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L. Grabowski – S. Kobielak – Z. Zamiar – M. Jagiełło *

INŠTALÁCIA BUNIEK NA MERANIE TLAKU ZEMINY V STAVEBNÝCH KONŠTRUKCIÁCH

INSTALLATION OF SOIL PRESSURE CELLS IN CIVIL ENGINEERING STRUCTURES

Článok sa zaoberá problémom inštalácie buniek určených na meranie pôdneho tlaku v rôznych stavebných konštrukciách. V článku sú uvedené príklady aplikácie okrajového typu tlakových buniek používaných na meranie tlaku zeminy pôsobiaceho na okrajových povrchoch takých stavebných konštrukcií, ako sú základy budov, tunely, šachty, piloty a oporné múry, ako aj vsadeného typu tlakových buniek používaných na zaznamenávanie tlaku v zemine násypov ciest alebo priehrad. Pri inštalácii tlakových buniek určených na takéto merania by sa mal použiť vhodný spôsob inštalácie, aby sa minimalizoval rušivý vplyv základovej pôdy v okolí tlakových buniek, ktorý značne ovplyvňuje ich údaje. V práci boli prezentované rôzne spôsoby inštalácie buniek.

The paper deals with the problem of cells installation encountered with the measuring of soil pressure in different civil engineering structures. In the paper are given application examples of boundary type of pressure cells used to pressure soil measurement acting on boundary surfaces of such civil engineering structures as building foundation, tunnels, shafts, piles and retaining walls as well as embedded type pressure cells apllied to stress record within soil of road or dam embankments. When pressure cells are installed for such measurements suitable installation techniques should be used to minimise ground disturbance in the vicinity of the pressure cells which affects considerably their indications. In the work different techniques of the cells installation have been presented.

1. Introduction

To evaluate the behavior of any engineering structures such as buildings, bridges, highways, tunnels, retaining walls, culverts or dams it is necessary to know the pressure distribution occurring in the contact plane between those particular structures or their elements (e.g. foundations) and the soil media surrounding them as well as the stresses inside these media. The pressure in the contact plane is measured by means of boundary cells (Fig. 1a), and inside the media – by means of sondes (buried cells, Fig. 1b). The basic way to obtain information about the values and the distribution of soil pressure is its direct measurement by means of pressure cells.

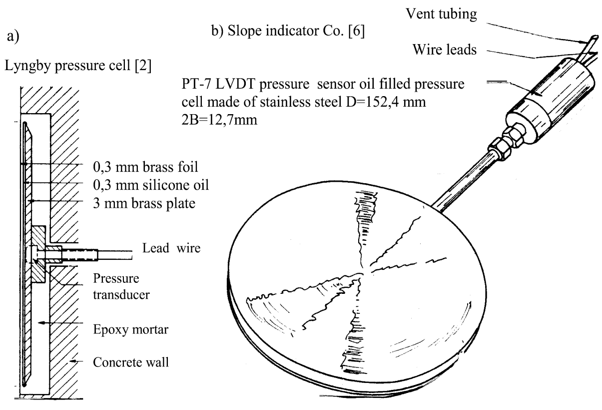


Fig. 1. Examples of a) boundary and b) buried type of pressure cells

In order to obtain reliable pressure measurement results it is necessary to:
- use adequate cells, characterized by reliable operation and stable indications in long-term measurements as well by being resistant to moisture and corrosion [11], [16], [22],
- minimize ground disturbances in the vicinity of the pressure cells by using suitably their installation (placement) procedures [9], [11], [12], [26].

This work focuses primarily on the analysis of the effect of pressure cell placement on the value of the recorded stresses and then the ways of cell installation have been presented both in made ground (e.g. in road and dam embankments), in virgin soil (e.g. motorway, railway and subsoil) and on the boundary surfaces of such structures as tunnels, shafts, piles, and retaining walls.

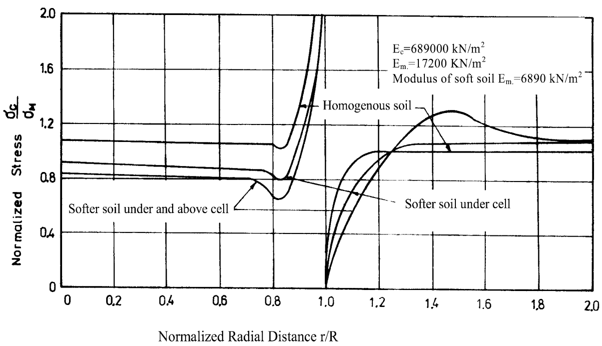
* [1]**Col. Dr Eng. L. Grabowski,** [2]**Dr Habil. Eng., Assoc. Prof. S. Kobielak,** [3]**Col. Dr Eng. Z. Zamiar,** [4]**Maj. M.Sc. M. Jagiełło**
[1]Professor of Military Engineering College im. T. Kościuszki in Wrocław, Poland
[2]Technical University of Wrocław, Poland
[3]Professor of Military Engineering College im. T. Kościuszki in Wrocław, Poland
[4]Military Engineering College im. T. Kościuszki in Wrocław, Poland

2. Effect of the technique the pressure cells is installed on their response

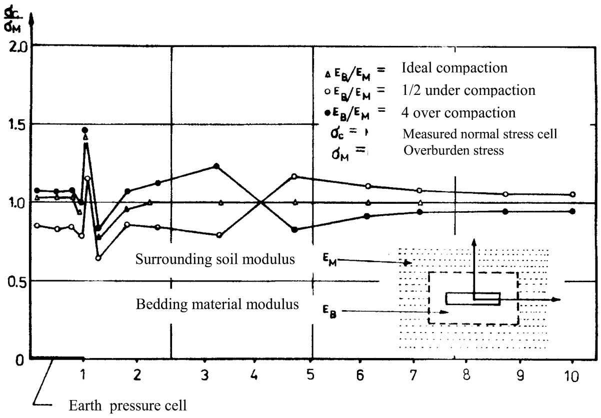
The identical soil pressure cells, placed in the same stress field do not necessarily have to record same stresses. One of the basic factors – apart from the characteristics of the cell itself (shape, relative rigidity, sensitive and total surface, transverse sensitivity, bulk density, free vibration frequency, sensitivity to temperature changes, and water tightness) that affects considerably the pressure cell indications – is the technique the cell is placed and how it is situated in relation to the structure walls.

Taylor [24] in 1947 and Monfore [15] in 1950 found out that in order to obtain a reproducible accurate pressure measurement, the cell rigidity should be equal or much larger than that (modulus) of the surrounding ground. Taylor [24] in the description of the phenomenon he called "pocket action" was the first to notice that if the material in the vicinity of the pressure cell (pocket) is less compact than the surrounding soil, then the pocket will be underloaded and the cell will over-register pressure values.

This finding has been confirmed by Krizek et al. [13] and by Audibert and Tavenas [3] who evaluated by means of the MES analysis the effect of the degree of the compactness of the soil filling the pocket on stress distribution disturbance (Fig. 2a and b).



a) Krizek et al.[13]



b) Audibert and Tavenas [3]

Fig. 2. Effect of the compactness degree of the bedding material on stress distribution in the vicinity of pressure cell after theoretical investigation of Krizek et al.[13] as well as Audibert and Tavenas [3]

From Fig. 2b it follows among other things that for the pressure cells to register actual pressure values the material compactness both in the pressure cell and in the bulk should be identical. This evidences the necessity to apply a proper way of placing the pressure cells.

Hadala [9] carried out comprehensive investigations on this issue for diaphragm and column cells (Fig. 3 a and b), both in laboratory and field conditions.

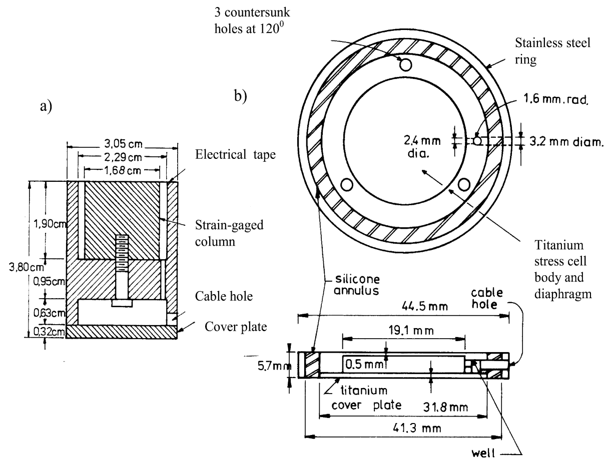


Fig. 3. Basic types of soil-stress cells [14] a) column type b) diaphragm type

He found out that even in the case of testing the pressure cells in the laboratory where there are better conditions to achieve repeatability of particular technique of installation as well as homogeneity of the hole medium and its particular layers, the alterations of cell indications reached even 40 %. A uniform repeatable method of stress cell installation affects to a decisive degree the reduction of an accidental error in soil stress measurements. Much less favorable conditions to achieve repeatable cell readings occur in stress measurements in field conditions where there is need of placing the pressure cells in excavations or drilled holes (pits). In this case the in situ material properties should be determined before a cell is installed, so that after its installation the pit could be backfilled with soil with maintaining its original properties in particular layers. In the case of placing diaphragm cell in soil, the best stress measurement accuracy is achieved when the method of placing the cell on the ground surface with subsequent burying it and leveling the ground [9] Two other ways technique of the cell installation are: a) driving in b) making a pit. Investigations concerning the evaluation of the methods of installation of column cells where the thickness (distance between end faces) is larger than in the case of diaphragm cells are presented in [19]. A wider handling of the method of installation of diaphragm and column cells and of the effect of their number on measurement accuracy has been presented in [12], [27]. An important factor affecting the accuracy of measurement of bulk material stresses is the proximity of the structure and clearance between adjacent cells. To avoid a measuring error resulting from the distribution of cells being too dense there should be clearance maintained between the cells vertical spacings of 4 cell diameters, horizontal distance 1–0.5 cell diameter. The latter is in the light of investigations [9] a larger distance and amounts to 3.5 cell diameters (Fig. 2b).

3. Installation of pressure cells in embankments

The requirements that should be met when pressure cells are to be installed in embankments are the following:
- suitable compactness of bulk material in the vicinity of pressure cells,
- selection of other material properties in the vicinity of the cell to minimize ground structure disturbance and to ensure a proper contact on the pressure cell-soil boundary.

Installation of cells to measure vertical stresses with regard to the above requirements has been illustrated with three examples of embankments: 1) road embankment made from a homogeneous material (Fig. 4), 2) dam (Fig. 5), and 3) highway (Fig. 6)

3.1. Installation of pressure cells in road embankments

The procedure of the installation of pressure cells in the case of a road embankment runs as follows [23].When the cells have been laid on the sand layer (pocket), but before pouring the covering sand layer, reading is made in order to check the correctness of the cell performance. Walking over the area performs initial compactness of the sand layer over the cells laid at suitable intervals. To make treading down the sand layers easier they are sprinkled with water. Then 30 cm of the same material is placed, watered and compacted with a hand-guided impact compactor. Readings are again obtained from the cells to ensure that the backfilling has not damaged them and to obtain a zero reading. The cells are monitored until the readings become constant indicating that the cells have reached equilibrium temperature with the surrounding soil. In this manner, no temperature correction is required for the zero reading. Any load registered above this equilibrium reading is considered as soil pressure. As the fill progresses in height, readings are taken at increments of 6m of fill. When the fill reaches the profile grade, the readings are obtained at longer intervals to check cell stability.

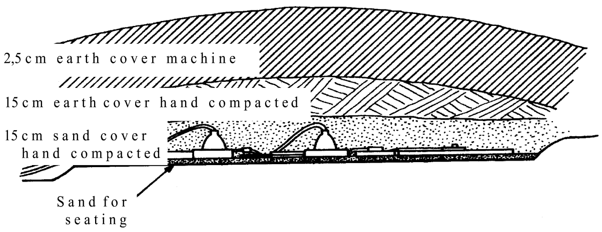


Fig. 4. Cell placement in test sites [23]

3.2. Installation of pressure cells at dams

A dam embankment consisting of a few layers each of which consists of bulk material of different properties requires an individual technique of pressure cell installation (Fig. 5).

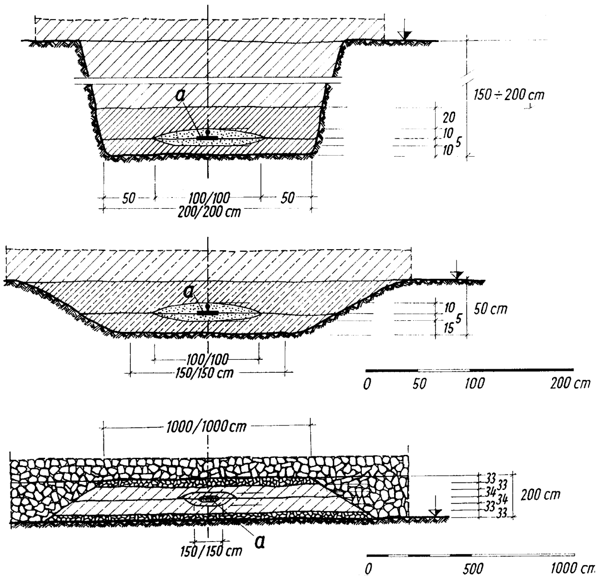


Fig 5. Installation of the cells in zones of dam embankment [21]: a) core zones of talus material and boulder clay b) transition zone of river deposit c) shell zone of quarry run and river deposits; 1 - pressure cell, 2 - sand 0–3mm, 3 - core material 0–80mm, 4 - core material 0–30mm, 5 - gravel 0–200mm, 6 - gravel 0–30mm, 7 - rock fill 0–1000mm, 8 - rock fill 0–300mm, 9 - compacted surface.

Figure 5 shows the structure of fill-lenses at the zone of installation. From this figure, it can be seen that pits up to 200cm in depth had to be excavated in the fine grained not very flexible core material cross-sections (Fig 5a) – to protect the cells against damage because of compaction with 40-t rubber-tired rollers. Similarly, in order to protect against damage resulting from passing of 60 t transportation trucks, more rigid gravel is put in two layers at the bottom of a 50 cm excavation (Fig. 5b) In turn, in the protective zone (Fig. 5c) the cells were placed in the middle of an excavation of the projection 10 × 10 m after which its compaction was performed by means of a 80 kN weight of vibratory roller. In each of these three cases of cell installation a pocket was used in order to eliminate any bridging action.

3.3. Pressure cells installation in excavation pit in the soil adjacent to pipe placed below the surface of highway

The example concerns soil instrumentation of a gas pipe 40.6 cm in diameter (Fig. 6). The pipe is placed 90 cm to 150 cm below the surface of finished highway. Both the soil stress cells and the soil strain gauges were manually implanted to ensure the proper location and alignment with reference to the pipe. The placement is accomplished in successive layers of lifts each of approximately 30 cm thick. The soil for each lift must be compacted by hand in the proximity of the gauges and their lead wires. A U-shaped picket provides a protective channel for lead wires as they pass through each successive lift. For the horizontal run to the readout station a conduit protects the lead wires.

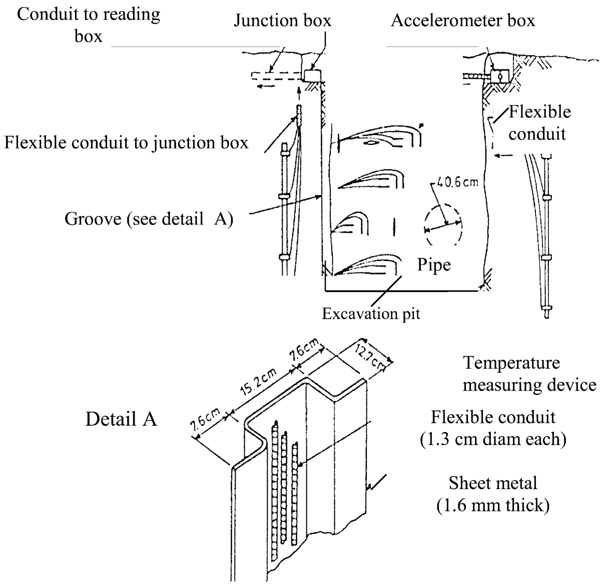


Fig. 6. Placement of soil pressure cell in fill of excavation pit [18]

3.4. Installation of cells in order to determine the plane state of stress in embankments and culverts

The techniques of cell installation discussed above concerned a measurement of one (vertical) component. And to determine the plane state of stress, in a plane three differently sloping cells should be placed (Fig. 7), in turn, establish the full state of stress – six cells. To accommodate a cell cluster, individual pockets for each cell are hand dug at the correct locations with flat faces at the required inclinations. The excavation as a whole should be stable with side slopes as necessary, and of dimensions not less than 4×4×2m deep. The cell pockets should be excavated with extreme care to avoid disturbance to the soil, each being of size approximately twice that of the cell.

Such pressure cell installing can take place in the practice of constructing highway embankments (Fig.8).

Below, a description is given of two major types of studies of soil stress in embankments [22]: (1) those involving measurements of the magnitude and direction of the principal stress within an embankment and (2) those involving measurements of the magnitude and distribution of earth pressures acting on culverts underneath fills. Figure 8a shows the instrumentation of type (1) of stress measurement on the embankment. The number in parentheses following the pressure cell cluster identification indicates the number of cells installed on that site to measure the components of earth pressure. Figure 8b shows the location of pressure cells placed in the type (2) of stress measurements in the embankments.

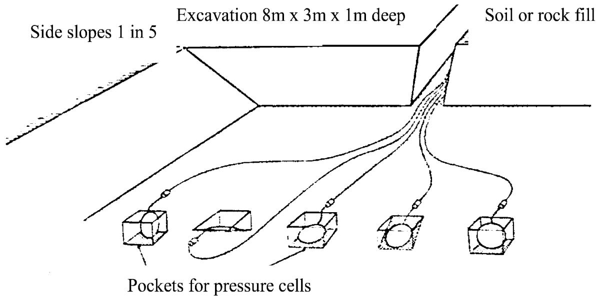


Fig. 7. Arrangement of pressure cells in pockets on the bottom of excavation to determine stress state in a single plane [7]

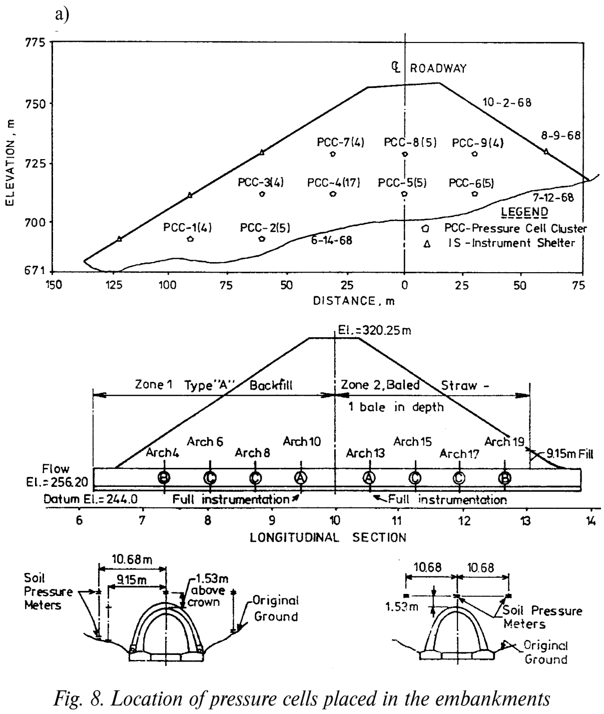


Fig. 8. Location of pressure cells placed in the embankments for measuring (Smith et al. [23]): a) stresses within embankment, b) pressures acting on culverts

The pressure cells were installed above the crown of the culvert and on the original ground near the footing in a 1.50 m × 3.00 m pit with sloping sides approximately 30 cm deep. A 60 cm square portion in the center of this area was prepared by removing all projecting rocks and by leveling the surface. A 60 to 90 cm layer of soil from the embankment material was then hand compacted on the prepared pressure cell site. After being placed, the cells were covered by another 7.5 to 10 cm layer of the same material, which was also hand compacted. A 15cm to 30 cm layer of selected material passing through a 2.0 cm sieve was then hand compacted over the site, followed by 60 to 90 cm layer of embankment material, compacted with a hand operated impact compactor. The lead wires from each pressure cell were encased in a flexible metal conduit passing from the cell through an opening in the culvert wall. The leads were then routed through a junction box and connected a cable raceway to a data collection point at the culvert crown.

4. Installation of pressure cells in virgin soil

In virgin soil the pressure cells are installed after a cavity is made in it or an opening drilled, and then the pit is backfilled with the removed soil with maintaining its physical features in situ in particular layers. In order to minimize the changes of the physical features of soil in the vicinity of the cell and to reduce the resulting erroneous readings, often departing from real stress values the applied techniques of installation of cells in virgin soil have been presented.

4.1 Pressure cell installation in virgin soil at an inconsiderable depth

To install the cells in a vertical and horizontal position at not a large depth, hand made pits of a diameter a little deeper than that of the pressure cell are used. The installation procedure by means of this method is illustrated in Fig. 9.

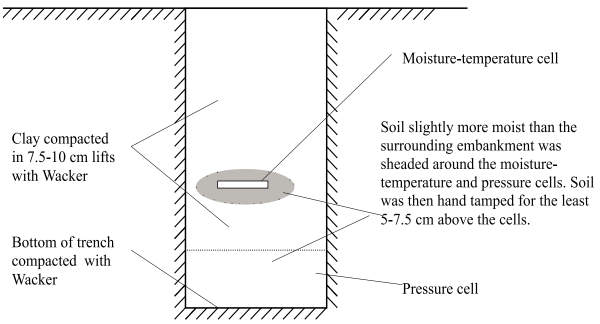


Fig. 9. Pressure cell installation detail in railway subgrade [6]

4.2 Pressure cell installation in virgin soil at a large depth

In the case of placing the pressure cells at the depth larger than 1.0 meter, the method of drilling an opening is used. Instances of the installation of pressure cells in bored holes have been presented in Fig. 10 and 11. In the former an opening 225 mm in diameter and 360 mm deep was bored first of all, above the foreseen location of the pressure cell center.

Soil from the borehole was placed in tight-closed plastic bags. To make a slot for placing the cells at a required depth, specially constructed instruments were used of their horizontal section the same as that of the cells.

Final leveling of the slot bottom was carried out by means of a half-round cutting tool of a radius equal to that of the pressure cell, a then the performed half-round surface was packed by means of a same shape disc, in order to make the cell not lie on loose ground. After the cell had been leveled, 1 l of epoxy resin was

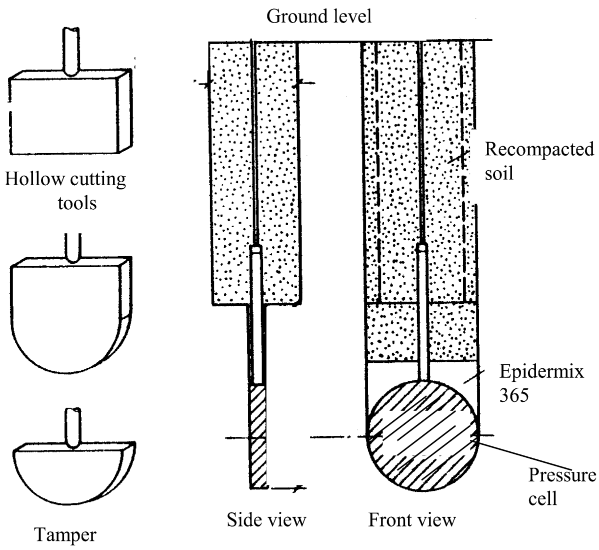


Fig 10. Procedure and tools to install gauges for horizontal pressure measurement in clay soil in situ [4]

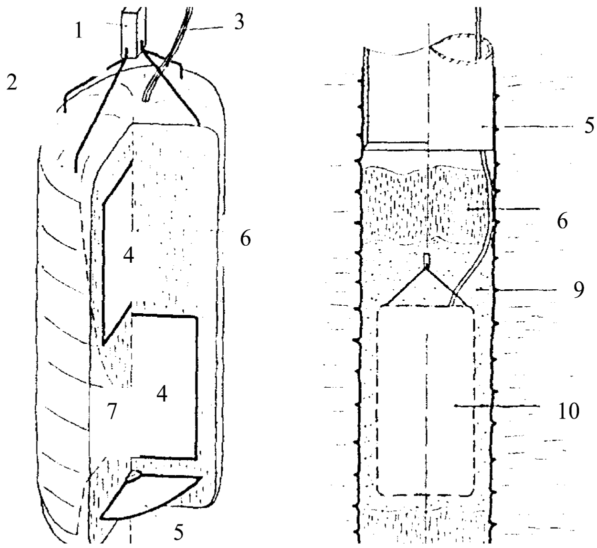


Fig 11. Installation of "Glotzl" cells in a borehole (Sauer and Sharma) [20]: a) cells oriented and fixed, covered with a clay cylinder, b) lowering of the cylinders in the borehole 1 - metal block, 2 - wire frame, 3 - connection pipe, 4,5 - pressure cells, 6 - clay, 7 - gauze, 8 - casing pipe, 9 - sand, 10 - clay cylinder with cells.

poured into the slot through a pipe. The amount of resin had been selected so that after the installation of the cell the slot should be filled approximately up to the level of 50 mm above the upper edge of the cell. The pressure cell was inserted into the slot by means of a rod ended with a grip matching the cell geometry. The next day the remaining part of the opening above the resin already solidified was filled up with soil of the properties possibly close to those in the untouched state. The inside of the pressure cells remained in the conditions of atmospheric pressure. In the case of a considerable sinking of the cells installed in boreholes, the method of so-called initial wrapping (prepacking) the cells up is used by Triandafilidis as well as by Sauer and Sharma [20] (Fig.11).

The installation takes place after the previous boring of holes at a required depth with the usage of steel protective pipes. The cells foreseen to be installed in a given place of the opening are fixed to a framework made from wire (Fig.11a), and then the pressure cells become wrapped up cylinder-shaped with virgin soil taken from the installation place and from the outside covered with gauze. These cylinders, 17.0 cm in diameter, with the pressure cells inside, were lowered down the pipe, filling their surroundings with sand, and above them – with virgin soil, i.e. in this case with clay. The method of initial packing ensures a minor scatter of measurement results. It can be applied as deep as 30 m [26].

5. Installation of pressure cells at the interface between soil an concrete

The measuring surface of the pressure cells applied to measure the pressure acting on the walls of such structures as tunnels, shafts, foundations and piles can in general find itself at an inconsiderable distance off the wall or strictly in the wall face. Soil pressure acting on the inwards withdrawn surface sensitive towards the structure wall face will be less than that resulting from the overlay weight and vice versa, a cell pushed forward outside the wall face will register a larger pressure than that resulting from the overlay weight. In order to obtain accurate pressure measurements the cells should be situated strictly in the boundary surface. In general the are two procedures of pressure cell installation in structure walls. The first is when there is a direct access to measuring surfaces of pressure cells i another one when there is no such access.

5.1. Installation of pressure cells with direct access to their measuring sensitive surfaces

Installation of pressure cells with direct access to their measuring surfaces is characterized by a relatively cheap and fast installation of the cells with a possibility of making the external surface corresponding to the wall structure (Fig.1a and 12 .). Figure 1a shows a typical pressure cell installation in reinforced concrete wall. The layers of epoxy and epoxy-mortar are kept as thin as possible, and the free surface is given a roughness comparable to that of the surrounding concrete even though the measuring signal from the cell is almost insensitive to deviations in roughness.

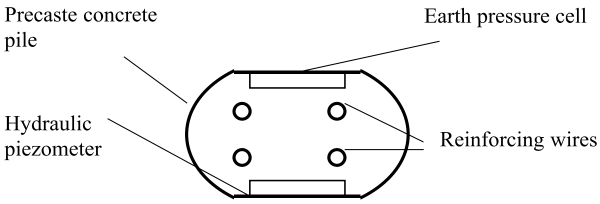


Fig 12. Instrumented cross-sections of a precast concrete pile (Gregersen et al.[8])

Figure 12 shows installation of cells in 8 m and 16 m long precast concrete piles driven into a very loose deposit of homogeneous sand [9]. The typical piles have a circular cross-section but the instrumented piles were specially made with flat surfaces on the opposite sides in order to install a row of vibrating-wire contact pressure cells and piezometers.

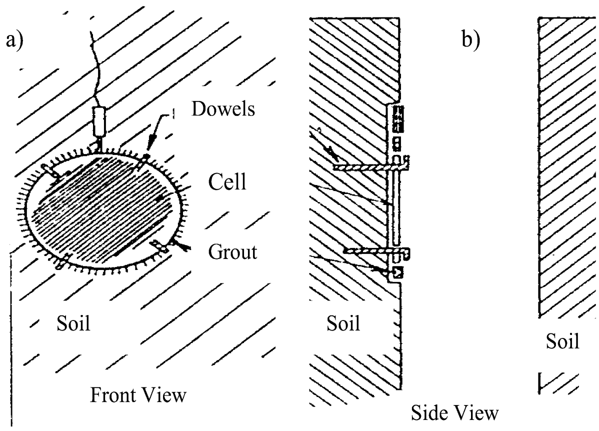


Fig 13. Determining of stress around drilled shaft (Wright et al. [28]): a) location of pressure cells on the shaft, b) installation method for pressure cells.

Figure 13 shows the installation method used in drilled shaft supporting underground structure [28], [17]. The cells were embedded in soil prior to placing the concrete. A cavity was cut in the side of the hole and the cell was placed against the soil. Dowel pins were used to hold the cell in place. Grout was packed around the periphery of the cell to prevent intrusion of concrete at the interface of the soil and of the back surface of the cell. A thermocouple was placed near each cell. Before the test shaft was installed, it was believed that some method of shoring the shaft excavation would be needed. The shoring was necessary due to the length of time required for the installation of pressure cells and because of the caving potential of the slickensided clay below 3.05m depth. Tying 6.10 m long boards to the outside of the reinforced cage shored the excavation. When placing cells adjacent to culverts, tunnels or other structures, the cells may be embedded in the backfill a short distance away from the structure (Fig. 14). The contact between the cell and the backfill material should be effected by means of a layer of fine-grained material as previously described.

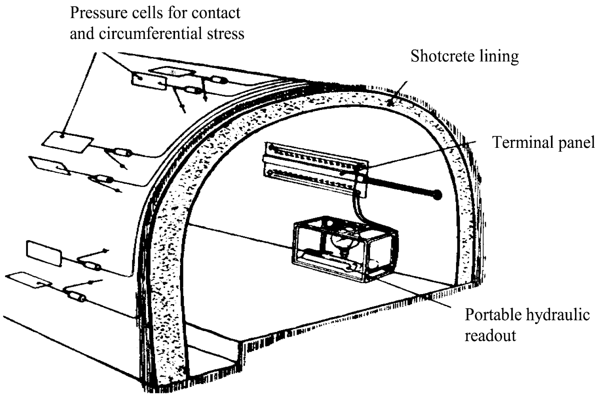


Fig 14. Installation of pressure cells in a tunnel lining [7]

5.2. Installation of pressure cells without direct access to their measuring surfaces

Pressure cell placement is more difficult, when there is no access to sensitive surface of the cells from the side of the surrounding ground. This kind of installation occurs e.g. when installed are the cells measuring the pressure acting on a conduit structure (Fig. 15) or the pressure acting on an excavated tunnel (Fig.16).

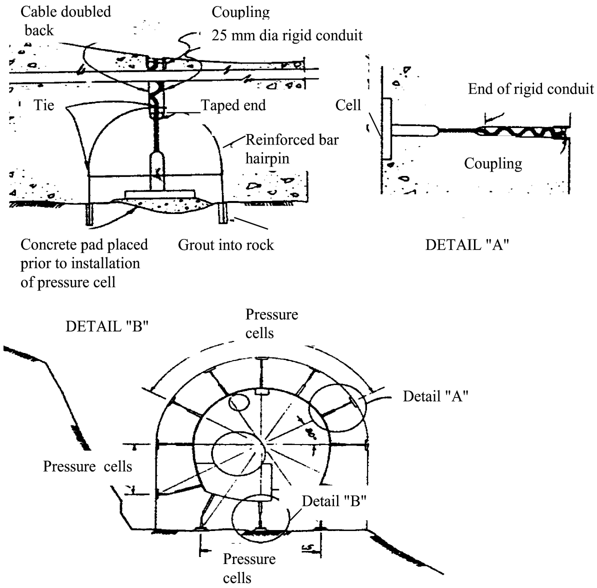


Fig 15. Pressure cells installation against the conduit foundation and outside conduit surface facing the embankment fill [16]

6. Conclusions

1. Cell placement plays an important role in cell response. The same soil pressure cells, placed in the same stress field do not necessarily have to record identical stresses.
2. Uniform placement technique is necessary to reduce the data scatter.
3. A stress measurement from a single cell should not be relied on as being representative of stress field.
4. An important factor affecting the accuracy of measurement of stresses within soil is the proximity of the structure and clearance distance between adjacent cells

Literatúra – References

[1] ABBOTT , P. A.: *Arching for vertically buried prismatic structures.* J. Soil Mech. Foundation Div. ASCE 93 SM 5, 233–255, 1967.
[2] ASKEGAARD, V.: *Design and application of stress and strain cells with small measuring errors,* NDT International, Oct. 1981, p. 271–277.
[3] AUDIBERT, J. M. E., TAVENAS, F. A.: *Discussion paper* [13] J. Geotech. Eng. Div. ASCE, vol. 101, No. GT7 July 1975 p. 705–707.
[4] BRACKLEY, I. J. A., SANDERS, P. J.: *In situ measurement of total natural horizontal stresses in an expansive clay,* Geotechnique 42, No. 2, pp 443–451.
[5] DIBIAGIO, E.: *Field instrumentation-a geotechnical tool*, NGI Publication No 115, Oslo, 1977.
[6] Embankment support for a railroad test track construction report, Shannon and Wilson, San Francisco 1972.
[7] FRANKLIN, J. A.: *Rock mechanics review.* The monitoring of structures in rock, Int. J. Rock Mech. Min. Sci. and Geomech. Abstr. 14, 1977, pp 163–192.
[8] GREGERSEN, O. S., AAS, G., DIBIAGIO, E.: *Load tests on friction piles in loose sand,* NGI Publication No. 99, Oslo, 1973.
[9] HADALA, P. F.: *The effect of placement method on the response of soil-stress gages,* Proc. of the Symp. on Wave Propagation and Dynamic Properties of Earth Materials, University of New Mexico, 1967
[10] JACKURA, K. A.: *Instruments for determining stress-displacements in soils,* California Department of Transportation, Rep. FHWA/CA/TL – 81/09, July 1981.
[11] KOBIELAK, S.: *Application of pressure cells in civil engineering,* Scientific Papers of the Institute of Building of Technical University of Wrocław. Mongraphs 1991
[12] KOBIELAK, S.: *Przyrządy i metodyka pomiaru materiałów rozdrobnionych w zbiornikach,* Prace Naukowe Instytut Budownictwa Politechniki Wrocławskiej, Monografie, Wrocław 1990.
[13] KRIZEK,R. J., FARZIN, M. H., WISSA, A. E. Z., MARTIN, R. T.: *Evaluation of stress cell performance,* J. Geotech Eng. Div. ASCE, Vol. 100 No GT 12, Dec. 1974, p. 1275–1295.

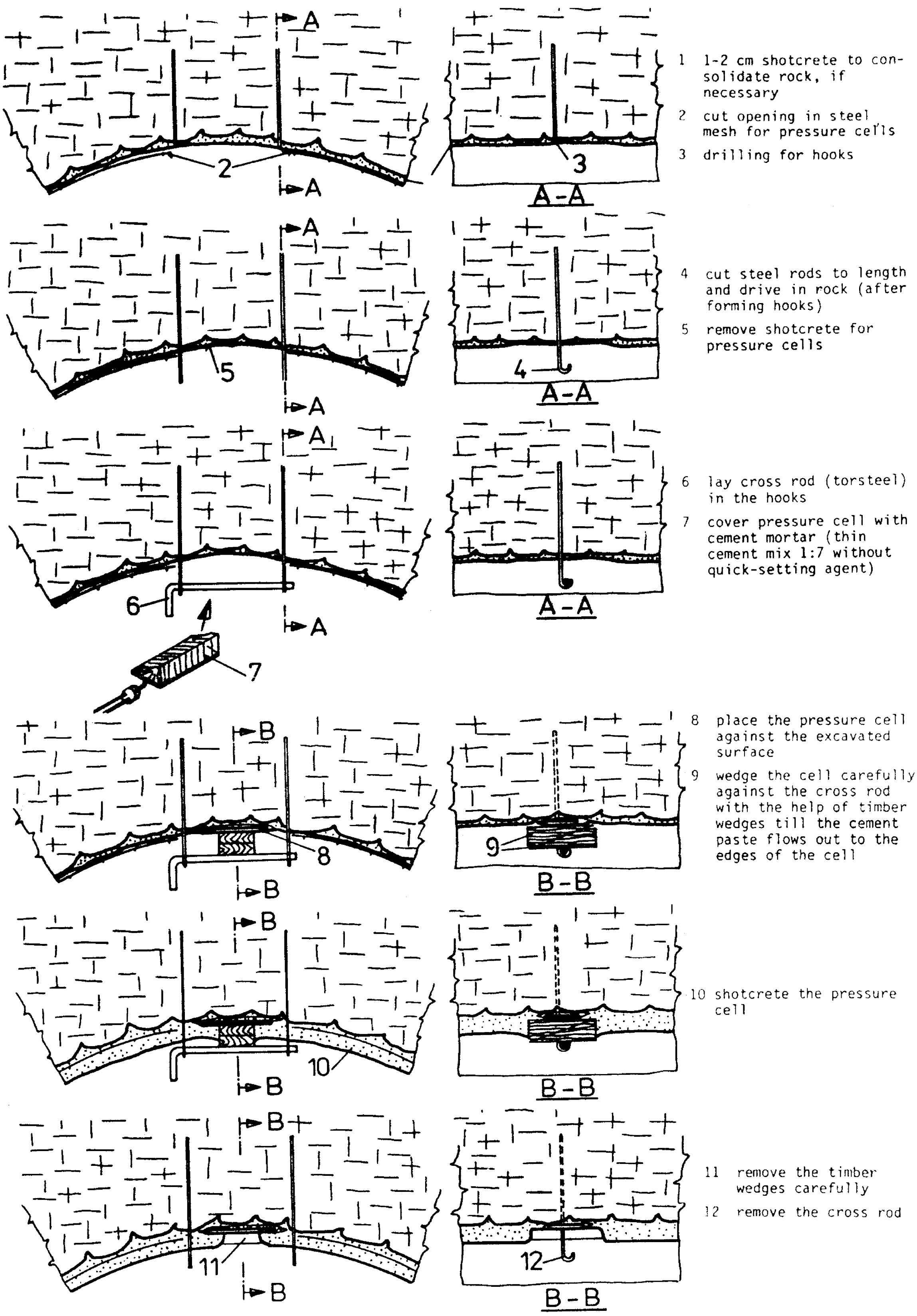
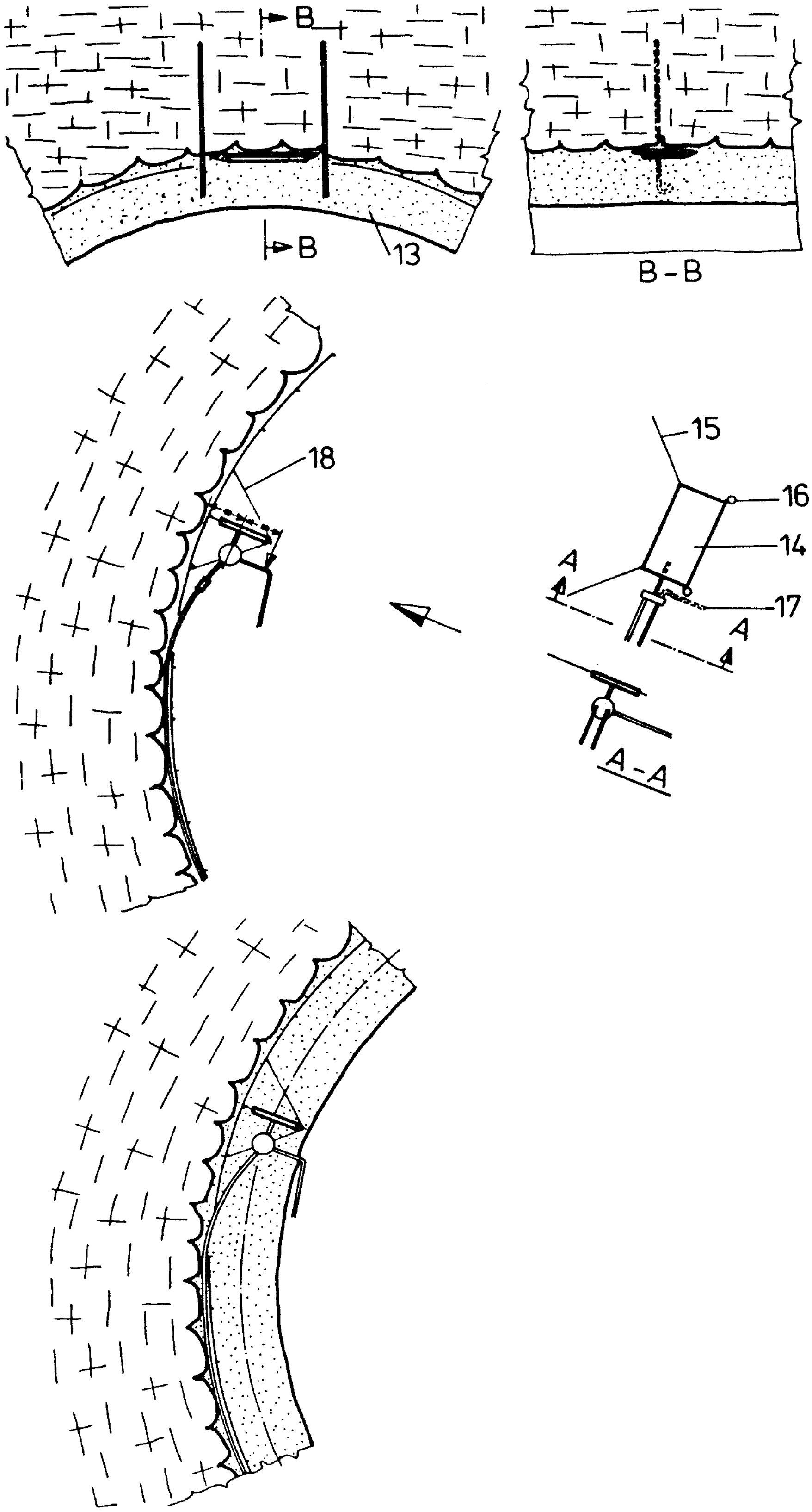


Fig. 16. (to be continued)



13 shotcrete around the pressure cell

14 tangential pressure cells

15 wire for fixing the cell and for controlling its position

16 fixing ring

17 repressurising tube

18 fix the pressure cell with steel mesh so well that it can not change its position during shotcreting

Fig. 16. Schema for installation of radial and tangential cells (Sauer and Sharma [20])

[14] LYNCH, R. E.: *Development of the University of New Mexico soil stress gage,* AF WL-TR-65-104, Kirtland Air Force Base, N. M., Aug., 1966.
[15] MONFORE ,G. E.: *An analysis of the stress distribution in and near stress gauges embedded in elastic solids,* Report SP 26 Washington: US Bureau of Reclamation, 1950.
[16] O'ROURKE, J. E.: *Soil stress measurement experiences,* J. Geotech Eng. ASCE Vol.104 No. GT 12, Dec. 1978 pp. 1501–1514.
[17] PENMAN, A. D. M., CHARLES, J. A.: *Deformations and stresses in rockfill over a rigid culvert*, Building Research Station, Rec. 1975.
[18] Raport on Racine Site, Design of field experiment Ill. Institute of Technology, Chicago, 1982.
[19] REIFF, C. M., LINGER, D. A.: *Investigation on buried domes-phase evaluation of instrumentation and preliminary tests,* Techn. Rep.AFWL-TR-67-110, Air Force Weapons Laboratory, Kirtland Air Force Base, N.M. 1967.
[20] SAUER, G. , SHARMA, B.: *A system for stress measurement in construction in rock,* Field Measurements in Rock Mechanics, Int. Symposium Zurich, 1977, pp 317–329.
[21] SCHOBER, W.: *Large scale application of Gloetzl type hydraulic stress cells at the Gepatsch Rockfill Dam Austria Baumesstechnik,* Spezial-Informationen uber baustatische Messungen, 1965.
[22] SMITH, T., NORDLIN E.: *Evaluation of commercial soil pressure cells,* State of California Highway Research Rep. No. M. and R. 636342, 1968.
[23] SMITH, T., SHIRLEY, E., FRAZIER, CH., BOSS, J. F.: *Field perfomance of soil pressure cells,* State of California, Department of Public Works, Interim Res. Rep. 638-954-1, May 1971.
[24] TAYLOR, D. W.: *Review of pressure distribution theories,* Earth pressure cell investigation, Rep. WES, 1947.
[25] TRIANDAFILIDIS, G. E., CALHOUN, D. E.: *Simulation of air blast-induced ground motion at Mc Cormick Ranch Test Site,* AFWL-TR-68-27, Vol.: Kirtland Air Force Base, N. M. 1970.
[26] TRIANDAFILIDIS, G.E.: *Soil-stress gage design and evaluation,* Journal of Testing and Evaluation, Vol. 2, No.3, May 1974 pp. 146–158
[27] WEILER, W. A., KULHAWY, F. H.: *Factors affecting stress cell measurements in soil,* J.Geotechn. Eng. Div. Proc. ASCE, Vol. 108, GT 12, Dec. 1982, p. 1529–1548.
[28] WRIGHT, W. V., COYLE, H. M., BARTOSKEWITZ, R. E., MILBERGER, L. J.: *New retaining wall design criteria based on lateral earth pressure measurements,* Res. Rep. No. 169–4F, Texas Transportation Institute, 1975.