Model 4850

NATM Style

VW Concrete Stress Cells

Instruction Manual



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1. INTRODUCTION

The basic cell is comprised of two stainless steel rectangular plates welded together around their periphery, leaving a thin space between the plates which is then filled with de-aired hydraulic oil. This fluid filled space is connected via a pressure tube to a vibrating wire pressure sensor. Pressure applied normal to the plate is balanced by a corresponding build-up of internal fluid pressure which is measured by the sensor.

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

The pinch tube is filled with de-aired hydraulic oil. One end is connected to the fluid filled space between the plates and the other end it is capped. The purpose of this pinch tube is to inflate the cell when the concrete around it has fully cured and has cooled off to the ambient temperature. During concrete curing, temperatures very often rise and will cause the cell to expand in the still green concrete. On cooling, the cell contracts leaving a space between it and the surrounding concrete which, if allowed to remain, would prevent the transmission of pressures from the concrete to the cell.

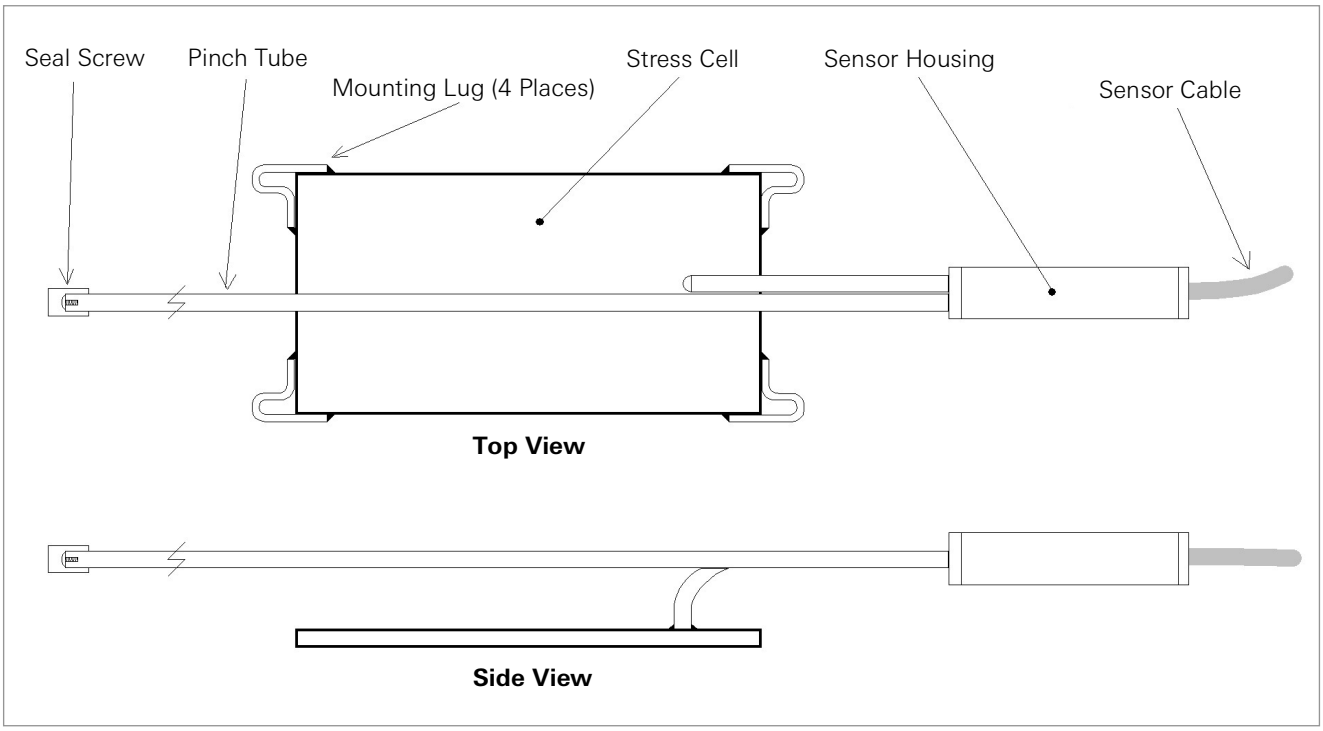


FIGURE 1: *Model 4850 Concrete Stress Cell*

The sensor is a standard GEOKON Model 4500H Vibrating Wire Pressure Transducer inside an all welded housing. The sensor is hermetically sealed and is connected via waterproof connectors to an electrical cable leading to the readout location. The sensor housing also incorporates a thermistor which permits measurement of temperature at the cell location.

1.1 THEORY OF OPERATION

The "New Austrian Tunneling Method", or NATM, calls for the support of a tunnel by the rapid application of shotcrete to the freshly exposed ground. The theory behind this method of support, particularly useful in weaker ground, is that if the inherent strength of the ground can be preserved, it will be almost self-supporting and will require much less artificial support in the form of concrete or steel. To preserve the inherent cohesion of the ground it is necessary to prevent it from breaking up in the first place and, hence, the need for a rapidly applied layer of shotcrete.

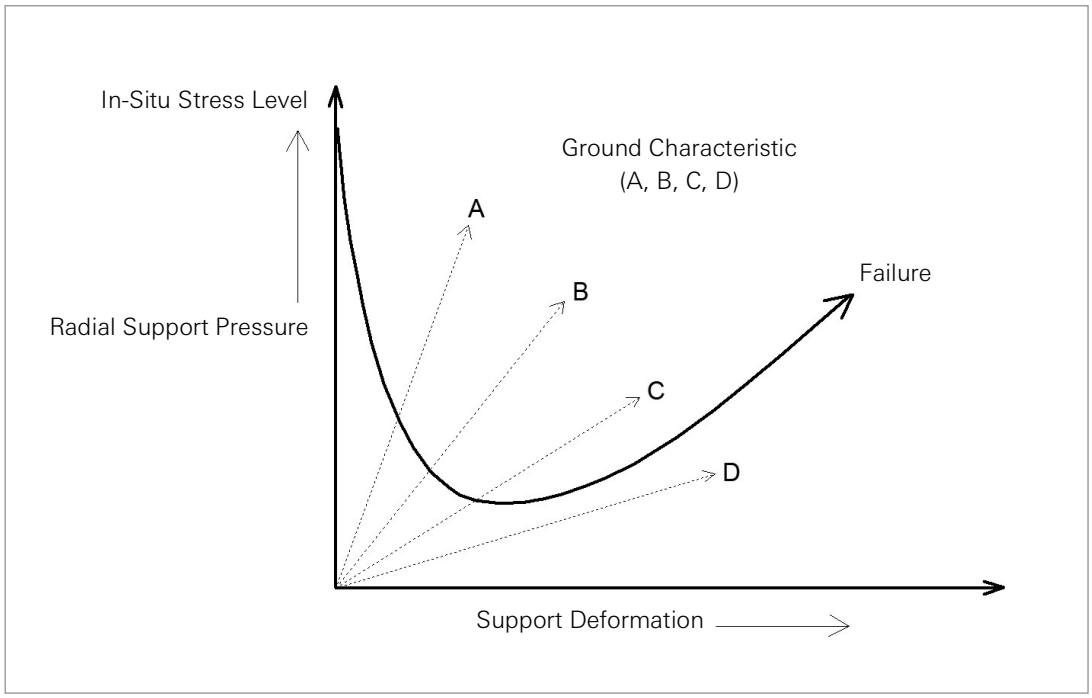


FIGURE 2: *Ground Reaction Curve*

The above figure graphically shows the ground reaction curve, i.e., the amount of support required versus the amount of inherent support and ground deformation. Thus, to prevent any support deformation (or tunnel closure) at all, would require a support pressure exerted on the tunnel walls equal to the original in-situ ground stress.

A strong lining with characteristics of curve A would allow only a small amount of ground deformation, but might, because it is too strong, be uneconomical. A thinner lining which would allow more deformation would have characteristics of curves B or C. However, a lining which is too thin, with characteristics shown by curve D, would allow too much deformation of the rock allowing it to weaken and ultimately fail.

The task of the NATM stress cells is to provide a measure of the support pressure which, when coupled with a measurement of tunnel closure using a tape extensometer, will allow an assessment to be made of the adequacy of the shotcrete lining, indicating the need for perhaps more or less shotcrete to maintain stability. It is this ability to monitor the performance of the shotcrete lining that can lead to significant reductions in tunnel support costs.

2. INSTALLATION CONSIDERATIONS

2.1 CABLE INSTALLATION AND SPLICING

The cable should be routed to minimize the possibility of damage due to moving equipment, debris or other causes. The cable can be protected using flexible conduit, which can be supplied by GEOKON.

Because the vibrating wire output signal is a frequency rather than a current or voltage, cable splicing has no ill effects. The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **It is very important that the shield drain wires be spliced together.** Always maintain polarity when possible by connecting color to color.

Splice kits recommended by GEOKON incorporate casts that are placed around the splice and are then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable in strength and electrical properties. Contact GEOKON for splicing materials and additional cable splicing instructions.

2.2 ELECTRICAL NOISE

Care should be exercised when installing sensor 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 sensor 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 the GEOKON data loggers and readouts should difficulties arise.

3. INSTALLATION

3.1 PRELIMINARY TESTS

Before installation, check the sensor for proper functioning. Each sensor is provided with a no load zero reading. The sensor electrical leads are connected to a readout box (see Section 4 for compatible readouts) and the zero reading given on the calibration report is now compared to a current zero reading. The two readings should not differ by more than ≈50 digits after due regard to corrections made for different temperatures, barometric pressures, height above sea level, and actual cell position (whether standing up or laying down).

By pressing on the cell, it should be possible to change the readout digits, causing them to increase as the pressure is increased.

Checks of the insulation can also be made using an ohmmeter. Resistance between any conductor and the shield should exceed 50 megohms. The thermistor inside the sensor can also be checked.

3.2 STRESS CELL INSTALLATION

Cells are positioned on the wall of the tunnel in two ways, one way to measure tangential stresses and the other to measure radial.

3.2.1 MODEL 4850-1 STRESS CELLS, TANGENTIAL INSTALLATION

The Model 4850-1 is designed to measure tangential stresses in the lining. Figure 3 shows one method of installation using short pieces of steel rebar grouted inside short boreholes and protruding into the area where the lining will be placed.

The pressure cells are tied to these rebars using soft iron wire connected to the lugs at the corners of the cell. The cable is fixed firmly to other pieces of rebar or to the reinforcing mesh, if one is used, and is strung out to the readout location which typically is made of a metal junction box with removable hinged cover. The cable is terminated inside this box. Sufficient cable is coiled inside the box to allow it to be pulled out and connected to a portable readout box.

Note: It is very important that the concrete makes intimate contact with the pressure cell. Therefore, the concrete should be sprayed on, first from below and then, after removing any rebound material, from above. The person spraying the concrete should receive special instructions so that no open shadow zones are created next to the cell.

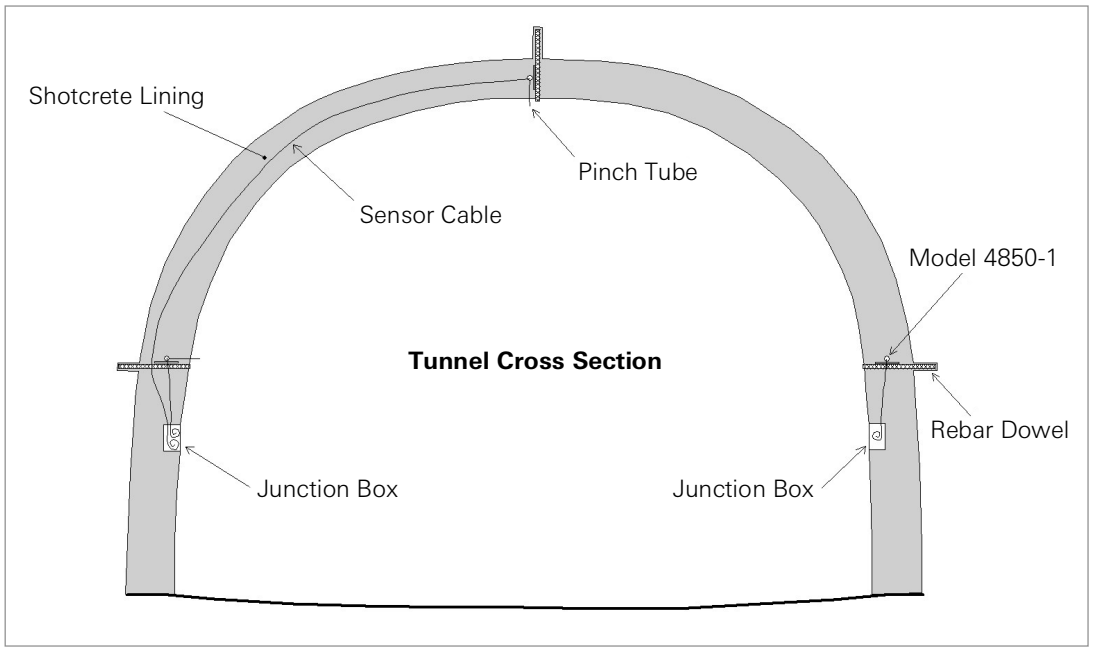


FIGURE 3: *Model 4850-1 Stress Cell, Tangential Installation*

The pinch tube is bent so that it will protrude from the lining after it has been placed. Or it can be wrapped in foam, plastic, etc. so that it can be dug out and retrieved after shotcreting.

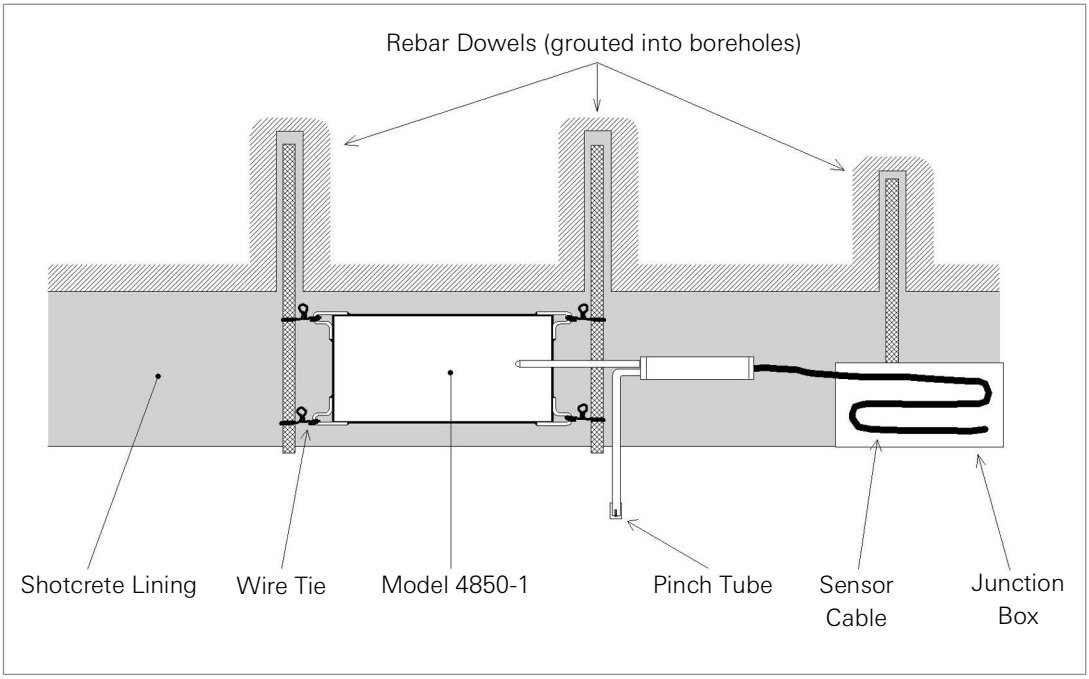


FIGURE 4: *Model 4850-1 Stress Cell, Tangential Installation Detail*

3.2.2 MODEL 4850-2 STRESS CELL, RADIAL INSTALLATION

The Model 4850-2 is designed to measure radial pressures on the tunnel lining (Figure 5).

To accommodate irregularities in the rock surface, it is necessary to fill the space between the rock surface and the cell with quick setting mortar.

The rock surface is prepared by smoothing it off and flattening it as much as possible with whatever hand tool will do the job. Nail, pins, pads, or pieces of rebar grouted into boreholes adjacent to the cell location are now fixed in place. A quick setting mortar pad is troweled onto the surface and the cell is then pressed down onto the pad causing the mortar to extrude sideways thus eliminating any air bubbles or spaces between the cell and the ground. When in place the cell must be gripped firmly using the previously installed hardware.

The cable is routed to the readout location and held firmly in place by tying it off to other rebars, nails, etc. driven into the ground or to the reinforcing mesh, of one is used. At the readout location the cable can be coiled inside a box, cast inside the shotcrete lining as before.

The pinch tube should be bent so as to protrude from where the lining will be or can be wrapped in foam, etc. so that it can be easily retrieved after shotcreting.

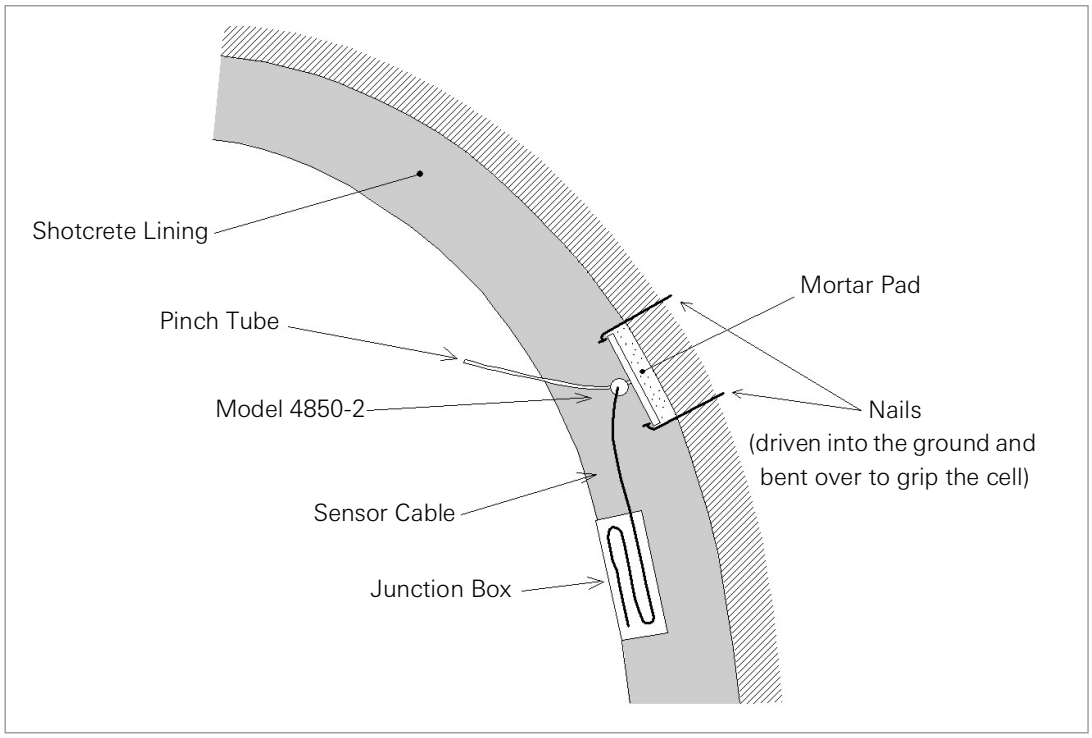


FIGURE 5: *Model 4850-2 Stress Cell, Radial Installation Detail*

3.3 INITIAL READINGS

After installation, but before shotcreting, take initial readings on all the sensors and record in the field book. Take all initial temperatures also using either a readout box or a digital ohmmeter (Section 4).

3.4 RE-PRESSURIZING THE CELL

3.4.1 STANDARD RE-PRESSURIZATION TECHNIQUE

After shotcreting, the sensor temperature and initial reading can be read again. Once the temperature has stabilized to ambient, the cells can be inflated using the pinch tube and a special set of accessory pliers. The sensor is first connected to the readout and then the pliers are used to squeeze the pinch tube flat beginning at the capped end.

Caution! Do not pinch the pinch tube closer than one inch from the end, otherwise the seal screw in the end of the tube could be damaged.

As the tube is progressively squeezed flat, the hydraulic oil is forced out of the tube and into the cell and the pressure will rise. It is necessary to make a chart showing the relationship between the length of flattened pinch tube and the corresponding reading on the readout box (which can be converted to a pressure if so desired, but this is not necessary).

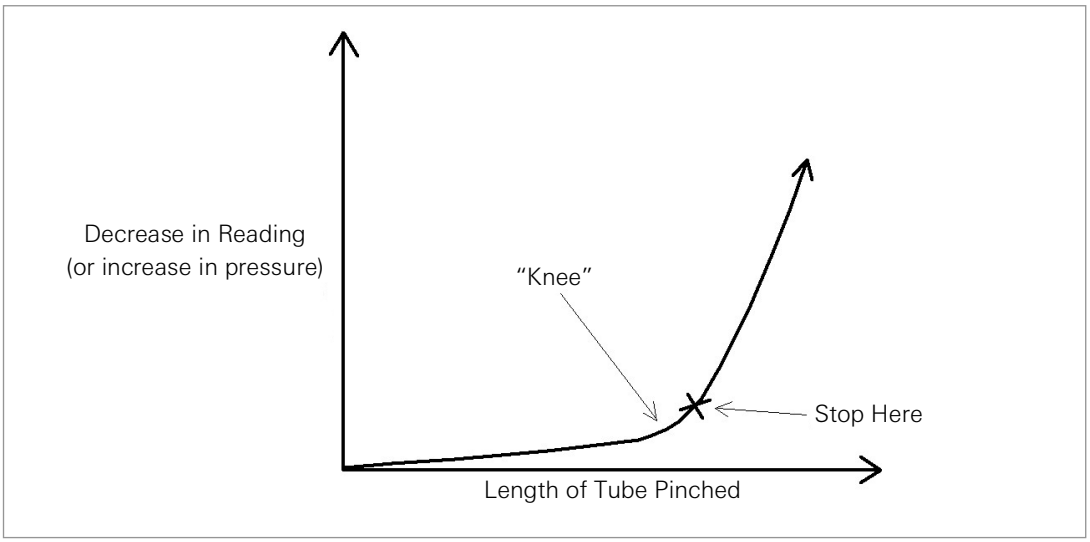


FIGURE 6: *Cell Re-Pressurization Graph*

As the cell expands inside any space that may exist, the pressure rise accompanying each pinch will be small (only one or two digits). But as soon as the cell starts to fill the space the pressure rise with each pinch will become larger.

A graph of the readings should show a pronounced "knee" where cell concrete contact is made (as shown in Figure 6). As soon as this "knee" is passed the pinching can cease and the pinch tube is bent out of the way, so that it lays flat on the tunnel lining surface. However, it is also possible that the cell is already in good contact with the concrete, so the pinching will immediately cause a pressure rise in the cell. If this is the case, then cease pinching immediately.

Continued pinching after the cell has made good contact could cause the concrete around the cell to split open which is not desirable and could lead to erroneous readings.

Record the pressure after the cell has stabilized, this will be the zero reading.

3.4.2 REMOTE RE-PRESSURIZATION TECHNIQUE

Occasionally the concrete stress cell may be located at some distance from an accessible surface and would require a pinch tube which is longer than is practical (i.e., over 3 m or 9.8').

In this case it is possible to use the GEOKON remote pinching apparatus.

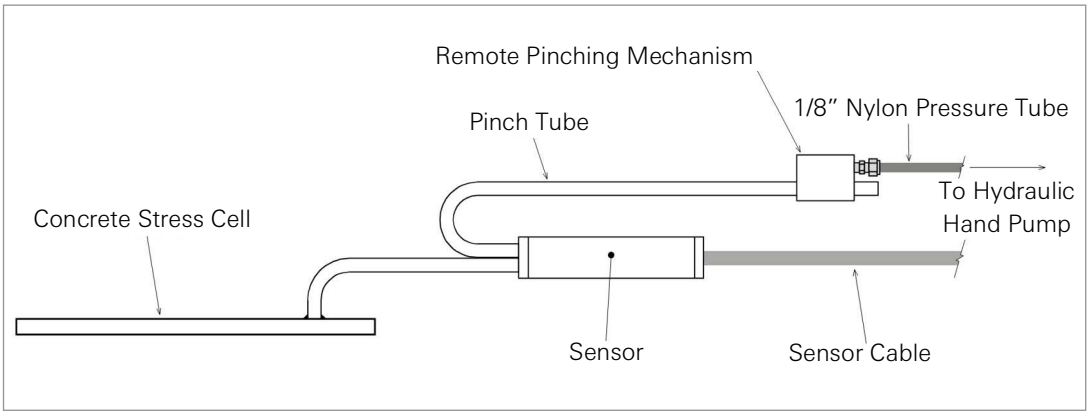


FIGURE 7: *Model 4850 with Remote Pinching Apparatus (Side View)*

A short pinch tube is pinched by a hydraulic piston on the end of a hydraulic line leading to a hydraulic pump.

While the concrete is curing it will be a good idea to take simultaneous readings of temperature and pressure to develop a temperature correction factor. See Section 5.2.1 for information on temperature corrections.

When the concrete has cured and cooled the tube is pinched by applying pressure with the hydraulic pump. The pinching effect begins at around 4 MPa (600 psi) when the pinched tube begins to crush and continues to about 10 MPa (1450 psi) when the tube is completely flattened. The maximum burst pressure of the hydraulic tube is 17 MPa (2500 psi).

Connect the sensor to a readout box (on channel B), while pinching. Stop pinching as soon as the pressure in the sensor starts to rise rapidly. At this point the cell is now in good contact with the surrounding concrete.

Generally, the pressure inside the stress cell should be increased until it is equal to about 110% of the estimated concrete stress. A slight relaxation of the cell after the re-pressurization procedure is normal and should drop the cell pressure to a value roughly equal to the concrete stress. From this point on, the cell pressure should then be equal to the absolute concrete stress.

Record the pressure after the cell has stabilized, this will be the zero reading.

4. TAKING READINGS

4.1 COMPATIBLE READOUTS AND DATA LOGGERS

GEOKON can provide several readout and data logger options. Devices compatible with this product are listed below. For further details and instruction consult the corresponding Manual(s) at geokon.com/Readouts and geokon.com/Dataloggers.

DIGITAL READOUTS:

- **GK-404**

  The Model GK-404 VW Readout is a portable, low-power, hand-held unit capable of running for more than 20 hours continuously on two AA batteries. It is designed for the readout of all GEOKON Vibrating Wire (VW) instruments, and can display the reading in digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 displays the temperature of the sensor (embedded thermistor) with a resolution of 0.1 °C.

- **GK-406**

  The Model GK-406 is a field-ready device able to quickly measure a sensor, save data, and communicate results with custom PDF reports and spreadsheet output. Measurements are geo-located with the integrated GPS allowing the GK-406 to verify locations and lead the user to the sensor locations. The large color display and VSPECT™ technology produce the best measurement possible both in the field and in the office.

DATA LOGGERS:

- **GeoNet Series**

  The GeoNet Data Logger series is designed to collect and transfer data from vibrating wire, RS-485, and analog instruments. GeoNet offers a wide range of telemetry options, including LoRa, cellular, Wi-fi, satellite, and local. Data loggers can work together to operate in a network configuration, or be used separately as standalone units. GeoNet devices arrive from the factory ready for deployment and may commence with data acquisition in minutes.

  Data is transferred to a secure cloud-based storage platform where it can be accessed through the GEOKON OpenAPI. Industry leading data visualization software, such as the free GEOKON Agent Software, can be used with the OpenAPI for data viewing and reporting. Data loggers without network capabilities are also available.

- **8600 Series**

  The Model 8600 Series Data Logger is designed to support the reading of a large number of GEOKON instruments for various unattended data collection applications using GEOKON Model 8032 Multiplexers. Weatherproof packaging allows the unit to be installed in field environments where inhospitable conditions prevail. The Nema 4X enclosure also has a provision for locking to limit access to responsible field personnel.

4.2 MODEL 4999 TERMINAL BOXES

Terminal boxes with sealed cable entries are available from GEOKON. These allow many sensors to be terminated at one location with complete protection of the lead wires. The interior panel of the terminal box can have built-in jacks or a single connection with a rotary position selector switch.

For further details and instruction consult the Model 4999 Instruction Manual (geokon.com/4999).

4.3 MEASURING TEMPERATURES

Each sensor is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Connect an ohmmeter to the thermistor leads coming from the sensor. Since the resistance changes with temperature are large, the effect of cable

resistance is usually insignificant. For long cables a correction can be applied equal to approximately 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions.

Look up the temperature for the measured resistance in Appendix B.

5. DATA REDUCTION

5.1 DATA CALCULATION

The basic units utilized by GEOKON for measurement and reduction of data from this sensor are digits. The calculation of digits is based on the following equation:

$$\text{digits} = \frac{\text{Hz}^2}{1000} \quad \text{or} \quad \text{digits} = \left(\frac{1}{\text{Period}}\right)^2 \times 10^{-3}$$

EQUATION 1: *Digits Calculation*

In typical installations the linear calculation is more than sufficient. However, if utmost accuracy is desired, the polynomial calculation can be used. Refer to the applicable section below.

5.1.1 LINEAR CALCULATION

To convert digits to pressure the following equation applies:

$$P = G(R_1 - R_0)$$

EQUATION 2: *Linear Pressure Calculation*

Where:
G = The gauge factor found on the calibration report, usually in terms of kPa, MPa, or psi per digit.
R_1 = The current readings in digits.
R_0 = The initial field zero reading in digits.

The Initial Reading (R_0) is normally obtained after repressurization. Make sure that the sensor has achieved temperature stability.

EXAMPLE:

The initial reading (R_0) at installation of a Model 4850-1-135 MPa is 8000 digits. The current reading (R_1) is 6300 digits. The calibration factor (G) is -0.008417 MPa/digit. The pressure change is:

$$P = -0.008417(6300 - 8000)$$

$$P = 14.31 \text{ MPa}$$

5.1.2 POLYNOMIAL CALCULATION

To convert digits to pressure using the polynomial expression the following equation applies:

$$P = AR_1^2 + BR_1 + C$$

EQUATION 3: *Polynomial Pressure Calculation*

Where:
R_1 = The current reading in digits.
A, B = The polynomial gauge factors found on the calibration report.
C = The polynomial gauge factor that needs to be calculated (see below).

To perform the polynomial calculation, gauge factor "C" must be calculated first. This is done by using the equation above, but replacing "P" with a value of zero, and "R_1" with the value of "R_0".

$$0 = AR_0^2 + BR_0 + C$$

EQUATION 4: *Calculation for Polynomial Gauge Factor "C"*

Where:
R_0 = The initial field zero reading in digits.
A, B = The polynomial gauge factors found on the calibration report.

The calculated "C" can then be used in Equation 3 to find the precise value of pressure (P).

EXAMPLE:

The given polynomial gauge factors on the calibration are:

A = -2.673E^{-08}

B = -0.008057

The initial reading (R_0) at installation of a sensor is 8000 digits. The current reading (R_1) is 6300 digits.

First, the gauge factor "C" must be calculated:

$$0 = AR_0^2 + BR_0 + C$$

$$0 = -2.673\times10^{-8} \times 8000^2 + (-0.008057) \times 8000 + C$$

$$0 = -66.16 + C$$

$$C = 66.16$$

The pressure change is:

$$P = AR_1^2 + BR_1 + C$$

$$P = -2.673\times10^{-8} \times 6300^2 + (-0.008057) \times 6300 + 66.16$$

$$P = 14.34 \text{ MPa}$$

5.2 OPTIONAL CALCULATIONS

5.2.1 TEMPERATURE CORRECTION

Equation 5 below shows the temperature correction for the VW transducer only, and usually this effect is insignificant and can be ignored. There can be much larger temperature effects caused by the mismatch between temperature coefficients of the cell and surrounding concrete. This effect is not quantifiable in the laboratory, but a theoretical treatment is given in Appendix D.

The best way to compensate for temperatures is to derive a thermal correction factor from simultaneous measurements of pressure and temperature at times when it can be safely assumed that the applied load is not changing (such as while the concrete is curing).

The following thermal correction equation (which only applies to the VW transducer) is calculated, then afterwards is added to the pressure calculation (Equation 2 or Equation 3):

$$T_{Correction} = K(T_1 - T_0)$$

EQUATION 5: *Thermal Correction for Pressure*

Where:
K = The thermal factor found on the calibration report, usually in terms of kPa, MPa, or psi per digit.

T_1 = The current temperature reading in °C.
T_0 = The initial field temperature reading in °C.

5.2.2 BAROMETRIC CORRECTION

The sensor is sealed and will respond to barometric pressure fluctuation. However, since the magnitudes are only on the order of ±0.5 psi, correction is generally not required. If a correction for these fluctuations is desired, then it is necessary to record the barometric pressure at the time of each reading.

The following barometric correction equation is calculated, then afterwards is subtracted from the pressure calculation (Equation 2 or Equation 3):

$$S_{Correction} = (S_1 - S_0) \times F$$

EQUATION 6: *Barometric Correction with Conversion Factor*

Where:
S_1 = The current barometer.
S_0 = The initial field zero barometer.
F = The conversion factor, see below for more detail.

Barometric pressure must be converted to the same engineering unit as the sensor pressure range (kPa or MPa). Barometric pressure is usually recorded in inches of mercury. The conversion factor (F) for inches of mercury to kPa is 3.3863 and from inches of mercury to MPa is 0.003386. Table 1 in Section 5.2.3 lists other common conversion factors.

5.2.3 ENGINEERING UNITS CONVERSION

To convert to a different engineering unit, take the result from data calculation (after other optional calculations have been completed, if applicable) and multiply it by the appropriate conversion multiplier from Table 1.

		Convert From											
		psi	**"H_2O**	**'H_2O**	**mm H_2O**	**m H_2O**	**"HG**	**mm HG**	**atm**	**mbar**	**bar**	**kPa**	**MPa**
Convert To	**psi**	1	.036127	.43275	.0014223	1.4223	.49116	.019337	14.696	.014503	14.5039	.14503	145.03
	"H_2O	27.730	1	12	.039372	39.372	13.596	.53525	406.78	.40147	401.47	4.0147	4016.1
	'H_2O	2.3108	.08333	1	.003281	3.281	1.133	.044604	33.8983	.033456	33.4558	.3346	334.6
	mm H_2O	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
	m H_2O	.70432	.025399	.304788	.001	1	.34532	.013595	10.332	.010197	10.197	.10197	101.97
	"HG	2.036	.073552	.882624	.0028959	2.8959	1	.03937	29.920	.029529	29.529	.2953	295.3
	mm HG	51.706	1.8683	22.4196	.073558	73.558	25.4	1	760	.75008	750.08	7.5008	7500.8
	atm	.06805	.002458	.029499	.0000968	.0968	.03342	.001315	1	.000986	.98692	.009869	9.869
	mbar	68.947	2.4908	29.8896	.098068	98.068	33.863	1.3332	1013.2	1	1000	10	10000
	bar	.068947	.002490	.029889	.0000981	.098068	.033863	.001333	1.0132	.001	1	.01	10
	kPa	6.8947	.24908	2.98896	.0098068	9.8068	3.3863	.13332	101.320	.1	100	1	1000
	MPa	.006895	.000249	.002988	.0000098	.009807	.003386	.000133	.101320	.0001	.1	.001	1

TABLE 1: *Engineering Units Conversion Multipliers*

5.3 ENVIRONMENTAL FACTORS

Since the purpose of the sensor installation is to monitor site conditions, factors that can affect these conditions should always be observed and recorded. Seemingly minor affects may have a real influence on the behavior 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, traffic, temperature and barometric changes, weather conditions, changes in personnel, nearby construction activities, excavation and fill level sequences, seasonal changes, etc.

6. TROUBLESHOOTING

Maintenance and troubleshooting of the sensor is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the sensor is usually inaccessible and remedial action is limited.

Should difficulties arise, consult the following list of problems and possible solutions. For additional troubleshooting and support visit geokon.com/Technical-Support.

SYMPTOM: SENSOR READINGS ARE UNSTABLE

- ☐ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, transformers, arc welders and antennas. Make sure the shield drain wire is connected to ground.
- ☐ Does the readout or data logger work with another sensor? If not the readout or data logger may be malfunctioning.
- ☐ Is the readout box position set correctly? If using a data logger to record readings automatically are the swept frequency excitation settings correct?

SYMPTOM: SENSOR FAILS TO GIVE A READING

- ☐ Check the readout with another sensor to ensure it is functioning properly.
- ☐ The sensor may have been damaged by over-ranging or shock. Inspect for damage.
- ☐ Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Cable resistance is about 48.5 Ω per km (14.7 Ω per 1000'). If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the sensor conductors may be shorted. If a break or a short is present, splice according to the instructions in Section . Refer to the expected resistance for the various wire combinations below.

  Vibrating Wire Sensor Lead Resistance Levels

  Red/Black Coil Resistance ≅180 Ω

  Green/White 3000 Ω at 25 °C

  Any other wire combination will result in a measurement of infinite resistance.

Note: Tests should be performed with a quality multimeter to accurately show possibilities of shorts. Sensors should be disconnected from other equipment while performing resistance tests, this includes surge modules, terminals, multiplexers and data loggers. Fingers cannot be touching the multimeter leads or sensor wires while testing.

Table 2 shows the expected resistance for the various wire combinations.

Table 3 is provided for the customer to fill in the actual resistance found.

Vibrating Wire Sensor Lead Grid - SAMPLE VALUES					
	Red	**Black**	**White**	**Green**	**Shield**
Red					
Black	**≅180 Ω**				
White	Infinite	Infinite			
Green	Infinite	Infinite	**3000 Ω at 25°C**		
Shield	Infinite	Infinite	Infinite	Infinite	

TABLE 2: *Sample Resistance*

Vibrating Wire Sensor Lead Grid - SENSOR NAME/##					
	Red	**Black**	**White**	**Green**	**Shield**
Red					
Black					
White					
Green					
Shield					

TABLE 3: *Resistance Worksheet*

APPENDIX A. SPECIFICATIONS

A.1 MODEL 4850 SPECIFICATIONS

Model	**4850-1 Tangental**	**4850-2 Radial**
Range	7 MPa (1000 psi) 20 MPa (3000 psi)	2 MPa (300 psi) 3.5 MPa (500 psi) 5 MPa (750 psi)
Resolution	0.025% F.S.	
Linearity	±0.25% F.S. (Standard) ±0.1% F.S. (Optional)	
Accuracy	0.1% F.S. with a polynomial expression	
Temperature Range	-30 to +70 °C	
Frequency Range	1400 - 3500 Hz	
Coil Resistance	180 Ω, ±10Ω	
Pinch Tube Length	600 mm (23.6")	
Dimensions	100 x 200 mm (4 x 8")	150 x 250 mm (6 x 10")
Material	316 Stainless Steel	
Cable Type	Two twisted pair (four conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")	

TABLE 4: *Model 4850 NATM Style VW Concrete Stress Cell Specifications*

Note: Consult GEOKON for other sizes or options available.

A.2 THERMISTOR

See Appendix B for more information.

Range: -80 to +150 °C

Accuracy: ±0.5 °C

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

Thermistor Types include YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3, and Honeywell 192–302LET–A01.

Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.15$$

EQUATION 7: *3KΩ Thermistor Resistance*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$
Note: Coefficients calculated over the –50 to +150 °C span.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	15.72K	-9	2221	32	474.7	73	137.2	114
187.3K	-49	14.90K	-8	2130	33	459.0	74	133.6	115
174.5K	-48	14.12K	-7	2042	34	444.0	75	130.0	116
162.7K	-47	13.39K	-6	1959	35	429.5	76	126.5	117
151.7K	-46	12.70K	-5	1880	36	415.6	77	123.2	118
141.6K	-45	12.05K	-4	1805	37	402.2	78	119.9	119
132.2K	-44	11.44K	-3	1733	38	389.3	79	116.8	120
123.5K	-43	10.86K	-2	1664	39	376.9	80	113.8	121
115.4K	-42	10.31K	-1	1598	40	364.9	81	110.8	122
107.9K	-41	9796	0	1535	41	353.4	82	107.9	123
101.0K	-40	9310	1	1475	42	342.2	83	105.2	124
94.48K	-39	8851	2	1418	43	331.5	84	102.5	125
88.46K	-38	8417	3	1363	44	321.2	85	99.9	126
82.87K	-37	8006	4	1310	45	311.3	86	97.3	127
77.66K	-36	7618	5	1260	46	301.7	87	94.9	128
72.81K	-35	7252	6	1212	47	292.4	88	92.5	129
68.30K	-34	6905	7	1167	48	283.5	89	90.2	130
64.09K	-33	6576	8	1123	49	274.9	90	87.9	131
60.17K	-32	6265	9	1081	50	266.6	91	85.7	132
56.51K	-31	5971	10	1040	51	258.6	92	83.6	133
53.10K	-30	5692	11	1002	52	250.9	93	81.6	134
49.91K	-29	5427	12	965.0	53	243.4	94	79.6	135
46.94K	-28	5177	13	929.6	54	236.2	95	77.6	136
44.16K	-27	4939	14	895.8	55	229.3	96	75.8	137
41.56K	-26	4714	15	863.3	56	222.6	97	73.9	138
39.13K	-25	4500	16	832.2	57	216.1	98	72.2	139
36.86K	-24	4297	17	802.3	58	209.8	99	70.4	140
34.73K	-23	4105	18	773.7	59	203.8	100	68.8	141
32.74K	-22	3922	19	746.3	60	197.9	101	67.1	142
30.87K	-21	3748	20	719.9	61	192.2	102	65.5	143
29.13K	-20	3583	21	694.7	62	186.8	103	64.0	144
27.49K	-19	3426	22	670.4	63	181.5	104	62.5	145
25.95K	-18	3277	23	647.1	64	176.4	105	61.1	146
24.51K	-17	3135	24	624.7	65	171.4	106	59.6	147
23.16K	-16	3000	25	603.3	66	166.7	107	58.3	148
21.89K	-15	2872	26	582.6	67	162.0	108	56.8	149
20.70K	-14	2750	27	562.8	68	157.6	109	55.6	150
19.58K	-13	2633	28	543.7	69	153.2	110		
18.52K	-12	2523	29	525.4	70	149.0	111		
17.53K	-11	2417	30	507.8	71	145.0	112		
16.60K	-10	2317	31	490.9	72	141.1	113		

TABLE 5: *3KΩ Thermistor Resistance*

APPENDIX C. TYPICAL CALIBRATION REPORT

GEOKON®

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4850-1-35 MPa

Date of Calibration: January 05, 2024

This calibration has been verified/validated as of 11/15/2024

Serial Number: 2321772

Temperature: 19.30 °C

Calibration Instruction: CI-Pressure Transducer (4 MPa~50 MPa)

Barometric Pressure: 1001.7 mbar

Cable Length: 20 meters

Technician: Dean O. Cowdery

Applied Pressure (MPa)	Gauge Reading 1st Cycle	Gauge Reading 2nd Cycle	Average Gauge Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	8815	8815	8815	0.067	0.19	0.009	0.03
7.0	7995	7995	7995	6.969	-0.09	6.984	-0.05
14.0	7166	7166	7166	13.95	-0.15	14.00	0.00
21.0	6334	6333	6334	20.95	-0.13	21.01	0.02
28.0	5497	5498	5498	27.99	-0.03	28.01	0.02
35.0	4658	4659	4659	35.05	0.15	34.99	-0.02

(MPa) Linear Gauge Factor (G): -0.008417 (MPa/ digit)

Polynomial Gauge factors: A: -2.673E-08 B: -0.008057 C:

Thermal Factor (K): 0.01203 (MPa/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

(psi) Linear Gauge Factor (G): -1.221 (psi/ digit)

Polynomial Gauge Factors: A: -3.876E-06 B: -1.169 C:

Thermal Factor (K): 1.745 (psi/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

Calculated Pressures: **Linear, $P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)$***

Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)$*

*Barometric pressures expressed in MPa or psi. Barometric compensation is not required with vented transducers.

Factory Zero Reading: 8847 Temperature: 22.4 °C Barometer: 996.7 mbar

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 8: *Typical Calibration Report*

APPENDIX D. TEMPERATURE EFFECT ON EARTH PRESSURE AND CONCRETE STRESS CELLS

The following theoretical treatment is by no means rigorous, there are some questionable assumptions and approximations, but it should give some idea of the magnitude of the thermal effect to be expected on hydraulic earth pressure cells, buried in soil, or installed at the contact between soil and structure, and on concrete stress cells embedded in concrete.

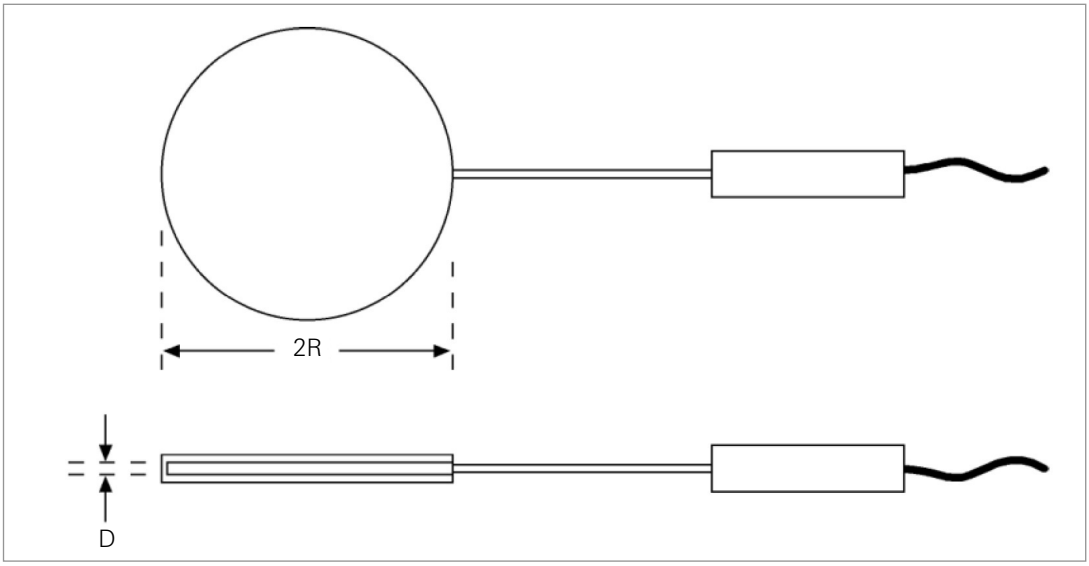


FIGURE 9: *Radius (R) and Thickness (D)*

D.1 FORMULAS

Consider a circular cell of radius (R) containing a liquid film of a thickness (D), coefficient of thermal expansion Kppm/°C, and bulk modulus (G).

For a temperature rise of 1 °C the expansion (Y_T) of the liquid film is given by the equation:

$$Y_T = KD$$

EQUATION 8: *Expansion of Liquid for a Temperature Rise of 1 °C*

Expansion of the liquid is resisted by the confinement of the surrounding medium (soil or concrete) and this causes a pressure rise (P) in the liquid, as well as a compression of the liquid (Y_c) given by the equation:

$$Y_c = PD/G$$

EQUATION 9: *Compression of Liquid*

The net expansion (Y) of the cell is equal to:

$$Y = D(K - P/G)$$

EQUATION 10: *Expansion of Liquid*

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formulas [Ref 1], where the deformation (Y), produced by a uniform pressure (P), acting on a circular area, (R) radius, on the surface of a material with modulus of elasticity (E) and Poisson's ratio (ν), is given by:

At the center of the cell:

$$Y = \frac{2\ PR(1-\nu^2)}{E}$$

EQUATION 11: *Deformation at the Center*

At the edge of the cell:

$$Y = \frac{4\ PR(1-\nu^2)}{\pi E}$$

EQUATION 12: *Deformation at the Edge*

The difference being:

$$\frac{PR(1-\nu^2)(2-4/\pi)}{E}$$

EQUATION 13: *Difference in Deformation*

The above formulas apply to pressures acting on a free surface. However, in the confined case, Y, at the edge of the cell, can be assumed to be nearly zero. Therefore, Y, at the center, is assumed to be the same as shown in Equation 12.

If the average Y across the cell is assumed to be half this value, and if the deformation of the medium on either side of the cell is assumed to be the same, then the average total expansion of the cell is given by:

$$Y = \frac{0.73\ PR(1-\nu^2)\times 0.5\times 2}{E} = \frac{0.73\ PR(1-\nu^2)}{E}$$

EQUATION 14: *Average Total Expansion of the Cell*

Equating Equation 10 and Equation 13 gives:

$$P\left(\frac{D}{G} + \frac{0.73\ R(1-\nu^2)}{E}\right) = KD$$

EQUATION 15: *Combined Equations*

If one side of the cell lies in contact with a rigid structure, e.g. a concrete retaining wall or a concrete bridge footing, then;

$$Y = \frac{0.73\ PR(1-\nu^2)\times 0.5}{E} = \frac{0.36\ PR(1-\nu^2)}{E}$$

And

$$P\left(\frac{D}{G} + \frac{0.36\ R(1-\nu^2)}{E}\right) = KD$$

Where (E) pertains to the soil material.

Since these expressions are only approximate they can be simplified even further:

For all $E < 10\times 10^6\ psi$ the term $\frac{D}{G}$ is negligible so long as the cell is designed and constructed properly, i.e., G is large, (no air trapped inside the cell), and D is small. Also, the term $(1-\nu^2)$ can be replaced by 0.91 since ν usually lies between 0.25 and 0.35.

Hence, the total embedment is given by:

$$P = \frac{1.5\ EKD}{R} \qquad psi/°C$$

EQUATION 16: *Total Embedment*

And for contact pressure cells:

$$P = \frac{3\ EKD}{R} \qquad psi/°C$$

EQUATION 17: *Total Embedment for Contact Pressure Cells*

Some typical values of the various parameters are:

Liquid	**K x 10^{-6}/°C**	**CG x 10^{6} psi**
Oil	700	0.3
Mercury	180	3.6
Water	170	0.3
Glycol	650	0.26
50/50 Glycol/Water	400	0.28
Embedment Material	**E x 10^{6} psi**	ν
Plastic Clay	0.003	
Soil	0.001 to 0.02 [Ref 2]	0.25 to 0.45
Sand	0.02 to 0.06 [Ref 3]	0.28 to 0.35
Compacted Ottawa Sand	0.2	
Weathered Rock	0.04 to 0.11 [Ref 4]	
Concrete	5.0	0.25

TABLE 6: *Typical Values of Various Cell Parameters*

D.2 EXAMPLES

Note: For contact pressure cells, multiply the values for P by two.

PLASTIC CLAY:

For a concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 3000 psi

ν = 0.3

P = 0.042 psi/°C

SOIL, MEDIUM STIFFNESS:

For a concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 10000 psi

ν = 0.3

P = 0.138 psi/°C

COARSE SAND:

For a concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 50000 psi

ν = 0.3

P = 0.69 psi/°C

CONCRETE:

For a concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 5 x 106 psi

ν = 0.25

P = 22.7 psi/°C

COMPLETELY RIGID MEDIUM:

For a concrete stress cell, nine-inch diameter and D=0.020 inches:

P = 210 psi/°C

References:

[1] Roark, R.J. and Young, W.C. "Formulas for Stress and Strain," McGraw Hill, fifth edition, 1982, p 519.

[2] Weiler, W.A. and Kulhawy, F.H. "Factors Affecting Stress Cell Measurement in Soil" J. Geotech. Eng. Div. ASCE. Vol. 108, No. GT12, Dec., pp1529-1548.

[3] Lazebnik, G.E., "Monitoring of Soil-Structure Interaction." Chapman & Hall. pp 224.

[4] Fujiyasu, Y. and Orihara, K. "Elastic Modulus of Weathered Rock." Proc. of the 5th Intl. Symp. on Field Measurements in Geomechanics - Singapore 1999. p 183.

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