

LARGE SCALE PHYSICAL MODEL EXPERIMENTS OF HYBRID GREEN-GRAY STRUCTURE PERFORMANCE FOR OVERTOPPING MITIGATION

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INTRODUCTION

Coastal regions across the globe are facing grand challenges associated with climate change, sea level rise, and increasing coastal flood hazard conditions. Effects of these threats are exacerbated by rising population densities and as aging infrastructure reaches or exceeds its design life. Therefore, finding sustainable, resilient adaptation alternatives is paramount to protecting coastlines and nearshore assets.

Recent interest in Nature-based Solutions (NbS), also termed Engineering With Nature (EWN), Building With Nature (BWN), “green” infrastructure, among others, has exploded in recent years, along with a growing body of observational evidence demonstrating these natural systems’ ability to attenuate wave heights, mitigate erosion, and reduce damages to inland infrastructure under operational and acute hazard conditions. Such solutions have been promoted as alternative or complementary designs to conventional “grey” infrastructure owing to their ability to provide engineering, environmental, and economic benefits. However, the performance of these systems remains uncertain, particularly considering:

- (1) What are the effects resulting from wave height attenuation through NbS on engineering performance metrics such as overtopping reduction?**
- (2) Can the performance of emergent vegetation be combined linearly with conventional coastal engineering structures such as revetments and bulkheads?**

This project presents the results of a large-scale (1:2) physical model experiment at the O.H. Hinsdale Wave Research Laboratory investigating the performance of a combined mangrove + bulkhead design and mangrove + revetment design to mitigate overtopping under a range of incident wave conditions. Multiple mangrove forest densities were considered. Subsequent tests were performed at the United States Naval Academy (USNA) at a 1:8 geometric scale to investigate potential scaling effects for reduced-scale experiments.

LARGE-SCALE PHYSICAL MODEL EXPERIMENTS

The 1:2 scale physical model was constructed in the Large Wave Flume at Oregon State University (Fig. 1). Mangrove trunk-prop root specimens constructed by Bryant et al. (2022) to test wave height attenuation were leveraged for this study; the specimens were constructed of 0.06 m diameter polyvinyl chloride (PVC) trunks [0.12 m full scale] with seven root pairs made of 0.016 m [0.032 m] PEX tubing.



Figure 1 - Photograph of mangrove installation for physical model experiments.

Seven configurations were tested in experiments, as shown in Fig. 2. A vertical wall was constructed 62 m from the piston-type wavemaker; fronting this wall, green and gray shore protection treatments were implemented to measure individual and combined effects of overtopping mitigation. A rock revetment with a 1:1.5 slope was constructed adjacent to the wall (Configuration A), and a 20-m mangrove forest was positioned seaward of the revetment. High-density (3.21 trees/m² [0.80 trees/m² full scale]) and medium-density (1.61 trees/m² [0.40 trees/m²]) forests were tested in combination with the rock revetment (Configurations B and C, respectively), before the revetment was removed to investigate the performance of the mangrove + bulkhead system. Medium- and low- (0.80 trees/m² [0.20 trees/m²]) density forests were considered in combination with the bulkhead (Configurations D and E, respectively), before the bulkhead-only configuration was tested (Configuration F). A baseline configuration (G) was tested to evaluate wave dissipation over the flume bottom and side walls.

For all configurations, a constant still water depth of 0.76 m [1.52 m full scale] within the section was considered, giving a freeboard of 0.09 m [0.18 m] at the wall. Regular and irregular wave conditions were tested, with significant wave heights between 0.13 m and 0.30 m [0.26 m and 0.60 m] and peak periods between 3 s and 8 s [4.2 s and 11.3 s]. Double-peaked wave spectra were also considered, with low- and high-frequency components of 8 s and 3 s, respectively.

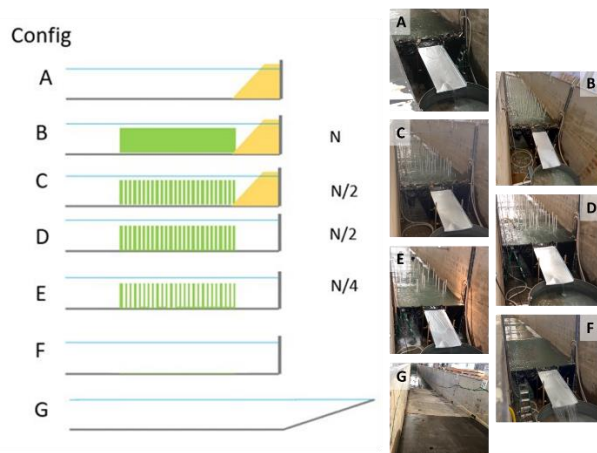


Figure 2 - Schematic profile views and photographs showing configurations tested in large-scale experiments: A- revetment-only; B- revetment + high-density mangroves; C- revetment + medium-density mangroves; D- bulkhead + medium-density mangroves; E- bulkhead + low-density mangroves; F- bulkhead-only; G- baseline for measuring dissipation due to flume bottom and sidewalls.

Overtopping was measured using a 1-m wide tray that directed overtopping water into a catchment basin instrumented with four load cells and a wire resistance wave gauge. Three pumps were used to return overtopped water to the flume during and after tests to maintain a constant still water level throughout trials. Wire resistance wave gauges and pressure gauges were installed along the length of the flume seaward of and within the mangrove forest section to separate incident and reflected wave conditions and to evaluate wave transformation through the forest. Wave orbital velocities were measured as well with Vectrino ADVs seaward of the mangrove forest and at the bulkhead toe.

PRELIMINARY RESULTS

Example time series of wave overtopping results for each configuration are shown in Fig. 3 for random waves with a target significant wave height of 24 cm and peak period of 4 s. As seen in the figure, the greatest overtopping was observed for the wall-only configuration. The presence of a medium- or high-density mangrove forest reduced overtopping compared to the wall-only, revetment-only, and wall + low density mangrove configurations, as expected. Overtopping by waves with longer peak periods seemed to be affected less by the mangrove system compared to overtopping by waves with shorter peak periods in single-peaked random wave tests. For all configurations, the discharge rates for the double-peaked random wave tests are greater than the sums of the rates for the wave tests performed with the single-peaked components of the double-peaked spectra.

REDUCED-SCALE EXPERIMENTS

A subset of experiments was repeated at a 1:8 geometric scale in a 0.61-m wide flume in the Naval Academy Hydromechanics Laboratory at USNA. Mangrove specimen replicas were constructed of brass rods and galvanized steel wire and installed within the flume.

Experiments focused on regular wave trials and mangrove + bulkhead configurations, and total overtopping volumes were measured at the end of each trial using a graduated cylinder. Experimental data will be compared to results from large-scale tests to identify any scaling effects introduced as specimens are scaled down from large-scale to increasingly reduced geometric scales.

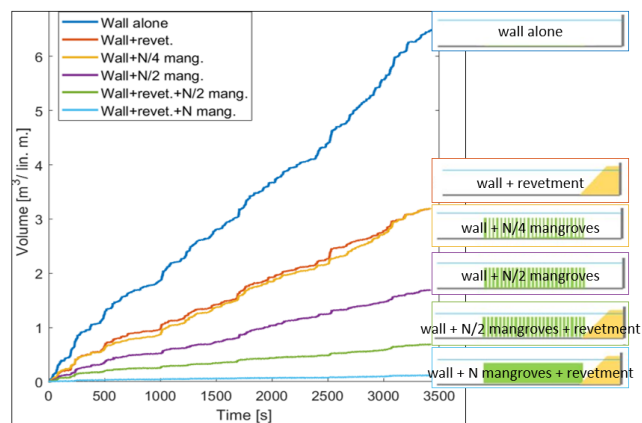


Figure 3 - Example time series of overtopping for configurations tested under irregular waves with target significant wave height 24 cm and peak period 4 s.

CONFERENCE PRESENTATION

The conference presentation will include a discussion of the complete analysis and the final results, comparing overtopping rates and volumes for each configuration. Specifically, we will investigate whether the combination of green and gray infrastructure can be linearly evaluated to predict overtopping reduction by mangrove forests. Existing formulations for wave height attenuation (Mendez and Losada, 2004) will be evaluated in sequence with established overtopping prediction methods (*i.e.*, Eurotop, 2018) and compared to measured values. Overtopping volumes measured in the reduced-scale physical model will also be compared to those measured in the 1:2 scale model to assess the potential for scale effects in reduced-scale experiments and precautions needed when interpreting results.

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