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Volume Change Measurements for Unsaturated Soils in Triaxial Equipment with Double Wall Cell

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ABSTRACT

The paper gives a brief description of double wall cell triaxial equipment for testing soil samples under unsaturated conditions and presents results of some of the calibrations necessary to achieve accurate measurements of inner cell water volume, pore water volume, pressure, load and displacement. The calibration of the measurement devices showed linear relationships between the raw readings and applied values with the regression constants differ from 1 and 0. The result of apparent volume change calibrations showed significant correlation between cell water volume fluctuation and temperature fluctuation inside testing room. A correction to the measured volume was therefore required to reduce the effects of long-term temperature fluctuation on the measured volume. Investigation of the accuracy of volume change measurement with the double wall cell showed excellent matching between the inner cell volume change and pore water volume change under saturated conditions, indicating the high reliability of the double wall system for apparent volume change measurements.

Keywords: Unsaturated Soils, Double Wall Triaxial Cell, Volume Change Measurement

قياس التغيرات الحجمية للترب غيرالمشبعة باستخدام خلية فحص الانضغاط الثلاثي المحاور ذات الجدار المزدوج

الخلاصة

يعطي البحث وصف مختصر لجهاز فحص الانضغاط الثلاثي المحاور لاجراء اختبارات على ترب غير مشبعة ويصف البحث مجموعة من المعايرات الضرورية لضمان قياسات دقيقة لحجم الماء في

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الخلية الداخلية وحجم الماء الموجود في الفجوات ومقاييس الضغط والحمل والازاحة العمودية. تشير نتائج المعايرة الى علاقة خطية بين القيم المسلطة الحقيقية والقيم المقروءه وان معاملات الانحدار الخطي مختلفة عن صفر و واحد. تشير معايرة التغير الحجمي الظاهري الى علاقة وثيقة بين التغير الحجمي وتغير درجة حرارة غرفة الاختبارات. لذلك اقترح معامل تصحيح لتقليل تذبذب درجة الحرارة. يشير تحري دقة قياس التغير الحجمي باستخدام تقنية الخلية الداخلية الى توافق كبير مع التغير الحجمي المقاس باستخدام حجم ماء الفجوات في حالة الاشباع مما يؤكد موثوقية القياس باستخدام هذه التقنية.

INTRODUCTION

Under unsaturated conditions the pores are partly filled with liquid (usually water) and partly filled with gas (usually air). In order to conduct a triaxial test on a soil specimen under unsaturated condition, two measuring/ controlling techniques have to be provided, related to suction and sample volume change (where suction is commonly defined as the excess of pore air pressure over the pore water pressure).

Suction can be controlled/ measured by various techniques including axis translation technique (commonly used for suctions less than 1500 kPa), osmotic control of matric suction (suction range depends on the concentration of the solution used but can be up to several MPa) and relative humidity control by using saturated salt solution (reliable for suction values higher than 10 MPa). The axis translation technique was proposed by Hilf (1956) [1] and involves elevating total stress, pore water and pore air pressures by the same amounts so that pore water pressure translates from negative to positive ranges. This technique is the most widely used technique to control matric suction during one-dimensional and triaxial compression tests because it is relatively easy to modify oedomenter or triaxial equipment to conduct tests under unsaturated conditions. The modification involves replacing the coarse filters of the top cap and base pedestal by high air entry filters and providing a source for air pressure.

Ideally, sample volume change, under unsaturated condition, could be obtained simply by summing pore air and pore water volume changes. Practically, measurement of pore air volume change, in contrast to measurement of pore water volume change, can be highly inaccurate because of the high compressible of the air and the effect of temperature fluctuation. Over the last four decades several techniques were proposed to measure/control total volume change of the specimen rather than measuring pore water and pore air volumes separately. Among those techniques are measuring the flow of fluid into or out of the cell (e.g. Wheeler, 1986 [2]; Sivakumar, 1993 [3]; Raveendiraraj, 2009 [4]), measuring axial and radial deformations (Clayton et al., 1989 [5]) or using techniques such as laser (e.g. Romero et al., 1997 [6]) and image processing (e.g. Rojas et al., 2012 [7]) to obtain sample deformation.

To measure sample volume change using the inflow/outflow of the water, many considerations must be taken into account such as the expansion of the cell with pressure increase (immediate and creep volume changes), the absorption of water by the wall (especially if the wall is made of acrylic [2]) and the effect of room temperature fluctuation on the volume measurements. Wheeler (1986) [2], based on the original design of Bishop and Donald (1961) [8], constructed a double wall cell (with inner and outer cells) and by applying the same pressure to both cells, it was then possible to prevent the expansion of the inner cell wall and therefore it was possible to measure sample volume change. However, the design had a few shortcomings such as that the inner cell was made of acrylic which absorbs water and that the inner cell top plate was not enclosed by the outer cell which allowed deformation to occur and hence caused some errors in volume measurement.

DOUBLE WALL TRIAXIAL CELL

The testing equipment was built by the company VJ Tech Ltd and consisted of a double wall triaxial cell (based on the work by Sivakumar et al., 2006 [9]), controlling and measuring devices and data acquisition system. The version of the double wall cell see Figure (1) included a major improvement of changing the material of the inner cell to high quality glass to eliminate water absorption by the acrylic wall as reported in Wheeler (1986) [2] and Sivakumar (1993) [3] and the inner cell is completely enclosed by the outer cell. The equipment is capable of testing soil specimens in both triaxial compression and in triaxial extension and, indeed, it was used by the authors to conduct a comprehensive testing programme to investigate the influence of evolving anisotropy on yielding and critical states of unsaturated soils (see Al-Sharrad et al., 2012 [10] and Al-Sharrad, 2013[11]).

Pedestal and top cap

The base pedestal and top cap were designed by the authors and manufactured by the VJ Tech Ltd (the design of the base pedestal is shown in Figure (2). To achieve efficient pore air drainage and pore water drainage and to achieve accurate volume change measurements, the design involved the following features:

a. Pore air drainage is arranged through the pedestal so that only a short PTFE tube connection was needed see Figure (1) and the amount of diffused air into cell and the effect of tubing compressibility on volume measurement during loading/ unloading stages could therefore be minimized.
b. A spiral flushing groove (2 mm width and 2 mm depth) is used see Figure (2) for the pore water drainage connections on both pedestal and top cap. This arrangement has two advantages; firstly, it increases water conductivity by providing sufficient contact between the high air entry ceramic filter and the water in the drainage lines; secondly, it provides higher efficiency in removing any trapped air beneath the ceramic filter as a single flushing path and no sharp corners are present in the water flow path during flushing.

c. Both base pedestal and top cap were made of stainless steel and stainless steel filter holders were attached to them by screws. Glued within each filter holder is a high air entry ceramic filter with an air entry value of 500 kPa.
d. In order to maintain good distribution of air pressure at the sample base, a porous annulus made of sintered brass is positioned on a shoulder set within the pedestal filter holder. An "O" ring is placed in a groove between the spiral flushing groove on the pore water drainage lines and the air line outlet in order to prevent any air leak to the water drainage line, see Figure (2).

LOGGING AND CONTROL SYSTEM

All pressure, volume, displacement and load transducers were connected to corresponding input channels of a data logger through a system of data cables and interfaces. The data logger communicated with the software "Clisp Studio" (developed by VJ Tech Ltd). In the software, a test can be divided into several stages i.e. suction equalization, loading, wetting, shearing, etc. with different parameters defined for each stage.

CALIBRATIONS FOR THE MEASUREMENT DEVICES

All measurement devices were already calibrated by the manufacturer in terms of pressure, volume or displacement against measured voltage. These calibrations were stored in the data logger and pressure/volume controllers. However, a decision was made to treat all the readings as raw readings and perform a new calibration, in the lab, of these raw readings of pressure, volume or displacement in order to confirm the accuracy and to identify suitable correction factors if necessary. Generally, all calibrations showed linear relationships between the raw readings and applied values. that can be expressed as:

$$\text{Corrected value} = A * \text{raw reading} + B \quad \ldots (1)$$

Where:

A and B are regression constants and their values were found to be different from 1 and 0 respectively, indicating that correction must be applied to the raw readings to obtain the actual values.

CALIBRATION FOR THE APPARENT VOLUME CHANGE

A double wall triaxial cell was used to ensure accurate measurement of overall sample volume change by measuring water flow into or out of the inner cell. To conduct a suction controlled test by using the axis translation technique, it is possible to set the cell pressure to a certain value and change the pore air pressure and pore water pressure as required. With this choice the accuracy of the measurement can be greatly enhanced by eliminating sources of error that are caused by variation of cell pressure.

Volume measurement can be affected by any of the following sources of error:

1. Compression of occluded air in the measuring system which increases with the increase in the pressure level. The rate of compressibility is decreasing with increase in the time under a constant pressure.
2. Compressibility/expansion of the water and parts of the system such as fittings, "O" rings, etc. which is proportional to the pressure level.
3. Diffusion of water through the flexible tubes which increases with increase in pressure difference across the tube's wall.
4. Temperature variation in the testing room which causes oscillations in the volume measurement due to the expansion or contraction of water in the measuring system.
5. Movement of the loading ram inside the inner cell.

Before the tests, the sample volume change measuring system was therefore calibrated for time dependency and temperature variation effects. Similarly, it was necessary to calibrate the pore water volume change measuring system for time and pressure dependent effects.

The above calibration included all parts of the testing system that could affect measurement of sample volume change and pore water volume change during an unsaturated triaxial test. During calibration, almost the same arrangement as in a real test was reproduced (a brass dummy cylindrical sample was placed but with the top cap and pedestal ceramic filters both replaced with acrylic stoppers). Cell pressure and pore water pressure were increased to target values of 900 kPa and 800 kPa respectively at a rate of 30 kPa/minute. Cell pressure was then kept constant over the calibration period. Once the volume change rate was stabilised (usually after 2-3 days), the pore water pressure was decreased by step changes to 600,400, 200 and 100 kPa. The variation of pore water volume was monitored and recorded for a period of 2-3 days under each pressure. The pore water pressure was then increased to 200, 400, 600 and 800 kPa following the same manner described above.

Figure (3) shows the variation of the inner cell volume against elapsed time. The variation of the inner cell volume against time could be separated into two parts; the first part represents the immediate changes in volume due to the application of the cell pressure whereas the second part represents the time dependent change in volume. It could be noticed from Figure (3) that the immediate volume change stabilized after approximately one day. In a real test, it was therefore decided to wait one day between pressurization of the cell and the first stage (usually suction equalization). The apparent fluctuation in the measured volume change reflected the effect of temperature variation on volume measurement. During the course of inner cell volume change calibration, pore water pressure was decreased in step change from 800 to 100, though, no evidence of any cell volume change was noticed during this process.

The variation of the pore water volume change against elapsed time is shown in Figure (4). The discontinuities in the plot refer to the instantaneous volume changes due to pressure change. On the pore water drainage line the rates of volume change at

Constant pressure was changing monotonically from -0.008 cm^3/day to 0.008 cm^3/day for pore water pressures decrease from 800 kPa to 100 kPa.

The decrease in the rate of volume change with the decrease in pore water pressure (under a constant cell pressure) can be explained with reference to the water/air diffusion and any creep expansion of the flexible tubes as set out in the next paragraph.

In terms of water diffusion through the PTFE tubes of the pore water drainage, the rate of inward diffusion to the pore water drainage line (from the water in the triaxial cell), for the sections of drainage line inside the cell, is expected to increase with decreasing pressure in the pore water drainage line. In addition, for the sections of drainage line outside the cell, the rate of outward diffusion from the pore water drainage line (to the atmosphere) is expected to decrease with decreasing pressure in the pore water drainage line. In terms of air diffusion, water inside the drainage tubes and the cell were of the same quality (de-aired), therefore no air diffusion was expected through the tubes inside the cell. On the other hand, air diffusion was expected to occur from the atmosphere to the section of pore water drainage line outside the cell, because the water inside the tube was not air-saturated. In terms of any creep expansion of the PTFE tubes, the drainage tubes inside the cell were expected to contract (external loading condition) whereas the drainage tubes outside the cell are expected to expand (internal loading condition). The positive rate of pore water volume change under 100 kPa, which indicates an increase in the volume of water inside the volume gauge, refers, therefore, to the net effect of these sources. The rate of pore water volume change under a constant pressure during the pressure increase steps was slightly less than the corresponding rate during the pressure decrease steps suggesting that the amount of air that came out of solution in the pressure decrease cycle is less than the original amount of air that went into solution during the first pressure increase.

Figure (5) shows the immediate changes in pore water volume after a change of pressure. If the volume change after initial pressurization of the cell is ignored (initial volume change is indeed ignored during a real test as the majority of the drainage lines are initially pressurized to 800 kPa) it is then possible to approximate the volume changes caused by both pressure decrease and increase by a single line.

CORRECTION FOR TEMPERATURE FLUCTUATION

The temperature control unit was set to maintain the temperature of the testing room at 21^{o}C with a tolerance of ±0.5^{o}C. As well as normal oscillations, additional fluctuations in room temperature were also observed when a rapid change in temperature occurred outside the room. Figure 6 shows the variation of the inner cell volume together with temperature variation. As it can be seen, volume change fluctuations were strongly correlated to temperature fluctuations and a correction for these fluctuations was therefore applied. It was observed that the application of a temperature correction could result in eliminating most of the errors in volume measurement caused by long-term changes in temperature but it could equally produce new small unwanted short-term oscillations in volume measurement (caused by small

Rapid fluctuation of temperature recorded by the temperature gauge, which did not reflect the average temperature of the water in the cell). A correction factor of 0.75 $cm^3/^oC$ was found adequate to eliminate most of the effect of changes in temperature. This correction factor produced about ±0.1 cm^3 oscillation in the inner cell volume change measurement which corresponded to approximately ±0.001 error in the measured specific volume.

CALIBRATION FOR LOADING RAM INTRUSION IN THE INNER CELL

Vertical movement of the loading ram during the application of the deviator stress implied a corresponding increase or decrease in the inner cell water volume due to the intrusion of the loading ram see Figure (1). Calibration for this effect was carried out by increasing the ram displacement at a given rate and measuring the corresponding change in the inner cell water volume. Figure (7) shows the change in the inner cell water volume against the axial displacement along with the best fit line. The calibration factor was 0.4948 cm^3/mm. The accuracy of the linear calibration was found to be ±0.03 cm^3.

INVESTIGATION OF THE ACCURACY OF VOLUME MEASUREMENTS IN THE DOUBLE WALL CELL

The accuracy of the sample volume change measurements was investigated by testing a saturated compacted sample in the double wall cell and comparing the measured sample volume change using the flow into the inner cell (with the various calibrations and corrections) against measured pore water volume changes. This was done during isotropic loading stage. Figure (8) shows the variation of specific volume with mean effective stress during isotropic loading stage. Inspection of this Figure indicates excellent matching between the two measurement techniques. This investigation confirms that the testing equipment for the unsaturated tests gave high quality volume change measurements.

CONCLUSIONS

The use of a double wall triaxial cell with a glass inner cell allowed accurate measurement of the sample volume change under unsaturated conditions. Proof of the excellent quality and repeatability of volume change measurement was confirmed by the very close similarity of the volume change measurements of a saturated soil sample achieved by this technique and by conventional measurement of the pore water inflow or outflow. An effective design of the pore water drainage and flushing system was adopted, particularly the spiral shaped groove beneath the HAE filters. The method of controlling radial net stress and suction (i.e. holding cell pressure constant while varying pore air pressure and pore water pressure as necessary) resulted in highly accurate measurements of sample volume change.

REFERENCES

[1]. Hilf, J.W., "An investigation of pore-water pressure in compacted cohesive soils", Tech. Memo., 654. U.S. Bureau of reclamation, Design and construction Div. Denver, USA, 1956.

[2]. Wheeler, S.J., "The stress-strain behaviour of soils containing gas bubbles", DPhil Thesis, University of Oxford, UK, 1986.

[3]. Sivakumar, V., "A critical state framework for unsaturated soil". PhD thesis, University of Sheffield, UK, 1993.

[4]. Raveendiraraj, A., "Coupling of mechanical behaviour and water retention behaviour in unsaturated soils", PhD thesis, University of Glasgow, UK, 2009.

[5]. Clayton, C.R.I., Khatrush, A.S., Bica, A.V. D. and Siddique, A, "The use of Hall effect semiconductors in geotechnical instrumentation", Geotechnical Testing Journal, 12(1):69-76, 1989.

[6]. Romero, E., Facio, J.A., Lloret, A., Gens, A., Alonso, E.E., "A new suction and temperature controlled triaxial apparatus", Proceedings of the 14th International Conference on Soil Mechanics and Foundation Engineering, Hambourg, 185-188, 1997.

[7]. Rojas, J.C., Gallipoli, D. and Wheeler, S.J., "Image analysis of strains in soils subjected to wetting and drying", Geotechnical Testing Journal, 35 (1):60-73, 2012.

[8]. Bishop, A.W. and Donald, I.B., "The experimental study of partly saturated soil in the triaxial apparatus", Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering, Paris,1, 13-22, 1961.

[9]. Sivakumar, R., Sivakumar, V., Blatz, J. & Vimalan, J., "Twin-cell stress path apparatus for testing unsaturated soils". Geotechnical Testing Journal, 29(2), 1-5, 2006.

[10]. Al-Sharrd, M., Wheeler, S. and Gallipoli, D., "Influence of Anisotropy on Yielding and Critical States of an Unsaturated Soil", Proceedings of the 2nd European Conference on Unsaturated Soils, Napoli, Italy, 2, 129-136, 2012.

[11]. Al-Sharrad, M.A., "Evolving anisotropy in unsaturated soils: experimental investigation and constitutive modeling", PhD thesis, University of Glasgow, UK, 2013.

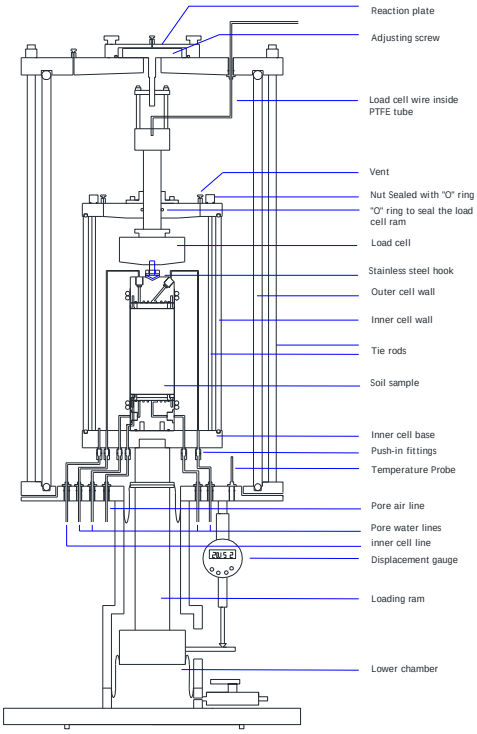

Figure (1) Schematic diagram and photograph of the Double wall cell apparatus.

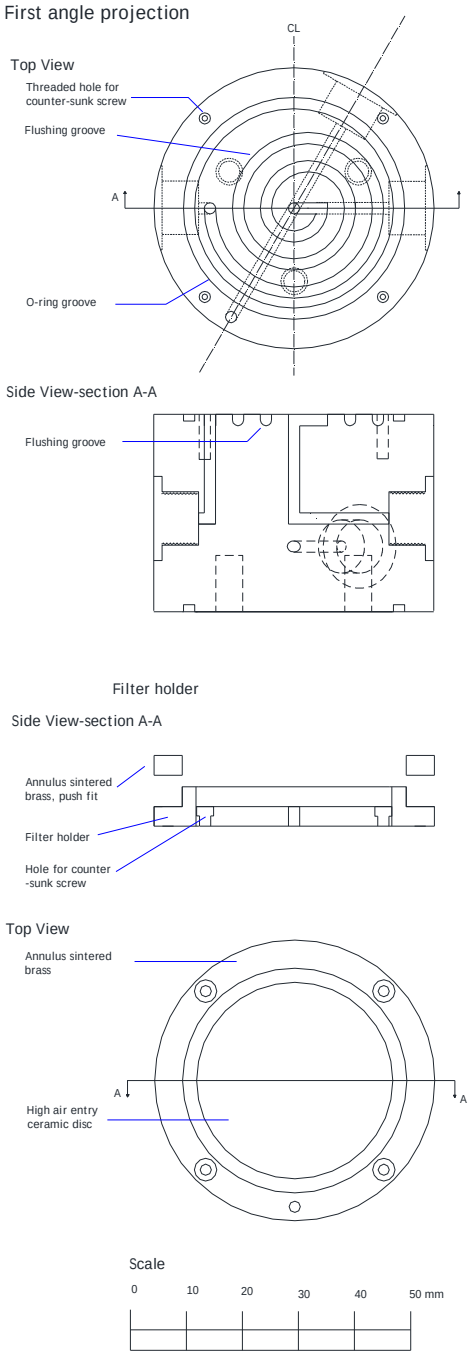

Figure (2) Base pedestal design.

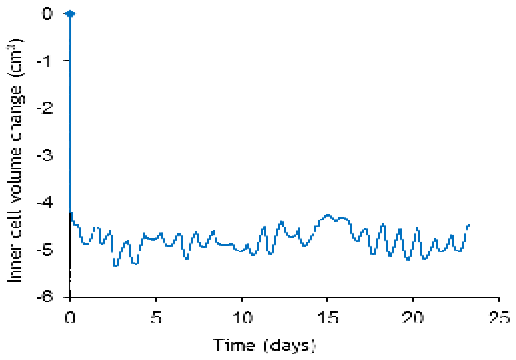

Figure (3) Variation of the inner cell volume Against elapsed time.

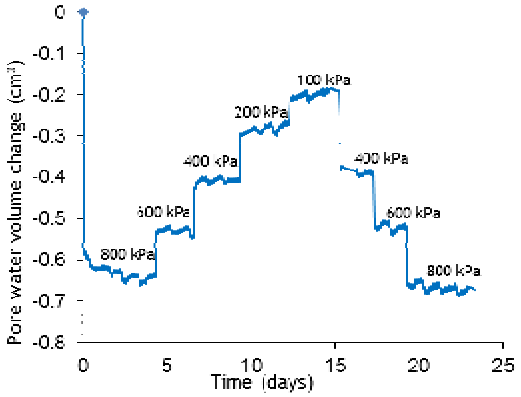

Figure (4) Variation of the pore water volume change against elapsed time.

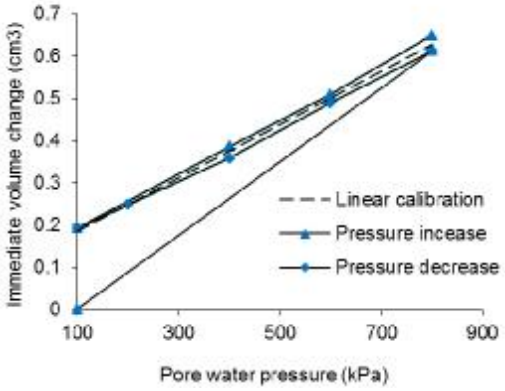

Figure (5) immediate pore water volume change Against pore water pressure.

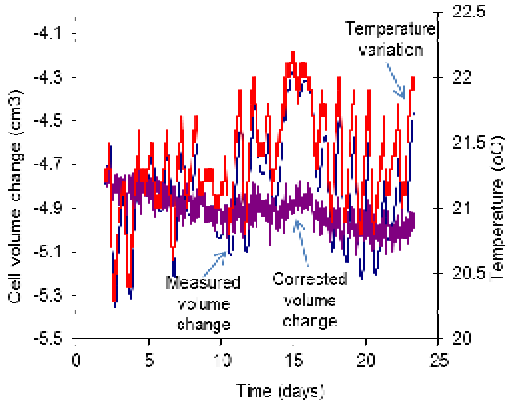

Figure (6) Variation of measured and corrected Volume change with time

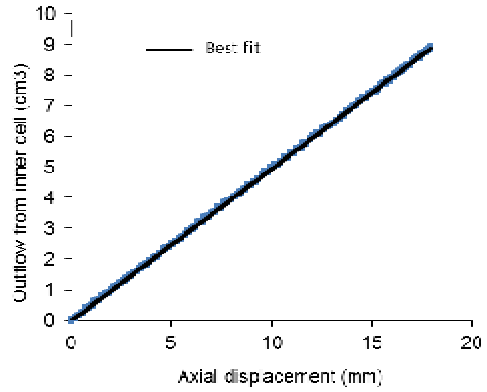

Figure (7) Calibration for stroke intrusion.

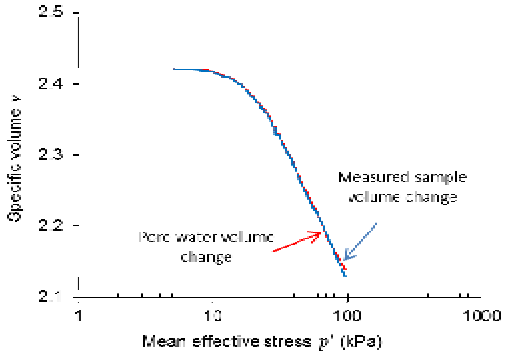

Figure (8) Sample of volume change and pour water Volume change of a saturated sample.