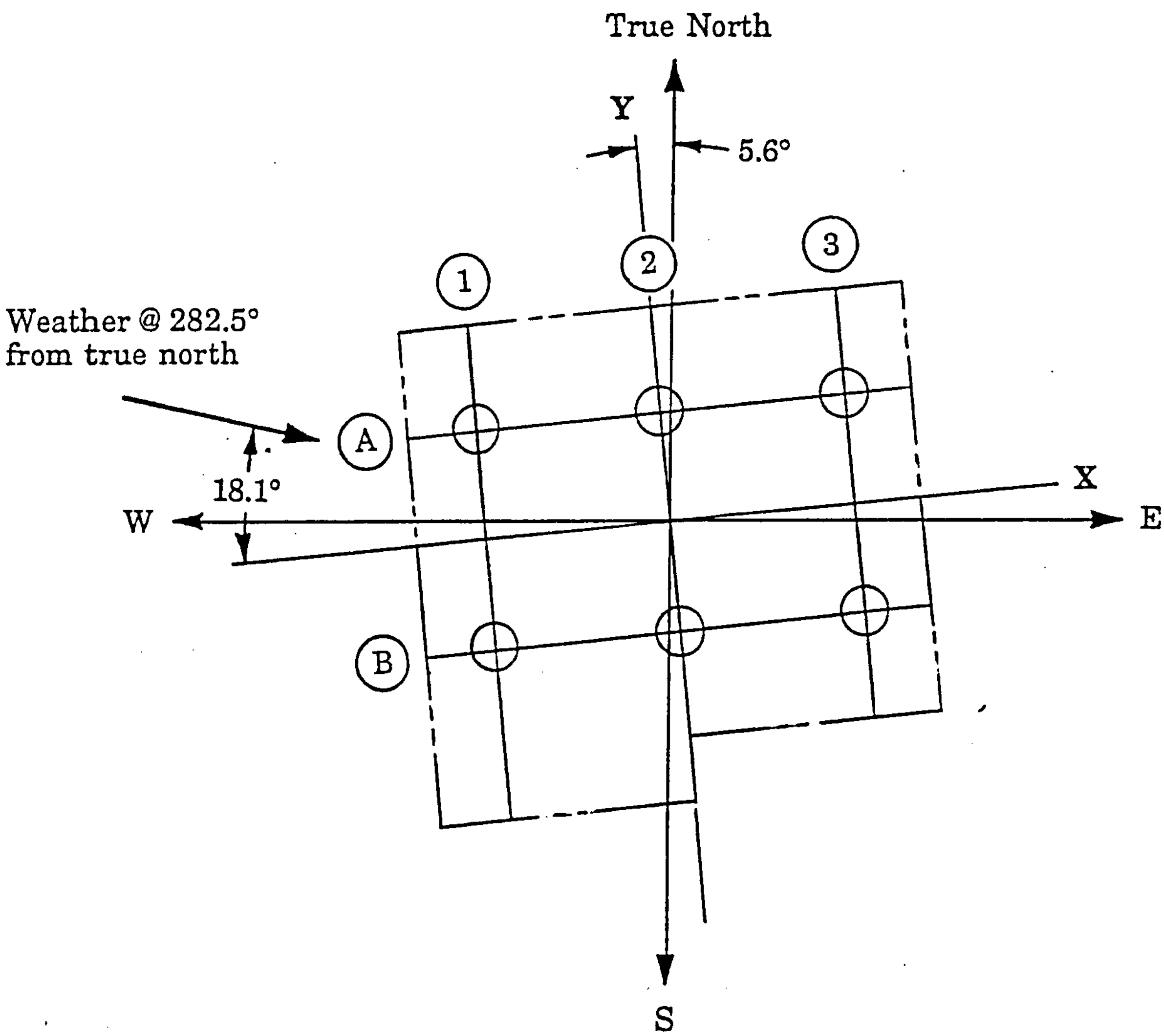


Figure 3.4 Weather components modeled in the extreme storm analysis.

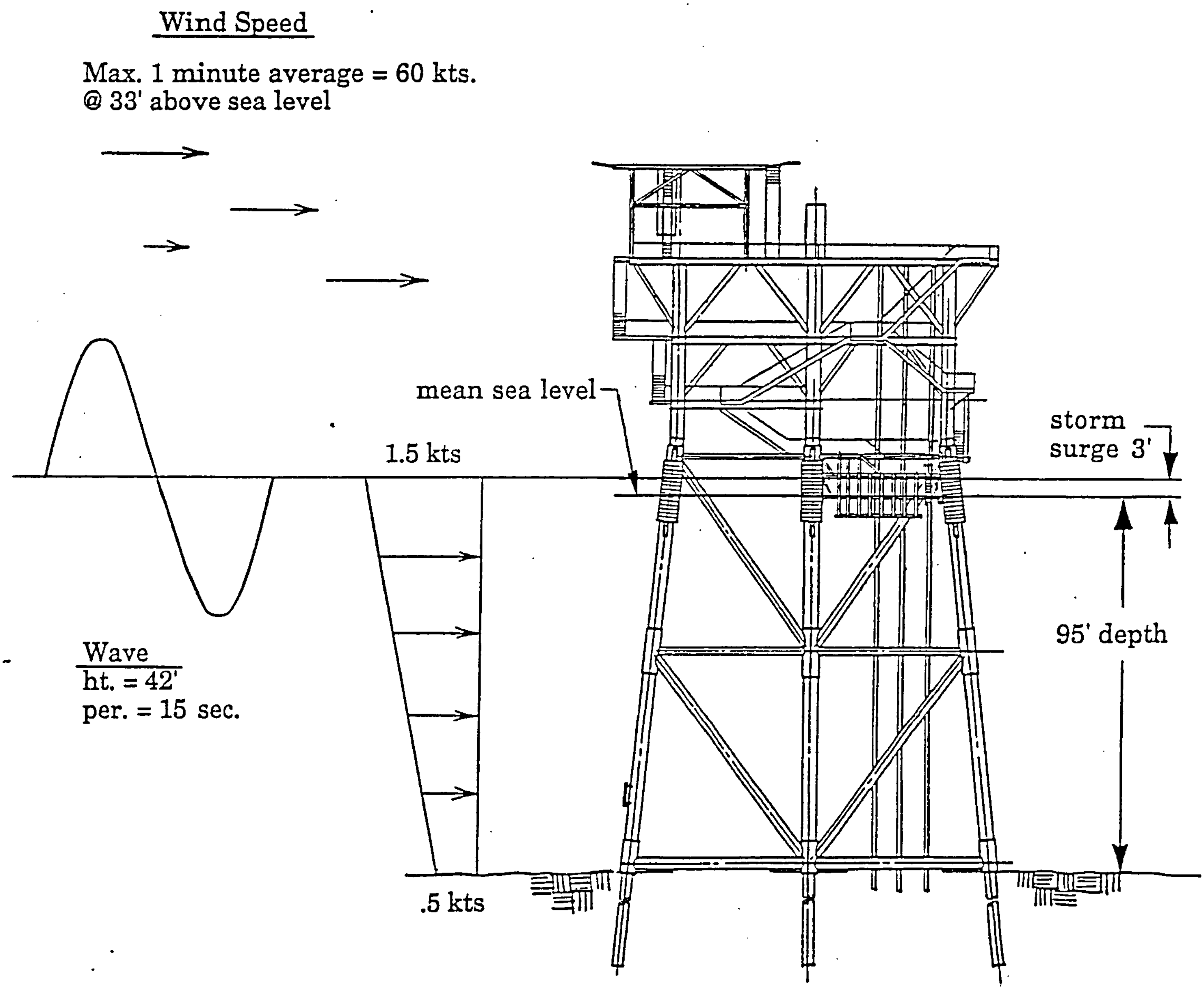
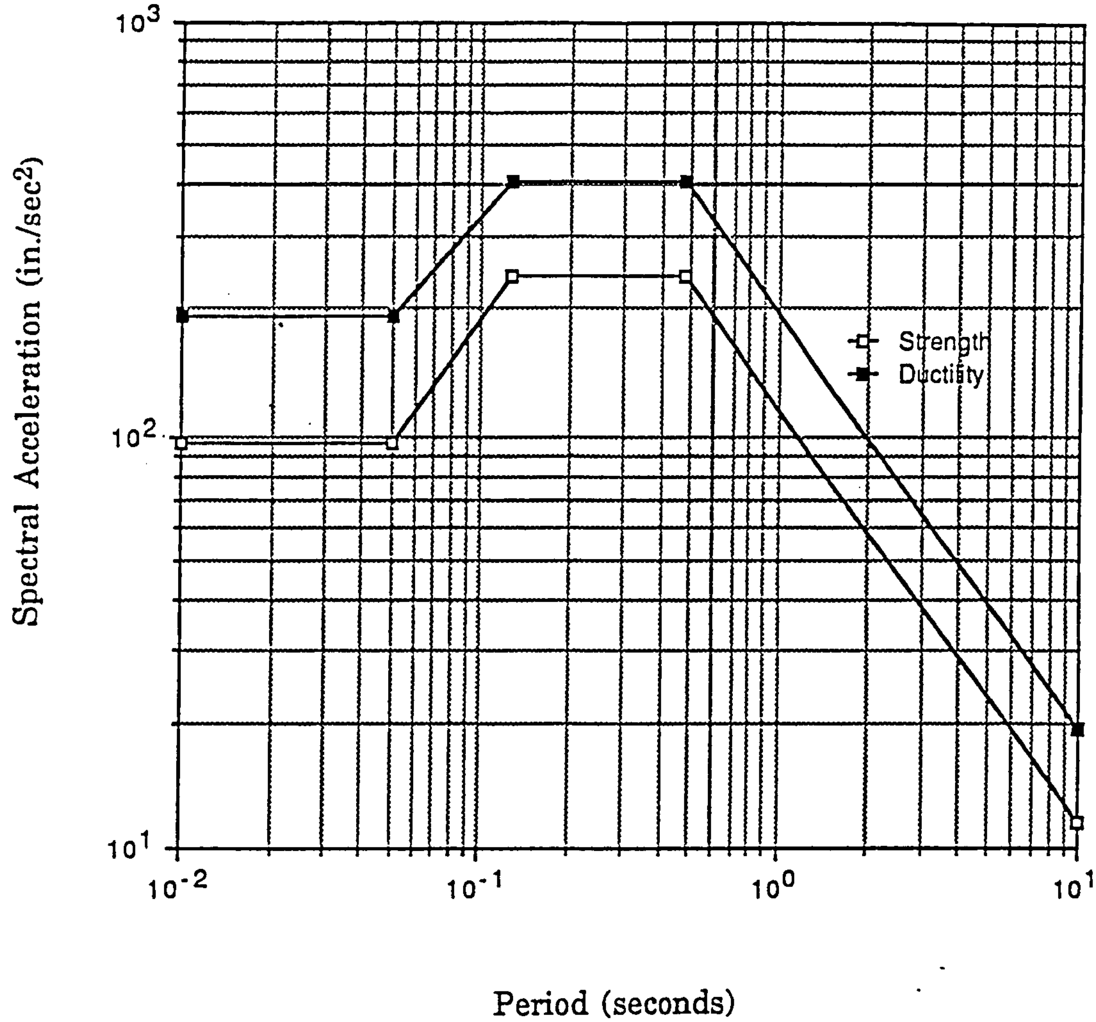


Figure 3.5 Response spectra for seismic analysis of Platform Gina.



4.0 FINITE ELEMENT MODELS

4.1 Basic Three Dimensional Model

The three dimensional global analyses of Platform Gina were performed with the finite element model shown in Figure 4.1. Each analytical load case required specific refinements to the basic model of Figure 4.1, and these modifications are described in Sections 4.2 - 4.4. This section describes the features of the finite element model that were common to all of the analyses.

The basic model consists of several element types. Geometrically, the locations of the elements are at the center-lines of the beams, and connections are at the center-line intersections. Standard beam elements were used to model the primary framing members of the deck floor systems, and pipe elements were used for the platform tubular structural members. At each deck level, plate elements were included to apply uniformly distributed loads and to model the stiffness of the filler beams and deck plate. The weight of individual pieces of equipment was distributed to the appropriate nodal locations and modeled with lumped mass elements. The finite element model ends just below the mud-line, but the stiffnesses of the piles and soil were included in the model with spring elements.

ANSYS has a special type of pipe element (submerged pipe, STIF 59) that allows hydrodynamic loading. This type element was used to model the structural components that are below sea level. The submerged pipe element formulation automatically accounts for buoyancy, current and wave forces, internal mass, pressure effects, etc. It was assumed that all of the bracing members of the jacket are full of air and sealed, resulting in a significant buoyant force.

The jacket legs are modeled as equivalent pipe elements that represent the combination of the pile, jacket, and grout, with the center bore filled with sea water. The grout was assumed to contribute only mass, and no strength to the composite section of the combined jacket leg/pile columns. All of the elements below sea level were assumed to have 3 inches of marine growth on their exterior surface.

The piles and soil below the mudline were modeled with spring elements in the axial, lateral, and rotational directions. The stiffness of the springs was derived from data provided by Staal, Gardner, and Dunne (5). The specific value of the spring stiffness varied for each type of analysis and is discussed in the sections below that describe the differences in the finite element models.

4.2 Gravity Load Finite Element Model

The finite element model used to analyze the maximum payload gravity load case included masses for all of the platform equipment filled to capacity. The analysis was performed by applying an acceleration of 386.4 in/s^2 in the vertical direction, modeling the effect of gravity. No other loads were considered for this load case, i.e, the wind, wave, current, and seismic loads were assumed to be zero. However, the buoyancy effect of being submerged was included, since the finite element model was constructed from submerged pipe elements.

Nonlinear springs were used to model the pile/soil interface at the mud-line. As previously noted, the values for the spring stiffnesses were taken from curves provided by Staal, Gardner, and Dunne. Figures 4.2-4.5 show the static force versus deflection curves that were used in the pile/soil interface elements. Note that different curves apply in the axial compression, axial tension, lateral, and rotational degrees of freedom.

4.3 Extreme Storm Load Finite Element Model

There are two main differences between the gravity load case and the extreme storm load case finite element models. First, the wave, current, and wind loads were included in the extreme storm analysis. Secondly, the gravity loads were reduced to levels more closely associated with operating rather than maximum design loads.

The weather-induced loads, as described in Section 3.2, were added to the model by specifying the wave height and period, current profile, and wind velocity and direction. The only physical change required to the finite element model was the addition of the well conductors. Although the conductor and casing weights are self-supporting, and therefore not necessary in the gravity analysis, the lateral reactions at the platform conductor guides from environmental loads had to be included in the extreme storm load analysis. This was done by independently modeling the 20 inch conductors with submerged pipe elements, and coupling the conductor nodes to the platform nodes in the lateral directions at the conductor guide locations. Figure 4.6 shows the location of the conductor elements in the finite element model.

On the drill deck, the hook load is assumed to be zero during the extreme storm, and the rest of the equipment loads are 75% of the values used in the maximum payload analysis (both dead and live loads). The production and sub-deck live loads were reduced by 25%, and the uniformly distributed deck loadings were also reduced to 75% of the values used in the maximum gravity analysis. With the exception of the drill deck equipment loading, all of the dead load remained as it was in the maximum gravity analysis.

4.4 Seismic Finite Element Model

While the overall finite element model used to perform the seismic response spectrum analysis of Platform Gina is the same as used in the other analyses, a considerably different approach was required. The analytical procedure is a three step process. First, a modal analysis was performed to determine the natural frequencies and mode shapes of the platform. Fifty master degree of freedoms were used in the eigenvalue extraction process in the lateral (x and y) directions and 150 were used for the vertical (z) direction. Master degrees of freedom are chosen based on the relative ratio of mass to stiffness at each degree of freedom. By selecting the degrees of freedom with the largest mass to stiffness ratios, the lowest frequencies with the highest response participation are calculated. The required number of degrees of freedom is governed by the total effective mass, in each direction, represented by the master degrees of freedom. It should be fairly close to the actual mass of the structure that is being modeled.

The next step in the analysis was to determine the spectral response of each significant vibration mode, and to combine them for each of the three principal directions. In the finite element program ANSYS, the significance level of each mode is based on a calculated value called the *mode coefficient*. The mode coefficient is an "effective amplification factor" that multiplies the calculated eigenvector to give the actual displacements in each mode. A mode is considered significant if its mode coefficient is greater than a fraction of the maximum mode coefficient of all modes. In the analysis of Platform Gina, a significance fraction of 0.005 was used in the horizontal direction, and 0.07 in the vertical direction. The adequacy of this significance fraction was checked by summing the mass fractions in each direction. Significant modes were combined with the complete quadratic combination (CQC) method. A summary of the results of the modal analyses for each direction is contained in Appendix B.

The third step in the seismic analysis process was to combine the directional responses (x, y, and z) from the second step of the analysis using the square root of the sum of the squares (SRSS) method. The resulting response represents the maximum values expected during the design level earthquake.

The response spectrum solution algorithm requires a linear finite element model. Therefore, the non-linear pile/soil spring elements used in the gravity and extreme storm analyses had to be modified to linear springs. Conservative axial stiffness values were calculated from the curves shown in Figures 4.2 and 4.3 based on preliminary estimates of the results. In the lateral and rotational directions, different curves were provided for cyclic loading, as opposed to static. These curves, used to calculate the linear spring rates in the seismic analyses, are presented as Figures 4.7 and 4.8.

Another refinement necessary for the seismic model was the addition of the appropriate internal casing string mass to the conductor elements, as well as lumped masses for the wellheads at the top of the conductors. It was assumed that the dry weight of the conductor and internal casing strings was 490 plf and that each wellhead assembly weighed 5 kips. Subsequent to the analysis, it was found that the actual weight of the wellhead was 6.08 kips and that the fully grouted weight of the conductor and casing strings is 467.6 plf. However, due to the preliminary nature of the analysis, the estimates used in the analysis were determined to be acceptable.

Figure 4.1 Basic three dimensional finite element model of Platform Gina.

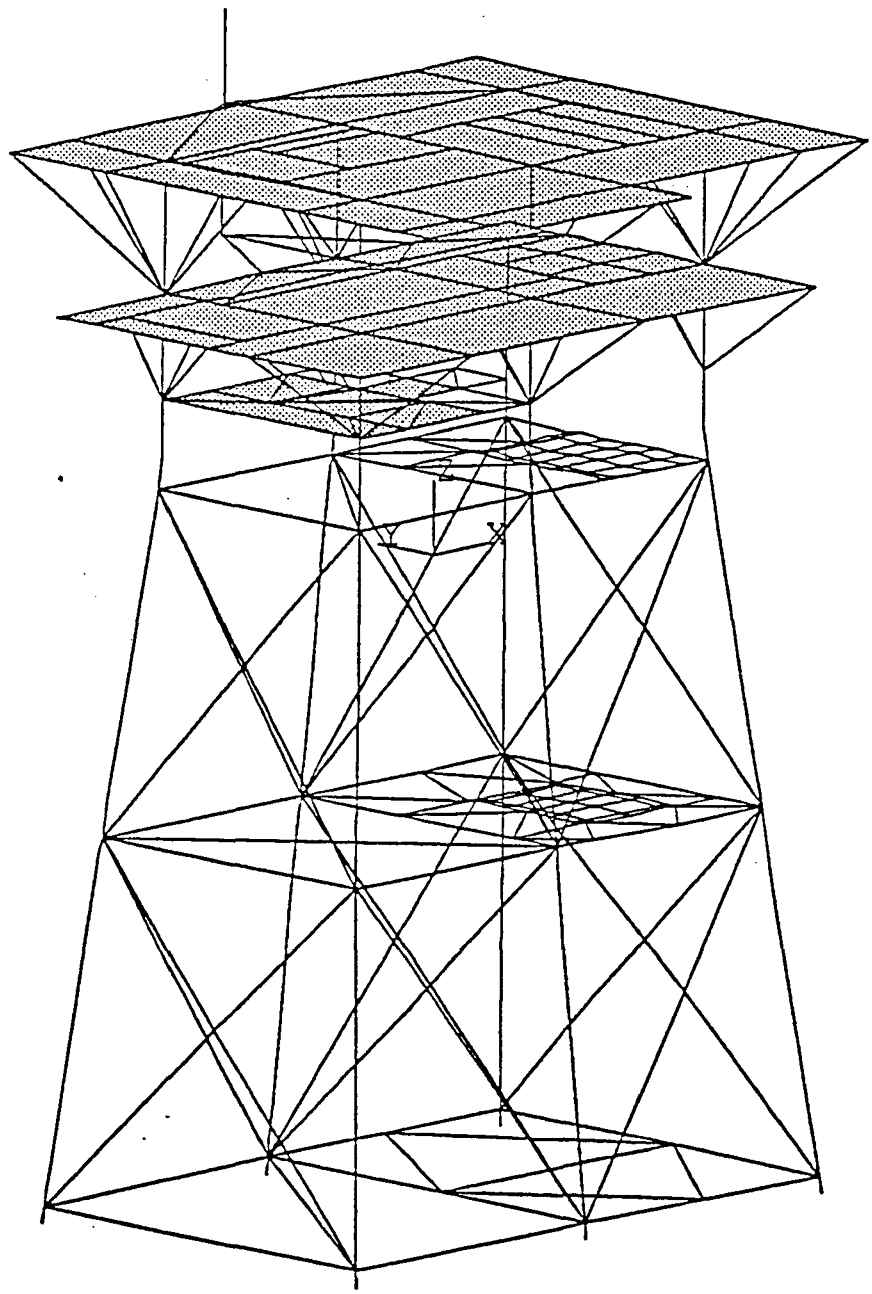


Figure 4.2 Axial compression versus deflection at the pile top.

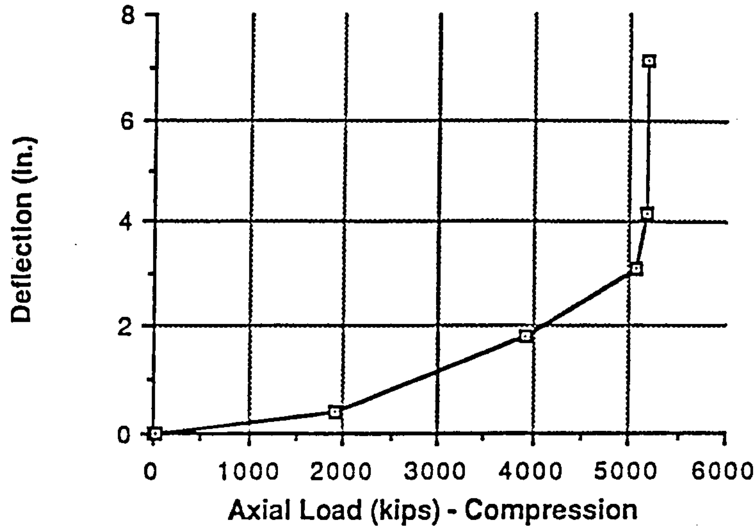


Figure 4.3 Axial tension versus deflection at the pile top.

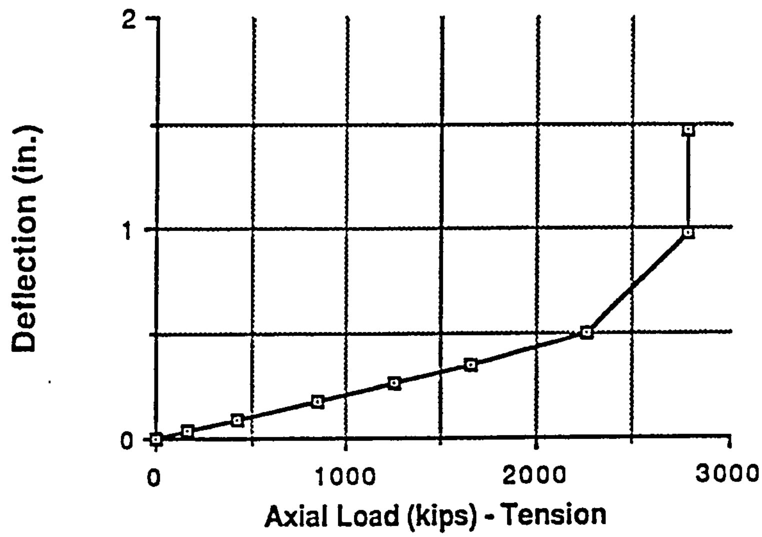


Figure 4.4 Static lateral force versus deflection at the pile top.

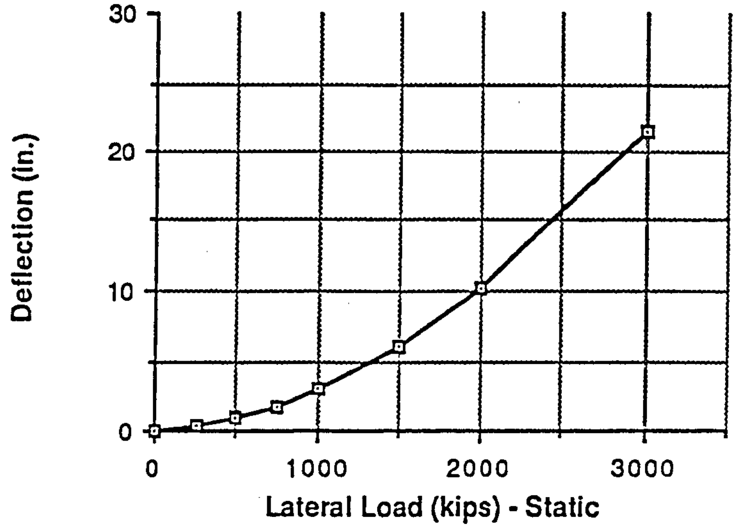


Figure 4.5 Static moment versus rotation at the pile top.

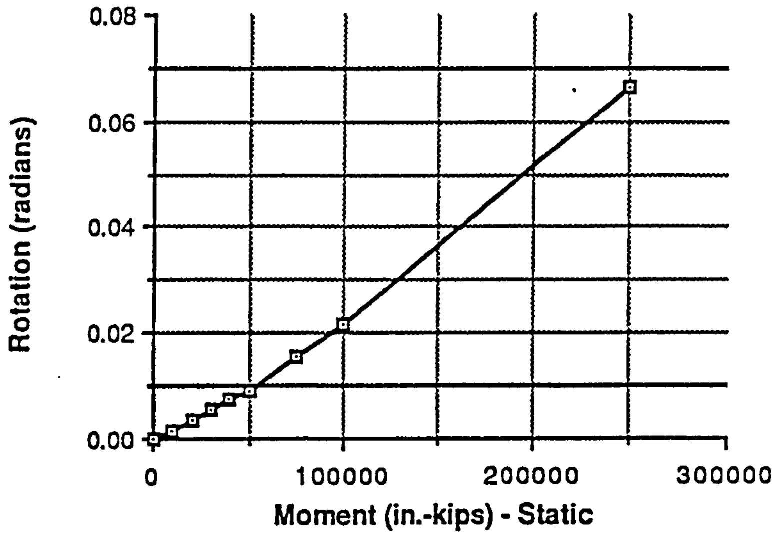


Figure 4.6 Finite element model of Platform Gina with 20 inch conductors.

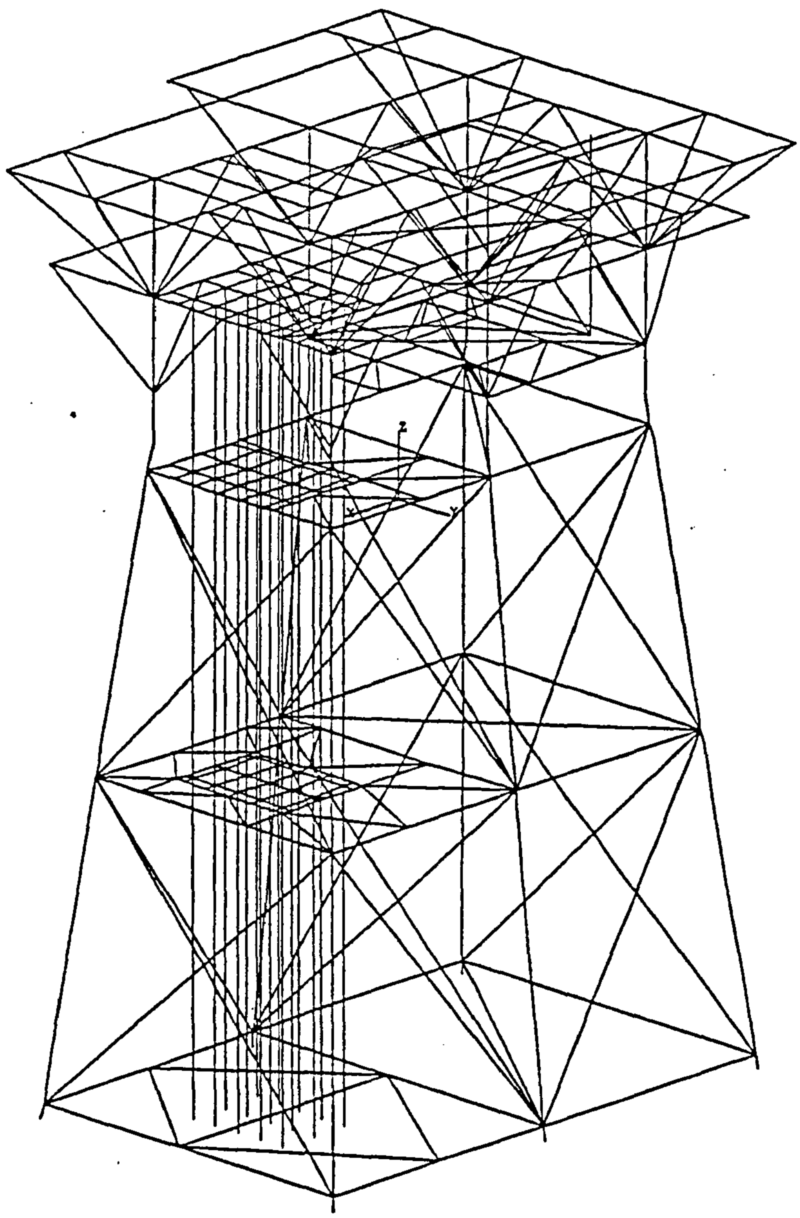


Figure 4.7 Cyclic lateral force versus deflection at the pile top.

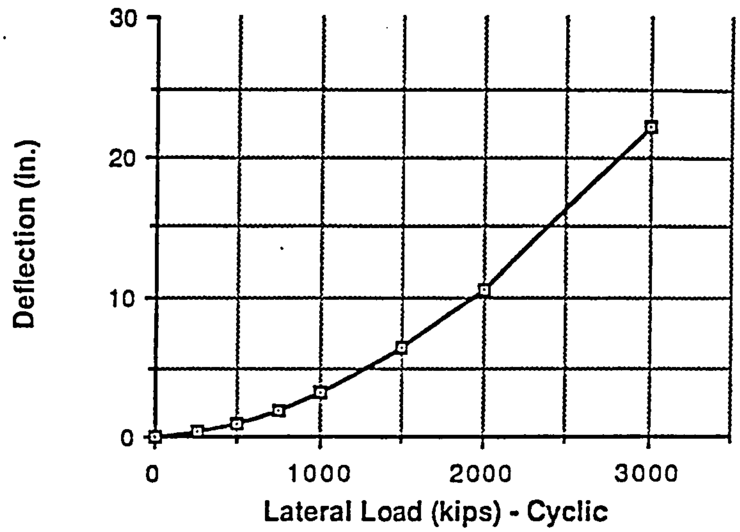
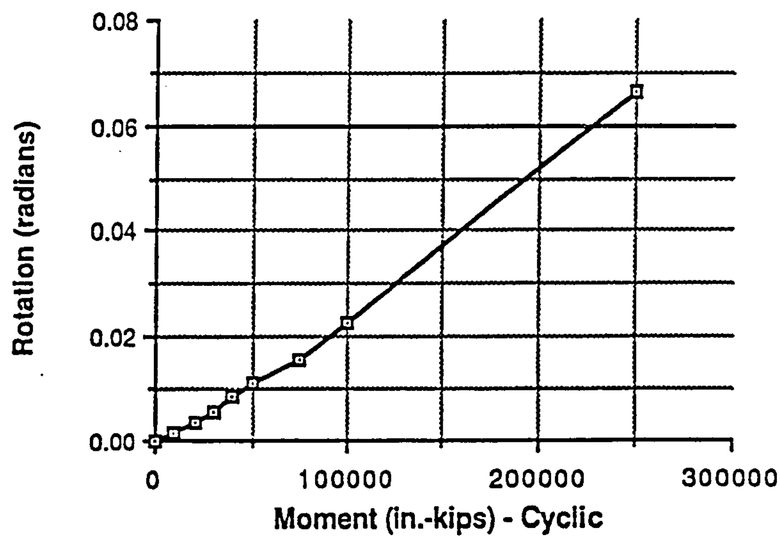


Figure 4.8 Cyclic moment versus rotation at the pile top.



5.0 ANALYTICAL RESULTS

As in the previous sections of this report, the analytical results are presented in three sections corresponding to the type of analysis that was performed—gravity, extreme storm, and seismic. The analytical results were evaluated with respect to the criteria of API RP 2A. The primary evaluation criteria is the ultimate axial pile factor of safety. This is most important because it is the one structural capacity that cannot be increased with structural modifications. The design ultimate axial pile capacities for Platform Gina are 5000 kips in compression and 2400 kips in tension (pullout).

5.1 Gravity Analysis

The basic factor of safety required in the gravity analysis is 2.0, with respect to the ultimate capacity of the pile. Table 5.1 presents the pile reactions for the maximum gravity load case. As indicated, the highest maximum compressive reaction is 1,494 kips at location A2, corresponding to an ultimate safety factor of 3.35. Since the gravity load case does not include any lateral or upward loads, the pullout safety factor is not applicable.

Table 5.1. *Pile reactions at the mudline under maximum gravity loads.*

	Pile Location					
Direction	B1	B2	B3	A1	A2	A3
1. Axial z (kips)	1040	1296	1072	989	*1494*	1361
•Ult. Safety Factor					*3.35*	
2. Lateral x (kips)	-14	-1	14	-1	15	29
3. Lateral y (kips)	-15	-2	4	6	26	30
4. Moment x (in-kips)	-113	62	-16	23	64	-183
5. Moment y (in-kips)	-134	-94	192	-281	-66	244

The displaced shape of the platform under the maximum gravity loads is presented in Figures 5.1-5.3. The maximum displacement is 1.3 inches, occurring in a beam on the drill deck. The displaced shape plots show that the finite element model is moving in the appropriate direction for this analytical load case, and they indicate the relative magnitude of motion in various parts of the platform.

A review of the stresses in the structural members indicated that all stress levels are within the basic allowable stress of 23.1 ksi (.66F_y). As in the case of displacement, the highest stresses were found to occur in the drill deck beams, and are associated with the large drilling loads. More extensive member stress checks will be performed during detailed design, with more specific drill deck load distributions, if the new reservoir development is pursued.

5.2 Storm Loading Analysis

Table 5.2 is a summary of pile reactions from the extreme storm analytical results. The required factor of safety is reduced to 1.5 for the extreme environmental load case. As shown in Table 5.2, the piles have a comfortable margin, since the minimum safety factor is 2.08 in compression, and 2.27 for pullout.

Table 5.2. *Pile reactions at the mudline under extreme storm loads.*

	Pile Location					
Direction	B1	B2	B3	A1	A2	A3
1. Axial z (kips)	-34	1565	***2400***	***-1055***	659	1961
•Ult. Safety Factor			***2.08***	***2.27***		
2. Lateral x (kips)	-349	-382	-319	-330	-374	-322
3. Lateral y (kips)	87	89	62	89	113	115
4. Moment x (in-kips)	-3000	-2748	-2971	-3011	-2694	-2696
5. Moment y (in-kips)	-7903	-9306	-8526	-8268	-9334	-8187

The magnitudes of the axial pile reactions are as expected based on simple equilibrium equations and the heading of the weather. The minimum pile reaction (maximum pullout) occurs at location A1, on the north-west corner of the platform, and the maximum (compression) is on the opposite, south-east corner.

The displacement of the platform under the extreme storm loads is depicted in Figures 5.4 and 5.5, where the maximum displacement is 4.10 inches. As in the previous displaced shape plots, the general trend and relative magnitudes of displacement can be readily observed.

The allowable stress level is increased by 1/3 for the extreme storm load condition, leading to a basic allowable stress of 30.8 ksi if yield is 35 ksi ($4/3 \times .66F_y$). A review of stress levels in the finite element results for the extreme storm load case indicated no stresses above the basic allowable for the primary structural members in Platform Gina.

5.3 Seismic Analysis

Seismic analysis of Platform Gina actually involved several separate analyses. Pseudo-dynamic response spectrum analyses were performed as described in Section 3, with two levels of earthquake loading—a strength and a ductility level. The results of these response spectrum analyses were then combined with operating gravity loads to determine the analytical seismic results.

As noted in Section 3, response spectrum analysis is a three step process. First, a modal analysis is performed; second, the modal responses are combined for each of the three orthogonal directions; and third, the directional responses are combined into an overall response. Appendix B contains the significant results from each step in the seismic response spectrum analyses of Platform Gina. Included are natural frequencies, mode shapes, and summaries of the seismic responses in each direction. The results discussed in the following sections are limited to the total seismic response as determined by combining the directional responses with the SRSS method and adding them to the operating gravity loads.

5.3.1 Strength Level Analysis

Table 5.3 is a summary of the pile reaction forces that were calculated from the response spectrum analysis of the strength level earthquake. Since the response spectrum method combines modal responses, the response values are magnitudes only, and can act in opposite directions (±). The reactions in Table 5.3 must be added to the gravity reactions to obtain the expected maximum strength level earthquake responses. Table 5.4 are the pile reaction forces for the gravity load case. Note that these reactions are not the same as the maximum gravity reactions that were presented in Section 5.1. Rather, they represent the nominal reactions of the platform, with the same gravity loads used in the seismic analysis.

Table 5.3. *Pile reactions at the mudline under strength level seismic loads.*

	Pile Location					
Direction	B1	B2	B3	A1	A2	A3
1. Axial z (kips)	±1727	±1143	±1736	±1696	±1155	±1719
2. Lateral x (kips)	±239	±275	±237	±245	±285	±246
3. Lateral y (kips)	±162	±199	±215	±159	±198	±223
4. Moment x (in-kips)	±5995	±5409	±6860	±6149	±7067	±7421
5. Moment y (in-kips)	±6554	±7847	±7015	±7026	±8135	±7125

Table 5.4. *Pile reactions at the mudline under nominal gravity loads.*

	Pile Location					
Direction	B1	B2	B3	A1	A2	A3
1. Axial z (kips)	917	1059	812	812	1120	936
2. Lateral x (kips)	86	-3	-82	82	4	
3. Lateral y (kips)	87	89	62	89	113	115
4. Moment x (in-kips)	-201	-2	-49	12	118	-73
5. Moment y (in-kips)	7	1	183	-160	-34	183

Adding the results of the strength level earthquake and the nominal gravity loads together gives a maximum compressive pile reaction of 2,663 kips at pile location A3. This leads to an ultimate axial safety factor of 1.88 with respect to the recommended allowable of 5,000 kips—well above the recommended minimum of 1.5. The maximum tensile pile reaction is 915 kips uplift at pile location B3, giving a factor of safety of 2.62 to the pullout capacity of 2,400 kips. Again, this factor of safety is well above the minimum value of 1.5 recommended in API RP 2A.

The displaced shape of the platform under the strength level earthquake loading is presented in Figures 5.6 and 5.7. As with the pile reactions, these displacements represent only absolute values and should not be interpreted as actual displaced positions. All of the displacements in the figures are shown in a positive direction, and would not occur at the same instant in time. However, the plots do provide a useful means of comparing relative maximum displacements at various locations throughout the structure.

As in the gravity and storm analyses, the stress levels in the structural components were reviewed and found to be acceptable, based on a simple comparison to basic allowable stresses.

5.3.2 Ductility Level Analysis

The ductility seismic analysis of Platform Gina was identical to the strength level analysis except that larger seismic loads were applied to the structure. Although the magnitude of the seismic ductility loads are two times the strength level loads, the reaction forces did not double. This is because a higher damping coefficient (8%) was used in the ductility level analysis.

Table 5.5 is a summary of the analytical pile reactions for the ductility level analysis. When the axial reactions are added to the nominal gravity reactions (Table 5.4), a maximum compressive pile reaction of 3,675 kips is calculated for the ductility level earthquake, corresponding to an ultimate safety factor of 1.36. The maximum uplift force is 1,932 kips—a safety factor of 1.24. Since the purpose of the ductility analysis is to ensure that collapse of the structure is prevented, a minimum safety factor of 1.0 is allowable. As was the case in the strength level analysis, the factors of safety are therefore acceptable, based on the guidelines in API RP 2A.

Several areas in the platform were found to have stress levels above yield for the ductility level seismic analysis. This stress level is not necessarily unacceptable, since the evaluation criteria for the ductility analysis is collapse. Yielding in parts of the structure can be tolerated in an intense seismic event if the platform has adequate structural redundancy. If it is decided to pursue the new field development, these issues will be addressed during the design phase of the project.

Table 5.5. *Pile reactions at the mudline under ductility level seismic loads.*

	Pile Location					
Direction	B1	B2	B3	A1	A2	A3
1. Axial z (kips)	±2732	±1782	±2753	±2667	±1802	±2731
2. Lateral x (kips)	±373	±440	±370	±389	±462	±391
3. Lateral y (kips)	±260	±324	±349	±258	±323	±363
4. Moment x (in-kips)	±10,755	±9738	±12,038	±11,089	±12,478	±12,746
5. Moment y (in-kips)	±11,395	±13,549	±12,198	±12,205	±14,053	±12,508

Figure 5.1 Displaced shape plot under maximum gravity loads—iso view.

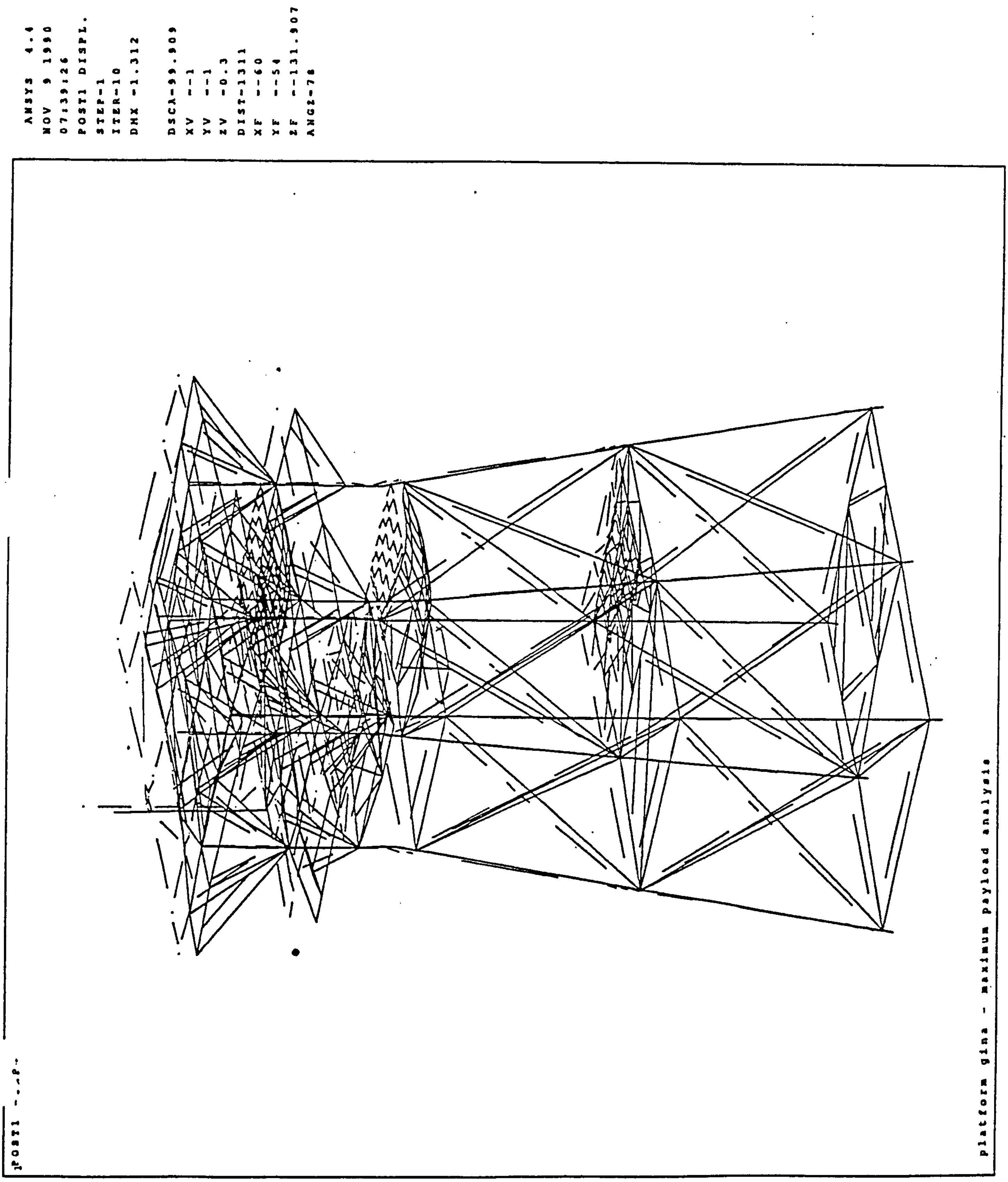


Figure 5.2 Displaced shape plot under maximum gravity loads—east view.

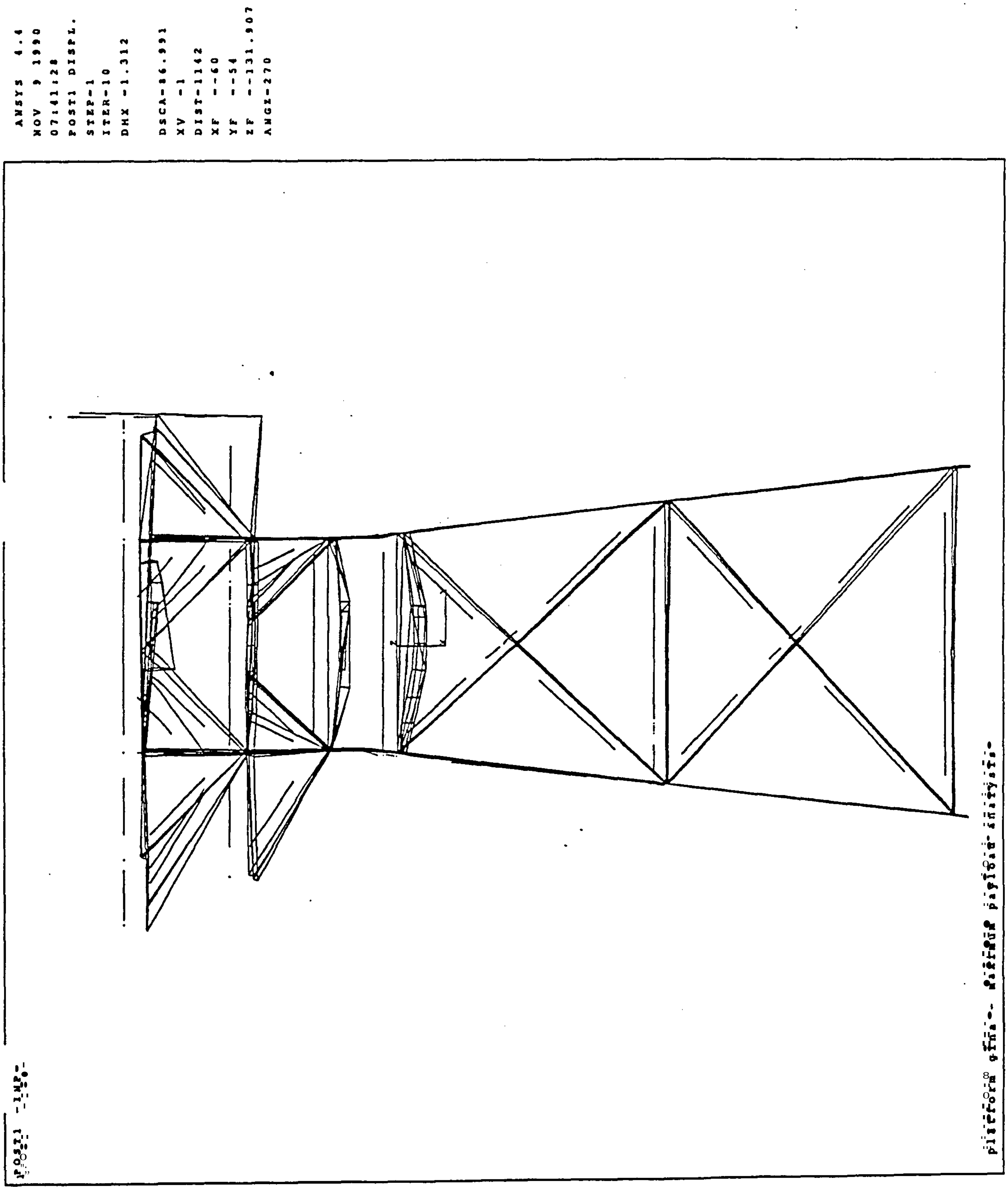


Figure 5.3 Displaced shape plot under maximum gravity loads—north view.

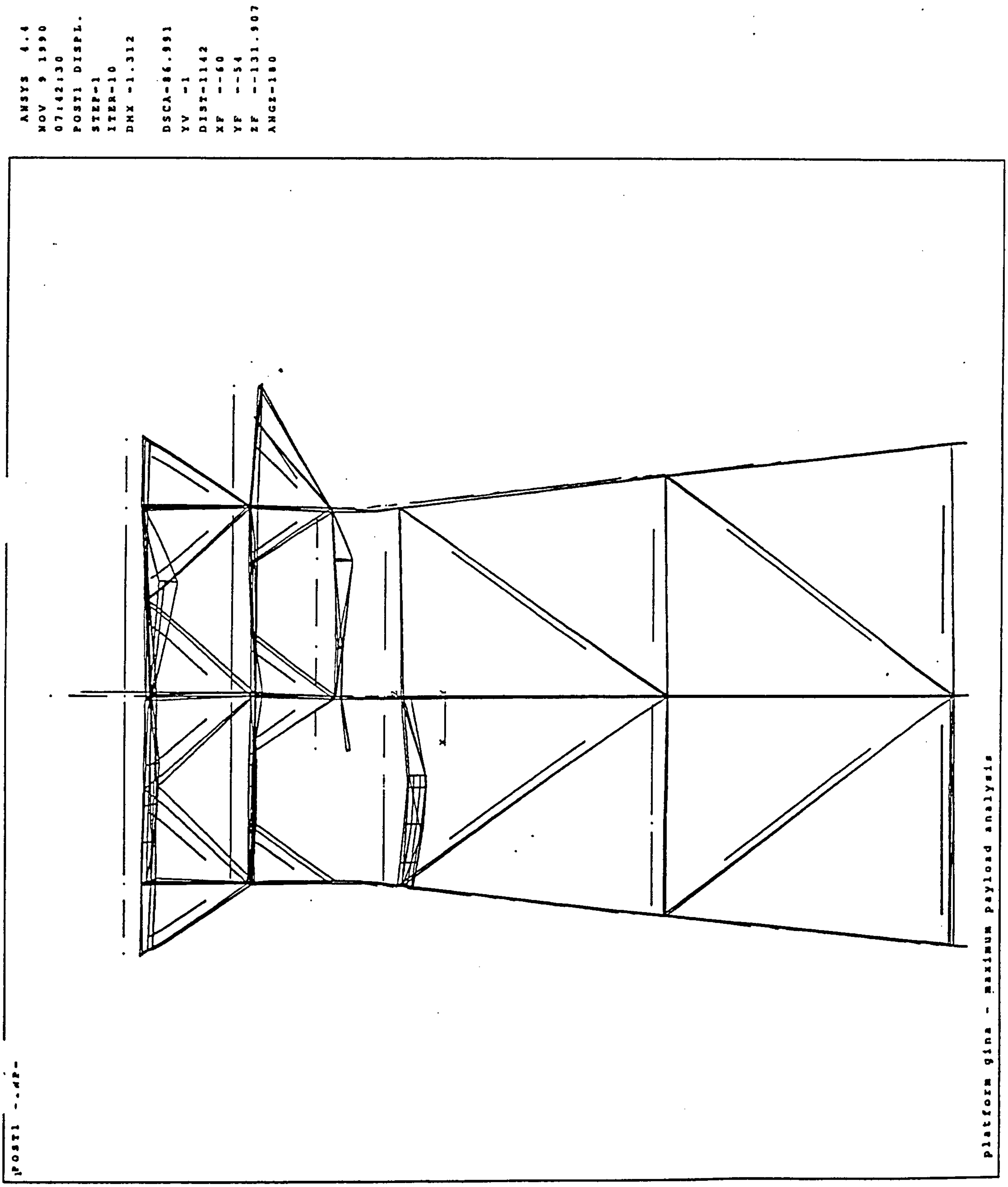


Figure 5.4 Displaced shape plot under extreme storm loads—east view.

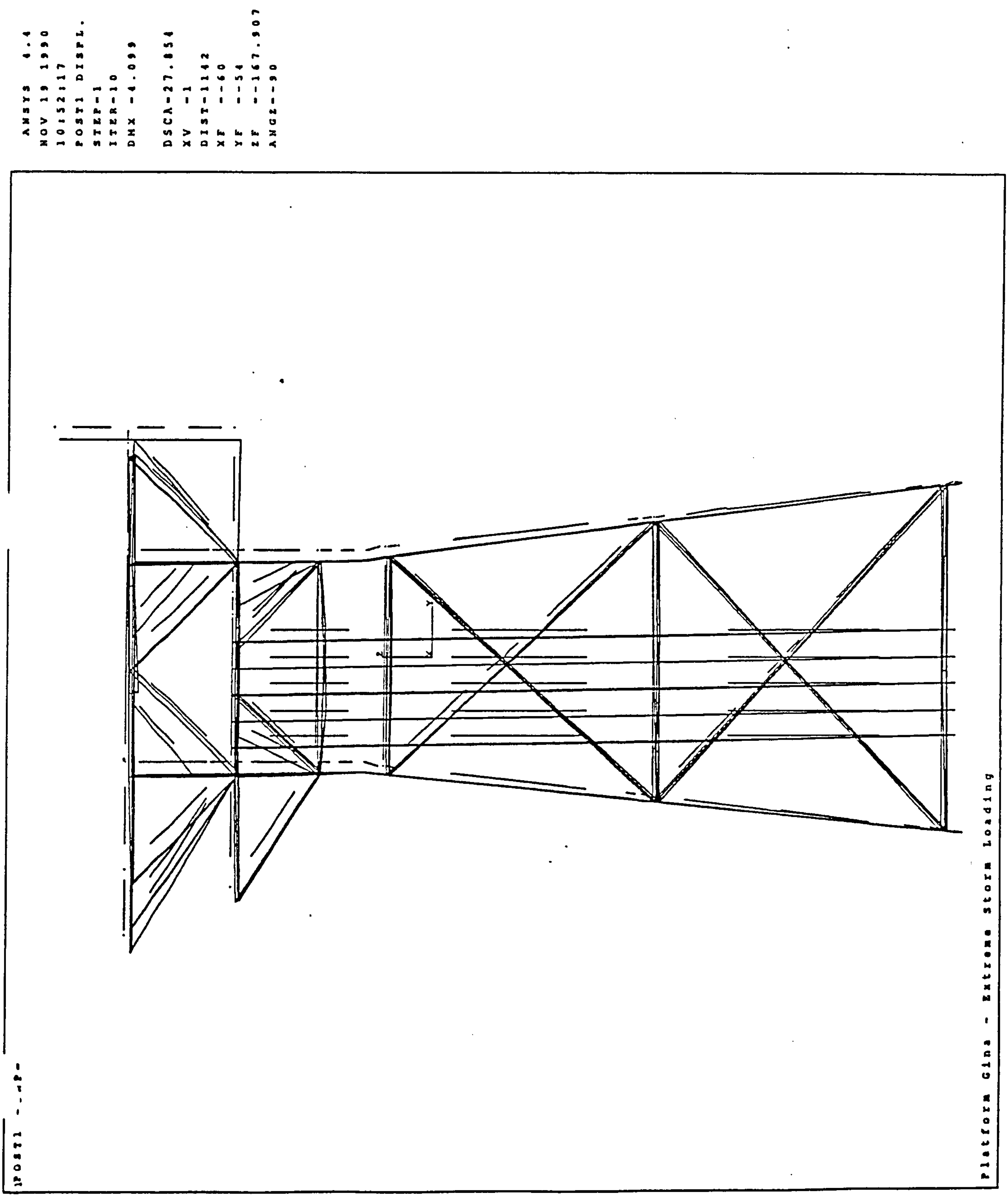


Figure 5.5 Displaced shape plot under extreme storm loads—north view.

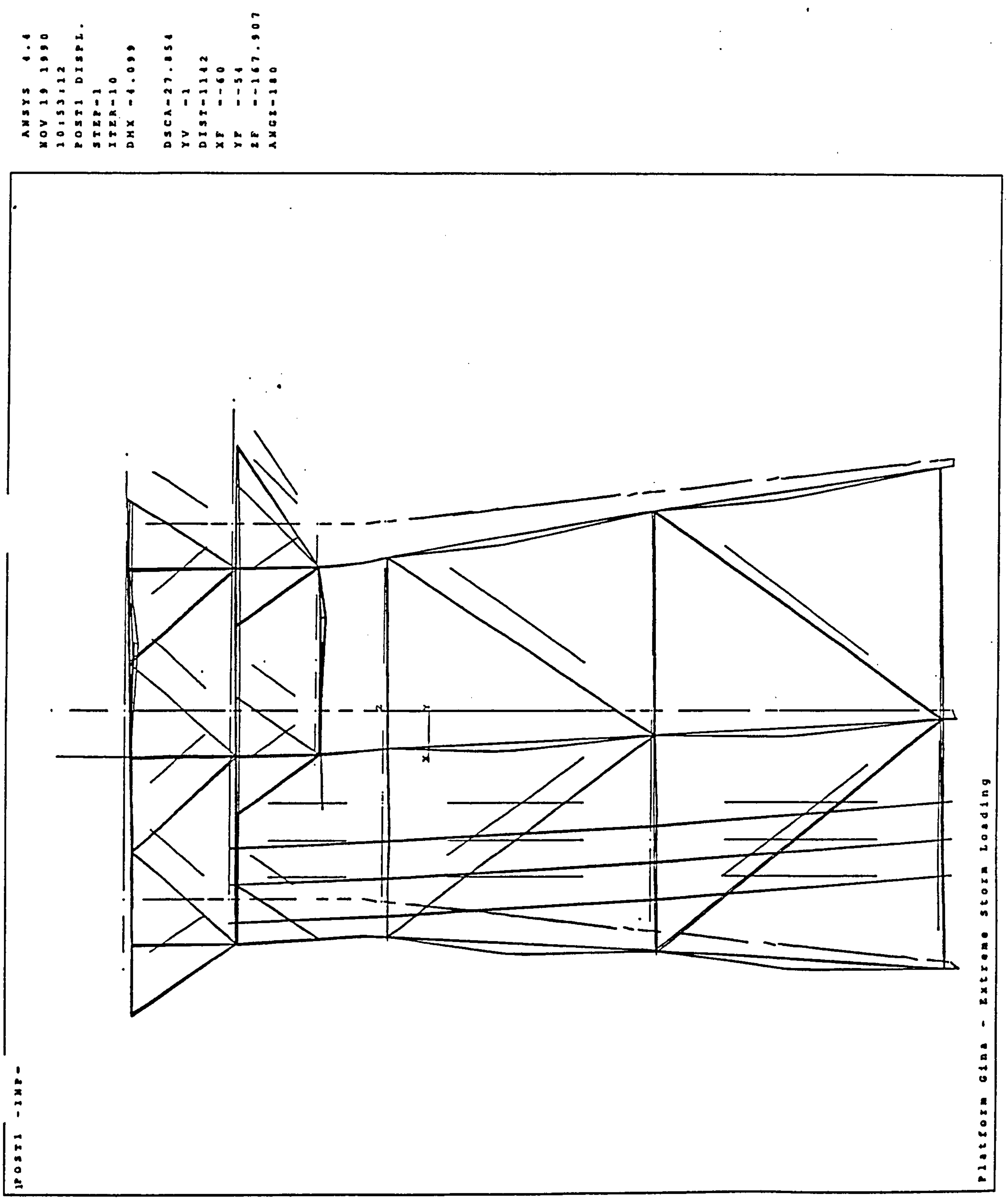


Figure 5.6 Displaced shape plot under strength seismic loads—east view.

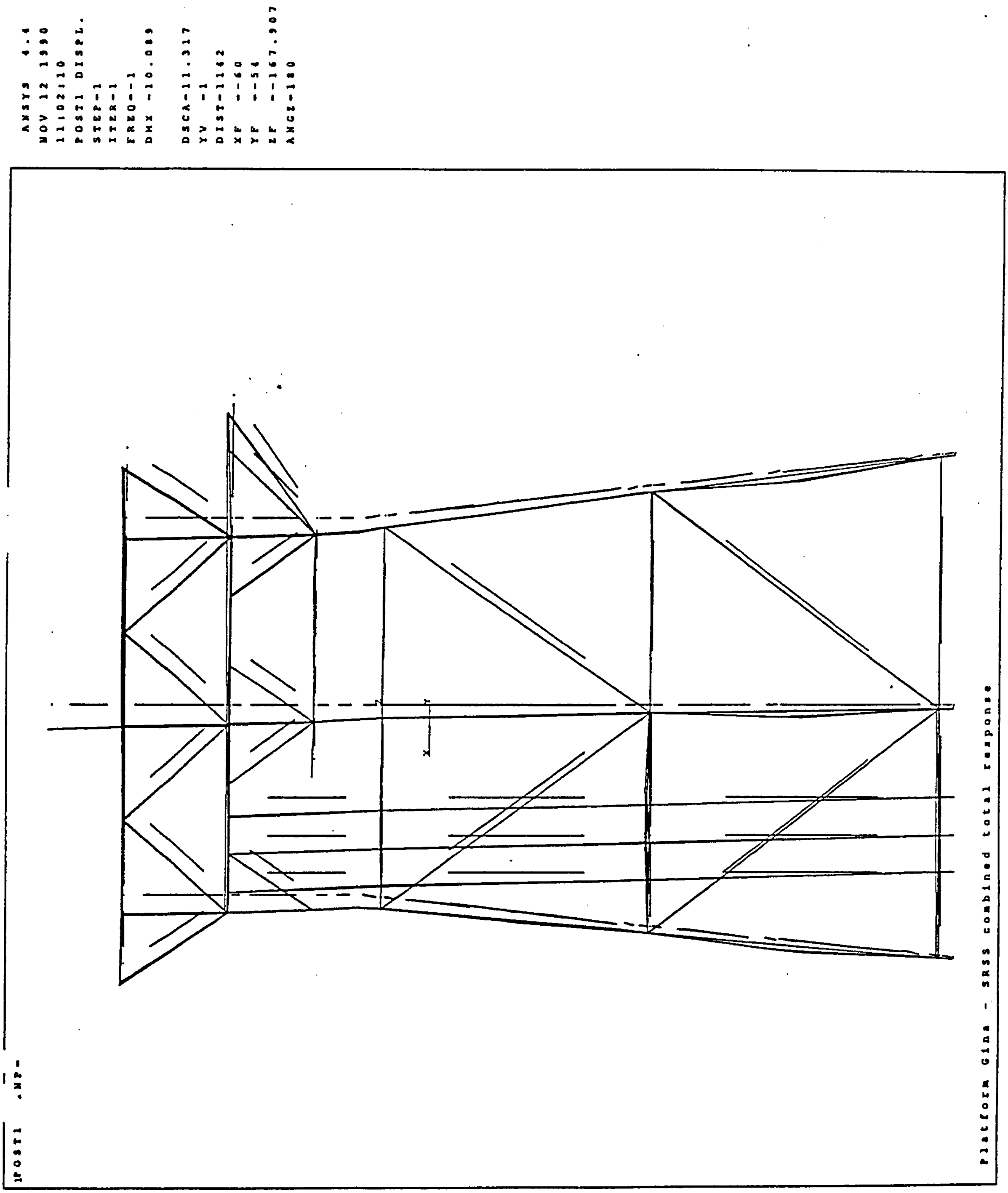
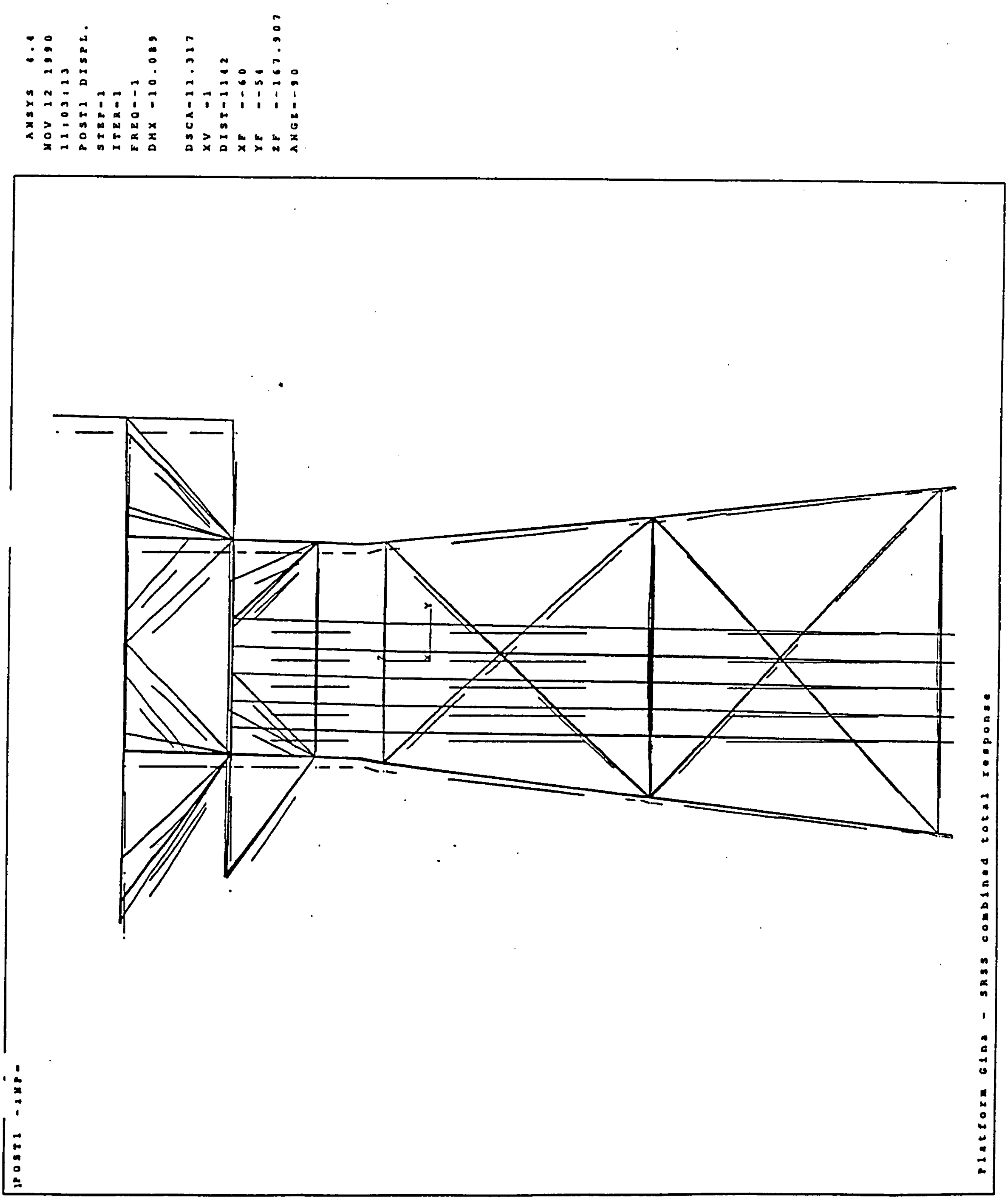


Figure 5.7 Displaced shape plot under strength seismic loads—north view.



6.0 REFERENCES

1. *RP 2A, Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms*, 18th Edition, American Petroleum Institute, September 1, 1989.

2. *Spec 6A, Specification for Valves and Wellhead Equipment*, 16th Edition, American Petroleum Institute, October 1, 1989.

3. *Platform Gina - Extreme Storm Criteria*, Pacific Weather Analysis, October 17, 1990.

4. *Seismic Hazard Analysis - Platform Gina*, Staal, Gardner & Dunne, Inc., October, 1990.

5. *Pile Capacity Analysis - Platform Gina*, Staal, Gardner & Dunne, Inc., October, 1990.

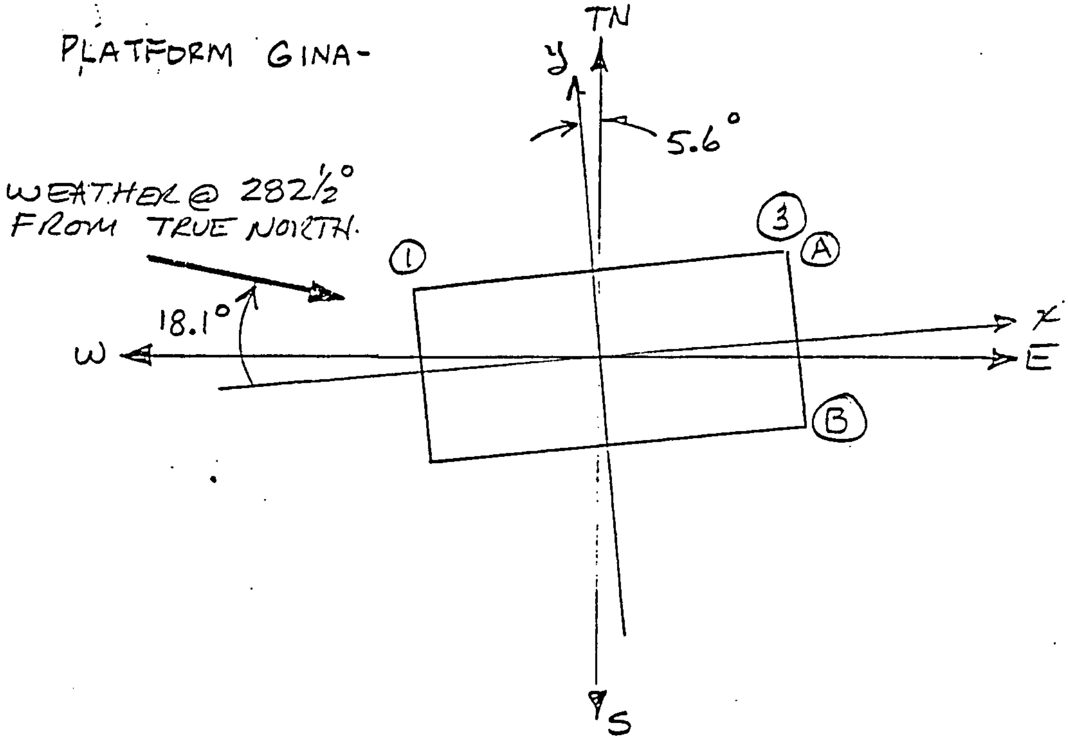
Appendix A: Hand Calculations

PROJECT PLATFORM GINA ENGINEER THOMAS DATE 11/6/90

SUBJECT FILE NO. SHT. 1 OF

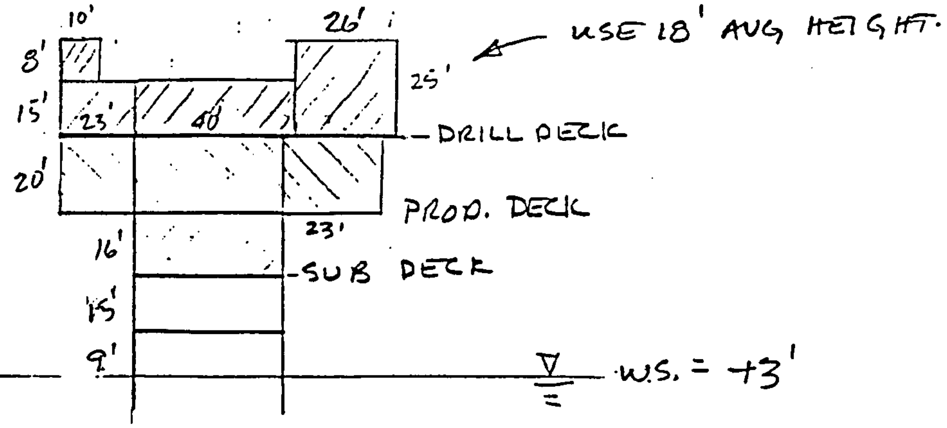
ENVIRONMENTAL ORIENTATION

PLATFORM GINA-



PROJECTED AREAS

WEST. ELEVATION



PROJECT ______ ENGINEER Thomas DATE 11/6/90
SUBJECT ______ FILE NO. ______ SHT. 3 OF ______

WIND LOADS (Ref. API RP-2A)

V_H = 60 KNOTS @ 33 ft.

$$\frac{V_y}{V_H} = \left(\frac{y}{H}\right)^{1/n} \qquad 1/n = 1/8$$

(1 KT = 1.151 MPH)

$$V_{DD} = 60\left(\frac{69}{33}\right)^{1/8} = 65.8\ \text{KTS} = 75.7\ \text{mph}$$

$$V_{PD} = 60\left(\frac{50}{33}\right)^{1/8} = 63.2\ \text{KTS} = 72.7\ \text{mph}$$

V_{SD} = N/A BECAUSE SUBMERGED

$$F = .00256\,(V)^2 C_s A$$

$$F_{DD} = .00256(75.7)^2(1.0)(2060) = 30.2^K$$ Drill Deck

$$F_{PD} = .00256(72.7)^2(1.0)(2182) = 29.5^K$$ Prod. Deck

PROPORTION TO EACH FACE:

WEST FACE – $F_{DD} = 30.2(.74) = 22.3^K$
– $F_{PD} = 29.5(.75) = 22.1$

NORTH FACE – $F_{DD} = 30.2(.26) = 7.9^K$
$F_{PD} = 29.5(.25) = 7.4^K$

ALL FORCES ACTING @ 282½° HEADING FROM TRUE NORTH.

PROJECT PLATFORM GINA ENGINEER THOMAS DATE 11/7/90

SUBJECT FILE NO. SHT. 4 OF

HORIZONTAL
WAVE LOADS ON SUB DECK (Ref. API RP-2A)

FLUID PARTICLE VELOCITIES:

Horizontal V = 272 ips = 22.7 fps
Vertical V = ϕ
Horizontal a = ϕ
Vertical a = -126 i/s² = 10.5 ft/s²

PROJECTED AREAS W/ RESPECT TO 282½° HEADING

WEST FACE = 611 ft²
NORTH FACE = 266 ft²
TOTAL = 837 ft²

$F = F_D + F_I \longrightarrow F_I = \phi$ for max velocity

$$F = C_D \frac{w}{2g} A v^2$$

C_D = 1.0 (PER M. CRAIG 11/7/90)
w = 64 pcf.
g = 32.2 ft/s²
A = PROJECTED AREA.
v = 22.7

WEST FACE $F = 1.0\left(\frac{64}{64.4}\right)(611)(22.7)^2 = \underline{\underline{313^k}}$

NORTH FACE $F = 1.0\left(\frac{64}{64.4}\right)(266)(22.7)^2 = \underline{\underline{136^k}}$

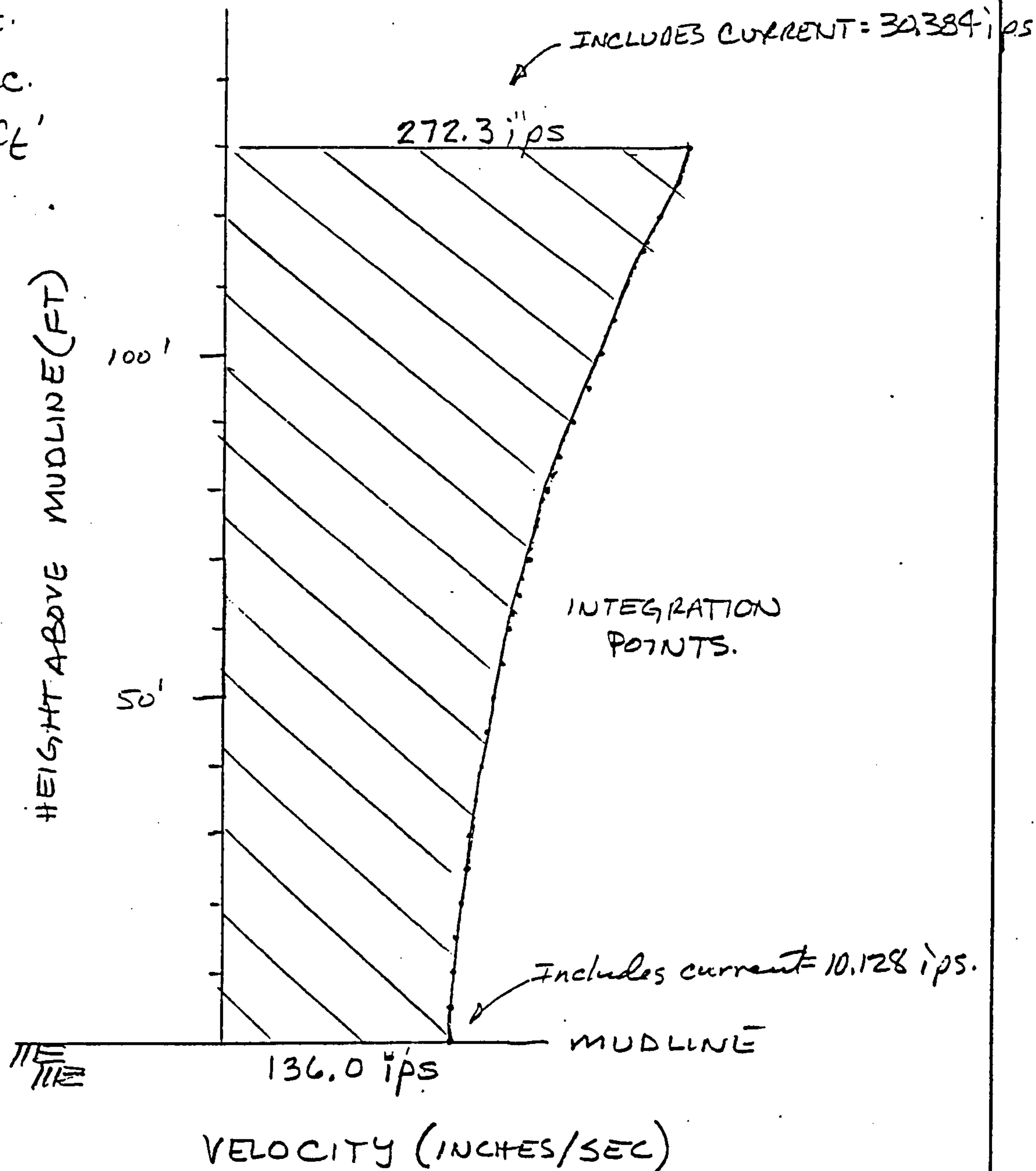
@ 282½° HEADING.

PROJECT Platform GINA ENGINEER Thomas DATE 11/7/90

SUBJECT FILE NO. SHT. 5 OF

Horizontal Water Particle
Velocity Profile - Stokes Fifth

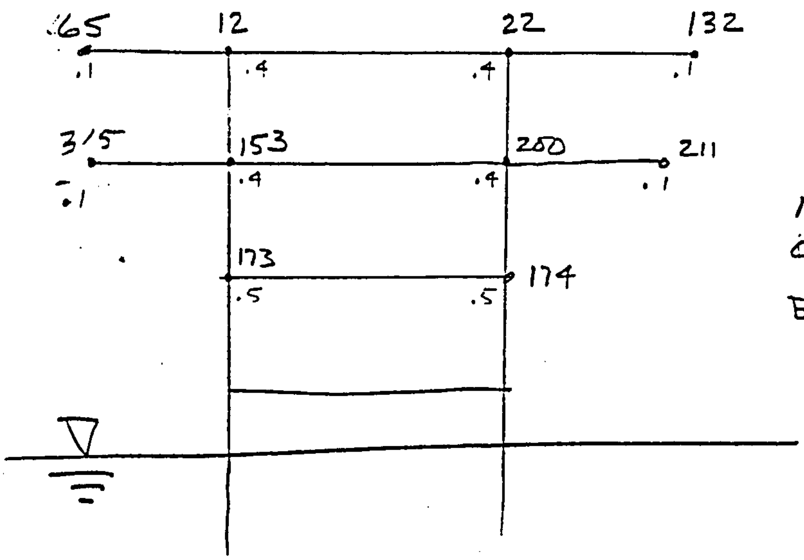
H = 42 ft.
T = 15 sec.
W.D = 98 ft'



PROJECT Platform GINA ENGINEER Thomas DATE 11/7/90

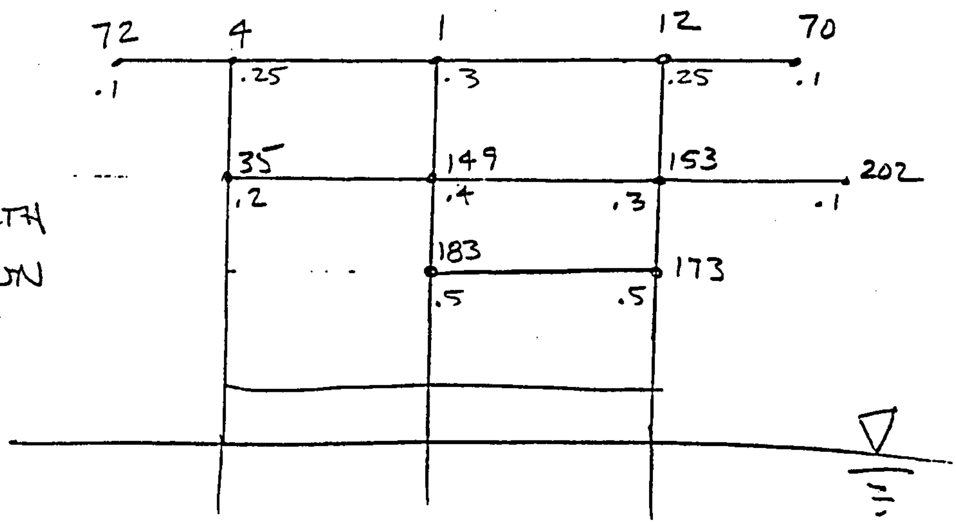
SUBJECT FILE NO. SHT. 1 OF 3

CALCULATE NODAL FORCES
FOR WIND & WAVE

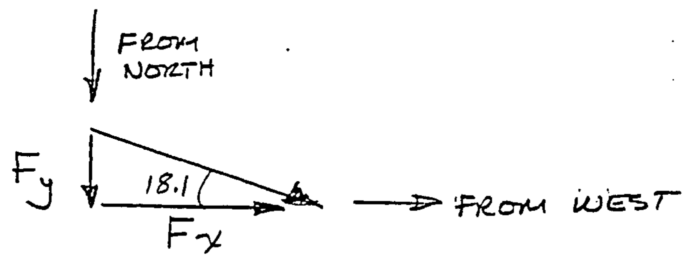


NODES
ON WEST
ELEVATION

NODES
ON NORTH
ELEVATION



PROJECT ______ ENGINEER Thomas DATE 11/7/90
SUBJECT ______ FILE NO. ______ SHT. 2 OF 3



NODE	WEST FACE	NORTH FACE	NODAL FORCE FX	NODAL FORCE FY
DRILL DECK				
1		2.37	2.25	-.74
4		1.98	1.88	-.62
12	8.92	1.98	10.36	-3.39
22	8.92		8.48	-2.77
65	2.23		2.12	-.69
70		.79	.75	-.25
72		.79	.75	-.25
132	2.23		2.12	-.69
PROD. DECK				
135		1.48	1.41	-.46
149		2.96	2.81	-.92
153	8.84	2.22	10.51	-3.49
200	8.84		8.40	-2.75
202		.74	.70	-.23
211	2.21		2.1	-.69
315	2.21		2.1	-.69

PROJECT ______ ENGINEER Thomas DATE 11/7/90

SUBJECT ______ FILE NO. ______ SHT. 3 OF 3

NODE	WEST FACE	NORTH FACE	FX	FY
SUB-DECK				
173	156.5	68.0	213.39	-69.75
174	156.5		148.76	-48.62
183		68.0	64.64	-21.13

LIST FORCES FOR ALL SELECTED NODES

NODE	LABEL	FORCE	CFORCE
1	FX	2.25000000	0.000000000E+00
1	FY	-0.740000000	0.000000000E+00
4	FX	1.88000000	0.000000000E+00
4	FY	-0.620000000	0.000000000E+00
12	FX	10.3600000	0.000000000E+00
12	FY	-3.39000000	0.000000000E+00
22	FX	8.48000000	0.000000000E+00
22	FY	-2.77000000	0.000000000E+00
65	FX	2.12000000	0.000000000E+00
65	FY	-0.690000000	0.000000000E+00
70	FX	0.750000000	0.000000000E+00
70	FY	-0.250000000	0.000000000E+00
72	FX	0.750000000	0.000000000E+00
72	FY	-0.250000000	0.000000000E+00
132	FX	2.12000000	0.000000000E+00
132	FY	-0.690000000	0.000000000E+00
35	FX	1.41000000	0.000000000E+00
35	FY	-0.460000000	0.000000000E+00
149	FX	2.81000000	0.000000000E+00
149	FY	-0.920000000	0.000000000E+00

MORE (YES,NO OR CONTINUOUS)=
cont

NODE	LABEL	FORCE	CFORCE
153	FX	10.5100000	0.000000000E+00
153	FY	-3.44000000	0.000000000E+00
200	FX	8.40000000	0.000000000E+00
200	FY	-2.75000000	0.000000000E+00
202	FX	0.700000000	0.000000000E+00
202	FY	-0.230000000	0.000000000E+00
211	FX	2.10000000	0.000000000E+00
211	FY	-0.690000000	0.000000000E+00
315	FX	2.10000000	0.000000000E+00
315	FY	-0.690000000	0.000000000E+00
173	FX	213.390000	0.000000000E+00
173	FY	-69.7500000	0.000000000E+00
174	FX	148.760000	0.000000000E+00
174	FY	-48.6200000	0.000000000E+00
183	FX	64.6400000	0.000000000E+00
183	FY	-21.1300000	0.000000000E+00

PROJECT	ENGINEER	DATE
SUBJECT	FILE NO.	SHT. OF

Calculate spectral values for ductility level analyses:

Use damping = 8% w/ G = .50

Per API RP-2A 18th Ed. p. 99

$$D = \frac{-\ln(n/100)}{\ln 20} = .84$$

Calculate Spectral Values:

Period	Freq.	Accel (g's)	Accel (IN/s²) (x & y)	(Z)
.04	25	.50	193.2	96.6
.050	20	.50	193.2	96.6
.125	8	1.054	407.2	203.6
.480	2.08$\overline{33}$	1.054	407.2	203.6
100	.01	.005	1.955	.977

PROJECT Platform Gina ENGINEER Thomas DATE 11/13/90
SUBJECT Ductility Analysis FILE NO. 102 SHT. 1 OF 2

Review Soil Spring Stiffnesses (Axial)

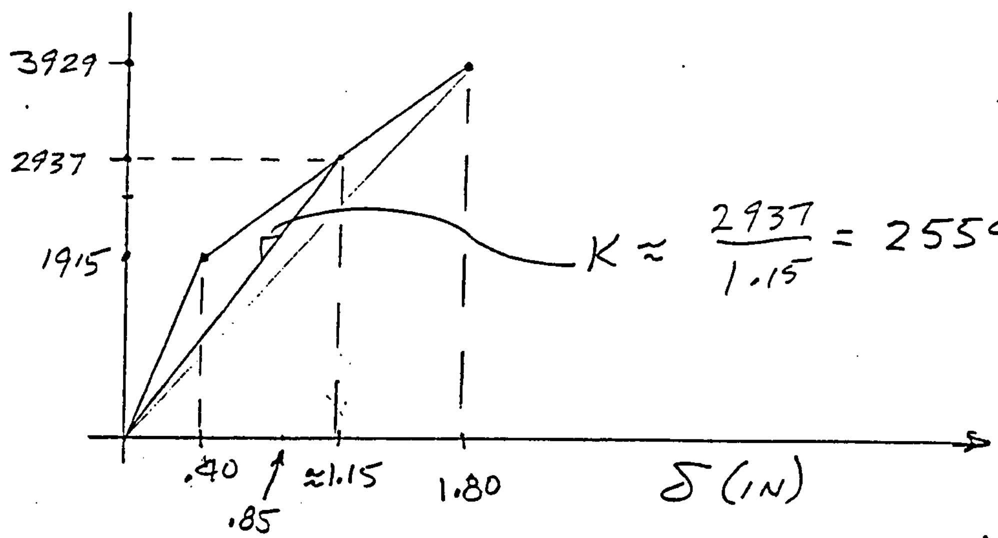
			TOTAL
CQC "X" STRENGTH	Q max = 1374 →		1736. ACTUAL
CQC 'X" DUCTILITY	Q max = 2325 ≈		2937 CALC'L

STIFFNESS BASED ON. 1915 KIPS.

COMPARE. STIFFNESSES: 4700k used

@ 1915 → $K = \frac{1915}{.4012}$ → 4773 k/IN

@ 3929 → $K = \frac{3929}{1.802}$ → 2180 k/IN.



$K \approx \frac{2937}{1.15} = 2554$ k/"

- Actual K is somewhere between 2554 & 4700 k/in
- Assume Q_{max} ≈ 2500 K then δ ≈ .85"

$K = \frac{2500}{.85} = 2941$ k/in → USE 3000 k/IN

PROJECT Platform Gina ENGINEER Thomas DATE 11/13/90
SUBJECT Ductility Analysis FILE NO. 102 SHT. 2 OF 2

Lateral

TOTAL

CQC "X" Strength $F_{xy} = 282^k \rightarrow$ 347^k

CQC "X" Duct. $F_{xy} = 481^k \rightarrow \approx 592^k$

COMPARE STIFFNESSES.

@ 500^k, $k = \frac{500}{1.036} = 483\ ^k/_{in}$ · USED IN STRENGTH

OK for DUCTILITY.

ROTATIONAL

TOTAL

CQC "X" Strength; $M_{xy} = 8088^{\prime\prime-k} \rightarrow$ $10,776^{\prime\prime-k}$

CQC "X" Duct; $M_{xy} = 13,680^{\prime\prime-k} \rightarrow \approx 18,227^{\prime\prime-k}$

@ $10,000^{\prime\prime-k}$, $k = \frac{10000}{.00175} = 5.714 \times 10^6 \frac{''\text{-K}}{\text{RAD.}}$ USED IN STRENGTH

@ $20,000^{\prime\prime-k}$, $k = \frac{20000}{.00375} = 5.333 \times 10^6 \frac{''\text{-K}}{\text{RAD.}}$

$\therefore$ USE $5.4 \times 10^6 \frac{''\text{-K}}{\text{RAD}}$

Appendix B: Seismic Analysis Results

B.1 Selected Significant Natural Vibration Mode Shapes

Figure B.1 Strength level seismic modal analysis—mode 2.

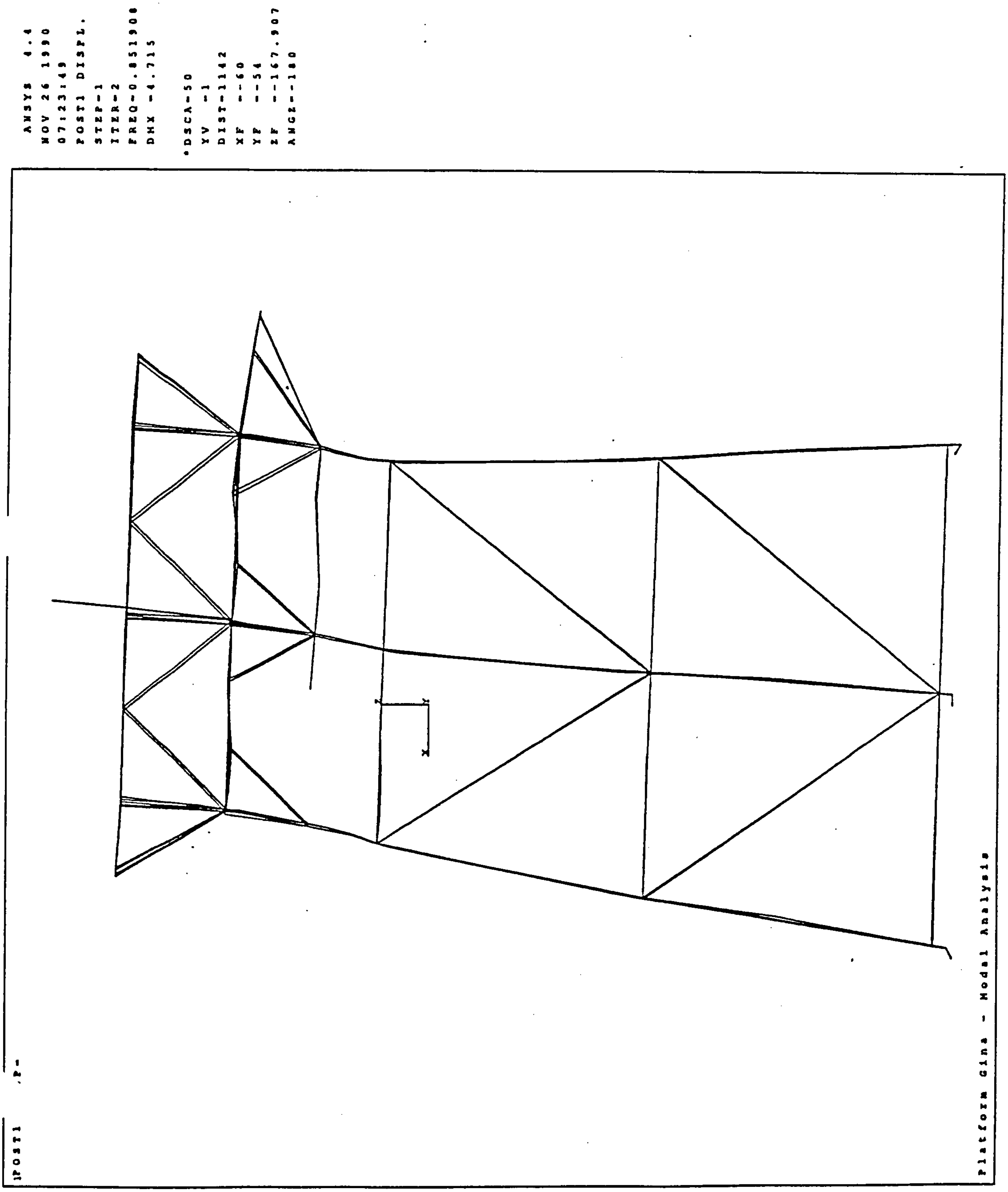


Figure B.2 Strength level seismic modal analysis—mode 3.

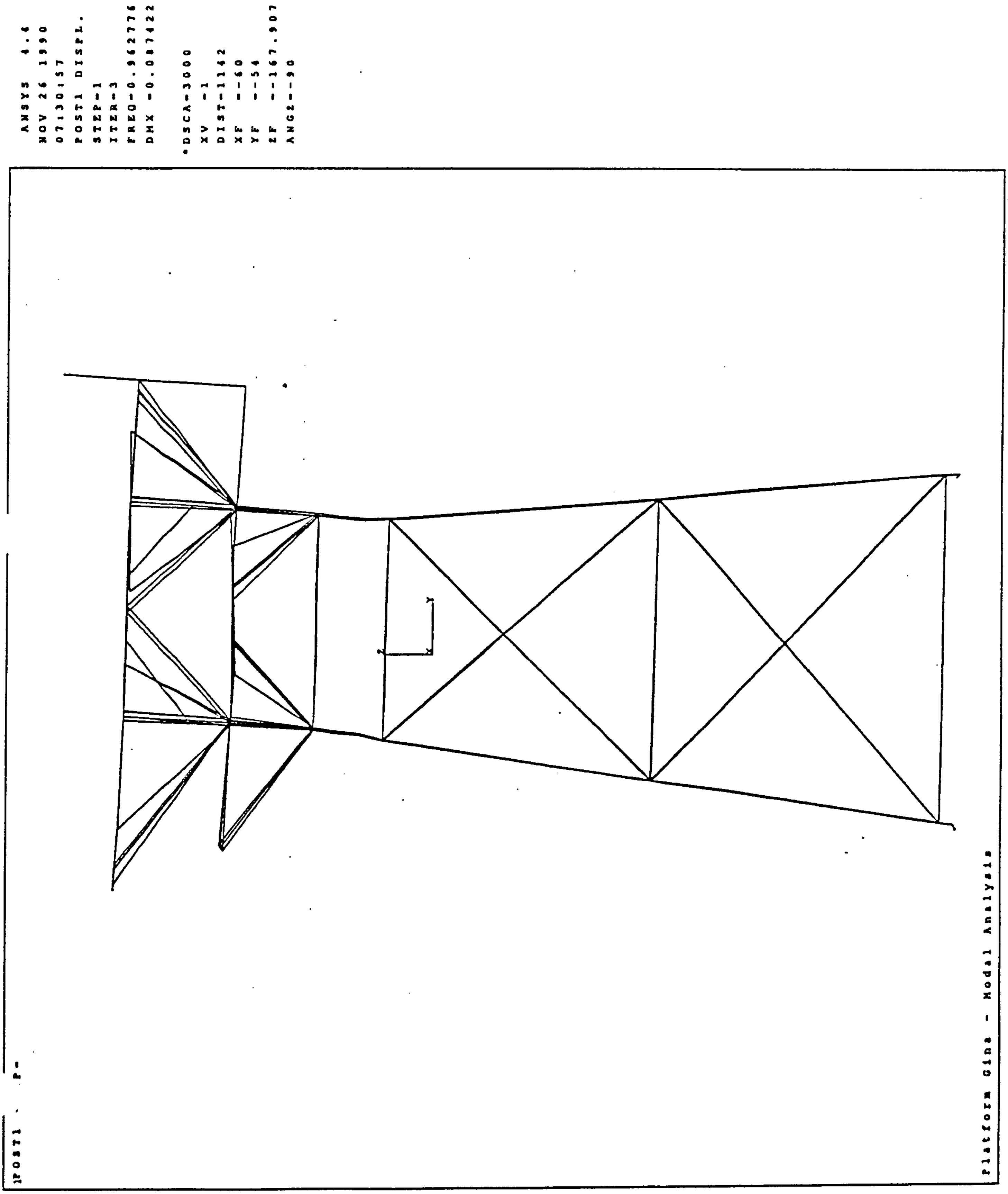


Figure B.3 Strength level seismic modal analysis—mode 4.

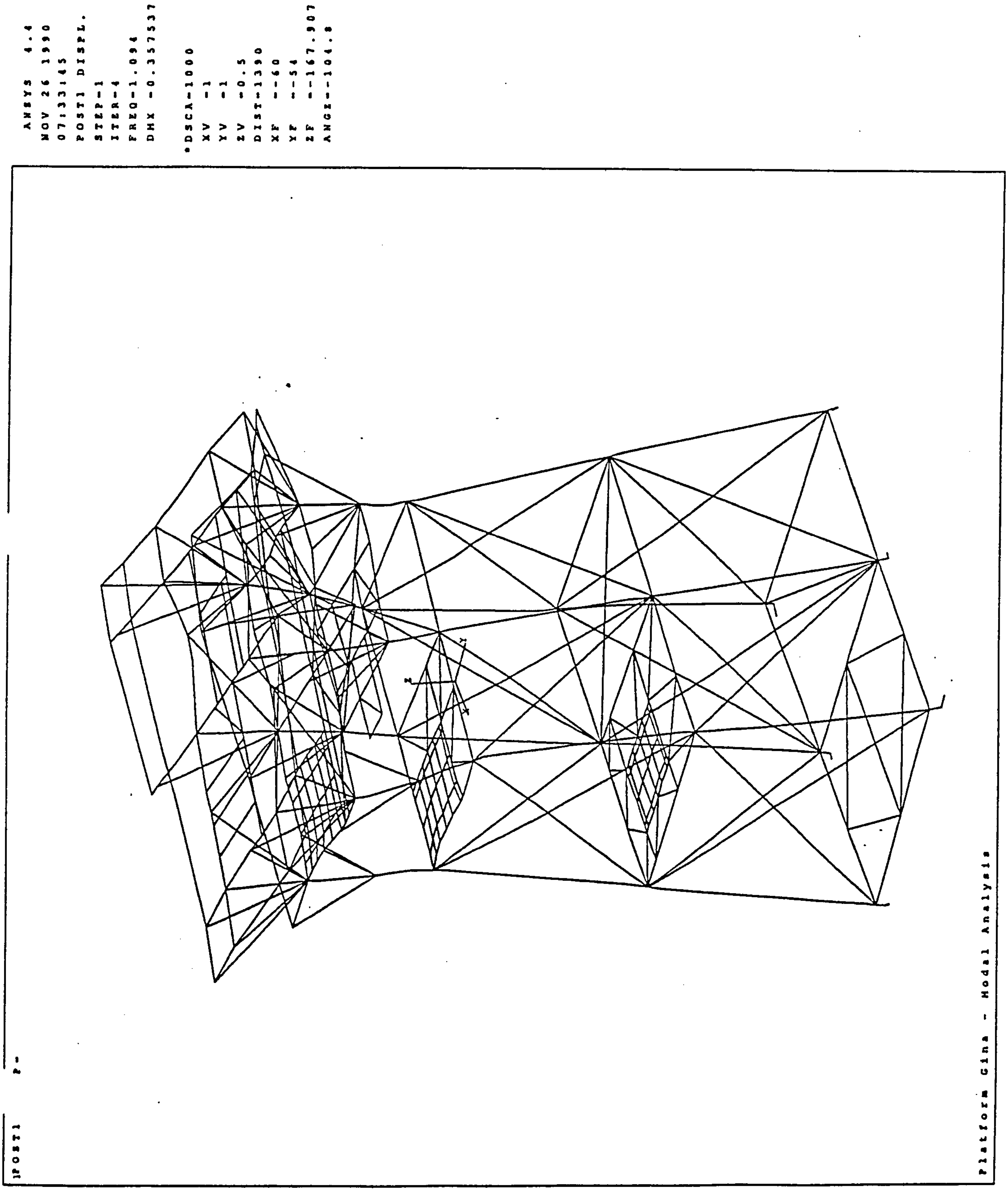


Figure B.4 Strength level seismic modal analysis—mode 7.

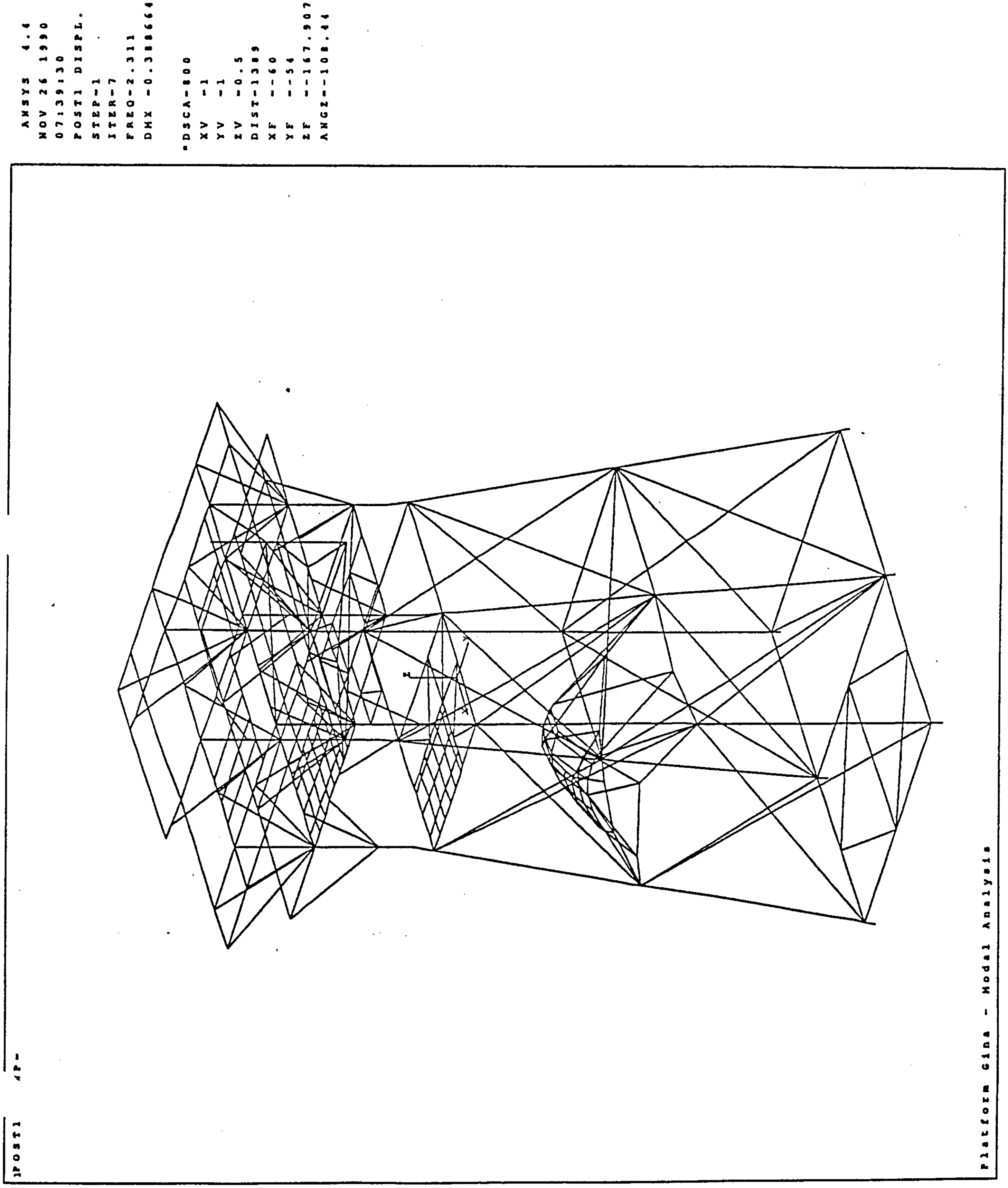


Figure B.5 Strength level seismic modal analysis—mode 8.

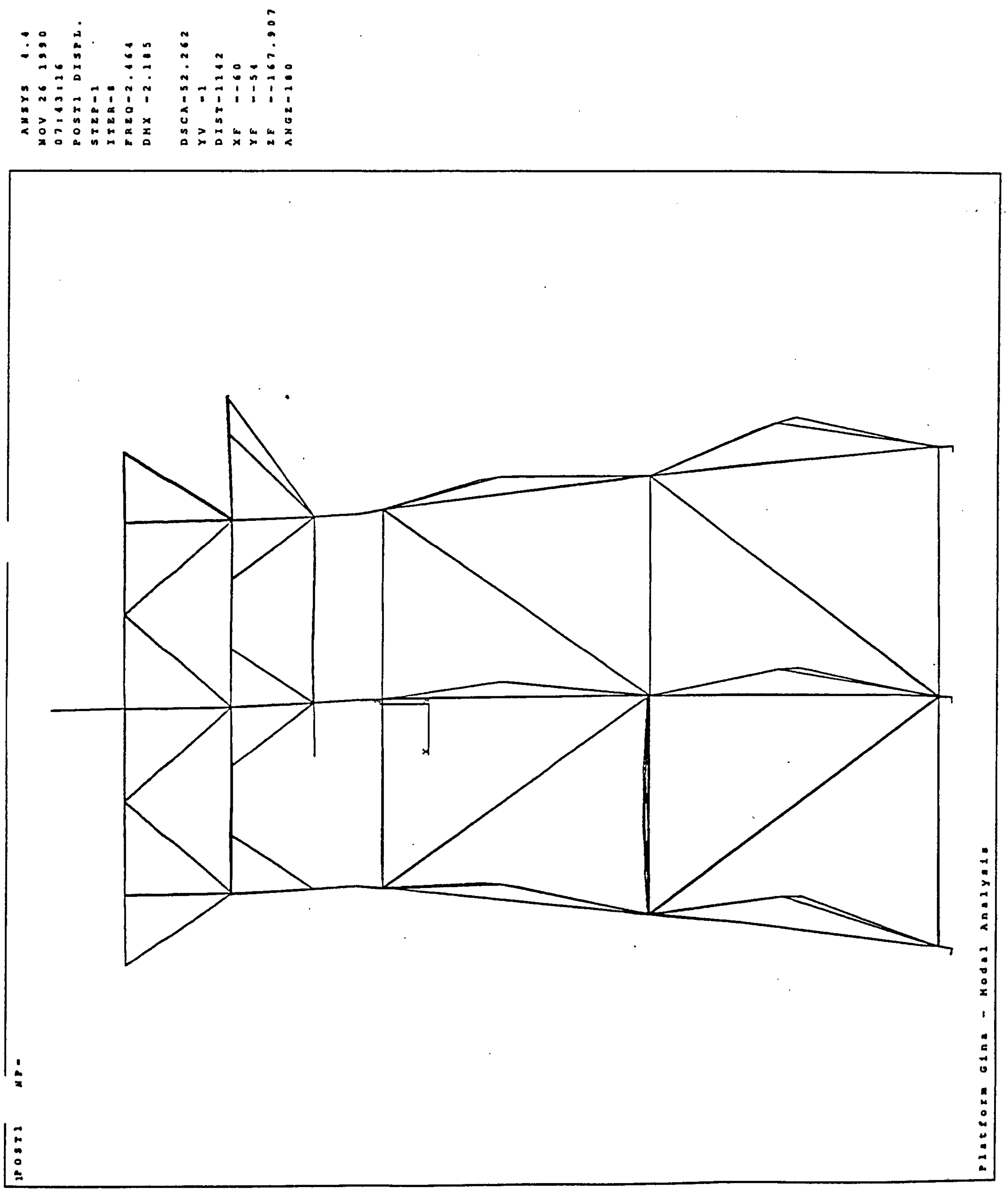


Figure B.6 Strength level seismic modal analysis—mode 9.

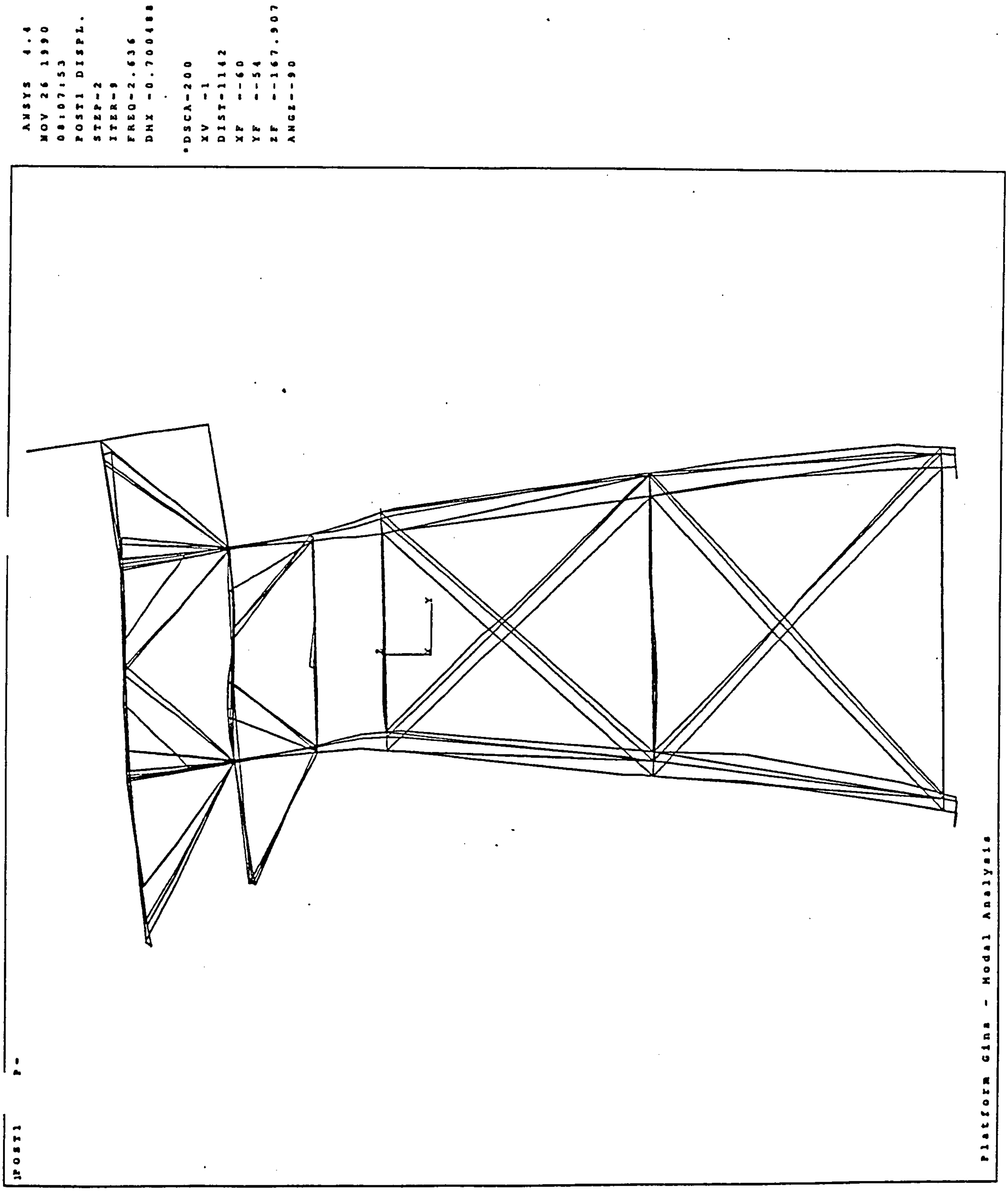


Figure B.7 Strength level seismic modal analysis—mode 10.

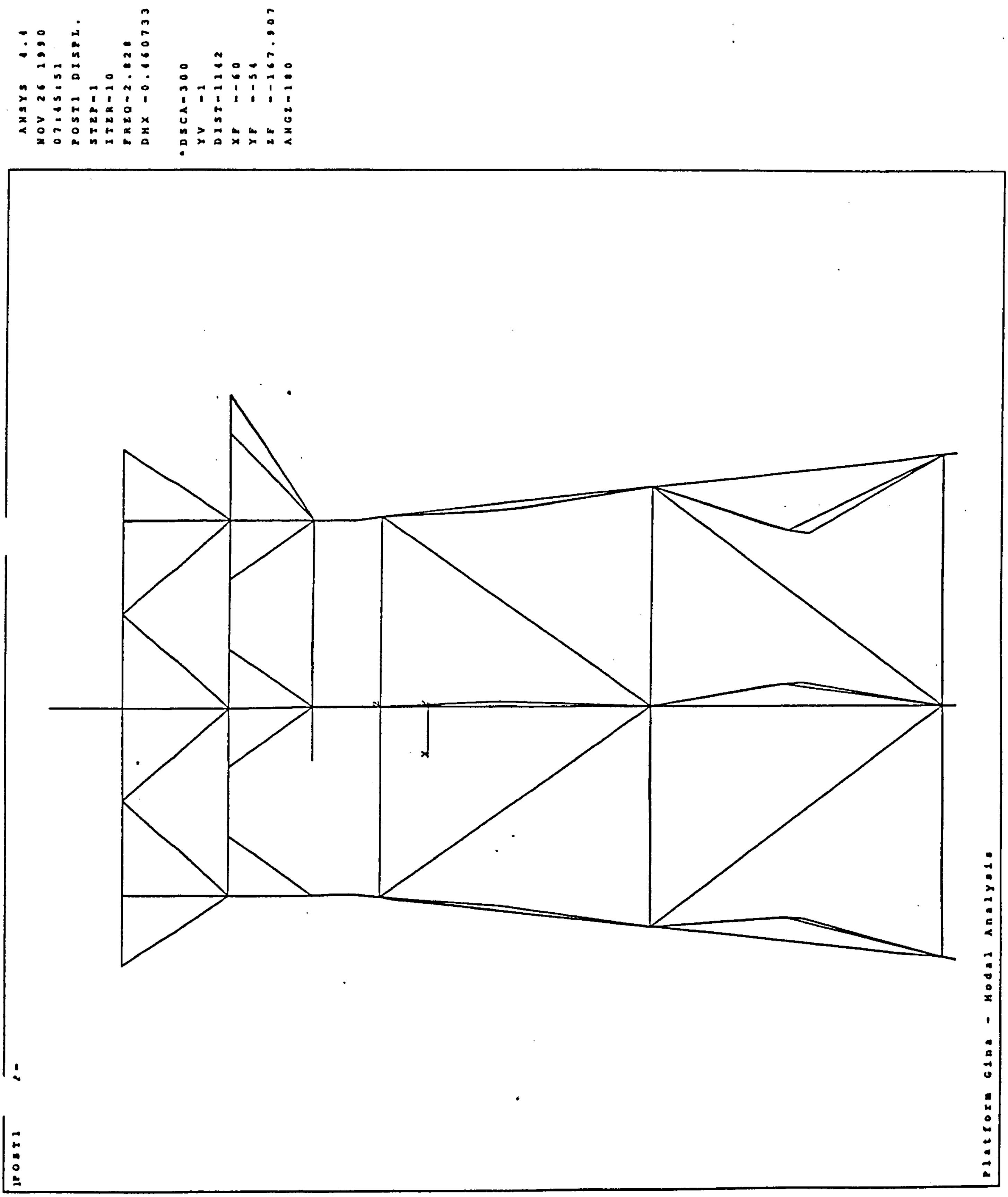


Figure B.8 Strength level seismic modal analysis—mode 11.

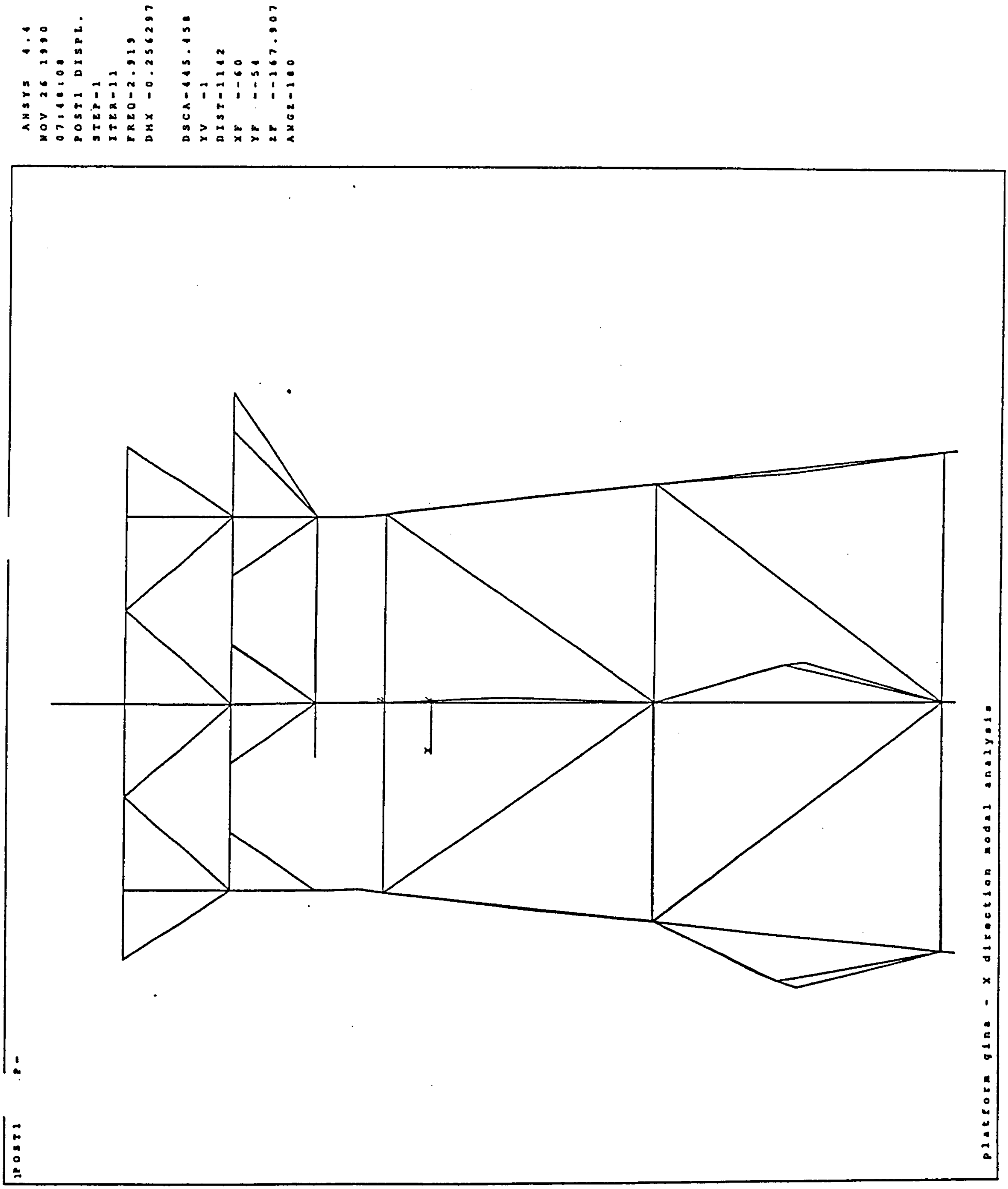


Figure B.9 Strength level seismic modal analysis—mode 12.

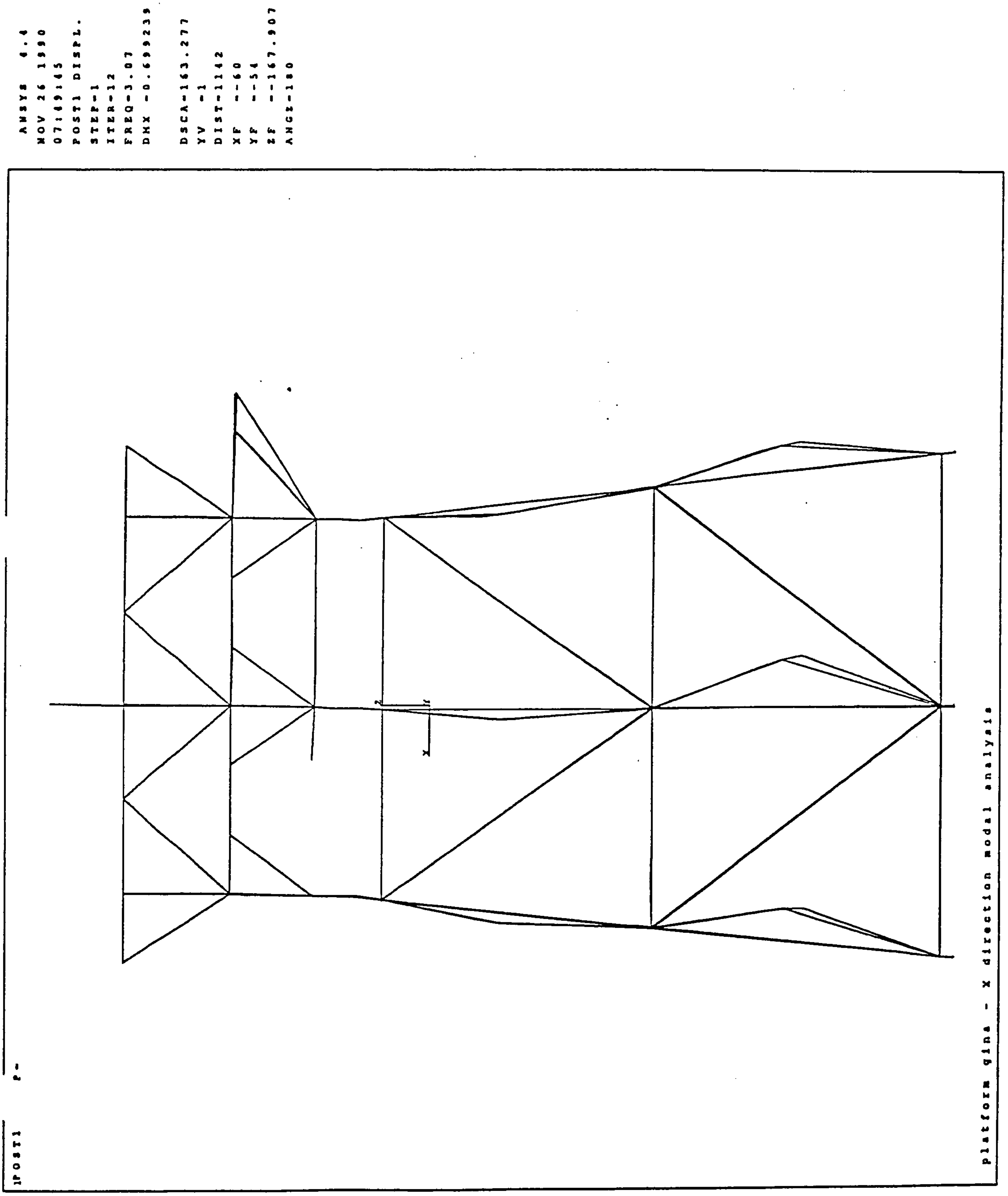


Figure B.10 Strength level seismic modal analysis—mode 13.

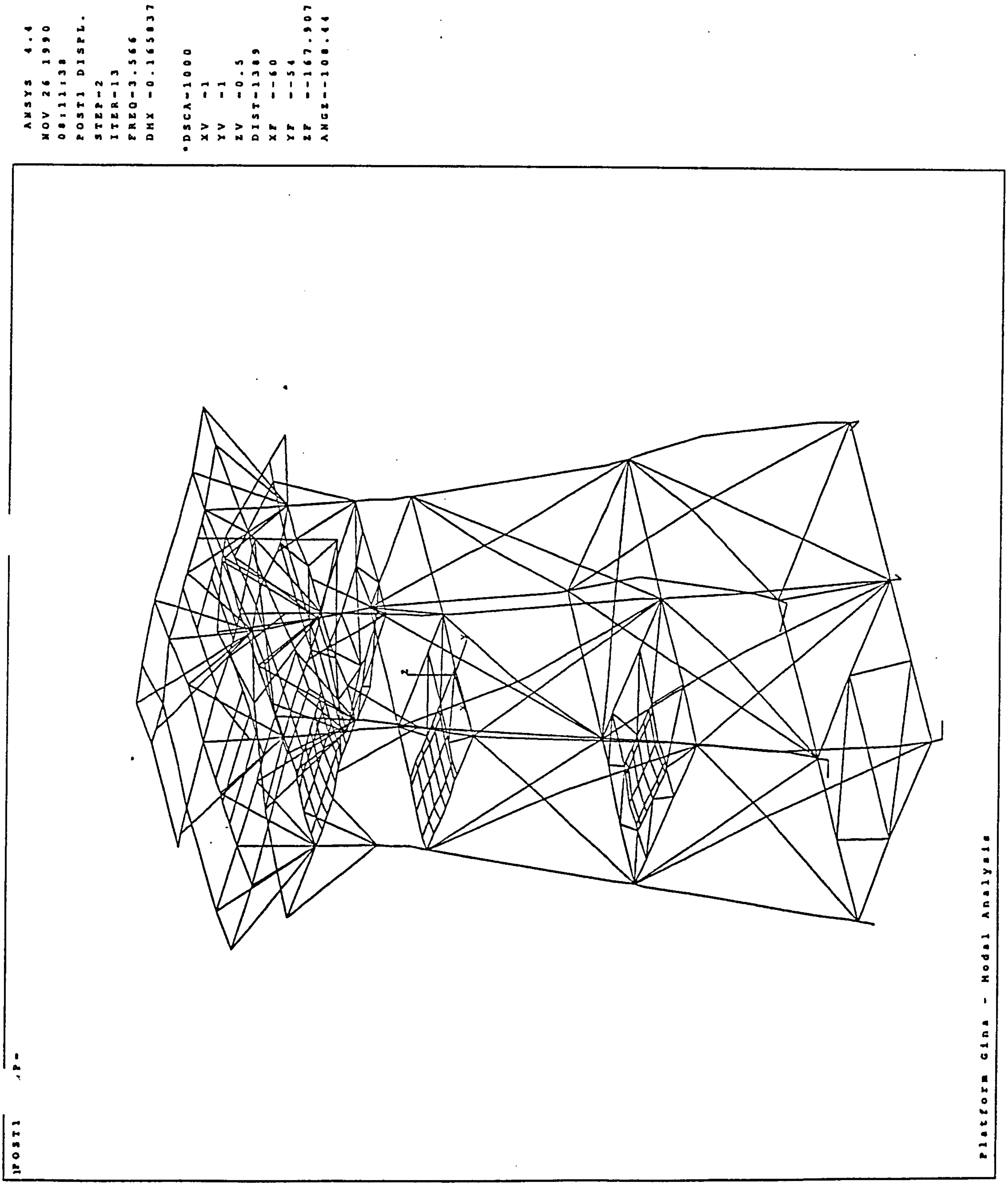
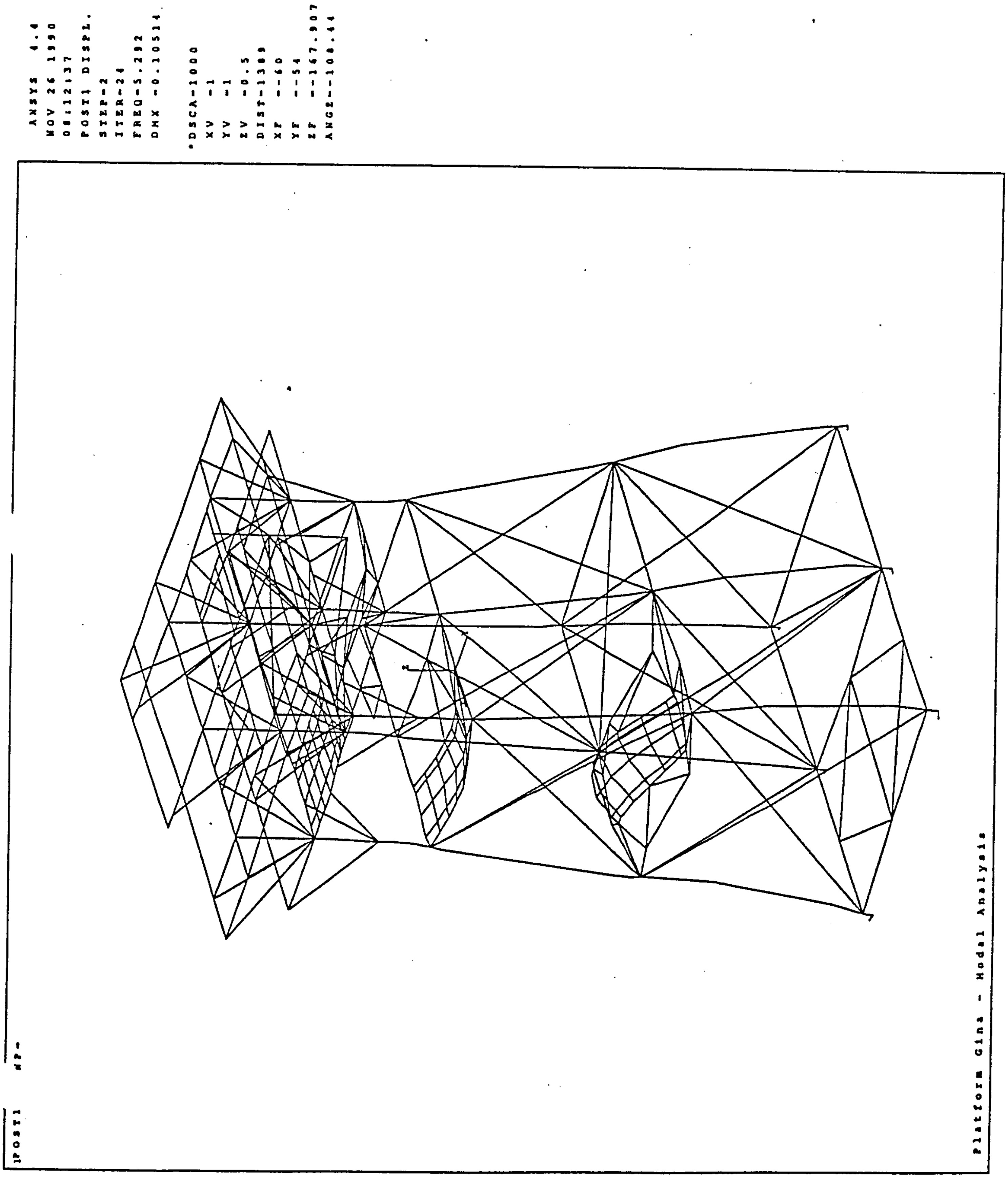


Figure B.11 Strength level seismic modal analysis—mode 24.



B.2 Strength Level CQC Directional Response

Figure B.12 Strength level x direction CQC combined response.

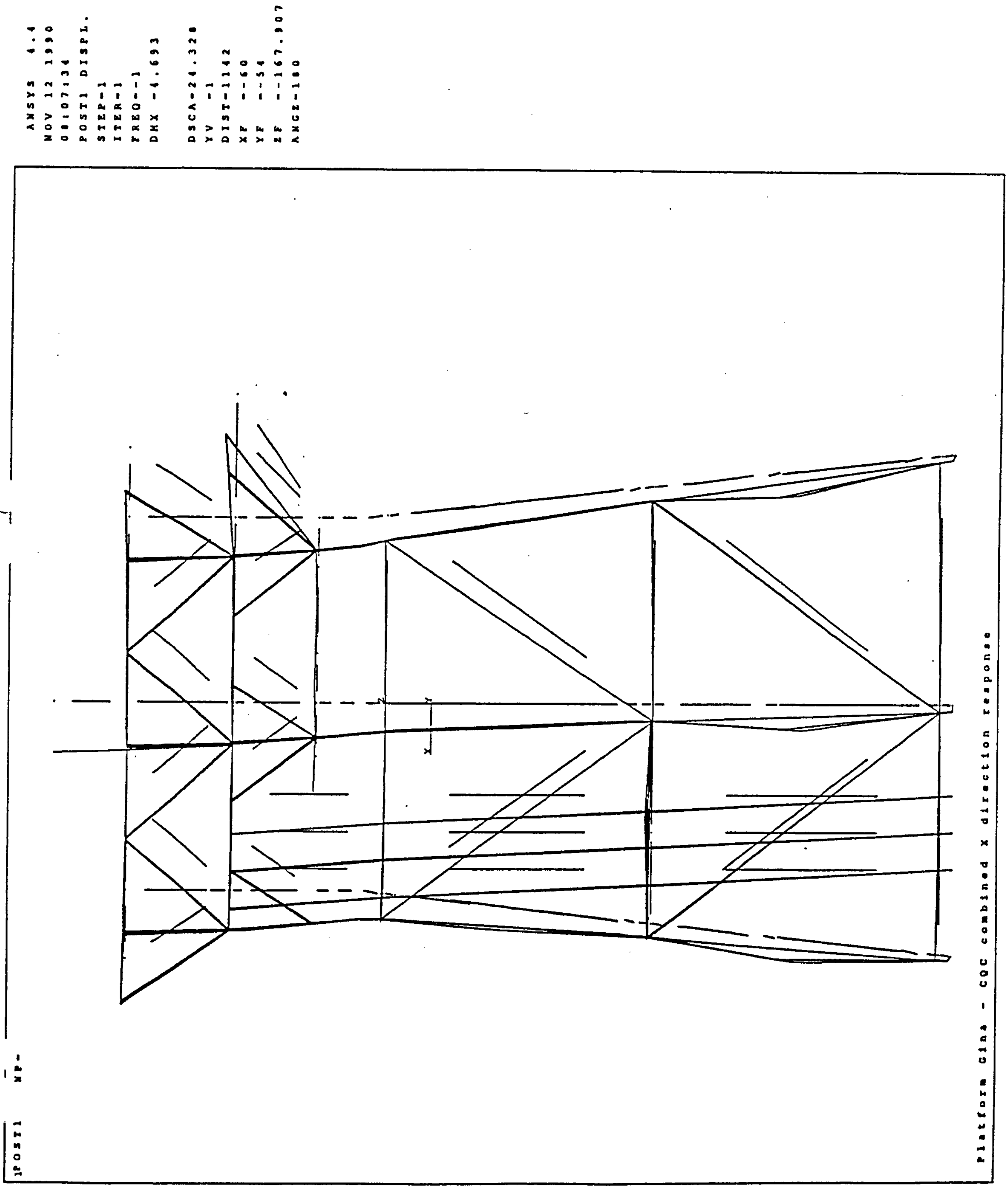


Figure B.13 Strength level y direction CQC combined response.

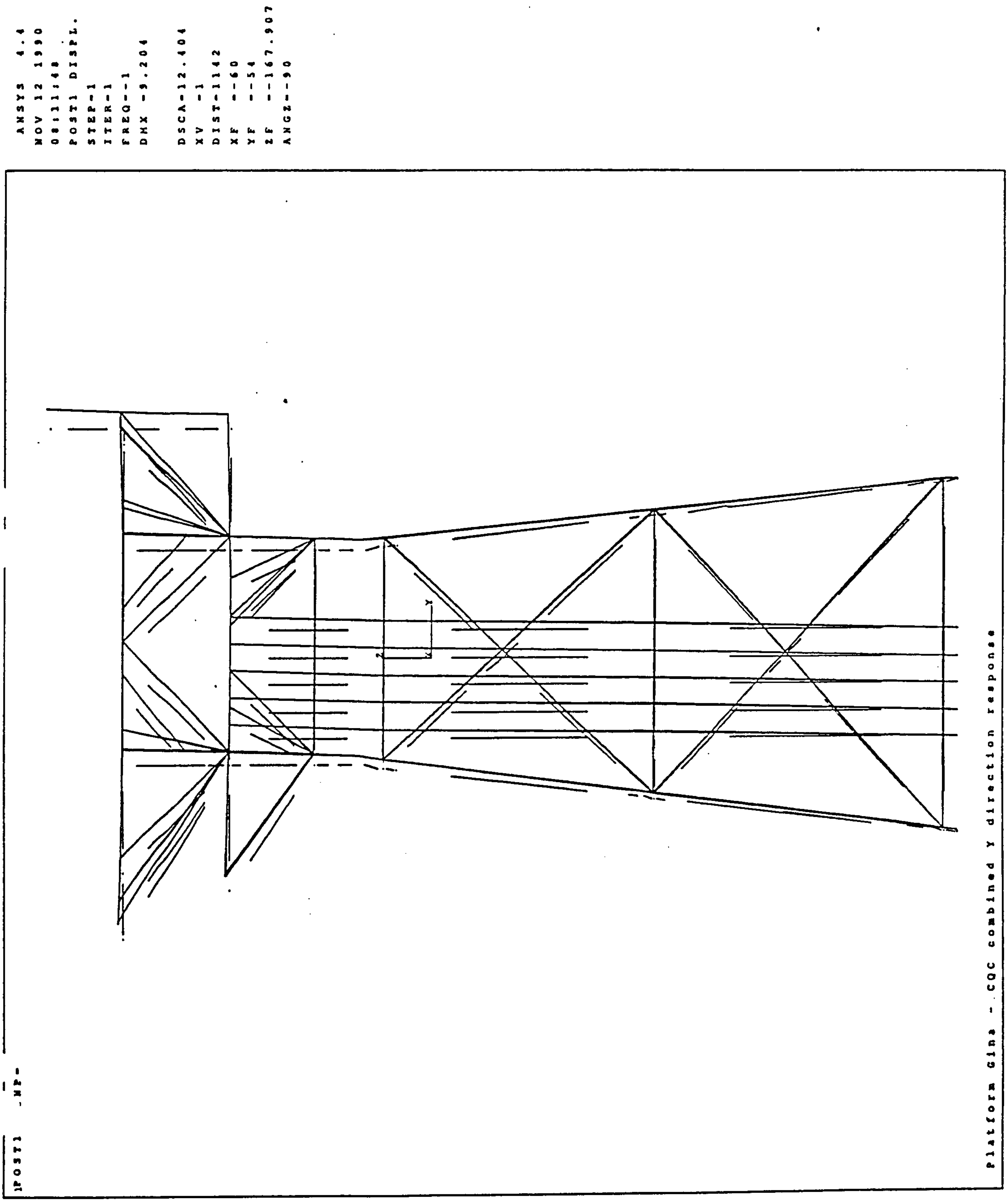
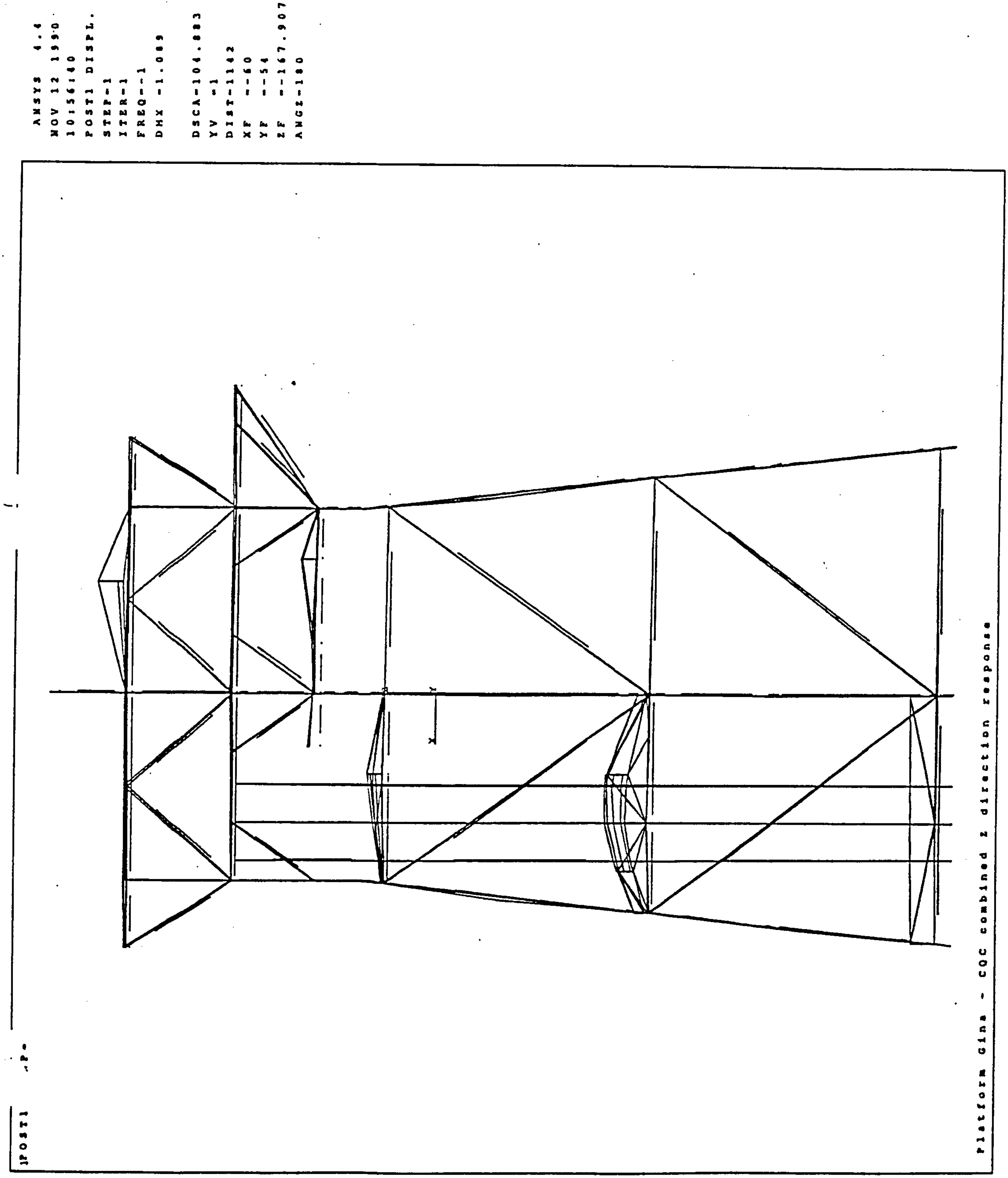


Figure B.14 Strength level z direction CQC combined response.



B.3 Modal Analysis Data Summary

STRENGTH LEVEL MODAL ANALYSIS
- X & Y DIRECTIONS
- 50 MDOF

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 21.719

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 48.036	IXX = 0.1032E+08	IXX = 0.9830E+07
YC = -6.1716	IYY = 0.1137E+08	IYY = 0.1083E+08
ZC = 149.41	IZZ = 0.4109E+07	IZZ = 0.4058E+07
	IXY = -0.2216E+06	IXY = -0.2280E+06
	IYZ = -0.2500E+06	IYZ = -0.2700E+06
	IZX = 0.1495E+06	IZX = 0.3054E+06

ONLY THE FIRST REAL CONSTANT MASS TERM IS USED FOR THE STIF21 ELEMENTS.

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	0.759371
2	0.414356
3	9.48716
4	1.57384
10	9.48441

RANGE OF ELEMENT MAXIMUM STIFFNESS IN GLOBAL COORDINATES

MAXIMUM= 0.136687E+09 AT ELEMENT 264.
MINIMUM= 0.483000E+03 AT ELEMENT 717.

INTEGER STORAGE REQUIREMENTS FOR ELEMENT FORMULATION CP= 112.302 TIME= 9.51556
FIXED DATA = 12734 TEMPORARY DATA = 0 TOTAL= 12734
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

*** ELEMENT STIFFNESS FORMULATION TIMES

TYPE	NUMBER	STIF	TOTAL CP	AVE CP
1	232	4	6.034	0.026
2	57	16	2.033	0.036
3	377	59	12.451	0.033
4	65	63	15.034	0.231
5	6	14	0.000	0.000
6	6	14	0.033	0.006
7	6	14	0.017	0.003
8	6	14	0.033	0.006
9	6	14	0.017	0.003
10	105	21	0.167	0.002

TIME AT END OF ELEMENT STIFFNESS FORMULATION CP= 112.319

MAXIMUM IN-CORE WAVE FRONT ALLOWED FOR REQUESTED MEMORY SIZE= 700.

INTEGER STORAGE REQUIREMENTS FOR WAVE FRONT MATRIX SOLUTION CP= 728.565 TIME= 9.69000
FIXED DATA = 12734 TEMPORARY DATA = 453152 TOTAL= 465886
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

MAXIMUM IN-CORE WAVE FRONT= 474.

MATRIX SOLUTION TIMES
READ IN ELEMENT STIFFNESSES CP= 10.066

NODAL COORD. TRANSFORMATION CP= 1.165
MATRIX TRIANGULARIZATION CP= -27800.465

TIME AT END OF MATRIX TRIANGULARIZATION CP= 728.598
EQUATION SOLVER MAXIMUM PIVOT= 0.20300E+09 AT NODE 525. ROTX
EQUATION SOLVER MINIMUM PIVOT= 31.688 AT NODE 32. UY

TIME AT START OF EIGENVALUE EXTRACTION CP= 728.748

NUMBER OF MODES AVAILABLE FROM REDUCED MATRICES= 50.

EIGENVALUE EXTRACTION TIME CP= 3.717

INTEGER STORAGE REQUIREMENTS FOR EIGENVALUE EXTRACTION CP= 734.248 TIME= 9.69194
FIXED DATA = 12734 TEMPORARY DATA = 12550 TOTAL= 25284
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

platform gina - X direction modal analysis 9.6919 NOV 11,1990 CP= 734.348

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE	FREQUENCY (CYCLES/TIME)
1	0.652947706
2	0.851908053
3	0.962775993
4	1.09388110
5	1.30987012
6	1.41917696
7	2.31135591
8	2.46417188
9	2.63554271
10	2.82761656
11	2.91872519
12	3.06989391
13	3.56552524
14	3.66076753
15	3.74036274
16	3.77880965
17	3.89172809
18	3.99978281
19	4.24312173
20	4.32794175
21	4.88802852
22	5.12997006
23	5.21069846
24	5.29188113
25	5.34084105
26	5.36374058
27	5.63018922
28	6.05778910
29	6.33714848
30	6.40787457
31	6.53906834
32	6.57545334
33	6.91451279
34	7.14873759
35	7.36819831
36	7.41718105
37	7.54878988
38	7.59404899
39	7.81226131
40	7.96981425
41	8.38477778
42	8.79502856
43	8.84227159
44	9.06713327
45	9.12067388
46	9.34315507
47	10.1488871
48	10.4102489
49	11.3993748
50	18.5087274

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	2003	UX	0.54381
2	394	UZ	0.34189E-01
3	940	UY	1.0011
4	485	UX	0.11332
5	425	UZ	0.93493E-01
6	922	UZ	0.39162E-01
7	2001	UX	0.48613
8	12	UY	6.1057
9	960	UZ	0.51926E-01
10	501	UX	0.11397
11	448	UX	0.50142
12	222	UX	5.6899
13	211	UZ	0.18108
14	825	UY	0.25453
15	460	UY	0.84707
16	2005	UY	0.58889
17	468	UX	1.2768
18	583	UX	0.11286
19	599	UX	0.12539
20	4	UZ	2.9652
21	448	UY	0.67058
22	493	UX	0.11641
23	919	UX	1.3884
24	2	UY	0.92511
25	452	UX	0.90727
26	78	UX	6.2106
27	2001	UY	0.62801
28	1022	UZ	0.55724E-01
29	464	UY	1.8459
30	591	UX	0.11828
31	466	UY	1.2666
32	201	UZ	0.27233
33	50	UZ	0.11195
34	316	UZ	1.2562
35	78	UZ	-0.10812
36	420	UZ	0.67341E-01
37	466	UX	0.92228

B21

38	1027	UX	1.4803
39	2005	UX	0.56594
40	446	UX	1.1133
41	426	UZ	0.78391E-01
42	68	UY	4.0098
43	11	UY	0.32638E-01
44	1021	UY	1.7584
45	392	UZ	0.35003E-01
46	51	UZ	0.16402
47	937	UZ	0.67151E-01
48	1070	UY	1.7585
49	822	UY	0.25579
50	1021	UX	1.6524

MASS(X,Y,Z) = 23.44 21.95 5.365

X DIRECTION

***** RESPONSE SPECTRUM CALCULATION SUMMARY ******

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
1	0.6529	75.6963	0.1603E-01	0.7210E-01	0.004761	0.257000E-03	0.110578E-04
* 2	0.8519	98.7635	-4.393	-15.14	1.000000	19.3024	0.830521
* 3	0.9628	111.6175	0.4300E-01	0.1312	0.008660	0.184887E-02	0.830600
* 4	1.094	126.8179	-0.2483	-0.6666	0.044016	0.616569E-01	0.833253
5	1.310	151.8601	0.2212E-01	0.4959E-01	0.003274	0.489167E-03	0.833274
6	1.419	164.5334	-0.3026E-01	-0.6262E-01	0.004134	0.915620E-03	0.833314
* 7	2.311	241.5000	0.1199	0.1373	0.009066	0.143767E-01	0.833932
* 8	2.464	241.5000	-1.734	-1.747	0.115375	3.00820	0.963364
9	2.636	241.5000	-0.8543E-01	-0.7523E-01	0.004968	0.729759E-02	0.963678
* 10	2.828	241.5000	0.2056	0.1573	0.010386	0.422654E-01	0.965497
* 11	2.919	241.5000	0.1326	0.9524E-01	0.006288	0.175899E-01	0.966253
* 12	3.070	241.5000	-0.4720	-0.3064	0.020231	0.222808	0.975840
13	3.566	241.5000	0.6690E-01	0.3219E-01	0.002126	0.447607E-02	0.976033
14	3.661	241.5000	0.2424E-01	0.1106E-01	0.000731	0.587500E-03	0.976058
15	3.740	241.5000	0.9743E-01	0.4260E-01	0.002813	0.949222E-02	0.976466
16	3.779	241.5000	-0.1393	-0.5967E-01	0.003940	0.194015E-01	0.977301
* 17	3.892	241.5000	0.4693	0.1896	0.012517	0.220282	0.986779
18	4.000	241.5000	0.4878E-01	0.1865E-01	0.001232	0.237942E-02	0.986881
19	4.243	241.5000	0.9698E-02	0.3295E-02	0.000218	0.940584E-04	0.986885
20	4.328	241.5000	0.1286E-01	0.4200E-02	0.000277	0.165384E-03	0.986893
21	4.888	241.5000	-0.2850E-01	-0.7297E-02	0.000482	0.812299E-03	0.986928
22	5.130	241.5000	0.1087	0.2527E-01	0.001669	0.118177E-01	0.987436
23	5.211	241.5000	-0.1673	-0.3770E-01	0.002490	0.280042E-01	0.988641
24	5.292	241.5000	-0.1613	-0.3523E-01	0.002326	0.260042E-01	0.989760
25	5.341	241.5000	-0.3061	-0.6564E-01	0.004334	0.936704E-01	0.993790
26	5.364	241.5000	0.3012	0.6404E-01	0.004229	0.907169E-01	0.997693
27	5.630	241.5000	0.9810E-02	0.1893E-02	0.000125	0.962422E-04	0.997697
28	6.058	241.5000	0.1866E-01	0.3111E-02	0.000205	0.348300E-03	0.997712
29	6.337	241.5000	-0.1662E-01	-0.2532E-02	0.000167	0.276198E-03	0.997724
30	6.408	241.5000	0.3273E-01	0.4876E-02	0.000322	0.107100E-02	0.997770
31	6.539	241.5000	0.3106E-01	0.4444E-02	0.000293	0.964836E-03	0.997812
32	6.575	241.5000	0.4247E-01	0.6009E-02	0.000397	0.180391E-02	0.997890
33	6.915	241.5000	-0.1156	-0.1479E-01	0.000977	0.133610E-01	0.998464
34	7.149	241.5000	-0.5332E-02	-0.6382E-03	0.000042	0.284262E-04	0.998466
35	7.368	241.5000	-0.3461E-01	-0.3900E-02	0.000258	0.119815E-02	0.998517
36	7.417	241.5000	-0.7532E-02	-0.8376E-03	0.000055	0.567371E-04	0.998520
37	7.549	241.5000	-0.3687E-01	-0.3958E-02	0.000261	0.135960E-02	0.998578
38	7.594	241.5000	0.5050E-01	0.5357E-02	0.000354	0.255015E-02	0.998688
39	7.812	241.5000	-0.3597E-01	-0.3605E-02	0.000238	0.129373E-02	0.998743
40	7.970	241.5000	-0.2154E-01	-0.2074E-02	0.000137	0.463921E-03	0.998763
41	8.385	230.4176	-0.1123	-0.9321E-02	0.000615	0.126067E-01	0.999306
42	8.795	219.6696	0.2268E-01	0.1631E-02	0.000108	0.514195E-03	0.999328
43	8.842	218.4959	0.1760E-01	0.1246E-02	0.000082	0.309871E-03	0.999341
44	9.067	213.0773	0.5949E-01	0.3905E-02	0.000258	0.353883E-02	0.999494
45	9.121	211.8265	-0.1049	-0.6769E-02	0.000447	0.110122E-01	0.999967
46	9.343	206.7824	-0.2529E-01	-0.1518E-02	0.000100	0.639766E-03	0.999995
47	10.15	190.3657	0.1509E-02	0.7064E-04	0.000005	0.227657E-05	0.999995
48	10.41	185.5863	-0.5293E-02	-0.2296E-03	0.000015	0.280127E-04	0.999996
49	11.40	169.4830	0.9346E-02	0.3088E-03	0.000020	0.873417E-04	1.000000
50	18.51	104.3832	-0.6557E-03	-0.5061E-05	0.000000	0.429954E-06	1.00000
				SUM OF EFFECTIVE MASSES=		23.2416	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 0.10000E-02

*SIGNIFICANT MODES

***** RESPONSE SPECTRUM CALCULATION SUMMARY ******   Y DIRECTION

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
Local * 1	0.6529	75.6870	1.959	8.810	0.794831	3.83822	0.174987
* 2	0.8519	98.7505	0.3456E-01	0.1191	0.010748	0.119462E-02	0.175042
* 3	0.9628	111.6024	3.634	11.08	1.000000	13.2088	0.777240
* 4	1.094	126.8002	0.4055	1.088	0.098199	0.164423	0.784736
Local * 5	1.310	151.8381	-0.5313	-1.191	0.107446	0.282256	0.797605
Local * 6	1.419	164.5092	-0.9083	-1.879	0.169552	0.825050	0.835219
7	2.311	241.5000	-0.1957E-02	-0.2241E-02	0.000202	0.383008E-05	0.835219
* 8	2.464	241.5000	0.1032	0.1039	0.009378	0.106462E-01	0.835705
* 9	2.636	241.5000	1.754	1.545	0.139387	3.07752	0.976011
10	2.828	241.5000	0.1297E-01	0.9925E-02	0.000895	0.168275E-03	0.976019
11	2.919	241.5000	0.1373E-01	0.9863E-02	0.000890	0.188644E-03	0.976027
12	3.070	241.5000	0.6440E-01	0.4180E-01	0.003771	0.414731E-02	0.976216
* 13	3.566	241.5000	0.5202	0.2503	0.022582	0.270567	0.988552
14	3.661	241.5000	0.3915E-01	0.1787E-01	0.001612	0.153265E-02	0.988622
15	3.740	241.5000	-0.6170E-02	-0.2698E-02	0.000243	0.380744E-04	0.988623
16	3.779	241.5000	0.1155E-01	0.4946E-02	0.000446	0.133297E-03	0.988629
17	3.892	241.5000	-0.2855E-02	-0.1153E-02	0.000104	0.814880E-05	0.988630
18	4.000	241.5000	0.1696E-01	0.6486E-02	0.000585	0.287745E-03	0.988643
19	4.243	241.5000	0.2210E-02	0.7508E-03	0.000068	0.488338E-05	0.988643
20	4.328	241.5000	0.9121E-02	0.2979E-02	0.000269	0.831855E-04	0.988647
21	4.888	241.5000	-0.3677E-01	-0.9414E-02	0.000849	0.135187E-02	0.988709
22	5.130	241.5000	0.4205E-01	0.9775E-02	0.000882	0.176837E-02	0.988789
23	5.211	241.5000	0.1156	0.2604E-01	0.002350	0.133615E-01	0.989398
* 24	5.292	241.5000	0.3503	0.7652E-01	0.006903	0.122696	0.994992
25	5.341	241.5000	-0.3360E-01	-0.7206E-02	0.000650	0.112902E-02	0.995044
* 26	5.364	241.5000	-0.2616	-0.5562E-01	0.005018	0.684274E-01	0.998163
27	5.630	241.5000	0.2988E-01	0.5766E-02	0.000520	0.892729E-03	0.998204
28	6.058	241.5000	-0.5993E-03	-0.9990E-04	0.000009	0.359131E-06	0.998204
29	6.337	241.5000	0.1133E-01	0.1727E-02	0.000156	0.128477E-03	0.998210
30	6.408	241.5000	0.5844E-01	0.8706E-02	0.000785	0.341486E-02	0.998366
31	6.539	241.5000	-0.1041	-0.1489E-01	0.001343	0.108319E-01	0.998859
32	6.575	241.5000	0.1178	0.1667E-01	0.001504	0.138787E-01	0.999492
33	6.915	241.5000	0.1672E-01	0.2139E-02	0.000193	0.279581E-03	0.999505
34	7.149	241.5000	-0.8309E-03	-0.9946E-04	0.000009	0.690402E-06	0.999505
35	7.368	241.5000	-0.9567E-02	-0.1078E-02	0.000097	0.915267E-04	0.999509
36	7.417	241.5000	0.5651E-02	0.6283E-03	0.000057	0.319322E-04	0.999511
37	7.549	241.5000	-0.1677E-01	-0.1800E-02	0.000162	0.281130E-03	0.999523
38	7.594	241.5000	0.3682E-01	0.3905E-02	0.000352	0.135551E-02	0.999585
39	7.812	241.5000	0.1180E-01	0.1183E-02	0.000107	0.139191E-03	0.999592
40	7.970	241.5000	-0.3056E-01	-0.2944E-02	0.000266	0.934136E-03	0.999634
41	8.385	230.4176	0.2476E-01	0.2056E-02	0.000185	0.613048E-03	0.999662
42	8.795	219.6696	-0.6949E-01	-0.4998E-02	0.000451	0.482843E-02	0.999882
43	8.842	218.4959	0.4607E-01	0.3261E-02	0.000294	0.212228E-02	0.999979
44	9.067	213.0773	0.6925E-02	0.4546E-03	0.000041	0.479502E-04	0.999981
45	9.121	211.8265	0.7731E-02	0.4986E-03	0.000045	0.597610E-04	0.999984
46	9.343	206.7824	0.9839E-02	0.5904E-03	0.000053	0.968143E-04	0.999988
47	10.15	190.3657	-0.1255E-01	-0.5877E-03	0.000053	0.157608E-03	0.999995
48	10.41	185.5863	-0.9714E-02	-0.4214E-03	0.000038	0.943575E-04	1.000000
49	11.40	169.4830	-0.2046E-02	-0.6760E-04	0.000006	0.418674E-05	1.000000
50	18.51	104.3832	0.1027E-02	0.7928E-05	0.000001	0.105518E-05	1.000000
				SUM OF EFFECTIVE MASSES=		21.9343	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 0.50000E-02

*SIGNIFICANT MODES

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE	FREQUENCY (CYCLES/TIME)
1	0.652932036
2	0.851526745
3	0.961897827
4	1.09217055
5	1.30964891
6	1.41836797
7	2.31052776
8	2.44233749
9	2.64312393
10	2.78046009
11	2.90098300
12	3.03627655
13	3.14213254
14	3.55583799
15	3.74270939
16	3.77356567
17	3.87652050
18	3.95188435
19	4.15873659
20	4.24191554
21	4.32495742
22	4.53974296
23	4.75847048
24	4.90198444
25	5.18172791
26	5.24934020
27	5.29413788
28	5.31813386
29	5.59328078
30	5.90033168
31	6.02424201
32	6.19571140
33	6.33620203
34	6.35691809
35	6.46096212
36	6.62000778
37	6.70517192
38	6.79816753
39	7.00244819
40	7.14840621
41	7.43394773
42	7.54818728
43	7.63590044
44	7.70193101
45	7.81895022
46	7.94421517
47	8.00988837
48	8.05224524
49	8.20254190
50	8.32542424
51	8.45458449
52	8.58988581
53	8.65516460
54	8.95440075
55	9.00124017
56	9.12098630
57	9.26117112
58	9.37730358
59	9.47023395
60	9.52707975
61	9.53373906
62	9.68674359
63	10.0082461
64	10.2805214
65	10.4149832
66	10.6806906
67	10.8037913
68	11.5167697
69	11.7991100
70	11.9160433
71	12.1130400
72	12.2737333
73	12.3849615
74	12.7883975
75	12.8731904
76	12.9884375
77	13.6439470
78	13.8405321
79	13.9695230
80	14.0656911
81	14.0656911
82	14.0656911
83	14.0656911
84	14.0656911
85	14.0656911
86	14.0656911
87	14.0656911
88	14.0656911
89	14.0656911
90	14.0656911
91	14.0656911
92	14.0656911
93	14.0656911
94	14.0656911
95	14.2872452

STRENGTH LEVEL MODAL ANALYSIS

- Z DIRECTION

- 150 MDOF INCLUDING ALL LUMPED MASSES IN "Z" DIRECTION

96	14.7181045
97	14.9414264
98	15.5916008
99	15.8712217
100	16.1161942
101	16.4469908
102	16.9342406
103	17.5377890
104	17.7415741
105	17.9486172
106	18.6131603
107	19.4563156
108	19.5482503
109	19.8206846
110	20.1291397
111	21.0093484
112	22.1226243
113	22.8236122
114	22.9474834
115	23.3276828
116	23.5574623
117	24.5353608
118	25.3233323
119	25.5048504
120	27.1164243
121	28.2437265
122	28.6788226
123	29.4447810
124	29.6786271
125	29.7309034
126	35.3882238
127	36.4053270
128	40.4601031
129	40.9169799
130	42.3771444
131	44.0961355
132	47.7937840
133	49.5606416
134	50.4534183
135	52.5687857
136	56.0222743
137	57.1773958
138	61.0461970
139	61.8764033
140	66.4197868
141	69.6181986
142	71.8560647
143	79.7129164
144	80.4698539
145	81.5519068
146	87.1929493
147	97.5893213
148	118.307375
149	148.532093
150	166.040141

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	402	UZ	0.15810E-01
2	7	UZ	0.32458
3	66	UZ	0.19989
4	51	UZ	0.58153E-01
5	316	UZ	0.25443
6	149	UZ	-0.79117E-01
7	420	UZ	0.61925E-01
8	745	UZ	0.38972E-01
9	752	UZ	0.48430E-01
10	68	UZ	0.39863
11	957	UX	1.0900
12	45	UZ	0.43815E-02
13	58	UZ	0.34687E-01
14	80	UZ	0.17703
15	338	UZ	0.24144
16	125	UZ	0.11728
17	65	UZ	0.51102
18	198	UZ	0.91118E-01
19	599	UX	0.69641E-01
20	178	UZ	0.92174E-02
21	152	UZ	0.27292
22	493	UX	0.11995
23	130	UZ	-0.17807
24	49	UZ	0.65015E-01
25	174	UZ	1.3945
26	132	UZ	-0.11263
27	2802	UZ	0.84733E-01
28	59	UZ	0.14043
29	2005	UX	0.52433
30	84	UZ	-0.16714
31	2	UY	0.92321
32	2005	UY	0.64888
33	458	UX	1.4489
34	14	UZ	-0.60387
35	489	UX	0.58279E-01
36	194	UZ	0.17816
37	583	UX	0.12063

B25

38	213	UZ	0.13885
39	15	UZ	0.30048E-01
40	212	UZ	0.12785
41	183	UZ	-0.22415
42	2864	UZ	0.84733E-01
43	453	UZ	0.66422
44	1027	UX	1.4591
45	937	UZ	0.68314E-01
46	13	UZ	0.11454
47	2799	UZ	0.84733E-01
48	78	UZ	0.62259E-01
49	2795	UZ	0.84733E-01
50	6	UZ	0.32251
51	63	UZ	0.92351E-02
52	68	UY	4.1309
53	449	UZ	0.73894
54	392	UZ	0.48272E-01
55	922	UZ	0.41220E-01
56	2796	UZ	0.84733E-01
57	180	UZ	0.33414E-01
58	2840	UZ	0.84733E-01
59	425	UZ	0.10134
60	1070	UY	1.7420
61	98	UZ	0.13203
62	25	UZ	0.63646E-01
63	2791	UZ	0.84733E-01
64	200	UZ	0.33644
65	426	UZ	0.10422
66	30	UZ	-0.37717E-03
67	222	UX	5.6806
68	394	UZ	0.38927E-01
69	176	UZ	0.16921E-01
70	448	UY	0.64820
71	2800	UZ	0.84733E-01
72	2792	UZ	0.84733E-01
73	151	UZ	0.22409
74	372	UZ	0.54289E-01
75	196	UZ	0.34839
76	126	UZ	0.38714
77	960	UZ	0.45676E-01
78	61	UZ	-0.72526E-01
79	47	UZ	0.85818E-01
80	825	UZ	0.14468
81	154	UZ	-0.22740
82	448	UX	0.53939
83	5	UZ	0.54889E-01
84	2839	UZ	0.84733E-01
85	75	UZ	0.49939
86	919	UX	0.99365
87	825	UY	0.25410
88	211	UZ	0.10654
89	485	UX	0.12844
90	310	UZ	0.83153E-01
91	11	UY	0.32360E-01
92	150	UZ	-0.37542E-01
93	28	UZ	0.97426E-01
94	46	UZ	0.30772E-01
95	162	UZ	0.57016E-01
96	70	UZ	-0.19573
97	48	UZ	-0.18582E-01
98	193	UZ	-0.26352E-01
99	2798	UZ	0.84733E-01
100	501	UX	0.11257
101	34	UZ	0.62111E-01
102	463	UZ	0.61040
103	2868	UZ	0.84733E-01
104	2	UZ	0.95036
105	460	UX	0.72520
106	460	UY	0.93399
107	452	UX	1.0139
108	452	UY	1.0029
109	457	UZ	0.32910
110	462	UY	0.90498
111	2001	UX	0.51206
112	940	UY	1.1291
113	822	UZ	0.19689
114	175	UZ	0.63604E-02
115	466	UX	0.84033
116	466	UY	1.1608
117	201	UZ	0.11934
118	822	UY	0.25526
119	50	UZ	0.57902E-01
120	336	UZ	0.15449E-01
121	24	UZ	0.28074E-01
122	2797	UZ	0.84733E-01
123	173	UZ	0.90592
124	4	UZ	1.4152
125	498	UX	0.12580
126	179	UZ	0.51605E-01
127	108	UZ	0.10120
128	52	UZ	0.39764E-01
129	2860	UZ	0.84733E-01
130	177	UZ	0.33891E-01
131	12	UY	6.5237
132	11	UZ	0.13566
133	9	UZ	0.54066E-01
134	67	UZ	0.29978
135	315	UZ	0.15312
136	206	UZ	0.47192
137	210	UZ	0.32079E-01

138	22	UZ	0.27091
139	20	UZ	0.44945
140	1	UZ	0.88449
141	78	UX	6.0112
142	1021	UY	1.9728
143	1021	UX	1.6301
144	2801	UZ	0.84733E-01
145	19	UZ	0.29366
146	16	UZ	-0.31223
147	12	UZ	0.88722
148	23	UZ	0.18177E-01
149	60	UZ	0.74692E-01
150	72	UZ	0.27952

MASS(X,Y,Z) = 23.20 22.26 18.29

*SIGNIFICANT MODES

***** RESPONSE SPECTRUM CALCULATION SUMMARY ******

Z DIRECTION

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
1	0.6529	37.8544	-0.2110E-02	-0.4745E-02	0.011302	0.445157E-05	0.242652E-06
2	0.8515	49.3668	0.1632E-01	0.2815E-01	0.067040	0.266405E-03	0.147642E-04
3	0.9619	55.7648	-0.1784E-01	-0.2723E-01	0.064853	0.318128E-03	0.321051E-04
* 4	1.092	63.3164	0.2946E-01	0.3962E-01	0.094355	0.868174E-03	0.794286E-04
5	1.310	75.9229	0.7429E-02	0.8329E-02	0.019838	0.551832E-04	0.824366E-04
6	1.418	82.2249	0.8425E-02	0.8723E-02	0.020775	0.709872E-04	0.863060E-04
* 7	2.311	120.7500	-0.6659	-0.3815	0.908703	0.443467	0.242594E-01
* 8	2.442	120.7500	0.8162E-01	0.4185E-01	0.099681	0.666226E-02	0.246225E-01
9	2.643	120.7500	-0.3837E-01	-0.1680E-01	0.040007	0.147202E-02	0.247028E-01
10	2.780	120.7500	-0.2511E-01	-0.9935E-02	0.023663	0.630611E-03	0.247371E-01
11	2.901	120.7500	0.5815E-01	0.2113E-01	0.050331	0.338088E-02	0.249214E-01
12	3.036	120.7500	0.7393E-01	0.2453E-01	0.058421	0.546612E-02	0.252194E-01
13	3.142	120.7500	-0.1408E-01	-0.4361E-02	0.010387	0.198183E-03	0.252302E-01
* 14	3.556	120.7500	0.1541	0.3728E-01	0.088800	0.237555E-01	0.265251E-01
15	3.743	120.7500	0.1116	0.2437E-01	0.058049	0.124596E-01	0.272042E-01
16	3.774	120.7500	0.1211	0.2601E-01	0.061938	0.146585E-01	0.280033E-01
17	3.877	120.7500	0.1000	0.2036E-01	0.048495	0.100076E-01	0.285488E-01
* 18	3.952	120.7500	2.144	0.4199	1.000000	4.59610	0.279079
* 19	4.159	120.7500	-2.160	-0.3820	0.909908	4.66674	0.533459
20	4.242	120.7500	-0.1483	-0.2522E-01	0.060056	0.220059E-01	0.534659
* 21	4.325	120.7500	0.2253	0.3683E-01	0.087729	0.507444E-01	0.537425
* 22	4.540	120.7500	2.119	0.3145	0.748933	4.48935	0.782136
23	4.758	120.7500	0.1319	0.1781E-01	0.042430	0.173935E-01	0.783084
* 24	4.902	120.7500	-0.9441	-0.1202	0.286199	0.891246	0.831665
25	5.182	120.7500	-0.2135	-0.2432E-01	0.057912	0.455625E-01	0.834148
* 26	5.249	120.7500	0.3820	0.4240E-01	0.100979	0.145899	0.842101
27	5.294	120.7500	-0.1049	-0.1145E-01	0.027265	0.110045E-01	0.842701
* 28	5.318	120.7500	-0.7298	-0.7892E-01	0.187965	0.532554	0.871730
29	5.593	120.7500	0.1375	0.1344E-01	0.032008	0.188956E-01	0.872760
* 30	5.900	120.7500	-0.4158	-0.3653E-01	0.086997	0.172856	0.882182
31	6.024	120.7500	-0.1592	-0.1342E-01	0.031958	0.253475E-01	0.883564
32	6.196	120.7500	0.1452	0.1157E-01	0.027552	0.210788E-01	0.884713
33	6.336	120.7500	-0.2917E-01	-0.2222E-02	0.005293	0.850861E-03	0.884759
34	6.357	120.7500	-0.5311E-01	-0.4020E-02	0.009575	0.282099E-02	0.884913
35	6.461	120.7500	-0.9213E-01	-0.6751E-02	0.016078	0.848841E-02	0.885376
36	6.620	120.7500	0.9880E-01	0.6895E-02	0.016423	0.976131E-02	0.885908
37	6.705	120.7500	-0.8106E-02	-0.5515E-03	0.001313	0.657146E-04	0.885912
38	6.798	120.7500	-0.2101	-0.1390E-01	0.033111	0.441240E-01	0.888317
39	7.002	120.7500	-0.2185	-0.1363E-01	0.032465	0.477535E-01	0.890920
40	7.148	120.7500	0.1660E-01	0.9938E-03	0.002367	0.275671E-03	0.890935
41	7.434	120.7500	-0.4172	-0.2309E-01	0.055001	0.174097	0.900425
42	7.548	120.7500	-0.7224E-02	-0.3878E-03	0.000924	0.521830E-04	0.900428
43	7.636	120.7500	0.9045E-02	0.4745E-03	0.001130	0.818068E-04	0.900432
44	7.702	120.7500	-0.2742E-03	-0.1414E-04	0.000034	0.751790E-07	0.900432
45	7.819	120.7500	0.1211	0.6056E-02	0.014424	0.146534E-01	0.901231
46	7.944	120.7500	0.1462	0.7085E-02	0.016875	0.213727E-01	0.902396
47	8.010	120.6009	0.2142E-01	0.1020E-02	0.002429	0.458799E-03	0.902421
48	8.052	119.9665	0.3338	0.1564E-01	0.037259	0.111416	0.908494
49	8.203	117.7684	0.1361	0.6034E-02	0.014371	0.185196E-01	0.909503
50	8.325	116.0301	0.6627E-01	0.2810E-02	0.006693	0.439165E-02	0.909743
51	8.455	114.2575	0.2310	0.9352E-02	0.022273	0.533462E-01	0.912651
52	8.590	112.4578	0.1148	0.4432E-02	0.010556	0.131791E-01	0.913369
53	8.655	111.6097	-0.7959E-02	-0.3004E-03	0.000715	0.633415E-04	0.913373
54	8.954	107.8799	-0.3467E-01	-0.1182E-02	0.002814	0.120193E-02	0.913438
55	9.001	107.3185	-0.1856E-01	-0.6229E-03	0.001484	0.344657E-03	0.913457
56	9.121	105.9096	0.7089E-01	0.2286E-02	0.005444	0.502516E-02	0.913731
57	9.261	104.3065	0.1247	0.3840E-02	0.009146	0.155392E-01	0.914578
58	9.377	103.0147	0.1683	0.4994E-02	0.011894	0.283237E-01	0.916122
59	9.470	102.0038	-0.7422E-01	-0.2138E-02	0.005093	0.550850E-02	0.916422
60	9.527	101.3952	0.4145E-02	0.1173E-03	0.000279	0.171771E-04	0.916423
61	9.534	101.3244	-0.6779E-01	-0.1914E-02	0.004559	0.459596E-02	0.916673
62	9.687	99.7239	0.2410	0.6489E-02	0.015455	0.581005E-01	0.919840
63	10.01	96.5204	0.6397E-01	0.1561E-02	0.003719	0.409161E-02	0.920063
64	10.28	93.9641	-0.5586E-01	-0.1258E-02	0.002996	0.312014E-02	0.920234
65	10.41	92.7510	0.1338E-01	0.2898E-03	0.000690	0.179018E-03	0.920243
66	10.68	90.4436	-0.6789E-01	-0.1364E-02	0.003247	0.460970E-02	0.920495
67	10.80	89.4131	0.2142E-01	0.4156E-03	0.000990	0.458798E-03	0.920520
68	11.52	83.8777	0.1006	0.1611E-02	0.003838	0.101179E-01	0.921071
69	11.80	81.8706	0.7399E-03	0.1102E-04	0.000026	0.547518E-06	0.921071
70	11.92	81.0672	-0.1090	-0.1576E-02	0.003753	0.118719E-01	0.921718
71	12.11	79.7488	-0.7314E-02	-0.1007E-03	0.000240	0.534883E-04	0.921721
72	12.27	78.7047	0.9844E-01	0.1303E-02	0.003103	0.969115E-02	0.922249
73	12.38	77.9978	0.3038E-01	0.3914E-03	0.000932	0.923153E-03	0.922300
74	12.79	75.5372	-0.3228E-01	-0.3777E-03	0.000900	0.104227E-02	0.922357
75	12.87	75.0397	0.3552E-01	0.4075E-03	0.000970	0.126198E-02	0.922425
76	12.99	74.3738	-0.7230E-01	-0.8073E-03	0.001923	0.522665E-02	0.922710
77	13.64	70.8006	-0.2658E-01	-0.2561E-03	0.000610	0.706601E-03	0.922749
78	13.84	69.7950	0.1379	0.1273E-02	0.003032	0.190268E-01	0.923786

79	13.97	69.1505	0.1280E-01	0.1149E-03	0.000274	0.163748E-03	0.923795
80	14.07	68.6777	-0.3024	-0.2659E-02	0.006333	0.914594E-01	0.928780
81	14.07	68.6777	0.7228E-01	0.6355E-03	0.001514	0.522385E-02	0.929065
82	14.07	68.6777	-0.2192E-01	-0.1927E-03	0.000459	0.480512E-03	0.929091
83	14.07	68.6777	0.6063	0.5332E-02	0.012698	0.367652	0.949132
84	14.07	68.6777	0.2913	0.2561E-02	0.006100	0.848348E-01	0.953756
85	14.07	68.6777	-0.2519	-0.2215E-02	0.005275	0.634359E-01	0.957214
86	14.07	68.6777	0.4620E-01	0.4062E-03	0.000968	0.213457E-02	0.957330
87	14.07	68.6777	0.4654	0.4092E-02	0.009746	0.216561	0.969135
88	14.07	68.6777	0.2494	0.2193E-02	0.005223	0.621979E-01	0.972525
89	14.07	68.6777	-0.2040	-0.1794E-02	0.004272	0.416082E-01	0.974793
90	14.07	68.6777	-0.1124	-0.9884E-03	0.002354	0.126350E-01	0.975482
91	14.07	68.6777	-0.4474	-0.3934E-02	0.009370	0.200179	0.986393
92	14.07	68.6777	0.4353E-01	0.3828E-03	0.000912	0.189484E-02	0.986497
93	14.07	68.6777	-0.3014	-0.2650E-02	0.006312	0.908300E-01	0.991448
94	14.07	68.6777	0.1726	0.1517E-02	0.003614	0.297801E-01	0.993071
95	14.29	67.6128	0.2677E-01	0.2246E-03	0.000535	0.716852E-03	0.993110
96	14.72	65.6335	0.8408E-01	0.6453E-03	0.001537	0.707015E-02	0.993496
97	14.94	64.6525	0.5247E-01	0.3849E-03	0.000917	0.275318E-02	0.993646
98	15.59	61.9564	0.4166E-01	0.2690E-03	0.000641	0.173594E-02	0.993740
99	15.87	60.8649	-0.8853E-01	-0.5418E-03	0.001291	0.783750E-02	0.994167
100	16.12	59.9397	-0.1243	-0.7268E-03	0.001731	0.154605E-01	0.995010
101	16.45	58.7341	0.7345E-02	0.4040E-04	0.000096	0.539459E-04	0.995013
102	16.93	57.0442	-0.2266E-01	-0.1142E-03	0.000272	0.513283E-03	0.995041
103	17.54	55.0811	0.2623E-01	0.1190E-03	0.000283	0.687857E-03	0.995079
104	17.74	54.4484	-0.1771	-0.7760E-03	0.001848	0.313641E-01	0.996788
105	17.95	53.8203	0.9343E-01	0.3954E-03	0.000942	0.872848E-02	0.997264
106	18.61	51.8988	0.2745E-01	0.1042E-03	0.000248	0.753619E-03	0.997305
107	19.46	49.6497	0.1734E-01	0.5762E-04	0.000137	0.300776E-03	0.997321
108	19.55	49.4162	-0.1488E-01	-0.4875E-04	0.000116	0.221465E-03	0.997334
109	19.82	48.7370	0.4586E-01	0.1441E-03	0.000343	0.210325E-02	0.997448
110	20.13	48.3000	0.3896E-02	0.1176E-04	0.000028	0.151771E-04	0.997449
111	21.01	48.3000	-0.7625E-01	-0.2113E-03	0.000503	0.581349E-02	0.997766
112	22.12	48.3000	-0.1888E-02	-0.4719E-05	0.000011	0.356385E-05	0.997766
113	22.82	48.3000	-0.1561	-0.3666E-03	0.000873	0.243615E-01	0.999094
114	22.95	48.3000	0.8126E-01	0.1888E-03	0.000450	0.660249E-02	0.999454
115	23.33	48.3000	0.3790E-01	0.8520E-04	0.000203	0.143612E-02	0.999532
116	23.56	48.3000	-0.1477E-04	-0.3256E-07	0.000000	0.218178E-09	0.999532
117	24.54	48.3000	0.5309E-01	0.1079E-03	0.000257	0.281821E-02	0.999686
118	25.32	48.3000	-0.8095E-02	-0.1544E-04	0.000037	0.655358E-04	0.999689
119	25.50	48.3000	-0.2605E-01	-0.4900E-04	0.000117	0.678858E-03	0.999726
120	27.12	48.3000	-0.4065E-01	-0.6763E-04	0.000161	0.165210E-02	0.999816
121	28.24	48.3000	-0.2026E-01	-0.3107E-04	0.000074	0.410510E-03	0.999839
122	28.68	48.3000	0.1435E-01	0.2134E-04	0.000051	0.205893E-03	0.999850
123	29.44	48.3000	0.1900E-01	0.2681E-04	0.000064	0.360825E-03	0.999870
124	29.68	48.3000	-0.4679E-02	-0.6499E-05	0.000015	0.218929E-04	0.999871
125	29.73	48.3000	0.1681E-01	0.2326E-04	0.000055	0.282516E-03	0.999886
126	35.39	48.3000	-0.2776E-01	-0.2712E-04	0.000065	0.770361E-03	0.999928
127	36.41	48.3000	-0.2970E-01	-0.2741E-04	0.000065	0.881949E-03	0.999976
128	40.46	48.3000	0.9028E-02	0.6747E-05	0.000016	0.815084E-04	0.999981
129	40.92	48.3000	0.2053E-02	0.1500E-05	0.000004	0.421335E-05	0.999981
130	42.38	48.3000	-0.8950E-03	-0.6097E-06	0.000001	0.800945E-06	0.999981
131	44.10	48.3000	0.1575E-01	0.9909E-05	0.000024	0.248009E-03	0.999995
132	47.79	48.3000	0.5421E-02	0.2903E-05	0.000007	0.293868E-04	0.999996
133	49.56	48.3000	0.6095E-02	0.3036E-05	0.000007	0.371487E-04	0.999998
134	50.45	48.3000	-0.2396E-02	-0.1152E-05	0.000003	0.574206E-05	0.999999
135	52.57	48.3000	0.2397E-04	0.1061E-07	0.000000	0.574415E-09	0.999999
136	56.02	48.3000	-0.5579E-03	-0.2175E-06	0.000001	0.311235E-06	0.999999
137	57.18	48.3000	0.1105E-03	0.4134E-07	0.000000	0.122012E-07	0.999999
138	61.05	48.3000	-0.1300E-02	-0.4269E-06	0.000001	0.169113E-05	0.999999
139	61.88	48.3000	0.6878E-03	0.2198E-06	0.000001	0.473092E-06	0.999999
140	66.42	48.3000	-0.2495E-02	-0.6920E-06	0.000002	0.622585E-05	0.999999
141	69.62	48.3000	-0.3734E-02	-0.9425E-06	0.000002	0.139414E-04	1.000000
142	71.86	48.3000	0.1453E-02	0.3442E-06	0.000001	0.210997E-05	1.000000
143	79.71	48.3000	-0.5780E-03	-0.1113E-06	0.000000	0.334040E-06	1.000000
144	80.47	48.3000	0.5504E-03	0.1040E-06	0.000000	0.302888E-06	1.000000
145	81.55	48.3000	0.4283E-03	0.7879E-07	0.000000	0.183426E-06	1.000000
146	87.19	48.3000	-0.1088E-03	-0.1750E-07	0.000000	0.118277E-07	1.000000
147	97.59	48.3000	0.4655E-04	0.5980E-08	0.000000	0.216655E-08	1.000000
148	118.3	48.3000	-0.6032E-03	-0.5272E-07	0.000000	0.363822E-06	1.000000
149	148.5	48.3000	0.3719E-04	0.2063E-08	0.000000	0.138329E-08	1.000000
150	166.0	48.3000	-0.2771E-04	-0.1230E-08	0.000000	0.767896E-09	1.000000
				SUM OF EFFECTIVE MASSES=		18.3455	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 1.5000

******************** DUCTILITY LEVEL MODAL ANALYSIS - X DIRECTION ********************

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 21.719

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 48.036	IXX = 0.1032E+08	IXX = 0.9830E+07
YC = -6.1716	IYY = 0.1137E+08	IYY = 0.1083E+08
ZC = 149.41	IZZ = 0.4109E+07	IZZ = 0.4058E+07
	IXY = -0.2216E+06	IXY = -0.2280E+06
	IYZ = -0.2500E+06	IYZ = -0.2700E+06
	IZX = 0.1495E+06	IZX = 0.3054E+06

ONLY THE FIRST REAL CONSTANT MASS TERM IS USED FOR THE STIF21 ELEMENTS.

DUCTILITY LEVEL MODAL ANALYSIS
- X & Y DIRECTIONS
- 50 MDOF

*** MASS SUMMARY BY ELEMENT TYPE ***

TYPE	MASS
1	0.759371
2	0.414356
3	9.48716
4	1.57384
10	9.48441

RANGE OF ELEMENT MAXIMUM STIFFNESS IN GLOBAL COORDINATES

MAXIMUM= 0.136687E+09 AT ELEMENT 264.
MINIMUM= 0.483000E+03 AT ELEMENT 717.

INTEGER STORAGE REQUIREMENTS FOR ELEMENT FORMULATION CP= 112.669 TIME= 14.23389
FIXED DATA = 12734 TEMPORARY DATA = 0 TOTAL= 12734
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

*** ELEMENT STIFFNESS FORMULATION TIMES

TYPE	NUMBER	STIF	TOTAL CP	AVE CP
1	232	4	5.917	0.026
2	57	16	2.050	0.036
3	377	59	12.217	0.032
4	65	63	15.117	0.233
5	6	14	0.000	0.000
6	6	14	0.017	0.003
7	6	14	0.017	0.003
8	6	14	0.033	0.006
9	6	14	0.017	0.003
10	105	21	0.150	0.001

TIME AT END OF ELEMENT STIFFNESS FORMULATION CP= 112.702

MAXIMUM IN-CORE WAVE FRONT ALLOWED FOR REQUESTED MEMORY SIZE= 700.

INTEGER STORAGE REQUIREMENTS FOR WAVE FRONT MATRIX SOLUTION CP= 732.515 TIME= 14.41250
FIXED DATA = 12734 TEMPORARY DATA = 453152 TOTAL= 465886
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

MAXIMUM IN-CORE WAVE FRONT= 474.

MATRIX SOLUTION TIMES
READ IN ELEMENT STIFFNESSES CP= 11.199

NODAL COORD. TRANSFORMATION CP= 1.098
MATRIX TRIANGULARIZATION CP= -27951.791

TIME AT END OF MATRIX TRIANGULARIZATION CP= 732.548
EQUATION SOLVER MAXIMUM PIVOT= 0.20300E+09 AT NODE 525. ROTX
EQUATION SOLVER MINIMUM PIVOT= 31.688 AT NODE 32. UY

TIME AT START OF EIGENVALUE EXTRACTION CP= 732.681

NUMBER OF MODES AVAILABLE FROM REDUCED MATRICES= 50.

EIGENVALUE EXTRACTION TIME CP= 3.917

INTEGER STORAGE REQUIREMENTS FOR EIGENVALUE EXTRACTION CP= 738.398 TIME= 14.41528
FIXED DATA = 12734 TEMPORARY DATA = 12550 TOTAL= 25284
FIXED AVAIL= 1001000 TEMPORARY AVAIL= 1001000 TOTAL AVAIL= 1001000

1 ANSYS - ENGINEERING ANALYSIS SYSTEM REVISION 4.4 ANACAPA COMPUT. MAY 1,1989

FOR SUPPORT CALL RICK BEERS PHONE (805) 652-0655 TWX

platform gina - X direction response spectrum analysis, ductility level 14.4156 NOV 13,1990 CP= 738.581

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE	FREQUENCY (CYCLES/TIME)
1	0.642683394
2	0.797627081
3	0.890690540
4	1.08303411
5	1.30707100
6	1.41063211
7	2.30872811
8	2.46402228
9	2.63157701
10	2.82711815
11	2.91835927
12	3.06793477
13	3.56633957
14	3.65180640
15	3.73989928
16	3.77773801
17	3.88607295
18	3.95729816
19	4.24090504
20	4.31900239
21	4.57452938
22	5.11670726
23	5.22908109
24	5.24288522
25	5.33349370
26	5.34888458
27	5.57121897
28	6.04486821
29	6.21720459
30	6.29872113
31	6.48459241
32	6.58371566
33	6.87467749
34	7.14839916
35	7.33908469
36	7.38647889
37	7.48712228
38	7.58515604
39	7.67770584
40	7.86587970
41	8.09380339
42	8.41922954
43	8.77002049
44	8.95784200
45	9.06598160
46	9.33781637
47	10.1133242
48	10.4075605
49	11.3768352
50	18.4852221

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	2003	UX	0.55430
2	201	UZ	0.31216
3	940	UY	1.0076
4	485	UX	0.11301
5	425	UZ	0.99997E-01
6	922	UZ	0.39026E-01
7	2005	UY	0.57469
8	12	UY	6.3133
9	960	UZ	0.51139E-01
10	501	UX	0.11668
11	448	UX	0.49407
12	2001	UX	0.48958
13	211	UZ	0.22998
14	426	UZ	0.88282E-01
15	460	UY	0.80624
16	822	UY	0.25624
17	468	UX	1.2977
18	583	UX	0.11377
19	222	UX	5.6773
20	4	UZ	3.2070
21	448	UY	0.69123
22	493	UX	0.11719
23	919	UX	1.4080
24	2	UY	0.92523
25	452	UX	0.90263
26	78	UX	6.1228
27	2001	UY	0.65387
28	394	UZ	0.35281E-01
29	464	UY	1.9001
30	825	UY	0.25506
31	466	UY	1.2410
32	68	UY	4.0702
33	11	UY	0.32567E-01
34	316	UZ	1.3846
35	591	UX	0.11839
36	599	UX	0.12475

37	466	UX	0.91683
38	1027	UX	1.4736
39	2005	UX	0.57777
40	446	UX	1.0848
41	937	UZ	0.68876E-01
42	372	UZ	0.52951E-01
43	80	UZ	0.14449
44	1021	UY	1.8059
45	392	UZ	0.38657E-01
46	50	UZ	0.12050
47	420	UZ	0.73607E-01
48	1070	UY	1.7664
49	51	UZ	0.15906
50	1021	UX	1.6733

MASS(X,Y,Z) = 23.38 22.30 6.106

***** RESPONSE SPECTRUM CALCULATION SUMMARY ****** X DIRECTION

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
1	0.6427	125.6382	0.1684E-01	0.1297	0.004748	0.283512E-03	0.121672E-04
*2	0.7976	155.9278	-4.401	-27.32	1.000000	19.3686	0.831231
*3	0.8907	174.1205	0.5560E-01	0.3091	0.011313	0.309084E-02	0.831364
*4	1.083	211.7211	0.2109	0.9642	0.035291	0.444745E-01	0.833272
5	1.307	255.5172	-0.2259E-01	-0.8558E-01	0.003132	0.510345E-03	0.833294
6	1.411	275.7619	0.2923E-01	0.1026	0.003756	0.854501E-03	0.833331
*7	2.309	407.2000	-0.1271	-0.2459	0.008999	0.161446E-01	0.834024
*8	2.464	407.2000	1.733	2.944	0.107746	3.00270	0.962887
9	2.632	407.2000	0.7267E-01	0.1082	0.003962	0.528120E-02	0.963114
*10	2.827	407.2000	-0.2047	-0.2642	0.009668	0.418996E-01	0.964912
*11	2.918	407.2000	0.1323	0.1603	0.005866	0.175111E-01	0.965663
*12	3.068	407.2000	0.4544	0.4980	0.018226	0.206485	0.974525
13	3.566	407.2000	0.7423E-01	0.6020E-01	0.002203	0.551005E-02	0.974761
14	3.652	407.2000	0.2457E-01	0.1901E-01	0.000696	0.603923E-03	0.974787
15	3.740	407.2000	0.9146E-01	0.6745E-01	0.002469	0.836534E-02	0.975146
16	3.778	407.2000	-0.1513	-0.1094	0.004003	0.228986E-01	0.976129
*17	3.886	407.2000	-0.4769	-0.3257	0.011921	0.227421	0.985889
18	3.957	407.2000	-0.9669E-01	-0.6368E-01	0.002331	0.934814E-02	0.986290
19	4.241	407.2000	-0.1955E-02	-0.1121E-02	0.000041	0.382223E-05	0.986290
20	4.319	407.2000	-0.2832E-01	-0.1566E-01	0.000573	0.801891E-03	0.986325
21	4.575	407.2000	0.5108E-01	0.2518E-01	0.000921	0.260905E-02	0.986436
22	5.117	407.2000	0.2092	0.8244E-01	0.003017	0.437821E-01	0.988315
23	5.229	407.2000	-0.1063	-0.4010E-01	0.001468	0.113010E-01	0.988800
24	5.243	407.2000	0.1930	0.7243E-01	0.002651	0.372562E-01	0.990399
25	5.333	407.2000	0.2738	0.9929E-01	0.003634	0.749795E-01	0.993617
26	5.349	407.2000	-0.3070	-0.1107	0.004050	0.942243E-01	0.997661
27	5.571	407.2000	-0.2699E-02	-0.8969E-03	0.000033	0.728407E-05	0.997661
28	6.045	407.2000	-0.2947E-01	-0.8320E-02	0.000305	0.868677E-03	0.997698
29	6.217	407.2000	-0.3221E-01	-0.8595E-02	0.000315	0.103739E-02	0.997743
30	6.299	407.2000	-0.1242E-01	-0.3228E-02	0.000118	0.154196E-03	0.997750
31	6.485	407.2000	-0.4592E-01	-0.1126E-01	0.000412	0.210830E-02	0.997840
32	6.584	407.2000	0.4309E-01	0.1025E-01	0.000375	0.185644E-02	0.997920
33	6.875	407.2000	-0.1123	-0.2450E-01	0.000897	0.126069E-01	0.998461
34	7.148	407.2000	0.3675E-02	0.7417E-03	0.000027	0.135027E-04	0.998461
35	7.339	407.2000	0.2437E-01	0.4667E-02	0.000171	0.593969E-03	0.998487
36	7.386	407.2000	-0.1421E-01	-0.2687E-02	0.000098	0.202043E-03	0.998495
37	7.487	407.2000	-0.3956E-01	-0.7279E-02	0.000266	0.156477E-02	0.998563
38	7.585	407.2000	-0.3800E-01	-0.6812E-02	0.000249	0.144383E-02	0.998625
39	7.678	407.2000	0.2291E-01	0.4010E-02	0.000147	0.525080E-03	0.998647
40	7.866	407.2000	-0.3845E-01	-0.6411E-02	0.000235	0.147876E-02	0.998711
41	8.094	403.3558	-0.3668E-02	-0.5721E-03	0.000021	0.134547E-04	0.998711
42	8.419	390.6233	0.1146	0.1600E-01	0.000586	0.131440E-01	0.999275
43	8.770	377.8616	0.2959E-01	0.3682E-02	0.000135	0.875337E-03	0.999313
44	8.958	371.4023	0.4679E-01	0.5486E-02	0.000201	0.218965E-02	0.999407
45	9.066	367.7935	-0.1154	-0.1308E-01	0.000479	0.133258E-01	0.999979
46	9.338	359.0575	-0.2002E-01	-0.2088E-02	0.000076	0.400729E-03	0.999996
47	10.11	336.4889	0.3474E-03	0.2895E-04	0.000001	0.120691E-06	0.999996
48	10.41	328.7276	-0.5012E-02	-0.3853E-03	0.000014	0.251239E-04	0.999997
49	11.38	305.7515	0.8406E-02	0.5030E-03	0.000018	0.706566E-04	1.000000
50	18.49	205.9870	-0.2918E-03	-0.4455E-05	0.000000	0.851269E-07	1.000000
					SUM OF EFFECTIVE MASSES=	23.3014	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 0.50000E-02

* SIGNIFICANT MODES

***** RESPONSE SPECTRUM CALCULATION SUMMARY ****** Y DIRECTION

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
* 1	0.6427	125.6227	2.326	17.92	0.915729	5.40897	0.244477
* 2	0.7976	155.9075	0.5038E-01	0.3127	0.015983	0.253802E-02	0.244592
* 3	0.8907	174.0973	3.520	19.57	1.000000	12.3895	0.804575
* 4	1.083	211.6917	0.2683	1.226	0.062684	0.719780E-01	0.807829
* 5	1.307	255.4803	-0.4269	-1.617	0.082643	0.182233	0.816065
* 6	1.411	275.7215	-0.6934	-2.434	0.124382	0.480797	0.837797
7	2.309	407.2000	-0.1253E-02	-0.2425E-02	0.000124	0.157048E-05	0.837797
* 8	2.464	407.2000	0.9613E-01	0.1633	0.008347	0.924102E-02	0.838214
* 9	2.632	407.2000	1.736	2.585	0.132126	3.01267	0.974382
10	2.827	407.2000	0.1124E-01	0.1450E-01	0.000741	0.126232E-03	0.974388
11	2.918	407.2000	0.1206E-01	0.1461E-01	0.000747	0.145554E-03	0.974394
12	3.068	407.2000	0.5879E-01	0.6443E-01	0.003293	0.345670E-02	0.974551
* 13	3.566	407.2000	0.5265	0.4270	0.021823	0.277225	0.987081
14	3.652	407.2000	0.3810E-01	0.2947E-01	0.001506	0.145198E-02	0.987146
15	3.740	407.2000	-0.6654E-02	-0.4907E-02	0.000251	0.442794E-04	0.987148
16	3.778	407.2000	0.1496E-01	0.1081E-01	0.000553	0.223821E-03	0.987159
17	3.886	407.2000	-0.1086E-01	-0.7417E-02	0.000379	0.117940E-03	0.987164
18	3.957	407.2000	0.1887E-01	0.1243E-01	0.000635	0.355914E-03	0.987180
19	4.241	407.2000	0.2539E-02	0.1456E-02	0.000074	0.644583E-05	0.987180
20	4.319	407.2000	0.1168E-01	0.6457E-02	0.000330	0.136351E-03	0.987186
21	4.575	407.2000	0.8581E-02	0.4230E-02	0.000216	0.736384E-04	0.987190
22	5.117	407.2000	0.5348E-01	0.2107E-01	0.001077	0.285994E-02	0.987319
* 23	5.229	407.2000	-0.4458	-0.1682	0.008595	0.198768	0.996303
24	5.243	407.2000	0.1081	0.4056E-01	0.002073	0.116857E-01	0.996831
25	5.333	407.2000	0.2857E-01	0.1036E-01	0.000529	0.816374E-03	0.996868
26	5.349	407.2000	-0.1685	-0.6076E-01	0.003105	0.284054E-01	0.998152
27	5.571	407.2000	0.3867E-01	0.1285E-01	0.000657	0.149514E-02	0.998220
28	6.045	407.2000	-0.7494E-02	-0.2115E-02	0.000108	0.561632E-04	0.998222
29	6.217	407.2000	0.3115E-01	0.8312E-02	0.000425	0.970256E-03	0.998266
30	6.299	407.2000	0.6285E-01	0.1634E-01	0.000835	0.395075E-02	0.998445
31	6.485	407.2000	0.2614E-01	0.6412E-02	0.000328	0.683368E-03	0.998475
32	6.584	407.2000	-0.1426	-0.3394E-01	0.001735	0.203403E-01	0.999395
33	6.875	407.2000	0.3683E-01	0.8038E-02	0.000411	0.135654E-02	0.999456
34	7.148	407.2000	-0.2284E-03	-0.4610E-04	0.000002	0.521698E-07	0.999456
35	7.339	407.2000	-0.7231E-02	-0.1385E-02	0.000071	0.522906E-04	0.999458
36	7.386	407.2000	0.1523E-01	0.2879E-02	0.000147	0.231896E-03	0.999469
37	7.487	407.2000	0.3074E-01	0.5656E-02	0.000289	0.944828E-03	0.999512
38	7.585	407.2000	0.3257E-01	0.5839E-02	0.000298	0.106071E-02	0.999560
39	7.678	407.2000	0.3050E-02	0.5336E-03	0.000027	0.930063E-05	0.999560
40	7.866	407.2000	0.2411E-01	0.4020E-02	0.000205	0.581478E-03	0.999586
41	8.094	403.3558	-0.1567E-01	-0.2444E-02	0.000125	0.245655E-03	0.999597
42	8.419	390.6233	0.3181E-01	0.4440E-02	0.000227	0.101156E-02	0.999643
43	8.770	377.8616	-0.8684E-01	-0.1081E-01	0.000552	0.754127E-02	0.999984
44	8.958	371.4023	-0.5854E-03	-0.6863E-04	0.000004	0.342651E-06	0.999984
45	9.066	367.7935	0.6344E-02	0.7191E-03	0.000037	0.402475E-04	0.999986
46	9.338	359.0575	0.9366E-02	0.9769E-03	0.000050	0.877191E-04	0.999990
47	10.11	336.4889	-0.1146E-01	-0.9553E-03	0.000049	0.131414E-03	0.999996
48	10.41	328.7276	-0.9450E-02	-0.7264E-03	0.000037	0.892941E-04	1.000000
49	11.38	305.7515	-0.2218E-02	-0.1327E-03	0.000007	0.492081E-05	1.000000
50	18.49	205.9870	0.1198E-02	0.1829E-04	0.000001	0.143522E-05	1.00000
				SUM OF EFFECTIVE MASSES=		22.1247	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 0.50000E-02

* SIGNIFICANT MODES

***** EIGENVALUE (NATURAL FREQUENCY) SOLUTION *****

MODE	FREQUENCY (CYCLES/TIME)
1	0.642649373
2	0.797320421
3	0.889834284
4	1.08089136
5	1.30679919
6	1.40979430
7	2.30761672
8	2.43846108
9	2.64161463
10	2.77620408
11	2.87619475
12	3.02590349
13	3.14166384
14	3.55204929
15	3.69938345
16	3.74449911
17	3.77412830
18	3.86985495
19	4.06658605
20	4.23960077
21	4.31177611
22	4.42559893
23	4.71145553
24	4.87340498
25	5.07518807
26	5.22644827
27	5.23977201
28	5.29396273
29	5.47068948
30	5.85479033
31	6.02080761
32	6.16330907
33	6.33318342
34	6.34213203
35	6.43174308
36	6.60128963
37	6.66936185
38	6.75368684
39	6.96658976
40	7.14833349
41	7.38073135
42	7.52735347
43	7.61040810
44	7.68336257
45	7.75246327
46	7.90485290
47	7.97945845
48	7.99541937
49	8.16322759
50	8.26150604
51	8.41464494
52	8.55037864
53	8.63464220
54	8.92097149
55	8.96690508
56	9.09172449
57	9.21688642
58	9.35412349
59	9.44994208
60	9.52099513
61	9.52468599
62	9.65489574
63	9.96565166
64	10.2347747
65	10.4112597
66	10.6310262
67	10.7852076
68	11.4856596
69	11.7924269
70	11.8807760
71	12.1026065
72	12.2570054
73	12.3762230
74	12.7785921
75	12.8524513
76	12.9685908
77	13.6395797
78	13.7825656
79	13.8903715
80	14.0656911
81	14.0656911
82	14.0656911
83	14.0656911
84	14.0656911
85	14.0656911
86	14.0656911
87	14.0656911
88	14.0656911
89	14.0656911
90	14.0656911
91	14.0656911
92	14.0656911
93	14.0656911
94	14.0656911

DUCTILITY
LEVEL
MODAL
ANALYSIS

- Z DIRECTION

- 150 MDOF INCLUDING
ALL LUMPED MASSES
IN "Z" DIRECTION

95	14.2699831
96	14.5783030
97	14.8221664
98	15.5782449
99	15.7859772
100	15.9972988
101	16.4343053
102	16.8469130
103	17.4865116
104	17.5537312
105	17.8748226
106	18.5410979
107	19.3877294
108	19.5374408
109	19.7765043
110	20.1221874
111	20.8500497
112	22.0980897
113	22.2479254
114	22.7286390
115	23.1616918
116	23.4196262
117	24.3614342
118	24.9614450
119	25.3350623
120	26.9200438
121	28.1893137
122	28.6183388
123	29.2175663
124	29.6704586
125	29.6958776
126	34.8051518
127	35.8620973
128	39.7379389
129	40.9026737
130	42.1824347
131	43.9305795
132	47.7644589
133	49.4391540
134	50.4415793
135	52.5553280
136	55.9491015
137	57.0866154
138	61.0415422
139	61.8065097
140	66.0323753
141	69.5539199
142	71.8781016
143	79.7132204
144	80.4716969
145	81.5515101
146	87.1908609
147	97.5886236
148	118.040862
149	148.530914
150	166.040533

***** REDUCED MASS DISTRIBUTION *****

ROW	NODE	DIR	VALUE
1	402	UZ	0.15593E-01
2	7	UZ	0.32008
3	125	UZ	0.11542
4	51	UZ	0.58221E-01
5	316	UZ	0.26284
6	149	UZ	-0.83435E-01
7	960	UZ	0.45374E-01
8	745	UZ	0.38962E-01
9	752	UZ	0.48094E-01
10	68	UZ	0.40243
11	957	UX	1.0912
12	45	UZ	0.30178E-02
13	58	UZ	0.34683E-01
14	80	UZ	0.17660
15	338	UZ	0.24349
16	2802	UZ	0.84733E-01
17	65	UZ	0.51853
18	198	UZ	0.84548E-01
19	599	UX	0.68673E-01
20	178	UZ	0.91716E-02
21	152	UZ	0.28558
22	493	UX	0.11994
23	130	UZ	-0.18231
24	49	UZ	0.65086E-01
25	34	UZ	0.64614E-01
26	2	UZ	0.95119
27	66	UZ	0.20275
28	2791	UZ	0.84733E-01
29	2005	UX	0.52101
30	84	UZ	-0.17096
31	2	UY	0.92328
32	2005	UY	0.65144
33	458	UX	1.4538
34	14	UZ	-0.61350
35	489	UX	0.57690E-01
36	194	UZ	0.18737

37	15	UZ	0.30033E-01
38	213	UZ	0.13717
39	25	UZ	0.61393E-01
40	174	UZ	1.7507
41	183	UZ	-0.24616
42	2864	UZ	0.84733E-01
43	453	UZ	0.75665
44	1027	UX	1.4591
45	937	UZ	0.68842E-01
46	13	UZ	0.11505
47	2799	UZ	0.84733E-01
48	78	UZ	0.61077E-01
49	2795	UZ	0.84733E-01
50	6	UZ	0.32503
51	63	UZ	0.81440E-02
52	68	UY	4.1546
53	449	UZ	0.89855
54	392	UZ	0.48730E-01
55	59	UZ	0.14043
56	2796	UZ	0.84733E-01
57	180	UZ	0.33415E-01
58	2840	UZ	0.84733E-01
59	425	UZ	0.10391
60	1070	UY	1.7759
61	98	UZ	0.13231
62	394	UZ	0.38764E-01
63	420	UZ	0.62496E-01
64	200	UZ	0.33659
65	426	UZ	0.10741
66	30	UZ	-0.19065E-02
67	222	UX	5.7231
68	922	UZ	0.41106E-01
69	176	UZ	0.10188E-01
70	448	UY	0.64890
71	2800	UZ	0.84733E-01
72	2792	UZ	0.84733E-01
73	151	UZ	0.22952
74	506	UX	0.12904
75	196	UZ	0.35307
76	212	UZ	0.12127
77	372	UZ	0.54532E-01
78	61	UZ	-0.74307E-01
79	47	UZ	0.88004E-01
80	825	UZ	0.14298
81	154	UZ	-0.23479
82	448	UX	0.53379
83	5	UZ	0.55035E-01
84	2839	UZ	0.84733E-01
85	75	UZ	0.49936
86	919	UX	0.99444
87	825	UY	0.25423
88	211	UZ	0.95089E-01
89	485	UX	0.12803
90	310	UZ	0.83155E-01
91	11	UY	0.32324E-01
92	150	UZ	-0.46392E-01
93	28	UZ	0.10028
94	46	UZ	0.32397E-01
95	162	UZ	0.57327E-01
96	70	UZ	-0.20161
97	48	UZ	-0.18947E-01
98	193	UZ	-0.34773E-01
99	2798	UZ	0.84733E-01
100	501	UX	0.11218
101	940	UY	1.1445
102	463	UZ	0.60066
103	2868	UZ	0.84733E-01
104	126	UZ	0.39222
105	460	UX	0.74059
106	460	UY	0.93780
107	452	UX	0.99982
108	452	UY	0.99445
109	457	UZ	0.24664
110	462	UY	0.91739
111	2001	UX	0.51576
112	822	UZ	0.19650
113	132	UZ	-0.11865
114	175	UZ	0.64131E-02
115	466	UX	0.84155
116	466	UY	1.1778
117	201	UZ	0.11705
118	822	UY	0.25537
119	50	UZ	0.57870E-01
120	336	UZ	0.15456E-01
121	24	UZ	0.27774E-01
122	2797	UZ	0.84733E-01
123	173	UZ	1.0001
124	4	UZ	1.4119
125	498	UX	0.12581
126	179	UZ	0.58278E-01
127	108	UZ	0.10294
128	52	UZ	0.39685E-01
129	2860	UZ	0.84733E-01
130	177	UZ	0.33890E-01
131	12	UY	6.5887
132	11	UZ	0.13766
133	9	UZ	0.54226E-01
134	67	UZ	0.30158
135	315	UZ	0.15799
136	206	UZ	0.49134

137	210	UZ	0.26557E-01
138	22	UZ	0.27070
139	20	UZ	0.45045
140	1	UZ	0.88644
141	78	UX	6.0470
142	1021	UY	2.0153
143	1021	UX	1.6446
144	2801	UZ	0.84733E-01
145	19	UZ	0.29202
146	16	UZ	-0.31624
147	12	UZ	0.89757
148	23	UZ	0.18069E-01
149	60	UZ	0.74692E-01
150	72	UZ	0.28427

MASS(X,Y,Z) = 23.31 22.47 18.89

***** RESPONSE SPECTRUM CALCULATION SUMMARY ****** Z DIRECTION

MODE	FREQUENCY	SV	PARTIC.FACTOR	MODE COEF.	M.C. RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION
1	0.6426	62.8087	-0.2019E-02	-0.7777E-02	0.005811	0.407599E-05	0.215398E-06
2	0.7973	77.9267	0.1487E-01	0.4616E-01	0.034488	0.221001E-03	0.118943E-04
3	0.8898	86.9695	-0.1289E-01	-0.3587E-01	0.026798	0.166188E-03	0.206766E-04
4	1.081	105.6445	0.3203E-01	0.7336E-01	0.054810	0.102577E-02	0.748842E-04
5	1.307	127.7263	-0.6395E-02	-0.1212E-01	0.009053	0.408982E-04	0.770455E-04
6	1.410	137.7939	0.5699E-02	0.1001E-01	0.007477	0.324737E-04	0.787616E-04
*7	2.308	203.6000	-0.7521	-0.7284	0.544256	0.565713	0.299741E-01
*8	2.438	203.6000	-0.1083	-0.9393E-01	0.070180	0.117281E-01	0.305939E-01
9	2.642	203.6000	0.4319E-01	0.3192E-01	0.023850	0.186540E-02	0.306925E-01
10	2.776	203.6000	-0.4895E-01	-0.3276E-01	0.024474	0.239640E-02	0.308191E-01
11	2.876	203.6000	-0.9294E-01	-0.5794E-01	0.043290	0.863740E-02	0.312756E-01
12	3.026	203.6000	-0.1097	-0.6182E-01	0.046187	0.120449E-01	0.319121E-01
13	3.142	203.6000	-0.2818E-01	-0.1473E-01	0.011003	0.794355E-03	0.319541E-01
*14	3.552	203.6000	-0.4090	-0.1672	0.124912	0.167286	0.407944E-01
*15	3.699	203.6000	-3.552	-1.338	1.000000	12.6140	0.707386
*16	3.744	203.6000	-0.6780	-0.2494	0.186330	0.459699	0.731679
*17	3.774	203.6000	-0.5300	-0.1919	0.143383	0.280930	0.746525
18	3.870	203.6000	-0.5742E-02	-0.1977E-02	0.001477	0.329702E-04	0.746526
*19	4.067	203.6000	1.085	0.3385	0.252927	1.17827	0.808793
20	4.240	203.6000	0.9539E-01	0.2737E-01	0.020450	0.909993E-02	0.809274
21	4.312	203.6000	-0.2443	-0.6777E-01	0.050634	0.596813E-01	0.812428
*22	4.426	203.6000	1.084	0.2854	0.213264	1.17505	0.874524
23	4.711	203.6000	-0.5132E-01	-0.1192E-01	0.008909	0.263390E-02	0.874663
*24	4.873	203.6000	-0.4470	-0.9706E-01	0.072522	0.199804	0.885222
25	5.075	203.6000	-0.3095	-0.6197E-01	0.046303	0.957993E-01	0.890285
26	5.226	203.6000	0.3771	0.7119E-01	0.053191	0.142178	0.897798
27	5.240	203.6000	0.2957	0.5555E-01	0.041507	0.874634E-01	0.902420
28	5.294	203.6000	0.8802E-01	0.1620E-01	0.012103	0.774835E-02	0.902829
29	5.471	203.6000	-0.6444E-02	-0.1110E-02	0.000830	0.415191E-04	0.902832
30	5.855	203.6000	-0.2796	-0.4206E-01	0.031427	0.781624E-01	0.906962
31	6.021	203.6000	-0.8848E-01	-0.1259E-01	0.009405	0.782789E-02	0.907376
32	6.163	203.6000	-0.7790E-01	-0.1058E-01	0.007902	0.606866E-02	0.907697
33	6.333	203.6000	-0.1397E-01	-0.1797E-02	0.001342	0.195249E-03	0.907707
34	6.342	203.6000	-0.3963E-01	-0.5081E-02	0.003797	0.157067E-02	0.907790
35	6.432	203.6000	-0.8370E-01	-0.1043E-01	0.007796	0.700545E-02	0.908160
36	6.601	203.6000	0.9404E-01	0.1113E-01	0.008315	0.884321E-02	0.908627
37	6.669	203.6000	-0.3728E-01	-0.4322E-02	0.003230	0.138984E-02	0.908701
38	6.754	203.6000	0.1584	0.1791E-01	0.013383	0.250945E-01	0.910027
39	6.967	203.6000	-0.1645	-0.1748E-01	0.013064	0.270752E-01	0.911458
40	7.148	203.6000	-0.1322E-01	-0.1335E-02	0.000997	0.174900E-03	0.911467
41	7.381	203.6000	-0.3365	-0.3185E-01	0.023801	0.113216	0.917450
42	7.527	203.6000	0.8438E-02	0.7681E-03	0.000574	0.712074E-04	0.917454
43	7.610	203.6000	0.9249E-02	0.8235E-03	0.000615	0.855364E-04	0.917458
44	7.683	203.6000	0.7397E-03	0.6462E-04	0.000048	0.547171E-06	0.917458
45	7.752	203.6000	0.7197E-01	0.6176E-02	0.004614	0.518003E-02	0.917732
46	7.905	203.6000	-0.1839	-0.1517E-01	0.011337	0.338010E-01	0.919518
47	7.979	203.6000	0.1378E-01	0.1116E-02	0.000834	0.189977E-03	0.919528
48	7.995	203.6000	0.1869	0.1508E-01	0.011268	0.349484E-01	0.921375
49	8.163	200.2812	-0.7781E-01	-0.5924E-02	0.004426	0.605502E-02	0.921695
50	8.262	198.3404	0.1265E-01	0.9313E-03	0.000696	0.160062E-03	0.921704
51	8.415	195.3982	-0.1823	-0.1274E-01	0.009520	0.332285E-01	0.923460
52	8.550	192.8705	-0.6901E-01	-0.4612E-02	0.003446	0.476272E-02	0.923711
53	8.635	191.3376	0.1212E-01	0.7878E-03	0.000589	0.146880E-03	0.923719
54	8.921	186.3254	-0.2140E-01	-0.1269E-02	0.000948	0.457958E-03	0.923743
55	8.967	185.5484	-0.1950E-01	-0.1140E-02	0.000852	0.380268E-03	0.923763
56	9.092	183.4730	-0.5221E-01	-0.2936E-02	0.002193	0.272603E-02	0.923907
57	9.217	181.4431	-0.9999E-01	-0.5409E-02	0.004042	0.999729E-02	0.924436
58	9.354	179.2740	0.1360	0.7058E-02	0.005274	0.184961E-01	0.925413
59	9.450	177.7935	0.5537E-01	0.2793E-02	0.002087	0.306633E-02	0.925575
60	9.521	176.7132	-0.2718E-01	-0.1342E-02	0.001003	0.738806E-03	0.925614
61	9.525	176.6574	-0.3364E-01	-0.1659E-02	0.001240	0.113160E-02	0.925674
62	9.655	174.7164	0.1509	0.7166E-02	0.005354	0.227791E-01	0.926878
63	9.966	170.2702	0.3870E-01	0.1681E-02	0.001256	0.149774E-02	0.926957
64	10.23	166.6181	-0.4667E-01	-0.1880E-02	0.001405	0.217821E-02	0.927072
65	10.41	164.3163	0.1067E-01	0.4096E-03	0.000306	0.113775E-03	0.927078
66	10.63	161.5470	-0.4662E-01	-0.1688E-02	0.001261	0.217329E-02	0.927193
67	10.79	159.6653	0.1895E-01	0.6588E-03	0.000492	0.359023E-03	0.927212
68	11.49	151.6961	0.7669E-01	0.2234E-02	0.001669	0.588154E-02	0.927523
69	11.79	148.4772	0.1085E-01	0.2934E-03	0.000219	0.117672E-03	0.927529
70	11.88	147.5782	0.8518E-01	0.2256E-02	0.001685	0.725486E-02	0.927912
71	12.10	145.3734	0.1511E-02	0.3798E-04	0.000028	0.228216E-05	0.927912
72	12.26	143.8816	-0.7394E-01	-0.1794E-02	0.001340	0.546703E-02	0.928201
73	12.38	142.7528	-0.2156E-01	-0.5089E-03	0.000380	0.464632E-03	0.928226
74	12.78	139.0844	-0.2762E-01	-0.5959E-03	0.000445	0.762733E-03	0.928266
75	12.85	138.4337	0.2305E-01	0.4893E-03	0.000366	0.531335E-03	0.928294
76	12.97	137.4241	-0.5275E-01	-0.1092E-02	0.000816	0.278207E-02	0.928441
77	13.64	131.8974	-0.2489E-01	-0.4469E-03	0.000334	0.619359E-03	0.928474

78	13.78	130.7829	-0.1107	-0.1931E-02	0.001443	0.122622E-01	0.929122
79	13.89	129.9564	0.1316E-01	0.2245E-03	0.000168	0.173133E-03	0.929131
80	14.07	128.6368	-0.6104	-0.1005E-01	0.007511	0.372608	0.948822
81	14.07	128.6368	0.2530	0.4167E-02	0.003114	0.640180E-01	0.952205
82	14.07	128.6368	0.4711	0.7760E-02	0.005798	0.221981	0.963936
83	14.07	128.6368	0.4457E-01	0.7341E-03	0.000548	0.198667E-02	0.964041
84	14.07	128.6368	-0.3805	-0.6267E-02	0.004683	0.144812	0.971693
85	14.07	128.6368	-0.1400	-0.2306E-02	0.001723	0.196030E-01	0.972729
86	14.07	128.6368	0.1914	0.3152E-02	0.002355	0.366271E-01	0.974665
87	14.07	128.6368	0.4586	0.7554E-02	0.005644	0.210346	0.985781
88	14.07	128.6368	-0.4058	-0.6683E-02	0.004994	0.164670	0.994483
89	14.07	128.6368	0.9127E-01	0.1503E-02	0.001123	0.832990E-02	0.994923
90	14.07	128.6368	0.1240	0.2042E-02	0.001526	0.153774E-01	0.995736
91	14.07	128.6368	-0.7164E-03	-0.1180E-04	0.000009	0.513253E-06	0.995736
92	14.07	128.6368	0.8055E-02	0.1327E-03	0.000099	0.648773E-04	0.995739
93	14.07	128.6368	0.9618E-02	0.1584E-03	0.000118	0.925131E-04	0.995744
94	14.07	128.6368	0.1026	0.1689E-02	0.001262	0.105175E-01	0.996300
95	14.27	127.1363	0.1773E-01	0.2804E-03	0.000210	0.314419E-03	0.996316
96	14.58	124.9441	0.6298E-01	0.9378E-03	0.000701	0.396622E-02	0.996526
97	14.82	123.2689	0.5127E-01	0.7287E-03	0.000544	0.262846E-02	0.996665
98	15.58	118.3783	0.3833E-01	0.4736E-03	0.000354	0.146942E-02	0.996742
99	15.79	117.1092	-0.8871E-01	-0.1056E-02	0.000789	0.786862E-02	0.997158
100	16.00	115.8488	0.7230E-01	0.8290E-03	0.000619	0.522732E-02	0.997435
101	16.43	113.3359	0.1638E-02	0.1742E-04	0.000013	0.268451E-05	0.997435
102	16.85	111.0721	0.2324E-01	0.2304E-03	0.000172	0.540268E-03	0.997463
103	17.49	107.7549	-0.1284	-0.1146E-02	0.000857	0.164926E-01	0.998335
104	17.55	107.4191	0.6648E-01	0.5871E-03	0.000439	0.442006E-02	0.998568
105	17.87	105.8463	0.4643E-01	0.3896E-03	0.000291	0.215608E-02	0.998682
106	18.54	102.7409	-0.1858E-01	-0.1407E-03	0.000105	0.345280E-03	0.998701
107	19.39	99.0751	0.1557E-01	0.1040E-03	0.000078	0.242530E-03	0.998713
108	19.54	98.4569	-0.9594E-02	-0.6268E-04	0.000047	0.920488E-04	0.998718
109	19.78	97.4874	0.3449E-01	0.2178E-03	0.000163	0.118977E-02	0.998781
110	20.12	96.6000	0.1372E-02	0.8290E-05	0.000006	0.188182E-05	0.998781
111	20.85	96.6000	-0.7214E-01	-0.4061E-03	0.000303	0.520432E-02	0.999056
112	22.10	96.6000	0.2361E-01	0.1183E-03	0.000088	0.557370E-03	0.999086
113	22.25	96.6000	0.1110	0.5489E-03	0.000410	0.123273E-01	0.999737
114	22.73	96.6000	0.2910E-01	0.1378E-03	0.000103	0.846664E-03	0.999782
115	23.16	96.6000	0.3711E-02	0.1693E-04	0.000013	0.137732E-04	0.999783
116	23.42	96.6000	0.1430E-01	0.6380E-04	0.000048	0.204532E-03	0.999793
117	24.36	96.6000	-0.3608E-01	-0.1487E-03	0.000111	0.130145E-02	0.999862
118	24.96	96.6000	-0.2884E-03	-0.1133E-05	0.000001	0.831884E-07	0.999862
119	25.34	96.6000	0.2160E-01	0.8234E-04	0.000062	0.466556E-03	0.999887
120	26.92	96.6000	0.2604E-01	0.8791E-04	0.000066	0.677879E-03	0.999923
121	28.19	96.6000	0.1244E-01	0.3829E-04	0.000029	0.154634E-03	0.999931
122	28.62	96.6000	-0.6621E-02	-0.1978E-04	0.000015	0.438349E-04	0.999933
123	29.22	96.6000	0.1177E-01	0.3375E-04	0.000025	0.138638E-03	0.999940
124	29.67	96.6000	-0.3845E-02	-0.1069E-04	0.000008	0.147828E-04	0.999941
125	29.70	96.6000	-0.9946E-02	-0.2760E-04	0.000021	0.989181E-04	0.999946
126	34.81	96.6000	-0.2202E-01	-0.4449E-04	0.000033	0.485035E-03	0.999972
127	35.86	96.6000	-0.1882E-01	-0.3581E-04	0.000027	0.354205E-03	0.999991
128	39.74	96.6000	0.5685E-02	0.8809E-05	0.000007	0.323168E-04	0.999993
129	40.90	96.6000	0.1614E-02	0.2360E-05	0.000002	0.260456E-05	0.999993
130	42.18	96.6000	0.1554E-02	0.2137E-05	0.000002	0.241575E-05	0.999993
131	43.93	96.6000	-0.9864E-02	-0.1251E-04	0.000009	0.973078E-04	0.999998
132	47.76	96.6000	-0.3466E-02	-0.3717E-05	0.000003	0.120099E-04	0.999999
133	49.44	96.6000	-0.3814E-02	-0.3818E-05	0.000003	0.145460E-04	0.999999
134	50.44	96.6000	-0.1345E-02	-0.1294E-05	0.000001	0.180925E-05	0.999999
135	52.56	96.6000	-0.7540E-04	-0.6680E-07	0.000000	0.568492E-08	0.999999
136	55.95	96.6000	0.4311E-03	0.3370E-06	0.000000	0.185862E-06	0.999999
137	57.09	96.6000	-0.5100E-04	-0.3829E-07	0.000000	0.260070E-08	0.999999
138	61.04	96.6000	0.8375E-03	0.5500E-06	0.000000	0.701362E-06	0.999999
139	61.81	96.6000	-0.3546E-03	-0.2272E-06	0.000000	0.125766E-06	0.999999
140	66.03	96.6000	0.1812E-02	0.1017E-05	0.000001	0.328211E-05	1.000000
141	69.55	96.6000	0.2305E-02	0.1166E-05	0.000001	0.531382E-05	1.000000
142	71.88	96.6000	-0.8998E-03	-0.4262E-06	0.000000	0.809710E-06	1.000000
143	79.71	96.6000	-0.3719E-03	-0.1432E-06	0.000000	0.138286E-06	1.000000
144	80.47	96.6000	-0.3490E-03	-0.1319E-06	0.000000	0.121835E-06	1.000000
145	81.55	96.6000	-0.2713E-03	-0.9980E-07	0.000000	0.735799E-07	1.000000
146	87.19	96.6000	-0.6961E-04	-0.2241E-07	0.000000	0.484602E-08	1.000000
147	97.59	96.6000	0.3041E-04	0.7813E-08	0.000000	0.924769E-09	1.000000
148	118.0	96.6000	-0.3957E-03	-0.6948E-07	0.000000	0.156556E-06	1.000000
149	148.5	96.6000	0.2377E-04	0.2637E-08	0.000000	0.565080E-09	1.000000
150	166.0	96.6000	-0.1769E-04	-0.1570E-08	0.000000	0.312937E-09	1.00000
				SUM OF EFFECTIVE MASSES=		18.9231	

SIGNIFICANCE FACTOR FOR EXPANDED MODES = 0.70000E-01

* SIGNIFICANT MODES