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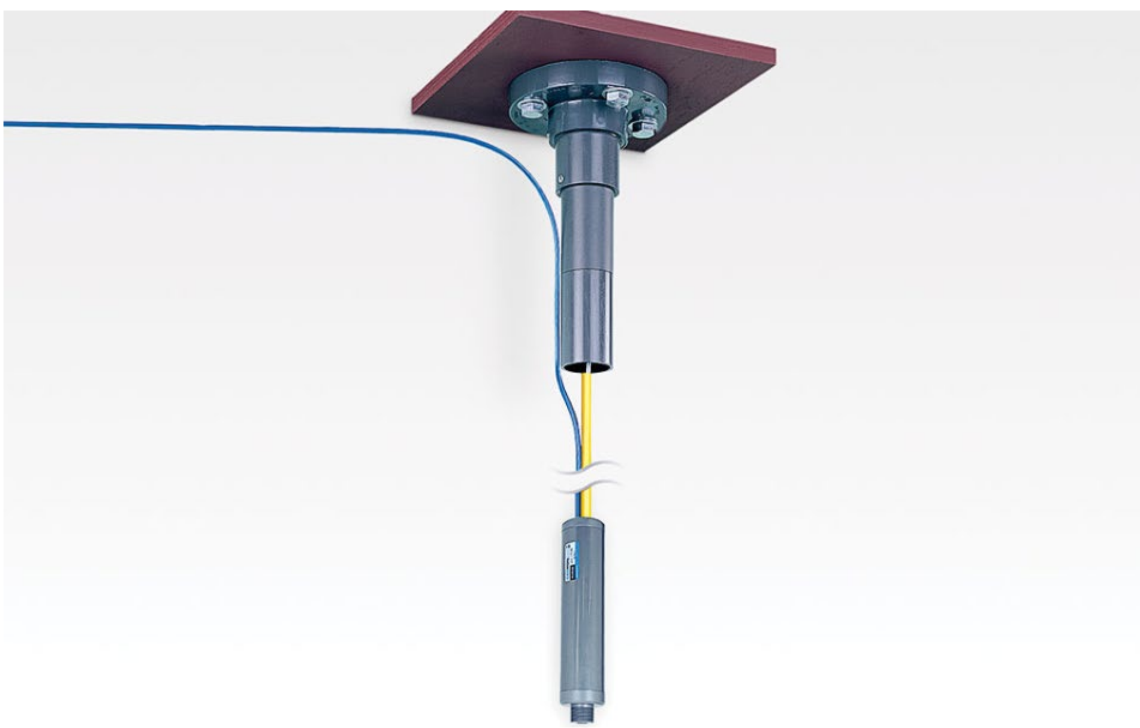
Instruction Manual

Model 4600

VW Settlement Sensor



Doc Rev S.1, 7/03/25

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1. GENERAL DESCRIPTION

(For Model 4600M Multilevel Settlement System, see Appendix C.)

The 4600 Settlement System is designed to measure the settlement of a point relative to a point located immediately below it, in solid ground (bedrock). The usual method of installation is shown in Figure 1.

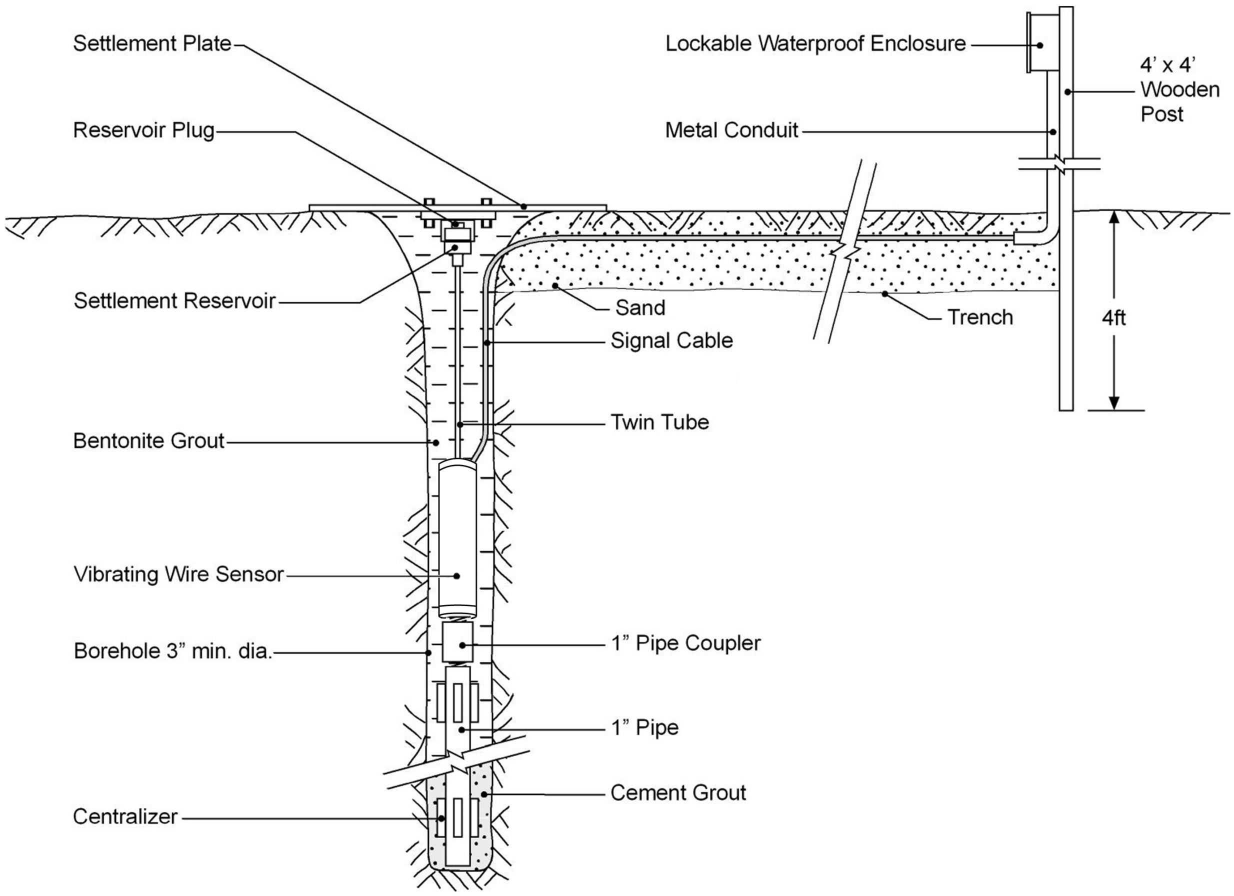

Figure 1 - Model 4600 VW Settlement System

The 4600 system has the disadvantage of requiring a borehole to reach solid ground but has the distinct advantage of avoiding the necessity for long horizontal runs of liquid-filled tubing to a remote readout location. A series of 4600 system, installed vertically above each other in a single borehole, can be used to monitor subsurface settlements at different elevations. The system is particularly suited to the measurement of settlements below sand islands constructed in marine environments.

A pressure sensor is installed in solid ground by attaching it to the upper end of a steel pipe, or rod, placed inside a borehole drilled to bedrock. The lower end of the pipe is grouted in place. A liquid-filled tube extends upwards from the sensor to the reservoir, which is attached to a settlement plate.

The settlement plate, usually located at the ground surface, (i.e., the elevation of the mouth of the borehole) settles with the ground, thus altering the height of the liquid column inside the liquid tube above the sensor. The sensor detects the change in liquid pressure, which is read by means of an electrical cable running to the readout location. Readout is accomplished by the GK- 404 or GK-405 Readout Boxes, or by a Datalogger. The sensor contains a thermistor for the measurement of temperatures as well as gas-discharge tubes for lighting protection.

Standard systems are filled with either de-aired water or de-aired antifreeze solution, with chemicals added to prevent the growth of algae. The system is “closed” in that the inside of the sensor is connected, via a vent line, to the space above the reservoir. A desiccant chamber prevents moisture from entering the vent line from the reservoir. This arrangement ensures that the sensor readings are not influenced by temperature changes inside the reservoir, or by changes in barometric pressure.

2. INSTALLATION PROCEDURES

2.1 Settlement System Installation

Installation generally requires a borehole to be drilled. The required borehole diameter is 75 mm (three inches) or larger. Any casing, if used, should have an inner diameter greater than 70 mm (two and a half inches). The recommended distance between the sensor and the reservoir for the standard sensor range (seven meters) is three to five meters. The minimum spacing can be smaller if the spacing exceeds three times the anticipated maximum settlement. Thus, if the anticipated maximum settlement is 0.5 meters, the sensor/reservoir spacing can be as close as one and a half meters.

The Model 4600 Assembly is usually shipped with the liquid tube prefilled with de-aired liquid. The liquid tube is of such a length to accommodate the spacing between sensor and reservoir specified at the time of ordering. Measure the depth of the borehole and prepare a length of pipe, (one-inch water pipe is ideal), which will place the sensor at the desired elevation. (As previously discussed, the elevation is normally from three to five meters below the surface, depending on the anticipated settlement.)

Dig a trench leading from the borehole to the readout location into which the signal cable can be buried. (Avoid sharp bends where the cable exits the borehole by excavating a broad sweep from the borehole to the trench.)

Attach the sensor to the upper end of the pipe (the sensor normally has a matching thread built into it). Tie a long piece of rope to the upper end of the pipe and lightly tape a grout pipe to the lower end of the pipe. Lower the pipe into the borehole until it rests on the bottom.

Tremie full strength grout into the bottom 1.5 meters of the borehole. Pull the grout pipe up two meters and tremie in a soft bentonite grout until the borehole is full.

If the hole is cased, the casing can be removed by completing the following: Tie the reservoir and signal cable to the rope. Next, tie the rope to the top of the drill mast so that the casing can slide over and around the reservoir and signal cable. The casing can now be removed.

Dig a trench leading from the borehole to the readout location into which the signal cable can be buried. (Avoid sharp bends where the cable exits the borehole by excavating a broad sweep from the borehole to the trench.)

To put the 4600 system into service, complete the following:

1) Push the provided metal needle onto the syringe.

2) Remove the Swagelok cap and expansion tube from the Swagelok fitting on the reservoir plug, then fully insert the needle into the fitting until it bottoms out. (Refer to Figure 2 and Figure 3 below.)

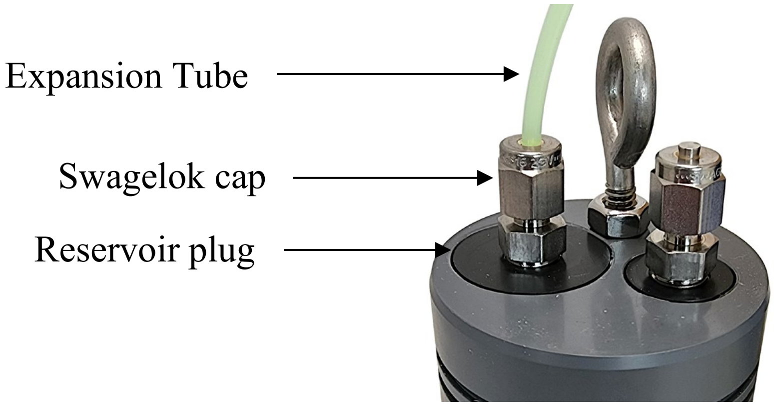

Figure 2 – Remove the expansion Tube

3) . Draw fluid from the reservoir (about 25cc) until air starts to be taken into the syringe.

Figure 3 – Fluid Removal

4) Add a few drops of light oil to the surface of the liquid in the reservoir to prevent evaporation.

5) Remove the cap from the second Swagelok fitting.

6) Connect the 4" (100mm) long, 1/8" diameter plastic tube to the Swagelok fittings using the supplied Swagelok caps (Figure 4). Tighten the Swagelok connectors per the instructions in Section 2.2.

Note 1: Make every effort to accomplish steps 1 – 6 as quickly as possible, esp. where the air is humid, to prevent moisture being drawn into the vent tube and damaging the vented VW Pressure Sensor below.

Note 2: The liquid and vent chambers of the reservoir are now connected. Make sure to keep the reservoir in an upright position at all times. Allowing the reservoir to tip too far to one side might allow liquid to enter the vent (air) line.

Note 3a: Flag, or fence off, the location of the settlement reservoir once it is covered with backfill to ensure construction vehicles do not encroach and cause the reservoir to tip and allow liquid to enter the vent line.

Note 3b: Take similar care with the signal cable running from the top of the borehole, such that passing construction vehicles do not drag it around the reservoir causing it to tip and allow liquid to enter the vent line.
If liquid finds its way into the vent line it will damage the vented VW pressure transducer in the sensor in the below.

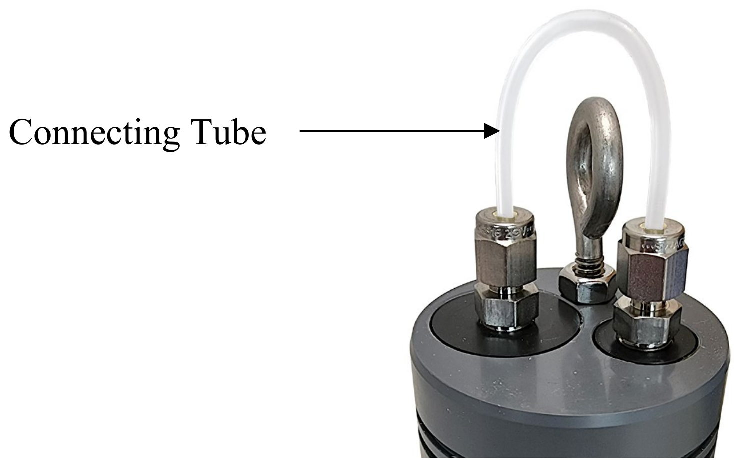

Figure 4 – Tube Connecting Vent and Liquid Sides of Reservoir

7) Install two O-rings (provided) into the grooves on the outside of the reservoir housing Figure 5.

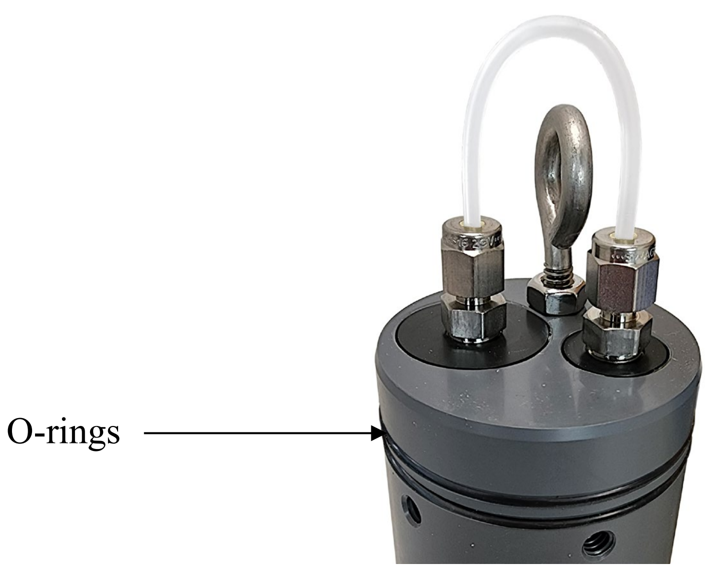

Figure 5 – Install O-rings

8) Attach the settlement flange to the settlement plate using the supplied bolts (Figure 6).

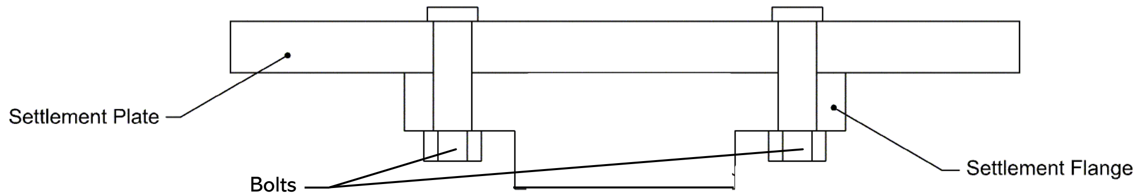

Figure 6 – Flange Attachment

9) Attach the settlement flange and plate to the reservoir using the four ¼-20 flat head screws provided (Figure 7).

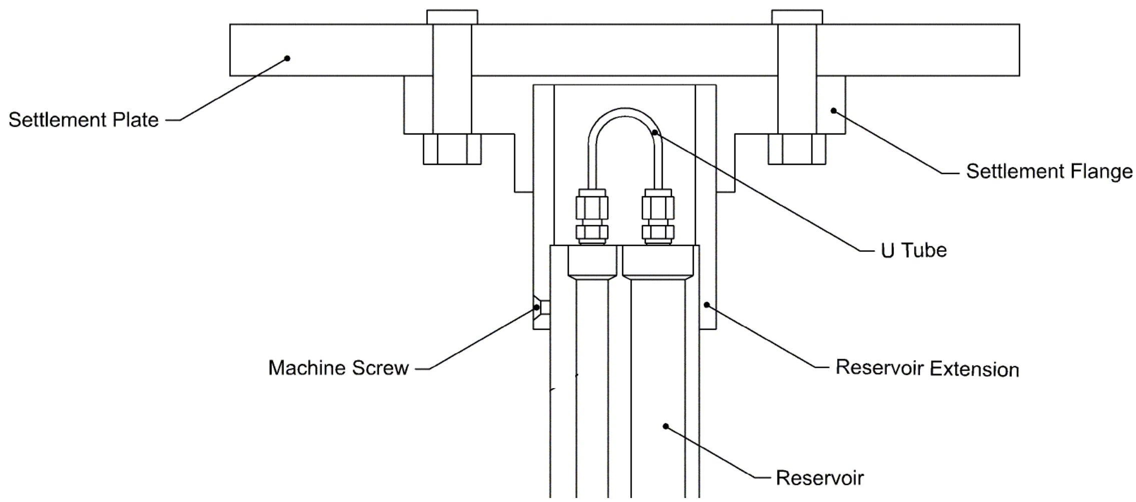

Figure 7 - Reservoir Attachment

10) Position the settlement plate at the top of the borehole.

11) Pack quick setting cement between the settlement plate and the ground surface.

12) Bury the signal cable in the trench. Use sand or other fine grain materials around the cable to protect it from damage.

13) Terminate the signal cable inside the readout enclosure.

14) Initial readings can now be taken. See Section 3 for readout instructions.

2.2 Swagelok Tube Fitting Instructions

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

2.2.1 Installation

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

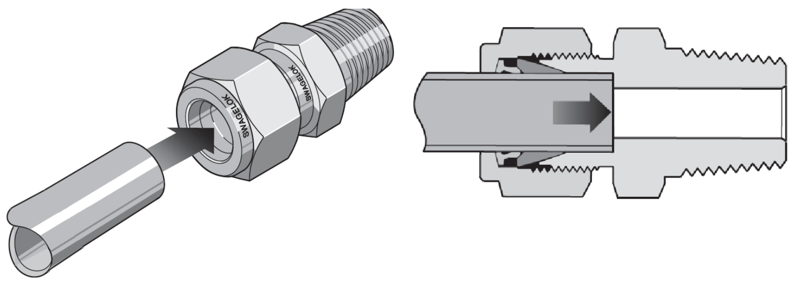

Figure 8 - Tube Insertion

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.

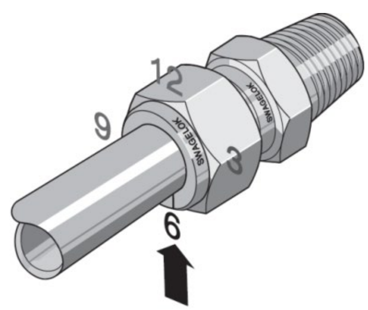

Figure 9 - Make a Mark at Six O’clock

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.)

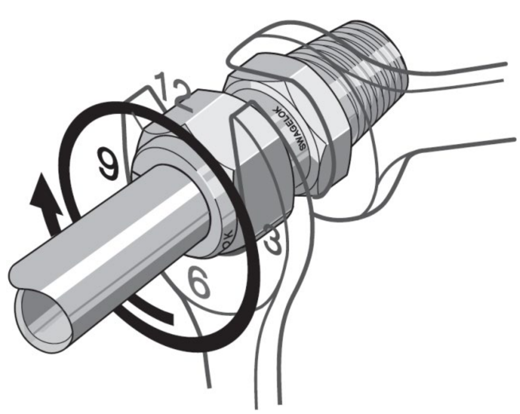

Figure 10 - Tighten One and One-Quarter Turns

2.2.2 Reassembly Instructions

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

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

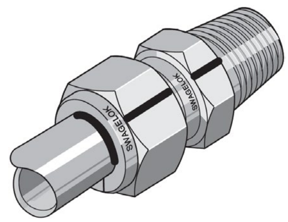

Figure 11 - Marks for Reassembly

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 12).

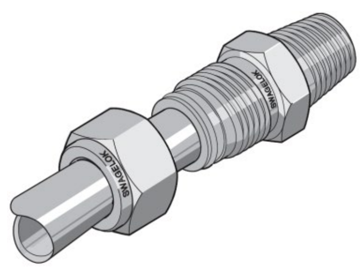

Figure 12 - Ferrules Seated Against Fitting Body

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.

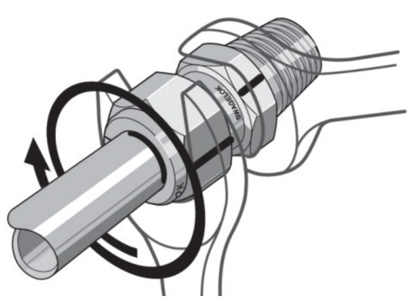

Figure 13 - Tighten Nut Slightly

3. TAKING READINGS

Take the initial reading, R_0, several times to ensure a good baseline reading. Read the temperature also. An in-situ calibration check, of sorts, can be made by raising the reservoir flange by a measured amount and observing the change in readout thus produced. Compare this calibration with the factory calibration. Alternatively, the initial gauge reading, when converted to a height of liquid column, should correspond with the known difference in elevation between the reservoir and sensor. When taking initial readings, conduct a level survey to determine the elevation, E_0, of the settlement flange.

For optimum accuracy, allow the system (sensor, tubing and reservoir) to stabilize and come to thermal equilibrium, before taking the initial reading R0. This is to mitigate the effect of thermal and volumetric transients which can be brought about by; differences between the pre-installed (above ground) and post installed (below ground) system temperatures, heat of hydration from the backfill materials, and where only certain parts of the system are situated below the groundwater level. Wherever possible allow two to three weeks before taking R0.

Readings should be taken by a Readout Box as described in the following sections. Where a Datalogger is used, the frequency limits should be set between 1400 to 3500 H_z. The black and red conductors are connected to the vibrating wire sensor and the green and white conductors to the thermistor.

3.1 GK-404 Readout Box

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

Before use, attach the flying leads to the GK-404 by aligning the red circle on the silver "Lemo" connector of the flying leads with the red line on the top of the GK-404 (Figure 14). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 14 - Lemo Connector to GK-404

Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare). Turn the GK-404 on by pressing the "ON/OFF" button on the front panel of the unit. The initial startup screen will be displayed. After approximately one second, the GK-404 will start taking readings and display them based on the settings of the POS and MODE buttons.

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

- The current Position: Set by the **POS** button, displayed as a letter A through F.
- The current Reading: Set by the **MODE** button, displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached gauge in degrees Celsius.

Use the **POS** button to select position **B** and the **MODE** button to select **Dg** (digits). (Other functions can be selected as described in the GK-404 Manual.)

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually, or if enabled, by the Auto-Off timer. If no reading displays or the reading is unstable, consult Section 5 for troubleshooting suggestions. For further information, please refer to the GK-404 manual.

3.2 GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components: The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application; and the GK-405 Remote Module, which is housed in a weatherproof enclosure and connects via a cable to the vibrating wire gauge to be measured. The two components communicate wirelessly. The Readout Unit can operate from the cradle of the Remote Module, or, if more convenient, can be removed and operated up to 20 meters from the Remote Module.

3.2.1 Connecting Sensors

If the sensor cable has a 10-pin bulkhead 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.

If the sensor cable has flying leads, attach the GK-403-2 flying leads to the bare leads of a GEOKON vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.2 Operating the GK-405

Press the button labeled “POWER ON”. A blue light will begin blinking, signifying that the Remote Module is waiting to connect to the handheld unit. Launch the GK-405 VWRA program by tapping on “Start” from the handheld PC’s main window, then “Programs” then the GK-405 VWRA icon. After a few seconds, the blue light on the Remote Module should stop flashing and remain lit. The Live Readings Window will be displayed on the handheld PC. Choose display mode “B”.

If no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions. For further information, consult the GK-405 Instruction Manual.

3.3 GK-403 Readout Box (Obsolete Model)

The GK-403 can store gauge readings and apply calibration factors to convert readings to engineering units. The following instructions explain taking gauge measurements using Mode "B". Consult the GK-403 Instruction Manual for additional information.

3.3.1 Connecting Sensors

If the sensor cable has a 10-pin bulkhead 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.

If the sensor cable has flying leads, attach the GK-403-2 flying leads to the bare leads of a GEOKON vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.3.2 Operating the GK-403

1) Turn the display selector to position "B".

2) Turn the unit on.

3) The readout will display the vibrating wire output in digits. The last digit may change one or two digits while reading.

4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.

5) Press the "Store" button to record the value displayed.

If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions.

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

3.4 Measuring Temperatures

All vibrating wire transducers are equipped with a thermistor, which gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor. GEOKON readout boxes will read the thermistor and display the temperature in degrees C.

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

4. DATA REDUCTION

The elevation (E) of the settlement flange at subsequent measurement times is given by the equation:

$$E = E_0 + (R_1 - R_0)\ G$$

Equation 1 - Elevation of Settlement Flange

Where;
R_0 is the initial reading on channel B.
R_1 is the subsequent reading on channel B.
G is the calibration factor supplied with the sensor. (Provided on the calibration report supplied by the factory. A typical calibration report is shown in Figure 15.)

For Example:
If;
E_0 = 541.62 meters
R_0 = 7510
R_1 = 7782
G = -0.001712 m/digit

Then;
E = 541.62 + (7782 – 7510) (-0.001712) meters
E = 541.15 meters

In other words, there has been a settlement of 0.47 meters.

4.1 Corrections for Temperature

The 4600 system is usually completely buried; therefore, temperature effects are negligible. Should temperature correction be required, the temperature correction to the elevation (E_T) is given by:

$$E_T = E_0 + (R_1 - R_0)\ G + (T_1 - T_0)\ K$$

Equation 2 - Temperature Correction

Where;
E_0, R_1, R_0, and G are the same as defined for Equation 1.
T_1 is the current temperature.
T_0 is the initial temperature.
K is the Thermal factor given on the calibration report.

Note: The calibration report shown in Figure 15 was developed using a simple manometer. It is good only over a range of three meters height differential between reservoir and sensor. If this range is exceeded by the initial setup or by large amounts of settlement, there are two options:
Option 1: Continue to use the Settlement System calibration report shown in Figure 15.
Option 2: Use the Pressure Transducer calibration report supplied with the equipment (Figure 16), which was developed by calibrating the pressure sensor over a wider range.

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

Settlement System Calibration Report

This Calibration has been Verified/ Validated as of: February 22, 2017

Model Number: 4600-1-70 kPa

Calibration Date: February 21, 2017

Serial Number: 1632661

Temperature: 20.4 °C

Transducer Range: 70 kPa

Calibration Instruction: CI-4600-4650

Tubing: 21 ft.

Technician: [signature]

Cable: 1000 ft.

*tubing filled and gage calibrated with 50 / 50 mix water/anti-freeze, specific gravity 1.0441

Height of Water Column m	Reading GK 401-404 Readout Pos. B	Difference
0.5	9082.0	
1.0	8806.0	276.0
1.5	8530.0	276.0
2.0	8252.5	277.5
2.5	7975.5	277.0
3.0	7697.5	278.0

Calibration Factor G: -0.001806 m / digit

Calibration Factor G: -0.00592 ft. / digit

Thermal Factor K: 0.00720 m / °C

Thermal Factor K: 0.02362 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.

Figure 15 - Typical Settlement System Calibration Report

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4600-1-70 kPa

Date of Calibration: October 11, 2016

This calibration has been verified/validated as of 02/21/2017

Serial Number: 1632661

Temperature: 23.70 °C

Calibration Instruction: VW Pressure Transducers

Barometric Pressure: 1010.8 mbar

Cable Length: 1000/21 feet

Technician: Kathy Rogers

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	9960	9961	9961	0.119	0.17	-0.006	-0.01
14.0	9206	9207	9207	13.97	-0.05	14.01	0.00
28.0	8448	8449	8449	27.90	-0.14	28.02	0.02
42.0	7687	7687	7687	41.89	-0.16	42.01	0.01
56.0	6923	6923	6923	55.93	-0.11	55.97	-0.05
70.0	6149	6150	6150	70.14	0.21	70.02	0.03

(kPa) Linear Gage Factor (G): -0.01837 (kPa/ digit)

Polynomial Gage factors: A: -6.9E-08 B: -0.01726 C: 178.78

Thermal Factor (K): 0.07325 (kPa/ °C)

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

(psi) Linear Gage Factor (G): -0.002665 (psi/ digit)

Polynomial Gage Factors: A: -1.001E-08 B: -0.002504 C: 25.931

Thermal Factor (K): 0.01062 (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: **Temperature:** **°C** **Barometer:** **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.

Figure 16 - Typical Pressure Transducer Calibration Report

5. MAINTENANCE AND TROUBLE SHOOTING

Since all the 4600 Settlement System components are buried, there is no maintenance to observe and little can be done in the event the readings become suspect. This said, it would be prudent to flag, or fence off, the location of the settlement reservoir once it is covered with backfill to ensure construction vehicles do not encroach and cause the reservoir to tip and allow liquid to enter the vent line.
Similarly, take care with the signal cable running from the top of the borehole, such that passing construction vehicles do not drag it around the reservoir causing it to tip and allow liquid to enter the vent line. If liquid finds its way into the vent line it will damage the vented VW pressure transducer in the sensor below.

Unstable readings, especially with data loggers, may be caused by electrical noise from nearby power lines or electrical equipment. Make sure that the ground conductor is connected to ground on the datalogger, or to the blue clip on the patch cord from the readout.

Resistance between the black and red conductors should be 180 ohms ± 10 ohms plus five ohms for every 100 meters of lead wire.

Resistance between the green and white wires depends on the temperature, as shown by the Thermistor Chart in Appendix B.

APPENDIX A. SPECIFICATIONS

A.1 Pressure Transducer

Model	4500AL
Available Ranges[1] (ft.) **Available Ranges[1] (m)**	0-10, 0-20, 0-50 3, 7, 15,
Resolution	0.025% FS
Linearity	0.5% FS[3]
Accuracy[2]	0.1% FS[4]
Overrange	2 × FS
Thermal Coefficient	<0.05% FS/°C
Frequency Range	1400-3500Hz
Temperature Range	-20 °C to +80 °C
Length x Diameter	Reservoir: 305 mm x 60 mm Sensor: 280 mm x 60 mm

Table 1 - Vibrating Wire Transducer Specifications

Notes:
[1] Other ranges available upon request.
[2] Laboratory accuracy. Total system accuracy is subject to site-specific variables. Accuracy of test apparatus: 0.05%.
[3] 0.1% FS linearity available upon request.
[4] Derived using 2nd order polynomial.

A.2 Thermistor (See Appendix B also)

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

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

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

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

Equation 3 - Resistance to Temperature

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

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

Table 2 - Thermistor Resistance Versus Temperature

APPENDIX C. MODEL 4600M, MULTILEVEL SETTLEMENT SYSTEM

C.1 General Description

The 4600M Multilevel Settlement System is designed to measure settlement in multiple zones within a settling soil mass. It is comprised of a series of anchors, which are hydraulically released when the sensors are at the desired location. Each anchor assembly contains a sensor at the top and a reservoir at the bottom. The anchor assemblies are interconnected by water-filled tubing. Figure 17 shows a typical 4600M installation.

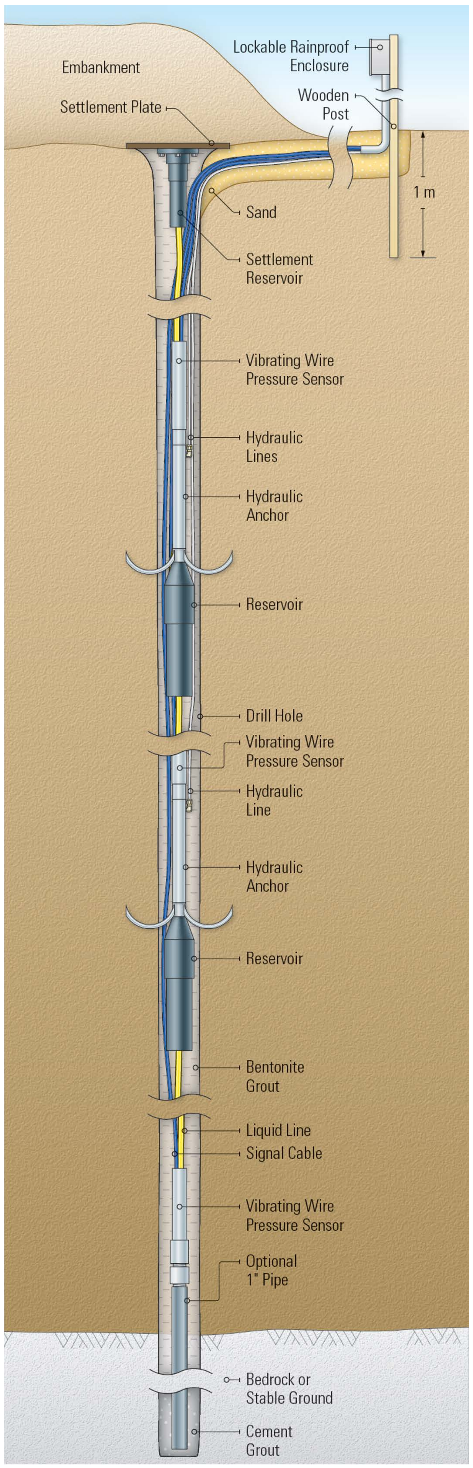

Figure 17 - A Typical 4600M Installation

The 4600M Multilevel Settlement System is designed for installation in boreholes. It has the disadvantage of requiring a borehole to reach solid ground but has the distinct advantage of avoiding long horizontal runs of liquid-filled tubing to a remote readout location. It can be used to monitor subsurface settlements at different elevations and is particularly suited to the measurement of settlements below sand islands constructed in marine environments. It is not recommended for installation in fills while the fill is being placed.

The sensor measures the head of water between itself and the reservoir above it. Settlement reduces this head, thus reducing the amount water pressure acting on the sensor. The sensor measures this change, allowing the system to measure settlement very accurately. Sensors also contain thermistors for the measurement of temperatures, as well as gas-discharge tubes for lighting protection.

Standard systems are filled with either de-aired water or de-aired antifreeze solution, with chemicals added to prevent the growth of algae. The system is "closed" in that the inside of the sensor is connected, via a vent line, to the space above the reservoir. This arrangement ensures that the sensor readings are not influenced by temperature changes inside the reservoir, or by changes in barometric pressure.

Sensor output is conducted by means of an electrical cable to the readout location where it is read by a portable readout. Datalogger systems, which allow remote, unattended data collection of multiple sensors, are also available. Contact GEOKON for additional information.

C.2 Borehole Requirements

Installation generally requires a borehole to be drilled. The minimum borehole size (or ID of casing) for the Borros anchors is 3.250", larger if using a tremie pipe.

The minimum spacing in any zone must be three times the anticipated maximum settlement, e.g., if the anticipated maximum settlement for a particular zone is 0.5 meters, the minimum sensor/reservoir spacing for that zone is 1.5 meters. The liquid tube lengths, specified at the time of ordering, need to be enough to accommodate the spacing between the sensors and reservoirs.

C.3 Anchor Spacing

Anchor spacing is sometimes dictated by geologic features and by the size and geometry of the rock mass being monitored. Drill cores can be inspected to reveal zones and planes of weakness, which would suggest appropriate anchor locations. At least one anchor, usually the deepest, should be installed in stable ground so that it can serve as a nonmoving point of reference for the rest.

C.4 Settlement System Installation

Figure 18 shows the standard single point Borros anchor assembly with the anchors retracted (left) and activated (right). The system is also available in a double point Borros anchor configuration for installations with sensor spacing greater than six meters (Figure 19).

Figure 18 - Single Point Anchor

Figure 19 - Double Point Anchor

NOTE: More than one person will be required to organize and control the 4600M as it is lowered into the borehole.

Tape the cable from the bottom sensor to the anchors in such a way that it does not lie directly over the ports from which the prongs will emerge. If the hole is to be grouted using a Bentonite grout, the grout tube should be taped to the bottom anchor using masking tape so that it can be broken free at the commencement of grouting.

Tie a nylon cord to the top reservoir and the signal cable. Suspend the 4600M by tying the nylon cord to the top of the drill mast in such a way that the casing can slide over and around the top reservoir and signal cable as it is removed from the borehole. When all the sensors and reservoirs have been lowered into the hole, the removal of the casing can begin (if the borehole is cased).

It is recommended that the bottom anchor be actuated as the first section of casing is pulled.

To actuate an anchor, complete the following:

1) Connect the hydraulic line to a hydraulic pump filled with hydraulic oil. When tightening the Swagelok fittings, follow the instructions in Section 2.2. (Do not overtighten the Swagelok as this may pinch the tube shut.)

2) Begin operating the hand pump. Pump SLOWLY at first. Watch the pressure gauge while pumping. It takes about 5 MPa (725 psi) to begin to drive out the prongs on the anchor. **Caution! The pressure should never exceed 17 MPa (2500 psi), more pressure than this can burst the tubing.**

3) Continue pumping until the anchor pressure holds steady at about 9 MPa (1300 psi). Disconnect the hydraulic pump. (Note: Tests have shown that the anchor will continue to hold even if the anchor pressure drops to zero).

After the bottom anchor has been actuated, the casing is pulled until the next anchor position is cleared. (Take care not to damage or pull on the cables coming from each sensor as the casing is removed.) As each section of casing is removed, the nylon cord is untied from the drill mast and the casing section is then threaded over it. The nylon cord is then retied back to the mast. Pull up on the suspension cable gently before actuating the next anchor to ensure it is in the proper location. The next anchor is then actuated. Repeat the above process for the remaining anchors.

Dig a trench leading from the borehole to the readout location into which the signal cable can be buried. (Avoid sharp bends where the cable exits the borehole by excavating a broad sweep from the borehole to the trench.)

The borehole may be left open, or it may be filled with a soft bentonite cement grout, tremied into the borehole as the tremie pipe is retracted.

To put the 4600 system into service, complete the following:

1) Remove the Swagelok cap and expansion tube from the Swagelok fitting on the reservoir plug (Figure 20).

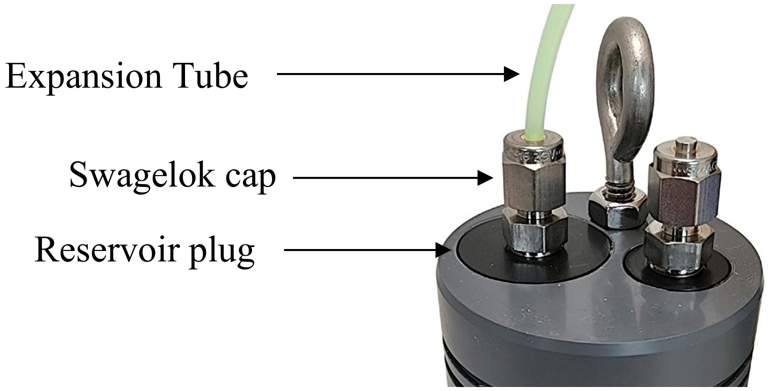

Figure 20 – Remove the Expansion Tube

2) Push the metal needle onto the syringe, then insert the needle into the Swagelok fitting in the reservoir plug.

3) Draw fluid from the reservoir until air starts to be taken into the syringe (about 25cc) as shown in Figure 21.

Figure 21 – Fluid Removal

4) Add a few drops of light oil to the surface of the liquid in the reservoir to prevent evaporation.

5) Remove the cap from the second Swagelok fitting.

6) Connect the 4" (100mm) long, 1/8" diameter plastic tube to the Swagelok fittings using the supplied Swagelok caps (Figure 22). Tighten the Swagelok connectors per the instructions in Section 2.2.

NOTE: The liquid and vent chambers of the reservoir are now connected. Make sure to keep the reservoir in an upright position at all times. Allowing the reservoir to tip too far to one side might allow liquid to enter the vent (air) line.

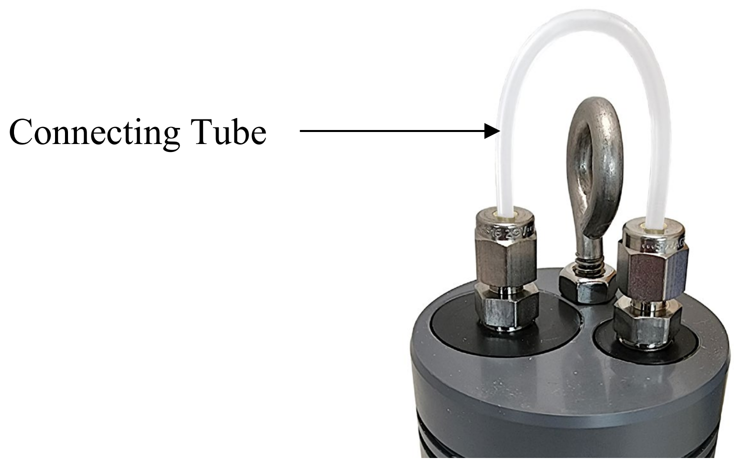

Figure 22 – Tube Connecting Vent and Liquid Sides of Reservoir

7) Install two O-rings (provided) into the grooves on the outside of the reservoir housing Figure 23.

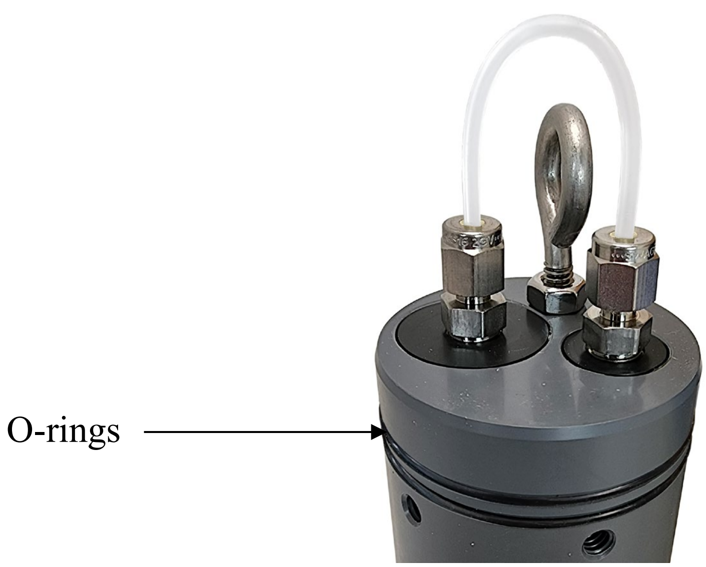

Figure 23 – Install O-rings

8) Attach the settlement flange to the settlement plate using the supplied bolts (Figure 24).

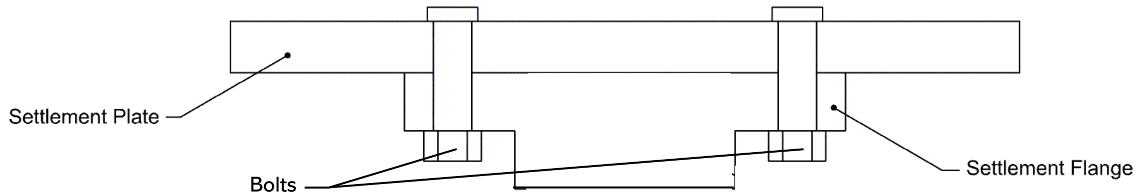

Figure 24 – Flange Attachment

9) Attach the settlement flange and plate to the reservoir using the four ¼-20 flat head screws provided (Figure 25).

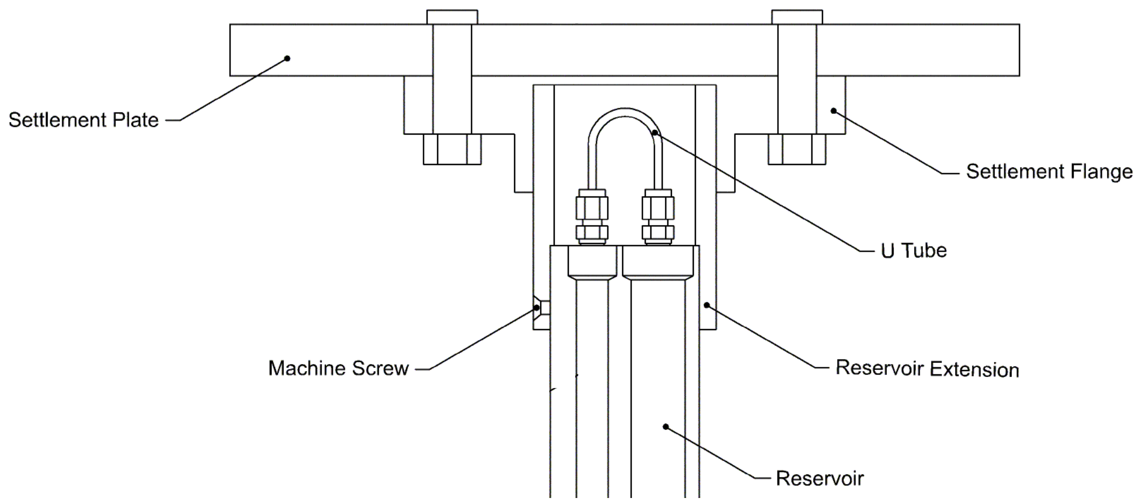

Figure 25 - Reservoir Attachment

10) Position the settlement plate at the top of the borehole.

11) Pack quick setting cement between the settlement plate and the ground surface.

12) Bury the signal cable in the trench. Use sand or other fine grain materials around the cable to protect it from damage.

13) Terminate the signal cable inside the readout enclosure.

14) Initial readings can now be taken. See Section 3 for readout instructions.