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Fully Nonlinear Wave-Current-Body Interactions by a 3D Viscous Numerical Wave Tank

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ABSTRACT

A finite-difference scheme and a marker-and-cell (MAC) method are used for numerical wave tank (NWT) simulations to investigate the characteristics of nonlinear wave motions and their interactions with a stationary three-dimensional body in the presence of steady uniform currents. The Navier-Stokes (NS) equation is solved for two fluid layers and the boundary values updated at each time step by a finite-difference time-marching scheme in the frame of rectangular coordinate system. The fully-nonlinear kinematic free-surface condition is satisfied by the density-function technique developed for two fluid layers. The incident waves are generated from the inflow boundary by prescribing a velocity profile resembling flexible flap-wavemaker motions, and the outgoing waves are numerically dissipated inside an artificial damping zone located at the end of the tank. Using the NS-MAC NWT, nonlinear wave and current interactions around a stationary vertical truncated circular cylinder are studied and the results are compared with the experimental results of Mercier & Niedzwecki, an independently developed potential-based fully nonlinear NWT, and the second-order diffraction computation.

KEY WORDS : Numerical Wave Tank, Uniform Currents, FDM, Fully Nonlinear Free-surface Condition, Navier-Stokes Equation, Vertical Truncated Cylinder, Higher-harmonic Forces

1. Introduction

The interactions of large-amplitude waves with fixed or floating bodies are of fundamental interest to free-surface hydrodynamics and of immediate practical importance to naval architecture and ocean engineering. During the past decade, a number of numerical wave tanks (NWT) have been developed to reproduce the main scientific features and nonlinear effects observed in physical wave basins. This development has been made possible by the continuous increase in computer power. However, the fully nonlinear free-surface computations are still computationally very intensive and require further development in methodology and algorithm.

In solving the fully-nonlinear waves and wave-body interactions, many researchers have used various potential-based boundary element methods (BEM). For instance, 2D problems have been investigated by Longuet-Higgins & Cokelet (1976) and Clement (1996) and 3D problems by Beck (1994) and Dommermuth & Yue (1987). The boundary surface is discretized by a number of surface elements and the velocity potential (or source strength) on each element is solved by the Fredholm-type integral equation. On the other hand, several authors tackled the NWT simulations by the volume-discretization method. For instance, Wu & Eatock-Taylor (1994) used a potential-based finite element method (FEM), while Chen et al. (1997) and Miyata & Park (1995) developed finite difference methods (FDM) to solve the Navier-Stokes (NS) equation with fully nonlinear free-surface conditions.

In this paper, a finite-difference simulation method has been developed using the Navier-Stokes (NS) equation and a Marker and Cell (MAC) method for the nonlinear interactions of steep waves with a three-dimensional body in a NWT. The viscous stresses and surface tension are neglected in the dynamic free-surface condition. The kinematic free-surface condition is satisfied by the density-function technique devised for two fluid layers. The method can simulate wave overturning around a three-dimensional body and the simulation can be continued even after wave breaking. The incident waves are generated by prescribing a flexible flap-wavemaker motions at the inflow boundary, and the outflow waves are numerically dissipated inside an artificial damping zone located at the end of the tank.

Using the developed NWT, nonlinear wave-body and wave-current-body interactions are studied. The computed results are extensively compared with the experiment of Mercier and Niedzwecki (1994) conducted at the OTRC wave basin at Texas A&M University. The NS-MAC NWT simulations are also compared with an independently developed potential-based