

## Validation of a Numerical Code by a Particle Method for Violent Free-surface Problems

Makoto Sueyoshi

Research Institute for Applied Mechanics, Kyushu University, Kasuga, Fukuoka, Japan

**A numerical code based on a particle method intended for violent free-surface simulations is validated through comparison of numerical simulations with experimental results of violent sloshing problems in a rectangular tank. The result shows good qualitative agreement and acceptable quantitative agreement.**

### INTRODUCTION

In the field of naval and ocean engineering, the reasonable estimation of impulsive loads from fluid is an important piece of information for the safety of ships and marine structures. The large deformation of the free surface is one of the most difficult problems for numerical simulations of fluid motion. There are many kinds of numerical techniques with which to treat the problem. Most of them have tried to capture the free surface by the use of some scalar function such as a density function on the grid system. On the other hand, there is a different approach to the problem: Particle methods that use moving particles as a proxy for a grid or mesh system. The most popular particle method is the SPH (Smoothed Particle Hydrodynamics) method. A technique to apply it to incompressible flow was initiated by Monaghan (1994). In the field of marine hydrodynamics, there are some applications of the SPH method (Fontaine et al., 2000; Landrini et al., 2002; Souto and Pavon, 2003). Its capability to treat violent free-surface flow has been already shown.

In this paper, the method is based not on the SPH method but on the MPS (Moving Particle Semi-implicit) method initiated by Koshizuka in the field of nuclear engineering in order to simulate violent motions of a boundary (1996). There is the preceding research of the MPS method by Goto et al. (2001). This method is quite different from the SPH method regarding the spatial discretization and velocity-pressure computing scheme.

### NUMERICAL METHOD

The MPS method is a type of particle method. It is based on a fully Lagrangian approach similar to the SPH method that is the most popular particle method for fluid problems. But there are 2 significant differences between the 2 methods.

One is the spatial discrete model for partial differential equations. The gradient model and diffusion model were initiated by Koshizuka et al. (1996).

The gradient of some scalar  $\Phi$  is described by:

$$\nabla\Phi_i = \frac{d}{\sum_{j \neq i}^N w(r_{ij})} \sum_{j \neq i}^N w(r_{ij}) \frac{\Phi_j - \Phi_i}{r_{ij}} \frac{\mathbf{r}_j - \mathbf{r}_i}{r_{ij}}. \quad (1)$$

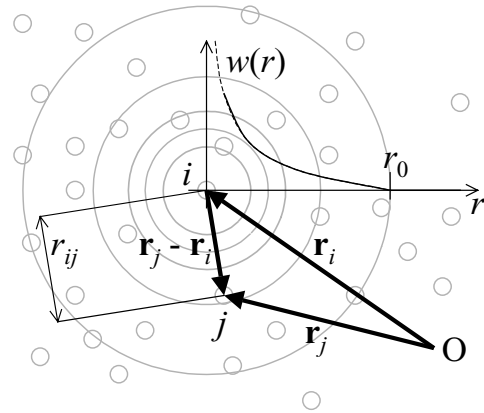


Fig. 1 Schematic of correspondence between formulation and actual geometric arrangement

$\mathbf{r}_i$  is the position vector of a particle denoted by subscript  $i$ . (In this paper, vector variables are shown in bold face.)  $r_{ij}$  is the distance between particle  $i$  and  $j$ .  $d$  is the number of dimensions, for instance,  $d = 2$  when the computation is 2-dimensional,  $d = 3$  when 3-dimensional.  $w(r)$  is an arbitrary kernel function of  $r$ . In this paper, Eq. 2 (Koshizuka et al., 1996) is used as the kernel function  $w(r)$ :

$$w(r) = \begin{cases} \frac{r_0}{r} - 1 & r \leq r_0 \\ 0 & r > r_0 \end{cases} \quad (2)$$

Fig. 1 shows the schematic of correspondence between the actual particle arrangement and formulation.

This gradient model is an average with the weight of the product of unit relative position vector and the difference of  $\Phi$  between particle  $i$  and  $j$ .

The number of particles summed in Eq. 1 is finite because the value of kernel function becomes zero in the range over  $r_0$ . The actual number of summation is smaller than the total number of particles. Due to this limitation, the method does not consume an unacceptable amount of computation for the usual  $N$ -body problem, that is, in proportion to the square of  $N$ , the number of all particles. In this study, as a kind of acceleration technique, a cell-partitioning method that is often used in molecular dynamics is applied to the  $N$ -body computation part. As a result, the time for computation of the distance among particles is almost in proportion to  $N$ , not  $N$  squared.

Received August 10, 2005; revised manuscript received by the editors June 1, 2006. The original version (prior to the final revised manuscript) was presented at the 15th International Offshore and Polar Engineering Conference (ISOPE-2005), Seoul, June 19–24, 2005.

KEY WORDS: CFD, particle method, MPS, free surface, sloshing, dam break, impulsive load.