WAVE TRANSFORMATION ACROSS MODULAR POROUS ARTIFICIAL REEFS

Jianjun Huang, The University of Western Australia, jianjun.huang@research.uwa.edu.au
Ryan J. Lowe, The University of Western Australia, ryan.lowe@uwa.edu.au
Marco Ghisalberti, The University of Western Australia, marco.ghisalberti@uwa.edu.au
Jeff E. Hansen, The University of Western Australia, jeff.hansen@uwa.edu.au

INTRODUCTION

Artificial reefs are often deployed for purposes of habitat creation, yet can also act as a nature-based solution for coastal protection due to their ability to attenuate wave energy. There is, however, a lack of quantitative understanding of wave transformation and dissipation over porous artificial reefs, and how this depends on reef geometry parameters and hydrodynamic conditions. This limited understanding has led to a lack of guidance on how to optimize reef design to maximize coastal protection benefits. Given that artificial reefs have some structural similarities to traditional submerged breakwaters, there may be similar wave transformation characteristics across these two structures. However, relative to submerged breakwaters that typically have relatively low porosities, artificial reefs are usually designed as highly porous structures for habitat provision. The increased porosity of an artificial reef has the potential to modify how waves transform across reefs and dissipate energy. In this study, physical modelling experiments were conducted in a wave flume with both an idealized cubic modular porous artificial reef and an impermeable reef, with the aim to examine how wave propagation, breaking and transmission characteristics differ over artificial reefs with high porosity.

METHODOLOGY

Experiments were conducted in a 54 m long by 1.5 m wide by 1.6 m tall wave flume at the University of Western Australia Coastal and Offshore Research Laboratory (CORL). An idealized porous artificial reef (PAR) was constructed with cubic modules that had a porosity of $n = 0.68$. An impermeable ($n = 0$) reef (IMAR) with the same dimensions was created by covering the porous reef with impermeable thin (3 mm) plates (Figure 1). With a geometric scaling of 1:8, two reefs were created with a 3.2 m crest length and 0.32 m reef height (h_r), and 1:1 sloping sections at both ends. In total 102 cases, both reefs were exposed to regular waves with incident wave heights H_0 = 0.05-0.25 m, periods T = 2.0-4.0 s, in water depths of h_0 = 0.32-0.56 m that created the crest depth of h_c=0-0.24 m (H_0=0.40-2.0 m, T=5.66-11.31 s, h_0=2.56-4.48 m, h_c=0-1.92 m at prototype). An array of wave gauges was used to measure water surface elevations from offshore to onshore of the reefs.

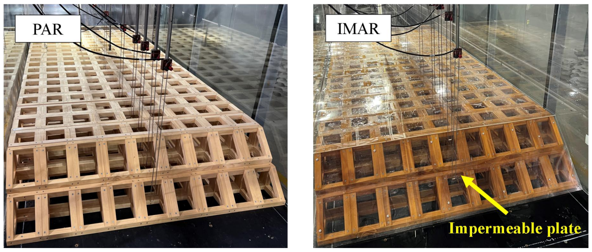

Figure 1 - Offshore view of cubic modular porous artificial reef (PAR) and impermeable artificial reef (IMAR).

RESULTS

All results that follow are expressed in laboratory (model) scale.Waves are dissipated by breaking and/or drag mechanisms when they propagate across the reefs. For the wave hydrodynamic condition of H_0=0.12 m, T=3.0 s and h_0=0.44 m, waves break on the IMAR, whereas they transform across the PAR without breaking (Figure 2). The breaking process results in a much more pronounced reduction in H / H_0 onshore of the IMAR (70% reduction) compared to the PAR (50% reduction). For the PAR, due to the absence of wave breaking, wave attenuation is due to drag forces exerted by the reef. The difference in wave breaking between the two reefs indicates that the PAR functions as having a much deeper 'effective crest depth' that accounts for the additional volume of fluid within the porous reef interior, given as $h_{c,e} = h_c + n \cdot h_r$, rather than h_c for the IMAR.

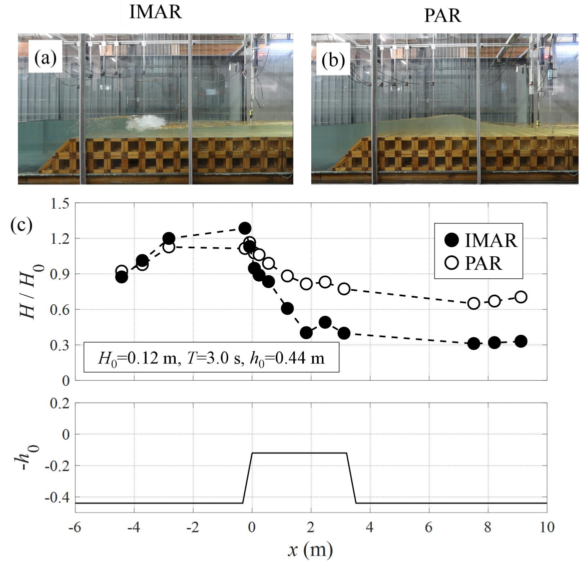

Figure 2 (a)-(b) Photos of wave transformation (with propagation from left to right) and (c) measured wave height variation over impermeable and porous artificial reefs.

The greater effective crest depth in PAR with high porosity can be further evident by comparison of wave celerities across each reef (Figure 3). A lagged cross-correlation analysis between different wave gauge surface elevation timeseries was used to define wave celerity variation across the reefs. In shallow water, the wave celerity C can be related to the local water depth.

While wave celerity in the IMAR is predicted by h_c, an underprediction can be observed across the PAR due to its high porosity. Relative to h_c, the use of $h_{c,e}$ can greatly improve the wave celerity predictions across the PAR (Figure 3).

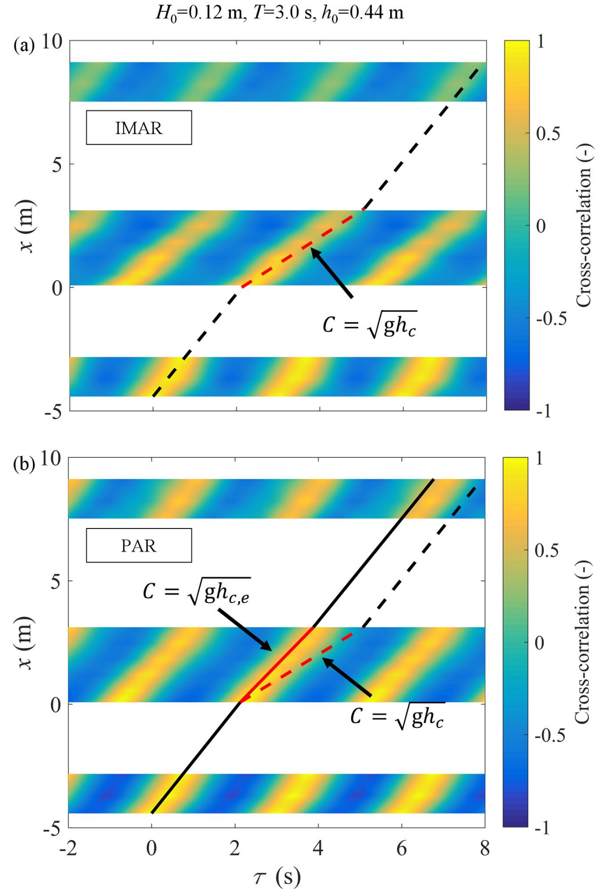

Figure 3 – A cross-correlation analysis between surface elevation measurements at different wave gauges for the (a) IMAR and (b) PAR respectively. The dashed lines indicate celerity predictions based on crest depth h_c , while the solid lines represented predictions based on the effective crest depth $h_{c,e}$.

The relative crest depth (the ratio of crest depth to wave height) of submerged structures is commonly regarded as a critical parameter controlling wave transmission over low-crested structures. Given the importance of the effective depth in controlling wave celerity, we investigate here the wave transmission coefficients K_t (defined as the ratio of onshore transmitted wave height to incident wave height) both for the IMAR and PAR as a function of the effective relative crest depth $h_{c,e}/H_0$ (Figure 4). Note that for IMAR $h_{c,e}$=h_c due to its impermeable characteristic. The effective relative crest depth controls wave transmission across these reefs. At each h_c/h_r, for $h_{c,e}/H_0 < 2.5$, K_t increases linearly; beyond this point, K_t remains approximately constant. With h_c/h_r increases, the constant K_t for $h_{c,e}/H_0 \geq 2.5$ increases.

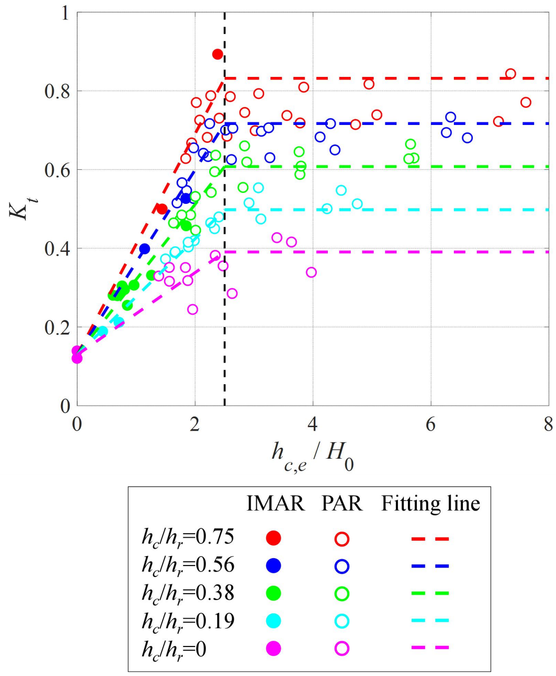

Figure 4 – Wave transmission coefficients (K_t) for both the IMAR and PAR as a function of the effective relative crest depth $h_{c,e}/H_0$. The vertical black dashed line denotes a critical transition value of $h_{c,e}/H_0$=2.5.

CONCLUSION

This work highlights the significant differences in wave transformation across porous and impermeable artificial reefs. The high porosity in artificial reefs can affect the effective depth of the reef, which can control the kinematic properties of waves, breaking and transmission characteristics. The use of an effective relative crest depth $h_{c,e}/H_0$ can explain differences in the characteristics of wave transformation and transmission across the different reefs for different hydrodynamic conditions. The improved understanding of wave transformation characteristic across the porous artificial reefs can contribute to the development of reef design guidelines for future nature-based coastal protection projects using artificial reef structures.