International Journal of Civil Engineering and Technology (IJCIET)
Volume 7, Issue 4, July-August 2016, pp. 13–23, Article ID: IJCIET_07_04_002
Available online at
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=7&IType=4
Journal Impact Factor (2016): 9.7820 (Calculated by GISI) www.jifactor.com
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

EXPERIMENTAL AND NUMERICAL SIMULATION OF TSUNAMI BORE IMPACT ON A BUILDING

Md Mostafizur Rahman
Department of Civil Engineering. and Architecture, University of the Ryukyus

Eizo Nakaza
Department. of Civil Engineering. and Architecture, University of the Ryukyus

ABSTRACT

Buildings must have well design against tsunami impact to mitigate the damages. This study presents the numerical simulations of tsunami impact on a building model structure. Series of experiment were carried out in the laboratory for a simple building model structure for different initial tsunami bore heights. Numerical simulation with the newly improved three-dimensional moving particle semi-implicit (3D-MPS) method performs here to validate with the physical experimental results and also comparing with the original MPS method. The newly improved 3D-MPS method shows good qualitative and quantitative agreement with the experimentally recorded pressure and height. Consequently, tsunami bore impact on the building model structure was investigated by the numerical simulation. The changes of the tsunami bore height and velocity around the building model structure has been found which can lead to varied tsunami bore impact. This study can help in understanding the mitigation against the tsunami bore impact around the coastal houses and infrastructures.

Key words: Coastal infrastructure, three-dimensional particle method, moving particle semi-implicit (MPS) method, building model structure

Cite this Article: Md Mostafizur Rahman and Eizo Nakaza, Experimental and Numerical Simulation of Tsunami Bore Impact on a Building. *International Journal of Civil Engineering and Technology*, 7(4), 2016, pp.13–23.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=7&IType=4

1. INTRODUCTION

Frequent natural disasters show the catastrophic effect on the coastal communities. The Tohoku region coastal communities of Japan have experienced a recent terrifying effect of giant tsunami wave in 2011. The Indian Ocean tsunami in 2004 triggered one of the worst natural hazards in human history.

Existing building codes, design practices and disaster planning could not have shown enough attention to the wave impact on building comparing with the other loads such as earthquakes and strong wind (Chen, 2011). However, several research (Ghobarah et al. 2006; Nistor et al. 2005; Yamamoto et al. 2006) have shown the damages on the coastal structures due to the overwhelming tsunami impact. Furthermore, it was observed from recent destructive tsunami impact in Tohoku region of Japan that all buildings were stand good after huge earthquake but those were washed away by the progressing tsunami impact. Hence, building must have well design against tsunami impact to mitigate the damages.

Wave-structure interaction is a complex phenomenon and only analytical explanation could not be able to lead to better understanding of this substantial fact. Experiments (Lindt et al. 2009; Nouri et al. 2010; Palermo and Nistor, 2008; Rahman et al. 2012) have performed to understand the tsunami impact phenomena on structures. However, a verified numerical method is urgent to have the insight of the tsunami wave structure interaction phenomenon. Experimental and numerical simulations on tsunami wave and structure interaction problem have been conducted in different research (Gomez-Gesteira and Dalrymple, 2004; Nakaza et al. 2010; Nistor et al. 2010; Yim, 2005). Hence, both experimental and numerical simulations have been desired to clarify the underlying physics of this event.

This study represents the experimental and numerical simulations of tsunami bore impact on the structure. Series of experiment were carried out in the laboratory to attain the tsunami bore impact on the coastal structures. A simple building model structure is considered here. In addition, numerical simulation with the newly three-dimensional moving particle semi-implicit (improved 3D-MPS) method (Iribe and Nakaza, 2011) performs here to validate with the physical experimental results and also comparing with the originally developed moving particle semi-implicit (MPS) method (Koshizuka and Oka, 1996). Qualitative and quantitative verification with the experiments are shown. Numerical results show good consistency with the experimental results. Numerical simulation is then applied to investigate the tsunami bore impact around the structure. Tsunami bore velocity and heights have been observed qualitatively by the numerical simulation around the building model structure.

2. EXPERIMENTS

Physical experiments were conducted in an open channel about 11 m long, 0.60 m wide and 0.40 m deep. The plan view of the experimental scheme is shown in Figure 1. Water reservoir, which can produce wave, was placed behind a gate. Three types of impoundment depth (0.30 m, 0.20 m and 0.10 m), which are induced to different incident tsunami bore height in front of the building model structure as 0.19 m, 0.16 and 0.06 m respectively, were adopted. A simple building model structure with the geometry 0.12 × 0.12, 0.12 m was used to observe the tsunami bore-induced pressure impact. The model structure was placed at the middle position on to the open channel. Four pressure sensors were vertically fixed on the front side section of the structure. The position of the pressure sensors were 1 cm, 3 cm, 5 cm and 7 cm from the bottom and they were set as 1st, 2nd, 3rd and 4th sensor respectively. The pressure sensors were placed along the middle of the front cross section of the structure. Figure 2 shows the model structure with pressure sensors. Pressures on the building model structure due the tsunami bore impact were recorded. One wave gauge was placed just in front of the model structure to get the tsunami height. A digital camera was deployed to observe the instantaneous impact of tsunami bore on the structure.

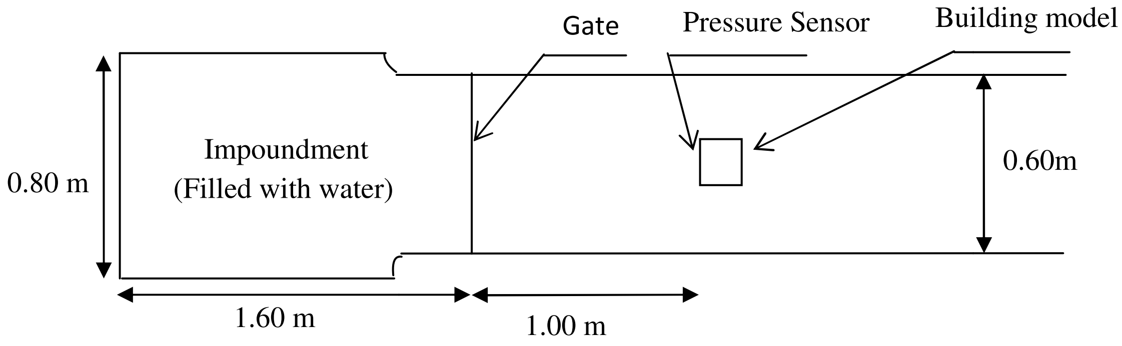
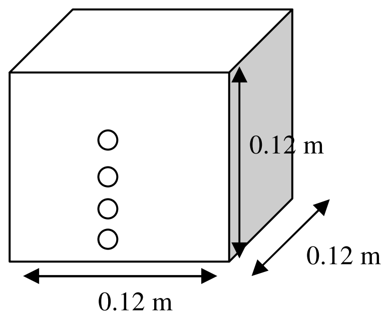
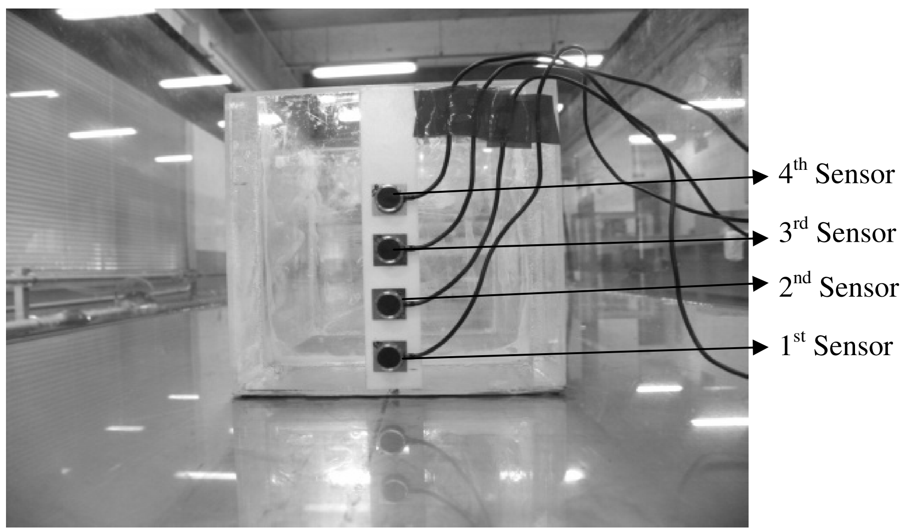


Figure 1. Experimental channel with the building model structure: plan view



3D Building Model Structure



Building Model Structure in the Experiment

Figure 2. Building Model Structure with the Pressure Sensors.

3. NUMERICAL SIMULATION

Newly improved 3D-MPS method (Iribe and Nakaza, 2011) was applied here for the numerical simulation of tsunami impact on building. MPS method has been used by some researchers for complex flow with wave breaking (Iribe et al. 2012; Khayer and Gotoh, 2009; Koshizuka et al. 1998; Nakaza et al. 2012; Nakaza et al. 2010; Shibata et al. 2009).

4. NUMERICAL CONDITIONS

Initial distance between particles was 0.01 m and the time increment for calculation was 0.001 s. The building model structure consisted of 1,584 particles. Total number of particles for the boundary condition was 677,471. The numbers of particle used for the numerical model are shown in Table 1.

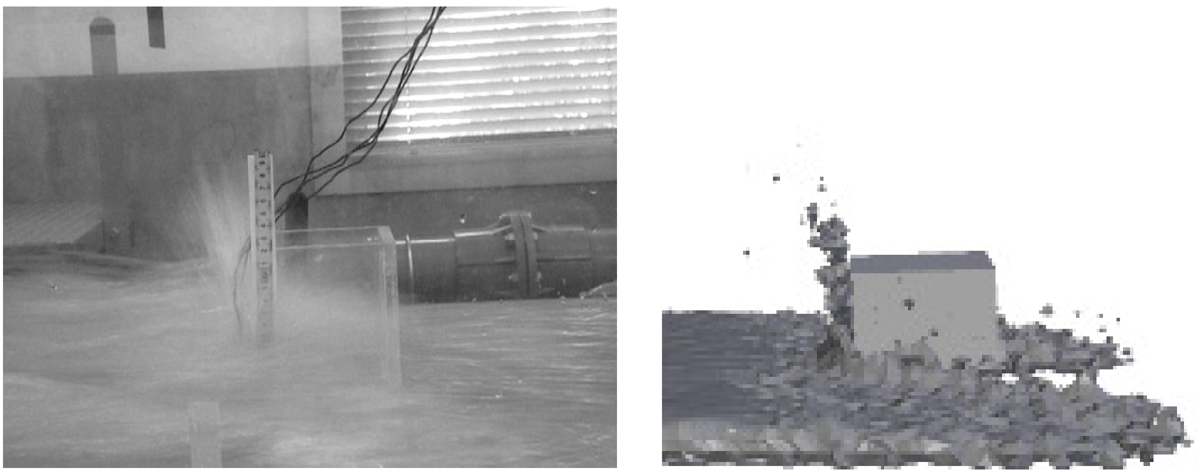
Table 1. Number of Total Particles for Different Incident Wave Heights.

Impoundment Depth	Incident Wave Height (m)	Water Particle Number	Total Particle Number
0.30	0.19	371 339	105 0394
0.20	0.16	247 559	926 614
0.10	0.06	123 779	802 834

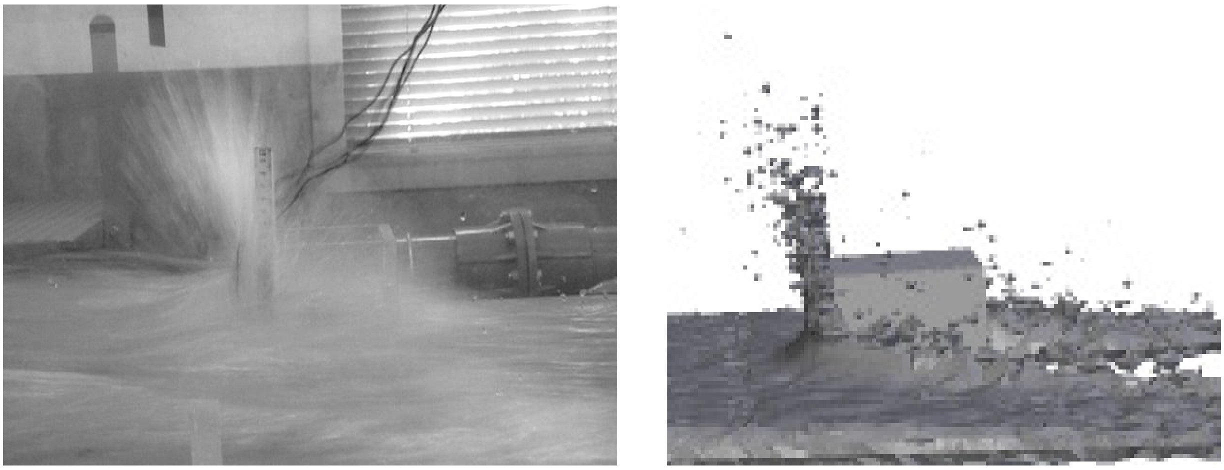
5. RESULTS AND DISCUSSIONS

5.1. Tsunami Bore Impact on the Building

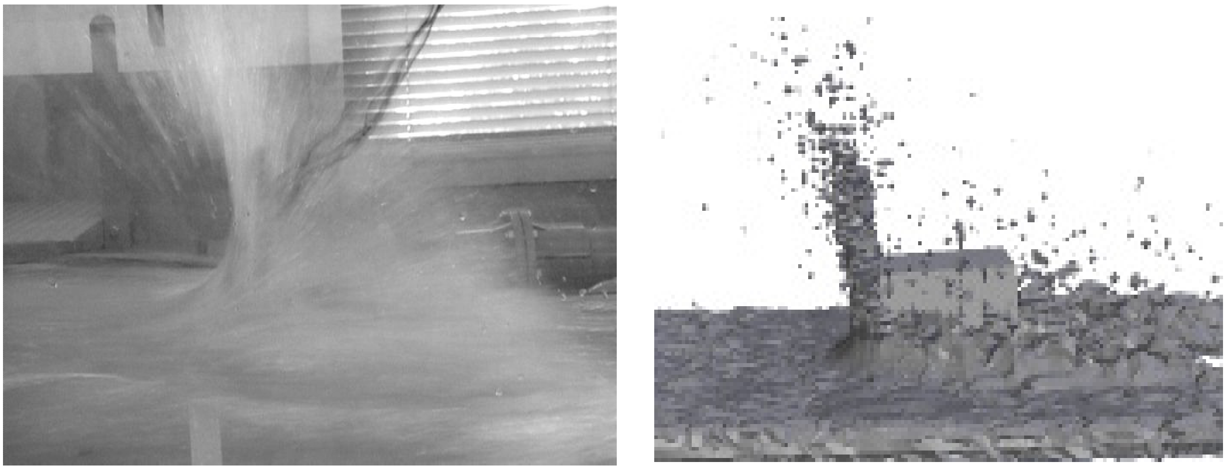
Tsunami bore impact phenomena on the building model structure was recorded from the physical experiments by employing a digital camera. Figure 3 shows the comparative qualitative phenomena between experimental and numerical simulations. The tsunami bore impacts on the structure with splash (0.45 s). Subsequently, the bore height increase in front of the structure with high splash. However, the higher bore height can be observed in case of experiments than the numerical simulations in the same time (0.48 s and 0.51 s). This difference leads to the differences of pressure impact between experimental and numerical results.



t = 0.45 s



t = 0.48 s



t = 0.51 s

Experiment **Numerical Simulation**

Figure 3 Tsunami bore impact on the building model structure.

5.2. Tsunami Bore Acting Pressure on the Building

Pressure fluctuations according to the time history are shown in Figure 4 for 0.19 m tsunami incident wave height in front of structure. Both, original and improved 3D-MPS method shows good agreement with the experimental results. However, improved MPS method shows better consistency in the pressure fluctuation than in the original method. Moreover, the impact pressure fluctuation results show instable pattern for the case in original MPS method simulation. Original method shows the higher initial pressure peak than the improved simulation results. Both numerical simulations show gradual pressure decrease after the initial pressure peak comparing to the experimental results. The experimental pressure fluctuation results show the abrupt decrease after the impact, then increase and again gradually decreasing pattern. Same phenomena could be found in St-Germain et al. (2011). They have argued that the air entrainment could lead this difference between experimental and numerical results. In the present numerical simulation method, air entrainment fact is not considered. The initial pressure peak is not similar between experimental and numerical results. However, the overall pressure fluctuation patterns show good agreement between experimental and numerical simulation results. In the experiments, 1st sensor always shows higher pressure value than that of other pressure sensors. Initial pressure peak and after it the pressure fluctuation shows decrease pattern consistently for the 1st, 2nd, 3rd and 4th sensor. Same cases could be identified in both numerical simulation methods. In case of numerical results, the 3rd and 4th sensor do not show same initial peak as in the experimental results at the same time. The height of tsunami bore between experimental and numerical simulation results shows differences in different time (Figure 3). Therefore, the higher pressure value on 3rd and 4th sensor could be observed after some moments (comparing to the experimental results) in the numerical simulation results.

The height of tsunami bore between experimental and numerical simulation results shows differences in different time (Figure 3). Therefore, the higher pressure value on 3rd and 4th sensor could be observed after some moments (comparing to the experimental results) in the numerical simulation results.

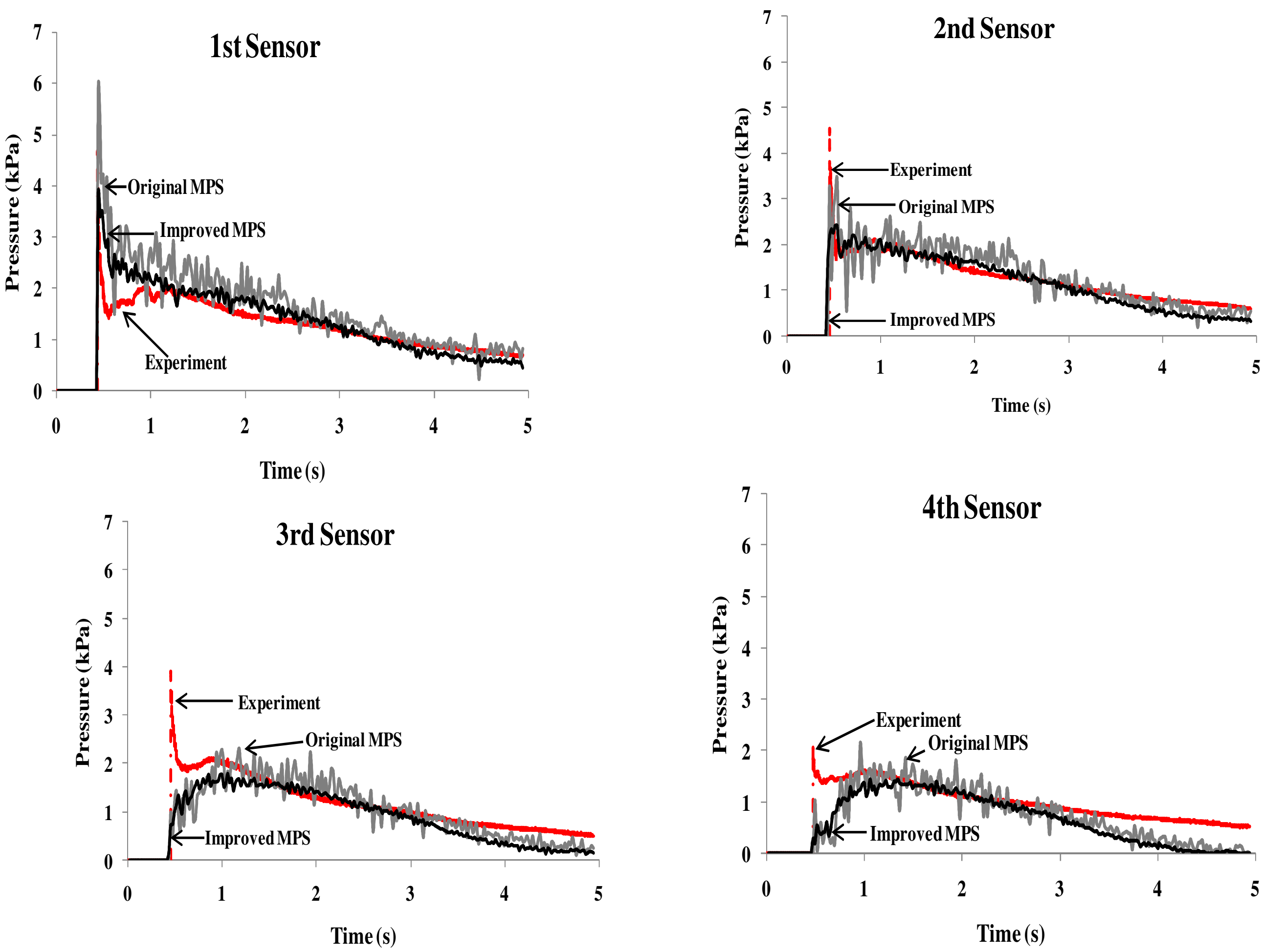
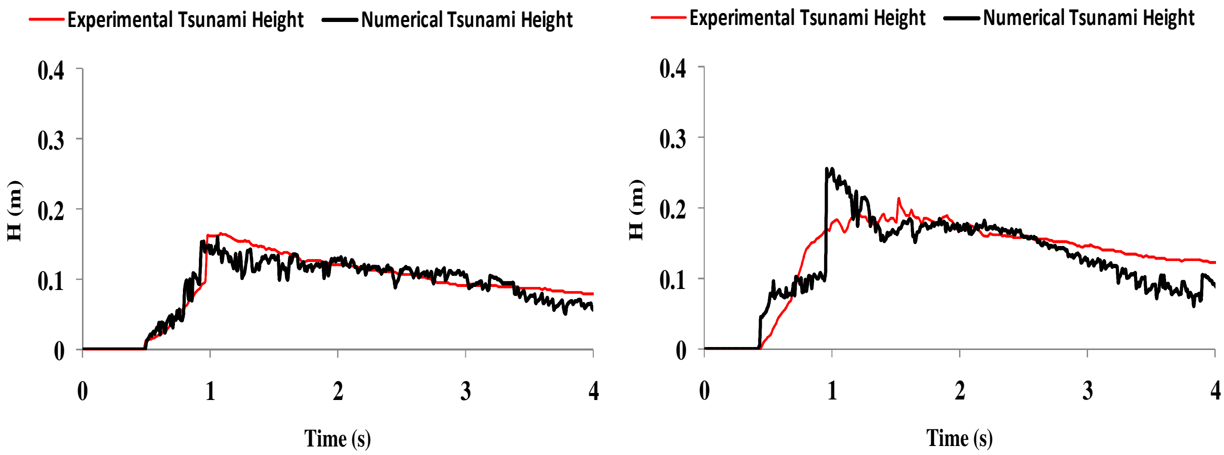


Figure 4. Pressure Time-History Comparisons on Different Pressure Sensors

5.3. Tsunami Bore Height in Front of the Building

Palermo and Nistor (2008) explained that the tsunami bore-induced pressure is for the surge impact, hydrodynamic and hydrostatic loading. Figure 5 shows the comparison of tsunami bore height in front of structure between experiment and numerical simulation, and it shows good agreement. Here only improved 3D-MPS method has been applied.



0.19 m Incident Wave Height **0.16 m Incident Wave**

Figure 5. Tsunami height time-history comparisons between experiment and numerical simulation.

5.4. Tsunami Bore Acting Phenomena Around the Building

Figure 6 exhibits the numerical simulation results of tsunami bore-structure interaction phenomena in different time steps. As the experiment has limitation to figure out this qualitative phenomenon, only numerical simulations have been applied. The height of tsunami bore proportional to the intensity of particle color. Tsunami bore makes breach behind the building model structure for some moments (phenomena in 0.79 s and 1.29 s). After that, it inundates the whole area around the building model structure (1.79 s). Then it moves towards the upstream and the tsunami bore height increases in front of the structure. Figure 7 shows the velocity field around the building model structure. It exhibits with different colors according to the velocity field. The velocity field around the building model structure shows decreasing pattern unlike the bore height in Figure 6. The bore velocity around the building model structure decreases whereas the height increases at the same moment. Tsunami bore impact pressure on the front section of the building model structure depends on both bore velocity and bore height. From the above explanation, it could have the information that at the beginning of the tsunami bore impact pressure on building model structure may largely depend on the bore velocity, however, after some moments, this dependency of bore impact pressure may proceed to the bore height.

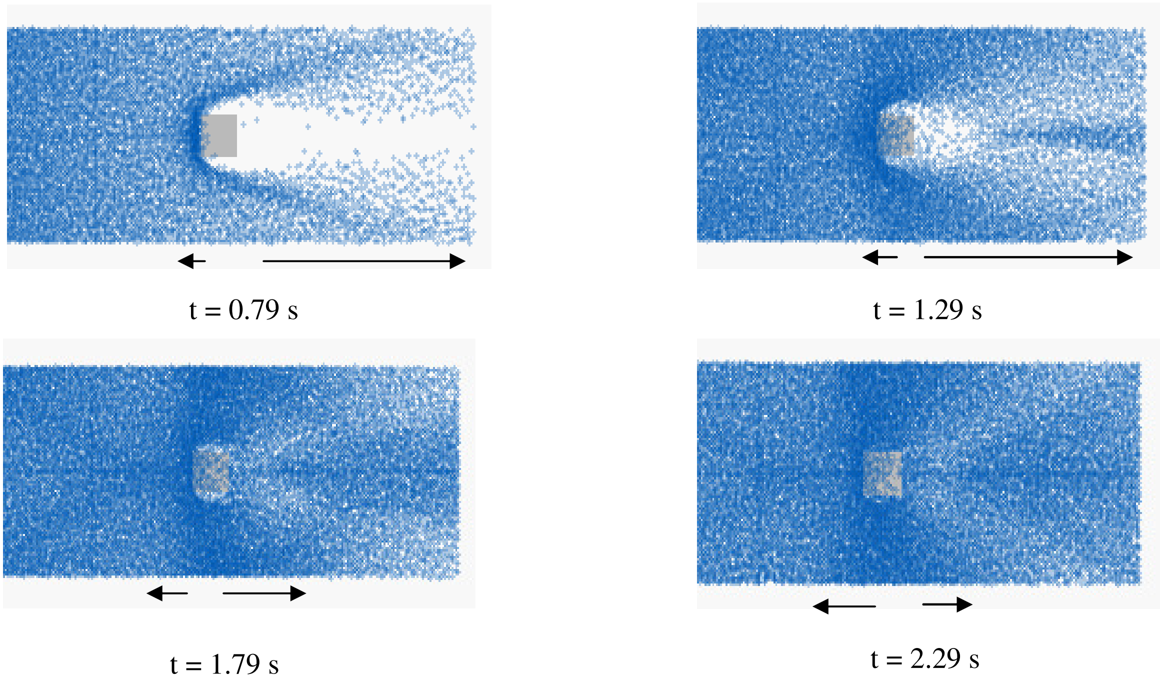


Figure 6. Top View of Tsunami Bore-Building Model Structure Interaction (Black Arrow Shows the Bore Direction).

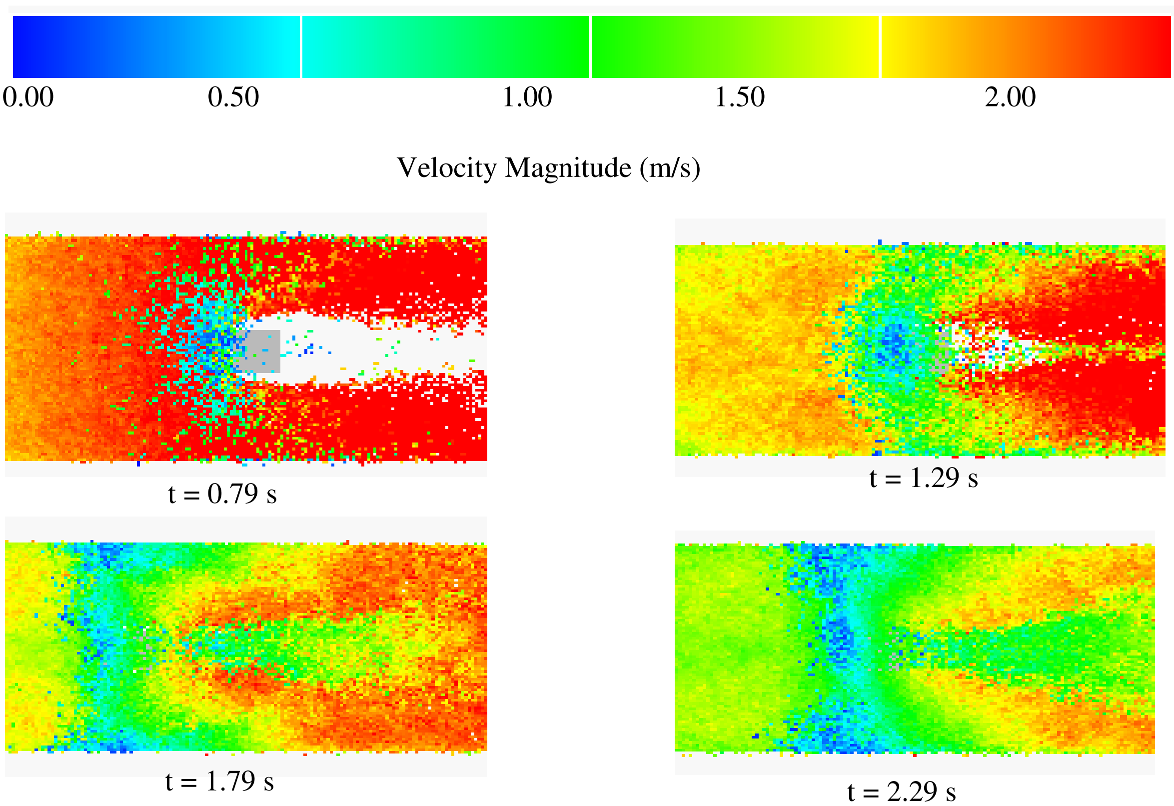


Figure 7. Tsunami Bore Velocity Field around the Building Model Structure.

6. CONCLUSIONS

Tsunami bore impact can cause terrifying effect on the coastal social and economical communities. Huge destructions have been experienced on the coastal houses and infrastructures due to the tsunami bore impact. This study exhibits the tsunami bore impact on the building structure by using both experimental and numerical simulations. The intensity of tsunami bore impact depends on initial tsunami height. The base of the building faces huge impact compare to the upper level. Improved numerical simulation method shows better agreement with the experimental results than that of the original one. The changes in impact pressure on the building model structure are due to the differences in the tsunami bore height and velocity around the building model structure. This study can give some tsunami bore destructive information, and thereby the tsunami bore mitigation information on the coastal infrastructures due to the tsunami bore by using experimental and verified numerical simulation results. Moreover, it can give information to design guidelines for building around coastal area.

REFERENCES

[1] Arnason, H., 2005. Interactions between incident bore and a free-standing coastal structure. Seattle: University of Washington, Ph.D. thesis, 172 p.

[2] Chanson, H., 2006. Tsunami surges on dry coastal plains: Application of dam break wave equations. *Coastal Engineering Journal*, 48(4), 355-370.

[3] Chen, X., 2011. Hydrodynamic loads on buildings caused by overtopping waves. The Netherlands: Delft University of Technology, Master's thesis, 104 p.

[4] Cross, R.H., 1967. Tsunami surge forces. *Journal of the Waterways and Harbor Division*, ASCE, 93(4), 201-231.

[5] Fukui, Y.; Nakamura, M.; Shiraishi, H., and Sasaki, Y., 1963. Hydraulic study on tsunami. *Coastal Engineering in Japan*, 6, 67-82.

[6] Ghobarah, A.; Saatcioglu, M., and Nistor, I., 2006. The impact of 26 December 2004 earthquake and tsunami on structures and infrastructure. *Engineering Structures*, Elsevier, 28, 312-326.

[7] Gomez-Gesteira, M. and Dalrymple, R.A., 2004. Using a three-dimensional smoothed particle hydrodynamic method for wave impact on a tall structure. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 130(2), 63-69.

[8] Iribe, T. and Nakaza, E., 2011. A study to improve accuracy of MPS method by a new gradient computation method. *Coastal Engineering Journal,* JSCE, 6(1), 36-48 (*in Japanese*).

[9] Iribe, T.; Nakaza, E.; Rusila, S.; Rahman M.M., and Seiya I., 2012. Estimations of impact wave force of tsunami acting on a vertical sea wall with MPS method. *33rd International Conference on Coastal Engineering* (Santander, Spain), ICCE, 33.

[10] Khayyer, A. and Gotoh, H., 2009. Modified moving particle semi-implicit methods for the prediction of 2D wave impact pressure. *Coastal Engineering Journal*, 56, 419-440.

[11] Koshizuka, S. and Oka, Y., 1996. Moving particle semi-implicit method for fragmentation of incompressible fluid. *Nuclear Science and Engineering,* 123, 421-434.

[12] Koshizuka, S.; Nobe, A., and Oka, Y., 1998. Numerical analysis of breaking waves using the moving particle semi-implicit method. *International Journal for Numerical Method in Fluid*, 26, 751-769.

[13] Lindt, J.W. van de.; Gupta R.; Cox D.T., and Wilson J.S., 2009. Wave Impact Study on a Residential Building. *Journal of Disaster Research*, 4(6), 419-426.

[14] Nakaza, E.; Iribe, T., and Rouf, M.A., 2010. Numerical simulation of tsunami currents around moving structures. *Proceedings of 32nd International Conference on Coastal Engineering* (Shanghai, China), ICCE, 32.

[15] Nakaza, E.; Iribe, T.; Rusila, S.; Rahman M.M., and Seiya I., 2012. Numerical simulation of the runup of solitary waves with the improved MPS method. *33rd International Conference on Coastal Engineering* (Santander, Spain), ICCE, 33.

[16] Nistor, I.; Palermo, D., and Cornett, A., 2010. Experimental and numerical modeling of tsunami loading on structures. *Proceedings of 32st International Conference on Coastal Engineering* (Shanghai, China).

[17] Nistor, I.; Palermo, D.; Al-Feasly, T., and Cornett, A., 2009. Modelling of tsunami-induced hydrodynamic forces on buildings. *33rd IAHR Biennial Congress* (Vancouver, BC).

[18] Nistor, I.; Saatcioglu, M., and Ghobarah, A., 2005. The 26 December 2004 Earthquake and tsunami - hydrodynamic forces on physical infrastructure in Thailand and Indonesia. *Proceedings 2005 Canadian Coastal Engineering Conference* (Halifax, Canada), pp. 1-15.

[19] Nouri, Y.; Nistor, I., and Palermo, D., 2010. Experimental investigation of tsunami impact on free standing structures. *Costal Engineering Journal,* JSCE, 52(1), 43-70.

[20] Palermo, D. and Nistor I., 2008. Understanding tsunami risk to structures: a Canadian perspective. *Science of Tsunami Hazards,* International Tsunami Society, 27(4), 1-11.

[21] Rahman, M.M.; Iribe, T., and Nakaza, E., 2012. Experimental study of the pressure acting on structures due to tsunami bore impact. *Proceedings of International Sessions in Coastal Engineering,* JSCE, 4, in press.

[22] Ramsden, J.D. and Raichlen F., 1990. Forces on vertical wall caused by incident bores. *Journal of Waterways, Port Coasts and Ocean Engineering*, 116, 592-613.

[23] Ramsden, J.D., 1996. Forces on a vertical wall due to long waves, bores, and dry-bed surges. *Journal of Waterways, Port Coasts and Ocean Engineering*, 122(3), 134-141.

[24] Shibata, K.; Koshizuka, S., and Tanizawa, K., 2009. Three-dimensional numerical analysis of shipping water onto a moving ship using a particle method. *Journal of Marine Science and Technology,* 14, 214-227.

[25] St-Germain, P.; Nistor, I.; Palermo, D., and Townsend R., 2011. SPH modeling of extreme hydrodynamic forces on slender structures. *34th International Association of Hydraulic Engineering (IAHR) Congress* (Brisbane, Australia).

[26] Yamamoto, Y.; Takanashi, H.; Hettiarachchi, S., and Samarawickrama, S., 2006. Verification of the destruction mechanism of structures in Sri Lanka and Thailand due to the Indian Ocean tsunami. *Coastal Engineering Journal*, JSCE, 48(2), 117-146.

[27] Anupam Rajmani and Priyabrata Guha, Analysis of Wind & Earthquake Load for Different Shapes of High Rise Building. International Journal of Civil Engineering and Technology (IJCIET), 6 (2) 2015, pp. 38–45.

[28] Yim, S.C., 2005. Experimental and numerical simulations of tsunami-structure interaction. *Proceedings of the 37th Joint Panel Meeting on Wind and Seismic Effects* (Tsukuba, Japan), pp. 41-50.

[29] Rajeev Sharma Harish Nagar and G P Singh, Accurate Numerical Simulation of Higher order Soliton Decomposition in Presence of Tod and Self- Steepening. International Journal of Advanced Research in Engineering and Technology (IJARET), 7 (1) 2016, pp. 54–59.