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Effects of new variables on the overtopping discharge at steep rubble mound breakwaters — The Zeebrugge case

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ABSTRACT

This paper describes on the one hand parametric tests on wave overtopping for a steep rubble mound breakwater in Zeebrugge, Belgium. On the other hand the comparison between prototype measurements at the breakwater and their scale reproductions in two laboratories is dealt with. The objective is to gain information on possible scale and model effects for wave overtopping from this comparison. The prototype measurements are described together with the resulting dataset of 11 storms where wave overtopping occurred. Scale models and the laboratory measurements are described into detail mentioning similarities and differences to the prototype. Several model effects are identified and special attention is given to wind effects and to the placement pattern of the armour units, respectively. Monte Carlo simulations have been performed to get an idea about the influence of selected model uncertainties. Finally, scale effects are discussed and the influence of model and scale effects for the performed tests is quantified. Recommendations on how to treat these effects are presented.

1. Introduction

One of the main outcomes of the EC OPTICREST project was that wave run-up height on a rubble mound breakwater is underestimated in small scale models as compared to full scale by about 20% (De Rouck et al., 2001). Scale and model effects were suspected to be the reason for this difference. Since wave overtopping is closely related to wave run-up, model and scale effects are suspected for wave overtopping too.

Given the fact that the allowable amount of overtopping often is a governing parameter in the crest level design of coastal structures, possible scale/model effects can have important consequences. Therefore, one of the main objectives of the research project CLASH, was to solve the problem of suspected scale and/or model effects for wave overtopping. To accomplish this objective, field measurements on wave overtopping have been carried out at three locations in Europe. The three prototype sites have then been modelled in at least two different laboratories and laboratory results are compared to prototype results to come to develop new guidance on possible scale and/or model effects. The present paper deals with the laboratory tests carried out on small scale models of the breakwater. The focus is put towards model effects.

First the Zeebrugge prototype site and the measured storms are described. Then the scale models are described. Laboratory tests are described into detail and model effects are given and quantified. Finally a comparison between prototype and model overtopping results is made.

2. Zeebrugge rubble mound breakwater

The Zeebrugge breakwater is a conventional rubble mound breakwater with a low superstructure (Fig. 1).

The armour layer consists of grooved (Antifer) concrete cubes (25 t). The breakwater core consists of quarry run (2–300 kg). The filter layer is composed of rock (1 3 t). Design conditions for the breakwater are: return period $R_p = 500$ years, significant wave height $H_s = 6.20$ m, period $T_p = 9.0$ s and design water level DWL=Z+ 6.75 m (Z+0.00 m is chart datum). The cross section at the location of the overtopping measurements is shown in Fig. 1. An overall plan view of the location of wave and overtopping measurements is shown in Fig. 2.

Wave characteristics are measured by 2 wave rider buoys, at respective distances of 150 m and 215 m from the breakwater of which the latter one is directional. The water level just in front of the breakwater is determined by an infrared wave height meter and a radar placed on a measurement jetty as described in Troch et al. (1998). Water overtopping the breakwater's crest is captured in a

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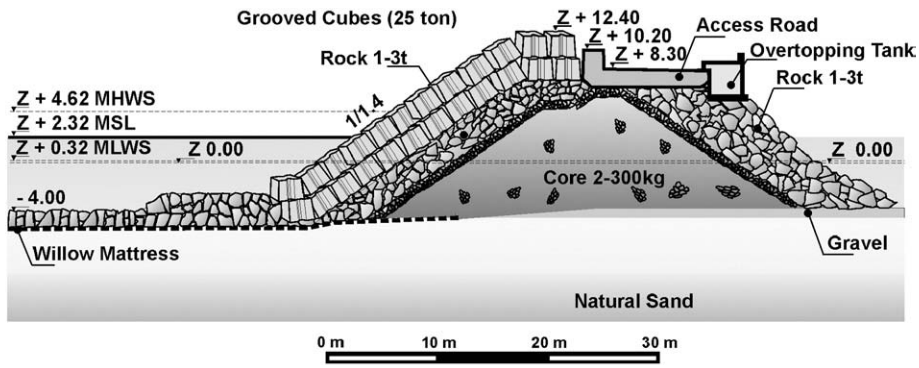

Fig. 1. Cross section of Zeebrugge rubble mound breakwater.

concrete overtopping tank (Fig. 3) with dimensions 7.4 m×2.0 m×2.0 m (length×width×height). The volume of overtopping water is determined by continuous water level measurements by pressure transducers at the bottom of the tank. Outflow of the tank is controlled by a calibrated weir. The water level measurements and the Weir's calibration formula allow calculating overtopping discharges.

3. Prototype storms

From 1999 to mid 2004, 11 storm events with wave overtopping have been measured. Wave heights H_{m0} vary between 2.60 m and 3.86 m, while wave periods T_p and $T_{m-1.0}$ range respectively between 7.3 s and 10.3 s and 6.49 s and 8.41 s. Crest freeboards A_c vary between 6.7 and 7.7 m. Characteristics for the storm with the highest measured average overtopping rate, q=0.86 l/s/m, were H_{m0}=3.86 m, T_p=8.6 s and A_c=7.42 m, in which A_c is the crest freeboard being the distance between SWL and the mean crest level (Z+12.02) in front of the overtopping tank. The value Z+12.02 is calculated as the mean crest level in front of the structure (see also Fig. 6) and is therefore different from the Z+12.40 level (Fig. 1), which is the top level. Full scale measurement data including detailed analysis of these data are found in Geeraerts & Boone (2004). Comparison of full scale data to literature prediction formulas are presented and discussed in detail in Troch et al. (2004). Table 1 gives an overview of these storms together with the measured mean overtopping discharges.

4. Laboratory test facilities and scale models

4.1. Wave generation

The wave flume at Leichtweiss Institute of Braunschweig University (LWI) is 100 m long, 2 m wide and 1.25 m deep. At LWI, waves are generated by a flap type wave paddle that is capable to produce regular and irregular waves (theoretical wave spectra and natural wave spectra) with wave heights up to 0.25 m and wave periods up to 6.0 s for water depths between d=0.60 m and 0.80 m. There is no active absorption available in the LWI wave flume.

The wind and wave test facility at Universitad Politécnica de Valencia (UPVLC) is 30 m long, 1.2 m wide and 1.2 m deep. At UPVLC, waves are generated by a piston type wave paddle that is capable to produce regular and irregular waves (theoretical wave spectra and natural wave spectra) with wave heights up to 0.40 m and wave periods up to 3.0 s for water depths at the test area between d=0.35 m and 0.65 m. There is no active absorption available in the UPVLC wind and wave test facility.

The influence of the lack of active wave absorption could be the accumulation of energy in the flume if reflections are high. However, when fitting wave spectra in the flume (see Section 6) to wave spectra from the prototype a limited number of waves were used (300 waves). When performing storm reproductions at least 1000 waves were used. The spectrum in the flume after the total test duration was always very similar to the fitted spectrum, which means that if there was an energy accumulation in the flume it was very limited.

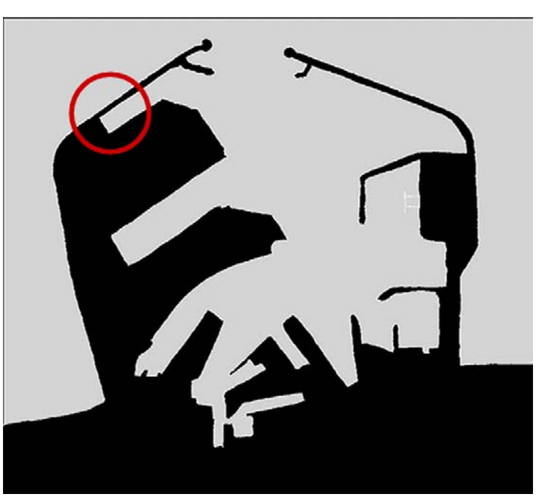

Fig. 2. Layout of Zeebrugge harbour indicating position of measurements.

Fig. 3. Overtopping tank behind crest.