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FEM for Time Domain Analysis of Hydroelastic Response of VLFS with Fully Nonlinear Free-surface Conditions

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A finite element method (FEM) is developed for the time domain analysis of the hydroelastic deformation of a pontoon-type very large floating structure (VLFS) with fully nonlinear free-surface conditions. A 3-dimensional free-surface flow is formulated in the scope of potential flow theory with the nonlinear free-surface conditions. To describe the motion of VLFS, the Mindlin plate modeling is adopted. The equation of plate motion is discretized by finite elements using the virtual work principle and integrated by the Newmark method. To consider the fluid-structure interaction, the nonlinear free-surface motion and the plate motion are numerically solved through an iterative method at each time step.

INTRODUCTION

To utilize the ocean space effectively, it is of great importance to investigate the dynamic response related to the safety and reliability of a very large floating structure (VLFS). In spite of previous research (Watanabe et al., 2004; Kashiwagi, 1998, 1999) on the hydroelastic response of a pontoon-type VLFS, there is still some work to be done. One thing to consider is the effect of nonlinear waves on the hydroelastic response of VLFS. In an extreme situation such as a large storm, the frequency domain analysis based on the linear theory is not appropriate. A time domain analysis is required to investigate the dynamic response of VLFS in such extreme circumstances.

There are some previous studies on the time domain analysis of the hydroelastic response of VLFS. Endo and Yago (1999) have carried out a series of weight-dropping tests and also developed a time domain analysis method based on an FEM scheme. Their FEM scheme utilized the memory effect function for hydrodynamic effects. Watanabe et al. (1998) presented a transient response analysis of a VLFS due to the impulsive landing of an airplane by FEM. Ohmatsu (1998) has analyzed the transient response of VLFS by using an impulse response function. Kashiwagi (2000, 2004) has developed a numerical method for the time-dependent elastic deflection of a structure by utilizing a superposition of mathematical modal functions. Liu and Sakai (2002) analyzed the hydroelastic responses of a flexible floating structure under waves by utilizing BEM for fluid domain and FEM for structure motion in 2-D space. Lee et al. (2003) proposed a hybrid method to analyze the transient hydroelastic response of VLFS by utilizing BEM for fluid domain and FEM for plate motion. Qui and Liu (2005) developed a time-dependent FEM to analyze the transient hydroelastic responses of VLFS subjected to dynamic loads. In most of the numerical methods, a VLFS is modeled as a simple rectangular or circular plate, and a linear theory is applied for wave force. But as noted, the linear theory is not applicable for an extreme condition such as a large storm.

In this study, a time domain numerical method with fully nonlinear free-surface conditions is developed to analyze the hydroelastic response of VLFS. To solve the fluid region with fully nonlinear free-surface conditions, the FEM based on the variational formulation is adopted. Any geometry can be easily adapted and solved by finite element discretization. Though the whole domain should be discretized in FEM, it produces the banded matrix equation so that it has some advantages compared to the conventional BEM, such as memory size, reduction of computing time and easy manipulation of the matrix equation. A pontoon-type VLFS is modeled as Mindlin plate. For the time integration method for the plate equation, the Newmark method is adopted. The interaction between fluid flow and the motion of structure is solved by the 4th-order predictor-corrector method until the converged solution is obtained.

To validate the developed numerical method, the experiment results of the weight-dropping test by Endo and Yago (1999) and the numerical results of Kashiwagi (2000) are compared with the present computed results. The comparison shows a reasonably good agreement. In another numerical computation, the elastic responses of VLFS are investigated by varying flexural stiffness when a huge solitary wave propagates in a shallow water region.

MATHEMATICAL FORMULATIONS

The Cartesian system is adopted as the coordinate system. The origin of the coordinates is at the center of the VLFS. The z axis is directed opposite to the direction of gravity, and the Oxy plane coincides with the free surface when the fluid is at rest. The pontoon-type VLFS is modeled as an elastic thin plate; Mindlin plate formulation is adopted for the thin plate. The length, width and draft of the plate are L, B and D, respectively. The plate is assumed to be freely floating. The length, width and depth of fluid domain are L_T, B_T and h, respectively. Boundary surfaces S_B, S_F and S_W represent body boundary, free surface and wall boundary, respectively. Fig. 1 shows the definition of the computation domain.

It is assumed that the fluid is incompressible and inviscid, and that its motion is irrotational. The surface tension is ignored. So

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