Options available for UNSAT

Sample sizes

38mm ✓   50mm ✓

70mm ✓   100mm ✓

Custom ✓

Available air entry values

300kPa ✓   500kPa ✓
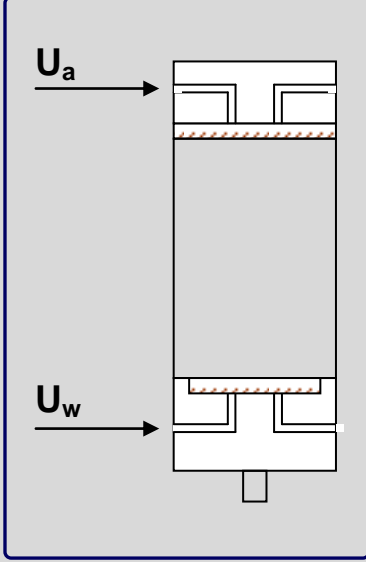
1500kPa ✓   Custom ✓

Volume change measurement methods

Direct air measurement ✓

HKUST inner cell ✓

Double cell ✓

On-sample measurement ✓

Method A: Can be used with the following systems,
- Triaxial
- Consolidation
- Back Pressure Shear Box.

Unsaturated Triaxial Testing of Soil (UNSAT)

What is it?

GDS Unsaturated Triaxial Testing of Soil (UNSAT) is an extension to traditional triaxial testing in that soils from above the water table may be tested under conditions approaching the in-situ stress state and degree of saturation or partial saturation. All features and methods described in this datasheet can be used to upgrade GDS triaxial testing systems to enable the testing of unsaturated soil, or existing triaxial equipment from other manufacturers may be modified.

The required changes to upgrade a typical GDS triaxial testing system consists of software and hardware elements. Some of the hardware elements are optional. These optional elements are made available to add further rigour to the test procedures if this is required (for example mid-plane suction probe, atmospheric pressure transducer and local measurement of strain).

How is it configured?

The GDS UNSAT provides a number of state-of-the-art methods to allow flexibility in the method used to perform unsaturated testing.

The 4 main methods that GDS uses are as follows:

- **method A:** direct volume measurement using a GDS pore air pressure/volume controller
- **method B:** HKUST inner cell
- **method C:** double cell
- **method D:** on-sample strain transducers

Each of these methods is described in detail over the following pages.

Technical specification

Method A
Resolution of measurement of pore pressure/volumes (air & water): pressure = 0.2kPa, volume = 1cu mm
Accuracy of measurement of pore pressure/volumes (air & water): pressure = <0.1% full range, volume = 0.25%

Method B
Operational resolution of volume change measurement using 16 bit resolution: <10mm^3
Accuracy of volume change measurement: estimated at 32mm^3 or 0.04% volumetric strain for a triaxial specimen 38mm in diameter, 76mm in height.

Method C
Resolution of measurement of cell volume: 1cu mm
Accuracy of measurement of cell volume: 0.25%

Method D
Resolution of on-sample displacement measurement using 16 bit data acquisition +/- 3.0mm = <0.1µm
Accuracy: Hall Effect = 0.8% FRO, LVDT = 0.1% FRO

Means for measuring total volume change

When testing unsaturated soils it is necessary to establish the total volume change of the test specimen. This can be achieved using the following techniques:

- control/measure the air and water pressures and volume changes directly within the test specimen. This involves using a special GDS pressure/volume controller to control the air pressure and air volume change in the test specimen. A second controller is used to control the pore-water pressure and volume change. The sum of the volume changes from these two controllers gives the total volume change in the test specimen. This method is known in this datasheet as **method A**.

- measure the change in head of water in an inner cell around the sample and a reference tube using a low range, high accuracy differential pressure transducer. This method is known in this datasheet as **method B**.

- measure the cell volume change and use this to establish the total specimen volume change. This technique is usually not very satisfactory because the cell stiffness is not infinite and therefore specimen loading changes and cell pressure changes cause a volumetric change in the cell. However, using a double cell and pressurising the outer cell to the same pressure as the internal cell, the internal cell wall can effectively be made to be infinitely stiff. This system needs excellent temperature stability. Small changes in temperature cause large changes in the volume of the cell water. This method is known in this datasheet as **method C**.

- Measure the local diameter and axial deformation directly on the test specimen using our Hall Effect or LVDT local strain transducers. From the measurements of local strain it is possible to estimate the total volume change of the test specimen. This method is known in this datasheet as **method D**.

High-air-entry porous disk

When testing unsaturated soils it is necessary to separate the pore-air and the pore-water so that differential pressures (known as matric suctions) can be maintained. This separation is achieved by the use of high-air-entry porous discs (HAEPD).

When a HAEPD is properly saturated it has the ability to maintain an air pressure on one side higher than the water pressure on the other side, without the air passing through the material. The maximum difference that can be held between these pressures is known as the 'air-entry value'. In a GDS system the HAEPD is bonded into the base pedestal (see Fig. 1). Other 'special' pedestals are available such as a HAEPD bonded into a bender element pedestal (see Fig. 2).

Fig. 1 HAEPD bonded into a standard triaxial pedestal

Fig. 2 HAEPD bonded into a bender element triaxial pedestal

GDSLAB 4D UNSAT software module

The GDSLAB UNSAT software module (see Fig. 3) provides the control and data acquisition of a general multiple stress path routine. This is a four dimensional stress path to enable simultaneous control of the pore air, pore water, radial and axial controllers.

The ability to control the pore air and pore water pressures enable the following tests to be carried out:

- desaturation ramps

- soil-water characteristic curve

- drained test saturated conditions
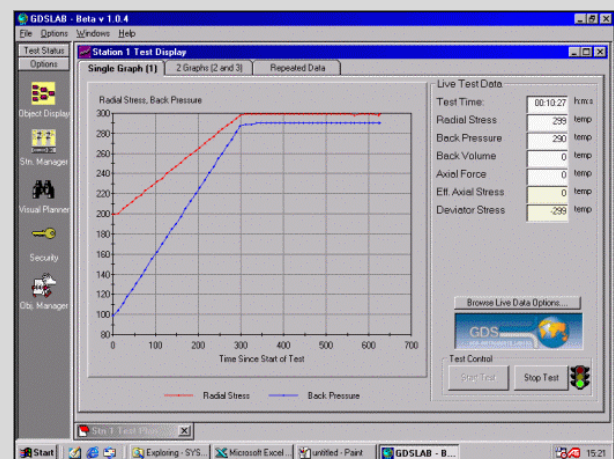
- drained test unsaturated conditions

Fig. 3 Test display showing a 4D unsaturated stress path test in progress

Method A – direct volume measurement using a GDS pore air pressure/volume controller

How is it used?

For direct volume measurement, a special GDS 1000cc/2MPa digital pressure/volume controller filled with air is used to control the pore air pressure and measure pore-air volume change. In addition, a GDS advanced 200cc/2MPa digital pressure/volume controller filled with de-aerated water is used to control the pore water pressure (back pressure) and to measure the pore water volume change. By calculation of the combined pore-air and pore-water volume changes the total volume change of the test specimen can be evaluated.

Pore air pressure is connected to the top of the test specimen (see Fig. 4), and is always at a higher value than the pore water pressure connected at the base. This enables the top porous disk to be standard as water cannot pass into the air line due to the higher pressure of the air. Air cannot pass into the water line due to the HAEPD. The air pressure and water pressure are maintained at different values to generate the 'matric suction' value present in unsaturated soils.

Axial force

Pore air pressure (Ua)

"Normal" porous disc

High-air-entry porous disk (HAEPD)

Pore water pressure (Uw)

Fig. 4 Schematic of test specimen connections when using GDS Method A

The advanced 2MPa/1000cc air pressure/volume controllers.

The GDS air pressure controllers are 1000cc/2MPa devices. Mechanically, they are identical to the normal GDS pressure controller for de-aerated water. The built-in control software (or firmware) for the controllers has been specially designed to cater for the much lower stiffness of air (e.g. see Adams, Wulfsohn and Fredlund, 1996 – contact GDS for a copy of this paper).
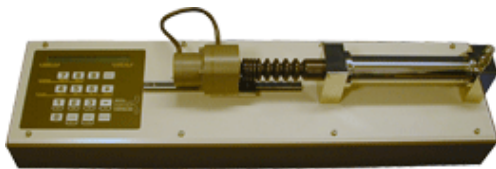

Fig. 5 2MPa/1000cc air pressure/volume controller

The following points should be noted when using air pressure controllers.

- The air pressure range is 2MPa with regulation to 1kPa. The volumetric range is 1000cc with regulation to 1cu mm (i.e. 0.001cc).
- The controllers have been specifically designed for controlling air pressure. This is because the pressure-seek algorithms built into the programming of the controller is different for air (which is very soft) from the algorithm used for water (which is very much stiffer than air).
- The controllers can be run up from zero pressure provided there is sufficient volumetric capacity in the controller. The 1000cc version is essential here. Alternatively, the controller could be pre-pressurised using a source of compressed air. This would "save" volumetric capacity used up in pressurising the air from zero.
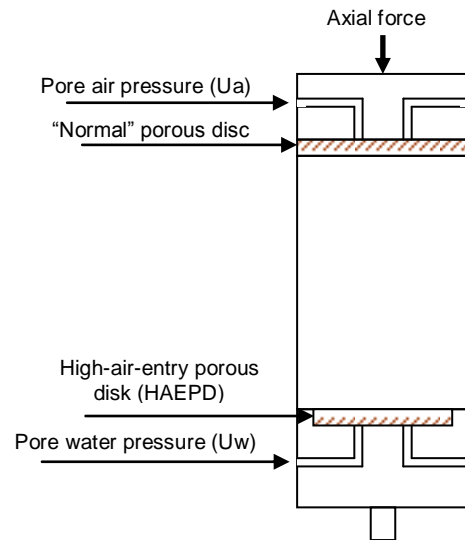

Method A technical specification

Advanced 2MPa/1000cc air pressure/volume controllers
- **Pressure ranges**: 2MPa
- **Volumetric capacity (nominal)**: 1000cc
- **Resolution of measurement and control**: pressure = <0.1% full range, volume = 0.5cu mm
- **Accuracy of measurement**: pressure = <0.1% full range, volume = 0.25%

Items required for Method A UNSAT upgrade
- Pedestal with bonded HAEPD
- GDS 2MPa/1000cc air pressure/volume controller
- GDSLAB 4D UNSAT software module

Optional Items required for Method A upgrade to Method D
- Local strain (Hall Effect or LVDT)
- Atmospheric air pressure transducer
- Access ring for triaxial cell

Method B – HKUST inner cell volume measurement

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

The HKUST (Hong Kong University of Science and Technology) volume change measurement method involves measuring the cell volume displaced by the sample in an inner cell within the main triaxial cell (see Fig. 6). Measurement of the volume change is made using a high accuracy differential pressure transducer (DPT). This enables the cell volume change to be measured from just the inner chamber thus minimizing the error due to temperature and pressure changes.

A GDS dual channel software controlled pneumatic regulator is used to control a) the cell pressure in both the inner and outer cell cavities and b) the pore air pressure in the sample.

The inner chamber containing the triaxial sample (see Fig. 7) is connected to a reference tube via the DPT (see Fig. 8). As the sample deforms it will displace water in the inner chamber causing the water level to rise or fall. By measuring the pressure in the inner chamber with respect to the pressure in the reference tube, it is possible with the correct calibration factor to determine the volume change in the inner chamber, and therefore the volume change of the specimen.
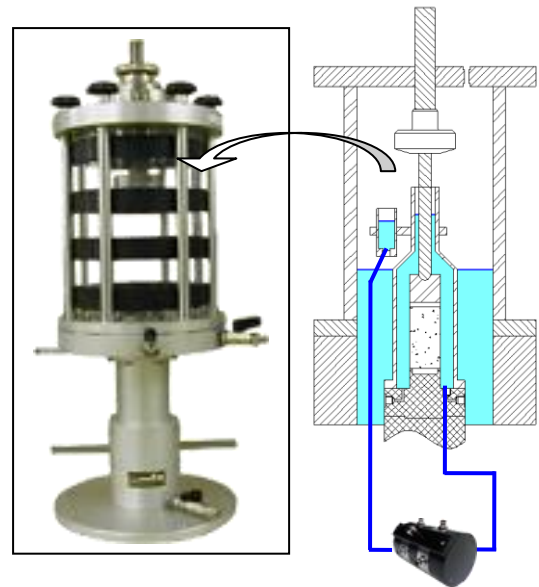

Fig. 6 Schematic of HKUST method showing external DPT

Fig. 7 HKUST inner cell

Fig. 8 High accuracy DPT attached to cell

Method B technical specification

- **DPT range**: +/- 1.5kPa (+/- 150mm of water head)
- **DPT accuracy**: <0.2% of full range output (FRO)
- **Operational resolution of volume change measurement (16 bit resolution)**: <10mm^3
- **Accuracy of volume change measurement**: estimated at 32mm^3 or 0.04% volumetric strain for a triaxial specimen 38mm x 76mm

Items required for HKUST UNSAT upgrade
- HKUST pedestal with bonded HAEPD
- HKUST pedestal with bonded HAEPD
- High accuracy, low range DPT
- GDSLAB 4D UNSAT software module
- Dual channel pneumatic controller (laboratory air supply or compressor required)
- Cell access ring

Method C – double cell volume measurement

The volume change in the soil specimen is measured by monitoring the flow of water into or out of an internal triaxial cell using a GDS pressure/volume controller. The inner triaxial cell wall, top and base are made to be infinitely stiff due to the fact that the cell is positioned inside a second triaxial chamber exerting an equal pressure on the outside faces of the internal triaxial cell (see Fig. 9).

The principal of the double cell volume change measurement is similar to method A (earlier in this datasheet). Method A can also measure the specimen volume by measuring the change in cell volume, and uses this measurement as a secondary measurement of sample volume change. However, large errors may be introduced not only by the expansion of the triaxial cell but, more importantly, by the time dependant creep that occurs with Perspex pressure vessels. The time dependency of the creep makes it extremely difficult to accurately calibrate for in the test results.

Attempts have been made in the past to produce stiffer triaxial cell walls (i.e. stainless steel) and to produce a double walled cell. The stainless steel cell is heavy and non-transparent and will still be exposed to some deflection effects. The double walled cell has the advantage of an infinite stiff cell wall, but the cell top and base may not be sufficiently restrained. For these reasons, a double cell, i.e. 'a cell within a cell', is generally considered the best system to use when performing tests with Method C.

Fig. 10 shows the double cell setup with two GDS controllers. Fig. 11 shows an alternative, lower cost setup whereby the inner and outer cell pressures are applied using a single device, and an external volume change device is used to measure the inner sample volume change.
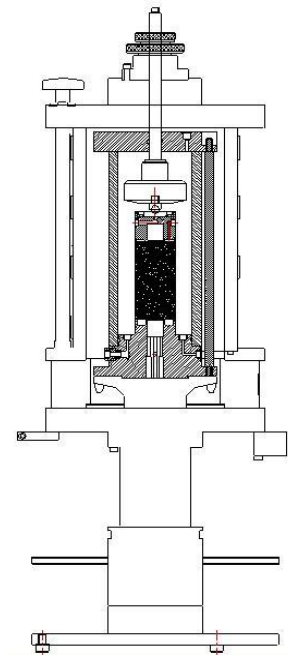
Fig. 9 Schematic of double cell within a GDS Bishop and Wesley triaxial cell

Outer cell pressure controller

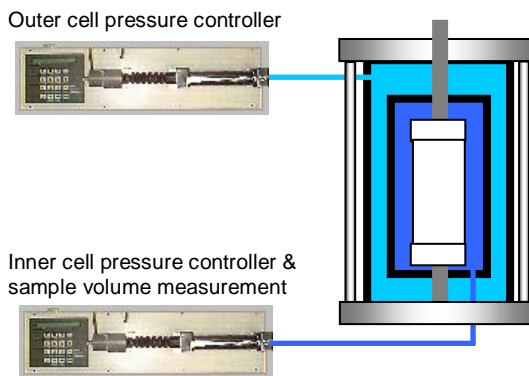Inner cell pressure controller & sample volume measurement

Fig. 10 Independent application of internal and external cell pressures. Volume reading from inner cell pressure/volume controller equates to ample volume change.
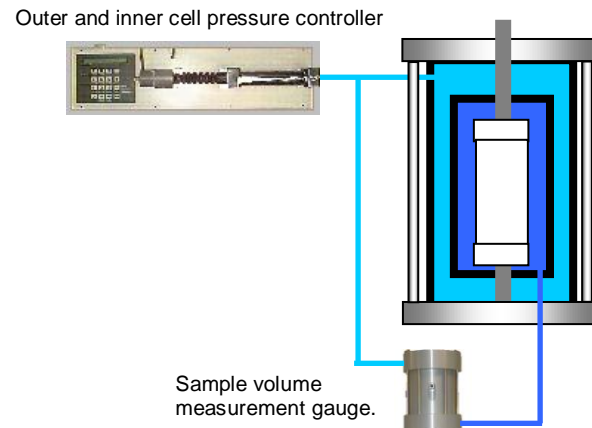
Outer and inner cell pressure controller

Sample volume measurement gauge.

Fig. 11 Application of internal and external cell pressures using single pressure device. Volume change measured using external volume change gauge.

Method C technical specification

Advanced 2MPa/1000cc air pressure/volume controllers
- **Resolution of measurement and control**: pressure = <0.1% full range, volume = 0.5cu mm
- **Accuracy of measurement**: pressure = <0.1% full range, volume = 0.25%

Items required for Method C UNSAT upgrade
- GDS double cell
- Pedestal with bonded HAEPD
- GDS pressure/volume controllers to suit
- GDSLAB 4D UNSAT software module

Optional Items required for Method C UNSAT upgrade
- Local strain (Hall Effect or LVDT)
- Atmospheric air pressure transducer
- Access ring for triaxial cell

Method for measuring volume change	Advantages	Disadvantages
Method A GDS pore water pressure/volume controller for pore water volume changes ΔV_{water} GDS pore air pressure-volume controller for pore air volume changes ΔV_{air} (Total test specimen volume changes are then $\Delta V = \Delta V_{air} + \Delta V_{water}$)	• Good accuracy and good resolution (1cu mm) of pore water pressure and volume source • Good accuracy and good resolution (1cu mm) of pore air pressure and volume source	• Must measure air volume change after pressure change, otherwise difficult to calibrate for compression of volumes of air in the line and air pressure source • Correct data using atmospheric pressure changes measured by GDS absolute pressure transducer • Errors caused by air moving into solution
Method B Wet-wet differential pressure transducer beneath water columns subtending airspace inside an inner cell (HKUST Double Cell). Note: HKUST Double Cell is different to a Double *Walled* cell	• High accuracy and resolution over full range of volume change measurement due to shape of the inner cell and the use of very accurate differential pressure transducer • Insensitive to the difference in pressure between the inner and outer cells • Does not need two independent pressure control and measurements for cell pressure as in double *walled* cell (method C) • More stable and less temperature sensitive compared to double *walled* cell • Good for large test specimens	• Requires careful calibration. • Use high quality de-aired water in cell • Make sure air bubbles are purged out of all connectors and lines
Method C GDS cell pressure-volume controller for cell water volume changes ΔV_{cell} Option to use double walled or metal chamber	• Good accuracy and good resolution (1cu mm) of cell pressure and volume measurement from a GDS pressure/volume controller	• Must use metal (not acrylic) cell chamber, double walled cell or ideal the double cell described here • Use high quality de-aired water in cell and make sure air bubbles are purged out of chamber and all connectors and lines
Method D GDS Hall Effect or LVDT local strain transducers (axial and radial)	• Transducers are suitable for small strains • Provides a good estimate of small volumetric strain • Can be combined with methods A and C above (no space inside inner cell to be used with method B)	• Not suitable for large strains • Assumes right cylinder

Requirement for measurement of atmospheric pressure

The on-board pressure transducer in the air pressure controller measures pressure relative to atmospheric pressure (known as 'gauge' pressure). Of course, this is correct for the system measurement of pressure because transducers are using the same reference. However, where the air volume change is concerned, the gas laws relate to the absolute pressure of gas. If we assume that atmospheric pressure can change from 900 milibars to 1100 milibars (this is a large range) this represents about +/- 10kPa around atmospheric pressure. Assuming a volume of 200cc at 15kPa gauge (about 115kPa absolute), the gas laws can be expressed as PV=kRT=constant which gives PV=115*200=23000. If the atmospheric pressure changes by 10kPa the controller will still regulate gauge pressure to 15kPa relative to atmospheric pressure. But this will be now 125(100+10+15) kPa absolute. Now PV = 23000 = 125*V, which gives 184cc. Therefore, with no apparent change in controlled pressure, there will be a measured volume change of 16cc caused by a change in atmospheric pressure.

From this kind of calculation it may be deemed necessary to take into account the atmospheric pressure. By using an absolute pressure transducer connected to the acquisition system, the measurements of atmospheric pressure can be used to correct the saved results.

Upgrade to local strain measurement (method D)

Any GDS system may be upgraded to perform local strain measurement using either Hall Effect or LVDT transducers. Both device types enable axial and radial deformation to be measured directly on the test specimen via lightweight aluminum holders.

Hall Effect transducers may be used in water up to 1700kPa.

LVDT transducers come in 2 versions:
- Low pressure (up to 3500kPa) version for use in water
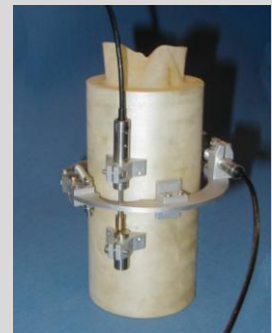- High pressure (up to 200MPa) version for use in non-conducting oil

Fig. 12 Hall Effect and LVDT local strain transducers

For further information on local strain measurement, please refer to the dedicated Hall Effect local strain and LVDT Local Strain datasheets.
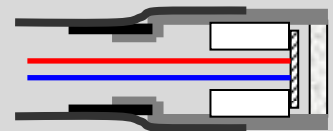
Unsaturated permeability:

For a full explanation of how to perform unsaturated permeability with a GDS UNSAT system, please refer to the separate datasheet.
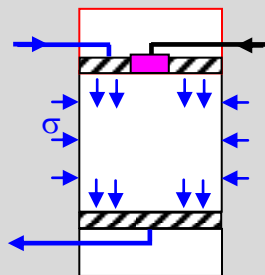
Mid-Plane Suction Measurement:

For a full explanation of how to perform mid plane suction measurement, please refer to the separate datasheet entitled "GDS Mid-Plane Suction Probe".

Why buy GDS UNSAT?

- choice of different methods to suit your testing requirements and budget
- developed in conjunction with HKUST, specialists in unsaturated soil testing
- methods may be 'mixed and matched' to create a custom system
- due to GDS's knowledge of many different unsaturated test methods, we can objectively advise customers on the best method for their test requirements. We are not limited to a single solution.
- GDS has more than 50 customers worldwide using it's unsaturated soil testing systems and software.

Due to continued development specifications may change without notice