Residual-state creep behavior of clayey soils

Clayey soils, Residual-state creep test,
Creeping displacement behavior

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1. INTRODUCTION

The shear strength of soil is generally defined as its maximum resistance to an applied shearing force. It is often evaluated in terms of peak strength and residual strength. When a soil sample is sheared, the shear stress usually reaches a peak value at a small shear displacement, which is called peak strength, and when the shear displacement is increased further to a larger value, it undergoes a post-peak strength loss until a constant minimum value reaches, which is called residual strength. Skempton (1985) has mentioned that the field residual strength value for the slip surface soil of landslide should be the same as the strength calculated from the back analysis of the landslide in which movement has reactivated along a pre-existing slip surface. It means the back-analyzed and lab-determined strength parameters must be the same if the lab tests are carried out under the precisely similar in-situ conditions. This shows the important of residual shear strength in understanding the creeping displacement behavior of landslide slip surface clay. If a ring shear apparatus can facilitate direct application of creep stress on the residual-state of shear and measurement of the displacement with respect to time, the test results obtained from it would be useful in understanding the creeping displacement behavior of clayey soils from landslide slip surfaces.

Few researchers have studied the creep behavior of clayey soils using triaxial compression cell and oedometer; however in most cases, they concentrate on the pre-peak state of shear (i.e., up to peak strength). A clayey soil from landslide is assumed to have already reached the residual state, which necessitates a study on residual strength to understand the creep displacement behavior of clayey soils from landslides. In this work, an attempt has been made to study residual-state creep behavior of clayey soils. For this purpose, a residual-state creep test apparatus is developed. The main objective of this study is to understand the residual-state creep behavior of clayey soils.

2. MATERIALS AND METHODS

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

Table 1 Physical properties of tested samples

Sample Type	G (gm/cm^3)	LL (%)	PL (%)	PI (%)	Soil 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

To perform the residual-state creep test, a torsional ring shear apparatus was modified considering a transitional change of the strain-controlled motor-driven shear into creep loading shearing without complete release of the applied shear stress. The modified ring shear apparatus is capable of measuring the creep displacement with respect to time under the application of a constant shear force. There are two main steps in the test procedure: (1) the ordinary ring shear test and (2) the residual-state creep test. The ordinary ring shear test is performed to obtain the residual state of shear in fully saturated state of sample. This state is confirmed after the shear state indicates constant values for the load-cell reading and dial gauge reading after a displacement range of 10-50 cm; RCSR (i.e., Residual-state Creep Stress Ratio) is introduced as a new term through this study for a precise interpretation of the application of constant creep stress. It is the ratio of creep stress with the residual strength. For example, if the creep stress applied is 90% of the residual strength, the value of RCSR will be 0.9000. In this study, the creep stresses are applied to achieve the RCSR values of 0.9000, 0.9500, 1.0000, 1.0025, 1.0050, 1.0075, 1.0100, 1.0125, 1.0150 and 1.0200.

3. RESULTS AND DISCUSSION

A typical residual-state creep test result of kaolin clay is shown in Fig. 1. Six more tests for each sample were conducted with varied creep stresses. The results of kaolin clay thus obtained are summarized in Table 2. Different stages of creep were observed during the tests especially with respect to change in displacement rate. In primary stage of creep, the rate of displacement decreased. In secondary stage of creep, the rate of displacement was found to be constant, and in tertiary stage of creep, the rate of displacement was found to increase abruptly leading to failure. In the figure, T_1 represents the time until the end of primary creep (i.e., the beginning of secondary creep) and D_1 represents the corresponding displacement. Similarly, T_2 and D_2 represent total time at the end of secondary creep (i. e., the beginning of tertiary creep) and total displacement at time T_2 respectively.

The different stages of creep are identified on the basis of concept of ideal creep curve for a soil material under the application of constant stress. The test results for each specimen of each case are found to perfectly match with the ideal creep curve. Lefebvre (1981) has proposed that creep to failure can occur at less than peak strength. Every soil is considered first to have a zone of creep just below the strength envelope with a lower bound equivalent to 90-95% of the angle of shearing resistance (Ter- Stepanian 1963, Yen 1969). But this study shows that the creep failure begins only when the applied stress is above the residual strength and that there is no significant creeping effect on or below the residual strength. This means when RCSR is less than or equal to 1, the soil does not creep under shear.

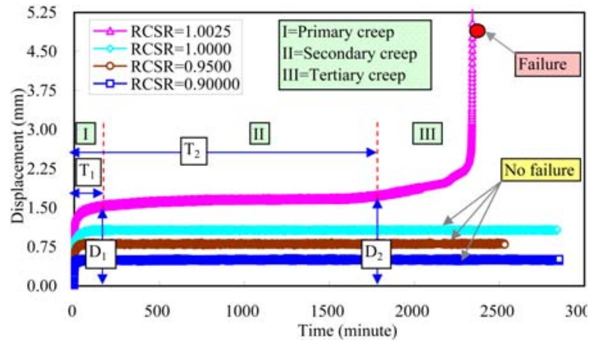
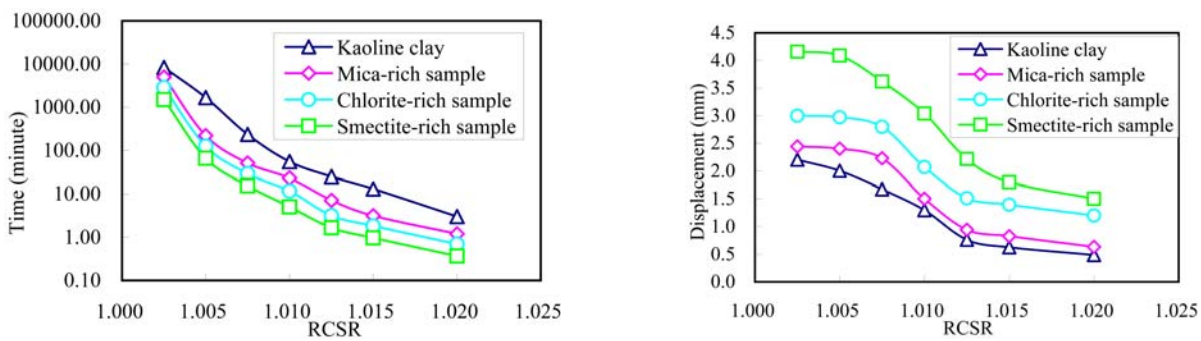


Fig. 1 Typical residual-state creep test on kaolin clay

Based on the tertiary stage of creep, prediction curves of creep failure are presented in Fig. 2. In Fig. 2 (a), time to complete failure (min) corresponding to an RCSR value can be predicted. For example, if an RCSR value is 1.0025, the smectite-rich sample will fail in about 1500 minutes, but in case of chlorite-rich sample, it is about 2850 minutes. Similarly, the mica-rich sample and kaolin clay entered the tertiary creep in about 5000 minutes and 8400 minutes, respectively. The failure trend shows that smectite-rich sample failed in short time compared to other samples while the displacement until the failure was found to be large, as shown in Fig 2 (b). These results indicate that presence of weaker clayey minerals such as smectite and chlorite significantly influence the reactivation of a landslide and its creeping displacement behavior.

Table 2 Summary of residual-state creep test on kaolin clay

Test	RCSR	T_1 (min)	D_1 (mm)	T_2 (min)	D_2 (mm)	Remarks
7	1.0200	0.23	1.42	3.03	0.49	Failure
6	1.0150	0.40	0.68	13.10	0.62	Failure
5	1.0125	1.20	0.81	25.03	0.76	Failure
4	1.0100	2.73	0.97	55.10	1.30	Failure
3	1.0075	7.63	1.06	233.50	1.67	Failure
2	1.0050	22.93	1.48	1673.67	2.00	Failure
1	1.0025	217.27	1.63	8357.00	2.20	Failure
1	1.0000	117.23	1.08	2840.33	1.08	No failure
1	0.9500	111.03	0.83	2531.33	0.79	No failure
1	0.9000	117.23	0.51	2851.67	0.48	No failure



(a) (b)

Fig. 2 Prediction curves

4. CONCLUSIONS

In this study, a residual-state creep test apparatus was developed, which is capable of measuring creep displacement with respect to time under the application of a constant shear force. The test results on four typical clayey soils show that the creep failure begins only when the applied shear stress is above the residual strength and that there is no creeping effect on or below the residual strength. Residual-state creep failure prediction curves are proposed as the major output of this study, which may be used to predict failure time and displacement of creeping landslides in future.

REFERENCES

Bishop, A.W., Green, G. E., Garge, V. K., Andersen, A., Brown, J. D., 1971, “A new ring shear apparatus and its application to the measurement of residual strength”, *Geotechnique*, Vol. 21, No. 4, pp. 273-328.

Skempton, A. W., 1985, “Residual strength of clays in landslides, folded strata and the laboratory”, *Geotechnique*, Vol. 35, No. 1, pp. 3-18.

Lefebvre, G., 1981, “Fourth Canadian Geotechnical Colloquium: Strength and slope stability in Canadian soft clay deposits”, *Can. Geotech. J.*, Vol. 18, pp. 420-422.

Ter-Stepanian, G., 1963, “On the long term stability of slopes”, *Nor. Geotech. Inst.*, Vol. 52, pp. 1-14.

Yen, B. C., 1969, “Stability of slopes undergoing creep deformation”, *Soil Mech. Found. Div.*, SM 4, pp. 1075-1096.