The Identification and Behavior of Compacted Expansive Clays

Identification et comportement des argiles expansives compactées

by Charles C. LADD Instructor
and
T. William LAMBE, Professor and Head, Soil Engineering Division, Massachusetts Institute of Technology, Cambridge, Mass. U.S.A.

Summary

Classification, heave and swell pressure tests were run on ten soils in order to supplement known empirical methods for predicting the swelling and shrinking behavior of soils. The heave and swell pressure tests were performed on samples of soil compacted at three water contents ranging from air dry to the plastic limit. For one soil, a detailed investigation was made of the variation of heave and swell pressure with molded water content.

The data show that the heave of a soil correlates well with its plasticity index. Equally good correlations were not obtained between the heave and the free swell, the shrinkage limit, the per cent clay, or the water content at various relative humidities. A reasonably good correlation was found between heave and swell pressure. The heave and swell pressure behavior of compacted clay can be controlled to a large degree by proper control of the molded water content and density.

A rating system is proposed to relate numerically soil properties which can be measured in the laboratory, such as heave and plasticity index, with the difficulties which may occur as a result of swelling and/or shrinkage from using the soil as a foundation for light structures.

Sommaire

Des essais de classification, de soulèvement et de pression de gonflement ont été effectués sur dix sols afin de suppléer aux méthodes empiriques mises au point pour apprécier le gonflement et le retrait des sols. Les essais de soulèvement et de pression de gonflement furent conduits sur des échantillons de chaque sol compacté à trois teneurs en eau variant entre la dessication complète et la limite de plasticité.

Pour l'un des sols on a effectué une recherche détaillée de la variation du soulèvement et de la pression de gonflement avec les teneurs en eau.

Les résultats montrent que le soulèvement d'un sol correspond bien à son P.I. (indice de plasticité), mais moins bien avec le gonflement libre, la limite de retrait, le pourcentage d'argile ou les teneurs en eau. Une assez bonne corrélation fut observée entre le soulèvement et la pression de gonflement. Le soulèvement et la pression de gonflement dans les argiles peuvent être régularisés jusqu'à un certain point par un contrôle approprié de la teneur en eau de moulage et de la densité.

Un système d'évaluation est proposé pour raccorder numériquement les propriétés des sols qui peuvent être mesurées en laboratoire comme le soulèvement et l'indice de plasticité avec les incidents que le sol peut provoquer dus au gonflement et au retrait si on l'emploie comme matériau de fondation pour des constructions légères.

I. Introduction

The need for a method for predicting the swelling and shrinking behavior of soils is evidenced by world wide reports of damage to structures founded on "expansive" clays (e.g., BARACOS and BOZOZUK, 1957; DAWSON, 1953, 1959; HOLTZ, 1959; JENNINGS, 1953; MEANS, 1959; SALAS and SERRATOSA, 1957; TSCHEBOTARIOFF, 1953; WARD, 1953; WOOLTORTON, 1950; YOUSSEF, et al, 1957). An accurate, rational method would have to be based on extensive field exploration and sampling, elaborate laboratory testing, the accumulation of climatic, hydrologic, pedologic, etc., data and theories interrelating this information. Such an approach, besides being impractical for most jobs, requires fields of knowledge which have not yet been fully developed, although progress is being made (e. g., CRONEY and COLEMAN, 1953; DE WET, 1957; FELT, 1953; JOHNS HOPKINS UNIVERSITY, 1954). Several simplified methods for predicting the magnitude of soil volume changes for complete drying and/or complete "saturation" have, however, been developed (e.g., HOLTZ, 1959; JENNINGS and KNIGHT, 1957; LAMBE and WHITMAN, 1959; MCDOWELL, 1959).

Since the type of soil greatly influences the amount of swelling and shrinking in the field, numerous empirical methods have been proposed for estimating the relative magnitude of the potential volume change of a soil, i.e., the volume change if the soil is subjected to large changes in climatic, hydrologic, etc., factors which lead to moisture changes. These empirical approaches are based on Atterberg limits, linear shrinkage, activity, free swell, per cent clay, etc., (e.g., ALTMEYER, 1956; DAWSON, 1959; DE BRUYN, et al, 1956; HOLTZ and GIBBS, 1956; KANTEY and BRINK, 1952; MCDOWELL, 1959; WILLIAMS, 1957). The purposes of this paper are : to add to this empirical approach; to show data on the influence of initial water content on volume changes; and to present a relationship between heaving and swell pressure.

II. Test Program

Classification, heave and swell pressure tests were run on ten compacted soils ranging from a sandy silt to very plastic clays, the clays all falling close to the A-line on the plasticity chart (CASAGRANDE, 1948). The classification tests consisted of Atterberg limits, grain size, free swell (HOLTZ and GIBBS, 1956), field moisture equivalent (F.M.E.) (D 426-39, ASTM, 1958) and the equilibrium water contents at relative humidities of 30, 50, 70 and 100 per cent (designated by w_{30}, w_{50}, w_{70} and w_{100}).

The heave and swell pressure tests were run on samples of soil compacted at three different "relative" water contents as follows : w_{50} (representing "Dry"); w_{100} (representing

"Moist"); and *PL* (representing "Wet"). The samples were compacted in fixed-ring consolidation containers (sample size : 2·75 in. diameter by 0·625 in. high in most cases, with top of sample 0·25 in. below top of container) by a 5.5 lb. hammer falling 12 in. giving compactive efforts of 13,000, 31,000 and 55,000 ft. lb. per cu.ft. for Wet, Moist and Dry molded water contents respectively. (The compactive effort was arbitrarily increased with decreasing molded water content in an attempt to simulate the highest densities encountered in the field.) Porous stones were placed on the tops and bottoms of the samples which were then inundated with water for the heave and swell pressure tests.

The heave test determined the final per cent change in sample height (designated by H_{200}) under a pressure of 200 lb. per sq. ft. From 1 to 4 days was usually required for equilibrium. For the swell pressure test, the pressure on the top of the sample, which was measured by a proving ring, was manually controlled to keep the sample height constant to within ·0002 in. An elapsed time varying from 1 hour to 1 day was required to attain the equilibrium pressure (designated by S.P.).

III. Test Results

The classification, H_{200} and *S.P.* data are listed in Table I. Column F of the table shows the calculated per cent volume change ($V_{F.M.E.\text{-}SL}$) resulting from drying a saturated sample from the *F.M.E.* to the shrinkage limit. Plots of H_{200} for Dry, Moist and wet samples versus *PI* are shown in Fig. 1. The relationship between *PI* and $V_{F.M.E.\text{-}SL}$ is presented in Fig. 2 and that between H_{200} and *S.P.* in Fig. 3. Heave and swell pressure data from Salas and Serratosa, 1957 (adjusted to conform to H_{200}) have been added for comparison. Plots of H_{200} and *S.P.* versus log time for Moist samples of two soils are presented in Fig. 4. The variations in H_{200}, *S.P.* and dry density with molded water content for Vicksburg Buckshot clay are shown in Figs. 5 and 6.

Table 1

Classification, heave and swell pressure test results.

Résultats des essais de classification, soulèvement, et pression de gonflement

No.	Name	Location	A: Atterberg Limits (%) LL	SL[1]	PI	B: Activity[2]	C: F.M.E. (%)[3]	D: Free[4] Swell (%)	E: Water Contents vs. Rel. Humidity w_{50}	w_{100}	F: $V_{F.M.E.\text{-}SL}$ (%)[5]	G: H_{200} (%) Dry	Moist	Wet	H: S.P. (lb./sq.ft.) Dry	Moist	Wet	I: PVC Rating
1.	Iredell Clay	Fairfax County, Virginia, U.S.A.	81	14·5	47	1·3	47	95	9·5	~ 17	40	25	22·5	7	~ 10,500	11,600	2,400	7·8
2.	Houston Black Clay	Temple, Texas, U.S.A.	71	18	44	0·65	47	—	8	19	35	~ 20	15	5·5	~ 8,000	—	—	6·8
3.	Enon Loam	Fairfax County, Virginia, U.S.A.	69	17	42	0·95	46	—	5	~ 17	36	14·5	13	4	—	—	1,400	6·1
4.	Vicksburg Buckshot Clay	Vicksburg, Mississippi, U.S.A.	65	16	38	1·1	48	75 (50-100)	7	~ 14	38	24	13	6·5	~ 8,000	7,000	2,800	6·4
5.	Texas Black Clay	Temple, Texas U.S.A.	58	—	34	0·7	38	75	7	14	30 (Estimated)	—	~ 17	4	—	5,400	1,900	5·7
6.	Siburua Shale	Siburua, Venezuela	62	15	30	0·4	34	135 (110-160)	—	~ 16	28	—	17	4	—	10,000?	650	5·6
7.	Keyport Soil	Norfolk County, Virginia, U.S.A.	44	17	21	0·7	33	43	3	9	23	7	8	~ 1	—	7,600	~ 400	3·2
8.	Boston Blue Clay	Cambridge, Mass. U.S.A.	35	18·5	13	0·25	29	15 (10-25)	1·5	~ 5	16	—	4·5	0·1	—	1,800	~ 200	1·8
9.	Vicksburg Loess	Vicksburg, Miss. U.S.A.	33·5	21·5	10	0·65	29	—	2·5	~ 7	11·5	~ 0	2·5	— 1	~ 200	900	< 200	1·2
10.	Guelph Sandy Loam	Sanilac County Michigan, U.S.A.	21	13 ?	7	0·7	16	35 (30-40)	—	~ 5	6	—	0·5	— 0·4	—	500	< 200	0·6

[1] Remolded shrinkage limit.
[2] Activity = *PI*/% clay size.
[3] *F.M.E.* = Field Moisture Equivalent.
[4] $\text{Free Swell} = \dfrac{(\text{Final Volume} - \text{Initial Dry Volume}) \times 100}{\text{Initial Dry Volume}}$
[5] $V_{F.M.E.\text{-}SL}(\%) = \dfrac{F.M.E. - SL}{\dfrac{F.M.E.}{100} + \dfrac{1}{G_S}}$

IV. Discussion of Test Results

Table I and Fig. 1 show that the amount of heave (H_{200}), for a given "relative" water content, correlates well with the *PI* of these soils. Less well defined correlations exist between H_{200} and ω_{100}, free swell, per cent clay and shrinkage limit. For a given soil, there is a large increase in H_{200} in going from a wet to a Moist "relative" water content (the compacted dry density also increased, often by 5 to 10 lb. per cu.ft.), but no consistent trend in going from Moist to Dry (if the compacted dry density decreased considerably, H_{200} remained almost constant or decreased). Since the *PI* of a soil is related to its $V_{F.M.E.\text{-}SL}$ (Fig. 2), a high swelling soil can also undergo large volume changes due to drying (the water content of samples compacted in the Moist condition after the H_{200} test averaged 93 per cent * of the *F.M.E.*).

Fig. 3 shows a reasonably good correlation between H_{200} and *S.P.* for pairs of samples, the samples of each pair having the same water content and density, of over twenty different soils. The *S.P.* of a sample develops much more rapidly than its H_{200} (Fig. 4) since much less water is required for full development.

The data in Figs. 5 and 6 (which corroborate corresponding data obtained by Holtz and Gibbs, 1956) demonstrate that the heave and swell pressure behavior of a compacted soil can be controlled to a large degree by proper control of the molded water content and density. (Seed and Chan, 1959, show that the type of compaction may also be important.)

To estimate the effect on heave of surcharge pressures greater than 200 lb. per sq. ft. during swelling, the following empirical approach is suggested. On a plot of heave versus pressure, mark H_{200} (from Fig. 1 or measured value) and the corresponding *S.P.* (from Fig. 3 or measured value).

* Wooltorton, 1954, quotes 75 per cent of the F.M.E. as an average for clayey subgrade soils not subjected to evaporation.

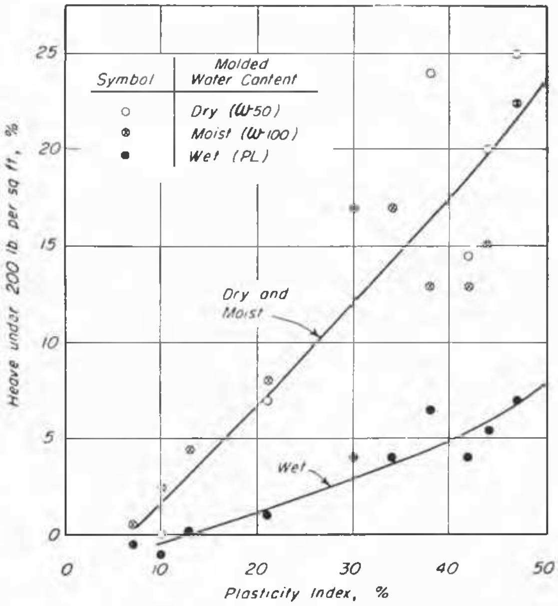

Fig. 1 Heave versus plasticity index.
Soulèvement en fonction de l'indice de plasticité.

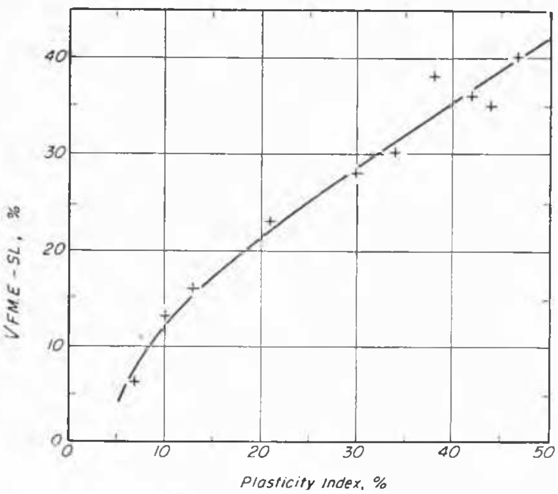

Fig. 2 Shrinkage versus plasticity index.
Retrait en fonction de l'indice de plasticité.

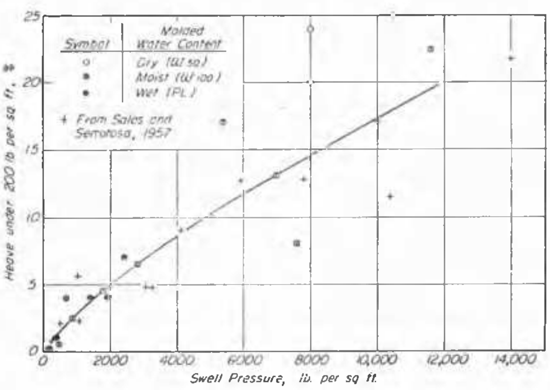

Fig. 3 Heave versus swell pressure.
Soulèvement en fonction de la pression de gonflement.

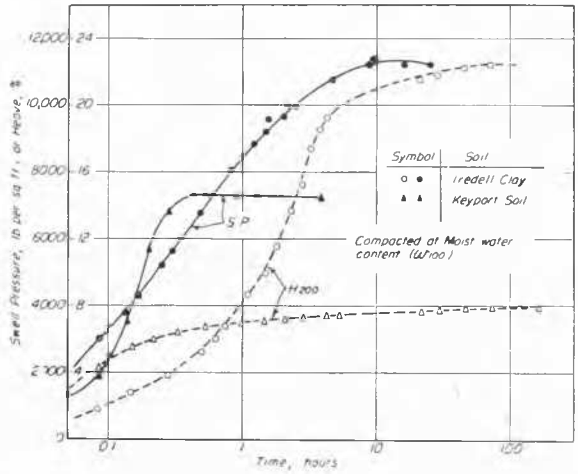

Fig. 4 Swell pressure and heave versus time.
Pression de gonflement et soulèvement en fonction du temps.

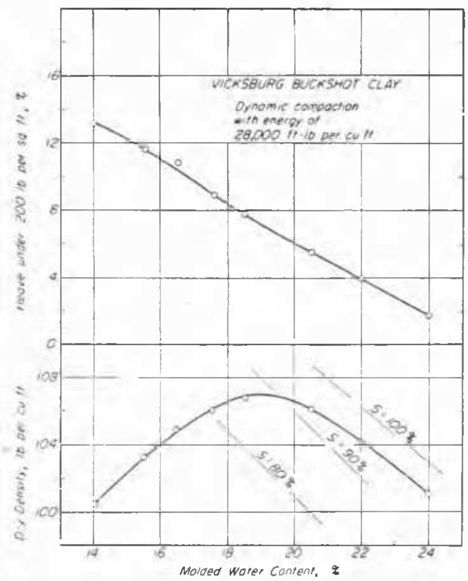

Fig. 5 Molded water content versus dry density and heave.
Teneur en eau au moulage en fonction de la densité sèche et du soulèvement.

At pressure values equal to 1/2 and 1/4 of the *S.P.*, plot heave values equal to 1/4 and 1/2 of H_{200} respectively. The curve connecting the four points estimates the relationship between the amount of heave and the confining pressure applied during swelling, as illustrated in Fig. 7. The heave values estimated in this manner are usually somewhat conservative, i.e., too high, when compared with measured values (Holtz and Gibbs, 1956; McDowell, 1959).

V. Conclusions

Using the curves in Fig. 1, one can obtain from the measured *PI* of a soil an approximate estimate of the potential heave of a compacted soil under a light load for extremes in initial "relative" water contents. Water contents in the Dry-Moist range are likely to occur in uncovered soils in climates characterized by rates of surface water evaporation which greatly exceed the rates of rainfall (Salas and Serratosa, 1957).

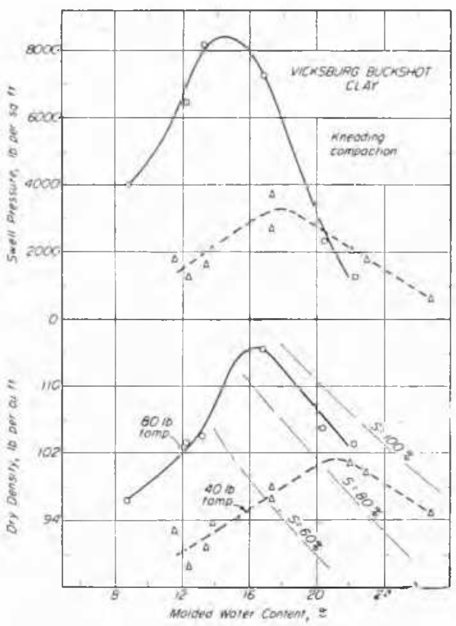

Fig. 6 Molded water content versus dry density and swell pressure.

Teneur en eau au moulage en fonction de la densité sèche et de la pression de gonflement.

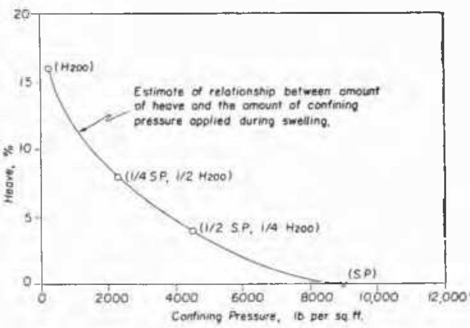

Fig. 7 Estimation of heave versus confining pressure.

Estimation du soulèvement en fonction de la pression d'étreinte.

The density of the compacted Dry and Moist samples was equal to 85 $\pm$ 10 per cent of the remolded shrinkage limit of the soils and probably exceeds the density of most undisturbed or compacted field samples for the same water contents. Thus heaves obtained from Fig. 1 should usually be conservative. Soils protected from evaporation or compacted near optimum for Standard AASHO are examples of situations wherein "relative" water contents in the Wet range are likely to occur.

One should use Fig. 1 only as a guide since : (1) the data were obtained on only 10 soils, most of which fall near the A-line ; (2) small changes in water content, surcharge pressure, and/or density (as caused by different compactive efforts, for example) can cause large changes in the amount of heave ; (3) undisturbed samples may heave far less than remolded samples at the same water content and density ; and (4) H_{200} represents the heave if the sample has unlimited access to water, which may not happen in the field.

To characterize the degree of "expansiveness" of soils, the authors suggest a tentative rating system called Potential Volume Change (PVC) based on measurements of H_{200}, PI, w_{100} and $V_{F.M.E.\text{-}SL}$. The PVC rating system, which is a modification of those reported by Holtz, 1959 ; Altmeyer, 1956 ; de Bruyn, et al, 1956 ; Dawson, 1959 and Kantey and Brink, 1952, and some methods for determining the PVC of a soil are presented in Table 2. Column I

Table 2

Classification of soils with respect to potential volume change due to swelling and shrinkage

Classification des sols se rapportant au changement de volume potential causé par gonflement et retrait

PVC	*Category*
< 2	Noncritical
2-4	Marginal
4-6	Critical
> 6	Very Critical

PVC	A H_{200}(%) *of Dry and/or Moist Samples*	B PI(%)	C w_{100}(%)	D $V_{F\cdot M\cdot E\cdot\text{-}SL}$
2	5	15	6	15
4	11	25	11	24
6	17	35	16	33

Note : (1) To interpolate, plot PVC values versus H_{200}, PI, etc. values (which form a straight line ; e.g., H_{200} = 8 % corresponds to PVC = 3.

(2) Combined PVC = (2 × A + B + C + D)/5. i.e., Column A counts double.

of Table 1 shows the PVC of the ten soils tested. This rating system attempts to correlate numerically several soil properties with the difficulties, as a result of swelling and/or shrinkage, which may occur from using the soil as a foundation for light structures. The value of this system is that it permits one to combine several methods of rating to achieve a single numerical rating, as suggested in Note (2) of Table 2. Since the PVC ratings proposed in Table 2 are tentative and since field behavior varies with climate (among other things), the authors hope that workers throughout the world will check and, if required, modify the proposed system to fit better the pattern of behavior of "expansive" soils in their area.

VI. Acknowledgements

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