

# Measurement of Earth Pressure

JOSEPH B. HANNON and KENNETH A. JACKURA

## ABSTRACT

Factors that affect the measurement of earth pressure are discussed. Several variables, including cell design, installation procedures, and environmental effects, are cited for their influence on pressure cell behavior. A sampling of pressure cell installation and monitoring experience by various agencies and organizations is presented along with comments on pressure cell failures, potential causes of failure, and suggestions for improved performance on future installations. An example of an alternative procedure for determination of horizontal earth pressure is presented. It is concluded that accurate measurements of earth pressure are difficult to achieve unless pressure-sensing instruments are properly selected, calibrated, and installed by experienced personnel.

Accurate measurement of earth pressure is helpful in evaluating the performance of a structure. Earth pressure measurements may be desirable at any point within a soil mass or at the interface between the soil mass and a structural element.

The most desirable way to detect total or changing stress conditions requires installation of some type of earth pressure sensing cell during construction. Cells for this purpose are diaphragm devices that sense pressure changes. These devices are sold commercially as earth pressure cells or soil stress meters. They are also called earth or soil stress cells. These pressure-sensing devices are pneumatic, hydraulic, vibrating wire strain gauge, or bonded or unbonded resistance strain gauge units. A description of each of these units follows.

### Fluid-Filled Cell (oil or mercury)

#### Pneumatic Readout System

An air- or gas-charged pneumatic readout system to balance out the soil stress imposed on the sensing diaphragm of the cell.

#### Hydraulic Readout System

Identical to the pneumatic cell except that oil rather than air or gas is used in balancing out the soil stress.

#### Electrical Readout System

- Vibrating wire strain gauge cell (transducer externally mounted)
- Bonded resistance strain gauge cell (externally or internally mounted transducer)
- Unbonded resistance strain gauge cell (externally mounted transducer)
- Piezoelectric cell (sensor mounted either externally or internally)

### Deflecting Diaphragm Sensing Cell (sealed air- or gas-filled cavity)

This cell has an electrical readout system (bonded strain gauge or vibrating wire strain gauge).

Not all earth pressure sensing systems are applicable to specific situations. The performance of a given pressure cell can be affected by its own design and by the environment in which it is installed.

The various factors that influence the accurate measurement of earth pressure will be discussed as will performance information on the reliability of different devices for earth pressure measurements for short- and long-term applications based on a sampling of experience. Suggestions on the use of alternative measurement systems to indirectly estimate earth pressure will also be presented.

## DISCUSSION

### General

Many agencies and organizations have experienced difficulties on one or more instrumentation projects that have failed to provide reliable data for project needs. Technical difficulties have sometimes been encountered with field data because of poor instrumentation devices and lack of experience with proper installation and data-collection procedures.

It is important to acquire instrumentation devices that provide accurate and reliable field data. To ensure success, instruments should be properly installed and calibrated.

In general, the California Department of Transportation (Caltrans) has experienced adequate success with most instrumentation except soil pressure cells. During the 1960s the data readout from pressure cells was often erratic, with time-dependent drifting of indicated pressures. Also, uncertainty existed as to data accuracy because of the abnormal stress distribution generated by the installation of the pressure cells within the soil.

These problems led Caltrans to research various cell types for accuracy, long-term stability, and best method of calibration (1,2). The effect of various types of bedding soils on pressure cell response was also evaluated. Factors affecting the accuracy of pressure cell (stress cell) measurements, as described by Weiler and Kulhawy (3), are given in Table 1.

### Environmental Effects

The main objective in the design of a pressure-sensing device is to minimize the effects of the

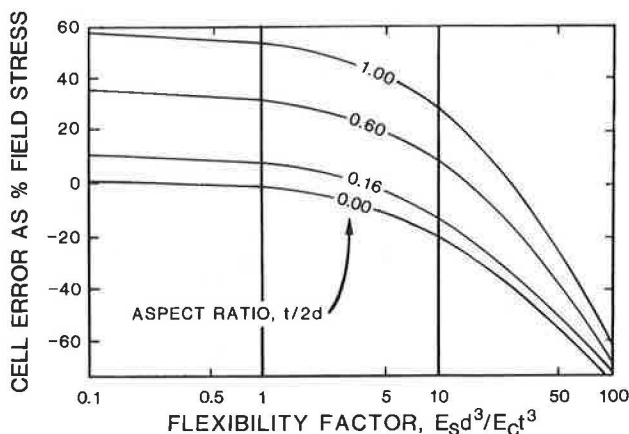
**TABLE 1 Factors Affecting Accuracy of Pressure Cell Measurements [Weiler and Kulhawy (3)]**

Factor	Description of Error	Correction Method
Cell thickness-to-diameter ratio	Cell thickness alters the stress field around the cell	Use relatively thin cells
Soil-to-cell stiffness ratio	Changing soil stiffness may cause a nonlinear calibration	Design cell for high stiffness and use correction factors
Diaphragm deflection (arching)	Excessive deflection changes stress distribution over cell	Design cell for low deflection
Stress concentrations at cell corners	Cause cell to overregister by increasing stress over active cell face	Use inactive outer rims to reduce sensitive area
Eccentric, non-uniform, and point loads	Soil grain sizes too large for cell size used	Increase stress cell active diameter
Lateral stress rotation	Presence of cell in soil causes lateral stresses to act normal to cell	Use correction factors
Stress-strain behavior of soil	Cell measurements influenced by confining conditions	Calibrate cell under near-usage conditions
Placement effect	Physical placing of the cell causes disturbance of the soil	Random error; use duplicate measurements
Proximity of structures and other stress cells	Interaction of stress fields of cell and structure causes errors	Use adequate spacing
Dynamic stress measurements	Response time, natural frequency, and inertia of cell cause errors	Use dynamic calibration
Corrosion and moisture	May cause cell "failure" by attacking the cell material	Use extra waterproofing precautions
Placement stresses	Overstressing during soil compaction may permanently damage cell	Check cell design for yield strength

device on the environment in which it will be placed, so that the actual state of stress can be measured. Numerous investigations have been conducted to determine the effects of pressure cell-soil interaction under loading. If the pressure cell is stiffer or less stiff than the soil around it, stress concentrations can develop and result in overregistration or underregistration, respectively.

Taylor (4) in 1947 found that thin, stiff cells will produce a maximum and determinable overregistration. Compressible cells will underregister but, due to variable soil-cell modular ratio ( $E_s/E_c$ ) under loading, will not have a constant underregistration value.

This phenomenon was graphically illustrated by Tory and Sparrow in 1967 (5) and is shown in Figure 1. Cell error is shown to be primarily a function of



**FIGURE 1 Variation of cell error with flexibility factor (5).**

the soil-cell modular ratio ( $E_s/E_c$ ) and the aspect ratio ( $t/2d$ ), where  $t$  and  $d$  are cell thickness and diameter, respectively. The ratio  $E_s d^3/E_c t^3$  is called the flexibility factor. Figure 1 shows that for small flexibility factors (stiff cells), cell error remains reasonably constant, but as the flexibility factor increases, cell registration error becomes quite dependent on soil modulus.

Because many soils have a stress-dependent modulus, Tory and Sparrow's information underscores the importance of using stiff cells in order to keep the registration error near the horizontal portion of the curve. The figure also shows that, for a given diameter, thin cells are necessary for greater accuracy in cell readout. Cell overregistration can also be controlled by limiting the cell's sensitive region to the central portion of the cell. Peattie and Sparrow (6) obtained greatly reduced registration error when they limited the sensitive portion to approximately 50 percent of the cell diameter.

### Cross Sensitivity

Brown and Pell (7) in 1967 uncovered a problem associated with strain-gauge bonded diaphragm cells in regard to their sensitivity to point loading of in-plane or radial forces. Because the purpose of a pressure cell is to be responsive only to pressures normal to its face, sensitivity to radial point loads, primarily due to Poisson's effect, is an undesirable feature. Insulating the inner sensitive diaphragm from the effects of in-plane loading was described by Weiler and Kulhawy (3) in 1978.

### Geometric Shape and Design

The work conducted by Monfore (8) and Peattie and Sparrow (6) and others to minimize registration error by reducing the sensitive region of the cell is one of the innovative advances in soil pressure cell design in recent years. However, Caltrans reinvestigated cell design theory and undertook a finite element study using a program developed by Herrman (9) to evaluate alternative geometric cell shapes with full face sensitivity to reduce registration error. If full face sensitivity could be successfully used with minimum registration error, larger soil masses could be measured (in contrast with cells of the same diameter with only 50 percent face sensitivity) and thus aid field stress measurement reliability. Furthermore, the Caltrans' finite element studies reported by Forsyth and Jackura in 1974 (10) indicated dramatic registration errors for cylindrical cell models having partial face sensitivity to in-plane orientation of the major principal stress ( $\sigma_1$ ). This phenomenon was not studied extensively by other investigators. With these factors in mind and assuming that fluid-filled cells would be more advantageous for pressure recordings because they are less sensitive to point loading or soil pressure eccentricities than are diaphragm deflecting cells, the Caltrans finite element study team reached the following conclusions:

1. A cell with cell-soil modular ratio ( $E_c/E_s$ ) near 10 is desirable to ensure that cell registration error is reasonably independent of variations in soil modulus ( $E_s$ ). A cell modulus ( $E_c$ ) of at least  $3 \times 10^5$  psi is recommended.

2. Pressure cell geometry is an important physical characteristic associated with minimizing registration error. For soil principal stress ratios between 2 and 2.5 where the theoretical test study was conducted, cell geometry can be effectively used to

minimize registration error regardless of cell orientation to the major principal stress.

3. The geometric cell shape most conducive to reducing cell registration error is a circular, long edge tapering configuration. If cells are going to be variably oriented to the major principal stresses, uniform thickness cells with either too soft or too rigid annuli are not considered viable pressure cell designs because of their sensitivity to orientation to the major principal stress.

4. The overall dimensions of the pressure cell should be related to soil particle size. The bedding soil contact with the pressure cell diaphragm should not be allowed to vary greatly from its surroundings or redistribution of stress may occur. Kallstenius and Bergau (11) suggest that, for flush-mounted piston-type cells in rigid walls, the cell diameter should be at least 50 times the largest soil particle size. For all other installations or cell types, cell diameter to particle size can be on the order of 5 to 10 (3).

5. Cells should be waterproof and cable entries should be strong enough to resist stresses and deformations during installation.

#### Calibration

Most manufacturers of earth pressure cells provide a calibration chart established by loadings in either air or water. However, an additional verification of a cell's calibration is generally necessary before use because commercially supplied calibration curves are sometimes insufficient.

The proper method of calibration is still somewhat debatable within the geotechnical community. Dunicliff (12) and others suggest that pressure cells should be calibrated in a large chamber using the same soil in which the cell is to be embedded and the same installation procedures, unless the installation is made in soft clay. Suitable calibration chambers are described by Hadala (13), Hvorslev (14), Selig (15), and Smith (2).

Jackura (16) reports that calibration can be adequately performed by hydraulic or pneumatic means provided the pressure cell design, construction, and geometry meet established criteria for acceptable performance (9,17,18). He also suggests that, when needed, cell action factors (registration errors) can be estimated by theory.

Laboratory calibration in soil can also become a matter of practicality because large cells would require enormous testing vessels to develop full pressure bulb regions and minimize sidewall frictional effects (16). Taylor (4) suggests minimum test vessel size-to-cell diameter and test vessel depth-to-cell diameter ratios of 8:1 and 4:1, respectively. As an example, for a cylindrical test mold arrangement, assuming the calibration of a 10-in.-diameter soil stress meter, this means soil volume of several cubic yards. Scaled-down sizes can possibly be made effective if side friction is reduced by a greased liner (13). However, even then, transmission pressure must be measured to determine residual sidewall friction. Walter et al. (19) present data on the use of a greased liner, which substantially reduced but did not eliminate sidewall friction.

Unless a user is familiar with the behavior of a particular pressure cell and the proper procedure for its calibration, installation, and bedding within an earth mass, pressure cells may be inappropriate and uneconomical. This is reinforced by the following statement from Weiler and Kulhawy (3, pp. 2-13 through 2-15).

The present need to calibrate the cells in the soil in which they will be used, as well

as the significant amount of time needed to acquire a familiarity with stress cell behavior, makes the use of stress cells uneconomical for most projects. When the cells are "economically" used (meaning no in-soil calibration and no time spent investigating how stress cells behave in soil), the results are nearly always unusable if not incredible. Accurate stress cell measurements are still almost exclusively limited to well-conducted laboratory model investigations.

It therefore appears that although accurate measurement of soil stress is desirable, it may be uneconomical for most installations. Users may sometimes need to settle for reasonable instead of accurate results. Users may be required to rely on alternate measurement systems to provide an estimate of field pressures.

#### Installation Procedure

A common method of cell installation for point of stress monitoring is to first construct the fill by normal compaction equipment to an elevation approximately 1 ft or more above the instrument level, then to excavate a trench for instrumentation placement. The trenches are then backfilled with several inches of either embankment material screened through a No. 4 or finer sieve or a concrete sand and are hand compacted to at least the same compaction as the surrounding fill. The cells are then fitted into their compacted layer and a 2- to 6-in. layer of the same hand-compacted backfill is placed over the cells to provide sufficient protection for the cells and uniform load transmission. Additional compactive effort is sometimes supplied by hand-guided compaction equipment. Dunicliff (12) believes that there is no better alternative to procedures of this type. He maintains that considerable underregistration can occur if the backfill is not brought to the same density and compressibility as the surrounding embankment soil.

Trapezoidal or V-bottom trenches with flat side slopes may be more desirable and provide better cell response with less soil bridging than do vertical trenches.

Adequate cell installations, required for measurement of soil stress at a soil-structure interface, are generally more difficult to achieve than that described previously for point stress monitoring. For these installations, it is extremely important to install and grout cells in preformed cavities within the structure's outer face at the soil contact. Control of backfill adjacent to each cell is also important. Representative compactive effort is generally difficult to achieve. Both overregistration and underregistration errors are common with interface stress cell locations because of overcompactive effort or insufficient cell-soil contact, respectively.

It is believed that a common cause of underregistration is backfilling around an installed pressure cell that has had insufficient time to adjust to the embankment temperature. Hydraulic cells are most susceptible to volume changes resulting from changes in temperature gradient under load and cannot be calibrated for this phenomenon. Thermal expansion coefficients of  $2 \times 10^{-5}$  in. per degree Fahrenheit for oil-filled cells and one-fifth of that for mercury-filled cells are quite likely. Cell contraction due to cooling will result in measured pressure decreases. Pressure decreases will be more pronounced in dense soils (especially granular

types) due to significant soil arching over the contracting cell. Where cells are placed flush mounted in concrete structures, cell cooling is expected to cause even greater pressure decreases, as a result of soil arching over the cell at the cell-structure interface, than are registered by cells placed wholly within soil. A temperature adjustment time of at least 6 hr at 55° ±5° F (average earth temperature) before cell placement will be sufficient to preclude most registration error.

#### PERFORMANCE AND RELIABILITY

Table 2 gives a sampling of experience by various agencies and organizations with various types of pressure cells and stress meters. The following section relates to Table 2 and provides comments on cell failures, potential causes of failure, and suggestions for improved performance of future installations.

#### California Department of Water Resources

The California Department of Water Resources (DWR) attributes the malfunction of stress meters to one or more of the following causes:

- Moisture,
- Improper installation,
- Improper backfill,
- Bad connections at junction boxes,
- Strong direct current, and
- Corrosion.

Moisture in contact with the instrument leads at several installations caused false readings and instrument failures when instruments were located below the groundwater surface.

DWR believes that proper installation is the key to good performance, which is dependent on perfect contact between the meter and the adjacent structure-soil interface. DWR engineers believe that improper meter placement, poor compaction, and so forth contributed significantly to the high failure rate of concrete stress meters on three projects. Instead of being encased in a surrounding layer of concrete, the meters were installed directly against the foundation material. These meters were not designed for an interface situation. Sand backfill placed around meters at one pumping plant location was actually transported away from the meter contact faces by rainwater. Meters were left with point contact in rock.

DWR procedures for splicing of lead cables at junction boxes were not standardized for all locations. Improperly sealed wires frequently shorted out. A method that proved successful was to solder the lead wires, cover them with a wire nut, and encapsulate the whole in an epoxy molding compound. Failures could also have been prevented by providing sufficient cable lengths to eliminate the need to splice.

Experience also indicates that any direct current near an electrical resistance stress meter may pass through the meter to the ground causing false or erroneous readings. Recorded stress measurements were generally good at four pumping plant locations before plant start-up. When plants went into operation, the readings gradually decreased toward tension. The same trend was experienced at all four pumping plants. The cathodic protection system at the four plants was also a possible source of the stray direct current. Corrosion was also cited as a possible cause of stress meter failure at one location.

#### Colorado DOT (Sinco & Gloetzl pneumatic pressure cells)

Typical pressure cell installation procedures consisted of constructing grade to approximate cell elevation, bedding cells, and backfilling 0.5 to 1 ft over cells with fine grained material. Reliance was placed on manufacturer's calibration curves and no independent cell calibration was made.

#### Georgia DOT (Irad vibrating wire pressure cells)

Experience in Georgia indicates that

1. Cell accuracy was questionable due to probable arching around vertical cells and settlement and installation method on horizontal cells,
2. Cells are electrical but simple to use,
3. Readout equipment is easily calibrated,
4. Protecting lead wires in embankment is somewhat difficult,
5. Overall reliability is considered fair,
6. Cells were installed and monitored by competent personnel,
7. It was assumed that cells were properly installed and their installation did not affect cell behavior,
8. Not much maintenance and care are required, and
9. Readings appeared reasonable but there was no way to double check except by comparing with theoretical readings.

#### University of Nottingham (Nottingham electrical resistance pressure cells)

Experience at the University of Nottingham indicated that

1. The accuracy of the pressure cells was considered to be within ±15 percent of the true stress in a clay.
2. The Nottingham pressure cell is perhaps the simplest arrangement possible; it uses a full bridge of strain gauges.
3. It is possible to switch in a resistance across one arm of the bridge to simulate a known stress for self-verification during bench testing.
4. Dead weight calibration is used for bench testing, and calibration was done with triaxial cell specimens of the subject soil to determine cell registration.
5. Cells have a titanium body that provides good durability. Failures occurred because of poor adhesion of strain gauges or moisture ingress at cable entry.
6. Cells provided good reliability in fine grained soils and fair reliability in coarser materials when protected with fine grained backfill.
7. Installations should be made by experienced laboratory staff. Minimum disturbance of existing material during installation is considered extremely important.
8. Good, clear, logical records should be kept.
9. Duplicate readings from different instruments are desirable, but measurement of the same parameter with at least three instruments is preferred.
10. It is desirable to gain the confidence of the resident engineer when installing instrumentation.

TABLE 2 Sampling of Pressure Cell Experience

Agency or Organization and Type of Facility	Instrument Type	Instrument Manufacturer	No. Installed	No. Survived	No. Functioning	Remarks
Caltrans						
Reinforced Earth with steel facing (Route 39)	Hydraulic	Gloetzl	50	50	50	Good response for vertical, horizontal, and inclined plane installations
Reinforced Earth with steel facing (Route 39)	Electrical resistance	Gentran	10	10	10	Good response for vertical, horizontal, and inclined plane installations
Mechanically stabilized embankment with concrete facing (Baxter, Calif.)	Electrical resistance (soil stress meter)	Carlson	6	6	6	2 overregister, 2 underregister, and 2 provide reasonable data (horizontal pressure cells incorporated in concrete facing)
Mechanically stabilized embankment with wood facing (Delhi, Calif.)	Pneumatic with valve manifold and nitrogen source	Gloetzl	10	10	10	Horizontal pressure cells with valve manifold and nitrogen source; about half of cells have underregistered
Jail Gulch embankment	Electrical resistance	Gentran	53	34	34	Pressure cell groups installed in trapezoidal trenches (3 ft deep with 1 ft bottom and sides on 6:1 slope); 19 failed initially and 13 more failed within 6 mo
DB & Cross Canyon (large culverts)	Electrical resistance	Cambridge Meters	96	96	90	6 meters failed electrically after 6 mo
	Electrical resistance (transducer)	Kyowa	160	159	159	Electronically most of the cells performed satisfactorily for 3 yr of data collection
	Electrical resistance concrete interface	Carlson	182	180	180	Data from some cells were erratic indicating abnormal pressure readings; no explanation given for this behavior
	Electrical resistance (transducer)	Ormond	170	168	168	It is believed that pressure cells reflected actual conditions
Mechanically stabilized embankments and Reinforced Earth (concrete facing)	Soil stress meters	Carlson	12	12	12	All cells provided reasonable data
California Department of Water Resources						
Several pumping plants	Electrical resistance soil stress meters	Carlson	82	81	45	19 are still functioning after 9 to 13 yr; other meters developed shorts or electrical damage
	Electrical resistance concrete stress meters	Carlson	54	41	27	None functioning after 9 to 13 yr; overregistration on several meters; 26 had erratic readings; 20 shorted out or had electrical damage
Castaic Dam	18-in. dynamic stress meter with Maihak vibrating wire transducers and Carlson-type strain gauge transducers	Aerojet General Corp.	15	15	15	Maihak transducers have performed well for 11 yr
Oroville Dam	Soil stress meters	Carlson	29	—	20	Erratic reading and electrical shorts
	18-in. dynamic stress meter with Maihak vibrating wire transducers and Carlson-type strain gauge transducers	Aerojet General Corp.	27	—	20	Erratic reading and electrical shorts
	30-in. dynamic stress meter with Maihak vibrating wire transducers (dynamic) and CEC resistance type sensors (static)	Aerojet General Corp.	15	15	15	About half function at present time
	Electrical resistance concrete stress meter	Carlson	9	9	9	6 installed in grout gallery and 3 installed on core block foundation; all meters still function
Colorado DOT						
Retaining walls in Glenwood Canyon	Pneumatic	Sinco	25	24	24	A total of 16 additional cells was lost during the first 2-year period for both cell types; remaining cells show a trend but underregister in most cases
	Pneumatic	Gloetzl	19	17	17	
Precast segmented IECO retaining wall	Pneumatic	Gloetzl	45	43	43	For horizontal and vertical pressure measurement; 4 cells cast in foundation; 1 cell provided no reading and 1 cell overregistered; too early to comment on performance of other cells
Georgia DOT (stabilized embankment)	9-in. vibrating wire pressure cell	Irada	10	9	8	5 placed for vertical pressure and 5 placed for horizontal pressure; medium silt-clay backfill around cells; breakage of wire was possible cause of initial failure
Harvard Square Station, Boston, Mass.	Vibrating wire pressure cell	Irada	6	6	0	Cast in slurry wall concrete to measure pressure at back of wall; could not seat at concrete-soil interface; judged unsuccessful
University of Nottingham						
Field studies of pavements and subgrades	Electrical resistance	University of Nottingham	17	17	14	Cells installed to compare vertical subgrade stresses and pavement performance
Laboratory study of pavement subgrades and bases	Electrical resistance	University of Nottingham	12	12	11	Cells installed to measure transient vertical and horizontal stresses in clay subgrades, granular bases, and asphalt mixes

#### ALTERNATIVE PROCEDURE FOR EARTH PRESSURE DETERMINATION

The following example is furnished to illustrate an alternative procedure for deriving lateral (horizontal) soil pressure when data from installed pressure cells appear unreliable.

This example involves a fully instrumented mechanically stabilized embankment (MSE) (reinforced soil retaining wall) with wood facing and steel bar-mat soil reinforcement (20). The facing for this temporary wall consisted of 1-1/8-in. plywood panels with 4 in. x 6 in. Douglas fir posts on 2-ft centers (Figure 2). The facing was supported by W5 wire (0.252 in. in diameter) bar-mats with 6 in. x 12 in. grid spacings. Bar-mats were secured to 4 in. x 6 in. posts on 2-ft vertical spacings and were embedded in a silty sand backfill material (Figure 3). The maximum wall height was 24 ft. Instrumentation consisted of Gloetzl cells with pneumatic readout installed at five different levels to measure horizontal pressure (Table 2). Strain gauges were placed in both the horizontal and the vertical wall face direction on the plywood facing elements. Strain gauges were also installed on the steel bar-mats behind the wall face.

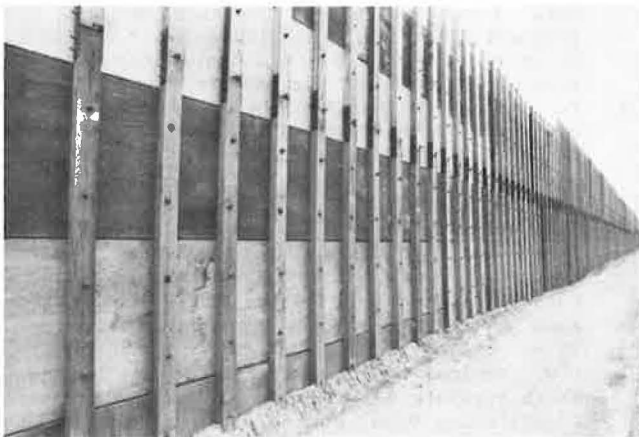


FIGURE 2 Front view of wood faced MSE.



FIGURE 3 Steel bar-mats behind wood faced MSE.

Pressure cell readings during wall construction indicated both under- and overregistration of lateral pressure on the wall face with almost complete pressure relaxation within a month of cell placement. The pressure cells were installed in precut recesses in the wood facing as shown in Figure 4.



FIGURE 4 Field installation of soil pressure cells behind plywood face.

It is assumed that the cell temperature under direct sunlight, before backfilling, rose to above 100°F, thereby creating a temperature differential of about 50°F between cell and soil at the time of soil placement. As suggested in an earlier portion of this paper, the pressure relaxation could be attributed to the volume change of the cells in their soil environment.

Figure 5 shows the results of pressure cell measurements in terms of lateral soil pressure plotted against overburden height in feet. Also shown are calculated lateral soil pressures from bar-mat stresses and strain gauge readings on the wall face and from laboratory vacuum testing of strain gauged plywood facing panels that were tested to model the field condition.

Although the data from pressure cells were quite scattered, data from the other three alternative systems of measurement provided realistic values for lateral pressure.

Figure 6 shows the results of a successful pressure cell installation and monitoring program by Caltrans for lateral (horizontal) wall pressures (21). Pressure measurements for this concrete-faced Reinforced Earth (RE) wall were found to correlate well with Rankine theory. Strain gauges installed on the steel reinforcing strips also provided an alternative means of verifying lateral pressure.

Lateral soil pressure behind the wall face was determined by Carlson soil stress meters carefully installed and flush mounted at the concrete-soil interface (see Caltrans, Soil Stress Meters, Carlson, in Table 2).

#### SUMMARY

Accurate or reasonable measurements of earth pressure are difficult to achieve unless pressure-

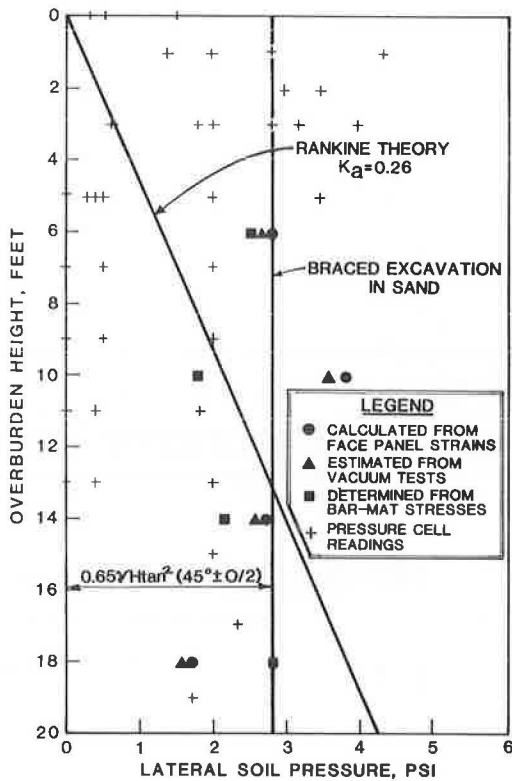


FIGURE 5 Lateral soil pressure test results versus theory (20).

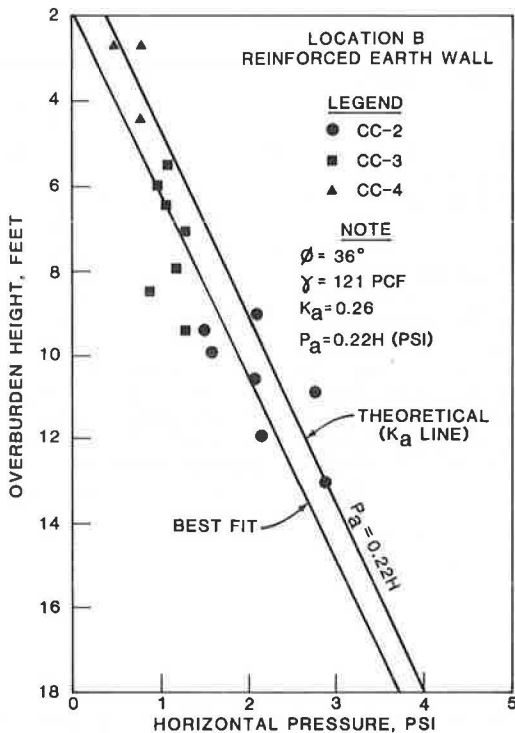


FIGURE 6 Soil pressure on wall face during construction (21).

sensing instruments are properly selected and special attention is given to proper installation techniques and calibration.

Instrumentation personnel should be experienced and knowledgeable about potential problems associated with the placement and monitoring of the particular instruments selected for use. All instruments should also be subject to bench or calibration testing, or both to ensure performance and compliance with specifications.

When feasible, alternative procedures should be used for backup to estimate soil stress conditions.

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## Reliability of Strain Gauges and Load Cells for Geotechnical Engineering Applications

LEE W. ABRAMSON and GORDON E. GREEN

### ABSTRACT

Strain gauges and load cells are often used to measure strain and load in concrete or steel components of geotechnical structures. Reliability problems are frequently cited for these instruments. The purposes of this paper are (a) to discuss the factors that affect the reliability of strain gauges and load cells used for geotechnical engineering applications, (b) to suggest the instrument types that have historically performed most reliably and are therefore preferred by some engineers, (c) to indicate which instruments should prove to be the best choice for future projects, and (d) to establish realistic survivability rates to be used in planning instrumentation programs. These objectives were accomplished by searching published literature and by surveying the opinions of more than 40 knowledgeable geotechnical engineers. The results of the survey as well as published information have been compiled and are included in the paper. The primary considerations for instrument reliability are instrument characteristics and selection. Other considerations include proper planning of the instrumentation program, ability of the instrument to perform the intended function, and field installation and handling techniques. Vibrating wire strain gauges are generally preferred for reliable strain measurement. Electrical resistance strain gauged load cells are generally preferred for reliable load measurement. Planning of an instrumentation program should anticipate the probability that one-quarter to one-half of the instruments may not survive installation or the period of monitoring.