HYDRAULIC PERFORMANCE OF ECOFRIENDLY BREAKWATER ARMOUR UNITS

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INTRODUCTION

Traditional coastal defence structures tend to foster less diverse aquatic populations and larger concentrations of invasive species than natural habitats, which can be harmful to the ecosystem (Firth et al., 2016). There is growing interest in implementing principles and methods of ecological engineering, which combines ecosystems with engineering principles to develop coastal structures to decrease their negative environmental effects. When designing coastal constructions, ecoengineering has the potential to build sustainable coastal protection structures and to improve coastal habitat. Developing eco-friendly breakwater design guidelines represents a new and inherent progression step for coastal ecoengineering.

OBJECTIVES AND NOVELTY OF THE STUDY

The objective of this experimental modelling program was to obtain information on the hydraulic performance and stability of low-crested and conventional rubble mound breakwaters (RMBW) built with ecologically engineered environmentally friendly armour units (Coastalocks™) under a variety of wave conditions. The physical testing program was developed by researchers at the University of Ottawa and conducted in cooperation with the National Research Council of Canada (NRC) and ECOncrete.

As the concept of an eco-friendly breakwater is still an emerging area of research, several breakwater model designs were tested to assess their performance. This novel experimental program will also be integrated with the ecological enhancement research of existing coastal structures as well as the design of future coastal structures with eco-friendly armour units (Baker et al., 2018). The physical model tests were conducted in the NRC's Large Wave Flume in Ottawa, Canada between June 2023 and August 2023.

EXPERIMENTAL SETUP

Using 2D low-crested (relative freeboard <0.5) and traditional rubble mound breakwater (RMBW) models (relative freeboard >1), the Coastalock armour units from ECOncrete were tested as a single layer armor in a variety of configurations at 1/15 scale by casting in concrete more than 600 armour units.

Figure 1. Coastalock armour units in the San Diego Port

The Coastalock armor units included in the tests are $1.42m^3$ in the prototype. The hydrodynamic performance of these environmentally-friendly armour units on these ecofriendly breakwater models were investigated under severe wave conditions.

The low-crested and conventional RMBW models were built as permeable structures using core material, underlayer rocks, toe armour, and Coastalock armour units placed along the seaside, crest, and lee side of the breakwaters, as shown in Figures 2 and 3 for low-crested breakwater model and Figures 4 and 5 for conventional RMBW model, respectively. Rock armor was also used as crest armor at half of the crest of the structures to investigate the effect of the structure with a rock armor crest.

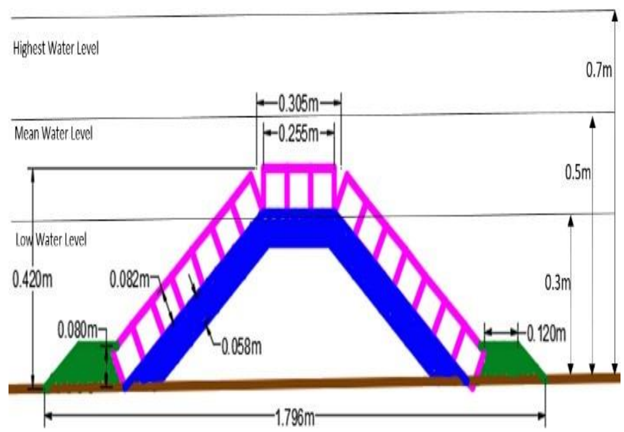

Figure 2. Low-crested Breakwater Model Cross-Section

Figure 3. Low-crested Breakwater Model Construction

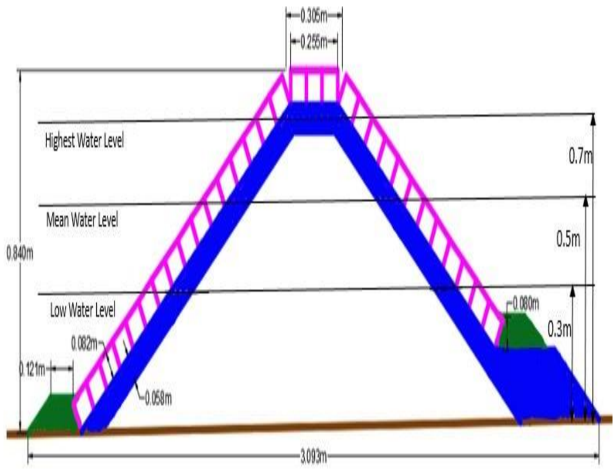

Figure 4. Conventional RMBW Cross-Section

Figure 5. Conventional RMBW Model Construction

In this test program, the unit spacing and underlayer rock size were varied parameters between the test series, whereas the shape and dimensions of the model cross-sections remained unchanged throughout each test series. The experiments used a variety of water depths, wave heights, and wave steepness. Wave heights varied between 1.2 to 5.7 meters (at prototype scale), while wave steepness ranged from 0.025 to 0.07.

The orientation of the Coastalock units was based on the "San Diego" configuration (Molenkamp, 2022). In this configuration, the bottom units have their cavities facing sideways, whereas the rest of the units have their cavities facing forward. This arrangement provides a cave and water-retaining elements for the formation of underwater and intertidal marine habitats.

TEST RESULTS AND ANALYSIS

The stability analysis showed that, under the wave conditions simulated, the Coastalock armour units at the crest and at the transition between the slope and the crest of the low-crested breakwaters were found to be relatively unstable. In the case of the low-crested breakwater model, the majority of the moving units are located at the transition zone from the front slope to the crest.

During the construction of the model, it was also found that larger underlayer rocks made it more challenging to place the Coastalock armour units, resulting in lack of interlocking between the units and, consequently, more moving units. However, the low-crested breakwater model performed well overall, in terms of stability under extreme wave conditions.

In the case of the conventional RMBW model tests, the highest percentage of moving units was also found among those positioned at the top of the front slope (at the transition zone between the slope and the crest), and along the entire crest. Although significant overtopping was observed during the high-water level tests, the back slope units nevertheless remained quite stable.

The authors concluded that given that the instabilities of the breakwaters occurred on the crest and around the crest of the structures, larger or modified armour units placed on the crest may reduce the number of rocking units. Due to the single-layer regular positioning of the armour units, it was also observed that the toe design is crucial since it was found that displacement of the leeward toe armour might result in a complete along-slope line of armour units sliding.

CONCLUSION

These new experimental studies provide unique information on the design of eco-friendly coastal structures. Following these physical modelling tests, an open-source numerical model (OLAFOAM) will be employed to model the eco-friendly breakwater under a variety of wave conditions (Higuera et al., 2015). In parallel to this research project a biological performance assessment of these armour units has been (Rella et al. 2023) and is being conducted in the port of San Diego (USA) and Vigo (Spain) respectively.

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