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Instruction Manual

Model 4600

VW Settlement Sensor

(Doc Rev E, 4/09)

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Contents

1. General Description

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.

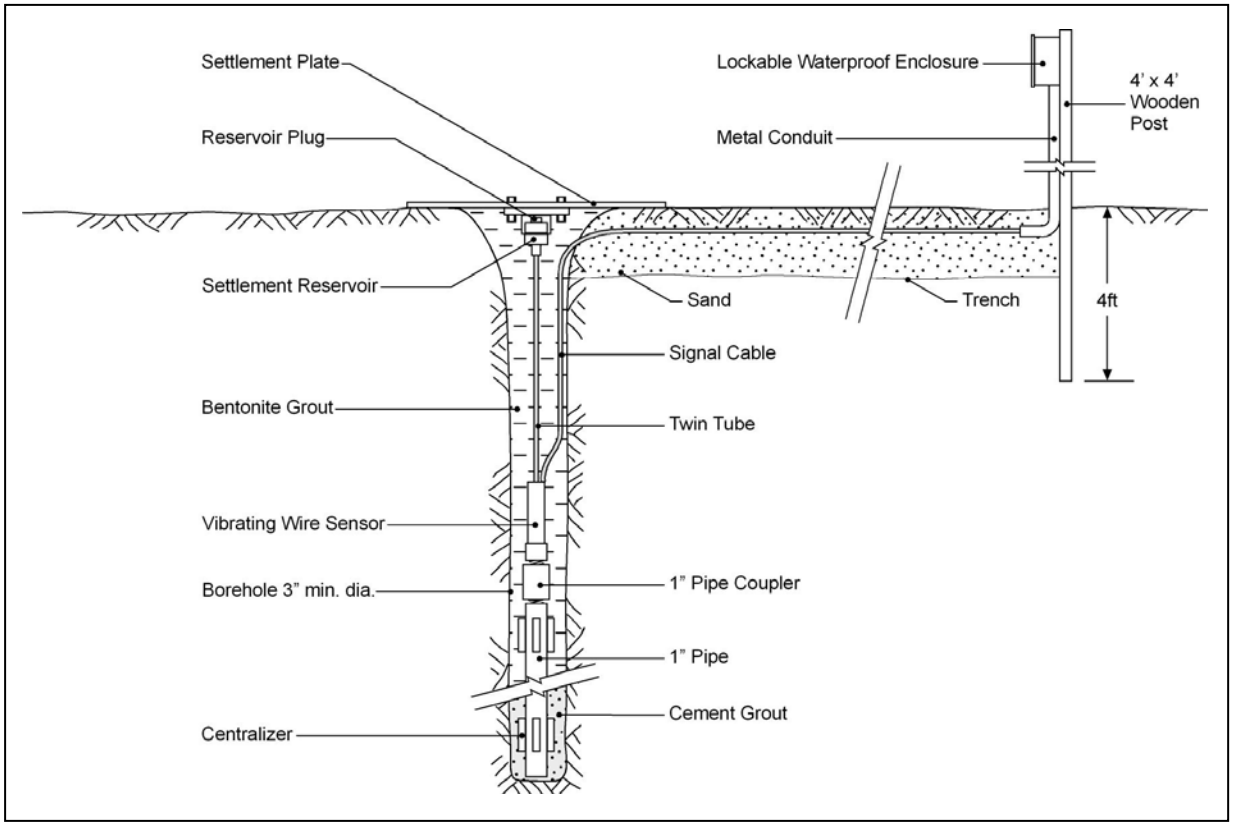

Figure 1. Model 4600 V.W. Settlement System.

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. The system is particularly suited to the measurement of settlements below sand islands constructed in marine environments.

A series of 4600 system, installed vertically above each other in a single borehole, can be used to monitor subsurface settlements at different elevations.

A pressure sensor is located 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 and is read by means of an electrical cable running up the borehole and then horizontally to the readout location.

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. Details of the reservoir assembly are shown in Figure 2.

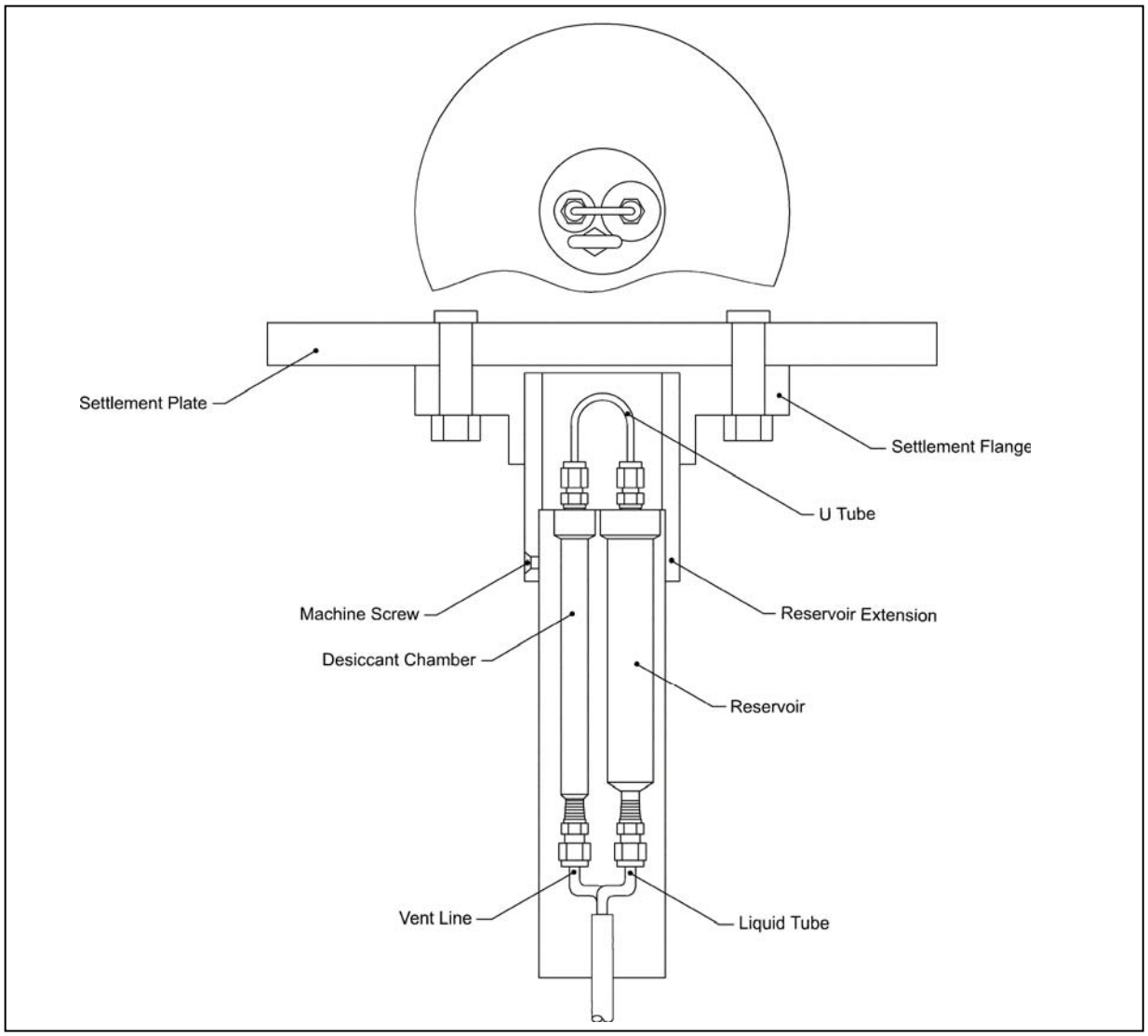

Figure 2. Model 4600 Settlement System – Reservoir Details

Readout is accomplished by GK-401 or GK-403 Readout Boxes or by the MICRO-10 Datalogger. The sensor contains a thermistor for the measurement of temperatures and also gas-discharge tubes for lighting protection.

2. Installation Procedures

2.1 Borehole Requirements

Installation generally requires a borehole to be drilled. The required borehole diameter is 75mm (3") or larger. Any casing, if used, should have an inner diameter greater than 70mm (2 ½"). The recommended distance between the sensor and the reservoir for the standard sensor range (7 meters) is 3 to 5 meters. The minimum spacing can be smaller so long as the spacing exceeds 3 times the anticipated maximum settlement. Thus if the anticipated maximum settlement is 0.5 meters, the sensor/reservoir spacing can be as close as 1.5 meters.

2.2

The Model 4600 Assembly is usually shipped with the liquid tube pre-filled 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, (1" water-pipe is ideal), which will place the sensor at the desired elevation, (usually from 3 to 5 meters below the surface depending on the anticipated settlement, as previously discussed.)

2.3

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.

2.4

Tremie full strength grout into the bottom 1.5 meters of the borehole. Pull the grout-pipe up 2 meters and tremie in a soft bentonite grout until the borehole is full.

2.5

If the hole is cased, the casing can now be removed. But first, tie the reservoir and signal cable to the rope and tie the rope to the top of the drill mast so that the casing can slide over and around the reservoir and signal cable as the casing is removed from the borehole.

2.6

4600 Settlement Systems are usually shipped with the reservoir completely filled with de-aired liquid so that there is no danger of air bubbles entering the liquid tube during shipment. To put the 4600 system into service it is necessary, now, to remove 10cc of liquid from the top of the reservoir and to connect the top of the reservoir to the desiccant chamber and vent line. Grip the Swagelock cap on top of the reservoir and pull the reservoir plug out of the top of the reservoir, (the larger of the two Delrin plugs). A syringe is provided for removal of the liquid and a short copper U-tube is supplied, with fittings, to be connected to the top of the reservoir after removal of the two Swagelock caps. Before replacing the reservoir plug and connecting the U-tube, add a few drops of light oil to the surface of the liquid to prevent evaporation.

2.7

Attach the settlement flange to the settlement plate using the bolts supplied.

2.8

While holding the reservoir in an upright position at all times, the settlement flange and plate can now be attached to the reservoir using the two machine screws provided or by using PVC cement obtained locally. (Federal Regulations prohibit the shipment of PVC cement). Apply PVC cement to the inside of the reservoir extension (see Figure 2) and to the outside of the top of the reservoir housing.

Be careful at all times not to allow the reservoir to tip over on its side which would allow liquid to enter the vent line.

2.9

Position the settlement flange at the top of the borehole and 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 (see Figure 1**).**

2.10

Bury the signal cable in the trench using sand or other fine grain materials around the cable to protect the cable from damage.

2.11

Terminate the signal cable inside a readout enclosure mounted on a post or pipe driven into the ground at the readout location.

3. Taking Readings

Take the initial reading, R_0, several times to ensure a good baseline reading. Read the temperature also. An insitu calibration check, of sorts, can be effected 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 gage reading, when converted to a height of liquid column, should correspond with the known difference in elevation between the reservoir and sensor.

Readings should be taken by a Model GK-401,GK-403 or GK-404 Readout Box set to display position B. Where a Micro 10 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.

When taking initial readings conduct a level survey to determine the elevation, E_0, of the settlement flange.

3.1. Measuring Temperatures

Each vibrating wire settlement sensor is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. The GK-401 Readout Box does not read temperatures – a digital ohmmeter is required.

1. Connect the ohmmeter to the two thermistor leads coming from the transducer. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Appendix A. Alternately the temperature could be calculated using the Equation in appendix A.

Note: The GK-403 and GK-404 readout boxes will read the thermistor and display temperature in °C automatically.

4. Data Reduction

4.1

The elevation, E, of the settlement flange at subsequent measurement times is given by the equation.

$$\mathbf{E = E_0 - (R_1 - R_0)\, G}$$

where $\mathbf{R_0}$ is the initial reading on channel B,

$\mathbf{R_1}$ is the subsequent reading on channel B,

and $\mathbf{G}$ is the calibration factor supplied with the sensor.

A typical calibration sheet, as supplied by the factory, is shown in Figure 3 (page 6).

$\mathbf{E_0}$ = 541.623 meters

$\mathbf{R_0}$ = 6030

$\mathbf{R_1}$ = 6800

$\mathbf{G}$ = 1.78 mm/digit

$\mathbf{E}$ = 541.623 – (6800 – 6030) 1.78 x 10^{-3}

$\mathbf{E}$ = 540.252 meters

Or, in other words, there has been a settlement of 1.371 meters.

4.2 Corrections for temperature

Usually, since the 4600 system is completely buried, temperature effects are negligible.

The temperature correction to the **elevation**, $\mathbf{E_T}$, is given by.

$$\mathbf{E_T = E_0 - (R_1 - R_0)\, G + (T_1 - T_0)\, K}$$

The amount of settlement, **S**, of the sensor is given by the equation

$$\mathbf{S = (R_1 - R_0)\, G}$$

And the temperature correction to the **settlement**, $\mathbf{S}$, is given by:

$$\mathbf{S = (R_1 - R_0)\, G - (T_1 - T_0)\, K}$$

where $\mathbf{T_0}$ is the initial temperature in °C,

$\mathbf{T_1}$ is the subsequent temperature in °C,

and **K** is the temperature correction factor given on the calibration sheet.

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. Unstable readings, especially with data loggers, may be caused by electrical noise form nearby power lines or electrical equipment. Make sure that the ground conductor is connected to the ground on the datalogger, or to the blue clip on the GK401 or GK403 patchcord.

Resistance between the black and red conductors should be 180 ohms ± 10 ohms plus 5 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 A (page 7).

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Settlement System Calibration

Model Number: 4600-1-10

Serial Number: 40913

Transducer Number: 7-531

Customer I.D. #: SSW2-6

Customer:

Job Number: 10681

Date: 8/11/97

Transducer Size: 10 psi (vented)

Tested By:

Temperature: 23.4 °C

Tubing: 3/16 twin x 1090'

Cable: 2 pr. yellow x 1090'

Elevation	Reading GK 401 Pos. B	Difference
2'	9903.6	
3'	9751.4	152.2
4'	9597.7	153.7
5'	9443.7	154.0
6'	9289.1	154.6
7'	9135.6	153.5
8'	8983.3	152.3

153.38 Average Digits per 12 inches

12.78 Average Digits per Inch

0.07824 Inches per Digit

-0.11187 Thermal Factor (inches/°C.)

Wiring Code

Red and Black: Gage White and Green: Thermistor

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

Figure 3. Typical Calibration Sheet

Appendix A:

Thermistor Linearization using Steinhart and Hart Log Equation

Tech Memo 91-03 Doc Rev 6-94, Geokon, Inc.

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Basic Equation:

$$\mathbf{T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2}$$

where:

T = Temperature in °C.

LnR = Natural Log of Thermistor Resistance

A = 1.4051×10^{-3}

B = 2.369×10^{-4}

C = 1.019×10^{-7}

Note: *Coefficients calculated over -50° to +150° C. span.*

Resistance versus Temperature Table

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

Appendix B:

Model 4600M Multilevel Settlement Monitoring System

General Description.

The Model 4600M multilevel is designed for installation in boreholes: it is not recommended for installation in fills while the fill is being placed. A drawing of the assembly is shown on page 10. A more detailed drawing of the Reservoir is shown below in Figure 4.

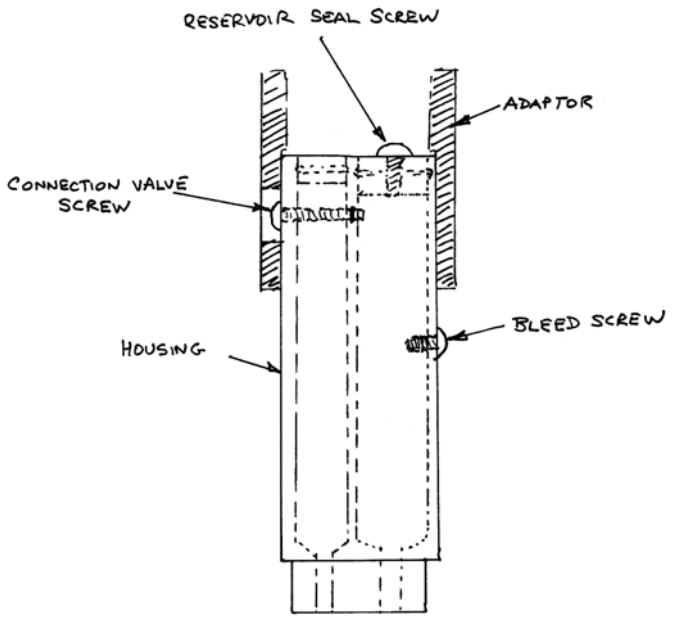


Figure 4. Details of the Multilevel type Reservoir Assembly

Installation Instructions.

The bottom sensor is usually anchored in solid ground and serves as a stable datum point to which all the other sensors are referred. This bottom sensor may be attached to a length of pipe and grouted in place, as described in Section 2.2 to 2.4, or it may be anchored to the walls of the borehole by means of a Model 1250-15 Hydraulic Bladder type borehole anchor.

The remaining intermediate sensor / reservoir combinations are anchored in the borehole by means of spring-loaded anchors which can be hydraulically or manually released when the sensor / reservoir is at its desired location.

The string of sensor / reservoir combinations can be assembled horizontally along the ground surface with the Connection Valve Screw kept closed. Make sure that the Connection Valve Screw is aligned with the hole in the Adaptor. 4600 Settlement Systems are usually shipped with the reservoir completely filled with de-aired liquid so that there is no danger of air bubbles entering the liquid tube during shipment. To put the 4600 system into service

it is necessary, now, to remove 10cc of fluid from each reservoir, as follows: First remove the Bleed Screw, (see

Figure 4 on page 8), from the side of the reservoir housing and, using the syringe supplied, remove about 10cc of fluid until the liquid level inside the reservoir is at the level of the Bleed Screw. Tilt the Housing slightly and add a few drops of light oil to the liquid surface to prevent evaporation. Now replace the Bleed Screw and tighten. It would be better if the Reservoir were not laid on its side from this point on.

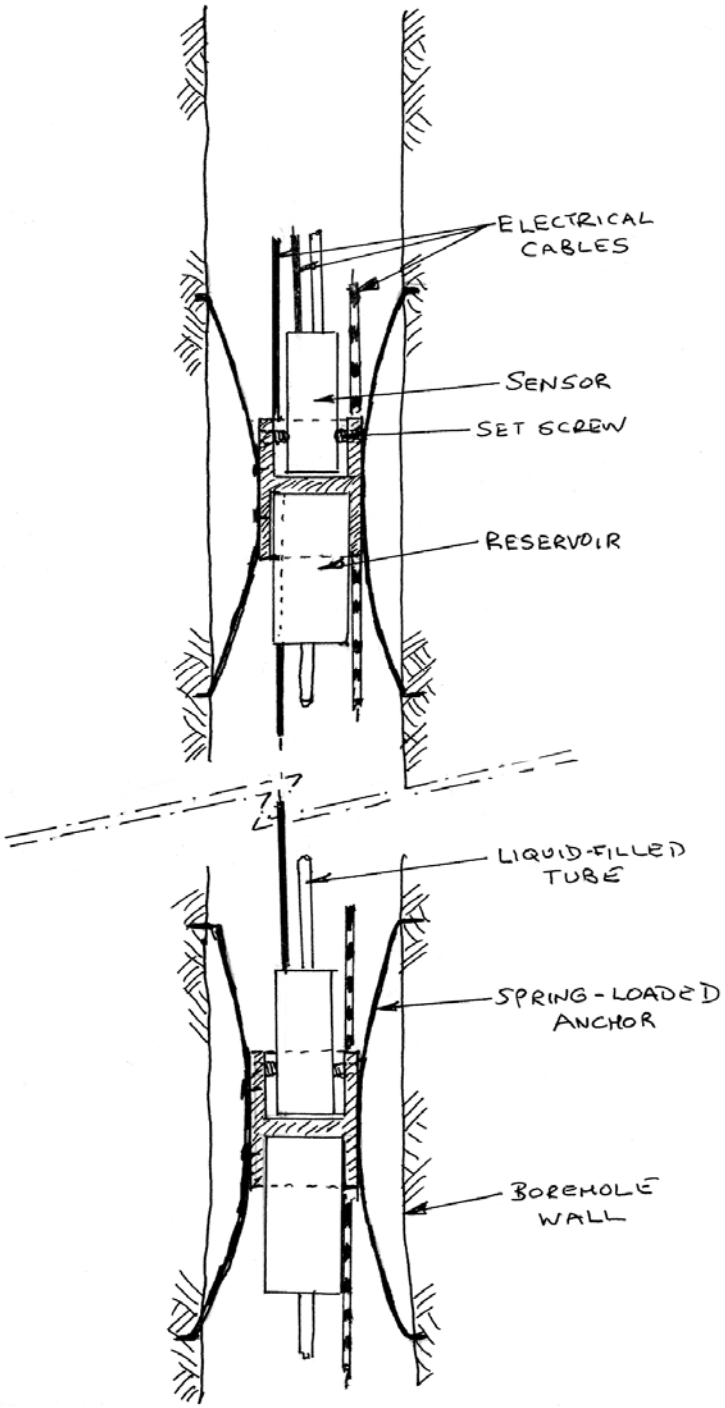
The spring-loaded anchors are tied and held in their closed position using the trip cords supplied. The hydraulically actuated cutter or the manually operated pull-pins are passed through the loops in the trip cords. A tremie pipe may be taped lightly to the lowermost sensor, or to the pipe on which it sits.

As the assembly is lowered into the borehole, each Connection Valve Screw is removed and replaced by the Seal Screw provided. Note: more than one person will be required to organize and control the various hydraulic leads/pull-cords, tubes and cables as they are lowered into the borehole. If pull-cords are used make sure that they are kept free at all times so that the anchors cannot be tripped prematurely.

The uppermost reservoir, if located at the surface, can be attached to a settlement plate, as described in Section 2.8

When all the sensors are in position, the casing can be pulled, (if the borehole is cased,) taking care not to damage or pull on the electrical cables coming from each sensor. As the casing is pulled, each spring-loaded anchor is tripped hydraulically as it clears the bottom of the casing. The borehole may be left open, or filled with a soft bentonite cement grout tremied into the borehole as the tremie pipe is retracted.

Model 4600M Assembly



Appendix C:

Specifications.

Model	4500AL[1]
Available Ranges[2] (ft) Available Ranges[2] (m)	0-10, 0-20, 0-50 3, 7, 15,
Resolution	0.025% FS
Linearity	0.5% FS[3]
Accuracy[1]	0.1% FS[4]
Over-Range	2 × FS
Thermal Coefficient	<0.05% FS/ °C
Frequency Range	1400-3500Hz

Vibrating Wire Transducer Specifications

Notes:

[1] Accuracy of test apparatus: 0.05%

[2] Other ranges available upon request.

[3] 0.1% FS linearity available upon request.

[4] Derived using 2nd order polynomial.