

IMPLICATIONS OF DECOUPLED PHYSICAL PROCESS ANALYSIS FOR HYBRID SOLUTIONS

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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). In 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, improving 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 implementation or in high-risk areas. In such cases, combining conventional engineering with NbS to obtain a so-called hybrid solution could 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 them in greater detail. To this end, an experimental campaign is being conducted and is complemented by numerical CFD modeling, coupling IH2VOF and OpenFOAM models. This, in order to better understand the coastal protection services provided by the combined solution and to assess the suitability of considering the effect produced by the ecosystem on the flow in order to subsequently analyze the interaction of the resulting hydrodynamic forcing with the rigid infrastructure.

EXPERIMENTAL SET-UP

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

base, allowing testing three different slopes: 1:5, 1:3, and 1:2.

Random wave conditions with significant wave heights ranging from 0.042 to 0.212 m and peak periods from 1.8 to 4.2 s are tested at three water depths: 0.30 m, 0.50 m and 0.70 m. All wave conditions are tested with and without vegetation mimics. Figure 1 provides an overview of the experimental setup, showing the two canopies and the ramp. Fifteen capacitive free surface gauges are positioned along each canopy, and an additional three capacitive parallel sensors are placed on each slope to measure wave run-up. To facilitate a more comprehensive study of this process, an overhead camera is used to track the motion of the free surface over the ramp. To enhance the contrast between the water and the ramp, water is dyed with rhodamine, and the slope is covered with white vinyl.



Figure 1 - Experimental set-up. Mangrove mimics at the left side and saltmarsh mimics at the right side. The smooth rigid slope covered with white vinyl is at the end of the wave tank and pink water can be observed due to the use of rhodamine for dyeing.

METHODOLOGY

This study focuses on the analysis of wave height evolution and wave run-up. The most common wave run-up formulations used in the design of engineering coastal structures depend on the incident wave height at the toe of the structure. This variable cannot be measured directly in laboratory experiments, nor calculated in the presence of vegetation with existing methods to analyze incident and reflected wave energy. Therefore, a hybrid methodology that involves laboratory data and numerical CFD modeling is followed. In this way, experimental data is used to calibrate and validate a coupling model performed by using IH2VOF and OpenFOAM. IH2VOF is a 2D CFD model, whereas OpenFOAM is a 3D numerical model. Then, first IH2VOF is used to generate and propagate the waves before the vegetation field to feed OpenFOAM, where the hybrid solution is reproduced. To account for the effect of bottom friction dissipation, tests performed without vegetation are first simulated to calibrate bottom friction

coefficients in the numerical model. Once bottom friction effects are well reproduced, the vegetation is also included in the model to simulate the wave height evolution produced along the field and get the wave height onshore the vegetation, which is the incident wave height at the toe of the structure. Then, this incident wave height is used to calculate the expected wave run-up with existing formulations and comparing them with the experimental data. Figure 2 provides an example of CFD simulations carried out for a benchmark case and a test where the hybrid solution is simulated.

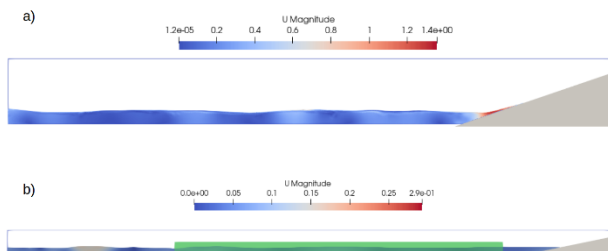


Figure 2 - Example of CFD numerical simulations. Both panels, the upper and the lower ones, show the flow velocity at a specific time for the numerical domain, and both of them are forced with random waves of 0.13 m wave height and 3.0 s of peak period. Panel a) corresponds to a case without vegetation, with a depth of 0.50 m and a ramp with a 1:3 slope. Panel b) corresponds to a case with vegetation of 0.50 m in height, a depth of 0.30 m, and a ramp with a 1:5 slope.

RESULTS

Wave run-up obtained by applying existing formulations is compared to the one recorded in the laboratory, that is, after obtaining the incident wave height at the toe of the structure (after the vegetation field). Ahrens (1981) formula is applied to estimate the run-up and this value is compared to the recorded value in the lab. While measured wave run-up agrees with the estimated value applying Ahrens (1981) for benchmark cases (cases without vegetation), for those with vegetation significant differences are observed, especially for cases where vegetation is emergent. These discrepancies highlight the importance of better understanding the physical processes present in the combined solution and the necessity of reviewing the approach used to analyze wave run-up in hybrid solutions. It is important to clarify that the Ahrens formulation (1981) is chosen for wave run-up because this formulation was derived for impermeable slopes with slopes within the range tested in the presented experiments and it best fits the data from cases conducted without vegetation.

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