# Coupling Analysis of FEM for Free-Surface Fluids and Rigid Body


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This paper presents a coupling method of rigid body motion and fluid dynamics analysis. This method will be required when we develop a numerical code for damage evaluation of structures under collision of tsunami debris. A debris is assumed to be a simple-shaped rigid body and a process of calculation of interaction between the rigid body and fluid FEM is described. Furthermore, the results are validated by a test result.

As for the fluid analysis method, the SUPG/PSPG stabilized FEM [1] and an interface capturing approach based on VOF technique [2] are adopted. There are three reasons that we choose FEM for fluids. The first is that FEM can express complicated domain shapes and can obtain accurate solutions by changing the resolution of mesh. It reduces excessive computational cost. The second is that it can easily achieve better efficiency in parallel computing by using a domain decomposition method. The adopted method is based on a stationary mesh and does not require any dynamic load balancing techniques as used in particle method [3]. The last one is that it is easier to calculate the physical values in domain. FEM can obtain the distribution of the physical values as well as the values at any point in domain with an element piece-wise function. They are used to calculate the interactive force between fluid and rigid body.

Fluid force applied to a rigid body is calculated by integrating fluid stress tensors on the rigid body's surface area included in each fluid element. The surface area is considered to be flat in the fluid elements, which lead us to calculate on the area of two types of shapes, triangle and quadrilateral. The surface integral of these values is calculated using shape functions of a plane element, and fluid force vectors are obtained. The force vectors are then applied to rigid body analysis. On the other hand, velocity and angular velocity are obtained by the rigid body analysis. The fluid velocity at the nodes overlapped with rigid body can be geometrically calculated, and it is applied to fluid analysis as constraint condition.

The proposed method is verified by simulating a rigid sphere motionlessly floating on the water surface. Figure 1 shows the overview of the numerical model. The diameter of the sphere is 20 mm and the density is half of the water. Figure 2 shows the displacements in X and Z directions divided by the diameter, obtained by the analysis. Small vibration can be observed in Z-direction, however, the sphere remains stable until 1.5 s in X-direction. Then, it starts to move largely in X-direction, which is assumed to be caused by numerical oscillation.

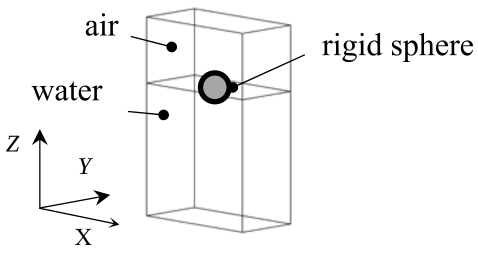
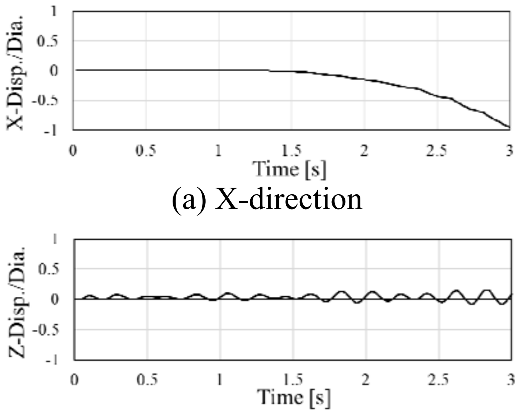


Fig.1 Numerical model of a floating rigid sphere



(a) X-direction

(b) Z-direction

Fig.2 Displacement divided by diameter of sphere

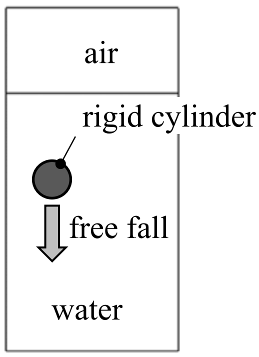


Fig.3 Test subject for a rigid cylinder free-falling in water

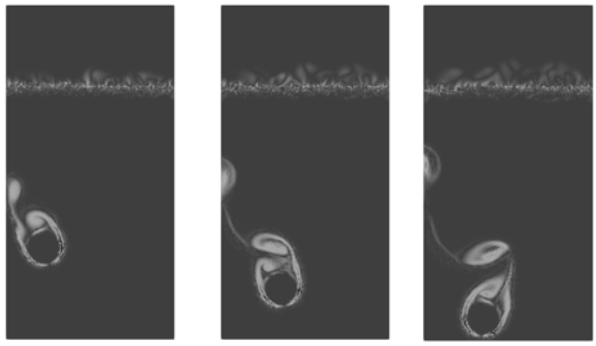

(a) 0.4 s (b) 0.55 s (c) 0.65 s

Fig.4 Contours of vorticity obtained by numerical analysis

Furthermore, the developed method is validated by comparing the numerical result with test results [4]. Figure 3 shows the overview of the test. Figure 4 shows the contours of vorticity obtained by the analysis at the time when the trailing vortex occurs. It is confirmed from the numerical results that the interaction between fluid and rigid body works practically well, although the computation process of the fluid force should still be improved.

References
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