EXPERIMENTAL STUDY ON THE PRESSURE ACTING ON STRUCTURES DUE TO TSUNAMI BORE IMPACT

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Tsunami bore impacts can exert devastating forces on houses and infrastructures along coastal regions. As such, there is an urgent need to clarify the impact pressure of tsunami bore acting on different types of coastal infrastructure. This study presents the experimental results on impact pressure of tsunami bore acting on two types of building model for three cases of tsunami height. The distribution of the maximum pressure and the time integration of pressure history on the front section of building models are shown. This distribution reveals that the strength of the impact pressure of the tsunami bore depends on the impoundment depth (tsunami height), and the distribution of pressure after the impact of the tsunami bore depends on the width of the structures.

Key Words : *Tsunami bore, impact pressure, building model, maximum pressure, time integration of pressure*

1. INTRODUCTION

Tsunamis can have a devastating impact on coastal areas and have been responsible for some of the worst natural disasters in human history, for example, the destruction of communities surrounding the Indian Ocean in 2004 and the devastation of the Tohoku region along the Pacific Coast of Japan in 2011.

Ghobarah et al. (2006), Nistor et al. (2005), and Yamamoto et al. (2006) reported that coastal structures were severely damaged by the tsunami bore impact. Chen (2011) suggested that sufficient attention should be given to the wave impact on buildings, as the wind and earthquake loads. Hatori (1984), Iizuka and Matsutimi (2000), Lindt et al. (2009), Nistor et al. (2009), and Thusyanthan and Madabhushi (2008) performed experiments on the impact pressure of tsunami bore on various structures.

The tsunami-structure interaction is a complex phenomenon, and researches still need to develop prominent information, such as the vertical pressure impact distribution, cause of pressure impact fluctuation, damaging status, etc on the structure due to the tsunami bore impact. In order to clarify the importance of studies on this interaction, especially the tsunami bore loading on structures; an experiment is conducted to reveal the tsunami bore impact pressure on two types of building model. The present study focuses on the distribution of the maximum impact pressure and the time integration of pressure history.

2. RELATED RESEARCH

Chanson (2006), Cross (1967) and Fukui (1963) experimentally and analytically determined the features of the tsunami bore impact. Ramsden (1996) developed an empirical formula for the bore impact forces on a vertical wall. Gomez-Gesteira and Dalrymple (2004) explained the numerical analysis of bore impact by addressing an existed dam break experiment. Arnason (2005) carried out experiments on the hydrodynamic impact on different structures and primarily discussed the initial impact phenomena of the hydrodynamic impact. Nistor et al. (2009) analyzed the vertical distribution of the bore impact forces and pressures on free-standing structures. Nistor et al. (2009) introduced several hydraulic elements such as the flow depth, the velocity, and the flow direction of the tsunami bore, which could play a crucial role during the impact of the tsunami on coastal structures. They also found that the tsunami-induced hydraulic bore is a complex phenomenon that could not be assessed by strictly analytical means. Therefore, clarification of this phenomenon requires experimental investigation.

As stated above, few studies have investigated the changes in the vertical distribution of tsunami bore impact pressure for different impoundment depths (tsunami height) and structural sizes. The present study reveals the vertical distribution of the impact pressure of the tsunami bore acting on the front sections of structures for three impoundment depths and two types of structure.

3. DESCRIPTIONS OF EXPERIMENT

Experiments were performed using an open channel having a length of 1,100 cm, a width of 60 cm, and a depth of 40 cm. **Fig. 1** shows a schematic diagram of the experimental setup. The dam break model has been adapted to observe the impact pressure of a tsunami bore on the building model.

Two types of building model (model A: 12 × 12 × 12 cm and model B: 6 × 6 × 12 cm) have been used, and different impoundment depths (30 cm, 20 cm, and 10 cm) behind the gate have been set, considering the initial tsunami height. The bottom slope of the channel is 1/65 towards downstream.

Five pressure sensors have been installed on the front face of the building model (**Fig. 2**). However, the upper most pressure sensor did not show good recording data. Hence, data from only the first four pressure sensors, from the bottom to the upper portion, are considered for analysis. The pressure sensors have been fixed at positions 1, 3, 5, and 7 cm from the bottom along the center of the cross section of the building model. These pressure sensors are labeled the 1st, 2nd, 3rd, and 4th sensors, respectively.

A digital camera has also been installed in order to provide qualitative information about the collision of the tsunami bore with the building model. The tsunami bore pressure based on the time history on the font face of the building model has been estimated. The distributions of the measured impact pressure were then analyzed. Three time trials have been regulated based on the impoundment depth for a building model. The average values of trial data are considered in discussing the results.

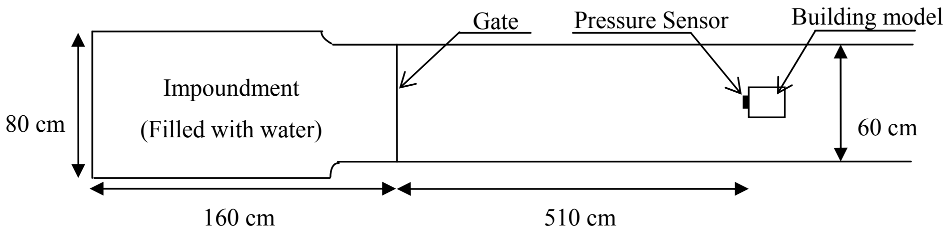


Fig.1 Experimental channel with building model: plan view.

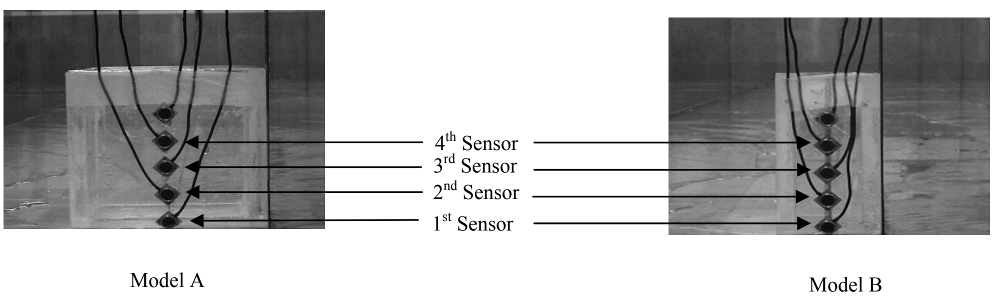


Fig.2 Building models with pressure sensors.

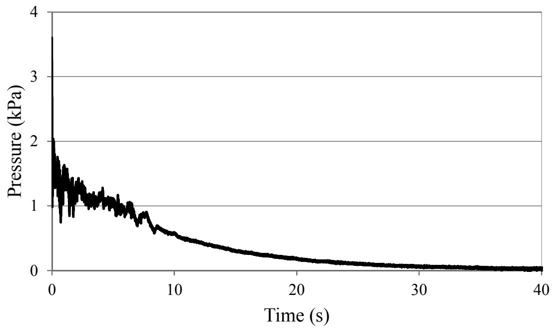
4. RESULTS AND DISCUSSION

Figs. 3 and **4** show instances of tsunami bore impacts and the pressure history from the 1st sensor on models A and B, respectively. Palermo and Nistor (2008) demonstrated that the first loading of the tsunami bore on the structure is the surge impact, and the second tsunami bore impact is the hydrostatic and hydrodynamic forces on the structure. In the figures, the first tsunami bore impact pressures are similar for both models. However, the pressure distributions are different between the models. In the case of the narrow model B, the tsunami bore can more easily pass through the side sections than that for the wider model. Thus, the bore flow around model B can attain a high velocity. Therefore, model B shows a higher pressure at the base than model A.

Fig. 5 shows the maximum pressure distribution due to the tsunami bore impact on the pressure sensors of both building models. The maximum pressure distribution patterns depend on both the type of building model and the impoundment depth. In the case of an impoundment depth of 10 cm, the distribution of the maximum pressure exhibits similar gradually declining values from the 1st sensor to the 4th sensor for both models. However, as the impoundment depth increases, the 2nd sensor exhibits a higher pressure than the 1st sensor. The differences in the maximum pressure distributions between the proposed models increase from the 1st sensor to the 4th sensor and the maximum differences are found at the 4th sensor. Furthermore, these differences become increasingly similar as the impoundment depth increases. In case of an impoundment depth of 30 cm, the 4th sensor exhibits the greatest difference between model A and model B.

As mentioned above, the tsunami bore can more easily pass through the side sections for model B than for model A, so the wider model A experiences a higher tsunami height at the upper portion than that for the narrower one model B. After the initial impact of the tsunami bore, the tsunami bore can accumulate height along the front face of the building model, so that the differences in this height cause the differences in the maximum pressure distributions between models.

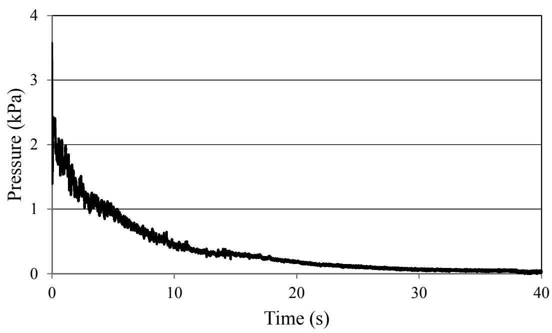
Moment of the impact of tsunami and the splash of water



Pressure history

Fig.3 Tsunami bore impacting model A (impoundment depth: 30 cm).

Moment of the impact of tsunami and the splash of water



Pressure history

Fig.4 Tsunami bore impacting model B (impoundment depth: 30 cm).

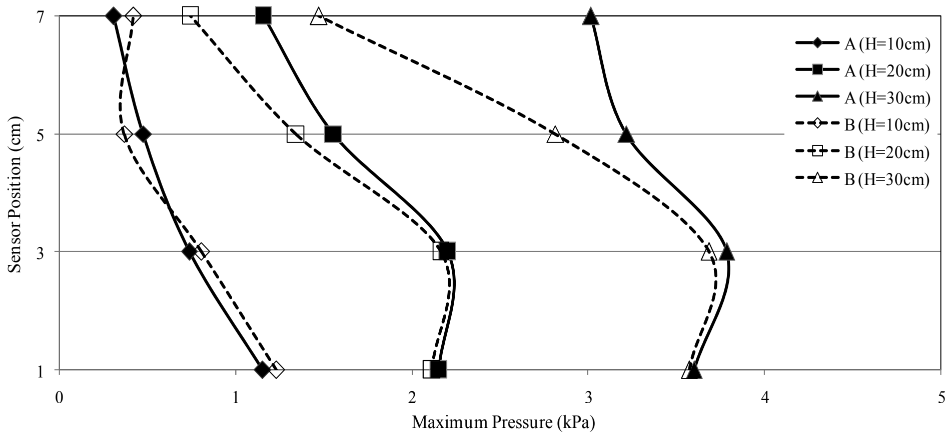


Fig.5 Maximum pressure distribution (A: model A, B: model B).

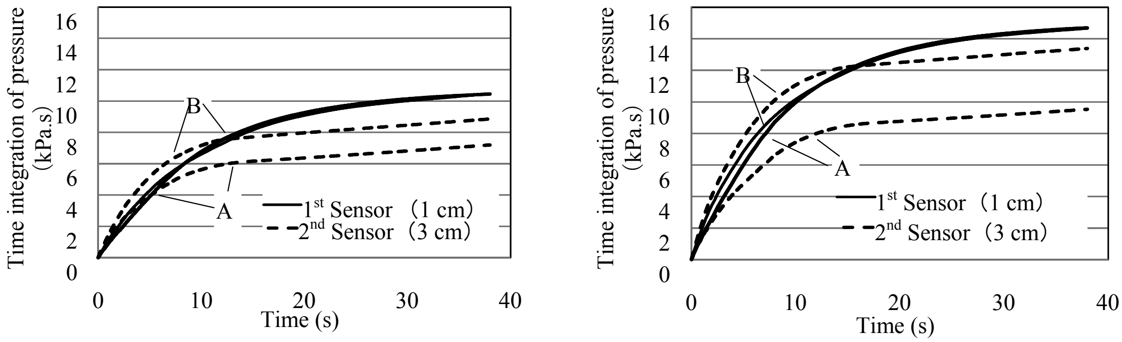


Fig.6 Time integration of impact pressure for impoundment depths of 20 cm (left) and 30 cm (right) on the 1st and 2nd sensors (A: model A, B: model B).

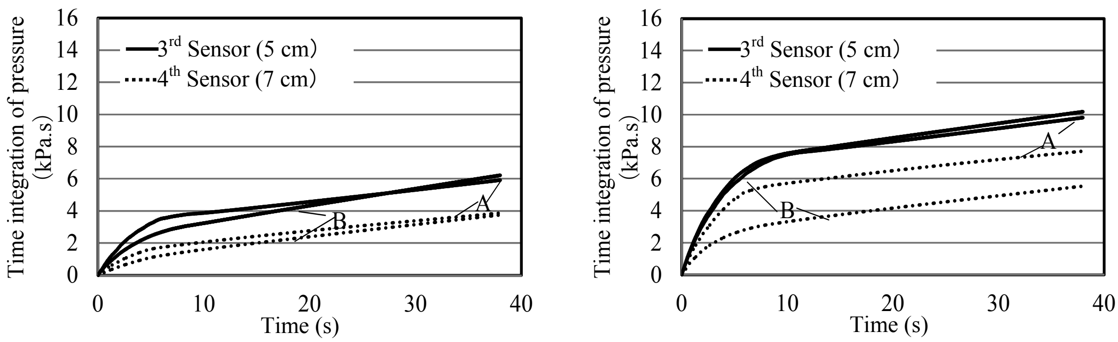


Fig.7 Time integration of impact pressure for impoundment depths of 20 cm (left) and 30 cm (right) on the 3rd and 4th sensors (A: model A, B: model B).

Figs. 6 and **7** show the time integration of the pressure history for impoundment depths of 20 cm and 30 cm. **Fig. 6** shows the time integration of pressure based on the base level sensors (1st and 2nd sensors), whereas **Fig. 7** shows the time integration of pressure based on the upper level sensors (3rd and 4th sensor).

In **Fig. 6**, the pressure integrations obtained from the 2nd sensor for both models exhibit similar values at the beginning of impact, compared to that from the 1st sensor. However, after a few moments, the pressure integration of the 1st sensor exhibits higher values than that of the 2nd sensor for both models. On the other hand, the pressure integration of the 2nd sensor for model B exhibits higher values than that for model A. Nevertheless, similar patterns can be observed on the 1st sensor for both models. As mentioned above, due to the existence of the high-velocity flow around model B, it can have a higher impact pressure near the base, as compared to that for model A. Hence, the 2nd sensor, which is almost at the level of the water surface during bore impact and thereby facing high flow velocity, exhibits a large difference between the pressure integrations obtained from model A and model B.

Fig. 7 shows the pressure integrations from the 3rd and 4th sensors, where the 4th sensor pressure integration for model A takes higher values than that for model B. Furthermore, this line always passes below the 3rd sensor pressure integration line. Although the 3rd sensor pressure integration exhibits higher values for model A in the case of an impoundment depth of 20 cm, the pressure integration from this sensor shows a similar pattern for both models. In these cases, the bore height in front of the models affects the strength of the pressure for both models.

The time integration of pressure also depends on the impoundment depth and the width of model, as observed in the maximum pressure distributions shown in **Fig. 5**.

5. CONCLUSIONS

Tsunamis can cause immense physical, social, and financial damages to coastal communities. However, these losses could be reduced by applying a proper design process to infrastructures in coastal regions. Considering the recent high frequency of tsunami events, it is important to develop methods by which to minimize the destruction to coastal structures caused by tsunami bore impact.

The present study revealed experimentally the features of tsunami bore impact on building models. Tsunami bore pressure depends on both the initial tsunami height (impoundment depth) and the width of the structure. The upper leveled of the wider building (model A) experiences higher pressures than that of the narrower building (model B). On the other hand, the time integration of pressure for the narrower building takes higher values than that for the wider building.

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