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論文

Hydrodynamic Forces Acting on the Submerged-Plate

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ABSTRACT : *The hydrodynamic forces acting on the submerged plate are composed of diffraction and radiation forces. Thus we have carried out the extensive experiments and numerical simulations to make clear the characteristics of the diffraction and radiation forces on the submerged plate. These experimental results are compared with the numerical ones, and we discuss the effect of nonlinear on the hydrodynamic forces acting on the submerged plate. As a result, we get the conclusion that the submerged plate is useful for reducing the wave exciting forces on the structure behind the submerged plate.*

KEY WORDS : *VLFS, submerged-plate, wave exciting force, radiation force, composite grid method*

1. INTRODUCTION

A new type floating breakwater system has been proposed for extending the operational area of VLFS to deeper sea with reducing environmental problems (Takaki et al., 2001). The system consists of Floating Breakwater using Submerged Plate(FBSP) and a VLFS with attached submerged plate. The submerged plate built into VLFS is called as the third submerged plate. The hydrodynamic forces acting on the submerged plate are composed of diffraction and radiation forces. Thus we have carried out the extensive experiments and numerical simulations to make clear the characteristics of the diffraction and radiation forces on the submerged plate. These experimental results are compared with the numerical ones, and we discuss the effect of nonlinear on the hydrodynamic forces acting on the submerged plate. As a result, we get the conclusion that the submerged plate is useful for reducing the wave exciting forces on the structure behind the submerged plate.

2. WAVE EXCITING FORCES

2.1 EXPERIMENTS

The experiments were carried out in the two-dimensional wave tank to understand the characteristics of the wave exciting forces using the 1/50 scale model of the third submerged plate. The test setup is shown in Fig.1. The tests were done every 0.141sec. from the period of 0.984 to 2.828sec. in regular waves with the wave amplitude of 10mm and 30mm respectively. We assume that the fore end part of VLFS is corresponding to the first float unit in the first float unit in the weather side. We measured the wave exciting forces for heave on the submerged plate and on the fore part of VLFS with/without submerged plate. Furthermore, we have performed the numerical simulation based on the MAC method.

2.2 DISCUSSION OF WAVE EXCITING FORCES

Fig.2 shows the wave exciting forces for heave acting on the submerged plate built into VLFS. The experimental results show the first order component to the 5th order component. We can observe that the first order components are dominant, thus we discuss only the first order components of the wave exciting forces in this study. It is noted that the results become constant with increase the wave periods.

Fig.3 shows the wave exciting forces for heave acting on the fore part of VLFS. The wave exciting forces with the submerged plate decrease much less than the ones without it in the condition with the large wave amplitude of a=30mm and the short wave periods

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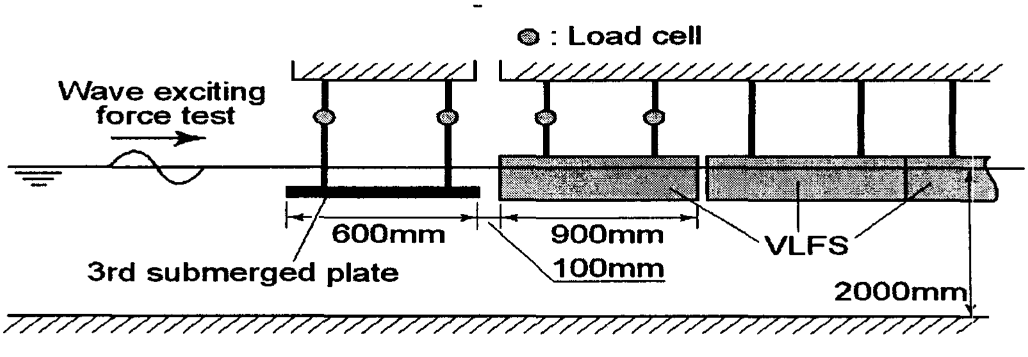


Fig. 1 Test setup of 2-D tank test for submerged plate

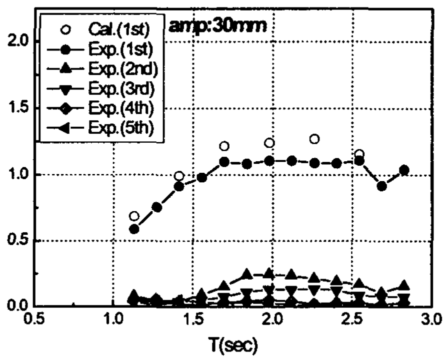


Fig.2 Wave exciting force on sub-plate

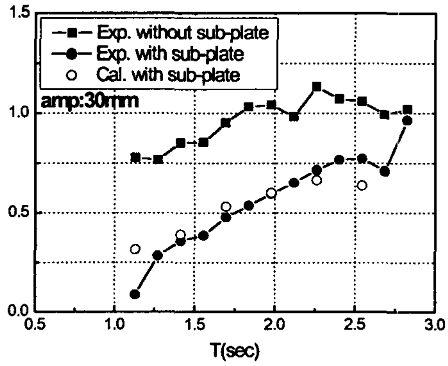


Fig.3 Wave exciting force on VLFS

because of breaking waves. As the wave periods become longer, the values of the wave exciting forces acting on VLFS with the submerged plate become closer the ones without it. This is why the long waves pass through the submerged plate without breaking waves. The numerical results are in good agreement with the experimental ones irrespective of the wave amplitude and periods.

In order to discuss the effect of the submerged plate on the wave exciting forces on VLFS, we define the reduction factor of them as follows

$$R = 1\text{-}A/B, \qquad (1)$$

where, A : wave exciting force on VLFS with the submerged plate.

B : wave exciting force on VLFS without the submerged plate.

This equation means that the submerged plate reduces strongly the wave exciting forces on VLFS, as the value of R becomes higher. The reduction factor R is shown in Fig.4. The value of R increases, as the wave period decreases. The reduction of elastic deflection amplitude of VLFS shows the same tendency at the reduction factors of the wave exciting forces. Therefore, it is seemed that the elastic deflection is

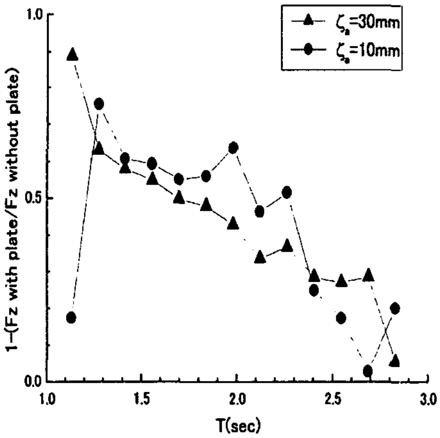


Fig.4 Reduction factor of wave exciting forces

influenced by the reduction of wave exciting force due to the submerged plate, especially for the short wave period.

3. RADIATION FORCES

3.1 NUMERICAL METHOD

In case of the radiation problem, it is difficult to deal with the relative motion between the moving body and

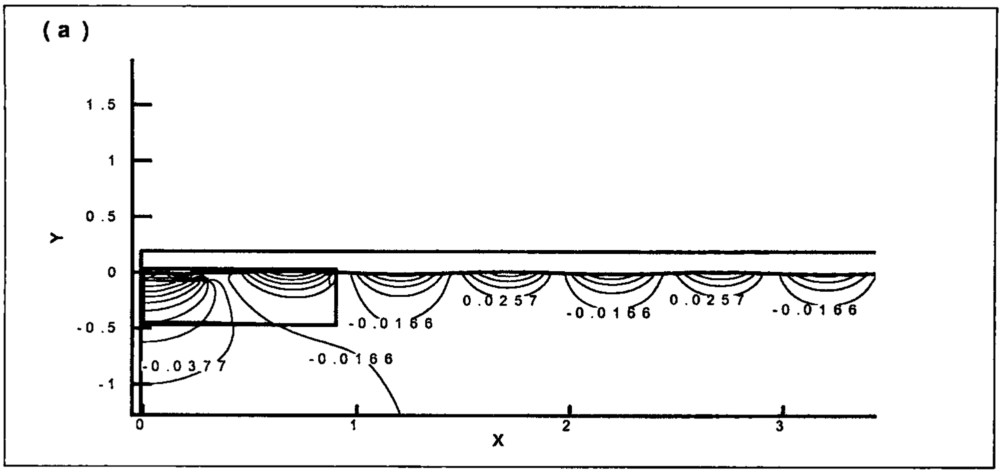


Fig.5 Pressure contour of the submerged plate for T=0.8sec., d=40mm, z_a=10mm

free surface. Thus we have developed a composite grid method for the solution of the radiation force. We divide the domain into two different grids; one is a moving grid system and the other is a fixed grid system. The moving grid is employed the body fitted coordinate system. The pressures are computed simultaneously on the entire flow field until convergence, while the momentum equations are solved independently on each sub-domain. Schwarz proposed an alternating solution procedure for elliptic function problems(Hinatsu et al.(1991)). Therefore the Schwarz iteration is used to calculate the pressure equation over the composite grids.

The Newton-Raphson interpolation method is employed at the different grids to transmit the flow data from one grid to another. The overlap regions change with time and the flagging of all the grid points of both grids is performed after each time step. In the overlap region, boundary conditions for one grid are obtained by interpolating from the other grid. The interpolated data can be expressed by

$$\phi = (1-X)(1-Y)\phi_A + X(1-Y)\phi_B + XY\phi_C + (1-X)Y\phi_D \quad (2)$$

where ϕ is the interpolated flow data, ϕ_A, ϕ_B, ϕ_C and ϕ_D are the value at the corner A, B, C and D of the cell, respectively. (X,Y) is the local coordinate of the interpolation point in the transformed system obtained by solving the following equations;

$$x = (1-X)(1-Y)x_A + X(1-Y)x_B + XYx_C + (1-X)Yx_D \quad (3)$$

$$y = (1-X)(1-Y)y_A + X(1-Y)y_B + XYy_C + (1-X)Yy_D \quad (4)$$

where (x,y) are the physical coordinates of the interpolated point.

The governing equations are the Navier-Stokes equation and the continuity equation for 2-dimensional, incompressible and viscous fluid. They can be written as

$$\nabla \cdot U = 0 \quad (5)$$

$$\frac{\partial U}{\partial t} + \nabla \cdot (U-V)U = -\frac{\nabla P}{\rho} + \nu \nabla^2 U - g \quad (6)$$

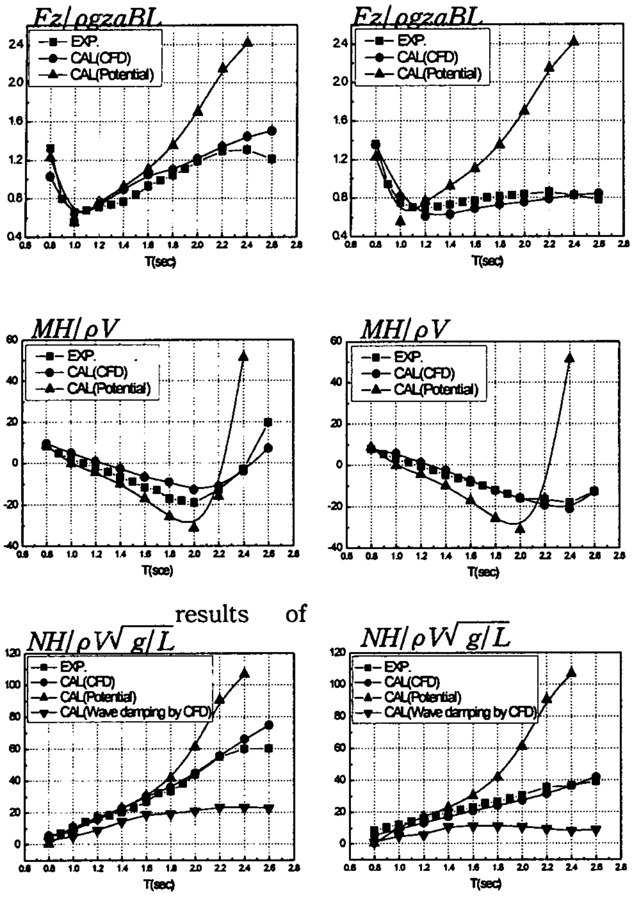
where $U=(u,w)$ is the fluid velocity vector, V is the moving grid velocity, and ν is the kinematic viscosity. By comparing with the fixed grid system, the velocity of moving grid is included in the convective terms (Demirdzic et al.,1990). The same equations and discretization methods which are based on the modified *TUMMAC-Vwv* apply to both the fixed and moving grids. Zero-normal gradient conditions are given for the velocity and the pressure at the bottom and outflow boundaries of the computational domain. We assume the axis symmetry condition on the center of entire domain. On the body surface, no flux and no slip conditions are imposed by

$$u = 0 \;\; ; \;\; w = z_a \omega \cos(\omega t) \quad (7)$$

3.2 RESULTS AND DISCUSSION

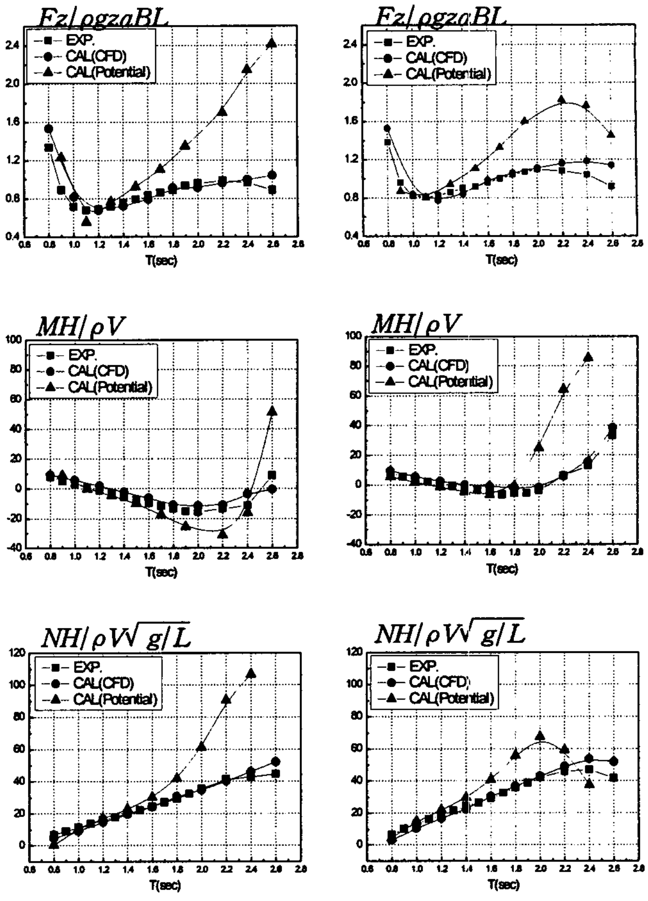
In order to investigate the characteristics of the radiation forces, we have performed the forced heaving tests for the 1/50 scale model under the different test conditions; d = 20, 40 and 60 mm, za = 10, 20 and 30 mm, T = 0.8-2.6 seconds. Fig.5 shows the pressure contour of the submerged plate corresponding to the short oscillation period , it has been shown that the radiation waves are properly propagated to outward direction.

Fig.6 shows the heaving radiation force(*FZ*), added mass(*MH*) and damping force coefficients(*NH*) correspond to the different amplitude(za=10 and 30mm) at same submergence depth(d =40mm). We compare the



z_a=10mm z_a=30mm

Fig.6 Comparison of heave radiation force, added mass and damping force coefficient for d=40mm



d=40mm d=60mm

Fig.7 Comparison of heave radiation force, added mass and damping force coefficient for z_a=20mm

results of numerical simulation(CFD), linear potential theory and experiments in Fig. 6 and 7. By comparing these results, the results due to the numerical simulation based on the composite grid method agree well with the experimental ones regardless of the amplitude and oscillation periods.

On the other hand, we notice that the linear theory results considerably deviate from others at the long oscillation periods. In general, it is noted that the differences between the linear theory and experiments increase at the large amplitude(za =30mm). It can be observed that the components of viscous damping force are larger than those of wave damping force at the long oscillation periods. In summary, these results seem to confirm that the effect of viscosity on the hydrodynamic force is significant at the long oscillation periods. We can observe that the added mass takes negative value for intermediate oscillation periods. Negative added mass means that the increase of restoring force. Therefore the submerged plate has the effect of reducing the hydroelastic deformation of VLFS for longer waves.

The heaving radiation force(FZ), added mass(MH) and damping force coefficients(NH) are shown in Fig.7 for the different submergence depth(d)=40 and 60mm at same amplitude(za=20mm). We notice that the deviations of linear theory results become larger with decrease of submergence depth. This means that the radiation force is highly nonlinear at the long oscillation periods when the plate is slightly submerged. We can also observe the negative added mass for the intermediate oscillation periods at the shallow submergence depth(d= 40mm).

5. CONCLUSION

We have carried out the experiments to understand the characteristics of the wave exciting forces and radiation forces acting on the submerged plate. Furthermore, we have performed the numerical simulation by applying the composite grid method, and the simulation results show the good agreement with experimental ones. We confirm that the submerged plate is useful for reducing the wave exciting forces on the structure behind the submerged plate. Finally, we have evaluated the viscosity effect on the hydrodynamic forces, and we notice that it is significant at long oscillation periods.

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