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IMPLEMENTATION OF THE SWASH MODEL INTO HIDRALERTA SYSTEM

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Abstract. *Early warning systems are an important tool for local authorities to detect emergency situations in advance and initiate the necessary safety measure. The To-SEAlert project has the aim of increasing the efficiency, robustness and reliability of the HIDRALERTA coastal hazards early warning system. This study shows a first intent to implement the SWASH numerical model to simulate wave overtopping for the Ericeira prototype. SWASH was implemented for one breakwater profile where overtopping discharge and associated risk levels are estimated. It was compared to the current approach used in HIDRALERTA, the neuronal network NN_OVERTOPPING2. Finally, both approaches were compared with previously analysed video images of the site. The results showed that SWASH generally overestimates overtopping and is not in good agreement with the NN_OVERTOPPING2 or the video images. A possible reason might be the wave direction, which cannot be included in one-dimensional simulations in SWASH.*

Keywords: *Early Warning System, Wave Overtopping, Risk Reduction, SWASH model*

1. INTRODUCTION

In times of rising sea levels and changes in storminess and wave regimes, early warning systems are fundamental tools for local authorities to prevent damage and loss of lives due to coastal flooding during storms. Although their development is still in its early stages, efforts have been made to implement early warning systems in Europe (e.g. Gracia *et al.*, 2014; van Dongeren *et al.*, 2018)).

HIDRALERTA (Fortes *et al.*, 2020; Pinheiro *et al.*, 2020; Poseiro, 2019; Santos *et al.*, 2020; Zózimo *et al.*, 2021) is an early warning system for forecast and risk assessment of wave overtopping in coastal zones. It provides forecasts 72 hours in advance and with a 3-hour interval, of wave characteristics and the risk levels associated with specific port activities and coastal receptors. The system uses datasets of several years of sea-wave/water level characteristics and/or pre-defined scenarios, to evaluate wave overtopping and flooding risks of the protected areas.

Six prototypes are operational in the HIDRALERTA system, three in mainland Portugal (Ericeira and Sines harbours, and Costa da Caparica coastal zone) and three in the Azores archipelago (Praia da Vitória, S. Roque do Pico and Madalena do Pico harbours). Presently, HIDRALERTA was extended to the port of Peniche and to Praia de Faro and Quarteira. These latter prototypes are under test. The system acquires daily forecasts from ECMWF, namelywind fields as forcing wave generator and wave characteristics as offshore boundary conditions, which are then propagated to the shore using the regional wave generation and propagation model SWAN (SWAN Team, 2006) and nearshore wave propagation model DREAMS (Fortes, 2002). The astronomical tide is computed with the XTIDE model (https://flaterco.com/xtide/)). In harbour areas, the neuronal network NN_OVERTOPPING2 (Coeveld *et al.*, 2005) computes the mean overtopping discharge q at each cross-section of the protection structures. As input conditions, the results of the DREAMS and XTIDE models are used. Warnings are triggered when pre-set thresholds for q are exceeded.

This study describes a first effort to implement the numerical model SWASH (Zijlema et al., 2011) to replace NN_OVERTOPPING2 in the HIDRALERTA system for the Ericeira prototype. Within the scope of the To-SEAlert project, SWASH was applied for one of the cross-sections of the structure to compute the mean overtopping discharge for a range of test cases and to compare the results and the associated risk levels with NN_OVERTOPPING2.

2. METHODS

2.1 Model setup

Ericeira harbour is located on the west coast of Portugal and is sheltered by a 430 m long breakwater, oriented to the south-west, with a quay in the rear side. The profile that was chosen for the implementation of the SWASH model has an armour layer of tetrapods and is in the vicinity of the quay on the lee side of the breakwater. The profile has an orientation of 309°N. Overtopping simulations with SWASH were performed in a one-dimensional mode for a computational period of 131 minutes with an additional spin-up period of 15% of the computational period and an initial timestep of 0.01 seconds. An automatic time step control was applied with a maximum Courant number of 0.5 and a minimum Courant number of 0.1. One vertical layer was used for the simulations. To account for bottom roughness, a Manning friction coefficient was applied to the natural bottom area (0.019 s/($m^{1/3}$)) and to the armour layer of tetrapods (0.078 s/($m^{1/3}$)).

The length of the numerical domain was 419 m, where 334.5 m corresponded to the area offshore, 48 m to the breakwater and 36.5 m to the lee side of the structure (Figure 1). Additionally, the command BOTCEL SHIFT was applied to read the bottom levels at the center of the computational cell from the upper-right cell corner. The bathymetry was constructed with data acquired from EMODnet (150 m grid spacing) and DGTerritorio (LiDAR survey of 2011, 2 m spacing). The profile had a constant grid spacing of 0.5 m.

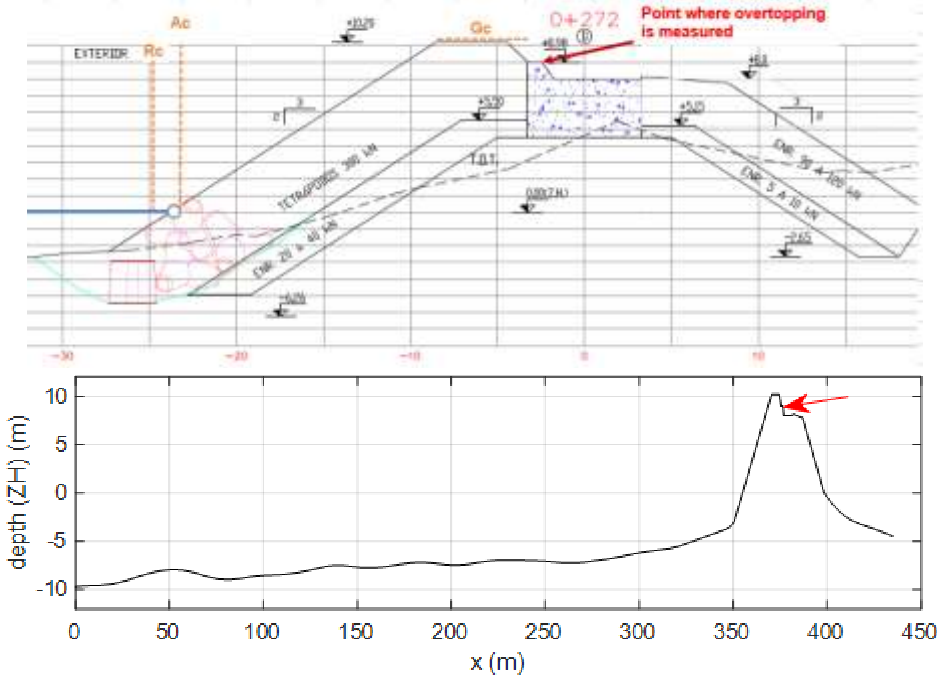

Figure 1 – Cross-section of the breakwater profile used for the simulations (top) and bathymetry used in SWASH, with the cross-shore distance referred to the wavemaker boundary and red arrow indicating where overtopping results were extracted (bottom).

At the offshore boundary, a Jonswap wave spectrum defined the shape of the irregular waves, with a peak enhancement parameter γ=3.3 and a weakly-reflective boundary was imposed. A sponge layer of 100 m was applied at the end of the domain to prevent the reflection of outgoing waves that could give rise to instabilities within the numerical domain. The boundary conditions were chosen based on existing overtopping studies (e.g. Suzuki *et al.*, 2014, 2017). For the non-hydrostatic pressure term, a Keller-Box scheme with ILU preconditioner was used to increase the stability of the model.

2.2 **Validation**

HIDRALERTA was used to generate overtopping discharges and the associated risk levels for 3 past events that covered overtopping and no-overtopping conditions. Four risk levels (no risk, low risk, moderate and high risk) were defined for five coastal receptors (Table 1).

Table 1 - Coastal receptors and overtopping thresholds in HIDRALERTA according to each risk level

Risk level	Trained staff	Aware pedestrian	Unaware pedestrian	Vehicles at low speed	Vehicles at moderate/high speed
No risk	[<1 l/s/m]	[<0.1 l/s/m]	[<0.01 l/s/m]	[<10 l/s/m]	[<0.1 l/s/m]
Low risk	[1-5 l/s/m[	[0.1-0.5 l/s/m[	[0.01-0.02 l/s/m[	[10-25 l/s/m[	[0.01-0.03 l/s/m[
Moderate risk	[5-10 l/s/m[	[0.5-1 l/s/m[	[0.02-0.03 l/s/m[	[25-50 l/s/m[	[0.03-0.05 l/s/m[
High risk	[≥10 l/s/m]	[≥1 l/s/m]	[≥0.03 l/s/m]	[≥50 l/s/m]	[≥0.05 l/s/m]

The results of HIDRALERTA with the newly implemented SWASH model were compared to the approach that is currently used in HIDRALERTA, where NN_OVERTOPPING2 is used to compute overtopping discharges. Additionally, both approaches were compared to previously analysed video images of the breakwater of 46 events. The videos were categorised into the same risk levels as presented in Table 1 for the two receptors "Aware pedestrian" and "Vehicles (low speed)".

3. RESULTS

The overtopping discharge computed by SWASH and by NN_OVERTOPPING2 in HIDRALERTA showed significant differences (Figure 2). While the SWASH model performed well at no-overtopping events, which mainly resulted in the same discharge (0 l/s/m), SWASH generally overestimated overtopping when compared to NN_OVERTOPPING2. The Root-Mean-Square-Error (RMSE) was 5.47 l/s/m, which is a large error considering that the average overtopping discharge of the test cases was 0.73 l/s/m.

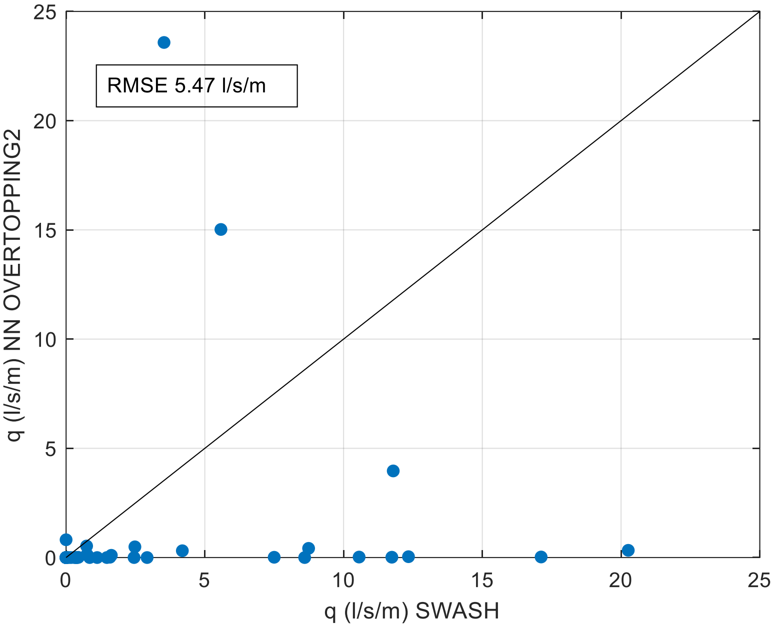

Figure 2 - Comparison of q estimated by HIDRALERTA using SWASH and NN_OVERTOPPING2.

As a consequence, the risk levels that were generated by HIDRALERTA based on the overtopping discharge resulted in higher alerts when using SWASH than when using NN_OVERTOPPING2. Figure 3 shows the differences in risk levels computed by HIDRALERTA with SWASH and NN_OVERTOPPING2. It could be observed that the majority of the cases resulted in the same risk level for all five receptors. This majority included 38 of the 63 total cases which were no-overtopping events. Once overtopping occurs, however, especially for the receptors with lower thresholds for *q*, the SWASH simulations resulted in higher risk levels than NN_OVERTOPPING2. For aware and unaware pedestrians and vehicles at high speed, the risk level was overestimated by SWASH in 38%, 29% and 31% of the cases, respectively, and a maximum difference of three risk levels was found. For vehicles at low speed, which have high thresholds for *q* compared to the other receptors, a maximum difference of one risk level was found.

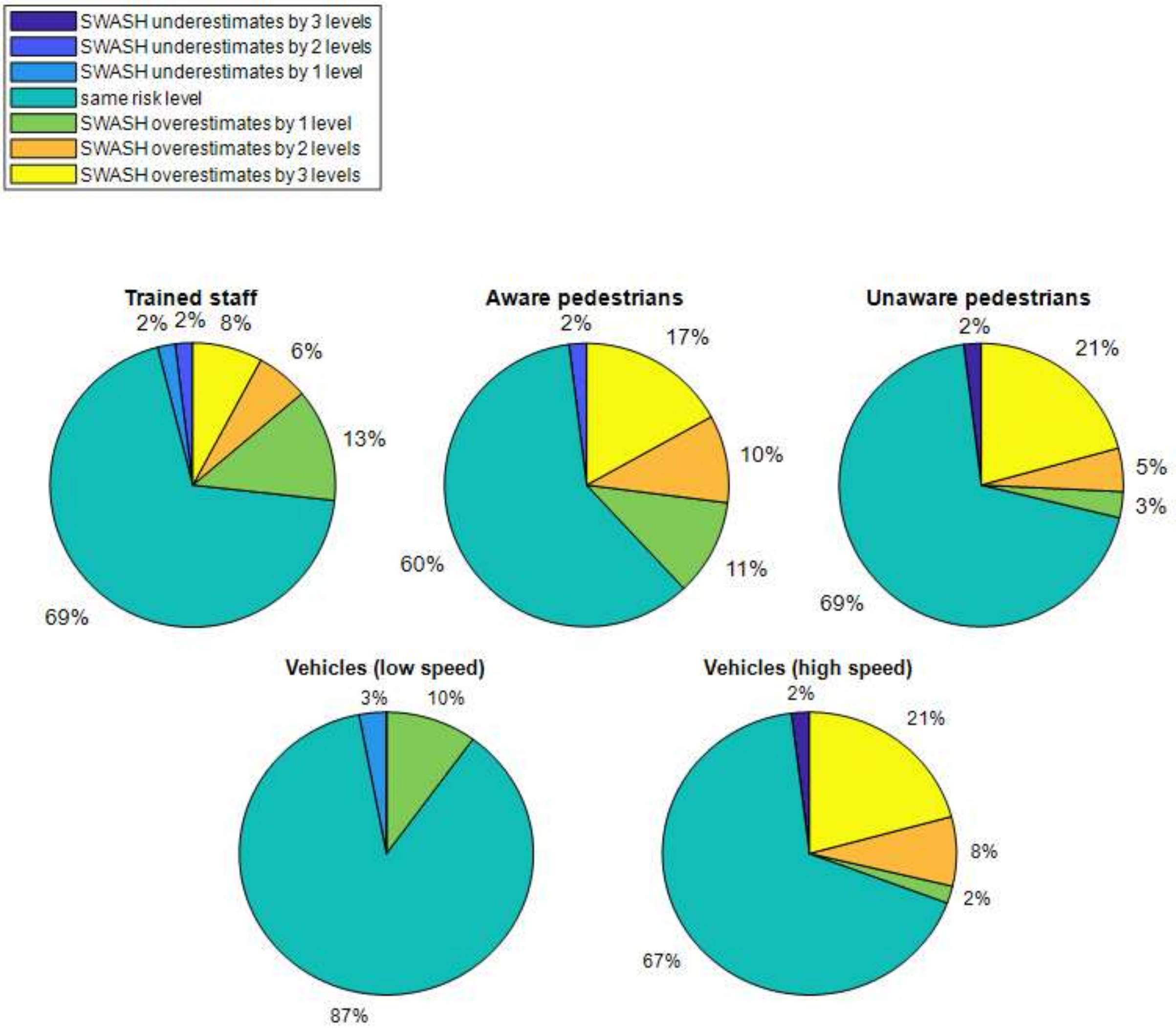

Figure 3 - Risk levels generated for the five receptors by HIDRALERTA.Comparison between results of SWASH and NN_OVERTOPPING2

The validation with video images revealed an overall better performance of NN_OVERTOPPING2 (Figure 4). For aware pedestrians and low speed vehicles the neuronal network generates the same risk level for the majority of cases (69% and 92%, respectively). Again, for low speed vehicles, a maximum difference of one risk level was found due to the higher thresholds. SWASH showed good results for vehicles, with 85% of consensus and 4% and 11% of one level under- and overestimation, respectively. For the lower thresholds of the pedestrians, in 42% of the cases it overestimates the risk level.

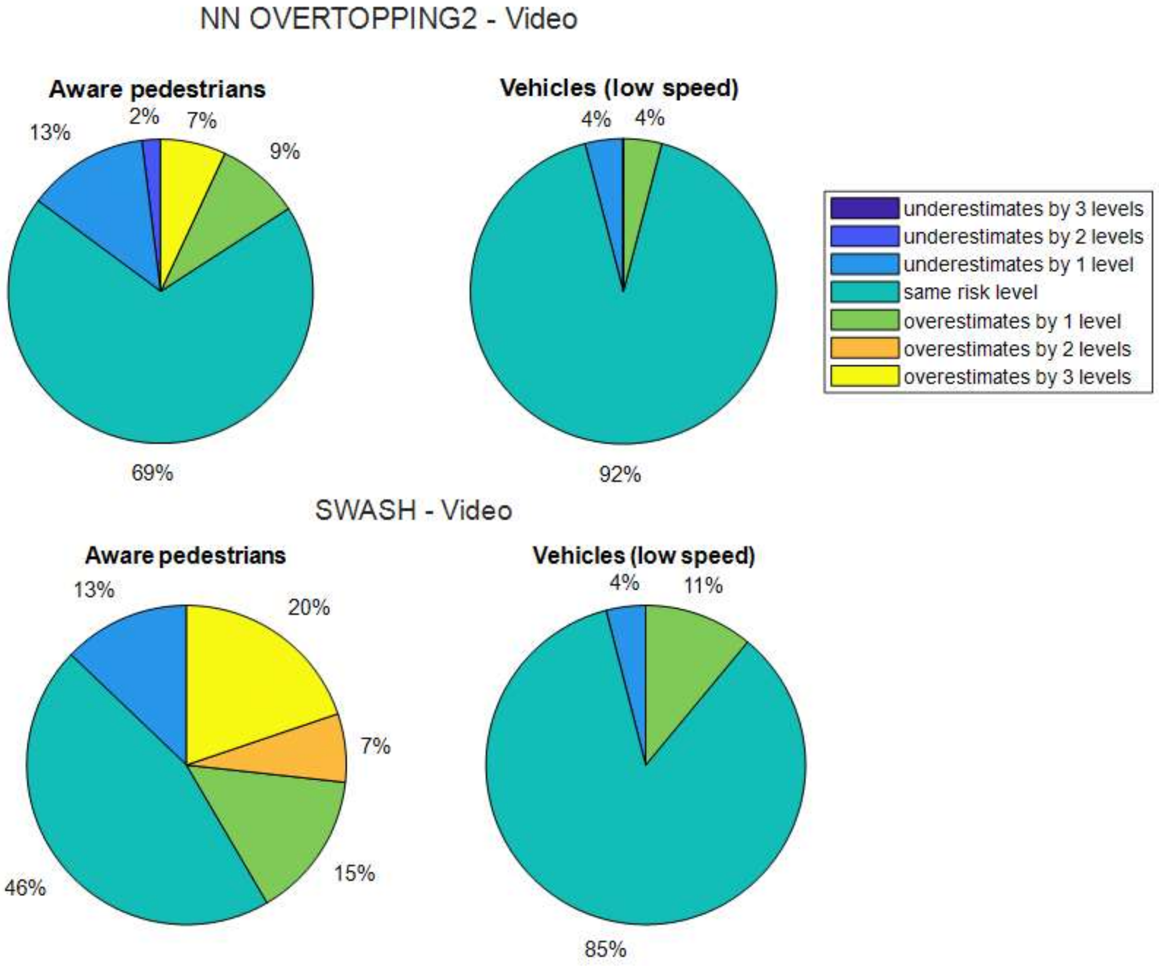

Figure 4 - Risk levels generated for aware pedestrians and slow driving vehicles. Comparison between results of NN_OVERTOPPING2 and video images (top) and SWASH and video images (bottom).

There are several factors that may influence the performance of SWASH within HIDRALERTA. While NN_OVERTOPPING accounts for wave obliquity, it is not possible to include the wave direction in one dimensional simulations in SWASH and wave obliquity affects the amount of wave overtopping at a coastal structure (e.g. EurOtop, 2018). Consequently, SWASH assumed in each case that waves approached the structure perpendicularly and the results for q may have been particularly high due to this assumption. Furthermore, in this first test phase, a constant Manning coefficient for the armour layer of the breakwater was applied for the overtopping simulations of SWASH. Previous studies have shown (e.g. Manz, 2021; Zhang *et al.*, 2020) that the performance of SWASH improves when the Manning coefficient is calibrated for a particular breakwater material and that it is correlated with the dimensionless crest freeboard and wave steepness. While the video images implied an opportunity to compare the forecasted risk levels against records, it must be considered that the analysis of the videos and categorization of risk levels is partially subjective and furthermore dependent on the visibility and quality of the material. In general, the video validation confirmed what the comparison of the two approaches had shown: an overall overestimation of discharge (and thus, of risk) by the SWASH model.

4. CONCLUSIONS

This study demonstrated that the implementation of the SWASH model into HIDRALERTA for the chosen profile was successful but did not deliver good results. The results outlined that SWASH computes significantly higher overtopping discharges than NN_OVERTOPPING2, except in cases of no overtopping, where it mostly agreed with the neuronal network. It can be concluded that the wave direction, which is not considered in one-dimensional simulations of SWASH, might play a role in causing these discrepancies. Future work will include implementing an empirical equation for the definition of the Manning friction coefficient, which considers the angle of wave attack and material of the breakwater.

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