Ⅲ-27 Landslide stability analysis with lab-determined strength parameters

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BACKGROUND

While carrying out landslide stability analysis, reverse calculation, commonly known as back analysis, is still dominant over the analysis employing lab-determined strength parameters. One prominent reason for this choice is difficulty in undisturbed sampling of slip surface soil, which could be tested in the laboratory to give precise values of strength parameters to be employed in the stability analysis. Yagi & Yatabe (1984), however, claim that the strength parameters for a soil do not have any effects of sampling disturbance if the parameters are viewed from effective stress considerations. It means that the sample disturbance does not really result in much variation of lab-determined strength parameters from their field values. However, it may have significant effect on the residual strength of a soil, which is defined as a strength possessed by the soil under shear after having all involved platy clay particles completely reoriented in the direction of the shear (Skempton, 1985), and is governing especially in case of landslides undergoing large but slow displacements. One of the effects due to sample disturbance might be underestimation of the residual strength in the laboratory because the influence of field conditions on the strength of a slip surface soil must be significant in comparison to the laboratory conditions. For example, presence of coarse or gravelly particles in the field shear zone may account for a higher value of residual strength, while inclusion of bigger particles in lab test samples involves technical difficulties, such as restriction on specimen thickness, amount of sample available, etc.

Knowing whether or not a landslide slip surface soil has reached its laboratory residual state is not easy. Likewise, evaluating the slip surface soil from peak strength point of view can never be correct for the reason that the strength of a soil already undergoing shear displacement is always less than its peak value. Skempton (1985) mentions that the peak strength for an overconsolidated soil sample is exhibited after 0.5-3.0mm of displacement, and that for a normally consolidated sample is exhibited after 3.0-6.0mm of displacement (Figure 1). It means that the strength of a soil that has already undergone a displacement higher than the above values lies somewhere in between the peak and residual strengths. If we suppose that the slip surface soil of a landslide has not yet reached its residual state, we are left with no particular values of the strength parameters because we can be sure of extreme two values only, i.e., peak and residual strength parameters. Moreover, the strength parameters obtained from the laboratory tests may not be representative to the mean field values.

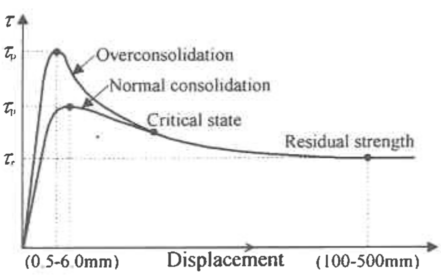

Figure 1: Strength curves from ring shear tests.

Determination of strength parameters by the back analysis technique, on the other hand, reduces the errors involved in laboratory testing. However, it requires certain assumptions in addition to the assumptions made in developing the stability analysis methods. Two important assumptions made in the back analysis technique are: 1) the factor of safety is unity and 2) cohesion is a function of depth of slip surface related by $c_d=0.1z$ (i.e., $c_d=0.981z$ kN/m^2), where c_d is cohesion (tf/m^2) and z is depth of slip surface below the ground (m), which is based on in-situ shear tests performed by Fujita et al. (1985). The factor of safety for landslides, especially the creeping ones, however, remains a little greater than unity (Patton, 1986). Yagi et al. (1989) also performed undrained triaxial creep tests, in which they found the failure to take place at a state when the ratio of applied shear stress to the maximum shear strength was 0.95, which means the factor of safety was greater than 1.0. Likewise, estimating the cohesion results in direct effect on the value of ϕ, which may differ from the actual value. Figure 2, which is based on Mohr-Coulomb equation for soil strength, shows the variation in effective angle of friction (ϕ') with the error in estimating the cohesion. It is clear from the figure that the effect of change in cohesion on the angle of friction is higher under lower overburden effective pressure.

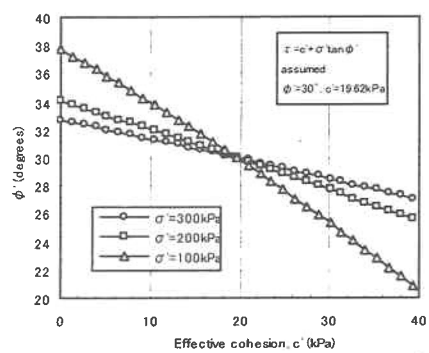

Figure 2: Change in ϕ' due to error in cohesion.

Skempton (1985) mentions that the field residual strength value for the slip surface soil of a landslide should be the same as the strength calculated from back analysis of the landslide in which movement has been reactivated along a pre-existing slip surface. It means the back analyzed and lab-determined strength parameters must be the same provided that the lab tests are carried out under perfectly in-situ conditions. Figure 3 shows the evidence of back analyzed strength parameters being nearly the same as lab-determined values for London clay. This paper therefore discusses the applicability of lab-determined strength parameters in landslide stability analysis in context of reducing errors due to assumptions made in back analysis technique with the help of ring shear tests.

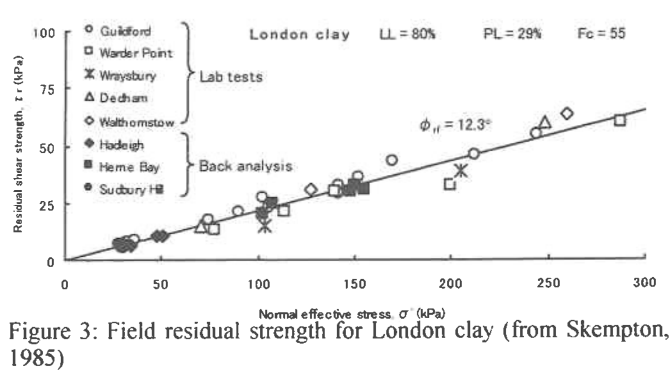

Figure 3: Field residual strength for London clay (from Skempton, 1985)

室内実験による強度定数を用いた地すべり安定解析に関する研究

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TEST RESULTS AND DISCUSSION

The tests conducted in this study consist mainly of ring shear tests based on direct shear principal to estimate strength parameters for slip surface as well as off-slip surface samples from a couple of landslide sites in Ehime. Efforts were made to maintain the original grain size distribution in the samples so that the measured strength parameters would nearly equal the field values. In addition, all the tests were carried out on normally consolidated specimens with a supposition that there is no effect of stress history on residual strength of a soil.

As pointed out by Enoki et al. (1989), the effective angles of shear resistance for landslide clays determined by triaxial compression tests are significantly greater than the back analyzed values. It is because the field strength of slip surface soil results in residual angle of shear resistance while carrying out back analysis. In contrast, the effective cohesion for normally consolidated clay samples are measured to be nearly zero, which means assuming a cohesion value for the slip surface soil is incorrect. In addition, if the slip surface soil has attained the steady residual state, the significance of cohesion value becomes meaningless. In such a situation, measurement of strength parameters by triaxial compression tests makes less sense, especially in case of the landslides. In addition, triaxial test does not result in final steady value of the residual strength, which for a sample having a clay fraction more than 50% is recovered after considerably large displacements (i.e., from 100 up to 500mm), for a test specimen.

Residual strength of a soil is largely influenced by its clay fraction and is a result of drop in strength due to reorientation of platy clay particles along the shear direction. Skempton (1985) discusses the post-peak drop in strength of over-consolidated intact soils from two different points of view: first, due to increase in water content (dilation), and second, due to reorientation of clay particles parallel to the direction of shearing. It can therefore be said that drop in strength for coarser particles is due to the first reason, and that for finer ones is due to the second reason. Figure 4 depicts a clear drop in the residual angle of shearing resistance against the increased clay fraction for slip surface as well as off-slip surface samples (grain size below 2000μm) from Kariya, Nishinotani, and Senbon landslides. Although the values of the angle of shearing resistance are quite scattered, an average line through the points in the figure may clearly represent a fine drop against the increased clay fraction. The scatter can be attributed to many other factors, some of which may be clay mineralogy, grain size distribution, particles shapes, etc.

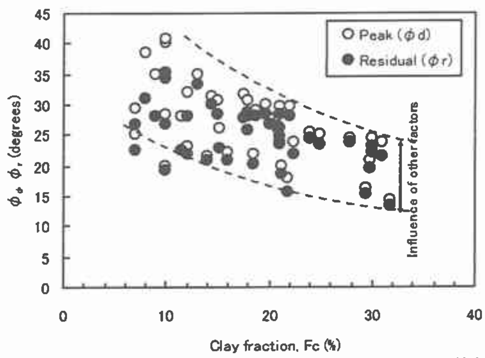

Figure 4: Results of ring shear tests on landslide soil samples.

As also seen from Figure 4 the ring shear tests on landslide soil samples have shown that the values of angles of shear resistance considerably differ from sample to sample. Even the values for two different samples from the same slip surface but two different locations may not be the same. Therefore, the angle of shearing resistance for the samples from two different blocks of the same landslide is often determined to be significantly different. Figure 5 illustrates a big variation in the values of lab-determined angles of shear resistance for different blocks of Kariya landslide. Despite having such variations, the back analyzed value is calculated to be the same, which clearly reflects a fact that the back analysis method can not take into account the type of involved slip surface soil. The figure also makes it clear that the residual angles of shearing resistance from the lab tests result to be smaller than those calculated by the back analysis method. It might be said from this result that the field strength of slip surface soil in the Kariya landslide might have not reached the residual state.

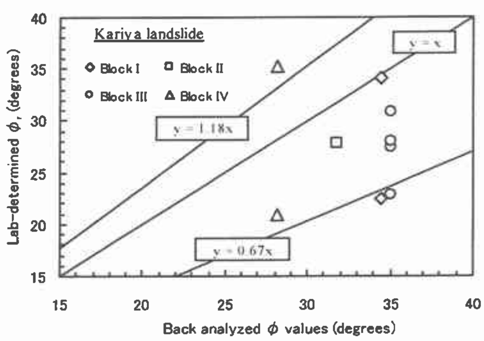

Figure 5: Comparison of back analyzed and lab-determined ϕ values.

CONCLUSION

Attempts were made to review the comparative study on back analysis and analysis based on lab-determined strength parameters. The paper also discussed the aspects of residual strength of landslide soils with the help of ring shear tests on slip surface samples. As a conclusion, it can be said that the application of lab-determined strength parameters in landslide stability analysis might be less preferable due mainly to easiness involved in back analysis method. However, as the assumptions made in back analysis technique may not apply in actual situations, especially for the creeping landslides, the stability analysis must not completely depend on back analysis. Simultaneous cross-check of the values from the laboratory tests and the back analysis may increase the reliability of the analysis and design.

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REFERENCES

Enoki, M., Yagi, N., and Yatabe, R., 1989. Back analysis of strength parameters on landslides and its problems, Proc. the Japan-China Symposium on Landslides and Debris Flows, Tokyo, Japan, p.19-24.

Fujita, H. et al., 1985. *Soil Mechanics and Foundation*, Japanese Society of Soils and Foundations, No.27, p.137-146.

Patton, F.D., 1984. Groundwater pressures and stability analyses of landslides, IV International Symposium on Landslides, Vol.3.

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

Yagi, N., Enoki, M., and Yatabe, R., 1989. Stability analysis on landslides in fracture zone, Proc. the Japan-China Symposium on Landslides and Debris Flows, Niigata, Japan, p.147-152.

Yagi, N. & Yatabe, R., 1984. Shearing characteristics of disturbed saturated clay. *Journal of JSCE*, No.352, p.179-186. (in Japanese)