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Numerical Simulations of a Two-Dimensional Wave Tank in Viscous Fluid

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ABSTRACT

The first results of the study of a two-dimensional numerical wave tank in viscous fluid are presented in this paper. Navier-Stokes equations are solved by an original, fully coupled solver to compute unsteady, incompressible free surface flows in viscous fluid by second order finite difference schemes. Exact nonlinear free-surface boundary conditions and the moving grid technique are used. Generation and propagation of waves in a tank are simulated. A numerical damping method has been used for wave absorption at the outlet boundary. First comparisons with experimental results show a good agreement for waves of moderate steepness.

INTRODUCTION

Over the last two decades several numerical methods to compute two-dimensional nonlinear and unsteady free-surface flows have appeared in the literature. We will especially focus on numerical wave tanks with or without a body in or at the surface of the fluid domain. In this case it consists in computing free surface flow with a wavemaker at one lateral boundary and an absorption mechanism at the other boundary in order to let the waves exit the flume without significant reflection.

Concerning the potential flow theory, methods based on the Mixed Euler-Lagrange (MEL) approach first proposed by Longuet-Higgins and Cokelet (1976) have been used by many authors. Classical hydrodynamic problems have been successfully treated in this way: Interaction between colliding waves, simulation of plunging wave breaking (Dommermuth et al., 1988), interaction of monochromatic waves or solitary wave with an immersed body. One of the most serious problems in the numerical simulation of a wave tank is the absorption of outgoing waves. In potential flow theory efficient absorption methods like the numerical beach method or active absorption have been developed. The first one, called numerical beach or sponge layer, consists in adding dissipative terms to the free-surface boundary conditions in a short zone located at the end of the flume. The second one consists in implementing an active paddle (piston or hinged wavemaker) at the outflow boundary, driven by the frequency of the incident signal. Clément (1996) has shown that the coupling of the above methods leads to a very good absorption for all frequencies, the sponge layer being efficient primarily for high frequencies and the active absorption for low frequencies.

Numerical studies based on Navier-Stokes solvers with free-surface boundary conditions are more recent. Two families of methods have been developed to follow the unsteady free-surface motion.

The first one consists in discretising the liquid domain and the domain above the free surface in a fixed Cartesian mesh. Navier-Stokes equations are then solved in both domains. Free-surface elevation is updated by using a set of Lagrangian marker particles as in the Marker And Cell (MAC) method first proposed by Harlow and Welch (1965) or by using a fraction of fluid function as in the Volume Of Fluid (VOF) method (Hirt and Nichols, 1981). Among several improved versions of the MAC method, the TUMMAC method can be noticed for a study of wave propagation (Hino et al., 1983) and breaking (Miyata, 1986) or wave-body interaction.

The other point of view is the moving grid technique: Only liquid domain is meshed. Navier-Stokes equations are solved in a curvilinear coordinate system and the mesh is regridded at each iteration, following the free surface. Such a 2D numerical tank was developed by Daubert and Cahouet (1984). Ananthakrishnan (1997) and Yeung et al. (1994) solved 3D problems of wave radiation or wave-vortex interaction, respectively.

The great advantage of the MAC or VOF methods and equivalent is the ability to compute intricate free-surface movements like wave breaking, unlike the moving grid method which requires only average slopes to ensure metric calculation.

In return moving grid methods are more accurate and lead to better results for moderate steep waves.

The original moving grid method presented here was first developed by Alessandrini and Delhommeau (1995) to compute unsteady, incompressible and turbulent 3D, free-surface flows in viscous fluid around a ship hull. It is based on the discretisation of Navier-Stokes equations by second order finite difference schemes in space and time. A single linear coupled system is solved for the velocity, pressure and free-surface unknowns at each iteration. The exact nonlinear free-surface boundary conditions are satisfied. Unlike weakly coupled methods, the convergence rate of nonlinearities is high and it ensures accurate, unsteady free-surface flow computations.

This method has been implemented in the 2D case to simulate waves generation and propagation in a tank. A numerical damping method is described here in order to simulate a semi-infinite tank as closely as possible.

Results for free-surface elevations at some probes located along the tank and harmonic analysis of these signals are presented and compared with experimental data.

The final purpose of this study is to predict physical phenomena which can occur in a wave tank (return flow or longitudinal natural frequency of a basin).

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KEY WORDS: Navier-Stokes equations, fully coupled solver, nonlinear free-surface flows, numerical wave tank, damping beach, return flow.