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QUANTIFYING OVERTOPPING PERFORMANCE OF GREEN-GRAY HYBRID INFRASTRUCTURE

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1 INTRODUCTION

Wave overtopping of shoreline infrastructure can lead to significant flooding and consequent loss of life, impairment of transportation systems, and ecological damage. Coastal defenses against overtopping traditionally include hard structures, such as seawalls and revetments, and design guidelines for these structures, *e.g.*, the EurOtop manual (Van der Meer *et al*., 2018), have been developed from empirical studies of overtopping. Recently, natural and nature-based features (NNBF) including mangroves, wetlands, reefs, and other systems have gained attention as alternatives to conventional engineered coastal protection systems. Field observations have identified the potential of emergent vegetation, particularly mangrove forests, to mitigate damage during extreme coastal flood events (Alongi, 2008; Tomiczek *et al*., 2020). However, there is a lack of research on engineering NNBF systems to achieve specific design requirements for overtopping protection.

Hybrid or multi-tiered approaches to shoreline protection have also been proposed, where natural ("green") features are combined with hardened ("gray") infrastructure to protect coastlines and near-coast assets from erosion and/or flood-based hazards. For overtopping mitigation, hybrid designs can add the performance provided by emergent vegetation to the services of a revetment or a wall. It is unknown whether the green and gray features in a hybrid system perform independently and can be considered as separate design elements, or if the inclusion of one feature affects the performance of the other such that the hybrid system must be considered as a single, complex design element. This study constructed a large-scale physical model to investigate the overtopping performance of a hybrid system with an idealized *Rhizophora* mangrove forest seaward of a revetment abutting a vertical wall compared to that performance of the wall fronted by the revetment only, the wall fronted by vegetation only, and the wall alone.

2 METHODS

2.1 Model Design

The study took place during the summer of 2023 in the Large Wave Flume at the O.H. Hinsdale Wave Research Laboratory in Oregon State University. A vertical wall representing a seawall or bulkhead vulnerable to overtopping was constructed 62 m from the piston-type wavemaker. A rock revetment with a 1:1.5 slope was placed adjacent to the wall. The crest of the revetment was approximately even with the top of the wall. The model mangroves were constructed with PVC and PEX pipe as tree trunks with emergent prop roots. The tested model configurations and the placement of the mangroves and the revetment in the flume are shown in Figure 1. The model was constructed at a 1:2.1 geometric scale to prototype.

2.2 Hydrodynamic Conditions

For all tests, the water depth at the wall was 0.76 m, giving a freeboard of 0.09 m. The depth was constant from the seaward boundary of the forest to the wall. Tested wave conditions included random and regular waves with significant wave heights of 0.13 – 0.23 m and peak periods of 3 – 8 s. Double-peaked wave spectra, with a low-frequency (8 s) component and a high-frequency (3 s) component were additionally tested, and the resulting overtopping rates were compared to the sum of the tests for the single-peaked component spectra. Tsunami-like transient waves were also tested.

2.3 Measurement and Instrumentation

Surface-piercing resistance wave gauges and pressure gauges were placed at regular intervals along one side of the flume in the region of the mangrove forest to measure the wave transformation through the vegetation or over the bare bed. An ADV was installed at each end of the mangrove forest. Offshore of the mangrove forest, an array of surface-piercing wave gauges was placed so that the incident and reflected waves could be separated. At the shoreward boundary of the system, a 1-m wide tray was positioned at the center of the wall to direct discharged water downward into a catchment basin. Water overtopping the wall on either side of the tray was allowed to flow under and around the basin. Three pumps were used to return overtopped water to the flume during and after the tests to maintain a constant still water level throughout the experiment. Four load cells were positioned underneath the basin to continuously weigh the water in the basin over the test duration, and a surface-piercing wave gauge was placed against the inside of the basin to corroborate the results calculated from the load cells.

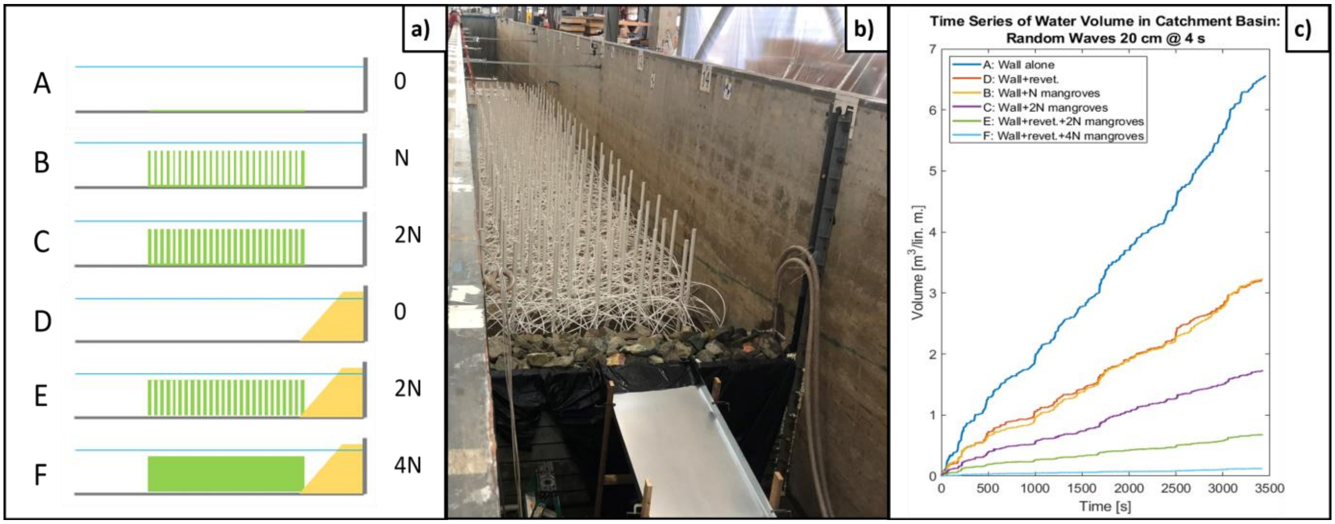

Figure 1. Physical model of the hybrid system. Configurations are listed in (a) with the mangrove density of each system indicated by *N*, the number of mangrove trees per unit area. The system with the 4N forest and revetment is shown in the photograph (b). A comparison of the overtopping volume time series for all configurations given a particular wave condition is shown in (c).

3 CONCLUSIONS

The performance of the protection features was defined as the percentage reduction in overtopping relative to that measured for the vertical wall alone. The mangroves and the revetment performed independently. The measured overtopping performance of the hybrid system (mangroves + revetment) was the sum of the performance of the mangroves and the revetment minus the intersection (product) of the performance of the mangrove and the revetment. An associated indicator of independent performance was that when the wall-alone or wall + revetment configurations were considered as two alternative "gray" systems, the 2N mangrove forest reduced the overtopping of each by a near-identical percentage. The relationship between overtopping discharge rate and vegetation density was consistent with exponential decay. For all configurations, the discharge rates for the double-peaked random wave tests were greater than the sums of the rates for the wave tests performed with the single-peaked components of the double-peaked spectra. The conference presentation will include a discussion of the complete analysis and final results.

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