Aalborg Universitet

Model Study of Wave Overtopping of Marine Structure for a Wide Range of Geometric Parameters

Kofoed, Jens Peter

Published in:
Ph.D.-Papers in Technology and Science : Spring 2000

Publication date:
2000

Document Version
Publisher's PDF, also known as Version of record

MODEL STUDY OF WAVE OVERTOPPING OF MARINE STRUCTURE FOR A WIDE RANGE OF GEOMETRIC PARAMETERS

Jens Peter Kofoed

Hydraulic & Coastal Engineering Laboratory, Department of Civil Engineering, Aalborg University, Sohngaardsholmvej 57, DK-9000 Aalborg, Denmark

Abstract: The objective of the study described in this paper is to enable estimation of wave overtopping rates for slopes/ramps given by a wide range of geometric parameters when subjected to varying wave conditions. To achieve this a great number of model tests are carried out in a wave tank using irregular 2-D waves. On the basis of the first part of these tests an exponential overtopping expression for a linear slope, including the effect of limited draught and varying slope angle, is presented. The plans for further tests with other slope geometries are described.

Keywords: Wave overtopping, physical model tests, utilization of wave energy.

1. INTRODUCTION

When designing sea defence structures such as seawalls, breakwaters and dikes, one of the main objectives is to minimize or even eliminate wave overtopping. For this reason numerous investigations have been performed over the past fifty years to determine the amount of overtopping occurring for typical sea defence structures. This also means that the vast majority of these investigations have focused on structure designs that minimize the amount of overtopping and wave situations where small or moderate amounts of overtopping occur (see e.g. Burcharth and Hughes (2000) or Van der Meer (1998) for an overview).

For some marine structures, such as "wave pumps" (for circulation of water in harbour basins in areas with insufficient tidal range for natural circulation) or wave energy devices based on the overtopping principle, it is desirable to maximize the amount of overtopping. Furthermore, a number of the proposed wave energy devices utilizing overtopping are floating structures, which means that the structure is not extending all the way to the seabed, but has a limited draught. It has been found that very little useful information is available in the literature on how to estimate overtopping of such structures.

In the light of this a physical model study is performed, in which it is investigated how a wide range of different geometric parameters influence the overtopping rate when the structure is subjected to varying wave conditions.

2. METHODS

During the model tests the influence on the overtopping rate of the following geometrical parameters is investigated (see Fig. 1):

- Profile shape.
- Draught.
- Crest freeboard.
- Shape of cross section.
- Shape of guiding walls.

All model tests are performed in a wave tank with a constant water depth of 0.5 m. The model tests are performed using fixed structures.

In general the amount of overtopping depends on a number of wave parameters, such as wave height and period, spectral shape, angle of wave attack, directional spreading, etc. In the performed tests the wave situations have been limited to irregular 2-D waves. The irregular waves are generated using the parameterized JONSWAP-spectrum with a spectral

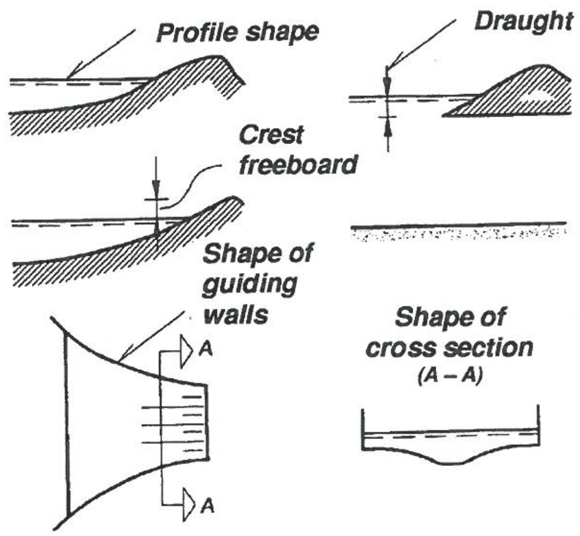

Fig. 1. Geometric parameters investigated.

enhancement factor γ = 3.3 – this corresponds to wave conditions in the North Sea. Each of the tested geometrical setups has been subjected to 37 different wave situations with wave steepness (ratio between wave height and length) varying from 0.01 to 0.09. Each of the wave situations consists of 1.100 to 3.600 waves, depending on the wave peak period.

Furthermore, overtopping is dependent on the geometric parameters describing the structure and also on surface roughness and permeability of the structure. However, it is commonly accepted that introduction of surface roughness and permeability decreases the overtopping, and therefore only smooth and non-permeable structures are investigated in this study.

The model study has been divided into two phases. In the first phase tests have been performed with a straight profile. For this type of structure the influence of varying crest freeboard, draught and angle of the slope on the overtopping has been thoroughly investigated. In the second phase which has yet to be carried out, focus has been put on the influence on the overtopping of modifications to the slope geometry, in terms of the shape of slope cross section and guiding walls.

3. RESULTS

3.1 Overtopping of straight slope

In the first test phase the ranges for the varied geometrical parameters are as follows:

- Relative crest freeboard R (=R_c/H_S): 0.1 to 2.4.
- Relative draught (d_r/d): 0.2 to 1.0.
- Slope angle: 20° to 60°.

In total 13 series of tests with a straight profile have been performed. This corresponds to 481 individual tests.

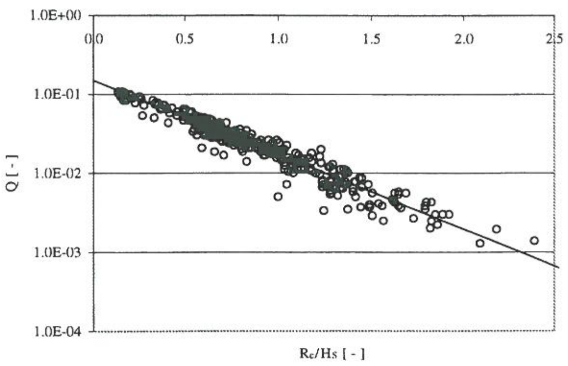

Fig. 2. Non-dimensional overtopping rates as measured in model tests with straight slope profile as a function of the relative crest freeboard. The line represents eq. (1).

From these tests it is found that an overtopping formula on an exponential form ($Q = Ae^{-BR}$) as proposed by Owen (1980), Van der Meer (1998) and others, describes the non-dimensional average overtopping rate Q well. In order to take the influence of varying slope angles and limited draught into account if the factors γ_θ and γ_{d_r} is introduced:

$$Q = \frac{q}{\gamma_\theta \gamma_{d_r} \sqrt{gH_s^3}} = Ae^{-B\frac{R_c}{H_s}} \qquad (1)$$

where

$$\gamma_\theta = \cos^\beta(\theta - \theta_0)$$

$$\gamma_{d_r} = 1 - \alpha \frac{\sinh\left(2k_p d\left(1-\frac{d_r}{d}\right)\right) + 2k_p d\left(1-\frac{d_r}{d}\right)}{\sinh(2k_p d) + 2k_p d}$$

and

A found to be 0.15 by best fit.
B found to be 2.2 by best fit.
θ_0 is the slope angle at which the largest overtopping rates are obtained, all other parameters being equal. Found to be 30°.
β is controlling the degree of influence of the slope angle. Found to 3 by best fit.
α is controlling the degree of influence of the limited draught. Found to 0.4 by best fit.
q is the average overtopping rate pr. ramp width.
g is acceleration of gravity.
H_S is the incident significant wave height.
R_c is the crest freeboard.
θ is the slope angle to horizontal.
k_p is the wave number $2\pi/L_p$.
L_p is the local wavelength corresponding to T_p.
T_p is the wave peak period.
d is the water depth.
d_r is the draught.

The measured data from the model tests along with the expression given in eq. (1) is shown in Fig. 2. A comparison of measured data and eq. (1) results in a R^2 value (the coefficient of determination) of 0.92 indicating a reasonably good fit.

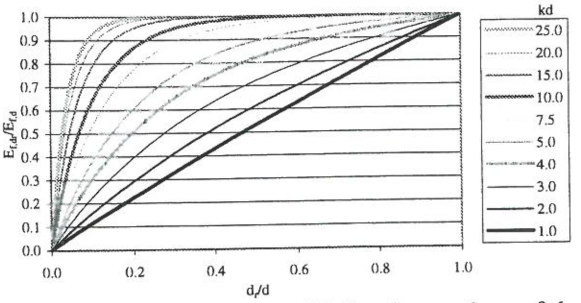

Fig. 3. The variation of eq. (2) for given values of the product *kd* (small value shallow water, deep water corresponding to deep water).

The dependency of the draught introduced through the factor γ_{d_r} is based on the time averaged ratio between the amount of energy flux integrated from the draught up to the surface (E_{f,d_r}), and the energy flux integrated from the seabed to the surface ($E_{f,d}$).

$$\frac{E_{f,d_r}}{E_{f,d}} = \int_{-d_r}^{0} p^+ u \, dz \Big/ \int_{-d}^{0} p^+ u \, dz \qquad (2)$$

$$= 1 - \frac{\sinh\left(2kd\left(1-\frac{d_r}{d}\right)\right) + 2kd\left(1-\frac{d_r}{d}\right)}{\sinh(2kd) + 2kd}$$

where

p^+ is the excess pressure caused by the wave.
u is the horizontal particle velocity component.

The variation of $E_{f,d_r}/E_{f,d}$ as a function of d_r/d and the product *kd* is illustrated in Fig. 3.

In the derivation of eq. (2) linear wave theory for a harmonic wave is used. Because of the limitations in the linear wave theory eq. (2) cannot completely describe the effect of limited draught on overtopping. Using γ_{d_r} equal to eq. (2) would lead to an estimation of zero overtopping for $d_r = 0$ which is not be the case for all combinations of H_S and R_C. Therefore the coefficient α is introduced and the expression for γ_{d_r} given in eq. (1) is obtained.

The expression for γ_θ in eq. (1) is formulated so it is 1 for the optimal slope angle in terms of maximum overtopping and decrease when the difference between the optimal and actual slope angle increases.

3.2 Tests with modified slope geometry

In order to limit the already large number of model tests needed, the tests of modified slope geometry are performed for a single choice of crest freeboard, angle of slope and draught. The influence of the following modifications to the slope geometry is investigated in the second phase:

- Slope with convex upper part (sector of circle, sector of ellipse).
- Slope with concave upper part (sector of circle).
- Converging leading walls (straight).
- Converging leading walls (sector of circle, sector of ellipse).
- Ditch in slope.

Finally, utilizing the results of this investigation the optimal combination of these modifications is tested. This part of the study has not yet been concluded.

4. CONCLUSION AND DISCUSSION

Eq. (1) is found to give a good estimation of the overtopping of a linear, smooth and impermeable ramp for varying draught, slope angle, crest freeboard and wave conditions. Eq. (1) agrees well with overtopping expression found in the literature, e.g. Van der Meer (1998) who suggests a similar expression with comparable coefficients for comparable conditions. The major difference between earlier published overtopping expressions and eq. (1) is the introduction of the dependency of the draught and the slope angle.

Using the results of the second phase of the model testing, the effect of geometric changes of the ramp on the overtopping will be included in the overtopping expression. This expression can then be used for overtopping of marine structures given by a wide range of geometric parameters and for varying wave conditions.

ACKNOWLEDGEMENT

The study is carried out at Hydraulics & Costal Eng. Lab., Aalborg University, and has been cofunded by the Danish Energy Agency under the Wave Energy Program.

REFERENCES

Burcharth, H. F. and S. Hughes (2000). Coastal Engineering Manual, Fundamentals of Design. Chapter 5, Part VI. To be published by Coastal Engineering Research Center, Waterways Experiment Station, US Army Corps of Engineers,Vicksburg, USA.

Owen, M. W. (1980). Design of Sea Walls Allowing for Wave Overtopping. Rep. EX 924, HR Wallingford.

Van der Meer, J. W. (1998). Wave Run-Up and Overtopping. Chapter 8 in Dikes and Revetments, Design, Maintenance and Safety Assessment. Ed. K. W. Pilarczyk, A. A. Balkema, Rotterdam, Brookfield.