Science and Mathematics Academy

Mitigating tsunami impacts on coastal communities with breakwaters

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Introduction

Tsunamis are generated by large water column displacement via earthquakes, landslides, and other events. Tsunamis have the highest mortality rate of any natural disaster and leave behind immense property damage and millions of dollars in repair costs (National Oceanic and Atmospheric Administration, 2024).

Breakwaters are off-shore structures intended to diminish wave energy against beaches. During the 2011 Tohoku tsunami event, the composite emerged breakwaters displayed a reduction in tsunami wave height (Sugano et al., 2014). Tsunami wave height directly correlates to community damage; therefore, reduction in wave height may be a critical factor in mitigating the detrimental effects of tsunamis. In order to quantify the degree of damage from tsunamis, The New Tsunami Intensity Scale (ITIS-2012) was developed as a rubric depicting varying degrees of damage from a tsunami and provides an Intensity Rating of one to twelve, twelve being complete destruction (Lekkas et al., 2013).

The goal of this project was to design breakwater mechanisms and test the effect on wave height and intensity rating at the shoreline via tsunami wave generation model prototype.

Materials and Methods

Specific design characteristics regarding the wave generation model are presented in Table 1. The wave generation model (Fig. 1) used a pulley system and release shackles to drop a weight into the tank and trigger the tsunami wave event.

Table 1 (right): Components that comprise the wave generation model with their respective location related to the tank, materials, and function and materials for breakwater construction.

Component	Tank Location	Materials	Function
Seabed	Inside	Sand, glue, sealant	Represent the incline of land up to a beach
Community	Inside	PLA plastic	Demonstrate damage to a community
Crane base	Outside	Wood	Provide support and structural stability
Upper crane	Outside	Wood, pulleys, release shackles, and paracord	Support the vertical movement the elevator
Counterweight	Outside	Wood, dowel, weight, and carabiner	Suspend the elevator prior to release
Elevator	Outside	Wood	Trigger the tsunami event

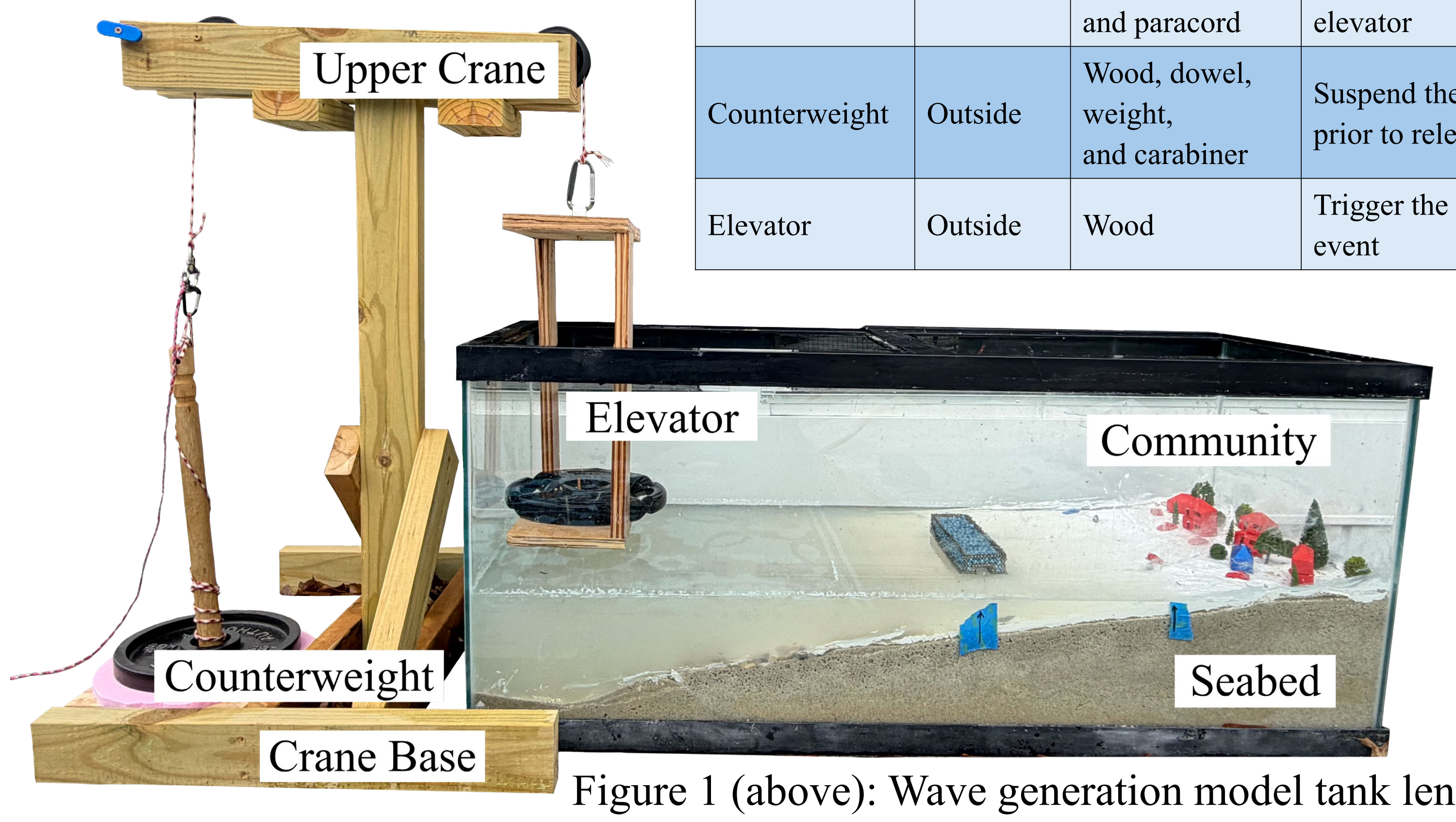


Figure 1 (above): Wave generation model tank length 48″.

Materials and Methods (continued)

Three breakwater styles were designed and tested: submerged, emerged, and floating (Fig. 2). Submerged and emerged breakwaters were rubble mound style while the floating was U-shaped. All were porous and constructed from 1/8-inch-thick balsa wood sticks, nylon mesh, PLA plastic, foam balls, and rocks, held together with various adhesives. Breakwaters were placed 22 inches from the community end of the tank.

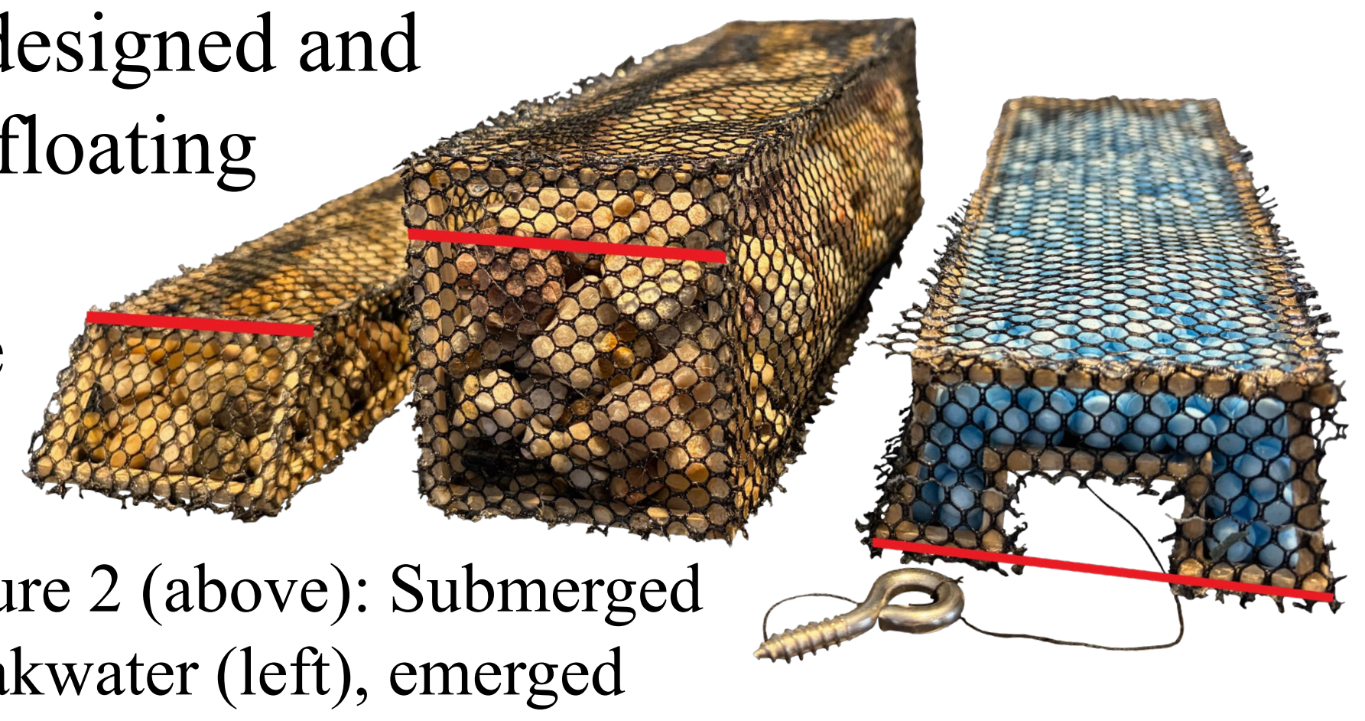


Figure 2 (above): Submerged breakwater (left), emerged breakwater (middle), and floating breakwater (right). Red line indicates sea level and the width was 2″.

Repeatability testing was conducted to determine the consistency of wave generation. The largest wave height (cm) from the tsunami event for 40 trials was recorded. Coefficient of variation (CV) was calculated for wave height as the ratio of the standard deviation over the mean.

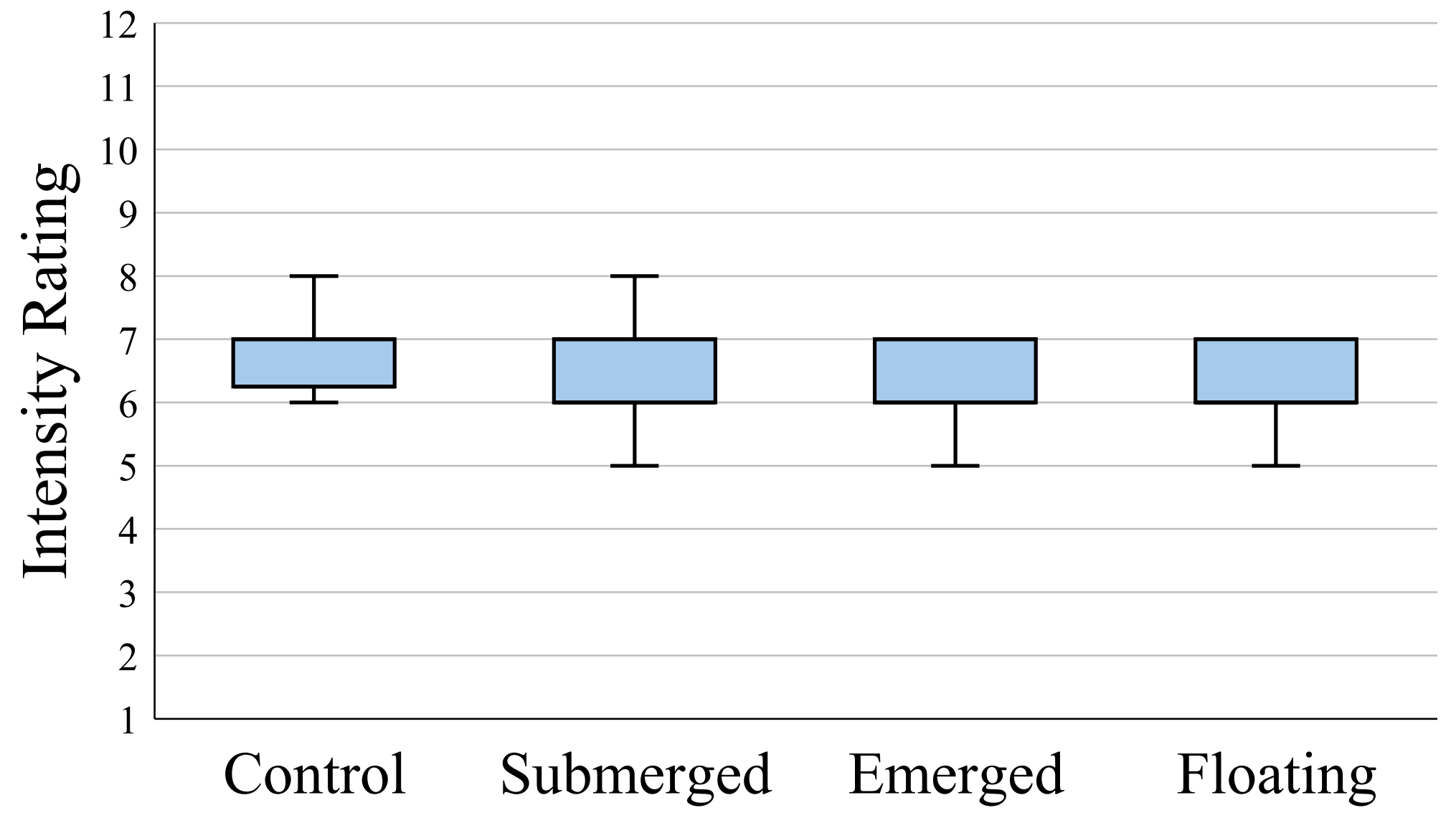
Breakwater testing was conducted to measure the largest wave height of the tsunami event and to quantify Intensity Rating. Breakwater testing consisted of 20 trials for four breakwater conditions: control (no breakwater), emerged, submerged, and floating. Trials were video recorded with OBS software, wave height was analyzed via Kinovea, and Intensity Rating determined through video analysis. A one-way ANOVA was run to determine the effect of breakwater mechanism on wave height. Tukey HSD post hoc pairwise comparisons were run and effect sizes were calculated (Hedges' g) for significant main effects. Alpha level was set a priori at 0.05.

Results

Wave height CV was 5.79% (*M* = 2.44 cm, *SD* = 0.14) suggesting the mechanism produced consistent wave heights between trials.

Intensity Rating did not differ meaningfully across breakwater conditions. Median ratings were similar indicating comparable levels of damage.

Effect of breakwater mechanism on Intensity Rating



Graph 1 (right): Median and interquartile range for Intensity Rating across all breakwater conditions.

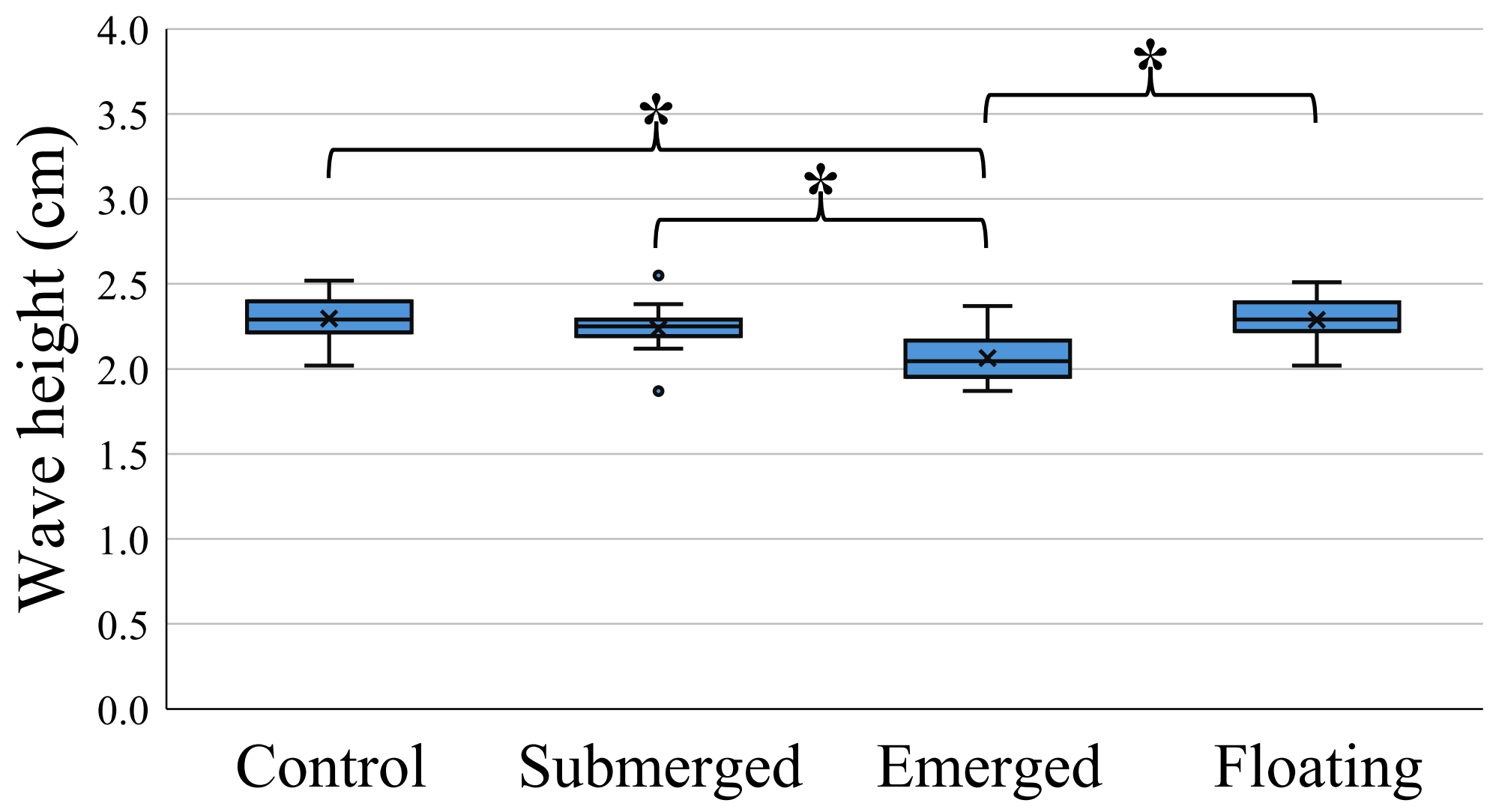
A main effect of breakwater condition was observed on wave height ($F(3, 79) = 13.23$, $p < .001$). Wave height for the emerged condition

Results (continued)

(*M* = 0.64 cm, *SD* = 0.13) was significantly lower than the control (*M* = 2.44 cm, *SD* = 0.14), submerged (*M* = 1.98 cm, *SD* = 0.15), and floating conditions (*M* = 1.45 cm, *SD* = 0.15) $p < .001$ for all (Graph 1).

Effect size was calculated for each paired comparison. Wave height differences ranged from negligible to large, with the emerged condition consistently producing the largest effects (g > 1.2) and floating the smallest (g < 0.2).

Effect of breakwater mechanism on wave height



Graph 2 (right): Mean, median, and interquartile range for wave height across all conditions. The * indicates significant post hoc comparison ($p < .05$).

Conclusion

The emerged breakwater produced the smallest tsunami wave height and had a large effect which could ultimately provide the most protection from tsunami wave destruction for coastal communities. By implementing porous rubble mound, emerged breakwater mechanisms along the shoreline, at-risk coastal communities may increase likelihood of decreased infrastructure damage, mortality rate, and economic distress.

It should be noted that the small length of the tank and limited force generation of the model restricts generalizability of the results as the waves generated were not scaled to real-life tsunami waves and did not account for other potential environmental factors. Findings from this project, however, can guide research on mitigating effects of tsunami wave destruction on coastal communities.

Future research should investigate the effects of more styles of breakwaters and the optimal distance from the shoreline of breakwater implementation.

References

Lekkas, E. L., Andreadakis, E., Kostaki, I., & Kapourani, E. (2013). A proposal for a new integrated tsunami intensity scale. *Bulletin of the Seismological Society of America, 103*(2B), 1493–1502. https://dx.doi.org/10.1785/0120120099

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