# WAVE FORCES ON CROWN WALLS OF MOUND BREAKWATERS USING WAVE OVERTOPPING DISCHARGES

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## INTRODUCTION

Mound breakwaters usually have a concrete crown wall on top to increase the crest freeboard decreasing the use of quarry material. The crown wall stability is crucial to control the wave overtopping discharges. The crown wall also provides enough space to improve the accessibility of pedestrians and vehicles as well as to install the necessary facilities for port operations.

Although the crown wall has several failure modes, sliding and overturning are the most common when it is analyzed as a rigid body. The crown wall has to resist wave forces as well as earth pressures due to filter rocks and concrete armor units. Wave attack on the crown wall generates both up-lift and horizontal wave forces, which are difficult to measure at laboratory and prototype scale. Existing methods in literature to predict wave forces on crown walls are mainly based on laboratory tests, where the pressure distributions on the crown wall are usually extrapolated from punctual pressure measurements with pressure transducers.

Several studies use the wave run-up as a key variable to estimate wave forces on crown walls (Pedersen (1996), Martín et al. (1999), Berenguer and Baonza (2006), Norgaard et al. (2013), Molines (2016)). Wave run-up is a hydrodynamic variable which is not easy to measure at laboratory scale, since it needs specific tests on non-overtopped cross-sections. Therefore, wave forces estimators based on run-up use run-up estimators developed by other authors such as Losada and Giménez-Curto (1980) or Van der Meer and Stam (1992).

Molines et al. (2018) proposed to use the dimensionless mean wave overtopping discharge (Q) as a key variable to estimate wave forces on crown walls. Wave overtopping is easy to measure at laboratory scale with an extensive set of predicting tools available in literature (such as Van Gent et al. (2007) and EurOtop (2018)). This study focuses the attention on the use of wave overtopping to estimate wave forces on crown walls.

## METHODOLOGY

Molines et al. (2018) used two datasets of structures in non-breaking wave conditions: tests conducted by Smolka et al. (2009) on cube and Cubipod-armored mound breakwaters and tests conducted by Pedersen (1996) on Dolos, cube and rock-armored mound breakwaters.

Molines et al. (2018) developed a Neural Network (NN) methodology to analyze the influence of seven explanatory variables on the wave forces on crown walls. The candidate explanatory variables considered geometrical and hydrodynamic parameters, including the virtual wave run-up $\gamma_f Ru/H_{m0}$ (where $\gamma_f$ is the roughness factor and $H_{m0}$ is the incident significant wave height) and the dimensionless mean wave overtopping discharge $Q=q/(gH_{m0}^3)^{0.5}$ (where q is the mean wave overtopping discharge).

The NN methodology was able to rank the influence of the seven candidate explanatory variables on the wave forces. New estimators were created considering the number of explanatory variables which provided the highest coefficient of determination, $R^2$.

## RESULTS

Q was selected as the most relevant explanatory variable for both the up-lift and horizontal wave forces. Figure 1 illustrates the prediction of the dimensionless horizontal wave forces associated to the 0.1% probability of exceedance (Fh) using the NN model with the input logQ. Eq. (1) is the simplest estimator to evaluate Fh depending on logQ with $R^2$=57%. Similar estimators were obtained for the up-lift forces.

$$Fh=3.6+0.6\log Q \qquad (1)$$

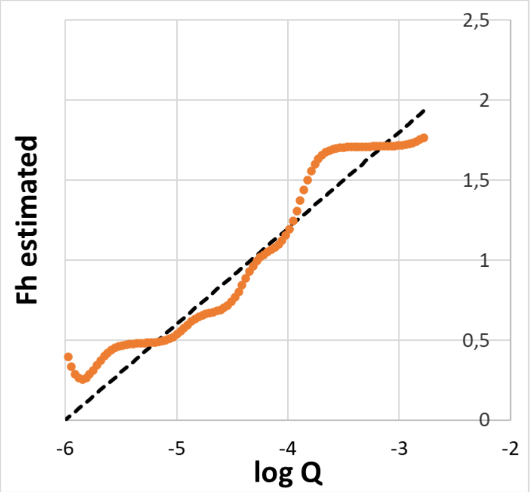

Figure 1 – Dimensionless horizontal wave forces, Fh, predicted with NN model using only logQ

The best estimators for Fh and the dimensionless up-lift pressure associated to 0.1% probability of exceedance provided $R^2$=65% and 60%, respectively. Using the same tests, Molines (2016) and Pedersen (1996) provided similar errors with $R^2$=73% and 9%, respectively. Figure 2 illustrates the cross-validation graph of Eq. (1) and the method given by Pedersen (1996).

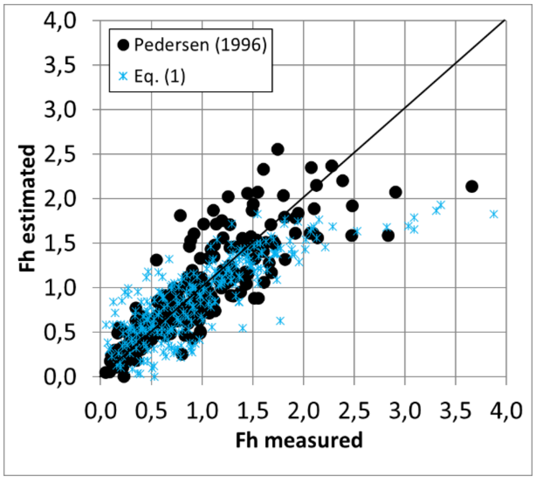

Figure 2 - Validation of Eq. (1) and the method given by Pedersen (1996).

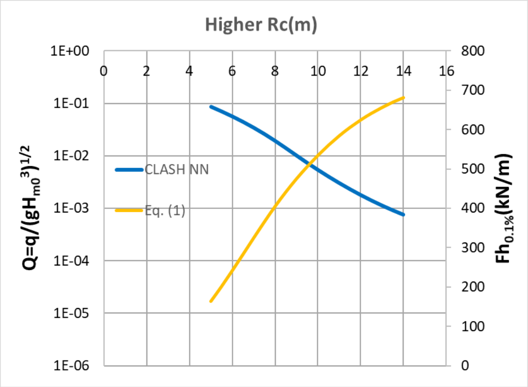

Figure 3 - Sensitivity to overtopping rates and wave forces on crown walls of increasing Rc.

## CONCLUSIONS

Wave overtopping is an indicator of the amount of wave energy that reaches the crown wall, the higher the wave overtopping discharges, the lower the wave forces on the crown wall.

This study concludes that the dimensionless mean wave overtopping discharges are a key parameter to estimate up-lift and horizontal wave forces.Although the new set of wave forces estimators based on logQ provide lower $R^2$ values, they are much easier to use than existing formulas given in the literature which use the wave run-up as key explanatory variable.

During the design stage, wave overtopping discharges are estimated with empirical formulas or methods. In those cases, lower $R^2$ are expected since the prediction of the wave forces accumulate both the error on the wave overtopping and the wave forces estimators. The wave force estimators provided in Molines et al. (2018) based on logQ are a useful set of tools to optimize the crest design considering both wave overtopping and wave forces. Given a conventional double layer cube armored mound breakwater, Figure 3 illustrates the wave forces on the crown wall if Rc is increased to reduce wave overtopping discharges (logQ was estimated using the CLASH Neural Network described in Van Gent et al. (2007)).

## ACKNOWLEDGEMENTS

The second author is funded through the Juan de la Cierva 2020 program (FJC2020-044778-I) by "European Union - NextGenerationEU en el marco del Plan de Recuperación, Transformación y Resiliencia de España", Spanish Ministry of Science and Innovation. This work is supported by two projects (1) PID2021-126475OB-I00 and (2) PID2021-128035OA-I00, funded by the MCIN/AEI/10.13039/501100011033 and, as appropriate, by "ERDF A way of making Europe", by the "European Union NextGenerationEU/PRTR".

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