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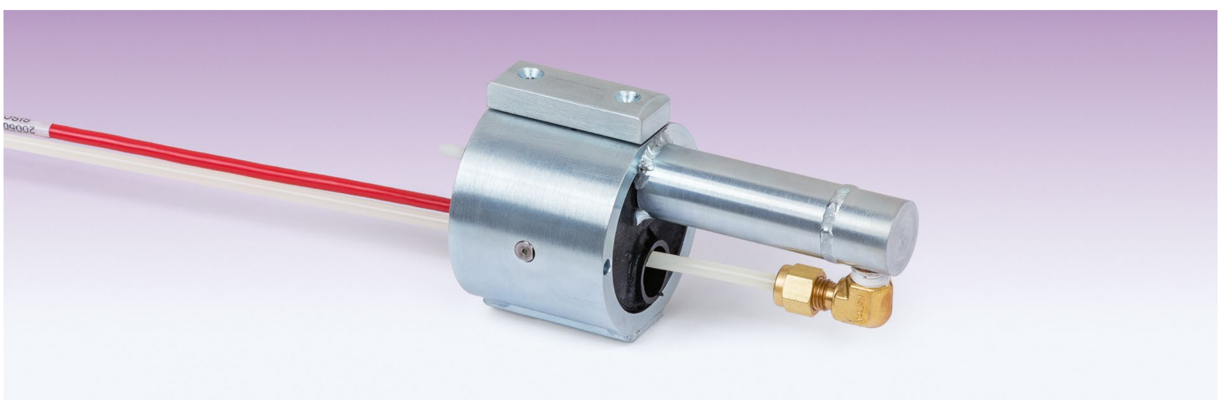
Instruction Manual

Model 4360

VW Soft Inclusion Stress Cells



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EQUATIONS

1. THEORY OF OPERATION

GEOKON vibrating wire soft inclusion stress cells (SISC) are designed primarily for long-term measurements of stress changes in rock, by utilizing a vibrating wire strain gauge to measure the deformation of a steel ring.

Gauge installation is accomplished by expanding a wedge mechanism between the gauge body and the platen which contacts the borehole walls (see Figure 1). This can be done mechanically or hydraulically. An example of a hydraulically activated gauge is shown in Figure 2. An example of a mechanically activated gauge is shown in Figure 3.

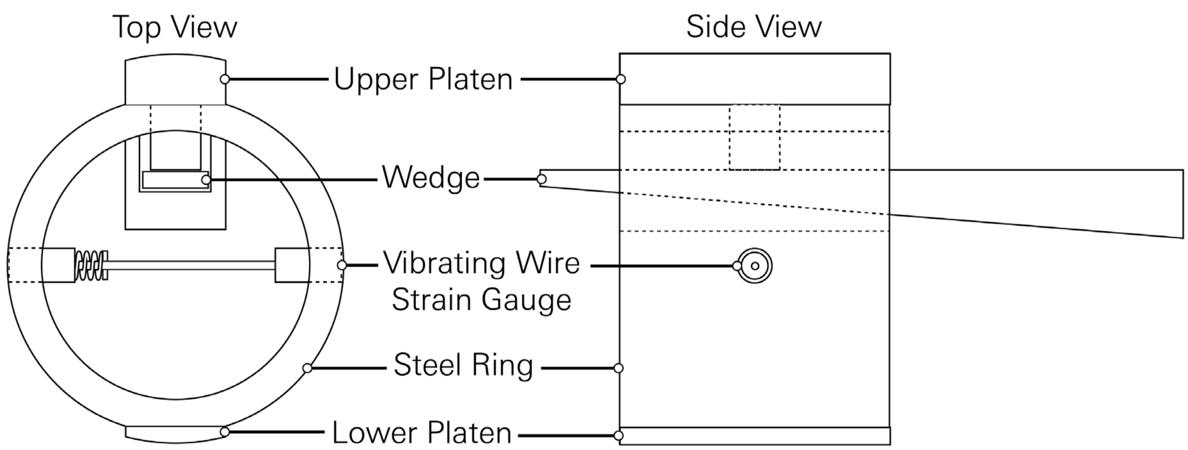


Figure 1 - Vibrating Wire Soft Inclusion Stress Cell (SISC)

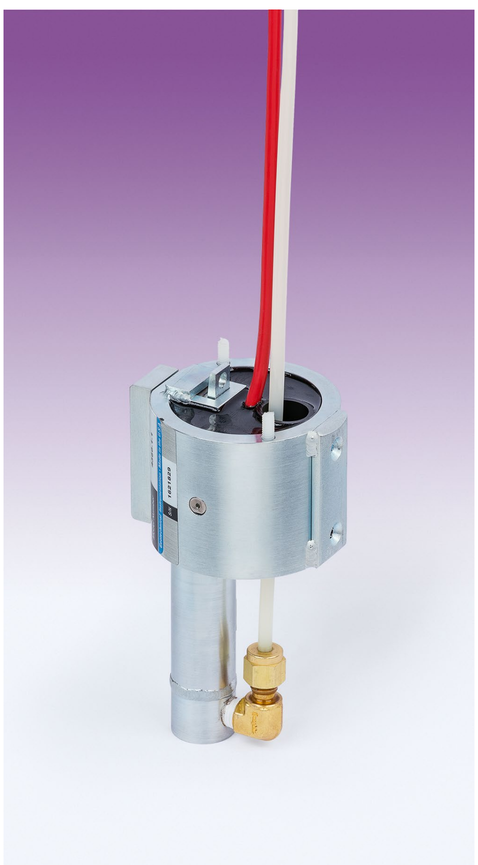


Figure 2 - Example Hydraulic Gauge

Figure 3 - Example Mechanical Gauge

A coil and magnet assembly is clipped over the strain gauge assembly. In use, a pulse of varying frequency (swept frequency) is applied to the coils causing the wire inside the gauge to vibrate primarily at its resonant frequency. Portable readouts and dataloggers available from GEOKON provide the necessary voltage pulses to pluck the wire. During vibration, a sinusoidal signal is induced in the coils and transmitted to the readout where it is conditioned and displayed.

In use, changing rock stresses impose changing loads on the steel ring causing it to deflect. This deflection produces a change in the tension of the vibrating wire located within the strain gauge element fixed across one diameter of the cell. The change in tension causes a change in the frequency of vibration of the wire. 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.

Because the vibrating wire in the Model 4360 Series SISC cells runs perpendicular to the direction in which the gauge body is loaded, the gauge has a very high range. Also, since the wire gets tighter as the load increases, the wire never goes slack.

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 SISC cell with respect to the principal rock stress direction, and the platen contact area. Thus, the accuracy of the gauge reading is largely indeterminate, and the indicated stress magnitude can only be approximate.

In theory, the effective modulus of the SISC cell is very low and does not impede the free movement of the host material; therefore, conversion of the readings to changes in stress requires an accurate knowledge of the rock modulus. For this reason, the term “soft inclusion stress cell” is used to describe this device.

The SISC cell is a uniaxial device; therefore, to completely evaluate stress changes in a given plane, three SISC cells are required. The three cells must be installed at orientations of 0°, 45°, and 90°; or, 0°, 60°, and 120°.

Preloading of the cell is accomplished by actuation of the wedge mechanism; SISC cells set at a high preload can measure reductions of compressive stresses in the host material.

2. INSTALLATION

2.1 Preliminary Checks

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

1) For some models it may be necessary to attach the readout cable to the gauge in the center of this SISC cell. Slide the slot in the coil assembly (located at the end of the instrument cable) over the narrow center of the gauge. Install the hose clamp over the assembly and tighten using a nut driver.

2) Connect the gauge to a readout box. (See Section 3 for information on using readout boxes.)

3) The gauge reading (in digits) should coincide with the Zero Reading (nominal) in Table 2 within ±10%.

4) The temperature displayed by the readout should match the ambient temperature.

5) Record the zero reading and temperature.

6) Confirm that squeezing the SISC cell makes the readings change.

2.2 Borehole Requirements

Model 4360 SISC cells are designed to be used in smooth-walled diamond drilled holes. SISC cells can be set in drag bit or percussively drilled holes if 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. After drilling, the hole should be thoroughly cleaned by washing out with water or blowing out with compressed air.

Standard sized SISC cells can monitor boreholes with diameter from 76 mm (3") to 150 mm (6"). Table 1 shows GEOKON'S standard SISC cell models and the corresponding borehole sizes.

Model Number	Borehole Size	Borehole Diameter	Borehole Variation
4360-1	NX	76 mm (3")	75 mm-77 mm
4360-2	Six-inch	152 mm (6")	151 mm-157 mm*
4360-3	HQ	93 mm (3.65")	91 mm- 95 mm*
4360-4	PQ	123 mm (4.83")	122 mm-127 mm*

Table 1 - Borehole requirements

*Actual range of expansion of the wedge mechanism is 3 mm. Oversize boreholes can be accommodated by installing shims between the body of the SISC cell and the platens.

2.3 GO / NO-GO Gauges

The setting tools for models 4360-1-1 and 4360-1-2 include a set of GO / NO-GO gauges. These gauges can be used to check the borehole diameter to ensure the SISC cell will fit properly.

2.3.1 Model 4360-1-1

Complete the following:

1) Attach the adapter to the setting rod by depressing the button on the adapter, aligning the corresponding hole in the setting rod, and then releasing the button. (*It is advisable to wear gloves during this procedure to protect the thumb while depressing the buttons on the 3/4" rods.)*

Figure 4 - Unassembled GO/NO-GO Gauges with 3/4" Rod and Adapter

2) Screw the “GO” gauge onto the adapter by rotating it *counterclockwise*. (Figure 5 shows the completed assembly.)

Figure 5 - GO Gauge Assembly

3) Push the “GO” gauge into the borehole, adding more sections of 3/4" rod as needed 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.

4) Remove the “GO” gauge from the borehole and unscrew it from the adapter by turning it *clockwise*.

5) Screw the “NO-GO” gauge onto the adapter by rotating it *counterclockwise*.

6) 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.

7) Remove the “NO-GO” gauge from the borehole.

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

9) Repeat the steps above until the borehole is sized correctly.

10) When the borehole is sized correctly, remove the adapter from the 3/4" rod by depressing the button on the adapter and pulling it out of the 3/4" rod.

2.3.2 Model 4360-1-2

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 *counterclockwise*. (Note: All male ends of the 1/4" rods have normal right-hand threaded connections except for the first section which has a left-hand thread.)

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

3) Add a section of 1/4" rod to the assembly by inserting the threaded male end into the female coupler and turning it clockwise.

4) Continue to add sections of 1/4" 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.

5) Remove the “GO” gauge from the borehole and unscrew it from the 1/4" rod by turning it *clockwise*.

6) Screw the “NO-GO” gauge onto the 1/4" rod by rotating it *counterclockwise*.

7) 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.

8) Remove the “NO-GO” gauge from the borehole and unscrew it from the 1/4" rod by turning it *clockwise*.

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

10) Repeat the steps above until the borehole is sized correctly.

2.4 Installing SISC Cells Using the Slide Hammer Setting Tool

These instructions apply to SISC cells designed to be mechanically set using the slide hammer setting tool (model 4360-1-2).

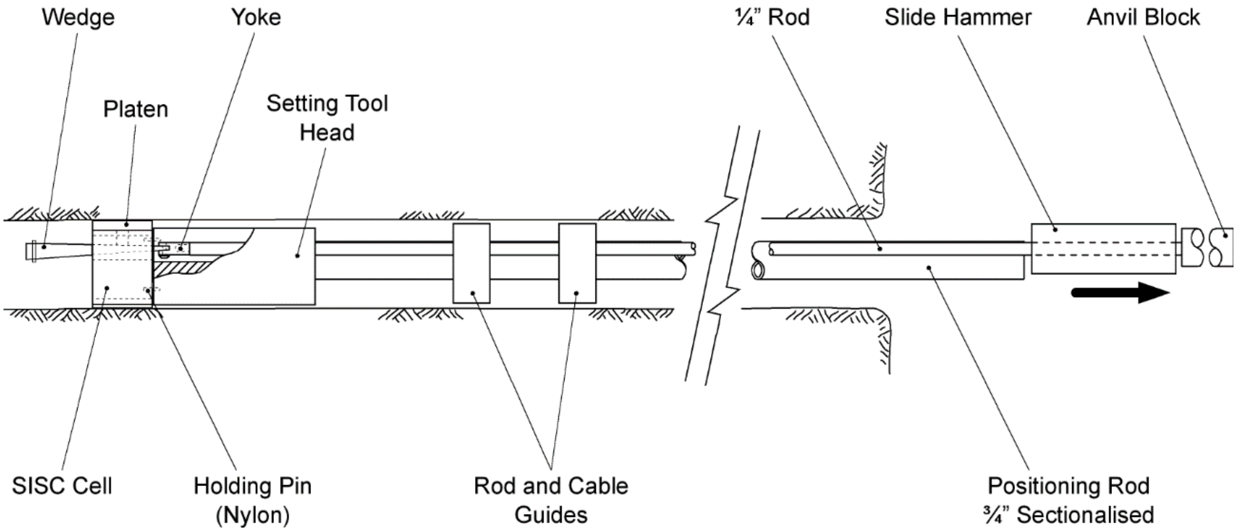


Figure 6 - Slide Hammer Installation Tool Assembly

Referring to Figure 6, complete the following:

1) Feed the gauge leads through the slot in the setting tool head.

2) Mount the SISC cell on the setting tool by pushing the threaded nylon holding pins of the SISC cell 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 SISC cell and the setting tool.

3) Feed the first section of 1/4" rod (the one with a ¼-20 Left Hand Thread on it) through the hole in the setting tool head and connect it to the "yoke" located on the thin end of the wedge by turning the rod *counterclockwise*. (Note: All male ends of the 1/4" rods have normal right-hand threaded connections except for the first section which has a left-hand thread.)

4) Attach the first section of the 3/4" positioning rod to the back of the setting tool head by depressing the button on the male coupler, aligning the corresponding hole in the setting rod, and then releasing the button. (*It is advisable to wear gloves during this procedure to protect the thumb while depressing the buttons on the 3/4" rods.)*

5) Add a section of 1/4" rod by inserting the threaded male end into the female coupler and turning it clockwise.

6) Push the SISC Cell into the borehole, adding more sections of the 3/4" positioning rod and 1/4" setting rod as needed.

7) Use the buttons on the setting rod as a guide to orientate the SISC cell as it is pushed into the hole. (The buttons on the setting rod connectors are in line with the wedge and platen assembly.) Usually it is best to align the cell in the direction of the anticipated maximum principal compressive or tensile stress.

8) When the desired depth has been reached, move the slide hammer over the last section of 1/4" rod and then thread the anvil block onto the outer end of the rod.

9) Take an initial gauge and temperature reading. (See Section 3 for information on taking readings using GEOKON readout boxes.)

10) Holding the SISC cell firmly at its correct depth and orientation, use the slide hammer to strike the anvil. Strike the anvil with a sharp firm blow. This will pull the wedge into the cell, thereby expanding the platens of the cell against the wall of the borehole.

11) Observe the gauge reading.

12) Use as many blows of the hammer as necessary to achieve the correct preload reading according to the values shown in Table 2 below. For situations where the expected stress change is compressive, the minimum preload reading can be used. For negative stress (i.e. a diminution of compression, or tension), or in situations where blasting vibrations could dislodge the cell, a heavier preload can be used. **NOTE: The preload readings should never be set below the minimum or above the maximum values given in Table 2.**

Table 2 shows the suggested preload readings in **DIGITS**:

Model	Zero Reading (Nominal)	Min Preload	Mid Preload	Max Preload
4360-1	2500	+ 500	+ 2000	+ 3000
4360-2	500	+ 150	+ 450	+ 800
4360-3	1250	+ 400	+ 1200	+ 2500
4360-4	800	+ 200	+ 500	+1200

Table 2 - Preload Readings in Digits

13) When the desired reading has been achieved, disconnect the 1/4" rod from the wedge yoke by turning the rod *clockwise*.

14) Remove the 1/4" rod from the hole.

15) Disengage the setting tool from the SISC cell by pulling on it.

Note that the SISC cell initial readings will probably diminish slightly over the first day or two as the cell beds firmly into place.

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

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

2.5 Installing SISC Cells Using the Torque Type Setting Tool

These instructions apply to SISC cells designed to be mechanically set using the torque type setting tool (model 4360-2-2).

Complete the following:

1) For oversized boreholes it may be necessary to install the provided shims underneath the platens of the SISC cell. To install a shim, complete the following:
    a. Remove the two cap head screws that secure the lower platen to the SISC cell.
    b. Place the shim under the lower platen, making sure to align the holes in the shim and the platen with the threaded holes in the SISC cell.
    c. Secure the platen and shim to the cell by reinstalling the two cap head screws.
    d. If necessary, install a shim underneath the upper platen by repeating the steps above.

2) Feed the gauge leads through the slot in the Installation Head (item #1 in Figure 7 on page 10).

3) Mount the SISC cell onto the front face of the installation head by pushing the threaded nylon pins of the SISC Cell into the mating holes on the Installation Head. *Push straight in with moderate force.* Make sure the pins are inserted fully so that no gap exists between the SISC cell and the setting tool. (It may be necessary to twist the Socket Weldment [item #3 in Figure 7] so that hex socket in the installation head fits around the hex-headed bolt on the SISC cell.)

4) For downward holes, secure the cell to the head by using tape that will break loose once the cell has been wedged into the borehole. (This is not necessary for horizontal or upward inclined holes.)

5) Attach a section of 3/4" setting rod to the rod coupler (item #6 in Figure 7) of the Installation Head by depressing the button (item #7 in Figure 7) on the rod coupler, aligning the corresponding hole in the setting rod, and then releasing the button. (*It is advisable to wear gloves during this procedure to protect the thumb while depressing the buttons.)*

6) Attach the first section of 1/2" pipe to the socket weldment by turning the pipe *counterclockwise*. (The threads on the weldment and on all sections of the 1/2" pipe are left-hand threads.)

7) Use a pipe wrench to tighten the threads on the pipe.

8) Push the SISC Cell into the borehole, adding more sections of setting rod and pipe as needed.

9) Use the buttons on the setting rod as a guide to orientate the SISC cell as it is pushed into the hole. (The buttons on the setting rod connectors are in line with the wedge and platen assembly.) Usually it is best to align the cell in the direction of the anticipated maximum principal compressive or tensile stress.

10) When the proper depth has been reached, take an initial gauge and temperature reading. (See Section 3 for information on taking readings using GEOKON readout boxes.)

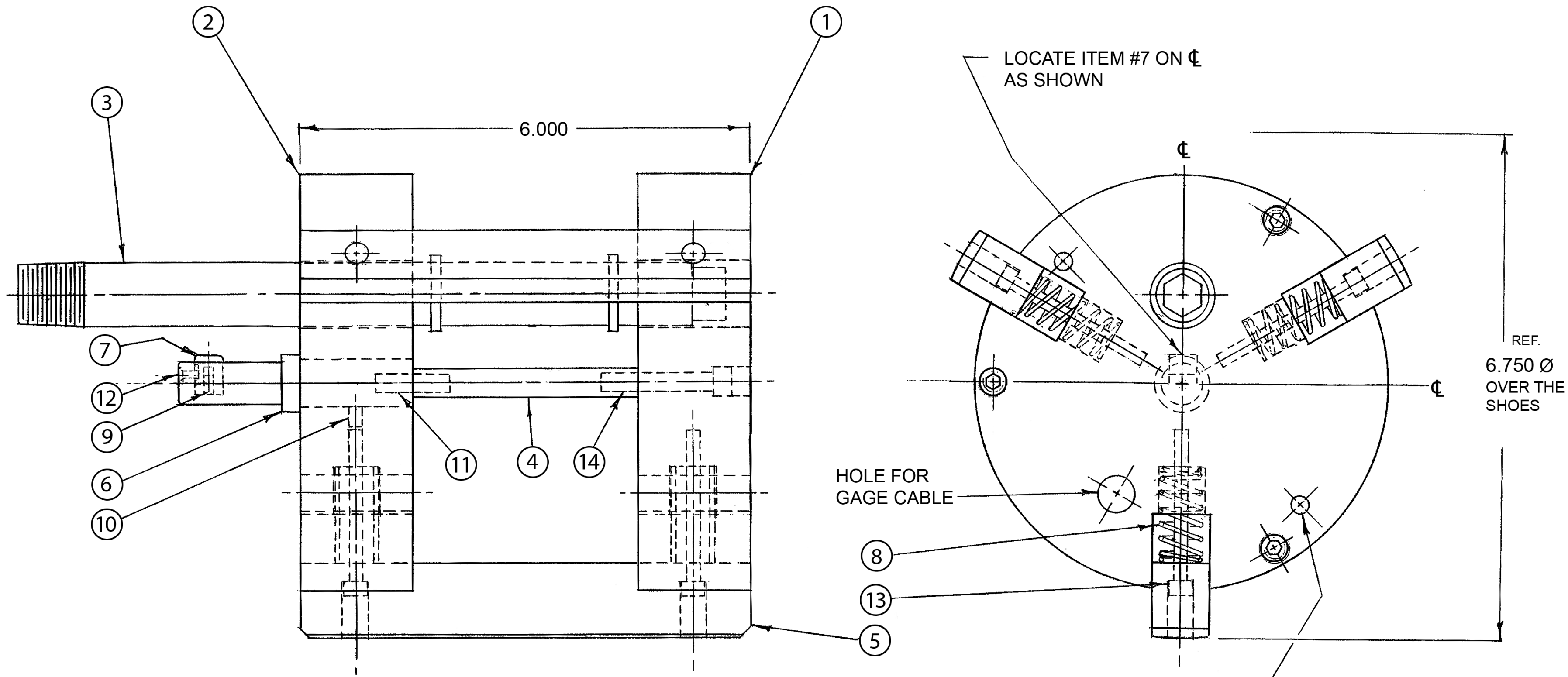
11) To expand the wedges on the SISC Cell, use a pipe wrench to turn the setting pipe in a *counterclockwise* direction.

12) Continue to turn the setting pipe until the correct preload reading is achieved according to the values shown in Table 3 on the following below. For situations where the expected stress change is compressive, the minimum preload reading can be used. For negative stress (i.e. a diminution of compression, or tension), or in situations where blasting vibrations could dislodge the cell, a heavier preload should be used. **NOTE: The preload readings should never be set below the minimum or above the maximum values given in Table 3.**

Table 3 shows the suggested preload readings in **DIGITS**:

Model	Zero Reading (Nominal)	Min Preload	Mid Preload	Max Preload
4360-1	2500	+ 500	+ 2000	+ 3000
4360-2	500	+ 150	+ 450	+ 800
4360-3	1250	+ 400	+ 1200	+ 2500
4360-4	800	+ 200	+ 500	+1200

Table 3 - Preload Readings in Digits



14	CAPSCREW, 1/4-20 X 1 1/2"	3
13	CAPSCREW, #10-32 X 2"	6
12	FLAT HD. MACH. SCREW, #4-40 X 1/4"	1
11	CUP PT. SETSCREW, 1/4-20 X 1"	3
10	CUP PT. SETSCREW, #10-32 X 1/4"	1
9	SPRING, MUSIC WIRE (LC-022A-3)	1
8	SPRING, MUSIC WIRE (LC-063H-7)	6
7	BUTTON	1
6	ROD COUPLER, MALE	1
5	SHOE	3
4	STAND-OFF	3
3	SOCKET WELDMENT	1
2	SETTING ROD DISC	1
1	INSTALLATION HEAD	1
ITEM	DESCRIPTION	QTY.

Figure 7 - Torque Type Installation Head for Model 4360-2-2 SISC Cell

2.6 Installing SISC Cells Using the Hydraulic Installation Tools

These instructions apply to SISC cells designed to be hydraulically set in the borehole (models 4360-1-1, 4360-2-1, 4360-3-1, 4360-4-1).

This type of SISC cell contains a hydraulic piston, which activates the wedge and platen assembly that is used to preload the gauge into the borehole. The hydraulic pressure is provided by a hand pump with a pressure gauge to monitor the activation of the wedge assembly. Figure 8 shows a hydraulically activated SISC cell attached to the setting tool assembly.

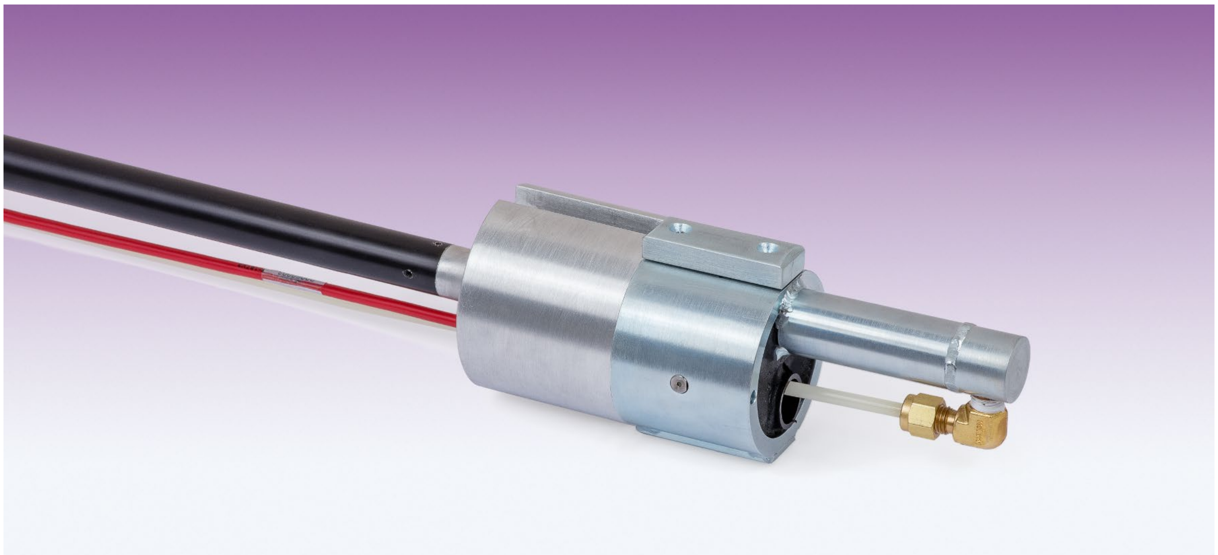


Figure 8 - Hydraulically Activated Soft Inclusion Stress Cell and Setting Tool Assembly

To install the SISC cell, complete the following:

1) For oversized boreholes it may be necessary to install the provided shims underneath the platens of the SISC cell. To install a shim, complete the following:
   a. Remove the two cap head screws that secure the lower platen to the SISC cell.
   b. Place the shim under the lower platen, making sure to align the holes in the shim and the platen with the threaded holes in the SISC cell.
   c. Secure the platen and shim to the cell by reinstalling the two cap head screws.
   d. If necessary, install a shim underneath the upper platen by repeating the steps above.

2) Feed the gauge leads through the slot in the setting tool head.

3) Mount the SISC cell on the setting tool by pushing the threaded nylon pins of the SISC cell 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 SISC cell and the setting tool.

4) Attach a section of 3/4 setting rod to the setting tool head by depressing the button on the rod coupler, aligning the corresponding hole in the setting rod, and then releasing the button. (*It is advisable to wear gloves during this procedure to protect the thumb while depressing the buttons on the 3/4" rods.)*

5) Push the SISC Cell into the borehole, adding more sections of setting rod as needed. Be careful not to strain the cable or the hydraulic line as the cell is being installed.

6) Use the buttons on the setting rod as a guide to orientate the SISC cell as it is pushed into the hole. (The buttons on the setting rod connectors are in line with the wedge and platen assembly.) Usually it is best to align the cell in the direction of the anticipated maximum principal compressive or tensile stress.

7) When the proper depth has been reached take an initial gauge and temperature reading. (See Section 3 for information on taking readings using GEOKON readout boxes.)

8) To expand the wedges on the SISC Cell, slowly apply hydraulic pressure while observing the gauge output.

9) Continue to expand the SISC cell until the correct preload reading is achieved according to the values shown in Table 4 below. (This will probably require hydraulic pressure between 500 and 1000 PSI.) For situations where the expected stress change is compressive, the minimum preload reading can be used. For negative stress (i.e. a diminution of compression, or tension), or in situations where blasting vibrations could dislodge the cell, a heavier preload should be used. **NOTE: The preload readings should never be set below the minimum or above the maximum values given in Table 4.**

Table 4 shows the suggested preload readings in **DIGITS**:

Model	Zero Reading (Nominal)	Min Preload	Mid Preload	Max Preload
4360-1	2500	+ 500	+ 2000	+ 3000
4360-2	500	+ 150	+ 450	+ 800
4360-3	1250	+ 400	+ 1200	+ 2500
4360-4	800	+ 200	+ 500	+1200

Table 4 - Preload Readings in Digits

10) After the correct preload reading has been obtained, release the hydraulic pressure.

11) Observe the gauge output; it should settle to a value near the one set with the hydraulic pressure applied.

12) Detach the setting head by pulling on and removing the setting tools from the borehole.

2.7 Recovering a Hydraulic Type SISC Cell

After tests, the SISC cell can be removed from the borehole using the setting tool. Only the setting rods and setting tool head are required. Align the setting tool head so that the flat part of the front face lies opposite of the wedge on the SISC cell. Strike the outer tip of the wedge with the setting tool head. This will drive the wedge out from under the platen and allow the cell to be removed from the borehole.

2.8 Cable Installation and Splicing

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

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

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 ill effects, and in some cases may in fact be beneficial. The 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.** Always maintain polarity by connecting color to color.

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

Cables can be terminated by stripping and tinning the individual conductors and then connecting them to the patch cord of a readout box. Alternatively, a connector can be used which will plug directly into the readout box or to a receptacle on a special patch cord.

2.9 Electrical Noise

Care should be exercised when installing instrument cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC power lines. The instrument cables will pick up the 50 or 60 Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact the factory concerning filtering options available for use with the GEOKON dataloggers and readouts should difficulties arise.

2.10 Lightning Protection

Model 4360 SISC cells, unlike numerous other types of instrumentation available from GEOKON, does not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem, however, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gauge and possibly destroy it.

Note the following suggestions:

- If the gauge is connected to a terminal box or multiplexer components such as plasma surge arrestors (spark gaps) can be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from GEOKON provide locations for installation of these components.

- Lighting arrestor boards and enclosures are available from GEOKON that install near the instrument. The enclosure has a removable top, allowing access to the protection board. In the event that the (LAB-3) is damaged, the user can service the components or replace the board. A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the gauge. Consult the factory for additional information on these or alternate lightning protection schemes.

- Plasma surge arrestors can be epoxy potted into the gauge cable close to the sensor. A ground strap would connect the surge arrestor to earth ground, either a grounding stake or other suitable earth ground.

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 can display 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.

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 9). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 9 - 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** button to select position **A** 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 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.

Figure 10 - GK-405 Readout

3.2.1 Connecting Sensors

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.

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).

3.2.2 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 “A”.

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

3.3 A Note Concerning Discontinued Readouts GK-401 and GK-403

If using the discontinued readout models GK-401 or GK-403 to read the gauge, the position switch must be set to Position A (microseconds) because the frequency of the gauge installed in the SISC cell may be just outside the excitation range of position B (digits). Readings taken in position A can be converted to digits using the following equation:

GK-403, Position A, microseconds is converted to digits by using Equation 1.

$$\text{Digits} = (1/A)^2 \times 10^9$$

Equation 1 - Converting Microseconds to Digits

Where A = The reading in microseconds (taken in position A).

For Example:
If the reading taken in position A = 850 microseconds

Then;
$(1/850)^2 \times 10^9 = 1384$ Digits

3.4 Measuring Temperatures

All vibrating wire gauges 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.

The GK-404 and GK-405 readout boxes will read the thermistor and display the temperature in degrees C.

To read temperatures using an ohmmeter:

1. Connect an ohmmeter to the green and white thermistor leads coming from the SISC cell. (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 14.7Ω per 1000 ft. / 48.5Ω per km 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, Table 8.

4. DATA REDUCTION

4.1 Calibration

The output of the SISC sensor is not very linear and for greater accuracy the use of a third order polynomial is recommended. If the linear gauge factor is used, remember to use the regression zero shown on the calibration report and not the zero reading at no load. Example calibration reports are given in Appendix C.

4.1.1 Linear Calibration

The following equation can be used to obtain the change in borehole diameter:

$$U = (R - R_{REG})\ G$$

Equation 2 - Change in Borehole Diameter

Where;
U = Deflection in mm or micro inches.
R_{REG} = The regression zero reading shown on the calibration report.
R = Reading in digits at a subsequent stress level.
G = Calibration factor (in mm or microinches) taken from the calibration report supplied with the SISC cell.

For example:
If;
The calibration factor (G) = 3.9691 microinches per digit
The Regression Zero reading (R_{REG}) = 2657.3
The subsequent reading (R) is 4134.5

Then;
The calculated displacement (U) = (4134.5-2657.3) x 3.9691 = 5863 microinches.

4.1.2 Polynomial Calibration

For greater accuracy, a third order polynomial can be used. The difference in accuracy between the linear calibration and the polynomial calibration is shown on the calibration report provided with the instrument. (See Appendix C for sample calibration reports.)

4.2 Corrections for Temperature Changes

Because the material used to construct the body of the SISC cell is the same as that of the vibrating wire, the device is relatively unaffected by changes in ambient temperature. It should be noted, however, that this is only true for a gauge in a free field with no restraints.

Since the SISC cells are normally installed underground, in constant temperature environments, corrections for temperature are not normally applied. If it is determined that temperature effects need to be accounted for in field conditions, where the gauge is wedged inside a borehole, the gauge temperature sensitivity is dependent on the gauge/rock interactions, and these relationships depend on the thermal properties of the rock. In-situ calibration would be required for accurate temperature effect corrections. This could be done by taking readings over a time period when the temperatures are changing, and the in-situ rock stress can be assumed to be constant.

4.3 Environmental Factors

Since the purpose of the SISC cell installation is to monitor site conditions, factors that might 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.

4.4 Theoretical Considerations

The deformation of a borehole in a biaxial stress field is given by the equation:

$$U = [(S+T) + 2(S-T) \cos 2\theta] \, d/E$$

Equation 3 - Deformation of Borehole in a Biaxial Stress Field

Where;
U = The deformation of the borehole, i.e., change in length of the diameter. When θ is 0°, $U = (3S-T) \times d/E$. When θ is 90°, $U = (3T-S) \times d/E$
θ = The angle measured positive in a counterclockwise direction from the direction of S to the direction of the measured diametral change U.
d = The diameter of the borehole.
E = The modulus of elasticity of the host material.
S and T = The applied stresses, as detailed below:

In uniaxial stress fields:
T is zero and $\theta = 0°$
$S = EU / 3d$

In biaxial stress fields:
$S+T = (U_1 + U_2 + U_3) \times E / 3d(1-\nu^2)$
$S-T = [(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_1 - U_3)^2)]^{1/2} \times \sqrt{2}\, E / 6d(1-\nu^2)$
$\tan 2\theta_1 = \sqrt{3}\, (U_2-U_3) / (2U_1-U_2-U_3)$

In the equations above, U_1, U_2, and U_3 are deformations measured across diameters 60° apart and θ_1 is the angle measured positive in a counterclockwise direction from S to U_1. See Figure 11.

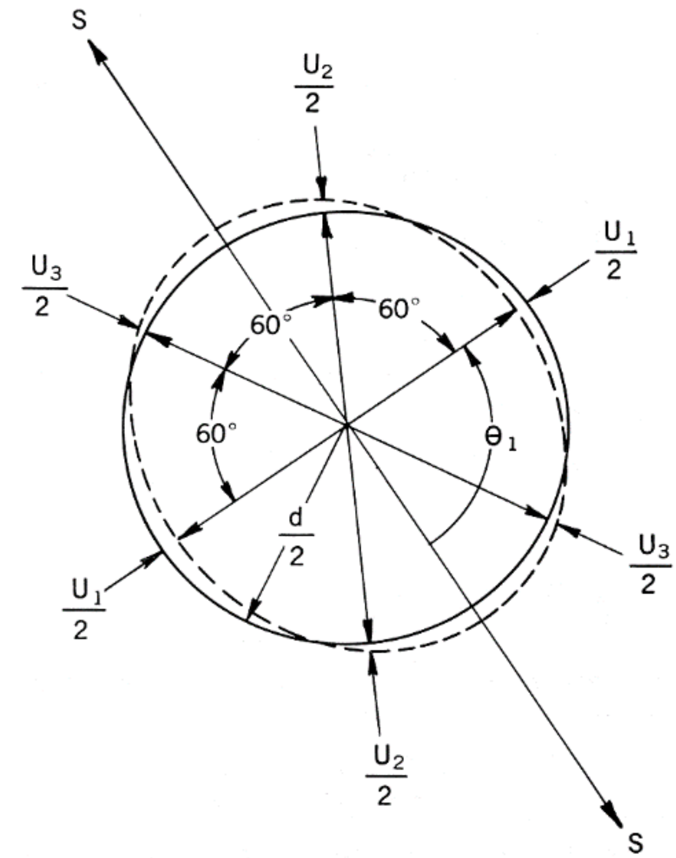


Figure 11 - Cross-section for a 60° Deformation Rosette

5. TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire SISC cells is confined to periodic checks of cable connections and maintenance of terminals. 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.**

Symptom: Thermistor resistance is too high

- ✓ It is likely that there is an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 2.8.

Symptom: Thermistor resistance is too low

- ✓ It is likely that there is a short. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 2.8.
- ✓ Water may have penetrated the interior of the gauge. There is no remedial action.

Symptom: SISC Cell Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically, are the swept frequency excitation settings correct?
- ✓ 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.
- ✓ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Symptom: SISC Cell Fails to Read

3. Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 5 shows the expected resistance for the various wire combinations; Table 6 is provided for the user to record the observed values. (For long cables a correction can be applied, equal to approximately 14.7Ω per 1000 ft. / 48.5Ω per km at 20 °C. Multiply these factors by two to account for both directions.) If the resistance is very high or infinite, the cable is probably broken or cut. If the resistance is very low, the gauge conductors may be shorted. If a cut or a short is located in the cable, splice according to the instructions in Section 2.8.

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

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

Table 5 - Sample Resistance

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

Table 6 - Resistance Work Sheet

APPENDIX A. SPECIFICATIONS

A.1 Model 4360 SISC Cells

Standard Range[1]	±35 MPa
Resolution[1]	35 KPa
Accuracy[2]	±0.5% F.S.
Temperature Range[3]	−20°C to +80°C
Borehole Diameter[3]	NX, PQ, HQ, 152 mm

Table 7 - Specifications

Notes:
[1]Depends on rock modulus, value shown is where E= 0.03×10^6
[2]Established under laboratory conditions.
[3]Other ranges and diameters available on request.

A.2 Thermistor

(see Appendix B also)

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

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

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

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

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 8 - Thermistor Resistance Versus Temperature

APPENDIX C. SAMPLE CALIBRATION REPORTS

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

S.I.S.C. Calibration Report

Model Number: 4360-2-1

Date of Calibration: November 5, 2009

Serial Number: 0927627

Temperature: 24.3 °C

Technician:

Average Displacement (inches)	Average Reading GK-404 (digits) pos. A	Calculated Displacement (Linear)	Linearity (% FS)	Calculated Displacement (Polynomial)	Error (% FS)
0.000000	600.0	0.000634	4.51	0.00001	0.05
0.004728	775.0	0.004100	-4.47	0.00470	-0.21
0.008229	950.0	0.007565	-4.72	0.00827	0.31
0.011260	1125.0	0.011031	-1.63	0.01123	-0.21
0.014062	1300.0	0.014496	3.09	0.01407	0.05

Linear Gage Factor, G = 19.803 microinches / digit

Regression Zero R_{REG} = 568.0

Linear, Displacement = $G(R - R_{REG})$

Where R = Reading in Digits

Polynomial Gage Factors:

A = 1.5518E-11
B = -5.43067E-08
C = 7.93554E-05
D = -0.031407

Calculated Displacement (inches) = $AR^3 + BR^2 + CR + D$

Wiring code: Red and Black: Gage White and Green: Thermistor

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.

Figure 12 - Sample SISC Calibration Report

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

S.I.S.C. Calibration Report

Model Number: 4360-3-1

Serial Number: 0927081

Date of Calibration: November 5, 2009

Temperature: 23.1 °C

Technician:

Average Displacement (inches)	Average Reading GK-404 (digits) pos. A	Calculated Displacement (Linear)	Linearity (% FS)	Calculated Displacement (Polynomial)	Error (% FS)
0.000000	1500.1	0.000273	2.19	0.00000	0.01
0.003600	2125.3	0.003369	-1.85	0.00360	-0.02
0.006716	2750.0	0.006464	-2.02	0.00672	0.03
0.009607	3375.2	0.009560	-0.37	0.00960	-0.02
0.012475	4000.1	0.012656	1.45	0.01248	0.01

Linear Gage Factor, G = 4.953 microinches / digit

Regression Zero R_{REG} = 1445.0

Linear, Displacement = $G(R - R_{REG})$

Where R = Reading in Digits

Polynomial Gage Factors:

A = 1.57045E-13
B = -1.60442E-09
C = 1.00061E-05
D = -0.011929

Calculated Displacement (inches) = $AR^3 + BR^2 + CR + D$

Wiring code: Red and Black: Gage White and Green: Thermistor

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.

Figure 13 - Sample SISC Calibration Report