48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603·448·1562
Fax: 603·448·3216
Email: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 4350BX

Biaxial Stressmeter

(Doc Rev I.1, 03/10/25)

Warranty Statement

Geokon warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by Geokon, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of Geokon's control. Components which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon or any breach of any warranty by Geokon shall not exceed the purchase price paid by the purchaser to Geokon for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

TABLE of CONTENTS

FIGURES

TABLES

EQUATIONS

1. THEORY OF OPERATION

The Standard Geokon Model 4350 Biaxial Stressmeter is designed to measure changes in stress in hard rocks, rock-salt, potash, concrete, ice and other elastic and viscoelastic materials. The sensor consists of a thick-walled steel cylinder, which is grouted in a borehole or embedded in the material to be investigated. Three or six vibrating wire sensors measure the radial deformation of the cylinder and, using theoretically derived equations, the associated stress changes can be determined. The three or six measurements are made in the plane perpendicular to the borehole at 60º intervals allowing determination of the changes in the biaxial stress field in the material around the sensor. Two sensors can also be incorporated into the biaxial stressmeter for the measurement of longitudinal deformations of the stressmeter. This allows the correction of effects due to variations in the stress directed along the borehole. Also, two vibrating wire temperature sensors are connected to compensate for temperature variations. (The ice gauge variant, USS+ACE CRREL style, uses only three radial gauges and one thermistor to measure the temperature).

The sensing elements are vibrating wire strain transducers, which are anchored across the diameter of the cylinder and are used to precisely measure the deformation of the cylinder. Coil and magnet assemblies, located close to the wires, are used both to excite the wires and sense the resultant frequency of vibration. When a gauge is connected, a pulse of varying frequency is applied to the coil and magnet assembly, and this causes the wire to vibrate at its resonant frequency. The wire continues to vibrate and an electrical current, at the gauge frequency, is induced in the pickup coil and transmitted to the readout box where it is measured and displayed.

The term, stressmeter, is used for this device because its effective modulus is deliberately kept high (13 x 10^6 psi) so that variations in the modulus of the surrounding medium cause only small variations in the calibration of the gauge. For example, if the modulus of the medium varies by a factor of 10 the stressmeter calibration varies by a factor of two only.

Installation of the gauge is accomplished by inserting the gauge into a grout-filled borehole using a setting tool and self-aligning setting rods. When the proper location and orientation is achieved, a cable connected to an anchor release pin is pulled, freezing the gauge in place and allowing the setting equipment to be removed. Special expansive grouts are normally used to ensure that the gauge is in complete contact with the surrounding rock. Theoretical computations, given in Appendix C, assume that the stressmeter is perfectly bonded to the surrounding medium.

2. INSTALLATION

2.1 Preliminary Tests

Upon receipt of the stressmeter and prior to installation, the zero readings should be checked and noted. Wiring diagrams are shown in Appendix D.

The gauge should be allowed to come to ambient temperature before zero readings are recorded, and this can take as long as a few hours because of the great mass of the gauge. The readings should check very closely with factory zero readings.

2.2 Borehole Requirements

The Model 4350 Stressmeter is designed for grouting inside a BX (60 mm / 2.36") diamond drill boreholes. The stressmeter body is 57.2 mm (2.25") in diameter and centering buttons extend to a 59 mm (2.32") circle. A test plug, 57.2 mm (2.25") in diameter, can be pushed down the hole to check for a minimum diameter, and the centering buttons can be filed off if they protrude too far. If the hole is oversize the buttons can be fitted with a screw or some other device to enlarge the centering circle. A larger annulus means a thicker layer of grout and this will have some influence on gauge output.

For horizontal holes, the hole should be drilled slightly downwards, enough to ensure that the grout will not drain from the borehole and that the stressmeter will be fully surrounded with grout. Upward directed boreholes are not recommended.

After drilling, the hole should be thoroughly cleaned by washing out with water or blowing out with compressed air.

If the borehole diameter checks out, the installation can proceed.

2.3 Grouting

To ensure that the gauge is in intimate contact with the surrounding rock, an expansive grout should be used. A grout that has been used with good success is manufactured by the U.S. Grout Company called “5 Star Micro Aggregate Special Grout 400”. This is a microfine cable anchor grout with very high strength.

The hole should be filled with grout from the bottom. After removing the grout pipe the stressmeter can be installed by pushing it into the grout until it reaches the desired location.

Note: In highly fractured rocks, the borehole may require grouting and re-drilling to ensure that the gauge is completely grouted. In ice, the gauge is simply allowed to freeze in place.

2.4 Setting the Stressmeter

The stressmeter is shipped with two snap-ring anchors mounted on the back end. These anchors are retained in their retracted position by means of a pull-pin. When the pull-pin is removed the snap-rings expand and grip the side of the borehole holding the stressmeter in place while the grout sets up. **Be careful not to trip the anchors prematurely.**

Mount the stressmeter on the setting tool by engaging the pin on the back of the stressmeter into the bayonet arrangement on the tool. The pin is aligned with the No. 1 wire. Connect a cable to the anchor pull-out pin and then connect the first setting rod to the setting head. Slowly, push the gauge down the hole while maintaining orientation. Continue to add setting rods until the final location is reached. At this time, the orientations should be checked. Pin 1 is frequently aligned with the vertical or some other well-defined direction. It is desirable to take additional readings as a final check before setting. When the gauge is ready to be set, pull on the anchor pull-pin cable using the setting rod for reaction. When the anchors have been set the pull-pin and cable are removed from the hole. Carefully disengage the setting tool and remove it and the rods from the borehole. Be sure to thoroughly clean the grout off the tool and rods. At this time, it is recommended to top-up the hole with grout to maintain some grout pressure in the gauge area.

2.5 Taking Initial Readings

Readings should be taken at intervals immediately following installation to insure good zero data and to see if the grout applies any small preload to the gauge. The grout should gain strength according to the manufacturer’s specifications and full strength should be achieved within a few days.

3. TAKING READINGS

3.1 GK-404 Readout Box

The Model GK-404 Vibrating Wire Readout is a portable, low-power, handheld unit that can run continuously for more than 20 hours on two AA batteries. It is designed for the readout of all Geokon vibrating wire gauges and transducers; and is capable of displaying the reading in either digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 also displays the temperature of the stressmeter (embedded thermistor) with a resolution of 0.1 °C.

Before use, attach the flying leads to the GK-404 by aligning the red circle on the silver "Lemo" connector of the flying leads with the red line on the top of the GK-404 (Figure 1). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 1 - Lemo Connector to GK-404

Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

To turn the GK-404 on, press the "ON/OFF" button on the front panel of the unit. The initial startup screen will be displayed. After approximately one second, the GK-404 will start taking readings and display them based on the settings of the POS and MODE buttons.

The unit display (from left to right) is as follows:

- The current Position: Set by the **POS** button, displayed as a letter A through F.
- The current Reading: Set by the **MODE** button, displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached gauge in degrees Celsius.

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 GK-404 Manual.)

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually, or if enabled, by the Auto-Off timer. If no reading displays or the reading is unstable, consult Section 6 for troubleshooting suggestions.
For further information, consult the GK-404 manual.

3.2 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; and the GK-405 Remote Module, which is housed in a weatherproof enclosure and connects via a cable to the vibrating wire gauge to be measured. The two components communicate wirelessly. The Readout Unit can operate from the cradle of the Remote Module, or, if more convenient, can be removed and operated up to 20 meters from the Remote Module.

3.2.1 Connecting Sensors with 10-pin Bulkhead Connectors Attached

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

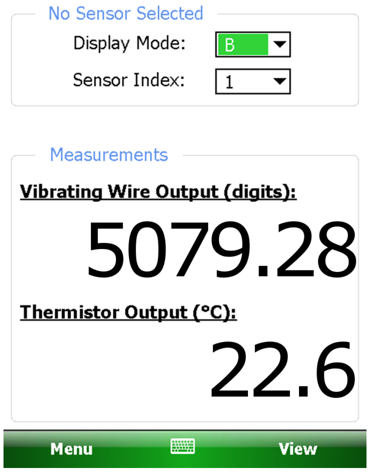
3.2.2 Sensors with Bare Leads

Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.3 Operating the GK-405

Press the button labeled "POWER ON". A blue light will begin blinking, signifying that the Remote Module is waiting to connect to the handheld unit. Launch the GK-405 VWRA program by tapping on "Start" from the handheld PC's main window, then "Programs" then the GK-405 VWRA icon. After a few seconds, the blue light on the Remote Module should stop flashing and remain lit. The Live Readings Window will be displayed on the handheld PC. Choose display mode **B**. Figure 2 shows a typical vibrating wire output in digits and thermistor output in degrees Celsius on display mode B.

If no reading displays or the reading is unstable, see Section 6 for troubleshooting suggestions. For further information, consult the GK-405 Instruction Manual.


No Sensor Selected
Display Mode: B
Sensor Index: 1

Measurements
Vibrating Wire Output (digits):
5079.28
Thermistor Output (°C):
22.6

Figure 2 - Live Readings – Raw Readings

3.3 GK-403 Readout Box (Obsolete Model)

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

3.3.1 Connecting Sensors with 10-pin Bulkhead Connectors Attached

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

3.3.2 Connecting Sensors with Bare Leads

Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.3.3 Operating the GK-403

1) Turn the display selector to position **B**
2) Turn the unit on.
3) The readout will display the vibrating wire output in digits. The last digit may change one or two digits while reading.
4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.
5) Press the "Store" button to record the value displayed.

If the no reading displays or the reading is unstable, see Section 6 for troubleshooting suggestions.

The unit will automatically turn off after approximately two minutes to conserve power.

3.4 Measuring Temperatures

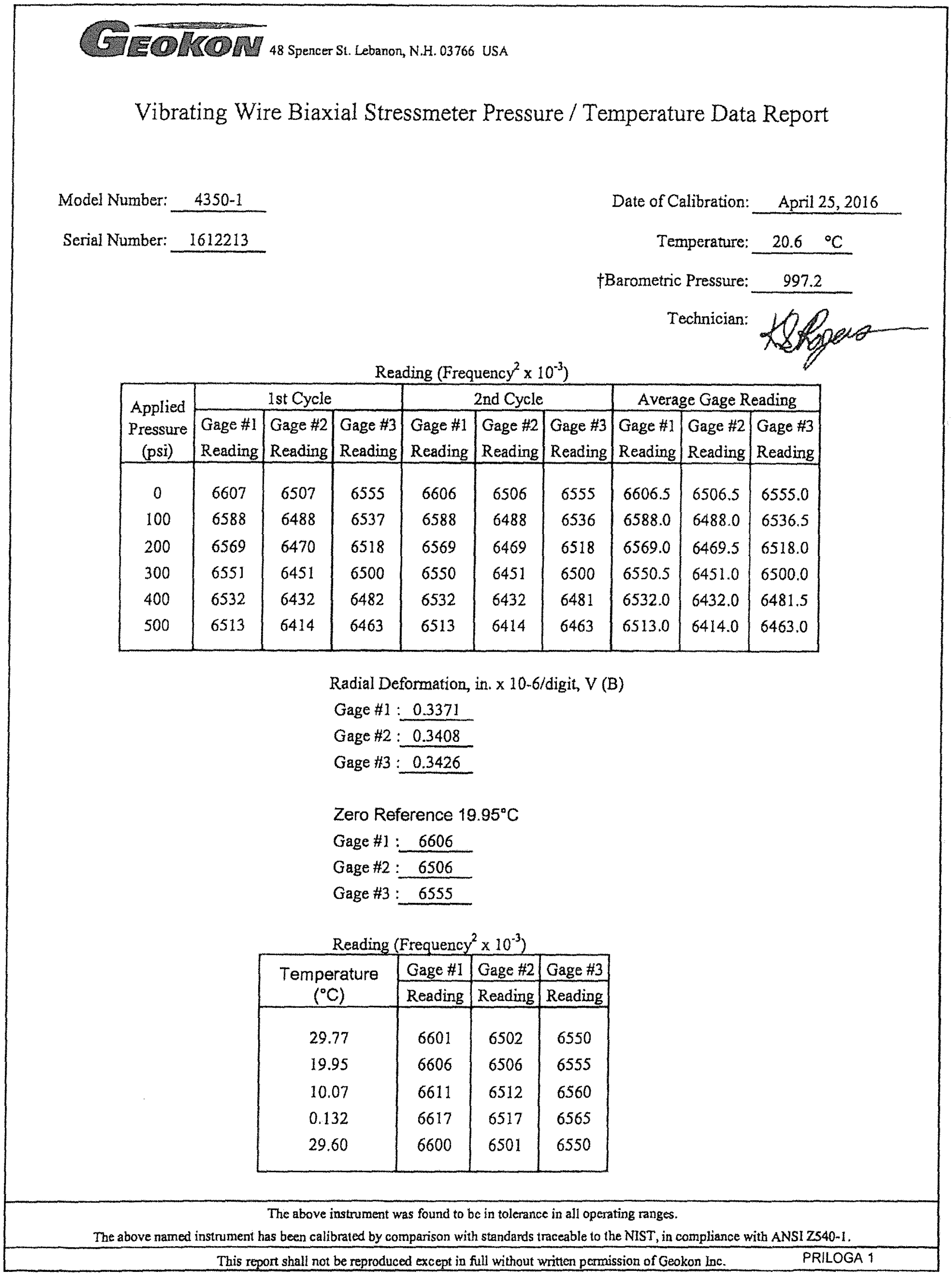
All vibrating wire stressmeters are equipped with a thermistor, which gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor.

Readout boxes will read the thermistor and display the temperature in degrees C.

To read temperatures using an ohmmeter: Connect an ohmmeter to the green and white thermistor leads coming from the stressmeter. (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 14.7 Ω for every 1000 ft., or 48.5Ω per km at 20 °C. Multiply these factors by two to account for both directions.) Look up the temperature for the measured resistance in Appendix B, Table 2.

4. CALIBRATION

Biaxial Stressmeters are calibrated by applying a known radial pressure and measuring the radial gauge outputs. Thermal coefficients are derived for measurements of reading changes on radial and longitudinal gauges at various controlled temperatures.
Typical calibration reports are shown in Figure 3 and Figure 4 below.



GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

Vibrating Wire Biaxial Stressmeter Pressure / Temperature Data Report

Model Number: 4350-1

Serial Number: 1612213

Date of Calibration: April 25, 2016

Temperature: 20.6 °C

†Barometric Pressure: 997.2

Technician: KRogers

Reading (Frequency^2 x 10^{-3})

Applied Pressure (psi)	1st Cycle Gage #1 Reading	1st Cycle Gage #2 Reading	1st Cycle Gage #3 Reading	2nd Cycle Gage #1 Reading	2nd Cycle Gage #2 Reading	2nd Cycle Gage #3 Reading	Average Gage Reading Gage #1 Reading	Average Gage Reading Gage #2 Reading	Average Gage Reading Gage #3 Reading
0	6607	6507	6555	6606	6506	6555	6606.5	6506.5	6555.0
100	6588	6488	6537	6588	6488	6536	6588.0	6488.0	6536.5
200	6569	6470	6518	6569	6469	6518	6569.0	6469.5	6518.0
300	6551	6451	6500	6550	6451	6500	6550.5	6451.0	6500.0
400	6532	6432	6482	6532	6432	6481	6532.0	6432.0	6481.5
500	6513	6414	6463	6513	6414	6463	6513.0	6414.0	6463.0

Radial Deformation, in. x 10-6/digit, V (B)
Gage #1 : 0.3371
Gage #2 : 0.3408
Gage #3 : 0.3426

Zero Reference 19.95°C
Gage #1 : 6606
Gage #2 : 6506
Gage #3 : 6555

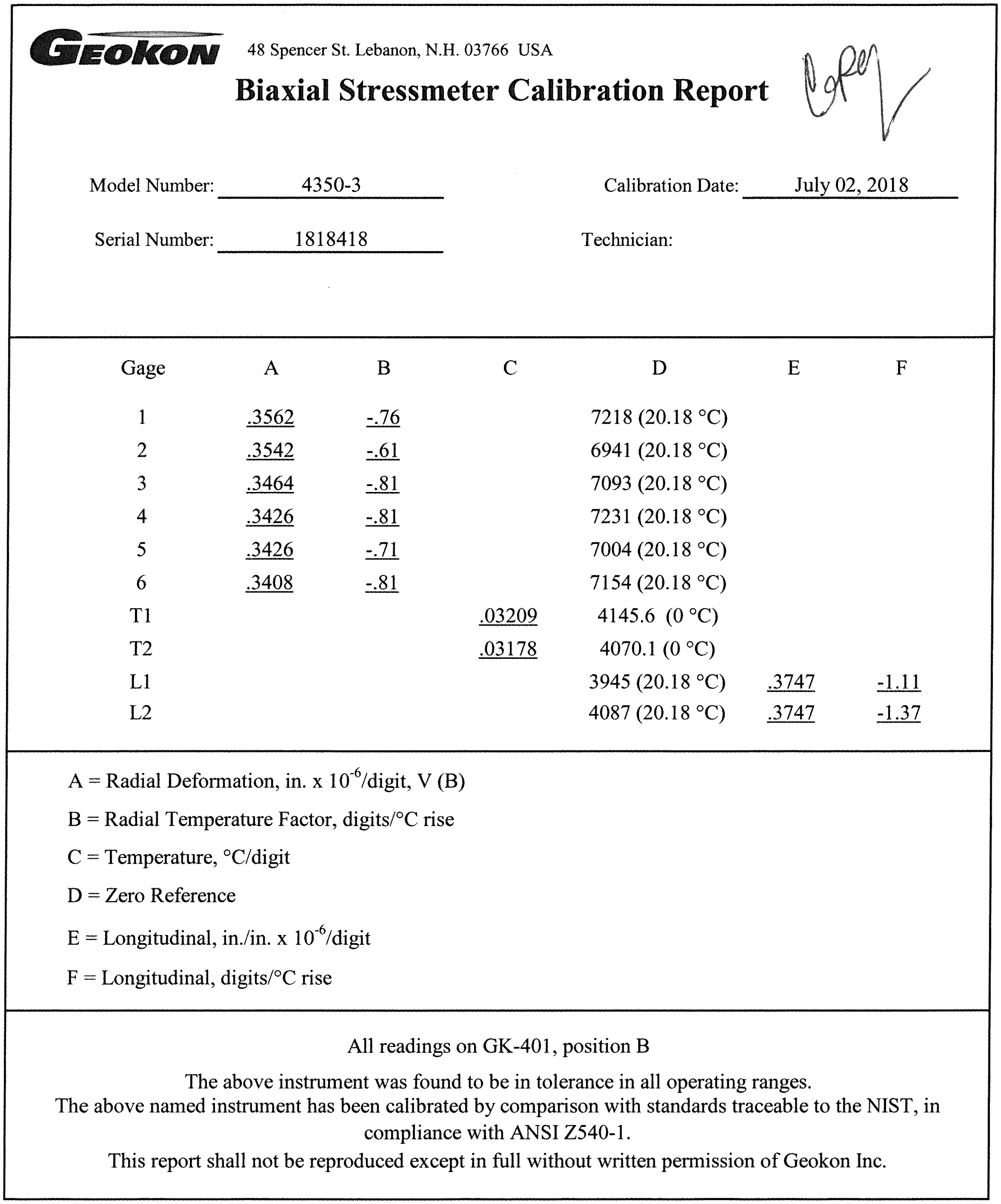
Reading (Frequency^2 x 10^{-3})

Temperature (°C)	Gage #1 Reading	Gage #2 Reading	Gage #3 Reading
29.77	6601	6502	6550
19.95	6606	6506	6555
10.07	6611	6512	6560
0.132	6617	6517	6565
29.60	6600	6501	6550

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.

This report shall not be reproduced except in full without written permission of Geokon Inc. PRILOGA 1

Figure 3 - Typical 4350-1 Calibration Report



GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

Biaxial Stressmeter Calibration Report

Model Number: 4350-3

Calibration Date: July 02, 2018

Serial Number: 1818418

Technician:

Gage	A	B	C	D	E	F
1	.3562	-.76		7218 (20.18 °C)		
2	.3542	-.61		6941 (20.18 °C)		
3	.3464	-.81		7093 (20.18 °C)		
4	.3426	-.81		7231 (20.18 °C)		
5	.3426	-.71		7004 (20.18 °C)		
6	.3408	-.81		7154 (20.18 °C)		
T1			.03209	4145.6 (0 °C)		
T2			.03178	4070.1 (0 °C)		
L1				3945 (20.18 °C)	.3747	-1.11
L2				4087 (20.18 °C)	.3747	-1.37

A = Radial Deformation, in. x 10^{-6}/digit, V (B)

B = Radial Temperature Factor, digits/°C rise

C = Temperature, °C/digit

D = Zero Reference

E = Longitudinal, in./in. x 10^{-6}/digit

F = Longitudinal, digits/°C rise

All readings on GK-401, position B

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.
This report shall not be reproduced except in full without written permission of Geokon Inc.

Figure 4 - Typical 4350-3 Calibration Report

5. DATA REDUCTION

5.1 Gauge Orientation

Sensor 1 coincides with the pin on the back end of the gauge. Sensor 2 is 60º clockwise looking down the borehole and Sensor 3 is at 120º clockwise. (The Model 4350-2 has six radial sensors. Sensor 4 is lined up with Sensor 1, Sensor 5 is lined up with Sensor 2, and Sensor 6 is lined up with Sensor 3. These extra sensors provide a measure of redundancy.)

5.2 Data Reduction Process

The GK-403 or GK 404 Readouts excite the gauge and times the period of 255 (or less) cycles of gauge vibration using a 6.144 MHZ quartz oscillator and displays the period to a resolution of 0.1 microseconds in Position "A". In Position "B" which is used for stressmeters, the processor converts the period readings to units of frequency squared, which is directly proportional to wire strain, gauge deflection and applied stress.

The theory of the vibrating wire stressmeter is given in Appendix C.

The process of data reduction is as follows:

First, calculate the radial deformation V_1, V_2, and V_3 from Equation 6 in Appendix C.2.
From knowledge of the Young's Modulus and Poisson's Ratio for the rock, concrete or ice, refer to Figure 6 and Figure 7 (or use calculations) in Appendix C.3 to obtain values for the factors A and B. Insert the values of V_1, V_2, V_3, A and B in Equation 11, Equation 12, and Equation 13 in Appendix C.4 to obtain p, q, and θ.

Apply any correction required for longitudinal stress in the direction of the borehole axis. This is only possible with a stressmeter incorporating a longitudinal strain sensor measuring $\varepsilon \ell$.

For Example:

For a rock with a Young's Modulus of 5 x 10^6 psi and Poisson's Ratio of 0.3.

Initial readings on Channel B (Model GK-404 Readout Box) are:
Axis 1: 6050 Axis 2: 6235 Axis 3: 6198

After application of stresses (p) and (q), readings are:
Axis 1: 5020 Axis 2: 6405 Axis 3: 6400

Gauge factors G are:
Axis 1: 0.3602 x 10^-6 Axis 2: 0.3588 x 10^-6 Axis 3: 0.3614 x 10^-6

From Equation 6:
$V_{r1} = 371 \times 10^{-6}$
$V_{r2} = -61 \times 10^{-6}$
$V_{r3} = -73 \times 10^{-6}$

From Figure 6, or by calculations: $A = 0.0325 \times 10^{-6}$
From Figure 7, or by calculations $B = 0.138 \times 10^{-6}$

From Equation 11, Equation 12, and Equation 13:
$P = 2273$ psi
$q = 157$ psi
$\theta = 0^{\circ}$

5.3 Longitudinal Sensor

The Longitudinal Sensor measures the overall change in length of the stressmeter by using two vibrating wires strung from one end of the gauge to the other. Assuming the gauge is fully bonded to the surrounding rock, the formula for longitudinal strain along the borehole is:

$$\varepsilon\ \ell = (R_0 - R_T),\ \times F \text{ microstrain}$$

Equation 1 - Longitudinal Strain Along the Borehole

Where;
R_0 = the initial reading (GK-404 or GK-405 Position “B”)
R_T = the current reading
F = longitudinal gauge factor (from column E of the Calibration Report after reversing the sign)

For example:
$R_0 = 5{,}000$
$R_T = 4{,}800$
$\varepsilon\,\ell = (R_0 - R_T) \times F = (5{,}000 - 4{,}800) \times 0.3574 = 71.48$ micro-strain shortening of the borehole

To apply the correction for longitudinal strain, the increment $\nu_i \varepsilon\ \ell_l E_i$ should be added to the values computed for p and q.
Where;
ν_i = Poisson’s Ration of the rocks, concrete or ice.
E_i = Young’s Modulus of the rocks, concrete or ice.
$\varepsilon\,\ell$ =Longitudinal strain which, for a compressive strain, would be positive.

5.4 Temperature Correction Factors

Temperatures are measured by a thermistor in the model 4350-1. The thermal correction factor may be obtained by plotting the data given in the calibration report, (see Section 4 for example calibration reports), supplied with the stressmeter. Plotting digits on the Y-axis and temperature on the X-axis yield a straight line the gradient of which is the temperature correction factor, in digits/degree, after the sign has been reversed.

Temperature changes for models 4350-2 and 4350-3 are measured by two Model 4700, internal vibrating wire temperature gauge(s). L1 is located at the cable end (and L2 located at the tip). Temperatures can be computed from the equation:

$$T = K(S_T - S_0)$$

Equation 2 - Temperature Calculation

Where;
K is the thermal gauge factor shown in column C of the calibration report; (see Figure 3 and Figure 4 in Section 4 for sample calibration reports)
S_0 is the reading taken from column D of the calibration report
S_T is the current reading

For example:

If;
$K = 0.03209$
$S_0 = 4145$
$S_T = 5300$

Then;
The temperature (T) = 0.03209(5000-4145) = 27 °C

Temperature corrections for the radial sensors are shown on the Calibration Report under column B. For instance, if this temperature factor, is -0.81 digits per degree then the temperature correction equation would be:

$$\varepsilon \ell T = [\ (R_0 - R_T) + 0.81(T_T - T_0)]G \text{ microinches}$$

Equation 3 - Temperature Correction for Radial Sensors

Where;
G is the radial gauge factor
T_T is the current temperature
T_0 the initial temperature at installation

The Longitudinal Sensor has a slight temperature sensitivity, which can be corrected for using the correction factor shown on the Calibration Report under column F.

For example:

If the digits change /degree C rise is -1.11 the temperature correction equation would be:
$\varepsilon \ell T = [(R_0 - R_T) + 1.1(T_T - T_0)]F$ microinches

5.5 Environmental Factors

Since the purpose of the stressmeter installation is to monitor site conditions, factors, which may affect these conditions, should always be observed and recorded. Seemingly minor effects may have a real influence on other 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, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

6. TROUBLE SHOOTING

Maintenance and troubleshooting of stressmeters is confined to periodic checks of cable connections and maintenance of terminals. The setting rods should be kept clean and the button mechanisms kept lightly oiled.

Once installed, the gauges are usually inaccessible and remedial action is limited. Should difficulties arise, consult the following list of problems and possible solutions. Return any faulty gauges to the factory. **Gauges should not be opened in the field.** For additional troubleshooting and support, contact Geokon.

Symptom: Thermistor resistance is too high:

- ✓ There may be an open circuit. Check all connections, terminals, and plugs.

Symptom: Thermistor resistance is too low:

- ✓ There may be a short. Check all connections, terminals, and plugs.
- ✓ Water may have penetrated the interior of the Stressmeter. There is no remedial action.

Symptom: Instrument 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?
- ✓ Is there a source of electrical noise nearby? Likely candidates are generators, motors, arc welding equipment, high voltage lines, etc. If possible, move the instrument cable away from power lines and electrical equipment or install electronic filtering.
- ✓ Make sure the shield drain wire is connected to ground. Connect the shield drain wire to the readout using the blue clip. (Green for the GK-401.)
- ✓ Does the readout work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Symptom: Instrument Fails to Read:

- ✓ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the gauge leads. Nominal coil resistance is 90 Ω (180 Ω for temperature and longitudinal sensors). Cable resistance is approximately 48.5Ω per km (14.7Ω per 1000 ft.) of 22 AWG wire. (Multiply this factor by two to account for both directions.)

  If the resistance is very high or infinite (megohms), the cable is probably broken or cut. If the resistance is very low (<20Ω), the gauge conductors may be shorted.

- ✓ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

APPENDIX A. SPECIFICATIONS

Range (compression only)	30,000 psi
Approximate Sensitivity* (Hydrostatic)	5.4 psi
Accuracy (Hydrostatic)	± 0.1% F.S.
Operating Temperature Standard	–30 to +65 ºC
High Temperature Option	–60º to +200 ºC
Frequency Range	1400-3500 Hz
Borehole Diameter	BX models 60 mm (2.36")
Dimensions	R_2 = 28.6 mm (1.125") R_1 = 16.5 mm (0.650") R_c = 25.4 mm (1.000") Length with end caps = 317.5 mm (12.5") Length without end caps = 177.8 mm (7.0")
Weight	15.4 kgm (7 lb.)
Accessories	Setting Rods – 6 feet or 2 meter, self-orienting Setting Head Anchor Actuating Cable
OPTIONAL SENSORS	
VW Longitudinal Deformation Sensor:	Range = 2,000 microstrain Sensitivity = 0.4 microstrain
VW Temperature Sensors:	Range = –60º to +200 ºC Sensitivity = 0.035 ºC

Table 1 - Specifications

*With GK-404 Readout Box on Channel B

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
Resistance to Temperature Equation:

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

Equation 4 - Resistance to Temperature

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	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 2 - Thermistor Resistance versus Temperature

APPENDIX C. BIAXIAL STRESS THEORY

C.1 Biaxial Stress Theory

The measurement of stresses in rock, concrete or ice with an embedded sensor requires precise knowledge of the strain in the sensor, the stress-strain relationship of the sensor material and the sensor's inclusion factor under different loading conditions. Fortunately, the modulus of the biaxial steel sensor is known, and the gauge deformation can precisely determine using vibrating wire technology. Analytical solutions are also available that describe the behavior of a cylindrical inclusion in a plate under loading.

Since we are generally interested in compressive stress, compressive displacements and stresses are taken to be positive as is often done in rock mechanics. Principal stresses are designated by p and q. The major principal stress, p, is the larger compressive stress, such that p > q. All angles are measured clockwise from the p direction.

C.2 Gauge Deformation

The diametral deformation of the gauge is determined by measuring the resonant frequency of each of the three vibrating wires. The fundamental frequency of each wire is proportional to the strain in the wire and is related to the wire strain by the equation:

$$\mathrm{f} = \frac{1}{2\ell_w}\sqrt{\frac{\varepsilon \mathrm{E_w}}{p_w} g}$$

Equation 5 - Wire Frequency in Relation to Wire Strain

Where;
f = natural frequency of the wire (s^{-1})
ℓ_w = wire length (5.08×10^{-2} m) (2.00 ins.)
ε = wire strain
E_w = wire modulus (207 Gpa) (30×10^6 psi)
p_w = wire density (7.83×10^3 kg/m^3) (0.283 lbs./cu.ins)
g = acceleration of gravity (386 in./sec./sec.)

Equation 5 may also be expressed as:
$E = kf^2$ *or* $\Delta\varepsilon = k\,\Delta\,(f^2)$

Where;
$G = \frac{4\ell^2{}_w p_w}{E_w g}$ (theoretical)
$\Delta(f^2) = (f_0^2 - f_T^2) = (R_0 - R_T) \times 10^3 / \sec^2$ where R_0 and R_T are the readings on Channel B on the GK-404 Readout Box at time zero and time T.

In practice, stressmeters are calibrated at the factory using a hydraulic test chamber to exert known radial pressures and measure actual wire deformations. In this way, an empirically derived G factor is measured and used. For the standard BX size stressmeter, the factor G is approximately 0.35 x 10^{-9} sec.^{2}. The actual calibration factor G is shown. In column A of the Calibration Report supplied.

Since the radial deformation of the cylinder: V_r at $\ell_w/2$ radius is equal to $V_r = (\ell_w/2)\, \Delta\varepsilon$

we have: $V_r = (\ell_w/2)\, G\, \Delta\, (f^2)$
and since, $\ell_w = 2.00$ ins. and $\Delta\, (f^2) = (R_0 - R_T) \times 10^3 / \text{sec}^2$
therefore:

$$V_r = G\, (R_0 - R_T) \times 10^{-6} \text{ ins.}$$

Equation 6 - Radial Deformation of the Cylinder

C.3 Stresses Associated with Cylindrical Sensors

The stress-deformation relationship for cylindrical elastic inclusions in elastic and viscoelastic materials has been examined both analytically and experimentally. Savin (1961), Berry and Fairhurst (1966), Williams (1973) and others have developed analytical solutions for elastic materials. Experimental tests have verified that the analytical solutions accurately describe the stress distribution in an elastic plate (Suzuki 1969, Wilson 1961). The analytical solutions also describe the deformation of cylindrical elastic inclusions in viscoelastic and other time-dependent materials in uniaxial and biaxial loading experiments (Hawkes 1969a, b, Skilton 1971, Williams 1973, Busell et al. 1975, Johnson and Cox 1980).

The stress and displacement equations used in the following to describe the behavior of the biaxial stress sensor and surrounding rock, concrete or ice are based on the work of Savin (1961), who developed a set of analytical equations to describe the behavior of an elastic ring welded in an elastic plate. Even though the rock, concrete or ice has time-dependent properties, the analytical results of Berry and Fairhurst and the experimental work of Hawkes, Skilton, and Buswell indicate that Savin’s equations can still be used.

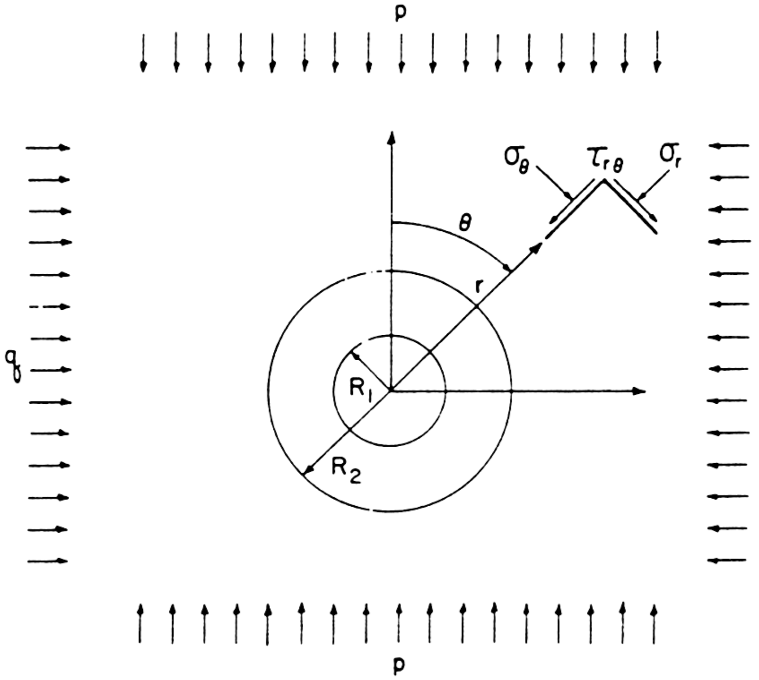


Figure 5 - Plan View of Cylindrical Sensor Embedded in Rock, Concrete, or Ice

Generally, we are interested in measuring in-plane stresses in the rock, concrete or ice. Consider a cylindrical sensor that is embedded into an infinite isotropic medium (Figure 5). The sensor is oriented normal to the plane, which is subjected to in-plane principal stresses p and q. The sensor has an outer radius R_2 and an inner radius R_1.

The stress (σ_r, σ_θ and $\tau_{r\theta}$) and displacement (V_r and V_θ) equations for the sensor ($R_1 < r < R_2$) in polar coordinates are:

$$\sigma_r = \left(\frac{p+q}{2}\right)\left(C_2 - \frac{C_5}{2}\frac{R_2^2}{r^2}\right) + \left(\frac{p-q}{2}\right)\left(\frac{C_7}{2} - 2C_1\frac{R_2^2}{r^2} - \frac{3}{2}C_4\frac{R_2^4}{r^4}\right)\cos 2\theta$$

$$\sigma_\theta = \left(\frac{p+q}{2}\right)\left(C_2 + \frac{C_5}{2}\frac{R_2^2}{r^2}\right) - \left(\frac{p-q}{2}\right)\left(\frac{C_7}{2} - 6C_3\frac{r_2^2}{R_2} - \frac{3}{2}C_4\frac{R_2^4}{r^4}\right)\cos 2\theta$$

$$\tau_{r\theta} = \left(\frac{p-q}{2}\right)\left(3C_3\frac{r^2}{R_2^2} - \frac{C_7}{2} - C_1\frac{R_2^2}{r^2} - \frac{3}{2}C_4\frac{R_2^4}{r^4}\right)\sin 2\theta$$

$$V_r = \frac{(p+q)}{8\mu_s}R_2\left(C_2(X_s-1)\frac{r}{R_2} + C_5\frac{R_2}{r}\right) + \frac{(p-q)}{8\mu_s}R_2\left(C_3(X_s-3)\frac{r^3}{R_2^3} + C_7\frac{r}{R_2}\right.$$
$$\left. + C_1(X_s+1)\frac{R_2}{r} + C_4\frac{R_2^3}{r^3}\right)\cos 2\theta$$

$$V_\theta = \frac{(p-q)}{8\mu_s}R_2\left(C_3(X_s+3)\frac{r^3}{R_2^3} - C_7\frac{r}{R_2} - C_1(X_s-1)\frac{R_2}{r} + C_4\frac{R_2^3}{r^3}\right)\sin 2\theta$$

Equation 7 - Equations for the Sensor in Polar Coordinates

The stress and displacement equations for the surrounding medium ($r > R_2$) are:

$$\sigma_r = \left(\frac{p+q}{2}\right)\left(1 - \frac{C_6}{2}\frac{R_2^2}{r^2}\right) + \left(\frac{p-q}{2}\right)\left(1 - 2C_8\frac{R_2^2}{r^2} - \frac{3}{2}C_9\frac{R_2^4}{r^4}\right)\cos 2\theta$$

$$\sigma_\theta = \left(\frac{p+q}{2}\right)\left(1 + \frac{C_6}{2}\frac{R_2^2}{r^2}\right) - \left(\frac{p-q}{2}\right)\left(1 - \frac{3}{2}C_9\frac{R_2^4}{r^4}\right)\cos 2\theta$$

$$\tau_{r\theta} = -\left(\frac{p-q}{2}\right)\left(1 + C_8\frac{R_2^2}{r^2} + \frac{3}{2}C_9\frac{R_2^4}{r^4}\right)\sin 2\theta$$

$$V_r = \frac{(p+q)}{8\mu_i}R_2\left((X_i-1)\frac{r}{R_2} + C_6\frac{R_2}{r}\right)$$
$$+ \frac{(p-q)}{8\mu_i}R_2\left(2\frac{r}{R_2} + C_8(X_i+1)\frac{R_2}{r} + C_9\frac{R_2^3}{r^3}\right)\cos 2\theta$$

$$V_\theta = \frac{(p-q)}{8\mu_i}R_2\left(-2\frac{r}{R_2} - C_8(X_i-1)\frac{R_2}{r} + C_9\frac{R_2^3}{r^3}\right)\sin 2\theta.$$

Equation 8 - Stress and Displacement Equations for the Surrounding Medium

The coefficients C_1 through C_9 depend on the sensor geometry and the material properties of the sensor and rock, concrete or ice, where:

$$C_1 = 2\left(\frac{1+X_i}{D}\right)\left[\left(\frac{\mu_i}{\mu_s}-1\right)+n^6\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]$$

$$C_2 = \frac{n^2(1+X_1)}{2\left(\frac{\mu_i}{\mu_s}-1\right)-n^2\left[\left(\frac{\mu_i}{\mu_s}-1\right)-\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]}$$

$$C_3 = -2\,\frac{(1+X_i)}{D}\,n^4(n^2-1)\left(\frac{\mu_i}{\mu_s}-1\right)$$

$$C_4 = -2\,\frac{(1+X_1)}{D}\left[\left(\frac{\mu_i}{\mu_s}-1\right)+n^4\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]$$

$$C_5 = \frac{2C_2}{n^2}$$

$$C_6 = 2 - 2\,\frac{(n^2-1)}{n^2}C_2$$

$$C_7 = 2\,\frac{(1+X_i)}{D}\left[\left(\frac{\mu_i}{\mu_s}-1\right)(4-3n^2)+n^6\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]n^2$$

$$C_8 = 2-2\,\frac{(1+X_i)}{D}\left[\left(\frac{\mu_i}{\mu_s}-1\right)(3n^6-6n^4+4n^2-1)+n^6(n^2-1)\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]$$

$$C_9 = -2+2\,\frac{(1+X_i)}{D}\left[\left(\frac{\mu_i}{\mu_s}-1\right)(4n^6-7n^4+4n^2-1)+n^4(n^4-1)\left(1+X_s\frac{\mu_i}{\mu_s}\right)\right]$$

Equation 9 - Equations for Calculating Coefficients C_1 through C_9

In the above equations:

$$n = \frac{R_2}{R_1}$$

$$\mu = \frac{E}{2(1+v)}$$

$$X = \frac{(3-v)}{(1+v)}$$ for plane stress

$X = (3-4v)$ for plane strain

D =

$$\left(X_i + \frac{\mu_i}{\mu_s}\right) n^2 \left[\left(\frac{\mu_i}{\mu_s} - 1\right)(3n^4 - 6n^2 + 4) + n^6\left(1 + X_s\frac{\mu_i}{\mu_s}\right)\right] + \left(X_s\frac{\mu_i}{\mu_s} - X_i\right)\left[\left(\frac{\mu_i}{\mu_s} - 1\right) + n^6\left(1 + X_s\frac{\mu_i}{\mu_s}\right)\right]$$

E is Young's modulus

ν is Poisson's ratio where the subscripts s and i denote the material properties of the sensor and surrounding medium respectively.

θ is the angle measured clockwise from the principal stress direction p to the direction of Sensor 1.

C.4 Determination of Stresses in the Medium

The magnitude and direction of the principal stresses in the medium are determined from the measured radial deformation of the sensor in three directions. In the biaxial stress sensor, the measurement directions are 120º apart, and from an equation shown in Equation 7 above, we have for the displacements of the three wires:

$$V_{r1} = A(p+q) + B(p-q)\cos 2\theta_1$$
$$V_{r2} = A(p+q) + B(p-q)\cos 2\theta_2$$
$$V_{r3} = A(p+q) + B(p-q)\cos 2\theta_3$$

Equation 10 - Displacement of the Wires

Where;

$$A = \frac{R_2}{8\mu_s}\left[C_2(X_s - 1)\frac{R_c}{R_2} + C_5\frac{R_2}{R_c}\right]$$

$$B = \frac{R_2}{8\mu_s}\left[C_3(X_s - 3)\frac{R_c^{\,3}}{R_2^{\,3}} + C_7\frac{R_c}{R_2} + C_1(X_s + 1)\frac{R_2}{R_c} + C_4\frac{R_2^{\,3}}{R_c^{\,3}}\right]$$

$\theta_2 = \theta_1 + 60^\circ$

$\theta_3 = \theta_1 + 120^\circ$

In the above equations, θ_1 is the angle measured clockwise from principal stress direction p to the measurement direction V_{r1}; $2R_c$ is the length of the vibrating wire sensor, 25.4 mm (1").

Solving for p, q and θ, we obtain:

$$p = \frac{1}{2}\left[\frac{1}{3B}\left((2V_{r_1} - V_{r_2} - V_{r_3})^2 + 3(V_{r_2} - V_{r_3})^2\right)^{1/2} + \frac{1}{3A}(V_{r_1} + V_{r_2} + V_{r_3})\right]$$

Equation 11 - To Obtain p

$$q = \left[\frac{1}{3A}(V_{r_1} + V_{r_2} + V_{r_3}) - p \right]$$

Equation 12 - To Obtain q

$$\theta_1 = \frac{1}{2}\cos^{-1}\left[\frac{V_{r_1} - A(p+q)}{B(p-q)} \right]$$

Equation 13 - To Obtain θ

But, because cos (θ) = cos $(-\theta)$, the equation for θ_1 has two solutions:
If — $V_{r2} = A(p+q) + B(p-q) \cos 2(\theta_1 + 60^o)$ — then θ_1 is positive.
If — $V_{r2} = A(p+q) + B(p-q) \cos 2(\theta_1 + 120^o)$ — then θ_1 is negative.

In general, the approximate location of the p direction can be intuited by examination of the relative magnitude of the measured diametral changes so that any ambiguity about the sign of θ can be resolved in this way.

The coefficients A and B depend upon the geometry and mechanical properties of the sensor and the mechanical properties of the surrounding medium. A and B for the biaxial stress sensor are plotted again Young's modulus of the surrounding medium for different Poisson's ratios in Figure 6 and Figure 7.

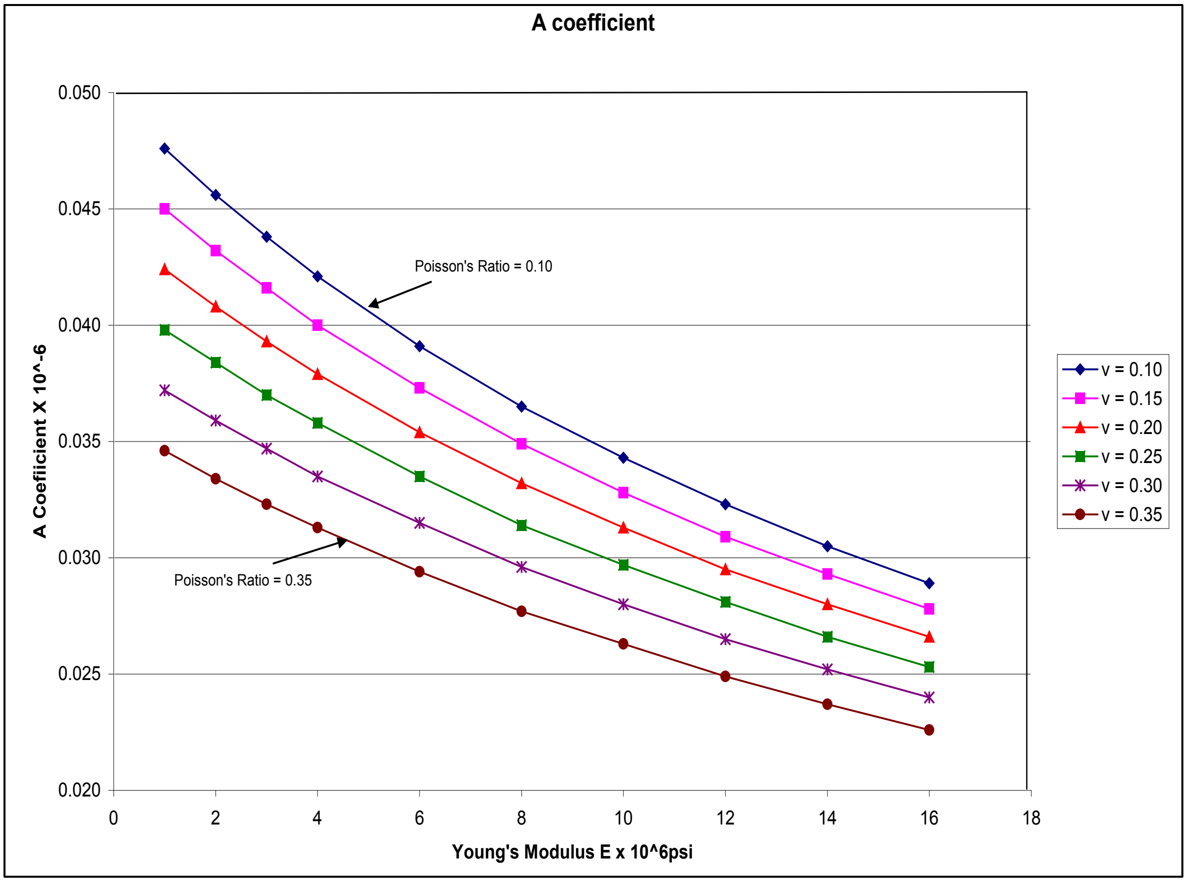


Figure 6 - A Coefficient

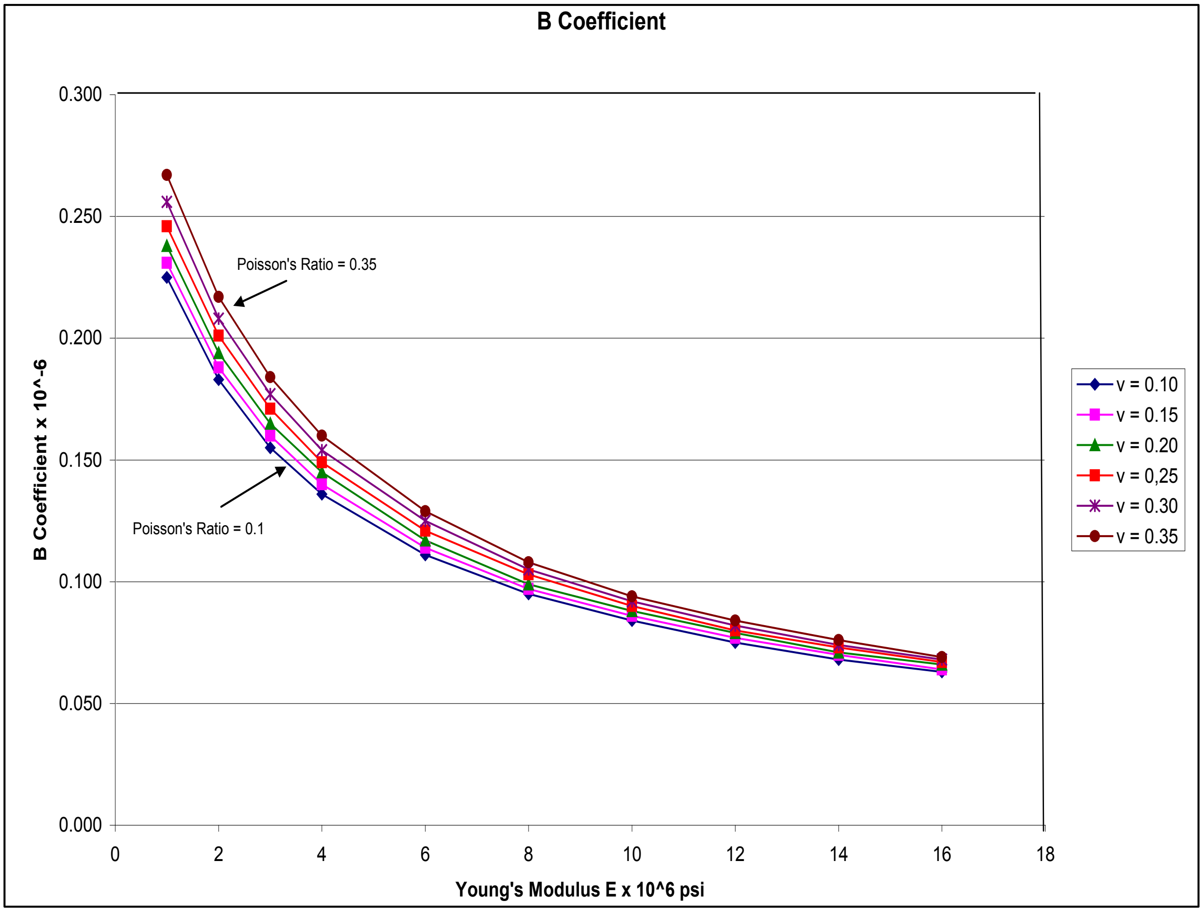


Figure 7 - B Coefficient.

A and B have the units inch^3 / lbf

To convert to metric, multiply A and B by 3684 x mm^3 /Newton. (Or 3.684 x 10^{-6} meters^3 /Newton)

To convert to metric, multiply E psi by 0.006895 MPa

To convert from metric, multiply mm^3/Newton by 0.0002714 to get inch^3 / lbf
(Or from meters^3/Newton multiply by 2.714 x 10^5 to get inch^3 / lbf)

To convert from metric, multiply GPa by 0.1451 to get psi x 10^6

APPENDIX D. WIRING CODES

D.1 Wiring Code for Model 4350-1, Three Gauge Biaxial Stressmeter

The Stressmeter uses a four pair violet-colored cable and each pair has a black lead. Careful attention to the wire code is a must to obtain correct readings.

Sensor Number (Looking Down Hole)			
1	0º Radial 1	Red	Pair
1	0º Radial 1	Red's/Black	
2	60º radial 2	White	Pair
2	60º radial 2	White's Black	
3	120º radial 3	Green	Pair
3	120º radial 3	Green's Black	
T	Thermistor	Blue	Pair
T	Thermistor	Blue's Black	
S	Shield	Shield	All

Table 3 - Model 4350-1 Wiring Chart

D.2 Wiring Code for Model 4350-3, Six Gauge Biaxial Stressmeter

The Stressmeter uses a six pair orange-colored cable and each pair has a black lead. Careful attention to the wire code is a must to obtain correct readings.

Sensor Number (Looking Down Hole)			
1	0º Radial 1	Red	Pair
2	60º Radial 2	Red's/Black	
3	120º radial 3	Brown	Pair
L_1	Longitudinal 1	Brown's Black	
L_2	Longitudinal 2	Yellow	Pair
T_1	Temperature 1	Yellow's Black	
4	0º Radial 4	Blue	Pair
5	60º Radial 5	Blue's Black	
6	120º Radial 6	Green	Pair
T_2	Temperature 2	Green's Black	
	Common lead for 1, 2, 3, L_1, L_2, T_1 (used with three radial gauges)	White's Black	Pair
	Common lead for 4,5,6,T_2, (used with six radial gauges)	White	

Table 4 - Model 4350-3 Wiring Chart

.

D.3 Wiring Code for 4351, Three Gauge Biaxial Ice Gauge

The Ice gauge uses a four pair TPR cable and each pair has a black lead. Careful attention to the wire code is a must to obtain correct readings.

Sensor Number (Looking Down Hole)			
1	0º Radial 1	Brown	Pair
1	0º Radial 1	Brown's/Black	
2	60º radial 2	Red	Pair
2	60º radial 2	Red's Black	
3	120º radial 3	Green	Pair
3	120º radial 3	Green's Black	
T	Thermistor	Yellow	Pair
T	Thermistor	Yellow's Black	
S	Shield	Shield	All

Table 5 - Model 4351 Ice Gauge Wiring Chart