NUMERICAL MODELLING OF MOORED VESSEL MOTIONS CAUSED BY PASSING VESSELS IN THE PORT OF BRISBANE

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1 ABSTRACT

This paper presents the results of the establishment and calibration of a numerical modeling approach for simulating moored ship motions induced by the drawdown from a passing vessel in the Port of Brisbane. The numerical modeling approach consisted of a one-way coupling of a finite volume Reynolds averaged Navier-Stokes model calculating the drawdown, and a linear diffraction-radiation model calculating the moored vessel motions in response to the incident hydrodynamic flow field in the time domain. The model domain represented a 0.5 km wide river basin with a maximum water depth of 11.1m. Identical hull geometries were used for the moored vessel and the passing vessel, representing oil tankers with a L_{OA} of 200.4 m and a displacement of 46,900 m^3. The mooring system consisted of linear lines and bollards. Calibration of the models was undertaken by comparison with results from physical modeling of different combinations of vessel passing distances, passing speeds and moored vessel line pre-tensions. The predicted moored vessel motions showed to be in excellent agreement with physical model test data, which meant that the models could be confidently used.

2 INTRODUCTION

During recent years, long period motion of moored vessels induced by nearby passing vessels has been of growing concern to harbor masters and port officials around the world. The phenomenon becomes particularly problematic when large vessels are moving in constrained channels, such as rivers and narrow estuaries. In these instances the passing vessel can induce a surge motion to nearby moored vessels of several meters, which can cause hazardous conditions at the berth. Growing ship sizes and increased port traffic calls for regulations dictating minimum vessel passing distances and upper speed limits, as well as optimization of the mooring system of the affected vessels, in order to ensure safe working conditions on the moored vessel. Until recently, physical model tests were the only option in addressing this problem, but now recent advances in numerical modeling have made it possible to apply numerical modeling techniques. This allows for more rapid assessments to be conducted that consider a wider range of variables than was possible with physical model and provides a cost effective solution to assessing moored vessel motions.

This paper describes the establishment and calibration of the hydrodynamic and moored vessel motion models that have been used to reproduce moored vessel motions occurring at the Shell Terminal at the Port of Brisbane.

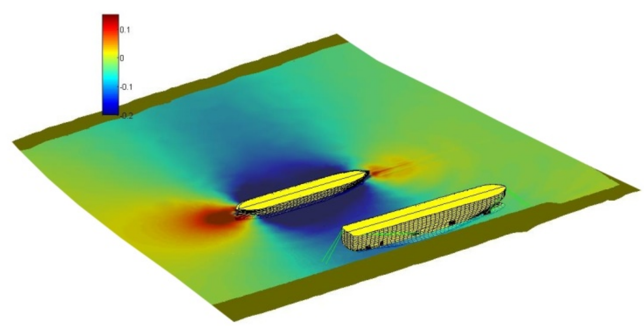

Figure 2-1 - Drawdown produced by passing vessel

3 NUMERICAL MODELLING APPROACH

The numerical modeling approach used in this study consists of a one-way coupling of the MIKE 21 FM hydrodynamic model and the linear diffraction-radiation vessel response model WAMSIM both developed by the DHI.

The hydrodynamic model provides the flow field around the vessel and the generated displacement wave. A potential limitation is that, as the hull displacement is represented by a surface pressure field, the detailed three-dimensional geometry of the vessel hull is not represented, including the submerged bulb keel and the stern. As a result,

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there will be variations in the flow field in these areas that the model is unable to represent. This is not considered to be a major deficiency as the model will be able to represent the drawdown, which is the main factor in the displacement waves. Also, as the hydrodynamic model is based on the assumption of shallow water relative to wavelength, it is not capable of modeling the short period waves in the wake of the vessel, which are termed Kelvin waves. These waves are not the source of the vessel movements that cause adverse vessel interactions (DHI, 2003 and DHI, 2004) and are not the subject of this study. The calculated flow field at the location of the moored vessel is extracted from the hydrodynamic model and used as input to the vessel response model.

The vessel response model WAMSIM is capable of simulating wave-induced motion of a moored or freely floating structure in the time domain. All non-linear external forces, such as those due to the mooring system or viscous/frictional damping are included. The wave exiting force is calculated assuming a superposition of long-crested (uniform along one horizontal dimension) waves. The results of each WAMSIM simulation are presented as time-series of motions for surge, sway, heave, roll, pitch and yaw and as forces in the mooring lines and vessel diffraction forces.

4 PHYSICAL MODEL DATA

The hydrodynamic and vessel motion models have been verified against data from physical model testing. Model testing was carried out in the DHI's physical model test facilities in Denmark in 2004 to investigate the moored vessel motion caused by passing ships at the Shell Terminal located in the Upper Lytton Reach of the Brisbane River (DHI, 2004). A single vessel type was used to represent both the moored and passing vessels. The characteristics of the two vessels are summarized in Table 4-1 below.

Table 4-1 Model Vessel Characteristics

Characteristic	Value
L_{oa} (m)	200.4
B (m)	30.3
Draft (m)	10
Displacement (m^3)	46900

The specification of the mooring conditions of the berthed model vessel was based on the mooring arrangements used by the tanker *Helix* at the Shell wharf. This consisted of a traditional mooring arrangement, with two sets of spring lines, two sets of breast lines and a set of bow and stern lines (as shown in Figure 4-1 below).

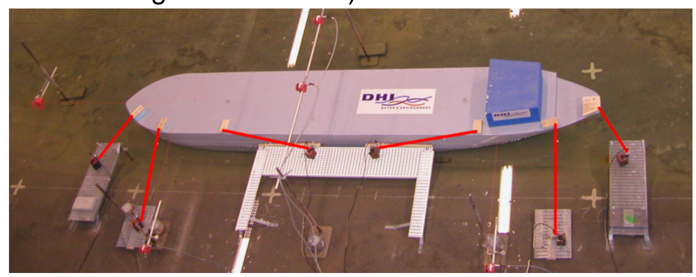

Figure 4-1 - photo of moored model vessel in the scale model.

At each mooring position two lines were represented by a single line. The individual mooring lines were *Atlas 6 strand ropes* with a diameter of 62 mm with a breaking strength of 74 tones. The mooring line pretension was defined at 10 tones in each model mooring line for the majority of the model tests, which represented two prototype lines with 5 tones pretension in each line and 20 tones pretension (10 tones in each line) for a limited number of tests.

The ship was moored against two breasting islands. The breasting islands consisted of piled structures with the front row of timber piles (shown in Figure 4-2). The wharf did not have energy absorbing fenders, and the ship forces were simply taken by the front timber piles. In the physical model each breasting island was given a stiffness of 1,000 tones/m, based on estimates of the performance of the breasting islands.

Figure 4-2 - Front of model breasting islands in the scale model.

The passing distances between the centre line of the moving vessel and the centre line of the moored vessel was 130 m and 150m. Tests were carried out for passing speeds of 6 and 8 knots by

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towing the passing vessel along pre-determined tracks representing varying passing distances (see Figure 4-3).

Figure 4-3-Vessel towing arrangement

The surge, sway and yaw motion of the moored ship were measured using instruments mounted on the moored vessel and a wave gauge was used to measure the drawdown caused by the passing vessel.

5 HYDRODYNAMIC MODEL SET-UP AND CALIBRATION

The computational domain used in the MIKE21 HD model was set up using an unstructured mesh in order to provide a sufficiently high resolution in the vicinity of the moving vessel trajectory and location of the moored vessel, while allowing a coarser mesh resolution in areas away from the areas of interest, where a detailed spatial discretization is not required.

The moving vessel trajectory path consisted of a quadrangular grid with a cell dimension of 3m x 3m. In the immediate area containing the moored vessel a triangular mesh was used with a maximum cell area of 8m^2. In the far field a triangular grid with a maximum area of 500 m^2 was used. The full model domain is shown in Figure 5-1, whilst an enlargement of the area around the moored vessel is shown in Figure 5-2, which also provides the model bathymetry in this area.

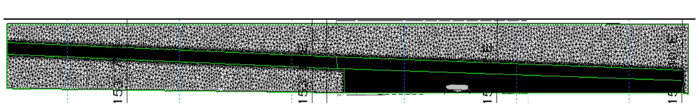

Figure 5-1 - Computational mesh used for the MIKE21 HD simulations (black areas are of high resolution)

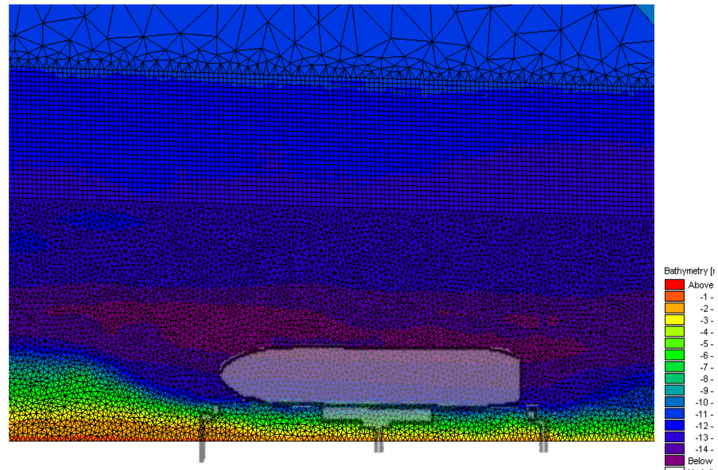

Figure 5-2 - Computational mesh in the vicinity of the moored vessel.

The pressure field used to simulate the moving vessel was generated from a grid file containing the hull x-y-z data, which was then interpolated to model grid file with a spatial resolution of 1m x 1 m. The resulting deformations in the water surface elevation around the passing vessel are shown in Figure 5-3.

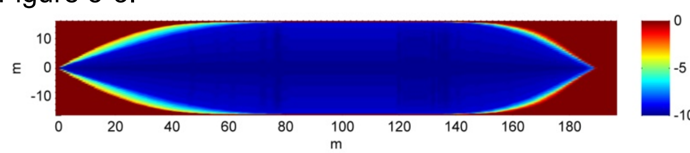

Figure 5-3 – surface elevation displacement caused by the passing vessel

In order to avoid shock waves in the model, the ship used a path of 2,500 m to accelerate from zero to the passing speed and subsequently 1,000 m traveling at the passing speed in order to assure a fully developed wake before passing the moored vessel. After passing the moored vessel, the moving vessel continues its path for a further 2,000 m in order to assure the wave field time series extracted at the moored vessel location has a sufficient length to carry out the analyses used in WAMSIM.

The results of the MIKE 21 HD simulations of drawdown for 6 knot and 8 knot passing speeds and separation distances of 130 m and 150m are shown in Figure 5-4 to Figure 5-7 respectively compared against the physical model test data.

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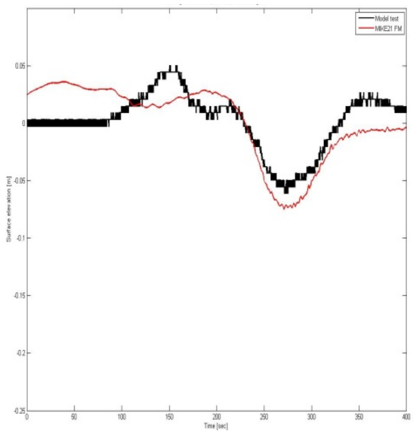

Figure 5-4 - Surface elevation comparison at 6 knots, passing distance 130 m

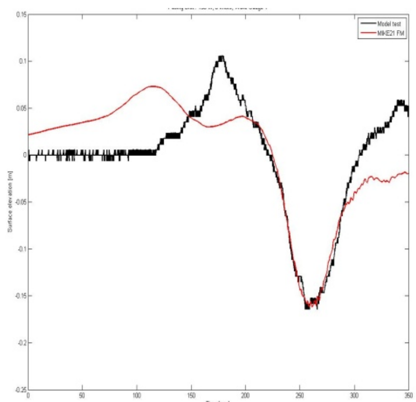

Figure 5-5 - Surface elevation comparison at 8 knots, passing distance 130 m

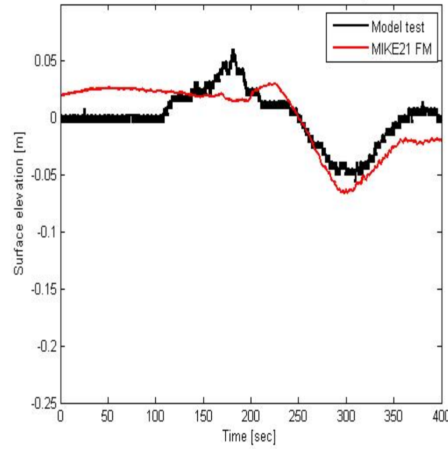

Figure 5-6 Surface elevation comparison at 6 knots, passing distance 150 m

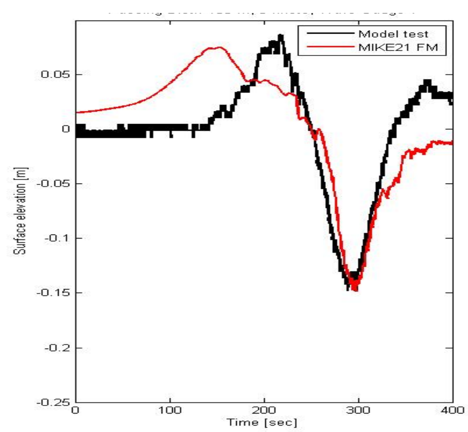

Figure 5-7 Surface elevation comparison at 8knots, passing distance 150

The comparison between the MIKE 21 HD results and physical model test data show that the numerical model has accurately represented the magnitude of the drawdown at the moored vessel for all vessel passing simulations. At the 8 knot passing speed the representation in the numerical model is particularly good for both passing distances.

The numerical model, however, has not reproduced the surge in water elevations either side of the drawdown. This most likely because the surge is caused by the effects of the bulb keel and vessel's stern, which as discussed above the two-dimensional numerical model is unable to represent. This is not considered to be a major limitation as the drawdown is the mechanism governing the moored vessel motions of concern. This conclusion is supported by the comparisons of

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the predicted vessel motions by WAMSIM and the physical model tests discussed below.

The hydrodynamic flow fields produced by MIKE 21 HD were extracted and used as input for the WAMSIM vessel motion model.

6 VESSEL MOTION MODEL SET UP AND CALIBRATION

The ships' hulls used in the physical model tests were digitized from the original model drawings and transformed into a panelized hull (as shown in Figure 6-1 below). WAMIT was used to calculate the frequency impulse response functions and added mass coefficients and the radiated wave potential, which were used as input for WAMSIM.

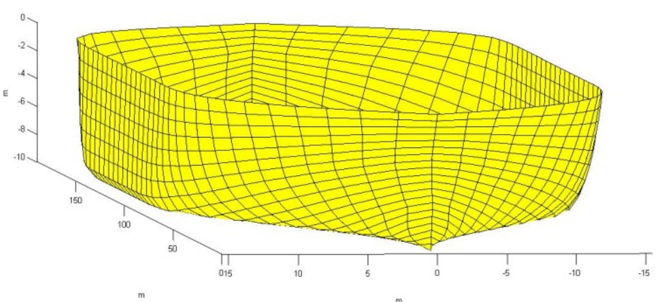

Figure 6-1 Panelized grid of the ship hull used in WAMSIM

The WAMSIM model was set up to represent the line arrangement and line types in the physical model tests and the two line tensions that were previously tested. The stiffness of the berthing islands was represented by four fenders, two located at the ends of each island and each with a stiffness of 500 tones/m. The eight physical model tests were reproduced using WAMSIM and a comparison of the predicted surge, sway and yaw motions with those from the physical model tests presented in Figure 6-2 to Figure 6-9.

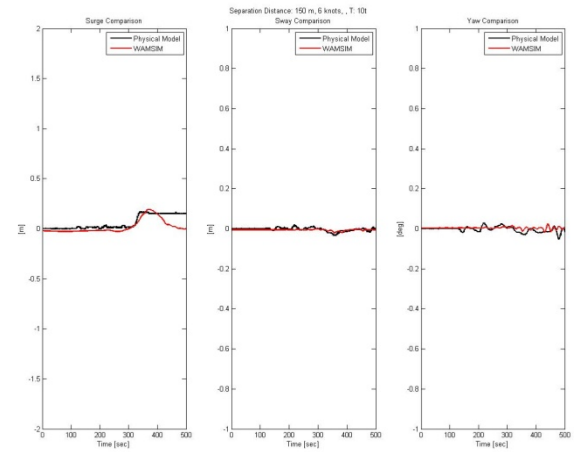

Figure 6-2 - Motion comparison for a passing distance of 150 m and a passing speed of 6 knots and a moored vessel line pre-tension of 10 t.

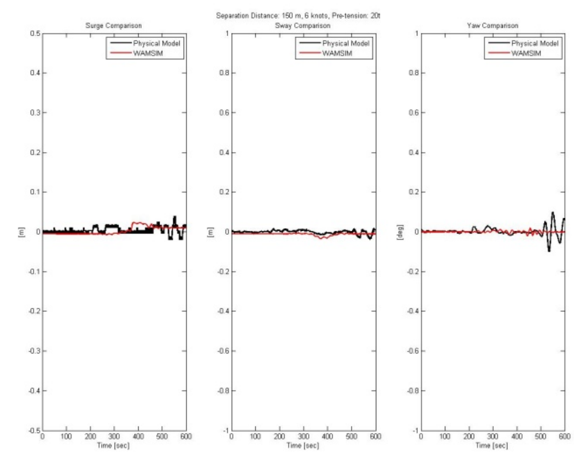

Figure 6-3- Motion comparison for a passing distance of 150 m and a passing speed of 6 knots and a moored vessel line pre-tension of 20 t.

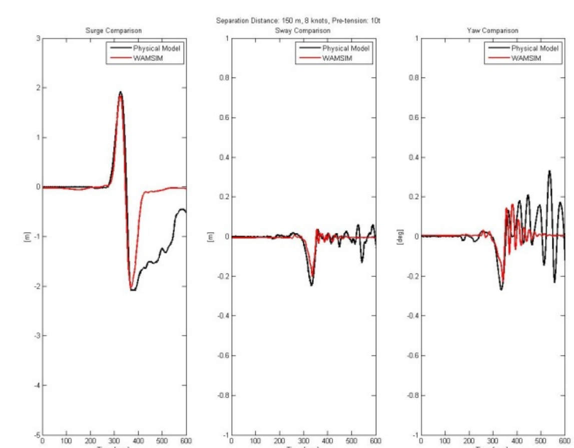

Figure 6-4 - Motion comparison for a passing distance of 150 m and a passing speed of 8 knots and a moored vessel line pre-tension of 10 t.

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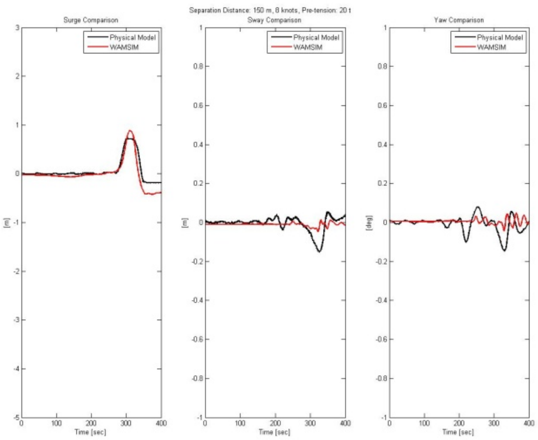

Figure 6-5 - Motion comparison for a passing distance of 150 m and a passing speed of 8 knots and a moored vessel line pre-tension of 20 t.

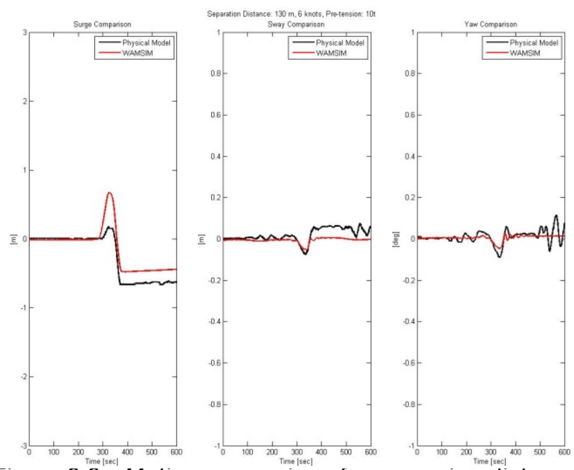

Figure 6-6 - Motion comparison for a passing distance of 130 m and a passing speed of 6 knots and a moored vessel line pre-tension of 10 t.

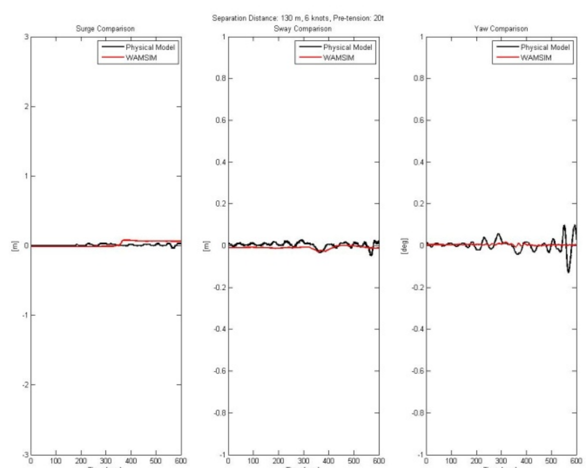

Figure 6-7 - Motion comparison for a passing distance of 130 m and a passing speed of 6 knots and a moored vessel line pre-tension of 20 t.

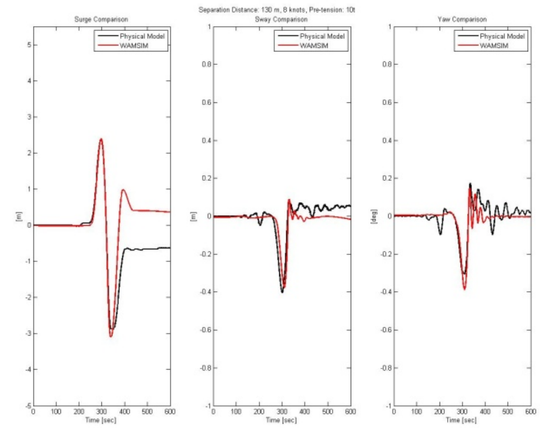

Figure 6-8 - Motion comparison for a passing distance of 130 m and a passing speed of 8 knots and a moored vessel line pre-tension of 10 t.

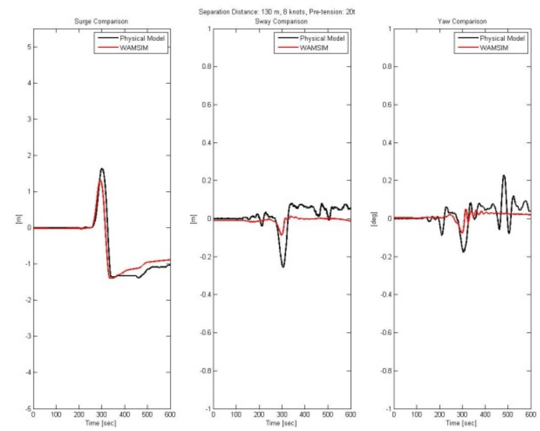

Figure 6-9 - Motion comparison for a passing distance of 130 m and a passing speed of 8 knots and a moored vessel line pre-tension of 20 t.

The comparison demonstrates there is very good agreement between the numerical model predictions and physical model test data for the peak-to-peak surge motions for all eight calibration runs. The numerical model, however, does not in all tests capture the behavior of the surge return motion, where the ship gradually slides along the pile structure and get stuck before reaching neutral position. This may be due to the limitation of the simplistic formulation of the ship friction against the wooden berthing islands in WAMSIM, as given above in Equation 8. The continued yaw motion measured in the physical model after the moving vessel has passed is caused by wave reflections in the physical model test tank which has a limited extension.

The sway and yaw motion caused by the drawdown when the moving vessel is passing the moored vessel are very accurately predicted by WAMSIM,

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except for in Figure 6-5 and Figure 6-9. When considering the yaw motion measured in the two physical model tests it was noticed that a small oscillating yaw motion was present before the passing of the moving vessel. This suggests that the model ship was not completely still before the passing vessel's run, which could have slightly changed the vector orientation of the mooring line forces compared to the original configuration, thereby resulting in a different sway and yaw motion.

7 CONCLUSION

A numerical modeling approach consisting of a coupling of MIKE21 FM and WAMSIM was used to simulate the moored vessel motion induced by the drawdown produced by a passing vessel at the Port of Brisbane Shell Terminal. The numerical model was validated against a test matrix of eight physical model tests containing two vessel passing distances, two vessel passing speeds and two moored vessel line pre-tensions. It was found that the numerical model was able to very accurately predict the critical peak-peak surge motion for all eight cases. The numerical model was also capable of predicting the very small induced sway and yaw motion for all but two test cases, where it was likely that the physical model results could have been affected by small oscillatory motions in the moored vessel prior to the passing of the moving vessel.

It is concluded that the modeling approach presented in this paper is appropriate to simulate the motions of moored vessel caused by displacement waves generated by passing vessels. This approach can now be used with confidence to test a range of options for controlling such moored vessel motions, including operational constraints on the passing vessels, mooring design and operation of the mooring system, a rapid and more cost effective manner than physical model testing.

8 REFERENCE

DHI (2003). Port of Brisbane, Vessel Interaction Study, Phase 1 Identification of Vessel Interaction Phenomena. DHI Water and Environment, June 2003.

DHI (2004). Port of Brisbane, Vessel Interaction Study, Phase 2 Vessel Monitoring and Physical Modelling. DHI Water and Environ

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