Numerical Simulation of Bore Type Tsunami Force Acting on the Cylindrical Structure

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1. Introduction

Tsunamis commonly amplify in the shallow water areas and will transfer into bore type after it breaks. Mizutani, S. and Imamura, F., [2001] pointed out that a hydrodynamic pressure due to bore type tsunami should be considered properly in a design of coastal structures. Moreover, through physical experiment, Fukui et al. [1962] underlined that the hydrodynamic pressure of bore type tsunamis were larger than one in gravity wave and it may cause impulsive force on structure. Therefore to reveal the impact, the investigation of bore force acting on the structure is needed.

Nowadays, next to physical experiment model, numerical simulation also offers as useful tools to gain more understanding in the hydrodynamic process, include tsunami phenomenon. The development in tsunami propagation models shows that volume of fluid (VOF) method has been proven to accurately compute numerical simulations on the route to practical purposes (Hieu, P.D. [2006]). Coastal Development of Institute of Technology had developed a numerical wave channel based on VOF method (CADMAS-SURF), and the wave channel is now extended into three-dimensional (3D) model. The model can conduct a 3D numerical analysis that includes the effect of free surface and wave breaking impact, as well as those that occur on tsunami phenomenon.

In case of bore type tsunami simulation, time history of wave surface elevation and fluid velocity are required as boundary condition to generate tsunami wave in this numerical wave channel. However, the difficulty is laid on the estimation of mean wave velocity priory for the wave profile. To overcome this problem, analytical equation is applied to estimate the fluid velocity under bore type tsunami. Firstly, this paper discusses the applicability of analytical equation with the verification of physical experiment, and follow by the discussion of wave pressure and wave force characteristic acting on the cylindrical structure.

2. Methodology

2.1. Physical Experiment

As seen on the Figure 1, an open channel of 12 m in length, 0.4 m in width and 0.4 m in height was used to record wave surface elevations, wave velocities and wave forces under bore type tsunami. At the downstream, a dike of 11 cm height was installed and a cylindrical structure of 15 cm in height with 11 cm in diameters was attached to beam and located above the dike. While at the upper side, a division plate was set to generate various height of bore type tsunami (*H1*) by instantly pulling up the division plate. Water level on the upper side of plate (*h1*) was changed in the range from 15 cm to 30cm, and while at the down side (*h2*) was set in 4.5cm.

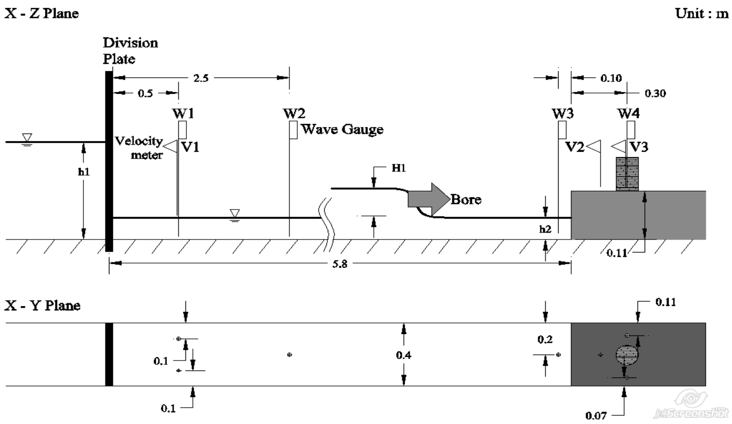

Figure 1. Experiment Setup (units in m)

In order to verify with numerical simulation, four wave gauges (*W1, W2, W3, W4*) and three velocity meters (*V1, V2, V3*) were placed on propagation area and run-up area. A strain-stress gauge was installed on the beam, which supports the cylinder, to measure the wave forces.

2.2. Numerical simulation

It is quite difficult to obtain fluid velocity under tsunami propagation in fields, because the velocity is rarely measured. On the other hand, the fluid velocity profile is indispensable to conduct a numerical simulation with CADMAS-SURF. In this study, we employed the following analytical equation which was derived by Fukui et.al [1962], to estimate the fluid velocity profile.

$$U = \frac{C\zeta}{H} = \zeta\sqrt{\frac{gH(H+h)}{2H(H+\eta\zeta)}} \qquad (1)$$

Where U is the mean velocity, g the acceleration of gravity, $H=h+\zeta$ the total depth from the datum, ζ the bore height, and η is the velocity coefficient which was taken from the ratio of water level and wave height.

3. Results and Discussions

With using Eq.1, the fluid velocity profile at Sta.1 was estimated from wave profile at the same location to get the input matrix data for CADMAS SURF 3D. Simulations were conducted in the same configuration as physical experiment with the output of wave surface elevations, fluid velocities and wave pressures in various sections. Wave pressures were recorded in two faces of cylindrical structure, e.g. front and side face, and three locations in each face, namely top (just below the water level), middle and bottom. Figure-2 shows the wave profiles obtained from physical experiments and numerical simulations. The bore type tsunami propagates with steep front face as shown in the profile at Sta.2 and the height increases at Sta.3 due to the effect of the dike. Figure-3 also shows the velocity profiles obtained from physical experiments and numerical simulations. The velocity increases quickly when the bore passes the gauge, and it shows the gradual decreasing tendency. From both figures, numerical results show fairly good agreements with physical experimental ones both in wave profile and fluid velocities. These results mean that Eq.1 provides an appropriate fluid velocity profiles to simulate the propagation of bore type tsunami. However, we confirmed that in some cases, the numerical model tend to slightly overestimate the wave profile and fluid velocity.

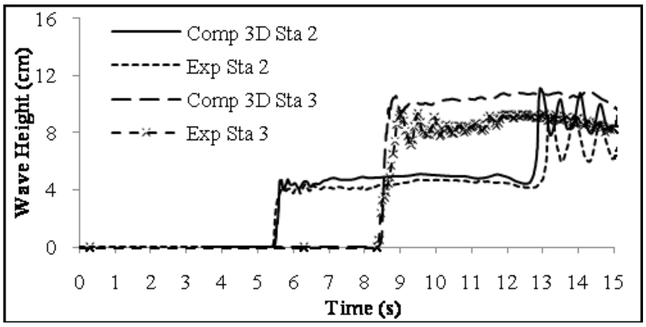

Figure 2. Wave Profile at Station 2 and 3

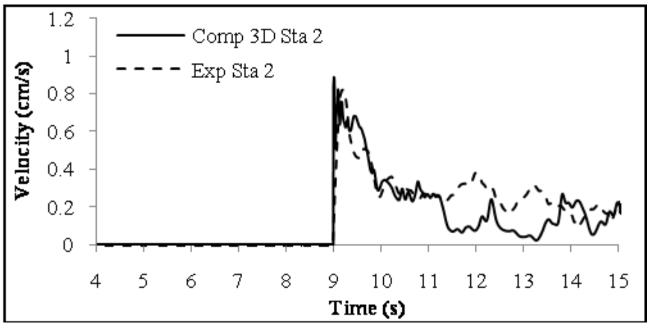

Figure 3. Fluid Velocity at Station 2

Figure-4 and Figure-5 show the wave pressure profiles at front face and side face. On the front face, the inundated bore type tsunami hit the cylinder impulsively, and the wave pressures at each location increase quickly. After the pressures take peak values, they decrease gradually to hydrostatic pressures. It can be seen that the wave pressure value and trend are same for top, middle and bottom sections. The wave pressure profiles include some sharp fluctuations like spike, and those fluctuations are considered coming from numerical instability.

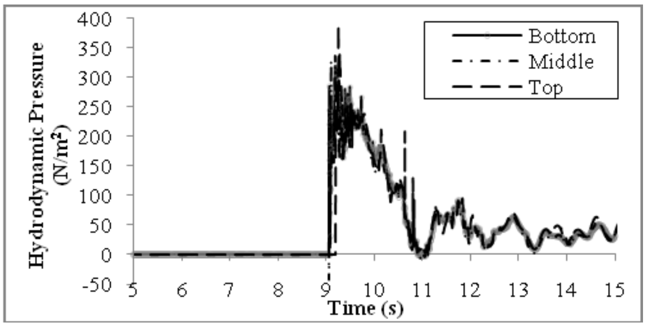

Figure 4. Hydrodynamic Pressure at Front Face

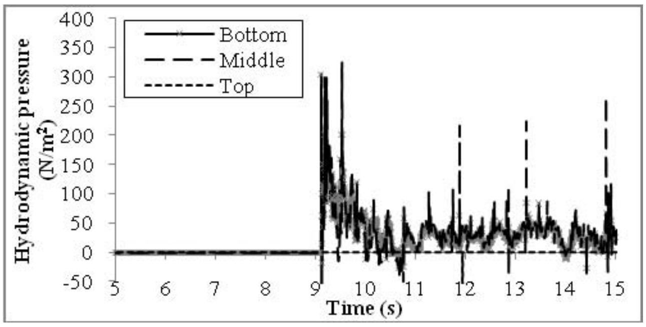

Figure 5. Hydrodynamic Pressure at Side Face

Figure-6 shows profiles of wave force acting on the cylinder. The wave force obtained from the numerical simulation was evaluated by integrating wave pressures on the cylinder. Maximum wave force shows good agreement between experimental result and numerical one. However, the difference of wave forces can be seen between an initial contact and maximum force in experiment. In this range, the numerical simulation overestimates the experimental wave force. The reason of this difference may be assumed as a difference of attaching method of cylindrical structure to the dike. The agreement of the wave force between numerical results and experimental ones should be investigated more in the other wave conditions.

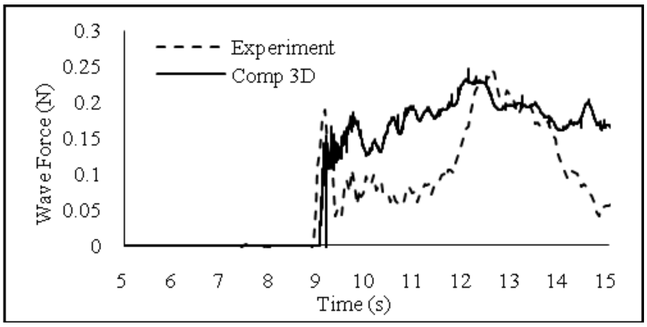

Figure 6. Wave Force

4. Conclusions

This study reveals the applicability of analytical equation to generate bore type tsunami in 3D numerical analysis. The results of numerical simulation showed fairly good agreement with experimental results in both wave profile and velocity one on the run-up area as well as on an offshore area. Moreover, this study shows the characteristics of hydrodynamic pressure and forces of bore type tsunami on the circular cylinder for bore type tsunami.

5. References

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[2] Hieu, P.D., [2006] "Verification of a VOF-based two phase flow model for wave breaking and wave-structure interactions". *Ocean Engineering 33*, pp.1565-1588, 2006, available online at www.sciencedirect.com

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