Modelling wave overtopping with XBeach and IH2VOF. Preliminary results.

This work addresses the numerical modelling of the wave overtopping phenomenon on a seawall using the XBeach hydro-morphodynamic model and the IH2VOF hydrodynamic model. The objective is to assess the models' performance by comparing the run-up and overtopping discharge time series, for representative conditions of the study zone in Gala-Cova. These results are the first step to the assessment of overtopping conditions and processes validation against empirical formulas and laboratory results.

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1.INTRODUCTION

This numerical modelling work addresses the study of the wave overtopping phenomenon on a longshore coastal defence structure, using the XBeach hydro-morphodynamic model (Roelvink *et al.*, 2009) and the IH2VOF hydrodynamic model (Lara *et al.*, 2006).

The two most relevant features differing in the numerical models are the mutual interactions between the hydrodynamics and the morphodynamics of the sandy bottom accounted for in XBeach and the possibility to model disconnected fluid areas over a solid bottom in IH2VOF, which theoretically allows a more precise modelling of the overtopping phenomenon. The combined application of the models under the same representative conditions for a study site in the Portuguese west coast, Cova-Gala, allows a clearer understanding of coastal defence response to wave overtopping, as well as each model's practical limitations and advantages in modelling the overtopping phenomenon.

The same hydro-morphodynamic conditions and a compatible model setup are considered in both models for two case scenarios with a solid bottom profile and distinct hydrodynamic forcing. Overtopping is assessed for two cases of combined incident wave and sea level conditions: case A, designed for the non-occurrence of overtopping, and case B, where overtopping occurs. The model results are compared for the free surface elevation (η) along the model domain, wave runup and overtopping discharge.

2.DATA AND METHODS

Topo-bathymetric conditions

The topo-bathymetric characteristics adopted for the numerical modelling are representative of Cova-Gala. The XBeach model was applied at the prototype scale and the IH2VOF model was applied at a reduced scale, using a scale factor of 34.5. The 450m long cross-shore profile is a representation of a profile located in-between two groynes, limited by a seawall at the backshore (Fig. 1). For both cases, A and B, the bottom is considered solid and impermeable.

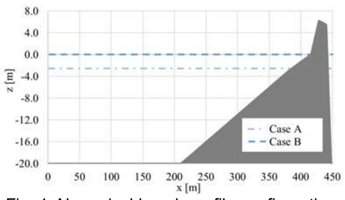

Fig. 1. Numerical beach profile configuration used in the XBeach model (prototype scale). Water level for cases A and B.

Hydrodynamic conditions

The models were forced with the same hydrodynamic conditions, differing in cases A and B. At the prototype scale, in case A, a regular wave with H=4 m and T=12 s was generated at the offshore boundary. The still water level (SWL) was set at the slope transition, 17.25 m above the bottom of the profile at the offshore boundary (Fig. 1). In case B, a JONSWAP spectrum with the parameters Hs=8 m, Tp=12 s, peak enhancement factor γ=3.3 and directional spreading coefficient s=5 was generated in XBeach and imported into IH2VOF as the η time series at the numerical boundary, guaranteeing equal hydrodynamic forcing in the models when using a wave spectrum. The SWL was set at the seawall toe, 20 m above the profile flat bottom (Fig. 2).

Numerical modelling

The Non-Hydrostatic X version of the hydro-morphodynamic model XBeach and the IH2VOF two-dimensional hydrodynamic model developed from the COBRAS-UC model were used. For the XBeach model setup, the bottom was considered as a structure via a non-erodible layer to guarantee the bottom compatibility with IH2VOF. The resolutions 0.138 m (prototype) and 0.004 m (reduced scale) were adopted, respectively, in XBeach and IH2VOF, to reduce computational cost and maintain the same resolution of the processes in both models.

Twelve gauges were considered along the modelling domain to allow a proper calibration of the models and analysis of the results (Fig. 2). In case A, the maximum wave steepness criterium (*maxbrsteep*) parameter in XBeach was calibrated by comparing the η time series obtained in gauge 1 (x=17.25 m at the prototype scale) with the time series obtained in IH2VOF. This parameter was kept constant for the simulation of case B. A warm-up period of 7 waves was considered for both models and the η and wave runup were analysed for the subsequent 20 waves in case A. In case B, overtopping was assessed for a period of 50 waves. Since there is no overtopping of the seawall in case A, the wave runup was compared for the two models. In case B, the η and the horizontal velocity in gauge 10 were used to calculate the overtopping discharge and the results between the numerical models were compared.

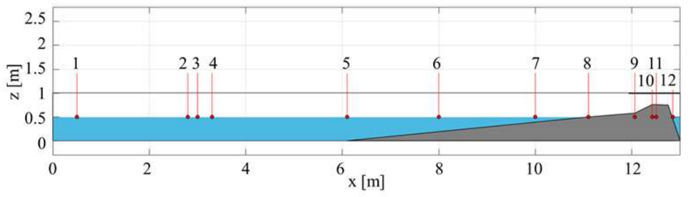

Fig. 2. Numerical beach profile configuration in the IH2VOF model (reduced scale). Case A. Location of the 12 gauges.

3.RESULTS AND DISCUSSION

Case A: non-occurrence of overtopping

The η variation obtained in gauges 1 and 8 using XBeach and IH2VOF, considering the SWL as reference, is depicted in Fig. 3.

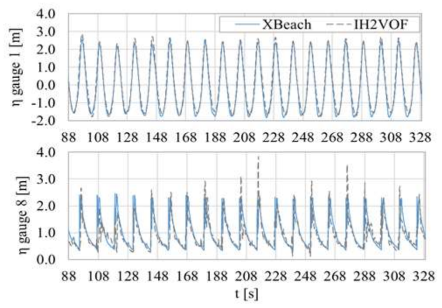

Fig. 3. Free surface elevation time series at gauges 1 and 8 in XBeach and IH2VOF.

The η predictions in both models are similar, especially in the extension where the waves shape is less affected by the profile bottom (gauges 1 to 6). For the same hydrodynamic forcing, XBeach seems to underestimate the wave energy during the wave propagation process, in comparison to IH2VOF. In gauges 1 to 6, lower levels are obtained in XBeach, which reduces the probability of the occurrence of wave overtopping with this model. In the breaking zone, the η differences are more significant, especially in gauges 7 and 8, due to the different approach of the wave breaking phenomenon considered in each models, leading to greater variations in the wave runup time series.

The runup time series obtained using XBeach and IH2VOF is depicted in Fig. 4 for the same simulation period. Table II presents the average (R), minimum (Rmin), maximum (Rmax) wave runup and the two percent exceedance value ($R_{2\%}$), calculated for both model results.

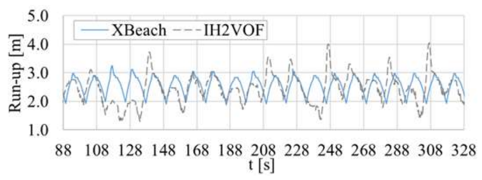

Fig. 4. Runup time series in XBeach and IH2VOF.

Table II. Average, minimum, maximum and two percent wave runup in XBeach and IH2VOF.

Model	R [m]	Rmin [m]	Rmax [m]	R2% [m]
XBeach	2.56	1.88	3.24	3.05
IH2VOF	2.46	1.29	4.05	3.61

The XBeach model slightly overestimates the overall average runup, but the runup levels obtained in IH2VOF are more extreme, reaching a maximum of 4.05 m, 0.80 m above the maximum XBeach runup level. The $R_{2\%}$ is 0.56 m higher in the IH2VOF predictions. The IH2VOF runup time series presents greater variations compared to the constant amplitude of XBeach (Fig. 4). In this case, IH2VOF is more prone to predict the occurrence of wave overtopping since these irregular and extreme peaks values are the main cause for this process.

Case B: overtopping occurrence

Fig. 5 shows the overtopping flow (Q) and the accumulated overtopping volume (Accum V) obtained in case B. Table III presents the average (Qav) and maximum (Qmax) overtopping flow values, and the total overtopping volume (Vtot) obtained in the two models.

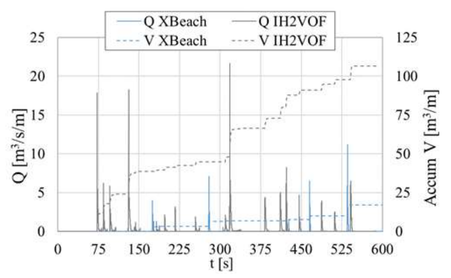

Fig. 5. Overtopping flow and accumulated overtopping volume in XBeach and IH2VOF.

Table III. Average and maximum overtopping flow and total overtopping volume in XBeach and IH2VOF.

Model	Qav [m3/s/m]	Qmax [m3/s/m]	Vtot [m3/m]
XBeach	0.03	11.17	16.88
IH2VOF	0.18	21.65	107.57

XBeach predicted the occurrence of 7 overtopping events while IH2VOF predicted 18 events, more than the double. The XBeach Qmax was half of the IH2VOF value, and the average value was at large underpredicted by XBeach, representing only 16% of the average IH2VOF value. The total overtopping volume in XBeach was 16.88 m^3/m, representing 17% of the 107.57 m^3/m predicted in IH2VOF. XBeach underestimated both the frequency and intensity of the overtopping occurrences predicted by IH2VOF.

Wave overtopping is a random process with respect to time and volume. A single parameter calibration (*maxbrsteep*) was used for this study, achieving a good η correspondence between models while minimizing the overall energy dissipation in XBeach. The runup analysis in case A supports the overtopping analysis in case B: XBeach underestimates the wave energy predicted in IH2VOF and, consequently, the occurrence of overtopping. The precision of the IH2VOF model comes at a high computational cost: the simulations presented in this paper, which consider simplified topo-bathymetric and hydrodynamic conditions, take weeks to run using IH2VOF over a few hours using XBeach. The model choice requires a compromise between precision and computational cost, especially when it comes to model complex field conditions.

4.CONCLUSIONS

The XBeach and IH2VOF numerical models' performance was assessed in modelling wave overtopping on a seawall, for the same hydro-morphodynamic conditions.

The results for the two scenarios modelled, with and without overtopping, show that the two models display greater differences in the breaking and swash zones.

In spite of the calibration methodology adopted, XBeach underestimates the wave energy predicted by IH2VOF, considered to be more precise due to its possibility to model disconnected fluid areas, which leads to an underestimation of both the frequency and intensity of the overtopping occurrences predicted by IH2VOF.

This paper corresponds to the phase I of a two-phase study on wave overtopping using numerical models and empirical formulations. Future work will include the morphological evolution of the profile, using XBeach and the empirical MASE formulas, to analyse overtopping during storm conditions and varying sea levels.

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ACKNOWLEDGEMENTS:

FCT Ph.D. Grant PD/BD/128508/2017

CYTED Grant 2017-PE-PROTOCOL.