Proceedings of the 9th International Conference on Physical Modelling in Coastal Engineering (Coastlab24)

Delft, Netherlands, May 13-16, 2024

Extended Abstract, DOI: 10.59490/coastlab.2024.813

Coastlab24

13-16 May 2024, Delft University of Technology, NL

ANALYSIS OF HYBRID SOLUTIONS FOR COASTAL PROTECTION COMBINING PHYSICAL AND NUMERICAL CFD MODELING

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KEYWORDS: Hybrid solutions, Nature-based Solutions, flooding, coastal protection, CFD model.

1 INTRODUCTION

Historically, flooding and erosion challenges in coastal areas have been addressed through conventional gray/rigid structures such as breakwaters, dikes, and walls (Morris et al., 2017). As a consequence of the context of climate change, which is accompanied by a global biodiversity crisis and an increasing risk to coastal systems and communities, Nature-based Solutions (NbS) have emerged in recent years as an alternative to conventional engineering options. NbS can completely or partially mitigate coastal flooding and erosion problems while offering several additional co-benefits, such as carbon sequestration, improved water quality, habitat creation, and more (Sutton-Grier et al., 2015). Nevertheless, NbS may not be effective on their own in areas where there is insufficient available space for their development or in high-risk areas. In such cases, combining conventional engineering with nature-based solutions to obtain a so-called hybrid solution can represent an optimal approach, capable of providing the necessary risk reduction and realizing the benefits associated with natural solutions (Vuik et al., 2016). This makes hybrid solutions a highly attractive option that is currently gaining increasing interest. However, due to the limited number of real cases implemented, their relatively novel nature, and existing gaps in our knowledge about their hydrodynamic behavior, there is a pressing need to study hybrid solutions in greater detail. To this end, an experimental campaign is being conducted and is complemented by numerical CFD modeling, coupling IH2VOF and OpenFOAM models, to better understand the coastal protection services provided by the combined solution and to assess the suitability of the method of process superposition, commonly used to analyze the interaction between the flow and the hybrid solution. The main variables analyzed for this purpose are the evolution of wave height and wave run-up.

2 EXPERIMENTAL SET-UP

Experiments were conducted in the Directional Wave Tank at the University of Cantabria. The wave tank measures 28 meters in length, 8.6 meters in width, and 1.2 meters in height. To facilitate simultaneous testing of two ecosystems, the wave tank was divided into two sections, each 4.6 meters wide. Mimics replicating mangrove roots and saltmarsh plants were created based on field conditions, maintaining hydraulic similarity between the mimics and real elements. The mangrove mimics were constructed using 3 cm-diameter wooden cylinders, while the saltmarsh mimics were made of 6 mm-diameter polyamide cylinders. Both types of mimics had a length of 0.50 meters. Stem densities for mangroves and saltmarshes were set at 12 and 300 mimics/m2, respectively, resulting in the same submerged solid volume fraction. Both canopies were 12 meters long. The rigid structure was represented by a smooth flat ramp, which was designed to rotate about a pivot point located at its base, allowing testing at three different slopes: 1:5, 1:3, and 1:2.

Random wave conditions with significant wave heights ranging from 0.042 to 0.212 meters and peak periods from 1.8 to 4.2 seconds were tested at three water depths: 0.30 meters, 0.50 meters, and 0.70 meters. Figure 1 provides an overview of the experimental setup, showing the two canopies and the ramp. Fifteen capacitive free surface gauges were positioned along each canopy, and an additional three capacitive parallel sensors were placed on each slope to measure wave run-up. To facilitate a more comprehensive study of this process, an overhead camera was used to track the motion of the free surface over the ramp. To enhance the contrast between the water and the ramp, water was dyed with rhodamine, and the slope was covered with white vinyl.

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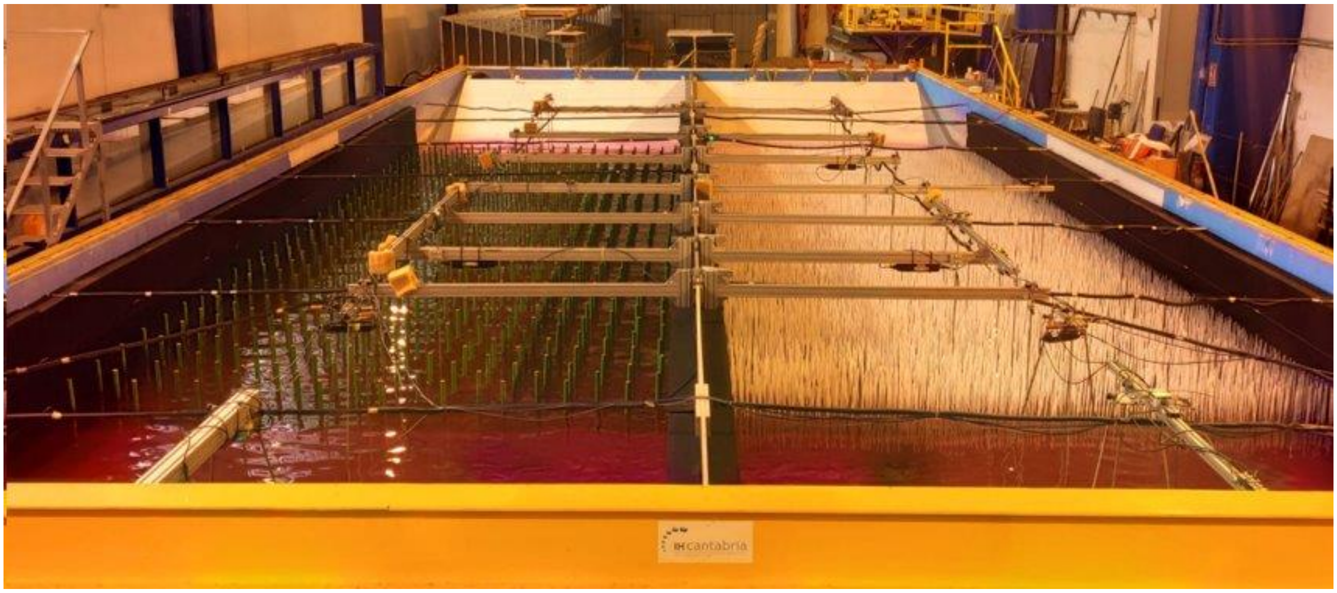

Figure 1. Overview of physical experiments.

3 RESULTS

The most common run-up formulations used in the design of engineering structures depend on the incident wave height at the structure's toe. This variable cannot be directly measured in laboratory experiments. Therefore, this parameter was estimated using a numerical CFD setup, which involves coupling IH2VOF and OpenFOAM. This setup was previously calibrated and validated to adequately account for flow-vegetation interaction and bottom friction. Significant differences were observed between the wave run-up obtained from existing formulations (which used the numerical model wave height as input) and the wave run-up measured in most of experiments. These discrepancies highlight important weaknesses in the commonly used approach of superposition of processes, in which: 1) the waves propagate through the vegetation field, and 2) the resulting wave height is used as the main input to calculate wave run-up with existing equations. The results underscore the need to reconsider the traditional method in order to analyze the hydrodynamic variables within the hybrid solution in a more integrated way, avoiding the decoupling of physical processes during the flow-vegetation-structure interaction.

ACKNOWLEDGEMENT

Grant TED2021-130804B-I00 of the project funded by MCIN/AEI/10.13039/501100011033 and by the "European Union NextGenerationEU/PRTR". Grant PDC2022-133579-I00 of the project funded by MCIN/AEI/10.13039/501100011033 and by the "European Union NextGenerationEU/PRTR". This study also forms part of the ThinkinAzul programme and was supported by Ministerio de Ciencia e Innovación with funding from European Union NextGeneration EU (PRTR-C17.I1) and by Comunidad de Cantabria.

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