Unsaturated triaxial testing

Introduction

Research in testing techniques and equipment design for unsaturated soils is being carried out in many parts of the world. In Europe, the European Commission has set up a Research Training Network. "Mechanics of Unsaturated Soils for Engineering" (MUSE) of which Wykeham Farrance is an Industrial partner. From this research, equipment and techniques may be challenged, therefore it is advisable to contact the Wykeham Farrance technical department for further developments in the subject.

General information

In many, if not most, parts of the world, soils exist in an unsaturated state. This is particularly true in tropical and arid regions, but even in temperate climatic zones soils exist above the ground water table and remain unsaturated.
Unlike a saturated soil, where all the voids between the soil particles are filled with water, an unsaturated soil contains both air and water within the soil voids. The presence of surface tension forces at the interface between air and water within an unsaturated soil allows different pressures to exist in the air and the water. In an unsaturated soil in the field, the pore air pressure is usually at atmospheric pressure and the pore water pressure is lower than the air pressure.
Since atmospheric pressure is normally treated as zero pressure, then the pore water pressure becomes negative (since it will be less than atmospheric) and is generally called "suction" since, if the soil is put in contact with water at atmospheric pressure, it will suck water into the soil.
The unsaturated layer can extend to great depths, which is governed by environmental conditions. The value of suction is what determines the strength of the unsaturated material. It is when this suction changes that unsaturated soil can behave differently to that expected of a saturated soil.

Application

Testing of soil in an unsaturated state with measurement of suction is vital to understand soil behaviour properly. For example, in collapsible soils the change in moisture content can produce a sudden reduction in volume and also have a dramatic effect on the strength of the material.
Some examples of field situations where unsaturated soil conditions must be seriously investigated are listed below:

- **Rainfall-induced landslide**

Slopes may stand at steep angles when they are supported by suctions as these impart additional shear strength to the soil.
When rain infiltrates the slope, the suctions reduce and the slope falls due to a loss of shear strength.

- **Swelling soils**

The volume change of expansive soils is controlled by the suction changes that take place as a result of water ingress. Swelling causes differential movements in structures, which can cause extensive cracking.

- **Collapsing soils**

Loose clayey soils may be held in a loose, stable state by the presence of suction. If water penetrates the soil the suction is reduced and the loose fabric can become unstable. Large volume reductions can take place suddenly and these cause disruption and damage to structures.

Main features

- ***High air entry stones cemented into the base pedestal***
- ***High capacity suction transducer for direct measurement (up to–1000 kPa)***
- ***Double wall triaxial cell for correct volume change measurement 70–100 mm specimen dia.***
- ***The operator can select between two methods of testing:***
  - ***Axis translation using elevated air back pressure***
  - ***Direct suction measurement***

The fundamental difference between the triaxial testing of a soil sample in a saturated condition compared to an unsaturated condition is that the behaviour of the saturated soil is controlled entirely by total stress and pore water pressure (through effective stress). The positive pore water pressures are pushing the soil particles apart and hence reduce the strength of the soil.
In an unsaturated soil both air and water fill the voids, and surface tension forces create a negative pore water pressure (or suction). This suction pulls the soil particles together and increases the strength of the soil.

WF 17420

Double wall triaxial cell for unsaturated tests on 100 mm samples complete with 6 ports

In the traditional triaxial systems, where saturated samples are tested, the volume change measurement is a simple monitoring of the water entering or leaving the sample by a volume change transducer.

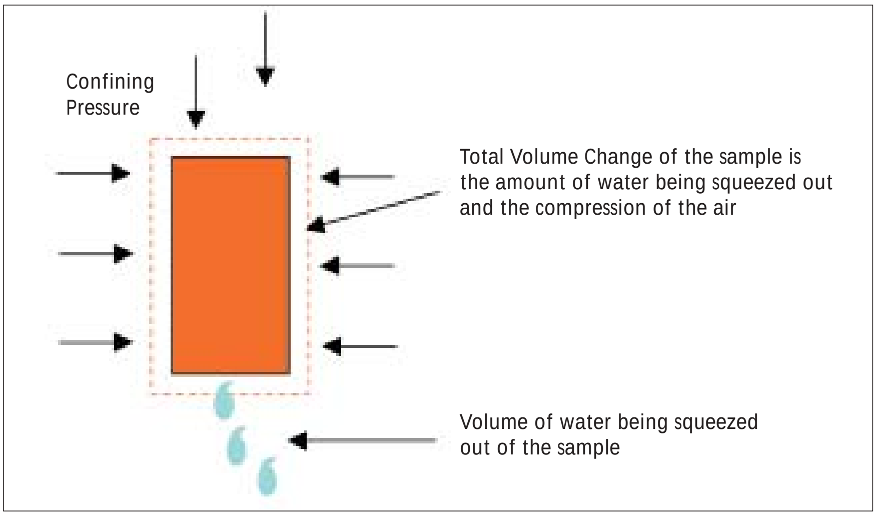
On the contrary, in the unsaturated systems volume change measurements are complicated by the compressibility of air. If an increase of confining pressure is applied to an unsaturated sample, a movement of water out of the sample will occur but at the same time the size will change due to the compression of the air in the voids.

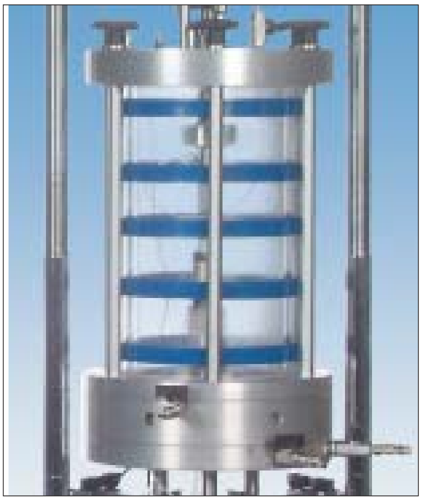
A correct measurement requires the volume of water leaving the sample and the total volume change of the sample as shown in the sketch. With these two measurements, by difference the volume change due to water being squeezed out of the sample and the volume change due to the compressibility of air can be determined.

A double walled triaxial cell can be the solution: the same pressure inside and outside of the inner cell wall will produce zero expansion of the inner cell and allow to measure the total volume change from a volume change transducer inserted in the cell pressure line.

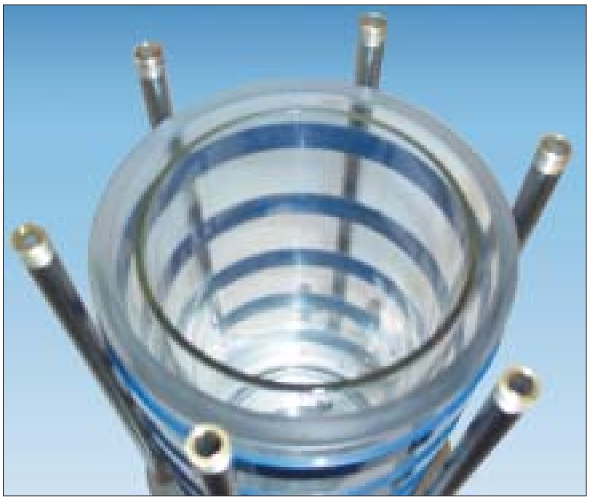
The inner wall of the cell above is made from glass: this eliminates the problem of water absorption.

The cell pressure is applied equally to the inside and outside of the glass wall: this eliminates the problem of expansion.





WF 17420



A double wall triaxial cell for 70 mm dia samples is also available (Code WF 17410)

Accessories for double wall triaxial cell WF 17410	Accessories for double wall triaxial cell WF 17420
WF 17411 Base Pedestal for 70 mm sample with High Air Entry Stone	***WF 17421*** Base Pedestal for 100 mm sample with High Air Entry Stone
WF 17412 Base Pedestal for 70 mm samples Suction Transducer	***WF 17422*** Base Pedestal for 100 mm samples Suction Transducer
WF 17413 Top Cap 70 mm for Unsaturated Cell	***WF 17423*** Top Cap 100 mm for Unsaturated Cell

4. Unsaturated triaxial testing *(continued)*

General description of the test apparatus

High air entry stone

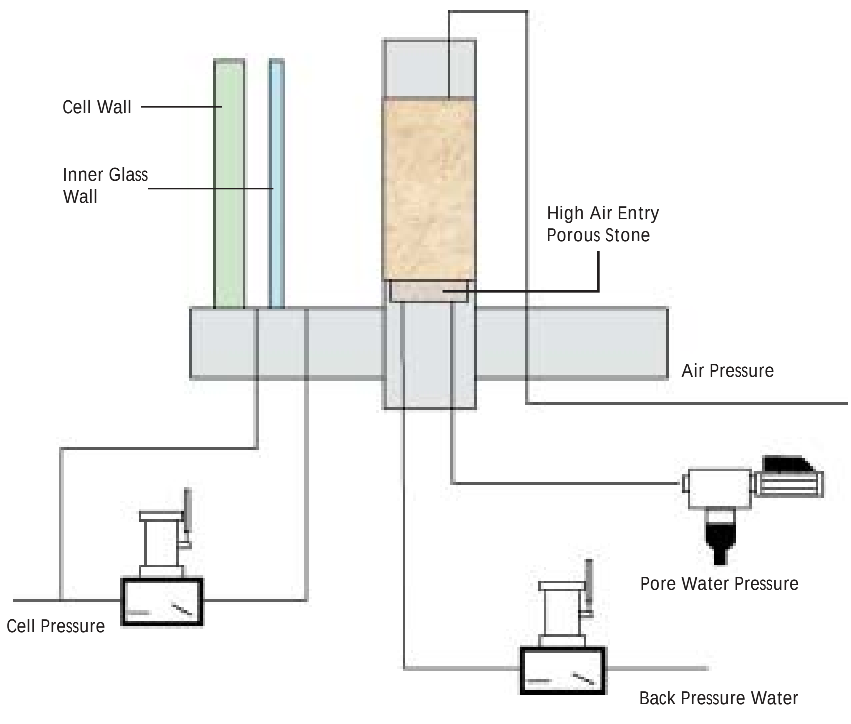
One of the problems when a sample with a high suction is to be tested, is to prevent the sample from sucking the water from the porous stone on the base pedestal and cause cavitation in the triaxial cell pore water measuring system.
To prevent this happening the porous disc has been replaced with a high air entry stone, cemented into the base pedestal. The high air entry stone will allow water to pass through but not air at various values. For example, a 5 bar stone will not allow air under 5 bar pressure to pass through the stone.

Cavitation is the major problem in the triaxial cell

To stop this happening and to enable the suction to be measured, an air pressure is applied to the pore space in the sample. Suction is caused by the surface tension forces providing a difference in pressure between the air and the water pressure. If the air pressure is zero (atmospheric) then the water pressures will be negative. If we increase the air pressure in the pore space the water pressure will also increase, keeping the difference between the air and water pressures the same. The air pressure is increased until the water pressure becomes positive. The suction is still maintained because the water pressure is still lower than the air pressure.

The air pressure is applied via the top cap (in the same way as a water back pressure in a saturated test) at about 200 kPa below the air entry value of the porous stone. This will raise the pressure inside the sample to a positive value and in turn will apply a positive pressure to the porous stone and the pore water pressure transducer. The difference between the air back pressure and the pore water pressure is the value of suction in the sample. This test method is generally known as “the axis translation method”. This method is usually applicable on compacted soils.

Schematic of Axis Translation system



Base pedestal showing pore pressure parts without high air entry stone

WF 17062

High capacity soil suction transducer, 1 MPa soil tensiometer

Wykeham Farrance has developed a Suction transducer that will measure suctions as low as –1000 kPa and can be placed into the base pedestal so that direct suction measurement can be obtained without having to raise the sample air pressure, which in an in-situ state is at atmospheric pressure.
Using the WF suction transducer mounted in the base pedestal gives the user the option and the ability to try the two methods of testing unsaturated samples:

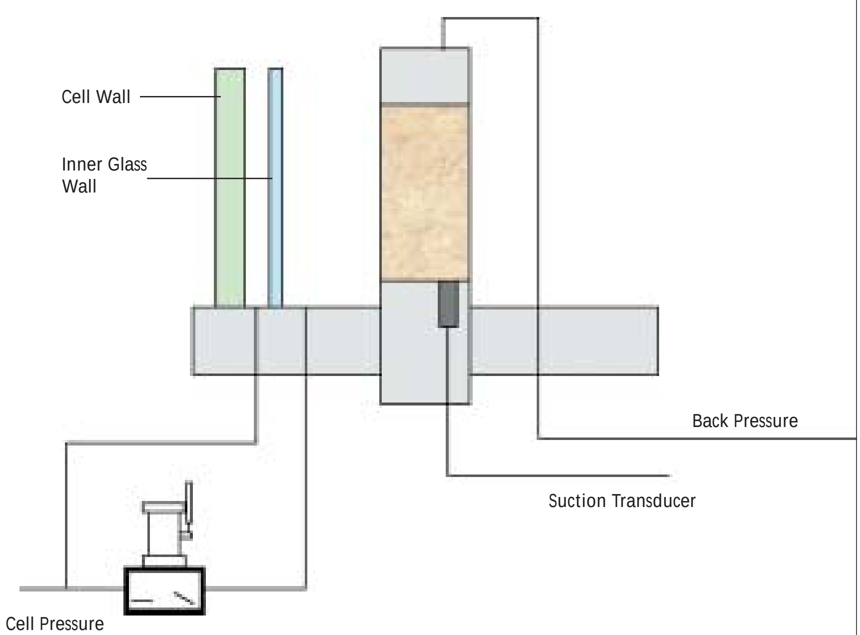
- The axis translation using elevated air back pressure
- The direct suction measurement.

The benefits of this method are:

- Soils can be tested in a state where the sample pore air pressure is at atmospheric pressure and the pore water pressure is negative
- Unsaturated Samples can be tested in the in situ condition.

Pedestal showing the hole for suction transducer. Two access for high air entry stones

Schema of Direct Suction Measurement



WF 17062 Suction transducer

4. Unsaturated triaxial testing *(continued)*

To produce the correct test conditions for the unsaturated soil sample, we must be able to:

- Control the pore air pressure within the sample (independently of the pore water pressure)
- Deal with the negative pore water pressure (or suction) within the sample during test
- Successfully measure the volume change of the sample

The specific test apparatus is a Double wall triaxial cell (models WF 17420 and 17062), which has to be used with a standard triaxial system.

Unsaturated stress path system with provision for permeability tests. It includes 3 pressure controllers, 3 volume change and on air control valve