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MEMORANDUM

To:	Rob Holmlund (Humboldt Bay Harbor, Recreation, and Conservation District)
From:	Casey Connor, P.E.
Date:	April 25, 2024
Subject:	Wet Storage Capacity Analysis
Project:	Redwood Marine Multipurpose Terminal Replacement Project
Location:	Eureka, California
M&N Job No.:	212991-03
Cc:	Shane Phillips

Disclaimer: *This draft technical memorandum is a work-in-progress and is intended to be an internal document for use by the Humboldt Bay Offshore Wind Heavy Lift Marine Terminal Project team as a part of the conceptual design process and the ongoing permitting process. This memorandum is meant to be read as a part of a comprehensive packet of technical analyses. It is not written to be a standalone document and it is assumed that the reader has substantial project knowledge and context to understand the memorandum's content. All aspects of this memorandum are subject to change and may become less accurate over time. To better understand the project, please review the more comprehensive and up to date documents posted to the Humboldt Bay Harbor District's website at https://humboldtbay.org/humboldt-bay-offshore-wind-heavy-lift-marine-terminal-project-3.*

The purpose of this memorandum is to document Moffatt & Nichol's (M&N's) evaluation process of wet storage capacity for floating offshore wind turbines. This memorandum is organized as follows:

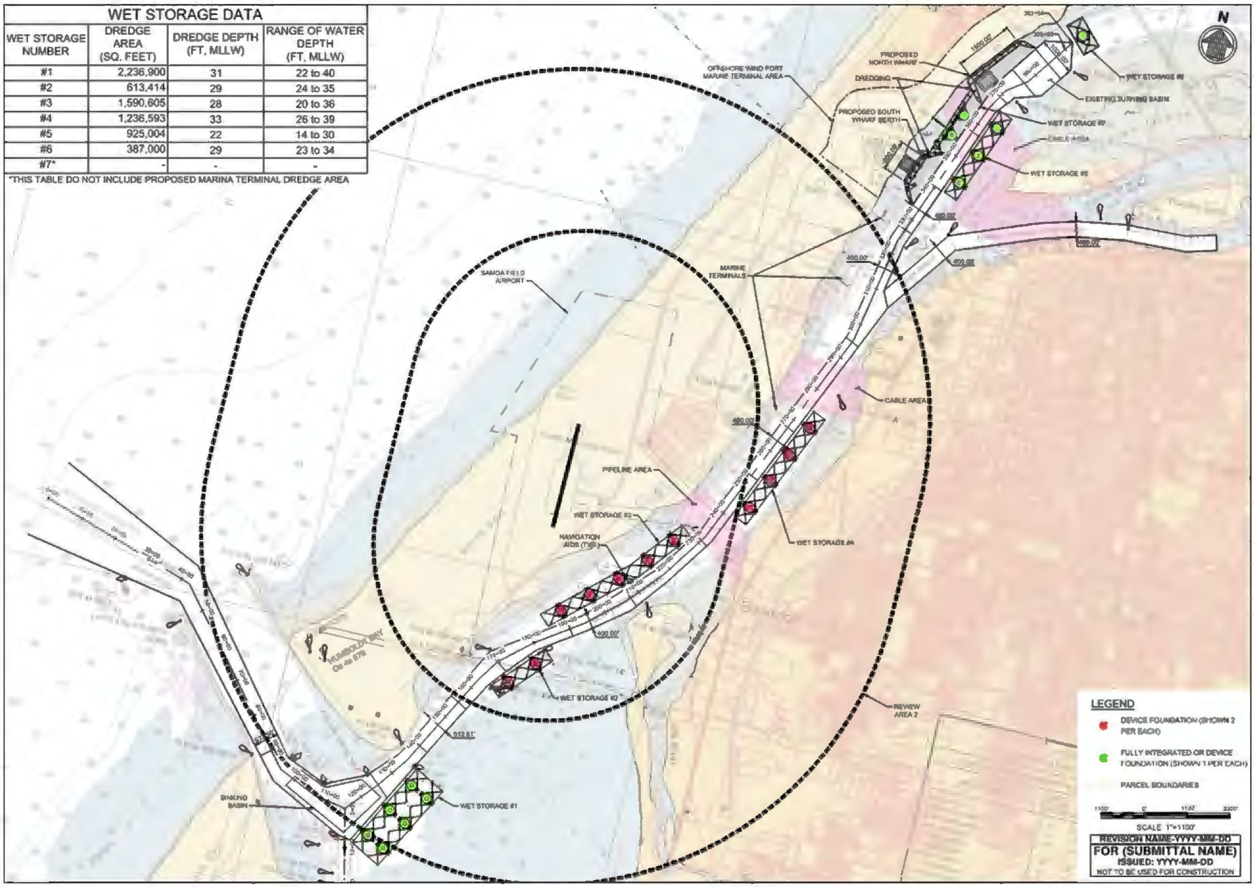
1. Introduction
2. Wet Storage Location
3. Navigation, Dredging, Mooring, and Berthing Criteria
4. Public Navigation
5. Moorings
6. Wet Storage Alternatives
7. Findings
8. Limitations
9. Next Phase Considerations

1. INTRODUCTION

The proposed Redwood Multipurpose Marine Terminal will require wet storage locations to meet the operational needs of the facility. The following constraints have been considered to date for siting the wet storage location(s):

Airspace Flight Safety Prism

The project area is in the vicinity of the Samoa Field Airport, as shown in Figure 1. Previous coordination with airport officials suggests that wet storage locations should avoid the flight safety prism shown, limiting the wet storage locations to in the immediate vicinity of the Redwood Multipurpose Terminal.



WET STORAGE DATA

WET STORAGE NUMBER	DREDGE AREA (SQ. FEET)	DREDGE DEPTH (FT, MLLW)	RANGE OF WATER DEPTH (FT, MLLW)
#1	2,236,900	31	22 to 40
#2	613,414	29	24 to 35
#3	1,590,605	28	20 to 36
#4	1,236,593	33	26 to 39
#5	925,004	22	14 to 30
#6	387,000	29	23 to 34
#7*	-	-	-

*THIS TABLE DO NOT INCLUDE PROPOSED MARINA TERMINAL DREDGE AREA

Figure 1: Airspace flight safety prism and potential utility crossing locations.

Utility Crossings

Mooring elements associated with the wet storage area will need to avoid utility crossing locations within the Samoa Channel. Three potential utility crossing locations were discovered in a previous phase, shown as pink polygons in Figure 1. The northernmost potential utility crossing was recently investigated by SHN who believes the area is likely a “set-aside” area for a future utility crossing. This area and the potential for utility conflicts should be further evaluated as the project progresses into final design.

Minimum Offset from Edge of Navigation Channel

At this time, there is not a published minimum offset that moored WTGs or their associated moorings will need to have from the Samoa Channel. Similarly, there is not a published minimum offset that WTGs should keep from moored vessels during tow-out operations. These should be further evaluated as the project progresses into final design.

Air Draft Limits within Navigation Channel

Currently, there is no standard WTG blade tip clearance from the tip of the blade to edge of the channel. A vertical clearance of 75 to 100 feet is estimated in BOEM (2018). Assuming the nacelle can be locked into a “Y” position during tow-out, air draft limitations are unlikely; however, this should be further evaluated as the project progresses into final design.

USCG Aids to Navigation

The US Coast Guard installs and maintains all federal aids to navigation, including the aids installed along the federal navigation channels within Humboldt Bay. Wet storage locations should avoid these locations. Any required changes or impacts to aids to navigation will require coordination with the USCG.

Sensitive Habitats

The project area contains environmentally sensitive intertidal mudflats, eelgrass and salt marsh. These habitats should be avoided to the extent possible, and any impacts may require compensatory mitigation.

2. WET STORAGE LOCATION

To maintain an appropriate distance from the Samoa Field Airport, the wet storage locations will be in the immediate vicinity of the project site, as shown in Figure 2. Wet Storage Area 1 is proposed along the pier and wharf, representing wind turbine generators (WTGs) that are moored during the staging and integration (S&I) and/or manufacturing/fabrication (MF) processes. Wet Storage Area 2 is proposed across the Samoa Channel and will be primarily used to temporarily moor fully integrated (FI) WTGs awaiting tow-out for installation. Wet Storage 2 is approximately 681 ft wide by 3,489 ft long. Wet Storage Area 3, proposed between the northern terminus of the Samoa Channel Turning Basin and the Route 255 Bridge, will temporarily moor foundations (FO) awaiting full integration. Wet Storage Area 3 is approximately 939 ft wide by 1,880 ft long. Wet Storage 2 and Wet Storage 3 will be the focus of this memorandum.

Figure 2: Proposed wet storage locations.

3. NAVIGATION, DREDGING, MOORING, AND BERTHING CRITERIA

Tow Vessels

Three (3) types of tugboats are anticipated to be utilized including anchor handling tugboats, ocean towing tugboats, and harbor tugboats. Ocean Towing Tugboats and Harbor Tugboats are likely to be used during local maneuvering between the wharf and wet storage locations. An Anchor Handling Tugboat, supported by Ocean Towing Tugboats and/or Harbor Tugboats, is anticipated to be used to tow the WTG for installation. The vessel parameters assumed for the design are shown in Table 1.

Table 1 – Summary of Vessel Parameters

Type of Tugboat	Length [ft]	Beam [ft]	Draft [ft]
Anchor Handling Tugboat	180 to 305	46 to 72	15 to 26
Ocean Towing Tugboat	100 to 146	40 to 46	18 to 22
Harbor Tugboat	75 to 150	35 to 40	12 to 18

Tugboats will need sufficient space between WTGs, mooring elements, and other in-water obstructions to safely navigate through wet storage areas. Based on minimum unobstructed clearance recommendations by ASCE (2020), a 300 ft diameter turning circle and 120 ft wide gap between obstructions within the wet storage areas should be provided for safe passage and maneuvering of Ocean Towing Tugboats and Harbor Tugboats.

Anchor Handling Tugboats will be required during the tow-out operation of FI WTGs from the wet storage area to the installation site. Two (2) Ocean Towing Tugboats or Harbor Tugboats are expected to assist the Anchor Handling Tugboat (three tugboats in total) during the dead ship tow sequence. During tow-out operations of FI WTGs, tugboat captains will need to closely coordinate with the Port of Humboldt Bay Pilots, Captain of the Port, and Samoa Field Airport.

Wind Turbine Generator – Foundation Only (FO)

The wind turbine generator substructure is expected to be a semi-submersible, floating steel foundation. Delivery of the foundation is anticipated to be fully assembled on a semi-submersible vessel, partially assembled on a Roll On-Roll Off vessel, or fully manufactured in Humboldt. For a complete discussion on these delivery options, please refer to the Preliminary Basis of Design (M&N, 2022). Additional information can also be found in the Navigation Assessment Technical Memo (M&N, 2024).

Based on discussions with Crowley and other wind industry developers, the following geometric parameters were developed for the design of the new facility:

- Design Size (estimated 18MW Turbine Size):
  - Beam: 350 ft
  - Draft: 23 ft
- Future Size (estimated 22MW Turbine Size):
  - Beam: 400 ft
  - Draft: 28 ft

Wind Turbine Generator – Fully Integrated (FI)

Based on discussions with Crowley and other wind industry developers, the following geometric parameters were developed for the design of the new facility:

- Design Size (estimated 18MW Turbine Size):

- Beam: 350 ft
- Draft: 35 ft
- Rotor Diameter: 918 ft

- Future Size (estimated 22MW Turbine Size):
  - Beam: 400 ft
  - Draft: 45 ft
  - Rotor Diameter: 1,017 ft

Dredging

Dredging will be required to provide suitable water depths for safe maneuvering of WTGs within the wet storage areas. Wet Storage 2 will be dredged to an elevation of -40 ft MLLW with a 2 ft overdredge allowance to accommodate a 35 ft draft fully integrated unit. Wet Storage 3 will be dredged to an elevation of -28 ft MLLW with a 2 ft overdredge allowance to accommodate a 23 ft draft semi-submersible unit with a minimum under keel clearance of 2 ft.

4. PUBLIC NAVIGATION

A dedicated public recreation channel will provide continuity of navigable access through or around Wet Storage 3, between the Samoa Channel and Arcata Bay. Typical vessels in the area, shown in Figure 3, include center console, bay boats, and small sailboats due to the relatively shallow water depths of Arcata Bay and air draft limitations of the Route 255 Bridge (approximately 45 feet at MHHW). However, larger vessels, such as the Cal Poly Humboldt Marine Laboratory R/V Coral Sea, shown in Figure 3, may occasionally transit the area.

Figure 3: (left) Typical vessels in the area. (right) R/V Coral Sea (source: https://marinelab.humboldt.edu/coral-sea)

The following geometric parameters were developed for the design of the public recreation channel:

- Typical vessel
  - Length: 25 to 50 ft
  - Beam: 8 to 15 ft
  - Draft: 3 to 7 ft
- R/V Coral Sea
  - Length: 90 ft
  - Beam: 22 ft 4 inches
  - Draft: 9 ft

Based on navigation channel design recommendations by ASCE (2020), a 125 ft wide navigation channel should provide sufficient space for two-way vessel traffic. The navigation channel should be positioned to provide at least 3 ft of under keel clearance as well as sufficient air draft to safely clear the Route 255 Bridge. Reference the Navigation Assessment Technical Memo (M&N) for additional information.

5. MOORINGS

Moorings will need to be installed to safely moor WTGs throughout the wet storage areas. Each mooring will need to be developed to resist berthing loads and environmental loads such as winds, currents, and waves. Moorings include floating moorings such as single-point mooring buoys and multi-point mooring buoys and fixed moorings such as dolphins and monopiles.

Floating Moorings

Single-Point Mooring Buoys

Single-point mooring buoys are generally referred to as swing mooring systems which allow the moored vessel to swing 360 degrees around the mooring location, depending on the prevailing conditions at the time, as shown in Figure 4. There are two types of single-point moorings: catenary and elastic. Catenary moorings are the most widely used, utilizing one or more anchors and heavy chains to resist environmental forces. The catenary mooring is well-suited in areas of large tidal variations, requiring a chain length of typically 3 to 5 times the water depth to provide elasticity in the mooring system to minimize snap loads, reducing the risk of damage to the vessel or mooring (PIANC, 2020). Trot moorings are a variation of the single-point catenary mooring where a row of single-point mooring buoys are linked together by a heavy bottom chain anchored at each end.

Figure 4: Single-point mooring buoy example.

One main benefit of using a catenary style system is that it is easy to install and requires only an anchor and a chain. Additionally, since this mooring system only experiences forces in the horizontal plane, a relatively light anchor can be used. However, it also requires a significant amount of space so that the vessel can freely swing about the mooring anchor.

An elastic mooring system consists of an embedment anchor(s) and an elastic rode to resist environmental forces. These moorings work best where the tidal variation is small relative to the water depth and/or are in environmentally sensitive areas as there is very little impact to bottom habitats. Considering the anticipated environmental loads, complexity required for installation, and environmental impacts associated with the dredging required to achieve suitable water depths at the wet storage areas, elastic moorings were removed from further consideration.

Multi-Point Mooring Buoys

Multi-point mooring buoys utilize more than one single-point mooring buoy to moor a vessel. These types of moorings work well in locations where environmental forces are not colinear and/or where relatively fixed positioning of a moored vessel is desirable. By reducing the swing area, multi-point mooring buoys can improve the efficient use of space within the wet storage areas, as shown in Figure 5. An example layout of a multi-point mooring buoy arrangement is shown in Figure 6.

Figure 5: Multi-point mooring buoy example (source: https://www.portofrotterdam.com/en/sea-shipping/buoys-and-dolphins).

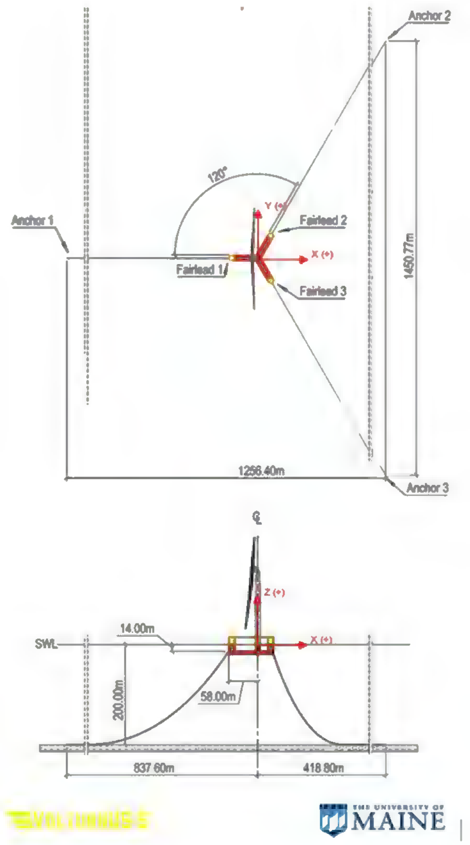


Figure 6: Catenary mooring system from NREL IEA 15MW semi-submersible.

Mooring Anchors

The drag anchor is one of the most common types of anchors used with catenary mooring systems. One example is the Stevpris MK6, shown in Figure 7, developed by Vryhof (now Delmar Systems), which was specifically designed with floating offshore wind in mind. The weight of the anchors varies from 1 to 50 metric tons, which provides over 3,000 metric tons of tension force per anchor. The dimensions of the anchor are based on the selected weight which are installed by pushing them off the back of a vessel into position.

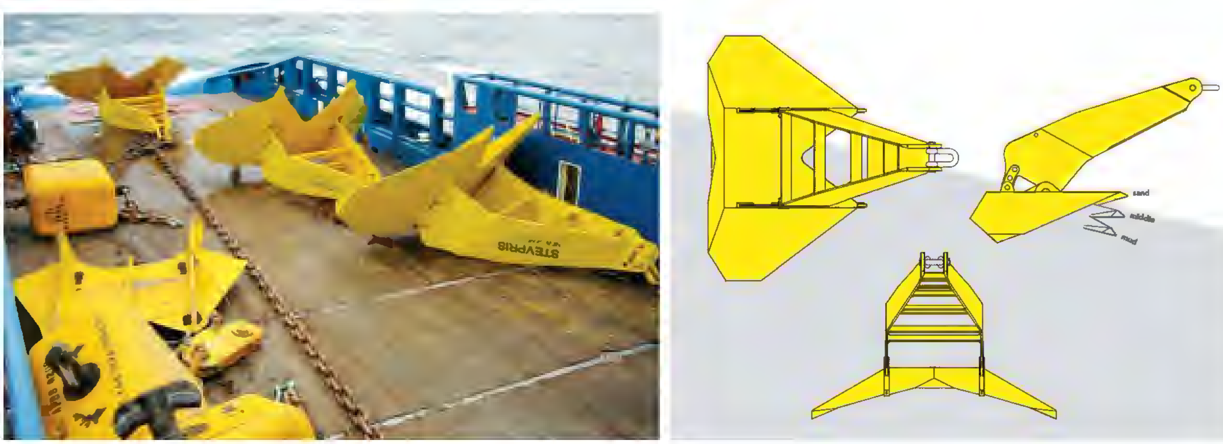


Figure 7: (left) Stevpris MK6 anchor installation. (right) Stevpris MK6 drawing. (source: Delmar brochure)

Other types of anchors that could be used are driven pile, gravity (or clump weight), and suction pile anchors. Driven pile anchors are the most secure and permanent; however, these require a separate installation vessel which can result in a relatively high cost. Gravity anchors require significant mass to achieve holding capacities similar to other anchors. This results in an anchor that is harder to transport and an installation that is less precise. Suction anchors can vary greatly depending on the soil type. They are cheaper and easier to install, but not as secure.

Tension Leg Systems

Tension legged mooring systems have also been used in floating offshore wind projects. In this case, the load is mainly in a vertical plane, with the anchor and chain under tension to limit movement. The benefit of this system is that it is much more space effective, with the mooring lines generally being under the footprint of the semi-submersible platform, as shown in Figure 8. However, the anchor types cost more to install (depending on soil conditions) and requires more time to tension the legs. This type of anchoring system is not anticipated at the wet storage sites due to this extra time needed for tensioning and de-tensioning when mooring and un-mooring while in wet storage.

Figure 8: Example of a tension leg platform for offshore wind (source: Modec)

Fixed Moorings

Fixed moorings, such as dolphins and monopiles, are used when a fixed mooring location is warranted. Fixed moorings are permanent structures that would require dedicated areas to be constructed. A major benefit of a fixed mooring system is that all lateral movements from the semi-submersible platforms would be mitigated, resulting in potentially less space between moored platforms compared to floating moorings, increasing the number that can be moored, as shown in Figure 9

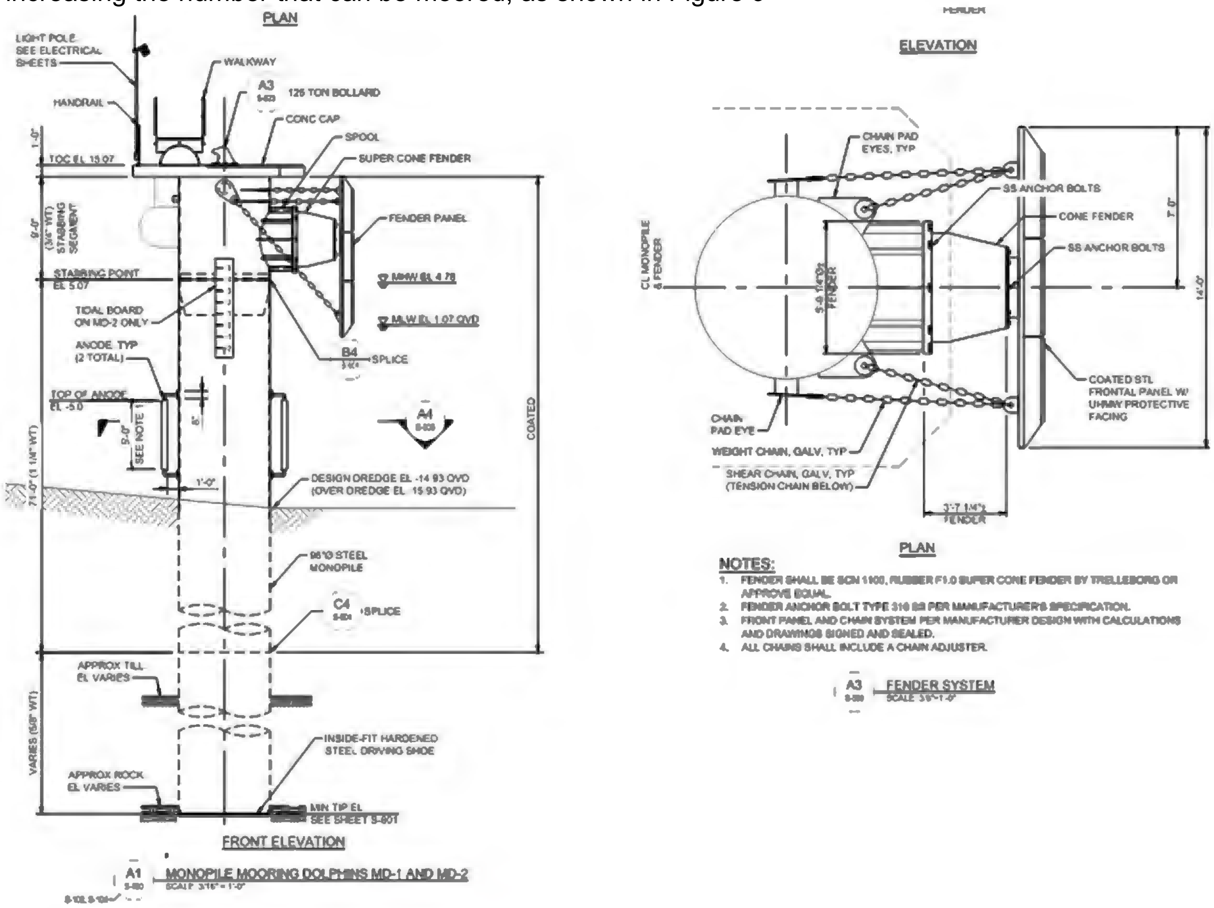


Figure 12: Reference monopile and fender sizing example.. Additionally, there may be improved operational efficiencies gained from a fixed mooring system as there would be no need to connect or disconnect from a floating mooring system.

Figure 9: Fixed mooring example (source: Statkraft/KOWL).

Dolphins are pile-supported structures which look similar to a constructed wharf, with a concrete deck capping a combination of vertical and batter piles. Attached to this structure would be fenders placed periodically on the edge, along with bollards where semi-submersible platforms could be moored. While this type of structure can be built on a range of soil types, they can be expensive, typically being a main cost driver in port construction. Due to the batter piles not being vertical, more space may be needed than what the surface profile provides, potentially limiting the number of moorings in wet storage.

Figure 10: Examples of breasting and mooring dolphins.

A series of monopiles could also be an effective strategy for a fixed mooring system. An example system may include 3 to 4 monopiles connected by fenders. Vertically driven monopiles would require the least amount of horizontal space, potentially allowing more semi-submersible platforms to be moored in wet storage. The size of the monopiles will depend on the environmental loading conditions, but a standard estimation for monopile diameter is 72 to 96 inches. Due to advancements in offshore construction, monopiles of this size (and larger) are now able to be installed in a wider range of seafloor and subsea conditions. A conceptual plan view layout example for monopiles in wet storage is shown in Figure 11. An example monopile and fender system designed by Moffatt & Nichol for a previous project is shown in Figure 12.

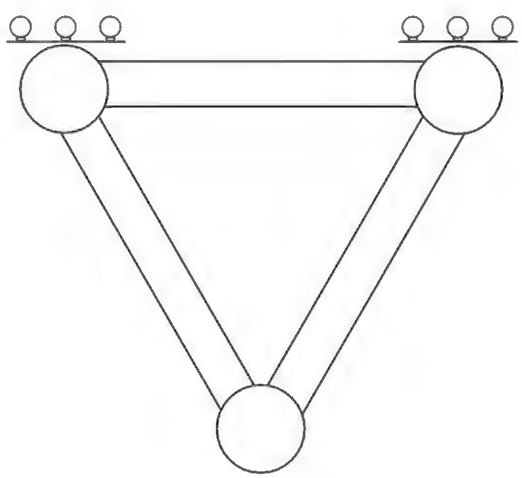


Figure 11: Conceptual plan view layout of monopile design.

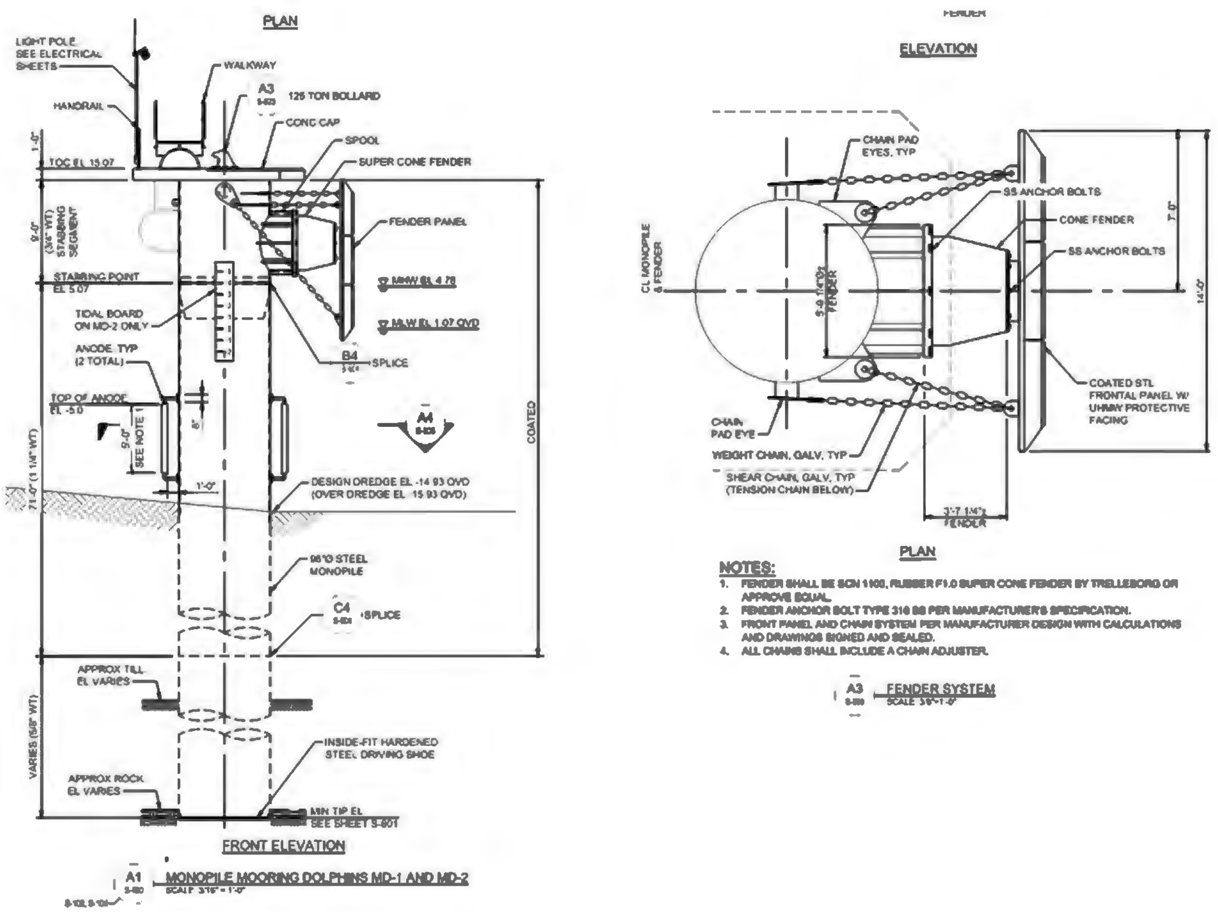


Figure 12: Reference monopile and fender sizing example.

6. WET STORAGE ALTERNATIVES

Several wet storage alternatives were conceptually developed to evaluate the range of estimated storage capacities for the various types of moorings. Actual wet storage capacities will depend on mooring line elasticity under loading conditions, operational cadence and preferences, tugboat availability, power, and maneuverability, and environmental factors during mooring or tow-out such as winds, currents, and if operations will occur at night. All wet storage alternatives assume a 350 ft foundation beam, three-column semi-submersible platform with the WTG affixed to one of the three columns. Other platform styles are anticipated to have similar results. Each alternative was also evaluated on its ability to accommodate a 400 ft beam foundation platform and 22MW turbine if future market conditions warrant. A summary of conceptual wet storage alternatives considered are shown in Table 2, below. Example mooring arrangement alternatives considered as presented on December 7, 2023, are included as an appendix.

Table 2: Conceptual wet storage alternatives analysis summary.

Mooring Style	Wet Storage Area 2	Wet Storage Area 3	Recreation Channel Location	400 ft beam and 22MW turbine?
Single-point mooring buoy	0 FI	2 FO	Between center of channel and Tuluwat Island	No
Multi-point mooring buoy	4-5 FI	3 FO	Center of channel	Likely
Multi-point mooring buoy	4-5 FI	5-6 FO	Along Tuluwat Island shoreline	Likely
Fixed mooring	5-6 FI 1 FO	8 FO	Center of channel	No
Fixed mooring	4-5 FI	6-7 FO	Center of channel	Likely

7. FINDINGS

The following is a summary of findings from the review of the conceptual wet storage alternatives:

- Fixed moorings are needed if the greatest capacity of wet storage mooring is needed. The upper limit of capacity for wet storage utilizing fixed moorings is approximately 10-15 (combined) FI and SO WTGs.
- Single point mooring buoys are feasible in Wet Storage Area 3, but not Wet Storage Area 2.
- Multi-point mooring buoys can provide wet storage mooring capacities that are similar to fixed moorings, but the necessary anchor chains may be an operational hindrance. The upper limit of capacity for wet storage utilizing multi-point mooring buoys is approximately 7-11 (combined) FI and SO WTGs.
- Higher-density configurations require a “first in-last out” mooring arrangement, requiring careful planning with upland operations to maximize efficiency. Higher-density configurations also require more favorable environmental conditions for towing operations (e.g. calmer winds).
- Lower-density configurations can accommodate an “any in-any out” mooring arrangement, allowing a WTG to be towed into or out of wet storage. Lower-density configurations can also accommodate a wider range of environmental conditions (e.g. stronger winds).

8. LIMITATIONS

The purpose for the work conducted in this phase was to help advance a conceptual design for purposes of project planning, initiation of environmental permitting and regulatory processes, and to aid in development of an overall project narrative and budget estimate. Additional wet storage investigation and analysis will be required in subsequent phases of work to refine and update the results and recommendations outlined in this memorandum.

9. NEXT PHASE CONSIDERATIONS

At the start of the next phase of work, the following are critical steps in the continuation of the planning, analysis, and design work.

- Perform a cursory analysis on the environmental, berthing, and mooring loads of moored WTGs to determine the structural characteristics and conceptual costs of the selected mooring arrangement(s). This work will be based on the conditions identified in the Preliminary Basis of Design Memo (M&N, 2022) and preliminary nearshore geotechnical data program previously collected. Outreach with Crowley and offshore wind component manufacturers will continue and include component weights and ballasting requirements. Unless otherwise specified, the following criteria will be used in the analysis:
    - Wet Storage Area 2
        - Vessel: fully integrated (FI) WTGs
        - Vessel Berthing Speed: 2 knots
        - Winds: 50.0 knots (50 year return period)
        - Currents: 1 knot (maximum currents at Berth 1)
        - Waves: 2.2 ft peak wave height (H_{mo}) and 2.7 second wave period (T_p)
    - Wet Storage Area 3
        - Vessel: foundations (FO)
        - Vessel Berthing Speed: 2 knots
        - Winds: 50.0 knots (50 year return period)
        - Currents: 1 knot (maximum currents at Berth 1)
        - Waves: 2.2 ft peak wave height (H_{mo}) and 2.7 second wave period (T_p)
- Pending feedback of the selected mooring arrangement(s), develop work sequencing for installation to reduce risks for construction and to outline the construction requirements and procedures for narratives to be captured in the environmental permitting process. Unless otherwise specified, the environmental permitting process will include an alternative featuring fixed and floating moorings for flexibility during the final design and construction phases.

10. REFERENCES

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Bureau of Offshore Energy Management (2018). Summary Report: Bureau of Ocean Energy Management's Offshore Wind and Maritime Industry Knowledge Exchange. Baltimore, MD.

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