A Double Cell Triaxial System for Unsaturated Soils Testing

Joao Mendes, David G. Toll, and Fred Evans

Abstract. The presence of different pore fluids present in unsaturated soils (water and air) complicates the measurement of sample volume change. Since volume change of the air phase is difficult due to the compressibility of the fluid, it becomes necessary to measure sample volume change by measuring the change in volume of water in the surrounding triaxial cell. This paper introduces and assesses a new double cell triaxial cell developed by Wykeham Farrance. The design of the new triaxial system is similar to the Wheeler modified triaxial cell (Wheeler, 1988) but uses a glass inner cell wall, to avoid problems of absorption of water by Perspex. Furthermore, the cell has been designed to use a high capacity suction probe that can be fitted through the base pedestal. Issues of de-airing the cell and the accuracy of volumetric measurements that can be achieved are discussed in the paper.

Keywords: unsaturated soils, volume measurements, soil suction.

1 Introduction

The traditional method for sample volume change used in triaxial testing of saturated soils involves measuring the pore fluid that leaves or enters the sample. This is no longer sufficient in an unsaturated soil as water volume and sample volume

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are not linked. To monitor volume change of unsaturated samples the simplest arrangement is to monitor the volume of the fluid (i.e. water) that leaves or enters the triaxial cell (Bishop & Donald, 1961). If a single wall Perspex cell, i.e. the traditional triaxial system, is used this indirect method to monitor the volume of fluid is not reliable due to volume variations in the Perspex part of the cell. These changes are due to cell volume changing with cell pressure, water absorption and thermal expansion (Wheeler, 1988) as well as creep of the cell under constant cell pressure. Although small, these changes still impose significant errors. In this paper a new double cell triaxial system is presented that can be used for triaxial testing of unsaturated soils.

2 The Design of the New Double Cell Triaxial Cell

To overcome the difficulties when using a traditional triaxial cell, a double cell is preferred, such as is shown in Figure 1, developed by the Wykeham Farrance Division of Controls Testing Equipment Ltd. The cell volume resulting from changes in cell pressure is greatly reduced by having two cells since the inner cell is subject to equal pressures on both sides of the cell wall. The Wykeham Farrance (WF) design is similar to the Wheeler cell (Wheeler, 1988). However, the WF double cell system differs from the Wheeler cell by having an interior cell wall made of glass instead of Perspex; with the intention to eliminate the water absorption by the wall of the inner cell. The WF equipment is double celled (rather than doubled walled), meaning that the top cap of the inner cell is also subjected to equal pressures inside and out. In earlier designs a double walled cell was trialled, where a common top cap was used for inner and outer cells. It was found that extensions of the tiebars produced volume changes that could affect results.

The biggest difference between the new system and other testing systems found in the literature is the ability to install a DU-WF high capacity suction probe in the pedestal in order to measure matric suction, as shown in figure 2. Since suction probes can cavitate during testing, the pedestal was designed to allow the user to remove/insert the probe while a test is underway. Information on the suction probe design and operation can be found in Lourenco et al (2006) with specific information about the use with the new double cell triaxial cell given in Mendes (2011).

The dimensions of the double cell triaxial cell are presented in table 1 and the cell components are shown in Figure 1b) and c). The inner cell can accomodate samples with diameters from 38mm up to 100mm. The loading ram passes through both outer and inner cell tops; there is no need for separate outer and inner ram arrangements, as is needed in some other systems.

Table 1. Dimensions of the double cell triaxial cell.

Height	41.6	cm
Inner cell inner diameter	19	cm
Inner cell outer diameter	20	cm
Outer cell inner diameter	22.35	cm
Volume of water in the inner cell	11795	cm^3
Volume of water in the outer cell	3252	cm^3

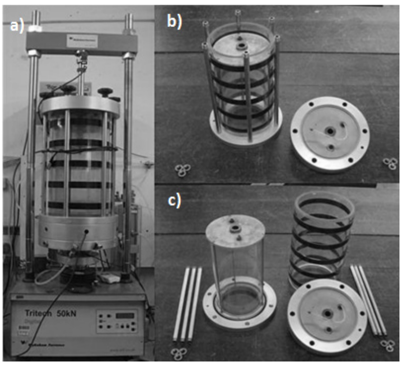

Fig. 1. Wykeham Farrance double cell triaxial system a) fully assembled, b) without outer cell top cap and c) view of the inner cell.

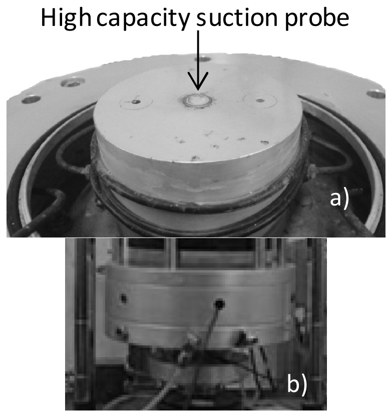

Fig. 2. a) Close up view of the 100mm pedestal on the triaxial frame, b) Access to remove/insert the probe below the cell base

3 Calibration of the New Double Cell Triaxial Cell

Calibrations were preformed on the WF double cell triaxial cell for creep under a constant pressure. The inner and outer cells were filled with de-aired water and afterwards a constant pressure of 600kPa was applied in both cells. The pressure was maintained for an extended period (weeks) to observe and quantify possible creep of the inner cell. Later, pressure cycles were performed to verify the volume changes due to pressure changes. A volume gauge of the rolling bellofram type device developed at Imperial College was used for the measurement of volume water exchanges in the inner cell (Maswoswe, 1985), while the confining pressure was imposed by a stepper motor driven hydraulic pump built by Wykeham Farrance. No specimen was used during testing.

A full view of the test can be observed in figure 3. During the tests it was observed that at a constant pressure of 600 kPa there was a small flow of water entering the inner cell ranging between 0.0016 to 0.0027 cm^3/hour and during the total duration of the test (almost 3 months) a total volume increase of 2.5cm^3 was observed inside the inner cell.

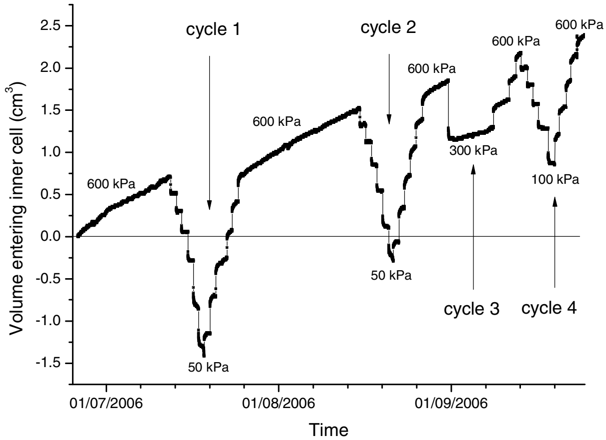

Fig. 3. Volume changing of the inner cell as a response to pressure.

Pressure cycles were performed by changing the pressure initially starting from 600 kPa, then decreasing in increments of 100 kPa down to 100 kPa with a further reduction of 50 kPa and then increasing back to 600 kPa at the same rate. These cycles had the intention of observing the reaction of the cell to pressure changes but also to attempt to estimate the flow rates for other pressures. During the pressure cycles a fixed flow rate was not achieved as the cell did not reach an equilibrium state; however, the flow rates generated were extremely low reaching a maximum 0.0042 cm^3/hour for a confining pressure of 400kPa during the 4^{th} cycle. Nevertheless, the creep effect observed on the double cell triaxial cells was found to be minimal, as low as 0.0008 cm^3/hour reaching a maximum of 0.0042 cm^3/hour. During triaxial testing this creep effect would have: during 3 months of testing at constant pressure a maximum increase of the measurement by 9 cm^3 and, during 24 hours (such as a shearing stage) a maximum increase by 0.1 cm^3. When compared with the volume of sample with 100mm in diameter by 200mm in height (1571 cm^3) this represents an error of 0.6% for the period of 3 months and as low as 0.006% for 24 hours.

The calibration also included the effect of volume changing due to the penetration of the loading shaft into the inner cell. The piston was pushed inside the inner cell increasing its volume inside the inner cell. The load cell was lowered by 8mm inside the inner cell at a rate of 0.05 mm/min and maintaining a constant pressure of 1500 kPa, as presented graphically in Figure 4. This meant that, considering the diameter of the shaft of the load cell as 25 mm, where each millimetre of travel from part of the piston represents an increase 0.49 cm^3, a displacement of 3.93 cm^3 of water exiting the inner cell should have been observed. In fact, the measured volume was slightly higher, 4.24 cm^3, resulting in a difference of 0.31 cm^3.

The volume was measured using a volume gauge using a bellofram seal where, for a good operation of this system, it is necessary to ensure that no air bubbles are trapped inside. It is possible that the differences between measured and expected values in Figure 4 could be related with the performance of the volume gauge itself, perhaps due to poor de-airing. Another factor could be the change in direction of the volume gauge. When the cell is being pressurised, the water flow will be entering the cell. However, when the loading piston is entering the inner cell at a constant pressure, the flow of water will be exiting the cell and this change could explain why the volume gauge lags in response. In summary, the change in direction of the water flow could possibly result in the differences between the predicted and measured values. In any case, the observed changes in volume were minimal.

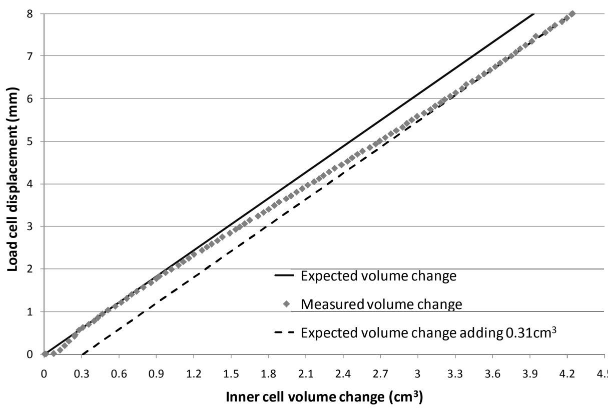

Fig. 4. Volume change originated by the displacement of the load cell entering the inner cell.

4 Other Observations about the WF Double Cell

One important deficiency encountered while testing with the WF double cell was the design of the top caps in both the inner and outer cells. It was found that a substantial volume of air was always trapped in the top of both cells when filling the cell. Applying a small vacuum at the top of the inner cell during filling can help with removing air bubbles, but it does not remove them entirely. Since the volumetric measurement is made indirectly, having air bubbles trapped will affect greatly the obtained results. However, if the cell is pressurised the air bubbles are compressed and eventually dissolve in the water. The effect of the air bubbles was observed during calibration. In Figure 3 the volume was still changing inside the cell at a constant pressure of 600 kPa even after a month period. This could mean that the air bubbles were still being compressed into solution even after such a long equalisation period. Nevertheless, providing the pressure remains constant through the test the effects of initial air bubbles on the volumetric measurement can be neglected. To overcome the problem of air being trapped an intermediate solution is to pressurise the cell while maintaining the sample net stress close to zero so no deformation (consolidation) of the sample can occur.

Initially it was intended to use only one hydraulic pump to pressurise both cells. However, some increase in pressure in the outer cell was observed when the load cell was entering the inner cell. This increase in pressure in the outer cell, while maintaining the pressure constant in the inner cell endangered the glass wall of the inner cell. To avoid failure of the glass wall, both cells were separated by a valve and a second pump was installed. The cause of the pressure rise in the outer cell was not fully identified, but it was thought to be due to sticking of the volume gauge allowing a differential pressure to build up between the pressure at the base of the gauge (feeding the outer cell) and the top (feeding the inner cell).

5 Conclusions

In this work a new double cell triaxial system developed by Wykeham Farrance (Controls Equipment Testing Ltd) was assessed. The double cell arrangement enables more accurate measurement of the volume change of samples when carrying out tests on unsaturated soils. The observed creep developed at constant pressure was found to be minimal for long and short duration triaxial tests as was the influence of the volume changes generated by the load cell movement inside the inner cell. However, problems were encountered with the design of top caps of both cells (inner and outer) where air can be easily trapped; this can be minimized by pressurizing the cell and sample (so net stress remains equal to zero) in order to dissolve the air into water.

Two features makes the Double Cell Triaxial System a suitable piece of equipment to carry out triaxial tests on unsaturated samples: (i) the wall of the inner cell being made in glass eliminated the water absorption problem identified in cell walls built in Perspex and (ii) the placement of a high capacity suction probe in the pedestal enabled pore water pressure measurements directly in the sample which could be replaced during testing if the device cavitated.

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