

UNDERSTANDING THE WAVE ATTENUATION CAPACITY OF A VEGETATED FLOATING CANOPY

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INTRODUCTION

Nature-based solutions (NBS) are being explored as a sustainable, adaptable option for coastal protection in urban areas to combat rising sea levels and intensifying extreme storms without relying on traditional grey infrastructure (e.g., groins and seawalls; [Temmerman et al., 2013; Zhu et al., 2020; Hopkins et al., 2022; Landmann et al., 2022]). However, NBS require more rigorous field and laboratory datasets to both quantify their efficacy as protection against coastal flooding and to assist in identifying important design parameters [Zhu et al., 2020; Hopkins et al., 2022; Landmann et al., 2022]. Artificial floating islands (AFI) are variations of floating breakwaters that provide deployment flexibility for developed urban coastlines and have additional potential environmental benefits including the removal of pollutants and nitrogen [Chang et al., 2012; Barco & Borin, 2020]. This study evaluates the performance of one engineered AFI, named the Emerald Tutu, which utilizes a network of interconnected and moored floating vegetated mats to attenuate wave energy. Using a dataset collected at the Oregon State University O.H. Hinsdale Large Wave Flume (OHLWF), the two primary objectives of this study are to: 1.) determine the wave attenuation capacity of a single AFI prototype, and 2.) determine the pathways for wave energy dissipation around a single AFI prototype.

METHODS

Over the Summer of 2022, we conducted lab experiments at the OHLWF to determine how variations of a full-scale (1.7 m diameter, 0.84 m thickness) AFI prototype responded to regular wave conditions. The prototype was constructed of canvas and stuffed with woodchips for density and foam blocks for buoyancy. We tested five different configurations of the prototype with combinations of extra weight to increase the draft, extra material on the bottom to increase roughness, and added strands of flexible plastic to represent seaweed growth on the bottom. We placed four wave gauges in front of, and four behind, the prototype to collect wave height data to quantify the wave reduction for each trial (Figure 1). We ran several wave conditions, including wave heights of 0.2 m, 0.3 m, and 0.35 m and wave periods ranging from 2 s to 3 s with resolution of 0.2 s and one case with 4 s.

To supplement the wave flume dataset and to investigate the flow profiles around the prototype and quantify generated vorticity, we developed a computational fluid dynamics (CFD) model of the OHLWF experiment [OpenFOAM; Weller et al., 1998].

Specifically, we used an OpenFOAM add-on called olaFlow to simulate wave flume conditions [Higuera, 2018]. olaFlow contains a solver, olaDyMFlow, capable of mimicking a piston wavemaker. It is adept at dynamic mesh refinement and mesh motion to account for floating bodies, which makes olaFlow an optimal tool for simulating wave conditions and their impact on the AFI in our OSU lab tests [Higuera, 2018; Li et al., 2022].

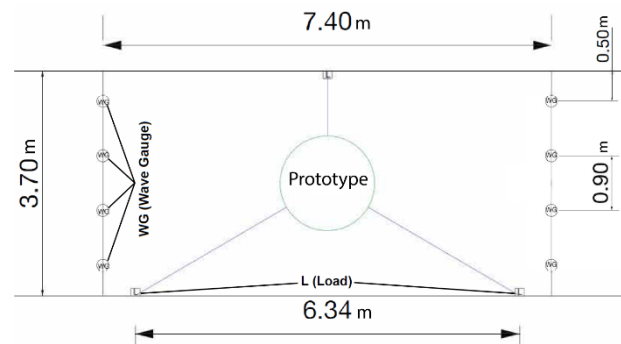


Figure 1 - Top view of experimental setup in the OSULWF with the Emerald Tutu AFI prototype (center), anchored to load cells on the walls at 3 points. The figure shows 8 wave gauges, 4 offshore (left) and four onshore (right). All distances (in meters) are labeled for the instrument locations.

We utilized the blockMesh tool to create an empty wave flume mesh. We used Autodesk Fusion 360 to design the AFI prototypes, and then used the snappyHexMesh tool to create a dynamic overset mesh that was merged with the empty wave flume mesh to incorporate the AFI motion during the trials (Figure 2).

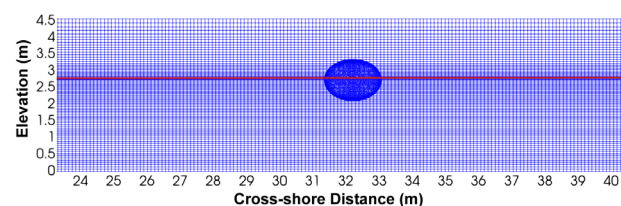


Figure 2 - Side view of the OHLWF OpenFOAM mesh using the blockMesh tool with a bare AFI prototype incorporated using snappyHexMesh (ellipsoidal shape centered at 32 m). The red line denotes the still water level at 2.74 m.

We assessed model accuracy by comparing free surface elevation model outputs to measurements from the wave gauges in the lab experiment. Following validation, we

used the model to assess how variations of the AFI prototype configurations altered flow profiles and dissipated energy (e.g., differences in generated turbulent kinetic energy and vorticity). We also used the model to run additional wave conditions that weren't tested in the wave flume (e.g., wave heights between 0.35 m and 0.5 m and wave periods between 3 s and 4 s), as well as expanding on the AFI prototype parameters tested (such as changing the diameter of the AFI, increasing the draft in stages).

RESULTS

Comparisons of wave measurements from the lab flume experiment before and after waves encounter the prototype demonstrate a slight increase in wave reduction with increases in wave steepness (defined as wave height/wavelength) (Figure 3). This indicates that the AFI prototypes are more efficient at attenuating shorter wavelengths. Additionally, the prototypes that incorporate vegetation analogues (e.g., seaweed and enhanced roughness) attenuate more wave energy than the AFI prototype with no seaweed, no weight, and normal roughness. This suggests that a combination of submerged vegetation, enhanced surface roughness, and increased draft increase AFI prototype wave energy dissipation.

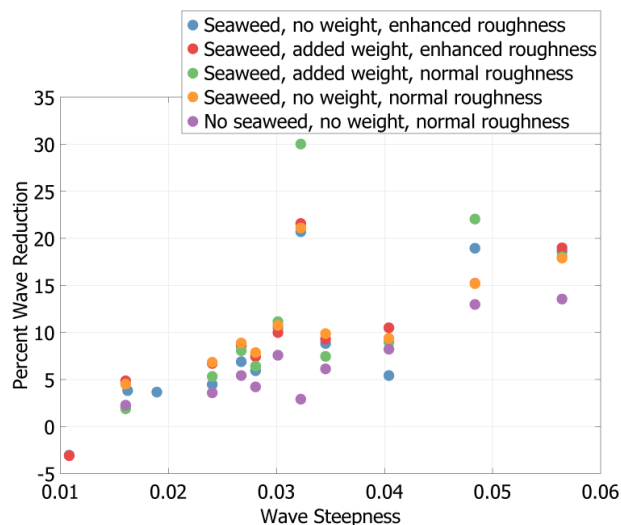


Figure 3 - Wave steepness versus wave reduction for different configurations of AFI prototypes. The different configurations include: seaweed analogues (seaweed) with standard draft (no weight) and biofoul wrapped around the bottom of the prototype (enhanced roughness) [blue], seaweed with twice the draft (added weight) and enhanced roughness [red], seaweed with added weight and normal roughness [green], seaweed with no weight and normal roughness [orange], and a unit without seaweed, no weight, and normal roughness [purple].

We use the developed OpenFOAM model to evaluate AFI prototype performance against additional wave scenarios and AFI prototype configurations. Using model outputs of velocity, turbulent kinematic energy, turbulent dissipation, and turbulent viscosity, we are able to study the mechanisms by which the AFI

prototypes dissipate energy and alter the velocity field. The main pathways for energy dissipation with the single prototype, and how this might expand to a larger network of these AFI units, are discussed.

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