Rheological properties of fine-grained soils according to temperature and water content

Geun-Woo Park[1], S. Kang[1], D. Lee[1], and J.-S. Lee[1]

[1] School of Civil, Environmental and Architectural Engineering, Korea University, 145, Anam-ro, Seongbuk-gu, Seoul, 02841, Korea.

ABSTRACT

The rheological properties of fine-grained soils, which are greatly affected by temperature and water content, are some of the most important factors for the reduction of debris flow damage. In this study, the variation of rheological properties is investigated on fine-grained soils according to temperature and water content. After the rheological properties of fine-grained soils are evaluated by rheometer, the plastic viscosity and yield stress of fine-grained soils are calculated based on the Bingham model. The plastic viscosity and yield stress of the specimens with three liquid indices (1.0, 1.5, and 2.0) are evaluated at different temperature conditions (15°C~35°C). The rheometer test results show that the plastic viscosity and yield stress of fine-grained soils at high temperature are smaller than those at low temperature. The plastic viscosity and yield stress of fine-grained soils decrease with an increase in the liquid index. The fine-grained soils at 15°C have twice higher plastic viscosity than those at 35°C. This study demonstrates that debris flow under the conditions of high temperature and high water content may have lower plastic viscosity and lower yield stress than that at low temperature and low water content.

Keywords: liquid index; rheometer; temperature; viscosity; yield stress

1 INTRODUCTION

The damage of human life and property has been caused by landslide and debris flow in rainy season globally. To reduce the damages, many researchers have been studying the behavior of landslide and debris flow. The damage and scale of landslide and debris flow are decided by the velocity and distance of debris flow, and those are determined by the rheological properties of fine-grained soils (Imran et al., 2001).

The rheological properties of debris flow, that is, the flow of the liquified soils, may differ according to the water contents of the soils(Suetsugu and White, 1983). In addition, the temperature condition of soils affects the rheological properties of debris flow(Nguyen, 2007). Thus, both factors may influence on the behavior of debris flow. This paper is composed of test apparatus, samples, test procedure, test results, analyses, and conclusions.

2 RHEOMETER TEST

2.1 Test apparatus

Rheometer has been used for evaluating rheological properties. This test apparatus is composed of a vane spindle, a sample cup, and controllers, as shown in Fig. 1. The vane spindle, which has four blades, is connected to a spindle controller in the center of the rheometer. The bottom of the rheometer includes temperature controller and sample cup, which may control the sample temperature condition.

During the test, the vane spindle rotates in the sample cup at various revolutions per minute (RPM), and the torque of the vane spindle is measured by spindle controller. RPM and torque are used to calculate the shear rate and shear stress.

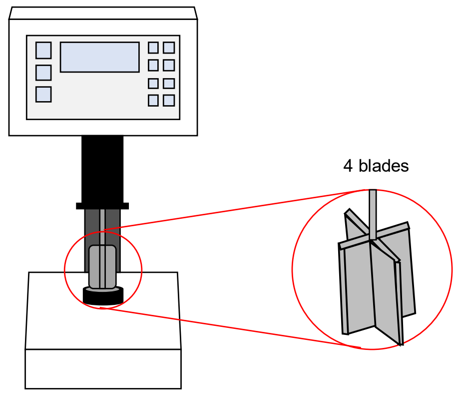

Fig. 1. Rheometer.

2.2 Samples

The samples are prepared using mountain fine soils, which is finer sieve no.200. The index properties of the specimen are summarized in table 1. The liquid and plastic limit of the soil sample are 69.73% and 49.75% based on ASTM D4318 (2005), respectively. Thus, the plasticity index is 19.98%. The specific gravity is measured as 2.71 (ASTM D854, 2009), and the maximum and minimum void ratios of sample are 1.12 and 0.81 (ASTM D4253, 2006; ASTM D4254, 2006), respectively. The soil sample is classified as inorganic silt (MH) according to the unified soil classification system (USCS).

Table 1. Index properties of sample.

Properties	Value
Liquid limit	69.73%
Plastic limit	49.75%
Plasticity index	19.98%
Specific gravity	2.71
Maximum void ratio	1.12
Minimum void ratio	0.81

2.3 Test procedure

The rheometer tests are conducted at three different temperatures and three water contents, which are represented by liquidity index (LI). For LI=1.0, the rheometer tests are conducted at 15°C, 25°C, and 35°C. The rheological properties are measured at three liquid indices (LI = 1.0, 1.5, and 2.0) at the temperature of 15°C.

All tests are performed at the same range of shear rate (1s-1~1000s-1), and shear stresses are continuously measured as the shear rate increases. For calculating plastic viscosity and yield stress, the relationship between shear rate and shear stress is graphically represented. And then, plastic viscosity and yield stress are calculated based on the Bingham model.

2.4 Test results

The test results are represented at Fig. 2 and Fig. 3. Fig. 2 shows the rheometer test results for different temperature conditions. The relationships between shear rate and shear stress, and between plastic viscosity and shear rate are plotted in Fig. 2(a), and Fig. 2(b), respectively. Fig. 3(a) shows that shear stress decreases with an increase in the temperature at the fixed shear rate. In addition, the plastic viscosity at the higher temperature is smaller than that at the lower temperature when the shear rate is greater than $10s^{-1}$.

(a) (b)

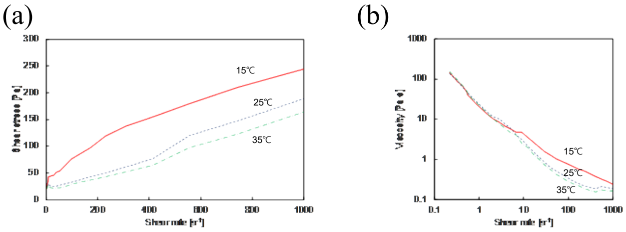

Fig. 2. Rheometer test results for three temperatures:(a) Shear rate vs. Shear stress; (b) Shear rate vs. Viscosity.

The rheometer test results for three liquid indices are plotted in Fig. 3, which shows that shear stress decreases with an increase in the liquid index. In addition, the plastic viscosity at the higher liquid index is smaller than that at the lower liquid index.

(a) (b)

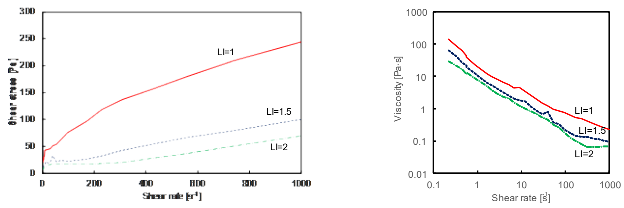

Fig. 3. Rheometer test result for three liquid indices:(a) Shear rate vs. Shear stress; (b) Shear rate vs. Viscosity.

Fig. 2(a) and Fig. 3(a) show that the difference in shear stress decreases as the temperature or liquid index increases. In addition, the difference in shear stress increases with an increase in the shear rate. Plastic viscosities are almost the same if the shear rate is less than $10s^{-1}$ even at different temperature.

The yield stress of all specimens is calculated based on the Bingham model. Bingham yield stress can be calculated by y-intercept in the shear stress-shear rate curve as shown in Fig. 2(a) and Fig 3(a). Calculated yield stresses are summarized in Table 2. Table 2 shows that Bingham yield stresses at high temperature and liquid index are smaller than those at low temperature and liquid index. In addition, the difference in Bingham yield stress decreases with an increase in the temperature and liquid index.

Table 2. Bingham yield stress of samples.

Sample	Bingham yield stress[Pa]
15°C, LI=1.0	92
25°C, LI=1.0	43
35°C, LI=1.0	28
15°C, LI=1.5	24
15°C, LI=2.0	16

2.5 Analyses

The experimental studies show that the plastic viscosity and yield stress of fine-grained soils are dependent on the temperature and liquid index. These relationships can be explained in the physicochemical point of view. Plastic viscosity and yield stress are determined by the physicochemical connection of soil particles (Park et al., 2017). However, water and heat disturb this physicochemical connection. Thus, plastic viscosity and yield stress at the high temperature and high liquid index are greater than that at the low temperature and low liquid index.

The plastic viscosity and yield stress, which are rheological properties, are factors of the velocity and distance in rheology. Thus, plastic viscosity and yield stress may be proportional to the velocity and distance of0 debris flow. Thus, the velocity and distance of debris flow at the high temperature and high liquid index may have higher than those at the low temperature and low liquid index.

3 CONCLUSIONS

The main observations from this study are as follows:

(1) The plastic viscosity and yield stress decrease under high temperature.

(2) The plastic viscosity and yield stress decrease under high liquid index.

(3) The difference in Bingham yield stress decreases as the temperature or water content increase.

(4) Thus, debris flow can be faster at the high temperature and high liquid index. In addition, the movement is longer at the high temperature and high liquid index.

4 ACKNOWLEDGEMENTS

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