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Passing ship effects on water surface elevations

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***Abstract*— Following the work presented at the TELEMAC User Conference 2019 [1], about the ship-current interactions using TELEMAC and HR Wallingford's Navigation Simulator, the investigation of ship effects within TELEMAC has been expanded.**

TELEMAC-3D hydrodynamic model has been used to examine the effects of passing ships on water surface elevations at berth. A range of scenarios were modelled to investigate how water surface elevations varied as a result of the number of passing ships, variations in their speed, distance between passing ships, the effects of deceleration and altering slowing locations.

As well as estimating the free surface elevations, the TELEMAC model results were used to develop separate time series of surge and sway forces, and yaw moments that could be used as input to the SHIPMOOR dynamic mooring model. These time series were used to determine whether the effects of multiple passing vessels traveling in convoy, and decelerating upstream of a berth, are likely to result in increased vessel motions and mooring forces above certain thresholds.

I. Introduction

In an effort to understand the instances of mooring line failures at a berth located within a channel, HR Wallingford undertook a passing vessel study. A TELEMAC-3D hydrodynamic model was built and validated to determine the surface elevations at the berth for a range of variables, including ship speeds, distance between vessels and deceleration point.

II. Model setup

A. *Model extent and model bathymetry*

A TELEMAC-3D model (hydrostatic) was set up to cover approximately a 25 km length of channel, including the Port of interest. The area of the whole model is shown in Fig.1.

TELEMAC-3D is used for this study because it reduces the instabilities near the moving ship, compared to using TELEMAC-2D.

In terms of bathymetry, because of the limited available information outside the main navigation channel, the bathymetry in the shallow area to either side of the channel was estimated using two cross sections given: one cross section was at the north measurement site, the other one was at the south measurement site.

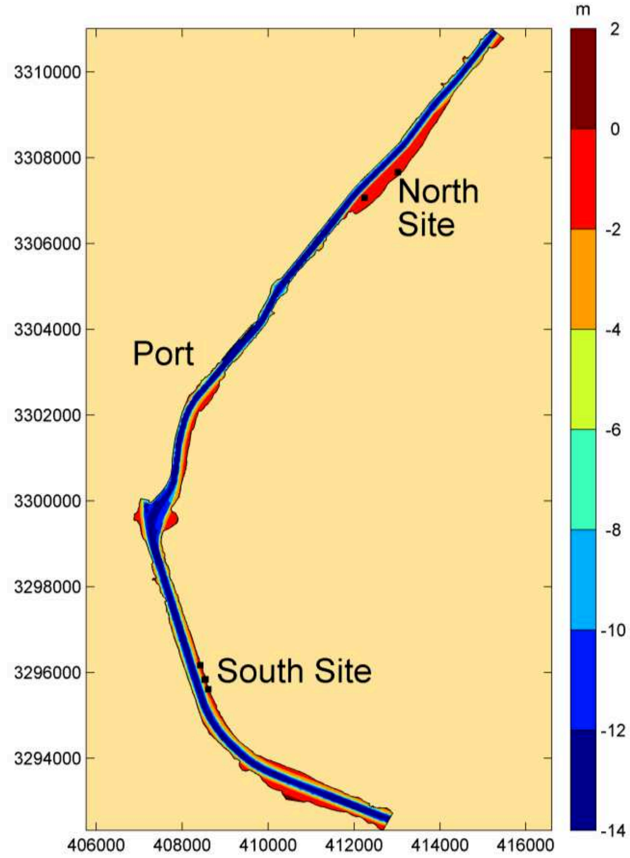

Figure 1: TELEMAC-3D model extent

B. *Model mesh*

The model horizontal mesh size is 5m along the centre line of the channel, where the ships travel. In the shallower areas, to the sides of the channel, the mesh size is 10m. In terms of vertical mesh size, the model was set up to use only three horizontal planes. Sensitivity tests were carried and the number of planes had little impact on model results at locations of interest. The model mesh for the area around the berth of interest is shown in Fig. 2.

C. *Ship representation*

The moving ships are modelled by imposing a pressure field on the surface corresponding to the hull shape. The applied pressure is proportional to the depth of the hull below the water free surface, according to the equation below:

$$P = \rho g d \qquad (1)$$

where *P* is the pressure (in kg/ms^2 or N/m^2), ρ is the sea water density (1,025 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2) and *d* is the depth of the ship's hull below the water free surface (in m).

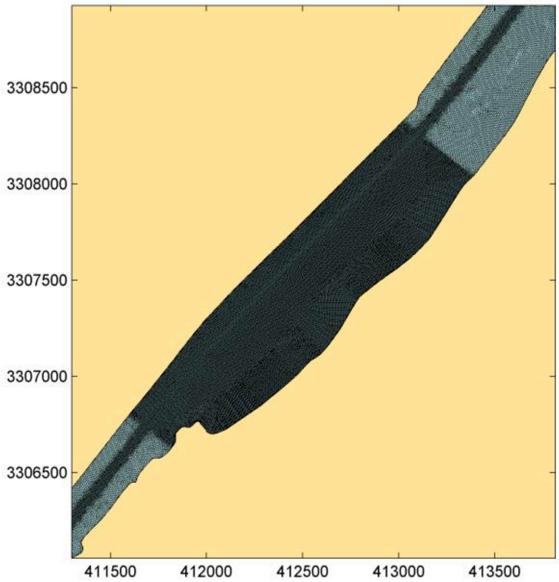

Figure 2: Model mesh at the berth of interest

III. Model Validation

To validate the TELEMAC-3D model, runs were carried out and compared against measured surface elevation and current speed data for passing ships. Model runs were carried out where the most complete information on vessel characteristics and measurements were presented.

The model was run for two scenarios (Ship 1 and Ship 2) where surface elevations and currents were measured at locations at the North site and South site, in relatively shallow water away from the main shipping channel. The model results are compared with time histories of observed level and current speed at a number of locations shown in Fig. 3 and Fig. 4.

A. Ship 1

Ship 1, a tanker 250 m long, 41 m wide with a 12 m draught, travelled inbound to the North at slack tide, so no mean flow has been imposed in the model. The ship was travelling at 8.6 knots past the South site and at 8.3 knots past the North site.

The modelled ship track was shifted 25 m west to the centre of the channel. The vessel track was not provided and was therefore part of the validation process.

Fig. 5 to Fig. 8 show comparison between predicted and measured water elevations. For the South Pressure Cell 1 and the South Capacitance Gauge, the modelled drop in level and subsequent rise in level is in good agreement with measurements. For the North pressure Cell (Fig. 7), the model matches the observations for the drop in the level and the start of the following rise in level, but does not rise to the observed level for the later time.

For the North Capacitance Gauge (Fig. 8), the drop in the model elevation agrees well with the observations, but the model rise in level occurs later than in the observations. An alternative point (40m away from the channel) was taken in the model to compare against the North Capacitance Gauge. The comparison for this point (Fig. 9) shows that the level rise in the model agrees better with the observed rise.

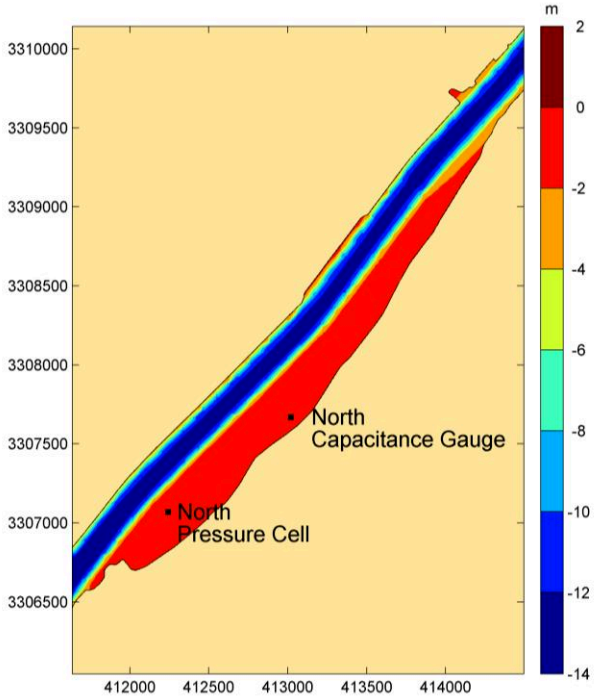

Figure 3: North Site

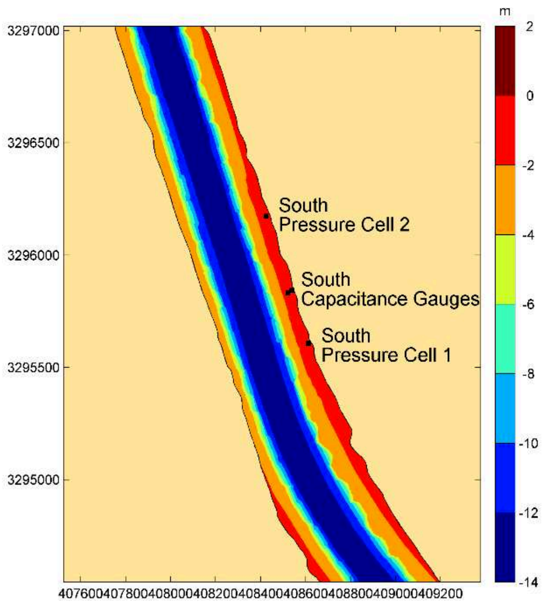

Figure 4: South Site

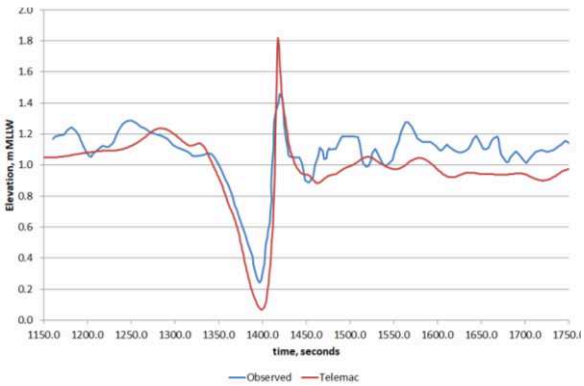

Figure 5: Ship 1. Elevation time series. South Pressure Cell 1.

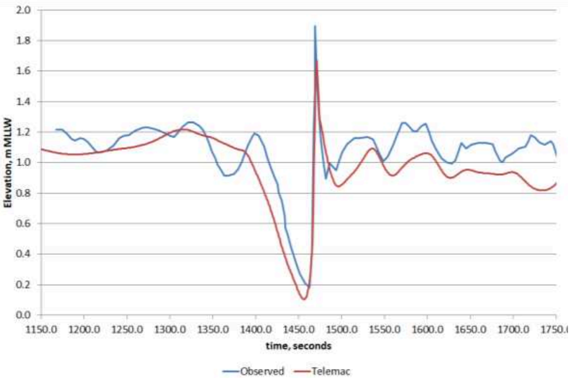

Figure 6: Ship 1. Elevation time series. South Capacitance Gauge (shoreline)

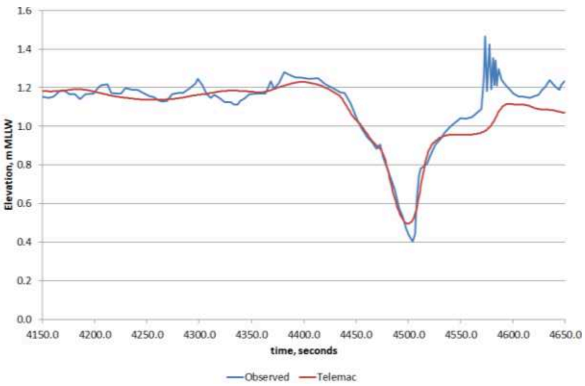

Figure 7: Ship 1. Elevation time series. North Pressure Cell

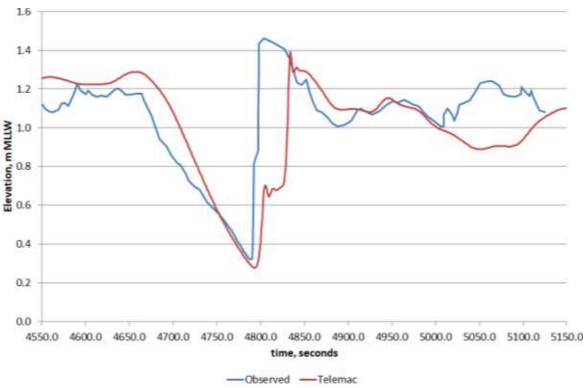

Figure 8: Ship 1. Elevation time series. North Capacitance Gauge

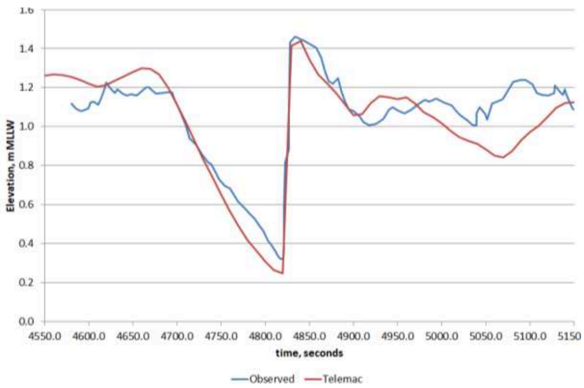

Figure 9: Ship 1. Elevation time series. North Capacitance Gauge. Alternative point

B. Ship 2

Ship 2, a tanker 250 m long, 42 m wide with a 11 m draught, travelled inbound at slack tide, so no mean flow has been imposed in the model. The ship was travelling at 8.2 knots past the South site.

Fig. 10 to Fig. 12 show comparison between predicted and measured water elevations.

Fig. 10 shows the model matches very well the observations for the drop in level and subsequent rise at South Pressure Cell 1. Fig. 11 shows that the model drop and rise are slightly bigger than observed and the rise occurs slightly earlier at South Pressure Cell 2. For South Capacitance Gauge (channel), Fig. 12 shows that the drop and rise are about the same magnitude as observed, but the rise occurs slightly later.

Predicted current speed were compared with observed speed at South Capacitance Gauge (channel), 0.6m above the bed. Fig. 13 shows that the value of the predicted peak speed is slightly smaller than the observed peak. However, the observed speed is noisy and seems to indicate a mean channel flow of about 0.3 m/s. If this mean speed is added on to the predicted peak, then the agreement between the predictions and the observations is better.

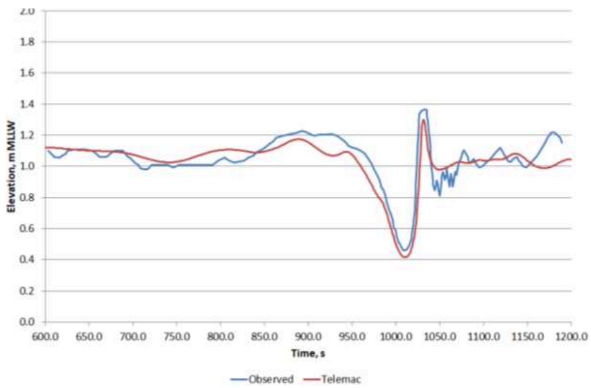

Figure 10: Ship 2. Elevation time series. South Pressure Cell 1.

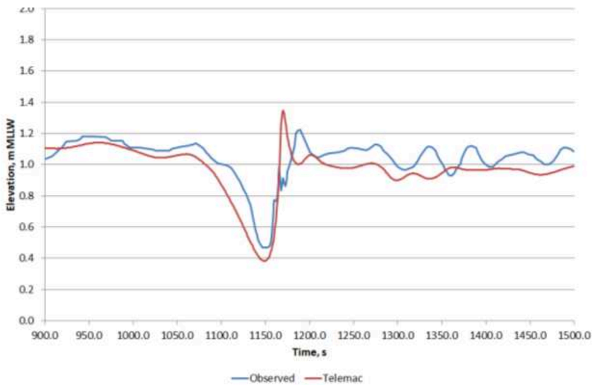

Figure 11: Ship 2. Elevation time series. South Pressure Cell 2.

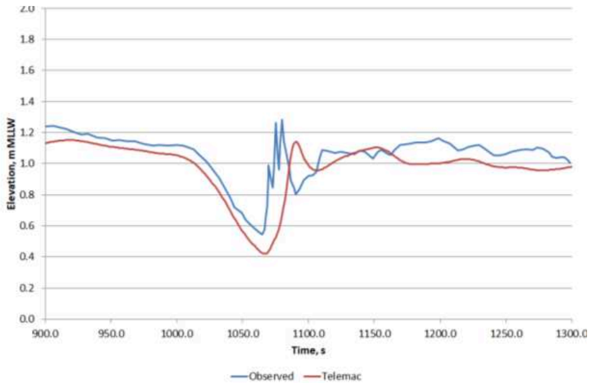

Figure 12: Ship 2. Elevation time series. South Capacitance Gauge.

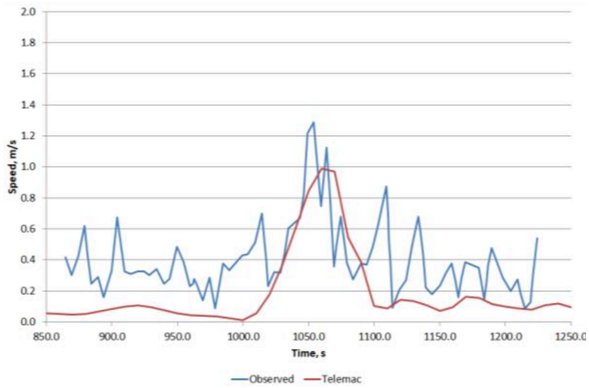

Figure 13: Ship 2. Speed time series. South Capacitance Gauge (channel).

C. *Model validation conclusions*

The overall conclusion from the validation of the TELEMAC-3D model is that the model reproduces the measured surface elevations and currents due to passing ships well. This is bearing in mind the limited information provided on which the model runs were performed, e.g. the bathymetry in the shallow regions where the measurements were taken and the vessel track.

IV. Passing vessel study

In order to gain a good insight into the important hydrodynamic processes, including the interaction of two ships and the deceleration approaching the berth, TELEMAC-3D model runs were carried out covering a range of scenarios. The scenarios, as summarised in Table 1, were selected to account for:

- 2 operating vessel speeds
- Up to 2 vessels in convoy
- Distance between vessels
- An example / typical deceleration profile based on data provided by the pilots.

Further tests were also performed to examine the sensitivity of the results to vessel transit direction and the effect of tidal currents. To generate the current in the model, a level difference at the two ends of the model was applied so that the target current speed was achieved. For example, for Case 15, with a current speed of 1.5knot ebb current the surface elevation level was raised by 0.15 m at the North and lowered by 0.15 m at the South. This method was used because imposing the desired current directly at a model boundary caused the model to become unstable.

All model runs were carried out with a ship moored starboard side alongside Berth 3 and a passing ship transiting along the centreline of the channel.

Track information for two ships, from data provided, was used to derive a representative deceleration profile for the modelling. Fig. 14 shows the ship speeds plotted against the distance north of the berth. For the test runs with deceleration, the ship moved at 8 knots until it was approximately 1.5Nm upstream of the berth. It then decelerated uniformly until it was at 3 knots, at the berth. The same deceleration profile was also applied to test cases where the point at which the ships start to decelerate was moved 1Nm further upstream (2.5Nm upstream). These two locations are shown in Fig. 15.

The results of the TELEMAC-3D modelling are presented as time series plots of the free surface elevation at a point along the centre of the navigation channel, adjacent to the Berth 3. Each time series graph shows the onset of the vessel generated pressure waves adjacent to the berth, the passing of the ship or ships, shown as the abrupt discontinuity in the time series record, and the residual disturbance after the vessel has passed, before returning back to a relatively undisturbed state.

The time series plots are grouped so that the relative differences can be compared between different simulations. For example, Cases 1, 5, and 9 are grouped together in Fig. 16, as these all show the results from one or two outbound vessels all travelling at constant speed of 4 knots, and if there are two vessels they have a separation of 1 or 2 nautical miles. This figure shows that although the time series are different, the general amplitude and maximum free surface elevation is higher for two vessels (Cases 5 and 9) compared with one vessel (Case 1).

Case	Number of ships	Constant overground speed (knots)	Passing ship course	Variable overground speed deceleration profile (knots)	Deceleration point (upstream of Berth 3)	Separation when Ship 1 is passing berth (Nm)	Current speed (knots)	Current direction
1	1	4	Outbound		n/a		0	
2	1	3	Outbound		n/a		0	
3	1		Outbound	8 to 3	1.5Nm		0	
4	1		Outbound	8 to 3	2.5Nm		0	
5	2	4	Outbound		n/a	1	0	
6	2	3	Outbound		n/a	1	0	
7	2		Outbound	8 to 3	1.5Nm	1	0	
8	2		Outbound	8 to 3	2.5Nm	1	0	
9	2	4	Outbound		n/a	2	0	
10	2	3	Outbound		n/a	2	0	
11	2		Outbound	8 to 3	1.5Nm	2	0	
12	2		Outbound	8 to 3	2.5Nm	2	0	
13	1	4	Inbound		n/a		0	
14	1	3	Inbound		n/a		0	
15	1	4	Outbound		n/a		1.5	Ebb
16	1	3	Outbound		n/a		1.5	Ebb
17	1	4	Outbound		n/a		1.5	Flood
18	1	3	Outbound		n/a		1.5	Flood
19	2		Outbound	8 to 3	1.5Nm	1	1.5	Flood
20	2		Outbound	8 to 3	2.5Nm	1	1.5	Flood

Table 1. Scenarios modelled

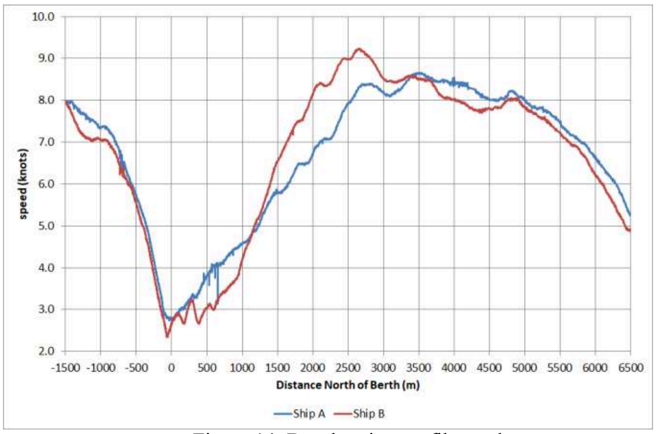

Figure 14: Deceleration profile used

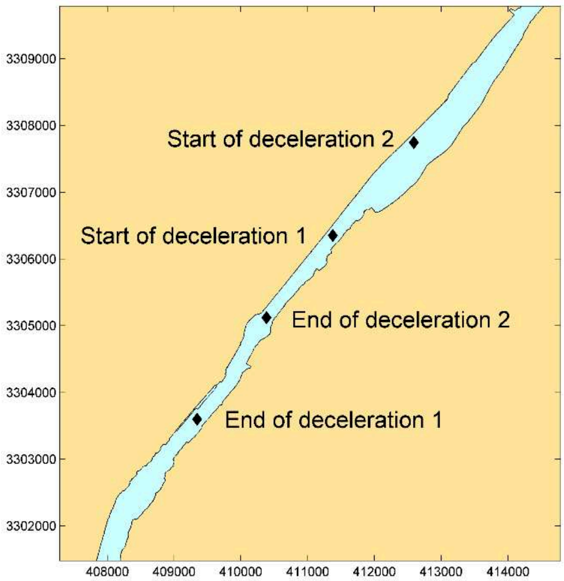

Figure 15: Location of deceleration points considered in the modelling

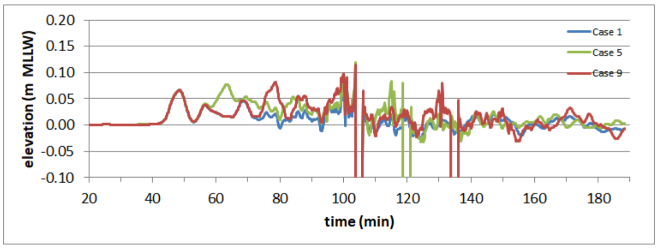

Figure 16: Model elevation time series at berth. Cases 1 (1 ship), 5 (2 ships 1Nm separation) and 9 (2 ships 2Nm seperation). Ship speed of 4 knots

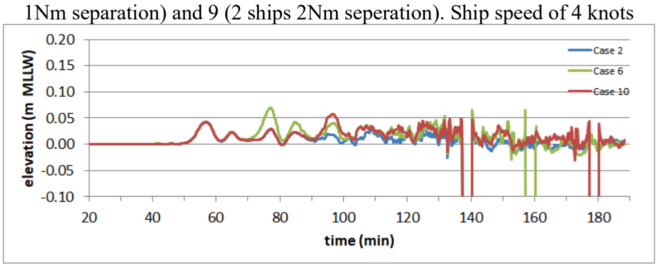

Figure 17: Model elevation time series at berth. Cases 2 (1 ship), 6 (2 ships 1 Nm separation) and 10 (2 ships 2 Nm seperation). Ship speed of 3 knots

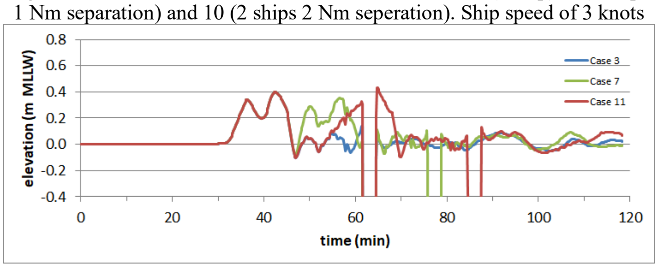

Figure 18: Model elevation time series at berth. Cases 3 (1 Ship), 7 (2 ships 1 Nm separation) and 11 (2 ships 2 Nm seperation). 8 to 3 knots, 1.5 Nm decleration

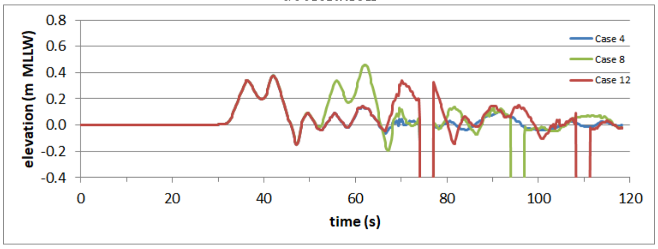

Figure 19: Model elevation time series at berth. Cases 4 (1 ship), 8 (2 ships 1 Nm separation) and 12 (2 ships 2 Nm seperation). 8 to 3 knots, 2.5 Nm deceleration

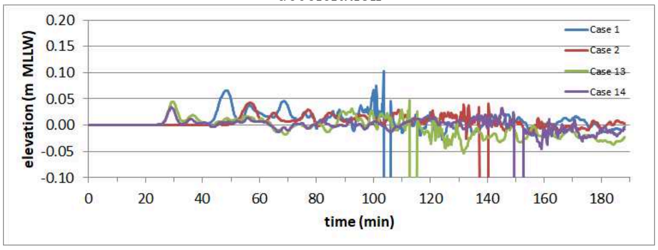

Figure 20: Model elevation time series at berth Cases 1 (inbound ship 4 knots), 2 (inbound ship 3 knots), 13 (outbound ship 4 knots) and 14 (outbound ship 3 knots)

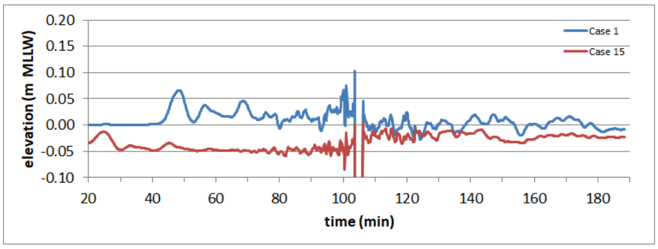

Figure 21: Model elevation time series at berth Cases 1 and 15 (effect of ebb current, 4 knots)

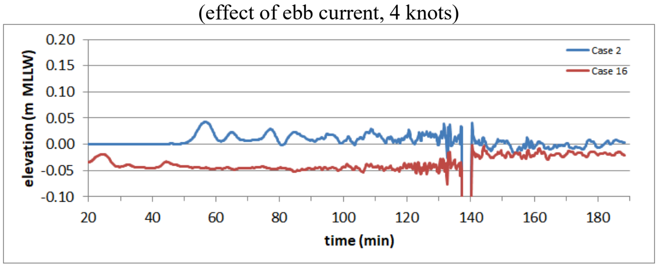

Figure 22: Model elevation time series at berth Cases 2 and 16 (effect of ebb current, 3 knots)

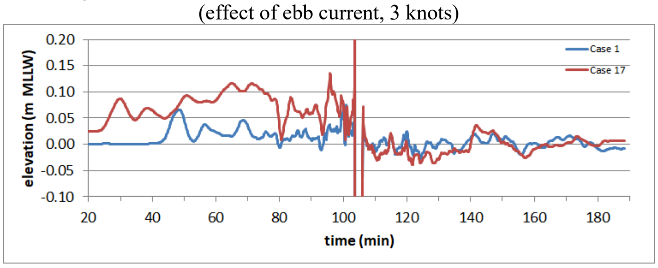

Figure 23: Model elevation time series at berth Cases 1 and 17 (effect of flood current, 4 knots)

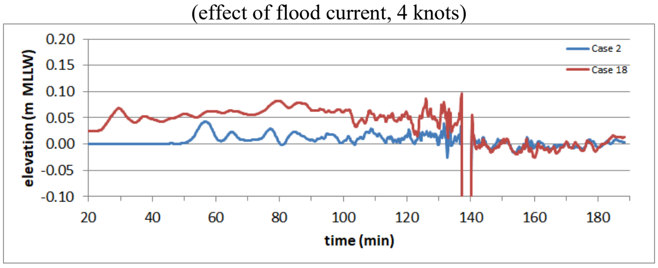

Figure 24: Model elevation time series at berth Cases 2 and 18 (effect of flood current, 3 knots)

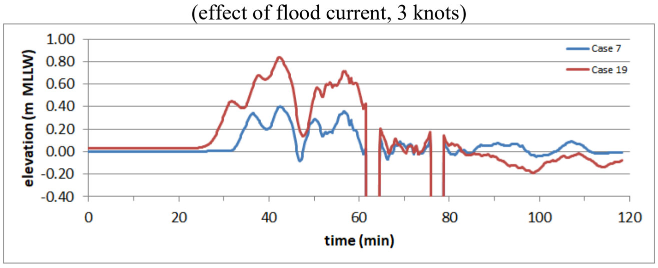

Figure 25: Model elevation time series at berth Cases 7 and 19 (effect of flood current, 8 to 3 knots, 1.5 Nm deceleration)

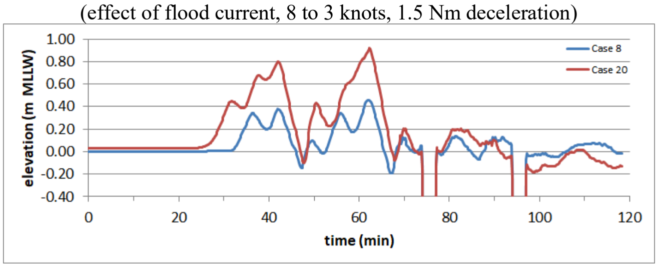

Figure 26 : Model elevation time series at berth Cases 8 and 20 (effect of flood current, 8 to 3 knots, 2.5 Nm deceleration)

Fig. 17 shows the corresponding results, but for vessels traveling at 3 knots. Compared with Fig. 16, this figure shows that travelling at 3 knots, leads to a noticeably lower free surface elevation, but again two vessels travelling in convoy leads to generally higher free surface elevations at the berth location.

The results of tests including vessel deceleration from 8 to 3 knots are shown in Fig. 18 and Fig. 19. Fig. 18 shows the results with the deceleration point (approximately 1.5Nm upstream of Berth 3), whereas Fig. 19 shows the results from beginning to decelerate approximately 2.5Nm upstream of Berth 3. Both sets of results show a significant increase in the water surface elevations when there are two ships (Cases 7 and 11 or Cases 8 and 12), compared with one ship (e.g. Case 3 or Case 4).

The effect of vessels travelling inbound (to north) as opposed to outbound (travelling south) is illustrated in Fig. 20. This figure show a similar range in the predicted free surface elevations, with the high speed (4 knots for Cases 1 and 13) leading to slightly higher surface elevations than when travelling at 3 knots.

Fig. 21 and Fig. 22 show the effect of an ebb current of 1.5 knots, i.e. in the same direction of the outbound ships being simulated. To generate the target current speed, a level difference at the two ends of the model was applied. For example, for Case 15 (Fig. 21) with an ebb current of 1.5 knots, the level was raised by 0.15 m at the North and lowered by 0.15 m at the South. This resulted in an initial condition at the berth where the level was below zero. This negative elevation continues throughout the run. For both ebb current cases, the predicted free surface elevation range is noticeably lower when including the tidal current effect.

In contrast, as shown in Fig. 23 to Fig. 26 the effect of the 1.5 knots opposing current, noticeably increases the predicted free surface elevations. To generate the flood current, a level difference at the two ends of the model was applied. This resulted in an initial condition at the berth where the level was above zero. This positive elevation continues throughout the run. The increase in predicted surface elevation shown is not surprising as the ship speed through the water is increased by the speed of the opposing current. For the Cases 19 and 20 the effect of the opposing current gives the highest predicted free surface elevations of all simulations.

A. Vessel study conclusions

If a single ship passing at a constant speed of 4 knots is taken as the reference case, representative of the limit of acceptable passing speeds from earlier analysis, the model predicts water surface elevations to increase slightly when ships are traveling at a constant speed in convoy. However, when the effects of deceleration are considered, model predictions of the water surface elevations are significantly greater than the reference case. Also important is when there is a current running against the direction of ship travel, as the associated water surface elevations also noticeably increase.

Whilst the model results presented provide a useful insight into the free surface elevations and currents associated with the different scenarios, it is not possible to conclude from these results alone that the increased water surface elevations will result in a corresponding increase in moored vessel motions and mooring line forces. TELEMAC-3D modelling results were then used to develop a force time series as input to the SHIPMOOR model in order determine whether the increased water surface elevations resulted in a corresponding increase in moored vessel motions and mooring line forces.

V. SUMMARY

A computational modelling study using a TELEMAC-3D model has been performed to examine the effects of passing ships on water surface elevations. After verifying that the model performed well against measurements, a range of scenarios were modelled to investigate how water surface elevations varied as a result of the number of passing ships, variations in their speed, distance between passing ships, the effects of deceleration and altering slowing locations.

As well as estimating the free surface elevations, the TELEMAC-3D model results were used to develop separate time series of surge, sway forces, and yaw moments that could be used as input to the SHIPMOOR dynamic mooring model. These time series were used to determine whether the effects of multiple passing vessels traveling in convoy, and decelerating, are likely to result in increased vessel motions and mooring forces above that estimated in the previous passing vessel study.

When compared against a case of a single passing vessel travelling at a constant speed, vessel surge motions and mooring forces are predicted to increase as a result of passing vessels travelling in convoy and decelerating upstream.

It has not been possible to fully understand the complex relationships between the forcing parameters as part of this study. Further research is required to further understand the relationship between the following parameters and the relative mooring forces and surge motions:

- the location of the deceleration point
- distance between vessels in convoy and passing speed
- width and draught of the ships
- direction and magnitude of the currents

REFERENCES

[1] J. Parisi, M. Turnbull, A. Cooper, and J. Clarke (2019) “Ship-current interactions with TELEMAC,” *XXVIth TELEMAC-MASCARET User Conference*, 2019.