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.2024.747

EXPERIMENTAL OBSERVATIONS AND PREDICTION OF WAVE ATTENUATION USING A CORAL REEF RESTORATION APPROACH

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KEYWORDS: Coral Reef, Hydrodynamic Forces, Wave Attenuation, Physical Modelling, Coastal Engineering

1 INTRODUCTION

The large bottom roughness typical of coral reefs can be effective at reducing wave energy incident to coastlines through the dissipation induced by how wave-driven oscillatory flows interact with the roughness to determine hydrodynamic forces (i.e., drag and inertial). A physical understanding of these fluid-structure interaction processes is essential in designing coral reef restoration projects that can enhance coastal protection as well as deliver other beneficial ecosystem services, as a more sustainable alternative over conventional engineered structures (e.g. breakwaters and seawalls). In this study we quantify both wave attenuation and hydrodynamic forces across progressive stages of a coral reef restoration solution developed by Mars Sustainable Solutions. The Mars Assisted Reef Restoration System (MARRS) involves propagating coral fragments onto hexagonal steel structures called Reef Stars, which are connected in tessellating patterns over degraded reef flats (Figure 1).

Figure 1. Array of MARRS Reef Stars shortly after being deployed (left) and then during restoration (right).

2 EXPERIMENTAL TESTING

Experimental testing was undertaken at the University of Western Australia Coastal and Offshore Research Laboratory (CORLab) in a 54 m long, 1.5 m wide and 1.6 m high wave flume. A piston type wave maker with active absorption was used to generate regular cnoidal waves in the flume given the application of this study to shallow to intermediate depths in the coastal zone. Testing was conducted at 1:3 geometric scale with an 8-m-wide reef star canopy (equivalent to 24 m at prototype scale), consisting of 240 model reef stars, installed in the wave flume. Three different coral covers were attached to the reef star using 3D-printed branching and plating coral colonies (Figure 2). Water surface elevations were measured at 16 locations across the reef canopy to quantify rates of wave dissipation for a range of different wave periods and water depths at each coral cover. Additionally, horizontal and vertical force time series were obtained for a representative reef star located within the canopy during each test using a 3-axis loadcell. Vertical profiles of the horizontal flow velocity were then taken for a subset of conditions to quantify flow attenuation with the canopy.

Figure 2. Model scale Reef Star canopy with the largest coral cover attached in plan view (left) and looking down the canopy (right) when installed in the wave flume.

3 RESULTS

Wave attenuation measured across the reef star canopy increased with coral cover, wave height and at shallower water depths (e.g. Figure 3). The attenuation of wave induced flows within the canopy similarly increased with coral cover as well as the wave orbital excursion length. The measured force time series were well parameterised through the Morison equation by drag and inertia coefficients once accounting for variations in flow attenuation within the canopy as well as using an appropriate definition of the canopy frontal area across the different coral covers tested. The dissipation of wave energy due to the rate of work done by the hydrodynamic forces was then calculated directly using the synchronised velocity and force time series, which agreed well with dissipation inferred from wave height attenuation. Finally, we use the results to develop predictive formulations to quantify wave attenuation over arbitrary coral reef canopies as a function of coral canopy properties, wave and water depth conditions. This model can be used to broaden the design of coral restoration projects and incorporate coastal protection across different target sites with varying wave conditions and reef depths, as well as over varying time scales of restoration and coral growth.

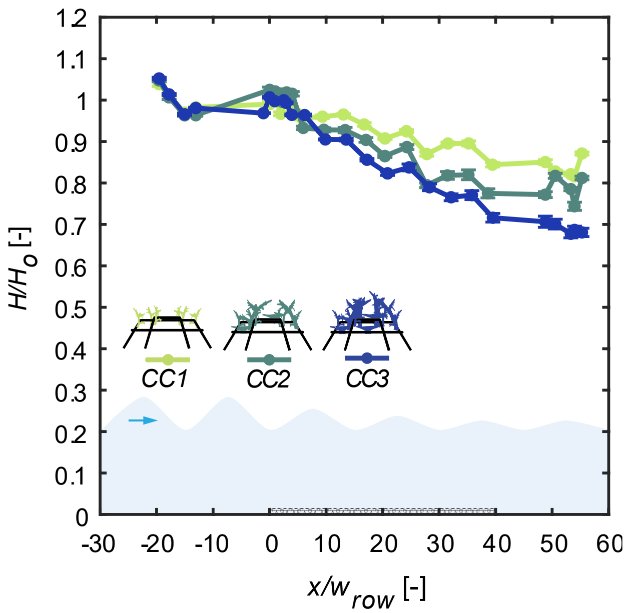

Figure 3. Example profiles of the measured wave height (*H*) across the canopy of reef stars normalised by the offshore wave height (*H*$_o$) at locations defined by the distance from the leading edge of the reef in the direction of wave propagation (*x*) normalised by the width of one row of reef stars (*w*$_{row}$). The mean profiles are for the repeat model scale 2.5s period cases tested at each coral cover (CC) across all wave heights with the error bars indicating the standard error of the mean.