PIER 400 BERTH 408
MARINE OIL TERMINAL DEVELOPMENT
AT THE PORT OF LOS ANGELES

PASSING SHIP MOORING STUDY

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EXECUTIVE SUMMARY

A comprehensive study of passing ship effects has been prepared for the Pier 400 Marine Oil Terminal for Panamax to VLCC classed tankers. Forces on the moored vessel were calculated due to a passing post-panamax containership at various speeds and distances from the berth. A dynamic mooring model was used to assess the resultant mooring line loads and vessel motions at berth. The table below summarizes the analyzed cases and the mooring model results (labeled Cases A-M). The variables in the analysis were passing speed, passing distance, number of mooring lines, and vessel class. The analysis showed that passing speeds of 5 knots or greater may result in loads that are higher than the safe working load (SWL) of the vessel mooring lines for berthed VLCC tankers. Adding additional mooring lines reduces the loads, but SWL is still exceeded (see Cases I-J, below).

However, if speed is reduced to 4 knots or less and passing distance is maintained at 300 feet or greater, mooring line loads are kept within acceptable limits and manifold excursions are reduced to less than 1 meter (Case G).

It was found that the smaller tanker classes were less susceptible to passing ship effects; therefore the VLCC represents the limiting condition. The analysis shows that the deeper the vessel draft, the larger the hull displacement, the smaller the underkeel clearance, the higher the resulting passing vessel forces.

The limiting case of 4 knots and 300-foot separation was also analyzed coincident with a 30-knot gusting wind. While the wind resulted in higher mooring forces, the mooring line loads remained within the safe working limits.

An important assumption for the analysis is that mooring lines are pretensioned during mooring. This analysis assumes that a pretension of 10% of the minimum breaking load of the mooring lines (or about 11mt) is maintained. Low pretensions or slack lines could result in larger loads and motions than the vessel's mooring systems are equipped to handle. For effective mooring at the terminal, slack lines should be tended throughout unloading and tide changes.

The loads and vessel motions imposed by passing vessels at the terminal can be managed to acceptable levels so long as a minimum mooring line pre-tension is maintained at all times. It is recommended that passing vessels be limited to a speed of 4 knots and a hull-to-hull passing distance of 300 feet or greater, especially when mooring laden VLCCs.

Moored VLCC Passing Vessel Analysis at Pier 400 Marine Oil Terminal

	Passing Speed (knots)	Passing Distance (feet)	Number of Mooring Lines	VLCC Draft (feet)	Acceptable Mooring
Case A	5 knots	180 feet	12	71.8	No
Case B	4 knots	180 feet	12	71.8	No
Case C	5 knots	600 feet	12	71.8	No
Case D	4 knots	600 feet	12	71.8	Yes
Case E	4 knots	500 feet	12	71.8	Yes
Case F	4 knots	400 feet	12	71.8	Yes
Case G	4 knots	300 feet	12	71.8	Yes
Case H	3 knots	180 feet	12	71.8	Yes
Case I	5 knots	180 feet	14	71.8	No
Case J	5 knots	180 feet	16	71.8	No
Case K	5 knots	180 feet	18	71.8	No
Case L	4 knots	180 feet	12	50.0	Yes
Case M	4 knots	600 feet	12	50.0	Yes

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1. INTRODUCTION

This letter report describes the findings of a ship mooring study for the proposed Pier 400 Marine Oil Terminal. The purpose of the study was to examine the loads imposed by passing vessels at the proposed Pier 400 Marine Oil Terminal. The location of the berth relative to the navigation channels is shown in Figure 1.1. The study purpose is to establish a preliminary allowable passing speed and distance from the berth to maintain safe mooring loads and motions. Figure 1.2 shows the general arrangement of the proposed mooring structures, the position of moored vessels, and proximity to the navigation channel.

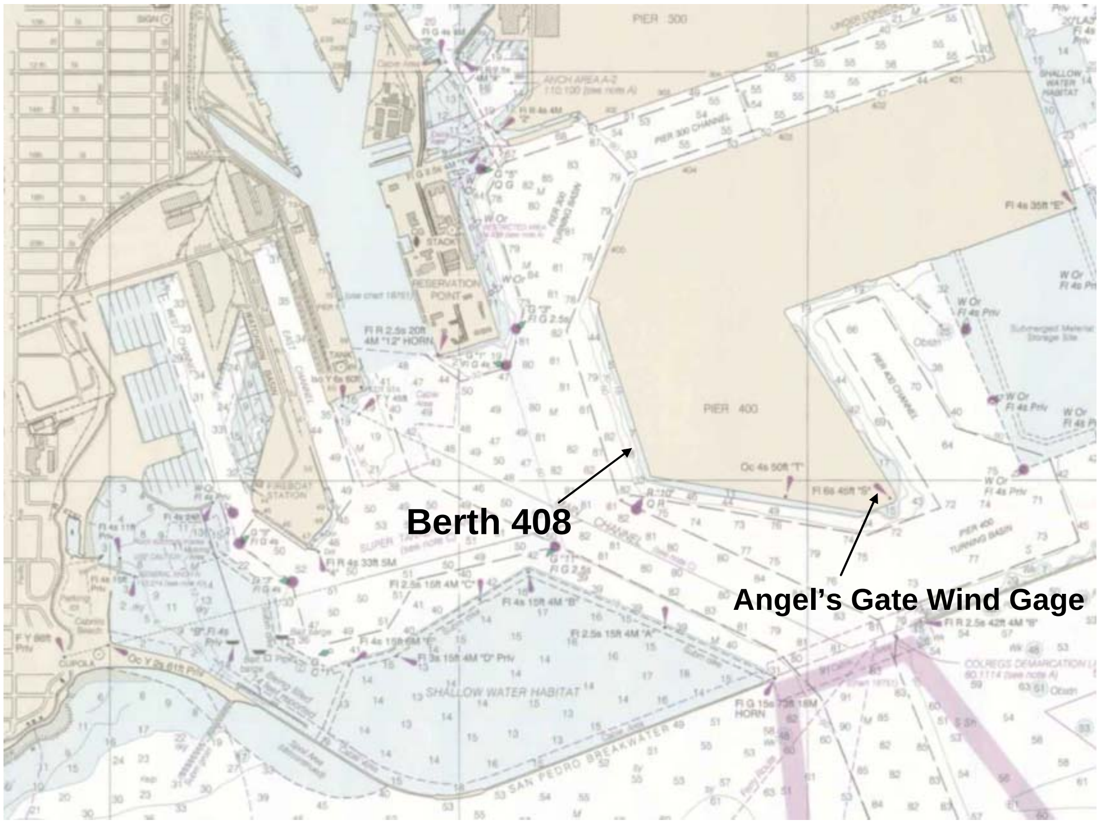


Figure 1.1 Site Map and Proposed Marine Oil Terminal Berth 408 Location

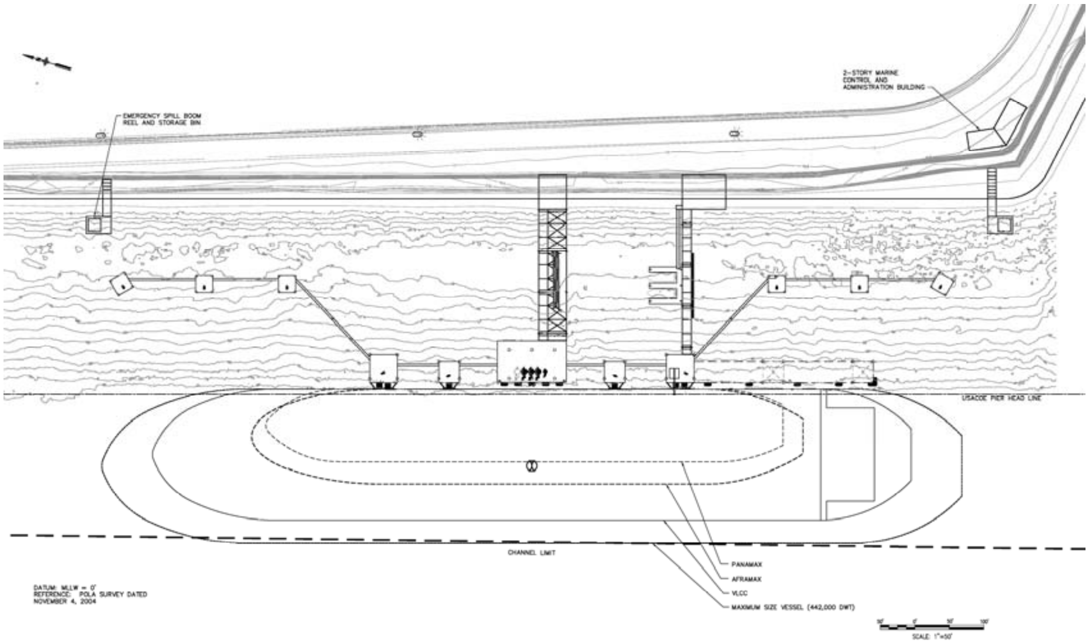


Figure 1.2 Site Map and Proposed Marine Oil Terminal Berth 408 Location

2. DESIGN PASSING VESSEL

The design passing vessel for the terminal was selected as the largest ship anticipated to pass the terminal. The selected design vessel was the post-panamax containership *Susan Maersk.* The principal characteristics of the vessel are given in Table 2.1.

Table 2.1: Post-Panamax *Susan Maersk* Characteristics

Deadweight	104,676 tonnes
Length Overall	347 m
Beam	42.8 m
Hull Depth	24.1 m
Loaded (Design) Draft	14.5 m

As shown in Figure 1.2, if a vessel were to travel on the edge of the existing channel, the minimum separation distance between the hull of the passing vessel and the hull of a moored VLCC would be 180 feet (See Figure 2.1).

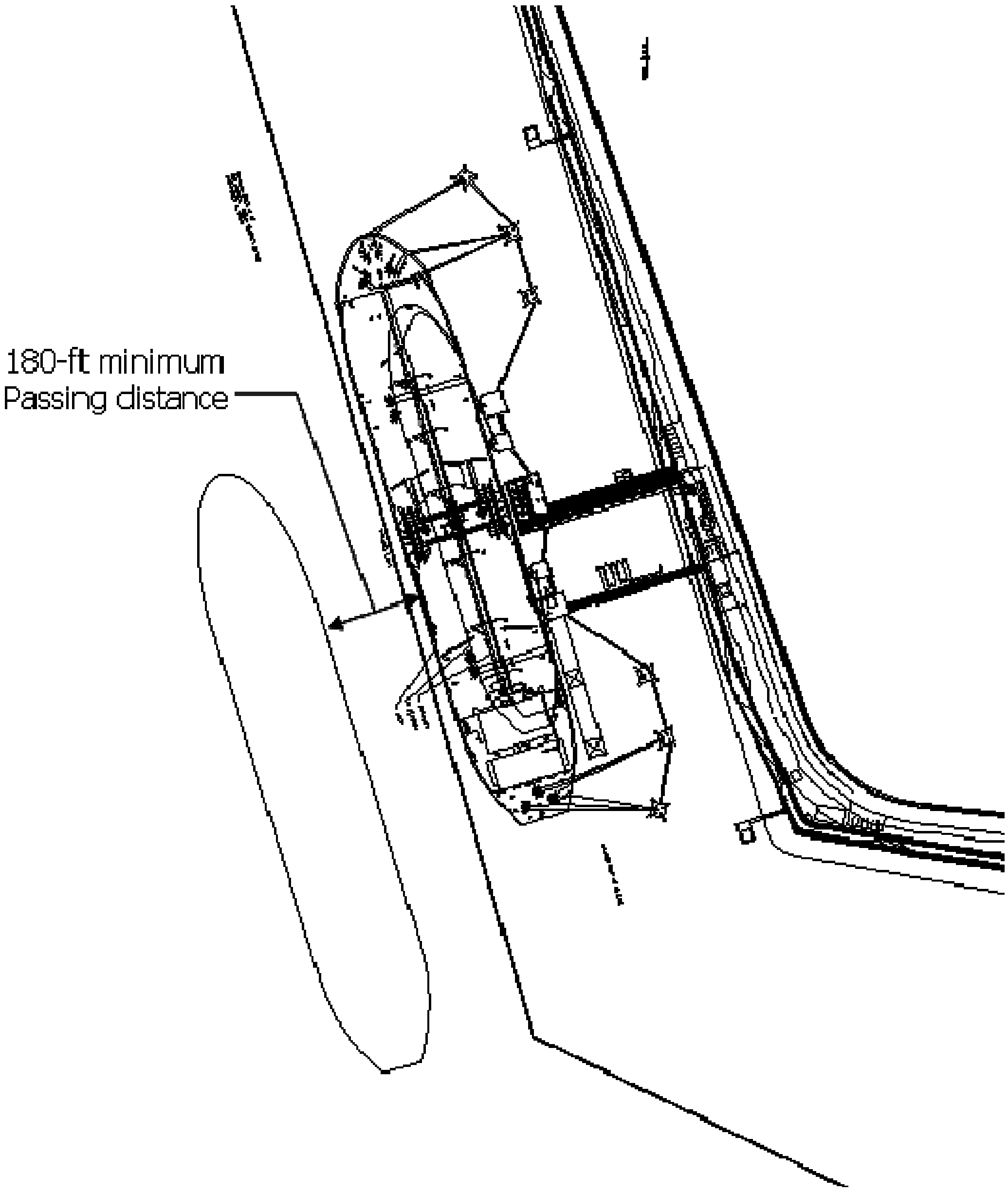


Figure 2.1 Minimum Passing Distance

3. MOORING SYSTEM

Four moored vessels were considered in this study, spanning the range of vessel classes expected to call at the terminal. The principal dimensions of all four vessels are shown in Table 2. For this analysis, all vessels were analyzed at full draft as this will yield the largest passing vessel loads. Water depth at the berth is 81 feet MLLW.

Table 3.1 Design Vessel Characteristics

Vessel Class	**PANAMAX**	**AFRAMAX**	**SUEZMAZ**	**VLCC**
Deadweight, tonnes	69,000	105,000	152,000	307,000
Length Overall, Feet	726.2	800.5	883.2	1092.2
Length Between Perpendiculars, Feet	695.4	764.4	846.5	1049.6
Moulded Breadth, Feet	118.1	137.8	150.0	197.1
Moulded Depth, Feet	63.0	70.0	80.0	91.2
Displaced Volume Loaded, Feet^3	2,697,451	4,315,417	5,857,079	12,406,750
Displaced Volume Ballast, Feet^3	1,267,811	1,958,516	2,239,444	5,052,930
Draft Loaded, Feet	41.1	48.6	57.4	71.8
Draft Ballast, Feet	19.3	23.0	23.6	31.8
Projected Side Area Loaded, Feet^2	18,870	20,957	25,131	27,412
Projected Side Area Ballast, Feet^2	33,997	39,568	53,426	69,542
Projected Front Area Loaded, Feet^2	5,949	7,728	8,962	12,792
Projected Front Area Ballast, Feet^2	8,521	10,753	13,989	20,688

Table 3.2 lists the mooring equipment of each design vessel. The ship mooring system is comprised of mooring lines (i.e., wire ropes with nylon tails) and buckling “cell-type” fenders. The allowable safe working load (SWL) in the mooring lines was set at 55% of the minimum breaking load (MBL). The allowable working load in the fenders was the rated reaction at maximum deflection (55%). The mooring line SWL is 75 tons. The same lines and fenders were used for each vessel size. It should be noted that a line pretension of 10% of the line MBL (11 tonnes) was used in all simulations. This is an important assumption as it implies that this pretension will be maintained while vessels occupy the berth.

Table 3.2 Tanker Mooring Equipment Characteristics (typical)

	PANAMAX	AFRAMAX	SUEZMAX	VLCC
Number of wind-mounted wires	16	16	16	20
Wire Minimum Breaking Load (MBL)	72mt	78mt	114mt	114mt
Nylon Tail MBL	110mt	131mt	171mt	171mt
Safe Working Load (SWL)	40mt	49mt	63mt	63mt

Initially, all ships are assumed to be moored with 12 mooring lines. In the mooring arrangement, 8 lines are connected to the mooring dolphins, while 4 lines are connected to the breasting dolphins as spring lines. Figures 3.1 to 3.4 show the VLCC at berth with arrangements using 12, 14, 16, and 18 lines.

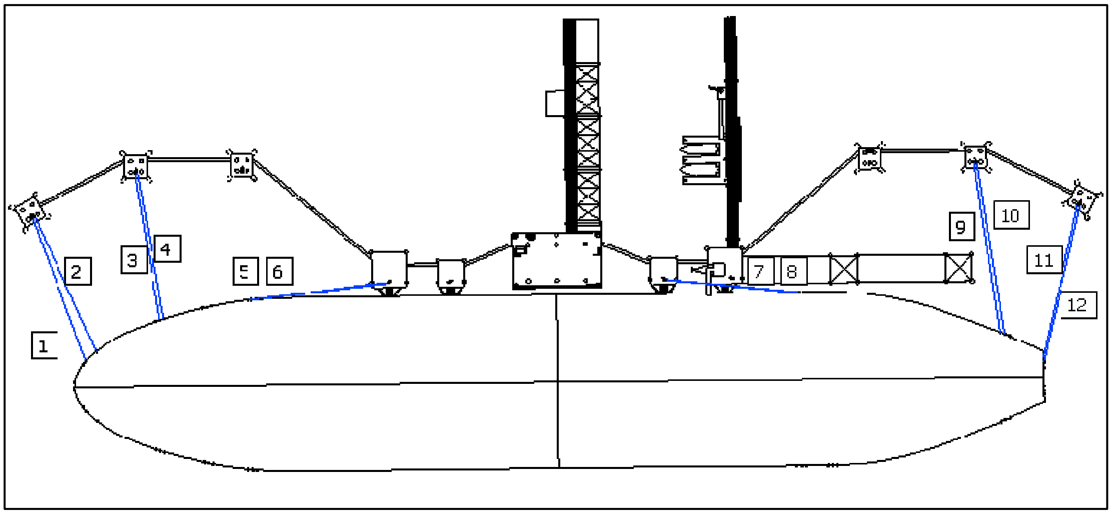


Figure 3.1 Moored VLCC, 12 Lines

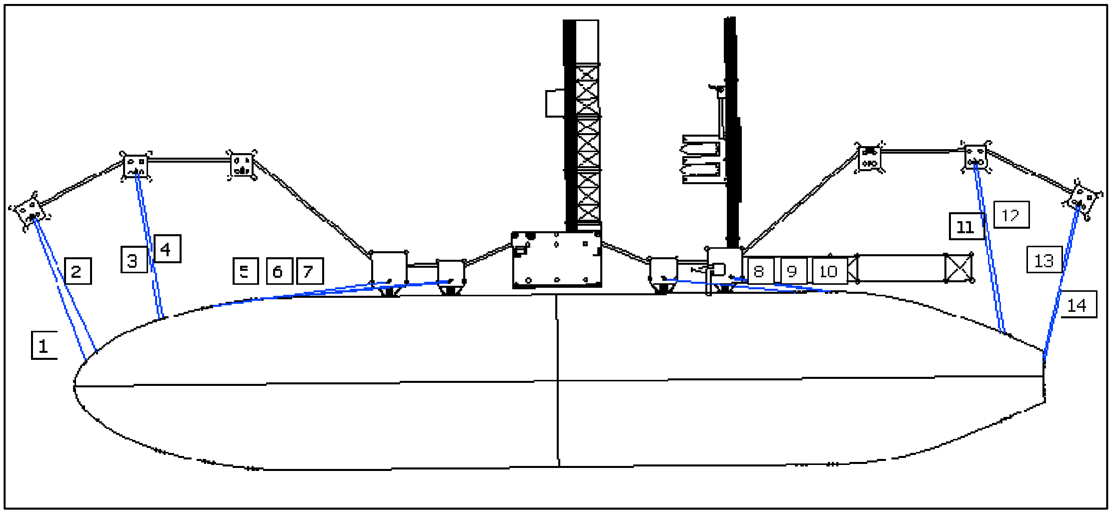


Figure 3.2 Moored VLCC, 14 Lines

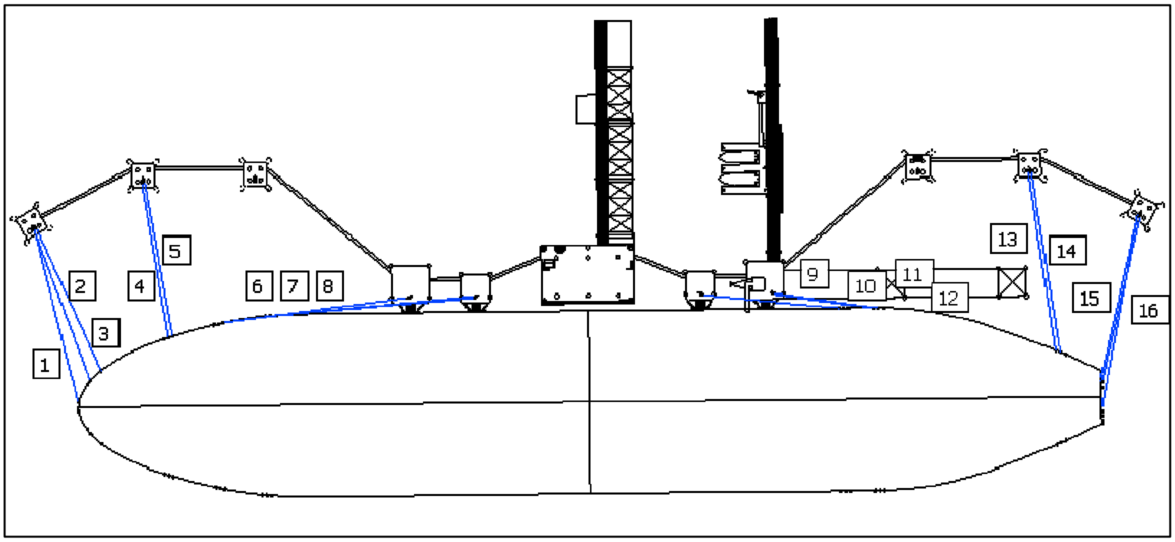


Figure 3.3 Moored VLCC, 16 Lines

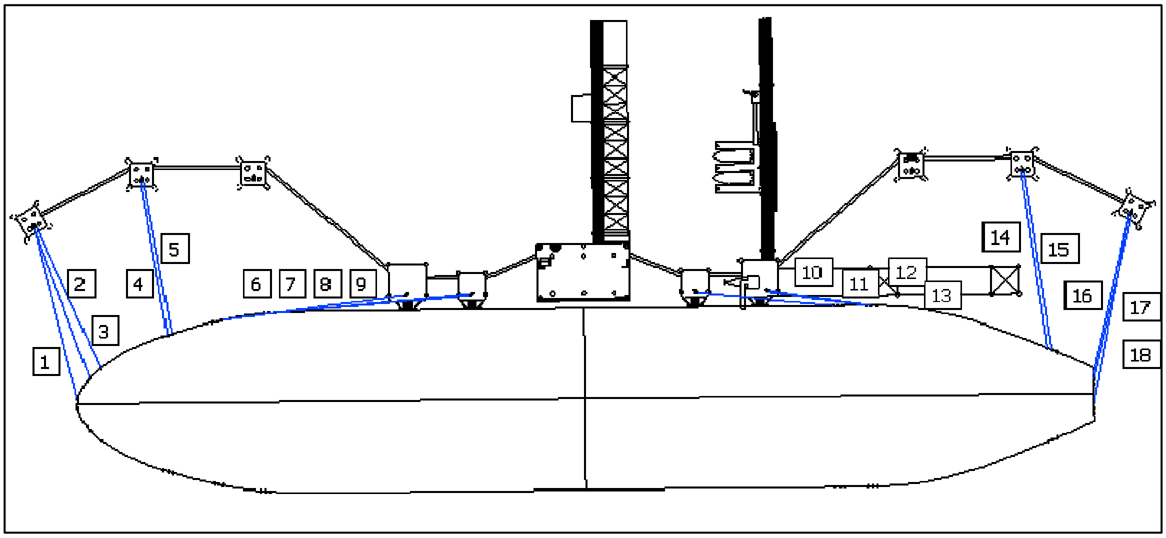
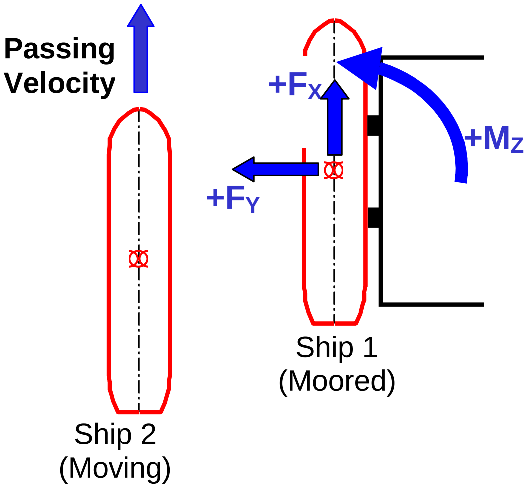


Figure 3.4 Moored VLCC, 18 Lines

4. PASSING SHIP HYDRODYNAMIC LOADS

Passing ships traveling at high speed and/or proximate to moored vessels will impose large forces and moments on the moored vessel. These forces can be sufficiently large to part mooring lines or produce large vessel motions. A number of references have emphasized methods for computation of the hydrodynamic forces imposed on the moored vessels (e.g., Seelig, W. (2001), “Passing Ship Effects on Moored Ships”, Naval Facilities Engineering Center, Technical Report TR-6027-DCN and many others). The typical problem of a beam to beam passing scenario is illustrated in Figure 4.1.

Figure 4.1 Passing Ship Geometry



The passing ship imposes a longitudinal and lateral force as well as a moment on the moored vessel. Typical results are shown in Figure 4.2 and demonstrate that a relatively large, but transient load is experienced by the moored vessel. The forces on the moored vessel are dependant on the distance to the passing vessel, the speed of the passing vessel, the underkeel clearance of both vessels, and the displacement of the two ships. The method of calculation used in this report is based on the theoretical predictions developed by Wang (1977). Seelig (2001) and Kriebel (2005) modified the theoretical values to include corrections for shallow water effects based on physical model studies.

Figure 4.2 Typical Results for a Beam to Beam Passing

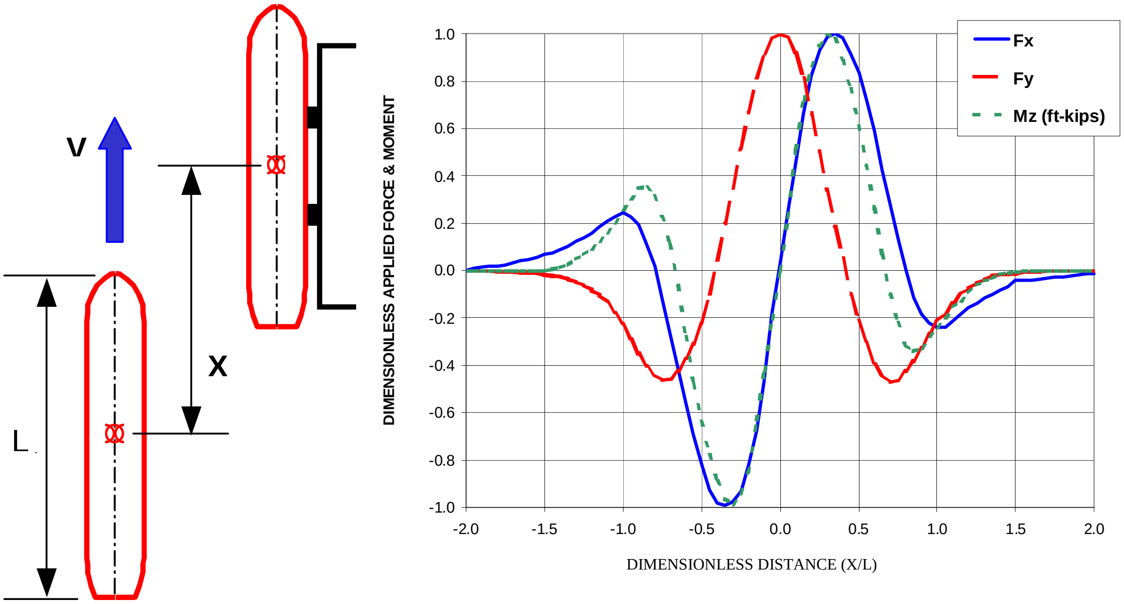
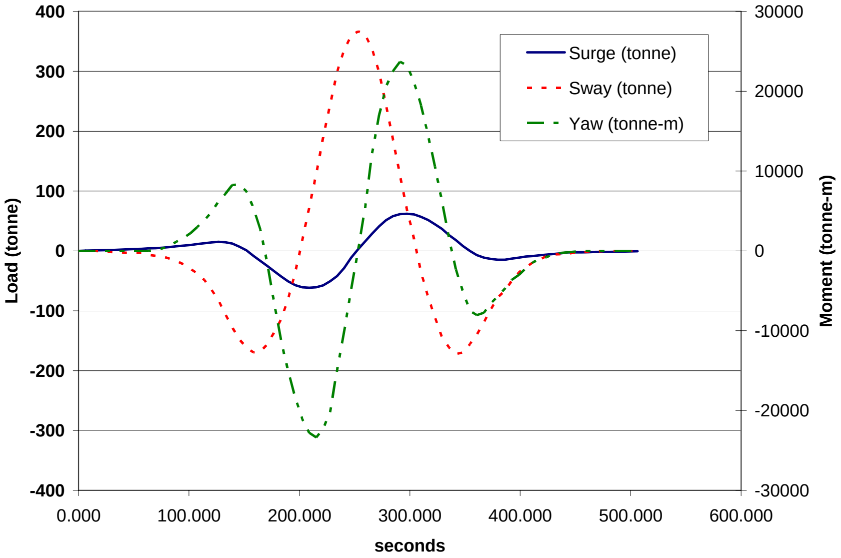


Figure 4.3 presents the forces predicted on the moored VLCC by the design passing vessel at a speed of 5 knots and a side-to-side separation of 180 feet. It should be noted that the forces presented in Figure 5 represent the total forces and moment imposed on the moored ship hull. Mooring line/fender forces and ship motions are developed from the dynamic mooring analysis presented in the following section.

At Pier 400, the closest line of approach to the moored tanker is when vessels are passing parallel to the berth. More oblique angles will result in a vessel track further from the moored tanker. The side-to-side passing analysis, therefore, represents a conservative scenario for assessing the terminal vulnerability to passing effects.

Figure 4.3 Passing Ship Forces- 5 knots, 180-foot Separation Distance



5. DYNAMIC MOORING ANALYSIS

The above applied hydrodynamic forces are an essential element in examination of passing ship problems. 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 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 problems where passing ship problems have been experienced, M&N have found that dynamic analysis is imperative for practical applications, rather than static analysis.

The passing ship problem was examined using the TERMSIM computer program which is a six degree of freedom time domain model for mooring dynamics. TERMSIM is a fully dynamic time-domain ship mooring analysis program 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 wind coefficients are based on the Oil Companies International Marine Forum (OCIMF) recommendations, the generally accepted standard. Both gusting and constant winds can be modeled. For high wind velocities, gusting winds are more representative and tend induce dynamic response in vessels. For this study gusting winds were applied in conjunction with passing ship forces. The nonlinear mooring line stretch characteristics are based on actual mooring lines and tails. The geometry of the berth mooring points and the vessel fairleads can be modeled exactly.

Passing ship forces are evaluated by simulating the mooring response to the imposed forces. The forces in the mooring lines must remain less than the safe working load (55% MBL per OCIMF) for the mooring to be categorized as safe for the passing scenario. Manifold motions are also reported for use in specifying loading arm envelopes.

5.1 Mooring Simulations, VLCC

The initially examined scenario was the post-panamax containership passing the berthed VLCC at 5 knots and a side-to-side distance of 180 feet. This scenario resulted in mooring line loads greater than the MBL of the mooring wires, therefore the following set of simulations (Table 6.1) was conducted to determine the minimum safe passing speed and distance. The critical water level for passing simulations is the minimum underkeel clearance, therefore all simulations were conducted at Mean Lower Low Water (MLLW).

Table 5.1. Passing Simulations Matrix, VLCC

	Passing Speed (knots)	Passing Distance (feet)	Number of Mooring Lines	VLCC Draft (feet)
Case A	5 knots	180 feet	12	71.8
Case B	4 knots	180 feet	12	71.8
Case C	5 knots	600 feet	12	71.8
Case D	4 knots	600 feet	12	71.8
Case E	4 knots	500 feet	12	71.8
Case F	4 knots	400 feet	12	71.8
Case G	4 knots	300 feet	12	71.8
Case H	3 knots	180 feet	12	71.8
Case I	5 knots	180 feet	14	71.8
Case J	5 knots	180 feet	16	71.8
Case K	5 knots	180 feet	18	71.8
Case L	4 knots	180 feet	12	50.0
Case M	4 knots	600 feet	12	50.0

Figures 5.1 to 5.13 illustrate the results of Cases A-M. For each case the maximum load in each mooring line is reported relative to the SWL and MBL. In addition, a plot of the manifold motion track in the horizontal plane is shown. Table 5.2 presents the maximum mooring line load, surge distance, and sway distance for each case. Note that all simulations

are conducted at full draft (with the exception of Cases L and M). Forces induced by passing vessels increase with submergence of the vessel hull and decreased underkeel clearance; therefore the largest loads on the mooring will occur when the vessel is at full draft.

The results of the mooring simulation for Case A show that at the minimum passing distance of 180 feet and a speed of 5 knots, the loads in the forward spring lines exceed the MBL and loads in the forward breasting lines exceed SWL. Manifold excursions are over 2 meters in surge and 1.4 meters in sway. In order to manage the mooring loads, speed must be reduced or passing distance increased.

When speed is reduced at the same passing distance (Cases B and H) loads are reduced, but loads in the spring lines are still greater than SWL. Increasing passing distance to 600 feet while maintaining 5 knots speed (Case C) reduces loads to SWL.

Reducing speed to 4 knots at distances of 600, 500, 400, and 300 feet (Cases D-G), keeps line loads well below SWL and manifold motions to less than one meter.

Cases I-K re-evaluate Case A with increase number of mooring lines (14, 16, and 18, respectively). All three cases exceed the SWL of the mooring lines. Case 18 is marginal, with loads just exceeding SWL in one line. While deploying more lines improves performance, 5-knots speed remains unsafe at the minimum distance.

Case L and M show the influence of the hull displacement and underkeel clearance. By reducing draft to 50 feet, loads are reduced to well below SWL (compare Case L to Case B). When the passing distance is increase to 600-feet, loads and motions are negligible at 50-foot draft.

The analysis shows that for moored VLCCs, it is important that speed and distance restrictions are established. It is recommended that passing vessels be limited to 4 knots or less and that a minimum passing distance of 300 feet be maintained (Case G). Lines should be heaved in to a pretension of approximately 10% MBL and the maximum practicable number of lines should be deployed.

Table 5.2 VLCC Mooring Results, Line Loads and Manifold Motions

	Maximum Line Load (mt)	Acceptable Load	Surge		Sway	
			Max (ft)	Min (ft)	Max (ft)	Min (ft)
Case A	123.4	No	6.9	-3.6	4.6	-0.3
Case B	67.6	No	4.6	-1.6	3.0	-0.3
Case C	64.2	No	4.6	-2.3	2.6	-0.3
Case D	31.1	Yes	2.3	-1.0	1.0	-0.0
Case E	31.1	Yes	2.3	-1.0	1.0	-0.0
Case F	27.6	Yes	2.0	-0.7	0.7	-0.0
Case G	35.6	Yes	2.6	-1.0	1.6	-0.3
Case H	27.1	Yes	2.0	-0.7	1.0	-0.0
Case I	86.4	No	4.0	-1.4	4.8	-0.4
Case J	85.2	No	2.8	-1.2	4.8	-0.4
Case K	66.3	No	3.0	-1.2	4.0	-0.4
Case L	20.5	Yes	1.2	-0.7	0.0	-0.1
Case M	11.8	Yes	0.0	0.0	0.0	-0.1

5.2 Passing Ship with Panamax, Aframax, and Suezmax Vessels

Additional simulations were conducted with the Panamax, Aframax, and Suezmax vessels at berth. Results of these cases are shown in Figures 5.14 through 5.16. All three vessels were simulated under Case A conditions: 5-knots passing, 180-ft separation, full draft. Due to the reduced displacement of the vessel and the increased underkeel clearance, loads were greatly reduced. Line loads were less than SWL and motions were minimal for all three vessels.

5.3 VLCC Passing Ship with Wind

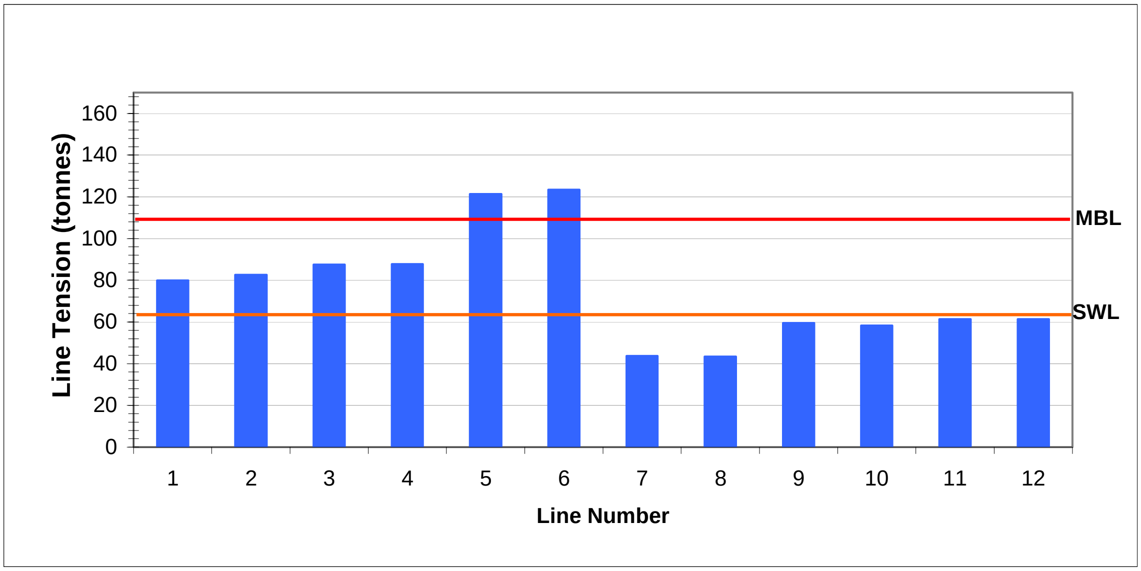
Additional dynamic mooring analyses were prepared for the VLLC Case G with a 30-knot gusting wind applied to the vessel. This case was examined in order to determine if the vessel could be safely moored under the combined effects of applied wind and passing vessel loads, 30 knots being the assumed limit for safe navigation within the harbor. An unsteady wind was simulated using an Ochi-Shin gusting spectrum. Wind was examined from all directions. Winds from directly abeam pushing the vessel off-berth were found to result in the highest loads, with mooring line factors of safety just below SWL (see Figure 5.17). Maximum manifold excursions are less than 1 meter in surge and 0.5 meters in sway. The model predicts it should be possible to pass at 4 knots with a 30-knot wind, provided that a distance of 300 feet is maintained.

Figure 5.1 Case A Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Mooring Line Loads



Manifold Motion

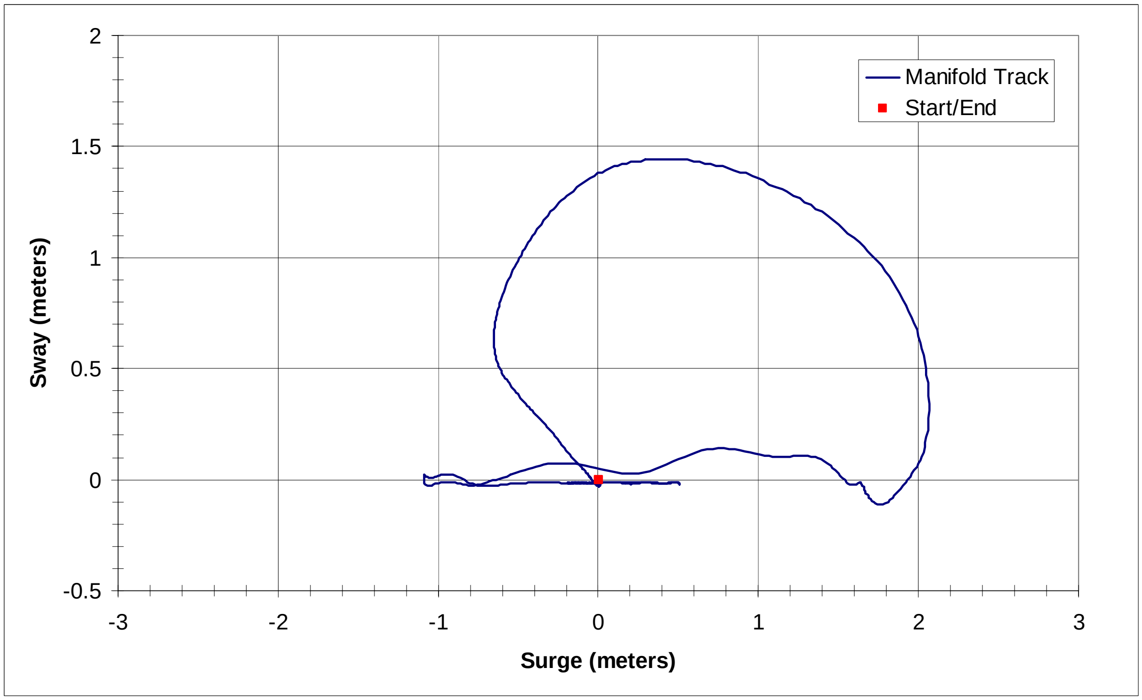
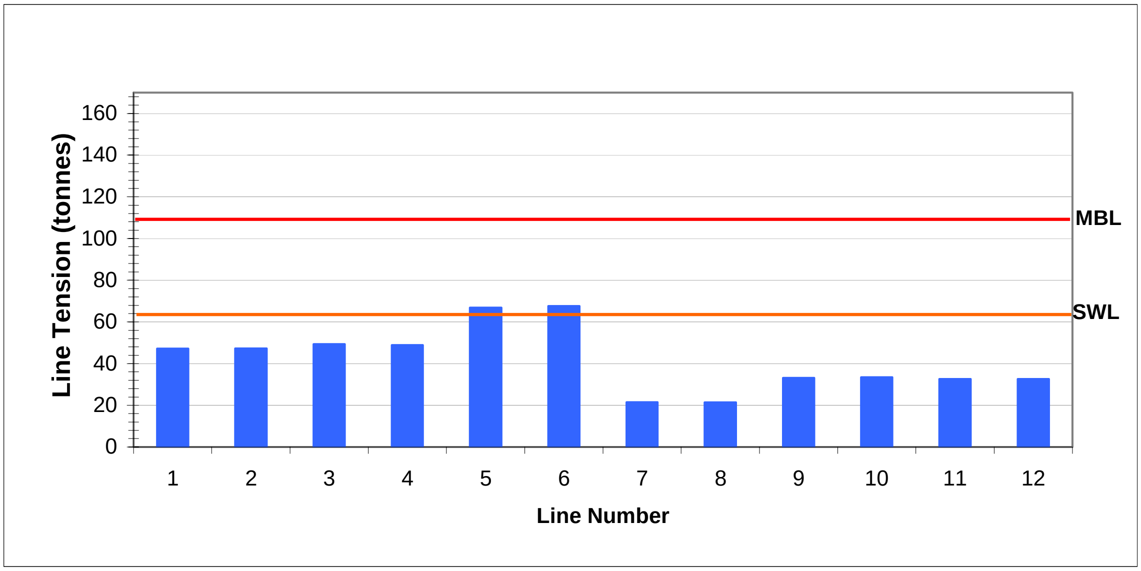


Figure 5.2 Case B Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 180 feet

Mooring Line Loads



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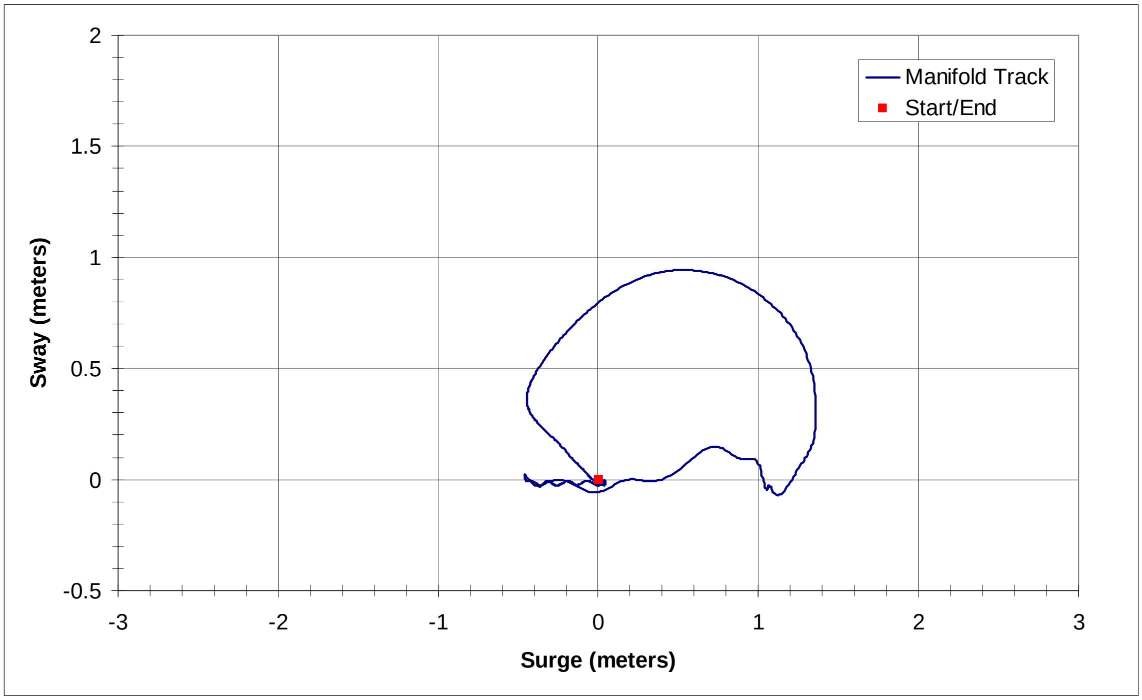
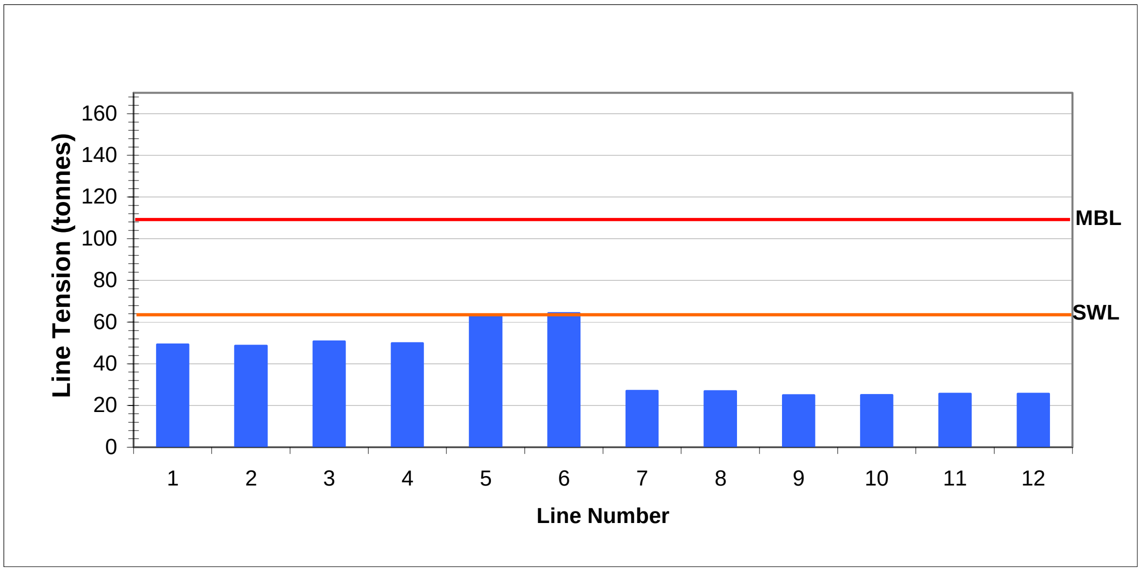


Figure 5.3 Case C Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 600 feet

Mooring Line Loads



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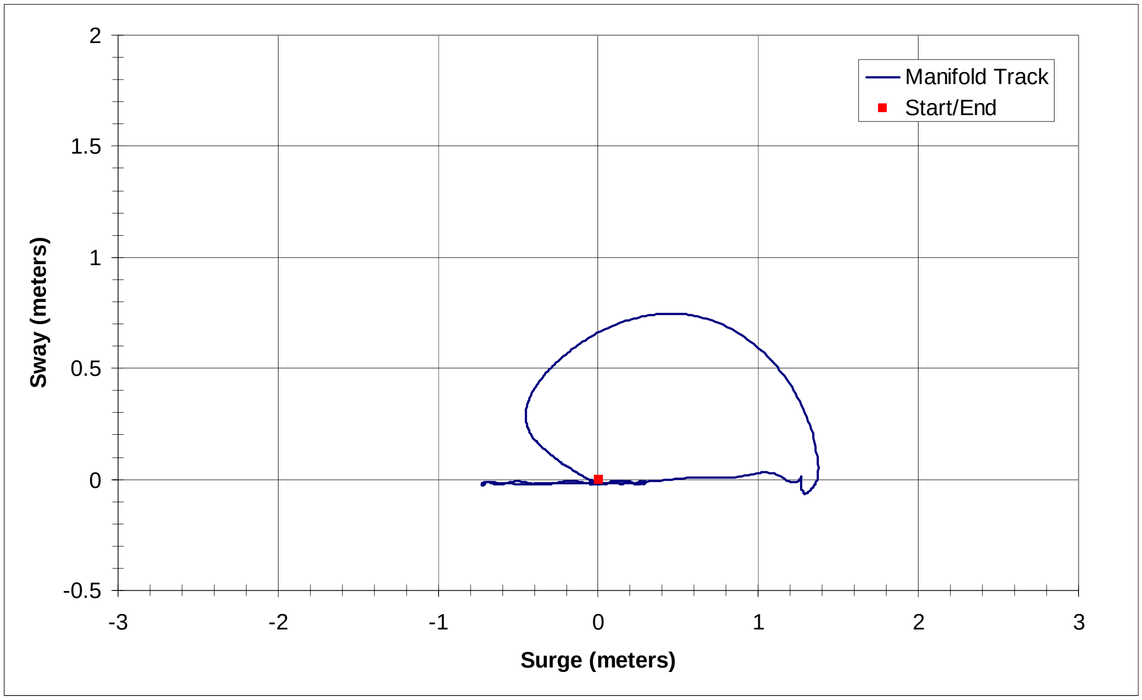
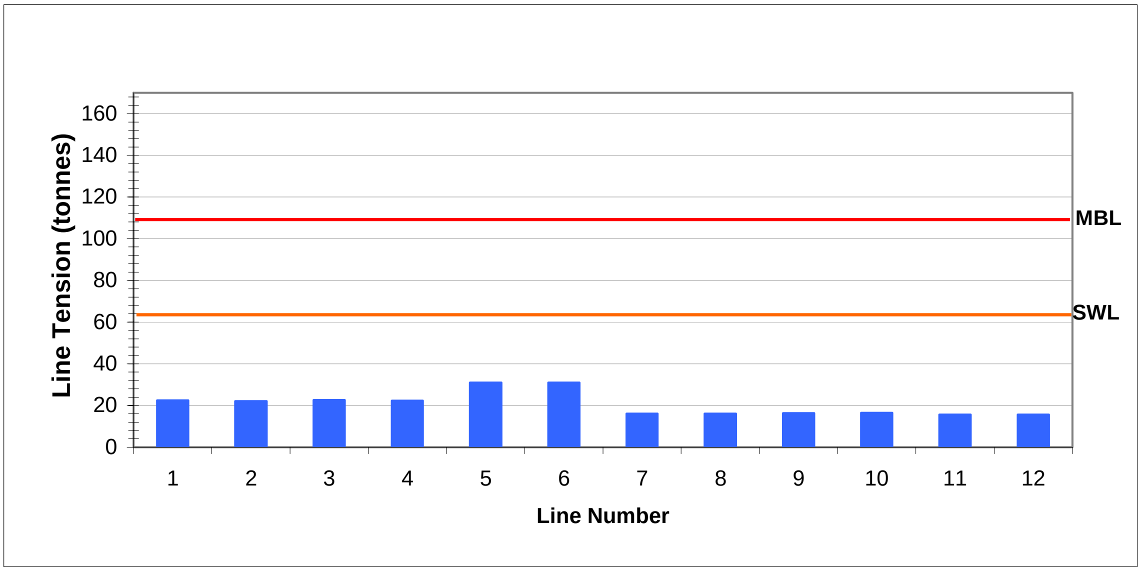


Figure 5.4 Case D Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 600 feet

Mooring Line Loads



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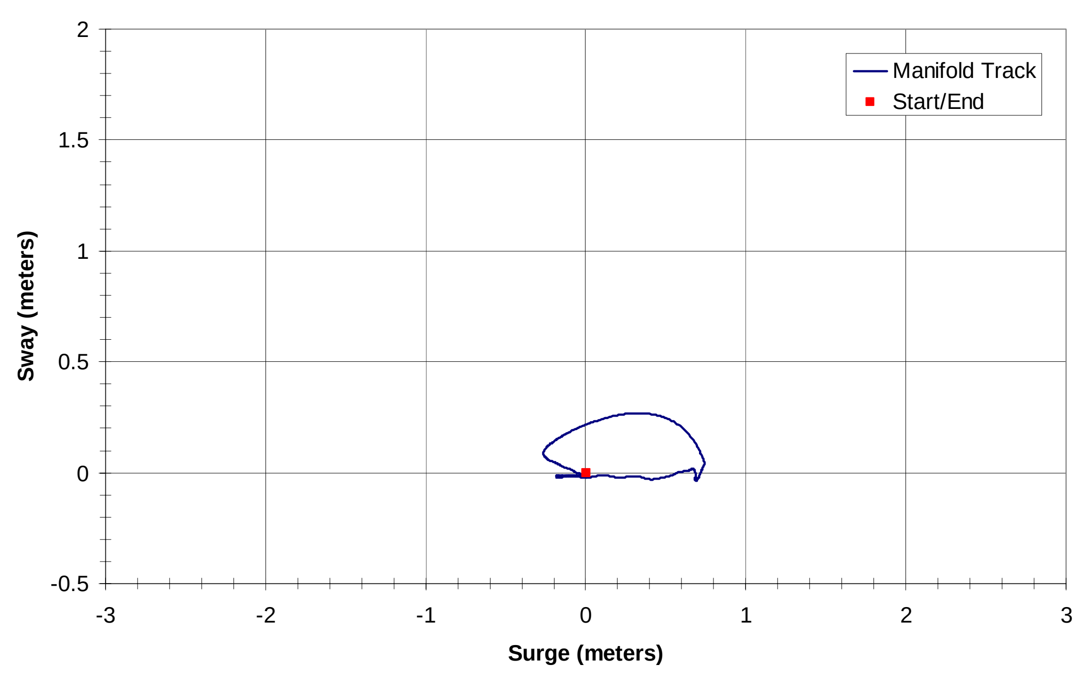
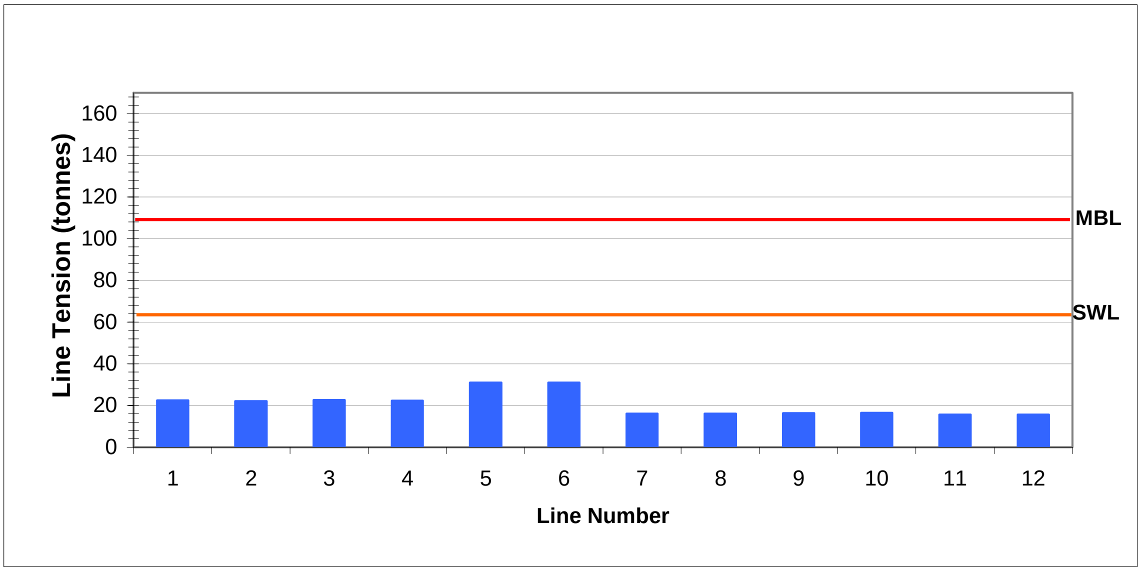


Figure 5.5 Case E Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 500 feet

Mooring Line Loads



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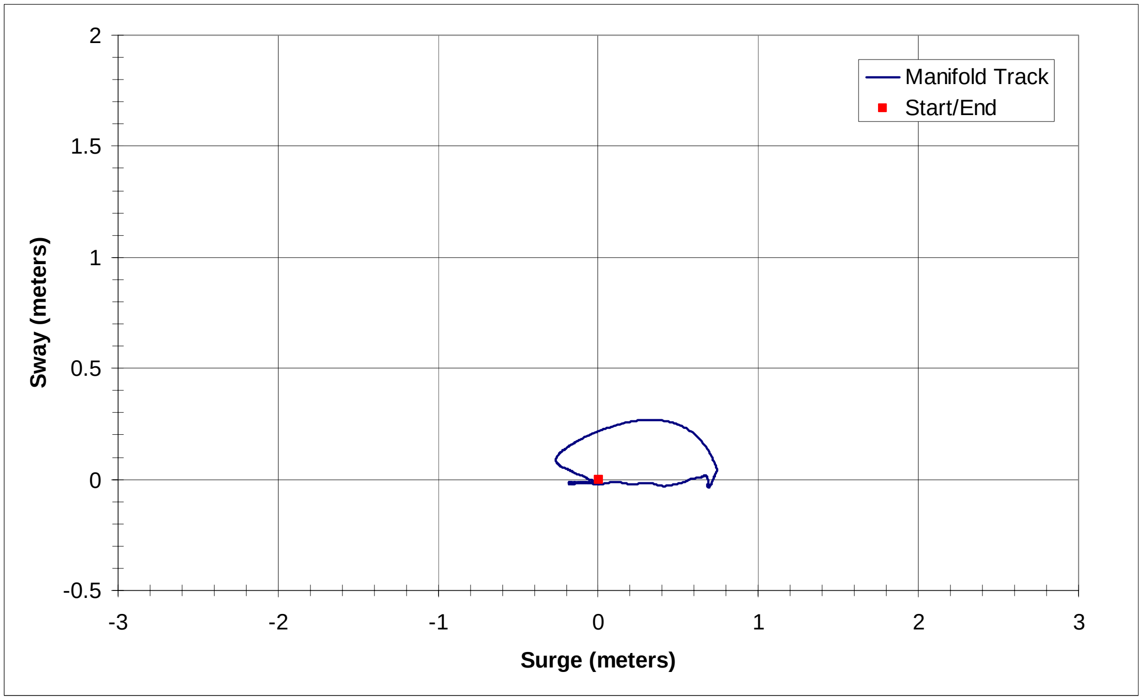
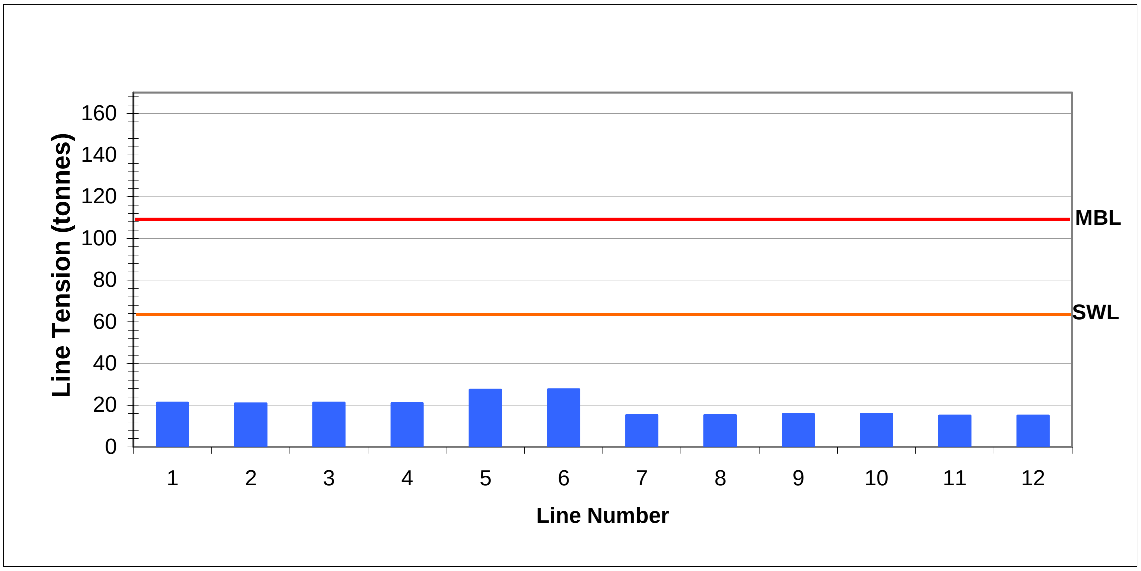


Figure 5.6 Case F Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 400 feet

Mooring Line Loads



Manifold Motion

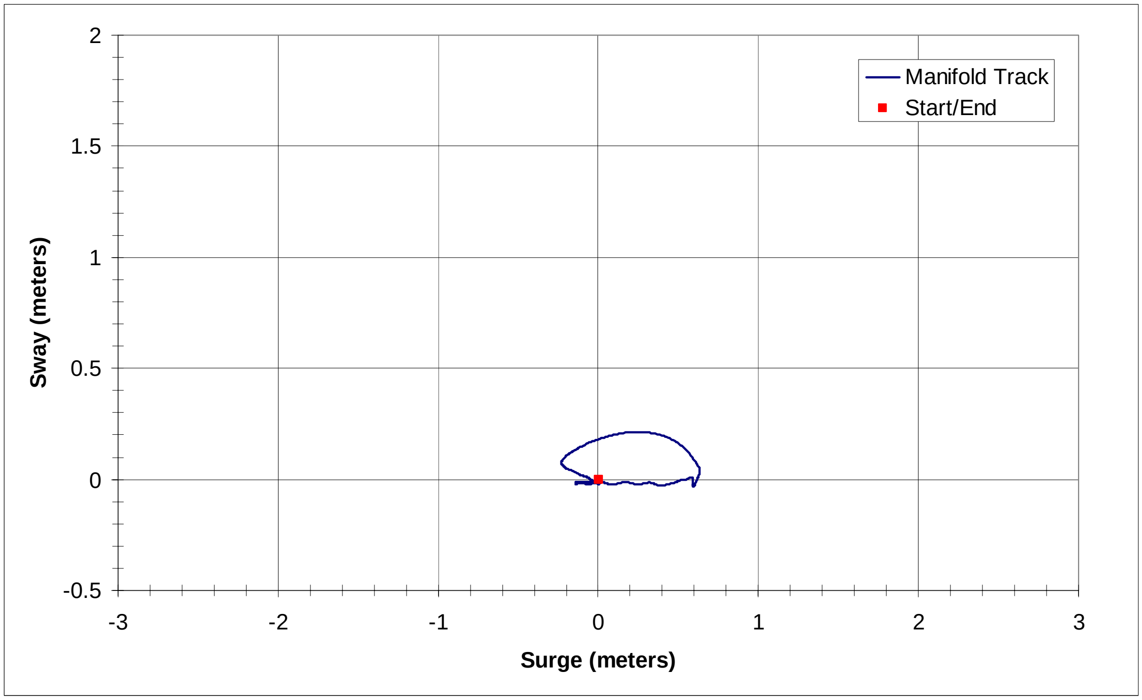
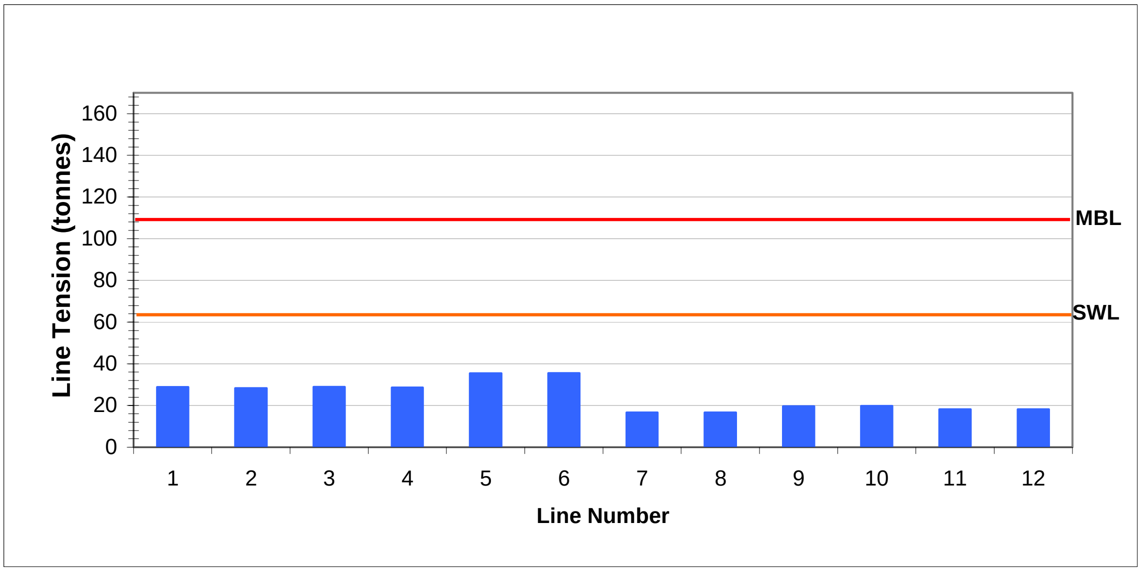


Figure 5.7 Case G Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 300 feet

Mooring Line Loads



Manifold Motion

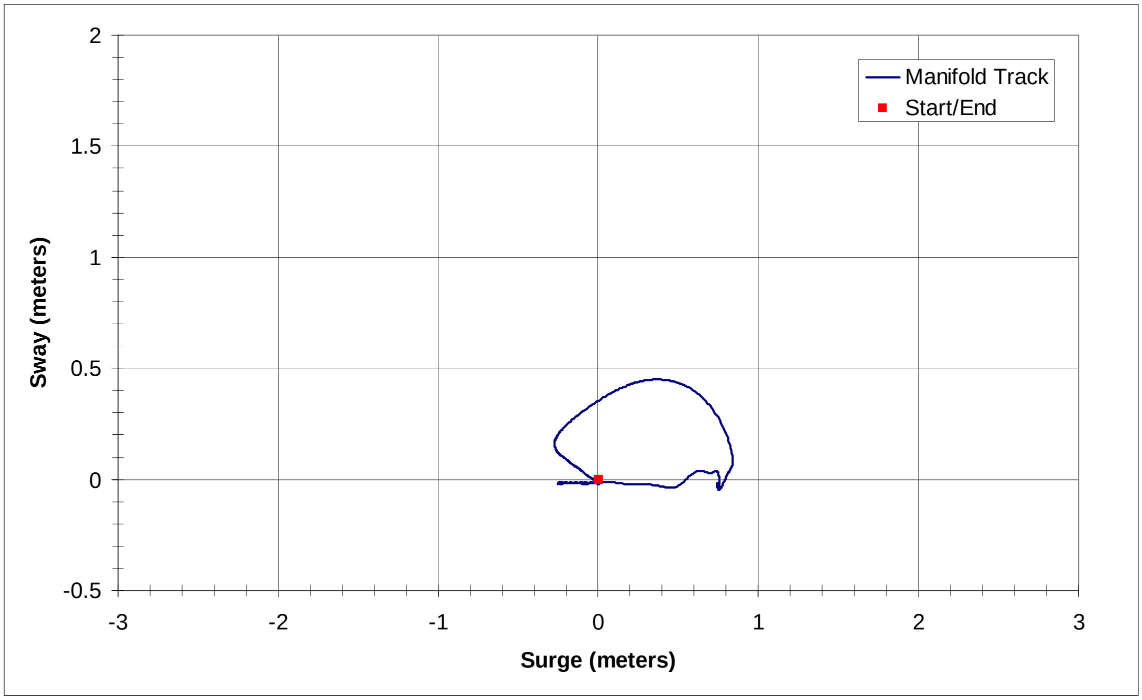
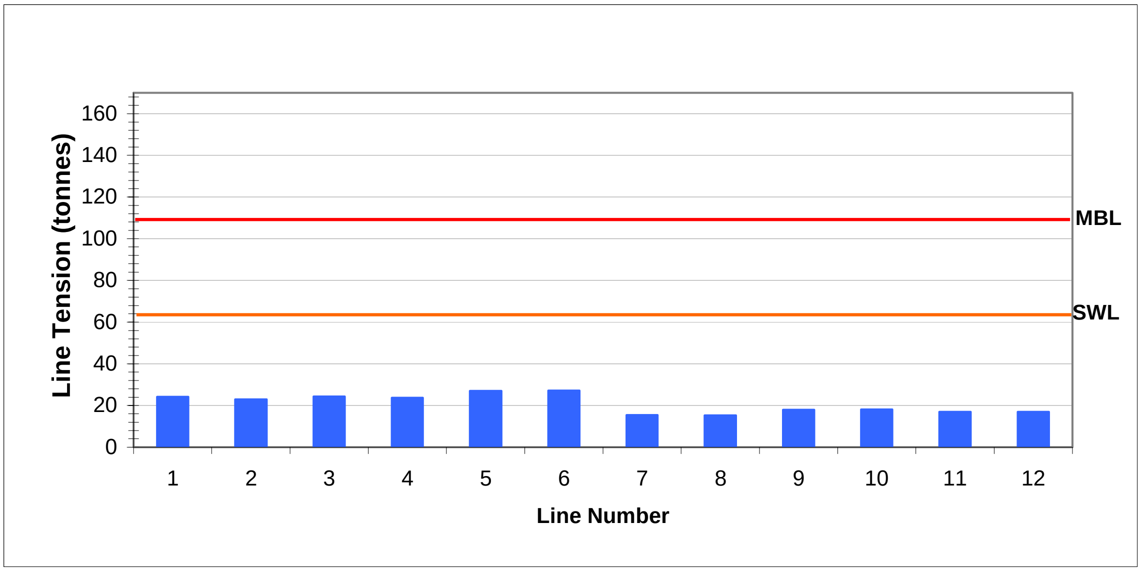


Figure 5.8 Case H Results

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 3knots
Separation Distance 180 feet

Mooring Line Loads



Manifold Motion

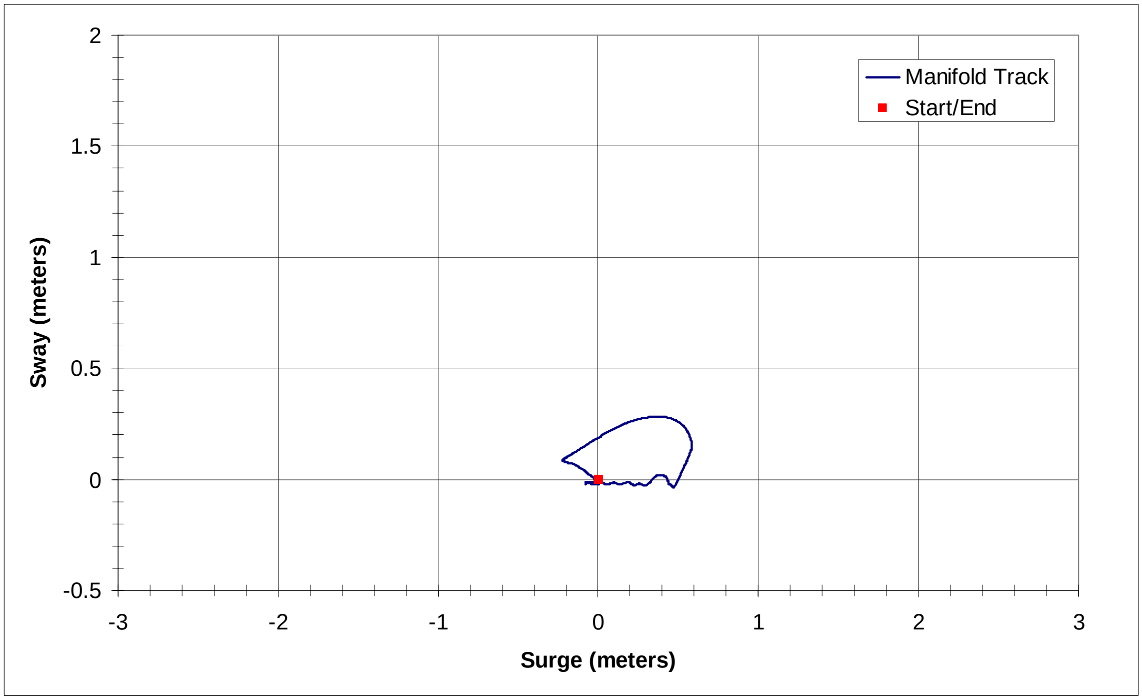
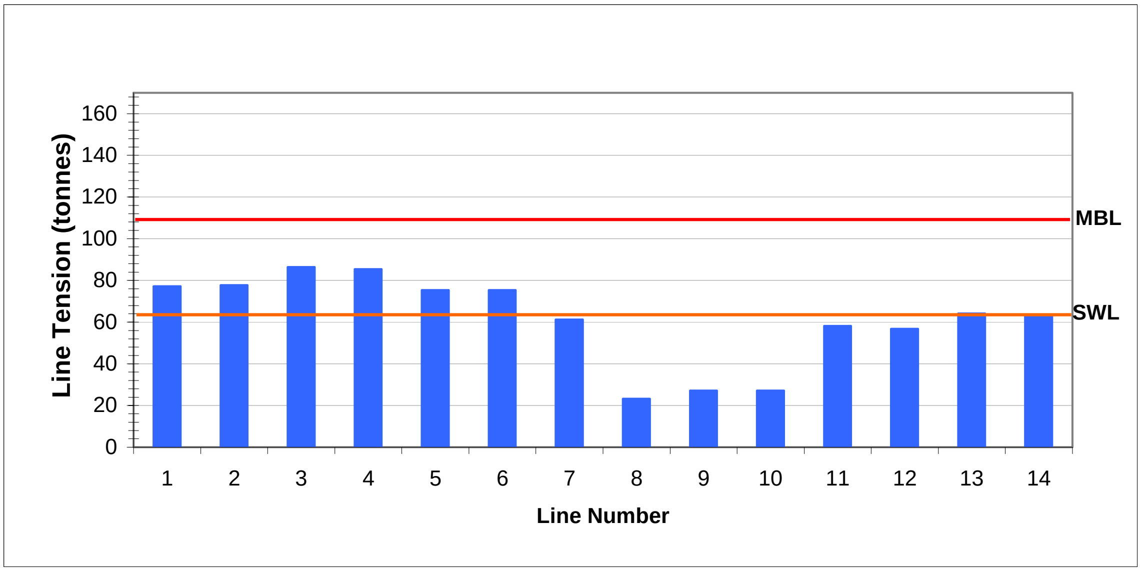


Figure 5.9 Case I Results

Moored VLCC at Full Draft
14 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Maximum Mooring Line Loads, metric tonnes



Manifold Motion

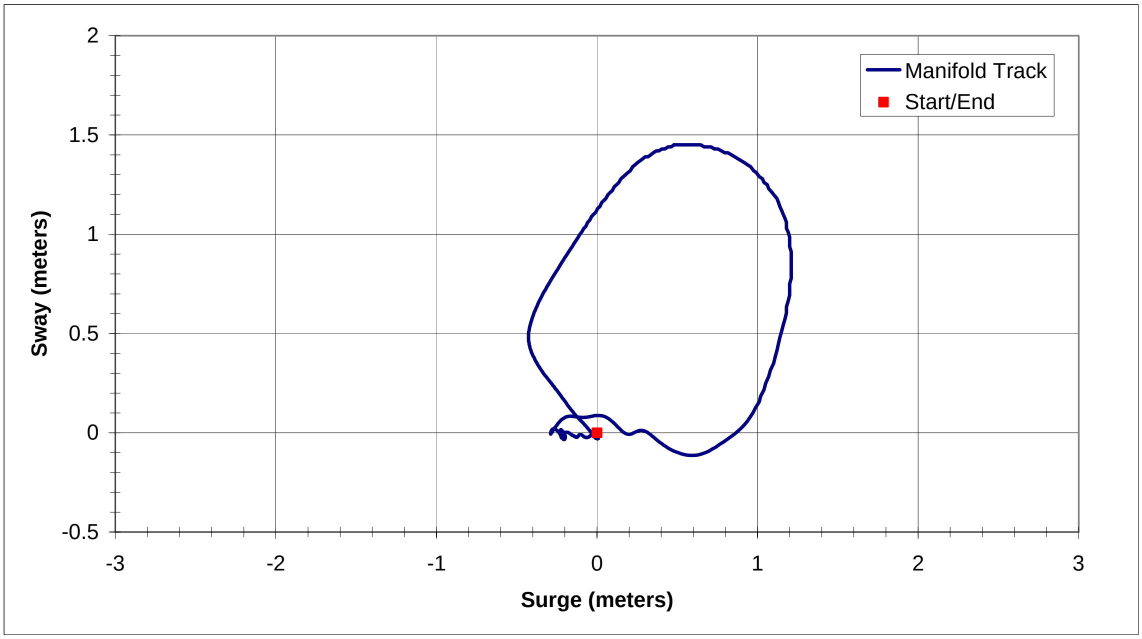
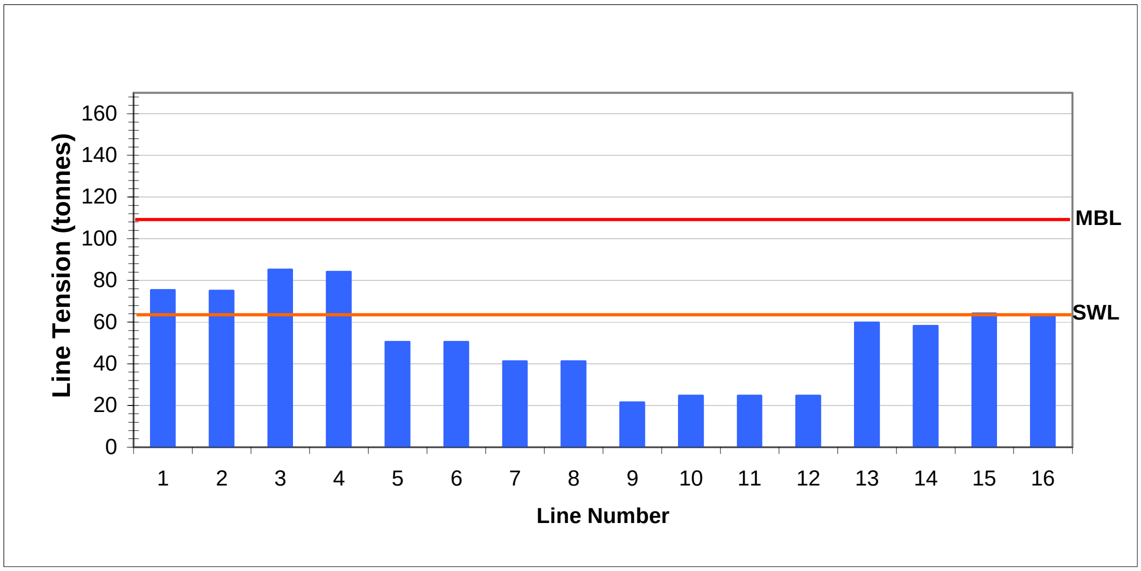


Figure 5.10 Case J Results

Moored VLCC at Full Draft
16 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Maximum Mooring Line Loads, metric tonnes



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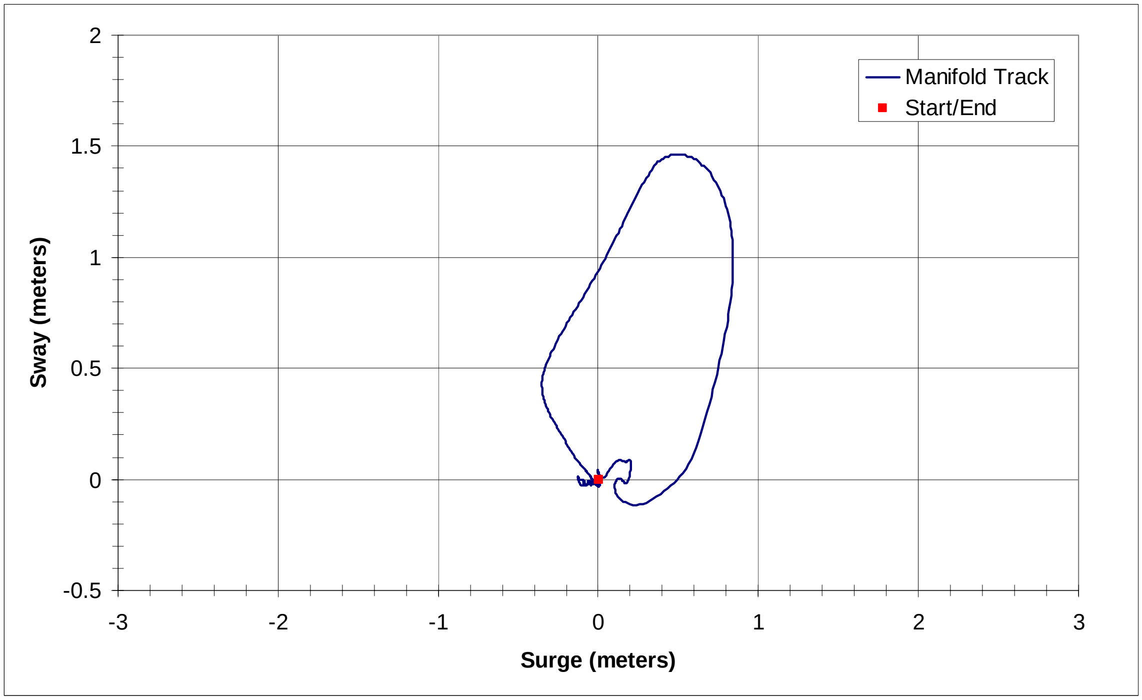
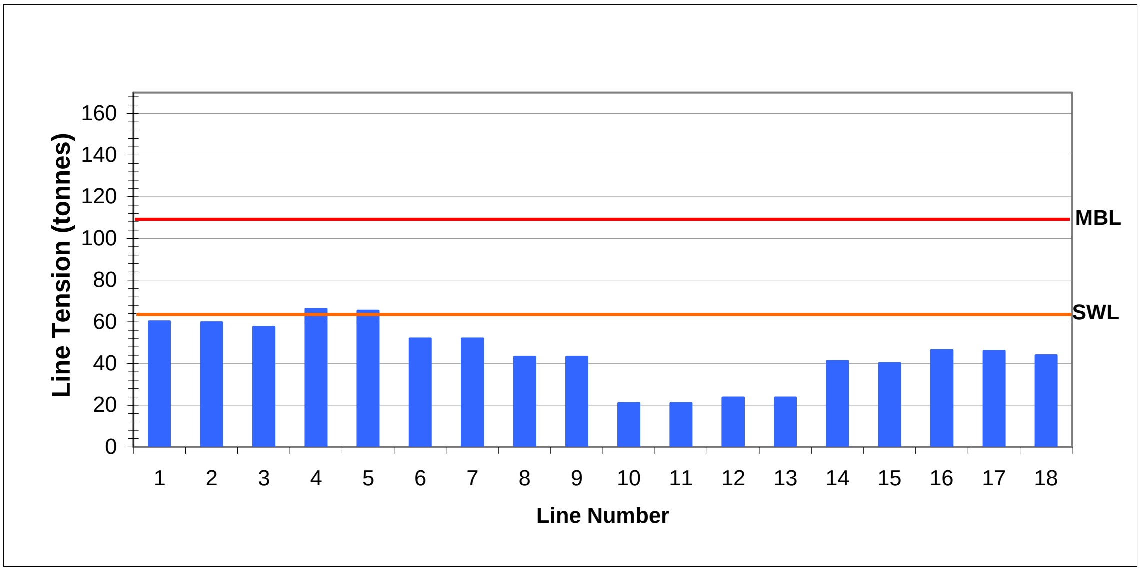


Figure 5.11 Case K Results

Moored VLCC at Full Draft
18 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Maximum Mooring Line Loads, metric tonnes



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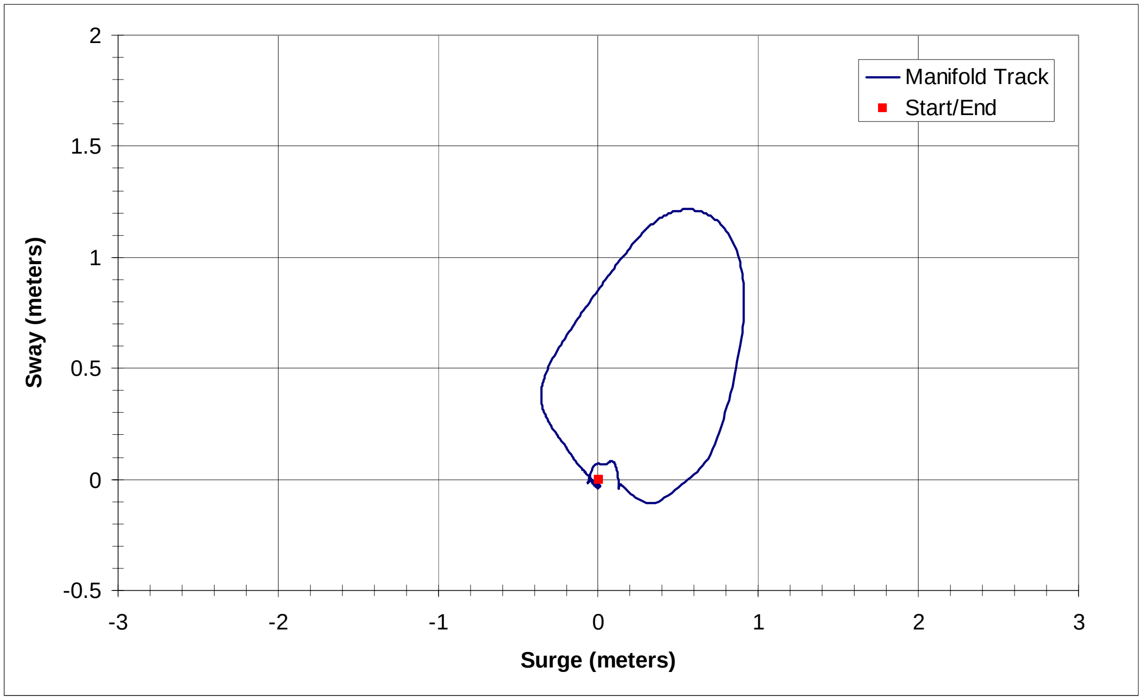
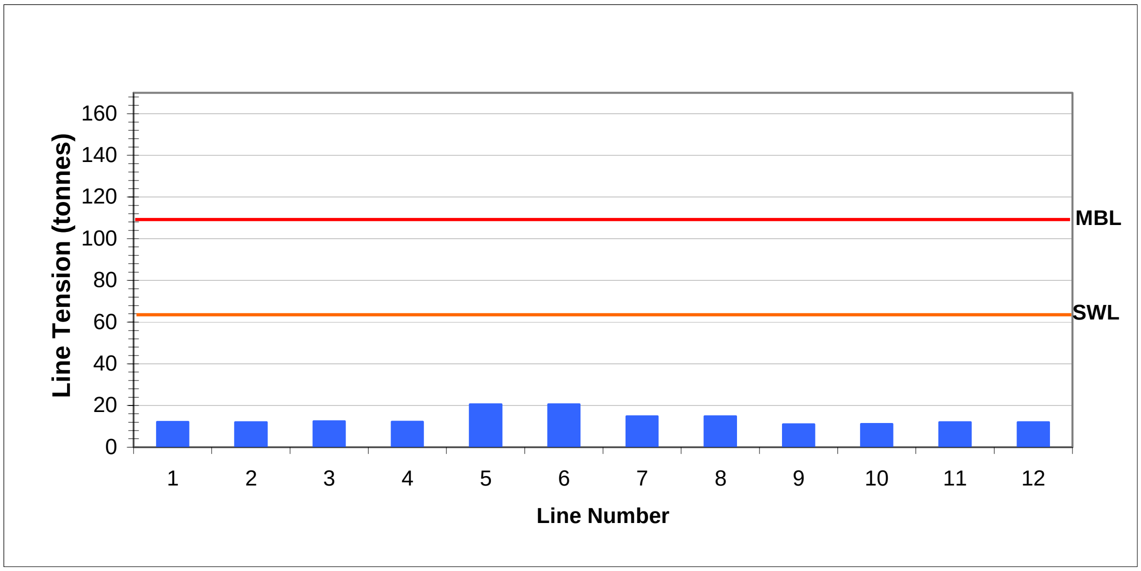


Figure 5.12 Case L Results

Moored VLCC at 50-foot Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 180 feet

Maximum Mooring Line Loads, metric tonnes



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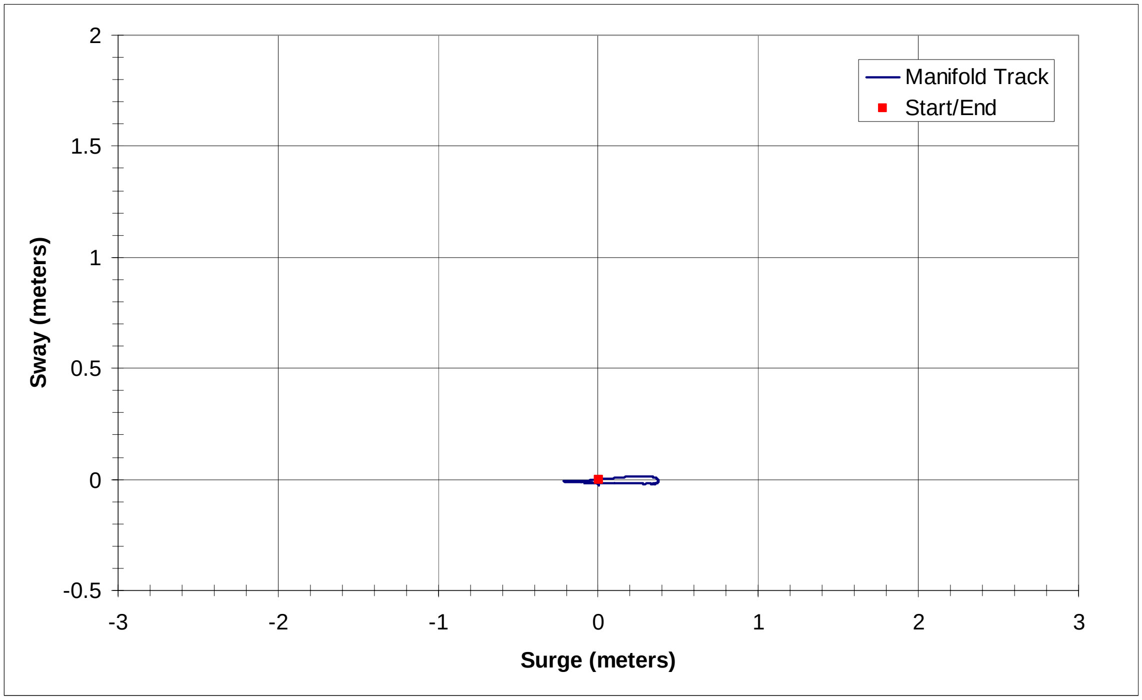
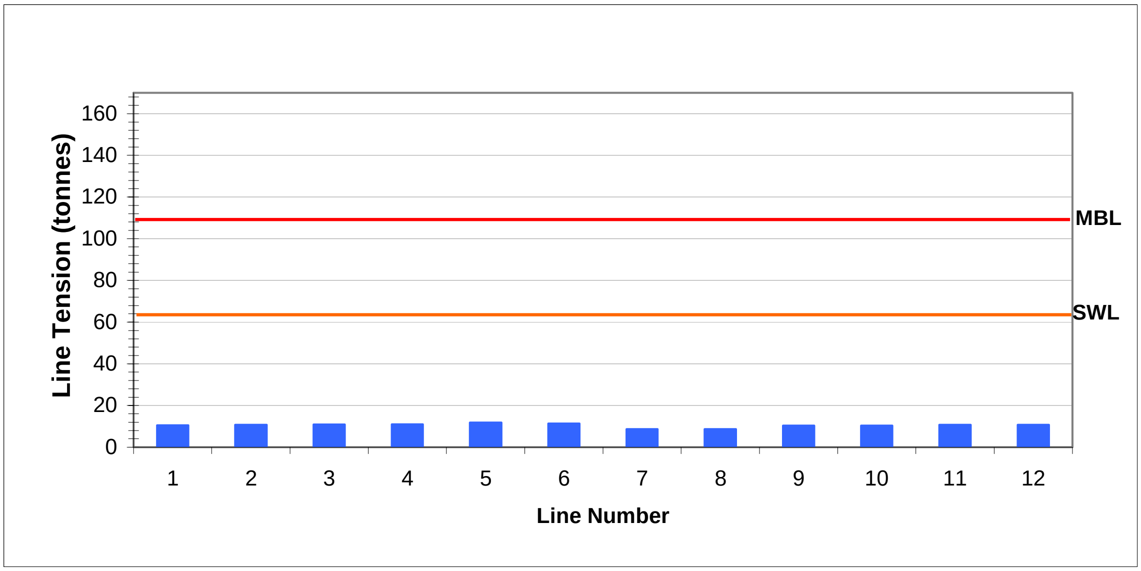


Figure 5.13 Case M Results

Moored VLCC at 50-foot Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 600 feet

Maximum Mooring Line Loads, metric tonnes



Manifold Motion

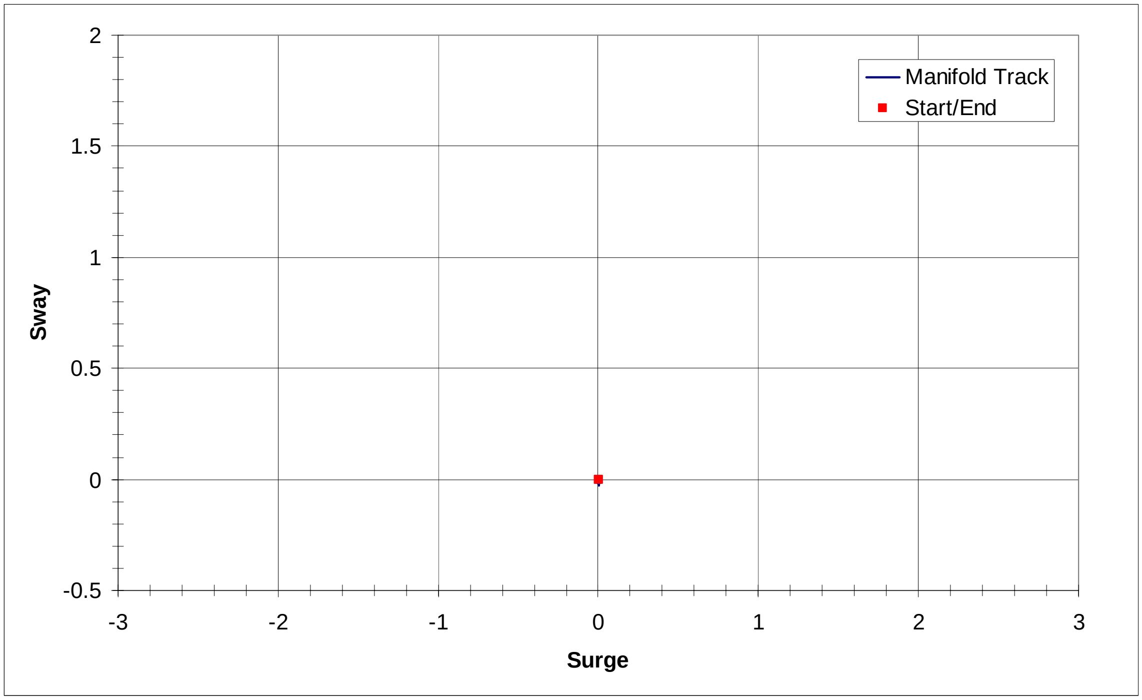
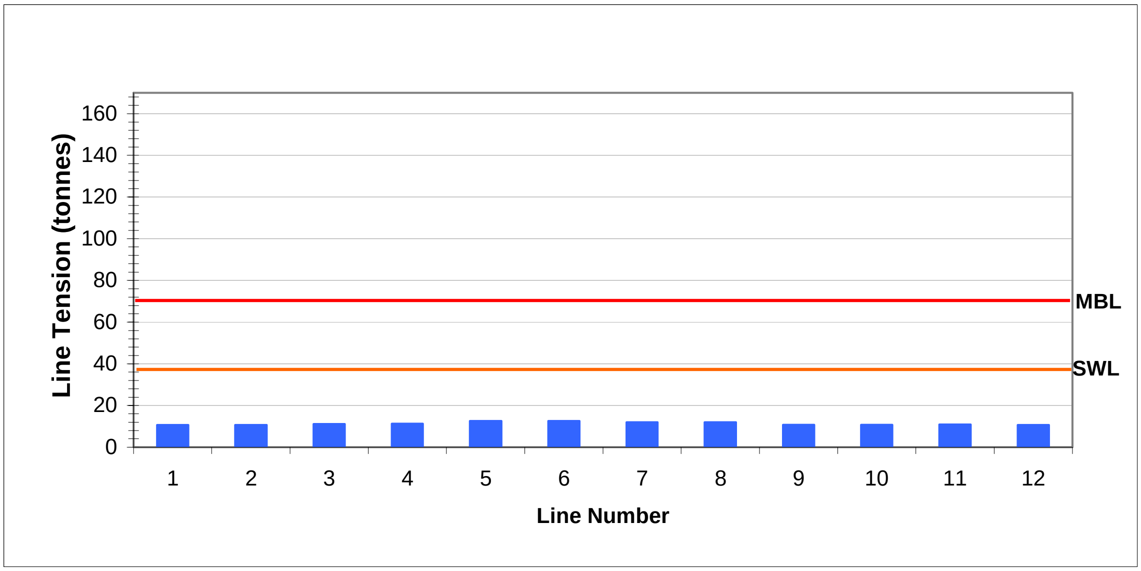


Figure 5.14 Case A, Panamax Tanker

Moored Panamax at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Mooring Line Loads



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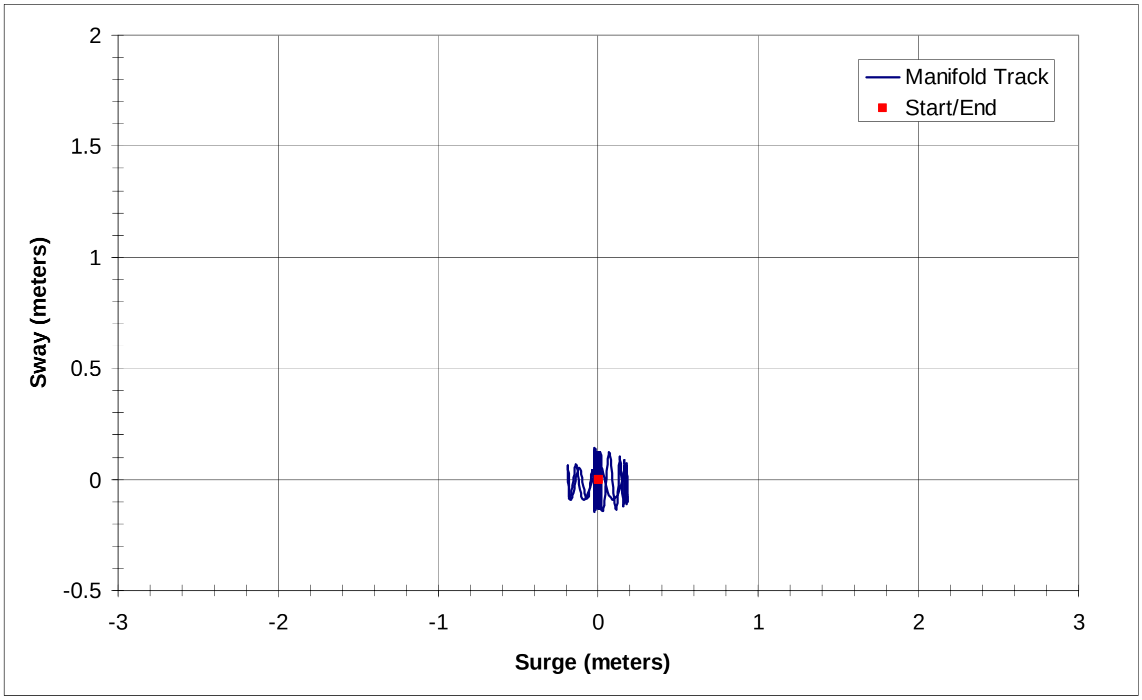
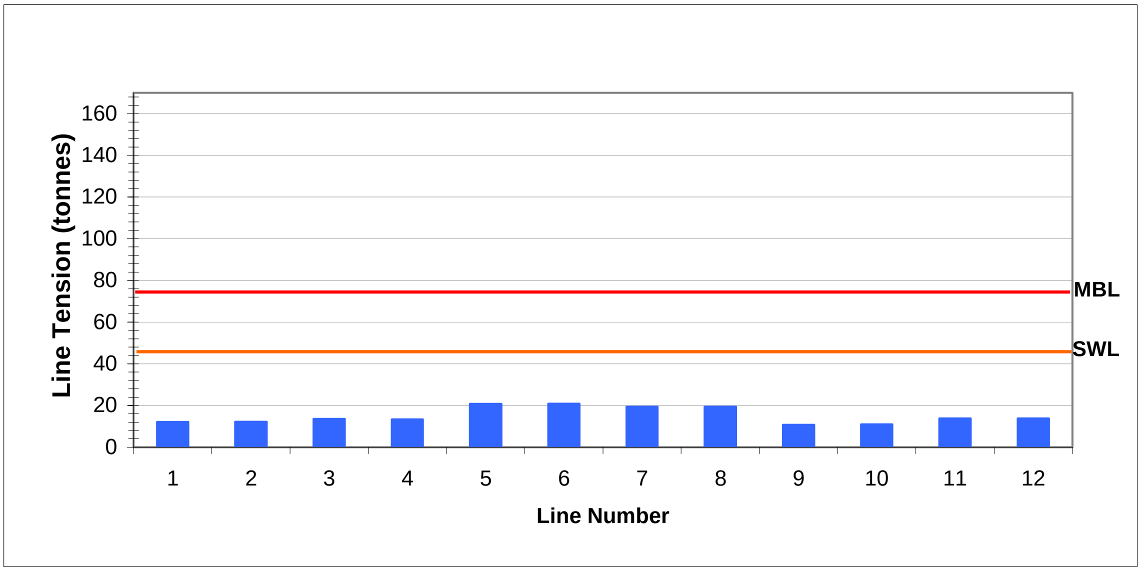


Figure 5.15 Case A, Aframax Tanker

Moored Aframax at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Mooring Line Loads



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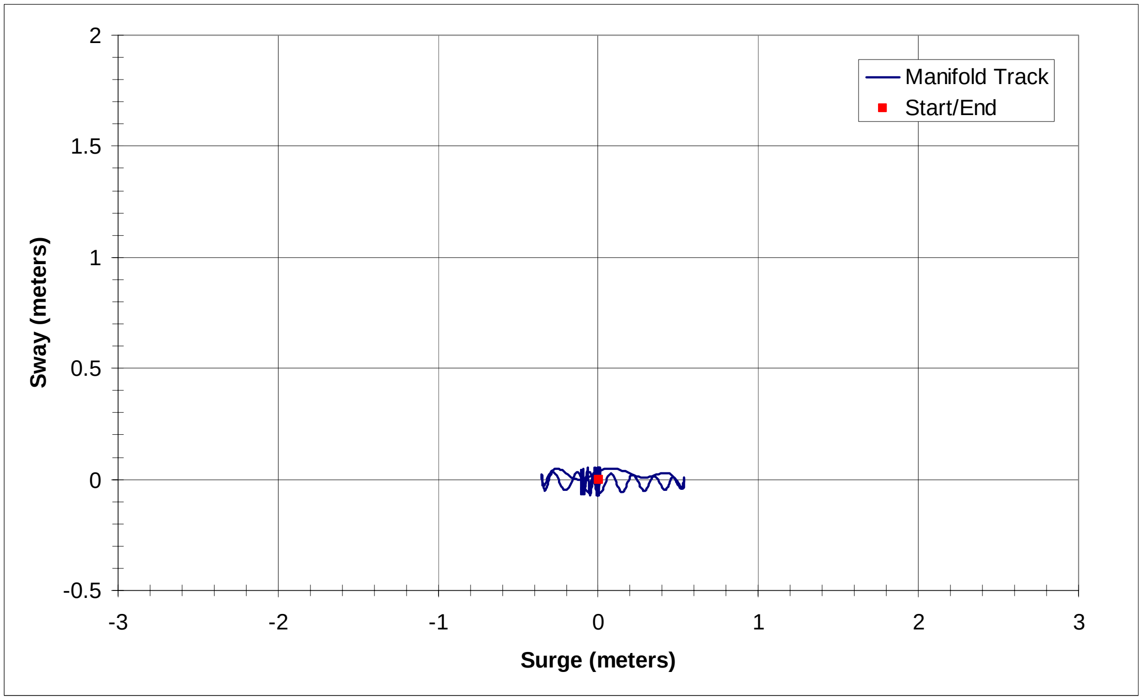
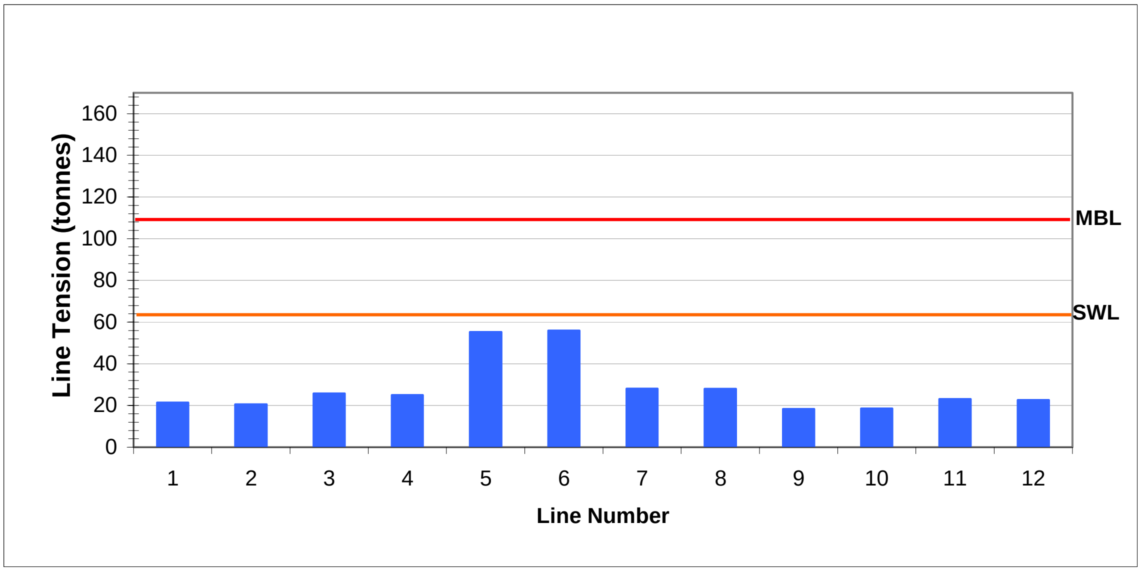


Figure 5.16 Case A, Suezmax Tanker

Moored Suezmax at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 5knots
Separation Distance 180 feet

Mooring Line Loads



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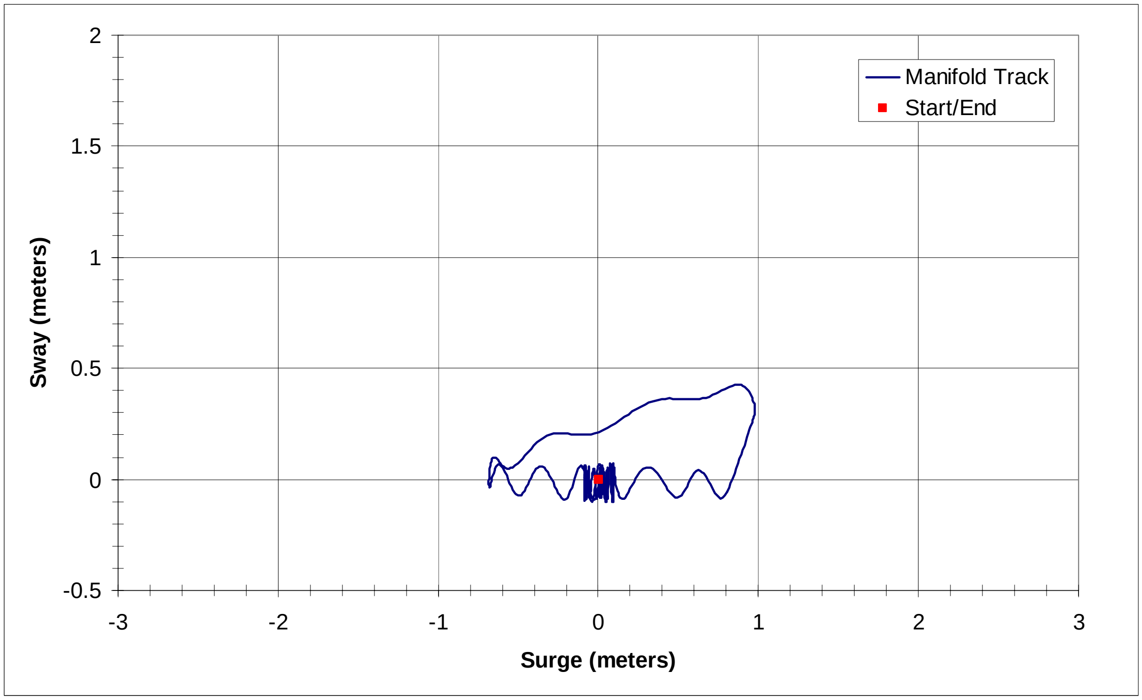
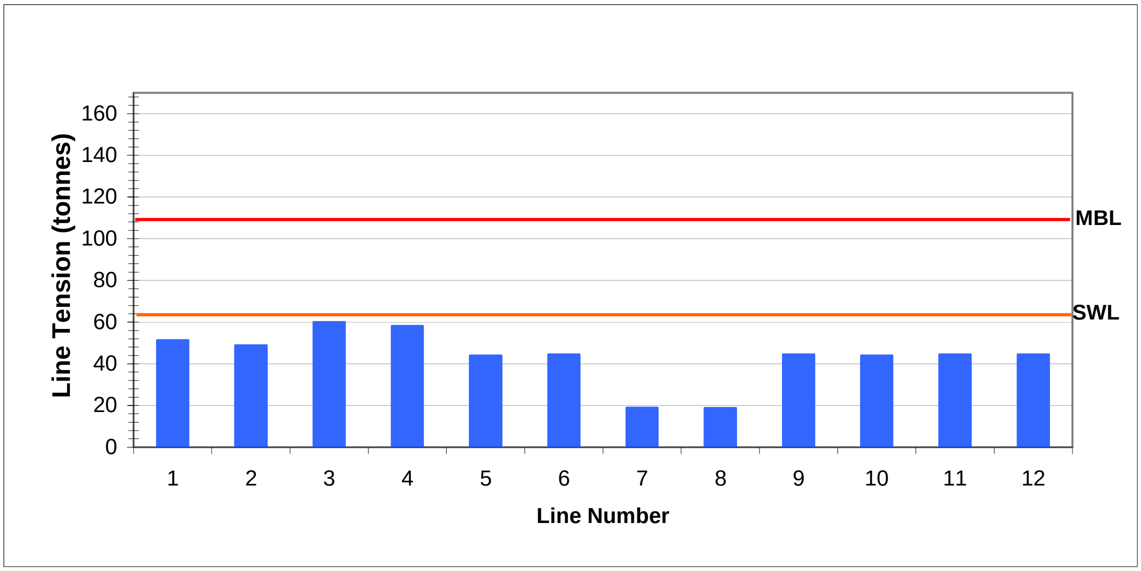


Figure 5.17 Case G, 30-knot Wind Beam-on to Vessel

Moored VLCC at Full Draft
12 Mooring Lines

Passing Post-Panamax Container Ship @ 4knots
Separation Distance 300 feet

Mooring Line Loads



6. SUMMARY AND CONCLUSIONS

This report summarizes detailed dynamic mooring analyses of the proposed tanker berth at Pier 400 as regards the vulnerability of the berth to the effects of passing ships. The analyses show that moored tankers (panamax to VLCC classes) and their mooring systems will be exposed to rather large passing ship forces. While large, these forces are manageable even for the large vessel size simultaneously exposed to a 30-knot wind, provided speed and distance restrictions are applied at the berth. Critical to the safe operation of these berths is the maintenance of pretension on all mooring lines. Lines should be heaved in to the highest achievable pretension and the maximum practical number of lines should be deployed. Low pretensions or slack lines could result in larger loads and motions than the vessel's mooring systems are equipped to handle. It is recommended that passing vessels be limited to a speed of 4 knots and a hull-to-hull passing distance of 300 feet or greater.

7. REFERENCES

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