53:139 Foundation Engineering
The University of Iowa
Spring Semester, 2002
Foundations on Expansive Soils

It is estimated by some† that each year expansive soils in the U.S. inflict approximately $9 billion in damages to buildings, roads, airports, and pipelines. If this fact is correct, then the monetary damage caused by expansive soils is more than twice the combined average annual damage due to all earthquakes, floods, tornados and hurricanes combined. This being the case, it is essential that the savvy foundation engineer be aware of the potential damage that expansive soils pose to structures. By being aware of how expansive soils can damage structures and their foundations, the engineer can intelligently minimize such damage.

A. The Nature of Expansive Soils

1. What are expansive soils?

- Quite simply, expansive soils are those that when exposed to water absorb the water and significantly increase in volume. The phenomenon of soils expanding when exposed to water is analogous to various metals expanding when their temperature is elevated.
- Expansive soils are primarily clays. Recall that clays are fundamentally very different from sands, gravels, and silts which are comprised primarily of bulky, inert, coarse-grained particles. The mechanical properties of sands, gravels, and silts depend on such properties as the size, shape, texture, and gradation of the particles. Clay soils, on the other hand, are comprised of extremely small plate-like particles, having extremely large specific surface areas (m^2/g). Furthermore, the surfaces of the plate-like clay particles have inherent electrical charges. As the specific surface area (SSA) of clay particles increases, the importance of the charged surface properties of the clay particles becomes increasingly prominent. There are numerous types of clay particles, for example those listed below:

Type	SSA (m^2/g)	Thickness ($A°$)	Lat. Dim. ($A°$)
Kaolinite	15	10^2 – 10^3	1,000 – 20,000
Illite	80	50 – 500	1,000 – 5,000
Montmorillonite	800	10 – 50	1,000 – 5,000

Table 1: Clay Types and Characteristics.

† D.E. Jones and K.A. Jones, "Treating Expansive Soils," *ASCE Civil Engineering* **57** No. 8 (1987).

2. What causes clays to expand?

a. Ability to Absorb Water

Certain clays have a remarkable ability to absorb water and to assimilate it into their microstructure. You may recall from your introductory lectures in soil mechanics, how the shape, size and charged properties of individual clay particles allow them to assimilate water molecules which are themselves charged and polar. A picture of clay particles showing how they attract and "hold" polar water molecules is shown in Figure 1. The larger the surface area of clay particles, and the higher the charge density, the more that clay soils are able to assimilate water into their structure.

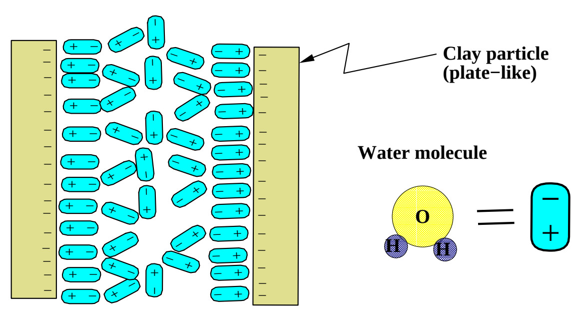

Figure 1: Charged clay particles and attracted dipolar water molecules.

Depending on the type of particles comprising a soil, we should thus be able to observe a wide range of behaviors in the presence of water. At one extreme, imagine a beaker of dry sand. When a large volume of water is added to the beaker, the volume of the soil skeleton will remain essentially unchanged (Figure 2). We would thus characterize sand particles as *inactive* in the presence of water. If the same experiment were performed on a beaker of highly active dry clay soil, one would observe that the clay soil skeleton volume increases significantly when the water is added. Activity is thus a measure of how much the soil skeleton volume increases with changes in water content.

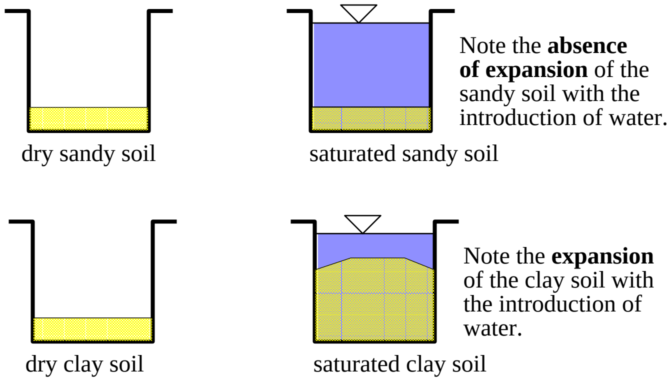

Figure 2: Expansion of clay soils when water is added.

Traditionally, the expansive nature and changes in mechanical behavior of clay soils with varying water content are measured in the Atterberg Limit Tests (Figure 3). The ability of a soil to assimilate water into its structure is measured by the LL and PI. Kaolinite clays are relatively inactive and have a negligible to moderate swelling potential. Illite clays are moderately expansive, and montmorillonite clays are highly expansive. In pure form, montmorillonite clays can swell to more than 15 times their original volume when going from a dry state to a fully saturated liquid limit state! Fortunately, montmorillonite clays are never found in pure form in the field but rather occur as mixtures with more stable clays, sands, and silts. Thus under the worst of circumstances, one would not expect more than 30% to 50% volume expansion in the field. Still, even volume expansions approaching these levels could have potentially disastrous effects on structures and their foundations. Given the highly expansive nature of montmorillonite clays, it is wise to be able to detect their presence.

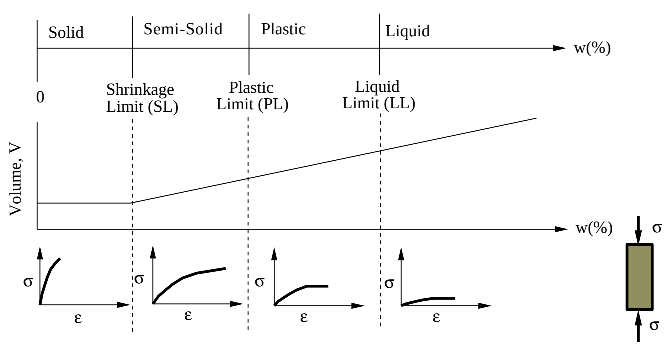

Figure 3: Atterberg limits of fine-grained soils, and their expansive as well as mechanical behaviors.

b. Other Factors

The existence of highly active clay soil deposits, does not necessarily mean that they will undergo significant shrinking and swelling behaviors. It is only **changes** in water contents and wetting conditions that lead to shrinkage/expansion. For example, active clay deposits that are always dry will not expand. Problematic expansion can be observed in active clay deposits located in climate zones having both wet, humid seasons and dry arid seasons. These variations will lead to variations in soil moisture contents and hence shrinkage/expansion of the soils. As one might guess, for buildings and foundations, significant problems can occur when foundations are placed on apparently stable, dry, active soil deposits that might be common after long droughts or dry spells. Once the structure is built on such soils, either natural variations in water content as due to rainfall, or induced variations in water content as from watering of landscaping and/or focusing of rainwater runoff can lead to significant expansions and changes in soil properties. Thus there are numerous factors which can lead to potential problems. These are: (1) climatic factors; (2) depth of the active zone; and (3) human activities.

1. Climatic Factors

The most significant climatic factors are precipitation rates and evaporation/transpiration rates. In particular, transpiration rates are controlled by the vegetation covering a site.

2. Depth of Active Zone

The active zone is defined as the region of soil near the surface in which the water content varies due to precipitation and evapo-transpiration (Figure 4). The deeper the active zone is, the larger the region over which soil expansion can occur and thus the larger the potential for heave due to soil expansion.

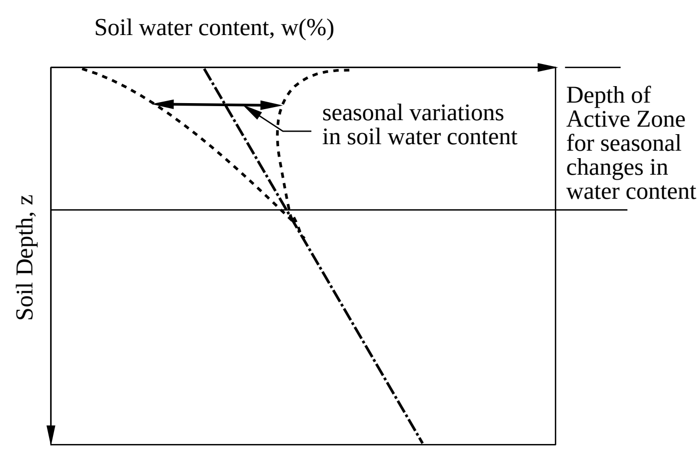

Figure 4: Active zone in soils experiencing seasonal changes in water content.

There are numerous factors which can influence the depth of the active zone. Two, among others, are the existence of shrinkage cracks in the soil, and the existence of sand layers and lenses which can transport surface water deeper into the soil deposit (Figure 5).

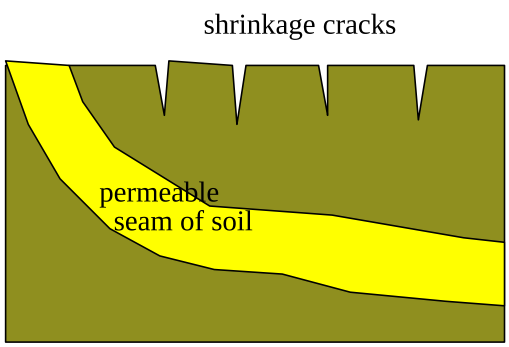

Figure 5: Factors which increase depth of the active zone: shrinkage cracks and permeable seams/lenses of soil.

3. Human activities

There are numerous human activities associated with constructed facilities that can increase the water content of soil deposits near constructed facilities.

- Irrigation of landscaping near foundations;
- Removal of vegetation such as trees which serve to remove water from the soil via transpiration;
- Placing slabs directly on the grade, which reduces evaporation rates; and
- Improper channeling of runoff.

B. Laboratory Tests to Evaluate Expansive Clays

1. Atterberg Limit Tests

As mentioned previously, the Atterberg limit tests give some information on the expansive nature of clay soils. For example, Table 2 correlates the expansive potential of soils with their Atterberg limits as follows:

LL(%)	PI(%)	SWP(%)†	Classification
< 50	< 25	< 0.5	low
50 – 60	25–35	0.5–1.5	moderate
> 60	> 35	> 1.5	high

† Swelling potential = $[(H - H_o)/H_o] \cdot 100\%$ at the overburden pressure.

Table 2: Expansive Potential of Soils.

2. Free-Swell Test

This test involves placing a naturally occurring soil specimen in an oedometer at $\sigma'_{v_o} = 1$psi. The sample is then inundated with water and swelling is observed. In the experiment,

$$S_{w\ free}(\%) = \frac{\Delta H}{H_o} \cdot 100\%.$$

To roughly estimate how much uplift might be observed under a shallow foundation due to soil swelling, the following extrapolation formula is sometimes used in practice:

$$\Delta S_F = 0.0033 Z S_{w\ free}(\%),$$

where ΔS_F is the free-surface heave, and Z is the depth of the active zone.

3. Swelling Pressure Test

The swelling pressure test also involves placing a naturally occurring soil specimen in an oedometer. The initial vertical effective stress p'_o placed on the specimen is taken as a value representative of the actual bearing stresses that would be observed under a foundation of interest. The soil sample is then inundated with water. In this test, however, the soil is restrained from expanding vertically by gradually increasing the vertical stress applied to the specimen. The stress required to suppress swelling is measured, and this is called the swelling pressure. Once this pressure is successfully measured, the soil is then allowed to expand, and the percent swell is also measured. A schematic or results obtained from a swelling pressure test is shown below in Figure 6.

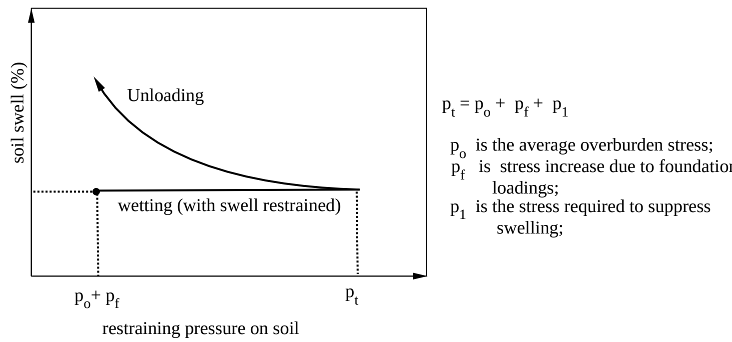

Figure 6: Schematic of results from a swelling pressure test, showing soil swelling versus restraining pressure.

C. Prevention of Structural Distress from Expansive Soils

1. Structural Distress Patterns

Depending on the causes leading to soil wetting and drying in the vicinity of structures and their foundations, various patterns of structural distress are frequently observed (Figure 6). Typical examples are: (1) Edge lift; (2) Center lift; (3) Localized heave due to drainage; and (4) Local shrinkage due to transpiration.

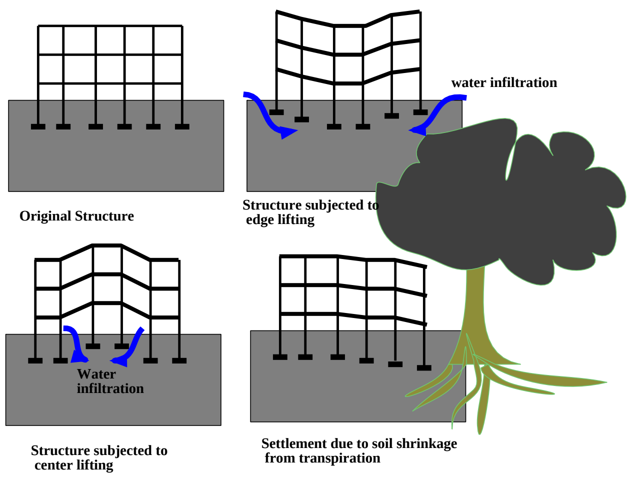

Figure 7: Factors leading to changes in water content of expansive soils. Such changes can lead to lifting of the structure, or settlement of the structure.

2. Preventitive Measures

There are many ways to prevent damage to structures from expansive soils. These methods can be classified as follows:

a. Controlling water's access to the soil;

b. Altering the soil properties; and

c. Altering the method of construction.

A very brief expansion of these concepts is provided below:

a. Controlling water's access to the soil

The primary idea here is to keep all water away from the soil surrounding the foundations. This involves such common sense measures as:

i Controlling surface drainage by making sure that the ground surface slopes away from the structure and the foundation.

ii Draining rainfall sufficiently far away from the foundations.

iii Not placing landscaping that will require extensive watering near a structure.

iv Using impervious liners that serve as moisture barriers to isolate foundations from surface water.

b. Altering the soil properties

Strategies for altering the soil properties might involve:

i Excavation and replacement of the active soil;

ii Chemical treatment of the active soil (for example lime treatment or mixing the soil with pfa [pulverized fuel ash]) to reduce its expansive potential; and

iii Pre-wetting of the soil. The idea is to build the foundation on a soil that has already expanded rather than a soil that will expand after the foundation is in place.

c. Altering the method of construction

Typically, it is shallow spread footings, mat foundations, and basement walls that are highly susceptible to damage from expansive soils. To protect basement walls from buckling under laterally expanding soils, basement backfill soils should be constructed with non-expansive, well-compacted soils. Strategies that can be employed for foundations are:

i Bypassing the expansive clay soils in the active zone by resorting to deep foundations.

ii When using mat or spread footings, using "waffled" foundations. The "waffle" pattern has the advantages that it allows the soil to expand into the voids, and that the foundations are quite stiff. This reduces differential settlement and heave due to expansion and shrinkage.

iii An alternative technique is to construct highly flexible structures and foundations. These same types of structures are often constructed on very weak and compressible soils. When large differential heave and/or settlement of the individual footings is experienced, the flexible structure can be put back into alignment using pre-installed leveling jacks and other devices.

To find out more about Foundations on Difficult Soils beyond what is included here and in your textbook, a good reference to consult is *Foundation Design: Principles and Practices* by D.P. Coduto, Prentice-Hall (1994).