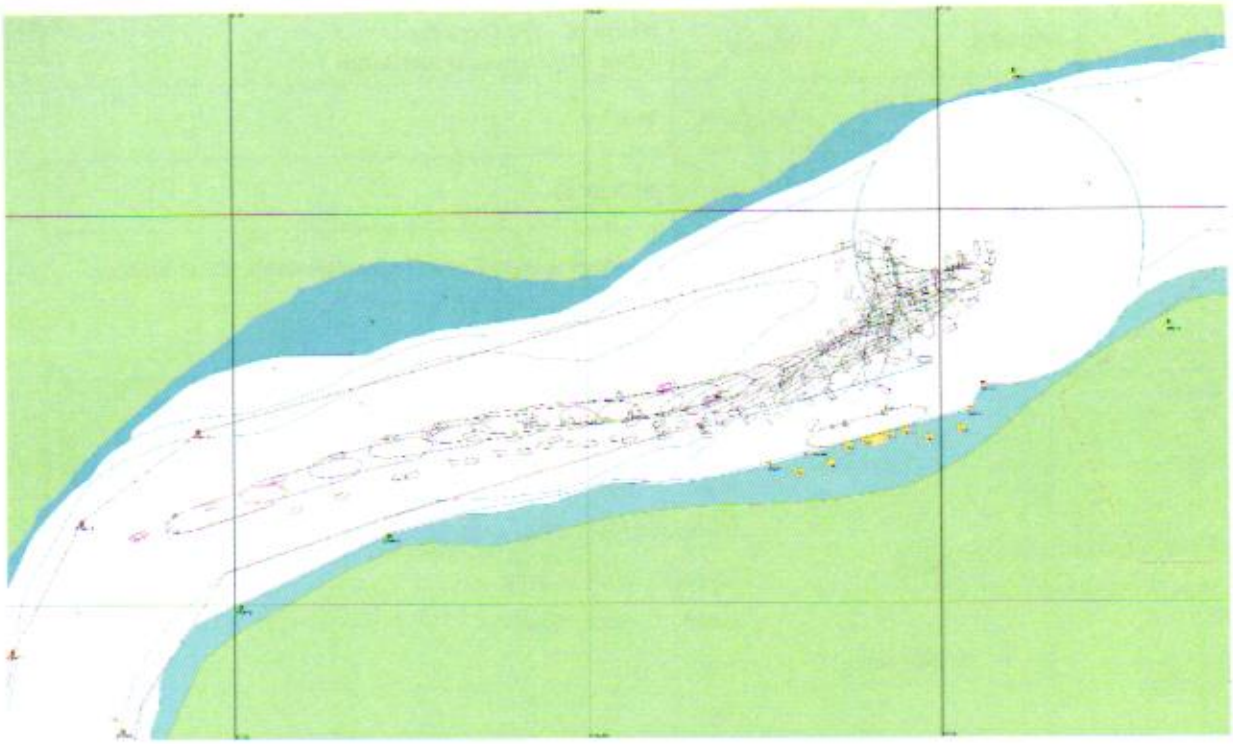
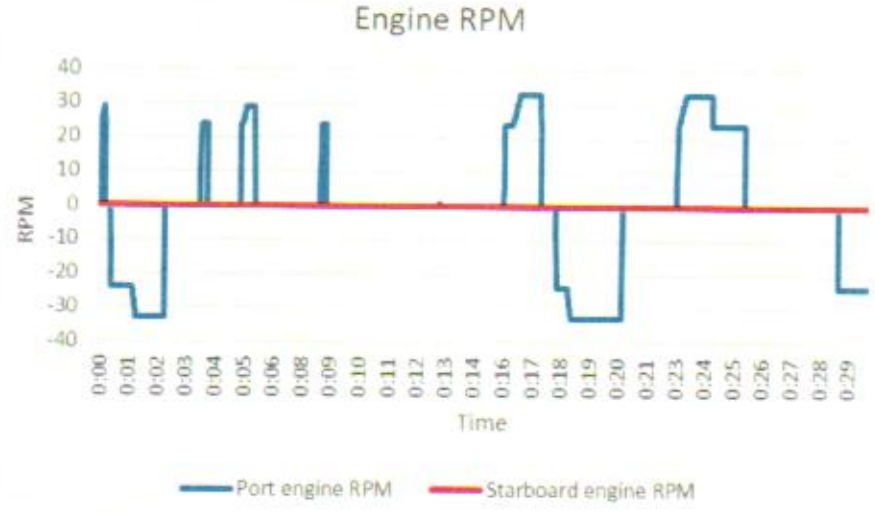
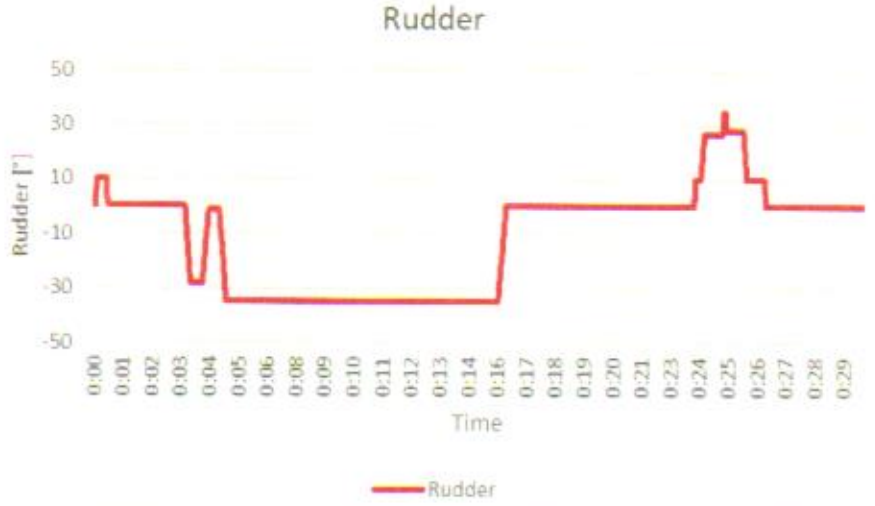
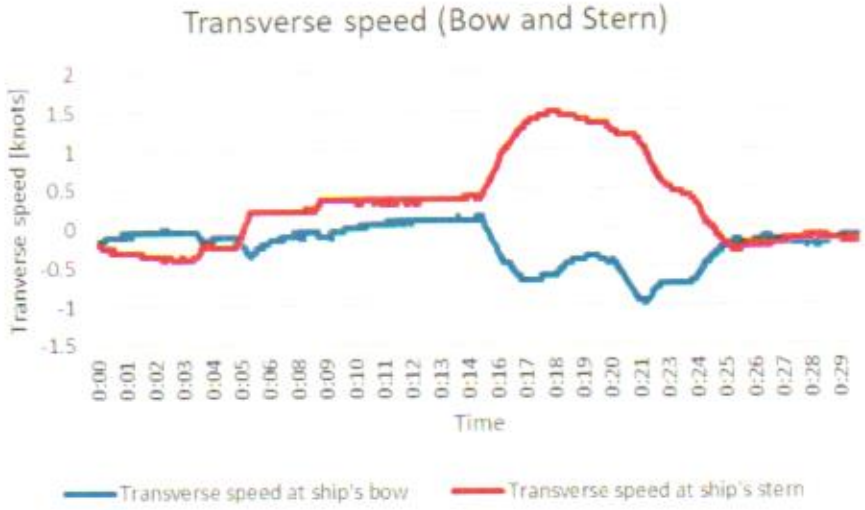
Date:	29/03/2019		Project:	Mitsubishi – JGC Corporation Tabeer LNG Terminal at Port Qasim	
Time start:	16:10		Time finish:	16:45	
Run n.	28		File name:	MTI2019_28	
Manouvre description:			Arrival with Moss 170k m³ vessel – Flood 1 hour before HAT & 253° at 10 knots		
Captain			Ian Simpson		
Vessel	Type	Q-Max	(345m – 53.8m – 266,000m3)		☐
		Q-Flex	(315m – 50.0m – 210,000m3)		☐
		Moss	(300m – 52.0m – 177,000m3)		☒
		Membrane	(274m – 43.3m – 130,000m3)		☐
	Condition	Loaded	(Draft: 11.55 m)		☒
		Ballast	(Draft: 9.50 m)		☐
	Thruster used	Yes			☐
		No			☒
Condition	Position	From buoys B1-B2 to Terminal			☐
		From Terminal to buoys B1-B2			☐
		From buoys B1-B2 to second bend			☐
		From second bend to Terminal			☒
	Manoeuvre	Arrival			☒
		Departure			☐
	Tugs	N.: 4 tugs			
Metocean	Current	Dir.: Flood	Speed: 1 hour before HAT		
	Wind	Dir.: 253°	Speed: 10 Kts		

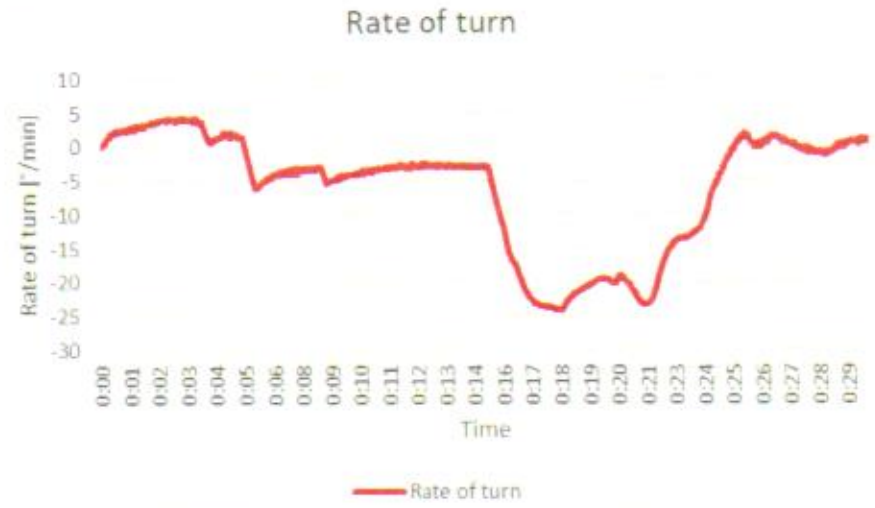
Note:
To investigate arrival and swing in typical environmental conditions with alternative swinging strategy. In addition, to investigate minimum space required for swinging this vessel in non- extreme conditions.
Sufficient space exists for vessel to safely swing adjacent to the terminal without provision of an additional turning circle.

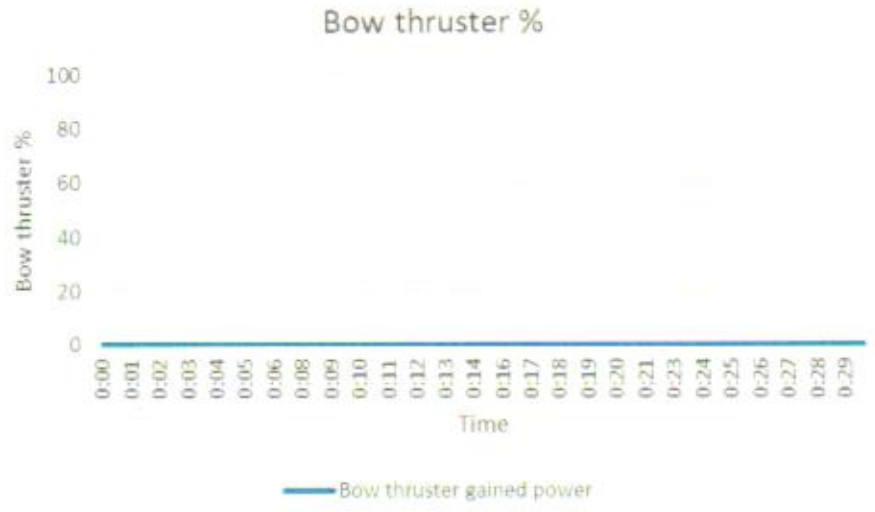


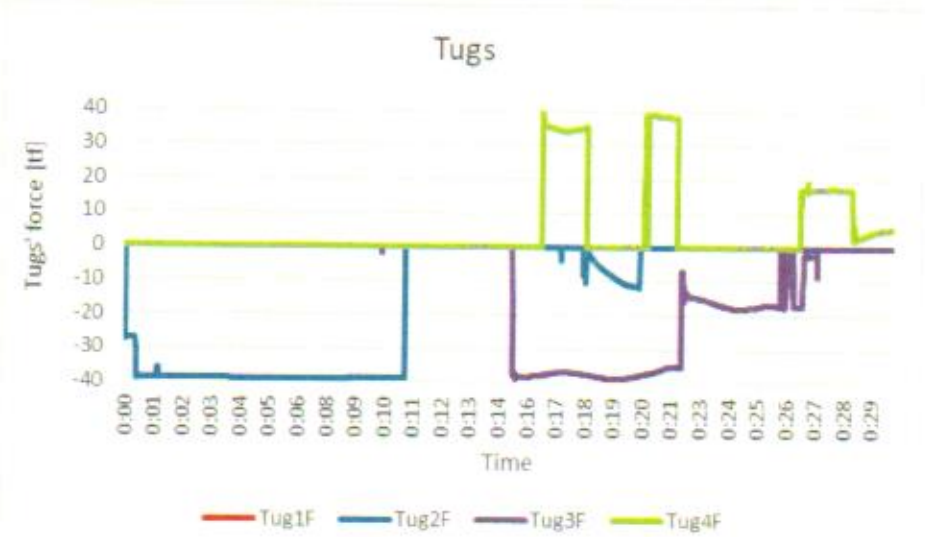


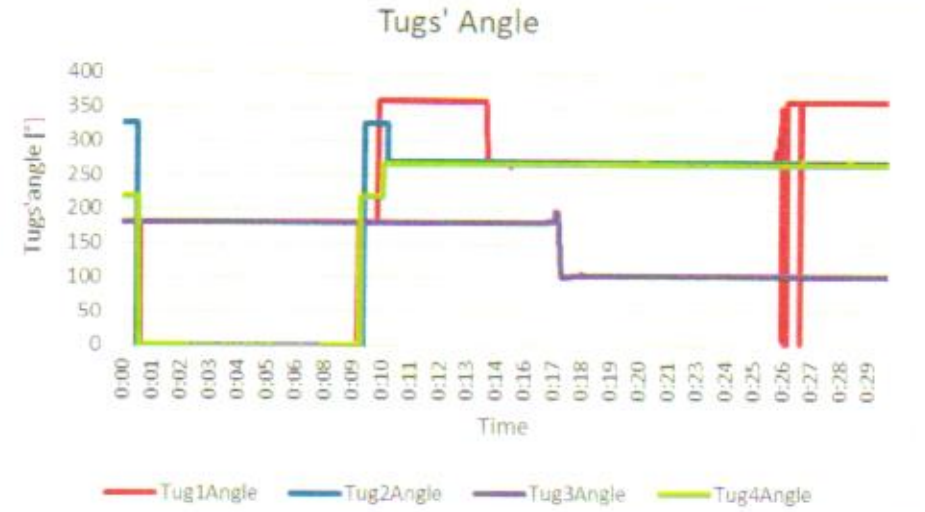








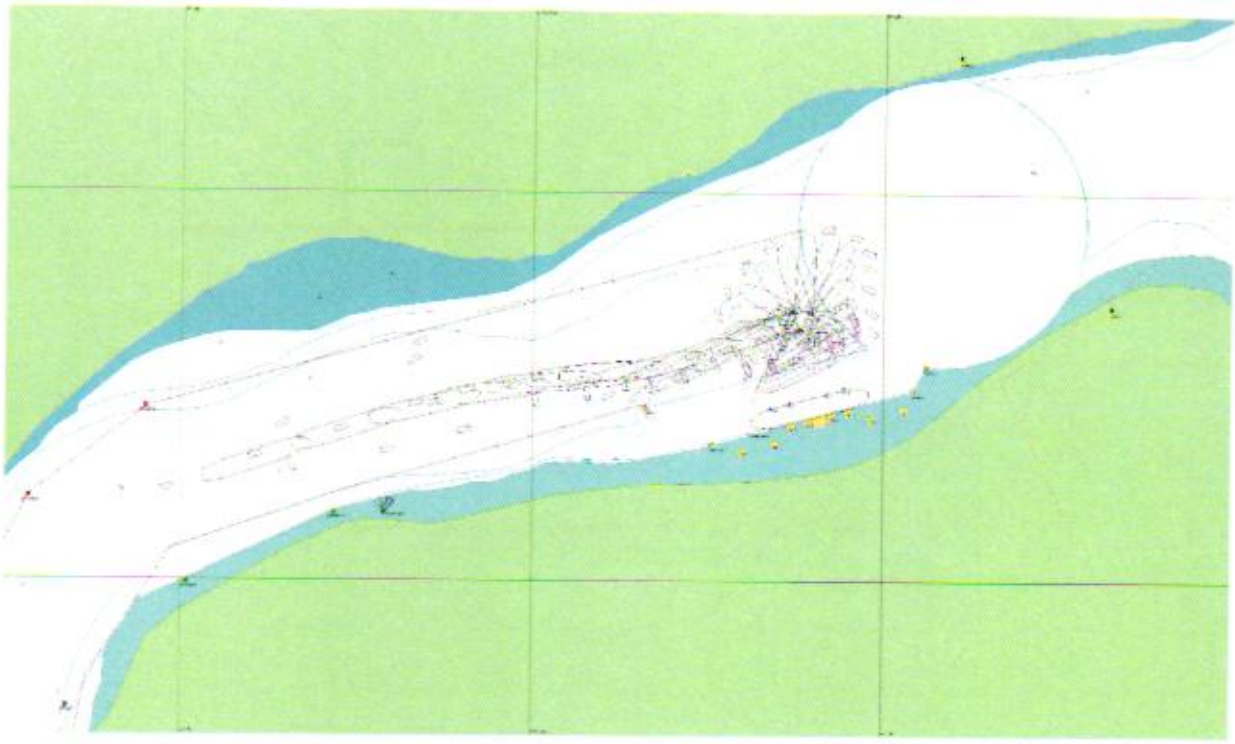


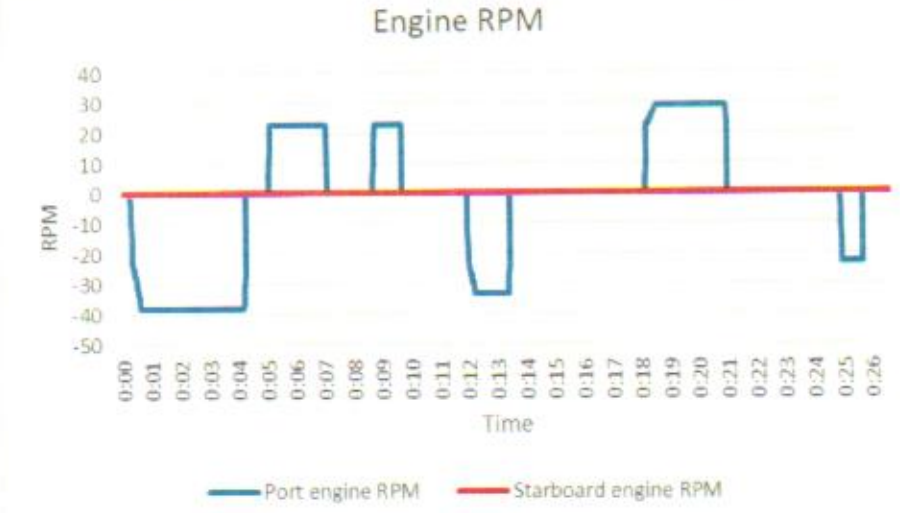


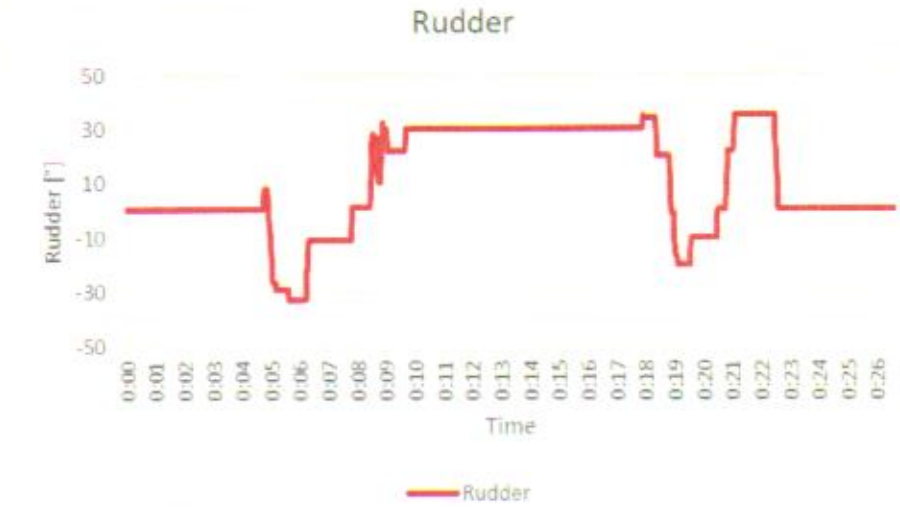
Date:	29/03/2019	Project:	Mitsubishi – JGC Corporation Tabeer LNG Terminal at Port Qasim
Time start:	16:55	Time finish:	17:20
Run n.	29	File name:	MTI2019_29
Manouvre description:		Arrival with Membrane 130k m³ vessel – Flood 1 hour before HAT & 253° at 10 knots	
Captain		Ian Simpson	

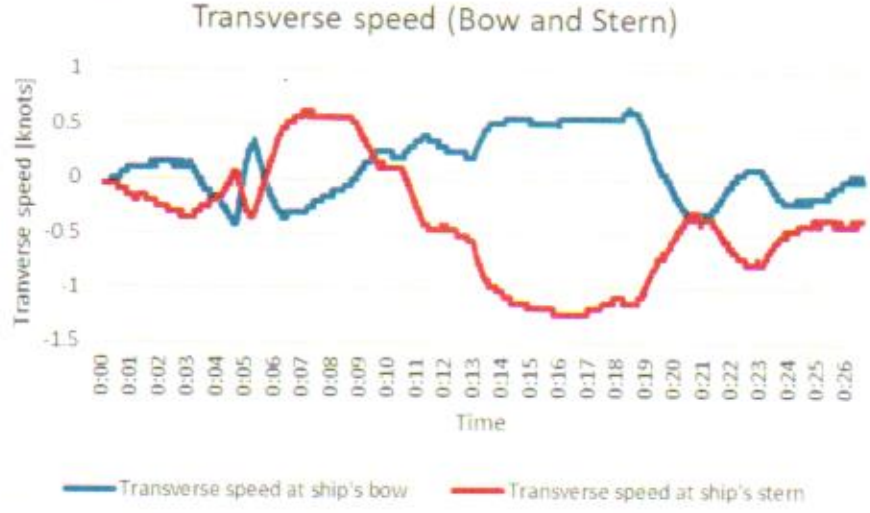
Vessel	Type	Q-Max	(345m – 53.8m – 266,000m3)	☐
		Q-Flex	(315m – 50.0m – 210,000m3)	☐
		Moss	(300m – 52.0m – 177,000m3)	☐
		Membrane	(274m – 43.3m – 130,000m3)	☒
	Condition	Loaded	(Draft: 10.86 m)	☒
		Ballast	(Draft: 9.50 m)	☐
	Thruster used	Yes		☐
		No		☒
Condition	Position	From buoys B1-B2 to Terminal		☐
		From Terminal to buoys B1-B2		☐
		From buoys B1-B2 to second bend		☐
		From second bend to Terminal		☒
	Manoeuvre	Arrival		☒
		Departure		☐
	Tugs	N.: 4 tugs		
Metocean	Current	Dir.: Flood	Speed: 1 hour before HAT	
	Wind	Dir.: 253°	Speed: 10 Kts	

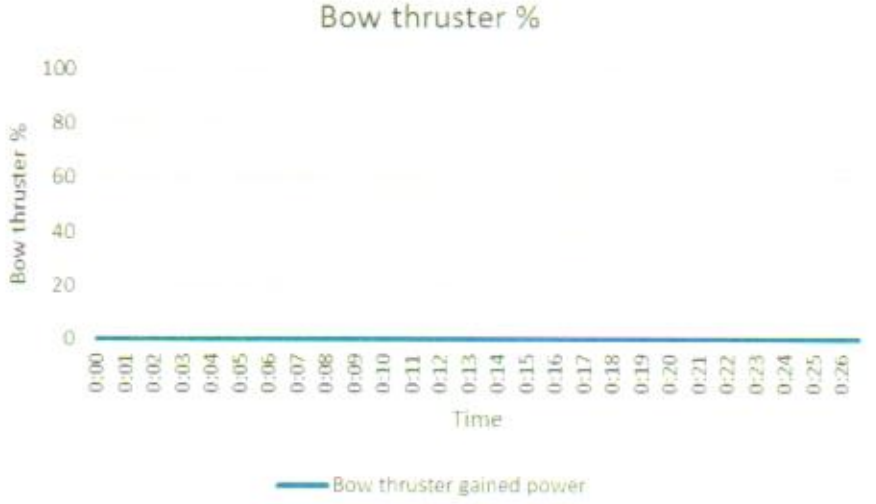
Note:
To investigate arrival and swing in typical environmental conditions with smaller vessel. In addition, to investigate minimum space required for swinging this vessel in non- extreme conditions.
Sufficient space exists for vessel to safely swing adjacent to the terminal without provision of an additional turning circle.

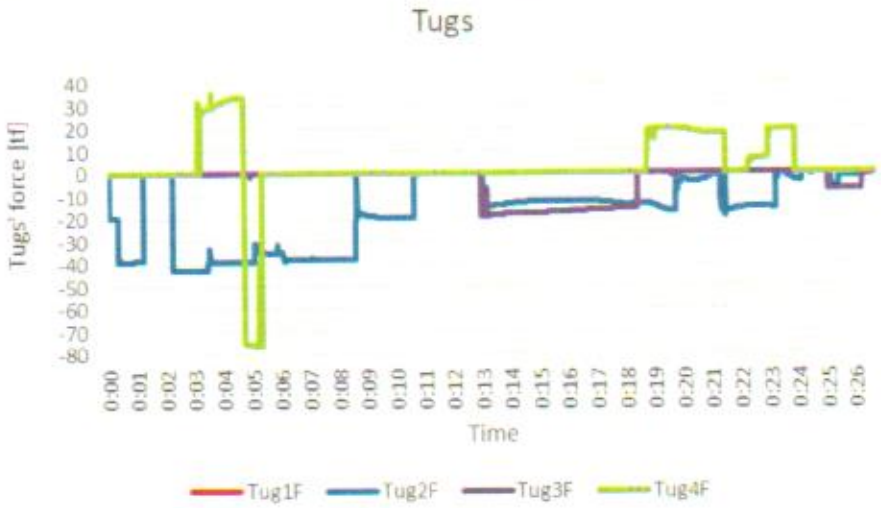












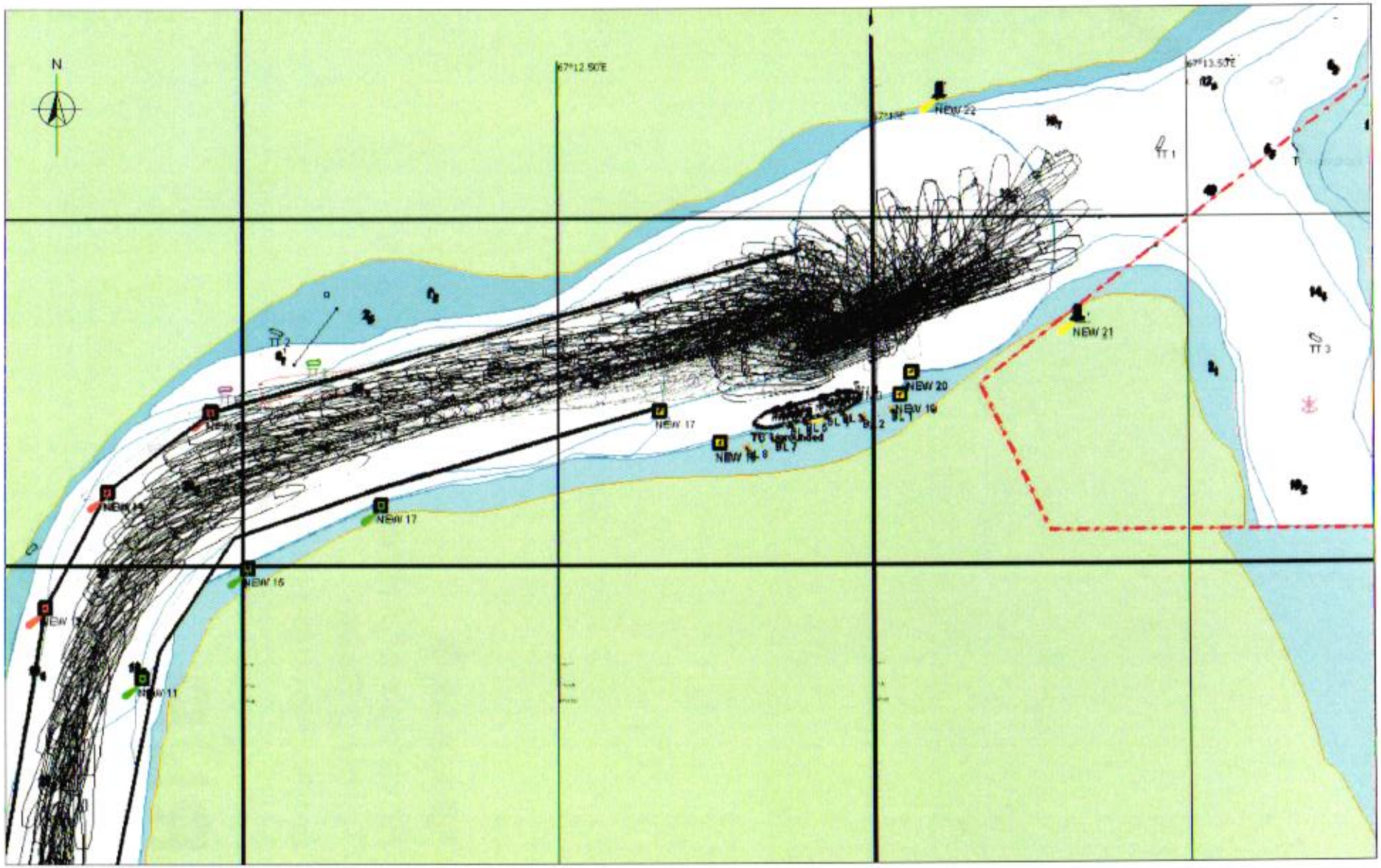
1056

APPENDIX B

Appendix B
Envelope of Arrival Manoeuvers in Turning Basin

Doc. No. P0014168-1-H1 Rev. 4 – July 2019

RINA



TURNING BASIN PLOT RUNS ENVELOPE - ARRIVAL

1958

RINA Consulting S.p.A. | Società soggetta a direzione e coordinamento amministrativo e finanziario del socio unico RINA S.p.A.
Via San Nazaro, 19 - 16145 GENOVA | P. +39 010 31961 | rinaconsulting@rina.org | www.rina.org
C.F./P. IVA/R.I. Genova N. 03476550102 | Cap. Soc. € 20.000.000,00 i.v.

	JOB No.	DOC. No.	Rev.
TABEER ENERGY	0-8069-20	S-000-13M0-211	2
	DATE 30 - Sep - 2019	SHEET 1 OF 99	
	PREP'D	F. Cogordan	
	CHK'D	K. Uchino	
	APP'D	K.Kou	

MOORING ANALYSIS DYNAMIC SIMULATION

Pakistan LNG Receiving Facilities / FEED Activities

FOR FINAL FEED

REV.	Date	Page	DESCRIPTION	PRE'D	CHK'D	APP'D
0	29-Mar-19	ALL	Issue for Review	N. Inoue	K.Uchino	K.Kou
1	21-Aug-19	ALL	Issue for Final FEED	F.Cogordan	K.Uchino	K.Uchino
2	30-Sep-19	3,6,9,36,40	Issue for Final FEED	F.Cogordan	K.Uchino	K.Kou

JGC JGC CORPORATION

Contents

1. INTRODUCTION

1.1. Scope

The scope of the dynamic mooring analysis is to confirm that the FSRU can be permanently moored at the Jetty and LNG carriers safely moored against the FSRU, discharging LNG into the FSRU by means of ship-to-ship cargo transfer. This report examines and confirms the Jetty/Dolphins layout by means of geometric study, dynamic mooring analysis and limitations in mooring safety.

2. SUMMARY

2.1. Results of FEED-Stage Analysis

Results of the dynamic mooring analysis indicates that safe mooring can be achieved at the terminal under conservative combinations of forces resulting from environmental conditions, as well as forces generated by large passing ship (Q-max). Limitations in mooring safety are induced by the FSRU's mooring lines in all case scenarios evaluated in accordance with the Appendix and were defined using the worst-case combination of tidal current speed and direction, wind speed and direction, tidal elevation and vessel loading condition.

Results of the dynamic mooring analysis indicates that the environmental load case is the governing case for fender design, as it yields 98% of rated fender reaction at 580mm deflection and an energy absorption of 2130kN.m; this is controlled by an environmental case, and not by a berthing or ship passing case. Details are provided in Figure A

3. APPENDIX

Dynamic Mooring Analysis Pakistan FSRU FEED Study, Mott MacDonald, Revision 8, 11 September 2019.

PAKISTAN FSRU

SCK CELL FENDERS

FENDER DESIGN SUMMARY

FENDER TYPE:	SCK 2500 E 2.8	
Fender Depth:	2,500.00	mm
RATE ENERY CAPACITY :	5,681	kN.m
RATED REACTION:	5,176	kN

Intermediate Deflections

D (%)	0	5	10	15	20	25	30	35	40	45	50	**52.5**	55
E (%)	0	2	7	16	26	38	50	61	72	83	94	**100**	106
R (%)	0	32	60	81	94	99	99	96	92	92	96	**100**	106

Nominal rated deflection may vary at RPD. Refer to the Performance Tolerances table in the Fender Application Design Manual.

BERTHING

LOADING TYPE	LOADING CASE	Berthing Energy Demand (kN.m)	Safety Factor for Berthing Energy	Temperature Factor	Angle Factor	Velocity Factor	Manufacturing Tolerance (%)	Energy Capacity of Fender Required (kN.m)	Remark	Percentage of Rated Energy Capacity Utilised (%)	Fender Deflections (mm)	Percentage of Fender Deflection (%)	Fender Reactions (kN)	Percentage of Fender Rated Reaction (%)
Berthing	Normal Berthing Energy	604.3	1.0	Fender for Berthing are sized based on Abnormal Berthing Energy					Since 1,158kN.m is < than 5,681kN.m, therefore Fender selected is OK	11	320	13	3,588	69
	Abnormal Berthing Energy	906.5	1.5	0.947	0.909	1.00	10	1,158		16	375	15	4,192	81

ENVIRONMENTAL LOAD

LOADING TYPE	LOADING CASE	Fender Energy Capacity Utilised (kN.m)	Percentage of Rated Energy Capacity Utilised (%)	Fender Deflections (mm)	Percentage of Fender Deflection (%)	Reactions (kN)	Percentage of Fender Rated Reaction (%)
Enviromental Load		2,045	36	580.00	23	5,072	98.00

PASSING SHIP

LOADING TYPE	LOADING CASE	Fender Energy Capacity Utilised (kN.m)	Percentage of Rated Energy Capacity Utilised (%)	Fender Deflections (mm)	Percentage of Fender Deflection (%)	Reactions (kN)	Percentage of Fender Rated Reaction (%)
Passing ship		1,172	21	433	17	4,503	87.0

Figure-A. Fender Design Summary

MOTT MACDONALD

Dynamic Mooring Analysis

Pakistan FSRU FEED Study

11 September 2019

1064

1065

Mott MacDonald
152 Beach Road
#35-00 Gateway East,
189721
Singapore

T +65 6293 1900
F +65 6293 1911
mottmac.com

Dynamic Mooring Analysis

Pakistan FSRU FEED Study

11 September 2019

1066

1067

Issue and Revision Record

Revision	Date	Originator	Checker	Approver	Description
0	3/12/19	Fenical	Toh	S. Harris	DRAFT for internal review
1	3/26/19	Fenical	Toh	S. Harris	DRAFT for client review
2	3/28/19	Fenical	Toh	S. Harris	DRAFT for owner review
3	4/26/19	Fenical	Toh	S. Harris	DRAFT for owner review
4	5/22/19	Fenical	Toh	S. Harris	FINAL REPORT
5	5/28/19	Fenical	Toh	S. Harris	REVISED FINAL REPORT1
6	7/04/19	Fenical	Toh	S. Harris	REVISED FINAL REPORT2
7	7/22/19	Fenical	Toh	S. Harris	FINAL FINAL REPORT3
8	7/24/19	Fenical	Toh	S. Harris	FINAL FINAL REPORT4
8	9/11/19	Fenical	Toh	S. Harris	FINAL FINAL REPORT5

Document reference: 398607 | 1 | A

Information class: Standard

Contents

Executive Summary

Dynamic mooring analysis was performed by Mott MacDonald (MM) upon request from JGC Corporation (JGC) to provide an assessment of mooring and operational conditions under wind, current and passing ship forces at Pakistan FSRU (Floating Storage and Regasification Unit) Project, Port Mohammad bin Qasim, Pakistan. This report describes FEED stage dynamic mooring analysis, performed subsequent to pre-FEED static/dynamic mooring analysis described below for reference.

Summary of Previous Pre-FEED Analysis (Mott MacDonald 2018a)

During the previous pre-FEED stage of the project, static and dynamic mooring analysis simulations were performed using the OPTIMOOR program. The analysis utilized MM's proprietary hydrodynamic modeling tools to develop passing vessel forces on moored FSRU and LNG Carriers (LNGCs). Analyses included evaluation of passing ship, current and wind forces, and mooring safety for one primary mooring line arrangement specified by JGC. Static mooring analysis was conducted to evaluate wind mooring limits for the berthed vessels for a conservative representation of tide, current and full range of vessel drafts at the terminal. A berthing analysis was also performed per guidelines from PIANC (2002) and British Standard (2014), which resulted in recommended fender type and size/capacity for berthing conditions. Analysis considered the FSRU berthing at the terminal, and two different LNGCs berthing against the FSRU. Cell-type fenders were recommended for the terminal, and pneumatic fenders were recommended for the Ship-to-Ship (STS) fenders.

Summary of FEED-Stage Analysis

The present FEED stage of the project included only dynamic mooring analysis, with variable winds (gusting), tidal currents and integration of those environmental conditions with passing ship forces using scenarios considered during the pre-FEED analysis. The present FEED stage analysis included the same FSRU and guest vessels, same terminal layout, and same environmental conditions.

Results of the FEED-stage dynamic mooring analysis indicate that safe mooring can be made at the terminal under conservative combinations of forces from environmental conditions, as well as forces generated by large passing ships. The mooring arrangement developed as part of the study results in reasonable line angles and adequate load sharing between the mooring lines and structures. Fender optimization was performed which resulted in use of only 2 fenders at the berth (one on each breasting dolphin), each of which has significantly larger capacity than required according to the berthing analysis. Ship-to-ship fenders (pneumatics) recommended during the pre-FEED stage were retained.

Limitations in mooring safety are induced by the FSRU's mooring lines in all situations evaluated here. Under a worst-case combination of tidal current speed and direction, wind direction, tidal elevation and loading condition, the FSRU (alone) can achieve safe mooring for wind speeds up to 41 knots (mean 1-hour duration) which corresponds to an approximately 900-year return period. The wind limit for mooring for FSRU with guest Qmax LNG carrier (which partially utilizes shore bollards) is 33 knots, which has an approximately 35-year return period. The wind limit for mooring for FSRU with guest smaller LNG carrier Grace Dahlia (which does not utilize shore bollards) is 25.5 knots, which has an approximately 1-year return period.

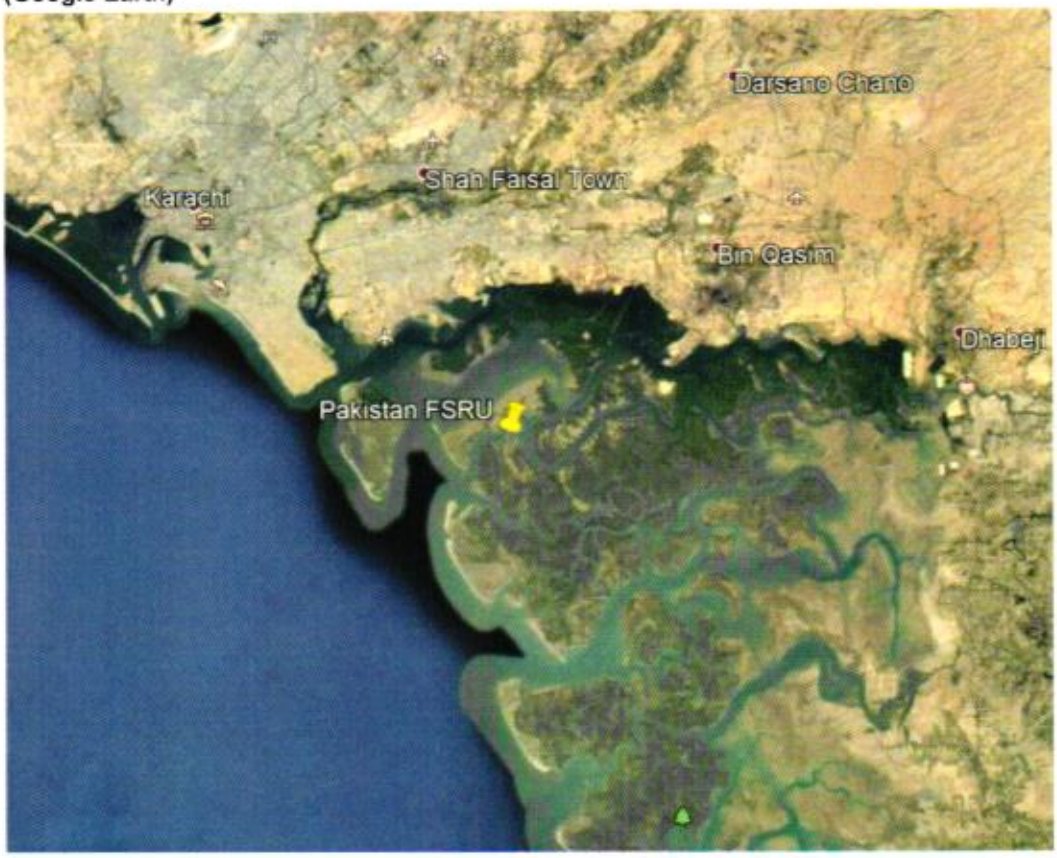
Additional dynamic mooring simulations were performed using passing ship forces calculated in the pre-FEED stage, but with inclusion of conservative dynamic winds and steady tidal currents. The maximum wind speed for safe navigation near the terminal is 20 knots per regulations from Port Qasim Authority (Port Qasim Authority 2015), and as noted in RINA full bridge simulations (RINA 2018). Passing ship simulations were performed (in pre-FEED) for fully laden Qmax passing at low water (0.0m CD) along the channel centreline at 7.0 knots and 10.0 knots, resulting in dynamic forces that were used as input to new simulations. FEED-stage dynamic simulations with these passing ship forces were performed with 1-hour mean wind speed 19.3 knots (equivalent to 20 knots at Beaufort scale 10-min average), from worst-case wind direction, with peak gusts coincident with peak passing ship forces, and worst-case tidal current conditions. The results indicate that safe mooring can be achieved for 7-knots passing speed event (fully loaded Qmax vessel through the water along the channel centreline), for all berthed vessel loading (draft) conditions, for the FSRU alone, as well as for FSRU with either guest vessel. For 10-knots passing speed event, surge motions for both host FSRU and guest Qmax Al Ghuwairiya were found to exceed PIANC advised motion limits of +/- 1m. FSRU line loads also exceed limits advised by OCIMF (2008). However, fender loads for both berth and STS fenders were well within fender capacities during 10-knots passing ship event.

The results of the analysis and conclusions in this report are specific to the vessels, waterway configuration, mooring assumptions, and terminal configurations used in the analysis. For the mooring analysis, the environmental (metocean) conditions at the project site were informed by short term measurements carried out by a third party. These data were analyzed to determine conservative coastal conditions to be used in the mooring analysis. Analysis of both the on-site measurements and numerical modeling results indicate that the tidal current scenarios used in the mooring analysis are conservative. The berth configuration, vessel details and all inputs to the analysis were based on the information available at the time of the analysis and were either prescribed by or coordinated with JGC.

1 Introduction

Dynamic mooring analysis was performed by Mott MacDonald (MM) upon request from JGC Corporation (JGC) to provide an assessment of mooring and operational conditions under wind, current and passing ship forces at Pakistan FSRU (Floating Storage and Regasification Unit) Project, Port Mohammad bin Qasim, Pakistan. The present analysis was performed as part of the FEED stage of the project. The approximate location of the Pakistan FSRU project is shown below in Figure 1.

Figure 1. Location of Pakistan FSRU Project, near Port Mohammad bin Qasim, Pakistan (Google Earth)



2 Input Parameters

2.1 General

This section describes the analysis input parameters, including the proposed marine terminal configuration and design vessels used in the hydrodynamic modeling and static/dynamic mooring analysis.

2.2 Design Vessels

Design vessels evaluated in the dynamic mooring analysis included the same vessels utilized in the pre-FEED stage of the project. General particulars of the design vessels used in the FEED stage analysis are provided in Tables 1-3. Additional sensitivity analysis was performed to evaluate potential variation in the FSRU mooring line types. The sensitivity analysis was performed because two sources of conflicting data were provided, and a third set of data that were also different were found in the Q88 form for the FSRU prototype vessel (Hoegh Esperanza). Q88 forms (www.q88.com) are standardized questionnaires used in the oil and gas industry which are completed by vessel owners/operators, for the purpose of facilitating a rapid determination as to whether a particular berth can accommodate a particular vessel. These forms are commonly relied upon for critical data in mooring analyses. Owner-provided data indicated steel wire of two different types for HN2909, and also steel wire for Hoegh Esperanza, whereas HMPE lines are indicated in the Q88 form for Hoegh Esperanza. Mooring tails also differed slightly, with polypropylene tails reported in the Q88 form and nylon tails reported in the owner-provided data. However, results of a sensitivity analysis indicate very similar mooring performance regardless of the mooring line type, given the similar elasticity (low) and capacities listed in all data sources. Wind limits for mooring induced by loads reaching 50% of MBL (per OCIMF 2008) for synthetic HMPE lines listed in the Q88 form are approximately 1 knot lower than wind limits for mooring induced by loads reaching 55% of MBL for steel wire lines (per OCIMF 2008) of slightly lower capacity found in the owner-supplied data. Therefore, all results shown here were generated using the HMPE lines found in the Q88 form for Hoegh Esperanza. These lines are slightly conservative in that they result in lower wind limits, however the nylon tails reported in the owner-supplied data result in slightly higher motions. However, all motions were well within advised limits for all line types at wind speeds at or below the reported wind limits.

2.3 Terminal Configuration

Mott MacDonald utilized the same conceptual terminal configuration developed during pre-FEED stage for the purposes of the dynamic mooring analysis. However, in addition to the four (4) fender configuration (hereinafter FC2-2) analyzed in pre-FEED stage, two new fender configurations FC1-1-1 (with a total of 3 fenders) and FC1-1 (with a total of 2 fenders) were analyzed. Figure 2 and Figure 3 show the terminal configuration, mooring arrangement, the mooring system and fender locations for FSRU with Qmax LNGC Al Ghuwairiya, and FSRU with smaller LNGC Grace Dahlia, respectively. Four berth fenders are labelled as "aa", "bb", "cc" and "dd" in Figure 2 and Figure 3. Four STS fenders are labelled as "a", "b", "c" and "d". Only two fenders "aa" and "dd" were used for fender configuration FC1-1, and only three fenders "aa", "bb", "cc" were used for configuration FC1-1-1. Location of berth fender "bb" varies depending on the fender configuration (see discussion below). Each bollard letter represents a system of quick-release hooks, with either 2 or 3 hooks per system. CAD mooring arrangement

plans which represent each of these ship-to-ship mooring configurations are included in Appendix A.

Table 1. Design Vessel Particulars for Smaller LNGC Grace Dahlia

Particular	LNGC Grace Dahlia (Moss-type)
Length Overall, LOA [m]	299.98
Length between Perpendiculars, LBP [m]	286
Maximum Beam [m]	52
Moulded Depth [m]	28
Parallel Body: Forward/Aft to mid-point manifold at Ballast Draft [m]	40.44/95.56
Longitudinal/Lateral Wind Area [m^2]	2140/9330
Design Loaded Draft [m]	11.55
Ballast Draft [m]	9.5
Mooring Lines: Type/Product/Size/MBL	48.0mm ropes/HMPE 164MT[1] 8 Fwd and 8 Aft
Winch Brake Limit [MT]	60% MBL per OCIMF[3]
Mooring Tails: Type Product/ Size	92mm dia, 11m long[2] Polypropylene-Polyester 205MT[2]
Mooring Line Pre-Tension Target (% MBL)	10

Notes:

1. Line MBL is not included in owner-supplied data. Based on the line material and diameter provided by owner, and per manufacturer's specifications for Bridon Steelite Xtra HMPE lines, line MBL of 164mt was assumed.
2. Tail length and MBL are not included in owner-supplied data. Tail length (11m) and tail MBL (125% line MBL) were assumed per OCIMF recommendations.
3. Design holding capacity of winches in owner-supplied data is 124 metric tons. However, winch brakes are set in service to hold 60% of the mooring line MBL.

Table 2. Design Vessel Particulars for Qmax LNGC Al Ghuwairiya

Particular	LNGC Qmax Al Ghuwairiya
Length Overall, LOA [m]	345
Length between Perpendiculars, LBP [m]	333
Maximum Beam [m]	55
Moulded Depth [m]	27
Parallel Body: Forward/Aft to mid-point manifold at Ballast Draft [m]	77.01/91.37
Longitudinal/Lateral Wind Area [m^2]	2236/10242
Design Loaded Draft [m]	12.2
Ballast Draft [m]	9,52
Mooring Lines: Type/Product/Size/MBL	44.0mm ropes/HMPE 10 Fwd and 12 aft/137 MT
Winch Brake Limit [MT]	60% MBL per OCIMF
Mooring Tails: Type/Product/ Size	85mm dia, 22m long Nylon-6 Wires/10 Fwd and 12 aft//185MT
Mooring Line Pre-Tension Target (% MBL)	10

Notes:

1. Design holding capacity of winches in owner-supplied data is 75 metric tons which is extremely low, and in conflict with the Q88 form. Winch brakes are set in service to hold 60% of the mooring line MBL.

1075

Table 3. Design Vessel Particulars for FSRU Hoegh Esperanza

Particular	FSRU Hoegh Esperanza
Length Overall, LOA [m]	294.07
Length between Perpendiculars, LBP [m]	282
Maximum Beam [m]	46
Moulded Depth [m]	26
Parallel Body: Forward/Aft to mid-point manifold at Ballast Draft [m]	54.2/79.0
Longitudinal/Lateral Wind Area [m^2]	1883/7608
Design Loaded Draft [m]	11.6
Ballast Draft [m]	9.2
Mooring Lines: Type/Product/Size/MBL	HMPE ropes[1]/44.0mm/ 11 Fwd and 11 aft/136MT[1]
Winch Brake Limit [MT]	60% MBL per OCIMF and Owner-supplied data
Mooring Tails: Type/Product/ Size	72mm High Performance 11m Long, Polyester[1]/181MT[1]
Mooring Line Pre-Tension Target [% MBL]	10

Notes:

1. Line and tail properties are per Q88 for Hoegh Esperanza. See discussion in Section 2.2.

Figure 2. Terminal configuration and assumed mooring arrangement for FSRU with Qmax LNGC Al Ghuwairiya (note: bollards C and H not used)

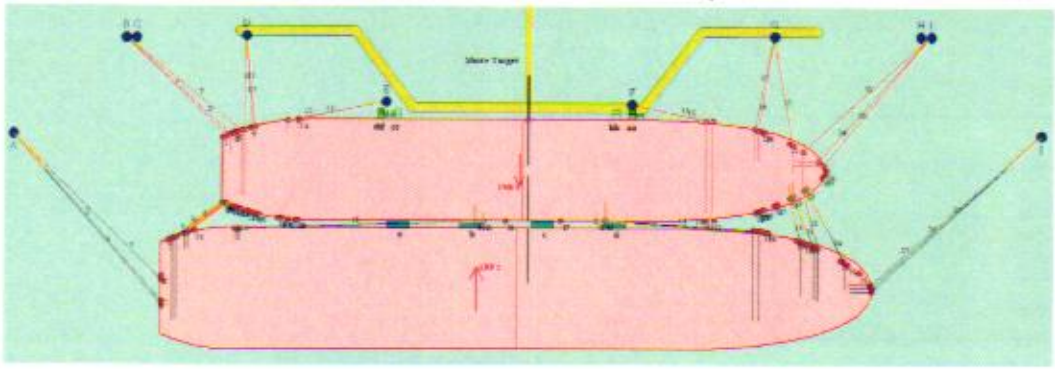
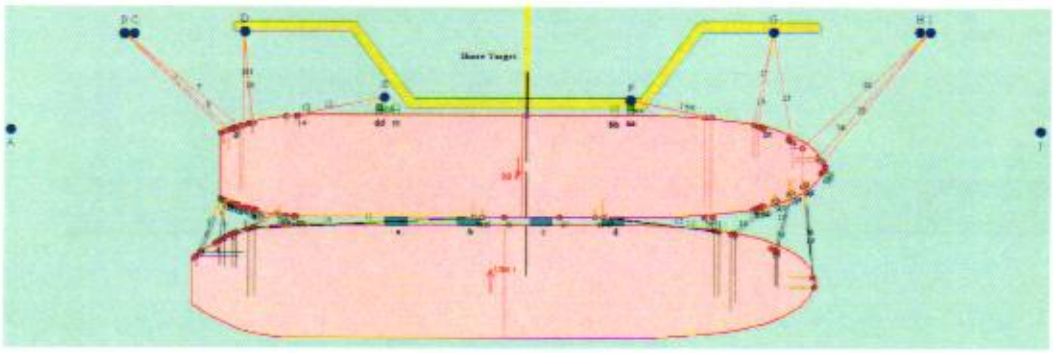


Figure 3. Terminal configuration and assumed mooring arrangement for FSRU with smaller LNGC Grace Dahlia (note: bollards C and H not used)



Per drawings provided by JGC on 02/21/2019, locations of aft berth fenders were adjusted to provide enough room for gangway footprint. The locations and elevations of the fenders for the three configurations FC2-2, FC1-1-1 and FC1-1 are shown below in Table 4, Table 5, and Table 6, respectively. Per email communication with JGC on 02/21/2019, breasting and mooring dolphins were assumed at elevation 7.5m (CD), and fenders were assumed at centreline elevation 5.5m (CD). The locations of bollards were not altered from the pre-FEED stage analysis. Bollard locations, elevations, and capacities are shown below in

Table 7. All mooring points were assumed to be quick-release hooks, with individual hook capacity of 150 metric tons. As shown in Appendix A, the vessels were analyzed and appropriate locations chosen for the fenders based on parallel body information. As in the pre-FEED stage, the terminal depth was assumed to be 14.0m (CD).

Table 4. Fender Arrangement for Fender Configuration FC2-2

	aa	bb	cc	dd
Distance from Jetty Centreline [m]	50.5	42.5	-63.3	-71.3
Height Above Datum [m, CD]	5.5	5.5	5.5	5.5
Fender Width [m]	3.0	3.0	3.0	3.0

Table 5. Fender Arrangement for Fender Configuration FC1-1-1

	aa	bb	cc
Distance from Jetty Centreline [m]	50.5	-10.4	-71.3
Height Above Datum [m, CD]	5.5	5.5	5.5
Fender Width [m]	3.0	3.0	3.0

Table 6. Fender Arrangement for Fender Configuration FC1-1

	aa	dd
Distance from Jetty Centreline [m]	50.5	-71.3
Height Above Datum [m, CD]	5.5	5.5
Fender Width [m]	3.0	3.0

Table 7. Bollard Arrangement Details

	A	B	D	E	F	G	I	J
Distance from Jetty Centreline [m]	-249.8	-195.3	-136.6	-68.9	50.3	119.3	195	248.9
Distance from Fenders [m]	-6.7	37	38	8.1	7	38.1	38.2	-6.7
Height above Dolphins [m]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max Allowable Load per QR System [mt]	450	450	450	300	300	450	450	450
# of Quick-Release Hooks	3	3	3	2	2	3	3	3

2.3.1 Fender Selection

Fender selection was based on the results of berthing and mooring analysis performed during the pre-FEED stage. All scenarios with FSRU alone and FSRU with guest vessels were analyzed. Berthing analysis used a berthing energy factor of 1.5 and the resulting fender was the cell fender SCK 1700 E2.0. However, based on the utilized energy capacity and fender reaction that was computed in the mooring analysis scenario for FSRU with Qmax (and fender configuration FC 1-1), the SCK 2500 E2.8 cell fender was selected. It has rated reaction 528 mt (5176 kN) and rated energy capacity of 5681 kN-m, both at 52.5% compression. STS fenders (Yokohama 50kPa pneumatic fenders, 3300x10600mm) were not altered from the pre-FEED stage analysis. Fender performance curves for berth and STS fenders are shown in Figure 4 and Figure 5, respectively, with peak deflections in the analysis (and hence corresponding peak reaction and energy absorption) shown with vertical lines.

Figure 4: Load-deflection (left) and energy-deflection (right) curves for berth fenders

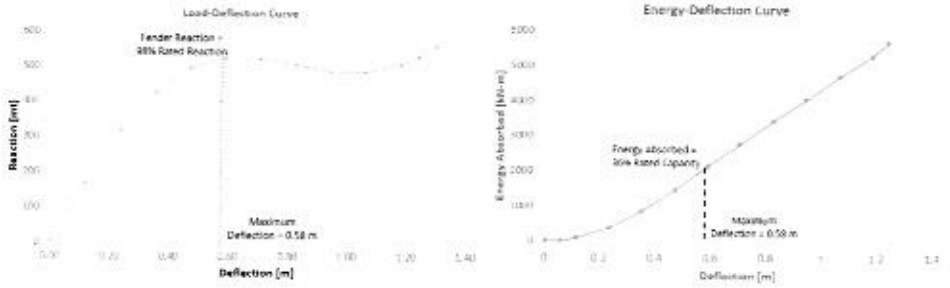
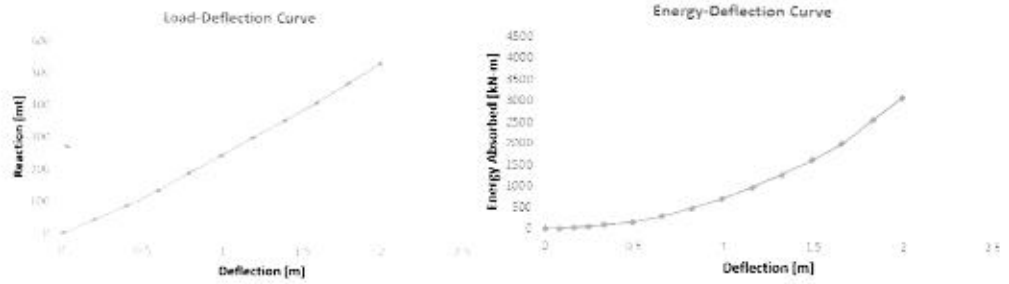


Figure 5: Load-deflection (left) and energy-deflection (right) curves for STS fenders



3 Environmental (Metocean) Conditions

3.1 General

Environmental conditions used in the FEED dynamic mooring analysis were taken directly from the pre-FEED study without modification. The pre-FEED mooring analysis report describes the water levels, winds, currents and waves evaluated in the analysis. This section describes the environmental conditions carried forward for use in dynamic mooring simulations.

3.2 Overview of Regulatory Limits on Operations

3.2.1 Wind Limits for Mooring

Wind speed limits for terminal operations were provided by JGC via email on June 28, 2018. The wind limits were taken from "Port Qasim Authority – Standard Operating Procedures for operating conventional LNG carriers (30th April 2016)". These operational wind limits include mean wind speeds of 20 knots (assumed to use Beaufort scale for duration averaging) for Berthing FSRU/LNGCs, 25 knots for stopping LNG transfer and disconnecting arms, and 30 knots for LNGC departure from the berth.

3.2.2 Wind Limits for Ships Navigating Past the Berth

Wind speed limits for vessels manoeuvring past the berth were assumed based on "Port Qasim Authority – Standard Operating Procedures for operating conventional LNG carriers (30th April 2016)". These operational wind limits include mean wind speeds of 20 knots for navigation. RINA (2018) performed full bridge simulations with Qmax vessels in the channel and did not consider wind speeds larger than a mean wind speed 20 knots in the simulations. RINA (2018) includes a reference to the Beaufort scale for winds, therefore the maximum wind speed used in passing ship dynamic mooring analysis was 20 knots mean wind speed with averaging duration 10 minutes and 10m elevation. Wind speeds were converted to speed 19.3 knots with 1-hour duration for input to the simulations.

3.3 Environmental Conditions for Dynamic Mooring Simulations

Regulatory wind limits for mooring were not used in the analysis; to determine wind limits at the terminal for development of design loads, winds were increased in hourly mean wind speed over several iterations until mooring criteria were violated. At this limiting wind speed, conservative combinations of other conditions (wind direction, currents, tide) were used to determine peak loads in fenders. Winds were combined with conservative combinations of tides and currents, as described below.

Key analysis cases taken from pre-FEED analysis of the current measurements are shown below in Table 8. These cases were applied with conservative water levels ranging from MLLW (0.6m, CD) to MHHW (2.9m, CD). The two Cases generating the lowest wind speed limits for safe mooring (in different situations) were either Case 2 or 3, depending on the vessel mooring configuration. These two Cases were carried forward into FEED-stage analysis. MLLW tidal elevation was utilized with these two different Cases (CD or lower is overly conservative).

1079

Table 8: Cases Evaluated in the pre-FEED Stage Static Mooring Analysis

Case	Current Speed [kts]	Current Angle Relative to Berth [deg]
1	0.1	90
2	2.3	20
3	2.9	10
4	1.2	40
5	0.1	90
6	0.1	-90
7	2.3	-20
8	2.9	-10
9	1.2	-40
10	0.1	-90

Note:

1. The directions are angles off the berth (and vessel centreline), with positive indicating currents that push the vessel off the dock. Flood and ebb currents are assumed to be the same.
2. Only Case 2 and Case 3 were carried forward into FEED-stage dynamic mooring analysis, as they generated the largest forces.

3.4 Environmental Conditions Excluded from the Analysis

Waves from offshore and locally-generated wind-waves were not included in the mooring analysis. The site is sheltered from offshore wave activity with limited fetch and as such is exposed to only small, short-period wind waves which do not significantly affect mooring safety for these large vessels.

Short-period waves generated by passing vessels of all sizes, otherwise known as Kelvin wakes, are not significant in the mooring analysis because they do not induce motions in large LNGCs. Pressure fields, or bulk water displacement effects, are significant for the mooring analysis and therefore were considered as part of the passing ship dynamic mooring analysis. Further details on excluded environmental conditions is provided in the pre-FEED report.

4 Passing Ship Hydrodynamic Forces

4.1 General

Passing vessel hydrodynamic forces induced by pressure fields (bulk water displacement effects) were calculated during the previous pre-FEED stage using the Vessel Hydrodynamics Longwave Unsteady (VH-LU) model (Fenical *et al.*, 2006). The VH-LU model predicts water level and velocity fluctuations surrounding passing ships, and the resulting hydrodynamic loads on berthed vessels. The results of the hydrodynamic analysis include time histories of surge force, sway force, and yaw moment for each of the hydrodynamic modeling scenarios.

No changes to the modeling domain, berth configuration or turning basin configuration were made during the FEED stage of the project. The hydrodynamic forces computed in the pre-FEED stage of the study were used directly in the present FEED stage. Further details on the modeling system, model setup, and forces generated by the passing ships were provided in the pre-FEED mooring analysis report.

4.2 Passing Ship Modeling Scenarios

Table 9 shows all the passing vessel scenarios that were simulated during the FEED-stage analysis. During the pre-FEED study, both inbound and outbound tests were performed, with nearly identical results. Therefore, only inbound passing vessels were considered in the dynamic mooring analysis. Also, in pre-FEED stage, both 7-knot and 10-knot passing speeds were simulated. All hydrodynamic simulations were performed at tidal elevation 0.0m (CD).

Table 9. Critical Passing Ship Scenarios

Scenario	Berthed Vessel(s)	Passing Speed [kts]	Wind Conditions
1	FSRU	7.0 and 10.0	19.3 knots (1-hour mean), all directions at 15 deg intervals
2	FSRU with Qmax Al Ghuwairiya	7.0 and 10.0	19.3 knots (1-hour mean), all directions at 15 deg intervals
3	FSRU with Grace Dahlia	7.0 and 10.0	19.3 knots (1-hour mean), all directions at 15 deg intervals

4.3 Forces on Berthed Vessels

Time histories of passing vessel forces (surge and sway) and yaw moments were provided in pre-FEED report for all scenarios evaluated during the pre-FEED stage of the project. Table 10 summarizes the peak load and moment magnitudes induced on each vessel (FSRU and guest LNGC) for the three FEED-stage passing ship scenarios.

Table 10. Peak Loads (mt) and Moments (mt-m) for All Scenarios

Scenario	Berthed Vessel(s)	Speed (kts)	Peak +Surge	Peak -Surge	Peak +Sway	Peak -Sway	Peak +Yaw	Peak -Yaw
1	FSRU	7	30	-30	34	-35	912	-872
2	FSRU	10	82	-95	53	-42	1913	-1669
3	FSRU	7	35	-33	27	-34	915	-957
	Qmax Al Ghuwairiya	7	56	-57	72	-117	3529	-3215
4	FSRU	10	99	-118	41	-52	2434	-2537
	Qmax Al Ghuwairiya	10	146	-171	72	-155	7970	-6663
5	FSRU	7	35	-34	28	-33	979	-1030
	Grace Dahlia	7	48	-49	46	-78	1912	-1709
6	FSRU	10	97	-113	45	-47	2523	-2458
	Grace Dahlia	10	123	-140	57	-114	4234	-3663

Note: Surge positive aft, sway positive to port, and yaw positive CCW looking down

5 FEED-Stage Dynamic Mooring Analysis

5.1 Methodology

Dynamic mooring analysis was performed utilizing the dynamic wind effects, tidal current effects, and passing ship effects. This analysis was performed using OPTIMOOR dynamic version with seakeeping capabilities and included all terminal data vessel data, time-dependent hydrodynamic loads and moments from the passing ship model, dynamic loads from winds (see Section 5.2) and static loads from tidal currents. Dynamic simulations were performed with 1) only environmental forces, and 2) separately with the inclusion of both passing ship forces and environmental forces.

5.1.1 Environmental Forces Only

The goal of the dynamic mooring analysis with only environmental forces was to develop wind mooring limits and loads in mooring system components for use in design by JGC, for conservative combinations of winds, tides, currents, and vessel drafts. All three fender configurations (FC1-1, FC 1-1-1, and FC 2-2) discussed in Section 2.3 were considered for mooring analysis with only environmental forces.

5.1.2 Passing Ship and Environmental Forces

The goal of the dynamic mooring analysis with both environmental forces and passing ship forces was to determine if a fully loaded Qmax vessel could safely pass the terminal along the channel centreline at 7 knots through the water, combined with tidal current forces, and during the maximum navigable wind speed of 20 knots (Port Qasim Authority 2015). Analysis was performed for the FSRU alone, FSRU with guest Qmax, and FSRU with guest LNGC Grace Dahlia. All simulations utilized the worst-case wind direction. Since higher fender loads were observed in scenarios with only environmental forces, only fender configuration FC1-1 (two total fenders) was considered for mooring analysis with both environmental forces and passing ship forces. In the dynamic mooring simulations of passing ship effects, tidal elevation 0.0m (CD), which is a very low water level, was used, consistent with the hydrodynamic simulations. Lower water levels result in higher passing ship forces; therefore, this is a conservative assumption.

5.1.3 Mooring Safety Criteria

Berthed vessel motions, mooring line loads, loads in quick release hooks, and fender loads were evaluated relative to the criteria described below (same as pre-FEED stage):

- Berthed vessel motion limits: Surge +/- 1.0m either direction from initial position, sway 2.0m off the dock, and roll motion +/- 1.0 degree (PIANC, 1995).
- Peak line load limit: 50% of Minimum Breaking Load (MBL) for synthetic mooring lines and 55% MBL for steel wires (OCIMF, 2008).
- Fender load and compression limit: Within rated reaction 528 metric tons (5176 kN) for shore fenders, and 536 metric tons for Ship-to-Ship fenders.
- Bollard load limits: Within rated capacity (assumed 150 metric tons for individual quick-release hooks).

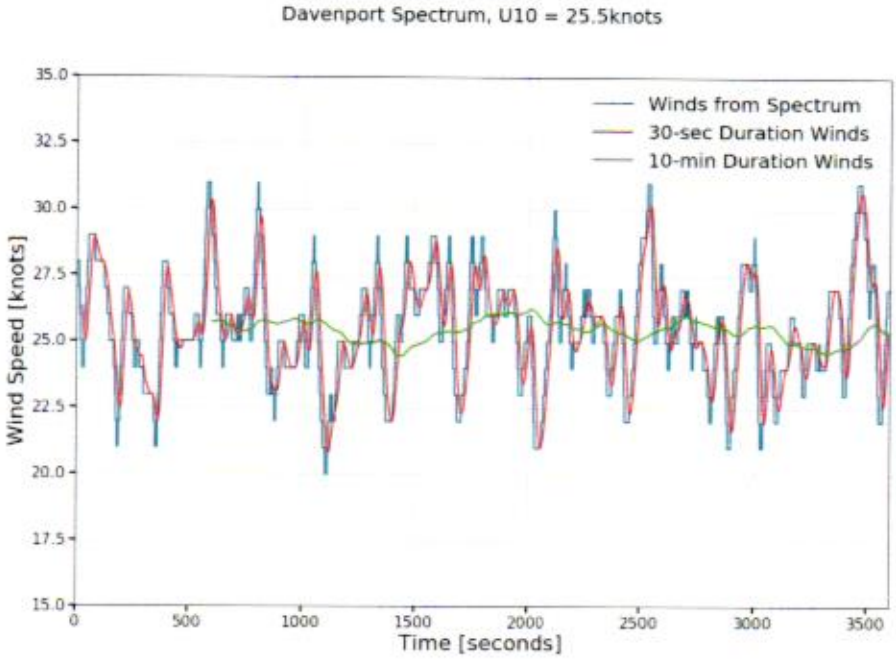
5.2 Wind Input

Wind spectra evaluated for use on the project included Davenport, Harris and NPD. It was determined that he Davenport and Harris spectra were more applicable since the project is

better represented by over-land winds, and these two spectra are more conservative in gusting than NPD. Since they resulted in the same results, Davenport spectrum was used for the analysis. A roughness height of 0.01m was used, representative of "Open country without significant buildings" and "Coastal areas with onshore winds" (DNV GL 2018), resulting in a computed roughness coefficient of 0.0034.

A slightly conservative roughness coefficient of 0.004 was used for mooring analysis in OPTIMOOR. Figure 6 shows an example wind time history generated within OPTIMOOR, for a mean wind speed of 25.5 knots. Analysis of the 1-hour time series indicates a confirmed 1-hour average of 25.5 knots, 10-minute average of 26.3 knots, and 30-second average of 30.6 knots.

Figure 6: Typical wind time history generated in OPTIMOOR from Davenport spectrum with roughness coefficient 0.004



5.3 Mooring Arrangements

All scenarios utilized the port-side-to mooring position and line arrangement as shown in Figure 2 for Qmax LNGC Al Ghuwairiya, and Figure 3 for LNGC Grace Dahlia. A maximum of one mooring line per individual quick release hook was used. No more than 3 quick release hooks were employed on a single mooring dolphin. To optimize locations and number of fenders, three fender configurations (FC 2-2, FC 1-1-1 and FC 1-1) were considered separately in dynamic mooring analysis with only environmental conditions (no passing ships).

Vertical mooring line angles for the three vessels were extracted under static mooring conditions for all combinations of host and guest vessel drafts, and for MHWS and MLWS tidal elevations. Worst-case vertical line angles for each vessel are shown in Table 11. Vertical line angles are reasonable, and within OCIMF (2008) recommendations.

Worst-case line angles for the FSRU occur when the vessel is at ballast draft, at MHWS tidal elevation. Worst-case vertical line angles for the guest vessels Qmax Al Ghuwairiya and

smaller LNGC Grace Dahlia occur during the scenario when FSRU is fully loaded, and guest vessels are at ballast draft. The worst-case vertical line angle in any simulation in the FEED-stage dynamic mooring analysis was 19 degrees.

Table 11: Worst-case Vertical Line Angles for Each Vessel (All Configurations/Scenarios)

FSRU Line #	FSRU Vertical Line Angles [deg]
1	Not Used
2	7°
3	6°
4	Not Used
5	Not Used
6	Not Used
7	6°
8	10°
9	Not Used
10	10°
11	10°
12	15°
13	16°
14	Not Used
15	19°
16	18°
17	17°
18	17°
19	Not Used
20	Not Used
21	Not Used
22	14°
23	9°
24	9°
25	9°

Qmax Line #	Qmax Vertical Line Angles [deg]
1	5°
2	5°
3	5°
4	Not Used
5	Not Used
6	6°
7	7°
8	8°
9	8°
10	Not Used
11	2°
12	2°
13	2°
14	2°
15	Not Used
16	Not Used
17	Not Used
18	9°
19	Not Used
20	Not Used
21	7°
22	6°
23	Not Used
24	5°
25	Not Used
26	Not Used
27	7°
28	7°
29	7°

Grace Dahlia Line #	Grace Dahlia Vertical Line Angles [deg]
1	Not Used
2	9°
3	10°
4	Not Used
5	14°
6	15°
7	Not Used
8	-2°
9	-2°
10	0°
11	0°
12	4°
13	4°
14	9°
15	10°
16	Not Used
17	9°
18	9°
19	6°
20	5°

5.4 Dynamic Mooring Analysis (DMA), with Only Environmental Forces

Table 12 lists the dynamic mooring analysis (DMA) simulations that included only environmental forces, along with the corresponding conditions. Winds from all directions were simulated, at 15-degree intervals. Current directions and speeds were the same as in pre-FEED analysis (Table 8). Hourly mean wind speed, which was used to generate variable winds using a Davenport spectrum, was iteratively increased until mooring limits were reached.

Results show that FSRU's mooring line loads reach 50% MBL before any other limit is reached (motions, fenders, QRHs), in all situations and for all mooring configurations (FSRU only, FSRU with Qmax, and FSRU with Grace Dahlia). Analysis determined that each of these configurations has its own omni-directional wind limit. Using these omni-directional wind limits, a worst-case combination of other factors was prescribed (current, tide, loading condition), to establish critical scenarios that generate worst-case fender loads, and critical scenarios that generate peak vessel motions.

Table 12: Dynamic Mooring Simulations with Environmental Forces Only

Configuration	Mean Wind Speed [kts]	Wind Directions [deg]	Currents	Water Levels	Loading Condition
FSRU	Varied	All directions at 15° interval	Pre-FEED	MHHW, MLLW	Loaded, Ballast
FSRU-Qmax	Varied	All directions at 15° interval	Pre-FEED	MHHW, MLLW	Loaded, Ballast
FSRU-Grace	Varied	All directions at 15° interval	Pre-FEED	MHHW, MLLW	Loaded, Ballast

Limiting scenarios for the FSRU and governing criteria are listed in Table 13. For example, in Scenario EC-1 for FSRU alone, omni-directional wind limit was found to be 41 knots, which results in maximum line load of 50% MBL in at least one of the FSRU lines. The worst-case wind direction that resulted in the maximum line load was found to be 135° TN. At this wind limit of 41 knots, worst-case load in berth fenders was observed for winds blowing from 25° TN and with current speed 2.3-knots from 55° TN (Scenario EC-2). Maximum excursion for FSRU was observed for winds blowing from 180° TN and with current speed 2.3 knots from 235° TN (Scenario EC-3).

Similarly, limiting scenarios for guest LNGCs Qmax and Grace Dahlia and governing criteria are listed in Table 14. For example, in Scenario EC-10 for the FSRU-Qmax configuration, omni-directional wind limit of 33 knots resulted in the peak load in Qmax's mooring lines for winds blowing from 120° TN. At this wind limit of 33 knots, the worst-case load in STS fenders was observed for winds blowing from 25° TN and for current speed 2.9 knots from 65° TN (Scenario EC-11). Maximum Qmax excursion was observed for winds blowing from 55° TN and for current speed 2.9 knots from 85° TN (Scenario EC-12).

Analysis also indicated that for the FSRU alone configuration, ballast draft induced the lowest wind limits for safe mooring. However, when guest vessels are present, both vessels at design draft result in the lowest wind limits for safe mooring due to combined tidal current-induced forces acting on the hulls of both vessels. Results of dynamic mooring analysis for scenarios with FSRU alone and FSRU with guest LNGCs are discussed below in details.

Table 13: Critical Scenarios for Host FSRU, identified using Simulations in Table 12

Configuration	Scenario	Limiting Criteria	Omni-Directional Wind Limit [kts]	Worst-Case Wind Direction [deg]	Worst-Case Current [kts]	Worst-Case Water level [m, CD]	Worst-Case Vessel Loading Condition
FSRU	EC-1	FSRU Line Loads	41.0 kts	150° TN	2.3 kts, 95° TN	MLLW	Ballast
	EC-2	Berth Fender Loads		25° TN	2.3 kts, 55° TN	MLLW	Loaded
	EC-3	FSRU Motions		180° TN	2.3 kts, 235° TN	MHHW	Ballast
FSRU-Qmax	EC-4	FSRU Line Loads	33.0 kts	150° TN	2.3 kts, 95° TN	MLLW	Both Loaded
	EC-5	Berth Fender Loads		35° TN	2.3 kts, 55° TN	MLLW	Both Loaded
	EC-6	FSRU Motions		180° TN	2.3 kts, 235° TN	MHHW	Both Ballast
FSRU-Grace Dahlia	EC-7	FSRU Line Loads	25.5 kts	135° TN	2.3 kts, 95° TN	MLLW	Both Loaded
	EC-8	Berth Fender Loads		25° TN	2.3 kts, 55° TN	MLLW	Both Loaded
	EC-9	FSRU Motions		180° TN	2.3 kts, 235° TN	MHHW	Both Ballast

Table 14: Critical Scenarios for Guest Vessels, identified using Simulations in Table 12

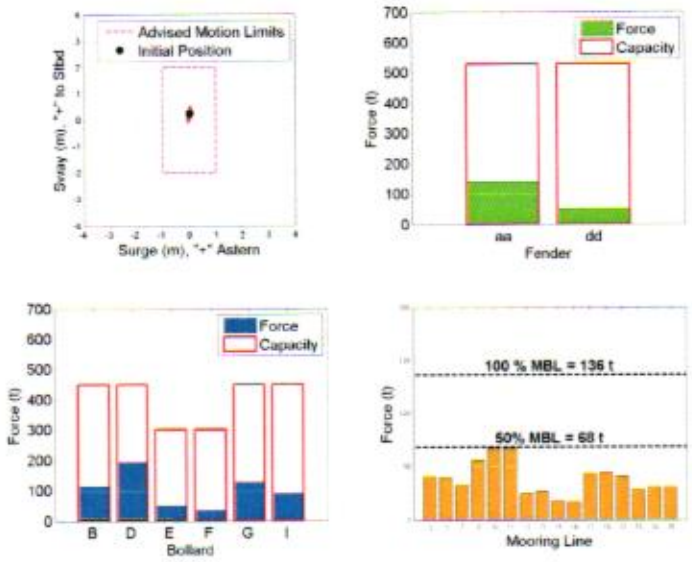
Configuration	Scenario	Limiting Criteria	Omni-Directional Wind Limit [kts]	Worst-Case Wind Direction [deg]	Worst-Case Current [kts]	Worst-Case Water level [m, CD]	Worst-Case Vessel Loading Condition
FSRU-Qmax	EC-10	Guest Line Loads	33.0 kts	120° TN	2.3 kts, 95° TN	MLLW	Both Loaded
	EC-11	STS Fender Loads		25° TN	2.9 kts, 65° TN	MLLW	Both Loaded
	EC-12	Guest Vessel Motions		180° TN	2.9 kts, 245° TN	MHHW	Both Ballast
FSRU-Grace Dahlia	EC-13	Guest Line Loads	25.5 kts	120° TN	2.3 kts, 95° TN	MLLW	Both Loaded
	EC-14	STS Fender Loads		315° TN	2.3 kts, 275° TN	MLLW	Both Loaded
	EC-15	Guest Vessel Motions		180° TN	2.9 kts, 245° TN	MHHW	Both Ballast

5.4.1 Results for FSRU Alone

Results indicate good mooring capability for the FSRU. Under these worst-case conditions, wind limits on the FSRU are imposed by forces in the FSRU's shortest breasting lines exceeding 50% of Minimum Breaking Load (MBL). The wind speed limit (1-hour average at elevation 10m Mean Sea Level) under these conservative combinations of current/tide conditions and draft is approximately 41 knots. At this wind limit, FSRU motions are within +/- 1m (surge) and 2m (sway off the dock) limits advised by PIANC (1995) and berth fender loads reach a maximum of 64% of the fender rated reaction (528 mt, 5176 kN). Fender energy absorption at this fender compression (0.26m) is only 9% of the fender's rated energy absorption (5,681 kN-m).

Figure 7 below shows results of the dynamic mooring simulation for Scenario EC-1. As shown in Figure 7, the environmental conditions for Scenario EC-1 generate load of ~50% MBL in Line #10 which is a stern breasting line to QRH system "D". For FSRU alone configuration, results for Scenario EC-2 which results in critical berth fender loads, and for Scenario EC-3 which results in maximum FSRU excursion are shown in Appendix B for all three fender configurations. Fender configuration FC 1-1 results in maximum fender load of 338mt or 64% of the fender reaction (528 mt, 5176 kN) as shown in Figure B4 Appendix B (Scenario EC-2). Maximum FSRU excursion is 0.33 m as shown in Table 15.

Figure 7: DMA results summary for Scenario EC-1 (Fender Configuration FC1-1), FSRU Alone



5.4.2 Results for FSRU with Qmax LNGC Al Ghuwairiya

Dynamic mooring simulations were performed for FSRU with guest LNGC Qmax Al Ghuwairiya for all scenarios in Table 12, and the critical scenarios identified are listed in Table 13. Results show that the wind limits for hosting Qmax are also imposed by forces in the FSRU's shortest breasting lines exceeding 50% of Minimum Breaking Load (MBL). The wind speed limit (1-hour average at elevation 10m Mean Sea Level) under these conservative combinations of current/tide conditions and draft is approximately 33 knots. At this wind limit, both host and guest vessel motions are within +/- 1m (surge) and 2m (sway off the dock) limits advised by PIANC (1995) No wind limits are imposed by the guest vessel's mooring lines or ship-to-ship fenders.

Figure 8 below shows results of the dynamic simulation for Scenario EC-4 with mean wind speed 33 knots. As shown in Figure 8, the environmental conditions for Scenario EC-4 generate load of ~50% MBL in FSRU's Line #10 which is a stern breasting line to QRH system "D". Results for Scenarios EC-4, EC-5 and EC-6 for FSRU with Qmax are shown in Appendix B for all three fender configurations. Fender configuration FC 1-1 results in maximum fender load of 98% of berth fender rated reaction (528 mt, 5176 kN) as shown in Figure B5 in Appendix B (Scenario EC-5). Fender energy absorption at this fender compression (0.58m) is only 36% of the fender's rated energy absorption (5,681 kN-m). Maximum FSRU excursion is 0.38m, as shown in Figure B16 in Appendix B (Scenario EC-6) and also in Figure 4.

Figure 9 shows results of the dynamic simulation for Scenario EC-10. The environmental conditions for Scenario EC-10 generate maximum peak load in Qmax's lines when berthed side-to-side with host FSRU vessel. Qmax line loads do not exceed 50% MBL at 33 knots. Results for Scenario EC-10 are very similar to the results for Scenario EC-4 discussed above.

Figure 8: DMA results summary for Scenario EC-4 (Fender Configuration FC1-1), FSRU with Qmax LNGC Al Ghuwairiya. FSRU results (top) and guest Qmax LNGC Al Ghuwairiya results (bottom).

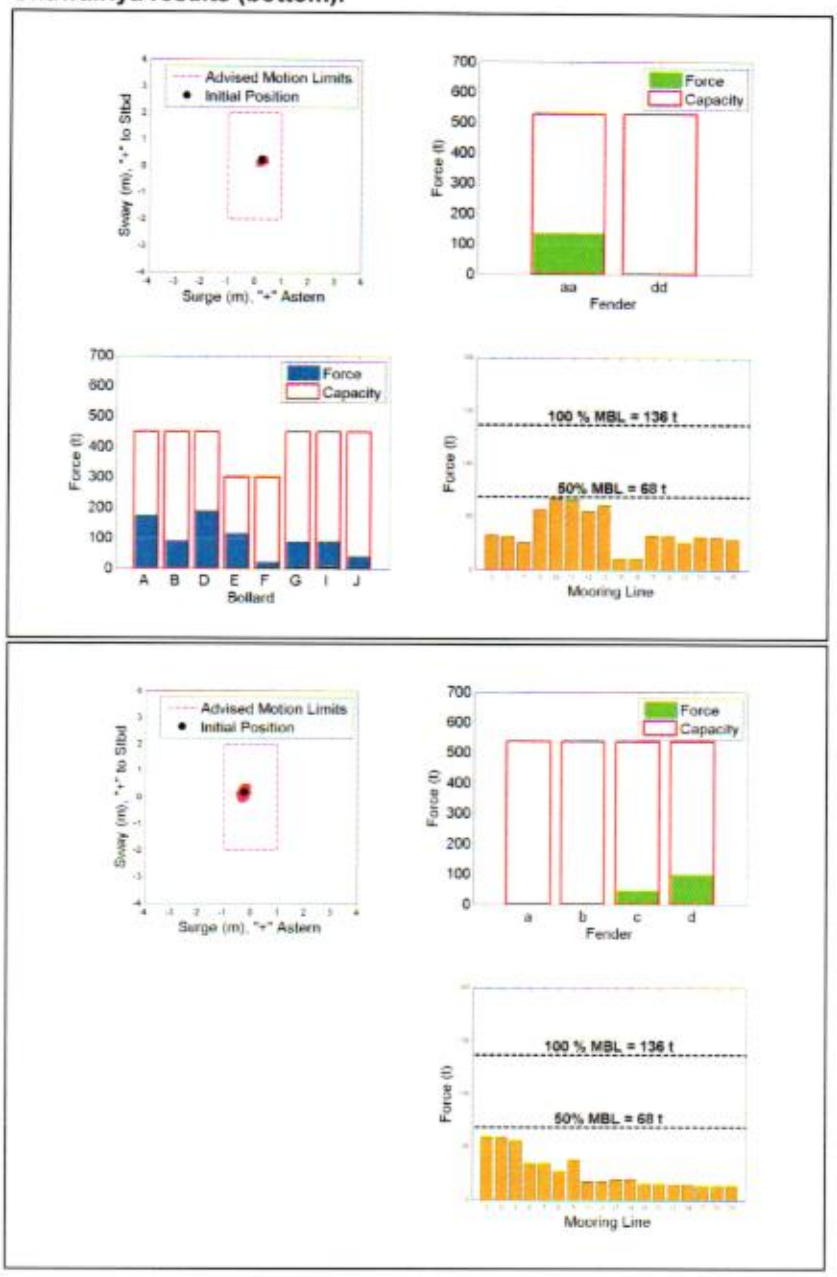


Figure 9: DMA results summary for Scenario EC-10 (Fender Configuration FC1-1), FSRU with Qmax LNGC Al Ghuwairiya. FSRU results (top) and guest Qmax LNGC Al Ghuwairiya results (bottom).

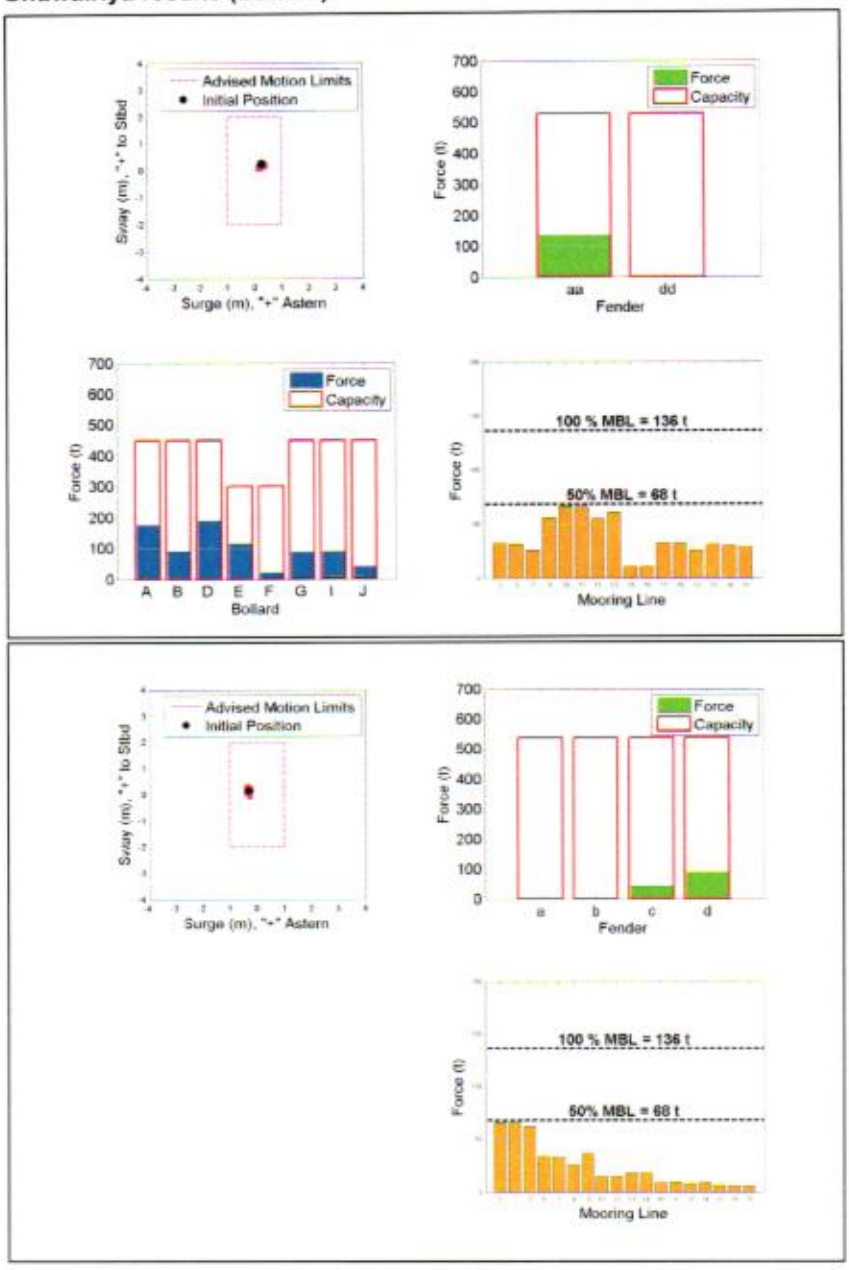
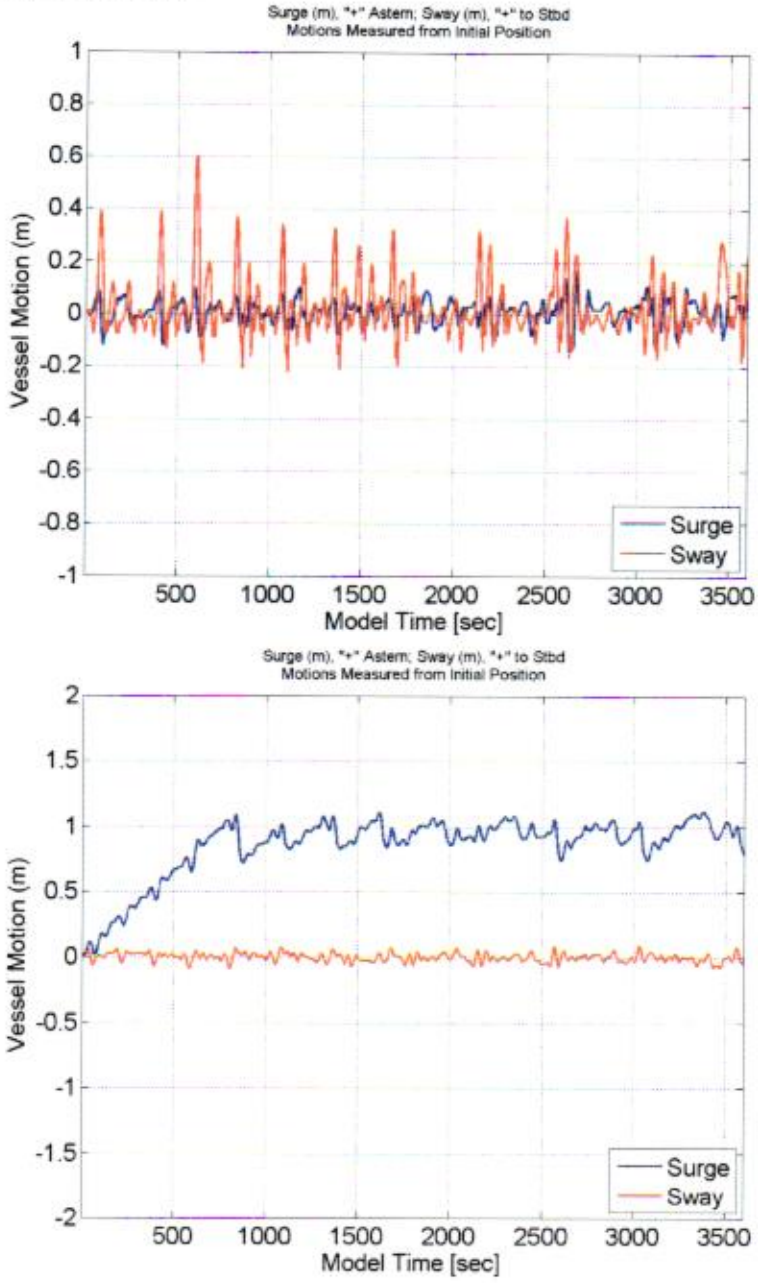


Figure B8 in Appendix B shows DMA summary results for Scenario EC-5. Figure 10 below shows motion time histories for scenarios EC-5 and EC-6. Results for scenario EC-6 show that the guest Qmax's surge motion is well within PIANC advised limits of +/- 1m. For scenario EC-5, the guest Qmax's surge motion (during 1-hour mean wind from NE of 33 knots) slightly exceeds PIANC advised limits of +/- 1m. However, the motions are not dynamic and occur very slowly in

time. The surge motion in scenario EC-5 is a static displacement generated by the vessel moving slowly over approximately 15 minutes to a new equilibrium position. The dynamic component of overall surge motion is relatively small. Also, at speeds below the omni-directional operational wind limit of 25 knots, surge motion for scenario EC-5 is found to be within PIANC advised limits of +/- 1m.

Figure 10: Time histories of guest Qmax surge and sway motions for Scenario EC-6 (top) and EC-5 (bottom)



5.4.3 Results for FSRU with Smaller LNGC Grace Dahlia

Dynamic mooring simulations were performed for FSRU with smaller guest LNGC Grace Dahlia for all scenarios in Table 12 and the critical scenarios identified are listed in Table 13. Results show that the wind limits for hosting LNGC Grace Dahlia are also imposed by forces in the FSRU's shortest breasting lines exceeding 50% of Minimum Breaking Load (MBL). The wind speed limit (1-hour average at elevation 10m Mean Sea Level) under these conservative combinations of current/tide conditions and draft is approximately 25.5 knots. At this wind limit, both host and guest vessel motions are within +/- 1m (surge) and 2m (sway off the dock) limits advised by PIANC (1995), and berth fender loads reach a maximum of 68% of fender rated reaction (528 mt, 5176 kN). Fender energy absorption at this fender compression (0.28m) is only 10% of the fender's rated energy absorption (5,681 kN-m). No wind limits are imposed by the guest vessel's mooring lines or ship-to-ship fenders.

Figure 11 below shows results of the dynamic mooring simulation with mean wind speed 25.5 knots from worst-case direction 135 deg TN, for both vessels at loaded draft, with 2.3-knot currents from 95 deg TN and MLLW tidal elevation (0.6m, CD). As shown in Figure 11, the environmental conditions for Scenario EC-7 generate load of ~50% MBL in Line #10 which is a stern breasting line to QRH system "D". Results for Scenarios EC-7, EC-8 and EC-9 for FSRU-Grace Dahlia configuration are shown in Appendix B for all three fender configurations. Fender configuration FC1-1 results in maximum fender load of 68% of berth fender rated reaction (528 mt, 5176 kN) as shown in Figure B6 in Appendix B (Scenario EC-8). Maximum FSRU excursion is 0.18m as shown in Table 15. Figure 12 shows results of the dynamic simulation for Scenario EC-13. The environmental conditions for Scenario EC-13 generate maximum peak load in smaller LNGC Grace Dahlia's lines when berthed side-to-side with host FSRU vessel. Line loads for Grace Dahlia do not exceed 50% MBL at 25 knots. Results for Scenario EC-13 are very similar to those for Scenario EC-7 discussed above.

Figure 11: Results of dynamic mooring simulation EC-7 and Fender Configuration FC1-1, FSRU with smaller LNGC Grace Dahlia. FSRU results (top) and guest LNGC Grace Dahlia results (bottom)

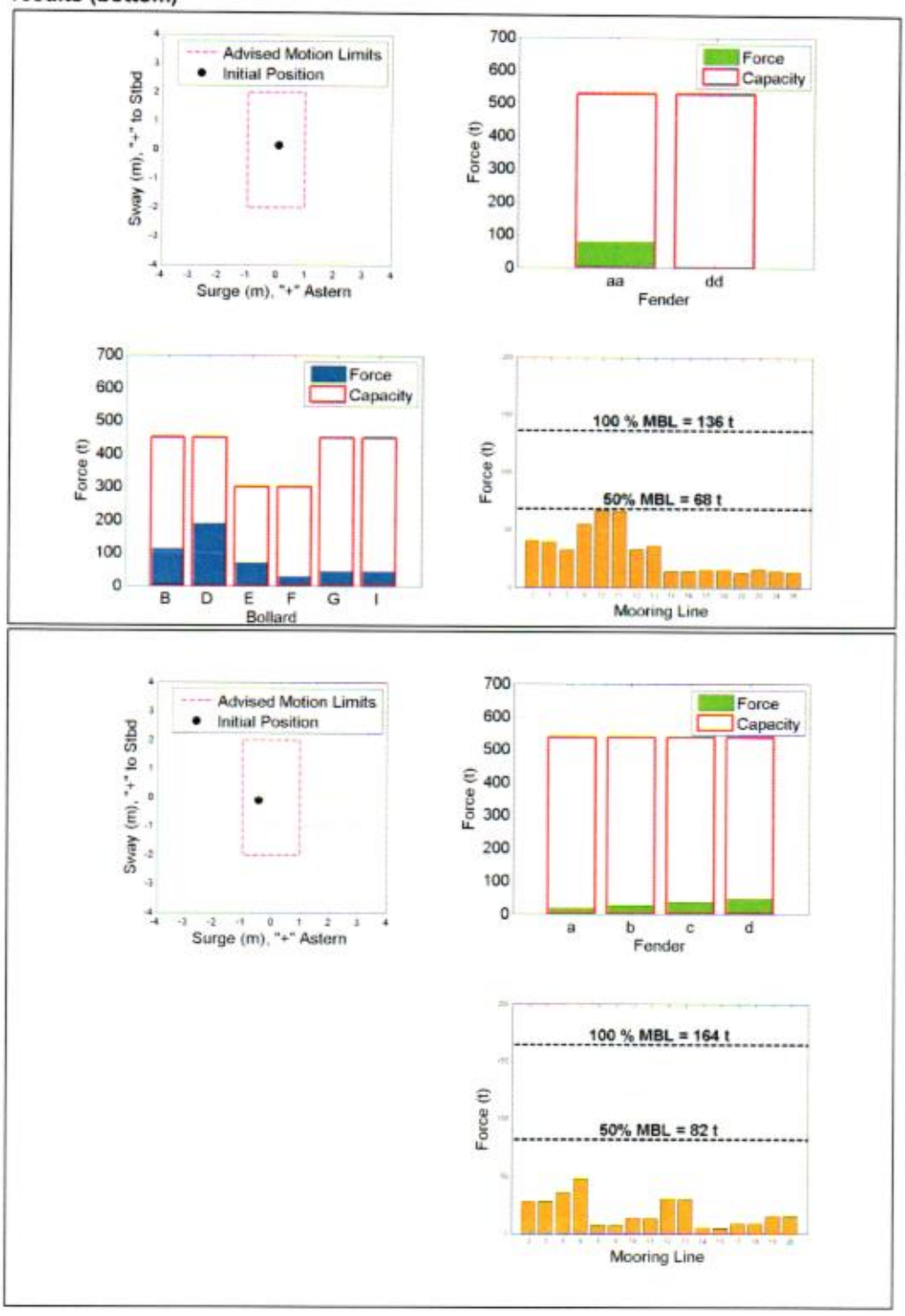
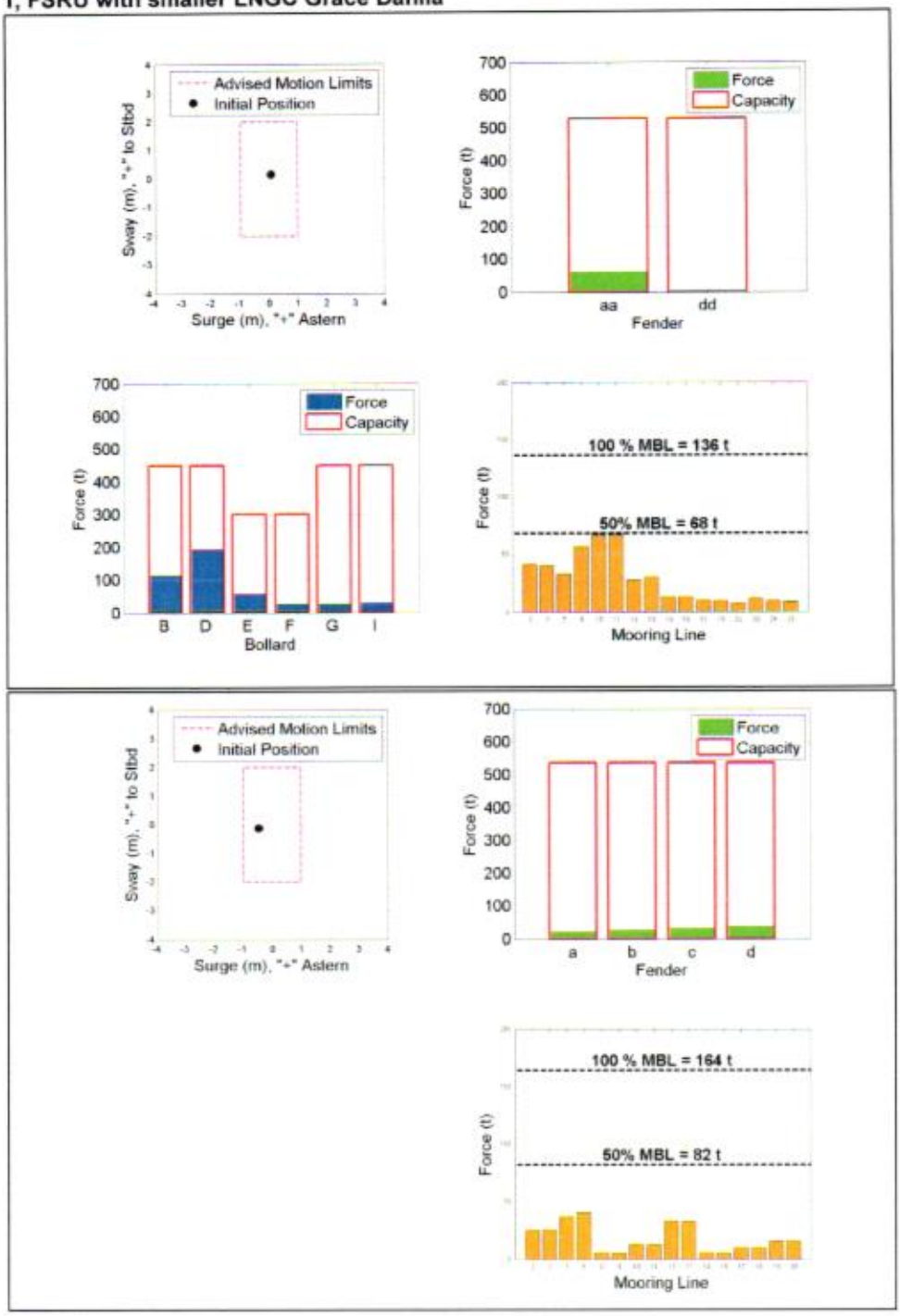


Figure 12: Results of dynamic mooring simulation EC-13 and Fender Configuration FC1-1, FSRU with smaller LNGC Grace Dahlia



5.4.4 Summary of Dynamic Mooring Analysis, with Only Environmental Forces

In general, the mooring capability for FSRU alone is strong under environmental forces. The wind speed limit (1-hour average at elevation 10m Mean Sea Level) under the conservative combinations of current/tide conditions and draft is approximately 41 knots. Wind limits for hosting guest vessels Qmax Al Ghuwairiya and smaller LNGC Grace Dahlia are 33 knots and 25.5 knots, respectively. Wind limits, for FSRU with and without LNGCs, are always imposed by forces in the FSRU's shortest breasting lines.

Table 15 below provides a summary of the dynamic mooring analysis results, including peak motions, line forces, fender forces and bollard forces, all as a percentage of capacities/maximum allowable motions. Results for the FSRU and berth fenders were derived from critical scenarios for the FSRU, listed in Table 13. Similarly, results for guest LNGCs were derived from the results of critical scenarios listed in Table 14. Berth fender forces are provided for all three fender configurations FC1-1, FC1-1-1 and FC2-2; however, since the effect of fender configuration on line forces, bollard forces, vessel motions, and STS fender loads is minimal, these quantities are only reported for configuration FC1-1. Maximum berth fender load (98% of berth fender rated reaction) was observed for the FSRU hosting Qmax with fender configuration FC1-1. Maximum berth fender load in all cases lies on the first ascending part of the fender-deflection curve shown in Figure 4 (left). Numerical values of line forces, bollard forces, and fender forces for all scenarios EC-1 to EC-15 are provided in Table B1 for FSRU and in Table B2 for both guest LNGCs.

Table 16 below shows return periods associated with the three wind limits (41 knots, 33 knots and 25.5 knots). These return periods were estimated from the results of extreme value wind analysis conducted during the pre-FEED stage of the project (Mott MacDonald 2018b). An offshore wind record with length 38 years (OceanWeather Inc., 2017) was used to perform the extreme value analysis. Results indicate that the lowest omni-directional wind limit of 25.5 knots, found for hosting the smaller LNGC Grace Dahlia, has an approximate return period of 1 year. It is to be noted that these winds were computed for a location offshore and are considered conservative for the terminal site since the terminal is located inland, where overland friction tends to reduce mean wind speeds. The wind limits shown in Table 16 are also conservative because they were determined assuming the limiting wind speeds coincided with the worst-case combination of wind direction, tidal current speed, tidal current direction, tidal elevation, and loading condition for both FSRU and guest vessels. Given the extremely low frequency of occurrence of these wind speeds (see Table 16), downtime at the terminal is expected to be minimal.

Table 15. Peak Loads and Motions for Scenarios with Environmental Forces only

Configuration	Peak Surge [m]	Peak Sway [m]	Peak QRH System Load [%]	Peak Line Load [% MBL]	Peak Fender Load [%] FC 1-1	Peak Fender Load [%] FC1-1-1	Peak Fender Load [%] FC 2-2
FSRU	0.05	0.33	42(D*)	50	64	51	37
FSRU	0.17	-0.38	43(A*)	50	98	74	56
Qmax Al Ghuwairiya	0.25	0.60	43(A*)		36 (STS)	36 (STS)	36 (STS)
FSRU	0.11	0.18	43(D*)	50	68	55	40
Grace Dahlia	0.10	0.12	43(D*)		17 (STS)	17 (STS)	17 (STS)

Notes:

1. Peak FSRU sway motions are off the dock, from initial position. Peak FSRU surge motions are largest in either direction, from initial position.
2. Peak guest vessel motions are relative to FSRU, from initial position.
3. Peak fender loads are shown as percentage of berth fender rated reaction for FSRU, and percentage of ship-to-ship fender rated reaction for guest vessels.
4. *Letter in parenthesis shows name of the QRH system that experiences peak load. Peak QRH system loads are maximum horizontal load imparted to each quick-release system, as percentage of capacity assuming 150 metric tons per individual hook (see
5. Table 7 for number of hooks per bollard).

Table 16: Wind Limits and Omni-Directional Return Periods

Mooring Configuration	Wind Limit for Mooring [kts]	Return Period [yr]	Occurrence Frequency [% of hourly records, 38-year period]
FSRU	41	900	0
FSRU with Qmax Al Ghuwairiya	33	35	0.001%
FSRU with Grace Dahlia	25.5	1	0.078%

1. Winds are 1-hour average duration mean winds, at 10m elevation (MSL)
2. Return periods computed based on extreme value analysis described in Mott MacDonald (2018b)
3. Winds are omni-directional.

5.5 Dynamic Mooring Analysis, with Passing Ship Forces

Passing ship hydrodynamic forces were developed assuming a fully laden Qmax (Al Ghuwairiya) moving along the channel centreline at tidal elevation 0.0m (CD), with all berthed vessels at maximum draft. The assumed passing ship conditions are conservative and result in relatively large forces. Passing speeds were assumed to be 7 knots and 10 knots through slack water. Complete results of the passing ship hydrodynamic simulations are shown in the pre-FEED report. Dynamic simulations performed during the FEED stage with passing ship forces also included variable winds. Winds included in the simulations were 20-knot winds (10-minute duration), which are the largest winds for safe navigation of the passing vessels (Port Qasim Authority 2015). Sensitivity analysis was also performed to study the impact of steady 1.5 knots currents with passing Qmax at 7.0 and 10.0 knots (see Section 5.5.3).

All wind directions at 15-degree intervals were considered. All dynamic mooring simulations were performed at tidal elevation 0.0m (CD). To capture worst-case loading due to combined effects of passing vessel and variable winds, the peak load generated by passing vessel was assumed to coincide with the peak wind gust.

5.5.1 Passing Qmax at 7 knots

Dynamic mooring analysis was first performed for FSRU alone and for FSRU with guest LNGCs with passing Qmax at 7 knots. Table 17 below summarizes all simulations that were considered for 7-knots passing speed. Based on the results (peak line load, peak fender load, peak vessel excursion) of these simulations, critical wind directions were identified, and the corresponding critical scenarios are listed in Table 18. Results for the FSRU alone and with guest LNGCs are described further below.

Table 17: Simulations for Combined Passing Vessel and Dynamic Wind effect

Configuration	Passing Vessel Speed [kts]	Mean Wind Speed [kts]	Wind Directions [deg]
FSRU	7.0	19.3*	All directions at 15° intervals
FSRU-QMAX	7.0	19.3*	All directions at 15° intervals
FSRU-GRACE	7.0	19.3*	All directions at 15° intervals

Note: *1-hour mean wind of 19.3 knots is equivalent to 20-knot, 10-minute duration wind speed.

Table 18: Critical Scenarios for Combined Passing Vessel (at 7 knots) and Dynamic Wind effects

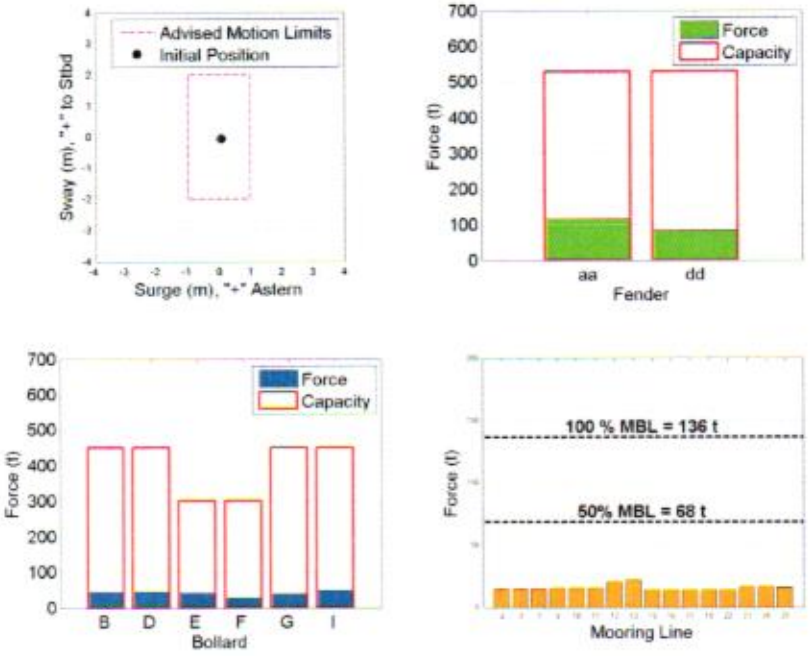
Configuration	Scenario	Selection Criteria	Critical Wind Direction [deg]
FSRU	PV-1	FSRU Line Load	285° TN
	PV-2	Berth Fender Load	315° TN
	PV-3	FSRU Excursion	285° TN
FSRU-QMAX	PV-4	FSRU Line Load	270° TN
	PV-5	Berth Fender Load	300° TN
	PV-6	FSRU Excursion	300° TN
	PV-7	Qmax Line Load	15° TN
	PV-8	STS Fender Load	315° TN
	PV-9	Qmax Excursion	30° TN
FSRU-GRACE DAHLIA	PV-10	FSRU Line Load	270° TN
	PV-11	Berth Fender Load	300° TN
	PV-12	FSRU Excursion	300° TN
	PV-13	Grace Dahlia Line Load	105° TN
	PV-14	STS Fender Load	315° TN
	PV-15	Grace Dahlia Excursion	45° TN

5.5.1.1 Results for FSRU Alone

Dynamic simulations were performed for the FSRU alone configuration with Qmax passing at 7 knots, and 19.3-knot mean wind speed (1-hour duration) blowing from the directions given in Table 17: Simulations for Combined Passing Vessel and Dynamic Wind effect for scenarios PV-

1 to PV-3. Detailed mooring analysis results of line loads, berth fender loads, and vessel excursions for scenarios PV-1, PV-2 and PV-3 are provided in Figure B19, Figure B20 and Figure B21, respectively (see Appendix B). Results indicate that at 7 knots passing speed through the water, the FSRU motions and loads in mooring lines are well within advised motion limits even with forces from maximum navigable winds. Loads in the berth fenders and quick release hooks are well within rated capacities. Results indicate that the distance from passing vessel to FSRU, and appropriate mooring layout have resulted in a good capability to resist passing ship forces when the vessel is alone at berth. Figure 13 below shows results of the dynamic simulation with mean wind speed 19.3 knots from worst-case direction (285° TN, scenario PV-1) that causes the maximum line load of 21.6mt.

Figure 13. DMA results summary for Scenario PV-1, for FSRU alone (fully laden Qmax passing at 7 knots inbound along channel centreline)



5.5.1.2 Results for FSRU with Guest Qmax LNGC Al Ghuwairiya

Results of the analysis show that the presence of the guest LNGCs, and transfer of larger loads to the FSRU, result in larger FSRU vessel motions and loads in the mooring system. Results for six (6) scenarios, PV-4 to PV-9, are shown in Figure B22-B29 in Appendix B. At passing speed 7 knots, forces and moments generate relatively small berthed vessel motions (within limits advised by PIANC, 1995), and forces in all mooring system components are well within limits advised by OCIMF (2008). As mentioned above in Table 18, scenarios PV-4 and PV-7 generate the maximum loads in FSRU mooring lines and in Qmax mooring lines, respectively. Figure 14 shows results of the dynamic simulation for scenario PV-4 (wind direction 270° TN) that produces maximum loads in the FSRU's mooring lines. Figure 15 shows similar results for scenario PV-7 (wind direction 15° TN) that causes peak loads in guest LNGC Qmax's mooring lines.

Figure 14: DMA results summary for Scenario PV- 4 (fully laden Qmax passing at 7 knots inbound along channel centreline, winds from 270 deg TN), for FSRU with LNGC Qmax Al Ghuwairiya. FSRU results (top) and LNGC Qmax results (bottom)

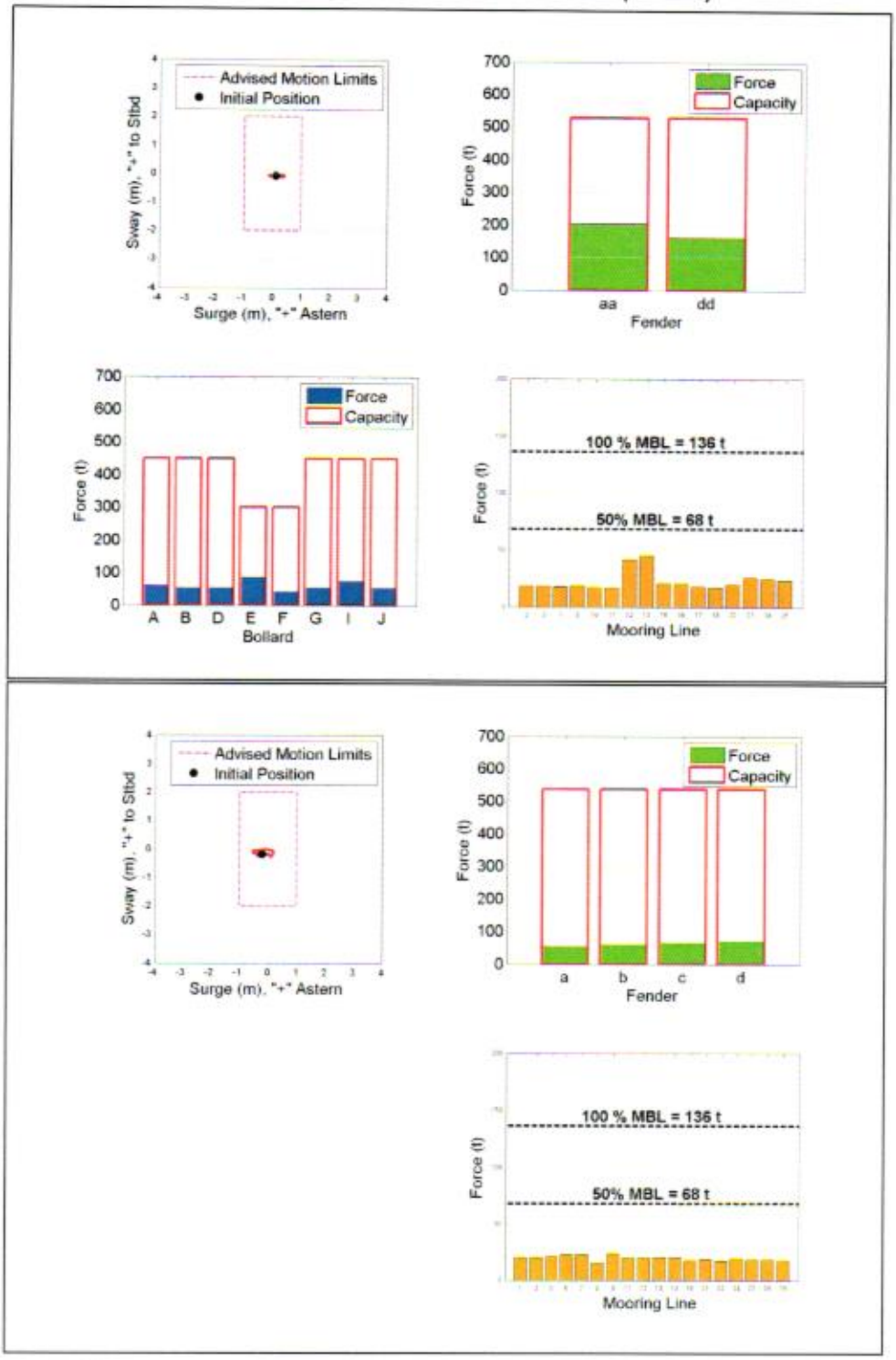
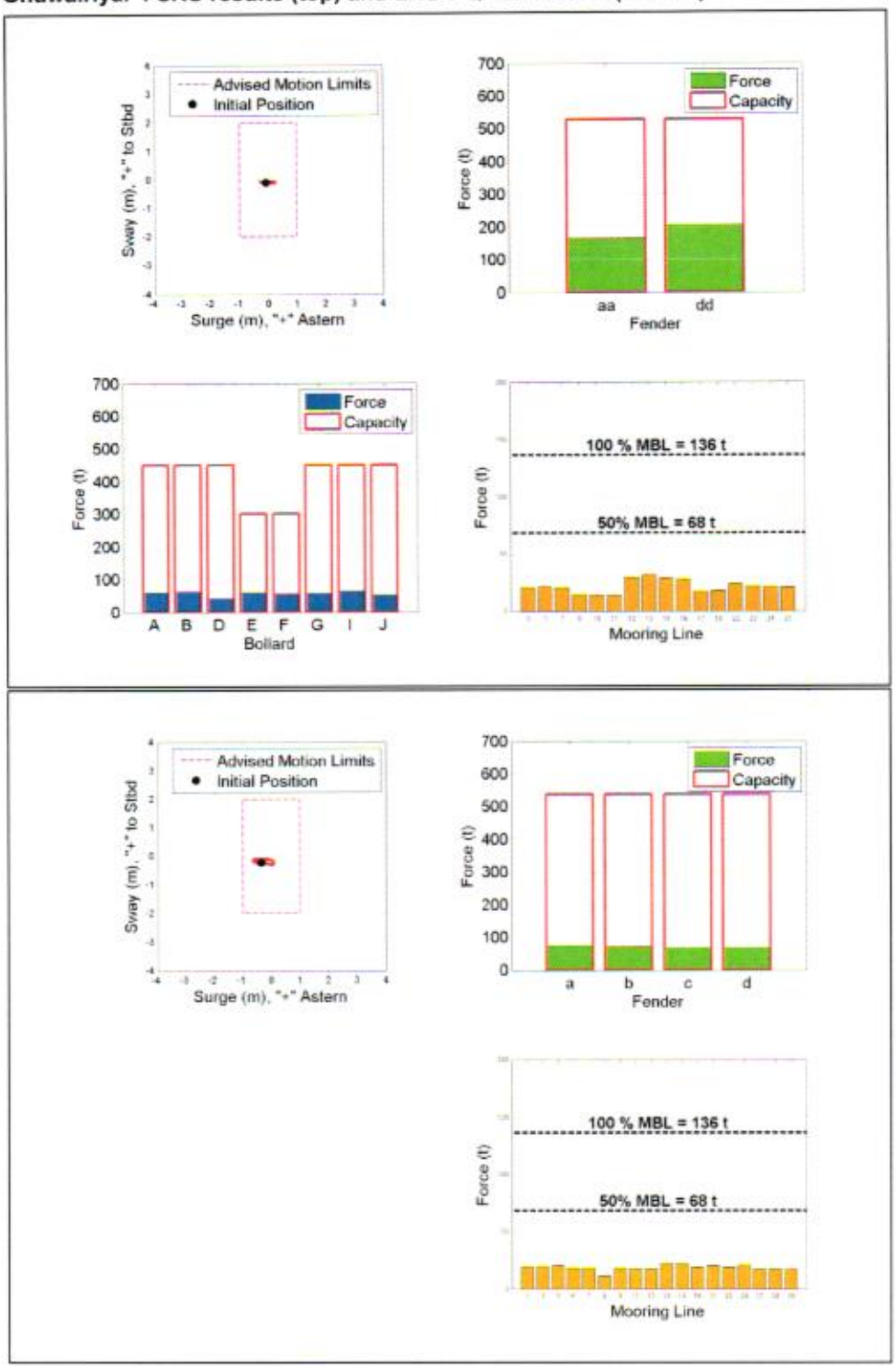


Figure 15: DMA results summary for Scenario PV- 7 (fully laden Qmax passing at 7 knots inbound along channel centreline, winds from 15 deg TN), for FSRU with LNGC Qmax Al Ghuwairiya. FSRU results (top) and LNGC Qmax results (bottom)



5.5.1.3 Results for FSRU with Guest Smaller LNGC Grace Dahlia

Results of the analysis show that the presence of the guest LNGCs, and transfer of larger loads to the FSRU, result in larger FSRU vessel motions and loads in the mooring system. Results for six (6) Scenarios PV-10 to PV-15 are shown in Figures B30-B37 in Appendix B. At passing speed 7 knots, forces and moments generate relatively small berthed vessel motions (within limits advised by PIANC, 1995), and forces in all mooring system components are well within limits advised by OCIMF (2008). As mentioned above, Scenarios PV-10 and PV-13 result in peak loads in the FSRU's mooring lines and in LNGC Grace Dahlia's mooring lines, respectively. Figure 16 shows results of the dynamic simulation for Scenario PV-10 (wind direction 270° TN) that produces the peak load in the FSRU's mooring lines. Figure 17 shows results for Scenario PV-13 (wind direction 105° TN) that results in the peak line load in the guest LNGC Grace Dahlia's mooring lines.

5.5.2 Passing Qmax at 10 knots

Based on the results of dynamic mooring analysis simulations for scenarios listed above in Table 18, it is observed that the passing vessel effects for the FSRU with Qmax case generate maximum line loads in FSRU and Qmax lines, maximum berth fender loads, and maximum vessel excursions for both guest and host vessels (rather than FSRU alone or FSRU with LNGC Grace Dahlia). Therefore, to investigate the impact of passing vessel at 10 knots, only FSRU with Qmax configuration was considered. Variable winds at 15-degree intervals were considered and based on the results (peak line load, peak fender load, peak vessel excursion) of these simulations, critical wind directions were identified. The corresponding critical scenarios are listed in Table 19. Results for the dynamic mooring analysis are described further below.

Table 19: Critical Scenarios for Combined Passing Vessel (at 10 knots) and Dynamic Wind effects

Configuration	Scenario	Selection Criteria	Critical Wind Direction [deg]
FSRU-QMAX	PV-16	FSRU Line Load	240° TN
	PV-17	Berth Fender Load	240° TN
	PV-18	FSRU Excursion	240° TN
	PV-19	Qmax Line Load	240° TN
	PV-20	STS Fender Load	240° TN
	PV-21	Qmax Excursion	240° TN

As shown in Table 19 for FSRU with Qmax configuration, peak line loads and vessel excursions for both host and guest vessels, and peak fender loads (for both berth and STS fenders) are all observed for winds blowing from 240 degrees TN. Scenarios PV-16 to PV-21 are identical (same wind speeds and directions), and therefore the results shown in Figure 18 are applicable to all scenarios PV-16 to PV-20. Motion time histories for surge and sway motions are shown in Figure B38 in Appendix B. Results show that, at 10 knots passing speed, surge motion for both guest and host vessels exceed limits advised by PIANC (1995), and forces in FSRU mooring lines exceed limits advised by OCIMF (2008). However, both berth and STS fender loads are found to be within rated capacities of 528mt (5176 kN) and 536mt (5257 kN), respectively.

Figure 16: DMA results summary for Scenario PV-10 (fully laden Qmax passing at 7 knots inbound along channel centreline, winds from 270 deg TN), for FSRU with LNGC Grace Dahlia. FSRU results (top) and LNGC Qmax results (bottom)

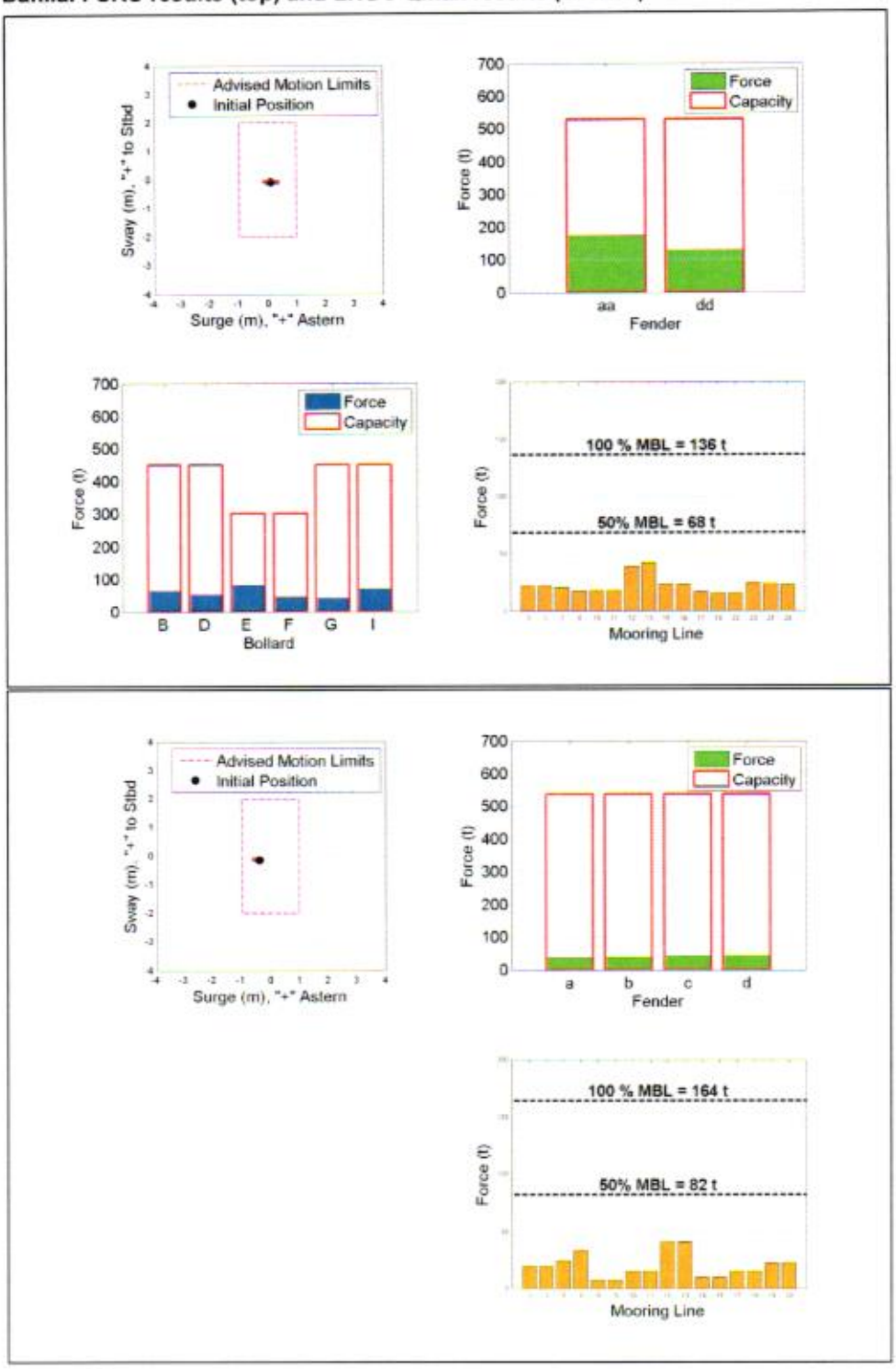


Figure 17: DMA results summary for Scenario PV-13 (fully laden Qmax passing at 7 knots inbound along channel centreline, winds from 105 deg TN), for FSRU with LNGC Grace Dahlia. FSRU results (top) and LNGC results (bottom)

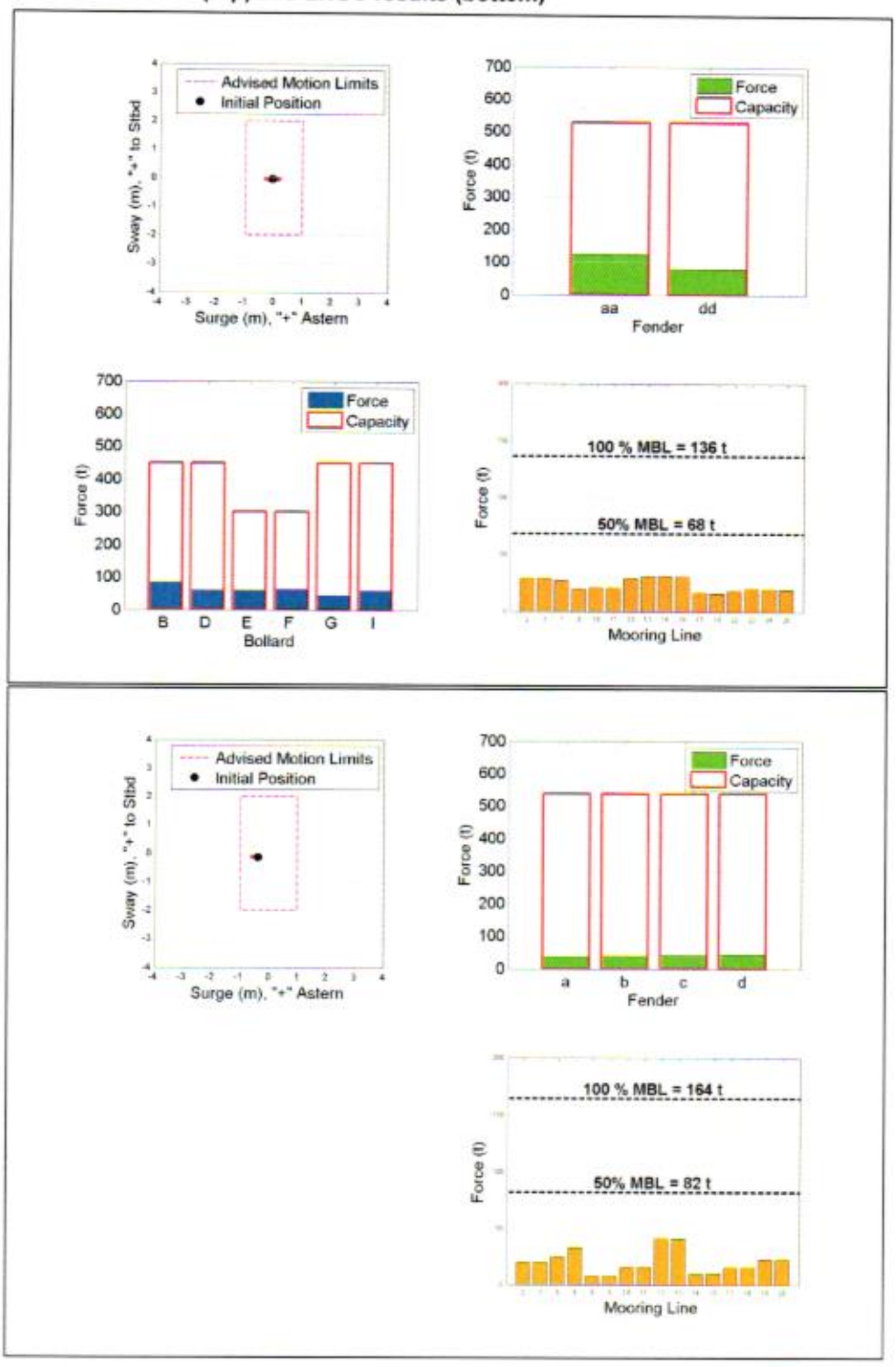
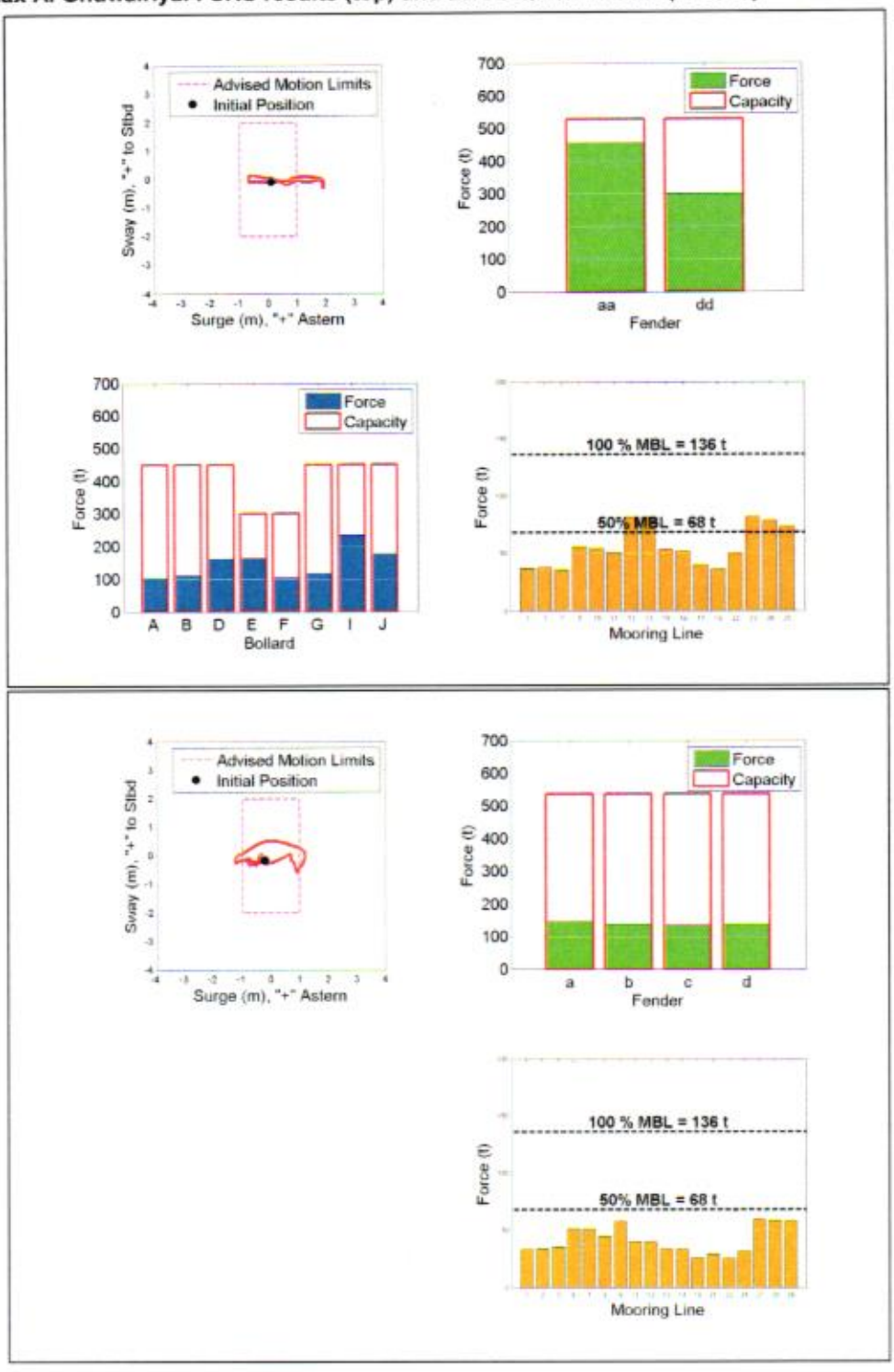


Figure 18: DMA results summary for Scenarios PV-16 to PV-21 (fully laden Qmax passing at 10 knots inbound along channel centreline, winds from 240 deg TN), for FSRU with Qmax Al Ghuwairiya. FSRU results (top) and LNGC Qmax results (bottom)



5.5.3 Effects of Steady Currents on Passing Ship Mooring Results

To identify the impact of passing vessel effects on mooring performance in the presence of steady currents around berthed vessels, scenario PV-5 (7 knots passing speed) was simulated with 1.5 knots steady currents from 300 deg TN and scenario PV-17 (10 knots passing speed) was simulated with 1.5 knots steady currents from 240 deg TN. For scenario PV-5, the current direction was assumed to be the same as the wind direction. However, for 10 knots passing speed case, multiple current directions were analyzed and found that currents from 240 deg TN produced maximum fender loads. DMA summary results for scenario PV-5 are shown in Figure B23 in Appendix B. Figure 19 shows FSRU results for scenario PV-5 without steady currents (top) and with steady currents (bottom). Figure B39 shows DMA summary results for scenario PV-17 with steady currents. It is observed for scenario PV-5 that the presence of steady currents increases the maximum fender load by approximately 15%, however, the presence of steady currents does not change the maximum fender load for scenario PV-17. This is likely due to significantly higher passing vessel loads and moments at 10 knots passing speed that the effects of currents on fender loads is marginal. Effects of including steady currents on line loads, vessel excursion and bollard loads were found to be marginal for both scenarios.

5.5.4 Summary of Passing Ship Dynamic Mooring Analysis

In general, the FSRU demonstrates good mooring capability under passing ship forces, due to the longitudinal (surge) restraint capacity in its mooring arrangement. The likely passing speed at which mooring safety is compromised when the FSRU is alone at berth was not determined as part of this analysis. Table 20 below provides a summary of the dynamic mooring analysis results, including peak motions, peak line forces, and peak fender and bollard forces, all as a percentage of capacities. For both host and guest vessels, forces in mooring lines, bollards and fenders, and vessel motions are within advised limits at 7 knots passing speed. However, at 10 knots passing speed, surge motion for both guest and host vessels exceed limits advised by PIANC (1995), and forces in FSRU mooring lines exceed limits advised by OCIMF (2008). However, both berth and STS fender loads are within rated capacities of 528mt (5176 kN) and 536mt (5257 kN), respectively. Maximum berth fender load in all cases lies on the first ascending part of the fender-deflection curve shown in Figure 4 (left). Numerical values of line forces, bollard forces, and fender forces for all scenarios PV-1 to PV-21 are provided in Table B3 for FSRU and in Table B4 for both guest LNGCs.

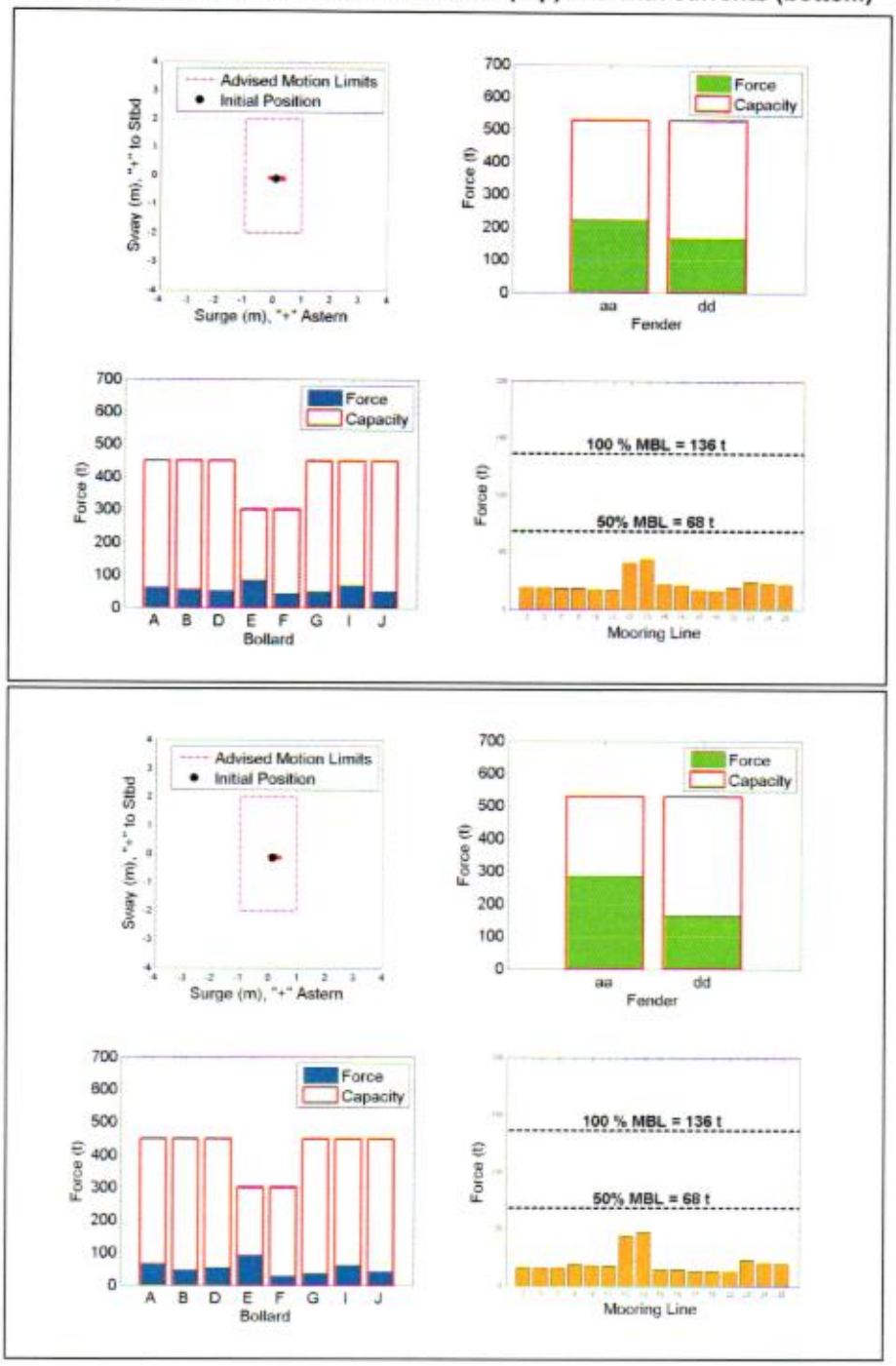
Table 20. Peak Loads and Motions for All Passing Ship Scenarios

Scenario	Berthed Vessel(s)	Speed (kts)	Peak Surge [m]	Peak Sway [m]	Peak QRH System Load [%]	Peak Line Load [% MBL]	Peak Fender Load [%]
1	FSRU	7	0.07	0.03	11(I*)	16	24
2	FSRU	7	0.32	0.15	29 (E*)	34	43
	Qmax Al Ghuwairiya	7	0.42	0.13	--	18	15 (STS)
3	FSRU	7	0.32	0.11	28(E*)	31	34
	Grace Dahlia	7	0.21	-0.10	--	26	11 (STS)
4	FSRU	10	1.96	0.33	52 (I)	60	87
	Qmax Al Ghuwairiya	10	1.15	0.55	--	43	27 (STS)

Notes:

1. Peak FSRU sway motions are off the dock, from initial position. Peak FSRU surge motions are largest in either direction, from initial position.
2. Peak guest vessel motions are relative to FSRU, from initial position.
3. Peak fender loads are shown as percentage of shore fender rated reaction for FSRU, and percentage of ship-to-ship fender rated reaction for guest vessels.
4. *Letter in parenthesis shows name of the QRH system that experiences peak load. Peak QRH system loads are maximum horizontal load imparted to each quick-release system, as percentage of capacity assuming 150 metric tons per individual hook (see Table 4 for number of hooks per bollard).

Figure 19: DMA results summary for Scenario PV-5 (fully laden Qmax passing at 7 knots inbound along channel centreline, winds from 300 deg TN), for FSRU with Qmax Al Ghuwairiya. FSRU results without currents (top) and with currents (bottom)



6 References

DNV GL, 2018. DNVGL-RP-C205 Environmental conditions and environmental loads - Recommended Practice.

Fenical, S., Kolomiets, P., Kivva, S., and M. Zheleznyak. 2006. *Numerical Modeling of the Impacts on Berthed Vessels and Shorelines*. International Conference on Coastal Engineering.

Mott MacDonald. 2018a. *Mooring Analysis and Arrangement – Pakistan FSRU Pre-FEED Study*. August 13, 2018.

Mott MacDonald. 2018b. *Pakistan FSRU Pre-FEED Marine Studies – Wave Modelling*. September 10, 2018.

OceanWeather Inc., 2017. Global Reanalysis of Ocean Waves Fine Northern Indian Ocean Hindcast (GFNI). Project Description. Revised March 22, 2017.

Oil Companies Marine Forum (OCIMF). 2008. *Mooring Equipment Guidelines - 3rd Edition*, 2008.

Permanent International Association of Navigation Congresses (PIANC). 1995. *Criteria for Movement of Moored Ships in Harbours: A Practical Guide*. Working Group 24, Supplement to Bulletin #88. PIANC 1995.

Port Qasim Authority. 2015. *Standard Operating Procedures for Operating LNG Carriers*. PQA Notice 001/ 15 Dated 11th April 2015. Addendum to Port Qasim Regulations 1981.

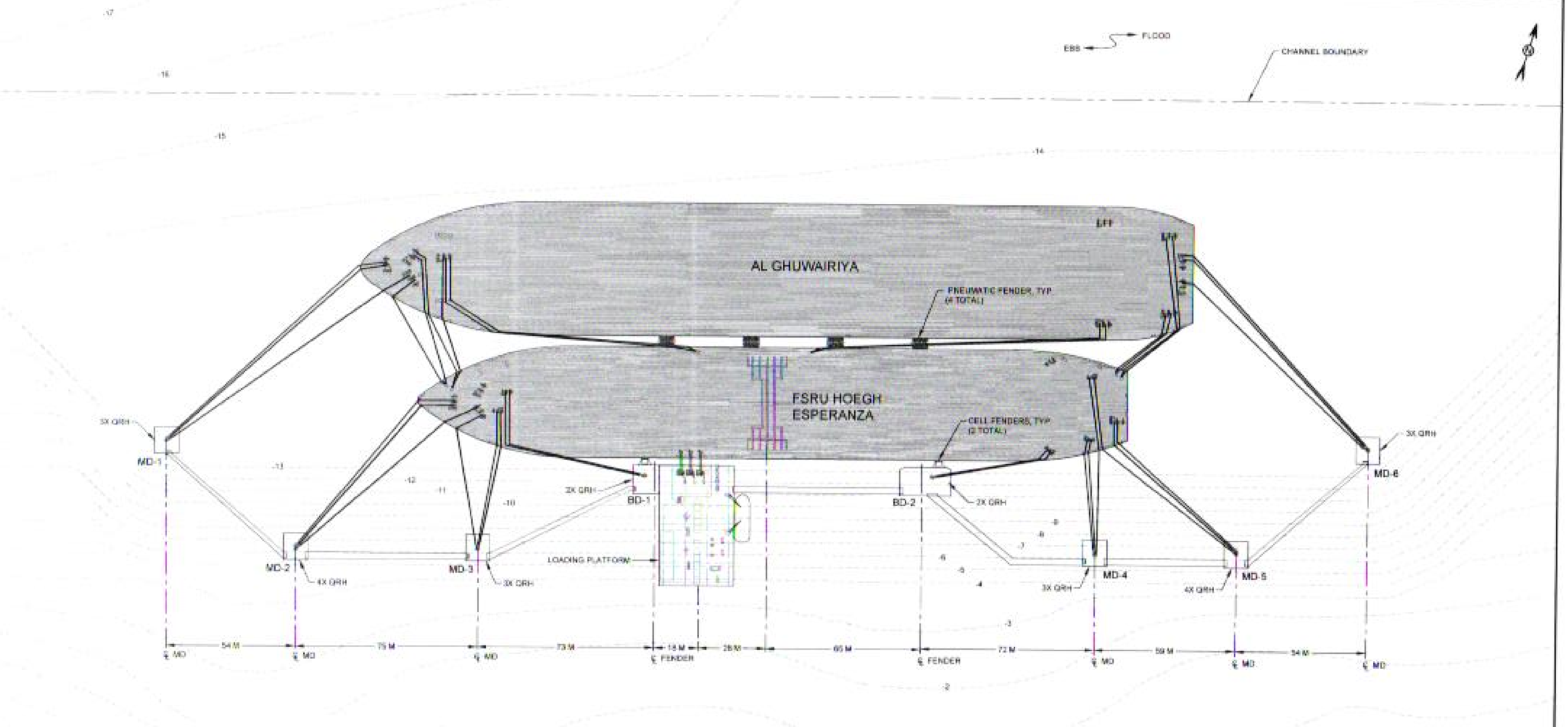
RINA. 2018. *Navigation Simulations for Tabeer LNG Terminal at Port Qasim: Navigation Study Report*. Doc. No. P0009270-1-H3 Rev. 3 – November 2018.

Appendices

A. Mooring Arrangement Drawings

B. Dynamic Mooring Analysis Results Figures (FEED)

A. Mooring Arrangement Drawings



NOTES:

1. WINCH LOCATIONS APPROXIMATE
2. EXCEPT IN PROPOSED DREDGING AREA, CONTOURS FROM SURVEY TAKEN JUNE 13, 2018
3. TERMINAL LAYOUT CONCEPTUAL IN NATURE AND ONLY SHOWN FOR THE PURPOSES OF MOORING ANALYSIS
4. LNG CARRIER PORT SIDE MANIFOLD LOCATED 250M FROM NAVIGATION CHANNEL CENTERLINE

0 20 40
SCALE 1" = 20

MOTT MACDONALD

Rev	Date	Drawn	Description	Ch'k'd	App'd
	3/14/19	SDK	CONCEPTUAL		

DRAFT

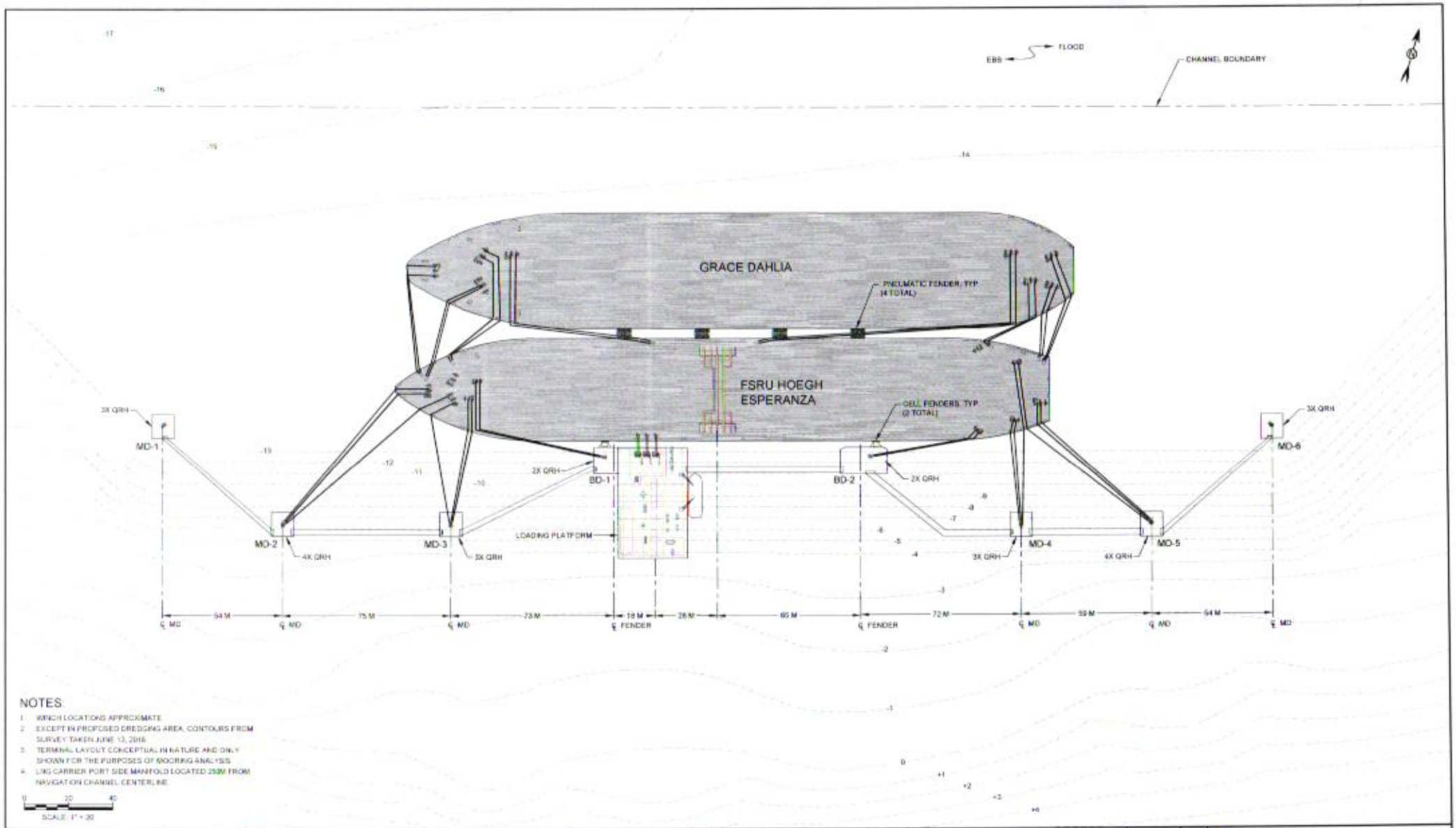
Project Number: 398607 | Sheet: 2 | Total: 2

Designed: S. FENTON | Drawn: S. KOMMINENI | Eng check | Coordination | Dwg check | Approved | Scale at ANSI D | Status | Rev | Security | Drawing Number

Title: MOORING ARANGEMENT PLAN

FSRU HOEGH ESPERANZA & AL GHUWAIRIYA

53 / 99



NOTES:

1. WINCH LOCATIONS APPROXIMATE.
2. EXCEPT IN PROPOSED DREDGING AREA, CONTOURS FROM SURVEY TAKEN JUNE 13, 2018.
3. TERMINAL LAYOUT CONCEPTUAL IN NATURE AND ONLY SHOWN FOR THE PURPOSES OF MOORING ANALYSIS.
4. LNG CARRIER PORT SIDE MANIFOLD LOCATED 250M FROM NAVIGATION CHANNEL CENTERLINE.

0 20 40
SCALE: 1" = 20'

M MOTT MACDONALD

Rev	Date	Drawn	Description	Chkd	Appd
	3/14/19	SDK	CONCEPTUAL		

DRAFT

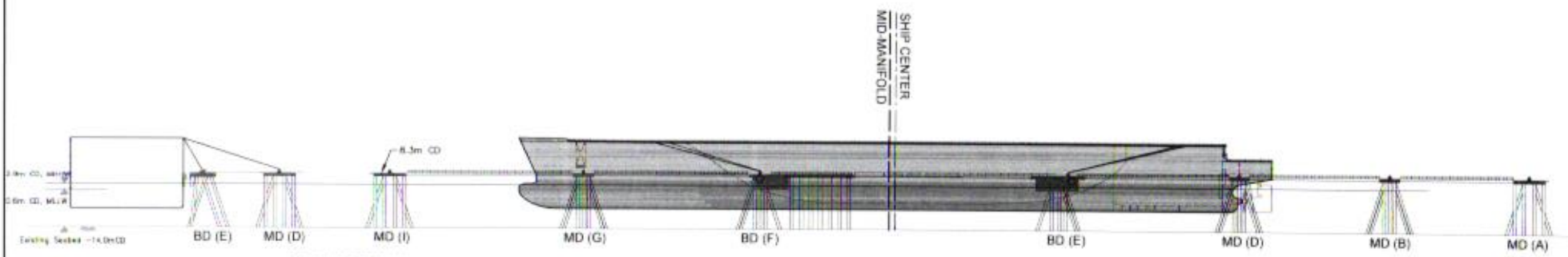
Project Number	SEQ	Total
398607	1	2

Designed	S. FENICH	Engineer	
Drawn	S. KHARGHAM	Coordinator	
Dwg check		Approved	
Scale at ANSI D	Status	Rev	Security
Drawing Number			

MOORING ARANGEMENT PLAN

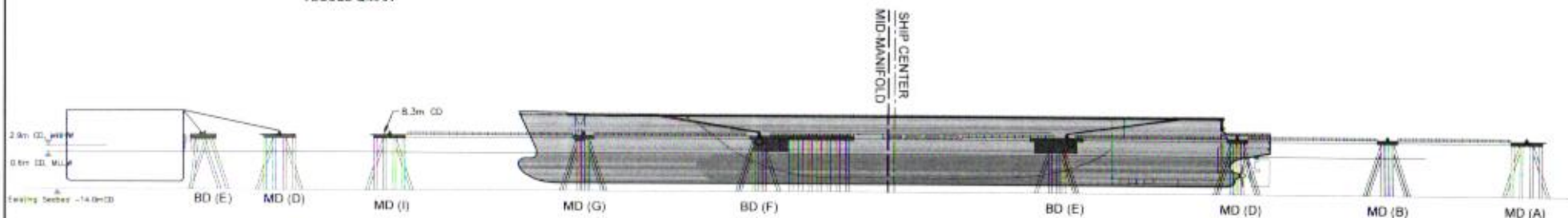
FSRU HOEGH ESPERANZA & GRACE DAHLIA

54 / 99



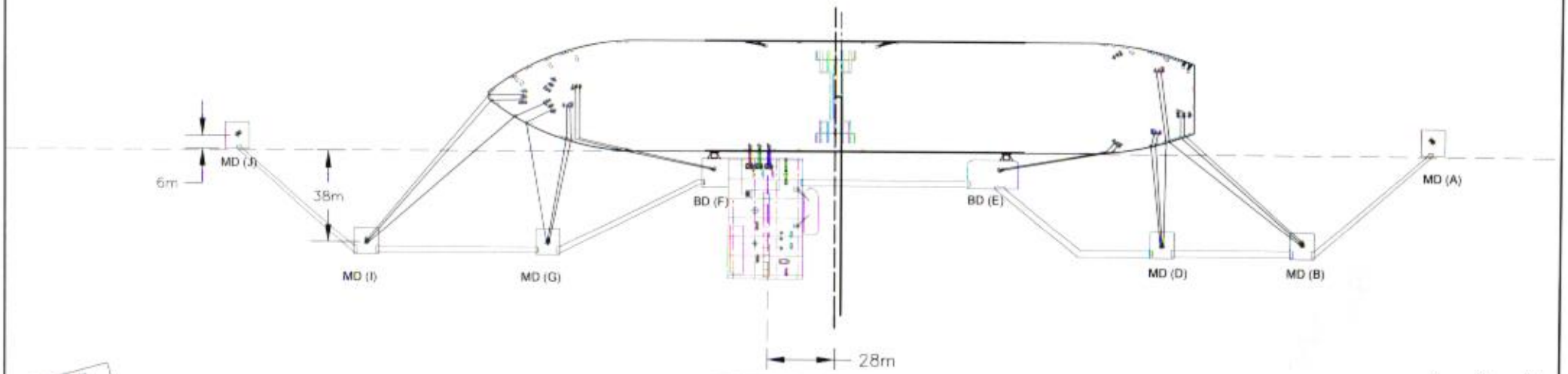
MD (J) NOT SHOWN
WHICH IS USED BY GUEST
VESSEL QMAX

PORT ELEVATION (BALLASTED) AT MHHW



MD (J) NOT SHOWN
WHICH IS USED BY GUEST
VESSEL QMAX

PORT ELEVATION (LOADED) AT MLLW



PORT MOORING PLAN

SCALE IN METERS

B. Dynamic Mooring Analysis (DMA) Results Figures (FEED)

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

B 1 DMA Results, with Environmental Forces Only

B 1.1 Scenarios with worst case FSRU line load (Fender Configuration FC 1-1)

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

Figure B1: DMA results summary for Scenario EC-1 (41 knots winds from 150 deg TN, 2.3 knots currents from 95 deg TN, for FSRU Hoegh Esperanza, no LNGC present

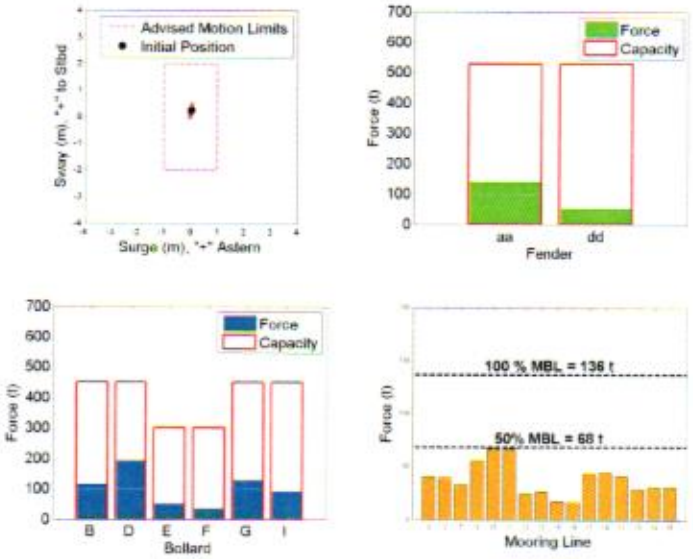


Figure B2: DMA results summary for Scenario EC-4 (33 knots winds from 150 deg TN, 2.3 knots currents from 95 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present

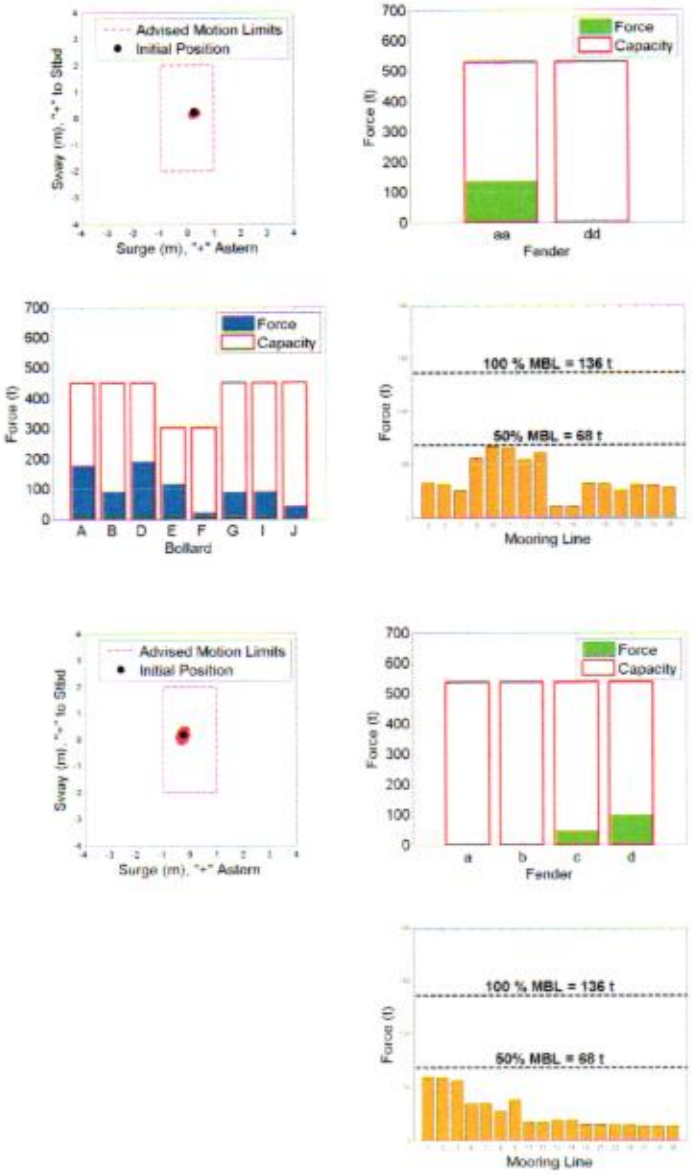
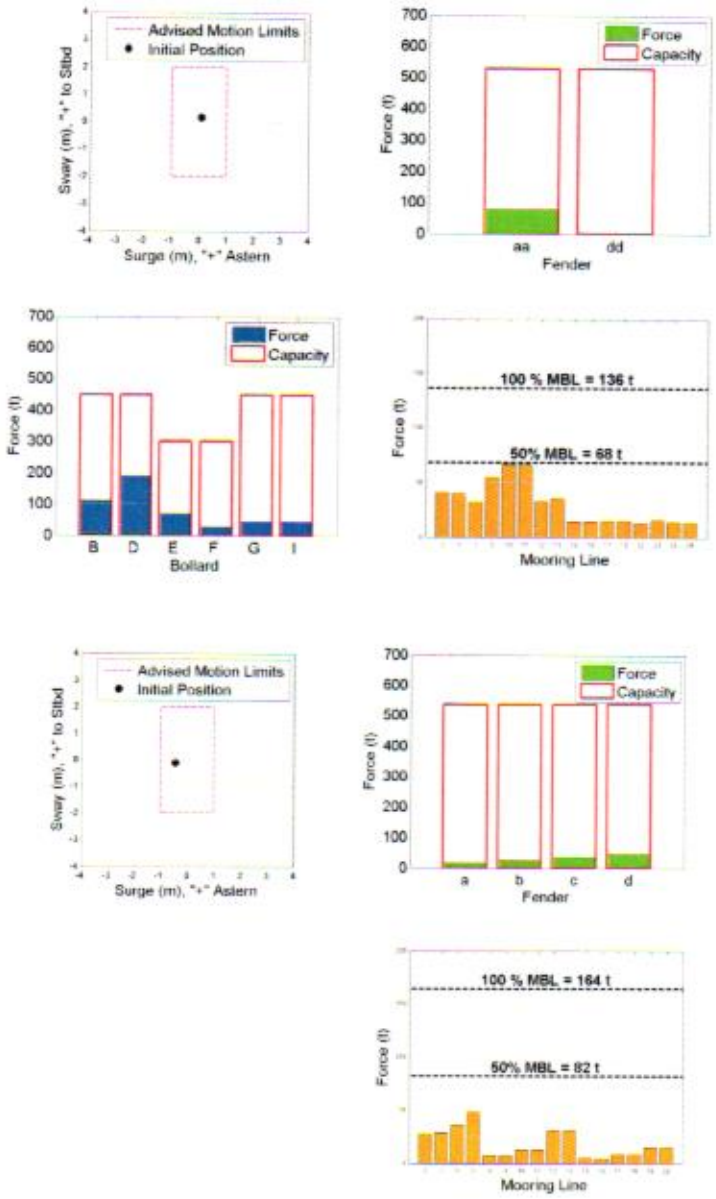


Figure B3: DMA results summary for Scenario EC-7 (winds from 135 deg TN, 2.3 knots currents from 95 deg TN), for FSRU Hoegh Esperanza with LNGC Grace Dahlia present



B 1.2 Scenarios with worst case berth fender load (All Fender Configurations)

B 1.2.1 Fender configuration FC 1-1

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

Figure B4: DMA results summary for Scenario EC-2 (41 knots winds from 25 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza, no LNGC present

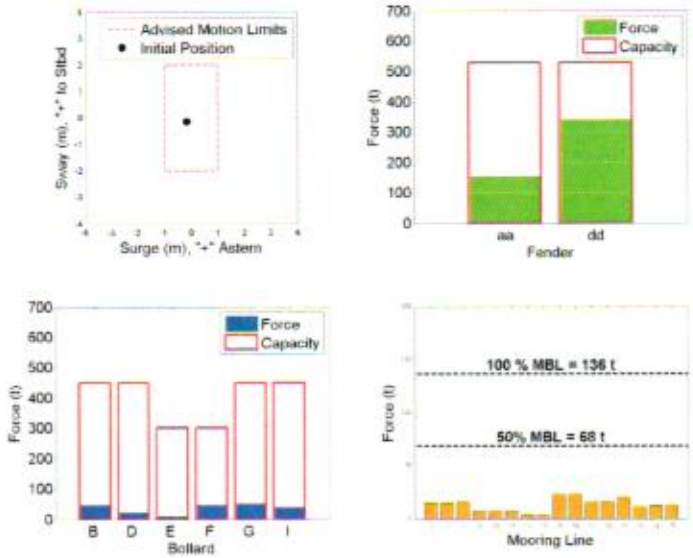


Figure B5: DMA results summary for Scenario EC-5 (33 knots winds from 35 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present

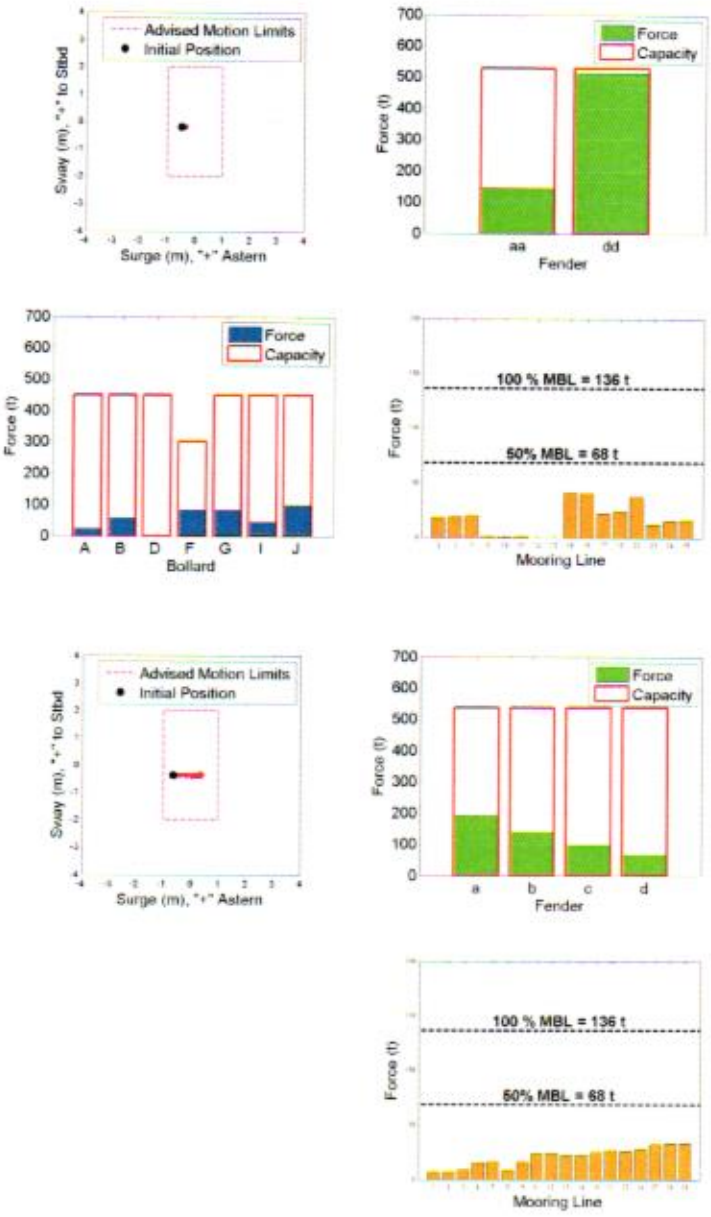
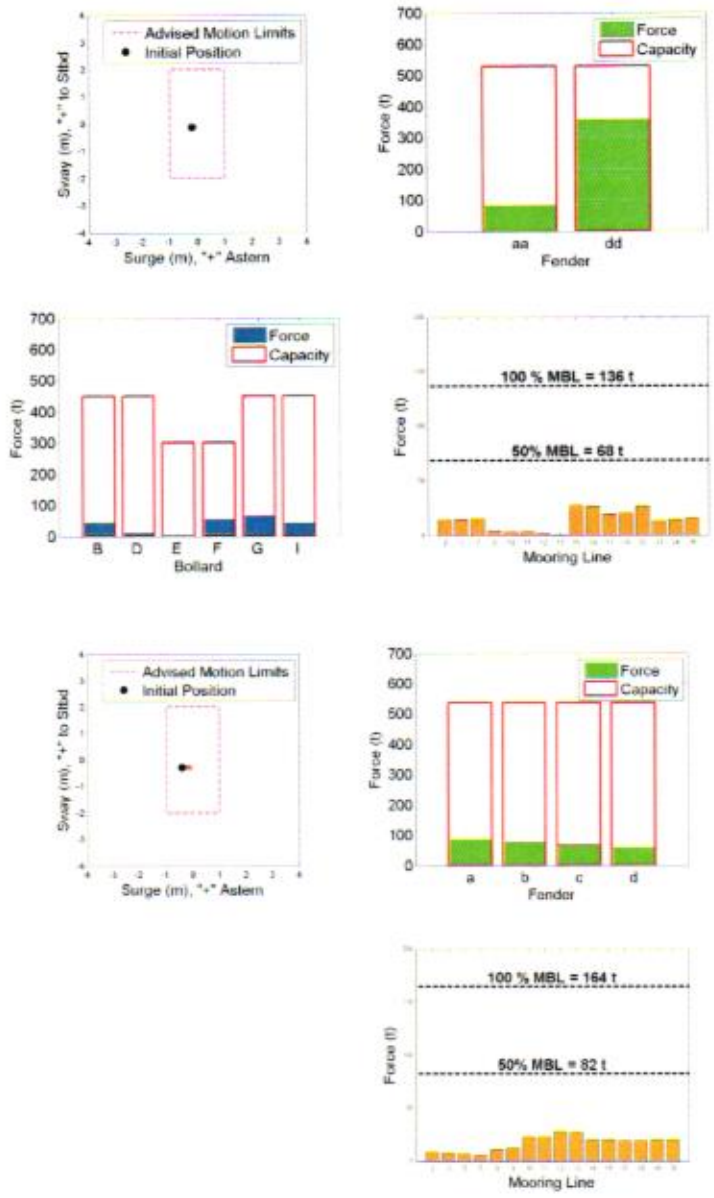


Figure B6: DMA results summary for Scenario EC-8 (25.5 knots winds from 25 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza with smaller LNGC Grace Dahlia present



B 1.2.2 Fender configuration FC 2-2

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

Figure B7: DMA results summary for Scenario EC-2 (41 knots winds from 25 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza, no LNGC present

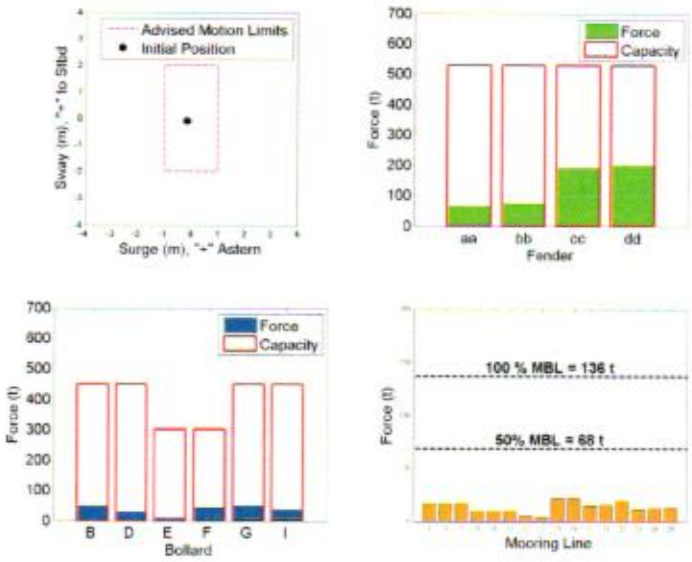


Figure B8: DMA results summary for Scenario EC-5 (33 knots winds from 35 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present

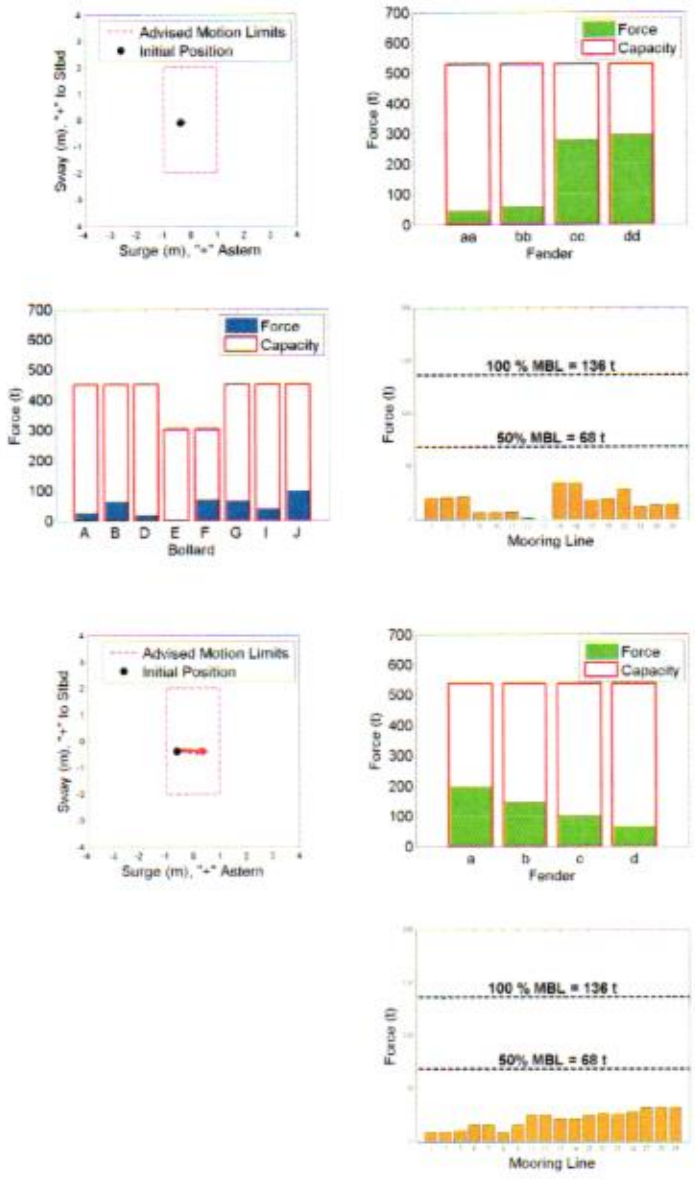
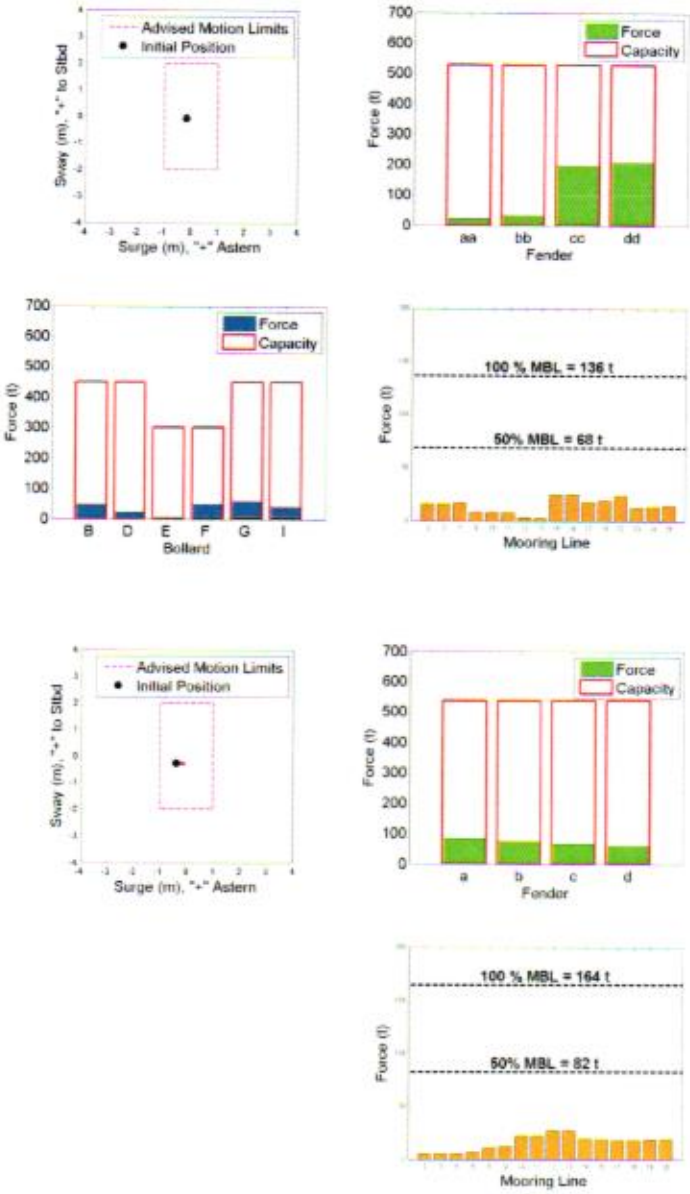


Figure B9: DMA results summary for Scenario EC-7 (winds from 135 deg TN, 2.3 knots currents from 95 deg TN), for FSRU Hoegh Esperanza with LNGC Grace Dahlia present



B 1.2.3 Fender Configuration FC 1-1-1

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

Figure B10: DMA results summary for Scenario EC-2 (41 knots winds from 25 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza, no LNGC present

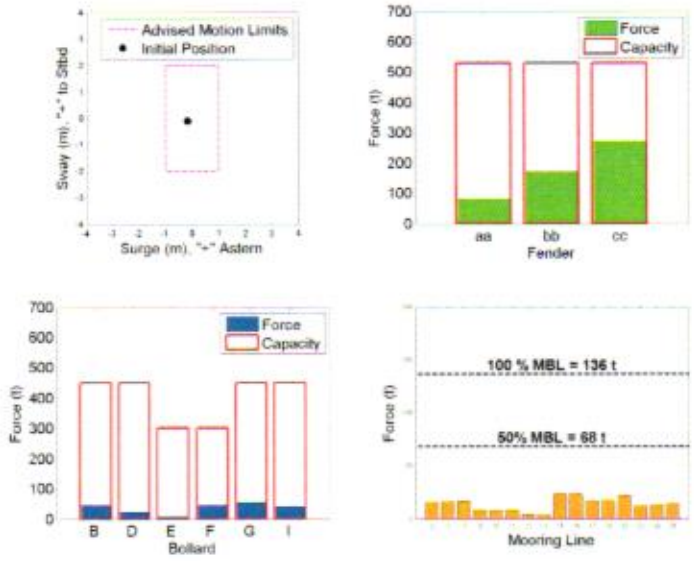


Figure B11: DMA results summary for Scenario EC-5 (33 knots winds from 35 deg TN, 2.3 knots currents from 55 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present

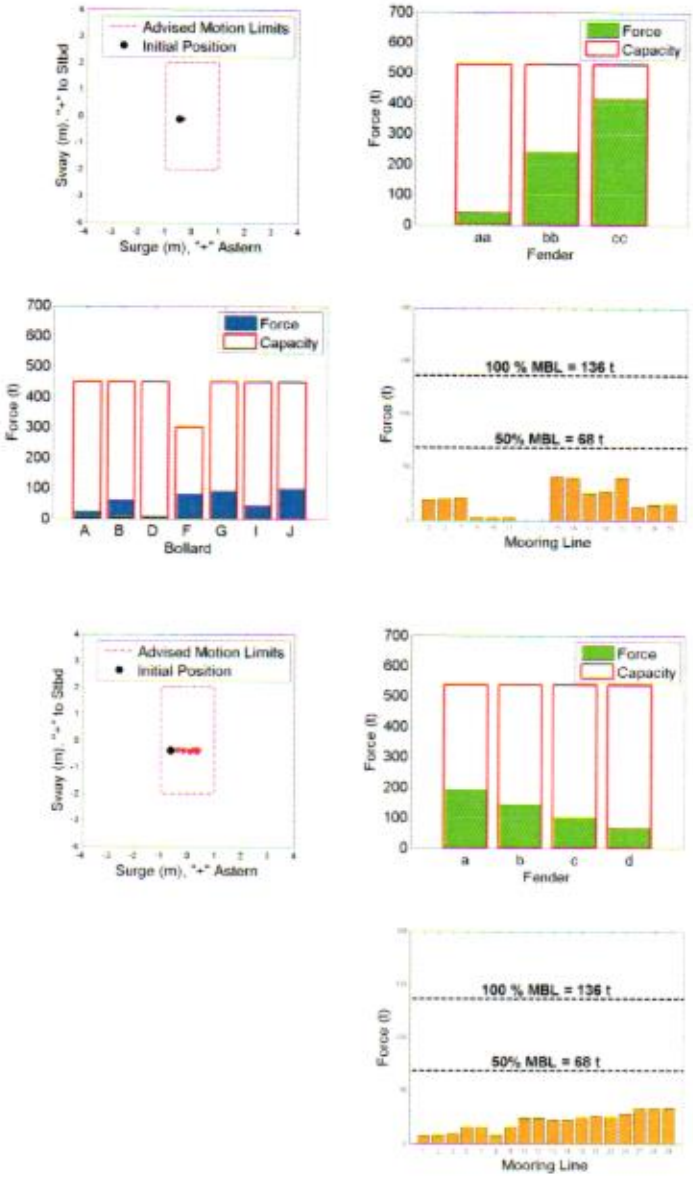
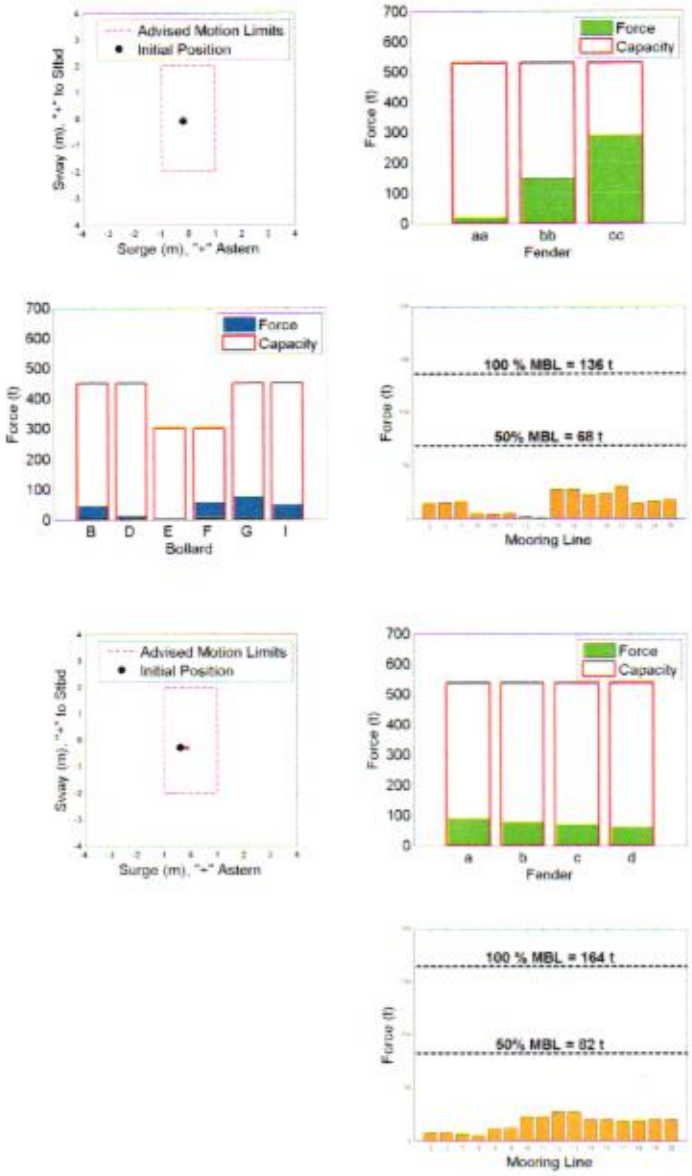


Figure B12: DMA results summary for Scenario EC-8 (winds from 135 deg TN, 2.3 knots currents from 95 deg TN), for FSRU Hoegh Esperanza with LNGC Grace Dahlia present



B 1.3 Scenarios with worst case FSRU excursion (Fender Configuration FC 1-1)

Figure B13: DMA results summary for Scenario EC-3 (41 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza, no LNGC present

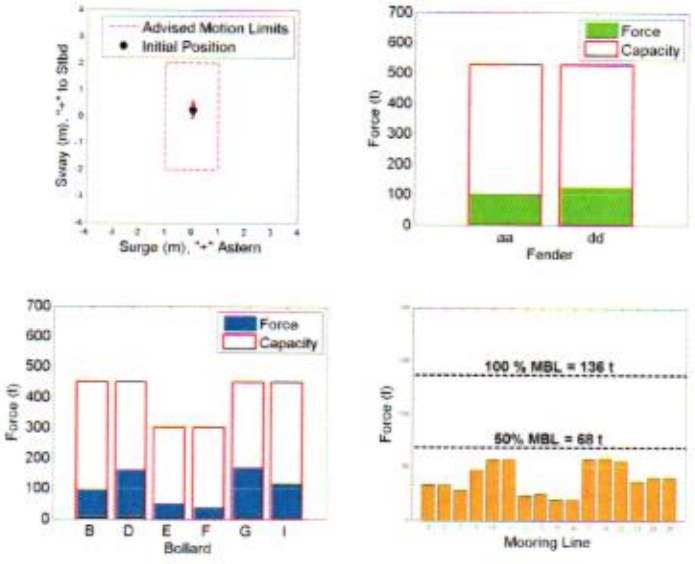


Figure B14: Time histories of surge and sway motions for Scenario EC-3 (41 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza, no LNGC present

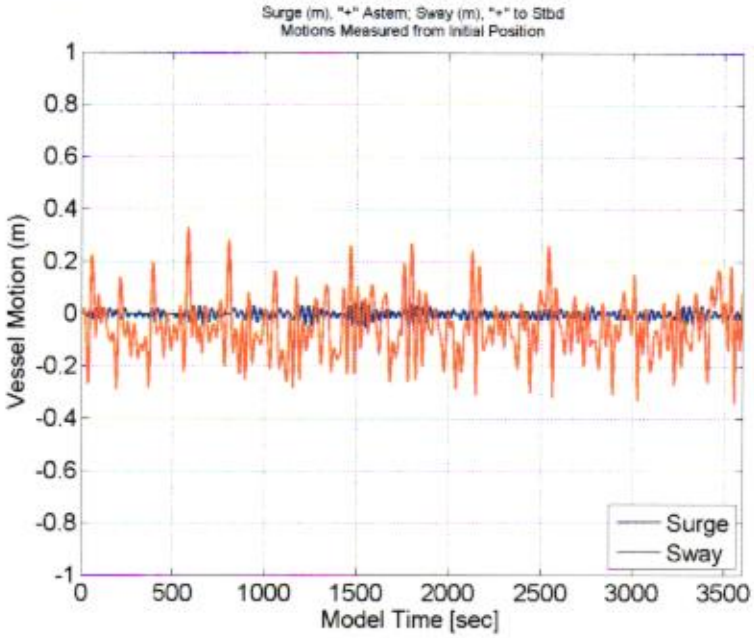


Figure B15: DMA results summary for Scenario EC-6 (33 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present

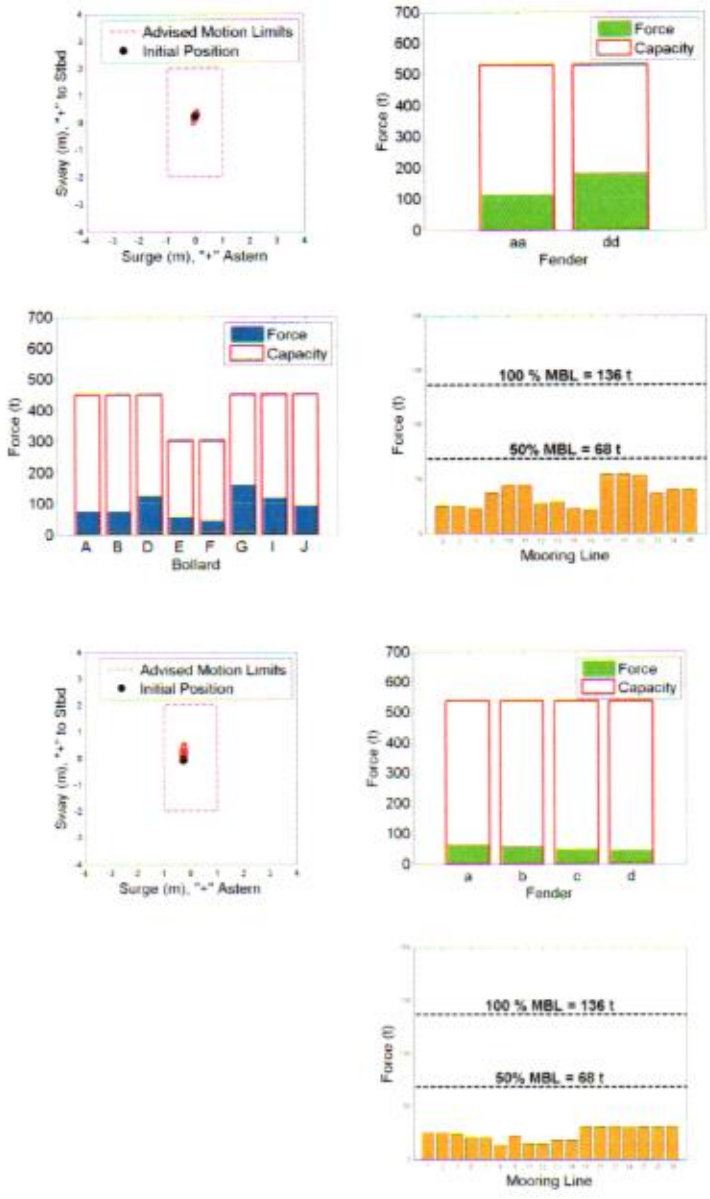


Figure B16: Time histories of surge and sway motions for Scenario EC-6 (33 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya present. FSRU motions (top) and Qmax motions (bottom)

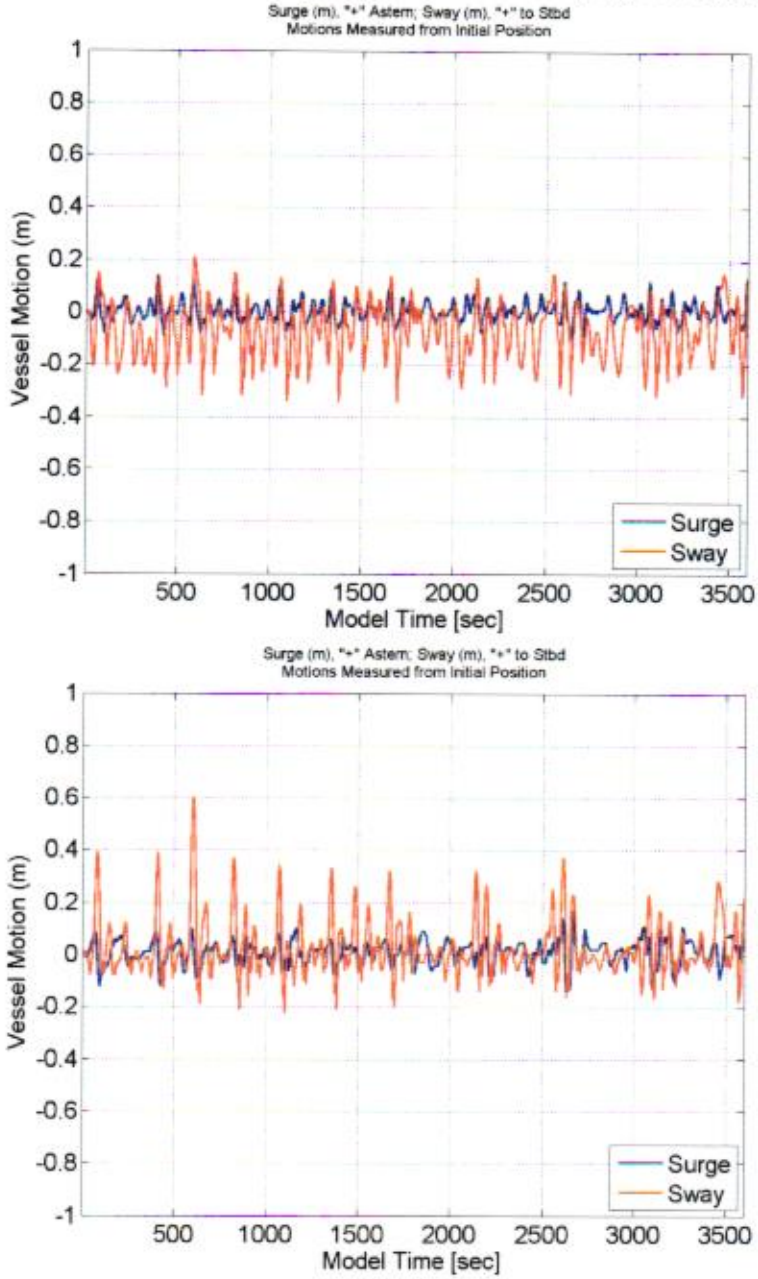


Figure B17: DMA results summary for Scenario EC-9 (33 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza with smaller LNGC Grace Dahlia present

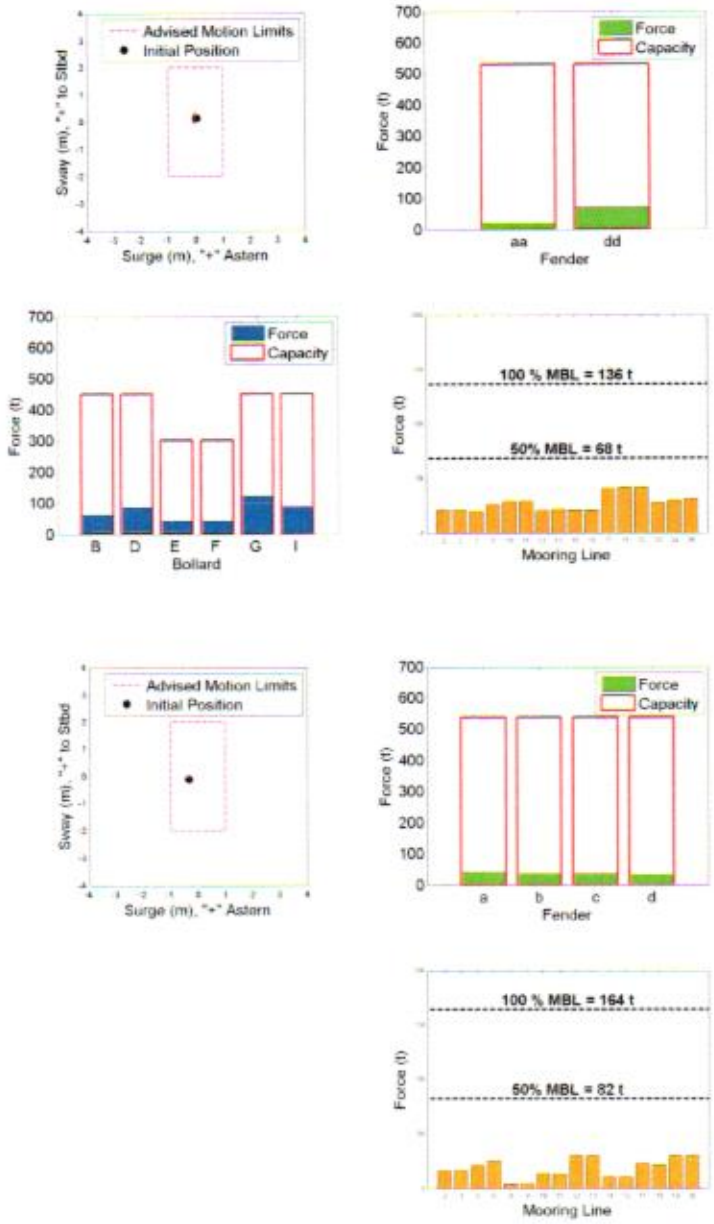
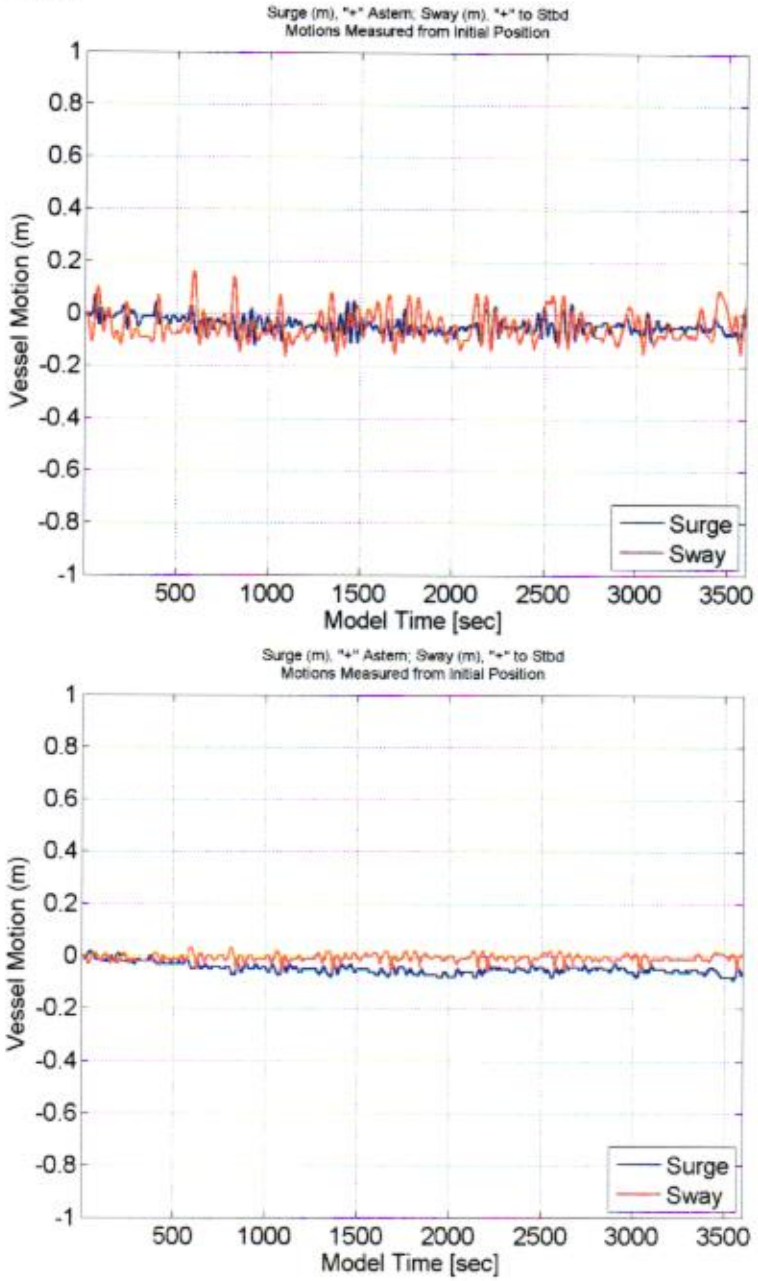


Figure B18: Time histories of surge and sway motions for Scenario EC-9 (33 knots winds from 180 deg TN, 2.3 knots currents from 235 deg TN), for FSRU Hoegh Esperanza with smaller LNGC Grace Dahlia present. FSRU motions (top) and Grace Dahlia Motions (bottom)



B 2 DMA Results, with Passing Vessel Forces (Fender Configuration FC 1-1)

The following figures show results of dynamic simulations for single vessel mooring with only the FSRU, ship-to-ship mooring with guest Qmax Al Ghuwairiya, and ship-to-ship mooring with guest smaller LNGC Grace Dahlia.

Mooring results figures include:

- Track plot of motions at manifold (top left)
- Peak fender loads (top right)
- Peak quick-release total system loads (bottom left), and
- Peak mooring line loads (bottom right).

Peak loads in the figures are not necessarily coincident in time. Ship-to-ship simulation results show the same plots as described above, for each vessel (host, and guest). Each figure showing loads for the guest vessel lacks the bottom left figure showing peak loads in the berth quick release hooks. Capacities in the quick release hooks on the FSRU were also assumed to be 150 mt.

Figure B19: DMA results summary for Scenario PV-1 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 285 deg TN), for FSRU Hoegh Esperanza, no LNGC present

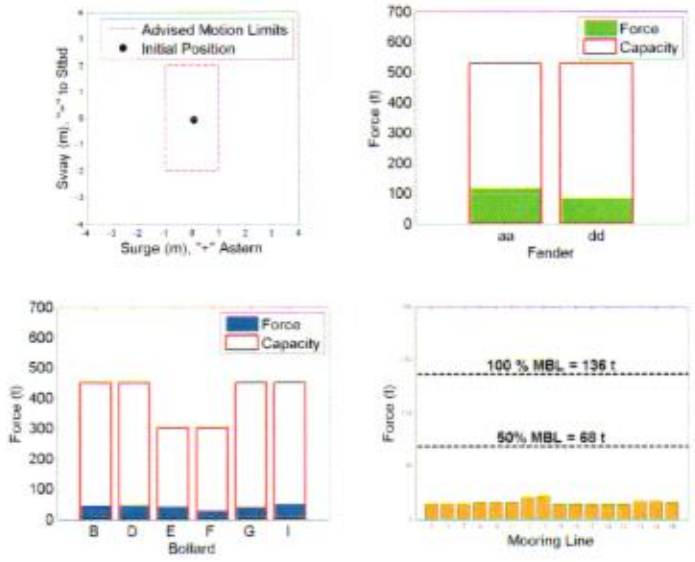


Figure B20: DMA results summary for Scenario PV-2 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 315 deg TN), for FSRU Hoegh Esperanza, no LNGC present

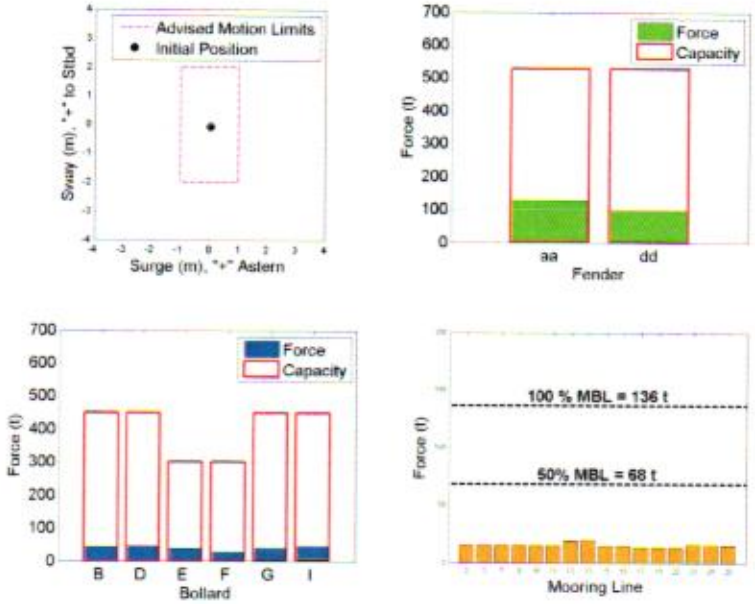
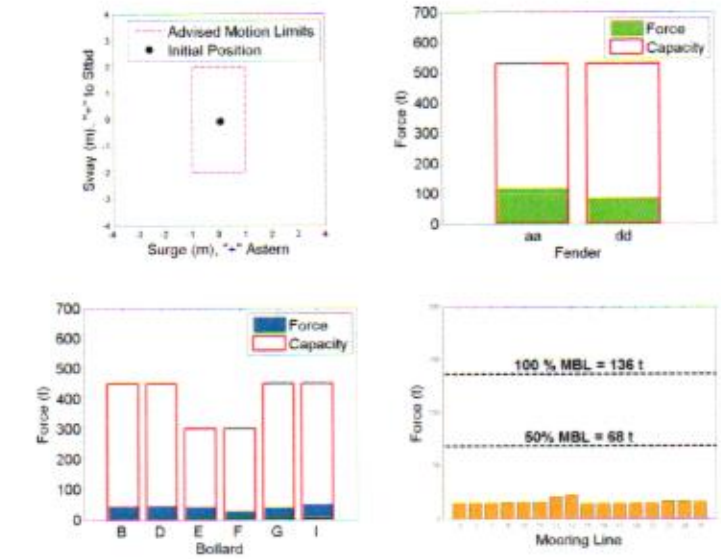


Figure B21: DMA results summary (Top) for Scenario PV-3 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 285 deg TN), for FSRU Hoegh Esperanza, no LNGC present. FSRU time histories of surge and sway motions (Bottom).



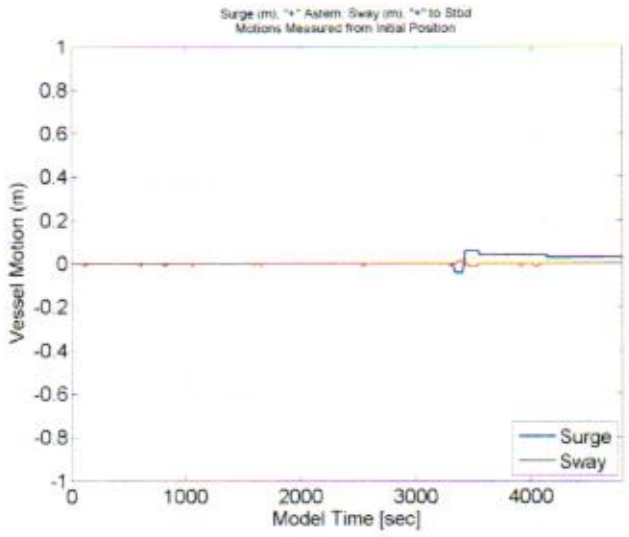


Figure B22: DMA results summary for Scenario PV-4 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 270 deg TN), for FSRU Hoegh Esperanza LNGC Qmax Al Ghuwairiya present

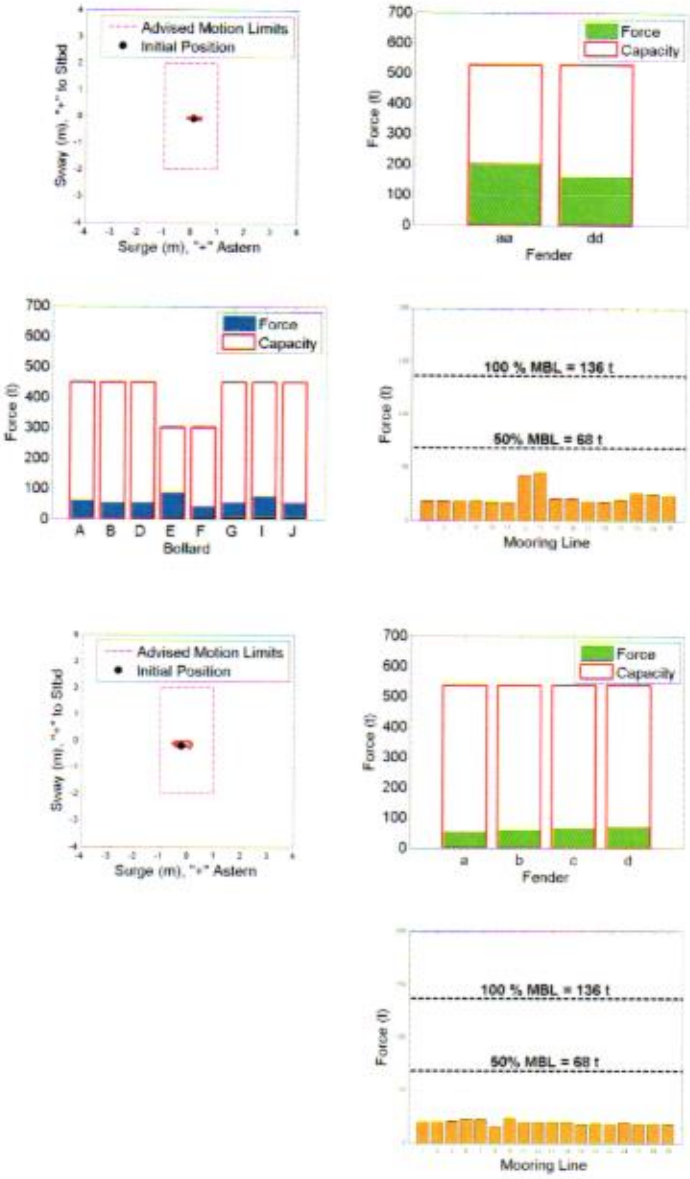


Figure B23: DMA results summary for Scenario PV-5 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 300 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya

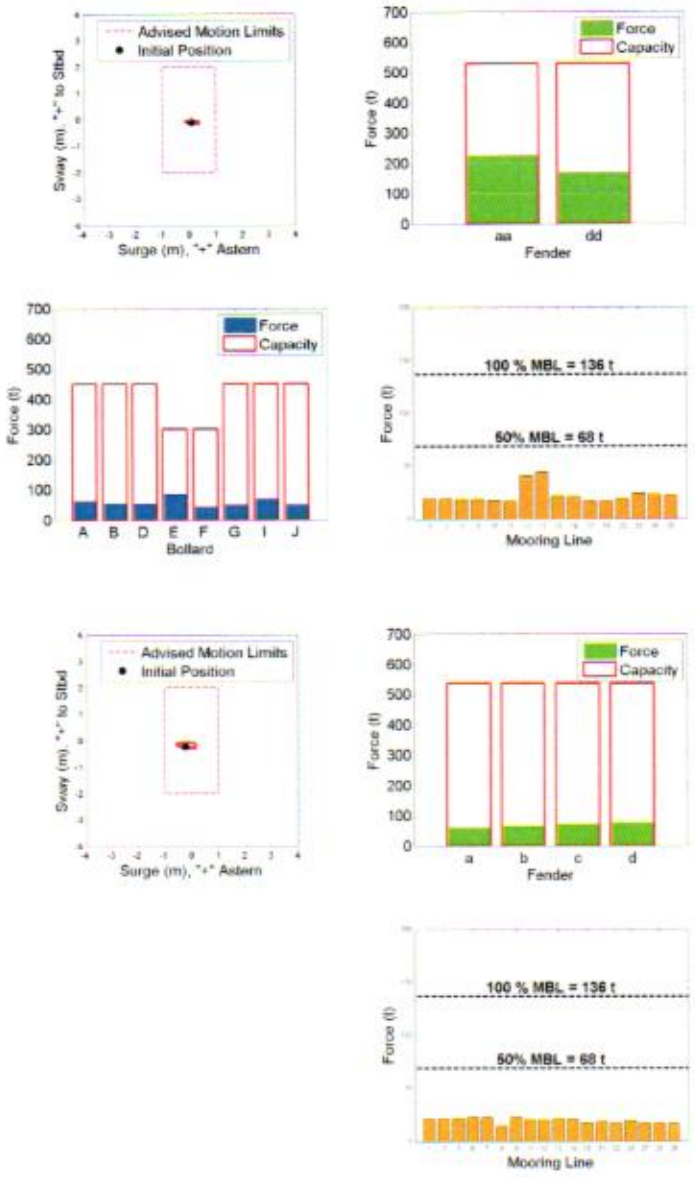


Figure B24: DMA results summary (Top) for Scenario PV-6 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 300 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya. FSRU time histories of surge and sway motions (Bottom).

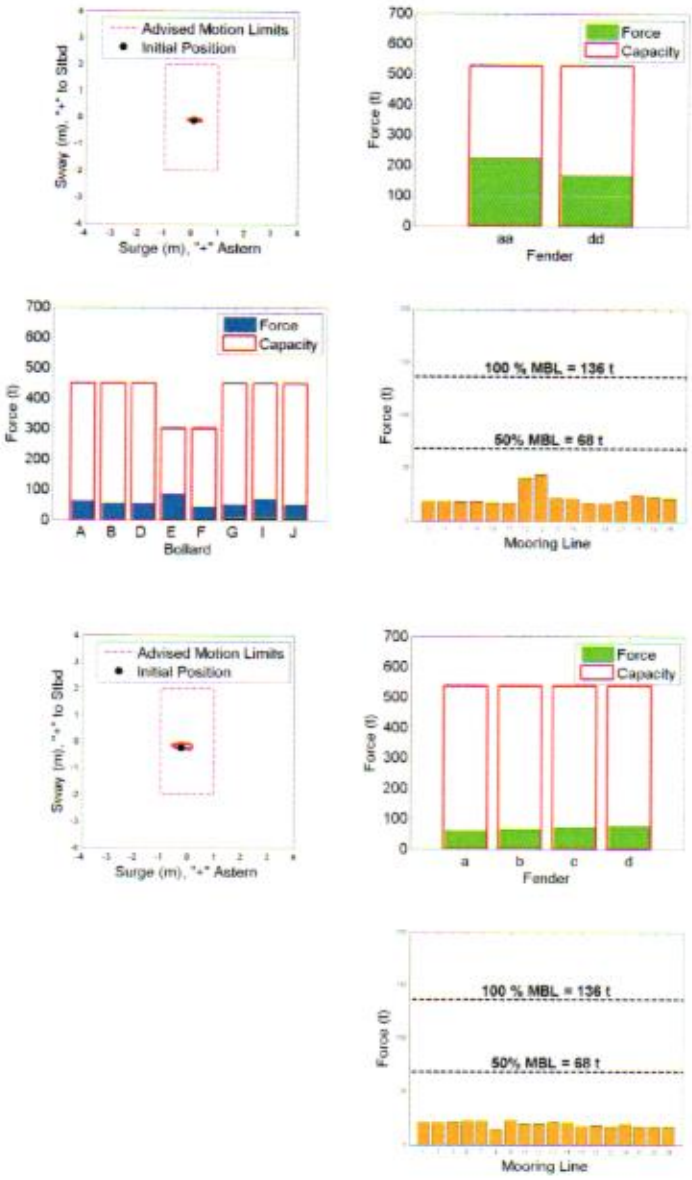


Figure B25: Time histories of surge and sway motions for Scenario PV-6. FSRU motions (Top) and Qmax motions (bottom).

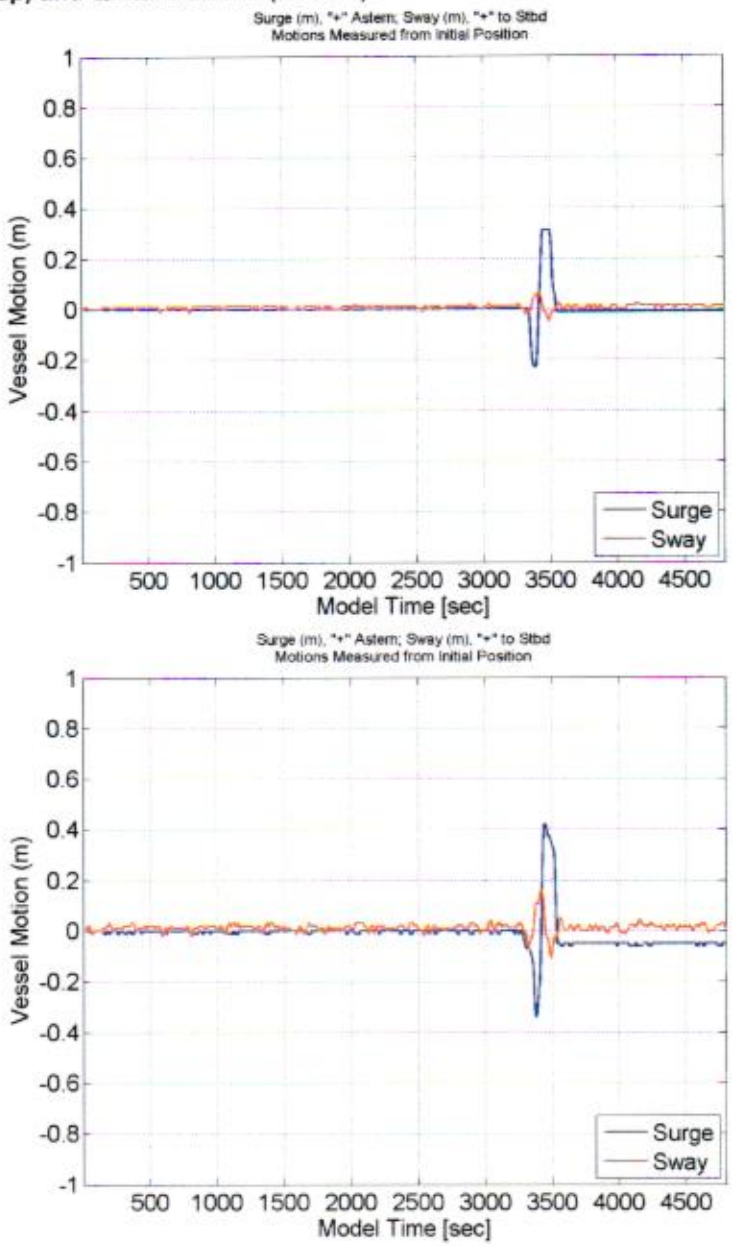


Figure B26: DMA results summary for Scenario PV-7 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 15 deg TN), for FSRU Hoegh Esperanza present with LNGC Qmax Al Ghuwairiya present

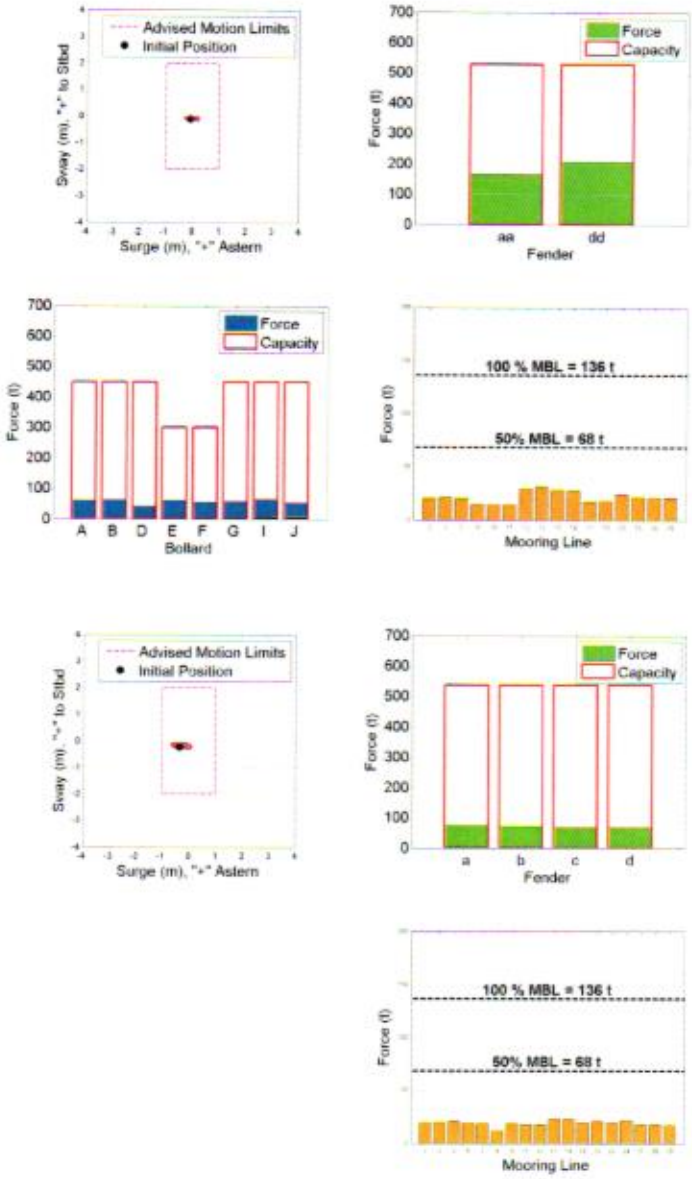


Figure B27: DMA results summary for Scenario PV-8 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 315 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya

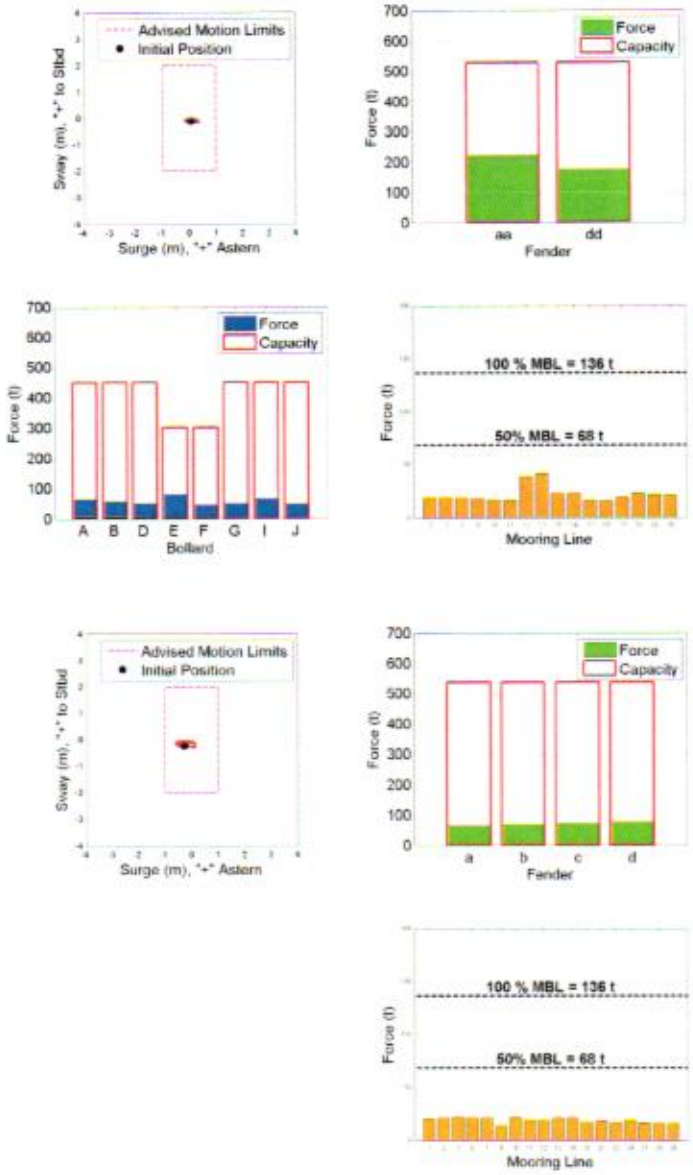


Figure B28: DMA results summary for Scenario PV-9 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 30 deg TN), for FSRU Hoegh Esperanza with LNGC Qmax Al Ghuwairiya. Qmax time histories of surge and sway motions (Bottom).

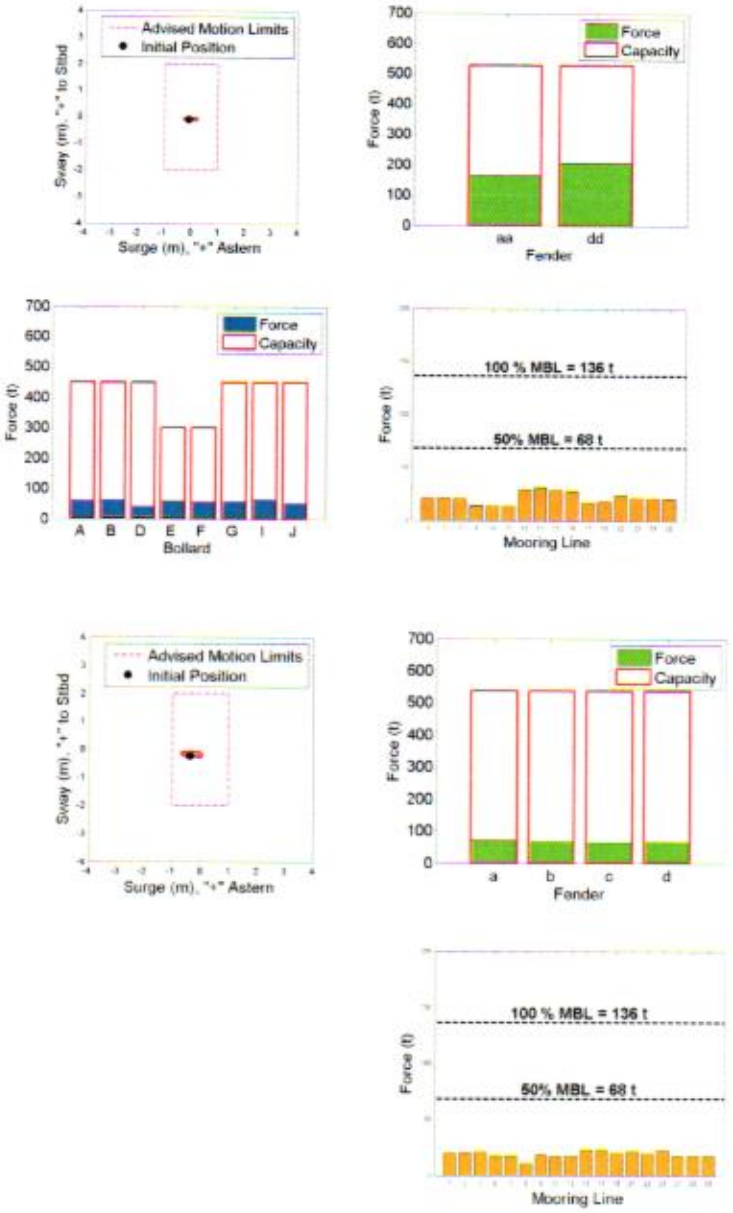


Figure B29: Time histories of surge and sway motions for Scenario PV-9. FSRU motions (Top) and Qmax motions (bottom).

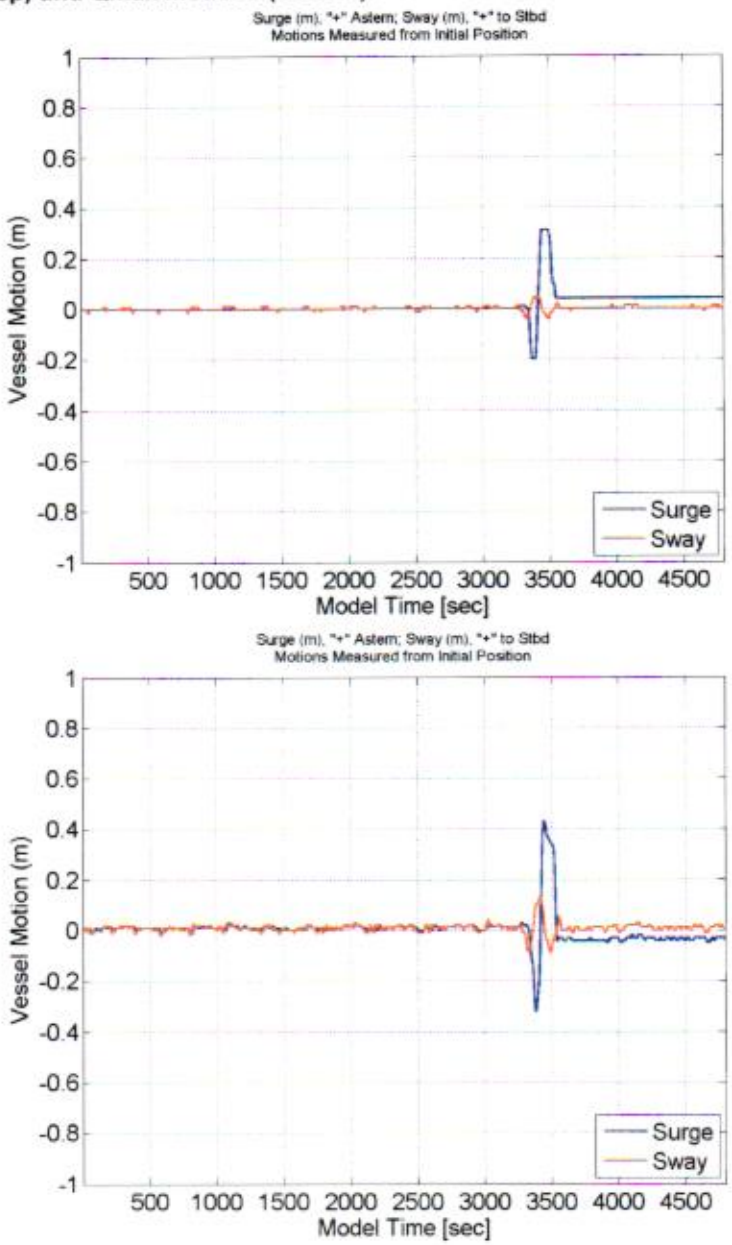


Figure B30: DMA results summary for Scenario PV-10 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 270 deg TN), for FSRU Hoegh Esperanza with smaller LNGC Grace Dahlia

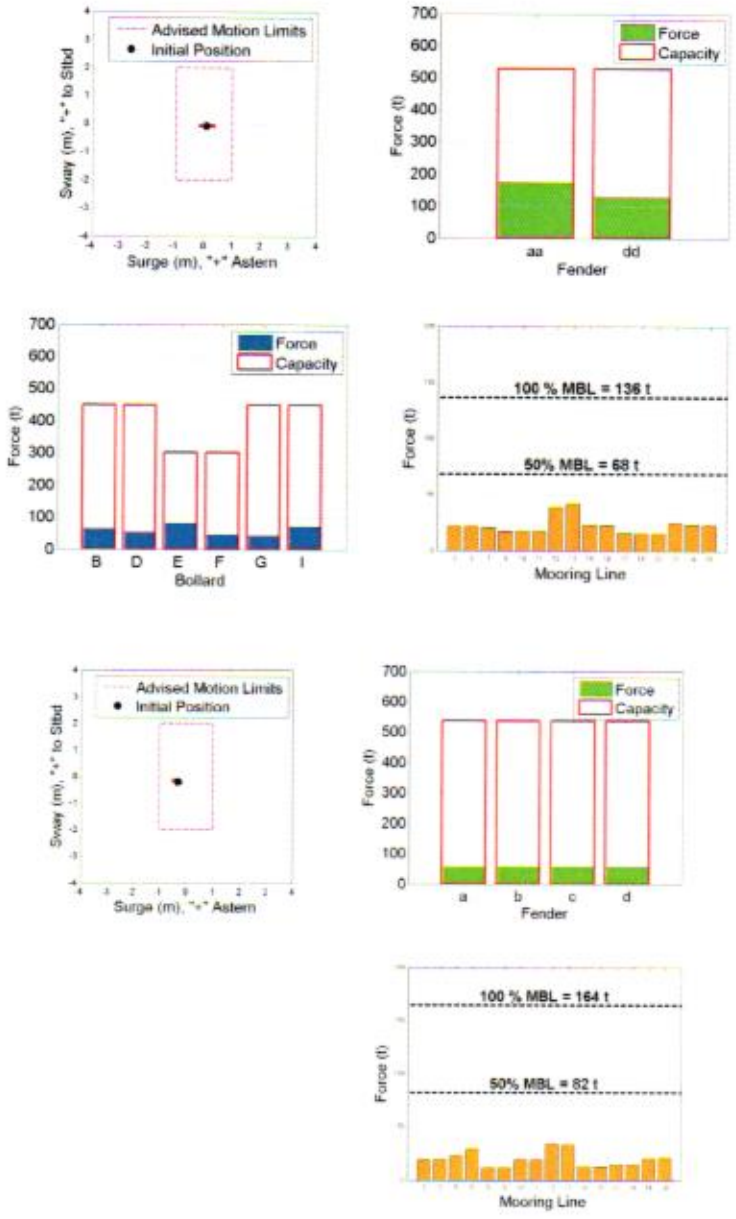


Figure B31: DMA results summary for Scenario PV-11 (fully laden Qmax passing at 7 knots inbound along channel centreline, 20 knots winds at 300 deg TN), for FSRU Hoegh Esperanza with smaller LNGC Grace Dahlia