Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam
Visakhapatnam Chapter

Development of Calibration Methodology for Earth Pressure Cells for Installation on Full Scale Retaining Wall

Dinesh Bishnoi[1], Mrunmay Junagade[2] and Dasaka S. Murthy[3]

[1]PhD. Student, Department of Civil Engineering, IIT Bombay, Powai, Mumbai-400076
[2]Research Assistant, Department of Civil Engineering, IIT Bombay, Powai, Mumbai-400076
[1]Professor, Department of Civil Engineering, IIT Bombay, Powai, Mumbai-400076
dinesh_bishnoi@iitb.ac.in, mrunmay.24@gmail.com,
dasaka@iitb.ac.in

Abstract. Earth pressure cells (EPC) are one of the crucial instruments in geotechnical field for obtaining soil pressure on various structures such as retaining walls, foundations etc. The most common and economical type of EPC are sensors which quantify the deflection of sensing diaphragms by means of strain gauges or hydraulic type connected to vibrating wire transducers. The present paper covers the literature related to various types of earth pressure cells and factors affecting their response. Calibration of EPCs is very important prior to its application and thus available calibration methods are discussed. The developments done in the area of EPCs is also covered and recommendations are suggested for better utilization of EPC to obtain reliable measurements.

Keywords: Earth pressure cell, Calibration, Soil.

1 Introduction

Earth pressures measurement and its reliability are the necessity for various geotechnical structures such as retaining wall, foundations, tunnels etc. These measurements are made to verify the design methodology adopted, for improving the present design methods and for monitoring of the structures. There are various types of earth pressure cells (EPCs) available to measure the earth pressure having different operating principles. Keykhosropur (2018) [8] mentioned the types of pressure cells, which are stiff pressure cells, tactile sensors and fiber optic sensors. Stiff pressure cells are further classified into two types i.e. force-balance type (hydraulic and pneumatic sensors) and diaphragm pressure cells (strain gage based or vibrating wire based).

There are various factors related to sensors which affects the response of EPCs. Hanon and Jackura (1985) [7] covered installation methods and monitoring experience for various types of sensors such as hydraulic, pneumatic, vibrating wire and electrical resistance type. The authors have cited various factors affecting the response of sensor and some of the important factors such as environmental effects, geometric shape and design, calibration and installation methods. Environmental effects and geometric factors cause incompliance of sensors with the surrounding and leads to under or over-registration of measurements. The effect of calibration is covered in subsequent section with more details.

The present study is focused on the stiff pressure cells and the various factors which needed to be considered for better understanding of the sensors. The present study is literature review covering sensor types and their modifications, calibration methods available and their performance.

2 Earth Pressure Cells (Epcs) and Factors Affecting Performance Measurement

There are various types of sensors available for earth pressure measurement but deflecting diaphragm and vibrating wire sensors are more common so mainly these will be covered. Diaphragm type sensors measures the deflection caused by the earth pressure in electrical outputs such as mV/V or in strains and through sensitivity plots the earth pressure is found out. The deflection causes redistribution of stresses around the sensor and arching may develop depending on the amount of deflection which leads to erroneous measurement. They are suitable for static as well as dynamic measurement but their suitability for long-term monitoring is doubtful [4]. The vibrating wire sensors works by measuring the frequency of vibration of a prestressed wire which changes its length and thus frequency of vibration when subjected to pressure. The vibrating wire is suitable for static measurements and its performance in long term is verified [4].

The EPCs response is affected by the presence of soil and several researchers studied various factors which affects its performance. Coyle (1974) [3] used Terratec pneumatic and Geonor vibrating wire sensor to measure earth pressure behind retaining wall in order to develop more economical design. The effect of grouting and temperature was studied, the grout did not affect the readings but there was shift in zero-gauge readings with increase in temperature. Felio and bauer [5] used pneumatic EPCs and studied the effect of temperature, contacting material and installation method. It is neccesary to monitor the temperature as it has predominant role in earth pressure measurements and needs to be calibrated for determining correction factors. The effect of contacting material and installation method was not much significant. Clayton and bica [2] studied the effect of various soil conditions on diaphragm type EPC. They defined a term CAF (cell action factor) to quantify the measurement error, which is defined as the ratio of normal stress measured by EPC and the stress that would be applied in the absence of cell. The CAF depends on the flexibility ratio, F which is defined in equation 1. The value of CAF should be close to 1, it is found that flexibility ratio should be less than 0.25 if the CAF is to be greater than 0.95. The ratio of the diameter of the cell diaphragm to the displacement at its center is not less than some threshold value which varies from 1000 to 10000 to access the performance of cells. It is emphasized that while determining the above, the modulus of soil should be considered especially for dense sands.

$$F=(E_{soil} \times R^3)/(E_{cell} \times t^3) \qquad (1)$$

where E_{soil}, E_{cell} is Youngs modulus of soil and diaphragm respectively, R and t is radius and thickness of diaphragm.

It is found out that the EPCs should be calibrated for the actual field conditions and it is not always necessary that the contacting material will be soil. The trend of using geosynthetics is increasing such as in drainage, base separation etc. and the sensors should be calibrated accordingly. Gade and Dasaka [6] used diaphragm based EPCs of different make and studied the effect of grade III sand and geofoam as contact material. Effect of sand thickness, geofoam thickness, geofoam density and rate of loading was studied. It was found that EPC response depends on the stress-strain behaviour of contacting material and in case of geofoam, the output of EPC resembles the stress-strain behaviour of geofoam as shown in Fig. 1. The effect of displacement rate is insignificant for both soil and geofoam. The EPC response of geofoam is higher than the sand and the effect of geofoam thickness is not significant.

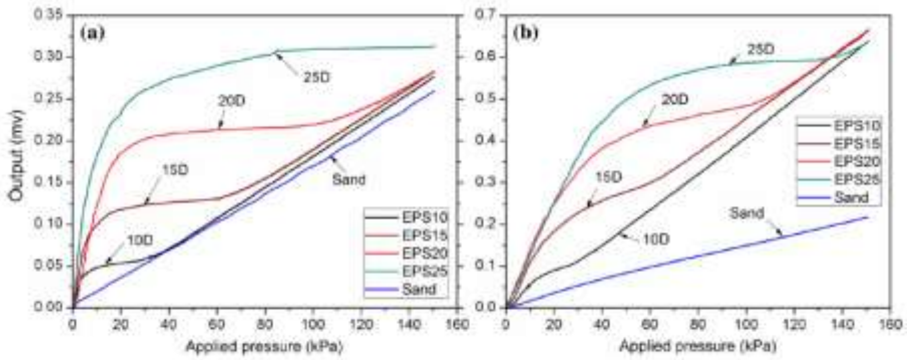

Fig. 1. Response from two different EPCs ((a) KEPC and (b) REPC) makes for geofoam with different densities and sand in contact with the sensor. (Gade and Dasaka [6])

3 Calibration of EPCs

EPCs output is generated in electrical units such as mV/V, strains or in frequency i.e. Hz, these outputs are correlated with the pressure known as sensitivity plots or calibration plots. Each EPCs is generally provided with calibration charts from the manufacturer but the calibration is generally done in fluid or air pressure, which may not give accurate results for soil. There are two types of calibration which are fluid calibration and soil calibration. Fluid calibration is generally done in laboratory also to check the response of EPCs to uniform loading and to verify the calibration charts provided by manufacturers. It is essential to calibrate the sensor as close to field conditions as possible for reliable results thus soil calibration is required. Researchers developed various calibration chamber to perform soil calibration as it depends on numerous parameters such as side wall friction, effect of particles, installation type etc. Selig [10] described an easy to construct and inexpensive calibration chamber which consists of 17 layers of different material and thickness. Pneumatic type and diaphragm type EPCs were used, which were then calibrated with fluid, soil as well as with concrete interface conditions. For pneumatic type over-register, small amount of hysteresis and non-linearity was observed and for electrical type, under registration, significant hysteresis and non-linearity. It was found that the accuracy of the results is a function of the gage, the installation procedures, the soil properties, and the state of stress. Take and Valsangar [11] used miniature diaphragm type sensor (6.35 to 7.37mm) for centrifuge testing and thus they did fluid calibration, soil calibration at 1g and 38g for loose and dense sand. Three types of cells were used, one is rigid and 2 flexibles. For rigid cells high capacity sensors were used to accommodate scale effects. They found that the stiff subminiature cells can be used successfully to measure earth pressure in centrifuge tests. When flexible sensors are to be used, it is important to calibrate them with soil having stiffness similar to the adjacent zone of cells rather than bulk stiffness.

Uniaxial calibration chamber (Fig. 2.) and universal calibration chamber (Fig. 3.) are two types of calibration chambers which is used by various researchers for calibration of EPCs ([1], [9], [15], [16]). Theroux et al. [15] performed uniaxial calibration tests on Kulite diaphragm type EPCs with silica sand and proposed sand pocket method. A sand pocket container method is for measuring the soil pressure in the field mainly for vertical pressure. The suitability of the sand pocket container was checked in laboratory with universal calibration chamber under static and rapid loading. Field suitability was also checked for pavement under static loading and loads caused by moving trucks.

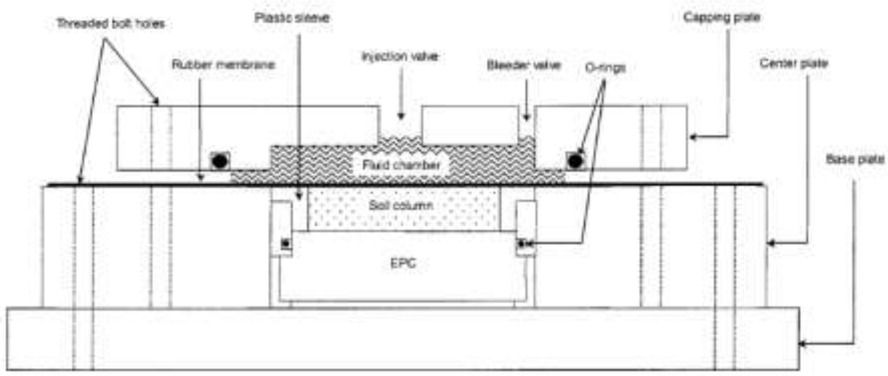

Fig. 2. Uniaxial calibration device (Theroux et al. [15])

Wachman and labuz [16] used hydraulic type sensor having diameter of 117 mm and performed fluid calibration as well as soil calibration in universal calibration chamber. Calibration procedure for an EPC is reviewed and soil-structure interaction model is proposed to understand why soil calibration is necessary. The EPCs were found to over-register by 15-18%. A soil-structure interaction analytical model was developed, and it is found that when the load is distributed over 56% of EPC area, the over-registration can be 10-20% as observed during calibration of EPCs. It is also mentioned that change in soil density can change contact stress distribution even though the total load remains same. The EPCs may also under-register depending on the distribution of stresses.

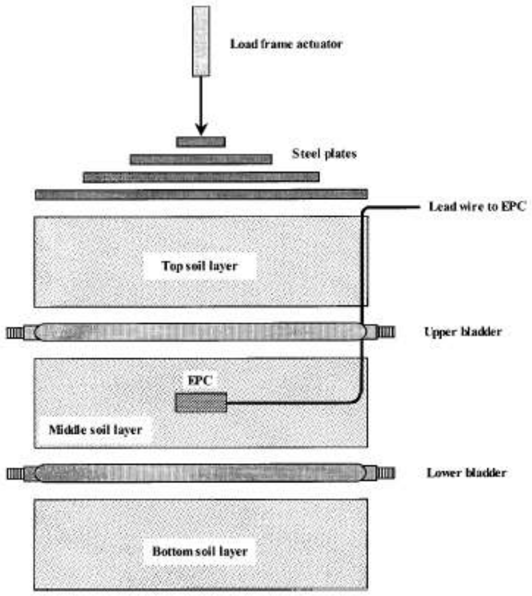

Fig. 3. Universal calibration chamber (Theroux et al. [15])

4 Development in EPCs

The researchers are coming up with different techniques to improve the performance of the EPCs so that reliable measurements can be made. Traditional EPCs are affected by numerous factors such as material compliance, stress history, contacting material and its size, temperature etc. Few researchers used the diaphragm type sensors with hydraulic layer, this system enhances the resolution of sensor as small variations can be detected easily. Bentler et al. [1] used Kulite diaphragm type EPCs with small fluid chamber under the active face and Geokon hydraulic pressure cells with strain gage transducers to measure soil pressure behind a cantilever retaining wall for a period of 12 months. The study was carried out to better understand the design process and decrease the cost of construction. Kulite EPCs soil calibration under-registered by up to 25% when compared with the manufacturers calibration factor. The uniaxial calibration factors predicted the stress in the soil to within 5% of the applied stress when checked in the universal chamber. Geokon under-registered by 5-15% mainly because the manufacturers calibration is for transducer and not for whole device. The reading from Geokon EPCs were loweer in magnitude than the kulite EPCs caused due to hardware problem with the multiplexer. Labuz and Theroux [9] used diaphragm type with semi-conductor strain gage and a hydraulic oil film and performed fluid calibration (all arounnd, uniaxial on active face only and radial loading around the perimeter) as well as uniaxial calibration and universal calibration for sand. For rigid outer rim, sensitivities computed from soil calibration were 20% lower than the fluid calibration. For fluid calibration, the values agreed well with the manufacturer's value. Arching analysis was also done to understand the behaviour of EPC used.

Talesnick [12] proposed a new sensor called as null soil pressure system in which calibration is not required and the pressure can be measured directly for embedded type. Four types of soil covering mean particle size from 0.2mm to 14 mm were used. Three sizes of null sensor were used to check the effect of sensor size on measurement. The response of the null-sensor is not affected by particle sze, stress history and mildly affected by soil stiffness with inherent linear response. The cells over-registered by 3-4%. The purpose of 3 different sensor size was to study the effect of particle size by sensor diameter and it is found that the ratio should not exceed 1:7 for null sensors. Talesnick [13] also used null pressure sensor for soil-structure physical models. The null sensor response is compared with diaphragm type sensor of different thickness for a range of particle sizes. The usage of null sensors in loading conditions involving shear loading is also checked. The response of diaphragm type sensor is different for different size of particles, but the null pressure sensor is not affected by the particle size. It is found that the particle size to sensing diameter can be as small as six particles across the sensor diameter for reliable results and this can be used for physical/centrifuge model testing. The presence of shear stresses does not impede the reliable measurement of normal stresses by null sensors. Drawbacks of null sensor are that the system requires significant peripheral equipment and is more complex, expensive than passive system. The system is difficult to employ in field conditions [14].

Keykhosropur et al. [8] designed a simple, robust and cost-effective new sensor with large sensing area and homemade assembly for measurement of soil pressure on solid surface. Static calibration with weights and dynamic calibration using linear mass shaker were performed. The sensor is suitable for soils with relatively uniform gradation. The suitability of the sensor is checked in field testing for earth pressure on abutment wall, dynamic shallow foundation footing pressure and vertical underground structure during shake table testing. The sensor is versatile in the sense that the housing material can be changed to account the compliance issue and capacity can be changed as per our requirement. The sensing area has a benefit of reducing localization effects.

Talesnick et al. [14**]** developed a sensor which is combination of deflecting diaphragm and fluid filled soil pressure sensor. The new system was implemented in compacted engineered fill of 1.8m height. The importance of design is to minimize membrane deflection without limiting the resolution of cell. The soil arching does not develop which was shown by lack of hyteresis in load-unload cycle and the system inherently deals with temperature effects. In field, the cells were able to perform satisfactorily for static and dynamic (11Hz) loading caused due to compaction of fill.

5 Conclusions and Recommendations

For achieving optimized design, it is essential to measure earth pressures in retaining walls, underground structures etc. using EPC. In this paper literature related to earth pressure cells (EPCs), factors affecting EPCs, calibration methods and the development in EPCs is covered. It is found that the response of sensor depends on large number of factors which may cause under-registration or over-registration in the measurements caused due to incompliance in the sensor materials with the surrounding. The fluid calibration chart supplied by the manufacturer is not enough and proper calibration should be done considering the intended use, installation method and surrounding soil conditions. Though various improvements in EPCs is done, the use of traditional EPCs is more due to its large user experience and availability of performance record.

Theroux et al. [15] recommended to use sand pocket methods, so that the arrangement around sensor remains same and the laboratory curves can be used effectively. It is also recommended by Hanon and Jackura [7] that sometimes users may have to settle for reliable results instead of accurate results irrespective of the type of EPCs and users may be required to rely on alternative measurement system to backup estimate field pressures if feasible.

Acknowledgements

Authors thanks the financial support received from MHRD (UAY scheme), SAVI Infrastructure Limited and IIT Bombay.

References

1. Bentler, J. G., Labuz, J. F., Schultz, A. E.: Earth pressure behind a retaining wall. Report no. 2005-14, Minnesoa Department of Transportation, Minnesota (2005)
2. Clayton, C. R. I. and Bica, A. V. D.: The design of diaphragm-type boundary total stress cells. Geotechnique 43, No. 4, 523-535 (1993).
3. Coyle, H. M., Bartoskewitz, R. E., Milberger, L. J., and Butler, H. D.: Field measurements of lateral earth pressures on a cantilever retaining wall. Transportation Research Record no. 517, 16-29 (1974).
4. Dunnicliff, J.: Geotechnical instrumentation for monitoring filed performance. NCHRP Synthesis 89, Transportation Research Board, Washington, D. C. (1982).
5. Felio, G. Y. and Bauer, G. E.: Factors affecting the performance of a pneumatic earth pressure cell. Geotechnical Testing Journal, GTIODJ, Vol. 9, No.2, 102-106 (1986).
6. Gade, V. K. and Dasaka, S. M.: Influence of contacting material on calibration response of diaphragm earth pressure cells. Indian Geotech Journal 50 (1),133-141 (2020).
7. Hanon, J. B. and Jackura, K. A.: Measurement of earth pressure. Transportation Research Record 1004, 6-13 (1985).

8. Keykhosropour, L., Lemnitzer, A., Star, L., Marinucci, A., and Keowan, S.:Implementation of soil pressure sensors in large-scale soil-structure interaction studies. Geotechnical Testing Journal, Vol. 41, 730-746 (2018).
9. Labuz, J. F. and Theroux, B.: Laboratory calibration of earth pressure cells. Geotechnical Testing Journal, Vol. 28, No. 2, 188-196 (2005).
10. Selig, E. T.: Soil stress gage calibration. Geotechnical Testing Journal. GTJODJ, Vol. 3, No. 4, 153-158 (1982).
11. Take, W. A. and Valsangkar, A. J.: Earth pressures on unyielding retaining walls of narrow backfill width. Canadian Geotechnical Journal 38, 1220-1230 (2001).
12. Talesnick, M.: Measuring soil pressure within a soil mass. Canadian Geotechnical Journal 50, 716-722 (2013).
13. Talesnick, M. L., Avraham, R. and Ringel, M.: Measurement of contact soil pressure in physical modelling of soil-structure interaction. International Journal of Physical Modelling in Geotechnics, Vol. 14 (1), 3-12 (2014).
14. Talesnick, M., Ringel, M., and Rollins, K.: Development of hybrid soil pressure sensor and its application to soil compaction. Canadian Geotechnical Journal, manuscript (2020).
15. Theroux, B., Labuz, J. F. and Dai, S.: Field installation of an Earth Pressure Cell. Transportation Research Record 1772, Paper no. 01-3356, 12-19 (2001).
16. Wachman, G. S. and Labuz, J. F.: Soil-structure interaction of an Earth Pressure Cell. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 137, No. 9, 843-845 (2011).