Strength and dilatancy characteristics on compacted Shirasu sandy soil

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Shear infiltration, Box shear test, Unsaturated Soil

1 INTRODUCTION

The safety factor of residual or compacted soil slopes with deep groundwater table depends on, among other factors, the magnitude of the negative pore-water pressure above the groundwater table which contributes to additional shear strength of the soil (Fredlund and Rahardjo, 1993). With precipitation, the pore-water pressure becomes less negative or even positive. As a result, the shear strength of the soil decreases and this may trigger landslides. Thus, it is important to understand the characteristics of pore-water pressure changes in soils due to water infiltration in order to predict the extent of reduction in shear strength under a certain rainfall condition.

The objective of this study is to investigate the strength and deformation characteristics of the compacted soil during infiltration by the effects of loading history and shear level for soaking. The loading history of the compacted soil is represented using the compaction pressure, the vertical pressure, and the matric suction. Shear tests on a compacted soil were conducted using a modified direct shear apparatus.

2 SAMPLE AND TEST APPARATUS USED

The non-plastic volcanic sandy soil named “Shirasu” (particle size less than 0.85 mm) has been used in this study. To determine the compressible and shear strength parameters in the laboratory, all of the soil specimens are prepared with the same relative density and initial water content. The diameter, height and spacing of the specimen are 60 mm, 21 mm, and 1 mm, respectively. The properties of Shirasu soil are shown in Table 1. The soil was compacted into the direct shear box with 65% of relative density. Pore air pressure, pore-water pressure, and normal stress were applied to the soil specimens for a period to allow sufficient time to reach its equilibrium. The pore-air pressure was connected to atmospheric at the upper surface of the soil specimen. The pore-water pressure was maintained at atmospheric conditions through the ceramic base plate. The shear rate in all the test was 0.2 mm/min. Vertical load “σ_v”, shear force “τ”, vertical displacement “ΔV_D”, horizontal displacement “Δh”, suction values “s_u” and changes of water contents “Δw” were automatically measured during testing by an upper load cell, load cell for shear, vertical and horizontal dial gauges, pore water pressure transducer through ceramic disk and theta probes, respectively.

3 STRENGTH AND DILATANCY CHARACTERISTICS

Based on the τ-Δh and ΔV_D-Δh relationships of Shirasu sandy soil, Figures 1 and 2 are depicted by Hormdee et al. (2005a and 2005b). Figure 1 shows the relationships between normal stresses and shear stresses at peak state of the soil with three kinds of water contents. Then, Figure 2 shows the shear stresses at peak state normalized by the corresponding normal stress against the dilatancy index defined by $-(\Delta V_D/V_D)/(\Delta h/V_D) = -(\Delta V_D/\Delta h)$. From these figures, even though the failure envelope defined by the peak shear stresses is strongly dependent on the initial water contents as shown in Fig.1, the normalized failure shear stresses shown in Fig.2 is uniquely determined by the dilatancy index, irrespective of the initial water contents and normal stresses. Therefore, we can say that such unique relationship is effective and essential not only in the case of saturated specimen, but also in the case of unsaturated ones. Figure 3 shows the stress-dilatancy relationships of Shirasu sandy soil with different normal stresses, in which the normalized shear stresses, τ/σ_n, divided by the corresponding normalized stresses at peak state, τ_{peak}/σ_n, are used as a vertical axis. It should be emphasized that although there exists some scatter especially at low normalized stress ration, the normalized stress ratio, $(\tau/\sigma_n)/(\tau_{peak}/\sigma_n)$, against the dilatancy index, $-(\Delta V_d/\Delta h)$, is explained by a unique line, irrespective of normal stresses.

Table 1 Index properties of volcanic sandy soil.

Property	Shirasu soil
Specific gravity	2.54
Sand: Silt: Clay	85%: 13%: 2%
Air dried water content	0.6-1.2 %
OMC	8.1 %
Maximum dry density	1.44 g/cm^3
γ_{dmin}	0.954 g/cm^3
γ_{dmax}	1.297 g/cm^3

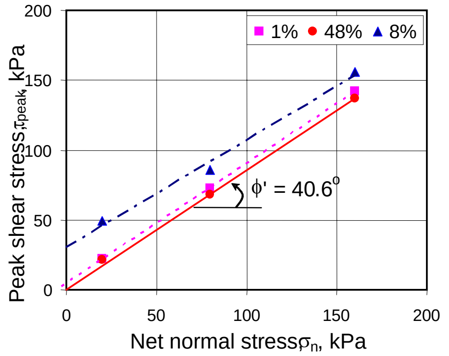

Fig.1 Relationship between net normal stress and strength for compacted specimens with Dr = 65%

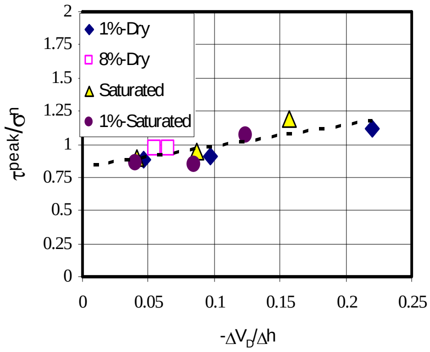

Fig. 2 Relationship between dilatancy index and normalized peak strength under various water contents and confining pressures

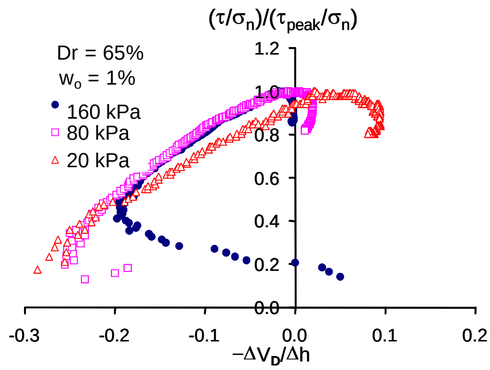

Fig. 3 $(\tau/\sigma_n)/(\tau_{peak}/\sigma_n)$-$dV_D/dh$ relationships under various water contents and confining pressures

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4 EFFECT OF SHEAR LEVEL AT SOAKING ON COLLAPSE VOLUMETRIC CHANGES

Figure 4 shows the effect of shear stress level under infiltration process on the collapse volumetric changes, in which; τ-δh relationships, ΔV_D-Δh relationships and -($\Delta V_D/V_{D0}$)- Δh relationships are depicted in Figs. 4(a), (b) and (c), respectively. In this study, -($\Delta V_D/V_{D0}$) is assumed to be roughly equivalent as the volumetric strain during shear process. Thus for simplicity, term ε_v is used instead of term -($\Delta V_D/V_{D0}$) named as normalized vertical displacement. In these figures, the behaviors at soaking processes are indicated as the plots of marks. It is clear that the volumetric changes at soaking decrease with increasing shear stress level. On the other hand, the horizontal displacements increase with the increasing stress level at soaking. Where, shear stresses during soaking were always kept constant by automatically controlling a stepping motor. Figure 5 shows the relationship between ε_{vs} during soaking and the corresponding normalized shear stress level (τ_{soak}/σ_n)/(τ_{peak}/σ_n) with normal stresses of 20kPa, 80kPa and 160kPa. It can be seen that the incremental normalized collapsible vertical displacements non-linearly decrease with the increasing normalized shear stress level during soaking and also depend on the applied normal stresses. If such tendency could be properly expressed as a simple function for practical use, it must be effective in evaluating the collapse volumetric strains under an arbitrary shear stress level. Such trial will be considered as a next step.

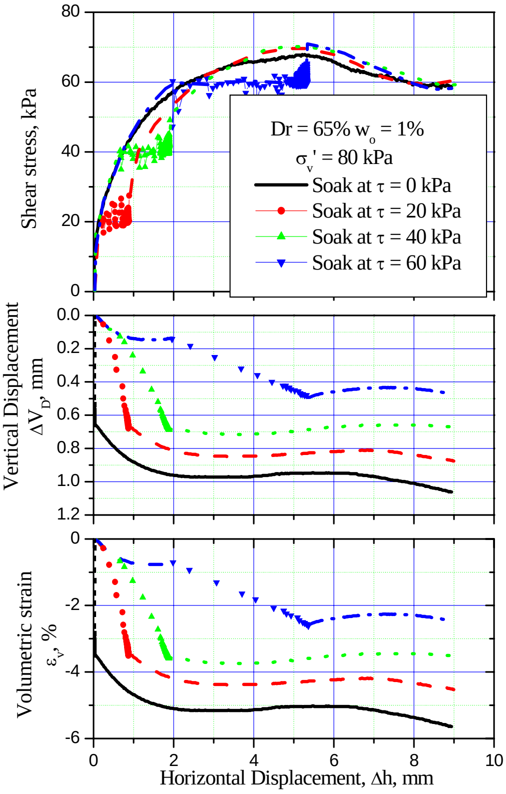

Fig. 4 The relationships on effect of shear level of infiltration process of a) τ-Δh, b) ΔV_D–Δh, c) -($\Delta V_D/V_{D0}$)–Δh

5 ESTIMATION OF DILATANCY PROPERTIES AT SOAKING WITHOUT ANY STRESS CHANGES

The dilatancy property at soaking process is shown in Fig. 6, which is indicated as the relationship between the dilatancy index -d($\Delta V_D/V_{D0}$)/d($\Delta h/\Delta V_D$) at soaking and the normalized stress ratio defined by (τ_{soak}/σ_n)/(τ_{peak}/σ_n), where τ_{soak} is a shear stress τ at soaking. It should be noted that the dilatancy index at soaking is determined by assuming that the ΔV_D-Δh relationship at soaking process in Fig. 6 can be approximated by a unique straight line. Therefore, one value of -d($\Delta V_D/V_{D0}$)/d($\Delta h/\Delta V_D$) under soaking process is obtained at a fixed stress level. It can be seen from this figure that the dilatancy index has a roughly unique relationship with the normalized stress ratio, irrespective of the applied normal stresses and the initial water contents. This relationship may be expressed as follows:

$$\left(\frac{-d\left(\Delta V_D/V_D\right)}{d\left(\Delta h/V_D\right)}\right)_{at\ soaking} = \left\{1-\left(\frac{\tau/\sigma_n}{\tau_{peak}/\sigma_n}\right)^2\right\} \Bigg/ \left\{2\left(\frac{\tau/\sigma_n}{\tau_{peak}/\sigma_n}\right)\right\} \quad (1)$$

which is analogy with the dilatancy equation of Modified Cam-clay. In Fig. 6, the predicted result is also depicted for comparison, which gives a good agreement with the experimental data in relating the normalized collapse vertical displacements with the corresponding shear displacement upon collapse under soaking process.

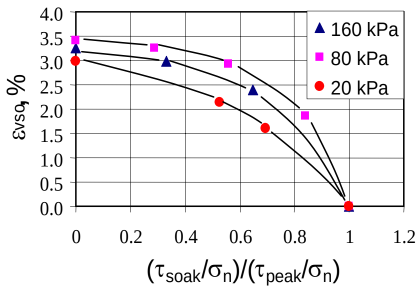

Fig. 5 Relationship between ε_{vso} during soaking and normalized shear stress level (τ_{soak}/σ_n) / (τ_{peak}/σ_n) at soaking

6 CONCLUSIONS

- The effects of shear stress level at soaking on the corresponding collapse volumetric strain are experimentally made clear. The collapse volumetric strains decrease with increasing shear stress level at soaking.
- The dilatancy property at soaking is expressed as a unique relationship with the normalized stress ratio, irrespective of the applied normal stresses and the initial water contents. It is concluded that the relationship is effective in relating the collapse volumetric strains with the corresponding collapse shear displacement or strains under soaking process.

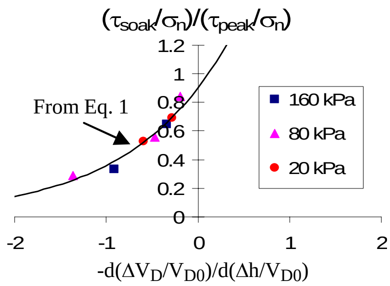

Fig. 6 Relationship during soaking process between (τ_{soak}/σ_n)/(τ_{peak}/σ_n) and –d($\Delta V_D/V_{D0}$)/d($\Delta h/\Delta V_{D0}$)

REFFERENCES

Fredlund, D.G. & Rahardjo, R. 1993 “The rule of unsaturated soil behavior in geotechnical engineering practice.” *11th SEAGC in Singapore* 37-49

Hormdee, D., Ochiai, H. & Yasufuku, N. 2005a. “Advance direct shear testing for collapsible soils with water content and matric suction measurement” *Geo-Frontriers 2005 Conference* in Texas.

Hormdee, D., Ochiai, H. & Yasufuku, N. 2005b. “Direct shear and compression behaviors for an unsaturated compacted soil with water content and matric suction measurement” *EXPRUS Conference* in Trento (to be submitted).