Wave Overtopping at Ericeira harbour. Validating SWASH and NN_OVERTOPPING2 estimations with video.

A. Zózimo (1), A. Manz (1), J. Garzon (2), C. Fortes (1), M. Reis (1), R. Capitão (1), R. Taborda (3), A. Silva (3)

(1) Departamento de Hidráulica e Ambiente, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal. aczozimo@lnec.pt

(2) CIMA – Centre for Marine and Environmental Research, FCT, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal.

(3) Instituto Dom Luiz, Universidade de Lisboa.

Abstract: The To-SEAlert project has the aim of increasing the efficiency, robustness and reliability of the HIDRALERTA system. One of its tasks is to implement and test numerical models to estimate wave overtopping in order to complement/replace the neuronal network overtopping tool (NN_OVERTOPPING2) currently available in HIDRALERTA. Here, we investigate the perfomance of the HIDRALERTA system and process-based model (SWASH) to predict overtopping discharges at two profiles at the trunck and the head of Ericeira breakwater by comparing their results against information taken by a video-monitoring system. This comparison reveals that, in the overall, HIDRALERTA presented a better match than SWASH for the trunk profile and a worse performance for the head profile. SWASH overestimated the overtopping discharges of HIDRALERTA and the corresponding alerts issued by the system.

keywords: Early Warning Systems, HIDRALERTA, To-SEAlert, video-monitoring, wave overtopping.

1. INTRODUCTION

While the world's population continues to grow and concentrate in coastal areas, communities become more vulnerable to flooding and erosion caused by extreme ocean events. Often socio-economic activities rely on the ability of coastal structures to reduce the impacts of wave-induced flooding, which has a negative impact on society, environment and economy. Early Warning Systems (EWSs) have been identified as important tools that anticipate emergency situations and initiate the necessary safety procedures (Lavell *et al.*, 2012).

In Portugal, a country highly exposed to coastal hazards, no fully operational national flood forecast and early warning system exists yet. The HIDRALERTA system aims to fill this gap (Poseiro, 2019, Fortes *et al.,* 2020), as it is a wave overtopping and flood forecast system with early warning and risk assessment capabilities. This system can identify emergency situations in coastal and harbour areas 72 hours in advance. The system is running in a real-time mode and uses the neuronal network tool NN_OVERTOPPING2 (Coeveld *et al.*, 2005) to compute mean overtopping discharges, q, at each cross-section of a structure. When pre-set thresholds for q are exceeded, warnings are triggered and forecasts are sent to decision-makers. Within the scope of the To-SEAlert project (whose main objectives are to increase the efficiency, robustness and reliability of the HIDRALERTA system), the numerical model SWASH (Zijlema *et al.*, 2011) was calibrated for two different breakwater profiles of the Ericeira harbour and empirical expressions were developed to automatically obtain the Manning friction coefficient for the tetrapod and antifer armour layers of the profiles (Manz, 2021). In this study, wave overtopping estimations provided by NN_OVERTOPPING2 and SWASH of selected events were validated against data collected by the video-monitoring system implemented at Ericeira harbour, to investigate the performance of each tool.

2. METHODS

2.1. Study site

The Ericeira harbour, on the west coast of Portugal, is sheltered by a 430 m long breakwater, oriented to the south-west, with a quay in the rear side (Fig. 1).

Two breakwater profiles were chosen to perform the simulations: Profile-T is located at the trunk of the breakwater, has an armour layer of tetrapods and an orientation of 309°N; Profile-A is located at the head of the breakwater, its armour layer consists of antifer cubes, and has an orientation of 262°N. The profiles differ in their slope, the crest freeboard, R_c, the armour freeboard, A_c, and the width of the crest, G_c (Fig. 1).

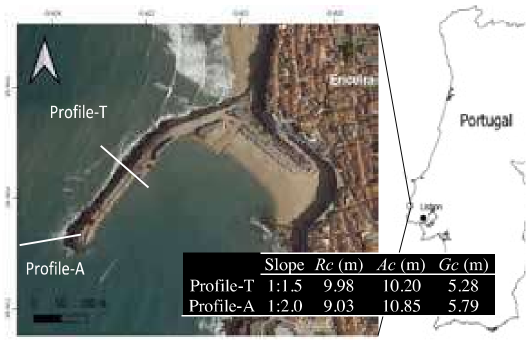

Fig. 1. Location of Ericeira harbour and of profiles T and A.

2.2. Wave overtopping predictions

To obtain the wave overtopping predictions, wave conditions were extracted with the approach used in HIDRALERTA for the selected events, which covered overtopping and no- overtopping conditions. The offshore boundary conditions were acquired from ECMWF forecasts (wind and wave characteristics) and were propagated to the shore by using numerical wave propagation models SWAN (SWAN Team, 2006) and DREAMS (Fortes, 2002). The astronomical tide was obtained with the XTIDE model ((https://flaterco.com/xtide/).). Then, based on the extracted local oceanic conditions and the profile characteristics, NN_OVERTOPPING2 computed overtopping discharges. The numerical set-up for the simulations performed with the SWASH model can be found in Manz (2021).

2.3. Validation with video images

For the selected events, videos were analyzed for identifying overtopping occurrences. A total of 104 videos were analysed. Due to the range of applicability of the expressions for the definition of Manning friction coefficients for Profile-T and Profile-A (Manz, 2021), not all of the events could be simulated. The number of events used for each comparison is presented in Tab. i.

Tab. i. Number of events used in the analysis

Comparison between	Profile-T	Profile-A
SWASH *vs*. HIDRALERTA	65	17
SWASH *vs*. Video	44	14
HIDRALERTA *vs*. Video	104	102

Then, the information extracted from the images was used to categorize the risk levels as presented in Tab. ii. After the video analysis, the mean overtopping discharges computed with SWASH and NN_OVERTOPPING2 (hereafter refered to as HIDRALERTA) were used to determine the risk level of the overtopping events based on discharge thresholds (see Tab. ii). Finally, the risk levels observed and predicted were compared. These levels were applied to the following receptors: pedestrians (Profile-T and Profile-A), vehicles on the breakwater (Profile-T) and the structural elements (breakwater itself, Profile-T and Profile-A).

3. RESULTS AND DISCUSSION

For pedestrians at Profile-T (Fig. 2a), SWASH mainly gives higher alerts than HIDRALERTA (49% of the events), originating the same risk level for 35% and a lower risk level for 16% of the events. Regarding the comparison with the video, SWASH overestimates the alerts in 68% of the events, from which 32% in three levels. The match is only obtained for 25% of the events and a small part (7%) is underestimated. When comparing HIDRALERTA results with the video images, the match is better (61%), although it underestimates the video alerts in 24% of the events and overestimates in 16%.

For vehicles on Profile-T (Fig. 2b), SWASH performance is better than for pedestrians, where 75% of the cases agree with the observations, against 82% of HIDRALERTA. SWASH overestimates or underestimates the video only up to one level, while HIDRALERTA, although with a higher match, underestimates or overestimates up to two levels of alert. Comparing SWASH with HIDRALERTA, a match of 82% was obtained, with an overestimation of 14% and an underestimation of 5%.

For pedestrians on Profile-A (Fig. 2c), SWASH and HIDRALERTA have a 100% match. Regarding the comparison with the video observations, SWASH highly overestimates the alerts (94% of the events, with a similar distribution over the number of risk levels) and only obtained a 7% match.

HIDRALERTA also overestimated the video alerts in 97% of the events (with 51% in three levels), only presenting matches in 2%.

Altough not shown here, the observed and predicted risks for the structural elements were always green, and therefore the match was perfect.

Tab. ii. Risk level definition used in the video images analysis and HIDRALERTA overtopping thresholds (in brackets).

Risk Level	Pedestrians	Vehicles	Structural elements
No Risk	No injuries [<0.1 l/s/m]	Safe to drive [<10 l/s/m]	No damage [<200 l/s/m]
Low Risk	Minor injuries [0.1-0.5 l/s/m[	Light motorbikes or bicycles become unstable [10-25 l/s/m[	Movements and fall of blocks, without need of immediate repair [200-300 l/s/m[
Moderate Risk	Multiple minor injuries or some serious injuries [0.5–1.0 l/s/m[	Serious damage that affect its use, but without temporary stoppage [25-50 l/s/m[	Fall of blocks with filter exposure. Superestructure affected [300-400 l/s/m[
High Risk	Multiple serious injuries and/or loss of lives [≥1.0 l/s/m]	Serious damage that don't allow its use [≥50.0 l/s/m]	Filters damaged; significant movements of the superestructure; eventual collapse [≥400 l/s/m]

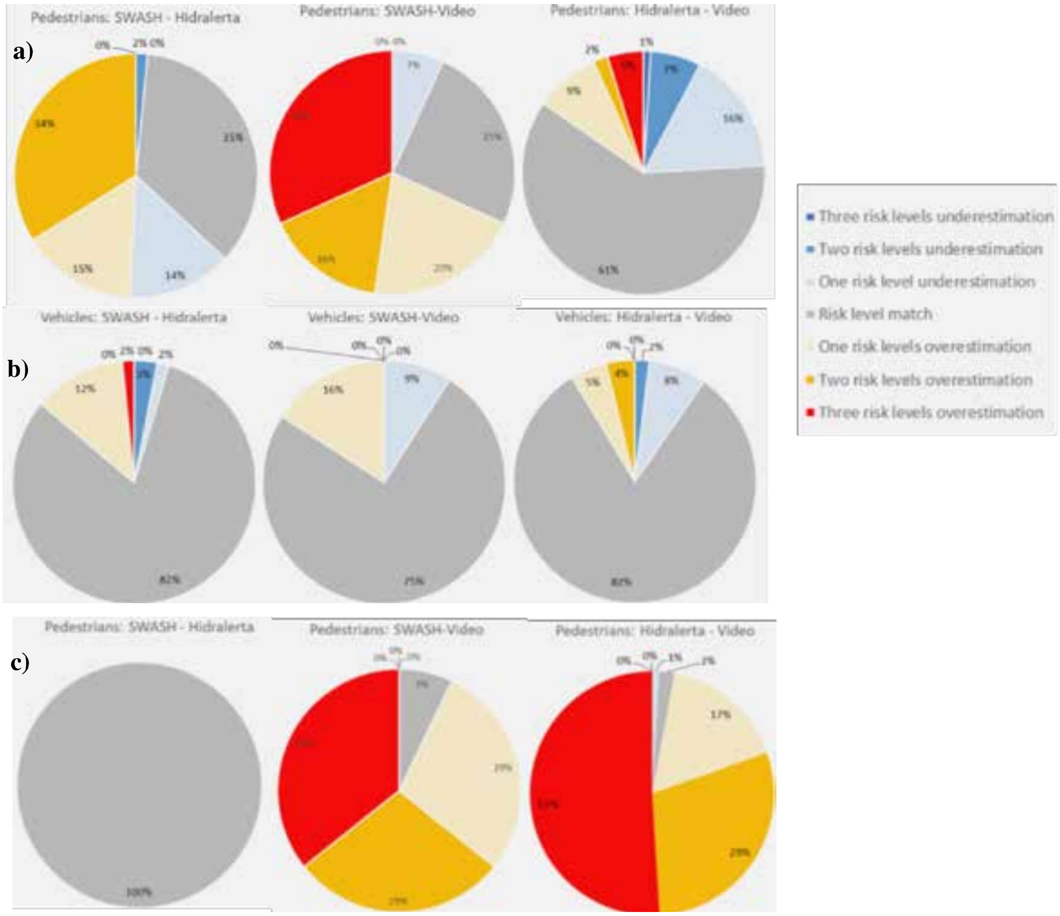

Fig. 2. Comparison of results between SWASH and HIDRALERTA and validation of SWASH and HIDRALERTA results with the video images. a) Profile-T, Risks for Pedestrians, b) Profile-T, Risks for Vehicles, c) Profile-A, Risks for Pedestrians.

It was found that the lower the thresholds for the alert levels, the worse was the performance of both SWASH and HIDRALERTA. HIDRALERTA performed better than SWASH for Profile-T (pedestrians and vehicles) and worse for Profile-A (pedestrians). The discrepancies for HIDRALERTA and SWASH can be due to bathymetric and breakwater representation issues (the bathymetry used is from 2011 and the structure had repair works after December 2019 storms that are not reflected in the profiles used). Also, some of the videos were taken from a location that did not allow a clear view of the profile and in other cases, the visibility was poor due to fog and rain. Finally, it is not easy, when analysing the videos, to define levels of alert, especially for pedestrians. Some splashes were considered as green level in the video analysis, but due to the very low threshold for a green warning in HIDRALERTA and SWASH (<0.1 l/s/m) the alert level can be higher than the one from the video. Fig. 3 and Fig. 4 present the comparison of q estimated by SWASH with q estimated by HIDRALERTA and the values of the following statistical parameters: *BIAS* and correlation coefficient (r):

$$BIAS = \bar{S} - \bar{H} \quad \text{(E1)} \qquad r = \frac{\sum_{i=1}^{N}[(H_i-\bar{H})(S_i-\bar{S})]}{\sqrt{\sum_{i=1}^{N}(H_i-\bar{H})^2 \sum(S_i-\bar{S})^2}} \quad \text{(E2)}$$

where S_i are SWASH q values, H_i are HIDRALERTA q values, $\bar{S}$ and $\bar{H}$ are, respectively, the average of SWASH and HIDRALERTA q values.

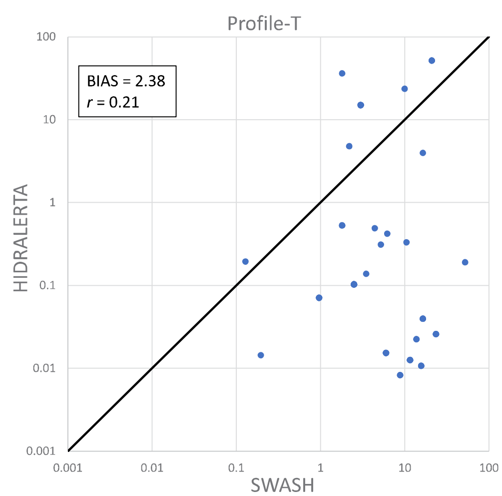

Fig. 3. Profile-T. Comparison of q estimated by SWASH with q estimated by HIDRALERTA.

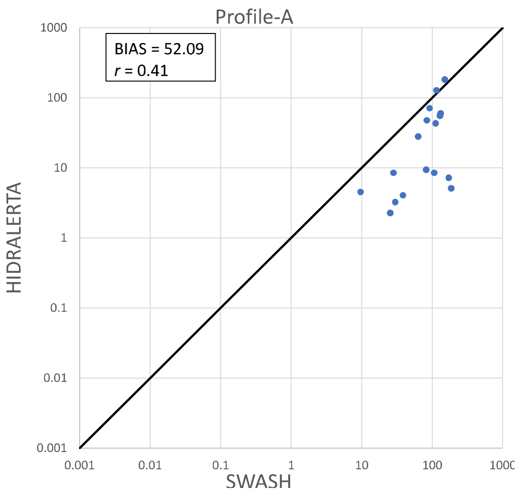

Fig. 4. Profile-A. Comparison of q estimated by SWASH with q estimated by HIDRALERTA.

From the statistical analysis, it can be seen that SWASH originates higher discharge values than HIDRALERTA, and the correlation was not good for both profiles. The very high discharges in the SWASH model can be due to the very low values of the Manning coefficient obtained from the empirical expressions for the analysed events. Those values were very often near or equal to the minimum value allowed (0.02 s/m$^{1/3}$). Even if SWASH highly overestimated HIDRALERTA, when this was translated into an alert level, both systems could obtain a high level of agreement (e.g. pedestrians on Profile-A). The reason is that for values higher than the high risk theshold, it results in the same alert level regardless of the difference in *q* values.

4. CONCLUSIONS

It was concluded that overall HIDRALERTA presented a better agreement with the observations than SWASH for Profile-T (pedestrians and vehicles) and a worse performance for Profile-A (pedestrians). When comparing SWASH and HIDRALERTA, SWASH overestimated both the alerts and the discharges.

The high discharges for HIDRALERTA and SWASH can be due to bathymetric and breakwater representation issues. Due to dredging works and to the fact that the area is prone to accretion, the bathymetry has to be updated. A drone survey of the breakwater from early 2022 is already available and can be used to update the profile conditions. The video analysis also presents some challenges, due to the camera location and the poor visibility during storm conditions. Moreover, the classification of risk levels from the video imagery relied on expert judgment and therefore the interpretation can be biased. More work on SWASH simulations is also needed, including the increase in the range of applicability of the empirical expressions for the Manning coefficient.

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