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Andersen, Thomas Lykke; Burcharth, H. F.

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OVERTOPPING OF BERM BREAKWATERS EXTENSION OF OVERTOPPING FORMULA

LYKKE ANDERSEN, T.

Department of Civil Engineering, Aalborg University, Sohngårdsholmsvej 57 DK9000 Aalborg, Denmark. E-mail: i5tla@civil.aau.dk, Phone: +45 96358486

BURCHARTH, H. F.

Department of Civil Engineering, Aalborg University, Sohngårdsholmsvej 57 DK9000 Aalborg, Denmark. E-mail: i5hfb@civil.aau.dk, Phone: +45 96358482

ABSTRACT

In this paper is presented an improved version of the overtopping formula by Lykke Andersen & Burcharth (2004) valid for berm breakwaters with initial slopes of 1:1.25. In the present paper guidelines is given on how to modify the formula to take into account the initial slope angle. Further the formula is improved so it gives reliable estimates also for more stable structures. The extension of the overtopping formula is based on analysis of front slope stability data from many different data sets. In most cases there is only a small difference between the Lykke Andersen & Burcharth (2004) formula and the present improved formula. However, for a more stable structure and low wave steepness the improved formula performs better. Six different data sets are used to study the validity of the Lykke Andersen & Burcharth (2004) formula, the present improved formula and the CLASH neural network model. The present improved formula seems to be the best choice. The CLASH NN-Model performs very well for berm breakwater data sets included in the fitting of the NN-Model, but much worse for those not included. This demonstrates some degree of overlearning of the neural network due to limited data for berm breakwaters.

1. INTRODUCTION

The berm breakwater concept is basicly rather old, but was not used very much until it was “reinvented” in the early 1980’ties, when a slope protection for an airfield runway extending into the sea in the Alutian Islands, Alaska was designed, Rauw (1987). Since then, many berm breakwaters have been built, especially in Iceland. Fig. 1 illustrates the reshaping berm breakwater concept.

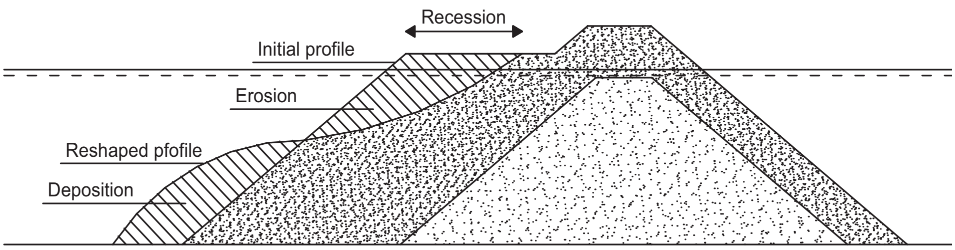

Figure 1: Typical initial and reshaped profile.

It is very difficult to destroy a berm breakwater by incoming head-on-waves, unless the structure is overtopped or the berm is too narrow. Overtopping waves can easily damage the rear side of a berm breakwater and an erosion process may start which quickly causes a breach in the breakwater.

Until recently the available information on overtopping of berm breakwaters was very limited and no systematic study existed. However, Lykke Andersen & Burcharth (2004) presented a dimensionless overtopping formula for berm breakwaters based on a large parametric model test study with berm breakwaters. More than 700 tests were performed to derive the formula. The formula was derived for statically and dynamically stable berm breakwaters as well as non-reshaping statically stable berm breakwaters, all with homogenous berms.

The formula presented by Lykke Andersen & Burcharth (2004) is based on tests with initial front slopes 1:1.25 only, and the formula does not include the influence of other slopes. The main purpose of this paper is to present an improved formula and to give guidelines on how to modify the formula to take into account the front slope. The former formula as well as the present formula and the CLASH NN-model by Pozueta et. al (2005) are compared using present data and data of five other researchers. As data for multi-layer berm breakwaters (Icelandic type) are included, the conclusions on the usage of the derived formula will cover also multi-layer berm breakwaters. The following data of other researchers is used for evaluation of the overtopping formulae:

- Bolatti Guzzo and Marconi (1991) measured overtopping on a reshaping berm breakwater. Three test series are available with overtopping measurements at the back of the crest.

- Lissev (1993) and Lissev and Tørum (1996) measured irregular wave overtopping on berm breakwaters for two different core configurations using one cross-section only. Lissev and Tørum (1996) concluded that the core could be extended into the berm without significant influence on the reshaping and the overtopping. A non-dimensionless overtopping formula was presented by Lissev (1993). However, because only one cross section was tested it is not possible to establish a generic overtopping formula on basis of this formula.

- Viggosson et. al. (1993) performed 3D model tests with a multi-layer berm breakwater proposed for the Keilisnes harbour. Overtopping was measured at the trunk section. For this data set only total (incident + reflected) waves are given as no reflection analysis was performed. Due to very low wave steepness and a very stable steep structure, reflection coefficients (C_r) around 40% could be expected giving an incident significant wave height of 92.8% of the total recorded significant wave height. The latter compensation was made in the present analysis, but not made in the analysis of Viggosson et. al (1993).

- Kuhnen (2000) performed model tests measuring wave ovetopping on a multilayer berm breakwater for the Sirevåg breakwater (Three test series).

- Porarinsson (2004) performed physical model tests with a proposed multilayer berm breakwater cross section for the Porlakshöfn breakwater. The tests were carried out in the same flume as used by Lykke Andersen & Burcharth (2004), and overtopping was measured in 13 test series.

2. MODEL TESTS

The present model test study is described in details in Lykke Andersen & Burcharth (2004) and includes 700 tests with an initial cross-section as shown in Fig. 2. R_c, B, G_c, h_b, h, $D_{n,50}$ and sea states are varied in the model tests. Both reshaping and non-reshaping berm breakwaters were tested. Overtopping was measured at the back of the crest as illustrated in Fig. 2.

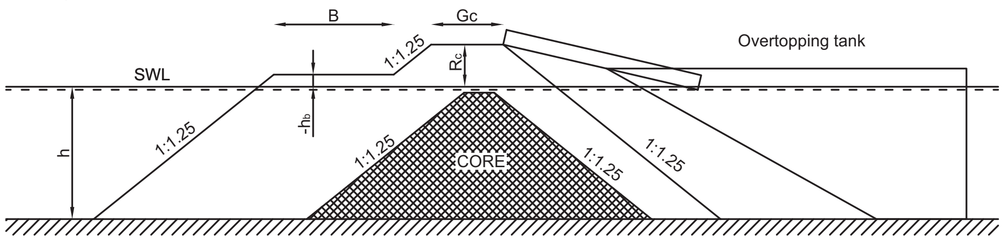

Figure 2: Initial geometry of breakwater.

3. ICCE2004 OVERTOPPING FORMULA

The following overtopping formula was derived by Lykke Andersen & Burcharth (2004):

$$Q_* = 4.56 \cdot 10^{-3} \cdot \left(H_0 T_0\right)^{1.31} \cdot s_{0p}^{-2.95} \cdot \exp\left[-13.9 \cdot R_*^{0.40} - 0.92 \cdot G_*^{1.24} - 0.76 \cdot h_{b*}^{1.32} \cdot B_*^{1.24}\right] \quad (01)$$

where

$$Q_* = \frac{Q}{\sqrt{g \cdot H_{m0}^3}}$$

H_{m0} is the significant wave height at the toe of the structure (frequency domain parameter).

$$R_* = \frac{R_c}{H_{m0}} \ ; \ G_* = \frac{G_c}{H_{m0}} \ ; \ B_* = \frac{B}{H_{m0}} \quad (02)$$

$$h_{b*} = \frac{3 \cdot H_{m0} - h_b}{3 \cdot H_{m0} + R_c} \quad (03)$$

When $h_b > 3H_{m0}$ use $h_{b*} = 0$. Note h_b is negative when the berm is above water level.

$$H_0T_0 = \frac{H_{m0}}{\Delta \cdot D_{n50}} \cdot \sqrt{\frac{g}{D_{n,50}}} \cdot T_m \qquad (04)$$

As the formula only contains non-reshaped geometrical parameters, H_0T_0 was included as an indicative measure of the reshaping, as more overtopping was observed on the reshaped profile. No reshaping takes place for $H_0T_0 < 30$. For such cases use $H_0T_0 = 30$. For multi-layer berm breakwaters it is proposed to use the largest stones when calculating $H_0T_{0,}$ as very little reshaping is allowed.

4. GUIDELINES FOR INITIAL SLOPES OTHER THAN 1:1.25

The present tests are all performed with initial slopes 1:1.25. For other initial down slopes one could still use the formula because the reshaped profiles are almost identical for the same volume of stones independent on the lower slope. This is valid at least for dynamically stable profiles, and leads to the conclusion that B has to be enlarged by $0.5\cdot(h\text{-}h_b)\cdot(\cot(\alpha_d)\text{-}1.25)$ in the formula for a slope different than 1:1.25. For a very stable structure with very limited damage it is believed that the down slope has very little influence on the overtopping discharge. Therefore the correction should not be done in such cases as it could lead to unsafe results for slopes flatter than 1:1.25.

For initial front slopes above the berm different from 1:1.25 it is proposed to enlarge/reduce B and G_C so the distance to the back of the crest is the same as for a slope 1:1.25. That means increasing both B and G_C with the distance $0.5\cdot(R_C+h_b)\cdot(\cot(\alpha_u)\text{-}1.25)$.

5. EVALUATION OF ICCE2004 OVERTOPPING FORMULA

In Fig. 3-9 the overtopping formula is evaluated against the data of Lykke Andersen & Burcharth (2004) applying the guidelines given in chapter 4 for slopes different from 1:1.25. Dashed lines show the 90% confidence bands.

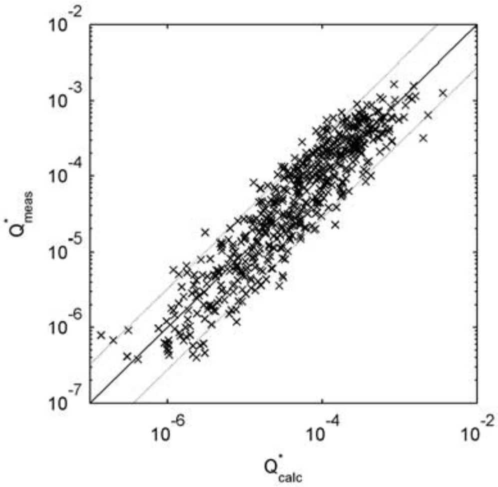

Figure 3: Evaluation of present overtopping formula against data by Lykke Andersen & Burcharth (2004).

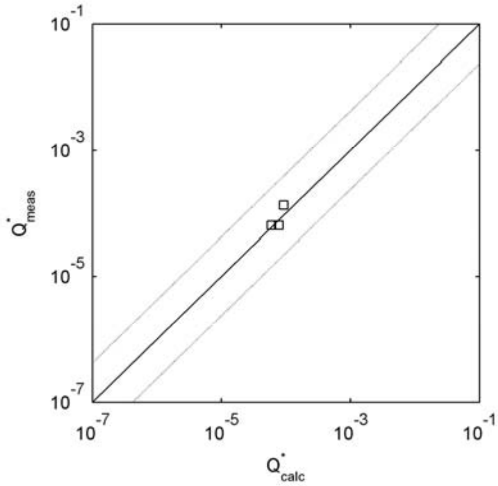

Figure 4: Evaluation of present overtopping formula against data by Bolatti Guzzo and Marconi (1991).

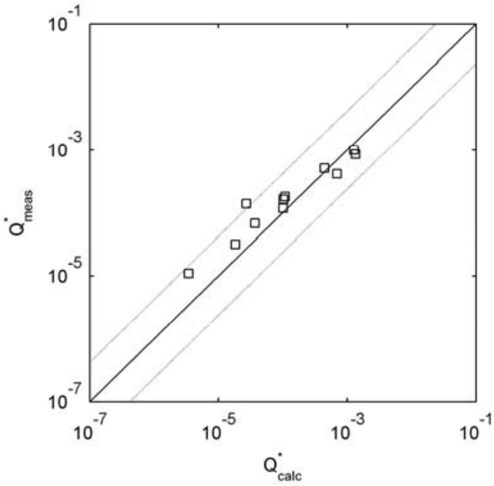

Figure 5: Evaluation of present overtopping formula against data by Lissev (1993).

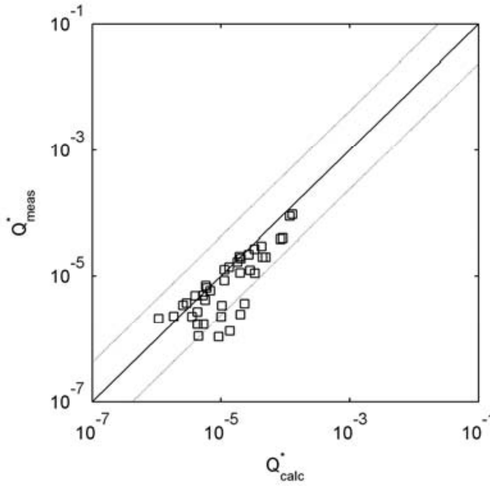

Figure 6: Evaluation of present overtopping formula against data by Viggosson et. al. (1993).

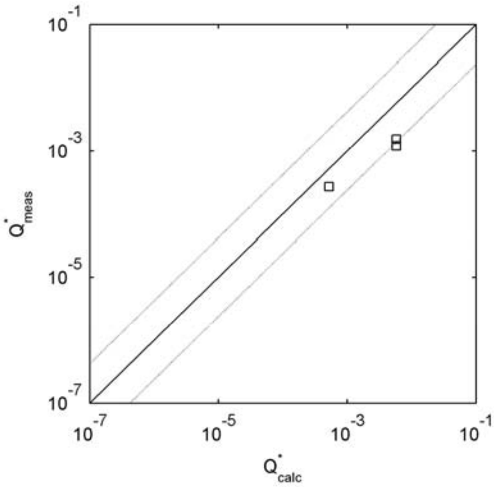

Figure 7: Evaluation of present overtopping formula against data by Kuhnen (2000).

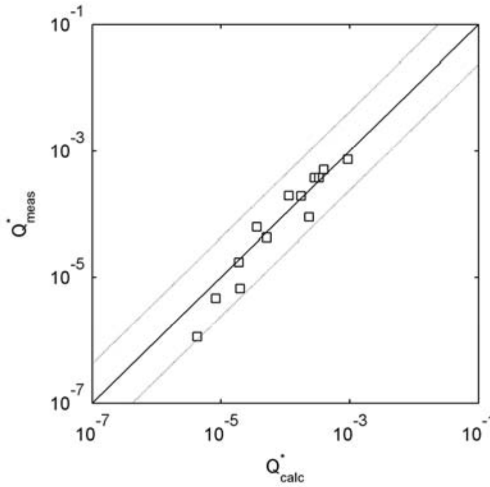

Figure 8: Evaluation of present overtopping formula against data by Porarinsson (2004).

Overall the formula performs well also for data of other researchers when the guidelines on the initial slopes are applied.

6. IMPROVED OVERTOPPING FORMULA

After publishing the ICCE2004 formula a lot of recession data was analysed and it was found that the H_0T_0 parameter is not so good to describe reshaping on more stable structures as it overpredicts the influence of the wave period. It was found that the governing parameter for recession of the berm is the parameter f_{H0} defined in Eq. 8. Inclusion of this parameter and fitting to all available data resulted in the following overtopping formula:

$$Q_* = 1.79 \cdot 10^{-5} \cdot (f_{H0}^{1.34} + 9.22) \cdot s_{0p}^{-2.52} \cdot \exp\left[-5.63 \cdot R_*^{0.92} - 0.61 \cdot G_*^{1.39} - 0.55 \cdot h_{b*}^{1.48} \cdot B_*^{1.39}\right] \tag{05}$$

where

$$Q_* = \frac{Q}{\sqrt{g \cdot H_{m0}^3}}$$

H_{m0} is the significant wave height at the toe of the structure (frequency domain parameter).

$$R_* = \frac{R_c}{H_{m0}} \;;\; G_* = \frac{G_c}{H_{m0}} \;;\; B_* = \frac{B}{H_{m0}} \tag{06}$$

$$h_{b*} = \frac{3 \cdot H_{m0} - h_b}{3 \cdot H_{m0} + R_c} \quad (07)$$

When $h_b > 3H_{m0}$ use $h_{b*} = 0$. Note h_b is negative when the berm is above water level.

$$f_{H0} = \begin{cases} 19.8 \cdot \exp\left(-\frac{7.08}{H_0}\right) \cdot s_{0m}^{-0.5} & for\, T_0 \geq T_0^* \\ 0.07 \cdot H_0 T_0 + 11 & for\, T_0 < T_0^* \end{cases} \quad (08)$$

$$H_0 = \frac{H_{m0}}{\Delta \cdot D_{n50}} \quad (09)$$

$$T_0 = \sqrt{\frac{g}{D_{n,50}}} \cdot T_m \quad (10)$$

$$T_0^* = \frac{19.8 \cdot \exp\left(-\frac{7.08}{H_0}\right) \cdot s_{0m}^{-0.5} - 11}{0.07 \cdot H_0} \quad (11)$$

For multilayer berm breakwaters it is proposed to use the largest stones when calculating $f_{H0,}$ as very little reshaping is allowed. For probabilistic design one should take into account the scatter of the data. Coefficient of variation ($\delta = \sigma/\mu$) on the factor $1.79 \cdot 10^{-5}$ is 2.21.

In Fig. 9-15 the overtopping formula is evaluated when the guidelines for initial slope implementation given in chapter 4 is applied. Dashed lines show the 90% confidence bands calculated from the variation coefficient given above. It can be seen that the largest change, when comparing to the ICCE2004 formula, is for the data of Viggosson et. al. (1993) which is due to very low wave steepness combined with a very stable structure. Overall the performance of the formula is equally well for the data of other researchers and the present data. This demonstrates that the formula could be applied for multi-layer berm breakwaters with the same accuracy as for homogeneous berm breakwaters.

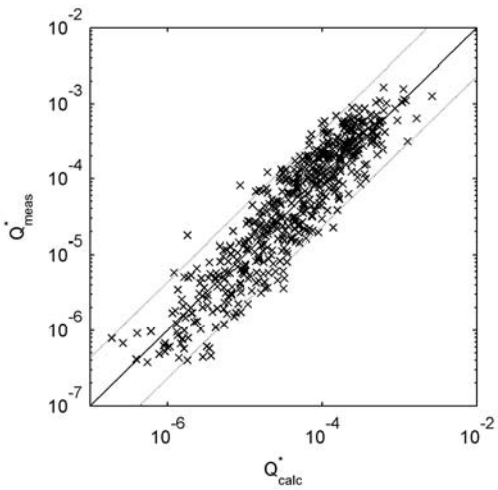

Figure 9: Evaluation of present overtopping formula against data by Lykke Andersen & Burcharth (2004).

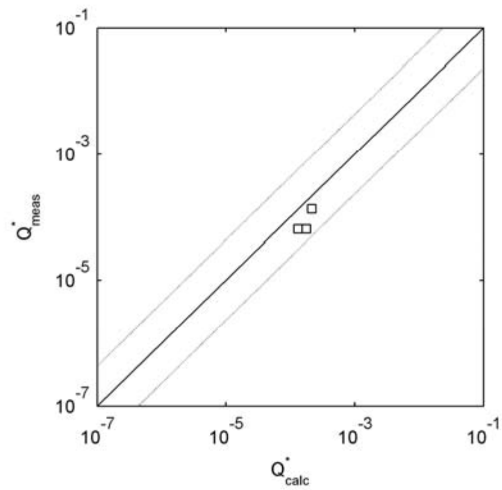

Figure 10: Evaluation of present overtopping formula against data by Bolatti Guzzo and Marconi (1991).

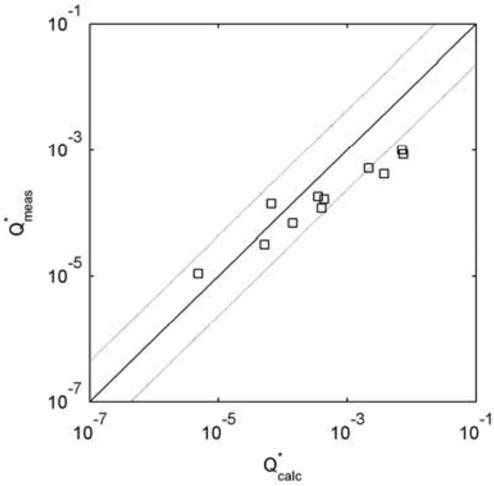

Figure 11: Evaluation of present overtopping formula against data by Lissev (1993).

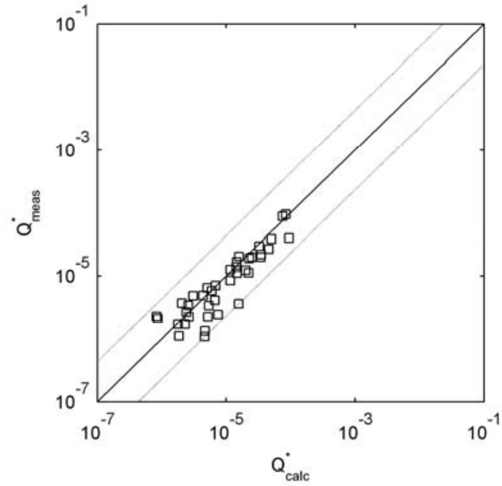

Figure 12: Evaluation of present overtopping formula against data by Viggosson et. al. (1993).

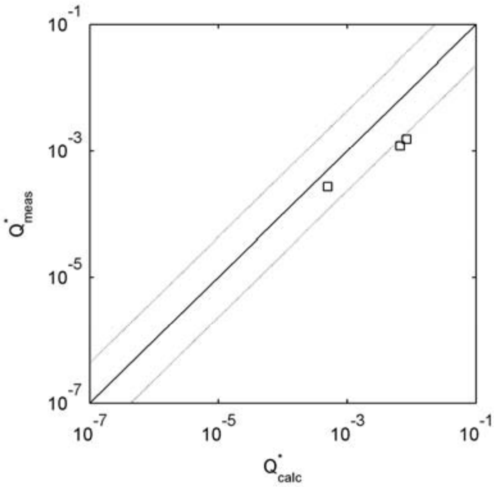

Figure 13: Evaluation of present overtopping formula against data by Kuhnen (2000).

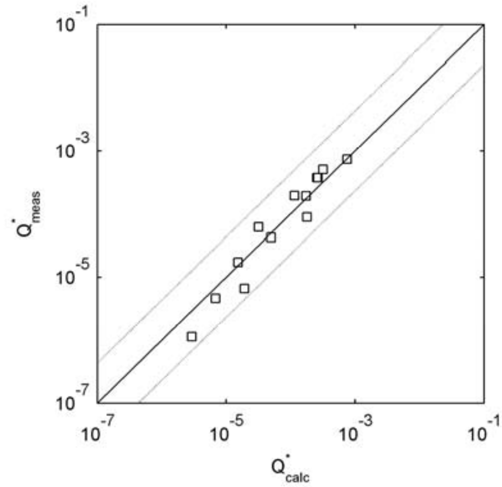

Figure 14: Evaluation of present overtopping formula against data by Þorarinsson (2004).

7. CLASH NN-MODEL

In the CLASH project a neural network model for wave overtopping was developed. The neural network model must be regarded as state of the art in estimating average overtopping discharges, as it is based on approximately 10,000 overtopping tests with all kinds of structures. Also some of the present tests are included in this data base. To use the CLASH NN-model the user should specify sea state parameters and some geometrical parameters related to the reshaped profile. In the CLASH model reshaping berm breakwaters are given a roughness/permeability factor (γ_f) of 0.45 and non-reshaping berm breakwaters are given a value of 0.40.

In Fig. 15-21 the model test results are compared to the predictions by the CLASH NN-model, when profile parameters are related to actual measured reshaped profiles. The profiles were schematized as good as possible, but due to the complex geometry of reshaping berm breakwaters, it is in some cases difficult to get a good schematization. Design of reshaping berm breakwaters using the CLASH NN-Model obviously requires a reliable method to calculate the reshaped profile.

It can be seen that too little amount of data for berm breakwaters were used in the training, as the network does not give that reliable predictions for berm breakwater tests not included in the training. 82 of the present tests were included in the fitting process, and for these tests the CLASH NN-Model predicts the overtopping discharge with very good accuracy. Also the data of Lissev (1993) and Viggosson et. al. (1993) was included in the training process, but for the Viggosson et. al. (1993) data without correction due to measuring total waves instead of incident waves. For the Viggosson et. al. (1993) data the predictions are much better with no correction due to measuring total waves, which is due to overlearning of the NN-Model as the data was not correcting before the training process. For all data with berm breakwaters included in the training process the predictions are very good, but much worse for those not included, this show some degree of overlearning of the network for berm breakwaters.

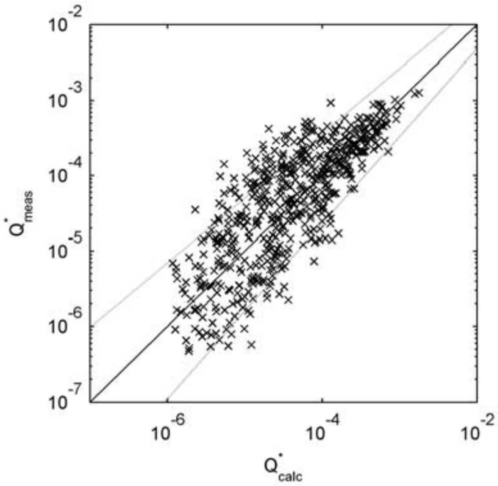

Figure 15: Evaluation of CLASH NN-Model against data by Lykke Andersen & Burcharth (2004).

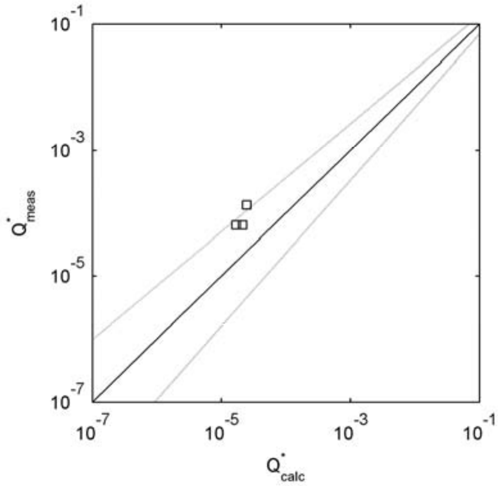

Figure 16: Evaluation of CLASH NN-Model against data by Bolatti Guzzo and Marconi (1991).

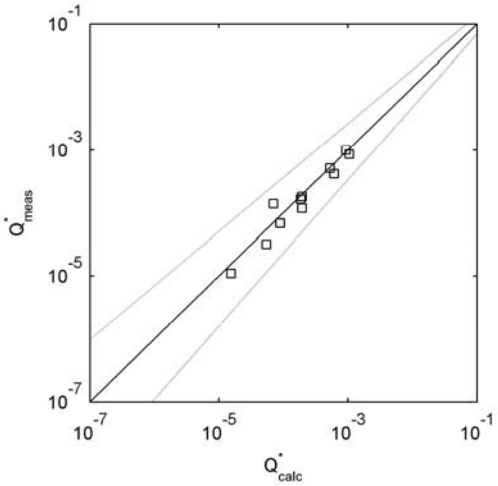

Figure 17: Evaluation of CLASH NN-Model against data by Lissev (1993).

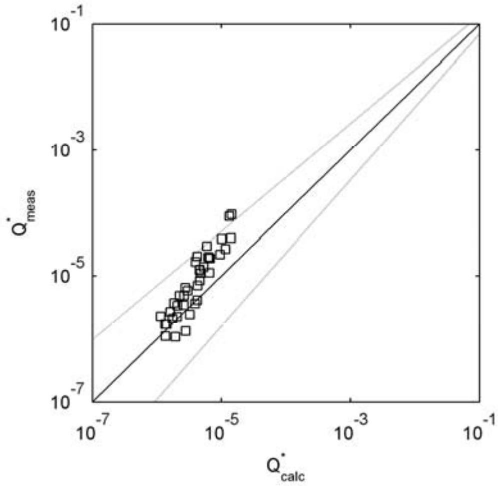

Figure 18: Evaluation of CLASH NN-Model against data by Viggosson et. al. (1993).

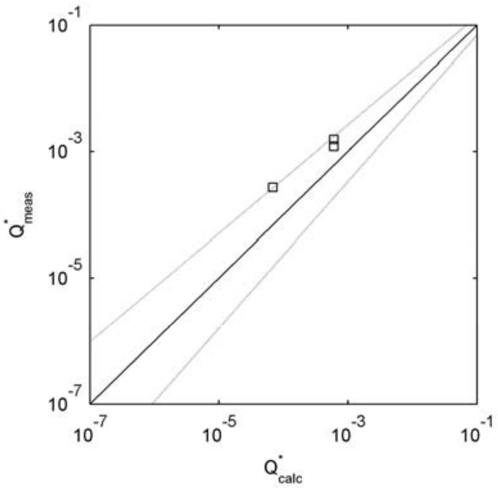

Figure 19: Evaluation of CLASH NN-Model against data by Kuhnen (2000).

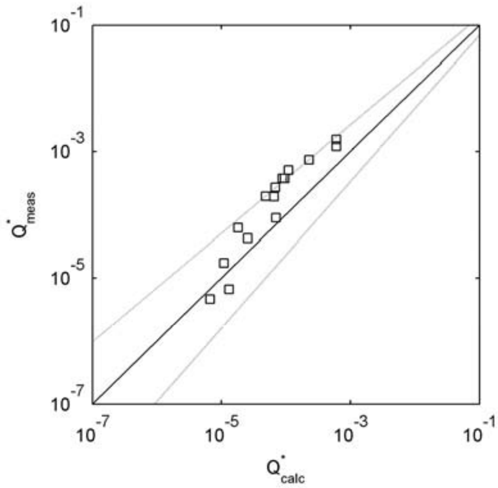

Figure 20: Evaluation of CLASH NN-Model against data by Porarinsson (2004).

8. CONCLUSION

In the present paper an improved version of the overtopping formula by Lykke Andersen & Burcharth (2004) is presented. The formula is improved in the following ways:

- A parameter more directly related to reshaping is included instead of H_0T_0. This change is especially important for a more stable structure and low wave steepness.

- Guidelines are given on how to take into account the front slope. These guidelines are based on observed development of the front side profile and volume conservation.

The formula is evaluated against the data of Lykke Andersen & Burcharth (2004) and data of five other researchers, which also includes tests with multi-layer berm breakwaters. The formula performs generally very well, and can be used with same accuracy for multi-layer berm breakwaters when the largest stone size is applied in the formula. The largest stone size should be applied due to limited reshaping allowed on a multi-layer berm breakwater.

The CLASH NN-Model performs not as good as the present derived formula. This is due to limited data with berm breakwaters included in the training process. It is believed that much more reliable estimates could be given if the NN-Model is updated with the new results. However, to use the NN-Model for design purposes one still needs accurate predictions of the reshaped profile. This is overcome in the present model as only non-reshaped geometrical parameters are included in the formula.

9. ACKNOWLEDGEMENT

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