Research Journal of Applied Sciences, Engineering and Technology 4(17): 2874-2878, 2012
ISSN: 2040-7467

Submitted: November 25, 2011 Accepted: January 04, 2012 Published: September 01, 2012

Engineering Significant of Swelling Soils

Behzad Kalantari
University of Hormozgan, Bandar Abbas, Iran

Abstract: This study describes some of the most important swelling characters of expansive soils when used as foundation materials to support various types of civil engineering structures. Expansive soils are considered among difficult foundation materials and expand upon wetting and shrink upon losing moisture. They are considered problematic soils for architectural and civil engineers. These types of soils may cause minor to major structural damages to pavements as well as buildings. It is therefore essential to detect swelling soils from non-problematic foundation soils before any civil engineering projects are constructed over or adjacent to them. The study begins with definition of expansive soils and shows its distributions in the world as well as the basic causes for swelling potential that these type of soils poses. It is also shown that, the most probable depth of expansion to check for possible swelling potential for swelling soils is soil's active zone. This zone is the most upper depth of expansive soil and it may extend up to 20 ft. (6 m) below ground level. The moisture content of soil through active zone varies during different seasons while in lower part of expansive soil the moisture content stays constant during hot and cold season. Among various methods to check for swelling potential, plastic index and liquid limits are two most crucial factors, as these factors tend to increase, the swelling potential increase as well.

Keywords: Active zone, atterberg limits, clay particles, colloid content, expansive soils, swell index

INTRODUCTION

Among different types of clay soils there are many that swell (heave) considerably when water is added or absorbed to them and shrink with lose of water. This type of soil is termed expansive (Coduto *et al*., 2010).

When a soil deposit is loaded, for example, by a structure or man made fill, deformation will occur. Normally, deformation downward is called settlement. Deformation may also upward which is then called heave. A common cause of heaving is that a building or pavement is constructed when the top soil layer is relatively dry. The structure covering the soil increases in water content due to capillarity action and the soil swells. Heave will result if the pressure exerted by the pavement or building is less than the swelling pressure. The heave is usually uneven and causes structural damage (Holts and Kovacs, 1981).

Documented evidence shows that problems associated with expansive soils are world wide and occur in areas such as South Africa, Australia, India, United States, South America and the Middle East (Bowels, 1988; Kalantari, 1991). Figure 1 shows some of the reported places having swelling soils.

Swelling soils causes serious engineering problems. Estimates indicate that some twenty to twenty five percent of land area in United States is covered with soils that are expansive and economic damage has increased from 5.5 billion dollars in 1984 to 7 billion dollars in 2003 per year (Hung, 2003).

In general, to reduce or eliminate damages caused by expansive soil to various types of structures, it is essential for design engineers to investigate the causes of swelling and also to detect the degree of swelling potential for this type of problematic soils.

CAUSE OF SWELLING

Even an expansive soil may never swell, if its moisture content stays constant at all times, but it is obvious that soils undergo moisture content change for a variety of reasons (Tomilson, 1980). When an increase in moisture of expansive soils occurs, it causes the soil to expand (swell) and heave. The phenomena may results in expansive soils for the following reasons (Gromko, 1974; Hunt, 1984; Hunter, 1988; Murphy, 2010):

- Rain fall and rise in the ground water table
- Reducing load condition, such as surcharge loads increases the swell
- Transmission of moisture with time; moisture transmission through soil is slow and requires weeks and even years to saturate depending upon the permeability and thickness of stratum
- Dry density, dense clays will swell more when they are wetted than the same clay at lower density with the same moisture content
- Mineral type and amount, soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics

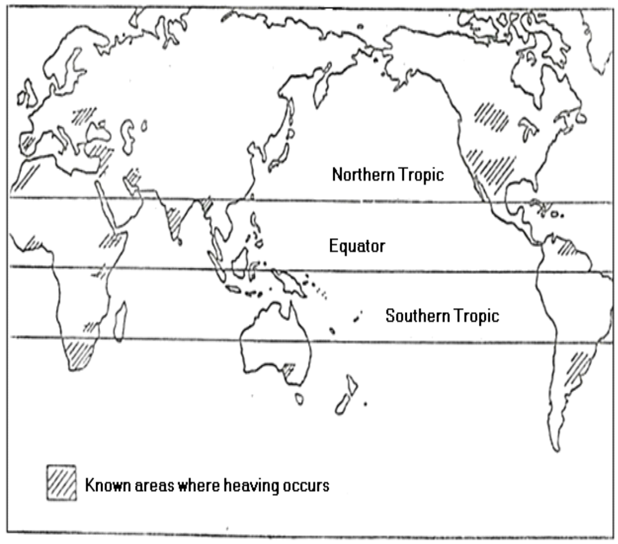

Fig. 1: Distribution of reported instances of heaving (Leonard, 1984)

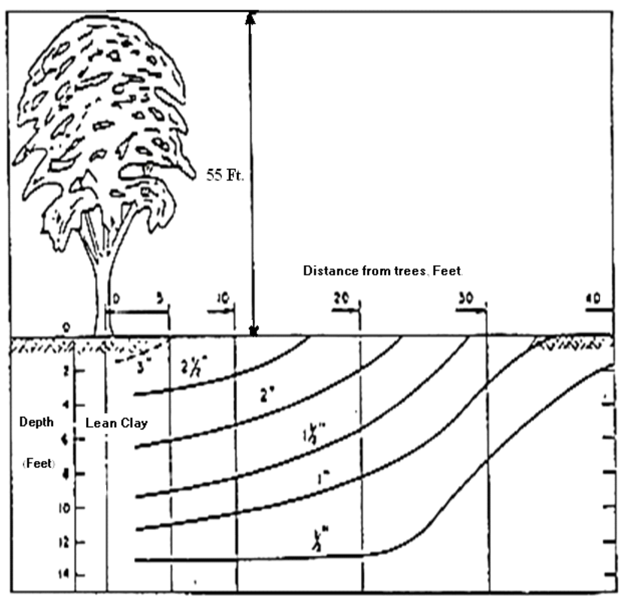

Fig. 2: Variation in maximum ground movement due to transpiration (Leonard, 1984)

- Retarding evaporation; by covering the ground with a structure or pavement
- Transpiration; the roots of trees and shrubs can extract considerable quantities of water from surrounding soil which aggravate the swell as well as shrink problem (Fig. 2)

SEASONAL VARIATION IN MOISTURE CONTENT (ACTIVE ZONE) OF EXPANSIVE SOILS

In a zone ranging in depth from a foot (30 cm) to as much as more than 20 feet (6 m), depending on the locality, the soil expands and shrinks and is usually referred to as the depth of seasonal variation in moisture content or active zone (Fig. 3), this zone is subjected to high volume change due to moisture fluctuations.

Active zone can most readily be judged in some localities by inspection in large-diameter bore holes.

In the zone of variation, the soil has blocky structure and fragments are often slick sided. Below the zone, the structure is likely to appear fairly massive and intact and slick sides are uncommon (Peck *et al*., 1974).

Active zone depth can be determined by plotting the liquid index Eq. (1) versus the depth of the soil profile over several seasons. An example of active zone

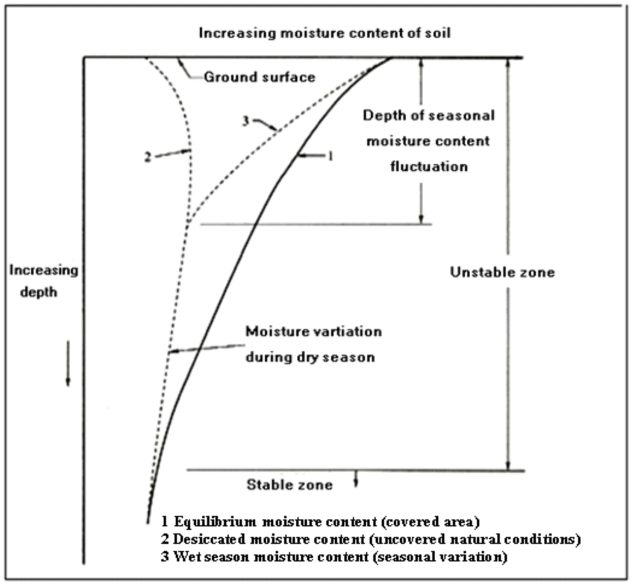

Fig. 3: Moisture content variation with depth below ground surface (Murphy, 2010)

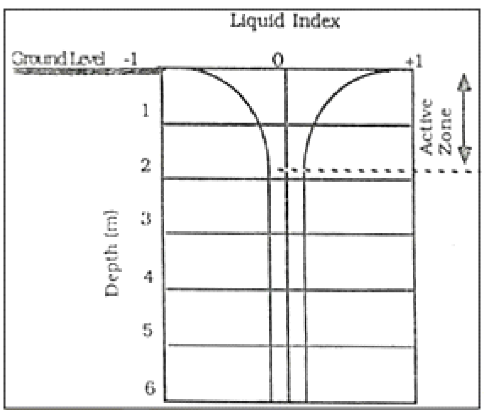

Fig. 4: Active zone determination for Houston, Texas (Kalantari, 1991)

determination is shown in Fig. 4 for an area in Houston (United States).

$$Li = (W_n - PL) / (PI) \quad (1)$$

where,
Li = Liquid index
W_n = Natural water content
PL = Plastic limit
PI = Plastic index (PI = LL-PL)
LL = Liquid limit

PREDICTION OF SWELL (EXPANSION)

Swelling potential of soils is defined as the percentage of swell of a laboratory confined sample in an oedometer test which is soaked under a surcharge load of 7 kPa (1 lb/in^2) after being compacted to maximum dry density at optimum moisture content according to AASHTO compaction test. Swelling potential of soils can be measured on the basis of certain inherent characteristics of the soil. Some of the most commonly used direct or indirect methods to measure the swelling potential of various types of expansive soils include the followings:

Table 1: Relation between swelling potential with plasticity index (Bowels, 1988)

Plasticity index (PI)	Swelling potential (%)
0-15	Low
10-35	Medium
20-55	High
35 and above	Very high

Table 2: Relation between swelling potential, shrinkage limits and linear shrinkages (Altmeyer, 1955)

Shrinkage limit (%)	Linear shrinkage (%)	Degree of expansion
<10	>8	Critical
10-12	5-8	Marginal
>12	0-5	Non-critical

- Atterberg limits
- Linear shrinkage
- Colloid content
- Activity index
- Swell index

Atterberg limits: Holtz and Gibbs (1956) demonstrated that the plasticity index (PI) and Liquid Limit (LL) and plastic limit (PL) indices for determining the swelling characteristics of most clays. Also a study from Koerner (1984) shows that the plasticity index and especially the shrinkage index are indicators of potential expansion.

Table 3: Estimates of probable volume change for expansive soils (Chen, 1988; Murphy, 2010)

Colloid content (%)	Probable total volume increase (%)	Degree of expansion
>28	>30	Very high
20-13	20-30	High
13-23	10-30	Medium
<15	<10	Low

Table 4: Relations between atterberg limits and swelling potential (Pitts, 1984; Kalantari, 1991)

Liquid limit (%)	Plastic index (%)	Swelling potential
<50	<25	Low
50-60	25-35	Marginal
>60	>35	High

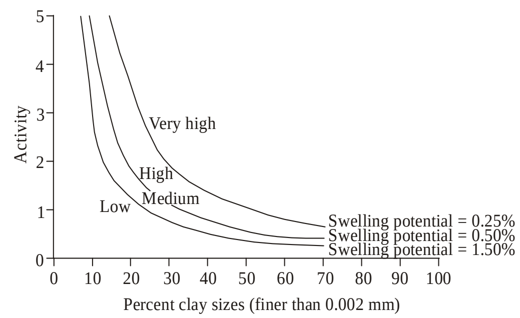

Fig. 5: Relationship between percent clay sizes with the activity to provide swelling potential of soil (Holts and Kovacs, 1981)

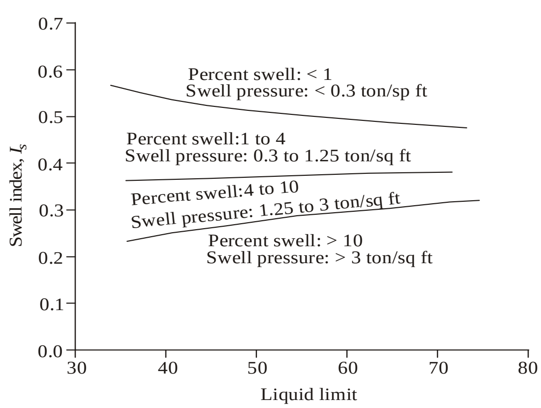

Fig. 6: Relationship between swell index and liquid limit for expansive clays (Murphy, 2010)

Since the LL and the swelling of clay both depend on the amount of water clay tries to absorb, it is natural that they are related. The relation between the swelling potential of clays and the plasticity index has been established as given in Table 1.

Shrinkage limit and linear shrinkage: The swell potential is presumed to be related to the shrinkage limit as well as linear shrinkage. Altmeyer (1955) suggested the values given in Table 2 as a guide to the determination of potential expansiveness based on shrinkage limits and linear shrinkages.

Colloid content: Colloid content is the percentage of particle sizes less than 0.001 mm in diameter. Studies indicate that colloid particles contribute to soil expansion most effectively and therefore can be used to detect expansive soils from non-expansive soils. Table 3 indicates some estimates between colloid content and expansion potential (Chen, 1988; Murphy, 2010).

Activity index: Activity index is defined by the following expression Eq. (2)

$$A = PI / C \tag{2}$$

PI = Plastic index
C = Percentage of clay size finer than 0.002 mm by weight

Relationship between percent clay sizes with the activity of clay found from Eq. (2) is shown in Fig. 5.

Swell index: Vijayvergia and Focht (1972) suggested a simple way of identifying the swell potential of clays, based on the concept of the swell index. They defined the swell index, I_s, as follows Eq. (3).

$$I_s = W_n / LL \tag{3}$$

where,
W_n = Natural water content in percent
LL = Liquid limit in percent

The relationship between swell index and swell potential for a wide range of liquid limit is shown in Fig. 6. Swell index is widely used for design of post-tensioned slabs on expansive soils (Murphy, 2010).

There are several other methods to identify and confirm the swelling potential of expansive soils as well. Some of these methods are; potential volume change (PVC) method, Expansion Index (EI), Van Der Merew method and consolidation test (Hauck, 1959; Peck *et al*., 1974).

Pitts (1984), suggests only the LL and PI values shown in Table 4 for a quick reference to cohesive soils with various degree of swelling potential.

CONCLUSION

Expansive clays are considered difficult foundation materials. Theses type of soils are cohesive and behave differently when wetting with when drying while cohesionless soils react almost the same due to moisture content variations.

Depending on the mineralogy and depositional patterns, cohesive soils can exhibit swell under various degrees of loading and moisture ingress. Every year millions of dollars are spent dealing with the consequences of swelling (expanding) soils. Volume changes are common to occur within the upper 3-20 feet (1-6 m) of soil deposit. This upper zone is more likely to be affected by seasonal moisture content changes due to climatic changes and is known as the active zone. Active zone is an important consideration in foundation design. The percentage of volumetric swell of a soil depends on several factors such as the type of fine materials, Atterberg limits, dry density, permeability, presence of vegetation and trees as well as soil access to source of water intrusions.

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