8th IAHR EUROPE CONGRESS
LISBON - PORTUGAL
4-7 JUNE 2024

Deep Neural Network Enhanced Early Warning System for Ports Operations

Liliana PINHEIRO[1], Juana FORTES[1], Andreia GOMES[1]

[1]Laboratório Nacional de Engenharia Civil, Portugal
email: lpinheiro@lnec.pt, jfortes@lnec.pt, ahgomes@lnec.pt

ABSTRACT

Downtime of port terminals results in large economic losses and has a major impact on the overall competitiveness of ports. Early Warning Systems (EWS) are an effective tool to reduce ports' vulnerability by increasing their preparedness and planning capacity to either avoid or efficiently respond to emergency situations.

The SAFEPORT EWS predicts met-ocean variables and their impact on ships (navigating, docking or moored) and port operations daily, Pinheiro et al. (2020), and provides alerts for emergencies and operational constraints. It is currently implemented in six ports, namely: Praia da Vitória, São Roque do Pico and Madalena do Pico, in the Azores archipelago, and Sines, Aveiro and Figueira da Foz, on the west coast of Portugal.

All information provided by this EWS is available in a dedicated website and mobile application. In addition, an alert bulletin is sent by e-mail to interested parties. This provides port stakeholders with a decision support tool for timely implementation of mitigation measures to prevent accidents and economic losses.

This system is now being enhanced with artificial neural network tools to obtain more accurate results from numerical wave propagation models and to allow the use of complex and time-consuming numerical models in an operational framework.

As with any EWS, its usefulness depends heavily on its reliability, accuracy, and consistency. Two types of ANN have therefore been developed.

1. The Early Warning system

The SAFEPORT EWS follows a series of EWS from the HIDRALERTA platform, which includes three Azorean ports: Praia da Vitória, S. Roque do Pico and Madalena do Pico, (Poseiro, 2019 & Pinheiro et al., 2020), five other ports on the west coast mainland: Sines, Aveiro, Figueira da Foz, Ericeira and Peniche, and three coastal areas: Costa da Caparica, Faro and Quarteira. All the EWS of HIDRALERTA include coastal flooding and/or wave overtopping of coastal structures. Some of the ports in Hidralerta have implemented the SAFEPORT Port Navigation and Operations Alert System for certain vessels.

The system uses available forecasts of regional offshore wind and wave characteristics, together with astronomical tidal data, as inputs to a series of numerical models. These numerical models provide estimates of wave and wind characteristics at all scales, from regional, simulated with multiple nested grids using the SWAN model (Booij et al., 1996), to local, using a non-linear Boussinesq-type model or a linear mild-slope model (Figure 1). Finally, the ship's response to these wave and wind forcings is computed using a 3D panel method hydrodynamic model (Korsemeyer et al. 1988) and a motion equation solver.

Predicted hourly movements and mooring forces are compared with pre-set thresholds. An assessment of the probability of these values being exceeded gives a hazard level. The risk levels depend on the Maximum Breaking Load (MBL) of the mooring lines (OCIMF, 1992). 0 corresponds to no risk (green symbol), 1 corresponds to 50% of the MBL (yellow symbol), 2 corresponds to 80% of the MBL (orange symbol) and 3 corresponds to 100% of the MBL (red symbol). Finally, on the basis of the predicted risk level, emergency situations and the safety of port operations can be foreseen in advance (72 hours) and appropriate warnings can be issued.

All the information provided by this EWS is available on a dedicated website and mobile application. In addition, an alert bulletin is sent by e-mail to interested parties. This provides port stakeholders with a decision support tool for timely implementation of mitigation measures to prevent accidents and economic losses. Numerical simulations are run on the Central Node for Grid Computing (NCG) of the Portuguese Infrastructure for Distributed Computing (INCD), a 64-node high-performance computing facility.

2. Wave modelling

The wave propagation model includes 3 numerical wave propagation models and a finite element mesh generator. The SWAN numerical model is a spectral non-linear model based on the wave action conservation equation, which simulates the propagation of an irregular wave spectrum, transferring the wave characteristics from the offshore area to the harbour entrance. The EWS uses DREAMS and BOUSS-WMH to transfer the wave characteristics from the harbour entrance area to the harbour interior. The numerical model DREAMS (Fortes, 2002) is a linear finite element model based on the mild slope equation to simulate the propagation of monochromatic waves. The BOUSS-WHM model, (Pinheiro et al., 2011) is a nonlinear finite element model based on the extended Boussinesq equations derived by Nwogu (1993), capable of simulating the propagation of regular and irregular waves.

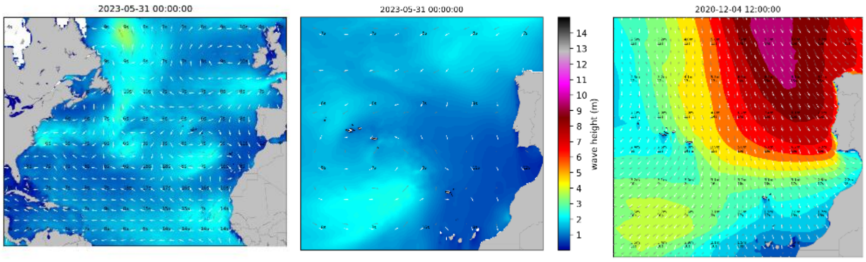

Fig. 1. Wave and wind forecasts. ECMWF-WAM & CMEMS Copernicus Marine Service Forecasts in the North Atlantic region.

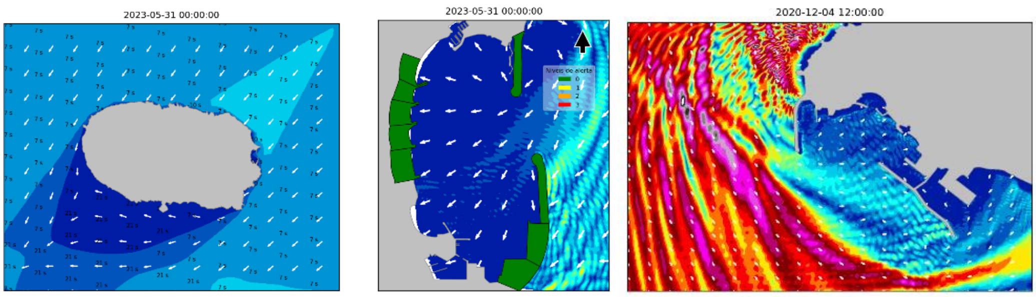

Fig. 2. Wave forecasts and Alerts for the Praia da Vitória Port (Azores). SWAN (left) and DREAMS (right) numerical models results.

3. Ship behaviour modelling

SWAMS - Simulation of Wave Action on Moored Ships (Pinheiro et al. 2013) is an integrated numerical tool capable of simulating the response of a free or moored ship in a port under the action of sea waves, wind and currents, and is used to simulate the behaviour of different ships. For example, in the port of Sines, an oil tanker, a general cargo ship and a container ship are simulated entering the port and moored at their respective terminals. Table 1 shows the general geometric characteristics of the simulated ships in Sines as well as the mooring arrangements that are part of the EWS implemented and in operation.

Table 1 - General geometric characteristics of the simulated ships in Sines Port.

Ship	Draft (m)	Beam (m)	Length Overall (m)	Moorings
Oil Tanker	22.0	26.5	340	8ML + 3FD
General Cargo	10.5	30.0	220	8ML + 5FD
Container Ship	8.0	19.0	120	10ML + 6FD

Fig. 3. Port of Sines. Access routes (left) and location of the terminals (right).

4. ANN to optimize wave forecasts

The first type of ANN uses available measured data to train the ANN and then calibrate/correct the numerical results to achieve more accurate predictions.

After a long-term error analysis was performed using a 40-year data set (wave and wind data) from the European Centre for Medium-Range Weather Forecasts, ECMWF, ERA5 reanalysis model (Persson, 2001), which uses the WAM model (WAMDI group, 1988) to initiate SWAN simulations exactly as they are implemented in the EWS, the results were found to be an overestimation of the actual measured parameters. The Root Mean Square Errors (RMSE) for the significant wave height, Hs, at the buoy location are 0.395m (with SWAN overestimating buoy measurements) and 2.36s for the mean period, Tz (also overestimation).

Using the available database of buoys, pressure sensors and meteorological stations, three neural networks were trained to evaluate the possibility of improving the accuracy of these forecasts. The Keras open source neural network library, written in Python, was used to develop the NNs. A NN consists of an input layer, a number of hidden layers and an output layer. Each layer has a number of nodes. The nodes in the hidden layers are neurons. The neurons are distributed in several hidden layers that apply different transformations to the input data. Every neuron in a hidden layer is connected to every neuron in the next layer. The output layer is the last layer in the network and receives input from the last hidden layer.

Five input layers were used for the development of these NN. Offshore wave parameters (Hs, Tz and q) and wind data (speed and q). Input nodes data consist of the offshore wind and sea-waves 40-years dataset are supplied by ECMWF, significant height (Hs), the mean period (Tz) and the average direction (θm) of the sea waves and wind speed and direction, between 1988 and 2018. Training data consists of an available dataset of measured wave characteristics from the Sines 1D wave buoy which has been deployed since 1988 and all the available data until 2018 wave buoy data was used.

In this case three different NN were created, one for each wave parameter at the buoy, Hs, Tz and q, so only one output per NN was required. 80% of the data was used to train the network and 20% was used to test it. The cost function is the mean squared error, mse, of the entire training set. The rectified linear unit (ReLU) activation function is used to introduce non-linearity to the network.

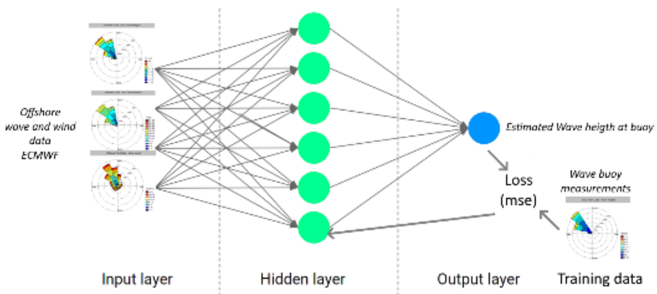

Fig. 4. Structure of the Neural Network for the wave height estimation/forecast at the Sines Buoy.

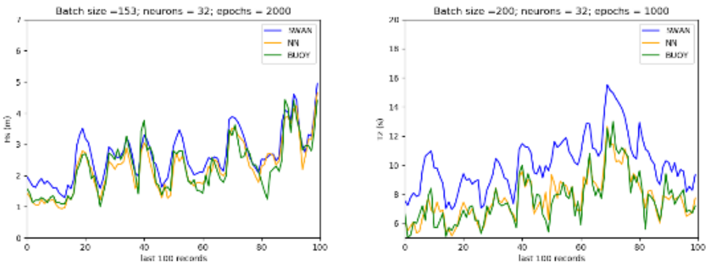

Fig. 5. Comparison of the last 100 records of the Buoy measurements, Neural Network output and SWAN numerical simulations. Significant wave height (left) Mean wave period (right)

The trained networks have been shown to provide more accurate estimates for certain variables and thus to improve the reliability of the EWS.

5. ANN to optimize computational times

The second type of ANN uses an extensive set of pre-run complex numerical simulations to train the ANNs and produce the same output immediately. So, the output of this ANN will not be better than the numerical model, but it will make it possible to use very complex simulation models that would take several hours or even days to run in a few seconds. In this way, it will be possible to simulate all the complex physical phenomena involved in the hydrodynamics of fluid flow in shallow waters with wave and wind forcing and complex sheltered areas and around the 3D ship hull.

To do this, an initial ANN is trained to include all possible non-linear wave propagation simulations using a Boussinesq-type numerical model for the harbour area. Results can be extracted at any number of points along the ship's navigation channels, berths and moorings.

And a second ANN is trained to reproduce the ship's response to these wave and wind forcings using a 3D panel method hydrodynamic model (Korsemeyer et al. 1988) and a motion equation solver. Each specific ship hull and mooring arrangement will have its own specific ANN.

The development of such ANNs is an undertaking of great computational effort that translates into a much simpler, easy-to-use and EWS.

Acknowledgements

The authors thank the financial support of LIFE garachico Project (LIFE20 CCA / ES / 001641), "Fundo Azul" project BlueSafePort (Ref: FA_04_2017_016) - Safety System for Manoeuvring and Moored Ships in Ports and the FCT project To-SeAlert: (Ref. PTDC/EAM-OCE/31207/2017).

References

Booij, Holthuijsen, Ris (1996) The SWAN wave model for shallow water. ICCE´96 Orlando, pp. 668-676.
Fortes, C.J.E.M. (2002). Transformações não lineares de ondas em portos. Análise pelo método dos elementos finitos. Tese de doutoramento. Lisboa: IST/DEM.
Korsemeyer, Lee, Newman, Sclavounos (1988): The analysis of wave effects on tension-leg platforms, 7th International Conference on Offshore Mechanics and Arctic Engineering, Houston, Texas, pp. 1-14.
Pinheiro, Fortes, Reis, Santos, Guedes-Soares (2020): Risk Forecast System for Moored Ships. Coastal Engineering Proceedings, (36v), management.37. https://doi.org/10.9753/icce.v36v.management.37
Pinheiro, Fortes, Reis, Santos, Guedes-Soares (2022) Neural Networks For Optimization Of An Early Warning System For Moored Ships In Harbours. Coastal Engineering Proceedings, (36v), management.37.
Pinheiro, Fortes, Santos, Fernandes & Walkley (2011). Boussinesq-type Numerical Model for Wave Propagation Near Shore and Wave Penetration in Harbors. MARTECH 2011 1st International Conference on Maritime Technology and Engineering. Lisboa, 10-12 May.
Pinheiro, Fortes, Santos, Fernandes, (2013). Numerical software package SWAMS – Simulation of Wave Action on Moored Ships. Proc. PIANC 3nd Mediterranean Days of Coastal and Port Engineering, 22 a 24 de maio, Marseille, França.
Poseiro, Gonçalves, Reis, Fortes, (2017) – Early warning systems for coastal risk assessment associated with wave overtopping and flooding. Journal of Waterway, Port, Coastal, and Ocean Engineering.