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A study on strength recovery of slip layer clay during stagnant periods of creeping landslides

○ Netra P. Bhandary (正) and R. Yatabe (正)
Faculty of Engineering, Ehime University

1. INTRODUCTION

Unlike creep behavior of materials, which is exhibited under constant stresses, the landslide creep may be interpreted to take place under varying effective pressures, such as due to rise and fall in groundwater level. This often results in imperceptibly fluctuating displacement behavior of creeping landslides. Especially during wet periods the displacement rate increases while it goes down during dry periods. When the rate of creep displacement is reduced or the landslide comes to nearly stagnant state, there are chances that some structural changes take place in the slip surface clay causing slight increase in the shear resistance even if the clay has already reached its residual state of shear. The possible reasons for the rise in shear resistance due to retarded displacement or a static state of landslide may be: 1) reconsolidation of slip layer soil (clay) due to increased effective pressure following a fall in groundwater level, 2) development of cementation between the clay particles due to chemical action of underground water as well as high overburden pressure, 3) extinction of the existing slip surface, etc. This paper therefore attempts to study the influence of static state of landslides on the strength of slip layer soils with the help of laboratory experiments based primarily on the ring shear tests (Bishop et al, 1971) and discusses the role of strength regaining characteristic of slip surface clay at residual state on the concept of landslide creep.

2. TEST METHOD

The test program consisted of ring shear tests on two arbitrarily selected soil samples; one representing the ordinary landslide clay available in Shikoku Region and other representing the non-landslide soil (marine silt). The tests were planned as multistage shearing of the samples at their residual state (or steady state of shear) with varying amounts of static period between two successive shearings. The ring shear apparatus employed in the test program was of direct shear type with drainage facility having 12 cm outer and 8 cm inner diameters. The specimen thickness at the time of shearing was ensured to be above 10 mm with the shear plane at mid height, i.e., 5 mm from the specimen bottom.

To ensure a fully drained condition in the ring shear apparatus, the rate of shear displacement was set to minimum as available in the apparatus (i.e., 0.15 mm/min until the sheared sample exhibited peak shear resistance and exhibited a considerable drop in strength, and after this the shear rate was doubled so as to make the shearing time shorter) for the clay sample, whereas for the silt sample it was set to 0.36 mm/min. The time intervals between two shearings (i.e., no shearing time or time of static state) adopted this time were 7 days, 5 days, 3 days, and 1 day. The shear displacement at one shearing was set to more than one complete rotation of the ring shear apparatus, which was equivalent to about 31.5 cm through the central line in the flat-ring shaped specimen. Keeping in view the overburden pressure on the slip layer soil of a medium size landslide, the shear tests were carried out under a vertical pressure (i.e., s_v) of 196.2 kPa.

3. RESULTS AND DISCUSSION

The physical properties of the tested samples are shown in Table 1. It is seen that the landslide clay tested was moderately plastic with plasticity index below 50. The marine silt, on the other hand, is non-plastic with more than 70% silt content. It is also clear from the table that the landslide clay is more well-graded than the marine silt, which means that the particle contact area must be greater in the clay sample.

Table 1: Physical properties of the tested samples

Sample	ρ_s (gm/cm^3)	W_L (%)	W_P (%)	I_P	Grain size distribution (%)		
					<5μm	5~75μm	75~425μm
Landslide clay	2.64	60.14	20.03	40.11	38.0	33.0	29.0
Marine silt	2.30	-	-	NP	11.5	73.5	15.0

Figures 1 and 2 show the results of ring shear tests on landslide clay and marine silt samples, respectively in terms of shear strength plotted against the shearing time. In Figure 1, the shearing of landslide clay under an effective pressure of 196.2 kPa is seen to have resulted in more than 50% post-peak drop of strength. While the peak shear resistance even under normal consolidation has reached about 62 kPa after 6.1 mm of shear displacement, giving an angle of shearing resistance of 17.5° (note: the cohesion for a normally consolidated clayey soil is zero), the residual shear resistance has dropped to 25 kPa after 350 mm of displacement, which gives an angle of residual friction of as low as 7.2°. On the other hand, the shear resistance of the silt sample under the same effective pressure is indicated in Figure 2, and it is clear that no distinct peak has been obtained. Moreover, no clear state of steady shear was achieved even after a shear displacement of 82 cm, which may be due to rolling-type shear under the effect of larger particles and their relatively rounded shapes (Skempton 1984). The steady-state shear resistance of the silt sample under the applied effective pressure was obtained as 125 kPa, which gives an angle of steady-state shear resistance of 32.5°.

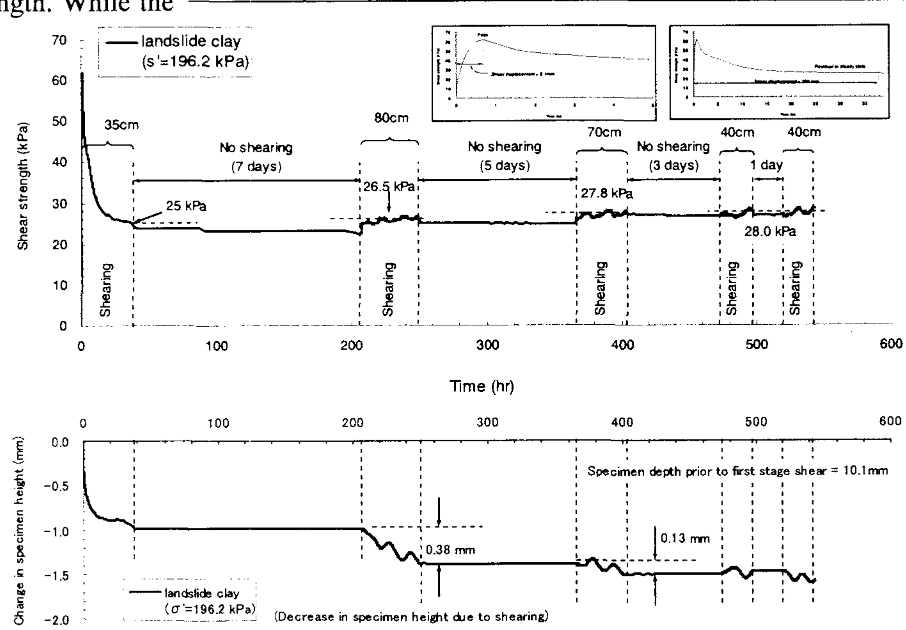

Figure 1. Results of ring shear test on landslide clay sample in terms of shear strength and drop in specimen height during the shear.

The static state of shear can be seen to have caused some changes in the shearing resistance, as shown in Figure 1 as well as Figure 2. Especially, the static states of 7 days and 5 days have resulted in slight increase in the shearing resistance. In case of the landslide clay (Figure 1), the shear resistance after 7-day static state is found increased by 1.5 kPa, which is equivalent to 0.5° of angle of residual shearing resistance for this particular test. Similarly, after 5-day static state, it is found increased by 1.3 kPa, i.e., 0.4° of angle of residual shear resistance. However, no significant increase can be seen in 3 days and 1 day of static states. The case of marine silt sample is also similar (Figure 2). Although the steady state of shear is hard to locate in the figure, an average line shows that the increase in shear resistance after 7-day static state is about 9 kPa, which is equivalent to 1.8° of angle of steady-state shear resistance. Similarly, the 5-day static state has resulted in an increase of 6 kPa equivalent to 1.2° of angle of steady-state shear resistance. The 3-day static state does not seem to have resulted in any significant increase, but 1-day static state raises a question about the reliability of the test results by showing a sudden rise in the shear resistance, which is equivalent to about 2° of angle of shear resistance. The sources of errors in the ring shear apparatuses employed may be several, but as the test conditions were kept unaltered throughout the tests and extreme care was taken not to let any unknown frictions develop, it was considered that the data obtained had enough reliability.

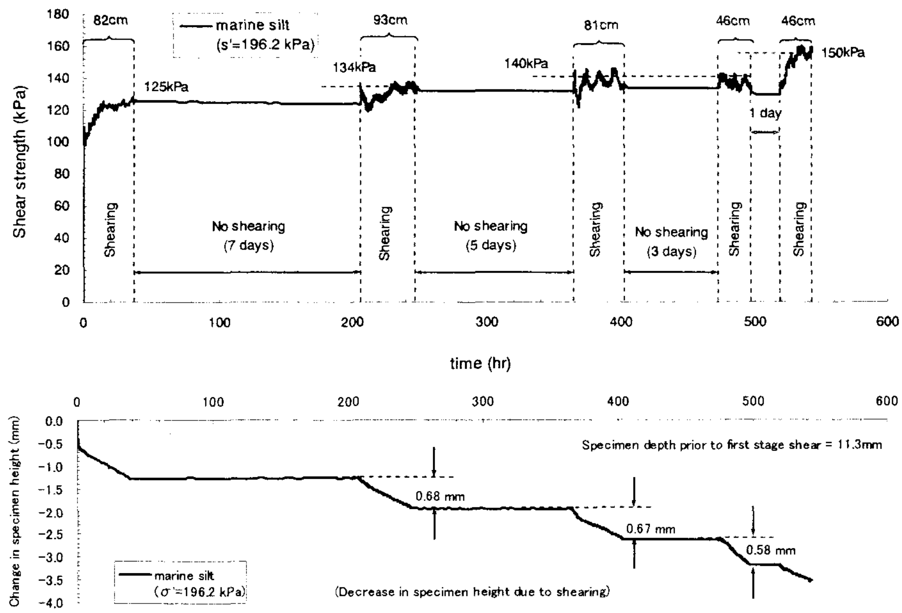

Figure 2. Results of ring shear test on marine silt sample in terms of shear strength and drop in specimen height during the shear.

From the above figures it is also clear that the change in specimen volume (i.e., specimen height), which is negative in these particular tests, does occur with every stage of shearing, especially after longer static states of shear in case of the landslide clay. Although overall specimen height has dropped, slight ups and downs can be seen in the course of shearing, which may be attributed to occasional entry of coarser particles into the slip surface. The drops in specimen height of silt sample are seen to be similar for every stage of shearing. Although it was not confirmed experimentally this time, the drop in depth of silt specimen might have occurred as a result of grain crushing. The decrease in specimen height surely results in increased density or greater particle-to-particle contact area, thereby causing higher frictional resistance. It is therefore of significant importance to look into the mechanism of drop in specimen height even after achieving steady state caused particularly by the static state of shear.

One of the factors responsible for the drop in specimen height may be considered redevelopment of shear band involving a few millimeters of soil above and below the previously developed shear surface. It may take place because the developed slip surface at residual or steady state of shear may regain some strength under the influence of a constant pressure resulting in transfer of the shear stress to neighboring planes and creating a new shear zone or shear band involving a few particle layers above and below the previous slip surface. Reorientation of particles in the shear band and resulted reduction in volume of nearby voids might have caused the drop in specimen height (Lupini et al, 1981). On top of that, if this speculation is correct, what is more important is the mechanism of regaining of strength by the slip surface that has already undergone a shear displacement required to cause residual or steady state. Mitchell (1976) also mentions that the coefficient of static friction is generally greater than the sliding friction, which may be interpreted to support the idea of this paper. After a substantial drop in the rate of landslide displacement, the slip layer soil experiences a static state, thereby recovering the coefficient of static friction, which is supposed to increase with a longer duration of static state. However, why the coefficient of static friction is greater than that of sliding friction may be a topic for further research. Chemical action of water and development of cementation effect in relation to regaining of strength by soil may be an appropriate phenomenon to investigate about further.

4. CONCLUSIONS

This paper made a preliminary attempt to study the influence of relatively static state of landslides on the strength of slip layer soil at its residual state of shear (i.e., steady state of shear) with the help of laboratory experiments, which revealed the following conclusions. A slight increase in shear resistance of soil at its residual or steady state due to static condition can be seen, which is supposed to be due to regaining of shear strength by the soil particles in the slip surface. Moreover, longer the duration of static state, greater might be the rise in shear resistance, which may be due to development of weak cementation between the clay particles in the shear surface. From the viewpoint of landslide stability and economical countermeasures, it may be important to take into account the increase in strength of slip layer soil due to achievement of a static state during dry or non-rainy periods.

REFERENCES

Bishop, A. W., Green, G. E., Garga, V. K., Andresen, A., & Brown, J. D. (1971). A new ring shear apparatus and its application to the measurement of residual strength, *Geotechnique*, 21(4), 273-328.

Lupini, J. F., Skinner, A. E., & Vaughan, P. R. (1981). The drained residual strength of cohesive soils, *Geotechnique*, 31(2), 181-213.

Mitchell, J. K. (1976). *Fundamentals of Soil Behavior*, John Wiley & Sons, Inc. p.310.

Skempton, A. W. (1985). Residual strength of clays in landslides, folded strata and the laboratory. *Geotechnique*, 35(1), 3-18.