Development of SPA-500 Type Unsaturated Soil-water Characteristics and Hydraulic Parameters Test System

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Abstract

This manuscript describes the test system of SPA-500 unsaturated soil and water characteristics and hydraulic parameters. The system contains double pressure chamber, pressure framework, pressurized cylinder, stress and strain measuring controller, back pressure and volume change measuring controller, underwater load sensor, displacement sensor, pore pressure sensors etc. It can be used to research SWCC relating to moisture absorption or dehumidifying and water (air) migration rules under triaxial pressure and suction paths control. The load sensor is put inside the double pressure chamber. And the sample volume change measuring controller combined with the surrounding pressure device is used in the system. The system can work independently by using high impedance linear amplification technology, A/D conversion technology, stepper motor driving control technique etc. The software programmed by Delphi language has capability of data acquisition and real-time graphics by means of automatic control. The SPA - 500 type test data is reliable based on the test results which show that the SPA - 500 type test data and GDS test data have good comparability.

Keywords: unsaturated soil, soil and water characteristic curve (SWCC), permeability, technical index, control precision

1. Introduction

The soil and water characteristic curve (SWCC) is a curve of soil matric potential with water content change. It expresses the relationship between amount and energy of water in soil. It is important for SWCC and moisture migration to predict mechanics properties, shear strength, slope stability and slope deformation of unsaturated soil (Agus, 2001). Li invented SPA - 500 type of unsaturated soil water characteristics and hydraulic parameter experiment system (SPA experimental system) to attain SWCC, permeability etc.

The SWCC of unsaturated soil can be attained by using of the tension meter and heat conductivity probe in-situ (Li, 2007). Indoor SWCC test methods contain the pressure plate volume meter method (Fredlund, 1993), temple instrument method (Fredlund, 1993), the filter paper method (Ye, 2005) and so on. But greater differences between SWCC tests under different soil conditions show different behavior characteristics. The pressure plate volume meter apparatus and temple produced by American Soil-moisture Equipment in 1985 can measure SWCC of soil without overburden pressure. At the beginning of the 21st century, USA GCTS company produce the pressure plate apparatus of SDSWCC relating to stress, which can measure SWCC under the action of axial stress. Ye invented a kind of soil permeameter, which adopted GDS pressure controller to realize control and measurement of fluid pressure and volume, in order to obtain soil permeability under different void ratio and stress conditions (Ye, 2005). Miao invented a kind of consolidation and joint measurement device for unsaturated soil, which can be used for consolidation and SWCC (Miao, 2007). Chen invented consolidation apparatus and permeability gas meter of unsaturated soil to reveal moisture migration rules of unsaturated soil and special soil (Chen, 2011). Li invented SPA - 500 type of unsaturated soil water characteristics and hydraulic parameter experiment system (SPA experimental

system) to attain SWCC, permeability etc. The measurement details of pore-water pressures, volumetric water contents, temperatures, and relative oxygen concentrations in unsaturated soil layers under asphalt pavement, aeration slab, and turf cover, as well as weather conditions are described by field instrumentation (Indrawan, 2012). The small dual-probe sensors were used to measure heat and water transport of unsaturated sandy soil which was subjected to a wetting and drying cycle (Bristow, 1998). Watanabe et al measured liquid water content and relative permittivity of various unsaturated soils at above-zero and subzero temperatures by using pulsed nuclear magnetic resonance (NMR) and time-domain reflectometry (TDR) (Watanabe, 2009). The unsaturated soil was tested in a modified triaxial apparatus using independent stress state variables to describe stresses in the specimen (Wulfsohn, 1998).

2. Experimental System

2.1 Instrument composition

SPA experiment system is a new type of double pressure chamber suction control system which relates to stress using to measure soil water characteristic curve and permeability. The system consists of double pressure chamber (a), pressure framework (b), pressurized cylinder, stress and strain measurement controller (c), back pressure and volume change measurement controller (d), underwater load sensor, displacement sensor, pore water pressure controller (e) etc. as shown in Fig. 1.

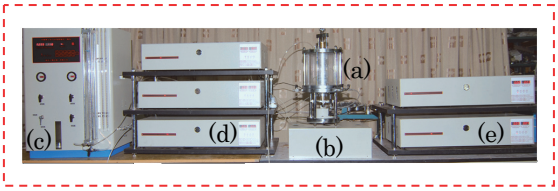

Fig. 1 SPA-500 unsaturated soil and water characteristic and hydraulic parameters test system

2.2 Main functions

The system can be used to study soil and water characteristic curves (SDSWCC) and water phase (gas phase) permeability rules (WAPC) of unsaturated soil which are related to dry-wet stress under the action of independent triaxial stress and suction path. The specific functions include many functions, such as, measuring SWCC under the conditions of desorption and wet by the axis-translation technique. It can measure pore water permeability coefficient and pore gas permeability coefficient of unsaturated soil through flexible stress control and suction path. It can measure the high pressure consolidation coefficient of unsaturated soil through the consolidation test base. It can be used to measure triaxial shear strength and volume change of unsaturated and saturated soil via the double pressure chamber and back pressure device. It can be used to measure vertical stress changes of sample by using the built-in high precision pressure sensor. Also, it can be used to test axial deformation of sample through the high precision displacement sensor.

2.3 Working principle

SPA experiment system is a kind of double pressure chamber with a built-in load sensor and axial load applied as one of the test device. It can be used to accurately measure principal stress difference and the total volume change of specimen. The inside pressure chamber is mounted within the interior chamber, and will be filled with water. The change of the sample volume will cause the changes of water level in the pressure chamber by connecting inside pressure chamber and volume change reference tube. The volume change is measured by the high precision differential pressure sensor and volume change measurement control. The high intake value clay plate is installed on sample base. And the porous plate is installed on pressure cap. The air intake and water inflow are respectively set up corresponding channels to provide matrix suction to realize pore air permeability, pore water infiltration and SWCC measurement of unsaturated soil. The matrix suction can be controlled in the range of 0.1 to 500kPa by axis-translation technique. The confining pressure can be controlled automatically by adopting the precise electric proportional valve. The total volume change can be controlled automatically by using volume change tube device. Software system can realize the real-time data acquisition and graphical display, and control the test process according to the given stop conditions.

2.4 Main technical indicators

Axial force range: 0 ~ 6 kN. Control modes: (1) the strain control with 0.002 ~ 4mm/min, control accuracy ±10%, (2) stress control with 0 ~ 6kN, control accuracy ±1%. Dimension of soil sample: Φ61.8mm x 20mm, 61.8mm x 40mm or Φ61.8mm x 120mm. Confining pressure range: 0 ~ 1.0MPa, control precision with1.0kPa. Pressure range of pore pressure controller: 0 ~ 0.8MPa, control precision with 1.0kPa. Gas volume change measuring range: 0 ~ 400ml, 1.0 mm^3 resolution. The pore water pressure controller pressure range 0 ~ 1.0MPa, control accuracy with 1.0kPa. Water change measuring range: 0 ~ 400 ml, 1.0 mm^3 resolution. Pressure range of pore pressure sensor: 0 ~ 1MPa, the control precision with1.0kPa. Displacement sensor measurement range: 0 ~ 30mm. Sample volume change range: 0 ~ 200ml. Clay plate inlet value: 500kPa and 1500kPa. Pressure chamber uses double pressure chamber structure.

3. Design of Experimental System

3.1 Precision realization of axial load, confining pressure and suction control

The axial load control technology of the experimental system based on step motor as the source of power to drive screw nut mechanism, which makes rolling diaphragm cylinder to obtain pressure, is used to apply axial load on sample by stress approaches or strain rate. Rolling diaphragm cylinder has the performance characteristics of rolling friction and low friction resistance. The precision of strain rate and stress control is greatly improved for low friction cylinder, step motor technology and built-in load sensor technology.

The electrical proportional valve which is made in Japanese company SMC is used in confining pressure control and improving pressure control precision to be less than 1kPa. The exchange between gas and water is achieved by volume change tube. The gas equaling to confining pressure enter into the interlayer of dual chamber pressure chamber. The water equaling to confining pressure enter into inside pressure chamber to apply confining pressure on sample. And at the same time, the volume of water, namely the total volume change of sample can be measured.

The electrical proportional valve of SMC Company is also used in the air volume controller, which provides the pore air pressure. The controller using the high precision pressure sensor produced in USA, controls the inlet value 1kPa precision and measure air volume change of in and out of the gas volume controller at the same by controlling back the stepping motor driven actuators. Moisture absorption control adopts stepper motor to drive screw nut mechanism, which promotes the oil cylinder to control the water pressure. So water pressure can be applied on the top and bottom of sample in constant flow or equal water pressure. The precision pressure sensors are used to control the water pressure with precision of 1kPa and the water volume with precision of 1 ml by controlling back stepping motor driven actuators.

3.2 Test control method and the realization of data transmission accuracy

The system consists of two sets of pore gas control device, two sets of pore water control device, a set of axial force of control device and the confining pressure control device. The devices can work independently according to the parameters set by the human. The system uses the computer software programming technique and software design for test method. It reduces the working strength and improves the working efficiency. Control mode of the system uses multiple computer communication technology.

The devices are organized together by the software control. The devices issue instructions, acquire data and process according to the software requirements. The character-oriented synchronization protocol is used in the instruction model to solve the communication security problem of test control. It ensures the security and integrity of system data transmission. And it avoids that distractions (such as electromagnetic) may cause information error.

3.3 Realization of volume change measurement for double pressure chamber

In order to ensure the accuracy of total volume change measurement of sample, the built-in load sensor is used in double pressure chamber structure of the system. The confining gas and water respectively enter into the isolation layer and the inner chamber of the pressure chamber to ensure that the inner pressure chamber can endure balanceable pressure and reduce the deformation. The accuracy of the volume change measurement can be carried on by calibrating confining pressure and the relationships between in and out of the water.

3.4 Implementation of sensor measurement accuracy and stability

The system adopts precision pressure sensor made in the Meas-Spea company in USA. It also uses the high impedance linear amplification and A/D conversion technology to ensure the stability and precision of the measurement requirements. The mathematical model of simple moving average method is adopted in the software to solve the stability problem of the sensor measurement data in the static measurement.

3.5 System software programming

According to GB/T50123-1999 "test procedures" and BS1377 (1990) test method, the Delphi language is used for computer control oriented programming to ensure automatic test according to the parameters of the experiment requirement. Software provides real time curve display to facilitate participants to determine whether a test process is normal.

The test data is stored in access database to ensure the reliability of the datum. After test the datum can be output in the form of Excel. The treatment method of anomalies such as power outage is designed in the software. The test will continue after connecting the datum of last test when the abnormal situation is dealt. The control parameter values in the software can be changed any time in the process of normal test. And the test will continue on the basis of the new control values.

3.6 The advanced nature of the instrument

Multifunction flexible control method used in this system, not only can accomplish triaxial tests (including UU, CU, CD test) and penetrant tests of

saturated soil, but also can complete all kinds of tests of unsaturated soil, such as triaxial shear test under the condition of matric suction control, moisture absorption test.

The system uses double pressure chamber structure with a built-in load sensor, and soil sample volume change measurement system combined with the surrounding pressure device. The axial force device uses the rolling diaphragm cylinder actuator to ensure the realization of the strain and stress control mode. The air intake value of pore air control device can reach a minimum of 2 MPa. The pore water control device can control the water pressure precision of 1kPa and flow measuring resolution of 1 ml. The clay plate at the bottom of sample base is set up the spiral groove structure to effectively eliminate the bubbles of clay accumulation at the bottom of the plate. The system uses high precision sensors to ensure the accuracy and stability of the test measurement data. The advanced communication technology is used to ensure the accurate test instructions and secure receive of data. Test method oriented programming technique, which is easy to be modified, ensures that the test can be carried on automatically according to the requirement.

4. Deformation Test Instrument

The purpose of instrument deformation test is to ensure the accuracy of the soil sample volume variation and reduce instrument deformation effect on measured result. The standard specimen rigidity is put in the pressure chamber filled with water. Then the specimen is carried on the confining pressure of 100 kPa, 200 kPa, 400 kPa, 600 kPa, 800 kPa respectively. A mathematic model of the surrounding pressure and body variables is established by measuring water change in volume change tube. The model is used to correct the volume change variables in the practical unsaturated soil test to obtain accurately total deformation of soil sample.

5. Experimental Data Analysis

The expansive soil in a highway in Hubei is used to test SWCC respectively by the British commercial GDS instrument, which is famous in unsaturated soil test, and SPA - 500 type equipment. The basic physical and mechanical properties of the soil are shown in table 1. The soil and water characteristic curves are obtained by test as shown in figure 2. The datum is fitted by the polynomial. The results show that the SPA - 500 type test data and GDS test data have good comparability. So the SPA - 500 type test data is reliable.

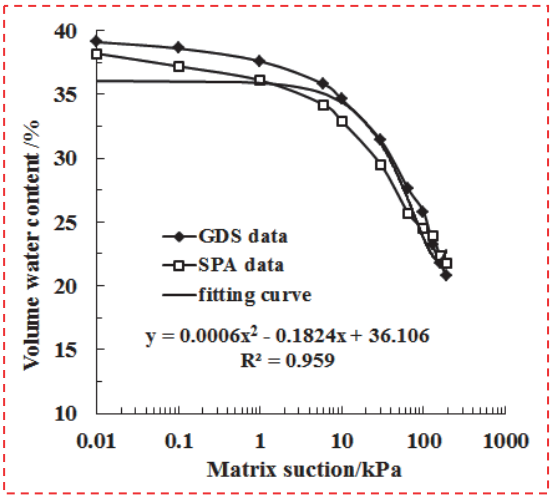

Fig. 2 Comparison between GDS data and SPA data

6. Conclusions

The system can be used to research soil and water characteristic curves relating to dry and wet stress, water and gas migration regularity of unsaturated soil under the independent triaxial stress and suction path.

The system controller uses A/D conversion technology, high impedance linear amplification technology and stepper motor drive control technology. It is able to work independently. Also it can be controlled to acquire data by computer software. It has many characteristics such as high measuring accuracy, stable control, convenient operation etc.

The system uses double pressure chamber structure with a built-in load sensor. The confining gas pressure and water pressure respectively enter into the isolation layer and the inner chamber of the

Table 1 The physical and mechanical parameters of samples

Type	ρ_d / g·cm^{-3}	w_o / %	w_p / %	w_L / %	I_P	δ_{ef} / %	c / kP$_a$	φ/°
Expansive soil	1.55	22.0	24.8	50.4	25.6	60～80	32.0	22.4

ρ_d —Dry density ; w_o — initial water content; w_p —liquid limit; w_L— plastic limit; I_P— plastic index; δ_{ef} —free expansion ratio; c —cohesive force; φ — internal friction Angle

pressure chamber to ensure that the inner pressure chamber can endure balanceable pressure and reduce the deformation. The accuracy of the volume change measurement can be carried on by calibrating the relationships between confining pressure and in and out of the water.

Test method oriented programming technology is used in the system to ensure the test automatically according to customer's parameter requirements. The test data is stored by Access database, and the system can display the data real-time graphics.

The SPA - 500 type test data is reliable based on the test results which show that the SPA - 500 type test data and GDS test data have good comparability.

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References

Agus, S.S., Leong, G.E.C. and Rahardjo, H.R. (2001) : Soil-water characteristic curves of Singapore residual soils, Geotechnical and Geological Engineering, Vol. 19, pp. 285- 309.

Bristow, K.L. (1998): Measurement of thermal properties and water content of unsaturated sandy soil suing dual-probe heat-pulse probes, Agricultural and Forest Meteorology, Vol.89, pp. 75- 84.

Chen, Z.H. (2011) :Mechanics theories and application of unsaturated soil and special soil, Journal of Logistical Engineering University, Vol. 27, No. 4, pp.1-7.

Fredlund, D.C. and Rahardjo, H.R. (1993): Soil mechanics for unsaturated soils, Canada: Jonh Wiley & Sons, Inc. Press, pp. 92- 95.

Indrawan, I.G.B., Rahardjo, H. and Leong, E.C. (2012) : Field instrumentation for monitoring of water, heat, and gas transfers through unsaturated soils, Engineering Geology, Vol. 151, pp. 24-36.

Miao, L.C. (2007): Measuring device and method for consolidation and SWCC of unsaturated soil, Chinese patent, ZL2005100382100.

Li, Z.Q., Li, T. and Hu, R.L. (2007): Property of soil-water characteristic curves for unsaturated soil, China journal of Highway and Transport, Vol. 20, No. 3, pp. 23- 28.

Watanabe, K. and Wake, T. (2009): Measurement of unfrozen water content and relative permittivity of frozen unsaturated soil using NMR and TDR, Cold Regions Science and Technology, Vol. 59, pp. 34-41.

Wulfsohn, D., Adams, B.A. and Fredlund, D.G. (1988) : Triaxial testing of unsaturated agricultural soils, J. agric. Engng Res. , Vol. 69, pp. 317-330.

Ye, W.M., Chen, B. and Bai, Y. (2005) :Soil infiltration meter, Chinese patent , ZL200510024691X.