Cambridge insitu

Innovate.
Investigate.
Inform.

Specialist Pressuremeter & Dilatometer testing.

Introduction

Pressuremeter testing (PMT) is a recommended insitu testing technique for ground investigation, referenced in Eurocode 7 (EN 1997-2).

The objective of a pressuremeter test is to measure the insitu-deformation of soils and rocks by the measured expansion of a cylindrical pressurised membrane (EN 1997-2).

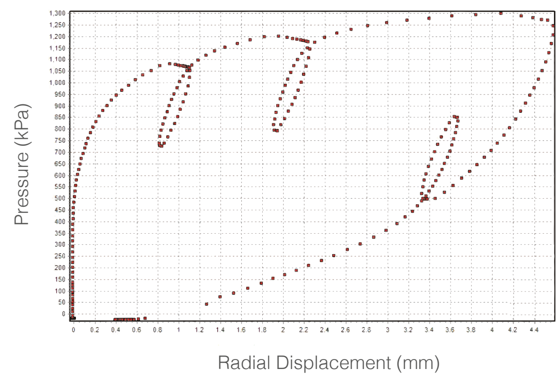
Radial displacement (or, direct-strain measuring) pressuremeters are a specific sub-division of pressuremeter. They have a cylindrical flexible membrane which expands when pressure is applied (like inflating a balloon). During a live test, compressed air or oil is applied down an umbilical (insulated-electrical and fluid pass through), in order to reach the instrument. This causes the flexible membrane to inflate, pushing against the walls of the borehole causing deformation as a pressure-driven expansion is undertaken.

The radial displacement pressuremeter is an instrumented probe; that is to say down-hole measurements are taken directly via strain gauge transducers (sets of either 3 or 6), which are spaced evenly around the central axis of the expanding section. These strain gauges measure the displacement of the membrane continuously during a test. A further single (or sometimes double) transducer measures the internal total pressure of the probe during the test. Combined, the transducers provide incredibly precise and reliable data for pressure (stress) and displacement (strain) for the duration of a pressuremeter test. Typical transducer resolutions are equal to 0.1 kPa and less than a Micron.

During a pressuremeter test, the instrument is positioned in a borehole having either been inserted into a pre-bored ‘pocket’, pushed in, or drilled in as self-bored. Once in this position, compressed air or oil is applied to the pressuremeter from surface, via an umbilical. The flow rate of hydraulic/pneumatic pressure in, and out, is finely controlled and the resulting changes of pressure/displacement observed via a computer running the logging software.

The test is therefore entirely controlled from surface in the desired manner respective of the material the instrument is within.

Arm Average vs Total Pressure



There are three types of Cambridge pressuremeter. These three are all based on the same concept as outlined above, as they all have capacity to measure stress and strain during a test. The below table explains some of the individualities of each.

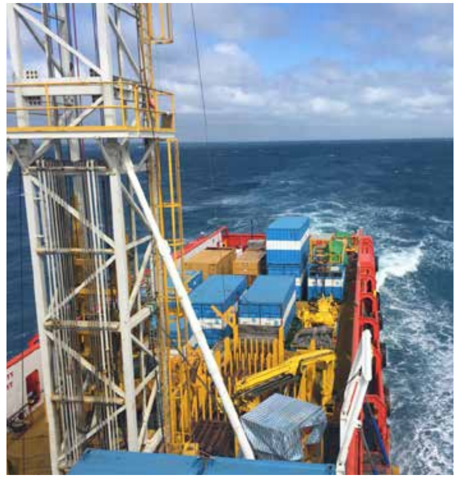
Feature	High Pressure Dilatometer	Reaming Pressuremeter	Self-Bored Pressuremeter
Max working pressure	20MPa	10MPa	10MPa
Probe diameter	73-75mm / 95-97mm	47mm	88mm
Length of expanding section	725mm / 570mm	285mm	535mm
No. of strain arms	6	3	6
Total pressure cells	2	1	1
Pore water pressure cells	0	0	2
Pre-bored	Yes	Yes	No
Self-bored	No	No	Yes
Pushed	No	Yes	No

Our Services

Cambridge Insitu has been designing, manufacturing and operating scientific instruments used for soil and rock mechanics since 1972, as well as subsequently analysing and reporting the data collected.

With operations based in Cambridge, UK, as well as British Columbia in Canada, we have continually pushed our equipment and software design alongside our site operations and analytical techniques. It is fair to say that a wealth of experience has been collected following our involvement in major construction projects undertaken across the world.

Recently, we have been involved in large scale hydropower projects in Canada, High speed rail projects in the UK, metro transport projects in Sweden, Canada, Belgium and Germany, nuclear power plant developments in the UK, and offshore wind in the North Sea and Taiwan Strait; to name but a few.



Our services include:

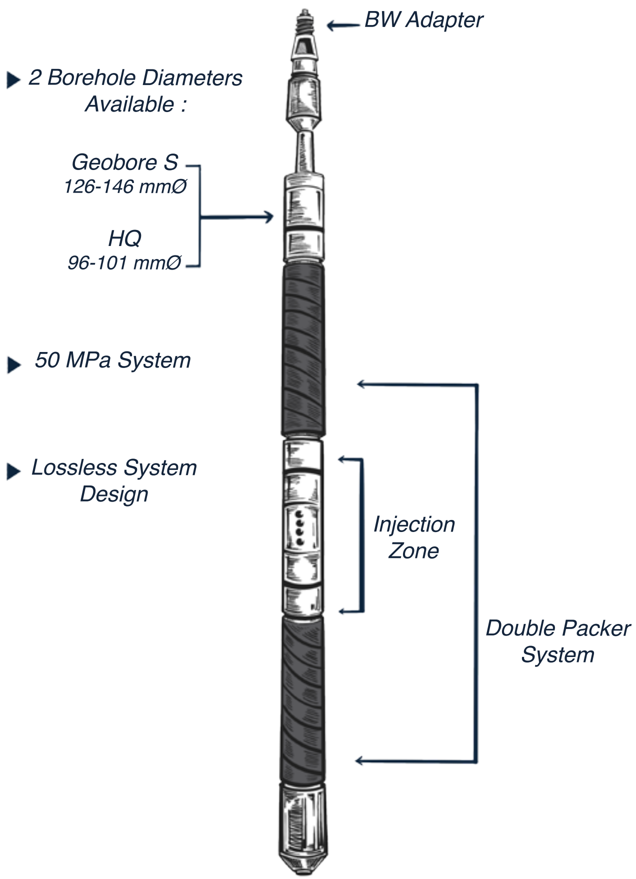
- A one-stop land or marine-based contracting service. Our trained and experienced engineers visit sites anywhere in the world with all the equipment required to undertake high quality pressuremeter testing. We work both on land, dynamically positioned drill ships, jack up barges and platforms. All our staff are appropriately qualified.
- All our engineers are trained and competent in repairing our equipment in the event of damage whilst on site, and many of them are heavily involved in our manufacture processes. This has been proven to keep downtime due to breakdowns to an absolute minimum.
- Provision of specialist analytical and reporting based services, including technique reccomendations.
- Specialist Hydraulic Fracture Testing and analysis services.
- Training; equipment use, and/or data interpretation.
- Maintenance and repair of equipment, either in field location or in our Cambridge (UK) based workshop.
- Supporting or leading PMT aspects of academic research projects.

Please contact cam@cambridge-insitu.com with any queries regarding our services.

Hydraulic Fracture Testing

Hydraulic Fracture Testing is conducted to determine the tensile strength of the rock mass and the magnitude of maximum and minimum horizontal stresses.

When employed in conjunction with either a televiewer or impression packer, this technique can also be used to determine horizontal stress orientation and anisotropy. This is an insitu technique suited to hard rock applications in competent and unfractured rock masses.



The instrumentation and equipment utilised for Hydraulic Fracture Testing includes a double packer system with an injection zone between packers. The packers are inflated either side of the injection zone, creating a sealed section of the bore hole. Subsequently, water is pumped down a hose to the injection zone; the pressure is gradually increased until a tensile fracture occurs. The fracture is then closed and then re-opened several times to determine the insitu stress.

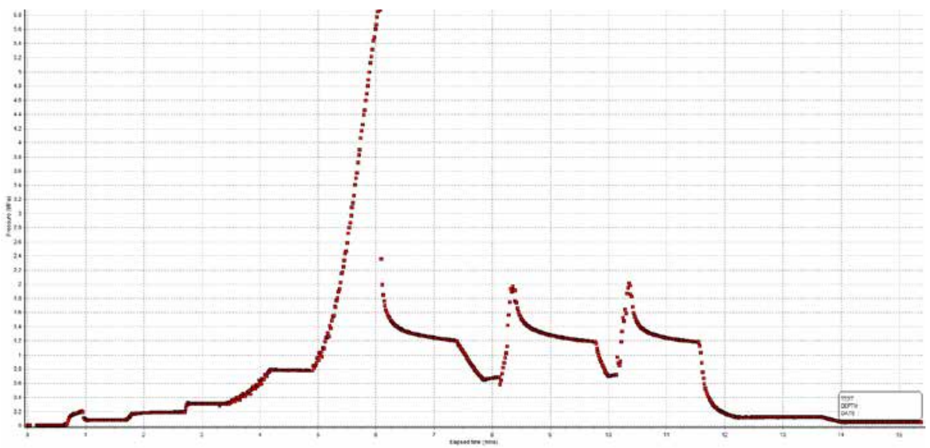
We have capacity to run two 50MPa systems. The first is suitable for testing a Geobore S borehole with a 126 – 146mmØ. The second is suitable for a smaller HQ 96 – 101mmØ.

Either diameter system uses two umbilicals. There is one pneumatic line to the inflate the packers, and another hydraulic (water) hose to pressurise the injection zone and conduct the actual test.

This is a lossless system ensuring a higher flowrate accuracy, as opposed to a rod system with potentially leaky joints.

The equipment on surface includes a series of pumps providing the required flow rates and pressures to achieve the requirements of the test, these are instrumented to monitor the flowrate and pressure. All transducers provide a high frequency live digital data feed displayed on a laptop.

The instrument should be lowered on the rods used by the rotary rig, but wireline deployment may be possible by prior discussion.



Our Equipment

Reaming Pressuremeter

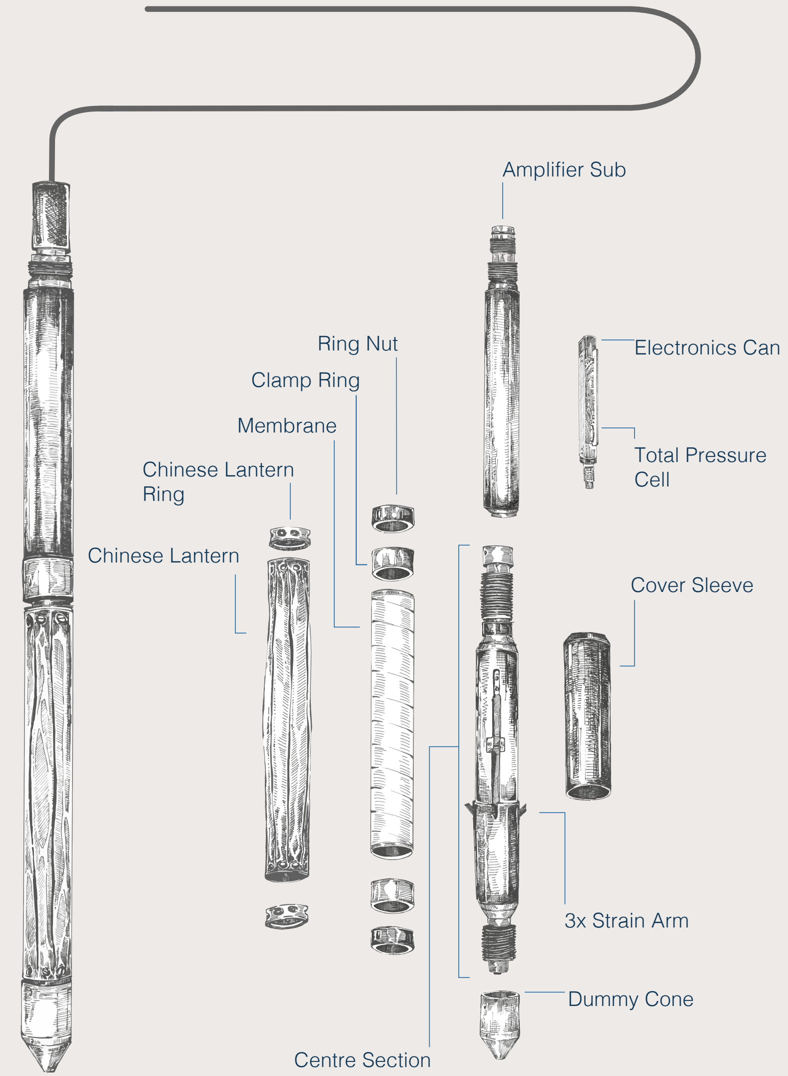
The Reaming Pressuremeter (RPM) is a versatile small diameter pressuremeter (Ø47mm OD). This probe can be used in materials ranging from weak rock such as weathered chalk, to very weak clays.

Insertion techniques for the RPM can be either by pushing with hydraulic rams, or, pre-boring with an SPT split spoon, 50mm drag bit or a rotary core barrel.

This instrument can be configured to take a 15cm^2 live cone (CPT), thus changing the instrument from a Reaming Pressuremeter to a Cone Pressuremeter. The CPT operates entirely separately to the pressuremeter.

Probe Diameter	47mm.
Length	945mm (Excluding sub arrangement etc.)
Umbilical	12mm diameter reinforced hose with electrical pass through & pneumatic capability.
Powered	10 MPa maximum working pressure (compressed breathing air), 12V supply from surface, via umbilical.
Transducers	3x Strain Arms (spaced at 120 degrees). 1x Total Pressure Cell.
Maximum Strain	42.5% (10mm measurable radial displacement).

Reaming Pressuremeter



High Pressure Dilatometer

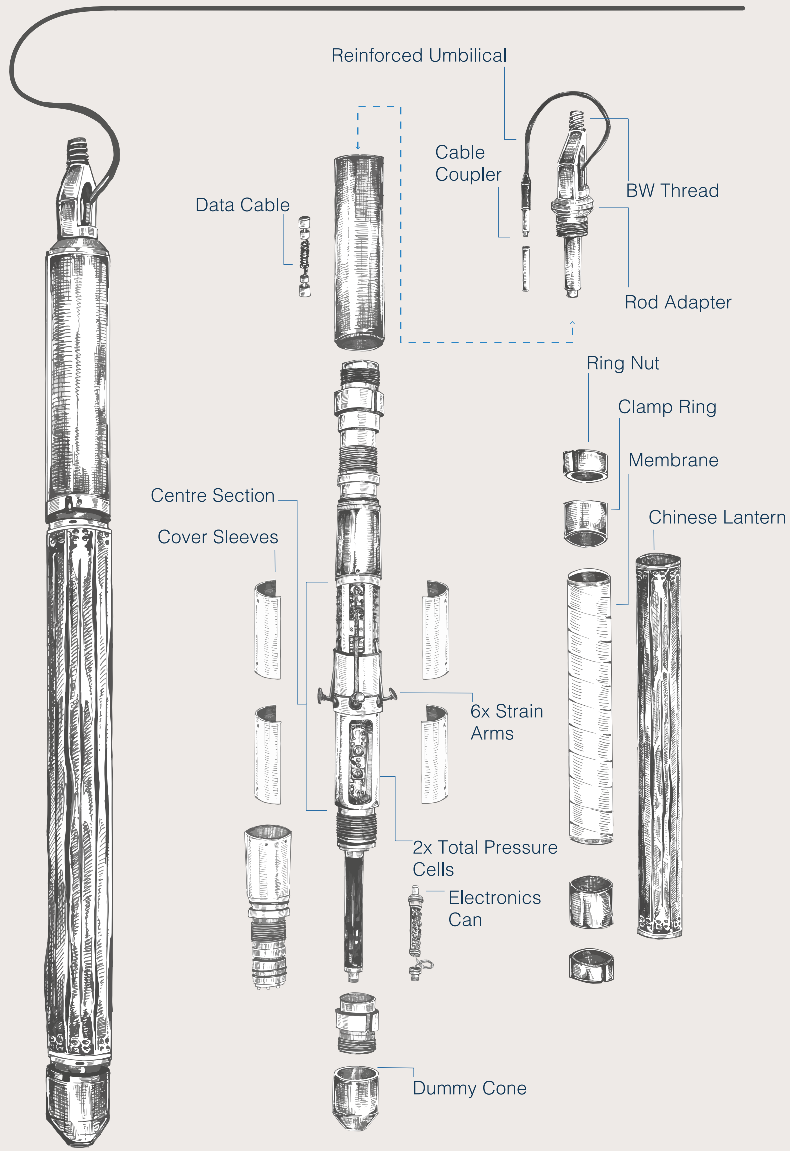
The High-Pressure Dilatometer (HPD) is the largest pressuremeter at Ø95mm OD. This probe also has the highest available maximum pressure and as such can be used in materials ranging from rock, such as mudstone or chalk, to very weak clays.

The 95mm HPD is a pre-bored pressuremeter, so can only be inserted into 'pockets' of between 1.5 – 3.0m length, and nominally of between 98 – 101mm Diameter. A common choice for pre-boring (creating a 'pocket' for the instrument) is by utilising a 3m T6H core barrel.

This instrument can be configured to include a digital electronic compass measuring and recording magnetic field. This can allow some insight to the anisotropy of the data collected during a test.

Probe Diameter	95-97mm (also available as 73-75mmØ).
Length	2735mm
Umbilical	14mm diameter reinforced hose with electrical pass through & hydraulic/pneumatic capability.
Powered	20MPa maximum working pressure with compressed breathing air or oil, 12V supply from surface, via umbilical.
Transducers	6x Strain Arms (spaced at 60 degrees). 2x Total Pressure Cell.
Maximum Strain	42.1% (20mm measurable radial displacement).

High Pressure Dilatometer



Self-Boring Pressuremeter

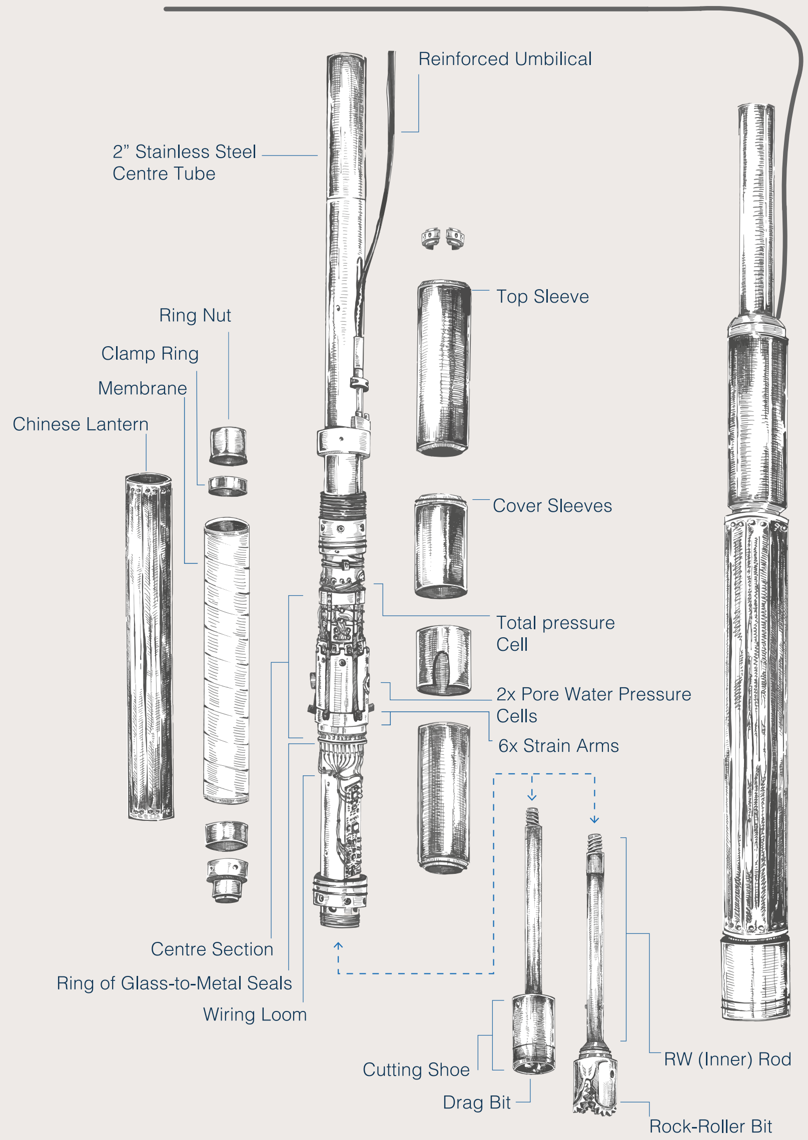
The Self-Boring Pressuremeter (SBPM) has the capability to achieve testing in minimally disturbed, near-insitu conditions. This is done by the probe acting similar to a small tunnel-boring machine; the cutting shoe and rotating drag bit (or rock roller) cuts and flushes material out of the borehole, replacing the cut material instantly with the probe itself. This technique minimises the material relaxing upon the probe's insertion, achieving a test in near-undisturbed conditions.

This instrument is best used in soils (drained or undrained), although can also be used in weak rock. The two Pore Water Pressure Cells located 180 degrees from one another on the membrane measure and record the pore water pressure response both during insertion (drilling), and during the live test.

The SBPM can also be used for permeability testing, to determine the insitu horizontal conductivity.

Probe Diameter	88mm.
Length	1465mm
Umbilical	12mm diameter reinforced hose with electrical pass through & pneumatic capability.
Powered	10MPa maximum working pressure with compressed breathing air, 12V supply from surface, via umbilical.
Transducers	6x Strain Arms (spaced at 60 degrees). 1x Total Pressure Cell. 2x Pore Water Pressure Cell.
Maximum Strain	13.6% (6mm measurable radial displacement).

Self Boring Pressuremeter



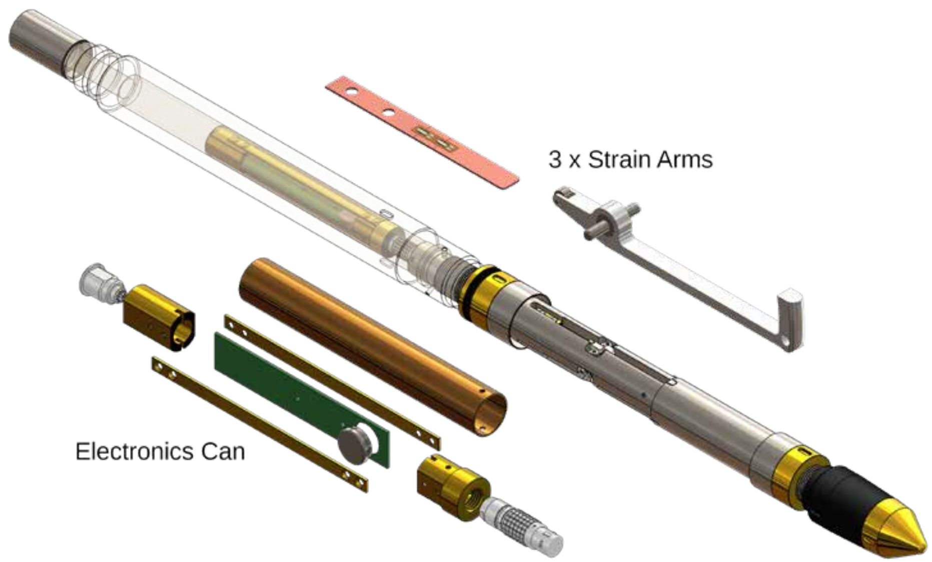
Design & Innovation

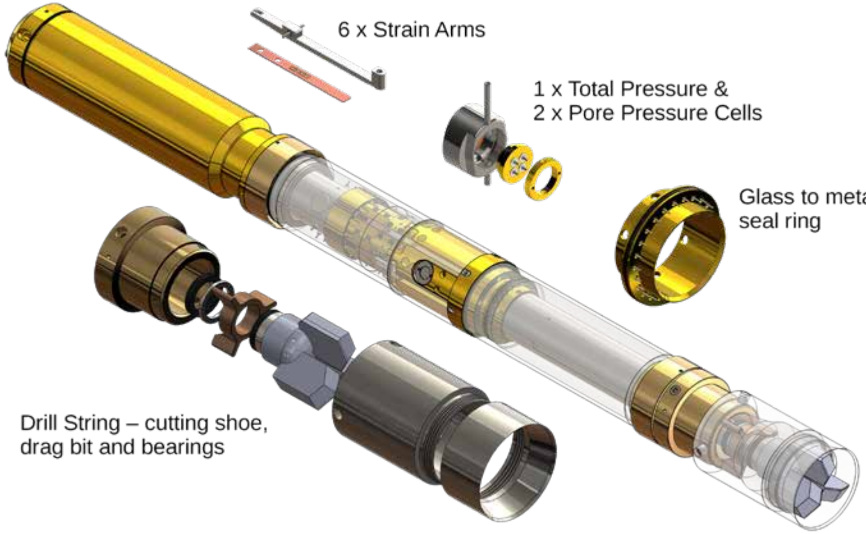
At Cambridge Insitu we are constantly striving to develop our equipment, analysis and procedures with modern innovations that result in a tangible impact on site. This can include reducing standing time by improving reliability or by making the equipment more user friendly.

The Design & Development department at Cambridge Insitu have been expanding on in-house capabilities to include Software development (specialising in C#), CAD/CAM capabilities utilising the SolidWorks software suite, and finite element analysis (FEA). Together with our established machining and electrical engineering resources, these capabilities have allowed development on several different hardware and software lines, with some case studies of existing and future concepts shown in the following short chapter.

The compact size and ease of transport has helped to make the **Reaming Pressuremeter** an extremely useful probe for a large variety of situations. It can be easily carried into restrictive access jobs in basements or taken on a plane if needed. We have deployed the probe offshore, testing marine alluvium from drill ships, and in hand augured holes where the probe is lowered in by hand – it is truly versatile.

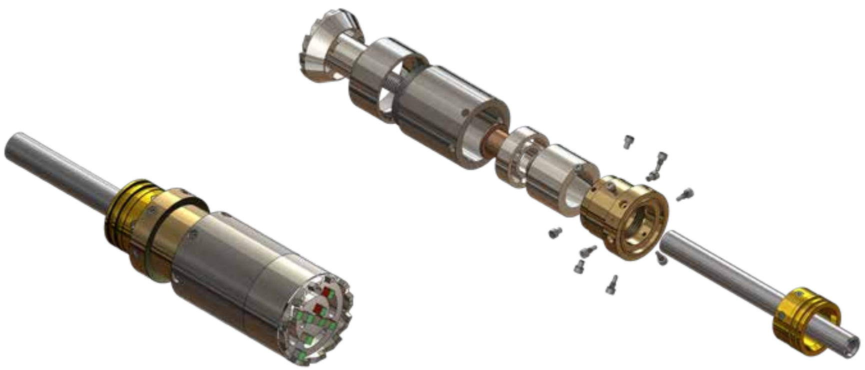
We have had great success mobilising the RPM alongside our SBPM on jobs where the geology is expected to change at depth to a harder/stiffer material. This gives us the ability to get high quality results through the required range of test depths, without unnecessary downtime.



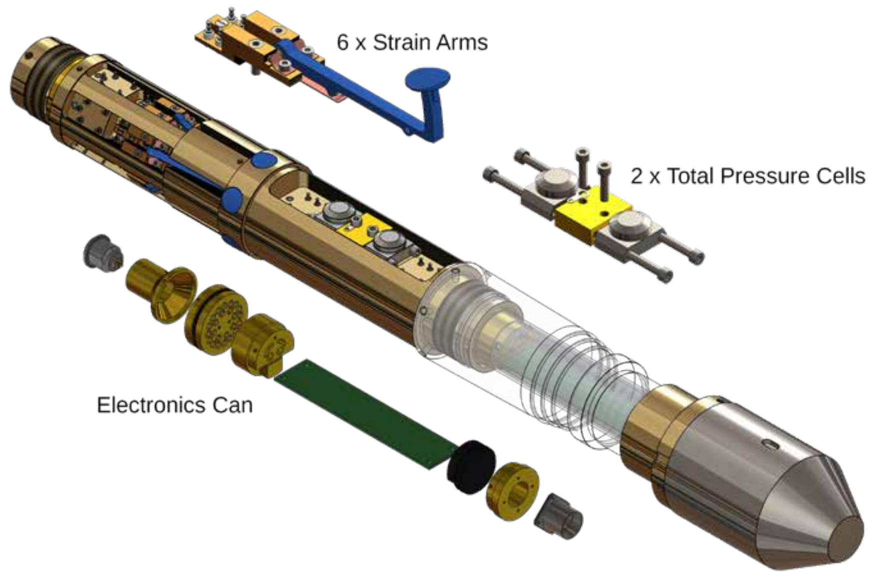


The Self-Boring Pressuremeter's cutting shoe can be set up with either a drag-bit for clays and sands, or with a rock-roller for stiff clays and weak rock. The SBPM uses an inner and outer rod assembly, where the inner rod provides rotation and water flush to the bit while the outer 2" acts as casing and allows the flush and cuttings to return to the surface without degrading the pocket. With the pore pressure cells being in contact with the borehole wall throughout the drilling phase and testing phase, the changes in pore water pressure can be accurately measured.

The design of our cutter-drive technologies are constantly under development to find the most efficient, material-specific system for advancing this instrument downhole.



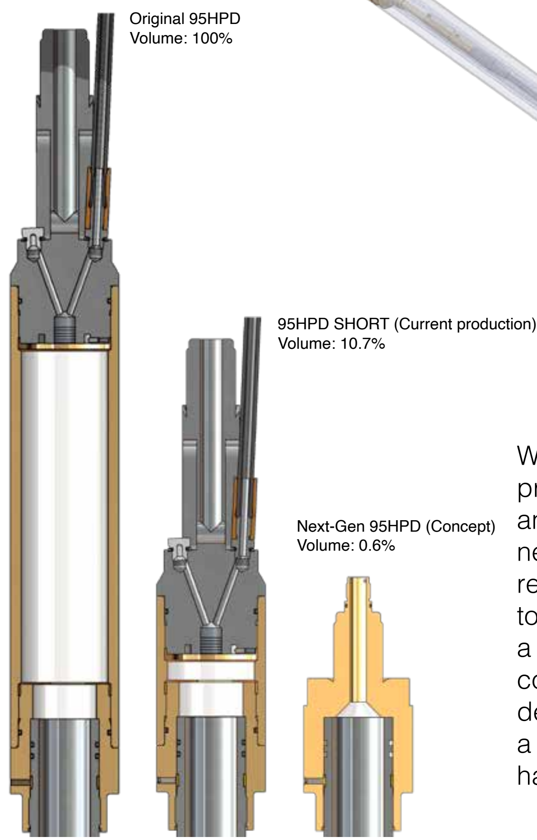
The High Pressure Dilatometer has been designed to have a substantial level of redundancy in the form of two Total Pressure Cells and 6 strain arms. The electronics can is outside of the pressurised area but still protected by the body of the probe, making the probe robust to the rigors of sitework.



Our current **95HPD SHORT** design has proven itself over many challenging projects all around the world. From North Sea Off-Shore wind farms to remote Canadian land sites it has provided high quality data that has been hugely beneficial for engineering design and reduced production costs due to more accurate engineering data.

This HPD has been extensively modelled, modified and tested to make it more reliable. We found that reducing the internal volume of the probe had a marked impact on the severity of potential damage after a high pressure burst (such as in bad ground).

We modified the top of the probe to remove unused space. This dramatically reduced the internal volume by a total of 89.3%, resulting in less water ingress and minimising down time during a high pressure burst. Shortening the overall length of the probe also has the added benefit of reducing the required pocket length.



We have taken this design into production for our customers and are currently working on the next iteration: an even greater reduced internal volume of the top end, down to only 8ml, with a higher level of protection for components while dramatically decreasing weight and length – a significant bonus for manual handling.

Geotechnical Parameters & Analysis

The objective of a pressuremeter test is to measure the insitu-deformation of soils and rocks by the measured expansion of a cylindrical pressurised membrane (EN 1997-2).

The pressuremeters outlined in this article have the capacity to record pressure and displacement, which can be converted into stress and strain. From here, the pressuremeter data can be analysed to produce several engineering parameters of significant use in design. This procedure requires careful selection and categorisation of data. Correct data selection is key to inferring accurate geotechnical parameters.

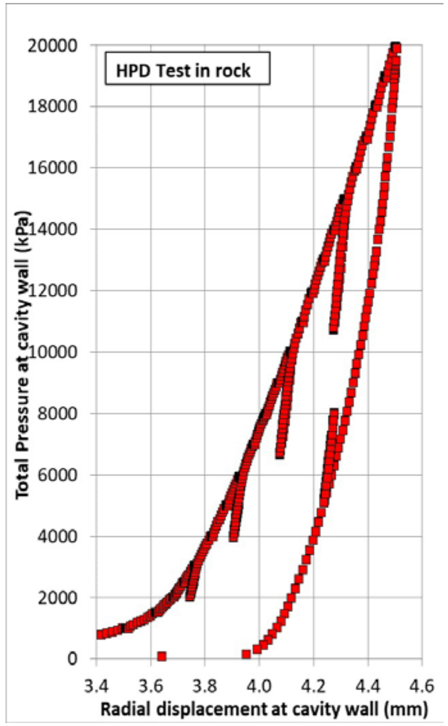
The below table gives an overview of **some** of the common parameters that can be derived from pressuremeter data*.

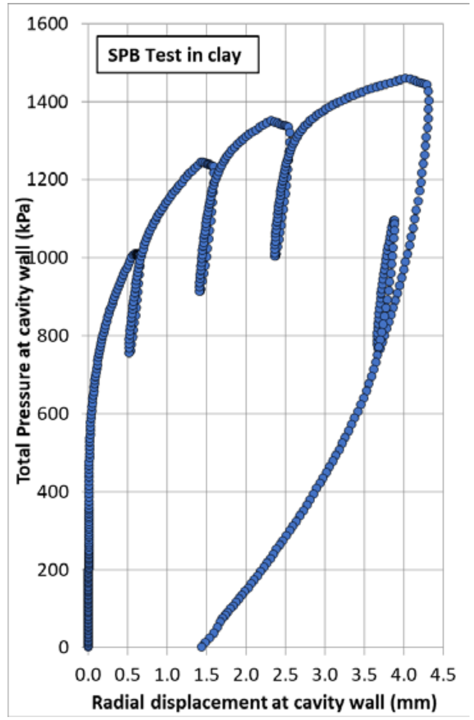
Geotechnical Parameters

Insitu horizontal stress	σ_{ho}
Yield stress	P_f
Limit pressure	P_{lm}
Undrained shear strength	C_u
Frictional strength properties	ϕ_{cv} , ϕ_{pk} , C'
Initial shear modulus	G_i
Shear modulus	G_{ur}
Young's modulus	E

**depending on quality of testing.*

Typically, a sheet of paper has a thickness of about 0.1mm. The instruments that Cambridge Insitu develop, manufacture, and deploy, reliably measure changes of displacement more than 100 times smaller than this; about the wavelength of infra-red light. This level of resolution allows the shear stress/ shear strain response of the ground to be determined for shear strains of less than 0.01% to over 25%.



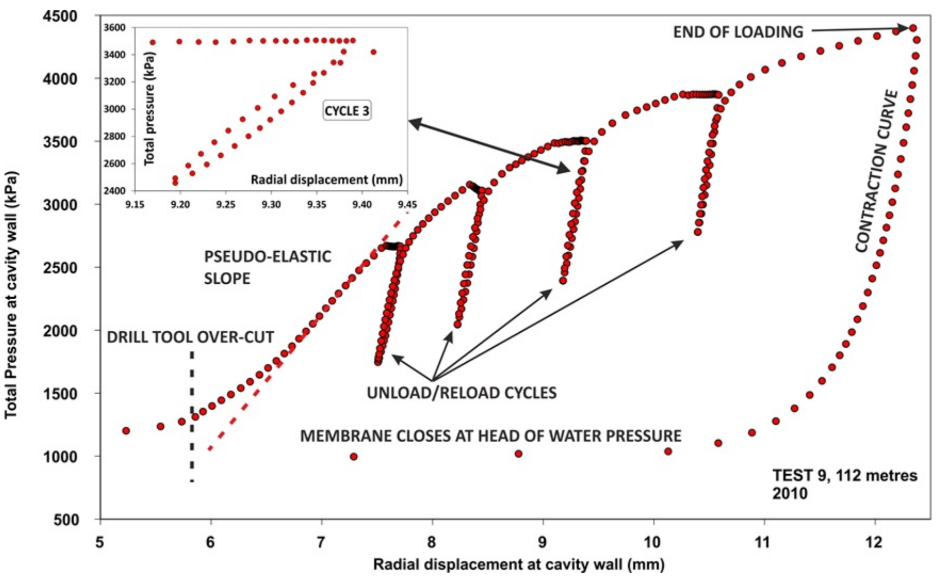


With this versatility and precision, analysed data from pressuremeter testing can be used to inform optimised geotechnical design. Typically, from our high resolution pressuremeters we can determine stiffness, strength and estimated insitu stress state.

A pressuremeter curve has three key parts:

- The loading
- The unloading
- The unload/reload cycles (or reload/ unload cycle on the unloading)

Each of these sections of the curve can be used to determine geotechnical parameters based on cavity expansion and contraction theory. The below example identifies key parts of the curve.



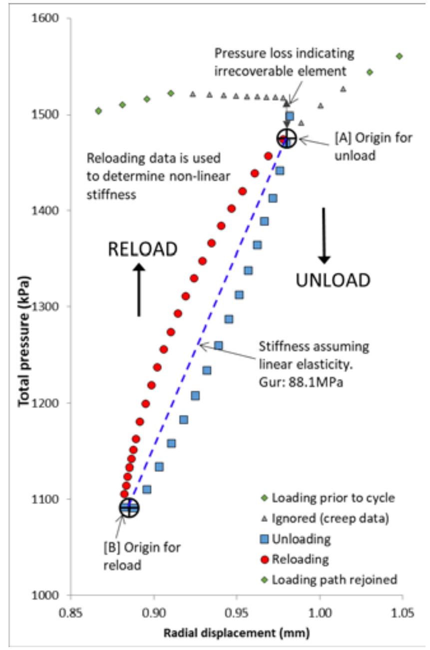
Additionally, test procedure and analysis are always able to be tailored to priorities (such as targeting a specific parameter). Some examples of this include:

- Developing new methods and analysis for determining the major and minor horizontal insitu stress in elastic rock when other methods failed.
- Providing technique recommendations and facilitating the derivation of the limit pressure for a project with innovative pile design.
- Advising on probe choice and insertion method for a project only focused on obtaining high quality stiffness information.
- Working alongside academics to conduct experimental testing on complex and challenging ground.

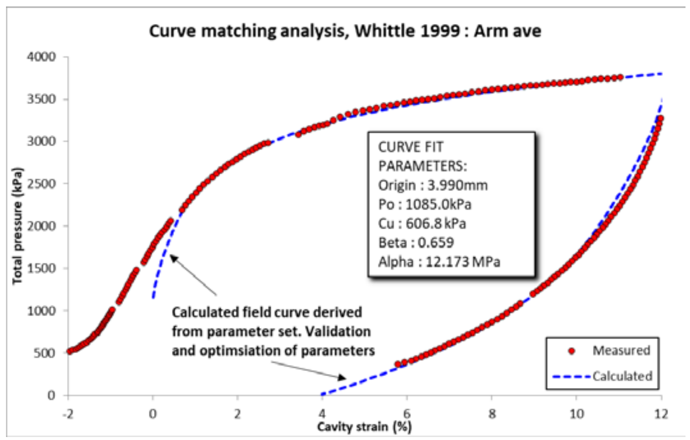
Tests in Soil

Testing in soils is typically split into two categories: drained (frictional) and undrained (cohesive) materials. It is possible to determine if a material is undrained or drained based on the change in stiffness with stress level. If the material is cohesive, after failure, the mean effective stress is constant, and all unload/reload cycles give a similar response.

Plausible and consistent data for shear modulus can be obtained from the unload/reload cycles, with several such cycles incorporated into each test. These cycles can be interpreted as linear elastic or non-linear. A non-linear interpretation is more suitable for soils.



Various techniques are used to determine strength and insitu stress, dependent on material and inserstion technique. Optimisation of these strength and stress parameters are then conducted through curve fitting techniques.



Recent innovation has progressed the analysis of c’-phi materials and the drained analysis of pushed tests.

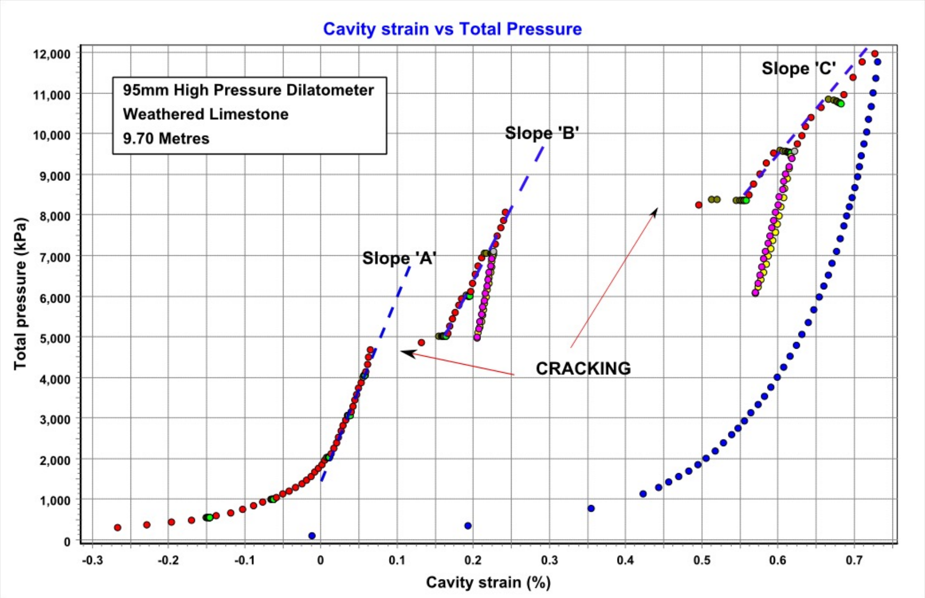
Tests in Rock

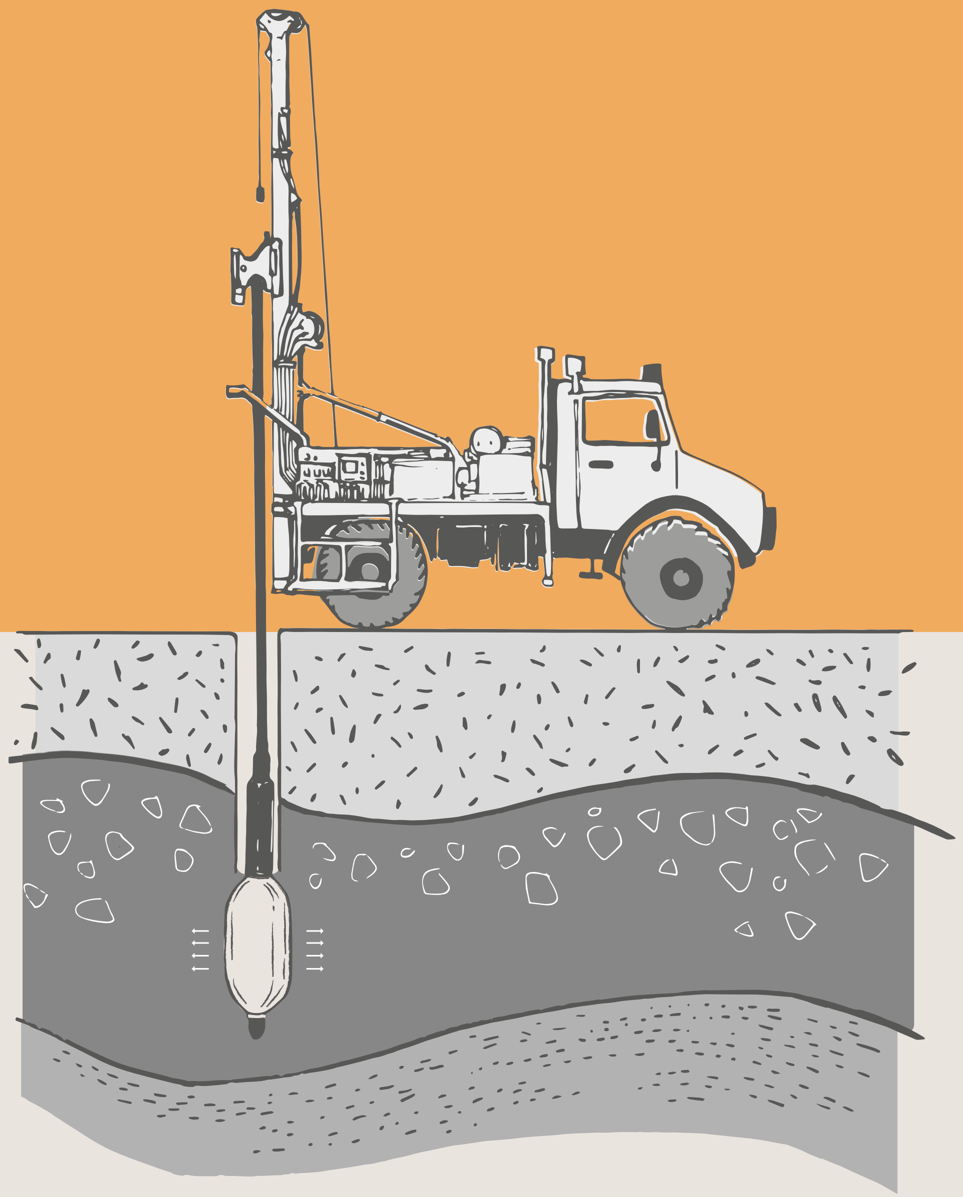
Pressuremeter testing in rock can be split into two types of test:

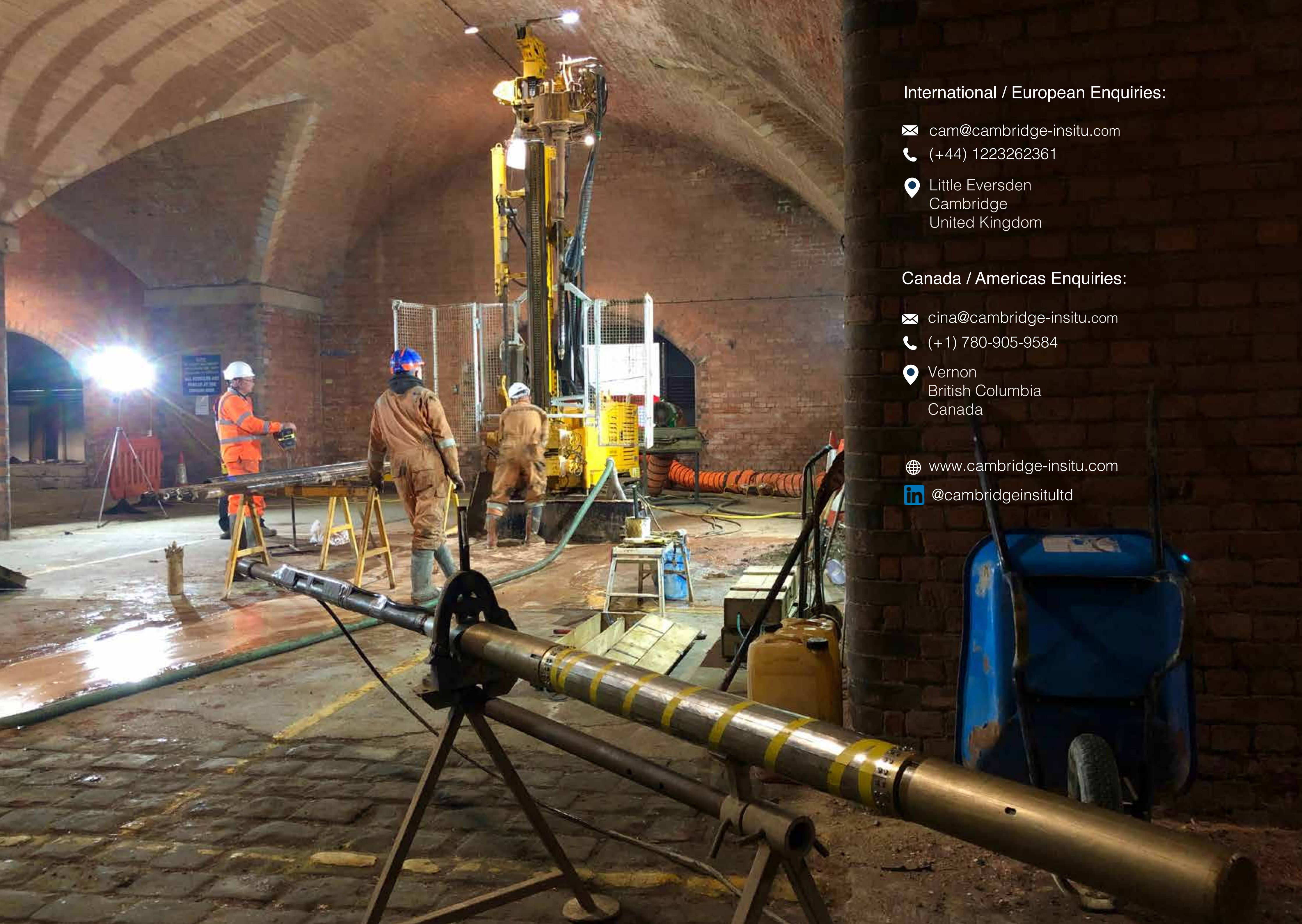
- Type A: Tests where the maximum pressure capability of the probe is the limiting factor, and the material does not yield in shear.
- Type B: material yields well before the maximum pressure capability of the equipment is reached and nonlinear behaviour is observed.

Type B tests are analysed using the same technique as those in soil and the same parameters can be derived. It is regularly found that the test can be extended to a point where structural break down starts to be observed.

For type A tests, when plotting pressure against displacement, a test curve is produced with a typical linear elastic characteristic. The interpretation is predominantly concerned with producing values for stiffness and occasionally insitu stress. Often tensile failures can be observed. The figure below is an example of significant fracturing occurring at the points highlighted as “cracking”. After the second fracture, the slope of the loading changes. This is unlikely to be a shear failure – but instead is anticipated to be multiple tensile failures.







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