Passing Vessel Effect on Mooring System of a Berthed Ship—A Case Study at Jawahar Dweep Berth No: 5, Mumbai Port

Keshav Sundar, V. Nandhini and S. Nallayarasu

Abstract The proposed new oil berth at Jawahar Dweep Island, Mumbai, is planned adjacent to the approach channel leading towards Pir Pau and Jawaharlal Nehru Port. The width of the channel is around 200 m and straight at the location. An existing berth J4 which is located adjacent to the new berth had in the past some incidences of breaking of mooring lines during monsoon season. The present study was done to study the effect of passing vessel effect and the environmental loading on a vessel berthed at that location. The study includes a complete simulation of mooring line forces due to wind, wave and current for the vessel ranges from 150,000 DWT to 250,000 DWT and arriving at the quick release mooring hook capacities. The passing vessel effect on the selected mooring hook capacities was reviewed by carrying out the combined effect of wind, wave and current together with the passing vessel effect. A critical review of the existing methods including OPTIMOOR simulation has been carried out to determine the suitable method for the present situation. The study indicated that the mooring hook capacities selected for the environmental loads shall be increased by 25% to cater for the combined effect of passing vessel. Several parametric studies have been carried out to include the distance between the passing vessel and the moored vessel, vessel speed, and vessel sizes, and the results are presented and discussed.

Keywords Mooring · Passing vessel · Berthed ship · Case study

K. Sundar
Mumbai Port Trust, Mumbai 400001, India

V. Nandhini · S. Nallayarasu (✉)
Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600036, India
e-mail: nallay@iitm.ac.in

K. Murali et al. (eds.), *Proceedings of the Fourth International Conference in Ocean Engineering (ICOE2018)*, Lecture Notes in Civil Engineering 22,
https://doi.org/10.1007/978-981-13-3119-0_14

1 Introduction

The Mumbai Port is natural harbour sheltered between Mumbai island and mainland. Within the Mumbai harbour area, the ports handling liquid, solid and container cargo are located. The Mumbai harbour houses the Mumbai Port Trust (MbPT) Jetties located in Jawahar Dweep (JD) Island, Pir Pau Jetties and Jawaharlal Nehru Port Terminals on the east. The dock area located on the east coast of Mumbai island houses various naval docks. The map of Mumbai harbour is shown in Fig. 1.

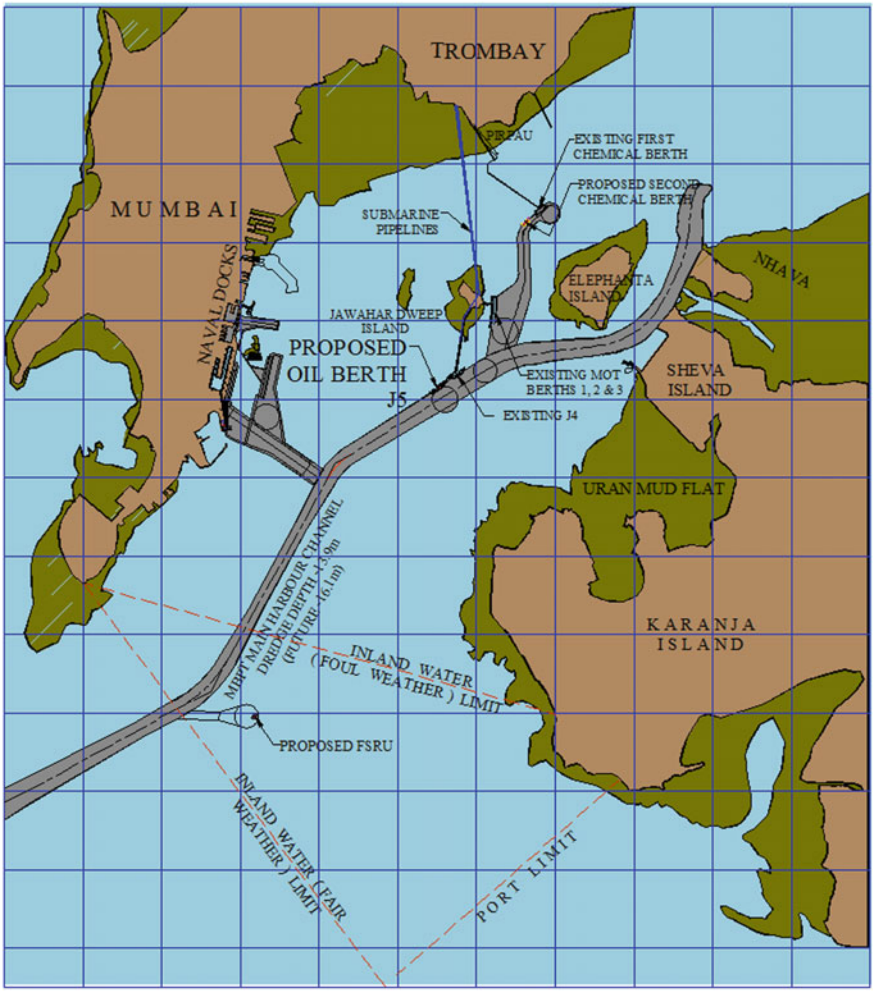

Fig. 1 Mumbai harbour area

Mumbai Port Trust (MbPT) is constructing a new oil jetty (J5) at Jawahar Dweep adjacent to the existing Jetty J4. The proposed jetty location is shown in Fig. 1, and the jetty is adjacent to the approach channel of width 200 m. A vessel berthed at such location would be subjected to motions in moored condition due to reasons as follows:

(a) External environmental loads due to wave, wind and current.
(b) Water movement associated with disturbances generated due to passing vessels in the vicinity of the moored ship.

The case study has been carried out to determine the effect of combining environmental loads together with the passing vessel effects on mooring loads of a ship berthed adjacent to the approach channel specifically for the proposed jetty at Jawahar Dweep (J5).

2 Literature Review

The passing vessel effect causes surge force (along the vessel length), sway force and yaw moment on the moored vessel. There are existing methods to calculate these forces and moment. They are mainly empirical equations based on some experimental data.

There are several methods available to determine hydrodynamic loads on moored vessel due to passing vessel. Some of the relevant methods are mentioned here. Wang [1] developed a slender body theory to derive forces on the moored ship due to the passing ship in infinite water depth. He also further developed shallow-water correction factors to account for under keel clearance into account. Seelig [2], developed shallow-water correction factors to Wang's equation in deep water. Flory [3] developed independent empirical equations using the model tests of various past researchers. Kriebel [4] developed correction factors for Wang deep-water equations as well as independent empirical equations for the calculation of forces on the moored vessel. Seelig's and Flory's work were based on experimental tests by Remery [5] and Muga [6], who studied the effect of several parameters on passing vessel forces and also the effect of type of mooring lines (in the form of spring constant) in resisting the passing vessel forces.

Methods based on Seelig [2] and Flory [3] are available in OPTIMOOR software, and the same is used for the present study.

The following points were observed from the literature study:

- The main parameters that influence the passing vessel forces are the passing vessel speed, the displacement ratio and the separation distance between the vessels.
- The empirical equations are based on experiments of specific parameters, and they can be used to estimate the passing vessel forces within those ranges of parameters.
- OPTIMOOR's dynamic analysis can be utilized for this study.

The objective of this case study is to analyse the increase in mooring line loads due to the passing vessel effect. The scope of the study is as follows:

- Optimum mooring layout development for vessels to be berthed at J5.
- Static mooring analysis using quasi-static methods for deriving mooring line loads from wind, wave and current.
- Passing vessel loads on the moored vessel by empirical methods described in the literature.
- Dynamic mooring analysis using OPTIMOOR software including the effect of passing vessel forces.
- Recommendations on channel widening, reduction of approach speed to MbPT
- Detailed mooring analysis report.

3 Jetty/Approach Channel Layout

3.1 Jetty Layout

The mooring analysis is performed to determine the maximum possible loads on the mooring points considering all directions of wind, wave and current approach, on the existing orientation of the berth. The BS/OCIMF [7, 8] requirements were used for fender layout verification. The layout of fenders showing the spacing and position along the length of the berth is shown in Fig. 2. These structures shall be positioned and spaced based on guidelines of PIANC [9] and Oil Companies International Marine Forum (OCIMF).

The spring lines and bow/stern lines are arranged depending on the vessel bollard and winch locations. The proposed shore-based mooring points shall allow such variations and typical configurations are shown in Fig. 3 for 150,000 DWT vessels.

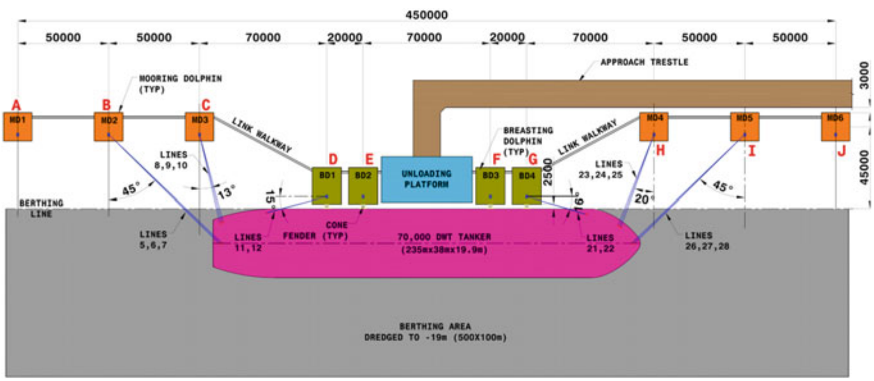

Fig. 2 Fender arrangements

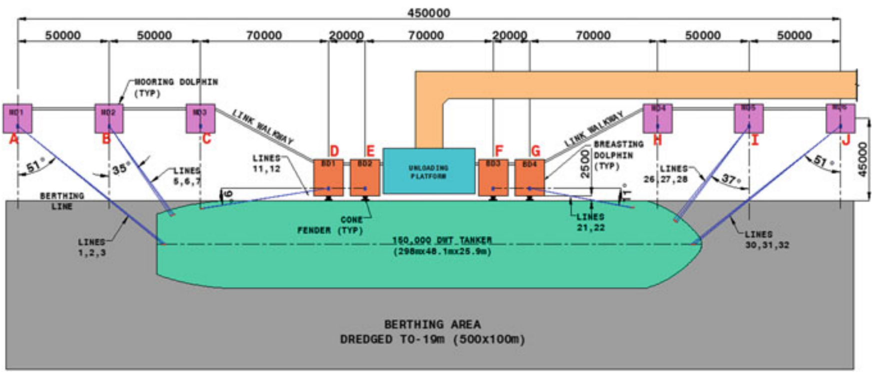

Fig. 3 Mooring layout for 150,000 DWT vessel

The mooring line angles are to follow the guidelines of OCIMF [7]. The mooring line loads are assessed using the mooring layout configuration shown in the figure.

3.2 Approach Channel Layout

The layout of the approach channel (width) greatly influences the passing vessel forces. The plan view of the approach channel and the location of the proposed jetty are shown in Fig. 4. Sectional view of the approach channel in front of J5 is shown in Fig. 5. The passing vessel effects on the moored vessel is considered for clear spacing of 75, 100, 150 and 200 m to determine the acceptable spacing and define conditions for the traffic during monsoon.

3.3 Moored Vessel Data

The oil companies (HPCL and BPCL) using the oil jetties at Jawahar Dweep, Mumbai, required that J5 be designed to handle fully laden Suez Max tankers for crude import to achieve economy in freight charges. The vessel sizes considered for the purpose of layout planning and structural design of the proposed jetty J5 are summarized in Table 1.

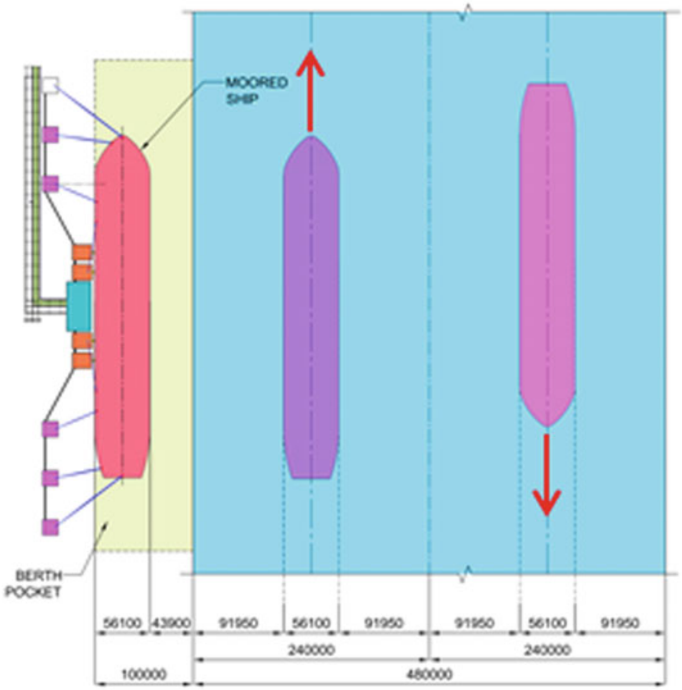

Fig. 4 Plan of approach channel

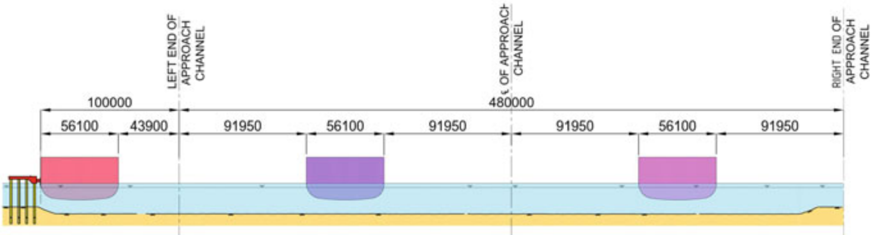

Fig. 5 Section of approach channel

3.4 Passing Vessel Data

The proposed J5 is located alongside of existing approach channel. The existing approach channel in front of J4 and J5 is widened from 370 to 480 m as shown in Fig. 4. The tankers primarily container vessels proposed to be moving along the channel are summarized in Table 2.

Table 1 Design vessel sizes

Tanker	DWT	LOA (m)	Beam (m)	Fully loaded draft (m)	Maximum permissible loaded draft (m)	Laden draft (m)
VLCC	250,000	349	56.1	26.0	16.8[a]	8.4
Suezmax	150,000	298	48.1	17.4	16.7[a]	8.4
Aframax	100,000	263	42.5	15.4	15.4	7.7
Panamax	70,000	225	36.0	12.5	12.5	6.3

[a]Partially loaded to 140,000 parcel size

Table 2 JNPT tankers moving alongside J5

Vessel type	Displacement (tonnes)	LOA (m)	Beam (m)	Fully loaded draft (m)	Cb
12000 TEU	200,000	366	50	15	0.7
14000 TEU[a]	240,000	400	55	15.5	0.7

[a]Not considered in the study at present as it is planned for future

4 Environmental Loads on Moored Ships

4.1 General

The environmental loads include the effect of wind, wave and current at the location. The environmental data for the concerned case study includes the wind, wave and current characteristics with reference to their predominant direction of occurrence.

4.2 Wind

The maximum wind speed is about 30 m/s with its percentage of occurrence less than 1%. For the purpose of determining the mooring loads, it is considered omni-directional with a maximum wind speed of 30 m/s, in accordance with OCIMF [10] guidelines.

4.3 Wave

The predominant wave approach is from south-west not including the effect of local wind generated waves. The wave data extracted from the CWPRS report [11] is tabulated in Table 3.

Table 3 Wave data extracted from CWPRS report

Description	223°	225°	223°
	WNW	W	WSW
Significant wave height (m)	0.2	0.44	0.6
Wave period (s)	10	10	10

Note WNW, W and WSW represent the offshore wave entry conditions

Table 4 Design mooring load combination—dynamic mooring analysis

Description	N	NE	E	SE	S	SW	W	NW
	0°	55°	90°	135°	180°	225°	270°	315°
Wind[1] (m/s)	√	√	√	√	√	√	√	√
Wave[3]	–	–	–	–	–	√	–	–
Current[2] (m/s)	–	√ (0.71)	√ (0.10)	–	–	√ (1.05)	√ (0.17)	–
Passing vessel	√	√	√	√	√	√	√	√

Notes
1. Wind speed of 30 m/s (58 knots) is used for all directions
2. Current speed is given for each direction
3. Wave height of 0.6 m with a period of 10 s is to be considered

4.4 Current

The flood current is towards north-east during flooding and south-west during ebb though some variations are noted.

Flood flow is from J5 to J4 and north, and ebb flow is from J4 towards J5. The flow during flood is higher than the ebb. The above directional current is used for the mooring analysis. For flood, average direction of 225° is used instead of three directions (220, 230 and 240).

4.5 Combinations of Wind, Wave and Current

The berth is oriented towards 57° from north towards east. The bearing of the berthing line is aligned south-west to north-east with a bearing angle of 57° towards east. The mooring analysis shall be carried out considering all critical directions of wind, wave and current combinations. Figure 6 shows the directions of the environmental loads considered for the analysis combining wind, wave and current.

The combination of wind, wave and current used for dynamic mooring analysis is given in Table 4. For static analysis, the passing vessel effect was not considered.

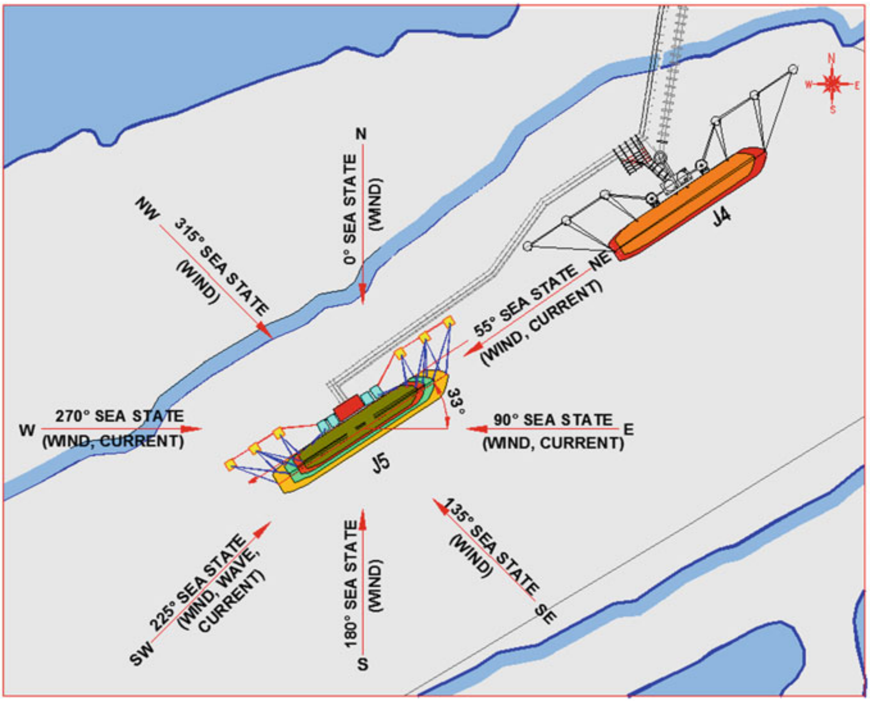

Fig. 6 Design mooring environments

4.6 *Forces on Moored Vessel*

The forces acting on a moored ship alongside a berth can be defined as shown in Fig. 7.

The equation for longitudinal wind force on the moored vessel can be calculated using the guidelines of OCIMF [10] as follows

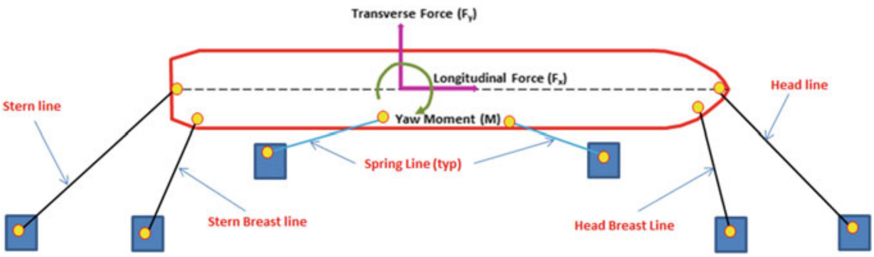

Fig. 7 Forces on a moored ship

$$F_{\mathrm{Xw}} = \frac{1}{2} C_{\mathrm{Xw}} \rho_{\mathrm{a}} V_{\mathrm{w}}^2 A_{\mathrm{T}} \tag{1}$$

The equation for transverse wind force on the moored vessel can be calculated using

$$F_{\mathrm{Yw}} = \frac{1}{2} C_{\mathrm{Yw}} \rho_{\mathrm{a}} V_{\mathrm{w}}^2 A_{\mathrm{L}} \tag{2}$$

The equation used within OPTIMOOR for the calculation of yaw moment is given by

$$M_{\mathrm{XYw}} = F_{\mathrm{Yw}} \left(\frac{X_{\mathrm{w}}}{L_{\rho\rho}} \right) \tag{3}$$

The more traditional equation for yaw moment due to wind is given by

$$M_{\mathrm{XYw}} = C_{\mathrm{XYw}} \left(\frac{\rho_{\mathrm{w}}}{7600} \right) V^2 A_{\mathrm{L}} L_{\mathrm{BP}} \tag{4}$$

Thus the yaw moment arm becomes

$$X_{\mathrm{w}} = \left(\frac{C_{\mathrm{XYw}}}{C_{\mathrm{Yw}}} \right) L_{\mathrm{BP}} \tag{5}$$

where

A_{L}	lateral wind area
A_{T}	transverse wind area
C_{Xw}	longitudinal wind force coefficient
C_{Yw}	lateral wind force coefficient
C_{XYw}	wind yaw moment coefficient
F_{Xw}	longitudinal wind force
F_{Yw}	lateral wind force
L_{BP}	length between perpendiculars
M_{XYw}	yaw moment due to wind
V_{w}	velocity of wind
X_{w}	moment arm at which lateral force is applied in producing moment
ρ_{a}	density of air

The value 7600 is a conversion factor of (tonne–metres)/(kilogram–knot–second).

The wind force coefficients are based on wind velocity at 10 m above the free surface. They are based on guidelines of OCIMF [10]. The following formula can be used to convert a wind velocity determined at some other elevation to that 10 m elevation:

$$V_{\mathrm{w10}} = V_{\mathrm{Wh}} \left(\frac{10}{h} \right)^{1/7} \tag{6}$$

where

h elevation of known wind velocity
V_{w10} wind velocity at 10 m elevation
V_{wh} wind velocity at elevation h.

4.7 Current Loads

The general equation for longitudinal current force on moored vessel can be written as follows based on the guidelines of OCIMF [10]

$$F_{Xc} = \frac{1}{2} C_{Xc} \rho_w V_c^2 L_{BP} T \quad (7)$$

The general equation for lateral current force on moored vessel can be written as

$$F_{Yc} = \frac{1}{2} C_{Yc} \rho_w V_c^2 L_{BP} T \quad (8)$$

The general equation for yaw moment on moored vessel can be written as

$$M_{XYc} = \frac{1}{2} C_{XYc} \rho_w V_c^2 L_{BP}^2 T \quad (9)$$

The lateral moment arm X_c is obtained by:

$$X_c = \left(\frac{C_{XYc}}{C_{Yc}} \right) L_{BP} \quad (10)$$

Hence, the yaw moment can be calculated using

$$M_{XYw} = F_{Yw} \left(\frac{X_w}{L_{BP}} \right) \quad (11)$$

where

A_L lateral current area
A_T transverse current area
C_{xc} longitudinal current force coefficient
C_{yc} lateral current force coefficient
C_{xyc} current yaw moment coefficient
F_{xc} longitudinal force due to current
F_{yc} lateral wind force due to current
L_{BP} length between perpendiculars
M_{xyc} yaw moment due to current
V_c velocity of current

X_c moment arm at which lateral force is applied
ρ_w density of water
T draft of vessel

The coefficients for longitudinal, lateral forces and yaw moment due to current are based on OCIMF guidelines [10].

4.8 Wave-Induced Loads

The forces generated by waves cannot be calculated using simplified formulation due to diffraction effect of large bodies and complex shape of the hull. Hence, the wave-induced loads and motions are calculated using the following approach.

- Response amplitude operators for six degrees of freedom for different shapes of the HULL are available from OPTIMOOR and can be purchased and included in the software. In this case, typical VLCC hull RAO has been included and selected for the present simulation.
- The software then uses these RAO to calculate the motion response in terms of surge, sway and heave for a given wave height and period by simple linear interpolation and apply to the equilibrium position of the tanker and obtain the forces induced on the mooring line.

5 Passing Vessel Loads on Moored Ships

5.1 Existing Guidelines

The passing vessel loads are caused due to the effect of a vessel crossing at the vicinity at some speed. Figure 8 shows an illustration of the passing vessel effect. When the ship 2 is moving, water gets displaced from bow towards the stern. At the bow, the water gets compressed and there develops a high-pressure field. Similarly, the displaced water converges at stern to form another high-pressure field. Along the sides of the same ship, due to the velocity of water, a low-pressure field is formed, due to Bernoulli's suction effect. The water slopes from high-pressure to low-pressure field. When a ship like ship 1 is present at this vicinity, it will be subjected to forces and moment due to this effect. This is called passing vessel effect.

The moored vessel subjected to forces due to this pressure gradient will undergo motions. The motion of moored ship alongside a berth can be in six degrees of freedom. These motions will induce loads on mooring lines attached to the jetty and the vessel. These forces need to be evaluated carefully to prevent the mooring lines from breaking thus avoiding the free movement or drift of the vessel away from the jetty. Such incidents could cause considerable damage to the ship–shore connections such as loading arms and fluid connections and environmental damage due to pollution.

This paper is mainly concerned on how the addition of passing vessel loads to the mooring line analysis affects the determination of mooring hook capacity and the effects if they are ignored.

5.2 Estimation by Wang's Method

Wang used slender body approach to determine passing vessel forces. The coordinate system considered for forces is shown in Fig. 9.

The longitudinal, transverse forces and yaw moment given by Wang [1] are Eqs. (12), (13) and (14), respectively.

$$F_{X\_\mathrm{WANG}}(X,C)=\frac{\rho V^2}{2\pi}\int\limits_{L_\mathrm{m}} S_1'(x_1)\int\limits_{L_\mathrm{p}}\frac{S_2'(x_2)(x_2-x_1+X)\mathrm{d}x_2}{\left[(x_2-x_1+X)^2+C^2\right]^{3/2}}\mathrm{d}x_1 \tag{12}$$

$$F_{Y\_\mathrm{WANG}}(X,C)=\frac{\rho V^2 C}{\pi}\int\limits_{L_\mathrm{m}} S_1'(x_1)\int\limits_{L_\mathrm{p}}\frac{S_2'(x_2)\mathrm{d}x_2}{\left[(x_2-x_1+X)^2+C^2\right]^{3/2}}\mathrm{d}x_1 \tag{13}$$

$$M_{z\_\mathrm{WANG}}(X,C)=\frac{\rho U^2 C}{\pi}\int\limits_{L_\mathrm{m}} S_1'[(x_1)x_1+S_1(x_1)]\int\limits_{L_\mathrm{p}}\frac{S_2'(x_2)\mathrm{d}x_2}{\left[(x_2-x_1+X)^2+C^2\right]^{3/2}}\mathrm{d}x_1 \tag{14}$$

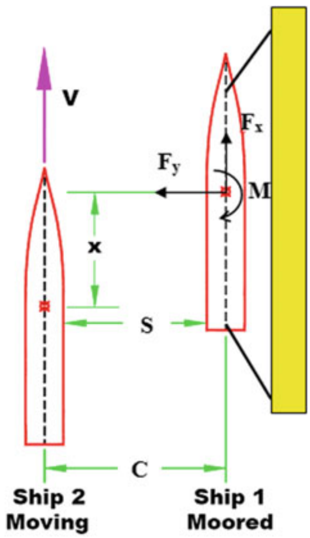

Fig. 8 Passing ship arrangements

Symbols used in Eqs. (12–14) are summarized below:

$F_{X\text{-WANG}}$	longitudinal force (surge) (N)
$F_{Y\text{-WANG}}$	lateral force (sway) (N)
M_{Z_WANG}	yaw moment (Nm)
X	centre to centre longitudinal distance between the ships (m)
S	lateral distance between the ships (m)
C	centre to centre lateral distance between the ships (m)
ρ	density of water (kg/m^3)
V	speed of the passing vessel (m/s)
L_m	length of the moored ship (m)
B_m	breadth of the moored ship (m)
L_p	length of the passing ship (m)
B_p	breadth of the passing ship (m)
$S_{1(X1)}$	parabolic sectional area distribution of moored ship
$S_{2(X2)}$	parabolic sectional area distribution of passing ship

The sectional area $S_1(x_1)$ and it slope $S'_1(x_1)$ are calculated using the following relationship for the moored ship

$$S_1(x_1) = S_1\left(1 - \left(\frac{-2x_1}{L_1}\right)^2\right) \tag{15}$$

$$S_1'(x_1) = \frac{-8S_1x_1}{L_1^2} \tag{16}$$

where x_1, L_1 and S_1 are the location of the section, length and the mid-ship area of moored ship, respectively.

The sectional area $S_2(x_2)$ and it slope $S'_2(x_2)$ are calculated using the following relationship for the moored ship.

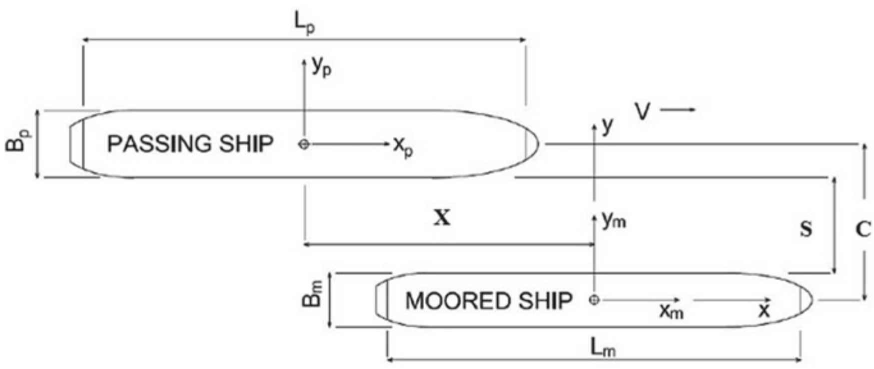

Fig. 9 Passing ship definitions of variables

$$S_2(x_2) = S_2\left(1 - \left(\frac{-2x_2}{L_2}\right)^2\right) \tag{17}$$

$$S_2'(x_2) = \frac{-8S_2x_2}{L_2^2} \tag{18}$$

where x_2, L_2 and S_2 are the location of the section, length and the mid-ship area of passing ship, respectively. The calculated normalized forces and moment for normalized distance with respect to the length of the ship are shown in Fig. 10. It can be observed that the forces, longitudinal and lateral do not occur at same time. But, longitudinal force and the moment occur at same time.

5.3 Estimation by Flory's Method

Flory [3] developed empirical formulas based on various model test results and the theoretical results from Wang [1].

$$\begin{aligned} F_{X\_\mathrm{MAX\_FLORY}} = 1.5 \times 10^{-5} L_{\mathrm{m}}^2 \mathrm{e}^{\left(0.0955 - \frac{0.6367d}{D}\right)} V^2 [0.171 + 0.134 \ln(\Delta_{\mathrm{D}})] \\ - \{0.71 + 0.28 \ln(\Delta_{\mathrm{D}})\} \ln(\Delta_{\mathrm{S}} - 0.06) \end{aligned} \tag{19}$$

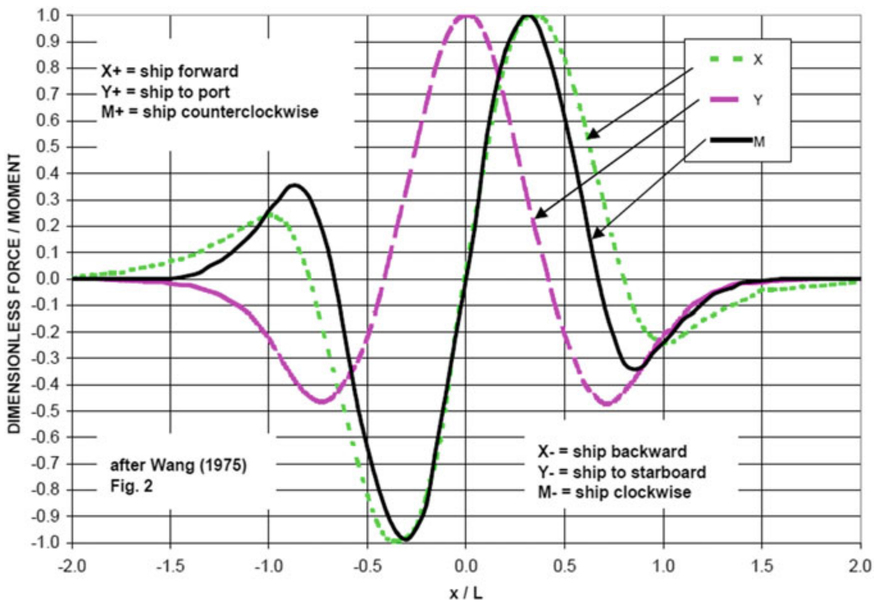

Fig. 10 Normalized forces and moment

$$F_{Y\_\mathrm{MAX\_FLORY}} = 1.5 \times 10^{-5} L_{\mathrm{m}}^{2} \mathrm{e}^{\left(0.5157-\frac{3.348d}{D}\right)} V^{2}$$
$$\left[\mathrm{e}^{(1.168\Delta_{R}-2.25)} - \{4.41 + 1.93 \ln(\Delta_{\mathrm{R}})\} \ln(\Delta_{\mathrm{S}})\right] \tag{20}$$

$$M_{z\_\mathrm{MAX\_FLORY}} = 59 \times 10^{-9} L_{\mathrm{m}}^{3} \mathrm{e}^{\left(0.343-\frac{2.288d}{D}\right)} V^{2}$$
$$\left[\mathrm{e}^{(-0.47\Delta_{\mathrm{D}}+2.651)} - \{171.9 + 51.4 \ln(\Delta_{\mathrm{D}})\} \ln(\Delta_{\mathrm{S}} - 0.06)\right] \tag{21}$$

Symbols used in Eqs. (19–21) are summarized below.

$F_{X\text{-MAX-FLORY}}$	surge force (N)
$F_{Y\text{-MAX-FLORY}}$	sway force (N)
$M_{Z\_\text{MAX-FLORY}}$	yaw moment (Nm)
D	draft of the moored ship (m)
V	passing vessel speed (m/s)
$\mathrm{L_m}$	length of the moored ship (m)
d	water depth (m)
Δ_{D}	displacement ratio
Δ_{S}	separation ratio

5.4 Estimation by Seelig's Method

Seelig [2] based on existing experiments developed shallow-water correction factor for deep-water forces given by Wang [1]

$$CF_{X\_\mathrm{SEELIG}} = 1 + 16\left(\frac{D}{B_{\mathrm{m}}}\right)\mathrm{e}^{\left(-0.08\left(\left(\frac{S}{B_{\mathrm{m}}}\right)-3.5\right)^{2}\right)} \tag{22}$$

$$CF_{Y\_\mathrm{SEELIG}} = \mathrm{CM}_{Z} = 1 + 25\left(\frac{D}{B_{\mathrm{m}}}\right)^{-0.35}\left(\frac{D}{d}\right)^{4}\mathrm{e}^{\left(-0.08\left(\left(\frac{S}{B_{\mathrm{m}}}\right)-3.3\right)^{2}\right)} \tag{23}$$

Symbols used in Eqs. (22) and (23) are given below.

$CF_{X\text{-SEELIG}}$	correction factor for surge force
$CF_{Y\text{-SEELIG}}$	correction factor for Sway force
CM_{Z}	correction factor for yaw moment
D	draft of the moored ship (m)
d	water depth (m)
B_{m}	beam of the moored ship (m)
S	clear spacing between the moored and passing ship (m).

5.5 Estimation by David Kriebel's Method

Kriebel [4] developed empirical shallow-water correction factors to forces and moments calculated by deep-water theory by Wang [1] as an alternative to Seelig [3] correction factors.

$$CF_{X\_\mathrm{KRIEBEL}} = 1 + 1.70\mathrm{e}^{\left(2.94\left(\frac{D}{d}\right)\right)}\mathrm{e}^{\left(-0.08\left(\left(\frac{S}{B\mathrm{m}}\right)-3\right)^2\right)} \tag{24}$$

$$CF_{Y\_\mathrm{KRIEBEL}} = 1 + 0.52\mathrm{e}^{\left(4.33\left(\frac{D}{d}\right)\right)}\mathrm{e}^{\left(-0.08\left(\left(\frac{S}{B\mathrm{m}}\right)-2\right)^2\right)} \tag{25}$$

$$CM_{Z\_\mathrm{KRIEBEL}} = 1 + 0.48\mathrm{e}^{\left(3.87\left(\frac{D}{d}\right)\right)}\mathrm{e}^{\left(-0.08\left(\left(\frac{S}{B\mathrm{m}}\right)-2\right)^2\right)} \tag{26}$$

Symbols used in Eq.(24–26) are given below.

$CF_{X\text{-KRIEBEL}}$	correction factor for surge force
$CF_{Y\text{-KRIEBEL}}$	correction factor for sway force
$CM_{Z\text{-KRIEBEL}}$	correction factor for yaw moment
D	draft of the moored vessel (m)
d	water depth (m)
B_m	beam of the moored ship (m)
S	clear distance between the ships (m)

Kriebel [4] also developed empirical equations to calculate forces and moments on the moored ship due to passing ship using the latest experimental results

$$F_{X-\_\mathrm{KRIEBEL}} = \frac{1}{2}\rho D L_\mathrm{m} V^2 \left\{0.0074\Delta_\mathrm{D}\mathrm{e}^{2.6\left(\frac{D}{d}\right)}\mathrm{e}^{-1.5(\Delta_\mathrm{s})}\right\} \tag{27}$$

$$F_{Y+\_\mathrm{KRIEBEL}} = \frac{1}{2}\rho D L_\mathrm{m} V^2 \left\{0.0126\Delta_\mathrm{D} e^{3.6\left(\frac{D}{d}\right)}\mathrm{e}^{-2.0(\Delta_\mathrm{s})}\right\} \tag{28}$$

$$M_{z-\_\mathrm{KRIEBEL}} = \frac{1}{2}\rho D L_\mathrm{m} V^2 \left\{0.0044\Delta_\mathrm{D}\mathrm{e}^{3.2\left(\frac{D}{d}\right)}\mathrm{e}^{-3.4(\Delta_\mathrm{s})}\right\} \tag{29}$$

Symbols used in Eqs. (27–29) are given below.

$F_{X\text{-KRIEBEL}}$	surge force (negative peak) (N)
$F_{Y\text{-KRIEBEL}}$	sway force (maximum positive) (N)
$\mathrm{FM}_{Z\text{-KRIEBEL}}$	yaw force (maximum negative) (Nm)
D	draft of moored ship (m)
d	water depth (m)
L_m	length of the moored ship (m)
V	speed of passing ship
Δ_D	displacement ratio
Δ_S	separation ratio.

5.6 *Parametric Evaluation*

The effect of vessels passing through the neighbouring approach channel to JNPT has been assessed based on 200,000 tonnes displacement container vessels with 366 m LOA.

Longitudinal and transverse forces applied to the moored vessels due to passing vessel have been obtained using the **Flory method** for different passing speeds and spacing. The notation for the variables is shown in Fig. 11.

The maximum transverse force occurs when the passing vessel is crossing the centre of the moored vessel, while the longitudinal force occurs before and after crossing, and they are opposite in magnitude. This means that the longitudinal and transverse forces do not occur at the same time and require combining the forces in time domain. This can only be done in dynamic analysis unless if we decide to take the maximum longitudinal and transverse forces and combine them in a single static analysis conservatively. The calculation of forces and moment was done for different passing vessels, separation distances and vessel speed. The results are tabulated. Tables 5 and 6 give the forces longitudinal (F_x) and transverse (F_y) on 250,000 DWT vessels due to the passing vessel. The effect due to the separation distance and passing vessel speed is studied as illustrated here.

Figures 12, 13, 14, and 15 shows the variation of the longitudinal and transverse forces for four different passing vessel spacing of 75, 100, 125 and 150 m for different passing vessel speeds from 5 knots to 12 knots. Same data is represented in a different manner to show the effect of vessel speed and spacing in Figs. 16 and 17. It can be observed that the longitudinal and transverse forces reduce by 50% when the spacing is increased to 150 m. And the higher the passing vessel speed, higher would be the forces, and hence, the speed of the passing vessel should be restricted by some criteria. Figures 18 and 19 show the variation of the longitudinal and transverse forces for different passing vessel spacing and displacements of the moored vessel. From the figures, it can be noted that the main influencing factors are passing vessel's displacement, speed and the separation distance between the two vessels.

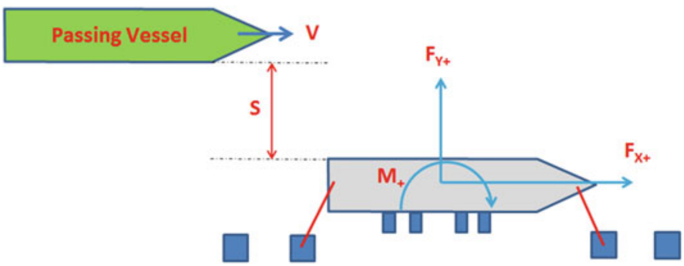

Fig. 11 Notations used in the simulation (OPTIMOOR)

Table 5 Calculated longitudinal and transverse force in tonnes (250,000 DWT)

Vessel speed (knots)	Passing vessel spacing (m)							
	75 m		100 m		125 m		150 m	
	F_y	F_x	F_y	F_x	F_y	F_x	F_y	F_x
5	98	39	81	32	68	27	57	23
6	142	56	117	46	97	39	81	33
7	193	77	159	63	132	53	111	45
8	252	100	208	82	173	69	145	58
9	319	126	263	103	219	87	183	74
10	394	156	324	128	270	107	226	91
11	477	189	392	155	327	130	274	110
12	567	225	467	184	389	154	326	131

Table 6 Variation with spacing for different passing speeds

Spacing (S) (m)	Vessel speed (V) (knots)							
	5	6	7	8	9	10	11	12
Transverse force F_y (tonnes)								
75	98	142	193	252	319	394	477	567
100	81	117	159	208	263	324	392	467
125	68	97	132	173	219	270	327	389
150	57	81	111	145	183	226	274	326
Longitudinal force F_x (tonnes)								
75	39	56	77	100	126	156	189	225
100	32	46	63	82	103	128	155	184
125	27	39	53	69	87	107	130	154
150	23	33	45	58	74	91	110	131

6 Static Mooring Analysis

6.1 Mooring Wires

The characteristics of mooring wires used in the analysis are given in Table 7.

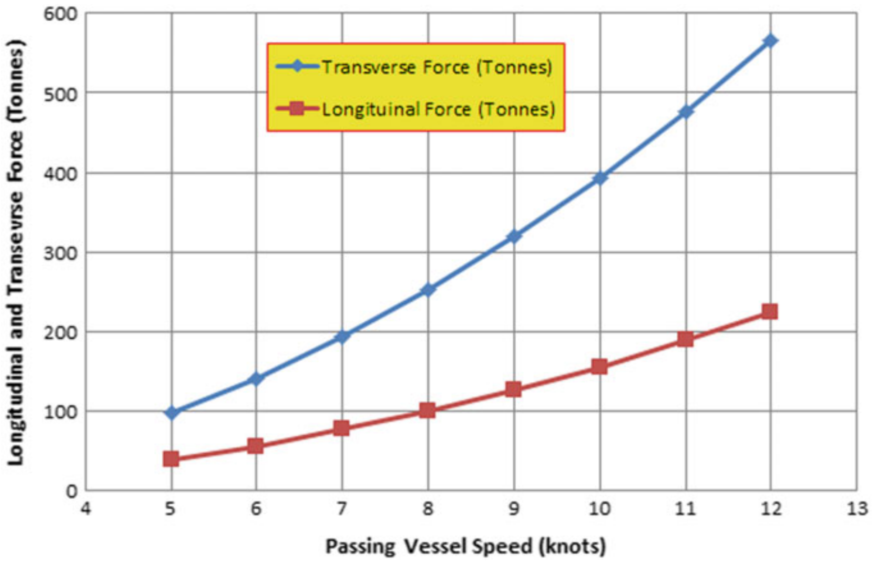

Fig. 12 Longitudinal and transverse force with speed of passing vessel (spacing = 75 m)

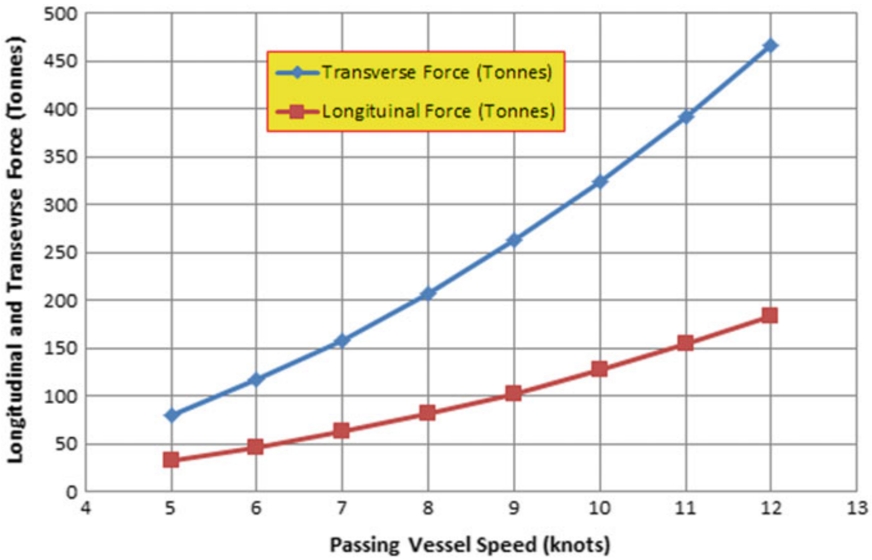

Fig. 13 Longitudinal and transverse force with speed of passing vessel (spacing = 100 m)

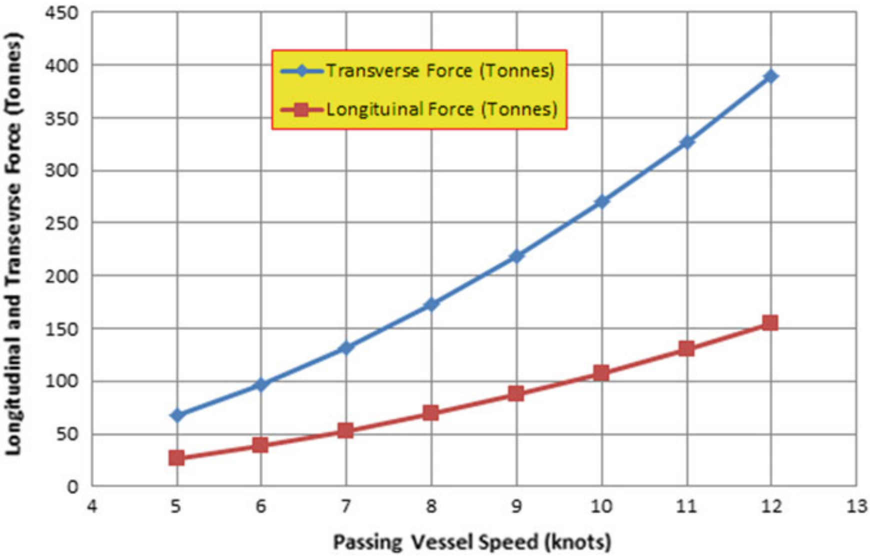

Fig. 14 Longitudinal and transverse force with speed of passing vessel (spacing = 125 m)

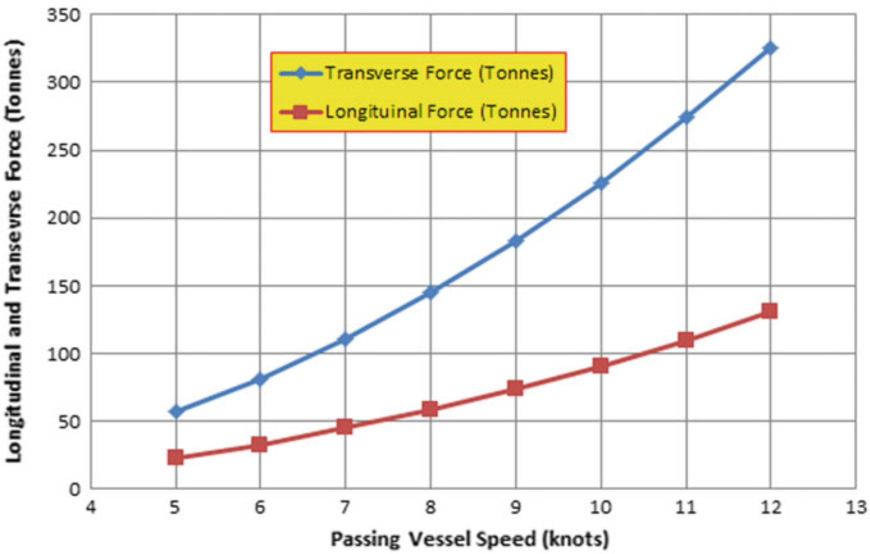

Fig. 15 Longitudinal and transverse force with speed of passing vessel (spacing = 150 m)

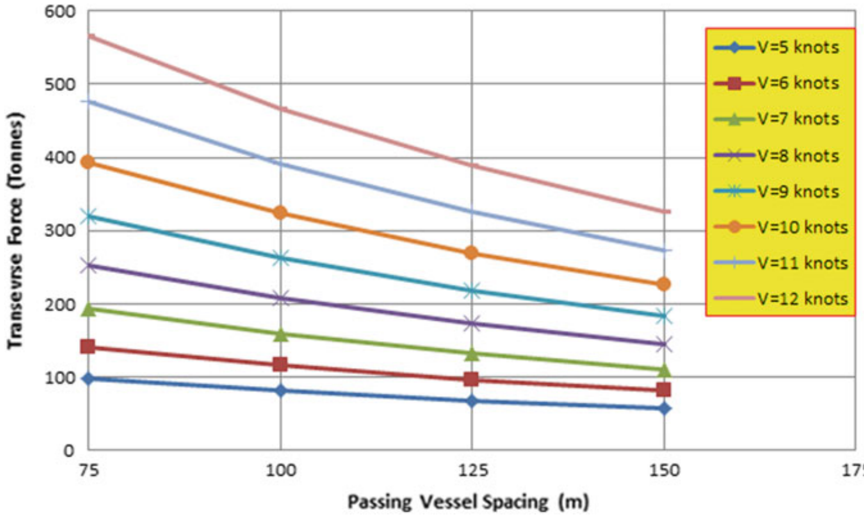

Fig. 16 Variation of transverse force with spacing of vessels

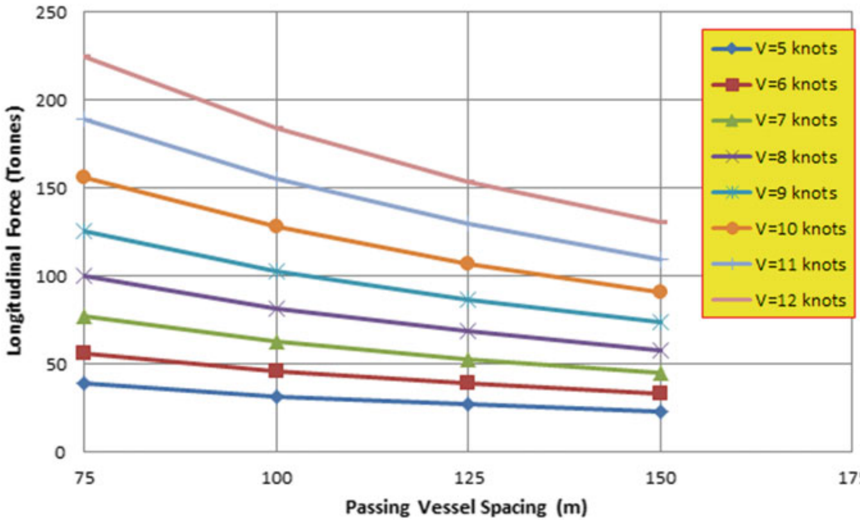

Fig. 17 Variation of longitudinal force with spacing of vessels

6.2 Mooring Design Criteria

The criteria given in Table 8 are meant for mooring lines that are properly maintained and inspected. Also, the mooring lines should have proper breaking hardware that has equivalent breaking strengths to that of mooring lines.

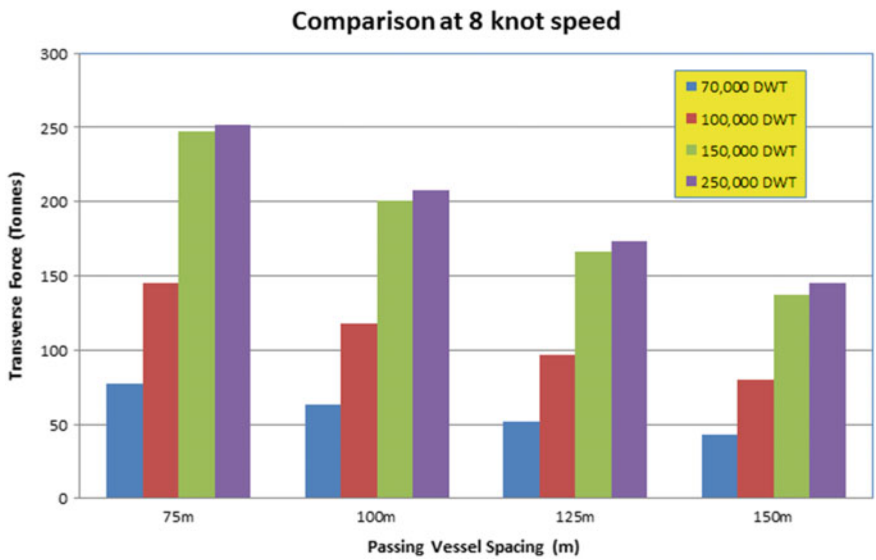

Fig. 18 Variation of transverse force with spacing of vessels

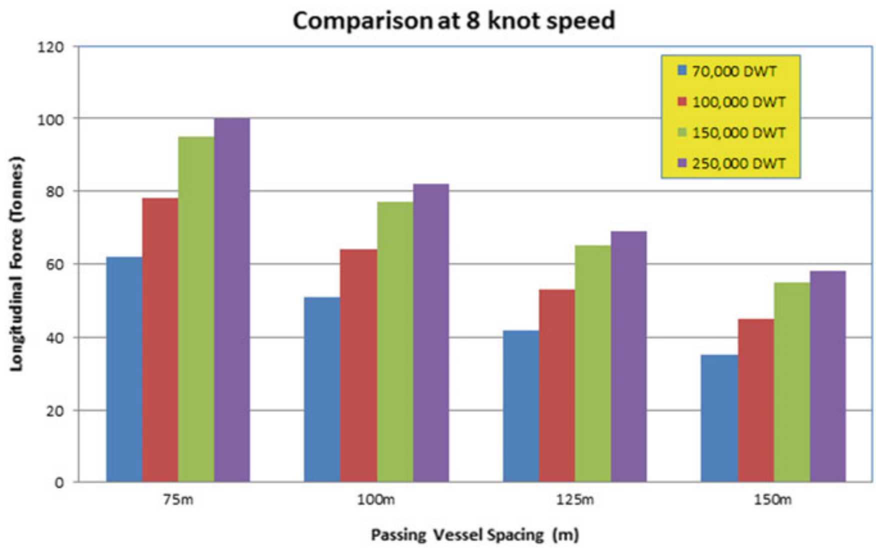

Fig. 19 Variation of longitudinal force with spacing of vessels

6.3 *Modelling Fenders*

The fenders are provided at breasting dolphins between the structure and the vessel. Hence, when the environmental loads are applied to the vessel, the fenders will

Table 7 Tanker mooring equipment characteristics (typical)

	PANAMAX (70,000 DWT)	AFRAMAX (100,000 DWT)	SUEZMAX (150,000 DWT)	VLCC (≥250,000 DWT)
Number of mooring wires	16 nos	16 nos	20 nos	20 nos
Type of mooring wire	6 × 36 IWRC Steel wire	6 × 36 IWRC Steel wire	6 × 36 IWRC Steel wire	6 × 36 IWRC Steel wire
Diameter of mooring wire (mm)	40	50	60	80
Wire minimum breaking load (MBL)	110 MT	168 MT	236 MT	410 MT
Safe working load (SWL)	60.5 MT	92.4 MT	129.8 MT	225.5 MT
Tail diameter (mm)	40	50	60	80
Minimum breaking load (MBL)	42T	64T	91MT	158MT

Table 8 Mooring line tension criteria

	Analysis method	Tension Limit % MBL
Intact	Quasi-static	55
Intact	Dynamic	55

be compressed. The fenders are nonlinear compression elements and hence shall be modelled accordingly. Based on the design done by the detailed engineering consultant, the fender selected was SCN 2000 E3.0 with a rated maximum reaction of 4660 kN at 72% axial compression. Typical load–deflection relationship for a fender is shown in Fig. 20.

The load-axial deformation characteristics used in the simulation are shown Fig. 21.

6.4 *Modelling Mooring Lines*

The mooring lines are modelled as linear elastic tension cable element in OPTI-MOOR. The stiffness of the cable is calculated using its axial properties and its length provided as input. The length of mooring line is calculated by the program based on the geometry of the line from its fairlead point to the mooring hook.

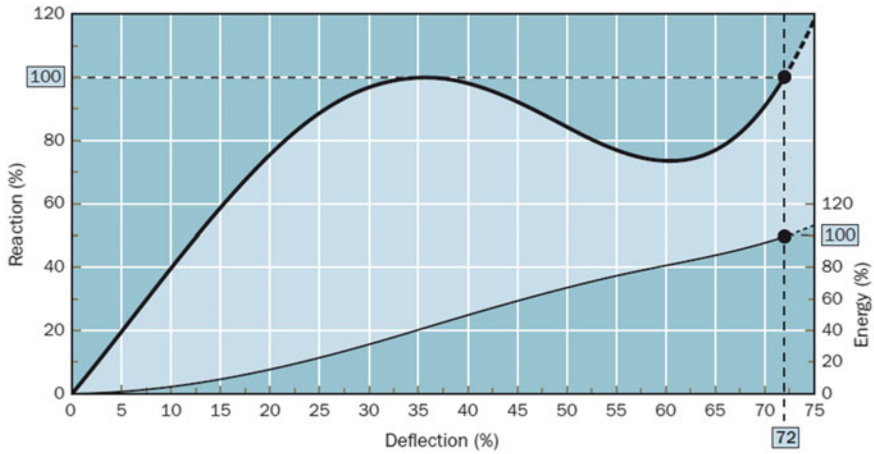

Fig. 20 Typical load–deflection relationship of rubber fender

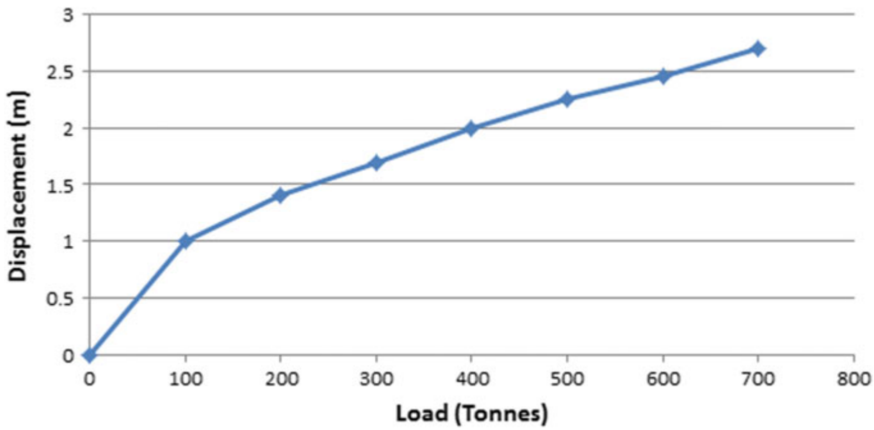

Fig. 21 Load–deflection relationship of rubber fender SCN2000 E3.0

The breasting and mooring dolphin structures are considered to be rigid and not moving when the mooring loads are applied.

6.5 *Mooring Analysis Simulation*

Environmental loads on the moored vessel are calculated using OCIMF [10] guidelines as discussed in Sect. 4. The static analysis is carried out to determine the mooring line tension using equilibrium of the vessel considering the mooring line elasticity and geometric restraint. Each time data is entered or altered on the mooring screen (or arrangement screen), the OPTIMOOR computer program carries out a series of calculations to seek the vessel position which satisfies the force and moment equations for the system. This series of equations can be represented by the following:

$$\begin{aligned} &\sum F_x + \sum P_x = 0 \quad \text{Surge} \\ &\sum F_y + \sum P_y = 0 \quad \text{Sway} \\ &\sum M_{xy} + \sum N_{xy} = 0 \ \text{Yaw} \end{aligned} \tag{30}$$

where

F_x is the x vector component of an externally applied force, e.g. wind, current, or wave or effects from passing vessel.
P_x is the x vector component of mooring line force (fenders exert no force in the x direction).
F_y is the y vector component of an externally applied force, eg. wind, current, or wave or effects from passing vessel.
P_x is the y vector component of mooring line force or fender force.
M_{xy} is the moment in the x-y plane produced by an externally applied force, e.g. wind current, or wave or effect from passing vessel.
N_{xy} is the moment in the x-y plane produced by an mooring line force or fender force.

The program seeks an equilibrium position which satisfies these equations by applying small iterations to the position of the moored vessel, first in the x (longitudinal) direction, then in the y (transverse) direction and then in the x-y (rotation) direction. After each iteration in a particular direction, the program checks to see if the applicable equilibrium equation is satisfied. If the equation is under satisfied, the program then applies an iteration of the same magnitude in the same direction. If it is over satisfied, the program then applies a smaller iteration in the opposite direction. During each iteration step, the program recalculates the force in each mooring line and each fender for the iterated vessel position. The various mooring line force vectors are determined by the relative positions of the respective fairlead and bollard points. The fender vectors are applied perpendicular to the side of the vessel at the respective fender positions.

6.6 Environmental Loads

The mooring loads for the various approach of environmental loads are summarized in Table 9 for 70,000, 100,000, 150,000 and 250,000 DWT vessels. The variation of longitudinal and transverse forces for all tankers simulated is shown in Fig. 22. It can be observed that the largest forces occur for the 250,000 DWT tankers. The variation of the environmental loads in various directions is shown in Fig. 23.

Table 9 Environmental loads on vessels for loaded draft (metric tonnes)

Direction	70000 DWT		100,000 DWT		150,000 DWT		250,000 DWT	
	F_x	F_y	F_x	F_y	F_y	F_y	F_x	F_y
North (0°)	15.2	−90.6	18.0	−111.4	21.6	−150.2	25.4	−265.2
North-east (55°)	46.3	0.2	54.7	0.1	67.1	0.5	91.8	0.3
East (90°)	26.7	60.9	31.7	74.7	38.2	101.5	48.2	182.1
South-east (135°)	3.0	107.1	3.5	131.7	4.3	177.5	5.7	311.5
South (180°)	−15.4	91.2	−18.2	112.5	−22.3	150.6	−31.1	252.6
South-west (225°)	−41.0	62.2	−48.9	81.1	−58.9	105	−80.3	118.5
West (270°)	−25.5	−70.1	−30.1	−86.8	−37.0	115.3	−50.9	−185.3
North-west (315°)	−5.3	−107.1	−6.3	−131.8	−7.6	−177.3	−9.3	−308.9

Note Negative Fy values moves the vessel towards the jetty inducing compression on the fenders

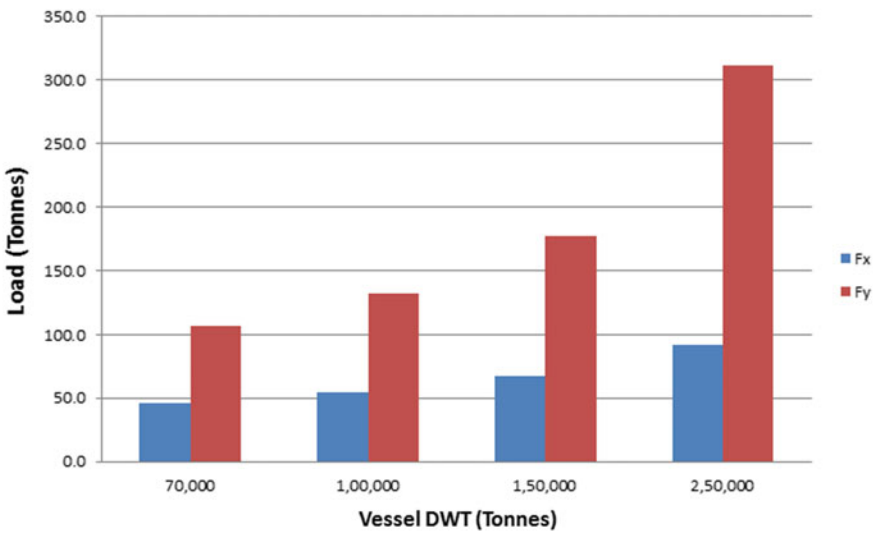

Fig. 22 Variation of environmental loads on vessels (loaded draft)

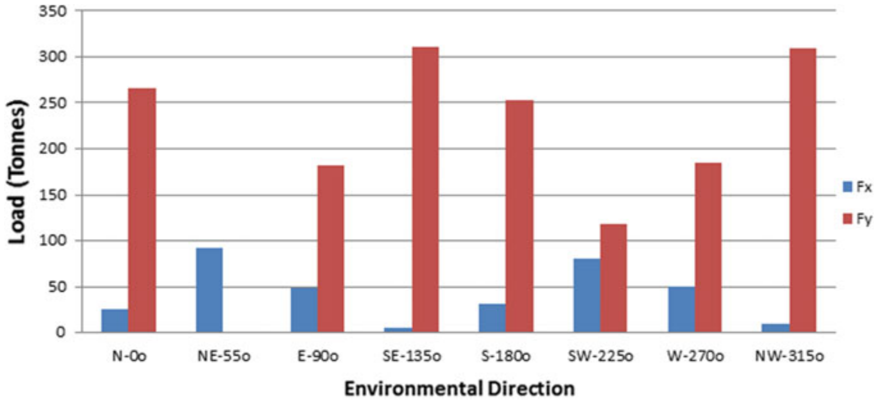

Fig. 23 Variation of environmental loads for 250,000 DWT tankers (loaded draft)

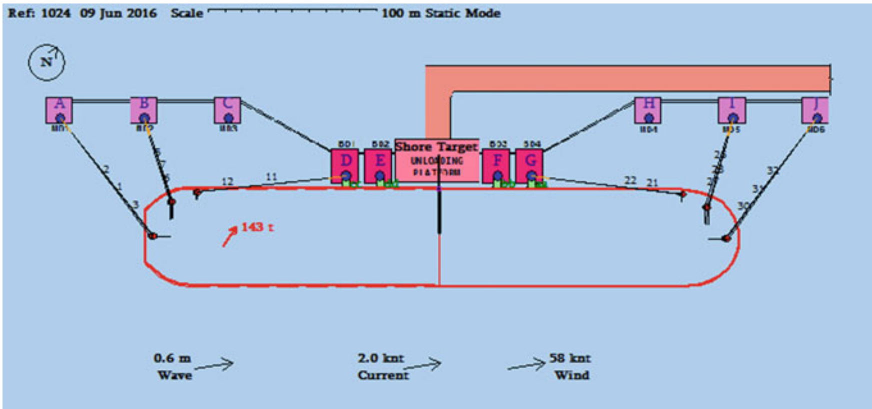

Fig. 24 Mooring loads for 250,000 DWT (loaded draft) (head = 3 lines, stern = 3 lines, breast = 3 + 3 lines, spring = 2 + 2 lines, total = 16 lines)

The mooring pattern and simulated environmental loads for 250,000 DWT tankers with loaded draft are shown in Fig. 24 as a typical example of simulation in OPTIMOOR.

A total of 16 lines are used for 70,000 DWT, 100,000 DWT, 150,000 DWT and 250,000 DWT tankers. The figure also represents the direction of loading of waves, wind and current.

Table 10 Mooring line tensions for 250,000 DWT vessels (loaded draft)

Line no.	Mooring line tension (metric tonnes)							
	N-0°	NE-55°	E-90°	SE-135°	S-180°	SW-225°	W-270°	NW-315°
A-1	19.7	0.0	0.0	0.0	0.0	0.0	25.6	29.7
A-2	19.4	0.0	0.0	0.0	0.0	0.0	25.2	29.3
A-3	19.1	0.0	0.0	0.0	0.0	0.0	24.9	28.9
B-5	30.4	0.8	0.0	0.0	0.0	0.0	33.7	44.4
B-6	30.1	0.3	0.0	0.0	0.0	0.0	33.4	43.8
B-7	29.7	0.0	0.0	0.0	0.0	0.0	33.1	43.4
D-11	10.1	37.4	24.1	0.0	0.0	0.0	6.0	12.5
D-12	10.1	37.5	24.1	0.0	0.0	0.0	6.0	12.6
G-21	0.0	0.0	0.0	1.6	32.1	55.4	1.1	0.0
G-22	0.0	0.0	0.0	1.6	32.5	56.2	1.1	0.0
I-26	28.1	1.2	0.0	0.0	13.4	19.8	6.8	24.2
I-27	28.1	0.7	0.0	0.0	14.4	21.0	6.7	24.2
I-28	28.1	0.2	0.0	0.0	15.3	22.2	6.7	24.1
J-30	22.8	9.7	0.5	4.6	10.6	8.1	5.0	19.5
J-31	22.9	9.4	0.3	4.7	11.2	8.8	4.9	19.6
J-32	23.0	9.0	0.1	4.9	11.9	9.5	4.9	19.6

6.7 Results from Static Analysis

Mooring line tension. The mooring line tension for each type of moored vessel is presented here. Table 10 gives the line tension for each mooring line of 250,000 DWT vessels when subjected to loads from different directions. Figure 25 of the 250,000 DWT vessels in loaded and laden conditions. It can be seen that the line tensions are more for loading at south-west 225°. The mooring line tension for the other mooring vessels is compared and presented in Figs. 26 and 27 for loaded and laden draft.

Mooring hook capacity. The mooring hook capacity for different vessel lines was analysed, and the arrived mooring hook capacity is shown in Table 11.

7 Dynamic Mooring Analysis

7.1 Time-Domain Dynamic Analysis

The analysis must be carried out in the time domain to combine these forces with wind, wave and current. The result from the passing vessel is superimposed on the mooring loads due to wind, wave and current.

Table 11 Mooring hook capacity

Mooring point	Mooring lines	Maximum mooring line tension (tonnes)		Utilization ratio		Mooring hook capacity provided (tonnes)
		Loaded draft	Laden draft	Loaded draft (%)	Laden draft (%)	
MD1	A-1, A-2, A-3,*A-4*	29.7	48.8	29.7	48.8	3 × 100
MD2	B-5, B-6, B-7	44.4	71.3	44.4	71.3	3 × 100
MD3	C-8, C-9, C-10	17.6	17.6	17.6	17.6	3 × 100
BD1	D-11, D-12,*D-13*	37.5	45.8	50.0	61.1	3 × 75
BD2	*E-14, E-15, E-16*	–	–	–		3 × 75
BD3	*F-17, F-18, F-19*	–	–	–		3 × 75
BD4	*G-20*, G-21, G-22	56.2	56.9	74.9	75.9	3 × 75
MD4	H-23, H-24, H-25	11.9	11.9	11.9	11.9	3 × 100
MD5	I-26, I-27, I-28	28.1	55.9	28.1	55.9	3 × 100
MD6	*J-29*, J-30, J-31, J-32	23.0	41.4	23.0	41.4	3 × 100

Note A-4, D-13, E-14, E-15, E-16, F-17, F-18, F-19, G-20 and J-29 are not used in the simulation

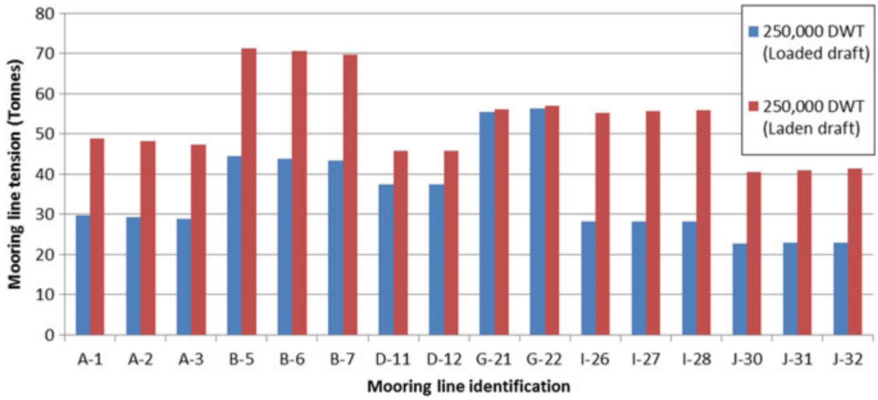

Fig. 25 Mooring line tension for 250,000 DWT

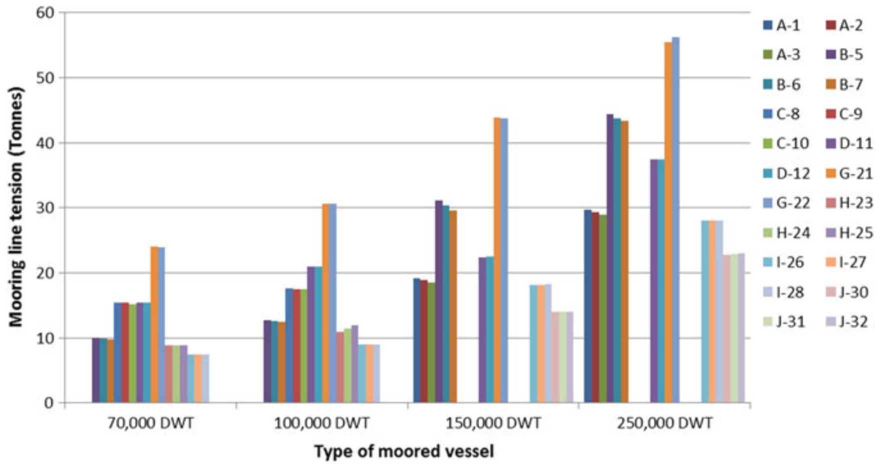

Fig. 26 Mooring line tension comparison (loaded draft)

7.2 Mooring Analysis Cases

Dynamic mooring analysis has been carried out for tankers with prevailing environmental conditions and passing vessel effects as summarized in Tables 12, 13, 14 and 15. The governing case results are presented for moored vessels 70,000 DWT and 100,000 DWT, and 150,000 DWT and 250,000 DWT tankers with passing vessel (200,000 DWT) for 75 m spacing and 300 m spacing with eight-knot speed, respectively. The load combinations are tabulated in Tables 12, 13, 14 and 15.

Table 12 Dynamic mooring analysis for 70,000 DWT vessels

Environment	Wind + current + monsoon wave			
Spacing/speed (m)	Five knots	Six knots	Seven knots	Eight knots
75	√	√	√	√
100	√	√	√	√
150	√	√	√	√

Table 13 Mooring failure 100,000 DWT vessels

Environment	Wind + current + monsoon wave			
Spacing/speed (m)	Five knots	Six knots	Seven knots	Eight knots
75	√	√	√	√
100	√	√	√	√
150	√	√	√	√

Table 14 Mooring failure 150,000 DWT vessels

Environment	Wind + current + monsoon wave			
Spacing/speed (m)	Five knots	Six knots	Seven knots	Eight knots
150	√	√	X	X
200	√	√	√	√
300	√	√	√	√

X—Mooring line failure and hence mooring analysis discontinued

Table 15 Mooring failure 250,000 DWT vessels

Environment	Wind + current (no monsoon wave)			
Spacing/speed (m)	Five knots	Six knots	Seven knots	Eight knots
150	√	X	X	X
200	√	√	X	X
300	√	√	√	√

X—Mooring line failure and hence mooring analysis discontinued

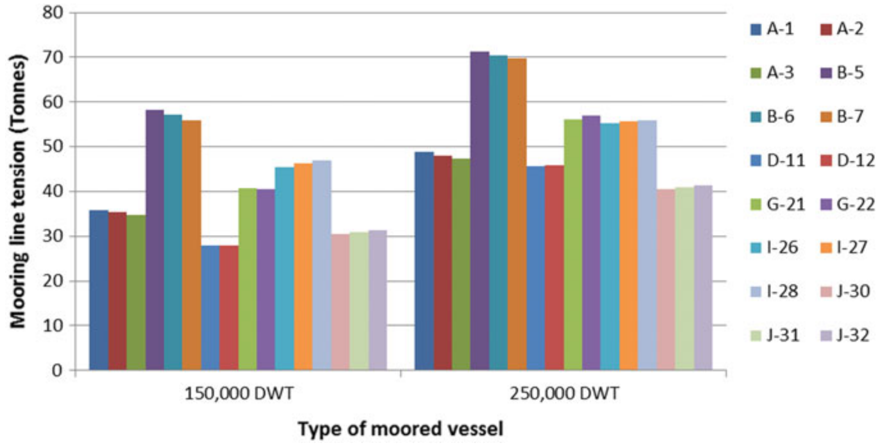

Fig. 27 Mooring line tension comparison (laden draft)

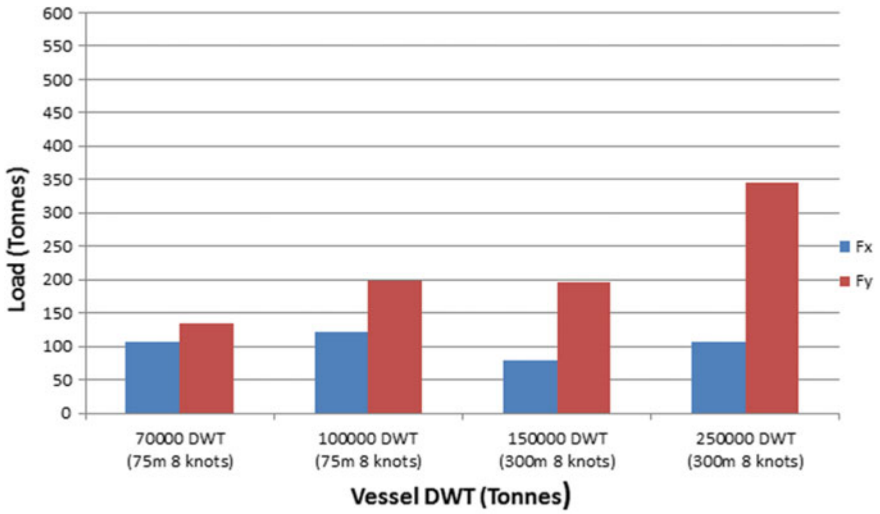

Fig. 28 Variation of passing vessel loads and environmental loads on moored vessels

7.3 *Combined Passing Vessel Forces and Environmental Loads Acting Moored Vessel*

The passing vessel loads with environmental loads are simulated in OPTIMOOR as shown in Fig. 30. The mooring loads for various environmental loading directions and passing vessel effects are summarized in Table 16 for 70,000, 100,000, 150,000 and 250,000 DWT vessels. Figure 28 shows a variation of loading for different passing vessel speeds, and Fig. 29 gives the variation with environmental load directions.

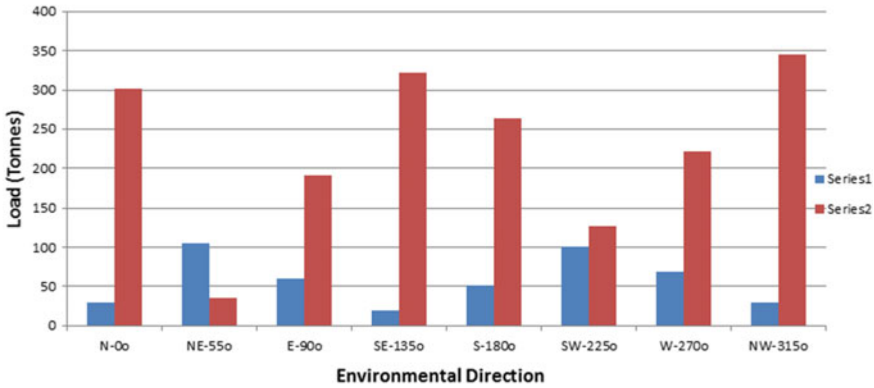

Fig. 29 Variation of passing vessel loads with environmental loads for 250,000 DWT tankers (300 m—eight knots)

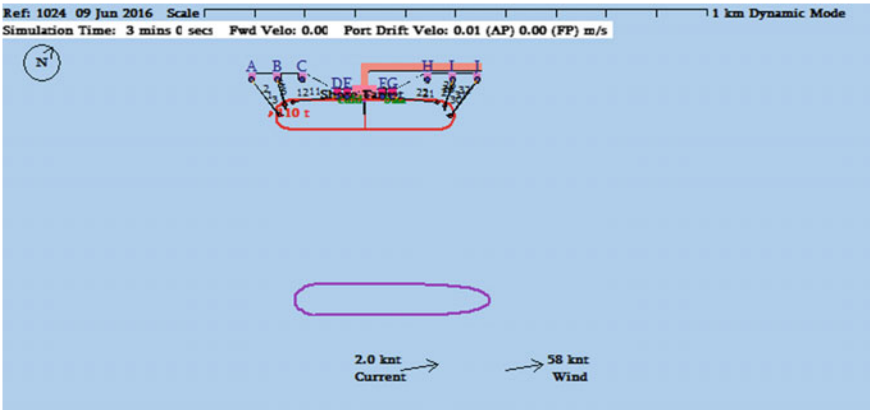

Fig. 30 Mooring loads for 250,000 DWT (300 m—eight knots)

A typical layout of OPTIMOOR simulation of passing vessel effects is shown in Fig. 34.

7.4 *Spring Lines Configuration*

Mooring analysis with 2 or 3 spring lines has been carried out, and the results indicate that the vessel gets detached due to large passing vessel loads combined with wave from south-west direction. The simulation with 2 and 3 spring lines is shown in Figs. 31 and 32.

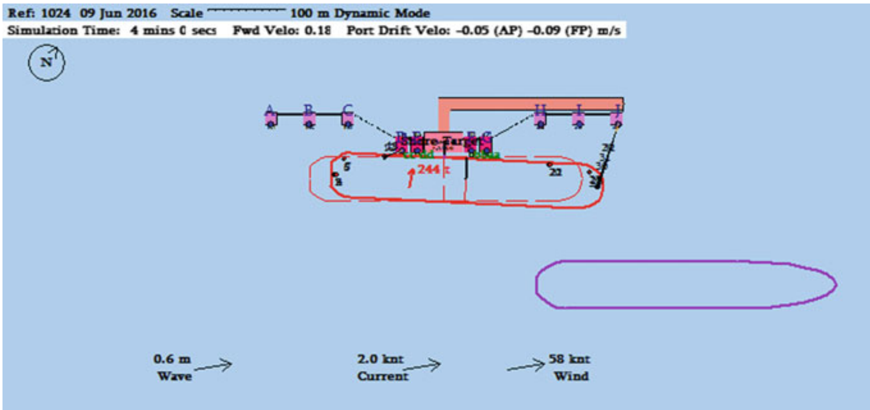

Fig. 31 Mooring arrangement with two spring lines

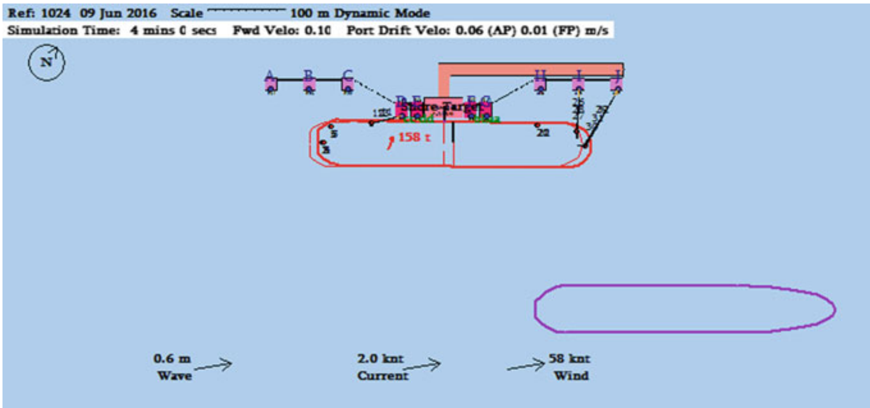

Fig. 32 Mooring arrangement with three spring lines

7.5 Results from Dynamic Mooring Analysis

Mooring line tensions. The line tension of mooring lines for the 250,000 DWT moored vessel is tabulated in Table 17, and the maximum tension in each mooring line is represented in Fig. 33. The increase in line load due to direction specific loads is mentioned in the table, and the same has been compared between different vessels in Fig. 34. The mooring line tension was compared for different moored vessels, and it has been found to be high for the 150,000 DWT vessels. Since, the wave loading was excluded for the 250,000 DWT vessels, the forces were found to be lesser.

Mooring hook capacity. The mooring line tension due to the effect of both the environmental loads with passing vessel effect is summarized in Table 18. It can be

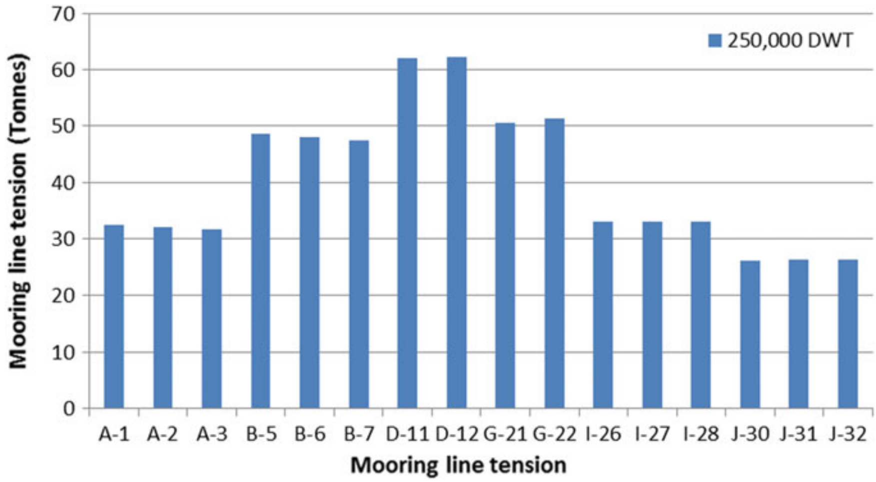

Fig. 33 Mooring line tension for 250,000 DWT

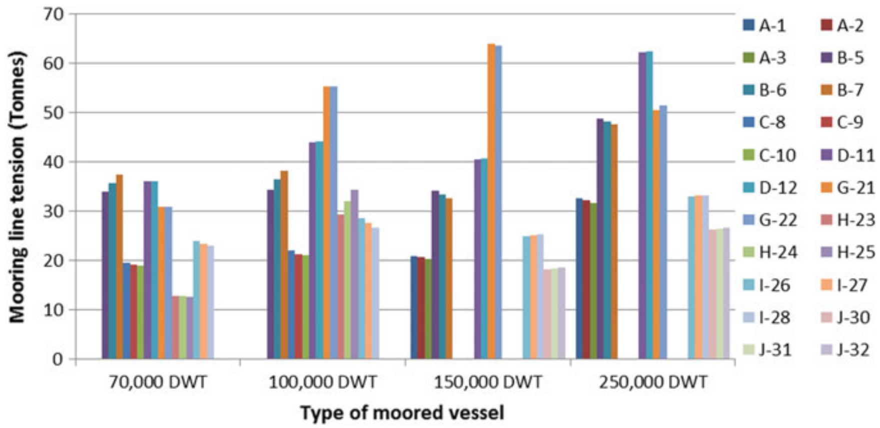

Fig. 34 Mooring line tension comparison between different moored vessels

observed that the maximum line tension exceeds 55% of MBL of mooring lines and the utilization ratio for mooring hooks is more than 0.8 for spring lines.

8 Comparison of Mooring Hook Capacity

A comparison of mooring hook capacities between the simulations with and without passing vessel forces is presented in Table 19. The comparison indicates that there is a considerable increase in line tension with the inclusion of passing vessel effects

Table 16 Mooring loads on vessels due to passing vessel effect with environmental loads (metric tonnes)

Direction	70000 DWT (75 m—eight knots)		100,000 DWT (75 m—eight knots)		150,000 DWT (300 m—eight knots)		250,000 DWT (300 m—eight knots)	
	F_x	F_y	F_x	F_y	F_y	F_y	F_x	F_y
North (0°)	−38.7	−117.6	84.4	−177.3	32.8	−169.0	28.9	−300.9
North-east (55°)	107.0	24.9	120.9	−71.3	78.1	−19.6	105.6	−35.1
East (90°)	88.8	84.1	103.7	116.5	50.6	109.8	59.8	191.6
South-east (135°)	63.9	130.4	−71.8	172.3	15.5	185.9	19.5	322.5
South (180°)	−69.4	114.5	−93.5	153.3	−41.2	158.9	−51.0	263.5
South-west (225°)	−85.2	86.8	−116.7	124.7	−77.4	113.8	−100.4	127.4
West (270°)	−83.0	−96.6	−106.5	−165.7	−55.5	−137.6	−69.1	−221.8
North-west (315°)	−59.2	−134.2	−81.4	−197.7	−26.5	−196.1	−29.2	−344.6

and hence the utilization ratio. This indicated the need to increase the mooring hook capacity, and it has been revised as mentioned in the recommendations.

9 Summary and Recommendations

9.1 Summary

The following points summarize the salient details of the detailed mooring analysis carried out for the vessels moored at the J5 berth.

- Static mooring analysis has been carried out for 58-knot wind speed, 2-knot current and 0.6 m wave height as recommended in CWPRS report. The results indicate that the proposed mooring hooks have adequate capacity.
- An assessment of effect of vessels passing through the neighbouring approach channel to JNPT has been done based on 200,000 tonnes displacement container vessels with 366 m LOA.

Table 17 Mooring line tensions for 250,000 DWT vessels (300 m—eight knots)

Line No.	Mooring line tension (metric tonnes)							
	N-0°	NE-55°	E-90°	SE-135°	S-180°	SW-225°	W-270°	NW-315°
A-1	32.5	22.5	0	0	0	0	0	29.5
A-2	32.1	22.2	0	0	0	0	0	29.2
A-3	31.6	21.9	0	0	0	0	0	28.8
B-5	48.6	34.5	2.8	0	0	0	0	38.9
B-6	48.1	34.1	2.2	0	0	0	0	38.6
B-7	47.5	33.8	1.7	0	0	0	0	38.3
D-11	62.1	18	62.1	27.5	0	0	0	10
D-12	62.3	18.1	62.3	27.6	0	0	0	10
G-21	50.5	2.5	0	0	1.8	32.3	50.5	5.2
G-22	51.3	2.5	0	0	1.8	32.8	51.3	5.2
I-26	33	33	3.5	0	2.3	15.2	12.8	12.4
I-27	33.1	33.1	3	0	2.4	16.2	13.8	12.4
I-28	33.1	33.1	2.3	0	2.6	17.2	14.9	12.3
J-30	26.2	26.2	15.6	3.9	7.1	11.7	3.6	8.1
J-31	26.4	26.4	15.1	3.7	7.2	12.4	4.1	8.2
J-32	26.5	26.5	14.6	3.5	7.3	13	4.5	8.2

Table 18 Mooring hook capacity

Mooring point	Mooring lines	Maximum mooring line tension (tonnes)	Utilization ratio (%)	Mooring hook capacity provided (tonnes)
MD1	A-1, A-2, A-3,*A-4*	32.5	32.5	3 × 100
MD2	B-5, B-6, B-7	48.6	48.6	3 × 100
MD3	C-8, C-9, C-10	21.9	21.9	3 × 100
BD1	D-11, D-12,*D-13*	62.3	83.1	3 × 75
BD2	*E-14*,*E-15*,*E-16*	–	–	3 × 75
BD3	*F-17*,*F-18*,*F-19*	–	–	3 × 75
BD4	*G-20*, G-21, G-22	63.8	85.1	3 × 75
MD4	H-23, H-24, H-25	34.2	34.2	3 × 100
MD5	I-26, I-27, I-28	33.1	33.1	3 × 100
MD6	*J-29*, J-30, J-31, J-32	26.5	26.5	3 × 100

Note A-4, D-13, E-14, E-15, E-16, F-17, F-18, F-19, G-20 and J-29 are not used in the simulation

Table 19 Comparison of mooring hook capacity with and without passing vessel forces

Mooring point	Mooring lines	Passing vessel loads + environmental loads		Environmental loads (loaded draft)		Environmental loads (laden draft)	
		Maximum mooring line tension (tonnes)	Utilization ratio (%)	Maximum mooring line tension (tonnes)	Utilization ratio (%)	Maximum mooring line tension (tonnes)	Utilization ratio (%)
MD1	A-1, A-2, A-3, A-4	32.5	32.5	29.7	29.7	48.8	48.8
MD2	B-5, B-6, B-7	48.6	48.6	44.4	44.4	71.3	71.3
MD3	C-8, C-9, C-10	21.9	21.9	17.6	17.6	17.6	17.6
BD1	D-11, D-12, D-13	62.3	83.1	37.5	50.0	45.8	61.1
BD2	E-14, E-15, E-16	–	–	–	–	–	
BD3	F-17, F-18, F-19	–	–	–	–	–	
BD4	G-20, G-21, G-22	63.8	85.1	56.2	74.9	56.9	75.9
MD4	H-23, H-24, H-25	34.2	34.2	11.9	11.9	11.9	11.9
MD5	I-26, I-27, I-28	33.1	33.1	28.1	28.1	55.9	55.9
MD6	J-29, J-30, J-31, J-32	26.5	26.5s	23.0	23.0	41.4	41.4

- Mooring pattern for the VLCC oil tankers (150,000 and 250,000 DWT) has been provided with 2 + 2 spring lines and 3 + 3 breast lines and 3 + 3 head and stern lines to limit the mooring line tension as discussed with the harbour master.
- The combined effect of passing vessel and the environmental loads has been investigated. The mooring load case with wave approaching from south-west direction is the most critical, and the vessel mooring lines break, and the vessel starts to drift. Hence during monsoon, the passing vessels shall be allowed in only one direction and away from the J5 berth by at least 300 m at a reduced speed of five knots. Considering the requirement of additional mooring lines, it is suggested to increase the longitudinal restraint capacity by increasing the mooring hook at breasting dolphins from 3 $\times$ 75 to 3 $\times$ 100 tonnes.

Table 20 Recommended mooring hook capacity

Mooring point	Mooring hook capacity proposed (tonnes)	Remarks (tonnes)
MD1	3 × 125	Revised from 3 × 100
MD2	3 × 125	Revised from 3 × 100
MD3	3 × 125	Revised from 3 × 100
BD1	3 × 100	Revised from 3 × 75
BD2	3 × 100	Revised from 3 × 75
BD3	3 × 100	Revised from 3 × 75
BD4	3 × 100	Revised from 3 × 75
MD4	3 × 125	Revised from 3 × 100
MD5	3 × 125	Revised from 3 × 100
MD6	3 × 125	Revised from 3 × 100

- Similarly, the mooring line tension for the head and stern increases with combined effect, and hence, any variation to the predicted wind and current could overstress the line, and hence, it is suggested to increase the mooring hook capacity at mooring dolphins from 3 × 100 to 3 × 125 tonnes.
- The recommended mooring hook capacities are summarized in Table 20, and the same shall be adopted for the detail design of mooring structures.

9.2 Recommendation

Based on the points listed in Sect. 9.1, the proposed mooring hook capacities are summarized in Table 20. The analysis carried out indicates the significant increase in line loads due to passing vessel effects, when added to the environmental loads.

References

1. Wang S (1975) Dynamic effects of ship passage on moored vessels. J Waterways Harb Coast Div ASCE
2. Seelig W (2001) Passing ship effects on moored ships. Technical Memorandum TM-6027-OCN, Facilities Engineering Service Center
3. Flory JF (2002) The effect of passing ships on moored ships. In: Prevention first 2002 symposium, California State Lands Commission, Long Beach, CA, Sept 10–22
4. Kriebel D (2005) Mooring loads due to parallel passing ships. Technical Report, TR-6056-OCN, Naval Facilities Engineering Service Center
5. Remery GFM (1974) Mooring forces induced by passing ships. In: Sixth annual offshore technology conference, Houston, May 6–8
6. Muga B, Fang S (1975) Passing ship effects—from theory and experiment. In: OTC 16719, Offshore technology conference, ASCE

7. OCIMF—guidelines and recommendations for the safe mooring of large ships at piers and sea islands
8. BS 6349—code of practise for maritime structures
9. PIANC—guidelines for the design of fender system (2002)
10. OCIMF guidelines for prediction of wind and current loads on VLCCs
11. CWPRS Central Water And Power Research Station report 4756