Model 4660

VW Settlement System

Instruction Manual

GEOKON®

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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 that wear or are damaged by misuse are not warranted. This includes fuses and batteries.

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EQUATIONS

1. GENERAL DESCRIPTION

The 4660 VW Settlement System is designed to measure the differential settlement between two points. A reservoir is located at a stable reference point and is connected to a sensor located at the settlement point by two liquid filled tubes. The sensor senses the pressure of liquid within the tube. This provides a measure of the height of the liquid column, which in turn gives a measurement of the elevation difference between the reservoir and the sensor.

The sensor contains a thermistor for measurement of temperature, as wells as gas discharge tubes for protection against lightning damage. The cable contains a vent tube that connects the air inside the sensor to the space above the reservoir. This ensures that the sensor readings are unaffected by any changes in barometric pressure. A desiccant chamber located at the reservoir end of the vent line prevents moisture from migrating into the line. The figures below show the details of the sensor assembly with the vented signal cable attached. Note that the seal screw shown in Figure 1 should not be removed.

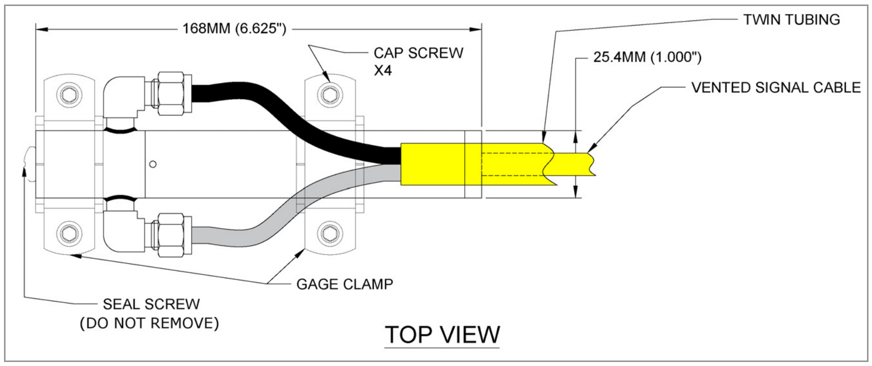

FIGURE 1: *Sensor Detail Top View*

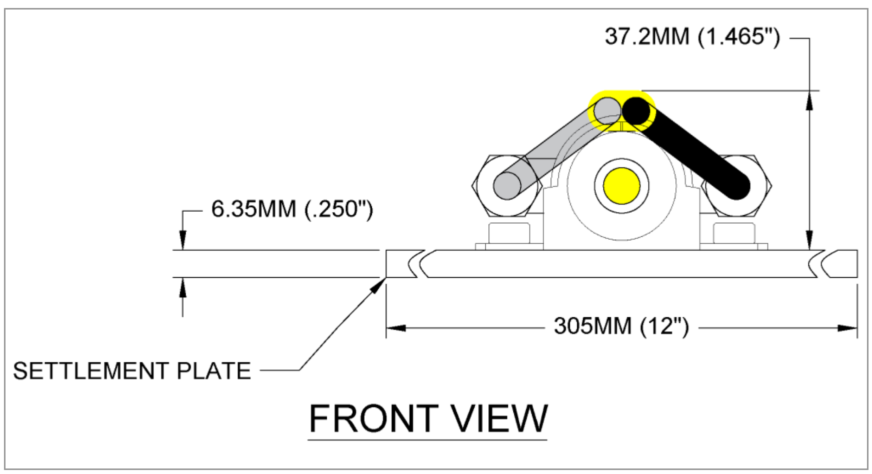

FIGURE 2: *Sensor Detail Front View*

Figure 3 below shows a typical installation used to measure the settlement inside an embankment. The sensor is read by means of an electrical cable extending to the readout location. Readout may be by any GK-404, GK-405, or CR-6 datalogger. The sensor contains a thermistor for measurement of temperature and has gas discharge tubes for protection against lightning damage. The cable also contains a vent tube that connects the air inside the sensor to the space above the reservoir. This ensures that the sensor readings are unaffected by any changes in barometric pressure. A desiccant chamber located at the reservoir end of the vent line prevents moisture from migrating into the line. Single and two-channel reservoirs (Models 4650-4A and 4650-4B) have a thermistor mounted to the back of the PCB inside the reservoir to record temperature changes at the readout terminal.

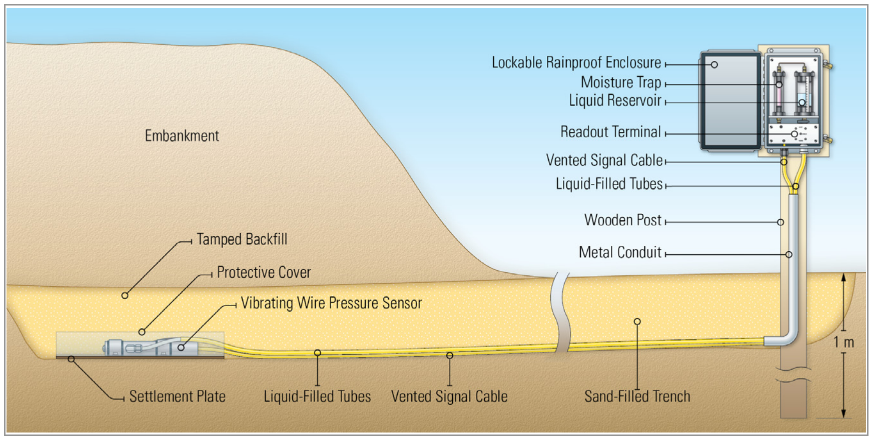

FIGURE 3: *Typical Installation of Vibrating Wire Settlement System*

The figure below shows details of a typical reservoir system. Two liquid filled tubes are provided for each sensor and more than one sensor can be connected to a single reservoir. The use of two liquid filled tubes permits the tubing to be flushed periodically to remove any accumulation of air bubbles. With this type of liquid settlement sensor, it is vital that there be no air bubbles in the liquid line. The liquid used is typically a de-aired antifreeze mixture, which resists the growth of algae and is not susceptible to freezing.

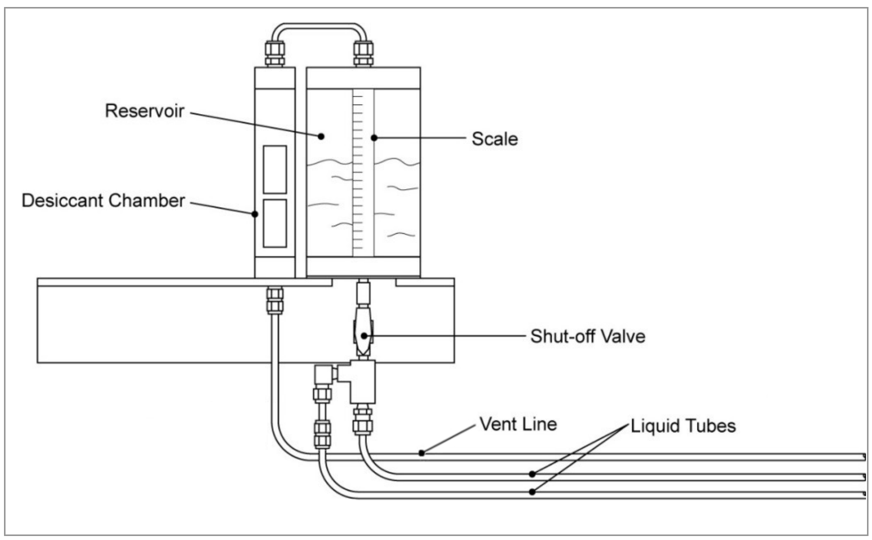

FIGURE 4: *Reservoir Details*

2. INSTALLATION PROCEDURES

Most installations are in fills and embankments where the sensor and cables are buried. Elsewhere the cables and sensors may be attached directly to structures undergoing settlement of heave. The reservoir location must always be at a higher elevation then the sensor and higher than any part of the liquid filled connecting tube.

Prefilled systems are usually delivered with de-aired antifreeze solution already in the liquid lines. An extra length of small diameter tubing is connected to the outer ends of the liquid lines to allow the system to breath during transportation while simultaneously protecting the sensor from being over-ranged by temperature or pressure fluctuations and preventing the entry of air bubbles into the main liquid lines.

Alternatively, systems may be provided with the tubing empty for filling in the field.

2.1 INSTALLING THE SENSOR

The sensor is usually attached to a settlement plate using the bracket(s) provided.

The settlement plate might be attached directly to a structure, using bolts. In the case of installation in fills, a smooth, flat-bottomed excavation should be made about 300 to 600 mm (12 to 24") deep. The sensor plate is placed on this flat surface and covered with fine material, similar to the fill, with all particles over 10 mm (0.4") in size removed. This material should be tamped down around the cell until the excavation is filled back to the original ground surface. The elevation of the settlement plate should be measured at the time of the installation using conventional level survey techniques. Check also that the sensor is still functioning after tamping.

2.2 INSTALLING THE CABLES AND LIQUID FILLED TUBES

Cables and tubing need to be placed in a trench approximately 300 to 600 mm (12 to 24") deep. The trench should not undulate, and individual cables and tubes should be laid side by side without touching or crossing each other. In no place should the tubing be higher than the reservoir location. Before backfilling the trench, examine the tubing for signs of air bubbles. If any are noted, the tubing will need to be flushed before initial readings are taken.

Compact the material in the trench around the cables. Do not allow large angular pieces of rock to rest directly on the cable. To prevent migration of water along the trench, bentonite plugs can be constructed at intervals.

Trenches in earth dam embankments should never penetrate entirely through the clay core. Compaction of the fill above the cables can proceed in a normal manner when the cover exceeds 600 mm (24") depth. Where cables are not buried, they should be adequately supported along their length to prevent undulations. They should also be protected from direct sunlight and insulated from rapid temperature fluctuations by encasing them in Styrofoam or urethane foam, etc.

2.3 INSTALLING THE RESERVOIR, CONNECTING THE SENSOR TUBES AND VENT TUBE

The reservoir should be installed on stable ground or at a location that can be level surveyed. The terminal housing should be affixed to stakes grouted firmly into the ground or preferably into a concrete pad poured at a location. The elevation of the reservoir pad should be surveyed and recorded at the time of installation. The reservoir should never be located where it is exposed to direct sunlight.

To fill the reservoir, first make sure that the valve at the bottom is closed, then completely remove the vent line Swagelok fitting from the top and half-fill the reservoir with antifreeze solution (supplied) using the syringe supplied. To avoid foaming, poke the tube from the syringe to the bottom of the reservoir and keep it below the surface of the liquid while filling.

The sensor tubes are shipped full of de-aired antifreeze solution. One tube is capped and to the other tube is attached a long, small-diameter breather tube which is also full of antifreeze solution. The purpose of the breather tube is to prevent air from entering the sensor tube during shipment while at the same time allowing the barometric pressure to equalize inside and outside the sensor. It ensures that when the cap and the breather tube are removed from the ends of the sensor tubing air is not sucked into the tubing by a built-up negative pressure. When connecting the tubes from the sensor to the reservoir do not allow air to be trapped inside the tubing.

INSTALLATION IS AS FOLLOWS:

1. With the reservoir valve closed, remove one of the caps from the fitting at the base of the reservoir, as well as the cap that does not have the breather tube from the end of the sensor tube.
2. Make sure that water is oozing out of the tube. Elevate the breather tube if necessary.
3. Open the reservoir valve slightly so that water dribbles out.
4. Connect the tube fitting to the mating reservoir fitting and tighten one turn only.
5. Remove the breather tube from the end of the other sensor tube. Make sure that water is oozing out of the tube.
6. Remove the second cap from the other fitting on the base of the reservoir.
7. Slightly open the reservoir valve.
8. While the water is dribbling out connect the second sensor tube fitting and tighten.
9. Remove the cap from the end of the vent line.
10. Make sure that the vent line to the sensor is not blocked. This can be checked using an aspirator bulb, (or simply by sucking), to draw a vacuum on the vent line while observing the sensor reading change on the GK-404 or GK-405 readout box.
11. Attach the vent line to the vent line manifold using the Swagelok fittings.

    Follow the instructions in Appendix D to ensure the Swagelok fittings are tightened properly!
12. Add fresh desiccant to the desiccant chamber (or the vent line manifold).
13. Add more liquid to the reservoir to bring up to the half-full point. A few drops of light oil added through the top of the reservoir will prevent evaporation from the liquid surface.
14. Reconnect the vent line fitting to the top of the reservoir.

2.4 SENSOR CONNECTION

2.4.1 SINGLE AND TWO-CHANNEL RESERVOIRS (MODELS 4650-4A & 4650-4B)

1. Slide the sensor cable(s) into the reservoir through the entry in the bottom of the enclosure.
2. Remove the PCB from the reservoir by unscrewing the four Phillips head screws that hold it in place.
3. Wire the conductors of the cable into the "Gauge 1" terminal block by pressing down on an orange tab, inserting the bare end of the conductor into the terminal block, and then releasing the tab. For two-channel models, repeat this process with the second sensor on the "Gauge 2" terminal block. Refer to Figure 5 and Table 1 below for sensor wiring information.

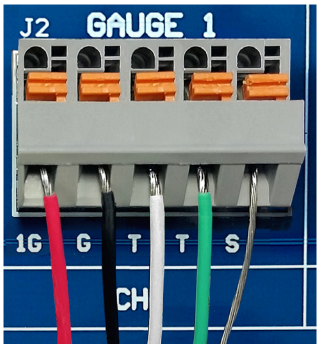

FIGURE 5: *Terminal Connections*

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Position	Color	Description
1G	RED	Vibrating Wire +
G	BLACK	Vibrating Wire -
T	WHITE	Thermistor +
T	GREEN	Thermistor -
S	BARE	Analog Ground (shield)

TABLE 1: *One & Two-Channel Sensor Wiring*

4. Gently pull on each conductor to make sure it is secure.
5. If a datalogger is being used, the "Logger" terminal block(s) and the "Local Therm" terminal block to the desired channels on the datalogger.
6. Reinstall the PCB into the reservoir.

2.4.2 THREE CHANNEL RESERVOIRS (MODEL 4650-4C)

1. Slide the sensor cables into the reservoir through the entry in the bottom of the enclosure.
2. Remove the switch plate from the reservoir by unscrewing the four Phillips head screws that hold it in place.
3. Remove the plastic bag of spade crimps from the back of the switch plate. Crimp a spade crimp onto the end of each conductor of all three sensors.
4. Wire each conductor of the sensors to the terminal strip by loosening a Phillips head screw, inserting the spade crimp of the conductor under the head of the screw, and then tightening the screw. The terminal strip wiring is shown in Table 2 and Figure 6.
5. Reinstall the PCB into the reservoir.

Gauge #	Position	Color	Description
1	1G	RED	Vibrating Wire +
1	G	BLACK	Vibrating Wire -
1	T	WHITE	Thermistor +
1	T	GREEN	Thermistor -
1	S	BARE	Analog Ground (shield)
2	2G	RED	Vibrating Wire +
2	G	BLACK	Vibrating Wire -
2	T	WHITE	Thermistor +
2	T	GREEN	Thermistor -
2	S	BARE	Analog Ground (shield)
3	3G	RED	Vibrating Wire +
3	G	BLACK	Vibrating Wire -
3	T	WHITE	Thermistor +
3	T	GREEN	Thermistor -
3	S	BARE	Analog Ground (shield)

TABLE 2: *Three & Four-Channel Sensor Wiring*

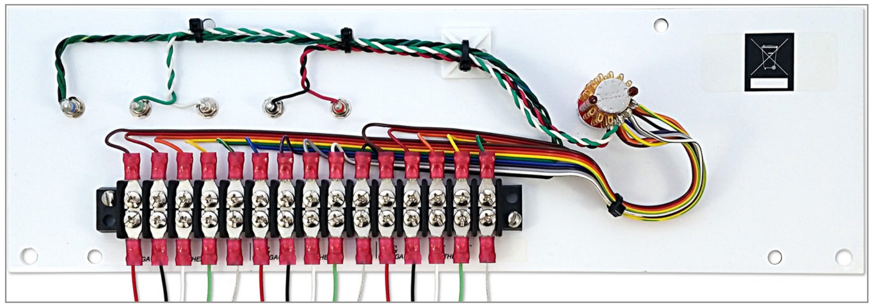

FIGURE 6: *Switch Panel Wiring*

2.5 INITIAL READINGS

Initial readings must be taken with great care; they are the base line readings to which all subsequent readings are compared. For optimum accuracy, allow 2 – 3 weeks for the system to stabilize (to permit the underlying soil to accommodate the self-weight of the sensor and tubing, and for the post supporting the reservoir to achieve fixity) before taking the initial reading R_0.

It is also important to allow the system to come to thermal equilibrium, and that the liquid filled tubes be at a constant temperature. If the tubes are not completely buried the readings should be taken at a time when the temperature is relatively constant (first thing in the morning, before sun up). Readings should never be taken when the tubes are exposed to direct sunlight. In addition, there should be no air bubbles in the liquid tubes. If air bubbles are detected the tubes should be flushed before the initial readings are taken. If there is any doubt, take readings, flush the tubing, and take readings again. Repeat if necessary, until the readings are stable. (See Section 3 for readout instructions.) Always record the ambient temperature when taking readings.

Take careful measurement of the elevation of the liquid level inside the reservoir sight tube. Make a mark on the tube opposite the liquid level. This will serve as a quick visual check on any fluctuations and enable a quick means of measuring the magnitude of the change. For correction of subsequent calculations of settlement, see Section 4. (Reservoir level fluctuations may be due to temperature or pressure fluctuations or due to leakage.)

3. TAKING READINGS

3.1 GK-404 VIBRATING WIRE READOUT

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

FIGURE 7: *GK-404 Readout*

3.1.1 OPERATING THE GK-404

FIGURE 8: *Lemo Connector to GK-404*

1. Attach the flying leads by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 8). Insert the Lemo connector into the GK-404 until it locks into place.
2. Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).
3. To turn on the GK-404, press the **On**/**Off** button on the front panel of the unit. The initial startup screen will display.
4. After a delay, the GK-404 will start taking readings and display them based on the settings of the **Pos** and **Mode** buttons.

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

- The current position: set by the **Pos** button, displayed as A through F.
- The current reading: set by the **Mode** button, displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached instrument in degrees Celsius.

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

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

For more information, consult the GK-404 manual.

3.2 GK-405 VIBRATING WIRE READOUT

The GK-405 Readout is made up of two components:

- The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout application.
- The GK-405 Remote Module, which is housed in a weather-proof enclosure.

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

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

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

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

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

FIGURE 9: *GK-405 Readout*

3.2.1 CONNECTING SENSORS WITH 10-PIN BULKHEAD CONNECTORS ATTACHED

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector, labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

3.2.2 CONNECTING SENSORS WITH BARE LEADS

Attach the flying leads to the bare leads of a GEOKON vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.3 OPERATING THE GK-405

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

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

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

Set the Display mode to . For more information, consult the GK-405 Instruction Manual.

3.3 MEASURING TEMPERATURES

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

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

TO READ TEMPERATURES USING AN OHMMETER:

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

4. DATA REDUCTION

4.1 CALCULATION OF SENSOR ELEVATION

Readings can be used to calculate the elevation of the sensor and to plot them on a graph versus time. The graph should also show the elevation of the fill above the sensor at the time of each reading. A plot of temperature can also be included. For the standard 4660 settlement system, using type 4500SV or 4500ALV transducers, the readings will get smaller as the sensors settle relative to the reservoir.

For these sensors, the elevation (E) of the sensor is given by:

$$E = E_0 - (R_1 - R_0)\,G + \Delta E_{RES}$$

EQUATION 1: *Elevation*

Where:
E_0 is the sensor elevation at installation.
ΔE_{RES} is any change of the fluid level inside the reservoir sight glass.
(If the fluid level falls, ΔE_{RES} is negative. If the fluid level rises, ΔE_{RES} is positive.)
R_0 is the initial sensor reading.
R_1 is the subsequent sensor reading.
G is the calibration factor supplied with the sensor. (A typical calibration report supplied by the factory is shown in Figure 10.)

Please note: The calibration report shown in Figure 10 was developed using a simple manometer and is good only over a range of three meters (ten feet) height differential between reservoir and sensor. If this range is exceeded by the initial setup, or by large amounts of settlement, then there are two options:

1. Continue to use the calibration report shown in Figure 10.
2. Use the second calibration report, supplied with the equipment, which was developed by calibrating the pressure sensor over a wider range**.**

For Example:
If:
E_0 = 541.62 meters
R_0 = 9030 digits
R_1 = 8800 digits
G = -0.001765 meters/digit
ΔE_{RES} = –10 mm (i.e. the level of water in the reservoir sight tube is 10 mm lower than the level measure at the time of the initial reading).

Then the new sensor elevation equals:
$E = 541.62 - [(8800 - 9030) \times -0.00175] + (-0.010)$
$E = 541.204$ meters
In other words, there has been a settlement of 0.416 meters.

4.2 CORRECTION FOR SETTLEMENT OR HEAVE OF THE RESERVOIR TERMINAL

Periodic level surveys should be made of the elevation of the concrete pad on which the reservoir terminal is located. Any measured settlement of the reservoir should be subtracted from the calculated sensor elevations.

4.3 CORRECTIONS FOR TEMPERATURE

Temperature effects on liquid volume (liquid density) and on the expansion and contraction of the liquid confines can be quite complex and, in some ways, self-canceling. Liquid lines in fills are generally well insulated so that temperature effects tend to be insignificant. Systems exposed to the atmosphere and to sunlight may suffer from rapidly changing temperatures at different parts of the system causing significant fluctuation of the readings. In such cases, precautions may be necessary to obtain readings at times of maximum temperature stability, and/or to apply "system temperature corrections", as described below.

Temperature effects on the sensor can be corrected for but are usually quite insignificant, especially if the sensor is buried, and can be ignored in most cases.

The elevation (E_T) corrected for changes in sensor temperature is given by:

$$E_T = E_0 - [(R_1 - R_0)\ G + (T_1 - T_0)\ K] + \Delta E_{RES}$$

EQUATION 2: *Elevation, corrected for temperature*

Where:
T_0 is the initial temperature.
T_1 is the current temperature.
K is the temperature correction factor included on the calibration report.

A thermal factor for the sensor alone is given on the calibration report. A thermal factor for the entire system could be determined empirically by measuring the temperature as well as the sensor outputs at times when no settlement is taking place and then calculating the K factor from the slope of the line of a plot of temperature v readout digits x gauge factor.

In practice, system temperature corrections are more effective in minimizing the effects due to changing temperatures. A system temperature correction factor is detemined empirically, by measuring the temperature of the reservoir (using the thermistor so provided) at 2 or 3 times (or more) different ambient temperatures, along with the corresponding sensor readings, at times where no settlements taking place. The system temperature correction factor is then determined from the slope of the line from a plot of temperature vs sensor reading x the calibration factor (provided on the calibration sheet).

Where systems are connected to dataloggers, apply system correction factors rather than sensor temperature correction factors. Do this by connecting the thermistor in the reservoir to the datalogger via a separate cable,by using a 3-pair cable from the reservoir to the datalogger, or by simply ignoring the sensor thermistor (by disconnecting its green and white leads), and connecting the reservoir in its place (see Section 2.4).

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

Settlement System Calibration Report

This Calibration has been Verified/ Validated as of: August 25, 2017

Model Number: 4660-1-70 kPa

Calibration Date: August 24, 2017

Serial Number: 1727453

Temperature: 21.4 °C

Transducer Range: 70 kPa

Calibration Instruction: CI-4600-4650

Tubing: 100 ft.

Technician:

Cable: 100 ft.

*tubing filled and gage calibrated with 50 / 50 mix water/anti-freeze, specific gravity 1.0446

Height of Water Column m	Reading GK 401-404 Readout Pos. B	Difference
0.5	9446.0	
1.0	9164.0	282.0
1.5	8880.5	283.5
2.0	8597.5	283.0
2.5	8315.0	282.5
3.0	8029.0	286.0

Calibration Factor G: -0.001765 m / digit

Calibration Factor G: -0.00579 ft. / digit

Thermal Factor K: 0.00455 m / °C

Thermal Factor K: 0.01494 ft. / °C

DO NOT EXCEED 7 m (23 feet) BETWEEN RESERVOIR & TRANSDUCER

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

The above instrument was found to be In Tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 10: *Typical Calibration Report*

5. TOOLS AND PROCEDURES

5.1 SPECIAL TOOLS AND APPARATUS REQUIRED FOR TEST PROCEDURES

- GK-404 or GK-405 Readout Box
- Assorted wrenches
- Nitrogen supply cylinder with regulator valve
- Pressure tanks filled with de-aired liquid (50% antifreeze solution made with distilled water and containing dye)
- Vacuum pump and rubber connecting hoses with pinch clamps
- Motor generator (Gasoline powered)
- Auxiliary reservoir
- Miscellaneous connecting tubes and fitting

5.2 FLUSHING PROCEDURES

Periodic flushing of the liquid filled tubes may be required to remove air bubbles. A 300 meter (1,000 foot) length of tubing requires 2.5 liters (0.67 gallons) of liquid. Tubes should always be filled with de-aired liquid. Dye, such as red food coloring, can be added to the new flushing fluid to indicate when the flushing is complete.

The best way to de-air a liquid is to use a Nold DeAerator (ask Geokon for more details). De-aired liquid is also available from Geokon in two gallon or five-gallon pressure tanks specially designed to prevent air from reaching the fluid. The liquid should also resist the growth of algae and should not be liable to freeze in cold climates. The growth of algae can be prevented by dissolving a crystal of copper sulfate in the liquid or by using commercial grade ethylene glycol solutions, which also prevent freezing. The use of distilled water, rather than tap water, is recommended. The figure below shows the apparatus recommended for flushing the tubes.

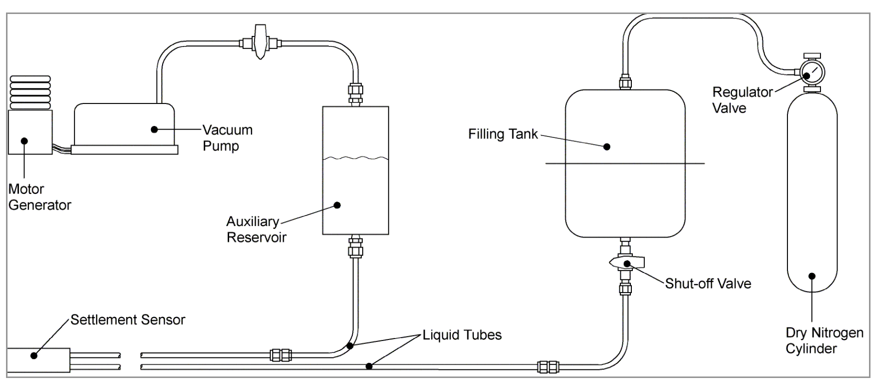

FIGURE 11: *Flushing Apparatus*

Note: A hand pump can be used in place of the nitrogen cylinder.

1. Close the shut off valve at the base of the reservoir.
2. Disconnect one of the tubes and then reconnect it to the base of a filling tank that is filled with de-aired liquid.

3. The second tube is disconnected and attached to the base of an auxiliary reservoir. (For tubes longer than 200 meters (650 feet), attach a vacuum pump to the top of the auxiliary reservoir to hasten the flushing process.)
4. Connect a nitrogen cylinder with regulator to the top of the filling tank.
5. Start the vacuum pump running then open the valve at the bottom of the pressure tank.
6. Adjust the nitrogen pressure until the settlement sensor reads at its maximum range value on the Readout Box. (See Section 3 for Readout instructions.) Be careful not to over range the sensor by more than 20%.

   CAUTION! Do not allow the nitrogen pressure to exceed the pressure rating marked on the outside of the filling tank (usually 100 psi (700 kPa). Failure to observe this precaution could result in injury.
7. Continue flushing until all the old liquid has been removed. (As flushing proceeds, the auxiliary reservoir may need to be emptied periodically.)
8. Store the flushed liquid in a container for later disposal. Do not allow any liquid to enter the vacuum pump as this could ruin it.
9. When flushing is complete, reconnect the fluid lines to the base of the reservoir. **Be careful not to introduce air bubbles during this process.**

5.3 PURGING THE VENT LINES

The vent line must always remain open because it connects the inside of the sensor to the space above the reservoir. Any blockage of the vent line due to pinching, dirt, or moisture will cause false readings that fluctuate and/or are sensitive to temperatures.

Blockages due to pinched tubes can be confirmed by applying a vacuum to the vent line and observing the reading on the sensor. If the sensor does not respond the tube is blocked by dirt or pinched, and this might be correctable if the blockage is accessible. Blockages due to moisture and condensation can be purged using a vacuum pump to evacuate the vent line. As the vacuum is applied watch for signs of water in the vent line. When the vacuum has stabilized, stop the pump, disconnect the vent line, and quickly reattach either a desiccant chamber containing fresh desiccant, or a cylinder of dry nitrogen. This ensures that the gas drawn back into the vent line is dry. Make sure the vent line connection is open between the desiccant chamber (or vent line manifold) and the top of the reservoir.

6. IN SITU CALIBRATION

A valuable feature of the Model 4660 settlement system is the ability to perform in situ calibrations. Do this by connecting an auxiliary reservoir to one of the fluid lines, as shown in the figure below.

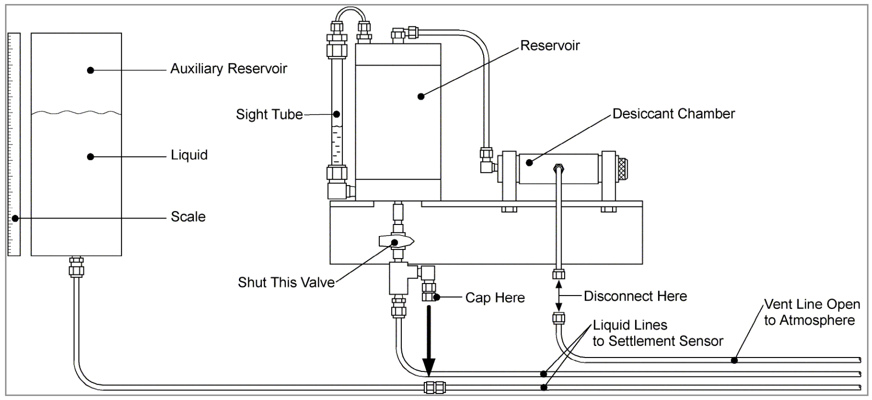

FIGURE 12: *In Situ Calibration Apparatus*

First close off the valve at the bottom of the reservoir, half-fill the auxiliary reservoir with the same liquid used in the reservoir and connect it via a short length of tubing to one of the fluid lines, being careful not to introduce air into the lines. Cap off the open fitting on the reservoir connection and disconnect the vent line from the vent manifold. Raise and lower the auxiliary reservoir by measured amounts using a scale to measure the elevation of the water level.

Read the sensor using a GK-404 or GK-405 readout box. (See Section 3 for readout instructions.) Record the readings after allowing sufficient time for the readings to stabilize (usually requires around one to five minutes although it will be noted that the sensor responds instantaneously to change of water elevation even where the liquid tubes are very long.) Record the sensor readings at five or more different elevations, then, from the data calculate the calibration factor and compare it with the factory generated value on the calibration report.

Remove the auxiliary reservoir and reconnect the fluid line to the base of the reservoir and the vent line to the desiccant chamber or vent line manifold. Reopen the valve at the base of the reservoir.

6.1 IN SITU ZERO CHECK

This procedure is not recommended as a regular procedure but only one to be undertaken if there is some serious doubt as to the zero stability of the sensor or to confirm a sudden or critical change in the amount of settlement which is causing concern.

Disconnect the vent line from the desiccant chamber. Close the valve at the bottom of the reservoir. Disconnect the liquid lines from the bottom of the reservoir connect one of them to a nitrogen cylinder. Turn on the nitrogen and adjust the pressure so that the sensor reading is at its maximum value. (Do not exceed 20% above this maximum range.) The other tube can be left open (with long lengths of tubing (>200 m) the process can be speed up by attaching a vacuum pump to the end of the other fluid line.) Once all the liquid has been purged from the lines, allow the nitrogen to flow for another 30 minutes. This will tend to dry out the inside of the tubing. Turn off the nitrogen and disconnect the ends of the tubing so that they are both open to atmosphere along with the open vent line. Wait until the sensor reading stabilizes and then record this zero reading. Compare this reading with the factory zero reading shown on the calibration chart.

Refill the liquid lines following the flushing procedures described in Section 5.2 with the following difference: If a vacuum pump is used, allow the vacuum pump to run for 30 minutes (or until the sensor reading has stabilized), before opening the valve at the bottom of the filling tank to allow liquid to enter the lines. This will greatly reduce the chances of air being trapped inside the tubing and sensor cavities.

7. MAINTENANCE AND TROUBLESHOOTING

7.1 MAINTENANCE

EVERY 3 MONTHS:

- ☐ Conduct a visual examination of the reservoir terminal housing. Check for leaks by observing the water level in the reservoir sight tube. Add additional fluid as necessary by removing the top connector of the Tygon sight tube. Alternatively, if the water level in the reservoir begins to rise this may be due to squeezing of the tubing by ground pressures. It is important not to let the fluid overflow from the reservoir into the vent line; this could adversely affect the readings. Drain off any excess fluid before it reaches the top of the reservoir. If regular maintenance is not possible then it is advisable to disconnect the tubing connecting the top of the reservoir to the desiccant chamber and leave them both open to the atmosphere.
- ☐ Replace the desiccant capsules in the vent line manifold or desiccant chamber. Desiccant capsules are dark blue when active and pink when inactive.

EVERY 12 MONTHS:

- ☐ Flush the liquid tubes with fresh de-aired liquid.
- ☐ Check the in situ calibration as described in Section 6.

7.2 TROUBLE SHOOTING

Faulty readings may show up as unstable, fluctuating readings, sudden large changes of readings or readings of 9999 on dataloggers, unrelated to physical phenomena. The first task should be to see if the fault lies with the readout device. If a datalogger is in use, try reading the sensors with a portable GK-404 or GK-405 Readout box.

7.2.1 UNSTABLE READINGS

Unstable readings with dataloggers may be caused by electrical noise from nearby power lines or electrical equipment. Remove such equipment, if possible, or read the sensors when the power is switched off.

Fluctuating readings may also be the result of air bubbles in the liquid lines or of plugged vent lines. Follow the procedures outlined in Section 5.2 and Section 5.3.

7.2.2 READING OF 9999

These will show up on dataloggers if the reading is overrange. This can happen if the electrical leads are shorted or open. Check the resistance between the black and red conductors. The resistance should be 180 ohms ±10 ohms plus five ohms for every 100 meters (328 feet) of lead wire. If the resistance is substantially different from these values check for loose connections in the terminal box and for visible signs of cable damage.

7.2.3 SUDDEN OR LARGE CHANGES IN READINGS

Large or sudden changes in readings may be caused by leakage of liquid from the liquid lines. Check the reservoir sight tube. If leakage is detected and there is more than one sensor connected to the reservoir turn off each sensor valve at the base of the reservoir one by one until the leaking sensor is found. If preferred this sensor can be left isolated from the system so that it will not to disrupt the others.

APPENDIX A. SPECIFICATIONS

A.1 MODEL 4660 VW SETTLEMENT SENSOR

Standard Ranges[1]	7, 17 m
Resolution	0.025% F.S.
Sensor Accuracy[2]	± 0.1% F.S.
Temperature Range[1]	-20 °C to +80 °C (-4 °F to +176 °F)
Length x Diameter	Reservoir: 152 x 51 mm (6 x 2") Sensor: 168 x 25 mm (6.6 x 1")
Length x Width x Height	Plate: 305 x 305 x 6 mm (12 x 12 x 0.24") Cover: 305 x 127 x 45 mm (12 x 5 x 1.8")
Frequency Range	1400-3500 Hz
Electrical cable	Model 02–335VT8, two shielded pairs 22 gauge with ground wire and integral 3.175 mm (1/8") diameter polyethylene vent tube. 9.525 mm (3/8") diameter polyurethane jacket. Resistance 5.25 ohm/100 m (14.7 ohms/1000 ft.).
Liquid tubes	Twin type 11 nylon tubes 6.35 mm (1/4") O.D. covered with one-millimeter polyethylene jacket.
Liquid	A de-aired 55/45 solution of distilled water mixed with commercial grade propylene glycol. Specific gravity = 1.041. Freezing point is –30 °C (-22 °F).
Desiccant Capsules	Geokon Model 4500-8

TABLE 3: *Specifications*

[1] Other ranges available on request.

[2] Laboratory accuracy. Total system accuracy is subject to site-specific variables.

A.2 THERMISTOR

Range: -80 to +150° C (-112 to +302 °F)

Accuracy: ±0.5° C (0.9 °F)

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

Thermistor Types:

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

Resistance to Temperature Equation:

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

EQUATION 3: *3kΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

$A = 1.4051 \times 10^{-3}$

$B = 2.369 \times 10^{-4}$

$C = 1.019 \times 10^{-7}$

Note: Coefficients calculated over the –50 to +150 °C span.

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

TABLE 4: *3KΩ Thermistor Resistance*

APPENDIX C. SPLICING 4660 SETTLEMENT SENSOR TUBING AND CABLE

C.1 REPLACING A TRANSDUCER

The most critical aspect of this operation is making sure that no air is allowed to get into the liquid lines.

The first step is to remove the faulty sensor by cutting both the liquid line and the cable from the faulty sensor using the procedures below.

C.2 LIQUID LINE

Extreme care must be exercised during this operation. The first step is to carefully strip a section of the outer (yellow) jacket off the tubing bundle to in preparation for splicing to the new sensor. This is a somewhat delicate operation as the jacket is tightly wrapped around the inner tubes. Practice the operation first on a waste piece of tubing bundle.

The new sensor should have the union already attached and ready to accept the tubing. Check to see that the sections of exposed tubing (including the part that must be prepared for the connection) will be short enough to fit into the splicing kit, and the outer jacket will be in the epoxy when finished.

Be sure that the reservoir water level is maintained during the splicing operation and that the balance tube is disconnected from the top of the reservoir.

1. Cut one of the tubes about 50 mm (2") beyond the yellow jacket and immediately block the end so that no fluid can flow.
2. Place the correct nut and ferrule pack over the end of this tube, and then block the flow.
3. Next, remove the cap from one of the lines on the replacement sensor and make sure the fluid is right at the top of the exposed tube. If the fluid is not there, top this up with the small syringe provided with the sensors.
4. Attach the previously cut tube with the nut and ferrule to the Swagelok union with fluid flowing from the reservoir to avoid any air being trapped in the joint. (See Appendix D for Swagelok instructions.)
5. The next operation is to repeat steps one through four with the other tube — with one exception — before making the connection with the tube and the union, keep the tube with the nut and ferrule blocked while removing the cap from the union and letting a small amount of liquid flow from the union. Next, block that flow and let a little flow from the tube to be attached. Attach the tube, allowing a little fluid to flow while making the connection. Tighten the Swagelok per the instructions in Appendix D.

C.2.1 SPLICING THE CABLE

1. Cut the cable from the faulty sensor and strip the jacket back approximately 50 to 75 millimeters (two to three inches).
2. The cable has four conductors and a drain wire (bare), as well as a barometer equalization tube. The wire insulation should be stripped about 13 mm (½") in preparation for crimping together with the wires from the new sensor.
3. Strip the new sensor wires back the same way.
4. Crimp the wires together using the special crimper and test each connection for strength.

5. Using the supplied union, splice the vent tube. **Follow the instructions in Appendix D to ensure the Swagelok fittings are tightened properly!**
6. Take readings at the readout station to make sure the sensor and its thermistor are reading properly.
7. Place the cable in its epoxy splice kit and make the splice.
8. Then do the same for the tubing assembly.

C.3 ADDING AN EXTENSION TO A SENSOR ASSEMBLY

The first step in this operation is to connect the supplied section of tubing to the reservoir. This should be done with the liquid flowing from the reservoir in the same way that the operation is done when connecting a sensor.

After connecting the extension to the reservoir, the splice to the existing tubing bundle and cable should be made as in the connection for a replacement sensor. Be sure to remove the equalization line from the reservoir during this operation and keep liquid in the reservoir at all times.

Remember that for both operations the prime concern is preventing air getting into the liquid lines and making sure that all electrical connections are good before finishing the splices.

The splices should be allowed a couple of hours to cure before placing fill and compacting over them.

APPENDIX D. SWAGELOK TUBE FITTING

These instructions apply to 25 mm (1") and smaller fittings.

D.1 INSTALLATION

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

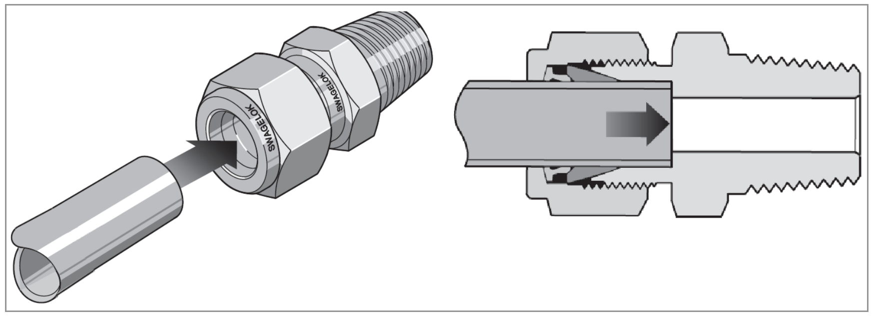

FIGURE 13: *Tube Insertion*

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.

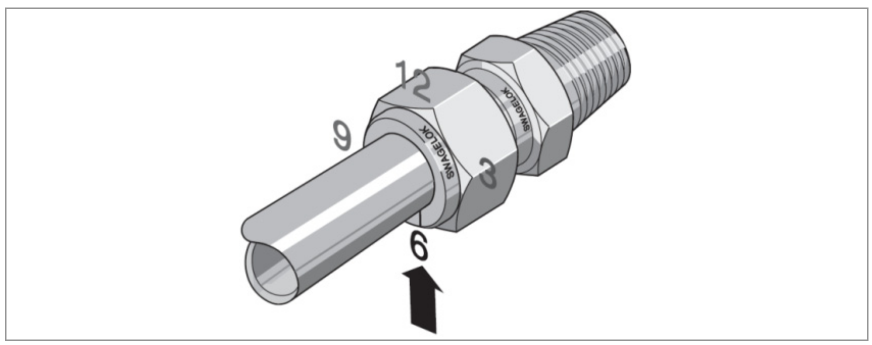

FIGURE 14: *Make a Mark at Six O'Clock*

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.

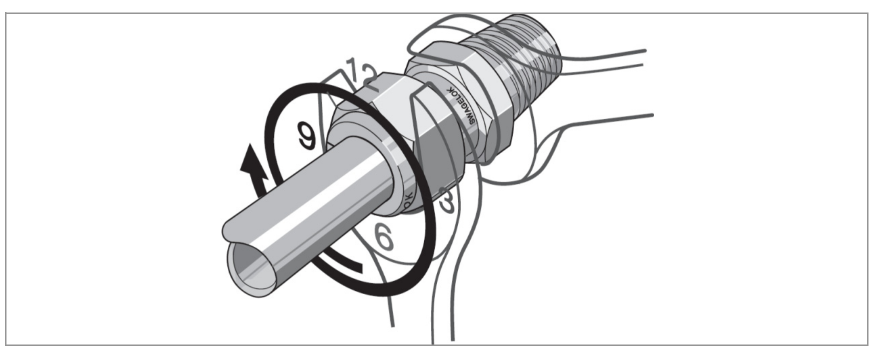

FIGURE 15: *Tighten One and One-Quarter Turns*

D.2 REASSEMBLY INSTRUCTIONS

Swagelok tube fittings can 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.**

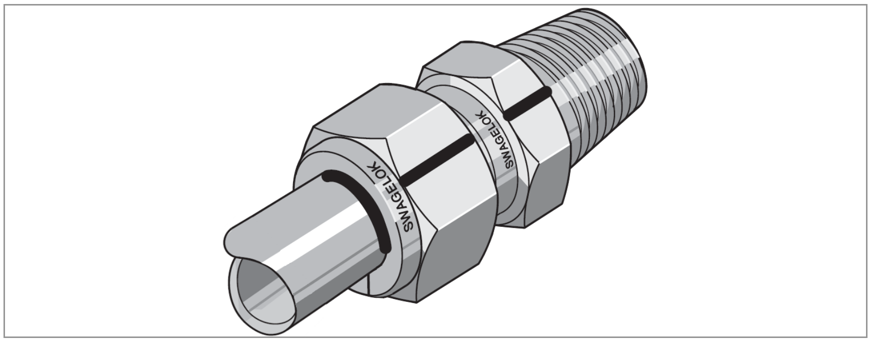

FIGURE 16: *Marks for Reassembly*

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.

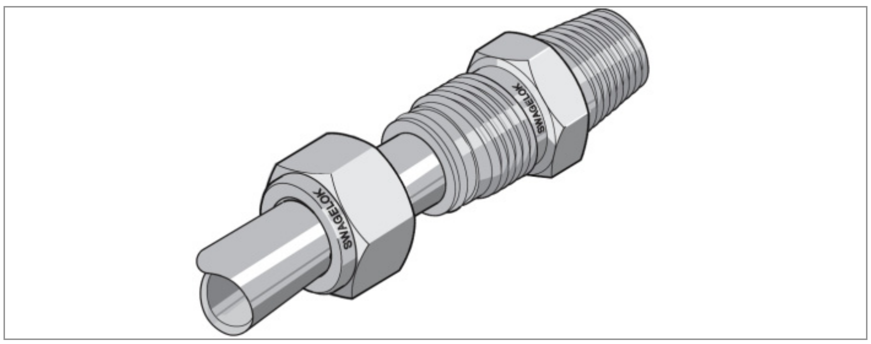

FIGURE 17: *Ferrules Seated Against Fitting Body*

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.

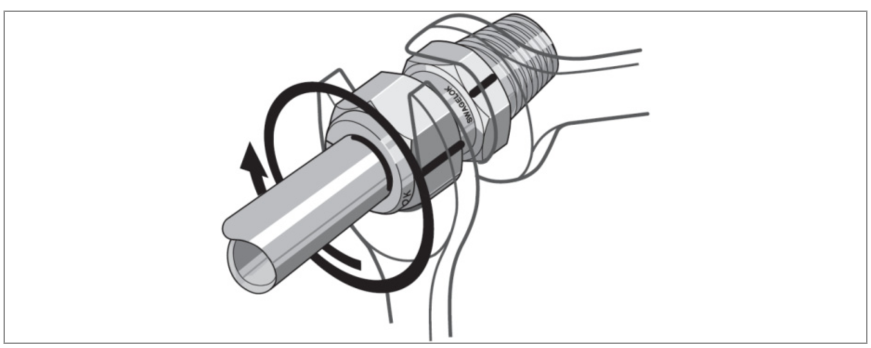

FIGURE 18: *Tighten Nut Slightly*

GEOKON
48 Spencer Street
Lebanon, New Hampshire
03766, USA

Phone: +1 (603) 448-1562
Email: info@geokon.com
Website: www.geokon.com