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Numerical Simulations of Fully Nonlinear Wave Motions in Numerical Wave Tank

Ho-Hwan Chun[1], Jong-Chun Park[1], Il-Ryong Park[2]

[1] Department of Naval Architecture and Ocean Engineering
Pusan National University
30 Jangjeon-dong, Geumjeong-gu, Pusan, Korea

[2] Marine Transportation System Research Laboratory
KRISO, KORDI

ABSTRACT

Virtual reality by use of computational fluid dynamics (CFD) has been realized by high accuracy of simulation technique and high performance of computer power. Especially, System-Design-By-Simulation techniques for marine structures are quite effective for design of the structures, based on understanding of physical phenomena. Of these, Numerical Wave Tank (NWT) simulation techniques have been also developed to more advanced technology, and it can be first utilized for the purpose of elucidating nonlinear physical phenomena related to nonlinear wave motions, and then applied to the purpose of designing or inventing new systems in ocean or coasts. In near future, it is believed that all experimental towing tank tests would be alternated with numerical towing tank tests, including not only resistance tests but also motion and maneuvering tests in random sea conditions.

However, the numerical implementation of the fully nonlinear free-surface condition is in general complicated and difficult. The major difficulties associated with the fully nonlinear free-surface simulations around 3D structures consist in (i) the complicated nonlinear free-surface boundary conditions that have to be satisfied on the instantaneous free-surface position not known *a priori*, (ii) various types of numerical instabilities, (iii) the appropriate open-boundary conditions representing open-sea condition, (iv) the treatment of body-surface condition of complex geometry in the vicinity of free-surface, and (v) large CPU time and storage required to keep satisfactory degree of accuracy.

In the present study, efforts have been focused on the nonlinear free-surface motions using a marker-density function (MDF) method. The method is basically similar to the volume-of-fluid (VOF) method (Hirt and Nichols, 1981) in that the interface can be defined by the volume fraction of fluid within a cell. However, the numerical treatment of the MDF method is more easily applicable to complicated free-surface flows around a 3D body. The MDF technique was originally devised by Miyata et al. (1988) to cope with two-layer flows involving strongly interacting interface. However, the accuracy of the method in the wave formation was not fully verified at that time. Park et al. (1993) improved the accuracy of the interface treatment through numerical experiments with non-breaking regular periodic waves. The technique has since been upgraded and used for various engineering problems including the 2D breaking waves (Park & Miyata, 1994), 3D breaking waves around a ship and an offshore structure (Miyata & Park, 1995; Miyata et al., 1996; Sato et al, 1999; Orihara & Miyata, 2000), the fully-nonlinear NWT simulations (Park et al., 1999 & 2003; Kim et al., 2001), the bubbly flow (Kanai & Miyata, 2001), etc. Similar methods using the same MDF concept have been developed recently, which include the continuum surface force (CSF) method by Brackbill et al. (1992), the CIP method by Yabe et al. (1993), and the level-set method by Sussman et al. (1994).

In this paper, emphasis is put on a numerical wave tank (NWT) simulation technique and their applications. The simulation technique has been developed by authors to investigate the interactions of fully nonlinear waves with 3D marine structures. A finite-difference/volume method and a modified marker-and-cell (MAC) algorithm have been used, which are based on the Navier-Stokes (NS) and continuity equations. The fully nonlinear kinematic free-surface condition is implemented by the marker-density function (MDF) technique or the Level-Set (LS) technique developed for one or two fluid layers. Some applications for various engineering problems with free-surface are introduced and discussed, for instances numerical simulation of marine environments by simulation equipments, fully nonlinear wave motions around offshore structures, nonlinear ship waves, ship motions in waves and marine flow simulation with free-surface.

From the all presented simulations, it seems that the developed NWT simulation technique can handle various engineering problems with free-surface and reliably predict hydrodynamic features due to the fully-nonlinear wave motions interacting with such marine structures.

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