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THE INFLUENCE OF BERMS AND ROUGHNESS ON WAVE OVERTOPPING AT ROCK-ARMOURED DIKES

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ABSTRACT

Average overtopping discharge is a crucial parameter for design and reinforcement of dikes. Rock armours and berms are widely used to reduce wave overtopping discharge by introducing slope roughness and energy dissipation. Since methods for estimating the influence of a rock berm and roughness of rock armour at dikes on the average overtopping discharge still need to be developed and/or validated, this study aims to empirically develop better quantification of the reductive influence of rock armour on wave overtopping, compared to existing procedures. That is derived based on the analysis of experimental data from physical model tests. Moreover, the influence of roughness of a rock armour applied only on part of waterside slopes is estimated by introducing location weighting coefficients. Results show that the newly derived methods for evaluating the influence of berm and roughness for rock-armoured dikes lead to significantly better predictions of the average wave overtopping within the tested ranges compared to existing ones.

Keywords: dikes, coastal structures, wave overtopping, physical model tests, rocks.

1 INTRODUCTION

Dikes protect coastal areas from flooding due to wave overtopping. With the background of climate change and sea-level rise, existing dikes may require reinforcement. Berms and roughness elements (e.g. rocks) are often applied to dikes, which can effectively reduce the average overtopping. Accurate estimations of the berm and roughness influence on overtopping discharge would help the cost-effective design and safety assessment of a dike. TAW (2002) and EurOtop (2018) provide empirical formulae for the average overtopping discharge (q), both characterised by the structure $q = A\exp(-B\,R_c)$, taking the effect of berms and roughness on wave overtopping discharge into account by introducing the dependence of A and B on berm and roughness influence factors (γ_b and γ_f). Those are 1.0 when no influence is present, while smaller values indicate a larger reductive influence due to a berm or slope roughness. R_C is the crest freeboard.

For the roughness influence factor, values are provided for various types of roughness elements (e.g. γ_f=0.55 for rocks on an impermeable core). Further research showed that γ_f varies with wave conditions and structure configuration and that there is still no validated method to evaluate that for rock armours. For the estimation of the berm influence, TAW (2002) and EurOtop (2018) provide equations to calculate γ_b for impermeable berms, but there are no validated ones for permeable rock berms. Chen et al. (2020a) developed new expressions for γ_b and γ_f, taking all those aspects into account for slopes covered by concrete blocks.

2 DEVELOPMENT OF NEW METHODS

This research aims to recalibrate and adapt empirical coefficients of the following Eqs. [1]-[2]-[3] by Chen et al. (2020a) to the case of permeable slope revetment made of rocks.

$$\gamma_b = 1 - b_0\frac{r_b(1-r_{dh})}{\sqrt{s_{m-1,0}}} \qquad 0.6 < \gamma_b < 1.0 \qquad [1]$$

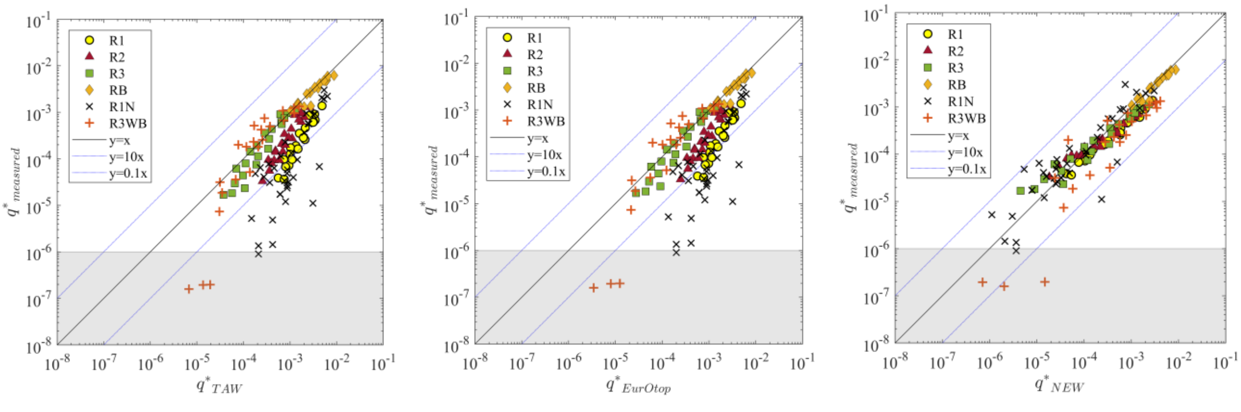
$$\gamma_f = 1 - c_0\frac{R_C}{H_{m0}\ \xi_{m-1,0}} \qquad [2]$$

$$\gamma_f = \frac{\alpha_1\gamma_{f,1}L_1 + \alpha_2\gamma_{f,2}L_2 + \alpha_3\gamma_{f,3}L_3}{\alpha_1 L_1 + \alpha_2 L_2 + \alpha_3 L_3} \qquad [3]$$

where b_0 and c_0 are empirical coefficients affected by the type of armour layer. A larger value of b_0 (c_0) means a larger reductive influence of the berm (roughness) on the average overtopping discharge; $s_{m-1,0}$ is the wave steepness; r_b and r_{dh} can be calculated as given by TAW (2002) and EurOtop (2018). Eq. [3] is used for varying roughness along the slopes (L is the effective length).
Physical model tests (139 in total) have been performed in the Pacific Basin (Deltares, Delft, The Netherlands) in order to collect a database to set up a calibration and validation process of influence factors expressions. Different roughness configurations were tested, as rocks were applied alternatively on the whole slope, on the upper slope only, on the upper slope and berm and on the berm only. Irregular wave conditions were applied to all physical model tests, based on JONSWAP spectrum and characterised by a wave steepness range of 0.013÷0.044. The crest freeboard varied between 0.12÷0.2m. The berm width was fixed (0.2m) for all configurations, except for the one with a larger berm (0.5m). The wider berm was tested to investigate how the proposed expressions for influence factors behave for such a different structure. More details on the tests are provided in Chen et al. (2020b).

3 CONCLUSIONS

Test results confirm that the application of a berm and rock armour significantly reduces the average overtopping discharge compared to that at smooth straight slopes. New expressions for berm and roughness influence factors of rock-armoured dikes are derived based on experimental data by calibrating the empirical coefficients in [1]-[2] as b_0=0.19 and c_0=0.70. It was also found that, for Eq. [3], the values of location weighting coefficients as proposed by Chen et al. (2020a) (α_1=0.65, α_2=0.22, α_3=0.13) for structures with other slope protections, appear to be valid for rock-armoured slopes as well.
The performance of new methods has been validated by using experimental data with wider ranges of test conditions, getting an improvement (from *NSE*=-1.32 to *NSE*=0.7) on estimates of average overtopping discharge over the structure with rock armour applied on the upper slope. For the structure with a wider berm ($\frac{B}{H_{m0}}$> 3.7), there is no improvement using new methods compared to TAW (2002). The influence of roughness on rock-armoured slopes needs further investigation for smaller relative freeboards ($\frac{R_c}{H_{m0}}$ < 1.1) in combination with wide berms ($\frac{B}{H_{m0}}$> 3.7). Overall, new methods to account for the influence of berms and roughness of rock-armoured dikes significantly improve predictions of average overtopping discharges as shown in Figure 1, where each data point corresponds to 1 test (shape and colour indicate the different test conditions) with *NSE*=0.8 within tested ranges.



(a) (b) (c)

Figure 1. Measured and calculated dimensionless overtopping discharges for all datasets, using (a) TAW (2002), (b) EurOtop (2018) and (c) new methods for the estimation of influence factors.

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