Expansive Clay Related Critical Issues and Treatment Methods

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ABSTRACT
Based on the experience, literature review and testing of field clay soils critical issues related to the expansive clays have been identified. Some of the critical issues include the chemical composition of the clay soil based on the geological history, fluctuating moisture content due the environmental conditions (weather, trees and drainage) and the depth of the expansive clay deposit with the volume of clay and also the distance from the water table (active zone). Expansive clays have been characterized based on the liquid limit, plasticity index and shrinkage limit. Standard test methods are used to determine the free swelling and swelling of clay under various stress conditions. There is no information about the swelling and shrinkage of clay related to the rate of moisture content changes in the clay. Expansive clay soils are a continuous disaster on earth impacting all types of structures and infrastructures on the surface and also buried in the ground. Treatment methods are being developed to reduce the swelling of the expansive clay soils.

1. INTRODUCTION
Expansive soils are a worldwide problem in all five continents on earth as they cause continuous extensive damage more than twice the combined average annual damage due to earthquakes, flooding and hurricanes to the infrastructures (Estabragh et al. 2013). Expansive soils undergo large volume changes due to moisture fluctuations because of seasonal variations and other factors. The volumetric changes are caused by swelling and shrinkage movements in the highly plastic soils (high plasticity index), which can lead to severe damage to foundations, buildings, pipelines, tunnels and roads. Also it is becoming big challenge in maintain the infrastructures including the roadways.

2. OBJECTIVES
Overall objective is to review the issues related to expansive clays and treatment methods to minimize the problem. The main objectives are as follows:

1. Based on the literature review and experience identify the critical issues related expansive soils.
2. Review the treatment methods to minimize issues related to expansive clays.

3. LITERTURE REVIEW
Clay soils are encountered in all types of earth surface and underground constructions. Based on the geological formation, the clay soils have highly varying short-term (shrinkage, swelling, strength) and long-term properties such as consolidation with fluctuating shrinkage, swelling and strength that will influence the construction and durability of the long-term stability of the supporting structures and pipelines. Swelling clays can cause damages to pipe joints resulting leaks of water, wastewater, oil and gas. Clay soils cover one-fourth of the surface area of the United States and are found in every state (Jones et

al., 1987). Compared to other natural disasters and damages due to clay soils is probably the least publicized natural hazard. The expansive clay soils alone inflict at least $2.3 billion per year in damages to houses, buildings, roads, and pipelines. Also it has been reported that damages from expansive soils are more than twice that which is caused by floods, tornadoes, and earthquakes (Jones et al., 1987).

Based on the data collected the free swelling of clay soils with varying liquid limits are shown in Figure 1. It must be noted that clay swelling will also depend on the initial moisture content of the clay. Clay soils cause problems in certain areas with repeated periods of rainfalls and droughts. Expansion of clays in the presence of moisture is a problem that causes extensive damages to physical infrastructure, such as dams, irrigation canals and roads (Inyang et al., 2007). Wet and dry cycles in clayey soils would cause volumetric changes which may result in considerable damage to the surrounding structures. To overcome the swelling problems caused by expansive soils, many innovative techniques such as stabilization by chemical additives, pre-wetting, squeezing control, overloading, and moisture control have been suggested (Al-Rawas et al., 2005). Stabilization of these problematic soils by employing a suitable additive is one of the preferred techniques of dealing with such soils (Inyang et al., 2007; Vipulanandan et al. 2016, 2020).

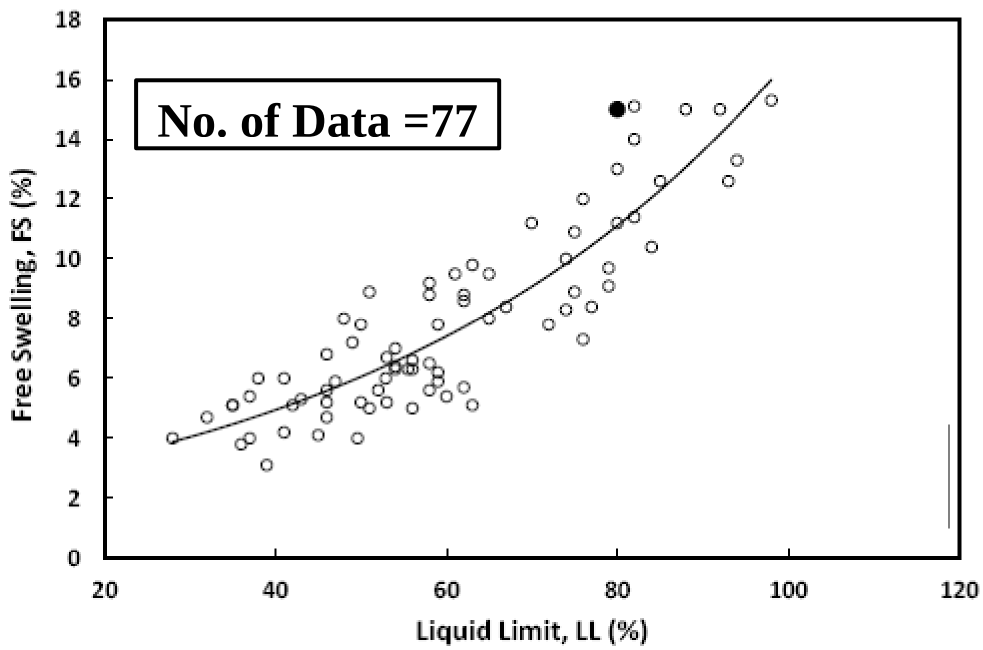

Figure 1 Variation of Free Swelling with the Liquid Limit of the Soils

Some of the critical issues related expansive clay swelling (S) that needs to be considered are as follows:

1. **Chemical composition of the clay soil and clay content (C, ΔC)**: Sodium montmorillonite (MMT) is considered to one of the highly swelling clays. It has a 2:1 clay mineral structure with Vander Waal force (very week bonding force) holding the minerals together. Also the sodium (Na+) cation will attract more water. Using a microstructural study using the X-ray diffraction spectroscopy (XRD) it can be detected. Performing the index test, if the clay is CH clay with the data point is close to the H-line it has the potential to have sodium montmorillonite clay.

2. **Initial and Changes in Moisture (Wi , ΔW)**: With the increase in the moisture content the clays will swell, volume changes in different directions based on the in-situ stress conditions. The changes in the moisture content in the clay will be due to rain, leaking pipes and tree roots.

   Hence the swelling of the clay can be represented as follows:

$$S = f(C, \Delta C, Wi, \Delta W) \quad (1)$$

3. **Rate of change in moisture (dw/dt):** There is no information in the literature related to the effect of rate of moisture change on the swelling of clays. Since the rate of moisture supply in the ground can vary from point to-point and affecting the inhomogeneous swelling of the clay. The basic concept is similar to the pore pressure dissipation in consolidating clay soils.

Treatment Methods

It is important to minimize the swelling of expansive clay soils by treating them to minimize the damages. Several traditional solid form and liquid form stabilizer materials have been used to stabilize subgrades to minimize the expansive and shrinkage of the clay soils (Onyejekwe et al. 2015; Vipulanandan and Mohammed 2015). The traditional stabilizers include ordinary Portland cement, lime and fly ash. Nontraditional stabilizers are polymers and enzyme types (Mohammed and Vipulanandan 2014).

Inorganic Stabilizers

Many studies have been performed on the subject of soil stabilization using various additives, the most common methods of soil stabilization of clay soils supporting highway pavements are by adding cement, fly ash or lime (Al-Rawas et al. 2005; Mohammed and Vipulanandan 2015). To achieve effective soil stabilization based on the application, special attention has to be given to proper type and concentration of the stabilizer. For effective subgrade stabilization, a more rigorous soil classification which considers the soil mineralogy is needed for evaluating and assessing the use of certain type of chemical additives such as water soluble polymers for enhancing soil properties (Huang et al. 2012; Wang et al. 2012; Gilazghi et al. 2016). Cokca (2001) investigated the expansive CH soil stabilizing using low calcium and high calcium class C fly ash mixtures. The study also included comparison with treating the soil using lime and cement. The results showed that a soil treated with 20% fly ash had nearly the same stabilizing effect on the swelling potential as a soil treated with 8% lime. It was also found that the addition of the stabilizers changed the classification of the treated soil. This observed change was due to the additional silt size particles added from the fly ash and also was related to the chemical reaction that caused immediate flocculation of the clay particles. Bell (1996) studied the linear shrinkage of montmorillonite CH soil with different percentages of lime additive and showed that the shrinkage decreased with the addition of lime, but the decrease was not linear. The study also showed that the unconfined compression strength did not increase linearly with the addition of lime and excessive addition of lime actually reduced the strength. During this treatment, mineralogical and microstructural changes occurred, which lowered the plasticity and also enhanced the compressive strength and enable soil compaction to higher density. Arabani et al. (2007) observed that an increase in the lime content beyond 6% had negligible effect on the compressive strength of treated clay soils. Effects of soil stabilization with lime on the performance of various types of clay soils have been documented in the literature by several researchers in the past decade. Reaction of lime with alumino–silicate in clays, produced hydrated cementitious products that bonded to the soil particles and the results reported are for 7 and 28 days of curing (McCarthy et al. 2009). Most of the studies have used 6% of lime treated the expansive soil and the specimens were prepared and tested near the optimum moisture content (OMC %) (Harris et al. 2004; Knattab et al. 2007; Pedarla et al. 2011; Consoli et al. (2012)). In some of the studies lime has been used in treating clays by varying the lime content up to 10%.

Organic Stabilizers

There are many types of polymers that are being used to treat the clay soils. Mirzababaei. et.al. (2009) tested the properties of three soils, one high plasticity clay and other high plasticity silts with three organic polymers, Furan [C_4H_4O] (3%-10%), Poly methyl methacrylate (PMMA) [($C_5O_2H_8$)n] (1%-5%) and Poly vinyl acetate (PVA) [($C_4H_6O_3$)n] (1%-5%). Free swelling decreased significantly with increasing furan content from 3% to 10%. The addition of furan lead to formation of aggregations and clothed silty grains. The swell percentage of all soils decreased with increase in PMMA up to 5% except for the high plasticity silt. PVA did not cause significant change for both the high plasticity clay and silt soils. For high plasticity silt, the swell percentage significantly reduced with an increase in PVA content up to 3%. They concluded that the optimum furan content is 10% and optimum PMMA content is 1% -3% of dry soil mass.

Yazdandoust et al. (2010) investigated the effects of cyclic wetting and drying on the swelling behavior of the polymer stabilized expansive clays. In this study, urea formaldehyde (3% and 5%) and melamine formaldehyde (5%) were used to reduce the swelling behavior. It was observed that the polymer stabilization unlike that of lime didn't lose its effect on the soils, though subject to cycles of swelling and shrinkage. The decrease in swell potential and axial deformation stabilized after the fourth cycle.

Jin Liu et al. (2011) have suggested the top soil stabilization on the slopes by the usage of an organic polymer (STW), polyvinyl acetate (acetic-ethylene ester polymer) with $–OOCCH_3$ as its functional group. The study was focused on increasing the unconfined compressive strength (UCS), water stability and erosion resistance. The polymer that was used had the primary long chain macromolecule and polarity carboxyl ($–OOCCH_3$). It was reported that the $–OOCCH_3$ to be a hydrophilic group and through ionic, hydrogen and Van der Waals bonds the polymer holds the aggregate and enwraps it. The polymer also filled up the voids, resulting in an increase in the unconfined compressive strength and erosion resistance. In the initial 24 hrs. of stabilization a rapid increase in the strength was observed. It was suggested that 30% addition of the STW produced the best results.

Naeini et al. (2011) used and acrylic polymer and it was mixed was mixed at 2, 3, 4 and 5% by total weight of amount of water needed to achieve the OMC. It was observed that 4% dosage of polymer increased the UCS to a higher percentage compared to other percentages. UCS value increased rapidly after 8 days of mixing and reached a constant value up to 14 days. Plasticity index had a rapid decrease due to the addition of the polymer.

Azzam (2014) investigated the addition of polypropylene [(C_3H_6)n] in a liquid state, with 5, 10 and 15% dosages. Xylene was used as a solvent for the polypropylene solution. The polymer was added to the dry soil. Polymer solution dosage of 15% was found to be most effective and reduced the swelling pressure by 86%. After 28 days of curing there was 90% reduction in free swelling of the soil. The UCS increased by 220%

Mousavi et. al. (2014), tested the effect of a commercial polymer called Road Packer Plus on a CH soil with 0.019%, 0.04% and 0.06% of the polymer. It improved the maximum dry density of clay also reducing the liquid limit, plastic limit and plasticity index. Treated soil showed significantly lower swelling potential and swelling pressure and reduced with increased polymer content but had no effect of curing period. The CBR of the soil increased with the addition of polymer but the recommended polymer content (0.019%) was not effective for the required change.

In recent years water soluble polymers are being used to treat the expansive clay soils with and without other types contamination such as gypsum (CaSO4) (Mohammed and Vipulanandan (2014, 2016); Vipulanandan and Mohammed 2020). Polymer treatment of clay soils reduced the liquid limit and also the plasticity index and substantially reduced the swelling (2021Vipulanandan and Mohammed 2020; Gattu and Vipulanandan 2021).

5. CONCLUSIONS

The focus of this study was to investigate the effect of expansive clay soils and also review the treatment methods. Based on the experience, literature review and testing of field clay soils following conclusions were advanced:

5. Expansive clay soils with the swelling and shrinkage behavior are major problem around the world. It impacts the structures on the surface and also buried pipelines and tunnels. It also impacts the maintenance of the infrastructures including the road and highways.
6. The effect of rate of moisture change on the swelling of clay has not been discussed in the literature. It will be an important factor to consider since affect in homogenous swelling of the clay.
7. Treatment methods are being developed to minimize the swelling of the expansive clay. Use of water soluble polymer has shown some very encouraging results.

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