Numerical Investigations on Responses of Two Moored 3D Floating Structures to Steep Waves

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ABSTRACT

This paper presents some results about the responses of two moored 3D floating structures to steep waves obtained by using the QALE-FEM (quasi arbitrary Lagrangian-Eulerian finite element) method based on FNPT (fully nonlinear potential theory) models. In this method, the computational mesh is efficiently moved at every time step to conform to the variation of the fluid domain, eliminating the necessity of very costly procedure of regenerating mesh which is required by the conventional FEM method. By using this method, various cases with two moored 3D floating structures in steep waves are numerically simulated and the nonlinearity involved is investigated.

KEY WORDS: Floating structures; Nonlinear water waves; Potential flow; Nonlinear response; QALE-FEM method

INTRODUCTION

The development of the oil/gas industry results in increasing uses of floating structures, such as LNG/LPG carriers. They are often moored near another one (for instance, a vessel is moored near a floating platform during offloading) and are often exposed to extremely steep waves. In such cases, the responses of the floating structures may be dramatically affected by each other. In addition, both structures undergo a motion with 6 degrees of freedom (DoFs) even when they are in head seas. Therefore, the nonlinear responses of two floating structures to steep waves needs to be carefully investigated for the purpose of optimizing the design/operation of the structures and avoiding the risk from the waves.

Because of the strong nonlinear factors involved in this problem, the linear or higher order analytical solutions may be insufficient for the accuracy demands of offshore engineering and so a fully nonlinear model may be necessary (Beck & Read, 2000). Two types of fully nonlinear models, i.e. NS model (governed by the Navier-Stokes and the continuity equations together with proper boundary conditions) and FNPT models (fully nonlinear potential model), may be used to simulate the body-wave interaction problem. The latter are much easier to solve and needs less computational resource than the former with satisfactory accuracy.

The problems formulated by FNPT model are usually solved by a time marching procedure suggested by Longuet-Higgins and Cokelet (1976). In this procedure, the key task is to solve the boundary value problem by using a numerical method, such as the boundary element method (BEM) and the finite element method (FEM). The conventional BEM (linear or higher order) has been attempted by many researchers (e.g., Kashiwagi, 1996; Ferrant, 1998; Liu, Xue & Yue, 2001; Corte and Grilli, 2006). An alternative one called desingularized boundary integral method were employed by Cao, Schultz & Beck (1991), Celebi, Kim & Beck (1998), Kim, Celebi & Kim (1998) and so on. Recently, Bai and Eatock Taylor (2007) combined the BEM and domain decomposition technique to study the diffraction and radiation of cylinders. It is noted that a fast BEM method was recently published by Fochesato & Dias (2006), which could be 6 times faster than the conventional BEM as shown by their numerical tests on 3D overturning waves, but it has not yet been found to be applied to wave-body interactions, though it has such a potential. The FEM has been developed by Wu & Eatock Taylor (1994) Westhuis & Andonowati (1998) and Clauss & Steinhagen (1999) for 2D cases and by Ma, Wu & Eatock Taylor (2001) for 3D cases. Readers may be referred to Liu, Xue & Yue (2001) and Ma & Yan (2008) for more detailed reviews.

Both the BEM and the FEM have been proved efficient but the later requires less memory and is therefore computationally more efficient for fully nonlinear wave-body problems, as indicated by Ma, Wu & Eatock Taylor (2001) and Wu & Eatock Taylor (1994). In the conventional FEM, the computational mesh, which is usually unstructured for complicated geometries, needs to be regenerated at every time step to follow the motion of waves and floating bodies. This procedure may take a major part of CPU time and so make the overall simulation very slow. To overcome the difficulty in the development of efficient FEM dealing with the interaction between water waves and freely floating bodies, Ma and Yan (2006) have recently devised a QALE-FEM (Quasi Arbitrary Lagrangian-Eulerian Finite Element Method). The main idea of this method is that the complex unstructured mesh is generated only once at the beginning of calculation and is moved at other time steps to conform to the motions of boundaries. This feature allows one to use an unstructured mesh with any degree of complexity without the need of regenerating it at