PHYSICAL MODEL EXPERIMENTS ON TSUNAMI DEBRIS IMPACT AND DAMMING FORCES ON SLENDER COLUMNS

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INTRODUCTION

Tsunami events have major impact on coastal communities including loss of life and high economic damage. Tsunamis have led to greater interest in, and awareness of, the risks posed by tsunamis to coastal communities. Tsunamis can damage coastal structures in a variety of different ways. In many cases, waterborne debris has been found to be a significant factor in structural failure (Shekhar et al., 2020). However, only recently emphasis was placed on evaluating debris transport, impact, and damming forces (Shekhar et al., 2020; Stolle et al., 2018; ASCE 2022).

This study describes an extensive series of large-scale experiments to create a comprehensive dataset of horizontal hydrodynamic, impact and damming forces of tsunami-like and waterborne debris on slender columns as those found in elevated coastal structures. The experimental work presented herein is part of a multi-year experimental campaign to better understand the mechanisms that lead to debris damming and increased structural loading (Doyle, et al., 2024).

This study will include a detailed description of the experimental procedures, model layout, instrumentation, and dataset characteristics. The work also includes the description of the different wave and water level conditions tested, and the uncertainty analysis of the results via model characterization and repeatability tests.

TEST FACILITY AND INSTRUMENTATION

The experiments were conducted in the Large Wave Flume (LWF) at the O.H. Hinsdale Wave Research Laboratory (HWRL) at Oregon State University. The flume is 104.24 m long, 3.66 m wide and 4.57 m deep. The LWF is equipped with a piston-type dry-back wavemaker with a 4.2 m maximum stroke hydraulic actuator assembly.

During the tsunami-debris experiments, transient long-waves were generated via an error function displacement profile. Generated waves propagated along the flume and transformed into a hydraulic bore over a flat wet bed testing area. The testing area included a platform where different debris configurations were placed.

For these experiments, the bathymetry was configured to comprise a combined 1:12 and 1:24 impermeable slope 25.59 m long, followed by a 25.60 m long horizontal section, and then another 14.84 m long 1:12 slope to dissipate waves. In this bathymetry configuration, the top of the horizontal section is 1.75 m from the flume bottom. Experiments were executed for water depths at the test section ranging from 3.5 to 14 cm, depending on the debris characteristics and platform layout.

Debris elements used were made of HDPE and wood, representing 1:20 reduced models of simplified standard shipping containers, cuboid vehicles, construction plates and boxes, and cylinders representing poles. The debris elements considered two different densities (in all cases less than the water density), carefully attained by adding embedded steel cylinders paying attention to the position of the debris Center of Gravity and buoyancy stability.

The model specimen consisted of a series of interchangeable sets of aluminum vertical slender columns fixed to a submersible force balance plate (see Fig. 1 and DesignSafe, 2022), located 59.78 m from the wave generator and 12.8 m from the beginning of the horizontal test section.

Along the different test phases, the surface elevation was measured at up to 9 locations along the flume with resistive and acoustic gauges to define wave conditions at the offshore and nearshore locations. Acoustic Doppler Velocimeters were deployed at 3 locations, while up to 3 submersible multi-axial load cells were used to capture the hydrodynamic forces acting upon individual columns. Additionally, stand-alone IMUs measuring accelerations, rotation rates and orientation were also installed on some columns and in selected debris elements as part of the characterization efforts of the structure. Overhead and side-looking video was captured on each trial. Video and stand-alone IMUs were synchronized with the data acquisition system of the wave gauges, ADVs, and load cells using an unambiguously random signal captured by video cameras observing an intermittent LED and by the IMUs using a solenoid. The force balance plate, capturing at 1000 Hz, was also synchronized with the wave maker start signal, recorded as well by the data acquisition system.

TEST PROGRAM

The full experimental campaign consisted in three phases:

i) Wave undisturbed tests. To characterize the hydrodynamics of the overland flow and its effect on the coastal structure, in the absence of debris.

ii) Debris tests. With different debris geometries, number, and individual densities, and for a range of tsunami-like wave heights, wave lengths, and depths.

iii) Structural characterization tests, including hammer tests for structural response dynamics, as well as debris mass properties.

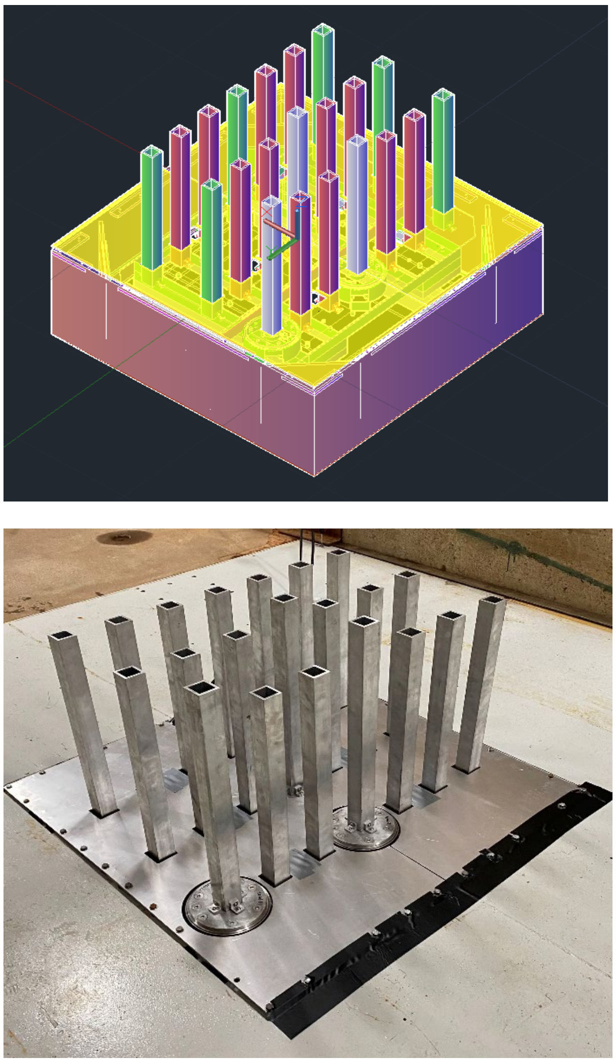

Figure 1 - Design render and constructed model of the complete set of vertical slender columns during the tsunami debris damming experiments.

Overall, 578 trials have been carried out. The test program also considered a comprehensive repeatability series for uncertainty analysis. Fig. 2 presents a selected image of the experiments carried out during the test campaign.

RESULTS

The findings of these experiments will inform scientists interested in detailed modelling of tsunami debris impact and damming loads, as well as practitioners working on the design of coastal structures subject to natural hazards. A second-phase research campaign is already planned for additional testing of mixed debris impacts and damming.

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Figure 2 - Image of waterborne debris transported by a tsunami-like wave prior of impacting a set of vertical columns. Impact and damming loads were measured at selected individual columns and overall forces were measured for the whole specimen.

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