

EFFECTIVENESS OF CORAL REEF RESTORATION IN WAVE ATTENUATION APPLICATIONS

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INTRODUCTION

Coral reefs are not only one of the most biologically diverse ecosystems, but they also deliver critical ecosystem services to millions of people worldwide, for example coastal hazard mitigation. Extreme surface waves associated with storm systems generate coastal flooding and erosion that can impact coastal populations and infrastructure. The large roughness of healthy coral reefs has the potential to significantly attenuate this wave energy prior to reaching the shoreline through the drag forces that coral roughness exerts on the water column. The magnitude of these drag forces is dependent on how the complex geometries of corals interact with wave-driven oscillatory flows. This interaction is most commonly described both physically and numerically with idealised models of canopies, typically using arrays of submerged cylinders that lack the natural complexity of coral reef roughness.

A physical modelling approach with a canopy of complex coral shapes is needed to sufficiently investigate the properties of the canopy which best represent their interaction with wave-driven oscillatory flows resulting in the attenuation of wave energy. In this study we investigated the performance of a coral reef restoration approach developed by MARS Inc. to attenuate wave energy across a range of incident wave conditions, water depths and coral cover.

EXPERIMENTAL TESTING

A detailed physical modelling study was conducted to investigate wave attenuation over an 8 m long and 1.5 m wide reef of 1:3 scaled MARS Inc. reef stars within a 54 m long and 1.5 m wide wave flume at the University of Western Australia Coastal and Offshore Engineering Laboratory (Figure 1). Wave heights were measured at multiple locations along the reef to quantify rates of wave attenuation by the coral canopy for a range of incident wave conditions, mean water levels and three different coral covers (representing temporal changes in coral reef development). The different coral covers were constructed using 3D printed and casted fragments of different morphologies. In addition, horizontal and vertical force time series were obtained for each coral cover on a representative reef star in isolation and then within the reef itself, using a 3-axis load cell.

The composition of the three different coral covers included; Coral Cover 1 (CC1) with 6 small coral fragments; Coral Cover 2 (CC2) with 6 small coral fragments, 2 large branching colonies and 2 large plating colonies; and Coral Cover 3 (CC3) with 6 small coral fragments, 4 large branching colonies and 4 large plating colonies (Figure 2)



Figure 1 - 8m long and 1.5m wide reef of MARS Inc. reef stars with 3D Printed corals attached within the University of Western Australia Coastal and Offshore Engineering Laboratory wave flume

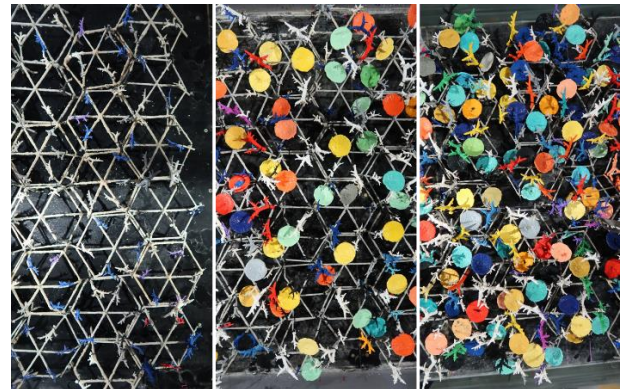


Figure 2 -Plan view examples of Coral cover 1 (left), Coral Cover 2 (middle) and Coral Cover 3 tested in this study.

RESULTS

Wave attenuation across the reef was greatest during wave conditions with shorter wave period as well as larger incident wave height and shallower water depth. Attenuation was most sensitive to variations in the incident wave height in comparison to wave period. This is demonstrated in Figure 3 below with the influence of wave period investigated across 1.5 s - 5.5 s at a fixed wave height of 0.1 m at scale, and the influence of wave height investigated across 0.05 m - 0.15 m with a fixed wave period of 2.5 s at scale. The coral cover (*CC2*) and water depth (0.35 m at scale) are fixed.

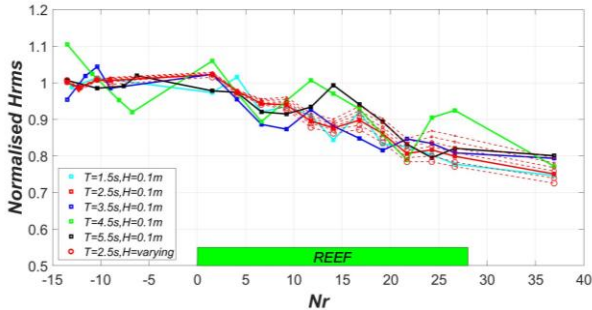


Figure 3 - Normalised root mean squared wave height (*Hrms*) attenuation across the reef at different wave periods as well as wave heights (larger circle equates to a larger incident wave height). *Nr* is a measure of distance being the number of rows of scaled MARS Inc. reef stars within the flume from the leading edge of the reef.

As the coral cover increased so did the overall wave attenuation (Figure 4). The load cell data enabled us to decompose the hydrodynamic forces (drag and inertial) and therefore relate differences in attenuation to the increase in drag force dissipation which is directly proportional to the increased normalised frontal area of the coral cover. The drag coefficient *Cd* of all three coral covers collapsed reasonably well when plotted against the Keulegan-Carpenter number, where the coral cover was parameterised with a characteristic length scale equal to the ratio of coral volume to frontal area (Figure 5).

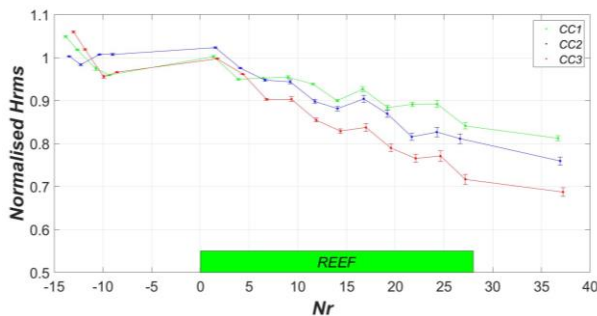


Figure 4 - Normalised root mean squared wave height (*Hrms*) attenuation across the reef at different coral covers. The error bars are representative of the standard error of the mean due to variations in incident wave height at a period of 2.5 s at scale. *Nr* is a measure of distance being the number of rows of scaled MARS Inc. reef stars within the flume from the leading edge of the reef.

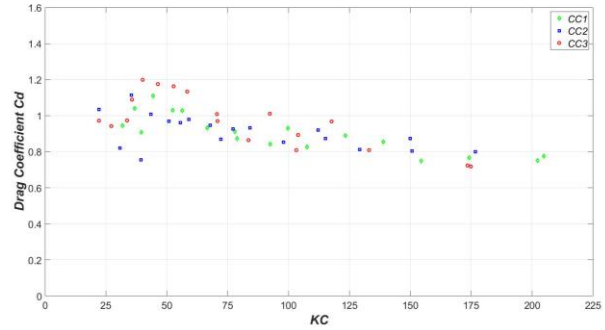


Figure 5 - The drag force coefficient *Cd* of each coral cover parameterised by the Keulegan-Carpenter number *KC*

SUMMARY

Using the data collectively we parameterise the drag forces due to complex coral canopies in oscillatory flow as well as develop and validate a model to predict attenuation over reef structures. This model can be used to broaden the design of coral restoration, including using reef structures for coastal protection at different sites with varying wave conditions and reef depths, as well as over varying time scales of restoration and coral growth.