ABSTRACT

The combination of various hydraulic models (both physical and numerical) and available field data is a unique research platform to setup an intercomparison between different results of these models. This kind of research is rather scarce due to lack of data or only one single model in most research projects.

In a large integrated research project for the port of Zeebrugge, Flanders Hydraulics Research had the opportunity to combine the results of two models in order to perform a detailed analysis of the tidal current in front of a coastal port and to find the best alternative layout for this port. It was also a good occasion to evaluate and to improve the various modeling techniques.

The model intercomparison showed corresponding results and also differences in the current velocity. Based on the analysis it can be recommended to consider not only the output values of a model but to calculate the relative outcome of different runs to interpret the impact of modified layouts of the port.

KEYWORDS: physical model, numerical model, hydrodynamics, tidal current.
2 THE PHYSICAL AND NUMERICAL MODELS

2.1 Physical model

A distorted physical scale model of the port configuration was constructed (Willems et al., 2011) at Flanders Hydraulics Research (FHR), with a fixed bed, an area of 2000 m² (16 km by 10 km in prototype) and a 1:300 horizontal and 1:100 vertical scale. The size of the physical model and provisional boundary conditions of water levels, velocities and discharges were calculated by using a Delft3D numerical model especially calibrated for the Zeebrugge area. By optimizing the time varying boundary conditions and the roughness of the breakwaters and the nearshore zone, the physical model was successfully calibrated (Willems et al., 2014) to obtain a very good agreement for the tidal current (both magnitude and direction) in the access channel to the port. Also the eddy formation in the outer port was modeled correctly.

The physical model simulates a mean spring tidal cycle (12.5 hours in prototype, 25 min in model) and repeats this tidal cycle continuously. The model needs one tidal cycle to start up; model measurements can be performed from the second tidal cycle.
Different measuring techniques are used to measure water level variations and flow velocities. The water level in the model is measured by analog remote ultrasonic sensors. Flow velocities are measured in two different ways:

- The time varying magnitude and direction of the tidal current at specific locations are registered by six 4 quadrant electromagnetic liquid velocity meters at a certain level in the water column (point measurement).
- The time varying surface velocities and current patterns are calculated in specific areas by the Particle Tracking Velocimetry technique (PTV). Two video cameras register 50000 floating hollow white polypropylene particles (diameter 15 mm). In the Streams software these particles are identified in the captured images and all movements are tracked to calculate the velocity vector of all particles (Nokes, 2012). The PTV software generates Lagrangian flow statistics and is able to interpolate these velocities onto a regular grid to obtain Eulerian velocity information. Finally this technique results in velocity vector maps of the area under investigation over the tidal cycle (e.g. Figure 8, left plot).

In the physical model the velocity was measured up to 3000 m in front of the port.

2.2 Numerical model

The numerical Telemac3D model is used to simulate the spring tidal cycle around the port at a larger domain than the physical scale model. The domain of the Telemac model spans a circle with a radius of 70 km around the port of Zeebrugge. The bathymetry close to and inside the port is identical to the physical model (Figure 5).
In the Telemac model the 3D shallow water equations are solved by the finite element method in combination with the advection-diffusion equation for tracers like salinity and temperature. All parameters are discretized in a triangular grid (IMDC, 2013). After choosing the right parameters for the time step, vertical layers, boundary conditions, viscosity and HLES, the model was calibrated by optimizing the Manning coefficient.

The Telemac3D model simulated a neap tide – springtide – cycle (fourteen days) with the springtide at the end of this cycle. The on-site data used for this calibration (Vlaamse Hydrografie, 2016) is different from the data used for the calibration of the physical model.

3 SCENARIOS

Three different port layouts were selected for the comparison (Figure 6).

- scenario T0 present situation with 2 breakwaters (reference layout for model calibration, Figure 6a);
- scenario T17 layout with a modified bathymetry in front of the port entrance (sea bed level lowered 10 m below the actual access channel, in the curved rectangle in Figure 6b);
- scenario T20_2 layout with a modified seabed in front of the entrance (= T17) and an additional western breakwater (Figure 6c).

The reference layout T0 was used to calibrate both models based on prototype measurements. As the available prototype measurements were different for both models, the calibration results were slightly different.

The two modified layouts T17 and T20_2 were designed to reduce the cross current in the access channel in front of the port entrance (Hassan et al., 2014). It was verified and confirmed that the additional breakwater in T20_2 did not introduce model effects due to the distance between the breakwater and the model boundaries.
4 RESULTS AND DISCUSSION

4.1 Water level

The water levels in the 2 models and in prototype are shown in Figure 7. The presented prototype curve is the mean springtide. In general there is a very good agreement between the models and prototype, taking into account the differences in the setup and the calibration of both models. However, there is a small difference between 6h and 3h before highwater but this is acceptable because it is within the confidence band and at the end of the ebb phase when the tidal current is relatively small. In the rest of the tidal cycle, and especially the last 2 hours before highwater when the level raises quickly and the tidal flood current is strong, the water levels are almost identical.

![Figure 7. Comparison between the water level of the models and prototype (scenario T0).](image)
4.2 Velocity

In this section the velocity of the maximum flood current in the tidal cycle (50 minutes before highwater) is discussed. Figure 8 shows the velocity of the maximum flood current in scenario T0 as predicted by both models. The values of the color maps are the same in both figures. Although both figures look very different at first sight, the flow fields are comparable and the flow velocity in the access channel is very similar. The difference in cross current in the access channel is 0.20-0.25 m/s (Figure 9) and the velocity gradient along the channel is almost the same. These observations are important to assess the nautical accessibility of the port.

![Figure 8. Velocity of the maximum flood current in scenario T0 (left: PhysMod – right: Telemac).](image1)

![Figure 9. Maximum velocity of the cross current in the access channel (scenario T0).](image2)

Figure 10 shows the predicted velocity of the maximum flood current in scenario T17 by both models. The velocity difference with scenario T0 (lower plots in Figure 10) shows that the lowering of the bathymetry in front of the entrance has the same effect in both models.

The difference in cross current in the access channel is approximately 0.20 m/s (Figure 11, left), and the velocity gradient along the channel is almost the same. The reduction of the cross current (Figure 11, right) is identical in both models. This means that both models show the same impact of this scenario on the existing tidal current. To overcome the small differences between the calibrated models to assess the nautical accessibility of the port for this scenario, the simulated impact should be applied velocities measured in the field.
Figure 10. Velocity of the maximum flood current in scenario T17 and velocity difference with scenario T0 (left: PhysMod – right: Telemac).

Figure 11. Maximum velocity (left: scenario T17) and reduction (right: (T17-T0)/T0*100) of the cross current in the access channel.

Figure 12 shows the velocity of the maximum flood current in scenario T20_2 (upper plots) and the velocity difference with scenario T0 (lower plots) in both models. It is clear that the new breakwater results in the same increase in velocity in front of the breakwater head and in the same reduction in velocity near the port entrance in both models. On the other hand, the increase of the velocity extends over a different distance. The increased velocity just crosses the access channel in the physical model (left plots) but it drops just before the access channel in the Telemac3D model (right plots). As a consequence there is a difference in cross current in the access channel at 700-2000 m in front of the port entrance (Figure 13). This difference has significant consequences for the evaluation of the nautical access as the safety limit (1 m/s) is violated in the physical model but achieved in the Telemac3D model. Finally the cross current at 200-300 m in front of the port entrance is approximately 70% smaller in both models.
This conclusion shows that model results have to be analyzed carefully, and some uncertainty about the magnitude and the location of the maximum velocity of the tidal current has to be considered.

Figure 12. Velocity of the maximum flood current in scenario T20_2 and velocity difference with scenario T0 (left: PhysMod – right: Telemac).

Figure 13. Maximum velocity (left: scenario T20_2) and reduction (right: \((T20_2 - T0)/T0 \times 100\)) of the cross current in the access channel.
5 CONCLUSIONS

The tidal current in front of the port of Zeebrugge has been investigated in a physical scale model as well as in a numerical model. Both models were successfully calibrated based on different on-site data. A detailed intercomparison has revealed a good agreement between the models but also some differences in the results that have to be considered when analyzing the impact of a modified port layout.

Based on this unique combination of available field data and models, it is proven that velocities calculated in different models can be somewhat different and uncertainty about the current velocities should be taken into account. In this case it is better to analyze the relative impact of a modified scenario by comparing the altered velocities with the calibrated ones. This relative impact can then be used on field data to obtain the best possible results for scenario analysis.

REFERENCES