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Fully Nonlinear Hydrodynamic Interaction Between Two 3D Floating Structures in Close Proximity

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This paper uses the quasi arbitrary Lagrangian-Eulerian finite element method (QALE-FEM), based on the fully nonlinear potential theory (FNPT), to numerically investigate the nonlinear hydrodynamic interaction between 2 floating structures. The forced-motion problem is mainly considered. Several cases with different configurations are numerically simulated. For some cases, the predicted results are compared with those from other methods available in literatures. The nonlinearity is investigated and found to be very significant.

INTRODUCTION

With the increasing demand by the gas/oil industry, more and more floating structures—such as floating production storage and offloading (FPSO) systems, floating storage and regasification units (FSRU) and liquefied natural/petroleum gas (LNG/LPG) carriers—have been built and utilised. These structures may be moored side by side with a relatively small gap during an operation, e.g. when an LNG/LPG carrier is being loaded from an FPSO. Under such conditions, the hydrodynamic interaction between 2 structures may be of great concern since it can influence the motion of the structures and thus their availability for offloading, and it may even affect their safety.

Many experimental and numerical studies on the hydrodynamic features of a single floating body have been made. A great deal of knowledge has been accumulated and utilised to guide the design of floating structures. For a detailed review, readers may be referred to Ma and Yan (2009). However, laboratorial observations (Kashiwagi et al., 2005; Hong et al., 2005) and numerical investigations (e.g. Yan and Ma, 2008) have confirmed that the hydrodynamic behavior of 2 floating bodies in close proximity may be significantly different from those of a single body, due to the complex interaction between the bodies. This calls for detailed studies on this kind of problems for which both experimental and numerical works have been found in literatures. The numerical method is employed in this study, and the related reviews on numerical investigations are mainly given in this section.

To numerically study this problem, one may consider a single floating body near a vertical wall. Such cases are equivalent to those with 2 identical floating bodies under a symmetrical condition. By using this strategy, Hsu and Wu (1996) investigated a 2D oscillating rectangular structure on a free surface beside a vertical wall; Zheng et al. (2004) studied the radiation and diffraction of water waves by a 2D rectangular structure; Teng et al. (2004) simulated a uniform cylinder in front of a vertical wall. By applying a symmetrical boundary at the wall, the size of the computational domain in such a case is half of that used by the corresponding direct simulation of 2 structures. Thus, less computational resources and CPU time are required. However, the symmetrical condition is rarely seen in reality. This limits the application of this strategy.

Due to the limitation of the above strategy, direct simulations involving 2 or more floating bodies are more commonly performed. The numerical studies on the hydrodynamic features of multiple floating bodies with a small gap in between have been carried out for 2D and 3D cases. Examples of 2D studies are Wu and Price (1987), Maiti and Sen (2001), Li et al. (2005), Koo and Kim (2007). Although these 2D investigations resulted in some useful conclusions—such as the different characteristics of the hydrodynamic parameters near resonant frequency and the occurrence of sloshing waves in the gap between 2 barges (Wu and Price, 1987)—they can only represent those bodies with very large or infinite length, such as breakwaters. For real floating structures, e.g. FPSO and LNG/LPG carriers whose sizes may be very different, 3D methods will be necessary.

In studies of 3D cases, Oortmerssen (1979) investigated the cases with one truncated cylinder and one barge, followed by Xie and Gao (1999) and Zhu et al. (2006); Kagemoto and Yue (1993) studied 2 or more truncated cylinders; Seah and Yeung (2006) and Elkin and Yeung (2007) studied the sway and roll hydrodynamics of twin rectangular cylinders and revealed symmetric resonant modes between them; Zhu et al. (2005) investigated the influence of gaps between two 3D floating barges on wave forces, followed by Zhu et al. (2008). Sannasiraj et al. (2000) and Gesraha (2006) considered 2 floating barges in directional waves and oblique waves, respectively. Kashiwagi et al. (2005) and Chen and Fang (2001) have also made contributions in this area. It should be noted that many numerical methods have been developed to investigate the hydrodynamic parameters for arrays of cylinders, such as Utsunomiya and Eatock Taylor (2000), Kashiwagi and Ohwatari (2002), Yilmaz (2004), Newman (2005), Taylor et al. (2007), Wang and Wu (2007) and Walker et al. (2008). Although these methods have not been used to simulate the cases with 2 general 3D floating structures, they seem to have no difficulty in being extended to do so.

In most of the investigations listed above, either 2D or 3D, the nonlinearity involved is ignored. Their results may be applicable for cases with small incident waves and small motion of the float-

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