**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.
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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 Figure 1.

![Figure 1 - Vibrating Wire Stressmeter](image)

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 and 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 for each of the models is as follows:

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:

1) Screw the “GO” gauge onto the section of 1/4" rod that has a ¼-20 left handed thread on one end by rotating it clockwise.

2) Push the “GO” gauge into the borehole.

3) Add new sections of 1/4” rod and continue to push the gauge into the hole until it reaches the desired depth of the stressmeter installation. If the borehole diameter is correct, the “GO” gauge will fit into the borehole. If the “GO” gauge does not fit into the borehole, or gets stopped prior to reaching the installation depth, the borehole is too small.

4) Remove the “GO” gauge from the borehole and unscrew it from the 1/4” rod.

5) Screw the “NO-GO” gauge onto the 1/4” rod by rotating it clockwise.

6) Check the diameter of the borehole by attempting to pushing the “NO-GO” gauge into the borehole. If the borehole diameter is correct, the “NO-GO” gauge will not fit into the borehole. If the “NO-GO” gauge does fit into the borehole, the borehole diameter is too large.
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 Readout instructions.)

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) A check of electrical continuity can be made using an ohmmeter. The resistance between the two lead wires (usually red and black) should be around 180 ohms for Models 4300BX and 4300NX, 90 ohms for Model 4300EX. Remember to add the cable resistance at approximately $14.7\Omega/1000'$ ($48.5\Omega/km$) 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 5 in Appendix B, 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. Remove the nut and then use the nylon screw to attach the wedge/platen assembly to the Stressmeter Body. Orient the wedge so that the narrow end is facing in the same direction as the cable, (see Figure 2 in the next section). 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: 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).

2.4 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 $1/4''$ rod to the yoke attached to the thin end of the wedge. Note that the first section of rod has one end with a $\frac{1}{4}-20$ left handed thread on it. This will connect to the left-handed thread in the yoke.
Attach the first section of the 3/4” 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 3/4” positioning rod is pushed into the hole, add new sections of both 3/4” and 1/4” rod until the desired depth has been reached. **It is advisable to wear gloves during this procedure to protect the thumb while depressing the buttons on the 3/4 inch rods.**

Slide the slide-hammer over the last section of 1/4” rod and then thread the anvil block onto the outer end of the 1/4” rod. Connect the readout box to the lead wires and take initial readings. (See Section 3 for readout instructions.)

![Figure 2 - Vibrating Wire Stressmeter Installation Tool Assembly](image)

Holding the positioning rod firmly at its correct depth and orientation, slide the slide-hammer back up the 1/4” rod, then slide 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 1/4” rod from the wedge yoke by turning clockwise. Remove the 1/4” 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.
2.5 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).

2.6 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 Readout Box

The Model GK-404 Vibrating Wire Readout is a portable, low-power, handheld 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 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 3). Insert the Lemo connector into the GK-404 until it locks into place.

![Figure 3 - Lemo Connector to GK-404](image)

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 button to select position B for BX and NX models or position F for EX models. Use 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 5 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 sensor 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 for BX and NX models or display mode F for EX models. Figure 4 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 5 for troubleshooting suggestions. For further information, consult the GK-405 Instruction Manual.

![Figure 4 - Live Readings – Raw Readings](image-url)
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 sensor 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 for BX and NX models or position F for EX models.
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 5 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 5.
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;
\(\sigma\) = Stress change, in psi.
\(R_0\) = Initial reading after the gauge has been set in place.
\(R_1\) = Reading at subsequent stress.
\(G\) = Sensitivity factor taken from Section 4.3.

Table 1 gives example calculations for the various models.

<table>
<thead>
<tr>
<th>Model</th>
<th>EX</th>
<th>BX</th>
<th>NX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout initial display (R_0)</td>
<td>10,000</td>
<td>4,000</td>
<td>2,500</td>
</tr>
<tr>
<td>Subsequent display (R_1)</td>
<td>12,000</td>
<td>5,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Values entered into Equation 1</td>
<td>(\sigma = (12,000 - 10,000) 0.50)</td>
<td>(\sigma = (5,000 - 4,000) 2.5)</td>
<td>(\sigma = (3,000 - 2,500) 6.0)</td>
</tr>
<tr>
<td>Change in Stress =</td>
<td>(\sigma = 1,000) psi</td>
<td>(\sigma = 2500) psi</td>
<td>(\sigma = 3,000) psi</td>
</tr>
</tbody>
</table>

Table 1 - Sample Calculations

If using the GK-403 Readout, note that the GK-403 excites the gauge, measures the period of 255 cycles (or less) of gauge vibration, using a 6.144 MHz quartz oscillator, and displays the period to a resolution of 0.1 microseconds in position “A”. 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 5, Figure 6, and Figure 7 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 5 - Model 4300EX Sensitivity Factor vs. Rock Modulus](image)

![Figure 6 - Model 4300BX Sensitivity Factor vs. Rock Modulus](image)
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;
$\sigma_T$ = 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. 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. If a cut is located in the cable, splice according to instructions in Section 2.6.

Symptom: Thermistor resistance is too low:

- There may be a short. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 2.6.
- 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. Table 2 shows the expected resistance for the various wire combinations; Table 3 is provided for the user to record the observed values. Cable resistance is approximately 14.7 Ω per 1000' 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. If a cut or a short is located in the cable, splice according to the instructions in Section 2.6.

- Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.
### Table 2 - Sample Resistance

<table>
<thead>
<tr>
<th>Vibrating Wire Sensor Lead Grid - SAMPLE VALUES</th>
<th>Red</th>
<th>Black</th>
<th>White</th>
<th>Green</th>
<th>Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red</strong></td>
<td>N/A</td>
<td>BX and NX ≥ 180Ω</td>
<td>BX and NX ≥ 90Ω</td>
<td>infinite</td>
<td>infinite</td>
</tr>
<tr>
<td><strong>Black</strong></td>
<td>BX and NX ≥ 180Ω</td>
<td>BX and NX ≥ 90Ω</td>
<td>N/A</td>
<td>infinite</td>
<td>infinite</td>
</tr>
<tr>
<td><strong>White</strong></td>
<td>infinite</td>
<td>infinite</td>
<td>N/A</td>
<td>3000Ω at 25°C</td>
<td>infinite</td>
</tr>
<tr>
<td><strong>Green</strong></td>
<td>infinite</td>
<td>infinite</td>
<td>3000Ω at 25°C</td>
<td>N/A</td>
<td>infinite</td>
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<tr>
<td><strong>Shield</strong></td>
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<td>infinite</td>
<td>infinite</td>
<td>infinite</td>
<td>N/A</td>
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</table>

### Table 3 - Resistance Work Sheet

<table>
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<th>Vibrating Wire Sensor Lead Grid - SENSOR NAME/## :</th>
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<th>Black</th>
<th>White</th>
<th>Green</th>
<th>Shield</th>
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<td><strong>Black</strong></td>
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<tr>
<td><strong>White</strong></td>
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<tr>
<td><strong>Green</strong></td>
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<tr>
<td><strong>Shield</strong></td>
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</table>

Table 3 - Resistance Work Sheet
APPENDIX A. SPECIFICATIONS

A.1 Model 4300 Stressmeter

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

Table 4 - 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 (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:

\[ T = \frac{1}{A + B \ln(R) + C \ln(R)^3} - 273.15 \, ^\circ C \]

Equation 3 - Resistance to Temperature

Where;

\( T \) = Temperature in °C.

\( \ln R \) = 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.

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<th>Ohms</th>
<th>Temp</th>
<th>Ohms</th>
<th>Temp</th>
<th>Ohms</th>
<th>Temp</th>
<th>Ohms</th>
<th>Temp</th>
<th>Ohms</th>
<th>Temp</th>
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<td>+110</td>
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</table>

Table 5 - Thermistor Resistance versus Temperature
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:

\[
U = \frac{d}{E_r} \left[ (\sigma_1 + \sigma_2) + 2 (\sigma_1 - \sigma_2) \cos 2 \theta \right]
\]

Equation 4 - Plane Stress

Where;
- \( \sigma_1 \) and \( \sigma_2 \) are the principle stresses in the plane of the borehole.
- \( \theta \) is the angle measured counterclockwise from the direction of \( \sigma_1 \).
- \( d \) is the diameter of the borehole.
- \( E_r \) 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 \( d/E_r \) 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 \( (\sigma_R) \) in any direction \( (\theta) \) the following equation applies: (Note: \( \theta \) is measured counterclockwise from \( \sigma_1 \))

\[
\sigma_R = \frac{1}{3} (\sigma_1 + \sigma_2) + \frac{2}{3} (\sigma_1 - \sigma_2) \cos 2 \theta
\]

Equation 5 - Stress in any Direction

Using this relationship and three uniaxial stress change measurements at 45° to each other, the secondary principle stresses \( \sigma_1 \) and \( \sigma_2 \) and the angle \( (\theta) \) are given by:

\[
\begin{align*}
\sigma_1 &= \frac{3}{2} a + \frac{1}{4} b \\
\sigma_2 &= \frac{3}{2} a - \frac{1}{4} b \\
\theta &= \frac{1}{2} \sin^{-1} \left( \frac{(a - \sigma_{45})}{b} \right)
\end{align*}
\]

Equation 6 - 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 \( \theta \) angles, it must be determined what quadrant the angle lies in. The inequalities to do this are as follows:

- If \( \sigma_{45} \leq a \) and \( \sigma_0 \geq 90 \), then \( 0 \leq \theta \leq 45^\circ \)
- If \( \sigma_{45} \leq a \) and \( \sigma_0 \leq 90 \), then \( 45^\circ \leq \theta \leq 90^\circ \)
- If \( \sigma_{45} \geq a \) and \( \sigma_0 \leq 90 \), then \( 90^\circ \leq \theta \leq 135^\circ \)
- If \( \sigma_{45} \geq a \) and \( \sigma_0 \geq 90 \), then \( 135^\circ \leq \theta \leq 180^\circ \)

Note: \( \theta \) is measured clockwise for \( \sigma_0 \) (this is same as counterclockwise for \( \sigma_1 \)).
For Example:

Three gauges are set in borehole. The first is at 0° (σ₀), the second at 45° (σ₄₅) and the third at 90° (σ₉₀), measured counterclockwise from 0. The uniaxial stress changes for each gauge are determined by the reading change times the calibration factor. Substitute the constants into the equations to obtain the magnitude of the changes of the two secondary principal stresses σ₁ relative to 0°.

Stress Changes:
Gauge 1, σ₀ = 600 psi
Gauge 2, σ₄₅ = 800 psi
Gauge 3, σ₉₀ = 300 psi

Calculate the values for constants, a and b:

\[
a = σ₀ + σ₉₀ = 600 + 300 = 900
\]

\[
b = \left[\left((σ₄₅ - a)^2 + (σ₀ - a)^2\right)^{1/2}\right] = \left[\left((800-900)^2 + (600-900)^2\right)^{1/2}\right] = 380.79
\]

\[
σ₁ = \frac{3}{2}a + \frac{3}{4}b = \frac{3}{2} \times 900 + \frac{3}{4} \times 380.79 = 960.59 \text{ psi}
\]

\[
σ₂ = \frac{3}{2}a - \frac{3}{4}b = \frac{3}{2} \times 900 - \frac{3}{4} \times 380.79 = 389.41 \text{ psi}
\]

\[
\sin 2θ = -0.92
\]

\[
θ = 33.40°
\]

σ₁ Direction: since σ₄₅ > a and σ₀ > σ₉₀, then 135 < θ < 180°. Therefore, θ = 180 – 33.40 = 146.6°. This is measured clockwise from σ₀.

References:
Merrill, R.H. and Peterson, J.R.; DEFORMATION OF A BORE HOLE IN ROCK; U.S. Bureau of Mines, RI 5881.