Dissertation Abstract

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Dissertation Title: "**Residual-state Creep Behavior of Clayey Soils and its Implication in Landslide Displacement Prediction**"

Abstract:

Soil creep is a time dependent phenomenon in which the deformation exhibits under the application of constant stress. Extensive works have been done in the laboratory using the triaxial compression cell and oedometer to explore the creep behavior of various kinds of soils in the past, but almost all of them focus only at pre-peak state creep behavior of soil materials. The slip surface soil materials of the large-scale creeping type landslide have already experienced very high shear deformation (or displacement) and reach a stable or steady state, which is called residual state. Therefore, the pre-failure creep test does not truly explain the creep behavior of such soil materials that undergo large displacement at close-to-residual state of shear. This necessitates the importance of further studying creep behavior of clayey soils in the residual-state of shear. However, the creep behavior of clayey soils and associated geotechnical issues are not fully understood, especially in relation with the displacement behavior at the residual-state of shear. Hence, this dissertation has primarily addressed this issue with the help of experimental results and has attempted to interpret the results towards the possibilities of predicting landslide displacement.

This study is divided into seven core parts. In the first part, a series of ring shear tests were carried out on typical clayey soils (i.e., high, medium, and low plasticity soils) to understand the shear rate effect on residual strength of clayey soils. The shear rates were varied from 0.073 mm/min to 0.586 mm/min (as 0.073 mm/min, 0.162 mm/min, 0.233 mm/min, 0.313 mm/min, 0.398 mm/min, and 0.586 mm/min). Slight increases in the residual shear strength were observed after the shear rate of 0.233 mm/min to 0.586 mm/min. The residual shear strengths were slightly greater in higher plastic soils, exhibiting a larger drop from the peak strength value to the residual strength value than in low plastic soils at the shear rates range from 0.233 mm/min to 0.586 mm/min. However, clayey soils exhibit negligible effect on the residual shear resistance of shear rates range from 0.073 mm/min to 0.162 mm/min. Therefore, it was recommended to use the shear rate of 0.162 mm/min for the discontinued shearing on residual strength and the residual-state creep test.

In the second part, a series of discontinued shearing on residual strength were performed to study the effect of discontinued shearing on residual strength of clayey soils. Typical clayey soils (i.e., high, medium, and low plasticity soils) were tested using the ring shear machine for the discontinued rest periods of 1, 3, 7, 15, and 30 days at an effective normal stress of 98.1kN/m^2. The results indicate that soil strength recovery in a ring shear test was minimal after a rest period of 3 days. It was found that the recovered shear strength from the residual value would be greater in high plasticity soils than in low plasticity soils. However, the recovered strength was lost after the specimen undergoes a small shear displacement. On the other hand, there were not any recoveries of the shear strength from the residual-state of shear up to the rest period of 3 days. From the residual-state creep test results on the same typical clayey soils, it was observed that most of the tested samples exhibit the creep behavior within a small increment of the applied constant creep stress (which is less that the recovered shear strength) before 3 days, but the discontinued shearing tests show that the recovered shear strengths were hardly noticed after the rest period of 3 days. Therefore, it can be concluded that there were not any effect of recovered shear strength on residual strength during the residual-state creep test.

In the third part, residual-state creep test procedure was developed using a modified ring shear machine. The ring shear machine has been modified in such a way that it can shear a clayey material in strain-controlled as well as stress-controlled patterns under drained condition. In the beginning, the material is sheared under strain-controlled pattern, and after the sample reaches its residual-state of shear, different sets of constant shear loads were applied until the sample in the machine fails again and again. The newly developed residual-state creep test set-up is capable to measure the displacement with respect to time under the application of a constant creep stress. A new concept of the residual-state creep test and its testing procedure were developed to understand the creep behavior of clayey soil materials at their residual-state of shear.

In the fourth part, twelve artificial clayey soil samples (i.e., high, medium, and low plasticity soils) were tested using the residual-state creep test procedure. The residual friction angles of the tested samples were varied in a range of 11.03° to 29.46°. The applications of constant creep stress were varied from the residual-state creep stress ratio (R_{RCS}) of 0.9 to 1.03 (as 0.90, 0.95, 1.00, 1.0025, 1.0050, 1.0075, 1.010, 1.0125, 1.0150, 1.0175, 1.02, 1.025, and 1.03) until the specimen leading to failure. The newly introduced term residual-state creep stress ratio (R_{RCS}) is the ratio of the applied constant creep stress to the residual strength. The ideal creep curve for a soil material was verified in the test procedure and was found to perfectly match with obtaining results. The displacement required for the beginning of a tertiary stage of creep of a particular soil material, i.e., early stage of creep failure was measured the same or constant for all set of creep loads. When the residual friction angle (ϕ_r) of clayey soils was small, the value of the critical displacement (δ_c) was found to be large and vice versa.

In the fifth part, the relation between residual-state creep stress ratio (R_{RCS}) and failure time (t_f) were presented based on the residual-state creep test results of clayey soils. Besides that, creep behavior of clayey soils, creep mechanisms, evaluation of the creep zone etc were also covered in this part. The results obtained out of these tests reveal that in residual-state of shear, a soil material show the creep behavior only under a shear stress greater than the residual strength condition. That means when $R_{RCS} \leq 1$, the soils did not show the creep behavior, and the soil underwent creep behavior when $R_{RCS} > 1$. The creep behavior of clayey soils exhibited up to the applied creep stress equivalent to 1.03 times that of the residual shear strength (i.e., up to the R_{RCS} of 1.03). The role of the coefficient of static friction (μ_s) and the coefficient of dynamic friction (μ_k) may lead to mechanisms of different stages of creep on soil. In the primary and secondary stages of creep, the coefficient of static friction (μ_s) was working which kept the specimen in the steady or stable condition. But the coefficient of dynamic friction (μ_k) was acting on the tertiary stage of creep which leads to failure. The prediction curves were proposed based on the results of the residual-state creep stress ratio (R_{RCS}) and the failure time (t_f), which could be used to predict the failure time of clayey soils.

In the sixth part, regression models for residual-state creep failure were developed using the 106 residual-state creep test results of different clayey soils. The regression analysis was done by using R. The following equations (1) and (2) were proposed to predict the failure time (t_f) and the critical displacement (δ_c).

$$\log t_f = \frac{4.567685 + 0.062283\phi_r}{R_{RCS}^{109.667266 - 2.053669\phi_r}} \qquad (1)$$

$$\delta_c = -0.1337\phi_r + 5.266 \qquad (2)$$

The results predicted from the residual-state creep failure prediction model were found in close agreements when compared with experimental results.

In the final part, the proposed residual-state creep failure prediction models were applied to predict the failure time (t_f) and the critical displacement (δ_c) of typical landslide soils. The results thus obtained were compared with the experimental results for the validation of the proposed model and found in good agreements with each others. Therefore, this model has given good insight on the application and further development for landslide displacement prediction in the future.