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Time Domain Analysis of Hydroelastic Response of VLFS Considering Horizontal Motion

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A time domain analysis of the hydroelastic deformation of a pontoon-type very large floating structure (VLFS) is investigated considering the horizontal motion effect. In our previous study on time domain analysis, the only vertical motion of VLFS was considered in the analysis of hydroelastic responses, which is appropriate for operational conditions. But in the survival-condition state, the horizontal motion coupled with the hydroelastic response would be very important in designing the VLFS mooring system. In this study, a 3-dimensional free-surface flow with fully nonlinear free-surface conditions is formulated in the scope of potential flow theory. A finite element method based on the variational principle is employed both for fluid motion and structural response. The VLFS elastic response is analyzed by the Mindlin plate model. For numerical simplicity, the only surge motion is considered for the horizontal motion.

INTRODUCTION

Research and technology developments of VLFS (very large floating structures) have been carried out for various applications, such as floating airports, terminals and military utilities. For operational safety and reliability, it is of great importance to investigate the dynamic response of VLFS to harsh environments at sea. Recently, global warming has seemed to cause disastrous weather conditions such as typhoons and hurricanes to occur frequently in coastal areas. Since VLFS are assumed to be constructed near shore, the damage to the mooring system by an episodic wave such as a tsunami and a solitary wave would be more dangerous than a storm wave, because breakwater protection is not effective against such an extreme wave. Thus, VLFS survivability in an extreme wave condition should be investigated as worthy of significant consideration. Such an extreme condition requires time domain analysis to investigate the dynamic response of VLFS to strong nonlinearity. Reviews on the hydroelasticity of VLFS (Watanabe et al., 2004; Kashiwagi; 1998, 1999) mentioned that more studies are required for the hydroelastic response of VLFS under highly nonlinear waves; it is important to estimate the mooring force to ensure a safe mooring system in those extremely nonlinear wave conditions. In the past decade, some approaches were proposed for the estimation of drift and mooring forces. Takagi (1996) has investigated the mooring force and elastic deformation of a VLFS induced by tsunami waves. Liu et al. (2001) carried out a model experiment in a 2-dimensional wave tank and proposed a practical prediction of a tsunami-induced mooring force on a flexible floating structure. Masuda et al. (2003) have also studied the hydroelastic response of a floating structure under various tsunami wave conditions by both model experiment and numerical computation using 2-D BEM. A practical estimation was proposed by Takagi et al. (2002) for wave drift force and moment acting on a VLFS of arbitrary geometry. Utsunomiya and Watanabe (2001) have studied the breakwater effect on the drift force acting on VLFS.

In previous research, estimations of tsunami wave-induced mooring force were made mainly by 2-D numerical methods such as 2-D BEM and a modified Boussinesq equation. But to estimate the hydroelastic response and mooring force in various conditions, a more general numerical approach which can handle a 3-D case and arbitrary body geometry is required.

In this study, a 3-D numerical method with fully nonlinear free-surface conditions considering the horizontal motion of VLFS is developed in time domain. To solve the fluid flow with fully nonlinear free-surface conditions, the finite element method (FEM) based on the variational formulation is adopted. Kyoung et al. (2006) have already reported on the advantages and versatilities of FEM in time domain analysis. A pontoon-type VLFS is modeled by Mindlin plate. For the time integration of the plate equation, the Newmark method is adopted. The interaction between fluid flow and structure motion is solved by the 4th-order predictor-corrector method until the converged solution is obtained. A VLFS with a dolphin-fender mooring system is considered. A practical approach including a radiation wave is proposed to consider the horizontal motion effect of VLFS.

To validate the developed numerical method, the experimental data (Kim et al., 2006) of VLFS horizontal motion and elastic response in a regular wave are compared with the computations. As another numerical computation, the elastic responses and mooring forces on VLFS are investigated by varying the wave height of a solitary wave in a shallow water region.

MATHEMATICAL FORMULATIONS

The Cartesian coordinate system is employed. The origin of the coordinate 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 VLFS is modeled as a pontoon-type elastic thin plate. For numerical simplicity, the surge motion is considered for the horizontal motion. The spring corresponding to the dolphin mooring system is assumed to be linear. 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_{OB}, S_{OW}, S_F, S_{WM} and S_W, represent the bottom and sidewall of VLFS, the free surface, wave maker and wall boundary, respectively. Fig. 1 shows the definition of the computation domain.

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