METHODOLOGY TO ANALYZE THE MOORED SHIP BEHAVIOUR DUE TO PASSING SHIPS EFFECTS

by

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ABSTRACT

This paper describes the studies carried out and the methodology developed to analyze the feasibility of a new solid bulk terminal from an operational point of view. The aim of the study is to analyze the effects of passing ships, selected from traffic data in the area, on moored vessels at the new terminal.

The study starts with the determination of the expected passing speed and passing distance to moored vessels in the new terminal of those vessels operating in the nearby berths for different wind conditions (direction and speed) using a fast-time ship manoeuvring software. The results (speed and distance) are used as input data to determine the suction forces and moments generated by the passing vessel on the moored vessels.

The dynamic response of the moored vessels under different weather conditions together with lines and fender forces generated by the passing vessels are also simulated by using specific software. In view of all the previous results, different alternatives are proposed in order to improve the conditions obtained in the analysis and raise the operation limits. The final phase of the study includes real-time manoeuvring simulations in order to verify the results obtained along the process in a realistic working environment.

A complete set of simulation tools is applied sequentially in order to develop a global and precise analysis and elaborate a clear picture of the safety level of the operations. Fast-time manoeuvring simulation (SHIPMA), passing ship effects (ROPES), dynamic response of moored vessels (SHIP-MOORINGS) and Real-time shiphandling simulator. AIS data (Automatic Identification System) covering the vicinity of the new terminal were also considered and analyzed to define manoeuvring strategies executed by the current vessels in the area. The methodology is explained and developed based on a real case in the Port of Barcelona (Spain).

Because of the increase in traffic and the presence of larger ships in port areas, interference between sailing and moored ships is becoming more and more, causing situations where the loading/unloading processes are hindered and safety might become threatened. It is necessary to deal with these scenarios using complete and accurate information in order to ensure safety and efficiency in port operations.

1. INTRODUCTION

A new solid bulk terminal is planned to operate in the Port of Barcelona (Spain). Before it starts operating, the Port is interested in the analysis of the operation of different reference vessels using the facilities under the effects of passing ships expected to operate in the nearby berths.

The new facility is located in a narrow area (210 m width approx.) which gives access to one of the inner areas of the Port. Moored vessels at the new terminal might be affected by the passing ship effect. The design vessels to operate in the terminal are two bulk carriers 186 m and 230 m Loa respectively. These ships will be moored at the berth simultaneously and might be affected by hydrodynamic interaction forces.

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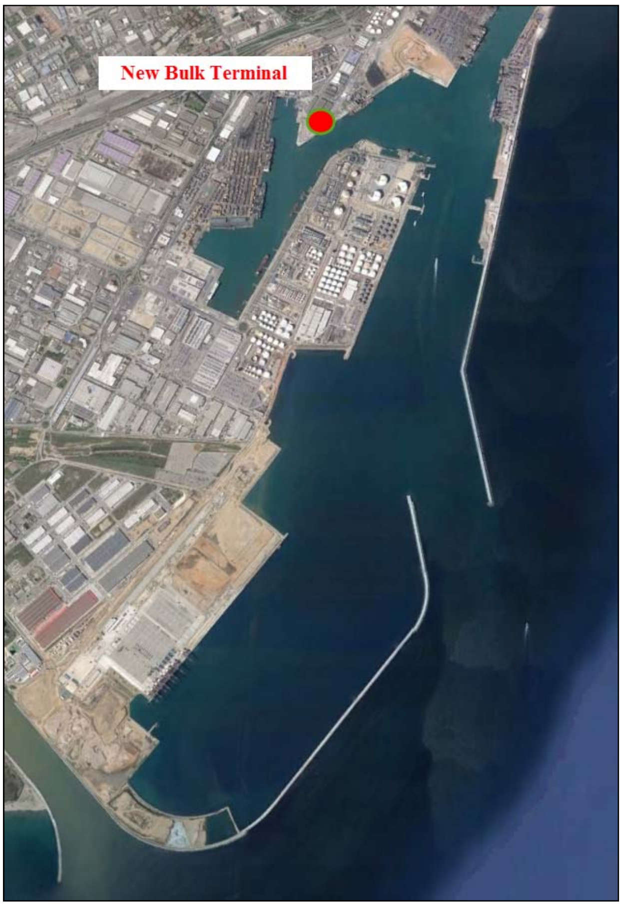


Figure 1: Location of the new bulk terminal in the Port of Barcelona

The passing ships considered in the study have been selected using the traffic data in the different areas of the port and have the maximum size of those expected to operate in the nearby terminals. A car carrier 265 m Loa and a tanker 200 m Loa have been selected among the passing vessels.

Tanker 200 m LOA	
Length over all	200.0 m
Length between perpendiculars	192.9 m
Beam	32.2 m
Draft fully laden	11.5 m
Draft ballast	8.8 m
Displacement fully laden	60 410 t
Displacement ballast	44 100 t

Table 1: Passing vessel. Tanker 200 m

Car carrier 265 m LOA	
Length over all	265.0 m
Length between perpendiculars	216.6 m
Beam	32.2 m
Draft fully laden	10.5 m
Dead weight	43 878 t

Table 2: Passing vessel. Car carrier 265m

Bulk carrier 230 m LOA	
Length over all	230.0 m
Length between perpendiculars	222.0 m
Beam	32.2 m
Draft fully laden	13.5 m
Draft ballast	7.0 m
Displacement fully laden	71 910 t
Displacement ballast	43 470 t

Table 3: Moored vessel. Bulk carrier 230 m

Bulk carrier 186 m LOA	
Length over all	186.0 m
Length between perpendiculars	181.3 m
Beam	28.7 m
Draft fully laden	10.5 m
Draft ballast	7.9 m
Displacement fully laden	36 450 t
Displacement ballast	30 000 t

Table 4: Moored vessel. Bulk carrier 186 m

2. AIS DATA ANALYSIS

AIS data (Automatic Identification System) covering the vicinity of the new terminal have been considered to define manoeuvring strategies executed by the current vessels in the area.

The available AIS data include one year of recorded data and a total number of 740 vessels. They mainly focus in bulk carrier and tanker vessels that have navigated in the vicinity of the new terminal. They cover 1330 operations. For the aims of the study the following information is extracted:

- Track of the vessels. Different positions of each vessel during the manoeuvre.

- Passing distance. This value is between one ship beam (B=32) and 2 beams (2B=64 m), taking a Panamax vessel as a reference.

- Sailing speed. Reference speed for access manoeuvres is 4-5 knots and for departures 5-6 knots. Speed does not depend on the length of the vessel.

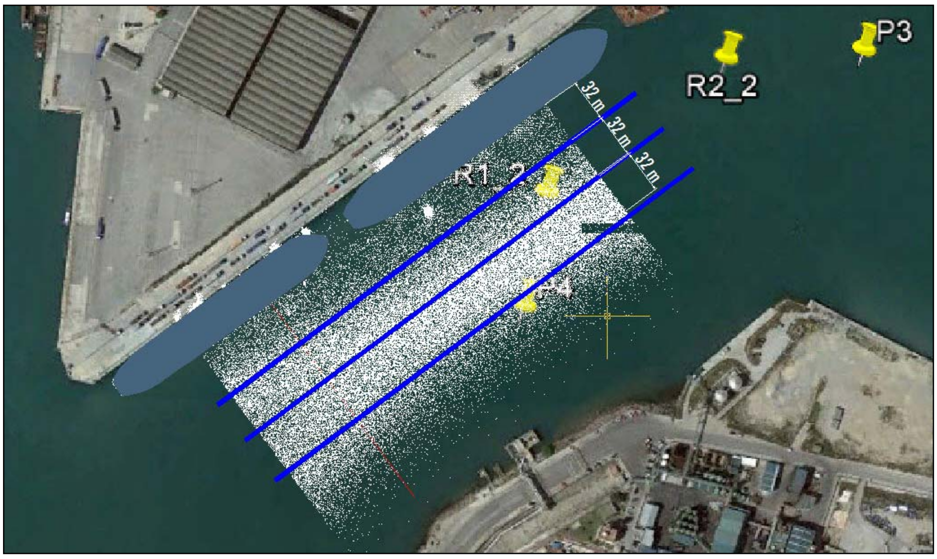


Figure 2: AIS data considered for analysis

3. MANOEUVRES WITH FAST-TIME SIMULATION PROGRAM (SHIPMA)

In order to meet the objectives of the study, the first step is to know the **minimum speed** of each selected vessel to maintain control during the whole manoeuvre as well as the **minimum passing distance to moored vessels**. This phase of the study is developed using a **fast-time simulation** program **SHIPMA**.

This tool simulates the manoeuvring behaviour of a ship. The mathematical model computes the track and course angle of a vessel, taking into account the influences of external forces (wind, waves, currents, shallow water, and bank suction).

The manoeuvres are developed under the local conditions in the Port, which include 3 different wind directions and 3 wind speeds (10, 15 and 20 kts). The strategy for the manoeuvres developed with SHIPMA is defined using the AIS data available, in terms of vessels track, distances, courses, ... The main factor affecting the vessels during manoeuvres in the port is wind. Therefore, different wind directions and intensities are considered for evaluation. The analysis of the manoeuvres includes the occupation of the nearby berths by two bulk carriers 230 m and 186 m Loa respectively. Fully laden condition is considered for both passing ships: tanker 200 m Loa and car carrier 265 m Loa.

Simulation runs are developed in order to define the minimum speed to maintain the vessel controlled using the ship's manoeuvring means. It should be noted the large change of course required for the vessels to access the inner harbour. For the analysis and evaluation of results a maximum course deviation of 5º and 15 m deviation from the reference path are considered valid. Next figure shows one of the approach manoeuvres of the tanker using fast-time simulation (SHIPMA).

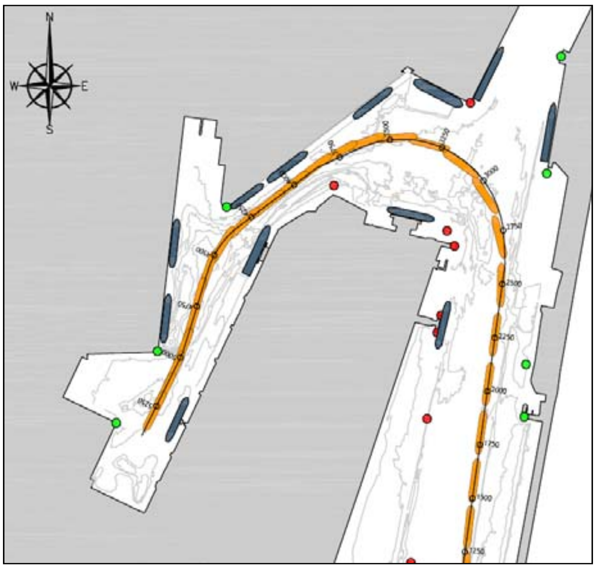


Figure 3: Fast-time simulation (SHIPMA). Access manoeuvre of a tanker 200 m Loa

The results are very similar to those obtained from AIS data. For departure manoeuvres the AIS values are 2 knots above the speed obtained with SHIPMA. One conclusion is that the minimum speed to be controlled highly depends on the intensity and direction of the wind. For strong cross wind, the vessels need to sail with higher speed to keep under control. The following figures show the results:

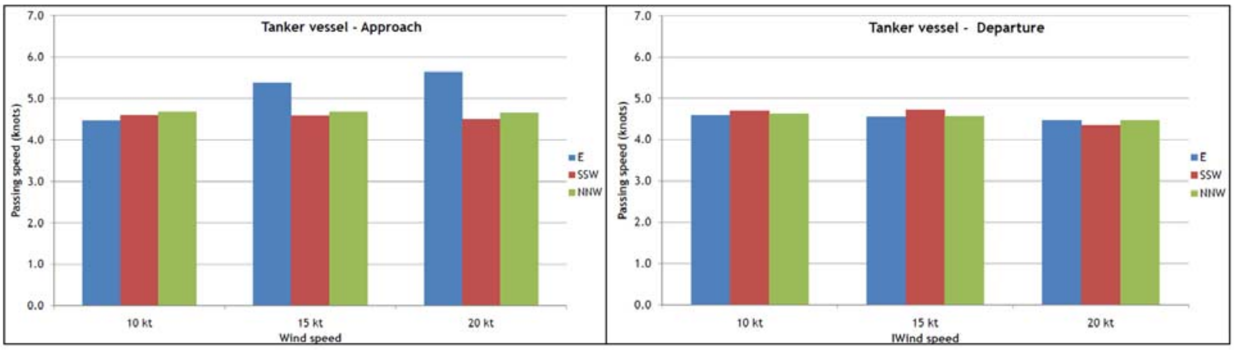


Figure 4: Passing speed - Wind (direction and intensity). Tanker 200 m Loa

4. SHIP TO SHIP INTERACTION FORCES. PASSING SHIP EFFECTS

The traffic in the area, vessels sailing in front of the new terminal, generates passing ship forces on the moored ships. This phenomenon is produced through hydrodynamic interaction between both hulls and induces dynamic loads in lines and fenders. A suction force is generated between vessels caused by the speed and the pressure field variation. This flow variation also depends on the load condition, channel depth and channel cross section.

The interaction effects between a moored ship and one or more passing ships can be computed by means of methods based on 3-D potential theory. The flow is assumed to be inviscid and incompressible and the passing ships are travelling at low speed. In such cases the so-called “double-body solution” can be applied. The solution assumes that the free-surface effects are negligible. This has been shown to be applicable in many cases of large vessels travelling slowly. When the fairway geometry has discontinuities (i.e., docks and harbours openings onto the fairway) the disturbances caused by passing ships can set up seiche-like fluid motions in the basin which can produce important loads on ships moored.

PMH BV (Pinkster Marine Hydrodynamics BV, The Netherlands), Svašek Hydraulics, MARIN and Deltares coordinated the JIP (Joint Industry Project) ROPES which resulted in a numerical model tool. This program allows the user to obtain the calculation of the ship to ship interaction forces and moments on shallow waters, considering the effects of bathymetry changes and lateral restrictions (navigation channels, vertical structures, slopes, ...). The system calculates the forces and moments on the vessels in all 6 degrees of freedom (surge, sway, heave, roll, pitch and yaw) and on the structures in time-domain. The tool considers the influence of the mooring terminal geometry in the water movements induced by the “Passing Ship” effect of vessels, and also the hull forms of each vessel.

The output of the computations are time-domain records of the 3 forces and 3 moments acting on the vessels, as well as other structures (slopes, vertical quays, …). Results are given in table and graphic format.

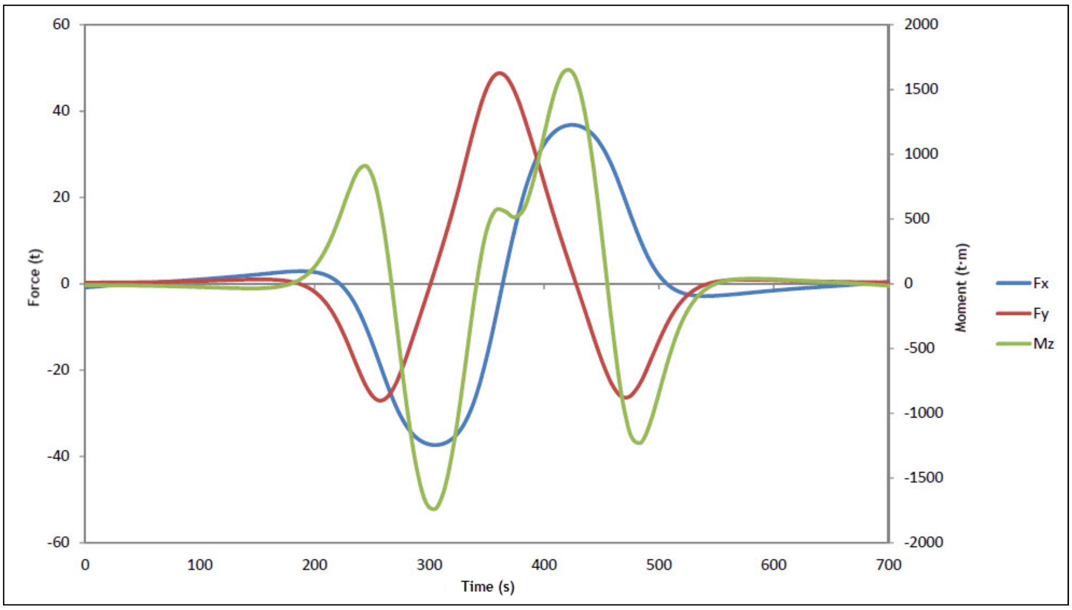


Figure 5: Time series of interaction forces obtained from ROPES

The following factors define the interaction forces and are taken into account in the numerical model: hydrodynamic characteristics of the vessels, speed of the passing ship, course with respect to the centreline of the moored vessels, depth of the channel, distance between vessels and cross-section of the channel (vertical walls, side-slopes, etc.).

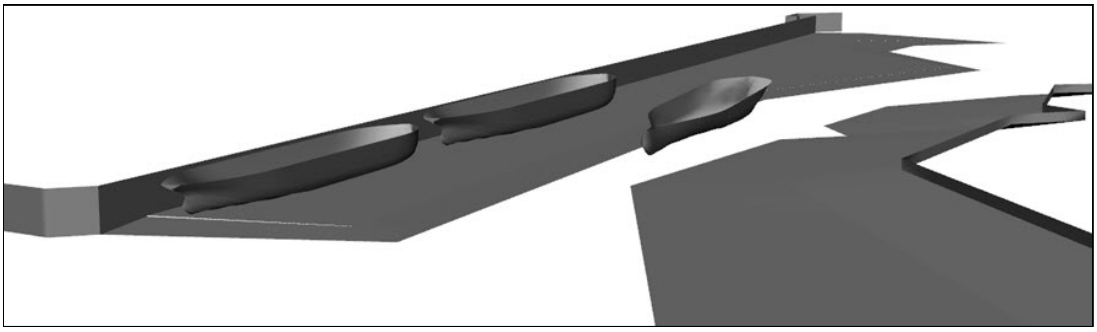


Figure 6: 3D model of the channel with moored and passing vessels

For this phase, different cases (24) are analyzed considering, among others, two moored vessels berthed simultaneously (Panamax bulk carrier 230 m Loa and bulk carrier 186 m Loa), two passing vessels (car carrier 265 m Loa and tanker 200 m Loa) as well as different passing speeds and 2 passing distances (32 m and 48 m, equivalent to 1.0 and 1.5 Panamax beam). The matrix of cases includes both access and departure manoeuvres.

Different suction forces and moments on the moored ships are obtained for each case. The time series of suction forces and moments on the moored vessel clearly depicts a very characteristic situation that varies with the sailing distance of the passing vessel. The following graphs show the variation of interaction forces on moored vessels (surge and sway direction) for access and departure manoeuvres of the car carrier and the tanker according to different passing speeds and passing distances. Blue line is for the moored bulk carrier 230 m Loa and the red one is for the smaller bulk carrier 186 m Loa.

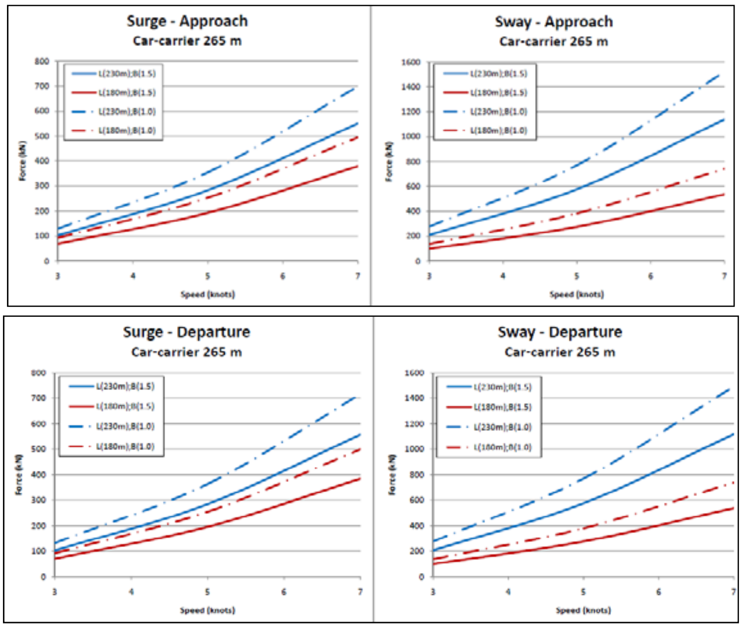


Figure 7: Forces on the moored vessels produced by the passing car carrier

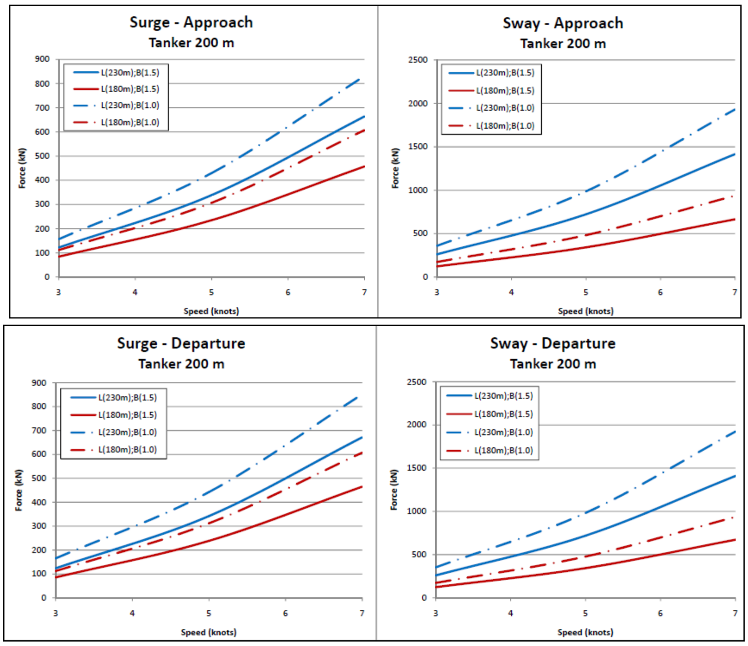


Figure 8: Forces on the moored vessels produced by the passing tanker

The following conclusions can be can be drawn from the analysis:

- The tanker generates suction forces and moments on moored vessel higher than those generated by the car carrier for the same speed and passing distance. These differences are up to 20-30% for suction forces and 20-40% for moments. This is due to the higher displacement, draught and block coefficient.

- Loads on the Panamax bulk carrier 230 m Loa are higher than those on the smaller bulk carrier 186 m Loa. This result does not depend on the passing vessel.

- Forces and moments on moored vessel have a quadratic dependence with the speed of the passing vessel and are inversely proportional to the passing distance.

5. DYNAMIC MOORING ANALYSIS

ROPES results are used as input data to calculate the dynamic response of the moored vessels. The response of the moored vessel is simulated by using the numerical model **SHIP-MOORINGS** developed by Alkyon-Arcadis (Hydraulic Consultancy & Research, Netherlands). This model reproduces the behaviour of a specific ship at berth under the combined action of wind, waves, currents and external forces (such as passing effects). The system solves the equations of ship motion in 6 degrees of freedom (surge, sway, yaw, heave, pitch, roll) in the time domain, without limitations on the motion amplitudes. The simulation results have assessed the motion amplitudes of the ship and the loads transmitted to the fenders and the mooring lines under the combined action of environmental factors typical for the location (wind).

Using the time series of forces and moments obtained from **ROPES** as input for **SHIP-MOORINGS** model, the **movements of the moored ships** and the resulting **loads** on **mooring lines** and **fenders** are calculated. It is then possible to determine the relevant forces and displacements. The calculation includes the interaction between the two vessels combined with wind from the most adverse direction.

The mooring arrangements for the two moored vessels consider their dimensions and the mooring equipment on board as well as the mooring facilities on the berth. The vessels are berthed port side alongside in a bow out position. The initial mooring arrangement comprises 10 lines: 0 head lines (forward) + 3 breast lines (forward) + 2 springs (forward) + 2 springs (aft) + 3 breast lines (aft) + 0 stern lines (aft).

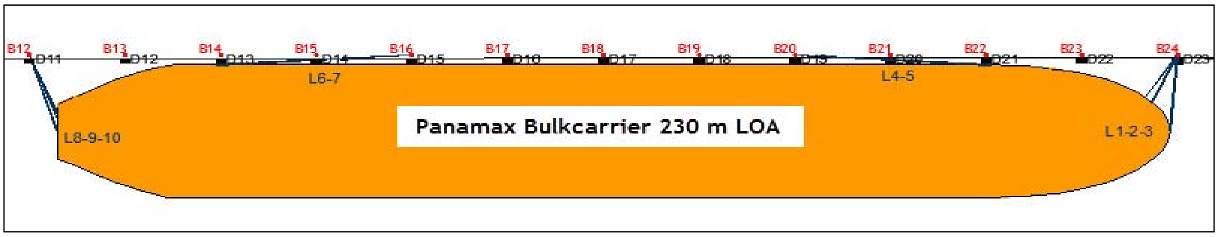


Figure 9: Mooring layout. Bulkcarrier 230 m Loa

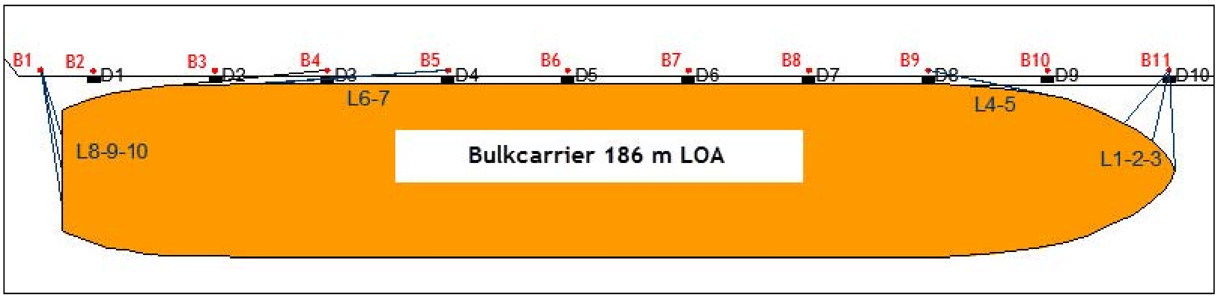


Figure 10: Mooring layout. Bulkcarrier 186 m Loa

The dynamic analysis, response of the moored vessel and line and fender forces, is focused on the bulk carrier 230 m Loa as it showed higher loads than the smaller bulk carrier. A sensitivity analysis regarding wind intensity was done, showing that the effect of the wind on the moored vessel is much less significant than the passing ship effect.

The analysis is focused on defining the operating limits in terms of maximum speed and passing distance for which the mooring system does not exceed acceptable values. The reference wind speed for the analysis is 20 knots with the vessel in loaded condition under the interaction of passing ships for a reference passing distance of 32 m.

Some conclusions of the analysis are as follows:

- The maximum load on lines and fenders does not exceed the defined limits (safe working loads).

- The speed limit for the passing vessels depends on the dimensions of the passing vessel, the loading condition of passing and moored vessels, and the mooring arrangement.

- Conservative values are obtained, as the analysis considers a passing distance of only one beam (32 m), the most adverse wind direction and maximum occupation of the nearby berths.

- The maximum recommended passing speed is above the reasonable speed obtained with the fast-time simulation program.

- From this evaluation different alternatives are proposed in order to obtain less restrictive limits such as: modified manoeuvring strategy, reinforcement of the mooring arrangement and analysis of the dimensions of the passing vessels.

6. ANALYSIS OF ALTERNATIVES

In order to increase the limits of passing speed and passing distance while keeping safety and operability in the terminal, the following alternatives are proposed for analysis:

- **Limit the passing speed in front of the new terminal to maximum values obtained from the dynamic analysis of moored vessels**

For the evaluation of this alternative, fast-time simulation manoeuvres are considered (approach and departures) including the assistance of two tugs with special propulsion and a bollard pull of 75 t. These tugs are similar to those available at the Port. The main conclusions from the evaluation are:

- The use of tugs allows to reduce speed in front of the new terminal under strong cross wind and limits the passing ship effects, as they can keep control the vessel even with engine stopped.

- These results should be verified using advanced analysis tools such as the real-time simulator. This tool allows to assess the possibility of reducing speed under the limit in detail, including the human factor.

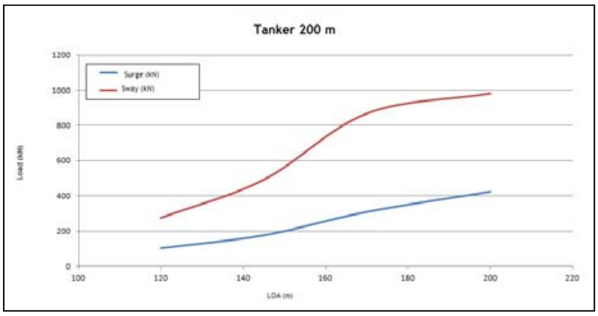
- **Different mooring arrangements**

After the analysis of the dynamic behaviour, different mooring arrangements are considered: 2 for the bulk carrier 230 m Loa and 1 for the bulk carrier 186 m Loa. For the larger bulk carrier, the first alternative comprises 12 lines (0-4-2-2-4-0) and the second one includes 14 lines (0-5-2-2-5-0). For the smaller bulk carrier, the new mooring configuration comprises 12 lines (0-3-3-3-3-0).

The main conclusion is that the maximum passing speed for the sailing vessel could be increased (above 0.8 knots) as long as the mooring arrangement for the bulk carrier 230 m Loa has 14 lines and 12 lines for the bulk carrier 186 m Loa respectively.

- **Assess the operating limits for a different loading condition, passing distance and size of the passing vessel**

A sensitivity analysis of the response of the moored vessels is developed for different Loa of the passing vessels, different drafts of the tanker vessel (passing ship) and different passing speeds. The results are shown in the following figures:



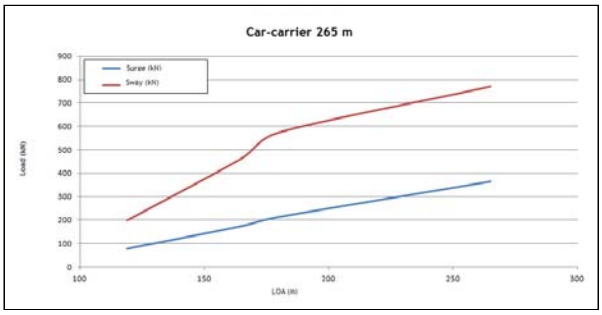


Figure 11: Loads on moored vessels for different Loa of the passing vessel

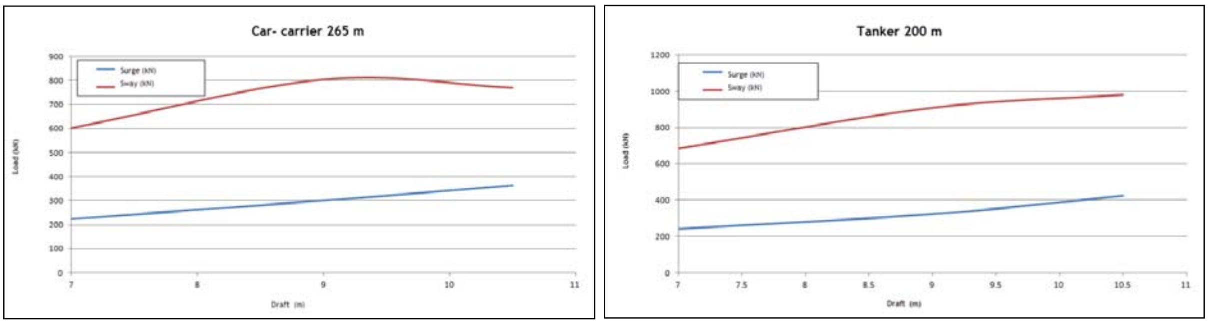


Figure 12: Loads on moored vessels for different draught values of the passing vessel

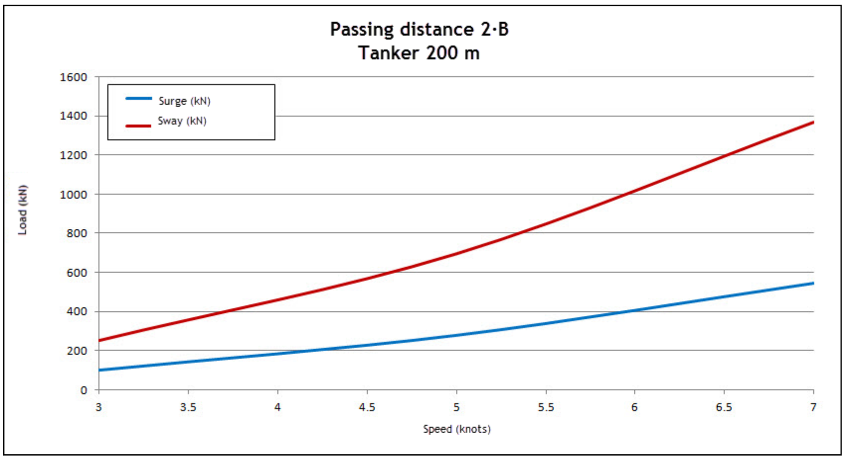


Figure 13: Loads on moored vessels for a passing distance of 2B (64 m) and different passing speeds

From the previous figures it is observed that the interaction forces on the moored vessels decrease significantly when the draught is below 7.0 m and the length below 160 m.

7. REAL-TIME SIMULATOR ANALYSIS

The objective of this final phase of the study is to verify the results and conclusions obtained using the fast-time manoeuvring model (SHIPMA). For this purpose, a real-time ship bridge simulator is used as it is an advanced tool adequate for this type of detailed analysis.

Siport21 real-time ship bridge simulator (MERMAID 500 model developed by MARIN-MSCN (The Netherlands)) reproduces the behaviour of a specific ship while manoeuvring in port areas under the effects of environmental agents (wind, current, waves, limited depth, bank suction, etc.). A Captain or Pilot operates in a main bridge mock-up with real instruments and a radar screen, so human factor is included. The motions of the ship are seen on a 260º wide screen 12 m diameter and sounds (engine, wind, horns) are also perceived.

The ship manoeuvring mathematical model handles 6 degrees of freedom models, with horizontal and vertical motions, and reproduces the ship's behaviour under the action of the following forces: hydrodynamic forces on the hull, propulsion, rudder forces, bow/stern thruster forces, variable depth, wave, wind and current forces, bank suction effects, “squat”, collision forces and hull interaction between ships. Tug operation in the simulator is very detailed, and either conventional or special units are properly modelled.

Figure 14: Siport21 real-time simulator in operation

A total number of 11 manoeuvres were carried out including approach and departure manoeuvres with a tanker 200 m Loa and a car carrier 265 m Loa. These manoeuvres were developed under the most frequent conditions in the port and 2 wind speeds (10 and 15 knots - mean value). The scenarios included the occupation of the nearby berths to restrict the space available for manoeuvres. Some manoeuvres included the use of two tugs of 75 t bollard pull. The objective was to verify that the speed and passing distance were below the limits defined in previous phases.

Figure 15: Real-time simulator manoeuvres: approach manoeuvre of the car carrier and departure manoeuvre of the tanker

From the manoeuvres executed in the real-time simulator the following conclusions were drawn:

- For the tanker 200 m Loa, the passing speed in approach manoeuvres could be reduced below the limits defined in previous phases for 15 knots winds with the assistance of 2 tugs. It is also possible to obtain passing speeds below the limit without tug assistance up to 10 knots wind speed. Results show passing distance to moored vessels increases compared with previous results using SHIPMA.

- In departure manoeuvres of the tanker using 2 tugs, passing speed could also be reduced below the limits and the passing distance increased up to 1.6·B.

- For the car carrier 265 m Loa in approach manoeuvres, the tugs control the vessel with passing speed below the limits for 15 knots wind speed and distance to moored vessels even more than 60 m (2·B). Without tug assistance, passing speed increases above the limits and passing distance decreases down to 1.0-1.6 ·B. The passing speed for departure manoeuvres of this vessel could be reduced below the limits defined. Under this condition the passing distance is 1.6·B, above the results obtained in the fast-time manoeuvres.

- The tugs maintain the vessel controlled when a low passing speed is required which guarantees the safety for the moored vessels at the terminal.

8. CONCLUSIONS

This paper presents the methodology developed to analyze the moored ships behaviour due to passing ship effects with the aim to guarantee a safe operation of moored vessels in a new bulk terminal located in a narrow area of the Port of Barcelona. The analysis combined calculations with four different numerical models: fast-time simulation (SHIPMA), ship-ship interaction (ROPES), dynamic mooring analysis (SHIP MOORINGS) and real-time manoeuvring simulator (MARIN Mermaid).

After a first analysis of AIS data available to know the type of vessels in the area and their manoeuvring strategy (track, course, passing distance and passing speed) a fast-time simulation analysis was developed with the selected design vessels to obtain the minimum passing speed and passing distances. These results (passing distance and passing speed) were used as input data for calculation of ship to ship interaction: effect of passing vessel on the moored vessels in the new terminal using ROPES. Interaction forces and moments on the moored vessels obtained with ROPES were included as an input in the dynamic mooring analysis to define the operational limits using the mooring analysis program SHIP MOORINGS.

A sensitivity analysis was also developed to assess different alternatives which allow a safe operation of the moored vessels in the berth. The final phase of the study consisted of manoeuvres in a real-time simulator with the aim to conduct a detailed analysis of manoeuvres including the human factor in order to verify the previous results obtained during the analysis.

9. ACKNOWLEDGEMENTS

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