



## Unsaturated Testing of Soil (UNSAT)

**Overview:** GDS Unsaturated Triaxial Testing System (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. All GDS triaxial testing systems (as well as triaxial equipment from other manufacturers\*) can be modified to allow for unsaturated triaxial testing. GDS provide 4 methods to perform unsaturated testing.

Unsaturated testing can also be added to the following test types, Shear, Hollow Cylinder, Resonant Column, Consolidation and True Triaxial Testing.

*\*Please confirm existing equipment with GDS to check for compatibility.*

### Key Features:

### Benefits to the User:

Choice of different methods:	To suit your testing requirements and budget, see options A, B, C & D below.
Hong Kong University of Science and Technology:	Method B has been developed in conjunction with HKUST (Hong Kong University of Science and Technology), who are specialists in unsaturated soil testing.
Mixed and matched:	Methods may be 'mixed and matched' to create a custom system.
GDS experience:	GDS has knowledge of many different unsaturated test methods and can objectively advise customers on the best method for their test requirements. GDS are not limited to a single solution and have currently over 100 unsaturated systems in use.

### Triaxial Unsaturated Testing Methods:

- Method A: Direct volume change measurement of pore air and water using a GDS pore air pressure/volume controller, water pressure controller and measurement of atmospheric pressure.
- Method B: HKUST inner cell - Total specimen volume change is measured from the change in water level in an inner cell using a differential pressure transducer.
- Method C: Double walled cell - A GDS pressure volume controller is used to measure inner cell volume change which is directly related to sample volume change. Due to the outer cell pressurisation, the inner cell wall is considered to be infinitely stiff.
- Method D: On-sample local strain transducers measure directly on sample to calculate total volume change.

### Technical Specification:

<b>Method A:</b>	<b>Resolution of measurement:</b> <b>Accuracy of measurement:</b>	Pressure = 0.2kPa, volume = 1mm <sup>3</sup> Pressure = <0.1% full range, volume = 0.25%
<b>Method B:</b>	<b>Resolution of volume change measurement:</b> <b>Accuracy of sample volume change measurement:</b>	<10mm <sup>3</sup> Estimated at 32mm <sup>3</sup> or 0.04% volumetric strain for a triaxial specimen 38mm in diameter, 76mm in height
<b>Method C:</b>	<b>Resolution of measurement of cell volume:</b> <b>Accuracy of measurement of cell volume:</b>	1mm <sup>3</sup> 0.25%
<b>Method D:</b>	<b>Resolution of displacement:</b> <b>Accuracy:</b>	<0.1µm Hall Effect = 0.8% FRO, LVDT = 0.1% FRO

## 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. 1), 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.

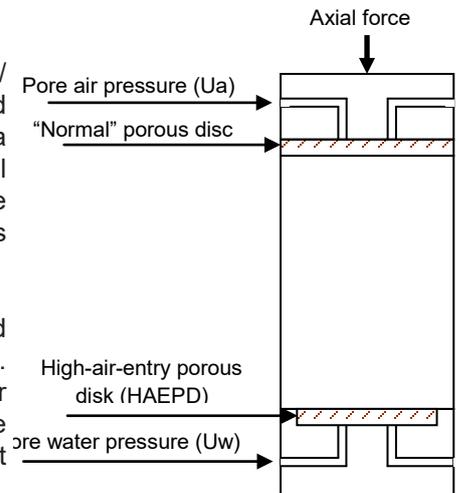


Fig. 1 Schematic of test specimen connections when using GDS Method A

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



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

- 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

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. 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. 3) is connected to a reference tube via the DPT. 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.

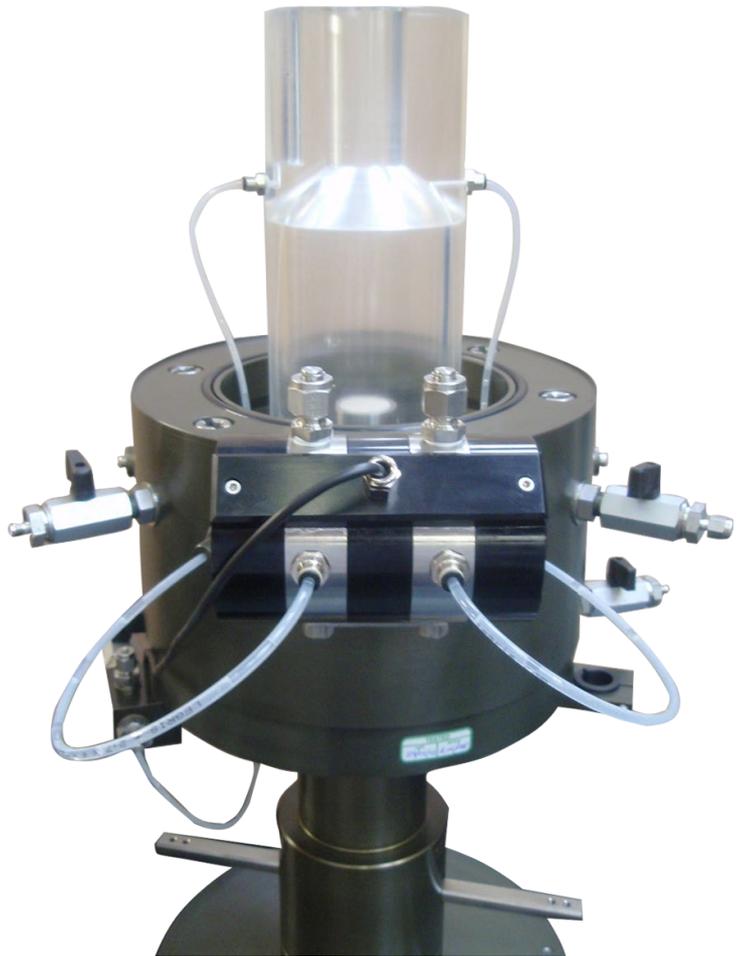


Fig. 3 Show HKUST inner cell with DPT attached to the front of the frame.

### 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<sup>3</sup>
- Accuracy of volume change measurement: estimated at 32mm<sup>3</sup> or 0.04% volumetric strain for a triaxial specimen 38mm x 76mm

### Items required for HKUST UNSAT upgrade

- Inner Cell
- HKUST pedestal with bonded HAEPD
- HKUST topcap
- 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 or Double Wall Volume Measurement

Method C options for measuring volume change involve either the use of a double walled cell or a double cell. A normal triaxial cell cannot be used for volume change measurement because of the error caused by the cell wall stretching and creeping.

In a double walled or double cell there is no pressure difference across the inner cell wall and so no radial stretch/creep to cause error in the reading. A double walled cell is made of an inner glass wall and an outer perspex wall. Two GDS pressure/volume water controllers are used to control the cell/radial pressure, the first connected to the inner cell and the second to the outer cell. Cell pressure targets are simultaneously sent to both the inner and outer controllers. Sample volume change is measured by the volume change in the inner cell.

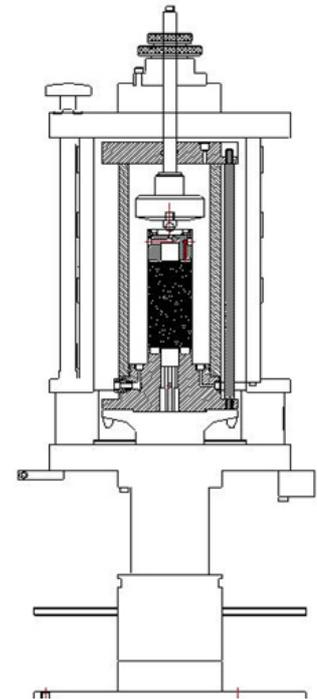
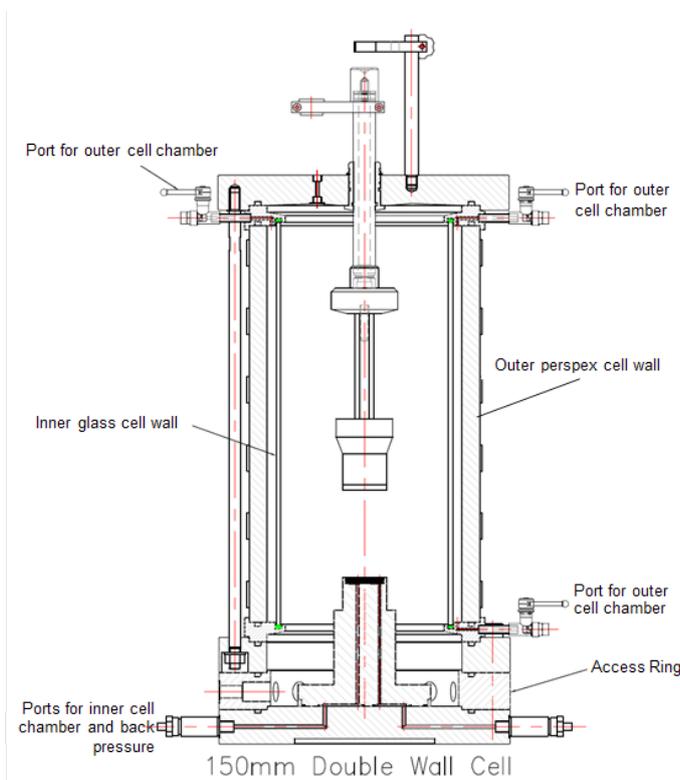


Fig 4. Schematic of double cell within a GDS Bishop and Wesley triaxial cell



Attempts have been made in the past to produce very stiff triaxial cell walls (i.e. stainless steel) instead of the double walled approach. The stainless steel cell is heavy, non-transparent and will still be exposed to some deflection effects.

Fig 5. Schematic of double walled cell

### Method C technical specification

#### Advanced 2MPa/1000cc air pressure/volume controllers

- Resolution of measurement and control: pressure = <math><0.1\%</math> full range, volume = 0.5cu mm
- Accuracy of measurement: pressure = <math><0.1\%</math> 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 D – Local Strain Measurement

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. 6 Hall Effect and LVDT transducer

### 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.



Fig. 7 show an UNSAT pedestal (left) used for Methods A & C and a HKUST pedestal used in method B.

### Upgrade to Bender Element Testing

Any UNSAT system may be upgraded to perform P and S wave bender element testing with the addition of the following items:

- Bender element pedestal & top-cap with bender element insert.
- High-speed data acquisition card.
- Signal conditioning unit which includes amplification of source and received signals (P and S-wave) with user controlled gain levels (via software).

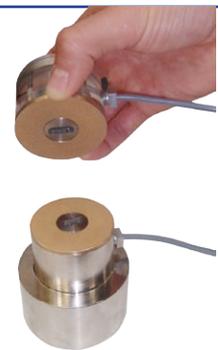


Fig. 8 GDS Bender Elements

### GDSLAB 4D UNSAT software module

The GDSLAB UNSAT software module (see Fig. 9) 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

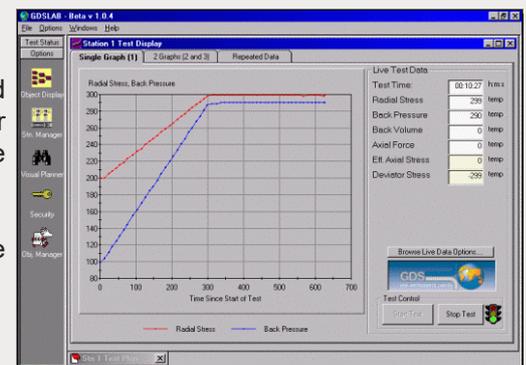


Fig. 9 Test display showing a 4D unsaturated stress path test in progress

### Comparison of Methods A, B, C & D

Method for measuring volume change	Advantages	Disadvantages
<p><b>Method A</b> - Direct volume measurement using a GDS pore air pressure/volume controller</p>	<ul style="list-style-type: none"> <li>• Good accuracy and good resolution (1cu mm) of pore water pressure and volume source</li> <li>• Good accuracy and good resolution (1cu mm) of pore air pressure and volume source</li> </ul>	<ul style="list-style-type: none"> <li>• 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</li> <li>• Correct data using atmospheric pressure changes measured by GDS absolute pressure transducer</li> <li>• Errors caused by air moving into solution</li> </ul>
<p><b>Method B</b> - HKUST inner cell volume measurement</p>	<ul style="list-style-type: none"> <li>• 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</li> <li>• Insensitive to the difference in pressure between the inner and outer cells</li> <li>• Does not need two independent pressure control and measurements for cell pressure as in double walled cell (method C)</li> <li>• More stable and less temperature sensitive compared to double walled cell</li> <li>• Good for large test specimens</li> </ul>	<ul style="list-style-type: none"> <li>• Requires careful calibration.</li> <li>• Use high quality de-aired water in cell</li> <li>• Make sure air bubbles are purged out of all connectors and lines</li> </ul>
<p><b>Method C</b> - Double cell or Double Wall Volume Measurement</p>	<ul style="list-style-type: none"> <li>• Good accuracy and good resolution (1cu mm) of cell pressure and volume measurement from a GDS pressure/volume controller</li> </ul>	<ul style="list-style-type: none"> <li>• Must use metal (not acrylic) cell chamber, double walled cell or ideal the double cell described here</li> <li>• Use high quality de-aired water in cell and make sure air bubbles are purged out of chamber and all connectors and lines</li> </ul>
<p><b>Method D</b> - Local Strain Measurement</p>	<ul style="list-style-type: none"> <li>• Transducers are suitable for small strains</li> <li>• Provides a good estimate of small volumetric strain</li> <li>• Can be combined with methods A and C above (no space inside inner cell to be used with method B)</li> </ul>	<ul style="list-style-type: none"> <li>• Not suitable for large strains</li> <li>• Assumes right cylinder</li> </ul>

## Why Buy GDS?

### GDS have supplied equipment to over 84% of the world's top 50 Universities:

GDS have supplied equipment to over 84% of the world's top 50 Universities who specialise in Civil & Structural Engineering, according to the "QS World University Ranking 2019" report.

GDS also work with many commercial laboratories including BGC Canada, Fugro, GEO, Geolabs, Geoteko, Golder Associates, Inpijn Blokpoel, Klonn Crippen, MEG Consulting, Multiconsult, Statens Vegvesen, NGI, Ramboll, Russell Geotechnical Innovations Ltd, SA Geolabs, SGS, Wiertsema and Partners to name a few.

**TOP  
50**

### Would you recommend GDS equipment to your colleague, friend or associate?

**100% of our customers answered "YES"**

Results from our post-delivery survey asked customers for feedback on their delivery, installation (if applicable), supporting documentation, apparatus and overall satisfaction with GDS. The survey ran for two years.



### Made in the UK:

All GDS products are designed, manufactured and assembled in the UK at our offices in Hook. All products are quality assured before they are dispatched.

GDS are an ISO9001:2015 accredited company. The scope of this certificate applies to the approved quality administration systems relating to the "Manufacture of Laboratory and Field Testing Equipment".

**40 YEARS OF  
BRITISH  
INNOVATION** 

### Extended Warranties:

All GDS apparatus are covered by a 12 month manufacturers warranty. In addition to the standard warranty, GDS offer comprehensive extended warranties for 12, 24 and 36 months, for peace of mind against any repairs in the future. The extended warranties can be purchased at any time during the first 12 months of ownership.



### GDS Training & Installation:

All installations & training are carried out by qualified engineers. A GDS engineer is assigned to each order throughout the sales process. They will quality assure the apparatus prior to shipping, if installation has been purchased, install the apparatus on the customers site & provide the training.



### Technical Support:

GDS understand the need for ongoing after sales support, so much so that they have their own dedicated customer support centre. Alongside their support centre GDS use a variety of additional support methods including remote PC support, product helpsheets, video tutorials, email and telephone support.

