A numerical study on complicated motions of floating bodies

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SUMMARY

Some of numerical simulations concerning flooding, extremely large motion of a 2 dimensional floating body are carried out. We directly handle equations of fluid in time domain, numerically. Because of large deformation of boundaries and violent free surface dynamics, these problems are quite difficult to apply ordinary CFD techniques. But applying grid-less method so called particle method to these problems, we can show the availability for them. Some calculated results are shown as followings.

NOMENCLATURE

d	Dimension number (2 dimensional: $d = 2$)
dS	An area of each element
$\mathbf{g}$	Gravity acceleration vector
$\mathbf{n}_i$	Normal vector on a hull
P	Pressure
$\mathbf{r}_i$	Position vector (Subscripts i indicates each particle.)
$\mathbf{r}_G$	Position vector of center of gravity
t	Time
$\mathbf{u}$	Velocity vector
Φ_i	Scholar quantity
ν	Kinematic viscosity
ρ	Density of fluid

1. INTRODUCTION

After recent tragic losses of ships, many researches have been studied about the ship's damage stability and deck wetness. In these studies, they have always pointed out that behaviour of water on the deck is very important. On the deck, shallow water rush around side as it deforms. However violent free surface flow and dynamic effect of flow have not been considered much. Almost studies of damage stability are stand on the quasi-static assumption about the behaviour of water motion on the inner deck of ships. The deck wetness and the green water load acting on the structure have been treated with model experiments.

In spite of an increase of computational resources in recent years, there has hardly been direct numerical simulation of these phenomena with CFD techniques. The reason of this exists as a difficulty in handling the violent free surface flow like fragmentation of fluid. Then SOLA-VOF and its refined methods which use space fixed grid system has been used in several past studies. These methods are effective in handling violent free surface flow, but they include some of problems like numerical diffusion of free surface, stair effect, robustness of calculation and so on.

Another difficulties of numerical simulation about these problems exist in handling very large motion of boundary like the capsized hull. BEM with ALE grid has been used in researches of the numerical wave tank to simulate motion of floating body. In last decade, Tanizawa et al. successfully carried out BEM non-linear simulations for various 2 dimensional ship's situations: liquid cargo, different above-water hull form, etc. However it is difficult to handle breaking waves, damaged hull's opening, etc. even if using ALE grid.

In the last decade, a new numerical method, that is the particle method has been developed. There are many kinds of particle method for various fluid problems. MPS(Moving Particle Semi-implicit) method is one of them. It is advocated by Koshizuka et al. to simulate incompressible flow like water. It has unique advantages:

- Strict mass conservation
- No numerical diffusion of free surface
- Robustness in computation

In order to carry out numerical simulations of violent free surface problem, these characteristics should not be lacking. Enormous consumption of computation time and memories is disadvantage of the method. However, as computational resources have increased, the method for 2 dimensional problems has become available. We show numerical results of motions of floating bodies in waves with the method.

2. THEORY

Governing equations are the mass, momentum conservation equations as

$$\frac{D\mathbf{u}}{Dt} = -\frac{1}{\rho}\nabla P + \mathbf{g} + \nu\nabla^2\mathbf{u}\,, \tag{1}$$

$$\frac{d\rho}{dt} = 0\,. \tag{2}$$

Our aim is to present availability of MPS method. You can see more details of MPS method by reference. So the only outline of formulation is described.

Particles are Lagrangian calculation points to discrete space. They are substitutes for node points, which are used in usual grid methods. So they should not be considered as molecular particles. Using the Lagrangian calculation point, Koshizuka advocated following spatial discrete models. The gradient model of a scholar quantity Φ at point i is described as equation (3). The diffusion model is described as equation (4).

$$\nabla\Phi_i = \frac{d}{\sum_j^N w(r_{ij})}\sum_{j\neq i}^{N} w(r_{ij})\frac{\Phi_j - \Phi_i}{r_{ij}}\frac{\mathbf{r}_j - \mathbf{r}_i}{r_{ij}} \tag{3}$$

$$\nabla^2\Phi_i = \frac{2d}{\lambda}\sum_{j\neq i}^{N} w(r_{ij})(\Phi_j - \Phi_i) \tag{4}$$

$$r_{ij} = |\mathbf{r}_j - \mathbf{r}_i| \tag{5}$$

$$\lambda = \sum_{j\neq i}^{N} r_{ij}^{\ 2} w(r_{ij}) \tag{6}$$

$$w(r) = \begin{cases} \dfrac{r_0}{r} - 1 & : r \leq r_0 \\ 0 & : r > r_0 \end{cases} \tag{7}$$

In equation (3) and (4), w (r) is the kernel function of length between particles r_{ij}. The function which has cut off radius r_0, presented by equation (7). Therefore, number of particles N is not number of all particles. N is the smaller limited number of particles in the region determined by the cut off radius r_0.

The gradient model is a weighting average of each gradient vector between neighbour particles. And the diffusion model is a distributor of scholar quantity to neighbour particles. In equation (4), λ is a parameter of the diffusion model represented by equation (6).

These models are characterised by no necessity of information of connectivity relationship among particles. They require nothing but relative position vectors. Therefore, if particles move anywhere as time marching, these spatial discrete models can be applied to problems without numerical break down.

Another advantage of these models is that all of materials can be expressed with particles' arrangement. Any complex boundaries, a free surface, a moving wall and a floating body are described with fixed or moving particles. Then we are free from workload like the traditional grid generation.

On the other hand, the algorithm of velocity pressure coupling is like MAC method. It is shown in Fig. 1 simply. In the Fig.1, the symbol * is sign of a temporal value for pressure calculation at each time step. Equation (8) is Poisson equation of pressure, same as MAC method. The n_i is the particle number density at a particle i represented with equation (9).

The pressure Poisson equation has the source term, which is represented by deviation of the particle number density from constant value. So its solution uniforms particle number density. It means that the density of fluid becomes constant, namely fluid is incompressible.

$$\nabla^2 P_i = -\frac{1}{\rho}\frac{(n_i^* - n_{const})}{n_{const}} \tag{8}$$

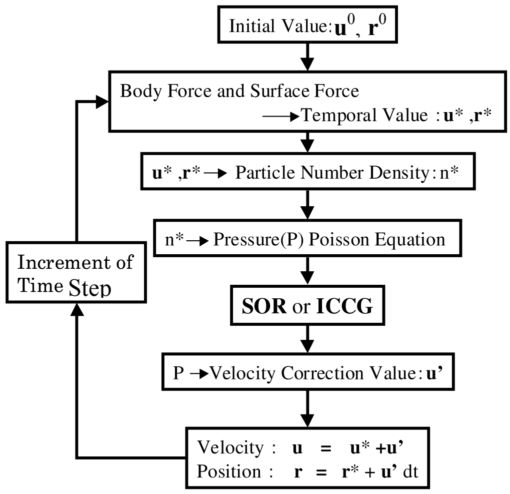


Fig. 1 Algorithm of MPS method

$$n_i = \sum_{j\neq i}^{N} w(r_{ij}) \tag{9}$$

In addition, the MPS method is very simple to apply to 3 dimensional problems. However, the calculation using the particle method needs time consuming.

Actual boundary conditions for numerical simulations are very simple handling. On the free surface, pressure is given as constant value. And on a solid wall boundary is represented with a space fixed particles' array.

A freely movable boundary like a floating body can be handled easily too. The way to determine ship motions is to solve equations of motion explicitly. In the procedure to solve equations of motions, forces acting on surface points of the body are integrated directly. The force and the moment acting on the hull are represented with equation (10) and (11).

$$\mathbf{F} = \sum_i P_i \ dS \ \mathbf{n}_i \tag{10}$$

$$\mathbf{M} = \sum_i P_i \ dS \ \mathbf{n}_i \times (\mathbf{r}_i - \mathbf{r}_G) \tag{11}$$

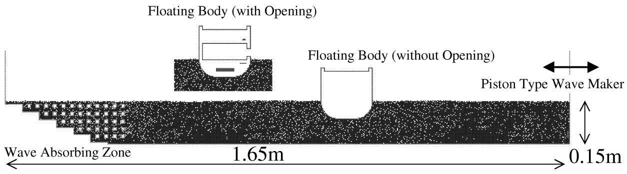
3. NUMERICAL RESULTS

Numerical simulations are carried out on following assumptions.

- The problem is considered as 2 dimensional one.
- Viscosity, surface tension and air effects are neglected.

We show several examples of motions of floating bodies in regular waves.

Fig.2 shows initial particle arrangements and the dimensions of the floating bodies and the wave tank. The vertical wall at right side is movable horizontally. It



Condition of Tank

Amplitude of Wave Maker	0.025 m
Depth	0.15m
Length	1.65m

Dimension of Floating Body

B	0.15 m
D	0.15 m
d	0.05 m
M	6. 43 kg
I	0.024 kg m^2

	GM	T_w	Opening
Case A	1.8cm	0.60sec.	No
Case B	1.8cm	0.60sec.	Yes
Case C	1.8cm	0.93sec.	No
Case D	0.8cm	0.60sec.	No
Case E	0.8cm	0.60sec.	Yes

Fig. 2 Particle arrangement for simulations of free motion in waves and co-ordinate system.

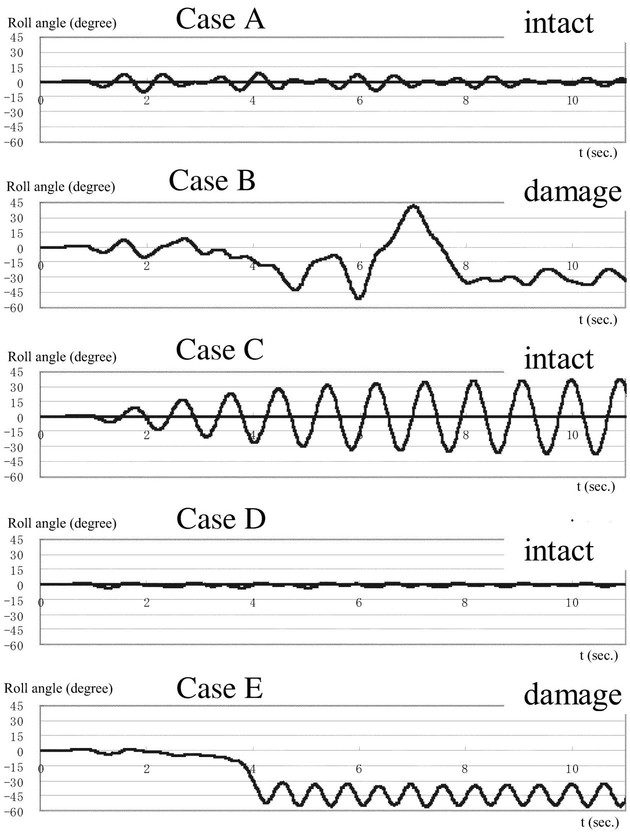


Fig. 3 Time series of roll motion of the floating bodies in regular waves.

plays a piston type wave maker. The left side stair like beach and multiple blocks play the wave-absorbing zone. It is not enough to absorb waves, because it is under development and still tentative wave-absorbing zone. In addition the length of the tank is short. So following results include effects of reflection of waves.

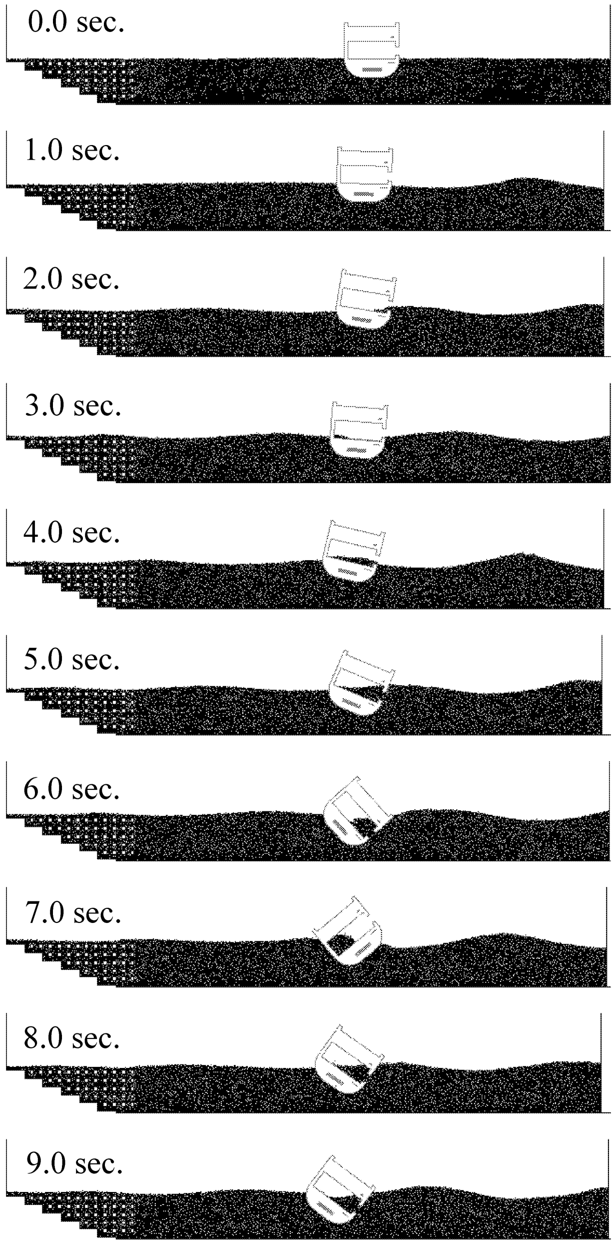


Fig. 4 Snapshots of simulation.(CaseB: Damage body)

Two shapes of floating body are used. One is an intact hull and another is a damaged hull, which has a damage opening on the right side of the hull. The total number of particles is 29,655 with intact case. In another damaged case, 29,886 particles are used. Initial length between particles is 2.5mm, the breadth of hull is 60 times as long as it.

Fig.3 shows time series of roll angle.

In CaseB,E, the cases of the damaged hull, water invades with waves from the damage opening. Because of water

invasion ships lost stability, and motions are very complicated ones.
In CaseB, owing to the low centre of gravity, the stabilised point of the hull is hard to transfer to new point.
In CaseE, the hull heels over with invasion of water. The stabilised point is transferred to new one soon. After that, the inertia of water area is enlarged and the height of centre of gravity falls. Then resonance period shifts to higher frequency.
In CaseC, the incident wave period is almost same as the resonance period. Then the amplitude of roll motion becomes very large, over 30 degrees.
Fig.4 shows snapshots of CaseB at every 1.0sec.
We can understand that in the 2 dimensional cases, the opening effect on the roll motion is very large.

3. CONCLUSIONS

It is confirmed that MPS method has availability for various violent free surface problems. Calculated results show realistic behaviour. But actual problems are all 3 dimensional ones. The 3 dimensional calculation of the method requires enormous computational resources. Therefore the sophisticated parallel version of computation code should be developed.

4. REFERENCES

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APPENDIX

More strongly non-linear problems of a floating body's motion can be handled with MPS method. Fig. 5 shows an example of a launching problem. The method is applied to the problem, which has violent free surface phenomena, successfully.

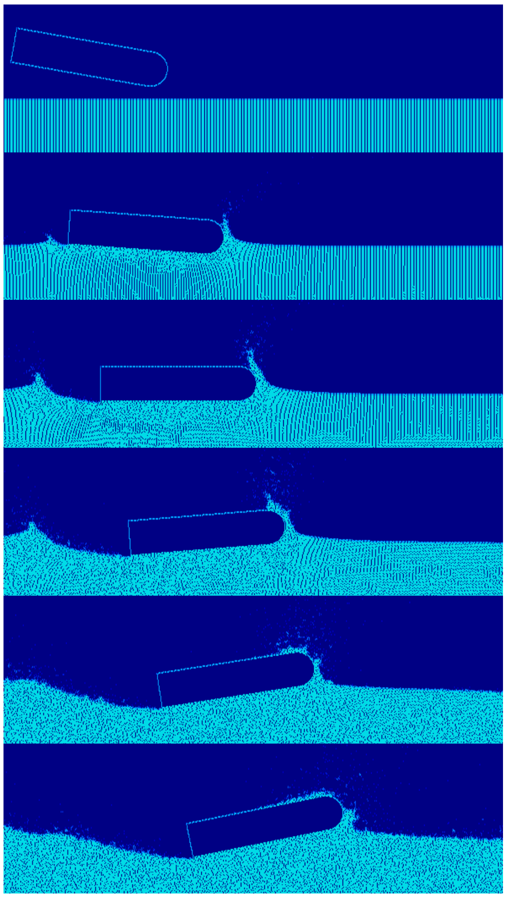

Fig. 5 Launching of a vessel on free surface.