Water Retention Measurement of Soils Using an Automated Suction Controlled Triaxial Apparatus

Luky HANDOKO, Noriyuki YASUFUKU, Hazarika HEMANTA, Kiyoshi OMINE
Dept. of Civil and Structural Engineering, Kyushu University

1. INTRODUCTION

Based on Fredlund et al (1997), unsaturated soil properties (such as Soil Water Retention Curve (SWRC), Hydraulic Conductivity Function (HCF) and Shear Strength Function (SSF)), can be obtained in three different ways, shown in **Table 1**. The first option is to conduct direct measurement of all properties, which lead to the best accuracy but takes very long time and very high cost. The second option is to conduct direct measurement of SWRC, and use the measured SWRC to predict the other properties. This option results to less accuracy than the first option, but still in reasonable accuracy. It has advantages in less cost and less time consumed. In the third option, all unsaturated soil properties are obtained by prediction method, and it will lead the most inaccurate results among of other options.

Table 1 Determination of unsaturated soil properties (Fredlund et al, 1997)

Options	SWRC	HCF	SSF	Accuracy
1	○	○	○	High accuracy
2	○	△	△	Less accuracy
3	△	△	△	Lowest accuracy

Note ○= Direct Measurement
△= Prediction

To obtain reasonable accuracy of unsaturated soil properties in low cost and time consumed, the second option can be chosen. It means direct measurement of SWRC is important to be conducted. To do so, an apparatus for measuring water retention of soil is needed. This paper is focused on developing suction controlled triaxial apparatus to measure SWRC.

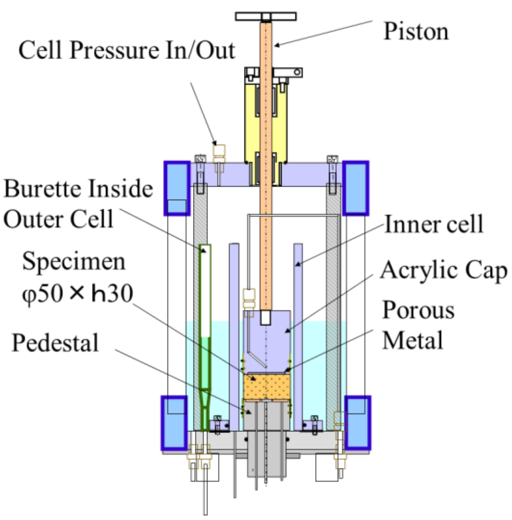
2. TRIAXIAL APPARATUS

Due to climatic change, SWRC shows hysteresis, it has different path under wetting and drying process. To measure this hysteresis characteristic, an apparatus which able to control both air and water pressure and to measure volume change is needed.

A suction controlled triaxial apparatus has been developed in Geotechnical Engineering Laboratory of Kyushu University. The schematic diagram is shown in **Fig 1**. 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. Due to the similar system, this apparatus can also be used to measure water retention of soil. The advantage is that this system has similar boundary and environmental condition from reality in the field ground. And also, the degree of saturation of soil can be calculated by taking into account the volume change of the sample.

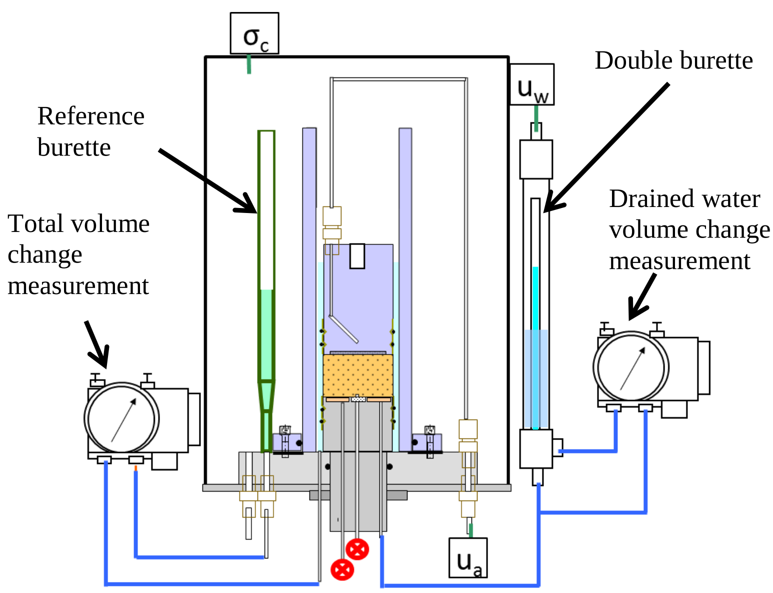
Pressure control/measurement

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 saturating the specimen or during saturated triaxial test. Three pressure transducers are placed to measure water pressure, air pressure and cell pressure at any specified time.



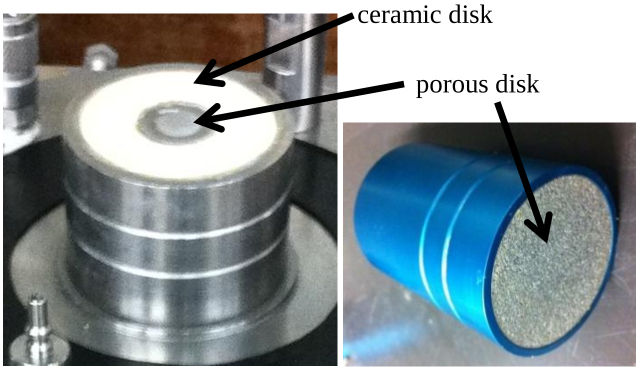
(a)

Figure 1 Triaxial Apparatus: (a) schematic diagram; (b) volume change measurement



(b)

Keywords: unsaturated soils, axis translation method, suction controlled apparatus, soil water retention curve, hysteresis
Address: 〒819-0395, 744 本岡西区福岡. TEL: 092-802-3378



(a) (b)

Figure 2 porous disk (a) high air entry value (bottom), and (b) normal porous disk (top)

Drained water measurement

This apparatus is able to measure both total volume and drained water volume. The fluctuating water level inside the inner cell is representing the total volume change. To measure total volume of specimen, the pressure difference between water level inside the inner cell and reference burette is measured using pressure differential is measured **(Fig 1(a))**. Water drained volume is also measured in this apparatus by measuring the pressure differential in double burette as shown in **Fig 1(b)**. Monitored drained water volume with the increasing of pore water pressure is shown in Figure 2. When no significant amount of water drained in or out of the specimen, it can be defined as the equilibrium state.

3. APPARATUS PERFORMANCE

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/m^3), compacted in about 3 cm height and 5 cm in diameter mold

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 3, 10, 30, 100, 170, 250, 100, 30 kPa. Air pressure is increased after reaching at equilibrium condition to apply higher value of matric suction to the specimen **(Fig 2)**.

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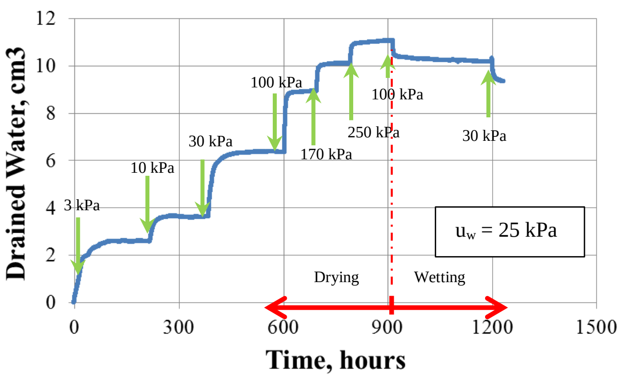

Figure 3 Monitored drained water volume

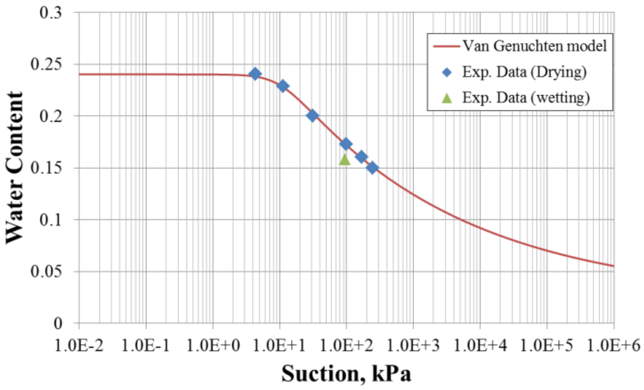

Figure 4 SWRC exp. data and Van Genuchten fitting curve

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 Fig.4. The data is then fitted by using Van Genuchten model using constant α = 0.0054/kPa, n = 0.467 and m = 0.504.

The ability of the apparatus to conduct shear strength test and SWRC test can be summarized as shown in **Table 2**. 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 10^{-7}% and best to be used no more than 5%. For large strain measurement, external LVDT is used and has accuracy about 10^{-3}%.

Table 2 Apparatus ability

Feature	**Capacity**	**Accuracy**
Pressure control	1MPa	1kPa
Drained water measurement	0-25cm^3	1x10^{-5} cm^3
Total volume change	±28cm^3	1x10^{-5} cm^3
Small strain	0-5%	1x10^{-7} %
Axial strain	0-10%	1x10^{-3} %

4. 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.

REFERENCES

Fredlund, M. D., Wilson, G. W., & Fredlund, D. G. (1997). Indirect Procedures to Determine Unsaturated Soil Property Function. *Proceedings of the 50th Canadian Geotechnical Conference.* Ottawa.