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A Review of the Stabilisation Techniques on Expansive Soils

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ABSTRACT

Background: One of the problems in geotechnical engineering is the presence of unsuitable soils on project sites. Some soils, called reactive soils, exhibit deviations in volume due to climatic variations causing a big concern during the structural designing of pavements and foundations on these soils and the post-construction stability of such structures. **Objective:** There are several soil stabilisation approaches to counter the hazards presented by these soils. This paper elaborates various studies on the current soil stabilisation techniques. **Results:** The conventional methods to improve texture, plasticity and strength of the soils include mechanical stabilisation by blending of different soils, compaction controlled soil replacement, surcharge loading, pre-wetting or chemical stabilisation by introducing specific percentages of additives like fly ash, slag, gypsum, cement and lime. Alternative and greener stabilisation techniques like scrap tires, polymers, fibers and recycled materials. **Conclusion:** Each method has its merits and demerits in terms of efficiency, cost-effectiveness and environmental concerns.

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INTRODUCTION

The soil that causes damage to the overlaying structures such as foundations and pavements is called “reactive” or “expansive” soil. It mainly consists of a specific type of clay which causes it to swell with an increase in its water content, and shrink with the reduction. The changing seasonal conditions are usually responsible for these fluctuations in the soil moisture content. The variation in the soil’s volume causes vertical or horizontal deformation of the ground. The expansive soils can result in enormous damage to buildings and roads (Karunarathne *et al*., 2012; Fredlund, 2006; Ozer *et al*., 2012; Siddique and Hossain, 2013; Salahudeen *et al*., 2014). Several factors that affect the swelling and shrinkage of such soils include amount and type of clay minerals, total cations, dry density, water content and loading conditions (Grim, 1968; Seed *et al*., 1962; Nelson and Miller, 1992; Yilmaz and Marschalko, 2014; Jayasree *et al*., 2014).

The upper soil strata or the “active zone” is the main problematic zone in the expansive soils as most of the climate-influenced volumetric changes occur in that zone (Nelson *et al*., 2015). The extent or the depth of this zone may depend upon the geo-climatic conditions of the region (Jones and Jefferson, 2012).

Extensive research work has been carried out to define treatment procedures for stabilising expansive soils. The reduction in the volume change of expansive soils can be done by one of the several methods that are currently practiced.

The treatment method for expansive soil is also referred to as soil stabilisation defined as a mechanical or chemical treatment intended to sustain stability, reduce compressibility, improve engineering properties (i.e., shear strength) and or limit water absorption capacity of the treated soil (Harris, 2005).

Soil stabilisation may involve blending soils together to get a target gradation or mixing certain proportions of commercially produced materials or industrial by-products as additives that can modify

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gradation, texture, plasticity and strength or acting as binders for soil cementation (Joint Departments of the Army and Air Force, 1994; Rahmat *et al*., 2015).

The mechanical stabilisation involves mixing of native soil with another of different gradation to get a targeted gradation of the final mixture. It can be performed directly in the field or at a separate location before the mixture is returned to the job site and spread and compacted to the required density. The chemical stabilisation is performed by adding other additive materials at a certain portion of the treated soil. The choice of stabiliser depends on the treated soil. Due to the chemical reaction between the additive and soil, improvements occur in strength and stiffness and may also improve gradation, workability and plasticity of subgrade soil.

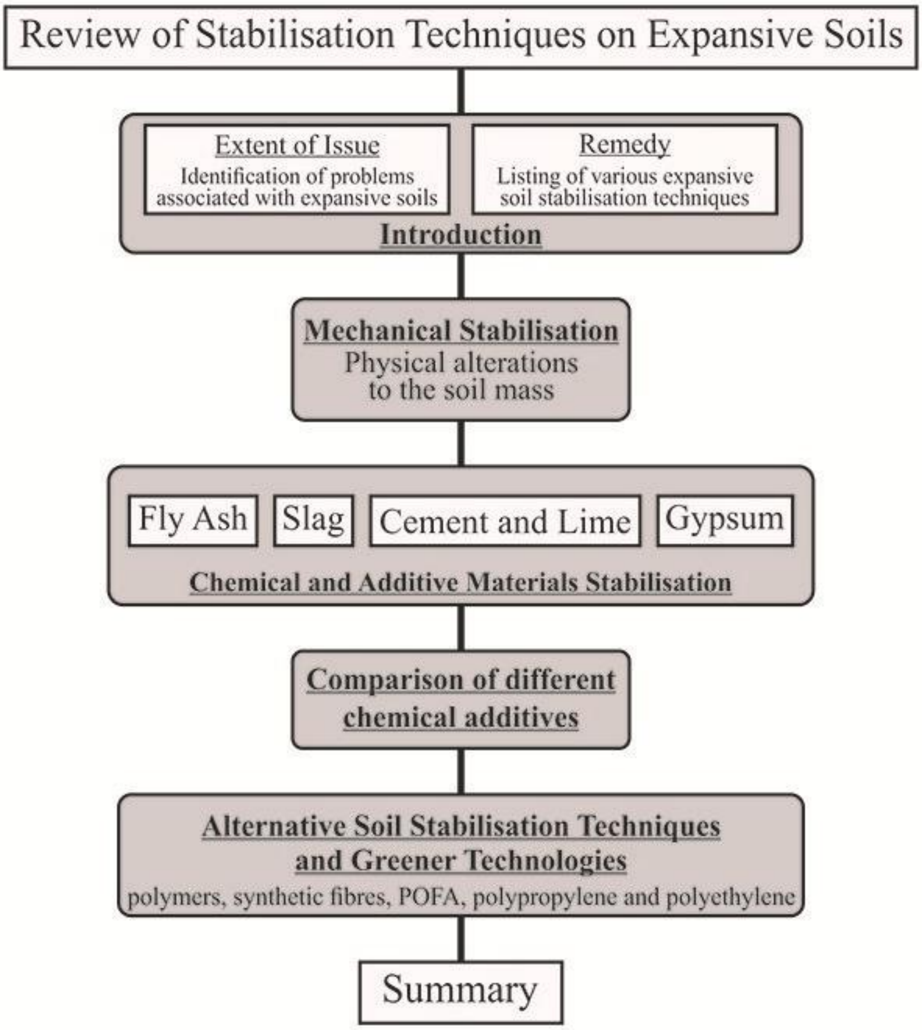

Fig. 1: Structure of the paper.

Edil *et al*. (2002) specify replacement of unsuitable soil with a material having better ability to support loads, such as rock as the best approach. However, due to the higher replacement costs of some unsuitable soils like expansive soil, the more economic improvement technique may involve an appropriate stabilisation method. The most suitable treatment could be determined after initial field investigations and laboratory evaluation of expansive soil properties.

Nelson and Miller (1992) have reported some treatments for expansive soils such as chemical additives, pre-wetting, soil substitution with control of compaction, moisture content and loading of surcharge and thermal treatment. The additives used may include a variety of materials from other soils to binders; chemical reagents; geo-, synthetic and biopolymers; recycled materials like slag, scrap tires, glass, fly ash, bitumen, salts etc. (Nicholson, 2015) . Pre-wetting aims to increase water content of expansive foundation soils so that most of the expansion occurs pre-construction. Then shrinkage is prevented by maintaining the high water content condition (Schanz and Elsawy, 2015). The swelling potential of soil can be reduced by modifying the soil compaction practice (Yilmaz, 2006). This soil compaction treatment can be applied on highway construction or light building. The swelling pressure exerted by expansive soils with low to moderate swelling pressures can be countered by placing a heavy surcharge load on the soil surface (Chu *et al*., 2014).

Although the addition of small amounts of additives might not produce an extensive change in the physical characteristic of the original soil, a mix of untreated soil and any other material in significant amount can form a composite soil with considerably different geotechnical parameters (Chegenizadeh and Nikraz, 2011b). Soil stabilisation can also be achieved by adding some materials with higher tensile strengths such as fibre to improve the strength of the soil (Chegenizadeh and Nikraz, 2011d; Viswanadham *et al*., 2009).

The resulting reinforced soil generally exhibits different characteristics such as compaction behaviour as compared to the characteristics of the original expansive soil which alters its compaction behaviour (optimum moisture and dry density (Chegenizadeh and Nikraz, 2011c). It has also been reported by Chegenizadeh and Nikraz (2011a), that the reinforced soil may generate higher shear strength.

Due to the comparatively greater focus of researchers on stabilisation of expansive soil through the addition of chemical admixtures, the main focus of this paper is to review the chemical additive soil stabilisation techniques through the use of the conventional additives including fly ash, slag, cement and lime. Nonetheless, brief review of the researches in mechanical and alternative greener stabilisation techniques has been conducted. The structure of this paper has been shown in Figure 1.

Mechanical Stabilisation:

The mechanical techniques for soil stabilisation have been applied for many years. The most widely known practices are soil compaction, dynamic and vibro-compaction; soil replacement and blending; and soil reinforcements and installation of barriers (Shillito and Fenstermaker, 2014). The effect of replacement of expansive bentonite with blended sandy-recycled EP (expanded polystyrene) was investigated by Abdelrahman *et al*. (2013). The soil replacement reduced the volumetric expansion-reduction of the expansive soil and increased the optimum moisture content with increasing EP beads content.

Pre-wetting of the soil has also been practiced over time. The main concept is to provide moisture to the expansive soil to allow the heaving to occur before the construction execution. However, the moisture content has to be kept at the higher value to maintain the soil volumetric variation at a fixed state (Chen, 2012).

Soil replacement is among the most commonly applied mechanical soil stabilisation techniques. The depth of the soil to be replaced depends upon the local soil profile, conventional practices and governing building code recommendations (Chen, 2012).

Chemical and Additive Materials Stabilisation:

One of the most commonly used methods for soil treatment is chemical stabilisation. The aim of chemical stabilisation of soils is to improve their stability. This can be achieved by increasing the particle size of soil through a decline of plasticity index, decreasing the shrinking-swelling potential and cementation. In chemical stabilisation, soil stabilisation is achieved by introducing a specific amount of a chemical compound to the expansive soil. Over the years lime, fly ash, cement, and some other chemical compounds have been successfully employed for soil stabilisation (Neeraja D. and Rao Narsimha A.V., 2010).

Sometimes, a more stable soil is needed to support the structural works and or as a subgrade for road works (pavements). Specifically for the pavements, the additives that are commonly used as ingredients of pavements are cemented base additives. Petry and Little (2002) have listed some cemented stabilising additives and divided them as traditional, by-product and non-traditional stabilisers. The traditional stabilisers include Portland cement, fly ash and hydrated lime while by-product stabilisers incorporate the dust from cement, lime kiln and slag. Other additives such as potassium compounds, polymers, ammonium chloride, sulphonated oils and enzymes are categorised as non-traditional stabilisers.

Several factors as recommended by the Texas Department of Transportation (2005) can be employed to select a suitable stabiliser namely; soil classification which includes gradation and plasticity, soil mineralogy and content (sulphates and organics), objectives of treatment, mechanisms of additives, material properties (modulus, strength), environmental conditions (water table, drainage), design life, and desired engineering and the economic constrains (cost–effectiveness).

Fly Ash:

Fly ash (FA) is a residual product or by-product that is generated during the thermal processing of pulverized coal in coal-fired electric and steam generating plants. In a study by (Pandian and Krishna, 2003), class-F FA (FFA) up to 100% was added to black cotton soil at an increment of 10%. They found out that the CBR values (California bearing ratio values) increased up to the 20% addition of FA, then after initially decreasing upon further FA increments, it showed an increase to attain an optimum value with 70% FA content. Another research by Phani Kumar and Sharma (2004) also investigated the influence of FFA addition on some geotechnical properties of expansive soil. Their study also noticed improvements in these properties with addition of FA.

Ji-ru and Xing (2002), Zha *et al*. (2008) and Bose (2012) were among some other researchers that examined the effects of lime and FFA adding upon the expansive soil behaviour and observed positive results. FFA and cement stabilisation of expansive soil was investigated by Amu *et al*. (2005). They noticed that the effect of 9% cement and 3% FA was better as compared with that of 12% cement in terms of soil stabilisation. Cokca (2001), Nalbantoglu and Gucbilmez (2001), Pandian and Krishna (2003) and Misra *et al*. (2005) researched influence of class-C fly ash (CFA) addition in expansive soils with different geotechnical characteristics and had found varied success.

In a study conducted by Ji-ru and Xing (2002) and Zha *et al*. (2008), only FA was used for expansive soil stabilisation without the addition of any other stabiliser. They observed no considerable improvement in the early UCS test (unconfined compressive strength test); but, the UCS values showed a sudden increase after 7 days of curing. Another investigation performed by Solanki and Zaman (2010) confirmed that the increment in UCS values of their samples followed the same trend. This result was observed when they evaluated the performance of two subgrade soils (CL and CH) stabilised with three different stabilisers (hydrated lime or lime), CFA, and cement kiln dust (CKD).

Slag:

Veith (2000) has suggested that environmental consideration should be regarded during the selection of an appropriate stabiliser for soils. Due to this reason, the utilisation of slag (a by-product and waste material) in soil stabilisation has emerged as a popular choice for engineers in comparison with lime and cement which may cause large amount of carbon dioxide (CO2) emissions during their production phase. Since CO2 is a greenhouse gas, it may cause warming of the Earth's surface by reducing outward radiation. Moreover, slag is cheaper as compared to many other cementing agents, rendering the economic feasibility of highway projects possible.

Ortega-López *et al*. (2014) performed the stabilisation of clayey soils soil using five different types of ladle furnace slag at a proportion of 5% as recommended by Manso *et al*. (2013). They observed positive results such as reduction in the swelling potential of soil, strength and volumetric stability and higher CBR indices as compared with the untreated soils.

In their study of soft soil stabilisation using granulated blast furnace slag (GBS), Yadu and Tripathi (2013) reported that the increment of the slag in stabilised specimens resulted in increased UCS values. The increase was as high as 28% from the UCS value of untreated soil when 9% of slag was introduced in the mix.

Cement and Lime:

Two of the most widely used additives for expansive soil stabilisation are cement and lime such as quicklime, lime slurry and extinct lime. The procedure is used in pavement and foundation engineering and mainly involves reduction of plasticity and resulting increase in bearing capacity.

Al-Rawas *et al*. (2005) used different percentages and combinations of pozzolan cement and lime for expansive soil stabilisation. The swelling potential was distributed into two components as swell pressure (constant volume method) and swell percent (from loaded-swell method) (Al-Rawas, 1993). Their results showed changes in different soil characteristics with variations in additives and a reduced swell potential for stabilised soil. They concluded that lime exhibited better suitability to reduce the swelling potential of soil in comparison whereas pozzolan increased the swelling potential.

In the study conducted by Saride *et al*. (2013) on organic expansive soils (OES), the optimum percentage of cement for soil-cement and lime for soil-lime were obtained at range of 3% - 6.5% (based on soil type) producing 1035kPa UCS after seven days of curing. They observed that the organic content (OC) of soils increase their OMC. They also recorded reduced dry density of treated OES due to decrease in soil's unit weight. In addition, they reported that the lime caused larger decrease in plasticity as compared to cement and the increment in the UCS for soils treated with any of the two additives was negligible (for lime) or even decreased (in case of cement) after 28 days curing period. Du *et al*. (1999) have also made observations related to the OC of the expansive soil. They reported that lime treatment of the expansive soil containing 7% lesser OC caused more improvement in the UCS to 893 kPa compared with other types of expansive soil samples under study.

Another recent work studying the stabilisation of over-consolidated expansive soil was carried out by Khemissa and Mahamedi (2014) with various cement-lime mixing ratios. It was noted that addition of stabilisers decreased the swelling potential of the soil from a higher methylene blue value of greater than six to just above two. It was also observed that CBR values increased with treatment and optimum results were obtained when cement and lime were added (2% and 8%) for soaked CBR. Meanwhile for the un-soaked CBR the optimum results were reached with addition of 8% cement and 4% lime. Also the direct shear tests (DST) showed that the optimum value for the improved bearing capacity of soil is obtained with an 8% cement and 4% lime mixture.

Gypsum:

A detailed review of cement and lime stabilisation of expansive soil has been provided earlier. However various researchers have identified that other stabilising agents; such as gypsum can also be used. An important research investigating the stabilisation of expansive clayey soils was carried out by Yilmaz and Civelekoglu (2009). They prepared samples at OMC with various percentages of gypsum (2.5, 5, 7.5 and 10) and bentonite (which consists of pure reactive clay mineral montmorillonite). They obtained data for Atterberg limits as per British Standards (1975), CEC (Cation exchange capacity), free swell (ASTM D-4546:, 1994) and UCS (ASTM D-2166:, 1994) tests on treated and untreated specimens tested through Standard Proctor compaction effort at determined OMC and cured for a week. They deduced that expansive clays can be effectively stabilised with gypsum which has a lower cost than lime and waste as observed through the increased UCS of bentonite with gypsum percentages equal to or less than 5% for optimum results. Conversely the researchers also acknowledged that the usage of gypsum can result in contamination of groundwater.

Comparison of Different Chemical Additives:

In an effort to compare the effectiveness of different additives, Seco *et al*. (2011) mixed expansive soil with different percentages of different combinations of additives for example cement; lime; steel, rice husk and cereal fly ashes; aluminate filler and gypsum. The free swell was determined for the one day cured test specimens and a second set of tests were carried out on the samples cured at 7, 14 and 28 days to calculate the UCS values of the treated and untreated expansive soil specimens. They observed an escalation of UCS while decline in the swelling potential. A combination of cement and lime additive mix and 4% of cement or lime addition with 5% rice husk fly ash were considered to show most notable improvements. Swelling potential reduced to 0.7% when 5% rice husk fly ash was introduced while it increased the compaction strength to two to four times in comparison to that of the untreated expansive soil.

Alternative Soil Stabilisation Techniques and Greener Technologies:

The evolution of technology has given rise to the research in establishing alternate soil stabilisation techniques. They can be more cost effective and environment-friendly than the conventional soil stabilisation methods. The “greener” soil stabilisation methods normally induce polymers, tree resins, fibres, alkali chlorides and enzymes. Viswanadham *et al*. (2009) analysed the swell behaviour of an expansive soil reinforce stabilised by different fibre percentages, with varying aspect ratios. The results of oedometer swell-consolidation test showed the maximum decrement in swell pressure with lower aspect ratio at both fibre percentages. Studies have indicated that recycled fibres from random sources, such as scrap rubber tires, can be used for soil stabilisation (Belabdelouahab and Trouzine, 2014). The 2% tire content has been found as optimum for UCS increment by Akbulut *et al*. (2007). They also found 0.2% of polypropylene and polyethylene to be optimum for UCS. The fibre addition at these percentages also increased the shear moduli and damping ratios of treated samples.

Alternatively, waste products from industries such as the food industry have been researched as suitable soil stabilisers (Ahmad *et al*., 2008). Pourakbar *et al*. (In Press) investigated the effect of palm oil fuel ash (POFA) and POFA- cement mix on clay properties. They found that the addition of POFA significantly reduced the plasticity index and optimum moisture content. The cement-POFA mix produced better improvements in the UCS than the pure POFA.

Summary:

There are different approaches to achieve soil stabilisation for reactive soils. The problematic soil can be mixed with a different soil to obtain the required plasticity, strength and workability. Other mechanical methods such as replacing the unsuitable soil, moisture control and pre-wetting of soil to have the expansion pre-construction can be practised but the application of these techniques might escalate the cost of projects. Researchers have investigated stabilisation of expansive soils through the addition of different chemical stabilisers such as cement, gypsum, FA and lime to enhance bearing capacity with reduced plasticity. However, the production of these additives can cause hazards to the environment and can be costly in some cases. Even though gypsum has been an effective stabilising agent for bentonite, it has limitations in terms of availability, ease of stabilisation and probable toxication of the groundwater.

The researchers have investigated the usage of industrial waste products namely; slag and fly ash for expansive soil stabilisation instead of gypsum, lime and cement. FA has shown success in increasing the CBR value of treated soils for the subgrade. Slag has also exhibited promising results in increasing the UCS values of the reactive soils and decreasing the swelling potential. Different types of geo-, synthetic and biopolymers and other alternative materials originating from different resources such as scrap tires, polystyrene, polypropylene and polyethylene were also investigated for expansive soil stabilisation. However, it should also be noted that the percentage and efficiency of any particular additive mix to achieve optimum results are highly dependent upon the particular type of expansive soil, clay mineralogy, soil chemistry, initial moisture content, physical composition, plasticity and climatic moisture variations. Therefore, the effectiveness of any particular additive mix cannot be determined unless it has been laboratory tested for a particular type of expansive soil.

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