International Journal of Navigation and Port Research
Vol.31, No.7 pp. 569~578, 2007 (ISSN-1598-5725)

Hydroelastic Response of VLFS with Submerged-Plate Using Modified Hydrodynamic Coefficients

† *Sang-Min Lee**

* *Dept. of Marine Science & Production, Kunsan National University, Kusan 573-701, Republic. of Korea*

Abstract : *The primary objective of this study is to present a modified method of hydroelastic analysis and application of it to the VLFS with submerged plate. The modal analysis method is applied to the VLFS with the submerged plate using the modified hydrodynamic coefficients. Namely, the wave exciting forces are modified by the transmission wave coefficients, while the interaction factor is used for the modification of radiation forces. To validate the proposed method, comparisons between the numerical calculations and experimental data have been carried out for the deflections of VLFS, and it shows good agreement between the calculation and experiment. The results presented in this study demonstrate that the elastic response of the VLFS is strongly affected by the hydrodynamic interaction induced by the submerged plate. As a result, we can confirm that the submerged plate is useful for reducing the hydroelastic deflection of VLFS, and the proposed method is valuable for predicting the elastic response of VLFS with attached the submerged plate.*

Key words : *Hydroelasticity, VLFS, Submerged plate, Wave exciting forces, Radiation forces, Modified hydrodynamic coefficients*

1. Introduction

Wave-induced motions and loads on pontoon-type floating airport proposed in Japan have been extensively investigated by linear hydroelastic theory. Many studies have been performed where various methods, such as panel method (Maniar and Newman, 1996), modal expansion method (Lin and Takaki, 1998) and application of ray theory (Takagi and Kohara, 2000) have been used successfully in the numerical analysis of the response of VLFS in waves. In order to reduce the undesirable deflection of VLFS, a device has been developed, which is the submerged plate attached to the weather side of VLFS with a clearance gap. In case of the VLFS without the submerged plate, the numerical methods to determine the elastic response of VLFS have been already proposed (Takaki and Gu, 1996). These numerical methods could estimate accurately the motion of VLFS without the submerged plate. However, it is necessary to predict the hydrodynamic interaction effects between the VLFS and the submerged plate because these effects are affecting to the other structure and the fluid motions around the submerged plate become highly nonlinear behaviors. Thus, we have to modify the hydrodynamic coefficients on the VLFS considering the interference influence induced by the submerged plate. In this study, the hydroelastic behaviors of VLFS with submerged plate are analyzed by applying the modified hydrodynamic coefficients. The analysis techniques for response of VLFS are based on the hydroelasticity, in which the coupled hydrodynamics and structural dynamics problems are solved simultaneously.
The motion equation for a elastic structure has been solved by using the *Lagrange*'s equation that ensures the satisfaction of energy conservation principle. The unknown deflection and hydrodynamic pressure of the structure are both discretized with bi-cubic B-spline function. The B-spline expressions of the dry-eigenmodes of the structure are obtained by solving the eigenvalue problem of the proposed motion equation (Lin and Takaki, 1998). Hydrodynamic pressures due to the structure motion and incident waves are calculated by applying the pressure distribution method (Yamashita, 1979) with the resultant eigenmodes. The usage of B-spline discretization for hydrodynamic pressure makes it possible to predict the hydroelastic response in very short wavelength cases.

The primary objective of this study is to present a modified method of hydroelastic analysis and application of it to the VLFS with submerged plate. The modal analysis method is applied to the VLFS with the submerged plate using the modified hydrodynamic coefficients. Namely, the wave exciting forces are modified by the transmission wave coefficients, while the interaction factor is used for the modification of radiation forces. To validate the proposed method, comparisons between the numerical calculations and experimental data have been carried out for the deflections of VLFS, and it shows good agreement

† Corresponding Author : smlee@kunsan.ac.kr 063)469-1814

between the calculation and experiment. Finally, the effect of submerged plate for reducing the elastic deflection is discussed from the view point of hydrodynamic forces.

2. Hydrodynamic pressure

The size of the floating structure considered in this study is several kilometers in length and about one kilometer in width, and in comparison with these scales the depth of the structure is only a few meters. Therefore we simplify the structure to an elastic plate floating on the free surface. In addition, the displacement of the structure along horizontal direction will be very small comparing with that along the vertical direction and will be neglected in this study. Therefore, deflection vector of the structure, $\boldsymbol{W}(x,y;t)$, is given by

$$\boldsymbol{W}(x,y;t) = W(x,y;t)\boldsymbol{e}_z \tag{1}$$

The coordinate system and the sketch of the structure are shown in Fig. 1.

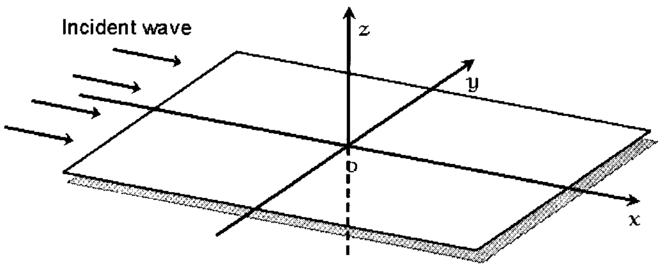


Fig. 1 Coordinate system and notations

In this method, the structure is discretized into a number of B-spline elements. The unknown vertical deflection W is represented by fourth order bi-cubic B-spline functions. The deflection vector is given in a form of

$$\boldsymbol{W}(x,y;t) = \Re\left[\varsigma_a \sum_l \alpha^l B_l(x,y)e^{i\omega t}\right]\boldsymbol{e}_z \tag{2}$$

Where $B_l(x,y)$ is the product of B-spline basis functions with respective to x and y, and α^l denotes the unknown polygon vector. Substituting this expression into *Lagrange*'s equation and omitting the l -th generalized forcing term F_l, we get the following generalized eigenvalue problem

$$\lfloor\tilde{K}\rfloor\{\alpha\} = \lambda\lfloor\tilde{M}\rfloor\{\alpha\} \tag{3}$$

The expressions of matrices $\lfloor\tilde{M}\rfloor$ and $\lfloor\tilde{K}\rfloor$ are given in the form of

$$\tilde{M}_{ij} = \rho d\iint_{S_h} B_i(x,y)B_j(x,y)ds, \tag{4}$$

$$\tilde{K}_{ij} = D\iint_{S_h}\left\{\frac{\partial^2 B_i}{\partial x^2}\frac{\partial^2 B_j}{\partial x^2}+\frac{\partial^2 B_i}{\partial y^2}\frac{\partial^2 B_j}{\partial y^2} +\upsilon\left(\frac{\partial^2 B_i}{\partial x^2}\frac{\partial^2 B_j}{\partial y^2}+\frac{\partial^2 B_i}{\partial y^2}\frac{\partial^2 B_j}{\partial x^2}\right) +2(1-\upsilon)\frac{\partial^2 B_i}{\partial x\partial y}\frac{\partial^2 B_j}{\partial x\partial y}\right\}ds \tag{5}$$

By solving this eigenvalue problem, we can obtain the shape functions of dry-eigenmodes of the structure. The r-th eigenmode can be expressed in term of the r-th eigenvector $\{\alpha_r\}$ like

$$w_r(x,y) = \sum_l \alpha_r^l B_l(x,y) \tag{6}$$

Time harmonic motions of fluid field and the VLFS will be induced by regular incident waves. We can express the velocity potential in the fluid field, Φ, pressure distribution on the bottom of the VLFS, P, and vertical deflection of the structure, W, in following forms

$$\Phi(r,t) = \Re\left[i\omega\varsigma_a\phi(r)e^{i\omega t}\right], \tag{7}$$

$$P(x,y;t) = \Re\left[\rho g\varsigma_a p(x,y)e^{i\omega t}\right], \tag{8}$$

$$W(x,y;t) = \Re\left[\varsigma_a w(x,y)e^{i\omega t}\right] \tag{9}$$

where $\boldsymbol{r}=(x,y,z)$, ω is the circular frequency, ς_a is the amplitude of the incident wave, ρ is the fluid density and g is the gravitational acceleration. Their spatial components are given by

$$\phi = \phi_I(\boldsymbol{r}) + \phi_D(\boldsymbol{r}) + \sum_r \frac{q^r}{\varsigma_a}\phi_r(\boldsymbol{r}) \tag{10}$$

$$p = p_I(x,y) + p_D(x,y) + \sum_r \frac{q^r}{\varsigma_a}p_r(x,y), \tag{11}$$

$$w = w_I(x,y) + w_D(x,y) + \sum_r \frac{q^r}{\varsigma_a}w_r(x,y) \tag{12}$$

Suffix I represents the quantities with respective to the incident wave, and suffix D is to the scattering component. w_r is the shape function of the r-th eigenmode, q^r is its complex amplitude, and p_r is the radiation pressure on the bottom due to the motion of the r-th eigenmode with unit amplitude. The potential function $\phi(x,y,z)$ must satisfy the following boundary conditions,

$$\left.\begin{array}{llll} \nabla^2\phi & = 0 & in & \Omega \\ K\phi-\dfrac{\partial\phi}{\partial z} & = 0 & on & S_F \\ K\phi-\dfrac{\partial\phi}{\partial z} & = -p & on & S_H \\ \dfrac{\partial\phi}{\partial z} & = 0 & on & S_B \end{array}\right\} \quad (13)$$

The incident potential ϕ_I is given by

$$\phi_I(x,y,z) = \frac{1}{K}e^{Kz-iK(x\cos\theta+y\sin\theta)} \quad (14)$$

We apply the pressure distribution method to determine the pressure distributions of the diffraction and radiation problems. Using the pressure distribution method, the velocity potential in fluid domain can be determined by an integral over the wetted surface S_h

$$\phi\ (\boldsymbol{r}) = -\iint_{S_h} p\ (\boldsymbol{r}')\ G\ (\boldsymbol{r},\boldsymbol{r}')\ ds \quad (15)$$

where $\boldsymbol{r}=(x,y,z)$ and $\boldsymbol{r}'=(\xi,\eta,0)$ represent the field point and source point respectively. *Green*'s function for finite water depth h is given by

$$G\ (\boldsymbol{r},\boldsymbol{r}') = \frac{1}{2\pi}\lim_{\mu\to 0}\int_0^\infty \frac{\cosh k(z+h)J_0(kR)k}{k\sinh kh-(K-i\mu)\cosh kh}dk \quad (16)$$

where $R=\sqrt{(x-\xi)^2+(y-\eta)^2}$, $K=\omega^2/g$ and J_0 is the *Bessel Function* of the zero-th order. The pressure distributions on the bottom of the VLFS must satisfy equation

$$\begin{aligned} p_r\ (\boldsymbol{r}) + K\iint_{S_h} p_r\ (\boldsymbol{r}')\ G\ (|\boldsymbol{r}-\boldsymbol{r}'|)\ ds &= -w_r\ (\boldsymbol{r}) \\ p_D\ (\boldsymbol{r}) + K\iint_{S_h} p_D\ (\boldsymbol{r}')\ G\ (|\boldsymbol{r}-\boldsymbol{r}'|)\ ds &= w_I\ (\boldsymbol{r}) \end{aligned} \quad (17)$$

Notice that $\boldsymbol{r}$ is also on the bottom of the plate in this equation, we can rewrite *Green*'s function in the form of $G(\boldsymbol{r},\boldsymbol{r}') = G\ (|\boldsymbol{r}-\boldsymbol{r}'|)$. Boundary integral equation (17) is solved with B-spline Galerkin panel quadrature. Similar to the discretization of the deflection, we discretize the pressure due to the r-th radiation motion in terms of bi-cubic B-spline functions

$$p_r(x,y) = \sum_i \beta_r^i B_i(x,y) \quad (18)$$

To obtain the i-th unknown polygon β_r^i, we substitute this expression into equation (17), multiply the equation by $B_i(x,y)$ and make an integral over the bottom surface S_h. This procedure leads to a linear system of simultaneous equations

$$\sum_j [T_{ij}+KG_{ij}]\beta_r^j = -W_i \quad (19)$$

where

$$\begin{aligned} T_{ij} &= \iint_{S_h} B_i(x,y)B_j(x,y)dxdy, \\ G_{ij} &= \iint_{S_h} B_i(x,y)\left[\iint_{S_h} B_j(\xi,\eta)G(|r-r'|)d\xi d\eta\right]dxdy, \\ W_i &= \iint_{S_h} B_i(x,y)w_r(x,y)dxdy \end{aligned} \quad (20)$$

We estimate the radiation pressure p_r by solving equation (19). The scattering pressure p_D can be determined in exactly the same way. Then we will determine the amplitudes of the motion of each radiation freedom, q^r/ς_a, with the resultant pressure distributions p_D and p_r.

3. Motion equation

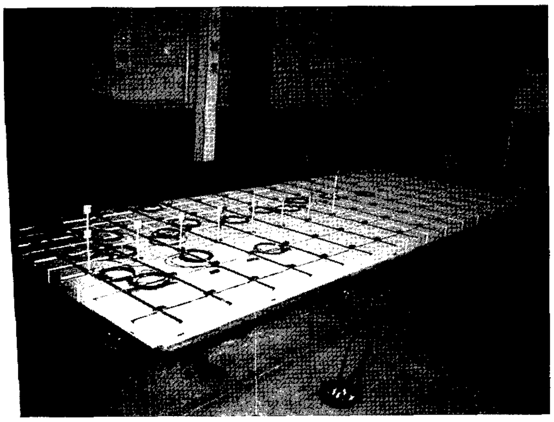
We apply *Lagrange*'s equations to obtain the motion equation of the structure. *Lagrange*'s equations represent the energy conservation principle of the structure and have general forms of

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}^r}\right)-\frac{\partial T}{\partial q^r}+\frac{\partial U}{\partial q^r} = F_r \quad (21)$$

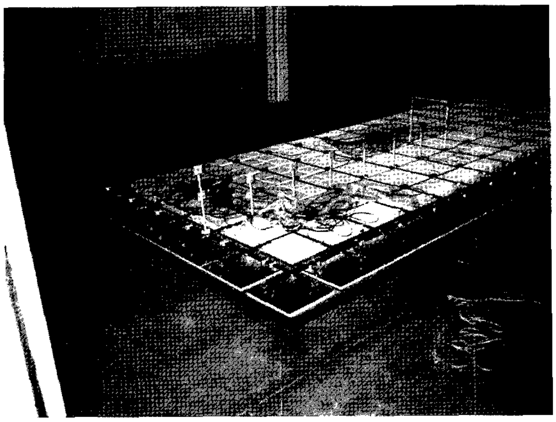
where

q^r : the r-th generalized coordinate,

T : kinetic energy of the structure,



(a) Without submerged plate



(b) With submerged plate

Fig. 2 VLFS model with and without submerged plate

U : deformation potential energy of the structure,

F_r : the r-th generalized force.

T, U and F_r are all the functions of structural deflection. To a structure, we can generally define its deflection by a vector

$$W(r, t) = \sum_r q^r(t) \; W_r(r) \tag{22}$$

where r is the position vector of the structure. With definition (22), we have the kinetic energy and generalized hydrodynamic force

$$\begin{aligned} T &= \frac{1}{2}\iiint_V \rho_S\left(\frac{dW}{dt}\cdot\frac{dW}{dt}\right)dv \\ &= \frac{1}{2}\sum_r\sum_s M_{rs}\dot{q}^r\dot{q}^s \end{aligned} \tag{23}$$

$$F_r = -\iint_{S_h} P(r, t)\; n\cdot W_r\; ds \tag{24}$$

ρ_S is the density of the structure, P denotes the hydrodynamic pressure on wetted surface S_h of the structure, and n represents the normal vector points inward the fluid domain. With stress tensor σ^{ij} and strain tensor ε_{ij}, we have the deformation potential energy

$$U = \frac{1}{2}\iiint_V \sigma^{ij}\varepsilon_{ij}dv = \frac{1}{2}\sum_r\sum_s K_{rs}q^r q^s \tag{25}$$

ε_{ij} and σ^{ij} are functions of the deflection $W(r, t)$, and they satisfy the generalized *Hook*'s law

$$\sigma^{ij} = E^{ijkl}\varepsilon_{kl} \tag{26}$$

where E^{ijkl} is the tensor of *Young*'s modulus.

Hydrodynamic pressure on wetted surface S_h is defined by formula (8) and (11), and the deflection is defined by formula (9) and (12). Using these definitions together with isotropic plate assumption, we have generalized mass M_{rs} and stiffness K_{rs} for the plate

$$M_{rs} = \rho d\iint_{S_h} B_r(x,y)B_s(x,y)ds, \tag{27}$$

$$\begin{aligned} K_{rs} = D\iint_{S_h}\Bigg\{ & \frac{\partial^2 B_r}{\partial x^2}\frac{\partial^2 B_s}{\partial x^2} + \frac{\partial^2 B_r}{\partial y^2}\frac{\partial^2 B_s}{\partial y^2} \\ & + \nu\left(\frac{\partial^2 B_r}{\partial x^2}\frac{\partial^2 B_s}{\partial y^2} + \frac{\partial^2 B_r}{\partial y^2}\frac{\partial^2 B_s}{\partial x^2}\right) \\ & + 2(1-\nu)\frac{\partial^2 B_r}{\partial x\partial y}\frac{\partial^2 B_s}{\partial x\partial y}\Bigg\}ds \end{aligned} \tag{28}$$

where $D = Ed^3/12(1-\nu^2)$ is the flexural rigidity of the structure, E represents the *Young*'s modulus, ν denotes the *Poisson*'s ratio, and d is the thickness of the structure. The final form of motion equation of the elastic structure for determining the amplitude of the r-th mode is

$$\sum_s\left(-K\frac{M_{rs}}{\rho} + \frac{K_{rs}}{\rho g} - \iint_{S_h} w_r p_s ds\right)\frac{q^s}{\varsigma_a} = \iint_{S_h} w_r p_D ds \tag{29}$$

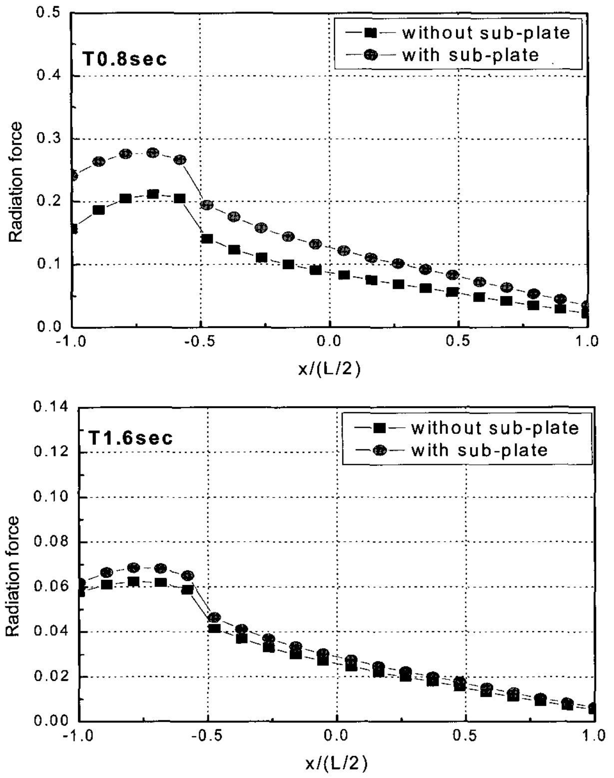


Fig. 3 Radiation forces on the VLFS with/without submerged plate

K represents the wave number of incident waves. Effects of structural damping has been ignored in this equation.

After obtaining the amplitudes, we can estimate the structural loads. Namely, we can evaluate the bending moments M_x and M_y with the resultant vertical deflection like

$$\left.\begin{aligned} M_x &= -D\left(\frac{\partial^2 W}{\partial x^2}+\nu\frac{\partial^2 W}{\partial y^2}\right) \\ M_y &= -D\left(\frac{\partial^2 W}{\partial y^2}+\nu\frac{\partial^2 W}{\partial x^2}\right) \end{aligned}\right\} \tag{30}$$

In the following section, we will apply the proposed method to the VLFS with submerged plate considering the hydrodynamic interaction effects.

4. Modification of the hydrodynamic forces

We assume that the structure has been discritized by the finite element method, and the equation can be written as

$$[M_S]\{\ddot{z}\}+[K_S]\{z\}=\{F\} \tag{31}$$

where $[M_S]$ and $[K_S]$ are the structural mass and stiffness matrices, respectively, and $\{z\}$ is the vector of nodal displacement. $\{F\}$ is the vector of nodal forces resulting from the distributed fluid forces. These forces can be expressed as

$$\{F\}=\{F_R\}+\{F_H\}+\{F_W\} \tag{32}$$

where the vectors on the right side of Eq.(32) correspond to radiation, hydrostatic and wave exciting forces, respectively.

In order to estimate more accurately the hydroelastic deflection of VLFS with submerged plate, we have modified the hydrodynamic forces, which are composed of wave exciting forces and radiation forces.

First of all, we have carried out the numerical simulation to investigate the interaction of heave radiation forces for various cases. Fig. 3 shows the results of heave radiation forces on the VLFS with and without the submerged plate, and the marks represent the first order component through the fourier analysis. As shown in Fig. 3, it is noted that the heave radiation forces are increased due to the effect of submerged plate. Therefore, the radiation pressures in the equation (32) have to be modified by the interaction factor, which is defined to the increase ratio of radiation forces induced by the submerged plate. As shown in Fig. 3, we can see that the increasing ratio of radiation force is the largest at the short oscillation period. On the other hand, we can find that the radiation forces are increased about 6% due to the effect of submerged plate at the long oscillation period.

Secondly, we have modified the wave exciting force in order to consider the effect of submerged plate. The characteristic of hydroelastic response is regarded as the characteristic of energy propagation in waves. The energy of propagation wave consists of incident wave energy, reflection wave energy and dissipation wave energy. It is considered that the increase of dissipation wave energy and the decrease of incident wave energy will reduce the energy of the propagation wave. The breaking wave induced by the submerged plate is a typical example of the dissipation wave energy. Therefore, the attachment of additional structure on the weather side of VLFS, which is the submerged plate, can result in the reduction of propagation wave energy. Thus, the wave exciting forces have been modified by the transmission wave coefficients as shown in Fig. 4 in order to consider the effect of submerged plate. The transmission wave coefficient C_t is defined by the ratio of the transmission wave amplitude to the incident wave amplitude (Takaki and Lin, 2000). Computations were performed to predict the transmission wave coefficients for submergence depth of submerged plate d=20mm, wave amplitude ζ_a=50mm, and wave period T_w= 0.8~1.8 seconds. Fig. 5 shows the instantaneous pressure contour and velocity vector field around the submerged plate for short wave period (T_w=0.8sec.). The results obtained by this simulation, i.e., transmission wave coefficient C_t, are shown in Fig. 4. According to this result, it is noticeable that the amplitude of transmission wave is remarkably decreased due to the submerged plate especially at short wave periods. Thus, these transmission wave coefficients are used for the modification of wave exciting force $\{F_W\}$ in the Eq.(32).

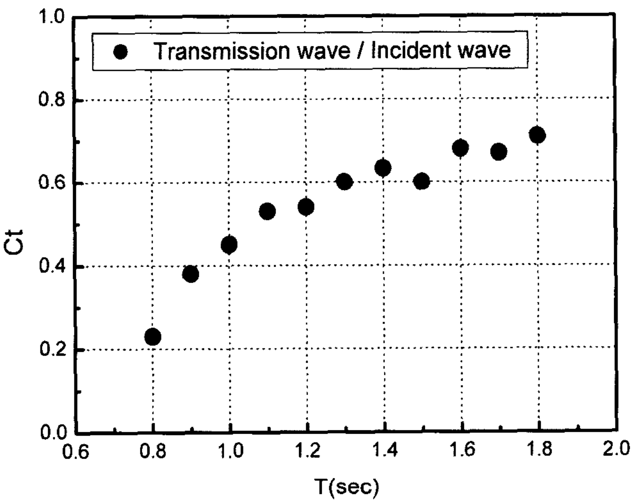


Fig. 4 Transmission wave coefficient C_t

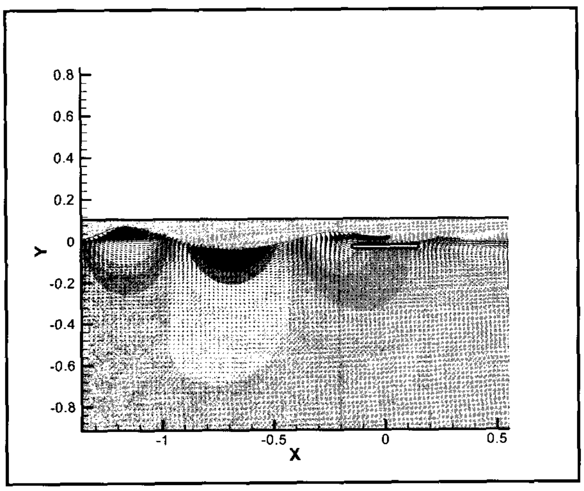


Fig. 5 Pressure contour and velocity vector field for T_w=0.8sec.

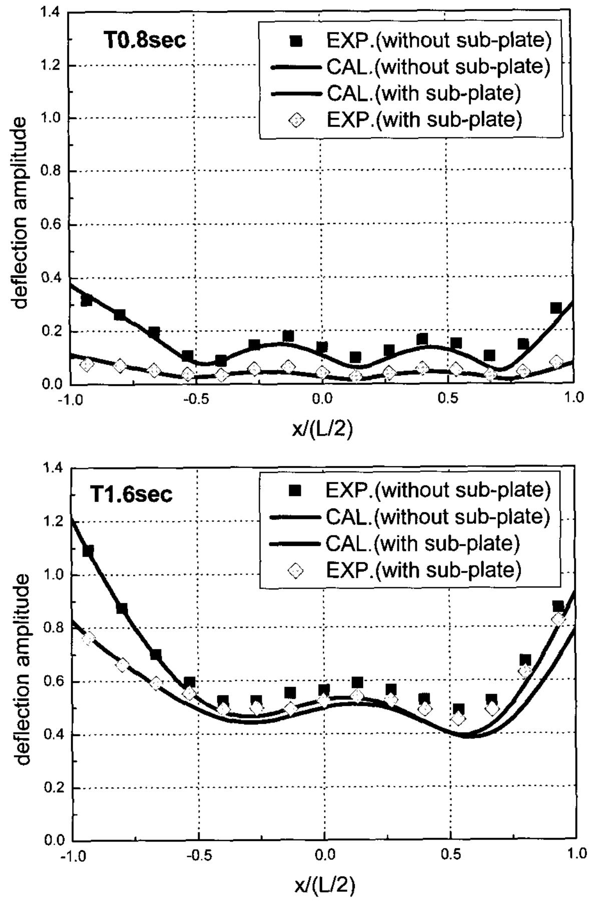


Fig. 6 Deflection amplitude along the centerline of VLFS with and without submerged plate

5. Results and discussion

Table 1 Principal particulars of the VLFS model

Scale Ratio	1/100
Length (m)	5.24
Width (m)	2.09
Depth (m)	0.07
Draft (m)	0.02
ζ_a (m)	0.05
E (kgf/m^2)	2.1◈1010
ν	0.3
Stiffness EI (kgf·m)	117.1
Water Depth (m)	3.0

We apply the present numerical method to the 1/100 scale model to investigate the elastic response of VLFS with and without the submerged plate. The model test had been carried out at Hiroshima University (Ikeda and Fujii, 2002), and the principal particulars of the VLFS model are listed in Table 1. The VLFS model consists of the aluminum grillage beam and the styrene-form floaters (340mm×340mm unit) as shown in Fig. 2. The submerged plate has been modeled by the aluminum plate which is attached on the styrene-form plate for canceling the aluminum weight. The submergence depth of the submerged plate is 20mm and the thickness is 20mm.

Fig. 6 shows the non-dimensionalized amplitudes of deflections of VLFS with and without the submerged plate obtained by the proposed method and experiments for the wave periods T_w = 0.8 and 1.8 seconds. From this figure, we can find that the submerged plate is available for reducing the elastic response of the VLFS, especially for the short wave periods. It is observed that the deflection is decreased over the full length of VLFS in the short waves, whereas only the weather side of VLFS is decreased in the long waves. The comparisons of the results have shown a good agreement between the numerical calculations and experiments, and confirmed the reliability and accuracy of the present method.

The amplitudes of diffraction pressure ($|p_D|$), radiation pressure ($|p_R|$) and vertical displacement ($|w|$) on the VLFS with and without the submerged plate are shown in Figs. 7 and 8. Here, the non-dimensionalized values of vertical displacement and pressure are made by using ς_a and $\rho g \varsigma_a$, respectively. The distributions of pressure and displacement without submerged plate are drawn on the left, and the ones with submerged plate are on the right side of the figure. The radiation pressure p_R is defined by

$$p_R = \sum_r \frac{q^r}{\varsigma_a} p_r(x, y) \tag{33}$$

From these Figs., it can be seen that the hydrodynamic pressures are decreased due to the influence of submerged plate. We can observe that the diffraction pressure at the short wave period is almost zero inside the VLFS without submerged plate but increase sharply near the weather side (see Fig. 7a), and it is considerably reduced by the submerged plate (see Fig. 7b). At the long wave period (see Fig. 8), it is noted that the magnitude of decreased pressure is smaller than that in the short wave period. According to these results, we can see that the submerged plate has very good performance for reduction of wave exciting force at the weather side, and the effect of submerged plate is small at the middle and lee side on the VLFS. Moreover, the effectiveness of the submerged plate for the radiation pressure is relatively small comparing with the diffraction pressure. Therefore, it is considered that the submerged plate is more effective for the short wave period and for the reduction of wave exciting force. As clearly shown in the figures, the elastic response of VLFS is drastically decreased when the submerged plate is considered.

It is considered that the reduction of the elastic response of VLFS in the short wave periods is due to the decrease of wave exciting force, and the increase of damping force induced by interaction effect between the VLFS and submerged plate. On the other hand, the deflection of the weather side in the long wave periods is decreased due to the negative added mass on the submerged plate, and the increase of added mass on the fore part of VLFS. The results presented in this study demonstrate that the elastic response of the VLFS is strongly affected by the hydrodynamic interaction induced by the submerged plate.

6. Conclusions

In this study, we have developed a modal analysis method for predicting the wave-induced motion of a Very Large Floating Structure considering the hydrodynamic interaction effects between the VLFS and the submerged plate. Bi-cubic B-spline functions are used in the discretizations of both structure deflection and pressure distribution. Hydrodynamic pressures of the diffraction and radiation problems are estimated by applying the modified hydrodynamic coefficients. Through the present study we obtained the following conclusions:

(1) The hydroelastic behaviors of VLFS with submerged plate are analyzed by applying the modified hydrodynamic coefficients. Namely, the wave exciting force is decreased by the transmission wave coefficient while the interaction factor is used for the modification of radiation force. The comparisons of the results have shown a good agreement between the numerical calculations and experiments, and confirmed the reliability and accuracy of the present method.

(2) It is considered that the reduction of the elastic response of VLFS in short wave periods is due to the decrease of wave exciting force, and the increase of damping force induced by interaction effects between the VLFS and the submerged plate. On the other hand, the deflection of the weather side in long wave periods is also decreased due to the reduction of wave exciting force. Moreover, it is decreased due to the occurrence of negative added mass on the submerged plate, and the increase of added mass on the fore part of VLFS.

(3) The results presented in this study demonstrate that the elastic response of the VLFS is strongly affected by the

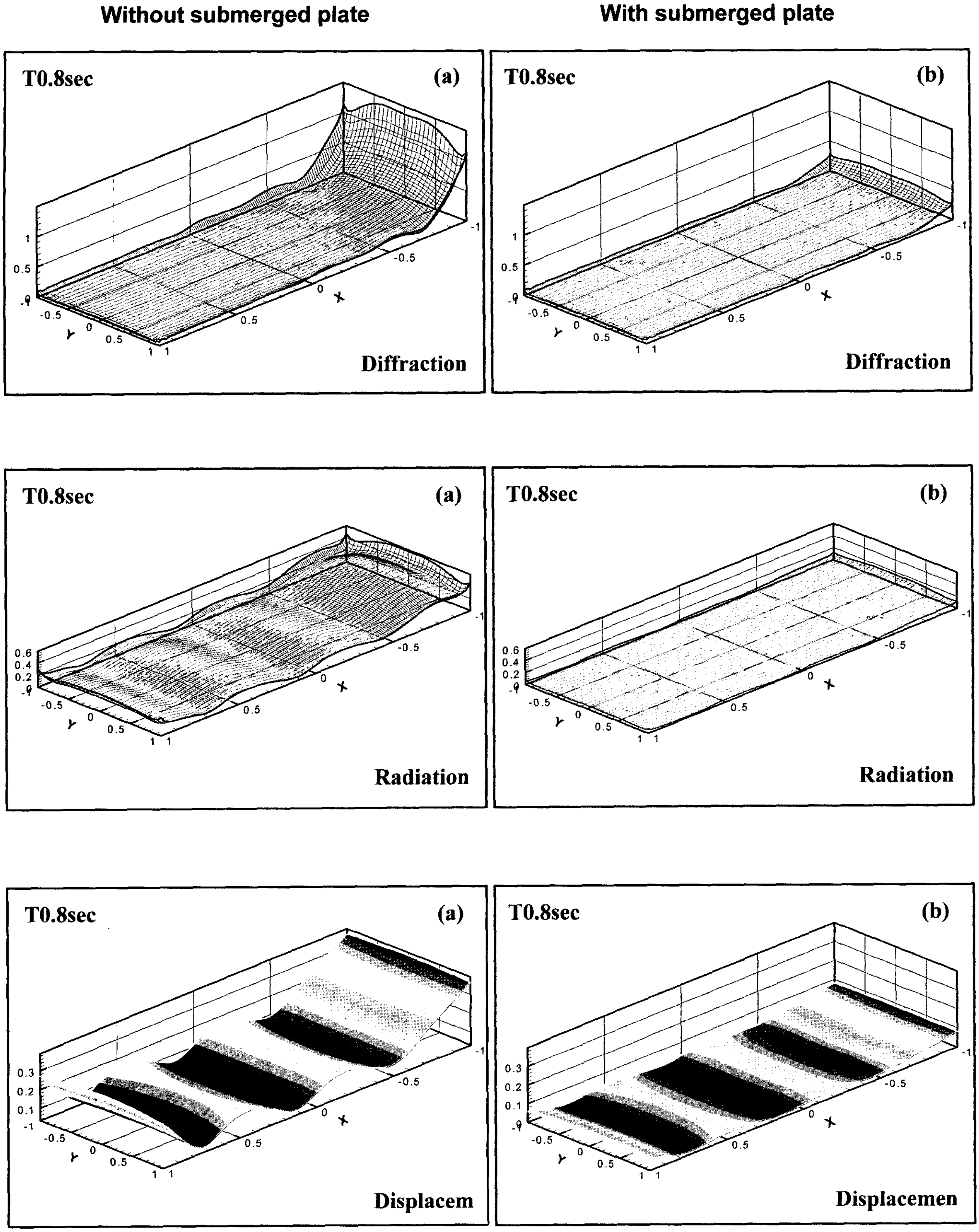


Fig. 7 Distribution of diffraction pressure(upper), radiation pressure(middle) and displacement(lower) on VLFS (a)without submerged plate and (b)with submerged plate

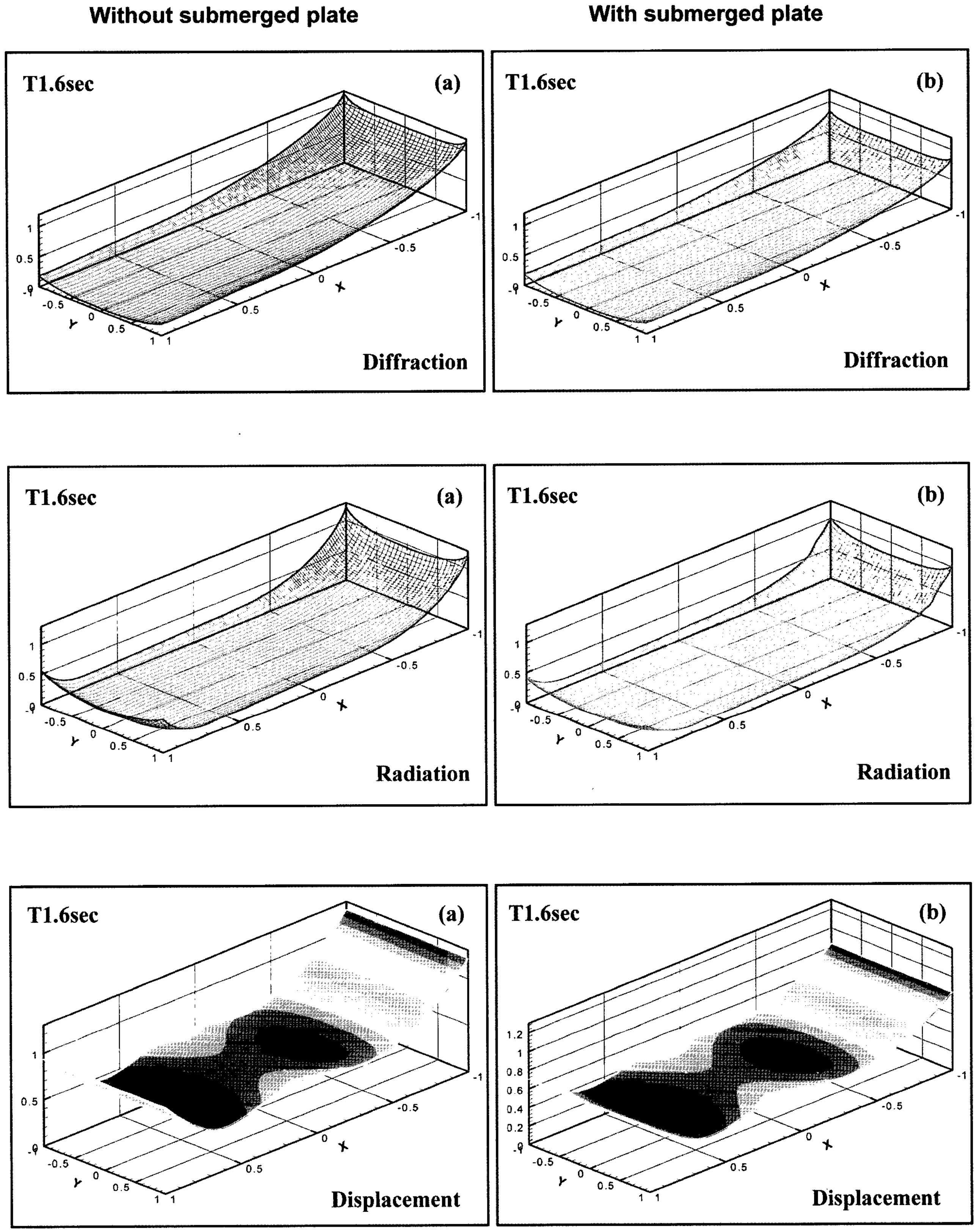


Fig. 8 Distribution of diffraction pressure(upper), radiation pressure(middle) and displacement(lower) on VLFS (a)without submerged plate and (b)with submerged plate

hydrodynamic interaction induced by the submerged plate. As a result, we can confirm that the submerged plate is useful for reducing the hydroelastic deflection of VLFS, and the proposed method is valuable for predicting the elastic response of VLFS with attached submerged plate.

Acknowledgement

This work was supported by the Fisheries Science Institute of Kunsan National University.

References

[1] Ikeda, H. and Fujii, Y.(2002), "Study on the Elastic Response of a Very Large Floating Structure with Submerged-Plate", *Graduation Thesis*, Hiroshima University.

[2] Lin, X. and Takaki, M.(1998), "A B-Spline Element Method for Predicting the Hydroelastic Responses of a Very Large Floating Structure in Waves", *JSNAJ*, Vol.183, pp.219-225.

[3] Maniar, H. D. and Newman, J. N.(1996), "Wave Diffraction by a Long Array of Circular Cylinders", *11th Workshop on Water Wave and Floating Bodies*, Hamburg.

[4] Takagi, K. and Kohara, K.(2000), "Application of the Ray Theory to Hydro-Elastic Behavior of VLFS", *Proc. 10th ISOPE*, Seattle, Vol. I, pp.72-77.

[5] Takaki, M. and Gu, X.(1996), "Motions of a Floating Elastic Plate in Waves", *JSNAJ*, Vol.180, pp.331-339.

[6] Takaki, M. and Lin, X.(2000), "Hydrodynamic Forces on a Submerged Horizontal Plate Type Breakwater", *Proc. 10th ISOPE*, Seatttle, Vol.III, pp.532-539.

[7] Yamashita, S.(1979), "Motions and Hydrodynamic Pressures of a Box-Shaped Floating Structure of Shallow Draft in Regular Waves", *JSNAJ*, Vol.146. pp.165-172.

Received 5 September 2007
Accepted 28 September 2007