Model 3500

Semiconductor Earth Pressure Cells

Instruction Manual

GEOKON®

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1. INTRODUCTION

GEOKON Model 3500 Earth Pressure Cells, sometimes called total pressure cells or total stress cells are designed to measure stresses in soil or the pressure of soil on structures. Cells will respond not only to soil pressures but also to ground water pressures or to pore water pressure, hence the term total pressure or total stress. Pressure cells are used primarily where rapidly changing pressures are to be measured such as the measurement of live traffic loads on roadbeds or railway beds, or the response of structures to blasting vibrations.

Earth Pressure Cells are constructed from two stainless steel plates welded together around the periphery to leave a narrow space between them. This space is filled with de-aired hydraulic oil that is connected hydraulically to a pressure sensor where the oil pressure is converted to an electrical signal which is transmitted through a signal cable to the readout location.

In general, GEOKON Earth Pressure Cells use an all welded construction so that the space confining the oil is entirely metal not requiring o-rings which tend to trap air and reduce the cell stiffness. The oil is de-aired using a Nold DeAerator™ which materially improves the fluid stiffness and the performance of the cell. The pressure sensor normally employed is a semiconductor type that is available in several different pressure ranges. The cable is attached to the sensor in a sealed, water-resistant manner. For earth pressure cells located inside a soil mass the cable may be armored and provided with strain relief at the cell to reduce the likelihood of pullout.

Pressure sensors with voltage (0-100 mV or 0-5 VDC) or current (4-20 mA) output are available for dynamic readout capability. Consult the factory for additional information. A thermistor is also included inside the sensor housing for measurement of temperature at the cell location.

The readout cable for remote sense uses four individually shielded pairs of cable. Two pairs are connected to the semiconductor bridge, one pair is connected to a thermistor, and one pair is used for remote sensing when there are long cables (>50 m). For pressure cells with 4-20 mA outputs, a two pair construction is used.

1.1 THEORY OF OPERATION

The earth pressure acts to squeeze the two welded plates of a pressure cell together thus building up a pressure inside the fluid. A simultaneous measurement of pore water pressure (μ), using a piezometer, is necessary to separate the effective stress (σ') from the total stress (σ) as defined by Terzaghi's principle of effective stress where;

$$\sigma' = \sigma - \mu$$

These parameters coupled with the soil strength characteristics will determine soil behavior under loads.

If the plates are flexible enough, i.e. if they are thin enough relative to their lateral extent, then at the center of the plate the supporting effect of the welded periphery is negligible, and it can be stated that **at the center of the cell the external soil pressure is exactly balanced by the internal fluid pressure.**

This is true only if the deflection of the plates is kept to a minimum and thus it is important that the cell be stiff. This in a practical sense means that the fluid inside the cell should be as incompressible as possible and that the pressure sensor required to measure the fluid pressure should also be stiff having very little volume change under increasing pressure.

Tests conducted by various researchers (as reported by Dunnicliff, 1988) have shown that the introduction of a flat stress cell into a soil mass will alter the stress field in a way dependent on the relative stiffness of the cell with respect to the soil and also with respect to the aspect ratio of the cell, i.e. the ratio of the width of the cell to its thickness. A thick cell will alter the stress more than a thin cell. Hence, for these reasons, a thin, stiff cell is best, and studies have shown an aspect ratio of at least 20 to 1 to be desirable.

Ideally, the cell ought to be as stiff (compressible) as the soil. But in practice this is difficult to achieve. If the cell is stiffer (less compressible) than the soil, then it will over register the soil pressure because of a zone of soil immediately around the cell which is "sheltered" by the cell so that it does not experience the full soil pressure. This can be represented schematically as shown in Figure 1.

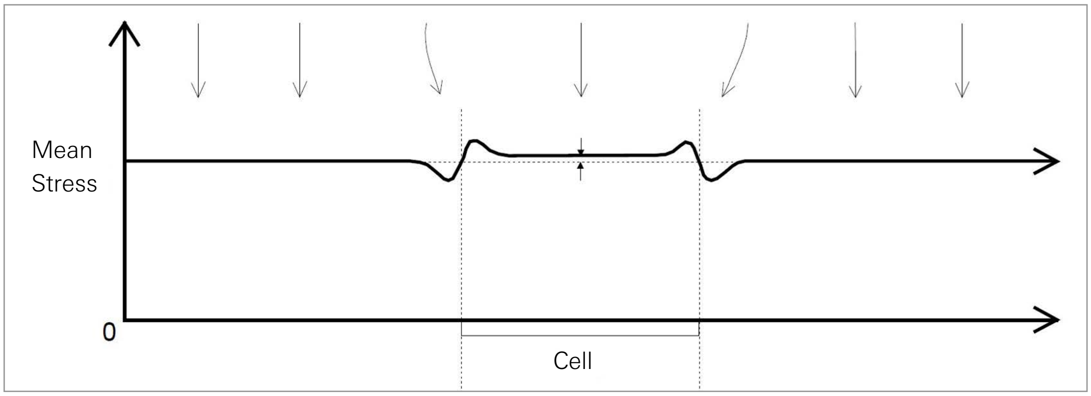

FIGURE 1: *Stress Redistribution, Weak Soil with Stiff Cell*

As can be seen there is a stress concentration at the rigid rim but in the center of the cell the soil stress is only slightly higher than the mean soil stress, i.e. only slightly higher than the stress which would obtain were the cell not present.

In a stronger soil the de-stressed zone around the edge of the cell is more extensive and hence at the center of the cell the degree of over registration of the mean stress is greater. This is represented schematically in Figure 2.

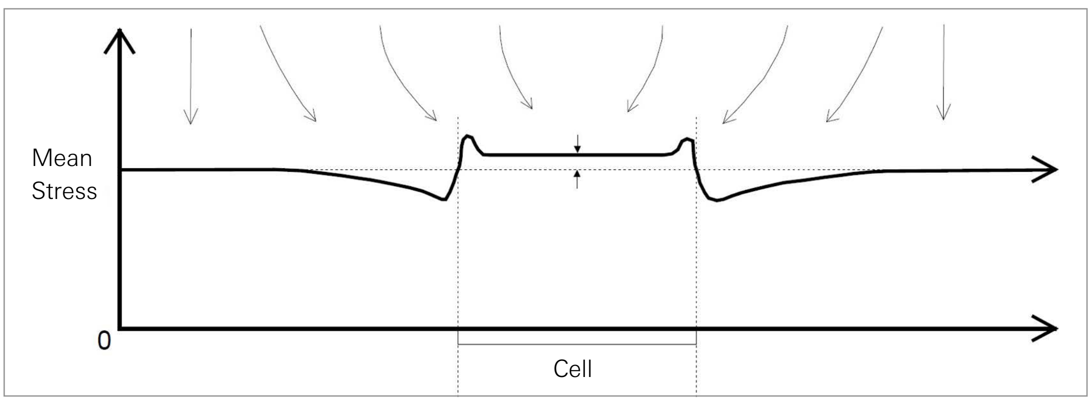

FIGURE 2: *Stress Redistribution, Strong Soil with Stiff Cell*

In a stiff soil the cell may be less stiff (more compressible) than the soil, in which case the cell will under register the mean soil stress as the stresses in the soil tend to "bridge" around the cell. This is represented schematically in Figure 3.

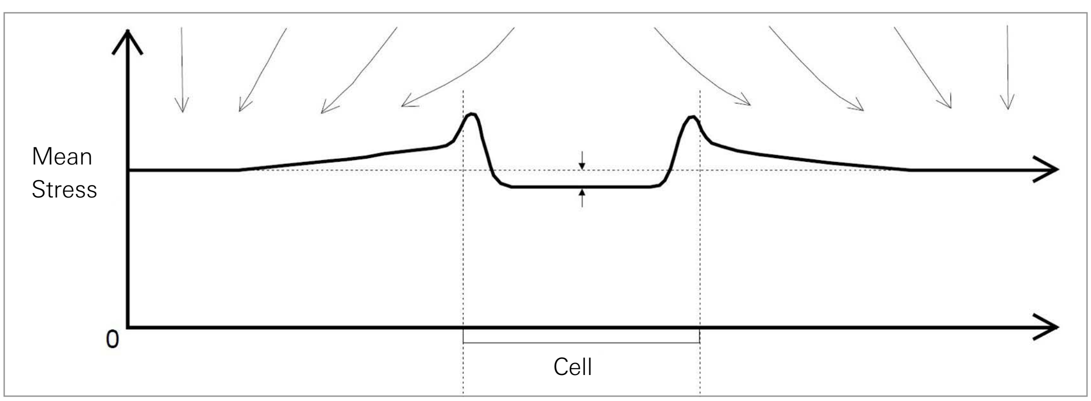

FIGURE 3: *Stress Redistribution, Stiff Soil with Weak Cell*

Tests conducted at the University of Ohio (Ohio, USA) with several different soil types have shown that for GEOKON cells the maximum degree of over or under registration amounts to 15% of the mean soil stress.

Other factors should be kept in mind. The inherent variability of soil properties which give rise to varying soil stresses at different locations, and a corresponding difficulty in getting a good sample of the mean stress from a limited number of cell locations. Also, the response of the cell to its immediate surroundings depends very largely on how closely the soil mass immediately around the cell has the same stiffness or compressibility or the same degree of compaction as the undisturbed soil mass. Installation methods will need to pay particular attention to this detail.

1.2 EARTH PRESSURE CELL CONSTRUCTION

1.2.1 MODEL 3500 EARTH PRESSURE CELL

Model 3500 Earth Pressure Cells may be rectangular or circular in shape. The standard size for the rectangular Model 3500 is 150 mm × 250 mm (6" × 10"), for the circular it is 230 mm (9") in diameter. Standard thickness for both styles is 6 mm (aspect ratio > 20). For laboratory tests smaller, thinner cells can be manufactured. Contact the factory for additional information.

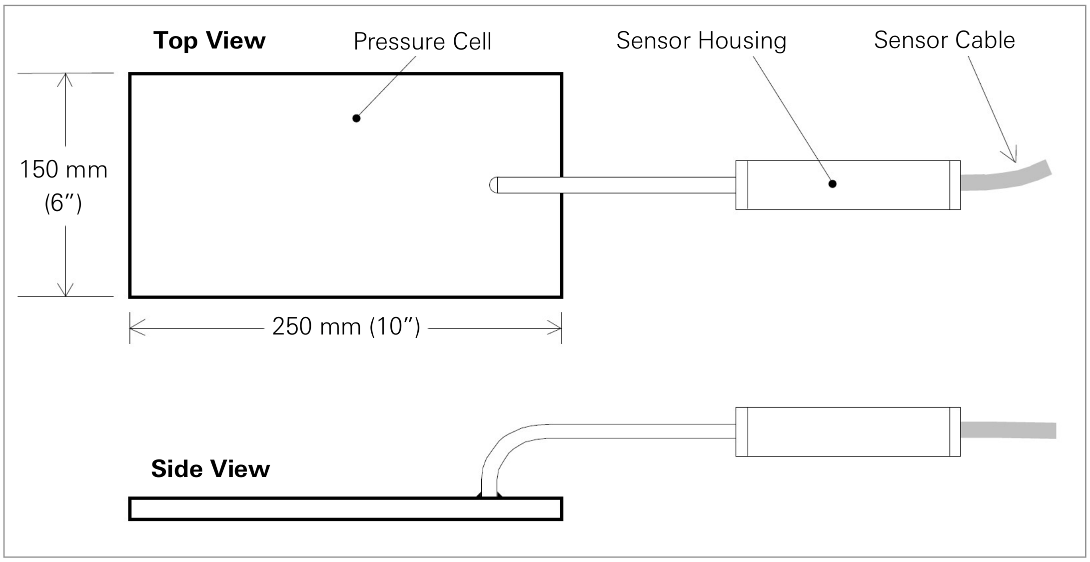

FIGURE 4: *Model 3500 Rectangular Earth Pressure Cell*

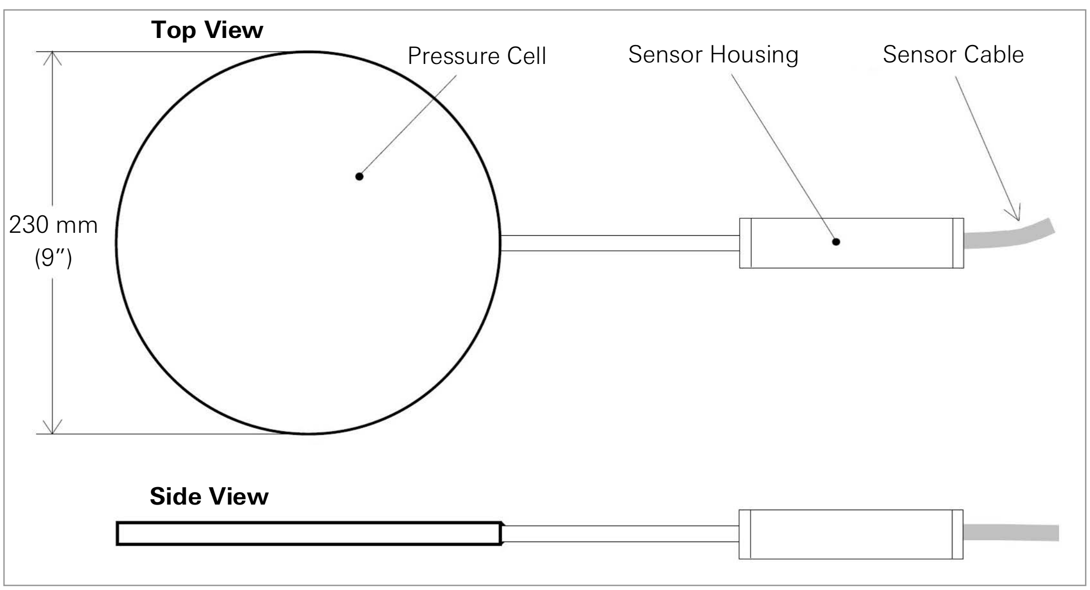

FIGURE 5: *Model 3500 Circular Earth Pressure Cell*

1.2.2 MODEL 3510 CONTACT ("FAT BACK") PRESSURE CELL

Model 3510 Earth Pressure Cells are designed for measuring dynamic soil pressures on structures. One of the plates is thick and designed to bear against the external surface of the structure in a way that will prevent flexure of the cell. The other plate is thin and reacts to the soil pressure.

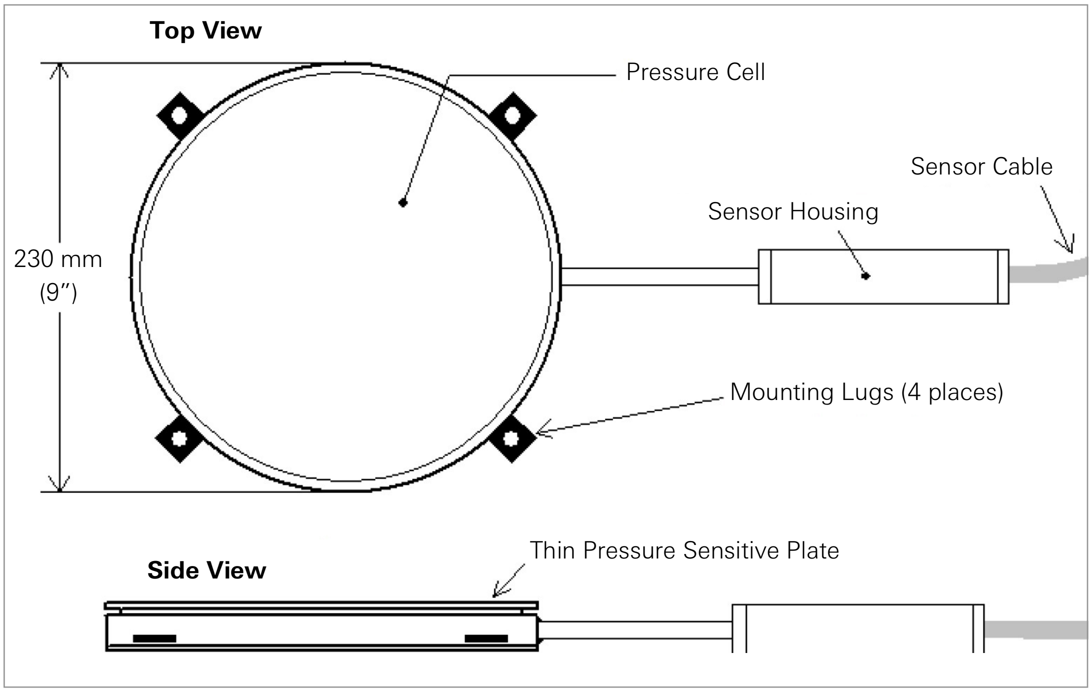

FIGURE 6: *Model 3510 Contact Pressure Cell*

1.2.3 MODEL 3515 GRANULAR MATERIALS PRESSURE CELL

Model 3515 Granular Materials Pressure Cells are the best choice for the measurement of dynamic pressure changes in railroad ballast. In this configuration both plates are thick so that they will not deflect locally under the point loads from surrounding gravel and rocks. The pressure sensor housing is connected directly to the edge of one of the thick back plates

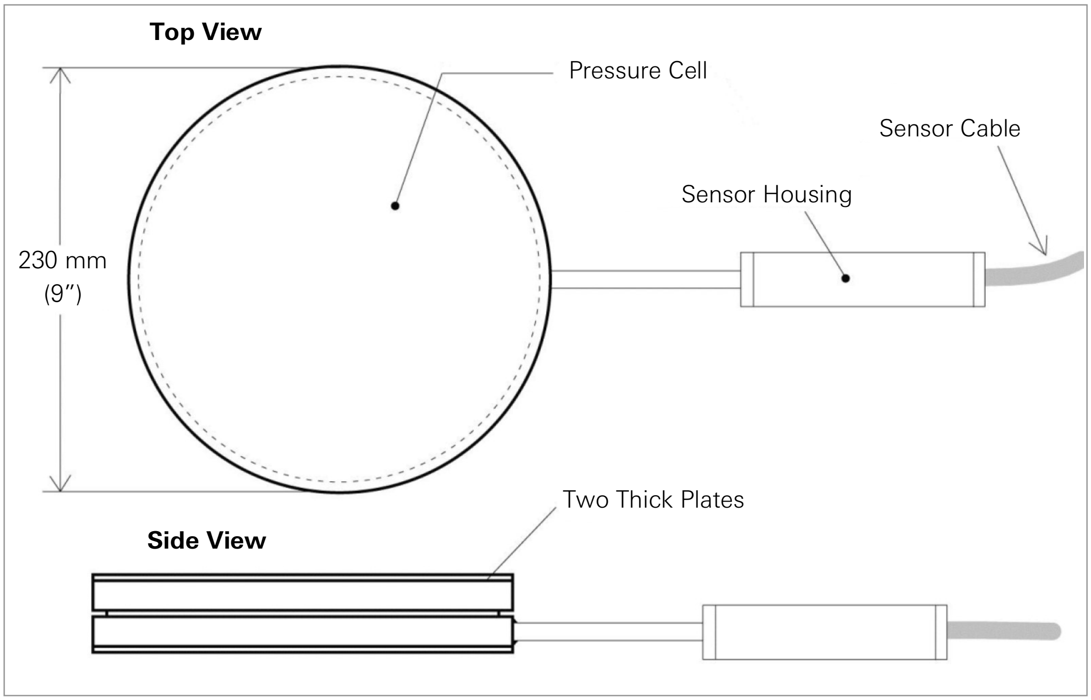

FIGURE 7: *Model 3515 Granular Materials Pressure Cell*

1.2.4 MODEL 3530 PUSH-IN PRESSURE CELL

Model 3530 Push-In Pressure Cells are designed to be pushed in place for the measurement of total pressures in soils and earth fills. The semiconductor pressure sensor enables measurement of dynamic pressures. A thread is provided on the end of the cell to allow for installation using lengths of pipe or drill rods.

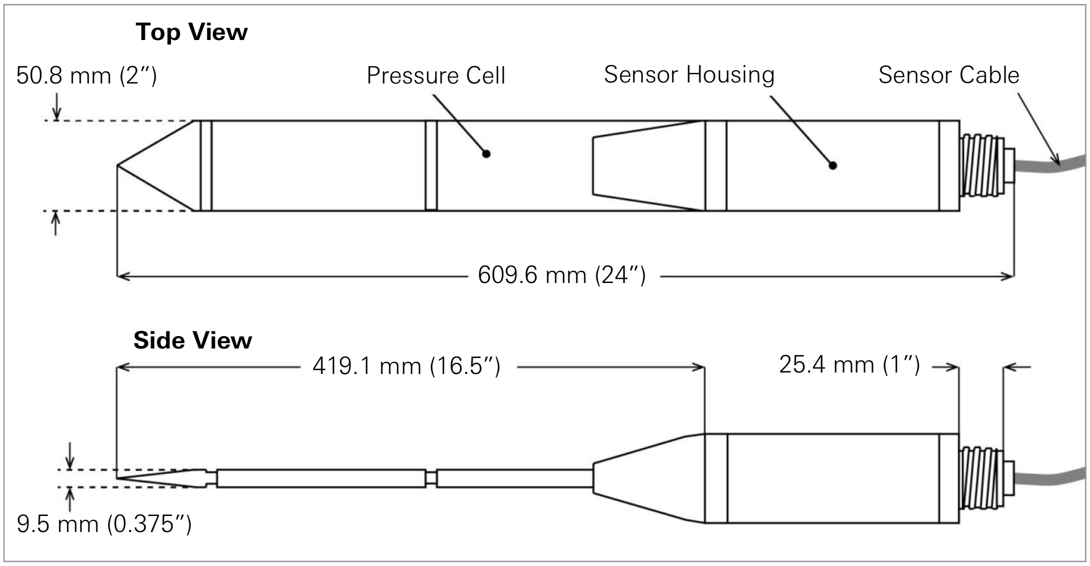

FIGURE 8: *Model 3530 Push-In Pressure Cell*

2. INSTALLATION CONSIDERATIONS

2.1 CABLE INSTALLATION AND SPLICING

The cable should be routed to minimize the possibility of damage due to moving equipment, debris or other causes. The cable can be protected using flexible conduit, which can be supplied by GEOKON.

The sensor type is a bonded resistance semiconductor and, as such, has very low-level output signals. If cables are damaged or improperly spliced, the outputs can be seriously degraded. Therefore, it is absolutely necessary to provide a high degree of cable protection and if cables must be spliced only recognized high quality techniques should be used.

The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **It is very important that the shield drain wires be spliced together.** Always maintain polarity when possible by connecting color to color.

Splice kits recommended by GEOKON incorporate casts that are placed around the splice and are then filled with epoxy to waterproof the connections. Contact GEOKON for splicing materials and additional cable splicing instructions.

2.2 ELECTRICAL NOISE

Care should be exercised when installing sensor cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC power lines. The sensor cables will pick up the 50 or 60 Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact the factory concerning filtering options available for use with the GEOKON dataloggers and readouts should difficulties arise.

3. INSTALLATION

3.1 PRELIMINARY TESTS

Before installation, check the cells for proper functioning. Each cell is provided with a no load zero reading. The cell electrical leads are connected to a multimeter and power supply (see Section 4 and Appendix C) and the zero reading given on the calibration report is now compared to a current zero reading. The two readings should not differ by more than 1% F.S. after due regard to corrections made for different temperatures, barometric pressures and height above sea level and actual cell position (whether standing up or laying down).

By pressing on the cell, it should be possible to change the readout digits, causing them to increase as the pressure is increased.

Checks of the insulation can also be made using an ohmmeter. Resistance between any conductor and the shield should exceed 50 megohms. The thermistor inside the cell can also be checked.

3.2 PRESSURE CELL INSTALLATION

The installation procedure is different depending on the model number.

3.2.1 MODEL 3500 EARTH PRESSURE CELLS INSIDE FILLS & EMBANKMENTS

(See also Appendix F for an alternative method for installation.)

This section details installation instructions for the Model 3500 Earth Pressure Cell for the measurement of total stress in earth or rock fills and embankments. These procedures are only for cells totally surrounded by earth. Where contact stresses between earth and a structure are required see Section 3.2.2 and 3.2.4.

Earth pressure cells are normally installed with the flat surfaces horizontal to measure vertical stresses. However, they can be placed at other orientations, inside the fill, to measure stresses in other directions i.e. a cell placed with the flat surfaces vertical will measure horizontal stresses in a direction perpendicular to the plates of the cell. The position and orientation of the cells can be maintained during installation by means of plywood templates. These templates can be removed by hand after the sand or fine material immediately surrounding the cells has been placed and carefully hand compacted.

When installing the cells, it is important to avoid direct contact with large rocks. Such contact could locally deform the plates to such an extent that the external pressure is no longer transmitted entirely to the interior fluid. For this reason, all chunks larger than 10 mm (0.4") should be removed from the material immediately surrounding the cell. It is preferable to surround the cell using the material of the fill rather than another material (e.g. sand) since the stiffness will conform better to the rest of the fill. In areas containing appreciable coarse material, the lenses of fine material should be enclosed in transitional layers of successively coarser material to establish a graduation outward to the maximum size material.

Earth Pressure Cells clusters, placed according to the methods outlined above, may be installed either in trenches, below the temporary embankment grade, or in ramps above the temporary embankment grade. In dams, for example, it is usually convenient to install in trenches in the impervious rolled fill core, and in ramps in the filter zones and compacted rockfill shell zones. In earth embankments it is convenient to install in trenches. By doing so, adequate degrees of compaction of the backfill can be more easily obtained without damage to the cell clusters or cable arrays. As the cells are being covered and compacted, repeated readings should be taken to ensure that the cells are continuing to function properly.

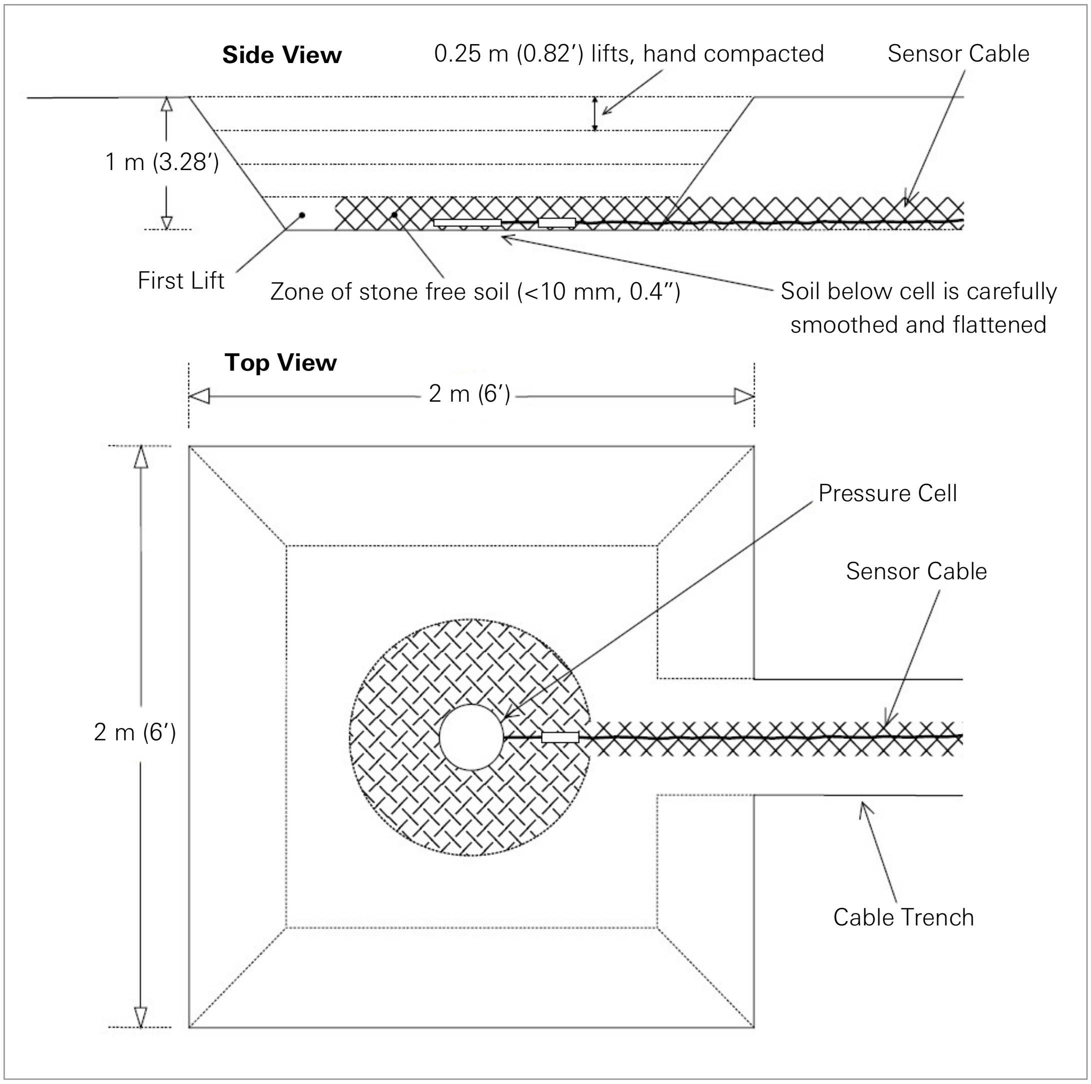

FIGURE 9: *Model 3500 Earth Pressure Cell Installation*

The cable may be marked by using Mylar cable labels. For an individual cable the identification number should be taped near the end of the cable. Additional cable labels might be specified at regular intervals along the cable to aid in identification if cables need to dug up for splicing, etc.

Cable installation details are described later. The precautions to be observed in protecting the cable from damage by heavy vibratory compaction equipment should also be observed in connection with the cell clusters. In general, all fine material in the sensor lenses should be placed by hand and compacted with pneumatic or gasoline backfill tampers. The first layers of transitional material over the lenses should be placed in 250 mm (10") lifts and similarly compacted until at least 500 mm (18") of material had been placed. At that time equipment with rubber tires can cross the lens location, but no vibratory rollers should be permitted across the lens until it is protected by a compacted thickness of at least 1 m (3.28’).

In embankments, cables may be embedded in a protective covering of sand or selected fine embankment materials. A typical installation might comprise the positioning of a series of cables on a prepared layer consisting of not less than 200 mm (8") of compacted selected fine material. To establish an acceptable grade without undue interference with construction operations, the prepared layer may be located either in a trench or on an exposed ramp. In rockfill dams with earthfill cores, for example, it is frequently convenient to install cable in trenches in the core and fine filter zones, and in ramps in the coarse filter and compacted rock fill shell zones. Individual cables should be spaced not less than 12 mm (0.5") apart, and no cable should be closer than 150 mm (6") to the edge of the prepared layer. In instances in which cables must cross each other, or in which more than one layer of cables must be placed in a given array, the cables should be separated from each other by a vertical interval of not less than 50 mm (2") of hand compacted sand or selected fine embankment material. Since the elongation capability of electrical cable is quite substantial, it is **not** necessary to place the cable with "S" shaped meanders, which in any case serve no purpose.

During the backfill of trenches in earth dams, a plug, approximately 0.5 meter (2’) in width, made of a mixture of 5% bentonite (by volume) from an approved source and exhibiting a free swell factor of approximately 600%, and 95% embankment material, can be placed in the trenches at intervals of not greater than 20 meters (50’). The purpose of the bentonite plugs is to reduce the possibility of water seepage through the embankment core along the back filled trenches.

3.2.2 MODEL 3510 CONTACT (“FAT BACK”) PRESSURE CELL

This section details installation instructions for the Model 3510 Earth Pressure Cells, which are used for the measurement of earth pressures on structures. In backfills for piers, piles, bridge abutments, retaining walls, culverts and other structures the cells may be installed either inside a concrete structure being poured or directly on the surface of an existing structure.

INSTALLATION IN POURED CONCRETE:

When pouring concrete, the cells can be held to the forms using nails through the lugs welded to the edge of the cell. Position the cell so that the thin pressure sensitive plate is directly against the concrete form. Nail the plates to the form lightly in such a manner that they engage the concrete sufficiently so that they do not pull out of the concrete when the forms are removed. Route the cable inside the concrete to a convenient readout location or to a block out inside where excess cable can be coiled. Protect the cable from damage during concrete placement and vibration, by tying it to adjacent rebars.

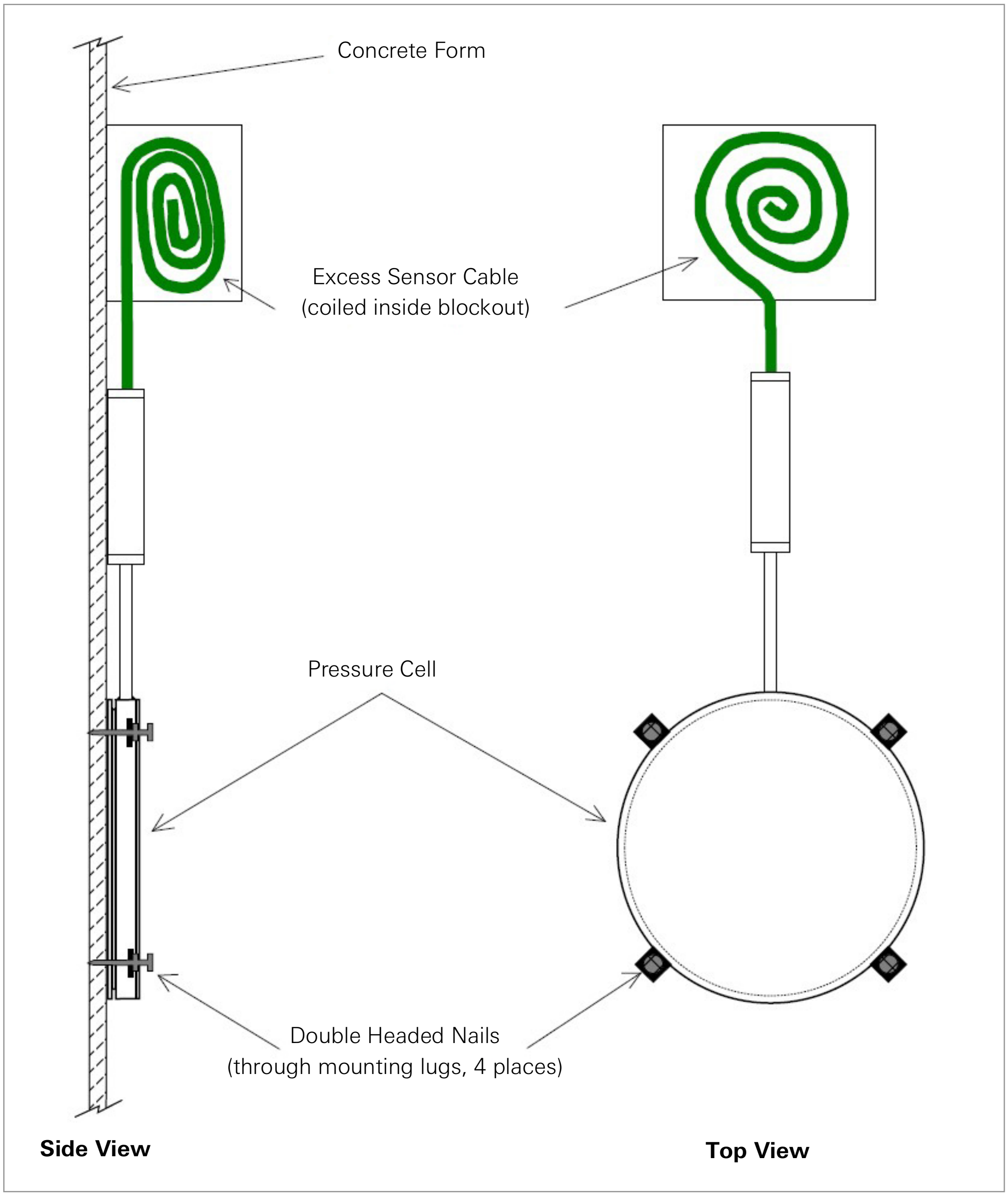

FIGURE 10: *Attachment of Model 3510 to Concrete Form*

INSTALLATION ON EXISTING STRUCTURES

Again, the lugs welded to the edge of the cell can be used to hold the cell against the structure using nails, lag bolts, tie wire, etc. Even if the surface is smooth, but especially where the surface is rough or irregular a mortar pad between the cell and the structure is required.

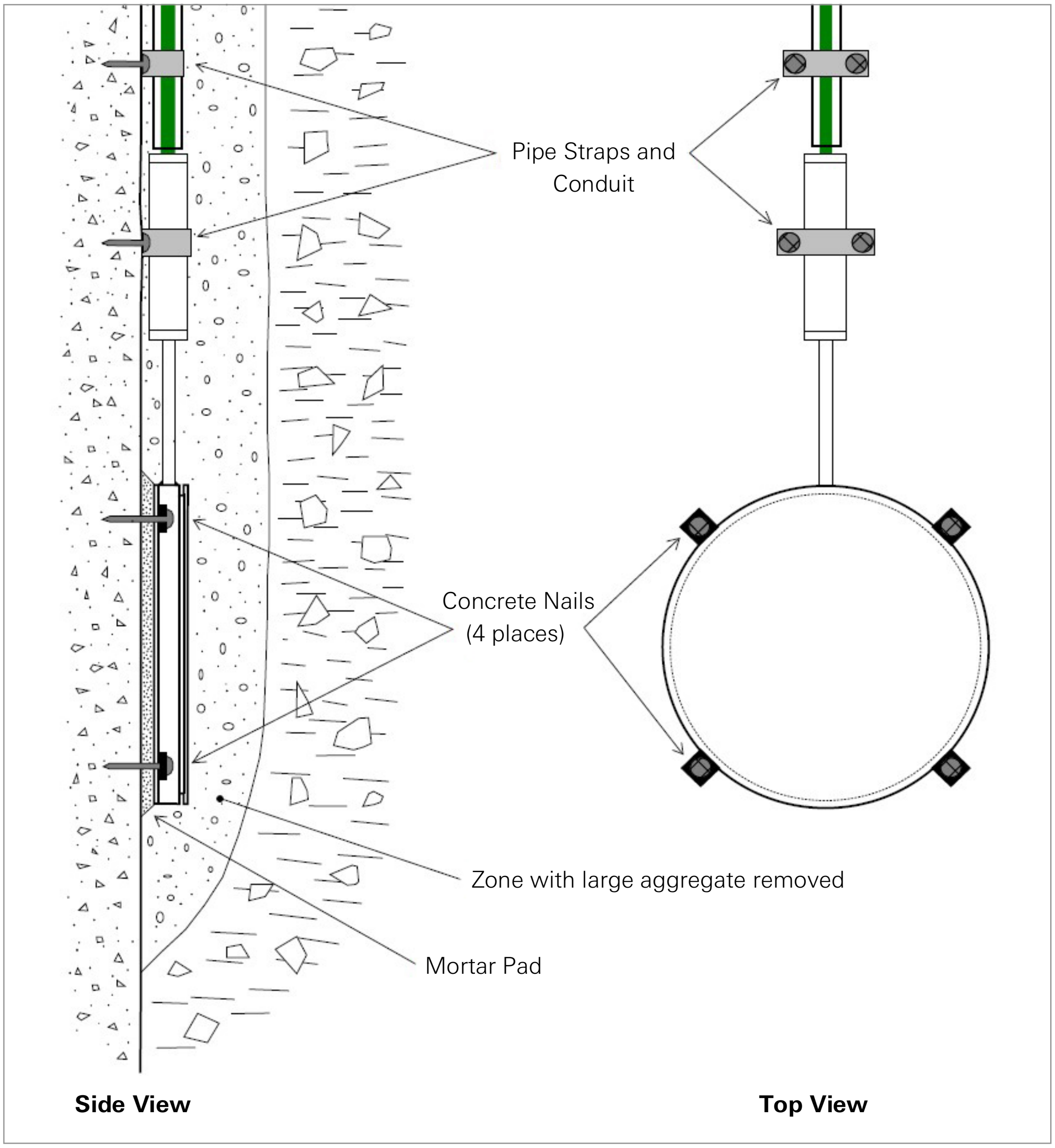

FIGURE 11: *Model 3510 Contact Pressure Cell Installation*

Use the lugs on the cell as a template to locate the position for drilling holes for the installation of expanding anchors or install the anchors nearby and use wire to hold the cells in place. Alternately the cell may be nailed in place using the lugs as a guide. First, mix up some quick setting cement mortar or epoxy cement. Trowel this onto the surface then push the cell into the cement so that the excess cement extrudes out of the edges of the cell. Hold the cell in place while the cement sets up then complete the installation by adding the lag bolts (using the expansion anchors) and tightening or nailing the cell in place. Protect the cell, sensor housing and cable from direct contact with large chunks of rock by covering them with fine grained fill material from which all pieces larger than about 10 mm (0.5") have been removed. This fine material is kept next to the cell and cable as the fill is placed. Additional cable protection can be achieved by using metal conduit strapped to the surface of the structure.

3.2.3 INSTALLATION OF MODEL 3515 GRANULAR MATERIALS PRESSURE CELL

In the railroad ballast application, the pressure cell is placed in the ballast directly below one or both tracks.

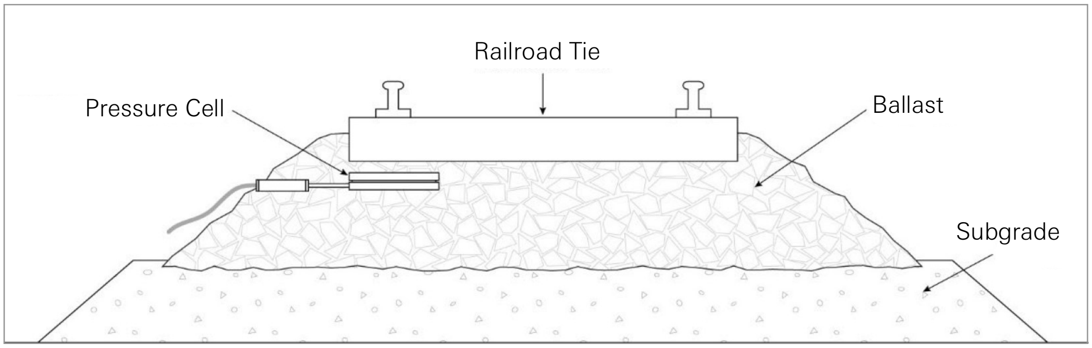

FIGURE 12: *Model 3515 Granular Materials Pressure Cell in Railroad Ballast*

3.2.4 INSTALLATION OF MODEL 3530 PUSH-IN PRESSURE CELLS TO MEASURE LATERAL EARTH PRESSURES

The Model 3530 is designed to be pushed into soft soils using available drill rods, usually AW. Unless the ground is very soft it is recommended that a borehole be drilled to within about two feet of the desired location and then push the cell the rest of the way.

A couple of things to note and be aware of:

- **Temperature effects:**

  This pressure cell is relatively stiff due to the geometry and the need for a robust construction for pushing into the ground. It is always advisable to obtain the pre-installation zero pressure readings in the borehole at the borehole temperature. It may take a significant amount of time for the sensor to come to thermal equilibrium, but this is an important measurement and if it is not possible to take this reading in the borehole it may be possible to take the reading in a bucket of water that is at the ground temperature.

- **Overpressure:**

  When pushing the cell into the ground it is possible that pressures in excess of the sensors full scale range can be generated causing the sensor to experience a zero shift or even permanent damage. To prevent this, readings should be taken as the sensor is pushed. When the indicated pressure approaches 150% of full scale the pushing operation should be terminated until the sensor output comes back within its calibrated range.

3.3 INITIAL READINGS

Initial readings must be taken and carefully recorded along with the barometric pressure and temperature at the time of installation. Take the initial readings while the cell is in position, just prior to it being covered by fill and pouring of concrete.

4. TAKING READINGS

The Model 3500 uses a semiconductor sensor with an output of either 0-100mV (Model 3500-1), 0-5 Volts (Model 3500-2), or 4-20 mA (Model 3500-3).

For the 0-100mV type, the output voltage is directly proportioned to both pressure and input voltage, therefore it is very important that the input voltage be accurately controlled @ 10V DC. If any other voltage is used, the data calculation must be adjusted accordingly. The 0-5 volt and 4-20mA sensors require an unregulated input of 24 VDC (7-32 VDC).

Readings are taken with an ohmmeter and VDC regulated power supply, use the applicable wiring chart in Appendix C.

Warning! Incorrect connection may cause permanent and irreparable damage to the sensor.

4.1 COMPATIBLE READOUTS AND DATALOGGERS

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

Dataloggers

DATALOGGERS:

- **8600 Series**

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

Model 4999 Manual

4.2 MODEL 4999 TERMINAL BOXES

Terminal boxes with sealed cable entries are available from GEOKON. These allow many sensors to be terminated at one location with complete protection of the lead wires. The interior panel of the terminal box can have built-in jacks or a single connection with a rotary position selector switch.

For further details and instruction consult the Model 4999 Instruction Manual.

4.3 MEASURING TEMPERATURES

Each pressure cell is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Appendix C shows which cable conductors are connected to the thermistor. Connect an ohmmeter to the thermistor leads coming from the sensor. Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied equal to approximately 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions.

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

5. DATA REDUCTION

5.1 DATA CALCULATION

The basic units utilized by GEOKON for measurement and reduction of data from this sensor are millivolt (mV), Volt (V), or milliamp (mA).

In typical installations the linear calculation is more than sufficient. However, if utmost accuracy is desired, the polynomial calculation can be used. Refer to the applicable section below.

5.1.1 LINEAR CALCULATION

To convert mV, V, or mA to pressure the following equation applies:

$$P = G(R_1 - R_0)$$

EQUATION 1: *Linear Pressure Calculation*

Where:
G = The gauge factor found on the calibration report, usually in terms of kPa or MPa per mV, V, or mA.

R_1 = The current reading in mV, V, or mA.
R_0 = The initial field zero reading in mV, V, or mA.

The Initial Reading (R_0) is normally obtained during installation immediately prior to loading the cell. Make sure that the pressure cell has achieved temperature stability. Shield it from direct sunlight and wait until the reading has stabilized after handling it.

As mentioned in Section 4, if reading a **millivolt** sensor using an input voltage other than 10 VDC, the data calculation must be adjusted. To do this, multiply the equation above by $10/V_1$.

EXAMPLE:

The initial reading (R_0) at installation of a Model 3400-1-100 kPa (0-100mV sensor) is 0.500 mV. The current reading (R_1) is 40 mV. Readings were taken with an input voltage of 12 VDC, so for this specific example the input voltage adjustment must be calculated. The calibration factor (G) is 1.0021 kPa/mV. The pressure change is:

$$P = G(R_1 - R_0) \times 10/V_1$$

$$P = 1.0021(40 - 0.500) \times 10/12$$

$$P = 32.99 \text{ kPa}$$

Increasing (positive) readings indicate an increased depth of 3.36 m (11.04’) (if calculating for fresh water) using the engineering units conversion in Section 5.2.2.

5.1.2 POLYNOMIAL CALCULATION

To convert mV, V, or mA to pressure using the polynomial expression the following equation applies:

$$P = AR_1^2 + BR_1 + C$$

EQUATION 2: *Polynomial Pressure Calculation*

Where:
R_1 = The current reading in mV, V, or mA.
A, B, C = The polynomial gauge factors found on the calibration report.

As mentioned in Section 4, if reading a **millivolt** sensor using an input voltage other than 10 VDC, the data calculation must be adjusted. To do this, find R_P and **substitute R_P in place of R_1** in Equation 2.

$$R_P = R_1 \times 10 / V_1$$

EQUATION 3: *Calculation for Current Reading Adjustment "R_P" when reading in mV*

Where:
R_1 = The current reading in mV.
V_1 = Input voltage when taking the reading.

EXAMPLE:

The given polynomial gauge factors on the calibration are:

A = 5.87E^{-05}

B = 0.9962

C = -0.4177

The current reading (R_1) of a Model 3400S-1-100 kPa (0-100mV sensor) is 40 mV. Readings were taken with an input voltage of 12 VDC.

First, for this specific example, the input voltage adjustment must be calculated:

$$R_P = R_1 \times 10 / V_1$$

$$R_P = 40 \times 10 / 12$$

$$R_P = 33.33$$

The pressure change is:

$$P = AR_P^2 + BR_P + C$$

$$P = 5.87 \times 10^{-5} \times 33.33^2 + 0.9962 \times 33.33 + (-0.4177)$$

$$P = 32.84 \text{ kPa}$$

Increasing (positive) readings indicate an increased depth of 3.35 m (10.99') (if calculating for fresh water) using the engineering units conversion in Section 5.2.2

5.2 OPTIONAL CALCULATIONS

5.2.1 TEMPERATURE CORRECTION

The cell is quite sensitive to temperature fluctuations. Equation 4 below shows the temperature correction for the VW transducer only, and usually this effect is insignificant and can be ignored. There can be much larger temperature effects caused by the mismatch between temperature coefficients of the cell and surrounding concrete. This effect is not quantifiable in the laboratory, but a theoretical treatment is given in Appendix E.

The best way to compensate for temperatures is to derive a thermal correction factor from simultaneous measurements of pressure and temperature at times when it can be safely assumed that the applied load is not changing (such as while the concrete is curing).

The following thermal correction equation (which only applies to the VW transducer) is calculated, then afterwards is added to the deformation calculation (Equation 1 or Equation 2):

$$T_{Correction} = K(T_1 - T_0)$$

EQUATION 4: *Thermal Correction for Pressure*

Where:
K = The thermal factor found on the calibration report, usually in terms of kPa, MPa, or psi per digit.

T_1 = The current temperature reading in °C.
T_0 = The initial field temperature reading in °C.

5.2.2 BAROMETRIC CORRECTION

The sensor is sealed and will respond to barometric pressure fluctuation. However, since the magnitudes are only on the order of ±0.5 psi, correction is generally not required. If a correction for these fluctuations is required, then it is necessary to record the barometric pressure at the time of each reading.

The following barometric correction equation is calculated, then afterwards is subtracted from the deformation calculation (Equation 1 or Equation 2):

$$S_{Correction} = (S_1 - S_0) \times F$$

EQUATION 5: *Barometric Correction with Conversion Factor*

Where:
S_1 = The current barometer.
S_0 = The initial field zero barometer.
F = The conversion factor, see below for more detail.

Barometric pressure must be converted to the same engineering unit as the sensor pressure range (kPa or MPa). Barometric pressure is usually recorded in inches of mercury. The conversion factor (F) for inches of mercury to kPa is 3.3863 and from inches of mercury to MPa is 0.003386. Table 1 in Section 5.2.2 lists other common conversion factors.

5.2.3 ENGINEERING UNITS CONVERSION

To convert to a different engineering unit, take the result from data calculation (after other optional calculations have been completed, if applicable) and multiply it by the appropriate conversion multiplier from Table 1.

Convert To	Convert From											
	psi	**"H_2O**	**'H_2O**	**mm H_2O**	**m H_2O**	**"HG**	**mm HG**	**atm**	**mbar**	**bar**	**kPa**	**MPa**
psi	1	.036127	.43275	.0014223	1.4223	.49116	.019337	14.696	.014503	14.5039	.14503	145.03
"H_2O	27.730	1	12	.039372	39.372	13.596	.53525	406.78	.40147	401.47	4.0147	4016.1
'H_2O	2.3108	.08333	1	.003281	3.281	1.133	.044604	33.8983	.033456	33.4558	.3346	334.6
mm H_2O	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_2O	.70432	.025399	.304788	.001	1	.34532	.013595	10.332	.010197	10.197	.10197	101.97
"HG	2.036	.073552	.882624	.0028959	2.8959	1	.03937	29.920	.029529	29.529	.2953	295.3
mm HG	51.706	1.8683	22.4196	.073558	73.558	25.4	1	760	.75008	750.08	7.5008	7500.8
atm	.06805	.002458	.029499	.0000968	.0968	.03342	.001315	1	.000986	.98692	.009869	9.869
mbar	68.947	2.4908	29.8896	.098068	98.068	33.863	1.3332	1013.2	1	1000	10	10000
bar	.068947	.002490	.029889	.0000981	.098068	.033863	.001333	1.0132	.001	1	.01	10
kPa	6.8947	.24908	2.98896	.0098068	9.8068	3.3863	.13332	101.320	.1	100	1	1000
MPa	.006895	.000249	.002988	.0000098	.009807	.003386	.000133	.101320	.0001	.1	.001	1

TABLE 1: *Engineering Units Conversion Multipliers*

5.3 ENVIRONMENTAL FACTORS

Since the purpose of the sensor installation is to monitor site conditions, factors that can affect these conditions should always be observed and recorded. Seemingly minor affects may have a real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to, blasting, rainfall, tidal levels, traffic, temperature and barometric changes, weather conditions, changes in personnel, nearby construction activities, excavation and fill level sequences, seasonal changes, etc.

6. TROUBLESHOOTING

Technical Support

Maintenance and troubleshooting of the sensor is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the sensor is usually inaccessible and remedial action is limited.

Should difficulties arise, consult the following list of problems and possible solutions. For additional troubleshooting and support visit geokon.com/Technical-Support.

SYMPTOM: SENSOR READINGS ARE UNSTABLE

- ☐ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, transformers, arc welders and antennas. Make sure the shield drain wire is connected to ground.
- ☐ Does the readout or datalogger work with another pressure cell? If not the readout or datalogger may be malfunctioning.

SYMPTOM: SENSOR FAILS TO GIVE A READING

- ☐ Is the cable cut or crushed? This can be checked with an ohmmeter. This can be checked with an ohmmeter. If the resistance reads infinite or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<100Ω), a short in the cable is likely.
- ☐ Does the readout or datalogger work with another pressure cell? If not the readout or datalogger may be malfunctioning.

APPENDIX A. SPECIFICATIONS

A.1 MODEL 3500 SPECIFICATIONS

Model	3500-1	3500-2	3500-3
Output	0-100 mV (10 mV/V)	0-5 VDC	4-20 mA
Supply Voltage	10 VDC Regulated (2.5 to 12 V)	24 VDC (7-32 VDC)	24 VDC (7-32 VDC)
Pressure Range[1]	Vacuum to 80 bar (875 psi)		
Over Pressure[2]	2 x Full Scale (F.S.)		
Performance			
Long Term Drift	±0.5% F.S./year typical (±0.1% F.S. maximum)		
Accuracy	±0.2% F.S. (other options available)		
Thermal Error	1.5% F.S. typical (optional 1% F.S.)		
Compensated Temperatures	-20° to 80 °C (-4° to 176 °F)		
Operating Temperatures	-55 to +125 °C (-67 to +257 °F) Internal Sensor		
Zero Tolerance	1% F.S. (mV Versions: ±3.0 mV)		
Span Tolerance	1% F.S. (mV Versions: ±3.0 mV)		
Mechanical Configuration			
Pressure Port	7/16-20 UNJF Male 74° External Cone		
Wetted Parts	316L Stainless Steel & Hastelloy C276		
Electrical Connection	see ordering chart		
Vibration	30 g, 10 to 2000 Hz		

TABLE 2: *Model 3500 Earth Pressure Cell Specifications*

Note:

[1] Other ranges available on request.

[2] Up to 200 bar for ranges ≤70 bar and up to 1200 bar for ranges >70 bar.

A.2 THERMISTOR

See Appendix B for more information.

Range: -80 to +150 °C

Accuracy: ±0.5 °C

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

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

Resistance to Temperature Equation:

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

EQUATION 6: *3KΩ Thermistor Resistance*

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

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

TABLE 3: *3KΩ Thermistor Resistance*

APPENDIX C. WIRING CHARTS

Warning! Incorrect connection may cause permanent and irreparable damage to the sensor.

C.1 0-5 VOLT DIRECT CURRENT OUTPUT SENSORS

Multimeter set to read in Volts (V) DC and power supply set at 24 VDC (7-32 VDC).

GEOKON **Cable #04-375V9 (Violet)**	**Multimeter Connection**	**Power Supply Connection**	**Function/Description**
Red	N/C	Red (+)	Power +
Red's Black	N/C	Black (-)	Power -
White	Red (+)	N/C	Signal +
White's Black	Black (-)	N/C	Signal -
Blue	N/C	N/C	Thermistor
Blue's Black	N/C	N/C	Thermistor
Shield	N/C	N/C	Ground

TABLE 4: *0-5 Volt Direct Current Output Sensors*

C.2 0-100 MILLIVOLT OUTPUT SENSORS

Multimeter set to read in millivolts (mV) DC and power supply set at 10 VDC Regulated (2.5 to 12 V).

GEOKON **Cable #04-375V9 (Violet)**	**Multimeter Connection**	**Power Supply Connection**	**Function/Description**
Red	N/C	Red (+)	Power +
Red's Black	N/C	Black (-)	Power -
White	Red (+)	N/C	Signal +
White's Black	Black (-)	N/C	Signal -
Green	N/C	N/C	Remote Sense + (optional)
Green's Black	N/C	N/C	Remote Sense - (optional)
Blue	N/C	N/C	Thermistor
Blue's Black	N/C	N/C	Thermistor
Shield	N/C	N/C	Ground

TABLE 5: *0-100 Millivolt Output Sensors*

C.3 4-20 MILLIAMP OUTPUT SENSORS

Multimeter set to read in milliamps (mA) DC and power supply set at 24 VDC (7-32 VDC).

Connect the black (-) leads of the multimeter and power supply together.

GEOKON **Cable #02-250V6 (Blue)**	**Multimeter Connection**	**Power Supply Connection**	**Function/Description**
Red	N/C	Red (+)	Power +
Black	Red (+)	N/C	Power -
White	N/C	N/C	Thermistor
Green	N/C	N/C	Thermistor
Shield	N/C	N/C	Ground

TABLE 6: *4-20 Milliamp Output Sensors*

APPENDIX D. TYPICAL CALIBRATION REPORT

GEOKON®

Pressure Transducer Calibration Report

This Calibration has been Verified/ Validated as of: August 1, 2023

Model Number: 3500-1-100 kPa

Date of Calibration: July 24, 2023

Serial Number: 2307150

Temperature: 20.8 °C

Pressure Range: 100 kPa

Technician:

Calibration Instruction: CI-Pressure Transducers 7 kPa~3.5 MPa

Applied Pressure (kPa)	Gauge Reading (mV) 1st Cycle	Gauge Reading (mV) 2nd Cycle	Average Gauge Reading	Linearity (%FS)	Polynomial Fit (%FS)
0	0.282	0.284	0.283	-0.07	0.01
20	20.31	20.31	20.31	0.00	-0.01
40	40.32	40.32	40.32	0.06	0.00
60	60.27	60.28	60.28	0.06	0.00
80	80.18	80.18	80.18	0.02	0.00
100	100.03	100.04	100.04	-0.08	0.00

Linear Gauge Factor (G): 1.0024 (kPa / mV) **Regression Zero: 0.354**

Polynomial Gauge Factors: A: 5.80E-05 B: 0.9966 C: -0.2765

Calculated Pressures: **Linear, $P = G(R_1 - R_0) \times 10 / V_I$**

Polynomial, $P = AR_P^2 + BR_P + C$ $[R_P = R_1 \times 10 / V_I]$

Input Voltage, V_I: 10 VDC

Wiring Code: See manual for further information.

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 13: *Model 3500-1 Typical Calibration Report*

GEOKON

Pressure Transducer Calibration Report

This Calibration has been Verified/ Validated as of: August 21, 2023

Model Number: 3500-2-400 kPa

Date of Calibration: August 17, 2023

Serial Number: 2311202

Temperature: 20.3 °C

Pressure Range: 400 kPa

Technician:

Calibration Instruction: CI-Pressure Transducers 7 kPa~3.5 MPa

Applied Pressure (kPa)	Gauge Reading (Volts) 1st Cycle	Gauge Reading (Volts) 2nd Cycle	Average Gauge Reading	Linearity (%FS)	Polynomial Fit (%FS)
0	0.000	0.000	0.000	-0.09	0.00
80	1.005	1.006	1.006	0.02	0.00
160	2.008	2.008	2.008	0.07	0.00
240	3.008	3.008	3.008	0.08	0.00
320	4.005	4.005	4.005	0.02	0.00
400	4.999	4.999	4.999	-0.10	0.00

Linear Gauge Factor (G): 80.01 (kPa / Volt) **Regression Zero: 0.0047**

Polynomial Gauge Factors: A: 1.14E-01 B: 79.45 C: 0.002

Calculated Pressures: **Linear, $P = G(R_1 - R_0)$**

Polynomial, $P = AR_1^2 + BR_1 + C$

Input Voltage: 24 VDC

Wiring Code: See manual for further information.

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 14: *Model 3500-2 Typical Calibration Report*

GEOKON

Pressure Transducer Calibration Report

This Calibration has been Verified/ Validated as of: September 15, 2023

Model Number: 3500-3-600 kPa

Date of Calibration: August 23, 2023

Serial Number: 2312733

Temperature: 20.3 °C

Pressure Range: 600 kPa

Technician:

Calibration Instruction: CI-Pressure Transducers 7 kPa~3.5 MPa

Applied Pressure (kPa)	Gauge Reading (mA) 1st Cycle	Gauge Reading (mA) 2nd Cycle	Average Gauge Reading	Linearity (%FS)	Polynomial Fit (%FS)
0.0	3.994	3.992	3.993	-0.18	0.00
120.0	7.228	7.225	7.227	0.03	0.00
240.0	10.445	10.444	10.445	0.14	0.00
360.0	13.645	13.644	13.645	0.14	0.00
480.0	16.829	16.827	16.828	0.04	0.00
600.0	19.994	19.993	19.994	-0.18	0.00

Linear Gauge Factor (G): **37.497** **(kPa/ mA)** **Regression Zero:** **4.021**

Polynomial Gauge Factors: A: **3.13E-02** **B:** **36.747** **C:*** **-147.21**

Calculated Pressures: **Linear, $P = G(R_1 - R_0)$**

Polynomial, $P = AR_1^2 + BR_1 + C$

Input Voltage: 24 VDC

Wiring Code: See manual for further information.

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: *Model 3500-3 Typical Calibration Report*

APPENDIX E. TEMPERATURE EFFECT ON EARTH PRESSURE AND CONCRETE STRESS CELLS

The following theoretical treatment is by no means rigorous, there are some questionable assumptions and approximations, but it should give some idea of the magnitude of the thermal effect to be expected on hydraulic earth pressure cells, buried in soil, or installed at the contact between soil and structure, and on concrete stress cells embedded in concrete.

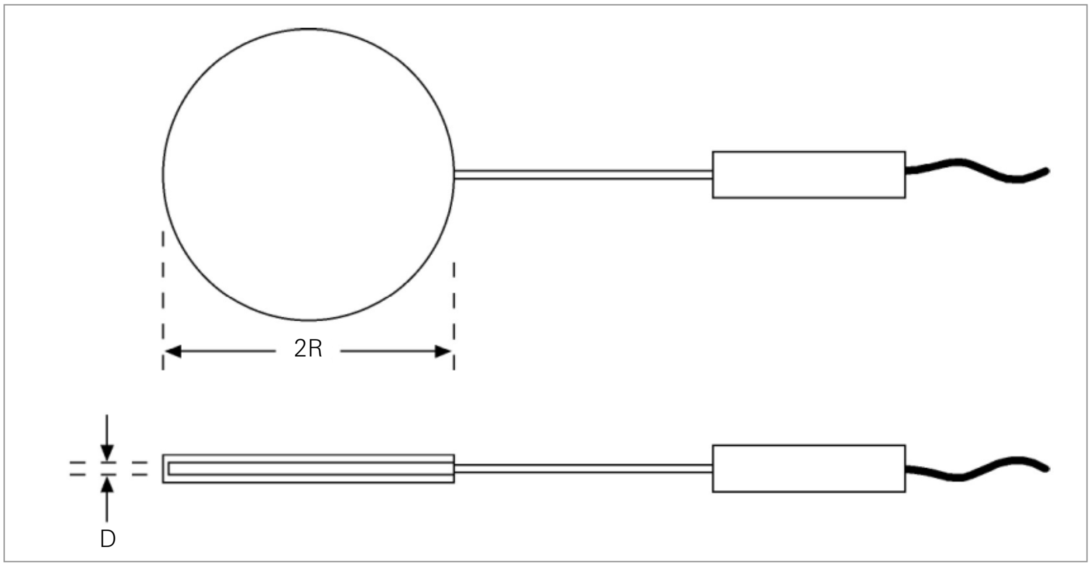

FIGURE 16: *Radius (R) and Thickness (D)*

E.1 FORMULAS

Consider a circular cell of radius (R) containing a liquid film of a thickness (D), coefficient of thermal expansion Kppm/°C, and bulk modulus (G).

For a temperature rise of 1 °C the expansion (Y_T) of the liquid film is given by the equation:

$$Y_T = KD$$

EQUATION 7: *Expansion of Liquid for a Temperature Rise of 1 °C*

Expansion of the liquid is resisted by the confinement of the surrounding medium (soil or concrete) and this causes a pressure rise (P) in the liquid, as well as a compression of the liquid (Y_c) given by the equation:

$$Y_c = PD/G$$

EQUATION 8: *Compression of Liquid*

The net expansion (Y) of the cell is equal to:

$$Y = D(K - P/G)$$

EQUATION 9: *Expansion of Liquid*

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formulas [Ref 1], where the deformation (Y), produced by a uniform pressure (P), acting on a circular area, (R) radius, on the surface of a material with modulus of elasticity (E) and Poisson's ratio (ν), is given by:

At the center of the cell:

$$Y = \frac{2\ PR(1 - \nu^2)}{E}$$

EQUATION 10: *Deformation at the Center*

At the edge of the cell:

$$Y = \frac{4\ PR(1 - \nu^2)}{\pi E}$$

EQUATION 11: *Deformation at the Edge*

The difference being:

$$\frac{PR(1 - \nu^2)(2 - 4/\pi)}{E}$$

EQUATION 12: *Difference in Deformation*

The above formulas apply to pressures acting on a free surface. However, in the confined case, Y, at the edge of the cell, can be assumed to be nearly zero. Therefore, Y, at the center, is assumed to be the same as shown in Equation 12.

If the average Y across the cell is assumed to be half this value, and if the deformation of the medium on either side of the cell is assumed to be the same, then the average total expansion of the cell is given by:

$$Y = \frac{0.73\ PR(1 - \nu^2) \times 0.5 \times 2}{E} = \frac{0.73\ PR(1 - \nu^2)}{E}$$

EQUATION 13: *Average Total Expansion of the Cell*

Equating Equation 9 and Equation 13 gives:

$$P\left(\frac{D}{G} + \frac{0.73\ R(1 - \nu^2)}{E}\right) = KD$$

EQUATION 14: *Combined Equations*

If one side of the cell lies in contact with a rigid structure, e.g. a concrete retaining wall or a concrete bridge footing, then;

$$Y = \frac{0.73\ PR(1 - \nu^2) \times 0.5}{E} = \frac{0.36\ PR(1 - \nu^2)}{E}$$

And

$$P\left(\frac{D}{G} + \frac{0.36\ R(1 - \nu^2)}{E}\right) = KD$$

Where (E) pertains to the soil material.

Since these expressions are only approximate they can be simplified even further:

For all $E < 10 \times 10^6\ \text{psi}$ the term $\frac{D}{G}$ is negligible so long as the cell is designed and constructed properly, i.e., G is large, (no air trapped inside the cell), and D is small. Also, the term $(1 - \nu^2)$ can be replaced by 0.91 since ν usually lies between 0.25 and 0.35.

Hence, the total embedment is given by:

$$P = \frac{1.5\ EKD}{R} \qquad psi/°C$$

EQUATION 15: *Total Embedment*

And for contact pressure cells:

$$P = \frac{3\ EKD}{R} \qquad psi/°C$$

EQUATION 16: *Total Embedment for Contact Pressure Cells*

Some typical values of the various parameters are:

Liquid	**K x 10^{-6}/°C**	**CG x 10^{6} psi**
Oil	700	0.3
Mercury	180	3.6
Water	170	0.3
Glycol	650	0.26
50/50 Glycol/Water	400	0.28
Embedment Material	**E x 10^{6} psi**	ν
Plastic Clay	0.003	
Soil	0.001 to 0.02 [Ref 2]	0.25 to 0.45
Sand	0.02 to 0.06 [Ref 3]	0.28 to 0.35
Compacted Ottawa Sand	0.2	
Weathered Rock	0.04 to 0.11 [Ref 4]	
Concrete	5.0	0.25

TABLE 7: *Typical Values of Various Cell Parameters*

E.2 EXAMPLES

Note: For contact pressure cells, multiply the values for P by two.

PLASTIC CLAY:

For an oil-filled concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 3000 psi

ν = 0.3

P = 0.042 psi/°C

SOIL, MEDIUM STIFFNESS:

For an oil-filled concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 10000 psi

ν = 0.3

P = 0.138 psi/°C

COARSE SAND:

For an oil-filled concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 50000 psi

ν = 0.3

P = 0.69 psi/°C

CONCRETE:

For an oil-filled concrete stress cell, nine-inch diameter and D=0.020 inches:

E = 5 x 106 psi

ν = 0.25

P = 22.7 psi/°C

For the same cell, filled with mercury instead of oil:

P = 5.8 psi/°C

COMPLETELY RIGID MEDIUM:

For an oil-filled concrete stress cell, nine-inch diameter and D=0.020 inches:

P = 210 psi/°C

For the same cell, filled with mercury instead of oil:

P = 650 psi/°C

References:

[1] Roark, R.J. and Young, W.C. "Formulas for Stress and Strain," McGraw Hill, fifth edition, 1982, p 519.

[2] Weiler, W.A. and Kulhawy, F.H. "Factors Affecting Stress Cell Measurement in Soil" J. Geotech. Eng. Div. ASCE. Vol. 108, No. GT12, Dec., pp1529-1548.

[3] Lazebnik, G.E., "Monitoring of Soil-Structure Interaction." Chapman & Hall. pp 224.

[4] Fujiyasu, Y. and Orihara, K. "Elastic Modulus of Weathered Rock." Proc. of the 5th Intl. Symp. on Field Measurements in Geomechanics - Singapore 1999. p 183.

APPENDIX F. ALTERNATIVE METHOD FOR INSTALLING EARTH PRESSURE CELLS IN FILLS

The method described in Section 3.2.1 suffers from the drawback that it is very difficult, if not impossible, to get perfect compaction of the soil around the cells without running the risk of damaging the cells.

An alternative method used successfully in South Africa[Ref 1] essentially uses the techniques described in Section 3.2.3:

Installation of the cells begins when the fill has reached a height of 800 mm (31.5") above the sensor level. The sensor location and the cable trenches are excavated 500 mm (20") deep, a pocket, with 45° sloping sides, of only a further 300 mm (12") depth is required to be excavated at the sensor location. The cells, (with pinch tubes), are positioned on a thin layer of non-shrink sand-cement grout and are nailed in position using the lugs on the cells provided for this purpose. The excavated pocket is then backfilled with a weak concrete (19 mm or 0.75" of aggregate), in 100 mm (4") layers, vibrated with a poker vibrator. After 24 hours the cells are pressurized, by pinching the pinch tubes until the pressure in the cell, displayed on a connected Readout Box, starts to change.

The sensor location containing the grouted cells and the cable trench is then backfilled in 100 mm (4") layers, using the techniques described in Section 3.2.1. Each layer is compacted by a vibratory trench roller. After this, standard construction filling and compaction practices can continue.

References:

[1] Oosthuizen, C., Naude, P.A. & Hattingh, L.C. 2003. Total and Pore Cells: Method in the Madness. Proceedings of the 6th International Symposium on Field Measurements in Geomechanics 2003, Oslo, Norway, 2003. Balkema.

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