Numerical analysis of Mud flow using VOF scheme with Non-Newtonian model

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Abstract
The behavior of high concentration sediment flow was examined as incompressible viscosity free surface fluid with a pseudo-plastic non-Newton fluid model, and the validity is verified by accuracy verification by experiment.
The dam break experiment is conducted with various water content ratios, and the fluid-analysis result and experimental result by the VOF method are compared. Correlations between water content ratio and the dynamic viscosity in N-S equation was examined. The result can reproduce the almost same form and it is thought that the correlation between dynamic viscosity and moisture content can be examined.

Keywords
. High concentration sediment flow **,** Fluid analysis , Moisture weight percentage, Dynamic viscosity

1. Introduction

Under the influence of non-Newtonian effect, the water with high sediment concentration flows with characteristics of soil structure. Research of sediment flow has been advanced for low-concentration sediment flow, such as a mudflow and a muddy stream of a flood in hydraulic engineering.
According to Cui[1)], it has been reported that sediment flow begin to show behavior as non-Newton fluid if the volume concentration of sediment exceeds 10% . Assume the case that flood flow of Yellow River , the sediment flow with low volume concentration less than 30% was examined.
Under the influence of the non-Newtonian effect, it is very difficult to treat the sediment flow with high volume concentration more than 30% by Hydraulic engineering, usually.
On the other hand, the soil including a large quantity of water transforms like fluid. It can be observed in case of a landslide by heavy rain or mud flow by liquefaction. Although these phenomena transform like fluid, it is completely different from usual water behavior by influence of internal soil structure.
Thus, high concentration sediment flow exists in the interdisciplinary domain of soil mechanics and hydrodynamics, and it can be said that handling is one of the very difficult phenomena.
The purpose of this research is to clarify the characteristic of the sediment flow with high concentration including flow with soil structure as non-Newtonian fluid using VOF(Volume of Fluid) scheme.

2.Experiment of dam break

The dam break problem is well used for accuracy verification of the free surface fluid analysis technique, and also has accumulation of data. Therefore, we conducted experiment and analysis for dam break problem, and examined correlation between water content and dynamic viscosity.

2.1 The experiment method

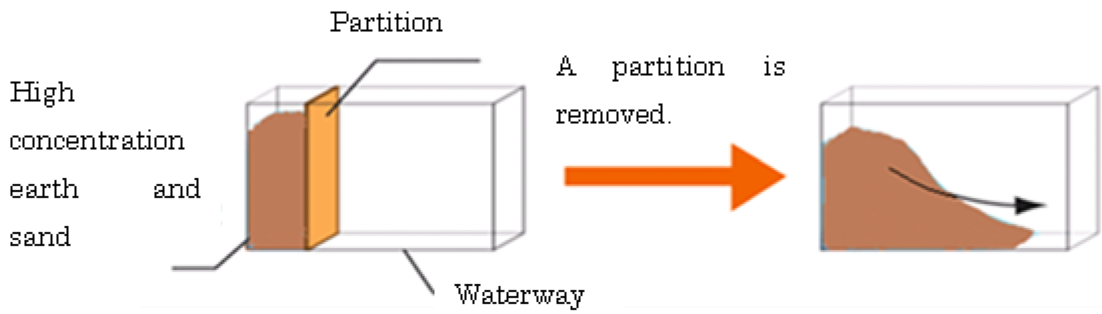

Fig. 1 Experimental Model

Fig.1 shows experimental model of dam break.2-dimensional water cannel was used. We prepared the space (12cm length, 12cm height and 30cm width) in upper side (left side in the Fig.1) of the channel by partition plate.Mixture of soil and water with controlled volume water content is poured into the space.After having stirred the mixture well, remove the partition plate. Motion of the mixture behavior was observed by camera.

After collapsing of mixture, front position of the mixture was measured.

The grain size distribution of soil used for the experiment is shown in Fig. 2

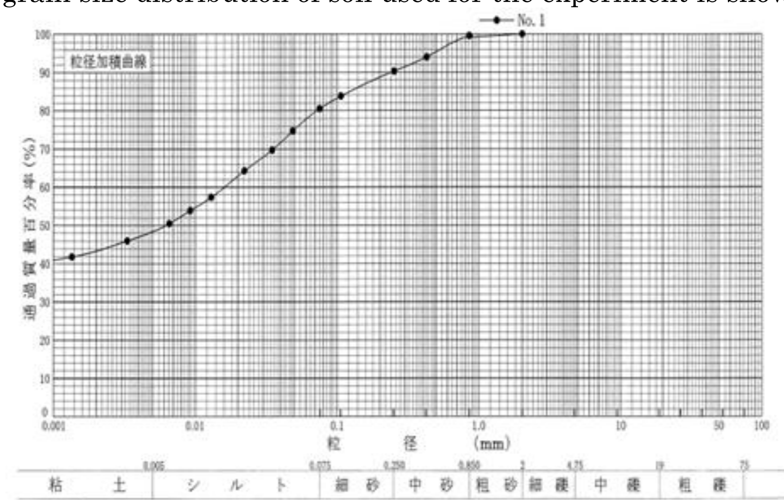

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Fig. 2 Grain size accumulation curve

2.2Experimental results

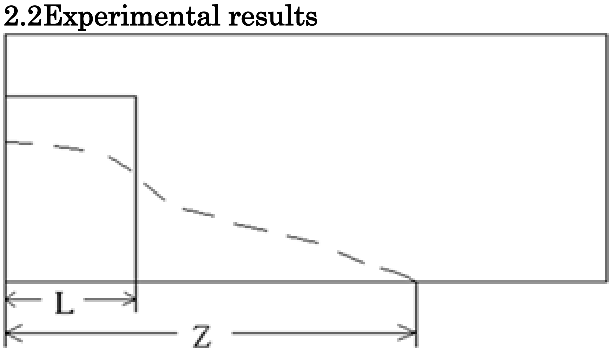

Fig.3 The variable definition of front position dimensionlessness

(L: Initial thickness Z: Front position)

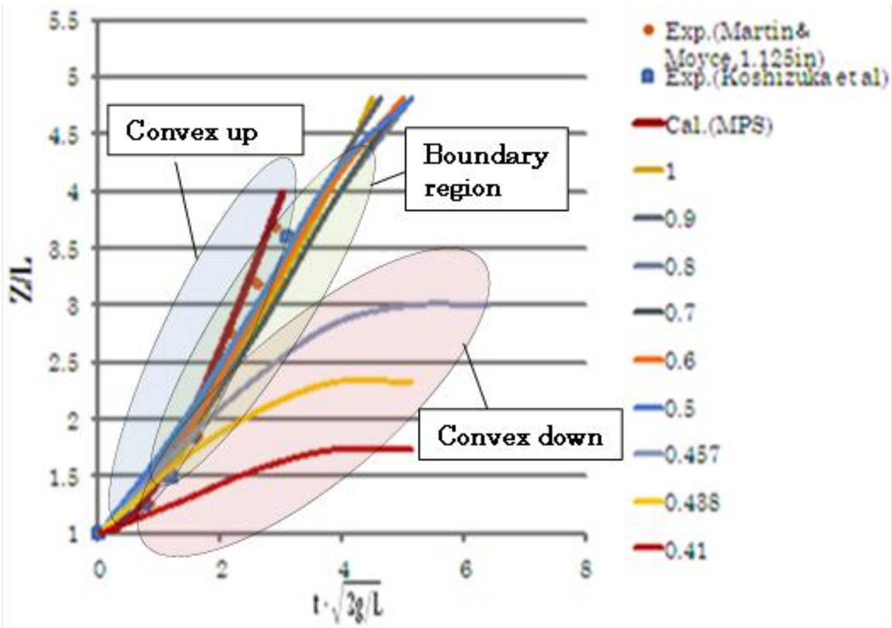

Fig. 4. Front length in each time

Fig. 4 shows variation per time of the front position after dam breaking. In Fig.4, horizontal axis is dimensionless time. Vertical axis is dimensionless length between original and front position of the breaking dam mixture divided by initial width of the dam mixture.
In Fig. 4, experimental result with 100% water contents shows good agreement with past studies. In 40% water content, mixture was not flowed. In 41 to 46% water content, a graph is a convex up form. Therefore, it turns out that breaking mixture slows down. Although at first, convex up shape appears, convex down shape appears in later. with 50 to 80% water content. This means that the breaking mixture was changing from the acceleration condition to the slowdown state. In 90% and 100% water content, the graph of Fig. 4 shows convex down form from the start of a graph.
Results in 50% and 80% were extracted in Fig. 5.
Acceleration state is shown in blues lines, slowdown state is shown in red lines, and linear state is shown in green lines.

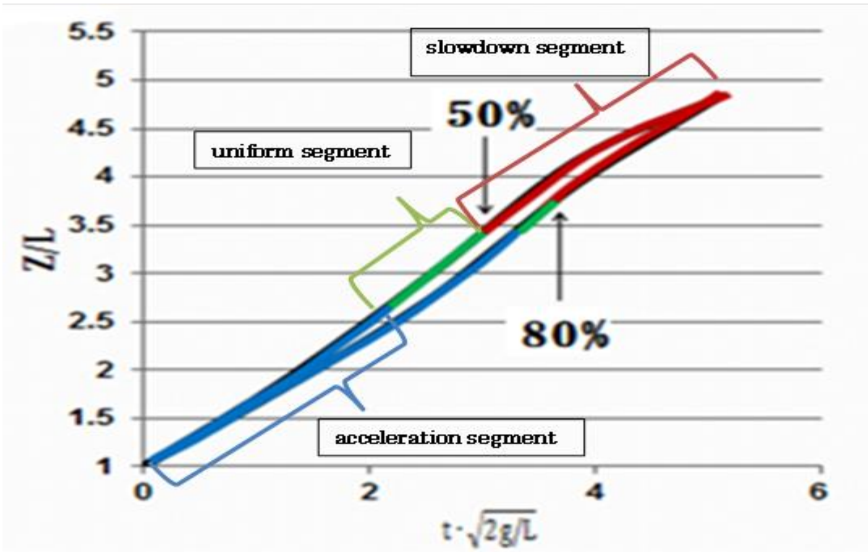

Fig. 5 variation per time of the front position in 50% and 80% water content

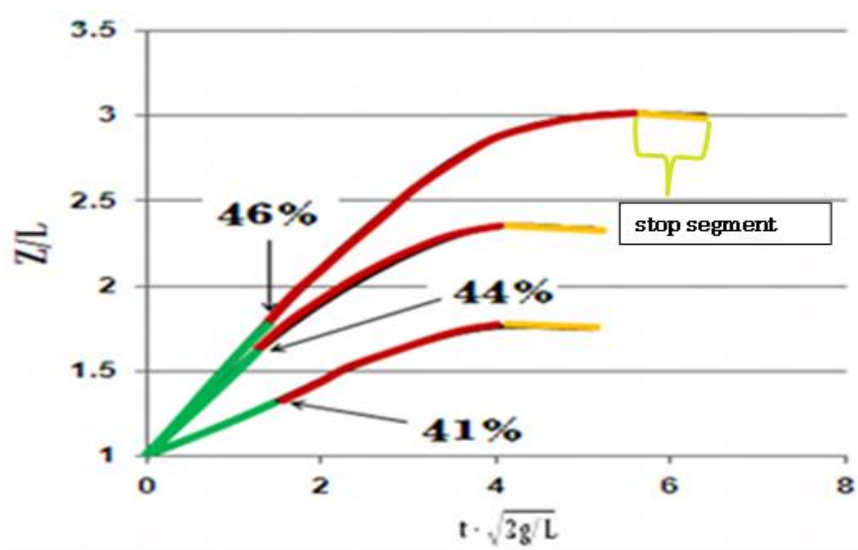

Fig. 6 variation per hour time of the front position in 41%, 44%, and 46% water content

Fig. 5 indicates that mixture flows with accelerating in the start of the movement . After that, mixture flows with uniform motion, and finally, mixture flows with decelerating. (Comparison between result in 50% and 80% water content indicates that mixture with 80% water content flows in accelerating condition for a long time than mixture with 50%.)
In Fig. 6 , the results from 41% to 46% water content, mixture flows with uniform motion at first. After that, they decelerate and finally, they stopped. Acceleration segment was not able to be confirmed.
Fig. 7 shows (correlation between time when the mixture start to decelerates and water content. In Fig. 7, we can confirm that the time when the mixture start to decelerate increases in proportion to the water content.)

3. Numerical analysis using VOF scheme

Numerical analysis using VOF (Volume of Fluid) scheme was performed to examine the non-Newtonian effect in behavior of soil-water mixture.

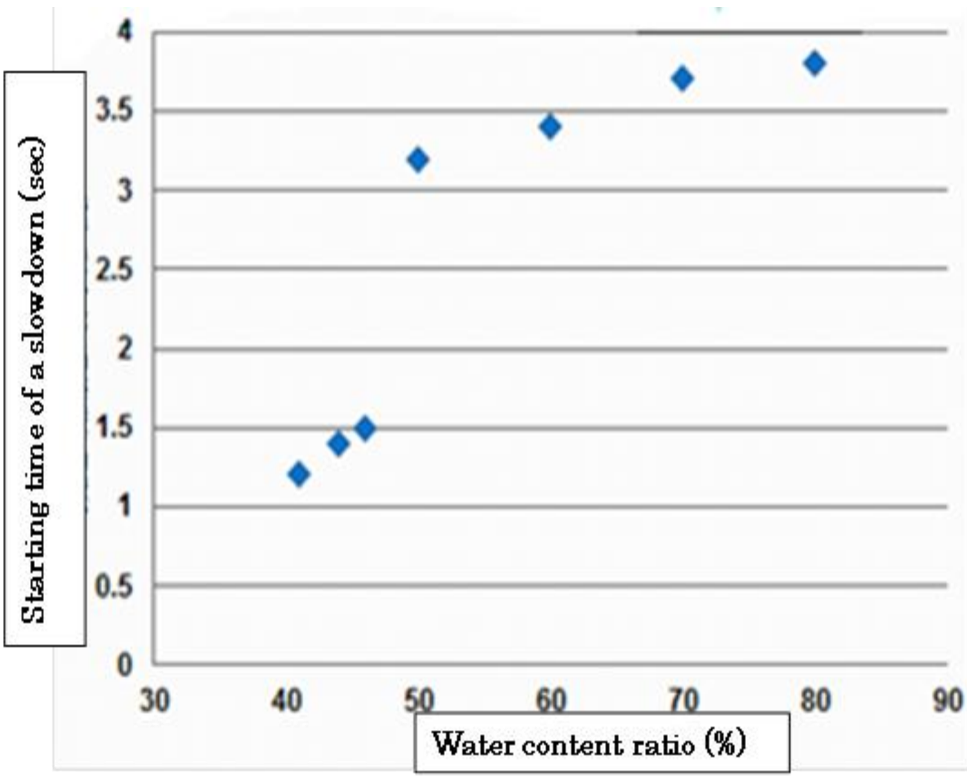

Fig. 7 Time which mixture in various water content began to slow down

The primitive equations used by this research are the continuity equation (1.1) to incompressible viscous fluid, a Navier-Stokes equation (1.2), (1.3), (1.4), and an advection equation (1.5).

$$\frac{\partial u}{dx}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1.1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=X-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad (1.2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=Y-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad (1.3)$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=Z-\frac{1}{\rho}\frac{\partial p}{\partial z}+\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \quad (1.4)$$

$$\frac{\partial F}{dt}+\frac{\partial (Fu)}{\partial x}+\frac{\partial (Fv)}{\partial y}+\frac{\partial (Fw)}{\partial z}=0 \quad (1.5)$$

here, u, v, and w are velocity components of x, y, and z direction, respectively.
X, Y, and Z are the external force of x, y, and z direction, respectively.
p is pressure, ν is a coefficient of kinematic viscosity and F is a rate of volume of fluid in VOF

scheme.

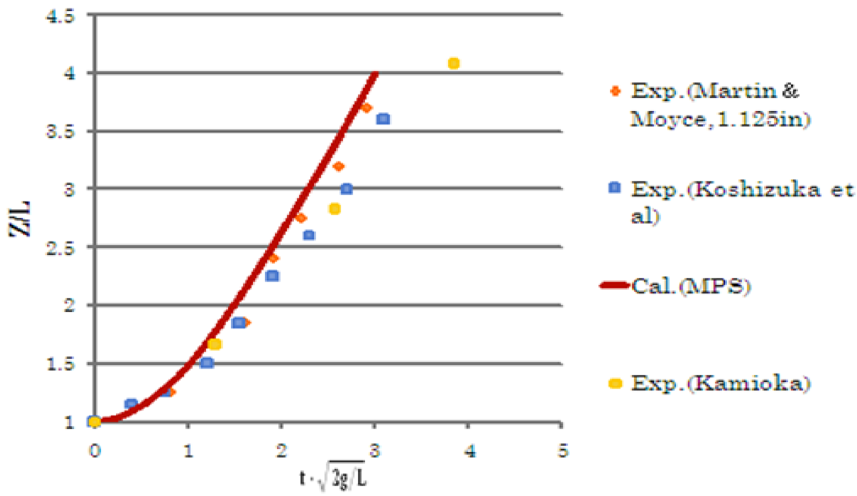

Fig. 8 Comparison between experimental and numerical analysis of variation per time of the water front in dam break problem.

Fig. 9 shows comparison between experiment and numerical analysis using VOF scheme of dam break problem.
Result of the numerical analysis shows good agreement with the experiment. It indicates that the numerical analysis has good accuracy.

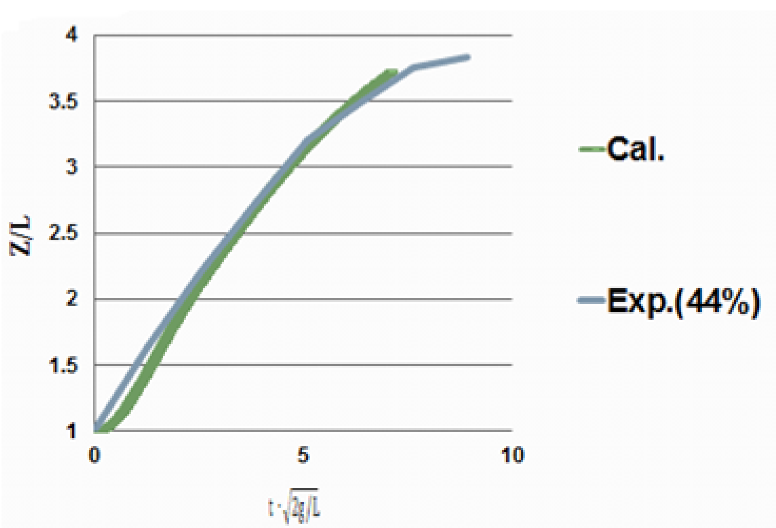

Fig. 9 Comparison between experimental and numerical analysis of variation per time of the soil-water mixture front in 44% water content.

Fig. 9 shows comparison between experimental and numerical result in 44% water content. By adjusting the parameter of the non-Newton fluid model on numerical computation, two results have been reproduced in the almost same form. The setting method of parameter values is performed so that an experimental result can be reproduced. It is thought that the further examination about setting methods of coefficient of the dynamic viscosity in N-S equation, and the internal mechanical characteristic of high concentration sediment flow will be examined in detail.

4. Conclusion

The main results obtained by this research are as follows. A soil-water mixture shows various actions by changing a water content ratio. (The lower the water content of the mixture become, the longer the accelerating time of flowing mixture.) However, (examination of internal mechanism of mixture is) considered as the future subject.
Moreover, it is possible by adjusting the parameter values on numerical computation to reproduce an experimental result. Although, the setting method of the parameter values on numerical computation was performed to simulate the experimental results , the relation of a setup and physical phenomenon of parameter values is not clear. This elucidation is a future subject.

5. References

1) Cui , Omoto and Koga ;The resistive characteristic of the high concentration sediment flow which has the non-Newtonian fluid characteristic, applied mechanics collected papers, Vol.9, pp.883-892, 2006.

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