NUMERICAL SIMULATION OF WAVE OVERTOPPING OVER A SMOOTH IMPERMEABLE SEA DIKE

Introduction

Dikes protect the coastlines of Belgium, The Netherlands, Germany, Denmark and Poland over several thousands of kilometres from waves and flooding. Therefore the correct design of these coastal structures is very important to avoid high costs, in both cases of overdesign and underdesign. In general the design is based on design storm surge levels and a 2% exceedance wave run-up. However wave overtopping has to be taken into account due to the remaining uncertainties in storm surge level and wave run-up.

Physical model tests on a smooth impermeable sea dike have been performed recently in the wave flume of Leichtweiss Institut für Wasserbau (LWI, Germany). Measurements from layer thickness, overtopping velocities, individual overtopping volumes and average overtopping rates are available for validation of numerical simulations.

In this study, numerical simulations of wave overtopping over a smooth sea dike have been carried out using the numerical model VOFbreak^2. VOFbreak^2 is a two-dimensional model based on the Navier-Stokes equations for incompressible fluid flow and the Volume-Of-Fluid (VOF) method for treating the free surface configuration. The main objective is to compare the results of numerical simulations of the wave overtopping over the dike with experimental data from the physical model.

Methodology

The geometry of the sea dike is shown in Fig. 1. The seaward (or outer) slope is 1:6, the landward (or inner) slope is 1:3. The crest height is 0.80 m. The crest and both slopes are impermeable and smooth to the external fluid flow. For the numerical simulations, the water depths d = 0.70 m, 0.75 m and 0.80 m have been used. The computational grid covers the area depicted in Fig. 1. The foreshore area is limited to 1.0 m. The outer slope 1:6 and the crest are included in full length. Only part of the inner slope is included (a length of 0.20 m). The height of the wave flume is 1.0 m. On the crest, two sections S1 and S2 are defined at the seaward (position x = 5.8 m) and landward side (x = 6.1 m) of the crest. These are used for calculation of the overtopping quantities.

The non-uniform grid of the computational domain (Fig. 1) is composed of 160 x 28 cells with varying cell sizes: Δx ranges from 0.020 m at $x = 5.5$ m to 0.060 m at $x = 0$ m; Δy ranges from 0.020 m at $y = 0.70$ m to 0.056 m at $y = 0$ m. Using this set-up the highest resolution is obtained along the outer slope between the Still Water Level (SWL) and the crest, and on the dike crest itself. It is believed that these areas are most critical for accurate numerical calculations. The dike slopes and dike crests have been modelled as impermeable boundaries cutting through the cells, thus allowing a perfect representation of the dike slope.

Nine simulations with varying wave height, wave period and water depth have been carried out.

Results

Fig. 2 shows the typical result from a numerical simulation of the sea dike using VOFbreak^2, for tests 2, 2_75 and 2_80 (with increasing water depth), for a

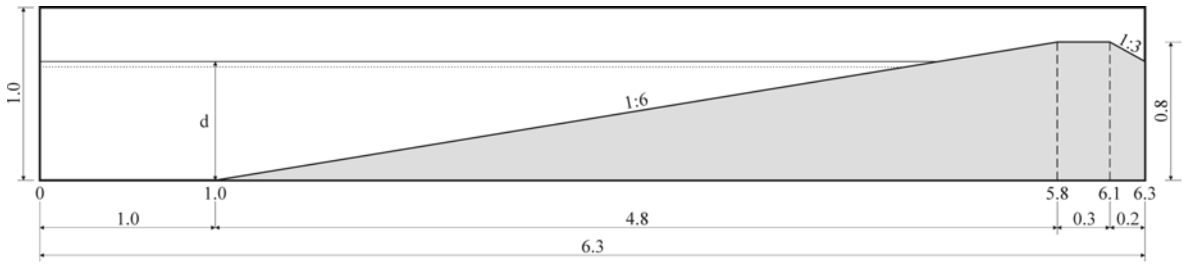

Fig. 1. *Cross section of the sea dike cf. physical model tests at LWI .*

zoomed area near the dike crest (between $x = 4.0$ m and $x = 6.3$ m). The three plots show the free surface configurations at $t = 9.0$ s. The wave running up the slope is clearly observed. A comparison of wave overtopping on the dike crest for test 2, 2_75 and 2_80 respectively, at $t = 9.0$ s is made. For higher water depths the layer thickness on the crest and the volume of overtopping water increases clearly. Fig. 2 illustrates that the physical processes of wave run-up and overtopping seem to be modelled in a realistic way.

Fig. 3 shows the time series of cumulative volume of overtopped water $V(t)$ at both sections S1 (at x = 5.8 m) and S2 (at x = 6.1 m), for test 3. A regular pattern of the wave overtopping in section S1 is present. The cumulative overtopping volume in section S2 is time shifted (time required for the water to propagate over the crest), and seems to underestimate slightly the recorded overtopping volume in section S1. Seven individual overtopping events are present. The cumulative volume of water increases first and decreases slightly afterwards, during one wave period. This effect is due to the negative values of the discharge meaning that water is flowing in the negative (i.e. seaward) direction at the start of the run-down.

The resulting average overtopping rates have been derived. A quantitative comparison of the results from the simulations (q_{num}) and the physical model tests (q_{lab}) show good agreements for the average overtopping rates: a ratio q_{num}/q_{lab} = 0.81 on average is obtained. This agreement is better for higher overtopping volumes. It has been shown that the results are very much dependent on the grid definition.

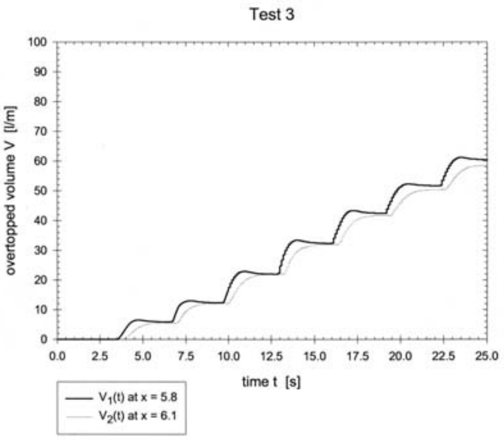

Fig. 3. *Time series of cumulative volume of overtopped water* $V(t)$ *at both sections S1 and S2, for test 3.*

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Contact

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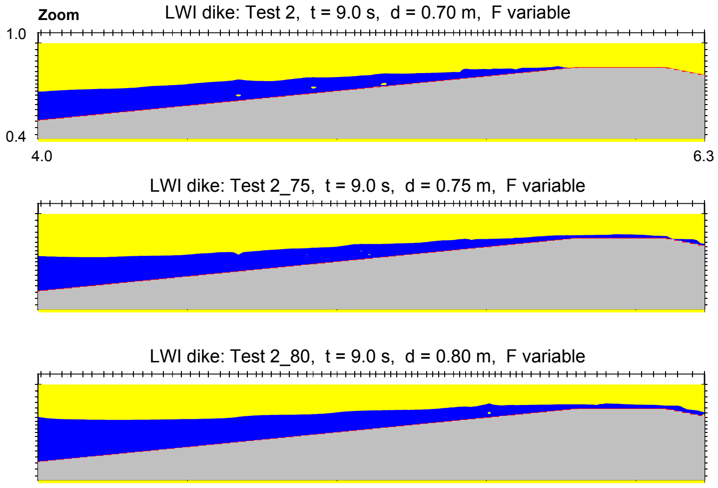

Fig. 2. *Free surface configurations at t = 9.0 s, for a zoomed area near the dike crest, for test 2, test 2_75 and test 2_80 (with varying water depth).*