OBSERVATIONS OF WAVE RUNUP REDUCTION BY POROUS STRUCTURES

Arnold van Rooijen, The University of Western Australia, arnold.vanrooijen@uwa.edu.au
Julia Schwab, The University of Western Australia, 22493351@student.uwa.edu.au
Ryan Lowe, The University of Western Australia, ryan.lowe@uwa.edu.au
Renan Fonseca da Silva, The University of Western Australia, renan.silva@uwa.edu.au

INTRODUCTION

Coastal and estuarine flooding and erosion are expected to intensify considerably over the next decades due to sea level rise and increase in extreme storm events. Foreshore managers have typically responded to flooding and erosion threats by constructing hard, impermeable structures (e.g., rock walls, revetments). The downsides of these structures, however, are increasingly recognized, such as loss of beaches, negative effects on ecosystems and substantial installation and maintenance costs.

Concurrently there is increasing evidence that aquatic ecosystems (e.g., salt marsh, mangroves) can provide effective flood and erosion protection in addition to ecosystem services such as habitat and carbon sequestration (e.g. Morris et al., 2018). Restoration of degraded foreshore habitats is thus increasingly being recognized as an effective nature-based solution for enhancing resilience against flooding and erosion. However, it usually takes considerable time before vegetation is mature enough to withstand wave forces and reach full shoreline protection capacity. To provide shelter and temporary shoreline protection, porous structures made from organic materials (e.g., bamboo or brushwood), sometimes referred to as bioengineered structures, have become increasingly popular in the past decade globally. Across a wide range of field applications, they have been found to be effective in reducing wave impact, thereby allowing vegetation to regrow and reduce foreshore flooding and erosion risk.

While the benefits of these structures have been shown in the field, physical understanding of how they interact with waves is limited and therefore quantitative design guidelines are currently lacking. Few studies have focused on wave attenuation by porous structures (e.g., Losada et al., 1995; Requejo et al., 2002), however the influence on wave runup remains largely unknown, particularly its components; setup, and infragravity and sea-swell swash. In this study, we aim to take a first step in filling that gap and evaluated the effect of idealized porous structures on wave runup through experiments in a large-scale wave tank using irregular wave conditions. The experimental findings are considered an important initial step towards better understanding of how bioengineered structures can provide shoreline protection and shelter for habitat restoration, and towards the development of quantitative design guidelines.

EXPERIMENTAL SETUP

Experiments were carried out in a 54-m-long wave flume equipped with a hinge- and piston-type wave paddle (Ellwood et al., 2022). Here, the piston wave maker was used in combination with second-order wave generation. The experimental setup included a 1:10 sloping beach that extended from the flume bottom up to 1.2 m height.

To represent the porous structures, we used sheets of perforated marine plywood that were fixed on the slope and extended from wall to wall (Figure 1). Three different porosities (Φ = 0.16, 0.38 and 0.56) were obtained by drilling 51 mm holes in a staggered formation with ranging hole-to-hole distance. This idealized design, where water could only flow through the holes, allowed us to focus on the effect of porosity directly while dissipation due to friction or drag were considered negligible. The structures were placed at three different locations along the profile at and near the still water level (Figure 2). A total of 24 experimental runs with a range of structure design and irregular wave conditions were tested with significant wave heights varying from 0.1 to 0.15 m and peak periods from 1 to 3 seconds. In addition, all wave conditions were repeated without structure. A total of 15 synchronized resistance-type wave gauges (Edinburgh Designs) were placed along the center line of the wave flume, of which 5 offshore and 10 along the slope (Figure 2). To measure wave runup, a 3-m-long resistance-type runup gauge was placed along the slope approx.10 mm height from the slope, and a digital compact camera (Powershot G7x Mark III, Canon Inc.) was set up on the dry beach facing the swash zone.

Figure 1 - Photograph of a wave passing through the perforated plywood board during the experiment with the structure placed at SWL with H_s = 0.15 m and T_p = 3 s..

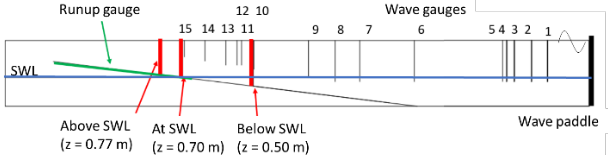

Figure 2 - Schematic view of experimental setup (not to scale) with wave gauges (numbered 1-15), porous structure locations (red) and runup gauge (green).

DATA ANALYSIS

The data analysis focused on assessing the influence of structure porosity and location on wave setup, infragravity swash and sea-swell swash, as well as extreme wave runup levels (i.e., 2% exceedance runup level, $R_{2\%}$, and maximum runup observed within a single experiment, R_{max}).

We found considerable reduction in extreme wave runup with increasing effect for decreasing porosity (see example results in Figure 3 and 4). Most reduction was found for the structure at SWL -0.2 m and Φ = 0.16, ranging between 47 to 60% relative to the case with no structure. While a substantial runup reduction was also found for the case with highest porosity (Φ = 0.56) with the structure at SWL -0.2 m (Figure 3), the influence was negligible for the other two locations (Figure 4). The results for runup reduction with medium porosity (Φ = 0.38) were consistent with the values reported for other porosities. The effect on wave setup was generally found negligible except for the case with highest wave period (T_p = 3 s) lowest porosity (Φ = 0.16) in combination with the structure placed at SWL -0.2m. The total (sea-swell + infragravity) swash motion was considerably reduced, ranging between 10 and 24% reduction across all cases.

Overall, we found a strong relation between wave runup reduction and structure porosity and location, and these findings are used in upcoming experiments and numerical modelling efforts. Further analysis on the current dataset includes the separation of infragravity and sea-swell swash, as well as a wave reflection analysis.

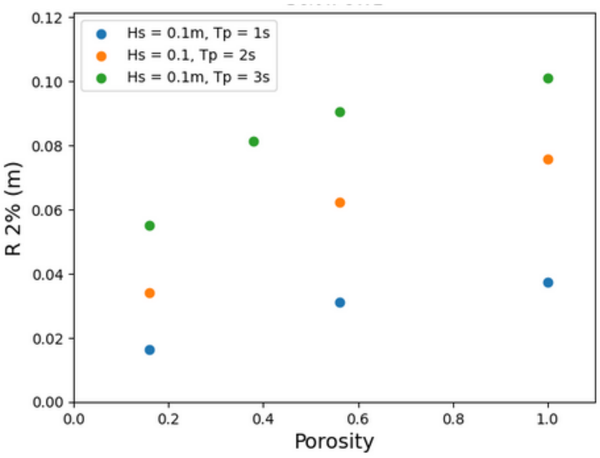

Figure 3 - Observed extreme wave runup (*R2%*) for three different wave conditions (colored markers) as function of porosity with structure placed at z = SWL -0.2 m.

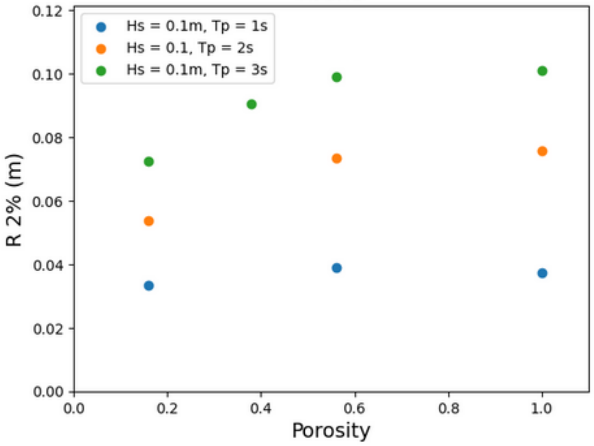

Figure 4 - Observed extreme wave runup (*R2%*) for three different wave conditions (colored markers) as function of porosity with structure placed at z = SWL.

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