

NEW SIMPLE AND EXPLICIT FORMULA FOR WAVE REFLECTION ON MOUND BREAKWATERS USING NEURAL NETWORK MODELING

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INTRODUCTION

Wave reflection from breakwaters may influence beaches and the entrance of harbors due to dangerous wave conditions and may compromise the structure stability due to the induced scour at the structure toe. These problems will have a greater impact in the future due to climate change, sea level rise and stronger wave storms (Camus et al., 2019). The challenges of protecting coasts and harbors from the effects of global warming and the correct estimation of reflected energy from coastal structures demand more precise and easy-to-apply design formulas for mound breakwaters.

Several empirical formulas found in the literature for predicting wave reflection, K_R , are based on the Iribarren number, ξ_0 , or other dimensionless parameters with calibrated coefficients and dimensionless variables selected on empirical grounds (Postma, 1989; Zanuttigh and Van der Meer, 2008). These works considered an extensive experimental database tested with wave conditions, measurement devices and techniques specific in each laboratory. In some cases, K_R were measured in research tasks focused on the hydraulic stability, wave overtopping or wave transmission. The consequence of this variety of methods was a high uncertainty on the results and thus imprecise wave reflection estimations and empirical formulas valid only for very limited ranges.

Over the last two decades, new empirical formulas, complex estimators and numerical models have been used to achieve more accurate predictions for wave reflection (Vílchez et al., 2016; Díaz-Carrasco et al., 2021). Wave reflection is also estimated using Neural Network (NN) models (Zanuttigh et al., 2013), which are complex multi-parametric formulas that offer greater accuracy and low computational cost. The correlations made by NN between the input and output variables are not intuitive and difficult to obtain without using the NN model as a toolbox itself. These alternatives models significantly improve the predictions for reflected wave energy on breakwaters, but they provide formulas which are extremely complex and require many fitting parameters.

Hence, the main objective of this work is to find an easy-to-apply and more precise explicit formula to estimate wave reflection on conventional mound breakwaters under non-overtopping and non-breaking conditions.

METHODOLOGY

The NN benefits of weighting and correlation between input and output variables were used as a tool to (1) rank the influence on wave reflection of 11 candidate explanatory variables, and (2) obtain a simple and explicit

relationship between the main explanatory variables and the squared wave reflection coefficient, K_R^2 , by NN estimations. The methodology comprises three main phases:

(1) Formula development by applying the NN model to experimental data performed at University of Granada (UGR) with regular and irregular waves. The experimental database of UGR included tests from a conventional mound breakwater with double-layers of cube armor and rock homogeneous breakwaters with two seaward slopes angles.

(2) Formula validation with experimental data performed at Aalborg University (AAU) with irregular waves. The experimental database of AAU included tests from conventional mound breakwater with double-layers of cube and rock armors, three seaward slope angles, different composition of the porous media and various water depths.

(3) Formula application to experimental data from other studies (Zanuttigh et al., 2023) with irregular waves. The experimental database included tests from conventional mound breakwaters with different concrete armor unit types (Dolos, Cubipods, Tetrapods, among others) and rock armors.

Figure 1 represents the estimations obtained with the NN model using as input variable the relationship between the relative water depth, h/L , and the seaward slope angle, α , that is: $(h/L)/\tan \alpha$. Figure 1 shows an exponential relationship between K_R^2 and the $(h/L)/\tan \alpha$ for both slope angles tested at UGR.

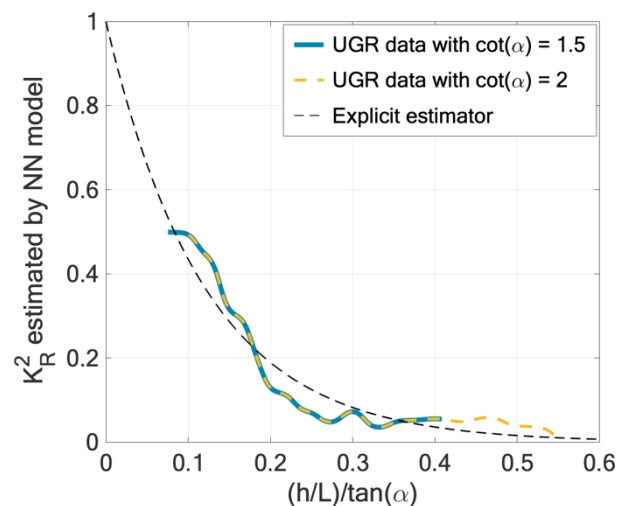


Figure 1 - Square wave reflection coefficient, K_R^2 , given by the NN model with input variable $(h/L)/\tan \alpha$. The dash black line represents the exponential relationship between the explanatory variables and K_R^2 .

RESULTS

Using NN modeling, it was obtained that the main explanatory variable is $(h/L)/\tan\alpha$. An exponential relationship between K_R^2 and $(h/L)/\tan\alpha$ with one fitting parameter was found (Díaz-Carrasco et al., 2023):

$$K_R^2 = \exp\left[-8 \cdot \left(\frac{h/L}{\tan\alpha}\right)\right] \quad (1)$$

where the wavelength, L , is calculated by the linear dispersion equation using the wave period, $T = 1.05 \cdot T_{01}$, for irregular waves; being T_{01} the spectral mean wave period.

The explicit exponential formula (Eq. 1) showed a good agreement ($R^2 = 0.88$) between K_R^2 calculated and K_R^2 measured from UGR tests. The proposed wave reflection formula was validated using the experimental tests of AAU. Figure 2 illustrates the good agreement ($R^2 = 0.91$) between the K_R^2 calculated by Eq. 1 and that measured from the tests with irregular waves, various water depths, different composition of the porous media and three slope angles performed at AAU.

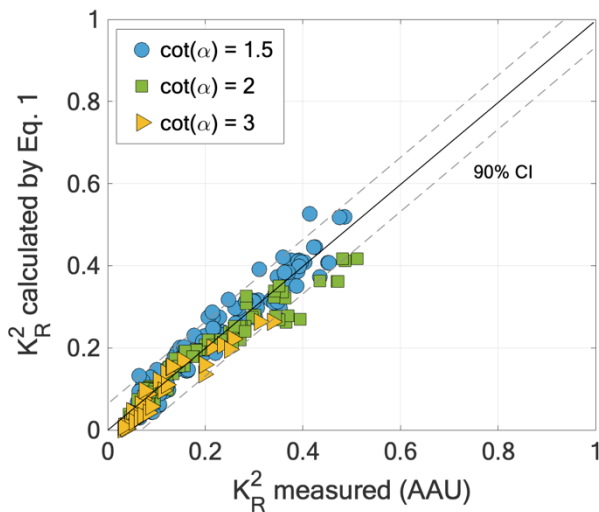


Figure 2 - Validation of the new wave reflection formula. Squared reflection coefficients estimated by Eq. 1 and 90% confidence interval (CI) compared to squared reflection coefficients measured at AAU.

CONCLUSIONS

The new formula is the simplest (only one explanatory variable and only one fitting parameter) formula which significantly improves the estimations of wave reflection of conventional mound breakwaters under non-overtopping and non-breaking wave conditions. Eq. 1 is valid for mound breakwaters with different armor unit types, core permeabilities, seaward slope angles in the range $1.5 \leq \cot\alpha \leq 3$ and relative water depths in the range $0.05 \leq h/L \leq 0.31$. Outside this range of variables and mound breakwater characteristics, the proposed formula should be used with caution.

At the Conference, results of applying the new proposed formula to other experimental data from studies found in the literature as well as a detailed explanation of the use of NN for estimating the wave reflection formula will be shown.

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