Model 4500 Series

Vibrating Wire Piezometer

Instruction Manual

GEOKON®

Document Revision: RR.2| Release date: 1/2/24

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1. INTRODUCTION

GEOKON Model 4500 Vibrating Wire Piezometers are intended primarily for longterm measurements of fluid depths and pore pressures in standpipes, boreholes, embankments, pipelines, and pressure vessels. Several different models are available to suit a variety of geotechnical applications. Calibration data is supplied with each piezometer.

All GEOKON vibrating wire piezometers utilize a sensitive stainless steel diaphragm (with the exception of model 4500C, which employs bellows) to which a vibrating wire element is connected. During use, changing pressures on the diaphragm cause it to deflect. This deflection is measured as a change in tension and frequency of vibration of the vibrating wire element. The square of the vibration frequency is directly proportional to the pressure applied to the diaphragm. A filter is used to keep out solid particles and prevent damage to the sensitive diaphragm. Standard filters are 50-micron stainless steel. High-air entry value filters are available upon request.

Two coils, one with a magnet insert, the other with a pole piece insert, are installed near the vibrating wire. In use, a pulse of varying frequency (swept frequency) is applied to these 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.

Portable readout units are available to provide the excitation, signal conditioning, and readout of the instrument. Datalogger systems, which allow remote, unattended data collection of multiple sensors, are also available. Contact GEOKON for additional information.

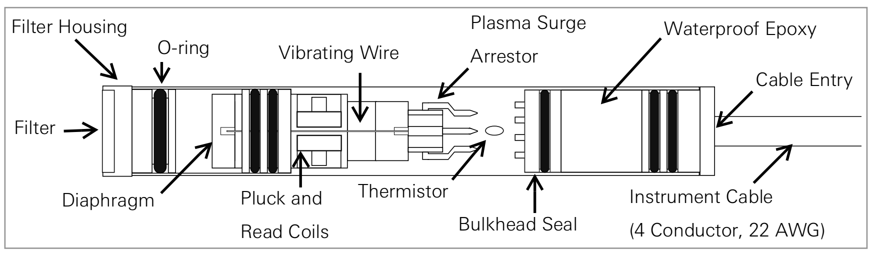

FIGURE 1: *Model 4500S Vibrating Wire Piezometer*

All exposed components are made of corrosion resistant stainless steel. If proper installation techniques are used, the device should have an unlimited life.

In salt water, it may be necessary to use special materials for the diaphragm and housing. The 4500INCO and 4500TI series piezometers are specifically designed to be used in this type of environment. For example, both models incorporate enhanced seals at the cable entry and filter connection; the 4500INCO uses a custom, dual O-ring seal, while the 4500TI is of an all-welded construction.

2. QUICK START INSTRUCTIONS

For those familiar with Geotechnical instrumentation and its installation, the following quick start instructions may be used. For more detailed instructions see Section 3.

1. Saturate the piezometer filter (see Section 3.1).

Warning! Do not allow the piezometer to freeze once the filter stone has been saturated!

2. Prior to installation, allow the piezometer to come to thermal equilibrium for a minimum of 15 minutes. (Alternatively, if the instrument is attached to a readout box, wait until the piezometer reading has stabilized.)
3. Record the piezometer reading, barometric pressure, and temperature while the piezometer is experiencing zero (atmospheric) pressure. This is what is known as the "initial zero" reading.
4. Verify that the initial zero reading for the piezometer is compatible with the factory supplied zero reading on the calibration report.
5. Carefully measure and mark the cable where it will lie at the top of the borehole, well, or standpipe, once the piezometer has reached the desired depth. (The piezo diaphragm lies 3/4 of an inch above the tip of the piezometer.)
6. For installation in standpipes or wells, see Section 4.1. For boreholes, see Section 4.2. For fills and embankments, see Section 4.3.

3. PRIOR TO INSTALLATION

3.1 SATURATING FILTER TIPS

Warning! Do not allow the piezometer to freeze once the filter stone has been saturated!

See Section 4.8 for information about protecting the piezometer from freezing.

Most filter tips can be removed for saturation and then reassembled. To maintain saturation, the unit should be kept underwater until installation. If the piezometer is used in a standpipe where it will be raised and lowered frequently, the filter housing may loosen over time, and a permanent filter assembly may be required. The removable filter may be fixed permanently by prick punching the piezometer tube approximately 1/16" to 1/8" behind the filter assembly joint.

Salts in the water can be deposited into the filter stone causing it to become clogged if it is allowed to dry out completely. Filter stones may be replaced with screens for standpipe installations. Screens available from GEOKON are less likely than standard filters to collect salt and become clogged.

3.1.1 SATURATING STANDARD FILTERS

For accurate results, total saturation of the filter is necessary. As the piezometer is lowered into the water, water is forced into the filter, compressing the air in the space between the filter stone and the pressure sensitive diaphragm. After a period, this air will dissolve into the water, filling the filter and the space above it entirely with water.

To speed up the saturation process, remove the filter from the piezometer by carefully twisting and pulling on the filter housing assembly (or unscrewing the point of the piezometer for model 4500DP). Hold the piezometer with the filter facing up and fill the space above the diaphragm with water. Slowly replace the filter housing, allowing the water to squeeze through the filter stone as it is installed. For piezometers with a range of less than 10 psi, take readings with a readout box while reinstalling the filter housing to ensure the piezometer is not over-ranged.

3.1.2 SATURATING HIGH AIR ENTRY CERAMIC FILTERS

Because of the high air entry characteristics of the ceramic filter, de-airing is particularly important. Different air entry values require different saturation procedures.

ONE BAR FILTERS

1. Remove the filter from the piezometer by carefully twisting and pulling on the filter housing assembly.
2. Boil the filter assembly in de-aired water.
3. Reassemble the piezometer under the surface of a container of de-aired water. Use a readout box while slowly installing the filter to monitor the diaphragm pressure. If the piezometer begins to over-range, allow the pressure to dissipate before pushing further.
4. Be sure that no air is trapped in the transducer cavity.

TWO BAR AND HIGHER FILTERS

The proper procedure for de-airing and saturating these filters is somewhat complex; therefore, it is recommended that saturation be done at the factory by GEOKON. If saturation must be done in the field, carefully follow the instructions below:

1. Place the assembled piezometer, filter down, in a vacuum chamber that has an inlet port at the bottom for de-aired water.
2. Close off the water inlet and evacuate the chamber. The transducer should be monitored while the chamber is being evacuated.
3. When maximum vacuum has been achieved, allow de-aired water to enter the chamber until it reaches an elevation a few inches above the piezometer filter.
4. Close off the inlet port.
5. Release the vacuum.
6. Observe the transducer output. It may take up to 24 hours for the filter to completely saturate and the pressure to rise to zero.
7. After saturation, the transducer should be kept in a container of de-aired water until installation. If de-aired at the factory a special cap is applied to the piezometer to maintain saturation.

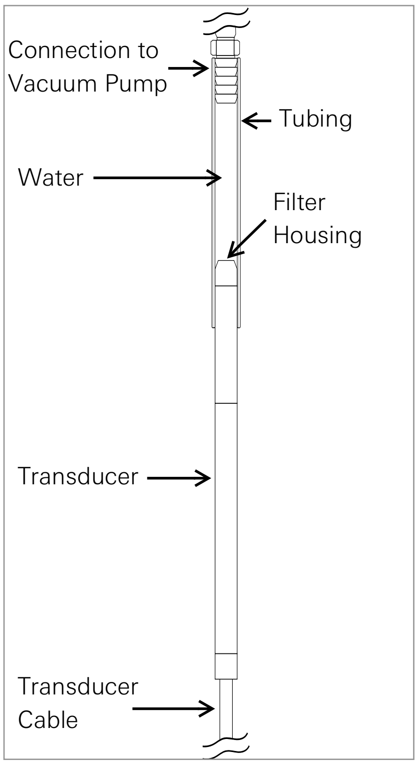

FIGURE 2: *4500C Saturation*

3.1.3 SATURATING MODEL 4500C FILTER TIPS

Warning! The filter housing is not removable on the 4500C. Any attempt to remove the filter stone or the housing will destroy the transducer!

If the pressure to be measured is less than 5 psi the filter stone must be saturated. A hand operated vacuum pump and short length of half inch surgical tubing is required. Hand pumps and tubing are available from the factory. (A hand pump that has been used successfully is the MityvacII® by Lincoln Industries Corp. of St. Louis, MO.)

The saturation procedure is as follows:

1. Attach the tube to the transducer as shown in Figure 2.
2. Fill the tubing with approximately two inches (five centimeters) of water.
3. Attach the other end of the tube to the hand vacuum pump.
4. While holding the transducer so that the water rests on the filter, but does not enter the pump, squeeze the hand pump to initiate a vacuum inside the tubing. This will draw the air out of the filter and the area behind it, replacing it with water. A vacuum of 20 to 25" Hg. (50 to 65 cm Hg.) is enough for proper air evacuation.

3.2 ESTABLISHING AN INITIAL ZERO READING

Vibrating wire piezometers differ from other types of pressure sensors in that they indicate a reading when no pressure is exerted on the sensor.

Note: 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. There are several different ways of taking an initial zero reading. The essential element in all methods is that the piezometer needs to thermally stabilize in a constant temperature environment while the pressure on the piezometer is barometric only. It usually takes the 15 to 20 minutes for the transducer to equalize in temperature.

A question may arise as to what to do with the filter stone while taking zero readings. It will not matter if the filter stone is saturated when using a standard stainless steel filter. However, if the piezometer is equipped with a ceramic high air entry filter stone, then it must be saturated while taking the zero readings.

It will be necessary to measure the barometric pressure only if the piezometer is unvented and it will be installed in a location that is subject to barometric pressure changes that would require correction, such as in an open well. In most instances, a piezometer sealed in place at depth will be affected by pressures in groundwater that is not hydraulically connected to the atmosphere, for which barometric pressure compensation would be inappropriate. See Section 6.3 for more information on Barometric corrections.

Calibration data is supplied with each gauge, a factory zero reading taken at a specific temperature and absolute barometric pressure is included. (See Section C for a sample calibration report.) Zero readings at the site should coincide with the factory readings within 50 digits, after barometric and temperature corrections are made. Barometric pressures change with elevation at a rate of approximately 3.45 kPa (1/2 psi) per 300 meters (1,000 ft). The factory elevation is +580 feet. All stated barometric readings represent absolute pressure uncorrected for height above sea level. A thermistor is included inside the body of the piezometer for the measurement of temperature.

NOTE REGARDING THE 4500C: The construction of this very slender vibrating wire transducer requires a miniaturization of the internal parts. **These transducers are delicate, handle with care during the installation procedure.** Despite taking every precaution to ensure that the transducer arrives unharmed, it is possible for the zero to shift during shipment due to rough handling. However, tests have shown that though the zero may shift, the calibration factors do not change. Therefore, it is doubly important that an initial load zero reading be taken prior to installation.

3.2.1 RECOMMENDED METHOD TO ESTABLISH INITIAL ZERO READING

1. Saturate the filter stone per Section 3.1.

Warning! Do not allow the piezometer to freeze once the filter stone has been saturated!

2. Replace the filter stone.
3. Hang the piezometer in the borehole at a point just above the water.
4. Wait until the piezometer reading has stopped changing.
5. Take the zero and temperature readings.

3.2.2 ALTERNATIVE METHOD ONE

1. Place the piezometer under water in a bucket.
2. Allow 15 to 20 minutes for the temperature of the unit to stabilize.
3. Use the instrument cable to lift the piezometer out of the water. Do not handle the piezometer housing; body heat from the hands could cause temperature transients.
4. Immediately take a zero and temperature reading.

3.2.3 ALTERNATIVE METHOD TWO

1. Allow 15 to 20 minutes for the temperature of the unit to stabilize.
2. Lift the piezometer by the cable only. Do not handle the piezometer housing; body heat from the hand could cause temperature transients.
3. Take a zero and temperature reading.

   (If using this method, be sure that the piezometer is protected from sunlight or sudden changes of temperature. Wrapping it in some insulating material is recommended.)

3.2.4 ALTERNATIVE METHOD THREE

1. Lower the piezometer to a known depth marked on the piezometer cable.(The diaphragm inside the piezometer is located approximately 15 mm (3/4") from the tip.)
2. Use a dip meter to accurately measure the depth to the water surface.
3. After temperature stabilization, read the piezometer pressure.
4. Using the factory calibration constants and a knowledge of the pressure of the water column above the piezometer (height times density), calculate the equivalent zero pressure reading if linear regression is used, or the factor C if the second order polynomial is used.

3.3 CHECKING THE PIEZOMETER PERFORMANCE

If a rough check of the piezometer performance is needed, the following procedure is recommended:

1. Lower the piezometer to a point near the bottom of a water-filled borehole, or below the surface of a body of water.
2. Allow 15 to 20 minutes for the piezometer to come to thermal equilibrium.
3. Using a readout box, record the reading at the current depth.
4. Raise the piezometer by a measured increment.
5. Record the reading on the readout box at the new depth.
6. Using the factory calibration factor, calculate the change in water depth.
7. Compare the calculated change in depth with the measured depth increment. The two values should be roughly the same.

ALTERNATIVE METHOD USING A DIP METER:

1. Lower the piezometer tip to a measured depth below the water surface.
2. Allow 15 to 20 minutes for the piezometer to come to thermal equilibrium.
3. Using a readout box, record the reading at that level.
4. Calculate elevation of the water surface using the given calibration factor.
5. Compare the calculated elevation to the elevation measured using the dip meter.

THINGS THAT CAN AFFECT THIS CHECKING PROCEDURE:

- If the density of the water is not one gram/cubic centimeter.
- If the water is saline or turbid.
- The water level inside the borehole may vary during the test. This is due to the displacement of water caused by the cable as it is raised and lowered in the borehole. The smaller the borehole is, the greater the displacement will be. For example, a Model 4500S-50KPA piezometer lowered 50 feet below the water column in a one-inch (0.875-inch ID) standpipe **will displace the water level by more than four feet.**
- Moisture on sidewalls of a casing can create friction that binds up the piezometer cable, such that it doesn't move freely to the designated depth. Additional weight can be added to the piezometer if this becomes an issue.

4. INSTALLATION

4.1 INSTALLATION IN STANDPIPES OR WELLS

1. Saturate the filter stone and establish an initial zero reading by following the steps outlined in Section 3.1 and Section 3.2.

Warning! Do not allow the piezometer to freeze once the filter stone has been saturated!

2. Mark the cable where the top of the well or standpipe will reside once the piezometer has reached the desired depth. (The piezometer diaphragm is located 3/4 of an inch above the tip of the piezometer.)
3. Lower the piezometer into the standpipe/well.
4. Be sure the cable is securely fastened to prevent the piezometer from sliding further into the well and causing an error in the readings.

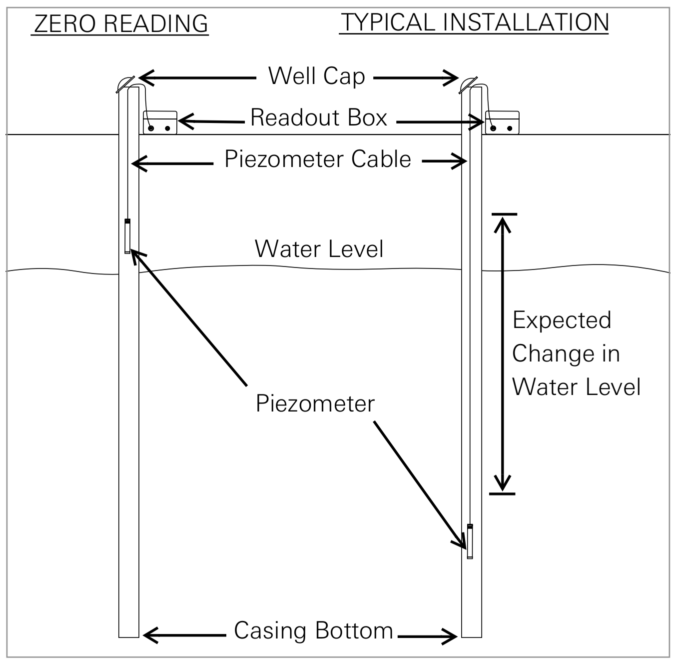

FIGURE 3: *Typical Level Monitoring Installation*

It is not recommended that piezometers be installed in wells or standpipes where an electrical pump or cable is nearby. Electrical interference from these sources can cause unstable readings. If unavoidable, it is recommended that the piezometer be placed inside a piece of steel pipe. In situations where packers are used in standpipes, special care should be taken to avoid cutting the cable jacket with the packer, as this could introduce a possible pressure leak in the cable.

4.2 INSTALLATION IN BOREHOLES

GEOKON piezometers can be installed in cased or uncased boreholes, in either single or multiple piezometer configurations. If pore pressures in a particular zone are to be monitored, careful attention must be paid to the borehole sealing technique.

The borehole should extend six to 12 inches below the proposed piezometer location. For installation methods A and B (below), if boreholes are drilled without using drilling fluid (mud), this drilling fluid should be of a type that degrades rapidly with time. Wash the borehole clean of drill cuttings.

Three methods of isolating the zone to be monitored are detailed below.

INSTALLATION A

Backfill the borehole with clean fine sand to a point at least six inches below the desired piezometer tip location. The piezometer can then be lowered into position. While holding the instrument in position, (a mark on the cable is helpful), fill the borehole with clean fine sand to a point at least six inches above the piezometer.

Immediately above the area filled with clean fine sand, known as the "collection zone", the borehole should be sealed by an impermeable bentonite cement grout mix, or with alternating layers of bentonite and sand backfill, tamped in place for approximately one foot, followed by cement-bentonite grout (see Figure 4).

If multiple piezometers are to be used in a single hole, the bentonite and sand should be tamped in place below and above the upper piezometers, as well as at interval between the collection zones. When using tamping tools special care should be taken to ensure that the piezometer cable jackets are not cut during installation, as this could introduce a possible pressure leak in the cable. For some installations, it may be cost effective to use a cement-bentonite grout between the multiple collection zones. It is recommended to hydrate the bentonite seals above and below the collection zones before placement of the grout.

INSTALLATION B

The borehole is filled from the collection zone upwards with an impermeable cement-bentonite grout. To keep the granular filter zone intact, care should be taken with this method to ensure that the grout does not bleed into the collection zone.

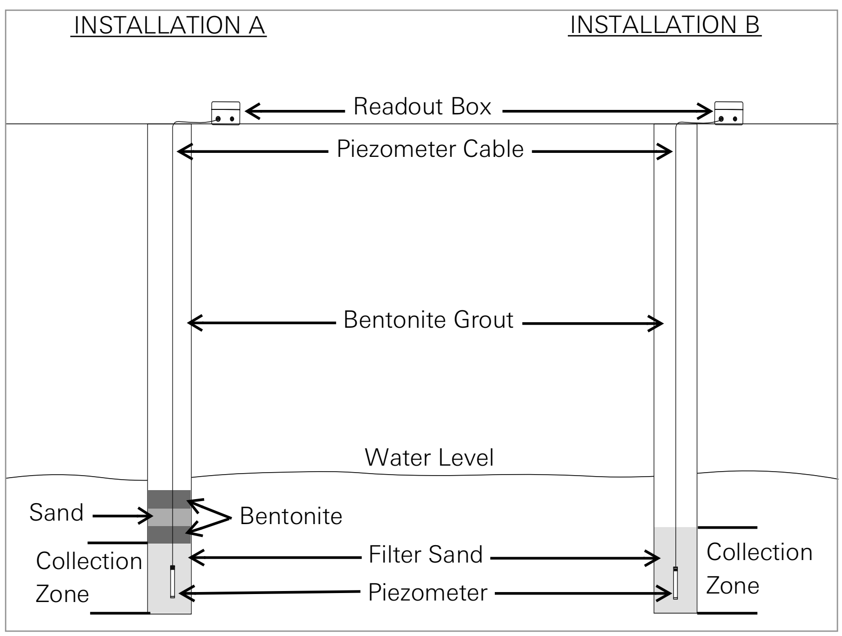

FIGURE 4: *Typical Borehole Installations*

INSTALLATION C

Since the vibrating wire piezometer is essentially a no-flow instrument, collection zones of appreciable size are not required. The piezometer can be placed directly in contact with most materials, provided that the fines are not able to migrate through the filter. As such, it is not necessary to provide collection zones of sand, the piezometer can be grouted directly into the borehole.

A cement-bentonite grout mix is suggested for backfilling a borehole. The cement-bentonite grout uses any kind of bentonite powder combined with Type I or Type II Portland cement. The exact amount of bentonite needed will vary.

Grout mixtures should be determined and adjusted to be of similar parameters to the surrounding soil. Throughout the depth of a borehole, the surrounding soil will typically not be all of the same strength and permeability. However, the use of several types of grout mixes within the same borehole may not be cost effective and practical. Unless it is necessary to do so, identify one type of grout mix that would be applicable to the entire length of the borehole.

The table below 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
Note:	The 28-day compressive strength of this mix is about 50 psi, similar to very stiff/hard clay. The modulus is about 10,000 psi.		The 28–day strength of this mix is about 4 psi, similar to very soft clay.	

TABLE 1: *Cement / Bentonite / Water Ratios*

Perform the following steps to mix the cement-bentonite grout:

1. Add the measured amount of clean water to the barrel then gradually add the cement in the correct weight ratio. Mix the cement thoroughly into the water.

   Tip: The most effective way of mixing the two substances is to use a drill rig pump to circulate the mix in a 50 to 200 gallon barrel or tub.

2. While mixing, slowly add the bentonite powder so that clumps do not form. Keep adding bentonite until the watery mix turns to a slimy consistency. Continue mixing for approximately five to 10 minutes to allow the grout to thicken.

3. Add more bentonite as required until it is a smooth, thick cream, similar to pancake batter, which is 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.

Warning! If the grout is pumped into the hole, rather than tremie piped, there is a danger that the piezometer will be over-ranged and damaged. Grout can also segretate if pumped into top of borehole, and may not fully backfill and encapsulate the piezometer. It is good practice to read the piezometer while pumping.

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.

4.3 INSTALLATION IN FILLS AND EMBANKMENTS

GEOKON piezometers are normally supplied with direct burial cable suitable for placement in fills such as highway embankments and dams, both in the core and in the surrounding materials.

For installations in non-cohesive fill materials, the piezometer may be placed directly in the fill, or, if large aggregate sizes are present, in a saturated sand pocket in the fill. If installed in large aggregate, additional measures may be necessary to protect the cable from damage.

Cables are normally installed inside shallow trenches with the fill material consisting of smaller size aggregate. This fill is carefully hand compacted around the cable. Bentonite plugs are placed at regular intervals to prevent migration of water along the cable path. In high traffic areas and in materials that exhibit pronounced "weaving", heavy-duty armored cable should be used.

Depending on the type of filter installed on the piezometer the material used and filter contact may vary.

STANDARD FILTER

In partially saturated fills (if only the pore air pressure is to be measured), the standard tip is satisfactory. It should be noted that the standard tip measures the air pressure when there is a difference between the pore air pressure and the pore water pressure. The difference between these two pressures is due to the capillary suction in the soil. The consensus is that the difference is normally of no consequence to embankment stability.

The standard tip is suitable for most routine measurements, and both the standard and high air entry installations shown in Figure 5 may be used.

HIGH AIR ENTRY (HAE) FILTER

In fills such as impervious dam cores, where subatmospheric pore water pressure may need to be measured, (as opposed to the pore air pressure), a ceramic tip with a high air entry value is often used. This type of filter should be carefully placed in direct contact with the compacted fill material. (See Figure 5).

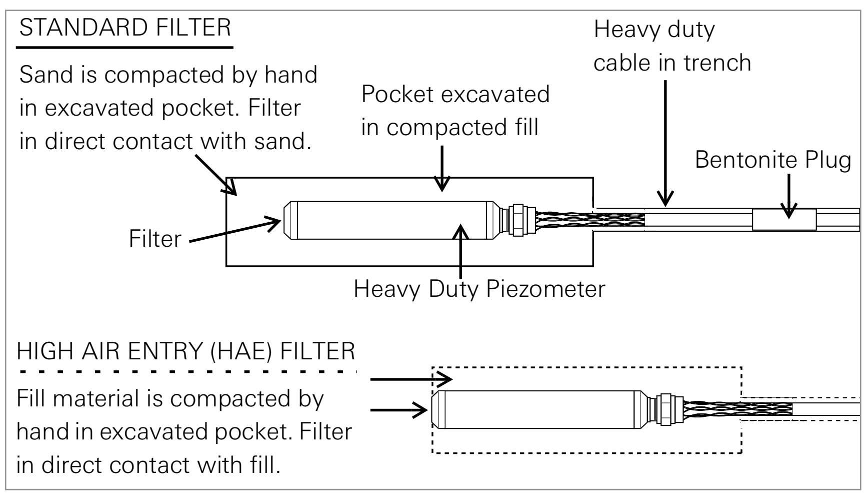

FIGURE 5: *Standard and High Air Entry Filters*

4.4 INSTALLATION BY PUSHING OR DRIVING INTO SOFT SOILS

The Model 4500DP piezometer is designed to be pushed into soft soils. In soft soils, it can be difficult to keep a borehole open. The 4500DP may eliminate the need for a borehole altogether. The unit is connected directly to the drill rod (AW, EW, or other) and pressed into the ground, either by hand or by means of the hydraulics on the rig (see Figure 6). GEOKON suggests these units not be driven into the soil, since there is a possibility that the driving forces may shift the zero reading.

The ground conditions need to be relatively soft for the 4500DP to be effective. Soft soils (like clays or silts) with SPT blow counts under 10 are ideal. In stiffer soils, it is possible to drill a hole and then push the 4500DP only a few feet below the bottom of the hole. If the soil is too stiff, the sensor may overrange or break.

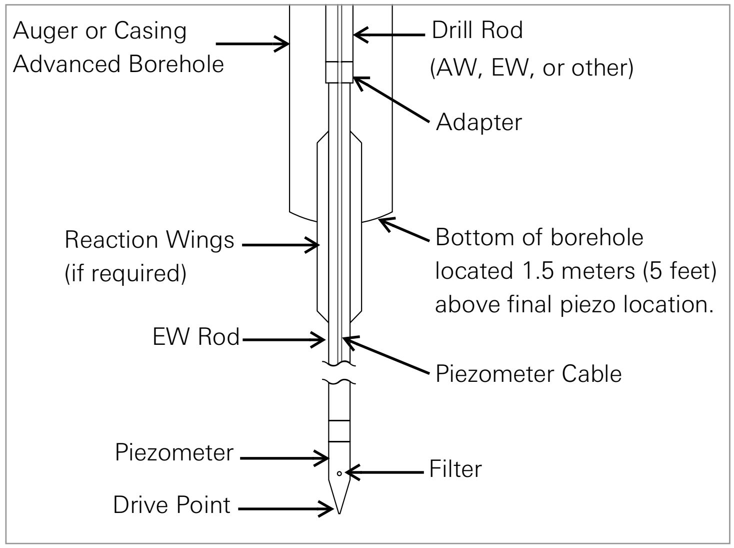

FIGURE 6: *Typical Soft Soils Installation*

The piezometer should be connected to a readout box and monitored during the installation process. If pressures reach or exceed the calibrated range, the installation should be stopped, and the pressure allowed to dissipate.

The drill rod can be left in place or it can be removed. If it is to be removed, a special five-foot section of EW (or AW) rod with reaction wings and a left-hand thread are attached directly to the piezometer tip. This section is detached from the rest of the drill string by rotating the string clockwise. The reaction wings prevent the EW rod from turning. A LH/RH adapter is available from GEOKON. This adapter is retrieved along with the drill string.

4.5 MODEL 4500H AND MODEL 4500HH TRANSDUCER

When connecting the Model 4500H transducer to external fittings, the fitting should be tightened into the 1/4-18 NPT female port by placing a wrench on the flats provided on the transducer housing. Avoid tightening onto a closed system; the process of tightening the fittings could overrange and permanently damage the transducer. If in doubt, attach the gauge leads to a readout box and take readings while tightening. For an easier and more positive connection to the transducer, PTFE (plumber's) tape on the threads is recommended. The maximum pressure for the 4500H is 3 MPa.

The GEOKON Model 4500HH is designed for high-pressure environments. This model uses a 7/16-20, 60-degree, female, medium pressure fitting. The maximum pressure for the 4500HH is 75 MPa.

Warning! All high-pressure sensors are potentially dangerous. Care must be taken not to overrange them beyond their calibrated range. Sensors are tested to 150% of their range to provide a factor of safety.

4.6 SPLICING AND JUNCTION BOXES

Because the vibrating wire output signal is a frequency rather than a current or voltage, variations in cable resistance have little effect on gauge readings. Therefore, splicing of cables has no effect, and in some cases may in fact be beneficial. For example, if multiple 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. This multi-conductor cable would then be run to the readout station. For these types of 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.).

Cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **When splicing, it is very important that the shield drain wires be spliced together.** Splice kits recommended by GEOKON incorporate casts that are placed around the splice and then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable in strength and electrical properties. Contact GEOKON for splicing materials and additional cable splicing instructions.

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

4.7 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 1).

Additional lightning protection measures available include:

- Placing a Lightning Arrestor Board (Model 4999-12L), in line with the cable, as close as possible to the installed piezometer (see Figure 7). 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 (Model 4999-12L) 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.

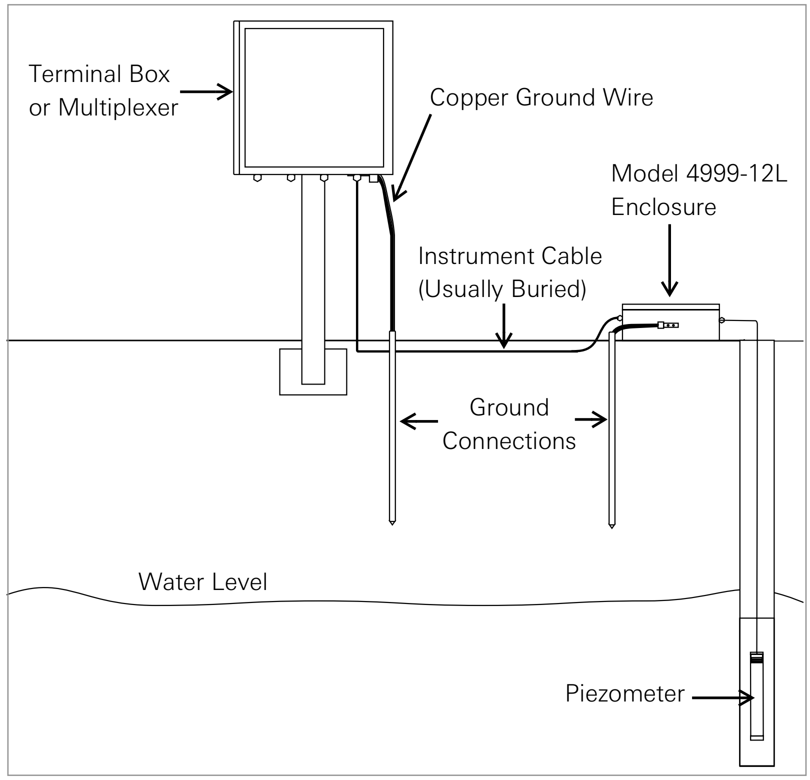

FIGURE 7: *Recommended Lightning Protection Scheme*

4.8 FREEZING PROTECTION

If the water around the piezometer freezes this could damage the piezometer diaphragm causing a large shift in the zero-pressure reading. If the piezometer is to be used in locations that are subject to freezing, GEOKON can provide a special modification that will protect the piezometer diaphragm.

5. TAKING READINGS

5.1 COMPATIBLE READOUTS AND DATALOGGERS

GEOKON can provide several readout and datalogger options. Devices compatible with this product are listed below. For further details and instruction consult the corresponding Manual(s).

DIGITAL READOUTS:

- **GK-404**

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

- **GK-406**

  The Model GK-406 is a field-ready device able to quickly measure a sensor, save data, and communicate results with custom PDF reports and spreadsheet output. Measurements are geo-located with the integrated GPS allowing the GK-406 to verify locations and lead the user to the sensor locations. The large color display and VSPECT™ technology create confidence of getting the best measurement possible both in the field and in the office.

DATALOGGERS:

- **8600 Series**

  The MICRO-6000 Datalogger is designed to support the reading of a large number of GEOKON Vibrating Wire instruments for various unattended data collection applications through the use of GEOKON Model 8032 Multiplexers. Weatherproof packaging allows the unit to be installed in field environments where inhospitable conditions prevail. The Nema 4X enclosure also has a provision for locking to limit access to responsible field personnel.

- **8800 and 8900 Series**

  The GeoNet Wireless Mesh Data Acquisition system consists of a Gateway and subordinate Wireless Mesh Data Loggers that transmit data collected from the connected sensors. The Gateway controls the network and is the aggregator of all the data from the Loggers in the system. The Cellular and Wi-Fi Gateways transfer the collected data to the GEOKON Cloud data storage platform, where it is securely stored and can be viewed in GEOKON Agent Software or exported to a third-party software platform through the Open API. A Local Gateway (no cellular or Wi-Fi capabilities) is available for applications where the data is to remain local or a third-party modem or ethernet connection is desired.

- **8920, 8930, and 8950 Series**

  GEOKON Model 8920, 8930, and 8950 Series Loggers offer a high-value, networked data collection option for all GEOKON Vibrating Wire instruments and digital sensor (MEMS IPI and VW) strings. Each logger comes from the factory ready for deployment and may commence with data acquisition in minutes.

Sensor data is collected and transferred via a cellular, Wi-Fi, or satellite network to a secure cloud-based storage platform where it can be accessed through the GEOKON OpenAPI. Industry leading data visualization software, such as Vista Data Vision, or the free GEOKON Agent program can be used with the OpenAPI for data viewing and reporting. Commissioning, billing and configuration are accomplished via the easy-to-use GEOKON API Portal.

- **8940 Series**

GEOKON Model 8940 Series Dataloggers offer a high-value data collection option for all GEOKON Vibrating Wire instruments and digital sensor strings. Waterproof single and four-channel GeoNet dataloggers housed inside rugged PVC enclosures are also available. Each logger is ready to be installed from the factory and acquires data in minutes.

Sensor data is collected on site by connecting the 8940 to a P.C. and using the free GEOKON Agent software program for data viewing and reporting.

5.2 MEASURING TEMPERATURES

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

The GK-404 and GK-406 readouts will read the thermistor and display the temperature in degrees Celsius.

USING AN OHMMETER TO READ TEMPERATURES:

Connect an ohmmeter to the green and white thermistor leads coming from the instrument. Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied equal to approximately 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions

Look up the temperature for the measured resistance in Appendix B.

6. DATA REDUCTION

6.1 PRESSURE CALCULATION

The digits displayed by the GEOKON Models GK-404 and GK-406 readouts on channel B are based on the equation:

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

EQUATION 1: *Digits Calculation*

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

Digits are directly proportional to the applied pressure, as can be seen by the following equation:

Pressure = (Current Reading - Initial Zero Reading) x 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% F.S., 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 Appendix C), 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_2O	m H_2O	"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_2O	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_2O	.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 approximate.

6.2 TEMPERATURE CORRECTION

The materials used in the construction of GEOKON vibrating wire piezometers have been carefully selected to minimize thermal effects; however, most units still have a slight temperature coefficient. Consult the calibration report 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 5.2 for instructions regarding obtaining the piezometer temperature.

The temperature correction equation is as follows:

Temperature Correction = (Current Temperature – Initial Zero Temperature) × Thermal Factor

Or

$$P_T = (T_1 - T_0) \times K$$

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 thermal factor.

6.3 BAROMETRIC CORRECTION (REQUIRED ONLY ON UNVENTED TRANSDUCERS)

Since the standard piezometer is hermetically sealed, 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 approximately one psi of error (or ≈ 2.3 feet if monitoring water level in a well). It is advisable to read and record the barometric pressure every time the piezometer is read. Having an onsite barometer also allows the monitoring of barometric changes to judge what extent they may be affecting the reading. A separate pressure transducer (piezometer), kept out of the water, may also be used for this purpose.

The barometric correction equation is as follows:

Barometric Correction = (Current Barometer – Initial Zero Barometer) × Conversion Factor

Or

$$P_B = (S_1 - S_0) \times F$$

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 in Section 6.1 lists other common conversion factors.

The user should be cautioned that this correction scheme assumes ideal conditions. 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 corrections is to use piezometers that are vented to the atmosphere (see Section 6.4). However, vented piezometers only make sense if the piezo is in an open well or standpipe and the user is only interested in the water level. If the piezo is buried it is not certain that the full effect of the barometric change will be felt immediately at the instrument and is more likely to be attenuated and delayed, in which case a vented piezo would automatically apply a correction that is too large and too soon.

The equation below 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*

6.4 MODEL 4500SV, VENTED PIEZOMETERS

FIGURE 8: *Vented Piezometers*

The Model 4500SV vented piezometer is designed to eliminate the effect of barometric pressure changes on water level measurements in wells, reservoirs, and boreholes that are connected directly to the atmosphere. They are better suited for water level monitoring applications, and typically not intended to be used to monitor pore pressures.

The space inside the transducer is not hermetically sealed and evacuated, as it is in the standard 4500 model piezometer, instead, it is connected via a tube (integral within the cable) to the atmosphere. A chamber containing desiccant capsules is attached to the outer end of this tube to prevent moisture from entering the transducer cavity. A 2.5 ft length of blue cable is spliced at the end of the tubing, this allows for a standard connection to a readout or datalogger as needed. Vented piezometers require more maintenance then unvented types, since there is always the danger that moisture may find its way inside the transducer and ruin it.

Installation of the piezometer is accomplished by lowering it to the desired level in the well, reservoir, or borehole. The piezometer can be placed inside a canvas bag filled with sand, if desired.

The desiccant capsule chamber needs to be positioned in some kind of housing to keep it dry. GEOKON can provide suitable housings on request.

To keep the desiccant fresh during storage and transportation, the end of the desiccant chamber is closed off by means of a seal screw before being 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.

6.5 ENVIRONMENTAL FACTORS

Since the purpose of the piezometer installation is to monitor site conditions, factors that can affect these conditions should always be observed and recorded. Seemingly minor affects 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.

7. 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

☐ Check for an open circuit. Check all connections, terminals, and plugs. If a cut is in the cable, splice according to instructions in Section 4.6.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

☐ Check for a short circuit. Check all connections, terminals, and plugs. If a short is in the cable, splice according to instructions in Section 4.6.

☐ 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.

☐ 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 over-ranging 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 readout with another gauge to ensure it is functioning properly.

☐ The piezometer may have been over-ranged or shocked. Inspect the diaphragm and housing for damage.

☐ Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Cable resistance is about 48.5Ω per km (14.7Ω per 1000'). If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the gauge conductors may be shorted. If a break or a short is present, splice according to the instructions in Section 4.6. Refer to the expected resistance for the various wire combinations below.

Vibrating Wire Sensor Lead Resistance Levels

Red/Black Coil Resistance values may vary for different model Gauges:

- Standard: ≅180Ω
- High Temp (HT): ≅100Ω
- 4500C: ≅100Ω

Green/White 3000Ω at 25 °C

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

Note: Tests should be performed with a quality multimeter to accurately show possibilities of shorts. Sensors should be disconnected from other equipment while performing resistance tests, this includes surge modules, terminals, multiplexers and dataloggers. Fingers cannot be touching the multimeter leads or sensor wires while testing.

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.

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

TABLE 3: *Sample Resistance*

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

TABLE 4: *Resistance Worksheet*

APPENDIX A. SPECIFICATIONS

A.1 4500 SPECIFICATIONS

Model	4500S	4500AL[1]	4500B	4500C	4500DP	4580
Available Ranges[2] (psi)	Refer to Model 4500 Series Datasheet					
Resolution	0.025% F.S.	0.025% F.S.	0.025% F.S.	0.05% F.S.	0.025% F.S.	0.01% F.S.
Linearity[3]	< 0.5% F.S.					
Accuracy[4]	0.1% F.S.					
Overrange	1.5 × Rated Pressure					
Thermal Coefficient	<0.025% F.S./°C	<0.1% F.S./°C	<0.025% F.S./°C	<0.05% F.S./°C	<0.025% F.S./°C	<0.025% F.S./°C
Temperature Range	-20 °C to + 80 °C					
Frequency Range	1400-3500 Hz					
OD	.75" 19.05 mm	1" 25.40 mm	.687" 17.45 mm	.437" 11.10 mm	1.3" 33.3 mm	1.5 / 2.5" 38.10 / 63.5 mm
Length	5.25" 133 mm	5.25" 133 mm	5.25" 133 mm	6.5" 165 mm	7.36" 187 mm	6.5" 165 mm

TABLE 5: *4500 Vibrating Wire Piezometer Specifications*

Notes:

Accuracy of test apparatus: 0.1%

Contact GEOKON for specific application information.

[1] Accuracy of test apparatus: 0.05%

[2] Other ranges available upon request

[3] 0.1% F.S. linearity available upon request

[4] Derived using second order polynomial

A.2 4500CR SPECIFICATIONS

Model	4500S / 4500INCO / 4500TI	4500SH / 450INCOH / 4500TIH	4500AL / 4500INCOAL / 4500TIAL
Available Ranges (kPa)	–100 to 350, 700 kPa; 1, 2, 3 MPa	0-100 to 5, 7.5, 10 20MPa	0-70 & 125KPa
Resolution	0.025% F.S.		
Linearity	< 0.5% F.S.		
Accuracy[1]	0.1% F.S.		
Overrange	1.5 × Rated Pressure		
Thermal Coefficient	<0.025% F.S./°C		
Temperature Range	–20 °C to + 80 °C		
Frequency Range	1400-3500 Hz		
Length x Diameter	133 x 19.05 mm / 5.25 x 75"	194 x 25.4 mm / 7.64 x 1"	194 x 25.4 mm / 7.64 x 1"

TABLE 6: *4500CR Vibrating Wire Piezometer Specifications*

Notes:

[1] Derived using second order polynomial

A.3 THERMISTOR

(See Appendix B also)

Range: –80 to +150 °C

Accuracy: ±0.5 °C

A.4 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 7: *Standard Piezometer Wiring*

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

Thermistor Types include YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3, and Honeywell 192–302LET–A01

Resistance to Temperature Equation:

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

EQUATION 6: *3KΩ Thermistor Resistance*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$
Note: Coefficients calculated over the –50 to +150 °C span.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	15.72K	-9	2221	32	474.7	73	137.2	114
187.3K	-49	14.90K	-8	2130	33	459.0	74	133.6	115
174.5K	-48	14.12K	-7	2042	34	444.0	75	130.0	116
162.7K	-47	13.39K	-6	1959	35	429.5	76	126.5	117
151.7K	-46	12.70K	-5	1880	36	415.6	77	123.2	118
141.6K	-45	12.05K	-4	1805	37	402.2	78	119.9	119
132.2K	-44	11.44K	-3	1733	38	389.3	79	116.8	120
123.5K	-43	10.86K	-2	1664	39	376.9	80	113.8	121
115.4K	-42	10.31K	-1	1598	40	364.9	81	110.8	122
107.9K	-41	9796	0	1535	41	353.4	82	107.9	123
101.0K	-40	9310	1	1475	42	342.2	83	105.2	124
94.48K	-39	8851	2	1418	43	331.5	84	102.5	125
88.46K	-38	8417	3	1363	44	321.2	85	99.9	126
82.87K	-37	8006	4	1310	45	311.3	86	97.3	127
77.66K	-36	7618	5	1260	46	301.7	87	94.9	128
72.81K	-35	7252	6	1212	47	292.4	88	92.5	129
68.30K	-34	6905	7	1167	48	283.5	89	90.2	130
64.09K	-33	6576	8	1123	49	274.9	90	87.9	131
60.17K	-32	6265	9	1081	50	266.6	91	85.7	132
56.51K	-31	5971	10	1040	51	258.6	92	83.6	133
53.10K	-30	5692	11	1002	52	250.9	93	81.6	134
49.91K	-29	5427	12	965.0	53	243.4	94	79.6	135
46.94K	-28	5177	13	929.6	54	236.2	95	77.6	136
44.16K	-27	4939	14	895.8	55	229.3	96	75.8	137
41.56K	-26	4714	15	863.3	56	222.6	97	73.9	138
39.13K	-25	4500	16	832.2	57	216.1	98	72.2	139
36.86K	-24	4297	17	802.3	58	209.8	99	70.4	140
34.73K	-23	4105	18	773.7	59	203.8	100	68.8	141
32.74K	-22	3922	19	746.3	60	197.9	101	67.1	142
30.87K	-21	3748	20	719.9	61	192.2	102	65.5	143
29.13K	-20	3583	21	694.7	62	186.8	103	64.0	144
27.49K	-19	3426	22	670.4	63	181.5	104	62.5	145
25.95K	-18	3277	23	647.1	64	176.4	105	61.1	146
24.51K	-17	3135	24	624.7	65	171.4	106	59.6	147
23.16K	-16	3000	25	603.3	66	166.7	107	58.3	148
21.89K	-15	2872	26	582.6	67	162.0	108	56.8	149
20.70K	-14	2750	27	562.8	68	157.6	109	55.6	150
19.58K	-13	2633	28	543.7	69	153.2	110		
18.52K	-12	2523	29	525.4	70	149.0	111		
17.53K	-11	2417	30	507.8	71	145.0	112		
16.60K	-10	2317	31	490.9	72	141.1	113		

TABLE 8: *3KΩ Thermistor Resistance*

B.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

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

EQUATION 7: *10KΩ Thermistor Resistance*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.127670 x 10^{-3}
B = 2.344442 x 10^{-4}
C = 8.476921 x 10^{-8}
D = 1.175122 x 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 9: *10KΩ Thermistor Resistance*

GEOKON

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4500S-350 kPa

Date of Calibration: November 09, 2023

This calibration has been verified/validated as of 11/13/2023

Serial Number: 2317618

Temperature: 20.80 °C

Calibration Instruction: CI-Pressure Transducer (7 kPa~3.5 MPa)

Barometric Pressure: 990.5 mbar

Cable Length: 40 feet

Technician: Dean O. Cowdery

Applied Pressure (kPa)	Gauge Reading 1st Cycle	Gauge Reading 2nd Cycle	Average Gauge Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	8888	8888	8888	0.467	0.13	0.008	0.00
70.0	8293	8293	8293	69.96	-0.01	69.99	0.00
140.0	7696	7696	7696	139.7	-0.07	140.0	0.01
210.0	7096	7097	7097	209.7	-0.09	210.0	-0.01
280.0	6494	6495	6495	280.0	0.00	280.1	0.01
350.0	5891	5892	5892	350.5	0.13	350.0	-0.01

(kPa) Linear Gauge Factor (G): -0.1168 (kPa/ digit)

Polynomial Gauge factors: A: -3.415E-07 B: -0.1118 C: ________

Thermal Factor (K): -0.1028 (kPa/ °C)

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

(psi) Linear Gauge Factor (G): -0.01694 (psi/ digit)

Polynomial Gauge Factors: A: -4.953E-08 B: -0.01621 C: ________

Thermal Factor (K): -0.01491 (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.

Factory Zero Reading: 8894 Temperature: 21.6 °C Barometer: 990.5 mbar

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.

APPENDIX D. IMPROVING THE ACCURACY OF THE CALCULATED PRESSURE

Most vibrating wire pressure transducers are sufficiently linear (±0.2% F.S.) 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% F.S.

This level of accuracy can be recaptured, even where the transducer is nonlinear, using 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 = The reading (digits channel B)
A, B, and C are coefficients
The figure under the "Linearity (%F.S.)" column on the calibration report is calculated as follows:

(Calculated Pressure - True Pressure) / Full Scale Pressure x 100%.

Or

$$\frac{G(R_1 - R_0) - P}{\text{Full Scale Pressure}} \times 100$$

EQUATION 9: *Linearity Calculation*

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

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 initial zero reading procedure. 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 report. 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.

APPENDIX E. PIEZOMETER PRESSURE AND WATER LEVEL

Frequently, when using a dip meter to check water levels in an open well, it happens that the water level, computed from a piezometer reading taken at the bottom of the well, does not agree with the water level measured directly by the dip meter. This will happen when the specific gravity of the water is not 1 gm/cc, the water is brackish or muddy, or both. It will also occur when there is a flow of water up or down the borehole. In addition, if the piezometer is removed to make room for the dip meter, the volume of the piezometer and cable displaces an equal volume of water, which can cause changes of the water level in a small diameter well.

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