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Distribution of Passive Earth Pressure on the Surface of a Square Vertical Plate Embedded in Soil

Butée des terres sur une plaque verticale carrée enfoncé dans le sol

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SUMMARY

This paper presents the results of model tests carried out to determine the passive earth pressure distribution, in both the horizontal and vertical directions, on the frontal surface of a rigid square vertical plate, measuring 30 by 30 cm, sunk into sand, and submitted to a gradually increasing horizontal force.

SOMMAIRE

On donne les résultats des essais effectués sur modèle pour déterminer la distribution de la butée des terres sur une plaque rigide de 30 × 30 cm, verticale, enfoncée dans le sable et soumise à une charge horizontale graduellement croissante.

A VERTICAL PLATE pressing on soil in a horizontal direction is known to create a passive earth pressure in the soil. The extent of passive earth pressure and its dependence on plate displacement have been the subject of numerous studies (e.g. Hueckel, 1957, 1961). The present study deals with the problem of distribution of pressures acting on the plate perpendicular to its surface while it presses upon the soil. This distribution is assumed to be, according to the classical theory, trapezium-like when taken in the vertical direction and rectangular in shape when taken in the horizontal direction.

The aim of the model tests carried out by the authors in the Laboratory of the Institute of Hydraulic Research of the Polish Academy of Sciences in Gdańsk has been to check the correctness of the classical assumptions quoted above, by means of model apparatus specially designed for this purpose. The case considered here was a rigid plate, rigidly displacing the soil, i.e., without rotating and without changing the level of its position. Dry beach sand was applied as soil material.

ARRANGEMENT OF TESTS

As in previous model tests (Hueckel, 1957), tests were performed using a wooden box, its interior measuring 222 by 205 by 100 cm high (Fig. 1). Sand was poured into the box in layers 10 cm thick. The sand was merely levelled if a low density index ($I_D = 0.46$) was desired. Whenever more dense soil was required (density index, $I_D = 0.63$), a light hand-operated roller (63 kg) was passed 100 times over each layer.

The main device consisted of two square plates, 300 by 300 mm. The plate, designated A, was made of steel, 7 mm thick and furnished with 27 pressure gauges, placed on its frontal surface (pressing against the ground), as shown in Fig. 2, to enable placement of the plate in both orientations, I and II (Figs. 2b and 2c respectively). This procedure facilitated repetition of the same tests with different alignments of gauges and control of the results obtained.

Pressure gauges were placed in circular openings, cut out of the plate (Fig. 3). Each consisted of a small circular plate, 16 mm in diameter, placed in the opening flush with

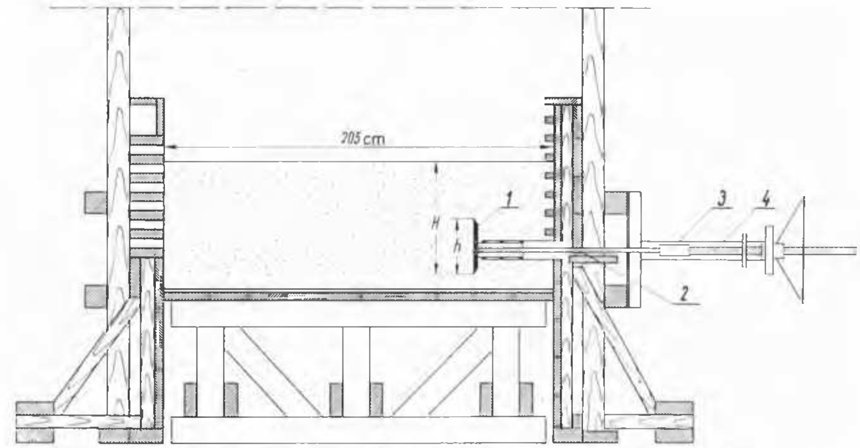

FIG. 1. Test box: 1, plate; 2, tie-rod; 3, dial gauge; 4, screw jack.

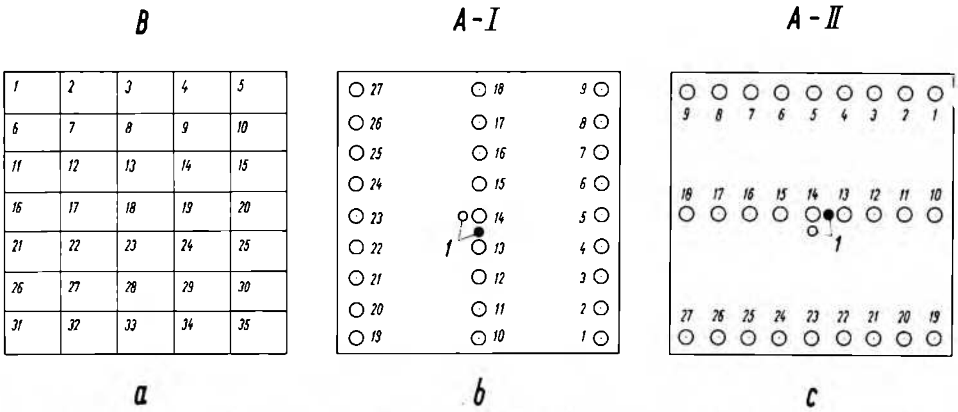

FIG. 2. Alignments of pressure gauges for plates B and A in two orientations. 1, points of connection with tie-rod.

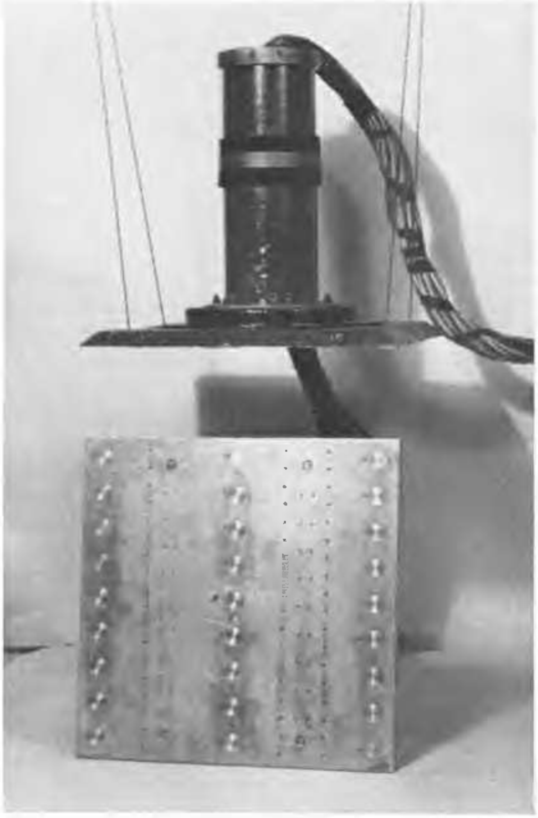

FIG. 3. Frontal face of plate A (the rear cover of plate is above).

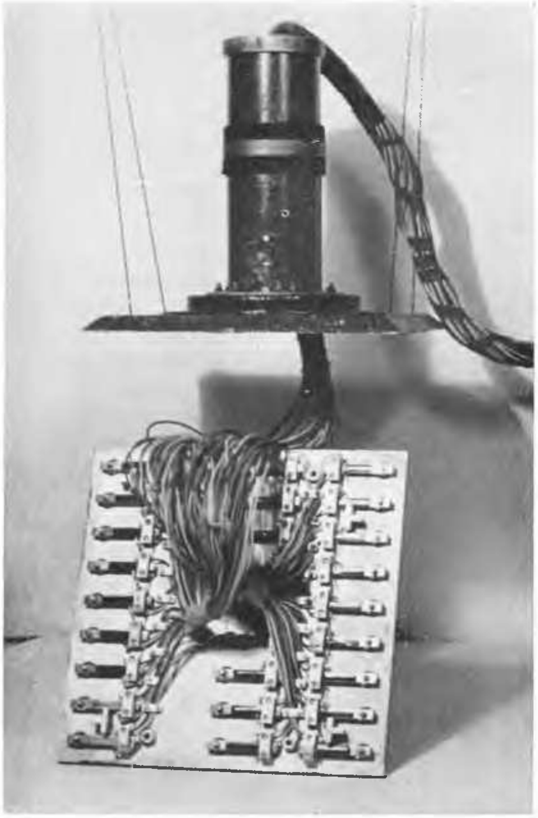

FIG. 4. Rear side of plate A.

the plate surface. Each circular plate rested on a flat spring in the shape of a steel cantilever fixed by an overlap placed on the rear plate surface (Fig. 4). Strain gauges were placed on each spring from both sides (Fig. 5). The combined surface area of pressure gauges in contact with the soil amounted to $s_a = 6.3$ per cent or 0.063 of the total frontal area of plate A.

This plate was used in a series of tests, however, the objection was raised that measurements taken by this device might be distorted as a result of arching of soil in front of each gauge, with the circular plate sinking gradually into its bedding as the pressure increased. For this reason, an additional plate, marked B, was constructed, which was free from these objections. Plate B was provided with 35 pressure gauges, arranged as in Fig. 2a. Fig. 6 shows a view of the fully mounted plate before it is covered with sand.

Fig. 7 presents plate construction along with that of one gauge, from which its principle of operation will be seen. The total gauge plate area s_b is 96 per cent or 0.96 of the total front area of the plate. Under soil pressure it presses against dynamometric springs, shaped as minute free-end beams provided with strain gauges. The frontal surfaces of plates A and B were coated with a thin plastic protecting foil. The pressure gauges of both plates were calibrated before and after each test. In this way true results of measurements were obtained, independent of possible inexactitudes of springs and strain gauges. Calibration was done in a special pneumatic apparatus shown in Fig. 8. In

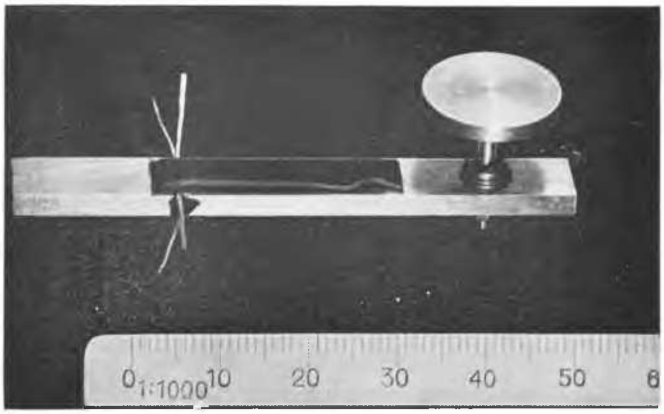

FIG. 5. Pressure gauge of plate A with strain gauge on the cantilever spring.

FIG. 6. Fully mounted plate B.

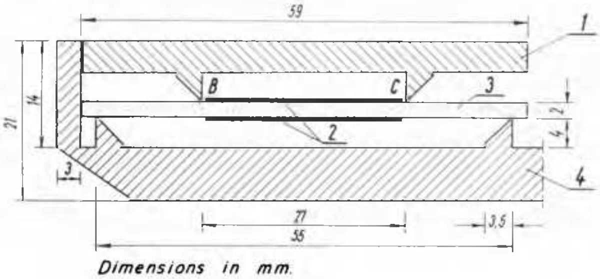

FIG. 7. Cross-section of a detail of plate B with the pressure gauge. 1, gauge plate; 2, strain gauges; 3, spring; 4, basic part of plate.

this device the plate is subjected to pressure acting through an elastic rubber membrane, which separates the frontal surface of the plate from the pressure chamber. Air in this chamber is compressed by an air compressor; the chamber itself is fitted with a valve and a precision manometer.

FIG. 8. Calibration apparatus.

Plates of both kinds, after they had been fitted in the test box, were rigidly connected to a horizontal screw jack by means of a steel tie rod, 26 mm in diameter and fixed to the rear plate side at $h_s = 0.445\,h$ (h being the height of the plate). The displacements of plates were measured by a dial gauge with an accuracy of 0.01 mm. Horizontal positioning of the rod was secured by two telescope tubes, one of which was connected to the model casing, and the other directly to the plate. These tubes gave protection to leads connecting the strain gauges to the resistance bridge. The hand-operated laboratory pusher jack consists of a frame, a driving screw, and a hand wheel. A proving ring with dial gauge was mounted on the pusher. The dynamometric scale range reached up to 1500 kg and its accuracy was 3.0 kg.

A resistance bridge produced in Poland was used to determine the strains recorded by the gauges. The range of strain measurements by this bridge was 26‰ and its accuracy was 0.005‰.

SOIL MATERIALS USED FOR TESTS

Tests were performed using beach sand of middle grain size ($d_{10} = 0.17$ mm, $d_{80} = 0.4$ mm), taken from the seashore of the gulf of Gdańsk (Sopot), artificially dried, and then very slightly moistened by the natural humidity of the air in the test room. Sand layers were laid without compaction or compacted. The mean values obtained from measurements are:

unit weight of soil particles (γ_s), 2.653 grams/cu cm
water content (w), 0.04 to 0.15 per cent
effective angle of shearing resistance (ϕ'), 34°20′ ± 30′
dense sand
  bulk density (γ), 1.670 ± 0.003 grams/cu cm
  density index (I_D), 0.63 ± 0.01
loose sand
  bulk density (γ), 1.617 ± 0.005 grams/cu cm
  density index (I_D), 0.46 ± 0.01

DESCRIPTION OF TESTS

The following measurements were taken in each test: (1) the total horizontal force P' applied to the plate corresponding to the first plate movement, and to displacement values equaling in sequence: 1, 5, 25, 70, 90, and 1 mm. (2) Forces p_i incidental to separate pressure gauges, corresponding to the respective displacement values as stated above, and their sum

$$\sum_{1}^{n} p_i.$$

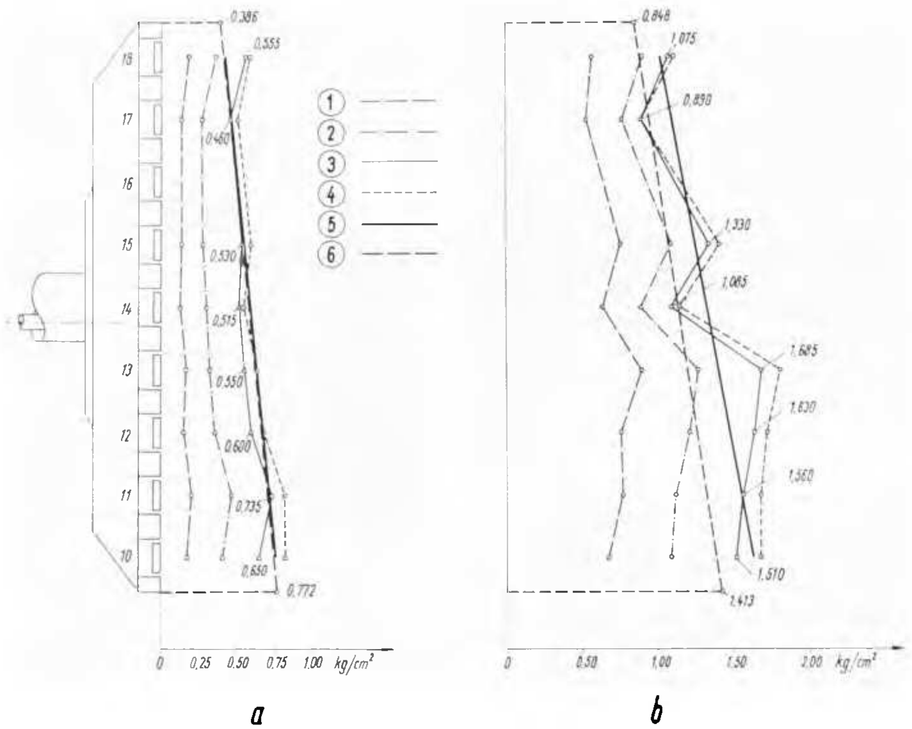

FIG. 9. Results of tests with plate A; (a) for $H/h = 2$, $I_D = 0.46$; (b) for $H/h = 2.5$; $I_D = 0.63$. Distribution of earth pressures in vertical axis of plate: 1, by the displacement of plate equal to 5 mm; 2, as above to 25 mm; 3, to 70 mm; 4, to 90 mm; 5, equalizing distribution in plate axis for displacement 70 mm; 6, theoretical distribution on whole plate surface for displacement 70 mm. The numbers give the pressures in kg/sq.cm. for displacement 70 mm.

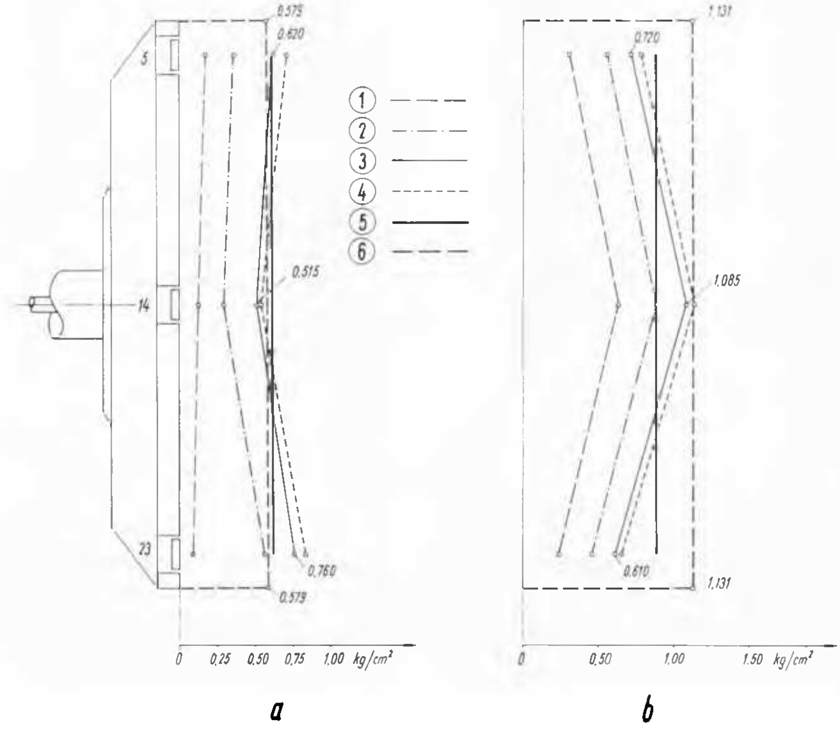

FIG. 10. Results of tests with plate A. Distribution of earth pressures in horizontal axis of plate; other notation as for Fig. 9.

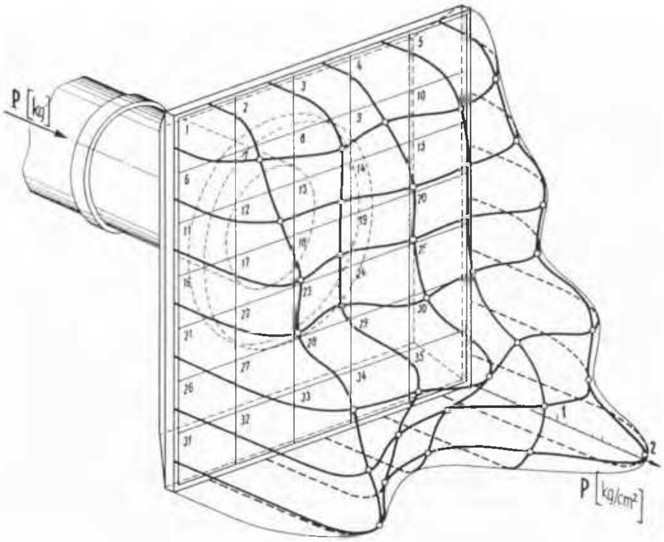

FIG. 11. Axonometric view of the earth pressures for $H/h = 2.5$ and $I_D = 0.63$.

This enabled the calculation of the following values for each test:

1. Value of total passive earth pressure in front of the plate, in its successive positions, calculated from the formula:

$$P = \frac{\sum_{1}^{n} p_i}{s_a} \quad \text{or} \quad P = \frac{\sum_{1}^{n} p_i}{s_b}$$

where $s_a = 0.063$ and $s_b = 0.96$ and are relations of the area of pressure gauges to the whole frontal area of the plate in contact with the soil.

2. Differences between values P' and P, which represent value of apparatus resistance and friction of soil against the pusher shaft, simultaneously including active earth pressure, if any, from the opposite part of the plate.

The measurements taken also allow the drawing of curves showing the relation of passive earth pressure and displacement of the plate, and curves showing distribution of pressures acting on the plates in vertical and horizontal direction. The first-mentioned curves do not contribute new elements to the problem, and for this reason they have been omitted from this study.

Figs. 9 and 10 present the results of tests, using plate A, concerning pressure distribution in vertical and horizontal axis of the plate, measured for two chosen tests performed in extreme conditions, with $H/h = 2.0$ and $I_D = 0.46$ and $H/h = 2.5$ and $I_D = 0.63$ or, with loose soil and a shallow position for the plate and with dense soil and a deeply set plate, respectively. These figures show simultaneously straight lines equalizing the test results and pressure distribution according to the classical theory. Analogical results were obtained in tests performed using plate B. Fig. 11 shows an axsonometric view of the figure of stresses for test performed for $H/h = 2.5$ and $I_D = 0.63$, with plate B, for a displacement equal to 70 mm.

CONCLUSIONS

Although no conclusions of universal importance can be drawn from the small number of tests described here, the results obtained under the above-mentioned restriction appear to be indicative of the following conclusions.

1. The exact pressure distribution does not strictly follow the classical pattern, but shows irregularities, depicted in Figs. 9–11. The pressure diagram is, generally speaking, concave (saddle-like). This concavity is more pronounced at the lower edge of the plate.
2. The character of pressure distribution will not alter essentially with the growth of the total force applied and with the displacement of the plate. Similarly, no essential differences will be found between the pressure distribution in the initial stages of tests and in the stages of soil failure.
3. When distributing in the classical manner the limit passive earth pressure P as determined by tests performed on the whole surface of the plate, one gets a diagram of pressures varying from the actual, equalized one within a range of 5 per cent.

Tests continue and the authors hope to be able to submit further observations during the Conference.

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