CHAPTER 4

LABORATORY INVESTIGATIONS

4-1. Identification of swelling soils

Soils susceptible to swelling can be identified by classification tests. These identification procedures were developed by correlations of classification test results with results of one-dimensional swell tests performed in consolidometers on undisturbed and compacted soil specimens. Classification data most useful for identifying the relative swell potential include the liquid limit (LL), the plasticity index (PI), the COLE (para 2-2*b*(2)), the natural total soil suction τ°_{nat}, and physicochemical tests. Several of the more simple and successful methods recommended for identifying swelling soil from classification tests described below were developed from selected soils and locations combined with the results of limited field observations of heave. These procedures assume certain environmental conditions for surcharge pressure (e.g., 1 pound per square inch) and changes in moisture from the initial water content (e.g., to saturation or zero final pore water pressure),

a. WES classification. Consolidometer swell tests were performed on 20 undisturbed clays and clay shales from the states of Mississippi, Louisiana, Texas, Oklahoma, Arizona, Utah, Kansas, Colorado, Wyoming, Montana, and South Dakota. Results of these tests for a change in moisture from natural water content to saturation at the estimated in situ overburden pressure (pressures corresponding to depths from 1 to 8 feet) indicated the degrees of expansion and potential percent swell S_p shown in table 4-1. The S_p represents the percent increase in the vertical dimension or the percent potential vertical heave. The classification may be used without knowing the natural soil suction, but the accuracy and conservatism of the system are reduced. Soils that rate low may not require further swell tests, particularly if the LL is less than 40 percent and the PI is less than 15 percent. Soils with these Atterberg limits or less are essentially nonexpansive. However, swell tests may be required for soils of low swelling potential if the foundation of the structure is required to maintain small differential movements less than 1 inch (para 4-2c).

Table 4-1. WES Classification of Potential Swell

Classification of potential swell	Potential swell S_p percent	Liquid limit LL percent	Plasticity index PI percent	Natural soil suction τ°_{nat} tsf
Low	<0.5	<50	<25	<1.5
Marginal	0.5-1.5	50-60	25-35	1.5-4.0
High	>1.5	>60	>35	>4.0

b. Texas Department of Highways and Public Transportation (TDHPT) method. This procedure, which is known as Tex-124-E of the TDHPT Manual of Testing Procedures, is based on the swell test results of compacted soils from Texas. Field heaves of each soil stratum in the profile are estimated from a family of curves using the LL, PI, surcharge pressure on the soil stratum, and initial water content. The initial water content is compared with maximum (0.47 LL + 2) and minimum (0.2 LL + 9) water contents to evaluate the percent volumetric change. The potential vertical rise (PVR) of each stratum is found from a chart using the percent volumetric change and the unit load bearing on the stratum. These PVRs for depths of as much as 30 feet or more are summed to evaluate the total PVR. This method may overestimate the heave of low plasticity soils and underestimate the heave of high plasticity soils.

c. Van Der Merwe method. This method evolved from empirical relationships between the degree of expansion, the PI, the percent clay fraction, and the surcharge pressure, The total heave at the ground surface is found from

$$\Delta H = \sum_{D=1}^{\bar{D}=n} F \cdot PE \qquad (4\text{-}1)$$

where

AH = total heave, inches
D = depth of soil layer in increments of 1 foot
= increment at the deepest level
F = reduction factor for surcharge pressure, $F = 10^{-D/20}$
PE = potential expansiveness in inch/foot of depth (fig. 4-1)

The PE is found by assumed values of PE = 0, ¼, ½, and 1 inch/foot for low, medium, high, and very high levels, respectively, of potential expansiveness, defined in figure 4-1 as functions of the PI and the minus 2μ fraction. The PE values are based on consolidometer swell test results and field observations. This method does not consider variations in initial moisture conditions.

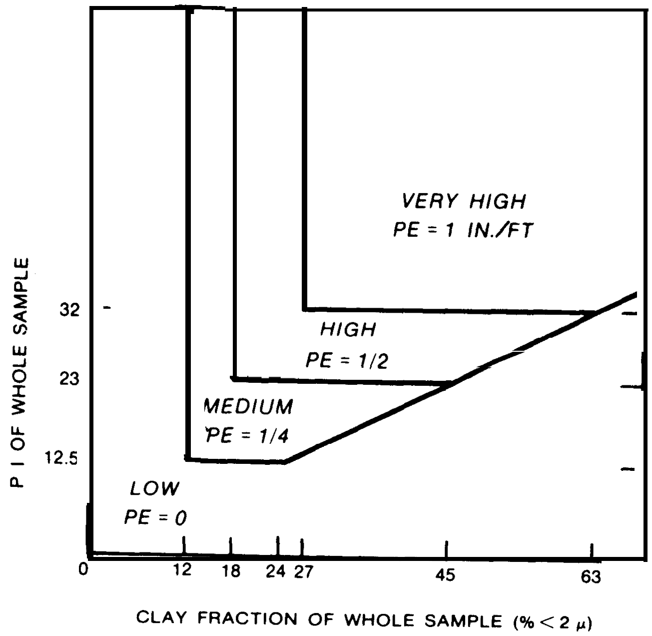
d. Physiochemical tests. These tests include identification of the clay minerals, such as montmorillonite, illite, attapulgite, and kaolinite, with kaolinite being relatively nonexpansive, cation exchange capacity (CEC), and dissolved salts in the pore water. The CEC is a measure of the property of a clay mineral to exchange ions for other anions or cations by treatment in an aqueous solution. The relatively expansive montmorillonite minerals tend to have large CEC exceeding 80 milliequivalents per 100 grams of clay, whereas the CEC of nonexpansive kaolinite is usually less than 15 milliequivalents. The presence of dissolved salts in the pore water produces an osmotic component of soil suction that can influence soil heave if the concentration of dissolved salts is altered. In most cases, the osmotic suction will remain constant and not normally influence heave unless, for example, significant leaching of the soil occurs.

e. Other methods. Other methods that have been successful are presented in table 4-2. These methods lead to estimates of the percent swell S_p or vertical heave assuming that all swell is confined to the vertical direction, and they require an estimate of the depth of the active zone X_a (para 5-4c). Both the TDHPT and Van Der Merwe methods do not require estimates of X_a since computations extend down to depths where the computed heaves become negligible. The Van Der Merwe, McKeen-Lytton, and Johnson methods tend to give maximum values or may overestimate heave, whereas the remaining methods tend to give minimum values or may underestimate heave when compared with the results of field observations at three WES test sections.

f. Application. These identification tests along with the surface examination of paragraph 3-2 can indicate problem soils that should be tested further and can provide a helpful first estimate of the expected in situ heave.

(1) More than one identification test should be used to provide rough estimates of the potential heave because limits of applicability of these tests are not known. In general, estimates of potential heave at the ground surface of more than 1/2 inch may require further laboratory tests, particularly if local experience suggests swelling soil problems. Soil strata in which the degree of expansion is medium or high should also be considered for further swell tests (para 2-2c).

(2) The McKeen-Lytton method of table 4-2 has been applied to the prediction of potential differential heave for average changes in moisture conditions by the Post-Tensioning Institute (PTI) for design and con-



(Based on data from Van Der Merwe, 1964, published in The Civil Engineer with permission granted by the S. A. Institute of Civil Engineers, Johannesburg, South Africa)

Figure 4-1. Relationship used to determine the potential expansiveness for Van Der Merwe's empirical method.

Table 4-2. Other Empirical Methods for Prediction of Potential Heave.

Method	Description[a]
Vijayvergiya and Ghazzaly	$\log S_p = 1/12(0.44LL - w_o + 5.5)$ from initial water content to saturation for 0.1-tsf surcharge pressure.
Schneider and Poor	$\log S_p = 0.9(PI/w_o) - 1.19$ for no fill or weight on the swelling soil to saturation.
McKeen-Lytton by McKeen	$S_p = -100\gamma_h \log_{10} \frac{\bar{\tau}_f}{\bar{\tau}_o}$ where γ_h = suction compression index τ_f = final weighted in situ suction τ_o = initial in situ weighted suction The γ_h is found from a chart using the CEC, PI, and percent clay. The weighted suction is given by $\bar{\tau} = 0.5\tau_1 + 0.3\tau_2 + 0.2\tau_3$ where τ_1, τ_2, and τ_3 are in situ suctions measured in the top, middle, and bottom third of the active zone.
Johnson	$PI \geq 40 \quad S_p = 23.82 + 0.7346PI - 0.1458H - 1.7w_o + 0.0025PIw_o - 0.00884PIH$ $PI \leq 40 \quad S_p = -9.18 + 1.5546PI + 0.08424H + 0.1w_o - 0.0432PIw_o - 0.01215PIH$ for 1 psi surcharge pressure to saturation.

---

[a] S_p = percent swell; LL = liquid limit in percent; PI = plasticity index in percent; w_o = initial water content in percent; H = depth of soil in feet.

struction of stiffened slabs-on-grade in expansive soils. The PTI structural design procedure is described in paragraph 6-3b.

4-2. Testing procedures

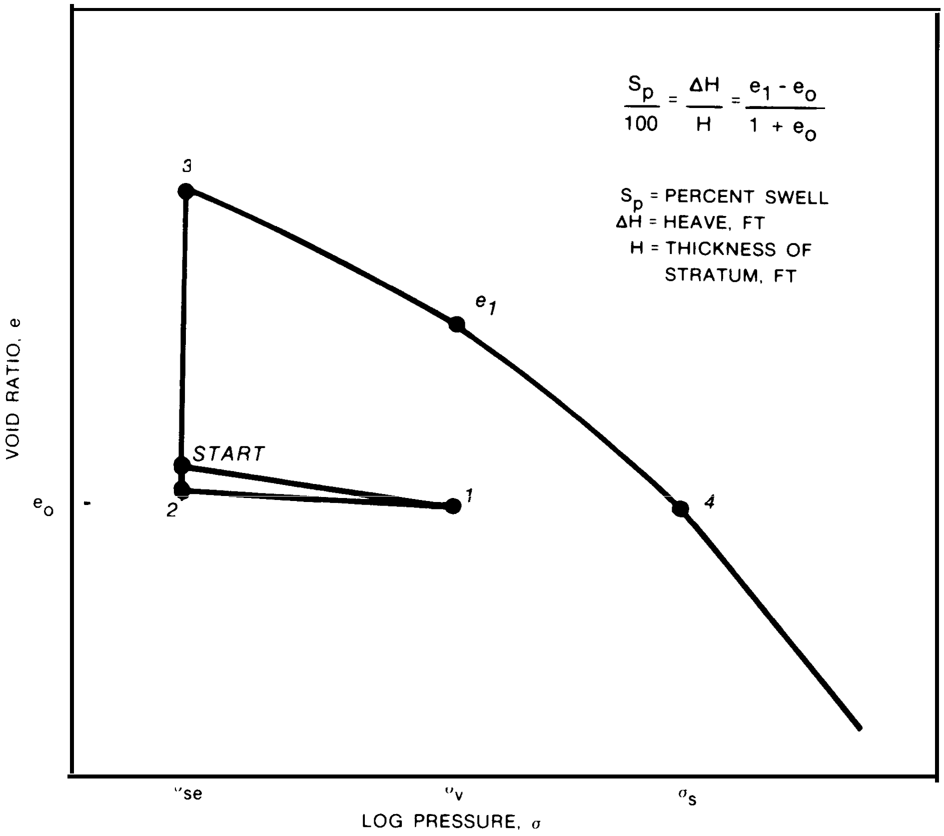
Quantitative characterization of the expansive soil from swell tests is necessary to predict the anticipated potential soil heave devaluation of swell behavior and predictions of total and differential heave are determined from the results of tests on undisturbed specimens. Strength tests may be performed to estimate the bearing capacity of the foundation soil at the final or equilibrium water content. A measure of shear strength with depth is also needed to evaluate soil support from adhesion along the perimeter of shaft foundations or the uplift that develops on the shaft when swelling occurs.

a. Swell tests. Laboratory methods recommended for prediction of the anticipated volume change or potential in situ heave of foundation soils are consolidometer swell and soil suction tests, The WES expansive soil studies show that consolidometer swell tests may underestimate heave, whereas soil suction tests may overestimate heave compared with heaves measured in the field if a saturated final moisture profile is assumed (chap 5). The economy and simplicity of soil suction tests permit these tests to be performed at frequent intervals of depth from 1 to 2 feet.

(1) *Consolidometer.* Recommended consolidometer swell tests include swell and swell pressure tests described in Appendix VIII of EM 1110-2-1906. The swell test may be performed to predict vertical heave AH of soil thickness H when the vertical overburden and structural pressures on thickness H are known prior to the test. The total vertical heave at the ground surface is the sum of the AH for each thickness H in the soil profile. Figure 5-4 illustrates the application of swell test data. The swell pressure test is performed to evaluate the swell pressure σ_s and swell index C_s required for prediction of vertical heave by equation (5-8) discussed in paragraph 5-4e. The confining pressure required to restrain heave is defined as σ_s. When little is known about swell behavior or groundwater conditions, an appropriate swell testis given in *(a)* and *(b)* below.

(a) An initial loading pressure, simulating field initial (preconstruction) vertical pressure &, should be applied to determine the initial void ratio e_o, point 1 of figure 4-2, then removed to the seating pressure σ_{se} (i.e., the lowest possible load) prior to adding distilled water, point 2. The specimen is allowed to expand at the seating pressure until primary swell is complete, point 3, before applying the consolidation pressures.

(b) The swell test of figure 4-2 can eliminate the need for additional tests when behavior is different than that anticipated (e.g., the specimen consolidates rather than swells following addition of water at loading pressures greater than the seating pressure). The void ratio-log pressure curve for final effective pressures, varying from the seating to the maximum applied pressure, can be used to determine heave or settlement with respect to the initial void ratio e_o. Net settlements will occur for final effective pressures exceeding the swell pressure σ_s. Figure 4-2 illustrates how the percent swell S_p or heave ΔH may be found with respect to the initial vertical pressure&.



U. S. Army Corps of Engineers

Figure 4-2. Simple swell test.

(*c*) The δ_s in figure 4-2 is defined as confining pressure that must be applied to the soil to reduce the volume expansion down to the (approximated) in situ e_o in the presence of free water. Consolidometer tests in appendix VIII of EM 1110-2-1906 tend to provide lower limits of the in situ swell pressure, while the simple swell test, figure 4-2, tends to provide upper limits. The maximum past pressure is often a useful estimate of the in situ swell pressure at e_o.

(2) *Soil suction.* Soil suction is a quantity that also can be used to characterize the effect of moisture on volume changes and, therefore, to determine the anticipated foundation soil heave. The suction is a tensile stress exerted on the soil water by the soil mass that pulls the mass together and thus contributes to the apparent cohesion and undrained shear strength of the soil. The thermocouple psychrometer and filter paper methods, two of the simplest approaches for evaluation of soil suction and characterization of swelling behavior, are described in appendix B. The suction procedure, which is analogous to the procedure for characterization of swell from consolidometer swell tests, is relatively fast, and the results can increase confidence in characterization of swell behavior.

b. Strength tests. The results of strength tests are used to estimate the soil bearing capacity and load/deflection behavior of shaft or other foundations. The critical time for bearing capacity in many cases is immediately after completion of construction (first loading) and prior to any significant soil consolidation under the loads carried by the foundation. The long-term bearing capacity may also be critical in expansive foundation soils because of reductions in strength from wetting of the soil.

c. Application. Sufficient numbers of swell and strength tests should be performed to characterize the soil profiles. Swell tests may not be necessary on specimens taken at depths below permanent deep groundwater levels.

(1) The representative mean of the swell and strength parameters (and lower limit of the scatter in strength parameters) of each distinctive soil stratum should be determined down to depths of 1.5 times the minimum width of mat slabs to a maximum of 100 feet and to at least three base diameters beneath the base of shaft foundations.

(2) One consolidometer swell and one strength test should be performed on specimens from at least five undisturbed samples at different depths within the depth of the anticipated active zone (e.g., within 10 to 20 feet beneath the base of the foundation). Suction tests may also be performed at relatively frequent depth intervals (e.g., l-foot increments) to better characterize swell behavior and thereby increase confidence in prediction of potential heave discussed in chapter 5.

(3) One consolidometer swell and one strength test should be performed on specimens from each undisturbed sample (or at intervals of 2.5 feet. for continuous sampling) at depths above the base of deep shaft foundations to permit evaluation of the adjacent soil heave and uplift forces exerted on the shaft/soil interface, Suction tests may also be performed to further characterize swell behavior and increase confidence in prediction of potential heave.

(4) Suction test results can characterize the pore pressure profile by indicating depths of desiccation and wetting, which are useful for minimizing potential foundation problems from soil movement and for evaluating remedial measures to correct problems.