

Multiphase-Model to Predict Arbitrarily-Shaped Objects Moving in Free Surface Flows

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ABSTRACT

This paper deals with a multi-phase model to predict the movements and transportations of the arbitrarily-shaped objects in free surface flows, such as the driftwoods and debris transported by wave flows and Tsunamis. In the prediction method, MICS (Multiphase Incompressible-flow solver with Collocated grid System), the solid objects in free-surface flows are treated as the multiphase phenomena, consisting of gas, liquid and solid phases. This multiphase field is modeled as a fluid-mixture composed of the immiscible and incompressible fluids which have different physical properties. The solid object, which is treated as a rigid body, is represented by multiple tetrahedron elements. Since the fluid-solid interactions are adequately taken into account, no empirical constants, such as a drag coefficient, are needed in the computational method. The validity of the MICS was discussed through the comparisons with some basic experimental results.

KEY WORDS: free-surface flow, object transportation, fluid-solid interaction, multiphase model

INTRODUCTION

A three-dimensional numerical method is proposed in this paper to predict the movements and transportation of rigid bodies in free-surface flows. In order to construct such prediction methods, it is necessary to estimate accurately the fluid resistance forces acting on the objects as well as the influences of the objects on the surrounding flow fields, including free-surface behaviors.

Although it is usual that boundary-fitted coordinates or unstructured grids are utilized to represent arbitrarily-shaped bodies in the flows, the numerical procedure becomes complicated when the multiple objects collide with each other and the flow field includes free-surfaces. Thus, in the present study, multiphase approach is employed. In the present computational method, which is called MICS (Multiphase Incompressible-flow

solver with Collocated grid System), the free-surface flows including large-scale solid objects are treated as the multiphase field, consisting of gas, liquid and solid phases. This multiphase field is modeled as a fluid-mixture of the immiscible and incompressible fluids which have different physical properties, as done by a CUP method (Xiao, Yabe, Ito, and Tajima 1997). The flow field consisting of different fluids is represented with a one-fluid model. The governing equations are discretized on a collocated-grid system and they are solved with a finite-volume method with sufficient numerical accuracy. The solid phases are treated as rigid bodies and they are dealt with a T-type solid model, in which an object is represented by multiple tetrahedron elements. The fluid-solid interactions are taken into account through the tetrahedron elements of the T-type model with a sub-cell method. The collisions among solid objects are dealt with the contact spheres placed near the T-type solid model.

It will be shown that the present computational method allows us to estimate the fluid forces acting on objects accurately as well as the attitudes and movements of the objects in free-surface flows.

NUMERICAL PROCEDURES

Basic Equations

The multiphase field consisting of gas, liquid and solid phases is treated as a mixture of fluids Ω , which is the collection of the immiscible and incompressible fluids Ω_i , as shown in Fig.1. The fluid components Ω_i in Fig.1 have different physical properties equivalent to the corresponding phases. This treatment enables us to estimate the fluid forces acting on the complicated-shaped objects in free-surface flows easily and accurately.

The mass-conservation equations in the Eulerian and La-