

Effects of an arbitrary sea bed on responses of moored floating structures to steep waves

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ABSTRACT

This paper uses a newly developed QALE-FEM (quasi arbitrary Lagrangian-Eulerian finite element) method based on the FNPT model to numerically simulate the responses of 2D floating bodies to fully nonlinear waves over an arbitrary seabed. The main difference between this method and the conventional FEM method is that the computational mesh is moved rather than regenerated to conform to the motion of the free surface and structures. This method is more than 6 times faster than conventional FEM method. The results of investigating the effects of different sea bed geometries by using the method are presented.

KEY WORDS: Nonlinear water waves; Potential flow; Arbitrary sea bed; QALE-FEM method; Floating structures

INTRODUCTION

As the oil/gas industries develop, more and more floating structures, such as LNG/LPG carriers are moored and/or operated in near-shore/shallow-water areas. In such areas, incident waves as well as the response of the floating body to them are most likely affect by the seabed geometry. Effects of the seabed, including reflection and shoaling, complicate the waves and may result in some undesirable problems. Therefore, a good understanding of the seabed effect on the responses of the floating structures to steep waves is very important for the purpose of optimizing the design/operation of the structures and avoiding the latent risk from the waves.

The seabed geometry in near-shore area is usually arbitrary or may be modified by the artificial structures, e.g. submerged breakwaters. This compounds the problem with very strong nonlinearity. Due to this fact, the linear or higher order analytical solutions may be insufficient for the accuracy demands of the naval engineering and a numerical simulation may be necessary. Many researchers used shallow-water equations, such as Boussinesq type models, to simulate waves in a near shore area (Fuhrman and Bingham, 2004). However, this type of equations requires that the fluid is continuous along the vertical direction and so has difficulty to solve the problem involving large motions of floating bodies because the fluid might be separated by the body in vertical direction. Alternatively, the fully nonlinear potential

theory (FNPT models) and NS models, where the Navier-Stokes and continuity equations together with proper boundary condition are solved, are employed. The former are much easier to solve and needs less computational cost than NS models with satisfactory accuracy (Ma and Yan, 2005; Yan and Ma, 2007).

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 a boundary value problem by using an efficient numerical method, e.g. the boundary element method (BEM) or the finite element method (FEM). The BEM has been attempted by many researchers, such as Cao, Beck & Schultz (1994), Tanizawa (1995), Kashiwagi, Momoda & Inada (1998), Tanizawa, Minami & Naito (1999), Kashiwagi (2000), Koo & Kim (2004), to simulate the 2D response of the floating structure to steep waves. The FEM has been developed by Wu & Eatock Taylor (1994, 1995) for 2D cases and Ma, Wu & Eatock Taylor (2001a,b) for 3D cases. Recently, Wang & Wu (2006) and Yan & Ma (2007) used this method to simulate 2D interaction between floating bodies and steep waves. Wu & Hu (2004) modeled the interaction between waves and a 3D cylindrical FPSO-like structure in which the FEM was applied. All the above applications only gave valuable results in cases with the flat sea bed with uniform depth.

Both the BEM and the FEM have been proved efficient but the later require less memory and is, therefore, computationally more efficient for fully nonlinear wave-body problems, as indicated by Ma, Wu & Eatock Taylor (2001a). A disadvantage of the FEM, however, is that a complex unstructured mesh is necessary for complicated geometries to achieve accurate results, which may need to be regenerated at every time step to follow the motion of waves and bodies. Repeatedly regenerating such a mesh may take a major part of CPU time and so makes the overall simulation very slow. To overcome the difficulty, the authors of this paper have recently invented a QALE-FEM (Ma and Yan, 2006; Yan & Ma, 2005, 2007). The main idea behind 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 motions of boundaries by using a novel spring analogy method. This feature allows one to use an unstructured mesh with any degree of complexity without the need of regenerating it at every time step. We compared the QALE-FEM with conventional FEM in terms of computational efficiency and accuracy and concluded that the QALE-FEM may require less than 15% of the CPU time required by the conventional FEM at the same accuracy level.