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Review and rebuttal of the paper

Maximum influence of wind on wave overtopping at rubble mound breakwaters under oblique wave attack

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Editor handling the paper: Eva Loukogeorgaki

The reviewers remain anonymous.

Round 1

Reviewer' comments and reply by authors to reviewers' comments

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

Reviewer No. 1

1. Line 45 – Line 126: The literature is referencing many works of Van Gent. I would like to challenge the authors to include a wider field of references, e.g. related to spray induced overtopping impacts carried out by TU Delft, University of Plymouth or Manchester University, to distinguish their ongoing work.

   Reply: Thank you for your comment. A number of additional references are added. References that are not closely linked to the investigated topic are not included.

2. Line 208: Table entry for the significant wave height should probably be **068** – 0.16 m instead of **0.68** – 0.16 m. Please adapt.

   Reply: Thank you for your comment. The typo in Table 3 has been corrected; the range of significant wave heights tested was 0.068 – 0.16m.

3. Line 208: What is the reasoning behind the selected hydraulic boundary condition ranges. Or is the selection based on a parametric study to cover a wide range of overtopping*?*

   Reply: Thank you for your question. Indeed, the hydraulic boundary conditions were selected to produce datapoints covering the relevant range of mean overtopping discharge. Text added: "This test programme was selected to obtain results that cover a wide range of relevant wave and wave overtopping conditions."

4. Line 259: Statement is made that the wind influence on overtopping is smaller in case of oblique waves, compared to perpendicular waves. However, no physical process explanation is given and only in Chapter 4 (starting in Line 336) it is hypothesized that this is due to longitudinal transport of the upward deflected water and geometric considerations which lead to lower overtopping water reaching behind the crest. I would strongly suggest to sketch-out this geometric consideration and include this drawing as part of the publication. Only reading the description of the process in Chapter 4 (starting in Line 336) is difficult to follow. Could the authors clarify what the observed oblique wave overtopping process at the paddle wheel itself was? Could it be that the (outer) sidewalls of the paddle wheel did reflect part of the upward deflected water body, so it would not be able to reach the collection chute? Did the paddle wheel reach sufficiently far seaward to collect all the upward deflected water into the collection chute?

   Reply: Thank you for your comments. Figure 2 and the corresponding text have been added to illustrate why oblique wave attack can change the influence of wind. Also a figure has been added in the discussion section.

   Reply: With respect to the item referring to the potential influence of the (outer) sidewalls of the paddle wheel, we want to mention the following items:
   a) If some wave overtopping events would hit the outer sidewall to some extent (leading to a somewhat too low amount of water in the overtopping box), the same could happen with an event hitting the other sidewall on the inside (leading to a somewhat too large amount of water in the overtopping box). If this would have occurred, we assume that the two would balance each other.
   b) On the occasion of a wave impact on the upstream outer side of the paddle wheel, we want to highlight that, if this happened, it was only under very energetic wave conditions, with high overtopping discharges and near zero wind influence. Consequently, in this case the discharge with wind is

approximately equal to overtopping discharge without wind, implying γ_w=1, so these few blocking incidences are not likely to have affected the investigation that focused on the low overtopping range – when the wind influence is relevant. This is in accordance with prior studies with perpendicular wave attack.

5. Line 284 (Figure 10, right): I suggest to clarify in the text whether the data-set was divided into training and test data, to avoid overfitting?

   Reply: Thank you for your question. The coefficient 2.5 in Eq.4 has been calibrated based on the entire data-set. Text added: "Note that all data from the present test programme has been used to calibrate the power 2.5 in Eq.4."

6. Line 284 (Figure 11): I suggest to remove Figure 11, as it gives the impression that several wave directions where investigated, while in reality only data for 45° wave direction is available and extrapolated using existing empirical formulations. Or clarify otherwise, by plotting both sides of 45° as dashed line and adapting the caption of Figure 11. Similarly the conclusion in Line 368 ("[…] negatively with the angel of wave incidence (ß) […]") seems very strong, given that only 1 wave angle was tested and could be softened.

   Reply: Thank you for your comments. The original Figure 11 has been deleted as suggested. With respect to the second item, the mentioned reference on the influence of oblique waves on wave overtopping used data covering the entire range of wave angles, showing that the negative correlation between overtopping discharge and wave angle is valid for the entire range of wave angles; in Line 368 (original line number in Conclusions), the negative correlation between the angle of wave incidence and wind influence factor only refers to a comparison between the perpendicular wave attack (0 degrees) and oblique wave incidence (45 degrees) tested in the present experimental campaign, although it is likely that the negative correlation is valid for the entire range, as it also is for wave overtopping without wind.

7. Line 383: Especially recommendation "[…] b) test structures with concrete armour units in addition to tested rock-armoured slopes […]" seems out of context and could be extended to any other structure for which wind generated wave overtopping is applicable. Please clarify why this structure is specifically prone to wind generated overtopping or why it was selected as a recommendation.

   Reply: Thank you for your comment. You are right, there is no clear physical explanation why the present results would not be applicable for structures with concrete armour units. This recommendation has been removed.

Reviewer No. 2

1. The study convincingly demonstrates that wind can have a significant effect on wave overtopping at rubble mound structures under oblique wave attack, which is an important contribution. However, it is not straightforward to directly incorporate this effect into the design of coastal structures, as the experimental results do not immediately translate into design guidance or predictive formulas. It would strengthen the paper if the authors could include a discussion on the practical implications of their findings for design, including potential limitations, and suggest how engineers might account for wind effects in practice, even qualitatively.

   Reply: Thank you for your comment. Recommendations into how engineers may account for the wind influence on wave overtopping are already provided in the manuscript, based on the data from the experimental campaign and the relevant proposed formula which suggests that the mean overtopping discharge increases in the presence of onshore wind, with a wind influence factor, γw. Designers may use this influence factor and design the coastal structures, e.g., adjust crest wall elevation, for the mean overtopping discharge under the maximum influence of wind. A sentence has been added (last sentence

of Chapter 5) with the recommendation to account for wind in the design of rubble mound breakwaters, using Eq.4 to account for wind, and adjust the height of the structure, mitigating the increased wave overtopping discharge due to wind.

2. Overall, the manuscript is well written and presents interesting results. However, I noticed several grammar and spelling errors throughout the text that should be corrected. I have highlighted some of them in the specific comments below. I recommend a careful, thorough review to ensure clarity and correctness.

   Reply: Thank you for your comment. Several grammar and spelling errors have been corrected.

3. Line 28. "… is investigated, **but** also the effect of wind on …"

   Reply: Thank you for your comment. Sentence has been revised.

4. Line 30. "Results show that ~~also~~ for oblique…"

   Reply: Thank you for your comment. Sentence has been revised.

5. Line 33. "This trend has **been** shown to be …"

   Reply: Thank you for your comment. Sentence has been revised.

6. Lines 70-71. The description of the wind influence formulation from the Shore Protection Manual (SPM, 1984) raises important questions regarding its origin. You mention that the expression was not derived from laboratory or field data and that its source and reasoning are unclear. In this case, further clarification is needed.

   Reply: Thank you for your comment. The SPM manual mentions that the expression was not derived from physical model tests. This reference is mentioned in the manuscript as it could be the first widely used design guideline to mention the wind influence on wave overtopping.

7. Line 96. The references from 1994, 1996 and 2006 are not considered recent.

   Reply: Thank you for your comment. Phrasing has been revised.

8. Lines108-111. The sentence describing the influence of wind in the "low overtopping regime" and "white overtopping" is difficult to follow due to dense terminology. Please consider simplifying the phrasing and briefly clarifying terms such as "white overtopping" and "advection of spray" to improve readability and accessibility for the reader.

   Reply: Thank you for your comment. Phrasing has been revised.

9. Line 112-113. Lines 112-113. "The approach … without the influence of wind". Please revise this sentence.

   Reply: Thank you for your comment. Sentence has been revised.

10. Line 115. "In addition, ~~also~~ numerical modelling …"

    Reply: Thank you for your comment. Sentence has been revised.

11. Line 121. The future reference "Van Gent and Van der Werf, 2029" should be corrected.

    Reply: Thank you for your comment. Reference date has been changed to "2019".

12. Lines 122-123. "In addition to such methods, ~~also~~ data-driven methods to estimate wave overtopping discharges are also available".

    Reply: Thank you for your comment. Sentence has been revised.

13. Line 126. The statement "The present tests aim to include effects of oblique waves on the influence of

wind" is too brief to adequately define the scope and contribution of the study. As it appears at the end of the literature review, this section should more clearly articulate the novelty and added value of the present work in relation to existing studies. Please expand this part to better highlight the research gap and explicitly state how your study advances current knowledge.

Reply: Thank you for your comment. This sentence has been further elaborated (several sentences have been added) highlighting the research gap and purpose of use of present findings.

14. Line 130. Why [to be added in a later version]? Did you forget to fill the missing information? The missing information will be provided after the review round? I don't get it.

    Reply: This is a requirement by the journal, which requires that the submission is anonymous. We are only allowed to add this information after acceptance of the manuscript.

15. Line 154. The statement "The slope of the rubble mound structure was 1:3" is a bit ambiguous, as it does not specify whether this refers to the seaward or landward slope. Please clarify which slope is being described to avoid misinterpretation.

    Reply: Thank you for your comment. Phrasing has been revised to "seaward slope".

16. Figure 2 lacks some important geometric parameters. In particular, the armour crest width G_c and the crest wall height h_c are not indicated. Including these dimensions in the figure would improve clarity and make the geometry of the structure more complete and self-explanatory.

    Reply: Thank you for your comment. The requested geometric details are now included in the figure title.

17. The same variable D_{n50} is used to describe the characteristic size of different layers (armour, filter layer, and core), which may lead to confusion. Please consider distinguishing these by adding appropriate indices (e.g., $D_{n50,a}$, $D_{n50,c}$, $D_{n50,f}$) to clearly indicate each layer.

    Reply: Thank you for your comment. Indices have been adjusted as recommended in the text of the manuscript.

18. Although a notation list is provided, key variables should also be briefly defined at their first occurrence in the text to improve readability. Relying solely on the notation section makes it difficult for the reader to follow the manuscript. Please ensure that all important symbols are introduced in context.

    Reply: Thank you for your comment. To the best of Authors' knowledge, all key variables are introduced in the text where they are used first. Caption of Figure 12 "Wind influence factor for volumes […]" has been slightly changed to ensure clarity in that regard.

19. Line 171. (Wolters and Van Gent, 2007); Van Gent et al., 2025). Remove the unnecessary parenthesis.

    Reply: Thank you for your comment. Parenthesis has been erased.

20. Line 174. Actually the paddle wheel structure is presented in Figure 4. Figure 5 illustrates the entire basin. No need to refer to Figure 5 here.

    Reply: Thank you for your comment. Referring also to Figure 5 (now Figure 6) helps the reader to locate the paddle wheel in the basin, that is why reference is made also to Figure 5 (now Figure 6).

21. Lines 175-182. The description of the paddle wheel is detailed in terms of geometry and positioning; however, it is not explained how the wheel is driven or how its rotation is generated and controlled. Is the rotation mechanically forced (e.g., motor-driven) or induced by the overtopping flow? Please clarify this point, as it is important for understanding the functioning of the system and the validity of the measurements.

Reply: Thank you for your comment. The paddle wheel is motor driven, and the properties of its rotation are mentioned in the manuscript, in line 182 (original manuscript). The sentence has been modified to: "The rotation frequency of the paddle wheel was motor driven and calibrated at 22 rotations per minute". The calibration was already performed by Wolters and Van Gent (2007).

22. Line 196. The text notes that the rotating paddle wheel causes a consistently lower discharge, but it does not explain why this occurs. It would be helpful to discuss possible mechanisms (e.g., flow obstruction, turbulence, or energy loss) to clarify the nature of the model effect.

    Reply: Thank you for your comment. The text mentions that in a small subset of the tests, less than 5 in 100 test cases, the wind influence factor was less than 1. This happened in cases with very small mean overtopping discharge, when for instance only one wave in a wave train of 1000 waves overtops. In such experimental conditions model effects may occur and reproducibility of a test is hard to obtain (that is, measure the same mean discharge in two consecutive tests), as the single wave that overtops the first time may or may not overtop the second time the simulation is performed. If flow obstruction was of concern, authors believe this would be visible in a greater subset of the test series.

23. Line 208. The caption of Table 3 'Hydraulic boundary conditions' is acceptable, but it could be clearer if it specified that these are the wave and flow parameters applied at the model boundary.

    Reply: Thank you for your comment. The referred boundary conditions were measured at the toe of the structure (now added in the Table caption).

24. The manuscript does not explain how the experimental wave conditions were selected. Please clarify the criteria used for choosing the wave parameters and indicate whether they are representative of specific prototype conditions or based on prior studies.

    Reply: Thank you for your comment. Wave boundary conditions are not based on an actual prototype structure but aimed at covering a wide range of relevant wave and wave overtopping conditions. Text added: "This test programme was selected to obtain results that cover a wide range of relevant wave and wave overtopping conditions."

25. Figure 3. What is the GRSM01 and WHM01-03 shown in Figure 3?

    Reply: Thank you for your comment. Explanations with respect to measurement instruments are mentioned in the figure title, i.e., the directional wave gauge (GRSM01, consisting of a wave gauge and a velocity meter) and wave height meters (WHM01-03) and now explained in the main text.

26. Figure 3. [to be added in a later version] again.

    Reply: This is a requirement by the journal, which requires that the submission is anonymous. We are only allowed to add this information after acceptance of the manuscript.

27. Figure 5. The caption of Figure 5 ("Experimental setup in basin") is too brief given that the figure presents multiple views of the basin and the setup from different angles. Please expand the caption to describe what is shown in each view and highlight the key components of the experimental setup.

    Reply: Thank you for your comment. A more elaborate description of Figure 5 (Figure 6 in the latest version) has been introduced in the text.

28. Figure 7 is not mentioned or described in the manuscript.

    Reply: Thank you for your comment. Figure 7 (Figure 8 in the latest version) is now mentioned in the text (line 207).

29. Line 224. Table 3 should be referred when you mention the various steepness values.

    Reply: Thank you for your comment. Table 3 is now referred to in the text behind the wave steepnesses (line 192 in the latest version).

30. Line 224. The description of the lower and higher crest walls is insufficient in the main text, as it is currently provided only in the caption of Figure 8. Please include a clear description of these configurations in the manuscript. This will improve clarity and ensure that the experimental setup is fully documented in the text.

    Reply: Thank you for your comment. Description of the crest wall configurations applied in the test campaign are provided in the manuscript, apart from Figure 9, in Table 2, Figure 3 caption, and in line 183 (Chapter 2.1 Test setup). Text added in original line number 224: "the lower (hc = 0.05 m) and higher crest wall (hc = 0.08 m)".

31. In Figure 8, the legend uses qualitative labels such as "Low crest wall," "High crest wall," and "Low/Mid/High steepness." While understandable, this is somewhat vague. It would be clearer and more informative to use the corresponding quantitative values in the legend. This would allow readers to directly interpret the conditions without referring back to the text. The same comment applies for Figures 10 and 12.

    Reply: Thank you for your comment. Figure 8 (Figure 9 in the latest version) is adjusted to include a more self-explanatory format with respect to the crest wall used per illustrated dataset.

32. In Figure 11, the x-axis is labeled as "Degrees," which is not appropriate. The axis should describe the variable being plotted (e.g., "Incident wave angle"), while "degrees" should be indicated as the unit.

    Reply: Thank you for your comment. The original Figure 11 has been removed from the manuscript (following the suggestion by Reviewer #1).

Round 2

Reviewer No. 1

Dear Authors,

thank you for addressing all review comments, which have sufficiently improved the quality of the submission.

Reviewer No. 2

Reviewer' comments and reply by authors to reviewers' comments

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

1. Lines 118-119. The sentence "Other studies on overtopping spray… maximum height of the spray" is grammatically incorrect and awkwardly structured. Please revise for clarity and readability.

   Reply: Thank you for your comment. The sentence has been revised to improve clarity.

2. The reference to Chen et al. (2023) remains too vague. The manuscript only states that the study used experimental campaigns and proposed a formula for spray height prediction, without explaining the actual scope or findings of the work. Please provide a more informative description of the study.

   Reply: Thank you for your comment. That part of the manuscript on Chen et al. (2023) has been elaborated.

3. Lines 138-140. The transition between the two paragraphs is awkward, particularly since the second paragraph begins abruptly with "The effects of wind…" and refers to the previous paragraph. In

addition, the phrasing is repetitive and difficult to follow ("effects of wind" / "influence of wind"). Please consider merging these statements into a single, more coherent paragraph and revising for clarity and readability.

Reply: Thank you for your comment. Phrasing has been revised to enhance clarity.

4. The newly added Figure 2 aims to conceptually explain the influence of oblique wave attack on wind-induced overtopping, which is appreciated. However, the figure remains somewhat difficult to interpret due to the large number of visual elements (ellipses, arrows, dots, labels, and symbols) and the highly schematic nature of the representation. In particular, the hypothetical ellipses and their physical meaning are not immediately clear. Please consider simplifying the figure and strengthening the accompanying explanation so that the intended mechanism can be understood more intuitively. Alternatively, a concise textual explanation may be sufficient.

   Reply: Thank you for your comment, textual explanation has been added in the text to support the figure and the sketch has been simplified.

5. Line 198. The explanation for the selection of the experimental wave conditions remains too general. Stating that the test programme covers "a wide range of relevant wave and wave overtopping conditions" does not explain how the experimental conditions were actually selected or what they are representative of. Please clarify the basis for selecting the wave parameters (e.g., prototype conditions, typical storm events, design conditions, previous studies, or scaling considerations) and explain in what sense these conditions are considered "relevant."

   Reply: Thank you for your comment. We have added some information on the selection criteria of the hydraulic boundary conditions. Please note that the major selection criteria are using testing conditions matching previous relevant studies, e.g. the values and range of wave steepness, while for parameters such as significant wave height and water level the upper and lower limits are based on the capabilities of the experimental facility and the relevant physical process to be measured, i.e. wave height large enough so that wave overtopped, water level low enough so that the basin remains operational and high enough for overtopping to occur.

6. In Figure 3 (previous Figure 2) G_c and h_c were added in the caption but they are still not indicated in the Figure. Including these dimensions in the figure would improve clarity for the reader.

   Reply: Thank you for your comment. Dimensions have been added in the figure.

7. Figure 13 is a useful addition for explaining the influence of oblique wave attack under wind conditions; however, its interpretation remains difficult. The left panel is somewhat blurry, while the meaning of the colored planes in the right panel not immediately clear. In addition, the term "3D planes" is geometrically confusing, since planes are inherently 2D entities embedded in 3D space. Please consider revising the terminology and improving the graphical clarity of the figure. Furthermore, the figure is only briefly mentioned in the text. Since it supports an important physical interpretation, a more detailed discussion in the manuscript would be beneficial.

   Reply: Thank you for your comment. We have revised the term "3D planes", three-dimensionality was mentioned to indicate the rotation of the plane. Additional description is added in the main text. Efforts were made to retrieve an image with better resolution, however since this is derived from a video recorded from the roof of the modelling facility, at a large distance, this was not possible.

Round 3

Reviewer No. 2

I would like to thank the Authors for providing a point to point response to my comments. The Authors have addressed all my comments and the quality of the manuscript has been improved significantly.

My opinion is that that the manuscript can be accepted for publication.