INSTRUCTION MANUAL

BOREHOLE DILATOMETER
(ROCK PRESSUREMETER)
Model PROBEX

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1 EQUIPMENT

1.1 GENERAL DESCRIPTION

The PROBEX is a borehole dilatometer (or rock pressuremeter), which consists of a cylindrical, radially-expandable borehole probe used mainly to determine the short-term deformability of rock in situ. Its use may also be extended to the measurement of the creep properties of creep-like materials such as salt or potash.

The PROBEX operates in 76 mm (N size) boreholes and has a maximum working pressure of 30 000 kPa. By measuring the total volume change of the probe upon loading, a mean modulus of the rock may be calculated.

A particularity of the PROBEX is that pressurization of the dilatable membrane is done immediately upstream by the movement of a piston actuated from a manual pump at the surface. By recording the displacement of that piston, volume changes may be calculated. This configuration allows the use of the dilatometer at substantial depths and eliminates the parasitic expansion of the tubing and pumping system.

The PROBEX probe is basically composed of three main elements (see image below):

- An expandable membrane
- A dual-action hydraulic module
- A measuring module

A manually-operated, hydraulic pump together with hydraulic tubing and a readout unit complete the PROBEX system.

The PROBEX probe is mounted on a steel core C, which is fitted with a saturation plug at its downstream extremity. Water saturation of the system fills the annular space between the dilatable membrane and the steel core as well as cylinder E.

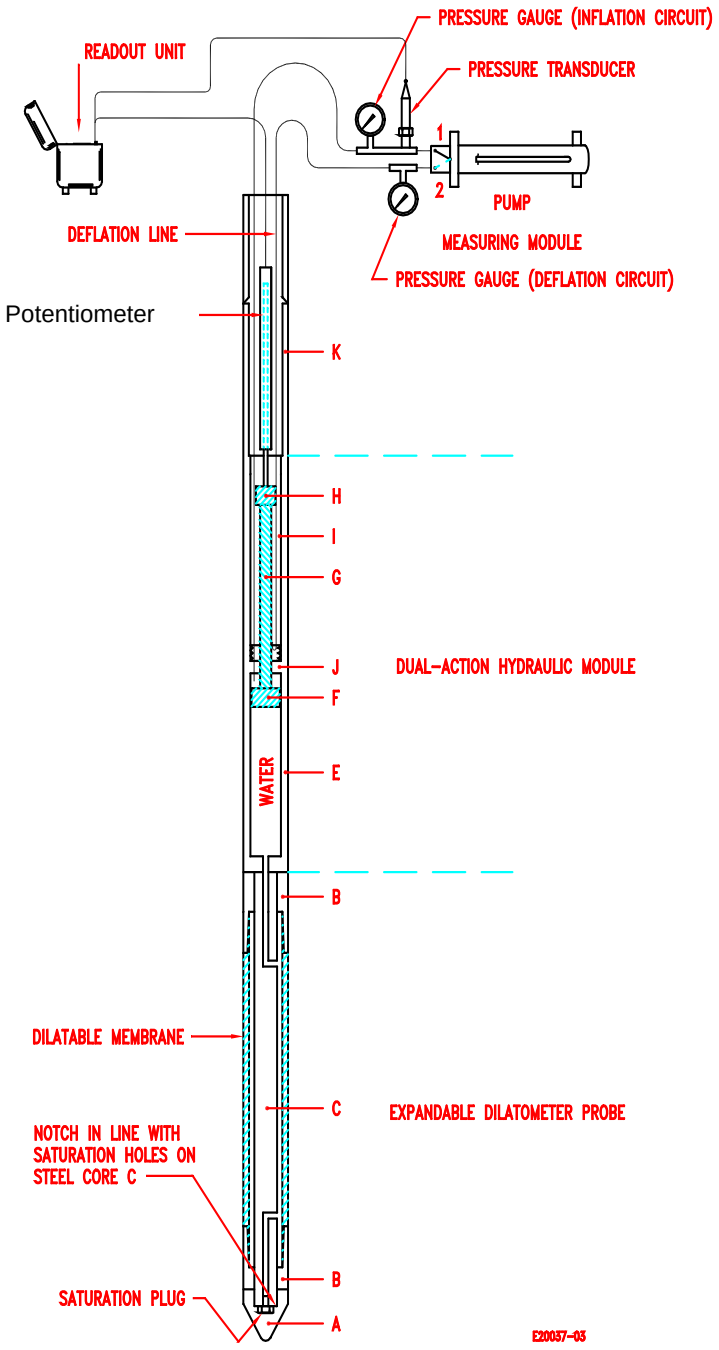
In order to inflate or deflate the PROBEX probe, the manual hydraulic pump acts on the dual-action, hydraulic module. The dual piston identified by letters F, G, and H is the moving part responsible for the expansion or deflation of the probe. Figure below shows this piston in its fully retracted position.

The hydraulic module contains two cylinders in which the piston travels. When the piston is fully retracted, cylinder E is completely filled with water and the cylinder is fully oil-saturated. With the small handle of the manual pump in the inflation position (No. 1), oil is pumped immediately behind extremity F and the whole piston moves downstream pushing water into the probe. Simultaneously, the oil contained within the cylinder is returned to the hydraulic pump via the deflation line.

To deflate the probe, the small handle on the manual pump is placed in the deflation position (No. 2) and the oil is pumped into the cylinder. The oil previously pumped into cylinder E is returned to the pump via the inflation line and the water is brought back into cylinder E.

It must be noted that prior to using the PROBEX, complete water and oil saturation of the circuit is necessary. The PROBEX is shipped saturated with oil - but without water - and with the piston F in retracted position.

The measuring module of the PROBEX consists of a linear potentiometer. It is fixed to the upstream end H of the dual piston and follows its displacement throughout the loading and unloading process. The readout unit is programmed in factory with calibration constants converting potentiometer and pressure transducer outputs into engineering values (cm^3 and MPa).



Schematic Representation of the PROBEX

1.2 PROBE

Portable Membrane

The PROBEX probe includes a portable membrane made of flexible material mounted on heat-treated, stainless steel ends. The nominal overall length of the membrane including the steel ends is 749 mm. The nominal length of the expandable membrane is 457 mm and the diameter is 73.7 mm. This configuration gives an L/D ratio for the dilatable portion of the probe greater than 6.

It cannot be overly emphasized that PROBEX tests should be run in well calibrated, N-size boreholes having diameters of 76 mm. Performance of the PROBEX will then be enhanced and the risk of damaging a probe greatly reduced.

Dual-Action Hydraulic Module

As explained above, it is the oil pumped right behind extremity F of the dual piston that displaces it downstream, pushing water into the probe. The internal diameter of cylinder E shown on figure above is 60.122 mm and the overall travel of the dual piston is set at 238.125 mm. This geometrical configuration allows a total volume of water equal to around 676 cc to be injected into the probe. The area on the water side of the piston F is slightly larger than the area of the hydraulic oil side by a ratio of 95.5%, this due to the area of rod G, which represents 4.5% of the piston area. The water pressure which acts inside the probe, may be obtained with the following equation

$$\mathbf{p_b = 0.955\ p_g + 6\ H}$$

where: p_b = water pressure in the probe (kPa)
p_g = oil pressure read on the pressure gauge (kPa)
H = vertical distance (m) between the probe and the pump

The value 6 H takes into account the effect of the oil column in the two hydraulic lines connecting the probe to the pump.

The pressure value displayed by the DP BOX readout is already corrected in order to take into account the effects of the difference of areas on each surface of the piston, but not for the oil column.

Measuring Module

The measuring module consists of a potentiometer enclosed in a watertight casing. It gives the displacement of the piston F which is proportional to the injected volume in the probe.

Type	Potentiometer Recti-P12
Rn	22 kilo ohms +/- 20%
Range	25 cm / 0 – 1 VDC
Linearity	0.5% F.S.

1.3 HYDRAULIC SYSTEM

The hydraulic system consists of the following elements:

The **hydraulic pump** is mounted with a 4-way control valve (2 positions). The right position No. 1 is used to inflate the probe and the left position No. 2 to deflate the probe. Pressure

rating of the pump is 69 MPa. A cyclic test valve is located on the inflation circuit between the gauge block and the pump (this valve must always be kept open except when doing cyclic load tests).

Two **pressure dial gauges** are mounted on the hydraulic pump. The gauge controlling testing pressure is installed on the inflation circuit (position No. 1). It has a pressure range of 35 MPa, and an accuracy of 1 % F.S. A second gauge is fixed on the deflation circuit. It has a smaller pressure range and is provided as a safety feature to prevent over-pressurization of the return cylinder when retracting the piston.

The inflation line is equipped with the 35 MPa **pressure transducer**.

The pressure gauges and transducer come with quick-connectors for easy installation on the hydraulic pump.

Dual high-pressure **hydraulic lines** connect to the hydraulic pump. The inflation line has a working pressure of 68 MPa and the deflation line a working pressure of 32.5 MPa.

1.4 READOUT UNIT

The model DP BOX is a portable datalogger equipped with rechargeable batteries. It directly provides the volume and pressure changes of the probe. This data must be used in conjunction with an Android-based tablet. See below for more information.

1.5 GENERAL SPECIFICATIONS

PROBE	
Maximum pressure	30 000 kPa
Minimum Diameter (deflated)	73.7 mm
Maximum Diameter (inflated)	85.5 mm
Length of membrane	457 mm
Probe upper threads	BW Casing female + NQ Rod adaptor
READOUT – Model DP BOX	
Function	Volume and pressure indicator
User interface	Bluetooth communication with an Android tablet
Resolution	
Diametrical change	0.001 mm (0.05 cm^3)
Pressure	0.25 % F.S.
Logging capacity	Typically over 10 000 data sets (tablet-dependent)
Communication interface	Serial port (USB adapter included)
Power supply interface	Universal AC wall plug with US/Euro adapter + adapter cable for car (lighter) and for external battery
Operating temperature	-20 to +70°C
Autonomy	> 8 hours
Battery	2 x 12 V 2.3 A, rechargeable
Case	Waterproof, shock resistant ABS plastic
Dimensions	25 x 28 x 12 cm (l x w x h)

2 OPERATING INSTRUCTIONS

2.1 ASSEMBLING THE EQUIPMENT

Referring to the figure below, assemble all parts of the PROBEX system.

Note 1 :

Two short optional hydraulic lines can be used instead of the long regular tubing for speeding up saturation and calibration processes.

Note 2 :

The ball and the notch on the tubing quick connects must be aligned for connection. Then, turn the ring to misalign the ball and the notch in order to prevent accidental disconnection when inflating the PROBEX. This will prevent the PROBEX from getting accidentally stuck in a borehole.



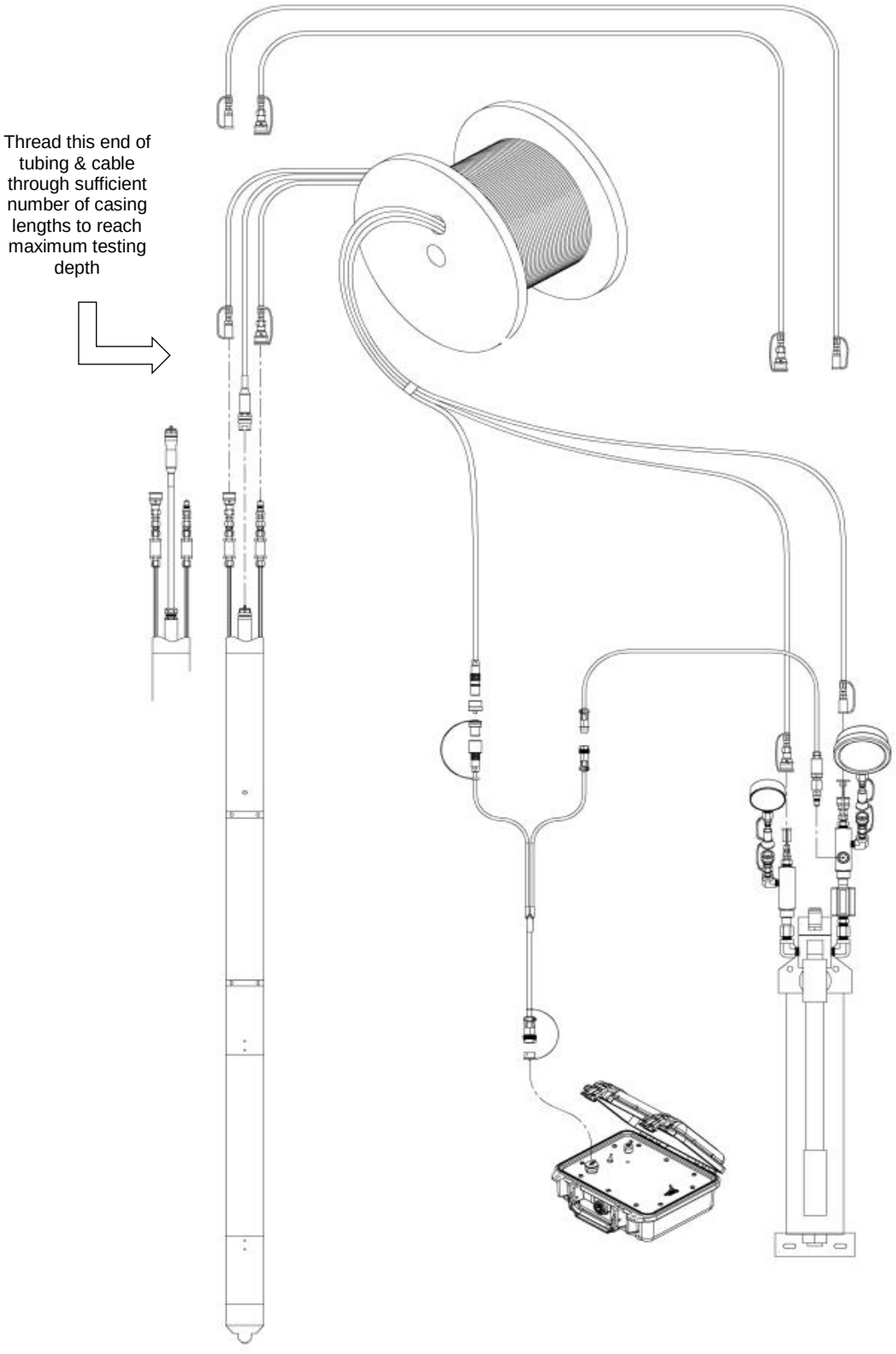
Note 3 :

WARNING: When disconnecting Lemo connectors, hold the connector itself and pull outward. Never pull on the cable



Note 4 :

WARNING: The operator must ensure that all 4 hydraulic connections to the pump and to the PROBEX probe are properly made to avoid potential damage to the hydraulic system.



PROBEX Assembly

2.2 USING THE DP BOX

2.2.1 DESCRIPTION



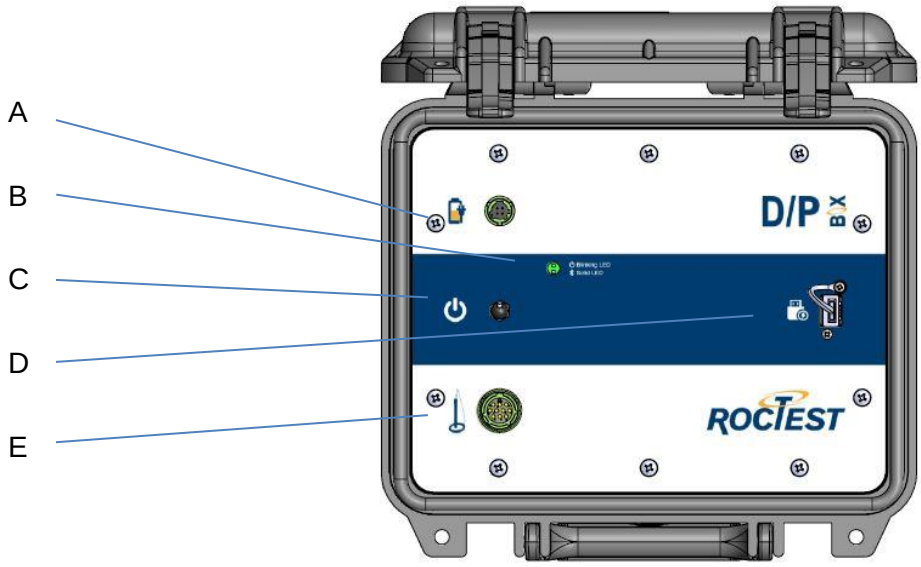
DP BOX communicating with a tablet by Bluetooth

The DP BOX is designed for reading and logging measurements obtained from pressuremeters and dilatometers manufactured by Roctest (including models DMP 95, TEXAM and PROBEX). Thanks to the Bluetooth communication feature and to the DP Box READER Application, the DP Box can be used in conjunction with a Tablet for reading the sensors, for configuring a calibration or a testing session, for visualizing and logging the test results in real time, and for reviewing any test data. These test data can be uploaded to a laptop via USB communication. The DP Box comes in a convenient water proof enclosure and is fitted with two 12-V rechargeable batteries providing over 8 hours of autonomy in normal conditions. The DP Box also comes with cable universal AC wall plug with US/Euro adapter + adapter cable for car (lighter) and for external battery. The battery can be charged every night. A charging circuit inside the readout limits charge time to a certain level.

The front panel is splash proof allowing the use the equipment in wet conditions. However do not let the readout with the cover lifted up under the rain over extended period of time, otherwise water could get into the unit.

The DP Box is compatible with Android-based tablet model.

Note that the Tablet should be set up in English or French only.



DP BOX Front Panel

A	4-pin Cannon connector for charging the DP Box batteries
B	LED indicating communication status: blinking slowly when the Bluetooth radio waits for a connection, then glowing faster when the connection is established.
C	Switch for turning ON / OFF the unit
D	USB port for charging the Tablet (if necessary)
E	10-pin connector for connecting the dilatometer / pressuremeter

2.2.2 INSTALLING THE DP BOX READER APPS

Prior from using the DP Box, the DP Box READER Application should be installed on a Tablet. This application can be downloaded from Roctest web site.

2.2.3 CONNECTING AND TURNING ON DP BOX

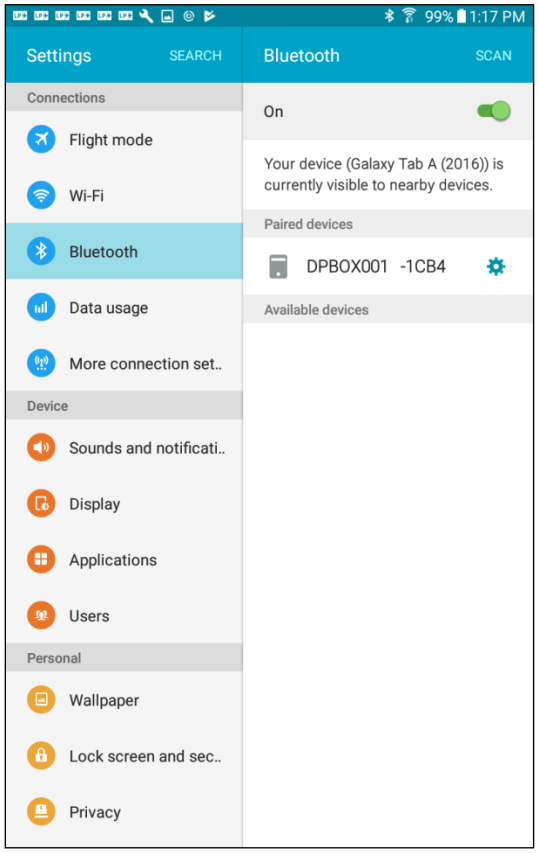
Connect the electrical cable of the testing equipment to the DP Box.

Turn on the DP Box. The LED on the front panel will then blink. Turn on the Tablet. Go in the Tablet Setup and make sure that the DP Box is available and paired with the Tablet.

Set up the Tablet as follows:

- Adjust the Display in ‘Outdoor Mode’ if necessary. But note that this will reduce the Tablet autonomy.
- Adjust the screen timeout (typically 5 min)
- Make sure Tablet is adjusted for dot-delimited numbers

- Make sure the battery voltage of the tablet is high enough for use.



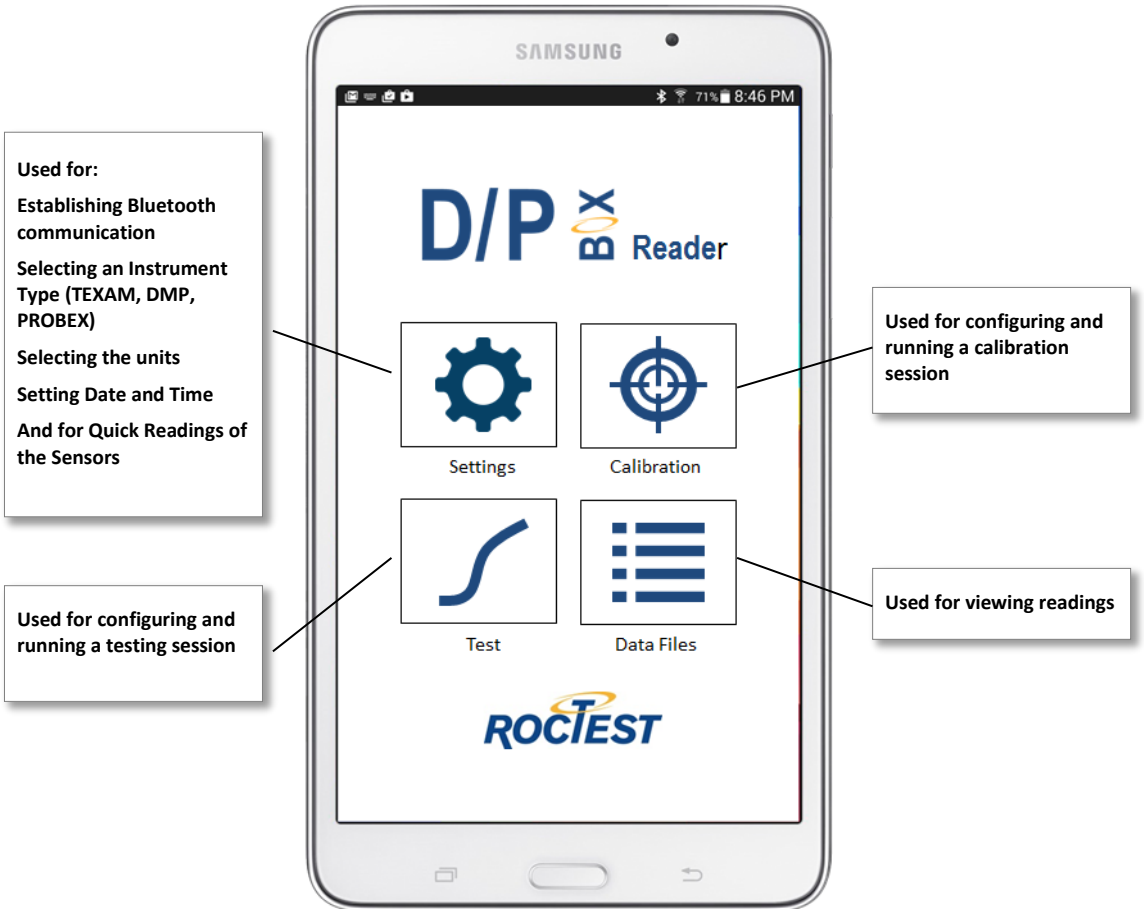
Open the DP Box Application and go in ‘Settings / Quick Reading’ for establishing Bluetooth communication between the DP Box and the Tablet, which will be confirmed when the DP box LED will blink quicker (see below for more information).

2.2.4 USING THE DP BOX READER APPS

The DP Box Application allows configuring the unit, to read and to log the data, and to review the results.

2.2.4.1 MAIN MENU

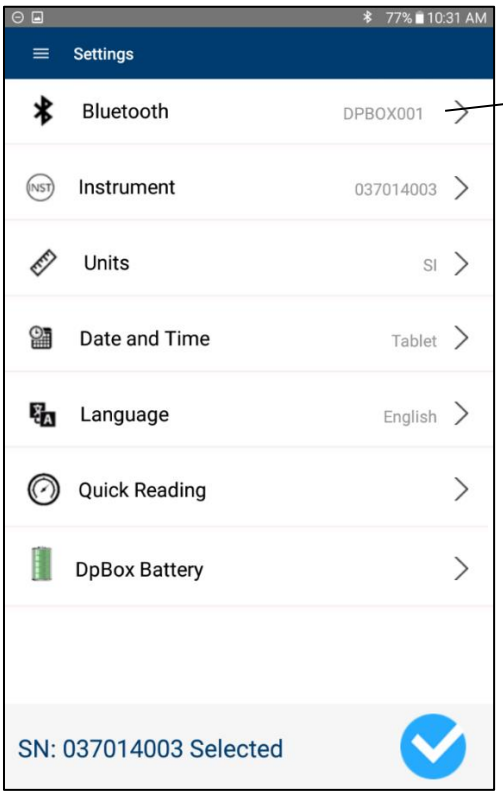
Main menu of the applications includes the following elements:



DP Box Application Main Menu

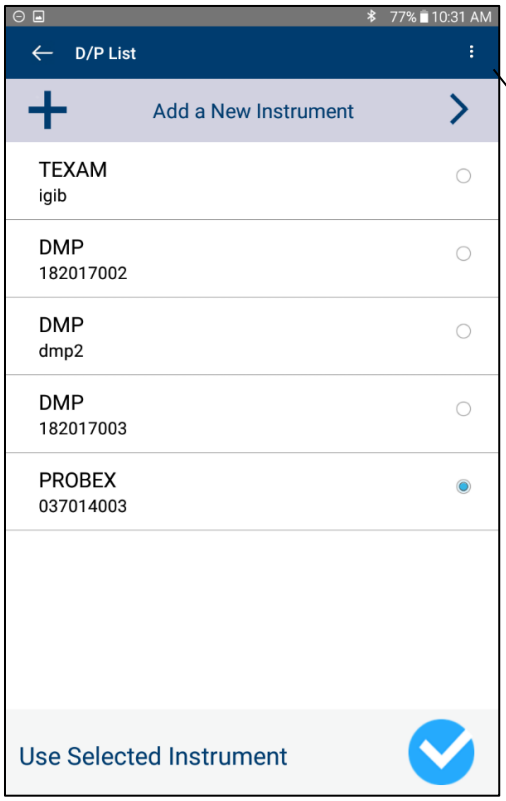
2.2.4.2 USING THE DP BOX READER APPS WITH THE PROBEX

First, Go to 'Settings'. The APPS will automatically scan for establishing Bluetooth communication with the DP BOX, which takes a few seconds. The name of the DP Box will then replace the 'Scanning' inscription.



The DP Box name should appear here

Go to 'Instrument / Add a New Instrument' and Select the 'Type of instrument' (PROBEX) and enter the serial number appearing on the control unit (e.g. 003717003).

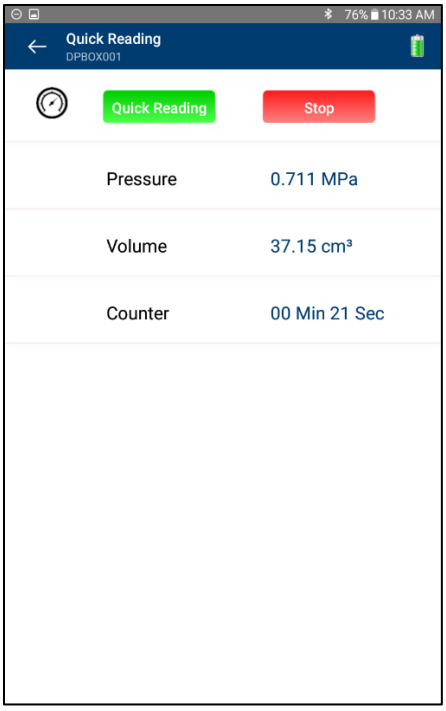


Select for additional functions (Editing, deleting instruments…)

Make sure the conversion factors associated to this instrument have been entered. Refer to the calibration certificate. For changing these, select ‘Calibration / Cal. Type / Review Factory Calibration’ and select ‘Change factory calibration’, make the appropriate changes and select ‘Save new factory calibration’ at the bottom of the screen. Finally select this instrument.

Set the date and time of the Tablet if necessary.

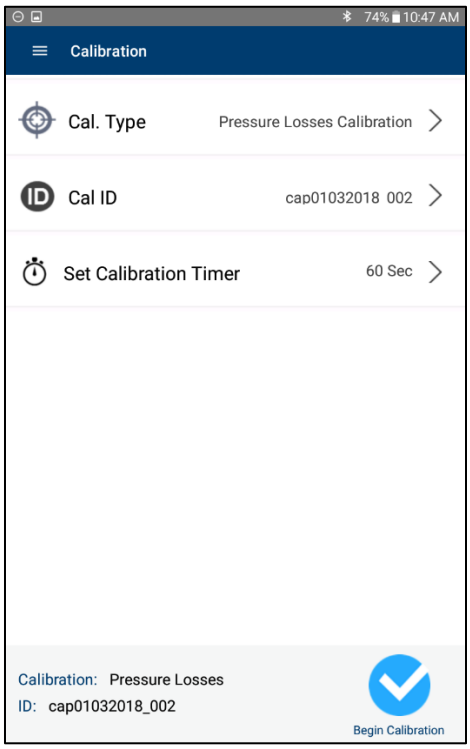
Go in ‘Quick Readings’ and press the green icon for reading the sensors.



Two types of calibrations can be done, one with the probe unconfined (‘Pressure Loss Calibration’) and one with the probe confined (‘Volume Loss Calibration’). See next section for more details.

For configuring a calibration, go to ‘Calibration’ and :

- Select the type of calibration
- Give a calibration ID
- Set the calibration timer



For configuring a test, go to ‘Test’ and proceed the same way.

Typical set up:

	ID [1]	Timer Typical (sec)
Pressure loss calibration	‘*CAP*+Date’	60
Volume loss calibration	‘*CAV*+Date’	60
Test	‘*TE*+Date’	60

[1] *The Apps will automatically increment selected ID*

Once setup is completed, select: ‘Begin Calibration or Test’ to start.

Once calibration or testing is started, a window like the one below will be displayed.

After saving the initial readings, the operator should press ‘Start’ for starting the timer. Readings will be recorded when timer gets to 0 second. Then the operator can increase the pressure to the first step and then press ‘Start’ for starting the timer, and so on until completing the calibration / test.



When the calibration or test is over, press on : 

For reviewing results, go to ‘Data Files’, the select ‘Calibration’ or ‘Field Test’. Then select the specific file you want to see.



Downloading Data

Date are recorded on the tablet only in.csv files. We suggest to frequently copying these files on a computer via USB connection. The .csv files can be open using the Excel software.

Autonomy of the Datalogger & Tablet

In ideal conditions, the battery autonomy of the datalogger will exceed 8 hours. The autonomy of the tablet will vary depending of the model and setup, especially how the display brightness is setup.

If necessary, the datalogger can be powered on site by external source by using the cable adapter for car (lighter) or for external battery provided with the datalogger.

If the Tablet's battery gets low, the Tablet can be connected to the DP BOX with the USB cable.

Periodically check battery voltage of the DP BOX; we suggest not to let it go under 11.3V.

WARNING NEVER FORGET TO TURN THE DP BOX OFF AFTER USING IT.

THE DP BOX SHOULD BE KEPT ON CHARGE EVERY NIGHT.

Allowing the battery to reduce its charge for an extended period of time will reduce its efficiency. Ultimately, the rechargeable battery and the lithium battery backup will get permanently discharged and will need to be replaced. Internal firmware will need to be re-installed. If so, please contact Roctest

2.3 SATURATION OF THE PROBEX

An adequate water saturation of the PROBEX probe and cylinder E is necessary before using the equipment. Sometime the probe is delivered pre-saturated. Please verify.

Note that **two short hydraulic lines** can be used for speeding up saturation process.

STEP 1. The PROBEX components are assembled.

STEP 2. The conical end cap A is removed from the probe.

STEP 3. The PROBEX is inclined at least 20 degrees the saturation plug being at its uppermost point. The probe is then turned until the small notch at the end of the steel core C is in the upper position. This will ensure good evacuation of the air. The saturation plug is then completely unscrewed.

STEP 4. The 1-m nylon tubing is screwed in place of the saturation plug.

STEP 5. Place the pump's small handle on position 1 and activate the pump to displace the piston to the end of its range. Maximum travel is reached when the volume displayed on the readout unit stabilises (around 676 cm^3), which should coincide with a jump in pressure reading.

STEP 6. Put the end of the tubing in a container filled with clean water or anti-freeze solution.

STEP 7. Place the pump's small handle on position 2 and activate the pump to return the piston to its fully-retracted position indicated by a constant volume reading on the readout (around 0 cm^3). Water in the tubing will be sucked into the probe.

WARNING: Stop pumping when the deflation circuit pressure gauge reaches 7000 kPa (1000 psi.) to avoid damaging the PROBEX

STEP 8. Place the pump's small handle on position 1 and activate the pump. If air is present in the probe, bubbles will be seen out of the tubing. Continue until air bubbles are no longer present and only water is coming out of the tubing. Repeat sucking in and expulsing water out of the probe until no air bubbles are expelled, which will mean that saturation is complete. Then fully retract the piston.

STEP 9. Remove the tubing and screw the saturation plug back onto the steel core taking care to put 3-4 layers of Teflon tape on the plug's threads. Screw the stainless steel, conical end cap back onto the probe.

2.4 CALIBRATION OF THE PROBEX

Two types of calibration must be run.

Note that **two short hydraulic lines** can be used for speeding up calibration processes.

2.4.1 PRESSURE LOSS CALIBRATION

The pressure calibration allows determining the PROBEX membrane stiffness (inertia), which must be deducted from pressure readings obtained during a test. The membrane stiffness is equivalent to the pressure necessary to dilate the unconfined probe. This calibration must be done a single time when using a new membrane. The procedure consists of:

STEP 1. Once the whole system is saturated, place the probe horizontally at ground level next to the pump. Inflate and deflate the probe two times in order to knead the membrane. Then bring the piston back to 0 cm^3.

STEP 2. Inflate the probe the in increments of 50 cm^3 up to 650 cm^3. Following each volume increment, the corresponding pressure is recorded after one minute. Draw the pressure correction curve.

The softer the rock, the greater the influence of the pressure calibration is.

2.4.2 VOLUME LOSS CALIBRATION

The volume calibration allows determining the correction corresponding to the deformation of the equipment when pressurized. This deformation comes essentially from membrane squeezing and from the compression of the small quantity of air in the water. It must be deducted from volume readings obtained during a test.

The calibration consists of inflating the probe up to 30 MPa in the calibration tube in pressure increments typically of 3 MPa. This calibration allows to: check for leaks, knead the membrane, and determine **'c'** (probe deformation)

The volume correction factor '**c**' is given by the following equation **c = a – b.**

Where **'a'** is the PROBEX volumetric expansion obtained from the Volume Calibration, and **'b'** corresponds to the (small) theoretical expansion of the calibration tube when pressurized.

NOTE: ***For a representative 'c', the user must conduct numerous volume calibrations prior to testing and in the same environmental conditions. When delay between calibrations and testing exceeds two hours, kneading of the membrane should be repeated. Therefore, we suggest beginning each testing day by doing these calibrations, which takes more than an hour.***

The procedure to determine the volume correction is as follows:

STEP 1. Place the probe in the calibration tube.

STEP 2. Pressurize the probe up to 30 MPa. Maintain pressurize and record readings every minute during 15 minutes. During this time, the conical tip (A) must be removed, and the operator must check for leaks. If a leak is found, it should be fixed. Bring pressure and volume back to 0 and put the conical tip back in place.

STEP 3. Inflate the probe in increments of 3 MPa up to 30 MPa. At each step of pressure, record the corresponding volume displayed on the readout unit after one minute. Then deflate the membrane.

STEP 4. Repeat last step 2 times. At the end of the last loading, decrease pressure from 30 to 15 MPa and then back to 30 MPa. At each step of pressure, record the corresponding volume displayed on the readout unit after one minute. Then deflate the membrane.

Ensure that the last two calibrations are repeatable enough i.e. that 'a' does not vary by more than +/- 0.01 cm^3 / MPa between 15 and 30 MPa.

Checking for leakage

During volume calibration, it is important to make sure the equipment is properly saturated and that it is not leaking. This is done by visual inspection (no water is leaking out of the probe, especially next to the probe saturation plug), and by getting ***'Delta V CC'*** **stabilizing between 3 & 4 cm^3 / 3 MPa between 15 and 30 MPa.**

NOTE: ***After running calibrations, make sure that the 'a' measured between 15 and 30 MPa is stable between 1 and 1.33 cm^3 / MPa.***

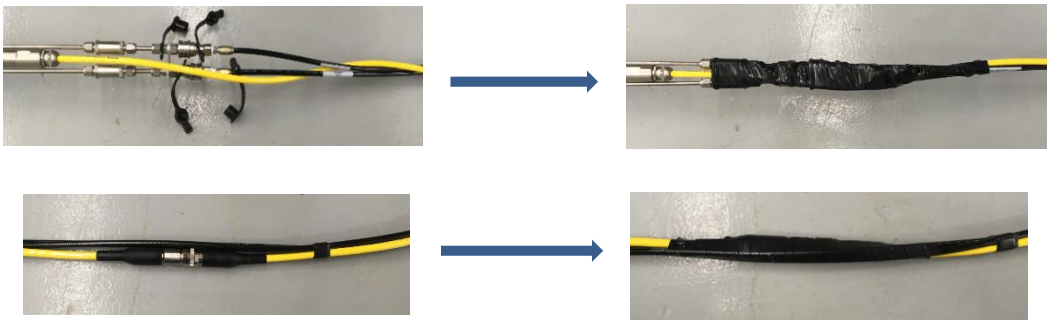
2.5 BOREHOLE

- Core borehole to the deepest testing elevation. In weathered rock, it might be necessary to use tricone + rotary drilling for achieving a tight hole. No percussion drilling can be done. Borehole walls yielded with this method are not smooth enough.
- Clean the borehole. No sand should settle around the probe during a test.
- Borehole walls must be smooth and as close as possible to 76 mm.
- Keep core samples available on site
- Try to reduce down time between drilling and testing, especially in soft rock.

2.6 SETTING THE PROBE IN PLACE

STEP 1. Unroll sufficient length of tubing and electrical cable, keeping in mind that normally tests are carried on from the deepest test elevation upward. Protect their free ends with dust caps. **Also, put some electrical tape on their free ends and apply some Molykote grease on them.** Thread the tubing & cable through enough casing lengths to reach testing depth. Be sure that the male thread of each length is at the lower end of the string of casings. **Lengths of 1.5-m are recommended.** Connect cable and tubing to the probe. The electrical cable is normally longer than the tubing. In order to reduce slack, twist the cable around the tubing and apply some electrical tape and Molykote grease on this bundle. Leave enough slack to allow insertion of the probe in the hole.

WARNING : CONNECTIONS BETWEEN THE PROBE AND THE TUBING & CABLE MUST BE PROPERLY PROTECTED BY APPLYING ELECTRICAL TAPE AND MOLYKOTE GREASE AS SHOWN BELOW.



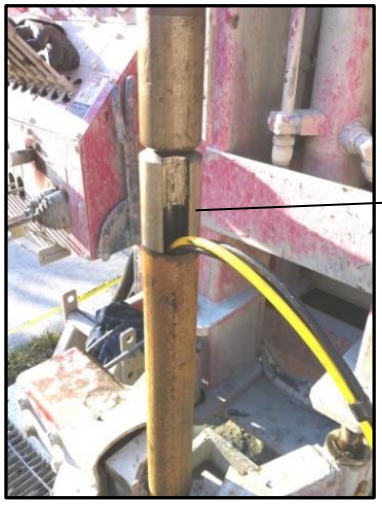
STEP 2. Make hydraulic and electrical connections to the manual pump and readout unit and check that the whole system is working well by inflating and deflating the probe. Check the battery charge.

STEP 5. Insert the PROBEX into the borehole. To avoid the risk of damaging or losing the probe in unstable boreholes, the electrical cable and tubing are normally threaded in a NQ rods (or BW casing) before inserting the probe in the borehole. The probe has a female BW casing thread at its upper end + an NQ rod adapter. Measure the distance between the centre of the inflatable membrane and the upper end of the PROBEX (including any adaptor) for exact determination of the elevation of the probe in the borehole. If possible, support the probe and casing string using a slotted adaptor provided by Roctest. The use of a pull plate is dangerous and not recommended. Additionally, a casing clamp or a pipe vise should be used.

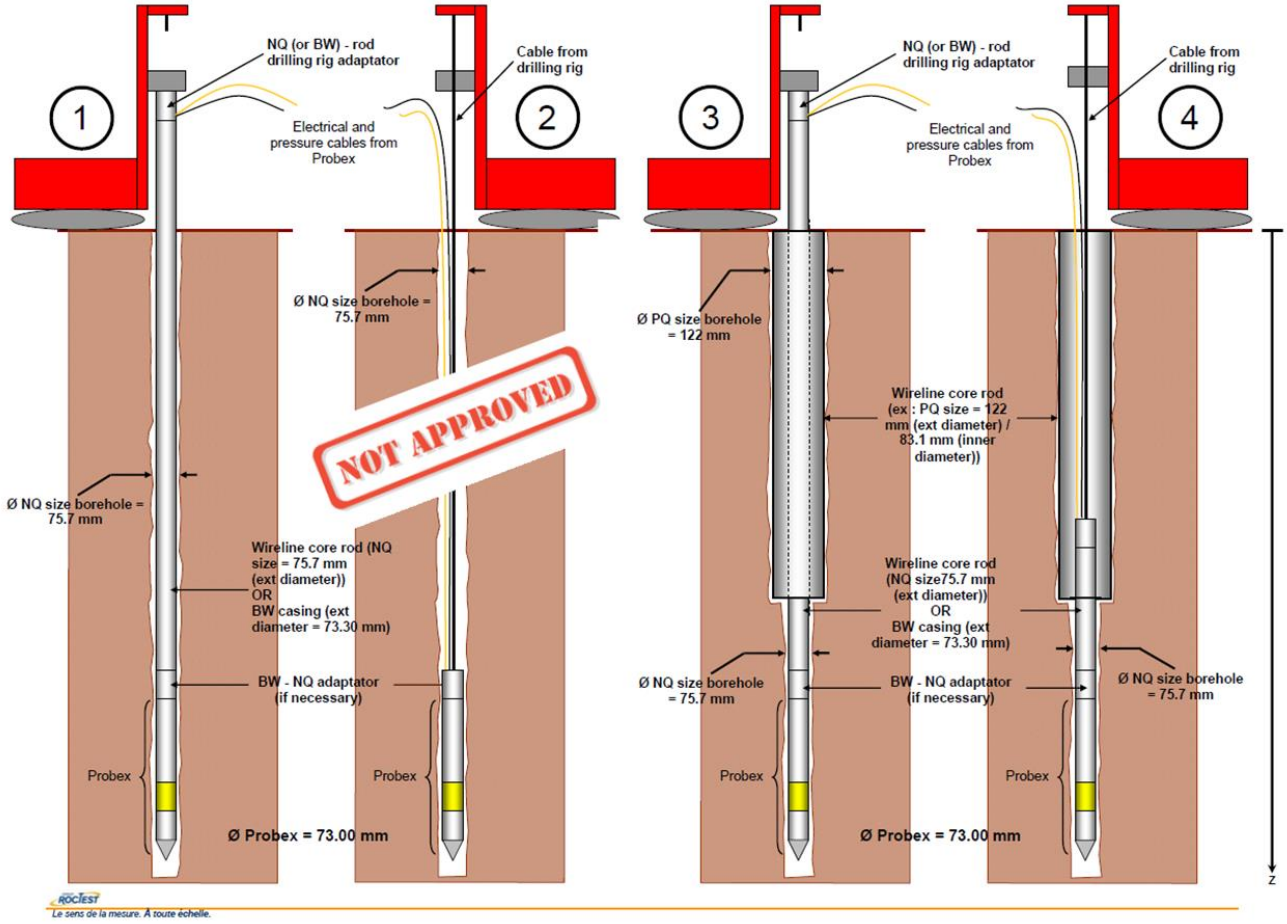
STEP 6. Position the deflated probe at the testing location, based on core examination. The membrane must not straddle large cracks or rock types of significantly different mechanical properties.

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

BE CAREFULL NOT TO TWIST PROBEX TUBING AND CABLE !



Slotted adapter
NQ to AW Rods or
BW Casing to NQ Rods



Methods Used for Lowering Probe in Place

2.7 TESTING PROCEDURE

STEP 1. Turn on the readout unit and wait long enough for the probe to reach temperature equilibrium with the surrounding rock (15 min typ.)

STEP 2. The dual-action piston must be in the completely retracted position.

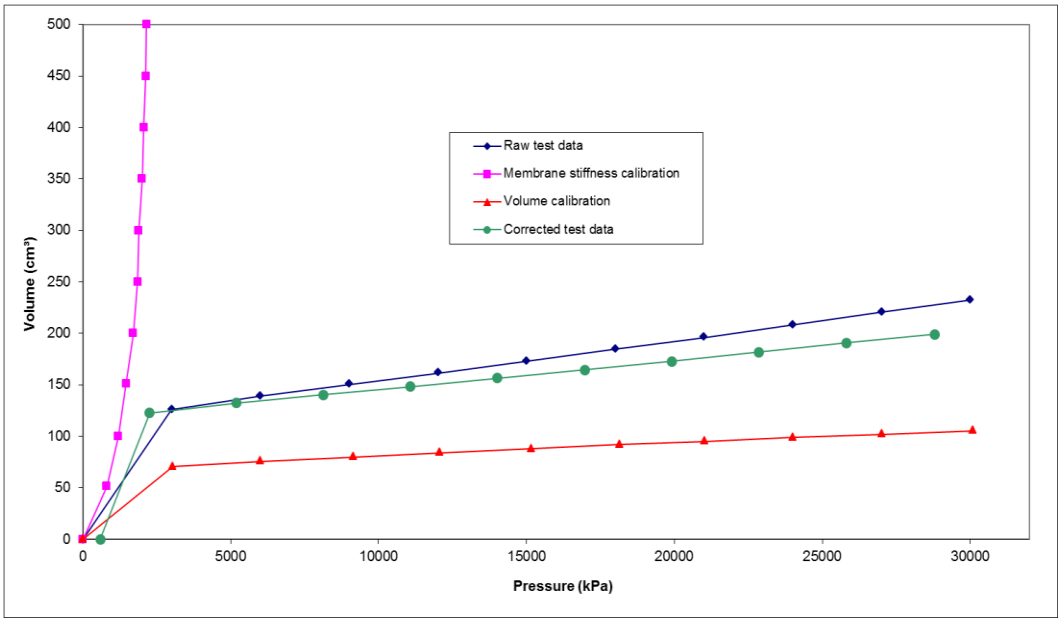
STEP 3. Set the manual pump control valve handle to position 1, ensure that the cyclic test valve is open.

STEP 4. Load the rock mass by stress control steps, typically 10 increments of 3 MPa up to 30 MPa. At each step, pressure and volume are recorded after a one-minute stabilization period for test duration of about 10 minutes. These steps can be smaller when working in a very soft rock, or when the borehole is very large.

STEP 5. If an unloading phase is required, close the cyclic valve and strike the handle of the pump valve from position 1 to 2. Open slowly the cyclic valve for reducing pressure. For increasing the pressure, strike the handle of the pump back in the position 1, and re-apply some pressure while opening the cyclic valve. It is suggested to practice cyclic loading with the probe in the calibration tube before attempting it during a test.

STEP 6. When the test is complete, deflate the probe by pumping with the control valve handle in position 2. The dual-action piston will be fully retracted when the readout shows a zero reading.

STEP 7. Withdraw the PROBEX from the hole or move it to the next testing position. Note that tests are normally carried out from lowest testing elevation upward. Standard spacing between tests is 1.5 m. Inflatable membrane should not be located closer than 0.5 m from the top of the rock or from the bottom of borehole.



Typical PROBEX Calibration and Test Results from the PROBEX

3 DATA REDUCTION

Test results from the PROBEX are essentially used for measuring in situ deformability of rock mass. The method for doing so is the same one used to reduce pressuremeter data. It is based on Lame's equations and it yields a mean modulus of deformation for the rock mass tested. The raw test data are corrected to compensate for membrane stiffness, probe deformability and for the hydraulic head between the pump and the probe.

Note that Roctest offers a spreadsheet PROBEX COMPANION for data reduction. Please contact Roctest to obtain a free copy.

The PROBEX modulus is determined with the following relation:

$$\mathbf{E = 2\,(1+v)\,(Vo + V_m)\,(\Delta P/\Delta V)}$$

Where:

E = Modulus of deformation calculated between P_1 and P_2 during a test
v = Poisson's ratio (set at 0.2 by default)
$\mathbf{V_o}$ = Theoretical volume of the measuring portion of the deflated probe
$\mathbf{V_m}$ = Corrected volume increase at the center of the ΔV volume increase
ΔP = Corrected pressure increase between P_1 and P_2
ΔV = Corrected volume increase between P_1 and P_2

Pressure and volume are corrected as follows:

$$\mathbf{P = P_r + P_l - P_c}$$

Where:

P = Corrected pressure.
$\mathbf{P_r}$ = Pressure reading on the datalogger.
$\mathbf{P_l}$ = Oil column between the pump and the probe.
$\mathbf{P_c}$ = Pressure correction for the stiffness of the membrane at corresponding volume, determined with the pressure calibration.

$$\mathbf{V = V_r - V_c}$$

Where:

V = Corrected volume.
$\mathbf{V_r}$ = Volume reading on the datalogger.
$\mathbf{V_c}$ = Volume correction for the volume expansion of the membrane during the test; determined with the volume calibration.

V_c is obtained with a volume correction factor "c" given by the following equation:
c = a - b
The correction factor **"a"** is calculated from the calibration in the calibration tube, typically between 15 and 30 MPa.
The **"b"** parameter takes into account the expansion of the steel tube during the calibration and is calculated with following equation:

$$\mathbf{b = (2V * (r + e * (1 + m))) / E_m * e}$$

Where:

V = Volume of the probe when in contact with the calibration tube
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 PROBEX is supplied with a standard, steel calibration tube having the following characteristics:

- nominal I.D.: 76.2 mm
- nominal O.D.: 101.6 mm
- **E_m** (modulus of elasticity): 207 x 10^6 kPa
- **m** (Poisson's ratio): 0.30

Using these values in the previous equation and assuming a dilatable length of the PROBEX membrane equal to 457 mm, one obtains the following "b" value:

b = 86.6 x 10^{-6} cm^3/kPa

Important considerations on volume correction

The volume correction factor **'c'** enters in the equation used to calculate the modulus of deformation of the rock. A high level of confidence in the modulus calculated therefore depends on the exactness of the **'c'** value and of its representativeness of the actual intrinsic deformation of the PROBEX during the tests. Normally, the factor **'c'** obtained from the last of the series of calibrations is used for data reduction. The correction factor **'c'** is calculated typically between 15 and 30 MPa. The stiffer the rock is the greater the influence of correction factor **'c'**. It is also recommended to run a volume calibration after a test if the operator has any reason to believe that the factor **'c'** might have changed.

Volume of the probe at rest (Vo)

Vo is theoretically **1950 cm^3** considering the theoretical length (45.7 cm) and diameter (7.37 cm) of the membrane. For a more representative result of **Vo** the user can either 1) measure directly the length of the dilatable portion (length between the steel ends) and the mean diameter on the specific membrane used during testing, or 2) use the following formulae according to the ASTM D4719 standard:

$$Vo = (pi*D^2/4)\ L - Vi$$

Where:
- **L** is the length of the membrane
- **D** is the inside diameter of the calibration tube
- **Vi** is the resulting intercept of a straight line extension of the volume calibration curve. Refer to the ASTM D4719 standard for more details.

In softer material, the yielding pressure can be determined and, as for a soil pressuremeter, a limit pressure P_L can be estimated.

Determination of Radial Expansion of the membrane

The volume reading can be converted into radial expansion using cylinder volume equation : **$V = (pi \times D^2 / 4) \times L$**

With: **V =** Volume in cc of the membrane
L = Length of the membrane (nominal value = 45.7 cm)
D = Diameter of the membrane (nominal value = 7.37 cm)

Injected volume (cm^3)	Diameter - approx. (cm) *
0	73.7
100	75.6
200	77.4
300	79.2
400	80.9
500	82.6
600	84.2
676	85.5

* Depending on Vo

4 MISCELLANEOUS

4.1 TESTING METHODOLOGY AND USE IN HARD ROCK

No existing standard specifically regulates the use of the PROBEX. Initially thought to be used as a dilatometer as defined in the ISRM *Suggested Method for Deformability Determination Using a Flexible Dilatometer* (ISRM 1987), the PROBEX became also commonly used as a rock pressuremeter i.e. according to testing sequences and interpretation methods associated to pressuremeters. The test procedure recommended by the manufacturer – and described above – consists in loading the rock mass in a single pass of 10 stress-control steps lasting 1 minute each before recording data. The number and magnitude of pressure steps can be modified when testing very soft rock. Two or three additional identical loading passes can be performed at the same testing elevation for better defining elastic and plastic behaviours of the rock.

The standard loading sequence is sometimes modified in order to yield additional or different information. For instance, it can be decided to record readings every minute at each pressure step until stabilization of volume reading. In addition, progressive loading cycles can be done following standards associated to conventional flexible dilatometers. However, it is not recommended to follow this unload-reload sequence with the PROBEX in hard rock.

The use of the PROBEX is possible in hard rock, but special precautions are necessary. First, the standard loading sequence provided by the supplier is recommended. The borehole needs to be very tight. Finally, de-aired water should be used for reducing the deformation of the probe. Additional information can be found in document (7) cited below.

4.2 TESTING AT GREAT DEPTH

This section gives guidelines to follow when doing tests at great depths (over 200 m).Two aspects will get critical as the testing depth increases : 1) the increased time lag for reaching pressure equilibrium within the equipment, and 2) the time required to lower the probe at the test depth.

Time Lag

The pressure in the probe is measured at the ground surface thanks to the digital pressure gauge located next to the pump. As the tubing length increases, the time required for reaching pressure equilibrium from the pump to the probe will increase from a few second up to a few dozens of seconds. Consequently, for deep testing, we recommend:

- Using optional shorter tubing lengths for accelerating calibrations
- Watch volume and pressure as the probe is been lowered in place
- During testing, at each step, record readings every minute up to 3 minutes
- Stop pumping at least 20 seconds before recording data (for 400 m of cable)

Time for setting the probe in place

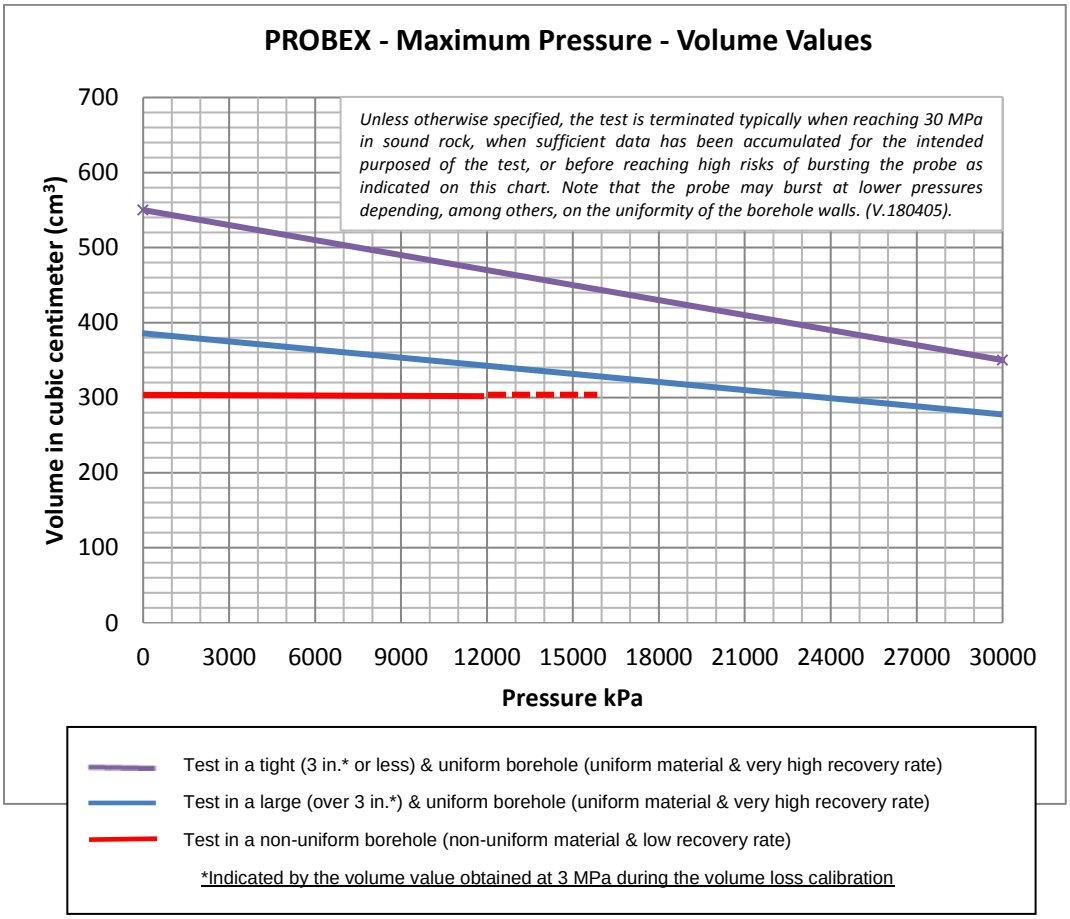
One purpose of the volume calibration is to knead the flexible membrane to ensure its repeatable behaviour. The effect of this kneading will start to decay after about two hours. After this delay, this kneading should be repeated. Otherwise, air will start to get into the rubber cavities and probe performances will be affected. Consequently, if it takes more than two hours to put the probe at testing elevation, it is suggested to knead the membrane by pressurizing it a couple of times against a casing or borehole walls

4.3 MEMBRANE BURST

In sound rock, a test will be typically stopped when reaching 30 MPa, which normally occurs before reaching 350 cm^3 if the borehole is tight and uniform (uniform material & high recovery rate). However, risk of bursting a membrane during a test is unfortunately always present. This risk depends mainly on the type of rock tested and the experience of the operator. The following guidelines should help reducing this risk.

- Make a borehole with a diameter as tight as possible in order for the membrane to make contact with the rock as soon as possible i.e. 3 inches or less.
- Avoid zones with recovery rates under 90%. When positioning the probe in the borehole, a special attention must be paid at the core samples in order to avoid clay seam or weak zone where the probe could bulge locally and burst. Measure accurately the length of rods used to lower the probe for knowing exactly the probe's position during a test. In zones with low recovery rate, never inject more than 150 cm^3 over 3 inches* and never exceed15 MPa.
- When risk of bursting is high, when the borehole is very large, or when the tested material is very soft, the operator should reduce the pressure increments (to 2, 1, or 0.5 MPa for instance) in order to obtain maximum information out of the test.
- Stop the test earlier in case of unusual rock response.

The following chart can be followed:



4.4 REPLACEMENT OF THE MEMBRANE

For clarification purposes, the user should note that when the PROBEX probe is taken off the steel core of the probe, he has in his hands a unit composed of elements No. 8, 9, 10, 11 and 14 shown on Figure below.

STEP 1. Remove the stainless steel, conical end cap No. 1 from the probe.

STEP 2. Unscrew the hexagonal nut No. 4 and washer No. 6 from the steel core (No. 3).

STEP 3. Using the 4-prong tool supplied, remove locking nut No. 7 from the steel core (No. 3).

STEP 4. Using strap wrenches on the upstream steel end of the probe (part No. 11), completely unscrew it from the probe.

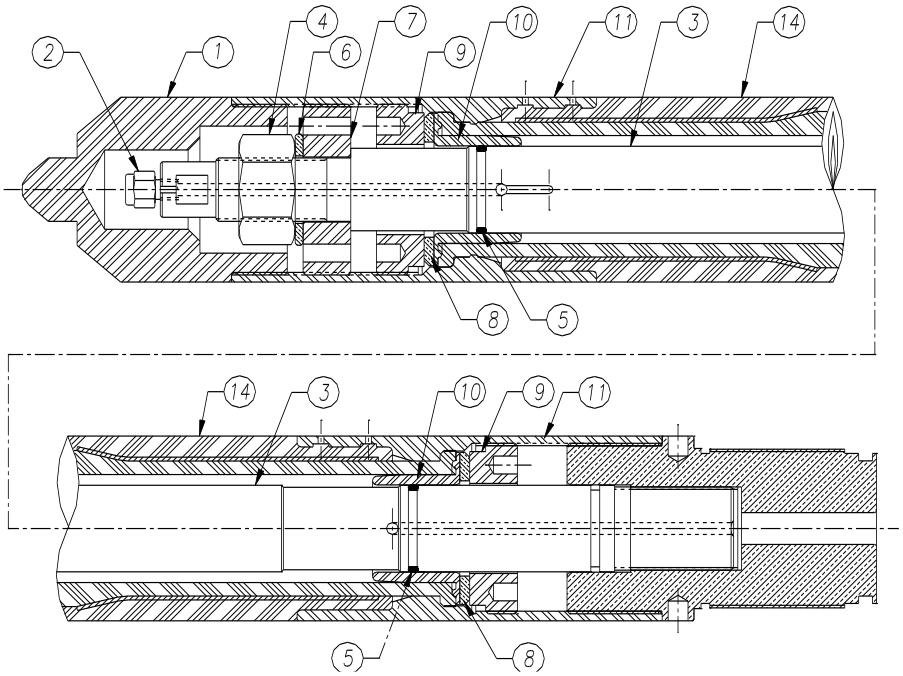
STEP 5. Carefully pull the probe away from the steel core. It will slide on the 'O' rings (No. 5) mounted at both ends of the steel core (No. 3) and the water contained in the annular space between the core and the membrane (No. 14) will flow out of the upstream end.

STEP 6. To reassemble a probe, the reverse procedure is followed and care must be taken with respect to the following details:

- Put a small amount of grease provided in the tool kit on the 'O' rings and on the internal surface of parts No. 10 and No. 9 in the probe.
- Tightening nuts No. 9 should be checked and screwed tightly against spacer No. 8 with the 4-prong tool supplied.
- The probe should be slid gently over the steel core to prevent damaging the 'O' rings No. 5.
- Locking nut No. 7, washer No.6, and the hexagonal nut No. 4 are screwed back in position without tightening them. Good contact is all that is needed.



Membrane Replacement



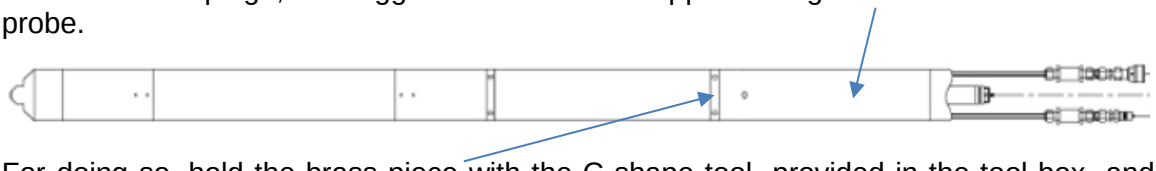
Probe Components

1- Conical end cap	7- Locking nut
2- Saturation plug	8- Washers
3- Steel core	9- Tightening nut
4- Hexagonal nut	10- Internal probe sleeve
5- O-rings	11- Outer probe steel ring
6- Washer	14- PROBEX membrane

4.5 MAINTENANCE

Cleaning the unit

After each campaign, we suggest to remove the upper casing section and to clean the probe.



For doing so, hold the brass piece with the C-shape tool -provided in the tool box- and unscrew the upper casing section with a pipe wrench. After cleaning the probe, re-assemble it. NEVER ROTATE THE BRASS PIECE !.

Membrane Diameter

With use, the PROBEX membrane will deform in a plastic way resulting in a diameter increase. This phenomenon will not invalidate test results, but may prevent PROBEX insertion in the calibration tube or in the borehole. For preventing that: **the membrane should be periodically sandblasted by hand. Please note that this operation can take long.**

4.6 COLD / HOT TEMPERATURE

In order to use the PROBEX at temperatures below 0°C, water in the probe must be replaced by an antifreeze solution. Two types of antifreeze can be considered.

Ethylene-glycol-based antifreeze (regularly used in engine antifreeze liquid) is less corrosive for the equipment. A 50-50 solution of water - ethylene glycol by volume will allow using the equipment at about -25°C, a 70-30 solution can be used down to about -10°C. Ethylene glycol is not environment-friendly. Methanol-based antifreezes (car windshield liquid) are sometimes used, but note that methanol is corrosive for the equipment. The equipment must be flushed and washed with clean water after each use.

When temperature drops below 0°C, we suggest using a heated shelter or minivan-type truck in which the operator can run the pump and readout. With this configuration, it should be possible to run tests down to at least -15°C. At some point not determined yet, between -20°C and -40°C, the oil will get too viscous and the tubing too brittle.

The PROBEX can also be used at hot temperature (over 40 °C). However always keep the PROBEX out of direct sun. The use of a canopy is ideal.

Try to avoid significant thermal changes on the probe. If inevitable, let the probe stabilize in temperature at the testing depth for about 15 minutes before starting a test.

4.7 REFERENCES

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(3) Gill D. E. and Leite M. H. 1995. *Dilatometer Testing of Rock.* ISP4, Balkema, Rotterdam, 249-256.

(4) ISRM (April 1987). *Suggested Method for Deformability Determination Using a Flexible Dilatometer*, Int. J. Rock Mech. Min. Sci., 24 (2), 123-134.

(5) Kaneshiro J. Y., Harding R.C., Johannesson P. and Korbin G.E. 1987. *Comparison of modulus values obtained from dilatometer testing with downhole seismic surveys and unconfined compressive tests at McKays Point Dam Site, Ca*, 28th US Symposium on Rock Mechanics, 211-221.

(6) Labrie D., Conlon B., Anderson T. and Boyle R.F. 2004, *Measurement of insitu deformability in hard rock,* Proceedings of 57th Canadian Geotechnical Conference, 9-16.

(7) Marcil L., Green R. and Baures T. and Boyle R.F. 2013, *The PROBEX: Over 25 Years of Experience in Measuring Deformability of Rock,* ISP6