GEOKON

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*INSTRUCTION MANUAL*

# Model 4850

## N.A.T.M. Style
## V.W. Concrete Stress cells


(Doc Rev H, 6/13)

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# 1. INTRODUCTION

## 1.1. Theory of Operation

The "New Austrian Tunneling Method", or N.A.T.M., 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.

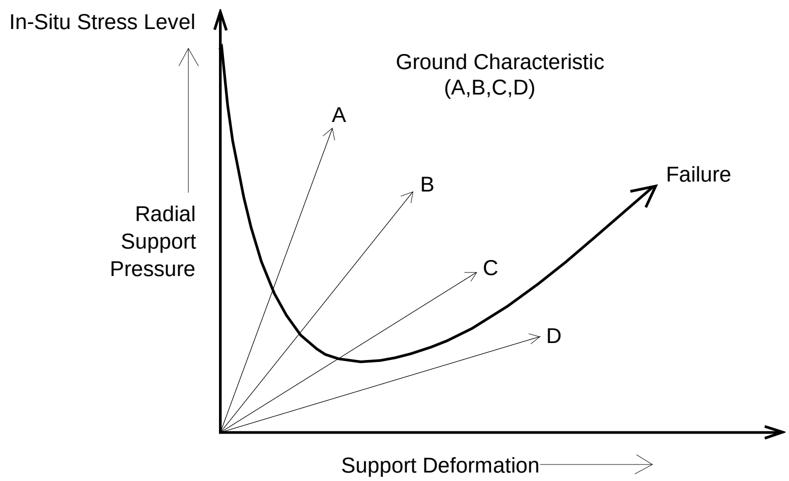


Figure 1 - Ground Reaction Curve

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 N.A.T.M. 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.

## 1.2. Stress Cell Design and Construction

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[1]. 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.

One further refinement is required; this is the pinch tube, which is filled with mercury or de-aired hydraulic oil and is connected at one end to the fluid filled space between the plates and the other end 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.

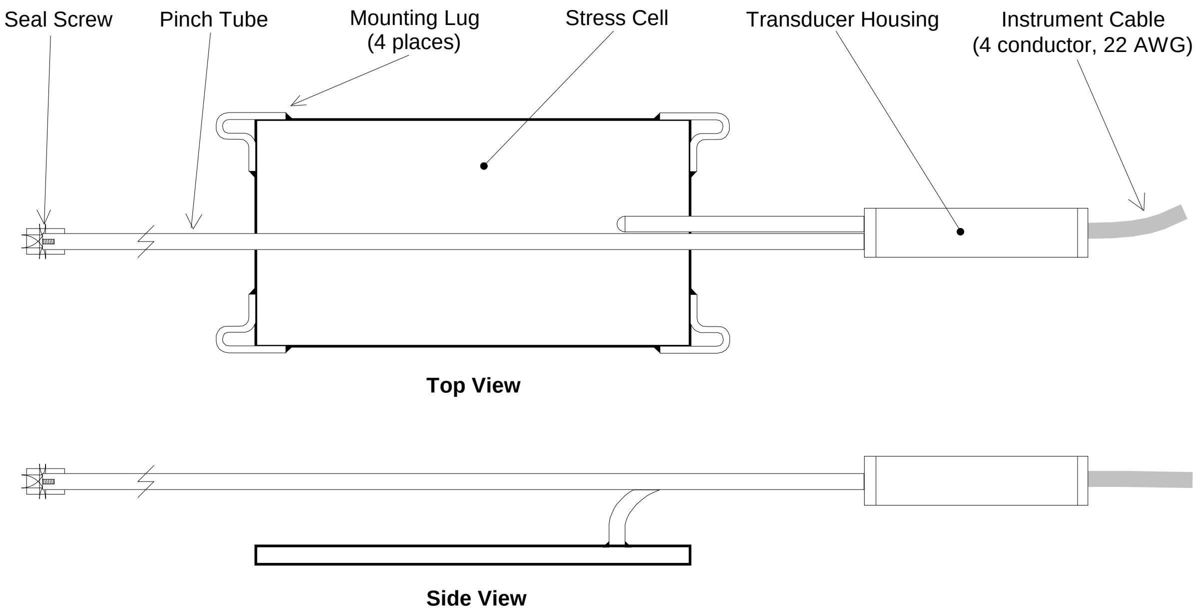


Figure 2 - Model 4850 Concrete Stress Cell

The vibrating wire sensor is a standard Geokon Model 4500H 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] Most other commercially available concrete stress cells are filled with mercury in order to achieve a sufficient cell stiffness. However, the filling procedures and the construction details of the Geokon cell are such that mercury is not required.

## 2. INSTALLATION

### 2.1. Preliminary Tests

It is always wise, before installation commences, to check the cells for proper functioning. Each cell is supplied with a calibration sheet which shows the relationship between readout digits and pressure and also shows the initial no load zero reading. The cell electrical leads (usually the red and black leads) are connected to a readout box (see section 3) and the zero reading given on the sheet 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 and 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 fall as the pressure is increased.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gage leads should be approximately 180 ohms, ±10 ohms. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table B-1, Page 14), and between any conductor and the shield should exceed 20 megohm.

### 2.2. 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.

#### 2.2.1. Installing the Model 4850-1

The Model 4850-1 is designed to measure <u>tangential</u> 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.**

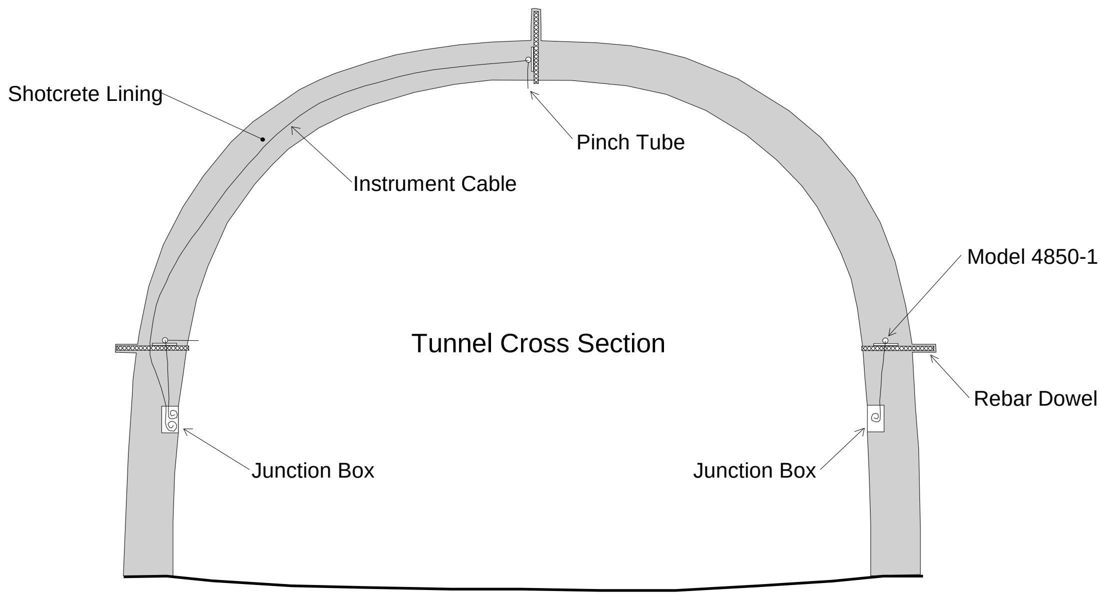


Figure 3 - Model 4850-1 Installation

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.

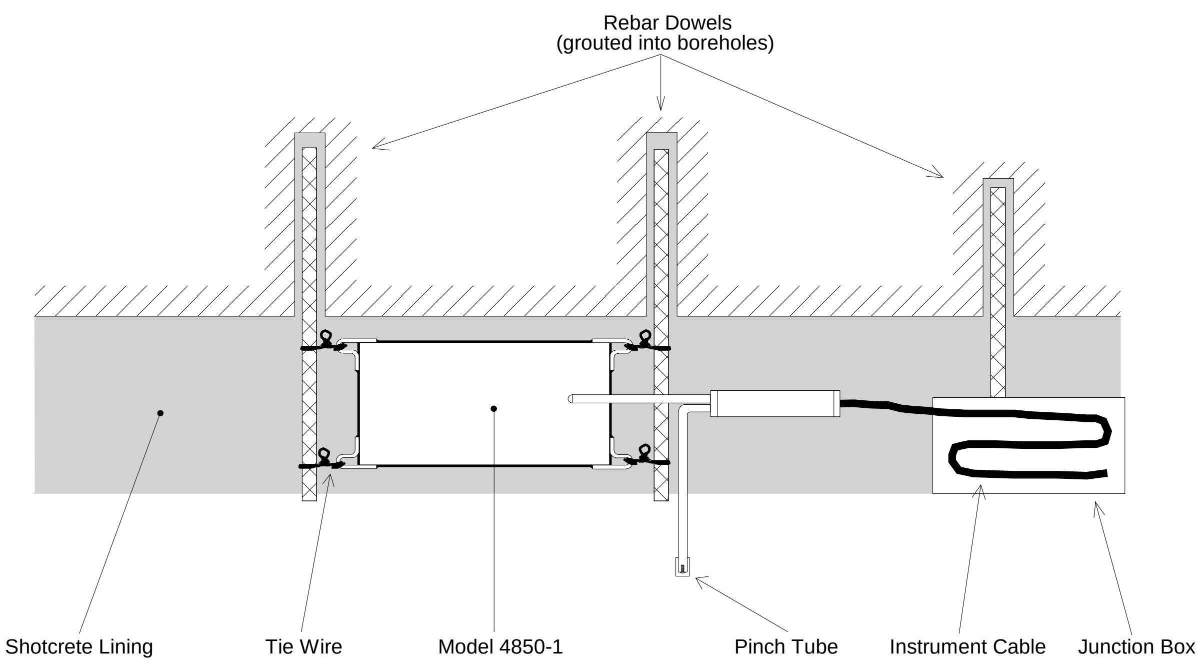


Figure 4 - Model 4850-1 Installation Detail

### 2.2.2. Installing the Model 4850-2

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

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, spads, or pieces of rebar grouted into boreholes adjacent to the cell location are now fixed in place. A quick setting mortar pad is trowelled 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. See Figure 5.

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.

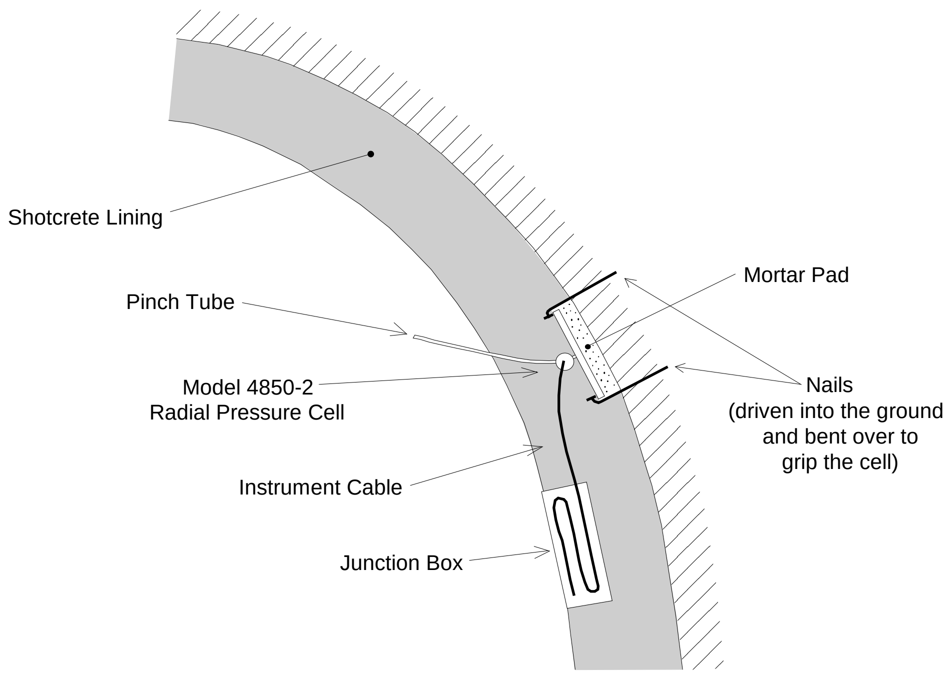


Figure 5 - Model 4850-2 Installation Detail

## 2.3. Initial Readings

Before shotcreting, take initial readings on all the cells and record in the field book. Take all initial temperatures also using either a GK-403 Readout Box or a digital ohmmeter.

## 2.4. Re-Pressurizing the Cell

### 2.4.1 Standard Re-Pressurization Technique

After shotcreting, the cells temperature and initial reading can be read again. Once the temperature has stabilized to ambient then the cells can be inflated using the pinch tube and a special set of accessory pliers. The cell is first connected to the readout (see section 4) 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).

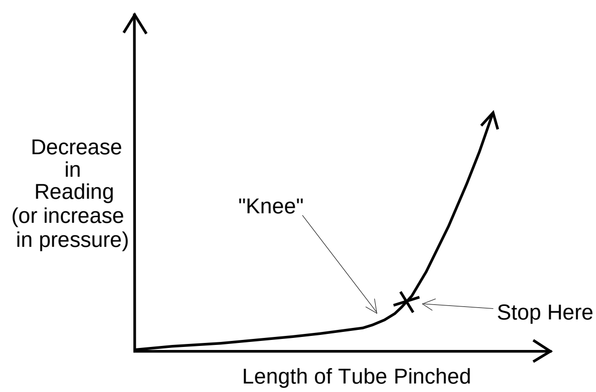


Figure 6 - Cell Re-Pressurization Graph

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. See Figure 6. As soon as this "knee" is passed the pinching can cease and the pinch tube is bent out of the way so 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 new initial pressure after the cell has stabilized.

### 2.4.2 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 (say over 3 meters).

In this case it is possible to use the Geokon remote pinching apparatus as shown in figure 7.

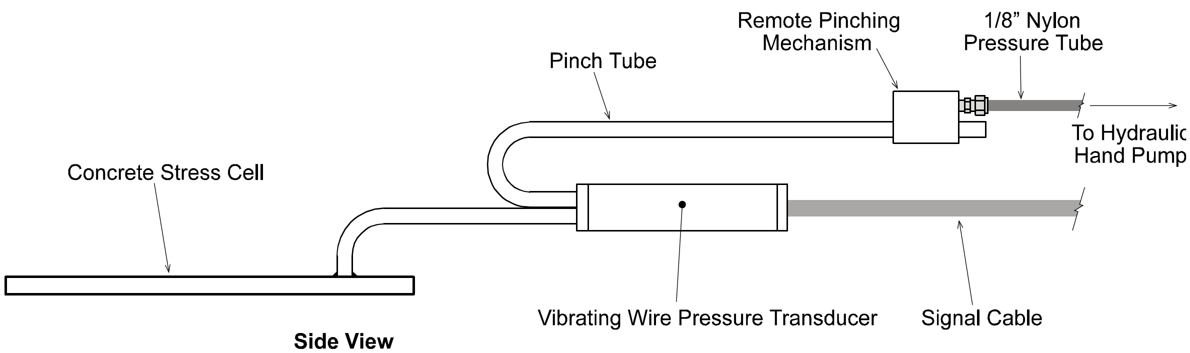


Figure 7 - Model 4850 with Remote Pinching Apparatus

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 for the purpose of developing a temperature correction factor. See section 4.2

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 stress cell to the Model GK-403. GK-404 or GK-405, readout box, (channel B), while pinching. Stop pinching as soon as the pressure in the cell 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.

### 2.5. Cable Installation

The cable should be protected from accidental damage caused by moving equipment or fly rock. This is best done by putting the excess cable inside a junction box (see Figures 4 and 5).

Cables may be spliced to lengthen them, without affecting gage readings. Always waterproof the splice completely, preferably using an epoxy based splice kit such the 3M Scotchcast™, model 82-A1. These kits are available from the factory.

### 2.6. Electrical Noise

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 the Geokon dataloggers and readouts should difficulties arise.

## 3. TAKING READINGS

### 3.1. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Mode "B".

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green clips are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "B". Readout is in digits (Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

### 3.2 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with

alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the POS (Position) button to select position B and the MODE button to select Dg (digits).
Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

### 3.3 Operation of the GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components:

- the Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application
- the GK-405 Remote Module which is housed in a weather-proof enclosure and connects to the vibrating wire sensor by means of:

1) Flying leads with alligator type clips when the sensor cable terminates in bare wires or,
2) by means of a 10 pin connector..

The two components communicate wirelessly using Bluetooth®, a reliable digital communications protocol. The Readout Unit can operate from the cradle of the Remote Module (see Figure 8) or, if more convenient, can be removed and operated up to 20 meters from the Remote Module


Figure 8 GK405 Readout Unit

For further details consult the GK405 Instruction Manual

### 3.4. Measuring Temperatures

Each Vibrating Wire Concrete Stress Cell is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor.

1. If an Ohmmmeter is used connect the ohmmeter to the two thermistor leads coming from the stress cell. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table B-1 Appendix B. Alternately the temperature could be calculated using Equation B-1, Appendix B.

Note: The GK-403, Gk-404 and GK-405 readout boxes will read the thermistor and display temperature in °C automatically.

## 4. DATA REDUCTION

### 4.1. Pressure Calculation

To convert digits to pressure the following equation applies;

**Pressure = (Current Reading - Initial Reading) × Calibration Factor**

or

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

Equation 1 - Convert Digits to Pressure

The Initial Reading is normally obtained during installation (usually the zero reading). The Calibration Factor (usually in terms of PSI or MPa per digit) comes from the supplied Calibration Sheet an example of which is shown in Figure 9.

### 4.2. Temperature Correction

The vibrating wire stress cell is quite sensitive to temperature fluctuations. The Calibration sheet shows the temperature correction for the VW transducer only and usually this effect isinsignificant and can be ignored. But, if a correction is desired it can be made using the factors supplied on the calibration sheet and Equation 2. However, 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 C.

**Temperature Correction = (Current Temperature - Initial Temperature) × Thermal Factor**

or

$$P_T = + (T_1 - T_0) \times K$$

Equation 2 - Temperature Correction **for Transducer Only**

**In practise the best way to compensate for temperatures is to derive a thermal correction factor from simultaneous measurments of pressure and temperature at times when it can be safely assumed that the applied load is not changing. Perhaps the best time to do this is while the concrete is curing.**

### 4.3. Barometric Correction

Barometric pressure fluctuations will be sensed by the cells. However, the magnitudes (±0.5 psi) are usually insignificant.

## 5. TROUBLESHOOTING

Maintenance and trouble shooting of Vibrating Wire Concrete Stress Cells is confined to periodic checks of cable connections. Once installed, the cells are usually inaccessible and remedial action is limited.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

***Symptom: Stress Cell Readings are Unstable***

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct? Channel A of the GK-401 and GK-403 can be used to read the stress cells. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-401 Readout connect the clip with the green boot to the bare shield drain wire of the stress cell cable. If using the GK-403 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another stress cell? If not, the readout may have a low battery or be malfunctioning.

***Symptom: Stress Cell Fails to Read***

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads (usually red and black leads) is 180Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<100Ω) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another stress cell? If not, the readout or datalogger may be malfunctioning.

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## Vibrating Wire Pressure Transducer Calibration Report

Model Number: S-A4500-2MPA

Date of Calibration: September 20, 2011

Serial Number: 1123562

Temperature: 22.6 °C

Barometric Pressure: 999.1 mbar

Technician: [illegible]

| Applied Pressure (MPa) | Gage Reading 1st Cycle | Gage Reading 2nd Cycle | Average Gage Reading | Calculated Pressure (Linear) | Error Linear (%FS) | Calculated Pressure (Polynomial) | Error Polynomial (%FS) |
|---|---|---|---|---|---|---|---|
| 0.0 | 8839 | 8839 | 8839 | 0.005 | 0.25 | 0.000 | -0.01 |
| 0.4 | 8136 | 8136 | 8136 | 0.400 | -0.02 | 0.400 | 0.02 |
| 0.8 | 7430 | 7429 | 7430 | 0.796 | -0.19 | 0.800 | 0.01 |
| 1.2 | 6718 | 6718 | 6718 | 1.196 | -0.22 | 1.200 | -0.02 |
| 1.6 | 5999 | 5999 | 5999 | 1.599 | -0.05 | 1.600 | 0.00 |
| 2.0 | 5275 | 5275 | 5275 | 2.005 | 0.27 | 2.000 | 0.01 |

**(MPa) Linear Gage Factor (G): -0.0005613 (MPa/ digit)** **Regression Zero: 8848**

**Polynomial Gage factors: A: -3.059E-09 B: -0.0005181 C: ______**

**Thermal Factor (K): -0.0003953 (MPa/ °C)**

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

**(psi) Linear Gage Factor (G): -0.08141 (psi/ digit)**

**Polynomial Gage Factors: A: -4.436E-07 B: -0.07514 C: ______**

**Thermal Factor (K): -0.05734 (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.

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 9 - Typical Calibration Sheet

## 6. APPENDIX A - SPECIFICATIONS

### A.1. Stress Cells

| Model: | 4850-1 Tangential | 4850-2 Radial |
|---|---|---|
| Ranges: | 7 MPa (1000 psi)<br>20 MPa (3000 psi) | 2 MPa (300 psi)<br>3.5 MPa (500 psi)<br>5 MPa (750 psi) |
| Sensitivity: | 0.025% FSR | |
| Accuracy: | 0.10% FSR | |
| Linearity: | 0.25% FSR (standard)<br>0.1% FSR (optional) | |
| Operating Temperature: | -30 to +70° C | |
| Frequency range | 1400-3500Hz | |
| Dimensions: | 100 × 200 mm, 4 × 8" | 150 × 250 mm, 6 × 10" |
| Pinch Tube Length: | 600 mm | |
| Material: | 303 & 304 Stainless Steel | |
| Electrical Cable: | 2 twisted pair (4 conductor) 22 AWG<br>Foil shield, PVC jacket, nominal OD=6.3 mm (0.250") | |

Consult the factory for other sizes or options available.

### *A.2 Thermistor (see Appendix B also)*

Range: -80 to +150° C
Accuracy: ±0.5° C

## APPENDIX B - THERMISTOR TEMPERATURE DERIVATION

**Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3**

**Resistance to Temperature Equation:**

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = 1.4051 × $10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
B = 2.369 × $10^{-4}$
C = 1.019 × $10^{-7}$

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

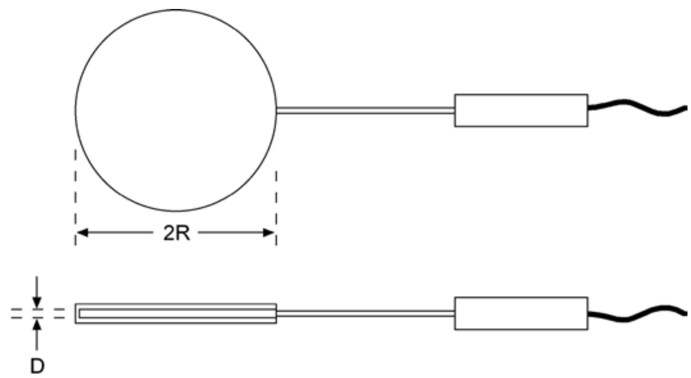
Table B-1 Thermistor Resistance versus Temperature

**APPENDIX C. Temperature Effect on Earth Pressure and Concrete Stress Cells –**

Some Theoretical Considerations

Barrie Sellers

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.




Consider a circular cell of radius R containing a liquid film of 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:

$$Y_T = KD \quad \text{①}$$

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 and a compression of the liquid, $Y_c$, given by the equation:

$$Y_c = PD/G \quad \text{②}$$

So that the net expansion, Y, of the cell is equal to:

$$Y = D\,(K - P/G) \quad \text{③}$$

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formulas found in [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 Poissons ratio, ν, is given by:

$$Y = \frac{2\,PR\,(1-\nu^2)}{E} \qquad \text{at the center}$$

And

$$Y = \frac{4\,PR\,(1-\nu^2)}{\pi E} \qquad \text{at the edge}$$

And the difference is

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

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 and so Y, at the center, is assumed to be:

$$\frac{PR(1-\nu^2)}{E}(2-4/\pi) \qquad \text{i.e. the same difference as before.}$$

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:

$$Y = 0.73\,PR\,(1-\nu^2) \times 0.5 \times 2/E = 0.73\,PR\,(1-\nu^2)/E \ldots\ldots ④$$

Equating ③ & ④ gives:

$$P\,(D/G + 0.73\,R\,(1-\nu^2)/E) = KD \ldots\ldots ⑤$$

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

$$Y = 0.73\,\underline{PR\,(1-v^2)} \times 0.5/E \quad = 0.36\,\underline{PR\,(1-v^2)/E} \quad \ldots\ldots ⑥$$

And

$$P\,(D/G + 0.36\,R\,(1-v^2)/E) = KD \ldots\ldots ⑦$$

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 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 $(1-v^2)$ can be replaced by 0.91 since v usually lies between 0.25 and 0.35.
Hence, for total embedment:

$$P = 1.5\,EKD/R \quad \text{psi} / {}^{o}C$$

And, for contact pressure cells:

$$P = 3\,EKD/R \quad \text{psi} / {}^{o}C$$

Some typical values of the various parameters are:

| Liquid | K x $10^{-6}$ / ºC | G x $10^{6}$ psi |
|---|---|---|
| Oil | 700 | 0.3 |
| Mercury | 180 | 3.6 |
| Water | 170 | 0.3 |
| Glycol | 650 | |
| 50/50 Glycol/Water | 400 | |

| Embedment Material | E x $10^{6}$ psi | v |
|---|---|---|
| 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 |

Examples.

For an oil-filled cell, 9 inches diameter and D = 0.060 inches, totally embedded in:

1. Plastic Clay, E = 3000 psi, v = 0.3,……….….P = 0.042 psi / ºC
2. Soil, medium stiffness, E = 10000 psi, v = 0.3 ……….. P = 0.138 psi / ºC
3. Coarse Sand, E = 50000 psi, v = 0.3…………..P = 0.69 psi / ºC

(For contact pressure cells, multiply the above values for P by 2.)

For a concrete stress cell, 9 inch diameter and D = 0.020 inches:

4. Concrete, E = 5 x $10^{6}$ psi, v = 0.25 ………….P = 22.7 psi / ºC

Same cell, embedded in concrete, filled with mercury instead of oil, ….. P = 5.8 psi / ºC
For an oil-filled cell embedded in a completely rigid medium …………. P = 210 psi / ºC
For a mercury-filled cell embedded in a completely rigid medium …….. P = 650 psi / ºC

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