Numerical Modeling of Wave Penetration in Ostend Harbour

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INTRODUCTION

The Ostend harbour, which is situated at the North Sea coast of Belgium, concentrates activities related to handling of goods and passengers. Therefore, safety and economical reasons lead to a plan of extension and modification of the initial Ostend harbour entrance (Fig.1a) with two new rubble-mound breakwaters (Fig.1b). The design of the breakwater layout depends on navigation requirements and wave penetration into the inner harbour. For the flood risk assessment of the adjacent and low lying city centre, the water level during storm conditions has to be analysed. Moreover long waves inside the inner harbour may cause unwanted ship agitation. Three port configurations are considered: the initial, an intermediate and the final configuration with two new rubble-mound breakwaters. In the frame of an integrated study of the wave penetration in Ostend harbour, the waves are being acquired through prototype measurements and physical and numerical modeling is carried out.

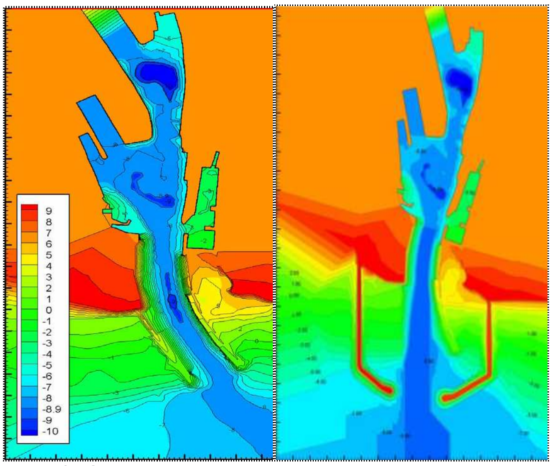

Fig. 1. Ostend harbour, bathymetry and geometry: a) initial situation, b) final situation

Two numerical models are used for the port study: SimWave, based on Nwogu's extended Boussinesq model equations and MILDwave, a mild-slope wave propagation model based on the equations of Radder and Dingemans. The present study concentrates on the various applications of the above mentioned numerical models, throughout the different design stages and construction phases, leading gradually to the final layout of the Ostend harbour.

PROTOTYPE MEASUREMENTS AND PHYSICAL MODELING

For the acquisition of field data, seven wave gauges have been placed inside the harbour (Fig. 2). Two wave buoys, east and west of the harbour entrance (approx. 800 m off the coast) measure the incident wave climate. All wave gauges (DRUCK pressure sensors) have battery power supply and dedicated signal conditioning and data-acquisition for stand-alone use. The sensors are placed approx. 2.0 m below low water level. Pressure is converted to surface elevations. Short and long waves, and storm set-up are derived, as well as 15 min wave spectra. Up to now a data-set of 4 years has been collected. The calibration of the models is based on the storms which occurred during the initial and intermediate harbour situation.

Physical model tests (3D; scale 1:100) carried out at Flanders Hydraulics Research (FHR, Belgium) target the study of the three different harbour situations. Wave gauges at the seven validation positions were also included in the physical model.

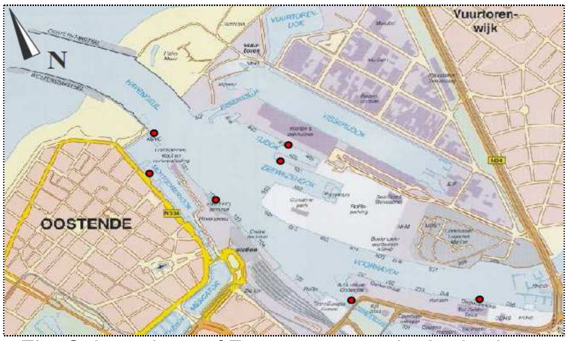

Fig. 2. Locations of 7 wave gauges in the harbour

NUMERICAL MODELING

The numerical results in the inner harbour are validated using the wave data acquired during the field measurement campaign. Runs using hydraulic conditions with return period 1 year simulate the condition in service and are used for the validation with field data. Runs with higher storm return period provide the risk of overtopping over the quay walls in the inner harbour. Results of the numerical simulations are presented in terms of significant wave heights and a disturbance coefficient (k_d) for the calculation domain. This coefficient is given by the ratio H_s/H_{sGB}, where H_s is the local significant wave height and H_{sGB} is the wave height at the wave generation boundary.

Throughout the different design stages and construction phases, numerical results have been used for various purposes, according to the needs of the evolving harbour layout. In this respect a number of wave conditions has been investigated numerically, i.e. different return periods and therefore focusing either on short term results (RP=1yr or daily wave conditions, which are more important during construction phases) or on a longer term (RP=100yrs;1000yrs). Other numerical studies provide wave conditions at particular port locations which become of great interest due to a dynamic situation within the harbour, caused by bathymetry and geometry changes. Numerical modeling is also used for the investigation of the most critical wave direction in terms of wave penetration in the outer and the inner harbour for each of the construction phases and for the simulation of prototype storms. Moreover, input for the armour stability calculations of the two breakwaters has been provided by the numerical models. Modifications with regard to the port bathymetry and geometry are numerically examined, i.e. changes in the bed level, the width or the direction of the access navigation channel, removal of the eastern jetty, submerged or emerged breakwaters according to the construction phase etc.

DESCRIPTION OF THE NUMERICAL MODELS

Two numerical models have been validated and are being used for the harbour studies. SimWave (Sinha et al., 1998) is a numerical model based on Nwogu's extended Boussinesq model equations, which are solved in the time domain. Wave propagation and transformation are simulated, including shallow water effects (e.g. shoaling, refraction, diffraction, wave run-up and breaking). Previous simulations have been carried out (Geeraerts et al., 2002) to study the wave propagation for the final situation.

The second numerical model is MILDwave, a mild-slope wave propagation model based on the equations of Radder and Dingemans (1985) and developed by Troch (1998).The phaseresolving model MILDwave is able to generate linear water waves over a mildly varying bathymetry and to calculate instantaneous surface elevations throughout the domain. Wave transformation processes such as refraction, shoaling, reflection, transmission and diffraction can be simulated intrinsically. MILDwave is able to provide with results in a time efficient way, even for large grids.

DISCUSSION OF RESULTS

A series of simulations concern the initial situation, the present configuration of the port, as well as the latest design modifications on the final situation.

Illustrative results are presented in the following figures. Figure 3 shows a validation of numerical and physical model results at several port locations using prototype data.

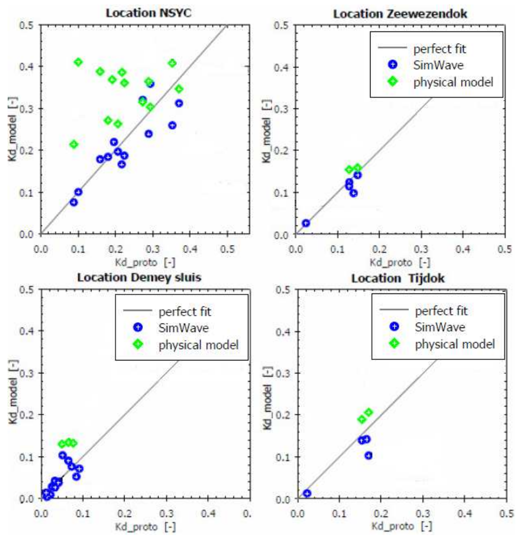

Fig. 3. Validation of model results at several port locations using prototype data

In Figure 4, a contour plot of the disturbance coefficient values (k_d) for the entire harbour area using SimWave results is presented.

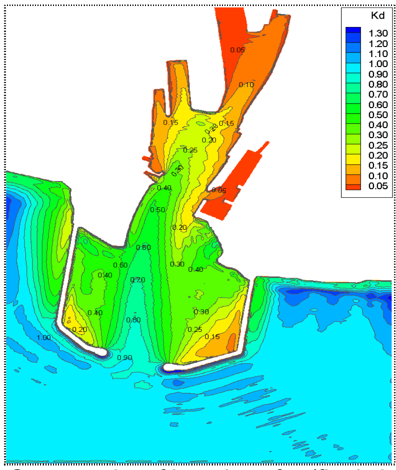

Fig. 4. Contour plot of k_d values for (final situation)

In Figure 5, k_d values of a longitudinal section located in the outer harbour are depicted for the two numerical models and good agreement is observed for both of the presented wave directions.

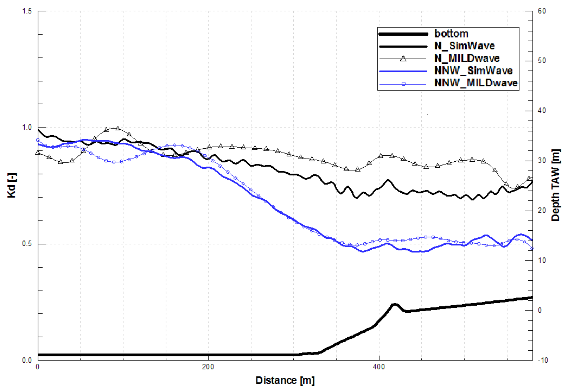

Fig. 5. Simwave and MILDwave results within a longitudinal section of the outer harbour

CONCLUSIONS

Extension and modification works have been planned and are carried out for the port of Ostend. Wave penetration into the extended Ostend harbour has been studied numerically using two numerical models: SimWave (solving Boussinesq equations) and MILDwave (solving mild slope equations). Validation using prototype data has been carried out. Results acquired by the two numerical models show, in general, good agreement. More detailed results will be presented in the paper.

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