Exploring the influence of seafront layout and water level on extreme overtopping events: a study based on focused wave groups

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INTRODUCTION

Assessing wave overtopping for coastal defense design is crucial, as it is vital for the evaluation of flood protections and essential to safety and risk mitigation. There is a debate about whether the average overtopping or the largest waves, which can cause the most damage, should be the primary design criterion. The EurOtop manual (2018) provides guidance, suggesting adaptability based on specific conditions and site use.

The ability to predict of extreme individual overtopping events, especially for human safety, is gaining importance (Suzuki et al., 2020). For this purpose, synthetic representations of wave groups containing the highest wave in a sea storm can replace irregular sea states. Using focused wave groups in experimental facilities can enhance efficiency, broaden test conditions, and refine understanding of overtopping. This method has been widely adopted in offshore engineering, with recent emphasis on exploring interactions between incident wave characteristics and wave-structure interactions (Hofland et al., 2014). Focused wave groups are indeed a valuable tool for studying wave overtopping when extreme events occur (Whittaker et al., 2017).

The proposed study implements focused wave groups in an experimental flume facility aiming to investigate the variability of maximum individual overtopping volumes at sea dikes with shallow water conditions and/or emergent toes. By employing focused wave groups, it is crucial to comprehend how the combination of focus phase, focus location, water levels, and sea front characteristics are affecting the measured volumes and represent a sea state storm. The ultimate objective is to achieve a parametric optimization of focused wave groups for laboratory practices and analyses of extreme overtopping events at coastal defenses. Here, we compare two different foreshore slopes and four different sea dike slopes, in combination with varying water levels and three different wave conditions, to provide a preliminary comparison of all cases. This will pave the way for further parametrization of the focused wave groups technique applied to model extreme overtopping events.

METHODOLOGY

This research has identified two pilot cases characterized by diverse wave forcing, foreshore slope and coastal layouts. Overtopping tests were carried out using irregular and focused wave generation to compare the results. Conducting this research presents numerous challenges due to the necessary variation of different parameters. These include geometrical factors - such as beach profiles and dike geometry - and hydrodynamic factors - such as hydrodynamic boundary conditions, focus amplitude, focus location, and phase angle.

Physical model tests were conducted at the small-scale wave flume laboratory (CIEMito) at the Universitat Politècnica de Catalunya - BarcelonaTech (LIM/UPC), Spain. The flume is equipped with a piston-type wavemaker. The water surface elevation was measured by eight resistive wave gauges and one ultra-sonic wave gauge. Overtopping volumes were measured in a tank located behind the dike. The time-varying water level within the tank was determined using an ultrasonic wave gauge, from which the volume was calculated. Model scale was 1:50. Two foreshore slopes, 1:8 (V:H) and 1:22.6, were tested, in combination with four different dike slopes: 1:2, 1:1, 1:0.5 and vertical one. Both foreshore and dike models were built in plywood (Figure 1). In all cases the height of the dike was 0.04m in model scale.

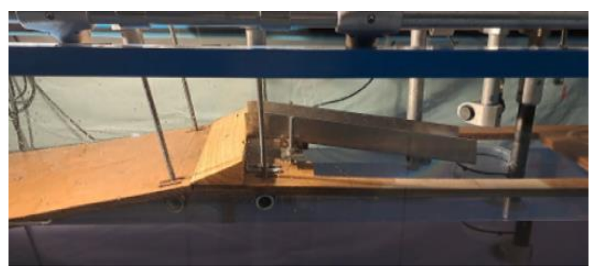

Figure 1 - Picture of the 1:8 foreshore and 1:2 dike model in CIEMito flume.

A total of 839 tests were carried out. Focused wave groups were generated by changing four focused location and four focused phases (0°, 90°, 180° and 270°). The linear focus amplitude was calculated based on spectral parameters, including significant wave heights in the range 0.06-0.08m, and peak periods in the range 1.13s-1.6s. Four different water levels were studied: 0.28m, 0.29, 0.30m and 0.31m, expressed in model scale at the wave generation location. The end of the foreshore was located at x=10.22m and x=10.55m, and the toe of the dike was located at z=0.32m and z=0.30m, for the 1:8 and 1:22.6 respectively (z=0 being the flume horizontal bottom). The dikes were positioned at two distinct locations: directly at the end of the foreshore and 0.05m further along, resulting in the formation of a layout featuring a toe berm preceding the dike.

Each time series representing a focused wave group was generated using the NewWave theory, as detailed in Whittaker et al.'s (2017) work: the authors demonstrated that the NewWave theory's range of applicability extends to shallow waters, indicating that even as bathymetric changes accentuate nonlinear effects, linear frequency dispersion remains the prevailing mechanism for the focused wave formation. The focus wave group energy reaches the structure in a compact, maximized form if the focus location is close enough to the structure. A NewWave-type focused wave group comprising N wave components is given by:

$$\eta(x,t) = \frac{A}{\sigma^2}\sum_{i=1}^{N} S_{\eta\eta}(\omega_i)\cos\left(k_i(x - x_f) - \omega_i(t - t_f) + \phi\right)\Delta\omega \quad [1]$$

where $S_{\eta\eta}$ is the power spectral density, ω is the angular frequency, t is time, σ is the standard deviation of the sea state (with an associated variance $\sigma^2 = \sum S_{\eta\eta}(\omega_i)\Delta\omega$ in this discretised form) and k_i is the wavenumber of the i-th wave component with angular frequency ω_i and related to it by the familiar linear dispersion relation $\omega^2 = gk * \tanh(kh)$ (where g is the acceleration due to gravity and h is the water depth), and x is the horizontal distance. All wave components come into phase at the focus location x_f and focus time t_f to form a large wave with a linear focus amplitude equal to A. A full range of focusing behaviours can be allowed by introducing the phase angle ϕ of the group at focus (crest, trough, otherwise), while the energy concentration within the group is independent of the value of ϕ. Yet, the wave shape can affect its breaking patterns and therefore the impacts exerted on the structure.

RESULTS

A comprehensive analysis of laboratory measurements was carried out for each focused wave group test. A filtering in Matlab was applied to the signal acquired by the ultra-sonic gauge to remove the noise produced by spurious water level oscillations. In Figures 2 and 3, we provide a visual representation of how the overtopping volume is affected by variations in focus location and phase for a given dike slope, namely 1:2 (i.e. cotα=2), and for 1:8 and 1:22.6 foreshore slope, respectively. The volume is scaled to dimensionless values based on the volume flux as defined by Ibrahim and Baldock (2020). N.B.The focus locations in these plots are defined with respect to position of the wavemaker at rest.

Clear differences are noticed between the two foreshores. While for the 1:8 foreshore the maximum overtopping volumes are caused by compact groups that focus in a wide range of focus locations and phases up to x_f =8.61m, different clusters can be identified for the 1:22.6 foreshore: one cluster very close to the dike toe and invariant to the focus phase, other two ones around x_f=7.66m for a skewed and asymmetric focus waves (ϕ= 90° and ϕ= 270°). We must highlight that the two plots include cases with different water depths and freeboards. The different clusters in Figure 3 correspond to different water depth values. The results suggest optimal ranges for applying focused wave group generation to model individual maximum overtopping volumes.

A more detailed analysis will be presented at the conference, including the comparison with individual volumes of irregular wave trains and the influence of combination of all geometrical and hydraulic parameters on the structural response.

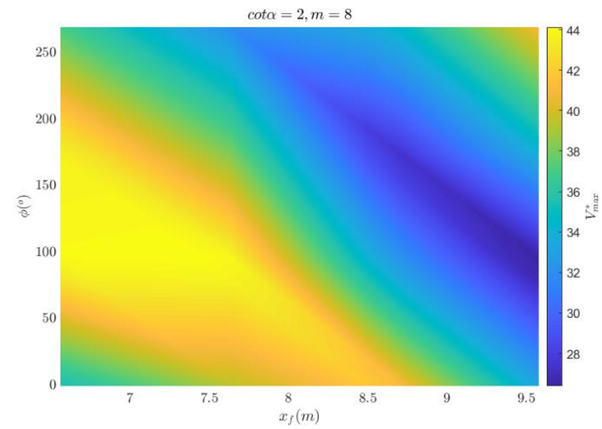

Figure 2 - Dimensionless overtopping volumes generated by focused wave groups with varying focus location and phase at focus for 1:8 foreshore and 1:2 dike.

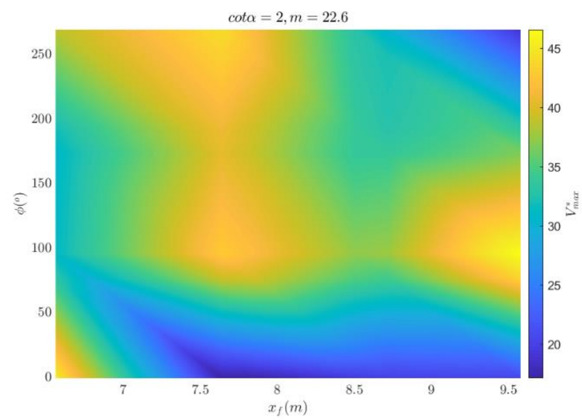

Figure 3 - Dimensionless overtopping volumes generated by focused wave groups with varying focus location and phase at focus for 1:22.6 foreshore and 1:2 dike.

ACKNOWLEDGEMENTS

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