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# *Instruction Manual*
# Model 3500, 3510, 3515, 3600
# Earth Pressure Cells

(Doc Rev L, 04/07)

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# 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 ($\mu$), using a piezometer, is necessary to separate the effective stress ($\sigma'$) from the total stress ($\sigma$) 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 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 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 ration 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.

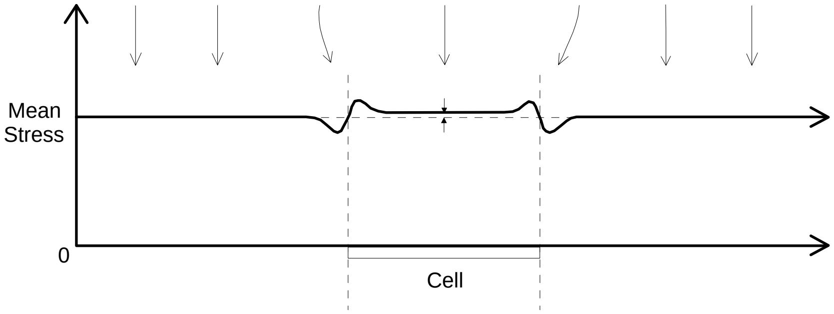


Figure 1 - Stress Redistribution, Weak Soil with Stiff Cell

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.

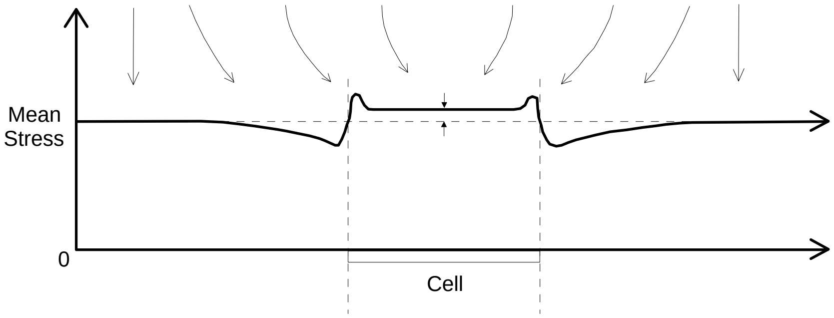


Figure 2 - Stress Redistribution, Strong Soil with Stiff Cell

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.

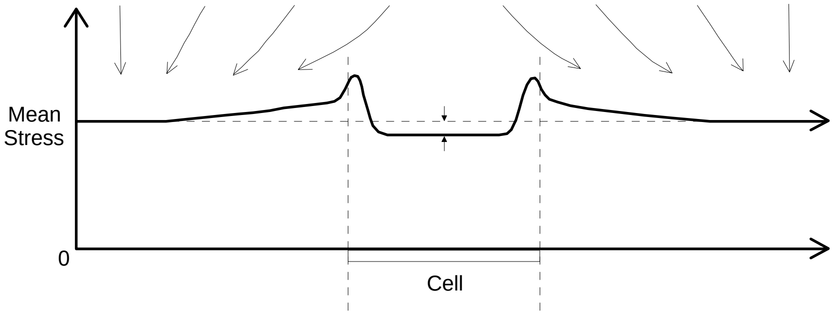


Figure 3 - Stress Redistribution, Stiff Soil with Weak Cell

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.

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 so as to leave a narrow space between them. This space is completely 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 pull-out.

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 (>50m). 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 figure 4.

| Cable Model 04-375V9. 4 pair.<br>VIOLET<br>mV/V output<br>Remote Sense.<br>Thermistor (optional) | |
|---|---|
| Red | Power + |
| Red’s black | Power - |
| White | Signal + |
| White’s Black | Signal - |
| Green | Remote Sense + |
| Green’s Black | Remote Sense - |
| Blue | Thermistor |
| Blue’s Black | Thermistor |
| Shields (5) | Ground |

| Cable Model 04-375. 4 pair<br>VIOLET<br>0 – 5 Volts output<br>Thermistor (optional) | |
|---|---|
| Red | Power + |
| Red’s Black | Power - |
| White | Signal + |
| White’s Black | Signal - |
| | |
| | |
| Blue | Thermistor |
| Blue’s Black | Thermistor |
| Shields (4) | Ground |

| Cable Model 02-250V6<br>BLUE<br>4 – 20 mA output<br>Thermistor (optional) | |
|---|---|
| Red | Current + |
| Black | Current - |
| White | Thermistor |
| Green | Thermistor |
| Shield (1) | Ground |
| | |
| | |
| | |
| | |

Figure 4. Model 3500 Wiring Diagrams

## 1.3. Earth Pressure Cell Construction

Major components of the Model 3500 (rectangular and circular), 3510 Earth Pressure Cells, 3515 Granular materials Pressure Cell and 3600 Concrete Stress Cell are shown in Figures 5 through 9, respectively.

**The 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 ration > 20). For laboratory tests smaller, thinner cells can be manufactured. Contact the factory for additional information.

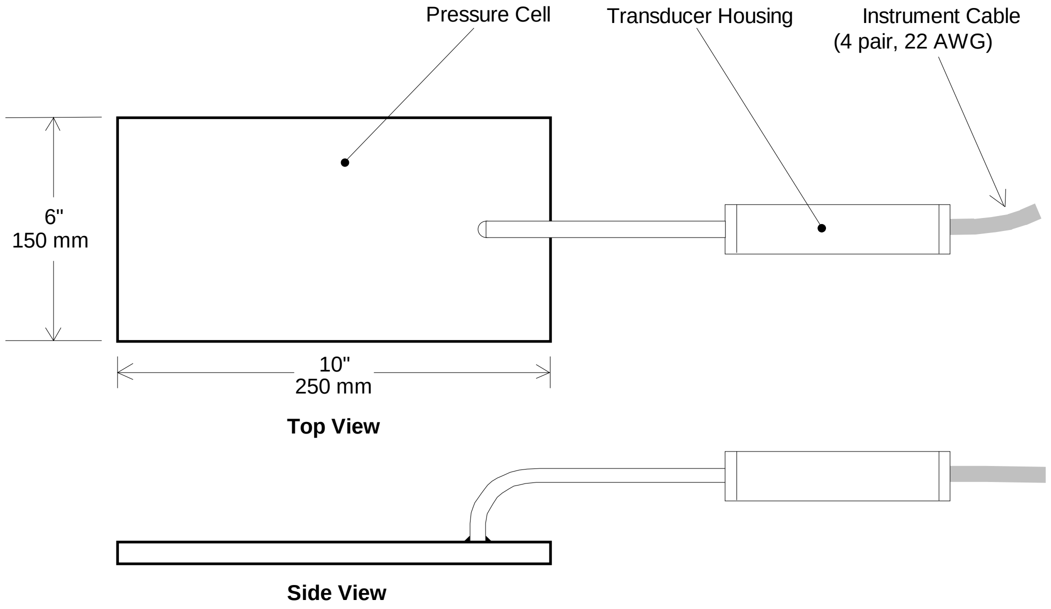


Figure 5 - Model 3500 Rectangular Earth Pressure Cell

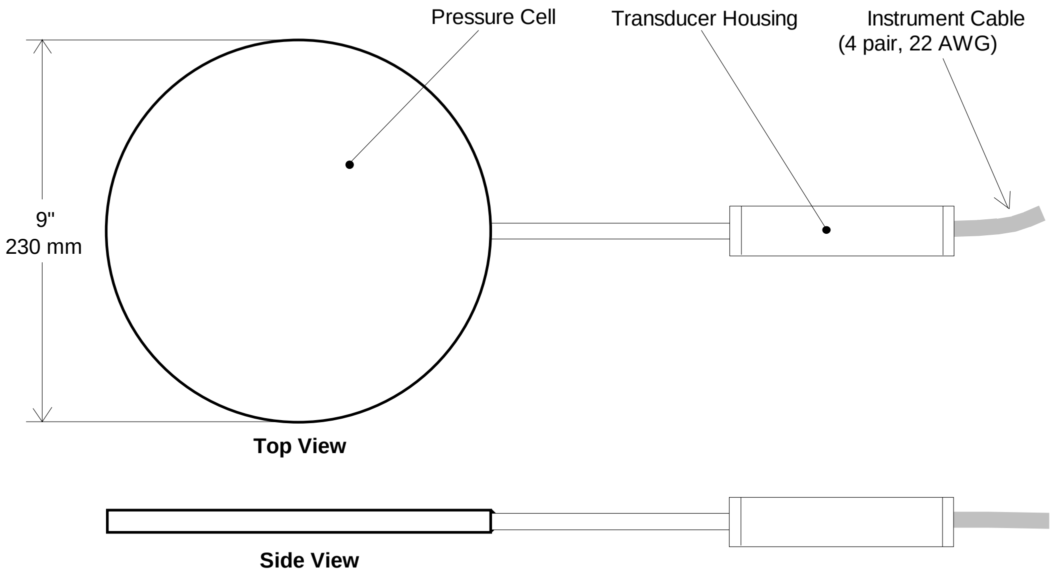


Figure 6 - Model 3500 Circular Earth Pressure Cell

**The Model 3510 Earth Pressure Cell or "contact" cell** is 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.

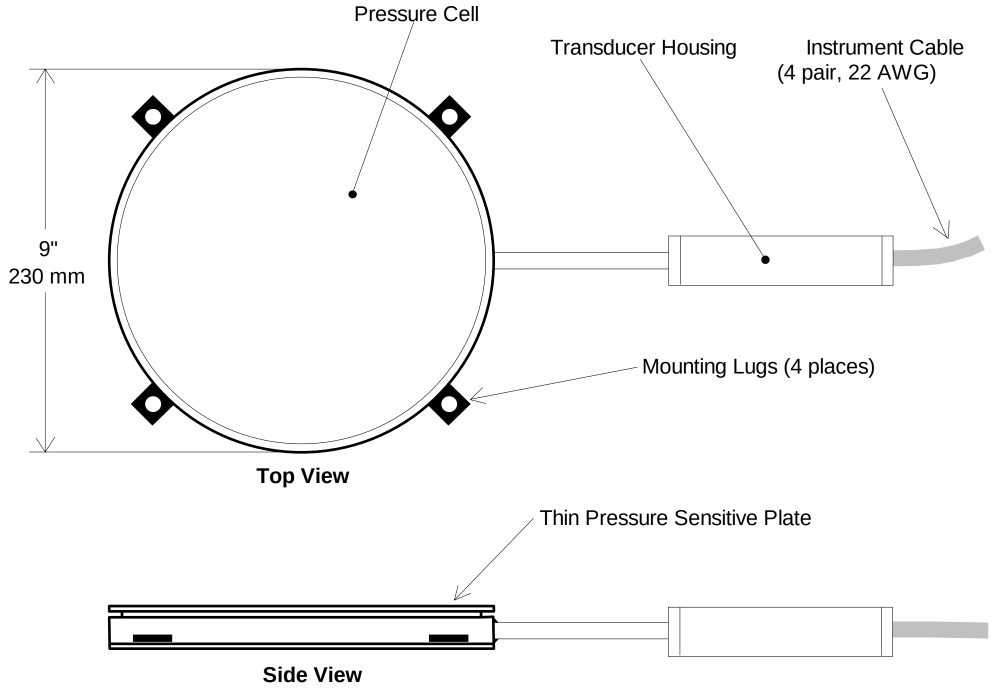


Figure 7 - Model 3510 Contact Pressure Cell

**The Model 3515 Granular Materials Pressure Cell** is the favorite 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

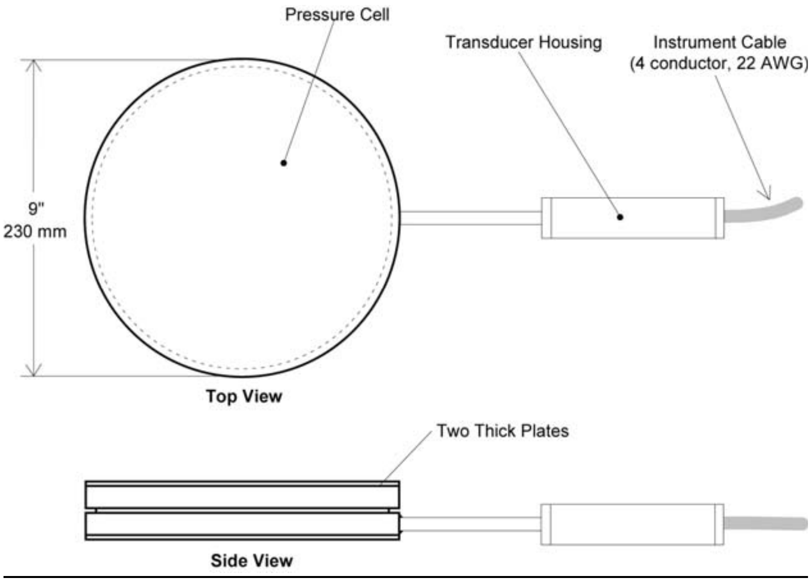


Figure 8 - Model 3515 Granular Materials Pressure Cell

**The Model 3600 Earth Pressure Cell for Footings and Floor Slabs etc**

The cells are designed for measuring earth pressures beneath slabs and footings. They are designed to be installed inside the concrete of the slab or footing and the distinguishing feature here is the pinch tube that is used to re-inflate the cell after the concrete has cured. This is required because as the concrete cures the temperature rises causing the cell to expand. On cooling the cell contracts and can lose contact with the surrounding concrete

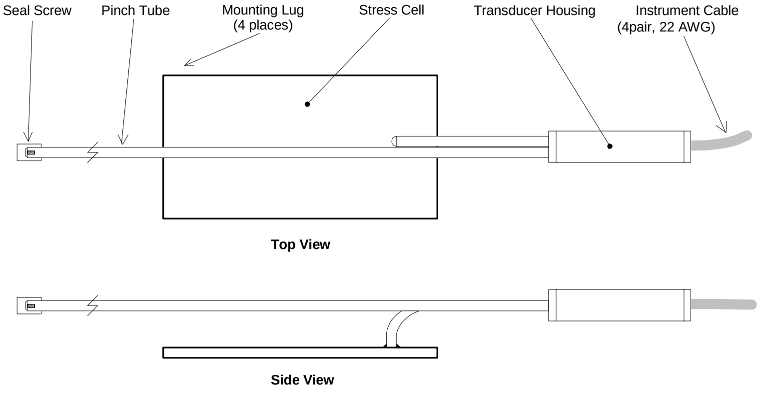


Figure 9 Model 3600 Concrete Stress Cell

# 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 sheet 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 megohm.

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, have 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 in order to establish a graduation outward to the maximum size material.

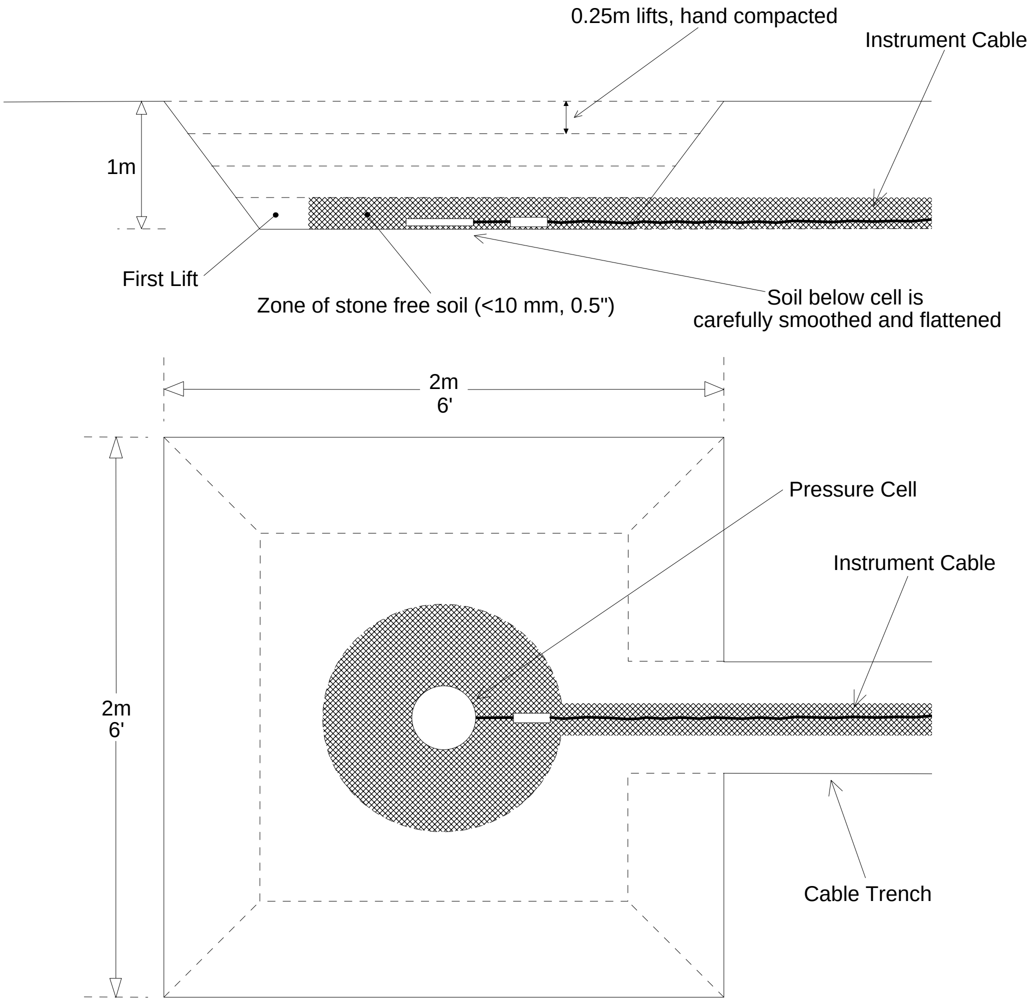


Figure 10 - Model 3500 Earth Pressure Cell Installation

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 rubber-tired equipment 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 meter (≈ 3 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 so doing, 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 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. In order 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 and the lugs welded to the edge of the cell (see Figure 7). Position the cell so that the thin pressure sensitive plate is directly against the concrete form (see Figure 11). 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 blockout inside where excess cable can be coiled. Protect the cable from damage during concrete placement and vibration, by tying it to adjacent rebars.

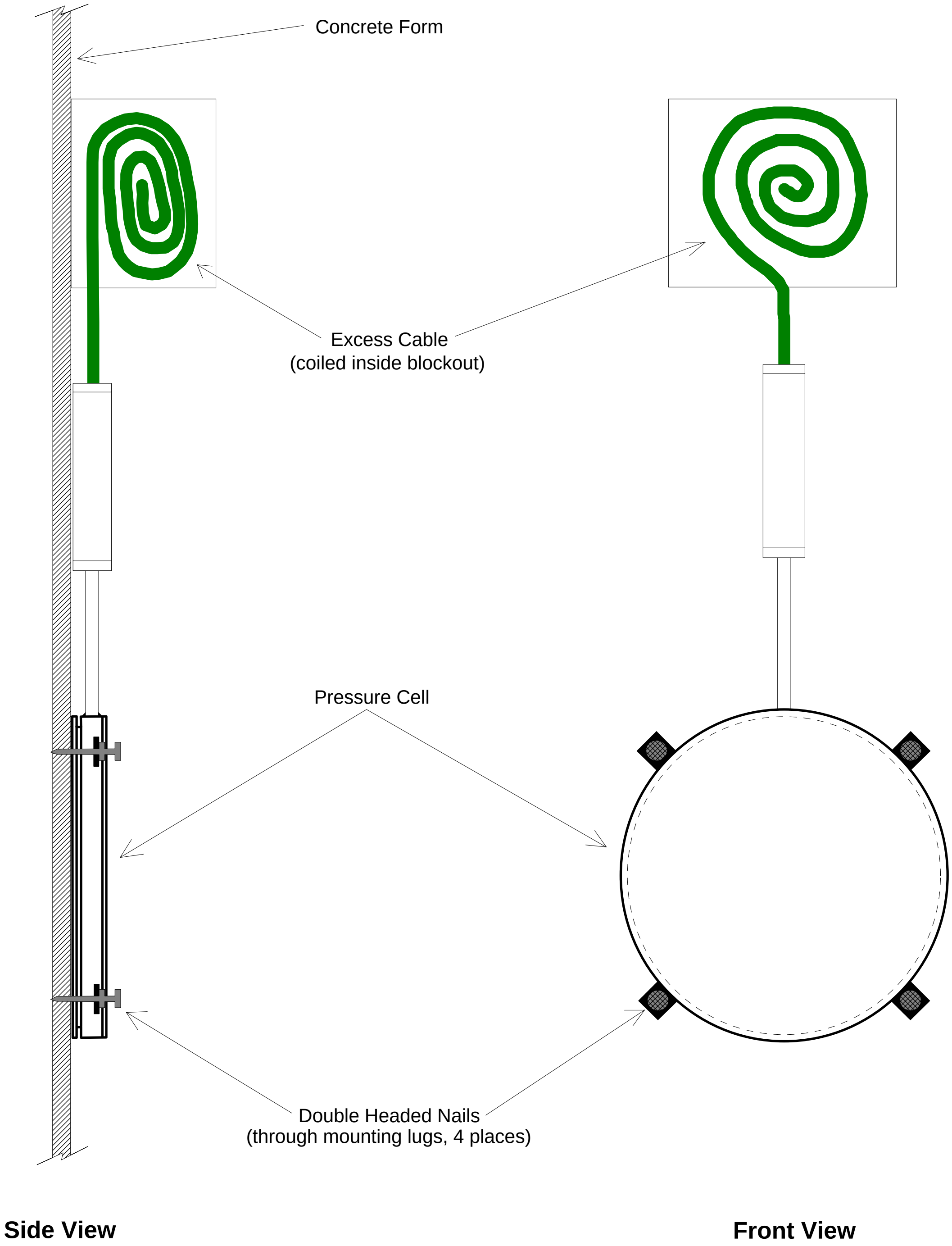


Figure 11 - Attachment of Model 3510 to Concrete Form

### *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 12.

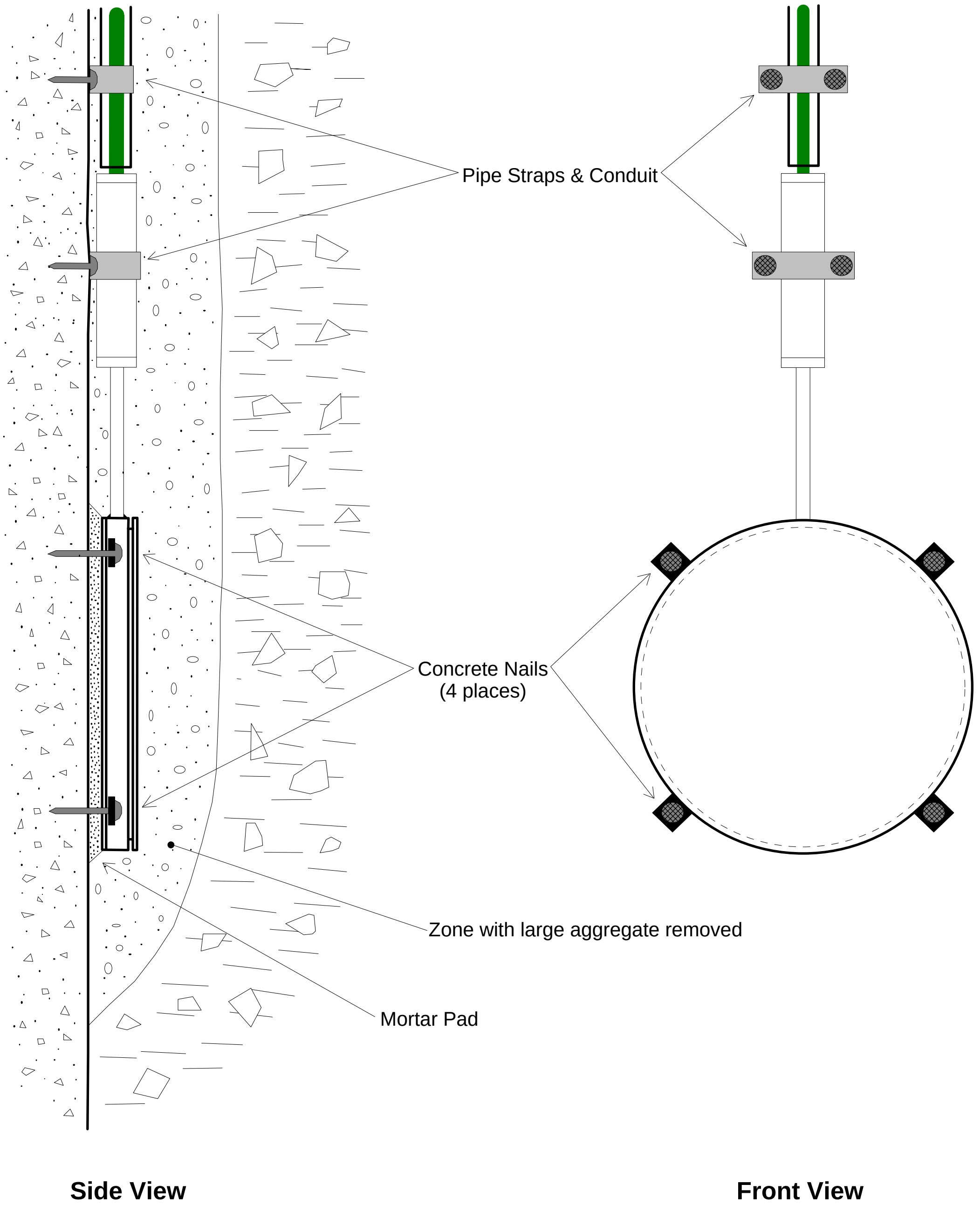


Figure 12 - Model 3510 Contact Pressure Cell Installation

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 of the tracks.

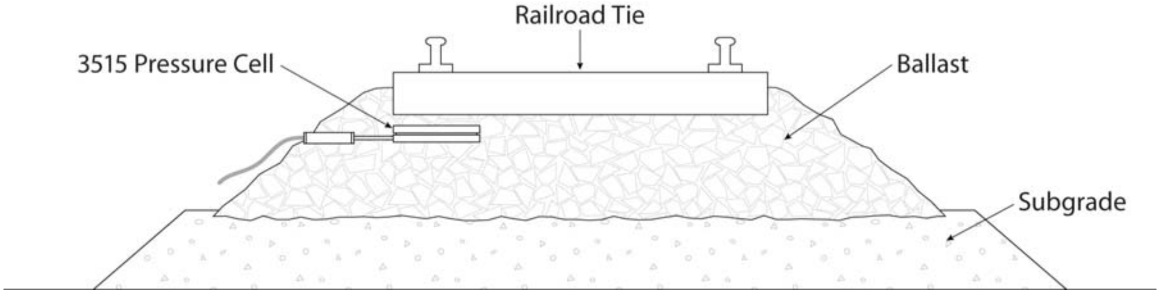


Figure 13 - Model 3515 Granular Materials Pressure cell in Railroad Ballast

### 2.2.4. Installation of Model 3600 Cells to Measure Earth Pressure at the Base of Footings, Floor Slabs, Pavements, Etc.

Experience has shown that attempts to measure contact earth pressures on the base of footings, floor slabs, pavements, etc., frequently meets with failure. The problem is twofold: First, the contact stress distribution can be inherently variable due to varying properties of the ground and varying degrees of compaction of the ground. Thus the contact stress at one location may not be typical of the surrounding locations. Secondly, a cell installed as described in section 2.2.1, could result in the creation of an anomalous zone immediately around the cell where there may be a different, finer grained material, under a lesser degree of compaction. (The material around the cell may be poorly compacted because of the need to avoid damage to the cell.)

In an earth fill, this zone of poor compaction would not be a problem, since the earth above would simply move downwards to fill the voids and consolidate the ground. However, where there is a concrete slab immediately above the cell this consolidation may not take place and in fact, under the influence of rain water and vibration, the spaces around the cell may grow so that the cell becomes completely de-coupled from the concrete above. In such a situation the concrete slab bridges over the gap and the loads in the concrete simply go around the cell instead of through it. The cell registers only a very low pressure, which does not change as the loads increase.

The best way to avoid the problem, if at all possible, is to cast the cell inside the concrete. This can often be done when the initial concrete bonding layer is spread over the surface of the ground. At this time a Model 3600 Concrete Stress Cell with a pinch tube, is pressed into the bonding layer so that it rests against the ground below. A weighted tripod can be used to hold the stress cell in place until the concrete hardens. The pinch tube is arranged to protrude above the bonding layer and, when the concrete has hardened, it is used to pressurize the cell and ensure good contact between the cell and the surrounding concrete. See Figure 14.

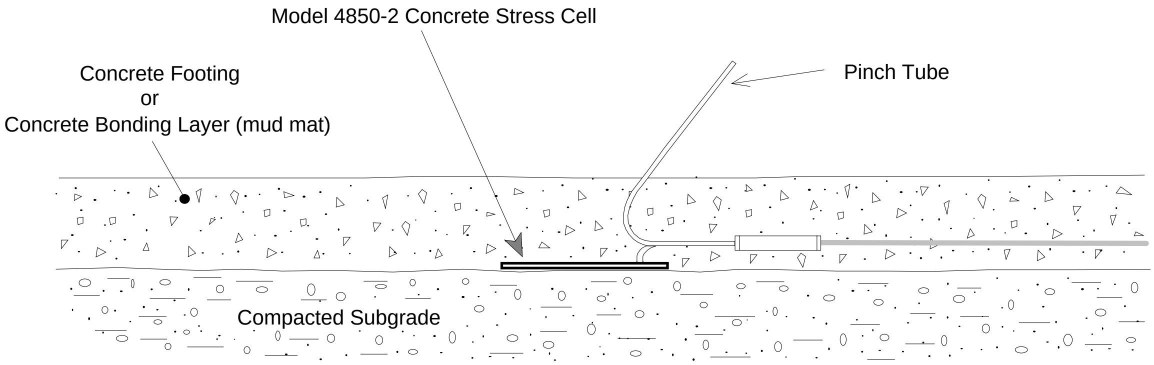


Figure 14 - Model 3600 Floor slabs and Footings Installation

The advantage of this method lies in its simplicity and in that it permits the ground below the concrete to be completely compacted in the normal way.

## 2.3. Cable Installation

Cable placement procedures vary with individual installations. In general, however, all installations have in common the requirements that; 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 gage transducer and, as such, has very low level output signals. If cables are damaged or improperly spliced the outputs can be seriously degraded. It is, therefore, 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 – use 3M Scotchcast model 82-A1. These 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

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. ***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 gage 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 gage 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

The gage factor, **G**, is determined by dividing the full-scale pressure range by the full-scale output which is either 100mV, 5 Volts or 16 mA. For instance a 350 kPa transducer with a 100mv FS output would have a gage factor, G, of 350/100 = 3.5 kPa/mV. Similarly a 3.5Mpa transducer with 4-20mA output would have a gage factor of 3500/16 = 218.75kPa/mA

### 3.2. Measuring Temperatures

Each piezometer is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Section 1.2 shows which cable conductors are connected to the thermistor. These conductors should be connected to a digital ohmeter

A Look up table for converting the measured resistance into temperatures is given in Table B-1 (Appendix B). Alternately the temperature can be calculated using Equation B-1 (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 2 for both directions.

# 4. DATA REDUCTION

## 4.1. Pressure Calculation

The pressure applied to the cell is determined by the following:

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

Where, **P** is the applied pressure in kPa, Mpa or psi, $\mathbf{R_1}$ and $\mathbf{R_0}$ are the current and initial output readings in millivolts, volts or milliamps.

**G** is the gage factor, as defined in Section 3.1.1

*Example,* Model 3500 –1 - 700kPa

$\mathbf{R_0}$ = -0.25 mV
$\mathbf{R_1}$ = 18.0 mV
**G** = 700/100 = 7 kPa/mV
**P** = (18.0 – (– 0.25)) 7 = 127.75kPa

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

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

## 4.3. 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 fairly 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 (<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. Consult the readout or datalogger manual for further direction.

## APPENDIX A - SPECIFICATIONS

Table A.1. Earth Pressure Cell 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, >=5000psi) |
| **Burst Pressure** | >35 x FS <= 6 bar (100psi)<br>>320 x FS <= 60 bar (1000psi)<br>>5 x FS <= 400 bar (6000psi) |
| **Fatigue Life** | Designed for more than 100 million FS cycles |
| **Performance** | |
| **Long Term Drift** | 0.2% FS/year (non-cumulative) |
| **Accuracy** | 0.25% FS typical (optional 0.15% FS) |
| **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<br>-20° to 80° C (-5° to 180° F) for elec. codes 2, D, G, 3<br>-20° to 50° C (-5° to 125° F) for elec. codes F, M, P<br>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<br>IP65 for elec. codes A, B, C, D, G, 1, 2, 3<br>IP67 for elec. code "F"<br>IP68 for elec. codes M, P<br>IP30 for elec. code "3" with flying leads |
| **Vibration** | 35g peak sinusoidal, 5 to 2000 Hz |
| **Acceleration** | 100g 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; 75g/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. |

## APPENDIX B - THERMISTOR TEMPERATURE DERIVATION

**Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3 (**Range: -80 to +150° C. Accuracy: ±0.5° C)

### Resistance to Temperature Equation:

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

Equation B-1 Convert Thermistor Resistance to Temperature

where: T = Temperature in °C.

LnR = Natural Log of Thermistor Resistance

$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the −50 to +150° C. span)

$B = 2.369 \times 10^{-4}$

$C = 1.019 \times 10^{-7}$

| 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 B-1 Thermistor Resistance versus Temperature

## Appendix C. An 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 800mm above the instrument level. The Instrument location and the cable trenches are excavated 500mm deep, a pocket, with 45° sloping sides, of only a further 300mm depth is required to be excavated at the instrument location. The cells, (Model 3600 complete 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 (19mm aggregate), in 100mm 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 100mm 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: Input voltage for Model # 3500-1, mV/V output is 10V d.c.**
**(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** |

**Input voltage for Model # 3500-2, 0–5VDC output is 6.5–35V d.c.**

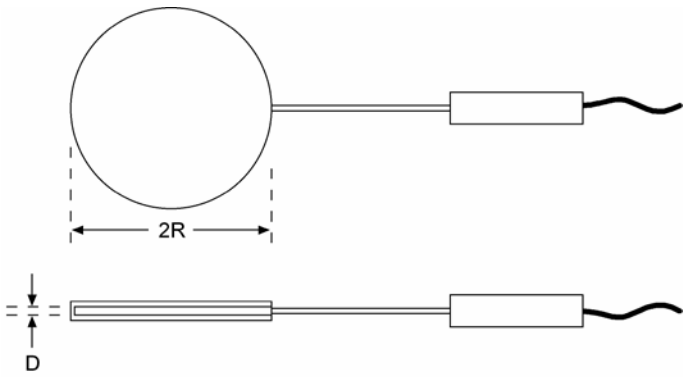
**4 – 20mA output**

| 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: Input voltage for Model # 3500-3, 4–20mA output is 6.5–35V d.c.**

## APPENDIX E. Temperature Effect on Earth Pressure and Concrete Stress Cells – Some Theoretical Considerations

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.



Consider a circular cell of radius R containing a liquid film of 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:

$Y_T = KD$ .................................................................. ①

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 and a compression of the liquid, $Y_c$, given by the equation:

$Y_c = PD/G$ ................................................................ ②

So that the net expansion, Y, of the cell is equal to:

$Y = D\,(K - P/G)$ ......................................................... ③

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formulas found in [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 Poissons ratio, ν, is given by:

$$Y = \frac{2\,PR\,(1-\nu^2)}{E} \qquad \text{at the center}$$

And $$Y = \underline{4\,PR\,(1-\nu^2)} \qquad \text{at the edge}$$

$$\pi E$$

And the difference is $\underline{PR(1-\nu^2)}(2-4/\pi)/E$

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 and so Y, at the center, is assumed to be:

$$PR(1-\nu^2)(2-4/\pi)/E \quad \text{i.e. the same difference as before.}$$

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:

$$Y = 0.73\,PR(1-\nu^2) \times 0.5 \times 2/E = 0.73\,PR(1-\nu^2)/E \;\ldots\ldots\ldots\ldots\; ④$$

Equating ③ & ④ gives:

$$P(D/G + 0.73\,R(1-\nu^2)/E) = KD \;\ldots\ldots\ldots\ldots\; ⑤$$

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

$$Y = 0.73\,\underline{PR(1-\nu^2)} \times 0.5/E \quad = 0.36\,\underline{PR(1-\nu^2)/E} \quad \ldots\ldots\ldots\ldots ⑥$$

And $P(D/G + 0.36\,R(1-\nu^2)/E) = KD \;\ldots\ldots\ldots\ldots ⑦$

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 $(1-\nu^2)$ can be replaced by 0.91 since $\nu$ usually lies between 0.25 and 0.35.
Hence, for total embedment:

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

And, for contact pressure cells:

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

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 |

Examples.

For an oil-filled cell, 9 inches diameter and D = 0.060 inches, totally embedded in:

1. Plastic Clay, E = 3000 psi, ν = 0.3,…………P = 0.042 psi / °C
2. Soil, medium stiffness, E = 10000 psi, ν = 0.3 ……….. P = 0.138 psi / °C
3. Coarse Sand, E = 50000 psi, ν = 0.3…………..P = 0.69 psi / °C

(For contact pressure cells, multiply the above values for P by 2.)

For a concrete stress cell, 9 inch diameter and D = 0.020 inches:

4. Concrete, E = 5 x $10^6$ psi, ν = 0.25 ………….P = 22.7 psi / °C

Same cell, embedded in concrete, filled with mercury instead of oil, ….. P = 5.8 psi / °C
For an oil-filled cell embedded in a completely rigid medium …………. P = 210 psi / °C
For a mercury-filled cell embedded in a completely rigid medium …….. 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