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Analysis of 2nd-Order Wave Force on Floating Bodies Using FEM in Time Domain

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The wave effect on hydrodynamic forces acting on offshore structures is numerically investigated with a focus on multibody hydrodynamic interactions by using the finite element method (FEM) in time domain. Boundary value problems were formulated up to the 2nd order, according to Stokes' perturbation expansion. The Laplace equation with boundary conditions was solved by the classical FEM based on weak formulation. The wave damping zone was employed to implement the radiation condition numerically. The time integration of the free-surface condition was conducted by the 4th-order Adams-Bashforth-Moulton method. Hydrodynamic forces on bottom-mounted and truncated cylinders up to the 2nd order were investigated as a validation study. Second-order forces such as drift force and diffraction force on bodies arranged side by side were analyzed and compared with model test data. The agreement between present computations and other results was fairly good.

INTRODUCTION

The investigation of higher-order hydrodynamic effects has become one of the major design concerns for performance evaluation and safety assurance of offshore structures under harsh environments. Wave drift forces on floating structures, wave run-up, gap analysis and sum-frequency excitations on the TLP tendon are typical examples of considering 2nd- or higher-order effects in state-of-the-art design procedures. As the size of container ships becomes larger and larger, the importance of considering the springing and whipping effects on fatigue analysis is increasing. Accordingly, the study of nonlinear hydrodynamic forces has a long history in spite of the complicated nature of phenomena associated with the problems.

For 2nd-order wave diffraction problems related to higher-harmonics component forces such as double frequency forces, there have been notable studies on the development of theoretically and numerically rigorous methods, as the contribution of 2nd-order wave potential is dominant in such cases. To name a few, Molin (1979), Eatock Taylor and Hung (1987), Kim and Yue (1989), and Teng and Kato (1999) have shown numerically very accurate and consistent results. More systematic reviews of the 2nd-order wave diffraction problem can be found in Newman (1990) and Wang and Wu (2007).

Concerning the wave drift force in which the contribution of the 2nd-order wave potential is relatively weak, there have been 2 approaches: the far-field method and near-field method. The far-field method is based on momentum and energy conservation (Maruo, 1960; Newman, 1990), which gives only mean force; the near-field method (Pinkster, 1980; Ogilvie, 1983) is making use of the direct integration of fluid pressure over the hull's wetted surface, which gives not only mean drift force but also the low-frequency part of drift force.

Up to 2nd-order wave problems, most engineering problems could be solved in frequency domain. Choi et al. (2001) solved the 2nd-order wave diffraction and radiation problem using the higher-order boundary method for TLP. Wang and Wu (2007) applied time-domain FEM to solve the 2nd-order wave diffraction problem for cylindrical geometries. Fully nonlinear time-domain approaches have been widely used for highly nonlinear wave problems such as numerical wave tank and hydroelasticity. However, the application to the engineering problem of fully nonlinear approaches is very limited because of the difficulty of treatment of the general body shape and inherent numerical distortion caused by averaging and filtering in the course of numerical integration. So the 2nd-order time-domain approach could be a candidate for a practical approach covering most of the important engineering topics.

As the development of oil and gas extended to deeper water, operations of floating structures became more complex, which required consideration of more complicated higher-order wave forces and hydrodynamic interactions of multiple bodies under harsh environments. Hong et al. (2002, 2005) and Kashiwagi et al. (2005) investigated numerically and experimentally hydrodynamic interactions up to mean drift forces for side-by-side moored vessels. They both employed the higher-order boundary element method (HOBEM) to get more accurate numerical results on multibody hydrodynamic interactions. They both showed resonant behavior of trapped water between 2 bodies for mean drift and diffraction force, respectively.

In this study, 2nd-order wave forces acting on offshore structures are numerically investigated with a focus on multibody hydrodynamic interactions. Boundary value problems were formulated up to 2nd order according to Stokes' perturbation expansion. The Laplace equation with boundary conditions was solved by the classical FEM based on the weak formulation in time domain. The wave damping zone was introduced to implement the radiation condition numerically. The time marching of the free-surface condition was conducted by the 4th-order Adams-Bashforth-Moulton method. Numerical calculations were made focusing on multibody hydrodynamic interaction. Hydrodynamic forces on a truncated cylinder up to the 2nd order were investigated as a validation study case; 2nd-order forces such as drift force and diffraction force on side-by-side arranged bodies were analyzed and compared with model test data. The agreement between present computations and other results was fairly good.

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