Abstract  This paper presents an effective scheme for calculating the wave-induced hydroelastic response of a pontoon-type very large floating structure (VLFS) when it is near a breakwater. The basic numerical calculation method is the one previously developed by the same author for a VLFS in the open sea (no breakwater), which is expanded to include the effect of the hydrodynamic mutual interaction between the breakwater and the floating structure. The efficiency and accuracy of the proposed method are validated through comparisons with other numerical results and with existing experimental results. After that confirmation, various numerical calculations were conducted, paying special attention to the resonance phenomena which will occur depending on the relation between the wavelength and the clearance between the breakwater and the floating structure. The irregular frequency phenomenon which appears in the calculation of the fluid dynamic problem is discussed in the appendices, including a method for its elimination.

Key words  Very large floating structure · VLFS · Hydroelasticity · Eigenfunction expansion-matching method · Mode-expansion method · Breakwater · Irregular frequencies

1 Introduction

Very large floating structures (VLFS) of several thousand meters in length are being considered for various applications such as a floating airport, an offshore city, and so on. To date, VLFS have been designed with a thin mat-like configuration and a very large horizontal area. A typical design, for example, is 5 km long and 1 km wide, while its height is only 7 m. This type of structure is very flexible, and the elastic deformation due to wave action will be more crucial than the rigid body motions. The study of this elastic behavior in waves is an important factor in attempts to achieve the required functions and safety of VLFS. For an analysis of the hydroelastic behavior of VLFS in waves, conventional numerical techniques can be applied in principle. However, the direct application of such methods is impossible in practice because the wavelength is very small relative to the horizontal size of the structure, and it requires an enormous computational burden. Several methods have been proposed in order to overcome this difficulty.\textsuperscript{1–7} Kashiwagi\textsuperscript{8} has reviewed these recent studies. Among them, is a new efficient numerical calculation method for the hydroelastic response of VLFS in open sea conditions.\textsuperscript{2} In that method, the three-dimensional eigenfunction expansion-matching method is used to calculate fluid forces, and the mode expansion method is used for the elastic behavior of the floating plate. To calculate the fluid force coefficient, the author used “the solution of the Dirichlet problem for the Helmholtz equation in a rectangular region.” This allows us to conduct the integration analytically. Because of this treatment, the scheme is recognized as one of the fastest known calculation schemes, and hence this computation code has been used effectively as a practical tool for the conceptual design of the Tokyo Bay model by the Technological Research Association of Mega-Float.

A VLFS sometimes needs to be sheltered by a breakwater, depending on the situation. There are some papers which treat the effects of the breakwater.\textsuperscript{5,7,9,10} All papers, except that by Nagata et al.,\textsuperscript{10} treat the breakwater as a separate part of the structure. Nagata et al.\textsuperscript{10} adopt the three-dimensional eigenfunction matching method, which treats the breakwater as part of the boundary of an additional fluid domain which is sur-
rounded by an actual breakwater and an imaginary boundary. All these treatments are somewhat time-consuming. Here, I develop an effective calculation method for the hydroelastic response of a VLFS, including the effect of a breakwater, based on the above-mentioned method. In this case, we have to solve the flow field, including the mutual interaction effect between the VLFS and the breakwater. However, to calculate the motion, we only need the fluid force acting on the VLFS, and there is no need to calculate the fluid force acting on the breakwater. We can therefore develop an efficient calculation method. Moreover, the author recently developed a new calculation method for the wave field diffracted by a thin breakwater. This treatment is successful because the thickness of the breakwater is usually very small compared with its length. In this method, a thin breakwater which has an arbitrary reflection coefficient is represented by a line distribution of source and doublet in the hydrodynamic sense. This is also included in the calculation method for the fluid force acting on a VLFS. This paper presents that calculation scheme as well as some numerical results which agree well with other numerical results and existing experimental results.

Moreover, it is well known that at certain so-called “irregular frequencies,” the solution of a hydrodynamic problem does not produce finite solutions when we use the singularity distribution technique. This irregular frequency phenomenon can also occur when we use the three-dimensional eigenfunction expansion-matching method to solve hydrodynamic problems. The estimation and elimination method for these irregular frequencies is discussed in Appendix A.

2 Theory of the calculation method for the hydrodynamic force in the case of a breakwater

2.1 Assumption for computation

The calculation method presented in this paper was developed using the following assumptions.

1. The water depth is finite and constant.
2. The floating structure is an isotropic, uniform, flat rectangular plate. The draft is assumed to be zero. The effect of the draft will be considered using the weight per unit area.
3. The wall of the breakwater is vertical and extends to the sea-bed.
4. The fluid is assumed to be inviscid and irrotational, and a velocity potential is introduced. It is further assumed that the amplitudes of the incident waves and the responses of the floating structure are small enough to be treated by a linear theory.
5. All events are periodic. The time factor $e^{-i\omega t}$ is omitted in the following descriptions.

6. The three-dimensional eigenfunction expansion-matching method is used to solve the hydrodynamic problem.
7. The mode-expansion method is used to represent the elastic behavior of the floating plate.

2.2 Diffraction problem

First, the solution method of the diffraction problem in the case of a breakwater is described. The coordinate system is defined in Fig. 1. Although the plan shape of the breakwater is arbitrary, the plan shape of the floating structure is rectangular. The fluid domain is divided into the outer part of the floating structure (domain I) and the inner part of the floating structure (domain II), and the velocity potentials must satisfy the following conditions in each domain.

\[
\begin{align*}
\left[L\right]\nabla^2 \Phi_1(x, y, z) &= 0 \quad \text{in domain I} \\
\nabla^2 \Phi_{II}(x, y, z) &= 0 \quad \text{in domain II} \\
\left[P\right] \frac{\partial \Phi_1}{\partial z} &= \frac{\alpha^2}{g} \Phi_1 \quad \text{at } z = 0 \quad \text{in domain I} \\
\frac{\partial \Phi_{II}}{\partial z} &= 0 \quad \text{at } z = 0 \quad \text{in domain II} \\
\left[B\right] \frac{\partial \Phi_1}{\partial z} &= \frac{\partial \Phi_{II}}{\partial z} = 0 \quad \text{at } z = -h \quad \text{in domains I and II}
\end{align*}
\]  

(1)

Here, $h$ indicates the constant water depth. We assume that the velocity potentials satisfying the above conditions in each domain are expressed as follows using eigenfunctions.

\[
\Phi_1(x, y, z) = \left\{Q(x, y) + f_0(x, y)\right\} \frac{\cosh k_0(z + h)}{\cosh k_0 h} + \sum_m f_m(x, y) \frac{\cos k_m(z + h)}{\cos k_m h}
\]  

(2)