Deformation characteristics of clay at slip lines in repetitive type landslides

Caractéristiques de la difformité d'argile à ligne de la fiche dans glissement de terrain du type répétitif

S. Ohtsuka and K. Isobe
Nagaoka University of Technology, Nagaoka, Japan

ABSTRACT

Landslides commonly occur as the result of pore water pressure increase in slopes from rainfall and melted snow. The shear strength of clay in slopes is generally determined by strain-controlled ring shear tests under fully drained conditions. These tests give peak and residual strength parameters, but no information on shear deformation properties. This paper reports empirical results of ring shear tests to clarify the deformation behavior of clay with increasing pore water pressure. Clay in slopes is subjected to shear stress by the slope inclination. With the increase in pore water pressure, stress approaches a failure threshold at which it deforms significantly. The stress-controlled tests were used rather than the more commonly employed strain-controlled tests in this study. Deformation property of clay was clarified for both virgin type and re-sliding type landslides.

RÉSUMÉ

Le glissement de terrain se produit communément suite à l'augmentation de la pression interstitielle dans l'inclinaison due à une chute de pluie et de la neige fondue. La résistance au cisaillement de l'argile dans l'inclinaison est déterminée généralement par une épreuve de cisaillement circulaire contrôlée par torsion dans des conditions de drainage total. Cependant, l'épreuve donne des paramètres sur la résistance maximale et la résistance résiduelle, mais ne donne aucune information sur la propriété de déformation par cisaillement. Cela rend compte des résultats empiriques de l'épreuve de cisaillement circulaire par torsion afin de clarifier un comportement de cisaillement de l'argile en cas d'augmentation de la pression interstitielle. L'argile dans l'inclinaison exerce unecontrainte de cisaillement causée par l'inclinaison de la pente. Avec l'augmentation de la pression interstitielle, la contrainte atteint un critère de défaillance et déforme de manière considérable. Ce phénomène a été examiné par une épreuve de cisaillement circulaire contrôlé par contrainte. La mise en oeuvre d'épreuves contrôlées par contrainte opposées à des épreuves contrôlées par torsion habituellement utilisées dans la pratique constitue une caractéristique de cette étude. Une série d'épreuves a été menée pour examiner un comportement de cisaillement de l'argile en simulant des conditions in situ dans un glissement de terrain.

Keywords: repetitive type landslide, ring shear test, stress controlled test

1 INTRODCTION

Landslides in the Hokuriku district of Japan are mostly the re-sliding type in which a distinct slip line forms in the slope as the result of large deformation and the shear strength of clay at the slip line falls to some residual value. Such landslides are caused by an increase in pore water pressure due to melted snow and/or rainstorm. The sliding soil mass initially moves at low speed, accelerates and finally fails. In the re-sliding type landslide, most movement is localized, but repeated year by year. Occurence of landslide movement is rather more important than the failure state in terms of disaster prevention engineering. Ring shear tests are widely performed to measure the shear strength of soil at slip lines. Since the strain-controlled test is used to simulate the residual state of soil (after deformation) at a slip line, it does not allow direct investigation of the deformation. In this study, a stress-controlled ring shear test is conducted to specifically study the deformation behavior of soil at the slip line with increased pore water pressure.

In the stress-controlled test, normal stress is steadily reduced under a constant shear stress, which simulates the stress condition at the slip line for increasing pore water pressure. Two testing conditions are considered: one test a virgin soil (homogeneous condition) and the other a pre-sheared soil in which the stress has reached the residual state. The former condition corresponds to a virgin type landslide (virgin shear test) and the latter corresponds to a re-sliding type landslide (residual shear test). Properties of both deformation and shear strength were investigated for various conditions of shear stress, consolidation ratio and stress history.

2 TESTING METHOD

The ring shear test is generally applied to investigate residual strength of soils where the soil deforms largely along a slip line. Strain-controlled testing is commonly employed, but it is different from in-situ deformation condition. The stress-controlled ring shear test (Ohtsuka et al, 2004) is implemented to investigate slope soil behaviors due to increased pore water pressure by applying a constant shear stress to simulate slope inclination and gradually reduced normal stress to simulate the increase in pore water pressure.

The tested soils were sampled from the Okimi landslide in Niigata prefecture. Physical properties of the soil are shown in Table 1. The soil was remolded by mixing with water and preconsolidated for 24 hours before setting of the soil specimen. Mechanical properties of the soils were determined by strain-controlled ring shear tests. Figure 1 shows the results. The internal friction angle was $\phi' = 24.7°$ at peak strength and $\phi_r' = 6.7°$ at residual strength. For peak strength, cohesion was seen at 12.1 kPa. The test soil for the virgin shear test was consolidated with prescribed pressures before appling shear stress. The test soil for the re-sliding type landslide test was subjected to strain-controlled shear deformation to attain residual state before the consolidation process.

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-1682

In the stress-controlled ring shear test, normal stress is reduced at constant rate while keeping shear stress constant. We estimate the effective normal stress assuming a fully drained condition. The appropriate rate of reduction in normal stress that will achieve this contition has to be determined prior to experiments. Figure 2 shows the empirical result of reduction rate effect on stress ratio at failure. To achieve fully drained tests, the normal stress reduction rate was determined to be 0.1 kPa/min as Fig.2 illustrates the stress ratio at failure settled to a constant magnitude around this value.

Table 1. Physical property of soil

Liquid limit W_L	101 (%)
Specific gravity of soil particles ρ_s	2.68 (g/cm^2)
Plastic limit P_L	29 (%)
Plasticity index I_p	72 (%)
Clay fraction content C_F	55 (%)

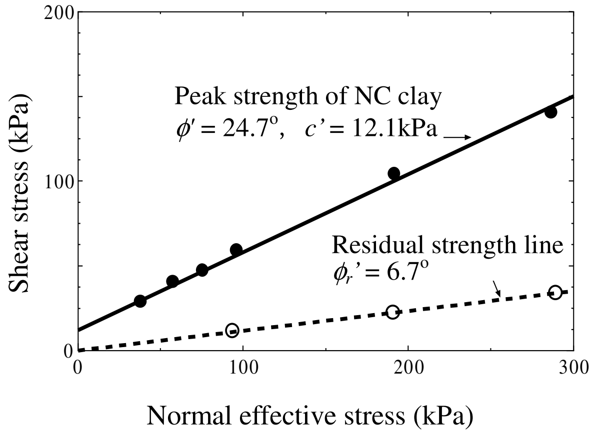

Figure 1. Strain controlled ring shear tests

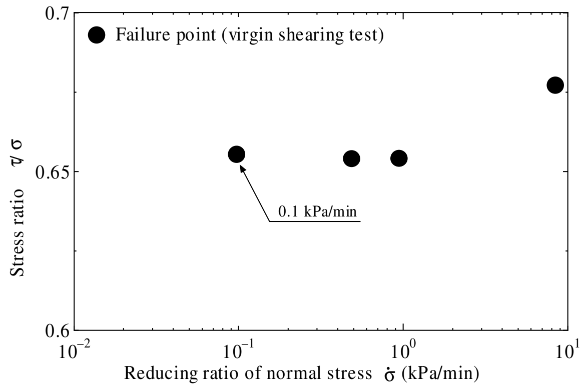

Figure 2. Effect of reduction rate in normal stress

3 TESTS FOR VIRGIN TYPE LANDSLIDE

Figure 3 shows the results of stress-controlled ring shear tests for a virgin type landslide. Testing samples were consolidated with a normal stress of 294 kPa. Applied shear stress was varied from 20 to 80 kPa. In Fig.3 the internal friction angle ϕ' is illustrated. Yield point was defined as that at which the displacement rate increased sharply; failure point was defined as that at which the shear stress reduced sharply due to large deformation. As normal stress was reduced, the soil specimen behaved elastically at the beginning of the test. Displacement was observed to increase with the reduction in normal stress. Displacements at yield points were almost the same (0.2 mm) in a series of tests although the reductions in normal stress approaching the yield point were varied. In the stress paths Fig.3, yield points were on the line of internal friction angle $\phi' = 24.7^\circ$ obtained by strain-controlled ring shear tests for peak strength, which coincides with the results of the pore water pressure loading test by tri-axial compression apparatus (Ohtsuka and Miyata, 2001; Ohtsuka, 2002; Ohtsuka et al, 2005). This fact shows that the internal friction angle is the strength parameter of the soil, but it also indicates the threshold at which soil will deform under normal stress reduction. In Fig.3 the failure points were seen to be leftward (lower normal stress side) of yield points. Displacements at the failure point were almost constant at 0.4 mm independent of the shear stress.

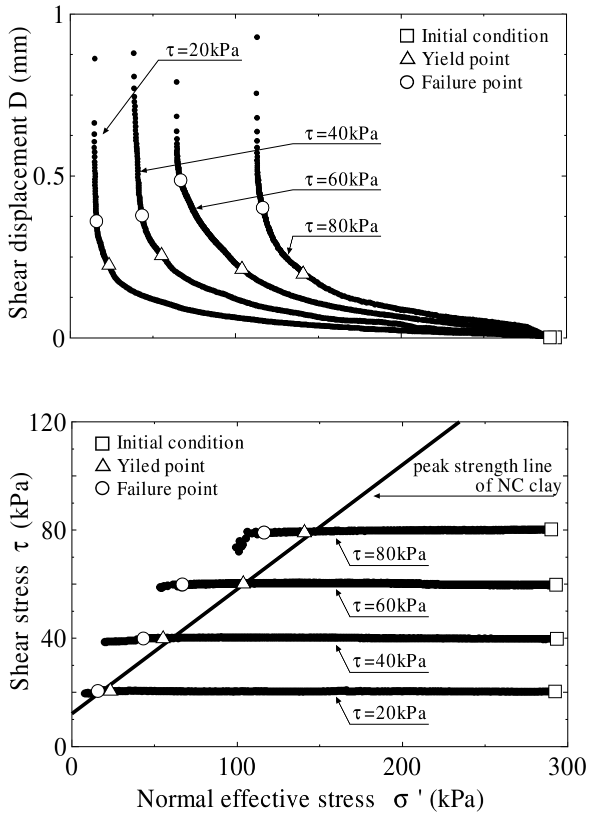

Figure 3. Stress controlled ring shear test for virgin type landslide

4 TEST FOR RE-SLIDING TYPE LANDSLIDE

Figure 4 shows the results of stress-controlled ring shear tests for the re-sliding type landslide. The test sample was completely sheared before testing and the shear strength of clay at slip line reached the residual state. The test soil was then consolidated with normal stress of 294 kPa. Shear stress was again varied from 20 to 80 kPa. In Fig.4 the residual internal friction angle ϕ_r' is illustrated. It is readily seen that the soil behavior is more brittle than the virgin type landslide (Fig.3). In Fig.3 there is little displacement before the yield point and the soil specimen failed rapidly almost at yield point. It is difficult to distinguish failure point from yield point. It is clearly seen that the yield and failure points were on the line of residual internal friction angle $\phi_r' = 6.7^\circ$ and it reveals the same tendency as the test for virgin type landslide. What is interesting to note in Fig.4 is that the threshold line for displacement generation is well correlated with residual internal friction angle.

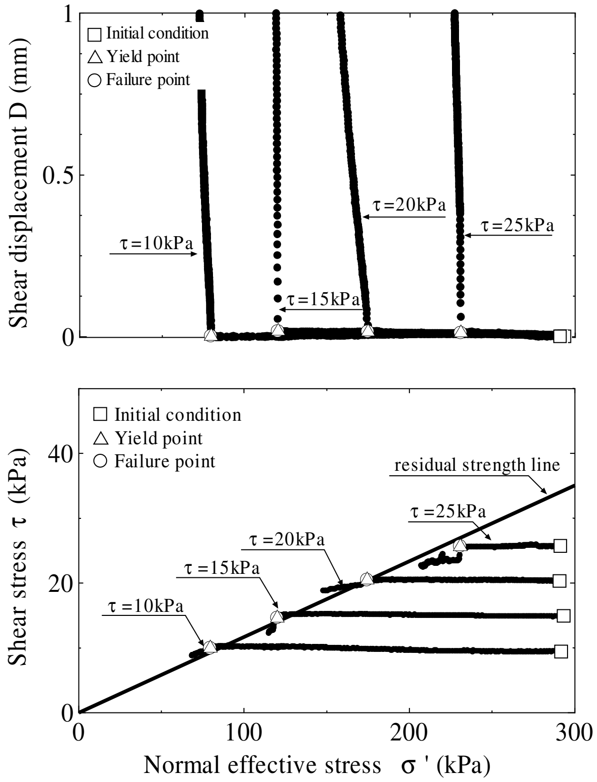

Figure 4. Stress controlled ring shear test for re-sliding type

5 CONSOLIDATION EFFECT ON YIELD AND FAILURE POINTS

It is well known that stress history such as over consolidation ratio (OCR) affects the shear behavior of the soil. In landslide slopes the change in underground water level causes consolidation and swelling to occur. In this context it is interesting to investigate the effect of stress history on both yield and failure points of the soil.

Figure 5 shows the results of stress-controlled ring shear tests for OCR values from 1 to 3 in virgin type landslide tests. Shear displacement for normal effective stress was similar in the three cases. Shear displacements for yield points were approximately 0.2 mm and for failure points approximately 0.35 mm. The obtained results are ordered in terms of stress ratio as shown in Fig.6. It is readily seen that stress ratios at yield points were almost identical with internal friction angle (ϕ') independent of OCR. At failure points, however, stress ratios increased with OCR showing a greater resistance to reduction in normal stress. It is clear that stress history affects the failure point in the case of virgin type landslides.

Figure 7 shows the results of stress-controlled ring shear tests for OCR values from 1 to 3 in re-sliding type landslide tests. Stress history (consolidation and swelling) was applied to the test sample after establishing a slip line. Since a slip line is locally deformed greatly, it is supposed to be a contact plane. It is interesting to investigate the effect of stress history on shear behavior of clay at slip line. The tendency of shear displacement was similar to that in the virgin type landslide tests. The results are ordered in terms of stress ratio as shown in Fig.8. It is notable that stress ratios at yield and failure points increased with OCR to resist more reduction in normal stress. Stress history clearly affected both the yield and failure points in spite of re-sliding type landslide test.

Strain-controlled ring shear tests were conducted to further examine the stress history (consolidation effect) on failure point in re-sliding type landslide test. It was implemented on test samples to which had been applied stress histories of both loading and unloading after setting a slip line. Figure 9 illustrates the results of the stress ratio - shear displacement relationship. It shows two stages of ring shear tests in which one is the setting of a slip line and the other, re-shearing along slip line. The recovery in stress ratio occurred at the failure point. Test results were then arranged in terms of stress ratio - OCR relationship as shown in Fig.10. In spite of strain-controlled ring shear tests, stress history of consolidation clearly affected the yield and failure points. Effect of stress history as swelling and consolidation on shear behavior of clay at slip line was investigated by stress controlled tests in the same way. The increase in stress ratio for OCR by strain controlled tests was found to match well with that of stress controlled tests.

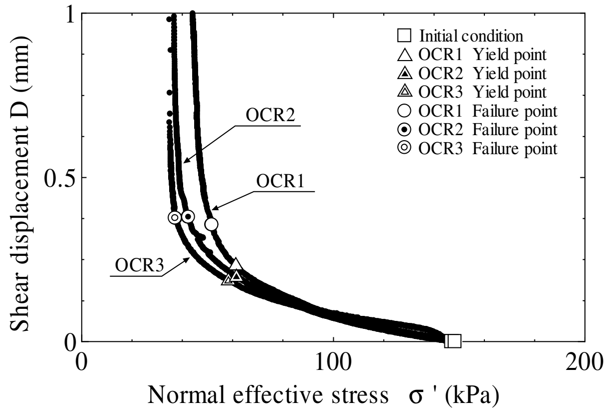

Figure 5. Over consolidation effect on shear deformation for virgin type landslide

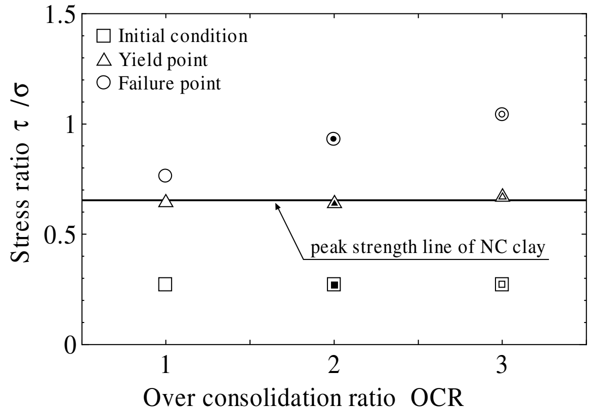

Figure 6. Over consolidation effect on yield and failure points for virgin type landslide

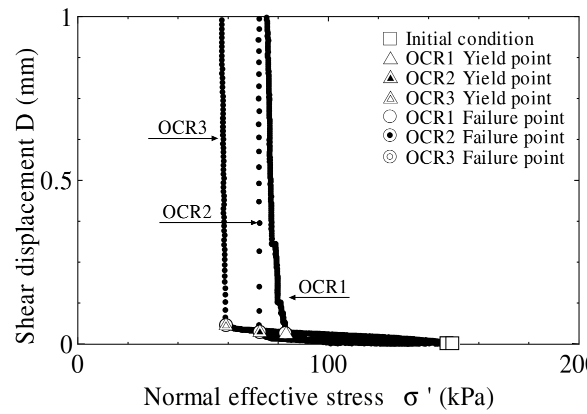

Figure 7. Over consolidation effect on shear deformation for re-sliding type landslide.

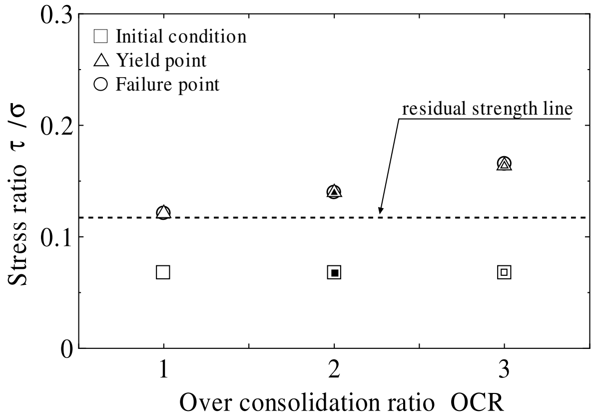

Figure 8. Over consolidation effect on yield and failure points for re-sliding type landslide

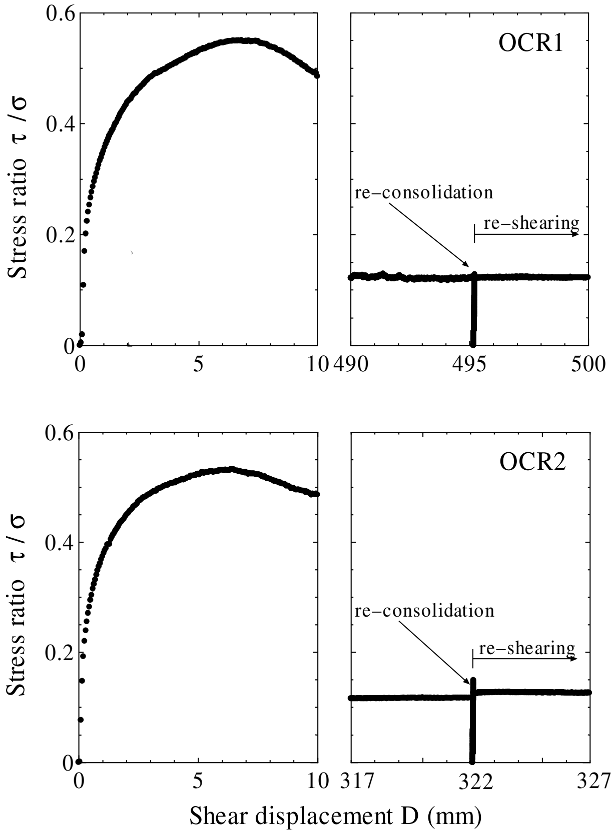

Figure 9. Strain controlled ring shear test of reconsolidated soil

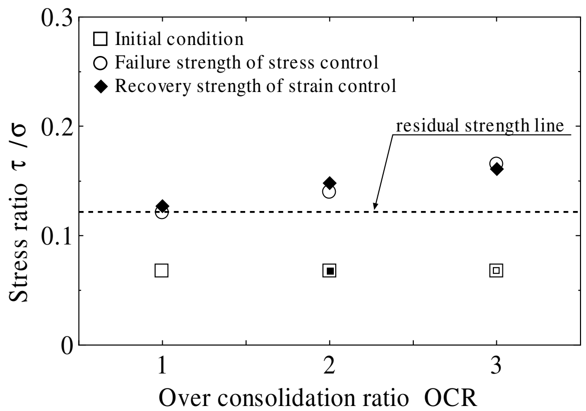

Figure 10. Over consolidation effect on yield and failure points by strain controlled ring shear test

6 CONCLUSIONS

The following conclusions were reached in this study:

1) In the shear tests for virgin type landslide, shear displacement increased gradually with the decrease in normal stress. Yield stresses were located on the shear strength line defined by the angle of shear strength in the conventional test. Failure stresses were obtained on a parallel line located at the left side of internal friction angle line. For the increase in OCR of the initial state, the yield stresses were constant, however the failure stresses decreased and showed high resistance for further reduction in normal stress.

2) In the shear test for re-sliding type landslide, the deformation behavior was clearly brittle under decreasing normal stress which made it difficult to define both yield and failure stresses separately. They were located on the residual shear strength line obtained in the conventional test.

3) Conventional design work with the internal friction angle was found to prevent landslide deformation in case of virgin type landslide, since the yield stress for recuction in normal stress matched the internal friction angle line. In case of re-sliding lnadslide, design work with the residual internal friction angle was found to prevent the deformation in the same way.

4) Strength recovery due to consolidation after the previous landslide was investigated by both the stress-controlled and the strain-controlled tests. Both results showed good agreement and some strength recovery was clearly obtained in the soil at slip lines after significant shear.

REFERENCES

Ohtsuka, S. and Miyata, Y. 2001. Consideration on landslide mechanism based on pore water pressure loading test, *Proc. of 15th International Conference on Soil Mechanics and Geotechnical Engineering*, ISSMGE, pp. 1233-1236.

Ohtsuka, S. 2002. Time dependent behavior of clay in pore water pressure loading test, Proc. of International Congress of Interpraevent 2002 in the Pacific Rim No. 2, pp. 531-536.

Ohtsuka, S., Yoshida, K. and Kawashima, K. 2004. Normal stress decrease test on clay with ring shear apparatus, 49th Geotechnical Engineering Symposium of JGS, pp. 21-26. (in Japanese)

Ohtsuka, S., Miyata, Y. and Iwabe, T. 2005. Shear strength of overconsolidated clay for repeats of pore water pressure loading, Journal of the Japan Landslide Society, Vol. 41, No. 5, pp. 29-36. (in Japanese)