

MODELLING WAVE REFLECTION BY IMPLEMENTING ARTIFICIAL NEURAL NETWORKS IN PORT AREAS

Anastasios Metallinos, Scientia Maris P.C., National Technical University of Athens, ametallinos@scientiamaris.com
Andreas Papadimitriou, Scientia Maris P.C., National Technical University of Athens, apapadimitriou@scientiamaris.com
Michalis Chondros, Scientia Maris P.C., National Technical University of Athens, michondros@scientiamaris.com

INTRODUCTION

Ports are vital links in the chain of maritime transport, serving as gateways for imports and exports, constituting vital hubs for economic activity. Numerical modeling of wave agitation inside port basins is indispensable for engineers desiring to obtain predictions of wave heights at berthing positions to ensure that the operability of the port is compromised.

Boussinesq-type wave models (e.g. Shi et al., 2012) have been traditionally employed to simulate wave agitation in port basins, however they are often associated with significant computational burden. An alluring alternative, with respect to the accuracy and efficiency, concerns models based on the time-dependent hyperbolic mild slope wave equation, However, the prescription of partial wave reflection in both the aforementioned model categories requires the definition of an eddy viscosity/ porosity coefficient which makes the pre-processing process a tedious task.

In this paper the training and validation of an Artificial Neural Network (ANN), that enables the efficient and accurate definition of the appropriate eddy viscosity coefficients depending on the desirable reflection coefficient, is presented. The trained ANN is an integral part of an enhanced hyperbolic mild slope (Chondros et al., 2021) wave model (entitled HMS thereafter) able to simulate wave propagation inside ports and coastal areas.

METHODOLOGY AND ANN TRAINING

The wave reflection coefficient of a coastal structure (e.g. composite breakwater) depends of a multitude of parameters (Chondros et al., 2021), most importantly the incident significant wave height, wave period and the depth at the structure's toe. Apart from that, several other parameters, such as the construction material of the structure's armor and if the incident sea-state is considered as regular or irregular have an influence on the outcome. The eddy viscosity coefficient used to formulate the partial wave reflection is considered a function of the following parameters:

$$v_h = f(H_s, T_p, h, L_e, C_R) \quad (1)$$

where H_s is the significant wave height, T_p is the peak wave period, h the still water depth at the toe of the structure, L_e the width of the cells seaward of the breakwater where the eddy viscosity values will be applied and C_R is the wave reflection coefficient. Considering an idealized case of a vertical wall placed in the middle of a beach with varying bed slope several simulations with the HMS model were carried out for several combinations of the input variables shown in equation (1). By employing a

Saltelli sampling scheme and the Fuzzy C-Means clustering algorithm, 4100 combinations of the input parameters were defined in total. Considering the eddy viscosity coefficient to vary between 0 and 25, the reflection coefficient C_R was directly correlated with the eddy viscosity, incident wave characteristics and depth at the structure's toe. Thereafter, a multilayer feed forward ANN, with two hidden layers consisting of 24 neurons each, has been trained and validated to predict the relationship between the reflection coefficient and the eddy viscosity values. The error and performance metrics of the ANN training are showcased in Figure 1.

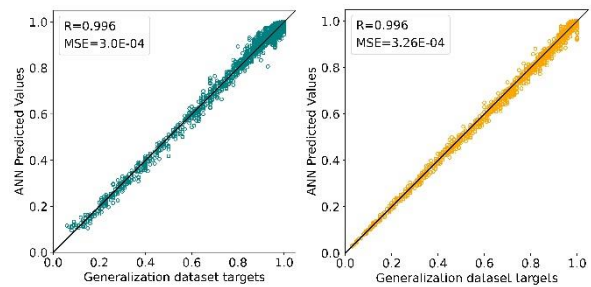


Figure 1 - Error and performance metrics of the training procedure: regular waves (left) unidirectional irregular waves (right)

RESULTS AND DISCUSSION

In order to thoroughly evaluate the ability of the HMS model to simulate wave penetration in harbours, as well as the capability of the ANN to predict partial wave reflection, the physical experiment presented in Van der Ven (2016) was numerically reproduced with HMS. In particular, the third case (unidirectional direct wave attack) was simulated with the HMS wave model, with the layout consisting of a main basin, a closable side basin connected to the main basin at a 45° angle, and a composite breakwater protecting the main basin.

The wave basin where the physical experiments were conducted was approximately 40 m x 40 m with a uniform water depth of 0.44 m. The main basin had dimensions of 8.66 m x 14.53 m while the side basin was 3.07 m x 10.49 m. The composite breakwater had a length of 4.6 m and a height of 0.7 m. To simulate partial wave reflection, a damping slope was considered both seaward and at the lee side of the breakwater. At either side of the main basin, as well as in its northern side, gravel slopes were placed to facilitate wave energy dissipation. In total 27 gauges were used to extract the significant wave heights, most of them placed near the vertical walls, positions with significant importance for loading and unloading operations conducted in ports. The vertical fronts of the quays were considered fully reflecting ($C_R = 1$), while the

composite breakwater and gravel slopes had $C_R = 0.4$ and $C_R = 0.2$ respectively. In order to reproduce the physical experiment, a prototype was constructed with a Froude scaling of 1:20. The rescaled incident wave characteristics were $H_s = 2.12$ m, $T_p = 6.67$ s. The layout of the prototype as well as the position of the measuring gauges is shown in Figure 2.

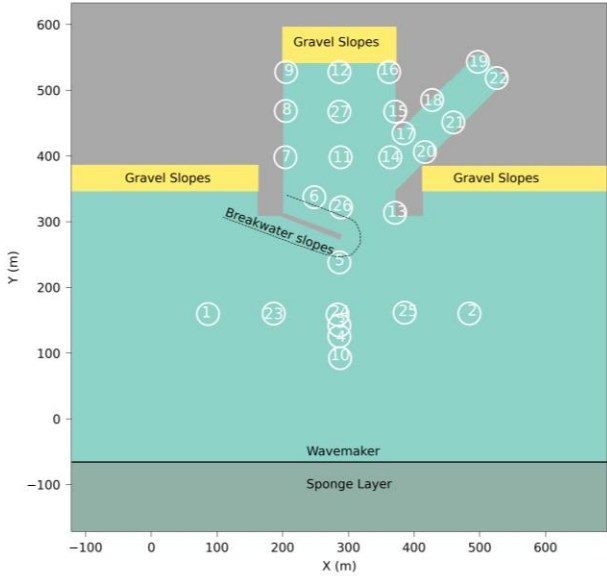


Figure 2 - Numerical layout of the experiments of Van Mierlo, 2014, and positions of measuring wave gauges.

To achieve the desirable level of wave reflection from the composite breakwater, a width (L_e) of 20 m was provided as input to the ANN. The predicted eddy viscosity values in relation to the reflection coefficients of the examined numerical case is shown in Figure 3.

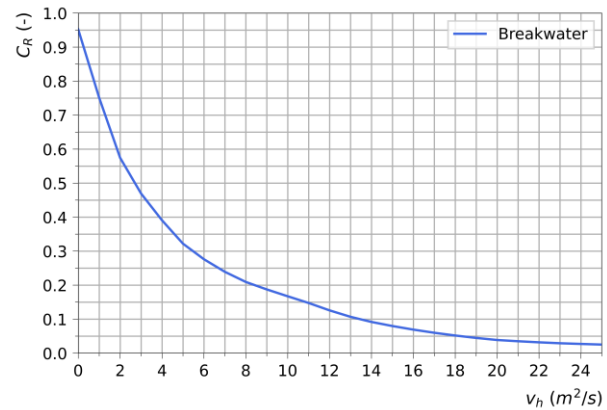


Figure 3 - Relationship between reflection and eddy viscosity coefficient as predicted by the ANN for the composite breakwater

The simulated wave heights at each wave gauge (triangle markers) are plotted against the experimental measurements (circles) in Figure 4. As can be observed

from Figure 4, the model predicts very satisfactorily the wave heights at the majority of the measuring gauges. Of particular importance are gauges 5 and 23, which are located seaward the composite breakwater and are influenced by reflected wave trains from the structure. Consequently, it is considered that the trained ANN can predict reasonably well the eddy viscosity coefficients required by the HMS model to simulate partial wave reflection. This is further supported by the comparisons at gauges 9, 12 and 16, which are located closely the dissipating gravel slopes. Finally, the model predicts in a very satisfying manner the increase of wave height at the gauges situated near the vertical walls of the main and the side basin, validating its use for the reliable estimation of wave agitation in complex port layouts.

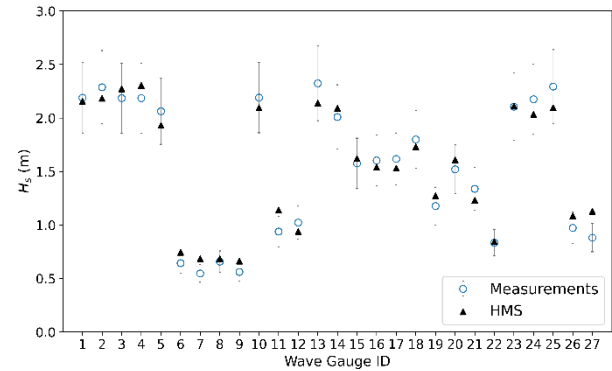


Figure 4 - Comparison of simulated (triangle markers) and measured (circular markers) of the wave heights at each wave gauge. The error bars correspond to a 15% percent margin.

CONCLUSIONS

In the present paper, the advancements of a robust nonlinear Hyperbolic Mild Slope wave propagation model are presented. The model is supported by a thoroughly trained and validated Artificial Neural Network that not only eases the excessive burden of the pre-processing tasks, but is also able to provide reliable modeling of partial wave reflection for a variety of structure configurations. The extended model has been applied in a complex port layout case with a very satisfying performance against the experimental measurements validating its capability in complex port applications.

REFERENCES

Chondros, Metallinos, Memos, Karambas, Papadimitriou (2021): Concerted nonlinear mild-slope wave models for enhanced simulation of coastal processes, Applied Mathematical Modelling, ELSEVIER, vol. 91, pp. 508-529.
 Shi, Kirby, Harris Geiman, Grilly (2012): A high-order adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation, Ocean Modelling, ELSEVIER, vol. 43-44, pp. 36-51.
 Van der Ven, P.P.D. (2016), Benchmark tests of wave penetration in harbours - Measurement report, Deltares Technical Report, reference 1209490-000-HYE-0001.