Model 4651

Vibrating Wire Settlement Profiler

Instruction Manual

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1. INTRODUCTION

The Model 4651 Vibrating Wire Settlement Profiler is shown schematically in Figure 1. It consists of a vibrating wire pressure sensor, a liquid-filled tube mounted on a portable reel, a reservoir with sight tube, and a vented signal cable leading from the sensor to a readout box.

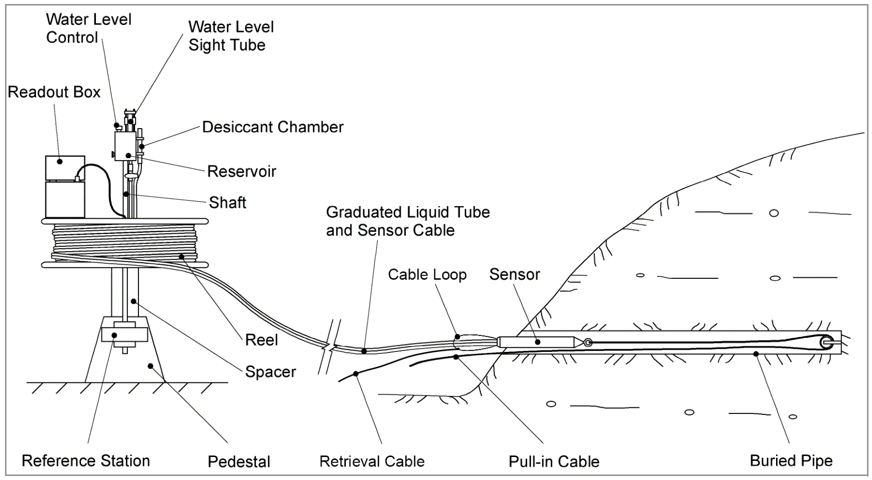

FIGURE 1: *Typical Settlement Profiler Assembly*

In use, the reel is mounted on a pedestal located on solid ground, and is free to turn as the sensor and liquid tube is pulled along a buried pipe, or as the sensor is carried from location to location. The sensor accurately measures the height of the liquid column between the sensor and the reservoir at any point along the buried pipe. The liquid-filled tube is graduated in either meters or feet so that the sensor can be located accurately and repeatedly inside the buried pipe.

Provision must be made to enable the sensor to be pulled into the pipe. This will require a pull-in cable passing over a pulley at the far end of the pipe. A retrieval cable can be attached to the back end of the sensor to allow the sensor to be retrieved without pulling on the instrument cable. Four wire rope clamps are included for attaching the retrieval cable to the sensor. Retrieval cable can be purchased from GEOKON.

The vibrating wire sensor is vented to atmosphere through the signal cable so that it is not affected by barometric pressure fluctuations. A desiccant chamber is mounted on the end of the vent tube to prevent moisture from reaching the sensor.

2. INSTALLATION

2.1 BURIED PIPE REQUIREMENTS

Buried pipes are best made from ABS or PVC plastic, 50 mm (2") internal diameter or larger. A pull-in cable must be installed inside the pipe. Any pulley system must be designed so that the cable cannot slip off the pulley and become jammed. A simple round bar is usually better than a pulley. Alternatively, a second pipe of the same or smaller diameter can be laid alongside the first pipe and connected to it by a U connector. If the far end of the pipe is accessible a second person can assist by pulling the sensor through the pipe from the far end. When not in use always secure the ends of the pull-in cable to some large object, which cannot be pulled inside the pipe.

2.2 ABOVEGROUND STATIONS

If the settlement stations are aboveground some provision must be made to ensure that the sensor is positioned precisely at the same location during each settlement profile survey. Either a hook, from which the sensor can be suspended, or a horizontal piece of pipe with an approximate I.D. of 75 mm (3"), in which the sensor can be placed, is acceptable.

2.3 PRELIMINARY CHECKS

The Settlement Profiler is shipped with the liquid tube filled with a de-aired antifreeze solution. There should be no air bubbles inside the liquid tube. Unreel the liquid tube and inspect for air bubbles. If any are found "chase" them back to the reservoir by elevating the tube ahead of the bubble and by rapping on the tube. Air bubbles inside the liquid tube will reduce the accuracy of the measurements.

2.4 PEDESTAL REQUIREMENTS

The concrete pedestal should be located on stable ground, if possible, and the reel elevation needs to be higher than any point along the buried pipe, or, higher than any sensor station in an above ground survey.

The reel is designed for mounting on a vertical shaft, supplied by Geokon, made from two lengths of 21 mm ($^{13}/_{16}$") rod — one 610 mm (24") length and one 305 mm (12") length. These two rods should be threaded together and the lower, 305 mm (12") length, should be cast inside the concrete pedestal when it is poured. Keep the rod joint flush with the top surface of the pedestal. The PVC spacer and 50 mm (2") washers, also supplied by Geokon, are positioned between the reel and the top of the pedestal, (see Figure 1). If necessary, the protruding 610 mm (24") length of rod can be removed between surveys by unscrewing it from the grouted-in rod. A M14x2 (½-13) hex-head bolt is supplied to tighten into the thread to keep it clean. Also mounted on the pedestal there needs to be a reference station, either in the form of a hook, from which the sensor can be suspended vertically, or in the form of a length of pipe, mounted horizontally, some 300 mm (12") long and 38 mm (1.5") I.D. into which the sensor can be placed.

2.5 MOUNTING THE REEL AND RESERVOIR

The reel is shipped and transported with the reservoir clamped to a bracket inside the reel. The reservoir is freed from the bracket by releasing the knurled clamping screw on the side of the reservoir. Slip the reel over the pedestal shaft, with the spacers in place, then slip the reservoir over the end of the shaft as shown in Figure 2.

Do not clamp the reservoir to the shaft since it needs to turn with the reel. Make sure that the shaft is bottomed out inside the reservoir recess.

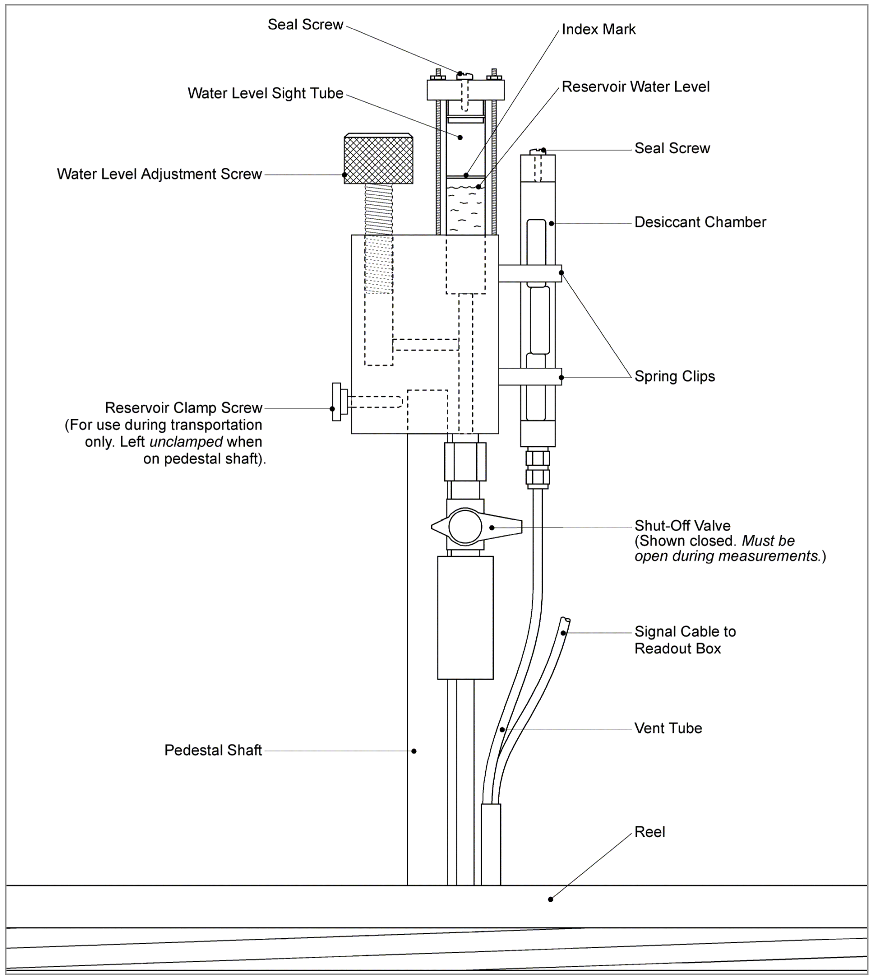

FIGURE 2: *Reservoir Details*

3. TAKING READINGS

3.1 REFERENCE STATION READINGS

Take the sensor and place it inside the reference station on the side of the pedestal. (Or hang it vertically from the reference hook.) Connect the red and black conductors of the sensor cable to the GK-404 or GK-405 Readout Box patch cord, color to color, or, if there is a connector on the sensor cable plug it directly into the "Transducer" plug on the readout box. Position the readout box on top of the reel so that it can turn with the reel. (A slip-ring option is available; consult the factory for details.) Switch the readout box "Display" switch to position B. Open the shutoff valve on the base of the reservoir and open both seal-screws, one on top of the water level sight tube and the other on top of the desiccant chamber. It is essential that these seal screws be open whenever readings are taken. The purpose is to balance the air pressure on the surface of the water inside the reservoir, and the air pressure on the inside of the sensor, so that the sensor is not affected by barometric pressure changes. Turn the seal-screws several turns, until they are quite loose, without becoming totally loose and, maybe, lost.

Use the water level adjustment screw (see Figure 2) to adjust the height of the water level so that it coincides with the index mark on the water level sight tube. Allow sufficient time for the sensor to achieve temperature stability. When the reading on the readout box becomes stable, record the reading. If a GK-404 or GK-405 readout box is in use the temperature is automatically displayed. To read the temperature with a digital ohmmeter, connect the green and white conductors to the ohmmeter's lead, and then use Table 3 in Appendix B to convert the measured resistance to temperature.

3.2 CONDUCTING THE SURVEY

3.2.1 BURIED PIPE SURVEYS

In buried pipe applications the sensor is attached to the end of the pull-in cable using a snap swivel on the end of the cable to snap over the eyebolt on the end of the sensor. **The sensor is then pulled to the far end of the buried pipe** until a cable marker is opposite the near end of the buried pipe. Allow sufficient time for the liquid inside the tubes to reach temperature stability and for the sensor reading to stabilize. Wait longer if there are large differences between the borehole temperature and the ambient temperature. Adjust the height of the water level to coincide with the index mark on the reservoir. Make sure that the vent line seal screws are loose, then take readings. Pull the sensor to the next cable marker and take readings promptly.

When all the settlement stations have been read take readings at the pedestal reference station. Again, allow sufficient time for temperature stabilization. Compare this final reading with the initial reading. If there is a significant difference between the two readings, this may be an indication of changing conditions during the survey, and, either the survey needs to be repeated, or the error needs to be distributed evenly amongst the survey readings in accordance with accepted surveying practice.

After all the readings have been taken, return the sensor to the reel, close the valve at the base of the reservoir, close the two seal screws, then clamp the reservoir to its bracket inside the reel. Disconnect the readout box from the sensor cable.

3.2.2 ABOVE GROUND SURVEYS

Above ground surveys can be conducted by one person carrying the sensor from station to station while a second person records the readings at the reservoir location. The sensor is sensitive to rapidly changing temperature transients and therefore it cannot be carried in the bare hands. Wrap the sensor in a layer of foam insulation and carry it in gloved hands instead. Experiment to find a method that allows the sensor readings to remain stable. If the ambient temperature changes rapidly during the survey (as might happen going from indoors to outdoors), allow sufficient time for the sensor readings to stabilize before continuing with the survey.

The readout stations themselves can be as simple as a hook, from which the sensor can hang, or a piece of horizontal pipe into which the foam-covered sensor will fit. If hooks are used, make sure that the sensor is not pulled away from the vertical by the rest of the liquid tube.

4. DATA REDUCTION

4.1 CALCULATION OF SENSOR ELEVATION

Readings can be used to calculate the elevation of the sensor at any point along the buried pipe and to plot the settlement profile as it changes with time. A plot of temperature can also be included. For the standard 4651 profiler 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 the equation:

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

EQUATION 1: *Elevation*

Where:
E_0 is the sensor elevation at installation
R_0 is the initial sensor reading at a given point along the buried tube
R_1 is the subsequent sensor reading
G is the calibration factor on the calibration report provided with the sensor. (A typical calibration report, as supplied by the factory, is shown in Appendix C.)

For Example:

If:
E_0 = 541.62 meters
R_0 = 9030
R_1 = 8800
G = -0.001570 meters/digit
Then the new sensor elevation equals:
$E = 541.62 - (8800\text{-}9030) \times -0.001570$
$E = 541.259$ meters. In other words, there has been a settlement of 0.361 meters.

4.2 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 can 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. Temperature effects on the sensor can be corrected, but are usually quite insignificant, especially if the sensor is buried.

The elevation (E_T) corrected for temperature is given by the equation:

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

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.

5. TROUBLESHOOTING AND MAINTENANCE

The sensor is a precision instrument and should be treated with care at all times; jarring of the sensor can cause zero shifts. Note also that the standard range sensor has a maximum range of seven meters (23 feet), i.e. this is the maximum allowable elevation of the reservoir above the sensor.

The main problem, typical of all liquid level devices, will be air bubbles inside the liquid tube, which will cause fluctuating, unstable, or nonrepeating readings. Examine the liquid tube for air bubbles and remove as described in Section 2.3.

Unstable readings can be caused by electrical interference from nearby electrical equipment and power lines. Check for sources of nearby electrical noise such as motors, generators, antennas, or electrical cables. Move the instrument cable away from these sources if possible. Contact the factory for available filtering and shielding equipment.

This problem can often be corrected by connecting the shield drain wire to the blue clip on the flying leads (green for the GK-401). Be sure to isolate the readout from the ground by placing it on a piece of wood or other insulator.

The pinout for a 10-pin connector attached to the cable is below:

Pin	Color	Function
A	Red	Gauge
B	Black	Gauge
C	White	Thermistor
D	Green	Thermistor
E	Shield	Ground

TABLE 1: *10-pin Connector Pinout*

The desiccant capsules, in the desiccant chamber, will require changing from time to time. Active capsules are blue and spent capsules are pink. Fresh capsules are available from GEOKON.

Perform in situ calibrations by raising the reservoir a known, measured amount, and recording the corresponding change in reading of the sensor.

With very long profilers it sometimes will happen that the water level in the reservoir cannot be made to align with the index mark even with the water level control screw screwed all the way in. If this is the case, back off the screw and add more water to the reservoir.

Unstable readings can also be caused by wind blowing across the open end of the reservoir after the seal screws have been removed. The wind creates a kind of Venturi effect by lowering the air pressure at the reservoir location.

If the wind is blowing and a Venturi effect is observable place a large container over the reservoir and seal it so that it is open to the atmosphere only through a small aperture.

Check the resistance of the cable by connecting an ohmmeter to the sensor leads; resistance is roughly 48.5Ω per km (14.7Ω per 1000') of 22 AWG wire.

If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the conductors may be shorted.

Refer to the expected resistance for the various wire combinations below.

Vibrating Wire Sensor Lead Resistance Levels
Red/Black ≅180Ω
Green/White 3000Ω at 25 °C

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

APPENDIX A. SPECIFICATIONS

Range (standard)[1]	7 meters (20 feet)
Sensitivity (standard)	1.5 mm (0.06")
Accuracy (standard)**	0.1% F.S.
Linearity (standard)	0.15% F.S.
Temperature Range	–20 °C to +50 °C
Frequency Range	1400-3500 Hz
Thermal Coefficient	0.05% F.S./°C (typical)
Dimensions	Sensor: 35 mm (1⅜") diameter Reel: 650 mm (24") diameter
Liquid - Tube Length[2]	100 meters maximum (330 feet)
Buried Pipe Diameter	50 mm (2") I.D.
Cable Connector	10-pin Bendix PT06A –12 –10 P (SR)

TABLE 2: *Specifications*

Notes:

[1] Other ranges available on request

[2] Liquid tube length to be specified when ordering

**This is the accuracy of the transducer calibration. The system accuracy will be closer to 0.25% FS

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

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 3:** 3KΩ Thermistor Resistance*

B.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

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

EQUATION 4: *10KΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.127670×10^{-3}

B = 2.344442×10^{-4}

C = 8.476921×10^{-8}

D = 1.175122×10^{-11}

Note: Coefficients optimized for a curve **J** Thermistor over the temperature range of 0 °C to +250 °C.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	0	7,402	32	2,157	64	763.5	96	316.6	128	148.4	160	76.5	192	42.8	224
31,029	1	7,098	33	2,083	65	741.2	97	308.7	129	145.1	161	75.0	193	42.1	225
29,498	2	6,808	34	2,011	66	719.6	98	301.0	130	142.0	162	73.6	194	41.4	226
28,052	3	6,531	35	1,942	67	698.7	99	293.5	131	138.9	163	72.2	195	40.7	227
26,685	4	6,267	36	1,876	68	678.6	100	286.3	132	135.9	164	70.8	196	40.0	228
25,392	5	6,015	37	1,813	69	659.1	101	279.2	133	133.0	165	69.5	197	39.3	229
24,170	6	5,775	38	1,752	70	640.3	102	272.4	134	130.1	166	68.2	198	38.7	230
23,013	7	5,545	39	1,693	71	622.2	103	265.8	135	127.3	167	66.9	199	38.0	231
21,918	8	5,326	40	1,637	72	604.6	104	259.3	136	124.6	168	65.7	200	37.4	232
20,882	9	5,117	41	1,582	73	587.6	105	253.1	137	122.0	169	64.4	201	36.8	233
19,901	10	4,917	42	1,530	74	571.2	106	247.0	138	119.4	170	63.3	202	36.2	234
18,971	11	4,725	43	1,480	75	555.3	107	241.1	139	116.9	171	62.1	203	35.6	235
18,090	12	4,543	44	1,432	76	539.9	108	235.3	140	114.5	172	61.0	204	35.1	236
17,255	13	4,368	45	1,385	77	525.0	109	229.7	141	112.1	173	59.9	205	34.5	237
16,463	14	4,201	46	1,340	78	510.6	110	224.3	142	109.8	174	58.8	206	33.9	238
15,712	15	4,041	47	1,297	79	496.7	111	219.0	143	107.5	175	57.7	207	33.4	239
14,999	16	3,888	48	1,255	80	483.2	112	213.9	144	105.3	176	56.7	208	32.9	240
14,323	17	3,742	49	1,215	81	470.1	113	208.9	145	103.2	177	55.7	209	32.3	241
13,681	18	3,602	50	1,177	82	457.5	114	204.1	146	101.1	178	54.7	210	31.8	242
13,072	19	3,468	51	1,140	83	445.3	115	199.4	147	99.0	179	53.7	211	31.3	243
12,493	20	3,340	52	1,104	84	433.4	116	194.8	148	97.0	180	52.7	212	30.8	244
11,942	21	3,217	53	1,070	85	421.9	117	190.3	149	95.1	181	51.8	213	30.4	245
11,419	22	3,099	54	1,037	86	410.8	118	186.1	150	93.2	182	50.9	214	29.9	246
10,922	23	2,986	55	1,005	87	400.0	119	181.9	151	91.3	183	50.0	215	29.4	247
10,450	24	2,878	56	973.8	88	389.6	120	177.7	152	89.5	184	49.1	216	29.0	248
10,000	**25**	2,774	57	944.1	89	379.4	121	173.7	153	87.7	185	48.3	217	28.5	249
9,572	26	2,675	58	915.5	90	369.6	122	169.8	154	86.0	186	47.4	218	28.1	250
9,165	27	2,579	59	887.8	91	360.1	123	166.0	155	84.3	187	46.6	219		
8,777	28	2,488	60	861.2	92	350.9	124	162.3	156	82.7	188	45.8	220		
8,408	29	2,400	61	835.4	93	341.9	125	158.6	157	81.1	189	45.0	221		
8,057	30	2,316	62	810.6	94	333.2	126	155.1	158	79.5	190	44.3	222		
7,722	31	2,235	63	786.6	95	324.8	127	151.7	159	78.0	191	43.5	223		

TABLE 4: *10KΩ Thermistor Resistance*

APPENDIX C. TYPICAL CALIBRATION REPORT

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

Settlement Profiler Calibration Report

Model Number: 4651-1-70 kPa

Calibration Date: July 19, 2013

Serial Number: 1304131

Temperature: 21.5 °C

Transducer Range: 70 kPa

Calibration Instruction: CI-4651

Cable: 95 m

Technician:

Tubing: 95 m

*tubing filled and gage calibrated with 50 / 50 mix water/anti-freeze, specific gravity 1.041

Height of Water Column m	Reading GK 401 Pos. B	Difference
0.5	9340.0	
1.0	9024.0	316.0
1.5	8706.0	318.0
2.0	8387.0	319.0
2.5	8068.0	319.0
3.0	7748.0	320.0

Calibration Factor G: -0.001570 m / digit

Calibration Factor G: -0.00515 ft. / digit

Thermal Factor K: 0.00511 m / °C

Thermal Factor K: 0.01678 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 3: *Typical Calibration Report*

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