SUBSTRUCTURE AND FOUNDATION

DESIGN BASIS

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Professional Certification. I hereby certify that these documents were prepared or approved by me, and that I am a duly licensed professional engineer under the laws of the State of Maryland, License No.41686, Expiration Date:2018-03-04.

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1 INTRODUCTION

1.1 General

This document has been prepared by Keystone Engineering Inc. (KEI) for US Wind to document and describe the criteria and methodology to perform the detailed engineering design of a met mast substructure and foundation for the Maryland Offshore Wind Energy Area Farm located approximately 11.5 miles from Ocean City, Maryland as depicted in Figure 1-1:

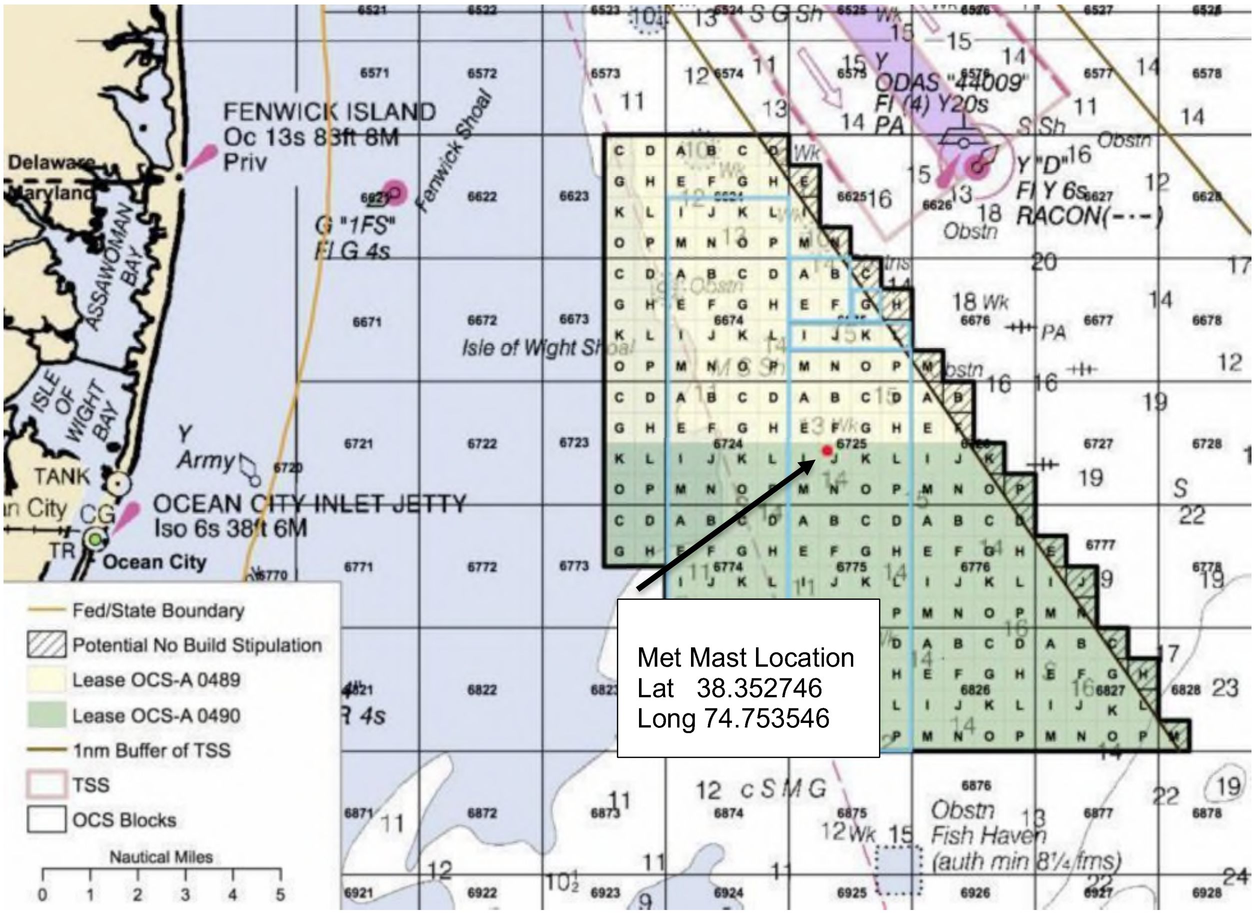

Figure 1-1: Maryland Offshore Wind Farm Location

1.2 Scope

The scope of this project is to perform the detailed engineering design of the foundation and substructure. This includes the following tasks:

- Design of the met mast foundation and substructure
- Design of equipment deck including equipment mounts
- Provide davit crane specifications
- Design of fendering and access/egress systems
- Design of ancillary structures, including safety and platform identification signage
- Design of power, lighting and navigational aid system

1.3 Objective

The objective of this document is to present the criteria and methodology for the detailed analysis and engineering design of the met mast substructure and foundation. This will include the design of the met mast substructure, foundation and associated secondary steel. The design of the power, lighting and navigational aid system will be addressed in a separate design basis document.

2 DESIGN PREMISES

2.1 Design Code

The met mast support structure, consisting of substructure and foundation, shall meet all applicable regulatory requirements of the State of Maryland, United States Bureau of Ocean Energy Management (BOEM), the United States Coast Guard (USCG), the Environmental Protection Agency (EPA), the Federal Aviation Administration (FAA), the Occupational Safety and Health Administration (OSHA), United States Bureau of Safety and Environmental Enforcement (BSEE) and other federal regulatory requirements for operation.

The support structure design shall conform to guidelines outlined in AWEA OCRP 2012 [1], which refers to API RP 2A Working Stress Design (WSD) [2] as a recognized offshore standard for the U.S. Outer Continental Shelf (OCS) and State waters. Hence the support structure will be designed in accordance with API RP 2A [2] and its normative references such as the AISC 335-89 [3], API RP 2MET [4], API RP 2GEO [5], API Spec 2C [6], AWS D1.1 [7] and others.

The edition of industry codes, standards, and specifications in effect on October 1, 2015 shall apply unless otherwise stated:

2.2 Design Life

The design life for the substructure and foundation, including ancillary equipment, shall be 30 years.

2.3 Reference Datum

All elevations shall be relative to Mean Lower Low Water (MLLW). The local coordinate system of the met mast substructure and assembly elevation are depicted in Figures 2.1 and 2.2 respectively.

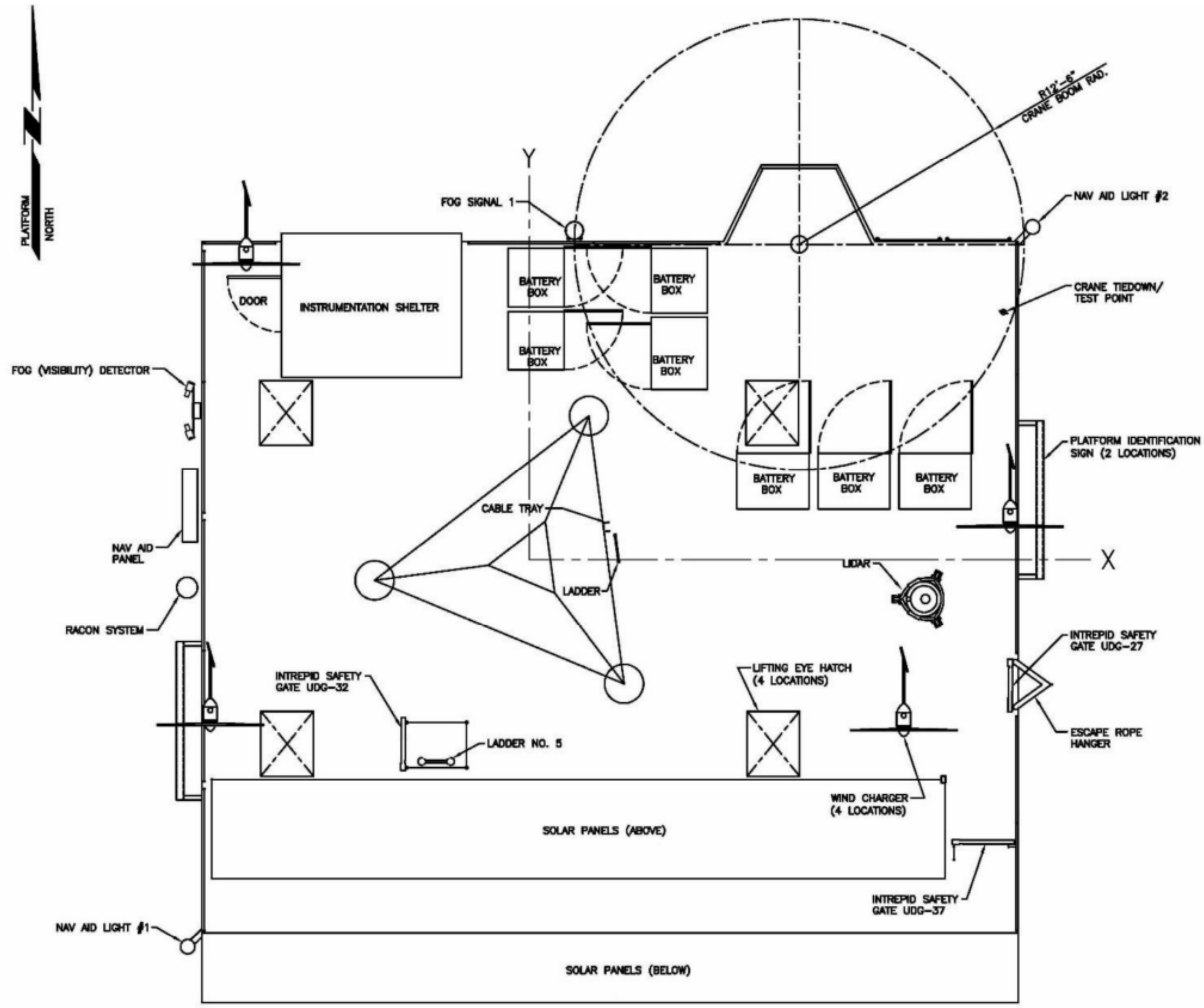

Figure 2-1: Coordinate System Met Mast Substructure

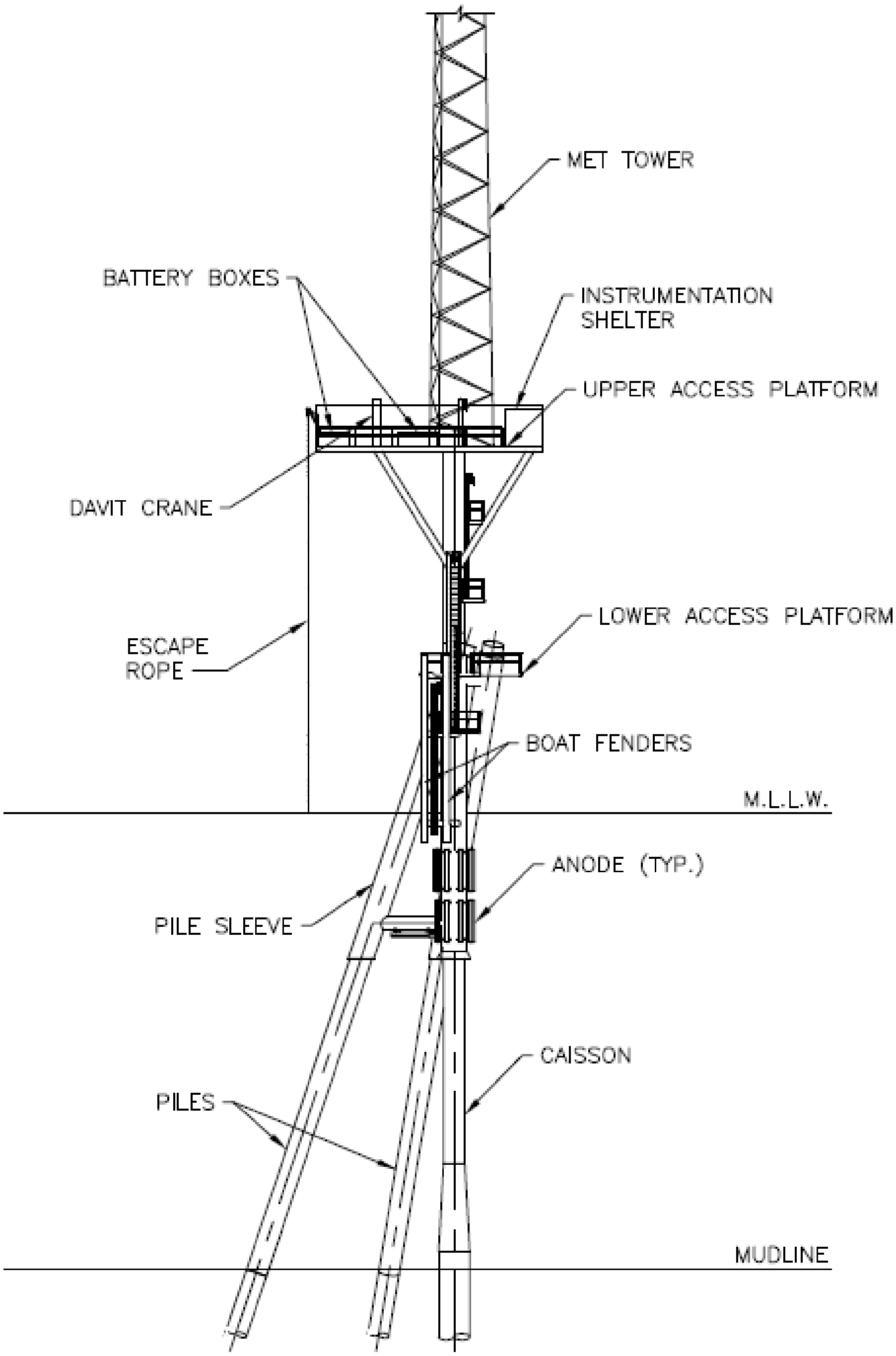

Figure 2-2: Met Mast Substructure Assembly Elevation

2.4 Design Load Cases

The analysis cases considered for the detailed design of primary steel shall be:

1. Operational Analysis

   The purpose of this analysis is to demonstrate that the substructure and foundation can resist operating metocean conditions with a return period of 1 year without exceeding the allowable capacity of any primary steel members or joints, and without exceeding the foundation allowable axial load capacity with a minimum safety factor of 2.0.

2. Design Analysis

   The purpose of this analysis is to demonstrate that the substructure and foundation can resist metocean conditions with a return period of 50 years without exceeding the allowable capacity of any primary steel members or joints, and without exceeding the foundation allowable axial load capacity with a minimum safety factor of 1.5. Allowable stresses may be increased by 33% for the design analysis.

3. Robustness Check

   The purpose of this analysis is to demonstrate that the substructure and foundation will resist metocean conditions with a return period of 500 years without failure or collapse as defined in API RP 2SIM [8]. The robustness analysis is performed with safety factors removed (safety factors = 1.0) per API RP 2A [2] and API RP 2SIM [8].

4. Fatigue

   The purpose of this analysis is to confirm that the main structural steel weld connections and the primary steel members have a predicted fatigue life greater than the design life stated in Section 2.2 of this document with appropriate safety factors per API RP 2A [2]. Fatigue loads exerted by the met mast on the substructure are considered negligible and will not be included in the fatigue analysis.

For the detailed design of secondary steel, the applicable operational and design load cases shall be analyzed.

2.5 Analysis Software

Bentley Systems SACS V8i 5.7 structural analysis package will be used to develop a space frame model that represents the mass and stiffness of the primary steel members of the support structure. The foundation members (i.e. piles and caisson) are represented by non-linear pile-soil interactions along the length of the piles and caisson. SACS is used to generate metocean loads (wind, wave, current). Wave loading is calculated by discretely stepping waves through the structure.

2.6 Units

All dimensions on drawings and 3-D model will be in U.S customary units.

3 SITE SPECIFIC METOCEAN CONDITIONS

The metocean conditions included in this section are based on A.H Glenn metocean reports for 50 year return period [9] and 500 year return period [10].

3.1 Water Levels

The design water depth for this site is 88.6 ft. (MLLW). Highest astronomical tide (HAT) water levels and estimated lowest astronomical tide (LAT) can be found in Table 3-1. Storm surge levels can be found in Table 3-2.

Table 3-1: Water Level

Water Level	Elevation ref. MLLW (m)
HAT	5.7 ft
LAT	-1.0 ft

Table 3-2: Storm Surge Level

Return Period	Positive Surge (ft)
50-year	2.7
500-year	3.2

3.2 Wind

3.2.1 Wind Speeds

Omnidirectional design wind speeds are extracted from the metocean study reports [9] [10] and presented in Table 3-3.

Table 3-3: Wind Speeds

Wind Speed (+32.8 ft Ref Elevation)	Unit	Return Period (Years)		
		1	50	500
1-hour Mean Wind Speed	mph	64	94	114
10-min Mean Wind Speed	mph	70	107	130
1-min Mean Wind Speed	mph	78	122	145
3-sec Gust	mph	89	144	174

The wind speed considered for 1 year return period is based on previous project experience and NOAA buoy 44009 data near site location.

3.3 Wave

3.3.1 Wave Characteristics

The omnidirectional wave parameters for different return periods are extracted from the metocean study reports [9] [10] and presented in Table 3-4:

Table 3-4: Wave Heights and Periods

Return Period (Years)	H_{sig} (ft)	Peak Spectral Period (s)	H_{max} (ft)	Period H_{max} (s)
1	16.0	9.5	29.9	10.8
50	30.4	13.7	56.5	13.4
500	37.4	15.2	69.6	14.9

The values considered for 1 year return period wave parameters are based on annual distribution of significant wave heights and the statistical relationship between the expected maximum individual wave height (Hmax), and the significant wave height (Hs) equal to 1.86 based on metocean study report [11].

3.3.2 Wave Directionality

The directional wave frequency distribution is shown in Table 3-5 as a percentage of occurrence for 12 directions and the wave scatter diagram is presented in Table 3-6.

Table 3-5: Wave Direction Occurrence

Direction	Percentage Occurrence (%)
0°	7.7
30°	7.8
60°	7.4
90°	6.1
120°	5.5
150°	6.6
180°	12.9
210°	11.4
240°	9.6
270°	8.7
300°	8.3
330°	8.0
Total	100

Table 3-6: Wave Scatter Diagram

	Significant Wave Height (ft)							Total Number of Waves
Wave Period (s)	**0 < 1.9**	**2 < 3.9**	**4 < 5.9**	**6 < 7.9**	**8 < 9.9**	**10 < 14.9**	**+ 15**	
0 < 2.5	19	2	0	0	0	0	0	21
2.5 < 3.5	67	38	7	1	0	0	0	113
3.5 < 4.5	85	76	33	9	1	0	0	204
4.5 < 5.5	80	79	43	22	10	5	0	239
5.5 < 6.5	35	56	42	23	14	11	2	183
6.5 < 7.5	15	21	20	16	12	11	3	98
7.5 < 8.5	8	9	7	7	7	9	2	49
8.5 < 9.5	4	5	5	4	3	3	1	25
9.5 < 10.5	4	5	4	3	2	2	0	20
10.5 < 11.5	4	4	3	2	1	1	0	15
11.5 < 12.5	4	4	2	1	1	1	0	13
12.5 < 13.5	3	3	2	1	1	1	0	11
+ 13.5	2	3	2	1	1	0	0	9
Total Number of Waves	330	305	170	90	53	44	8	1000

3.4 Current

Depth-averaged current velocity profiles combine wind driven, geostrophic, and tidal current velocities. The current profiles are given in Table 3-7:

Table 3-7: Current Speeds

Water Depth	Unit	Return Period (years)	
		50	500
Surface	ft/s	4.8	5.5
10% water depth below surface	ft/s	4.4	5.1
20% water depth below surface	ft/s	4.0	4.6
30% water depth below surface	ft/s	3.7	4.2
40% water depth below surface	ft/s	3.3	3.8
50% water depth below surface	ft/s	2.9	3.4
60% water depth below surface	ft/s	2.5	2.9
70% water depth below surface	ft/s	2.1	2.5
80% water depth below surface	ft/s	1.8	2.1
90% water depth below surface	ft/s	1.4	1.6
Mudline	ft/s	1.1	1.2

3.5 Ice and Snow

According to historical data from the National Snow and Ice Data Center, no sea ice formation is expected at the Maryland Offshore Wind Farm site. Further metocean data may provide additional guidance for ice and snow conditions. Design of the met mast tower shall include ice loading as applicable.

3.6 Marine Growth

Based on the report "Marine Fouling and Its Prevention" by the Woods Hole Oceanographic Institute (1952) [12], a marine growth thickness of 1.7 inches (43mm) can be expected near the site. However, based on prior project experience in the vicinity of the design site, the marine growth thickness considered for design is as shown in Table 3-8:

Table 3-8: Marine Growth

Elevation (ft) MLLW	Thickness (in)
Above +5.7	0
+5.7 to -15	3
Below -15	2.0

3.7 Temperature

The lowest anticipated service temperature (LAST) for air is -15°C the lowest anticipated service temperature (LAST) for water is 0°C for this site based on previous project experience and NOAA buoy 44009 data near site location.

3.8 Deck Elevation

The bottom of steel elevation of the upper access platform shall not be lower than the 1000 year return period maximum crest elevation based on the metocean study report [10]. Section 5.3.4.3 in API-RP-2A [2] provides guidance for the deck clearance requirements.

4 MATERIAL SELECTION

4.1 Structural Steel

Structural steel materials for various components of the sub-structure, foundation, and appurtenances will be selected based on their function and criticality. The following tables list the acceptable steel types and their typical applications for various components of the sub-structure framing and foundation members.

Steel procured and specified for the project shall be suitable for the expected environmental conditions at site. The designer shall specify appropriate grades or classes of steel with the necessary testing requirements. The lowest anticipated service temperature (LAST) shall be considered when specifying materials and material testing requirements for project

Table 4-1: Primary Structural Steel

Typical Use	Typical Specification US Grade(s)	Product Form	Minimum Yield Strength MPa (ksi)
Horizontal Braces Diagonal Braces Caisson Sleeve Pile Sleeves Caisson Seal Assembly Pile Centralizers (UNO)	API 2H GR50	Plate ≤ 2.5" thick	345 (50)
		Plate > 2.5" thick	324 (47)
	API 2W GR50	Plate	345 (50)
Joint Cans Special Plates	API 2H GR50 With Supplements	Plate ≤ 2.5" thick	345 (50)
		Plate > 2.5" thick	324 (47)
	API 2W GR50 With Supplements	Plate	345 (50)
Pile Sections (UNO) Caisson Sections (UNO) Pile Guides Caisson Guide	API 2H GR50	Plate ≤ 2.5" thick	345 (50)
		Plate > 2.5" thick	324 (47)
	API 2W GR50	Plate	345 (50)

Table 4-2: Secondary Structural Steel

Typical Use	Typical Specification US Grade(s)	Product Form	Minimum Yield Strength MPa (ksi)
Lift Points Hook On Points Landing Points Crane Pedestal Doubler Plates	API 2H GR50 with Supplements	Plate ≤ 2.5" thick	345 (50)
		Plate > 2.5" thick	324 (47)
	API 2W GR50 with Supplements	Plate	345 (50)
Secondary Steelwork Ladder Components	ASTM A709 GR50F With Zone 3	Open Sections Bar	345 (50)
Ladder Components Stiffeners Miscellaneous Plate	API 2H GR50	Plate ≤ 2.5" thick	345 (50)
		Plate > 2.5" thick	324 (47)
	API 2W GR50	Plate	345 (50)
Handrail System Fendering System Ladder Components Anode Cores Landings	ASTM A333 GR6 ASTM A106 GRB	Pipe	240 (35)
Upper Access Platform	ASTM A500 GRB	Square HSS Rectangular HSS	317 (46)
Stabbing Guides (Cones) Kick Plates Non-Structural Secondary Steelwork	ASTM A36	Open Sections Plate	250 (36)
Non-Structural Secondary Steelwork	ASTM A53 GRB	Pipe	240 (35)

5 CORROSION PROTECTION

Corrosion protection design will be based on API RP 2A [2] and in accordance with NACE SP0176 [13].

5.1 Atmospheric Zone

Coating system with an expected service life exceeding design life specified in Section 2.2 of this document will be applied to all structural members above elevation (+)17 ft. MLLW.

5.2 Splash Zone

Glass flake epoxy coating with an expected service life exceeding design life specified in Section 2.2 of this document will be applied to areas between elevations (+)17 ft. and (-)10 ft. MLLW.

5.3 Submerged Zone

The structural members below the splash zone will be protected by a passive cathodic protection system. Protection shall be by aluminum alloy sacrificial anodes with an expected service life exceeding the design life specified in Section 2.2 of this document.

6 GEOTECHNICAL INFORMATION

6.1 Soil Profile

The soil profile to be considered for this analysis was generated based on data gathered from the Gardline geotechnical marine survey investigation [14] [15]. Geotechnical engineering analysis and design curves were provided by Fugro Geotechnical Consultants [16].

Table 6-1: Soil Stratigraphy

Stratum	Depth (ft)	Description
I	0 – 0.3	Poorly graded Sand
II	0.3-41	Poorly Graded Sand
III	41-66	Poorly Graded Sand
IV	66 – 76	Sandy Silt
V	76 – 87	Clay with Sand
VI	87 – 144	Sandy Clay
VII	144 – 166	Poorly Graded Sand
VIII	166 – 181	Sandy Clay. Hard
IX	181 – 213	Clayey Sand

6.2 Scour

For a braced caisson type structure, the interaction between the pile legs and the central caisson is limited and will not cause global scour to develop around the pile group. Local scour around the piles and caisson due to wave and current is estimated based on API RP 2GEO [5] as 1.5 times the diameter of the pile or caisson member.

6.3 Pile Drivability

A pile drivability analysis shall be performed using a wave-equation program to determine the required wall thickness and hammer requirements. For assessing drivability with hydraulic hammers, the assumed global efficiency shall not exceed 90% without written verification of higher efficiencies from the hammer manufacturer. Drivability analyses shall model soft start and limit hammer energy to required energy for efficient driving. In addition, the length of pile sections may be limited by the strength of the pile to support the weight of the hammer during driving. A check will be performed for possible “hard-driving” to consider set-up time of 48 hours due to hammer repair.

6.4 Pile Driving Fatigue

A pile drivability analysis shall be performed using a wave-equation program to determine the soil resistance to driving and to develop a driving plan. Provided the drivability analysis shows no expectation of hard driving, 50% accumulated fatigue damage due to driving will be assumed.

7 SUBSTRUCTURE AND FOUNDATION FUNCTIONALITY

7.1 Met Mast Support

The loads transferred through the mast shall be considered in the global analysis as well as in the detailed design of the substructure. The connection between the foundation and the mast shall ensure that all loads are transferred without any permanent deformation of the structure.

The met mast is a 3 legged steel lattice tower composed of circular tube and round bar steel members, with equal leg spacing of 15'-0 3/8" (4.58 m) at the base.

The following met mast tower loads presented on Table 7-1 will be considered in the global analysis of the substructure and foundation.

Table 7-1: Met Mast Tower Loads

Met Mast Tower Loads	1 Year	50 Year	500 Year
Base Shear (Kips)	18.3	137	142
Overturning Moment (Kip-ft)	2130	15800	16400
Torsional Moment (Kip-ft)	7.8	59.2	60.8

7.2 Ancillary Equipment

The substructure shall provide support and access to equipment required for the operation of the met mast. This is to include at minimum the following items:

- Safety equipment
- Davit Crane
- Data acquisition equipment
- Power generation and storage equipment (solar panels, battery boxes, junction boxes, distribution panel, etc)
- Lighting fixtures
- Navigation aids
- Aviation hazard lights
- Platform identification signs

Data acquisition systems and instrumentation as provided by client are listed below:

- NRG 40 Anemometer at 100 m, 80 m, 60 m (boom length to be defined based on the met tower section)
- Thies first class at 100 m
- NRG 200P Wind Vane at 100 m and 80 m;
- NRG BP 20 Pressure at 5 m
- Ipack Voltmeter at 5 m
- NRG temperature at 100 m and deck level (above characteristic wave return height)
- Zephir 300 or similar
- Current meter (foundation)
- Wave meter (foundation)
- Power equipment required for an avian radar

7.3 Deck Live Loads

Uniform area live loads are used to account for equipment loads and distributions that may be expected during the design life of the structure. Various loading patterns (e.g. checkerboard, etc.) may be considered in addition to the environmental loads to determine maximum moments and reactions for design. The loads to be considered are listed below:

Table 7-2: Uniform Loads

Load Type	Uniform Load
Deck Equipment Load	200 psf
Walkway/Stairway	100 psf
Laydown Area	300 psf
Open Area	100 psf

For the design of the foundation and primary steel design a carrydown factor of 50% shall be applied to uniform applied loads.

7.4 Deflection Criteria

Vertical deflection criteria for steel beams shall be based on equipment operating requirements specified by the manufacturer or based on Table 7-3, whichever is more stringent.

Table 7-3: Deflection Criteria

Beam Type	Allowable Deflection
Primary Beam-supported at both ends	Span/240
Primary Beam – cantilevers	Span/180
Secondary Beam- supported at both ends	Span/200
Secondary Beam- cantilevers	Span/150

7.5 Accessibility

The substructure shall provide safe access to the met mast for personnel arriving on a service vessel. The substructure shall also provide means of transporting cargo such as parts, equipment and tools from the service vessel to base of the met mast.

The service vessel shall be provided by the owner and relevant information on the vessel, such as general arrangement, dimensions, mass and impact loads shall be considered in the detailed design of the access system.

Vessel access shall be provided for elevations corresponding with HAT and LAT for high water and low water elevation access, respectively. Additionally, the operational sea state criteria used for transfer operations of crew shall be considered in the range of vessel motions.

The deck area shall be sufficient to accommodate the above equipment and to allow for safe movement of personnel.

7.6 Fender and Boat Landing System

The sub-structure shall be designed with a suitable fendering and boat landing system for service vessels used for the transfer of personnel and small equipment.

The boat fendering system shall be designed for operational impact from authorized service vessels. Primary steel shall be designed for accidental impact from authorized service vessels. Accidental impact will be considered for 88.6 ft (27 m) Windcat workboat vessel with impact velocity of 1.64 ft/s (0.5m/s) per API RP 2A [2]. The vessel selected for this analysis is larger than the client proposed 25 ft SAFE Full Cabin vessel.

Vessel impact shall be considered as occurring within a range of elevations along the boat landing fender tubes consistent with the operating sea states of the O&M vessel, and for any vessel approach direction that is within at least 90° in the horizontal plane from the boat landing centerline.

The fender tubes of the boat landing shall be analyzed for local indentation due to operational ship impact. To avoid local indenting of the fender tubes, the ratio between external diameter and steel thickness (D/t) shall not exceed 25.

8 REFERENCES

[1] American Wind Energy Association, AWEA OCRP 2012. AWEA Offshore Compliance Recommended Practices. Recommended Practices for Design, Deployment, and Operation of Offshore Wind Turbines in the United States., 2012.

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[3] American Institute of Steel Construction, AISC 335 Specification for Structural Steel Buildings, 9th Edition., 1989.

[4] American Petroleum Institute, API RP 2MET Derivation of Metocean Design and Operating Conditions, 1st Edition., 2014.

[5] American Petroleum Institute, API RP 2GEO, Geotechnical and Foundation Design Considerations, 1st Edition, 2014.

[6] American Petroleum Institute, API Spec 2C, Offshore Pedestal-mounted Cranes, Seventh Edition, Oct. 2012.

[7] American Welding Society, AWS D1.1/D1.1M:2010. Structural Welding Code – Steel. 22nd Ed., 2010.

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[9] A.H. Glenn and Associates Services, 50 year storm wind, tide, wave and current characteristics, and combined wave - current forces: 88.6 ft (27 m) MLLW depth: offshore Maryland, Oct 2015.

[10] A.H. Glenn and Associates Services, 500 year storm wind, tide, wave and current characteristics, and combined wave - current forces: 88.6 ft (27 m) MLLW depth: offshore Maryland, Oct 2015.

[11] A.H. Glenn and Associates Services, A.H. Glenn and Associates Services, Average annual distribution of significant wave height and mean zero upcrossing wave period, and average annual wave directional distribution: 88.6 ft (27 m) MLLW depth: offshore Maryland, Oct 2015.

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