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A New Earth Pressure Cell

Nouvelle cellule de mesure de la pression des terres

by P. H. D. S. Wikramaratna, Lecturer, Department of Civil Engineering, University of Ceylon, Colombo, Ceylon

Summary

The cell, 2 in. diameter, is of the stiff elastic diaphragm type with a diameter-deflection ratio of 10 000 and measures steady earth pressure up to 1 lb. per sq. in. exerted on laboratory scale structures. The pressure acting on the cell is inferred from measurements of the central deflexion of 0-200 micro-in., using the pneumatic gauging technique with a magnification of 35 000. Despite this high magnification, the cell and the indicating equipment are robust, inexpensive and easy to maintain.

The calibration of the cell loaded with uniform fluid pressure was taken as standard. The cell when loaded with sand, carefully deposited in horizontal layers above the cell, gave readings between 95 and 105 per cent of the estimated earth pressure.

The author gives methods for overcoming difficulties arising from zero drift due to deposits of sub-micron size particles carried by the air used in the pneumatic gauging circuit, variation of the deflection due to ambient temperature variations and variation of calibration due to method of fixing the cell to the structure.

A project for using the technique for the measurement of pressure within a mass of soil is outlined.

The problem was to design an earth pressure cell suitable for fixing flush with the surface of laboratory-scale structures to measure steady earth pressure up to 1 lb. per sq. in. (70 g/cm²).

KALLSTENIUS and BERGAU (1956) demonstrated the importance of having a continuous curve for the deformation of the cell cover and maintaining a minimum displacement at the edge of the cell relative to the structure. Moreover, they showed the desirability of having a cell diameter-deflection ratio of 10 000 which is ten times the value recommended by the U.S. WATERWAYS EXPERIMENT STATION (1944).

It was therefore decided to use a 2 in. diameter cell of the stiff elastic diaphragm type and to infer the load from the accurate measurement of the deflection of approximately 200 micro-inches.

In two successful laboratory cells, 2 in. and 1 in. diameter, ROWE (1951) as well as TROLLOPE and LEE (1957) used electromagnetic methods to measure diaphragm deflections of 0-002 in. and 0-001 in. respectively. The necessity for a large number of cells of low first cost and robust enough for use under humid tropical conditions finally led to the use of the pneumatic gauging technique for measuring diaphragm deflections.

Principle of pneumatic gauging

Air maintained at a constant gauge pressure $P$ flows in a pipe of large bore fitted with two orifices in series, first the control orifice $C$ of flow area $A_c$ and then the measuring orifice $M$ of flow area $A_m$ open to the atmosphere (Fig. 1).

Considering a low pressure system the gauge pressure $p$ occurring between the orifices is given by

Fig. 1 Principle of Pneumatic Gauging: the curve illustrates only the basic theoretical relationships.

Elément de jauge pneumatique. La courbe démontre seulement la base des relations théoriques.
if density variations and pipe friction losses are neglected.

This result is shown plotted in Fig. 1 alongside the liquid column manometers. Experimental curves are found to be similar and in the range $0.6 < (p/P) < 0.8$ the curve is approximately linear.

In the cell $A_m = \pi dh$, where $h$ is the clearance between the diaphragm and the measuring head having an orifice diameter $d$ ($h < 0.1d$). Hence, if pneumatic circuit dimensions are suitably chosen, $p$ can be made to vary approximately linearly with cell deflections.

The French firm of Solex developed the practical application of pneumatic gauging in Industry. The analysis given above is due to Evans (1957 et 1958) who also described empirical methods for design based on work at the National Physical Laboratory. Teddington.

**Description of the cell**

The cell is machined from brass and consists essentially of a diaphragm $A$, 0.040 in. thick, soldered along its rim to the body $B$, 0.25 in. thick. Screwed into the body $B$ and locked in position by screw $E$ is the measuring head $M$ (Fig. 2).

![Fig. 2 Sectional view of the earth pressure cell, mounted ready to measure the pressure on the structure $G$.](image)

Coupe d'une cellule montée, mesurant des pressions de terre, prête à mesurer la pression de l'ouvrage $G$. $A$, diaphragme ; $B$, corps ; $E$, écrou pour fermer $M$ ; $F$, un des trois clous servant à monter la cellule ; $M$, tête de mesure ; $C$, orifice de contrôle.

Clean, partially dried air is fed into a manifold after flowing past the dip-tube bubble-tank combination which acts as a sensitive pressure regulator to maintain a working pressure of 1000 mm water gauge. The air flows from the manifold to the measuring head $M$ through a 1/4 in. bore P.V.C. tube in which is fitted the control orifice $C$. The pressure $p$ in the pipe between $C$ and $M$ is read on the vertical manometer tube $T$ connected to the reservoir $R$.

Each pneumatic circuit uses less than 0.02 cub. ft. per min. ($0.011/s$) of free air and therefore each cell can be provided with an independent circuit, with obvious advantage. All the manometer tubes $T$ as well as $S_0$ and $S_p$ are mounted on a fixed panel.

The procedure adopted in adjusting the circuit and taking readings is:—

(i) Adjust the level in the reservoir $R$ to bring $S_0$ to zero,

(ii) Adjust the depth of immersion of the dip-tube to bring $S_p$ always to the 1000 mm mark,

(iii) Read $p$ (cell reading) on mm scale fixed alongside the vertical tube $T$.

**Calibration**

Using a micrometer screw as the standard, the pneumatic magnification of the actual circuit was found to be about 35000; the exact value is immaterial.

The cell was next mounted flush with the surface of the heavy steel plate (Fig. 2) and after connecting $M$ to the circuit, $M$ was screwed into $B$ and locked in position to give a cell reading of about 600 mm at zero load.

The rotation of the cell from the horizontal to the vertical position gave a variation of 1.5 mm in the cell reading, only the weight of the diaphragm being responsible. The force exerted by the air jet on the diaphragm is almost constant and less than 0.006 lb. (3 g).

The steel plate, with the cell fixed in place, was bedded in plaster of Paris so as to be flush with the cement rendered brick floor of the laboratory. Using air pressure provided by bellows and measured by a U-tube containing water a uniform load was applied over the upper surface of the cell and plate. The resulting calibration curve (Fig. 4) showing cell reading $(p\text{ mm})$ against load $(g/cm^2)$, is almost linear.
Loading with sand:

Two methods were employed to attain the ideal of repeatable uniform vertical loading of the cell using dry graded coarse sand from the Kelani River.

In the first method, a large heap of sand was built up carefully in horizontal layers on the laboratory floor with the sides sloping at the angle of repose and the upper surface 6 ft. square, struck off level guided by an adjustable frame carried by four vertical slotted angles fitted to the laboratory walls 12.5 ft. apart. An independent scaffolding was used for access so that the heap was not disturbed.

In the second method sand was deposited in horizontal layers within a wooden bin 3 ft. square built up of sections 1.5 in. high at a time. This was similar to the method used by TROLLOPE (1957) but no plastic film was used here to separate the layers and every care was taken to avoid any shock or vibration capable of disturbing the bin and its contents.

In Fig. 5 and 6 are shown the calibration curves using sand in the heap and in the bin respectively. In each case the pressure inferred from the observed cell reading, using curve in Fig. 4, is plotted against the pressure which would be exerted on the cell assuming the sand to behave as a liquid of bulk density 1.48 g/cm³.

The density was obtained by weighing the bin placed on a large platform weighing machine and filled in exactly the same manner as in the calibration of the cell. The density is correct to ± 2 per cent for the filling of the bin and probably with a wider variation for the heap.

Zero Drift :

An erratic drift was noticed during preliminary tests due to changes of \( A_m \) caused by deposits of minute particles of oil, soot, and other impurities, carried by the air. A filter containing suitable filter paper placed upstream of the dip-tube...
removed the offending particles and eliminated the zero drift. This appears to be simpler than using a filter between C and M in each circuit, as suggested by Leiris (1938).

Variation of ambient conditions:

Reasonable changes of atmospheric temperature and pressure should cause neither zero drift nor changes of magnification of the pneumatic circuit (Evans). However, cell deformations will occur from differential expansion (between cell and structure and any temperature gradients across the cell despite identical thermal expansion coefficient of both body and diaphragm. At no load, cell readings changed by \( \pm 2 \text{ mm} \) with ambient temperature variations of \( \pm 5^\circ\text{F} \) \((3^\circ\text{C})\).

During extended use of a cell in the laboratory, suitable simple corrections can be made to allow for large temperature variations.

Conclusions

When the cell is loaded with fluid pressure the cell readings can be repeated to a tolerance of \( \pm 2 \text{ mm} \) when temperature variations are within \( \pm 5^\circ\text{F} \); hence, the load may be inferred correct to \( \pm 0.8 \text{ g/cm}^2 \).

When the cell is loaded with sand, the earth pressure inferred from the cell reading differed by approximately \( \pm 5 \text{ per cent} \) from the value estimated by using the depth and the bulk density of the sand. Only a few observations with larger errors were noticed. These errors produced mainly by arching of the sand are of the same order as the variation of the bulk density of the sand as deposited. The cell errors indicated by calibrations carried out so far appear to be smaller than those reported for other types of cells.

The performance of the cell has been so satisfactory, that the principle of pneumatic gauging is being used for two additional earth pressure cells now being developed by the author.

The first is a modification of the cell described, adapted for the measurement of pressure exerted on the curved surface of a structure. The load is collected by a rigid piston matching the contour of the structure and transmitted to a boss at the centre of the flexible diaphragm.

The second is a cell suitable for use within a soil mass. This cell has an external diameter of 4 in. and is 1/2 in. thick with a pressure responsive area of only 2 in. diameter as recommended by Peattie and Sparrow (1955). The deflection of about 400 micro-inches will be measured by pneumatic gauging.

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