Numerical and physical modelling of wave penetration in Oostende harbour during severe storm conditions

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1 Introduction

The harbour of Oostende is located on the Belgian coast facing the North Sea. As a part of the master plan for coastal safety for the Belgian coast, safety measures against flooding during severe storms are needed in the harbour. Therefore the hydrodynamic boundary conditions along all the tide and wave afflicted constructions in the inner harbour are required. At the moment the configuration of the outer harbour is being changed dramatically as the old harbour dams are replaced by two new rubble-mound breakwaters (cf. Figure 1) and the access channel is broadened and deepened.

![Figure 1: Harbour of Oostende, original harbour dam layout (left), future breakwater layout (right)](image)

The wave penetration is modelled using a physical model and several numerical models (MILDwave, Mike 21BW and SWAN). A comparative analysis of the results is made and finally the wave conditions along each structure in the inner harbour are determined.

2 Physical model wave data

The future configuration was modelled in a physical wave basin on a scale of 1:100. Wave measurements were performed inside the model harbour at more than 20 locations with non-directional wave gauges and are used to validate the numerical models. Storm conditions with a return period of 1000yrs are a water level of 7.0m TAW, significant wave height of 5.0m and peak wave period of 12.0s and a Jonswap spectrum. Three wave directions were simulated in the wave basin: NW, NNW and -37° which is the direction for which the most wave energy penetrates the harbour. In total 47 wave conditions were modelled.

3 Numerical modelling & comparative analysis

Several numerical models are applied to determine the wave conditions in the harbour under severe storm conditions. Both phase-averaged and phase-resolving numerical wave models are used, but for different purposes as will be explained.

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The most important physical processes in a harbour are diffraction, depth refraction/shoaling, (partial) reflection, transmission and non-linear wave-wave interactions (Battjes, 1994). The 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 the phase-averaged wave models. A linear time dependant mild-slope equation model MILDwave (Troch, 1998) and a more complex non-linear Boussinesq equation model Mike 21BW (DHI, 2009) are used. By comparing both models and validation with the physical model measurements, the applicability of each model is identified.

A severe storm is accompanied by extreme wind speeds, which cause local generation of very short waves in the harbour. The physical model and both phase-resolving models cannot account for this process⁵. The spectral model SWAN (TUDelft, 2010) is a phase-averaged wave model which can model wave generation by wind. Due to the local nature of this process, diffraction plays a minor role and use of the phase-averaged wave model SWAN is acceptable. Only wind and no waves are imposed at the model boundary.

The total wave climate on each location in the harbour is obtained by superposition of the wave penetration wave spectrum and the locally wind-generated wave spectrum. The contribution of the locally wind-generated waves becomes more important deeper into the harbour, where wave penetration from outside the harbour is becoming small and locally wind-generated waves are becoming larger due to the longer travelled fetch length.

Until now only short wave penetration (T < 20s) was considered, but long wave penetration (T > 20s) in Oostende harbour is also of interest. Long waves may lead to resonance and seiching. Resonance frequencies of the harbour are identified by imposing a fictional 'white noise' spectrum (equal amounts of energy at all frequencies) (Gierlevsen, 2001).

4 Resulting boundary conditions inner harbour

Design of the safety measures against flooding is based on a limitation of the overtopping discharge. Formulas to calculate overtopping require the incoming significant wave height, direction and extreme water level. The extreme wave heights along the structures in the inner harbour are determined by superposition of the wave penetration spectrum and locally wind-generated waves. Determination of the incoming significant wave height and wave direction is attempted by using the maximum entropy method on the results from the Mike 21BW model, by investigating the directional wave spectrum from the SWAN model and by analyzing surface elevation snapshots of the phase-resolving model results. The calculated resonance is added to the extreme water level to account for the long wave penetration.

5 Acknowledgements

The Flemish government is acknowledged for funding this research.

6 References


TUDelft (2010): SWAN (Simulating WAves Nearshore); a third generation wave model Copyright © 1993-2011 Delft University of Technology.

⁵ Wind generation of waves is currently under development for MILDwave by the University of Ghent.