Memo

Deltares

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From
Hans de Waal

Direct line
+31 (0)88 33 58 501

E-mail
hans.dewaal@deltares.nl

Subject
Review wave overtopping at (composite) vertical structures

Version	Date	Author	Initials	Review	Initials	Approval	Initials
2.0	july 2014	H. de Waal		B. Hofland		M. van Gent	

1 Introduction

1.1 Problem

As a part of the development of the WTI2017, a software module is required for the assessment of the mean wave overtopping discharge at water defence structures in the Netherlands.

Since the methods of WTI2011 are regarded as the reference (and fall back option) for all methods within WTI2017, the reference software for this overtopping discharge assessment is taken from WTI2011. This software module is based on the formulae for vertical walls from the 'Leidraad Kunstwerken' (TAW, 2003).

A more general overview of wave overtopping formulae is given in the EurOtop Manual 2007 (EurOtop, 2007). Preferably, the WTI methods should comply with these international standards. At this moment, however, new insights in the overtopping formulae of the EurOtop Manual 2007 are in the process of being published (Van der Meer and Bruce, 2014). These new insights will be incorporated in an update of the EurOtop Manual in 2015.

The main question to be addressed in this memo is how to deal with these new insights within the WTI2017 scope of specifying and delivering the required software module.

1.2 Scope

In this memo we focus on the *available formulae* for *mean wave overtopping discharge*, primarily for *vertical structures*.

Further development of wave overtopping formulae is beyond the scope of this WTI subtask.

Being a part of the WTI2017 programme, the approach within this subtask needs to find a balance between intended technical improvements (standards to be met in WTI methods) and project restrictions (WTI deadlines, budget, available capacity and manageability).

1.3 Approach

The approach to answer the question mentioned in section 1.1 consists of the following steps:
- Analysis of the new insights, in relation to the currently (within WTI) applied formulae and software
- Discussion with Jentsje van der Meer, the first author of (Van der Meer and Bruce, 2014)
- Discussion with Bob van Bree, who has valuable experience in assessing the safety of structures within the VNK project
- Draft version of a memo (present document)
- Review and final version of the memo

The following aspects of the new insights are covered:
- the improvement of the calculation method compared to the present method
- the impact on the execution of the WTI practice
- the status of the new calculation method
- the 'programmability' of the new calculation method (inventory of completeness; range of application, background)

The new insights (calculation method) will be compared with:
- Leidraad Kunstwerken (LK) formulae
- Hydra's, PC Overslag
- EurOtop 2007

1.4 Target group

This memo is intended for the members of the project group of WTI2017 Cluster 6 (Structures), both from Deltares and Rijkswaterstaat. For close reading (especially of the appendix) the reader of this memo is supposed to have the following documents at hand:
- Leidraad Kunstwerken (TAW, 2003)
- EurOtop Manual 2007 (EurOtop, 2007)
- The new insights publication (Van der Meer and Bruce, 2014)

No summary of these documents will be provided here.

1.5 Outline

In the next chapter the general evaluation will be presented. Chapter 3 provides the advice on the WTI2017 activities pertaining to wave overtopping at structures. The appendix presents a more detailed evaluation of the new insights from a computer programmer's point of view.

2 Evaluation

2.1 Introduction

The formulae which are currently applied in Dutch WTI practice consist of the following main components:

1) 'TAW' (TAW, 2002) formulae for slopes, being the minimum result of:
   a) a formula for breaking waves (mild slopes)
   b) a formula for non-breaking waves (steep slopes and/or low wave steepness)
2) 'LK' formula for vertical walls.

The corresponding components as provided by the EurOtop Manual 2007 are:

1) 'TAW' formulae for slopes, being the minimum result of:
   a) a formula for breaking waves (mild slopes)
   b) a formula for non-breaking waves (steep slopes and/or low wave steepness)
2) A set of formulae for different types of walls and hydraulic conditions, accompanied by a decision scheme for choosing the appropriate formula.

The new insights consist of the following aspects:

1	Slopes	: improved extension of ‘TAW’ (2002) formulae towards low and zero freeboard, resulting in a 'Battjes-like' formula.
2	Walls	: reunification of formulae for impulsive breaking and non-breaking conditions (the set of formulae mentioned in point 2 above in the EurOtop Manual)
3	Walls	: distinction between low and high freeboard
4	Walls	: distinction between vertical and composite structures (i.e. vertical walls combined with a toe protection berm)
5	Walls and slopes	: (for non-breaking conditions:) reunification of formulae for low and high freeboard; inclusion of steep slopes

This results in the new components for slopes and walls to be provided by the EurOtop Manual 2015, being the minimum result[1] of:

1) A 'Battjes-like' formula for waves breaking on the slope
2) A new set of formulae for steep slopes (up to vertical) and different hydraulic conditions, accompanied by a new decision scheme for choosing the appropriate formula.

2.2 Comparisons

2.2.1 Formulae

The single LK formula for vertical walls is attractive due to its simplicity and obvious robustness. On the other hand, the empirical formula represents a very large set of data covering a large variety of circumstances. Therefore, it is relatively conservative in many cases and the scatter (uncertainty) is fairly large.

[1] *Taking the minimum result is probably not always appropriate, which will be pointed out in the appendix.*

Both current (2007) and new (2015) EurOtop Manual approaches provide a set of formulae and a selection scheme as calculation method for vertical structures. This approach takes account of the differences between structure types and the hydraulic conditions affecting the overtopping discharge, thus reducing the uncertainty. On the other hand, especially the EurOtop Manual 2007 is quite nontransparant due to the different types of formulae involved. The consistency and robustness are not clear. By unifying the shape of the formulae, the transparancy of the new formulae is definitely improved. Nevertheless, the new method remains quite complex too. This may be partly due to the fact that (Van der Meer and Bruce, 2014) does not provide a complete set of formulae in itself. For several definitions and details the publication refers to the EurOtop Manual 2007.

For slopes TAW (2002) formulae and the EurOtop Manual 2007 are identical. In (Van der Meer and Bruce, 2014), however, an adapted basic formula is proposed, in order to improve the results for very low freeboards. Moreover, new formulations are provided which bridge the current gap between steep slopes (up to 1:1) and vertical walls. This fact raises the question whether the WTI 2017 method for overtopping at dikes should be adapted too. This topic was originally outside the scope of this analysis, but will be addressed in the advice in chapter 3.

2.2.2 Available software modules

Both PCRing and Hydra-Zoet use a Fortran software module for wave overtopping at vertical walls, which is based on the Leidraad Kunstwerken formulae, but the source code is not identical. PCOverslag is not applicable for vertical walls. The EurOtop 2007 formulae for vertical walls have not been implemented in a software module, which means they are not applied in Dutch WTI practice. The new insights have not been implemented in a software module yet. The fall back option for vertical walls in Hydra-Ring consists of the PCRing module.

For the overtopping formulae at slopes various software modules are available. PCOverslag and the Hydra models use a Delphi coded dll based on the TAW formulae. However, the (probabilistic) Hydra models do not allow all structure varieties that (the deterministic model) PCOverslag basically supports: for example, the use of a vertical wall on top of a crest is not allowed in Hydra, but supported in PCOverslag. PCRing includes several Fortran routines largely based on simplified TAW formulae. For Hydra-Ring a new Fortran module for slopes has been developed, based on the TAW formulae, but extended to account for overflow.

2.3 Improvement

In general, the formulae as presented in (Van der Meer and Bruce, 2014) may be regarded as a valuable improvement, both with respect to the present EurOtop manual 2007 and with respect to the Leidraad Kunstwerken (LK). The new formulae provide more insight in their mutual relationships due to the unification. Moreover, they are better fitted on the available data to take relevant characteristics into account. And last but not least, the range of applicability is extended.

In Dutch WTI practice however, the added value of the new formulae is less clear. This will be addressed in the next section.

2.4 Impact

In order to assess the impact of the new formulae for the Dutch WTI practice, first a global comparison between calculation results for vertical walls will be presented. Figure 2.1 presents a decision scheme based on Figure 20 in (Van der Meer and Bruce, 2014).

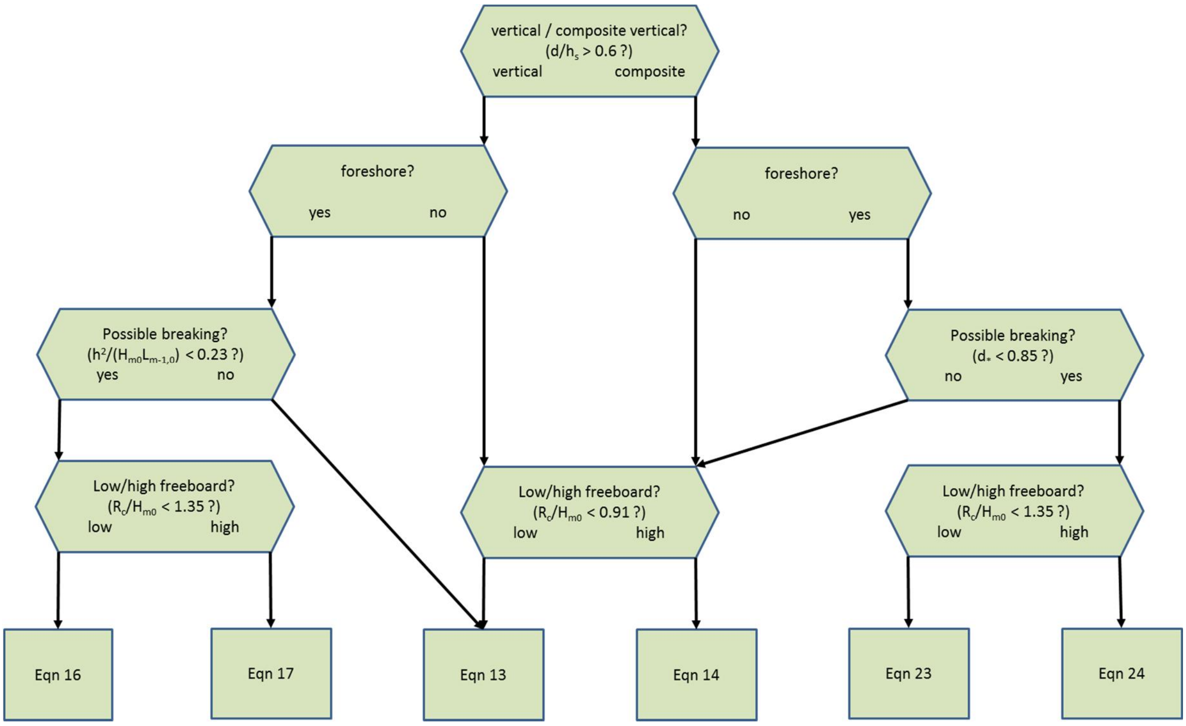

Figure 2.1 Decision scheme based on Figure 20 in (Van der Meer and Bruce, 2014).

Oral communication with Van der Meer clarified that the final version of this scheme may become as presented in Figure 2.2.

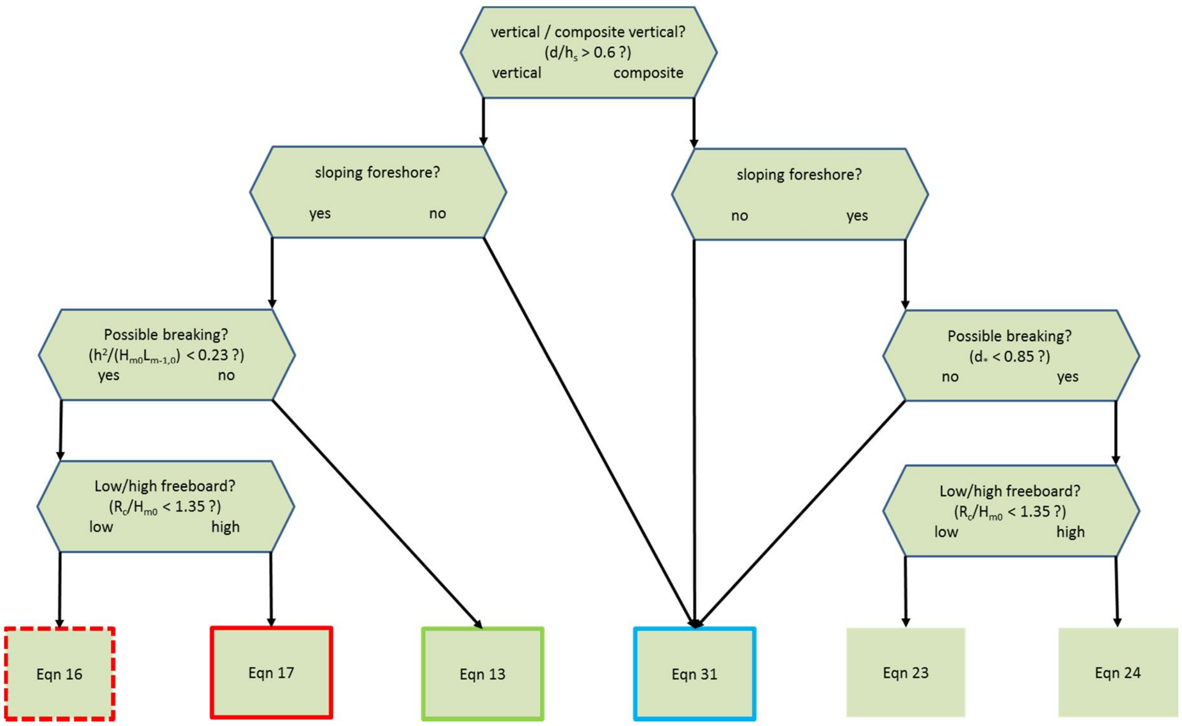

Figure 2.2 *Probably intended final decision scheme.*

In this brief analysis we focus on vertical (non composite) structures. Figure 2.3 presents the relationship between the (non dimensional) overtopping discharge and the (non dimensional) freeboard for several formulae. The black line refers to the LK formula. The line colours red, green and blue refer to the corresponding formula box colours in Figure 2.2.

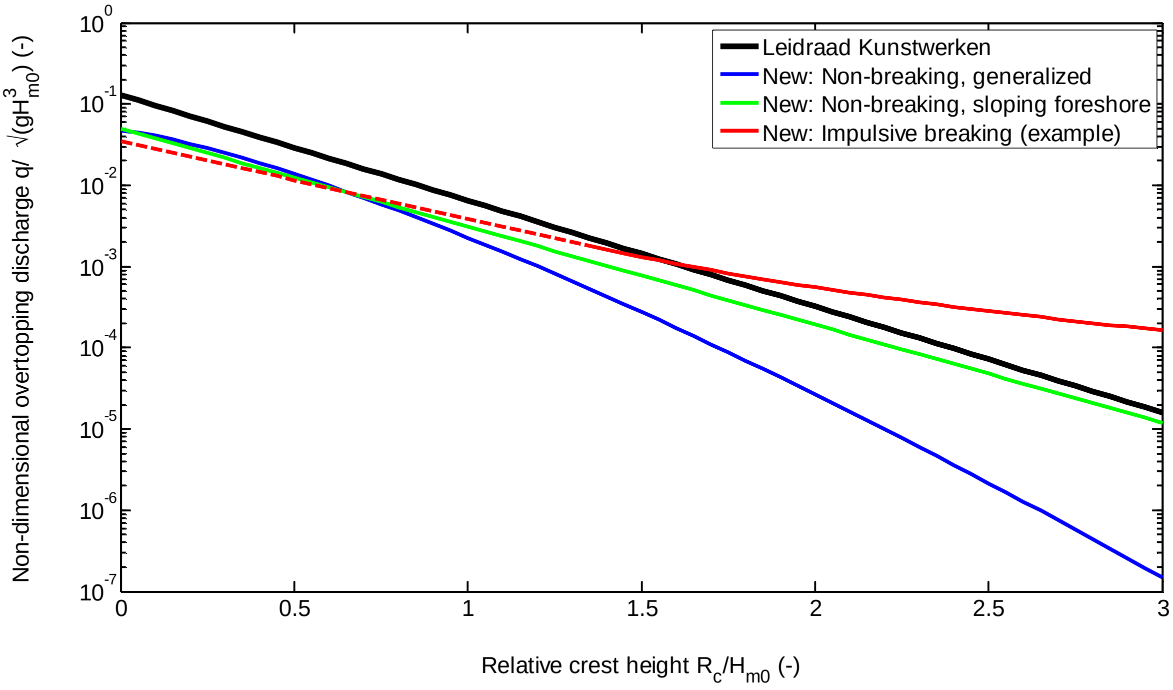

Figure 2.3 *Relation between freeboard and overtopping discharge from several overtopping formulae.*

From Figure 2.3 the following observations may be noted:

- For relatively small freeboards the different formulae within the new calculation method lead to fairly similar results; for higher freeboards the results strongly diverge.
- The LK formula yields (significantly) more conservative results than the new calculation method, except for impulsive breaking conditions combined with relatively high freeboards.

The impact of changing to a (generally) less conservative calculation method on the safety WTI assessment is probably small, since currently hardly any vertical wall structure is rejected on the basis of the wave overtopping criterion[2], using the LK formula (oral communication with B. van Bree). The same holds for the impact of a reduction in uncertainty about the overtopping discharge. In this respect it should also be noted that the uncertainty about the critical overtopping discharge remains quite large anyway.

The added ranges of application (very low crests, rubble mound toe in front of a wall, very steep slopes) are not encountered that often in Dutch WTI safety assessment practice. Therefore, the added value of these extensions for WTI is relatively small. On the other hand, a better formula describing the effect of a (small) wall on top of a dike (slope with or without a berm) would be valuable for WTI practice. Such an improved formula is not included in the present calculation method yet, but is expected to be ready in time to be included in the update of the EurOtop Manual.

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[2] *The overtopping criterion is fairly mild in many cases: the allowed overtopping rate can be high.*

The difference in results between the new formula for dikes (slopes) and the present TAW formula is small, only for very low freeboards the new results are better and less conservative.

2.5 Status

The new calculation method is accepted in a scientific journal. The method will be incorporated in the update of the EurOtop Manual. However, the WTI method would preferably refer to the new EurOtop Manual. As will be pointed out in section 2.6 and the appendix, it is expected that the method will be clarified and/or adapted at some issues before the final publication in the new EurOtop Manual. Therefore, the method as described in (Van der Meer and Bruce, 2014) does probably not have the status 'final' for the next EurOtop Manual yet.

Since the estimated impact of changing the calculation method is small for Dutch WTI practice, and the calculation methods are simplified and unified, the acceptance by users is not expected to become an issue.

2.6 Programmability

There is no (official or prototype) software code for the new calculation method yet. So there is no experience in programming the new formulae.

Earlier experience with programming the formulae as presented in the TAW (2002) report showed that the transition from scientifically solid looking formulae to software code requires serious attention. In many cases additional 'interpretation' of the calculation method appeared to be required.

In order to assess the manageability of programming the new calculation method within the scope of the WTI2017 project, the calculation method was analysed, having the following (types of) questions in mind:

- Is the method complete?
- Are the specifications unambiguous?
- Is the area of applicability clear?
- Is continuity in results guaranteed?

This analysis revealed that the method as presented in (Van der Meer and Bruce, 2014) may be sufficiently specified within the scientific context, but for the transition to software code quite some additional effort is required: the method is not complete yet, several parameters are not clearly defined and additional choices need to be made. The reader is referred to the appendix for more details. Considerable effort will be needed to program the calculation method such that the above four demands can be met.

3 Advised approach

The conclusions from Chapter 2 may be summarized as follows:

- The new calculation method leads to more accurate and in many cases less conservative results than the present LK formula. The new method is much more transparent and wider applicable than the method provided by the EurOtop Manual 2007.
- The impact of replacing the calculation method on Dutch WTI safety assessment results is expected to be small.
- The status of the new calculation method should not be regarded as 'final' (for the EurOtop Manual 2015) yet.
- Programming the formulae in software code may require considerable additional effort on clarifying details and filling in gaps in the current description of the calculation method.

This summary leads to the following general answer to the question "how to deal with these new insights within the WTI2017 scope of specifying and delivering the required software module":

> Implement the (for Dutch WTI practice) most useful and clear parts of the new method into a (prototype) software module, but do not put this development on the critical path of the WTI2017 project.

The latter restriction implies that at first the present WTI calculation method (LK formula) should be consolidated as the reference method for WTI2017.

In more detail the following steps within the WTI2017 project are advised:

1) Consolidate the present WTI calculation methods for wave overtopping:
   a) the TAW 2002 method for slopes
   b) the TAW 2003 ('LK formula') as the reference method for vertical structures (method A).
2) Develop a prototype module based on the new calculation method by Van der Meer and Bruce, but initially restricted to vertical walls (method B). Test the continuity in results, make comparisons with results of the LK method (method A) and the Neural Network method (method C).
3) Write a Functional Design for a generalized vertical wall module, incorporating methods A, B and C. Define the IO (input/output) and main functionality of a generalized module for wave overtopping at vertical walls, in which a choice can be made between methods A, B and C.
4) Experiment with using (the three methods within) the generalized module in Hydra-Ring, on a branch of the Hydra-Ring development.
5) Verify the status of the calculation method in the EurOtop Manual 2015 as soon as possible (in 2015), before deciding on
   a) formalizing method A for vertical walls or an adapted version of method A in the WTI edition of 2017, and
   b) whether or not to start experimenting with a unified calculation method for slopes (including crest walls), steep slopes and vertical walls for the WTI edition of 2023.

4 References

EurOtop, 2007. European Manual for the Assessment of Wave Overtopping. T. Pullen, N.W.H. Allsop, T. Bruce, A. Kortenhaus, H. Schüttrumpf and J.W. van der Meer. At: www.overtopping-manual.com.

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From | Direct line | E-mail
Hans de Waal | +31 (0)88 33 58 501 | hans.dewaal@deltares.nl

Subject
Review wave overtopping at (composite) vertical structures
Appendix: Considerations on new insights

1 Introduction

This memo is intended as an appendix of the memo 'Review wave overtopping at (composite) vertical structures'. In order to assess the manageability of programming the new calculation method presented in (Van der Meer and Bruce, 2014) within the scope of the WTI2017 project, the new calculation method was analysed, having the following (types of) questions in mind:

- Is the method complete?
- Are the specifications unambiguous?
- Is the area of applicability clear?
- Is continuity in results guaranteed?

We focus on the assessment of the mean overtopping discharge. The reader is expected to have direct access to the publication.

The remarks in this memo are not intended to be complete. They are intended to provide specific information in answering the question whether complications are expected in programming the calculation method.

2 Practical considerations and questions

2.1 New insights

2.1.1 Unification of formulae for slopes and (steep) structures

The new calculation method appears to consist of method components for slopes and walls being the minimum result of:
1) A 'Battjes-like' formula for waves breaking on the slope
2) A new set of formulae for steep slopes (up to vertical) and different hydraulic conditions, accompanied by a new decision scheme for choosing the appropriate formula.

However, we cannot always compute the result of the first component, certainly not for a vertical wall, since the value for the breaker parameter becomes infinite. Reducing the formula for an infinite value for the breaker parameter may be possible, but then it is still questionable whether taking the minimum result of the two approaches will lead to the intended result, especially in case of impulsive breaking at a vertical wall. Therefore, the necessity of computing this part of the formulae should be restricted to slope angles up to a certain limit, for example 1:1. Such a restriction is not provided yet.

The first component allows for defining a multi section profile: a profile composed of several straight sections, having different slope angles (originally up to 1:1) and roughness characteristics. It is not immediately clear that the second component is (presumably) applicable for single-section slopes only. This should be clarified.

2.1.2 Effect of a mound

At the top of the decision scheme (Figure 20) a distinction is made between vertical and composite vertical walls. Several remarks may be made:

There is no clear position for (very) steep slopes in this distinction.

The distinction should be clarified. Presumably the 'berm' in case of a composite vertical wall is supposed to be just a relatively small (rubble mound) toe protection. Otherwise the width of the berm and the outer slope would become important at some stage, just like in the multi-section approach for dikes (see section 2.1.1). This 'relatively small' should be specified (quantified); it is clear that the formula is not intended for a toe berm at SWL, but the actual range of applicability is not clear, i.e. a lower limit of applicability of d is needed.

The decision scheme provides a parameter 'h_s', which is not defined. (Probably 'h' was meant instead).

2.1.3 Effect of a (sloping) foreshore

The decision scheme includes the question 'foreshore?', which is too vague. From the text it can be derived that actually 'sloping foreshore?' was meant (and not 'shallow foreshore?' p.e.). Answering this actual question may be straightforward in the case of laboratory data, but in real life cases it is much less straightforward. Probably the wave length (wave period) is involved in selecting a relevant section of the foreshore bathymetry. This would add to the complexity of the calculation scheme. Also the slope angle should probably be included in the criterion (or a limiting factor, after which it can be called ‘flat’. This is not mentioned in the paper.

And even if the distinction is clarified, it is almost certain that the distinction in its present form will introduce a discontinuity in results. This should be avoided, which will probably require additional (transition) formulae.

2.1.4 Effect of (impulsive) breaking at the toe

The decision scheme includes the question 'possible breaking?'. From the formulae it can be expected that the transition between ‘no’ and ‘yes’ will result in a discontinuity in results.

Note that the transition may indeed be quite sudden for a single wave, but this transition should be smoothed for a standard random wave field. An actual jump (discontinuity) is not expected.

2.2 Influence factors

2.2.1 Introduction

It is relatively easily stated that the formulae for taking specific influences into account do not change. In practice this may lead to inconsistencies.

The decision scheme refers to several formulae (like 13, 14) in which no influence factors are involved. Is that really meant this way, or should the influence factors be included like in other formulae (as a fictive enhancement of the relative freeboard)?

2.2.2 Influence factor for wave angle

The effect of the wave angle for vertical walls differs from the effect for slopes. (For walls there is even a distinction between the wave angle effect for non-breaking versus impulsive breaking). Which formula one should be applied, when slopes and walls are covered by one set of formulae?

Is there information on the transition from very obliquely incident to offshore directed waves at vertical walls?

2.2.3 Influence factors for roughness

The TAW guide (2002) says that the effect of roughness γ_f depends on breaker parameter $\xi_{m-1,0}$ (optionally combined with the effect of a berm γ_b). The roughness effect diminishes for a breaking parameter increasing from 1.8 to 10. In the Eurotop Manual 2007 see page 113-114. Should this influence factor γ_f still be present in the formula describing the maximum for surging waves, or for vertical walls?

2.2.4 Influence factors for wind and / or a parapet

The new calculation method does not provide information on the effect of wind and or a parapet. Are the original formulae still applicable, without exceptions?

2.2.5 Influence factors for a crest wall

Expected formulae for the effect of a crest wall may fill in an important gap, but may also lead to (minor?) adaptations in existing formulas in order to get a consistent set.

2.3 Quantification of uncertainties

The unified formulae 6 and 7 contain two constants for which a mean μ and standard deviation σ are provided. What is the correlation between these two 'constants'?

The unified formula 31 for very steep slopes contains varying parameters a and b. For the initial (fixed) values of a and b the uncertainty is given; not for the final (varying) values of a and b.

3 More general considerations

3.1 Unification of slopes and walls

For slopes the (for wave overtopping) most relevant wave motion occurs at the horizontal 'bottom' range between the toe of the structure and the crest, with a more specific focus on the 'bottom' range between 1.5 H_{m0} below swl and the crest. ‘Bottom’ is used here in the sense of the bed that the wave ‘feels’ just before reaching the water line, which is on the dike slope, in case of sloping dike. The characteristics of this part of the 'bottom' are dominating the water motion and the wave overtopping.

For steeper slopes this bottom range becomes smaller and smaller, reducing to zero width for a vertical wall. In the latter case, and shallow water conditions, the water motion at the structure is dominated by the relevant bottom just in front of the structure: the near foreshore. Characteristics like relative depth and foreshore slope become important for the wave overtopping.

A unified method for both slopes and walls should cover all these input variables. This may be feasible for a neural network. For empirical formulae it may be considered too ambitious to completely combine the two areas of application and cover the transitional area without any discontinuity or gap in applicability.

3.2 Alternative: Neural network

In some cases (like eqns. 16 and 17) a formula includes a relative wave height (H_{m0}/h) divided by the wave steepness. In fact, this results in a ratio of deep water wave length over water depth ($L_{0,m-1,0}$/h). In the formula, the square root of this ratio is taken, which implies that the factor is proportional to the wave period $T_{m-1,0}$.

I think it would be very interesting to explore whether the Neural Network confirms such a linear relationship between the non-dimensional wave overtopping discharge and the wave period.

This is just one example of possible validating the relationships in the empirical formulae with those from the Neural network.

4 References

EurOtop, 2007. European Manual for the Assessment of Wave Overtopping. T. Pullen, N.W.H. Allsop, T. Bruce, A. Kortenhaus, H. Schüttrumpf and J.W. van der Meer. At: www.overtopping-manual.com.

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Enclosures