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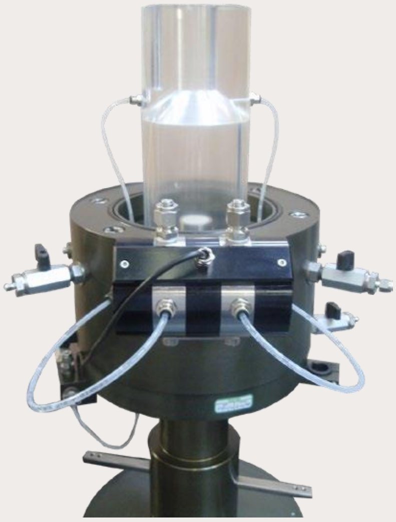


Unsaturated Triaxial Testing of Soil (UNSAT)

Overview: 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. GDS provides a number of state-of-the-art methods to allow flexibility in the method used to perform unsaturated testing, all using the axis translation method.

- 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

Key Features:	Benefits to the User:
Choice of different methods:	Measurement of sample volume change is one of the main challenges in unsaturated testing. To suit your testing requirements and budget, see options A, B, C & D.
All methods use the axis translation technique:	The axis translation method is the principle of elevating pore air pressures, which then allows matric suction to be controlled using positive pore water pressures. Based on the axis-translation principle, the matric suction can be controlled over a range far greater than the cavitation limit for water under negative pressure.

Tests that can be Performed:

One dimensional consolidation, Constant rate of Loading (CRL), Constant rate of strain (CRS), Multi-stage Testing, Quasi-static low speed/creep tests, ramp and cycle pressure or volume change, saturation, Stepped loading, Matric suction control, Stress Dependant Soil Water Characteristic Curve (SDSWCC).

Technical Specification:

Method A:	
Resolution of measurement of pore pressure/volumes (air & water):	pressure = 0.2kPa, volume = 1mm^3
Accuracy of measurement of pore pressure/volumes (air & water):	pressure = <0.1% full range, volume = 0.25%
Method B:	
Operational resolution of sample volume change:	<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:	1mm^3
Accuracy of measurement of cell volume:	0.25%
Method D:	
Resolution of on-sample displacement measurement using 16 bit data:	+/- 3.0mm range gives resolution of <0.1µm
Accuracy:	Hall Effect = 0.8% FRO, LVDT = 0.1% FRO

Requirement and Methods for Measuring Sample 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 between an inner cell around the sample (as the sample deforms) 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 (i.e. a cell within a cell), the internal cell wall can effectively be made to be infinitely stiff. This system needs excellent temperature stability. Small changes in temperature can 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 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), or high air entry porous stones.

When a HAEPD is fully 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’ and represents the maximum matric suction that can be applied, options are 1500kPa or 500kPa. 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
- Stress Dependant Soil-water characteristic curve (SDSWCC)
- Drained test saturated conditions
- Drained test unsaturated conditions

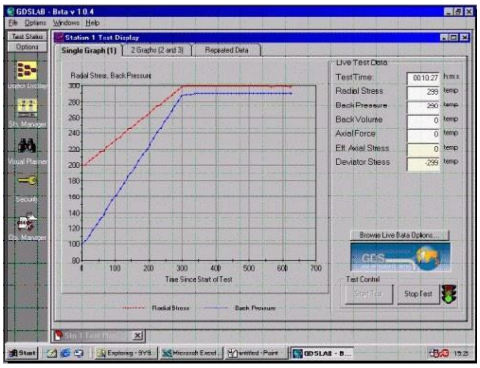


Fig. 3 Test display showing a 4D unsaturated stress path test in progress

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, which means this method is most like a standard triaxial test and is the easiest to upgrade to.

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 at the base due to the HAEPD. The air pressure and water pressure are maintained at different values to generate the required matric suction.

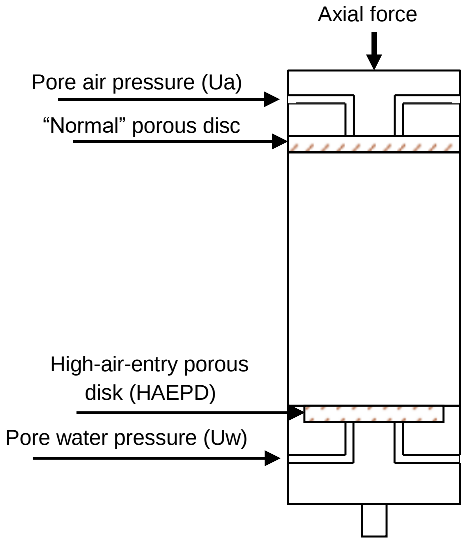


Fig. 4 Schematic of test specimen connections when using GDS Method A

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). 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.

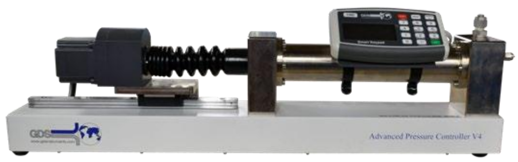


Fig. 5 2MPa/1000cc air pressure/volume controller

Method A - Technical Specifications:

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
- Atmospheric air pressure transducer (recommended)

Note: Method D can be used in conjunction with Method A.

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. 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.

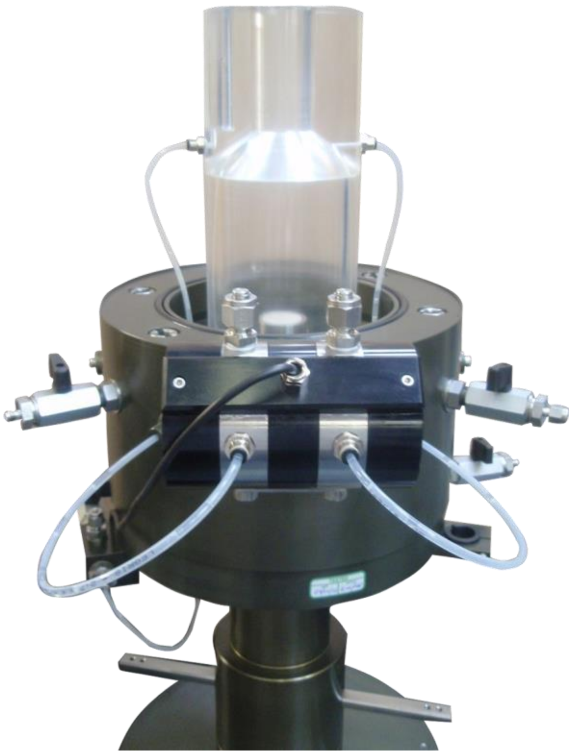


Fig. 6. HKUST method showing the inner cell and ultra low range DPT

Fig. 7 Ultra low range DPT attached to cell

Method B - Technical Specifications:

Method B technical specification
- DPT range: +/- 1.5kPa (+/- 150mm of water head)
- DPT accuracy: <0.5% of full range output (FRO)
- Operational resolution of volume change measurement (16 bit resolution): <10mm3
- Accuracy of volume change measurement: estimated at 32mm3 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 of 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 by positioning it inside a second triaxial chamber exerting an equal pressure on the outside faces of the internal triaxial cell (see Fig. 8).

A traditional non double walled cell, can be used to estimate specimen volume by measuring the change in cell volume. 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.

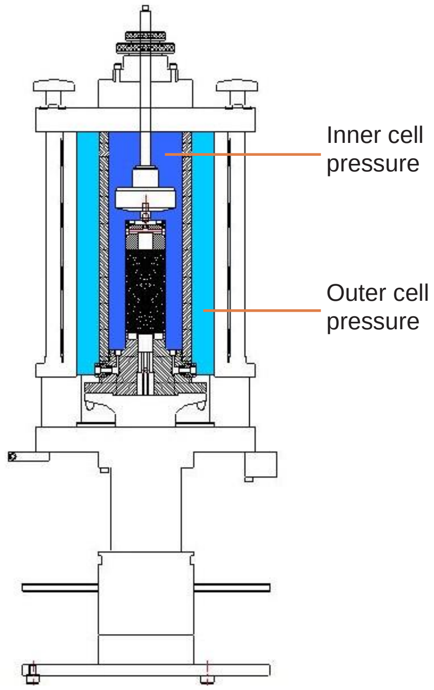
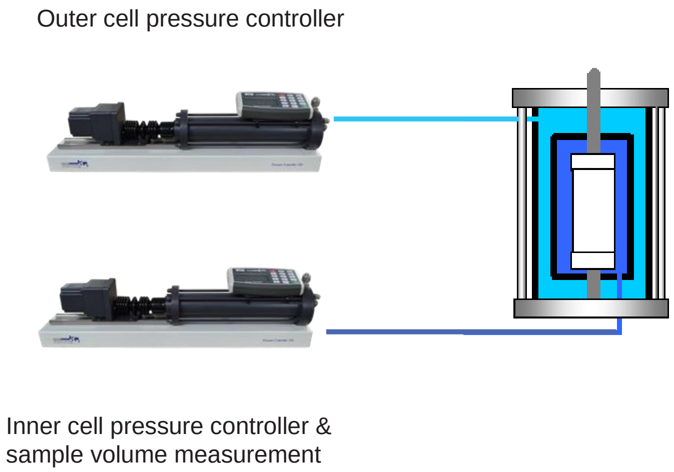


Fig. 8 Schematic of double cell within a GDS Bishop and Wesley triaxial cell



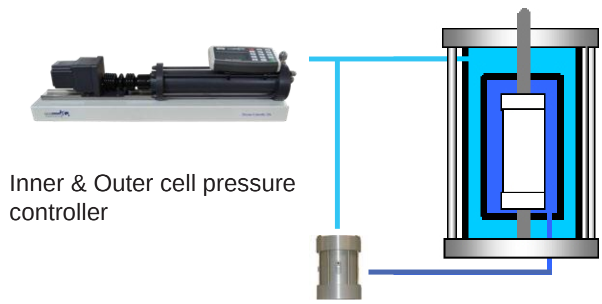


Fig. 9 Independent application of internal and external cell pressures. Volume reading from inner cell pressure/volume controller equates to ample volume change.

Fig. 10 Application of internal and external cell pressures using single pressure device. Volume change measured using external volume change gauge.

Method C - Technical Specifications:

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 D - Upgrade to 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 accurately measured directly on the test specimen via lightweight aluminium holders.

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

LVDT transducers come in 2 versions:

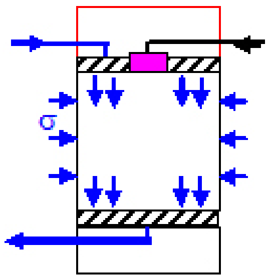
- Low pressure (up to 3500kPa) version for use in water
- High pressure (up to 200MPa) version for use in non-conducting oil

Fig. 11 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.

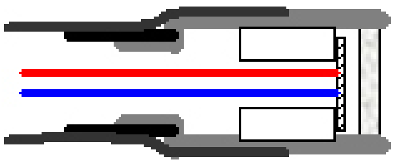
Unsaturated permeability:

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”.



Requirement for Measurement of Atmospheric Pressure in Method A:

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.

Comparison of the Methods for Measuring Volume Change (A,B,C,D):

	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 • The most complex method for the user

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

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Why Buy GDS?

GDS have supplied equipment to over 86% of the world's top 50 Universities:

GDS have supplied equipment to over 86% of the world's top 50 Universities who specialise in Civil & Structural Engineering, according to the "QS World University Ranking 2020" report.

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

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".

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.