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Fully Nonlinear Wave-body Interactions with Fully Submerged Dual Cylinders

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ABSTRACT

A 2-dimensional fully nonlinear numerical wave tank (NWT) is developed based on the potential theory, Mixed Eulerian-Lagrangian (MEL) time marching scheme and boundary element method (BEM). Wave deformation and wave forces on submerged single and dual cylinders are investigated using the NWT. The computed mean, 1st, 2nd- and 3rd-order wave forces on a single submerged cylinder are compared with those of Chaplin's experiment, Ogilvie's 2nd-order theory, and another nonlinear computation called high-order spectral method. The computed potential-based mean, 2nd and 3rd harmonic forces agree well with lab measurement, but there exists noticeable discrepancy in the 1st-order wave forces as the KC number increases, which can be attributed to viscous effects (clockwise circulation around the body). An independently developed 2-D viscous NWT confirmed the experimental observation. The NWT simulations for submerged dual cylinders show that the interaction effects can be significant when the gap is small. In particular, the higher harmonic forces on the rear cylinder can be greatly increased due to already deformed incident waves by the front cylinder. The potential NWT results for dual cylinders are also compared with those including viscous effects.

INTRODUCTION

Nonlinear waves usually have a higher/sharper crest and a shallower/flatter trough than sinusoidal waves. Their interactions with various shapes of ocean structures can be significantly different from those of linear theory, and the nonlinear effects can be of vital importance in certain applications. For instance, the resulting forces and kinematics by fully nonlinear simulations can be greatly amplified when compared with linear theory. In addition, nonlinear forces act at sum and difference frequencies and generate higher harmonics that may be close to the system's natural frequencies. Although linear wave-body interaction theory is still very useful, it is precisely the conditions of large motions and extreme loads for which high performance, safety and ultimate survivability are of concern.

In this paper, a 2-dimensional fully nonlinear numerical wave tank (NWT) is developed based on the potential theory, the Mixed Eulerian-Lagrangian (MEL) time marching scheme (the Runge-Kutta 4th order), and the boundary element method (BEM). The use of the fully nonlinear free-surface time stepping method for 2-D waves by the MEL technique was first introduced by Longuet-Higgins and Cokelet (1976). The time marching scheme requires solving the Laplace equation in the Eulerian frame at each time step, and updating the moving boundary points and values in the Lagrangian manner. Subsequently, many researchers have used the MEL scheme for various fully nonlinear wave-wave or wave-body interaction problems. The 2-D NWT examples include Dommermuth et al. (1988), Cointe et al. (1990), Cao et al. (1991), Clément (1996), Grilli et al. (1989), Tanizawa (1996), and Koo and Kim (2001). There are also several fully nonlinear 3-D NWT. Kim et al. (1999) presented an extensive NWT review.

Fully nonlinear wave simulation is still computationally very intensive and requires meticulous treatment of free-surface time marching, inflow/outflow boundaries, and possible saw-tooth instability caused either by variable mesh size/high-order aliasing or inherent singular behavior near the moving-body and free-surface intersection. In addition, the relative effectiveness and accuracy of various absorbing/open boundary conditions are still in debate. In this paper, an effective artificial damping scheme applied to both dynamic and kinematic free-surface conditions is developed. The free-surface nodes are restricted to move only in the vertical direction (semi-Lagrangian approach) to avoid the necessity of regridding. A material-node approach was also independently developed to verify the correctness of the semi-Lagrangian approach.

For the accurate prediction of nonlinear wave forces on ocean structures, it is absolutely critical to obtain the correct time derivative of the velocity potential. Many authors (among them Cao et al., 1991; Sen, 1993; Contento, 1996; and Tanizawa, 1996) have suggested various numerical methods, including the finite-difference formula and acceleration-potential method. In the case of floating bodies, the use of the acceleration potential is known to be the most accurate and stable, although the relevant theory and implementation look complicated. On the other hand, the use of the high-order finite-difference formula is satisfactory for stationary structures.

It is well known that the nonlinear wave itself can be accurately described by the potential theory. However, when a blunt body is present, viscous effects can be important, depending on wave condition, wake development and flow separation. In this regard, several authors (e.g. Tavassoli and Kim, 2001) have also developed viscous NWT. The role of viscosity can be clearly identified by comparing viscous and potential NWT.

In this study, the characteristics of fully nonlinear free-surface profiles and wave loads for a submerged cylinder are investigated by using the developed potential-theory-based NWT. The NWT simulations for the single cylinder are compared with Ogilvie's 2nd-order analytic solutions (1963), Liu's and Yue's high-order spectral method (1992), and Chaplin's experimental

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KEY WORDS: Fully nonlinear waves, wave-body interactions, submerged dual cylinders, boundary element method, nonlinear wave forces, numerical wave tank, viscous numerical wave tank.