Testing storm impact modelling at São Pedro de Moel beach

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Abstract: Numerical models are useful tools to predict the effects of storms in coastal areas. The objective of this work was to simulate the effects of storms in São Pedro de Moel beach by using XBeach. The nearshore sea state was obtained by propagating offshore conditions using the SWAN model. The XBeach model was divided into two setups to analyse overtopping events and coastal evolution. Sensibility tests, calibration, and validation, using information from different storms, were performed for the different setups. The results from the overtopping simulation were compared against results from an empirical formula. The comparison showed lower values obtained with the empirical formula. The coastal evolution run point out to the necessity of having better field data before and after storms to improve the model setting and accuracy.

Keywords: coastal evolution, coastal storms, , empirical formula, overtopping, XBeach.

1. INTRODUCTION

Coastal storms have possible outcomes (wave overtopping, flooding, and erosion) on the coast that can have harmful consequences to the local and regional economy, infrastructures, human wellbeing or, in the worst cases, even take human lives (e.g., Ciavola et al., 2014; Vousdoukas et al., 2011). This is even more critical within a climatic change scenario, where the sea-level rise and storminess of a region can lead to an increase of overtopping, flooding, and erosion events. Those factors and the concentration of population in the coastal zones, has led to an increase of interest and a need for understanding and predict the effects of storms in coastal zones (Plomaritis et al., 2018).

A way to predict and understand the impacts of storms in beaches and associated areas is numerical modelling of the coastal morphological behaviour (Vousdoukas et al., 2011). One numerical model widely used to simulate the coastal evolution during a storm is XBeach (Roelvink et al., 2009). XBeach is a hydrodynamic and morphodynamic model that evaluates the wave runup, overwash and beach morphodynamics in a coastal area during storm conditions. However, the use of this model is restricted to small areas due to the significant computational effort. Moreover, the model results depend on some intrinsic parameters which should be calibrated for each coastal area. Application of XBeach to different coastal areas considering different storms conditions contributes to a better knowledge of the model itself, limitations and advantages, and especially on the behaviour of its intrinsic parameters.

The west coast of Portugal is exposed to severe storms, frequently promoting flooding and erosion. The Portuguese west coast (according to data from Figueira da Foz buoy) is exposed to storm conditions in average for 19.9 days per winter (Costa et al., 2001), turning it an area of interest to use the XBeach model to predict and understand coastal hazards. Situated on the west coast of Portugal, the village of São Pedro de Moel (Fig.1) has been impacted by different storms events that caused overtopping, flooding, or coastal erosion. Hercules, in 2014 (from the 4th to the 7th of January 2014, Santos et al., 2014) and Elsa, in 2019 (from 19th to the 22nd of December 2019), for example, were two storms with known impacts in the study area.

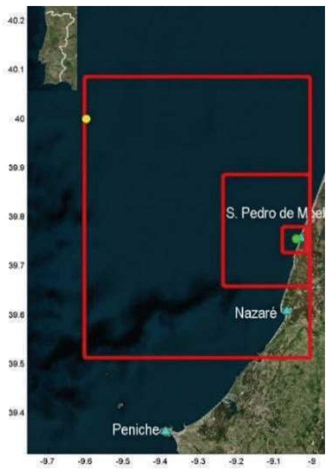

Fig. 1 – Study area and nested grid system used in SWAN (represented by the red rectangles). The yellow point represents where the offshore wave condition was extracted, and the green point represents the output positions of the SWAN results. São Pedro de Moel, Peniche and Nazaré are located by cyan triangles. Map built using MIRONE (Luis, 2007).

In this work, XBeach was used to simulate coastal storm effects on the beach of São Pedro de Moel, considering the above-mentioned storms and a storm that occurred in February of 2019 (from the 18th to the 19th of February 2019).

Two XBeach setups were used, one to study the overtopping, using the non-hydrostatic mode and another to access morphodynamic evolution, using surf beat mode with bottom updating. The non-hydrostatic setup allows to analyse the storm effect in terms of runup and overtopping on the coastal areas, although it does not consider morphologic changes. The surf beat setup solves the short-wave variations on the wave group scale and the long waves associated with them, and it also solves the morphological processes to analyse the beach evolution during a storm event.

2. METHODOLOGY

2.1. Topographic and bathymetric data

The main bathymetric data regarding the area offshore São Pedro de Moel was obtained through the EMODnet Bathymetry portal. This bathymetry, in conjunction with bathymetric data from LIDAR 2011 (nearshore) and the topographic data from field campaigns done on the 12th of February of 2019 (LNEC, 2019), were used. The topographic data from the field campaigns had high-resolution beach profiles of the São Pedro de Moel beach but also included the existing seawall and the main square connected to the seawall that has been subjected to overtopping events.

2.2. Wave and tide conditions

The offshore wave conditions were obtained from the ECMWF Centre (Richardson et al., 2013), at the coordinates -9.6º W, 40º N in the coordinate system EPSG:3763 ETRS89/Portugal TM06 (Fig.1) at a depth of 185 m below mean sea level (MSL). The water level (tide) information was obtained from WXTide32 (Flater, 2007) for a point near Peniche. To propagate the wave conditions from offshore to nearshore SWAN model (Booij et al., 1997) was used with three nested grid system. The resulting wave condition (significant wave height, Hs, peak period, Tp, mean period, Tm, and mean direction, Dir) were extracted at a point near São Pedro de Moel with the coordinates -9.045143º W 39.75535º N and at the bathymetric of 10 m below the MSL (Fig.1). The extracted data were used as input in the XBeach model and at the empirical formula.

2.3. XBeach

XBeach model is applied in a more restricted area, namely from the area behind the beach structure (7.5 m above MSL) until the bathymetric of 15 m below MSL. Two tests were performed by using non-hydrostatic, and surf beat XBeach setups. For each XBeach setup, a set of sensibility tests was performed to different intrinsic parameters. Then the XBeach setups were calibrated according to the available information. Finally, both setups were applied to the Hercules storm.

In the non-hydrostatic setup, the objective was to evaluate the discharge of the overtopping events at the structure crest and the maximum runup extension relative to the crest of the structure. For this setup, it was performed a sensibility test for the following parameters: *bedfriccoef, CFL, nhlay, maxbrsteep*, and bathymetry resolution (XBeach manual, Deltares, 2018). With the results from the sensitivity tests, the model was calibrated according to Elsa storm information (estimated from a national news report). The validation was performed by simulating the Hercules storm (2014) using the calibrated model. The calibration and validation were done by using estimated values regarding qualitative information (news and internet videos) for the runup extension and the theoretical mean overtopping discharge according to the CEM critical values (USACE, 2002) for each considered storm. The XBeach results (mean overtopping discharge) were also compared with the results from an empirical formula proposed by Mase et al. (2013). The empirical formula considered the wave results from SWAN for the Elsa and Hercules storms and the combined bathymetry data from 12 m below MSL to 7.5 m above MSL.

The surf beat setup focused on the beach morphology evolution. In this setup, it was necessary to define the structure (rigid) area to have no erosion effects at the seawall. For the sensitivity tests, the variables tested were *alpha*, bathymetry resolution, *bermslope*, *beta*, *CFL*, *delta*, *dryslp*, *dtheta_s*, *dzmax*, *facua*, *gamma*, *gammax*, *hswitch*, *lws*, *morfac*, *n*, *thetamax*, *thetamin*, *turb* and *wetslop* (XBeach manual (Deltares, 2018)). With the information from the sensitivity tests, the models were calibrated using the storm that occurred in February 2019, and the results compared with the survey performed by LNEC on 19th of February of 2019 (post-storm) (LNEC, 2019). After the model calibration, the Hercules storm (2014) was simulated.

3. RESULTS

3.1. Empirical Formula

The results from Mase et al. (2013) formula show that the mean overtopping discharge for the Elsa and Hercules storms are 4.27×10^{-06} $m^3/s/m$ and 4.05×10^{-05} $m^3/s/m$, respectively.

3.2. Non-hydrostatic setup

The results of the sensitivity tests demonstrated that the more sensitive parameters for the non-hydrostatic setup were *nhlay, bedfriccoef, maxbrsteep* and the bathymetric resolution. Those parameters were adjusted to calibrate the model until the results achieved the estimated values: near 18 m for maximum runup extension from the crest of the structure and an interval of [10^{-4} 10^{-3}[$m^3/s/m$ for the discharge at the structure crest. These results were defined as "ideal" for the Elsa storm after the observation of a national news report and the CEM table regarding the critical mean overtopping discharge values (USACE, 2002). The parameter settings that reached closer to those estimated values were *bedfriccoef*=0.0195 *nhlay*=0.33, *maxbrsteep*=0.6 and a bathymetric resolution of 0.5 m. Those parameters settings were used to simulate the Hercules storm (2014). Using the same sources (news/videos and CEM critical values), the estimated value for runup landward extension is near 29 m relatively structure crest and discharge of $\geq 10^{-3}$ $m^3/s/m$, for the Hercules storm. The results are shown in Table I.

Table I - Comparison between results from the model (runup extension related to the structure crest and the mean overtopping discharge at the structure crest (Disch)) against the estimated values for Elsa and Hercules storms.

	Calibration Storm Elsa		Validation Storm Hercules	
	Runup landward extension (m)	Disch. ($m^3/s/m$)	Runup landward extension (m)	Disch ($m^3/s/m$)
Estimated	~18	[10^{-4} 10^{-3}[	~29	$\geq 10^{-3}$
Results	16.1	9.74×10^{-4}	27.9	5.15×10^{-3}

3.3. Morphodynamic runs

The morphodynamic's sensibility tests demonstrated a stronger influence of the following parameters: *alpha*, bathymetric resolution, *beta, delta, facua, gamma, morfac, n, lws e bermslope*. The goal of the calibration of this type of run was for the results to be as near as possible to the post-storm profile obtained after the February 2019 storm (profile from 19th of February of 2019). The test that was closest to those results had a Brier Skill Score (BSS) of 0.85. The parameters values used in this calibration test were *alpha*=0.8, *beta*=0.8, *gamma*=0.8, *bermslope*=0.1, *facua*=0.15, *morfac*=5 and a bathymetric resolution of 1 m. However, it must be mentioned that the post-storm profile represented accretion (beach recovery) and not erosion (Fig.2).

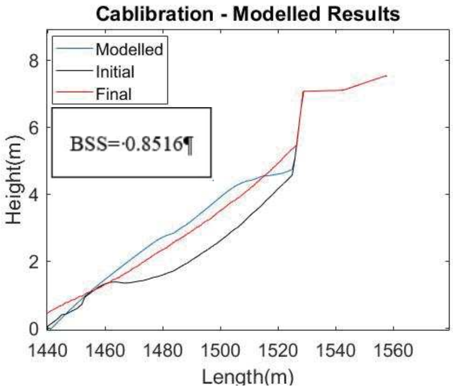

Fig. 2 - Modelled results after calibration runs (closest to the post-storm beach profile).

A simulation for the Hercules storm was performed using the above-mentioned parameters (Fig.3), which also resulted into beach accretion, a result that is opposite to the field observations, newspapers and video footages records, all showing strong erosion.

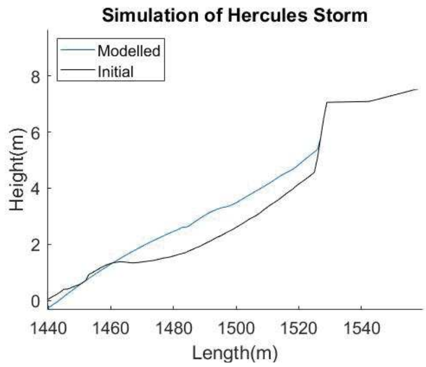

Fig. 3 - Result from the simulation of the Hercules storm using the calibration's parameter values.

4. DISCUSSION

The results of this work showed some limitations in both setups. In the non-hydrostatic setup, the inexistence of quantitative information was the major limitation. It was necessary to use nonscientific sources of information to establish values in order to calibrate and validate the setups. Table I shows that it was possible to adjust the model to reach the estimated values of the runup landward extension and mean overtopping discharge at the structure crest. This is highly valuable since it allows the further use of the validated model to estimate discharge values and runup extension to other storms at the study area.

When comparing the discharge values from the empirical formula and XBeach's non-hydrostatic setup, the empirical formula shows a lower value for both coastal storms. This suggests that by validating a process-based model, the obtained values can be more accurate than using a more generic formulation.

The surf beat setup demonstrates the limitations of applying a morphodynamic model without proper validation and calibration. The available data for this work was a recovery profile, showing accumulation on the post-storm profile regarding the February 2019 storm. The calibration was done using the only available data, and thus the model setup is tuned towards beach recovery. When applied to the Hercules storm, it also gave beach accretion (Fig.3), not allowing to mimic the generic observation of erosion caused by that storm. Thus, model calibration requires adequate data sets and a strong field effort, without which the obtained values are not trustable.

5. CONCLUSION

Two XBeach setups were used to simulate overtopping and beach evolution at São Pedro de Moel. The non-hydrostatic setup showed that it is possible to simulate overtopping events at São Pedro de Moel with good accuracy when compared to estimates. Nevertheless, the non-hydrostatic model still presented limitations due to the lack of quantitative information on overtopping events. Improvements will require *in situ* measurements using current meters, videos or holding tanks.

The surf beat setup provided erroneous results for the Hercules storm simulation as a consequence of the performed calibration (against a post-storm recovery profile). This demonstrates the need for having suitable field data immediately before and after storms. It also suggests that morphological data from low energy storms (with smaller erosion and quick recovery) might not be enough to promote adequate calibration for high energy events (like Hercules).

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