Development of a Seven-Face Earth Pressure Gauge

Jauge à sept faces de mesure des contraintes dans le sol

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Summary

The authors describe the development of a seven face earth pressure gauge. This is so designed that the components of stress can be easily calculated, and so that measured values can be checked. After laboratory tests confirmed its utility, two gauges were buried in an earth dam at Hokkaido.

Sommaire

On a construit une jauge à sept faces pour mesurer l'état des contraintes (tenseur) dans le sol. La jauge a été dessinée de telle façon que les composantes soient facilement calculées et, de plus, qu'elles soient elles-mêmes mesurées. Son utilité ayant été confirmée au laboratoire, deux exemplaires ont été mis en place dans un barrage en terre en Hokkaido.

Description of the Earth pressure Gauge

In the summer of 1957, the authors constructed a three-face earth pressure gauge which gave a 60 to 100 per cent concentration of stress when tested with sand in a laboratory [1]. The pressure cells were attached to the three faces along the side of a regular triangular prism, each cell on each face, being solid, hard, and heavy. Experience gave much information about the reduction of stress concentration in the design of a new gauge.

The new multi-face earth pressure gauge was constructed in the spring of 1959 for the measurement of the three-dimensional state of stress in the Aoyama earth dam at Hokkaido. In order to reduce concentration of stress, the pressure cells were made as thin as possible, and they were attached to frames of mild steel so that they could be regarded as isolated from each other (Fig. 1).

Fig. 1 Seven-face earth pressure gauge.
Jauge à sept faces de mesure des contraintes.

The frames were connected to form a 14-face solid, and pressure cells were fixed on seven faces not mutually parallel. The 14-face solid was produced from a cube and the pressure cells are thin cylinders; they are rigidly connected to the submits of the 14-face solid. The diameter of the pressure plate contained in a pressure cell is 50 mm and the edges of the frame are each 30 cm long (Fig. 1).

Earth pressure is measured by means of magnetostriction transducers, a compensation magnetostriction tube being contained in each pressure cell.

The water pressure is mechanically cancelled in order to facilitate checking of stress concentration. Water pressure on the pressure plate is transmitted through a porous stone behind the pressure cell into bellows, and raises the pressure of oil behind the pressure plate, pressing the plate in the reverse direction with an equal pressure.

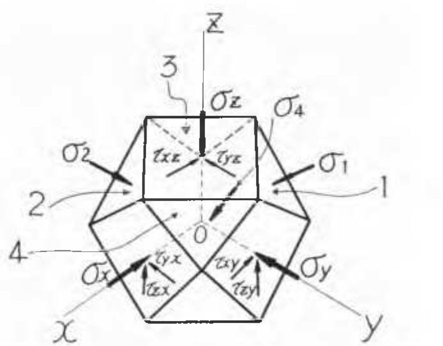

Fig. 2 Notations of planes and σ's of the seven-face earth-pressure gauge.
Notation des plans et de leurs σ de la jauge à sept faces.

Principles for Measurement

According to the analysis of stress, the normal stress, σ, on a plane of which the normal has direction cosines, l, m, n respectively to x, y, z axis is

$$\sigma = l^2\sigma_x + m^2\sigma_y + n^2\sigma_z + 2lm\tau_{xy} + 2mn\tau_{yz} + 2nl\tau_{zx} \quad \ldots\ (1)$$

Since a set of parallel two planes gives the same σ, seven faces of the fourteen which are not mutually parallel are used for the measurement, that is, faces x, y, z which are square, and 1, 2, 3, 4 which are triangular. Normal stresses on these faces will be represented by σ_x, σ_y, σ_z, σ_1, σ_2,σ_3, and σ_4, respectively. Direction cosines of normals of these seven faces are listed in Table 1.

Table 1

Direction cosines of normals of seven faces.

Faces	x	y	z	1	2	3	4
l	1	0	0	$-1/\sqrt{3}$	$1/\sqrt{3}$	$1/\sqrt{3}$	$1/\sqrt{3}$
m	0	1	0	$1/\sqrt{3}$	$-1/\sqrt{3}$	$1/\sqrt{3}$	$1/\sqrt{3}$
n	0	0	1	$1/\sqrt{3}$	$1/\sqrt{3}$	$-1/\sqrt{3}$	$1/\sqrt{3}$

Thus σ_1, σ_2, σ_3 and σ_4 are formulated :

$$\left.\begin{aligned}
\sigma_1 &= \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z - 2\tau_{xy} + 2\tau_{yz} - 2\tau_{zx}),\\
\sigma_2 &= \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z - 2\tau_{xy} - 2\tau_{yz} + 2\tau_{zx}),\\
\sigma_3 &= \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z + 2\tau_{xy} - 2\tau_{yz} - 2\tau_{zx}),\\
\sigma_4 &= \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z + 2\tau_{xy} + 2\tau_{yz} + 2\tau_{zx}).
\end{aligned}\right\} \quad \ldots\ldots (2)$$

Adding all the equations in (2), we have

$$\frac{1}{4}(\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4) = \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z). \quad \ldots\ldots (3)$$

Therefore, seven σ's are not mutually independent, but must satisfy formula (3). This gives a measurement check, which is one of the merits of this gauge.

After the adjustment of data by the use of (3), τ_{xy}, τ_{yz}, and τ_{zx} will be calculated by

$$\left.\begin{aligned}
\tau_{xy} &= \frac{3}{4}(2\bar{\sigma} - \sigma_1 - \sigma_2),\\
\tau_{yz} &= \frac{3}{4}(2\bar{\sigma} - \sigma_2 - \sigma_3),\\
\tau_{zx} &= \frac{3}{4}(2\bar{\sigma} - \sigma_3 - \sigma_1),
\end{aligned}\right\} \quad \ldots\ldots (4)$$

where

$$\bar{\sigma} = \frac{1}{4}(\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4) = \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z).$$

Formulae in (4) are obtained by solving (2) simultaneously on the condition of (3). Other components σ_x, σ_y and σ_z are obtained directly from measurement. Calculation is therefore simple, another merit of this gauge.

Laboratory tests

Tests in the laboratory were performed with an equipment described by PLANTEMA [2]. Inside this equipment is a thin rubber cylinder, which in the authors' case is 90 cm in diameter and 60 cm in height enclosing a cylindrical sample of soil [3]. When uniform pressure is applied both to the upper surface and to the circumference, a uniform state of stress takes place. The gauge buried in the rubber cylinder will therefore be under uniform pressure.

Pressure p_A and p_B of the rubber cushion which, filled with water, lie respectively on the upper and the lower surface of the rubber cylinder is measured by a U-tube manometer. Then, p_A shall be equal to $p_h + p_v$, where p_h is the water pressure applied on the upper surface of the rubber cylinder and the circumference as well, and p_v is the pressure applied through a hydraulic jack to the upper cushion. The above requirement is sufficiently satisfied in our equipment as shown in Fig. 3. The vertical pressure on the centre of the soil sample in the rubber cylinder is, therefore $(p_A + p_B)/2$ and the ratio, K, of the horizontal stress to the vertical is $K = 2p_h/(p_A + p_B)$.

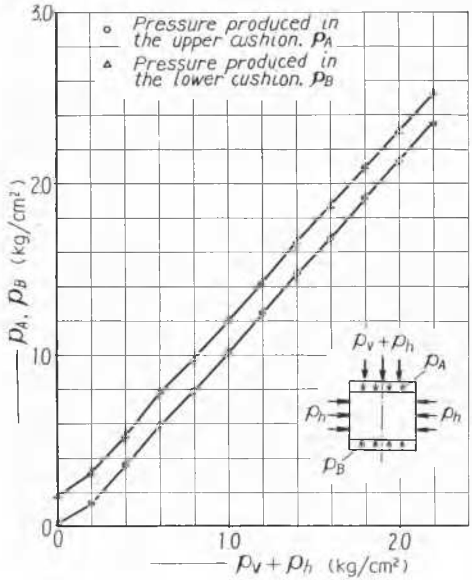

Fig. 3 Relationship between pressure on rubber cylinder and pressures produced in rubber cushions, p_A, and p_B.
Relation entre la poussée sur le cylindre en caoutchouc et les poussées produites dans les coussinets en caoutchouc, p_A et p_B.

The soils tested were those from the permeable and impermeable zones of the Aoyama earth dam. The former was sand containing sandy loam, and the latter, although called clay, was in fact sandy loam. The moisture content of the former, was 8 to 9 per cent and of the latter 48·2 to 51·5 per cent; and the unit density ranged from 1·95 ~ 2·03 grams per cub. cm, and 1·61 to 1·65 grams per cub. cm, respectively. Soil was packed into the rubber cylinder either layer by layer by hand or with the aid of vibration.

Fig. 4 shows, in comparison with the calibration by air, data of a pressure cell placed in the sand containing sandy loam, where seven pressure cells were arrayed at the summits and at the centre of a regular hexagon, the centre to centre interval being 24 cm, on the horizontal plane in the centre of the rubber cylinder. We can see from this that stress is not concentrated on a separate pressure cell in the case of sand.

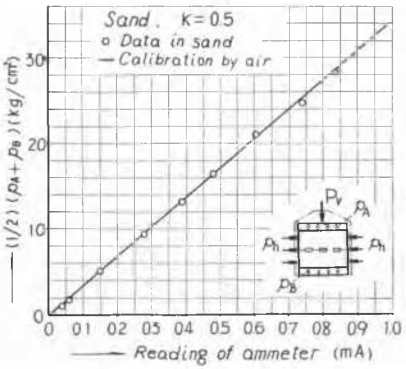

Fig. 4 An example of calibration curves in sand on a separate pressure cell.

Un exemple des courbes de calibrage d'une chambre de pression dans le sable.

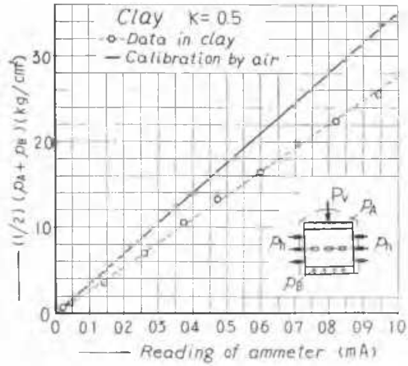

Fig. 6 An example of calibration curves in clay on a separate pressure cell.

Exemple des courbes de calibrage d'une chambre de pression dans l'argile.

The concentration of stress on the setup of seven pressure cells was tested on the pressure plate A_z which was perpendicular to the vertical principal stress. In this case, since A_z was 8 cm below the upper cushion, the vertical earth pressure on the pressure plate was assumed, for the check, to be equal to the water pressure of the upper cushion. Fig. 5 shows data of A_z in the sand, where K was 0·5 in comparison with calibration in air, from which we can see that stress in not concentrated in sand on a pressure cell even when set up in a frame. The authors obtained similar results for different values of K.

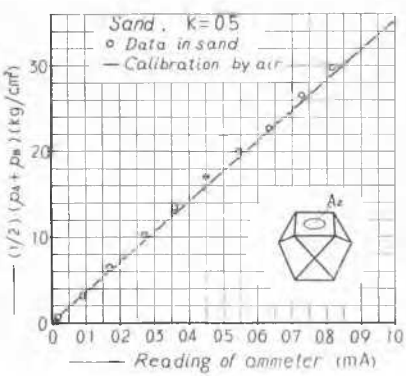

Fig. 5 Relation of earth pressure on A_Z and reading of ammeter (mA), when seven pressure cells are set up.

Relation entre les poussées des terres sur A_Z et les mesures à l'ammètre (mA), dans le cas où les sept chambres de pression opèrent simultanément.

Fig. 6 shows data of a pressure cell tested separately in clay. The reading of the ammeter increases in direct proportion in the same way as with the vertical pressure in the rubber cylinder, but in this case the reading of the ammeter is greater than the calibration by air at the corresponding pressure of the clay; in other words, stress concentration does occur in the clay. This may be because clay is more compressible than sand. The average value of seven readings of σ was about 20 per cent greater than that obtained by air calibration. The reading in the clay, although much reduced when compared with the readings from a three-face earth pressure gauge, must still be corrected by the use of calibration by air. Corrected values of the data measured on the set up of seven pressure cells are shown in Fig. 7, where σ_z is notably near to the vertical pressure in the rubber cylinder.

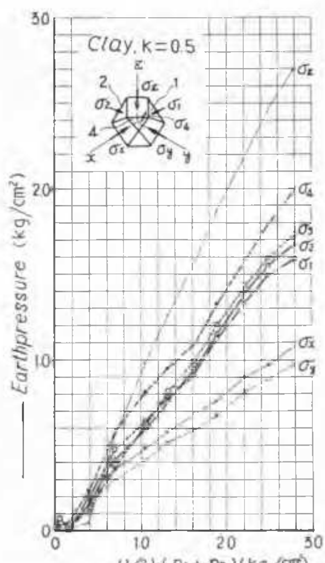

Fig. 7 Seven σ', measured in clay on the set up of seven pressure cells.

Valeurs des sept σ mesurés dans l'argile, dans le cas où sept chambres de pression opèrent simultanément.

Fig. 8 shows of formula (3), where the soil is the sand and $K = 1{\cdot}0$. The average of difference is about 6 per cent, where the difference is divided by the reading at each point. When $K = 0{\cdot}5$, the ratio of difference reached 8 per cent. In the clay, the ratio of difference was 9 per cent (Fig. 9). This ratio permits the use of the gauge in an earth dam.

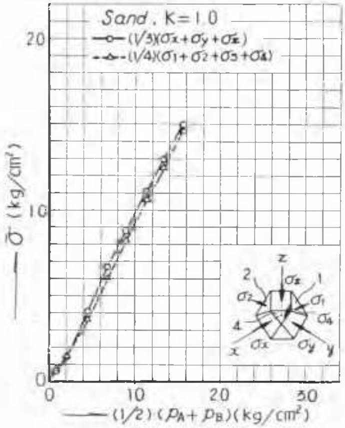

Fig. 8 Check of formula (3) in sand.
Recherche de la formule (3) dans le sable.

The ratio of difference appears to become larger when K becomes smaller. One of the reasons of this might be the mechanism of the rubber cylinder. Researches will be continued and data in the Aoyama earth dam will be published later. The full description of the content in this paper is given elsewhere [3].

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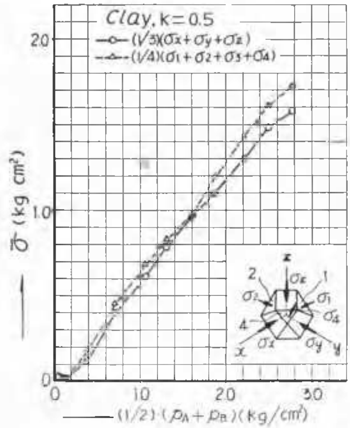

Fig. 9 Check of formula (3) in clay.
Recherche de la formule (3) dans l'argile.

References

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