Non-dimensional Parameters Governing Hyperconcentrated Flow

S. Member JSCE, O Muh. Saleh PALLU*
Member JSCE, Muneo HIRANO*
Member JSCE, Haruyuki HASHIMOTO*
S. Member JSCE, Akira FUKUTOMI*

1. Introduction

Debris flow, which contains sand and water at very high concentration, often moves at surprisingly high speed, and therefore has very strong destructive power. In Japan, there are many places prone to the occurrence of debris flow. Establishment of the countermeasures to prevent the disaster due to the debris flow needs the knowledge and behavior of rapid hyperconcentrated flow.

This paper deals with the introduction of non-dimensional parameters governing rapid hyperconcentrated flow in open channel. In the present work, we have investigated the flow resistance with rapid hyperconcentrated flow at various bed conditions.

2. Parameters Governing Flow Condition

A governing equation for two-dimensional steady rapid flows is given by

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial z}=-\frac{1}{\rho_t}\frac{\partial p}{\partial x}+\frac{1}{\rho_t}\left(\frac{\partial \tau_{zx}}{\partial z}+\frac{\partial \tau_{xx}}{\partial x}\right) \quad (1)$$

where ρ_t is density of mixture flows, p is pressure including gravity component of the flows, and τ_{zx} , τ_{xx} are intergranular-stresses. Here, the Reynold's stress due to the turbulence of the interstitial water is assumed negligibly minor compared to the intergranular-stresses. Further, for the two-dimensional shear flow, the equations of intergranular-stresses can be written in the form

$$\tau_{zx}=K_{zx}\,\sigma d^2\,F(C)\,(du/dz)^2$$
$$\tau_{xx}=K_{xx}\,\sigma d^2\,F(C)\,(du/dz)^2 \quad (2)$$

in which d is grain diameter, σ is grain density, and $F(C)$ is a function of grain concentration C. $F(C)$ increases with C [1].

Now, U being a characteristic velocity and L being a characteristic length, the inertia terms in Equation(1) are estimated as U^2/L and the inter granular-stress terms as $d^2F(C)U^2/L^3$. The ratio of these terms is

$$\frac{U^2/L}{d^2\,F(C)\,U^2/L^3}=\frac{1}{F(C)}\left(\frac{L}{d}\right)^2 \quad (3)$$

Thus L/d and C are two unknown parameters and should be determined experimental. At larger values of C and smaller values of L/d, intergranular stress terms play major role compared to the inertia terms. At smaller values of C and larger values of L/d, on the other hands, the inertia terms become important relative to intergranular-stress terms. Since the depth of shear layer is appropriate for a characteristic length, flow depth h can be chosen as L in the discussion of friction forces acting on a bed.

3. Experimental Method

We used three kinds of flumes with adjustable slope. In the experiments of mixture flow with larger depth, we used a movable bed flume 20 cm wide and 7 m long, while in those with smaller depth, we used a movable bed flume 10 cm wide and 10 m long. Further, in the experiments with very fine sand as bed material, we used a flume 12.5 cm wide with a movable bed 7 m long in the upstream and a fixed bed 5 m long in the downstream. Two kinds of fixed beds were used; one is made of acrylic board and the other of plywood. Prior to the start of a test, the sand bed 10 cm deep was saturated with seepage water.

The water discharge q_{wo} per unit width was supplied from upstream end of the flume, then a flow of sand-water mixture occurred on bed. Discharge q_t per unit width and flux-averaged concentration C_T were measured by catching the flow in buckets at the downstream end of the flumes. Flow depth h was also measured by taking the pictures of flows from the flume side direction, with either a V.T.R camera or a 16 mm high speed camera. The experimental conditions are shown in Table 1.

Table 1
Experimental Conditions

d(mm)	σ/ρ	Fixed Bed		Movable Bed	
		q_{wo}(cm²/s)	θ_0	q_{wo}(cm²/s)	θ_0
0.07	2.63	100	14°	—	—
0.09	2.60	100	14°	—	—
0.17	2.61	100,200	4°~18°	50~670	4°~18°
0.29	2.62	100	14°	50~730	4°~18°
0.55	2.65	100	14°	200~660	4°~18°
0.80	2.64	100,200	8°~18°	50~660	2°~20°
1.24	2.65	100	14°	100~660	6°~18°
1.94	2.61	100	14°	100~660	6°~18°
4.40	2.59	100,200	4°~18°	190~1120	2°~14°
4.60	2.59	100,200	4°~18°	200	2°~23°
7.00	2.63	100,200	8°~18°	—	—

* Department of Civil Engineering(Suiko), Kyushu University

4. Discussion of the Results

In section 2 relative depth h/d and concentration C are found to determine flow condition. C is approximated by C_T . Figure 1 shows the relation between friction coefficient f' and relative depth h/d. Here, the friction coefficient is defined as, $f' = 2(u_*/\overline{u})^2$ where $u_* = \sqrt{ghsin\theta_0}$ is friction velocity and $\overline{u} = q_t/h$ is average velocity. It is found that f' sharply decreases with h/d at smaller value of h/d and gradually decreases at the larger value of h/d for movable bed condition. On the other hand, the values of f' are almost constant in the case of fixed bed. Thus, it is found that the different values of f' occur at the region of $h/d \leq 25$, but the same values at the region of $h/d \geq 100$, for fixed and movable bed conditions.

Figures 2 and 3 show the variation of the friction coefficien f' with flux-averaged concentration C_T at the certain values of h/d. The values of f' become almost constant against C_T in the case of acrylic board, but for other cases, the value of f' increases with C_T as shown in Figure 2. Figures 2 and 3 also show that the value of f' sharply increases with C_T at smaller values of h/d and f' gradually increase at larger values of h/d.

Since intergranular-stresses become smaller at $h/d \geq 100$ in the three cases, the velocity distribution can be expressed as a logarithmic law

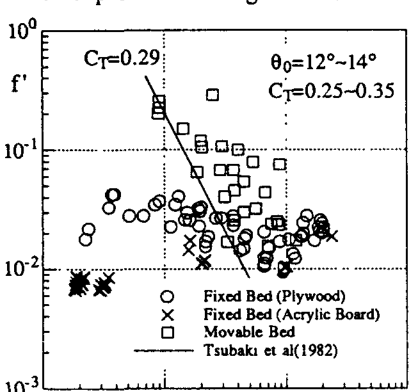

Figure 1. Variation of friction coefficient f' with relative depth h/d.

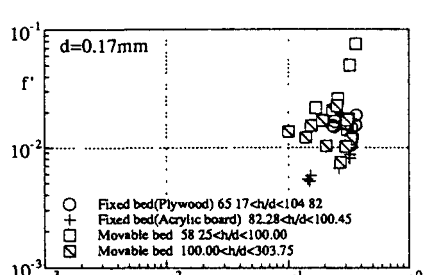

Figure 3. Variation of friction coefficient f' with flux-averaged concentartion C_T.

$$\frac{u_s - u}{u_*} = \frac{1}{\kappa} ln \frac{y}{h} \tag{4}$$

where u_s is surface velocity and κ is the Karman's constant . The κ values are plotted on Figure 4 . The experimental results give κ in Equation 4 approximately 0.25 ~ 0.46. So these values have large variety against grain concentration.

5. Conclusions

The ratio of flow depth to grain diameter and grain concentration are the non-dimensional parameters for the estimate of friction forces acting on a bed. At smaller relative depth and larger concentration in the motion equation, intergranular-stress terms play dominant role. At the larger value of h/d, on the other hand, major effect of the inertia terms has been confirmed.

Reference

[1] T.Tsubaki, H.Hashimoto and T.Suetsugi (1982), " Grain Stresses and Flow Properties of Debris Flow ", Proceedings, JSCE, N0.317, pp.79-91 (in Japanese).

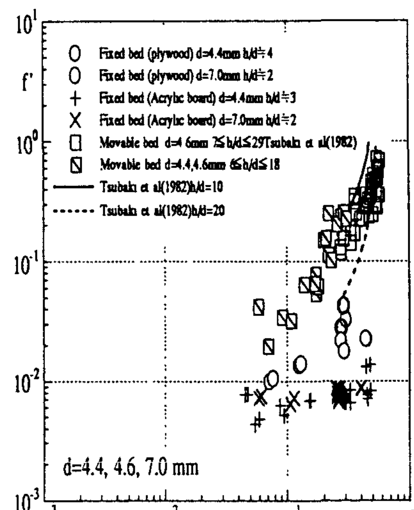

Figure 2. Variation of friction coefficient f' with flux-averaged concentartion C_T.

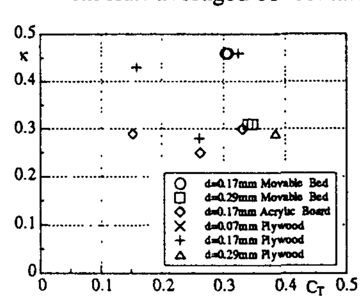

Figure 4. Variation in Karman's constant with concentration.