Appendix A - WMT BERTHING AND MOORING ANALYSIS

Trans Mountain Expansion Project

WMT Berthing and Mooring Analysis Final Report

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Westridge Marine Terminal – Berthing & Mooring Analysis Final Report

PRODUCED FOR TRANS MOUNTAIN PIPELINE LP

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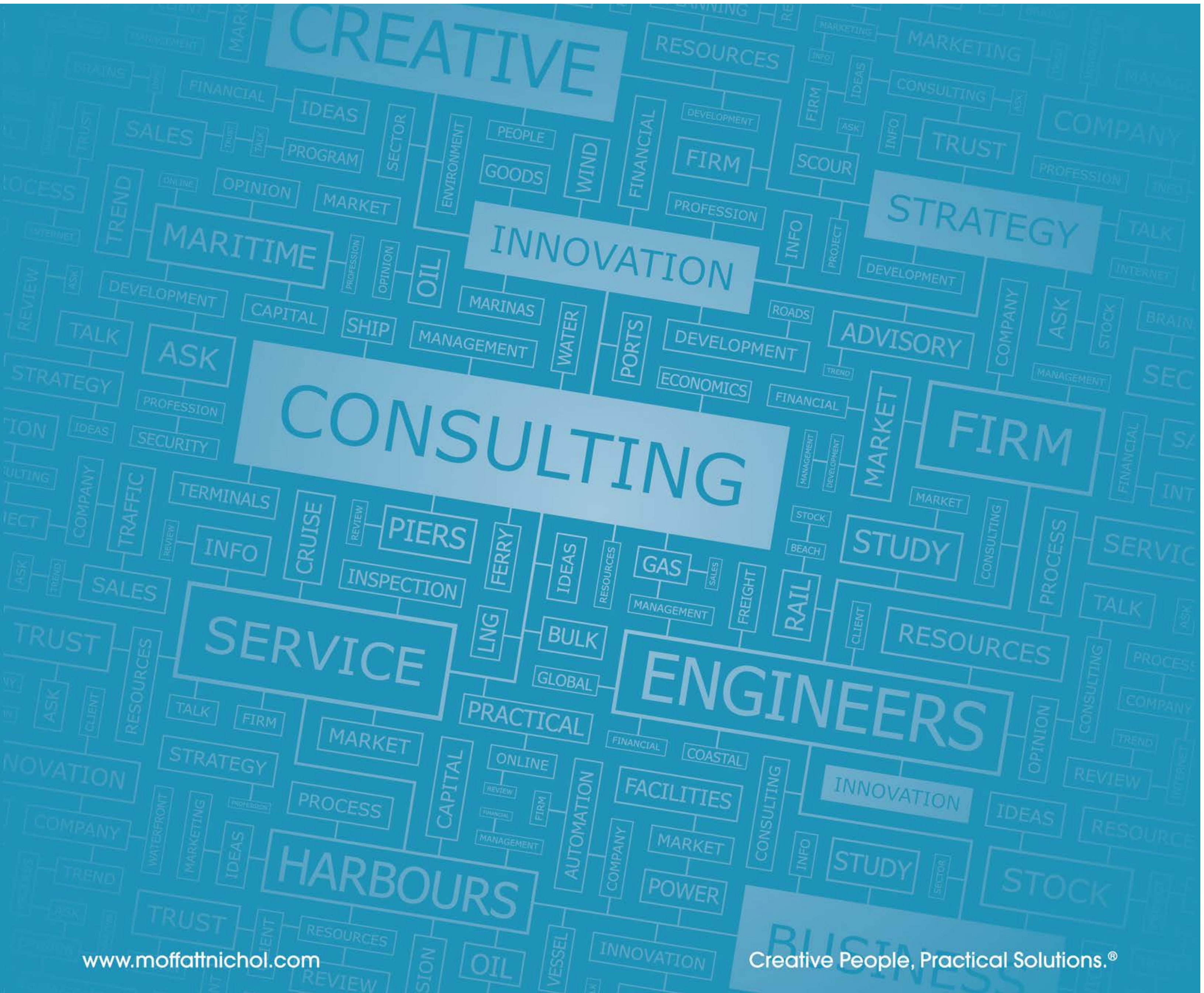

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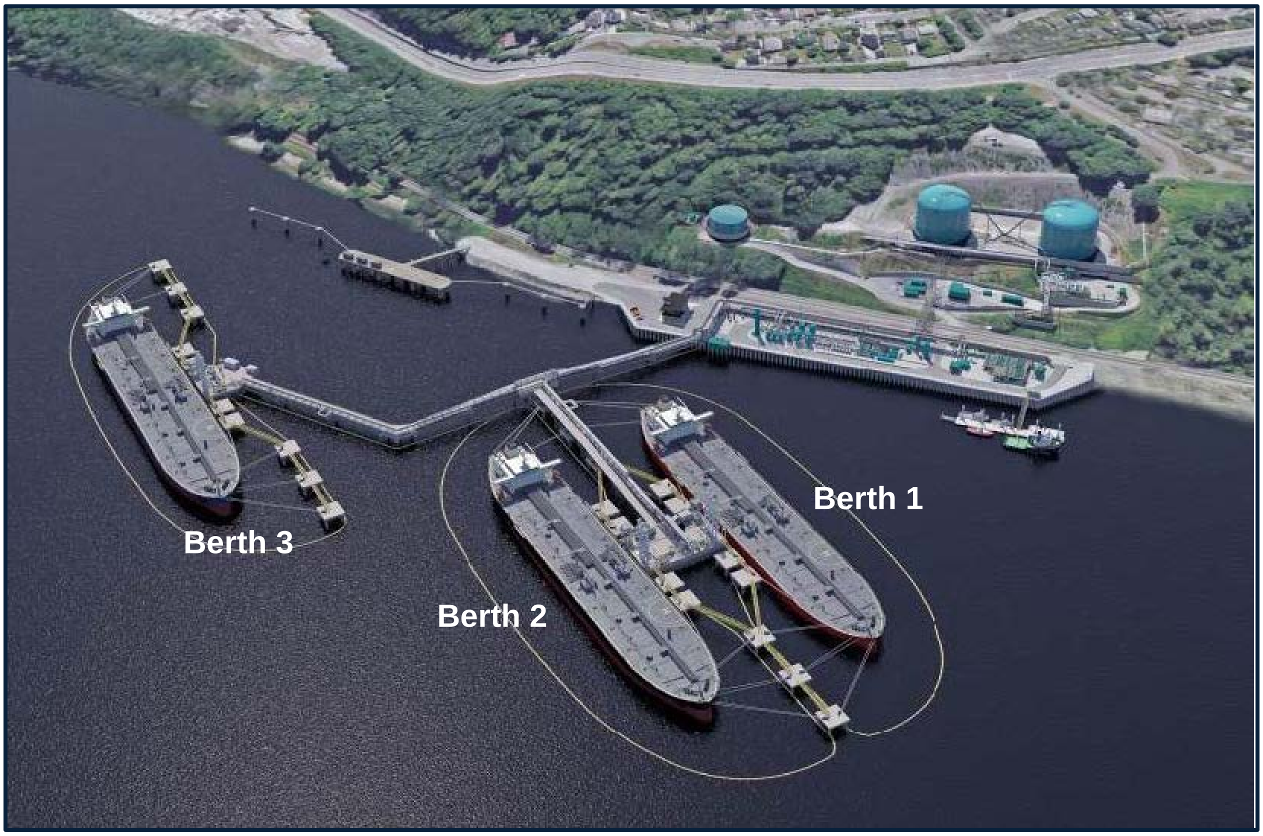
Executive Summary

As part of the Trans Mountain Expansion Project, Trans Mountain Pipeline (TMP) intends to expand its existing Westridge Marine Terminal in Burnaby, British Columbia. The expansion includes the construction of three new jetty berths, as shown in the figure below, which are capable of accepting vessels ranging from barges to Aframax tankers. Berth 1 shall accommodate vessels carrying jet fuel, crude and other oil that range from inland barges to Aframax tankers. Berth 2 and 3 shall accommodate vessels carrying only crude oils that range from inland barges to Aframax tankers.



ARTIST RENDERING OF THE PROPOSED WESTRIDGE TERMINAL EXPANSION

Moffatt & Nichol (M&N) has been retained by TMP to perform the detailed engineering design of the terminal's marine facilities. In this report, M&N presents the mooring analyses conducted for the design range of vessels to evaluate the loads on the mooring elements (mooring lines, mooring hooks, and fenders) and the vessel motions as a result of environmental forcing imposed by winds, currents, and waves, with the objective of presenting mooring arrangements and limiting environmental criteria that satisfy industry standards for safe operations.

Berthing Energy

Berthing energies were calculated using methods developed by the Wold Association for Waterborne Transportation Infrastructure (PIANC) for the design of fender systems. Berthing energies were calculated at both loaded and ballast draft for the design range of tankers and barges.

The largest displacement, Aframax tanker, at loaded draft develops a berthing energy demand of 275 mt-m. For the mooring and tsunami analyses presented in this report, a representative Trelleborg SCN 2000 F 1.0 CV was modeled, with an available reaction of 256 mt and energy absorption of 306 mt-m.

Static Mooring Analysis

Static mooring analyses were conducted using OPTIMOOR software for the Oil Companies International Marine Forum (OCIMF) recommended environmental conditions, which include an omni-directional 60 knot wind concomitant with a range of current velocities and directions. Analyses were conducted for the design range of tanker and barges.

Ballast draft conditions were examined at Extreme Highest High Water including 0.5 m of sea level rise of +3.0 m [Geodetic Datum (GD)], which results in the largest windage areas and highest (least efficient) mooring line angles. Loaded draft conditions were examined at Lower Low Water Large Tide (LLW-LT) of -3.0m (GD), which result in the smallest depth to draft ratio and which magnifies the effects of current on the increased wetted area. The OCIMF winds are representative of a 500-year wind conditions and currents exceed the criteria anticipated at the project site as a result of metocean data analysis and numerical modeling conducted by M&N and presented in the 2014 Metocean Study Report.

Safe mooring criteria for all analyses include:

- Limiting line tensions to 55% of minimum breaking load (MBL) for steel wire lines and 50% for synthetic lines; Note that typically MBL of any fitted synthetic lines is higher to compensate for the reduced limiting line tensions applicable to synthetic mooring ropes.
- Limiting winch brake holding capacity to 60% of minimum breaking load (MBL)
- Limiting fender reactions to the rated capacity of the selected fender (256 mt);
- Limiting surge and sway motions to ±3.0 meters, per PIANC guidelines for operational conditions.

All safe mooring criteria are satisfied for all OCIMF recommended environmental conditions for all tankers and barges examined, including all water level and draft conditions. For the Aframax and Panamax tankers, an extreme low water mooring arrangement has been developed, as tankers at LLW-LT may have interference issues with the optimal arrangement of spring lines with the fender system of the interior breasting dolphins.

Dynamic Mooring Analyses

Dynamic mooring analyses were conducted using the aNyMooR-TERMSIM software, a time -domain six degree of freedom mooring analysis software. Analyses were carried out for operational metocean conditions which are defined as an omnidirectional 40 knot wind speed, including a gust spectrum. The most conservative mooring conditions of the static mooring analyses are utilized for the dynamic mooring analyses, implying only ballast draft conditions are examined, as successful results at ballast draft predicate successful results at loaded draft. The same safe mooring criteria as applied for the static mooring analyses are utilized for dynamic analyses with the addition of reporting vessel motion referenced to the cargo manifold.

Results of the dynamic mooring analyses for the operational metocean conditions are successful for line tensions, fender reactions and vessel motions.

Tsunami Analysis

M&N conducted a tsunami assessment of the Westridge Terminal as part of the Trans Mountain Expansion Project, which evaluated the impact of landslide-generated tsunami in the Indian Arm and Burrard Inlet using a MIKE 21, two-dimensional hydrodynamic model. Time series of depth-averaged current velocities at the berths for each modeled landslide are available from this study. The highest depth-averaged currents were applied to the Aframax tanker to assess feasibility of sustaining a tsunami event combined with a 25-year wind of 36.8 knots (2-minute duration) wind. Tsunami analyses are considered only for the loaded Aframax tanker, on the predication that successful results for the largest design vessel will be successful for tankers with less wetted area for tsunami forces to act. Tsunami forces were also applied independently of the 25-year wind condition, to ensure that no motions are damped out as a result of applied wind force.

Results indicate that safe mooring criteria are not exceeded for the tsunami condition, with or without the addition of a 25-year wind.

1. Introduction

1.1. Scope

As part of the Trans Mountain Expansion Project (TMEP), Trans Mountain Pipeline (TMP) intends to expand its existing Westridge Marine Terminal in Burnaby, British Columbia. The expansion includes the construction of three new jetty berths which are capable of accepting vessels ranging from barges to Aframax tankers. TMP has engaged Moffatt & Nichol (M&N) to perform the detailed engineering design of the terminal's marine facilities, which includes:

- Crude oil loading jetties equipped to load crude tankers ranging in size from 17,000 DWT oil barges to 127,000 DWT Aframax tankers;
- Berthing and mooring structures for the tankers, complete with quick release mooring hooks and an automated mooring line load monitoring system;
- Access trestle, intermediate platforms and other structures providing access and support for pipelines and utilities from shore to the jetties;
- Utility berth to accommodate support tugs and spill response vessels; and,
- Bulkhead wall fill structure along existing shoreline

1.2. Purpose

This document describes the static and dynamic mooring analyses conducted for the range of design vessels in order to: 1) evaluate the loads on the mooring elements (mooring lines, mooring hooks, and fenders) and the vessel motions expected to occur due to conservative, yet plausible environmental conditions and; 2) make recommendations on the mooring arrangement and limiting environmental criteria to safely carry out operations according to industry standards.

1.3. Site Layout

Figure 1-1 shows an artist's rendering of the proposed Westridge Terminal. The three new berths are numbered from west to east, with berths 1 and 2 in a back to back configuration, sharing three (3) outboard mooring dolphins fore and aft. Berth 3 represents the western most berth of the proposed expansion plan and has a mooring arrangement identical to that of Berth 2.

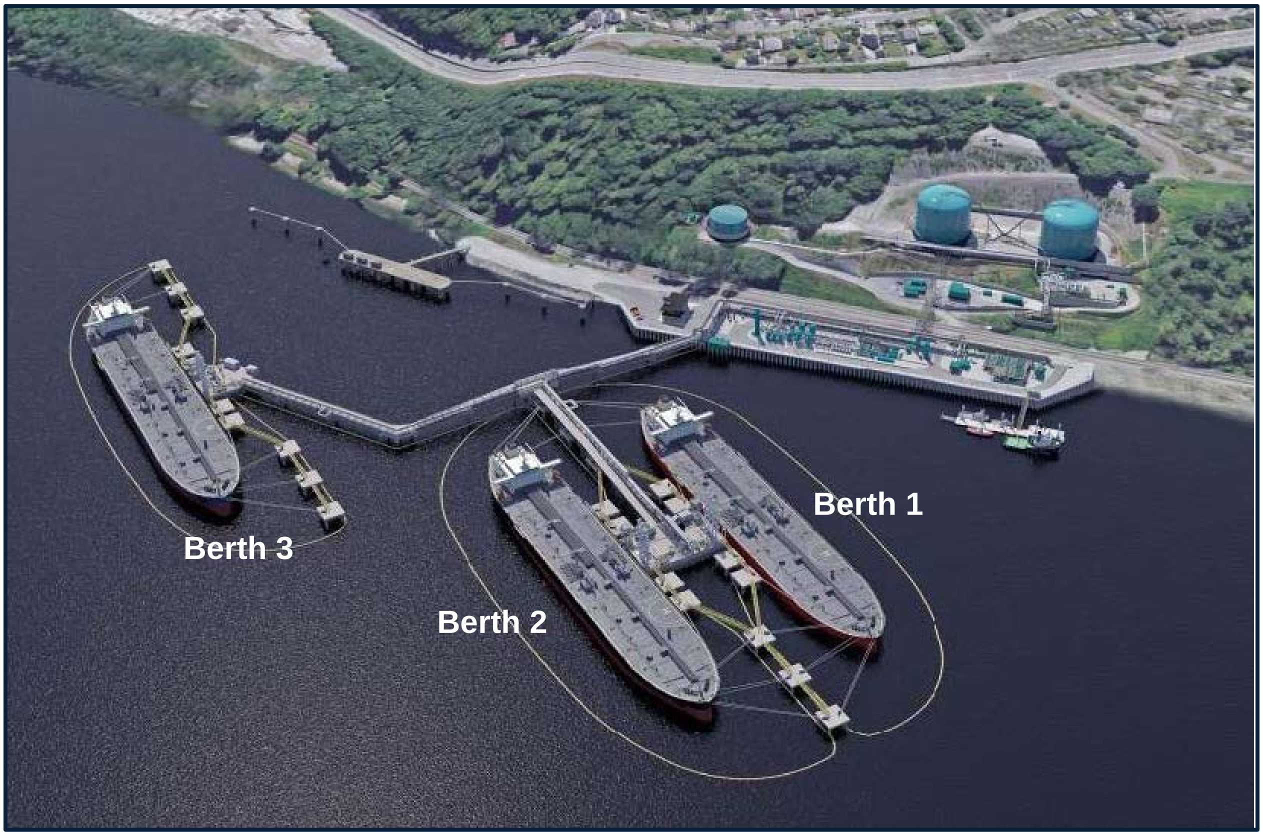


FIGURE 1-1: ARTIST RENDERING OF THE PROPOSED WESTRIDGE TERMINAL EXPANSION

2. Design Basis

The following are the design basis assumptions for the mooring analyses.

2.1. Design Vessel Characteristics

Table 2-1 presents a summary of the vessel types, classes, and anticipated cargo types which need to be accommodated by the marine facilities.

TABLE 2-1: BASIS OF DESIGN VESSELS

Vessel Class	DWT Range	Cargo Type
Aframax	80,000 - 120,000	Oil
Panamax	60,000 - 80,000	Oil
Handymax	40,000 - 50,000	Oil
Handysize	< 40,000	Jet Fuel
Jet Fuel Barge	15,000 - 30,000	Jet Fuel
Oil Barge		Oil

Table 2-2 presents a detailed summary of vessel characteristics for the design basis tankers and barges to be used for mooring analyses. These vessels are representative of the design range of tankers and barges. Where applicable, corrected deadweight and displacements are provided for the terminal's draft limit of 13.5 m.

Although the limiting water depth at the terminal is 18 m (Chart Datum), the draft limit of 13.5 m is currently imposed by the Port of Vancouver at Second Narrows through which vessels calling at the Westridge Terminal must navigate. As such, the mooring and berthing analyses conducted basis fully laden drafts of the design vessels are considered to be conservative.

TABLE 2-2: DESIGN VESSEL CHARACTERISTICS

Vessel		Oil Barge	Crowley 650-6	Handysize	Handymax	Panamax	Aframax
Cargo Type		Oil Barge	Jet Fuel	Jet Fuel	Jet Fuel / Oil	Oil	Oil
Berth		1,2,3	1	1	1,2,3	2&3	2&3
Deadweight Tonnage, DWT	Loaded Draft	15,242	27,456	16,775	50,000	70,297	117,654
	Limited 13.5 m	N/A	N/A	N/A	N/A	66,036	97,799
Length Overall, LOA (m)		115.82	179	144.05	183.2	228	250
Length Between Perpendiculars, LBP (m)		N/A	177.7	134	174	219	239
Beam (m)		23.16	22.56	23.3	32.2	32.23	44
Depth (m)		9.54	12.19	12.4	18.8	20.9	21
Draft	Loaded (m)	7.82	9.24	8.7	11.9	13.82*	15.10*
	Ballast (m)	1.65	4.95	6.21	7.18	9.9	7.13
Displacement	Loaded (mt)	17,583	33,558	21,977	54,915	84,204	136,337
	Limited 13.5 m	N/A	N/A	N/A	N/A	82,060	120,276
	Ballast (mt)	3,014	17,083	16,061	30,912	46,612	59,900
Side Windage	Loaded (m^2)	379	739	1,055	1,778	2,423	2,177
	Ballast (m^2)	1,011	1,485	1,390	2,595	3,177	4,169
Frontal Windage	Loaded (m^2)	182	661	320	723	709	800
	Ballast (m^2)	325	756	378	875	776	1,152
Bow to Center Manifold (m)		61.29	89.6	74.81	91.6	113.72	124.2
Q88 Bow to Center Manifold (m)		61.8	-	69	91.88	112.78	125.79
Parallel Midbody Forward of Manifold (m)		34.4	89.02	34	42.84	65.79	69.68
Parallel Midbody Aft of Manifold (m)		34.4	89.02	38	39.76	57.59	48.44
Mooring Line Type		Dyneema	Dyneema	PP/PE	Euroflex	Steel-Wire	Steel-Wire
Mooring Line Minimum Breaking Load (mt)		74	82	38	62	79	83

Vessel	Oil Barge	Crowley 650-6	Handysize	Handymax	Panamax	Aframax
Mooring Tail Type	N/A	N/A	N/A	Nylon	Nylon	Polyester
Mooring Tail Length (m)	N/A	N/A	N/A	11	11	11
Tail Minimum Breaking Load (mt)	N/A	N/A	N/A	80	120	116

*Denotes that Design Draft Values Exceed Existing Terminal Draft Limit of 13.5 m

2.2. General Arrangement of Marine Facilities

The layout of the three marine berths (Figure 2-1) considers the following criteria:

- Berth 1 is required to accommodate:
  - All vessels carrying jet fuel
  - All vessels carrying oil up to Aframax tankers as design maximum
- Berths 2 and 3 will have the same general arrangement and are required to accommodate:
  - All vessels carrying oil up to Aframax tankers as design maximum

Each berth will consist of a pile supported loading platform, four (4) breasting dolphins, and six (6) mooring dolphins whose function are to accommodate safe mooring and berthing of the design range of tankers and barges. Each Berth arrangement is identical in terms of number and placement of mooring structures. Berths 1 and 2 will share concrete caps for mooring dolphins.

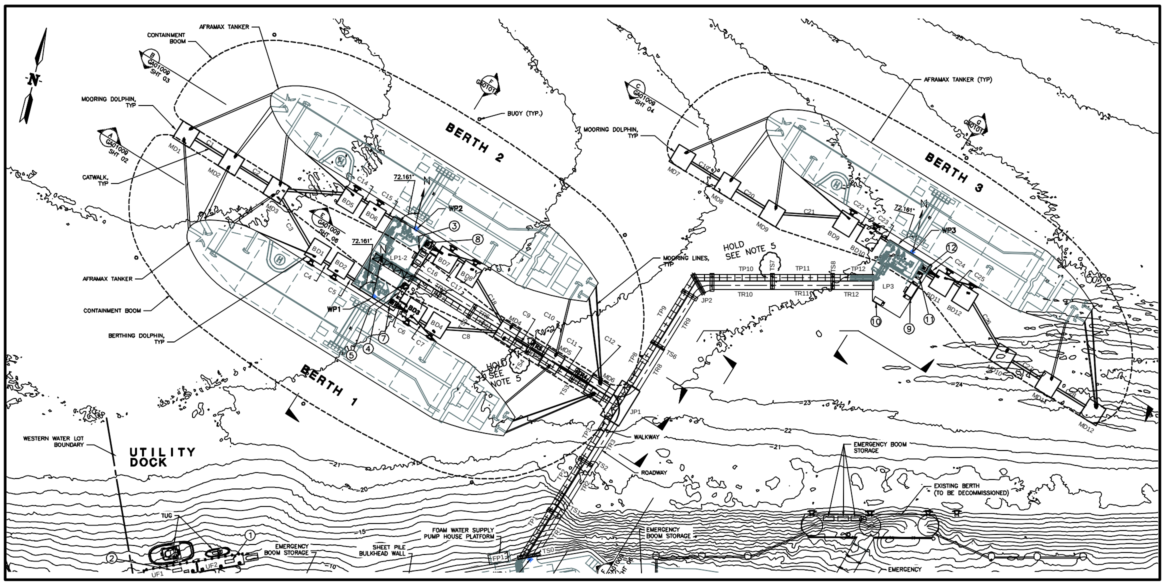


FIGURE 2-1: KM TMEP MARINE FACILITIES ARRANGEMENT

Industry guidelines provided by the Oil Companies International Marine Forum (OCIMF) and the World Association for Waterborne Transport Infrastructure (PIANC) were utilized for optimal placement of mooring and berthing structures.

2.2.1. Parallel Midbody Analysis

To determine the appropriate number and placement of breasting dolphins, a parallel mid-body analysis was conducted for the design range of tankers and barges.

The parallel mid-body is defined as the flat section of a vessel's hull which can make parallel contact with the fender system. To determine optimal fender location, the distance of the parallel midbody is measured at the waterline at ballast draft, where the dimensions are least. Figure 2-2 presents the side profile of a representative Panamax tanker indicating the midbody curve, and how the dimensions are calculated at ballast draft. As the fender and fender panel are located above the waterline, additional contact with the vessels parallel midbody is anticipated to be made over and above the dimensions provided at ballast draft.

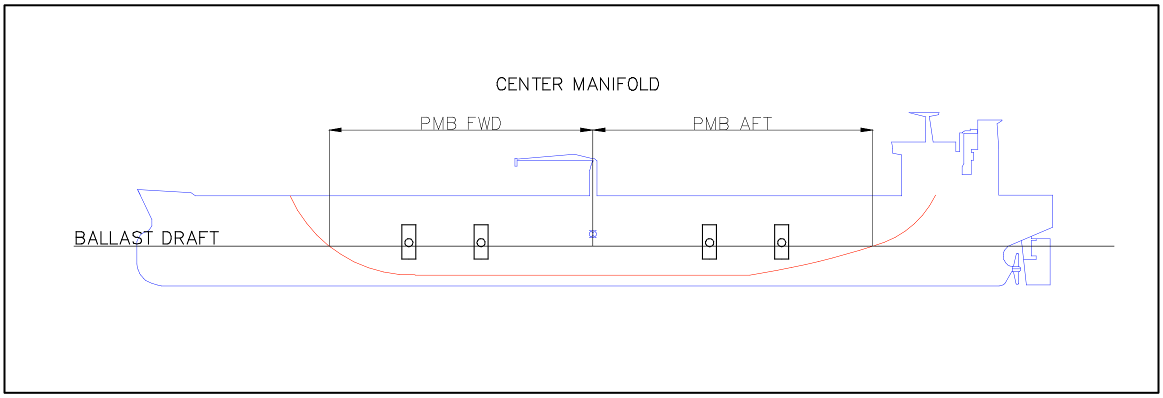


FIGURE 2-2: SIDE PROFILE – PARALLEL MIDBODY CURVE ON PANAMAX TANKER[1]

The INTERTANKO (Q88) database was polled for the design range of tankers and barges to determine parallel midbody dimensions for as many vessels as possible. The result is approximately 3,200 vessels which have reported information for the design range of vessels. Confidence intervals were determined and presented in Table 2-3 and utilized to help determine breasting dolphin locations.

TABLE 2-3: PARALLEL MIDBODY CONFIDENCE INTERVALS

	Confidence Level	5%	25%	50%	75%	95%
Barge	PBL FWD (Ballast)	31.4	42.3	50.5	56.7	65.8
	PBL AFT (Ballast)	29.3	40.9	48.0	64.0	89.0
Handysize	PBL FWD (Ballast)	23.5	31.9	40.0	45.0	56.5
	PBL AFT (Ballast)	24.0	32.2	40.0	47.1	53.9
Handymax	PBL FWD (Ballast)	33.1	38.6	43.0	44.5	50.6
	PBL AFT (Ballast)	29.0	36.0	39.9	46.4	53.2
Panamax	PBL FWD (Ballast)	46.2	62.1	67.1	69.1	70.9
	PBL AFT (Ballast)	42.9	52.0	57.5	61.2	70.3
Aframax	PBL FWD (Ballast)	50.7	59.1	61.8	67.2	73.0
	PBL AFT (Ballast)	41.5	45.9	49.7	53.0	62.8

2.2.1. Breasting Dolphin Locations

The functions of the breasting dolphins are to absorb the energy of the berthing vessels, resist breasting forces of a moored vessel, and to provide a foundation for the quick release mooring hooks which accommodate the vessels spring lines.

[1] Diagram is for illustrative purposes only – not necessarily to scale

Each breasting dolphin will support an independent fender system, which will consist of a frontal frame against which the vessels make contact and, behind the frame, a flexible energy-absorbing rubber element to provide a cushion between the vessel and the dolphin. Fender selection is presented in Section 3.8.

Additionally, the Oil Companies International Marine Forum (OCIMF) *Mooring Equipment Guidelines 3rd Edition* recommends limiting vessel overhang to 1/3rd length overall (LOA) with respect to the outboard fenders. Meaning that no more than 1/3rd of the vessel's overall length should extend past the last point of contact with the fender system. Overhang in excess of 1/3rd may potentially result in higher mooring line loads due to the increased moment arm pivot about the breasting dolphin. OCIMF finds that fender spacing on the order of 0.25-0.4 LOA is acceptable for berths considering a range of vessel lengths and types, as presented in Figure 2-3.

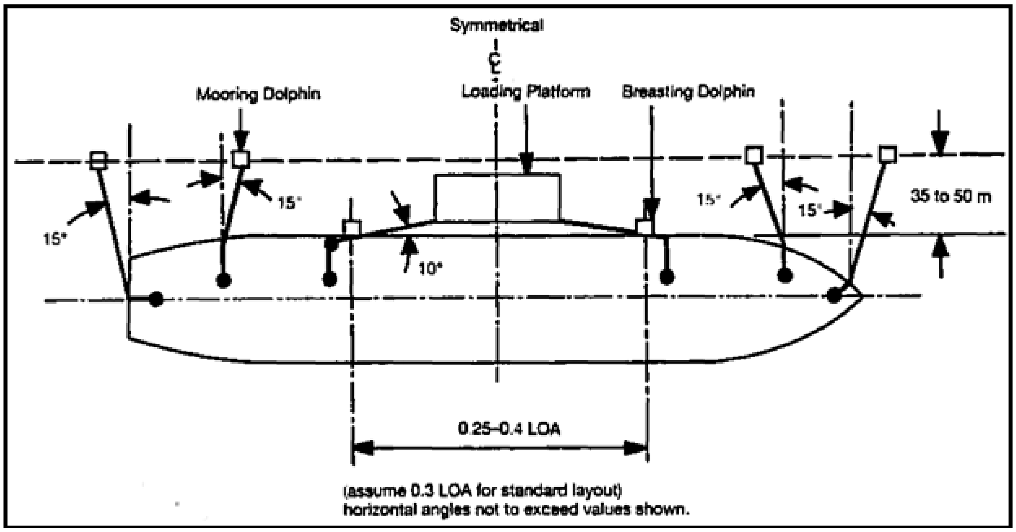


FIGURE 2-3: RECOMMENDED DOLPHIN SPACING (OCIMF MEG-3)

Figure 2-4 and Figure 2-5 present the general arrangement of berths 1-3 with dolphin dimensioning presented in meters. Figure 2-6 presents the arrangement of the loading platform for Berths 1 and 2. The layout of marine loading arms (MLA) is the same for Berth 3 as it is for Berth 2. The layout of the vapor line is to comply with tanker manifold configurations as specified by the OCIMF *Recommendations for Oil Tanker Manifolds and Associated Equipment*, as presented in Figure 2-7.

Breasting dolphin spacing accommodates the design range of tankers parallel midbody, with the exception of approximately 3% of tankers whose midbody does not make contact at ballast draft. These vessels are the lower 5% confidence intervals for the Handysize vessels. However, values reported by INTERTANKO are at ballast draft, at the waterline, and may in fact contact the fender system.

Figure 2-8 presents the breasting dolphin orientation, indicating the concrete cap to be +5.3 m Geodetic Datum (GD).

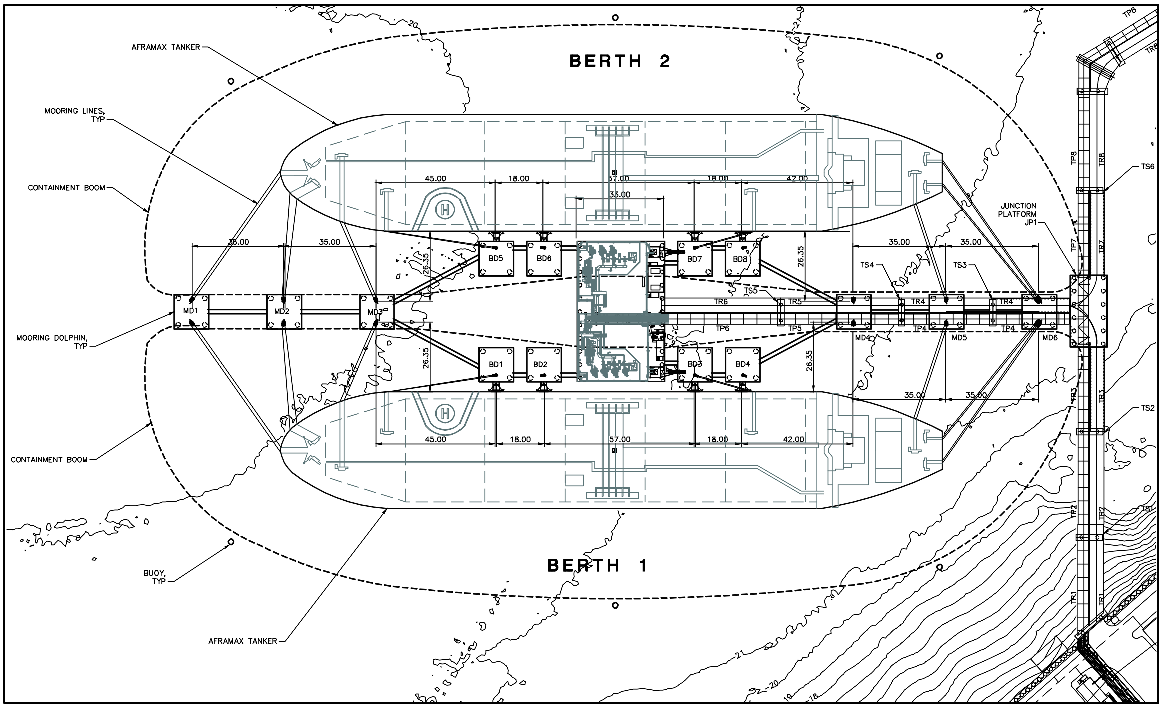


FIGURE 2-4: GENERAL ARRANGEMENT OF BERTHS 1&2 (ALL DIMENSIONS IN METERS)

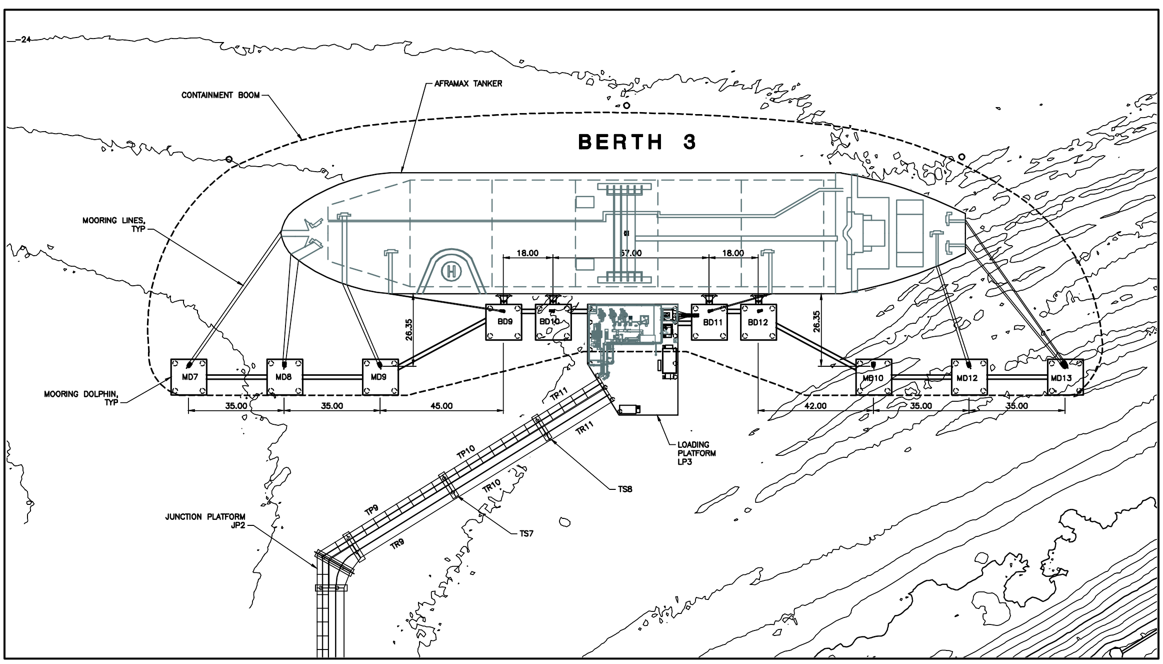


FIGURE 2-5: GENERAL ARRANGEMENT OF BERTH 3 (ALL DIMENSIONS IN METERS)

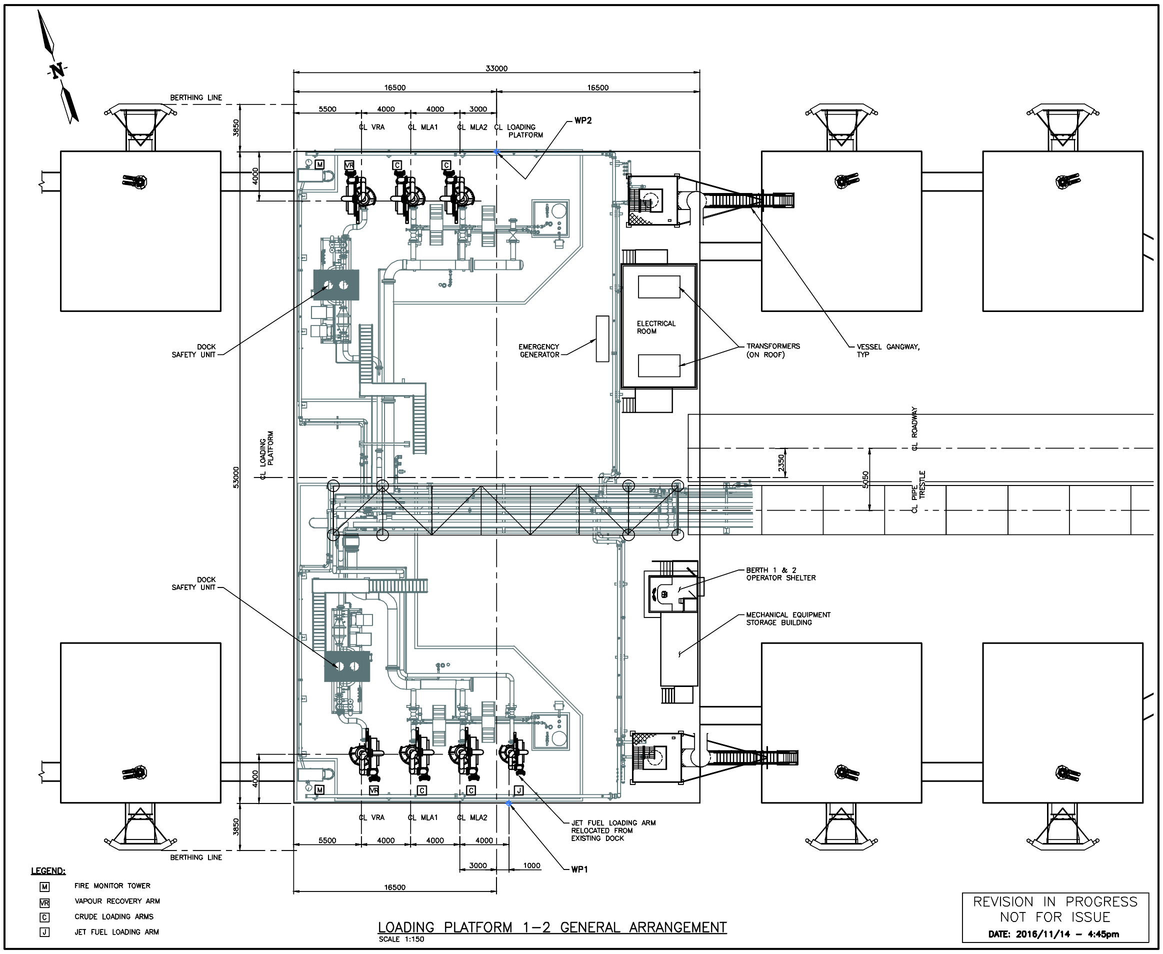


FIGURE 2-6: GENERAL ARRANGEMENT OF LOADING PLATFORMS (TOP: BERTH 2; BOTTOM: BERTH 1)

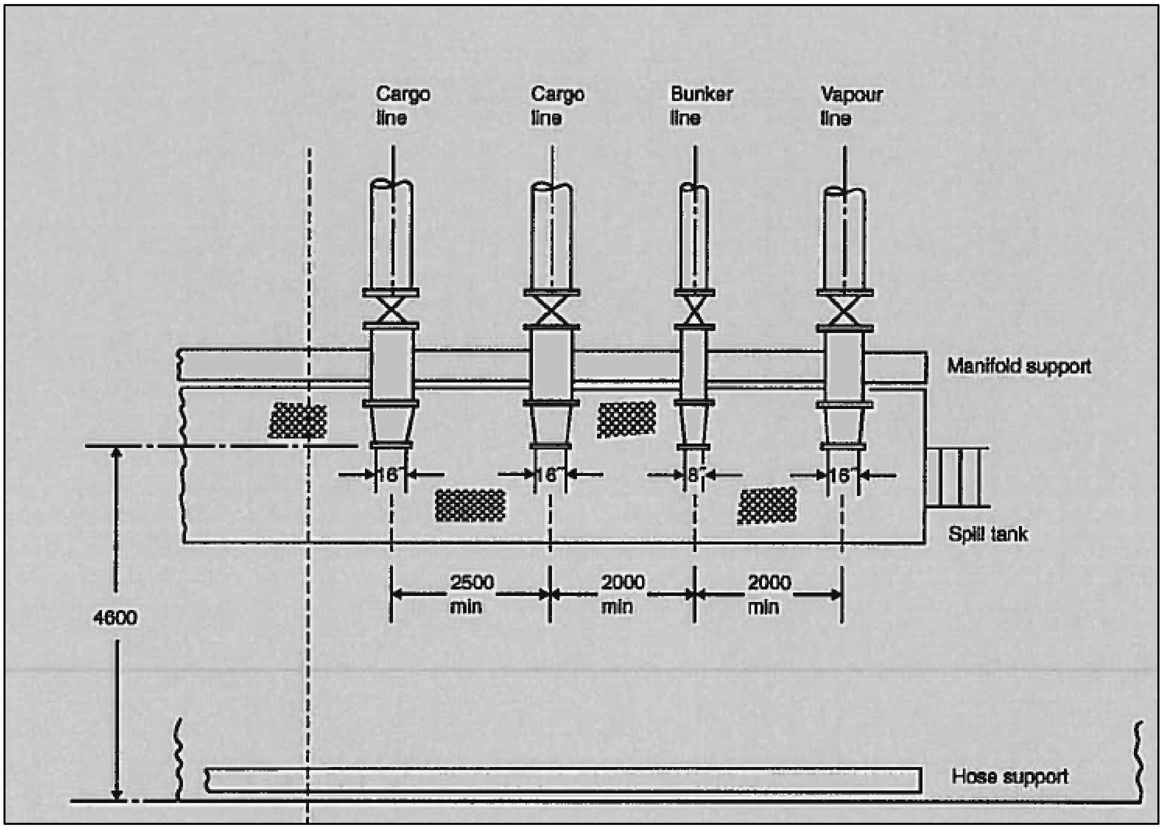


FIGURE 2-7: GENERAL ARRANGEMENT OF TANKER MANIFOLDS (OCIMF - 1991)

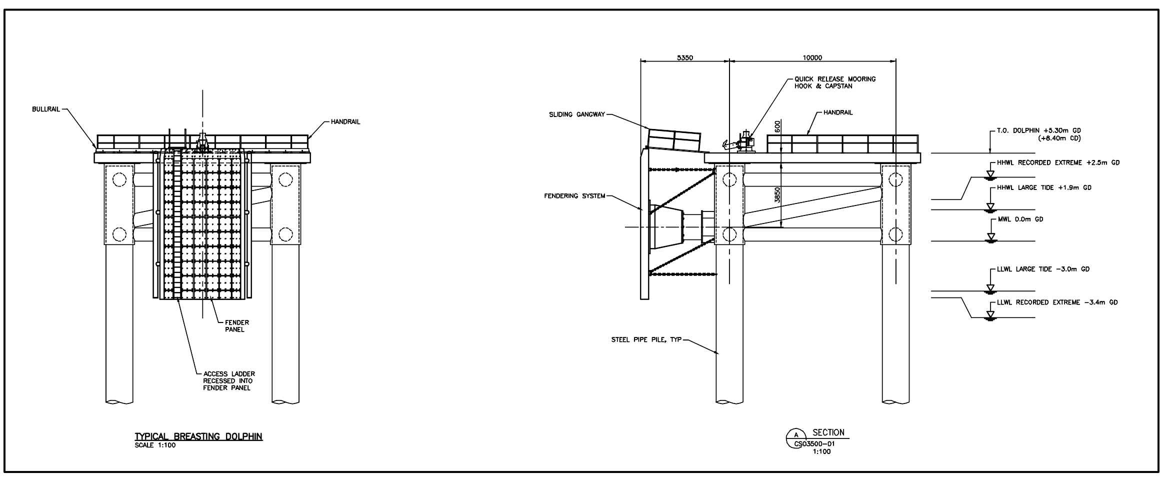


FIGURE 2-8: BREASTING DOLPHIN ELEVATION

2.2.2. Mooring Dolphins

The function of the mooring dolphins is to secure the vessels fore and aft mooring lines. All mooring dolphins have a deck elevation of +5.3 m GD and are equipped with quick release mooring hook (QRH) assemblies with remote release, load sensing and an electric reversing capstan. Mooring dolphin (MD) 6, which is shared by Berths 1 and 2, as well as MD 12, located on Berth 3, are equipped with quadruple QRHs. All remaining mooring dolphins are equipped with triple QRHs; all quick release hooks have a safe working load rating of 100 mt (each hook).

The number and placement of mooring dolphins is designed to accommodate the full design range of tankers and barges. As presented in Figure 2-3, OCIMF recommends that breasting lines remain as perpendicular as possible to increase efficiency for resisting loads which act to push the vessel off the berth.

When accommodating a large range of tankers and barges, whose characteristics can vary significantly, it may not be possible to have OCIMF recommended horizontal line angles which are 15 or less under all loading conditions; however, mooring arrangements still satisfy OCIMF maximum line tension and operating metocean criteria. The results of the mooring analyses, presented in this report, properly assess the functionality of the mooring structures placement.

2.3. Metocean Criteria

Two series of meteorological and oceanographic (metocean) criteria were utilized for the mooring analyses. First, criteria recommended by OCIMF Mooring Equipment Guidelines, 3rd edition were applied statically. These criteria serve to validate a vessels' mooring equipment established for worldwide trade. Secondly, dynamic, time-varying environmental conditions which are representative of operational conditions at the project location are applied. These dynamic criteria provide insight to vessel response under operational conditions.

2.3.1. OCIMF Criteria

OCIMF states that for tankers above 16,000 DWT, intended for worldwide trade, the mooring system should be capable of withstanding the following environmental conditions:

60 knots constant wind from any direction simultaneously with either:

- 3-knot current at 0 deg or 180 deg;
- 2-knot current at 10 deg or 170 deg; and,
- 0.75 knots current from the direction of maximum beam current loading.

Wind velocity is the velocity measured at the standard datum height of 10 m above ground and is representative of a 30 second average mean velocity. Current direction is direction traveling to and relative to the bow of the vessel.

2.3.2. Water Depth

According to a hydrographic survey conducted by Golder Associates in 2014, water depths over the footprint of the proposed expansion range from 18 to 21 m with respect to Chart Datum (CD). For mooring analyses purposes, the water depth at all three berths is assumed to be 18 m (CD).

2.3.3. Water Levels

Water levels at the project site are dominated by a semi-diurnal mixed tide, characterized by two unequal high and low waters in a day. Table 2-4 provides tidal datums at multiple sites in the vicinity of the Westridge Terminal from the Canadian Hydrographic Survey (CHS). An additional 0.5 m above the high tide line is included in the analysis of water levels to account for future sea level rise.

TABLE 2-4: CHARACTERISTIC TIDAL DATUMS IN THE SITE VICINITY

Datum	Vancouver Tide Table	Vancouver CHS Chart #3494	Port Moody Tide Table	Deep Cove CHS Chart #3494
EHHW (m, CD)	5.60	-	-	-
HHWLT (m, CD)	5.00	5.00	5.12	5.10
HHWMT (m, CD)	4.40	4.40	4.46	4.40
MWL (m, CD)	3.10	3.10	3.08	3.10
Chart Datum (m, CD)	0.00	0.00	0.00	1.00
LLWMT (m, CD)	1.10	1.10	1.07	1.10
LLWLT (m, CD)	-0.10	0.00	-0.10	0.20
ELLW (m, CD)	-0.30	-	-	-
EHHW: Extreme Highest High Water				
HHWLT: Higher High Water Large Tide				
HHWMT: Higher High Water Mean Tide				
MWL: Mean Water Level				
CD: the plane of Lowest Normal Tides to which charts and water levels are referred				
LLWMT: Lower Low Water Mean Tide				
LLWLT: Lower Low Water Large Tide				
ELLW: Extreme Lowest Low Water				
For the Vancouver Harbour area, Geodetic Datum is 3.1 m above CD (see BC Ministry of Env., 1995)				

In addition, Figure 2-9 presents the water level exceedance curve corresponding to the water levels measured at Station 7735 Vancouver, BC. The record extends from November 1909 to February, 2017 with a sample of one hour.

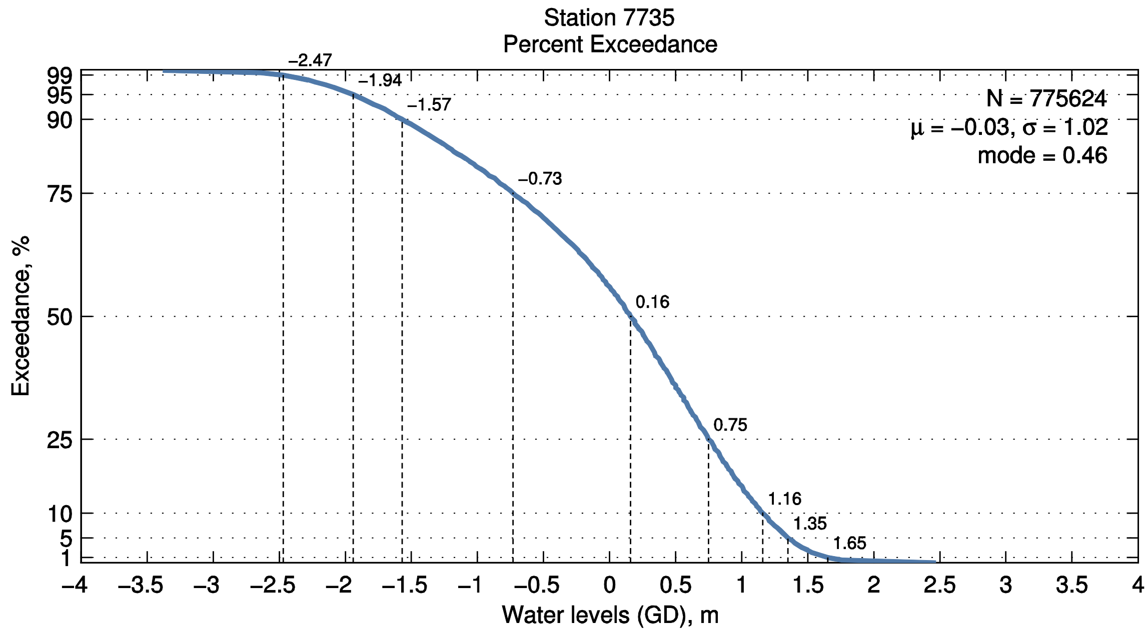
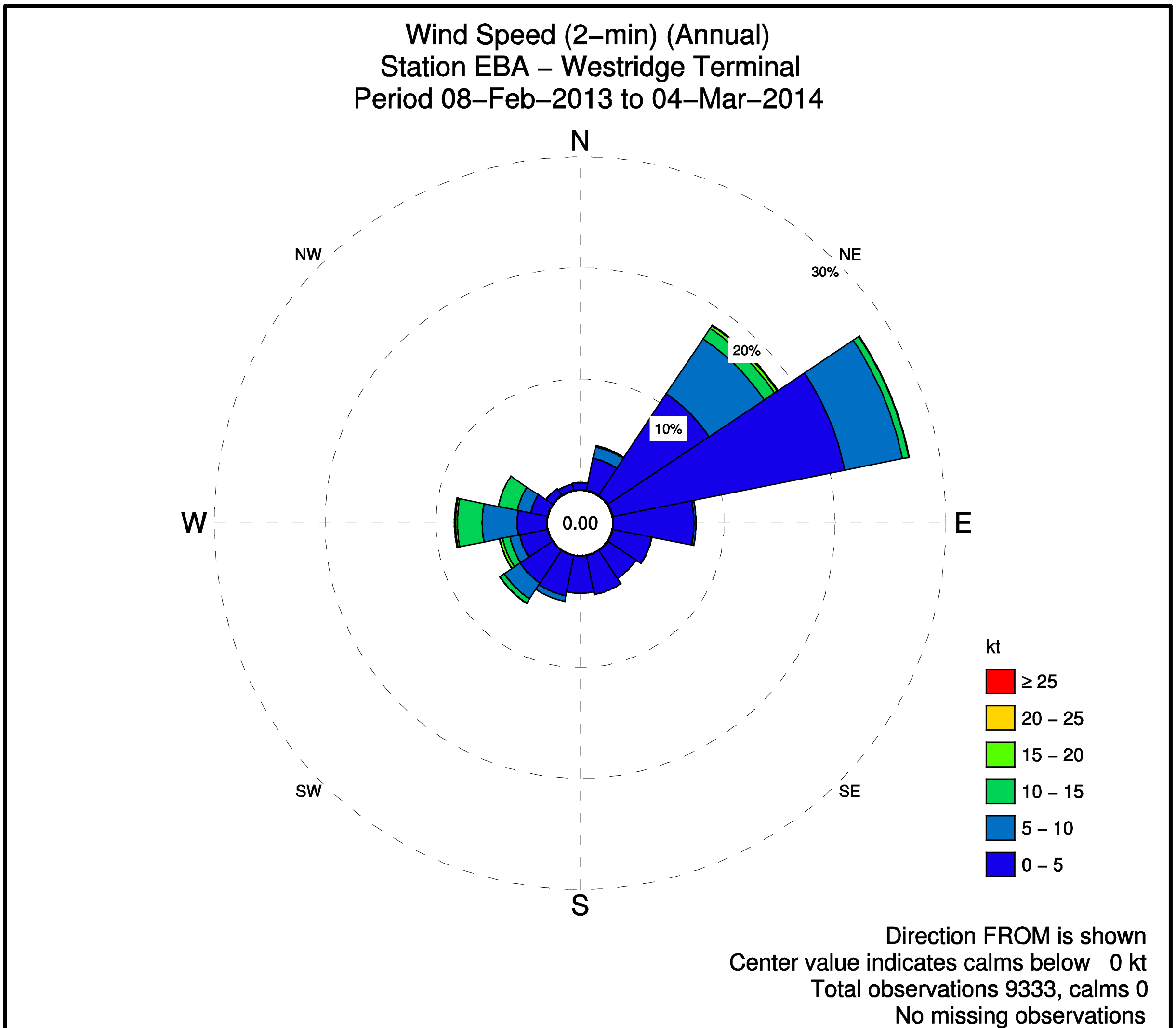


FIGURE 2-9: WATER LEVEL EXCEEDANCE CURVE AT STATION 7735 VANCOUVER

2.3.4. Winds

Winds at the terminal were measured from February 8, 2013 to February 28, 2014. As shown in the annual wind rose in Figure 2-10, winds primarily blow from the NE at speeds lower than 10 knots, followed by winds from the W of similar range. During the winter, winds from the NE prevail and are associated with outflows from the Indian Arm. During the summer, winds from the W increase in frequency and magnitude, and are associated with onshore sea breezes. The highest wind speed recorded during the period of measurements was 17.2 m/s (33.4 knots).



Percentage of Occurrence

Wind Speed (2–min), kt	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	0.62	4.09	18.45	27.27	7.45	3.60	3.05	3.60	3.35	4.22	5.74	4.41	8.34	4.53	0.72	0.55	100.00
25–																	
20–25																	0.17
15–20			0.30									0.27	0.18				0.86
10–15			1.13	0.59							0.47	0.68	2.22	1.76			6.91
5–10		1.06	5.97	5.29	0.18					0.51	1.71	0.89	3.16	1.23			20.06
0–5	0.61	2.93	10.98	21.33	7.26	3.57	3.05	3.60	3.35	3.71	3.54	2.57	2.69	1.54	0.72	0.55	72.00

FIGURE 2-10: ANNUAL WIND ROSE DEVELOPED FROM MEASUREMENTS AT THE SITE

Extreme wind speeds cannot be accurately predicted with one year of measurements. In the site vicinity, the Vancouver International Airport has the longest hourly record of measured wind speeds. The record extends from 1953 to present (March 2017).

Comparison of wind speeds for the overlapping period indicates that extreme winds at the site are approximately 25% lower than at the Vancouver International Airport. Thus, extreme wind speeds calculated from the historical record at the airport were reduced by 25% as a means to estimate extremes at the site. The resulting extremes are shown in Table 2-5. These values are slightly different than those presented in the Metocean Study Report (M&N, 2014a) because more years have been included in the present analysis.

TABLE 2-5: EXTREME WIND SPEEDS AT WESTRIDGE TERMINAL

Return Period (years)	Wind Speed (2-min, 10 m height), knots		
	5% non-Exceedance	Best Fit	95% non-Exceedance
1	25.5	26.3	27.0
2	28.6	29.4	30.1
5	30.9	32.0	33.2
10	32.2	34.1	35.9
25	34.0	36.8	39.5
50	35.3	38.8	42.3
100	36.6	40.8	45.1
200	37.8	42.8	47.9
500	39.5	45.5	51.5

The 60-knot, 30-second wind speed outlined in the OCIMF guidelines corresponds to a 2-minute wind speed of 52.9 knots. According to Table 2-5, this wind speed has a return period beyond 500 years; therefore, use of this wind speed for static analysis of the mooring system is conservative.

For dynamic mooring analyses, a 40 knot omni-directional wind speed is applied, as a typical limiting wind speed for vessels to remain at berth, disconnected from loading equipment. This corresponds approximately to the 100-year wind speed of 40.8 knots. In the event safe mooring criteria are exceeded, maximum allowable wind speeds are reduced.

2.3.5. Current

Measurements of current velocities at the site were made using an Acoustic Doppler Current Profiler (ADCP) for a 2-month period in April and May of 2013. The maximum current speed recorded along the water column was 0.64 m/s (1.2 knots) and the maximum depth-averaged current was 0.47 m/s (0.9 knots).

Depth-averaged currents at each berth were estimated from a 2-dimensional Mike 21 hydrodynamic model of Burrard Inlet. The Metocean Study Report (M&N, 2014a) describes in detail the model development and the results at the site.

Figure 2-11 presents the peak ebb currents as a result of the largest predicated tidal variation; Table 2-6 presents a summary of peak currents and directions. The OCIMF currents of 3 and 2 knots are conservative in comparison to the measured and model-predicted currents.

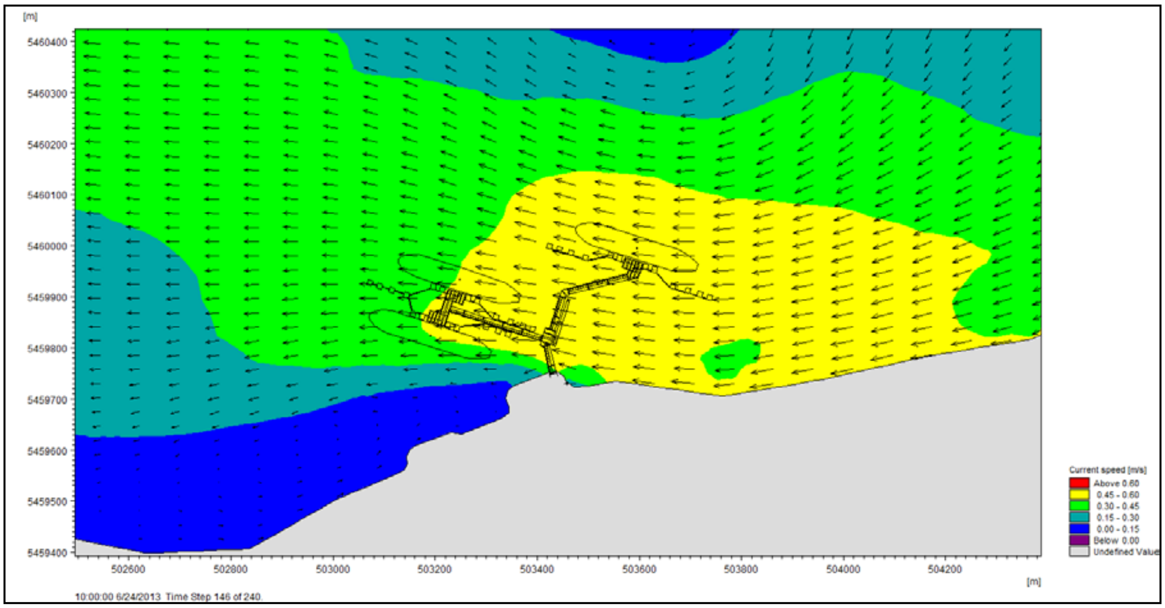


FIGURE 2-11: PEAK EBB (DEPTH-AVERAGED) CURRENTS

TABLE 2-6: PEAK DEPTH-AVERAGED CURRENT FROM HYDRODYNAMIC MODEL

Location	**Ebb**			**Flood**		
	Current Speed		**Direction**	**Current Speed**		**Direction**
	m/s	**knot**	**(°N)**	**m/s**	**knot**	**(°N)**
Berth 3	0.51	1.0	277.0	0.40	0.77	80.9
Berth 2	0.46	0.89	268.2	0.39	0.75	71.7
Berth 1	0.45	0.87	269.8	0.38	0.73	67.4
Utility Dock	0.54	1.05	278.7	0.45	0.87	74.0

2.3.6. Waves

Burrard Inlet is well sheltered from the long period waves characteristic of the Pacific Ocean. Waves at the site are generated by the local winds blowing over the limited fetch. M&N developed a Mike 21 wave model to assess wind-generated waves (M&N, 2014a). A number of wind speeds were evaluated, ranging from the 10th percentile to the estimated 100-year return period. The wind directions that were evaluated were the NE (35 °N) and W (270 °N) which provide the longest fetch.

The 100-year wave will be used for dynamic mooring analyses. The model results show that winds blowing from the NE generate a greater wave height compared to westerly winds. The parameters of the 100-year wave are: significant wave height, H_s = 0.6 m; peak wave period, T_p = 2.6 s, and mean wave direction, MWD = 35 °N.

2.3.7. Tsunami

M&N conducted a tsunami assessment of the Westridge Terminal as part of the TMEP (M&N, 2015). The study evaluated the impact of several hypothetical landslide-generated tsunamis in the Indian Arm and Burrard Inlet using a MIKE 21, two-dimensional hydrodynamic model. Time series of depth-averaged current velocities at the berths for each modeled landslide are available from this study. The highest depth-averaged current at the berths from all the tsunami scenarios was 1.86 knots, which is less than the 3-knot current considered in Section 2.3.1.

2.3.8. Selected Metocean Criteria

Static and dynamic mooring analyses will be conducted to determine the suitability of the mooring system. The metocean criteria that will be used for each analysis is presented in Table 2-7. The peak wave period of the wave used in the dynamic analysis was increased from 2.6 sec to 3.0 sec as this is the minimum peak wave period accepted by the program.

TABLE 2-7: METOCEAN CRITERIA FOR MOORING ANALYSES

Parameter	Static Analysis	Dynamic Analysis
Depth	18 m (CD)	18 m (CD)
Water Level	Vancouver Tides: 1) 6.1 m (CD) (HHWLT + SLR) 2) -0.1 m (CD) (LLWLT)	Vancouver Tides: 1) 6.1 m (CD) (HHWLT + SLR) 2) -0.1 m (CD) (LLWLT)
Winds	OCIMF Criteria: • Speed: 60 knot (30-sec duration) • Direction: Full compass	Analysis of Local Winds: • Speed: 40 knot (2-min duration) • Direction: Full compass • 100-year return period
Currents	OCIMF Criteria: 1) 3-knot at 0°or 180° 2) 2-knot at 10° or 170° 3) 0.75 knots from the direction of maximum beam current loading	Mike 21 Model Results: • Speed: 1.0 knot • Direction: Parallel to berth (ebb and flood)
Waves	NA	Mike 21 Model Results: • Sign. wave height, H_s = 0.6 m • Peak wave period, T_p = 3.0 s • Mean wave dir., MWD = 35 °N • 100-year return period
Tsunami	NA	Mike 21 Model Results: • Maximum calculated currents corresponding to Landslide 1 • Concurrent 25-year wind (36.8 knots)

3. Berthing Analysis

This section of the report presents the berthing analysis and selection of fenders. All three berths will be capable of handling Aframax class tankers as well as barges. The berthing structure layouts are similar with four breasting dolphins. This implies that the dominant berthing impact load and selected fender for one berth, determines the design condition for all three berths.

Vessels berthing and unberthing will be tug-assisted. A fast-time simulation performed by LANTEC Marine Incorporated determined that each berth has adequate space for assist tugs to work effectively and adequate maneuvering space for the ship itself.

3.1. Berthing Energy Requirements

The primary function of the fender is to absorb the berthing energy from the berthing vessel. Fender design method starts with estimating berthing energy for some appropriate design cases and selecting fender types. The method outlined in the World Association for Waterborne Transport Infrastructure (PIANC) Guidelines for the design of Fender Systems: 2002 (PIANC, 2002) is widely used and has been applied for this analysis. A brief description of the method is given.

Berthing impact kinetic energy is:

$$E = \frac{1}{2} V_b{}^2 M_D C_e C_m C_s C_{ab} \quad (1)$$

E = berthing impact energy (N-m)
V_b = berthing velocity normal to berth (m/s)
M_D = vessel mass, displacement tonnage (tonnes)
C_e = eccentricity coefficient
C_m = added mass coefficient
C_s = softness coefficient
C_c = berth configuration coefficient
C_{ab} = abnormal impact coefficient or factor of safety

The appropriate factors to be used in the kinetic energy method have been selected as per PIANC guidelines and fender manufacturer design aids.

3.2. Berthing Velocity

The berthing velocity is assumed to be 0.15 m/s for tankers and 0.25 m/s for barges. This is determined using the design approach velocities as recommended by Brolsma et.al. in 1977 shown in Figure 4.2.1 in PIANC (2002). As shown in the figure, the design berthing velocity is a function of navigation conditions and size of vessel. For the project site, the berthing velocities of vessels are based on tug-assisted berthing, easy berthing conditions in exposed water (category c). A vessel docking information system will provide real-time data on vessel approach speed, distance off, and angles of approach to assist vessel pilots in maintaining appropriate docking speeds.

3.3. Eccentricity Factor

The eccentricity factor (C_E) is used in the berthing energy calculation to allow for dissipating energy as the vessel rotates about an off-centre impact point. The eccentricity factor C_E has been calculated using the following formula as recommended by PIANC:

$$C_E = \frac{K^2 + R^2 * \cos^2 \varphi}{K^2 + R^2} \tag{2}$$

Where:

- C_E = Eccentricity factor
- K = Vessel radius of gyration (m)
- R = Distance from point of contact to vessel's center of mass (m)
- φ = Angle between the velocity vector and the line between the point of contact and the center of mass

3.4. Added Mass Factor

The virtual mass factor C_M accounts for the effective increase in the overall mass of the ship attributed to the entrained body of water carried along with the ship as it moves sideways. The calculation of the virtual mass factor has been performed using the Shigera Ueda and Vasco Costa methods, as recommended by PIANC (2002), with the most conservative result used for berthing energy calculation.

$$C_M = 1 + \frac{2 * D}{B} \tag{3}$$

Where:

- C_M = Virtual mass factor
- D = Vessel draught (m)
- B = Vessel beam (m)

3.5. Berthing Configuration and Fender Softness Factor

The softness factor, C_S, which allows for the energy absorbed by the elastic deformation of the ship's hull, and the berth configuration factor, C_c, which allows for the cushioning effect of the water trapped between the vessel and berth, have been determined as per the recommended values by PIANC as 1.0.

3.6. Abnormal Berthing Energy Factor

Abnormal berthing energy factor or factor of safety is recommended by PIANC to account for human error, malfunctions, exceptional weather conditions or combination of these factors. In this analysis a factor of 1.25 is assumed for tankers and 1.75 for barges per PIANC (2002) Table 4.2.5.

3.7. Berthing Loads

The three berths will be capable of accommodating fully laden Aframax vessels. Since this is an export facility the majority of the vessels will be ballasted while berthing, however the fenders need to have the capacity to accommodate both laden and ballasted vessels in the rare event that a laden vessel needs to return to the berth.

The berthing energy is calculated from Equation (1). Table 3-1 shows the berthing energies of the different design vessels. The berthing analysis shows that the berthing impact from a laden Aframax vessel governs the fender selection and design. Assuming that the breasting dolphin structure is exceptionally rigid absorbing no energy, the required energy absorption capacity of the fender is 2,700 kN-m.

TABLE 3-1: BERTHING ANALYSIS SUMMARY

Vessels							
Cargo		**Oil**	**Oil/Jet Fuel**	**Jet Fuel**	**Oil**	**Oil**	**Oil**
Vessel Class		**Oil Barge**	**ATB Barge**	**Handysize**	**Handymax**	**Panamax**	**Aframax**
DWT		13,005	27,456	16,775	50,000	70,297	11,7654
LOA	m	116.0	206.0	144.1	183.2	228.0	249.9
LBP	m	116.0	177.7	134.0	174.0	219.0	239.0
B	m	23.2	22.6	23.3	32.2	32.2	44.0
Berthing Energy- Fully Laden							
D	m	7.8	9.25	8.7	11.9	13.82	15.1
M	mt	15,697	33,558	21,977	54,915	84,204	136,337
Vb	m/s	0.25	0.25	0.25	0.15	0.15	0.15
Alpha	degrees	15.0	15.0	15.0	6.0	6.0	6.0
Cb		0.9	0.9	0.9	0.9	0.9	0.9
Cm		1.7	1.8	1.7	1.7	1.9	1.7
Ce		0.5	0.5	0.5	0.5	0.8	0.8
Cs		1.0	1.0	1.0	1.0	1.0	1.0
Cc		1.0	1.0	1.0	1.0	1.0	1.0
Cab		1.75	1.75	1.50	1.25	1.25	1.25
Ev	kNm	433	1,036	639	579	1,334	1,963
Evab	kNm	758	1,813	958	724	1,667	2,454
Edesign	kNm	834	1,994	1,054	796	1,834	2,700
Berthing Energy – Ballasted							
D	m	1.6	4.95	6.21	7.18	9.9	7.13
M	mt	2,690	17,083	16,061	30,912	46,612	59,900
Vb	m/s	0.25	0.25	0.25	0.15	0.15	0.15
Alpha	degrees	15.0	15.0	15.0	6.0	6.0	6.0
Cb		0.9	0.9	0.9	0.9	0.9	0.9
Cm		1.1	1.4	1.5	1.4	1.6	1.3
Ce		0.5	0.5	0.5	0.5	0.8	0.8
Cs		1.0	1.0	1.0	1.0	1.0	1.0
Cc		1.0	1.0	1.0	1.0	1.0	1.0
Cab		1.8	1.8	1.5	1.3	1.3	1.3
Ev	kNm	51	417	410	271	642	677
Evab	kNm	88	730	614	339	802	847

LOA	Length Overall	Cm	Added Mass Coefficient
LBP	Length Between Parallels	Ce	Eccentricity Coefficient
B	Beam	Cs	Softness Factor
D	Draught	Cc	Berth Configuration Factor
M	Displacement	Cab	Abnormal Berthing Factor
Vb	Berthing velocity	Ev	Normal Berthing Energy
Alpha	Angle of Approach	Evab	Abnormal Berthing Energy
Cb	Block Coefficient	Edesign	Design Energy includes manufacturer tolerance, angular, velocity, and temperature factors

3.8. Fender Selection

All breasting dolphins, for all three berths, are equipped with a single fender and fender panel. Trelleborg marine super cone fenders 2000 F1.0 CV are selected for the purposes of mooring analyses. The fender element has a rated reaction of 2,511 kN (256 mt) and an energy absorption of 3,000 kN-m (306 mt-m). Therefore, it is adequate for the range of design berthing energies presented in Table 3-1.

The super cone fenders supersede the previously proposed Trelleborg marine cone fenders MCN 2000 G1.2 per the project memorandum to TMP "Berthing Analysis and Fender Selection" (M&N, 2014b).

Figure 3-1 presents the generic super cone fender performance curve.

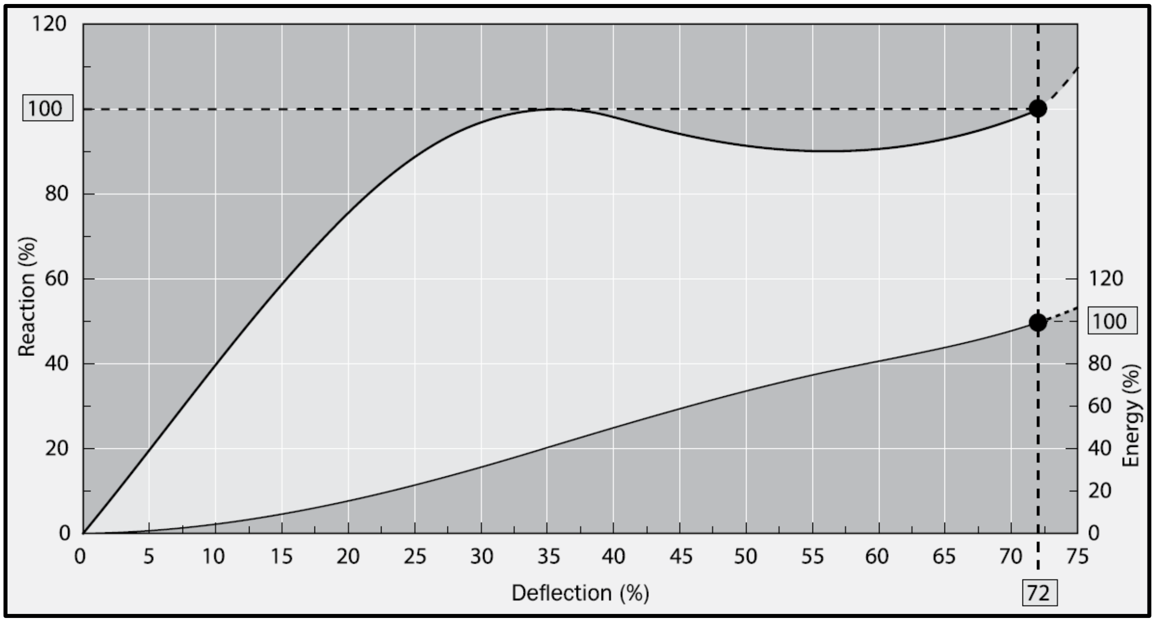


FIGURE 3-1: GENERALIZED PERFORMANCE CURVE OF TRELLEBORG SUPER CONE FENDER

Each fender system consists of one cone fender centered at elevation +0.85 m (GD). To accommodate barges at varying elevations of water level, it is recommended the fender panel be incorporated with mooring posts which flank the fender panel. For mooring analyses, it is assumed that mooring posts on each side of the fender panel are available with a load rating up to 100 mt.

Figure 3-2 present examples of the recommended fender panel with flanking mooring posts.

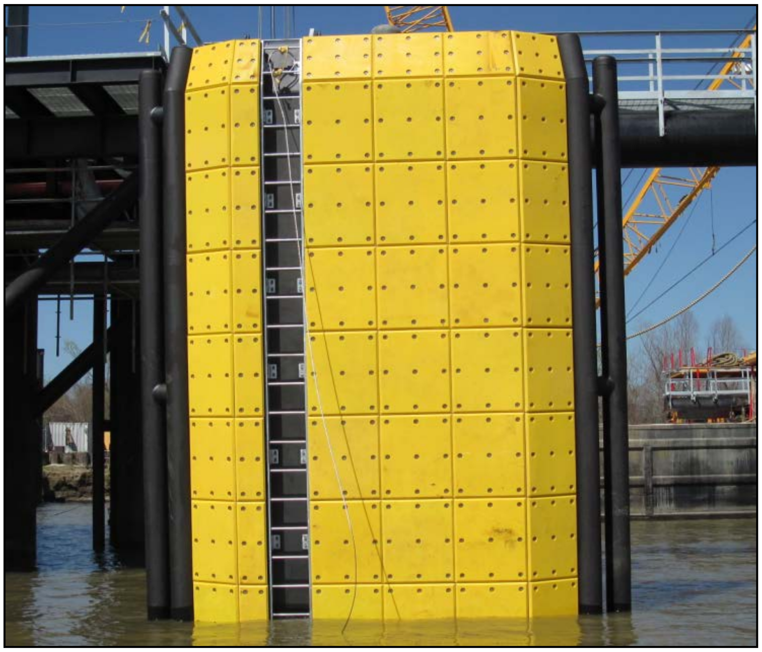


FIGURE 3-2: PHOTOGRAPH OF EXAMPLE FENDER PANEL WITH 100 MT CAPACITY FENDER POSTS

4. Mooring Point Loads

There are a number of publications which provide discretion, instruction, recommendations, and in some instances, requirements, with regards to the design of a mooring point tied to a jetty or wharf structure. This section summarizes the various available calculation methods and presents the method utilized for final design of mooring and breasting dolphins and sizing quick release hook (QRH) capacity.

4.1. MOTEMS

The Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) were initiated by the Marine Facilities Division (MFD) as a result of the California State Lands Commission (CSLC) which provide specifications and qualifications for marine oil terminals along California's coast. Although the statutory regulations identified in MOTEMS are enforceable only in California, MOTEMS is commonly used as an industry guidance document for terminals outside of California, and is included as a reference in WMT Design Basis Memorandum.

MOTEMS specifies that a mooring hook must be able to withstand the minimum breaking load (MBL) of the strongest anticipated mooring line, with a Safety Factor of 1.2. The following formula is utilized for multiple hook units:

$$F_d = 1.2\,(MBL) \times [1 + 0.75\,(n-1)] \quad (4)$$

Where:

n = Number of hooks on the assembly

MBL = Minimum Breaking Load

F_d = Design lateral load for the tie-down into the wharf

4.2. PIANC WG 153

The World Association for Waterborne Transport Infrastructure (PIANC) provides a publication titled "Recommendations for the Design and Assessment of Marine Oil and Petrochemical Terminals", which is the report of an international Working Group convened by the Maritime Navigation Commission. The report provides information and recommendations, however states: "conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances."

PIANC WG 153 states that for structural design practice, the combined hook assembly load on the mooring structure (F_{ZA}) can be calculated as:

$$F_{ZA} = SWL\,[1.0 + 0.6 \times (n-1)] \quad (5)$$

Where:

F_{ZA} = Design load for hook anchorage and supporting structure

SWL = Safe Working Load of the hook assembly, based on highest anticipated MBL of the design range of vessels.

n = Number of hooks in the assembly

For the case of n = 1, a factor of 1.18 is recommended

The load formula above is based on a failure sequence as follows:

- Ships winch brakes are set so that the holding capacity, beyond which it renders, equals 0.6 x the rated capacity of the ships mooring lines;
- The rated capacity of the mooring line is its minimum breaking load;
- The factor of 0.6 x MBL is based on the OCIMF recommendation for winch rated brake holding load;
- In the event of accidental overload of the mooring system, winches will render before exceeding the SWL of any individual hook;
- For the case of n = 1, the hook should be designed to sustain a load of 1.18 times the hook SWL, because the mooring fittings are designed for a safety margin against a yield of 1.18 per Oil Companies International Marine Forum (OCIMF) Mooring Equipment Guidelines.

4.3. British Standard (European Union)

The British Standard BS 6349 1-2 provides guidance on the planning, design, construction and maintenance of maritime structures and which are in line with Eurocodes, which are European standards for specifying structural design within the European Union. Eurocodes are mandatory for the specification of European public works which recently replaced national building codes. Eurocodes, however, are not implicitly required on private sector projects.

Table 4-2 presents guidance provided by British Standard for the design of mooring points.

TABLE 4-1: BS6349: 1-2 "TABLE H"

Number of Mooring Hooks per Mooring Point (N)	Total Accidental Mooring Point Load as Multiple of the Factored Rated Hook SWL (or factored rated MBL of vessel's mooring line, where appropriate)	Scenario for Derivation of Total Mooring Point Load from Mooring Line MBL
2	1.8 x 1.18 = 2.1	1 x 0.8 +1 x MBL = line on one mooring hook at MBL and the other at ship's winch design brake holding load
3	2.4 x 1.18 = 2.8	3 x 0.8 x MBL = lines on each hook at ship's winch design brake holding load
4	3.0 x 1.18 = 3.5	3 x 0.8 x MBL + 1 x 0.6 x MBL = 3 x MBL lines on each hook at ship's winch design brake holding load, one line at ship's winch brake setting

4.4. Determining Largest Mooring Line

To determine the appropriate minimum breaking load which services all methods of mooring point calculation, INTERTANKO (Q88) registry was queried for information regarding mooring line minimum breaking load for any/ all vessels which were labelled, "Aframax", and "Panamax". It is assumed that barges and smaller vessels will have lesser mooring line capacity.

Table 4-2 and Table 4-3 present confidence banding for mooring line strength for the Aframax and Panamax tankers, respectively. The largest MBL at the 95% confidence banding and is 93 metric tons.

Therefore, a QRH with a minimum capacity of 100 metric tons will satisfy the design range of tankers and barges.

TABLE 4-2: AFRAMAX CONFIDENCE BANDING

Confidence Level	5%	25%	50%	75%	95%
Cubic Capacity 98%	112,092	117,926	120,330	126,526	128,011
Ropes Forecastle (BS)	0.00	0.00	0.00	69.00	87.00
Wires Forecastle (BS)	64.00	74.00	81.00	85.00	93.00

TABLE 4-3: PANAMAX CONFIDENCE BANDING

Confidence Level	5%	25%	50%	75%	95%
Cubic Capacity 98%	37,426	79,649	83,613	84,314	86,652
Ropes Forecastle (BS)	0.00	0.00	63.00	72.00	87.00
Wires Forecastle (BS)	0.00	57.00	67.00	76.00	93.00

4.5. Method Selection

Table 4-1 presents a comparison summary of mooring point loads for a representative quadruple quick release hook. The PIANC recommended formulae are utilized for structural design, with the underlying design premise that each successive element of the mooring system from the ship's winch to the shore mooring structure should be designed to be progressively stronger. In the event of overload, this is intended to result in an inherent "fail safe" design where the mooring line would render out before the mooring line parts, before the mooring hook fails, and before the stability of the whole mooring structure is compromised. The PIANC load formula is based on a failure sequence which follows:

- Ships winch brakes are set so that the holding capacity, beyond which it renders, equals 60% of the rated capacity of the ships mooring lines;
- The rated capacity of the mooring line is its minimum breaking load;
- The factor of 0.6 x MBL is based on the OCIMF recommendation for winch rated brake holding load.
- In the event of accidental overload of the mooring system, winches will render before exceeding the SWL of any individual hook;

5. Mooring Analysis Methodology

All mooring analyses are performed at the following conditions:

- Ballast Draft at Extreme Highest High Water and Sea Level Rise: +3.0 m GD: This criterion ensures vertical line angles are the largest and least efficient; additionally, the ballast draft of the vessel has the largest windage area for the wind force to be imposed.
- Loaded Draft at Lower Low Water (Large Tide): -3.0 m GD: This criterion ensures the least amount of underkeel clearance which amplifies current force acting on the loaded draft vessel.

5.1. Static Mooring Model Software – OPTIMOOR

All OCIMF recommended criteria for mooring analyses are carried out using the static mooring program OPTIMOOR v.5.6.1, developed by Tension Technology International.

OPTIMOOR is a static mooring analysis program used widely in both industrial marine and naval mooring analyses. The program allows users to input vessel particulars, pier descriptions, and mooring arrangements. The environmental conditions can be applied at various speeds from any direction. The resultant wind force on the vessel is provided by the program and distributed to the mooring lines. The lines are modeled with the elasticity of actual mooring line.

5.2. Dynamic Mooring Model Software – aNyMoor

All operational metocean criteria for mooring analyses are carried out using the dynamic program aNyMoor-Termsim, developed by the Maritime Research Institute Netherlands (MARIN). The program is a time domain mooring software used to simulate the dynamic characteristics of mooring systems undergoing environmental forcing. The calculation methods are derived from the evolution of TERMSIM II (developed by MARIN), which was developed and verified through extensive model testing and is well accepted for industry use.

All metocean conditions examined use a simulation time of 3 hours (10,800 seconds) per wind direction that varied by 15 degree increments and include the API gusting spectrum. The program will not establish second order drift forces for waves whose peak period is less than three (3) seconds; therefore, all waves listed in Table 2-7 will have an increased peak wave period of at least three seconds.

5.3. Limiting Mooring Criteria

The following are criteria which establish industry guidelines for safe mooring conditions.

5.3.1. Mooring Line Tension Limits

The allowable safe working load (SWL) in the mooring lines was set at 55% of the minimum breaking load (MBL) per recommendations provided by OCIMF for steel wire mooring lines.

For synthetic mooring lines, OCIMF recommends a safe working load equal to 50% of the MBL.

5.3.2. Fender Loads

The allowable working load in the fenders was the rated reaction at design performance for the representative fender design which is 256 mt.

5.3.3. Motions

PIANC "Criteria for Movements of Moored Ships in Harbours" recommends ±3.0m (peak to peak) for surge and ±3.0 m (zero to peak) for sway. Values recommended by PIANC guidelines are conservative given the capabilities of modern marine loading arms, however serve as the primary limit for operational criteria.

5.4. Mooring Line Arrangements

Figure 5-1 through Figure 5-8 present the mooring line arrangements for the design range of vessels at Berth 1. All vessels at Berth 1 shall be moored starboard side to, while all vessels at Berths 2 & 3 shall be moored portside to. In all mooring scenarios, the preferred method of mooring allows the bow of the vessel to be pointed towards the channel to allow for emergency departure; and allows the stern of the vessel to maximize use of the quadruple quick release mooring hooks. As the layout of the mooring and breasting dolphins are symmetrical for vessels moored starboard side-to at Berth 1 and port-side-to at Berth 2; mooring analyses are conducted for vessels positioned at Berth 1, and are considered representative for all berths.

5.4.1. Aframax Tanker

Figure 5-1 presents the conventional mooring arrangement for the Aframax tanker; which deploys sixteen (16) mooring lines, and contacts all four (4) breasting dolphins. Due to the placement of onboard mooring winches, four (4) stern mooring lines are required to be sent to the aft-most mooring dolphin, equipped with the quadruple QRH.

Figure 5-2 presents the mooring line arrangement for the Aframax tanker at Lower Low Water-Large Tide (LLWLT). During extreme low water conditions, the tankers deck level, where winch mounted mooring lines are deployed, will be below the elevation of the QRH located on the interior breasting dolphins. As presented in Section 2.3.3, the LLWLT condition is exceeded only 1% of the time. Conditions where the tankers deck is lower than the top of dolphin is exceeded approximately 9% of the time. As a result, at low water, it may not be feasible to deploy the two aft spring lines (ML-9 and ML-10 as presented in Figure 5-1). Therefore an alternate mooring arrangement is provided, and the Aframax tanker is able to deploy fourteen (14) mooring lines, and contacts all four (4) breasting dolphins.

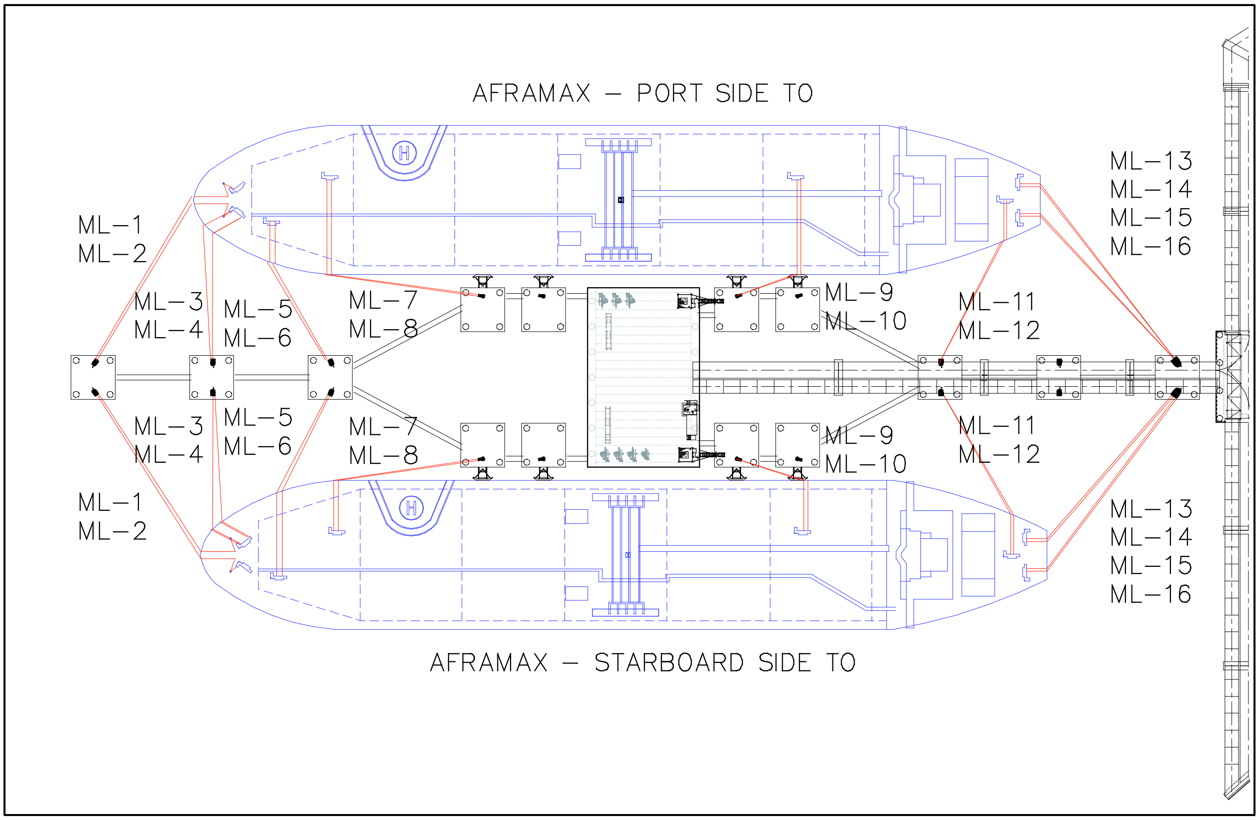


FIGURE 5-1: MOORING LINE ARRANGEMENT – AFRAMAX TANKER

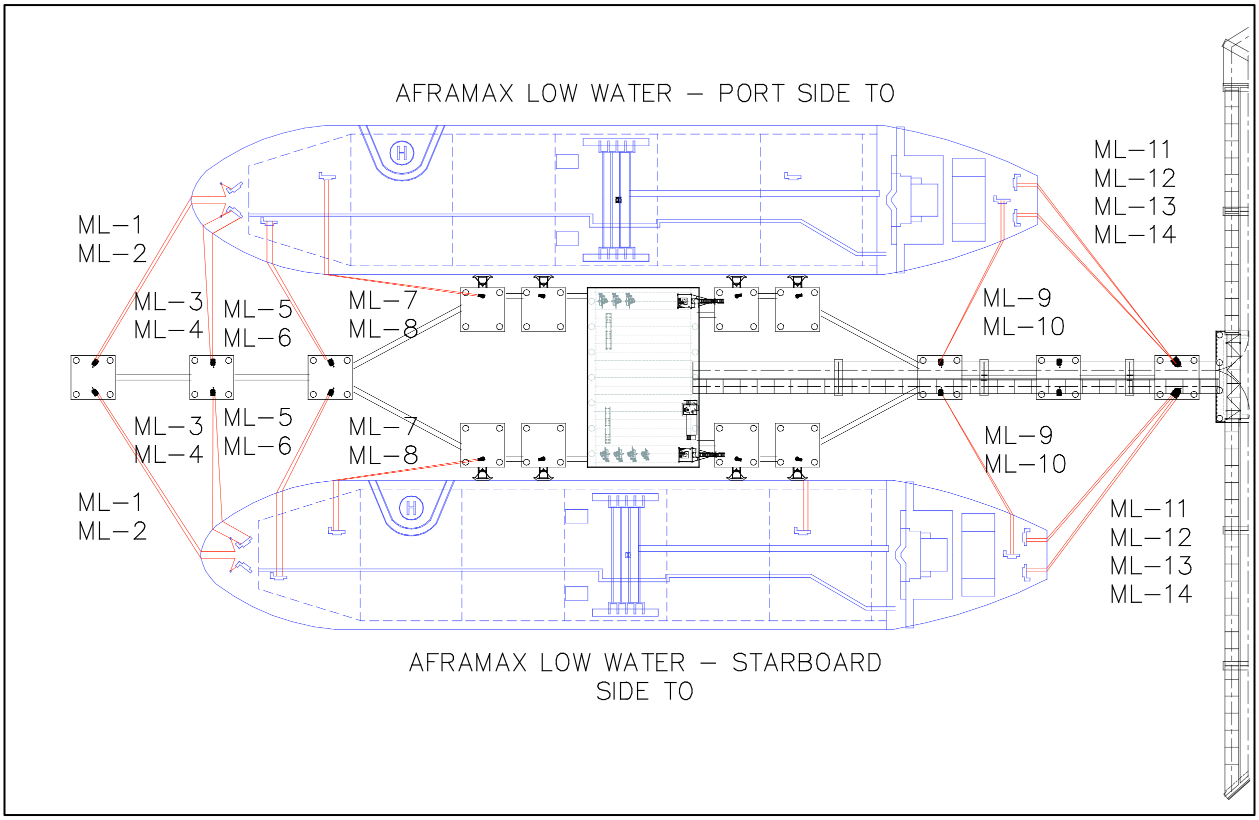


FIGURE 5-2: EXTREME LOW WATER MOORING LINE ARRANGEMENT – AFRAMAX TANKER

5.4.2. Panamax Tanker

Figure 5-3 presents the conventional mooring arrangement for the Panamax tanker; which deploys twelve (12) mooring lines, and contacts all four (4) breasting dolphins.

Figure 5-4 presents the mooring line arrangement for the Panamax tanker at LLWLT (-3.0 GD). During extreme low water conditions, the tankers deck level, where winch mounted mooring lines are deployed, will be below the elevation of the QRH located on the interior breasting dolphins. As a result, the spring lines, both forward and aft of the marine loading arm, must be attached to the quick release hooks located on the outer breasting dolphins. This placement of spring lines is not as efficient as the layout presented in Figure 5-3, however, allows spring lines to be deployed and maintain the use of all available winch mounted mooring lines. Conditions where the tankers deck is lower than the top of dolphin is exceeded approximately 5% of the time.

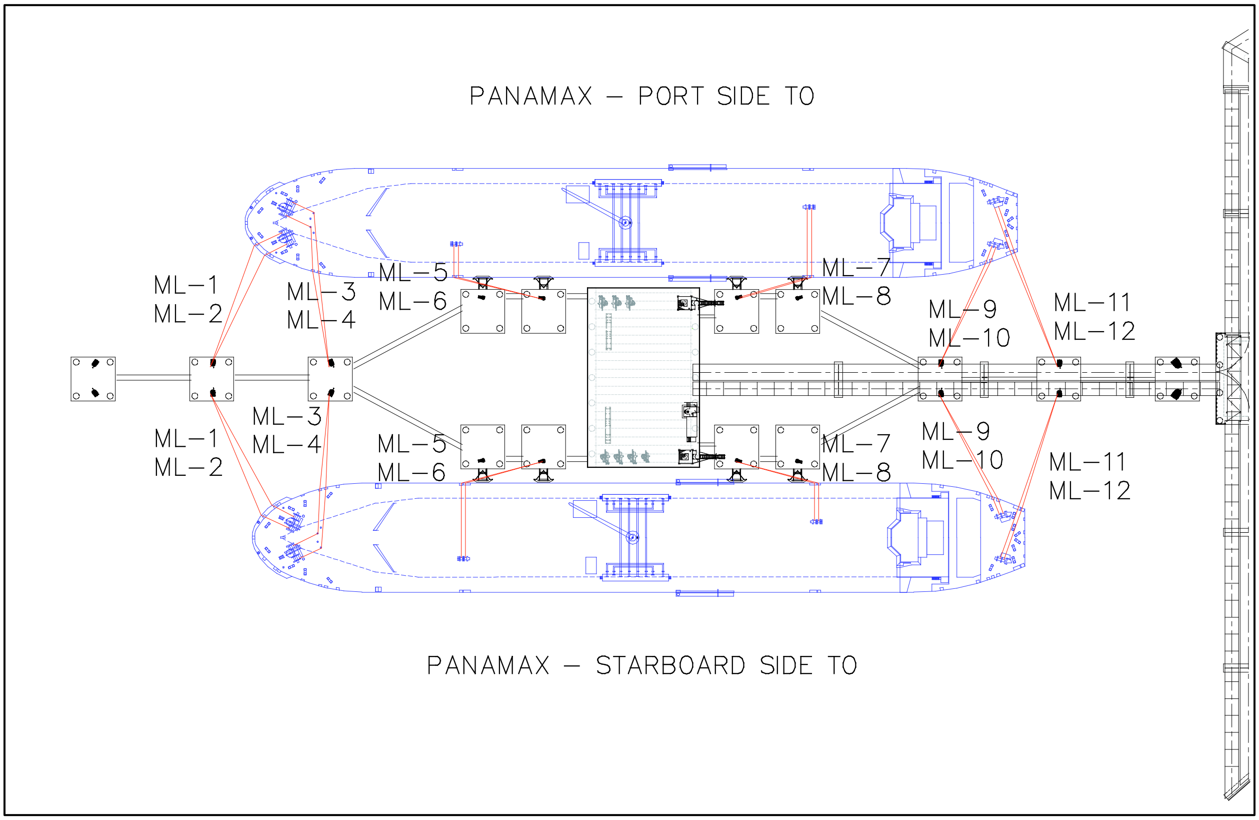


FIGURE 5-3: MOORING LINE ARRANGEMENTS – PANAMAX TANKER

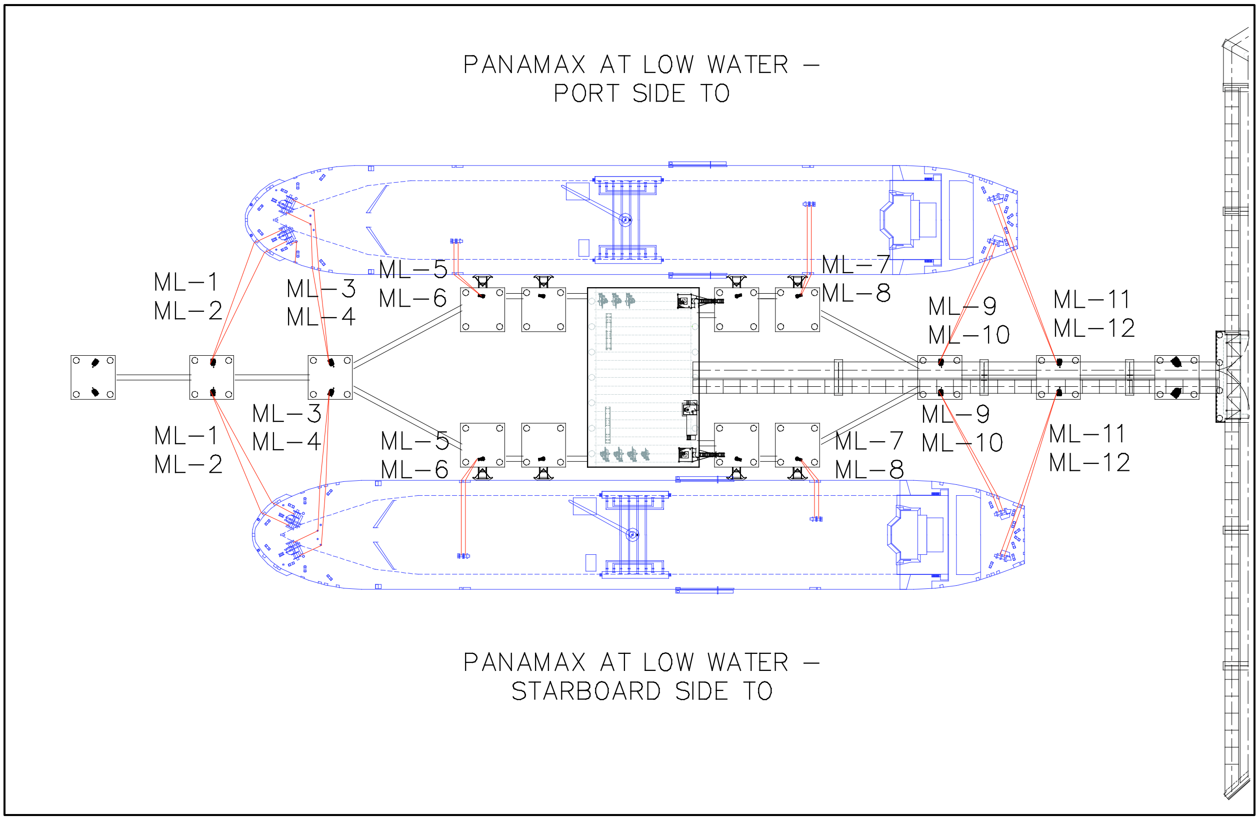


FIGURE 5-4: EXTREME LOW WATER MOORING LINE ARRANGEMENTS – PANAMAX TANKER

5.4.3. Handymax Tanker

Figure 5-5 presents the mooring arrangement for the Handymax tanker; which deploys twelve (12) mooring lines, and contacts all four (4) breasting dolphins. Due to the location of the winch-deployed mooring lines, the spring lines are sent to the interior breasting dolphins, and do not interfere with outer breasting dolphins at any water level.

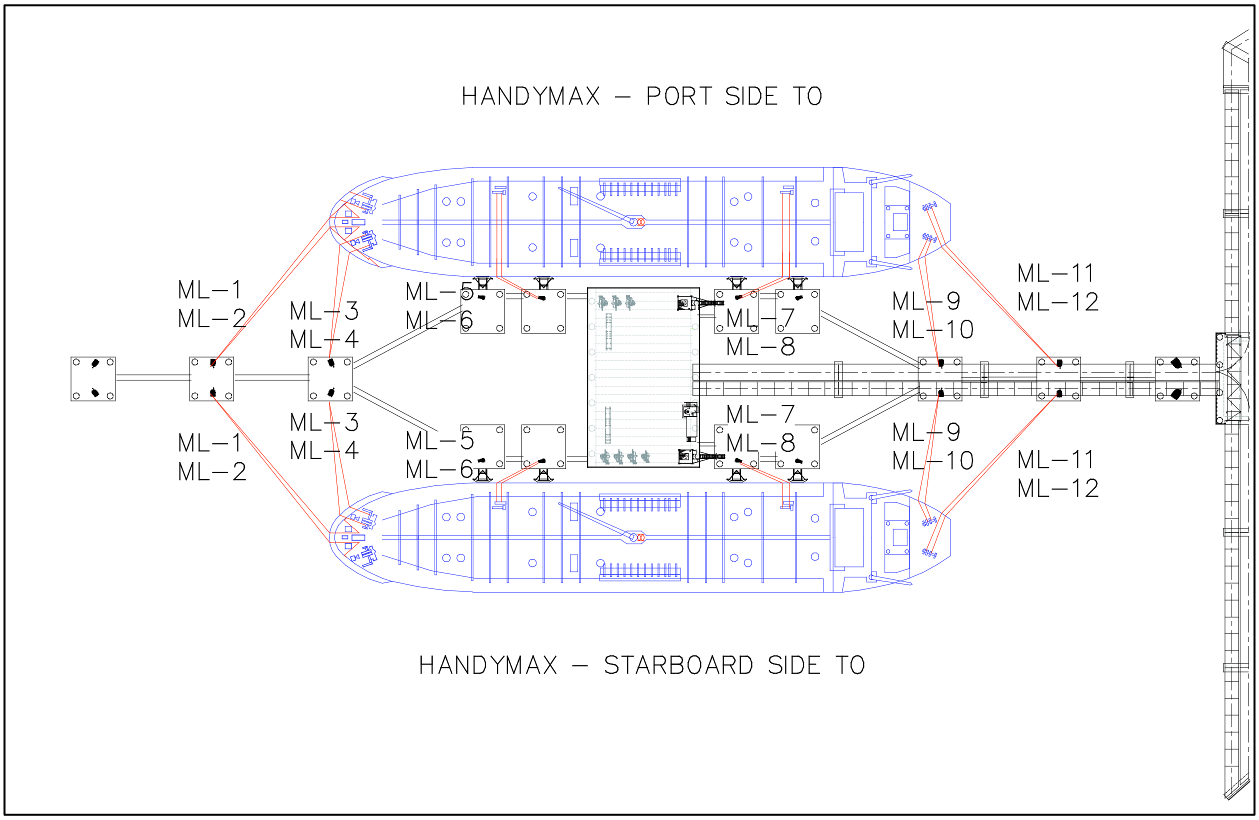


FIGURE 5-5: MOORING LINE ARRANGEMENTS – HANDYMAX TANKER

5.4.4. Handysize Tanker

Figure 5-6 presents the mooring arrangement for the Handysize tanker; which deploys twelve (12) mooring lines, and contacts the two inner breasting dolphins. Spring lines are deployed to the outer breasting dolphins, and do not require an alternate mooring line arrangement for extreme low water conditions. The handysize tanker is positioned only at Berth 1 with its central manifold spotted at the jet fuel marine loading arm.

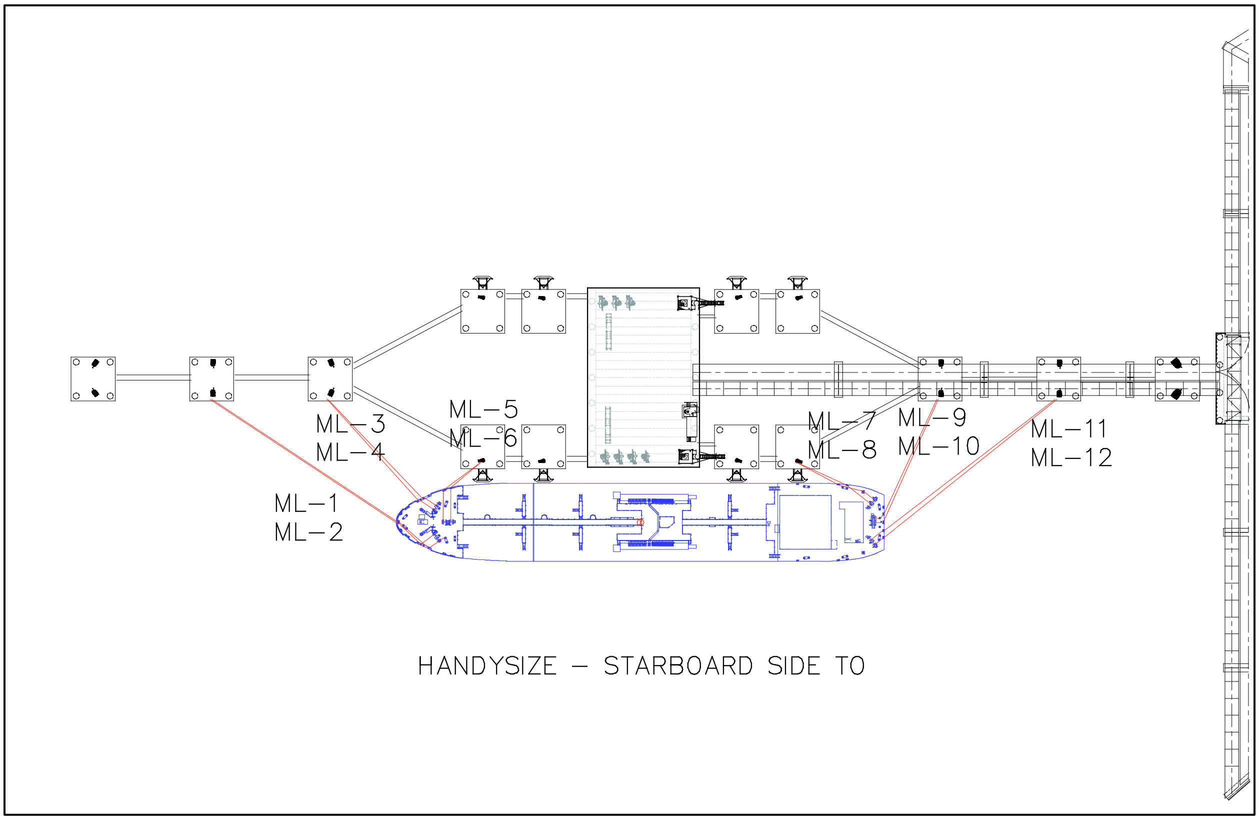


FIGURE 5-6: MOORING LINE ARRANGEMENTS – HANDYSIZE TANKER

5.4.5. Jet Fuel Barge

Figure 5-7 presents the mooring arrangement for ocean-going Articulated Tug Barge (ATB) servicing jet fuel; which deploys eight (8) mooring lines, and contacts all four (4) breasting dolphins. Spring lines are deployed to the outer breasting dolphins, and do not require an alternate mooring line arrangement for extreme low water conditions. The ocean going barge is positioned only at Berth 1 with its central manifold spotted at the jet fuel marine loading arm.

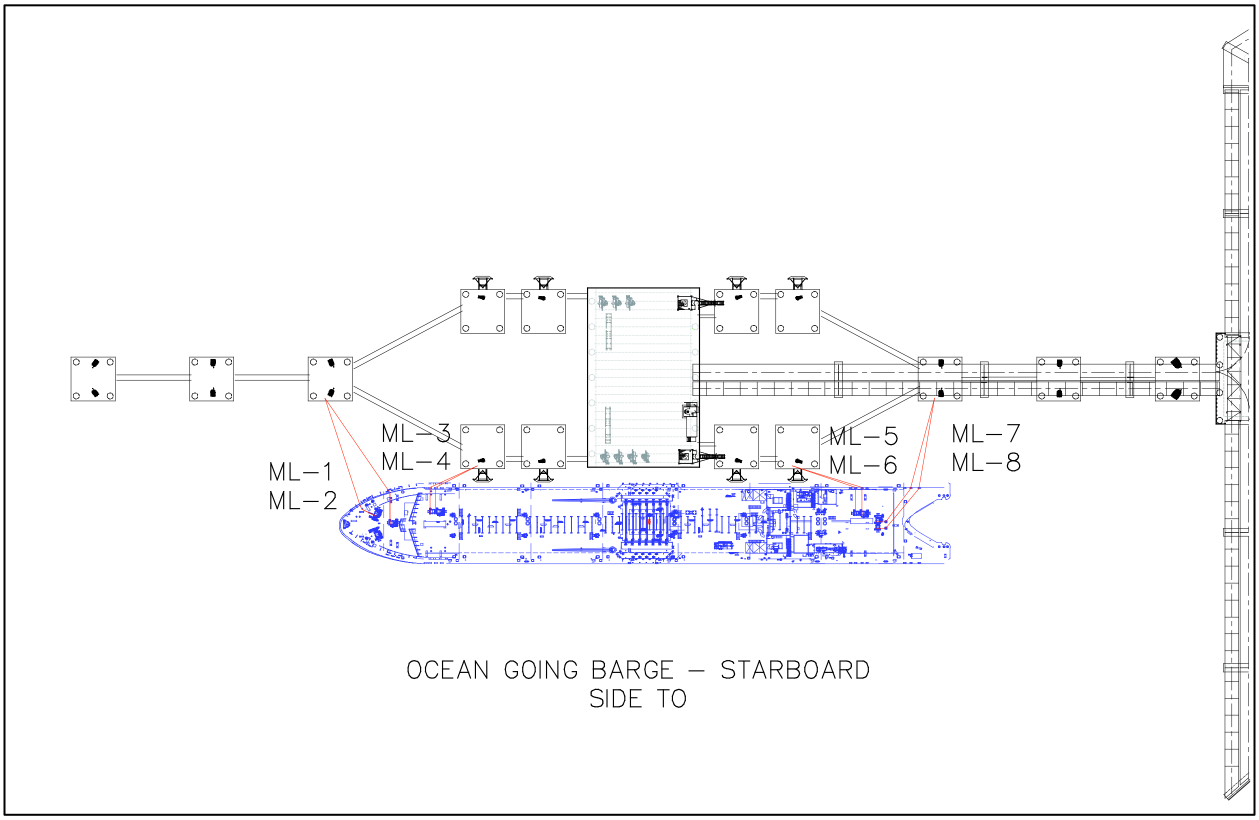


FIGURE 5-7: MOORING LINE ARRANGEMENTS – JET FUEL BARGE

5.4.6. Oil Barge

Figure 5-8 presents the mooring arrangement for the oil barge which deploys eight (8) mooring lines, and contacts three breasting dolphins at ballast draft; contact is made with the two forward most breasting dolphins, and with the inner breasting dolphin aft of the marine loading arms. At loaded draft, the barge makes contact with all four (4) breasting dolphin fenders.

Spring lines are deployed from bitts located onboard the barge, but are not deployed from winches, and therefore have no pretension. The spring lines are attached to the mooring posts on the outsides of the fender panels, as presented in Figure 3-2. The ocean going barge is positioned with its central manifold spotted across from the crude marine loading arm, as connecting the vapor recovery arm is not anticipated with small barges.

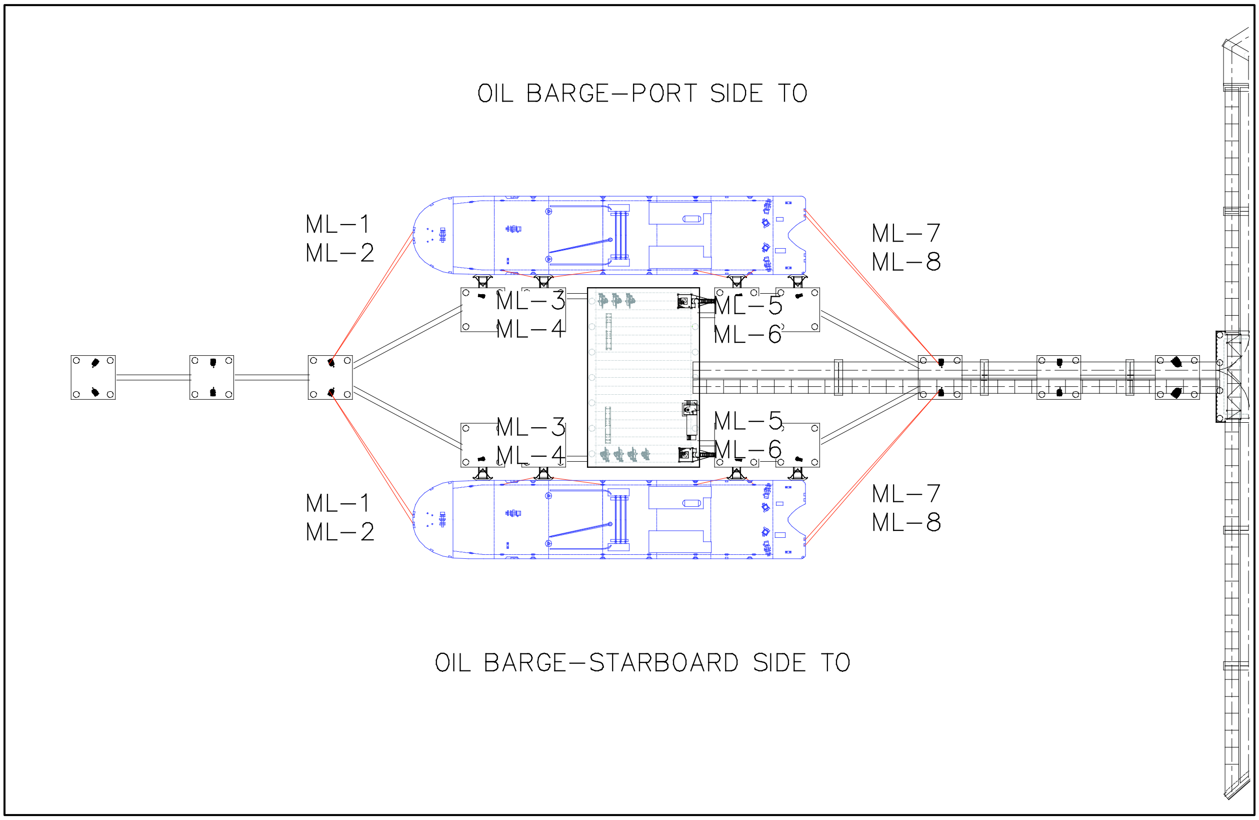


FIGURE 5-8: MOORING LINE ARRANGEMENTS – OIL BARGE

6. Static Mooring Analysis Results

Results from static mooring analyses are included for all examined design range vessels in this section. Results are presented in tabular format reporting the peak mooring line tension as a percent of the minimum allowable load. For mooring lines, peak line load is a percentage of its minimum breaking load (MBL) which can vary by vessel. Peak fender reactions are reported in kips, and should not exceed the combined fender and pile rated reaction of 256 mt. Peak loads are indicative of all environmental conditions and directions applied to the moored vessel. All tables indicate varied current directions, and include applied wind speed of 60 knots.

6.1. Aframax Tanker

Table 6-1 and Table 6-2 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-1 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 40% of the minimum breaking load (MBL) and occurs at ballast draft. No mooring line loads exceed the OCIMF recommended criteria of 55% MBL for wire lines. No fender reactions exceed their rated capacity.

Table 6-3 and Table 6-4 present a summary of peak mooring line and fender loads for the extreme low water mooring arrangement, as presented in Figure 5-2. Peak mooring load is 50% MBL, which does not exceed the OCIMF recommended criteria of 55% MBL.

TABLE 6-1: PEAK MOORING LOADS – AFRAMAX TANKER AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	26%	25%	27%	25%	25%	25%	27%
ML-2	26%	25%	27%	25%	25%	25%	27%
ML-3	30%	30%	30%	30%	29%	29%	32%
ML-4	31%	31%	31%	30%	30%	30%	32%
ML-5	22%	23%	21%	22%	21%	21%	23%
ML-6	23%	24%	22%	23%	21%	22%	24%
ML-7	14%	16%	12%	15%	13%	14%	14%
ML-8	14%	17%	12%	15%	13%	14%	14%
ML-9	24%	20%	27%	22%	25%	24%	23%
ML-10	24%	20%	27%	22%	25%	24%	24%
ML-11	39%	38%	40%[1]	37%	39%	37%	40%
ML-12	38%	37%	39%	36%	38%	37%	40%
ML-13	28%	29%	27%	28%	27%	27%	29%
ML-14	28%	29%	27%	28%	28%	27%	29%
ML-15	29%	30%	29%	29%	29%	28%	30%
ML-16	29%	30%	29%	29%	29%	28%	30%
BD-1	30%	31%	30%	31%	32%	32%	30%
BD-2	29%	29%	29%	30%	30%	30%	29%
BD-3	32%	33%	32%	34%	32%	34%	31%
BD-4	36%	36%	36%	38%	36%	37%	35%

[1]Shaded cell(s) indicates peak load for this condition

TABLE 6-2: PEAK MOORING LOADS – AFRAMAX TANKER AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	11%	9%	12%	13%	7%	10%	14%
ML-2	11%	9%	13%	14%	7%	10%	14%
ML-3	8%	8%	8%	12%	4%	7%	15%
ML-4	8%	8%	8%	12%	4%	7%	16%
ML-5	10%	12%	8%	14%	6%	9%	12%
ML-6	10%	12%	8%	14%	6%	9%	12%
ML-7	11%	14%	9%	13%	10%	11%	11%
ML-8	11%	14%	9%	13%	10%	11%	11%
ML-9	19%	15%	23%	16%	20%	18%	19%
ML-10	18%	14%	23%	16%	20%	18%	19%
ML-11	16%	14%	17%	6%	16%	10%	24%
ML-12	16%	14%	17%	6%	15%	10%	24%
ML-13	14%	16%	12%	9%	15%	11%	20%
ML-14	14%	16%	13%	8%	15%	11%	20%
ML-15	14%	16%	13%	8%	15%	11%	20%
ML-16	14%	16%	13%	8%	15%	11%	20%
BD-1	13%	13%	13%	11%	25%	18%	7%
BD-2	13%	14%	13%	15%	23%	19%	8%
BD-3	18%	18%	18%	30%	21%	24%	13%
BD-4	20%	20%	21%	35%[2]	21%	26%	14%

[2] The figure of 35% for BD-4 is the highest value in the table, but this is a reference to fender reaction force as a percent of rated reaction force, not an indication of mooring force.

TABLE 6-3: PEAK MOORING LOADS – AFRAMAX TANKER AT BALLAST DRAFT – EXTREME LOW WATER (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	30%	28%	33%	29%	31%	29%	31%
ML-2	30%	29%	34%	29%	32%	30%	31%
ML-3	31%	31%	31%	30%	30%	30%	32%
ML-4	33%	32%	33%	32%	31%	31%	34%
ML-5	17%	19%	16%	18%	16%	17%	18%
ML-6	18%	20%	17%	19%	17%	18%	19%
ML-7	13%	16%	11%	15%	12%	13%	13%
ML-8	13%	16%	11%	15%	12%	13%	13%
ML-9	48%	46%	50%	45%	49%	46%	50%
ML-10	48%	45%	50%	45%	48%	46%	50%
ML-11	26%	28%	25%	26%	25%	25%	27%
ML-12	26%	28%	25%	26%	26%	26%	27%
ML-13	28%	30%	27%	28%	28%	27%	29%
ML-14	28%	30%	27%	28%	28%	28%	29%
BD-1	32%	31%	33%	31%	34%	33%	30%
BD-2	29%	29%	30%	29%	30%	30%	28%
BD-3	32%	32%	32%	33%	32%	33%	31%
BD-4	36%	36%	35%	38%	36%	37%	35%

TABLE 6-4: PEAK MOORING LOADS – AFRAMAX TANKER AT LOADED DRAFT – EXTREME LOW WATER (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	21%	13%	28%	24%	18%	21%	20%
ML-2	22%	14%	29%	25%	19%	22%	21%
ML-3	8%	8%	8%	12%	4%	7%	16%
ML-4	9%	9%	9%	12%	4%	7%	17%
ML-5	9%	12%	7%	14%	5%	9%	10%
ML-6	9%	11%	7%	13%	5%	9%	10%
ML-7	10%	14%	7%	13%	9%	10%	10%
ML-8	10%	14%	7%	13%	9%	10%	10%
ML-9	25%	18%	33%	17%	30%	25%	32%
ML-10	26%	18%	34%	17%	31%	25%	32%
ML-11	13%	15%	11%	8%	14%	10%	18%
ML-12	13%	15%	11%	8%	14%	10%	18%
ML-13	14%	16%	12%	8%	14%	10%	19%
ML-14	14%	16%	12%	8%	14%	10%	20%
BD-1	13%	13%	15%	11%	27%	18%	7%
BD-2	13%	13%	14%	15%	24%	18%	8%
BD-3	18%	18%	17%	30%	20%	23%	12%
BD-4	20%	20%	20%	35%	20%	26%	14%

6.2. Panamax Tanker

Table 6-5 and Table 6-6 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-3 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 46% of the minimum breaking load (MBL) and occurs at ballast draft. No mooring line loads exceed the OCIMF recommended criteria of 55% MBL for wire lines. No fender reactions exceed their rated capacity.

Table 6-7 and Table 6-8 present a summary of peak mooring line and fender loads for the extreme low water mooring arrangement, as presented in Figure 5-4. Peak mooring load is 46% MBL, which does not exceed the OCIMF recommended criteria of 55% MBL for steel wire lines.

TABLE 6-5: PEAK MOORING LOADS – PANAMAX TANKER AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	18%	16%	19%	17%	11%	12%	24%
ML-2	18%	16%	19%	17%	12%	13%	23%
ML-3	20%	21%	19%	18%	10%	13%	28%
ML-4	20%	21%	20%	18%	9%	13%	28%
ML-5	19%	26%	15%	22%	18%	19%	20%
ML-6	19%	26%	15%	22%	18%	19%	20%
ML-7	18%	14%	23%	17%	20%	18%	18%
ML-8	18%	14%	23%	17%	19%	18%	18%
ML-9	23%	22%	24%	11%	21%	17%	30%
ML-10	23%	22%	24%	11%	21%	17%	29%
ML-11	30%	32%	28%	16%	28%	23%	38%
ML-12	30%	32%	28%	15%	28%	23%	38%
BD-1	16%	16%	15%	13%	24%	19%	12%
BD-2	16%	16%	16%	16%	23%	20%	13%
BD-3	21%	21%	22%	30%	23%	25%	17%
BD-4	25%	24%	25%	36%	24%	29%	20%

TABLE 6-6: PEAK MOORING LOADS – PANAMAX TANKER AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	32%	30%	33%	30%	29%	29%	34%
ML-2	30%	28%	32%	29%	28%	28%	32%
ML-3	36%	37%	36%	36%	33%	33%	39%
ML-4	37%	37%	36%	36%	33%	34%	40%
ML-5	21%	27%	18%	24%	19%	21%	22%
ML-6	21%	27%	18%	24%	19%	21%	23%
ML-7	20%	16%	25%	19%	23%	20%	20%
ML-8	20%	16%	25%	19%	23%	20%	20%
ML-9	35%	34%	36%	31%	35%	33%	38%
ML-10	34%	33%	35%	30%	34%	32%	37%
ML-11	44%	46%	42%	41%	42%	41%	46%
ML-12	44%	46%	42%	41%	42%	41%	46%
BD-1	25%	26%	25%	25%	27%	27%	24%
BD-2	24%	24%	24%	24%	26%	25%	23%
BD-3	28%	28%	29%	30%	29%	30%	27%
BD-4	32%	32%	33%	35%	32%	34%	31%

TABLE 6-7: PEAK MOORING LOADS – PANAMAX TANKER AT BALLAST DRAFT – EXTREME LOW WATER (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	27%	24%	29%	26%	26%	25%	29%
ML-2	26%	22%	28%	24%	25%	24%	27%
ML-3	32%	34%	31%	32%	29%	30%	35%
ML-4	32%	33%	31%	32%	29%	30%	35%
ML-5	28%	38%	24%	32%	24%	28%	29%
ML-6	27%	33%	24%	29%	24%	25%	29%
ML-7	22%	17%	26%	19%	24%	22%	22%
ML-8	24%	19%	29%	21%	27%	24%	24%
ML-9	29%	26%	31%	25%	29%	27%	31%
ML-10	28%	25%	30%	24%	28%	26%	30%
ML-11	42%	46%	40%	40%	41%	40%	45%
ML-12	42%	46%	40%	40%	40%	40%	45%
BD-1	26%	27%	26%	25%	28%	27%	25%
BD-2	25%	25%	25%	25%	27%	26%	23%
BD-3	29%	29%	29%	31%	29%	30%	27%
BD-4	32%	34%	33%	36%	32%	34%	31%

TABLE 6-8: PEAK MOORING LOADS – PANAMAX TANKER AT LOADED DRAFT – EXTREME LOW WATER (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	24%	17%	31%	25%	23%	24%	25%
ML-2	28%	20%	37%	28%	28%	28%	28%
ML-3	37%	46%	24%	46%	30%	37%	37%
ML-4	24%	31%	21%	29%	18%	22%	33%
ML-5	6%	6%	6%	6%	6%	6%	6%
ML-6	6%	6%	6%	6%	6%	6%	6%
ML-7	6%	6%	6%	6%	6%	6%	6%
ML-8	6%	6%	6%	6%	6%	6%	6%
ML-9	27%	19%	35%	21%	31%	27%	28%
ML-10	29%	20%	37%	22%	32%	28%	29%
ML-11	40%	46%	32%	39%	40%	37%	46%
ML-12	39%	46%	32%	36%	38%	35%	46%
BD-1	16%	15%	17%	13%	25%	19%	12%
BD-2	16%	15%	17%	15%	23%	20%	12%
BD-3	24%	28%	21%	35%	23%	28%	19%
BD-4	29%	34%	25%	44%	27%	34%	25%

6.3. Handymax Tanker

Table 6-9 and Table 6-10 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-5 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 50% of the minimum breaking load (MBL) and occurs at ballast draft. Mooring loads for the aft breast lines approach, but do not exceed the 50% MBL recommendation provided by OCIMF for synthetic lines.

TABLE 6-9: PEAK MOORING LOADS – HANDYMAX TANKER AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	25%	24%	26%	24%	25%	24%	26%
ML-2	25%	24%	26%	24%	25%	24%	26%
ML-3	37%	37%	37%	36%	35%	35%	39%
ML-4	39%	39%	39%	38%	37%	37%	41%
ML-5	24%	28%	21%	26%	22%	24%	24%
ML-6	23%	27%	21%	25%	22%	23%	23%
ML-7	31%	27%	34%	29%	33%	31%	31%
ML-8	31%	27%	35%	29%	33%	31%	31%
ML-9	48%	49%	48%	46%	48%	46%	50%
ML-10	50%	50%	50%	47%	49%	48%	50%
ML-11	29%	30%	27%	28%	28%	28%	30%
ML-12	29%	31%	28%	29%	28%	28%	30%
BD-1	22%	22%	22%	22%	23%	23%	21%
BD-2	21%	21%	21%	21%	21%	21%	20%
BD-3	25%	25%	25%	26%	25%	26%	24%
BD-4	29%	30%	29%	31%	29%	30%	29%

TABLE 6-10: PEAK MOORING LOADS – HANDYMAX TANKER AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	16%	15%	18%	15%	16%	16%	19%
ML-2	16%	15%	18%	16%	17%	16%	19%
ML-3	20%	20%	20%	19%	13%	15%	25%
ML-4	21%	21%	22%	20%	14%	16%	27%
ML-5	21%	25%	17%	23%	19%	21%	21%
ML-6	21%	25%	17%	23%	19%	21%	21%
ML-7	26%	21%	31%	23%	28%	26%	26%
ML-8	26%	21%	31%	23%	28%	25%	26%
ML-9	30%	31%	29%	18%	27%	23%	36%
ML-10	30%	31%	30%	18%	28%	24%	37%
ML-11	20%	22%	18%	16%	19%	18%	23%
ML-12	20%	23%	19%	16%	19%	18%	23%
BD-1	16%	15%	16%	13%	20%	17%	14%
BD-2	15%	15%	15%	14%	18%	17%	13%
BD-3	18%	19%	18%	23%	19%	21%	16%
BD-4	21%	22%	21%	29%	21%	23%	19%

6.4. Jet Fuel Barge

Table 6-9 and Table 6-10 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-7 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 50% of the minimum breaking load (MBL) and occurs at ballast draft. Mooring loads for the aft breast lines approach, but do not exceed the 50% MBL recommendation provided by OCIMF for synthetic lines.

TABLE 6-11: PEAK MOORING LOADS – HANDYMAX TANKER AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	25%	24%	26%	24%	25%	24%	26%
ML-2	25%	24%	26%	24%	25%	24%	26%
ML-3	37%	37%	37%	36%	35%	35%	39%
ML-4	39%	39%	39%	38%	37%	37%	41%
ML-5	24%	28%	21%	26%	22%	24%	24%
ML-6	23%	27%	21%	25%	22%	23%	23%
ML-7	31%	27%	34%	29%	33%	31%	31%
ML-8	31%	27%	35%	29%	33%	31%	31%
ML-9	48%	49%	48%	46%	48%	46%	50%
ML-10	50%	50%	50%	47%	49%	48%	50%
ML-11	29%	30%	27%	28%	28%	28%	30%
ML-12	29%	31%	28%	29%	28%	28%	30%
BD-1	22%	22%	22%	22%	23%	23%	21%
BD-2	21%	21%	21%	21%	21%	21%	20%
BD-3	25%	25%	25%	26%	25%	26%	24%
BD-4	29%	30%	29%	31%	29%	30%	29%

TABLE 6-12: PEAK MOORING LOADS – HANDYMAX TANKER AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	16%	15%	18%	15%	16%	16%	19%
ML-2	16%	15%	18%	16%	17%	16%	19%
ML-3	20%	20%	20%	19%	13%	15%	25%
ML-4	21%	21%	22%	20%	14%	16%	27%
ML-5	21%	25%	17%	23%	19%	21%	21%
ML-6	21%	25%	17%	23%	19%	21%	21%
ML-7	26%	21%	31%	23%	28%	26%	26%
ML-8	26%	21%	31%	23%	28%	25%	26%
ML-9	30%	31%	29%	18%	27%	23%	36%
ML-10	30%	31%	30%	18%	28%	24%	37%
ML-11	20%	22%	18%	16%	19%	18%	23%
ML-12	20%	23%	19%	16%	19%	18%	23%
BD-1	16%	15%	16%	13%	20%	17%	14%
BD-2	15%	15%	15%	14%	18%	17%	13%
BD-3	18%	19%	18%	23%	19%	21%	16%
BD-4	21%	22%	21%	29%	21%	23%	19%

6.5. Jet Fuel Barge

Table 6-13 and Table 6-14 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-7 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 31% of the minimum breaking load (MBL) and occurs at ballast draft. All mooring lines and fenders are within their safe working loads.

TABLE 6-13: PEAK MOORING LOADS – JET FUEL BARGE AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	18%	16%	18%	17%	17%	13%	19%
ML-2	17%	16%	17%	16%	16%	13%	18%
ML-3	24%	27%	22%	25%	23%	6%	24%
ML-4	24%	27%	22%	26%	23%	6%	24%
ML-5	20%	17%	22%	18%	21%	18%	20%
ML-6	19%	17%	21%	18%	20%	18%	19%
ML-7	30%	30%	29%	28%	29%	4%	31%
ML-8	29%	29%	28%	27%	28%	5%	30%
BD-1	7%	7%	7%	7%	8%	4%	7%
BD-2	8%	8%	8%	8%	9%	4%	8%
BD-3	13%	13%	13%	13%	13%	5%	13%
BD-4	15%	15%	15%	16%	15%	6%	14%

TABLE 6-14: PEAK MOORING LOADS – JET FUEL BARGE AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	13%	11%	15%	13%	13%	13%	13%
ML-2	13%	11%	15%	13%	13%	13%	13%
ML-3	23%	27%	19%	26%	21%	23%	23%
ML-4	23%	28%	19%	26%	21%	23%	23%
ML-5	18%	14%	22%	15%	20%	18%	18%
ML-6	18%	14%	21%	15%	20%	18%	18%
ML-7	15%	17%	15%	9%	15%	12%	20%
ML-8	15%	16%	14%	9%	15%	11%	19%
BD-1	5%	5%	5%	4%	8%	6%	4%
BD-2	4%	5%	4%	4%	7%	6%	3%
BD-3	7%	7%	8%	11%	8%	9%	6%
BD-4	9%	9%	9%	13%	9%	11%	7%

6.6. Oil Barge

Table 6-15 and Table 6-16 present a summary of peak mooring line and fender loads using the mooring arrangement presented in Figure 5-8 for the ballast and loaded draft conditions, respectively. For both draft conditions, peak mooring line load is 29% of the minimum breaking load (MBL) and occurs at ballast draft. All mooring lines and fenders are within their safe working loads.

TABLE 6-15: PEAK MOORING LOADS – OIL BARGE AT BALLAST DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	20%	20%	20%	20%	20%	20%	21%
ML-2	20%	20%	21%	20%	20%	20%	21%
ML-3	19%	20%	19%	19%	18%	19%	19%
ML-4	19%	20%	19%	19%	19%	19%	20%
ML-5	12%	14%	10%	12%	12%	12%	12%
ML-6	11%	10%	13%	11%	12%	11%	12%
ML-7	10%	12%	9%	11%	10%	10%	10%
ML-8	26%	23%	29%	25%	26%	26%	26%
BD-1	8%	8%	9%	8%	9%	9%	8%
BD-2	8%	8%	8%	8%	8%	8%	8%
BD-3	12%	13%	12%	12%	12%	12%	12%
BD-4	No Contact	No Contact	No Contact	No Contact	No Contact	No Contact	No Contact

TABLE 6-16: PEAK MOORING LOADS – OIL BARGE AT LOADED DRAFT (60 KNOTS WIND)

Mooring Line (ML)	No Current	3 knots		2 knots		0.75 knots	
		0°	180°	10°	170°	Beam On	Beam Off
ML-1	9%	8%	9%	7%	9%	8%	12%
ML-2	9%	8%	10%	8%	9%	8%	12%
ML-3	8%	9%	7%	8%	7%	8%	10%
ML-4	8%	9%	7%	8%	7%	8%	10%
ML-5	2%	4%	0%	2%	1%	2%	5%
ML-6	1%	0%	2%	1%	2%	1%	1%
ML-7	2%	4%	0%	2%	1%	2%	4%
ML-8	7%	3%	12%	7%	9%	8%	12%
BD-1	4%	4%	5%	7%	5%	6%	3%
BD-2	4%	4%	4%	6%	5%	5%	3%
BD-3	3%	3%	3%	3%	5%	4%	2%
BD-4	3%	3%	2%	2%	5%	4%	2%

7. Dynamic Mooring Analysis Results

Dynamic mooring analyses were conducted using the arrangements obtained from the static analysis. Ballast draft and high water were assumed for the simulations, as this combination was observed to provide the most conservative conditions from the static mooring analysis. The environmental conditions used in the simulations are those presented in Table 2-7, which in summary are: 100-year wind of 40 knots (2-min gust duration), ebb and flood current of 1.0 knot (parallel to berth), and 100-year wave from the NE (34 °N) with H_s = 0.6 m and T_p = 3.0 sec.

The oil barge's small overall length does not provide reasonable Froude scaling for hydrodynamic input to the dynamic mooring analysis program, and is therefore excluded from dynamic analysis. As the project area is dominated primarily by winds, the OCIMF criteria considered in the static analysis, which correspond to a 500-year wind condition, are sufficient for confirming the feasibility of the oil barge to be moored at the marine facilities.

Additionally, a time series of maximum tsunami currents, as described in Section 2.3.7, concomitant with the 25-year wind of 36.8 knots (2-minute duration) were carried out for the Aframax tanker. Tsunami analyses are considered only for the Aframax tanker, on the predication that successful results for the largest design vessel will be successful for tankers with less wetted area for tsunami forces to act. Tsunami forces are also applied independently of the 25-year wind condition, to ensure that no motions are damped out as a result of applied wind force.

7.1. Mooring Analysis Summary

All results for dynamic analyses, including peak mooring line loads, fender reactions, and vessel motions, are presented in Table 7-1 through Table 7-10 for all design vessels examined. Results are presented for the 40 knot wind condition (100-year wind) and indicate that safe mooring criteria for mooring lines, fender loads and vessel motions is not exceeded.

7.1.1. Tsunami Mooring Analysis Results

As noted in Section 2.3.7, M&N conducted a tsunami assessment of the Westridge Terminal as part of the TMEP (M&N, 2015). The study evaluated the impact of several hypothetical landslide-generated tsunamis in the Indian Arm and Burrard Inlet using a MIKE 21, two-dimensional hydrodynamic model. Time series of depth-averaged current velocities at the berths for each modeled landslide were produced. The highest depth-averaged current at the berths from all the tsunami scenarios was 1.86 knots. M&N performed a dynamic mooring analysis using the worst case current time series to evaluate the effect of a hypothetical tsunami on a moored vessel.

As presented in Table 7-1 and Table 7-2, the Aframax tanker is able to maintain safe mooring criteria for the applied tsunami forces. For many mooring lines, peak loads do not exceed the pretension set in the mooring lines, indicating the Aframax tanker is able to sustain the applied tsunami forces.

TABLE 7-1: PEAK DYNAMIC MOORING LOADS – AFRAMAX (BALLAST DRAFT AT HIGH WATER)

Element	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current	25-Year Wind with Tsunami Currents
ML-1	27%	30%	10%
ML-2	27%	30%	10%
ML-3	28%	32%	9%
ML-4	29%	32%	9%
ML-5	20%	21%	7%
ML-6	21%	21%	7%
ML-7	12%	10%	7%
ML-8	12%	10%	7%
ML-9	20%	20%	11%
ML-10	20%	20%	11%
ML-11	34%	38%	11%
ML-12	33%	38%	11%
ML-13	25%	25%	9%
ML-14	25%	25%	9%
ML-15	26%	27%	9%
ML-16	26%	27%	9%
FD-1	25%	29%	12%
FD-2	24%	26%	11%
FD-3	25%	25%	11%
FD-4	27%	27%	12%

* Minimum breaking load = 83 mt; Allowable MBL = 55%; Peak fender reaction = 256 mt

TABLE 7-2: PEAK MOORING MOTIONS – AFRAMAX (BALLAST DRAFT AT HIGH WATER)

Peak Motion	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current	25-Year Wind with Tsunami Current
Surge FWD [m]	0.25	0.24	0.11
Surge AFT [m]	-0.09	-0.12	-0.01
Sway OFF-Berth [m]	0.15	0.14	0.08
Sway On-Berth [m]	-0.6	-0.52	-0.04
Heave [+ deg]	0	0	-0.02
Heave [- deg]	-0.08	-0.07	-0.03
Roll [+ deg]	0.2	0.18	0.07
Roll [- deg]	-0.01	-0.01	0.06
Yaw [+ deg]	0	0	0
Yaw [- deg]	-0.01	-0.01	0

TABLE 7-3: PEAK DYNAMIC MOORING LOADS – PANAMAX (BALLAST DRAFT AT HIGH WATER)

Element	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
ML-1	35%	33%
ML-2	31%	30%
ML-3	44%	38%
ML-4	43%	38%
ML-5	18%	19%
ML-6	18%	19%
ML-7	14%	13%
ML-8	14%	13%
ML-9	35%	39%
ML-10	34%	38%
ML-11	50%	51%
ML-12	51%	52%
FD-1	47%	48%
FD-2	34%	42%
FD-3	35%	31%
FD-4	42%	39%

* Minimum breaking load = 79 mt; Allowable MBL = 55%; Peak fender reaction = 256 mt

TABLE 7-4: PEAK MOORING MOTIONS – PANAMAX (BALLAST DRAFT AT HIGH WATER)

Peak Motion	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
Surge FWD [m]	0.43	0.38
Surge AFT [m]	-0.64	-0.71
Sway OFF-Berth [m]	0.19	0.22
Sway On-Berth [m]	-1.12	-1.13
Heave [+ deg]	0	0.01
Heave [- deg]	-0.07	-0.07
Roll [+ deg]	0.23	0.25
Roll [- deg]	-0.02	-0.04
Yaw [+ deg]	0	0
Yaw [- deg]	-0.01	-0.01

TABLE 7-5: PEAK DYNAMIC MOORING LOADS – HANDYMAX (BALLAST DRAFT AT HIGH WATER)

Element	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
ML-1	22%	22%
ML-2	22%	22%
ML-3	33%	35%
ML-4	35%	37%
ML-5	15%	16%
ML-6	15%	16%
ML-7	17%	17%
ML-8	17%	17%
ML-9	41%	42%
ML-10	43%	44%
ML-11	22%	23%
ML-12	23%	23%
FD-1	56%	60%
FD-2	42%	50%
FD-3	43%	35%
FD-4	50%	42%

* Minimum breaking load = 62 mt; Allowable MBL = 50%; Peak fender reaction = 256 mt

TABLE 7-6: PEAK MOORING MOTIONS – HANDYMAX (BALLAST DRAFT AT HIGH WATER)

Peak Motion	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
Surge FWD [m]	1.07	1.09
Surge AFT [m]	-0.9	-0.85
Sway OFF-Berth [m]	-2.14	-2.29
Sway On-Berth [m]	0.24	0.26
Heave [+ deg]	0.02	0.03
Heave [- deg]	-0.13	-0.14
Roll [+ deg]	0.46	0.48
Roll [- deg]	-0.1	-0.14
Yaw [+ deg]	0	0
Yaw [- deg]	-0.01	-0.01

TABLE 7-7: PEAK DYNAMIC MOORING LOADS – HANDYSIZE (BALLAST DRAFT AT HIGH WATER)

Element	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
ML-1	19%	19%
ML-2	19%	18%
ML-3	29%	29%
ML-4	28%	28%
ML-5	32%	31%
ML-6	33%	32%
ML-7	18%	17%
ML-8	17%	16%
ML-9	33%	37%
ML-10	32%	36%
ML-11	19%	21%
ML-12	20%	22%
FD-1	-	-
FD-2	33%	48%
FD-3	46%	39%
FD-4	-	-

* Minimum breaking load = 38 mt; Allowable MBL = 50%; Peak fender reaction = 256 mt

TABLE 7-8: PEAK MOORING MOTIONS – HANDYSIZE (BALLAST DRAFT AT HIGH WATER)

Peak Motion	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
Surge FWD [m]	0.29	0.23
Surge AFT [m]	-0.47	-0.48
Sway OFF-Berth [m]	0.15	0.15
Sway On-Berth [m]	-1.78	-1.59
Heave [+ deg]	0.01	0.02
Heave [- deg]	-0.09	-0.09
Roll [+ deg]	0.43	0.44
Roll [- deg]	-0.08	-0.11
Yaw [+ deg]	0.01	0.01
Yaw [- deg]	-0.01	-0.01

TABLE 7-9: PEAK DYNAMIC MOORING LOADS – JET FUEL BARGE (BALLAST DRAFT AT HIGH WATER)

Element	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
ML-1	28%	30%
ML-2	25%	27%
ML-3	18%	22%
ML-4	19%	24%
ML-5	14%	13%
ML-6	14%	13%
ML-7	24%	26%
ML-8	23%	25%
FD-1	11%	14%
FD-2	11%	12%
FD-3	12%	11%
FD-4	14%	13%

* Minimum breaking load = 82 mt; Allowable MBL = 50%; Peak fender reaction = 256 mt

TABLE 7-10: PEAK MOORING MOTIONS – JET FUEL BARGE (BALLAST DRAFT AT HIGH WATER)

Peak Motion	40 knot Wind, 100-yr Wave, 1 knot Ebb Current	40 knot Wind, 100-yr Wave, 1 knot Flood Current
Surge FWD [m]	0.08	0.07
Surge AFT [m]	-0.09	-0.08
Sway OFF-Berth [m]	0.07	0.07
Sway On-Berth [m]	-0.25	-0.33
Heave [+ deg]	0	-0.01
Heave [- deg]	-0.05	-0.06
Roll [+ deg]	0.23	0.26
Roll [- deg]	-0.01	0.01
Yaw [+ deg]	0.01	0.01
Yaw [- deg]	-0.01	-0.01

8. Conclusions

Extensive mooring and berthing analyses have been conducted for the design range of tankers and barges.

- Static mooring analyses conducted using OPTIMOOR and OCIMF environmental conditions result in safe mooring criteria satisfied for line tensions and fender reactions for all vessels, all draft and water level conditions.
- Dynamic mooring analyses conducted for a 100-yr conditions yield successful results for safe mooring criteria.
- Tsunami forces were applied to the Aframax tanker with successful results.

9. References

Moffatt & Nichol (M&N). (2014a). "WMT Metocean Study Report." Trans Mountain Expansion Project, Westridge Marine Terminal. Prepared for Trans Mountain Pipeline LP. TMP Report No. 01-13283-TW-WT00-MD-RPT-0004 RA.

Moffatt & Nichol (M&N). (2014b). "WMT Berthing Analysis and Fender Selection." Trans Mountain Expansion Project, Westridge Marine Terminal. Prepared for Trans Mountain Pipeline LP.

Moffatt & Nichol (M&N). (2015). "WMT Tsunami Assessment." Trans Mountain Expansion Project, Westridge Marine Terminal. Prepared for Trans Mountain Pipeline LP. TMP Report No. 01-13283-TW-WT00-MFN-RPT-0008.

Moffatt & Nichol (M&N). (2017). "WMT Design Basis Memorandum" Trans Mountain Expansion Project, Westridge Marine Terminal. Prepared for Trans Mountain Pipeline LP. TMP Report No. 01-13283-TW-WT00-MFN-RPT-0002.

OCIMF (Oil Companies International Marine Forum): "Mooring Equipment Guidelines", 3rd Edition, 2008.

OCIMF (Oil Companies International Marine Forum): "Recommendations for Oil Tanker Manifold and Associated Equipment, Fourth Edition, 1991.

PIANC: "Guidelines for the Design of Fenders Systems: 2002", MarCom Report of WG33, 2002.

PIANC: "Criteria for Movements of Moored Vessels", MarCom Report of WG24 1995.

PIANC: "Recommendations for the Design and Assessment of Marine Oil and Petrochemical Terminals", MarCom report of WG153, 2016

California State Lands Commission (SLC), "Marine Oil Terminals Engineering and Maintenance Standards (MOTEMS). Chapter 31F, California Code of Regulations, Title 24, Part 2 (2010)

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