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Research Article

Mooring System for Very Large Ships at Berth

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Abstract

Sea water transport is the most economical mode of transport. More than 85% of bulk and liquid cargo is handled by the sea transport. Ships require safe berthing facilities for their loading/unloading operations. Safe mooring system restricts the ship movements due to environmental forces like waves, winds and currents. Ship should not exert large forces on berthing structure, for which fenders are provided at berthing face to absorb the shocks. With the development of special cargo handling terminals for bulk and liquid cargo, which cater for large ships, the mooring systems have also undergone large changes. In order to keep pace with modern marine transport trends the Indian Ports are also developing terminal facilities and mooring systems for large vessels. A study was undertaken to design a mooring system for a Very Large Crude Carrier (VLCC) for an Indian Port. A conceptual design for a marine oil terminal (MOT) including mooring system for a large oil tanker has been evolved. The studies reveal that the velocity and direction of currents are dominant in deciding orientation of MOT. A dolphin type marine oil terminal with four breasting dolphins and six mooring dolphins was found suitable for a VLCC of 300000 DWT.

Keywords: *Marine Oil Terminal, Ship Movements, Berthing Energy, Mooring System, Fenders.*

1. Introduction

India has a large coastline of about 7,500 km and has seen a rapid growth in the activities along the coast. These developmental activities include construction of ports and harbours for transport of goods, development of fisheries harbours, captive and special cargo handling terminals for transportation of modern cargo (container, LNG, Ro-Ro) and offshore terminals. There are large changes in methods of transport and cargo handling techniques resulting in overall efficiency and economy. There is increase in the total cargo handled by the Indian ports from 1 million tonnes in 1950 to 272 million tonnes in 1999. Whereas, it is predicted that the Indian sea transport will cross 870 million tonnes mark by 2016-17. In order to keep pace with the modern marine transport trends, the Indian ports are also developing terminal facilities and mooring systems for large vessels.

The main function of the harbour is to provide calm water body as well as sufficient draft for the ships. An ideal port requires various facilities such as navigational channels, harbour area protected by breakwaters, sufficient draft, optimum number of berths, storage facilities, road and railways, administrative blocks etc. Suitable berthing facilities like quays, wharfs or jetties and safe mooring systems are also important requirements of ideal port.

The ship requires safe mooring system at the berths to restrict its movements due to environmental forces like winds, waves and currents and to keep the ship stable for loading and un-loading operations. Furthermore, the ship should not exert large forces on the berthing structure, for which fenders are provided at the berthing face to absorb the shocks. Another function of fender is to operate as a shock absorber by absorbing the berthing energy of a vessel during the berthing operation and soften the berthing impact to the berth and the hull of the ship. The suitable fendering system helps to ensure smooth berthing operation. Whereas the mooring system along with the fenders control the ship motions at the berth and keep the ship in acceptable stable condition at the berth.

Environmental loads due to wave, wind and current on a ship are important aspects for the determination of the alignment of the berth structure and the mooring system. In recent years, changes of cargo handling techniques have resulted in changes of both ship and port installations. The rate of cargo loading and unloading operations depends on the degree of ship motions at berth. Therefore, the economy of the port directly depends on the mooring system where, the port installations, berth structure and ship body are protected by ship mooring systems in rough weather conditions. The marine transport needs to have

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minimum time for cargo loading and unloading operations at terminals. These operations are often disturbed by the excessive movements of ships at berth. If the ship movements are too large, cargo handling operations may be shut down for operational safety purpose. Therefore mooring arrangements play an important role in terms of safety of the ship, berth structure and fender systems as well as downtime of the berth.

A design methodology for marine oil terminal (MOT) including mooring system for large oil tankers has been reviewed and described in the present study. The size, shape and orientation of the Marine Oil Terminal (MOT), suitable fender and mooring arrangements for a Very Large Crude Carrier (VLCC) having Dead Weight Tonnage (DWT) of 300000 tonnes (Table 1) are determined considering the environmental conditions of waves, winds and currents at a typical Indian port.

Table 1 Typical Ship Dimensions of Large Oil Tankers

DWT	LOA (m)	LBP (m)	Beam (m)	Draft (m)
ULCC				
500000	415	392	73	24
350000	365	345	65.5	22
VLCC				
300000	350	330	63	21
200000	310	294	55	18.5

A suitable Fender system is selected for a Very Large Crude Carrier (VLCC), considering the characteristics of the ship. The mooring arrangement consists of steel ropes with nylon tails, which sustain the effect of high winds associated with currents and waves. Simulation of moored ship motions for moderate environmental conditions is carried out using software OPTIMOOR based on quasi-static approach. The ship motions in six degrees of freedom need to be within the permissible limits for safe cargo handling. The maximum rope tensions, fender compressions and bollard pull are also determined.

2. Literature review

An elaborate description of port development has been given in Port Engineering (Per Bruun, 1989). Historical information about various types of ports as well as the trend of development in the sea transportation has been compiled. Recent development trends in port engineering are characterized by the need to accommodate vessels with greater drafts. Tankers for crude oil have reached up to 0.6 million DWT (Dead Weight Tonnage). Also the ore carries of 0.4 million DWT and the container vessels up to 60,000 DWT are in use in the port sector. The new technologies like Roll-on Roll-off (RO-RO) are also in common use. All these developments require special port installations. This engineering is now called as "terminal technology" (Per Bruun, 1989).

The scenario of Indian port development has been described (Narsimhan, 2002). The ideal port requires various facilities such as navigational channels, harbour area, sufficient draft, optimum number of berths, storage facilities, road and railways etc. Suitable berthing facilities like quays, wharfs or jetties and safe mooring systems are also important requirement of ideal port (Narasimhan -2002).

Acomprehensive review of various berthing facilities like wharves, quays and piers, their requirements and the design aspects/methods have been taken (Per Brunn, 1989 and Narasimhan, 2002). The ship movements at the berths need to be restricted for easy loading and unloading operations. If the ship movements are large, cargo handling may take more time or even they are required to be stopped. The ship movements at the berths may damage to the ship as well as the port facilities. The Permanent International Association of Navigation Congresses (PIANC) commissioned special working group to study the movements of the moored ships in the harbours and establish guide lines for safe working and safe mooring conditions (PIANC, 1995). PIANC has also categorized different ships used in the world which are having different characteristics from view of ship movements, cargo handling operations and safe mooring conditions. Furthermore the factors affecting the ship motions have also been studied by working group of PIANC.

The movements of the moored ship have been caused by the various external forces such as: winds, currents, seiches, waves, tides, passing ships and cargo handling operations. The working group of PIANC has addressed all these parameters on the behavior of moored ship (PIANC, 1995). The guidelines are also available in the British Standards (1994) and the Bureau of Indian Standards: 4651, Part V (2012) for the assessment of ship movements. The movements of a moored ship at a berth can be either horizontal (surge, sway and yaw) or vertical (roll, pitch and heave). Vertical movements are almost independent of the mooring system, but horizontal motions are dependent on the loading conditions, mooring arrangement and the type berth.

The most important element with respect to the movements of moored ships at berth is the mooring lines and fenders, which can be considered as the more flexible elements in the mooring arrangement. The description of the types and characteristics of mooring lines and fenders, mooring arrangement principles and operational considerations has been briefed by the PIANC (1995) as well as the British Standards (1994) and the Bureau of Indian Standards: 4651, Part V (2012).

Computations of environmental loads due to wave, wind and current on a ship are important aspects for the determination of the alignment of the berth structure. The empirical formulae for estimating environmental loads on ships are recommended by the International Standards. The formulae for the computation of wind and current forces on a ship are recommended by the British Standard BS 6349: Part 1 (2000) and that of due to wave is given by the Spanish Standard ROM 0.2-90 (1990). Many research papers / reports are available on computing mooring forces (Per Brunn, 1989). Simulation of moored ship motions are carried out using quasi-static approach to predict mooring rope tensions, fender compressions and bollard pulls for moderate environmental conditions (Das, *et al*, 2015).

The criteria for selecting the fender are given in various standards. The manufactures of fenders usually list their fenders ability in their energy absorption, maximum deflection and maximum forces on their supports. A Quick Fender Selection Method (QFSM) based on the conversion of ship berthing energy is suggested (Das, *et al*, 2014). The procedure for computing the reaction forces, hull pressure and the natural forces has been described in the catalogues of M/s Shibata (Japan) and M/s Fentek (Germany) and (Per Brunn, 1989).

Mooring analysis of a vessel alongside a berth usually involves a number of non-linear mooring lines, extending at different vectors in both the horizontal and vertical planes, with elastic fenders, acted upon by wind, current, and sometimes other forces, which may vary in time and direction. Computer programs are now available which can quickly and accurately analyze such complex mooring arrangements. The OPTIMOOR Software developed by Tension Technology International (TTI), England (TTI, 2003) is based on guidelines prepared by the Oil Companies International Marine Forum (OCIMF) Mooring Equipment Guidelines, (OCIMF, 1992). The ship is defined by its dimensions, fairlead positions, mooring line size and material. The berth is defined by mooring point positions and fender characteristics. Wind and current velocities and directions are then entered. OPTIMOOR contains appropriate wind and current force and moment coefficients for typical vessels. The program calculates the resulting mooring line loads due to the wind and current conditions and state of tide. OPTIMOOR can perform a mooring analysis over time, predicting the effects of changes of draft, trim, tide, and tidal current on mooring line tensions. The software can be used to determine mooring arrangement.

3. Ship moments

The efficiency of the berth operations mainly depends on the stability of the ship at the berth. The mooring system designed to withstand the environmental forces and to hold the ships at the berth is responsible for deciding the efficiency of the ship operations at the berth. In view of this the problem is formulated to design the mooring system and fender system of a Very Large Crude Carrier (VLCC) of 300000 DWT. Oil tankers are used to transport crude oil and oil products. Oil products are transported in tankers under 70,000 DWT, while crude oil is transported in high-capacity tankers up to 420,000 DWT. A berth for oil tanker comprises breasting dolphin and mooring dolphin and loading platform. Berths for large tankers are located in deep water and at more exposed locations.

Movements of moored ships can be caused by various external influences such as: winds, currents, waves, tides, passing ships and cargo handling operations. The movements of a moored ship at a berth can be either horizontal (surge, sway and yaw) or vertical (roll, pitch and heave). These ship motions are shown in Fig. 1. Vertical ship motions are independent of mooring system. Horizontal motions are dependent on the loading conditions of ship, the mooring arrangements (i.e. geometry and stiffness of mooring lines and fenders and type of berth). The ship motion affects the efficiency of cargo handling.

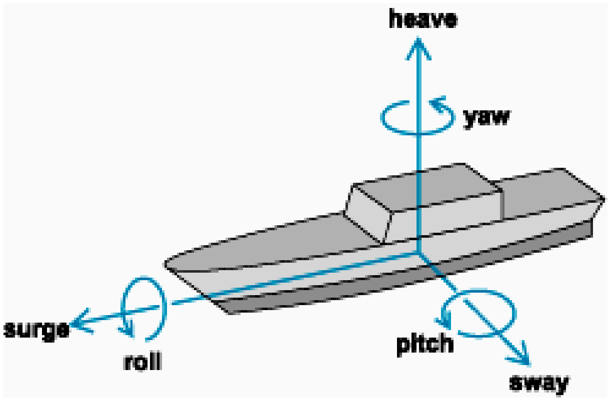


Fig.1 Ship motions

4. Berthing structures

Ships are loaded and unloaded, at port structures like wharfs or quays, piers and jetties, and sometimes alongside moles or breakwaters. The type of berthing structure depends on purpose of the berth, size of ship, type of cargo (i.e. oil, ore, coal, grains, containers etc). It also depends upon the environmental conditions. Quays and Wharfs are solid continuous walls, whereas Relieving Platforms, Jetties and Dolphins are open piled structures. For bulk cargo, open type construction with approach trestle is selected. For large oil Tankers Dolphin or island type berthing terminal is chosen. Bollards are the vertical posts on the wharf or quay to tie the mooring ropes to secure the ship. They are generally manufactured from cast iron. Spheroidal graphite cast iron increases its load capacity.

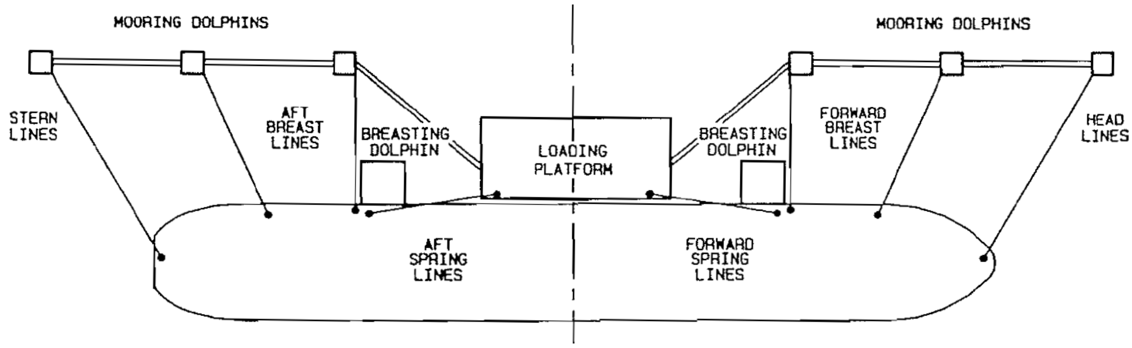


Fig.2 Typical mooring arrangement for oil tankers

5. Mooring arrangement

The ship needs to remain in stable condition at the berth to facilitate loading unloading operations. As such, the ship needs to be tied up with ropes to the berthing structure. This arrangement of ropes is called as mooring. The mooring arrangement for ships at berth; include the following elements (Fig. 2):

- Mooring lines which connect the ship at the berth
- Bollards on shore
- Fenders between the ship and berth

The most important elements with respect to movements of moored ships at berth the mooring lines and fenders, which are considered as the more flexible elements in mooring arrangements.

6. Fenders

Fender is used to absorb the kinetic energy of a boat or vessel while berthing against a jetty, quay wall or other berthing structure. Fenders are useful to prevent damage to boats, vessels and berthing structures. As such, the fenders usually have high energy absorption and low reaction force. Fenders are typically manufactured out of rubber, foam elastomeric or plastic. Rubber fenders are either extruded or made in a mould. The type of fender that is most suitable for an application depends on many variables, including dimensions and displacement of the vessel, maximum allowable stand-off, berthing structure, tidal variations and other berth-specific conditions. The size of the fender unit is based on the berthing energy of the vessel which is related to the berthing velocity.

Fenders are located between the hull of the moored ship and the quay or berth structure. They are important in the berthing as well as the mooring conditions of ships. During berthing conditions, fenders should be capable of absorbing the berthing impact energy. While during mooring conditions, fenders form an integral part of the mooring arrangements and absorb the loads of the ship when in contact with the fenders. Typical Fender systems are shown in Fig. 3. The general types of fenders according to their functioning are Elastomeric fenders, Pneumatic fenders and Foam-filled fenders

Fig.3 Typical Fender Systems

7. Principle of berthing

A ship which is to be berthed is to be brought to its position in front of the berth by tugs and/or by using her engine. It should be stopped at a short distance parallel to the berth. The ship is pushed slowly at the berth by achieving gentle contact while making a small angle with berth.

Since the ship will most frequently come alongside at a slight angle to the berth, it will initially make contact with only one fender. The ship will then rotate round before striking further fenders. Tugs, launches and other small craft will tend to approach their berths more directly than for large ships. Ferries and roll-on/roll-off (Ro-Ro) ships approach their berths in a rather different way. This berthing principles needs to be assumed when designing fendering systems in accordance with PIANC guidelines.

The fender systems should be designed to take into account the acceptable reactive forces and deflections of both the berth structure and the ship's hull, types and hull forms of vessels, the energy to be absorbed by the fender, tidal range and acceptable limits to the distance between berth and side of hull. The design of the fender system has to be integrated with that of the berth structure as not all types of fender are compatible with all types of structure.

7.1 Berthing Energy

The kinetic energy of the moving vessel is

$$E= 0.5* M * v^2$$

Where,

E= kinetic energy of the vessel (in kNm)

M= Mass of the vessel (in tonnes)

v= speed of the approaching vessel perpendicular to the berth (in m/s).

The berthing energy E_d (in kN·m) to be absorbed by the fender system is proportional to the kinetic energy and also depends on the properties of fenders. Each fender should be designed to absorb the berthing energy.

8. Design methodology

Each Fender needs to be designed to withstand the Berthing energy. The manufactures of the fenders provide the tables for selection of fender which takes the particular berthing energy. There are number of manufacturers. M/s. Sibata and Fentek are few of them. Once the fender is selected the spacing of fenders is decided based on the ship size and shape for straight continuous berth. However for Dolphin type berth, the fenders are provided on breasting dolphins.

The data sheets also provide the Reaction Force, Reaction Curve for the fender, the dimensions of the fender etc. Using these Data sheets Fender selection can be selected to withstand the berthing energy.

Mooring lines are required to keep the ship stable at the berth, while loading/unloading operations are in progress. The mooring lines can be categorised in three general groups Viz. Spring lines, Breast lines and Head & stern lines. Sprig lines are used to reduce the surge motion of a moored ship in order to keep ship in a fixed position along with the quay or berth. These lines should be parallel as possible to the ship (maximum 10 degree) and should have sufficient length. Breast lines are used to reduce sway and yaw motion. These lines should be perpendicular to the ship axis to be efficient and should be connected to ship's bollards positioned at the bow and stern. Head and stern lines used in addition to spring and breast lines. Its function is to reduce ship motion.

A wide variety of mooring lines (Ropes) are available. The distinguished categories are:

1. Natural fibre lines
2. Synthetic fibre lines
3. Steel wires
4. Combi-lines (Steel rope with Fibre tail)

The various principles to be considered when designing safe and efficient mooring arrangements for ships are enumerated in the British Standards.

8.1 Mooring analysis software

Mooring arrangement comprises bow and stern breast lines, spring lines, and fenders. With four mooring lines, the analysis involves six unknowns viz. the mooring line forces and the fender reactions. Thus a proper solution of this mooring arrangement is difficult. Real vessel mooring arrangements have many mooring lines. If fender deflection is considered, the solution becomes more complicated.

Computer programs are now available which can perform a complete mooring analysis of even a complex system. One such mooring analysis computer program is the OPTIMOOR program, developed by Tension Technology International. In the OPTIMOOR, the vessel is defined by its dimensions as well as by data on fairlead positions and mooring line size and material. Based on the mooring line information, OPTIMOOR determines the appropriate break strength and non-linear force-extension characteristics. The berth is defined by data on mooring point positions and fender characteristics. The user defines a mooring analysis case by calling up the vessel and the berth files and describing which vessel lines are connected to which mooring points on the berth. Wind and current velocities and directions are then entered. The program calculates the resulting mooring line loads due to the wave, wind and current conditions and state of tide. Wind and current velocities can be increased to check limiting conditions. OPTIMOOR can also perform a mooring analysis over time, predicting the effects of changes of draft, trim, tide, and tidal current on mooring line tensions.

9. Layout of Marine Oil Terminal

The layout and orientation of the berthing terminal depends on shape, size and draft of the ship, type of cargo and environmental conditions. For the fixed berthing facilities for the large oil tankers and liquid gas carriers, a loading platform is to be centrally located, with a pair of breasting dolphins and inner & and outer mooring dolphins arranged on each side. In case the vessel length is smaller than the nominated berth, sub-dolphins should be positioned if necessary.

In the design of Marine Oil Terminal (MOT) for VLCC of 300000 DWT, first we have to decide the type of berthing terminal. For VLCC generally MOT consisting of Mooring Dolphins (MD) and Breasting

Dolphins (BD) is to be considered as suggested in guidelines and Standard Codes. In the present case, a terminal with four breasting dolphins and six mooring dolphins has been considered. The mooring dolphins need to be located at some distance behind the berthing line i.e. fender line so that the longer mooring lines (such as bow, stern and breast lines) can be provided. Also sufficient space is available for the tug movements.

There will be four fenders located on breasting dolphins. A loading platform needs to be provided at the central location. The maximum and minimum sizes of the oil tanker, which are going to use the terminal, are assured as 300000 DWT and 50000DWT respectively. The minimum size of the ship is required to compute the spacing between the dolphins of the terminal, since the terminal is to be utilized for various sizes of the ships. The dimensions of 300000 DWT and 50000 DWT ships are given in Table 2 (Ref. PIANC 2002).

The length of the berth and the spacing between the dolphins was computed as per the guidelines given in British standards. The layout of the MOT for 300000 DWT VLCC was arrived as shown in Figure 4. The orientation of the berthing terminal needs to be decided based on the environmental forces of wind, waves and currents.

9.1 Berth Orientation

The environmental conditions and their effects on ship determine the orientation of berth structure. The berth should be oriented in such a direction so that the resultant force due to wind, waves and currents is the minimum on ship surface when it is in berthed condition. The data regarding environmental conditions at the selected port site indicates that the prevalent wind, wave and current conditions at site are as follows (Table 3):

Table 2 Dimensions of 300000 DWT and 50000 DWT large vessels

DWT	Length overall (m)	Length between perpendiculars (m)	Breadth (m)	Depth (m)	Draft Maximum (m)	Wind area (m^2) for loaded condition	
						Lateral	Front
300000	371	363		33.1	21.2	4600	1280
50000	211	204	32.3	17.6	12.6	1690	548

Table 3 Environmental conditions at the port site

Wave			Wind		Current	
Height	Period	Direction	Speed	Direction	Speed	Direction
(m)	(s)	(degree N)	(knot)	(degree N)	(knot)	(degree N)
1.o	7	90 -180	30	45 - 225	2	0 and 180

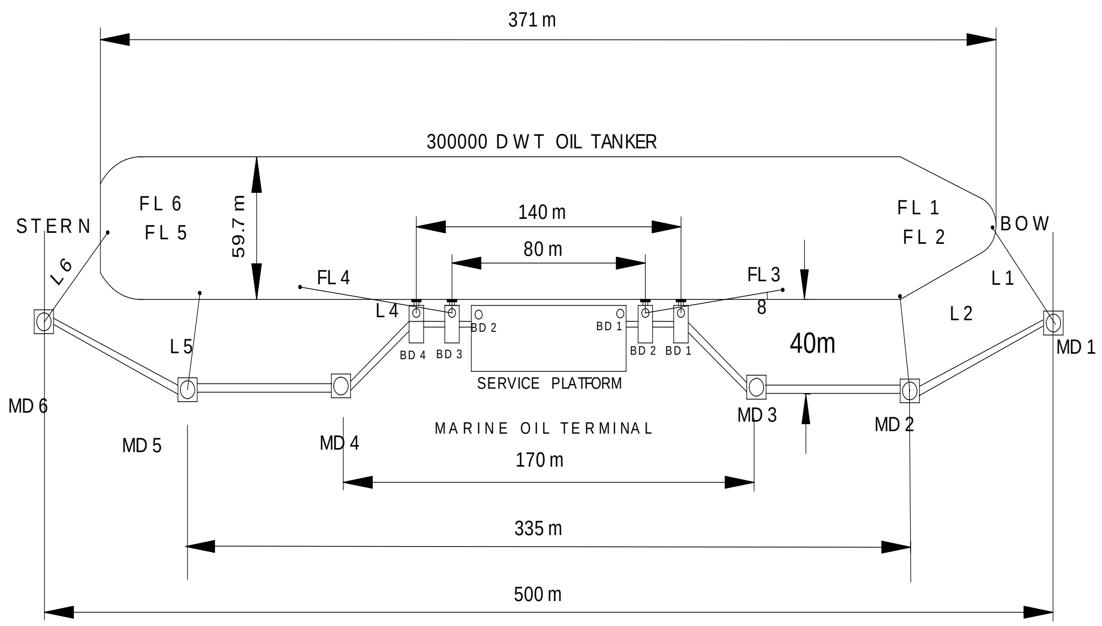


Fig. 4 Conceptual Design of Marine Oil Terminal

The wind, current and wave loads on VLCC were computed along transverse as well as longitudinal directions for three cases of 0°, 45° and 90°. The angles were with respect to longitudinal axis of ship, starting from bow in anti-clock wise direction. The force computations show that the order of magnitude of load due to current is substantially high as compared to the wave and wind loads. The load due to current is the minimum, when the berth orientation is along the direction of the current. The current force is the minimum when the broader side of the ship is parallel to the current. Therefore the marine oil terminal should be oriented along the direction of the current i.e. north-south in the present case as shown in Figure 5. With this orientation of MOT, sometimes the waves may act on beam to the oil tanker resulting maximum wave force on the ship. However this will be taken care by the fender system.

Thus the layout of 500 m long Island / Dolphin type Marine Oil Terminal with four Breasting Dolphins, six Mooring Dolphins and a service platform has been evolved for the 300000 DWT VLCC as shown in Figure 4. Sub-dolphins are provided between the inner breasting dolphins to facilitate small service boats. There fender line can be kept on the inner side so the larger ships do not hit these fenders.

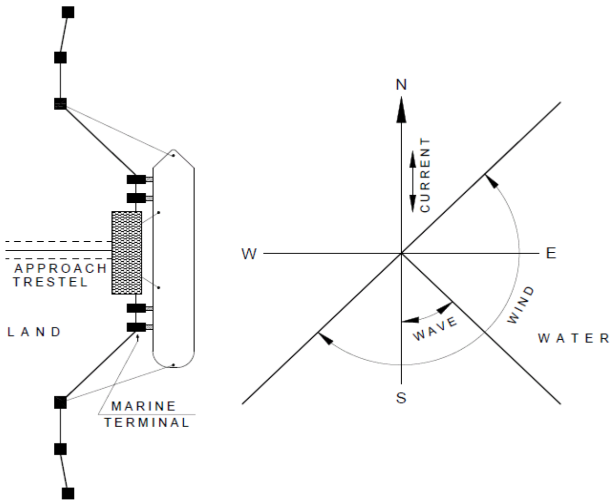
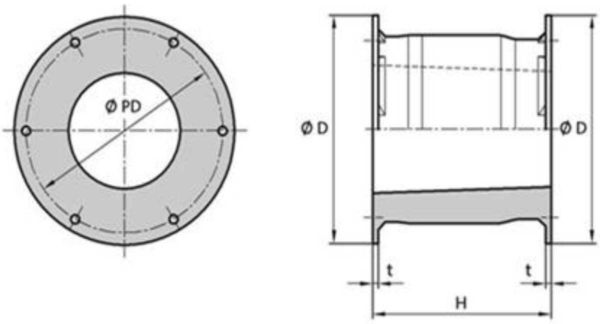


Fig. 5 Wave, wind and current directions and Orientation of Berthing Terminal

The berthing structure and the ship's hull should be able to withstand the reaction force of fender. The dimensions of the selected CSS fender as per Shibata manual are given in Figure 6.

The diameter of the front of the selected fender is 3.35 m. The front panel for this fender unit needs to be designed to distribute the reaction force on the surface of the ship i.e. hull pressure. The position of the fender at the breasting dolphin must be determined to protect and absorb the berthing energy of all types and size of the vessels at all the possible tidal ranges. Fender panels (or 'frames') are used to distribute the reaction forces from the rubber fender units into the ship's hull. They are generally of fabricated steel composite beam construction and are designed to suit each individual berth. The allowable hull pressure for different type of vessels has been given in PIANC guidelines. In the design of fenders oil tanker allowable hull pressure ranges from 150kN/m^2 to 200kN/m^2.

The frontal panel size needs to be decided to distribute the reaction force of 6620 kN. Thus, Surface area of the frontal panel = (Reaction force) / (Allowable hull pressure) is 33 m^2. Therefore a frontal panel of 6 m (height) x 5.5 m (width) is provided.



Fender	H (mm)	ΦD (mm)	t (mm)	ΦPD (mm)	Weight (Kg)
CSS 3000	3000	3350	82	3150	16100

Fig.6 Sibata CSS fender F0 type with 3000H

11. Mooring analysis

The motions of the moored 300000 DWT VLCC at the terminal were simulated using software OPTIMOOR. Numerical experiments were carried out to predict the ship motion, rope tensions and fender compressions for the environmental conditions given in Table 3.

The water level conditions at the port site are as follows:

Mean High Water Level (MHWL) = + 2.60 m
Mean Low Water Level (MLWL) = + 0.71 m

As such the tests were carried out with two conditions:

1. Fully loaded ship at mean low water level
2. Ballast loaded ship at mean high water level

In the ballast loaded condition, the oil tanker is emptied with oil and only the Ballast (often water) is present in the ship for stabilizing it. In the first condition the ship deck level will be at the lowest level, whereas in the second condition ship deck level will be at the highest level with respect to berth level. Thus these two conditions will produce the extreme cases in the mooring lines. The level of the berthing surface (Pier level) is kept as +5.0 m above chart datum, in the analysis.

11.1 Simulation with Fully Loaded Ship at Mean Low Water Level (MLWL)

Six mooring lines are considered to be connected initially at each bollard positioned at A, B, I, J mooring dolphins and E, F breasting dolphins as shown in Figure 7. In this test the direction of 2 knot current is taken along the axis of the ship i.e. from the North direction. Whereas, the 30 knot wind direction is kept as 45° with respect to North and the direction of 1 m height waves is taken as 135° with respect to North. There after the wind direction was varied through 0° to 360° to simulate the extreme environmental force conditions.

The Vessel data contains the dimensions of the oil tanker, positions of the fairleads, mooring lines available on the deck, type and characteristics of mooring ropes etc.

The test was run with six ropes. Since the ship was not stable with six ropes, the number of ropes was increased to eight. Ship motions along the six degrees of freedom were computed as well as the forces in the mooring lines, bollard pull and the fender compression were determined. The number of ropes their type and the respective forces were determined by the OPTIMOOR software. The SF type of ropes (i.e. Steel ropes with Fiber tail) have been selected by the SOFTWARE, which are normally used for oil tankers. The breaking strength of these ropes is 98 tonnes. It was seen that the rope tensions and fender compressions are within the failure limits. The maximum surge, sway, heave and roll are 0.3 m, 0.5 m, 0 m and 0.1° respectively. These motions are also within the limit recommended by PIANC (PIANC, 1995).

11.2 Simulation with Ballast Loaded Ship at Mean High Water Level (MHWL)

Mooring analysis of the oil tanker was then carried out with BALLAST LOADED condition at MHWL. Eight mooring lines are considered to be connected initially at each bollard positioned at A, B, I, J mooring dolphins and E, F breasting dolphins as derived in the first case. In this test the direction of 2 knot current is taken along the axis of the ship i.e. from the south direction. Whereas, the 30 knot wind direction is kept as 45° with respect to North and the direction of 1m height waves is taken as 135° with respect to North. There after the wind direction was varied through 0° to 360° to simulate the extreme environmental force conditions.

Table 4 Moored Ship Motions, Rope Tensions and Fender Compressions

Case	Maximum Ship Motion				Maximum Mooring line Tension		Maximum Fender Compression	Max. Bollard Pull
No.	Surge (m)	Sway (m)	Heave (m)	Roll (Deg)	Load (Ton)	% of BS	(m)	(ton)
1	0.30	0.50	0.0	0.1	22.8	23%	0.03	36.5
2	0.50	0.90	0.0	0.30	31.8	32%	0.05	74.4

BS: Breaking Strength = 98 tonnes

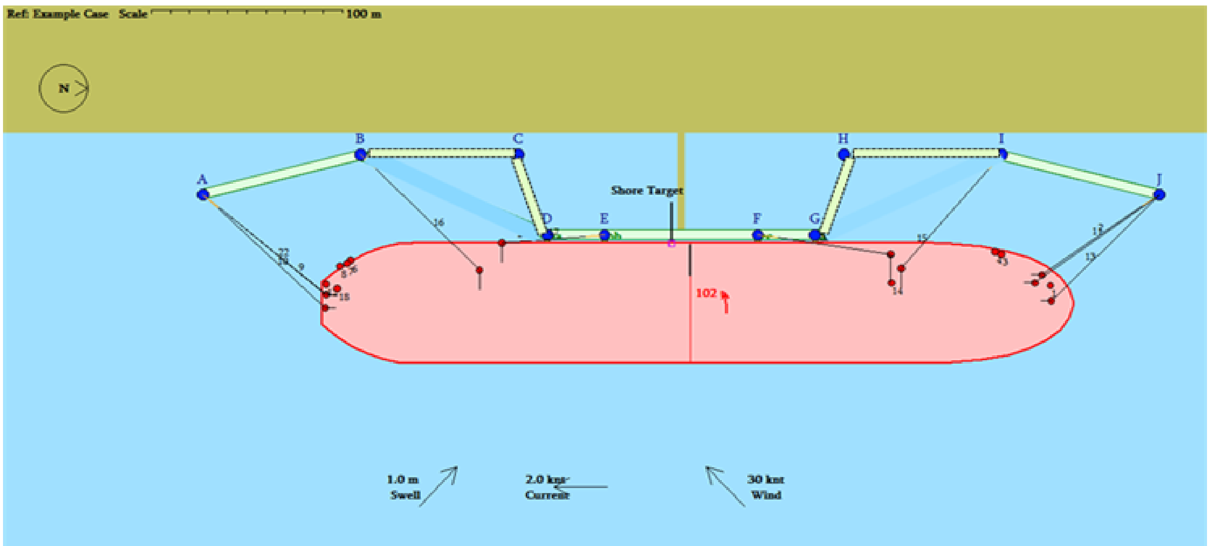


Fig. 7 Mooring configuration for ballast loaded ship at MHWL

The first trial showed that the number of eight ropes selected in the first case is not sufficient for the present environmental condition, since the ship is in empty state and the water level is high. The number of ropes was increased to twelve to make the ship stable. The output of this simulation is shown in Annexure III. The computed ship motions, rope tensions, fender compression and bollard pull are summarised in Table 4. It is seen that the rope tensions and fender compressions are within the failure limits. The maximum surge, sway, heave and roll are 0.5 m, 0.9 m, 0 m and 0.3° respectively. These motions are also within the limit recommended by PIANC (1995).

11.2 Selected mooring arrangement

Thus the mooring rope arrangement with eight ropes connected to six bollards was safe for the condition of Fully Loaded ship at MLWL. However, this arrangement was not safe for the condition of Ballast Loaded ship at MHWL. As such, the arrangement derived for the second case needs to be adopted for the safe mooring of 300000 DWT VLCC. The details of mooring lines for the selected arrangement are shown in Figure 7. The Fender Compression and Bollard pulls are given in Table 4.

The mooring arrangement and different levels for the second condition of the test are shown in Figures 8.

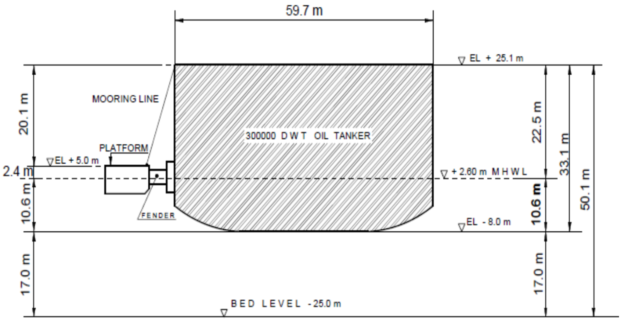


Fig. 8 Fully Loaded VCC at MLWL (+0.71 m)

Conclusions

The studies carried out for the hydraulic design of a marine oil terminal, and mooring system including the mooring configuration and fenders for Very Large Crude Carriers revealed that:

1) The type of ship and the environmental loads on the ships determine the type of berth, its orientation and layout. The dolphin/ island type terminals are suitable for the large oil tankers.
2) The fender design needs to be carried out for the berthing load of the ship rather than the environmental loads while the ship is moored at the berth.
3) The orientation of the marine oil terminal should be such that the ship is subjected to minimum environmental loads. The current forces are dominant in deciding the orientation of the MOT.
4) A dolphin type marine oil terminal with four breasting dolphins and six mooring dolphins has been evolved for a VLCC of 300000 DWT.
5) A Shibata fender, CSS F0 type with 3000H is found suitable for a VLCC of 300000 DWT.
6) The mooring rope arrangement with eight ropes connected to six bollards was found safe for the safe mooring of 300000 DWT VLCC.
7) The methodology evolved in the studies would be useful for preliminary design of marine oil terminal, its orientation and mooring arrangements for very large oil tankers (i.e. VLCC & ULCC) which are likely to be used in Indian ports.

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