Malaysian Journal of Civil Engineering 25 Special Issue(1):88-94 (2013)

INFLUENCE OF CLAY FRACTION ON VISCOSITY IN RELATION TO MUDFLOW

Budijanto Widjaja[1]* and Shannon Hsien-Heng Lee[2]

[1]*Department of Civil Engineering, Parahyangan Catholic University, Bandung, Indonesia*
[2]*Department of Construction Engineering Taiwan Tech Taipei, Taiwan, R.O.C.*

Corresponding author: geotek.gw@gmail.com*

Abstract: Mudflow is one type of natural disaster. This type of mass movement can be triggered by changing of water content due to increasing of rainfall intensity. The occurrence in Indonesia and Taiwan is relatively high. According to its definition, the material is dominant by fine grained soil. The viscosity as one of main rheology parameters governs mudflow movement. In order to overcome the conventional viscometer which could not measure around liquid limit, the authors developed a new laboratory test so called the flow box test (FBT). The governing equation is a couple of Terzaghi's trap door and Bingham model. From this test, one of the merit is this test can measure the viscosity around liquid limit. Using the case study in Indonesia (Ciwidey and Karangayar) and Taiwan (Maokong), the result shows that increasing of clay fraction is followed by increasing of viscosity. Hence, this research has a contribution to explain the influence of clay fraction on viscosity in relation to mudflow.

Keywords: *mudflow; water content; liquid limit; viscosity*

1.0 Introduction

Mudflow always occurs in Indonesia. As one of the mass movements, occurrence of mudflow is indicated by change of its water content for fine grained soils. Some researchers (Hungr et al. 2001; Cruden and Varnes 1996) believe when water content is equal to liquid limit, mudflow is initiated. In other hands, this movement has a velocity above 5 cm/sec (Hungr et al. 2001).

Landslide has a velocity lower than mudflow. Usually, in geotechnical engineering, for example, using a limit equilibrium method, it presents by a safety factor with a discrete failure surface (i.e., circular or translation). However, due to mudflow happens in viscous liquid state, the behavior could not explain using a conventional approach (e.g. Mohr Coulomb). Hence, to understand more about this behavior, we need to know a rheology model. Rheology studies of how material flow. One of the simple and famous models is Bingham's model. Two parameters are yield stress (cohesion) and viscosity.

In this paper, due to the main type of mudflow is fine grained soil, so the effect of clay content in viscosity is studied using some three case studies in both Taiwan and Indonesia. The locations are Maokong, Ciwidey, and Karanganyar.

2.0 Materials and Methods

The Bingham model is typically used to model mudflow behavior (Franzi 2000). This mechanical model has a viscous dashpot (i.e., reflects viscosity, η) and a friction plate (i.e., reflects yield shear stress, τ_y) in a parallel connection. The model can be expressed as

$$\tau = \tau_{yB} + \eta \dot{\gamma} \tag{1}$$

where τ is the shear stress, τ_{yB} denotes the Bingham yield stress, and $\dot{\gamma}$ represents the shear strain rate. Equation (1) indicates that when τ is lower than τ_{yB}, the material is in a plastic state. However, when τ is higher than τ_{yB}, the material flows (Krizek 2004). Many researchers believe that mudflow occurs when its water content (*w*) reaches its LL.

The Herschel-Bulkley model is a purely empirical curve-matching representation, applicable only to viscometer test results (Lorenzini and Mazza 2004; Takahashi 2007) with the equation

$$\tau = \tau_y + K(\dot{\gamma})^n \tag{2}$$

where K (consistent coefficient) and n (flow index) are the constant fitting parameters. Similar to the Bingham model, the Herschel-Bulkley model is characterized by dominance for relatively high-viscosity fluids with laminar flow (Huang and Garcia 1988). Chen (1988) recommended the use of this model for studying fine soil.

The FBT was developed using the trap door concept developed by Terzaghi (1943). Initially, this concept was applied to sand materials, and then subsequently extended to clay soil and rock (Lee et al. 2006). Thus, the FBT is intended for fine-grained soils. The equations used to calculate the values of simulated curves are presented in detail in Widjaja and Lee (2012).

The equilibrium of soil column was coupled with the Bingham model. The velocity at time t [v(t)] is expressed as follows:

$$v(t_2) = \frac{-c\left(2 + H/\left(BC_2\right)\right) + q - \dfrac{\gamma}{C_1} + \dfrac{\gamma H}{C_2}}{\eta H/\left(B^2 C_2\right)} + v(t_1) \tag{3}$$

where c is the cohesion, q pertains to the loading, γ denotes the unit weight, H is the sample height, B is the trap door width, $v(t_1)$ represents the velocity at time t_1, and $v(t_2)$ is the velocity at time t_2. Constants C_1 and C_2 are related to the dimension of the FBT. They are expressed as follows:

$$C_1 = \frac{P}{A} K_a \tag{4}$$

$$C_2 = \left(1 - e^{-C_1 \cdot H}\right) \tag{5}$$

where P is the perimeter, A pertains to the area, K_a denotes the coefficient of active earth pressure.

The velocity should decrease during testing. This requirement modifies Eq. 3, resulting in the minimum cohesion

$$c_{\min} = \frac{q - \frac{\gamma}{C_1} + \frac{\gamma H}{C_2}}{\left(2 + H/\left(BC_2\right)\right)} \tag{6}$$

From Eq. 6, c is related to a certain geometry and the loading of the FBT, not viscosity.

In obtaining the displacement profile (i.e., displacement and time relationship), the integration of the velocity profile is possible. Analogous to the Herschel-Bulkley model, the calculated displacement profile is calibrated and curve-fitted to the experiment data using

$$d = d_o + K(t)^n;\ \mathit{for}\ \mathrm{d} \geq \mathrm{d_o} \tag{7}$$

$$t = 0;\ \mathit{for}\ \mathrm{d} < \mathrm{d_o} \tag{8}$$

where d_o is the immediate displacement, and K and n are the constant fitting parameters, as defined in Eq. 2. d_o can be interpreted as the d at a very close initial time of the experiment ($t \approx 0$), possibly reflecting the instantaneous movement of mudflow.

The setup of the FBT is shown in Fig. 1. An 8 cm wide and 10 cm long trap door is placed in the lower chamber. The height of the sample was 5 cm, considering that the failure surface was vertical. The loading was 3.5 kPa. Using Eq. 6, $c_{\min}$ was determined to be 1.4 kPa. Thus, the FBT can be used for both plastic and viscous liquid states because the c at the LL is 2 kPa.

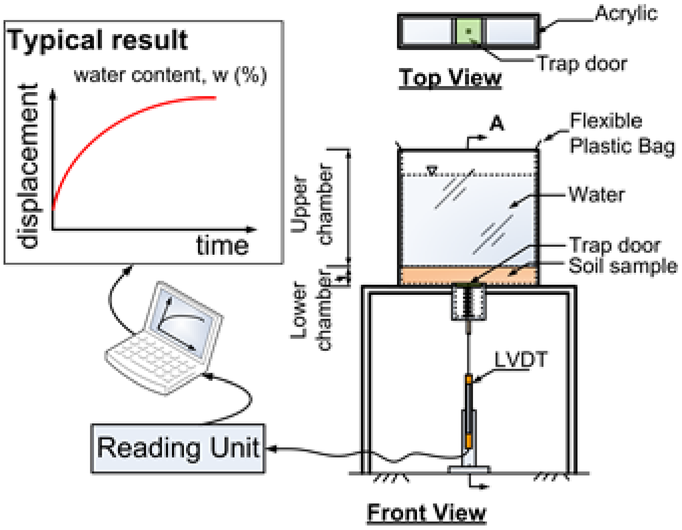

Figure 1 : Schematic used to obtain the displacement profile from the FBT

3.0 Results and Discussion

The parameters of the soil samples from Kaolin and Maokong are shown in Table 1. The clay fractions for Kaolin, Maokong, Karanganyar, and Ciwidey are 51%, 32%, 36%, and 34%, respectively. Using USCS, the soil samples from Kaolin, Maokong, and Ciwidey are classified as ML, whereas that from Karanganyar is classified as MH.

The scanning electron microscopy (SEM) images show that the water contents (w) are 42% for Kaolin soil and 40% for Maokong soil (Figs. 2 and 3, respectively). The microstructural arrangement in the viscous liquid state is shown. The flaky shapes of the Kaolin and Maokong soil samples are clearly observed.

Table 1: Soil Parameters

Sample No.	Soil	LL	PL	PI	G_s	CF %	USCS
1	Kaolin	32	24	8	2.62	51	ML
2	Maokong	33	26	7	2.66	32	ML
3	Karanganyar	53	34	19	2.71	36	MH
4	Ciwidey	45	32	13	2.63	34	ML

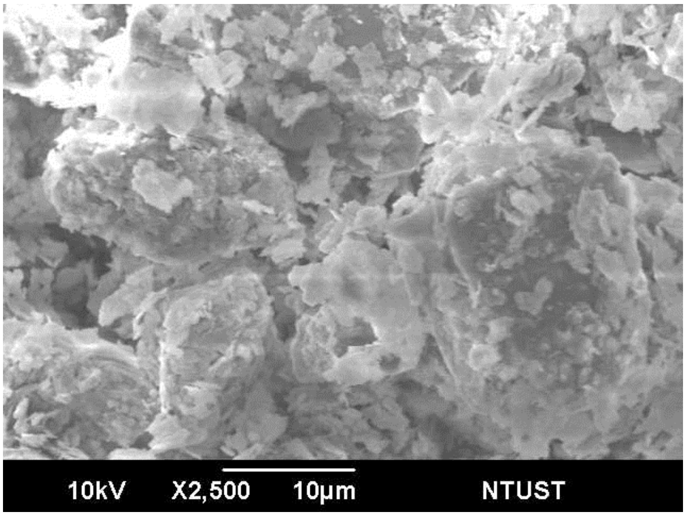

Figure 2 : Scanning Electron Microscopy for Kaolin with water content equal to 42% (viscous liquid state)

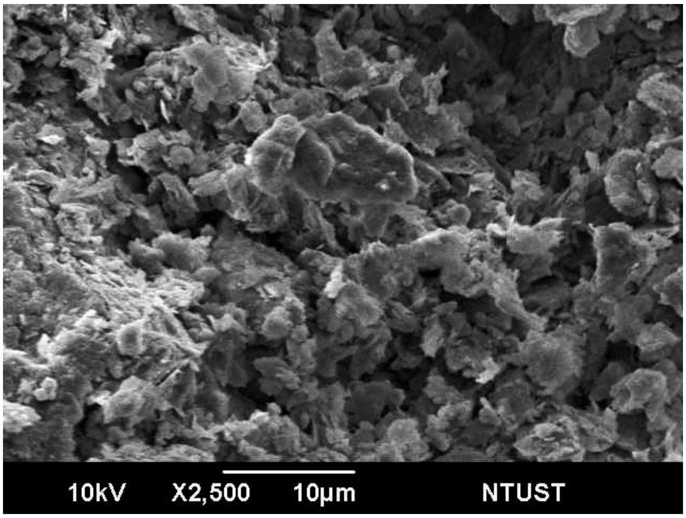

Figure 3 : Scanning Electron Microscopy for Maokong with water content equal to 40% (viscous liquid state)

The results of the flow box test (FBT) of the four soil samples are presented in Fig. 4. The general characteristic of all soil samples is that when the water content is lower than the liquid limit, the viscosity is represented by a steep slope. However, when the water content increases, the viscosity slope becomes gentler and smoother. The viscosity is higher in the plastic state than in the viscous liquid state.

The viscosity (η) range of the mudflow case (viscous liquid state) from the FBT is 0.08 Pa·s to 3 Pa·s. FBT can provide the viscosity in both plastic and viscous liquid states. However, a conventional viscometer can currently be used to measure the viscosity in the viscous liquid state only.

Fig. 4 shows that increased clay fraction results in increased viscosity, particularly in the viscous liquid state. For example, the Maokong soil sample, which has the lowest clay fraction, has the lowest viscosity (circle number 2). The trend of the plastic state is different possibly due to the change in the microstructure of the soil particles. This change is induced by the distinct roles of repulsive and attractive forces in the plastic state. On the other hand, in the viscous liquid state, the repulsive and attractive forces may be similar.

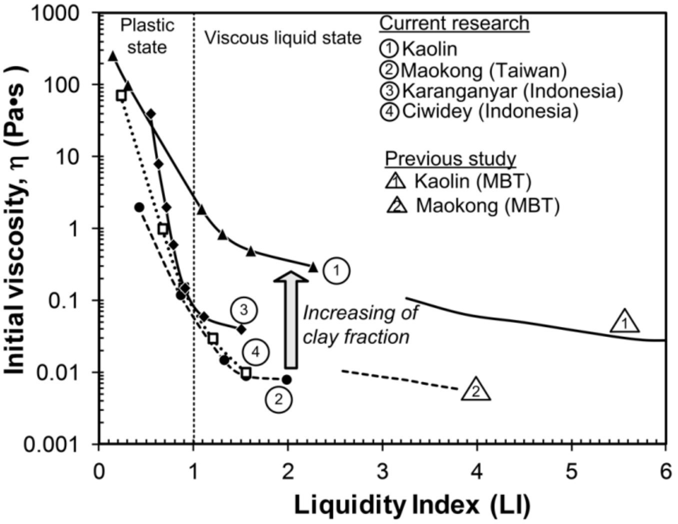

Figure 4: Relationship between initial viscosity and Liquidity Index

4.0 Conclusions

The FBT enables the determination of the initial viscosity for both plastic and viscous liquid states. The viscosity of mudflow in four cases (Kaolin, Maokong, Karanganyar, and Ciwidey) range between 0.08 and 3 Pa·s. The relationship between the initial viscosity and liquidity index indicates that increased clay fraction in the viscous liquid state results in increased initial viscosity. However, this characteristic may only be valid for the mudflow case. Further studies on other cases are needed to confirm this characteristic.

Acknowledgment

The authors greatly appreciate the financial support and scholarship grants from the Japan government, the World Bank, the Japan-Indonesia Presidential Scholarship, and Taiwan Tech in the production of this research.

References

Chen, C.L. (1988) General solutions for viscoplastic debris flow. *J. Hydraulic Engineering*, 114(3): 259-282.

Cruden, D.M., and Varnes, D.J. (1996) Landslide types and processes, In: A.K. Turner and R.L. Shuster (eds.), Landslides: investigation and mitigation, Transp. Res. Board., Spec. Rep., 247, 36-75.

Franzi, L. (2000) On the effect of clays on collisional stresses in debris flow, *Proc. 2nd IAHR Symposium on river, coastal and estuarine morphodynamics*, Obihiro, Japan, 375-384.

Huang, X. and Garcia, M.H. (1998) A Herschel-Bulkley model for mud flow down a slope. *J. Fluid Mech*., 374:305-333.

Hungr, O., Evans, S.G., Bovis, M.J. ,and Hutchinson, J.N. (2001) A review of the classification of landslides of the flow type.*" Environmental and Eng. Geoscience*, VII(3): 221-238.

Krizek, R.J. (2004) Slurries in geotechnical engineering. *12th Spencer J. Buchanan* Lecture, Texas: Texas A&M University.

Lee, C.J., Wu, B.R., Chen, H.T. and Chiang, K.H. (2006) Tunnel stability and arching effects during tunneling in soft clayey soil, *Tunnelling and Underground Space Technology*, 21:119-132.

Lorenzini, G & Mazza, N. (2004) Debris flow phenomology and rheological modelling. Boston: WIT Press.

Takahashi, T. (2007) Debris flow: mechanics, prediction and countermeasures. London: Taylor and Francis.

Terzaghi, K. (1943) Arching in ideal soils. In: Theoretical Soil Mechanics. New York: John Wiley & Sons.

Widjaja, B. and Lee, S.H.H (2012) Flow box test for the viscosity of soil in plastic and viscous liquid states. *Soils and Foundatio*ns (under review).