Foundations on Expansive Soils: A Review

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Abstract: This study describes various types of foundation designs to be considered for structural engineering projects when the subsoil foundation consists of expansive or swelling soils. Among civil and architectural engineers expansive soils are known to be difficult foundation materials and problematic. These type of soils swell when they are subjected to moistures and shrink due to moisture loss. Because of this different behaviour upon wetting and drying, they cause minor to major structural damages to pavements as well as buildings. Every year millions of dollars spent dealing with the consequences of swelling soils. For design of foundations on swelling soil, it is first essential to recognize and evaluate the soil based on its swelling potential, and then determining the most proper foundation design that can be constructed on this problematic soil. In general, this study presents some of the most common techniques to evaluate the swelling potential of expansive soils. Also, it discusses problems associated with swelling soil, classification of structural damages caused to buildings, and various foundation designs to combat the problems based on the degree of detrimental effects of swelling potential to civil engineering projects.

Keywords: Atterberg limits, expansive soils, shallow and deep foundations, structural damages, swelling potential

INTRODUCTION

Expansive or swelling soils usually are those types of soil that swell when they are subjected to moistures or partially saturated. Also, these types of soils shrink due to losing moisture contents. Generally their plasticity indices range high and their bearing capacities differ from when wetted with when dried. These soils are mostly found in arid and semi-arid areas and contain large amount of clay minerals. Expansive soils are found in large areas of southwest and western United States including Oklahoma, Texas, Colorado, Nevada, California, Utah, and others. These soils are also found in large areas of India, and Australia (some times called black cotton soils), South America, Africa, and the Middle East (Bowels, 1988; Kalantari, 1991; Murphy, 2010).

It is not very difficult to recognize the expansive soils at the field during either dry or wet seasons. The maximum width of these types of soil may sometimes become over 20 m. during dry seasons, and they become very sticky and hard to traverse during wet seasons. Also the presence of surface fissures in expansive soils deposit is an indication of expansion potential of swelling soils. Several classifications methods are used to identify expansive soils in the laboratory. Currently, there is not a standard classification procedure; different methods are used in various locations across the U.S. Typically, methods include the use of Atterberg limits and/or clay size percentage to describe a soil qualitatively as having low, medium, high, or very high expansion potential. In general soils classified as CL or CH in USCS as well as A-6, or A-7 in AASHTO classification systems may be considered expansive (Kalantari, 1991; U.S. Department of Transportation, 2006).

Research and studies of swelling characteristics of expansive soils have been in progress and numerous articles as well as book’s chapters have been published. The majority of researches have been done to find ways and means to combat the swelling potential of expansive soils in regard to structural damages.

Based on Chen (1988) and Murphy (2010) the six major natural hazardous are earthquake, landslides, expansive soils, hurricanes, tornado and flood, indicating that expansive soils ties with hurricane wind/storm surge for second place among America’s most destructive natural hazards in terms of dollar losses to buildings.

There have been many techniques developed to combat swelling potential of soils from removal of the expansive soil to construction of structures with great rigidity which can withstand detrimental effect of swelling soils. In general, types of foundations to be considered when the foundation subsoil is expansive depends on several technical factors including: degree of swelling potential, thickness of swelling soil, depth of swelling soil from possible water intrusions and also type of construction projects adjacent to expansive soils that are discussed with details in the following sections.

CAUSES OF DAMAGING SWELLS TO STRUCTURES

Holts and Kovacs (1981) summarized a total of three ingredients that are necessary for soil to cause swelling damages to structures:
Table 1: Potential soil volume changes as related to the Plasticity Index (PI) and the Liquid Limit (LL)

<table>
<thead>
<tr>
<th>Potential for volume change</th>
<th>Plastic index (PI %)</th>
<th>Shrinkage (SL %)</th>
<th>Liquid limit (LL %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt;18</td>
<td>&gt;15</td>
<td>20-35</td>
</tr>
<tr>
<td>Medium</td>
<td>15-28</td>
<td>10-15</td>
<td>35-50</td>
</tr>
<tr>
<td>High</td>
<td>25-41</td>
<td>7-12</td>
<td>50-70</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;35</td>
<td>&lt;11</td>
<td>&gt;70</td>
</tr>
</tbody>
</table>

Some researchers (Hauck, 1959; Peck et al., 1974; Das, 1984; Holts and Kovacs, 1981; Bowels, 1988; Kalantari, 1991; Coduto et al., 2010; Murphy, 2010) believe that in a zone ranging in depth from a meter to as much as 20 m from the ground level, 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. Thus, it is possible to state that, the damages to structures are caused due to volumetric changes occurring through the upper layer (zone) of expansive soil that is usually known as active or unstable zone.

**Classification of swelling potential of expansive soils:**
There are several classification systems for expansive soils based on the problems they can create in the construction of foundations (Kalantari, 1991). Bowels (1988) presents a summary of the obtained results from Holtz (1959), and Daskshanamurthy and Raman (1973) in a form of Table 1 that can be used to classify swelling potential of expansive soils.

**Problems associated with expansive soils:** Due to volume changes of expansive soils either under or
adjacent to any types of foundation, the structures may be subjected to various degrees of damages. Kalantari (1991) presents a list of most probable problems associated with expansive soils that includes the followings:

- **Buckling of pavements**: these types of damages usually occur in roads or highways upper layers. This problem is caused by swelling potential of the subsoil system (subgrade, subbase, and base). Figure 1 shows possible deformations of pavement due to swelling of subsoil.
- **Floor slab on grade cracking**: these types of damages are sequential and generally results in a hogging type of deformation (Fig. 2).
- **Differential movement and cracking of basement walls and building walls laterally and vertically** (Fig. 3).
- **Differential movement and cracking of buried pipes**: swelling soils in many occasions may cause buried pipes to be broken, specially when there is a source of water in the vicinity of the expansive soil surrounding the pipes.
- **Wall cracking due to presence of swelling soil as well as water seepage** (Fig. 4).

Table 2: Classification of visible structural damages (Boscardin and Cording, 1989)

<table>
<thead>
<tr>
<th>Class of damage</th>
<th>Description of damage</th>
<th>Approximate width of cracks (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>Hairline cracks</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Very slight</td>
<td>Fine cracks easily treated during normal redecoration. Perhaps isolated slightly fracture in building. Cracks in exterior brickwork visible upon close inspection.</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Slight</td>
<td>Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible, some repainting may be required for weather tightness. Doors and windows may stick slightly</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Moderate</td>
<td>Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable lining. Tuck pointing and possible replacement of a small amount of exterior brick worth may be required. Doors and windows sticking. Weather tightness often impaired.</td>
<td>5-15 or several cracks &gt;3 mm</td>
</tr>
<tr>
<td>Severe</td>
<td>Extensive repair involving removal and replacement of sections of wall, especially over doors and windows. Windows and door frames distorted, floor slopes noticeably, some loss of bearing in beams. Utilities service disrupted.</td>
<td>15-25</td>
</tr>
<tr>
<td>Very severe</td>
<td>Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

Fig. 3: Various types of damages to building walls due to differential movement of the foundation subsoil

Fig. 4: Visible cracks on the walls and around the windows caused by water seepage in to the expansive subsoil foundation
A classification system has been proposed by Boscardin and Cording (1989) and is shown in Table 2. It is based, in part on the ease of repair of the damage, and therefore provides a refined framework for the evaluation of damage.

**GENERAL METHODS FOR FOUNDATIONS ON EXPANSIVE SOILS**

Many researchers such as Peck *et al.* (1974), Bowels (1988), Kalantari (1991) and Murphy (2010) propose three general methods in order to prevent structural damages to newly constructed buildings when expansive soils are present.

- Elimination or reduction of swelling
- Use of sufficiently strong structures that will remain undamaged in spite of the swelling
- Isolating the structure from the swelling soil

Each of the mentioned methods can also describe one or several techniques that are explained with more details in the following sections.

**Elimination or reduction of swelling:** Elimination or reduction of swelling soil may be described in three ways:

- Replacing the expansive soil
- Changing the nature of soil
- Controlling the water content of subsoil foundation

**Replacing the expansive soil:** Das (1984) suggests that when moderately expansive soils of low thickness are present at the surface of the subsoil foundation, they can be removed and replaced by expansive soils and then compacted properly. Huat (2004) proposes mixing the problematic soil (expansive) with none problematic soil (cohesionless) will make the outcome product to be less of problematic costing less and probably acceptable.

After swelling soil replaced by a suitable soil and compacted properly, proper foundation (shallow or deep) may be constructed without fear of structural damages caused by heave of the expansive soil. Also, replacing or modifying the expansive soil may be done within the active zone only (if expansive soil is not shallow) and where there is a high potential of swelling problems to the foundation.

Providing a granular bed and cover below and around the foundation is considered to be an effective technique to combat detrimental effects of swelling on the foundation as well (Leonard, 1989; Murphy, 2010).

**Changing the nature of expansive soil:** Gromko (1974) proposes a number of techniques which would reduce heave of expansive soils, if not eliminate it completely. These techniques, which include the following are based on the economic and practicality of operation.

- Compaction control
- Chemical stabilization
- Prewetting

Gromko (1974) and Das (1984) agree that one of the most practical and economical method of controlling heave of expansive soil is through the use of compaction control. When a soil is compacted to a lower unit weight on the high side of the optimum moisture content (Fig. 5), possibly 3-4% above the optimum moisture content, its swelling potential is decreased. Even under such conditions a slab on ground is not recommended where the total heave exceeds 35 mm (Das, 1984).

Gromko (1974) developed a relationship between the climatic rating systems [from favorable (least reported swelling problem places) to extremely unfavorable climatic rating], percent required compaction and plasticity index of the soil under a slab foundation (Fig. 6).

Compaction control methods can be used successfully to support structures with shallow foundations. When used in conjunction with base course of open graded aggregates as long as the slab on ground is independent of the grade beams, columns and walls and...
the allowable pressure is around the allowable strength of the foundation subsoil (Fig. 7).

Chemical stabilization of expansive soil using various types of stabilizers such as lime, fly ash or cement have shown that they can reduce heave significantly; however, the lime stabilization have been used more than any other chemical substances for stabilization of expansive soil or clay. Mixing 4 to 8% of lime with plastic clay causes the plasticity index of top soil layer to reduce, as well as to increase its load bearing capacity (Gromko, 1974; Chen, 1988; O’Neill and Poormoayed, 1980; Bowels, 1988; Prusinski and Bhattacharja, 1999; Murphy, 2010; Ziaie et al., 2010).

Prewetting is also a technique for increasing the moisture content of the soil by submerging of an area in water. Das (1984) indicates that that submerging the swelling soil in water achieves most of the expected heave before construction. However this technique may be time consuming because of water seepage through highly plastic soil. Hauck (1959), and Gromko (1974) propose a 10 to 15 cm thick layer of coarse gravel, sand or granular soil on top of the area will aid considerably in providing a good working surface during and after prewetting. This layer has advantages in reducing evaporation, providing a minor surcharge, as well as making a level uniform subgrade. Prewetting technique of expansive soil may be suitable for single family homes. Also, the top wetted soil may be mixed with lime and compacted to reduce soil’s plasticity and increasing soil’s load bearing capacity as well (Kalantari, 1991).

Controlling the water content of subsoil foundation:

Controlling the water subsoil foundation is considered to be one the most effective method to control the heave potential of expansive soil. Most of moisture control methods are applied around the perimeter of structures in order to minimize edge wetting or drying of subsoil foundation. One of the more common methods of keeping constant moisture is through the installation of impermeable barriers (such as retaining walls and geotextile membrane) and adequate drainage systems and control of vegetation coverage (Gromko, 1974; O’Neill and Poormoayed, 1980).

Use of sufficiently strong structures that will remain undamaged in spite of swelling: Structures capable of remaining undamaged and undisturbed in spite of being supported directly on expansive soil must possess great strength and rigidity. It is possible to describe this type of technique to combat swelling problem of expansive soils in two ways:

- Controlling the direction of expansion
- Loading the soil to sufficient pressure intensity to balance swell pressure

Controlling the direction of expansion: This technique is described by Bowels (1988). The procedure is to allow the soil to expand into cavities built in the foundation movements may be reduced to tolerable amount. A common practice is to construct waffle slabs (Fig. 8). This type of construction, the reinforced concrete ribs hold the structural load. The waffle voids allow the expansion of soil.
Swelling soils usually have a stiff structure, and do not contain free water, therefore they may often constitute excellent ground for holes of piles or drilled piers at depth below the zone of seasonal volume change or active zone (Fig. 9).

Piles and piers may be placed at a sufficient depth and leaving an expansion zone between the ground surface and the building (Fig. 10). Swell can take place without causing structural damages to the building. This procedure is to use belled piers with sufficient depth in the ground in the ground with regard to shaft resistance forces do not pull it out and that volume change in the active zone does not heave the whole system. The piles and piers shaft should be as small as possible to avoid high-tension stresses due to the expansion pressure (Peck et al., 1974; Murphy, 2010). Sometimes it is possible to use materials such as straw, saw dust or course grain soil around the pile and within the unstable depth or zone [where swelling potential exists] (Fig. 11) to let the expansion from the swelling soil into the material’s voids instead of affecting the actual pile (Bowels, 1988).

CONCLUSION

Swelling soils are considered one of the problematic types of soils. They swell upon wetting, and shrink due to drying. Civil engineering projects constructed over or within them may be subject to distress, ranging from negligible cracks to very severe structural damages. In order to measure the magnitude of the detrimental effects of expansive soils on the foundations, it is necessary to determine their swelling potentials. Swell potential may be found by careful analysis of various tests. In general as the particle sizes that are less than 0.002 mm (clay and colloid) and their plastic index are increased in a soil, the swelling potential of that particular soil is increased as well. There are a number of remedial methods to overcome high swelling potential of expansive soils causing structural damages. Even for a given case; however, one specific method may not be the answer, and it might be necessary to combine several different methods. The most commonly used techniques include:

- Elimination or reduction of swelling potential of expansive soil
- Use of sufficiently strong structures that will remain undamaged in spite of the swelling
- Isolating the structure from the swelling soil

Slabs on ground are not recommended where expansive soils are present, though some times the top soil layer (80 to 100 cm) may be replace by a none expansive (e.g., granular) soil. Two types of structures have successfully performed in the presence of expansive soils, one of which is a rigid building and the other is a building independent of soil movement. The usual design
of the structure depends on swelling potential as well as the relative cost of alternative design.

REFERENCES


