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.2024.770

ANALYSIS OF UPGRADING LOW-CRESTED STRUCTURES AS AN ADAPTATION MEASURE TO CLIMATE CHANGE FOR COASTAL PROTECTION: A HYBRID APPROACH

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KEYWORDS: low crested structures, wave transmission, hybrid modelling

1 INTRODUCTION

Coastal zones have consistently been among the most appealing settlement areas due to their proximity to the sea, rich natural resources, and the high quality of life they offer (Lamberti et al., 2005). However, these regions are affected by climate change impacts, such as sea-level rise, storm surges, and an increased intensity of extreme weather events (Burcharth et al., 2014). Traditional low-crested rubble mound breakwaters are commonly used to protect coastal areas from wave damage. However, it is expected that the variability of climate conditions will induce a loss of functionality and structural integrity in the coming decades. Coastal communities and coastal managers, within the framework of sustainable development, are demanding new approaches that include not only the preservation of the hydraulic performance of the breakwaters, but also other factors, including social and environmental impacts. These requests significantly affect the traditional way to conceive those structures to be integrated into the coastal landscape. To cope with the variation of climate drivers, existing low-crested breakwaters must be adapted to accommodate social demands and environmental issues. Therefore, upgrading and maintaining the existing rubble-mound breakwater is a hot topic in coastal engineering, and deserves special attention due to the possible intensification of external loads resulting from the impacts of climate change (Stagnitti et al., 2023). Upgrading can be done by modifying the structure profile and/or adding structure elements (Burcharth et al., 2014). In 2011, Cappietti provided curves for the functional design of submerged breakwaters to be used in place of preexisting emergent breakwaters. Burcharth et al. (2014) explained that the best way to improve the structure is to put an additional layer of protection on the front slope, as long as the foreshore has a mild slope of around 1:100. But if the foreshore becomes steeper because of erosion, then a front berm will also be needed. Stagnitti et al. (2022) introduced a novel methodology based on the calculation of the failure probability during a lifetime due to independent failure modes. Their method was employed to evaluate the performance of upgraded breakwaters in response to climate change. Estimating the wave overtopping of both existing and upgraded breakwaters is essential for designing upgrade options that can ensure the safety of port operations. Stagnitti et al. (2023) applied the numerical model IH2VOF, which was calibrated using experimental data, to study the wave overtopping of damaged and upgraded rubble-mound breakwaters. The present work examines the feasibility of converting emerged rubble-mound breakwaters into submerged breakwaters to minimize their detrimental environmental effects. To achieve this goal, an investigation was conducted to evaluate the hydraulic performance of submerged breakwaters that are created by lowering the crest of existing emerged breakwaters. Additionally, two-dimensional numerical simulations were performed using IH2VOF to investigate wave interactions with the structures.

2 MATERIALS AND METHODS

2.1 Experimental Set-up

The experiments conducted in this study were carried out within a wave flume located at the Engineering Department of the University of Campania. The wave flume has dimensions of 0.8 m in width, 0.6 m in depth, and 13.4 m in length. The facility is equipped with a wave generation section on one end and a dissipative gravel beach for wave absorption on the other. A piston-type wave maker is applied to generate regular waves with different frequencies and irregular waves. Three wave gauges were placed at different locations prior to the barrier models to measure the incident wave heights. Another two wave gauges were placed on the rear side of the models for measuring the transmitted wave heights. The array of wave gauges in front of the model was used for wave reflection analysis. The wave gauges were meticulously calibrated before each experiment. The detailed specifications and characteristics of this facility can be found in the previous experimental work by Hassanpour et al. (2023). Figure 1 shows the plan and cross-section of the flume and experimental conditions.

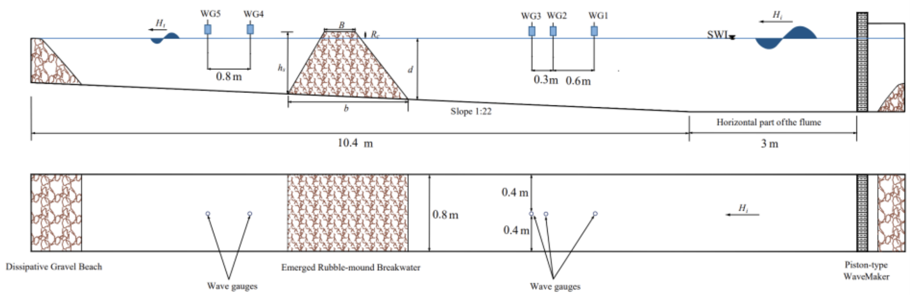

Figure 1. Plan and cross-section of the wave flume and experimental set-up

2.2 Numerical Modelling

In this work, the IH2VOF model (Lara et al., 2011) is used with the aim of evaluating its performance in reproducing the complex wave structure interaction phenomena as observed in the laboratory. IH2VOF solves the 2D Reynolds Averaged Navier–Stokes (RANS) equations at the clear fluid region and the Volume-Averaged Reynolds Averaged Navier–Stokes (VARANS) equations inside the porous media regions, based on the decomposition of the instantaneous velocity and pressure fields into mean and turbulent components, and the $k - \varepsilon$ equations for the turbulent kinetic energy k, and its dissipation rate ε. This permits the simulation of any kind of coastal structure (e.g. rubble mound, vertical or mixed breakwaters). The free surface movement is tracked by the volume of fluid (VOF) method for one phase only, water and void (Lara et al., 2008).

3 RESULTS

To evaluate the hydraulic performance of each breakwater configuration, wave transmission (K_t), wave reflection (K_r), and wave energy dissipation (K_d) coefficients were analyzed against different geometrical parameters for various wave climates. Results obtained from the analysis of the average wave transmission, reflection, and dissipation coefficient highlighted the importance of considering different wave climates separately in evaluating breakwater configurations. This categorization contributes to an improved understanding of selecting appropriate coastal protection measures designed for regions characterized by distinct wave climates. Figure 2 illustrates the outcomes derived from this consideration.

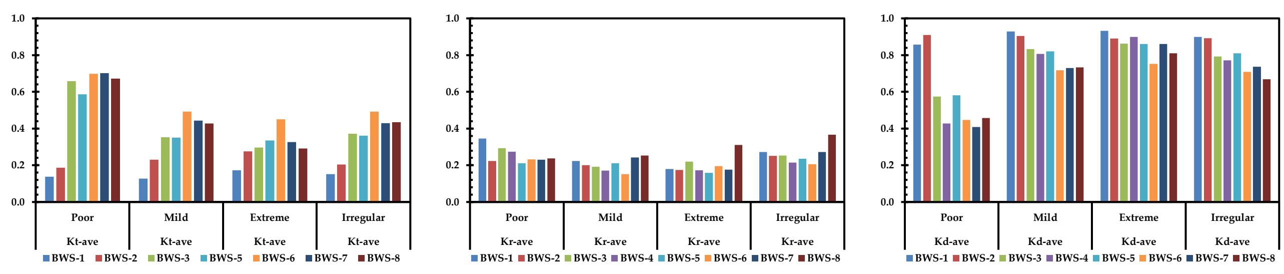

Figure 2. Impact of different wave climates on the average of transmission (K_t), reflection (K_r), and dissipation (K_d) coefficients

To investigate the interactions between different wave climates with innovative breakwater configurations, the IH2VOF model is employed as a numerical simulation tool. The initial phase involves calibrating the model using data from a specific wave climate, followed by thorough validation using varied wave climates. Subsequently, with the validated model, an in-depth exploration is conducted to analyze the impact of breakwater characteristics, such as freeboard and crest width, on the hydraulic performance of innovative breakwater configurations. Figure 3 displays the time series of free surface displacement recorded by each wave gauge positioned within the laboratory compared with the results of the numerical model. Additionally, Figure 4 illustrates a comparison between the transmission and reflection coefficients obtained from both the experimental and numerical campaigns. The results confirm that the model accurately predicts these coefficients, showing high level of reliability.

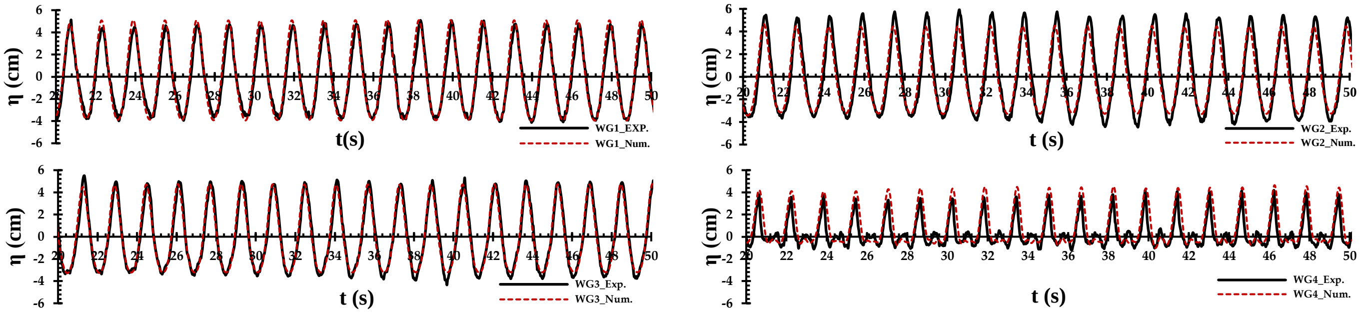

Figure 3. Free surface time series of for wave gauges solid lines: experimental data, dotted lines: numerical result

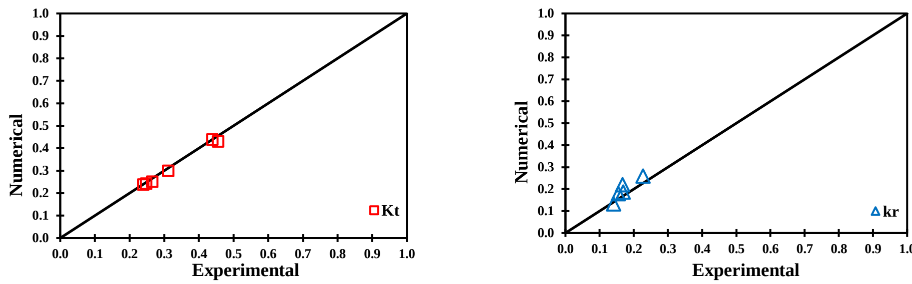

Figure 4. Transmission (K_r) and reflection (K_r) coefficients, experimental and numerical comparison

4 CONCLUSIONS

The study aims to provide insight into the possibility of upgrading existing emerged rubble mound breakwaters. Furthermore, the authors investigate the impact of various wave climates, including “poor”, “mild”, “extreme”, and “irregular” waves, on the hydraulic performances and wave energy dissipation for upgrading breakwater configurations. The study relies on a two-dimensional numerical investigation performed using the IH2VOF method. This investigation aims to gain a better understanding of each configuration's behaviour regarding wave-structure interaction. Overall, through this compose analysis, the study aims to provide valuable insights for coastal engineers and researchers interested in designing more sustainable and effective coastal protection structures. Furthermore, the results of this investigation will offer engineers deeper insights into breakwater functionality and operation in a changing climate to improve and increase the portfolio of existing adaptation measures.

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