The Flow Analysis of Virtual Channel depending upon the change of two ingates

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Abstract

SMAC method, one of the computational fluid dynamics techniques, is modified from the original MAC method for the time-dependent variation of flow analysis. The Navier-Stokes equations for incompressible time-dependent viscous flow are applied, and also marker particles that present the visualization of flow analysis are used. In this study SMAC technique is used to analyze the flow behavior in the water-filling of virtual channel . Then by changes of diameter of two ingates, the change of velocity and discharge when two ingates are filled the water to virtual channel are simulated. As a result, water-filling flow pattern in the virtual channel is simulated very well. Therefore, this numerical simulation will also be applied for the design of structures as open flume and porous breakwater.

keywords : SMAC method, Navier-Stokes equation, Marker particles, Visualization, Virtual channel

1. Introduction

Recently with the development of computer technology and CFD(computational fluid dynamics) methods, it is desirable to directly solve the Navier-Stokes equation for the simulation of many surface problems, including the fluid flow in the channel, wave breaking and overtopping processes. A computational method, which is based on a modified SMAC method, has been developed to analyze two dimensional incompressible viscous flow and to calculate the combined effects of the fluid flow during the transient filling of liquid water for the solidification period. This will predict the flow pattern, filling sequence, and its gradient distribution in the Virtual channel. In this work, by changes of diameter of two ingates, the change of velocity and discharge on two ingates are simulated. Simulation results expresse the form of visual information with plots of marker particle configurations and velocity vectors.

2. The Governing Equations

The governing equations for an incompressible two-dimensional free-surface flow are as

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follow:

Continuity equation:

$$D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

Navier-Stokes equations:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + F_x \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + F_y \tag{3}$$

where, u is horizontal velocity(x-direction), v is vertical velocity(y-direction). F_x, F_y are the convective terms in the x and y directions respectively. The variable t is time; p is mean pressure of liquid; and ν is kinematic viscosity of water; ρ is the density. When the diffusive terms in Eqs. (2) and (3) are transformed to the vorticity (ω) by using the continuity Eq. (1), the momentum equations are as follows:

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial (uv)}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}\right) + F_x \tag{4}$$

$$\frac{\partial v}{\partial t} + \frac{\partial (uv)}{\partial x} + \frac{\partial v^2}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - \nu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}\right) + F_y \tag{5}$$

In this study, these equations (1), (2), and (3) is performed by SMAC method. The more detail solving process of governing equations was presented by Kim and Kim(2000, 2001).

3. SMAC Simulation

First, the flow behavior in the water-filling of virtual channel is investigated, and computed result is compared with the laboratory experimental data by Martin and Moyce(1952) and result of the MPS(Moving-Particle Semi-implicit) method by Koshizuka and Oka(1996). The comparison between computed dimensionless positions of the leading edge of the water and the experimental data is shown in Fig. 2. From this figure, it is seen that the calculated results agree very well with the experimental data, and this model is applied for the simulation of the water-filling of virtual channel with the free surface problem.

Secondly, drawings of the vertical plates of the virtual channel with the two gates and initial conditions are shown in Fig. 3. In this simulation, the height of lower ingates are compared with d and $2d(d = 5.0cm)$. where, the computational grid cell is discretized by an orthogonal mesh into 30 cells in the horizontal direction and 40 cells in the vertical direction with the spatial distance of $\triangle y = d$ and $\triangle x = d$ respectively. Fig. 4 and Fig. 5 show the results of the numerical simulation for the different case as the marker particles and velocity vectors. When the two streams meet, the side jet at the right side of the plate. During the subsequent filling, a wavy motion occurs at the free surface, while two streams fill the channel from the ingates, as shown in Fig. 4 and 5. Several vortexes in the virtual channel. The fluid filling patterns illustrate a good agreement. Also, calculated velocities in the 4-points are plotted in Fig. 6 as a function of time in advance. The velocities in the ingates present a sawtooth shape. This results from an incompletely filled ingate during the filling of the fluid. When the ingates are completely filled, the velocity curves become smooth.

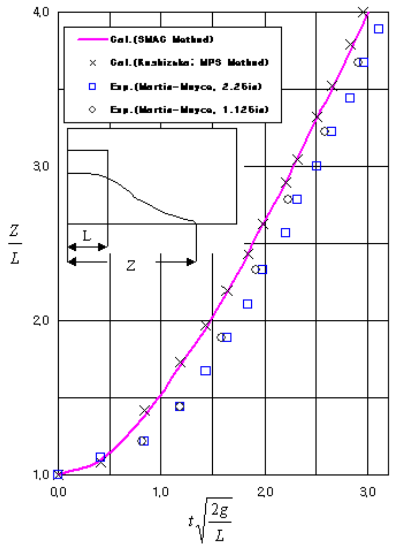


Fig 2. Comparison of SMAC result with experimental data and MPS result for the water column collapse problem

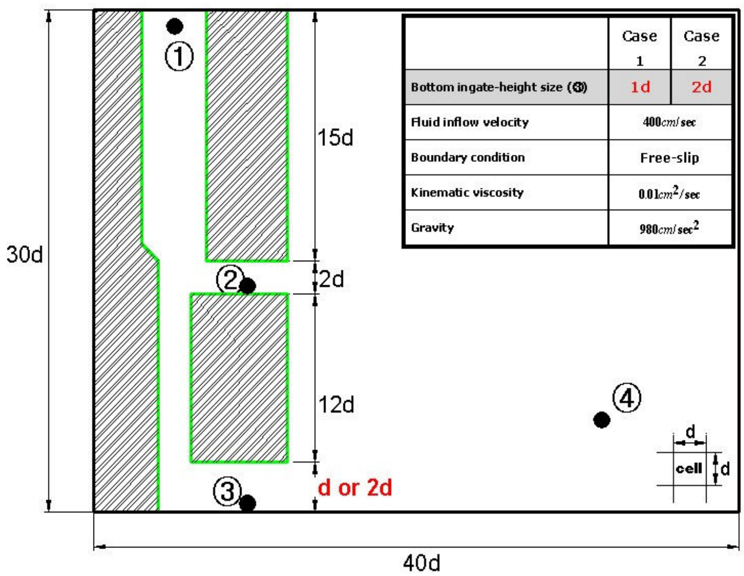
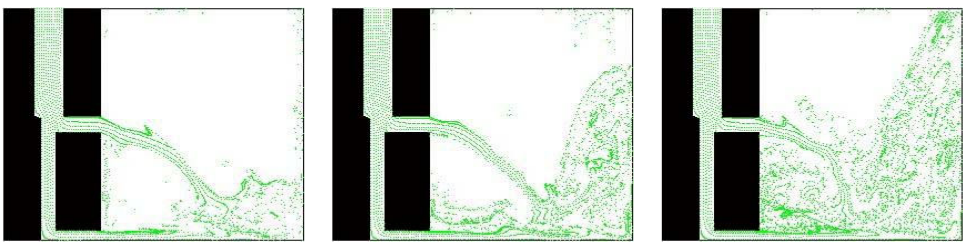
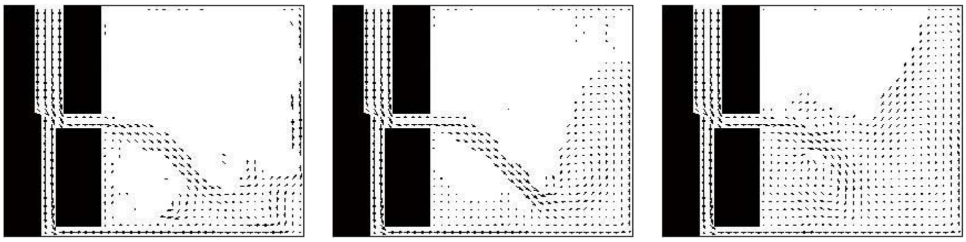


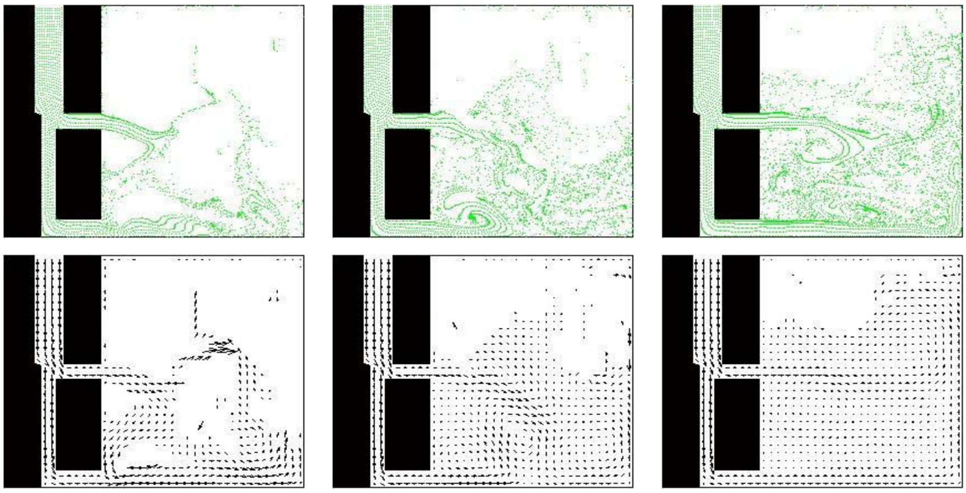
Fig 3. Dimension configurations and Calculation conditions for the virtual channel with 2 gates





t = 1.0 sec t = 1.5 sec t = 2.1 sec

Fig 4. Configuration of Marker Particles and Velocity vector profiles of filling a channel (Case 1).



t = 1.0 sec t = 1.5 sec t = 2.1 sec

Fig 5. Configuration of Marker Particle and Velocity Vector profiles of filling a channel (Case 2).

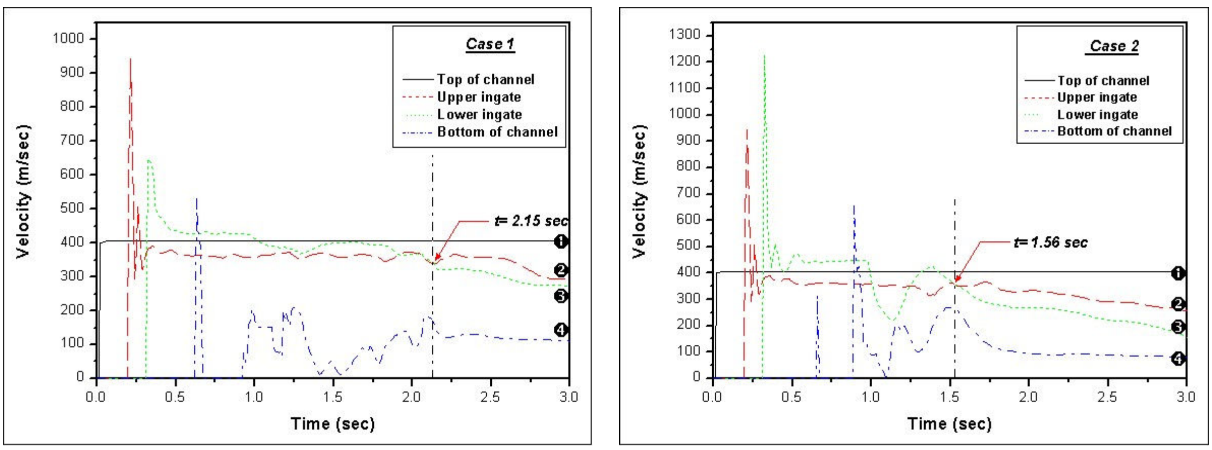


Fig 6. Fluid velocity as function of the filling time

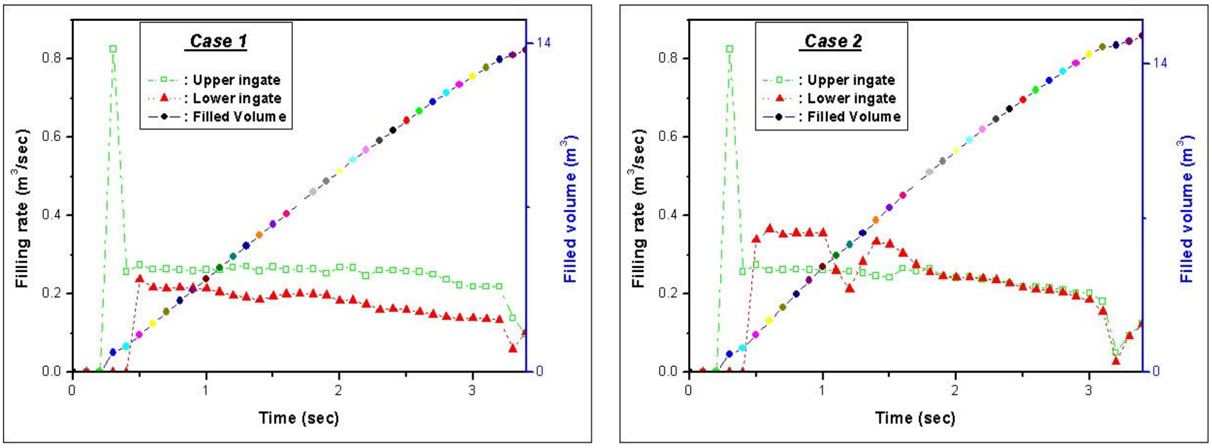


Fig 7. Filled rate and filled volume as a function of filling time at 2 ingates

The calculated Filled rate during filling of the virtual channel is shown in Fig. 7. It is obvious that the filled rate changes considerably. As shown in Fig. 7, the filled volume of the case 2 are filled more faster than that of the case 1. Consequently, the filled velocity and volume time is caused by changing the diameter of two ingates.

4. Remarks and Discussions

A modified SMAC method has been proposed for the simulation of trasient free surface flow problems. It can predict the flow pattern and can the filling sequence during the filling stage of virtual channel. The developted method in this study can be used to analyze a channel design with a complex geometrical shape.

References

Kim, N., and Kim, N.(2000). "The Visual Simulation for Fluid with Free Surface in Virtual Water Tank", Journal of Ocean Engineering and Technology, Vol 14, No 3, pp. 35-40 (in Korean).

Kim, N., and Kim, N.(2001). "Visualization of the Water Column Collapse by using SMAC Method", Journal of Korea Resources Association, Vol 34, No 6, pp. 605-615 (in Korean).

Koshizuka, S. and Oka, Y. (1996). "Moving-Particle Semi-implicit Method for Fragmentation of Incompressible Fluid.", *Nucl. Sci. Eng.*, Vol. 123, pp. 421-434.

Martin, J.C. and Moyce, W.J. (1952). "An Experimental study of the collapse of liquid columns on a rigid hofizontal plane." *Philos. Trans. R. Soc. London Ser. A*, pp. 312-324