NUMERICAL MODELING OF DYNAMIC RESPONSE OF SUBMERGERD FLOATING BREAKWATER

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Introduction: Floating breakwaters propose a better alternative solution to the traditional fixed breakwaters due to numbers of advantages, e.g. less impact on surrounding environment, lower cost, convenience of transportation and installation. Most floating breakwaters are made up of rectangular floating body, and moored to the seabed with cables or chains. The main criterion for designing floating breakwater is the ability or efficiency of reducing the transmitted energy by means of reflection, dissipation and wave breaking. However, wave energy is a highly promising renewable energy source which is expected to provide a small but significant proportion of future energy requirements without adding to pollution and global warming. Based on the concept of multi-objective and optimal utilization, a submerged floating breakwater type wave energy converter is proposed, which has two obvious advantages: 1) possibility of sharing cost; 2) improvement of performance due to energy absorption. This paper presents the dynamic analysis of the wave energy converter employing a numerical model of immersed boundary (IB) method and volume of fluid (VOF) method.

Experimental and Numerical investigation: To investigate the performance of the floating breakwater for the new type wave energy converter, experiments are carried out in a two-dimensional wave tank (Figure 1) at Nagoya University. Special mooring system is adopted in order to harvest more wave energy, which includes one impermeable plate on the offshore side and one perforated plate on the onshore side. In addition, numbers of springs are installed to simulate the resistance from the electricity generator. At the same time, a two-dimensional numerical model is developed to analyze the problem numerically and extend the modeling to various wave conditions and configurations. We used IB-VOF method [Lee and Mizutani, 2009], which is composed of the IB method for treating the floating breakwater and the VOF method for tracking the free surface, to calculate the interactions between the floating structure and wave. In the IB method, Physical Virtual Model (PVM) [Lima E Silva et al., 2003] is used to calculate the force field over a sequence of Lagrangian points, which represent the interface. Two-step projection [Chorin, 1968] method is applied to solve the governing equations including the continuity equation, the Navier-Stokes equation for viscous and incompressible fluid and the advection equation that represents the behavior of the free surface.

More importantly, the dynamic properties of the submerged floating breakwater due to its interaction with wave are formulated (Figure 2). The wave forces acting on the surfaces of the breakwater are calculated by integrating the pressures on the corresponding surface [Rahman, 2005]. In this study, three degrees of freedom for the motion of floating breakwater including rotational displacement with respect to horizontal axis (roll), displacement in horizontal direction (sway) and vertical direction (heave) are considered. For the floating body, considering the moments acting on the centre of gravity, resultant horizontal and vertical force acting on the body, the following equations can be presented.

$$\sum M_{c.g} = J_{FB}\alpha_{FB} \quad (1) \qquad \sum F_X = m\alpha_x \quad (2) \qquad \sum F_Z = m\alpha_z \quad (3)$$

For the mooring plates, considering the moments acting on the anchoring point at the bottom of wave tank, the following equations can be proposed.

$$\sum M_{mp1} = J_{mp1}\alpha_{MP1} \quad (4) \qquad \sum M_{mp2} = J_{mp2}\alpha_{MP2} \quad (5)$$

where, J_{FB}, J_{mp1}, J_{mp2} are the mass moments of inertia of the floating body, impermeable plate and perforated plate respectively; α_{FB}, α_{MP1}, α_{MP2} are the angular accelerations; α_x, α_z is the accelerations in X and Z direction; m is the mass of floating body.

Additionally, four more equations can be derived from the geometry relationship between floating body and mooring plates because the lengths of the mooring plates are constant. Then nine parameters including *T1, T2, T3, T4*, α_{FB}, α_x, α_z, α_{MP1}, α_{MP2} can be solved simultaneously.

Results and Conclusions: The results of experimental studies show that the floating breakwater type wave energy converter can significantly attenuate the wave heights transmitted to the shore. The mooring plates also contribute to the energy extraction compared with the chain system. Further experiments will be implemented soon to estimate the field energy output under different wave conditions employing a special gear system and small-scale electricity generation.

Numerical model results for sway and roll of motions of floating body are shown in Figure 3 and 4, respectively. This case is just a simple case; the mooring type is still chain. The aim of this numerical experiment is to estimate the performance of developed model in modeling the motion of floating body. The experimental data are compared with the numerical results to verify the proposed model. The results show a good agreement between them. Due to the smaller order of magnitude, the experiment data of heave motion are greatly influenced by the measure noise in that case. For the next step, the mooring plates will be coupled in the numerical model and heave motion will be investigated using cases in further experiments. More results are expected to be displayed in the presentation for the conference.

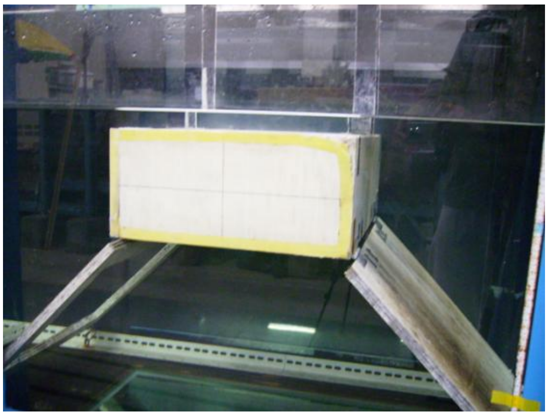

Fig. 1 Side view of the floating breakwater set up at the wave tank

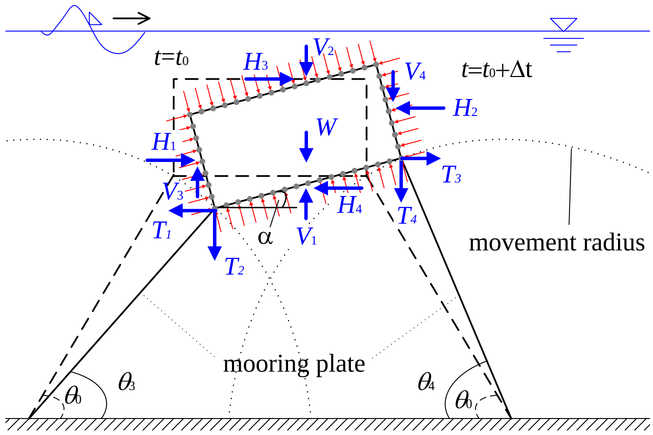

Fig. 2 Dynamic analysis of the floating body during its interaction with wave

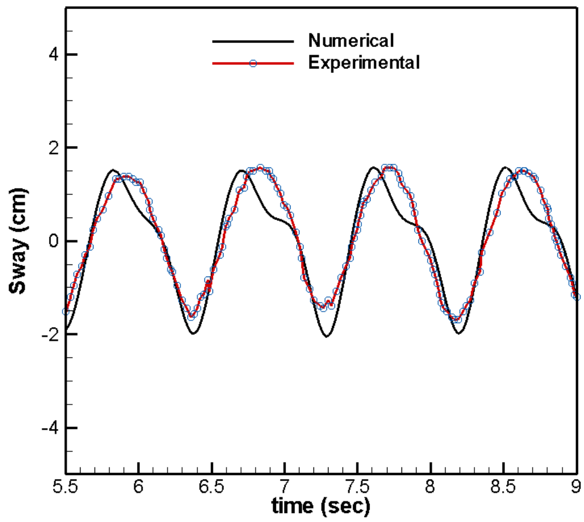

Fig. 3 Comparison of numerical and experimental results of the sway of the floating body (H=3.8cm, T=0.9sec, h=65cm)

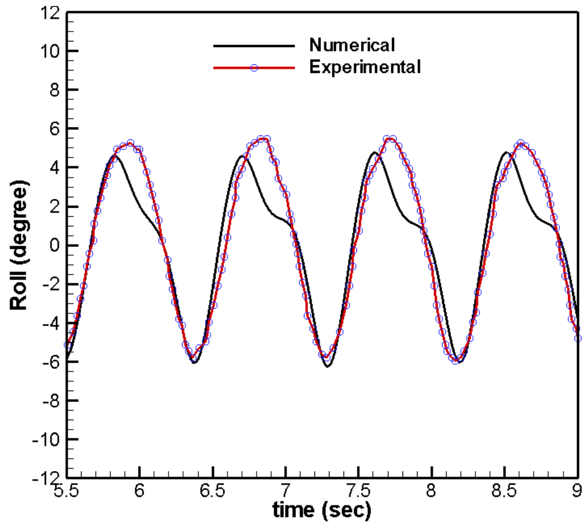

Fig. 4 Comparison of numerical and experimental results of the roll of the floating body (H=3.8cm, T=0.9sec, h=65cm)

References: (1) Lima e Silva, A. L. F., A. Silveria-Neto and J. J. R. Damasceno (2003): J. Comp. Phys., Vol. 189, pp. 351-370; (2) Lee, K. H. and N. Mizutani (2009): Coastal Eng. Journal, Vol. 51, pp. 27-48; (3) Md. Ataur Rahman: PhD thesis, Nagoya University , 2005.(4) Chorin, A.J. (1968): Numerical solution of the Navier-Stokes equations, Math. Comp., Vol. 22, pp.745-762.