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— **USERS' MANUAL** —

STRESS CELL
VIBRATING WIRE SHOTCRETE - CONCRETE
MODEL ESC-30V

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Contents

1   INTRODUCTION

In the 'New Austrian Tunnelling Method' (or NATM), the tunnel is supported by rapid application of shotcrete to freshly exposed excavated surface. NATM is particularly suitable for weaker grounds. In this method, the inherent strength of the ground is preserved to a greater extent to make it almost self-supporting, thus requiring much less artificial support in the form of concrete or steel.

1.1   Applications

Model ESC-30V Shotcrete-concrete stress cell (or stress cell) is designed for measurement of radial and tangential stress in shotcrete tunnel lining. They are often used in conjunction with borehole extensometer.

Proper evaluation of total stress in the lining may help in:

▪ Determining adequacy of shotcrete lining, indicating need for more or less shotcrete to maintain stability.

▪ Verifying design assumptions that will promote safer and more economical design and construction.

Figure 1.1: Shotcrete Pressure Cell

Encardio-rite manufactures a range of instruments for measurement of stress, including sensors, readout unit and data logger.

Stress cells are installed after excavating the tunnel, but before applying shotcrete. Radial stress cells are placed at the smoothened interface between the excavated ground surface and the shotcrete lining. Tangential stress cells may be mounted using short pieces of steel rebars grouted inside short bore holes on the excavated surface.

The development of vibrating wire shotcrete-concrete stress cell introduced a reliable and fast method of taking stress readings electrically. The cable is carried from the stress cell to the read out unit or the data logger preferably through a junction box and is protected against any possible damage during construction to give all around reliable data.

Encardio-rite vibrating wire stress cell is the electrical sensor of choice, as the frequency output of the vibrating wire transducer is almost immune to external noise, able to tolerate wet wiring conditions common in geotechnical applications and is capable of transmission of signals to long distances. The stress cell basically consists of a <u>flat rectangular capsule</u> and a vibrating wire <u>pressure transducer</u> connected to each other by a 6 mm $\phi \times$ 165 mm long stainless steel tube.

1.2   Conventions used in this manual

WARNING! Warning messages calls attention to a procedure or practice that if not properly followed, could possibly cause personal injury.

CAUTION: Caution messages calls attention to a procedure or practice, that if not properly followed, it may result in loss of data or damage to equipment.

NOTE: Note contains important information and is set off from regular text to draw the users' attention.

1.3   How to use this manual

This users' manual is intended to provide sufficient information for making optimum use of vibrating wire stress cell in your application. This user's manual covers description of the stress cell with its connected accessories, the installation procedure and maintenance of the sensor, method of taking observations and recording data from the sensor.

NOTE: The installation personnel must have a background of good installation practices and knowledge of the fundamentals of geotechnics. Novices may find it very difficult to carry on installation work. The intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

A lot of effort has been made in preparing this instruction manual. However the best of instruction manuals cannot provide for each and every condition in the field that may affect the performance of the sensor. Also, blindly following the instruction manual will not guarantee success. Sometimes, depending upon field conditions, installation personnel will have to consciously depart from the written text and use their knowledge and common sense to find the solution to a particular problem.

To make this manual more useful, we invite your valuable comments and suggestions regarding any additions or enhancements. We also request you to please let us know of any errors that you may find while going through this manual.

The manual is divided into a number of sections. Each section contains a specific type of information. The list given below tells you where to look for in this manual if you need some specific information.

*For specifications of the shotcrete concrete stress cell: See § 1.2 '*Specifications*'.*
*For an insight into N.A.T.M.: See § 2.1 '*Theory of operation'*.*
*For description of the shotcrete concrete stress cell: See § 2.2 '*Description of sensor'*.*
*For a typical test certificate on shotcrete concrete stress cell: See § 2.6-2.8 '*Sample test certificate'*.*
For complete operating Vibrating Wire readout unit EDI-54V: See Doc. # WI 6002.112
*For essential tools and accessories: See § 3 '*Tools and accessories required for installation'*.*
*For installation of concrete pressure cell: See § 4 '*Installation procedure'*.*
*For temperature measurement by thermistor: See § 5 '*Temperature measurement'*.*
For barometric pressure correction: See § 6.1 'Barometric pressure correction'.
For trouble shooting: See § 6.3 'Trouble shooting'

2   VIBRATING WIRE SHOTCRETE-CONCRETE STRESS CELL

2.1   Theory of operation

In 'New Austrian Tunnelling Method' (or NATM), the tunnel is supported by rapid application of shotcrete to the freshly exposed surface. The method takes maximum advantage of capacity of the excavated surface to support itself. As excavation is made, forces in overburden readjust themselves. They are managed carefully and deliberately through an appropriate support mechanism. Requirement of support is minimum when excavated surface has reached a point where loosening of rock is about to take place. To be aware of such a situation beforehand, Instrumentation plays an important role.

NATM is particularly suitable for weaker grounds. In this method of tunnel excavation, the inherent strength of the ground is preserved to make it almost self-supporting, thus requiring much less artificial support in the form of concrete or steel.

The excavated surface is prevented from breaking up and collapsing by rapidly applying a layer of shotcrete, thus preserving the inherent cohesion of the ground. A thick shotcrete lining will allow only a small amount of deformation of excavated surface and thus be costlier. A thin shotcrete lining, on the other hand will allow too much deformation of the excavated surface allowing it to weaken and ultimately fail.

The purpose of stress cells is to monitor radial as well as tangential stress in the lining and optimize its thickness. This results in significant reduction in cost of tunnel support. For such an analysis, a tape extensometer is very useful to correlate tunnel closure with developed stresses. Along with borehole extensometers, it helps in determining the adequacy of the shotcrete lining, indicating necessity for more or less shotcrete to maintain stability. In case it is necessary to separate water pressure from effective loading of the overburden, piezometers may be installed near the shotcrete concrete stress cells.

2.2   Description of sensor

2.2.1   *Fluid filled stress capsule*

The Encardio-rite model ESC-30V NATM style shotcrete concrete stress cell basically consists of a flat rectangular capsule and a pressure transducer connected to each other by a 6 mm $\phi \times$ 165 mm long stainless steel tube. The whole system is fluid filled. The rigidity of the cell exceeds 50,000 MPa and ensures that it will respond immediately to the onset of increasing concrete stress.

Lugs are provided at the corners of the rectangular plates to facilitate holding the cell in place while the shotcrete is applied.

Encardio-rite stress cell uses an all welded construction such that space confining the hydraulic fluid is entirely metal, not requiring 'O' rings that tend to trap air and reduce the cell stiffness.
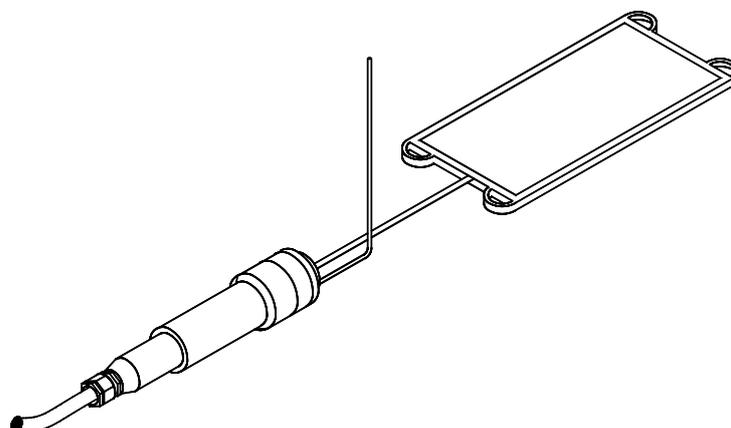
Figure 2.1

2.2.2   Vibrating wire pressure sensor

The pressure sensor constitutes of a vibrating wire and coil magnet assembly enclosed in a stainless steel body which is electron beam welded to the diaphragm.

This results in a vacuum of 1/1000 Torr inside the sensor making it completely immune to the effect of any ingress of water. As the pressure sensor is of stainless steel construction, it is not affected by normal chemical corrosion at locations in which it is used. The pressure sensor normally employed is the Encardio-rite pore pressure sensor (piezometer) model EPP-30V that is available in several different pressure ranges (1, 2, 3.5, 5, & 10 MPa). Sensors upto capacity of 35 MPa are also available.

A tripolar plasma surge arrestor inside the transducer housing protects the vibrating wire pluck and read coils from electrical transients such that it may be induced by direct or indirect lightning strikes.

A thermistor is provided to monitor the temperature.

2.2.3   Pinch tube

One end of a 600 mm long pinch tube filled with hydraulic fluid is welded to the pressure transducer (refer to figure 2.2). The other end is capped by welding. During concrete lining, the temperature very often rises and causes the capsule to expand in the still green concrete. On cooling, the capsule contracts, which if allowed to remain as such, would prevent the transmission of pressure from the concrete to the cell. The purpose of the pinch tube is to inflate the capsule after the concrete is complete. We need to wait for the area around the pressure cell is fully cured and has cooled off to the <u>ambient temperature</u>. A crimping tool is used to squeeze the hydraulic fluid in the pinch tube. The fluid is forced out of the tube into the capsule, which expands until the gap is eliminated.

2.2.4   Cable connection

Leads from coil magnet is terminated on a glass to metal seal that is integrally electron beam welded to stainless steel body of pressure sensor. The two pins marked red and black are connected to the coil magnet. The other two pins are connected to a thermistor for measurement of temperature. Cable joint housing and cable gland is provided for a cable connection. Cable is attached to the sensor in a sealed, water-resistant manner. For concrete pressure cell located inside a concrete block, cable may be armoured and provided with strain relief at cell to reduce likelihood of pull-out. For cable jointing, refer to User's Manual 6002.11.

2.2.5   Dimensions

The standard size of the rectangular model ESC-30V shotcrete concrete stress cell is 150 mm x 250 mm. Standard thickness is 7 mm giving an aspect ratio greater than 20. Dimensional details are as follows:
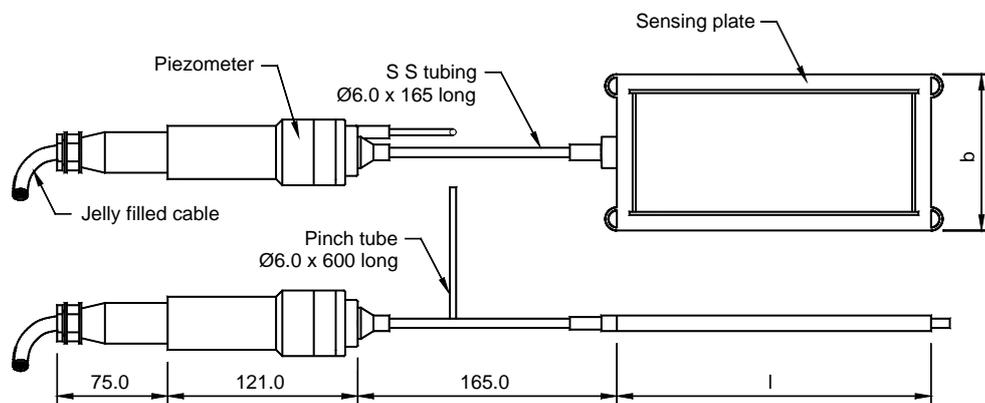
Figure 2.2: Shotcrete concrete stress cell with rectangular diaphragm

NOTE: The rectangular diaphragm (sensing plate) is available in three different sizes (l x b) that are 100 mm x 200 mm, 150 mm x 250 mm and 200 x 300 mm. Other sizes are also available if specifically requested by the customer. Refer to data sheet 1091-13 for further details on the range of shotcrete concrete stress cells manufactured by Encardio-rite.

2.3   Pressure transducer operating principle

Pressure sensor of a vibrating wire stress cell basically consists of a magnetic, high tensile strength stretched wire, one end of which is anchored and the other end fixed to a diaphragm that deflects in some proportion to applied pressure. Any change in pressure, deflects the diaphragm proportionally and this in turn affects the tension in the stretched wire. Thus any change in stress, directly affects the tension in the wire.

The wire is plucked by a coil magnet. Proportionate to the tension in the wire, it resonates at a frequency 'f', which can be determined as follows:

$$f = [\sigma g/\rho]^{1/2}/ 2l \text{ Hz}$$

where σ =   tension of wire

g   =   gravitational constant

ρ =   density of wire

l   =   length of wire

The resonant frequency, with which wire vibrates, induces an alternating current in the coil magnet. The stress is proportional to the square of the frequency and the Encardio-rite model EDI-54V readout logger is able to display this directly in engineering units.

2.4   Interpreting data

The hydraulic type stress cell described above is a standard internationally used design and is manufactured by most of the reputed manufacturers. Depending upon the application and how and where it is used, it may generally give a reading upto 10 % different from the actual. Even though the stress cell is embedded in concrete, to understand the reason for this difference in reading from the actual, the following explanation using soil as an example is given:

2.4.1   Two flat rectangular plates are welded together at the periphery and are separated by a small gap filled with hydraulic fluid. The concrete pressure squeezes the two plates together building up a pressure on the fluid. The plates being thin relative to their lateral extent, are quite flexible. However, please note that there is some supporting effect of the welded periphery at the centre of plate that may affect the reading.

2.4.2   The introduction of a flat stress cell into a mass alters the stress field in a way dependent on the relative stiffness of the cell with respect to the surrounding material and also with respect to the aspect ratio of the stress cell, i.e. the ratio of the width of the stress cell to its thickness. A thick stress cell will alter the stress more than a thin cell. Therefore, a thin stiff stress cell is best and studies have shown an aspect ratio of at least 20:1 to be desirable.

2.4.3   Ideally, the stress cell should be as stiff (compressible) as the material in which it is embedded. In practice, this is difficult. This is explained by the following examples in which the surrounding material could be soil, rock fill or concrete.

2.4.4   If the stress cell is stiffer (less compressible) than the material in which it is embedded (like soil) then it will over-register the pressure because a zone of material immediately around the cell is "sheltered" by the cell and does not experience the full pressure.

There is a stress concentration (figure 2.3) at the rigid rim but in the centre of the stress cell, the stress is only slightly higher than the mean stress, i.e only slightly higher than the normal stress had the stress cell not been there.
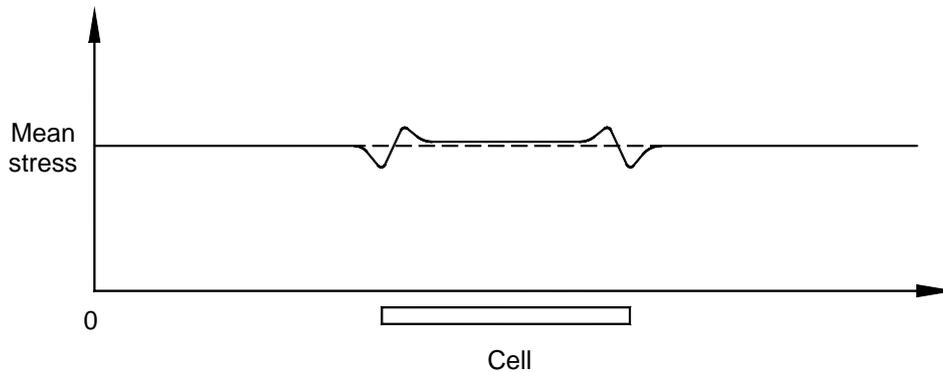
Figure 2.3 - Stress redistribution - weak surrounding material with stiff cell

2.4.5   In a stronger surrounding material the de-stressed zone around the edge of the stress cell is more extensive and hence at the centre of the stress cell the degree of over-registration of the mean stress is greater. This is represented schematically in Figure 2.4.
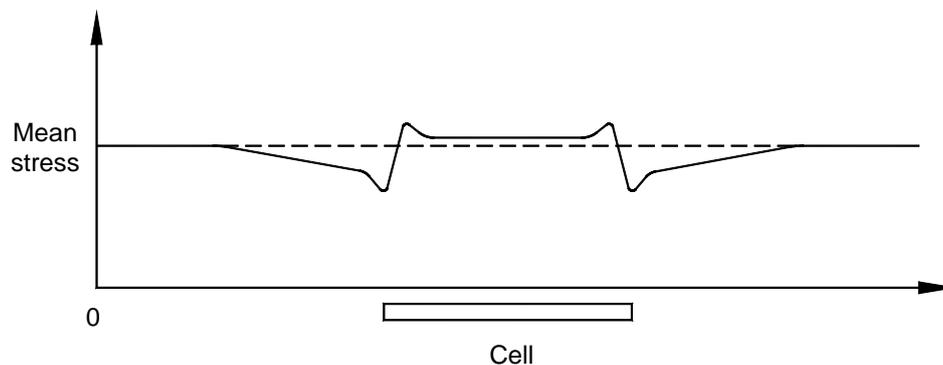
Figure 2.4 - Stress redistribution - strong surrounding material with stiff cell

2.4.6   In a stiff surrounding material like concrete the stress cell may be less stiff (more compressible), in which case the stress cell will under-register the mean stress as the stress in the surrounding material tends to "bridge" around the cell. This is represented schematically in Figure 2.5.
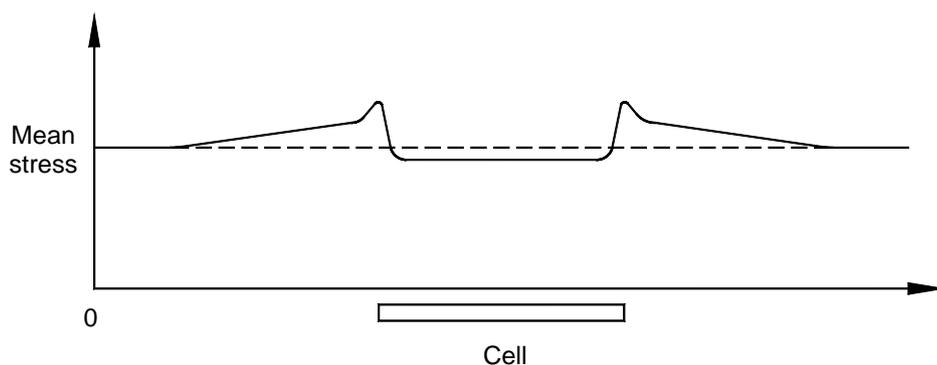
Figure 2.5 - stress redistribution - stiff surrounding material with weak cell

2.4.7   The last example (figure 2.5) is more applicable to concrete. Encardio-rite stress cell generally shows a degree of under-registration upto 10% of the mean stress.

2.4.8   Any closed hydraulic system is sensitive to temperature effects. Stress cell when embedded in concrete acts like a closed hydraulic system. Any change in temperature of surrounding concrete therefore gives an unauthentic or false reading, magnitude of which depends upon elasticity of surrounding concrete and relative coefficient of expansions of materials in contact & filled fluid inside the stress cell. In some cases this effect may be high enough to cause permanent damage to the pressure transducer and should be considered in determining capacity of sensor ordered. A thermistor is incorporated in each sensor to assist in determining temperature compensation factors that may be calculated by closely observing the in-situ stress cell performance.

2.5   Taking readings with the model EDI-54V vibrating wire indicator

The model EDI-54V vibrating wire indicator (figure 2.5) is a microprocessor-based read-out unit for use with Encardio-rite's range of vibrating wire sensors. It can display the measured frequency in terms of time period, frequency, frequency squared or the value of measured parameter directly in proper engineering units. It uses a smartphone with Android OS as readout having a large display with a capacitive touch screen which makes it easy to read the VW sensor.

The EDI-54V vibrating wire indicator can store cali-

bration coefficients from 10,000 vibrating wire sensors so that the value of the measured parameter from these sensors can be shown directly in proper engineering units. For transducers with built-in interchangeable thermistor, it can also display the temperature of the transducer directly in degree Centigrade.

Fig 2.5 (a) – Vibrating wire indicator

The vibrating wire indicator has an internal non-volatile memory with sufficient capacity to store about 525,000 readings from any of the programmed sensors. Each reading is stamped with the date and time the measurement was taken.

Refer instruction manual WI-6002.112 of model EDI-54V for entering the transducer calibration coefficients. The gage factor of the model ESC-30V shotcrete pressure cell is given in the test certificate provided with every supply. The initial reading IR will be the actual reading in digits from the shotcrete pressure cell after it is embedded and properly set in concrete.

An internal 6 V 4 Ah rechargeable sealed maintenance-free battery is used to provide power to the vibrating wire indicator. A battery charger is provided to charge the internal battery which operates from 90 V to 270 V AC 50 or 60 Hz V AC mains. A fully discharged battery takes around 6 hours to get fully charged. The indicator uses a smartphone as a readout that has its own internal sealed rechargeable Li-ion maintenance battery as a power source. A separate battery charger/adapter unit for the smartphone, operating from universal AC mains supply is supplied with each EDI-54V indicator unit.

The EDI-54V vibrating wire indicator is housed in an impact resistant plastic moulded housing with weatherproof connectors for making connections to the vibrating wire transducer and the battery charger.

2.6   Sample test certificate to be used with EDI-51V

<u>**TEST CERTIFICATE**</u>

DWT Traceable to certificate no. : P122301 875 TC

Instrument	:	Shotcrete concrete stress cell	Date	:	27.11.2018
Serial number	:	xxxxxx	Temperature:		20°C
Capacity	:	20 MPa	Atm. pressure:		0.100 MPa
Cable Length	:	xx meter			

<u>**Pressure transducer calibration data**</u>

Input pressure (MPa)	Observed value			Average	End Point Fit
	Up1 (Digit)	Down (Digit)	Up2 (Digit)	(Digit)	(MPa)
0.000	6753.9	6754.1	6754.1	6754.0	0.000
4.000	6500.1	6506.0	6500.2	6500.2	4.060
8.000	6251.0	6258.2	6251.6	6251.3	8.041
12.000	6001.6	6008.2	6002.4	6002.0	12.029
16.000	5751.2	5755.4	5751.6	5751.4	16.036
20.000	5503.4	5503.4	5503.9	5503.6	20.000
				Error (%FS)	0.30

Digit:	$f^2/1000$	
Pressure transducer gage factor:	1.5995E-02	MPa/digit
Thermal factor:	0.000	MPa/°C

<u>**Shotcrete concrete stress cell calibration data**</u>

Cell size:	100 X 200 mm	
Cell constant (multiplier):	1.0485	
Linear gage factor:	1.6771E-02	MPa/digit

(Use gage factor with minus sign with our read out unit model EDI-51V)

Pin configuration/wiring code:

Red & black : Signal   Green & white: Thermistor

Tested By:

2.7   Sample calibration constants for ESC-30V to be used with EDI-54V

Calibration Constants for EDI-54V Data Loggers

The constants will be used to read the Sensor Output in engineering unit (MPa)

Sl.No.	Pressure Sensor Sl. No.	Polynomial Constants				Linear Constants		
		A5,A3,A1	A4	A2	A0	A5,A4,A3,A1	A2	A0
1	43995	0	1.8362E-15	-4.6259E-07	2.5110E+00	0	-4.4249E-07	2.8314E+00
2	44006	0	1.9630E-16	-4.2461E-07	2.6567E+00	0	-4.2309E-07	2.6543E+00
3	44007	0	-2.9337E-16	-4.0744E-07	2.5885E+00	0	-4.1132E-07	2.6019E+00
4	44020	0	-1.9308E-16	-4.2233E-07	2.6675E+00	0	-4.2498E-07	2.6776E+00
5	44050	0	4.0604E-16	-4.4961E-07	2.8401E+00	0	-4.4592E-07	2.8302E+00
6	44066	0	3.5270E-15	-4.3925E-07	2.6177E+00	0	-4.0173E-07	2.5213E+00
7	44148	0	4.9612E-16	-4.5513E-07	2.8694E+00	0	-4.5044E-07	2.8609E+00
8	44155	0	2.2529E-15	-4.2783E-07	2.5889E+00	0	-4.0411E-07	2.5281E+00
9	44169	0	-6.8315E-16	-3.9056E-07	2.5110E+00	0	-3.9862E-07	2.5358E+00
10	44175	0	-4.9131E-17	-4.1682E-07	2.6646E+00	0	-4.1791E-07	2.6691E+00
11	44186	0	-1.8561E-15	-3.8740E-07	2.5307E+00	0	-4.0856E-07	2.5914E+00
12	44192	0	-9.7324E-16	-3.9361E-07	2.5154E+00	0	-4.0469E-07	2.5459E+00
13	44222	0	6.4001E-16	-4.1122E-07	2.5154E+00	0	-4.0489E-07	2.5608E+00
14	44255	0	7.2646E-16	-4.3504E-07	2.7026E+00	0	-4.2797E-07	2.6870E+00

(Q.C.Division)

2.8   Sample calibration constants for ESC-30V to be used with ESDL-30

Calibration Constants for ESDL-30 Series Data Logger

The constants will be used to read the Sensor Output in engineering unit (MPa)

Sl.No.	Pressure Sensor Sl. No.	Polynomial Constants			Linear Constants		
		A2	A1	A0	A2	A1	A0
1	43995	1.8362E-15	-4.6259E-07	2.5110E+00	0	-4.4249E-07	2.8314E+00
2	44006	1.9630E-16	-4.2461E-07	2.6567E+00	0	-4.2309E-07	2.6543E+00
3	44007	-2.9337E-16	-4.0744E-07	2.5885E+00	0	-4.1132E-07	2.6019E+00
4	44020	-1.9308E-16	-4.2233E-07	2.6675E+00	0	-4.2498E-07	2.6776E+00
5	44050	4.0604E-16	-4.4961E-07	2.8401E+00	0	-4.4592E-07	2.8302E+00
6	44066	3.5270E-15	-4.3925E-07	2.6177E+00	0	-4.0173E-07	2.5213E+00
7	44148	4.9612E-16	-4.5513E-07	2.8694E+00	0	-4.5044E-07	2.8609E+00
8	44155	2.2529E-15	-4.2783E-07	2.5889E+00	0	-4.0411E-07	2.5281E+00
9	44169	-6.8315E-16	-3.9056E-07	2.5110E+00	0	-3.9862E-07	2.5358E+00
10	44175	-4.9131E-17	-4.1682E-07	2.6646E+00	0	-4.1791E-07	2.6691E+00
11	44186	-1.8561E-15	-3.8740E-07	2.5307E+00	0	-4.0856E-07	2.5914E+00
12	44192	-9.7324E-16	-3.9361E-07	2.5154E+00	0	-4.0469E-07	2.5459E+00
13	44222	6.4001E-16	-4.1122E-07	2.5154E+00	0	-4.0489E-07	2.5608E+00
14	44255	7.2646E-16	-4.3504E-07	2.7026E+00	0	-4.2797E-07	2.6870E+00

(Q.C.Division)

3   TOOLS & ACCESSORIES REQUIRED FOR INSTALLATION

Following tools and accessories are required for proper cable jointing and installation of the shotcrete concrete stress cell (also refer user's manual on cable jointing - 6002.11):

1.   Soldering iron 25 watt
2.   Rosin 63/37 solder wire
3.   Thread sealant (Loctite 577 or equivalent)
4.   Cable jointing compound (Please refer to Encardio-rite user's manual "cable jointing of sensors" 6002.11 and WI-6002.11E for options that can be used)
5.   Acetone (commercial)
6.   Spanner 28/32 and 38/40
7.   Hacksaw with 150 mm blade
8.   Hammer
9.   Cable Cutter
10.   Surgical blade with holder
11.   Wire Stripper
12.   Pliers 160 mm
13.   Pouring funnel
14.   Stainless steel rod 2 mm ϕ 150 mm length
15.   Spatula
16.   Rotary tin cutter
17.   Fixture for jointing upto six concrete pressure cells (refer figure 3.1)
18.   Toothbrush
19.   Cloth for cleaning (lintless)
20.   75 mm nails - around 10 per sensor
21.   Crimping tool
22.   Digital multimeter
23.   Vibrating wire indicator (EDI-54V)

NOTE: A simple wooden fixture as shown below may be fabricated at site for faster cable jointing. It is also available from Encardio-rite**.**
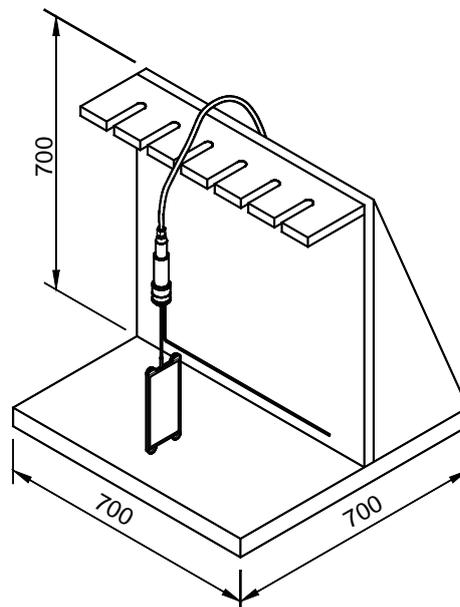

Figure 3.1

4   INSTALLATION PROCEDURE

4.1   Preparation of the sensor before installation

4.1.1   Remove the cable joint housing from the cable end of the stress cell. This gives access to the four pin terminal. Two of the terminals are marked with red and black colours. These are internally wired to the coil of the magnet assembly inside the sensor. The other two terminals are utilized for measurement of temperature using a thermistor. Clean the terminals with a toothbrush.

CAUTION: Do not use any acetone for cleaning as it may damage the glass to metal seal.

4.1.2   Check the working of the pressure transducer as follows:

- The coil resistance measured by a digital multimeter between the red and black pins, should lie between 120-150 Ω. Determine resistance at the room temperature from thermistor temperature chart in § 5. This resistance should be equal to that between pins marked green and white. For example, in case the temperature is 25°C, this resistance would be 3,000 Ω.

- The resistance between any lead and the protective armour should be > 500 MΩ.

- Connect the sensor to the Encardio-rite model EDI-54V portable readout unit and switch it on. The display will show (for e.g):

      Freq: 2629.8 Hz

 where the actual figure will vary depending on the transducer connected to the indicator.

 For the stress cell, the initial reading (offset) in frequency should lie between 2,250 - 2,750 c/s. The initial reading on the portable readout unit should be stable.

- Check whether sensor is responding to changes in pressure. A crude, but simple and very effective method of checking whether the sensor is responding to changes in pressure is as follows:

  - Press the diaphragm with the thumb and verify that the frequency reading on the indicator decreases.

  - This change in reading ensures that the deformation produced by the pressure of the thumb on the diaphragm is transmitted to the vibrating wire sensing element.

4.1.3   Connect required length of cable to sensor as per operating manual on cable jointing - 6002.11.

NOTE: The cable should always be unreeled by turning the cable drum so that the cable is laid out on the flooring. Cables should never by unreeled by pulling on the cable itself as the internal conductors can get damaged from excessive strain.

        Under no circumstances should the cable be unwound from any one side of the drum. This can happen, for e.g., when the cable drum is kept on its side and the cable is taken out without rolling the drum.

4.1.4   Check the working of the sensor again following the procedure described above in § 4.1.2.

NOTE: Remember to add the cable resistance when checking the resistance between the leads after the cable jointing. For the model CS 0401 cable, the resistance is around 26 Ohm/km and for the model CS 0406 cable, the resistance is around 48 Ohm/km. (multiply by 2 for both leads). In case any other cable is used, make the necessary addition in the resistance value.

4.1.5   In case cable is routed to a distant location it should be marked with permanent markers every 5 m by the use of stainless steel tags tied by stainless steel wire stamped with appropriate concrete pressure cell numbers. Alternatively, plastic tabs are also available. Temporary identification can be done by writing serial number of sensor, its code number and location at which it is installed, on a strip of paper, placing the strip on the cable and covering it with a transparent plastic cello tape.

Permanent identification is necessary to prevent errors in making proper connections in the junction box and to ensure correct splicing if cable is cut or broken.

CAUTION: Single most important factor leading to loss of worthwhile data from sensors is losing track of identification of cable ends. Proper identification and marking of the cables is generally taken most casually. Care should also be taken to put an identification tag at point where cable comes out of structure such that cable identity is not lost if cable gets accidentally cut.

4.2   Installation in shotcrete lining for NATM tunnel

Installing stress cell requires a lot of expertise and experience. It should not be taken casually.

The stress cell is mounted inside tunnel lining to measure tangential and radial stress. The designer of the instrumentation scheme and the site conditions will determine installation procedure.

The installation engineer may have to make some site corrections or modifications to the defined procedure. However a typical installation is shown in figure 4.1.
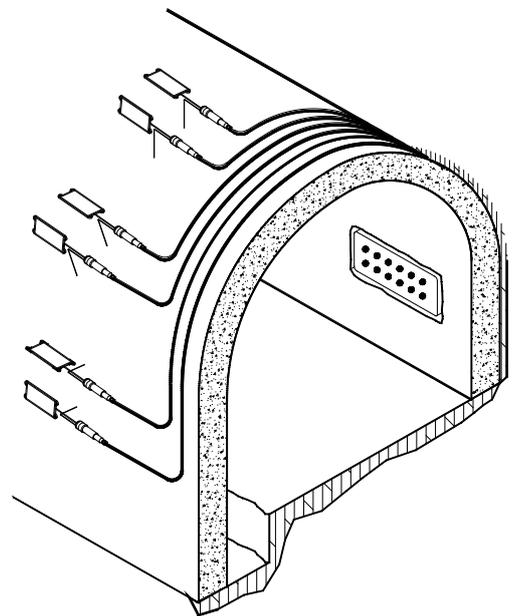
4.2.1   Tangential stress cell

A method of installation is shown in figure 4.2. Short pieces of steel rebars are grouted into holes drilled axially on excavated surface of the tunnel. Holes are drilled at a distance of around 50 mm more than the length of the flat rectangular capsule. The reinforced bars protrude out of the excavated surface to a distance where the cell is to be positioned.
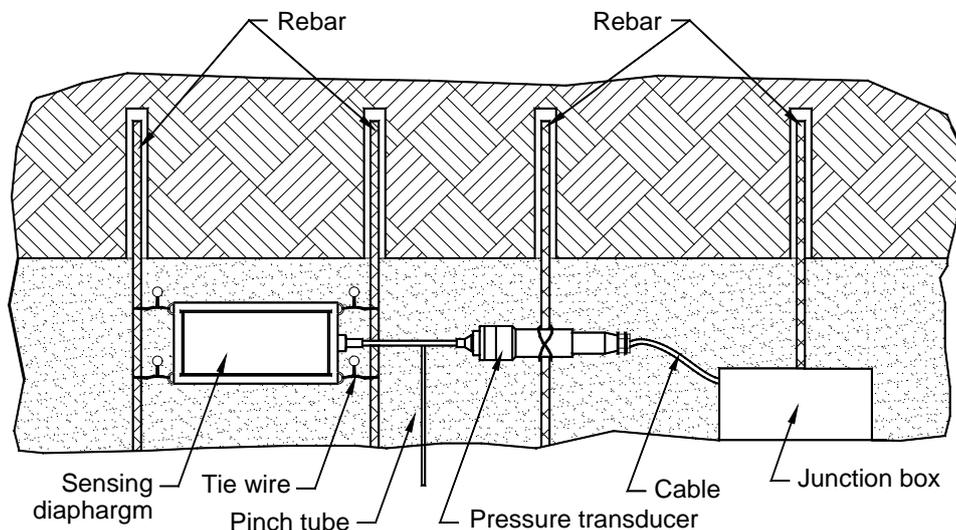

Figure 4.1

Figure 4.2

The flat rectangular capsule is firmly tied to the rebars by soft iron wire/cable ties using the four lugs provided. In case a reinforcing mesh is used, the flat rectangular capsule may be tied to this mesh. The cable is firmly fixed to another reinforced bar or reinforcing mesh and generally routed to a close by junction box. It is terminated here or later on joint to take the signal to a distant location.

Carefully bend the pinch tube such that when the shotcrete concrete stress cell is installed, it will protrude out from the shotcrete lining. It can also be wrapped in a foam etc. such that it can be easily retrieved (later on). When the concrete hardens, the pinch tube is used to pressurize the cell and ensure good contact between the cell and the surrounding concrete.

NOTE: Record initial reading and the temperature with EDI-54V for permanent record, when cell is placed in position and is about to be covered with the fill material. This will form the zero reading for the stress cell. Note the barometric pressure at the time of taking initial reading.

4.2.2   Radial stress cell

A method of installation is shown in figure 4.3.

Prepare the rock surface of the excavated tunnel where the cell is to be mounted by smoothing it off and flattening it as much as possible with any available hand tool, chisel or hammer. Hammer or grout 75 mm long nails to a depth of around 25 mm deep into the smoothened surface of the excavated tunnel to mark the periphery around the rectangular diaphragm and the pressure transducer. Alternatively, little pieces of small diameter reinforced bars may be grouted in boreholes drilled adjacent to the location where the cell would be located.

Carefully bend the pinch tube such that when the shotcrete concrete stress cell is installed, it will protruded out from the shotcrete lining. It can also be wrapped in foam etc. such that it can easily be retrieved (later on).
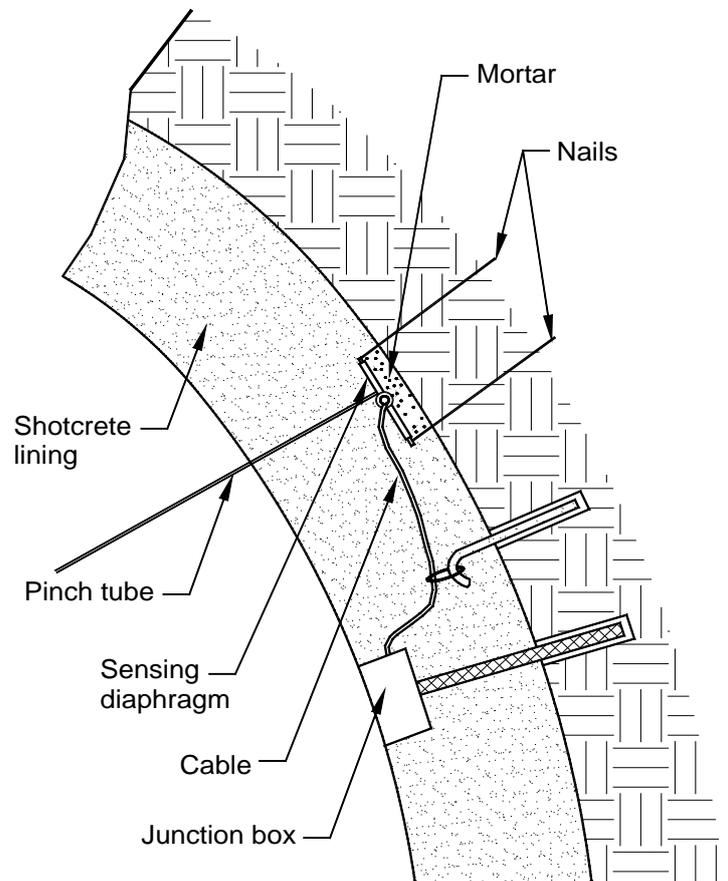

Figure 4.3

NOTE: Record initial reading and temperature with EDI-54V for permanent record, when cell is placed in a position and is about to be covered with the fill material. This will form the zero reading for the stress cell. Note the barometric pressure at time of taking the initial reading.

To accommodate irregularities in the excavated surface, it is necessary to fill the space between the surface and the cell with quick setting mortar (refer to figure 4.3). Trowel a quick setting mortar pad around 30 mm deep on the surface of the excavated tunnel. Press down the cell onto the pad with a little rotary or to and fro motion of the hands, causing the mortar to extrude sideways thus eliminating any air bubbles or spaces between the cell and the ground. Grip the cell firmly by bending the nails or the reinforced bars on the sides of the cell. Be careful that in doing so, the cell is not damaged. This can be verified by comparing the zero reading with the initial offset (see § 4.1.1).

4.2.3   Pinch tube

Once concrete is set and returns to ambient temperature, the cell can be inflated using pinch tube and a crimping tool. Connect cell to readout unit and gently squeeze pinch tube flat, using the pinch tube crimping tool. Start squeezing around 25 mm from the capped end and proceed downwards towards the concrete layer. In case the cell diaphragm is in good contact with the concrete, the pinching will immediately cause a pressure rise in the cell. Stop the pinching immediately. However in case the cell diaphragm expands inside any space that may exist, the pressure rise accompanying each pinch will be small. As soon as the cell starts to fill the space, the pressure rise with each pinch will become larger.
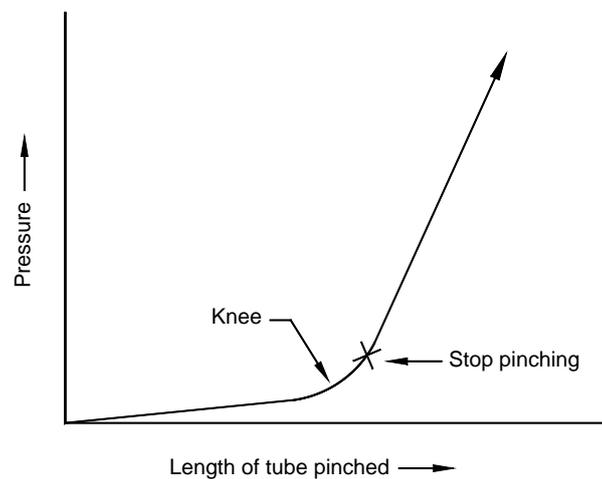
Figure 4.4

A graph of the readings would show a pronounced "knee" where contact between the cell diaphragm and concrete is made (see figure 4.4). As soon as this "knee" is passed, the squeezing of the pinch tube should immediately be stopped. Bend the pinch tube out of the way such that it lays flat on the concrete surface.

CAUTION: Do not pinch the pinch tube closer than 25 mm from the end; otherwise the sealed plugging end of tube could be damaged. As the tube is progressively squeezed flat, the fluid is forced out of the pinch tube into the cell and pressure will rise. It is necessary to make a chart showing the relationship between the length of flattened pinch tube and the corresponding pressure reading.

CAUTION: Continued pinching after the cell has made good contact would result in the reduction of the useful range of the shotcrete concrete stress cell. It can also cause the concrete around the cell to split open which is not desirable and could lead to erroneous readings.

Record new initial stress reading after the cell has stabilized in the field book.

4.3   Cable laying

Very careful and skilled cabling is required in installation of the stress cell as the sensor/cable joint and a part of the cable is permanently embedded and no future access is available for any maintenance and corrective action. Take precautions that the cable does not get damaged during shotcreting or movement of heavy equipment.

Procedure for laying of cables differs with individual installations. In general, however, all installations have the following requirement:

▪   Cable must be protected from damage by angular and sharp particles of the material in which the cable is embedded.

▪   Cables may be spliced without affecting the sensor reading; nevertheless splicing should be avoided wherever possible. If necessary, use special cable jointing kits available from the factory or use junction boxes.

Cable coming out of the junction box for remote monitoring should be properly tagged. It is preferable to use a multi core cable from the junction box. With the best possible precautions, mistakes may still occur. Tags may get lost due to the cable getting accidentally cut. In case individual cables are used, Encardio-rite uses the convention that looking from the cable end towards the sensor, the cable from the most distant sensor is always at the left hand side. In that order, the cable from the closest sensor is at the extreme right.

NOTE: A simple code for remembering this is "LL-SR". Longer (cable) left, shorter (cable) right when viewing the sensors from the observation room.

CAUTION: All cables should be properly identified by tagging them. The tags should be of a non-corrosive material like stainless steel or plastics.

CAUTION: Care should be exercised when installing instrument cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC power lines. The instrument cables will pick up the 50 or 60 Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact the factory concerning filtering options available for use with dataloggers and readouts should difficulties arise.

4.4   Installation in segmental lining for machine bored tunnels

Method of tunnel construction involves:

- Excavation by TBM and simultaneous erection of segmental concrete lining that provides both support and a final lining.

- The concrete segments are casted earlier and then transported to site. Easy way to install the instruments in segments (during concreting) is illustrated in the three adjoining pictures.

- Adjoining picture shows mounting of an Encardio-rite shotcrete-concrete pressure cell and a few Encardio-rite embedment strain gages in different axis before concreting. The bottom picture shows the segment being completed.
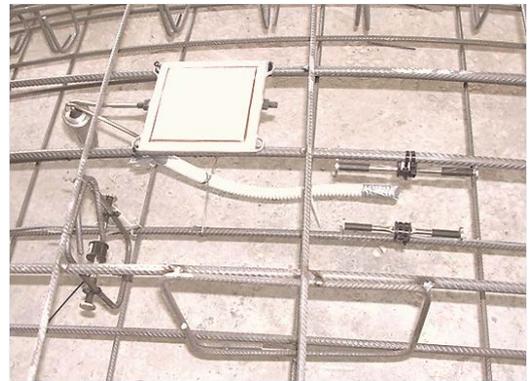

Figure 4.5: Stress cell installed with strain gages in concrete segments

Figure 4.6: Concrete segments with stress cells and strain gages installed inside

5   TEMPERATURE MEASUREMENT

5.1   Thermistor - temperature resistance correlation

Thermistor type: Dale 1C3001-B3
Temperature resistance equation

$$T = 1/ [A + B (LnR) + C (LnR)^3] - 273.2 \ ^oC$$

T	=	temperature in ^oC
LnR	=	Natural log of thermistor resistance
A	=	1.4051×10^{-3}
B	=	2.369×10^{-4}
C	=	1.019×10^{-7}

Ohm	Temp. °C	Ohm	Temp. °C	Ohm	Temp. °C
201.1k	-50	16.60K	-10	2417	+30
187.3K	-49	15.72K	-9	2317	31
174.5K	-48	14.90K	-8	2221	32
162.7K	-47	14.12K	-7	2130	33
151.7K	-46	13.39k	-6	2042	34
141.6K	-45	12.70K	-5	1959	35
132.2K	-44	12.05K	-4	1880	36
123.5K	-43	11.44K	-3	1805	37
115.4K	-12	10.86K	-2	1733	38
107.9K	-41	10.31K	-1	1664	39
101.0K	-40	9796	0	1598	40
94.48K	-39	9310	+1	1535	41
88.46K	-38	8851	2	1475	42
82.87K	-37	8417	3	1418	43
77.66K	-36	8006	4	1363	44
72.81K	-35	7618	5	1310	45
68.30K	-34	7252	6	1260	46
64.09K	-33	6905	7	1212	47
60.17K	-32	6576	8	1167	48
56.51K	-31	6265	9	1123	49
53.10K	-30	5971	10	1081	50
49.91K	-29	5692	11	1040	51
46.94K	-28	5427	12	1002	52
44.16K	-27	5177	13	965.0	53
41.56k	-26	4939	14	929.6	54
39.13K	-25	4714	15	895.8	55
36.86K	-24	4500	16	863.3	56
34.73K	-23	4297	17	832.2	57
32.74K	-22	4105	18	802.3	58
30.87K	-21	3922	19	773.7	59
29.13K	-20	3748	20	746.3	60
27.49K	-19	3583	21	719.9	61
25.95K	-18	3426	22	694.7	62
24.51K	-17	3277	23	670.4	63
23.16K	-16	3135	24	647.1	64
21.89K	-15	3000	25	624.7	65
20.70K	-14	2872	26	603.3	66
19.58K	-13	2750	27	582.6	67
18.52K	-12	2633	28	562.8	68
17.53K	-11	2523	29	525.4	70

5.2   Measurement of temperature

Thermistor for temperature measurement is incorporated in the sensor. The thermistor gives a varying resistance output related to the temperature (see § 5.1). The thermistor is connected between the green and white leads. The resistance can be measured with an Ohmmeter. The cable resistance may be subtracted from the Ohmmeter reading to get the correct thermistor resistance. However the effect is small and is usually ignored.

The Encardio-rite model EDI-54V read-out unit gives the temperature from the thermistor reading directly in engineering units.

5.3   Temperature correction

A pressure-temperature variation correlation factor (k) is provided in the test certificate for the <u>pressure sensor</u> of the shotcrete concrete pressure cell. In case correction for temperature effect is required in cell, use following equation:

$P_{correction}$ = K (current temperature - initial temperature)

The temperature correction value is added to the pressure value read from the EDI-54V read-out.

The effect of the temperature coefficient of expansion of concrete on the stress cell is almost impossible to determine. Temperature effect caused by mismatch between the temperature coefficient of cell and surrounded concrete is not quantifiable and hence no correction factor for this effect is supplied. If required, user may conduct his own tests under controlled conditions.

6   OTHER CONSIDERATIONS/TROUBLE SHOOTING

6.1   Barometric pressure correction

The pressure transducer used in the Encardio-rite vibrating wire shotcrete concrete stress cell is evacuated and hermetically sealed and will respond to barometric pressure fluctuation. In fact all the shotcrete concrete stress cell will respond to barometric pressure fluctuations unless they are manufactured in the gage pressure version and a capillary tube is provided in the cable that opens into the atmosphere.

Since the magnitude of barometric pressure fluctuations is of the order of $\pm$ 0.03 kg/cm^2, correction is generally not required. If a correction for these fluctuations is required then it is necessary to record the barometric pressure at the time of taking the reading. The initial barometric pressure at the time of installation must be recorded. The correction can be made by using the following equation:

$P_{correction}$ = (initial barometric pressure - current barometric pressure)

The pressure correction value is added to the pressure value read from the EDI-54V read-out.

6.2   Pressure conversion table

The test certificate gives the calibration coefficients suitable for reading in kg/cm^2. To convert the output to other engineering units, multiply the reading obtained from the model EDI-54V read-out unit in by the conversion factor given below:

bar	0.981
atm.	0.968
mm Hg	735.6
" Hg	28.96
psi	14.22
" H$_2$O	393.7
'H$_2$O	32.81
m H$_2$O	10
Newton/cm^2	9.807
kPa	98.07
MPa	0.098

6.3   Troubleshooting

The shotcrete concrete stress cell is embedded in concrete. Once installed, the cell is usually inaccessible and remedial action is limited. Maintenance and troubleshooting is consequently confined to periodic checks of cable connection and functioning of the read-out unit. Refer to the following list of problems and possible solutions should problems arise. For any additional help, consult the factory.

6.3.1   Symptom: shotcrete concrete stress cell reading unstable

- Check the insulation resistance. The resistance between any lead and the protective armour should be > 500 MΩ. If not, cut a meter or so from the end of cable and check again.

- Does the read-out work with another shotcrete concrete stress cell? If not, the read-out may have a low battery or be malfunctioning. Consult the manual of the readout unit for charging or troubleshooting instructions.

- Use another read-out unit to take the reading.

▪ Check if there is a source of electrical noise nearby? General sources of electrical noise are motors, generators, transformers, arc welders and antennas. If so, the problem could be reduced by shielding from the electrical noise.

6.3.2   Symptom: shotcrete concrete stress cell fails to read

▪ The cable may be cut or crushed? Check the nominal resistance between the two gage leads using an Ohmmeter. It should be within 120 - 150 Ω. The correct value is given in the shotcrete concrete stress cell test certificate. Please add the cable resistance when checking. For the model CS 0401 cable, the resistance is 26 Ω/km and for the model CS 0406 cable, the resistance is 48 Ω/km. (multiply by 2 for both leads). In case any other cable is used, make the necessary addition in the resistance value. If the resistance reads infinite or a very high value, a cut in the cable is suspected. If the resistance reads very low (<100 Ω), a short in the cable is likely.

▪ Does the read-out work with another shotcrete concrete stress cell? If not, the read-out may have a low battery or be malfunctioning. Consult the manual of the readout unit for charging or trouble shooting instructions.

▪ Use another read-out unit to take the reading.