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Numerical Simulation of Violent Sloshing Motion in Rectangular Tank Using Improved MPS Method

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ABSTRACT

The particle method is more feasible and effective than methods based on grid connection problems involving the violent free surface motions. This study modified MPS method to predict the impact pressure acting on the wall of partially filled with water rectangular tank. The numerical results compared with the experimental result by Kishev et al.(2006) for sloshing problems. And the time history of the pressure acting on the wall obtained the numerical simulation are shown to be in good agreement with experiment.

KEY WORDS: Particle method; Moving particle semi-implicit (MPS); Non-linear free-surface motion; Impact pressure;

INTRODUCTION

The accurate prediction of highly nonlinear free-surface flows and the corresponding impact loads by fluid is very important in various ocean-engineering applications including high waves, liquid sloshing, bow/deck slamming, or green waters. The numerical treatment of this kind of highly nonlinear free-surface behavior is usually very difficult and challenging due to the complexity of fully-nonlinear free-surface and body boundary conditions. In particular, how to trace free-surface particles in case of very violent motions, such as overturning, plunging, and splashing, is the most challenging task. There are several CFD techniques to handle such problems, i.e. SOLA-VOF (Hirt and Nichols, 1981), Level-Set (Sussman et al., 1994), Marker-Density function (MDF) (Miyata and Park, 1995) etc. Most of them are the techniques capturing the free surface on grid system. However, there is a different approach without grid system, so-called particle method by use of kernel function and Lagrangian treatment of particles. For example, Koshizuka et al. (1998), Sueyoshi and Naito (2003) developed MPS (Moving Particle Semi-implicit) method, while Monaghan (1988) and Dalrymple and Rogers (2006) used SPH (Smoothed Particle Hydrodynamics). In MPS method, kernel-function-based difference algorithms are used for differentiation but kernel functions are directly differentiated in SPH method. Also for the pressure calculation the Poisson equation is used and solved iteratively at each time step in MPS method, while the state equation is used in SPH method. It is well known that there are pros and cons in both MPS and SPH methods compared to each other.

The Moving Particle Semi-implicit (MPS) method was originally proposed by Koshizuka and Oka (1996) for incompressible flow. In the original MPS method, however, there were several defects including non-optimal source term, gradient and collision models, and search of free-surface particles, which led to less-accurate fluid motions and non-physical pressure fluctuations (Gotoh, 2009).

In the present study, we used a newly developed MPS method by Pusan National University (PNU-MPS), in which all the above defects are improved. sloshing phenomena in a rectangular tank for several frequencies and filling heights. The present simulation results are validated through the comparison with experimental result. And the time history of the pressure acting on the wall is calculated through the long-time simulation which is statistically analyzed.

GOVERNING EQUATIONS

The Governing equations for incompressible viscous flows are the continuity and Navier-Stokes equations as follows:

$$\frac{D\rho}{Dt} = 0 \quad (1)$$

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} + \vec{F} \quad (2)$$

The symbol ρ is the density, t the time, $\vec{u}$ the velocity vector, ∇ the gradient, P the pressure, ν the kinematic viscosity, and $\vec{F}$ the external force.

The continuity equation (1) is written with respect to the density, while velocity divergence is usually used in grid methods. The left-hand side of Navier-Stokes equation (2) denotes Lagrangian differentiation that is directly calculated by moving particles in a Lagrangian manner. The right-hand sides consist of pressure gradient, viscous, and external-force terms. To simulate incompressible flows, all terms expressed by differential operators should be replaced by the particle interaction models of the MPS method. In the present paper simulation, which can calculate the flow field with violent free-surface motion more accurately and stably compare to the original MPS supposed by Koshizuka and Oka(2005).