PRELIMINARY STUDY ON SOIL-WATER CHARACTERISTICS OF MARYLAND CLAY

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Abstract: Many studies have been conducted in the past on the determination of soil-water characteristics, but there is relative little literature on the SWCC for expansive soils. Also, little attention has been give to the necessity of measuring the deformation of the soil specimen. The SWCC of Maryland expansive clay was obtained in this study by combining the suction controlled oedometer test method with the desiccator method. The laboratory test results indicate that the 'true' air entry value for an expansive soil can only be discerned from the degree of saturation versus soil suction plot. The results also show that a reduction in void ratio due to increased net normal stresses applied to the specimen leads to a higher air entry value for the soil.

1. INTRODUCTION

Damage to lightly loaded structures founded on unsaturated expansive soils has been widely reported throughout the world. The problems are particularly significant in Australia as approximately 20% of the total land area is covered with expansive soils. Expansive soil problems are present in most capital cities and regional centres of Australia. Although research into expansive soil behaviour has been carried out in Australia since the late 1950's, the majority of research has focussed on Melbourne and Adelaide regions (Walsh and Cameron 1997).

As part of a long term study into the behaviour of unsaturated, expansive soils in the Newcastle-Hunter Valley region, a field site was established in early 1993, in Newcastle, Australia. The Maryland site was selected for this study because it is typical of many new and existing residential housing estates on the eastern seaboard of Australia, where seasonally induced ground movements of between 40 and 70 mm cause significant distress to old and poorly engineered residential structures. The site has been extensively instrumented to allow soil moisture conditions and ground movements to be closely monitored. The primary objective of the Maryland field study is to collect high quality field data that can be used to check current design methods for footings on expansive soils.

The outcome of the Maryland expansive soil project has been described in a number of publications (Allman et al. 1994; Fityus et al 2004). However, the soil-water relational behaviour of Maryland clay has not been published.

This research study focuses on the laboratory tests to measure the water retention characteristics of Maryland expansive clay using a suction controlled oedometer developed by the Geotechnical laboratory of the U.P.C. (Technical University of Catalonia, Barcelona, Spain). This paper presents the preliminary results of the laboratory tests.

2. BACKGROUND

The Soil-Water Characteristic Curve, (SWCC), defines the relationship between the water content of a soil and soil suction (i.e., matric suction and total suction). The water content of the soil can be expressed in terms of gravimetric water content, w; degree of saturation, S_r; or volumetric water content, θ. The SWCC has emerged as a practical and sufficient estimation tool for obtaining many unsaturated soil property functions such as volume-change characteristic, permeability and shear strength functions (Fredlund 2006). Therefore the measurement of soil-water characteristic curve is an important test required to put unsaturated soil mechanics into geotechnical engineering practice.

There are a number of methods available for obtaining the SWCC for a particular soil. These methods can broadly be divided into direct or indirect methods. The direct methods include the use of a pressure plate, pressure membrane, or tensiometer. The indirect methods include filter paper, transistor psychrometer, thermocouple psychrometer, chiller-mirror psychrometer, thermal conductivity sensor and electrical conductivity sensor. Among these methods, the conventional pressure plate apparatus is the most common method. All of the above-mentioned methods have been developed without the ability to apply vertical or confining stress and without the ability to measure volume change of the soil specimen. These limitations place restrictions on how data can be applied in geotechnical engineering (Fredlund, 2002).

In this study, the soil-water characteristic curves of Maryland Clay soil were determined in the laboratory through use of a newly developed suction controlled oedometer in which the total net normal stress could be controlled one-dimensionally and axial deformation could be measured. For comparison, the SWCC was also obtained through use of a chiller-mirror psychrometer and filter papers. Due to space limitation, only the results obtained by the suction controlled oedometer are presented and discussed in this paper.

3. SOIL CHARACTERISTICS AND SAMPLE PREPARATION

The soil used in this study is referred to as Maryland clay. Maryland clay is a heavy clay soil that occurs naturally at the Maryland expansive soil field site near Newcastle (Fityus *et al* 2004). Maryland clay can be described as a residual soil derived from a mudstone parent rock.

While relatively uniform on a large scale, Maryland clay exhibits larger structural and compositional variability on the scale of oedometer specimens. Localised plant roots and bioturbation, shrinkage cracking with topsoil infilling and fine to medium gravels occur in undisturbed samples (Fityus 1999). To eliminate possible effects due to natural differences between the composition and structure of undisturbed samples, as well as anisotropy and non-homogeneity within individual samples, the samples used in the experiments were remoulded. The following preparation procedure was used.

- After removing vegetation and topsoil, a pit was excavated at the Maryland field site. The soil was collected from a depth of approximately 500 mm.
- After returning to the laboratory, the soil was firstly dried in an oven at a temperature of about 100^{o}C until it became non plastic and was then crushed using a Los Angeles abrasion machine.
- The crushed soil was wet sieved using a 425µm screen to remove all coarse materials and vegetable matter.
- The soil passing through the sieve was combined and thoroughly mixed in a large rotary mixer.
- The slurry was then placed into a special purpose preconsolidation cell which used air pressure acting on a rubber membrane to apply a vertical pressure to the soil.
- After consolidating for about two weeks under 100 kPa of vertical pressure, the soil sample was placed into a vacuum bag hermetically sealed and stored in a room with a relative humidity greater than 85%.

The soil was prepared in a single batch with sufficient quantity to produce all of the required samples.

The index properties for remoulded Maryland clay are summarised in Table 1. The properties are in good agreement with typical results from undisturbed soils. Based the Unified Soil Classification System, Maryland soil is classified as clay of high plasticity.

Table 1. Index properties of Maryland clay

Property	Value
Liquid Limit, w_L(%)	64
Plastic Limit, w_p(%)	24
Plastic Index, I_p(%)	40
Linear Shrinkage, LS(%)	15
Specific Gravity, G_s	2.68
Percent finer than 425µm	100%
USCS Symbol	CH

4. APPARATUS AND TEST SETUP

The testing system includes an oedometer cell designed and constructed by the Geotechnical Laboratory of the Technical University of Catalonia, a pressure control system and a diffused air flushing system. The experimental setup is shown in Figure 1 together with a schematic diagram of apparatus illustrated in Figure 2.

The pore-air pressure, u_a, was supplied to the upper coarse porous stone through a conduit in the loading cap. The pore-water pressure, u_w, was measured and controlled through a high air entry value (HAEV) ceramic disc mounted at the base of the specimen. Through use of the axis-translation technique, the soil suction imposed on the specimen is equal to the difference between the applied pore-air and pore-water pressures and is called matric suction (u_a-u_w).

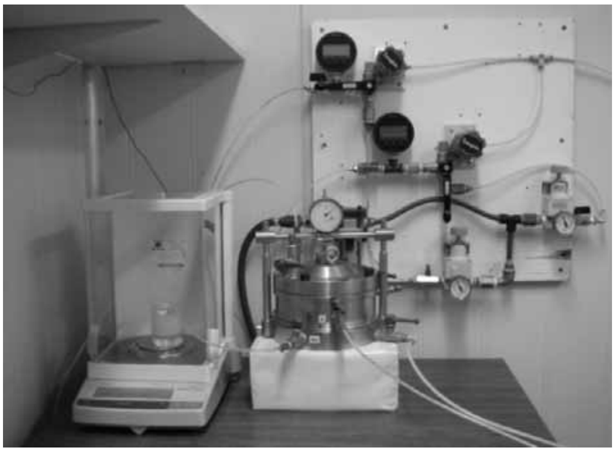

Figure 1. Experimental setup for suction controlled oedometer tests.

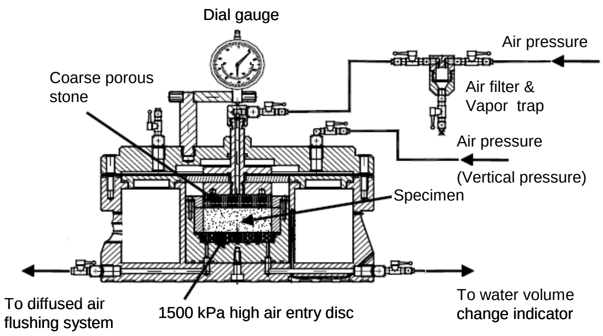

Figure 2. Schematic diagram of the UPC oedometer cell.

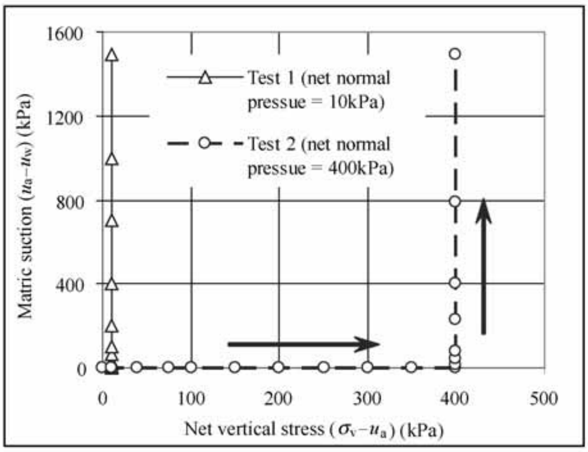

Figure 3. Oedometer test stress paths.

The HAEV ceramic disc used in this research has a rated air entry value of 1500 kPa (15 bars). A spiral grooved water compartment is located immediately below the HAEV ceramic disc for trapping and flushing air bubbles that may diffuse through the disc. Prior to each test, the HAEV ceramic disc was saturated using the procedure suggested by Fredlund & Rahardjo (1993) to resist the passage of free air at differential pressures less than the air entry value of the disc.

The vertical load was supplied by a compressed air system with air regulators. Two different loading pistons can be used. One system allows the application of a net vertical stress that is equal to the difference between piston pressure and pore-air pressure. The other system allows doubling the net stress acting on the specimen without changing the pressure on the piston. The loading chamber is separated from the pore-air pressure chamber by a 1-mm thick rubber membrane.

The pressure panel shown in Figure 1 has dual pressure regulators and gauges for maintaining high accuracy in both the low and high pressure ranges. This system allows the control of pressure to within a resolution of 1 kPa. The compressed air system used for testing is capable of producing pressures up to 2000 kPa. Dry compressed air bottles with a maximum working pressure of 4000 kPa have been connected to the air pressure line as a backup. If source pressures lower than 1800 kPa are detected (which is the case of an electrical power failure), the check valve connected to the gas bottles will be activated. Two air filters and vapour traps were also installed in the air pressure line.

The water released (or absorbed) from the specimen is measured using a water volume change indicator connected to the HAEV ceramic disc. In order to obtain accurate readings of water volume change, the oedometer tests were conducted in a constant temperature room at 20^{o}C.

A dial gauge with a resolution of 1 μm was used to measure the vertical displacements of the soil specimen. The size of specimen that can be accommodated in this oedometer cell is 50 mm in diameter and 20 mm in height.

5. TESTING PROCEDURES

The testing program (still in progress) included 4 oedometer tests at different net normal pressures. Two tests have been performed while the two other tests are still running. The stress paths followed during oedometer tests are shown in Figure 3. Only the desorption branch of the soil-water characteristic cure was measured in this study.

After the pre-consolidated soil sample was carefully trimmed to size and placed into the oedometer cell, the target net normal pressure (10 kPa for test 1 and 400 kPa for test 2) was applied gradually to the specimen and kept constant through the test. To determine the SWCC, the matric suction was increased to 1500 kPa progressively in 8-12 steps. As the suction increased, water was expelled from the specimen. The flow of water from the soil specimen into a marked burette was monitored at regular time intervals. Each applied suction value was maintained until equilibrium was achieved. Equilibrium conditions were assumed when no flow was observed in the burette for a minimum period of 10 hours.

Each oedometer test on Maryland clay usually required a period of at least 4 weeks. This long test period makes it possible for air to diffuse from the pressurised side the HAEV ceramic disc to other side through the liquid phase in the saturated disc. The accumulation of diffused air beneath the ceramic disc can introduce an error in water volume change measurement and reduce the hydraulic conductivity of the disc. Therefore air diffusion is a common and important problem which must be addressed when testing unsaturated soils. It should be noted that not only diffused air must be periodically removed from the compartment beneath the HAEV disc but also the volume of diffused air needs to be measured as the measured water volume changes must be corrected for the volume of diffused air.

Several devices have been developed to measure the volume of diffused air during unsaturated soil testing. The details of these devices can be found in Fredlund & Rahardjo (1993). In this research, a simple system is used to flush the diffused air from the oedometer cell. First, a known amount of de-aerated water was measured by using a high accuracy balance (readable to 0.0001g). The water was added to a burette connected to the water inlet on the base plate. A pressure gradient of up to a maximum of 20 kPa was then applied to flush water containing air bubbles from the compartment below the high air entry disc into a vessel placed on an electronic balance with a resolution of 0.0001g (Figure 1). The water volume equivalent to the volume of diffused air bubbles was measured as the difference between the mass of water added to the burette and the mass of water flushed out from the base plate compartment. The volume of diffused air was computed by applying the ideal gas law and considering the pressure gradient (Fredlund & Rahardjo 1993). The temperature corrections are not necessary as all the tests were carried out in a constant temperature room.

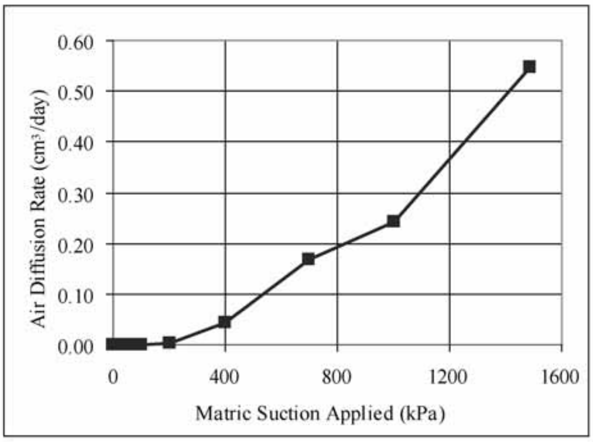

Figure 4. Air diffusion rate through 1500 kPa *HAEV ceramic disc.*

During each test, the suction-controlled oedometer cell was flushed once a day when the applied matric suction was less than 300kPa and twice a day when the matric suction range was 300 kPa to 1500 kPa. The air diffusion rates at different applied matric suction were computed after each flushing. Figure 4 shows the air diffusion rates obtained from Test 1. It can be seen that air diffusion through the ceramic disc is essentially negligible when the imposed matric suction did not exceed 400 kPa. Generally the rate of air diffusion increases with the applied matric suction.

Corrections to intermediate water volume change readings were made using a linear interpolation of diffused air flow with respect to time. A typical example is shown in Figure 5. The upper curve represents the uncorrected amount of water released from the specimen under an imposed matric suction of 1485 kPa and the lower curve represents the real water volume change after a correction for diffused air has been applied. The amount of diffused air was about 2.8 cm^3 after 5 days, which is higher than the corresponding amount of water flowing from the specimen during the test. This result emphasised the importance of frequent flushing when testing unsaturated soils.

The maximum matric suction allowed for the oedometer testes was limited to the air entry value of the HAEV ceramic disc (i.e.,1500 kPa). However, for expansive clays, the actual SWCC curves might extend well beyond the 1500 kPa limit. In most cases, the water content of the soils can generally be assumed to correspond to matric suction or total suction when the suctions are greater than 1500 kPa (Fredlund 2002). In other word, for a particular soil, the low suction range up to 1500 kPa represents matric suction and the high suction range beyond 1500 kPa represents total suction on the same graph. This gives the complete SWCC of the soil.

In this study, the suction range above 1500 kPa (i.e., total suction) was obtained by using a vacuum desiccator apparatus and a Dewpoint Potentiometer (WP4). Once the oedometer test was completed and the final mass and volume of the soil specimen were determined, the oedometer specimen was placed into a vacuum desiccator over the salt solutions for about 4 weeks. Immediately after being removed from the desiccator, the height and diameter of the specimen was measured using a digital vernier caliper. The suction of the specimen was then determined by a Decagon WP4 Dewpoint Potentiometer which uses the chilled-mirror dewpoint technique to measure total suction. The WP4 was calibrated using a 0.5 Molal/kg solution of potassium chloride as per the guidelines provided by the manufacturer. The accuracy of the WP4 is given by the manufacturer as ± 0.1 MPa for the suction range of 0 to 10 MPa and ±1% for the suction range of 10 to 40 MPa (Decagon, 2002).

6. EXPERIMETAL RESULTS AND INTERPRETAION

The SWCC of Maryland clay in terms of gravimetric water content and degree of saturation are plotted in Figures 6 and 7, respectively. The suction values above 1500 kPa were the total suctions obtained using the WP4. The data has been extrapolated to the extreme point (shown as dashed lines) by assuming that fully dry soils (i.e., zero water content or zero degree of saturation) has a suction of around 1,000,000 kPa. This value is supported by experimental evidence and theoretical thermodynamic considerations (Fredlund *et al* 1994).

As can be seen from Figure 6, at the beginning of applying matric suction, the soil specimen from Test 2 exhibited a lower initial gravimetric water content. This reduction in water content was attributed to a higher net normal stress of 400 kPa applied during Test 2. As the matric suction increased, the gravimetric water content of both specimens decreased but at different rates. The higher the applied net normal stress, the lower the desaturation rate of the specimen. However, as the suction increased to higher than 600 kPa, the two curves tend to converge.

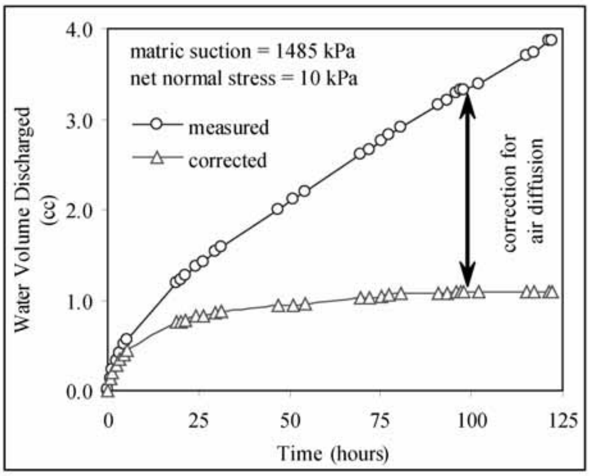

Figure 5. Water volume change versus time (applied matric suction = 1485 kPa*).*

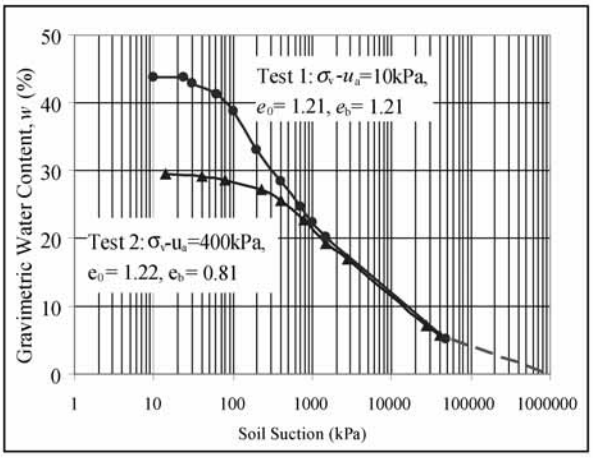

Figure 6. Gravimetric water content versus soil suction for Maryland clay.

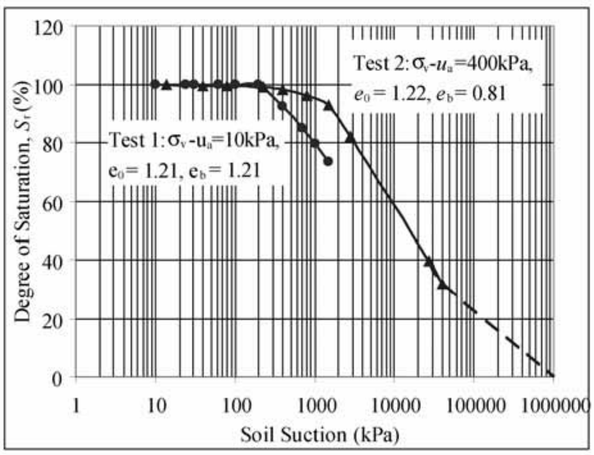

Figure 7. Degree of saturation versus soil suction for Maryland clay.

Compared to the results for non-expansive soils, the shape of the SWCC for Maryland clay shown in both figures is relatively flat, which indicates that expansive soil possesses a high water retention capability.

Figure 7 shows that the soil remained saturated up to a large value of suction for both cases although a significant reduction in the water content has occurred as shown in Figure 6. This can be explained by the fact that the amount of water draining out of the soil during drying from saturated conditions was accompanied by a corresponding reduction in the void ratio of the soil.

An increase in the air-entry value of the soil with increasing net normal stress is evident in both Figure 6 and Figure 7. However, it is believed that this increase depends mainly upon the void ratio, e_b (or density) of the soil at the beginning of applying the suction and not directly upon the stress state (Sun *et al* 2007). In other words, the smaller e_b (i.e., the denser the soil), the higher the air-entry value.

The interpretation of the SWCC for a low volume change soil such as sand and silt is based on the assumption that changes in void ratio approach zero and changes in water content becomes the sole function of relevance. Consequently, the soil-water characteristic curves in terms of gravimetric water content or degree of saturation essentially provide the same information (Fredlund 2002). However, the interpretation of the soil-water characteristic curves data for an expansive soil undergoes appreciable volume change following a change in soil suction. The differences in the interpretation of the data are clearly illustrated by the presented results. From Figures 6 and 7, it can be seen the plot of gravimetric water content versus soil suction and the plot of degree of saturation versus soil suction give different air-entry values for the same specimen. For Test 1, the air-entry value estimated from the degree of saturation plot (Figure 7) is 200 kPa, approximately four times higher than that estimated from the gravimetric water content plot (Figure 6). A similar difference can be observed from Test 2. In other words, the 'true' air-entry value for an expansive soil can only be discerned from a plot of the degree of saturation versus soil suction.

7. PERLIMINARY CONCLUSIONS

Based on the laboratory test results presented, the following conclusions can be drawn:

- Frequent flushing and the measurement of the diffused air volume are required during a suction controlled oedometer test for imposed matric suctions higher than 300 kPa.
- The degree of saturation versus soil suction plot, (not the gravimetric water content versus soil suction plot), should be used to interpret the soil-water characteristic curve for unsaturated soils.
- A reduction in void ratio due to a higher net normal stress applied to the specimen leads to a larger air-entry value for the soil.

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