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Motion Response of a Moored Semi-Submersible-Type Single Module of a VLFS in Multi-Slope Shallow Water

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The motion response of a moored semi-submersible-type single module (SMOD) of a Very Large Floating Structure (VLFS) is significantly influenced by the seabed topography and shallow water effects. To investigate the motion response of a moored SMOD that is located near islands, both numerical and experimental studies have been conducted. The hydrodynamic parameters of the SMOD were acquired by the use of the panel method. A finite-element model was adopted to calculate the tension forces of the mooring lines. It was found that the moored SMOD exhibited low-frequency characteristics in shallow water. As the seabed became more inclined, the roll motion became larger, while the sway and heave motions hardly changed. As the water depth became shallower, the heave and roll motions were mitigated; however, the sway motion was aggravated.

INTRODUCTION

As a key technology, the study of the positioning capacity of a Very Large Floating Structure (VLFS) is always a research focus in the field of ocean engineering, and many studies have been carried out and reported (Ohmatsu, 2005). Normally VLFSs can be classified into two types according to their geometry: pontoons and semi-submersibles (Lamas-Pardo et al., 2015). The pontoon-type VLFS is a very large floating pontoon structure. Mooring systems are often equipped for this kind of VLFS to keep the floating structures on site. The Mega-Float program in Japan is a typical pontoon-type VLFS research program, and many relevant studies have been addressed (Ohmatsu, 2005; Watanabe et al., 2004; Wang and Tay, 2011). The semi-submersible-type VLFS consists of an upper deck, some columns, and submerged pontoons. Because of the small waterline-area geometry, the semi-submersible-type VLFS is suitable for deep water in a harsh marine environment. The Dynamic Positioning (DP) system is thus regarded as being more appropriate for this kind of VLFS due to the requirement of mobility as well as the ability to resist the harsh sea condition. The Mobile Offshore Base (MOB) concept proposed by the U.S. Navy is a typical semi-submersible VLFS project that is still under research (Palo, 2005).

On the technical side, there are still lots of challenges in the hydrodynamic performance of these very large offshore structures. What is of great concern and what is also the greatest challenge is the hydroelastic response of the VLFS because of the large ratio of the length to the thickness (Lamas-Pardo et al., 2015). In the past decades, the theory of hydroelasticity has developed from a two-dimensional linear theory to a three-dimensional nonlinear theory (Betts et al., 1977; Bishop and Price, 1977; Faltinsen and Michelsen, 1974; Yamamoto et al., 1979; Wu et al., 1997). As for the analytical methods of hydroelastic responses, frequency-domain techniques, which are mainly Galerkin schemes (Kashiwagi, 1998a), Green function methods (Murai et al., 1999; Ohkusu and Namba, 1996; Namba and Ohkusu, 1999), and eigenfunction expansion approaches (Kim and Ertekin, 1998) or time-domain techniques, which are mainly direct integration schemes (Kashiwagi, 2004) and Fourier transformation techniques (Kashiwagi, 2000), have been employed. However, most studies were based on the hypothesis that a VLFS is a large, thin, and elastic plate. As for semi-submersible-type VLFSs, the hierarchical interaction theory (Kashiwagi, 1998b; Kashiwagi and Yoshida, 2001; Murai et al., 1999) was introduced to treat the hydrodynamic interactions. In the hierarchical interaction theory, the columns are grouped into several fictitious bodies, and these bodies are organized into some larger fictitious bodies.

In addition to the issues of the hydroelastic responses of VLFSs, second-order wave excitation forces are another challenge that needs to be paid attention to, especially when it comes to the estimation of the slowly varying wave-drifting forces. Because of the difficulty caused by the calculation of second-order forces, some studies have been carried out for simplification. The most well-known simplification is Newman's approximation (Newman, 1974), which approximated the quadratic transfer function (QTF) by the regular wave steady drift forces. It is widely used in practical engineering projects because Newman's approximation reduced the computing time well and performed well in deep water. However, it is suggested not to use Newman's approximation in shallow water because the approximation would underestimate the slowly varying second-order force since the second-order velocity potential contribution increases as the depth of the water decreases (Newman, 2001). Pessoa and Fonseca (2013) have investigated the effects of the depth on low-frequency drift forces by comparing different approximation methods, and they have confirmed that Newman's approximation would provide faulty results in shallow water.

On the other hand, the complex seabed topography has an influence on both the incident waves and the mooring system of an offshore structure, especially in shallow water. Kyoung et al. (2005) investigated the sea-bottom effects on a pontoon-type VLFS by using the finite-element method, and they concluded that the sea-bottom effects should be taken into consideration when the VLFS is located near the coast, particularly in the case of long waves. Chai et al. (2002) used a semi-analytical quasi-static formulation to deal with the inclined seabed interaction effects on mooring lines.

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