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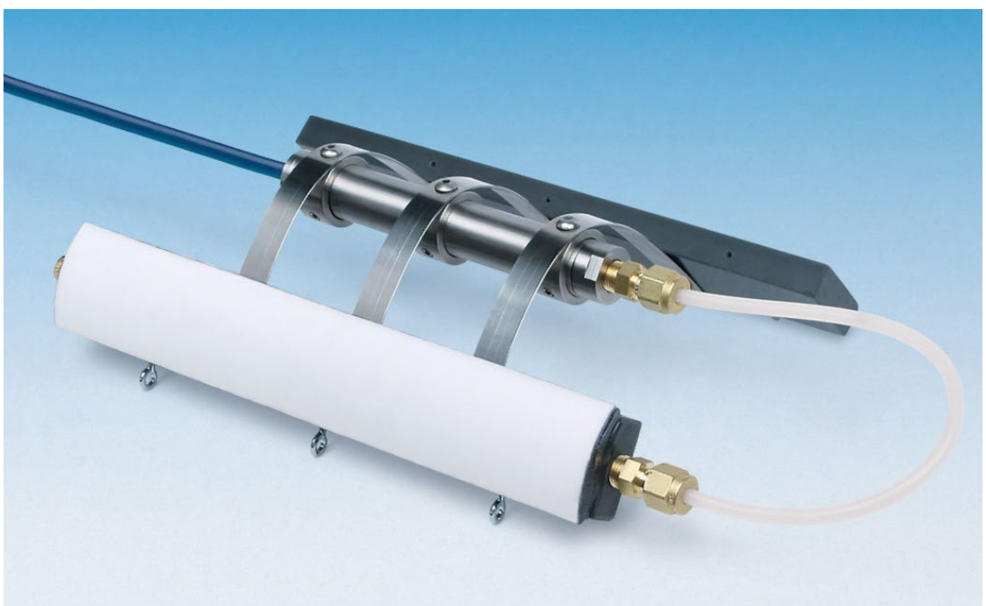
Instruction Manual

Model 4500MLP

Multilevel Vibrating Wire Piezometer



(REV J.1, 10/13/23)

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.

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EQUATIONS

1. THEORY OF OPERATION

Geokon Model 4500 Vibrating Wire Piezometers are intended primarily for long-term measurements of fluid, and/or pore pressures in standpipes, boreholes, embankments, pipelines and pressure vessels. The Model 4500MLP is designed to permit the easy installation of several piezometers inside a single borehole. It eliminates the need for alternating sand and bentonite zones by allowing the entire hole to be backfilled with bentonite grout by tremie piping it in through a grout pipe.

The basic Model 4500S piezometer (Figure 1) utilizes a sensitive stainless steel diaphragm to which a vibrating wire element is connected. In use, changing pressures on the diaphragm cause it to deflect. This deflection is measured as a change in tension and frequency of vibration in the vibrating wire element. The square of the vibration frequency is directly proportional to the pressure applied to the diaphragm.

Two coils, one with a magnet insert, the other with a pole piece insert, are located close to the vibrating wire. In use, a pulse of varying frequency (swept frequency) is applied to the coils causing the wire to vibrate primarily at its resonant frequency. When the excitation ends, the wire continues to vibrate. During vibration, a sinusoidal signal is induced in the coils and transmitted to the readout box where it is conditioned and displayed.

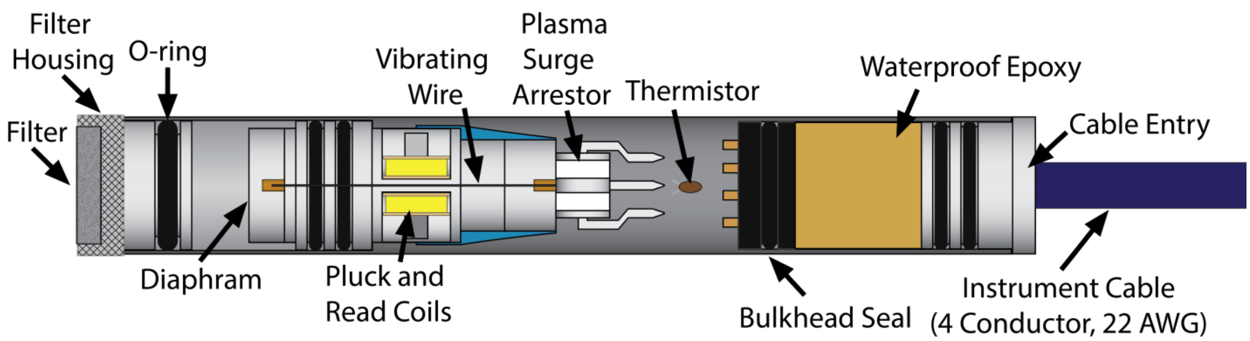

Figure 1 - Model 4500S Vibrating Wire Piezometer

Care needs to be exercised when choosing the pressure range of the piezometer. During installation, the full pressure of the wet bentonite grout will be felt by the piezometer. Geokon piezometers can withstand overranging up to 100 percent of the calibrated range without affecting the calibration, shifting the zero reading, or damaging the unit. At higher overrange pressures, the piezometer may temporarily cease reading until the grout sets up and the pressure returns to normal.

For the Model 4500MLP, the filter stone shown in Figure 1 is replaced by a tube leading to a much larger, curved, and porous filter stone, which is forced against the walls of the borehole by a spring mechanism. The spring mechanism can be actuated remotely after the piezometer has been lowered in its closed configuration to its desired location. This is shown schematically in Figure 2 and Figure 3.

With the filter stones pressed against the wall of the borehole in this manner, the borehole can be filled completely with bentonite cement grout without running the risk of getting the filter stone plugged with bentonite or having substantial amounts of the impervious bentonite interposed between the piezometer diaphragm and the ground water in the surrounding soil.

Figure 2 - Close up of 4500MLP

Figure 3 - 4500MLP System

2. PRIOR TO INSTALLATION

2.1 Saturating the Filter Stone

1) Disconnect the Swagelok union at the transducer.

2) Immerse the whole assembly, upside down, in a bucket of water.

3) Apply a vacuum to the nylon filter tube using the large syringe supplied with the system. This removes the entrapped air from the large filter stone.

4) Purge the transducer of air by injecting water into the Swagelok fitting as follows:
   a) Fill the syringe with water.
   b) Attach the small diameter tube supplied with the system to the syringe.
   c) Push the tube all the way down inside the Swagelok fitting and into the piezometer cavity.
   d) Inject water from the syringe into the piezometer cavity.

5) With the assembly still under water, reconnect the nylon tube from the filter stone to the transducer. Tighten the Swagelok per the instructions in Section 2.2.

6) Keep the assembly under water until ready to lower into the borehole.

Caution! Do not allow the piezometer to freeze once it has been filled with water.

2.2 Swagelok Tube Fitting Instructions

These instructions apply to one inch (25 mm) and smaller fittings.

2.2.1 Installation

1) Fully insert the tube into the fitting until it bumps against the shoulder.

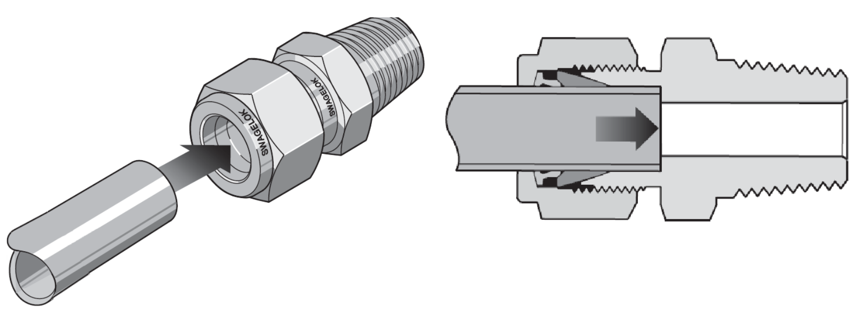

Figure 4 - Tube Insertion

2) Rotate the nut until it is finger-tight. (For high-pressure applications as well as high-safety-factor systems, further tighten the nut until the tube will not turn by hand or move axially in the fitting.)

3) Mark the nut at the six o’clock position.

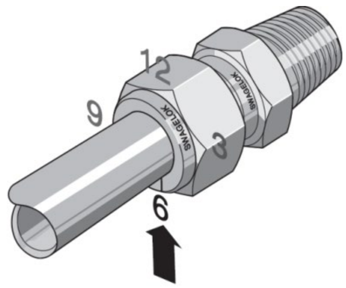

Figure 5 - Make a Mark at Six O'clock

4) While holding the fitting body steady, tighten the nut one and one-quarter turns until the mark is at the nine o'clock position. (Note: For 1/16", 1/8", 3/16", and 2, 3, and 4 mm fittings, tighten the nut three-quarters of a turn until the mark is at the three o'clock position.)

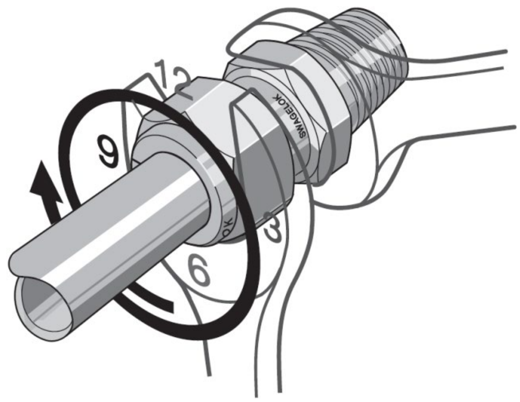

Figure 6 - Tighten One and One-Quarter Turns

2.2.2 Reassembly Instructions

Swagelok tube fittings may be disassembled and reassembled many times.
Warning: Always depressurize the system before disassembling a Swagelok tube fitting.

1) Prior to disassembly, mark the tube at the back of the nut, then make a line along the nut and fitting body flats. *These marks will be used during reassembly to ensure the nut is returned to its current position.*

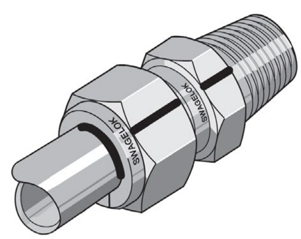

Figure 7 - Marks for Reassembly

2) Disassemble the fitting.

3) Inspect the ferrules for damage and replace if necessary. **If the ferrules are replaced the connector should be treated as a new assembly. Refer to the section above for installation instructions.**

4) Reassemble the fitting by inserting the tube with preswaged ferrules into the fitting until the front ferrule seats against the fitting body.

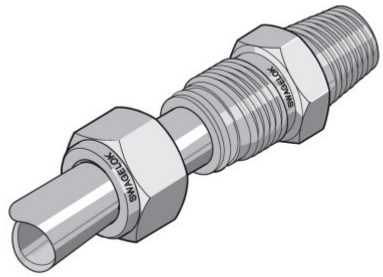

Figure 8 - Ferrules Seated Against Fitting Body

5) While holding the fitting body steady, rotate the nut with a wrench to the previous position as indicated by the marks on the tube and the connector. At this point, there will be a significant increase in resistance.

6) Tighten the nut slightly.

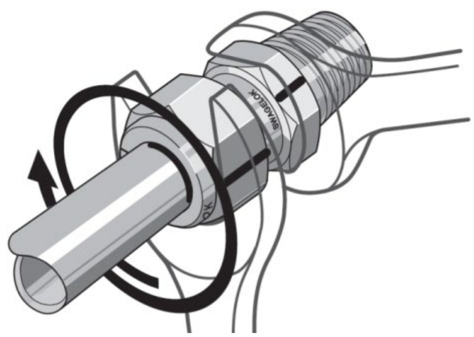

Figure 9 - Tighten Nut Slightly

2.3 Establishing an Initial Zero Reading

It is imperative that an accurate initial zero reading be obtained for each piezometer as this reading will be used for all subsequent data reduction.

Generally, the initial zero reading is obtained by reading the instrument prior to installation. Vibrating Wire Piezometers differ from other types of pressure sensors in that they indicate a reading when no pressure is exerted on the sensor.

Calibration data is supplied with each gauge, a factory zero reading taken at a specific temperature and absolute barometric pressure is included. (See Figure 18 for a sample calibration sheet.) Zero readings at the site should coincide with the factory readings within 20 digits after barometric and temperature corrections are made. (Barometric pressures change with elevation at a rate of about 3.45 kPa (1/2 psi) per 300 meters (1,000 ft.) A thermistor is included inside the body of the piezometer for the measurement of temperature.

To take an initial zero reading, complete the following:

1) Saturate the filter stone per the instructions in Section 2.1.

2) Allow the assembly to sit under water in a bucket for 5 to 15 minutes while the temperature stabilizes. (If possible, the temperature of the water in the bucket should be the same as the temperature of the water in the borehole. Use the thermistor inside the piezometer to measure the water temperature.)

3) Once the temperature has stabilized, take a zero reading. (See Section 4 for readout instructions.)

4) Note the barometric pressure if possible or record the time for later referral to local weather station data.

5) For maximum accuracy, record the depth of the piezometer below the water surface at the time of the reading. (The piezometer diaphragm is at the same level as the lowest leaf spring.)

3. INSTALLATION

Borehole sizes are not critical, but they should be **at least 100 mm (four inch**) in diameter and **not more than 30 mm** larger than the nominal size for which the spring-loaded mechanism was designed.

3.1 Grouting requirements

For more details on grouting, refer to “Piezometers in Fully Grouted Boreholes” by Mikkelson and Green, FMGM proceedings Oslo 2003. Copies are available from Geokon.

The general rule for grouting multilevel piezometers is to mimic the strength of the surrounding soil. The emphasis should be on controlling the water to cement ratio. This is accomplished by **mixing the cement with the water first.** The most effective way of mixing is in a 50 to 200-gallon barrel or tub, using the drill rig pump to circulate the mix.

Any kind of bentonite powder used to make drilling mud, combined with a Type 1 or Type 2 Portland cement can be used. The exact amount of bentonite added will vary somewhat. Table 1 shows two possible mixes for strengths of 50 psi and 4 psi.

	50 PSI Grout for Medium to Hard Soils		4 PSI Grout for Soft Soils	
	Amount	**Ratio by Weight**	**Amount**	**Ratio by Weight**
Water	30 gallons	2.5	75 gallons	6.6
Portland Cement	94 lb. (one sack)	1	94 lb. (one sack)	1
Bentonite	25 lb. (as required)	0.3	39 lb. (as required)	0.4
NOTES:	The 28-day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi		The 28-day strength of this mix is about four psi, similar to very soft clay.	

Table 1 - Cement/Bentonite/Water ratios

Add the measured amount of clean water to the barrel then gradually add the cement in the correct weight ratio. Next add the bentonite powder, slowly, so clumps do not form. Keep adding bentonite until the watery mix turns to an oily/slimy consistency. Let the grout thicken for another five to ten minutes. Add more bentonite as required until it is a smooth, thick cream, similar to pancake batter. It is now as heavy as it is feasible to pump.

When pumping grout (unless the tremie pipe is to be left in place,) withdraw the tremie pipe after each batch, by an amount corresponding to the grout level in the borehole.

3.2 Borehole Installation

In steeply inclined boreholes directed downwards, the drop weight method of installation is recommended. See Section 3.2.1.

(Note that the drop weight method cannot be used in holes that will not stay open, and in holes which require the casing to be removed as the piezometers are installed. This is because when using the drop weight method, the top piezometers are released first.)

For shallow inclinations and upward directed holes, (and for other situations where the drop weight method is not desired or possible,) the pneumatic cutter method or the pull-pin method can be used. See Sections 3.2.2 and 3.2.3.

3.2.1 The Drop Weight Method

4500MLP sensors are designed to be installed around **flush coupled, one inch, Schd 80 PVC** grout pipe; however, other grouting arrangements may be used.

Preparing the grout pipe:

1) Connect the sections of grout pipe together and lay them out along the ground.
2) Mark the desired locations of the piezometers on the grout pipe at the calculated depths.
3) Drill a single 7/32 or 1/4-inch drill hole diametrically through the pipe in each marked location.

Attaching the piezometers:

Each piezometer assembly is held to the grout pipe by means of a single 50 lb. nylon zip tie (supplied), which passes through the two holes on opposite sides of the pipe. The zip tie also holds the piezometer assembly in its closed position.

Pass the zip tie through the grout pipe, through the spaces between the leaf springs, around the two platens, and then back to itself. Keep the cables from lower piezometers **inside** the zip tie and leaf springs. The zip tie should pass just **below** the center leaf spring so that the bottom of the platen assemblies will be held tight to the grout pipe.

Pull the zip tie tight around the grout pipe (Figure 10).

Figure 10 - 4500MLP zip Tied for Drop Weight Method

As the grout pipe is assembled and pushed into the borehole, the piezometer assemblies are added, and the electrical cables are fed into the borehole. When the grout tube has reached its final position and the assembly is complete, a special weight (provided with the equipment,) is tied to a length of aircraft cable and allowed to fall freely down the inside of the grout pipe. As the weight hits each of the zip ties stretching across the pipe, the zip tie is snapped, allowing the leaf springs to expand and force the filter stones against the walls of the borehole.

3.2.2 Pneumatic Cutter Method

4500MLP sensors are designed to be installed around **flush coupled, one inch, Schd 80 PVC** grout pipe; however, other grouting arrangements may be used.

The assembly is held in its closed position during installation by two nylon zip ties (supplied). Making sure the grout pipe is between the platens, and the cables from the lower piezometers are kept **inside** the zip tie and leaf springs, attach the body of the piezometer to the grout pipe by passing the zip ties through the eyebolts in the platens and through the holes in the cutting tool. Orient the tool in such a way that it will be above the assembly when pushed into the borehole. See Figure 11.

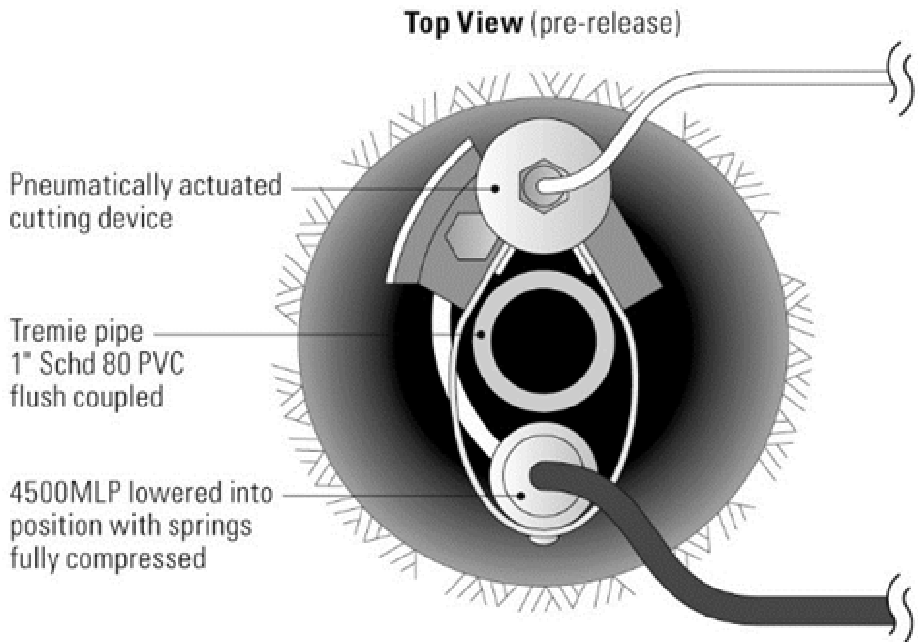

Figure 11 - 4500MLP Pre-release

If the grout pipe is going to be removed from the borehole the grout pipe is assembled and pushed into the borehole first, then each piezometer assembly is pushed around the grout pipe (and any lower piezometer cables) to the desired elevation. Piezometers should be installed sequentially, from the base of the borehole to the mouth.

If the grout pipe is to be left in place, the piezometers can be taped to the grout pipe. (Make sure not to put the tape around the outside of the filter stone and spring mechanism.)

When the desired elevation is reached, the cutting tool is activated by connecting the pneumatic tube from the piezometer to a bottle of CO_2. (CO_2 can be obtained locally from any welding supply outlet.) The CO_2 bottle should have a pressure regulator that is set to a pressure of at least 2.5 MPa (350 psi), with the shutoff valve closed (Figure 12).

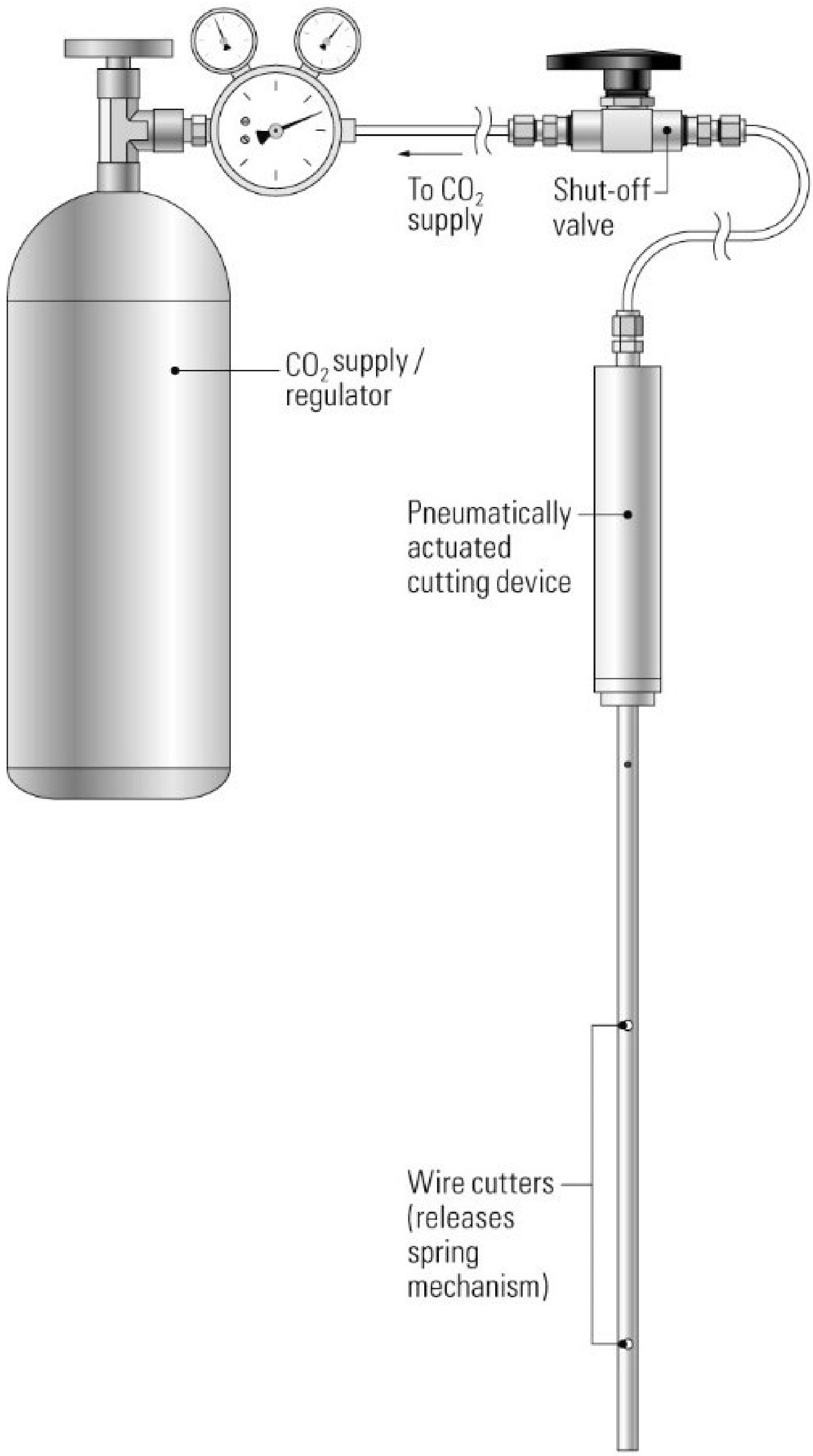

Figure 12 - Pneumatic Cutter Equipment

The shut off valve is then opened suddenly, allowing the pressure to reach the cutting tool. The cutting tool cuts the zip ties, releasing the spring-loaded platens against the borehole walls (Figure 13).

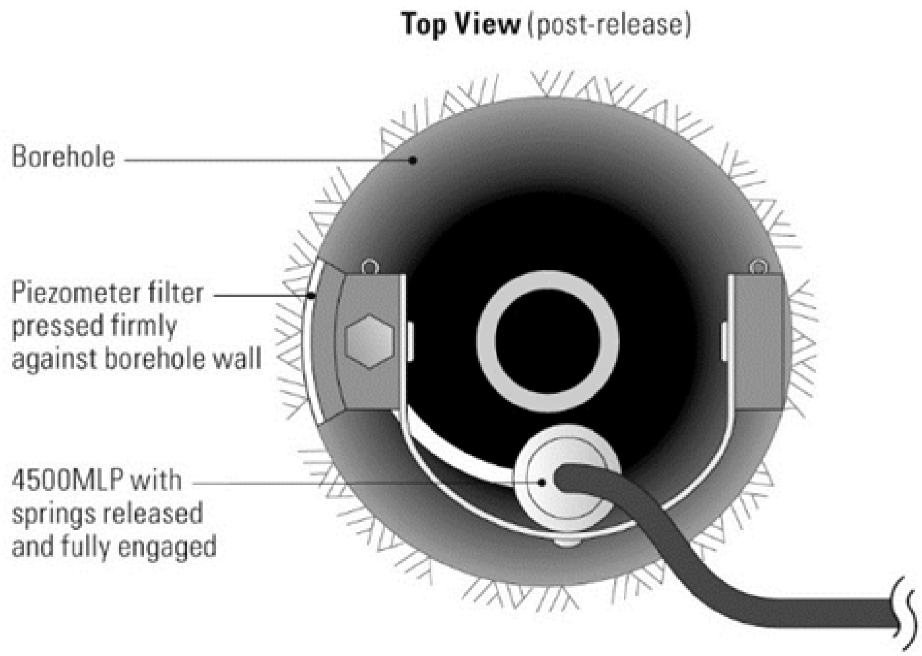

Figure 13 - 4500MLP Post-release

If installed in drill casing:

The sensor is lowered to the proposed elevation and the casing is pulled just above this elevation before the assembly is released. The cutting tool is then removed from the drill hole and the next assembly is prepared for installation.

When lowering the subsequent piezometers down the hole, feed the cables from the lower piezometers through the middle of the assembled piezometer rather than around the outside. (This will prevent the cables from interfering with the filter contacting with the borehole wall).

When all the assemblies are installed, the hole can be grouted from the bottom up using bentonite cement grout.

3.2.3 Pull-Pin Method

In this method, the piezometer assembly is held in its closed position by means of a pull-pin. After the filter stone and the platen are squeezed together, the pull-pin passes through two sets of three eyebolts each, which are mounted on the filter stone and the platen.

If the grout pipe is going to be removed from the borehole:

The piezometer assembly must be pushed around the grout pipe, down to the desired elevation. This is accomplished using a second pipe, which can be another length of the grout tube. While holding the piezometer in position by the second pipe, the pull-pin cable should be pulled gently until all the slack is taken out. With a sudden and strong jerk, pull on the pull-pin cable. This will release the platens without changing the position of the piezometer relative to the borehole. *(A bit of practice pulling the pins before the actual installation will give some "feeling" and confidence as to how the system works.)* Piezometers should be installed sequentially, from the base of the borehole to the mouth.

If the grout pipe is going to be left in the borehole:

The piezometer assemblies should be attached to the grout pipe in a manner that does not restrict the movement of the platens. The grout pipe is assembled, length by length, while the piezometer assemblies, (each with its own pull-pin,) are attached to it by taping the electrical cable to the grout pipe near the piezometer. The grout pipe and piezometer assemblies can then be pushed down the hole as a unit. When the final position is reached the pull-pins are pulled, activating the platens.

If installed in drill casing:

The sensor is lowered to the proposed elevation. The casing is pulled just above this elevation before the assembly is released. The tool is then removed from the drill hole and the next assembly prepared for installation. When lowering (or pushing) the subsequent piezometers down the hole, feed the cables from the lower piezometers through the middle of the assembled piezometer rather than around the outside. This will prevent the cables from coming between the filter and the borehole wall.

When all the assemblies are installed, the hole can be grouted from the bottom up using a bentonite cement grout. The grout pipe can either be removed from the hole or left in place.

3.3 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 piezometers 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. (See Figure 14.) This multi-conductor cable would then be run to the readout station. For these installations, it is recommended that the piezometer be supplied with enough cable to reach the installation depth plus extra cable to pass through drilling equipment (rods, casing, etc.).

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.**

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 itself 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 available. Contact Geokon for specific application information.

Figure 14 - Typical Multi-Piezometer Installation

3.4 Lightning Protection

In exposed locations, it is vital that the piezometer be protected against lightning strikes. A tripolar plasma surge arrestor, which protects against voltage spikes across the input leads, is built into the body of the piezometer. (See Figure 15.)

Additional lightning protection measures available include:

- Placing a Lightning Arrestor Board (LAB-3) in line with the cable, as close as possible to the installed piezometer. (See Figure 15.) These units utilize surge arrestors and transzorbs to further protect the piezometer. This is the recommended method of lightning protection.

- Terminal boxes available from Geokon can be ordered with lightning protection built in. The terminal board used to make the gauge connections has provision for the installation of plasma surge arrestors. Lightning Arrestor Boards (LAB-3) can also be incorporated into the terminal box. The terminal box must be connected to an earth ground for these levels of protection to be effective.

- If the instruments will be read manually with a portable readout (no terminal box) a simple way to help protect against lightning damage is to connect the cable leads to a good earth ground when not in use. This will help shunt transients induced in the cable to ground, away from the instrument.

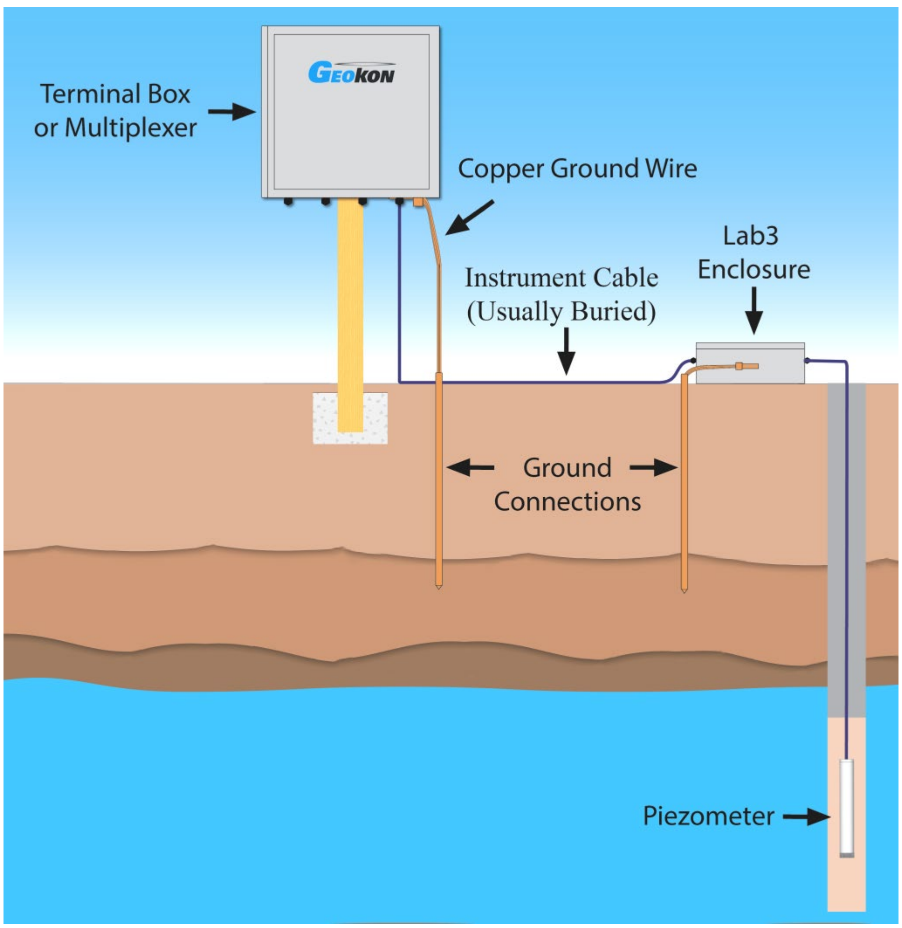

Figure 15 - Recommended Lab-3 Lightning Protection Scheme

4. TAKING READINGS

4.1 GK-404 Readout Box

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

4.1.1 Operating the GK-404

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

Figure 16 - 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 display:

Geokon Inc.
GK-404 verX.XX

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** 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.
For more information, consult the GK-404 manual.

4.2 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 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.

4.2.1 Connecting Sensors

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.

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).

4.2.2 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 on the handheld PC by tapping on "Start", 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, indicating that the remote module has successfully paired with the handheld PC. The Live Readings Window will be displayed on the handheld PC. Figure 17 shows a typical vibrating wire piezometer output in digits and thermistor output in degrees Celsius.

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

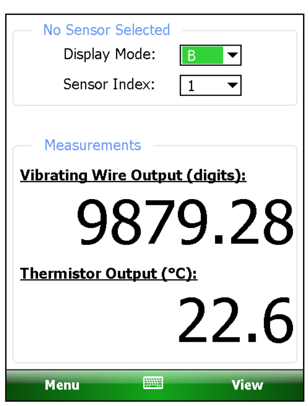

Figure 17 - Live Readings – Raw Readings

4.3 GK-403 Readout Box (Obsolete Model)

The GK-403 can store gauge readings as well as apply calibration factors to convert readings to engineering units. The following instructions explain taking gauge measurements using Modes “B” and “F”. Consult the GK-403 Instruction Manual for additional information.

4.3.1 Connecting Sensors

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.

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).

4.3.2 Operating the GK-403

1) Turn the display selector to position “B” (or “F”).
2) Turn the unit on.
3) The readout will display the vibrating wire output in digits (See Equation 1 in Section 5.1.) The last digit may change one or two digits while reading.
4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.
5) Press the “Store” button to record the value displayed.

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

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

4.4 Measuring Temperatures

All vibrating wire piezometers are equipped with a thermistor that 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-403, GK-404, and GK-405 readout boxes will read the thermistor and display the temperature in degrees C. (High temperature versions use a different thermistor, which must be read using an ohmmeter.)

To read temperatures using an ohmmeter:

1) Connect an ohmmeter to the green and white thermistor leads coming from the piezometer. (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 14.7 ohms per one thousand feet. Multiply this factor by two to account for both directions.)
2) Look up the temperature for the measured resistance in Appendix B, Table 7. For high temperature models use Appendix C, Table 8.

4.5 Checking the Calibration

The following procedure can be used to verify the calibration factor as supplied on the calibration sheet:

1) Saturate the filter stone and fill the space between it and the diaphragm with water (see Section 2.1).

2) Lower the piezometer to the bottom of a water-filled borehole using the cable to measure the actual depth.

3) Allow 15 to 20 minutes for the piezometer to come to thermal equilibrium.

4) Using a readout box record the reading at that level (see Section 4 for readout instructions).

5) Raise the piezometer a known amount and record the reading.

6) Calculate the calibration factor using the change in pressure and the reading.

7) Compare to the calibration sheet value. The two values should agree within ±0.5%.

When doing this test please be aware that the actual water level inside the borehole might change due to displacement of water by the different lengths of submerged cable. This is especially critical where the cable length is long and the borehole diameter small. Allowing enough time for the water level to equilibrate may solve this problem, or keep the borehole filled to the top.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4500INS-700 kPa

Date of Calibration: September 14, 2011

Serial Number: 1043811

Temperature: 21.7 °C

Barometric Pressure: 994.7 mbar

Technician: Stewart Kenney

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	9073	9074	9074	1.526	0.22	0.028	0.00
140.0	8303	8304	8304	139.7	-0.04	140.0	-0.01
280.0	7528	7528	7528	278.9	-0.15	280.0	0.00
420.0	6748	6749	6749	418.8	-0.16	420.0	-0.01
560.0	5963	5963	5963	559.8	-0.02	560.1	0.01
700.0	5174	5174	5174	701.5	0.21	700.0	-0.01

(kPa) Linear Gage Factor (G): -0.1795 (kPa/ digit) **Regression Zero: 9082**

Polynomial Gage factors: A: -7.113E-07 B: -0.1694 C: ______

Thermal Factor (K): 0.1319 (kPa/ °C)

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

(psi) Linear Gage Factor (G): -0.02603 (psi/ digit)

Polynomial Gage Factors: A: -1.032E-07 B: -0.02456 C: ______

Thermal Factor (K): 0.01913 (psi/ °C)

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

Calculated Pressures: Linear, $P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)^*$

Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)^*$

*Barometric pressures expressed in kPa or psi. Barometric compensation is not required with vented transducers.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Figure 18 - Sample Calibration Sheet

5. DATA REDUCTION

5.1 Pressure Calculation

The digits displayed by the Geokon Models GK-403, GK-404, and GK-405 Readout Boxes on channel B are based on the equation:

$$\text{Digits} = \left(\frac{1}{\text{Period}}\right)^2 \text{ x } 10^{-3} \text{ or Digits} = \frac{\text{Hz}^2}{1000}$$

Equation 1 - Digits Calculation

For example, a piezometer reading 8000 digits corresponds to a period of 354 μs and a frequency of 2828 Hz. Note that in the above equation, the period is in seconds. Geokon readout boxes display microseconds.

Digits are directly proportional to the applied pressure.

$$\text{Pressure} =$$

$$(\text{Current Reading - Initial Reading}) \times \text{Linear Calibration Factor}$$

Or

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

Equation 2 - Convert Digits to Pressure

Since the linearity of most sensors is within ±0.2% FS, the errors associated with nonlinearity are of minor consequence. However, for those situations requiring the highest degree of accuracy, it may be desirable to use a second order polynomial to get a better fit of the data points. The use of a second order polynomial is explained in Appendix D.

The instrument's calibration report, a typical example of which is shown in Figure 18, shows the data from which the linear gauge factor and the second order polynomial coefficients are derived. Columns on the right show the size of the error incurred by assuming a linear coefficient and the improvement that can be expected by going to a second order polynomial. In many cases, the difference is minor.

The calibration report gives the pressure in certain engineering units. These can be converted to other engineering units using the multiplication factors shown in Table 2.

From → To ↓	psi	"H_2O	'H_2O	mm H_20	m H_20	"HG	mm HG	atm	mbar	bar	kPa	MPa
psi	1	.036127	.43275	.0014223	1.4223	.49116	.019337	14.696	.014503	14.5039	.14503	145.03
"H_2O	27.730	1	12	.039372	39.372	13.596	.53525	406.78	.40147	401.47	4.0147	4016.1
'H_2O	2.3108	.08333	1	.003281	3.281	1.133	.044604	33.8983	.033456	33.4558	.3346	334.6
mm H_20	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_20	.70432	.025399	.304788	.001	1	.34532	.013595	10.332	.010197	10.197	.10197	101.97
"HG	2.036	.073552	.882624	.0028959	2.8959	1	.03937	29.920	.029529	29.529	.2953	295.3
mm HG	51.706	1.8683	22.4196	.073558	73.558	25.4	1	760	.75008	750.08	7.5008	7500.8
atm	.06805	.002458	.029499	.0000968	.0968	.03342	.001315	1	.000986	.98692	.009869	9.869
mbar	68.947	2.4908	29.8896	.098068	98.068	33.863	1.3332	1013.2	1	1000	10	10000
bar	.068947	.002490	.029889	.0000981	.098068	.033863	.001333	1.0132	.001	1	.01	10
kPa	6.8947	.24908	2.98896	.0098068	9.8068	3.3863	.13332	101.320	.1	100	1	1000
MPa	.006895	.000249	.002988	.0000098	.009807	.003386	.000133	.101320	.0001	.1	.001	1

Table 2 - Engineering Units Multiplication Factors

(Note: Due to changes in specific gravity with temperature, the factors for mercury and water in the above table are approximations.)

5.2 Temperature Correction

The materials used in the construction of Geokon’s vibrating wire piezometers have been carefully selected to minimize thermal effects; however, most units still have a slight temperature coefficient. Consult the calibration sheet supplied with the instrument to obtain the coefficient for the individual piezometer.

Since piezometers are normally installed in a tranquil and constant temperature environment, corrections are normally not required. If this is not the case for the selected installation, corrections can be made using the internal thermistor for temperature measurement. See Section 4.4 for instructions regarding obtaining the piezometer temperature.

The temperature correction equation is as follows:

$$\text{Temperature Correction} =$$

$$(\text{Current Temperature - Initial Temperature}) \times \text{Thermal Factor}$$

Or

$$P_T = (T_1 - T_0) \text{ x } K$$

Equation 3 - Temperature Correction

The calculated correction would then be added to the pressure calculated using Equation 2. If the engineering units were converted, remember to apply **the same conversion** to the calculated temperature correction.

For example: If the initial temperature was 22° C, and the current temperature is 15° C, and the thermal factor (K on the calibration report,) is +0.1319 kPa per °C rise. The temperature correction is +0.1319(15-22) = -0.92 kPa. Refer to the calibration report provided with the instrument for the initial temperature and thermal factor.

5.3 Barometric Correction (required only on unvented transducers)

Since the standard piezometer is hermetically sealed and unvented, it responds to changes in atmospheric pressure. Corrections may be necessary, particularly for the sensitive, low-pressure models. For example, a barometric pressure change from 29 to 31 inches of mercury would result in ≈1 PSI of error (or ≈2.3 feet if monitoring water level in a well). Thus, it is advisable to read and record the barometric pressure every time the piezometer is read. A separate pressure transducer (piezometer), kept out of the water, may be used for this purpose.

The barometric correction equation is as follows:

$$\text{Barometric Correction} =$$

$$(\text{Current Barometer} - \text{Initial Barometer}) \times \text{Conversion Factor}$$

Or

$$P_B = (S_1 - S_0) \text{ x } F$$

Equation 4 - Barometric Correction

The calculated barometric correction is subtracted from the pressure calculated using Equation 2. If the engineering units were converted, remember to apply **the same conversion** to the calculated barometric correction.

Barometric pressure is usually recorded in inches of mercury. The Conversion Factor for inches of mercury to PSI is 0.491, and from inches of mercury to kPa is 3.386.

Table 2 lists other common Conversion Factors.

Equation 5 shows the pressure calculation with temperature and barometric correction applied.

$$P_{corrected} = (R_1 - R_0)G + (T_1 - T_0)\,K - (S_1 - S_0)\,F$$

Equation 5 - Corrected Pressure Calculation

The user should be cautioned that this correction scheme assumes ideal conditions. In reality, conditions are not always ideal. For example, if the well is sealed, barometric effects at the piezometer level may be minimal or attenuated from the actual changes at the surface. Thus, errors may result from applying a correction that is not required. In these cases, Geokon recommends independently recording the barometric pressure changes and correlating them with the observed pressure changes to arrive at a correction factor.

An alternative to making barometric correction is to use piezometers that are vented to the atmosphere. See Section 5.4.

5.4 Vented Piezometers

Vented piezometers are designed to eliminate barometric effects. The space inside the transducer is not hermetically sealed and evacuated; instead, it is connected via a tube (integral with the cable) to the atmosphere. A chamber containing desiccant capsules is attached to the end of the tube to prevent moisture from entering the transducer cavity. Vented piezometers require more maintenance then unvented types, and there is always a danger that water can find its way into the inside of the transducer and ruin it.

To keep the desiccant fresh during storage and transportation, the outer end of the desiccant chamber is closed by means of a seal screw when shipped from the factory. **THIS SEAL SCREW MUST BE REMOVED BEFORE THE PIEZOMETER IS PUT INTO SERVICE!**

The desiccant capsules are blue when fresh. They will gradually turn pink as they absorb moisture. When they have turned light pink in color, they should be replaced. Contact Geokon for replacement capsules.

5.5 Environmental Factors

Since the purpose of the piezometer 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, traffic, temperature and barometric changes, weather conditions, changes in personnel, nearby construction activities, excavation and fill level sequences, seasonal changes, etc.

6. TROUBLESHOOTING

Maintenance and troubleshooting of vibrating wire piezometers is confined to periodic checks of cable connections and maintenance of terminals. The transducers themselves are sealed and are not user serviceable. **Gauges should not be opened in the field.**

Should difficulties arise, consult the following list of problems and possible solutions. For additional troubleshooting and support, contact Geokon.

Symptom: Thermistor resistance is too high

- ✓ Likely, 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 3.3.

Symptom: Thermistor resistance is too low

- ✓ A short is likely. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 3.3.
- ✓ Water may have penetrated the interior of the piezometer. There is no remedial action.

Symptom: Piezometer reading unstable

- ✓ Make sure the shield drain wire is connected to the blue clip on the flying leads. (Green for the GK-401.)
- ✓ Isolate the readout from the ground by placing it on a piece of wood or another insulator.
- ✓ Check for sources of nearby electrical noise such as motors, generators, antennas, or electrical cables. Move the piezometer cable away from these sources if possible. Contact the factory for available filtering and shielding equipment.
- ✓ The Piezometer may have been damaged by overranging or shock. Inspect the diaphragm and housing for damage.
- ✓ The body of the Piezometer may be shorted to the shield. Check the resistance between the shield drain wire and the Piezometer housing. If the resistance is very low, the gauge conductors may be shorted.

Symptom: Piezometer fails to give a reading

- ✓ Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 3 shows the expected resistance for the various wire combinations; Table 4 is provided for the customer to fill in the actual resistance found. Cable resistance is approximately 14.7Ω per 1000' of 22 AWG wire. Multiply this factor 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 instructions in Section 3.3.
- ✓ Check the readout with another gauge to ensure it is functioning properly.
- ✓ The Piezometer may have been overranged or shocked. Inspect the diaphragm and housing for damage.

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 3 - Sample Resistance

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

Table 4 - Resistance Work Sheet

APPENDIX A. SPECIFICATIONS

Standard Ranges[1]	0-70 kPa (0-10 psi) 0-170 kPa (0-25 psi) 0-350 kPa (0-50 psi) 0-700 kPa (0-100 psi) 0-1 MPa (0-150 psi) 0-2 MPa (0-300 psi) 0-3 MPa (0-450 psi) 0-5 MPa (0-750 psi) 0-7.5 MPa (0-1,100 psi)
Resolution	0.025% FS (minimum)
Linearity[2]	<0.5% FS
Accuracy[3]	0.1% FS
Overrange[4]	1.5 x Rated Pressure
Thermal Coefficient	<0.025% FS/°C
Temperature Range	-20 °C to +80 °C
Borehole Diameter	100-150 mm
Borehole Oversize Capacity	Nominal size +30 mm
Cable	(non-vented) 02-250V6 4-conductor PVC jacket, 6.4 mm diameter (vented) 02-335VT8 4-conductor Polyurethane jacket, 9.5 mm diameter
Filter	Porous Polyethylene, 60 micron
Thermistor Operating Accuracy	±0.5 °C
Frequency Range Hz	1400-3500

Table 5 - Vibrating Wire Piezometer Specifications

Accuracy of Geokon test apparatus: 0.1%
Contact Geokon for specific application information.
Notes:
[1] Piezometers with a range of 350 kPa and higher are capable of reading negative pressures to −100 kPa. Please contact GEOKON for more information.
[2] 0.1% FS linearity available upon request.
[3] Derived using second order polynomial.
[4] Maximum, without damage.

A.1 Standard Piezometer Wiring

Pin	Function	Wire Color
A	Vibrating Wire Gauge +	Red
B	Vibrating Wire Gauge -	Black
C	Thermistor	White
D	Thermistor	Green
E	Cable Shield	Shield
F-K	Not Used	

Table 6 - Standard Piezometer Wiring

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

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

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

Equation 6 - Resistance to Temperature

Where;
T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = 1.4051×10^{-3}
B = 2.369×10^{-4}
C = 1.019×10^{-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 7 - Thermistor Resistance versus Temperature

APPENDIX C. HIGH TEMPERATURE THERMISTOR LINEARIZATION

Resistance to Temperature Equation for *US Sensor 103JL1A*:

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

Equation 7 - High Temperature Resistance to Temperature

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 8 - Thermistor Resistance versus Temperature for High Temperature Models

APPENDIX D. IMPROVING THE ACCURACY OF THE CALCULATED PRESSURE

Most vibrating wire pressure transducers are sufficiently linear (±0.2 % FS) that the use of the linear calibration factor satisfies normal requirements. However, it should be noted that the accuracy of the calibration data, which is dictated by the accuracy of the calibration apparatus, is always ±0.1 % FS.

This level of accuracy can be recaptured, even where the transducer is nonlinear, by the use of a second order polynomial expression, which gives a better fit to the data then does a straight line.

The polynomial expression has the form:

$$\text{Pressure} = AR^2 + BR + C$$

Equation 8 - Second Order Polynomial Expression

Where;
R is the reading (digits channel B)
A, **B**, and **C** are coefficients

Figure 18 shows a typical calibration sheet of a transducer that has fairly normal nonlinearity. The figure under the "Linearity (%FS)" column is

$$\frac{\text{Calculated Pressure-True Pressure}}{\text{Full Scale Pressure}} \text{ x } 100\% = \frac{G(R_1\text{-}R_0)\text{-}P}{\text{F.S.}} \text{ x } 100\%$$

Equation 9 - Linearity Calculation

Note: The linearity is calculated using the regression zero for R_0 shown on the sheet.

For example, when P= 420 kPa, G ($R_1 - R_0$) = - 0.1795(6749-9082), gives a calculated pressure of 418.8 kPa. The error is 1.2 kPa equal to 122 mm of water.

Whereas the polynomial expression gives a calculated pressure of A $(6749)^2$ + B (6749) + 1595.7 = 420.02 kPa and the actual error is only 0.02 kPa or two millimeters of water.

Note: If the polynomial equation is used it is important that the value of C be taken in the field, following the procedures described in Section 2.3. The field value of C is calculated by inserting the initial field zero reading into the polynomial equation with the pressure, P, set to zero.

If the field zero reading is not available, the value of C can be calculated by using the zero pressure reading on the calibration sheet. In the above example the value of C would be derived from the equation 0 = $A(9074)^2$ + B(9074) from which C = 1595.7

It should be noted that where *changes* of water levels are being monitored it makes little difference whether the linear coefficient or the polynomial expression is used.