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# INDIVIDUAL WAVE OVERTOPPING VOLUMES ON MOUND BREAKWATERS

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## 1 INTRODUCTION

Mound breakwaters are widely used to protect harbors from wave attack. Wave overtopping is a key parameter on the breakwater design, since it affects the hydraulic stability, the port operativity and also generates risks to the facilities, vehicles and pedestrians. The estimation of the mean wave overtopping rate, q[m$^3$/s/m], has been extensively analyzed in the literature (see EurOtop, 2018 and Van Gent *et al.*, 2007). However, the maximum individual wave overtopping volume, $V_{max}$ [m$^3$/m], can be much larger than q[m$^3$/s/m] and it is a better variable to evaluate the direct hazards.

The prediction tools of q and $V_{max}$ are mainly based on laboratory tests, where q is registered much more easily than individual wave overtopping volumes. However, few of these studies detail the methodology to identify the number of overtopping waves and the associated individual wave overtopping volumes. The estimation of $V_{max}$ is usually made in literature (see Molines *et al.*, 2019 and EurOtop, 2018) using a 2-parameter Weibull distribution (shape and scale factor) fitted with utility functions which consider the 10%, 30% or 50% of the highest individual wave overtopping volumes. The shape factor (b) is fitted with the laboratory measurements and the scale factor (A) is obtained by forcing the mean value of the Weibull distribution to be equal to the registered mean individual wave overtopping.

In this study, a fully automatic detection methodology of the individual wave overtopping waves and volumes is developed using 2D physical tests. The performance of the 2-parameter Weibull and Exponential distributions to estimate $V_{max}$ is analyzed here with four utility functions to weight the data, f(u). The full findings of this study are available in Molines *et al.* (2019).

## 2 PHYSICAL TESTS

In this study, the 2D small-scale physical tests conducted by Smolka *et al.* (2009) are used. Tests were conducted in the wave flume of the Laboratory of Ports and Coasts at the *Universitat Politècnica de València* (LPC-UPV). The physical model was a conventional double-layer cube and single- and double-layer Cubipod armored mound breakwater with crown wall in non-breaking wave conditions. Three Iribarren numbers (Ir = 3, 4 and 5), two water levels (h[m]=0.50 and 0.55) and two crown wall heights (Ch[m]=0.20 and 0.26) were tested. After each test, armor stability, wave characteristics, wave overtopping and wave forces on crown wall were calculated. Figure 1 illustrates the longitudinal cross-section of the wave flume.

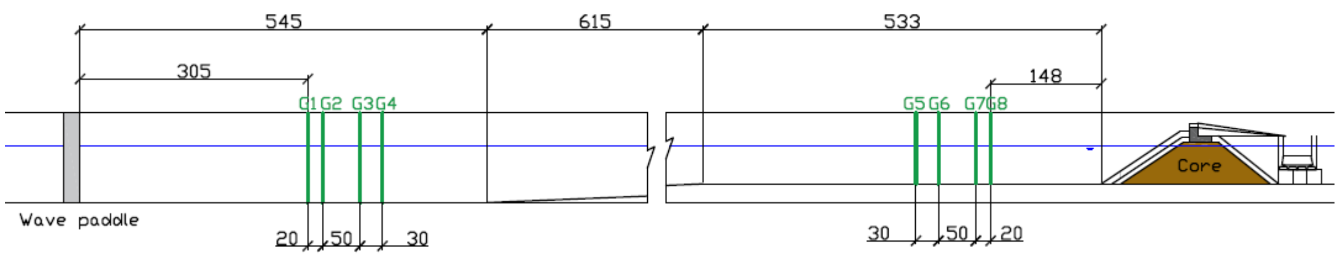


**Figure 1. Longitudinal cross-section of the wave flume of the LPC-UPV. Dimensions in centimeters.**

## 3 RESULTS AND DISCUSSION

In this study, a new fully automatic methodology was developed to detect the number of overtopping waves and their individual wave overtopping volumes using a weight register from laboratory tests. The methodology provided excellent results identifying low overtopping events, especially relevant in conventional mound breakwaters which are usually designed to allow low overtopping rates.

The fitting factors of the 2-parameter Weibull and Exponential distributions were fitted without any restriction. Figure 2.a illustrates the difference between a free fitted scale and shape factors to the 10% of the highest individual wave overtopping volumes, L1, and a fitted shape factor with a scale factor obtained when imposing the mean value of the Weibull distribution to be equal to the registered mean individual wave overtopping, L2. Thus, it is important to fit as free parameters any fitting factor of the representative statistical distribution.

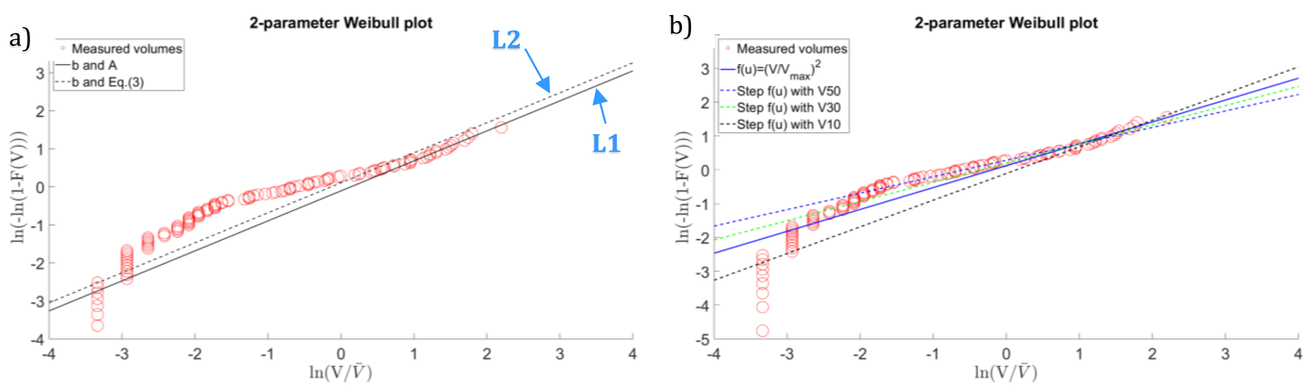


**Figure 2. 2-parameter Weibull distribution fitted to the individual wave overtopping volumes, a) influence of scale and shape factor, b) influence of the utility function.**

Figure 2.b illustrates the influence of the utility function on the 2-parameter Weibull distribution. Four utility functions are used in this study to fit the free parameters of the Weibull and Exponential distributions; three step utility functions considering the 10%, 30% and 50% of the highest data and one continuous quadratic utility function considering all data with a relative weight (larger individual volumes have a higher relative weight). The step utility functions have a subjective cut-off percentage which clearly influences the fitting parameters, so in this study the continuous utility function is proposed to avoid that inconsistency.

Two estimators depending on q are developed to estimate the number of overtopping waves, $N_{ow}$, and $V_{max}$. Using measured q of tests with $N_{ow}\geq 10$ and the continuous utility function to estimate $V_{max}$, both the 2-parameter Weibull and Exponential distributions provided a coefficient of determination, $R^2$, around 90%.

During the design stage, practitioners have to first estimate q and later $N_{ow}$ and $V_{max}$. If the CLASH Neural Network is used to estimate q (Molines and Medina, 2015 and Van Gent *et al.*, 2017), $V_{max}$ is estimated by both the 2-parameter Weibull and Exponential distributions with $R^2$ around 70%.


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