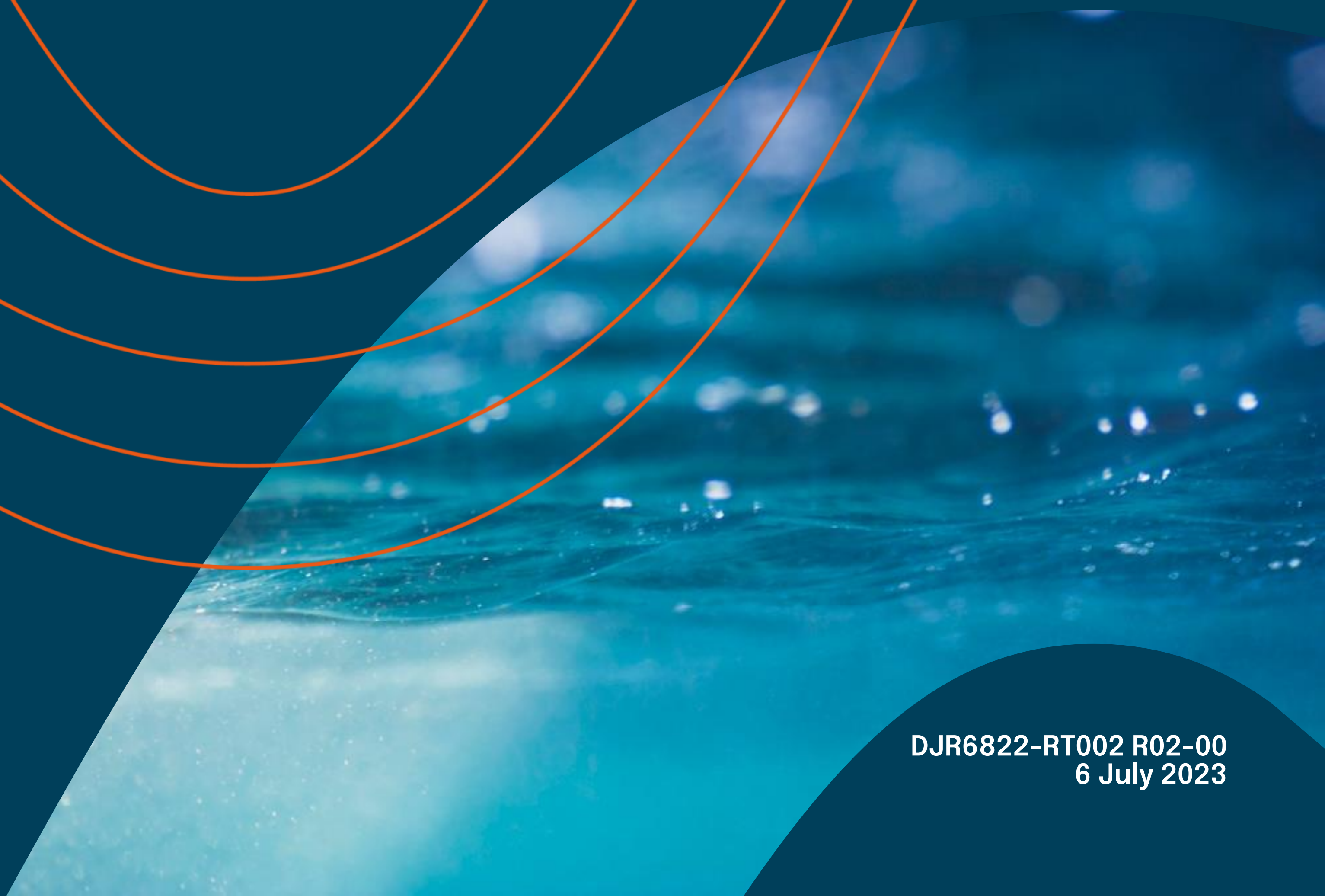
Dublin Port 3FM

Passing ship study



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Executive summary

As part of the Port Masterplan developed in 2012, Dublin Port Company (DPC) have set out proposals for major developments within the port up to 2040. The 3FM project includes the development of a new container terminal on the south side of the river with the existing NORA Oil berth incorporated in to the design as well as the development of RO-RO berths at the existing Berth 44 and 45.

As part of the development, there is a requirement to assess the berths and examine the impact of passing ships. This will be used to determine the speed limits for the channel adjacent to the berths being considered.

A full dynamic mooring analysis was used to assess the impact of passing ships on the proposed development of the New South Bank Container Terminal, NORA Oil berth and Berth 45 at Dublin Port. The analysis considered a total of five moored ships and four passing ships, representing the range of ships expected to transit the channel. There were three passing distances modelled, along the centreline and to the north and south. All passing speeds were considered as speeds over the ground and included a representative current taken from flow modelling carried out for the 3FM port layout.

The following conclusions have been drawn from the study.

New South Bank Container Terminal

- Both moored ships make good contact with fenders;
- Negative line angles were observed for the 150 m container ship and consideration is required regarding the quay elevation, anti-chafing protection on the quay and possible interaction with fenders;
- Static mooring analysis indicates the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment;
- Exceedances of the bollard SWL (80 t) occurred in some cases. Consideration is required to increase to the bollard SWL at the berth.

The maximum allowable passing speed (over the ground) for a centreline transit and with wind speeds of up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

150 m container ship – conventional

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier (“Jasmine A”) ≥9.0 knots.

225 m container ship – conventional

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) 6.5 knots;
- 160 m tanker 7.0 knots;
- 225 m bulk carrier (“Jasmine A”) 5.5 knots.

225 m container ship – automated mooring system

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) ≥9.0 knots;
- 160 m tanker ≥9.0 knots;

- 225 m bulk carrier ("Jasmine A") ≥9.0 knots.

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the 225 m container ship for all passing ships.

Due to the freeboard of the 150 m container ship and the quay elevation it would not be possible to connect an automated system that connects above the level of the quay to the ship. If it were able to connect, it would be expected to provide equivalent restraint observed with the 225 m container ship.

If an automated mooring system is to be installed at the berth, consideration is required regarding:

- Positioning of the units along the berth to maintain flexibility of where ships can moor;
- Ability to connect to smaller container ships with a lower freeboard.

NORA Oil berth

- Due to the berth configuration with breasting and mooring dolphins on the eastern end and the container quay on the western end, the mooring arrangements were asymmetric with significantly shorter mooring lines on the western end.
- The shorter lines on the western end of the berth led to steep mooring lines, up to 34°. Guidance suggests that vertical mooring line angles should be kept to a minimum, with angles less than 25° preferred. It would therefore be beneficial to have set-back bollards on the container quay which could be sunken and covered when not in use.
- The position of the winches used for spring lines on the 185 m tanker led to short aft springs lines, attached to the inner breasting dolphin, which also had reduced longitudinal restraint due to the angle of the line to the berth. Depending on the configuration of the marine loading arms, it would be beneficial to have a mooring point located on the eastern end of the container terminal.
- Although the mooring arrangements were shown to be suboptimal due to the asymmetry and steep mooring line angles , static mooring analysis indicated they provide adequate resistance to the wind and current conditions at the site.
- Some negative line angles are expected for the 120 m tanker at water levels below MLWN due to the relative height between the main deck and the quay/dolphin elevation (+7.11 mCD). Consideration is required regarding line rubbing on the quay edge and mooring lines catching on fender panels.
- Good fender contacts are feasible for both design ships. However, the outer breasting dolphin only provides a partial contact with the larger 185 m tanker. If ships longer than 185 m are not expected to make use of the berth, then a further assessment should be considered, assessing a wider range of ships, to determine if it would be beneficial to move the dolphin closer to the centre of the berth. Alternatively, it may be possible to make use of just one breasting dolphin.
- A higher specification fender is required for the oil berth compared to the container terminal. Given the berth will make use of fenders on the eastern end of the container terminal, the berthing line is required to be maintained as continuous. Therefore, either the same depth of fender is required or alterations are required on the quay to ensure the fender panels remain on the same berthing line.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds of up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

120 m tanker – conventional

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") 7.5 knots;

- 160 m tanker 8.0 knots;
- 225 m bulk carrier ("Jasmine A") 6.0 knots.

185 m tanker – conventional

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") 8.5 knots.

185 m tanker – automated mooring system

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") ≥9.0 knots.

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the 185 m tanker for all passing ships. Given the freeboard of the 120 m tanker and the quay elevation, it would not be possible to connect an automated system that connects above the level of the quay to the ship. If it were able to connect, it would be expected to provide equivalent restraint observed with the 185 m tanker.

If an automated mooring system is to be installed at the berth, consideration is required in the ability to connect to the smaller tankers.

Berth 45

- Mooring arrangements with bollards located along the quay face were shown to be inadequate for mooring the design ship. Three set-back bollards at the stern (by the linkspan on the western end) were included in the assessment to improve the mooring arrangement and reduce the vertical line angles. These were nominally set-back by 10m but setting them back further would be beneficial.
- Good contact with fenders is feasible for the moored design ship.
- High vertical line angles were observed of up to 52° for mooring lines at the bow of the ship. It would be beneficial to include set-back bollards at the bow (on the eastern end).
- Static mooring analysis indicates the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment.
- Exceedances for the allowable passing ships were a result of surge motions which is likely a result of the very soft mooring lines which are used by the ship. It may be possible to increase the allowable passing speeds with a stiffer mooring line which would provide improved movement restraint.
- The results are expected to be applicable to Berth 44 given the symmetry of the berth and mooring configuration.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

"MV Celine" – conventional

- 142 m general cargo ("Seatruck Pace") ≥6.0 knots;
- 235 m RO-RO ("MV Celine") 4.5 knots;
- 160 m tanker 5.0 knots;
- 225 m bulk carrier ("Jasmine A") 4.0 knots.

"MV Celine" - automated mooring system

- 142 m general cargo ("Seatruck Pace") ≥6.0 knots;
- 235 m RO-RO ("MV Celine") ≥6.0 knots;
- 160 m tanker ≥6.0 knots;
- 225 m bulk carrier ("Jasmine A") ≥6.0 knots.

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the design moored ship for all passing ships.

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1 Introduction

1.1 Overview

As part of the Port Masterplan developed in 2012, Dublin Port Company (DPC) have set out proposals for major developments within the port up to 2040. The 3FM project includes the development of a new container terminal on the south side of the river with the existing NORA Oil berth incorporated in to the design as well as the development of RO-RO berths at the existing Berth 44 and 45.

As part of the development, there was a requirement to assess the berths and examine the impact of passing ships. This will be used to determine the speed limits for the channel adjacent to the berths being considered.

This report describes a fully dynamic passing ship assessment that was carried out for the proposed container terminal, Berth 45 (also representative of Berth 44) and the NORA Oil berth.

1.2 Objectives

The main objectives of the study were to:

- Review the mooring requirements for ships moored at the proposed berths when port traffic is moving in the adjacent channel;
- Identify the allowable passing speeds at the proposed berths for a range of passing ships;
- Assess the impact of installing an automated mooring system at the berths.

2 Passing ship considerations

2.1 Passing ship effects

Passing ship effects are most usually of concern where berths are located along relatively confined waterways and/or close to navigation routes. In such locations, ships may pass relatively close to moored vessels whilst in transit to, or from, their berths. Such passing events may result in the disturbance of the moored vessels, which in some cases can cause disruption to cargo handling operations and excessive mooring loads.

The passing ship effect is primarily generated due to the pressure field that is present around any ship that is underway. As a moving ship advances, it pushes water in front of it and out of its path. This generates a high pressure region around the ship's bow. The water accelerated by the high pressure then flows along the hull sides in the direction of the stern, which generates a relatively low pressure region in the area at the sides of the ship. Finally, the moving water is brought to rest again in a high pressure region near the vessel's stern. The pressure distribution is therefore of high pressure at the bow and stern, with low pressure midships. The strength of the disturbance is naturally greatest close to the moving vessel and decreases with distance from the ship.

The general pattern of effects on a moored vessel as a moving ship travels past is:

- Repulsion as the high pressure field near the bow of the passing ship tends to force the moored and passing ships apart on approach;
- As the passing ship draws level, the repulsive forces change to attraction due to the low pressure region around the centre section of the passing ship, and the moored vessel tends to move towards the passing ship;

- As the passing ship starts to draw away, the moored vessel is initially drawn after it, still being pulled into the low pressure area;
- The attractive forces then change to repulsive as the effect of the high pressure at the stern of the passing ship becomes stronger. As a consequence the moored vessel is pushed back away from the passing ship.

The magnitude of the passing ship effect depends on a number of aspects, such as the:

- Size of both the passing ship and the moored vessel, with larger ships tending to generate greater passing effects and moored vessel movements;
- Under keel clearance of both the passing and mooring ships, where low under keel clearances tend to increase the passing ship effects;
- Speed of the passing ship, as the effects are proportional to the square of the moving ship's speed through the water;
- Separation distance between the passing and moored vessels, where the effects increase with decreasing separation distance;
- Local bathymetry, where narrow channels or constrained waterways can accentuate the passing ship effect due to blockage effects.

2.2 Existing limitations on passing ships at Dublin Port

Dublin Port currently have the following speed restrictions in place:

- 9 knots west of the breakwaters to the Port Operations Centre;
- 6 knots west of No.15 Starboard Lateral Buoy (adjacent to the proposed Berth 52) for Cruise Ships greater than 200 m in length;
- 4 knots west of the Port Operations Centre for all ships.

3 Computational models

The study was carried out using fully dynamic computational modelling simulation. This used HR Wallingford's established suite of models for determination of forces on moored ships and moored ship motion, named SHIPMOOR, which includes the passing ship model, PASSHIP. These models have been extensively verified against physical model results and full scale measurements, and have been used successfully in many similar studies over the last 40 years or so. Further details of the software are provided in Appendix A.

To represent the effects of the forces exerted by passing ships on a moored vessel, fully dynamic numerical simulation was carried out, solving the equations at increments in time using a time domain analysis to produce a time-series of motions and loads. The mooring line forces, fenders forces and movements of the moored vessel on its moorings were produced in the form of maximum and significant motions of surge, sway, heave, yaw, pitch and roll, for the specified options and test conditions.

This allowed a robust statistical based assessment, allowing the mean, significant and maximum mooring line and fender forces to be output from the models. These results were presented in tabular and graphical form, where appropriate, and were analysed and described with regard to the passing ship effects with a high level of confidence.

4 Site characteristics

4.1 Layout

The berths being considered as part of the assessment were the proposed container terminal, proposed NORA Oil Berth and the proposed RO-RO berth at Berth 45. These are shown in Figure 4.2.

4.2 Datum

Levels in this report are provided relative to chart datum (Dublin Port, mCD). It was noted that Ordnance Datum Malin (ODM) is also used at the port where 0.00 mODM = +2.51 mCD.

4.3 Dredged depths

Access to the port is via the Liffey Channel which is currently maintained at -7.8 mCD. For the purposes of the assessment, the future dredged depth was considered. The declared depth is expected to be -10.0 mCD. The container terminal and the NORA Oil Berth will have a dredged pocket at -13.0 mCD and Berth 45 will have a berth pocket dredged to -8.7 mCD. The bathymetry in the surrounding areas was taken from data provided by RPS from MIKE flow models for the 3FM layout.

4.4 Environmental conditions

4.4.1 Wind

A wind rose for Dublin airport is shown in Figure 4.1. Winds are predominantly from the westerly and south westerly sectors. The highest wind speeds are from between 240° and 270° and are expected at speeds of up to 35 knots. The modelled wind conditions are as follows. A calm wind scenario was also considered:

- From 225°N at 20 and 35 knots;
- From 270°N at 20 and 35 knots;
- From 045°N at 20 knots.

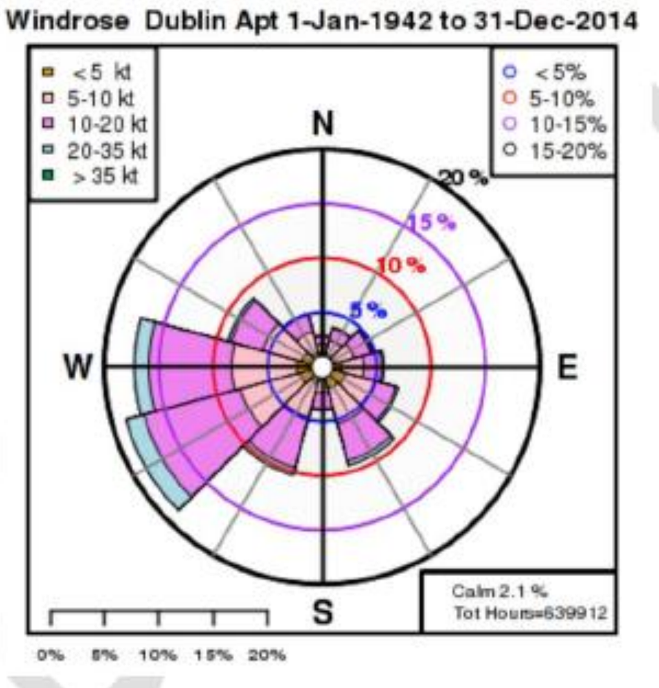

Figure 4.1: Wind rose at Dublin airport

Source: https://www.met.ie/climate/what-we-measure/wind

4.4.2 Currents and water levels

There were three water levels modelled, at low, mid and high tides, based on a neap tide. The currents associated with the selected water levels were extracted from flow modelling that was carried out by RPS for the 3FM layout and used during the real time navigation simulation study of the development. It was noted that the flow modelling was based on a typical spring tide and was therefore considered to provide conservative current speeds.

A summary of the water levels and current conditions are shown in Table 4.1.

Table 4.1: Water levels and associated currents

Berth	Tidal state	Water level (mCD)	Current speed (knots)	Current direction
New South Bank Container Terminal / NORA Oil Berth	Mean High Water Neaps (MHWN)	+3.4	0.35	Flood
	Mean Sea Level (MSL)[1]	+2.5	0.5	Ebb
	Mean Low Water Neaps (MLWN)	+1.5	0.3	Ebb
Berth 45	Mean High Water Neaps (MHWN)	+3.4	0.25	Flood
	Mean Sea Level (MSL)[1]	+2.5	0.45	Ebb
	Mean Low Water Neaps (MLWN)	+1.5	0.3	Ebb

Note: 1 – Mean Sea Level taken as average between MHWN and MLWN

4.4.3 Waves

The wave conditions at the site are expected to be negligible from a ship mooring perspective for all berths, due to the area being well sheltered and therefore were not represented.

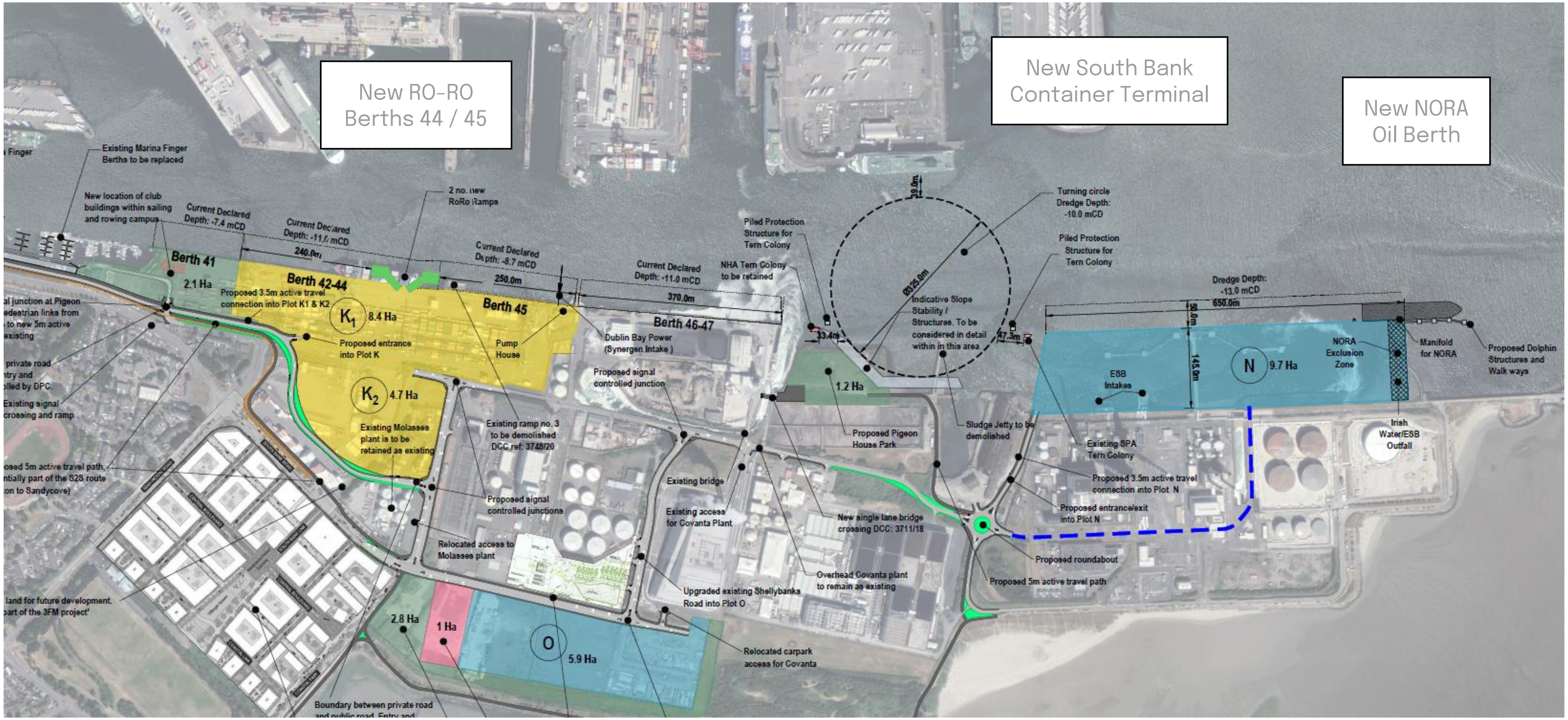

Figure 4.2: 3FM masterplan layout drawing

Source: Reference 1

5 Berth configurations

5.1 New South Bank Container Terminal

5.1.1 Overview

Reference 9 provides details of the configuration for the terminal (Figure 5.4). The berth will be a reclamation in the location of the existing NORA Oil berth. The quay is orientated on 092°N/268°N with an elevation of +7.11 mCD. The quay will have total useable length of 635 m with a berth pocket dredged to -13.0 mCD.

5.1.2 Bollards

Based on preliminary design discussions, bollards at the berth are located at 18.0 m centres (every third pile). The bollards were modelled with a 80 t SWL based on guidance in Reference 1 (Table 5) which suggests a nominal bollard SWL of 80 t for ships with displacements between 20,000 t and 50,000 t. The adequacy of the bollards were reviewed as part of the assessment.

5.1.3 Fenders

The fenders at the terminal are yet to be defined although a panel 9.6 m high and 2.5 m wide has been proposed. For the purposes of the study, a preliminary berthing energy calculation was carried out to determine a suitable fender. This is summarised in Table 5.1. Due to the height of the fender panel 2 x Trelleborg SCN110 F1.0 were selected. They have a combined rated reaction of 1,522 kN and rated energy of 1,000 kNm. The fender characteristics are shown in Figure 5.1.

Fenders are located at 18.0 m centres, offset 1 pile from the bollards, at an elevation of +2.2 mCD. The fender panels provide a total area of 24.0 m^2.

5.1.4 Automated mooring system

An automated mooring system may be considered for the berth. For the purposes of the analysis a Cavotec system was modelled, based on previous work at Berth 52 and 53. The locations and number of units was modelled as those on Berth 53, based on input from Cavotec (Section 5.4). Due to the low freeboard of the 150 m container ship and quay elevation, an automated mooring system positioned on the deck would not make contact with the ship and was therefore not considered as part of the assessment.

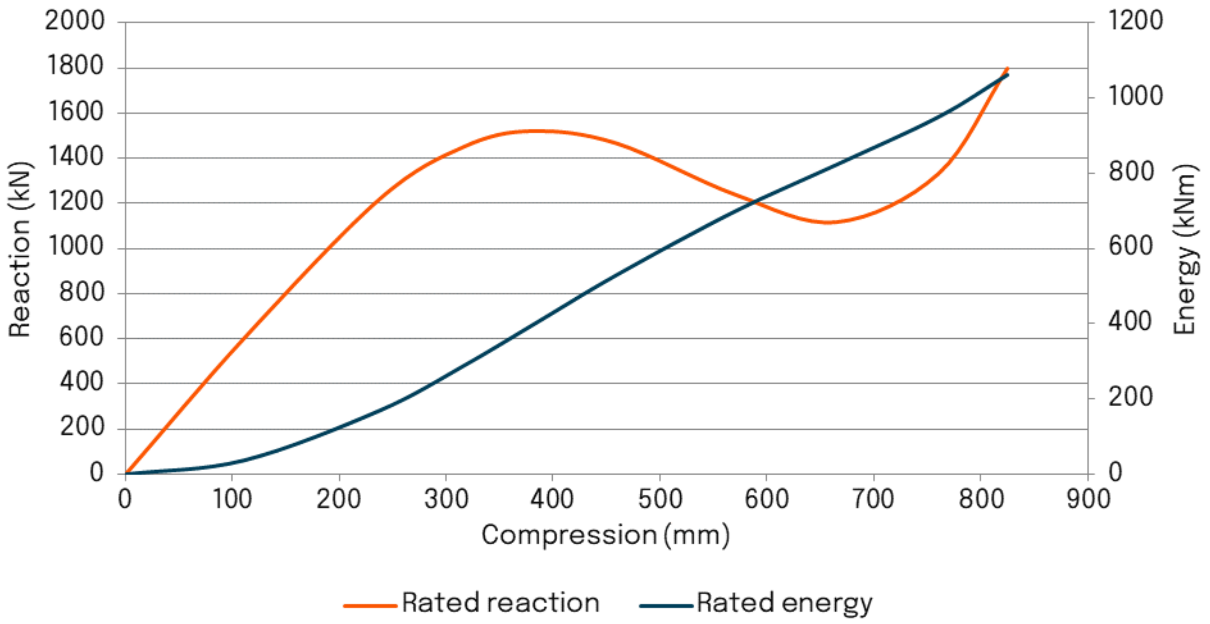

Figure 5.1: New South Bank Container Terminal preliminary fender characteristics

Notes: Based on 2 x Trelleborg SCN1100 F1.0 fenders

5.2 NORA Oil Berth

5.2.1 Overview

Reference 9 provides details of the configuration for the berth (Figure 5.4). Details on the berth configuration were also provided separately as exerts from a Royal Haskoning DHV report (Reference 10). The berth is to be located on the eastern end of the New South Bank Container Terminal, consisting of two breasting dolphins and two mooring dolphins on the eastern side and the container quay on the western side. The marine loading arms (MLAs) will be located on the eastern end of the container terminal reclamation. The berth is orientated on 092°N/268°N with an elevation of +7.11 mCD. It will have a berth pocket dredged to -13.0 mCD.

5.2.2 Bollards

Details in Reference 9 and 10 indicate that bollards will be located on the breast and mooring dolphins rated at 100 t SWL.

5.2.3 Fenders

The fenders at the terminal are yet to be defined. For the purposes of the study, a preliminary berthing energy calculation was carried out to determine a suitable fender. This is summarised in Table 5.2.

The design berthing energy for the NORA Oil berth are higher than for the container terminal and therefore higher capacity fenders are required. Given the berth will make use of the fenders on the eastern end of the container terminal, the berthing line is required to be maintained as continuous. Therefore, either the same depth of fender is required or alterations are required on the quay to ensure the fender panels remain on the same berthing line. For the purposes of the study 2 x Trelleborg SCN1300 F1.0 fenders were selected. They have a combined rated reaction of 2,308 kN and rated energy of 1,790 kNm. The fender characteristics are shown in Figure 5.1.

It would be possible to select a fender of the same depth used on the New South Bank Container Terminal allow with would require a high rubber grade and result in a stiffer fender.

It is assumed these fenders will be positioned on the breasting dolphins and the first 3 fender locations on the eastern end of the container terminal.

5.2.4 Automated mooring system

An automated mooring system may be considered for the berth. For the purposes of the analysis a Cavotec system was modelled, based on previous work at Berth 52 and 53. The number of units used was based on previous analysis with the automated mooring system, with 8 pairs of units utilised. As with the South Bank Container Terminal, the smaller 120 m tanker would not make contact with an automated mooring positioned on the quay and was therefore not considered as part of the assessment.

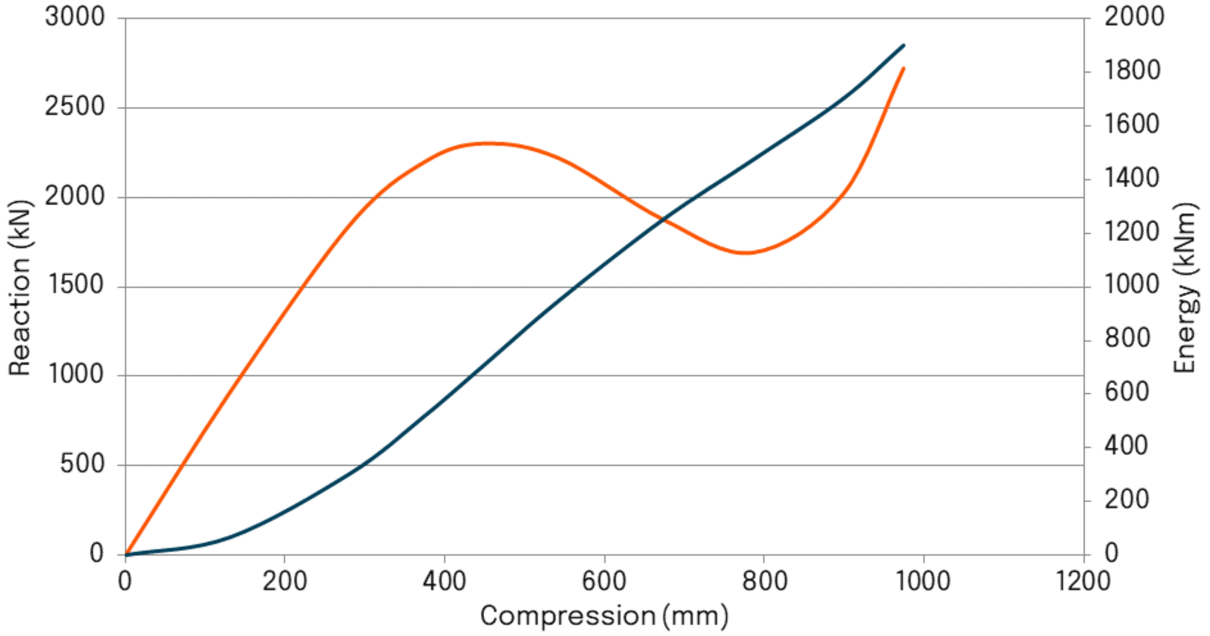

Figure 5.2: NORA Oil berth preliminary fender characteristics

Notes: Based on 2 x SCN1300 F1.0 fenders

5.3 Berth 45

5.3.1 Overview

Reference 9 provides details of the configuration for Berth 45 (Figure 5.5). The existing berths currently used for container ships (Berth 42 to 45) will be converted with the installation of a linkspan structure (for both Berth 44 and 45). The berth is orientated on 100°N/280°N with an elevation of +6.0 mCD. The quay will have total useable length of approximately 270 m with a berth pocket dredged to -8.7 mCD.

5.3.2 Bollards

Based on the drawing in Reference 9, the bollards were positioned at 14.6 m centres with a proposed SWL of 150 t.

5.3.3 Fenders

The proposed fenders at the terminal are shown in Reference 9 as Trelleborg SCN1150 although no fender grade was stated. The fender panels are shown as 9.6 m high and 2.5 m wide.

For the purposes of the study, a preliminary berthing energy calculation was carried out to determine a suitable fender. This is summarised in Table 5.3. Due to the height of the fender panel 2 x Trelleborg SCN1150 F1.0 were selected. They have a combined rated reaction of 1,816 kN and rated energy of 1,243 kNm. The fender characteristics are shown in Figure 5.3.

Fenders are also located at 14.6 m centres, offset by 2 piles from the bollards, with the elevation of the centre of the panel at -1.2 mCD. The fender panels provide a total area of 24.0 m^2.

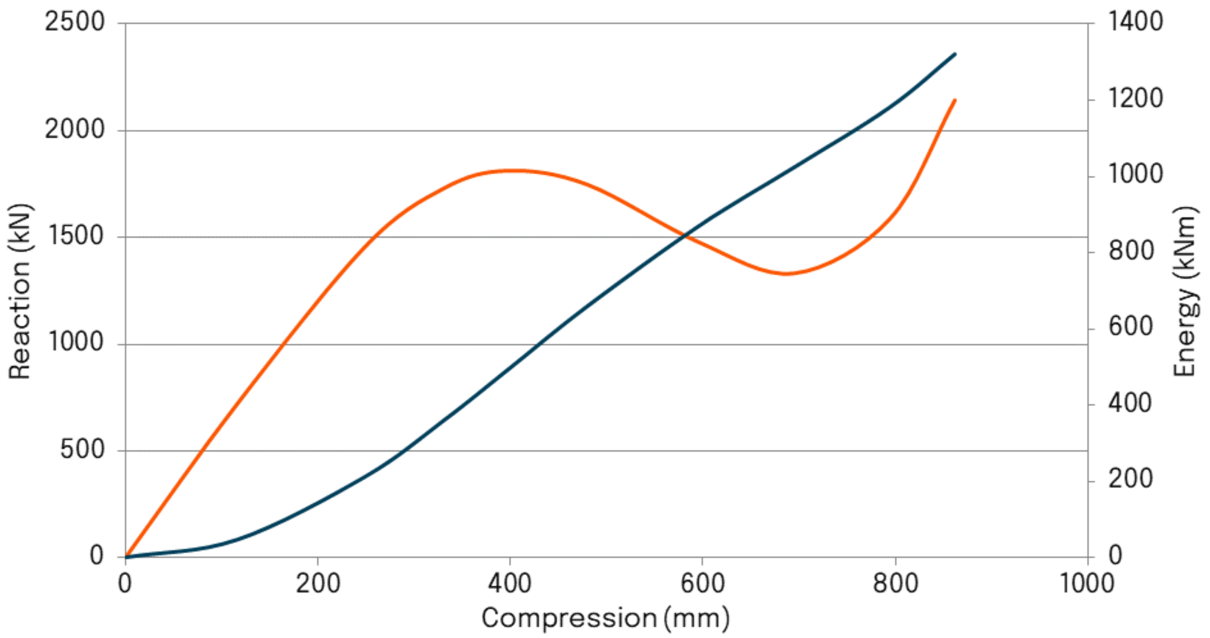

Figure 5.3: Berth 45 preliminary fender characteristics

Notes: *Based on 2 x Trelleborg SCN1150 F1.0 fenders*

5.3.4 Automated mooring system

An automated mooring system may be considered for the berth. For the purposes of the analysis a Cavotec system was modelled, based on previous work at Berth 52 and 53. The locations and number of units was modelled as those on Berth 53, based on input from Cavotec (Section 5.4).

5.4 Details of automated mooring system

An automated mooring system may be considered for the berths. Subsequently, for the purposes of the dynamic mooring analysis, a representation of such a system was modelled at the berth. Based on the previous work carried out as part of the MP2 project, discussions were held with a manufacturer of an automated vacuum mooring system, Cavotec. The use of NxG MoorMaster units were proposed, with a total of 16 units (8 pairs). The units were positioned along the berth based on previous discussions with Cavotec although this may need to be refined if considered further. It is expected other automated mooring systems would provide similar restraint but should be assessed separately.

The system is integrated in to the HR Wallingford's dynamic mooring analysis software based on details of the application of the force, in relation to the displacement and velocity of the moored ship. Each unit is intended to provide forces up to 100 kN in surge (about 10 tonnes along the berth) and up to 200 kN in sway (about 20 tonnes towards the berth). In reality, the Cavotec system is coordinated by a control system which determines the mode in which each of the units operate. For the purposes of the dynamic mooring analysis, each unit was selected to operate in either sway or surge for the entirety of each model run. Following completion of the model runs, changes to the operating mode of symmetrical pairs of units were considered if insufficient restraint was provided.

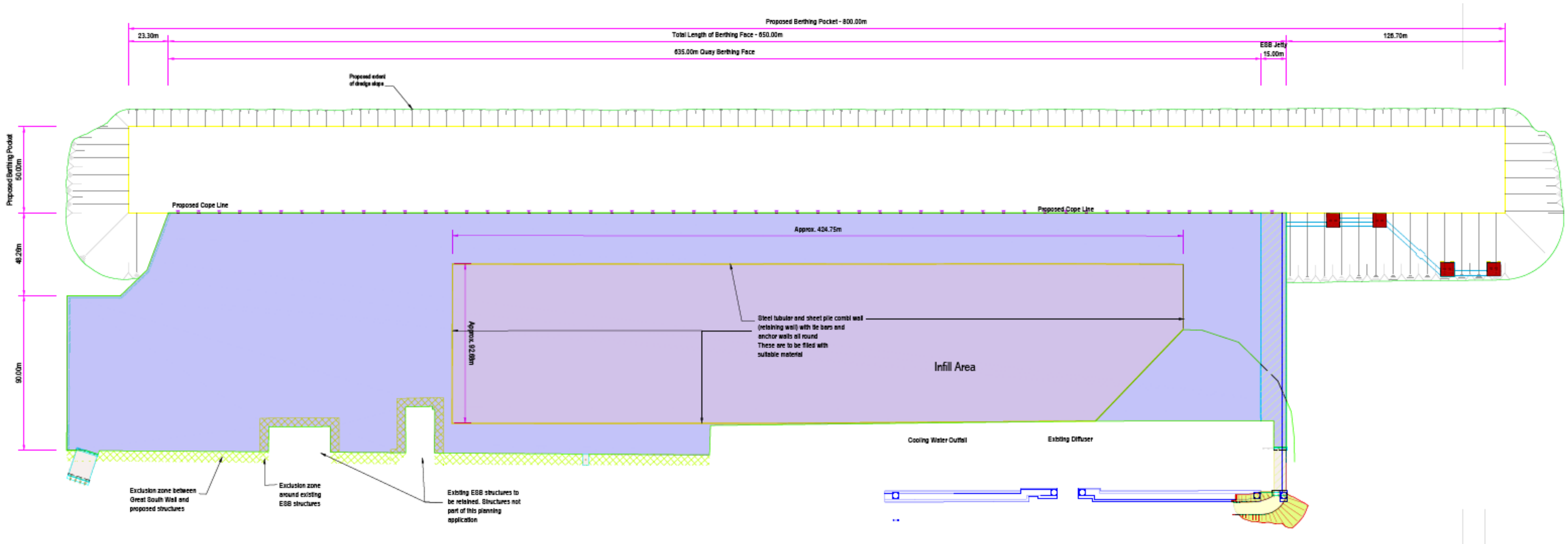

Figure 5.4: Proposed layout for the New South Bank Container Terminal and NORA Oil berth

Source: Reference 9

Table 5.1: Berthing energy calculations for New South Bank Container Terminal

Design ship	150 m Container	225 m Container	Notes
Ship type	Container	Container	
Length Overall, LOA (m)	153.0	222.2	
Length between perpendiculars, LBP (m)	142.8	210.0	
Beam, B (m)	24.5	30.0	
Block coefficient, Cb	0.75	0.67	
Design laden draught, D (m)	7.6	10.1	
Water depth at berth at LAT, d (m)	14.5	8.0	
UKC factor, d/D	0.91	0.44	
Displacement (t)	20,438	43,698	
Approach velocity, Vb	0.2	0.2	Based on Type A berth (PIANC WG145)
Number of fenders contacted	1	2	Assuming contact with two fenders due to angle and hull shape of larger ship
Eccentricity coefficient, Ce (see notes)	0.75	0.72	Eccentricity based on third point berthing
Softness coefficient, Cs	1.0	1.0	
Berth configuration coefficient, Cc	1.0	1.0	
Pitch gyradius, Kyy (m)	36.1	49.8	
Contact distance, R (m)	26.8	52.5	
Gamma (°)	56.8	54.6	
Angle of ship's approach (°)	6	6	
Hydrodynamic coefficient, Cm	1.80	1.80	Based on Vasco Costa Method (BS6349-4:2014)
Energy, e (kNm)	553	566	
Factor of Safety	1.5	1.5	For a continuous quay handling conventional cargo vessels (BS6349-4:2014)
Total energy absorption, E (kNm)	912	933	Includes 10% manufacturers tolerance
Preliminary fender	2 x Trelleborg SCN 1100 F1.0		
Energy absorption (kNm)	1,090		Sufficient for both design ships
Rated reaction (kN)	1,659		

Table 5.2: Berthing energy calculations for NORA Oil Berth

Design ship	185 m Tanker	120 m Tanker	Notes
Ship type	Oil tanker	Oil tanker	
Length Overall, LOA (m)	183.0	120.0	
Length between perpendiculars, LBP (m)	174.0	113.0	
Beam, B (m)	32.2	20.4	
Block coefficient, Cb	0.83	0.81	
Design laden draught, D (m)	9.0	8.7	
Water depth at berth at LAT, d (m)	13.5	13.5	
UKC factor, d/D	0.50	0.55	
Displacement (t)	42,899	16,668	
Approach velocity, Vb	0.2	0.2	
Number of fenders contacted	1	1	Dolphin structure/end berth
Eccentricity coefficient, Ce (see notes)	0.60	0.59	Eccentricity based on quarter point berthing
Softness coefficient, Cs	1.0	1.0	
Berth configuration coefficient, Cc	1.0	1.0	
Pitch gyradius, Kyy (m)	46.6	29.8	
Contact distance, R (m)	46.4	28.3	
Gamma (°)	63.7	30.0	
Angle of ship's approach (°)	6	6	
Hydrodynamic coefficient, Cm	1.56	1.85	Based on Vasco Costa Method (BS6349-4:2014)
Energy, e (kNm)	802	366	
Factor of Safety	2.0	2.0	Oil terminal and dolphin structures
Total energy absorption, E (kNm)	1,765	805	Includes 10% manufacturers tolerance
Preliminary fender	2 x Trelleborg SCN 1300 F1.0		
Energy absorption (kNm)	1,790		Sufficient for both design ships
Rated reaction (kN)	2,308		

Table 5.3: Berthing energy calculations for Berth 45

Design ship	MV Celine	Notes
Ship type	RO-RO	
Length Overall, LOA (m)	235.0	
Length between perpendiculars, LBP (m)	226.0	
Beam, B (m)	35.0	
Block coefficient, Cb	0.77	
Design laden draught, D (m)	7.5	
Water depth at berth at LAT, d (m)	8.7	
UKC factor, d/D	0.16	
Displacement (t)	46,900	
Approach velocity, Vb	0.2	Based on Type A berth (PIANC WG145)
Number of fenders contacted	2	Assuming contact with two fenders due to angle and hull shape of ship
Eccentricity coefficient, Ce (see notes)	0.75	Eccentricity based on third point berthing
Softness coefficient, Cs	1.0	
Berth configuration coefficient, Cc	1.0	
Pitch gyradius, Kyy (m)	57.9	
Contact distance, R (m)	41.5	
Gamma (°)	59.1	
Angle of ship's approach (°)	6	
Hydrodynamic coefficient, Cm	1.80	Based on Vasco Costa Method (BS6349-4:2014)
Energy, e (kNm)	633	
Factor of Safety	1.5	For a continuous quay handling conventional cargo vessels (BS6349-4:2014)
Total energy absorption, E (kNm)	1,045	Includes 10% manufacturers tolerance
Preliminary fender	2 x SCN 1150 F1.0	
Energy absorption (kNm)	1,243	Sufficient for the design ship
Rated reaction (kN)	1,816	

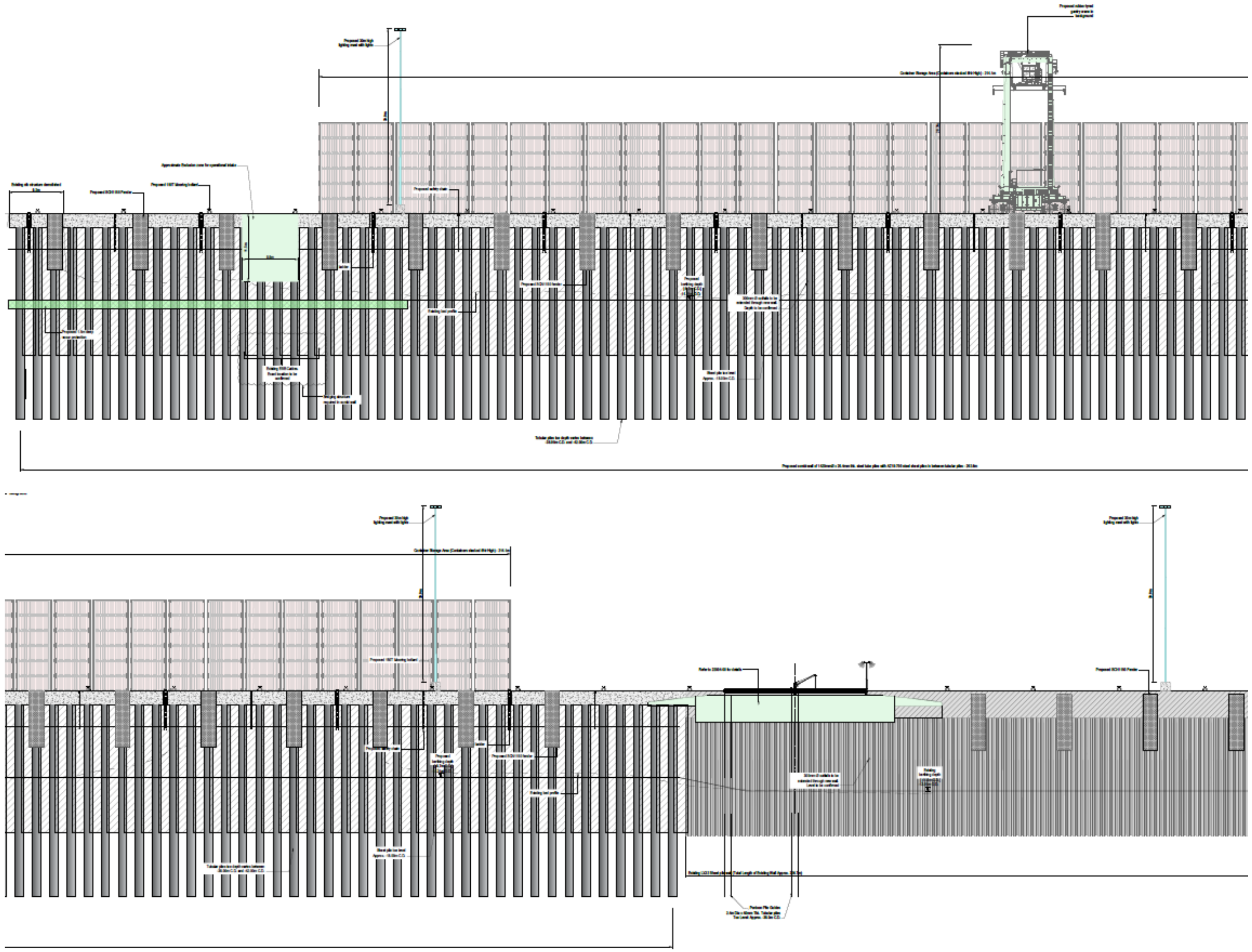

Figure 5.5: Berth 45 side elevation drawing

Source: Reference 8

6 Moored ships

6.1 Design ships

6.1.1 New South Bank Container Terminal

The design moored ships for the New South Bank Container Terminal for the dynamic mooring analysis were a 225 m container ship, representing the largest ship expect to call at the berth, and a 150 m container, representing a typical ship to call at the berth. Details of the design moored ships are shown in Table 6.1.

6.1.2 NORA Oil Berth

The design moored ships for the NORA Oil Berth for the dynamic mooring analysis were a 185 m MR tanker, representing the largest ship expected to call at the berth, and a 120 m tanker, representing the smallest ship expected to call at the berth. Details of the design moored ships are shown in Table 6.2.

6.1.3 Berth 45

The design moored ship for Berth 45 for the dynamic mooring analysis was a 235 m RO-RO, “MV Celine”, representing the largest ship expected to call at the berth. Details of the design moored ship is shown in Table 6.3.

Table 6.1: Ship characteristics for New South Bank Container Terminal

Parameter	Units	"BG Sapphire"	"Kota Pekarang"
Length overall (LOA)	m	153.0	222.2
Length between perpendiculars (LBP)	m	142.8	210.0
Beam	m	24.5	30.0
Moulded depth	m	11.8	16.8
Hydrostatic characteristics			
Loading condition	-	Laden	Laden
Modelled draught	m	7.6	10.1
Modelled displacement	t	20,440	43,700
Centre of mass from forward perp.	m	70.0	102.9
Centre of mass above keel	m	9.9	13.0
Radii gyration X (Kxx)	m	9.2	11.3
Radii gyration Y (Kyy)	m	35.7	52.5
Radii gyration Z (Kzz)	m	35.7	52.5
Transverse metacentric height (GMt)	m	1.7	1.8
Above deck windage			
Lateral/longitudinal	m^2	2,499/573	4,010/728
Mooring lines			
Diameter	mm	64	64
Line type	-	Polyester	Nylon
Minimum breaking load	t	80	81
Arrangement	-	2-2-2-2	2-2-2-2-2-2

Table 6.2: Ship characteristics for NORA Oil Berth

Parameter	Units	MR Tanker	"Tigris"
Length overall (LOA)	m	183.0	120.0
Length between perpendiculars (LBP)	m	174.0	113.0
Beam	m	32.2	20.4
Moulded depth	m	19.0	11.9
Hydrostatic characteristics			
Loading condition	-	Part laden	Laden
Modelled draught	m	9.0	8.7
Modelled displacement	t	42,900	16,670
Centre of mass from forward perp.	m	85.0	55.2
Centre of mass above keel	m	10.8	7.2
Radii gyration X (Kxx)	m	10.6	6.7
Radii gyration Y (Kyy)	m	43.5	28.3
Radii gyration Z (Kzz)	m	43.5	28.3
Transverse metacentric height (GMt)	m	3.3	1.5
Above deck windage			
Lateral/longitudinal	m^2	948/480	608/300
Mooring lines			
Diameter	mm	56	44
Line type	-	Polyester/ polypropylene	Polyester/ polypropylene
Minimum breaking load	t	60	36
Arrangement	-	2-2-2-2-2-2	2-2-2-2

Table 6.3: Ship characteristics for Berth 45

Parameter	Units	"MV Celine"
Length overall (LOA)	m	235.0
Length between perpendiculars (LBP)	m	226.0
Beam	m	35.0
Moulded depth	m	11.1
Hydrostatic characteristics		
Loading condition	-	Laden
Modelled draught	m	7.5
Modelled displacement	t	46,900
Centre of mass from forward perp.	m	112.5
Centre of mass above keel	m	15.9
Radii gyration X (Kxx)	m	13.4
Radii gyration Y (Kyy)	m	56.5
Radii gyration Z (Kzz)	m	56.5
Transverse metacentric height (GMt)	m	2.1
Above deck windage		
Lateral/longitudinal	m^2	5,472 / 1,042
Mooring lines		
Diameter	mm	60
Line type	-	Superwinchline Nylon
Minimum breaking load	t	68
Arrangement	-	2-2-2-2-2-2-2-2

7 Passing ships

7.1 Design ships

There were four passing ships considered for the study to represent the range of ships expected to pass the berths. These assumptions were based on ships that frequently operate to and from the port in discussion with DPC. The passing ships were considered to determine acceptable passing speeds for the moored ships and their characteristics are detailed in Table 7.1.

Table 7.1: Design passing ships

Parameter	"MV Celine"	"Seatruck Pace"	"Jasmine A"	160 m Tanker
Vessel Type	Ro-Ro cargo	General cargo	Bulk carrier	Oil tanker
Deadweight (DWT, t)	23,500	5300	76596	26000
Displacement (t)	47,000	10,900	86,820	33,552
Length overall, LOA (m)	235.0	142	224.9	159.98
Length between perpendiculars, LBP (m)	226.0	133.2	217	154
Beam (m)	35.0	23.0	32.3	26.8
Moulded depth	11.02	16.3	19.5	14.2
Laden draught	7.5	5.7	14.1	10.1
Modelled draught(s) (m)	7.5	5.7	10.25/11.25/ 12.25	9.0
Modelled displacement(s) (t)	47,000	10,900	61,180/67,840/ 73,830	29,500

Note: Jasmine A will be depth limited

7.2 Modelled draughts

The draughts of the passing ships were based on statistics of calls at Dublin Port. The Jasmine A will be depth limited and therefore the draught was based on the water level at the time of the call. For the future channel depth of -10.0 mCD, an under keel clearance of 1.25 m would be expected. Neap tides were used for the water levels and so the draughts that were modelled for the assessment are shown in Table 7.2.

Table 7.2: Modelled draught based on water levels

Passing ships	Modelled draught by water level (m)[1]		
	MHWN (13.4 m)	MSL (12.5 m)	MLWN (11.5 m)
"MV Celine"	7.5	7.5	7.5
"Seatruck Pace"	5.7	5.7	5.7
"Jasmine A"	12.15	11.25	10.25
160 m Tanker	9.0	9.0	9.0

Notes: 1 – Depth in channel shown in brackets

7.3 Passing speeds and distances

A total of three separation distances were considered to determine the impact of the transit of the passing ship, including a centreline transit. Passing ship speeds were modelled at 0.5 knot increments, to provide the required fidelity in the results to determine acceptable passing speeds. Passing speeds of 3 to 9 knots were considered for the New South Bank Container Terminal and NORA Oil berth and 3 to 6 knots for Berth 45 due to the speed limits at each of the berths. The separation distances considered (between the centrelines of the moored and passing ship) are shown in Table 7.3.

Table 7.3: Separation distances of moored ship to passing ship

Berth	Ship	Separation distances (m, between centrelines at midships)		
		Southerly	Channel CL	Northerly
New South bank Container Terminal	150 m container ship	109	150	194
	225 m container ship	107	148	192
NORA Oil Berth	120 m tanker	111	152	196
	185 m tanker	105	146	190
Berth 45	"MV Celine"	76	106	136

8 Limiting criteria

8.1 Overview

Limiting criteria was applied to each model run carried out to determine whether it was likely to be safe to moor the ship at the berth in the given conditions. The limiting criteria related to moored ship movements, mooring line forces, fender forces and forces on mooring points, as described in the following sections.

8.2 Moored ship movements

The moored ship movement results from the dynamic mooring analysis are given in terms of the conventional six modes of motion (6DOF) at the ship's centre of gravity (CoG). The six modes of motion are:

- Surge: longitudinal movement;
- Sway: lateral movement;
- Heave: vertical movement;
- Roll: rotation about the ship's longitudinal axis;
- Pitch: rotation about the ship's lateral axis;
- Yaw: rotation about the ship's vertical axis.

Motion criteria for container ships are generally based around efficiency of loading over the duration of time that the ship is at berth. Whilst motions due to passing ship may exceed these motions limits, they are unlikely to significantly affect the overall operability of the berth, unless passing ships impacts the motions frequently. On this basis, the most recent criteria for container unloading uses significant motions (References 3), meaning single large excursions (by passing ships) will not be taken into accounted. Earlier guidelines provided peak to peak movements for (un)loading, and so the relevant motion criteria that were considered are shown in Table 8.1.

Table 8.1: Motion criteria for container ships at berth

Motion	PIANC WG24 (1995)1
Surge	1.0m/2.0m
Sway	0.6m/1.2m
Heave	0.8m/1.2m
Roll	1°/1.5°
Pitch	1°/2°
Yaw	3°/6°

Source: Reference 3

Notes: 1 – Movements from PIANC WG24 (1995) are peak-to-peak values (except sway which are zero-to-peak) and are provided for 100% and 50% cargo handling efficiencies

The reference criteria for acceptable motions for ferries and RO-RO vessels were based on British Standards (Reference 5), as shown in Table 8.2, consistent with the previous passing ship analysis carried out for Berths 52 and 53.

Table 8.2: Motion criteria for Ro-Ro ships at berth

Motion	BS6349-8 (2007)
Surge	±0.3 m
Sway	+0.6 m/-0.3 m
Heave	±0.05 m
Roll	±2.0°
Pitch	±0.5°
Yaw	±0.25°

Source: Reference 5

The reference criteria for oil tankers were based on PIANC WG212 (In press, Reference 12) guidelines.

Table 8.3: Motion criteria for oil tankers at berth

Motion	PIANC WG24 (1995)
Surge	±1.0 m
Sway	+1.0 m
Heave	±1.0 m

Source: Reference 12

Notes: Motions considered at the shore side manifold connection

8.3 Mooring lines

Following the OCIMF Mooring Equipment Guidelines (MEG4, Reference 6), for synthetic lines, which are usually applied in all cases of ship mooring, the limiting mooring line loads, referred to as the mooring line's working load limit (WLL) were taken to be 50% of the line MBL in each case.

8.4 Fenders

Loads on fenders should not exceed their rated capacity, at which point the fender would buckle.

8.5 Mooring points

The bollards considered for the New South Bank Container Terminal have a SWL of 80 t, for the NORA Oil berth have a SWL of 100 t and for Berth 45 have a SWL of 150 t.

9 Berth assessment

9.1 Design guidelines

The design philosophy used for examining the mooring layouts was primarily based on the guidelines contained in the following references:

- British Standard BS6349-4, "Maritime Structures. Part 4: Code of practice for design of fendering and mooring systems", 2014 (Reference 1);
- PIANC, "Guidelines for the design of fenders systems", MarCom Report of WG 33, 2002 (Reference 7);

- OCIMF, "Mooring equipment guidelines", 4th Edition, (MEG4) Witherby Seamanship International, UK, 2018 (Reference 6, noting this is primarily for Oil and Gas Tankers).

According to the OCIMF (2018) guidelines (Reference 6), a mooring line deployment can be assumed to be acceptable if the following guidelines are adopted, as far as it is reasonably practicable to do so. Whilst the guidance is for oil and gas tankers, they are also applicable to other ship types. Mooring of container ships are often limited by the crane rails which lead to bollards located along the quay face and as a result short and steep mooring lines. Ro-Ro ships are typically limited in their ability to pass lines from the seaward side due to the use of stern ramps and linkspans. In both cases, setback ("storm") bollards can be used, along with raised mooring points at ferry berths, where practical to do so.

Head/stern lines:	Head and stern lines (i.e. up to 45° in plan) are not normally efficient in restraining a ship in its berth due to their longer lengths, and current practice advocates that mooring facilities with good breast and spring lines should allow a ship to be moored virtually within its own length. However, mooring patterns for custom or 'site specific conditions' (directional environment) may benefit from a possibly more efficient layout using head and stern lines than relying on using essentially breasting lines and springs.
Breasting lines:	Line angles 10° to 15° in plan (as perpendicular as possible and as far forward and aft as possible). If lines are too normal to the stern of the ship, then there is the possibility of lines breaking across it, which should be avoided.
Spring lines:	Line angles 80° to 90° to the breasting/mooring structure in plan (as parallel to the vessel as possible).
Outboard line:	Similar total length as possible (such that the resulting stiffness of the line lengths results in ship movements within the specified limits). The guidelines recommend lengths of up to 50m, except spring lines, but it is acknowledged that to avoid undue numbers of mooring structures, mooring line lengths can exceed this value. This can be advantageous in terms of load efficiency and line tending, but the extra compliance can allow greater vessel movement.
Symmetry:	To seek as symmetrical a layout as possible with due consideration to fairlead locations for as large a range of vessels as is deemed practicable. Layout to favour one side berthing but to be configured to accept any side berthing as far as it is possible to do so.
Vertical angles:	Lines run as close to the horizontal as possible (0° to 25°). Although it is possible to have negative line angles, provided certain operational precautions are taken, it is usually better if all the lines are angled upwards from the bollard/QRH to the vessel.

9.2 New South Bank Container Terminal

9.2.1 Mooring arrangements

The two design ships for the New South Bank Container Terminal were configured at the berth. The smaller 150 m container ship was configured with 8 lines in a 2-2-2-2 configuration based on a typical mooring arrangement and the available winches and bitts (Figure 9.7). The 225 m container ship was configured with 12 lines in a 2-2-2-2-2-2 configuration based on a typical mooring arrangement with all lines run to winches (Figure 9.8).

The berth layout provides the design ships with sufficient bollard locations to deploy a typical mooring arrangement for container ships.

9.2.2 Line angles

The vertical mooring line angles were considered as part of the berth assessment and are shown in Table 9.1. Vertical line angles range from 9° down to -7°. Negative lines angles were only observed on the smaller container ship due to the relative height between the main deck and quay elevation (+7.11 mCD). Reducing the elevation of the quay structure would be beneficial. If this is not feasible then consideration is required regarding line rubbing on the quay edge and mooring lines catching on fender panels.

Table 9.1: Vertical line angles

Ship	Water level	Vertical line angles (°, from bow to stern)											
		1	2	3	4	5	6	7	8	9	10	11	12
150 m container ship	MHWN	-1	-1	-1	0	4	3	6	6				
	MSL	-4	-4	-2	-2	2	2	4	4				
	MLWN	-7	-7	-4	-3	1	1	2	2				
225 m container ship	MHWN	4	4	9	9	3	3	4	4	9	3	3	9
	MSL	2	3	5	5	2	2	2	2	5	2	2	5
	MLWN	0	1	1	1	0	0	1	0	1	0	0	1

9.2.3 Fendering

The parallel mid body of the design container ships were based on available general arrangement drawings.

The contact with the fenders for the ships at MHWN and MLWN is shown in Figure 9.1 and Figure 9.2. The locations of the fenders at the berth are expected to provide good contact with the parallel middle body of the design ships. The fender panels also provide a good area of contact with the design ships.

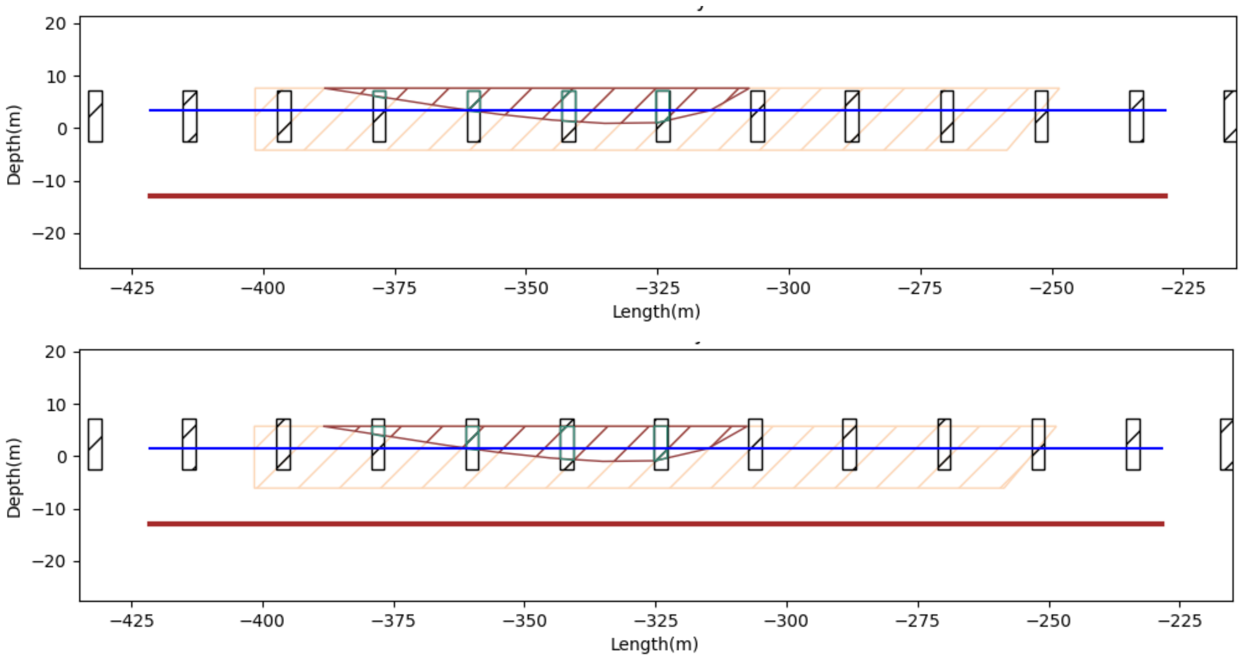

Figure 9.1: Fender contacts for 150 m container ship at MHWN (top) and MLWN (bottom)

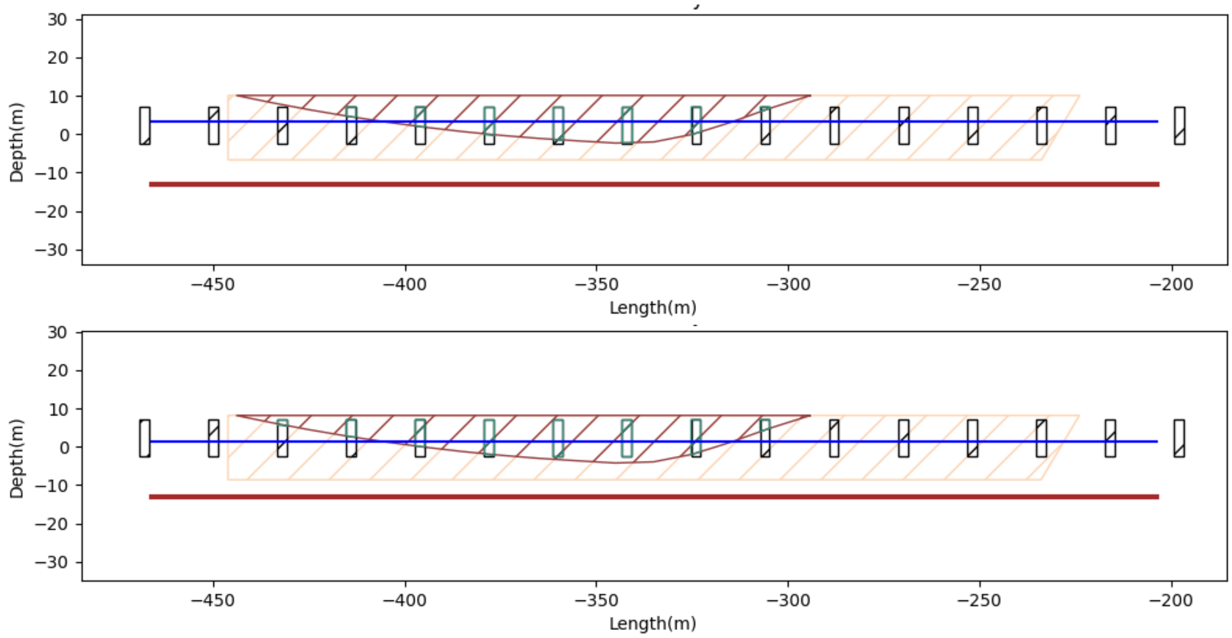

Figure 9.2: Fender contacts for 225 m container ship at MHWN (top) and MLWN (bottom)

9.2.4 Bollards

For mooring bollards, guidance from British Standards (BS6349-1-2:2016, Reference 11) states that each bollard should have a rated SWL of not less than the minimum breaking load (MBL) of the largest capacity line anticipated to be used for mooring of the design vessels. The designer should make an assessment of the number of lines likely to be connected to a single bollard.

The design mooring load on the mooring point structure should be assessed with respect to the likely joint probability of maximum line forces, or upon limiting loads from vessel's mooring equipment with appropriate partial factors as indicated in Section 29.4 of Reference 11.

Guidance from British Standards (BS6349-4, Reference 5), recommends a bollard capacity for vessels under 50,000 t displacement of 80 t. All vessels expected at the New South Bank Container Terminal are under 50,000 t displacement and the maximum MBL of the design ships is 81 t.

The proposed bollard capacity is considered as part of the dynamic passing ship analysis.

9.2.5 Static mooring analysis

A static analysis was carried out for the design ships in the form of a wind limit rose. These are shown in Figure 9.9 and Figure 9.10. These show the wind limit from all directions in 5° increments for the mooring lines, fenders and bollards and give an indication of the effectiveness of the mooring arrangements.

Due to the bollard SWL (80 t) and the WLL of two mooring lines attached to a bollard (80 t) being the same exceedances of the bollards and mooring line WLL were of a similar wind speed. These occurred below 60 knots for off berth wind directions with a minimum of 50 knots for the 150 m container ship and 45 knots for the 225 m container ship. Limiting wind speeds were generally above 60 knots when wind directions were not out of the southerly quadrant.

The wind limit roses indicate the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment.

9.3 NORA Oil berth

9.3.1 Mooring arrangements

The two design ships for the NORA Oil berth were configured at the berth. The smaller 120 m tanker was configured with 8 lines in a 2-2-2-2 configuration based on a typical mooring arrangement and the available winches and bitts (Figure 9.11). It is noted that the stern lines are in the order of 60 m long, including the on the deck length to the winches. OCIMF Vessel Particular Questionnaires for ships of this size indicated they have lines of between 200 m and 220 m.

The 185 m tanker was configured with 12 lines in a 2-2-2-2-2-2 configuration based on a typical mooring arrangement with all lines run to winches (Figure 9.12).

Due to the asymmetric configuration of the berth, only the mooring lines on the western side were be set back. This led to an asymmetric mooring arrangement with significantly shorter mooring lines on the eastern end of the berth. The position of the winches used on the 185 m tanker for spring lines led to short aft springs lines, attached to the inner breasting dolphin, which also had reduced longitudinal restraint due to the angle of the line to the berth. Depending on the configuration of the marine loading arms, it would be beneficial to have a mooring point located on the eastern end of the container terminal.

9.3.2 Line angles

The vertical mooring line angles of the mooring arrangements were considered as part of the berth assessment and are shown in Table 9.1. Vertical line angles range from 34˚ down to 0˚.

Due to the use of mooring points close to the berthing line, the vertical line angles are steep for the 185 m tanker. Mooring Equipment Guidelines (MEG4, Reference 6) notes that vertical angle of the mooring line should be kept to a minimum with angles less than 25˚ preferred. It would therefore be beneficial to provide set back mooring points for the oil berth on the container quay reclamation. These could be sunken in to the quay and covered when not required, noting that the end of the quay will be shared with container operations.

Negative lines angles are likely to occur at lower water levels (below MLWN) due to the relative height between the main deck and the quay/dolphin elevation (+7.11 mCD). Consideration is required regarding line rubbing on the quay edge and mooring lines catching on fender panels.

Table 9.2: Vertical line angles for NORA Oil berth

Ship	Water level	Vertical line angles (˚, from bow to stern)											
		1	2	3	4	5	6	7	8	9	10	11	12
120m tanker	MHWN	5	6	4	5	4	4	2	2				
	MSL	3	3	2	3	2	2	1	1				
	MLWN	0	0	0	0	0	0	0	0				
185m tanker	MHWN	9	9	31	34	11	11	19	17	8	8	6	6
	MSL	7	8	26	29	9	10	16	14	7	7	5	5
	MLWN	6	6	21	24	7	8	13	11	5	5	4	4

9.3.3 Fendering

The parallel mid body of the design ships were based on details available in Q88 questionnaires which provide details of the ship from the ship owners.

The contact with the fenders for the ships at MHWN and MLWN is shown in Figure 9.1 and Figure 9.2. A starboard side to case was also considered for the 185 m tanker to further examine contact with the outer breasting dolphin (Figure 9.5).

The position of the fenders are expected to provide good contact with the parallel middle body of the design ships. The outer breasting dolphin only provides a partial contact with the larger

185 m tanker. If ships longer than 185 m are not expected to make use of the berth then further assessment should be considered, assessing a wider range of ships, to determine if it would be beneficial to move the dolphin closer to the centre of the berth. Alternatively, it may be possible to make use of just one breasting dolphin. The fender panels also provide a good area of contact with the design ships.

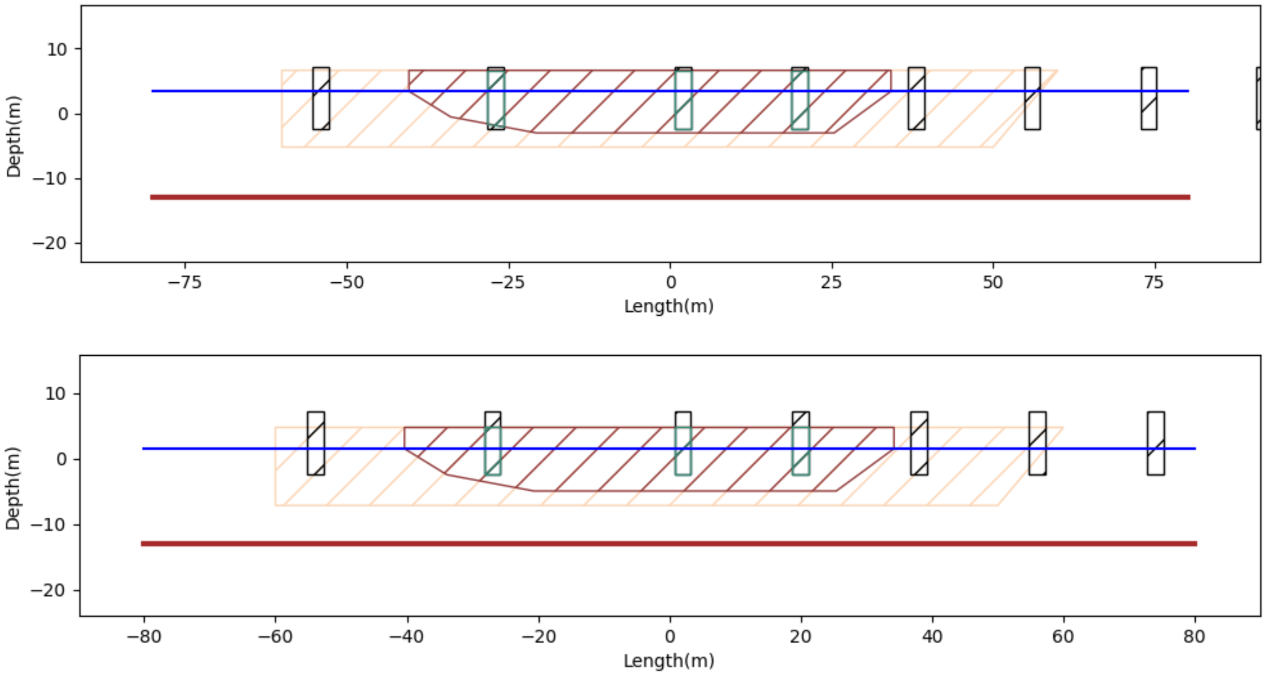

Figure 9.3: Fender contacts for 150 m container ship at MHWN (top) and MLWN (bottom)

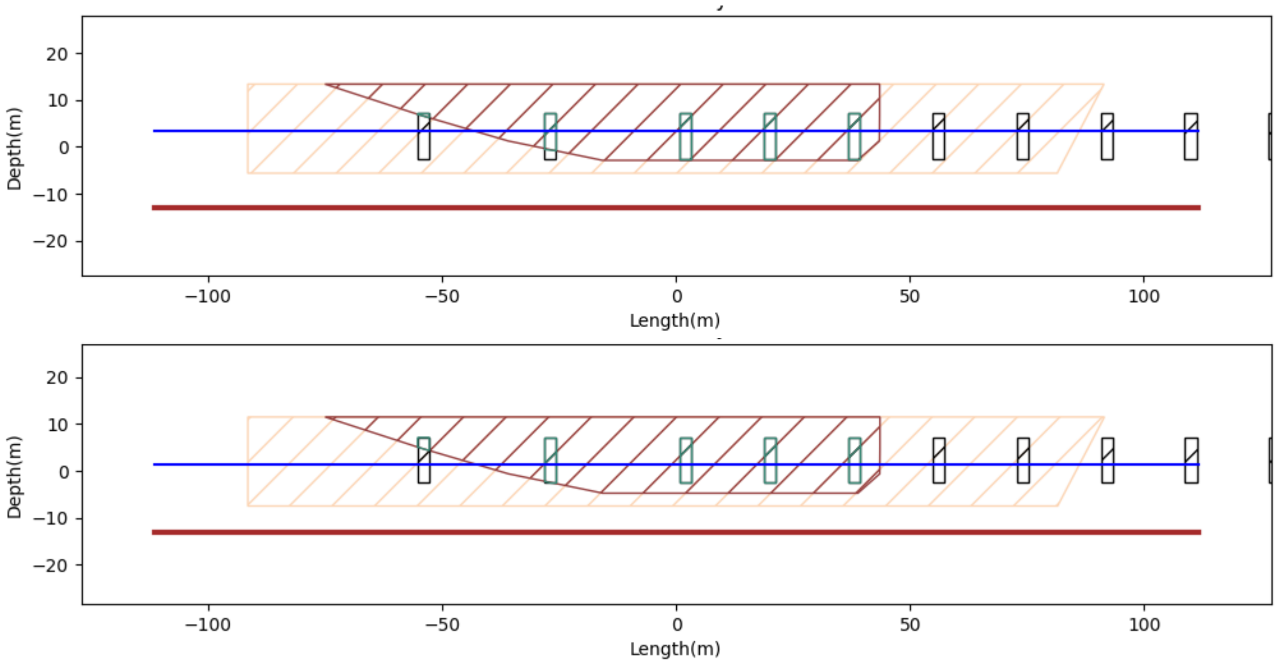

Figure 9.4: Fender contacts for 185 m tanker at MHWN (top) and MLWN (bottom)

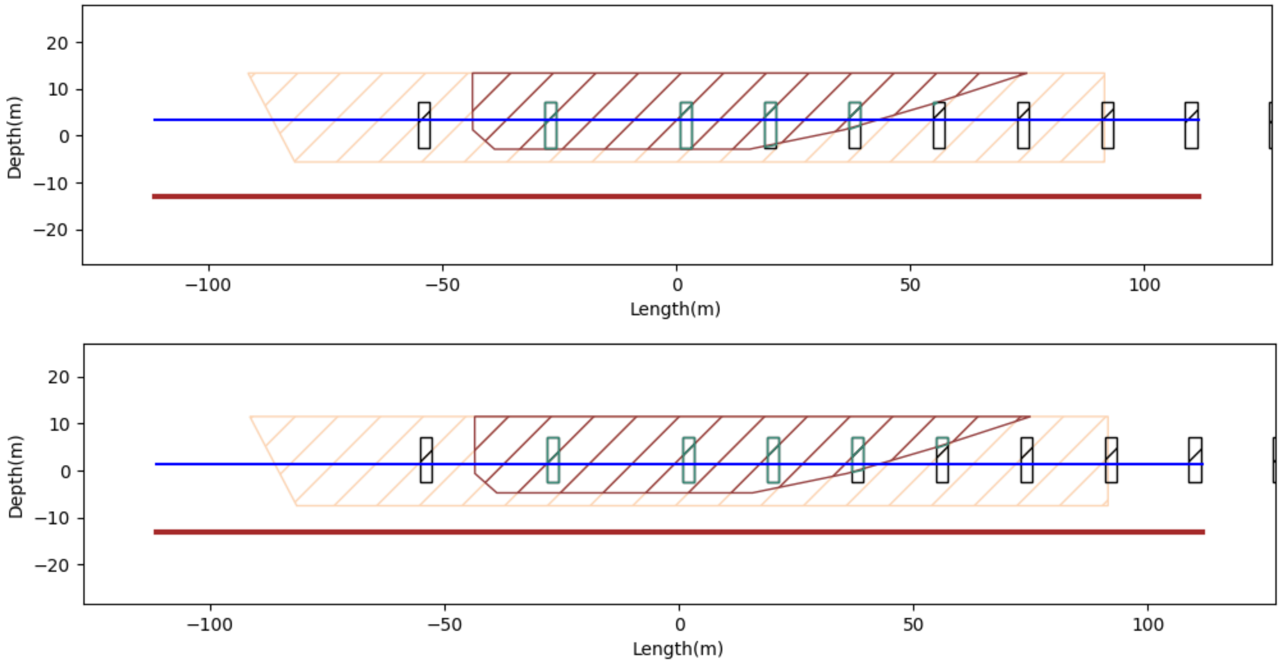

Figure 9.5: Fender contacts for 185 m tanker at MHWN (top) and MLWN (bottom)

9.3.4 Bollards

For mooring bollards, guidance from British Standards (BS6349-1-2:2016, Reference 11) states that each bollard should have a rated SWL of not less than the minimum breaking load (MBL) of the largest capacity line anticipated to be used for mooring of the design vessels. The designer should make an assessment of the number of lines likely to be connected to a single bollard.

The design mooring load on the mooring point structure should be assessed with respect to the likely joint probability of maximum line forces, or upon limiting loads from vessel's mooring equipment with appropriate partial factors as indicated in Section 29.4 of Reference 11.

It is understood the bollards at the berth are expected to be 100t. The maximum MBL of the design ships is 60 t.

The proposed bollard capacity is considered as part of the dynamic passing ship analysis.

9.3.5 Static mooring analysis

A static analysis was carried out for the design ships in the form of a wind limit rose. These are shown in Figure 9.13 and Figure 9.14. An additional assessment was carried out for the design ships in ballast as a sensitivity check (Figure 9.15). These show the wind limit from all directions in 5° increments for the mooring lines, fenders and bollards and give an indication of the effectiveness of the mooring arrangements. For all cases, the limiting wind speed was above 60 knots for all wind directions. Whilst the mooring arrangements were shown to be suboptimal due to the asymmetry and steep mooring lines they provide adequate resistance to the wind and current conditions at the site.

9.4 Berth 45

9.4.1 Mooring arrangements

"MV Celine" was configured at Berth 45 to assess the berth configuration and associated mooring arrangement. Due to the high sided nature of the ship and the stern ramp, mooring lines at the stern are routed through fairleads on the landward side of the ship. As a result, if bollards were utilised along the berth face, the vertical mooring lines would be very steep. Therefore, additional bollards setback approximately 10m from the berthing line were proposed. Initially, two bollards were considered, which was sufficient for 12 mooring lines to be deployed (4 aft breast/stern lines). However, following an assessment of the limiting wind conditions, which were close to 35 knots, an additional bollard was added to allow 16 mooring lines (6 aft breast/stern lines) to be deployed (Figure 9.16).

Following the changes to the berth layout, it was shown to provide the design ship with sufficient bollard locations to deploy an effective mooring arrangement.

9.4.2 Line angles

The vertical mooring line angles were considered as part of the berth assessment and are shown in Table 9.3. Vertical line angles range from 52° down to 11°. MEG4 (Reference 6) suggests that vertical line angles are kept to a minimum and ideally below 25°. This is not always possible with high sided ships alongside quay walls although the mooring lines have been alleviated by setting back the bollards at the stern. The bollards were setback by 10 m although if it is feasible to set them back further this would be beneficial to the mooring arrangement. It would also be beneficial to set the bollards the bow of the ship (western end) back to alleviate the highest mooring line angles.

Table 9.3: Vertical line angles at Berth 45

Ship	Water level	Vertical line angles (°, from bow to stern)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MV Celine	MHWN	16	16	25	26	39	52	15	15	15	14	49	48	37	36	32	25
	MSL	14	15	23	24	36	49	14	14	14	13	47	46	35	34	30	23
	MLWN	13	13	20	21	33	46	12	12	12	11	44	43	31	30	28	20

9.4.3 Fendering

The parallel mid body of the “MV Celine” at Berth 45 was based on general arrangement drawing of the ship. The contact with the fenders for the ship at MHWN and MLWN is shown in Figure 9.6. The fenders are expected to make good contact with the parallel middle body of the “MV Celine”. The fender panels also provide a good area of contact.

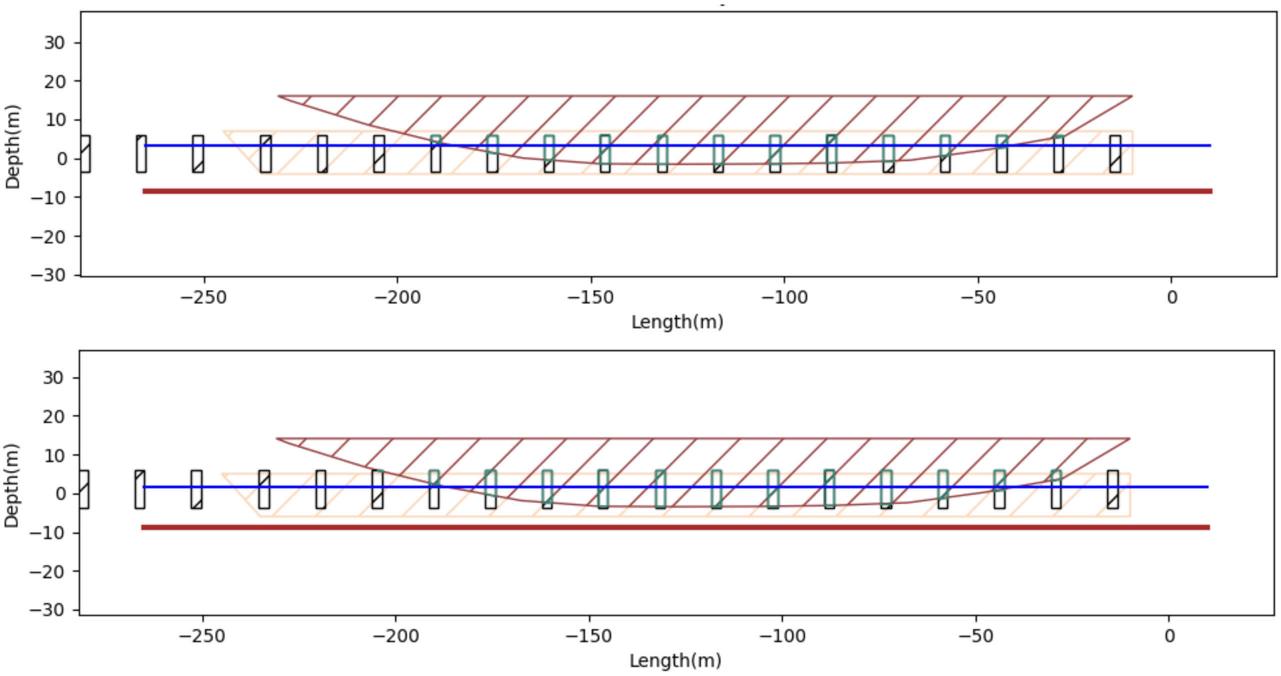

Figure 9.6: Fender contacts for MV Celine at MHWN (top) and MLWN (bottom)

9.4.4 Bollards

The bollards at Berth 45, which are to be rated at 150 t provide a SWL above the MBL of the mooring lines of the design ship (68 t MBL), assuming a maximum of two lines per bollards.

The proposed bollard capacity is considered as part of the dynamic passing ship analysis.

9.4.5 Static mooring analysis

A static analysis of the "MV Celine" at Berth 45 was carried out in the form of a wind limit rose for each of the water levels considered. These are shown in Figure 9.17. These show the wind limit from all directions in 5° increments for the mooring lines, fenders and bollards and give an indication of the effectiveness of the mooring arrangement.

Exceedances always occurred in the mooring lines for winds of up to 60 knots. These occurred below 60 knots for off berth wind directions with a minimum of 41 knots. Limiting wind speeds were generally above 60 knots when wind directions were not out of the southerly quadrant. In order to increase the limiting wind speed and decrease the vertical line angles, sensitivity tests were carried out with bollards setback by 20 m and 30 m at both the bow and stern. Wind limit roses for these cases at MHWN were produced (Figure 9.18). These showed an increase in the wind limit to approximately 46 knots and 49 knots, respectively.

The wind limit roses indicate the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment, but increasing the bollard setback both at the bow and stern would be beneficial.

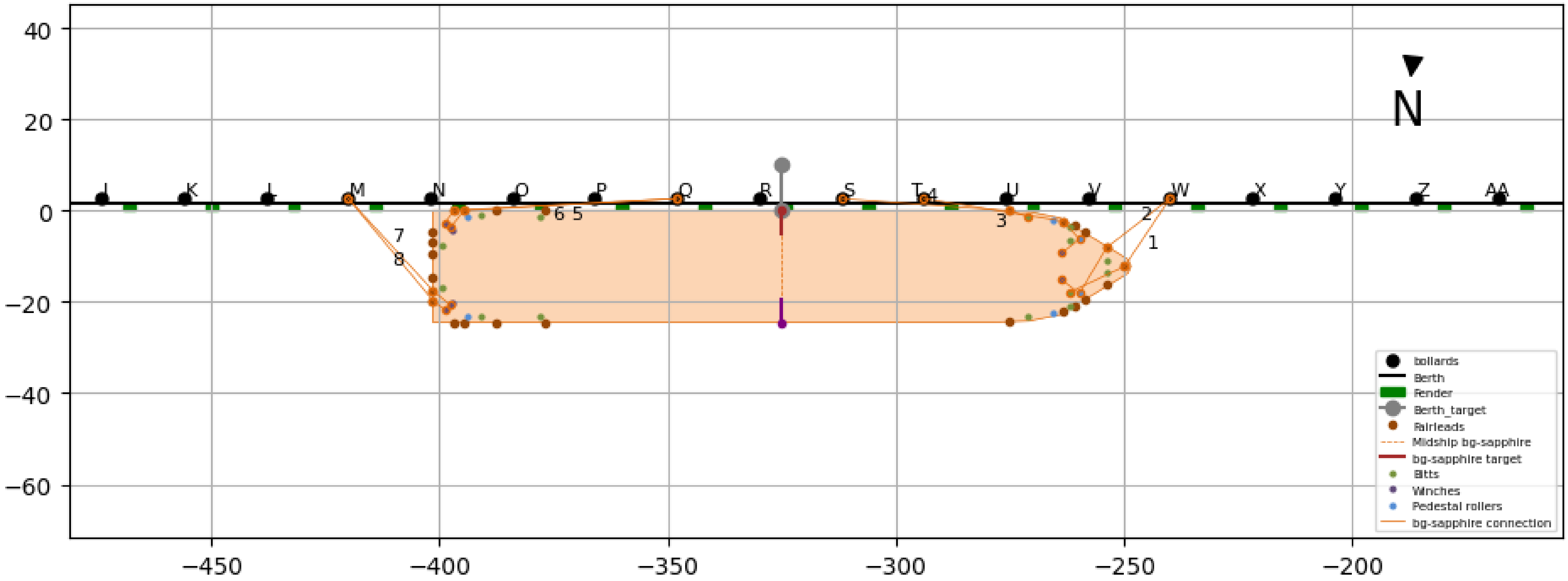

Figure 9.7: Mooring arrangement for 150 m container ship at the New South Bank Container Terminal

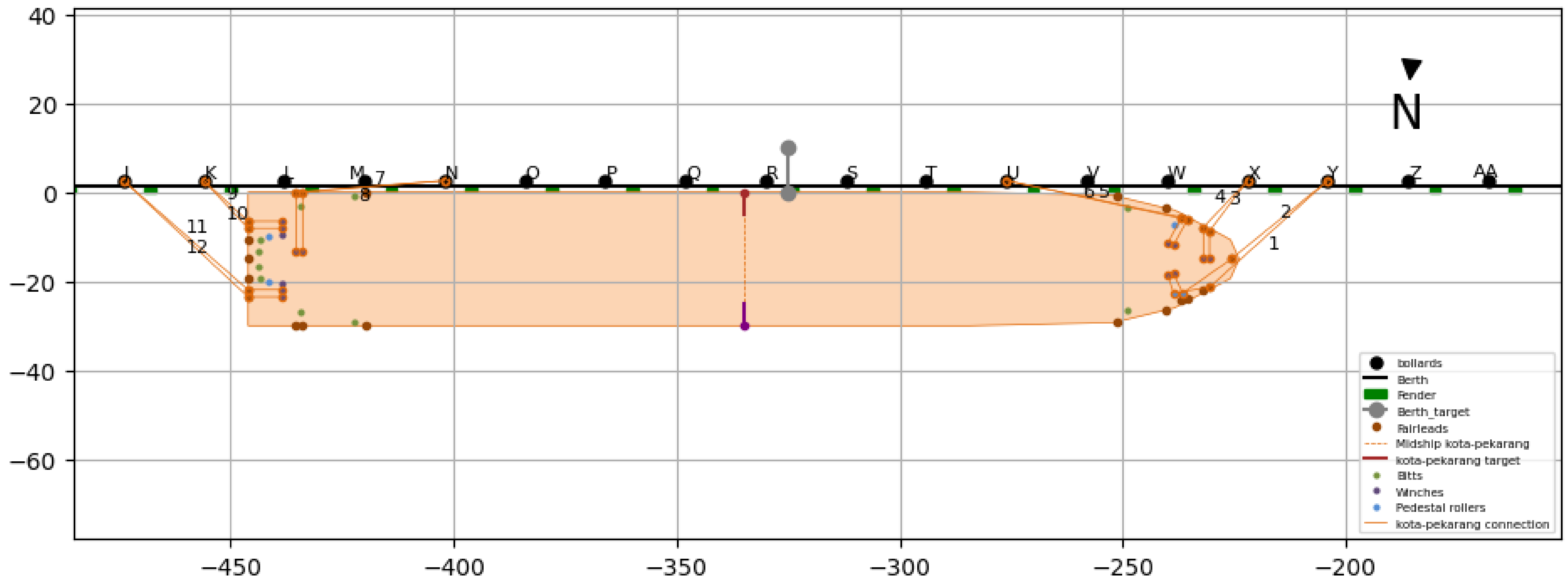

Figure 9.8: Mooring arrangement for 225 m container ship at the New South Bank Container Terminal

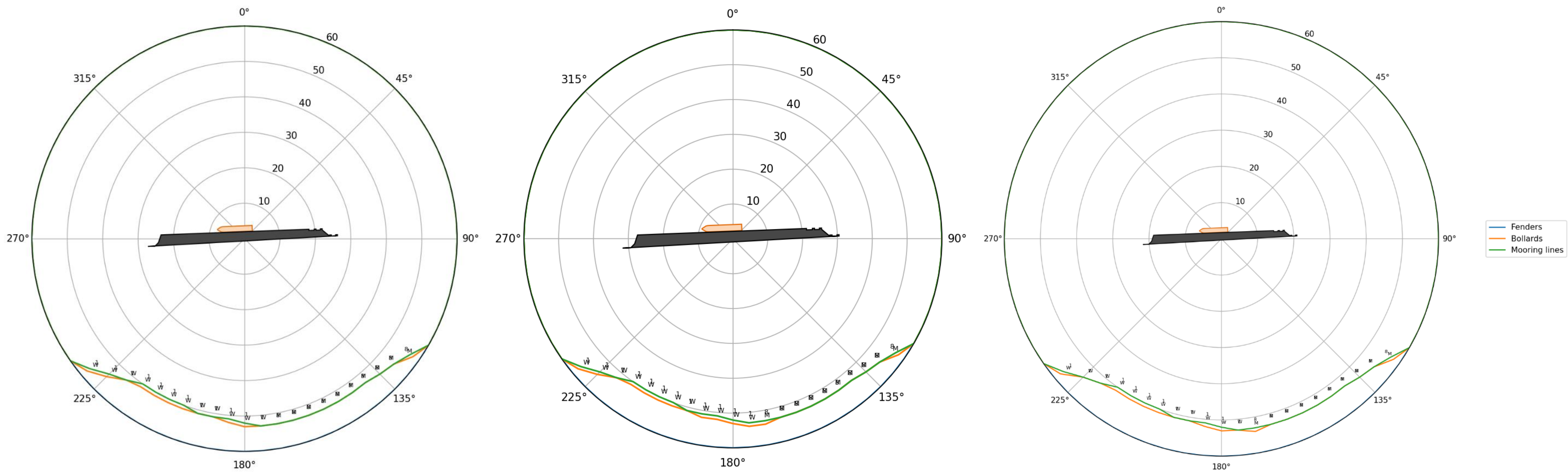

Figure 9.9: Wind limit rose for 150 m container ship at the New South Bank Container Terminal at MHWN (left), MSL (middle) and MLWN (right)

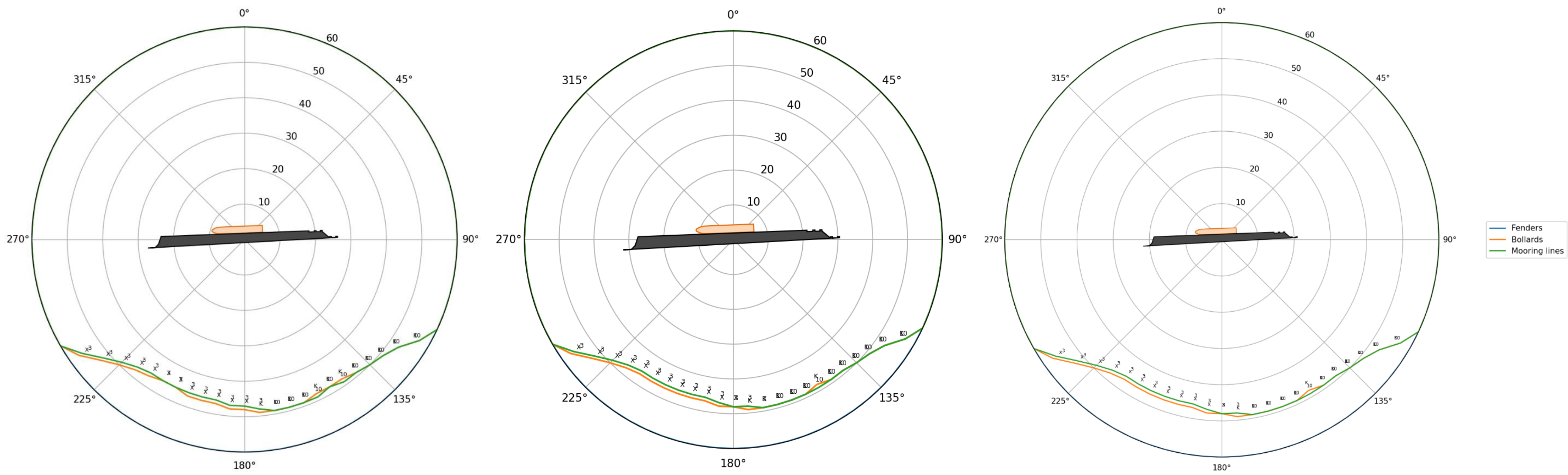

Figure 9.10: Wind limit rose for 225 m container ship at the New South Bank Container Terminal at MHWN (left), MSL (middle) and MLWN (right)

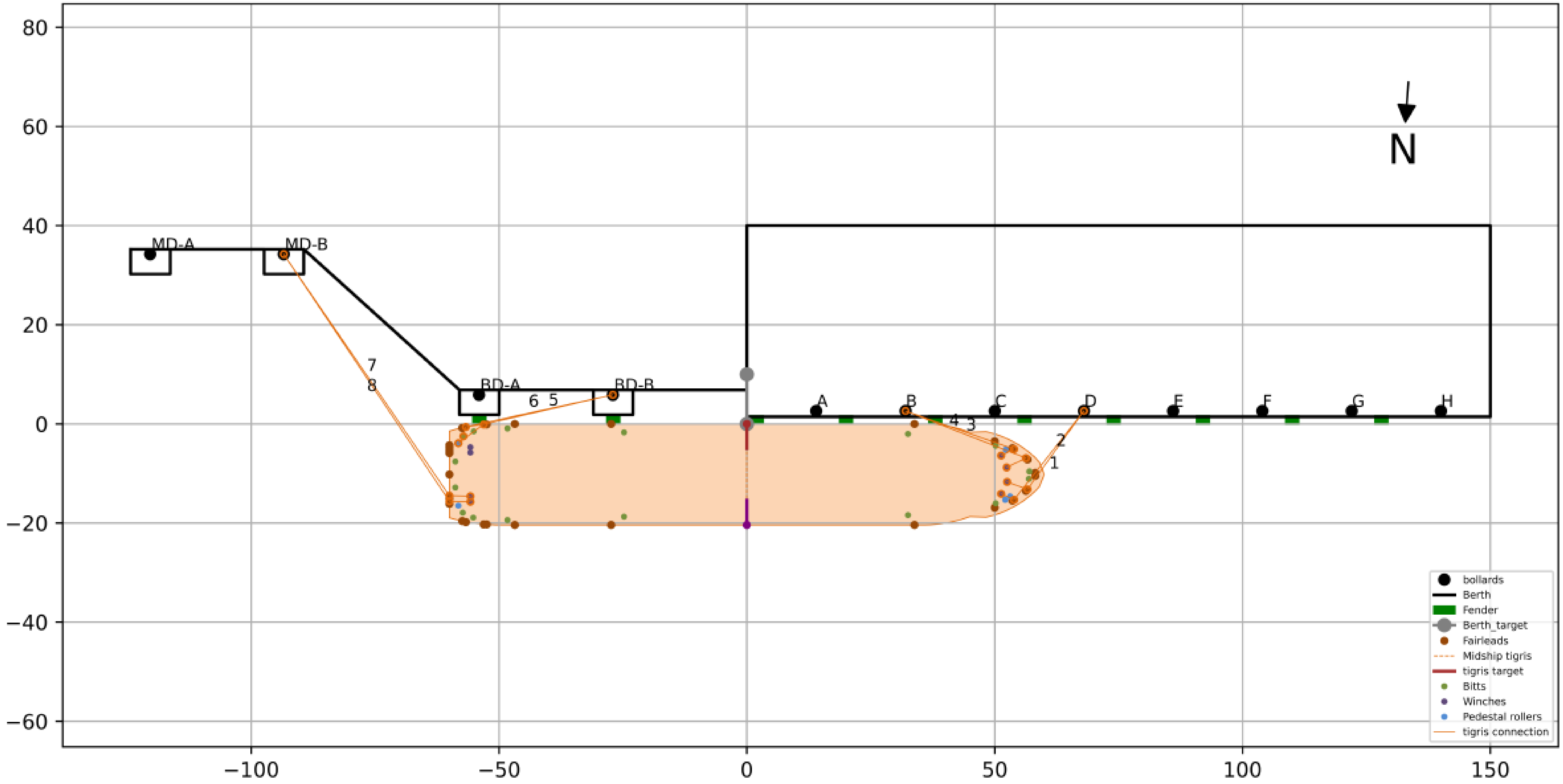

Figure 9.11: Mooring arrangement for 120 m tanker at the NORA Oil berth

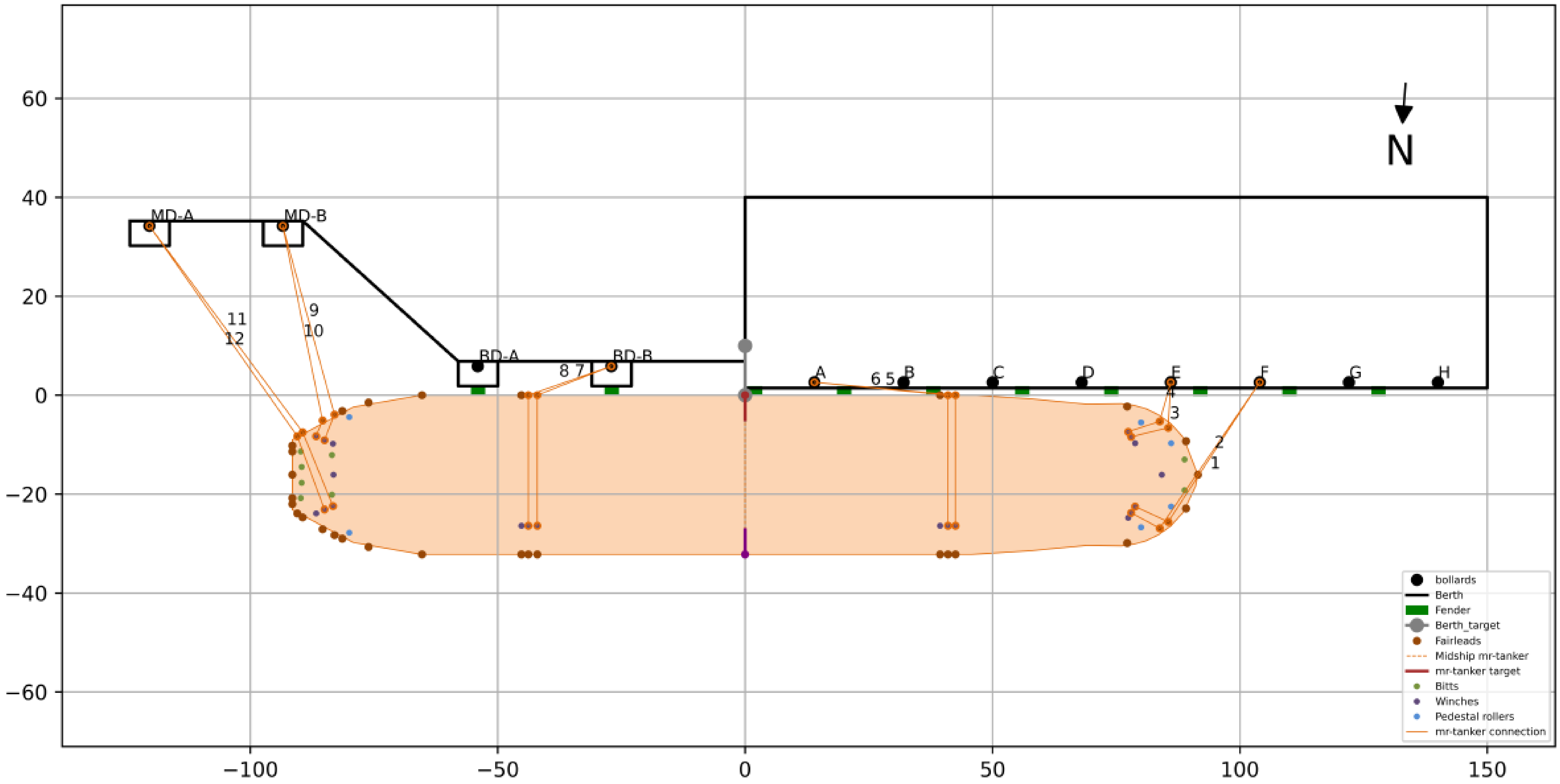

Figure 9.12: Mooring arrangement for 185 m tanker at the NORA Oil berth

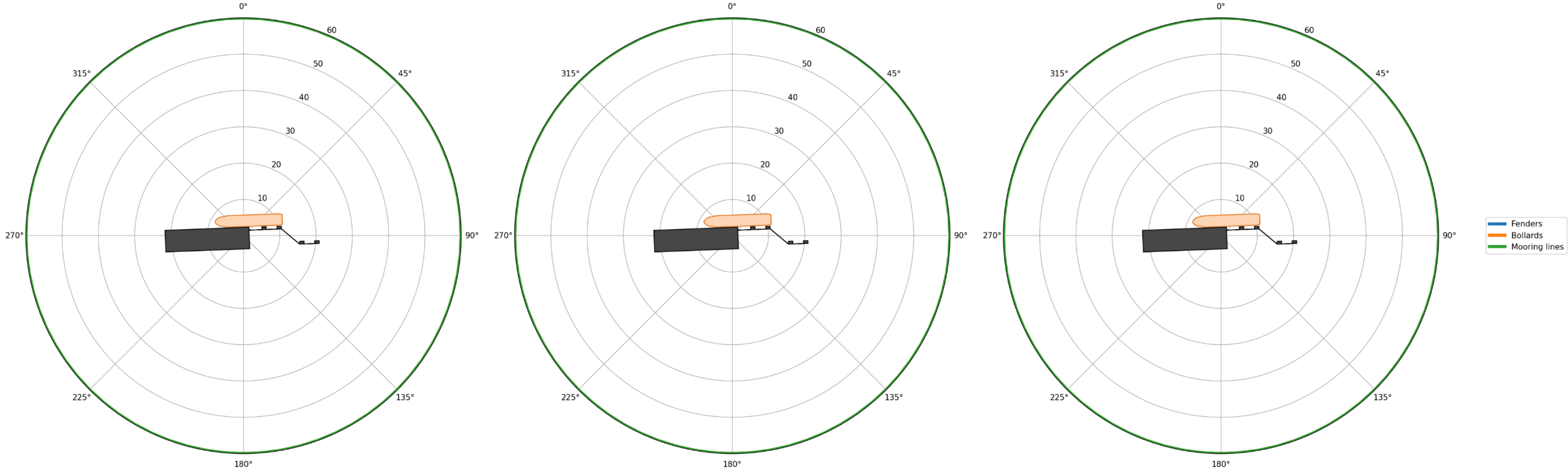

Figure 9.13: Wind limit rose for 120 m tanker at the NORA Oil berth at MHWN (left), MSL (middle) and MLWN (right)

Note: Limits are shown to be above 60 knots for all cases

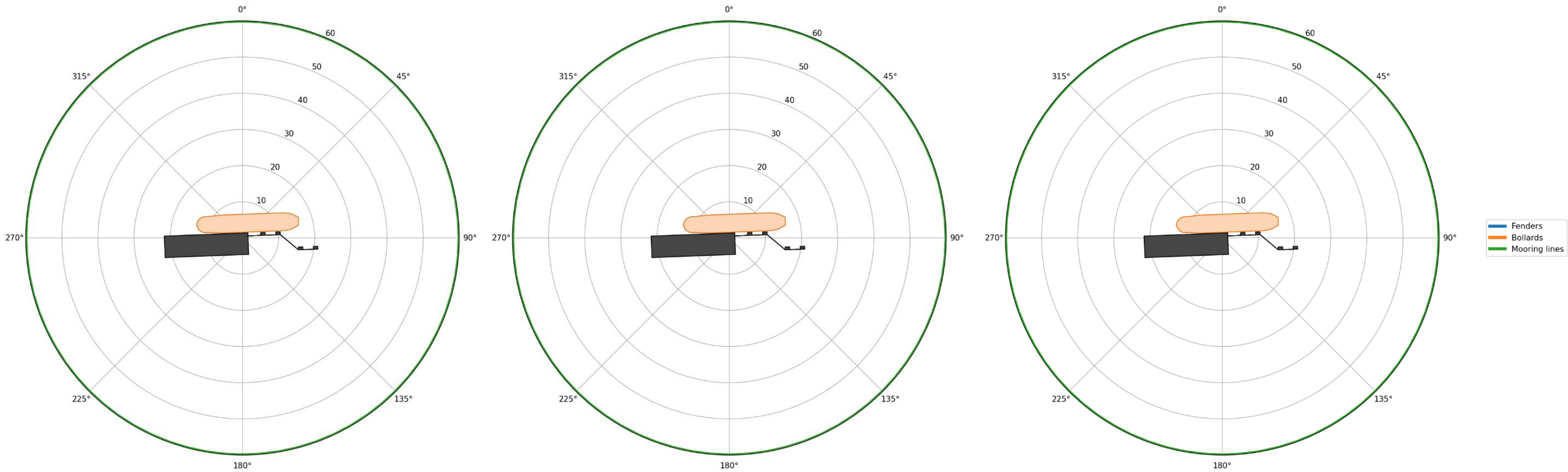

Figure 9.14: Wind limit rose for 185 m tanker at the NORA Oil berth at MHWN (left), MSL (middle) and MLWN (right)

Note: Limits are shown to be above 60 knots for all cases

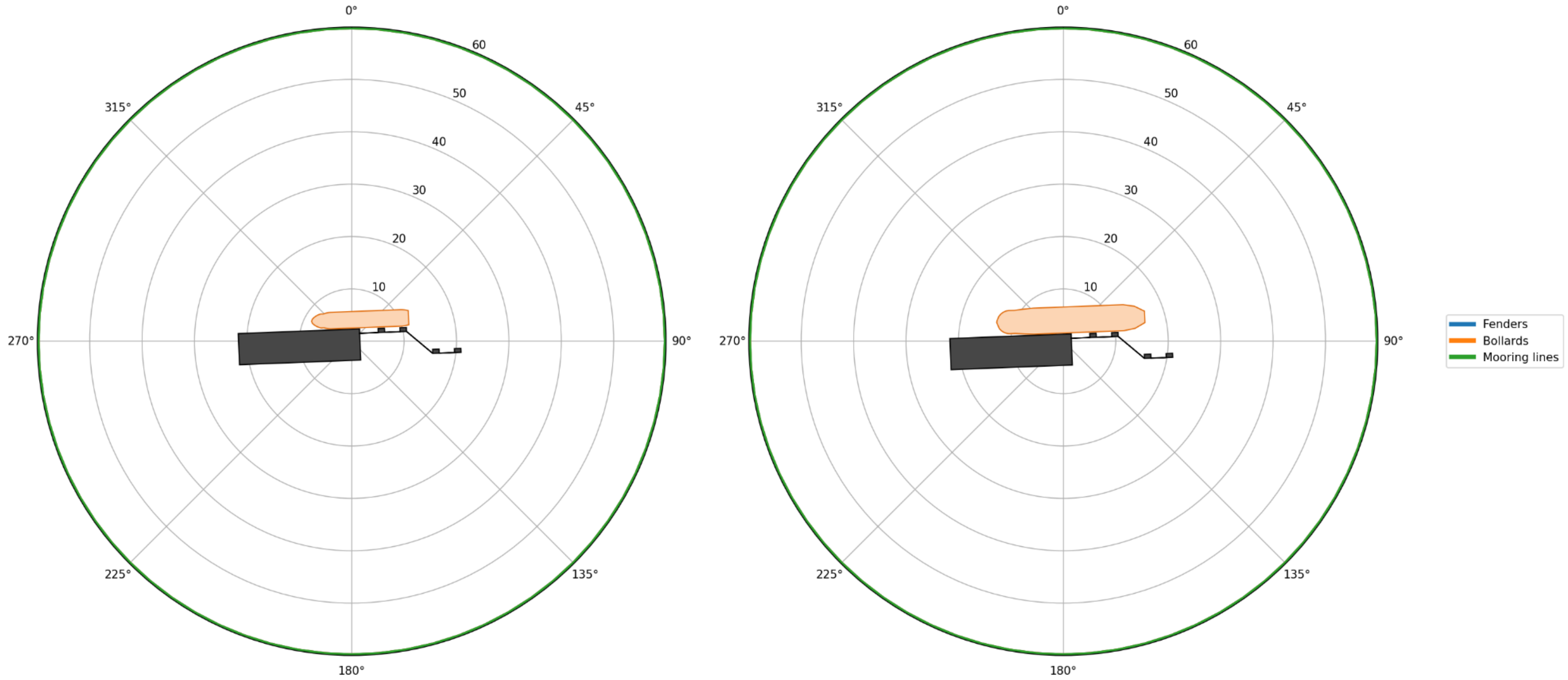

Figure 9.15: Wind limit rose for ballast 120 m (left) and 185 m (right) tanker at the NORA Oil berth at MHWN

Note: Limits are shown to be above 60 knots for all cases

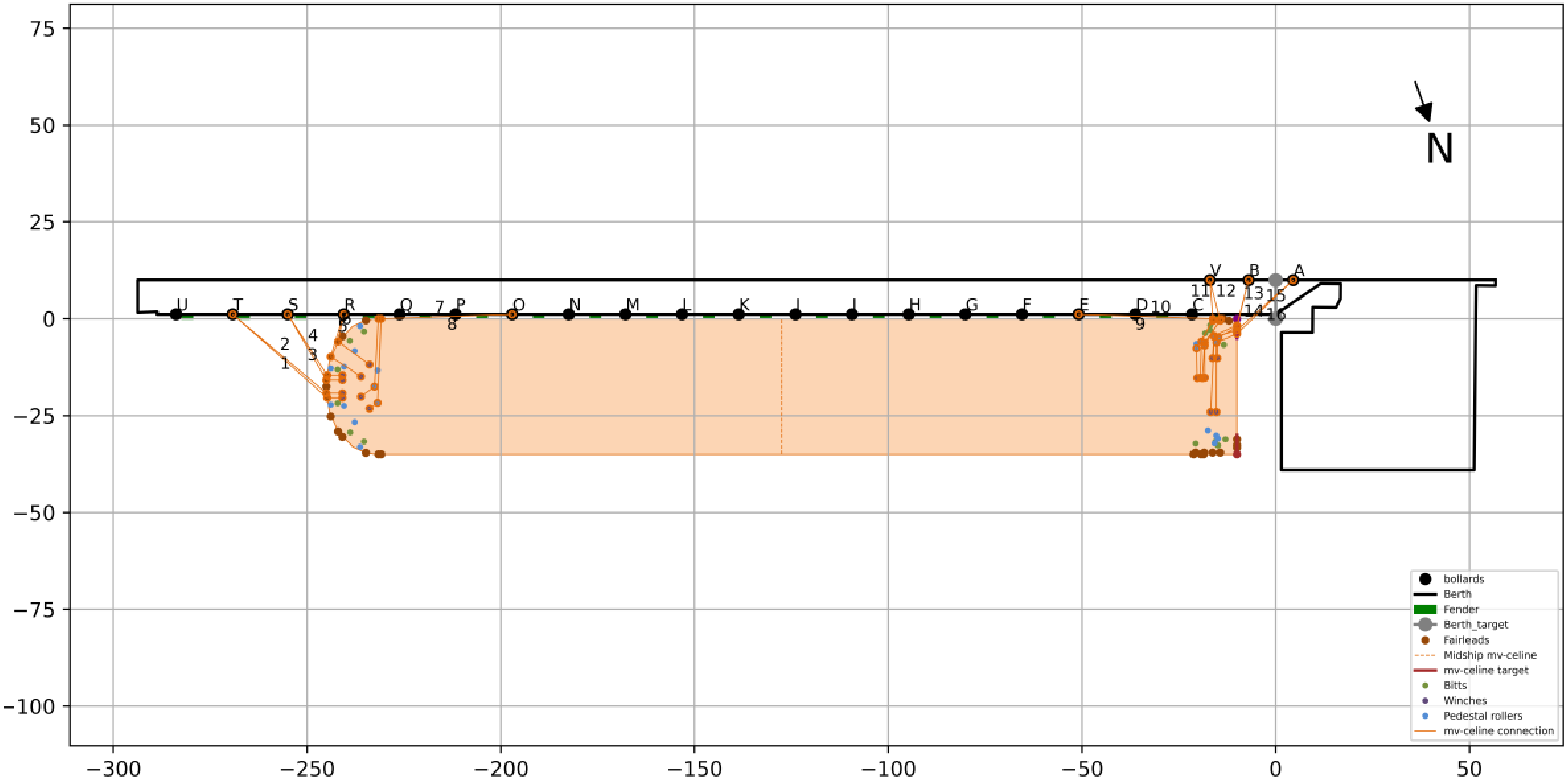

Figure 9.16: Mooring arrangement for MV Celine at Berth 45

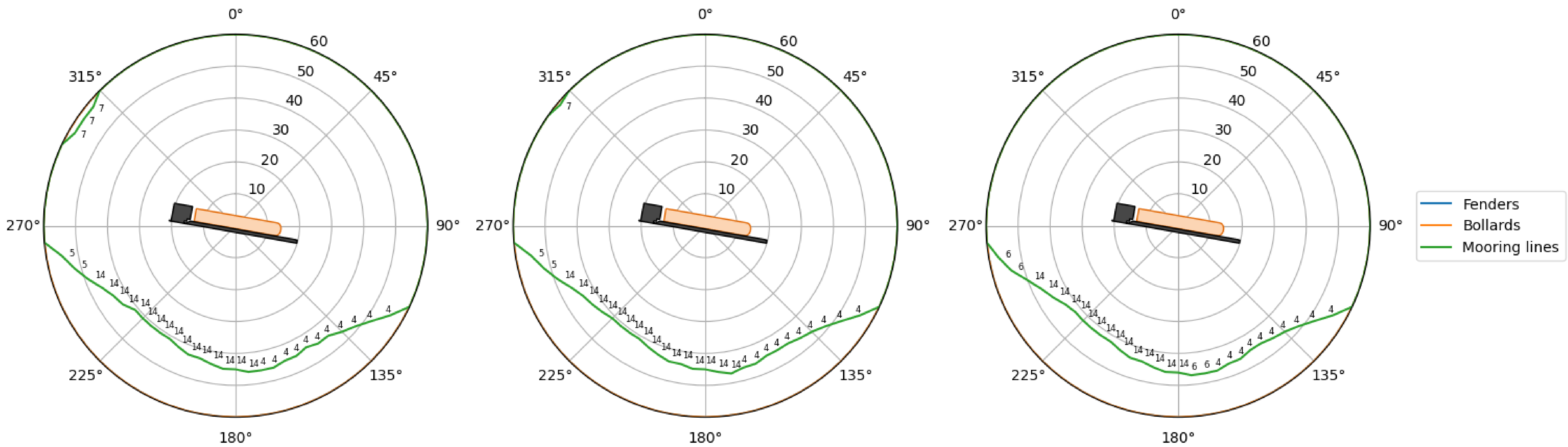

Figure 9.17: Wind limit rose for MV Celine at Berth 45 at MHWN (left), MSL (middle) and MLWN (right)

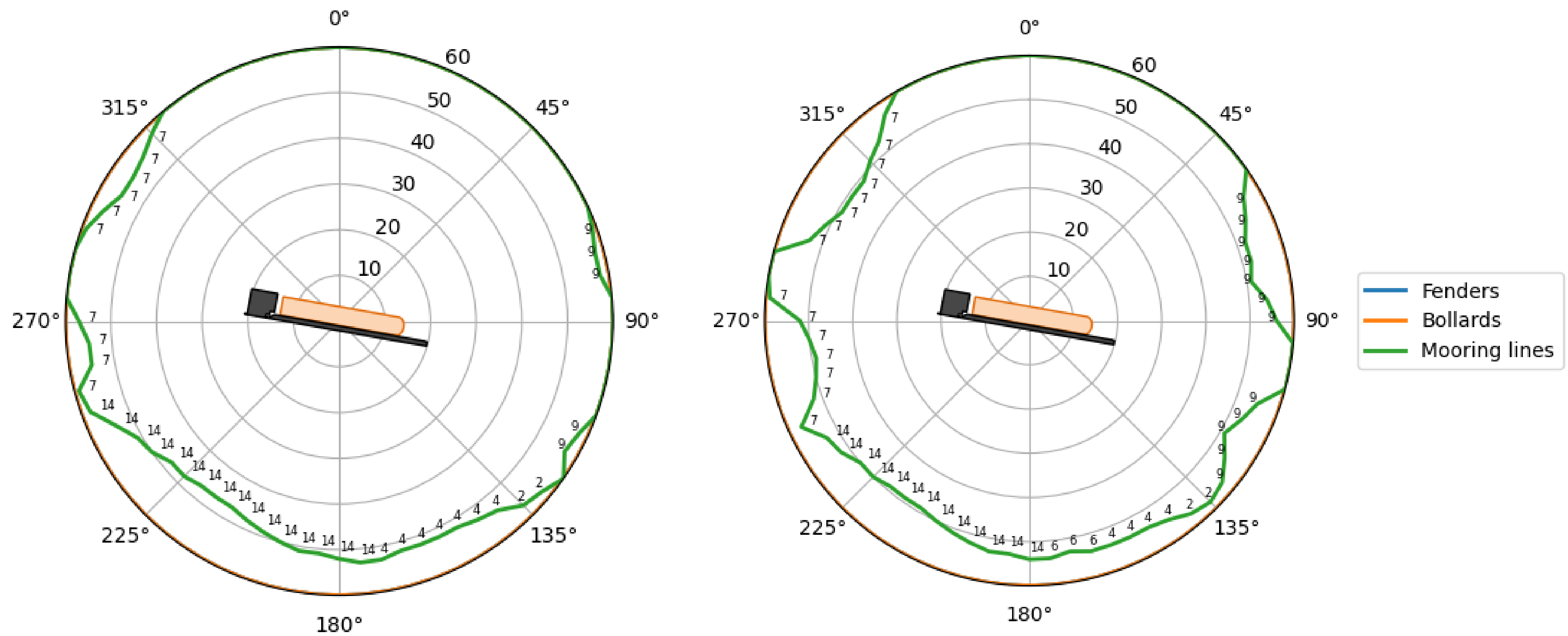

Figure 9.18: Wind limit rose for MV Celine at Berth 45 at MHWN for 20 m (left) and 30 m (right) setback bollards at the bow and stern

10 Dynamic mooring analysis

10.1 Scenarios

The scenarios considered in the passing ship analysis are summarised in Table 10.1. Over 60,000 model runs were completed to assess the impact of a range of ships passing moored vessels at three berths. Conventional mooring arrangements with mooring lines and an automated mooring system were considered at all berths. The results of the dynamic mooring analysis are discussed in the following sections.

In general terms, the allowable passing speeds were highest with a larger separation distance, on the north side of the channel, and with the lower the displacement of the passing ships as is to be expected.

Table 10.1: Passing ship study scenarios

Parameter	Cases	Details of variants
Moored ships	5	New South Bank Container Terminal (2), NORA Oil Berth (2), Berth 45 (1)
Moored ship draughts	1	Laden, as this is the worst case for passing ship effects
Moored ship orientations	1	
Mooring arrangements	1	Detailed in Section 9
Berth configurations	2	Conventional and automated mooring
Passing ships	4	Detailed in Section 7
Passing ship draughts	1	Laden (varying for bulk carrier)
Passing ship directions	2	Outbound, Inbound
Passing ship speeds	13	0.5 knot increments (ground speeds), up to 9 knots
Passing ship separation distances	3	Channel centreline and north and south side of the channel
Water levels	3	MLWN, MSL, MHWN
Current conditions	3	Peak flood, peak ebb and slack water (with associated water level)
Wind conditions	7	2 wind speeds from 3 wind directions and calm (no wind)
Total number of scenarios	65,520	

10.2 New South Bank Container Terminal

10.2.1 150 m container ship

The 150 m container ship was modelled at a draught of 7.6 m alongside the New South Bank Container Terminal. Tabulated summaries of the allowable passing speeds for all limiting criteria (motions, mooring lines, fenders and bollards) and mooring criteria (mooring lines, fenders and bollards) are shown in Table B.1 and Table B.2 respectively.

The maximum allowable passing speed for a centreline transit was 9 knots (maximum tested) for all wind speeds examined with no exceedances of the limiting criteria.

For closer transits, on the southern side of the channel, allowable passing speeds reduce to a minimum of 7.5 knots for the 225 m bulk carrier with faster passing speeds of up 9 knots with the 142 m general cargo ship. These transit offsets from the centreline may occur in case of ships meeting within the channel.

The limiting criteria that was exceeded was the motion of the moored ship in sway, with instances in which the mooring line and bollard SWL was also exceeded.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier (“Jasmine A”) ≥9.0 knots.

10.2.2 225 m container ship

The 225 m container ship was modelled at a draught of 10.1 m alongside the New South Bank Container Terminal. Tabulated summaries of the allowable passing speeds for all limiting criteria (motions, mooring lines, fenders and bollards) and mooring criteria (mooring lines, fenders and bollards) for conventional mooring are shown in Table B.3 and Table B.4 respectively. A tabulated summary of the allowable passing speeds for all limiting criteria with an automated mooring system is shown in Table B.5.

Conventional

The maximum allowable passing speed for a centreline transit in wind speeds up to 20 knots was 7 knots and 5.5 knots for winds up to 35 knots which were a result of the 225 m bulk carrier passing the berth. It was shown the 142 m general cargo ship was feasible when passing at 9 knots for all wind speeds with the 160 m tanker and 235 m RO-RO having similar allowable passing speed.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) 6.5 knots;
- 160 m tanker 7.0 knots;
- 225 m bulk carrier (“Jasmine A”) 5.5 knots.

For closer transits, on the southern side of the channel, allowable passing speeds reduce to a minimum of 4.5 knots for the 225 m bulk carrier with faster passing speeds of up 7.5 knots with the 142 m general cargo ship. These transit offsets from the centreline may occur in case of ships meeting within the channel.

The limiting criteria that was predominantly exceeded was the motion of the moored ship in surge and sway, with instances in which mooring line, fender and, in one instance, bollard SWLs were also exceeded.

Automated mooring system

For passing ship analysis with an automated mooring system installed on the berth, the 225 m container did not exceed any limiting criteria for all wind speeds up to 35 knots and for all passing distances.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier (“Jasmine A”) ≥9.0 knots.

10.3 NORA Oil berth

10.3.1 120 m tanker

The 120 m tanker was modelled at a draught of 8.7 m alongside the NORA Oil berth. Tabulated summaries of the allowable passing speeds for all limiting criteria (motions, mooring lines, fenders and bollards) and mooring criteria (mooring lines, fenders and bollards) for conventional mooring are shown in Table B.6 and Table B.7 respectively.

The maximum allowable passing speed for a centreline transit was 6.0 knots for winds up to 35 knots which were a result of the 225 m bulk carrier passing the berth. It was shown the 142 m general cargo ship was feasible when passing at 9 knots for all wind speeds with the 160 m tanker and 235 m RO-RO having similar allowable passing speed.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 23 5m RO-RO ("MV Celine") 7.5 knots;
- 160 m tanker 8.0 knots;
- 225 m bulk carrier ("Jasmine A") 6.0 knots.

For closer transits, on the southern side of the channel, allowable passing speeds reduce to a minimum of 5.0 knots for the 225 m bulk carrier with transits of 9.0 knots feasible with the 142 m general cargo ship. These transit offsets from the centreline may occur in case of ships meeting within the channel.

The limiting criteria that was predominantly exceeded was the motion of the moored ship in sway, with instances in which surge motion criteria was also exceeded.

10.3.2 185 m tanker

The 185 m tanker was modelled at a draught of 9.0m alongside the NORA Oil berth. Tabulated summaries of the allowable passing speeds for all limiting criteria (motions, mooring lines, fenders and bollards) and mooring criteria (mooring lines, fenders and bollards) for conventional mooring are shown in Table B.8 and Table B.9 respectively. A tabulated summary of the allowable passing speeds for all limiting criteria with an automated mooring system is shown in Table B.10.

Conventional

The maximum allowable passing speed for a centreline transit in wind speeds up to 20 knots was 9.0 knots and 8.5 knots for winds up to 35 knots which were a result of the 225 m bulk carrier passing the berth.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") 8.5 knots.

For closer transits, on the southern side of the channel, allowable passing speeds reduce to a minimum of 7.0 knots for the 225 m bulk carrier with transits of 9.0 knots feasible with the 142 m general cargo ship. These transit offset from the centreline may occur in case of ships meeting within the channel.

The limiting criteria that was predominantly exceeded was the motion of the moored ship in sway, with instances in which surge motion criteria was also exceeded.

Automated mooring system

For passing ship analysis with an automated mooring system installed on the berth, the 185 m tanker did not exceed any limiting criteria for all wind speeds up to 35 knots and for all passing distances.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

- 142 m general cargo (“Seatruck Pace”) ≥9.0 knots;
- 235 m RO-RO (“MV Celine”) ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier (“Jasmine A”) ≥9.0 knots.

10.4 Berth 45

10.4.1 “MV Celine”

The “MV Celine” was modelled at a draught of 7.5 m alongside Berth 45. Tabulated summaries of the allowable passing speeds for all limiting criteria (motions, mooring lines, fenders and bollards) and mooring criteria (mooring lines, fenders and bollards) for conventional mooring are shown in Table B.11 and Table B.12 respectively. A tabulated summary of the allowable passing speeds for all limiting criteria with an automated mooring system is shown in Table B.13.

Conventional

The maximum allowable passing speed for a centreline transit was 4.0 knots for winds up to 35 knots which were a result of the 225 m bulk carrier passing the berth. It was shown the 142 m general cargo ship was feasible when passing at 6.0 knots for all wind speeds. The 160 m tanker and 235 m RO-RO were shown to be able to pass at 5.0 knots and 4.5 knots respectively.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 4 knots, are:

- 142 m general cargo (“Seatruck Pace”) ≥6.0 knots;
- 235 m RO-RO (“MV Celine”) 4.5 knots;
- 160 m tanker 5.0 knots;
- 225 m bulk carrier (“Jasmine A”) 4.0 knots.

For closer transits, on the southern side of the channel, allowable passing speeds reduce to a minimum of 3.0 knots for the 225 m bulk carrier with transits of 5.5 knots feasible with the 142 m general cargo ship. These transit offsets from the centreline are less likely to occur adjacent to Berth 45 but may result from positioning of the ship on arrival or departure from Alexandra Basin West.

The only limiting criteria that was exceeded was the motion of the moored ship in surge. This is likely a result of the very soft mooring lines which are used by the ship. It may be possible to increase the allowable passing speeds with a stiffer mooring line which would provide improved movement restraint.

Automated mooring system

For passing ship analysis with an automated mooring system installed on the berth, the “MV Celine” did not exceed any limiting criteria for all wind speeds up to 35 knots and for all passing distances.

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

• 142 m general cargo ("Seatruck Pace")	≥6.0 knots;
• 235 m RO-RO ("MV Celine")	≥6.0 knots;
• 160 m tanker	≥6.0 knots;
• 225 m bulk carrier ("Jasmine A")	≥6.0 knots.

11 Conclusions and recommendations

Fully dynamic mooring analysis was used to assess the impact of passing ships on the proposed development of the New South Bank Container Terminal, NORA Oil berth and Berth 45 at Dublin Port. The analysis considered a total of five moored ships for four passing ships, representing the range of ships expected to transit the channel. There were three passing distances modelled, along the centreline and to the north and south. All passing speeds were considered as speeds over the ground and included a representative current taken from flow modelling carried out for the 3FM port layout.

The following conclusions have been drawn from the study.

11.1 New South Bank Container Terminal

11.1.1 Overview

- Both moored ships make good contact with fenders;
- Negative line angles were observed for the 150 m container ship and consideration is required regarding the quay elevation, anti-chafing protection on the quay and possible interaction with fenders;
- Static mooring analysis indicates the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment;
- Exceedances of the bollard SWL (80 t) occurred in some cases. Consideration is required to increase to the bollard SWL at the berth.

11.1.2 Allowable passing speeds

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

150 m container ship – conventional

• 142 m general cargo ("Seatruck Pace")	≥9.0 knots;
• 235 m RO-RO ("MV Celine")	≥9.0 knots;
• 160 m tanker	≥9.0 knots;
• 225 m bulk carrier ("Jasmine A")	≥9.0 knots.

225 m container ship – conventional

• 142 m general cargo ("Seatruck Pace")	≥9.0 knots;
• 235 m RO-RO ("MV Celine")	6.5 knots;
• 160 m tanker	7.0 knots;
• 225 m bulk carrier ("Jasmine A")	5.5 knots.

225 m container ship – automated mooring system

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") ≥9.0 knots.

11.1.3 Automated mooring system

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the 225 m container ship for all passing ships.

Given the freeboard and quay elevation, it would not be possible to connect an automated system that connects above the level of the quay to the smaller 150 m container ship. If it were able to connect, it would be expected to provide equivalent restraint observed with the 225 m container ship.

If an automated mooring system is to be installed at the berth, consideration is required regarding:

- Positioning of the units along the berth to maintain flexibility of where ships can moor;
- Ability to connect to smaller container ships with a lower freeboard.

11.2 NORA Oil berth

11.2.1 Overview

- Due to the berth configuration with breasting and mooring dolphins on the eastern end and the container quay on the western end, the mooring arrangements were asymmetric with significantly shorter mooring lines on the western end.
- The shorter lines on the western end of the berth led to steep mooring lines, up to 34°. Guidance suggests vertical mooring line angles be kept to a minimum with angles less than 25° preferred. It would therefore be beneficial to have set-back bollards on the container quay which could be sunken and covered when not in use.
- The position of the winches used for spring lines on the 185 m tanker led to short aft springs lines, attached to the inner breasting dolphin, which also had reduced longitudinal restraint due to the angle of the line to the berth. Depending on the configuration of the marine loading arms, it would be beneficial to have a mooring point located on the eastern end of the container terminal.
- Whilst the mooring arrangements were shown to be suboptimal due to the asymmetry and steep mooring lines, static mooring analysis indicated they provide adequate resistance to the wind and current conditions at the site.
- Some negative line angles are expected for the 120 m tanker at water levels below MLWN due to the relative height between the main deck and the quay/dolphin elevation (+7.11 mCD). Consideration is required regarding line rubbing on the quay edge and mooring lines catching on fender panels.
- Good fender contacts are feasible for both design ships. However, the outer breasting dolphin only provides a partial contact with the larger 185 m tanker. If ships longer than 185 m are not expected to make use of the berth then further assessment should be considered, assessing a wider range of ships, to determine if it would be beneficial to move the dolphin closer to the centre of the berth. Alternatively, it may be possible to make use of just one breasting dolphin.
- A higher specification fender is required for the oil berth compared to the container terminal. Given the berth will make use of fenders on the eastern end of the container terminal, the

berthing line is required to be maintained as continuous. Therefore, either the same depth of fender is required or alterations are required on the quay to ensure the fender panels remain on the same berthing line.

11.2.2 Allowable passing speeds

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

120 m tanker – conventional

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") 7.5 knots;
- 160 m tanker 8.0 knots;
- 225 m bulk carrier ("Jasmine A") 6.0 knots.

185 m tanker – conventional

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") 8.5 knots.

185 m tanker – automated mooring system

- 142 m general cargo ("Seatruck Pace") ≥9.0 knots;
- 235 m RO-RO ("MV Celine") ≥9.0 knots;
- 160 m tanker ≥9.0 knots;
- 225 m bulk carrier ("Jasmine A") ≥9.0 knots.

11.2.3 Automated mooring system

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the 185 m tanker for all passing ships. Given the freeboard and quay elevation, it would not be possible to connect an automated system that connects above the level of the quay to the smaller 120 m tanker. If it were able to connect, it would be expected to provide equivalent restraint observed with the 185 m tanker.

If an automated mooring system is to be installed at the berth, consideration is required regarding ability to connect to smaller tankers.

11.3 Berth 45

11.3.1 Overview

- Mooring arrangements with bollard located along the quay face were shown to be inadequate for mooring the design ship. Three set-back bollards at the stern (by the linkspan on the western end) were included in the assessment to improve the mooring arrangement and reduce the vertical line angles. These were nominally set-back by 10m but setting them back further would be beneficial.
- Good contact with fenders is feasible for the moored design ship.
- High vertical line angles were observed up to 52° for mooring lines at the bow of the ship. It would be beneficial to include set-back bollards at the bow (on the eastern end).

- Static mooring analysis indicates the berth configuration and mooring arrangements are adequate for the design ships considered for the assessment.
- Exceedances for the allowable passing ships were a result of surge motions which is likely a result of the very soft mooring lines which are used by the ship. It may be possible to increase the allowable passing speeds with a stiffer mooring line which would provide improved movement restraint.
- The results are expected to be applicable to Berth 44 given the symmetry of the berth and mooring configuration.

11.3.2 Allowable passing speeds

The maximum allowable passing speed (over the ground) for a centreline transit and wind speeds up to 35 knots for each passing ship, noting the speed limit in the channel adjacent to the berths is currently 9 knots, are:

"MV Celine" - conventional

- 142 m general cargo ("Seatruck Pace") ≥6.0 knots;
- 235 m RO-RO ("MV Celine") 4.5 knots;
- 160 m tanker 5.0 knots;
- 225 m bulk carrier ("Jasmine A") 4.0 knots.

"MV Celine" - automated mooring system

- 142 m general cargo ("Seatruck Pace") ≥6.0 knots;
- 235 m RO-RO ("MV Celine") ≥6.0 knots;
- 160 m tanker ≥6.0 knots;
- 225 m bulk carrier ("Jasmine A") ≥6.0 knots.

11.3.3 Automated mooring system

The passing ship analysis was carried out with an automated mooring system at the berth. It was shown to provide good restraint for the design moored ship for all passing ships.

12 References

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Appendices

A HR Wallingford's dynamic ship motion models

Dynamic Ship Mooring Analysis

HR Wallingford's UNDERKEEL, PASSHIP and SHIPMOOR computational models

1 Introduction

HR Wallingford has developed an established suite of computational models, which can be used in fully dynamic mooring analysis to simulate moored ship response to waves, swell, wind, currents and the effects of passing ships.

These models have been validated and verified by comparison with physical model test results and field data, and have been applied extensively over the last 40 years for all types of ships and berth.

The modelling suite is generally called SHIPMOOR, but the individually models are named UNDERKEEL, PASSHIP and SHIPMOOR.

The capability of the models used at HR Wallingford are as recommended in British Standard BS6349 Part 1-1:2013, in Section 20.2.2.4, which states:

> "In order to represent the effects of first and second order wave forces and in order to take into account irregular waves and non-linear mooring system behaviour, numerical simulation should be carried out for the moored ship, solving the equations at increments in time using a time domain analysis to produce a time-series of motions and loads.
>
> Note, this is often referred to as fully dynamic mooring analysis. Wave forces on the ship hull are often modelled using potential theory using a frequency domain analysis to sum the components of wave forces in the complete spectrum. This provides a hydrodynamic transfer function in which the wave force is calculated through the time increments in the time domain simulation. Simulations normally take into account a single sea state (expressed as a spectral function) acting on the complete ship at each point in the time domain…
>
> All numerical models should be validated against prototype data or physical model tests to demonstrate that the models replicate motions and line forces in idealized conditions."

In particular some of the advantages of the HR Wallingford modelling system are:

- Feedback between the real position of the vessels and the waves and moorings
- Resonance effects are included
- The principal forcing on moored ships, such as from swell, long period waves, second order waves and randomised motions caused by wind is included
- Swell waves are included
- Roll can be exaggerated in all computational ship mooring models, especially quartering to beam seas. This is recognised and dealt with accordingly

- The models have been calibrated against physical model studies, other numerical model studies and from site measurements, and, in particular, for side-by-side moored/double-banked ships
- In the case of ship-to-ship (STS) or side-by-side (SBS) operations, the coupling effects between the two vessels are included.

Further details of the models are contained in the remainder of this document.

2 UNDERKEEL

2.1 UNDERKEEL – First order

The UNDERKEEL computational model has been developed at HR Wallingford for the study of ship motions and wave forces on ships, specifically in shallow water. It employs the standard linearised wave theory with potential flow applied in the frequency domain (i.e. regular waves) to represent the behaviour of waves and water flows in the vicinity of the ship. This is implemented in conjunction with a strip or slender body theory treatment of boundary conditions at the hull adapted to allow accurately for flows underneath the keel. All six components of the vessel's motion are computed (three translational, three rotational), and all components of wave force and moment. The model has been verified by comparing computed values against field measurements and measurements of the movements of physical model vessels. Good agreement has been obtained in all cases.

The model has been used at HR in many commercial studies. Typical applications are:

- To estimate the vertical motions (including roll) of ships underway in a navigation channel in order to estimate the likely minimum dredged depth needed for safe transit in waves
- To calculate wave forces on a stationary vessel as a first stage in the estimation of moored vessel motions and mooring forces at a berth exposed to wave action.

Although the model operates in the frequency domain, following a regular sinusoidal wave input, superposition principles can be applied easily. UNDERKEEL can thus be used to compute first-order (linear) motions of a vessel or wave-induced forces acting the vessel for any given required random wave input, including short-crested (multi-directional) sea conditions. The vessel can be either stationary or moving slowly, the assumption used is that the vessel's forward speed is much less than the wave celerity. Other simplifying assumptions made in deriving the model require that the sea bed is level, the ship is slender in plan with tapered ends to the wetted hull, and the clearance distance between the hull bottom and the sea bed is small relative to the beam of the vessel. A full form hull is assumed, typical of many commercial ship types, with a generally flat-bottomed and an approximately rectangular cross-section over much of its length. The assumption that the sea bed is level is usually overcome in a navigation channel with varying depth, by dividing the channel into sections of relatively uniform depth and testing each of the sections. This is a normal process in the use of this model.

UNDERKEEL is also able to reproduce the effects on flows and waves due to an impervious, wave-reflecting vertical wall through the water surface in the vessel's vicinity. This feature enables the model to reproduce wave forces and ship motions in the presence of a nearby quay wall, breakwater or 'surface-piercing' channel bank.

2.2 UNDERKEEL – Second order

The second-order UNDERKEEL model computes the long period, second-order wave forces acting on a ship, and is typically used in conjunction with the main model. It reproduces the full range of wave, wave-induced flow and wave force phenomena represented in the first-order model, but extended to second-order.

Second-order forces are those due to:

- Surface stress
- The Bernoulli pressure effect
- Force rotation
- Pressure displacement
- Second-order wave diffraction effects
- Set-down and associated diffracted wave fields.

These force effects are proportional to wave height squared. They are generally small in magnitude compared to the linear, first-order effects that UNDERKEEL computes. Nevertheless, the second-order forces are important because the horizontal motions of a large moored ship are typically dominated by low frequency components. The velocities of these long period, slow drift motions are low, but the distances moved can be significant; the movement can consequently disrupt cargo handling and is potentially damaging to moorings in extreme conditions. Second-order forces are the predominant cause of low frequency excitation, particularly at berths that are relatively exposed to wave action. UNDERKEEL computes these low frequency second-order forces acting on a ship.

The model is based on the same wave and water flow theories as the main, first-order UNDERKEEL model, extended to second-order, and it employs the same optimization for small under-keel clearances. It thus shares the same advantages of economy of computation with accuracy in complicated wave conditions (including short-crested conditions).

A particular feature is that UNDERKEEL computes forces due to set-down bound waves (which are known to be the dominant forcing effect in many shallow water cases) without resorting to an approximate treatment of wave diffraction.

Second-order UNDERKEEL is a frequency domain model (like the first-order model). In the second-order case, it computes forces due to pairs of unit amplitude waves interacting. However, analogous superposition principles apply to those applied at first-order to the UNDERKEEL force outputs. Construction is therefore possible of long period second-order forcing due to any primary wave condition that may be required including random wave and short-crested cases.

3 PASSHIP

PASSHIP is the model used to compute the forces acting on moored ships due to passing vessels. It uses depth-averaged potential theory and computes a two-dimensional potential flow around and beneath the vessels, necessarily neglecting vertical velocities but satisfying mass conservation criteria and allowing for the obstructive effects of the ship hulls and seabed bathymetry. The flow induces a pressure distribution around the moored ship and from this, the forces and moments on the vessel are found. Since it is a potential flow model, effects such as vortex shedding, turbulent wakes and viscous forces do not appear. Comparison with published measured physical model test results has shown the method to be accurate.

The seabed bathymetry at the site is represented in the model on a rectilinear grid, allowing the representation of the constrictive and blockage effects on water flow of shallow water and the shoreline. The moored ship is placed in the grid as an additional stationary obstruction to flow, and the passing ship forms a further obstruction, to which sources and sinks are added at bow and stern, representing the vessel's displacement of water as it moves forwards. Progression of the moving ship and changing forces on the moored vessel are modelled by stepping the moving ship forward one grid square at a time, re-computing flows and forces at each step. Depth-averaged potential values are calculated for each grid square, and pressures are computed from the rates of change of potential. Integrating pressure over the wetted surface of its hull gives the forces and moments acting on the moored ship.

The output from the PASSHIP model forms a time history of forces and moments on the moored ship as the passing ship travels across the model area. Sometimes in combination with forces derived from UNDERKEEL, the PASSHIP force sequences are input to the SHIPMOOR model, which is used to compute moored ship motions and mooring forces.

4 SHIPMOOR

SHIPMOOR is the final model of the suite, which actually computes the movement of a moored ship, and mooring forces. It operates in the time domain (unlike UNDERKEEL, which is a frequency domain model).

Wave force time histories derived from the UNDERKEEL results, and calculated to reflect realistically wave conditions with a specified spectrum and direction, are taken as input. SHIPMOOR also takes as input data on vessel mooring lines and fenders, the ship's mass and moments of inertia, metacentric heights, buoyancy coefficients, and wind and current vectors.

Forces and moments on the ship generated by winds and currents are computed within SHIPMOOR using the OCIMF formulation and force coefficients. These can be steady winds and currents, generating a constant force, or wind loads with gust effects.

Mooring forces are computed based on the vessel's instantaneous position and orientation. Non-linear load-extension characteristics of mooring lines and fenders are taken into account where required.

Added inertia and damping forces are computed using the Impulse Response Function approach, which circumvents the problem of these forces being frequency-dependent, obviates the use of constant added inertia and damping coefficients, and gives correct values of forces for all vessel motions.

Summing over all force effects, the total forces and moments acting on the ship are ascertained, and hence the vessel's linear and angular accelerations. From the accelerations, the velocity and changing position of the moored ship are obtained evolving through time using standard methods of numerical quadrature. The movement of the ship is modelled in all six possible modes (translational: surge, sway and heave; and rotational: roll, pitch and yaw).

Computed motion and mooring force histories are analysed spectrally, and for maximum and minimum values. Motion or force time series may also be output if required for display or for further additional analysis.

5 Validation

At HR Wallingford, there has been a programme of continual improvement and validation testing since the earliest days of developing the SHIPMOOR modelling suite, including site measurements of ship movements and, in particular, the UNDERKEEL module which is used to calculate the wave forcing. This early work established that the comparison between results from the mathematical model and results obtained from random wave physical models showed good agreement in that the mathematical model describes the rapid variation in response that occurs with changes in wave period and height.

There were subsequently many improvements made to the models over the years with another validation exercise carried out in 1995 (which was published in Reference 1 in 1996). This exercise concluded that the agreement between computational and physical model tests results was in general very good and in some cases excellent. Particularly good agreement was found for surge response in head seas. Here the recommendation was to devote further effort into refining roll response. The corresponding refinements were carried out and incorporated into the model.

More recently, SHIPMOOR has been used to predict the movements of vessels moored side-by-side with validation against physical model results, as part of a Company research programme. This particularly challenging exercise concluded successfully with the computational model being verified. For applications of practical importance, the results of the computational model agreed well with physical model measurements. In particular, the UNDERKEEL and SHIPMOOR computational models were demonstrated and found to be applicable for modelling berths with FSUs/FSRUs moored side by side, and useful for accurately simulating possible variants and variations on the design berth and mooring arrangement. In general, the novel computational model features that were introduced for this project (that of simulating short-crested wave effects and linked multiple-body mooring) were verified. In addition, this work concluded that they can be further employed in future moored vessel modelling projects to which the UNDERKEEL and SHIPMOOR models are applicable.

6 Reference

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B Summary tables

Table B.1: Summary of allowable passing speeds for a 150 m container ship at the New South Bank Container Terminal, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	8.5	≥9	≥9	Sway	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
23 5m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	20	8	≥9	≥9	Sway	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	8.5	≥9	≥9	Sway	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	8	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	35	8.5	≥9	≥9	Lines, Sway	–	–
225 bulk carrier	Inbound	35	7.5	≥9	≥9	Lines, Bollards, Sway	–	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	8	≥9	≥9	Lines, Bollards	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.2: Summary of allowable passing speeds for a 150 m container ship at the New South Bank Container Terminal, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	8	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	35	8.5	≥9	≥9	Lines	–	–
225 bulk carrier	Inbound	35	7.5	≥9	≥9	Lines, Bollards	–	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	8	≥9	≥9	Lines, Bollards	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.3: Summary of allowable passing speeds for a 225 m container ship at the proposed South Bank Container Terminal, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	7	≥9	≥9	Surge	–	–
235 m RO-RO	Inbound	0	7	≥9	≥9	Surge	–	–
225 bulk carrier	Inbound	0	6	8	≥9	Surge	Surge	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	7.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	0	7.5	≥9	≥9	Fenders, Surge	–	–
225 bulk carrier	Outbound	0	6	7.5	≥9	Surge	Surge	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	6.5	≥9	≥9	Surge	–	–
235 m RO-RO	Inbound	20	6.5	8.5	≥9	Surge, Sway	Surge, Sway	–
225 bulk carrier	Inbound	20	5.5	7.5	≥9	Surge, Sway	Surge, Sway	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	6.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	20	6.5	8.5	≥9	Surge	Surge	–
225 bulk carrier	Outbound	20	6	7	8.5	Fenders, Surge, Sway	Surge	Surge
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	5	7	8.5	Lines	Lines, Sway	Lines, Sway
235 m RO-RO	Inbound	35	5	6.5	7.5	Lines, Sway	Lines, Bollards, Sway	Lines, Sway
225 bulk carrier	Inbound	35	4.5	5.5	7	Lines, Sway	Lines, Sway	Lines, Sway
142 m general cargo	Inbound	35	7.5	≥9	≥9	Lines	–	–
160 m Tanker	Outbound	35	6.5	8	≥9	Surge, Sway	Sway	–
235 m RO-RO	Outbound	35	6	7.5	≥9	Sway	Sway	–
225 bulk carrier	Outbound	35	5.5	6.5	7.5	Sway	Sway	Sway
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.4: Summary of allowable passing speeds for a 225 m container ship at the proposed South Bank Container Terminal, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	8.5	≥9	≥9	Lines, Bollards	–	–
225 bulk carrier	Inbound	0	7	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	8.5	≥9	≥9	Fenders	–	–
235 m RO-RO	Outbound	0	7.5	≥9	≥9	Fenders	–	–
225 bulk carrier	Outbound	0	6.5	8	≥9	Fenders	Fenders	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	7.5	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	20	7	≥9	≥9	Lines	–	–
225 bulk carrier	Inbound	20	6	8	≥9	Lines	Lines	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	7.5	≥9	≥9	Fenders	–	–
235 m RO-RO	Outbound	20	7.5	≥9	≥9	Fenders	–	–
225 bulk carrier	Outbound	20	6	7.5	≥9	Fenders	Fenders	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	5	7	8.5	Lines	Lines	Lines
235 m RO-RO	Inbound	35	5	6.5	7.5	Lines	Lines, Bollards	Lines
225 bulk carrier	Inbound	35	4.5	5.5	7	Lines	Lines	Lines
142 m general cargo	Inbound	35	7.5	≥9	≥9	Lines	–	–
160 m Tanker	Outbound	35	7	≥9	≥9	Lines	–	–
235 m RO-RO	Outbound	35	7	8.5	≥9	Lines, Bollards	Lines	–
225 bulk carrier	Outbound	35	6	7	≥9	Lines, Bollards	Lines	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.5: Summary of allowable passing speeds for a 225 m container ship at the proposed South Bank Container Terminal with automated mooring system, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	≥9	≥9	≥9	–	–	–
23 5m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	35	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.6: Summary of allowable passing speeds for a 120 m tanker at the proposed NORA Oil berth, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	7	≥9	≥9	Sway	–	–
235 m RO-RO	Inbound	0	6.5	8.5	≥9	Sway	Sway	–
225 bulk carrier	Inbound	0	5.5	7	≥9	Sway	Sway	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	7.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	0	7.5	≥9	≥9	Surge, Sway	–	–
225 bulk carrier	Outbound	0	6	7.5	≥9	Sway	Sway	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	6	8.5	≥9	Sway	Sway	–
235 m RO-RO	Inbound	20	6	7.5	≥9	Sway	Sway	–
225 bulk carrier	Inbound	20	5	6	8	Sway	Sway	Sway
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	7	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	20	6.5	≥9	≥9	Sway	–	–
225 bulk carrier	Outbound	20	5	6.5	8.5	Sway	Sway	Sway
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	5.5	8	≥9	Surge	Sway	–
235 m RO-RO	Inbound	35	5.5	7.5	≥9	Sway	Sway	–
225 bulk carrier	Inbound	35	5	6.5	8	Sway	Surge, Sway	Sway
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	6.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	35	6.5	8	≥9	Sway	Sway	–
225 bulk carrier	Outbound	35	5	6.5	8.5	Sway	Sway	Sway
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.7: Summary of allowable passing speeds for a 120 m tanker at the proposed NORA Oil berth, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	7.5	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	8.5	≥9	≥9	Lines	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	20	8.5	≥9	≥9	Lines	–	–
225 bulk carrier	Inbound	20	7	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	8	≥9	≥9	Lines	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	7	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	35	7	≥9	≥9	Lines	–	–
225 bulk carrier	Inbound	35	6	7.5	≥9	Lines	Lines	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	8.5	≥9	≥9	Lines	–	–
235 m RO-RO	Outbound	35	8.5	≥9	≥9	Lines	–	–
225 bulk carrier	Outbound	35	7	8.5	≥9	Lines	Lines	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.8: Summary of allowable passing speeds for a 185 m tanker at the proposed NORA Oil berth, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	8	≥9	≥9	Surge	–	–
235 m RO-RO	Inbound	0	8	≥9	≥9	Surge	–	–
225 bulk carrier	Inbound	0	7.5	≥9	≥9	Surge	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	8.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	8	≥9	≥9	Surge	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	7.5	≥9	≥9	Surge	–	–
235 m RO-RO	Inbound	20	8	≥9	≥9	Surge	–	–
225 bulk carrier	Inbound	20	7.5	≥9	≥9	Lines, Surge	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	8.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	8	≥9	≥9	Surge, Sway	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	7	≥9	≥9	Surge	–	–
235 m RO-RO	Inbound	35	7.5	≥9	≥9	Surge	–	–
225 bulk carrier	Inbound	35	7	8.5	≥9	Lines, Surge	Surge	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	8.5	≥9	≥9	Surge	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	7.5	≥9	≥9	Lines, Sway	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.9: Summary of allowable passing speeds for a 185 m tanker at the proposed NORA Oil berth, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	8	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	8.5	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	20	7.5	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	8.5	≥9	≥9	Lines	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	8	≥9	≥9	Lines	–	–
235 m RO-RO	Inbound	35	8.5	≥9	≥9	Lines	–	–
225 bulk carrier	Inbound	35	7	≥9	≥9	Lines	–	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	7.5	≥9	≥9	Lines	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.10: Summary of allowable passing speeds for a 185 m tanker at the proposed NORA Oil berth with automated mooring system, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	0	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	0	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	0	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	0	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	20	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	20	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	20	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	20	≥9	≥9	≥9	–	–	–
160 m Tanker	Inbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Inbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Inbound	35	≥9	≥9	≥9	–	–	–
142 m general cargo	Inbound	35	≥9	≥9	≥9	–	–	–
160 m Tanker	Outbound	35	≥9	≥9	≥9	–	–	–
235 m RO-RO	Outbound	35	≥9	≥9	≥9	–	–	–
225 bulk carrier	Outbound	35	≥9	≥9	≥9	–	–	–
142 m general cargo	Outbound	35	≥9	≥9	≥9	–	–	–

Table B.11: Summary of allowable passing speeds for MV 235 m RO-RO at Berth 45, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	5	≥6	≥6	Surge	–	–
235 m RO-RO	Inbound	0	4.5	5	≥6	Surge	Surge	–
225 bulk carrier	Inbound	0	3.5	4	5	Surge	Surge	Surge
142 m general cargo	Inbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	0	4.5	5.5	≥6	Surge	Surge	–
235 m RO-RO	Outbound	0	4	5	5.5	Surge	Surge	Surge
225 bulk carrier	Outbound	0	3.5	4	5	Surge	Surge	Surge
142 m general cargo	Outbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Inbound	20	4.5	5	≥6	Surge	Surge	–
235 m RO-RO	Inbound	20	4	4.5	5.5	Surge	Surge	Surge
225 bulk carrier	Inbound	20	3	4	4.5	Surge	Surge	Surge
142 m general cargo	Inbound	20	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	20	4.5	5	≥6	Surge	Surge	–
235 m RO-RO	Outbound	20	3.5	4.5	5	Surge	Surge	Surge
225 bulk carrier	Outbound	20	3	4	4.5	Surge	Surge	Surge
142 m general cargo	Outbound	20	5.5	≥6	≥6	Surge	–	–
160 m Tanker	Inbound	35	4.5	5	≥6	Surge	Surge	–
235 m RO-RO	Inbound	35	4	4.5	5.5	Surge	Surge	Surge
225 bulk carrier	Inbound	35	3	4	4.5	Surge	Surge	Surge
142 m general cargo	Inbound	35	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	35	4	5	≥6	Surge	Surge	–
235 m RO-RO	Outbound	35	3.5	4.5	5	Surge	Surge	Surge
225 bulk carrier	Outbound	35	3	4	4.5	Surge	Surge	Surge
142 m general cargo	Outbound	35	5.5	≥6	≥6	Surge	–	–

Table B.12: Summary of allowable passing speeds for MV 235 m RO-RO at Berth 45, mooring criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥6	≥6	≥6	–	–	–
235 m RO-RO	Inbound	0	≥6	≥6	≥6	–	–	–
225 bulk carrier	Inbound	0	≥6	≥6	≥6	–	–	–
142 m general cargo	Inbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	0	≥6	≥6	≥6	–	–	–
235 m RO-RO	Outbound	0	≥6	≥6	≥6	–	–	–
225 bulk carrier	Outbound	0	≥6	≥6	≥6	–	–	–
142 m general cargo	Outbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Inbound	20	≥6	≥6	≥6	–	–	–
235 m RO-RO	Inbound	20	≥6	≥6	≥6	–	–	–
225 bulk carrier	Inbound	20	5.5	≥6	≥6	Lines	–	–
142 m general cargo	Inbound	20	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	20	≥6	≥6	≥6	–	–	–
235 m RO-RO	Outbound	20	≥6	≥6	≥6	–	–	–
225 bulk carrier	Outbound	20	≥6	≥6	≥6	–	–	–
142 m general cargo	Outbound	20	≥6	≥6	≥6	–	–	–
160 m Tanker	Inbound	35	5	≥6	≥6	Lines	–	–
235 m RO-RO	Inbound	35	5	≥6	≥6	Lines	–	–
225 bulk carrier	Inbound	35	4.5	5.5	≥6	Lines	Lines	–
142 m general cargo	Inbound	35	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	35	5.5	≥6	≥6	Lines	–	–
235 m RO-RO	Outbound	35	5	≥6	≥6	Lines	–	–
225 bulk carrier	Outbound	35	4.5	≥6	≥6	Lines	–	–
142 m general cargo	Outbound	35	≥6	≥6	≥6	–	–	–

Table B.13: Summary of allowable passing speeds for MV 235 m RO-RO at Berth 45 with automated mooring system, all limiting criteria

Passing ship	Passing direction	Wind speed (knots)	Maximum allowable passing speed (knots, ground) by passing distance			Exceedance criteria by passing distance		
			North	Centreline	South	South	Centreline	North
160 m Tanker	Inbound	0	≥6	≥6	≥6	–	–	–
225 bulk carrier	Inbound	0	≥6	≥6	≥6	–	–	–
235 m RO-RO	Inbound	0	≥6	≥6	≥6	–	–	–
142 m general cargo	Inbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	0	≥6	≥6	≥6	–	–	–
225 bulk carrier	Outbound	0	≥6	≥6	≥6	–	–	–
235 m RO-RO	Outbound	0	≥6	≥6	≥6	–	–	–
142 m general cargo	Outbound	0	≥6	≥6	≥6	–	–	–
160 m Tanker	Inbound	20	≥6	≥6	≥6	–	–	–
225 bulk carrier	Inbound	20	≥6	≥6	≥6	–	–	–
235 m RO-RO	Inbound	20	≥6	≥6	≥6	–	–	–
142 m general cargo	Inbound	20	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	20	≥6	≥6	≥6	–	–	–
225 bulk carrier	Outbound	20	≥6	≥6	≥6	–	–	–
235 m RO-RO	Outbound	20	≥6	≥6	≥6	–	–	–
142 m general cargo	Outbound	20	≥6	≥6	≥6	–	–	–
160 m Tanker	Inbound	35	≥6	≥6	≥6	–	–	–
225 bulk carrier	Inbound	35	≥6	≥6	≥6	–	–	–
235 m RO-RO	Inbound	35	≥6	≥6	≥6	–	–	–
142 m general cargo	Inbound	35	≥6	≥6	≥6	–	–	–
160 m Tanker	Outbound	35	≥6	≥6	≥6	–	–	–
225 bulk carrier	Outbound	35	≥6	≥6	≥6	–	–	–
235 m RO-RO	Outbound	35	≥6	≥6	≥6	–	–	–
142 m general cargo	Outbound	35	≥6	≥6	≥6	–	–	–

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