An Apparatus for Measuring Lateral Soil Swelling Pressure in the Laboratory

Appareil de laboratoire pour mesurer le gonflement latéral du sol

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SUMMARY

In order to study the lateral pressures developed during the saturation of expansive clay soils, a special device was developed by modifying the usual type of consolidation cell unit. The type finally adopted utilized a special consolidation ring with a thin wall section in its central portion, allowing the use of electrical strain wires to determine the applied internal pressure. This device gave consistent and reproducible results both during calibration and testing of soil in swelling studies. It was found that this apparatus was also well adapted to measuring the at-rest pressures for clay and sand.

SOMMAIRE

Afin de pouvoir mesurer les pressions latérales qui apparaissent pendant la saturation des argiles gonflantes, un appareil a été developpé qui représente une modification de l'œdomètre habituel. La version finale de l'appareil utilise un anneau spécial avec un paroi mince dans sa partie centrale qui permet l'utilisation des comparateurs à fil électrique pour la détermination de la pression interne appliquée. Ce dispositif fournissait des résultats reproductibles et fidèles pendant la calibration et les études du gonflement. On trouve également que l'appareil était bien adapté pour mesurer la pression latérale de repos des argiles et des sables.

MUCH ATTENTION has been given to vertical movements and pressures associated with expansion and shrinkage of clay soils. Experience in Israel has shown that piles and other structures buried in a clayey soil are damaged by the action of horizontal swelling forces as well as vertical forces (Zeitlen and Komornik, 1960; Kassiff and Zeitlen, 1962). In some of these cases the clay was free to expand in the vertical direction and yet appreciable horizontal forces appeared. For proper analysis of actual conditions, the values of both vertical and horizontal swelling forces need to be determined.

Vertical swelling pressures are often determined by use of an oedometer or by other special apparatus (Alpan, 1957) but there has been little attention paid to the need for simultaneous measurement of lateral and vertical swelling pressures of expansive soils. Hence, for a basic study a special instrument was developed for the measurement of lateral swelling pressures under different vertical loadings.

SELECTION OF TYPE OF APPARATUS

Swelling pressures take appreciable time to reach their maximum when the soil is wetted. To allow the study of various conditions in as short a time as possible, it was decided to develop equipment which will allow the performance of numerous tests in as simple a manner as possible. Swelling data may be obtained with a triaxial-shear instrument, in which changes of volume and the amount of lateral pressure may be controlled and measured during the test. However, elaborate apparatus, special procedures, and constant attention and control are required, thus limiting the number of samples which can be tested during a particular period.

In view of the foregoing demands, the relatively simpler oedometer, or consolidation apparatus, was utilized by modifying a consolidation ring to allow measurement of the lateral pressures which appear as a result of the swelling of the clay. Various designs were investigated for the transformation of the consolidation ring into a pressure-sensitive membrane. The most promising was further checked, to see if the membrane movement affected results, by testing similar soil samples in both ordinary consolidation rings and swelling pressure rings.

The first of these rings was a thin-walled (0.5-mm) steel ring, 1.50 in. high, 112.5 mm internal diameter (specimen area of 100 sq.cm.). Three electrical wire conductors of the type used in electrical resistance gauges were wound around the external periphery of this ring. The second of the rings was actually an ordinary consolidation ring into which a thin-walled steel ring was placed, as closely fitting as possible, so that there was close contact between the rings. In the outer ring three elliptical openings were cut, which enabled the cementing of electrical strain gauges, of the SR-4 type, on the exterior surface of the thin-walled ring, which then acted as a membrane across the opening.

Combining the two types of rings resulted in a third type of ring, shown in Fig. 1. This ring was an ordinary consolidation ring with the lower portion turned down to a wall thickness of 0.3 mm, and a height slightly less than that of the sample under test, so that its action was that of a thin membrane. The lateral pressure was measured on part of the ring wall with the aid of three thin electrical wire conductors, stretched and cemented on top of thin paper using Araldite. A neoprene layer was used to cover the wires and protect them against moisture.

The rings were calibrated to determine the changes in the electrical resistance of the wires as a function of lateral pressure. Calibration of the first type of thin rings was attempted using two semicircular metal blocks which applied outward forces against the inside of the rings. Results were

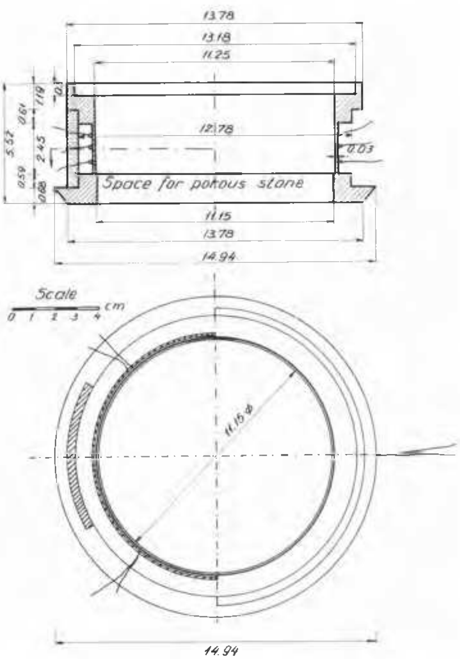

FIG. 1. Swelling ring for lateral swelling pressure measurements.

not uniform because of friction between the metal blocks and the ring, as well as non-uniformity of strains across the width of the ring. The remaining rings were calibrated by using a piston to apply pressure to oil inside the ring. Calibration using a fluid was not feasible in the case of the first type of thin ring inasmuch as the insertion of the piston within the ring gave rise to bending moments in the ring wall. In the other two types of ring, the relatively high rigidity of the upper and lower parts of the wall acted to prevent bending. Although the calibration of the second type of ring was successful, it was found to give inconsistant results when soil was tested, apparently because of localized inequalities in lateral pressure. The third type of ring was selected for final use in research, since it gave consistent and reproducible values both during calibration and testing of actual soil.

THEORETICAL DEFORMATION OF THE MEMBRANE AND COMPARISON WITH ACTUAL MEASUREMENTS

Since the swelling pressure measured in a clay specimen depends upon the amount of movement allowed, it is necessary to determine the possible deformation of the membrane in the swelling pressure rings. The ring system can be considered as a cylindrical shell fixed at both ends.

Calculation of the theoretical deflection of a thin portion of the ring shows that a change in the radius of 5.53 by 10^{-4} cm would be predicted per atmosphere of internal pressure at the mid-point of the ring. At the quarter height, deflection would be 4.55 by 10^{-4} cm per atmosphere.

The actual movement at the centre was measured with the aid of a dial gauge, showing 3.8 by 10^{-4} cm per atmosphere of pressure. It may be presumed that the application of the strain gauges strengthened the membrane to produce deflections smaller than the theory indicated. However, the ratio of the readings of the various electrical gauges surrounding the membrane at the half and the quarter levels was found to be in good agreement with the results calculated theoretically. The strain indicated by the electrical strain gauges at the quarter level was 88 per cent of the value given by the centre wire, as compared to the 82 per cent predicted. In the swelling pressure test, where vertical movement during wetting is prevented by loading, a deflectometer reading to 1/10,000 inch or about 2.5 by 10^{-4} cm is ordinarily utilized for the measuring of the movement. Since variations of several divisions may easily occur during such a test, it may be seen that the accuracy of the measurement in the vertical direction is more or less equal to that in the horizontal direction, and the amounts of movement are very small and of the same order of magnitude.

As a further test of the swelling pressure ring in comparison to the rigid consolidation ring, parallel tests were performed on specimens of compacted clay under similar conditions in the two types of rings. The results obtained showed that there was no difference in the amount of swell for the various samples under the same vertical pressure.

TYPICAL CLAY TESTED

In connection with studies of the lateral forces exerted on piles by swelling clays (Komornik, 1962) a local expansive clay soil was tested under various conditions by use of the apparatus which was developed. The clay possessed the following characteristics:

Classification Tests

Clay content (grain size smaller than 2μ)	62 per cent
Liquid limit w_L	76 per cent
Plastic limit, w_P	28 per cent
Plasticity index, I_p	48 per cent
Shrinkage limit w_s	9.5 per cent
Activity $= I_p$/Per cent 2μ	0.8 per cent
Free swell	140 per cent
Specific gravity, G	2.76 per cent
Optimum moisture content	24 per cent
Maximum density (Modified AASHO), γ_d	1600 kg/cu.m.

Chemical Analysis

Soluble salts, 1.4 per cent; organic material, 1.14 per cent; active calcium carbonate, 9.5 per cent; pH, 7.8. Total amount of Cations: 61.5 milli-equivalent per 100 grams of dry sample.

Exchangeable Cations

Na^+	4.5 milli-equivalent per 100 grams of dry material
K^+	2.0 milli-equivalent per 100 grams of dry material
Ca^{++}	28.0 milli-equivalent per 100 grams of dry material
Mg^{++}	25.2 milli-equivalent per 100 grams of dry material

Mineralogical Composition

By X-ray diffraction, it was found that the clay consisted of more than 70 per cent of minerals in the montmorillonite group, indicating a highly active clay. The grain size and the moisture density curves of the clay are given in Figs. 2 and 3.

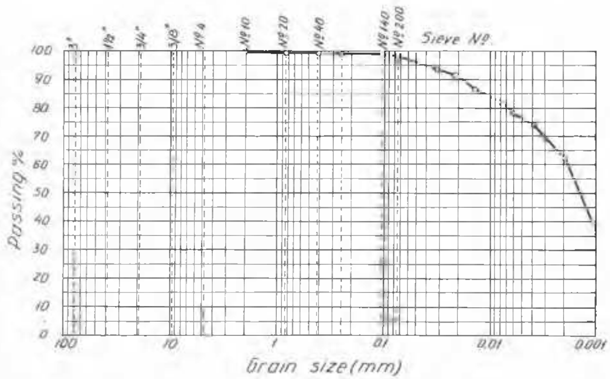

FIG. 2. Grain size distribution of the clay tested.

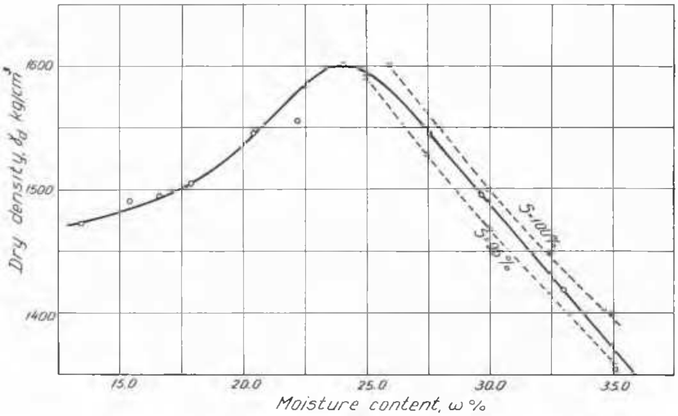

FIG. 3. Moisture-density relation for the clay tested.

TYPICAL TESTS RESULTS

The apparatus made it possible to obtain horizontal swelling pressure data with sufficient accuracy to permit comparisons of various procedures of testing compacted clay. Research in recent years has shown the importance of the structure of the clay on its behaviour (for example, Lambe, 1960; Seed and Chan, 1961). It was possible to execute a testing programme comparing the influence on swelling characteristics of such factors as method of compaction, and the timing and method of wetting. Fig. 4 shows typical test results from a series where a compacted clay is allowed to saturate while under a constant vertical pressure. The lateral pressure was noted immediately after compaction, as well as 12 hours later, when it was found to have decreased. The figure shows the increase in lateral pressure caused by wetting. Fig. 5 presents results for one of the series where relatively high densities were employed, in the form of percentage of swell *versus* both vertical and horizontal pressures. Although analysis of the clay behaviour is outside the scope of this paper, it is interesting to note how the lateral pressures remaining from compaction are much larger than the vertical pressures when swelling can occur.

OTHER APPLICATIONS OF THE APPARATUS

The devices have been of use in other research studies, such as determining at-rest pressures during the consolidation of a clay from the liquid limit to high pressures. The ability of the design to give average values around the circumference has allowed consistent results to be obtained for at-rest pressures in granular materials. One study has already been completed in the laboratory in which K_0 values were found for sands of various gradations (Teferra, 1963).

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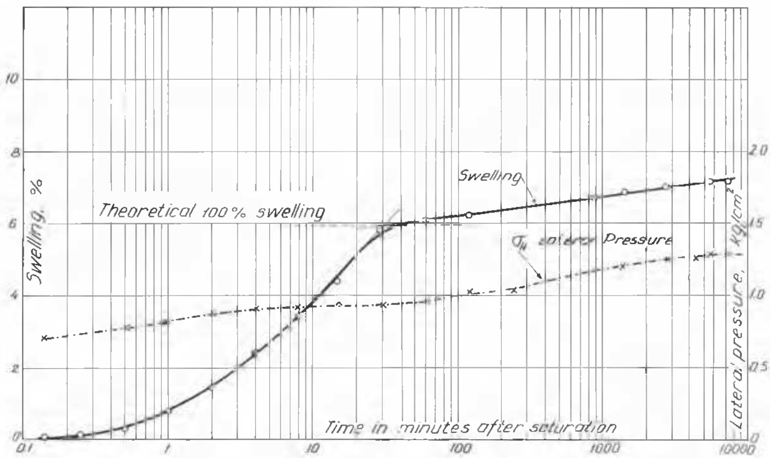

FIG. 4. Typical relations observed for variations in lateral swelling pressure and swell with time under constant load of 0.6 kg/sq.cm.

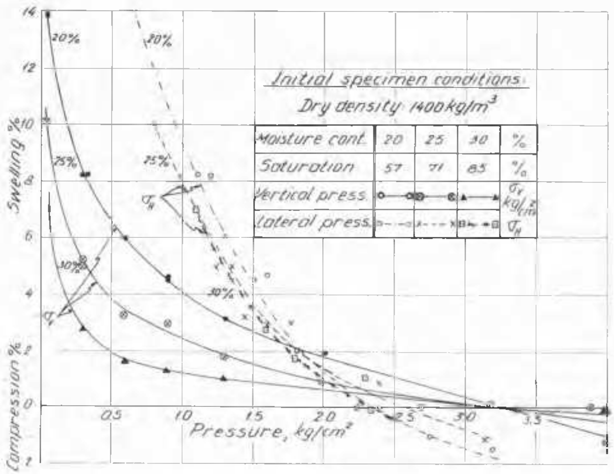

FIG. 5. Typical relations observed for vertical movements as a function of vertical and lateral pressures.

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