47mm Reaming Pressuremeter (RPM) Method Statement

Testing from a Heave Compensated DP Vessel via wireline

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Table of Contents

1.0 Equipment

A Cambridge Insitu (CI) manufactured 47mm Reaming Pressuremeter (47RPM) with 150m umbilical, electronic interface unit and high-pressure control panel (HPCP).

Bought/not-bespoke equipment is also provided including 0.5m BW rod and sub, 2 x 12l air cylinder, 12 Volt vehicle battery, pneumatic hoses, site tools and site laptop.

1.1 System Diagram

All units are millimetres. Overall length is indicative only as it depends on final sub arrangement.

Please see the RPM specification sheet for further instrument specific details at www.cambridge-insitu.com

Figure 1.0. CAD render of an 47mm RPM configured without subs.

2.0 Drilling Requirements

1. To carry out a test the main contractor will use downhole CPT equipment to produce a pocket 1.0-1.5m in length using a $10cm^2$ cone. It is recommended to have a $15cm^2$ cone system available should the ground conditions demand a larger diameter pocket for the RPM. The pressuremeter operator should be present when the CPT push is taking place to assess if the material will be suitable for the RPM.

2. The RPM is then to be attached to a modified Non-Coring Device (NCD) or core barrel via a suitable adapter supplied by the main contractor. This allows the RPM umbilical to pass safely through the latching assembly before being fastened to the wireline. These details are to be discussed with the main contractor before work commences.

3. Once a pocket of suitable length has been made, the drill string is pulled back only far enough to retrieve the downhole CPT tool, before attaching and lowering the RPM, then latching it into the drill string. (it is important that the umbilical is kept under as much tension as possible during lowering, to prevent the umbilical and wireline from tangling.) The RPM has an umbilical hose/cable which should be passed through an elevated sheave if available and taped to the wireline at regular intervals if possible (approx. every 6m). Once latched into the drill string the RPM will protrude from the bottom by approximately 1.0 metres. The test centre of the RPM is 0.3m above the dummy cone. The drill string is then carefully lowered to push the RPM into the pocket by at least 0.7m.

4. It is very desirable that we discuss the working procedure with the actual drilling sub-contractor before the contract starts and arrangements should be made for us to do this as soon as possible after the award of the contract.

3.0 Mobilisation of RPM

1. Prior to the project, the pressuremeter is calibrated. This includes transducer calibrations for each individual arm as well as the total pressure cell. Further to this, the Pressuremeters' system compliance is measured to account for any deformation of the probes body itself under pressure. Finally, the individual membrane fitted to the probe is calibrated, allowing for a correction to made in the live test. In the event of a membrane being replaced, the new membrane is also calibrated. All calibrations can be completed whilst on site if necessary. The Instruments' pre-project calibrations and any other calibrations undertaken will be included in the report.

2. The pressuremeter and its associated equipment shall be shipped to the vessel in a specified port ready for embarkation. The operator will join the vessel before testing is due to take place and ready the equipment.

3. The RPM is to be assembled on-deck on the supplied A-frame, with electronic interface box, HPCP and operators site laptop set up in a sheltered, dry location with access to electrical power. Compressed air cylinders (charged to >15MPa) are also to be set up on deck, strapped upright to prevent toppling movement, but at a suitable distance to the operators HPCP as to allow for pneumatic hose length.

4. Following successful set up of the instrument on deck, pre-test zeroes are to be taken using the electronic interface and laptop (using supplied '*Winlog*' software). These data readings denote the instruments recording values at atmospheric conditions and serve as a record of the instruments condition pre-test.

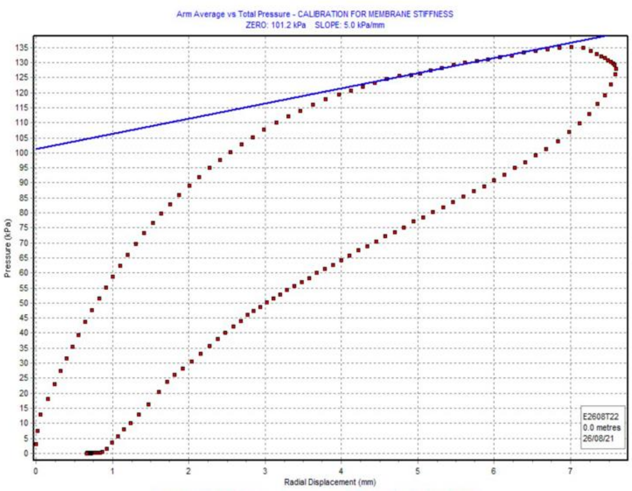

Figure 2.0. RPM membrane stiffness calibration, determining membrane slope.

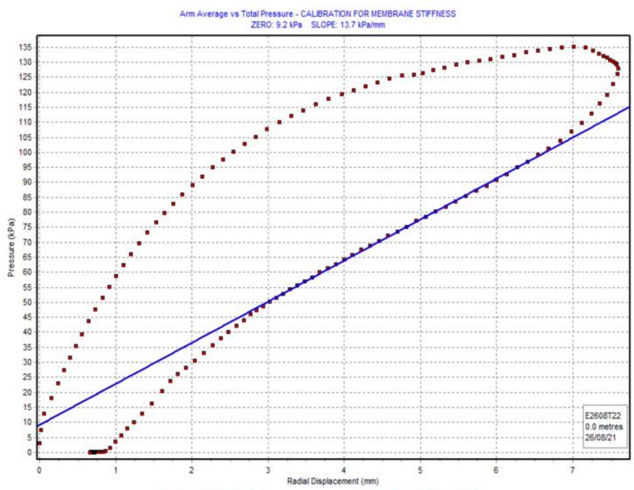

Figure 3.0. RPM membrane stiffness calibration, determining membrane zero.

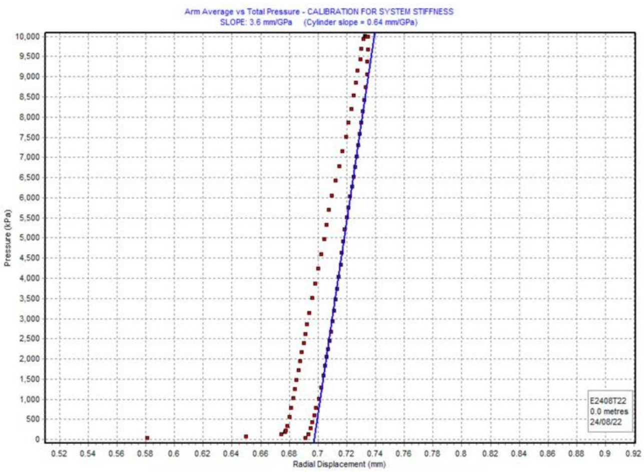

Figure 4.0. RPM system stiffness calibration, determining the entire systems deformation under stress.

4.0 Methodology for Operating Reaming Pressuremeter (RPM)

1. The RPM is intended to be inserted into the ground for testing via a pre-formed pocket, formed by a CPT stroke. The pressuremeter is then lowered into the borehole via a wireline system.

2. The RPM has an umbilical hose/cable which should be taped to the drill string at regular intervals, approximately every six metres. The instrument must be lowered to an adequate depth within the respective pre-formed pockets as for the entire expanding section to sit in a homogenous material. This can be decided via core samples or CPT data and is for the discretion of the Pressuremeter engineer.

3. Once the RPM is successfully located in the pocket, a cavity expansion test is carried out taking approximately 30 minutes for a typical test. Upon completion of the test, the RPM can be retrieved from the drill string and the borehole advanced to above the next test location.

4. The immediate results from the test are presented as a graphical plot (presented in *'Winlog'* software) of pressure (kPa) versus radial displacement (mm). These are direct measurements produced by the pressuremeter. Therefore, these graphs illustrate the data collected presented without any post processing, save the corrections made by calibrations. Following the completion of pressuremeter testing on the project, the graphs and the data they contain are analysed to produce the post-processed final results and engineering values. These are included in a factual report deliverable.

4.1 Testing Procedure Overview

The steps involved in the testing procedure as outlined below can be seen graphically explained in the figures 5.0, 6.0, 7.0 and 8.0 below. (Note: these plots are examples of this kind of test only).

To carry out a test the main contractor will need to form a pocket >0.6m in length made using either rotary drilling/coring, an SPT split spoon or CPT.

1. The cavity expansion test should be stress controlled with pressure and displacement readings being recorded every five seconds.
2. Unload/reload cycles should be taken once the level of stress has been raised high enough to overcome the total vertical stress.
3. In a test in a competent material such as a weak rock, pressure holds known as 'creep holds' should be taken at specific pressure increments during the test at the discretion of the operator.
4. At least three unload/reload cycles should be taken at different levels of strain to provide the best possible data for shear modulus.
5. Unload/reload cycles may be taken during the loading and unloading phases of the test, at the discretion of the operator.
6. The pressure should be held briefly before each unload/reload cycle to ensure that material creep is at a minimum.
7. During each unload/reload cycle the pressure should be decreased by approximately one third of the starting pressure of the cycle.
8. Each cycle should consist of approximately ten data points for the unloading and loading phases, a total of approximately 20 points. The stress level should remain above the total vertical stress throughout each cycle.

4.2 Notes on Methodology

The success of this method depends on the stability of the pocket left by the downhole CPT equipment. The common issue is that upon retracting the drill string after the CPT push, it is possible that the open borehole will shed material into the pocket making it impossible to push the RPM into it. It is important to only retract the drill string as far as is necessary to retrieve the CPT equipment therefore minimising the risk of this issue occurring.

The effects of ambient swell and current conditions on a test are of interest when testing offshore. The below figures 5.0 and 6.0 depict two tests conducted during significant wave action. The effects are manifested as “noise” amongst the data during the part of the test subjected to the swell conditions. In these cases, whilst reliability in the data is reduced, the results were still publishable, and could be correlated with other pressuremeter tests nearby. Furthermore, the presence of redundancy in the data (such as multiple unload-reload cycles) allows for confidence owing to repeatability.

A Pressuremeter test is defined as having taken place and being, therefore, chargeable when the Pressuremeter has reached the correct depth with all transducers working and pressure has been applied to it. The greatest care will be taken in designing and conducting the test to gather the maximum possible quantity of useful data. If the ground conditions are such that the instrument membrane bursts prematurely the test fee remains payable.

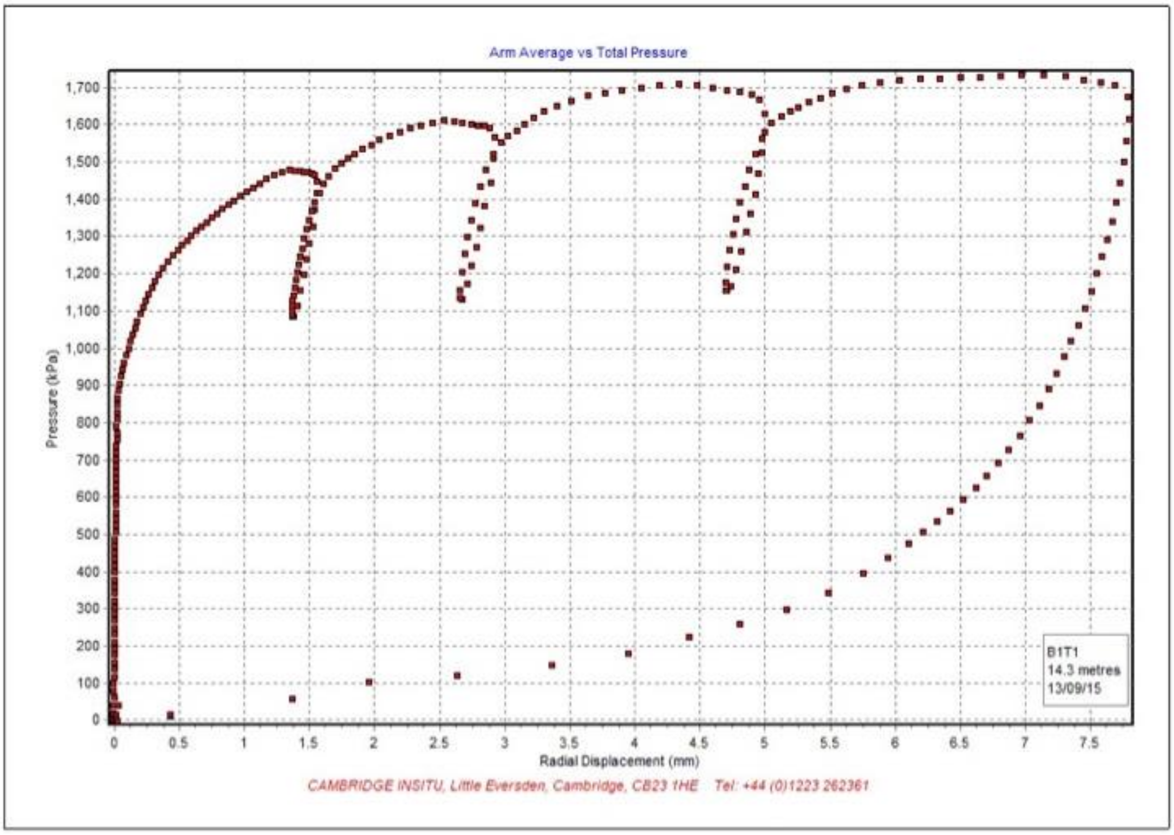

Figure 5.0. Wave action effecting initial loading portion of the test only.

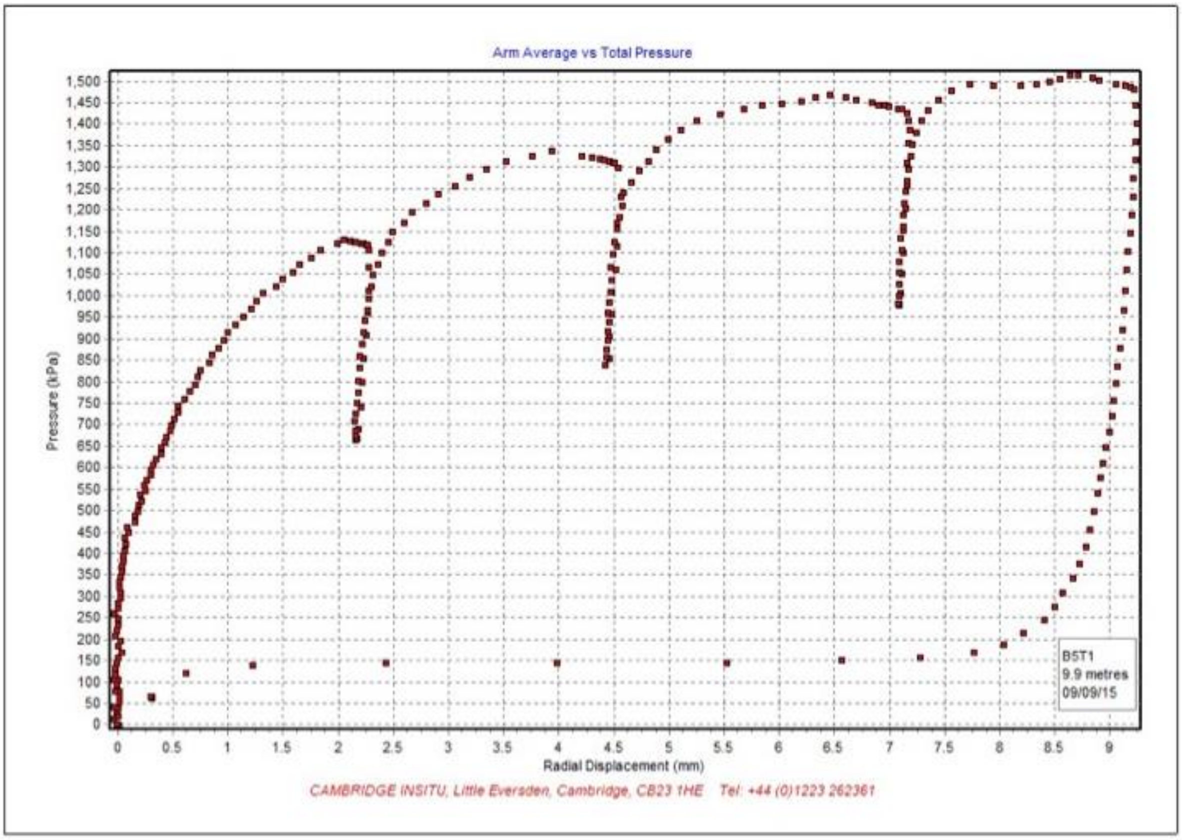

Figure 6.0. An example of the worst-case effects of wave action and ambient swell conditions.

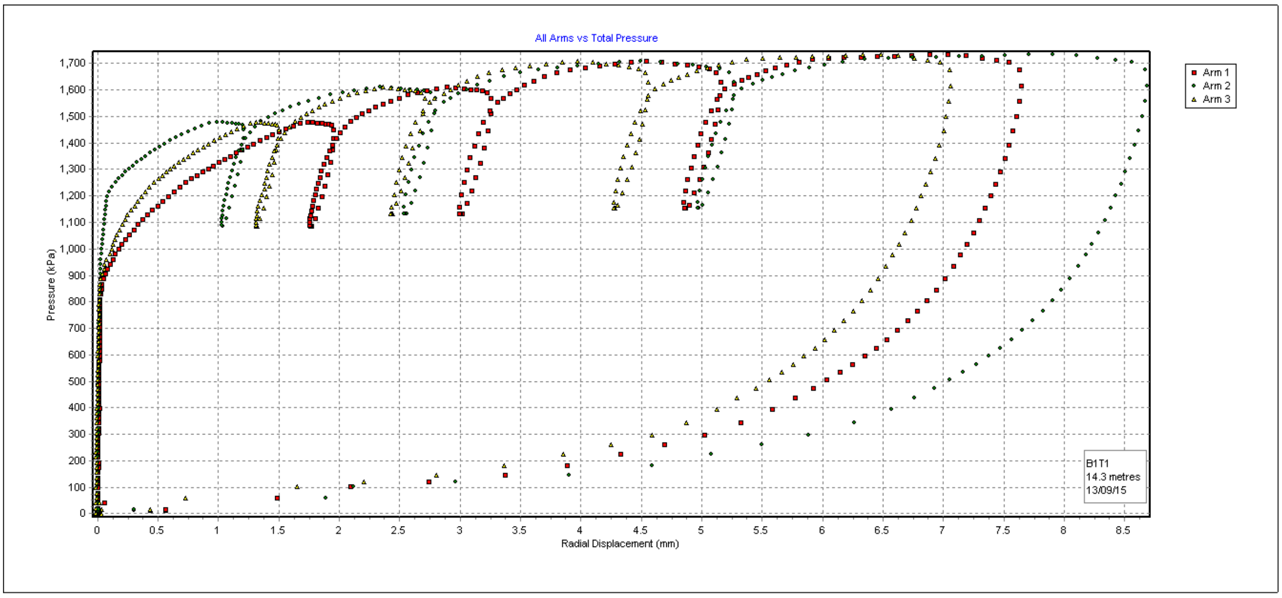

Figure 7.0. Data points as seen on software 'Winlog' during live testing. This plot illustrates the displacement data from all three individual arms (x) versus the total pressure in the probe (y).

Pressure hold before 1st unload/reload cycle to ensure creep is kept to a minimum.

Unload/reload cycle (2nd of 3 on the loading part of the test).

The unloading component of the test. The pressure is gradually reduced until reaching its initial stress-state.

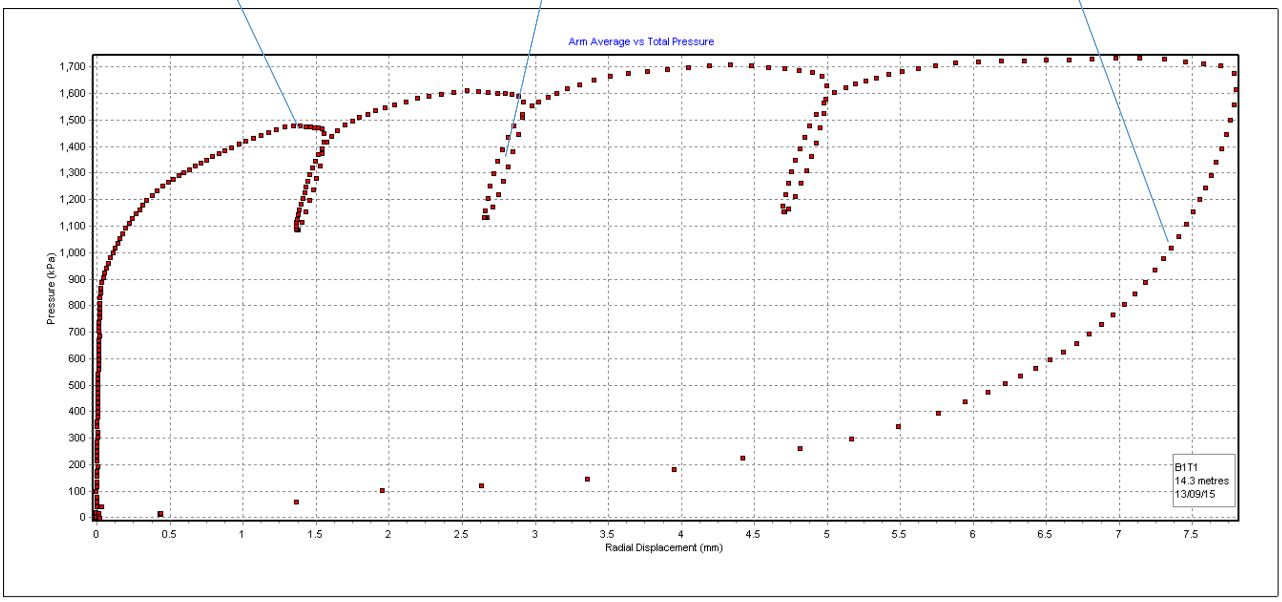

Figure 8.0. Data points as seen on software 'Winlog' during live testing. This plot illustrates the displacement data from the average of the three arms (x) against the total pressure in the probe (y).

5.0 Post Processing

Following completion of a successful test, the results on the graph displayed in figure 7.0 and 8.0 are processed using the 'Winsitu' software (Cambridge Insitu Limited in-house analytical software). An example of a typical test of this type being analysed can be seen in this chapter. Note: these graphs are examples only, the reported analysis techniques depend on the test type and quality.

The pressuremeter loading curve can be solved directly using mathematical expressions for the expansion of a cylindrical cavity. The solution conventionally is quoted in terms of stiffness and strength parameters for the material, specifically shear modulus, shear strength or friction angle as appropriate, and the insitu lateral stress. A number of simplifying assumptions are made about the nature of the test and the ground. For example it is assumed that the material is fully saturated, homogenous, isotropic and behaving as a continuum that fails in shear only and that the length of the pressuremeter is great enough for the test to be modelled as a plane strain expansion.

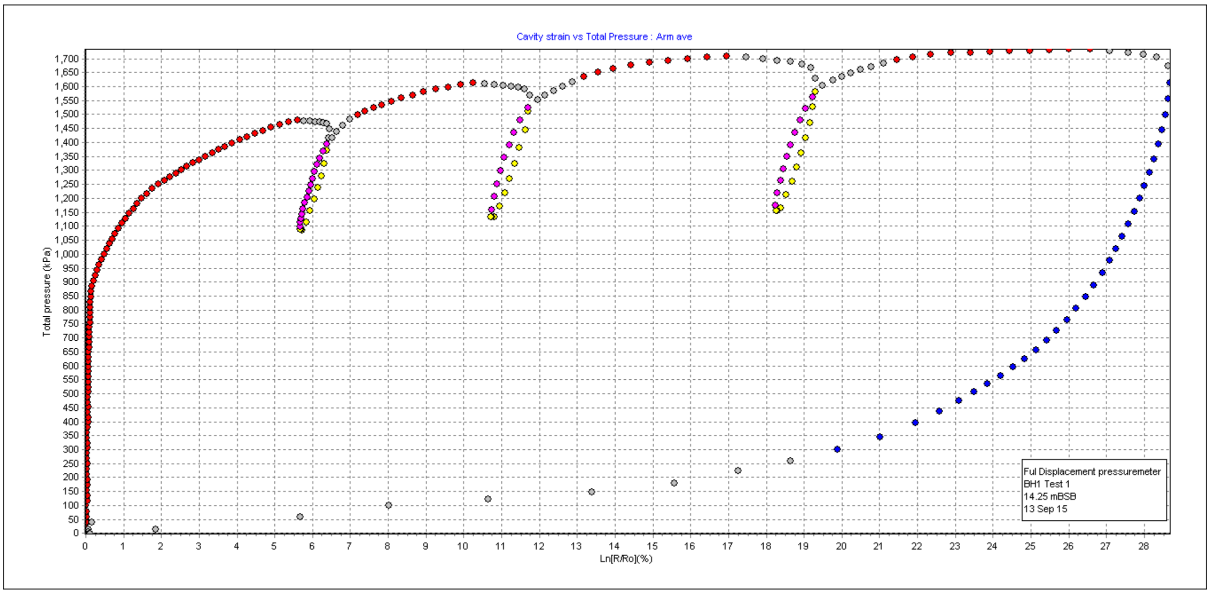

Figure 9.0. Data points as seen on software 'Winsitu' . This graph shows the plot of Cavity Strain vs Total Pressure (arm displacement average).

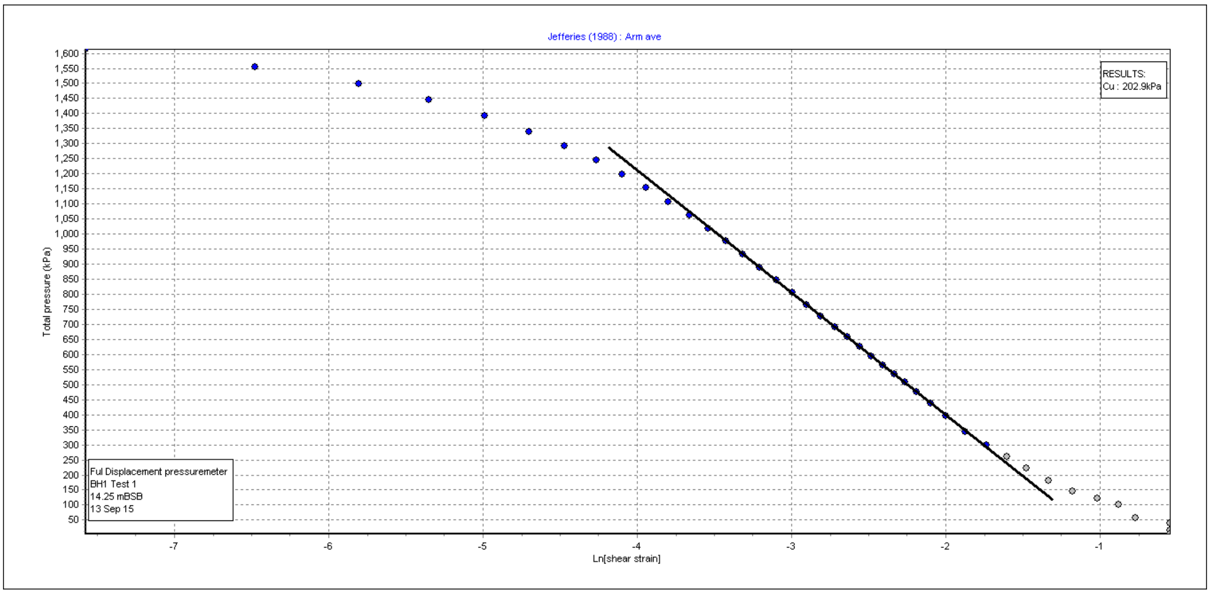

Figure 10.0. Data points as seen on software ‘Winsitu’. This graph shows the plot of the Jefferies (1989) analysis. NOTE this analysis is based on the data from the unloading part of the pressuremeter

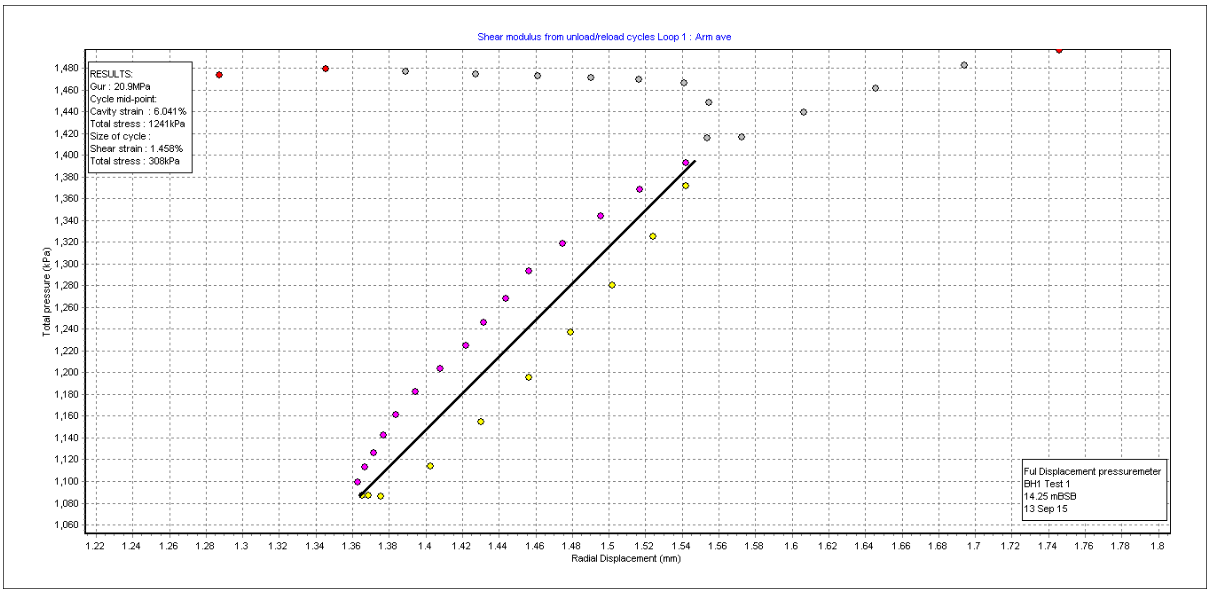

Figure 11.0. Data points as seen on software ‘Winsitu’. This graph shows the linear plot of the unload/reload cycles analysed to provide values of shear modulus. NOTE this is undertaken for each unload/reload cycle.

Modulus data is obtained from small cycles of unloading and reloading (as seen analysed in figure 11.0 and 12.0). These give consistent and repeatable descriptions of stiffness characteristics.

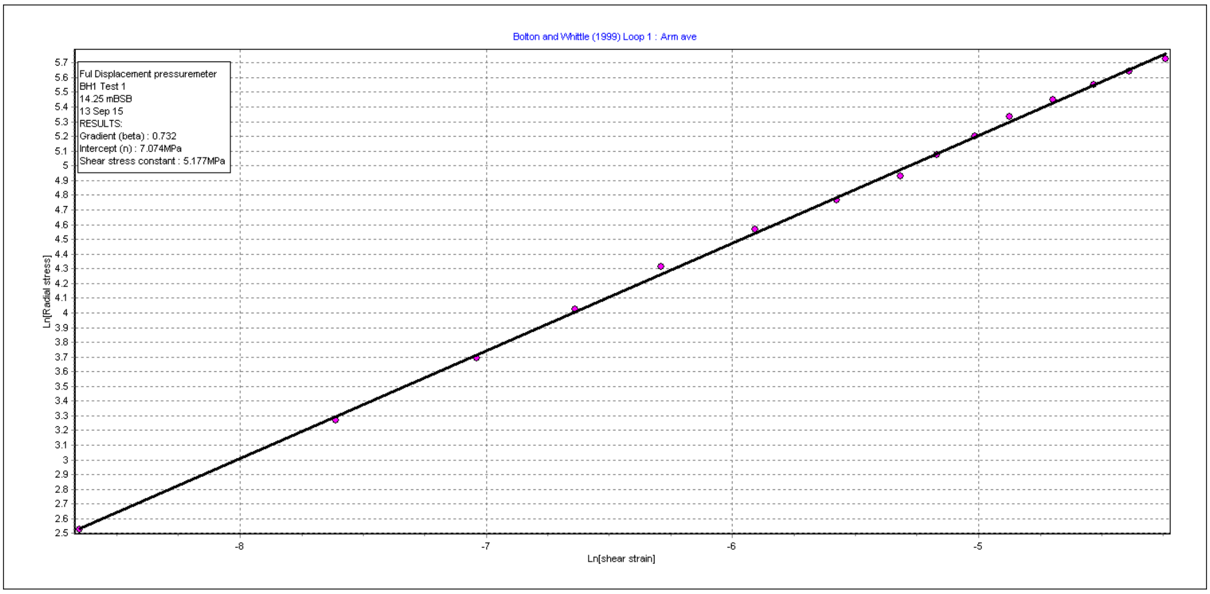

Figure 12.0. Data points as seen on software 'Winsitu'. This graph shows the non-linear plot of the unload/reload cycles. NOTE this is undertaken for each unload/reload cycle.

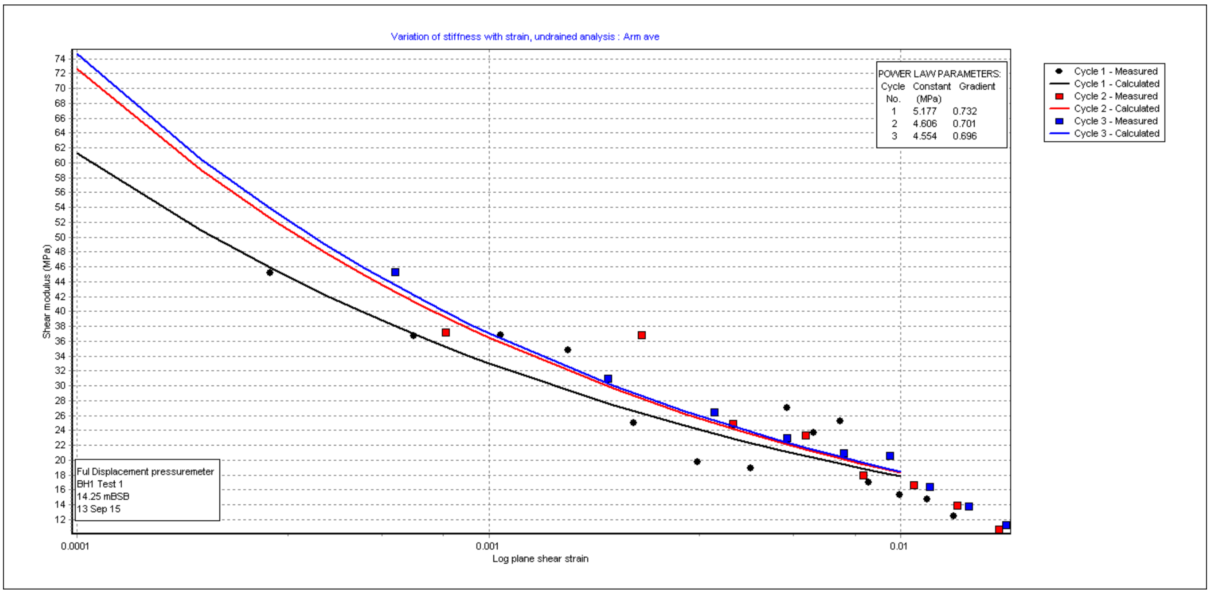

Figure 13.0. Data points as seen on software 'Winsitu". This graph shows the variation of stiffness with strain, undrained analysis.

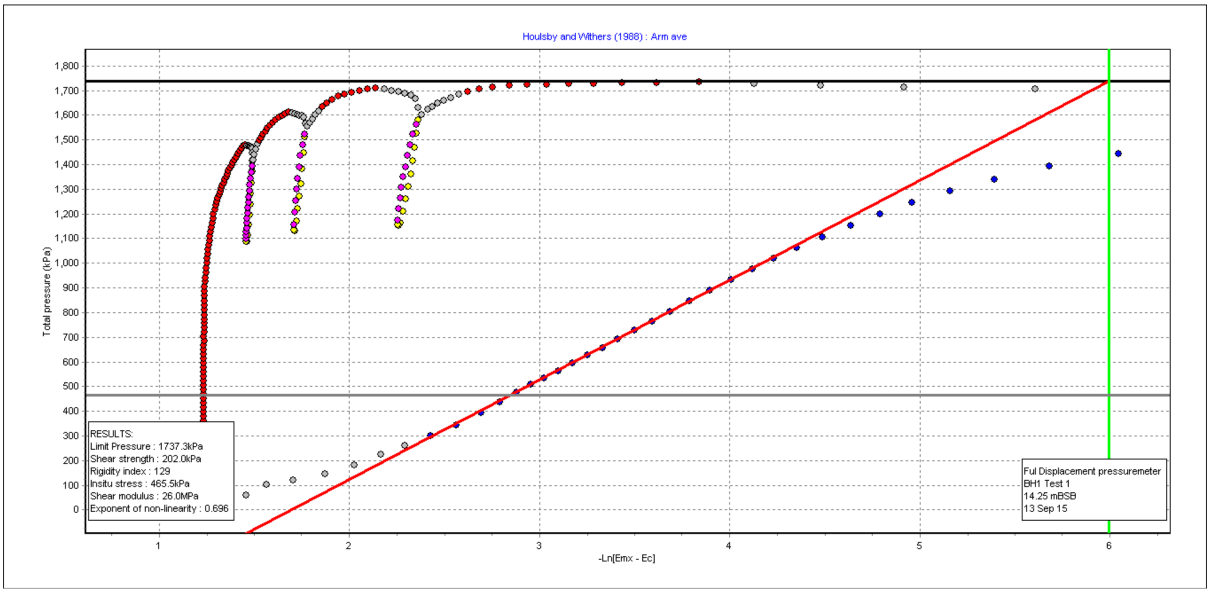

Figure 14.0. Data points as seen on software 'Winsitu'. This graph shows the Houlsby and Withers (1988) analysis.

Tests can been analysed as undrained expansions where the solution proposed by Houlsby & Withers (1987) are used to determine strength, limit pressure, shear modulus at failure and the cavity reference pressure. The analysis assumes a simple elastic:perfectly plastic shear stress:shear strain response from the pressuremeter unloading curve, and that the unloading starts from the material limit pressure.

6.0 Methodology for Operating Air Compressor and Air Cylinder

It is often necessary whilst undertaking Pressuremeter testing to charge/recharge the 12l air cylinder used to supply the compressed air to the probe during testing.

6.1 Equipment

Electric compressor Unit (44kg, Max Pressure 33MPa, 230V/50Hz – power requirements may vary depending on project). 2 x 12l air cylinders (17kg, Max Pressure 30MPa).

Note: Always follow manufacturers instruction manual when operating compressor.

6.1.1 Storage of Compressor and Air Cylinders

Both the air cylinders and compressor must be stored in a cool, dry place. Air cylinders must also be stored, strapped securely into place with a ratchet-strap standing up.

6.2 Charging Operation

6.2.1 Preparation/Pre-operation Checks (Air Compressor)

1. Check compressor for valid PAT test certificate and conduct visual check for damage of wires/cables, pneumatic hoses, plugs, valves, gauges, compressor housing and plastic casing.

2. Check compressor dipstick for sufficient oil level. Top up if required.
3. Check all valves on compressor are shut off completely.
4. Locate suitable location for charge, ensure position is protected from any rainfall or surface water and has a safe/reliable source of electrical power, as well as being away from people eg. away from main gangway/walkway/rest areas (Ask site manager for assistance if necessary).

6.2.2 Setup of Air Compressor

5. Position compressor in chosen location. This should be a two-person lift (compressor weighs 44kg, see Risk Assessment).
6. Connect compressor to Electrical power supply.
7. Ensure physical check that electrical plug connections are sound.

6.2.3 Preparation/Pre-operation Checks (Air Cylinders)

8. Check air cylinder's valve is shut off completely.
9. Check air cylinder has valid in-date inspection certificate and conduct visual check for corrosion/damage to cylinder, valve and rubber protective mesh/base.
10. Position air cylinder in reach of compressor pneumatic hose. Cylinder position must be strapped securely into place with a ratchet-strap standing up.

6.2.4 Charging

11. Connect compressor's pneumatic hose to air cylinder. Conduct physical check (twisting and pulling motion on pneumatic hose to ensure connection is secure.

At this point the air cylinder is now ready to be charged following the manufacturer's instructions.

12. During charging regularly inspect pressure gauge to ensure max pressure of cylinder is not exceeded.

NOTE: The air cylinders have a max pressure of 30MPa.

6.3 Post-Charging

Once the air cylinder is at the desired pressure as measured by the pressure gauge on the pneumatic hose, the operator needs to safely disconnect the cylinder from the compressor.

6.3.1 Disconnecting Air Cylinder

1. Shut cylinder valve off.
2. Open bleed valve on pneumatic hose (this will bleed the air pressure from the gauge-cylinder section of the hose, thus allowing the hose to be safely unscrewed/disconnected from the air cylinder).
3. Unscrew hose from cylinder.

6.4 Replacing Air Cylinders

When the pressure in a cylinder drops below a usable amount, the air cylinder must be replaced. This does not make the cylinder 'empty', and in some cases, there may still be up to 10MPa air pressure in the cylinder. This replacement process requires residual pressure to be bled from the system for it to be safe, and can be completed either mid-test or after/before a test.

6.4.1 Disconnecting Air Cylinder

1. Shut off HPCP valve, thus preventing air flow and pressure from the regulator to the HPCP output/probe. This will maintain the pressure in the probe, but obviously makes it impossible to increase the pressure.

2. The air cylinder valve can now be shut off completely, further isolating the system. This now only leaves the pneumatic hose (between HPCP and air cylinder) and the regulator section of the HPCP being left to bleed to be able to make a safe disconnection.

3. Both the pneumatic hose and the HPCP have bleed valves that can be used to bleed the system. Typically, the HPCP input bleed valve is the preferred option. Open this valve and the pressure in the hose and the regulator section of the HPCP will equalize to atmospheric pressure.

4. The hose can now be unscrewed from the air cylinder. The inadequately filled cylinder can now be refilled (see section 1.0 Methodology for Operating Air Compressor and Air Cylinder).

6.4.2 Connecting a New Air Cylinder

5. Take a full air cylinder and once strapped and secured upright screw the pneumatic hose into the cylinder valve. Ensure all the bleed valves are shut and hose connection is sound.

6. Open cylinder valve, slowly at first to ensure that the air pressure transferring from the bottle to the hose does not escape through a leak caused by an inadequate connection or similar fault. Once the system is secure, open the valve fully. This fully pressurizes the regulator section of the HPCP and the gauge pressure (on the HPCP) should reflect what quantity of pressure is now available to the system.

7. Open the HPCP valve, allowing air flow and pressure to transfer from the regulator to the probe. Continue testing as normal.