



INSTRUCTION MANUAL

VIBRATING WIRE PRESSURE CELLS

Model TPC & EPC

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1 APPLICATIONS

The TPC (Total Pressure Cell) and EPC (Earth Pressure Cell) series are designed to measure the combined pressure of effective stress and pore-water pressure. Generally, pressure cells are used in two types of applications:

- pressure measurement in a mass material like in embankments, mine backfill and concrete,
- and pressure measurement at the interface between soil and a structural element like tunnel linings, foundations, retaining walls, culverts...

In operation, the cell is embedded and oriented with its plane perpendicular to the anticipated direction of principal stress. A cluster of cells can be installed to permit the measurement of both the magnitude and the direction of the principal stress or to measure stress in different directions.

The vibrating wire strain gage of the cell sensor provides the necessary ruggedness, reliability, stability and ease of remote monitoring.

2 PRODUCT

2.1 GENERAL DESCRIPTION

The cell consists on a pressure pad, a stainless steel tube and a pressure sensor in a strong housing. The pad is made of two plates welded together around their periphery. This provides a central flexible membrane filled with a non-compressive fluid. Both sides of the pad are active which gives more reliance on measurements at the inner face. A short length of thick wall stainless steel tubing is welded into the edge of the pressure pad and communicates with a cylindrical housing containing a vibrating wire pressure transducer. A watertight cable allows remote reading of the pressure changes.

During construction, the cell is first put under a vacuum to remove any air, and de-aerated oil is injected into the pad under pressure to force the plates apart separating them by a thin fluid film. Oil also fills the tubing and cavity in the cylindrical housing containing the pressure transducer.

On demand, a re-pressurization tube of 1.2 m can be added to the cell. When adding some oil, it allows the pad faces to correctly make contact with their surrounding environment (especially in the case of mass concrete). Please contact RocTest – Telemac for further information.

2.2 DESCRIPTION DETAILS AND SPECIFIC USES

The main difference between a TPC and a EPC cell is the design of their pads. It affects the properties of the cell and then, their uses are different.

**Model EPC cell is very sensitive to temperature variations.
It has to be used in a very stable temperature environment.**

2.2.1 MODEL TPC

The TPC pad is made from stainless steel discs. Once welded, they are recessed on both sides. This construction and the small quantity of oil used give a high stiffness to the cell. Furthermore, the pad is very flexible thanks to its peripheral groove. This undercutting has the advantage of surrounding the active pad by a rigid annulus that greatly decreases its sensitivity to stresses in directions other than normal to the cell faces. The small quantity of oil minimizes the cell sensitivity to temperature changes.

High stiffness and low temperature sensitivity make the TPC cells suitable for embedment in hard soil, medium rock or concrete.

TPC cells are available in circular or rectangular shape, the latter being specially designed for the measurement of stress in mass concrete or in shotcrete tunnel linings. Please contact RocTest – Telemac for further information.

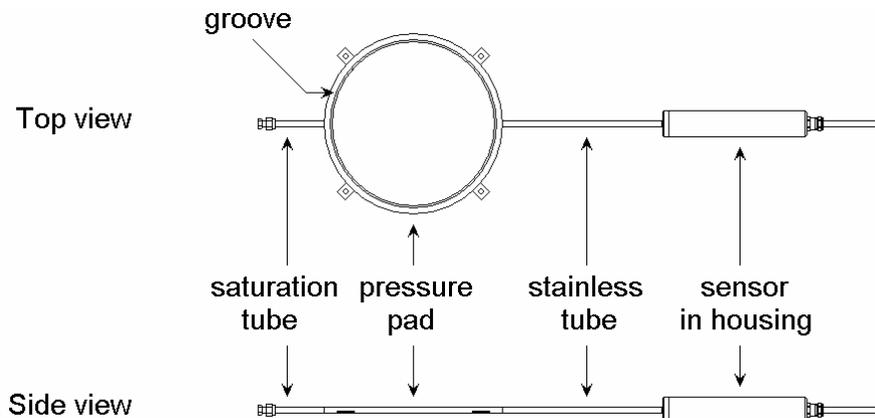


Figure 1: Model TPC pressure cell

2.2.2 MODEL EPC

The EPC pad consists of two thin flexible stainless steel plates with rolled edges, welded together around their periphery. The layer of oil between plates is much thicker than in the TPC model. Material used for the plates and the larger volume of oil makes the EPC cell less stiff. This property makes the EPC cell suitable for embedment in soft soil or mine backfill.

The larger volume of oil requires that this model be installed in relatively stable temperature environments with special care given to the uniformity of the bedding on which the cell is placed.

2.3 OPERATION PRINCIPLE

The external soil pressure deflects both sides of the membrane constituting the pad of the cell. Pressure is transmitted to oil and then to the vibrating wire sensor.

The sensing element of the pressure transducer is a piano wire attached to a diaphragm. A variation in oil pressure changes the position of the diaphragm and so affects the tension of the wire. The tension is directly proportional to the square of the resonant or natural frequency of the wire.

In operation, plucking voltages are applied to a coil and a magnet located near the wire in a spectrum of frequencies, spanning the natural wire frequency, thus forcing the wire into vibration. The oscillation of the wire generates a voltage in the coil. This signal is amplified by the readout unit, which also discriminates against harmonic frequencies, to determine the resonant frequency of the wire.

The relationship between the period N and the strain ε in the vibrating wire is expressed by the following equation:

$$\varepsilon = K \cdot \frac{10^9}{N^2}$$

where ε = strain in micro-strain

N = vibration period in microseconds

K = gage constant, specific for each type of gage

The vibrating wire technology offers the unique advantage of a frequency output signal virtually unaffected by line impedance, or contact resistance.

Cable length of several kilometres can be used without signal deterioration.

Portable units as the MB-6T(L) are available to read the vibrating wire sensor (excitation, signal conditioning, display of different readings). Contact Roctest – Telemac for further information.

2.4 CALIBRATION

A calibration data sheet is supplied with each cell. It enables conversion of gross readings into pressure values and temperature correction.

All the sensors are individually calibrated over their working range before shipment. The calibration factors and the thermal coefficient are established by running the calibration data points through a linear or polynomial regression formula.

During the calibration process, the pressure sensors are tested at 125% of their working range and at 40 degrees Celsius.

3 INSTALLATION PROCEDURE

3.1 PRE-INSTALLATION ACCEPTANCE READING

Reading of all instruments should be taken as the pressure cells are received to ensure they have not been damaged during shipment or handling on site.

Take the reading in LINEAR units with the cell completely unloaded. Then compare it with the factory reading shown on the calibration sheet. They should be similar. The difference on raw readings comes from the fact that temperature and barometric pressure are certainly different than those at the factory.

If the pressure cell pad is pressed, the readings should decrease.

Take also a reading of the temperature gage to be sure the thermistor is working properly.

For details about how to take readings or how to convert frequency into LINEAR units, please refer to next chapter (Reading procedure).

3.2 INITIAL READING

Before embedding the cell in its final location on site, an initial reading has to be taken to correctly convert measurements in LINEAR units into pressure when the cell is in operation. This process is necessary to be able to apply later temperature and barometric corrections.

Lay down the cell completely unloaded and out of direct sunlight exposition. Wait for thermal equilibrium (2 hours should be enough, depending on site conditions). Read and record the sensor value in LINEAR units (called L_0), the temperature (T_0) and the barometric pressure (S_0).

For details about how to take readings or how to convert frequency into LINEAR units, please refer to next chapter (Reading procedure).

A special calculation has to be done if using the polynomial relation to convert raw readings into pressure. The coefficient C of the calibration sheet must be recalculated because it depends on temperature and barometric pressure on site, which are different from those in factory. Use the following relation:

$$C' = -AL_0^2 - BL_0$$

where: C' = new calibration factor in kilopascal

A, B = calibration factors (see calibration sheet)

L_0 = initial reading in LINEAR unit

Note: It is not necessary to apply corrections to pressure calculation at this step, but it is important to record both temperature and barometric pressure.

3.3 SENSOR INSTALLATION

3.3.1 GENERALITIES

The TPC and EPC cells are shipped mounted to a wooden backing board. It is recommended that the cell is left taped on the board until the last possible minute. This will prevent undue deformation of both the connecting tube between the pad and the transducer housing and the re-pressurization tube (optional).

During installation, the cells should be read frequently and at the completion of each stage.

As the final purpose of installing cells is to measure the stress in soil or on structure interfaces, the main point to keep in mind during the installation is to try to reduce as much as possible the changes on the existing field stress due to that installation. Therefore, a few recommendations apply:

- The location for the cell or cells is determined according to the specific objectives of the measurements. However each cell should be located in ground that is undisturbed (by blasting for example) and typical of the surrounding materials.
- Cells are installed either individually, in pairs or clusters to measure pressures in different directions at the same location. Adjacent cells should be separated by a distance of at least 4 cell diameters in such a way as to prevent the presence of a cell affecting readings on adjacent cells.
- The cell must be uniform and in complete contact with the surrounding material. Soil or rock adjacent to the cell should be free from protrusions or unrepresentative material that would result in stress irregularities on the pad.

Cells should preferably not be located where they will be exposed to appreciable temperature changes, for example by the action of direct sunlight or cold winds on exposed surfaces. Insulation may be required in such cases.

3.3.2 INSTALLATION IN SOIL

The most important factors to take into consideration when installing pressure cells in soil or fill are:

- Ensure intimate contact between the cell and the cell bedding material making sure that the latter is uniformly compacted to the same density as the surrounding fill or soil.
- Avoid localized or point loading of the cell by large aggregate or pebbles. It is usually recommended that the largest sized aggregate in contact with the face of an earth pressure cell not be greater than 1/50 the pad diameter.
- Avoid disturbing the natural distribution of fill or surrounding soil as much as possible.

The pressure cell and its transducer are embedded in a lens of selected material to ensure uniform representative loading of the cell pad. To prevent damage to it, the cell and the lens are located on the base of an excavation, forming a mound, or inside a pocket dug in it.

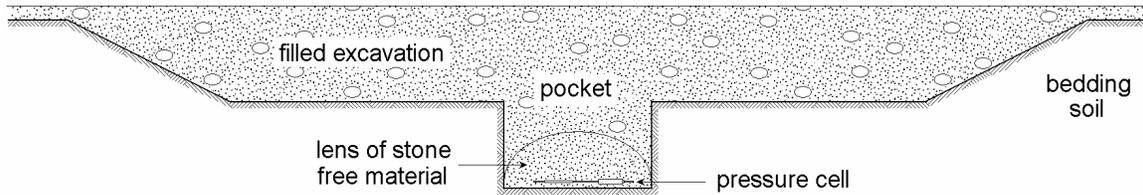


Figure 2: Typical layout of pressure cell

The pocket should be excavated with extreme care to avoid disturbance to the soil. The width of the pocket should be equal to a minimum of three pad diameters to avoid load bridging. The length of the pocket (parallel to the axis of the pressure transducer) should be six pad diameters to accommodate the length of the lens and to provide one pad diameter clearance at either extremity of the pressure cell. The pocket is enough deep to enclose the cell and its lens.

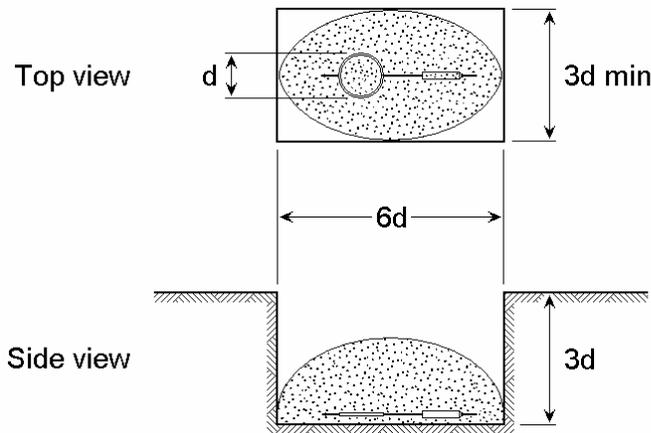


Figure 3: Draft of a pocket

The cell is then fixed in position taking care that it is fully in contact with the underlying material. If required, the position and orientation of the cell can be maintained during installation by means of a plywood template. This template is removed after the material immediately surrounding the cell has been placed and carefully hand-compacted.

The lens is made from stone free excavated material with the same water content and hand compacted to the same density as the surrounding soil.

The width of a lens should be at least three times the diameter of the cell pressure pad with no lens being smaller than ten times the diameter of the largest rock in the embankment material.

The lens should be long enough to encapsulate the pressure transducer and the pressure tube to avoid any differential movements in the area where the cell is embedded.

The total thickness of the embedment lens should be from third to half the length of the lens depending on the particle size shape and degree of compaction. Each cell is then backfilled with selected material hand-compacted to a density similar to that of the surrounding soil.

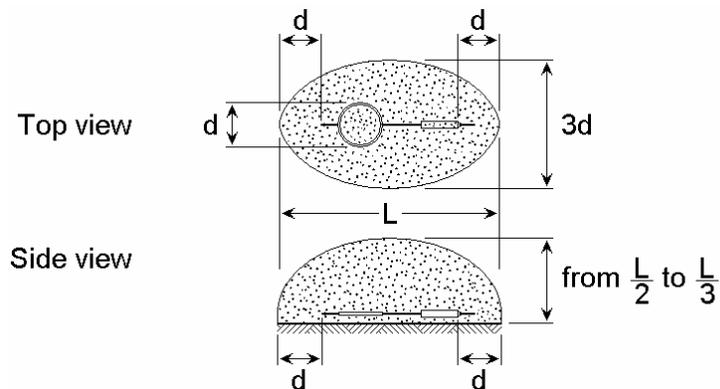


Figure 4: Draft of a lens

The bedding for the cell and the underlying material should be carefully compacted to the same density of the surrounding fill. Any protruding stones should be removed and replaced with compacted stone free excavated backfill. It is important that the cell bedding is made of uniformly compacted material.

In areas containing appreciable coarse material, the lens should be enclosed in transitional layers of successively coarser material in order to establish a gradation outward to the maximum size material.

The first layers of transitional material over the lens should be placed in 10 cm lifts and similarly compacted until at least 50 cm of material has been so placed. At that time rubber-tired equipment can cross the lens location, but no heavy vibratory rollers should be permitted across the lens until it is protected by a compacted thickness of at least 1.5 m of fill.

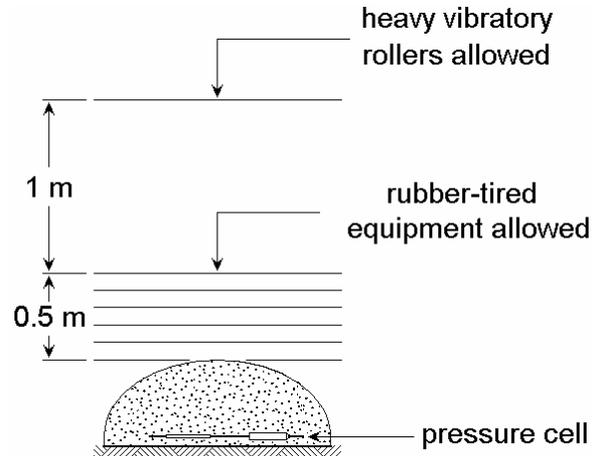


Figure 5: Authorized equipment over pressure cell

An example of excavation to accommodate a cluster of three cells is shown on drawing below. In this example, the cells are located in pockets in an excavation. The pockets should be located one meter away from adjacent pockets or the excavation walls.

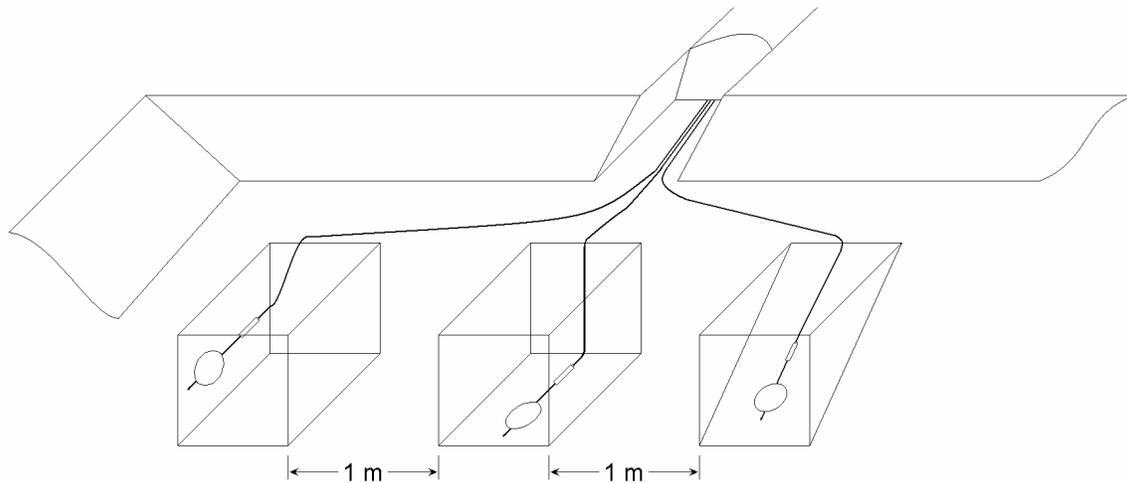


Figure 6: Layout example of cluster of cells

Total pressure cell clusters, placed according to the suggested methods outlined above, may be installed whether in trenches, below the temporary embankment grade, or in mounds above the temporary embankment grade. In dams, for example, it is usually convenient to install in trenches in the impervious rolled fill core, and in ramps in the filter zones and compacted rockfill shell zones. In earth embankments, it is convenient to install in trenches. By so doing, adequate degrees of compaction of the backfill can be more easily obtained without damage to the cell clusters or cable arrays.

Cable details are outlined below. The precautions to be observed in protecting the cable from damage by heavy vibratory compaction equipment should also be observed in connection with the cell clusters. In general, all material in the instrument lenses should be placed by hand and compacted with pneumatic or gasoline backfill tampers.

As the cells are being covered and compacted, repeated readings should be taken to ensure that the cells are continuing to function properly.

3.3.3 INSTALLATION FOR MEASUREMENTS ON STRUCTURES

In backfill for piers, piles, retaining walls, culverts and other structures where load measurements are desired, the cells are either attached to the forms and placed in the structure before concreting, fastened to the structure after concreting prior to backfilling or embedded in the backfill a short distance away from the structure. For the three methods, the contact between the cell and the backfill should be effected by means of a lens of stone free selected material, preferably the same as the surrounding fill material as described in the previous paragraph.

In the first method, where the cell is installed in the formwork before concreting, it is necessary to ensure that the cell is securely held in place against the formwork during the concreting operation. The cable should be secured to the formwork or reinforcing steel at intervals not exceeding 50 cm. Concrete vibrators should not be allowed to come in contact with the cell or cable.

Attaching the cell to an existing structure prior to backfilling can be accomplished using cement mortar.

A pad of cement mortar (for example 1:2 cement:sand, 4 second flow cone reading) is trowelled onto the structure's surface and the cell is placed against the pad squeezing out mortar until a layer no more than 5-10 mm thick remains beneath the pad. Entrapment of air bubbles must be avoided. The cell is secured in position such that the cell remains in place during the backfilling operation.

The cable is led along the wall of the structure or excavation to the terminal unit, is labelled and fixed securely.

In certain applications, because of individual structural configurations, it may be desirable not to place the cell directly in contact with the structure surface. The cell is bedded in a lens of stone free fill material with dimensions, density and water content as described for cells embedded in soils. In such instances, a minimum of 5 cm of fine selected material may be placed between the cell and the structure surface. If the cell is to be oriented other than parallel to the surface, the minimum spacing between the cell and the structure should also be at least 5 cm.

After installation, each cell has to be check for correct functioning.

3.3.4 INSTALLATION AT INTERFACE BETWEEN CONCRETE AND ROCK

The area of rock or concrete over which the cell is to be placed should be prepared flat ± 10 mm. Loose material should be removed. A pad of cement mortar (for example 1:2 cement:sand, 4 second flow cone reading) is trowelled onto the rock or concrete surface, in order to coat it with a 15 mm thick layer. The cell should be cleaned of grease. It is placed against the pad squeezing out mortar until a layer no more than 5 – 10 mm thick remains beneath the flat jack. Entrapment of air bubbles must be avoided. The cell is secured in position either by tying to pins in the rock or concrete, or by securing it to nearby reinforcement.

The cell is then coated with a 10 – 25 mm layer of the cement mortar which is allowed to set completely before the shotcreting operations begin. To avoid bridging between the cell and the concrete due to the differential expansion of the concrete and the cell, it is necessary to keep the temperature of the mortar as low as possible during the cure. This can be achieved by keeping the mortar covered with a wet burlap during the initial cure.

The cable is led along the wall of the structure or excavation to the terminal unit, is labelled, and is fixed securely to the reinforcement or to pins in the rock or concrete. If the cable is to be embedded in concrete or shotcrete, it must be secured at intervals not exceeding 3 m along its length. Kinks and constrictions in the cable must be avoided. A cable that is not to be protected by embedment in concrete must be protected by other means, for example by metal conduit.

The correct functioning of each cell has to be checked and any leaks repaired before concrete or shotcrete is placed.

3.3.5 INSTALLATION IN MASS CONCRETE

The cell is fixed to the reinforcement or the structure. Its positioning should be such as to ensure an all round cover of concrete. Entrapment of air must be avoided. Cell alignment should be within $\pm 10^\circ$ of that specified. Cells must be fixed securely to ensure that alignment is maintained during pouring of concrete.

Because the cell has a higher temperature coefficient than concrete, it will expand during the curing of the concrete and as the concrete cools the cell contracts and breaks contact with the concrete.

To overcome this problem, it is necessary to use one or a combination of the following methods:

- Use the optional model total pressure cell especially designed for the measurement of stress changes in concrete. A post-stressing tube is included with the cell, allowing for re-pressurization of the cell. Fluid is forced back into the cell by crimping the re-pressurization tube and noting the change in pressure versus the length of tubing crimped. Before complete contact between the concrete and the pressure cell is achieved, the pressure increase in the cell should be small per centimetre of crimping. Once complete contact is achieved, the pressure will rise quickly. From that moment, one more crimp on the tube should be enough to be sure of the contact between the pad and its environment.

See figure below for a typical plot of centimetres crimped versus internal pad pressure.

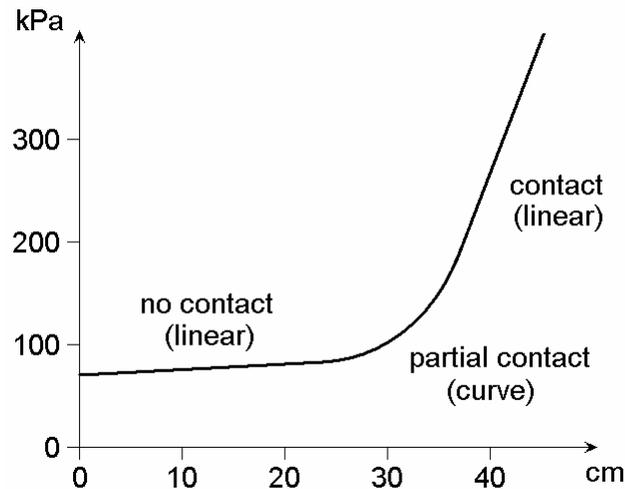


Figure 7: Typical re-pressurization curve

When crimping the re-pressurization tube, do not crimp within about 7½ cm of the fitting on the end to ensure that the internal ferrules do not become warped. A pair of heavy-duty vise grips with smooth jaws makes a good crimping device, and care should be taken to avoid cutting the tube during crimping. Monitor the pressure increase continually and avoid over pressurization.

The re-pressurization tube may be bent in order to route the tube through rebar, etc. out to an accessible area. However, the exposed tubing will need to be protected from equipment and personnel traffics because it is always an integral part of the sensing system. Care must be taken when bending the tube so that the inside diameter does not close.

- Cast the cell in a concrete briquette using the same as the mass concrete after having removed any aggregate larger than 30 mm. The briquette should not be cast sooner than 48 hours prior to the mass concrete pour.

The briquette should be at least two cell diameters wide by half of a diameter thick and long enough to encapsulate the pressure transducer.

When it is dried, it is advised to control the contact between the pad of the cell and the concrete with the optional re-pressurization tube. Use the same method as described above.

Encapsulate the cell in situ following the same method used for installing cells between concrete and rock.

All other aspects of the installation in mass concrete should follow the specifications described in previous paragraph.

After installation, each cell has to be check for correct functioning.

3.3.6 INSTALLATION ON TUNNEL LINING

Several pairs of rectangular TPC pressure cells are generally used on tunnel linings to measure both normal and tangential stresses around them.

Their installation depends strongly on the site conditions:

- If shotcrete is used, the procedure for cells which measure normal stresses is the same as installing cells between concrete and rock (as described in a previous paragraph). In a few words : prepare a flat surface, trowel a pad of cement mortar on it, press the cell against the pad and finally coat the instrument with another layer of mortar. Cells which measure tangential stresses are fixed to short re-bars spit into the rock or to the rebar cage if any. Eyelets around the cells are useful for that operation. Re-pressurization tubes are bended in order to come out from the shotcrete and the future lining. Route cables along the structure to the terminal unit (junction or switch box). Be sure that both cable and re-pressurization tube for each cell is well identified.

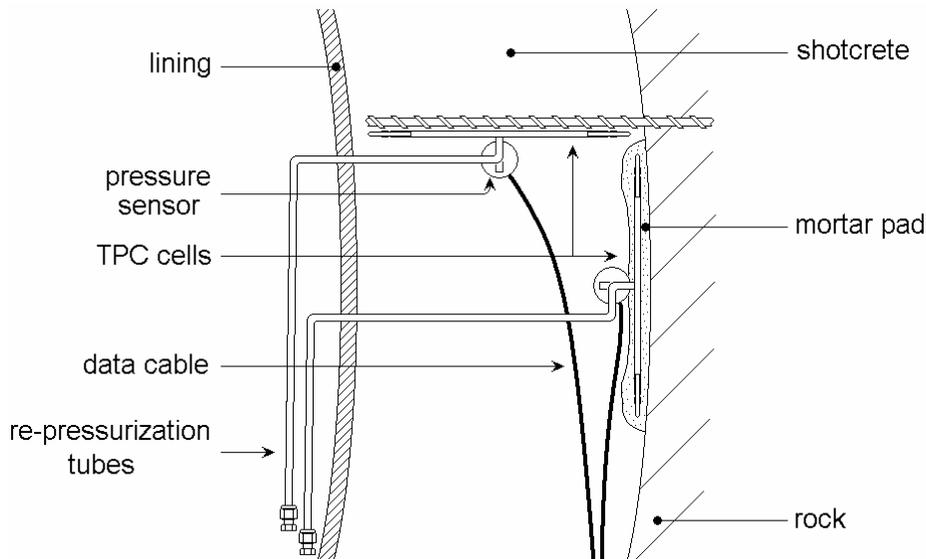


Figure 8: Typical installation on tunnel lining

- If precast linings are used and built in, we advice to fix the cells to the rebar cage using the eyelets, before concrete pouring. Cells which measure normal stresses have to be close to the external surface of the lining. Experiences on site gave good results and the installation is easier and safer for the instrument. Note the distance between the pad and the external surface of the lining. This will be helpful to understand stress differences between cells. Route data cables and bend re-pressurization tube safely into the cage until the other side of the lining, and protect them against damages during concrete filling and lining conveying. Be sure that both cable and re-pressurization tube for each cell is well identified.

In all cases, do not forget to re-pressurize the cells as explained in previous paragraph. This will restore the contact between the pad and the concrete. After installation, each cell has to be check for correct functioning.

3.4 CABLE INSTALLATION

3.4.1 CABLE IDENTIFICATION

The electrical signal coming from the sensor is transmitted through an electrical cable. This cable is generally supplied in rolls.

Cables are identified with the serial number that is labelled on the sensor housing. The serial number is stamped on a tag that is fastened to the readout end of the cable.

In the case where the sensor cable has to be cut or if the cable end is inaccessible, make sure to be able to identify it (by marking its serial number for instance with an indelible marker or using a color code). If there are a lot of risks of cuts, the cable should be marked using metal tags at regular intervals along its entire length. It is very important to clearly identify the instrument for reading or wiring purposes.

3.4.2 CABLE ROUTING

Before backfilling, the cable must be laid with the utmost care. Loop the cable around the recess; make sure it is resting on a bed of hand placed and compacted screened soil.

In embankments, cables may be embedded in a protective covering of sand or selected fine embankment materials. A typical installation comprises the positioning of a series of cables on a prepared layer consisting of not less than 20 cm of compacted selected fine material. The prepared layer may be located either in a trench or on an exposed ramp.

Route the cable towards the junction or switching panel. Make sure that the cable is protected from cuts or abrasion, potential damage caused by angular material, compacting equipment or stretching due to subsequent deformations during construction or fill placement. In concrete structures, the cable must be protected from vibration of concrete.

If necessary, run the cable through rigid or flexible conduit to the terminal location. To provide protection for cable running over concrete lifts, hand placed concrete is sometimes used, depending on site conditions.

Placement of cables to be embedded in concrete involves positioning and immobilizing the cables in such a way that damage during concrete placement and vibration is minimized.

Whenever possible, cables should be placed in the plane of reinforcing mats, and secured firmly to the mats with tie wire.

Check that the cable does not cross over itself or other cables in the same area.

Surface installations require continuous surveillance and protection from the earth moving equipment circulating on the field.

During the cable routing, read the instruments at regular intervals to ensure continued proper functioning.

Record the cable routing with care and transfer this routing to the drawings.

3.4.3 HORIZONTAL CABLE RUNS

Some of the more important considerations that must be given to horizontal cable runs are:

- Avoid traversing transition zones where large differential settlements could create excessive strain in the cable.
- Avoid cable splices. If necessary, refer to the special paragraph below.
- Do not lay cables one on top of the other.
- Use horizontal snaking or vertical snaking of the cable within the trenches. For most materials, a pitch of 2 m with amplitude of 0.4 m is suitable. In very wet clays increase the pitch to 1 m. It enhances the elongation capability of the electrical cable.
- Use a combination of horizontal and vertical snaking at transition zones.

In rock fill dams with earth fill cores, it is frequently convenient to install cable in trenches in the core and fine filter zones, and in ramps in the coarse filter and compacted rock fill shell zones. Individual cables should be spaced not less than 2 cm apart, and no cable should be closer than 15 cm to the edge of the prepared layer. In instances in which cables must be placed in a given array, the cables should be separated from each other by a vertical interval of not less than 15 cm of selected fine embankment material.

During the backfill of trenches in earth dams, a plug, approximately 60 cm in width, made of a mixture of 5% bentonite (by volume) from an approved source and exhibiting a free swell factor of approximately 60%, and 95% embankment material, can be placed in the trenches at intervals of not greater than 7.5 m. The bentonite plugs reduce the possibility of water seepage through the embankment core along the backfilled trenches.

3.4.4 VERTICAL CABLE RUNS

The procedure shown below is an efficient and safe way to route cables from the sensor to the top of the embankment or of the dam.

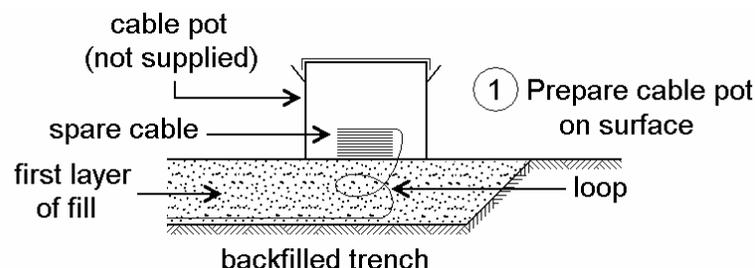


Figure 9: Procedure to route vertically cables (continued)

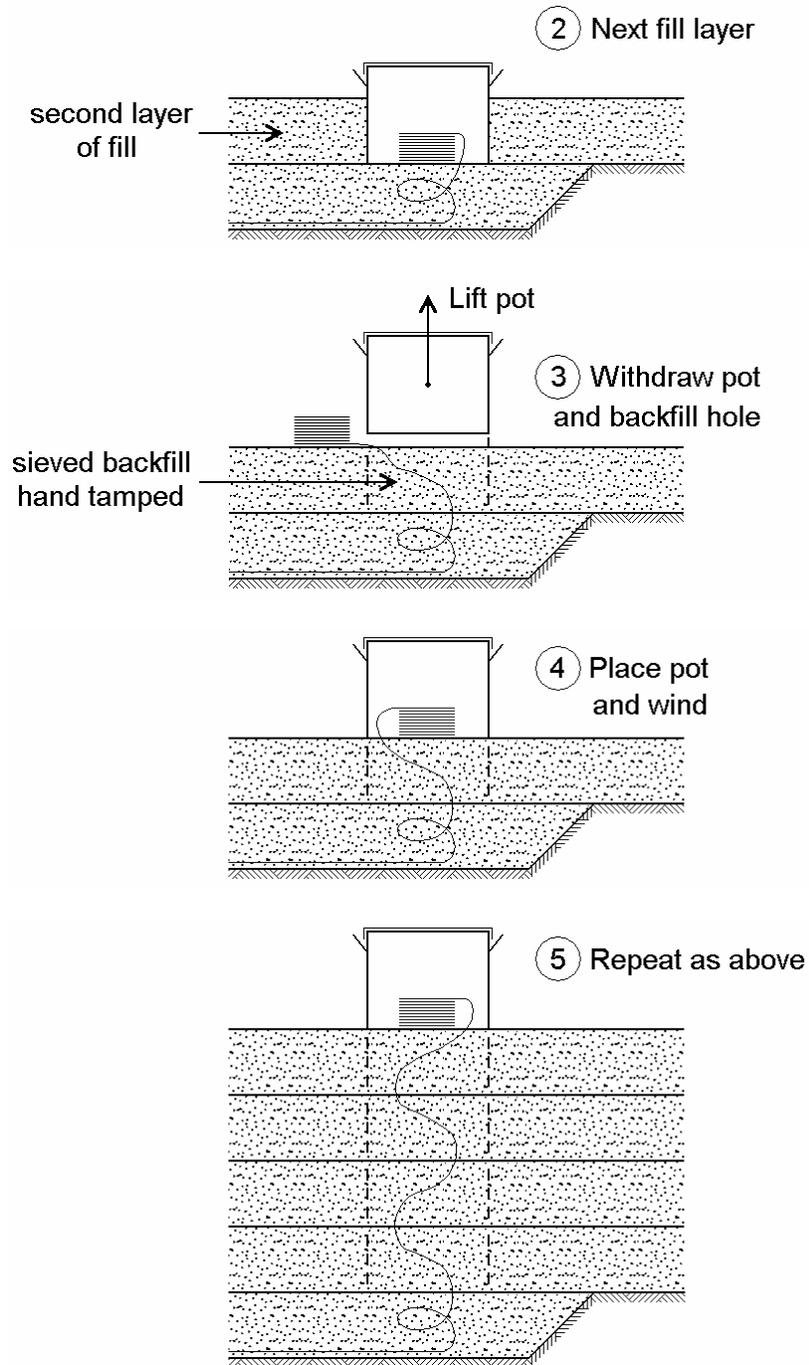


Figure 9: Procedure to route vertically cables

3.5 SPLICES

Generally, cable splices are to be avoided. If necessary, use only the manufacturer's approved standard or high-pressure splice kit. Splicing instructions are included with the splice kit.

Should the cable be cut, we recommend the use of our high pressure cable splice kits, especially if the splice is located underwater.

Because of the vibrating wire technology the sensor uses, the output signal is a frequency, not affected by the impedance of the cable. Therefore, splices have no effect on the quality of the readings.

Furthermore, in special cases on site (large distance between sensors, chain of instruments, readout position for example), splices are useful to limit the number of cables to lay. Actually, individual sensor cables can be merged into a multi-conductor cable using a splice or junction box.

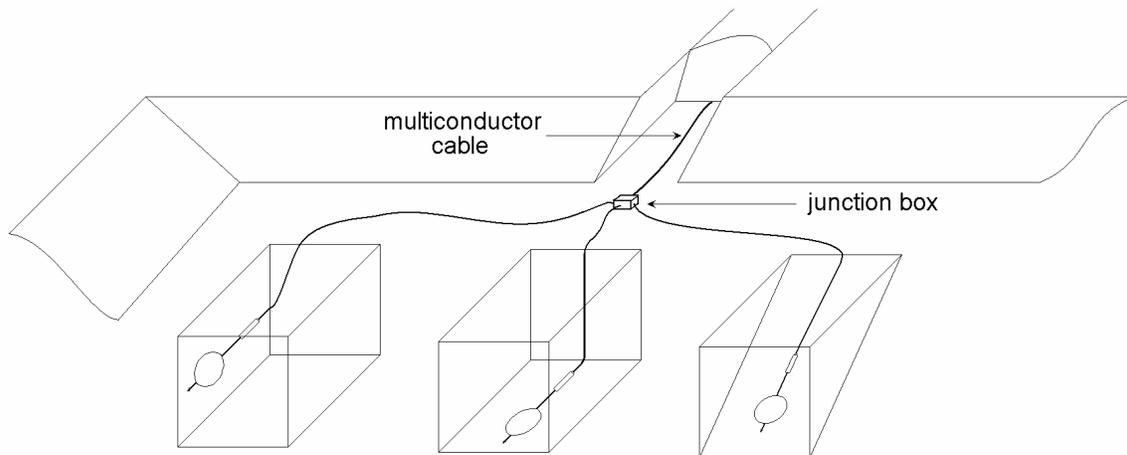


Figure 10: Example of junction box use

Please contact Roctest – Telemac for additional information about junction boxes and splice kits.

3.6 CABLE WIRING

Before cutting a cable, make sure of its identification. If a cable has to be cut to be connected to a junction box for example, cut it in such way to have enough length to obtain a correct installation (functional and aesthetic).

Strip back the conductor insulation by about 1cm. If possible, tin the exposed conductors with a solder.

3.7 LIGHTNING PROTECTION

At all times during the installation, any cable that is exposed to potential damage by lightning must be protected.

A large grounded metal cage placed over the cable bundle, combined with direct grounding of all leads and shields is an effective way to prevent lightning damage to the instruments and cables during the installation process.

A surge and over voltage protection is included inside the body of the pressure sensor. It protects the vibrating wire and not the temperature sensor. It consists of a double gas tube surge arrester.

Please contact Roctest – Telemac for additional information on protecting instruments, junction boxes and data logging systems against power surges, transients and electromagnetic pulses.

All junction boxes and data logging systems furnished by Roctest – Telemac are available with lightning protection.

4 READING PROCEDURE

4.1 GENERALITIES

Readings can be taken manually with a portable readout unit model MB-6T(L) or automatically when connected to a SENSLOG data acquisition system.

Each vibrating wire pressure cell (TPC or EPC) is equipped with a 3k Ω thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. So the temperature can also be read using an ohmmeter.

Manual readings of pressure and temperature of the cell can be taken either directly on the cable end or through a switching panel using the MB-6T or MB-6TL readout unit.

To facilitate reading a cluster of cells, the lead wires from each individual cell can be connected to a switching panel. The wiring instructions for connecting the cells to the wiring block with the junction box are included in the junction/switchbox manual.

4.2 TAKING MEASUREMENTS

The readout unit MB-6T(L) with the four-pin, male, panel-mounted electrical connector is supplied with one multi-core cable fitted with a mating female connector at one end and a set of four color coded alligator clips at the other. The conductor's insulation is color coded to match that of the alligator clips and the instrument cable conductors' insulation jacket.

Connect the alligator clips to the gage lead wire according to the table below.

| Cable | Connections | | | | |
|------------|--------------------|---------------------|-----------------------|-------------------------------|--------|
| | Wire High (red) | Wire Low (black) | Temp. High (white) | Temp. Low / Shield (green) | |
| IRC-41A(P) | red | black | white | green | shield |

Table 1: Wiring code for electrical cables

To obtain a reading, move the MB-6T(L) GAGE selector to position 4 (PWS) and the THERMISTOR selector to position B (3K).

Then, flick the power switch towards the “ON” position. The display will successively show:

- the readout self-testing sequence
- the gage and thermistor settings
- the gage NORMAL (N) and LINEAR (L) readings and the temperature of the gage in degrees Celsius and Fahrenheit.

Record these numbers as they appear on the display.

Physically, the NORMAL reading is the vibration period in μs of the wire (previously called N) and the LINEAR reading is proportional to the strain of the gage (previously called ε).

The jumper cables should never be short-circuited when they are connected to the readout unit front panel.

4.3 QUICK VERIFICATION OF MEASUREMENTS

On site, even before converting raw readings into engineering values, several checks can be done to prevent a bad measurement.

- Compare readings to previous ones. Are they in the same range? Are they changing slowly or abruptly? Consider external factors that can affect the measurements like construction activities, excavations or fills...
- In any case, it is advised to take several readings to confirm the measurement. Then, repeatability can be appreciated and dummy readings erased.

5 CONVERSION OF READINGS

The low pressure model of cells is very sensitive and barometric correction should be applied. If temperature variations are suspected, another correction is necessary.

5.1 PRESSURE VALUE

For the measurement of the pressure, the following equations apply using LINEAR units displayed by the MB-6T(L):

Linear equation:
$$P = C_f (L - L_0)$$

where: P = pressure in kilopascal
 C_f = calibration factors (see calibration sheet)
 L = current reading in LINEAR units (LU)
 L_0 = initial reading in LINEAR units (LU)

Polynomial equation:
$$P = A \cdot L^2 + B \cdot L + C'$$

where P = pressure in kilopascal
 L = current reading in LINEAR units (LU)
 A, B = calibration factors (see calibration sheet)
 C' = calculated constant in kilopascal

Examples:

The calibration sheet gives the following values:

$$C_f = -3.3592 \text{ kPa/LU}$$

$$A = -4.6833\text{E-}05 \text{ kPa/LU}^2$$

$$B = -3.0439 \text{ kPa/LU}$$

- Use of linear relation:

When the cell was in place, before backfilling on it, initial reading was recorded:

$$L_0 = 4\ 105 \text{ LU}$$

The current measurement is:

$$L = 3\ 655 \text{ LU}$$

We get:

$$P = -3.3592 \times (3655 - 4105) = 1\ 511.6 \text{ kPa}$$

- Use of polynomial relation:

When the cell was in place, before backfilling on it, initial reading was recorded:

$$L_0 = 4\ 105\ \text{LU}$$

The coefficient C' has to be calculated: (see paragraph on initial reading)

$$C' = -AL_0^2 - BL_0 = -(-4.6833 \cdot 10^{-5}) \times 4105^2 - (-3.0439) \times 4105 = 13\ 284.4\ \text{kPa}$$

The current measurement is:

$$L = 3\ 655\ \text{LU}$$

We get:

$$P = -4.6833 \cdot 10^{-5} \times 3655^2 + (-3.0439) \times 3655 + 13284.4 = 1\ 533.3\ \text{kPa}$$

Note that decreasing readings in LINEAR units indicate increasing load.

If the frequency is measured, convert it into LINEAR units using the following equation:

$$L = K \frac{F^2}{1000}$$

where L = reading in LINEAR units

K = gage constant for TPC or EPC pressure cell = 1.0156

F = frequency in Hz

Example:

With $F = 1\ 739\ \text{Hz}$,

$$\text{We get: } L = 1.0156 \times \frac{1739^2}{1000} = 3\ 071.3\ \text{LU}$$

5.2 TEMPERATURE VALUE

Although the MB-6T(L) readout box gives directly the correct value of temperature (in °C and in °F) (with the thermistor selector on position B), temperature can be read with an ohmmeter.

To convert the resistance value into temperature reading, please refer to the instruction manual of the TH-T gage.

5.3 TEMPERATURE AND BAROMETRIC CORRECTIONS

Material used in the vibrating wire sensors are specially chosen to minimize the temperature effects on the measurements. The thermal coefficient of expansion of the sensor body is very close to the wire's one, so that the temperature effects are self-compensated.

However, the hydraulic fluid inside the cell has its own coefficient of expansion. Therefore, it is important to correct the temperature effects. Because of the sensitivity of EPC (and TPC) cells, protect them from direct sunlight and wait for the cells to reach the ambient temperature before taking measurements.

In any case, especially for low range sensor, barometric pressure has to be corrected as well.

Use the following relation to apply corrections:

$$P_c = P - C_T(T - T_0) - (S - S_0)$$

where P_c = corrected pressure in kilopascal

P = pressure previously calculated in kilopascal

C_T = calibration factor for temperature (see calibration sheet), in kPa/°C

T = current temperature reading in degrees Celsius

T_0 = initial temperature reading in degrees Celsius

S = current barometric pressure reading in kilopascal

S_0 = initial barometric pressure reading in kilopascal

Example:

Initial reading : $T_0 = 26.1$ °C

$S_0 = 105.64$ kPa

Actual reading : $T = 18.5$ °C

$S = 99.57$ kPa

With: $P = 2\ 815.0$ kPa

$C_T = -4.2966 \cdot 10^{-1}$ kPa/°C,

We get: $P_c = 2815.0 - (-4.2966 \cdot 10^{-1}) \times (18.5 - 26.1) - (99.57 - 105.64) = 2\ 817.8$ kPa

Be careful to work all the time with the same units to apply correctly the corrections.

6 TROUBLESHOOTING

Maintenance and troubleshooting of vibrating wire transducers are required. Periodically check cable connections and terminals. The transducers themselves are sealed and cannot be opened for inspection.

6.1 UNSTABLE READING

- Check if the same troubles occur with other instruments. If so, compare cable routes or check the readout unit.
- Is the shield drain wire correctly connected to the readout unit?
- Isolate the readout unit from the ground by placing it on a piece of wood or similar non-conductive material.
- Check the battery of the readout unit.
- Check for nearby sources of electrical noise such as motors, generators, electrical cables or antennas. If noise sources are nearby, shield the cable or move it.
- If a data logger is used to take the readings, are the swept frequency excitation settings well adjusted?
- The sensor may have gone outside its range. See previous records.
- The sensor body may be shorted to the shield. Check the resistance between the shield drain and the sensor housing.
- Check the integrity of the cable.
- The sensor may have been damaged by shocks.

6.2 NO READING

- Check the battery of the readout unit.
- Check if the same troubles occur with other instruments. If so, the readout unit may be suspected and the factory should be consulted.
- If a data logger is used to take the readings, are the swept frequency excitation settings well adjusted?
- The sensor may have gone outside its range. See previous records.

- Check the coil resistance. Nominal coil resistance is $190\Omega \pm 10\Omega$, plus cable resistance (22 gage copper = approximately $0.07\Omega/m$).
 - If the resistance is high or infinite, a cut cable must be suspected.
 - If the resistance is low or near zero, a short must be suspected.
 - If resistances are within the nominal range and no reading is obtained, the transducer is suspect and the factory should be consulted.
- Cuts or shorts are located, the cable may be spliced in accordance with recommended procedures.
- The sensor may have been damaged by shocks or water may have penetrated inside its body. There is no remedial action.

6.3 TEMPERATURE TROUBLES

If troubles occur when reading the temperature, this is likely due to a cable cut or short because of the technology used (simple thermistor). Check the cable and splice it in accordance with recommended procedures.

If furthermore, no reading of pressure is got, water may have penetrated inside the sensor body. There is no remedial action.

6.4 OTHER TROUBLES

- If pressure decreases regularly and suspiciously, there may be a leak of the hydraulic fluid from the cell. If the latter can be removed, change it.
- If pressure variations are suspicious, check if those variations are correlated to recorded temperature and/or barometric pressure. Check if corrections to raw pressure are applied correctly.

7 MISCELLANEOUS

7.1 ENVIRONMENTAL FACTORS

Since the purpose of pressure cells installation is to monitor site conditions, factors which may affect these conditions should always be observed and recorded. Seemingly minor effects may have a real influence on the behaviour of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to: blasting, rainfall, tidal levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

7.2 CONVERSION FACTORS

| | To Convert From | To | Multiply By |
|------------------------|--|-----------------------|-------------|
| LENGTH | Microns | Inches | 3.94E-05 |
| | Millimetres | Inches | 0.0394 |
| | Meters | Feet | 3.2808 |
| AREA | Square millimetres | Square inches | 0.0016 |
| | Square meters | Square feet | 10.7643 |
| VOLUME | Cubic centimetres | Cubic inches | 0.06101 |
| | Cubic meters | Cubic feet | 35.3357 |
| | Litres | U.S. gallon | 0.26420 |
| | Litres | Can-Br gallon | 0.21997 |
| MASS | Kilograms | Pounds | 2.20459 |
| | Kilograms | Short tons | 0.00110 |
| | Kilograms | Long tons | 0.00098 |
| FORCE | Newtons | Pounds-force | 0.22482 |
| | Newtons | Kilograms-force | 0.10197 |
| | Newtons | Kips | 0.00023 |
| PRESSURE AND STRESS | Kilopascals | Psi | 0.14503 |
| | Bars | Psi | 14.4928 |
| | Inches head of water* | Psi | 0.03606 |
| | Inches head of Hg | Psi | 0.49116 |
| | Pascal | Newton / square meter | 1 |
| | Kilopascals | Atmospheres | 0.00987 |
| | Kilopascals | Bars | 0.01 |
| Kilopascals | Meters head of water* | 0.10197 | |
| TEMPERATURE | Temp. in °F = (1.8 x Temp. in °C) + 32 Temp. in °C = (Temp. in °F - 32) / 1.8 | | |

* at 4 °C

E6TabConv-990505

Table 2: Conversion factors

APPENDIX 1

EXAMPLE OF CALIBRATION SHEET



**CALIBRATION DATA SHEET
VIBRATING WIRE PRESSURE TRANSDUCER**

Model: TPC
Serial number: 78E04377
Range: 5000 kPa
Temperature: 23.2 °C
Barometric pressure: 101.64 kPa
Cable model: IRC-390
Cable length: 3 m
Thermistor type: 3 kohms

Color code: red & black (coil) green & white (thermistor)

| Applied pressure kPa | Reading linear unit LU | Error linear % FS | Error Polynomial % FS |
|-------------------------|------------------------------|-------------------------|-----------------------------|
| 0.10 | 4109.1 | -0.33 | -0.06 |
| 1000.00 | 3818.6 | 0.15 | 0.10 |
| 2000.10 | 3523.0 | 0.29 | 0.08 |
| 3000.10 | 3224.1 | 0.21 | -0.01 |
| 4000.20 | 2923.6 | 0.03 | -0.03 |
| 5000.20 | 2622.0 | -0.23 | 0.04 |
| 5000.00 | 2622.1 | -0.23 | 0.04 |
| 3999.80 | 2923.3 | -0.01 | -0.07 |
| 3000.10 | 3222.8 | 0.13 | -0.09 |
| 2000.00 | 3521.8 | 0.21 | -0.01 |
| 999.90 | 3818.0 | 0.11 | 0.06 |
| -0.10 | 4109.2 | -0.33 | -0.05 |
| Maximum error %: | | 0.33 | 0.10 |

Calculated Pressures:

$$P_c = P - P_T - (S - S_0)$$

P, P_c = Raw and corrected pressures

P_T = Temperature correction

S_0, S = Barometric pressures (at installation & current)

| Linear regression | Polynomial regression |
|--|---|
| $P = C_L (L - L_0)$ $P_T = C_T (T - T_0)$ | $P = AL^2 + BL + C$ $P_T = C_T (T - T_0)$ |
| $C_L = -3.3592E+00$ kPa / LU $C_T = -4.2986E-01$ kPa / °C | $A = -4.6833E-05$ kPa / LU ² $B = -3.0439E+00$ kPa / LU $C = 1.3301E+04$ kPa $C_T = -4.2986E-01$ kPa / °C |
| L_0 : Initial reading in LU L : Reading in LU; T_0, T : Temperatures in °C (initial, current) | |

Note : LU = Linear Unit with K = 1.0156, position 4 on the MB-6T readout

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Calibrated by: Dorina Jugureanu

Date: 08/11/2004

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APPENDIX 2

USE OF A FIBRE OPTIC SENSOR

Calibration

All gage transducers are individually calibrated before shipment and a gage factor (7-digit number) and the gage zero obtained at factory are supplied with each gage on a calibration sheet.

The calibration factor is recorded in the transducer's gage factor, which is registered on a label installed on the cable close to the fibre-optic connector. It can also be found on the calibration sheet of the gage.

Pre-installation acceptance reading

Gage readings should be taken as soon as the gage is received to ensure it has not been damaged during shipment. Before using a transducer with the Universal fibre-optic readout unit from Roctest – Telemac, its gage factor must first be saved in the readout memory and selected.

Initial reading

Fibre-optic pressure transducers must be zeroed at least once to adjust the zero before taking an initial reading. The zero adjustment of the transducer is necessary when using a pressure transducer for the first time. Obviously, the transducer should not be submitted to any pressure when zeroing and should be stabilized in temperature. To zero the transducer, follow the instructions given in the instruction manual of the readout unit.

It is also useful to take note of the current value at installation of the gage (value between 14000 and 24000) when doing a zero adjustment. Knowing it makes possible to re-enter the initial gage zero at installation in case the readout is reset or its memory content is lost. For more information about zero adjustment and taking note of the gage zero, please refer to the instruction manual of the readout unit.

Before installing the sensor, it is necessary to take an initial reading. Take a reading in air at a stabilized temperature and at a known barometric pressure. Record the reading, the temperature reading and the barometric pressure reading. Do not touch the transducer body with your hand because it will change the temperature of the transducer and change the reading.

Taking measurements

First, the gage must be connected in a channel number and the appropriate gage factor must be assigned. After the transducer has been zeroed, with the appropriate gage factor pre-selected, the reading will indicate 0 or a very small value.

- Check if the gage factors are saved into the readout memory.
- Connect each gage to one of the channel input connectors.
- Associate appropriate gage factor to the measuring channel.
- Null gages and record the gage zero in internal unit of Fabry-Perot cavity length.
- Select appropriate system of units.
- Finally, take the readings.

See the operating manual of your readout unit for more information about it.

Conversion of readings

The cells measure absolute pressure and it has to be corrected for barometric pressure changes. The cells are supplied with a temperature correction factor, which is used to correct the pressure reading for significant variations in temperature. To apply the temperature and barometric corrections, use the following equation:

$$P_c = P - C_T(T_1 - T_0) - (B_1 - B_0)$$

where P_c = corrected pressure in bars

P = pressure recorded in bars

C_T = calibration factor for temperature (see calibration sheet), in bar/°C

T_1 = current temperature reading in degrees Celsius

T_0 = initial temperature reading in degrees Celsius

B_1 = current barometric pressure reading in bars

B_0 = initial barometric pressure reading in bars

Example:

| | | |
|-------|---|---|
| P | = | 4.500 bars |
| C_T | = | 0.00143 bar/°C |
| T_0 | = | 20°C |
| T_1 | = | 25°C |
| B_0 | = | 1.013 bars |
| B_1 | = | 1.002 bars |
| P_c | = | $4.500 - 0.00143 (25 - 20) - (1.002 - 1.013)$ |
| | = | 4.504 bars |

APPENDIX 3

USE OF A PNEUMATIC SENSOR

As for a vibrating wire pressure cell, an initial reading in laboratory needs to be taken to take account of the reload value of the cell. This value is the pressure required at atmospheric pressure and no load condition on the pad, to actuate the diagram allowing the air feed to escape through the return line. This value may vary from a cell to another, due to the saturation pressure of the pad in our shops. This value is low and will generally vary from 0.5 to 1.5 kg/cm².

For information about taking measurements with a pneumatic sensor, please refer to the instruction manual of the PR20 readout unit.