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Suction Controlled Triaxial Apparatus for Saturated-Unsaturated Soil Test

Luky Handoko[1], Noriyuki Yasufuku[2], Kiyoshi Oomine[3] and Hemanta Hazarika[4]
[1,2,4] Faculty Of Engineering, Kyushu University, Japan; [3]Faculty of Engineering, Nagasaki University, Japan

ABSTRACT: A suction controlled triaxial apparatus has been developed in Geotechnical Engineering Laboratory of Kyushu University. The apparatus has been designed to obtain mechanical properties of unsaturated soil such as shear strength and stiffness, as well as hydraulic properties of unsaturated soil, i.e. Soil Water Retention Curve (SWRC) by measuring change of drained water volume during applied matric suction. Not only for unsaturated condition, this apparatus can be also used to conduct conventional test on saturated soil. This paper focuses on the performance of the apparatus, by performing a series of multistage test on unsaturated soil under drying and wetting path. The hydraulics and mechanical properties of unsaturated soil are presented and discussed.

Keywords: Triaxial Apparatus, Unsaturated Soils, Suction Control, Hydraulic and Mechanical Properties

1 INTRODUCTION

Stress state variable, such as net normal stress and matric suction has been successfully governing behavior of unsaturated soils [1]. Those variables have significant influence on hydraulics and mechanics properties. Many researchers have been focusing study on determining shear strength [2]-[4], small strain stiffness [5]-[7], and soil water retention curve [8]-[9] of unsaturated soil through laboratory experiments. To obtain hydraulic and mechanical properties of unsaturated soil, an accurate control and measurement equipment are needed. Triaxial apparatus for unsaturated soil has been developed by many researchers [10]-[13].

The main problem in conducting unsaturated soil test is due to its difficulties, time consumed and costly. Also, due to climate change, unsaturated soil prone to have hysteresis features and should no longer be ignored [14]. To investigate the hysteresis effect on unsaturated soil hydraulics and mechanics properties, an apparatus which able to control suction needs to be developed. This paper presents the development of suction controlled triaxial apparatus which can be used to conduct test on unsaturated soils as well as conventional saturated condition. The apparatus has independent control of cell pressure, pore air pressure and pore water pressure to control matric suction and net normal stress. It is equipped with Local Deformation Transducers (LDTs) to measure strain at small range and Pressure Differential Transducer to measure both drained water volume change and total volume change. With those equipment, it is possible to obtain both hydraulics and mechanics properties of unsaturated soil directly in a series of multistage test to reduce time consumed and cost needed to conduct the tests. Five centimeter diameter and ten centimeter height specimen was used in multistage triaxial test on different matric suction and stress path. Hydraulic and mechanical properties of the specimen obtained during the test are going to be presented and discussed.

2 TRIAXIAL APPARATUS

A suction controlled triaxial apparatus has been developed in Geotechnical Engineering Laboratory of Kyushu University in collaboration with Geo-Research Institute, Kobe, shown in Fig. 1. This apparatus can be used to perform test under unsaturated condition by adopting axis translation technique to control both pore water and air pressure in order to maintain matric suction within the specimen. Conventional saturated test condition can be conducted by applying back pressure through porous metal disk provided in the middle of ceramic disk.

Several instruments for control /measurement purposes are equipped in the apparatus, such as: external and internal load cell to measure deviator load; pressure transducer to measure cell pressure, pore water pressure at bottom of the specimen and pore air pressure at the top of specimen; Pressure Differential Transducer to measure drained water volume changes and total volume changes, LVDT to measure axial large strain range externally, LDTs and Pi-gauges to measure axial and radial small strain range internally.

Pressure control/measurement

Air pressure is supplied at a constant value about 700kPa to the pressure regulator. From pressure regulator, it is divided into four channels for controlling cell pressure, air pressure and two channel of pore water pressure independently.

Pore air pressure is applied at the top of the specimen through normal porous disk, while pore water pressure is applied at bottom through high air entry ceramic disk. The air entry value of ceramic disk is about 3 bars (300 kPa). High air entry ceramic disk was 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 to saturate specimen in unsaturated test condition or to apply back pressure and measure specimen volume change during saturated triaxial test. Fig. 2 shows the schematic diagram of pressure regulation in triaxial apparatus.

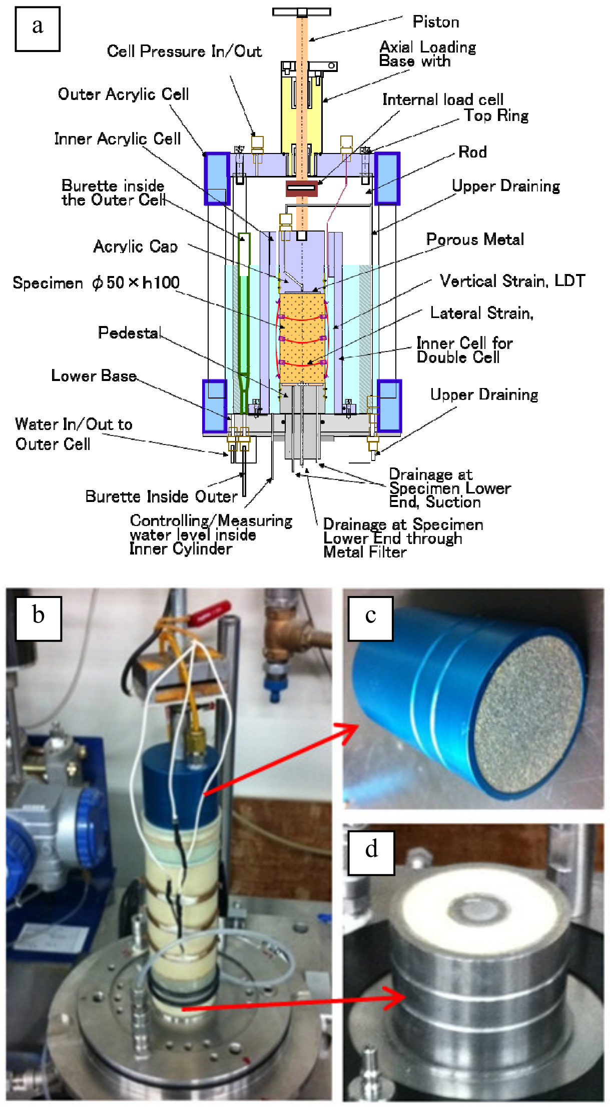


Fig. 1 Suction controlled triaxial apparatus, a) schematic diagram, b) photo, c) normal porous disk (top of specimen) and d) high air entry value disk and porous metal filter (bottom of specimen)

Volume change measurement

Total volume change and drained water volume change can be measured by using pressure differential technique [15]. Open ended inner cell is used to measure total volume change of soil. The fluctuation of water level inside the inner cell represents the change of total volume change. Drained water volume change is calculated by measuring the amount of water drained in or out of specimen. For complete description of pressure differential technique for measuring volume change please refer [15].

Strain Measurement

During shearing, strain of deformed specimen is measured externally and internally. Linear Variable Differential Transformer (LVDT) (range 0-20% strain) is placed outside the chamber to measure large strain range of specimen during shearing. Internally, two LDTs [16] are attached at the specimen to measure axial strain, while other three instruments so called pi-gauge are attached horizontally to measure lateral strain. The maximum displacement can be measured by LDT is about 1.5 mm (1.5% of strain). These LDTs and Pi-gauges were produced by Geo-Research Institute, Kobe.

3 TEST METHOD

3.1 Materials

Two types of soil were used in the tests; they are low plasticity silt called Red Soil from Okinawa Perfecture, Japan and sand soil called Toyoura sand. The grain size distributions are shown in Fig. 3 and the basic properties are shown in Table 1. Red soil was prepared to conduct soil water retention test, while Toyoura sand was prepared for shearing test. Specimen dimension prepared in the apparatus is 10 cm in height and 5 cm in diameter for shearing test. To reduce the time consumed in soil water retention test, specimen height was reduced to be 5 cm height, while the diameter is same.

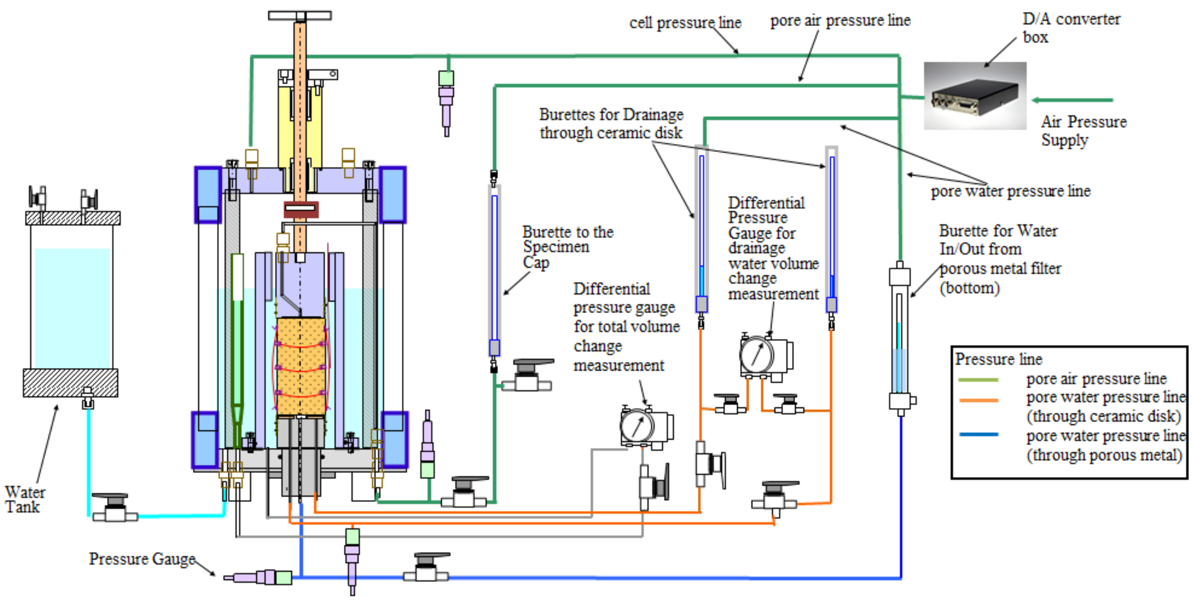


Fig. 2 Schematic diagram of pressure regulation

The specimen was prepared by using moist tamping method compacted at a split mold attached to the pedestal of triaxial apparatus [17]. Required amount of dry soil was mixed with predetermined amount of de-aired water and then kept about 16 hours before used. The specimen was compacted by 5 equal layers for soil water retention test and 10 equal layers for shearing test in order to make equal distribution of soil density.

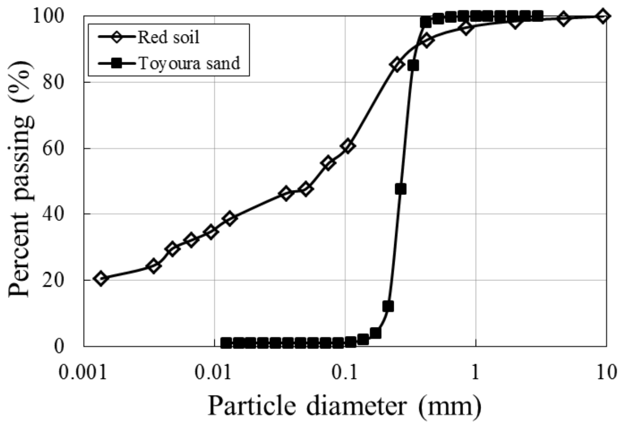


Fig. 3 Grain size distribution of soils

Table 1. Basic properties of soils

Soil type	G_s	e	w (%)	γ_d (kN/m^3)	γ_b(kN/m^3)
Red soil	2.64	0.63	10.6	16.23	17.95
Toyoura	2.65	0.68	10	15.8	17.38

3.2 Test Procedures

Reference [18] explained the multistage testing procedure in triaxial apparatus by increasing soil suction of unsaturated soil in each stage. This procedure is mainly used to provide unsaturated soil properties of different applied matric suction and different path by using single soil specimen. Even though it is possible to obtain hydraulics and mechanics properties by using single soil specimen, in this test, two different tests were conducted to evaluate the performance of the apparatus. Water retention test on Red soil and shearing test on Toyoura sand were conducted.

For water retention test, the specimen test was started from saturated condition. Pore air pressure and cell pressure was increased in the same value to maintain destined matric suction and to keep constant value of net normal stress. Pore water pressure was set constant about 25kPa. Net normal stress was also set constant about 50kPa. Matric suction was varied from 3kPa, 10 kPa, 30kPa, 100kPa, 170kPa, 250kPa, 100kPa and 30kPa.

For shearing test, consolidated drained condition was chosen with shear rate about 0.01 mm per minutes. The specimen was tested initially from saturated condition. After being saturated, the specimen was sheared until reaching peak value and then unloading. After shear loading and unloading was finished, consolidation for next stage predetermined matric suction started, and then sheared again after reaching equilibrium state. This condition was repeated for subsequent stage. A typical set of stresses for each stages are given in Table 2. Net normal stress variable was set to constant value at 20kPa.

Table 2. Applied pressure and matric suction

Stages	u_a (kPa)	u_w (kPa)	u_c (kPa)	u_a-u_w (kPa)
I	25	25	45	0
II	30	25	50	5
III	40	25	60	15
IV	30	25	50	5

4 RESULT AND DISCUSSION

Among of equipment mentioned above, LDTs performance may change with their use, so calibration is needed after used few times. For use in multistage test, LDTs will experience loading and unloading of deviatoric stress for many times in one series of test. This equipment needs to be calibrated properly before used by using digital micrometer as shown in Fig. 4.

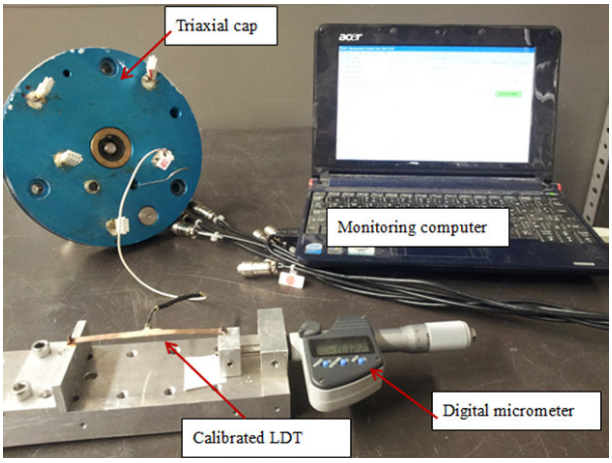
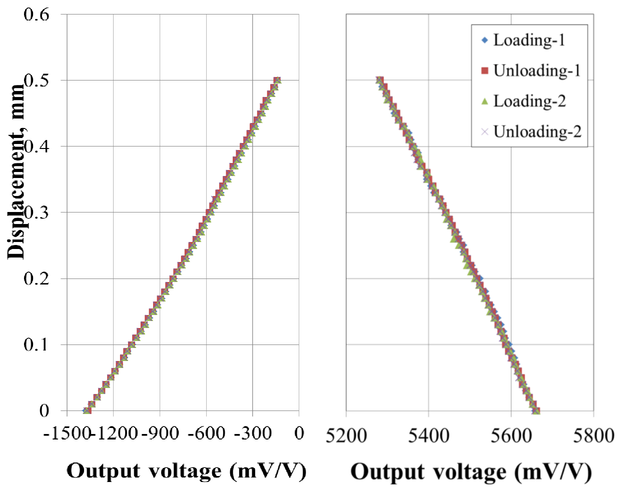


Fig. 4 LDT calibration techniques

Calibration for LDT fits with polynomial order two, while pi gauges follows linear curve. Fig. 5 presents the repeated calibration by loading and unloading for 2 times. It shows that the curve are coincided each other and does not change so much. It indicates that LDT and pi gauges are still in good calibration due to repeated loading. It is expected that LDT and pi gauges work properly during multistage test.



a) b)

Fig. 5 Repeated calibrations for a) LDTs and b) pi-gauges

Soil Water Retention Test

Fig. 6 shows the drained water evolution versus time. It shows that drained water volume change can be monitored well. The result shows that red soil reaches equilibrium time about 8-10 days. After finish all consolidation step, water content of specimen was measured, and then recalculating water content for each applied matric suction by back calculation method. As the result, SWRC of red soil can be drawn in Fig. 7. This figure shows the hydraulic hysteresis of red soil due to different process of drying and wetting path. At the same matric suction, wetting process will give lower water content than drying process. Boundary condition of specimen during soil water retention test in triaxial apparatus is more similar with field condition by applying radial pressure (cell pressure) at the specimen. This is one of the advantages of using triaxial apparatus to measure soil water retention curve compared with other apparatus.

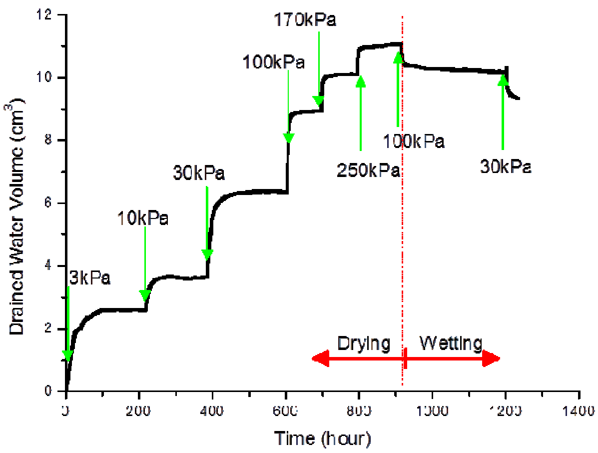


Fig. 6 Monitored drained water volume change

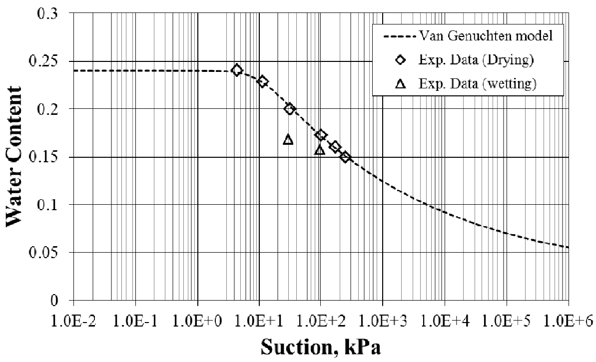


Fig. 7 SWRC experiment data fitted with Van Genuchten fitting curve

Shearing test

The stress-strain relationships for 4-stages (different matric suction) shearing test is shown in Fig. 8. It shows that the strength of soil increases as the increasing of matric suction. Similar result could be observed on the steepness of the stress-strain curves, means that stiffness is also increasing. At the early shearing test (matric suction = 0kPa), the curve seems to be incorrect. This problem might occur when the LDT was not attached properly. In this test, the LDTs were attached manually by using bare hand, and may unstable. Reference [16] suggested a fixing device to attach the LDT, so it can be aligned properly. There are two LDTs attached at the specimen, so the expected correct result can be drawn easily from the other LDT with correct result, shown in dashed line. Smaller strain range (below 0.01%) of stress-strain diagram and related elastic moduli at small strain are presented in Fig. 9 and Fig. 10. These figure more clearly show the stiffness of soil at small strain range. It shows that in small strain range, the stress-strain relationship can be represented by linear line. Elastic moduli of soil changes depend on the applied matric suction.

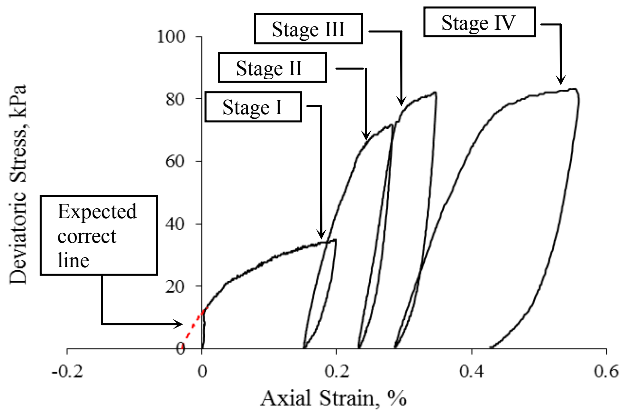


Fig. 8 Stress strain relationship of 4-stages multistage triaxial test

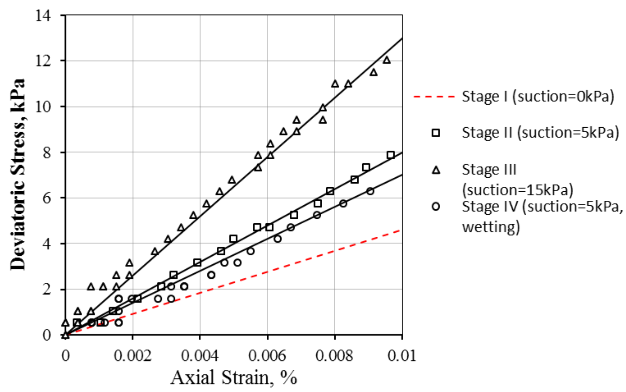


Fig. 9 Stress-strain diagram in small strain range of each stage

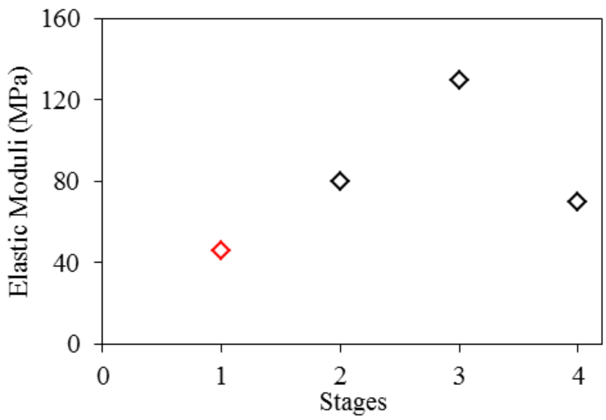


Fig. 10 Elastic moduli of each stage

5 CONCLUSION

A suction controlled triaxial apparatus has been developed in Geotechincal Engineering Laboratory of Kyushu University collaborating with Geo-Research Institute, Kobe. The apparatus has an automatic system to collect and store the data. It can be used to conduct multistage test to obtain hydraulic (SWRC) and mechanics (shear strength and stiffness) properties of soil directly using single specimen. Two different series of multistage test has been conducted to evaluate the performance of the apparatus. From the experimental test result, it can be conclude that:

- the developed suction control apparatus is able to provide good monitoring and storing data automatically,
- the apparatus equipped with LDTs is to measure small strain range and works well based on the test result,
- unsaturated soil is having hysteresis features due to different process (drying and wetting). This apparatus is able to observe this phenomenon. It can be shown clearly in the hydraulic properties (SWRC) test result.

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Pertinent discussion including authors' closure, if any, will be published in the March 2014 if the discussion is received by Sept, 2013.

Corresponding Author: Luky Handoko