INSTRUCTION MANUAL

PRESSUREMETER

Model TRI-MOD-S

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TABLE OF CONTENTS

1 GENERAL

1.1 DEFINITION AND PURPOSE OF TEST

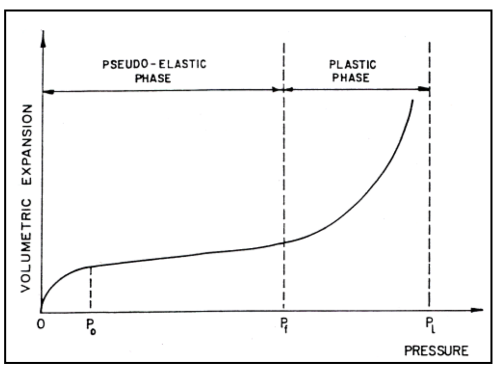
The pressuremeter test is a load test carried out in-situ in a borehole. An inflatable cylindrical probe is set at testing depth in a pre-drilled borehole. Thanks to its high working capacity and good resolution, the TRI-MOD-S can be used both in medium to stiff soils as pressuremeter and in rock as a dilatometer (or rock pressuremeter). This pressuremeter includes a hydraulic pump and a readout unit allowing to load and monitor the tested material's response. The data collected defines the stress-strain relationship of soil or rock with depth. The pressuremeter test data is mainly used to determine the limit pressure and pressuremeter modulus. The limit pressure is used to calculate the bearing capacity. The pressuremeter modulus is used to evaluate absolute and differential settlements for specific foundation designs.

1.2 PRINCIPLE OF TEST

The probe is set at the test depth using the method that will produce the least disturbance to the test material. In place, the probe is submitted to equal increments of increasing pressure. The probe radial changes for each pressure step. The pressure - radial (or volume) change data is plotted to determine the limit pressure P_L and the pressuremeter deformation modulus E. These values are used for foundation design using the methods described in suggested references presented in appendix.

1.3 RESULTS AND THEIR USE

Figure below shows a typical pressure-volume curve obtained from a pressuremeter test. Note that the pressure (or volumetric/radial change) parameter will be presented sometime on the abscissa, sometime on the ordinates depending on the user's choice.



Pressuremeter Curve

The curve can be divided into three parts:

1.3.1.1 FROM P = 0 TO P = P_0

This portion of the curve corresponds to the probe seating against the borehole wall. The wall disturbance induced by drilling or driving the probe into place has considerable influence on this segment of the curve. The difference in borehole and probe diameters also affects this segment.

1.3.1.2 FROM $P = P_0$ TO $P = P_F$

This segment represents the pseudo-elastic behavior of the tested material. The probe is in contact with the borehole walls. The loading is uniform along the probe length. This segment is quasi-linear and defines E, the deformation modulus of the tested material.

1.3.1.3 FROM $P = P_F$ TO $P = P_L$

P_f by definition is the pressure at which the mass enters a plastic state. In most cases where the TRI-MOD-S is used as a dilatometer in rock, P_f is not reached. Above P_f, the loaded mass' deformation accelerates up to the complete failure point. The pressure that defines failure is the limit pressure P_L. This fundamental mechanical characteristic of the mass is used to evaluate the stability of foundations in accordance with pressuremeter methods.

2 DESCRIPTION

The TRI-MOD-S pressuremeter requires N size (75 to 78 mm) boreholes and has a maximum working pressure of 20 MPa (3000 psi) with the limitations outlined further on in this manual.

The TRI-MOD-S pressuremeter consists of the following main elements:

- A probe,
- An Hydraulic pump and a compressed gas cylinder,
- A readout unit,
- Tubing and electrical cable,
- Two calibration tubes.

2.1 THE PROBE

The probe is comprised of a brass cylindrical core on which six feelers spaced 60 degrees apart are mounted. The displacement of the feelers is measured using strain gauged cantilever arms. The cantilevers are diametrically coupled in pairs to form three full bridges.

An inflatable outer metallic sheath covers the probe core. The sheath is comprised of an inner polyurethane membrane to which are bonded on its outer surface a series of reinforcing metal strips. This easy-to-change metallic sheath is held in place by steel sleeves and threaded nuts located at the extremities of the probe. The sheath is sealed by O-rings located under the steel rings.

The top part of the probe is fitted with:

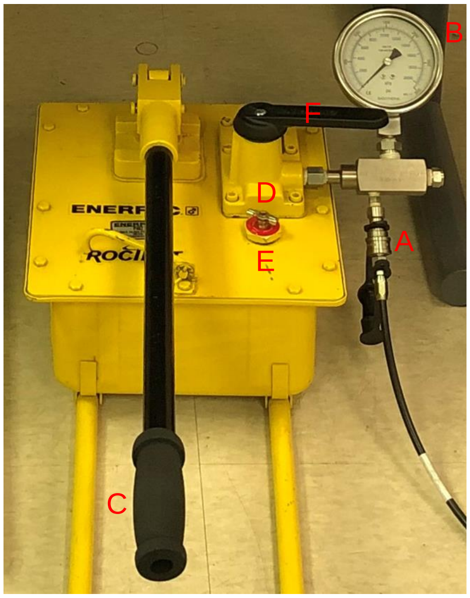
- Two hydraulic fittings to hook up the inflation and deflation lines;
- A multi-pin electrical connector which mates with the electrical cable leading to the readout unit;

- An outer threaded portion onto which the adapter used to connect the probe to the AW rods or BW casing screws. These rods or casing are used to lower the probe within the borehole to the test depth.

2.2 HYDRAULIC PUMP

The hydraulic pump is used to inflate the probe in pre-selected increments. It comprises:

- A female quick connect to hook-up the tubing leading to the probe (A)
- A 20 000-kPa range / 200-kPa resolution pressure gauge (B)
- A Lever (C)
- A Release Valve (D) – Keep open when pump is in use and close for transportation
- A Vent/Fill Cap (E)
- Valve (F) – Turn counter clockwise to open and clockwise to close.



Standard Model Enerpac P462 Pump main specifications:

- Maximum pressure rating : 700 bars
- Usable oil capacity : 7572 cc (extended when long tubing are used)
- Type of oil : Enerpac LX or HF oil

WARNING ! The model P462 pump provides a 2-stage flow : a high-flow stage under approximately 14 bars and a low flow stage over 14 bars. When pump pressure reaches approximately 14 bars, the user must momentarily stop pumping and raise the handle to shift to high pressure stage. After the pump shifts, pumping takes less effort.

2.3 COMPRESSED GAS CYLINDER (OR PNEUMATIC PUMP)

The gas cylinder is used to force back the oil into the hydraulic pump after a test. This gas cylinder normally comes with a pressure regulator and a 7000-kPa range / 250-kPa resolution manometer.

2.4 READOUT UNIT

The readout unit consists of a P-3 strain gauge indicator. The diametrical changes are displayed in mm, with a resolution of one micron. Pressures are read directly on the pressure gauge.

2.5 TUBING AND ELECTRICAL CABLE

The inflation tubing has the following characteristics:

- Outside diameter: 8 mm
- Inside diameter: 4 mm
- Working pressure (at 20°C): 32.5 MPa

The electrical cable has 10 conductors and an outside diameter of 11.6 mm.

2.6 CALIBRATION TUBES

The TRI-MOD-S must be used with the two steel tubes provided by the manufacturer. One tube has a nominal internal diameter of 76.2 mm, and a second tube has a nominal internal diameter of 82.5 mm. The exact internal diameter of each tube must be measured and marked on the tubes. These tubes serve as accurate references to determine the conversion factors in mm vs. mV/V for each TRI-MOD-S. For more details, see the section below on equipment verification.

3 ASSEMBLY AND CALIBRATION

3.1 SHEATH ASSEMBLY

The probe is delivered assembled and tested ready to use. Should it be necessary to change a damaged sheath, proceed as follows.

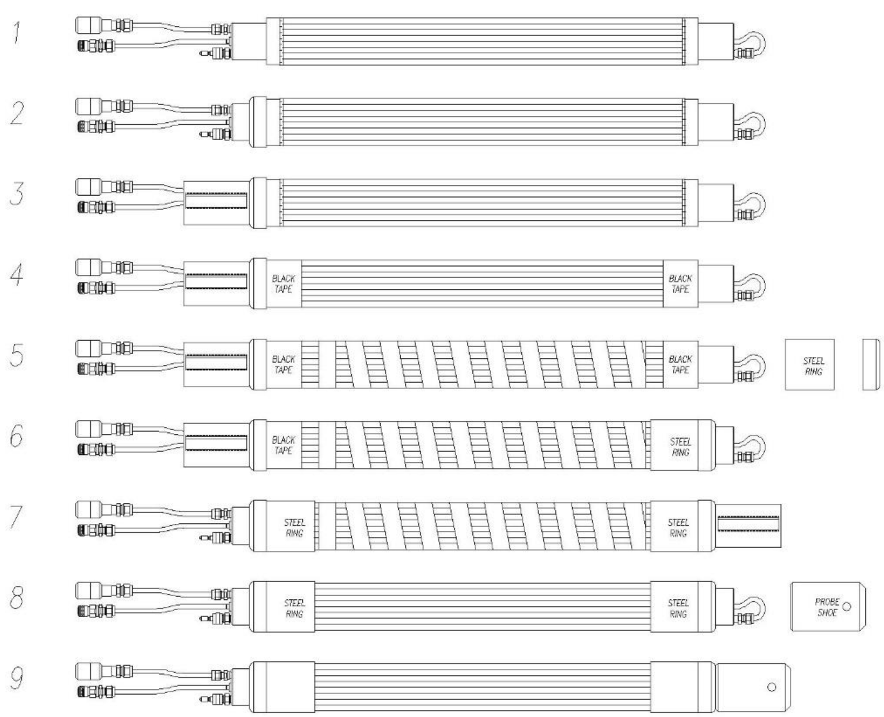
1. Screw the probe vice adapter to the threads at the probe bottom. Clamp the probe vice adapter firmly into the jaws of a bench vice.
2. Unscrew the upper probe nut retaining the steel ring in place.
3. Remove the steel ring using the two pin circular extractor provided for this purpose.
4. Screw the probe vice adapter to the other extremity of the probe and repeat the above steps to remove the remaining lower probe nut and steel ring.
5. Slide the damaged sheath toward the top of the probe, without rotating it so as not to damage the feelers.

To assemble a new sheath, proceed as follows. Please refer to the figure below.

1. Wipe and dry the probe core, the feelers and the cantilevers.
2. Install the two o-rings in the grooves at the probe core extremities.

3. Slide a new sheath over the probe core proceeding from the top end towards the bottom end, and center it.
4. Screw a retaining nut on the top end of the probe. Screw the probe vice adapter to the threads at the probe top and clamp the probe vice adapter firmly into the jaws of a bench vice.
5. Once the sheath is centered, <u>remove all electrical tape previously installed on the probe</u>. Then apply 4 to 5 turns of 5 cm wide electrical tape very tightly on both ends of the sheath to press it firmly to the probe body. Apply a small coat of "Molykole 33" grease on the electrical tape at both ends of the sheath.
6. Put filament tape in a spiral way, following the direction of the metal strips. Refer to the image below. This will hold the probe in place.
7. Install the bottom steel ring, then thread and tighten the bottom probe nut until 3 or 4 threads show at the end. Unscrew the probe vice adapter and screw it on those threads.
8. Install the steel ring and the retaining nut on the other end (top) the same way as with the bottom end. Screw until about 19 mm of threads are shown.
9. Screw bottom nut again. When completely tightened, approximately 19 mm of thread should show at both ends of the probe. Remove filament tape.

Warning ! Be careful not to drop the probe !



Sheath Assembly

Verification for leak:

After putting a new sheath on a probe, this one must be verified for leak. This is done by saturating the probe (see below for instructions), and pressurizing the probe in the smallest calibration tube up to 20 MPa. Maintain this pressure for 15 minutes and check for leaks. This procedure will also knead the membrane before using it.

3.2 TUBING AND ELECTRICAL CONNECTIONS

Prior to making the connections to the probe, it is necessary to thread both the tubing and the cable through the AW rod / BW casing adapter, extension and protective cylinder.

Each tubing is fitted with a quick connect at its lower extremity which connects to the top end of the probe. It is important that these fittings be kept clean and free from dirt. If necessary, clean them each time a connection is made.

Two locking rings for quick connects are provided to prevent accidental disconnection of the inflation/deflation lines. It is important to put them in place

Locking ring Installation

The electrical cable is fitted at its lower end with a watertight connector, which mates with the probe. It is equally very important that the connector remains clean and dirt free. When not in use, the protective cap should be in place. The upper (readout) end of the cable is fitted with a multi-pin electrical connector, which mates with the readout.

3.3 READOUT SETTINGS

P-3 Readout set up must be:

G.F. must be close to 2 (refer to calibration certificate) mV/V

Full scale: 10

Dec Places : auto

Units : mm

Recording: Disable

Balance mode: auto

Bridge Type : UnderF FB

There is no software provided with the P3. But the user will enter conversion factors in the P3 so the readout can display diametrical strain directly in mm.

The P-3 readout directly displays diametrical displacements only. The pressure readings must be taken on the analog dial gauge and written down manually. Normally, users will not utilize storage capability of the P-3. Readings are normally taken by hand. These can also be directly entered in the TrimodsCompanion Data Reduction Spreadsheet provided by the Roctest.

3.4 SATURATION PROCEDURE

It is essential to saturate the probe prior to a calibration or a test. To saturate the probe, proceed as follows.

1. Lay the probe horizontally.
2. Insert the probe in the 82.5-mm calibration tube for protection purpose.
3. Tilt slightly the probe to raise its upper end about 8 cm above the ground.
4. Rotate the probe to bring the deflation line fitting at the uppermost position.
5. Connect the inflation line to the hydraulic pump.
6. Connect the electrical cable to the readout unit.
7. Thread the electrical cable and the deflation and inflation lines through the rod adapter and the protective cylinder.
8. Place a pan under the valve of the deflation line to collect the oil, and then open the valve.

DO NOT CONNECT THE PNEUMATIC PUMP TO THE DEFLATION LINE.

9. Screw the rod adapter to the protective cylinder.
10. Connect the inflation/deflation lines and the electrical cable to the probe. Screw the rod adapter/protective cylinder assembly to the probe.
11. Turn the readout unit on and start pumping.

Note: Entire saturation may last up to half an hour, so patience is required.

12. When oil starts to pour out from the deflation line, stop pumping; close the deflation line valve, and open the main pump valve to let the overflow return into the pump.
13. Saturation is now completed. You may proceed to a calibration with the oil pump or to a test.

3.5 EMPTYING PROCEDURE

Air pressure is used to empty system. Air pressure required will increase in relation with test depth (or elevation differential between the pump and the probe).

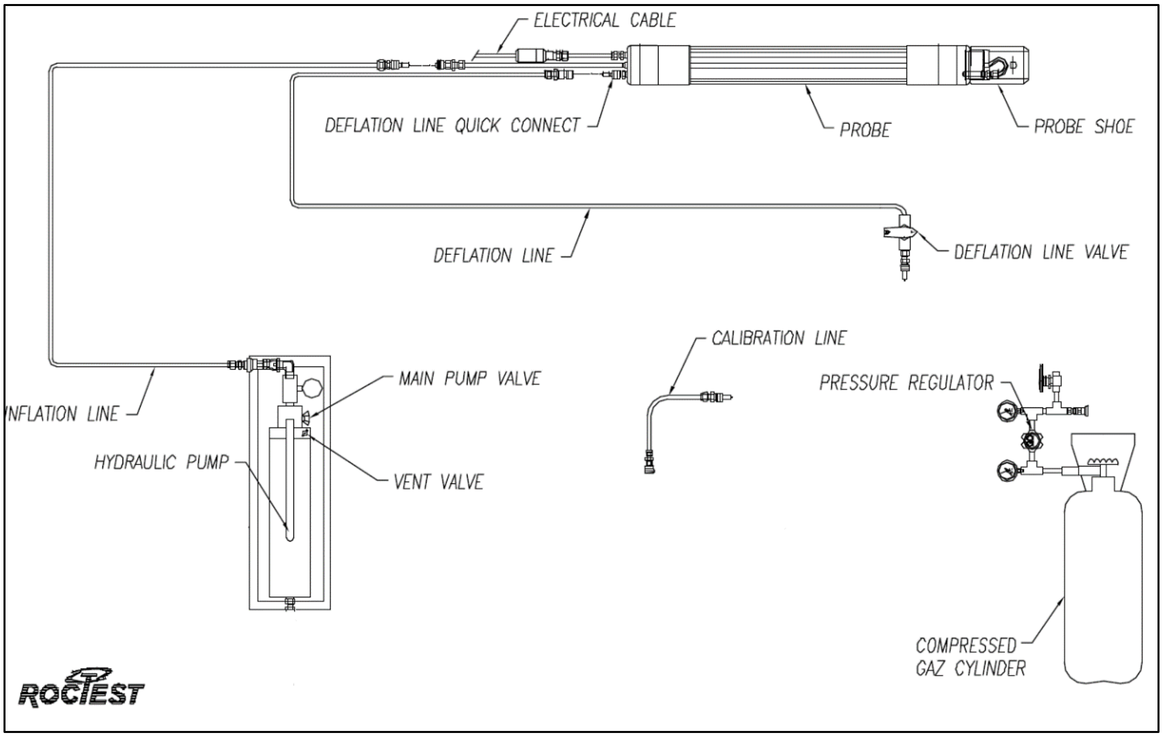
Note: The standard TRI-MOD-S is supplied with a gas cylinder. Prior to using it, check if the pressure range is sufficient for your special application.

Keep in mind that in a dry borehole (with no water in it), a differential elevation of 10 m requires approximately 100 kPa of air pressure to empty the system.

When emptying the probe, this one should be confined in a borehole or in a steel pipe.

To empty the system, proceed as follows:

1. Connect the air pump or the compressed gas cylinder to the deflation line.
2. Build up an approximate 500-kPa pressure and then open the deflation line valve. Be sure that main and vent valves of the oil pump are opened.
3. Blow air into the system until it is empty i.e. when gas is coming out inside the pump reservoir or from the auxiliary container when this later is used.



TRI-MOD-S Assembly

3.6 CALIBRATION FOR PRESSURE LOST

This calibration is done in order to determine the resistance – or inertia - of the sheath. It can be performed only once after putting on a new sheath on the probe. The effect of this calibration is more significant in softer materials (soils). Thus this calibration can be repeated when testing soft material.

The calibration is performed by dilating the unconfined probe to a specific volume. This measurement will be subtracted from the pressure readings of the gauge to determine the effective pressure applied to the borehole walls during a real test.

$$P = P_g - P_i$$

where: P is the effective pressure
P_g is the pressure shown by gauge
P_i is the probe inertia

The determination of P is done by inflating the probe in a vertical and unconfined position and recording all three diameter values obtained at increasing incremental pressure stages. The readings are taken one minute after a pressure stage is reached. We suggest pressure stages of about 100 kPa. The pressurization is stopped when the diameter reaches about 85 mm. Maximum pressure, which corresponds to $1.41R_0$ or about 98 mm (where R_0 is the initial radius of the probe at rest), is obtained by extrapolation. For each membrane, an inertia or pressure correction curve should be drawn. The inertia at $1.41R_0$ normally ranges between 500 and 900 kPa.

The effective pressure shall also be corrected for the oil column.

3.7 CALIBRATION FOR VOLUME LOST

This calibration allows to determining the compressibility of the sheath when squeezed. It should be repeated every testing-day.

The procedure to determine this correction is described below. Note that radial expansion is converted into volume expansion to suit the TRIMODS COMPANION spreadsheet methodology.

STEP 1. Once the whole system has been saturated, place the deflated probe in the 76.2-mm steel tube.

STEP 2. Inflate the probe up to its maximum working capacity of 20 000 kPa and deflate. This operation mechanically sets the components of the dilatometer probe subjected to pressure.

STEP 3. Inflate the probe in steps of 2 000 kPa to the maximum working pressure of the TRI-MOD-S. At each step of pressure, note the corresponding radius reading displayed on the readout unit after one minute.

STEP 4. Convert radius into volume. Draw the correction curve (Pressure vs. Volume). The correction factor "a" is calculated from the linear part of the curve, which normally stretches between 10 and 20 MPa.

The expansion of the thick wall metallic tube, determined theoretically and is expressed by the "b" parameter, must be deducted from the factor “a”, in order to get real correction “c” due to the membrane compression.

The factor "c" is given by the following equation:

$$c = a - b$$

Where:

$$b = \frac{2V\left[r + e(1+m)\right]}{(E_m \times e)}$$

Where:

- V: Volume taken by the dilatable membrane of the TRI-MOD-S when in contact with the metallic calibration tube (length of the TR-MOD-S membrane is 49 cm)
- r: Internal radius of the calibration tube
- e: Wall thickness of calibration tube
- m: Poisson's ratio of calibration tube material
- $E_{m:}$ Modulus of elasticity of calibration tube material

The TRI-MOD-S dilatometer is supplied with standard, steel calibration tubes having the following characteristics:

- E_m (modulus of elasticity): 207 x 10^6 kPa
- m (Poisson's ratio): 0.3

When conducting tests in very stiff material, a high level of confidence in the modulus calculated depends on the exactness of the "c" value.

$$V_{corr} = V_r - V_c$$

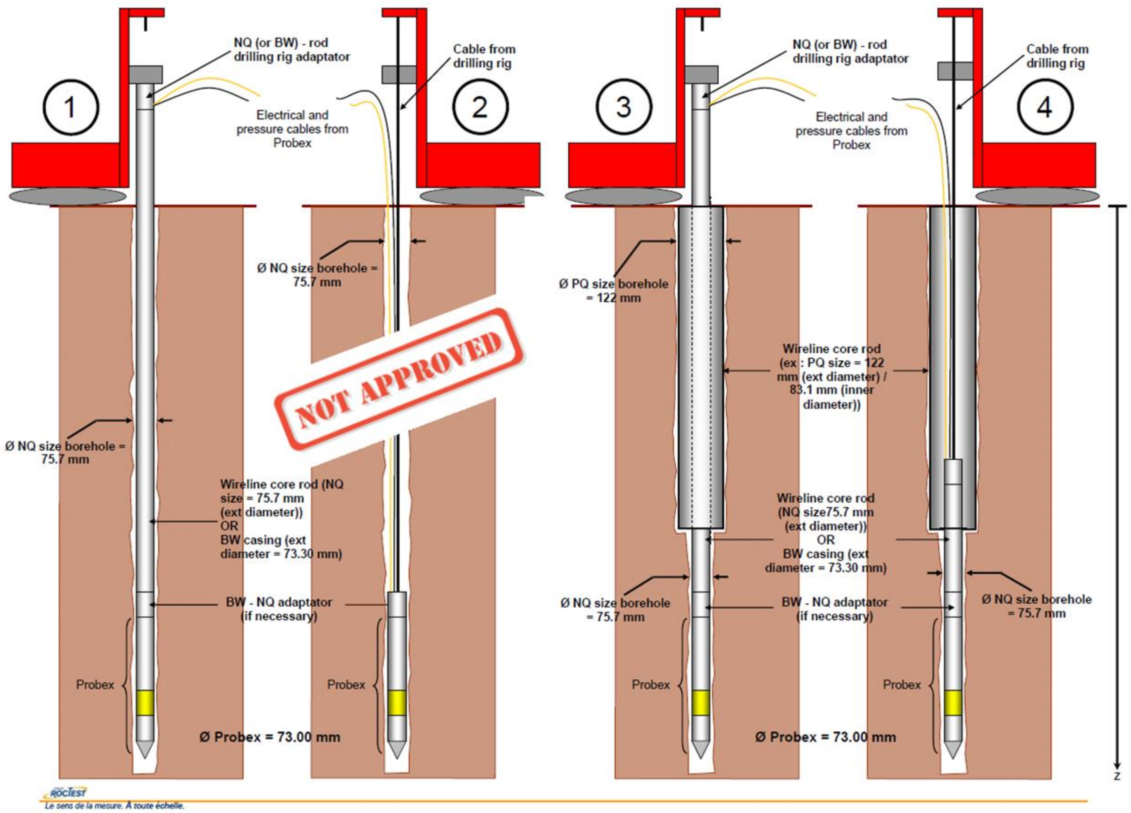
where : V_{corr} is the corrected volume
V_c is the correction due to membrane compressibility
V_r is the raw volume read during the test

4 TEST EXECUTION

4.1 BOREHOLE TEST

The test is carried out in an N size borehole (75 to 78 mm). Normally, AW rods are used to lower the probe in place in soils, whereas BW casing are recommended in rock. In that latter case, the electrical cable and tubing are threaded inside casing. Ideally, support the probe and casing string using a slotted adaptor. Additionally, a pipe vise or a casing clamp can be used. See images below.

It is essential to drill the borehole using the appropriate method, i.e. the one that minimizes the disturbance while giving the tightest hole. Core drilling is recommended in rock. Rotary drilling is recommended in weathered rock and soils. Please refer the methods described in the documents mentioned at the end of this manual.



Methods Used for Lowering Probe in Place in Rock

Slotted Adaptor

NEVER SUPPORT THE INSTRUMENT BY ITS TUBING OR CABLE.
BE CAREFUL NOT TO DROP THE PROBE !

4.2 TEST PROCEDURE

Tests can be done following procedures associated to soil pressuremeters (ASTM 4719) or to flexible borehole dilatometers in rock.

A standard test in soil is done by applying 10 equal increments of pressure and holding the pressure constant at each pressure stage for a one-minute period. To determine the size of each pressure increment, it is necessary to estimate the limit pressure and use a pressure increment equal to tenth of the size of the estimated limit pressure. The actual number of increments used during a test will depend on the estimate of the limit pressure. A minimum of 8 pressure steps is required to acceptably define a pressuremeter curve. A larger number of steps only prolong the test. To carry out a test, proceed as follows.

1. Prepare a sufficient number of AW rods to lower the probe to the proposed test depth. When BW casing are used, thread the electrical cable and tubing in the required amount of casing lengths.
2. Connect the inflation line to hydraulic pump.
3. Connect the cable to the readout unit.
4. Take readings on all three axes to ensure that they correspond approximately to the rest of the probe diameter i.e. 0 mm (since the "zero point" has been set in a 76.2 mm calibration tube) minus the difference between 76.2 mm and the probe diameter at rest which is about 70 mm, so the reading should be approximately -6 mm.
5. Proceed to a volume lost calibration as described above
6. Close the valve on the hydraulic pump. Keep the valve on the deflation line closed
7. Lower the probe down the borehole to the test depth. Fasten the electrical cable and inflation/deflation lines to the AW rods using electrical tape
8. Open the valve on the pump. Wait a minimum of 5 minutes for allowing temperature stabilisation of the probe
9. Read the three diameters: D1, D2, D3
10. Close the valve on the pump. Activate the hydraulic pump to apply a pressure equal, on the pressure gauge, to one tenth of the expected maximum pressure. Read D1, D2 and D3 thirty and sixty seconds after the pressure stage is reached.
11. Increase pressure in equal increments, stopping at each pressure stage to record the three diameter readings. Do so 30 and 60 seconds after the pressure stage is reached and stabilized.
12. **Be careful not to risk bursting the probe especially at high pressure, or when large probe diameter has been reached, or once the creep pressure is attained. The maximum diameters to reduce the risk of bursting the probe are as follows**.

Between : 0 and 10 000 kPa , D_{max} = 83 mm
Between : 10 000 and 15 000 kPa , D_{max} = 80 mm
Between : 15 000 and 20 000 kPa , D_{max} = 77 mm

13. At the end of the test, deflate the probe. To do so, open the valve, and wait for the membrane to push back the oil in the pump.
14. If this takes too much time, pneumatic pressure can be used. Build up required pressure with the compressed gas cylinder pressure regulator.
15. Connect the compressed gas cylinder deflation line and open the valve on the deflation line.
16. Wait until gas bubbles come into the hydraulic pump.
17. Close the valve on the hydraulic pump.
18. Disconnect the gas cylinder from the deflation line.

5 EQUIPMENT VERIFICATION

5.1 VERIFICATION

The zero reading and gauge factors of the equipment can be verified once in a while. We recommend doing so after replacing the sheath. For doing this verification, the two calibration tubes provided with the TRI-MOD-S should be used. The verification procedure is described below.

- This verification can be done using the hydraulic pump and the saturated probe. Or, in order to speed up the process, it is possible to use the compressed gas cylinder. In this case, follow the procedure described below, but connect the compressed gas cylinder directly to the unsaturated probe using the short white tubing.
- Make sure the inner surface of the calibration tubes is clean.
- Place it vertically inside the smallest calibration tube supplied with the instrument. The two-pin circular ring extractor must be used for putting and removing the probe from the calibration tube.
- Using the hydraulic pump, apply a 2600 kPa pressure and hold this pressure for 10 minutes
- Bring the pressure back to 0 kPa, then increase it to 1000 kPa
- After holding a 1000-kPa pressure for 1 minute, take a reading
- Average value should be close to 0.00 mm +/- 0.1 mm
- Deflate the probe and put it in the larger calibration tube.
- Pressurize the probe up to 1600 kPa. Hold this pressure 1 minute then write down the readings.
- Deflate the probe.
- The difference of the average readings between the small and large calibration tubes must be close to the difference of diameter of the tubes within +/- 1 %.

5.2 RESETTING GAUGES FACTORS AND ZERO READING

If necessary, the gauge factors and the zero reading can be re-adjusted as follows.

The three new gauge factors must be calculated as follows.

Using:

- The old gauge factor (GF_1)
- The actual reading (L)
- The exact difference between the internal diameters of the calibration tubes (ΔD) in mm.

Calculate the new gauge factor GF_2 using the following relation.

$$GF_2 = GF_1 \times \frac{L}{D}$$

Example: Adjusting the gauge factor on first axis

- GF_1: The old gauge factor is 2.031.
- L: Reading on first axis is 6.40.
- D: Difference between steel tube internal diameters is 6.37 mm.

The new gage factor becomes:

$$GF_2 = 2.031 \times \frac{6.40}{6.37} = 2.041$$

Repeat for the three axis.

Enter the new gauge factors into the P-3 readout following this procedure.

- Make sure probe is saturated.
- Place it vertically inside the smallest calibration tube supplied with the instrument. The two-pin circular ring extractor must be used for putting and removing the probe from the calibration tube.
- Apply a 2600 kPa pressure and hold this pressure for 10 minutes
- Bring the pressure back to 0 kPa, then increase it to 1000 kPa
- Select *G. F. Scaling* and enter the 3 new gauge factors
- Press *Balance* and *Record* for recording the new gauge factors
- Bring pressure back to 0 kPa. Turn off the recorder, then turn it on and make sure the new gage factors have been recorded.
- Repeat verification described above.

This procedure can also be followed using the alternative method described earlier i.e. using the pneumatic bottle.

Note that after resetting readings at zero in the smallest calibration tube, following readings will correspond to following diameters:

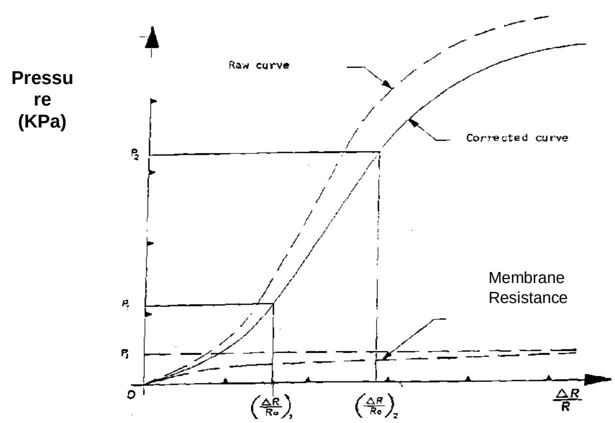
Mean reading on P-3 readout	Diameter of calibration tube – Example (mm)	Diameter of the probe (mm)
0	76.05	76.05
-6.37	76.05	69.68
+3.64	76.05	79.69
+5.76	76.05	81.81

6 INTERPRETATION

Note that Roctest offers a spreadsheet TRI-MOD-S COMPANION for data reduction. Please contact Roctest to obtain a free copy.

6.1 PRESSUREMETER CURVE

The pressuremeter test results can be expressed in terms of Pressure vs Volume increase (cm^3), Relative Radius Change ($\Delta R/R_o$), or in terms of Diametric increase (mm).



Pressiometer Curve.

On the graph above, $\Delta R/R_o$ is the relative radius change

where: R_0 = Deflated probe radius (about 3.5 cm)

ΔR = Increases in radius

P is the pressure applied against the borehole walls, P_L is the limit pressure.

Using the relative radius change of each feeler can be interesting when one wishes to measure the anisotropy of the soil. But for more reliable results, it is suggested to always consider the average value of increase of radius of the three axes:

$$\frac{\Delta R^n}{R_0} = \frac{\Delta R_1^n + \Delta R_2^n + \Delta R_3^n}{3 R_0}$$

where ΔR_n is the increase of radius for each axis and R_0 is the initial radius – normally close to 35 mm.

6.2 CONVERTING RADIUS READINGS INTO VOLUME READINS

The length of the measuring section of the TRI-MOD-S probe is 49 cm. The formula to convert radius in volume is:

$$V = L * (pi * R^2)$$

$$\mathbf{V = 153.9\ R^2}$$

Probe's Theoretical Radius R_0	Probe Theoretical Length L_0	Probe's Theoretical Initial Volume V_0
3.5 cm	49 cm	1885 cc

6.3 LIMIT PRESSURE

The limit pressure P_L is defined as the pressure at an inflation of twice the initial borehole volume. Several methods have been proposed to compute P_L.

When the graph is plotted in terms of radius, the contact of the probe with the borehole walls corresponds to:

$$\left(\frac{\Delta R}{R_0}\right)_1$$

and the limit pressure P_L is the pressure at:

$$0.41 + 1.41 \left(\frac{\Delta R}{R_0}\right)_1$$

When the graph is plotted in terms of volume, limit pressure is the pressure at:

Initial volume of the probe + (2 x Injected volume to make contact with borehole walls)

6.4 DEFORMATION MODULUS

The pressuremeter modulus is calculated using the theory of linear elasticity for the expansion of cylindrical cavity. The resulting equation is:

$$E = 2(1+\nu) \text{ x } V_m \text{ x} \left(\frac{\Delta P}{\Delta V}\right)$$

where E is the pressuremeter modulus; ν is the Poisson's ratio (estimated arbitrarily - normally 0.33 in soils and 0.2 in rocks); ΔP is the change in pressure over the straight portion of the curve; ΔV is the change in volume corresponding to ΔP; and V_m is the average volume of the test cavity over the interval considered.

This may be written in terms of relative increase in the probe radius as:

$$E = (1+\upsilon)(\Delta P) \text{ x } \frac{\left[1+\left(\frac{\Delta R}{R_0}\right)_2\right]^2 + \left[1+\left(\frac{\Delta R}{R_0}\right)_1\right]^2}{\left[1+\left(\frac{\Delta R}{R_0}\right)_2\right]^2 - \left[1+\left(\frac{\Delta R}{R_0}\right)_1\right]^2}$$

where $\left(\frac{\Delta R}{R_0}\right)_1$ and $\left(\frac{\Delta R}{R_0}\right)_2$ are the relative radius increases of the probe at the beginning and ending of the straight line portion.

When the test results are expressed in term of diametrical change (mm), the pressuremeter modulus can be determined with the following equation:

$$E = (1 + v) \varnothing P/d$$

where :

- v : rock or soil Poisson's ratio
- ∅ : diameter of the membrane when it first makes contact with the borehole walls (mm)
- P : pressure variation on the straight line portion considered (MPa)
- d : diametrical deformation on the straight line portion considered (mm)

7 APPENDIXES

TEST AT GREAT DEPTH

In its standard hydraulic configuration i.e. with the P462 Pump, the TRIMOD-S can be used down to about 200 m. Tests performed deeper would require the user either to use a special pump, or to adapt the equipment by himself to pneumatic mode. In all cases risks of having problems become significant and Roctest doesn't necessarily recommend it. Maximum test depth reported to us is 400 m.

REFERENCES

The use of the equipement and the interpretation of the test results can be done referring to the following works and articles:

ASTM Standard Test for Pressuremeter Testing in Soils, D4719-20***.***

Interpretation and Application of the Pressuremeter Test Results, Notice D.60, soils-sols, 1975, rev 2018.

The Pressuremeter and Foundation Engineering*,* F. Baguelin and al., Transtech Publication Clausthal-Zellerfeld, W. Germany, 1978.

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