

HARBOUR LAYOUT DESIGN IN A CHANGING CLIMATE BASED ON ADVANCED NUMERICAL MODELS AND MACHINE LEARNING: A CASE STUDY

Achilleas G. Samaras, Democritus University of Thrace, achsamar@civil.duth.gr
Lazaros Iliadis, Democritus University of Thrace, liliadis@civil.duth.gr
Theofanis V. Karambas, Aristotle University of Thessaloniki, karambas@civil.auth.gr

INTRODUCTION

Harbour layout design is the first and most critical stage in port design by Civil Engineers, typically done using numerical models for the simulation of wave dynamics and hydrodynamics around and inside harbour basins. In a changing climate, engineers have to deal with an increasing number of uncertainties, due to the observed/projected change in the characteristics of representative waves and sea level variations (i.e. the parameters that have the most significant effect on the technical and operational characteristics of the port) and the intensity/frequency of extreme events (De Leo et al., 2023; Vanem, 2016; Weisse et al., 2014). Yet, the bulk of studies on harbour-upgrading in literature focus on the functional design of harbour breakwaters, but not on the layout design itself (Burchart et al., 2014; Radfar et al., 2021).

Considering the previous, as well as the challenges embedded in running model applications for numerous design scenarios and interpreting their results, Samaras et al. (2023) proposed a novel, “intelligent”, methodology for harbour layout design in a changing climate based on Advanced Numerical Models and Machine Learning (ANM and ML in the following, respectively). This work presents core aspects of this methodology and implements it to a case study in Greece.

THE NOVEL METHODOLOGY

The novel methodology comprises the following components: (A) Marine Data Analysis, (B) Harbour Layout Analysis, (C) ANM Applications and (D) ML Applications (see Figure 1).

Component (A) involves the acquisition and analysis of marine data in order to define a series of Design Scenarios (DS) for past, present and future (climate change) conditions. DS are considered as the combinations of the marine characteristics used by engineers when designing a harbour layout and the harbour protection works, along with their frequencies of occurrence. These characteristics include: (i) the significant wave height, (ii) the mean wave period, (iii) the mean wave direction, and (iv) the sea level variation due to the synergy of tide, storm surge and eventual sea level rise due to climate change (the latter of course, only for future conditions). Component (B) involves the acquisition, analysis and classification of harbour layout data and port information in order to identify Typical Harbour Layouts (THL). The latter is done on the basis of layout geometry, harbour protection structures, harbour bathymetry and port characteristics (type, size, capacity). Component (C) involves the adaptation, testing and eventual implementation of ANM to the THL defined in Component (B), using as forcings the DS defined in Component (A). Models results are evaluated on the basis

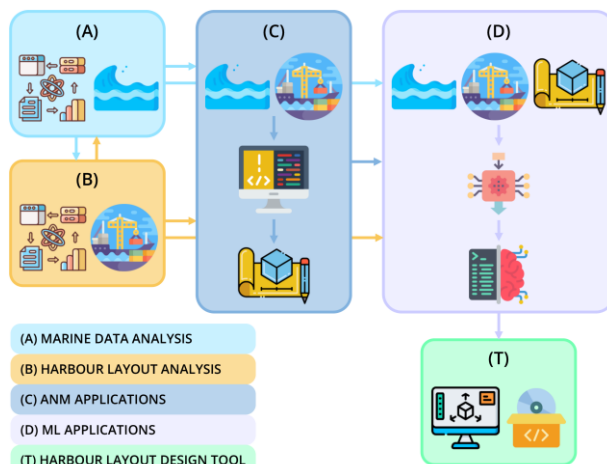


Figure 1 - Components and flowchart of the novel methodology for harbour layout design in a changing climate (ANM= Advanced Numerical Models; ML=Machine Learning; Samaras et al., 2023).

of changes in wave agitation at selected critical locations inside harbour basins and around harbour entrances, and Design/Redesign Solutions (DRS) are proposed for each THL, integrating design criteria/parameters and engineering experience (the process involves, of course, the implementation of ANM to all DRS as well). Component (C) in this work is based on “in-house” models for the simulation of coastal/harbour wave dynamics and hydrodynamics developed by the authors (Karambas and Samaras, 2017; Samaras and Karambas, 2021). Finally, component (D) involves the preprocessing of the data from Components (A), (B) and (C) and the development (training-validation-testing-assessment) of robust ML Models, capable to correctly classify THL to the optimal DRS based on the change in DS (McClarren, 2021; Prakash et al., 2021).

The final output of this methodology will be a tool (T), developed as a standalone application, whose users will be able to select one (or more) of the THL that better fit their project, load their DS for past/present/future conditions, and run the ML Models for the input dataset, getting as results the optimal DRS without the need of running an advanced wave and hydrodynamics model, as well as full reporting on the ML Models' performance.

THE CASE STUDY

The exemplary case study presented in this work regards a coastal area located in the East Macedonia and Thrace Region in Greece. Data from Copernicus Marine Service (CMEMS) and Copernicus Climate Service (CCS) are analysed for a representative coastal location in the

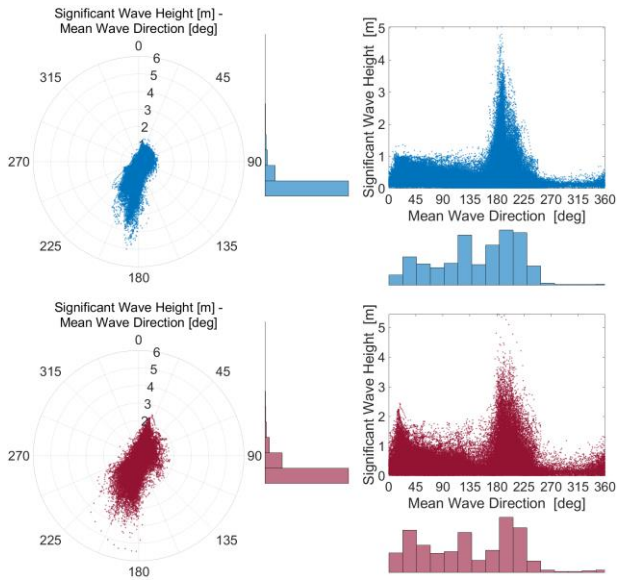


Figure 2 - Results of the past/present (top) and future (bottom) wave climate analysis for the study area based on data from Copernicus (CMEMS and CCS, respectively).

selected Region. Figure 2 presents results of the past/present and future wave climate analysis (top and bottom panels, respectively). The time series of significant wave height and mean wave direction are presented as rose diagrams (left panels) and scatter plots along with the respective frequency distributions of each parameter (right panels). Basic changes in wave climate are evident from Figure 2; in-depth combined analysis of all collected data provides insights on the projected changes in the characteristics used for the definition of DS in the specific study area.

Analysis of the natural (morphological, meteo-marine, climatic) and developmental characteristics of the East Macedonia and Thrace Region regarding port infrastructure led to the identification of the typical layout of a medium-sized harbour schematically represented in the top left panel of Figure 3, along with three indicative design/redesign solutions: DRS 1 and 2 suggesting extension of the windward breakwater (along its axis or at an angle, respectively) and DRS 3 suggesting construction of a detached breakwater near the harbour entrance.

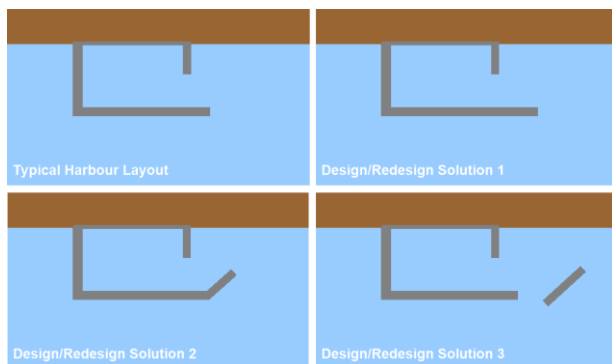


Figure 3 - Schematic representations of the Typical Harbour Layout and Design/Redesign Solutions.

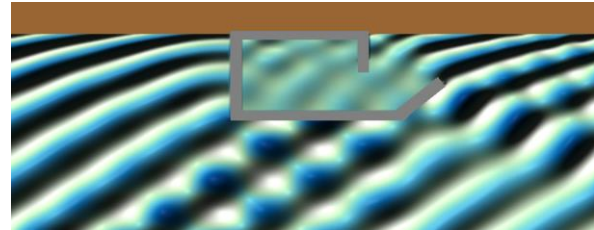


Figure 4 - Indicative Advanced Numerical Model results of sea surface elevation (snapshot) for Design/Redesign Solution 3 (see Figure 3).

The flowchart presented in the previous section (also see Figure 1) is implemented regarding ANM and ML Applications to the specific case study (Figure 4 presents indicative ANM results for DRS 3; see Figure 3). Results serve as proof-of-concept of the proposed novel methodology, leading to useful insights regarding the implementation of its core aspects and contributing towards the development of the Harbour Layout Design Tool (T) in future versions of this work.

REFERENCES

- Burcharth, Lykke Andersen, Lara (2014): Upgrade of coastal defence structures against increased loadings caused by climate change: A first methodological approach, *Coastal Engineering*, ELSEVIER, vol. 87, pp. 112-121.
- De Leo, Briganti, Besio (2023): Trends in ocean waves climate within the Mediterranean Sea: A review, *Climate Dynamics*, SPRINGER, 10.1007/s00382-023-06984-4.
- Radfar, Shafieefar, Akbari, Galiatsatou, Mazyak, A.R (2021): Design of a rubble mound breakwater under the combined effect of wave heights and water levels, under present and future climate conditions, *Applied Ocean Research*, ELSEVIER, vol. 112, 102711.
- Karambas, Samaras (2017): An integrated numerical model for the design of coastal protection structures, *Journal of Marine Science and Engineering*, MDPI, vol. 5, 50.
- McClarren (2022): *Machine Learning for Engineers*, SPRINGER, 247 pp.
- Prakash, Kannan, Alexander, Kanagachidambaresan (2021): *Advanced Deep Learning for Engineers and Scientists*, SPRINGER, 285 pp.
- Samaras, Karambas (2021): Modelling the impact of climate change on coastal flooding: Implications for coastal structures design, *Journal of Marine Science and Engineering*, MDPI, vol. 9, 1008.
- Samaras, Iliadis, Karambas (2023): A methodology for harbour layout design based on Machine Learning, *Proc. of the 40th IAHR World Congress*, Vienna, Austria.
- Vanem (2016): Joint statistical models for significant wave height and wave period in a changing climate, *Marine Structures*, ELSEVIER, vol. 49, pp. 180-205.
- Weisse, Bellafiore, Menéndez, Méndez, Nicholls, Umgiesser, Willems (2014): Changing extreme sea levels along European coasts, *Coastal Engineering*, ELSEVIER, vol. 87, pp. 4-14.