HYDRODYNAMIC BEHAVIOUR OF LOW-CRESTED SLOPES

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1. Introduction

The state-of-the-art knowledge on smooth coastal structures is mainly limited to mildly sloping dikes and vertical walls, which are particularly designed to limit wave overtopping and therefore typically feature a high crest freeboard. However, in severe storm conditions the crest freeboards of these structures are low, which means that their overtopping and reflective behaviour are expected to be inaccurately predicted by existing prediction formulae in those critical situations.

This paper presents the results of a fundamental study on the relationship between the geometry of low-crested slopes, the wave characteristics and (1) the amount of wave overtopping, (2) the reflective behaviour and (3) the probability distribution of the wave-by-wave overtopping volumes.

2. Methods

All three aspects are investigated based on an experimental study (Froude length scale 1:30 compared to wave characteristics in Danish North Sea). A test set-up is developed that is able to measure large overtopping volumes accurately (Figure 1), using a weigh cell. The average overtopping rate and individual overtopping volumes are derived based on the weigh cell signal. The accuracy of the measurement technique is determined by the accuracy of the calibration curve of the reservoir (in between two pumping events) and by the accuracy of the compensation for pumping (during a pumping event).

Tests with broad ranges of slope angle α ($0.36 \leq \cot\alpha \leq 2.75$), relative crest freeboard R_c/H_{m0} (ratio of crest freeboard R_c and characteristic wave height H_{m0}, $0.1 \leq R_c/H_{m0} \leq 2.0$) and wave steepness s (ratio of wave height and wave length, $0.02 < s < 0.05$) are carried out.
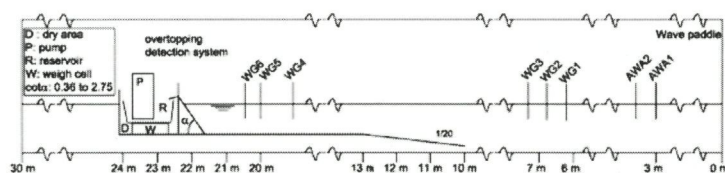

Figure 1. Sketch of developed test set-up. Tests carried out in wave flume with dimensions 30 m x 1.0 m x 1.2 m (l x w x h) at Ghent University, Belgium

3. Results, discussion and conclusions

3.1 Average overtopping rate

Measured overtopping rates are compared with average overtopping rates predicted by commonly used prediction models from literature (empirical formulae and a neural network tool). It appears that the slope angle and relative crest freeboard are the dominating parameters for the average overtopping rate of steep low-crested slopes. An increase in the relative crest freeboard causes a decrease in the average overtopping rate, which is less explicit for smaller relative crest freeboards.

Furthermore, the effect of the slope angle is relatively weak for milder slopes – although a maximum average overtopping rate is reached, while it is more explicit for steeper slopes: there is a significant decrease in average overtopping rate towards vertical walls. The effect of the slope angle is larger for larger relative crest freeboards. The effect of the wave period is relatively small; it corresponds to a dependency of the optimal slope angle (resulting in the maximum average overtopping rate) on the wave period.

The comparison with the predicted average overtopping rates shows that none of the existing prediction models is able to predict all of these effects accurately. Therefore, a set of new prediction formulae is derived based on the experimental test results. The reliability of the set of new formulae is discussed. A number of graphical examples - in which the measurements are compared to predictions by the set of new formulae - confirm the validity of the new formulae.

3.2 Reflection coefficient

The reflection coefficients are determined based on the signals of three wave gauges positioned in front of the slope. The reflection coefficients cover a broad range for the experiments (0.3 up to almost 1.0). Existing prediction formulae for the reflection coefficients exist for both structures without wave overtopping and structures with wave overtopping.

The formulae for the first type of structures are only a function of the slope angle and the wave characteristics. A reduction factor, which is a function of the relative crest freeboard, is applied for the structures with overtopping. This methodology has not yet been applied to overtopped non-porous structures before.

Based on the measured reflection coefficients, a new prediction formula is derived, composed of a formula for non-porous structures without wave overtopping and a reduction factor (both found in literature). Furthermore, the relationship between the reflection coefficient and the average overtopping rate is also discussed, based on the energy balance equation.

3.3 Probability distribution wave-by-wave overtopping volumes

It appears that the measured overtopping volumes for the steep low-crested slopes also follow a Weibull distribution. Furthermore, the shape factor is mainly dependent on the relative crest freeboard and the slope angle. An average shape factor of 0.75 is found for the larger relative crest freeboards, while shape factors up to 1.5 are identified for smaller relative crest freeboards (in between those of sea defence structures and dikes with a negative crest freeboard). A larger value of the shape factor corresponds to smaller values of the largest overtopping volumes. Furthermore, the shape factor linearly increases for a decreasing slope angle.

The probability of overtopping, which plays an important role for the scale factor of the Weibull distribution, is also mainly dependent on the relative crest freeboard and the slope angle. The effect of the relative crest freeboard is according to a Rayleigh distribution. An increase in slope angle decreases the probability of overtopping, expressed by a linear function of the cotangent of the slope angle.

Two formulae are derived which take into account the observed effects of the slope angle and relative crest freeboard on the shape factor and probability of overtopping.
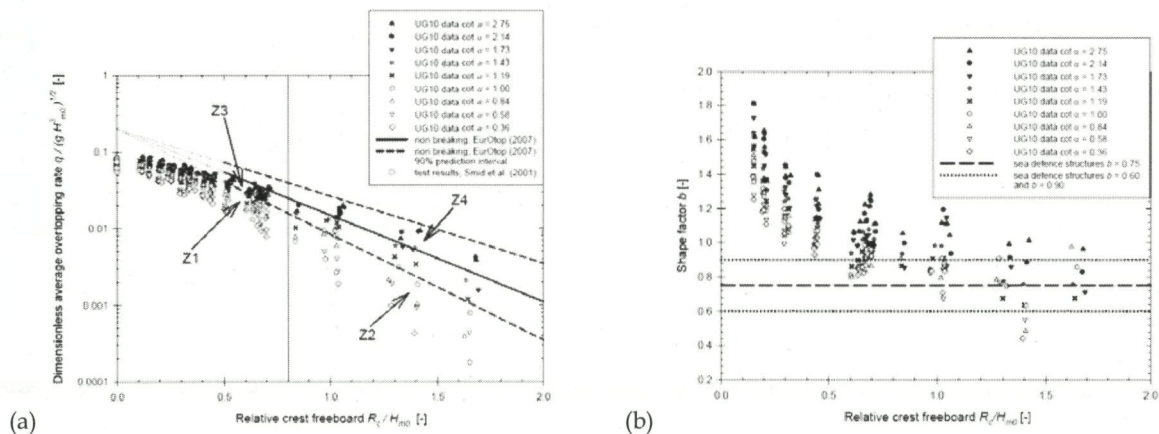

Figure 2. Important resulting figures on average overtopping rate (a) and shape factor of the Weibull distribution of individual overtopping volumes (b).

Acknowledgments

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