Performance of an Automated Suction Controlled Triaxial Apparatus

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1 Introduction

Stress state variable, such as net normal stress and matric suction has been successfully governing behavior of unsaturated soils. Those variables have significant influence on strength and deformation properties. Due to climate change, unsaturated soil prone to have hysteresis features and should no longer be ignored. To investigate the hysteresis effect on unsaturated soil properties, an apparatus which able to control suction need to be developed. A suction controlled triaxial apparatus developed in Geotechnical Engineering Laboratory of Kyushu University was used to conduct the test. The apparatus is able to measure or control pressure independently, to measure both total and drainage water volume change and to measure strain in small range by using local displacement transducer. Two different types of test, soil water retention test and shear test were conducted to investigate the performance of the apparatus. Soil water retention test used red soil from Okinawa as sample material. Specimen was molded into 5 cm diameter and 3 cm height. Shear test was conducted to investigate the effect of suction towards small stiffness, used Toyoura sand as sample material. Specimen was molded into same diameter with soil water retention test, while the height is 10 cm. The results of the tests are going to be discussed.

2 Triaxial Apparatus

A suction controlled triaxial apparatus has been developed in Geotechnical Engineering Laboratory of Kyushu University. The schematic diagram is shown in Figure 1a. This apparatus is mainly used for triaxial test on saturated and unsaturated specimen and using axis translation technique to maintain the suction by controlling both pore water and pore air pressure. This apparatus equipped with inner cell to measure total volume measurement by using pressure differential transducer. Drained water volume can be measured as well by similar technique. During shearing, strain and deviatoric stress was measured. External and internal load cell was used to measured deviatoric stress and local deformation transducer attached at specimen was used to measure strain at small strain range.

Pore air pressure is applied at the top of the specimen through porous disk, while pore water pressure is applied at bottom through high air entry ceramic disk (300kPa). Ceramic disk is glued and completely sealed at the pedestal and connected with water channel at the bottom. At the middle of ceramic disk, metal porous disk is installed, mainly used during saturation of the specimen or during saturated triaxial test for volume change measurement. Three pressure transducers are placed to measure water pressure, air pressure and cell pressure at any specified time. These transducers give feedback to pressure regulator for controlling the pressure at specified value.

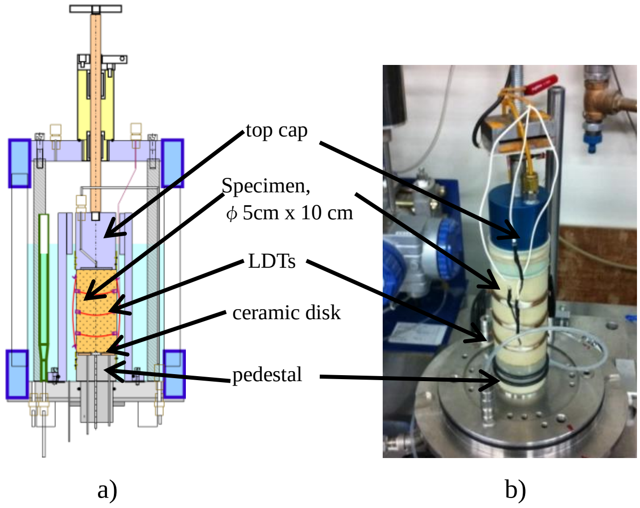

Figure 1 Suction controlled triaxial apparatus, a) schematic diagram, and b) photograph

Small strain was measured by using local deformation transducers (LDT) (Goto et al., 1991). LDT was attached at the sample at vertical and horizontal direction. Two of vertical LDT and three of lateral LDT were used. When attached well, LDT can be used to measure strain up to 1% (1mm). Figure 1b shows photos of specimen preparation with attached LDTs.

The ability of the apparatus to conduct shear strength test and SWRC test can be summarized as shown in Table 1. Accuracy of pressure control is about 1 kPa, and best for use in range of 50-300 kPa (less than 2% error). Volume change of water drained in or out of the specimen can be monitored up to 10^{-5} cm^3. The maximum value of drained water volume is depended on the volume of burette; in this apparatus is about $25cm^3$. Local differential transducer to measure small strain has accuracy about $5x10^{-6}$% and best to be used no more than 1mm. For large strain measurement, external LVDT is used and has accuracy about 10^{-3}%.

Table 1 Apparatus ability

Feature	**Capacity**	**Accuracy**
Pressure control	1MPa	1kPa
Drained water measurement	$0\text{-}25cm^3$	$1x10^{-5}$ cm^3
Total volume change	$\pm 28cm^3$	$1x10^{-5}$ cm^3
Small strain	0-1%	$5x10^{-6}$ %
Axial strain	0-10%	$1x10^{-3}$ %

4 Soil water retention curve

Red soil from Okinawa prefecture, classified as silt soil, is used as sample. Specimen was prepared at natural water content (10.6%) and specified dry density (16.23 kN/m3), compacted in about 3 cm height and 5 cm in diameter mold.

Keywords: unsaturated soils, suction controlled apparatus, soil water retention curve, small strain stiffness, multistage test
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The sample needs to be saturated prior to the test, by applying backpressure through porous metal below the sample. The procedure to saturate the sample is similar to those used in saturated test. The air pressure is then increased to give designed matric suction. The cell pressure also needs to be increased at the same value to keep the net normal stress in constant value. The value of pore water pressure is set 25 kPa, while pore air pressure is increased from 28, 35, 55, 125, 195, 275, 125, 55 kPa until reaching at equilibrium condition to apply higher value of matric suction to the specimen. Figure 2 shows the drainage water of specimen to reach equilibrium condition on each matric suction applied.

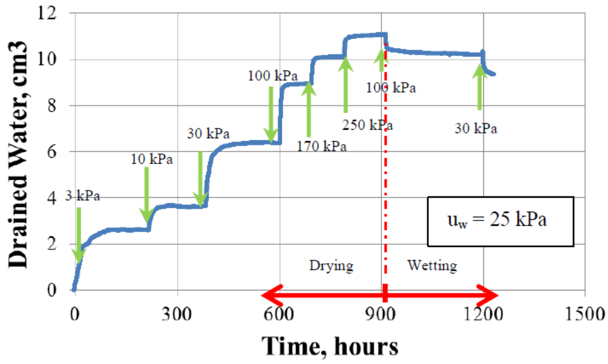

Figure 2 Monitored drained water volume

After finish all test, water content of specimen needs to be measured and marked as the water content of the last applied matric suction. Water content at other matric suction can be obtained by back calculation based on the volume of drained water at previous matric suction. As the result, SWRC can be obtained as shown in Figure 3. The data is then fitted by using Van Genuchten model using constant α = 0.0054/kPa, n = 0.467 and m = 0.504.

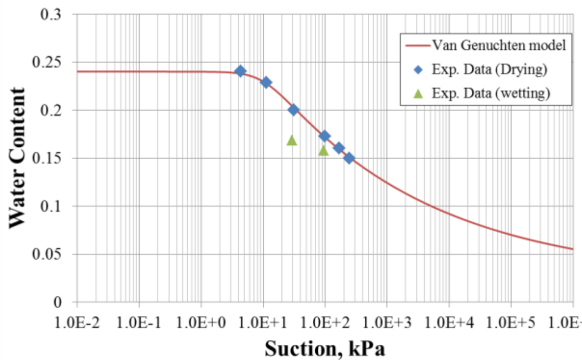

Figure 3 SWRC exp. data and Van Genuchten fitting curve

5 Effect of suction on small strain stiffness

Series of multistage triaxial test (Ho and Fredlund, 1982) at small strain range were performed to investigate the stiffness of unsaturated soils under different initial stress state variable, in this case is matric suction. Stress strain relationship was observed during the test and stiffness of soil was calculated at small strain. The results are shown in Figure 4 and Figure 5. Figure 4 describes the stress strain relationships for three different matric suction applied. It shows that the higher matric suction, the stiffer soil will behave. Based on this figure, at below 0.02% of strain, stress strain relationship can be assumed as linear condition, known as maximum stiffness. The value of maximum tangent modulus elasticity is shown in Figure 5. These values obtained from the inclination of the stress strain curve. Maximum modulus elasticity increases as the increasing of matric suction. This result shows that matric suction plays important roles in increasing soil stiffness.

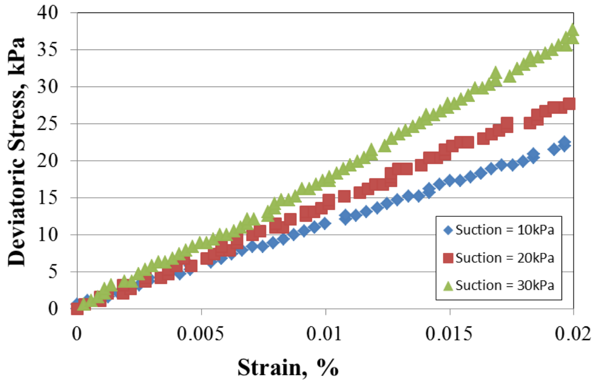

Figure 4 Stress strain relationship at small strain range

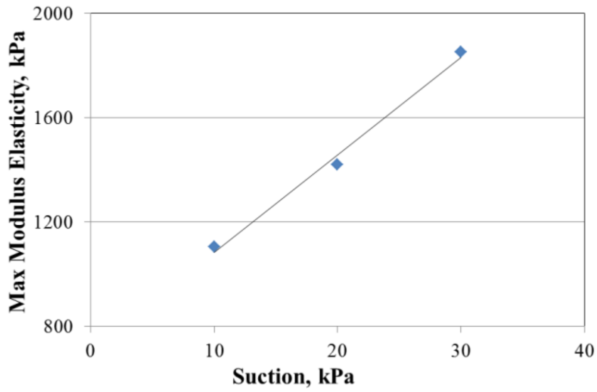

Figure 5 Evolution of maximum modulus elasticity versus matric suction

6 Conclusion

An automatic system of suction controlled triaxial apparatus has been developed to conduct both triaxial test (saturated-unsaturated condition) and SWRC test. It has ability to control stress path and suction in high performance. Combination between direct measurement of SWRC and prediction by using fitting curve is good way to produce SWRC accurately and reliably and reduce required time and cost consumed. Stiffness of unsaturated soil has been observed using LDT at small strain range. The result shows that matric suction plays important roles in in increasing stiffness of soil increases. As the increasing of matric suction, soil will have higher stiffness.

Acknowledgement

This research was supported by Grant-in Aid for scientific research (A) No. 22246064 from JSPS lead by N. Yasufuku.

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