Model 4300 Series

VW Stressmeter (EX, BX, NX)

Instruction Manual

GEOKON®

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1. THEORY OF OPERATION

GEOKON vibrating wire stressmeters are designed primarily for long-term measurements of stress changes in rock, by utilizing a vibrating wire transducer to measure the deformation of a thick-walled steel ring preloaded into a borehole by a wedge and platen assembly as shown in the figure below.

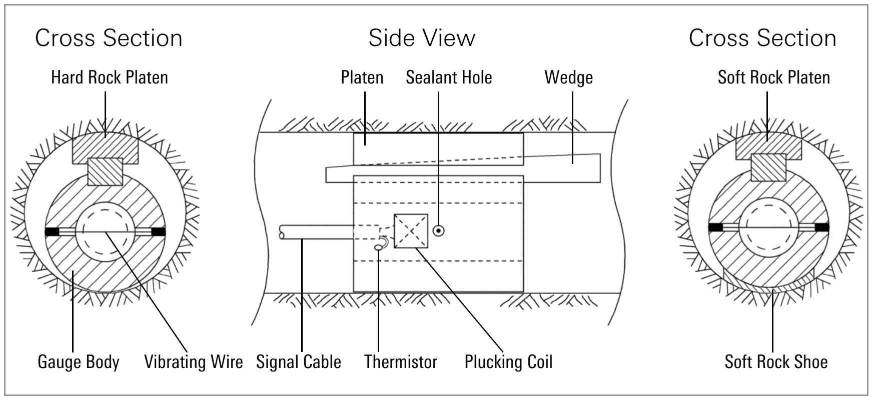

FIGURE 1: *Vibrating Wire Stressmeter*

In use, changing rock stresses impose changing loads on the gauge body causing the body to deflect, and this deflection is noted as a change in tension and resonant frequency of vibration of the vibrating wire element. The square of the vibration frequency is directly proportional to the change in diameter of the gauge and, by calibration, to the change in stress in the rock.

The actual calibration of the gauge depends upon many factors including the host rock elastic constants, the prestress applied during installation, the orientation of the stressmeter with respect to the principal rock stress direction and platen contact area. Thus, the accuracy of the gauge reading is largely indeterminate, and the indicated stress magnitude can only be approximate.

A coil and magnet assembly located close to the wire is used to both excite the wire and sense the resultant frequency of vibration. When the 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 a signal, at the gauge frequency, is induced in the pickup coil and transmitted to the readout box where it is conditioned and displayed.

In theory, where the effective modulus of the stressmeter (approximately 28 GPa (4 x 106 PSI)) is more than two times the modulus of the host rock, conversion of the readings to changes in stress does not require an accurate knowledge of the rock modulus, and this is the reason for using the term stressmeter for this device. However, in most rocks, and especially in harder rocks, the modulus must be known to improve the accuracy of the stress measurements, and calibration curves provided herein give sensitivity factors for materials of different moduli. It should be noted that as the rock modulus changes by a factor of 10, the gauge factor changes only by a factor of two.

The stressmeter is a uniaxial device. To completely evaluate stress changes in a given plane, three stressmeters, installed at 0°, 45°, and 90° orientations, are required.

The gauge wire in the Model 4300 Series stressmeters runs perpendicular to the direction in which the gauge body is loaded in an effort to minimize the effects of point loading, off center loading, etc. This gives the gauge a very high range and, since as the load increases the wire gets tighter, the wire never goes slack.

Gauge installation is accomplished by driving a wedge between the gauge body and the platen, which contacts the borehole walls. Preloading to desired levels is accomplished by further driving of the wedge with the setting tool. In soft rocks, a soft rock platen and soft rock shoe are used to increase the area of contact.

The gauge is constructed of corrosion resistant materials and should have an indefinite lifetime under even the most severe conditions.

2. INSTALLATION

2.1 BOREHOLE REQUIREMENTS

Stressmeters are designed to be used in smooth-walled diamond drill holes. Stressmeters can be installed in percussively drilled holes and drag bit drilled holes, provided that care is taken to get the proper hole diameter with a smooth wall. If the walls are rough, the gauge response (calibration) can be radically affected.

STANDARD HOLE CONFIGURATIONS:

Model 4300EX stressmeters are designed for use in EX diamond drill holes 38 mm (1.5"), and the hole can range in diameter from 37 mm (1.45") to 39 mm (1.55") when using the standard wedge and platen assembly.

Model 4300BX stressmeters are designed for use in BX diamond drill holes 60 mm (2.36"), and the hole can range in diameter from 59 mm (2.30") to 61 mm (2.40") when using the standard wedge and platen assembly.

Model 4300NX stressmeters are designed for use in NX diamond drill holes 76 mm (2.98"), and the hole can range in diameter from 75 mm (2.95") to 77.5 mm (3.05") when using the standard wedge and platen assembly. Oversize platens are available for oversize boreholes (consult factory).

After drilling, the hole should be thoroughly cleaned by washing out with water or blowing out with compressed air. The borehole diameter should then be checked using the GO / NO-GO gauges as follows:

Screw the "GO" gauge onto the section of ¼" rod that has a ¼-20 left-handed thread on one end by rotating it *counterclockwise*. (Note: All male ends of the ¼" rods have normal right-hand threaded connections except for the first section which has a left-hand thread.)

Push the "GO" gauge into the borehole.

Add a section of ¼" rod to the assembly by inserting the threaded male end into the female coupler and turning it clockwise.

Continue to add sections of ¼" rod while pushing the gauge into the borehole until the gauge reaches the desired depth of the stressmeter installation. If the borehole diameter is correct, the "**GO**" gauge **will fit** into the borehole all the way to the installation depth. If the "GO" gauge does not fit into the borehole, or does not reach the installation depth, the borehole is too small.

Remove the "GO" gauge from the borehole and unscrew it from the ¼" rod by turning it *clockwise*.

Screw the "NO-GO" gauge onto the ¼" rod by rotating it *counterclockwise*.

Attempt to push the "NO-GO" gauge into the borehole. If the borehole diameter is correct, the "**NO-GO**" gauge **will not fit** in the borehole at the intended installation depth. If the "NO-GO" gauge does fit into the borehole, the borehole diameter is too large.

Remove the "NO-GO" gauge from the borehole and unscrew it from the ¼" rod by turning it *clockwise*.

If the borehole did not pass the above tests rework it as needed.

Repeat the steps above until the borehole is sized correctly.

2.2 PRELIMINARY CHECKS

Before installing the gauges in the field, perform a preliminary check by completing the following

1. Connect the gauge to a readout box. See Section 3 for more information.
2. Take a reading. Zero readings at the site should coincide with the factory readings within a few digits after corrections for temperature are made. See Section 4.4 for information on temperature correction.
3. Use an ohmmeter to check electrical continuity. The resistance between the two lead wires (usually red and black) should be about 180 ohms for BX and NX models, and 90 ohms for EX model. Remember to add the cable resistance at approximately 14.7Ω/1000' (48.5Ω/km) at 20 °C. Multiply this factor by two to account for both directions.
4. Using an ohmmeter check the resistance between the two thermistor wires (usually white and green). Using Table 3, convert the resistance to temperature. Compare the result to the current ambient temperature.

2.3 ATTACHING THE WEDGE/PLATEN ASSEMBLY

The wedge/platen assemblies are shipped separately. They are held together by a nylon screw and nut. Do the following:

1. Remove the nut and then use the nylon screw to attach the wedge/platen assembly to the stressmeter body.
2. Orient the wedge so that the narrow end is facing in the same direction as the cable, as displayed in the figure below.

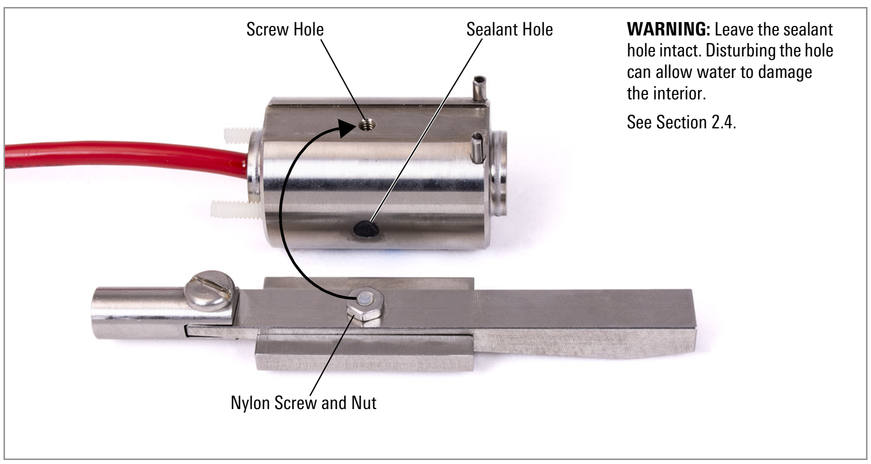

FIGURE 2: *Stressmeter with Wedge, Screw and Nut*

3. Tighten the nylon screw into the threaded hole in the body. **Do not overtighten the screw as it may break**; it is made of nylon so that it can be sheared easily later in the installation.

Note: Both the BX and NX stressmeters use the same wedge. There are two holes in the wedge: the one nearest the tip is for the BX model, the one farthest from the tip is for the NX model.

2.4 PROTECTING THE SEALANT HOLES

The sealant holes on EX models are filled with a sealant that makes the interior watertight. Take care not to disturb this sealant: doing so risks allowing water to penetrate the interior, which can render the stressmeter inoperable.

Note: The BX and NX models feature a metal cap welded over the sealant holes.

2.5 SETTING THE STRESSMETER (RECOVERABLE TYPE)

Mount the stressmeter to the setting tool by pushing the threaded nylon pins on the stressmeter into the matching holes in the setting tool head. Push straight in with moderate force. Make sure the pins are inserted fully so that no gap exists between the stressmeter and the setting tool.

Feed the gauge leads through the slot in the setting head.

Connect the first section of ¼" with a ¼-20 left hand thread on one end to the "yoke" located on the thin end of the wedge by turning the rod *counterclockwise*.

Attach the first section of the ¾" positioning rod to the back of the setting tool head. Push the stressmeter into the hole using the positioning rod. The buttons on the setting rod connectors indicated the orientation of the wedge/ platen assembly, e.g., for taking measurements in a vertical direction, keep the buttons to the top of the rod.

As the ¾" positioning rod is pushed into the hole, add new sections of both ¾" and ¼" rod until the desired depth has been reached**.**

Caution: Wear gloves during this procedure to protect the thumb while depressing the buttons on the ¾" rods.

Slide the slide-hammer over the last section of ¼" rod and then thread the anvil block onto the outer end of the ¼" rod. Connect the readout box to the lead wires and take initial readings. Refer to Section 3 for more information.

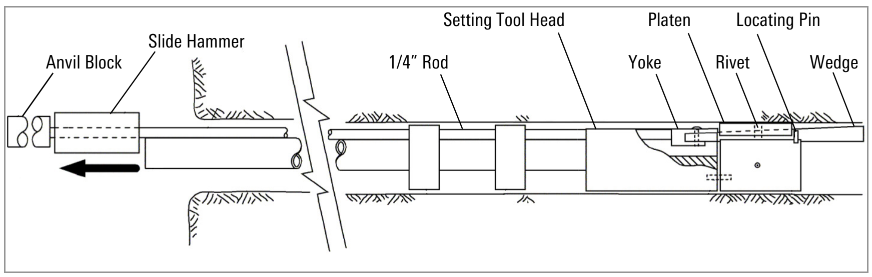

FIGURE 3: *Vibrating Wire Stressmeter Installation Tool Assembly*

Holding the positioning rod firmly at its correct depth and orientation, slide the slide-hammer back up the ¼" rod, then side it quickly back to the anvil striking it a sharp firm blow. This will shear the rivet holding the wedge to the platen and will pull the wedge into the platen thereby expanding it against the wall of the borehole.

After the first blow, take another reading on the readout box and observe the change in reading. The recommended preloads are as follows: For the EX size a reading change of 2000 digits on channel F, for the BX size a reading change of 400 digits on channel B, for the NX size a reading change of 200 digits on channel B. (Note that the stressmeter initial readings will probably diminish slightly over the first day or two as the instrument beds firmly into place.)

Use as many blows of the hammer as is necessary to achieve this reading. **Stop hammering when successive blows produce little or no change of reading. Continued hammering can break the wedge!** When the target reading has been achieved, or if successive hammer blows produce little or no change, disconnect the ¼" rod from the wedge yoke by turning **clockwise**. Remove the ¼" rod from the hole, and then disengage the setting tool from the stressmeter by pulling on it.

For multiple installations of gauges in a single hole, route the lead wires from deeper gauges through the recess in the side of the setting tool head. Maintain tension on these wires as subsequent gauges are pushed into the hole.

If necessary, after setting the gauges and obtaining the final readings, push the leads back into the borehole and seal the borehole using an expandable rockbolt anchor or a short bolt. This will discourage vandalism if this is a problem.

2.6 RECOVERING THE STRESSMETER

After tests, the stressmeter can be removed from the borehole by using the setting tool.

Only the larger setting rods are required, along with the setting tool head, which is used to strike the outer tip of the wedge. This will drive the wedge out from under the platen and allow the stressmeter to be pulled from the hole using the electrical cable. Make sure that the setting head is oriented so that the flat part of the front face lies opposite the wedge. The entire stressmeter can sometimes be recovered in this way i.e., the wedge, platen, and stressmeter body.

In order to reuse the stressmeter it will require a new nylon screw. (A few spare nylon screws are included in each shipment). However, there is a good chance that the wedge and platen may dislodge in the borehole and be lost; therefore, it is advised to order spares of these also.

Note: The BX size stressmeter and the NX size stress meter both use the same wedge. However, there are two holes in the wedge. The one nearest the tip is for the BX size; the one farthest from the tip is for the NX size.

2.7 SPLICING AND JUNCTION BOXES

Because the vibrating wire output signal is a frequency rather than a current or voltage, variations in cable resistance have little effect on gauge readings. Therefore, splicing of cables has no effect, and in some cases may in fact be beneficial. For example, if multiple stressmeters are installed in a borehole, and the distance from the borehole to the terminal box or datalogger is great, a splice (or junction box) could be made to connect the individual cables to a single multi-conductor cable. This multi-conductor cable would then be run to the readout station. For these types of installations, it is recommended that the stressmeter be supplied with enough cable to reach the installation depth, plus extra cable to pass through drilling equipment (rods, casing, etc.).

Cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **When splicing, it is very important that the shield drain wires be spliced together.** Splice kits recommended by GEOKON incorporate casts that are placed around the splice and 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.

Junction boxes and terminal boxes are available from GEOKON for all types of applications. In addition, portable readouts and dataloggers are also available. Contact GEOKON for specific application information.

3. TAKING READINGS

3.1 GK-404 VIBRATING WIRE READOUT

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

FIGURE 4: *GK-404 Readout*

3.1.1 OPERATING THE GK-404

1. Attach the flying leads by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 5). Insert the Lemo connector into the GK-404 until it locks into place.
2. Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).
3. To turn on the GK-404, press the **On**/**Off** button on the front panel of the unit. The initial startup screen will display.
4. After a delay, the GK-404 will start taking readings and display them based on the settings of the **Pos** and **Mode** buttons.

FIGURE 5: *Lemo Connector to GK-404*

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

- The current position: set by the **Pos** button, displayed as 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 instrument in degrees Celsius.

Use the **Pos** and **Mode** buttons to select the correct position and display units for the model of equipment purchased.

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually or by the Auto-Off timer (if enabled).

For more information, consult the GK-404 manual.

3.2 GK-405 VIBRATING WIRE READOUT

The GK-405 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.

The remote module can be wire-connected to the sensor by means of:

- Flying leads with alligator clips, if the sensor cable terminates in bare wires.
- A 10 pin connector.

The two units communicate wirelessly using Bluetooth®, a reliable digital communications protocol. Using Bluetooth, the unit can operate from the cradle of the remote module, or, if more convenient, can be removed and operated up to 20 meters away from the remote module.

The GK-405 displays the thermistor temperature in degrees Celsius.

For further details, consult the GK-405 Instruction Manual.

FIGURE 6: *GK-405 Readout*

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 CONNECTING SENSORS WITH BARE LEADS

Attach the 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 power button on the Readout Unit. After start-up completes, a blue light will begin flashing, signifying that the two components are ready to connect wirelessly. Launch the GK-405 VWRA program by doing the following:

1. Tap Start on the hand-held PC's main window.
2. Select Programs.
3. Tap the GK-405 VWRA icon.

After a few seconds, the blue light should stop flashing and remain lit. The Live Readings window will display on the hand-held PC.

Set the Display mode to **B** for BX and NX models, or to **F** for EX models. For more information, consult the GK-405 Instruction Manual.

3.3 MEASURING TEMPERATURES

All GEOKON vibrating wire instruments are equipped with a thermistor for reading temperature. The thermistor 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.

The GK-404 and GK-405 readouts will read the thermistor and display the temperature in degrees Celsius.

TO READ TEMPERATURES USING AN OHMMETER:

1. Connect an ohmmeter to the green and white thermistor leads coming from the instrument. 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.
2. Look up the temperature for the measured resistance in Appendix B.

4. DATA REDUCTION

4.1 CHANGE IN STRESS CALCULATION

To obtain the change in stress at any given time the following equation applies:

$$\sigma = (R_1 - R_0)\ G$$

EQUATION 1: *Change in Stress*

Where;
σ = Stress change in psi.
R_0 = Initial reading after the gauge has been set in place.
R_1 = Reading at subsequent stress.
Table 1 gives example calculations for the various models.

Model	EX	BX	NX
Readout initial display (R_0)=	10,000	4,000	2,500
Subsequent display (R_1)=	12,000	5,000	3,000
Values entered into the equation above	σ = (12,000 − 10,000) 0.50	σ = (5,000 − 4,000) 2.5	σ = (3,000 − 2,500) 6.0
Change in Stress =	σ = 1,000 psi	σ = 2500 psi	σ = 3,000 psi

TABLE 1: *Sample Calculations*

Positions F and B are used for stressmeters, the processor converts the period readings to units of frequency squared, which is proportional to wire strain, gauge deflection and applied stress. A reading of 10,000 on channel F corresponds to a period of 316.2 microseconds on channel A.

4.2 ENVIRONMENTAL FACTORS

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

4.3 GAUGE SENSITIVITY FACTORS

The graphs in Figure 7, Figure 8, and Figure 9 are used to determine the stress sensitivity or gauge factor for rocks of different moduli. Sensitivity factors are based on experimental data conducted on rock samples and can only serve as a guide. For more accurate determinations of stress sensitivity, calibrations must be performed in samples of the rock being monitored.

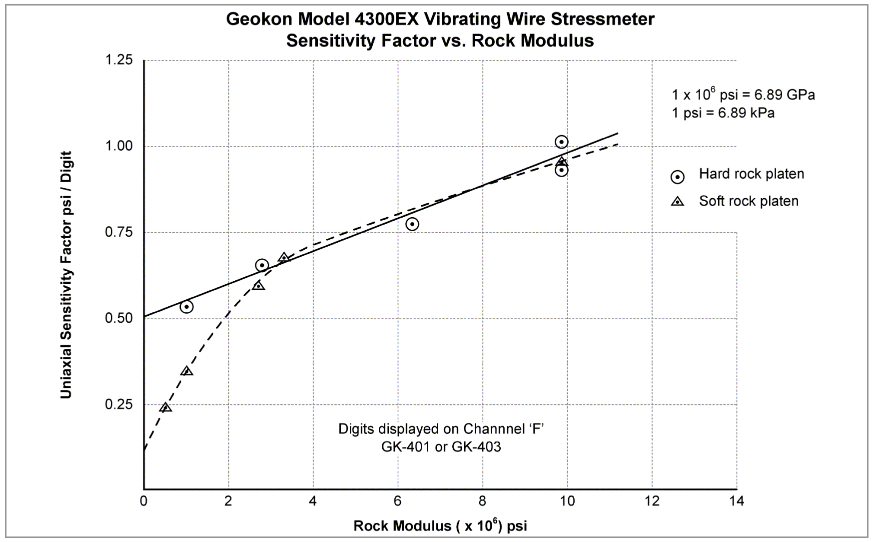

FIGURE 7: *Model 4300EX Sensitivity Factor vs. Rock Modulus*

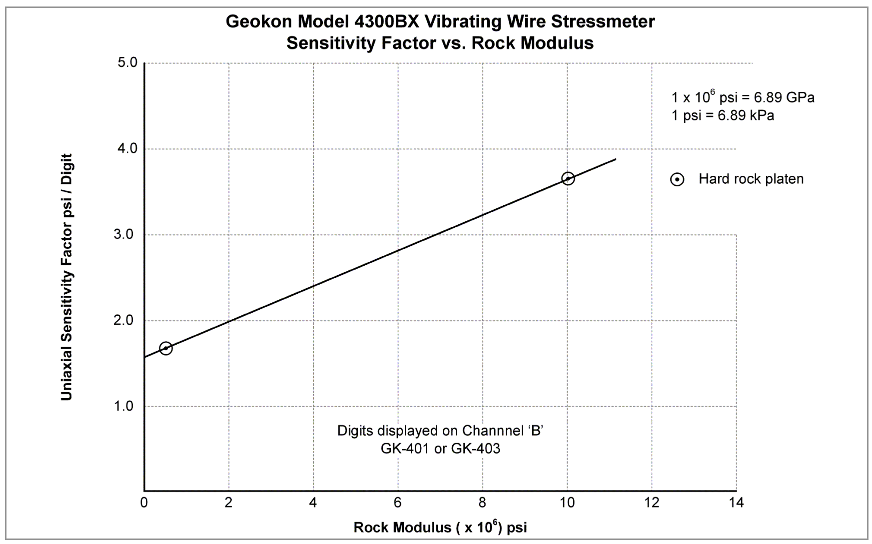

FIGURE 8: *Model 4300BX Sensitivity Factor vs. Rock Modulus*

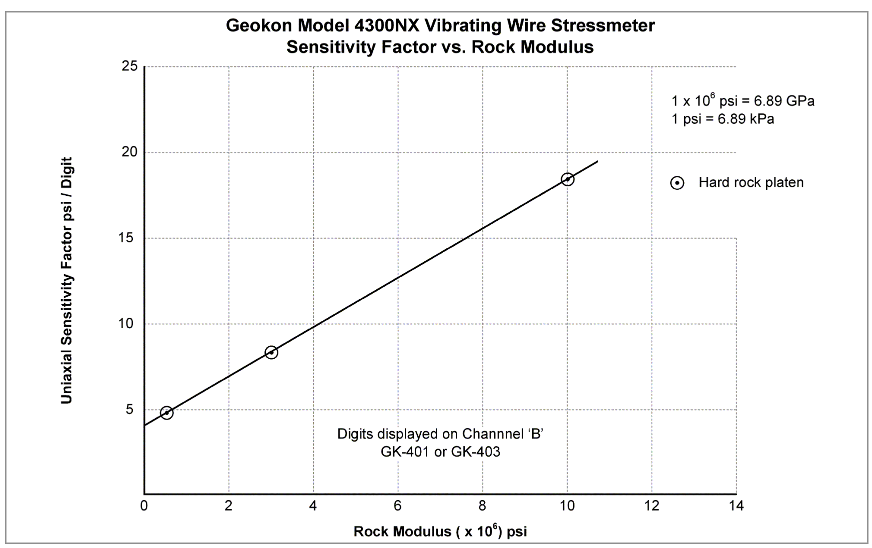

FIGURE 9: *Model 4300NX Sensitivity Factor vs. Rock Modulus*

4.4 CORRECTIONS FOR TEMPERATURE CHANGES

The materials used in the construction of the stressmeter are affected by changes in ambient temperature. Since these gauges are normally installed underground in constant temperature environments, corrections are not normally applied. However, if maximum accuracy is desired, or the temperature changes are extreme, a correction may be applied.

The temperature correction factor for the gauge reading on a readout box is two digits/°C, indicating an apparent decrease in rock stress for a temperature rise. Stress correction for temperature is given by the equation:

$$\sigma_T = (R_1 - R_0)\,G + (T_1 - T_0)\,2G$$

EQUATION 2: *Temperature Correction*

Where;
σT = The stress change corrected for temperature.
R_0 = Initial reading after the gauge has been set in place.
R_1 = Reading at subsequent stress.
T_0 = Initial temperature °C
T_1 = Subsequent temperature °C
G = Sensitivity factor taken from Section 4.3.

It should be noted that this temperature correction factor is for a gauge in a free field with no restraints. In a field condition where the gauge is firmly placed in a borehole the gauge temperature sensitivity is also dependent on the gauge/rock interactions, and these relationships are very complex and beyond the scope of this manual. Calibration would be required for accurate determination of the thermal characteristics of the gauge.

5. TROUBLESHOOTING

Maintenance and troubleshooting is confined to periodic checks of cable connections and maintenance of terminals. Once installed, these instruments 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. **Instruments should not be opened in the field.** For additional troubleshooting and support, contact GEOKON.

SYMPTOM: THERMISTOR RESISTANCE IS TOO HIGH

- ☐ Check for an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 2.7.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

- ☐ Check for a short circuit. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 2.7.
- ☐ Water may have penetrated the interior of the instrument. 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.
- ☐ Does the readout or datalogger work with another instrument? If not, it may have a low battery or possibly be malfunctioning.

SYMPTOM: INSTRUMENT FAILS TO READ

- ☐ Does the readout or datalogger work with another instrument? If not, it may have a low battery or possibly be malfunctioning.
- ☐ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads; resistance is approximately 48.5Ω per km (14.7Ω per 1000') of 22 AWG wire.

  If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the conductors may be shorted. If a break or a short is present, splice according to the instructions in Section 2.7.

  Refer to the expected resistance for the various wire combinations below.

  Vibrating Wire Sensor Lead Resistance Levels
  Red/Black ≅180Ω (BX,NX) ≅90Ω (EX)
  Green/White 3000Ω at 25 °C

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

APPENDIX A. SPECIFICATIONS

A.1 STRESSMETER

Model	EX	BX	NX
Nominal Range[1]	35 – 100 MPa (5000 – 15000 psi)		
Resolution	2 – 7 KPa (0.25 – 1 psi)	10 – 30 KPa (1.5 – 4 psi)	35 – 140 KPa (5 – 20 psi)
Accuracy[2]	± 20 %		
Operating Temperature[3]	–20 to +80 °C		
Thermal Zero Shift	0.02% F.S. / °C	0.04% F.S. / °C	0.04% F.S. / °C
Resonant Frequency Range	3000 – 5000 Hz	2000 – 3500 Hz	1500 – 2500 Hz
Length mm (inches)	44 mm (1.75 in)	70 mm (2.75 in)	76 mm (3.0 in)
Outer Diameter	29 mm (1.125 in)	48 mm (1.875 in)	64 mm (2.50 in)
Inner Diameter	13 mm (0.5 in)	22 mm (0.875 in)	32 mm (1.25 in)
Weight kgm (lbs.)	0.45 kgm (1 lbs)	0.9 kgm (2 lbs)	1.4 kgm (3 lbs)
Borehole Diameter mm (inches)	38 mm (1.485 in)	60 mm (2.36 in)	76 mm (2.98 in)
Gauge Material	Stainless Steel		
Cable	Two conductor or four conductor, 22 gauge, shielded, PVC jacket, 5 mm or 6 mm diameter		

TABLE 2: *Specifications*

Notes:

[1] Depends on rock modulus

[2] Accuracy depends to a large extent on the roughness of the borehole walls, gauge stiffness, and on the degree to which the platens bed into the surrounding material, thus increasing the area of contact. It also depends on the accuracy with which the host rock elastic constants are known.

[3] High temperature versions are available (–20°C to 200°C)

A.2 THERMISTOR

Range: –80 to +150 °C

Accuracy: ±0.5 °C

For more information, refer to Appendix B.

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

Thermistor Types:

- YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3
- Honeywell 192–302LET–A01

Resistance to Temperature Equation:

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

EQUATION 3: *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 3: *3KΩ Thermistor Resistance*

B.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR)^3+D(LnR)^5} - 273.15$$

EQUATION 4: *10KΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

$A = 1.127670 \times 10^{-3}$

$B = 2.344442 \times 10^{-4}$

$C = 8.476921 \times 10^{-8}$

$D = 1.175122 \times 10^{-11}$

Note: Coefficients optimized for a curve **J** Thermistor over the temperature range of 0 °C to +250 °C.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	0	7,402	32	2,157	64	763.5	96	316.6	128	148.4	160	76.5	192	42.8	224
31,029	1	7,098	33	2,083	65	741.2	97	308.7	129	145.1	161	75.0	193	42.1	225
29,498	2	6,808	34	2,011	66	719.6	98	301.0	130	142.0	162	73.6	194	41.4	226
28,052	3	6,531	35	1,942	67	698.7	99	293.5	131	138.9	163	72.2	195	40.7	227
26,685	4	6,267	36	1,876	68	678.6	100	286.3	132	135.9	164	70.8	196	40.0	228
25,392	5	6,015	37	1,813	69	659.1	101	279.2	133	133.0	165	69.5	197	39.3	229
24,170	6	5,775	38	1,752	70	640.3	102	272.4	134	130.1	166	68.2	198	38.7	230
23,013	7	5,545	39	1,693	71	622.2	103	265.8	135	127.3	167	66.9	199	38.0	231
21,918	8	5,326	40	1,637	72	604.6	104	259.3	136	124.6	168	65.7	200	37.4	232
20,882	9	5,117	41	1,582	73	587.6	105	253.1	137	122.0	169	64.4	201	36.8	233
19,901	10	4,917	42	1,530	74	571.2	106	247.0	138	119.4	170	63.3	202	36.2	234
18,971	11	4,725	43	1,480	75	555.3	107	241.1	139	116.9	171	62.1	203	35.6	235
18,090	12	4,543	44	1,432	76	539.9	108	235.3	140	114.5	172	61.0	204	35.1	236
17,255	13	4,368	45	1,385	77	525.0	109	229.7	141	112.1	173	59.9	205	34.5	237
16,463	14	4,201	46	1,340	78	510.6	110	224.3	142	109.8	174	58.8	206	33.9	238
15,712	15	4,041	47	1,297	79	496.7	111	219.0	143	107.5	175	57.7	207	33.4	239
14,999	16	3,888	48	1,255	80	483.2	112	213.9	144	105.3	176	56.7	208	32.9	240
14,323	17	3,742	49	1,215	81	470.1	113	208.9	145	103.2	177	55.7	209	32.3	241
13,681	18	3,602	50	1,177	82	457.5	114	204.1	146	101.1	178	54.7	210	31.8	242
13,072	19	3,468	51	1,140	83	445.3	115	199.4	147	99.0	179	53.7	211	31.3	243
12,493	20	3,340	52	1,104	84	433.4	116	194.8	148	97.0	180	52.7	212	30.8	244
11,942	21	3,217	53	1,070	85	421.9	117	190.3	149	95.1	181	51.8	213	30.4	245
11,419	22	3,099	54	1,037	86	410.8	118	186.1	150	93.2	182	50.9	214	29.9	246
10,922	23	2,986	55	1,005	87	400.0	119	181.9	151	91.3	183	50.0	215	29.4	247
10,450	24	2,878	56	973.8	88	389.6	120	177.7	152	89.5	184	49.1	216	29.0	248
10,000	**25**	2,774	57	944.1	89	379.4	121	173.7	153	87.7	185	48.3	217	28.5	249
9,572	26	2,675	58	915.5	90	369.6	122	169.8	154	86.0	186	47.4	218	28.1	250
9,165	27	2,579	59	887.8	91	360.1	123	166.0	155	84.3	187	46.6	219		
8,777	28	2,488	60	861.2	92	350.9	124	162.3	156	82.7	188	45.8	220		
8,408	29	2,400	61	835.4	93	341.9	125	158.6	157	81.1	189	45.0	221		
8,057	30	2,316	62	810.6	94	333.2	126	155.1	158	79.5	190	44.3	222		
7,722	31	2,235	63	786.6	95	324.8	127	151.7	159	78.0	191	43.5	223		

TABLE 4: *10KΩ Thermistor Resistance*

APPENDIX C. BIAXIAL STRESS CHANGES

The relationship between the radial deformation of a borehole, U, and two principle stresses in the plane of a borehole has been given by Hast (1958) and Merrill and Peterson (1961). The equation for Plane Stress is:

$$U = d/Er\ [(\sigma_1 + \sigma_2) + 2\ (\sigma_1 - \sigma_2) \cos 2\ \theta]$$

EQUATION 5: *Plane Stress*

Where;
σ_1 and σ_2 are the principle stresses in the plane of the borehole.
θ is the angle measured counterclockwise from the direction of σ1.
d is the diameter of the borehole.
Er is the Young's Modulus of the rock

If it is assumed that the stress measured across the stressmeter is proportional to the radial deformation that would have occurred in this direction if the stressmeter had not been there, then the term d/Er can be replaced by one reflecting the relationship between the rock modulus and the gauge modulus. Hast (1958) has shown this to be applicable for a uniaxial stressmeter.

For the measurement of stress (σ_R) in any direction (θ) the following equation applies:

Note: θ is measured counterclockwise from σ_1

$$\sigma_R = 1/3\ (\sigma_1 + \sigma_2) + 2/3\ (\sigma_1 - \sigma_2) \cos 2\ \theta$$

EQUATION 6: *Stress in any Direction*

Using this relationship and three uniaxial stress change measurements at 45° to each other, the secondary principle stresses σ_1 and σ_2 and the angle (θ) are given by:

$$\sigma_1 = 3/2\ a + 3/4\ b$$
$$\sigma_2 = 3/2\ a - 3/4\ b$$
$$\theta = 1/2 \sin^{-1} ((a - \sigma_{45})/b)$$

EQUATION 7: *Secondary Principle Stresses and Angle*

Where;
$a = \sigma_0 + \sigma_{90} /2$
$b = [(\sigma_{45} - a)^2 + (\sigma_0 - a)^2]^{1/2}$

To determine the θ angles, it must be determined what quadrant the angle lies in. The inequalities to do this are as follows:

If σ45 ≤ a and $\sigma_0 \geq 90$, then $0 \leq \theta \geq 45°$
If σ45 ≤ a and $\sigma_0 \leq 90$, then $45° \leq \theta \leq 90°$
If σ45 ≥ a and $\sigma_0 \leq 90$, then $90° \leq \theta \leq 135°$
If σ45 ≥ a and $\sigma_0 \geq 90$, then $135° \leq \theta \leq 180°$
Note: θ is measured clockwise for σ_0 (this is same as counterclockwise for σ_1).

FOR EXAMPLE:

Three gauges are set in a borehole. The first is at 0° (σ_0), the second at 45° (σ_{45}) and the third at 90° (σ_{90}), measured counterclockwise from 0. Determine the uniaxial stress changes for each gauge by the reading change times the calibration factor. Substitute the constants into the equations to obtain the change magnitude of the two secondary principal stresses σ_1 relative to 0°.

STRESS CHANGES:

Gauge 1, σ_0 = 600 psi
Gauge 2, σ_{45} = 800 psi
Gauge 3, σ_{90} = 300 psi

Calculate the values for these constants: a and b

$a = \sigma_0 + \sigma_{90}/2 = 600 + 300/2 = 450$
$b = [(\sigma_{45} - a)^2 + (\sigma_0 - a)^2]^{½} = [(800–450)^2 + (600–450)^2]^{½} = 380.79$
$\sigma1 = 3/2a + 3/4b = 3 \text{ x } 450/2 + 3 \text{ x } 380.79/4 = 960.59$ psi
$\sigma2 = 3/2a - 3/4b = 3 \text{ x } 450/2 - 3 \text{ x } 380.79/4 = 389.41$ psi
$\sin 2\theta = -0.92$
$\theta = 33.40°$
σ_1 direction: since $\sigma_{45} > a$ and $\sigma_0 > \sigma_{90}$, then $135 < \theta < 180°$. Therefore, $\theta = 180 - 33.40 = 146.6°$. This is measured clockwise from σ_0.

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