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Shear characteristics of an unsaturated compacted granite soil

Caractéristiques de cisaillement de sol compact insaturé de granit

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ABSTRACT

A series of triaxial compression tests were performed on the samples of compacted granite soil in the modified triaxial cell that can control pore air pressure(Ua) and pore water pressure (Uw) separately in order to examine the characteristics of pore pressure, volume change, and stress-strain behavior during the drained and undrained loading conditions. Triaxial samples of unsaturated compacted granite soil, which have dimensions 50mm diameter and 100mm height, were prepared by compaction in a mould. These samples were tested at 3 different suction values (0.5, 1.0, 2.0 kgf/cm^2), and at 3 different confining stresses (1.0, 2.0, 4.0 kgf/cm^2). Results showed a tendency to increase only effective cohesion without variation of friction angle according to matric suction.

RESUME

Cette etude consacre aux caracteres particuliers de "pore air pressure et pore water pressure", de "volume change" et de "stress-strain" du sol grantique par une serie de "drained and undrained loading conditions" en usant des "triaxial compression tests". Les materiaux de cette experience sont "unsaturated compacted granite soil" qui ont "dimensions 50mm diameter and 100mm height". L'examen est fait a "3 different suction values (0.5, 1.0, 2.0 kgf/cm^2) et a "3 different confining stresses (1.0, 2.0, 4.0 kgf/cm^2). On peut affirmer donc que "effective cohesion" augmente graduellement sans le changement de "friction angle".

1 INTRODUCTION

Most soils in nature or man made structures such as an embankment exist in partially or unsaturated state. In general, an unsaturated soil generates force that is necessary to absorb water by capillary effect or osmotic suction. Due to this force, the unsaturated soil behaves differently from a saturated soil. This force is defined as total suction. The total suction is divided into the matric suction that is difference between pore air pressure and pore water pressure, and osmotic suction. The osmotic suction occurs usually at special area and special soil, and its value is usually smaller than the matrix suction. Meanwhile, the matrix suction is developed by an attractive force between water molecules at contact area between water and air. Thus, the theory of effective stress for saturated soils may not be applicable to such an unsaturated soil.

The state of effective stress of an unsaturated soil can be defined using two sets of independent stress state variables that are the net stress state term,(σ_m-u_a) and suction term,(u_a-u_w). This study aimed at investigating the characteristics of pore water pressure, volume change and stress-strain behavior of an unsaturated weathered granite soil. A series of triaxial tests with the drained and undrained loading condition were conducted to achieve this objective. The tests were performed with different degree of saturation, confining pressure and suction values (0.5, 1.0, 2.0 kgf/cm^2).

2 LITERATURE REVIEW

Since the theory of effective stress for an unsaturated soil proposed by Bishop (1959), many researchers have studied on an unsaturated soil. For example, Bishop and Donald (1961) investigated the shear strength of an unsaturated clayey soil. Jenning and Burland (1962) presented that the stress state variables can be divided into the net average stress and suction. Fredlund (1978) proposed the equation of shear strength of an unsaturated soil in terms of two sets of stress variables. Later, he carried out several researches with his coworker, Morgenstern(1976, 1977). Rahardjo et al. (1990, 1995) investigated the characteristics of pore water pressure and volume change of an unsaturated soil in both drained and undrained conditions. Miller and Nelson (1993) published the results of the study on the characteristics of shear strength and relationship between suction and stress state.

In Korea, an investigation regarding to development of a constitutive model for an unsaturated soil using silty sand was performed by Song (1994). The equation of shear strength for an unsaturated soil proposed by Fredlund et al. (1978) is defined as follows.

$$\tau = c + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\tan\varphi^b \quad (1)$$

where c = effective cohesion; $\sigma - u_a$ = the net normal stress; ϕ = internal frictional angle; u_a-u_w = matric suction; ϕ^b = angle that indicates the increase of the effective cohesion due to the matric suction

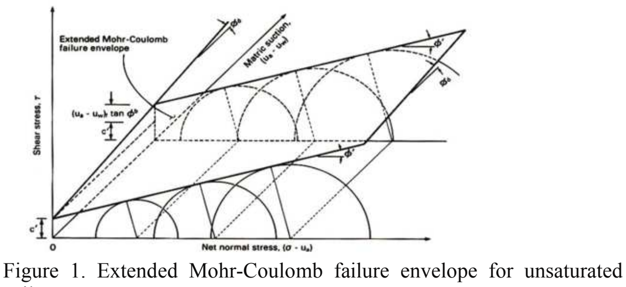

Figure 1. Extended Mohr-Coulomb failure envelope for unsaturated soils

Eq(1) indicates that the shear strength of an unsaturated soil increases as the net normal stress or the matric suction increase. The relationship between σ, τ and S is shown in figure 1. This figure shows that one failure surface is formed as the matric suction increases. The increase of cohesion due to increases of matric suction is defined as follows.

$$c = c' + (u_a - u_w)\tan\varphi^b \quad (2)$$

3 EXPERIMENT

3.1 *Material and specimen*

The weathered residual soil, which was used in this study had had sampled at areas around Pocheon Kyungkido Korea. The soil was air dried in a room temperature, and then filtered through the sieve #4. The basic material properties are shown in Table-1. Three sets of specimens that have the initial moisture content of 11.6 %(OMC), 6.5% (Dry side), 18.5 %(Wet side), and dry density of 1.7(g/cm^3) which is 92% of the maximum dry density were prepared. The specimens have dimensions 100mm height and 50mm diameter.

Table 1. Material properties on the Pocheon granite soil

γ_{dmax} (t/m^3)	O.M.C (%)	LL	PL	#200 (%)	G_s	Li (%)	USCS
1.85	11.6	NP	NP	17.15	2.67	2.80	SM

3.2 *Matric suction*

Matric suction of a soil can be measured by means of several methods such as filter paper method, thermocouple psychrometers method, and thermal matric potential sensors method etc. Of them is tensiometers method, which is able to measure in-situ using a fine porous ceramic sensing tip.

However, since pore water pressure in an unsaturated soil is negative, it is almost impossible to measure the pore water pressure in the condition of high suction. In this case, a high air entry ceramic disk, or a membrane should be used. The other method is to use a pressure plate apparatus, which adopted the axis transformation method developed by Hilf (1956).

In this study, a pressure plate apparatus (Model No. 1600, Soil Moisture Co., Santa Barbara, CA, USA) with a high air entry membrane and a porous ceramic stone was used. The high air entry membrane and the porous ceramic stone allow nothing but water to flow through. Experiments were performed based on the reference, ASTM D 2325.

3.3 *Triaxial compression test*

Triaxial tests for unsaturated soils were carried out using the modified triaxial compression apparatus that can control suction value. A series of drained and undrained triaxial tests with 3 different confining pressure (1, 2, 4 kgf/cm^2), and 3 different suction values (0.5, 1.9, 2.0 kgf/cm^2) were performed. The rate of strain set to be 0.1%/min. The detail of the test procedure is as follows.

A specimen is first consolidated with applying constant suction pressure. After having done the consolidation, the specimen is subjected to deviator stress. If the initial moisture content of the specimen is, during this stage, different from the matric suction, the deviator stress is applied after the specimen has reached the equilibrium state. In order to confirm whether or not the equilibrium state has been reached, the moisture content with respect to time is monitored. The minimum time that requires the specimen to be stable is then evaluated. The specimen is subjected to the deviator stress after time that is three times as long as the minimum time.

4 RESULTS AND DISCUSSION

4.1 *Moisture content*

Figure 2 shows the moisture content with respect to time that is required to reach the state of equilibrium. According to this figure, the sample with the matric suction of 0.4 kgf/cm^2 takes time longer than others, of which the matric suctions are 0.8, 1.0, 3.0 kgf/cm^2. This figure also shows that all samples generally reach the state of equilibrium after 15hours(900min). The moisture contents corresponding to the matric suctions are shown in Figure3. According to this figure, when the matric suction is over 3 kgf/cm^2, the changes in the moisture content are almost zero even though the matric suction increases. The matric suction corresponding to the moisture content of 17% is about 0.1 kgf/cm^2.

4.2 *Consolidated drained test*

In order to investigate the characteristics of stresses and volumetric change of an unsaturated granite soil, a series of drained triaxial tests with 3 different confining pressures of 1, 2, 4 kgf/cm^2 and 3 different matric suctions that include 0.5, 1.0, 2.0 kgf/cm^2 were carried out. The results are shown in Figure 4. As shown in the figure, the deviator stress and the volumetric

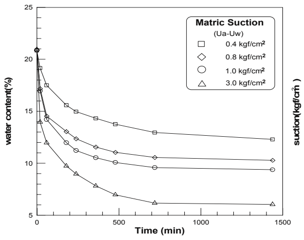

Figure 2. Moisture content with time

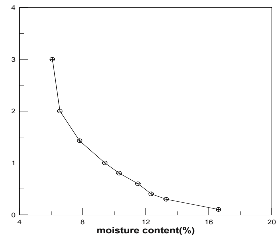

Figure 3. Moisture contents corresponding to the matric suctions

strain according to the initial water content vary slightly, and the maximum deviator stress seems to maintain almost constant. The deviator stress according to the matric suction appears to increase as the matrice suction increases. However, the change of the matric suction according to the change of the initial water content seems to be constant. From these tests, it might conclude specially for materials defined as SM that stress and volumetric change during drained triaxal compression test are much sensitive to matric suction than the initial water content.

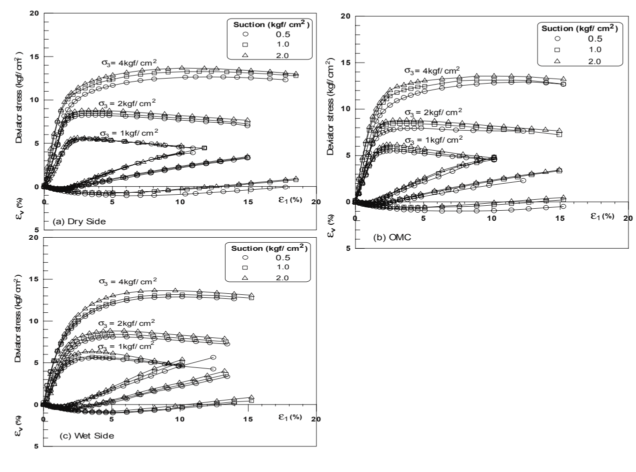

Figure 4. Consolidated drained test on unsaturated granite soils

In order to investigate the characteristic of shear strength, the net vertical stress, the matric suction, and the shear strength are plot at once. The results are shown in Figure 5. As shown, a failure surface is formed as the matric suction increases. This failure surface is defined as Mohr-Coulomb failure surface at constant suction. This figure indicates that the internal frictional angle(ϕ') remains almost constant while the effective cohesion appears to increase according to the initial water content and matric suction. The increases of the effective cohesion for each case of water content are ϕ^b =3.0˚ (dry side), 5.0˚ (OMC), and 6.8˚ (wet side).

Figure 6 shows the relationships between the matric suction and the cohesion. In this figure, the solid line represents a linear regression, and the dotted line represents a polynomial regression. As we can see, the change in cohesion for dry side of the initial water content appears to be 0.68, 0.77 for OMC, and 0.81 for wet side. In addition, the regression analyses for both linear and polynomial show that there is almost no difference between two analyses. Thus, we may conclude that it is independent on the regression analyses, when evaluates a slope that indicates increase of the effective cohesion due to an increase of the matric suction.

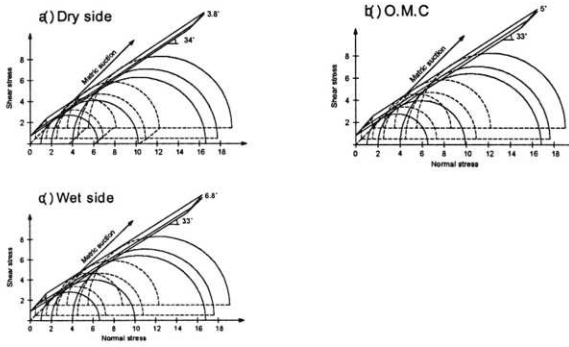

Figure 5. Extended mohr-coulomb failure envelope for consolidated drained test on the unsaturated Pocheon granite soil

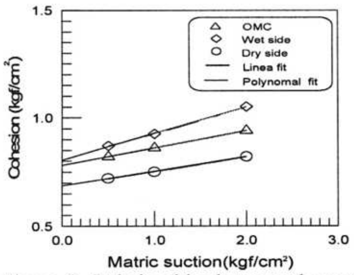

Figure 6. Relationships between the matric suction and the cohesion for consolidated drained tests

4.3 *Consolidated undrained test*

Deviator stresses and volume changes with respect to axial strain for each case are shown in figure 7. As indicated, the deviator stresses appear to decrease as the initial water contents increase.

The initial tangent seems to be a little stiff for the case that the initial water content is OMC than the wet side. In addition, the maximum deviator stress occurs at small strain. The deviator stress for the initial water content being dry side is less sensitive to the matric suction than that in wet side. That might be because of the attractive force between water molecules at contact area. The volumetric stain appears to be hardly affected by the initial water content. For the smaller confining pressure, the volume expands during shearing, while the volume dilates for the larger confining pressure at about 10% of axial strain. In case or the same confining pressure, similar phenomenon may occur at the larger matric suction.

Figure 8 plots the test results in the space of net normal stress, matric suction, and shear stress. According to this figure, as the matric suction increases it forms a failure surface in the space. This is the Mohr-Coulomb failure surface at constant matric suction. There seems to be small changes in internal frictional angle appears to be almost constant according to the matric suction, while effective cohesion seems to increase. The increases of the effective cohesion for each case are ϕ^b=3(dry side), 8 (OMC), and 9 (wet side).

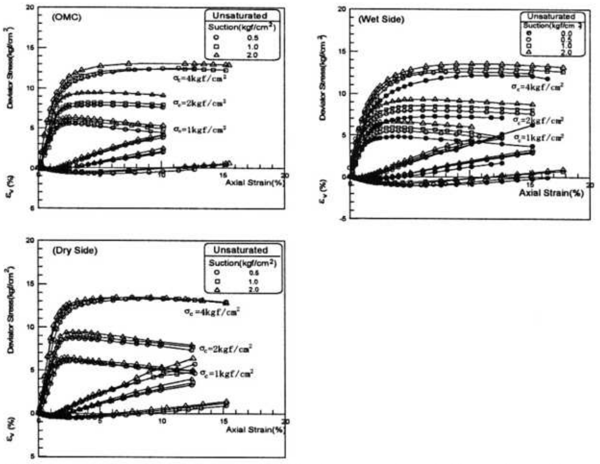

Figure 7. Consolidated undrained test on unsaturated granite soil

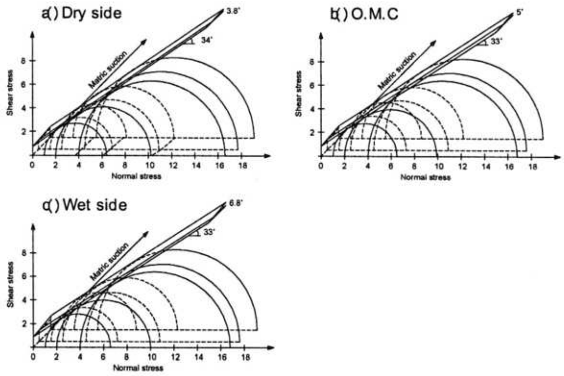

Figure 8. Extended mohr-coulomb failure envelope for consolidated undrained test on the unsaturated Pocheon granite soil

Figure 9 shows the relationships between the matric suction and the cohesion. In this figure, the solid line represents a linear regression, and the dotted line represents a polynomial regression. As we can see, the cohesion for dry side of the initial water content appears to be 0.98(linear regression), and 0.96 (polynomial regression). In the other two cases, we can hardly see difference between the linear and the polynomial regression. Thus, we may conclude that it is really not matter which regression analysis is chosen, when evaluates a slope that indicates increase of the effective cohesion due to increase of the matric suction.

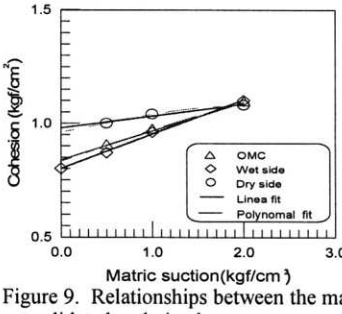

Figure 9. Relationships between the matric suction and the cohesion for consolidated undrained tests

4.4 *Pore air pressure*

Since the volume of an unsaturated soil varies during shearing undrained, and the void is filled with air and water, it may be important to bring attention to the mechanical characteristics of pore air pressure and water pressure. The changes in pore air pressure with respect to axial strain with different initial water contents, confining pressures, and matric suctions are shown in Figure 10. When the confining pressure is 1 kgf/cm^2, the pore air pressure appears to be positive values at the only beginning part of the axial strain. When the confining pressure is 4 kgf/cm^2, the values of the pore air pressure become positive during almost entire test. And they appear to be higher as the matric suctions increase, and the initial water content of the wet side is larger.

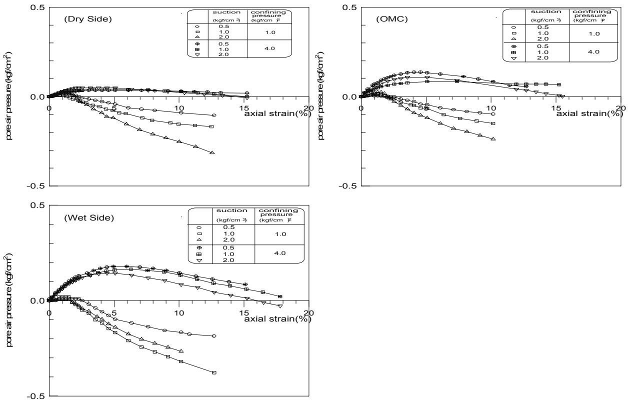

Figure 10. The changes in pore air pressure with respect to axial strain with different initial water contents, confining pressures, and matric suctions

4.5 *Pore water pressure*

The changes in pore water pressure with respect to axial strain with different initial water contents, confining pressures, and matric suctions are shown in Figure 11. The pore water pressure appears to be higher at the confining pressure of 1 kgf/cm^2 than the confining pressure of 4 kgf/cm^2. In case of the same confining pressure, the higher the matric suction the larger the pore water pressure. For instance, for the matric suction of 0.5 kgf/cm^2, the pore water pressure appears to be negative after certain amount of axial strain.

As discussed so far, for an unsaturated soil, volume change occurs during shearing, and pore air pressure and pore water pressure are developed. Finally, the strength appears to be higher than a saturated soil.

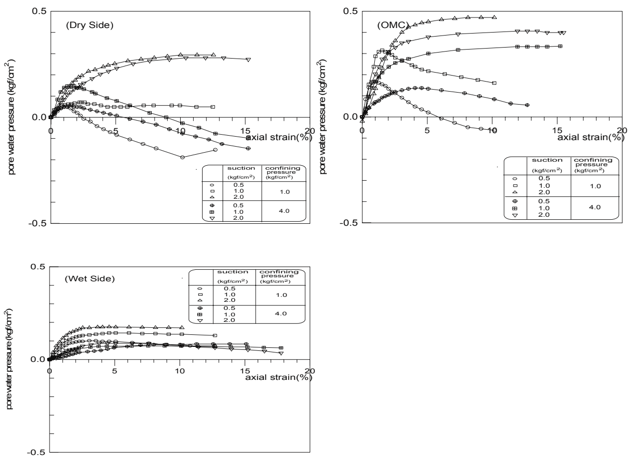

Figure 11. Pore water pressure with respect to axial strain with different initial water contents, confining pressures, and matric suctions

5 CONCLUSION

In order to investigate the characteristics of pore water pressure, volume change, and stress-strain behavior according to an initial water content of an unsaturated soil, a series of experiments were conducted. Drained and undrained triaxial compression tests were performed with several different confining pressure and matric suctions. Based on the investigation carried out in this research, we make the following observations and obtained the following results.

The water contents remain almost constant for the matric suction over 3 kgf/cm^2. The critical height of capillary occurs, when the matric suction is equal or less than 0.1 kgf/cm^2.

The volume change of an unsaturated soil during shearing drained and undrained is much sensitive to the confining pressure compared to the initial water content, and the matric suction.

The matric suction has more affection to the deviator stress, when initial water content is wet side. In most case, the volume expands during shearing. The volumetric strain is much larger at the smaller confining pressure, and at the higher matric suction.

The change of the internal frictional angle according to the initial water content and the matric suction is negligible. However, the effective cohesion appears to increase. The parameter, ϕ^b which indicates increase of the effective cohesion due to increase of the matric suction can be determined with linear regression.

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