Physical Modeling and Numerical Analysis of Tsunami Inundation in a City Scale

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Introduction

Knowledge of the hydrodynamic information of tsunami inundation such as spatial distribution of tsunami wave propagation, arrival time, tsunami height and acting forces is very important to establish the soft and hard countermeasure tsunami protection. Therefore, understanding of local tsunami behavior and hydrodynamics processes when a tsunami impacts urban infrastructures in a coastal city is needed. Since the mega tsunami events are very rare occurrences, physical modeling is very useful provide the dynamic information similar to real conditions.

In this study, the physical model to investigate inundation processes in a complex coastal city model was conducted using the HyTOFU (Hybrid Tsunami Open Flume in Ujigawa open laboratory). The goal of study are: (a). to investigate local tsunami behavior, tsunami inundation and other hydrodynamics processes on complex land structures in coastal areas and (b). to verify numerical model of 2D-Nonlinear Shallow Water Equation (2D-NSWE) and the Quasi-3D Euler Equation – Regional Ocean Modeling System (Q3D-ROMS) using data set of a physical modeling results based on 2011 Tohoku Earthquake tsunami event.

Experimental setup

The physical model was constructed at 1:250 scale as an idealization of the coastal town of Onagawa. The physical model represented the bathymetry condition of the Onagawa shore with a 13.7 m long flat sea floor section from the wave generator, followed by a 1:10 planar slope section and ending with a beach section where the Onagawa town physical model was fixed. The sea floor section was constructed from concrete and plastered by smooth cement mortar while the slope section was made of coated iron plate. The constant water depth was set at 0.84 m. The Onagawa town profile was downscaled and constructed with detailed accuracy, consisting of real topography and urban coastal infrastructures (e.g., buildings, houses, and streets, as well as hills and mountains) as macro-roughness elements. Vegetation, debris and other small parts were not included. Figure 1 shows 1:250 scale of model (*top*) and the plan and elevation view of the Onagawa model (*bottom*),

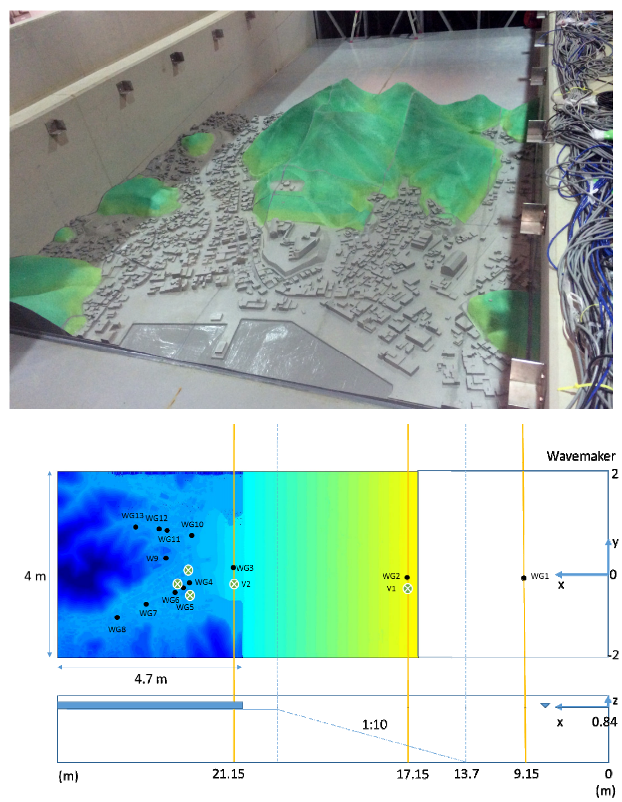

Figure 1. (*top*) 1:250 scale of model and (*bottom*) the plan and elevation view of the Onagawa physical model (*black circle:* wave gauges, *cross circle*: ADV).

The tsunami waves were generated using single mechanisms of the HYTOFU. Two tsunami waveforms were used, solitary wave and long period continuous flow, produced by the mechanical piston-type wave generator and the pump-type wave generator, respectively. To measure the water surface elevation, water velocities and wave pressure, 13 capacitance-type wave gauges, five ADV, and 19 pressure sensor were installed in the flume.

In this study, a comparison of results of experimental and numerical model has been examined using two different tsunami numerical models, a 2D-Nonlinear Shallow Water Equations (2D-NSWE) model and Quasi-3D Euler Equations with Regional Ocean Modeling System (Q3D-ROMS).

Results

Figure 2 shows the spatial distribution of tsunami inundation on the physical model. The flow speed in the southern region was faster than in the northern side. Based on the arrival time of the flow edge at each gauge, the average inundation speed in the southern and the northern region was calculated to be about 0.27 m/s and 0.15 m/s, respectively. Existence of macro-roughness elements (e.g. buildings, houses) and a steeper topography condition was recognized as the reason for inundation speed reduction along the street in the northern region.

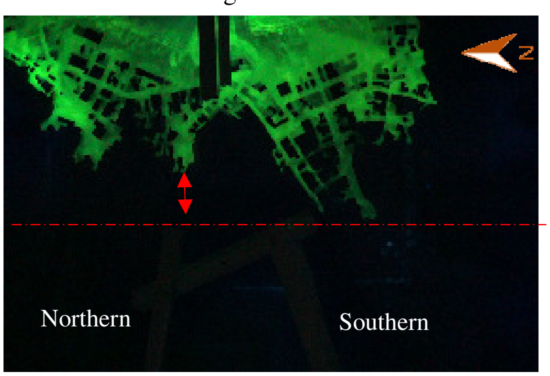

Figure 2. Snapshots of tsunami inundation on land

Comparison results of maximum water surface elevation and arrival time between experimental and numerical models at all wave gauges (WG2-WG13) is depicted in Figure 3. In general, the 2D-NSWE model and Q3D-ROMS model results agree well with experimental result in terms of maximum tsunami height, inundation depth and arrival time for the long period continuous flow case. However, for solitary wave case the maximum inundation depth of 2D-NSWE model results were underestimated and the arrival time in the numerical models were slower than experimental results. These facts evidently show that a nonlinear shallow water equation model might not be suitable in representing a tsunami waveform in terms of wave magnitude and spatial duration due to nearshore effects and wave diffraction by structures.

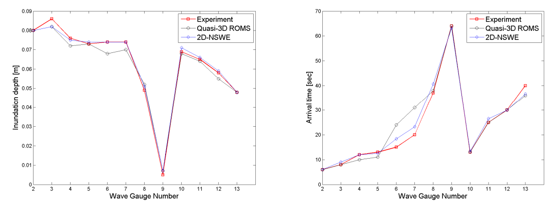

Figure 3. Comparison results of maximum water surface elevation (*left*) and arrival time (*right*) between experimental and numerical models at all wave gauges (WG2-WG13) for the long period continuous flow case (*red line*: experimental results, *black line*: Q3D-ROMS model, *blue line*: 2D-NSWE model)

Conclusions

Tsunami wave generation similar to the 2011 Tohoku Earthquake Tsunami in Onagawa was successfully reproduced and the spatial distribution of tsunami wave propagation and inundation processes on land was clearly observed.

A comparison of experimental and numerical models was performed using both 2D-NSWE and Q3D-ROMS. To validate and verify the numerical model sensitivity, physical modeling is very useful provide the dynamic information similar to real conditions. The experimental data set obtained from this study are valuable.