Experimental Study of Tsunami Waves and Forces on Simple Structures using a Hybrid Tsunami Generator

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Introduction

Understanding tsunami hydrodynamics such as run-up and force is an essential aspect in the development of tsunami resilient structures. Recently, many researchers used a conventional and simple waveform that idealize the tsunami waveform in hydraulic experiments. However, the 2011 event had different characteristics and shape. Hence, the option to use those waveform to represent a tsunami wave was categorized as outdated (Madsen et al., 2008).

To reproduce the 2011 Tohoku Earthquake-like tsunami with higher detail and accuracy, a new mechanism of tsunami generation in physical modeling is needed. The DPRI Kyoto University, built a new tsunami wave generator in 2014: the Hybrid Tsunami Open Flume in Ujigawa Laboratory (HyTOFU). HyTOFU is a cutting-edge laboratory-based wave model designed to model tsunami wave generation and is equipped with three types of wave makers: mechanical piston-type wave generator, head storage tank-driven wave generator, and pump-driven wave generator. These three mechanisms can not only be used individually but can be used concurrently in any combination of the above three types (Prasetyo et al., in press).

In this study, we used the HyTOFU to investigate tsunami run-up and force on simple structures and to understand the interaction of macro-roughness effects on tsunami wave transformation.

Experimental setup

A series of experiments was conducted to investigate tsunami run-up and force on structures using HyTOFU. The HyTOFU basin is 45 m long, 4 m wide, and 2 m deep with a 1:10 slope. The initial water depth is 0.7 m. We set up the experiment with seven combinations of solitary wave and constant flow inputs. Schematics of the experimental setup are illustrate in Figure 1.

In these experiments, the model scale was 1:20. We used an instrumented box or specimen to represent an 8 m long x 8 m wide Japanese house. The specimen was made of acrylic with dimensions 0.40 m long x 0.40 m wide x 0.50 m high and was equipped by pressure sensors with capacity 50 kPa on each side. Water surface elevations were measured using wire resistance wave gauges (WGs) along the flume. Various WGs were located onshore depending on the experimental configuration. We conducted an experiment for two conditions: single box experiment and multiple box experiment. For single box experiment. the specimen was placed in the flume at three different locations: 0.79 m (L_1), 1.59 m (L_2) and 2.39 m (L_3), respectively. For multiple box experiment, two different setups of macro-roughness were arranged by varying the number of boxes and spacing between boxes. We set a gap spacing between the box experiments representing a street around the houses with two conditions: a_1 = 0.2 m and a_2 = 0.4 m.

Experimental results

Figure 2 shows an example of time series of tsunami wave height for Case 7 (input maximum solitary wave 0.4 m and constant flow 0.1 m^3/s) with various configurations, showing the wave height measured on the front side of specimen (WG9). The wave began to propagate from offshore to inland with a symmetric waveform then changed as an asymmetric waveform when a tsunami wave propagate over the slope. In this figure, the oncoming tsunami wave as incident wave can be seen clearly and a small rise in water height occurred as a reflected wave, then followed by a constant flow. Comparison of wave height in the multiple box experiment indicates that water level for 0.4 m gap spacing was larger than that for the configuration with 0.2 m spacing. For example, maximum wave height at 3_box 0.4m increased by 128.2% compared with 3_box 0.2m and maximum wave height at 9_box 0.4m was increased 28.3% compared with 0_box 0.2m. Impulsive wave pressure occurred when the tsunami wave hit the specimen and obtained maximum pressure. Thereafter, decreasing of water level due to the wave receding seaward led to a decrease in maximum pressure. When the reflected wave occurred and produced the second rise, pressure also increased gradually as a run-up force. Then, constant flow as quasi-static flow condition led to a constant pressure on the specimen resulting in a quasi-hydrostatic force.

Figures 3 shows relationship between solitary wave input (η/h) and the maximum hydrostatic pressure ($\rho g\eta$) for each setback distance ($L1$ = 0.79 m, $L2$ = 1.59 m and $L3$ = 2.39 m). Increasing the incident solitary wave height from Case 1 (η/h = 0) to Case 3 ((η/h = 0.21) shows 1:1 agreement between the maximum pressure (at front side of specimen) and offshore hydrostatic pressure. However, the ratio of maximum pressure to hydrostatic force for Case 4 to Case 7 changes and becomes larger. The configuration with the specimen located closest to coastline ($L1$) received the highest pressure compared to $L2$ and $L3$, except in Case 4. Therefore, setback distance from the coastline gives a significant impact on the specimen.

Conclusions

This study clearly showed that varying the number of structures and the spacing between them can significantly influence both inundation and force to the structure. If a single structure faces a tsunami wave directly without any obstacle, the distance between the structure and the coastline can give a significant impact to the maximum pressure felt by the structure. Single structures also can feel larger pressures from tsunami waves compared to configurations with multiple structures. Therefore shielding a specimen can reduce the tsunami impact. Effects of macro-roughness element to the specimen itself depend on gap spacing between elements. Wider spacing between elements can contribute higher pressure to the structure.

References

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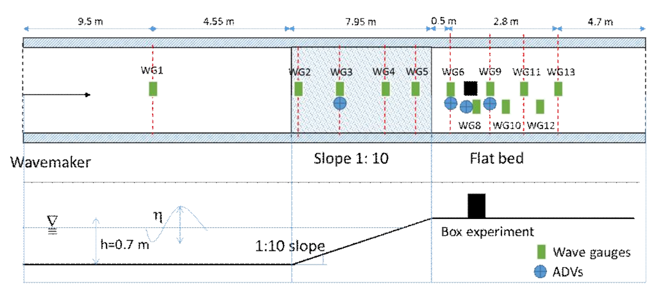

Figure 1. Schematics of the experimental

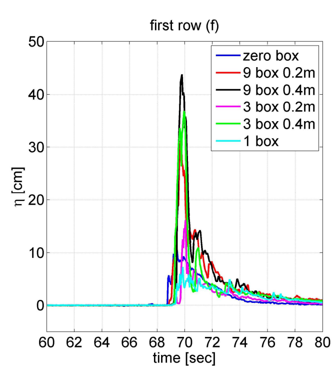

Figure 2. Examples of wave profile at front side of specimen

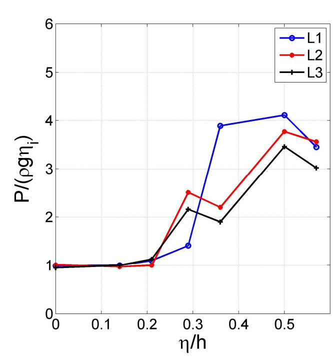

Figure 3. Relationship between solitary wave input and the maximum hydrostatic force