EXPERIMENTAL ANALYSIS OF HYBRID SOLUTIONS FOR COASTAL PROTECTION

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INTRODUCTION

In recent decades, climate change has already affected natural and human systems on all continents and in the oceans, with consequences for the economic, productive and social sectors, and is one of the major challenges facing society in the 21st century. The current climate trend will be maintained and accentuated in the coming decades due to the inertia of the global climate system. Coastal natural and socio-economic systems are particularly vulnerable to these effects and are subject to increasing risk, mainly due to flooding and coastal erosion resulting from sea level rise and the frequency and severity of extreme weather events. In addition to the context of climate change, the rapid urbanization and subsidence of certain areas are increasing their exposure and vulnerability, and thus the need for coastal communities around the world to manage these risks by adopting adaptation measures (Barbier et al., 2014). Among the newest strategies are nature-based solutions based on coastal ecosystems (Spalding et al., 2014; Jongman 2018). Such solutions have several co-benefits, such as habitat creation, increased water quality or carbon sequestration. However, these solutions may not be effective on their own in high-risk areas or in areas where there is not enough space for their implementation. In these cases, the union of conventional engineering with these nature-based solutions, the so-called hybrid solutions, can represent an optimal solution that provides the necessary risk reduction while reporting the co-benefits associated with natural solutions (Sutton-Grier et al., 2015; Vuik et al., 2016). This makes hybrid solutions a highly attractive option in which there is a growing interest. However, their relatively novel character, the few real cases implemented and the need for a strong integration of knowledge linking different disciplines pose a series of gaps in knowledge. To this end, an experimental campaign is proposed to study different typologies of hybrid solutions. The interaction between the ecosystem and the hard structure is studied to better understand the coastal protection service provided by the joint solution. To compare the performance of the different hybrid solutions, wave run-up over the rigid structure is analyzed and it is compared to the run-up obtained for the traditional rigid solution.

EXPERIMENTAL SET-UP

Experiments are run in the Directional Wave Tank of the University of Cantabria. The wave tank is 28 m long, 8.6 m wide and 1.2 m tall. To be able to test two ecosystems simultaneously, the wave tank is divided in two sections of 4.6 m. Mimics reproducing mangrove roots and saltmarsh plants are created based on field conditions and keeping the hydraulic similarity between the mimics and the real elements. Mangrove mimics are made of 3 cm-diameter wood cylinders, whereas saltmarshes are made of 6 mm-diameter polyamide cylinders. Both mimics have a length equal to 0.50 m. The stem density considered for mangroves and saltmarshes is 12 and 300 mimics/m^2, respectively, leading to the same submerged solid volume fraction. Three meadow lengths are tested: 12, 10 and 8 m. The 12 m long meadows end at the toe of the rigid structure whereas the 10 and 8 m long meadows result in a gap between the end of the meadow and the toe of the structure equal to 2 and 4 m, respectively.

The rigid structure is represented by a smooth flat ramp. The ramp rotates with respect to a rotation point located at its bottom. This allows testing three different slopes: 1:5, 1:3 and 1:2. Figure 1 shows a view of the experimental set-up where the two canopies and the modular slope are shown. Benchmark cases are also carried out where the ramp is tested without the presence of vegetation.

Random wave conditions with significant wave height ranging from 0.042 to 0.212 m and peak periods from 1.8 to 5.4 s are tested over three water depths equal to 0.30, 0.50 and 0.70 m. Thus, submerged, nearly emergent and emergent conditions are tested.

Free surface measurements are taken at 16 locations along each canopy using capacitive free surface gauges. Additionally, three capacity sensors are located at each slope at its middle section and at the center between this central section and both walls to measure wave run-up. To better study this process, an overhead camara is used to track the free surface motion over the ramp. To increase the contrast between the water and the ramp, water is dyed with rhodamine and the slope is covered with white vinyl, as can be observed in Figure 1.

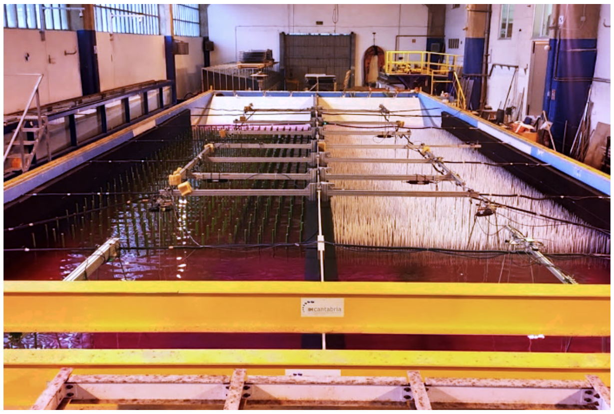

Figure 1 - Experimental set-up. Mangrove mimics at the left side and saltmarsh mimics at the right side. The smooth rigid slope covered with white vinyl is at the end of the wave tank and pink water can be observed due to the use of rhodamine for dyeing.

RESULTS

Wave height attenuation is obtained for the two canopies and the set of random wave conditions tested. Higher attenuation rates are found for the emergent conditions, in agreement with previous studies. These high attenuation rates result in a significant decrease of the wave height at the toe of the rigid structure and, consequently, in a decrease of the wave run-up produced over the ramp compared to the cases where the vegetation fields are not present.

Wave run-up is obtained for the different vegetation-ramp combinations, as well as for tests carried out in the absence of vegetation where only the rigid structure is present. Wave run-up is obtained by analyzing the images from the videos recorded in the tests and carrying out a geometric correction and an image treatment by increasing the contrast to each frame. Figure 2 shows an example of the analysis performed for a test carried out with a water depth equal to 0.50 m and ramp slope of 1:5.

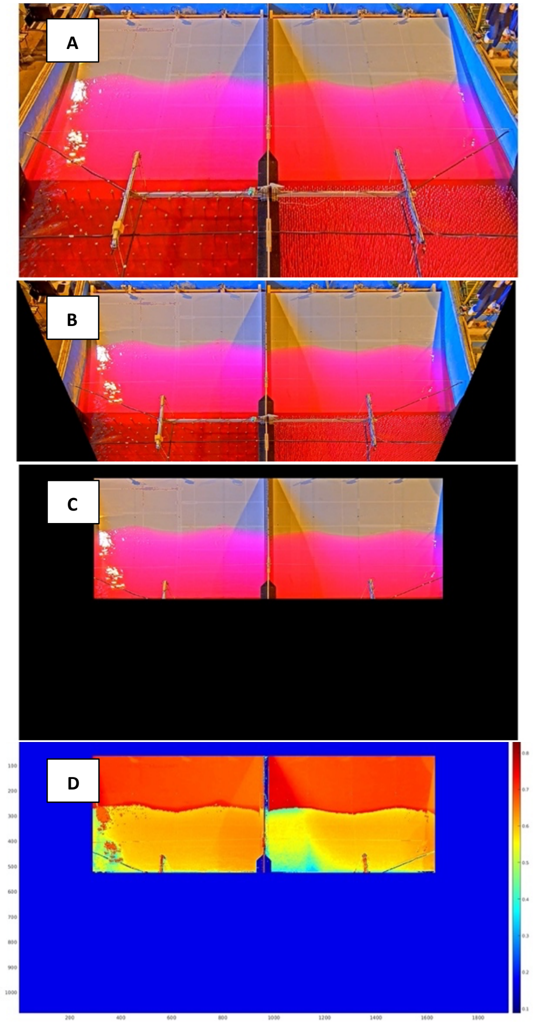

Figure 2 – Video images analysis to estimate wave run-up over the ramp for a benchmark case performed with a water depth equal to 0.70 m and a ramp slope of 1:5. Panel A shows the recorded image, Panels B and C image treatment and Panel D the final image used to get wave run-up.

Relative wave run-up height, defined as the ratio between the wave run-up that is exceeded by 2% of the number of incident waves and the incident wave height at the toe of the structure, is obtained for the different set of hybrid solutions and compared to the analytical results obtained following the Eurotop (http://www.overtopping-manual.com/). To properly estimate the value of the incident wave height at the toe of the structure, the numerical model IH2VOF (https://ih2vof.ihcantabria.com/) is used. First, the model is validated by reproducing the tests performed in the laboratory and then simulating a set of new cases in which the rigid slope is replaced by an absorbing boundary and the wave height after the vegetation field at the position of the toe of the structure is obtained. The obtained results do not agree with the Eurotop estimates, especially for the cases with emergent vegetation where the non-linear interaction between waves, vegetation and ramp is higher than for the submerged cases. The relative wave run-up height for the hybrid solutions turns out to be lower than that expected for the rigid solution. Therefore, the standard formulations used to estimate wave run-up on a rigid structure may lead to overestimates of this variable when applied to hybrid solutions.

CONCLUSIONS

This work presents the analysis of a set of hybrid solutions combining different types of vegetated ecosystems and flat slopes. The relative wave run-up height is analyzed for the different combinations. The obtained results show a disagreement with the estimation following the Eurotop. This highlights the need of new formulations that consider both the characteristics of the rigid structure and those of the ecosystem to properly estimate wave run-up produced in hybrid solutions.

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