INFLUENCE FACTORS FOR CREST WIDTH, ROUGHNESS AND WAVE PERIOD ON OVERTOPPING OF RUBBLE MOUND STRUCTURES

Koen Van Doorslaer, DEME & Ghent University, van.doorslaer.koen@deme-group.com
Mads Røge Eldrup, Aalborg University, mrel@build.aau.dk
Thomas Lykke Andersen, Aalborg University, tla@build.aau.dk
Jentsje van der Meer, Van der Meer Consulting BV & IHE Delft, jm@vandermeerconsulting.nl

INTRODUCTION

New data was collected in the wave flumes of Ghent University and Aalborg University on wave overtopping discharges over rubble mound structures, focusing on the influence of (large) crest width and surface roughness in combination with wave period. Combining these new data with existing data, analysis has led to the improvement of the guidance for wave overtopping prediction. The data and full analysis are presented in Eldrup et al. (2022). The present extended abstract adds a comparison of this improved guidance to the Neural Network prediction by Formentin et al. (2017), and to the EurOtop (2018) prediction.

AVAILABLE DATA

In the newly collected data (243 tests), the front slope angle (cotα = 1.5, 2 and 3) was varied, but also the crest width ($0.45 < G_c/H_{m0} < 5.2$), the freeboard ($0.53 < R_c/H_{m0} < 3.74$) and the wave steepness ($0.5\% < s_0 < 4.2\%$) had a wide spreading. These new tests were combined with 645 existing tests from 5 test campaigns, a.o. Bruce et al. (2009) which studied the influence of the roughness of different armour unit types, as well as Besley (1999) which studied the crest width influence. Details of the 888 tests are given in Eldrup et al. (2022).

EVALUATION OF EUROTOP (2018)

EurOtop (2018) gives guidance on the influence of roughness and crest width based on the available literature. Two papers are highlighted here.

First there is the work by Bruce et al. (2009), defining a roughness factor γ_f per armour type, which was improved in EurOtop (2018) to γ_{fS} as a function of $\xi_{m-1,0}$ for wave breaker parameters larger than 5 (Eq. (1)). This improvement accounts for long waves (low wave steepness, large breaker parameter $\xi_{m-1,0}$) who feel the armour roughness less. The influence factor γ_{fS} is included in the dimensionless freeboard of the overtopping equation Eq. (3).

$$\gamma_{fS} = \begin{cases} \gamma_f, & \xi_{m-1,0} \leq 5 \\ \gamma_f + \dfrac{(\xi_{m-1,0} - 5)(1 - \gamma_f)}{5}, & 5 \leq \xi_{m-1,0} \leq 10 \\ 1, & \xi_{m-1,0} \geq 10 \end{cases} \tag{1}$$

Second, there is the work by Besley (1999), which introduced a reduction factor C_r depending on the crest width G_c, directly to be multiplied with the discharge q: see Eq. (2) for C_r and Eq. (3) for q. C_r is an exponential decaying relation of the crest width, giving a big reduction in overtopping discharge when the crest width becomes larger than $0.75*H_{m0}$.

$$C_r = min\left(3.06exp\left(-1.5\frac{G_C}{H_{m0}}\right), 1\right) \tag{2}$$

Overtopping prediction over rubble mound breakwaters with short crest width ($G_c/H_{m0} < 1$) and fairly short waves on steep front slopes ($\xi_{m-1,0} < 5$) can be well predicted by Eq. (3), as proven in EurOtop (2018).

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.09 \exp\left(-\left(1.5\frac{R_c}{H_{m0}\gamma_{fS}\gamma_\beta}\right)^{1.3}\right)\cdot C_r \tag{3}$$

However, for wider crests (Figure 1) and/or longer waves (Figure 2), quite a lot of data fall outside of the 90% confidence band.

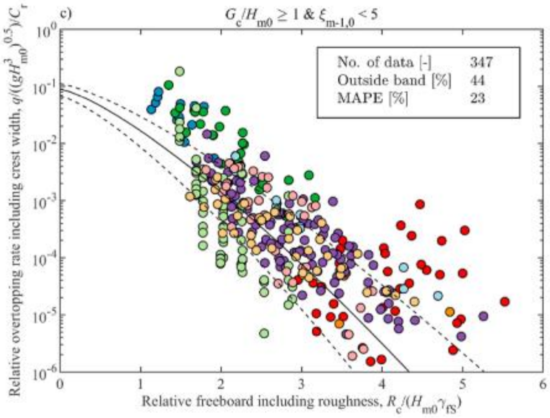

Figure 1. Overtopping data for wide crests and short waves by Eq. (3)

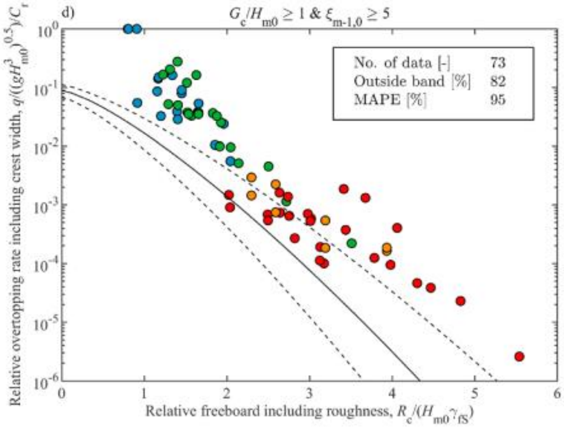

Figure 2. Overtopping data for wide crests and long waves by Eq. (3)

Eq. (3) underestimates overtopping prediction for rubble mound breakwaters with wide crests and/or longer waves. Or, in other words, γ_{fS} and C_r are too low for those cases and can be improved fitted on new data.

ANALYSIS

The new data extended the width of the data range from EurOtop (2018), mainly looking at wider crests ($G_c/H_{m0} > 1$), longer waves and/or milder front slope angles ($\xi_{m-1,0} > 5$).

The detailed analysis can be found in Eldrup et al. (2022). The conclusions are given here:

- Influence on overtopping discharges is also present for smaller breaker parameters ($\xi_{m-1,0} < 5$), as already included in EurOtop (2018) for wave run-up.
- Front slope and wave steepness have a different influence on the overtopping discharge, so it is better to uncouple them instead of using $\xi_{m-1,0}$.
- The γ_f values reported by Bruce et al. (2009) are slightly influenced by the crest width, which has to be corrected for in a new equation for γ_{fS}.
- The crest width influence factor should not be multiplied directly with q. The influence of the crest width is stronger for increasing relative freeboard. The influence factor will thus be included in the relative freeboard of the overtopping equation.

Combining these findings leads to the following set of equations (for non-breaking waves) for rubble mound structures:

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.09\exp\left(-\left(1.5\frac{R_c}{H_{m0}\gamma_{fS}\gamma_{cw}\gamma_\beta}\right)^{1.3}\right) \qquad (4)$$

$$\gamma_{cw} = \min\left(1.1exp\left(-0.18\frac{G_c}{H_{m0}}\right),1\right) \qquad (5)$$

$$\gamma_{fS} = \min\left(\gamma_f + 0.05s_{m-1,0}^{-0.5} - 0.07min(cot(\alpha),3) - 0.09,1\right) \qquad (6)$$

Note that Eq. (4) starts from Eq. (3) (the original equation in EurOtop (2018)) with inclusion of γ_{cw} and the improved γ_f (γ_{fS}).

EVALUATION OF IMPROVED METHODOLOGY

The data from Figure 1 and Figure 2 are plotted again, but instead of using Eq. (3), the improved equations (4), (5) and (6) are now used.

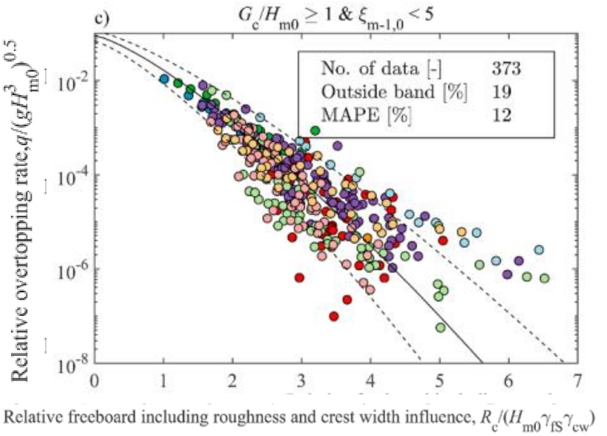

Figure 3. Overtopping data for wide crests and short waves using Eq. (4), (5) and (6)

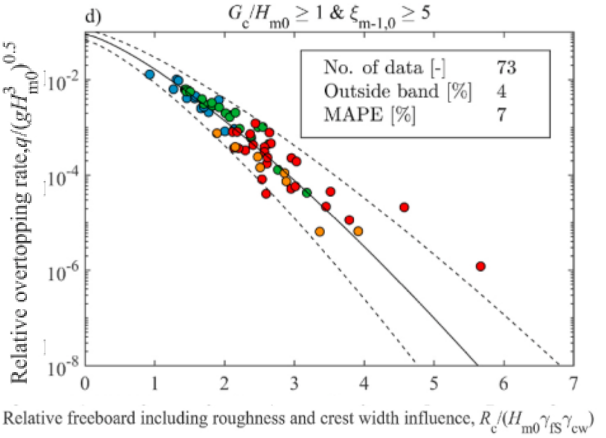

Figure 4. Overtopping data for wide crests and long waves using Eq. (4), (5) and (6)

Figure 3 and Figure 4 show that more data are now within the 90% confidence band. The new methodology (Eq. (4) to (6)) shows an improvement in describing data with wide crests and/or long waves.

Figure 5 presents a comparison of the new method to EurOtop (2018) and the Neural Network prediction (Formentin et al. (2017)), for all existing and new data used in this work (888 tests). The improvement compared to EurOtop (2018) is clear (RMSE reduction from 0.746 to 0.546). Compared to the NN, the improvement is less clear however the new method still gives a slightly better RMSE, mainly because the new data were not used to develop the NN.

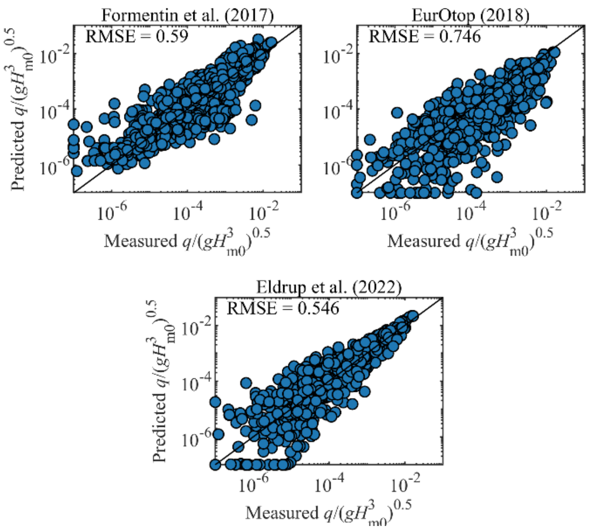

Figure 5. Comparison between overtopping prediction methods for data presented in Eldrup et al. (2022).

CONCLUSION

Where EurOtop (2018) shows a good prediction for the data range to which the equations were developed, it seems to underestimate wave overtopping discharges for rubble mound structures with wide crests and/or long waves (which were outside of its range).

New data has been added to the existing dataset, and analysis in Eldrup et al. (2022) has led to an improvement of the prediction method, mainly in the range of the new data: wide crests and long waves. The new methodology gives an overall improvement to EurOtop (2018) and a similar yet slightly better prediction compared to the Neural Network Approach by Formentin et al. (2017).

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