【 III －5】

Effect of discontinued shearing on residual shear strength of clayey soils

Clayey soils, Residual strength,
Ring shear test, Strength recovery

○Deepak R. Bhat, N. P. Bhandary, and R. Yatabe
Graduate School of Science and Engineering, Ehime University

1. INTRODUCTION

Residual shear strength is generally considered while designing preventive measures for slopes consisting of preexisting shear surfaces such as large-scale landslides (Skempton 1985). Recent studies suggest that the preexisting shear surface material of a reactivated landslide can regain strength with the passage of time, which needs to be considered in designing the slope landslide measures (Bhat et al. 2013). Gibo et al. (2002) used a ring shear machine (Bishop et al. 1971) to first observe the strength recovery effect in soil samples obtained from two different reactivated landslides. They conclude that the strength recovery effect should be considered in stability analysis of a reactivated landslide dominated by silt and sand particles at an effective normal stress less than 98.1kN/m^2. However, the use of normally consolidated specimens and the short test duration (i.e., 2 days) may not be sufficient to reach this conclusion. In this study, for further understanding of the strength recovery effect in the residual state of clayey soils, four clayey samples were tested using the Bishop-type ring shear machine (Bishop et al. 1971) in an over consolidated state. The main objectives of this study are: 1) to conduct the strength recovery test up to a discontinued shear period (or period of shear stagnation) of 30 days on clayey soils in their residual states of shear and 2) to understand the comparative pattern of recovered shear strength due to discontinued shearing at the residual state of shear among highly plastic clays and less plastic clays.

2. MATERIALS AND METHOD

In this study, four typical clayey soils were selected. One of them was commercially available kaolin clay and the other three were collected from the landslide sites in Japan and Nepal. A clay sample from a landslide site in Shikoku area of Japan was confirmed to have a comparatively high amount of chlorite, which is referred to as “chlorite-rich sample,” and a clay sample from a landslide site in Kobe area of Japan was confirmed to have a comparatively high amount of smectite, which is referred to as “smectite-rich sample.” Similarly, the sample from the Krishnabhir landslide area in Nepal was confirmed to have a comparatively high amount of mica, which is referred to as “mica-rich sample.” The physical properties of the tested samples are presented in Table 1.

Table 1: Physical properties of the tested samples

Sample Type	Solid density (g/cm^3)	LL (%)	PL (%)	PI (%)	Grain size classification (%)		
					Clay	Silt	Sand
Kaolin clay	2.72	52	22	30	74	26	0
Mica-rich sample	2.74	34	21	13	21	60	19
Chlorite-rich sample	2.75	48	31	17	20	68	12
Smectite-rich sample	2.65	97	59	38	24	55	21

The ring shear machine employed in this study is based on the concept reported by Bishop et al. (1971). In this machine, the specimen container has inner and outer diameters of 8 cm and 12 cm, respectively, and an average depth of 3.2 cm. The specimen is sheared through a depth of 0.7 cm from the bottom of the specimen container, and in this study, the shearing rate was fixed at 0.16 mm/min. There were two steps in this experimental study: 1) the ring shear tests were performed to obtain the residual state of shear and (2) the strength recovery tests were conducted after the specimens reached their residual state of shear. For the strength recovery tests, shearing was discontinued for the desired duration after the residual state of shear was achieved. The specimen was made to remain under the applied shear stress and effective normal stress (i.e., σ'_n = 98.1kN/m^2) during the stagnation period (i.e., period of discontinued shear). For example, after one day of discontinued shear, the shearing was restarted under the same test conditions as in the initial state of shear. The shear was continued until the specimen reached its residual state again. This process was repeated until the recovered strength was measured for the final duration of discontinued shear. In this study, we measured the recovered shear strength of all samples for the discontinued shear periods of 1, 3, 7, 15, and 30 days.

3. RESULTS AND DISCUSSION

The ring shear test results indicate that the difference between the peak strength and the residual strength of the kaolin clay is the lowest, and this trend is followed by the mica-rich sample, the chlorite-rich sample, and then the smectite-rich sample. It was observed that the kaolin clay is the strongest and that the smectite-rich sample is the weakest in terms of measured frictional resistance. The smectite-rich sample and the chlorite-rich sample demonstrate a high plasticity nature, while the kaolin clay demonstrates a low plasticity nature. Fig. 1 shows a typical variation of shear resistance (stress) and specimen depth (volumetric strain) with the shear displacement for kaolin clay including the results of strength

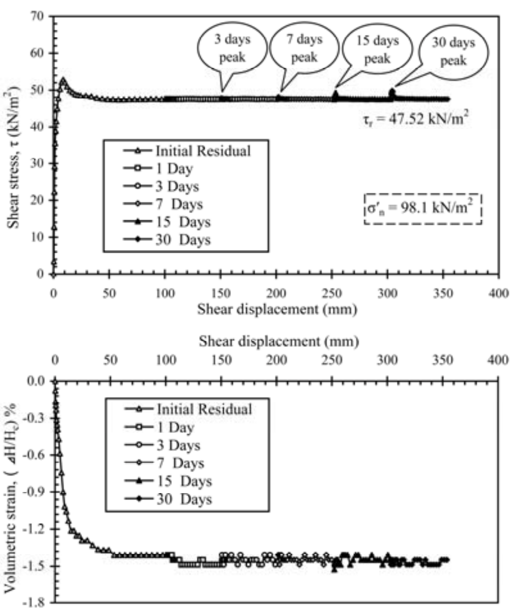

Fig. 1: Typical results of ring shear test and strength recovery tests (on kaolin clay)

recovery tests. The value of the residual friction angle (ϕ_r) and the difference between the drained recovered friction angle (ϕ_{Rec}) and residual friction angle (ϕ_r) (i.e., increase in the frictional angle, $\Delta\phi_r = \phi_{\mathrm{Rec}} - \phi_r$) of all tested samples are summarized in Table 2. For the same stagnation periods, the increase in internal friction angle is slightly greater in the case of the smectite-rich sample, followed by the chlorite-rich sample, the mica-rich sample, and then the kaolin clay (Table 2). Although there is no much increase in internal frictional angle for the discontinued shear period of 3 days, it slightly increases after this period of discontinued shear for all samples. This indicates that the shear strength recovery is negligible for a discontinued shear period of 3 days or less. The amounts of shear displacement during the strength recovery tests are summarized in Table 3. The shear displacement up to the recovered shear strength was found to be small compared to the initial shear displacement for the peak strength value. Also, the recovered shear strength of the kaolin clay reached a residual state of shear after a small shear displacement compared with the all tested samples as seen in Table 3. This is evident that the recovered shear strength dropped to the residual strength just within 1 mm of shear displacement. Moreover, the amount of recovered shear strength was found to be insignificant and it was lost after the specimen was sheared for less than a millimeter. Therefore, the recovered shear strength cannot be considered for analysis and design purposes. Relying on such a small amount of recovered shear strength is judged to be unrealistic in landslide management.

Table 2: Summary of strength recovery in terms of internal frictional angles

Sample Type	Residual Frictional Angles (ϕ_r, deg)	Increase in Frictional Angles (deg) ($\Delta\phi_r=\phi_{Rec}-\phi_r$) 1 Day	3 Days	7 Days	15 Days	30 Days
Kaolin clay	25.85	-	0.10	0.29	0.84	1.07
Mica-rich sample	24.50	-	0.13	0.40	0.96	1.33
Chlorite-rich sample	13.82	-	0.25	0.49	1.14	1.65
Smectite-rich sample	5.16	-	0.38	0.65	1.25	1.96

Table 3: Summary of shear displacements during strength recovery tests

Sample Type	Shear displacement upon recovered strength (mm) Initial	1 Day	3 Days	7 Days	15 Days	30 Days
Kaolin clay	7.29	-	0.48	0.73	0.97	0.97
Mica-rich sample	5.83	-	0.48	0.73	0.73	0.97
Chlorite-rich sample	4.37	-	0.48	0.73	0.97	1.46
Smectite-rich sample	2.43	-	0.73	0.97	1.46	1.46

Fig. 2 shows the ratio between the recovered shear strength and the residual shear strength as a function of stagnation time (i.e., period of discontinued shear). The strength ratio was found the highest for the smectite-rich sample and the lowest for the kaolin clay. The smectite-rich sample is a highly plastic in nature compared with the all other tested samples. From this, it is understood that a soil with a smaller drop from peak strength to residual strength has little recovery of shear strength when compared with a soil that has a greater drop from peak strength to residual strength. In other words, the recovered shear strength will be higher in high plastic soils while less in less plastic soils. From Fig. 2, it can also be understood that the trend of recovery of shear strength from the residual state of shear is in increasing trend with the increase in the period of discontinued shear. The reason why the recovered shear strength increases with the increase in duration of discontinued shear however needs further investigation.

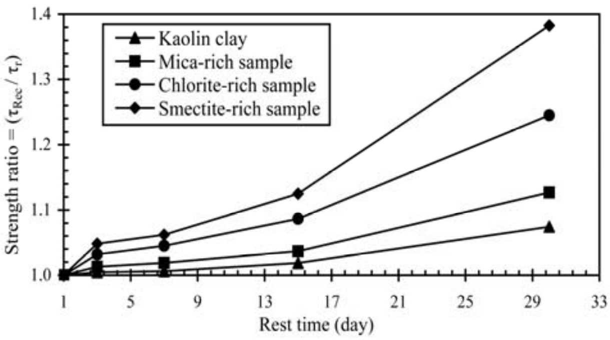

Fig. 2: Strength ratio versus rest time

4. CONCLUSIONS

The effect of shear discontinuation on residual shear strength of four clayey soils was investigated in a ring shear machine for 1, 3, 7, 15, and 30 days of shearing discontinuation while at residual state of shear. The test results revealed that the recovery of shear strength started to appear slightly after a discontinued shear period of 3 days. The present study re-establishes that the strength recovery from the residual value would be greater in high plasticity soils, with a large difference between the peak strength and the residual strength, than in low plasticity soils at an effective normal stress of 98.1kN/m^2. However, it was also understood that the recovered shear strength is lost after the specimen undergoes a small shear displacement.

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