An Apparatus for Measuring the Swelling Pressure in Expansive Soils

Un Appareil pour Mesurer la Pression de Gonflement dans les Sols Expansifs

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Summary

Under the climatic conditions of Israel, local clays are known to cause considerable trouble to structures erected on them. Seasonal moisture variations cause these soils to expand and shrink, producing differential heaving, detrimental to buildings.

A problem of similar nature is encountered in road and airfield construction, where moisture variations in the compacted subgrade cause volume changes and subsequent waving of the paved surface.

It has been established that moisture, density and soil structure are among the most important factors influencing volume change.

To study separately the influence of these factors, an apparatus has been designed which enables a soil to be tested for swelling pressure, developed throughout a range of moisture variation below full saturation. It is thought that the method constitutes an improvement in that it permits duplication of field conditions, where the maximum moisture content does not necessarily reach the full saturation value. It also makes it possible to test compacted soils, having identical placement conditions, for different moisture ranges, without introducing unknown structural changes due to variation in the compactive effort.

Sommaire

Dans les conditions climatiques d'Israël, certaines argiles du pays ont des effets nuisibles sur les constructions car les variations périodiques de leur teneur en eau causent le gonflement et le retrait de ces argiles, produisant ainsi les mouvements différentiels si nuisibles aux constructions.

Un problème d'un caractère semblable se pose dans le cas des routes et aérodromes où les variations de la teneur en eau dans le soubassement causent des variations de volume et, par conséquent, des ondulations du revêtement.

Parmi les facteurs les plus importants qui influent sur le changement de volume se trouvent la teneur en eau, la densité et la structure du sol.

Pour étudier séparément l'influence de ces facteurs, un appareil a été construit qui rend possible la détermination de la pression de gonflement, developpée par l'absorbtion d'eau dans un sol incomplètement saturé. Il semble que la méthode employée représente un certain progrès par le fait qu'elle permet la reproduction des conditions naturelles, où la teneur en eau maximale n'atteint pas nécessairement la valeur de saturation. Aussi est-il possible d'étudier les sols compactés, aux conditions initiales identiques, pour des teneurs en eau différentes sans introduire des changements structurels inconnus, dûs aux variations de l'effort de compactage.

Introduction

In certain clays the variation of the moisture regime activates internal forces which produce the processes known as swelling and shrinkage. The volume changes associated with these processes are liable to cause considerable distress to structures, such as foundations, roads and airfields, which are influenced and constitute an engineering problem of major importance in countries where large seasonal moisture variations occur in the soil.

On taking up moisture, expansive clays show volume increase or, if confined, exhibit considerable swelling pressures (over 10 kg/cm^2 are reported by GOLDBERG and KLEIN, 1952).

The study of swelling and swelling pressures has been the object of numerous investigations which attempted to identify the various factors influencing expansion and, if possible, evaluate them quantitatively. Apart from moisture, it has been shown that soil density and structure are among the most important (ALLEN and JOHNSON, 1936; WOOLTORTON, 1954). A study of the influence of these factors separately should contribute to the solution of the engineering problem discussed above.

A survey of past work shows—as far as the writer could ascertain—that, with minor variations, the following procedure has been adopted.

To study one-dimensional expansion of remoulded clays, samples, compacted at various initial moisture and density conditions, are placed in a ring (a mould or a consolidometer cell) and water is made available until they saturate.

Upon water intake either the expansion or the developed pressure is measured.

Basic Concepts

An apparatus to measure swelling pressures has been designed in the Soil Mechanics Laboratory of the Israel Institute of Technology.

This device helps to eliminate two objectionable features of the usual procedure: (a) in nature moisture variations are often in a range below that of full saturation; (b) to obtain a range of initial (placement) conditions of the soil various compaction energies have to be employed, thereby altering the structural arrangement of the soil particles.

It follows that the described laboratory procedure does not, on the one hand, duplicate conditions in the field and, on the other, does not succeed in controlling the important variation in soil structure.

The apparatus was developed in accordance with concepts of *soil suction*, as developed by Haines (KEEN, 1931) and particularly by SCHOLFIELD (1935).

When water is taken up by a soil, energy in the form of heat is liberated. If the process be reversed, i.e. water torn away, a certain force, the suction, has to be applied to effectuate the removal. This force will vary with the moisture condition of the soil. The suction–moisture content relationship is not unique but differs according to whether the soil is *dried*, by applying suction, or whether the soil is *wetted*, taking up moisture against a suction force. Fig. 1 illustrates the relationships discussed.

If a soil sample is brought into contact with water under tension it will take up moisture until a suction equilibrium is reached. At this stage the soil will have a moisture content, but not necessarily that of saturation. In fact, the higher the tension in the water, the further removed from full saturation the soil will be. By varying the water tension the soil may be made to obtain various degrees of saturation and its expansive behaviour studied.

The procedure, described above, also permits the study of a series of specimens, placed at identical conditions and brought

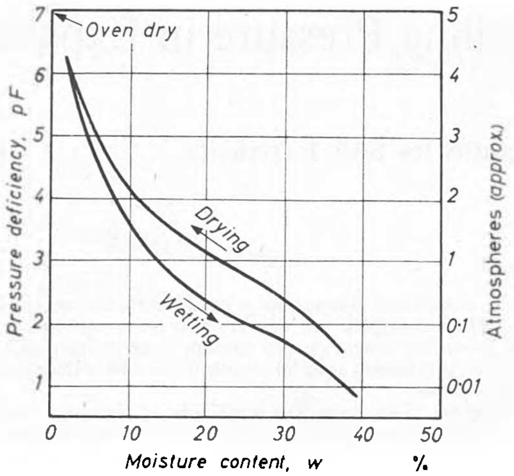

Fig. 1 Suction–moisture content of a loam (after Schofield)
Succion d'un limon en fonction de la teneur en eau (d'après Schofield)

to various degrees of saturation, whereupon full saturation is allowed. Thus the structural variations, due to varying compactive efforts, are kept relatively constant for specimens prepared at the same initial density.

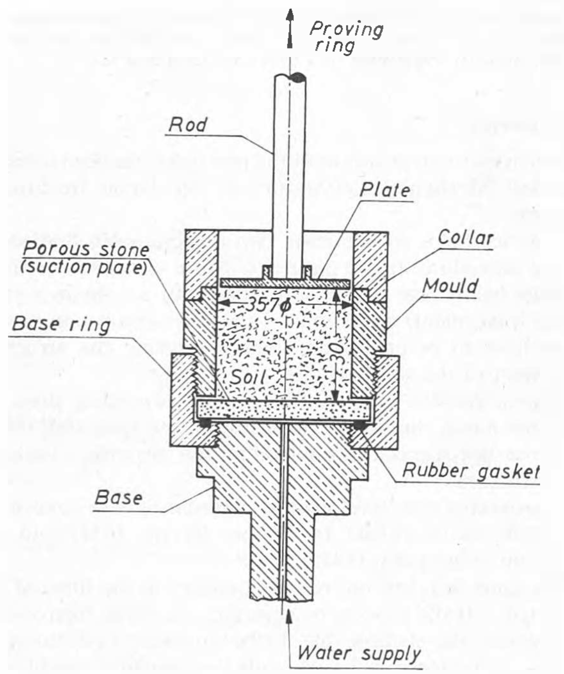

Fig. 2 Swell pressure cell
Cellule à mesurer la pression de gonflement

Description of Apparatus

Fig. 2 shows the special cell constructed for the purpose. A base ring, containing a porous suction plate, is mounted on the base which is connected to the water supply. The mould, into which the sample is compacted, is screwed into the base ring so as to press the porous plate on to the circular rubber gasket: in this way air is prevented from penetrating below the plate. The soil sample is covered with a metal plate which, through a rod, transmits the swelling pressure to a proving ring. A collar is fixed on the upper end of the mould. The porous suction plate was obtained according to specifications for the purpose: it held water on which a suction of over 700 mm mercury was applied ('air entry' value). Its permeability coefficient was average $K = 4{\cdot}90 \times 10^{-7}$ cm per sec.

The cell, described above, was mounted on to a triaxial machine, adapted for the purpose. The general layout is shown diagrammatically in Fig. 3. The arrangement permits

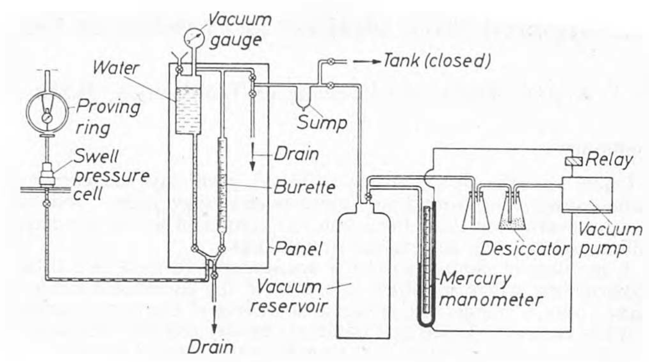

Fig. 3 Diagram of swelling pressure apparatus
Schema de l'appareil à mesurer la pression de gonflement

a vacuum to be applied to the water reaching the cell from a burette. The vacuum is controlled by means of a manometer which, when set at the desired pressure deficiency, operates a relay connected with the vacuum pump. The function of the large vacuum reservoir is to minimize pressure variations and, hence, the frequency of the vacuum operations. The sump and the Erlenmeyer flasks prevent water from reaching the pump. In addition to the manometer, the vacuum is checked by a gauge, mounted on the water reservoir.

The Tests

The tests were performed on the '–40' fraction (420 micron) of an expansive clay, compacted into the mould as previously described. The clay was believed to contain a rather high percentage of montmorillonite. Its additional properties were:

Clay content (–5 micron fraction) .	63%
Liquid limit	70·8%
Plastic index	39·7%
Shrinkage limit	10·9%

To assure good contact with the suction plate a thin layer of paste, prepared from the same clay, was spread on the plate. A pre-load of about 0·09 kg/cm² was applied to the sample. Before applying vacuum, water was introduced through the base under pressure to remove some air which was inevitably trapped in the narrow space between the base and the porous plate (see Fig. 2). The described vacuum was then applied to the water in the burette and observations started.

The swelling pressure was measured by one of two proving rings of different stiffness. The stiffness ratio of the two rings was about 1:40.

The table presents the results of four tests of which No. VI was conducted with the weaker ring as evidence by the maximum expansion recorded in column 7.

In Fig. 4 some curves of swelling pressure are shown. The effect of proving ring stiffness is brought clearly into evidence: the stiffer ring preventing expansion to a marked degree causes the greater swelling pressures to be developed and, also, the peak pressures to be reached in a shorter time.

Summary of 'Swelling-suction' Test Results
Résumé des Résultats de l'essai de Gonflement

Test No.	w_i %	γ_{di} g/cm³	S_{ri} %	*pF*	*max. S.P.* kg/cm²	*max. exp.* %	*Peak time* hrs.	S_{rf} %
1	2	3	4	5	6	7	8	9
V	12·5	1·40	35·0	2·30	2·79	0·262	165	85·0
VI	11·5	1·40	32·2	2·30	1·00	3·900	465	87·5
VII	12·4	1·39	34·2	2·02	1·74	0·168	149	97·2
VIII	12·5	1·25	28·3	2·02	0·91	0·089	85	78·2

w_i = initial moisture content
S_{ri} = initial degree of saturation
S.P. = Swelling Pressure
Exp. = increase of sample height
γ_{di} = initial dry density
pF = applied suction (log of tension head in cm water)
S_{rf} = final degree of saturation

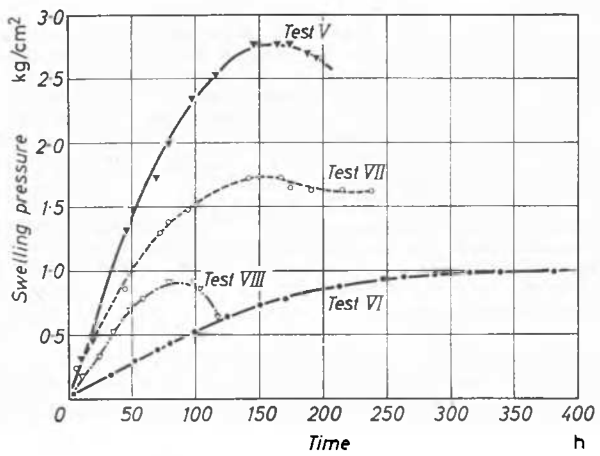

Fig. 4 Time curves of swelling pressure
Courbes representant la pression de gonflement en fonction du temps

Conclusions

The apparatus as presented above was designed specially to obviate the drawbacks, previously discussed, in testing swelling characteristics.

The tests accomplished in this initial stage of experimentation show that the performance of the apparatus warrants continuation of work in this direction. Future planning of research at the Israel Institute of Technology includes simultaneous testing of a number of specimens. The special cell, described above, is not very expensive and vacuum can be applied through a manifold. It is planned to operate a battery of cells simultaneously.

The apparatus described was designed for a research project, carried out at the Soil Mechanics Laboratory of the Israel Institute of Technology under the guidance of Mr. J. G. Zeitlen, U.N. Expert in Soil Mechanics and Adviser to the Institute. The co-operation of the Laboratory staff is gratefully acknowledged.

References

Allen, H. and Johnson, A. W. (1936). The results of tests to determine the expansive properties of soils. *Proc. Highway Res. Board*, **16**, 220

Alpan, I. (1956). The nature and measurement of volume changes due to moisture variation in soils. *Thesis submitted at the Israel Institute of Technology* (unpublished)

Goldberg, I. and Klein, A. (1952). Some effects of treating expansive clays with calcium hydroxide. *A.S.T.M. Symposium on Exhange Phenomena in Soils, Sp. Publ. No. 142*

Keen, B. A. (1931). *The Physical Properties of the Soil*, London; Longmans, Green

Schofield, R. K. (1935). The pF of water in soil. *Trans. 3rd International Congress of Soil Science*, vol. II, pp. 37–38; vol. III, Discussion

Wooltorton, F. L. D. (1954). *The Scientific Basis of Road Design*, London; Arnold