WESTRIDGE MARINE TERMINAL
VANCOUVER, BC

PASSING SHIP ANALYSIS

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PASSING SHIP ANALYSIS

M&N Project No. 7773-01

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1. INTRODUCTION

Kinder Morgan Canada (KMC) is currently considering expansion of marine facilities at their Westridge Terminal in Burnaby which includes the construction of new moorings capable of accepting 3 tanker vessels which may range from 17,000 DWT barges to Aframax tankers. The geographic location of these facilities provides about 190 meters of clearance between tankers moored at Westridge and the proposed channel realignment scheme within Port Metro Vancouver (PMV). KMC has engaged Moffatt and Nichol to investigate passing vessel effects on moored ships at the proposed Westridge Terminal expansion.

1.1 SCOPE OF WORK

The objective of this study is to determine the loads imparted by passing vessels under the proposed channel alignment on selected tankers berthed at the new Westridge facilities. In a meeting held on April 7 with KMC and PMV, specific scenarios were laid out for this analysis:

- Panamax and Aframax tankers were to be used as the moored vessels
- The considered passing vessel would be based on the largest vessel en route to Port Moody with dimensions similar to the dry bulk carrier Shi Dai 20
- The closest passing distance between berth 3 and the proposed channel realignment is approximately 190 meters (Figure 1-1)
- A transiting speed of 10 knots would be assumed for the passing vessel.

The analysis of the passing vessel effects on the moored vessels would be carried out in two steps: first, the forces imparted on the moored vessel by the passing ship are calculated, and then these forces are input into a time-domain mooring simulation model that computes the moored vessel response with the associated mooring line loads, fender loads, and vessel motions.

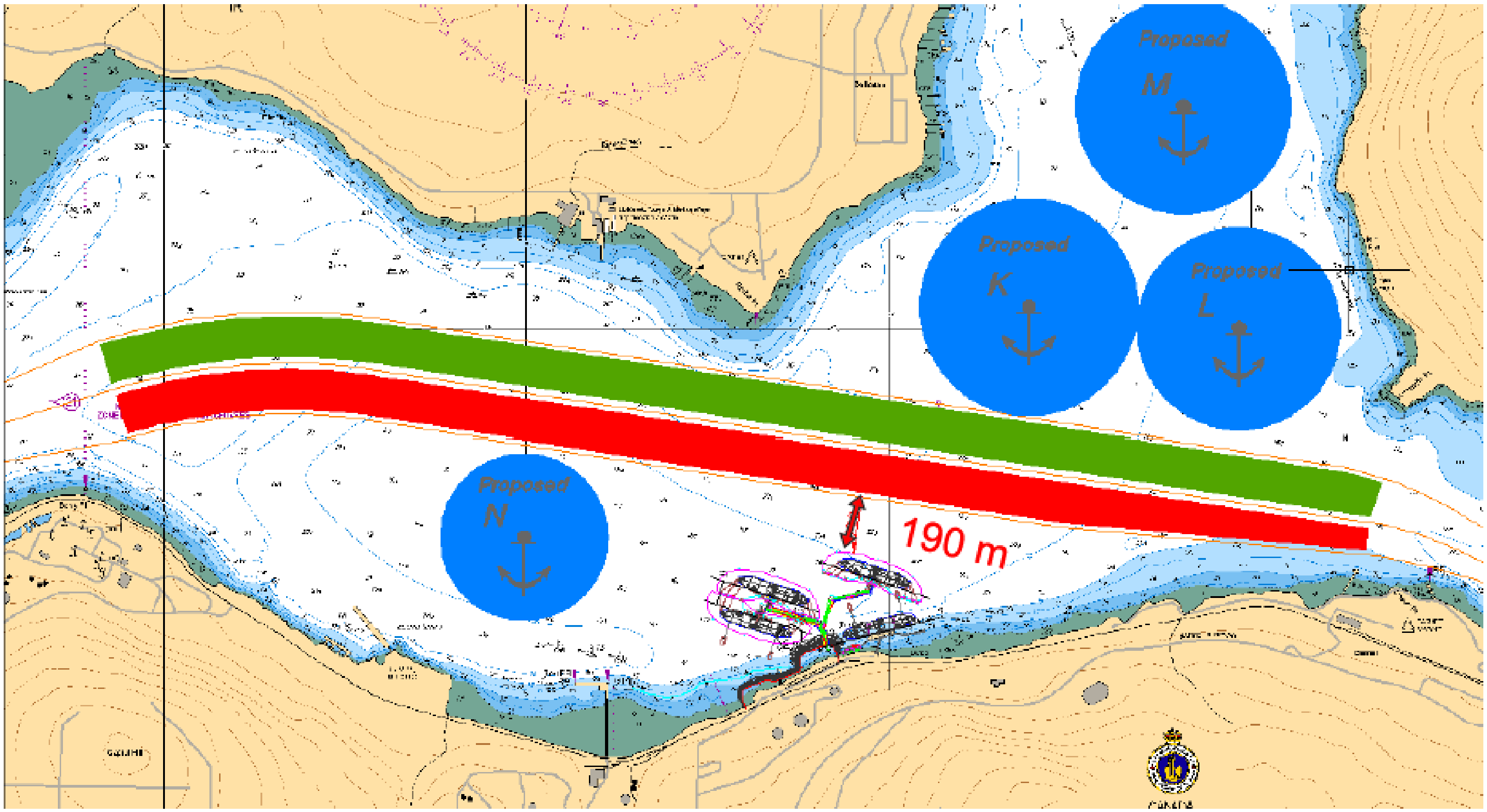

Figure 1-1: PMV Proposed Channel and Anchorage Realignment

2. PROJECT BACKGROUND

2.1 SITE LOCATION

The Westridge terminal is situated along the southern shore of Burrard Inlet within the port of Vancouver roughly 5 kilometers east of the Second Narrows Bridge and adjacent to the southern entrance to the Indian Arm (Figure 2-1).

Figure 2-1: Site Plan Overview

Vessel traffic in the immediate vicinity is typically limited to shallow draft vessels; deep draft vessel activity in the area is predominantly traffic calling at bulk terminals east of the site or at the anchorages just northwest of Westridge (Figure 2-2).

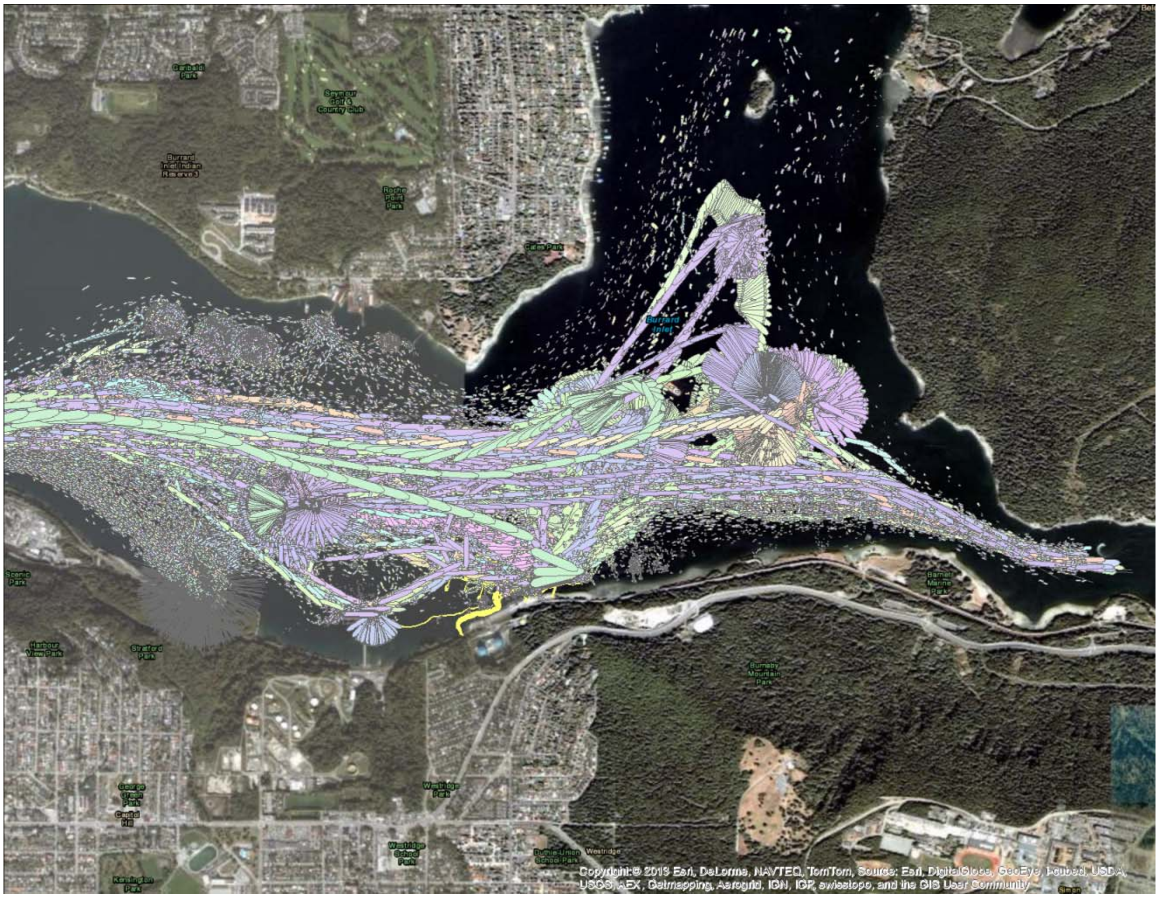

Figure 2-2: All Vessel Traffic in the Westridge Area

A general arrangement of the proposed facility is shown in Figure 2-3. The exact layout of the terminal is still evolving as the engineering process continues, so the final layout is expected to be somewhat different than is depicted here, but any potential changes in layout are not expected to have a material effect on this study.

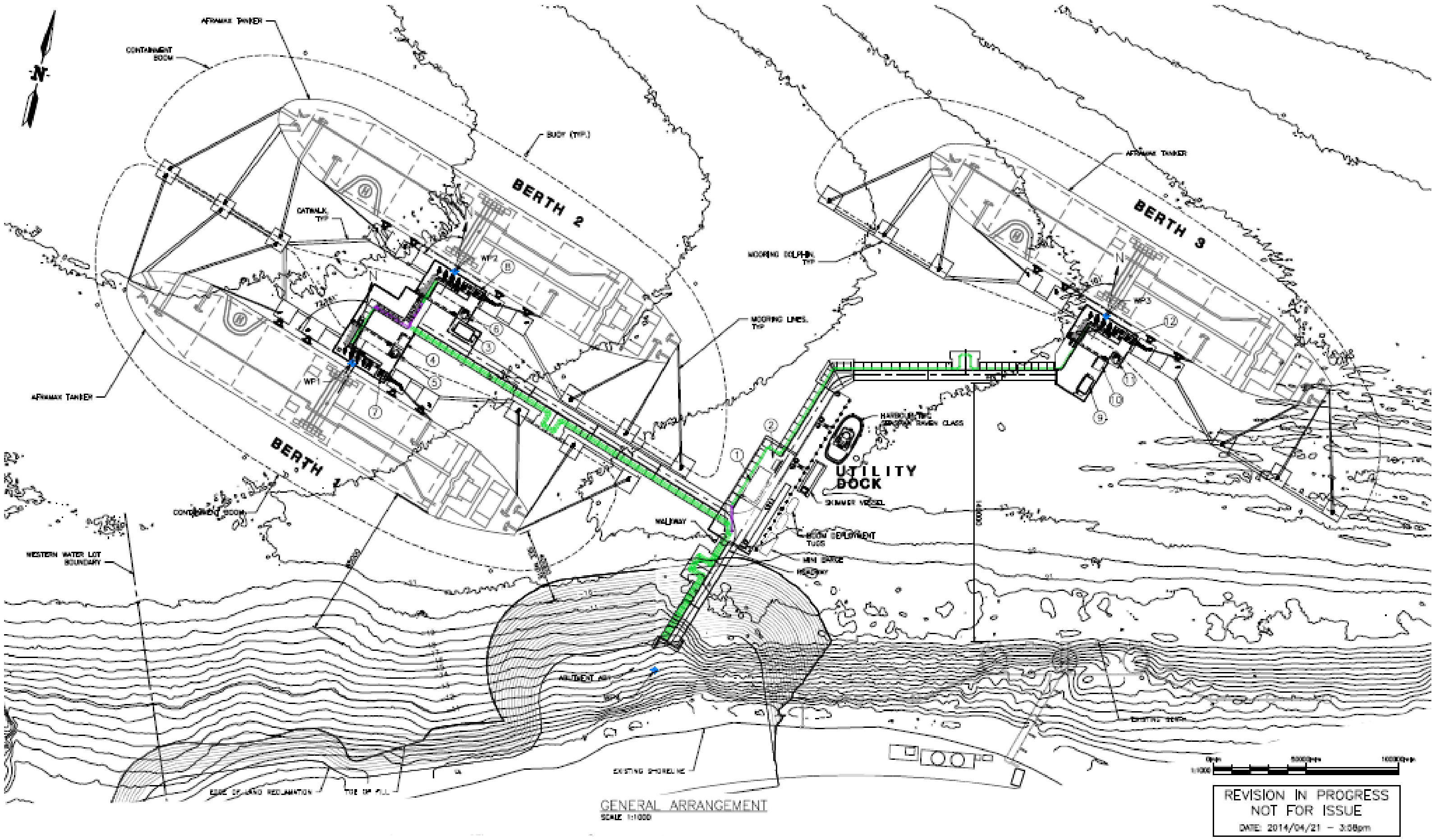

Figure 2-3: General Arrangement Plan for the Proposed Westridge Facilities

2.2 SITE BATHYMETRY

Bathymetry used in the analysis was taken from survey data delivered to M&N from Golder Associates on March 27, 2014. All three proposed berth locations are in naturally deep water with 20 meters or more of depth. Bathymetric slope from the berths to the proposed channel realignment is very mild with grades close to 30:1 (H:V). Bathymetric slopes closer to the shoreline are typically 8:1 until reaching the surface.

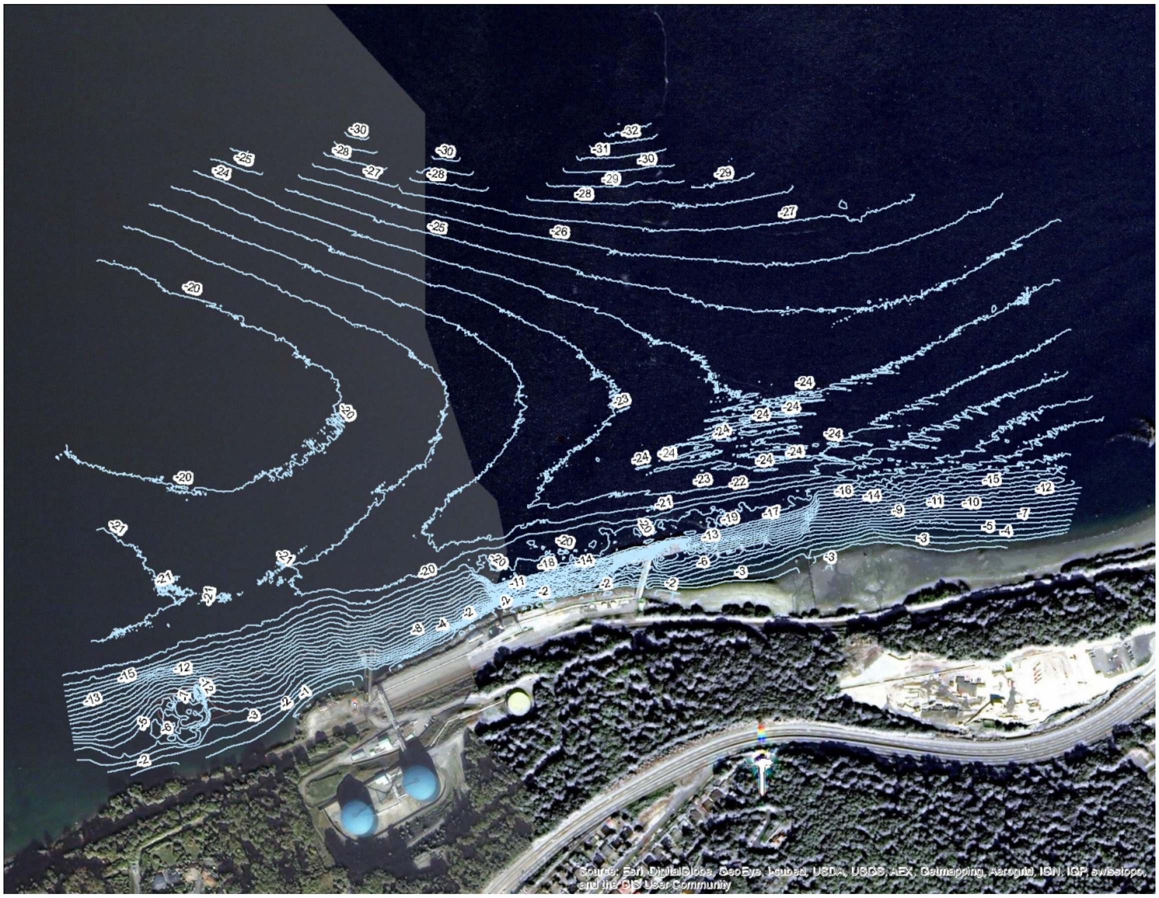

Figure 2-4: Site Bathymetry

2.3 PROPOSED FACILITY DESIGN

Proposed expansion plans at the Westridge facilities call for 3 new berths to be constructed in naturally deep water. The berths are numbered from west to east, with Berths 1 and 2 in a back-to-back configuration. Each berth has three mooring dolphins forward and three aft. The forward mooring dolphins for Berths 1 and 2 are combined structures whereas for the aft mooring dolphins they are separate structures to accommodate the roadway and piperack that passes between them.

Berth 3 represents the westernmost berth of the proposed expansion plan and has a mooring arrangement similar to that of Berth 2.

All berths moor vessels at a heading of 288 degrees true.

2.4 DESIGN VESSELS

The tanker vessels used for this analysis were based on characteristics and dimensions documented in M&N's mooring and berthing analysis submitted in November of 2012. PMV identified which vessel classifications should be used for the passing vessel. M&N selected representative vessels from those classes and obtained their principal characteristics from published ship databases such as Clarkson's Register. Table 2-1 presents a summary of the moored design vessel characteristics used. Passing vessel effects on deep draft, loaded ships is greater than on ballasted ships due to reduced underkeel clearance and greater submerged hull areas. Therefore, only loaded condition tankers were evaluated in this preliminary report.

Table 2-1: Moored Vessel Characteristics

Vessel		Panamax	Aframax
Name		Torm Ottowa	Nevisky Prospect
DWT		70,297	117,654
LOA (m)		228.0	250.00
LBP (m)		219.0	239.00
Beam (m)		32.23	44.00
Draft	Loaded (m)	13.82	15.10
Displacement	Loaded (mt)	84,204	136,337
Side Windage	Loaded (m^2)	1,378	2,177
Frontal Windage	Loaded (m^2)	448	800
Mooring Line Type		Steel-Wire	Steel-Wire
Mooring Line MBL (mt)		79	83
Mooring Tail Type		Nylon	Polyester
Mooring Tail Length (m)/ MBL (mt)		11m/ 120mt	11m/ 116mt

Vessel characteristics for the passing vessel were taken from the presentation given by PMV during the April 7 meeting with KMC and M&N. Table 2-2 provides the modeled passing vessel characteristics.

Table 2-2: Passing Vessel Characteristics

Vessel	Bulk Carrier
Name	Shi Dai 20
Gross Registered Tonnage	64,654
Deadweight (mt)	115,664
LOA (m)	254.0
Beam (m)	43
Draft (m)	13.5
Transit Speed (kts)	10

2.5 EXISTING TRAFFIC

Historical AIS ship movement data was accessed to identify the current traffic patterns and existing beam to beam clearances of navigation traffic from the proposed Westridge berths. Figure 2-5 displays recent vessel traffic around the proposed Westridge facilities for ships with a length overall greater than 150 meters and a speed over ground greater than or equal to 6 knots. With the exception of vessels passing immediately over the new facility locations, the current traffic separation scheme keeps inbound traffic more than 220 meters away from the berth 3; therefore the proposed 190 meter traffic separation scheme used in this analysis is considered conservative. Vessel speed over ground is displayed in Figure 2-6.

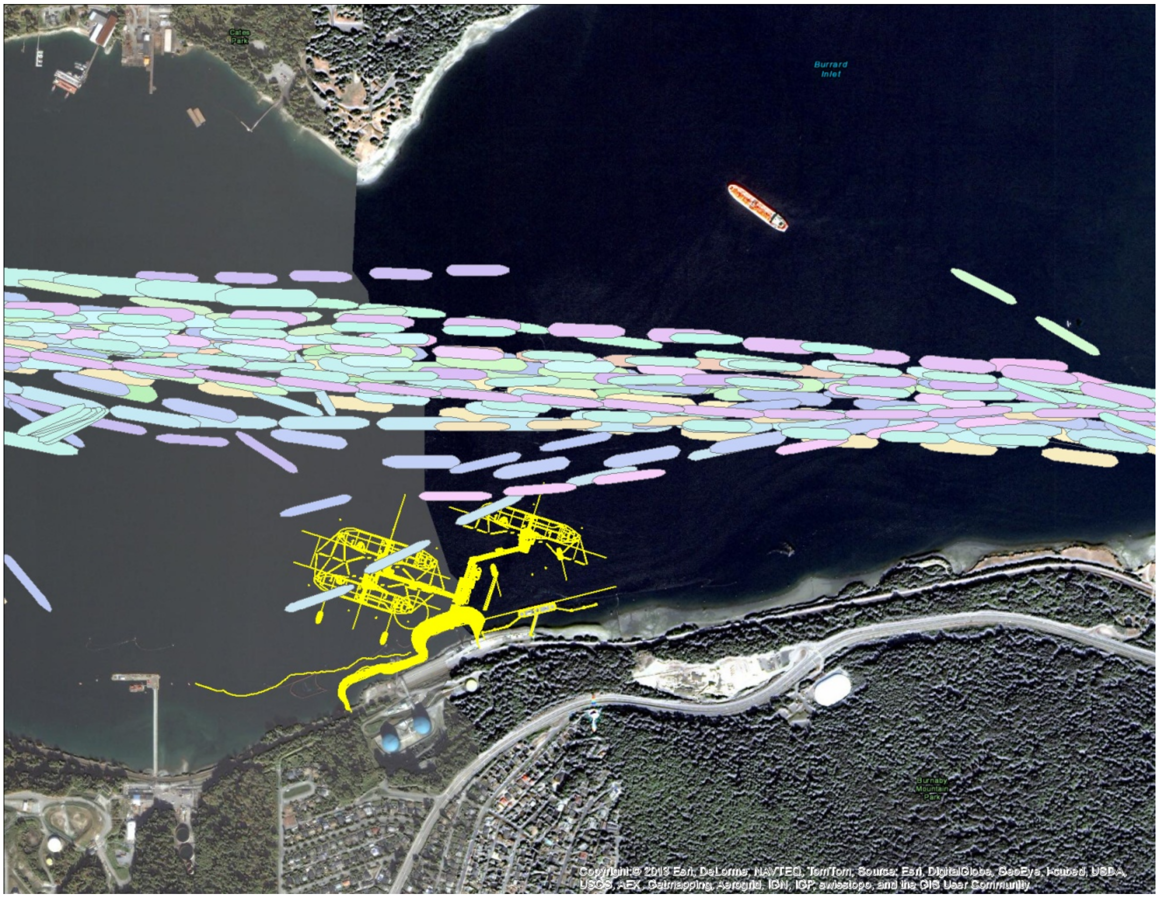

Figure 2-5: Recent Vessel Traffic (LOA > 150m SOG >= 6 kts) around the Westridge Facilities

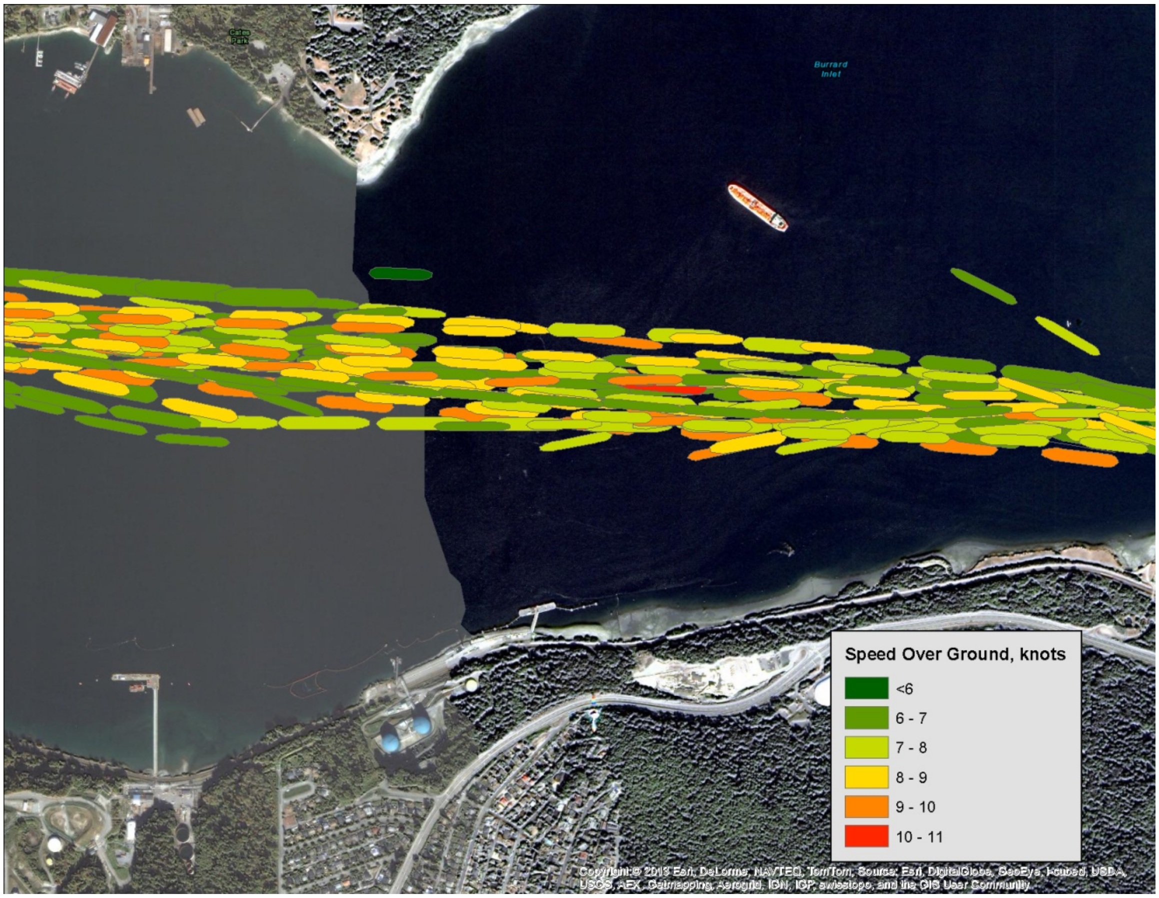

Figure 2-6: Vessel Speed Over Ground around the Westridge Facilities (Limited to Channel Traffic)

2.6 PROPOSED VESSEL TRAFFIC CORRIDOR

Port Metro Vancouver has reviewed the proposed Westridge Marine Terminal expansion and proposes defining a corridor within the Central Harbour for ship traffic to increase the separation distances and safety for large vessels passing the terminal. The proposed traffic corridor is shown in Figure 2-7. The minimum distance between inbound traffic within the corridor and a moored vessel at Berth 3 of the proposed Westridge facilities is about 190 meters (Figure 2-7). The proposed corridor will require adjusting some of the existing designated anchorages in the area. The proposed corridor and anchorage locations are considered draft locations for the purpose of doing this analysis, subject to finalized design to be carried out by PMV at a later date.

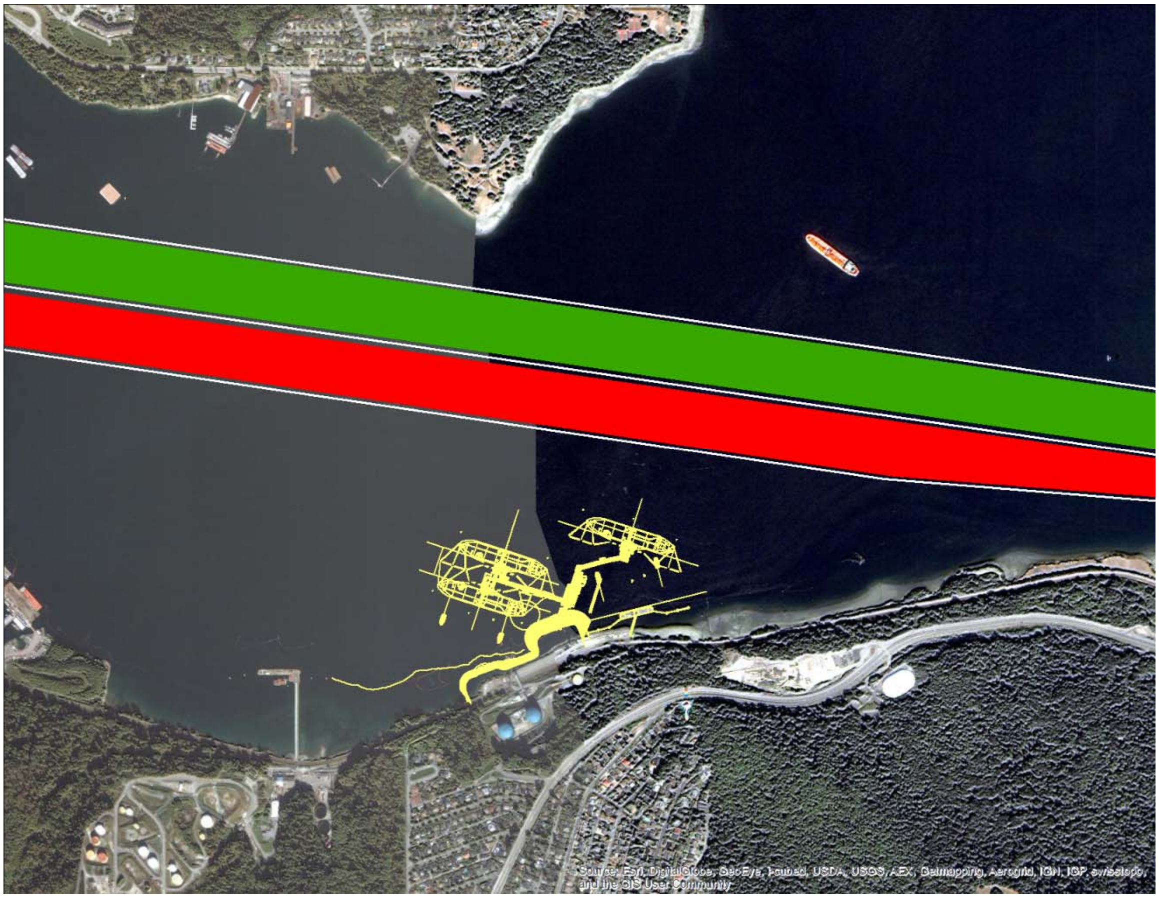

Figure 2-7: PMV's Proposed Traffic Channel Alignment near Westridge Terminal

3. PASSING VESSEL ANALYSIS

When transiting ships pass at high speed and/or in close proximity to a moored vessel, the moored vessel can experience transient dynamic mooring forces that can cause adverse ship movements and broken mooring lines. The forces imparted to the moored vessel are dependent on the distance to the passing vessel, the speed of the passing vessel, the underkeel clearance of both vessels, the displacement of the two vessels, hull geometry, channel bank geometry, and channel cross section. A representation of a passing vessel scenario is given in Figure 3-1 below.

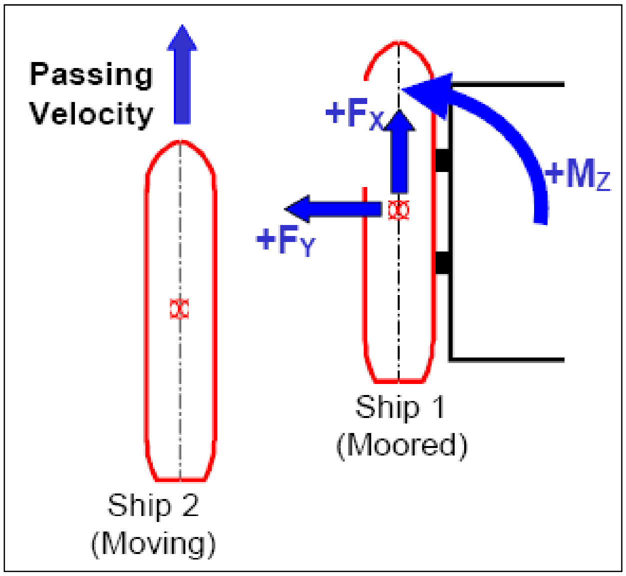

Figure 3-1: Typical representation of a passing vessel scenario

The primary loads imposed by the passing ship are longitudinal and lateral forces as well as a moment on the moored vessel, although forces are developed in all six degrees of freedom. Idealized forces based on a deep, open-water passing scenario are shown in Figure 3-2 and demonstrate that a relatively large, but transient load is experienced by the moored vessel. A surge force pulls the moored vessel aft then pushes forward as the vessel in transit passes while a suction force pulls the moored vessel away from the berth as the passing vessel is adjacent to the moored vessel. The curves in Figure 3-2 represent non-dimensional forces experienced at unconfined deepwater conditions. For shallow water and confined-channel conditions, more detailed methods are required. The method of passing vessel forces calculation used in this report is based on the ROPES numerical model which is based on computational methods developed by Pinkster Marine Hydrodynamics.

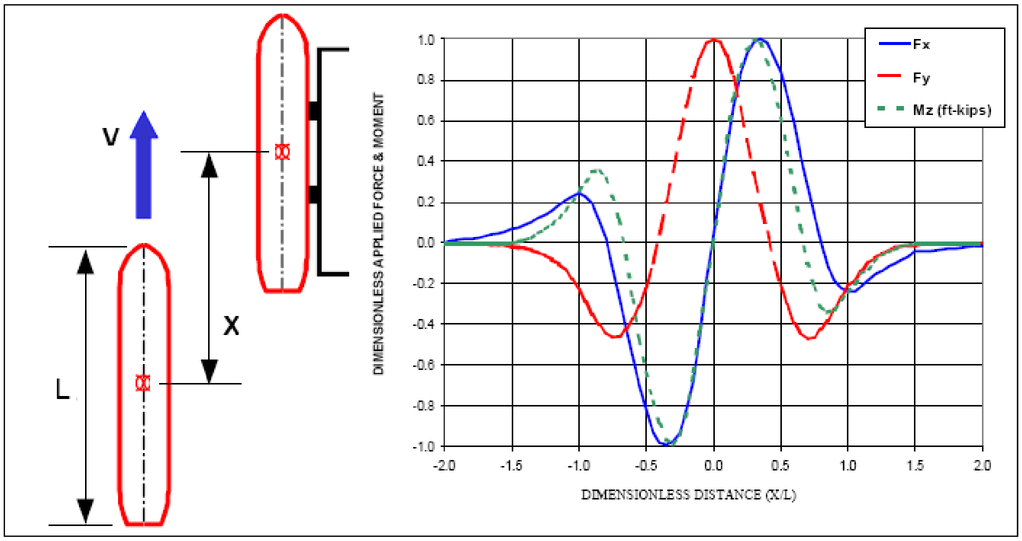

Figure 3-2: Non-dimensional results for a passing vessel scenario (Wang, 1975)

To fully examine practical problems, however, it is necessary to conduct a dynamic analysis that simulates the dynamic response of a moored vessel to the imposed hydrodynamic forces. The hydrodynamic forces are normally computed assuming the moored vessel hull is rigid. In reality, the moored ship is relatively free to move somewhat in response to the passing ship forces and will be restrained by mooring lines and fenders. The moored vessel may experience loads less than, equal to, or larger than the imposed passing ship forces depending on all the factors that dictate dynamic response (i.e. ship mass, system damping, mooring stiffness, etc.). Given the propensity for vessels to respond dynamically in most cases where passing problems have been experienced, M&N has found that dynamic analysis is imperative for practical applications, rather than static analysis.

The effects of the passing ship forces were examined using the TERMSIM computer program which is a six degree-of-freedom, time-domain model for mooring dynamics developed by the Maritime Research Institute of the Netherlands (MARIN). The six degree of freedom hydrodynamic characteristics of the ship used in the computer model are based on a series of tanker physical model tests. The model simulates the vessel response to incident waves, winds, and currents including damping and shallow water effects. The wind coefficients are based on Oil Companies International Marine Forum (OCIMF) recommendations. The forces generated by the passing vessel model may be directly applied on the moored vessel. TERMSIM computes the at-berth motions in all six degrees of freedom as well as the loads in the mooring lines and fenders. The program includes a database of the non-linear load-extension/deflection curves for typical mooring line and fender types. The user may also define the load-deflection curves manually. The output of the simulation is time trace signals of all motions and loads calculated in the mooring system.

3.1 ROPES

The ROPES 3-d diffraction model accounts for the classical suction forces which are a result of the interaction of the passing ship's draw down wave system with the port geometry. The model uses a potential flow calculation to compute the pressure fields and induced forces due to the passing ship. The model separately calculates the diffraction effects of channel and basin geometry to compute long-period disturbances in the channel. The effects of the potential flow and diffraction effects are then superposed to compute the total velocities, pressures, and fluid forces on the moored vessel. The model has been validated against scale and prototype scale measurements by the ROPES Joint Industry Project.

3.1.1 Passing Vessel Simulated Scenarios

Passing vessels forces were assessed for the moored design vessels identified above. The largest forces will be generated by large ships with low under-keel clearance; therefore, all ships were assumed at maximum draft. The analysis assumed that the passing ship travels at 10 knots along the proposed navigational channel realignment.

Bathymetric setup of the models mimicked the description provided in Section 2.2 above: a side slope of 8:1 was created from the water surface down to an elevation of -20 meters; a second slope of 30:1 was modeled from -20 meters to -30 meters. Bathymetry north of the transiting vessel was not modeled as local depths were deep enough and bathymetric slopes to the north were far enough away not to affect loads generated on either the passing ship or moored tankers.

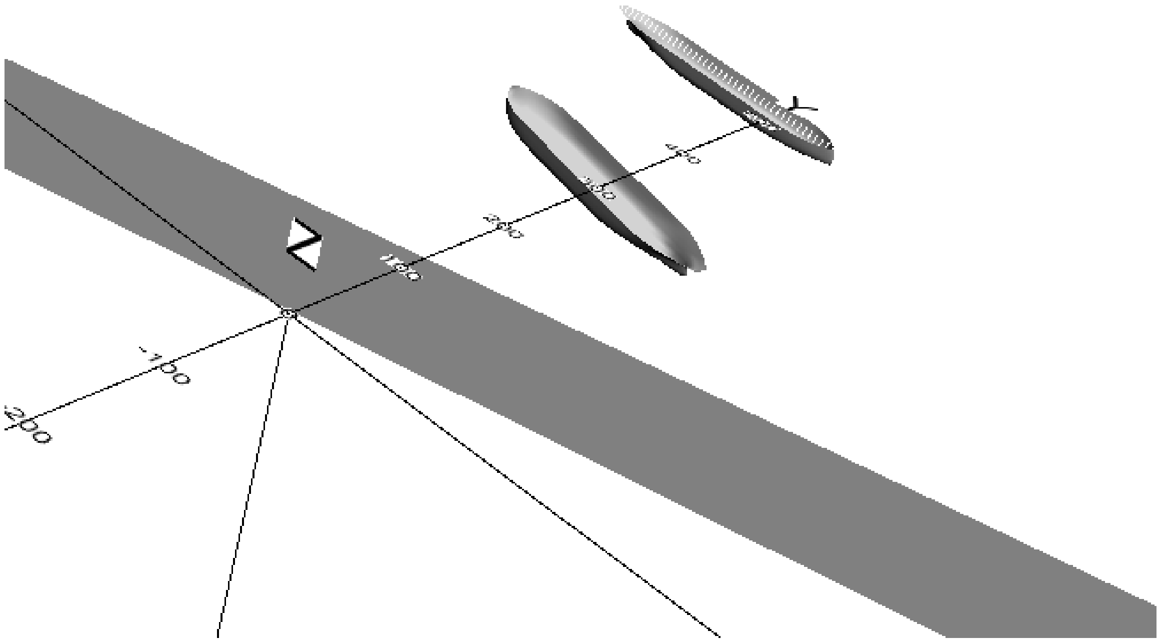

Figure 3-3: Snapshot of the ROPES model developed for moored Aframax tankers at Berth 3

In order to capture the effects of a stemming current on the passing vessel forces, the transiting vessel speed was increased to 11 knots to increase the apparent hydrodynamic speed of a passing vessel and generate forces related to such an event on the moored vessel.

Simulated scenarios are summarized in table Table 3-1 below.

Table 3-1: Simulated Passing Vessel Scenarios

Run Number	Berth Number	Moored Ship	Passing Distance	Passing Speed
1	1	Panamax	440 m	10 kts
2	1	Panamax	440 m	11 kts
3	2	Aframax	320 m	10 kts
4	2	Aframax	320 m	11 kts
5	3	Aframax	190 m	10 kts
6	3	Aframax	190 m	11 kts

3.1.2 Results

The loads generated in the passing ship simulations are presented below for each berth.

BERTH 1

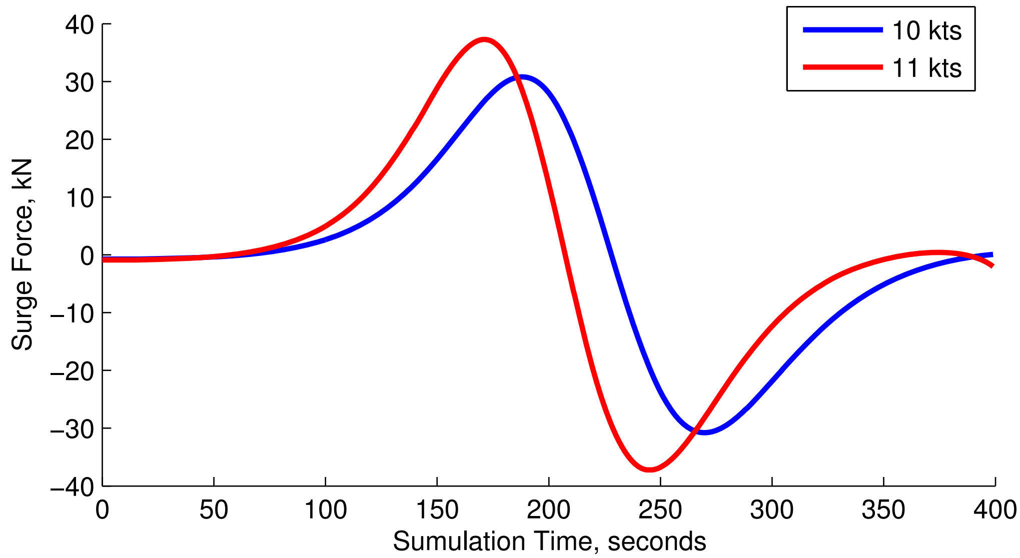

Figure 3-4: Modeled Surge Forces on the Panamax Tanker at Berth 1

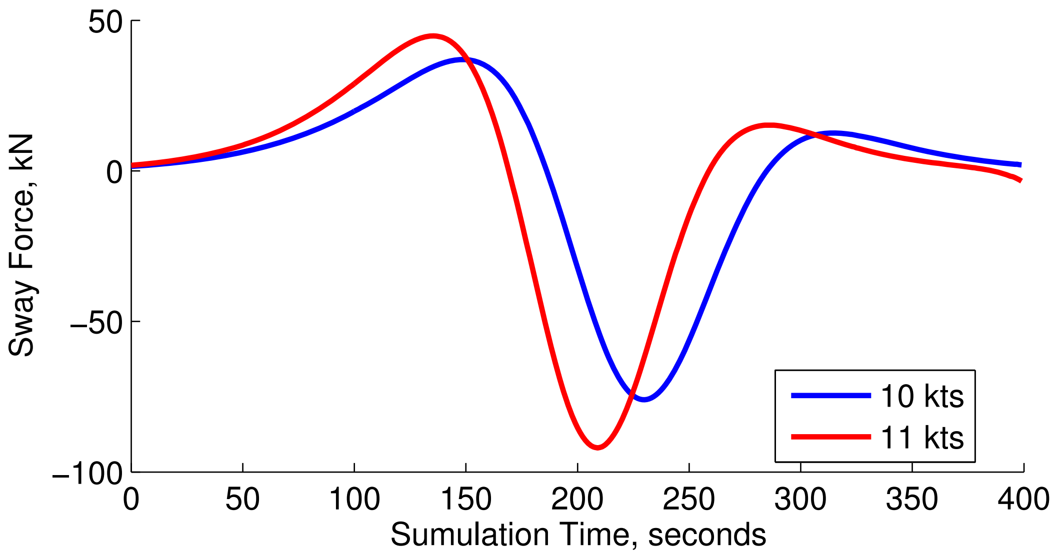

Figure 3-5: Modeled Sway Forces on the Panamax Tanker at Berth 1

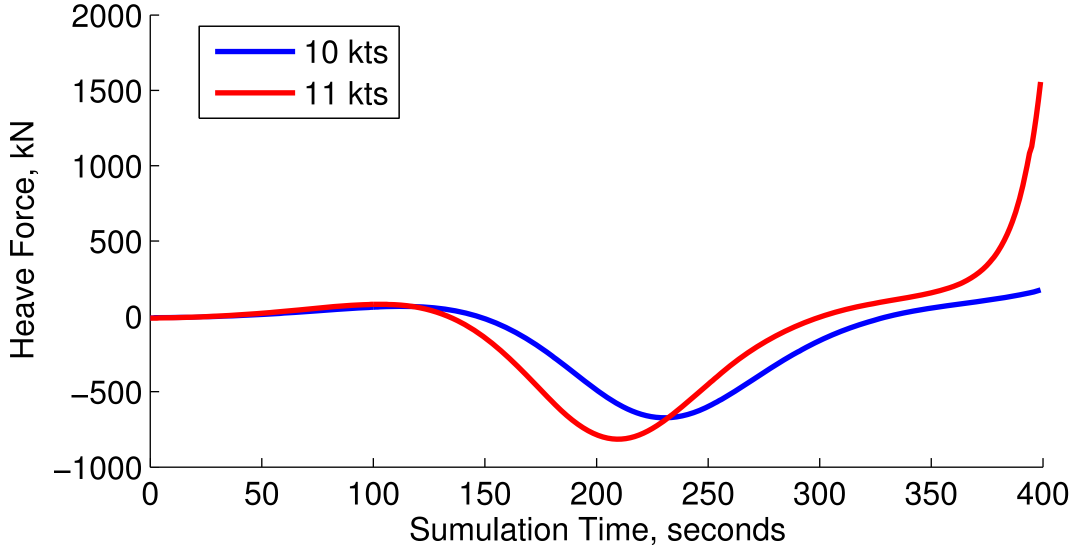

Figure 3-6: Modeled Heave Forces on the Panamax Tanker at Berth 1

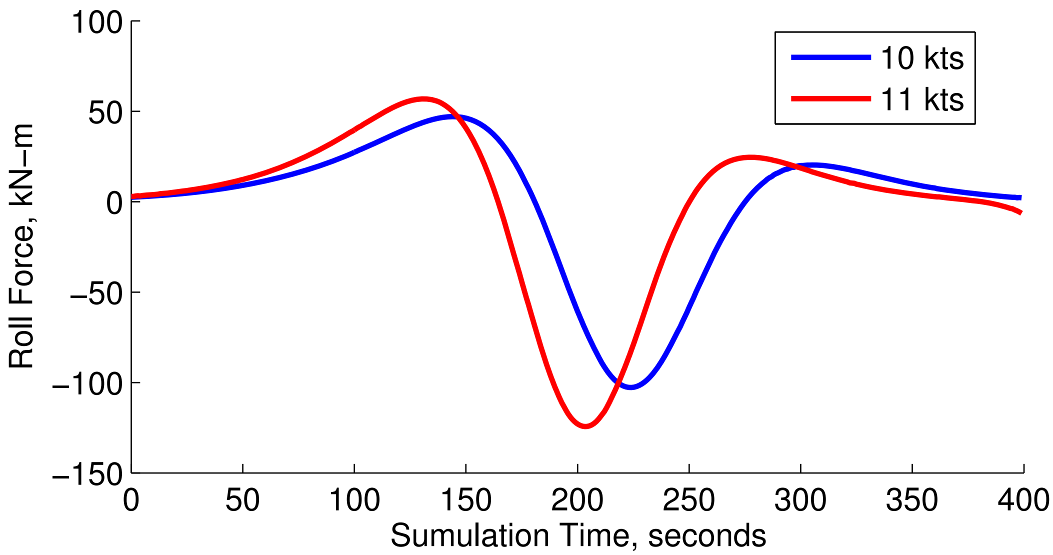

Figure 3-7: Modeled Roll Forces on the Panamax Tanker at Berth 1

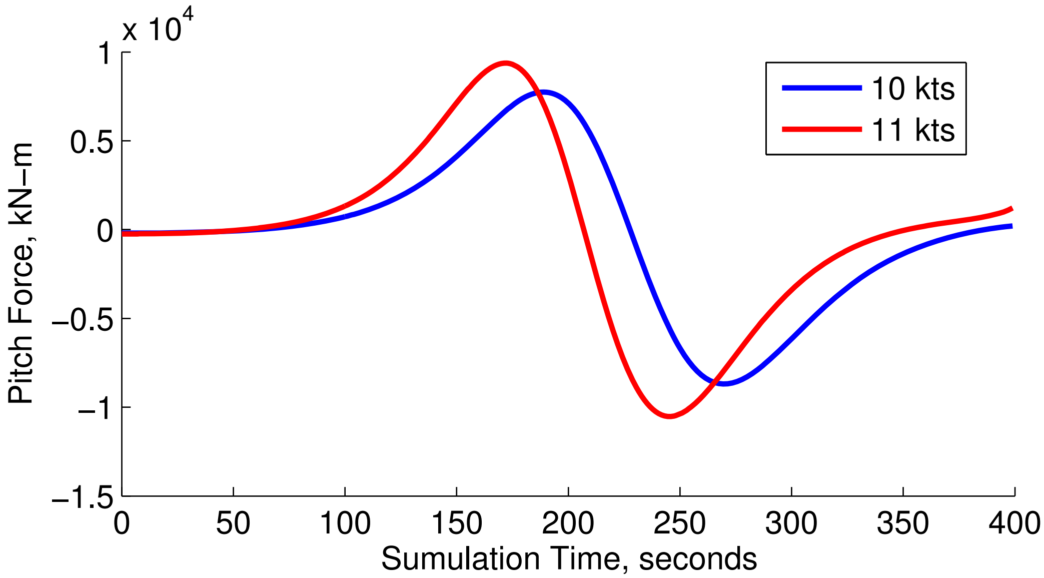

Figure 3-8: Modeled Pitch Forces on the Panamax Tanker at Berth 1

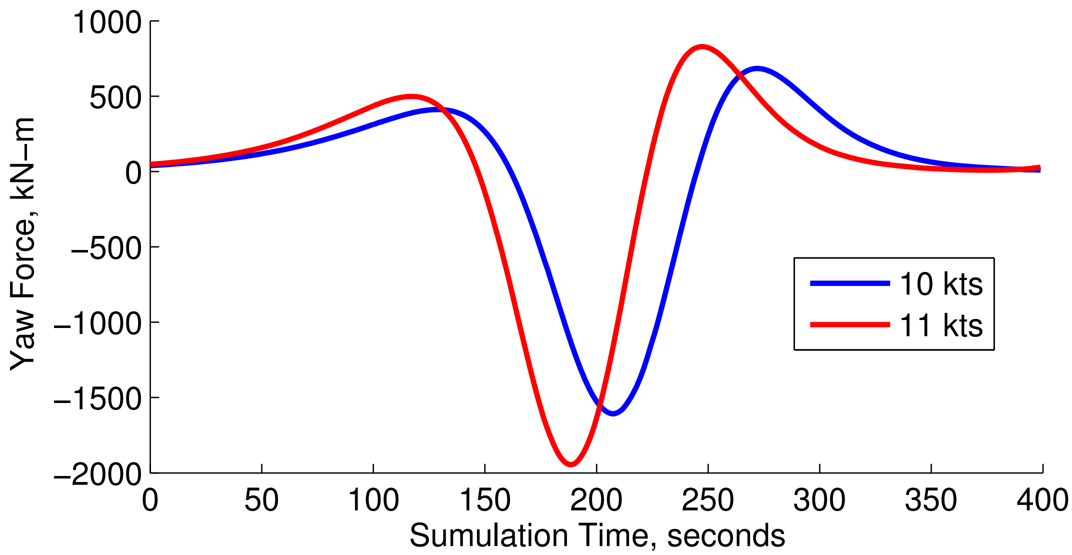

Figure 3-9: Modeled Yaw Forces on the Panamax Tanker at Berth 1

BERTH 2

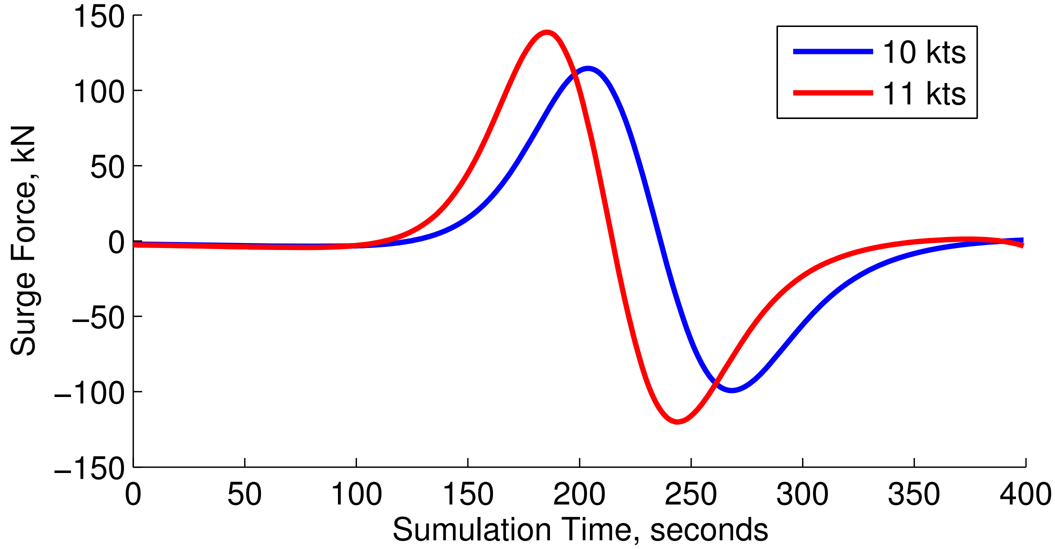

Figure 3-10: Modeled Surge Forces on the Aframax Tanker at Berth 2

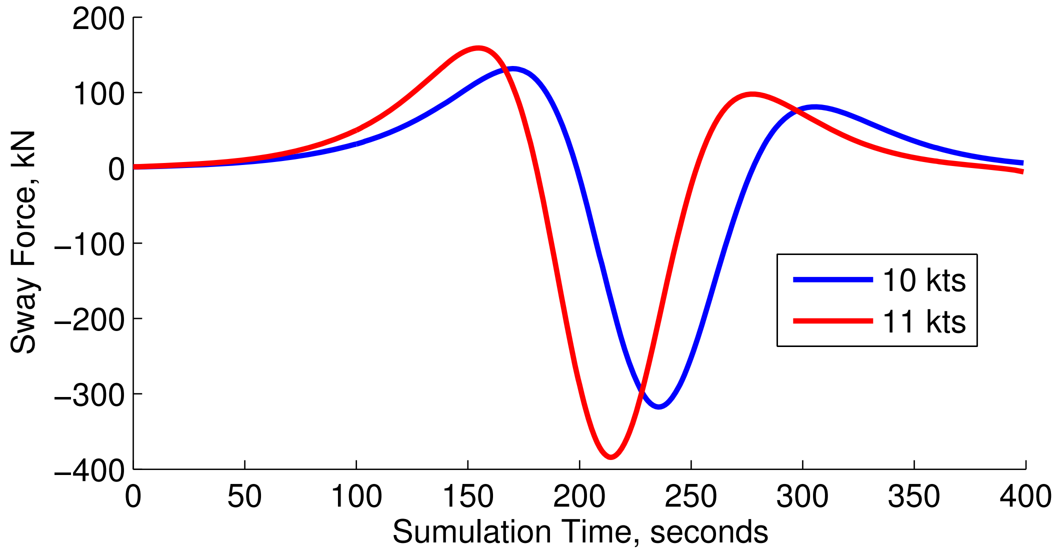

Figure 3-11: Modeled Sway Forces on the Aframax Tanker at Berth 2

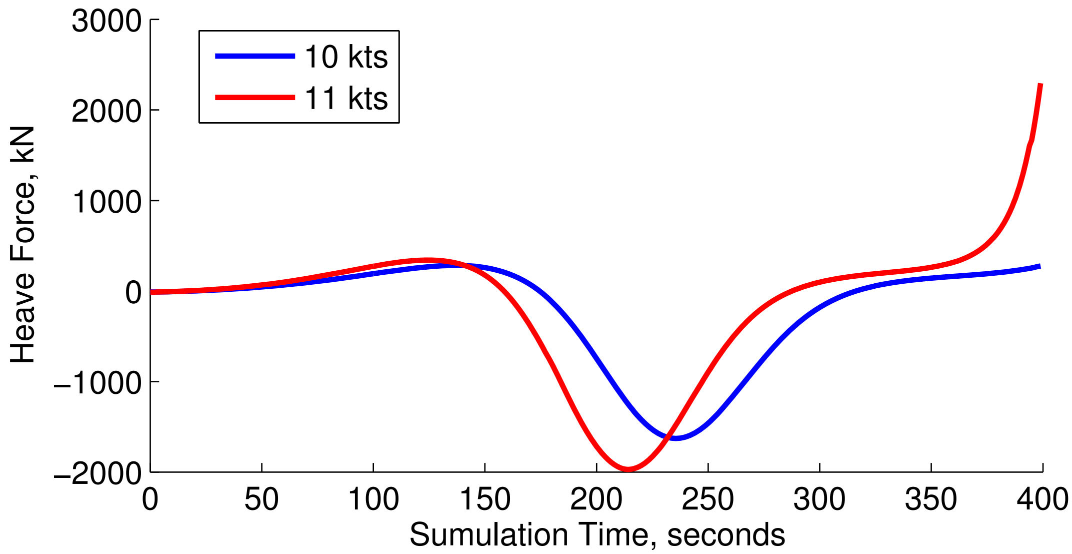

Figure 3-12: Modeled Heave Forces on the Aframax Tanker at Berth 2

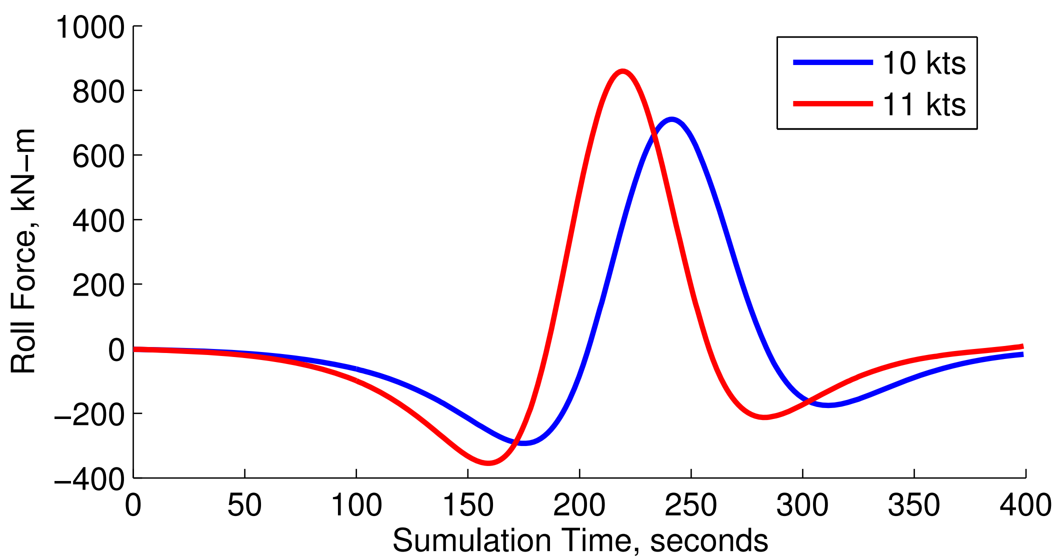

Figure 3-13: Modeled Roll Forces on the Aframax Tanker at Berth 2

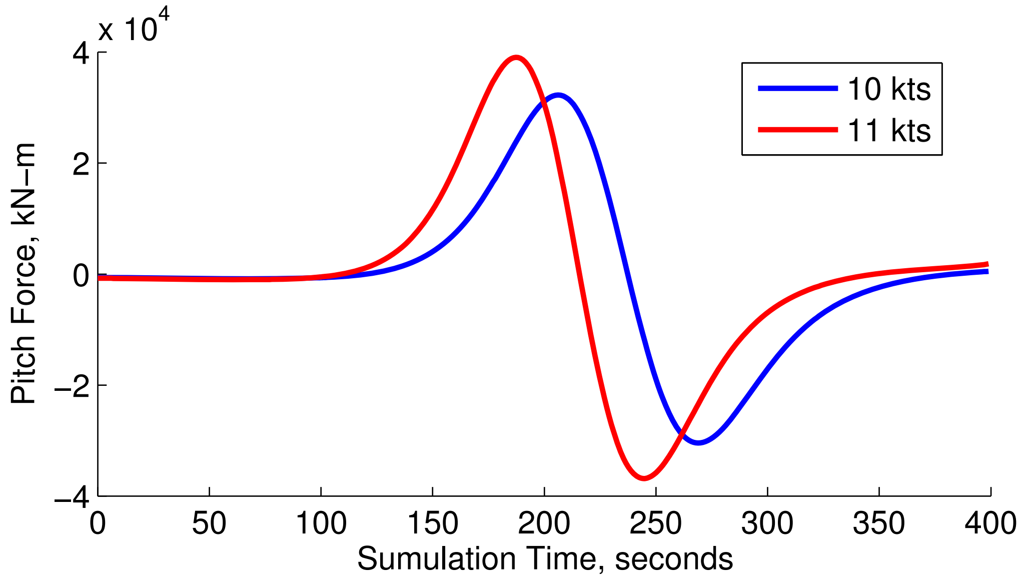

Figure 3-14: Modeled Pitch Forces on the Aframax Tanker at Berth 2

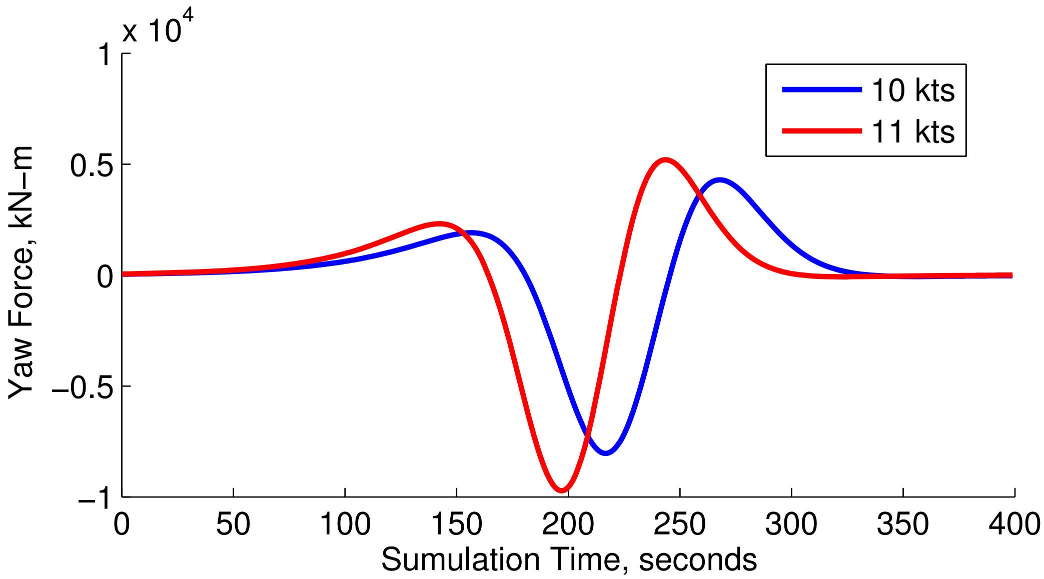

Figure 3-15: Modeled Yaw Forces on the Aframax Tanker at Berth 2

BERTH 3

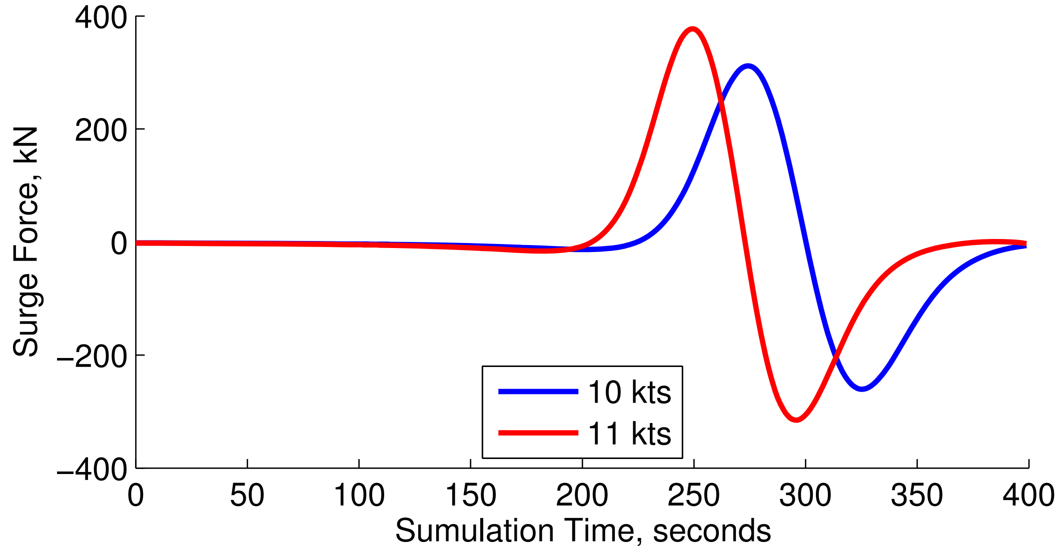

Figure 3-16: Modeled Surge Forces on the Aframax Tanker at Berth 3

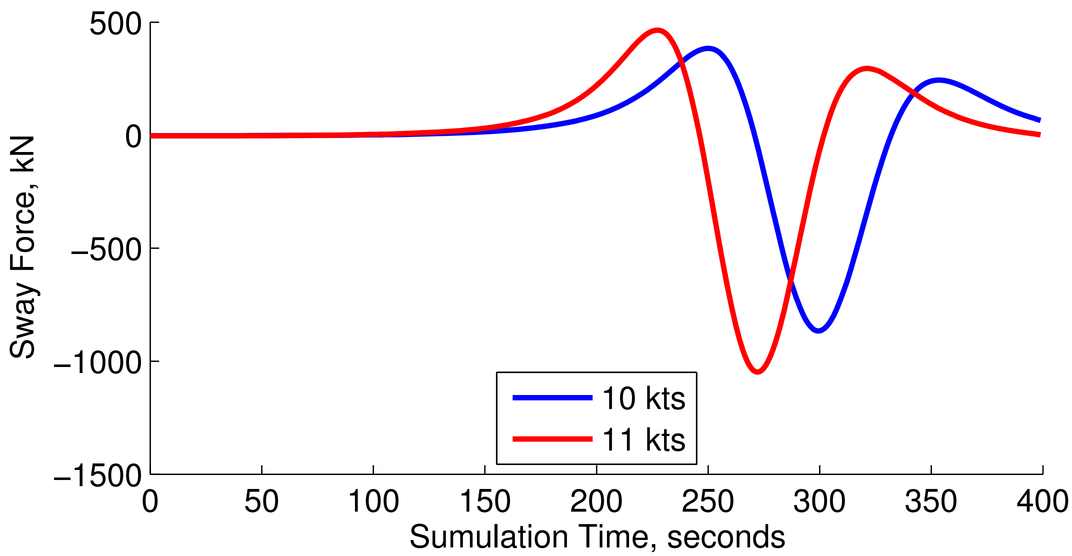

Figure 3-17: Modeled Sway Forces on the Aframax Tanker at Berth 3

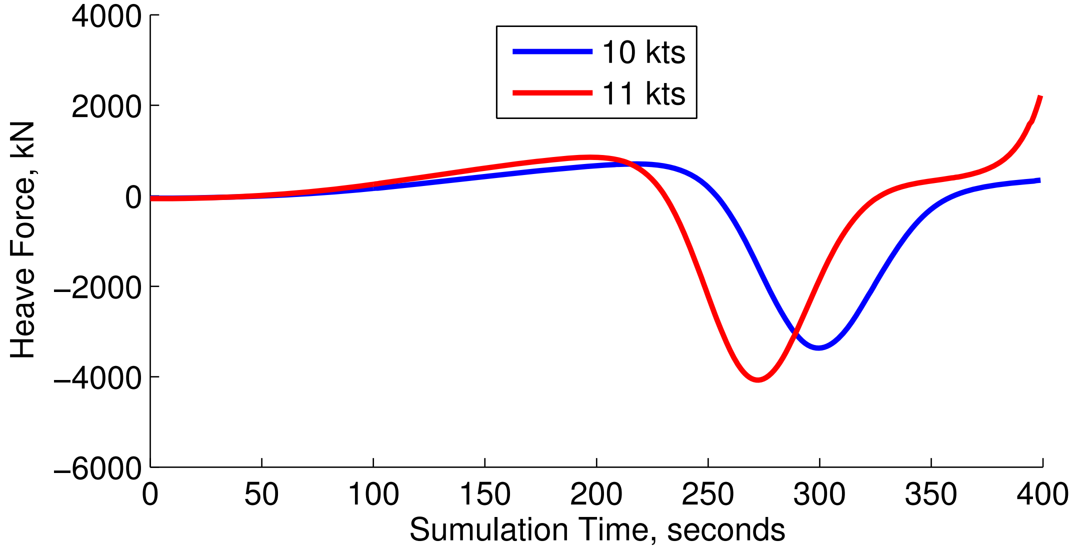

Figure 3-18: Modeled Heave Forces on the Aframax Tanker at Berth 3

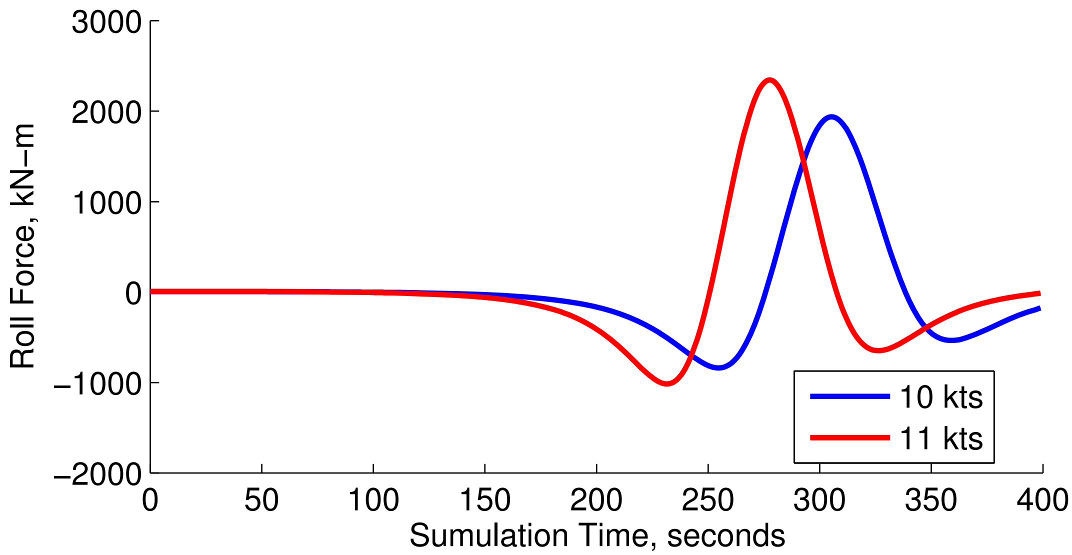

Figure 3-19: Modeled Roll Forces on the Aframax Tanker at Berth 3

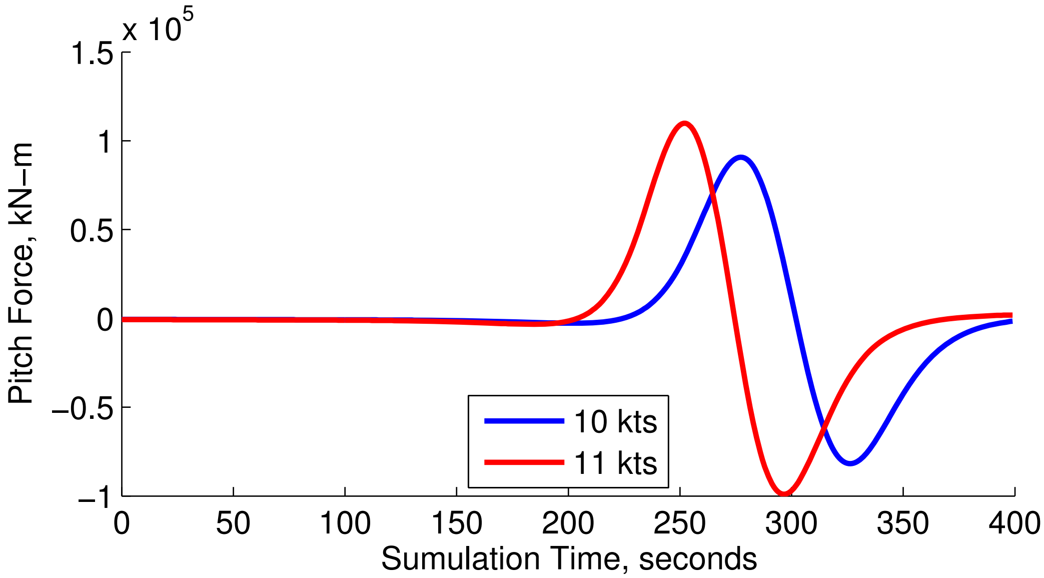

Figure 3-20: Modeled Pitch Forces on the Aframax Tanker at Berth 3

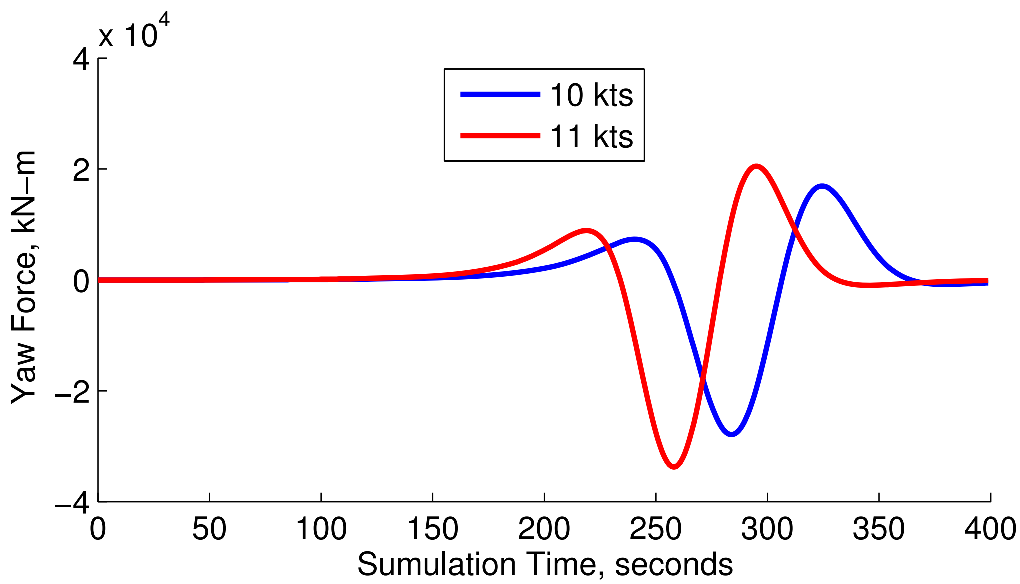

Figure 3-21: Modeled Yaw Forces on the Aframax Tanker at Berth 3

3.2 TERMSIM

The analysis of the mooring forces was computed using the mooring model TERMSIM. TERMSIM is a time domain program, developed by Maritime Research Institute Netherlands (MARIN), and is used to analyze the behavior of a moored vessel subject to wind, waves, and current. The mooring system may be a Single Point Mooring (SPM), a Multi Buoy Mooring (MBM) or a Jetty terminal, as in the case of the proposed Westridge facilities. The program simulates the mooring loads and vessel motions when the system is exposed to operational environmental conditions.

Vessel: The vessel is a generic tanker/bulker of regular dimensions. The hydrodynamic data for the vessel is based on the scale model tests of tanker-shaped hulls conducted at MARIN. Based on the main particulars of the bulker (e.g. length, breadth, draft, water depth, and displacement), a selection from the database is made and scaled to match the design vessel and site conditions. A user-defined vessel can also be input in the program.

Environment: The environmental conditions may include steady currents, steady or irregular wind fields, and/or swell and long crested irregular waves from arbitrary directions. Several spectral formulations for the wind, waves and swell are available. The program is capable of simulating vessels in both shallow and deep water. Environmental conditions were kept as static inputs to evaluate the effects of the passing vessel.

Databases: Several databases are delivered with the program.

-Mooring elements: The mooring element database contains particulars of common offshore chains, steel wires, synthetic ropes and fenders. For synthetic ropes, load-elongation characteristics are included. The load-compression curves for various fender types are included in the database. User-defined characteristics of lines and fenders may also be used.

-OCIMF wind and current coefficients: This database contains non-dimensional wind and current force/moment coefficients for calculation of wind and current loads on tanker-shaped vessels (valid for bulkers).

-OCIMF diffraction data: The new OCIMF diffraction database contains the results of diffraction analyses for several vessel configurations.

-Hydrodynamic reaction coefficients: This database contains non-dimensional coefficients for use in the formulation of hydrodynamic reaction forces.

Output: The output of each simulation consists of a binary file containing all samples of the calculated signals. The signals include vessel motions, loads in the mooring legs and other measures of mooring system behavior. In addition, an output file is produced summarizing the maximum, minimum, and mean forces and motions, as well as factors of safety. A comprehensive data processing package is delivered with the program to view, plot and print the results.

3.2.1 Environmental Parameters

The following environmental conditions were utilized in the mooring model:

- Wind: Static winds were run at every 15° at 25 knots. No wind scenarios were also conducted to evaluate if wind forces on the tankers damp out loads induced by the passing vessel.

- Current: A one knot current was applied to those simulations in which the passing vessel forces were simulated for a transit during a stemming tide. This current was applied 10° off of the starboard quarter of the vessels, in agreement with hydrodynamic model results developed for previous studies related to the new facility design.

3.2.2 Berth Geometries and Model Setup

All mooring models were set up to be identical to Optimoor mooring analyses developed in 2012. For reference, figures used to represent the mooring arrangements in the 2012 report are reproduced below.

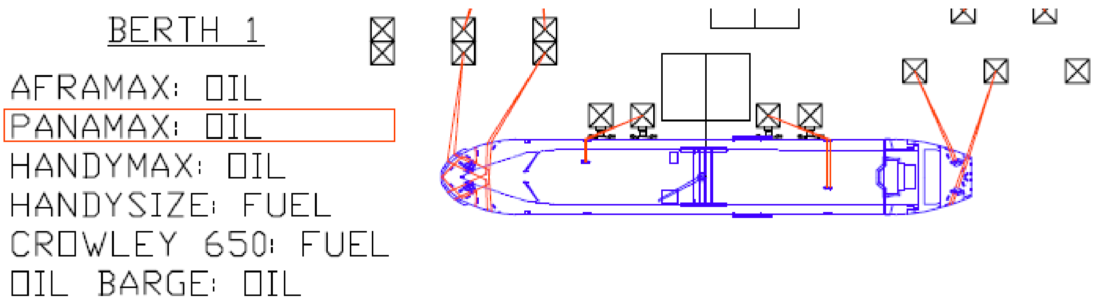

Figure 3-22: Panamax Mooring Arrangement at Berth 1

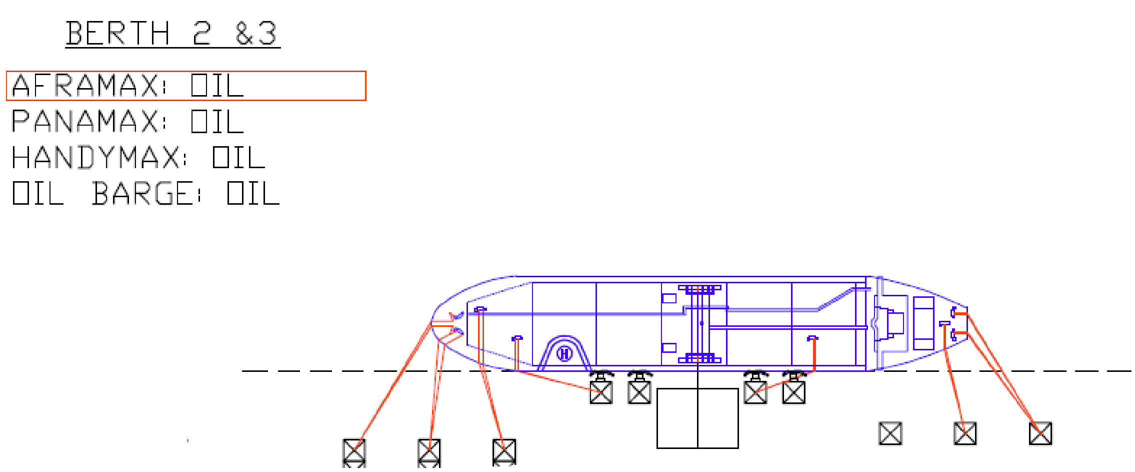

Figure 3-23: Aframax Mooring Arrangement at Berths 2 and 3

3.2.3 Mooring Evaluation Criteria

MOORING LINE TENSION LIMITS

Per recommendations provided by OCIMF, the allowable safe working load (SWL) in mooring lines is set at 55% of the minimum breaking load (MBL) for the steel wire lines found on tankers. Though each vessel deploys lines with 11 meter synthetic tails, the loading the steel lines will control the allowable safe working load limits.

FENDERS

Fenders were selected for the proposed facility based on requirements set by a berthing energy study conducted in 2012. Trelleborg Supercone Fenders SCN2000 (E1.0 rubber grade) were selected with a rated energy capacity of 305 t-m and a rated reaction of 295 mt. Acceptable fender loadings are those at or below the rate reaction of the fender at design performance (2894 kN).

MOTIONS

PIANC guidelines set envelopes for tanker motions at berth based on loading arm travel restrictions; these criteria allow for 3 meters of peak to peak motion in surge and 3 meters of zero to peak motion in sway for oil tankers.

3.2.4 Results

The following sections present the results of the dynamic mooring analyses for each modeled berth location. Tables are developed in an effort to evaluate the loading in the mooring lines (and hooks), bollards, fenders, and examine the induced vessel motions.

Directions presented below are referenced to true North. Mooring lines are numbered sequentially from the bow to the stern. Bollard load components are as follows: X-directional loading is parallel with the fender line, Y-directional loading is perpendicular to the fender line, and Z-directional loading is along the vertical axis of the bollard. Values presented for the magnitudes of vessel motions represent the envelope of motions during simulations; i.e. the amplitude between the maximum and minimum excursions of the vessel COG over the entire simulation.

BERTH 1: 10 KT PASSING SHIP

Table 3-2: Mooring Line and Hook Loads for Panamax Bulker at Berth 1 with 10 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	103	14.20%	12.9/80.0	0.0/120.0
2	103	14.20%	12.9/95.0	0.0/120.0
3	103	14.20%	12.9/80.0	0.0/120.0
4	103	14.20%	12.9/80.0	0.0/120.0
5	107	14.70%	12.9/140.0	0.0/120.0
6	107	14.80%	12.9/110.0	0.0/120.0
7	247	34.10%	12.9/290.0	0.0/120.0
8	247	34.00%	12.9/290.0	0.0/120.0
9	104	14.30%	12.9/200.0	0.0/120.0
10	104	14.30%	12.9/170.0	0.0/120.0
11	101	13.90%	12.9/200.0	0.0/120.0
12	101	13.90%	12.9/215.0	0.0/120.0

Table 3-3: Bollard Loads for Panamax Bulker at Berth 1 with 10 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	209	12.9/80.0	0.0/120.0	24	204	34
2	208	12.9/80.0	0.0/120.0	117	169	32
3	225	12.9/110.0	0.0/120.0	206	56	68
4	516	12.9/290.0	0.0/120.0	-479	120	148
5	211	12.9/170.0	0.0/120.0	104	179	40
6	204	12.9/200.0	0.0/120.0	160	123	26

Table 3-4: Fender Loads for Panamax Bulker at Berth 1 with 10 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	389	13.40%	12.9/155.0	0.0/120.0
2	349	12.10%	12.9/ 5.0	0.0/120.0
3	325	11.20%	12.9/50.0	0.0/120.0
4	321	11.10%	12.9/50.0	0.0/120.0

Table 3-5: Panamax Bulker Motions at Berth 1 with 10 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.67	12.9/290.0	0.0/120.0
Sway	0.056	12.9/20.0	0.0/120.0
Heave	0.013	12.9/95.0	0.0/120.0
Roll	0.289	12.9/20.0	0.0/120.0
Pitch	0.004	12.9/245.0	0.0/120.0

BERTH 1: 11 KT PASSING SHIP

Table 3-6: Mooring Line and Hook Loads for Panamax Bulker at Berth 1 with 11 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	103	14.20%	12.9/80.0	0.5/120.0
2	103	14.20%	12.9/65.0	0.5/120.0
3	103	14.20%	12.9/95.0	0.5/120.0
4	103	14.20%	12.9/95.0	0.5/120.0
5	107	14.70%	12.9/125.0	0.5/120.0
6	107	14.80%	12.9/95.0	0.5/120.0
7	257	35.40%	12.9/275.0	0.5/120.0
8	256	35.30%	12.9/275.0	0.5/120.0
9	104	14.30%	12.9/200.0	0.5/120.0
10	104	14.30%	12.9/185.0	0.5/120.0
11	101	13.90%	12.9/200.0	0.5/120.0
12	101	13.90%	12.9/170.0	0.5/120.0

Table 3-7: Bollard Loads for Panamax Bulker at Berth 1 with 11 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	209	12.9/65.0	0.5/120.0	24	204	34
2	208	12.9/95.0	0.5/120.0	117	169	32
3	225	12.9/95.0	0.5/120.0	206	56	68
4	535	12.9/275.0	0.5/120.0	-497	125	153
5	211	12.9/185.0	0.5/120.0	104	179	40
6	204	12.9/170.0	0.5/120.0	160	123	26

Table 3-8: Fender Loads for Panamax Bulker at Berth 1 with 11 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	426	14.70%	12.9/155.0	0.5/120.0
2	346	12.00%	12.9/ 5.0	0.5/120.0
3	217	7.50%	12.9/50.0	0.5/120.0
4	180	6.20%	12.9/50.0	0.5/120.0

Table 3-9: Panamax Bulker Motions at Berth 1 with 11 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.689	12.9/275.0	0.5/120.0
Sway	0.048	12.9/20.0	0.5/120.0
Heave	0.038	12.9/200.0	0.5/120.0
Roll	0.249	12.9/35.0	0.5/120.0
Pitch	0.005	12.9/200.0	0.5/120.0

BERTH 2: 10 KT PASSING SHIP

Table 3-10: Mooring Line and Hook Loads for Aframax Bulker at Berth 2 with 10 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	127	13.90%	12.9/290.0	0.0/120.0
2	128	14.00%	12.9/290.0	0.0/120.0
3	102	11.10%	12.9/185.0	0.0/120.0
4	103	11.20%	12.9/170.0	0.0/120.0
5	102	11.10%	12.9/185.0	0.0/120.0
6	102	11.10%	12.9/170.0	0.0/120.0
7	103	11.20%	12.9/185.0	0.0/120.0
8	177	19.30%	12.9/290.0	0.0/120.0
9	103	11.20%	12.9/80.0	0.0/120.0
10	103	11.20%	12.9/65.0	0.0/120.0
11	102	11.10%	12.9/80.0	0.0/120.0
12	102	11.10%	12.9/50.0	0.0/120.0
13	101	11.00%	12.9/80.0	0.0/120.0
14	101	11.00%	12.9/65.0	0.0/120.0

Table 3-11: Bollard Loads for Aframax Bulker at Berth 2 with 10 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	256	12.9/290.0	0.0/120.0	-128	-221	22
2	206	12.9/170.0	0.0/120.0	-16	-204	24
3	205	12.9/170.0	0.0/120.0	90	-183	24
4	207	12.9/185.0	0.0/120.0	202	-39	28
5	362	12.9/290.0	0.0/120.0	-337	-108	78
6	207	12.9/65.0	0.0/120.0	58	-197	29
7	407	12.9/50.0	0.0/120.0	236	-330	38

Table 3-12: Fender Loads for Aframax Bulker at Berth 2 with 10 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	504	17.40%	12.9/80.0	0.0/120.0
2	495	17.10%	12.9/215.0	0.0/120.0
3	545	18.80%	12.9/170.0	0.0/120.0
4	566	19.50%	12.9/170.0	0.0/120.0

Table 3-13: Aframax Bulker Motions at Berth 2 with 10 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.418	12.9/290.0	0.0/120.0
Sway	0.084	12.9/200.0	0.0/120.0
Heave	0.021	12.9/335.0	0.0/120.0
Roll	0.127	12.9/200.0	0.0/120.0
Pitch	0.01	12.9/305.0	0.0/120.0

BERTH 2: 11 KT PASSING SHIP

Table 3-14: Mooring Line and Hook Loads for Aframax Bulker at Berth 2 with 11 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	129	14.00%	12.9/290.0	0.5/120.0
2	129	14.10%	12.9/290.0	0.5/120.0
3	103	11.30%	12.9/155.0	0.5/120.0
4	106	11.50%	12.9/155.0	0.5/120.0
5	102	11.10%	12.9/170.0	0.5/120.0
6	102	11.10%	12.9/170.0	0.5/120.0
7	103	11.20%	12.9/170.0	0.5/120.0
8	168	18.30%	12.9/290.0	0.5/120.0
9	103	11.20%	12.9/65.0	0.5/120.0
10	103	11.20%	12.9/80.0	0.5/120.0
11	102	11.10%	12.9/65.0	0.5/120.0
12	102	11.10%	12.9/80.0	0.5/120.0
13	101	11.00%	12.9/65.0	0.5/120.0
14	101	11.00%	12.9/80.0	0.5/120.0

Table 3-15: Bollard Loads for Aframax Bulker at Berth 2 with 11 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	259	12.9/290.0	0.5/120.0	-129	-224	22
2	211	12.9/155.0	0.5/120.0	-16	-208	24
3	205	12.9/170.0	0.5/120.0	90	-183	24
4	207	12.9/170.0	0.5/120.0	202	-39	28
5	344	12.9/290.0	0.5/120.0	-320	-103	74
6	207	12.9/65.0	0.5/120.0	58	-197	29
7	407	12.9/65.0	0.5/120.0	236	-330	38

Table 3-16: Fender Loads for Aframax Bulker at Berth 2 with 11 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	478	16.50%	12.9/80.0	0.5/120.0
2	507	17.50%	12.9/215.0	0.5/120.0
3	647	22.40%	12.9/170.0	0.5/120.0
4	698	24.10%	12.9/170.0	0.5/120.0

Table 3-17: Aframax Bulker Motions at Berth 2 with 11 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.386	12.9/290.0	0.5/120.0
Sway	0.091	12.9/200.0	0.5/120.0
Heave	0.045	12.9/110.0	0.5/120.0
Roll	0.136	12.9/200.0	0.5/120.0
Pitch	0.012	12.9/335.0	0.5/120.0

BERTH 3: 10 KT PASSING SHIP

Table 3-18: Mooring Line and Hook Loads for Aframax Bulker at Berth 3 with 10 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	151	16.40%	12.9/320.0	0.0/120.0
2	153	16.70%	12.9/320.0	0.0/120.0
3	113	12.30%	12.9/155.0	0.0/120.0
4	114	12.40%	12.9/155.0	0.0/120.0
5	108	11.80%	12.9/125.0	0.0/120.0
6	108	11.80%	12.9/125.0	0.0/120.0
7	109	11.90%	12.9/80.0	0.0/120.0
8	317	34.60%	12.9/320.0	0.0/120.0
9	104	11.30%	12.9/65.0	0.0/120.0
10	104	11.30%	12.9/65.0	0.0/120.0
11	104	11.30%	12.9/80.0	0.0/120.0
12	103	11.30%	12.9/80.0	0.0/120.0
13	103	11.20%	12.9/80.0	0.0/120.0
14	103	11.20%	12.9/80.0	0.0/120.0

Table 3-19: Bollard Loads for Aframax Bulker at Berth 3 with 10 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	305	12.9/320.0	0.0/120.0	-152	-263	26
2	228	12.9/155.0	0.0/120.0	-17	-225	26
3	218	12.9/125.0	0.0/120.0	96	-194	26
4	220	12.9/80.0	0.0/120.0	215	-41	30
5	650	12.9/320.0	0.0/120.0	-604	-194	140
6	209	12.9/65.0	0.0/120.0	59	-199	30
7	414	12.9/80.0	0.0/120.0	240	-336	39

Table 3-20: Fender Loads for Aframax Bulker at Berth 3 with 10 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	514	17.80%	12.9/ 5.0	0.0/120.0
2	501	17.30%	12.9/215.0	0.0/120.0
3	572	19.80%	12.9/170.0	0.0/120.0
4	601	20.80%	12.9/170.0	0.0/120.0

Table 3-21: Aframax Bulker Motions at Berth 3 with 10 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.827	12.9/320.0	0.0/120.0
Sway	0.086	12.9/200.0	0.0/120.0
Heave	0.045	12.9/185.0	0.0/120.0
Roll	0.13	12.9/200.0	0.0/120.0
Pitch	0.028	12.9/185.0	0.0/120.0

BERTH 3: 10 KT PASSING SHIP

Table 3-22: Mooring Line and Hook Loads for Aframax Bulker at Berth 3 with 11 kt Passing Vessel Speed

Mooring Line	Max Load, kN	%MBL	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	167	18.20%	12.9/350.0	0.5/120.0
2	170	18.50%	12.9/350.0	0.5/120.0
3	130	14.10%	12.9/140.0	0.5/120.0
4	129	14.10%	12.9/140.0	0.5/120.0
5	131	14.20%	12.9/20.0	0.5/120.0
6	131	14.20%	12.9/ 5.0	0.5/120.0
7	126	13.80%	12.9/95.0	0.5/120.0
8	342	37.20%	12.9/350.0	0.5/120.0
9	103	11.20%	12.9/65.0	0.5/120.0
10	103	11.20%	12.9/50.0	0.5/120.0
11	103	11.20%	12.9/65.0	0.5/120.0
12	102	11.10%	12.9/65.0	0.5/120.0
13	101	11.00%	12.9/65.0	0.5/120.0
14	101	11.00%	12.9/80.0	0.5/120.0

Table 3-23: Bollard Loads for Aframax Bulker at Berth 3 with 11 kt Passing Vessel Speed

Bollard	Max Load, kN	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg	X-Component, kN	Y-Component, kN	Z-Component, kN
1	338	12.9/350.0	0.5/120.0	-168	-292	29
2	261	12.9/140.0	0.5/120.0	-20	-258	30
3	263	12.9/ 5.0	0.5/120.0	116	-234	31
4	255	12.9/95.0	0.5/120.0	248	-47	35
5	700	12.9/350.0	0.5/120.0	-651	-209	150
6	207	12.9/50.0	0.5/120.0	58	-197	29
7	409	12.9/65.0	0.5/120.0	237	-331	38

Table 3-24: Fender Loads for Aframax Bulker at Berth 3 with 11 kt Passing Vessel Speed

Fender	Max Load, kN	%Rated Rx	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
1	643	22.20%	12.9/ 5.0	0.5/120.0
2	526	18.20%	12.9/260.0	0.5/120.0
3	674	23.30%	12.9/170.0	0.5/120.0
4	732	25.30%	12.9/170.0	0.5/120.0

Table 3-25: Aframax Bulker Motions at Berth 3 with 11 kt Passing Vessel Speed

Motion	Magnitude, m/deg	Wind Speed, m/s / Direction, deg	Current Speed, m/s, Direction, deg
Surge	0.949	12.9/ 5.0	0.5/120.0
Sway	0.123	12.9/ 5.0	0.5/120.0
Heave	0.072	12.9/185.0	0.5/120.0
Roll	0.138	12.9/200.0	0.5/120.0
Pitch	0.034	12.9/200.0	0.5/120.0

4. CONCLUSIONS AND RECOMMENDATIONS

Passing vessel analysis at the three proposed berths revealed that the proposed realigned channel provides ample clearance between transiting and moored vessels. Peak surge forces induced on the loaded Aframax tanker at berth 3 were about 400 kN (40 mt) for the transiting bulker making 10 knots against a 1 knot stemming current. Coupling these passing vessel forces with static winds and currents did not overstrain the planned mooring arrangements and their related equipment. The largest line loadings were observed in the shortest forward spring lines when they were resisting the initial surge forward induced by the passing vessel.

Peak to Peak motions of all vessels at the berth were minimal and well within PIANC recommended envelopes. All lines and fenders maintained loading safety factors well below the suggested OCIMF criteria for moored tankers at berth.

The study also serves to illustrate the sensitivity of passing vessel forces to the vessel speeds; calculated loads were about 30% higher for the 11 knot simulations than those of the 10 knot. Potential flow theory demonstrates that changes in the modeled ships' draft, displacement, passing distance, and observed speed will greatly affect the observed forces on both vessels. Bathymetric effects also greatly contribute to these effects, but the bathymetry is deep and mildly sloping around the Westridge facility so as to provide ample under keel clearance and minimal amplification to passing vessel forces.

Moffatt and Nichol does not think it is warranted to repeat this analysis for transits at a higher speed, as it seems unlikely that deep draft vessels would exceed 10 kts at engine settings comfortable for harbour transit. Should vessels larger than those considered in the report call at facilities east of Westridge, it would be prudent to verify that these ships will not strain the proposed tanker moorings beyond acceptable limits.

While the layout of the proposed new Westridge Marine Terminal is still being optimized, it should not be necessary to repeat this analysis for the final layout, provided that the final configuration is no closer to the vessel corridor than 190m. Similarly, should PMV decide to realign the channel adjacent to the Westridge facilities so as to bring inbound traffic closer to the tanker berths, reanalysis of the passing vessel effects at that time would be warranted.

5. REFERENCES

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