



BACK ANALYSIS OF PARUNG PONTENG LANDSLIDE USING RHEOLOGICAL APPROACH

Budijanto Widjaja and Alex Bobby Setiawan

Parahyangan Catholic University, Bandung, Indonesia

E-Mail: geotek.gw@gmail.com

ABSTRACT

Mass movement is downslope movement of soil or rock debris due to gravitational pull or vertical sinking of the ground surface. Mass movements may occur for a considerably long duration or an extremely short period, such as landslides or rockfalls, and cause devastating consequences. Mass movement is a challenging subject because it cannot be explained by Mohr–Coulomb theorem. As such, an approach for predicting movement patterns must be developed. This research modeled a mass movement in Cihonje Hamlet in Parungponteng Village, Tasikmalaya District, West Java, Indonesia. The influence of viscosity and yield stress on the behavior of the mass movement was also investigated through back analysis. Results showed that viscosity and yield stress are inversely proportional to water content and both decrease as the water content approaches the liquid limit. Thus, low viscosity induces flow coverage.

Keywords: mass movement, viscosity, liquid limit, landslide, rheology.

INTRODUCTION

Mass movement is the bulk movement of soil and rock debris down slopes in response to the pull of gravity or the rapid or gradual sinking of the ground surface of the earth in a predominantly vertical direction [1]. Mass movements may occur for a considerably long duration or an extremely short period, such as landslides or rockfalls, and cause devastating consequences. Mass movement is a challenging subject because Mohr–Coulomb law does not apply to this condition. Accordingly, rheology is one of the many approaches used to elucidate the behavior of mass movement.



Figure-1. In situ photograph of the movement crown taken on 20 August 2014.

Figure-1 shows an in situ photograph taken onsite 7 days after a crown movement in Cihonje Hamlet, Parungponteng Village in Tasikmalaya District, West Java, Indonesia. The mass movement occurred on 13 August 2014 and yielded a deposition length of 120 m.

MATERIAL AND METHOD

Classification of mass movement

Confusions often arise in differentiating mass movement and landslide because of their similar

definitions. Mass movements are divided into three main categories according to the rate of movement, the type of carried material, and the characteristic of the movement as seen in Table-1 [2].

Slide movement is a mass movement in which the material remains fairly coherent and moves along a well-defined surface, which is approximately parallel to the slope. Flow movement is a mass movement in which the material moves downslope in a viscous fluid form [3]. Behavioral parameters, such as velocity, impact force, and deposition area coverage, which are used to determine the type of a movement, cannot be calculated using Mohr–Coulomb theorem only. Thus, an approach to fulfill the gap in mass movement classification must be developed.

Table-1. Classification of mass movement [2].

	Slowest	Increasing Velocities		Fastest
Velocity	< 1 cm/year	1 mm/day – 1 km/h	1 to 5 km/h	> 5 km/h
Movement				
Flow	Creep → Earthflow → Mudflow → Avalanche ← Debris Flow →			
Slide	← Debris Slide or Earth Slide → ← Rock Slide →			
Fall	Rock fall			
	← "Landslides" →			

Rheology as an approach

Rheology, based on its etymology, $\rho\omega$ (*/rheo/*) meaning flow and $\lambda\omicron\gamma\iota\alpha$ (*/-logia/*) meaning study, is the study of flow of matter in the liquid state but also of soft-solid or solid materials, which respond to a plastic flow rather than deform elastically in response to applied pressure.

Flowing materials are categorized into Newtonian and non-Newtonian fluids. In Newtonian fluid, viscous



stresses arising from its flow are linearly proportional to the local strain rate at every point. The viscosity of Newtonian fluid neither varies with deformation rate or time nor displays elastic properties or extensional anomalies [4]. By contrast, in non-Newtonian fluid, viscosity (η) is reliant on shear rate ($\dot{\gamma}$) or shear rate history; that is, the value of viscosity changes through time.

Viscosity (η) is the required shear force for fluid to move at a certain speed [5]. Yield stress (τ_y) is the stress at which the plastic deformation of a material begins. If yield stress (τ_y) is higher than shear stress (τ), then soil is in the plastic state; otherwise, the soil is in the viscous liquid state. For the simulation, Equations. 1 and 2 are used to calculate the corresponding flow pattern output based on viscosity and yield stress. Equation. 3 serves as input to Equations. 1 and 2 [6].

$$\eta = \alpha e^{\beta C_v} \quad (1)$$

$$\tau_y = \alpha e^{\beta C_v} \quad (2)$$

$$C_v = \frac{1}{1 + G_s w} \quad (3)$$

where h is viscosity (Pa·s), τ_y is yield stress (kPa), α and β are constants for FLO-2D input, C_v is concentration coefficient based on volume, G_s is specific gravity, and w is water content.

Figure-2 presents the correlation between C_v and η , and between C_v and τ_y . Line 1 (O'Brien line in viscosity and Fei line in yield stress) in both charts is used as a basis to determine the values of α and β during the trial.

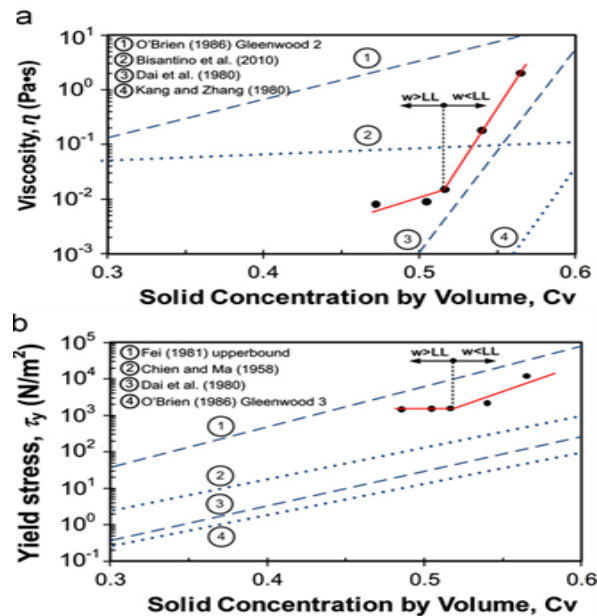


Figure-2. (a) Correlation between concentration by volume (C_v) and viscosity and (b) between C_v and yield stress [7].

RESULTS AND DISCUSSIONS

The Flo-2D simulation indicates that low viscosity value results in a wide coverage area and low yield stress. The back analysis culminates with the water content value of 38% with a viscosity of 2.9 Pa·s and a yield stress of 4 kPa, at which point the deposition length matches with the published measured deposition length on the field, that is, 120 m [8].

Figure-3 shows flow patterns from the final trial, and Figure-4 presents the cross-section of the movement over time. As shown in these figures, the mass movement exhibits elevation variability at certain distances; hence, the mass movement is earth slide according to Plummer's chart (Table-1) or typical landslide in geotechnical terms.

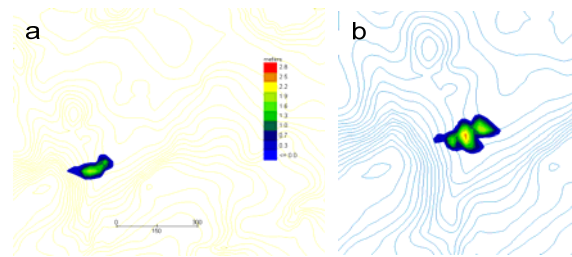


Figure-3. (a) Final trial results on 20 m x 20 m grid and (b) detailed result on 10 m x 10 m grid.

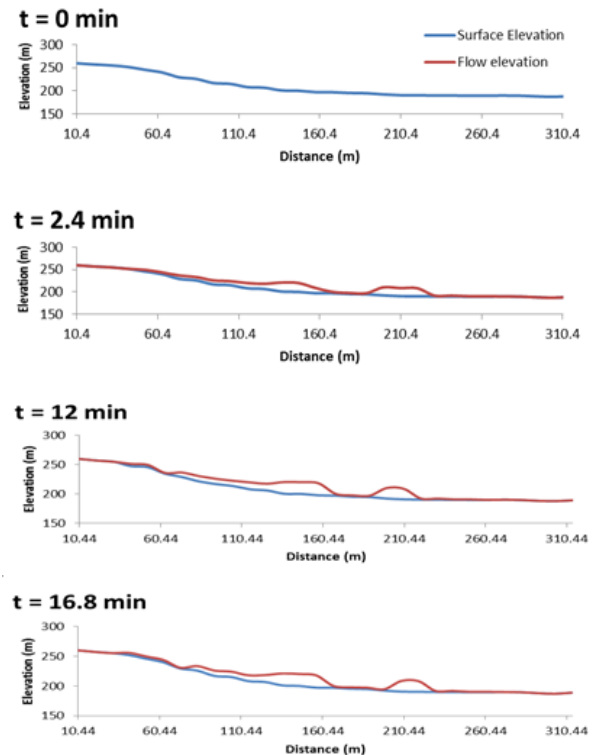


Figure-4. Elevation change over time for water content $w = 38\%$.



Table-2 provides the values of η and τ_y in the trials for the back analysis. Table-3 shows the results of flow behavior generated using the software.

Table-2. Result summary of viscosity and yield stress.

Trial number	Water content (w)	Solid Conc. by vol. (C_v)	Viscosity (η)	Yield stress (τ_y)
	[%]		[Pa·s]	[kPa]
1	45.0	0.443	1.0	1.0
2	40.0	0.473	2.3	3.4
3	35.0	0.506	4.0	7.0
4	37.5	0.488	3.0	4.0
5	42.5	0.458	2.0	2.0
6	38.0	0.485	2.9	4.0

Table-3. Result summary of flow behavior.

LL	50.75	Flow Properties					
Trial	w	Flow vector	L	B	H	v_o	v
	[%]		[m]	[m]	[m]	[m/s]	[m/s]
1	45	N 60 E	187.5	105	0.7-1.3	7	3
2	40	N 60 E	127.5	67.5	0.9-1.6	7.1	3
3	35	N 90 E	112.5	52.5	0.6-1.8	7.2	3.2
4	37.5	N 60 E	115	60	0.6-2.5	7.2	3.1
5	42.5	N 60 E	150	75	0.6-1.9	7.2	3.1
6	38	N 60 E	120	63.75	0.4-2.9	7.1	3.1

Note: LL is liquid limit, w is water content, L is deposition length, B is Average deposition width, H is Deposition height, v_o is Initial velocity (Source), and v is flow velocity.

As shown in Table-2, water content is inversely proportional to both viscosity and yield stress. Figure-5 and Figure-6 present the correlations of water content with viscosity and yield stress, respectively. Increasing the water content decreases the yield stress and thus reduces the viscosity. Given that the soil body loses its capability to resist itself to retain its solid shape, it “dissolves” and behaves like a liquid form. In Parungponteng case, the low liquid limit value induced the soil to become easily “liquefied” compared with soils with high liquid limits. This phenomenon could be attributed to the immediate dissolution of the lower part of the soil by water that slips through soil cracks, causing movement to take place.

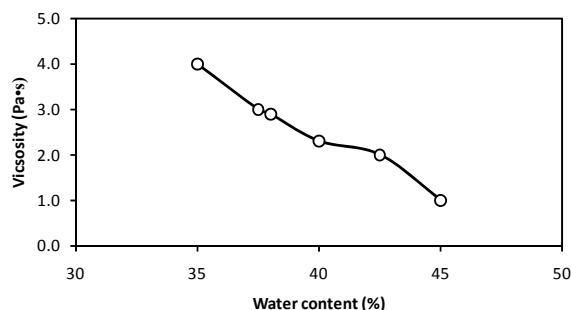


Figure-5. Increasing of water content is followed by decreasing of viscosity in Parungponteng mass movement.

Coverage area significantly increases with increasing water content, as shown in Figure-7. Increase in water content results in further and wider spread of the movement because of lack of resistance of the soil to the flow. However, the relationship between deposition height and water content is the opposite. High water content results in a low deposition area height.

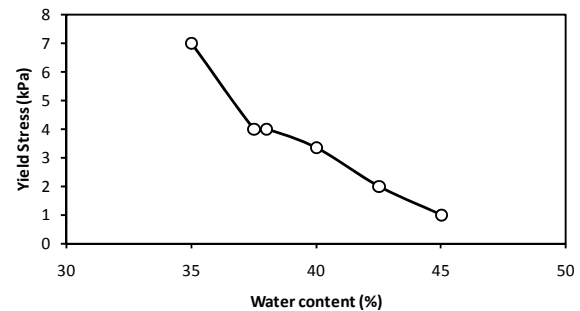


Figure-6. Reducing of yield stress caused by increasing of water content in Parungponteng mass movement.

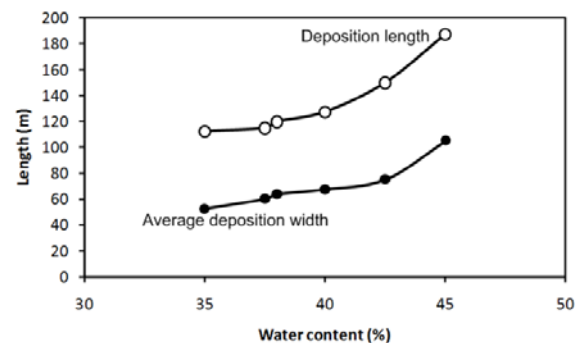


Figure-7. Correlation among water content, deposition length, and average deposition width.

The variation in velocity caused by changes in water content is insignificant, as presented in Figure-8. As a result of the short range between plastic and liquid limits, the narrow trial window for water content in the back analysis may have caused such irregularity. Moreover, velocity is directly proportional to water content. Hence, the less the resistance of the soil to flow, the higher the velocity will be.

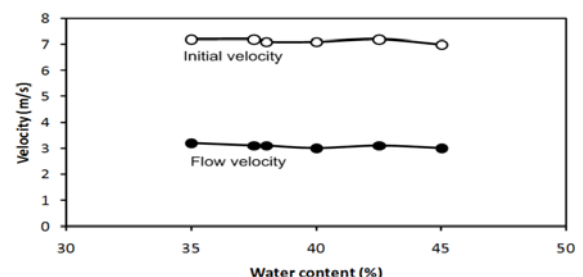


Figure-8. Correlation between water content and velocity.



Figure-9 presents the comparison of the results of the back analysis of the Parungponteng case with the published data. Results show that Parungponteng soil behaves in a similar manner to the Maokong sample.

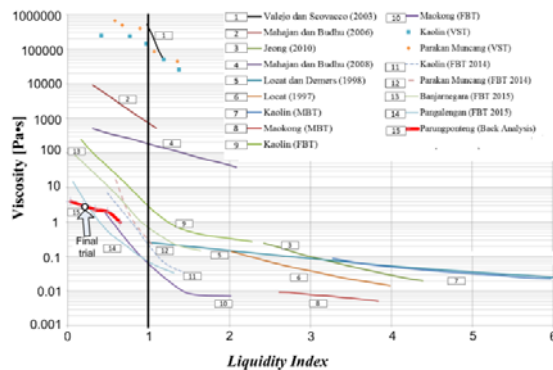


Figure-9. Comparison of back analysis results with published data [9].

CONCLUSIONS

Among all the simulations performed using back analysis, trial number 6, in which the water content is 38%, generated coverage results closest to the obtained data from the field survey.

The type of mass movement in Parungponteng is categorized as landslide because the water content is below the liquid limit ($w < LL$) and the flow velocity of the trial (11.16 km/h) is faster than 5 km/h.

Viscosity and yield stress are inversely proportional to water content. The closer the water content to the liquid limit is, the lower the yield stress and viscosity values are. As a result, the area covered in mass waste becomes wider.

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