SWELL PRESSURE MEASURED BY UNI-AND TRIAXIAL TECHNIQUES

PRESSION DE GONFLEMENT MESUREE DE MANIERE UNIE-ET TRIAXIALE

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SYNOPSIS In view of the limitations of the one dimensional consolidometer technique for the measurement of swelling potential of an active clay, it was endeavored to use the results of measurements by a triaxial technique for correlating theoretically and experimentally the swell pressures obtained by both techniques. The theoretical comparison of the effective all round pressure obtained by a triaxial device with the vertical effective pressure obtained by a consolidometer device yielded a simple expression for the ratio of these pressures, involving $(Ko)_s$ and Skempton's A coefficients. This expression was examined in the light of experimental results available on a particular Israeli clay and found to comply fairly well with them . For the particular clay examined it was found that for a practical range of placement conditions the average ratio of all round swell pressure to the vertical swell pressure measured by a consolidometer is approximately equal to 0.9, varying in a range of 0.63 to 1.15, depending on the initial dry density.

INTRODUCTION

The one dimensional consolidometer technique has been widely used for the measurement of swelling potential in the laboratory ever since it was originally suggested by Holtz and Gibbs (1952). This technique has a great number of advantages, mainly from the viewpoint of simplicity and standardization. It suffers, however, from serious limitations since in nature the movement of moisture as well as volume change frequently take place in three dimensions rather than the one assumed by the use of the lateral confinement in the latter device, the principal stress ratio is affected and probably does not reflect the actual field conditions. On the other hand, the development of equipment for three dimensional measurement of the swelling potential has been hindered by severe technical difficulties. In spite of this, a number of reports on studies made on expansive clays using three dimensional techniques are available in literature (Rengmark and Erikson 1953; Fost, 1962; Parcher and Ping Chuan Lim, 1965) which virtually show different behavior of the material under three dimensional conditions.

It is desirable, hence, to compare parameters measured by both techniques, with the object of predicting the swelling potential of the clay using the simpler technique. However, limitations inherent in the types of equipment developed for the three dimensional measurements do not make a simple comparison possible. A recent study (Baker, 1968) of the swelling potential of an Israeli clay using triaxial apparatus allowed such a comparison, as it was conducted on the same clay and at placement conditions investigated previously using consolidometer technique with measurement of the lateral stresses (Komornik, 1962; Komornik and Zeitlen, 1965;).

This paper deals first with the theoretical relationships between the pressures measured under the uni- and triaxial conditions for the same volume change, and later compares experimental results obtained in the investigations. At this stage the experimental comparison relates to swelling pressures only, as more data is necessary for comparing the other factors involved, such as the time and volume change.

In passing, it may be pointed out that although the theoretical comparison deals with the volume change in compression, there is no reason why it should not be applicable also to swelling.

THEORETICAL CONSIDERATIONS

Skempton and Bishop (1954) have suggested that for a fully saturated soil:

$$\frac{\Delta \sigma'_a}{\Delta \sigma'_1} = S_d \qquad (1)$$

where: $\Delta \sigma'_a$ is the change in all round pressure required to give a volume change equal to that given by a change $\Delta\sigma'_1$ in one principal stress, effective stress changes being considered, and S_d is a structural parameter.

The volume change under all round pressure conditions may be expressed by (Scott, 1965):

$$\frac{\Delta V}{V_o} = 3\,C_s\,\Delta\sigma'_{oct} = 3\,C_s\,\Delta\sigma'_a \qquad (2)$$

where: C_s is the compressibility coefficient under all round pressure and $\sigma'_{oct} = 1/3\,(\sigma'_1 + \sigma'_2 + \sigma'_3)$.

The volume change under uniaxial compression ($\Delta\sigma'_2 = \Delta\sigma'_3 = 0$) is:

$$\frac{\Delta V}{V_o} = C_s \Delta\sigma'_{oct} + D\Delta\tau_{oct} = C_s \Delta\sigma'_1 + \frac{\sqrt{2}}{3} D\Delta\sigma'_1 \qquad (3)$$

where D is an arbitrary coefficient related to dilatancy and

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

For equal volume changes, hence:

$$\frac{\Delta\sigma'_a}{\Delta\sigma'_1} = \frac{1}{3} + \frac{D\sqrt{2}}{9\,C_s} \qquad (4)$$

and combining Eq. (1) and (4) we obtain:

$$S_d = \frac{1}{3} + \frac{D\sqrt{2}}{9\,C_s} \qquad (5)$$

But according to Scott (loc. cit.) Skempton's A coefficient may be also expressed as:

$$A = \frac{\sqrt{2}}{9}\frac{D}{C_s} + \frac{1}{3}$$

which means that Skempton's coefficients A and S_d are theoretically identical (see also Table I). Alpan (1968) arrived at the same conclusion using a different approach.

TABLE I. Comparison of Typical Values of S_d and A Coefficients. (Skempton and Bishop, 1954)

Type	S_d	A
Ideal elastic material	+ 0.33	+ 0.33
Normally consolidated clay	+ 0.75	+ 0.5 to + 1.0
Haslemere clay, remolded	+ 0.80	+ 0.95
Silty clay, undisturbed	+ 0.3	
Compacted sandy clay		+ 0.25 to + 0.75
Heavily over-consolidated clay	- 0.62	- 0.50 to 0.0
Brasted sand, medium density	- 0.2	- 0.32

Skempton and Bishop (1954) also suggest that for the uniaxial consolidation, the volume change may be expressed by:

$$\frac{\Delta V}{V_o} = - C_c \Delta\sigma'_1 \cdot S_d \left[1 + K_o\left(\frac{1}{S_d} - 1\right)\right] \qquad (6)$$

whereas for the case of all round pressure:

$$\frac{\Delta V}{V_o} = - C_c \sigma'_a \qquad (7)$$

where C_c is the average compressibility. For equal volume changes, the combination of Eq. (6) and (7) gives the ratio of all round and vertical effective pressures as follows:

$$\frac{\Delta\sigma'_a}{\Delta\sigma'_1} = S_d \left[1 + K_o\left(\frac{1}{S_d} - 1\right)\right] \qquad (8)$$

where $K_o = \Delta\sigma'_3 / \Delta\sigma'_1$. But since $A \cong S_d$ Eq. (8) is reduced to:

$$\frac{\Delta\sigma'_a}{\Delta\sigma'_1} = K_o\,(1 - A) + A \qquad (9)$$

In applying Eq. (9) to swell pressures, the following assumptions should be pointed out:

a) The clay at the end of the test is nearing saturation, the pore pressure in the sample is approaching zero (since it is fed by water from a reservoir under atmospheric pressure) and, hence, the swell pressures are effective;

b) The effective stresses during the test remain constant, since there is no volume change, while only the pore pressure and the total stress change;

c) The expressions for the volume change are valid for infinitely small volume changes and hence may be valid also for the limiting case of zero volume change, which is supposedly the condition for the swell pressure test. In fact, minor volume changes take place during such a test and internal readjustment of structural changes certainly occur;

d) Equation (9) should be actually written as follows:

$$\frac{\Delta\sigma'_a}{\Delta\sigma'_1} = (K_o)_s\,(1 - A) + A \qquad (10)$$

where $(K_o)_s$ is the ratio of $\Delta\sigma'_3 / \Delta\sigma'_1$ for a swell pressure test of compacted clay.

e) The coefficient A is a soil characteristic determined after the soil has reached full saturation.

It is of interest to note, that Skempton (1961) arived at a similar expression for the ratio of capillary pressure and overburden pressure for London clay. *

COMPARISON WITH EXPERIMENTAL RESULTS

Komornik (1962) and Komornik and Zeitlen (1965) presented results of welling tests using consolidometer technique. In their study the lateral pressures were also measured making thus possible the determination of $(K_o)_s$ under various combinations of pressure and percent swell, including zero volume change. Table II summarizes these results in terms of the vertical and horizontal swell pressures for zero volume change.

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* According to Skempton:

$$p_k / p = K_o - A\,(K_o - 1) = K_o(1-A) - A.$$

Baker (1968) conducted a study of swell pressures of the same clay (w_L = 75%; I_p = 45%) under comparable placement conditions using triaxial technique. Table III summarizes these results in terms of the all round pressure for no volume change. Table IV presents the ratio of swell pressures measured by both techniques as given in the previous Tables.

TABLE II. Results of Swell Pressure Tests, Uniaxial Technique (Komornik, 1962)

Moisture content	Dry Density = 1.4 g/cm^3			1.3 g/cm^3			1.2 g/cm^3		
	σ'_1	σ'_3	$(K_o)_s$	σ'_1	σ'_3	$(K_o)_s$	σ'_1	σ'_3	$(K_o)_s$
%	kg/cm^2	kg/cm^2	-	kg/cm^2	kg/cm^2	-	kg/cm^2	kg/cm^2	-
20	3.3	2.4	0.73	1.20	1.4	1.15	0.7	0.8	1.14
25	3.3	2.6	0.80	1.25	1.3	1.04	0.65	0.75	1.15
30	3.2	2.3	0.72	1.50	1.4	0.94	0.6	0.6	1.0

TABLE III. Results of Swell Pressure Tests, Triaxial Technique $(K_o)_s$ = 1.0 (Baker, 1968)

Moisture Content	Dry Density	σ'_a		Moisture Content	Dry Density	σ'_a
%	g/cm^3	kg/cm^2		%	g/cm^3	kg/cm^2
25.4	1.45	3.70		25.4	1.31	1.4
27.3	1.45	3.40		27.2	1.31	1.3
30.7	1.45	3.25		30.5	1.31	1.25

TABLE IV. Ratio of Swell Pressures from Uni- and Triaxial Techniques

Moisture Content	Dry Density	σ'_a/σ'_1		Moisture Content	Dry Density	σ'_a/σ'_1
%	g/cm^3	-		%	g/cm^3	-
~ 25	~ 1.4	1.12		~ 25	~ 1.3	1.12
~ 30	~ 1.4	1.01		~ 30	~ 1.3	0.84

Analysis of the results presented in the Tables shows that for the placement conditions of the clay tested:

a. The coefficient of pressure at rest, $(K_o)_s$, (as seen from Table II), varies between a minimum of 0.72 and a maximum of 1.15, generally increasing with the decrease of the dry density. An average value of $(K_o)_s$ = 1.0 appears reasonable for the placement conditions selected for the study.

b. A comparison of the swell pressures obtained by both techniques at comparable placement conditions (as seen from Table IV) yields a pressure ratio, σ'_a/σ'_1, in a range of 0.84 to 1.12, with an average experimental value of approximately 1.0.

If, now, average values of $(K_o)_s$ = 1.0 and A = - 0.25

(heavily overconsolidated clay) * are introduced into Eq. (10) we obtain for the average ratio of pressures:

$$\frac{\sigma'_a}{\sigma'_1} = (K_o)_s\,(1-A) + A = 1.0\,(1 + 0.25) - 0.25 = 1.0 \quad (11)$$

which is in complete agreement with the experimental results. For obtaining the possible range of swell pressure ratios, minimum values of $(K_o)_s = 0.75$ and $A = -0.5$ and maximum values of $(K_o)_s = 1.15$ and $A = 0$ were introduced in Eq. (10):

$$\left(\frac{\sigma'_a}{\sigma'_1}\right)_{min} = 0.63 \quad (12)$$

and

$$\left(\frac{\sigma'_a}{\sigma'_1}\right)_{max} = 1.15 \quad (13)$$

When this range is compared with the experimental range (as seen from Table IV) it is recognized that both are in reasonable agreement.

CONCLUSIONS

The following conclusions may be derived from the paper:

a. A general expression relating effective all round and vertical pressures valid for compression and swelling is presented. In compression this relationship involves K_o and Skempton's A coefficients.

b. For the ratio of swell pressures measured by a triaxial and a consolidometer techniques the expression involves $(K_o)_s$ and Skempton's A coefficients after saturation was achieved.

c. The range of the theoretical swell pressure ratio varies between 0.63 and 1.15.

d. The expression for swell pressures has been examined in the light of tests conducted on a particular clay at a practical range of placement conditions and found to comply fairly well with the experimental results.

e. For the particular clay dealt with, it was found that the average ratio is approximately equal to 0.9, varying in a range of 0.8 to 1.1, depending mainly on the initial dry density.

f. In view of the technical difficulties involved in triaxial measurement of swell pressure, it is considered preferable to use one dimensional technique in the laboratory, applying the theoretical expression for the determination of the swell pressure under triaxial stress conditions.

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* Compacted clays are considered heavily over-consolidated since they exhibit similar stress-strain characteristics. The reason for this behavior is attributed to the effect of compaction on soil structure. From tests on typical compacted heavy clays the following values were detained for A = - 0.1, - 0.2 and - 0.4 (average of 4 tests).

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REFERENCES

Alpan, I., 1968 - "Mechanical Properties of Soils", to be published in Earth-Science Reviews, Elsevier Publishing Co. Amsterdam.

Baker, R., 1968 - "The Effect of Thixotropy on the Swelling Potential of Compacted Clay" - M.Sc. Thesis, Technion - Israel Inst. of Tech. Haifa, Israel.

Fost, R.B., 1962 - "Development of Equipment for Clay Swelling Tests", M.Sc. Thesis, Oklahoma State Univ. at Stillwater, Okla.

Holtz, W.G. and H.J. Gibbs, 1956 - "Engineering Properties of Expansive Clays". A paper presented at the Centennial Convocation of ASCE in 1952. Transactions, ASCE, Vol. 121 pp. 641-677.

Komornik, A., 1962 - "The Effect of Swelling Properties on Pile Foundations", D.Sc. (Tech) Thesis, Technion - Israel Inst. of Tech. Haifa, Israel.

Komornik, A. and J.G. Zeitlen, 1965 - "An Apparatus for Measuring Lateral Soil Swelling Pressure in the Laboratory", Proc. 6th I.C.S.M.F.E. Vol. 1, pp. 278-281.

Parcher, J.V. and Ping Chuan Lin, 1965 - "Some Swelling Characteristics of Compacted Clays" - ASCE Jour. of S.M. and F.Div.Proc. 4316, pp. 1-17.

Rengmark, F. and R. Erikson, 1953 - "Apparatus for Investigation of Swelling, Compression and Elastic Properties of Soils", Proc. 3rd I.C.S.M.F.E., Vol. 1, p. 180.

Scott, R.F., 1965 - "The Principles of Soil Mechanics", Addison - Wesley, p. 272.

Skempton, A.W. and A.W. Bishop, 1954 - "Soils", Building Materials, their Elasticity and Inelasticity, Edited by M. Reiner, North-Holland Publishing Company, Amsterdam, pp. 417-482.

Skempton, A.W., 1961 - "Horizontal Stresses in an over-Consolidated Eocene Clay", Proc. 5th I.C.S.M.F.E., Vol. 1, p. 351, Paris.