Swell-Shrink Behavior of Expansive Soils, Damage and Control

Masoumeh Mokhtari
Department of civil engineering, University of Hormozgan, Bandar abbas, Iran;
e-mail: mokhtarimasi@yahoo.com

Masoud Dehghani
Assistant professor, Department of civil engineering, University of Hormozgan, Bandar abbas, Iran;
e-mail: Mdehghani@Hormozgan.ac.ir

ABSTRACT

Expansive soils occurring in arid and semi-arid climate regions of the world cause serious problems on civil engineering structures. Such soils swell when given an access to water and shrink when they dry out.

Several attempts are being made to control the swell-shrink behavior of these soils.

The Swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors and Stress Conditions.

Each year, expansive soils cause in damage to houses, other buildings, roads, pipelines, and other structures. This is more than twice the damage from floods, hurricanes, tornadoes, and earthquakes combined. This article presents description of expansive soil, shrink - swell behavior and control it, Factors Influencing Swelling and Structural damage.

KEYWORDS: Expansive soils, swell-shrink behavior, Factors Influencing Swelling, Structural damage.

INTRODUCTION

Engineering problems due to expansive soils have been reported in many countries all around the world. They cause millions of dollars due to their severe damages on structures. These damages are most common especially in the arid and semi-arid regions. Expansive soils contain the clay mineral montmorillonite with claystones, shales, sedimentary and residual soils are capable of absorbing great amount of water and expand. The expansive nature of the clay is less near the ground surface where the profile is subjected to seasonal and environment changes. The more water they absorb the more their volume increases. Expansive soils also shrink when they dry out. Fissures in the soil can also develop. These fissures help water to penetrate to deeper layers when water is present. This produces a cycle of shrinkage and swelling that causes the soil to undergo great amount of volume changes. This movement in the soil results in structural damages especially in lightweight structures such as sidewalks, driveways, basement floors, pipelines and foundations.

The effect of cyclic swell-shrink on the swelling behavior of natural soil is studied by many researchers (Popesco 1980; Chen and Ma 1987; Subba Rao and Satyadas 1987; Dif and Blumel 1991; Day 1994; Al Homoud et al 1995; Bilsel 2002; Tripathy 2002). Some investigators studied the swelling characteristics of expansive soils after repeatedly wetting-drying cycles. Chen et al (1985), Chen and Ma (1987), Subba Rao and Satyadas (1987), Dif and Bluemel (1991) concluded that when soils were subjected to full swell and allowed to shrink to their initial water content, they showed less expansion due to the fatigue of clay after Popesco (1980), Day (1994) and Guney (2007) concluded that swelling potential increased with the number of cycles. Al Homoud et al (1995) stated that cyclic wetting-drying resulted in particle aggregation. He supported his findings by the reduction in clay content and the plasticity index values of the soils after the increasing number of cycles. This inevitably caused reduction in the swelling characteristics (Tawfiq, 2009).

Description of Expansive Soil

Most soil in the Front Range can be classified as a swelling soil. This means that the soil contains a high percentage of certain types of clay that absorb vast quantities of water. Expansive soils are also sometimes called **shrink-swell soils, swelling soils, adobe, clay,** or **caliche soils.** This can cause the soil to expand 10% or more as moisture enters it, usually during winter snow melt and spring runoff. The soil then exerts tremendous pressure on foundations, slabs, and other structures. Now, this soil also contracts when the moisture evaporates during our hot summer months, causing extreme differences in the pressure being generated on your foundation, driveway, or patios.

Identifying Expansive Soil

Soil that cracks or fractures when it dries is often a sign that it is expansive; however a lack of cracks does not necessarily indicate that the soil is not expansive. Soils containing expansive clays become very sticky when wet and usually are characterized by surface cracks or a "popcorn" texture when dry. expansive soils take on a popcorn like appearance when they dry, they look like someone spread little lumps of popcorn shaped dirt on the soil surface, it is shown in the Figure 1 . Expansive soils are often clay like, becoming very sticky when wet and hard and brittle when dry. The best way to determine if the soil at a location is expansive is to have an expansion test performed by a soil expert. Expansive soils are common in desert areas, and also in river bottoms or valleys formed by sediment. They typically form in areas that were once covered by seas or lakes. Often your local government building department can tell you if the soil in your area is known to have expansion problems.

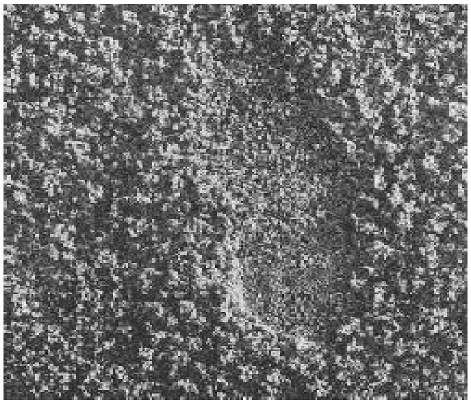

Figure 1: Expansive soil with "popcorn" texture (http://www.surevoid.com/..., 2006).

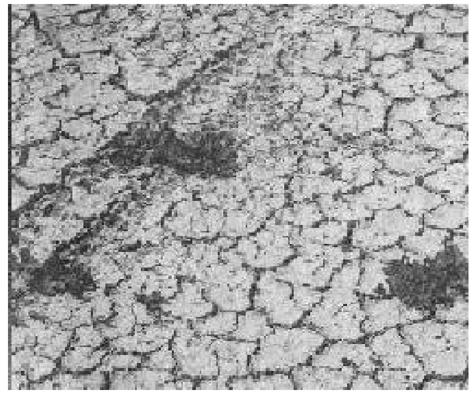

Figure 2: Expansive soil with cracks (http://www.surevoid.com/..., 2006).

Swell - Shrink Behavior

The swell - shrink potential of expansive soils is determined by its initial water content; void ratio; internal structure and vertical stresses, as well as the type and amount of clay minerals in the soil.

Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the volume changes are unevenly distributed beneath the foundation.

These minerals determine the natural expansiveness of the soil, and include smectite, montmorillonite, nontronite, vermiculite, illite and chlorite. Generally, the larger the amount of these minerals present in the soil, the greater the expansive potential. However, these expansive effects may become ‘diluted’ by the presence of other non-swelling minerals such as quartz and carbonate.

Excluding deep underground excavations (e.g. tunnels), shrinkage and swelling effects arerestricted to the near surface zone; significant activity usually occurs to about 3m depth, but this can vary depending on climatic conditions.

Fine-grained clay-rich soils can absorb large quantities of water after rainfall, becoming sticky and heavy.

Conversely, they can also become very hard when dry, resulting in shrinking and cracking of the ground. This hardening and softening is known as ‘shrink-swell’ behaviour.

When supporting structures, the effects of significant changes in water content on soils with a high shrink–swell potential can be severe.

Swelling and shrinkage are not fully reversible processes. The process of shrinkage causes cracks, which on re-wetting, do not close-up perfectly and hence cause the soil to bulk-out slightly, and also allow enhanced access to water for the swelling process.

In geological time scales shrinkage cracks may become in-filled with sediment, thus imparting heterogeneity to the soil. When material falls into cracks the soil is unable to move back, thus resulting in enhanced swelling pressures (Jefferson, 2011).

Factors Influencing Swelling

The swell potential of a Expansive Soil may be affected by either the soil properties influencing the nature of the internal force field, the environmental factors those may change the internal force system or the state of stress present on the soil.

Some physical factors such as initial water content, initial density,amount and type of compaction also influence the swell potential and swell parameters of soils (Baser, 2009).

These factors are summarized below:

A. Soil Properties Influencing Swell Potential

- **Clay Mineralogy:** Clay minerals which typically cause soil volume changes are montmorillonites, vermiculates, and some mixed layer minerals. Illites and Kaolinites are frequently inexpansive, but can cause volume changes when particle sizes are extremely fine.
- **Soil Water Chemistry:** Swelling is repressed by increased cation concentration and increased cation valence. For example, Mg^{2+} cations in the soil water would result in less swelling than Na^{+} cations.
- **Soil Suction:** Soil suction is an independent effective stress variable, represented by the negative pore pressure in unsaturated soils. Soil suction is related to saturation, gravity, pore size and shape, surface tension, and electrical and chemical characteristics of the soil particles and water.
- **Plasticity:** In general, soils that exhibit plastic behaviour over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinkage. Plasticity is an indicator of swell potential.
- **Soil Structure and Fabric:** Flocculated clays tend to be more expansive than dispersed clays. Cemented particles reduce swell. Fabric and structure are altered by compaction at high water content or remolding. Kneading compaction has been shown to create dispersed structures with lower swell potential than soils statically compacted at lower water contents.
- **Dry Density:** Higher densities usually indicate closer particle spacing, which may mean greater repulsive forces between particles and larger swelling potential.

B. Environmental Factors Affecting Swell Potential

- **Initial Moisture Content:** A desiccated expansive soil will have high affinity for water, or higher suction than the same soil at higher water content, lower suction. Conversely, a wet soil profile will loose water more readily on exposure to drying influences, and shrink more than a relatively dry initial profile. The initial soil suction must be considered in conjunction with the expected range of final suction conditions.
- **Moisture Variations:** Changes in moisture in the active zone near the upper part of the profile primarily define heave, it is in those layers that the widest variation in moisture and volume change will occur.

- **Climate:** Amount and variation of precipitation and evapotranspiration greatly influence the moisture availability and depth of seasonal moisture fluctuation. Greatest seasonal heave occurs in semiarid climates that have short wet periods.
- **Groundwater:** Shallow water tables provide source of moisture and fluctuating water tables contribute to moisture.
- **Drainage:** Surface drainage features, such as ponding around a poorly graded house foundation, provide sources of water at the surface; leaky plumbing can give the soil access to water at greater depth.
- **Vegetation**: Trees, shrubs, and grasses deplete moisture from the soil through transpiration, and cause the soil to be differentially wetted in areas of varying vegetation.
- **Permeability**: Soils with higher permeability, particularly due to fissures and cracks in the field soil mass, allow faster migration of water and promote faster rates of swell.
- **Temperature**: Increasing temperatures cause moisture to diffuse to cooler areas beneath pavements and buildings.

C. Stress Conditions Affecting Swell Potential

- **Stress History**: An overconsolidated soil is more expansive than the same soil at the same void ratio, but normally consolidated. Swell pressures can increase on aging of compacted clays, but amount of swell under light loading has been shown to be unaffected by aging. Repeated wetting and drying tend to reduce swell in laboratory samples, but after a certain number of wetting-drying cycles, swell is unaffected.
- **In situ Conditions:** The initial stress state in a soil must be estimated in order to evaluate the probable consequences of loading the soil mass and/or altering the moisture environment therein. The initial effective stresses can be roughly determined through sampling and testing in a laboratory, or by making in-situ measurements and observations.
- **Loading:** Magnitude of surcharge load determines the amount of volume change that will occur for a given moisture content and density. An externally applied load acts to balance inter-particle repulsive forces and reduces swell.
- **Soil Profile:** The thickness and location of potentially expansive layers in the profile considerably influence potential movements. Greatest movement will occur in profiles that have expansive clays extending from the surface to depths below the active zone. Less movement will occur if expansive soil is overlain by non-expansive material or overlies bedrock at shallow depth.

Damage to Structures from Expansive Soil

All structures experience various levels of damages during their lifetime. For structures to be economical especially those made of concrete, a certain degree of cracking is inevitable. The damages are due to design faults or no design at all, cheap construction materials, poor workmanship or calamities, poor drainage characteristics, climatic condition and intricate behavior of expansive soils.

The most obvious identifications of damage to buildings are doors and windows that get jammed, uneven floors, and cracked foundations, floors, masonry walls and ceilings. Moreover, different crack patterns mean different causes for different foundation materials.

In most cases, cracks due to shrinkage and expansive clay usually run from corner towards adjacent opening and are uniform in width or v-shaped, wider at the top than the foundation wall. This pattern of cracks happens when the moisture movement is from the perimeter to the centre of the house (Lucian, 2011). Several examples of damage to structures show in figures below.

Figure 3: Residential driveway damaged by expansive soil (http://www.surevoid.com/..., 2006).

Figure 4: Structural damage to house caused by ‘end lift’ (Jones, 2011).

Figure 5: Cracks in exterior walls, as a result of upward soil expansion (http://www.surevoid.com/..., 2006).

Figure 6: Major cracks in exterior walls at doors and windows (http://www.surevoid.com/..., 2006).

Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the volume changes are unevenly distributed beneath the foundation. For example, water content changes in the soil around the edge of a building can cause swelling pressure beneath the perimeter of the building, while the water content of the soil beneath the centre remains constant. This results in a failure known as end lift . The opposite of this is centre lift, where swelling is focused beneath the centre of the structure or where shrinkage takes place under the edges(Lee D Jones,2011).

Often, damage from expansive soils can be seen within the first few months or years after a home is constructed. As water from irrigation or rainfall migrates underneath the home's foundation, the soil around the edge of the foundation expands, pushing up on the edges of the foundation. This condition, called edge-lift, can cause cracking in the drywall and in the foundation itself. Over a period of years, as the moisture further migrates underneath the center of the slab, center-lift can occur, causing additional damage to the home.

Control the Swell-Shrink Behavior

Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet, the clay minerals absorb water molecules and expand; conversely, as they dry they shrink, leaving large voids in the soil. Swelling clays can control the behavior of virtually any type of soil if the percentage of clay is more than about 5 percent by weight. Soils with smectite clay minerals, such as montmorillonite, exhibit the most profound swelling properties.

Control the shrink-swell behavior through the following alternatives:

* Replace existing expansive soil with non-expansive soil.
* Maintain a constant moisture content.
* Improve the expansive soils by stabilization.

Replace existing expansive soil with non-expansive soil

The process involves replacing the original top expansive soil with compacted non-expansive backfill to a depth below which the seasonal moisture content will tend to remain constant. The idea behind is to capitalize on constant specific volume maintained by non-expensive soil when the water contents change .

However, soil replacement is economical for reasonable thickness of the expansive soil. Thus, if the expansive stratum extends to a depth too great to remove economically, then other treatments should be sought.

Maintain constant moisture content

a. Increased moisture content

The main source of soil moisture changes in the soils is rainfall. Other sources include poor drainage system and poor roof drainage, plumbing leakage and wet spots around the foundation, overwatering and trees. The following recommendations are put forward against each source.

i. Rainfall: the way out is to properly grade the soil around the building with a reasonable slop enough to carry all water well away from the foundation and beyond the backfill area. Gutters with downspouts should be provided to discharge rainwater into area drains with catch basins that divert rainfall away from the house to hard surfaces.
ii. Poor drainage: pave around the foundation with concrete or non-erodible surfaces. The overall grading must provide for positive drainage away from the foundation direct to the concrete channel drains. The channel drains should again discharge water away from the foundation.
iii. Plumbing line leaks: repair the leaks.
iv. Over-watering: plant flowers and shrubs away from the foundation that no watering takes place around the foundation.
v. Trees: always plant trees a distance greater than their mature height away from the foundation.
For existing trees, cut and cap their roots so that they do not trespass to the foundation.

b. Decreased moisture content

During hot days soil moisture content decreases considerably resulting into soil dehydration hence its shrinkage under the foundation. The best way is to assist the ‘mother nature’ by watering the soils surrounding the foundation as need arises. However, this recommendation is hypothetical in third world countries where water scarcity is the order of the day.

Improve the expansive soils by stabilization

Soil stabilization can improve the properties of expansive soils considerably. Possible materials for the stabilization could include lime, pozzolana, lime-pozzolana mixture, cement, resins or fly ash. The choice of a material or a combination of materials depends on the size and importance of the building (risk/damage acceptable) and economic consideration of the client. However, the need to strike a proper balance between quality and cost should not be overlooked (Charles Lucian,2011).

CONCLUSION

Expansive soil deposits occur in the arid and semi-arid regions of the world and are problematic to engineering structures because of their tendency to swell during wet season and shrink during dry season.

Expansive soils are soils that experience significant volume change associated with changes in water contents.

The Swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors.

Expansive soils present significant geotechnical and structural engineering challenges the world over, with costs associated with expansive behavior estimated to run into several billion annually.

Expansive soils are a worldwide problem that poses several challenges for civil engineers. They are considered a potential natural hazard, which can cause extensive damage to structures if not adequately treated.

Expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods .

Control and Mitigation of the swell-shrink behavior of expansive soil have been investigated in this article. Control of the swell-shrink behavior can be accomplished in several ways,for example by Replace existing expansive soil with non-expansive soil, Maintain constant moisture content and Improve the expansive soils by stabilization.

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