EXPANSIVE SOILS

The Clay Particle

The three basic minerals for the clay are:

1. Kaolinite
2. Illite
3. Montmorillonite

The following figure shows schematic diagrams of idealized structures of these three minerals. The bonding between the different building blocks plays a very important part in the behavior of the different minerals.

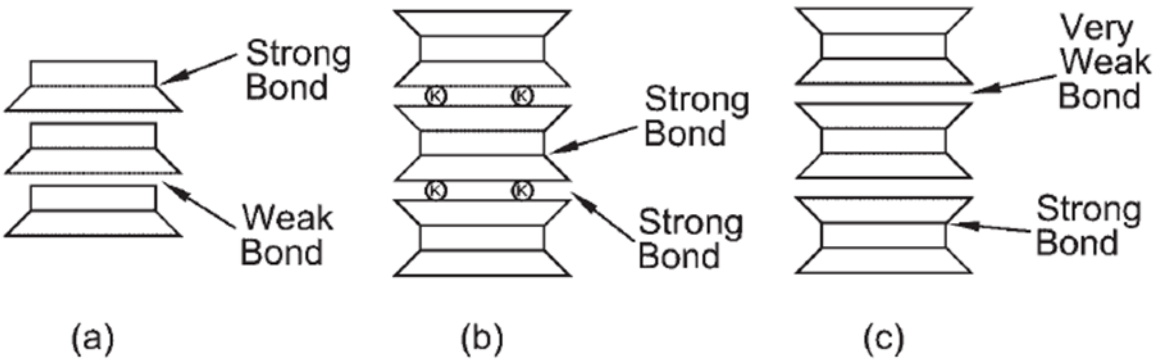


Figure (1): (a) kaolinite; (b) illite; (c) montmorillonite.

The term bentonite is often used in reference to expansive soils. This term refers to clays that are rich in montmorillonite. Bentonite is a highly plastic, swelling clay material containing primarily montmorillonite. It is mined commercially and is used for a variety of purposes such as drilling fluids, slurry trenches, cosmetics, paint thickeners, and many others. Not all expansive soils are bentonite, but they are frequently referred to simply as bentonite, usually by nonengineer laymen.

Table 2. 2 Some types of bentonite clay with free swell (Athanassopoulos, 2011)

Name	Free swell %
1.Sodium montmorillonite	1400 - 2000
2. Calcium montmorillonite	45 - 150
3.Halloysists	70 - 100
4. Indian bentonite	300 - 1000

Identification of Expansive Soils

The identification methods used to identify the swell potential of expansive soils can generally be grouped into two categories.

- The first category mainly involves measurement of physical properties of soils, such as Atterberg limits, free swell, and potential volume change.
- The second category involves measurement of mineralogical and chemical properties of soils, such as clay content, cation exchange capacity, and specific surface area.

Expansion Index (EI) Test

The expansion index test was developed in southern California in the late 1960s in response to requests from several local agencies for the standardization of testing methods in that area.

- The method was evaluated statistically by five different testing laboratories in California, and was adopted as a standard by many California government agencies and the Uniform Building Code (1997) (UBC Standard 18-2). ASTM International has published a standard method of test for the EI test (ASTM D4829).
- The test is basically a consolidation-swell oedometer test. The test consists of compacting a soil at a degree of saturation of 50% ± 2% under standard conditions. A vertical stress of 144 psf (7 kPa) is applied to the sample, and the sample is

inundated with distilled water. The expansion index, reported to the nearest whole number, is calculated by the following equation.

$$\mathrm{EI} = \frac{(\textit{final thickness} - \textit{initial thickness})}{\textit{initial thickness}} \times 1,000$$

The expansion potential of the soil is classified according to the expansion index, as shown in the table.

Expansion Potential Based on Expansion Index

Expansion Index (EI)	Expansion Potential
0–20	Very low
21–50	Low
51–90	Medium
91–130	High
> 130	Very high

Oedometer Testing

- When Terzaghi first set forth his concept of effective stress, his hypothesis was verified on the basis of experimental data obtained using a piece of equipment termed the oedometer (Terzaghi 1925 and 1943).
- This apparatus is also termed a consolidometer. This test has found widespread use for measurement of soil properties used in computing expected settlement of foundations. The test entails one-dimensional loading of a laterally confined soil sample to replicate geostatic conditions. Thus, it was only natural for this type of testing to be used for determining the requisite parameters for computing expected heave, or collapse, of unsaturated soils (Chen 1988; Nelson and Miller 1992; Fredlund, Rahardjo, and Fredlund 2012).
- The use of the oedometer test to measure swelling has a distinct advantage over other tests because the testing equipment is commonly available, and most

geotechnical engineers are familiar with the testing methods. A typical oedometer is shown in Figure 2.

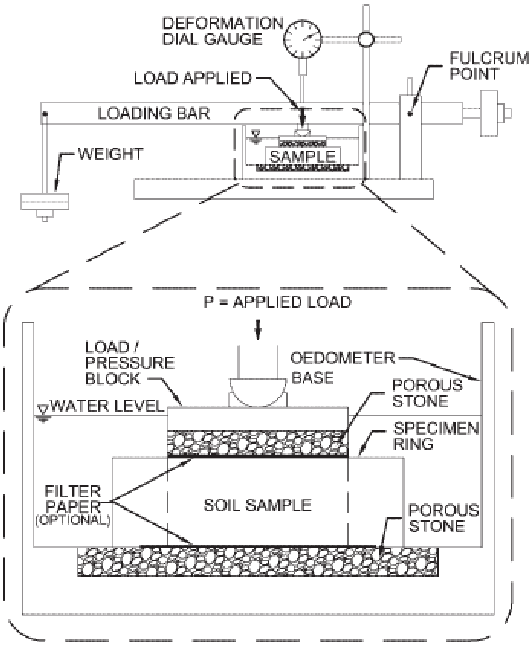


Figure (2): Oedometer apparatus.

- For expansive soils two basic types of oedometer tests are commonly performed. The most common type is the consolidation-swell (CS) test, in which the sample is initially subjected to a prescribed vertical stress in the oedometer, and inundated under that vertical stress. The vertical strain that occurs due to wetting, termed the percent swell, $\varepsilon s\%$, is measured. After the swelling has been completed the sample may or may not be subjected to additional vertical load. The stress that would be required to restore the sample to its original height is termed the "consolidation-swell swelling pressure," $\sigma''cs$.
- The constant volume (CV) test is another common method of test. In this test the sample is initially subjected to a prescribed vertical stress, but during inundation the sample is confined from swelling and the stress that is required to prevent swell

is measured. That stress is termed the constant volume swelling pressure, σ''_{cv}. These tests will be described and discussed in detail below.

- Standards for the performance of oedometer tests to measure **expansion potential** are set forth in ASTM D4546. In contrast to ASTM D2435/D2435M, which relates to compressibility of nonswelling soils, these test methods were developed specifically for expansive soils.
- Oedometer test results are normally plotted in the form of vertical strain as a function of the applied stress, which is plotted on a logarithmic scale. The typical forms of each test are shown in the following figure.

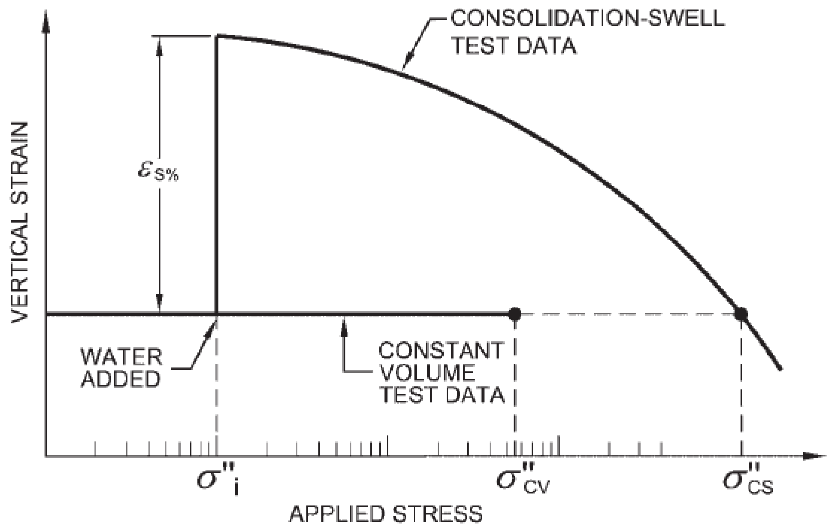


Figure 3: Oedometer test results.

Consolidation-Swell and Constant Volume Tests

In the CS test, a soil specimen is placed in a consolidation ring and subjected to a prescribed vertical stress, termed the inundation stress, σ''_i . After loading under the inundation stress for a period of time, usually about 24 hours, the specimen is inundated and allowed to swell while still being loaded at the inundation stress. The inundation stress may represent the overburden stress, overburden stress plus the applied load from the structure, or some other arbitrary value. An inundation stress of 24 kPa or 48 kPa is commonly used for foundations. Inundation stresses of 10 kPa are commonly used for pavement designs. After swelling, the specimen is subjected to additional load in increments, and may be unloaded in decrements.

- Figure 3 showed the two-dimensional depiction of oedometer test results. In consideration of the fact that the constitutive relationship is three-dimensional in nature as shown in Figure 4, the actual stress paths are three-dimensional in nature as well.
- The stress paths are shown in Figure 4. The initial state of the soil in an oedometer test is represented by the point labeled K in Figure 4. At that point the soil suction is equal to a value designated as ψ_{m1}. The net normal stress is that at which the sample will be inundated, i.e., the inundation stress, σ''_i . When the sample is inundated, the suction is reduced to ψ_{m0} and the soil swells along the path KB.
- The projection of that stress path on the plane defined by the axes for ε_s% and log σ'' is the line GB. The sample is then loaded back to its original height along the path BA. The value of stress corresponding to point A is the consolidation-swell swelling pressure, σ''_{cs}.
- In a conventional constant volume (CV) oedometer test, the sample begins at point K, but because it is constrained from swelling it develops a confining stress as the suction decreases to ψ_{m0} and the stress path would be along a line such as KE. The value of stress corresponding to point E is the constant volume swelling pressure, σ''_{cv}.
- Due to hysteretic effects, the value of σ''_{cv} is generally less than that of σ''_{cs}. The reason for this is somewhat intuitive in that it should be easier to prevent water molecules from entering into the soil lattice than to force the water out once it has entered into the soil. All of the factors contributing to the hysteresis are not known.
- We can consider next a sample inundated at a stress condition for which the initial stress conditions correspond to those existing at some point in an actual soil

stratum. Hypothetical conditions are labeled as point J in Figure 4.When inundated that sample would swell along a stress path such as JD. Point D will fall between points B and E. It has been shown that the line BDE is close to being a straight line (Justo, Delgado, and Ruiz 1984; Reichler 1997; Nelson, Reichler, and Cumbers 2006).

- Thus, the slope of the line BDE defines the relationship between the percent swell, $\varepsilon s\%$, that a soil will exhibit when wetted and the stress to which it is subjected when wetted. The slope of that line is a constitutive parameter, CH, which is termed the heave index.
- It is important to note that as shown in Figure 4, the line BDE, which defines CH, depicts the expansion due to suction changes. Thus, it is a constitutive relationship that recognizes both of the independent stress state variables, σ'' and (ua – uw).

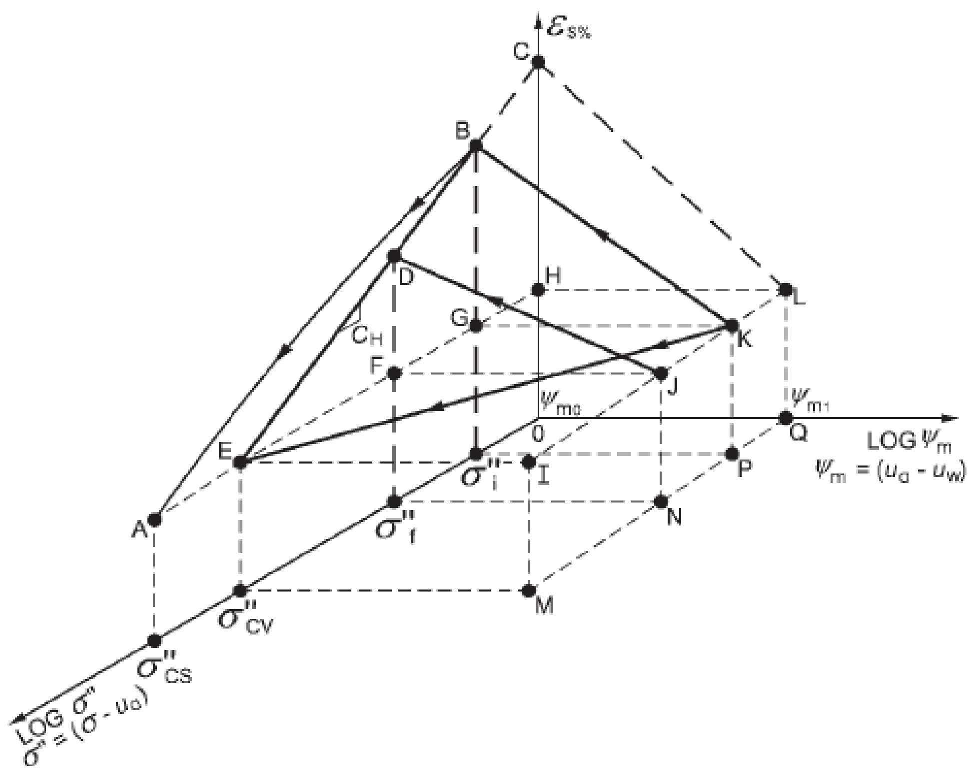


Figure (4): Stress path for soil expansion (data from Reichler 1997).

For practical purposes, it is not necessary to plot the entire three-dimensional stress paths in order to determine CH. Figure 5 shows the projection of the stress paths from Figure 4 onto the εs% and log σ'' plane. The results of both the consolidation-swell test and the constant volume test are shown as the paths GBA and GFE, respectively.

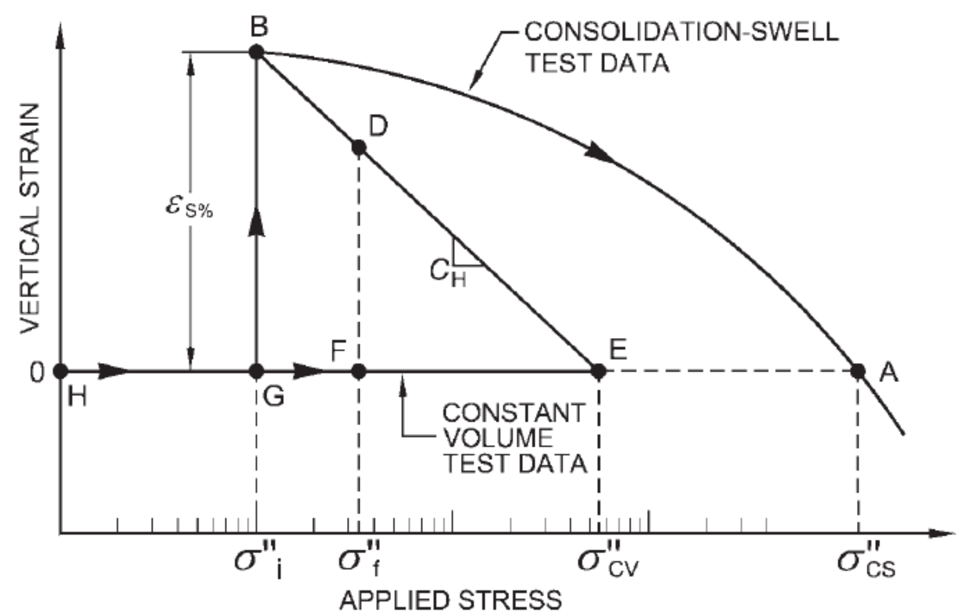


Figure 5: Determination of heave index, C_H.

The parameter CH, is the slope of the line BDE in Figure 5 and is given by the following equation:

$$C_H = \frac{\varepsilon_{s\%}}{100 \times \log\left[\frac{\sigma''_{cv}}{\sigma''_i}\right]}$$

where:

εs% = percent swell corresponding to the particular value of σ''i expressed as a percent, and

σ''i = vertical stress at which the sample is inundated.

The value of CH can be determined, therefore, from the results of a CS test and a CV test using identical samples of the same soil. In practice, it is virtually impossible to obtain two identical samples from the field.

Computation of Predicted Heave

The equation for predicting heave is based on the fundamental definition of strain:

$$\varepsilon_s = \frac{\varepsilon_{s\%}}{100} = \frac{\Delta H}{H}$$

where:

s = strain in the layer that is heaving,

εs% = percent swell that will occur when that stratum becomes wetted (strain in percent),

H = thickness of a layer of soil, and

ΔH = change in thickness of that layer due to heave.

In the figure the heave index defines a linear relationship between percent swell and applied stress:

$$\varepsilon_s = \frac{\varepsilon_{s\%}}{100} = C_H \log\left[\frac{\sigma''_{cv}}{\sigma''_f}\right]$$

And

$$\Delta H = C_H H \log\left[\frac{\sigma''_{cv}}{\sigma''_f}\right]$$

In actual application of the equation , a soil profile will be divided into layers of thickness H, and the value of heave for each layer will be computed. The incremental values will be added to determine the total free-field heave, ρ. Thus, the general equation for predicting total free-field heave, ρ, of a soil profile is as shown in the following equation. The value of $\sigma''f$ to be used in the equation is the stress at the midpoint of each layer.

$$\rho = \sum_{i=1}^{n} \Delta H_i = \sum_{i=1}^{n} \left\{ C_H H \log \left[\frac{\sigma''_{cv}}{\sigma''_f} \right] \right\}_i$$

where:

ρ = total free-field heave,

ΔHi = heave of layer i,

CH = heave index of layer i,

Hi = initial thickness of layer i,

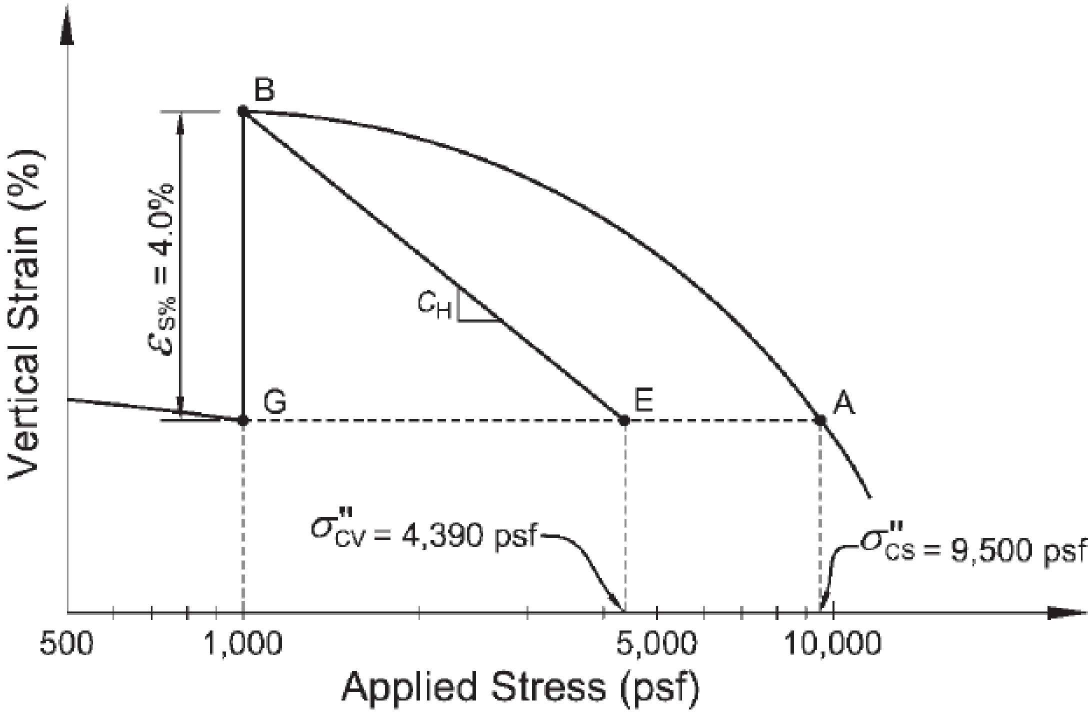
σ''cv = CV swelling pressure of layer i, and

σ''f = final vertical net normal stress of layer i.

EXAMPLE :

Given: The soil profile at a site containing a thick layer of expansive claystone. The dry density, γd, of the claystone is 115 pcf, with a gravimetric water content, w, of 12 percent and an initial degree of saturation of 64.7 percent. The specific gravity of the claystone solids is 2.79. The claystone was tested in a CS test and exhibited a percent swell, εs%, of 4 percent when inundated at an inundation stress, σ''i , of 1,000 psf. The results of the CS oedometer test are shown in the following figure. The swelling pressure, σ''cs, for the claystone was measured to be 9,500 psf. A CV test was also performed on the same soil and the CV swelling pressure was measured to be 4,390 psf.

Find: Ultimate free-field heave under conditions of full wetting.


B
G
E
A
C_H
$\varepsilon_{S\%}$ = 4.0%
Vertical Strain (%)
σ''_{cv} = 4,390 psf
σ''_{cs} = 9,500 psf
500
1,000
5,000
10,000
Applied Stress (psf)