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EFFECTS OF SATURATION ON SHEAR STRENGTH OF SOILS

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ABSTRACT

In an attempt to study effects of saturation ratio on the strength parameters of partly saturated soils, several series of triaxial compression tests were comducted on samples of silty sands to silty clay which were recovered from several sites of landslides triggered by heavy rainfalls in recent years. The results of the tests on samples compacted to in-situ densities showed that both the angle of internal friction and cohesion tend to decrease significantly with increasing saturation ratio.

Key words : saturation ratio, slope stability, soil strength (**IGC :** D 6/D 3)

INTRODUCTION

A number of shallow-depth slope failures have taken place during or just after heavy rainfall. Some of them seem to be caused not only by an increase of pore water pressure in soils resulting from a rise in the ground water level but also by the degradation of soil strength forming the slopes. The issue associated with reduction in shear strength due to the increase in degree of saturation have been addressed and investigated for the several types of soils (Uno and Miyashita, 1981 ; Kutara and Ishizuka, 1982 ; Kuwano et al., 1988 ; Kuwano and Chen, 1990).

Some of the studies have tried to formulate the strength reduction in terms of effective stress existing in partially saturated soils (Bishop and Blight, 1963 ; Karube et al., 1986). The effective stress in a partly saturated soil is affected not only by pore water pressure but also by pore air pressure. Therefore, its shear strength is generally represented by the equation including pore-air and pore-water pressures (Fredlund et al., 1978). This concept has been successfully used for evaluation of slope stability (Krahn et al., 1989) with the use of a tensiometer (Fredlund and Rahardjo, 1988) and seems to be worthwhile and give a well-established background for practical applications. However, an apparatus which can measure pore-air and pore-water pressure independently still requires somewhat complex procedures and is not widely used. Thus, it seems necessary to have a methodology for evaluating the shear strength of partly saturated soils in terms of the total stress. This method of approach becomes necessary particularly when a number of natural slopes in wide areas are to be analyzed for a firststep type evaluation of their

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Table 1. Physical properties of soils recovered from sites of rain-induced landslides

Site (Prefecture)	Year of landsliding	Soil type	In-situ dry unit weight γ(kN/m^3)	Liquid limit w_L	Plasticity index I_P	Specific gravity G_S
Omigawa-A (Chiba)	1971.9	silty sand (SM)	13.8	—	N_P	2.714
Omigawa-B (Chiba)	1971.9	silty sand (SM)	14.5	—	N_P	2.702
Mariya (Chiba)	1988.8	silty sand (SM)	12.0—13.0	—	N_P	2.694
Noto (Ishikawa)	1985.7	sandy silt (CH)	11.0—12.2	71.5	30.4	2.740
Kawabira (Nagasaki)	1982.7	clayey silt (CH)	12.7—14.5	70.9	40.0	2.789
Okuyama (Nagasaki)	1982.7	silty clay (CH)	11.7	72.6	41.1	2.788

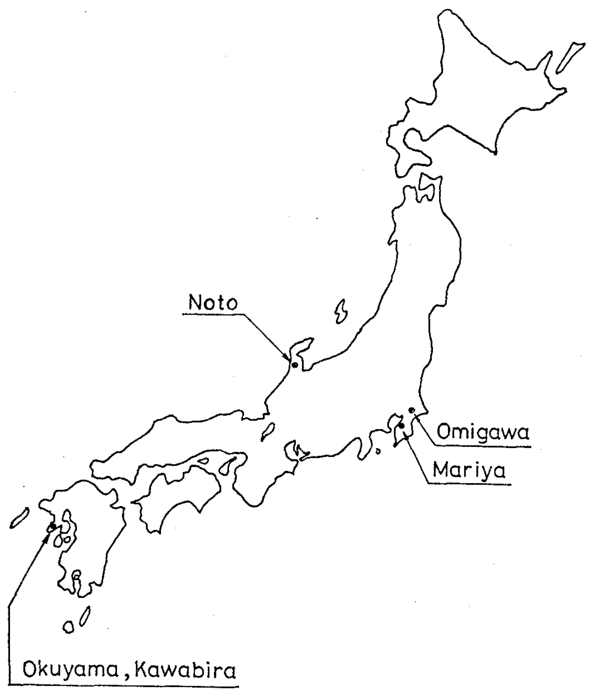


Fig. 1. Locations of sampling where rain-induced landslides took place

stability.

In this paper, a series of laboratory test results on samples secured from several landslide sites are collected and summarized to obtain a rule-of-thumb idea on the reduction of shear strength of partly saturated soils due to increased saturation ratio. The test data will be useful to evaluate the degree of stability of natural slopes consisting of silts to silty sands which generally pose much concern on their stability.

SOILS AND TESTING PROCEDURES

Disturbed soil samples were procured from six different sites, Omigawa-A, Omigawa-B, Mariya, Okuyama, Kawabira and Noto, where the slope failures had occurred due to recent heavy downfalls. The locations of these rain-induced landslides are shown in Fig. 1, and several items related to the landslides are presented in Table 1. The grada-

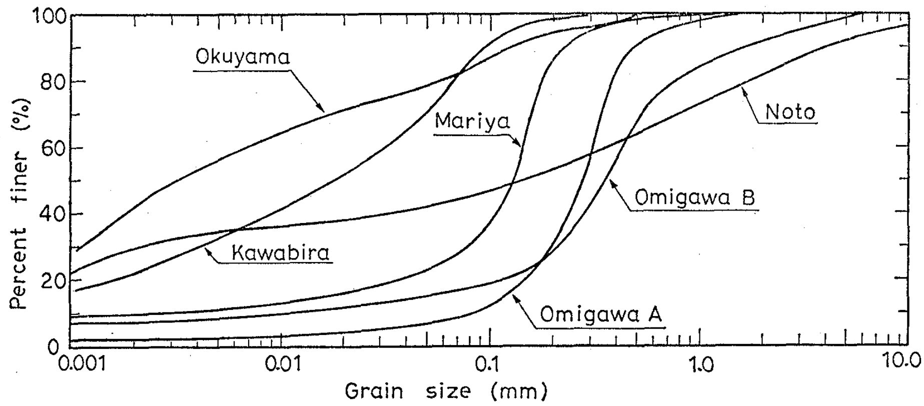


Fig. 2. Gradation of tested soils

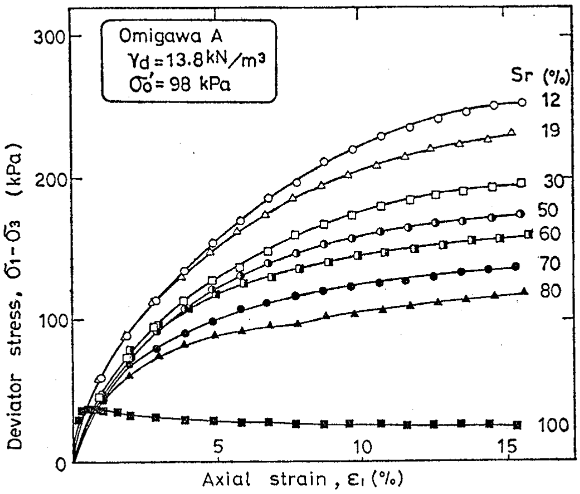


Fig. 3. Stress-strain curves obtained from the triaxial tests

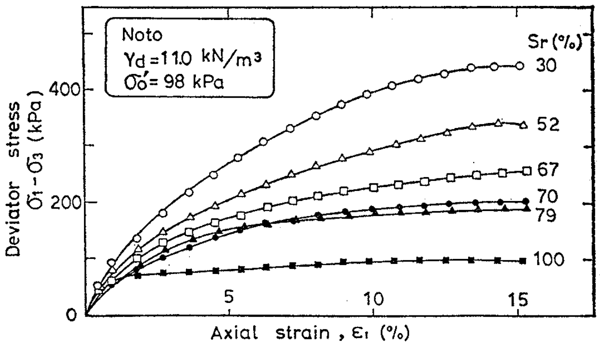


Fig. 4. Stress-strain curves obtained from the triaxial tests

tion curves of the soils procured from each site for laboratory tests are shown in Fig. 2 and their physical properties are summarized in Table 1. The soils from Omigawa-A, Omigawa-B and Mariya are classified as SM, whereas the soils from Okuyama, Kawabira and Noto are classified to be CH according to the Unified Classification System.

For the laboratory tests, coarse particles of most soils were screened out to obtain the maximum grain size of 2.0 mm, whereas the maximum grain size of soils from Noto was adjusted to be 4.76 mm. Water content of the soil was first adjusted to have an equal value of about 5 to 15% for each of the soils tested. The soil was then tamped in six layers in the mold to obtain a desired density. The compacted density of the samples was chosen so that they were approximately in the range of in-situ values which were determined from field density measurements as shown in Table 1. The reconstituted samples thus prepared were then set in place in the triaxial test apparatus and water was permeated to obtain desired degrees of saturation. The samples were then loaded undrained at an axial strain rate of about 0.5%/min, after the isotropic consolidation had been finished with an ambient pressure of σ_0'=49, 78 and 98 kPa. In all the tests, ordinary porous stones and filter papers were used at both ends of the sample enclosed in the triaxial chamber. Thus, no attempt was made to seperately measure pore water pressure from pore air pressure.

TEST RESULTS AND DISCUSSIONS

The undrained triaxial compression tests were carried out on isotropically consolidated samples. Fig. 3 shows the test results on the silty sand samples from Omigawa-A site consolidated at 98 kPa with a varying degree of saturation from 12 to 100%. It may be seen in Fig. 3 that the deviator stress is smaller at all strain levels for the samples having a larger degree of saturation. The difference in the behavior is most remarkable for the change of degree of saturation from 80% to 100%. The same tendency could be observed on sandy silt material from Noto site as shown in Fig. 4. Though the similar trend could be found for all other soils tested, the manner of decrease in the deviator stress with increasing degree of saturation is not always the same, but appears to depend on the soil type and the density of the sample.

The stress conditions at failure were read off from the test data such as those shown in Figs. 3 and 4, and plotted in terms of total stress in Figs. 5 to 7 for the soils from Omigawa-A, Mariya and Noto sites, respectively. The failure was determined by the stress condition causing an axial strain of 15%. The numeral beside the symbol denotes

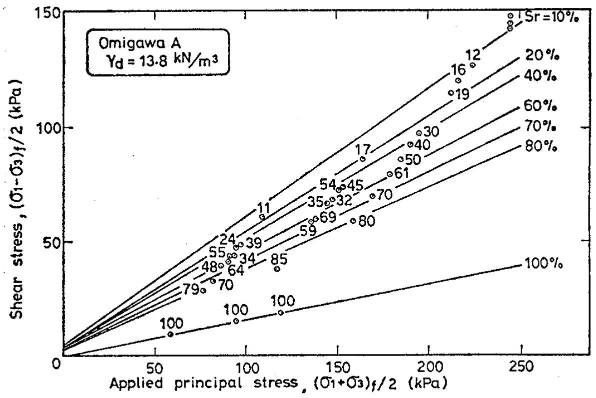
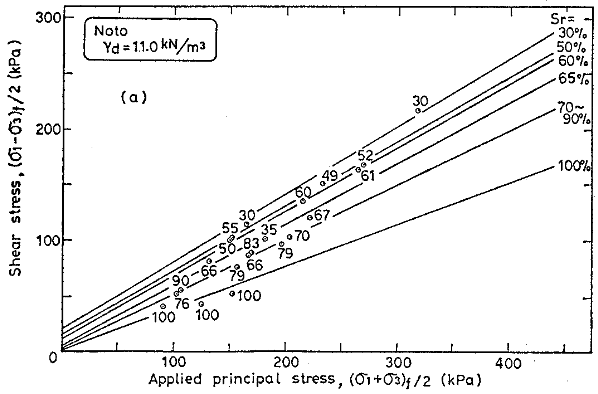


Fig. 5. Relationship between shear stress and principal stress causing failure in the sample



(a)

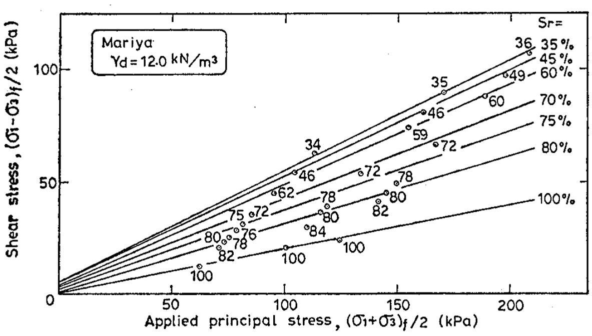
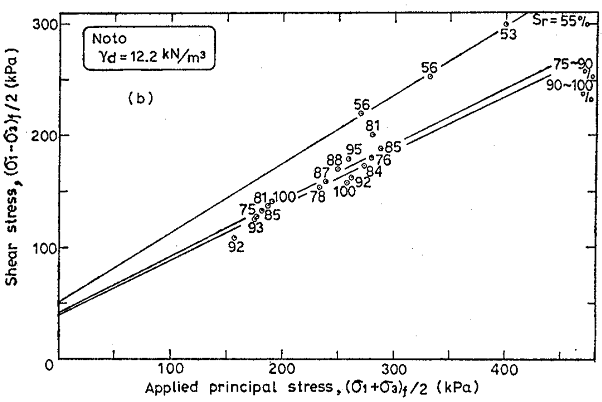


Fig. 6. Relationship between shear stress and principal stress causing failure in the sample



(b)

Fig. 7. Relationship between shear stress and principal stress causing failure in the sample

the degree of saturation for each specimen. As expected from Figs. 3 and 4, it may be seen in Figs. 5 to 7 that the shear strength of the soils decreases as the degree of saturation increases. Looking overall at these data points, it becomes possible to draw a set of several lines through average points which appear to represent the stress conditions at failure for each degree of saturation. They are approximated by straight lines, though there are some scatters among the test data. The soils in Figs. 5 and 6 are both sandy soils taken from Omigawa-A and Mariya sites, respectively. The soil at Omigawa-A shows a more pronounced drop in shear strength at a higher degree of saturation from 80% to 100% than does the soil from Mariya site. Similar test results on the Noto sandy silt are shown in Figs. 7(a) and (b) for different densities. As seen in these figures, deterioration in the shear strength at high degree of saturation is less for the denser specimen. The failure lines obtained for the soils from Omigawa-A, Mariya and Noto sites are summarized in Fig. 8 for comparison purposes. As seen in Fig. 1, the soils from Noto, Mariya, and Omigawa-A contain increasing amount of fines in this order. The shear strength is observed, roughly speaking, to become higher in the order of Noto, Mariya and Omigawa-A soils, though the dry density becomes lower in that order.

Angle of internal friction, ϕ, and cohesion, c, with respect to total stress are

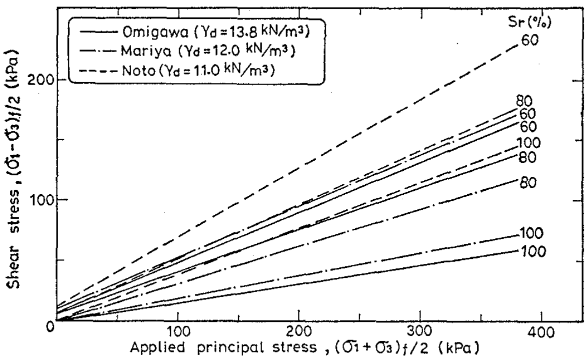


Fig. 8. Summary of failure causing stress conditions

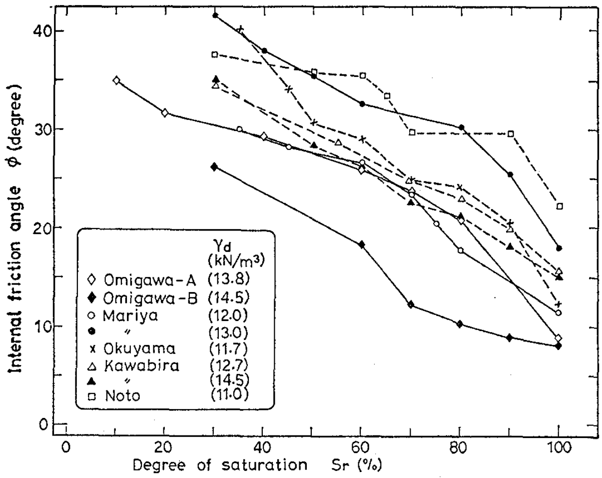


Fig. 9. Angle of internal friction versus saturation ratio

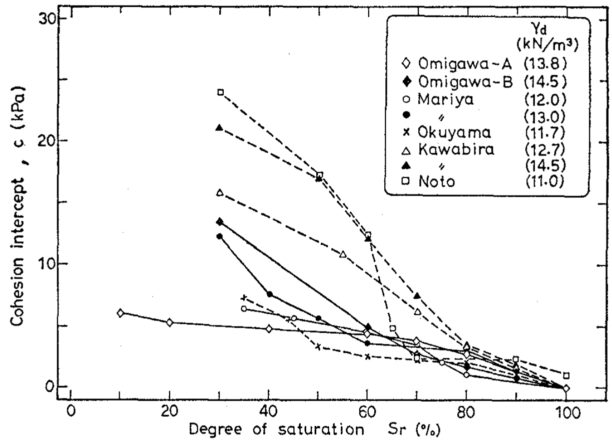


Fig. 10. Cohesion versus saturation ratio

determined from the failure lines described above. The angle of internal friction obtained for the six soil types are plotted versus the degree of saturation in Fig. 9, and the cohesion intercept is shown in Fig. 10. It is noticed that both angle of internal friction and cohesion tend to decrease with increasing degree of saturation. Uno and Miyashita (1981) reported that, while the cohesion decreases especially in the sandy soils with increasing saturation ratio, both cohesion and angle of internal friction decreases in the case of fines containing silty soils. In this study, more specifically speaking, the angle of internal friction is shown to decrease nearly at a constant rate with increasing saturation ratio until the frictional angle reaches a final value which is different depending upon soil type and density. Roughly speaking, it is shown that the finer the average grain size, the larger becomes the angle of internal friction. With respect to the cohesion, it tends to decrease sharply with increasing saturation ratio until it reaches a value of about 80% and eventually becomes equal to zero when the sample is fully saturated with a saturation ratio of 100%.

CONCLUSIONS

Several series of triaxial undrained compression tests were performed on silty sands to silty clay recovered from the sites of shallow-depth landslides induced by heavy rainfalls in recent years. Samples were compacted to in-situ densities with different saturation ratios. The results of the tests revealed that the cohesion intercept tends to decrease sharply with increasing saturation until it reaches a value of about 80%, but it becomes almost equal to zero, irrespective of soil type and density, when the sample is fully saturated with the saturation ratio of 100%. On the other hand, the angle of internal friction tends to decrease almost at a constant rate with increasing saturation ratio and the final value at 100% saturation is shown to be different depending upon soil type and density.

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