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THE SHEAR STRENGTH OF AN UNSATURATED SOIL SUBJECTED TO ONE-DIMENSIONAL COMPRESSION

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Abstract

In geotechnical practice, both volume change and shear strength of unsaturated soils are important for geotechnical engineers. Undrained shear strength, c', ϕ' and ϕ^b are strength parameter in unsaturated soils. In this study vane shear tests were performed to measure undrained shear strength of a compacted unsaturated silty soil. Test results defined that change vane shear strength has a close relationship with the pore pressure parameters of unsaturated soil subjected one-dimensional compression stress.

Introduction

Several researchers attempted to consider the unsaturated soil behavior in term of effective stress. Matyas and Radhakrishna (1968)[1] described a method which can be adopted to explain the behavior of unsaturated soils subjected to mainly to increasing proportional loading (all-round pressure and Ko-loading). Fredlund and Morgenstern (1976)[2] showed that two effective stress variables are to describe the constitutive relations for unsaturated soils. The shear strength theory in unsaturated soils was established by Fredlund, Morgenstren and Widger (1978)[3].

Shear strength parameters of unsaturated soils are necessary to analyze the stability of geotechnical stricture. Undrained shear strength is recognized as an important strength parameter. Undrained shear strength can be measured by performing unconfined compression tests or triaxial compression tests. Triaxial compression tests with matric suction constant or matric suction measurement is costly and long testing times.

In this study vane shear tests were performed to measure the undrained shear strength of a compacted unsaturated silty soil. Silty soil subjected to one-dimensional compression provide the negative pore-water pressure. Change in negative pore-water pressure is evaluated using Croney's pore pressure parameter. The tests results indicated that the failure envelope is non-linear for the undrained shear strength versus confining pressure. The relationship between the slope of the non-linear failure

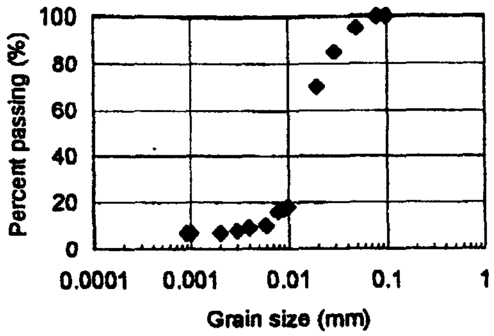

Fig.1. Grain size distribution curve of the soil for test programs

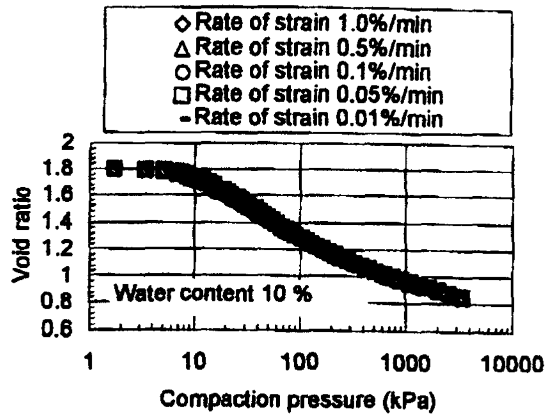

Fig.2. Influence of rate of strain on compression curve

envelope and pore pressure parameter is discussed.

Test procedure

The uniform grain size distribution of a silty soil used in this test program is shown in Fig. 1. A steel cylindrical mold with a height of 155 mm and a diameter of 60 mm was fitted to the triaxial cell. A soil specimen with initial height of 95 mm and initial void ratio of 2.0 was prepared in the test program. Negative pore-water pressures were measured at the lower surface of soil specimens. Ceramic disk used this tests had a air entry value of 200 kPa. It was assumed that pore-air pressure equal to atmospheric during one-dimensional compression. One-dimensional compression was applied to the soil specimens under undrained conditions (i.e., a constant water content). The axial displacement was measured using a dial gauge to calculate the over-all volume change of the soil specimens. Pilot tests were conducted to determine the suitable rate of strain for the silty soil subjected to one-dimensional compression. Fig. 2 show void ratio-compression curve relationship for silty soil. Rates of strain from 1.0 %/min to 0.01 %/min were tried. The results indicated that the rate of strain has little effect on the void ratio-compression curve relationship. A rate of strain of 0.5 %/min was selected.

Vane shear tests were performed on the silty soils which have been subjected to one-dimensional compression. The vane shear tests were conducted using a hand-held type vane shear apparatus. The vane had a height of 40 mm, and a diameter of 20 mm. The vane was inserted in upper surface of each soil specimens. Measured vane shear strength were evaluated as undrained shear strength of the compacted unsaturated silty soil.

Test results

Fig. 3 shows the relationships between measured matric suction and void ratio at constant water contents. Decreasing void ratio means the soil structures is getting denser and number of contacts

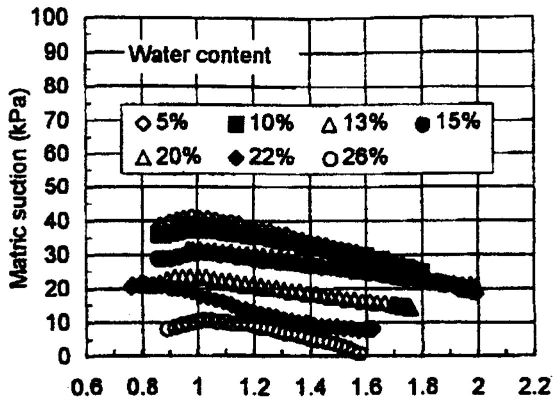

Fig.3. Relationship between matric suction and void ratio

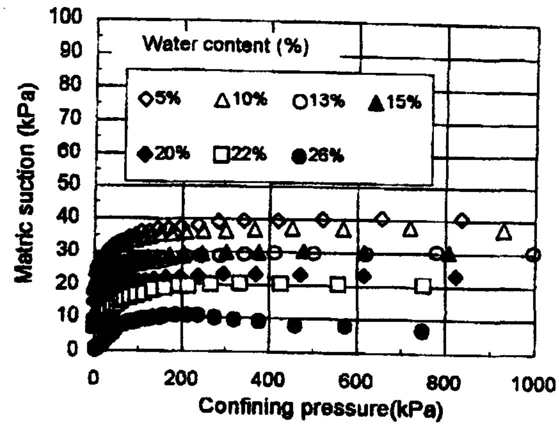

Fig.4. Relationship between confining pressure and matric suction

between the soil particles increase due to compression. Matric suction decreased with void ratio regardless of water content. Matric suction caused shrinkage of soil structure.

Test results show that the magnitude of the matric suction in compacted silty soil depends on both water content and void ratio. If the void ratio of soil specimens show constant, the matric suction increases with decreasing water content. Matric suction versus void ratio curves associated with one-dimensional compression had a peak around void ratio of about 1.0 for this silty soil.

The matric suction-confining pressure relationship is non linear as shown in Fig. 4. When confining pressure is small, the tangent to the matric suction-confining pressure curves has a maximum slope. The tangent to the matric suction-confining pressure curve gradually decrease with confining pressure. Beyond a confining pressure of 200 kPa, matric suction appear to be steady with confining pressure, with the exception of the soil specimen with water content of 26 %. The matric suction decreases slightly with confining pressure when the confining pressure indicated 200 kPa.

Fig. 5 shows the nonlinear vane strength versus confining pressure relationships for the compacted unsaturated silty soil. The relationship is approximately linear for confining pressure less than 200 kPa. The increment in the vane strength with confining pressure decreases with confining pressure when the confining pressure is greater than 200 kPa. There appears to be a unique vane strength versus confining pressure curve as the water content does not appear to have significant effect on the vane strength versus confining pressure relationship.

Pore pressure parameter

A knowledge of the matric suction is necessary to define the shear strength in compacted unsaturated soils for geotechnical engineers. The matric suction of compacted unsaturated soils are influenced by the compaction method, water content and void structure of soil. Mou and Chu-Hua (1981)[4] stated that the soil suction of statically compacted soils was higher than that of kneading compacted soils. Olso and Langfelder (1965)[5] and Krahn and Fredlund (1972)[6] defined that influence on matric suction is mainly water content. Croney (1952)[7] suggested the use of a pore

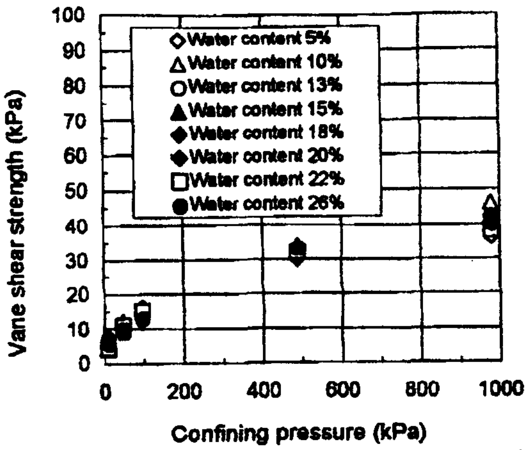

Fig.5. Relationship between confining pressure and vane shear strength

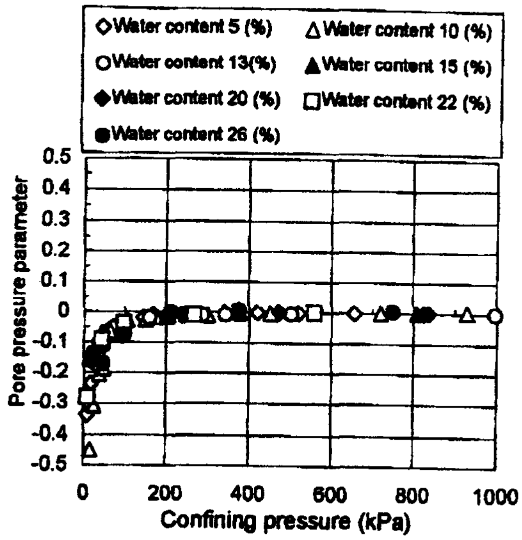

Fig.6. Relationship between confining pressure and pore pressure parameter

pressure parameter, α, to evaluate the change matric suction due to over burden pressure. The pore pressure parameter, α, was defined as follows;

$$\alpha = -\frac{\Delta(u_a - u_w)}{\Delta(\sigma_c - u_a)} \tag{1}$$

where: α = pore pressure parameter, $\Delta(u_a - u_w)$ = increment of matric suction, $\Delta(\sigma_c - u_a)$ = increment of confining pressure.

Croney and Coleman (1953)[8] applied the pore pressure parameter, α, to estimate the change in moisture/suction distribution in subgrade. The value of α is negative in equation (1), because of Croney (1952)[7] predicted that matric suction decreases with overburden pressure. The pore pressure parameter, α, was defined based on atmospheric pore-air pressure and constant water content condition. Fredlund and Rahardjo (1993)[9] stated that the parameter, α, is generally negative because the matric suction decreases with increasing confining pressure.

Croney's pore pressure parameter, α, was computed from one-dimensional compression tests results. Fig. 6 shows relationship between Croney's pore pressure parameter, α, and confining pressure. An unique curve is found to fit the in pore pressure parameter versus confining pressure relationship.

The pore pressure parameter, α, of a silty soil subjected to one-dimensional compression indicated a negative value. According to increasing confining pressure, the pore pressure parameter increased regardless of water content. The matric suction becomes a steady when the confining pressure reaches about 200 kPa.

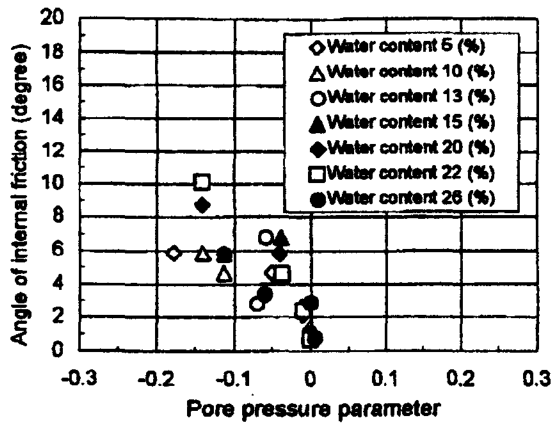

Fig.7. Relationship between pore pressure parameter and angle of internal friction

Relationship between vane shear strength and pore pressure parameter

The shear strength of unsaturated soils can be measured using triaxial compression apparatus and modified direct shear apparatus with matric suction control (Bishop, Alpan, Blight and Donald (1960)[10], Escario and Saez (1986)[11], Gan and Fredlund (1988)[12], Ho and Fredlund (19820[13]). Fredlund, Morgenstern and Widger (1978)[3] presented an equation for shear strength equation of unsaturated soil as follows;

$$\tau = c' + (\sigma_c - u_a)\cdot \tan\phi' + (u_a - u_w)\cdot \tan\phi^b \qquad (2)$$

where: τ = shear strength, c' = effective cohesion in soil, $(\sigma_c - u_a)$ = confining pressure, ϕ' = effective angle of internal friction, $(u_a - u_w)$ = matric suction, ϕ^b = angle of internal friction with regard to matric suction.

The effective angle of internal friction, ϕ', are evaluated as the tangent of the failure envelopes. The angle of internal friction have a unique relation with the pore pressure parameter, α, as shown in Fig. 7. When the pore pressure parameter, α, is low, the angle of internal friction with respect to confining pressure, ϕ', is large. However, ϕ' is going to decrease with increment of the pore pressure parameter, α. When the value of α approached to zero, ϕ' is approximately one degree. It would appear that the change in vane shear strength for a compacted unsaturated silty soil is closely related to the change in pore pressure parameter due to one-dimensional compression.

Conclusions

One-dimensional compression tests and vane shear tests using a compacted unsaturated silty soil were conducted in this study. Two tests programs were performed on the silty soil constant water content condition. The test results obtained can be summarized as follows:

(1) Matric suction versus confining pressure relationship is non linear.

(2)The Croney's pore pressure parameter, α, increases with confining pressure. The pore pressure parameter, α, approached to zero with increasing confining pressure.

(3)Vane shear strength of a compacted unsaturated silty soil has non linear relations with applied confining pressure. The angle of internal friction, ϕ', decreases with the pore pressure parameter, α.

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