Vessel Interaction – A Case Study

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Abstract

The growth in vessel sizes is placing ports under increasing pressure to safely and efficiently meet the demand. One major issue river ports in particular are facing is the unacceptable motions of a moored vessel generated by large passing vessels. This is causing both safety issues, where resulting breakage of lines can cause significant injury or death, and efficiency issues, where berths are required to stop loading while a vessel passes.

Decisions made by port operators on what measures to take for passing vessel scenarios are typically ad hoc and based only on experience. This generic approach may fail to address important safety and efficiency issues.

OMC has developed a scientifically-based model for determining optimum vessel passing speeds and distances given the prevailing environmental conditions, tidal levels and characteristics of both the moored and passing vessels. The model has been validated against full scale measurements, with excellent correlation between measured data and model outputs.

The model provides port operators with a tool for developing repeatable and auditable procedures for determining safe passing conditions with optimum efficiency.

A case study is presented which involves validation and design simulations of the OMC vessel interaction model at Port Hedland, Western Australia.

1 Introduction

Port Hedland is located at the mouth of an estuary in the Pilbara region of North Western Australia. Port Hedland Port Authority (PHPA) is the statutory authority with the primary purpose of facilitating trade through the port.

The main trade commodity of the port is iron ore with BHP Billiton exporting over 100 million tonnes annually in Cape size vessels making it Australia's largest port with respect to throughput.

Due to significant present and future escalating global demand for iron ore from China, the growth in iron ore exports from Port Hedland is predicted to triple over the next 10 years. Development plans for the port include construction of a number of additional iron ore berths throughout the estuary.

The layout of Port Hedland is shown in Figure 1. The iron ore berths are located at BHP Billiton's Berths "C" & "D" at Finucane Island near the western entrance of the estuary and berths "A" and "B" at Nelson Point, the most inland berths on the eastern side of the estuary.

Additional berths at Port Hedland include two Panamax berths, Berths "3" and "1" located seaward of Berths "A" and "B". Cape vessels departing Berths "A" and "B" pass within proximity of Berths "3" and "1" and can, at times, cause mooring interaction issues, including the occasional instance of parting of lines for the Panamax vessels. Similar issues can also occur for Cape vessels berthed at Finucane Island.

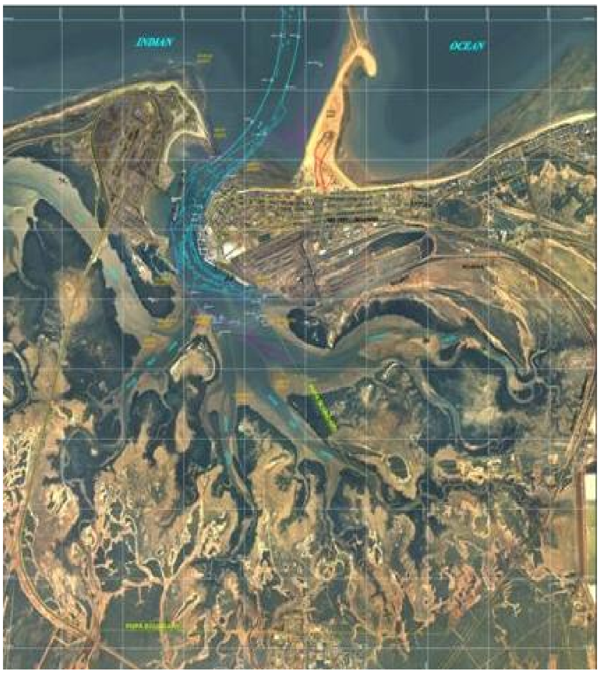

Figure 1: Port Hedland Port Layout (source: Cardo Lawson & Treloar)

The Port Authority has procedures in place to reduce the likelihood and impacts of mooring interaction incidents, including imposing speed restrictions and, at times, stopping loading at these berths during such passing events.

A passing event of a laden Cape vessel past a berthed Cape vessel is shown in Figure 2.

Figure 2: Passing Event at Port Hedland

The interaction problem will be exacerbated as the need to increase the number of deep draft vessels transiting the port grows with the port expansion.

In 2006, PHPA commissioned OMC to undertake a ship interaction study. The primary objective was for PHPA to use the findings of the study to refine the Port User guidelines and operating procedures to address particular identified risk situations, both for the present and throughout the expansion phases.

The major objectives of the interaction study were to determine:

- safe transit speeds for a range of ship movements past specified berths;
- whether loading at particular berths should stop for particular movements;
- mooring line loads resulting from vessel interaction;
- whether existing mooring arrangements are adequate to minimise line breakages.

2 Passing Vessel/Moored Vessel Interaction Theory

The problem of determining vessel interaction forces is a complex one. However, a reasonable approximation may be found by introducing simplifications. Solutions for vessels travelling on parallel paths were provided by Wang (1975) and Tuck and Newman (1974).

Both solutions make use of potential flow techniques and hence imply an ideal fluid. The problem can be further simplified by assuming the passing vessel travels at low speeds, in which case free surface effects may be neglected. This allows the method of reflection to be used with the water surface as a plane of symmetry.

A schematic overview of the adopted coordinate system is shown in Figure 3.

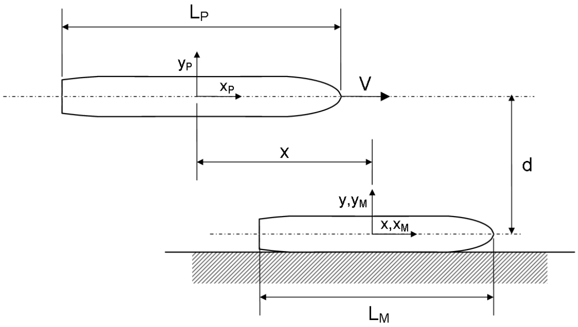

Figure 3: Passing Vessel Coordinate System

As per Wang (1975), the velocity potential Φ_P of the passing vessel in water of infinite depth may approximated by modelling a distribution of doublets with strength μ_p in a uniform flow with a velocity of –V. It is convenient to write the velocity potential relative to the ship-bound coordinate system of the moored vessel. In doing so, Φ_P can be written as a function of the passing vessel speed (V), separation distance (d) and stagger distance (X). See Eq. 1. The doublet strength μ_p is a function of the sectional area distribution S_P of the passing vessel.

$$\begin{aligned} &\Phi_P(x,y,z) = \\ &-V \int_{L_P} \frac{\mu(x_p) \cdot (x - x_p - X)}{\left((x - x_p - X)^2 + (y-d)^2 + z^2\right)^{3/2}} dx_p \\ &\mu_p = \frac{S_P(x_p) \cdot V}{2\pi} \end{aligned} \qquad \text{(Eq.1)}$$

The velocity potential generated by the passing vessel needs to be balanced by an interaction potential at the moored vessel to satisfy its boundary condition (Eq. 2).

$$\frac{\partial \Phi}{\partial \vec{n}_m} = 0 \qquad \text{(Eq. 2)}$$

The flows as a result of the interaction potential are of opposite and equal strength to the velocities induced by the passing vessel on the body axis of the moored vessel (Eq. 3)

$$\begin{aligned} u(x_m) &= -\frac{\partial \Phi_P}{\partial x}(x_m, 0, 0) \\ v(x_m) &= -\frac{\partial \Phi_P}{\partial y}(x_m, 0, 0) \end{aligned} \qquad \text{(Eq. 3)}$$

The interaction potential may now be found by placing the moored vessel hull, which again may be approximated by a distribution of doublets, in a uniform flow of $u(x_m)$ in longitudinal direction and

$v(x_m)$ in cross direction. Once the interaction potential has been determined, the unsteady Bernoulli equation (Eq. 4) can used to determine the pressure distribution on the moored vessel hull.

$$\frac{\partial \Phi}{\partial t} + \frac{V^2}{2} + \frac{p}{\rho} + gz = C(t) \qquad \text{(Eq. 4)}$$

The surge, sway and yaw forces may be found by integrating the pressure distribution over the length of the moored vessel hull.

Corrections for finite depth effects and current velocities have been applied to the derived results.

Figure 4 shows typical dimensionless surge and sway forces and Figure 5 shows typical yawing moments. The dimensionless forces and moments are shown as a function of the stagger distance X (the relative position of the passing to the moored vessel).
Positive surge and sway forces correspond to moored vessel displacements in positive X and Y direction respectively. Similarly a positive yaw moment corresponds to a rotation of the bow of the moored vessel to portside. See also Figure 3 for an overview of the adopted coordinate system.

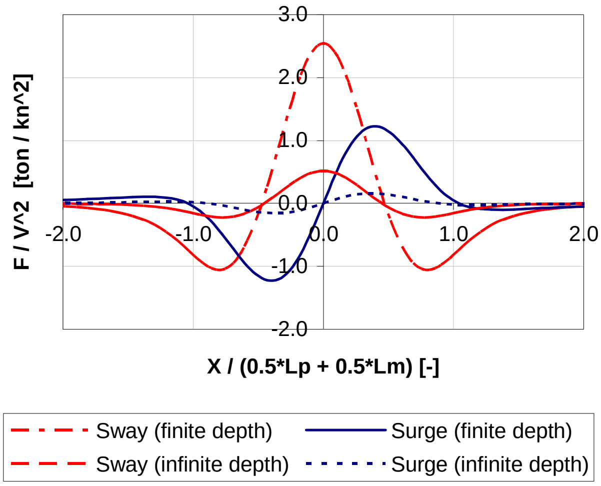

Figure 4 Typical Surge and Sway Interaction Forces on Moored Vessel

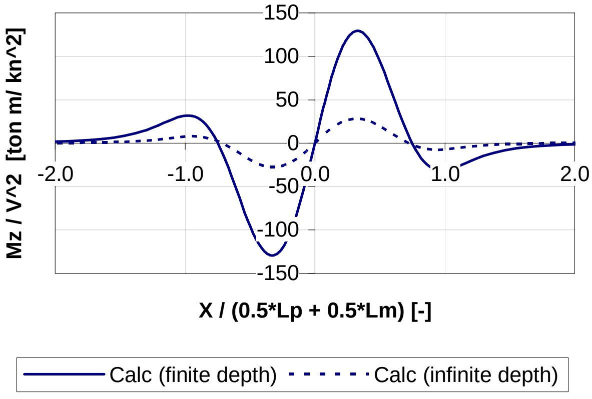

Figure 5 Typical Yaw Moments on Moored Vessel

These induced forces and moments on the moored vessel in the horizontal modes can only be absorbed through the minimal damping forces in these modes and the mooring line configuration. The induced hydrodynamic forces on the moored vessel can exceed the breaking strength of the lines, resulting in line breakage, occupational health and safety issues and potential damage to vessel and wharf structures.

3 OMC Interaction Model

The OMC vessel interaction model considers the dynamics of the vessel and mooring line and fender configuration to provide time domain predictions of the surge force, sway force and yaw moment and the induced vessel motions and mooring line loads.

The primary influences affecting the intensity of the passing forces and moment between vessels are included in the interaction model and are summarised as follows;

- displacements of the berthed and passing vessels
- speed of the passing vessel through the water
- separation distance between vessels
- UKC of the vessels
- mooring configuration
- environmental conditions at the time of transit (wave, wind, current)

The main component of the interaction model is the numerical model Simulation Package for the Motions of Ships or **SPMS** (O’Brien 2002), which has been developed by Dr. W.T. O'Brien of OMC for the analysis of various problems associated with the motions of moored and free moving vessels.

The methodology for the OMC interaction model involves two steps.

(i) Determination of the time series of exciting forces and moments induced by the passing vessel on the moored vessel, using the theory outlined in Section 2 above. Assumptions made include that the vessel passes parallel to the berthed vessel at a constant speed and that the flow around the passing vessel is not affected by any reflections from the surrounding harbour.

(ii) Input of the exciting forces and moments, together with the design environmental conditions, into the SPMS model to obtain time domain simulations of the six degree-of-freedom motions, fender forces and mooring line loads induced on the moored vessel by the passing vessel.

4 Case Study: Port Hedland Interaction Study

The Port Hedland interaction study was separated into two components:

Part A: validation of OMC's ship interaction model through full scale DGPS measurement of passing ship events.

Part B: utilisation of the validated OMC ship interaction model for analysis of design interaction scenarios from which PHPA can formulate the operating guidelines.

4.1 Part A: Full Scale Validation

To validate the OMC interaction model at Port Hedland, a site visit to Port Hedland was undertaken in November 2006. The objective was to record high accuracy DGPS measurements on the Panamax vessel "Santa Isabella" moored at PHPA No. 1 Berth.

The measurements involved placement of two roving Trimble 5700 DGPS instruments on the vessel and one Trimble 5700 DGPS base station on the shore near the PHPA Port Control Tower. An instrument was located on both the bow and stern centreline to enable the vessel horizontal displacements (surge, sway) and rotation (yaw) to be resolved. The instruments recorded vessel position every second. Figure 6 is a photo of the DGPS receiver setup on the stern of the "Santa Isabella".

Figure 6: DGPS instrument on stern of "Santa Isabella"

The instruments recorded three passing vessel events, namely an inbound Panamax vessel and two outbound laden Cape vessels.

At the time of each event, the loading condition of the "Santa Isabella" was recorded. The passing ship details and trajectory and speed were also recorded.

The mooring configuration of the "Santa Isabella", including number and location of lines, line types and pretensions and fender types was also recorded for each event.

The tidal level at the time of each measurement was recorded and used in the analyses.

The DGPS data for each event was post-processed and resolved into time series of horizontal excursions (surge, sway and yaw) for validation against the OMC interaction model.

The following general observations were drawn from analyses of the data:

1. The importance of vessel speed and separation was clearly shown with the smaller Panamax vessel, which passed closer to the moored vessel at significantly greater speeds, inducing interaction forces of similar magnitude to the much larger Cape Vessels.

2. There was significant interaction from all three events, with the measured surge in the order of at least 1m for all three events, and the stern displacement exceeding 1m for all three events.

The mooring conditions at the time of each event were recreated in the OMC interaction model.

Hydrodynamic modelling was conducted using the SPMS for the "Santa Isabella" moored in each loaded state and water level to determine added mass and damping coefficients for motions in six degrees of freedom.

For each simulation, the exciting forces and moments were determined based on the recorded passing vessel characteristics, the passing vessel speed and the separation distance between moored and passing vessel as detailed in Section 3. These exciting forces and moments, together with the frequency-independent added mass and retardation functions, were used in SPMS to determine the time domain series of induced vessel displacements, mooring line tensions and fender reactions for that scenario.

The OMC model displacements were then compared to the measured displacements for each event.

Figure 7 depicts the time series of measured and predicted sway motion of the "Santa Isabella" during the passing of the Cape vessel "Challenge Plus".

The validation measurements demonstrated that the OMC model correlated very well with the results from the measurements. In particular the magnitude and phasing of displacements are well within the expected accuracy, given assumptions made on mooring line condition and pretensions and passing vessel speed and trajectory.

The validation study provided full confidence in the validity of the output from the OMC model for use in the design simulations in Part B of the study.

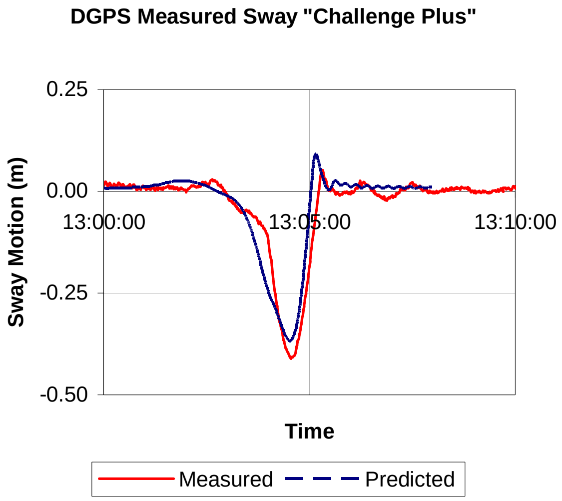

Figure 7: Example Time History of Measured & Predicted Sway Motions

4.2 Part B: Design Scenario Analyses

Four berths and prototype vessels were selected for the dynamic vessel interaction analyses utilising the validated model, as follows:

(i) BHP Berth A - laden Cape vessel
(ii) PHPA Berth 3 - laden Panamax vessel
(iii) PHPA Berth 1- laden Panamax vessel
(iv) BHP Berth D - laden Cape vessel.

The passing vessel for each berth was assumed to be a Cape vessel; ballast for inbound, laden for outbound.

In consultation with PHPA and the pilots, an envelope of passing speeds and separation distances for both outbound and inbound vessels was selected. The envelope covered the maximum and minimum realistic speeds and separation distances for passing each berth. The values have been determined as realistic and representative for a laden Cape vessel leaving from BHP Berth “B” and ballast Cape vessel transiting to Berth “B”.

The mooring and fender configuration at each berth were provided by PHPA.

The environmental conditions at each berth were provided by Cardno Lawson & Treloar (CLT). CLT undertook current, tidal and wave modelling for PHPA as part of this and other studies.

The assumed design current conditions imposed on each vessel during the interaction modelling were provided for typical spring and neap tides. A plot of the modelled current streams through the Port is given in Figure 9 for a typical spring tide. The largest current speed given by CLT for each berth *off* the fenders was used in the modelling as this provided the greatest moored vessel response during the passing event.

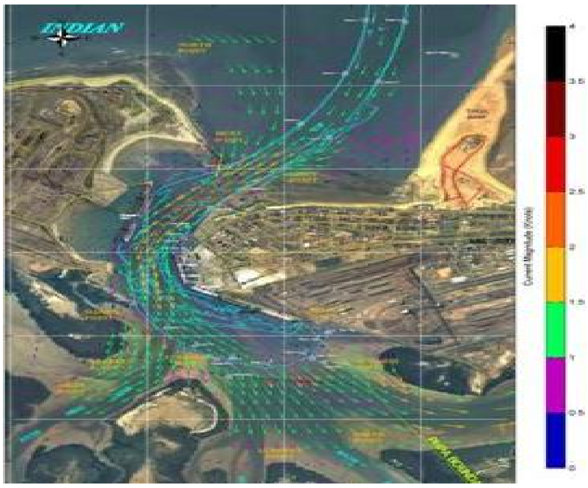

Figure 8: Port Hedland Spring tides (source: Cardo Lawson & Treloar)

The typical wave climate at each berth as provided by CLT was insignificant in terms of induced mooring loads and motions for these vessels and as such was not modelled.

The vessel hull shapes for each design vessel were modelled numerically for the specified loading conditions.

Hydrodynamic modelling was conducted using the SPMS for each of the design ships moored in their specified loaded state and water level.

A number of simulations were then undertaken for the envelope of design passing speeds and separation distances for each berth.

For each simulation, the exciting forces and moments were determined for the design conditions and then input into SPMS time domain simulations. The output was a time domain series of induced vessel displacements, mooring line tensions and fender reactions for that scenario.

For each scenario, two outcomes were examined:

1. Whether the modelled passing scenario would involve risk of line breakage. In such cases it was recommended that such a passing event not occur, and that a reduced speed or increased separation distance be adopted.

2. Where there was no threat of line breakage, whether the resulting horizontal motions would be greater than recommended for loading. For these cases it was recommended that loading should stop during such a passing event.

5 Discussion / Conclusion

The vessel interaction study has provided data to enable PHPA to refine the port guidelines and operating procedures with respect to safe passing vessel events.

For all berths, passing scenarios have been identified whereby the design vessel may pass the design berthed vessel without risk of line breakage and/or the requirement to stop loading during the passing.

Specifically, laden vessels provided the most critical passing events; however, for cases where the assumed inbound ballast vessel speed was significant compared to the outbound, then similar significant interaction may also occur.

This information obtained from this study can also feed into future design parameters both in terms of proximity of new berths to passing vessels but also in terms of simulation modelling of future port and channel capacity during the available tidal cycles.

6 Acknowledgements

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