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Instruction Manual

Model 3500 Series

Earth Pressure Cells

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EQUATIONS

1. INTRODUCTION

1.1 Theory of Operation

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. 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.

Earth pressure cells of the type described here are the hydraulic type; two flat plates are welded together at their periphery and are separated by a small gap filled with a hydraulic fluid. The earth pressure acts to squeeze the two plates together thus building up a pressure inside the fluid. 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 <u>at the center of the cell the external soil pressure is exactly balanced by the internal fluid pressure.</u>

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 transducer 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.

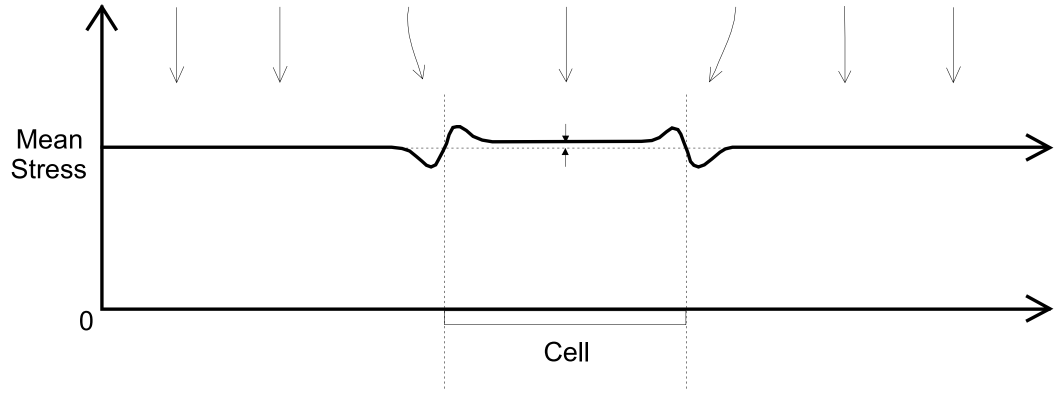

Figure 1 - Stress Redistribution, Weak Soil with Stiff Cell

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 <u>stronger</u> soil the destressed 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.

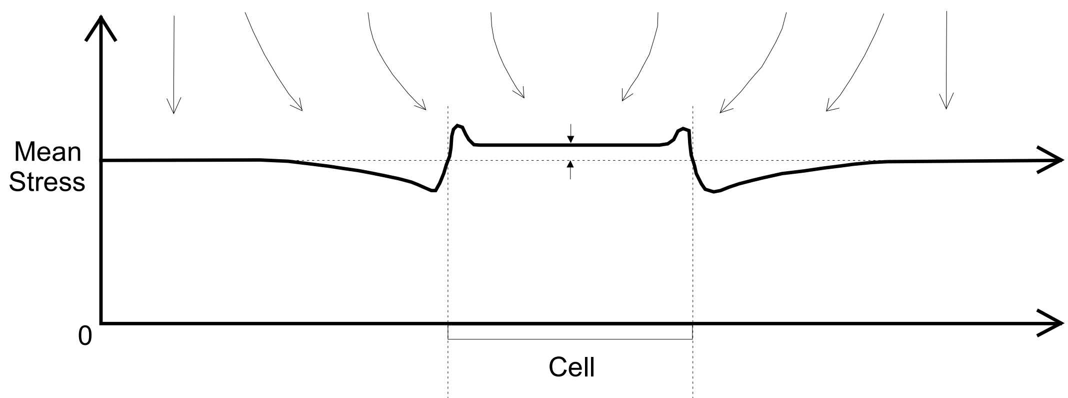

Figure 2 - Stress Redistribution, Strong Soil with Stiff Cell

In a <u>stiff</u> 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.

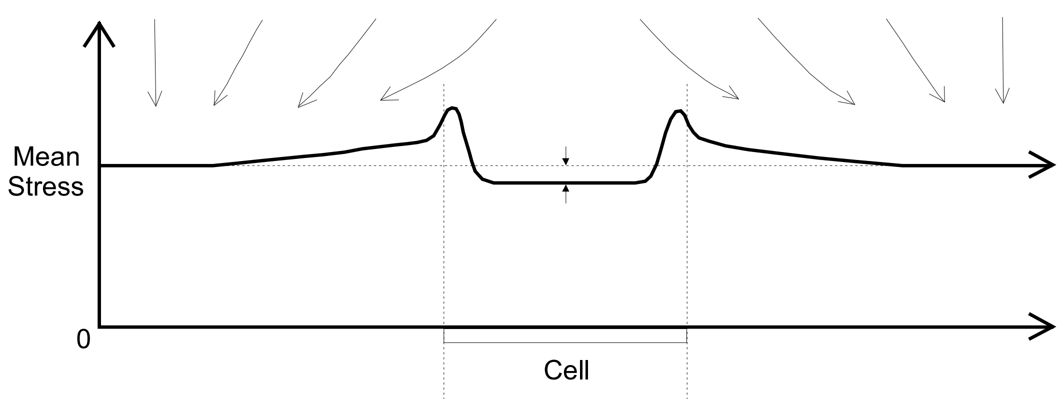

Figure 3- Stress Redistribution, Stiff Soil with Weak Cell

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.

The Model 3500 Total Pressure Cell is 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.

1.2 Earth Pressure Cell Design

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 transducer 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 transducer normally employed is a semiconductor type that is available in several different pressure ranges. The cable is attached to the transducer 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 transducers with voltage (0-100 mV, 0-5 VDC, 0-10 VDC) or current (4-20 mA) output are available for dynamic readout capability. Consult the factory for additional information. A thermistor may also be included inside the transducer 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 and one pair is used for remote sensing when there are long cables (>50 m). As an option, one pair can be used for connection to a thermistor. For shorter cables or 4-20mA outputs, a two pair construction can be used.

Wiring diagrams are shown in Appendix D.

1.3 Earth Pressure Cell Construction

1.3.1 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.

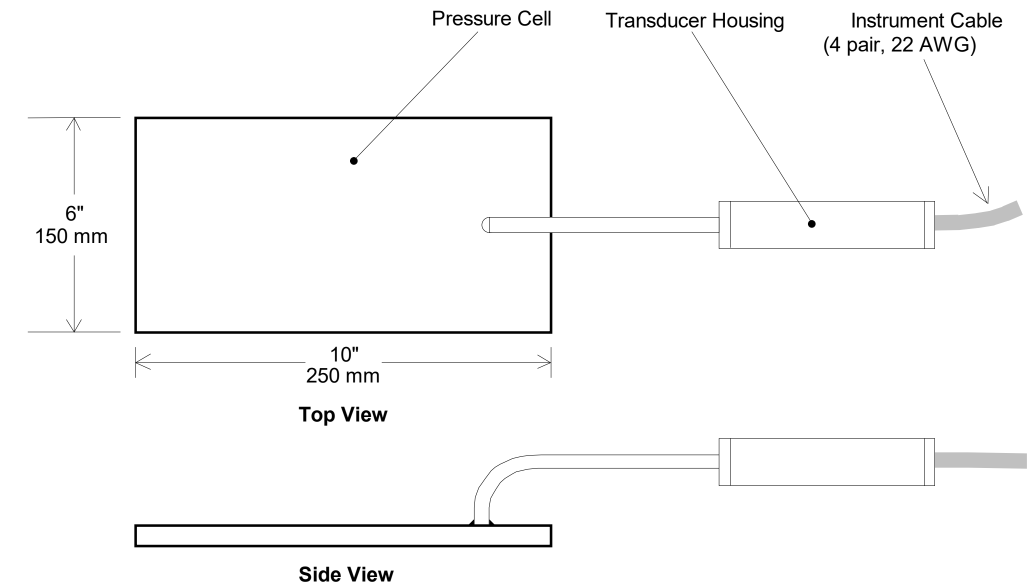

Figure 4 - Model 3500 Rectangular Earth Pressure Cell

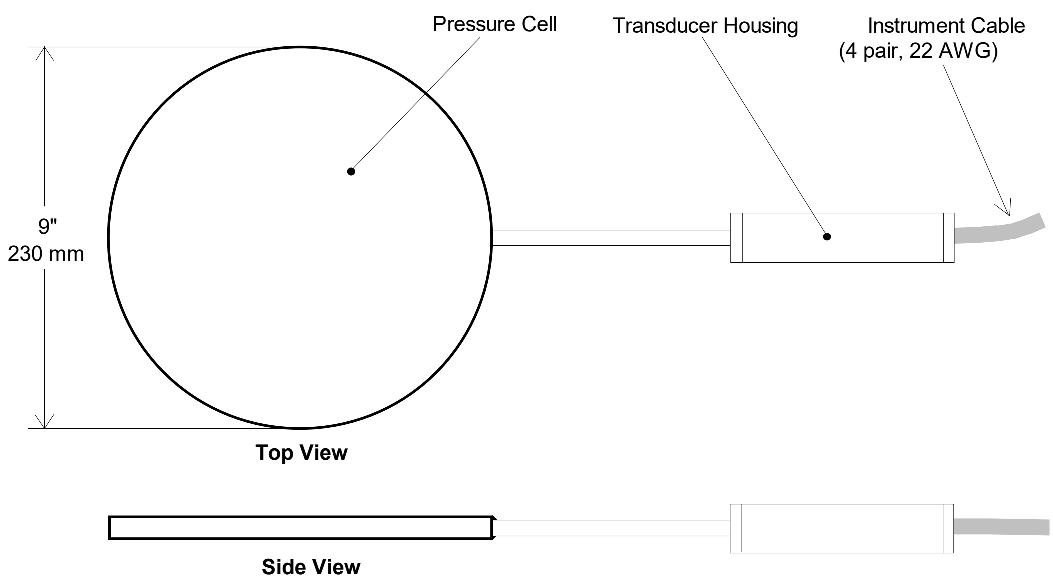

Figure 5 - Model 3500 Circular Earth Pressure Cell

1.3.2 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.

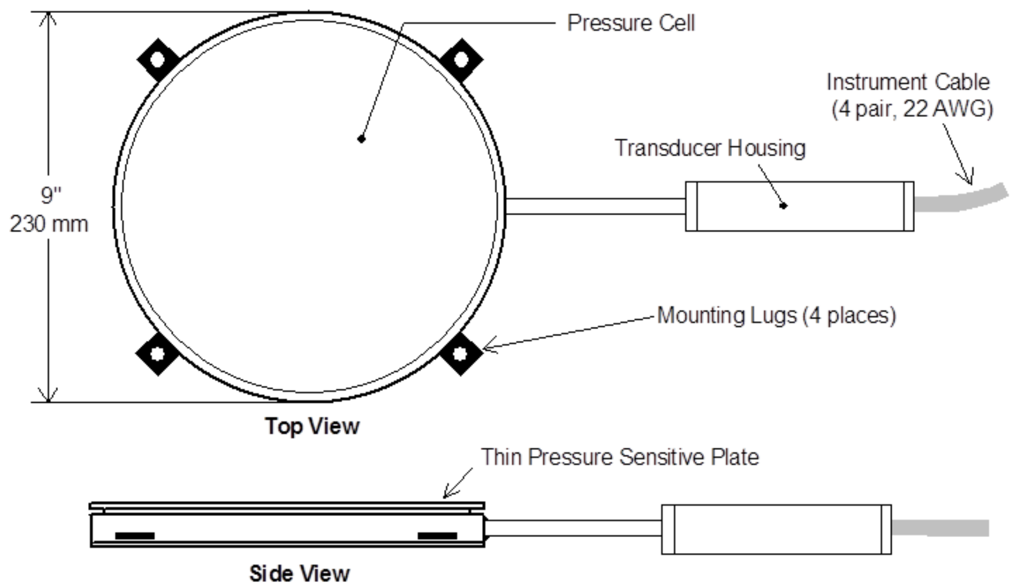

Figure 6 - Model 3510 Contact Pressure Cell

1.3.3 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 transducer housing is connected directly to the edge of one of the thick back plates

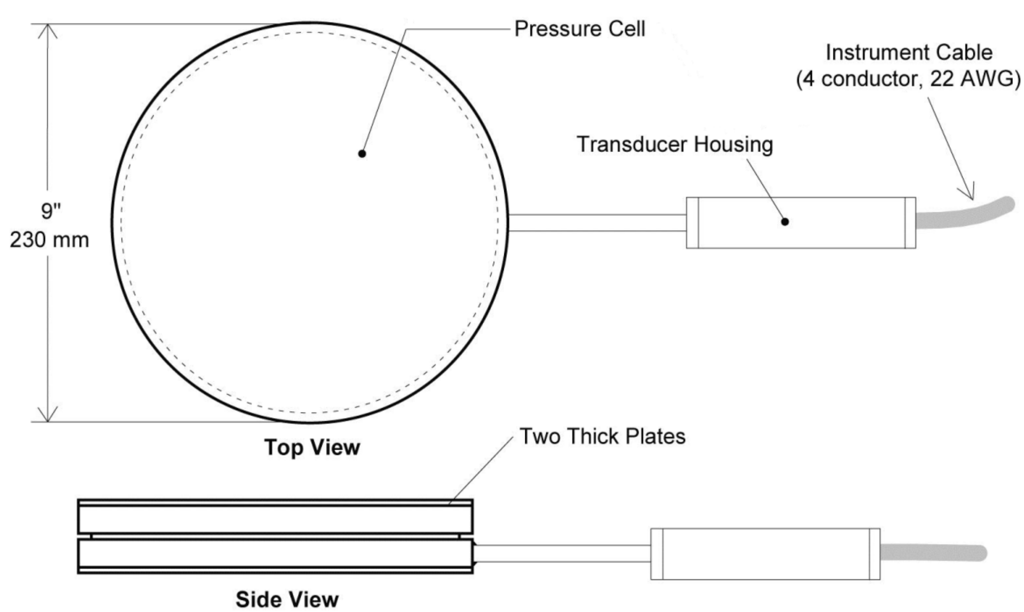

Figure 7 - Model 3515 Granular Materials Pressure Cell

1.3.4 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 transducer 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.

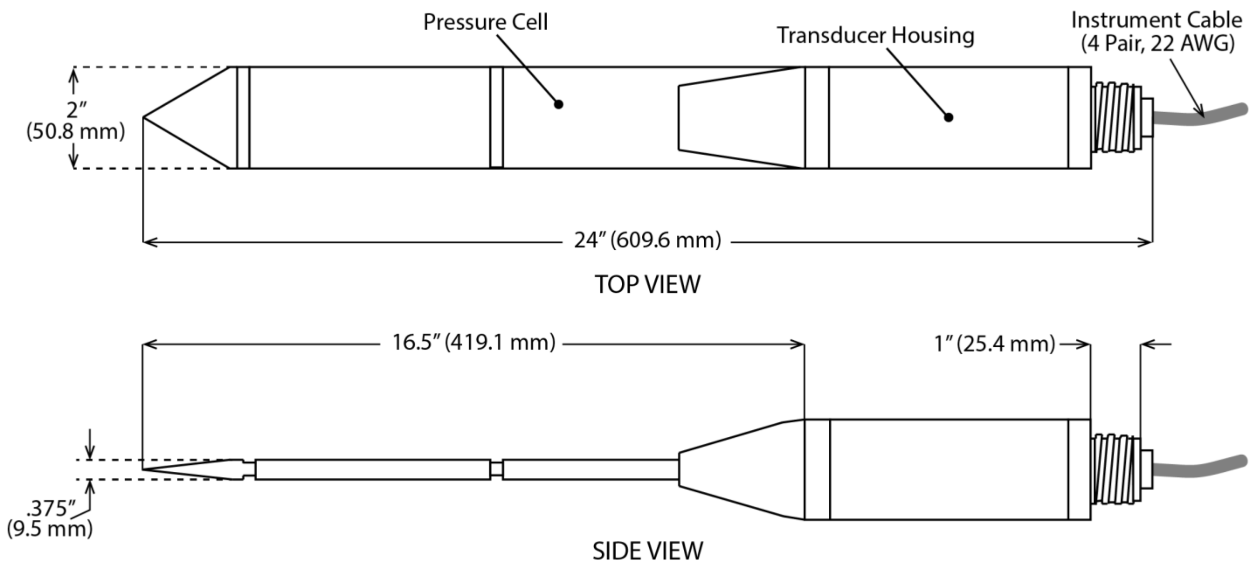

Figure 8 - Model 3530 Push-In Pressure Cell

2. INSTALLATION

2.1 Preliminary Tests

It is always wise, before installation commences, to check the cells for proper functioning. Each cell is provided with a no load zero reading. The cell electrical leads are connected to a readout box (see Section 3) 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.

2.2 Pressure Cell Installation

2.2.1 Installation of Model 3500 Earth Pressure Cells Inside Fills & Embankments

(See also Appendix C.)

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 Sections 2.2.2 and 2.2.4. 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 two plates are pinched together so that the external pressure is no longer transmitted entirely to the interior fluid. For this reason, all chunks larger than 10 mm (≈0.5") 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, if the compaction is performed properly, 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.

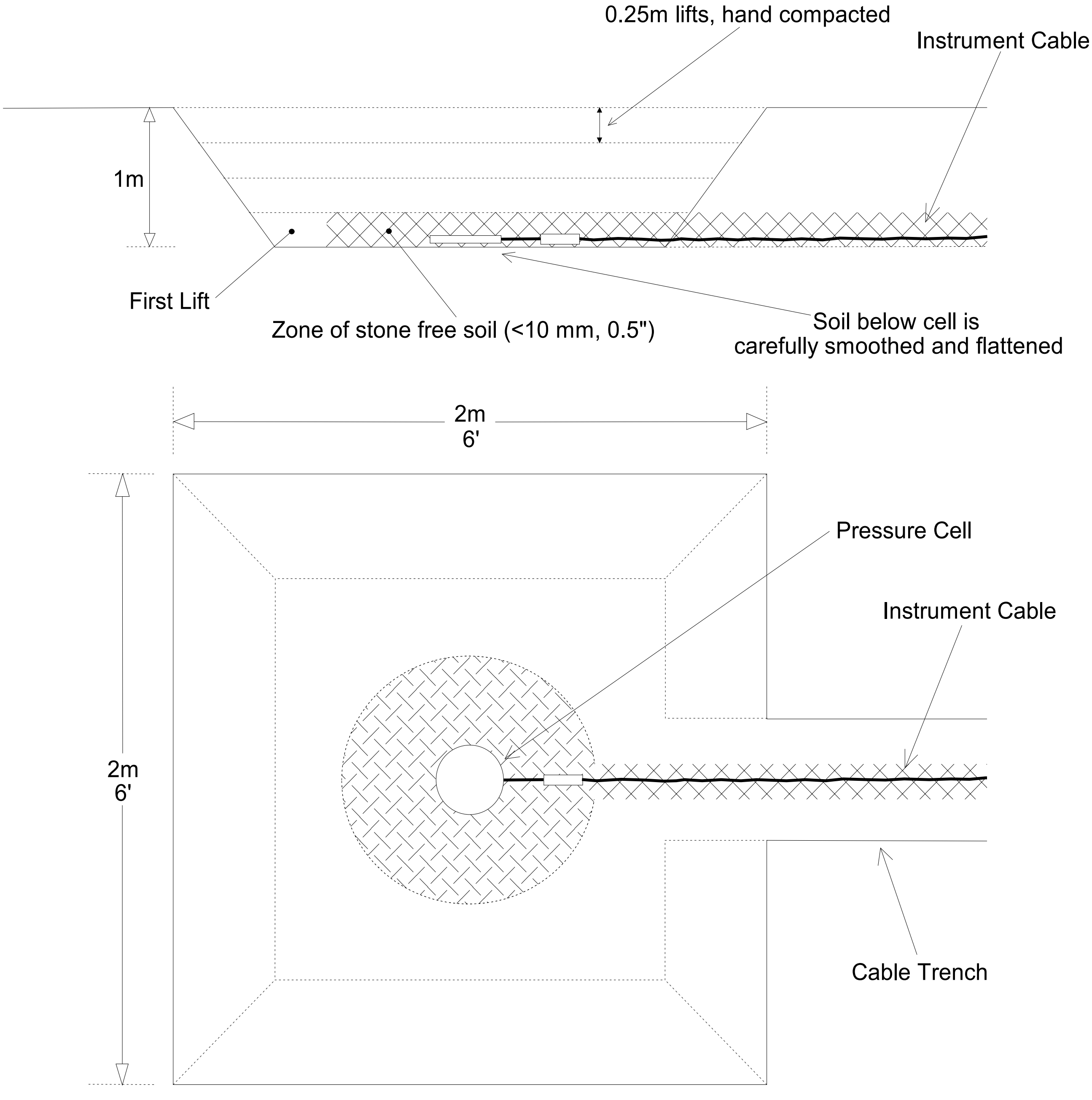

Figure 9 - Model 3500 Earth Pressure Cell Installation

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 instrument 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 one meter (≈ three feet).

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.

In embankments, cables may be embedded in a protective covering of sand or selected fine embankment materials. A typical installation might, for example, 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 feet) 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 feet). The purpose of the bentonite plugs is to reduce the possibility of water seepage through the embankment core along the back filled trenches.

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.

2.2.2 Installation of 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. See Figure 10.

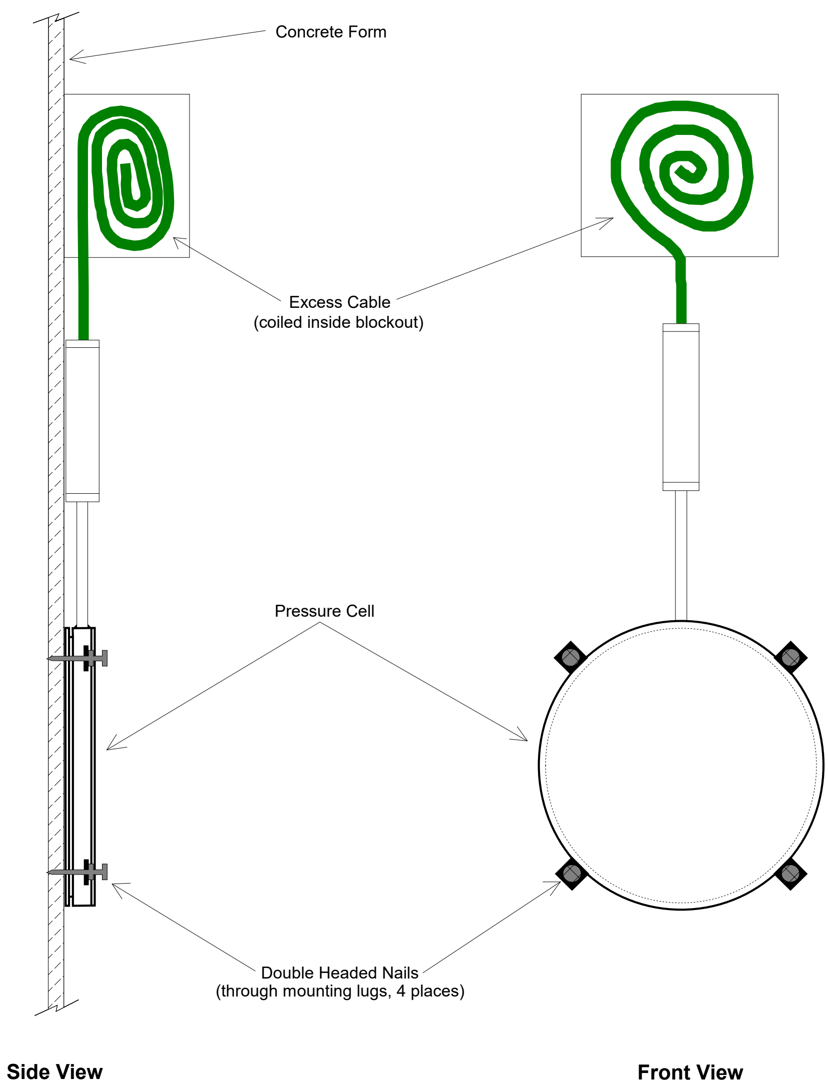

Figure 10 - Attachment of Model 3510 to Concrete Form

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. See Figure 11.

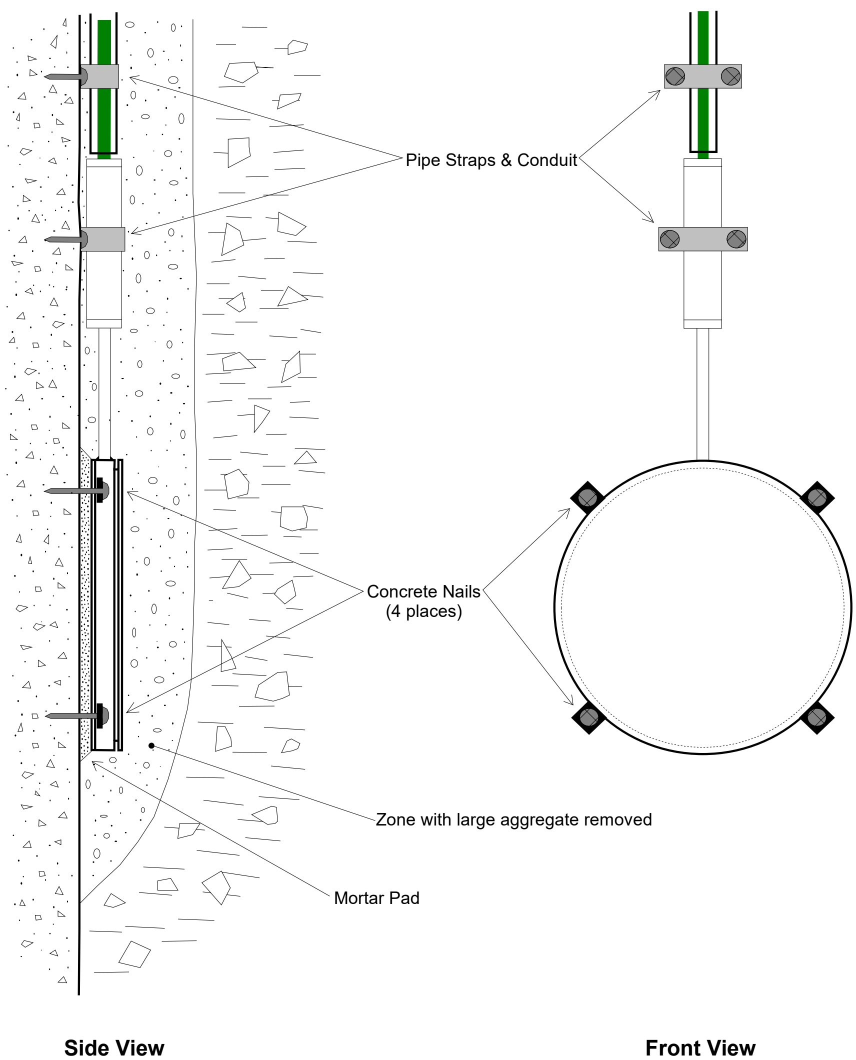

Figure 11 - Model 3510 Contact Pressure Cell Installation

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, transducer 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.

2.2.3 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.

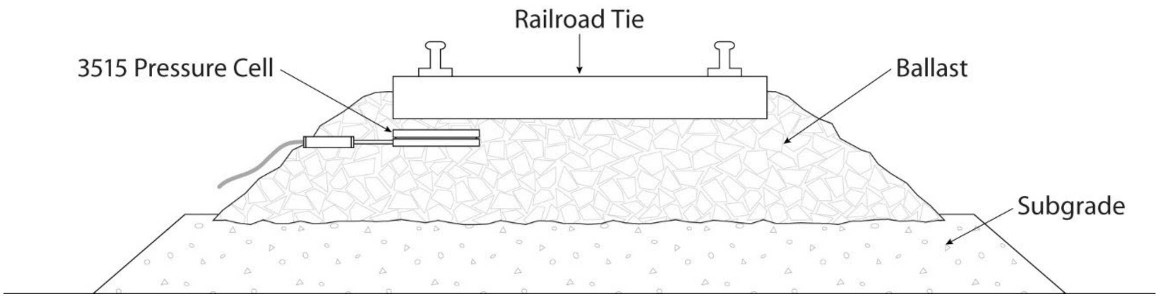

Figure 12 - Model 3515 Granular Materials Pressure cell in Railroad Ballast

2.2.4 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:

1) **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.

2) **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.

2.3 Cable Installation

Cable placement procedures vary with individual installations. In general, however, all installations have in common the following requirements:

1) The cable must be protected from damage by angular particles of the material in which the cable is embedded.

2) The cable must be protected from damage by compaction equipment.

3) In earth and rock embankments and backfills, the cable must be protected from stretching as a result of differential compaction of the embankment.

4) In concrete structures, the cable must be protected from damage during placement and vibration of the concrete.

2.4 Cable Splicing

The Model 3500 utilizes a bonded resistance strain gauge transducer 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 splice should be waterproofed completely. Splice kits are available from the factory.

2.5 Electrical Noise

Care should be exercised when installing instrument 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 instrument 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.

2.6 Initial Readings

<u>Initial readings must be taken</u> 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. ***Again, it is imperative that initial readings at zero load are taken!***

3. READOUT PROCEDURES

3.1 Reading Pressure

The Model 3500 uses a semiconductor strain gauge type transducer 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 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 gauge factor G must be adjusted accordingly. The 0-5 volt and 4-20mA sensors require an unregulated input of 7-35 VDC.

3.1.1 Calibration

Calibration reports for the three types of Model 3500 pressure cells are supplied with the sensors. Examples of typical calibration reports are shown in Appendix E.

3.2 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 D shows which cable conductors are connected to the thermistor. These conductors should be connected to a digital ohmmeter.

A table for converting the measured resistance into temperatures is given in Appendix B (Table 3). Alternately, the temperature can be calculated using Equation 2 in Appendix B. For example, a resistance of 3400 ohms is equivalent to 22° C. When long cables are used the cable resistance may need to be taken into account. Standard 22 AWG stranded copper lead cable is approximately 14.7Ω/1000' or 48.5Ω/km, multiply by two for both directions.

4. DATA REDUCTION

4.1 Pressure Calculation

Formulas for converting readout voltages to pressure are shown on the calibration reports. Both linear and polynomial expressions are shown. For better accuracy the polynomial expression should be used with this proviso that the value for the C coefficient be derived in the field by taking an initial reading when the sensor is subject to atmospheric pressures only as described in Section 3.1. Then substituting this initial value into the formula and setting the value of P to zero will yield the correct value for C.

The pressure applied to the cell is determined by the following using the linear calibration factor

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

Equation 1 - Pressure Calculation

Where;
P is the applied pressure in kPa, Mpa or psi.
R_1 and R_0 are the current and initial output readings in millivolts, volts or milliamps.
G is the gauge factor, as shown on the calibration report.
(Note that gauge factor is for an excitation of 10 volts. For any other excitation voltage (V) the gauge factor shown must be multiplied by 10/V)

Example:

Model 3500 –1 - 600 kPa (from Figure 13)

R_0	=	-0.68 mV
R_1	=	60.325 mV
G	=	5.973 kPa/mV
P	=	(60.325 – (– 0.68)) x 5.973 = 364.38 kPa

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.

Alternatively, the polynomial can be used for greater accuracy

For example:
R_1 = 60.325mV/V
P = 3.14E04$(60.325)^2$ + 5.9417(60,325) + 0.4233 = 360 kPa

Which can be seen is a more accurate solution.

To convert the output to other engineering units, multiply the Calibration Factor by the conversion multiplier listed in Table 1.

From → To ↓	psi	"H_2O	'H_2O	mm H_20	m H_20	"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_20	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_20	.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	.0024583	.0294996	.0000968	.0968	.03342	.0013158	1	.0009869	.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	.0024908	.0298896	.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	.00000981	.009807	.003386	.000133	.101320	.0001	.1	.001	1

Table 1 - Engineering Units Multiplication Factors

4.2 Temperature Correction

Corrections for temperature are not easily quantified because the pressure cell, when in use is surrounded and confined by soil or soil and concrete each with its own (different) temperature coefficient of expansion. Commercially it is not practical to measure the overall effect without incurring huge expenses. Suffice to say that the effect is usually small, especially at depths where the temperature is rather constant. **If temperature fluctuations are great, then the thermistor should be used to measure temperatures. By observing the cell output versus temperature variation over short periods of time, when it can be reasonably assumed that the load on the cell is not changing, it is often possible to derive empirically the temperature correction factor**. (See also Appendix E).

4.3 Barometric Correction

The pressure transducer used in GEOKON Model 3500 Earth Pressure Cells is sealed and will respond to barometric pressure fluctuation. However, since the magnitudes are only on the order of ±3 kPa, 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.

5. TROUBLESHOOTING

Maintenance and troubleshooting of Model 3500 Pressure Cells is confined to periodic checks of cable connections. Once installed, the cells are usually inaccessible and remedial action is limited. Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Pressure Cell 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 whether using a portable readout or datalogger.

✓ Does the readout work with another pressure cell? If not, the readout may have a low battery or be malfunctioning. Consult the appropriate readout manual for charging or troubleshooting directions.

Symptom: Pressure Cell Fails to Read

✓ Is the cable cut or crushed? 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 ($<100\Omega$), 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. Consult the readout or datalogger manual for further direction.

APPENDIX A. SPECIFICATIONS

Specifications	**Model 3500, 3510**
Input	
Pressure Range	Vacuum to 400 bar (6000 psi)
Proof Pressure	2 x Full Scale(FS) (1.5 x FS for 400 bar, >=5000 psi)
Burst Pressure	>35 x FS <= 6 bar (100 psi) >320 x FS <= 60 bar (1000 psi) >5 x FS <= 400 bar (6000 psi)
Fatigue Life	Designed for more than 100 million FS cycles
Performance	
Long Term Drift	0.2% FS/year (noncumulative)
Accuracy[1]	0.25% FS (Dependent on readout instrument)
Thermal Error	1.5% FS typical (optional 1% FS)
Compensated Temperatures	-20° to 80° C (-5° to 180° F)
Operating Temperatures	-40° to 125° C ((-22° to 260°) for elec. codes A, B, C, 1 -20° to 80° C (-5° to 180° F) for elec. codes 2, D, G, 3 -20° to 50° C (-5° to 125° F) for elec. codes F, M, P Amplified units > 100C maximum 24 Vdc supply
Zero Tolerance	1% of span
Span Tolerance	1% of span
Mechanical Configuration	
Pressure Port	see ordering chart
Wetted Parts	17-4 PH Stainless Steel
Electrical Connection	see ordering chart
Enclosure	316 ss, 17-4 PH ss IP65 for elec. codes A, B, C, D, G, 1, 2, 3 IP67 for elec. code “F” IP68 for elec. codes M, P IP30 for elec. code “3” with flying leads
Vibration	35 g peak sinusoidal, 5 to 2000 Hz
Acceleration	100 g steady acceleration in any direction 0.032% FS/g for 1 bar (15 psi) range decreasing logarithmically to 0.0007% FS/g for 400 bar (6000 psi) range.
Shock	Withstands free fall to IEC 68-2-32 procedure 1
Approvals	CE
Weight	Approximately 100 grams (additional cable; 75 g/m)
Individual Specifications	
Millivolt Output Units	
Output	100mV ± 1mV
Supply Voltage (VS)	10Vdc (15Vdc max.) Regulated
Bridge resistance	2600-6000 ohms
Voltage Output Units	
Output	see ordering chart
Supply Voltage (Vs)	1.5 Vdc above span to 35 Vdc @6mA
Supply Voltage Sensitivity	0.01% FS/Volt
Min. Load Resistance	(FS output / 2) kohms
Current Output Units	
Output	4-20mA (2 wire)
Supply Voltage(VS)	24 Vdc, (7-35 Vdc)
Supply Voltage Sensitivity	0.01% FS/Volt
Max Loop Resistance	(Vs-7) x 50 ohms.

Table 2 - Earth Pressure Cell Specifications

[1]0.1% F.S. available on request. The stated accuracy is the accuracy of the pressure transducer itself. The system accuracy depends on many factors as discussed in Section 1.1 of the manual.

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

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

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

Equation 2 - 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 3 - Thermistor Resistance versus Temperature

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

The method described in Section 2.2.1 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 [1] essentially uses the techniques described in Section 2.2.3:

Installation of the cells begins when the fill has reached a height of 800 mm above the instrument level. The Instrument location and the cable trenches are excavated 500 mm deep, a pocket, with 45° sloping sides, of only a further 300 mm depth is required to be excavated at the instrument 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 aggregate), in 100 mm 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 instrument location containing the grouted cells and the cable trench is then backfilled in 100 mm layers, using the techniques described in Section 2.2.1. Each layer is compacted by a vibratory trench roller. After this, standard construction filling and compaction practices can continue.

[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.

APPENDIX D. WIRING CHARTS

Model # 3500

mV/V output:

GEOKON Cable #04-375V9 (Violet)	Internal Sensor Wiring	Function / Description
Red	Red	Power +
Red's Black	Black	Power -
White	White	Signal +
White's Black	Black	Signal -
Green	Red	Remote Sense +
Green's Black	Black	Remote Sense -
Blue	N/C	Thermistor
Blue's Black	N/C	Thermistor
Shields (5)	N/C	Ground

Note: Model # 3500-1 input voltage = 10V d.c.; output = 0-100mV
(Power -, Signal -, Remote Sense -, are connected internally.)

0–5VDC output:

GEOKON Cable #04-375V9 (Violet)	Internal Sensor Wiring	Function / Description
Red	Red	Power +
Red's Black	Black	Power -
White	White	Signal +
White's Black	Black	Signal -
Blue	N/C	Thermistor
Blue's Black	N/C	Thermistor
Shields (5)	N/C	Ground

Note: Model # 3500-2 input voltage = 6.5–35V d.c.; output = 0–5VDC

4–20mA output:

GEOKON Cable #02-250V6 (Blue)	Internal Sensor Wiring	Function / Description
Red	Red	Power +
Black	Black	Power -
White	N/C	Thermistor
Green	N/C	Thermistor
Shields (1)	N/C	Ground

Note: Model # 3500-3 input voltage = 6.5–35V d.c.; output = 4–20mA

APPENDIX E. SAMPLE CALIBRATION REPORTS

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

Pressure Transducer Calibration Report

Model Number: 3500-1

Date of Calibration: October 09, 2012

Serial Number: 1232779

Temperature: 22.7 °C

Pressure Range: 600 kPa

Barometric Pressure: 1002 mbar

Calibration Instruction: CI-VW Pressure Transducers

Technician:

Applied Pressure (kPa)	Gage Reading (mV) 1st Cycle	Gage Reading (mV) 2nd Cycle	Average Gage Reading	Change	Linearity (%FS)	Polynomial Fit (%FS)
0	-0.067	-0.069	-0.068		0.07	0.00
120	20.102	20.092	20.097	20.17	0.01	-0.01
240	40.245	40.231	40.238	20.14	0.06	0.00
360	60.330	60.320	60.325	20.09	0.06	0.00
480	80.380	80.370	80.375	20.05	0.02	0.00
600	100.380	100.370	100.375	20.00	0.07	0.00

Linear Gage Factor (G): 5.973 (kPa / mV) **Regression Zero: 0.000**

Polynomial Gage Factors: A: 3.14E-04 B: 5.9417 C: 0.4233

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 - Typical Calibration Report for Model 3500-1 with 100mV output

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

Pressure Transducer Calibration Report

Model Number: 3500-2

Serial Number: 1303292

Pressure Range: 250 kPa

Date of Calibration: February 20, 2013

Temperature: 21.1 °C

Barometric Pressure: 991.2 mbar

Calibration Instruction: CI-VW Pressure Transducers

Technician:

Applied Pressure (kPa)	Gage Reading (Volts) 1st Cycle	Gage Reading (Volts) 2nd Cycle	Average Gage Reading	Change	Linearity (%FS)	Polynomial Fit (%FS)
0	0.011	0.011	0.011		0.26	0.01
50	1.026	1.027	1.027	1.02	0.03	-0.03
100	2.036	2.038	2.037	1.01	0.22	0.00
150	3.040	3.039	3.040	1.00	0.25	0.03
200	4.029	4.030	4.030	0.99	0.03	-0.02
250	5.015	5.015	5.015	0.99	0.28	0.00

Linear Gage Factor (G): **49.95** **(kPa / Volt)** **Regression Zero:** **0.0242**

Polynomial Gage Factors: A: **2.07E-01** **B:** **48.91** **C:** **-0.502**

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

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

Factory Zero Reading: 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.
This report shall not be reproduced except in full without written permission of Geokon Inc.

Figure 14 - Typical Calibration Report for Model 3500-2 with 0 to 5 Volt output

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

Pressure Transducer Calibration Report

Model Number: 3500-3

Date of Calibration: October 12, 2012

Serial Number: 1234237

Temperature: 22.8

Pressure Range: 100 kPa

†Barometric Pressure: 997.1

Calibration Instruction: CI-VW Pressure Transducers

Technician:

Applied Pressure (kPa)	Gage Reading (mA) 1st Cycle	Gage Reading (mA) 2nd Cycle	Average Gage Reading	Change	Linearity (%FS)	Polynomial Fit (%FS)
0	3.981	3.980	3.981		-0.03	-0.01
20	7.188	7.190	7.189	3.21	0.03	0.02
40	10.383	10.392	10.388	3.20	0.02	0.01
60	13.586	13.575	13.581	3.19	-0.02	-0.03
80	16.784	16.789	16.787	3.21	0.02	0.02
100	19.985	19.976	19.981	3.19	-0.02	0.00

Linear Gage Factor (G): **6.25** **(kPa/ mA)** **Regression Zero:** **3.985**

Polynomial Gage Factors: A: **4.63E-04** **B:** **6.24** **C:*** **-24.86**

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 - Typical Calibration Report for Model 3500-3 with 4 to 20mA output

APPENDIX F. 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.

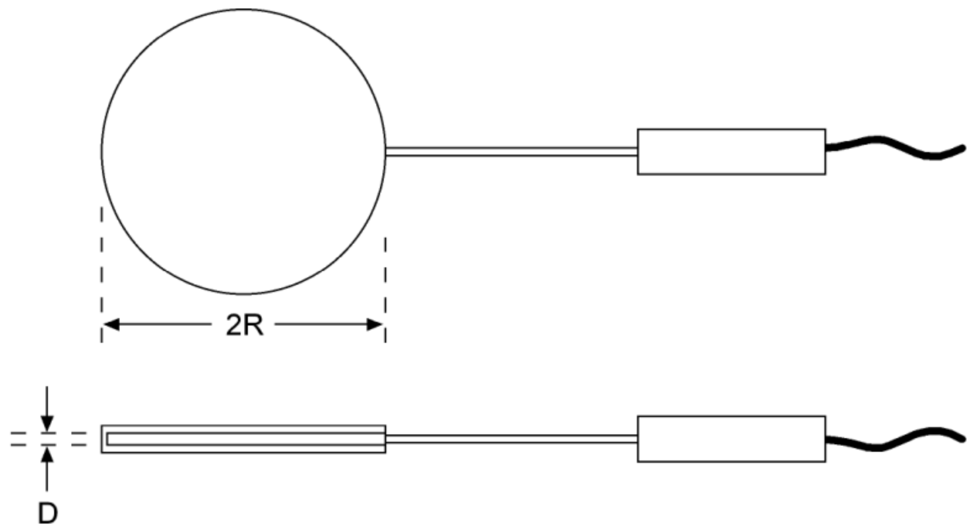

Figure 16 - Radius (R) and Thickness (D)

F.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 3 - 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 4 - Compression of Liquid

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

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

Equation 5 - Expansion of Liquid

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formula found in Equation 3, 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 6 - Deformation at the Center

At the edge of the cell:

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

Equation 7 - Deformation at the Edge

The difference being:

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

Equation 8 - 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 8.

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:

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

Equation 9 - Average Total Expansion of the Cell

Equating Equation 5 and Equation 9 gives:

$$P\ (D/G + 0.73\ R\ (1-\nu^2)/E) = KD$$

Equation 10 - 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;

$Y = 0.73\ PR\ (1\text{-}v^2) \times 0.5/E = 0.36\ PR\ (1\text{-}v^2)/E$

And

$P\ (D/G + 0.36\ R\ (1\text{-}v^2)/E) = KD$

Where (E) pertains to the soil material.

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

For all $E < 10 \times 10^6$ psi the term 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 $(1\text{-}v^2)$ can be replaced by 0.91 since ν usually lies between 0.25 and 0.35.

Hence, the total embedment is given by:

$$P = 1.5\ EKD/R \qquad \text{psi} / {}^{o}\text{C}$$

Equation 11 - Total Embedment

And for contact pressure cells:

$$P = 3\ EKD/R \qquad \text{psi} / {}^{o}\text{C}$$

Equation 12 - Total Embedment for Contact Pressure Cells

Some typical values of the various parameters are:

Liquid	**K x 10^{-6} / °C**	**G 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 4 - Typical Values of Various Cell Parameters

F.2 Examples

For an oil-filled cell, nine-inch diameter and D = 0.060 inches, totally embedded in:
(For contact pressure cells, multiply the values for P by two.)

Plastic Clay:

E = 3000 psi
ν = 0.3
P = 0.042 psi / ºC

Soil, medium stiffness:

E = 10000 psi
ν = 0.3
P = 0.138 psi / ºC

Coarse Sand:

E = 50000 psi
ν = 0.3
P = 0.69 psi / ºC

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

Concrete:

E = 5 x 10^6 psi
ν = 0.25
P = 22.7 psi / ºC

Completely rigid medium:

P = 210 psi / ºC

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

Concrete:

P = 5.8 psi / ºC

Completely rigid medium:

P = 650 psi / ºC

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.