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NUMERICAL MODELLING OF WAVE PENETRATION, COMPARISON WITH PHYSICAL MODEL AND FIELD MEASUREMENTS IN ZEEBRUGGE HARBOUR

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1. Introduction

The harbour of Zeebrugge is located on the Belgian coast facing the North Sea (cf. Figure 1). It is an important economic port with a LNG-terminal. As a part of the master plan for coastal safety for the Belgian coast, safety measures (e.g. storm walls) are needed in some parts of the harbour to prevent coastal flooding during severe storms. Especially next to the large sea sluice (cf. circle in Figure 1), called the "Vandamme" sluice, there is danger for wave overtopping due to wave penetration.

Figure 1. Zeebrugge harbour (Port of Zeebrugge, 2012). "Vandamme" sluice is encircled.

The wave penetration is modelled using two types of numerical models: MILDwave (Troch, 1998) and Mike 21BW (DHI, 2009). A comparative analysis is done with the results of a physical model and with field measurements as a validation. Separately, SWAN (TUDelft, 2011) is also used to model local wave generation by extreme wind speeds.

2. Numerical modelling of wave penetration

The most important physical processes in a harbour are diffraction, depth refraction/shoaling, (partial) reflection, transmission and non-linear wave-wave interactions. Phase-resolving numerical models are used for the modelling of wave penetration because they can simultaneously account for diffraction and reflection (and standing waves) as opposed to phase-averaged wave models. A linear time dependant mild-slope equation model MILDwave and a more complex non-linear Boussinesq equation model Mike 21BW are used.

The same models were previously employed for the harbour of Ostend (Stratigaki *et al.*, 2010; Gruwez *et al.*, 2011). Applying the sponge layer technique from Brorsen (2000) to model partial reflection, very good agreement between the numerical models and the physical model was obtained for the case of Ostend. The same method is used for the harbour of Zeebrugge, which allows investigation of its robustness for different configurations.

Simulated conditions include H_s=~5.7 m, T_p=~12.0 s, SWL=+6.40 m TAW to +7.90 m TAW,[a] for wave directions N, NNW, NW. Both long (σ=0°) and short crested (σ=20°) waves have been modelled.

The influence of the navigation channel leading to the harbour on the wave climate in the harbour is also investigated. It appears that the navigation channel has a large influence on the wave climate inside the harbour. This was previously also observed in the physical model of Zwamborn and Grieve (1974).

3. Physical modelling and field measurements

A physical model was built by Flanders Hydraulics Research (Wens and Verbist, 1985) for wave agitation studies in the outer harbour of Zeebrugge. Scaling was done according to the Froude law with a geometric undistorted scale ratio of 1:150. Wave measurements were performed inside the model harbour on a 1 m x 1 m grid (on scale of the model) with non-directional wave gauges.

[a] TAW = Tweede Algemene Waterpassing; Belgian standard datum level.

Long crested and monochromatic waves with a wave height H, of 3.0 m and a wave period T, of 9.0 s have been modelled for a still water level SWL, of +4.60 m TAW. The following wave directions were simulated in the wave basin: WNW, NW, NNW, N, NNE and NE. The bathymetry of the physical model included only part of the navigation channel outside the harbour.

Field measurements were performed by IMDC (2011) in the harbour of Zeebrugge during the period between February 2010 and April 2011 (excluding the summer months June, July and August). Pressure sensors of the type PDCR 1830 were placed at three locations in the harbour (cf. Figure 2, right). The highest measured significant wave height at location ZBG_A was 1.00 m for a significant wave height of 2.30 m outside the harbour.

Furthermore, wave measurements are being done continuously by the Coastal Division of the Flemish government with a wave buoy (ZOK) on a location just inside the harbour (cf. Figure 2, left).

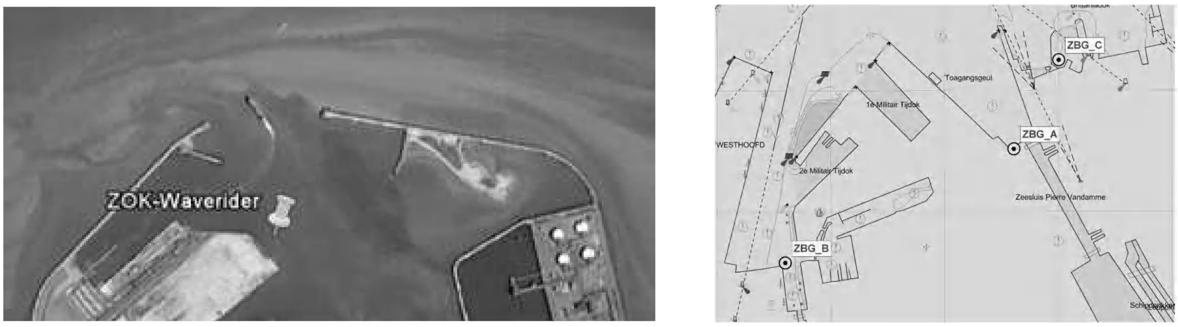

Figure 2. Left: location of wave buoy ZOK (courtesy of ©Google Earth 2010). Right: locations of pressure sensors ZBG_A, B and C (courtesy of Coastal Division).

4. Comparisons

To be able to compare the Mike 21BW model with the physical model and field measurements, the same wave conditions are simulated. Comparing the wave penetration of the numerical and physical model at the wave gauge locations, sometimes large differences can be observed. This is mainly explained by the refraction of long crested and monochromatic waves which is very sensitive to bathymetric differences between the two models. In the main areas of the harbour, however, the evolution of the wave penetration over all wave directions is comparable between the models. The Mike 21BW model including the navigation channel in the bathymetry and applying short crested waves (σ=30°) shows the best correspondence with the field measurements.

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