SIMULATION OF HURRICANE LORENZO AT THE PORT OF MADALENA DO PICO, AZORES, BY USING THE HIDRALERTA SYSTEM

Maria Inês SANTOS[1], Conceição Juana FORTES[2], Maria Teresa REIS[2], Liliana PINHEIRO[2], Vera SERRAZINA[2], Marília SALVADOR[3], Francisco VIEIRA REIS[4], Eduardo BRITO DE AZEVEDO[4]

1. Gaspar Frutuoso Foundation (ECOMARPORT project), São Miguel, Azores,, misantos@lnec.pt

2. National Laboratory for Civil Engineering, Lisbon, jfortes@lnec.pt, treis@lnec.pt, lpinheiro@lnec.pt, vserrazina@lnec.ptl

3. Portos dos Açores SA (ECOMARPORT project), Terceira, Azores, msalvador@portosdosacores.pt

4. IITAA – Univ. Açores(ECOMARPORT project), Terceira, Azores, vieirareis.f@gmail.com, eduardo.mv.azevedo@uac.pt,

ABSTRACT

HIDRALERTA is a forecast, early warning and risk assessment system of port and coastal areas that uses measurements/estimates of sea-waves and water levels to evaluate overtopping/flooding. The calculation of the mean overtopping discharge over a maritime structure is performed through artificial neural network-based tools and/or empirical formulae. The system is composed of four modules developed in open source Web technology, mainly using the Python language. This paper presents its application to reproduce the hurricane Lorenzo conditions and impacts at Madalena do Pico port, Azores, on October 2 2019. This hurricane was regarded as the strongest storm to hit Azores in 20 years. The application of HIDRALERTA focus mainly on the second and fourth modules: wave run-up/overtopping and warning system.

Keywords: HIDRALERTA; warning system, overtopping, risk assessment, Madalena do Pico

1. INTRODUCTION

The length of the Portuguese coast, the severity of the sea conditions and the importance of the coastal zone regarding socio-economic activities justify the relevance of studying wave-induced risks and, in particular, overtopping due to wave action. Indeed, emergency situations caused by adverse sea conditions are frequent and put in danger the safety of people and goods, with negative impacts for society, the economy and the environment, Figure 1.

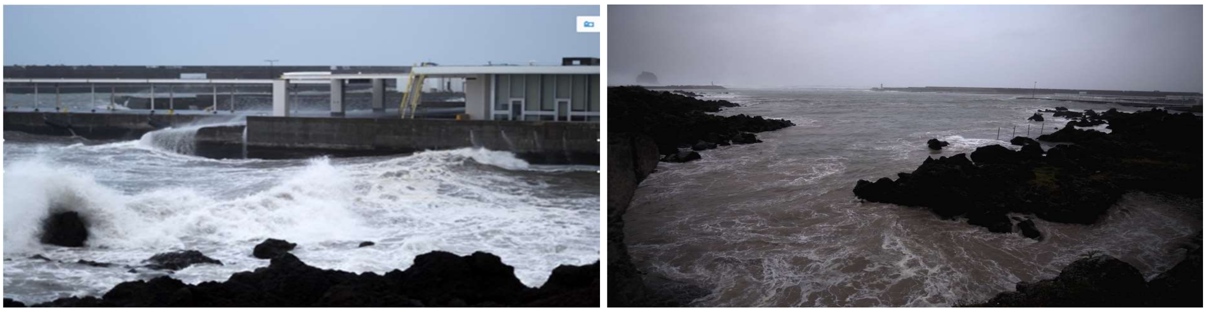

Figure 1. Wave overtopping events at Madalena do Pico, during Hurricane Lorenzo

Therefore, a methodology to assess the overtopping risk in port and coastal areas is essential for a proper planning and management of these areas. A detailed characterization of sea waves, water levels and currents is essential to improve risk assessment methodologies, increasing the reliability of the results, enabling the issue of warnings and supporting the preparation of mitigation plans.

In this context, the National Laboratory for Civil Engineering (LNEC), Portugal, has been developing the HIDRALERTA system (Poseiro, 2019), which is a set of integrated decision-support tools for port and coastal management, whose focus is to identify and prevent emergency situations and to enable the selection of measures by national authorities to avoid loss of lives and minimize damage. Moreover, the system may also act as a long - term management tool, since it can simulate the response to future scenarios related to climate change, such as the increase of the mean sea level and/or of the storm severity, which will increase coastal flooding probability and intensity.

In 2015, the first prototype of the HIDRALERTA system was implemented in the port of Praia da Vitória, in Terceira island, Azores, and it has been operating since then. Under the framework of the ECOMARPORT project (INTERREG - MAC/1.1b/081), other prototypes of the system have been under development and implemented at the ports of Madalena do Pico and S. Roque do Pico, both at the Pico island, Azores. This paper presents the system application to reproduce the hurricane Lorenzo conditions and impacts at the port of Madalena do Pico, on October 2 2019. Methodologies and accomplishments of the HIDRALERTA project achieved so far are herein described, with main focus on the second and fourth modules: wave run-up/overtopping and warning system.

2. THE HIDRALERTA SYSTEM

The HIDRALERTA system (Poseiro et al., 2013; Sabino et al., 2018; Poseiro, 2019) is a wave overtopping/flooding forecast system with early warning and risk assessment capabilities. As a forecast and early warning tool, HIDRALERTA enables the identification, in advance, of the occurrence of emergency situations, prompting the responsible entities to adopt measures to avoid loss of lives and minimize damage. As a long-term planning tool, 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, allowing the construction of risk maps (Poseiro, 2019).

The HIDRALERTA system was developed in a Python framework and encompasses four main modules: I - Sea-state Characterization; II - Wave Run-up and Overtopping; III - Risk Assessment; III - Warning System. As a forecast and warning tool, the system uses modules I, II, and IV, as illustrated in this paper (section 3. The system is set to provide daily forecasts, for a period of 72 hours, includind wave conditions, overtopping and warning whenever any port is in danger. It usually takes 3 hours and 30 min to run the system: 2 hours and 30 min to get ECMWF forecasts and 1 hour to run the models to obtain overtopping and waning results.

3. CASE STUDY – HURRICANE LORENZO AT MADALENA DO PICO PORT, AZORES

3.1. HURRICANE LORENZO

Hurricane Lorenzo was regarded as the strongest storm to hit the Azores islands in 20 years still as hurricane Category 2 to 1, breaking records as the most northeasterly Category 5 storm ever observed in the North Atlantic basin.

Lorenzo developed from a tropical wave that moved off the west coast of Africa on September 22, growing larger in size over the course of its development. The storm continued to intensify and reached its initial peak of intensity with maximum sustained winds of 230 km/h and a central pressure of 939 mbar early on September 27. Later on September 29, Lorenzo reached Category 5 strength, becoming the easternmost hurricane of such intensity recorded in the Atlantic basin, exceeding any of the 35 Category 5 hurricanes that have occurred in records since the 1920s. With a fastening northeastward track and expanding wind field, Lorenzo skirted the western Azores on October 2, passing just west of Flores island between 4:00 and 4:30 am as a Category 2 to 1 hurricane, and brought high winds of about 163 km/h, pounding surf and storm surge to the islands, reaching significant wave heights of 15m, coming mainy from the southwest. Over 171 incidents were reported in all the islands. After hitting Azores, hurricane Lorenzo began its transition to an extratropical cyclone, racing towards Ireland and the United Kingdom.

3.2. THE PORT OF MADALENA DO PICO

The port of Madalena do Pico is located on the northwest coast of the Pico island and is protected by two breakwaters (Figure 2): the North and the West breakwaters.

Figure 2. Pico Island, Madalena do Pico port

The North breakwater represents the main port protection structure against sea waves, mainly from W-N. With a total length of approximately 530 m, only about 250 m correspond to the berthing quay, the so-called "Madalena

Dock". At the breakwater root, the 3(V):4(H) armor is protected by two layers of 150 kN tetrapods, placed over a rock filter of 90-120 kN. Approximately 150 m after the breakwater bend, the weight of the tetrapod units increases to 240 kN, over a rock filter of 1-3 ton. At the breakwater head, the 1:2 armor is protected by 300 kN Antifer cubes. On the inner side, the 2:3 armor is protected by 5-8 ton rock units and a rock filter of 1-3 ton.

The West breakwater protects the port from the southwest wave conditions. It is a rubble mound breakwater with 300 kN Antifer cubes on a 2:3 slope, which ends on a 10-30 kN rock mattress located above the natural rocky bottom. Its deepest part is located at about -10.5 m (ZH). The breakwater crest is at +5.5 m (ZH), with ZH the chart datum.

According to local authorities, during Lorenzo hurricane, several overtopping events occurred, especially at the West and North breakwaters. Moreover, the wave conditions inside the port were significant, Figure 1.

3.3. APPLICATION OF HIDRALERTA

3.3.1. Module I – Wave characteristics

The system starts by requesting from the dada source (ECMWF - European Centre for Medium-Range Weather Forecasts) wave and wind fields from the WAM model (WAMDI Group, 1988) and pressure parameters from HRES (Persson, 2001). The ECMWF forecasts usually arrive 2 hours and 30 min after the user request. Then, it creates different layouts for each instant to represent the offshore sea state (using matplotlib library from the Python programming language), firstly, for the North Atlantic and then to the Azores archipelago (Figure 3 a)). Given the WAM model results, one selects the closest value to the Pico island that can represent the boundary conditions for sea-wave propagation models to be used afterwards. These values are transferred firstly to the vicinity of the port of Madalena do Pico by using the spectral wave propagation model, SWAN (Booij *et al*., 1999) (Figure 3 b)) and then to the port entrance and inside the port by DREAMS (Fortes, 2002) (Figure 3 c)). Figure 3 illustrates the layouts produced by the system for 9 am of 2 October 2019, the most critical moment of the hurricane at Madalena do Pico.

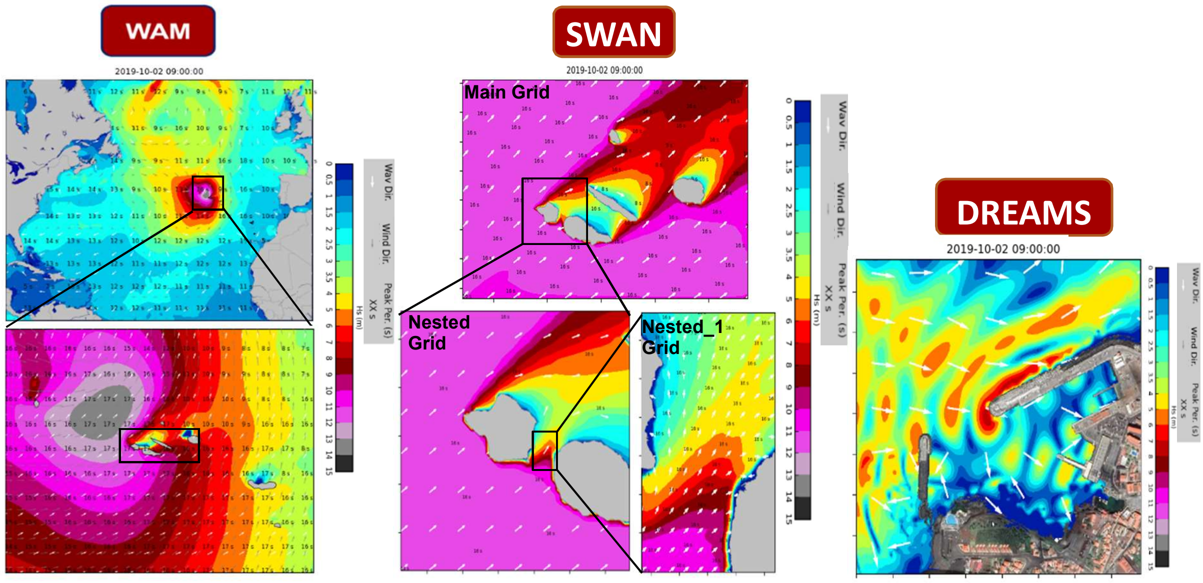

Figure 3. Madalena do Pico port. Example of layouts generated by the system for the a) WAM, b) SWAN and c) DREAMS model on 2 October 2019, 9 am, H_s and θ

3.3.2. Module II – Wave run-up and overtopping

The estimates of overtopping are obtained by using the ANN tool NN_OVERTOPPING2 (Coeveld et al., 2005). With the results of the DREAMS model at the toe of each structure of the port, and considering their main characteristics, it is possible to calculate mean overtopping discharges, q, at 50 cross-sections for the port of Madalena do Pico. From the overtopping predictions, a layout is generated for each instant (Figure 4). To provide an idea of the overtopping intensity, red circles with different diameters are shown for the 50 cross-sections. The larger the circle, the highest the mean overtopping discharge. The layout also indicates the maximum mean overtopping discharge.

3.3.3. Module IV – Warning system

The maximum mean overtopping discharge predicted for the case study for each instant at each cross-section of the structures is compared with established pre-set thresholds of q. These thresholds have been defined in close collaboration with the local authorities of Madalena do Pico and are based on existing EurOtop (2007, 2018) recommendations on tolerable wave overtopping. Figure 4 provides an example of the layout generated by the HIDRALERTA system for 9 am, overtoping predictions and warning levels for each stretch of the structures

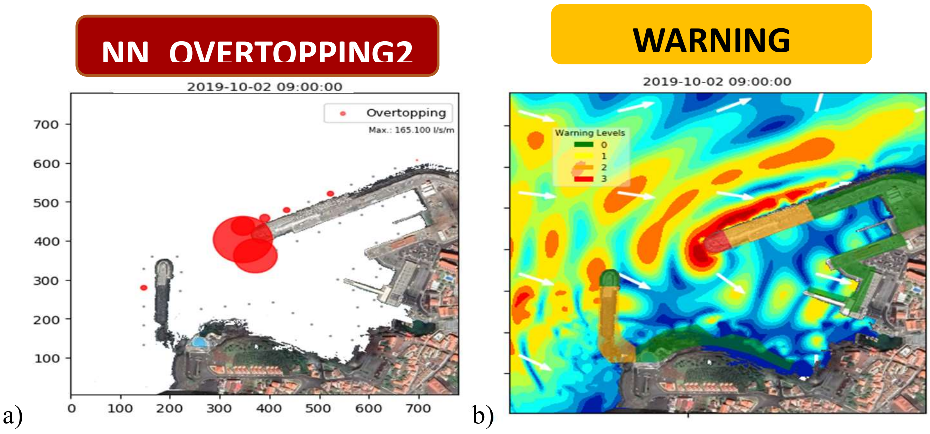

Figure 4. Madalena do Pico port. a) overtopping and b) warning layouts generated by the system on 2 October 2019, 9 am

4. CONCLUSION

Currently, the HIDRALERTA system is in operation for the ports of Praia da Vitória, S. Roque do Pico and Madalena do Pico, with all the necessary elements to issue real-time warnings. However, to ensure the reliability of the system for the last two ports, there are still some aspects of its validation that need to be improved with the collaboration of the local authorities and the use of historical data. Through reporting of dangerous situations by local authorities and residents, and their perception of existing risks, a better understanding of wave overtopping and flooding impacts in local communities may be achieved.

5. ACKNOWLEDGEMENTS

The works related with the participation of M.I. Santos, M. Salvador and E. B. de Azevedo on the simulation of the application of HIDRALERTA System to the Port of Madalena, have been done under the framework of the ECOMARPORT (MAC/1.1b/081), with the financial support of 85% by the EU (FEDER, MAC 2014-2020), and 15% from the Regional Government of the Azores. F. V. Reis is responsible for the wave data and wave database used by the system. The works of C.J.E.M. Fortes, M.T. Reis, L.V. Pinheiro and V. Serrazina have been developed under the framework of To-SEAlert, Ref. PTDC/EAM-OCE/31207/2017 and BSafe4Sea, Ref. PTDC/ECI-EGC/31090/2017. The authors also acknowledge Portos dos Açores.

6. REFERENCES

Booij, N.; Ris, R.C. & Holthuijsen, L.H. (1999). A third-generation wave model for coastal regions, Part I, Model description and validation. *J. Geographical Res.*, C4, 104, 7649-7666.

Coeveld, E.M.; Van Gent, M.R.A. & Pozueta, B. (2005). *Neural Network: Manual NN_OVERTOPPING2*. CLASH WP8 – Report BV.

EurOtop (2007). *Wave Overtopping of Sea Defences and Related Structures: Assessment Manual*. Pullen, T.; Allsop, N.W.H.; Bruce, T.; Kortenhaus, A.; Schuttrumpf, H. & Van der Meer, J.W.

EurOtop (2018). *Manual on Wave Overtopping of Sea Defences and Related Structures. An overtopping manual largely based on European research, but for worldwide application*. Van der Meer, J.W.; Allsop, N.W.H.; Bruce, T.; De Rouck, J.; Kortenhaus, A.; Pullen, T.; Schüttrumpf, H.; Troch, P. & Zanuttigh, B. www.overtopping-manual.com.

Fortes, C.J.E.M. (2002). *Transformações Não Lineares de Ondas em Zonas Portuárias. Análise pelo Método dos Elementos Finitos*. PhD Thesis, IST-UL.

Persson, A. (2001). *User Guide to ECMWF Forecast Products*. ECMWF.

Poseiro, P. (2019). *Forecast and Early Warning System for Wave Overtopping and Flooding in Coastal and Port Areas: Development of a Model and Risk Assessment*. PhD Thesis. IST-UL.

Poseiro, P.; Fortes, C.J.E.M.; Reis, M.T.; Santos, J.A.; Simões, A.; Rodrigues, C. & Azevedo, E. (2013). A methodology for overtopping risk assessment in port areas: Application to the port of Praia da Vitória (Azores, Portugal). *Proc. SCACR 2013*, 4-7 June, LNEC, Lisbon.

Sabino, A.; Poseiro, P.; Rodrigues, A.; Reis, M.T.; Fortes, C.J.E.M.; Reis, R. & Araújo, J. (2018). Coastal risk forecast system. *Journal of Geographical Syst.*, 20(2), 159-184. https://doi.org/10.1007/s10109-018-0266-5

WAMDI Group (1988). The WAM Model - A third generation ocean wave prediction model. *Journal of Physical Oceanography*, 18, 1775-1810.