JOURNAL OF COASTAL AND HYDRAULIC STRUCTURES

Review and rebuttal of the paper

Guidelines on wave overtopping discharges at rubble mound breakwaters including slope angle effects

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Editor handling the paper: Hans Bihs

The reviewers remain anonymous.

Review Round 1

Reply: The authors want to thank the reviewers for their time and evaluations.

Reviewer #1

The authors have derived empirical formulae by including the effects of the structure slope and the wave steepness in the existing expressions. The modifications are based on the presented model tests by the authors and the improved formulae have shown good agreements with the tests.

The rationale is clear: to include a wide range of parametric studies and the structure slope and the wave steepness effects beyond existing formulae.

The test matrix is sound and reasonable, and the results are backed by the observations. The significance of the work is an improved guideline in for rubble mount breakwaters. The study has also identified limitations for other conditions outside the tested scenarios, such as oblique waves in combination with severe breaking waves. The authors have also mentioned the potential use of machine learning for future investigations.

Reply: Thank you for your positive comments and evaluation.

Major comments for further improvement:

However, one of the important contributions of this work is not discussed, that is, the implications for numerical modelling of wave overtopping. As the presented work focuses on rubble mount breakwater with established design, new and varying breakwater designs might need additional work, which can be investigated with numerical tools, such as different berm designs (Chen et.al., 2021), double-dike type structures (Jin et.al., 2022) and damaged and upgraded rubble-mount breaking waters (Stagnitti et.al., 2023). Some discussions on the numerical perspective are encouraged to be included in the introduction or conclusion.

Reply: Thank you for your suggestion. We have added the following section in the introduction: "However, also numerical modelling of wave overtopping at coastal structures can be used to estimate wave overtopping parameters, see for instance Chen *et al*. (2021, 2022), Jin *et al*. (2022), Irías Mata and Van Gent (2023) and Stagnitti *et al*. (2023). Numerical modelling can be used in combination with physical modelling by studying the influence of parameters over a wider range than those applied in physical model tests."

This comprehensive test presented in this study provides excellent validation data and analytical formulae for numerical wave model development, which should be mentioned as a contribution and impact in the conclusion.

Reply: Thank you for your suggestion. We have added the following text in Section 5 "Conclusions and recommendations", last-but-one paragraph: "The data and prediction method can also be applied to validate numerical models that simulate wave overtopping."

References:

Chen W., Warmink J.J., van Gent M.R.A. and Hulscher S.J.M.H. (2021) Numerical modelling of wave overtopping at dikes using OpenFOAM®, Coastal Engineering, Vol.166: 103890.

Jin Y., Wang W., Pákozdi C., Kamath A. and Bihs H. (2022) Numerical Investigation on Wave Overtopping at a Double-dike Defence Structure in Response to Climate Change Induced Sea Level Rise, Fluids, Vol. 7, Nr. 9: 295

Stagnitti M., Lara J.L., Musumeci R.E. and Foti E. (2023) Numerical modeling of wave overtopping of damaged and upgraded rubble-mound breakwaters, Ocean Engineering, Vol. 280: 114798

Reply: These suggested references have been mentioned in the text and added in the list of references.

Reviewer #2

The influence of the slope angle of statically stable rubble mound breakwaters with permeable core and the wave steepness on the mean wave overtopping discharge is studied. Five slopes were tested (1:1.5 to 1:8). A state-of-the-art model set-up was applied to record the new results. Besides a well derived approach to predict the mean overtopping discharge for a variety of slope geometries, also the limitations of the approach are clearly addressed.

This is an excellent, high-quality manuscript in its field. The authors are extremely knowledgeable about the history of the research, its genesis, and the current need for improvement (Section 2 provides an excellent overview of the stat-of-the art and guides the reader into the improvements achieved since EurOtop (2018)). They present the data in a very clear way, and there is hardly any need for further improvement. Some minor suggestions for improvement are provided:

Reply: Thank you for your positive comments and evaluation.

Figure captions are short, sometimes too short (e.g. Fig. 3 or Fig. 6) and do not allow to fully understand all information provided in the figures without searching in the full text. It is suggested to provide more information in the figure captions.

Reply: Thank you for your suggestion. We have added additional information in the figure captions of Figures 3, 4, 5, 6, 7 and 8.

line comment

47 The given formula holds true for c=1. But, e.g. EurOtop (2018) – a kind of agreed design standard – provides b and gamma within the brackets of the dimensionless freeboard height with the exponent c. The reviewer is aware of the discussion that most gamma values are derived according to TAW (2002) where c=1 and the presented formula is the correct presentation mode. An additional comment to this important point might strengthen the manuscript.

Reply: The suggested comment has been added: "If, unlike in Eq.1, the influence factor γ were to be used to a power c, as applied in EurOtop (2018), the value of the influence factor γ needs to be modified if c is unequal to one".

141 As the influence on the permeability of the core on the measured mean overtopping discharges is highlighted in the discussion (line 338ff.) it would be helpful to quantify the permeability (e.g. provide the P-value).

Reply: In the description of the tested structures (text above Figure 1) it has been added (twice) that the core is permeable. Quantification of the permeability like with a P factor (P=0.4) is common in some stability expressions but not for wave overtopping. In the discussion on the permeability (Section 4, third bullet) also a sentence has been added: "For estimates of wave overtopping discharges at rock-armoured slopes with a permeable core as tested here, the derived expressions are considered valid. However, numerical modelling by Irías Mata and Van Gent (2023) and Castiglione et al (2023) indicate that for permeable structures with a relatively low permeability (non-standard), wave overtopping discharges can increase up to a factor two to three."

150 Unwanted shift in the labelling for "Armour Filter Core" and "Filter Core"?

Reply: Labels in figure have been improved.

175ff. A quantification of "low", "mid" and "high" steepness in the provided legends might improve the quality of the figure, e.g. low steepness (s_min < H/L < s_max).

Reply: The quantification of the steepness has been added in the text describing Figure 3 (Section 3.2).

181 Subfigure captions a), b), c)… in Fig. 3 instead of "upper left panel" will facilitate the discussion of the individual findings in the text. The dashed line in the upper left panel does not appear in the legend or the figure caption. Recommendation: Text elements "breaking waves" and non-breaking waves" in the upper left panel would strengthens readability of the figure's story.

Reply: The meaning of the dashed line has been added in the figure caption and text has been added in the upper left panel. Subfigure caption with indication of slopes is preferred over letters to indicate the panels.

200 Readers unfamiliar with semilogarithmic axes may misinterpret the term 'well described by straight lines' as referring to linear trends. Mentioning exponential trends would be more appropriate.

Reply: Thank you for the suggestion. Text modified: "… data can be described reasonably well with straight lines in these graphs with logarithmic vertical axes."

268 Can the authors elaborate on the definition range of RMSLE. When is a result considered as good, when as very good. Is there a standard definition applied e.g. 40% error → RMSLE=ln(1.4)=0.33 is reasonable good? Where and why have the authors chosen which thresholds?

Reply: At the introduction of RMSLE in Section 3.3. the following definition is stated: "Here, a RMSLE value lower than 0.4 is considered as a good agreement, a value between 0.4 and 0.5 is considered as a reasonably good agreement and a value larger than 0.5 is considered as a relatively poor agreement."

295 Defining Eq. 8 (mean, solid line) and 9 (max, dashed line) in the figure will improve clarity. The definition is introduced too late (line 361). Readers have to guess.

Reply: Explanation of lines in Figure 8 has been added in the figure caption. Text related to the dashed line is added now at the description of the low right panel of Figure 8: "The dashed line in the lower right panel of

Figure 8 shows an expression for a design including safety (5% of all tests are above the dashed line), as will be discussed in the next section."

Reviewer #3

Thank you for the interesting manuscript! I think this is very valuable for design of breakwaters. It states clearly novel aspects compared with previous works given in complete literature review. Objectives and methodology are brought out well. Paper is properly organized and clear.

Reply: Thank you for your positive comments and evaluation.

Some comments

Line 178: Perhaps you could change caption of Figure 3: Measured overtopping discharges **($q^*>1\cdot10^{-6}$)** versus the non-dimensional freeboard (Rc/Hm0) for various slopes and various wave steepnesses.

Reply: Figure caption has been changed with the definition of q* at the position directly after "measured overtopping discharges" and $q^*>1\cdot10^{-6}$ later in the caption.

Line 186: Comparing Q for the same Rc/Hm0 I would say that the difference between the results with low and high steepness is also wide for slopes 1:4.

Reply: Agreed, text slightly modified to "very clear for the milder slopes 1:4, 1:6 and 1:8"

Line 194: Figure 4 illustrates that the dependencies of the slope and wave steepness are not sufficiently taken into account via the surf-similarity xm-1,0 alone. Could you expand it a bit for unexperienced readers?

Reply: Sentence extended to: "Figure 4 illustrates that by using the non-dimensional freeboard divided by the surf-similarity parameter $\xi_{m-1,0}$, there still is a dependency on the slope angle, indicating that the dependency of the slope is not sufficiently taken into account via the surf-similarity $\xi_{m-1,0}$ alone.".

Line 310: B1 and B2: You have included Hmo-swell into the formulae. If there is no swell, then Hm0 should be used instead?

Reply: Text in Section 3.1 (lines 207+208 in original manuscript) "and no swell or infragravity waves in a second wave field ($\gamma_b=1$, $\gamma_v=1$, $\gamma_\beta=1$, $\gamma_w=1$, $H_{m0\text{-}swell}=0$)." mentions that if there is no swell as a second wave field $H_{m0\text{-}swell}=0$. Because in Section 4 swell component is not discussed again, we prefer not to repeat this in Section 4.

B8: is it possible that q* could be higher than 1? Like high waves and low freeboard. This would make q.design smaller. I guess then the values of q are so high that are already unacceptable.

Reply: Indeed $q^*>1$ is not of interest and outside the range of applicability. Text added in caption: ($1\cdot10^{-6}\leq q^*\leq 1\cdot10^{-1}$).

Review Round 2

Reviewer #1

The authors have incorporated the feedback from both reviewers and made appropriate revisions, the revised manuscript is considered acceptable for publication now.