LARGE SCALE LABORATORY OBSERVATIONS OF WAVE FORCE REDUCTION ON COASTAL BUILDINGS BY AN IDEALIZED MANGROVE FOREST

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INTRODUCTION

As coastal communities face increasing chronic and acute hazards, nature-based coastal engineering solutions have experienced a rapid growth in popularity and interest. Recent works on this topic have shown that this “green infrastructure” may be effective at mitigating coastal hazards and thus have potential as sustainable adaptation alternatives to traditional engineering solutions such as seawalls and breakwaters. However, the amount of protection that green infrastructure can provide has yet to be quantified broadly. The purpose of this study is to quantify the wave force attenuation on coastal buildings by an idealized mangrove forest at a prototype scale and provide guidance to engineers in the design and management of mangrove forests to reduce damage due to storm waves over moderate cross-shore distances.

LABORATORY INVESTIGATION

For our study a 1:1 scale physical model of a red mangrove forest (*Rhizophora mangle*) was built in the Large Wave Flume at the O.H. Hinsdale Wave Research Laboratory at Oregon State University (Figure 1). A test wall was placed behind the model mangrove forest, representing a coastal building. Regular and random waves at four different water depths were generated by a piston-type wavemaker, propagated through the forest, and impacted the test wall on which the wave-generated pressures were measured. Wave heights before and after the model forest were used to compare empirical wave force equations with the integrated wave pressures (forces) and assess attenuation caused by the mangrove forest at two different stem densities. The model tree and forest parameters were determined based off existing studies (Ohira et al., 2013) that defined and quantified the characteristic morphological parameters of a mangrove forest such as average diameter at breast height, average diameter of the roots and the stem density of the forest in trees per meter squared. The forest specimens were constructed using commercially available materials using polyvinyl chloride (PVC) pipe for the trunks and cross-linked polyethylene (PEX) for the prop roots (Figure 2). Two forest densities and a control case with no trees were tested. A field study was also completed as part of this experiment, which examined six locations with both undisturbed and restored forests, near the Port St. Lucie Inlet in Jupiter, Florida.

Mangrove effects on wave-induced load reduction were assessed by measuring the wave-induced pressures on a vertical wall positioned 7 m leeward of the mangrove forest section. The vertical wall, made of a structural aluminum frame, was 3.66 m wide and 3.66 m high, and secured and sealed to the concrete sides of the flume using iron clips, 2.54 cm bolts, rubber bands and heavy-duty tape. The wall was fitted with PDCR 1830 and 830 pressures gauges along the centerline (Figure 3).

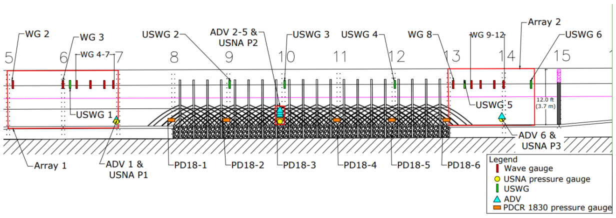

Figure 1 - Schematic detailed profile of the mangrove test section at the center, showing the locations of instrumentation and test wall.

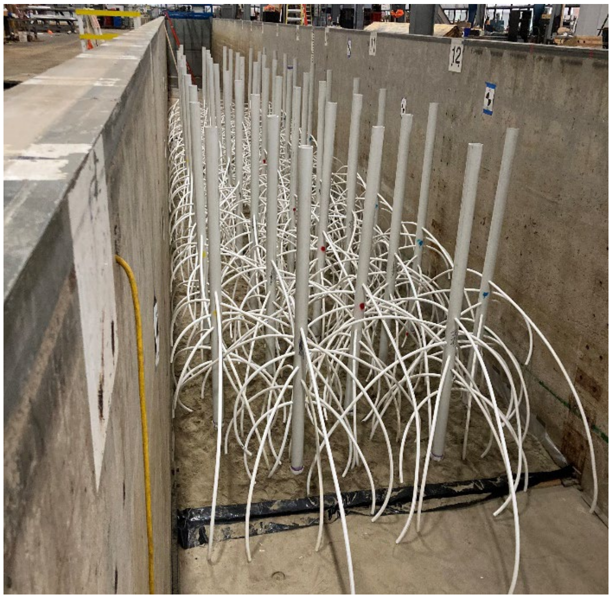

Figure 2 - High-density mangrove forest test section looking offshore. Wave machine is seen in the background.

Hydrodynamics during the experiments were measured with resistive and ultrasonic wave gauges (WG and USWG, respectively), acoustic Doppler velocimeters (ADVs), and submerged PDCR1830 pressure gauges, distributed on the seaside, leeside and along the mangrove tree forest.

A total of 23 regular, 11 random and 6 transient (tsunami-like) wave cases have been executed, with different incident wave height and period conditions (*H,*

T for regular waves, H_{m0} and T_p for random waves), and 4 water depths (h_v). The wave heights and periods were varied within the four water depth conditions to obtain six equivalent non-dimensional regular wave cases (20 waves) and three non-dimensional random wave conditions (JONSWAP γ=3.3, 300 waves), as shown in Figure 4.

Figure 3 - Leeside of the vertical aluminum wall placed in the flume. Red clips fix the wall to the flume concrete sides. Note the location of the pressure gauges installed along the centerline.

DATA ANALYSIS

Incident and reflected waves were estimated on Arrays 1 and 2 (seaward and leeward of the mangrove tree forest) following Zelt and Skielbreia (1992) for linear waves and Andersen et al. (2017) for nonlinear waves. Our experiments found that as waves propagate through the mangroves, the wave heights are reduced, and the wave periods remain relatively constant. Additionally, the hydrodynamic pressures underneath the wave are not significantly changed.

Wave forces on the wall are computed by the vertical integration of the dynamic pressure time series measured along the centerline, yielding a force time series of horizontal forces acting on the wall (Figure 6). Further analysis provides the ensemble average force time series and its corresponding uncertainty for regular waves, as well as the full probability distribution of wave forces acting on the wall for random waves. Moreover, peak identification of wave forces has also been used to find the elapsed time where the pressure distribution yields the design force, and the distribution has been compared with standard methodologies (e.g. Goda, 2010). This procedure has been performed for the peak horizontal positive as well as negative forces, extending the classical design methods to consider pushing as well as pulling forces on coastal structures.

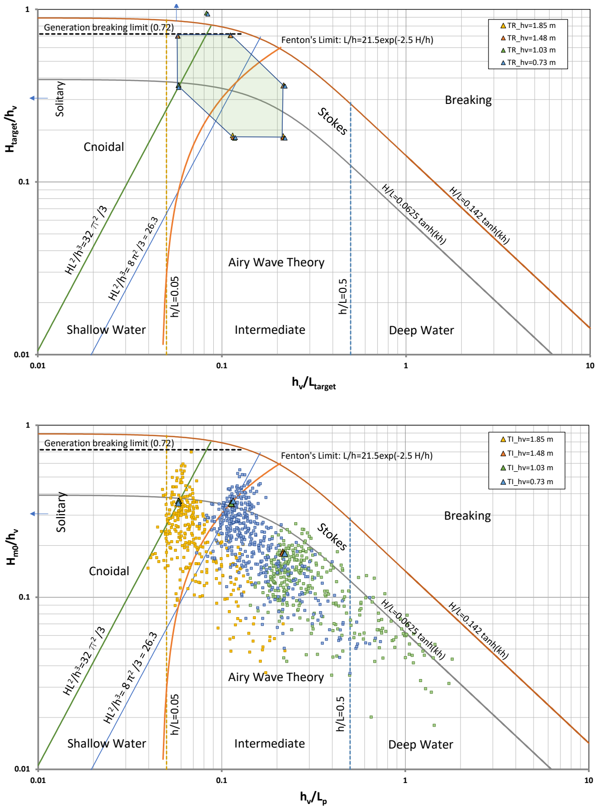

Figure 4 - Wave conditions tested expressed in dimensionless form in terms of height (H/h) and depth (h/L). (Top) Regular waves, (Bottom) Random waves.

Figure 5 shows an example of waves interacting with the high-density mangrove forest and test wall for a local water depth h_v=1.03 m.

Figure 5 - Testing wave-mangrove-wall interaction for the high-density forest, regular waves and a local water depth of h_v=1.03 m.

DISCUSSION

With these results, our study shows that engineers can model the wave heights with the drag coefficients quantified in Kelty et al. (2022) and then use the new wave heights as an input into existing empirical models for wave-induced forces on coastal structures. Our study found that the underlying assumptions upon which these existing works were built hold true even with the presence of an offshore mangrove forest, showing that the existing wave forces estimation tools and works investigating wave height attenuation from mangroves can be combined and used in the design of green infrastructure engineering solutions.

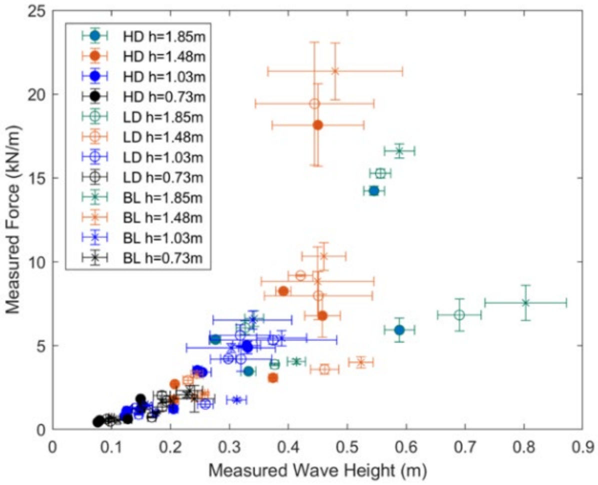

Figure 6 - Wave force reduction by mangroves. Star symbols are baseline case (no mangrove). Open and closed symbols show the force reduction for low and high-density vegetation.

The conference presentation will focus on the description of the experimental design, instrumentation, testing, and data analysis. Preliminary results include comparisons of measured forces with existing formulas for engineering design based on the work of Goda (2010) and Cuomo et al. (2010).

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