International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:12, 2013

Chemical Amelioration of Expansive Soils

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Abstract**—**Expansive soils swell when they absorb water and shrink when water evaporates from them. Hence, lightly loaded civil engineering structures founded in these soils are subjected to severe distress. Therefore, there is a need to ameliorate or improve these swelling soils through some innovative methods. This paper discusses chemical stabilisation of expansive soils, a technique in which chemical reagents such as lime and calcium chloride are added to expansive soils to reduce the volumetric changes occurring in expansive soils and to improve their engineering behaviour.

Keywords**—**Expansive soils, swelling, shrinkage, amelioration, lime, calcium chloride.

I. Introduction

EXPANSIVE soils are highly problematic in nature by virtue of their inherent capacity to undergo volumetric changes corresponding to changes in moisture regime. They swell when they absorb water and shrink when water evaporates from them. As expansive soils are rich in mineral montmorillonite which has an expanding lattice structure, swelling occurs when water is absorbed by these soils. The building blocks of the expanding lattice structure of the mineral get separated when water enters them. Thus, swelling takes place in expansive soils. Shrinkage or volumetric reduction is also notable in expansive clays because of swelling or volumetric increase [1], [2].

A field expansive clay layer undergoes swelling during rainy seasons and shrinkage during summers. Hence, lightly loaded civil engineering infrastructure such as residential buildings and road pavements are subjected to severe distress and develop unsightly cracking. It has been found that the loss of property due to damage caused by expansive soils is quite immense. Often, the cost of repair exceeds even the cost of the original structure.

Hence, there is a need to ameliorate or improve expansive clays so that the volumetric changes are reduced. Many innovative foundation practices have been devised to reduce the volumetric changes in expansive soils. These practices can be classified as physical alteration techniques, mechanical alteration techniques and chemical alteration techniques. Some other innovative foundation techniques include tension-resistant foundation techniques, which are straight-shafted drilled piers, belled piers, under-reamed piles and granular pile anchors (GPAs).

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II. Mechanical and Physical Alteration

In this technique, the top few layers of the expansive clay stratum are removed and replaced by a reasonably well compacted non-swelling soil layer. Two techniques of this example are quite prominent. They are sand cushion technique and cohesive non-swelling (CNS) layer technique.

In sand cushion technique (see Fig. 1) the top layer of the expansive soil is replaced by a sand layer [3]. This technique came to be called 'sand cushion' because of its inherent advantages.

i. In rainy seasons, water infiltrates into the expansive clay layer through the sand cushion, saturating the sand layer in the process. As a result, expansive clay layer undergoes swelling, but the saturated sand cushion gets compacted, reduces in its thickness and hence accommodates the heave undergone by the expansive clay layer lying underneath.
ii. In summers, water evaporates from the system. As a result, expansive soil undergoes shrinkage and its thickness decreases. But, the unsaturated sand increases in its volume through bulking and hence, it accommodates the shrinkage undergone by the expansive clay layer. Thus, sand cushion technique has an inherent advantage of adjusting its thickness and volume in different seasons to accommodate the heave and shrinkage undergone by the underlying expansive clay layer.

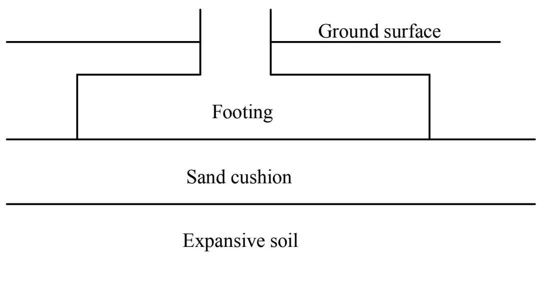

Fig. 1 Sand cushion technique

In CNS layer technique [4], the top few layers of the expansive clay stratum are replaced by a cohesive non swelling (CNS) layer compacted to take care of the bearing capacity criterion. The contention is that, at a depth of 1m in the CNS layer, cohesive forces develop and reduce swelling of expansive clay. The material recommended for CNS layer is moorum, which has some cohesive clay which is non-swelling in nature.

In physical alteration technique, non-swelling materials such as sands and gravels are mixed with expansive soil in different proportions and placed back at a reasonable dry density so that the bearing capacity criterion is not violated. These artificial sand-clay mixes and gravel-clay mixes have been found to be quite effective in controlling swelling of expansive soils. In this technique, swelling gets reduced because the expansive soil is replaced by non-expansive materials [5], [6]. Phanikumar et al. [6] found that the rate and amount of heave decreased with sand content in the blends. Further, swell potential and swelling pressure decreased with increase in sand content.

The technique of chemical alteration is discussed towards the end of the paper.

III. Tension-Resistant Foundation Techniques

Tension-resistant foundation techniques are devised to absorb the tensile force generated in an expansive clay stratum due to swelling. The examples of tension-resistant foundations are drilled piers, belled piers, under-reamed piles and granular pile anchors (GPAs). These techniques are briefly described below:

Drilled piers are straight shafted piers, drilled into expansive clay stratum. They are small diameter piers [1]. The zone affected by wetting is the active zone, and that unaffected by wetting is the inactive zone. Swelling pressure causes uplift in the active zone and the resistance to uplift is mobilised in the inactive zone. Hence,

$$P_u = p_s f(D-d)2\pi r \quad (1)$$

where p_s = swelling pressure and f = uplift coefficient; and

$$P_R = W_{pier} + 2\pi r s d \quad (2)$$

where W_{pier} = weight of the pier and s = shear strength of the clay.

Hence, the factor of safety (F.S.) with reference to uplift is

$$FS = \frac{P_R}{P_U} = \frac{W_{pier} + 2\pi r s d}{p_s f(D-d)2\pi r} \quad (3)$$

Belled piers [1] are piers with enlarged bases. Hence, in the case of belled piers, resistance to uplift is mobilised over an enlarged perimeter. The factor of safety (F.S.) with reference to uplift of belled piers is written as,

$$FS = \frac{P_R}{P_U} = \frac{(W_{pier} + W_{soil} + 2\pi R s d)}{p_s f(D-d)2\pi r} \quad (4)$$

Under-reamed piles [7] are bored cast in-situ piles with enlarged bases and connected at their top with plinth beams. In under-reamed piles also, the resistance to uplift is mobilised over an enlarged perimeter. Under-reamed piles are quite effective in reducing heave when under-reams (enlarged portions) are laid in the inactive zone. Fig. 2 shows the concept of an under-reamed pile.

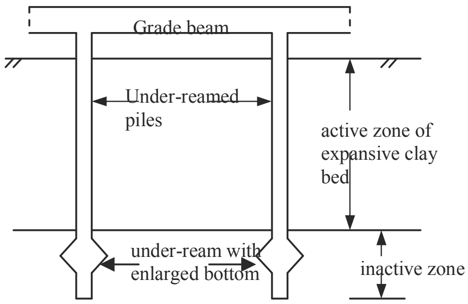

Fig. 2 Under-reamed pile foundation

Granular pile-anchors (GPAs) are a recent innovative foundation technique devised for expansive soils [8]. In a GPA, the foundation is anchored to a base plate at the bottom of the granular pile anchor through a mild steel anchor rod. Fig. 3 shows the concept of a GPA.

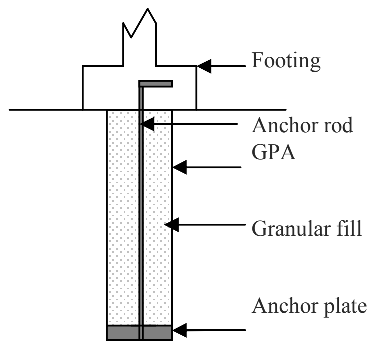

Fig. 3 Concept of a GPA

It can be seen from the figure that swelling pressure acting in the bottom of the foundation causes uplift and resistance to uplift is mobilised over the GPA-clay interface because of the anchoring effect of the GPA. The resistance to uplift is, therefore, mobilised due to the shear parameters of the GPA-clay interface (c' and φ') and also the weight of the GPA. Hence,

$$P_u = p_s\left[\frac{\pi}{4}\left(D_f^2 - D_{GPA}^2\right)\right] \quad (5)$$

where, D_f is the diameter of the footing and D_{GPA} is the diameter of the granular pile-anchor.

The resisting force P_R can be written as,

$$P_R = W_{GPA} + \pi d l\left[\{c' + K\sigma' \tan\phi'\} + K_s p_s \tan\phi'\right] \quad (6)$$

where, W_{GPA} is the weight of the GPA, K is the coefficient of earth pressure at rest, σ' is the overburden pressure and K_s is the coefficient of lateral swelling pressure.

A number of laboratory scale model tests were conducted on the concept of GPA [8] and promising results were obtained. Heave tests, compressive load tests and pull-out tests conducted on GPAs yielded excellent results [8], [9]. Field scale tests were also conducted on GPAs and similar results were obtained [10]-[12].

IV. Chemical Alteration Techniques

In chemical alteration technique, different chemicals such as lime, cement, calcium chloride and fly ash are added to expansive clays for controlling swelling and shrinkage. These chemicals have been found to reduce the plasticity, improve engineering properties such as compaction characteristics, shear strength, and compressibility [1], [2], [13], [14].

When lime is added to expansive clays in presence of water, two important reactions take place: one is flocculation and the other is cementation. Flocculation takes place immediately after the addition of lime wherein, cation exchange takes place resulting in increase in particle size and reduction of plasticity. Liquid limit (LL) decreases and plastic limit (PL) increases with increase in lime content, resulting in reduction of plasticity index (PI). Fig. 4 shows the effect of lime content on LL, PL and PI. Generally, 4% lime is known as the optimum lime content.

It has also been found that free swell index (FSI), which reflects the potential a soil has for swelling, also decreases with increasing lime content up to 4%. Fig 5 shows the variation of FSI with lime content. The second reaction taking place upon the addition of lime is cementation, which is a time-bound reaction [15]. As an effect of this reaction, cementitious products in the form of calcium alumino-silicates develop in the blend.

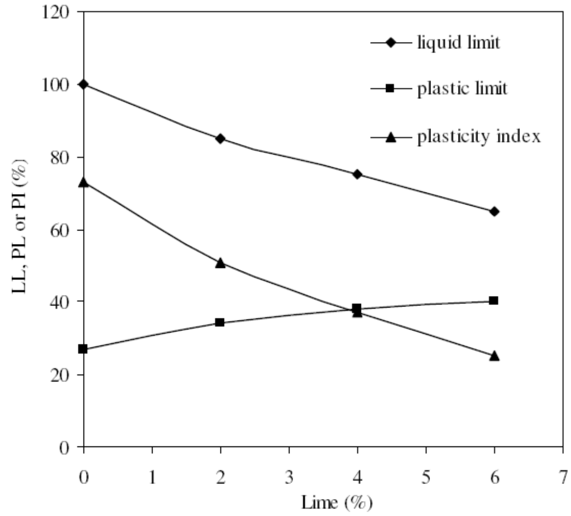

Fig. 4 Effect of lime content on LL, PL and PI

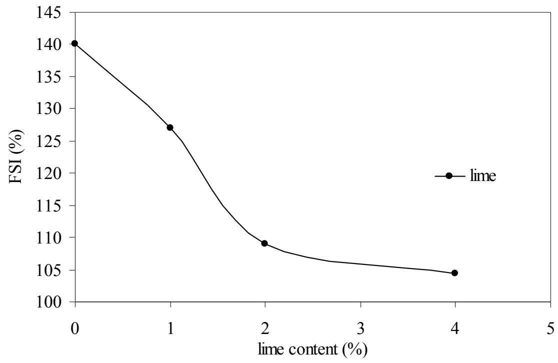

Fig. 5 Variation of FSI with line

Swell potential decreases with increasing lime content. But, swelling pressure has been found to increase with lime content beyond a certain lime content, a fact which can be attributed to the development of cementitious products. Some innovative practices have also been developed using lime. Two of such techniques which are prominent are lime-slurry pressure injection (LSPI) and lime-soil columns.

Calcium chloride is a hygroscopic or deliquescent salt which absorbs moisture from the atmosphere. $CaCl_2$ is also known to reduce swelling. If expansive clays are treated with $CaCl_2$, the blends retain wetness and shrinkage cracks do not result. Fig. 6 shows the effect of $CaCl_2$ on FSI. FSI decreased to a maximum extent up to a $CaCl_2$ content of 1% and thereafter it increased. So, the percent reduction in FSI at 1% $CaCl_2$ was 40%. The degree of expansion of the blend was 'moderate' at 85% FSI.

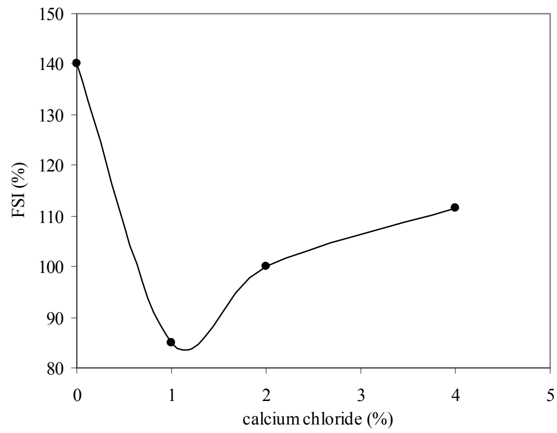

Fig. 6 Effect of calcium chloride content on FSI

Fly ash is an industrial waste produced from flue gases generated by burning coal in power plants [16]. Fly ash is a silt-sized, non-plastic material as it is also a pozzolanic material. It results in flocculation when it is added to expansive clays in presence of water [17]. Hence, LL and PI decrease with increase in fly ash content. Fig. 7 depicts this. LL of the test expansive clay decreased from 100% to 90% and PI from 72% to 50% when the fly ash content was increased from 0% to 20%.

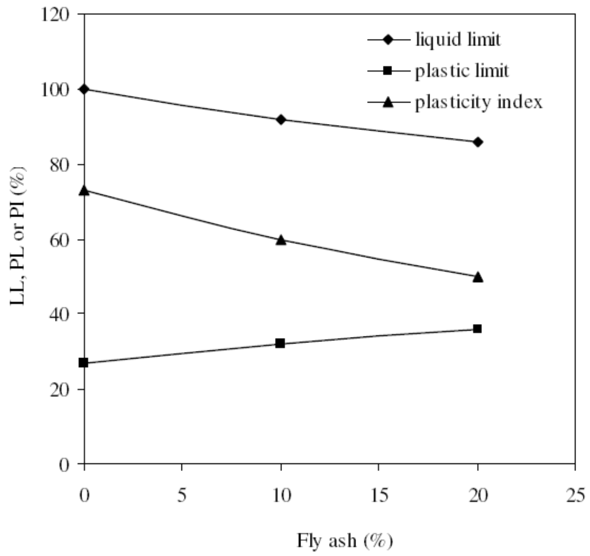

Fig. 7 Variation of LL, PL and PI with fly ash content

FSI, swell potential and swelling pressure also decrease with increase in fly ash content. Fig. 8 shows the influence of fly ash content on FSI. FSI of the test expansive clay decreased from 140% to 80% when the fly ash content increased from 0% to 20% [18].

Of all the above additives, lime has been found to be the most effective chemical stabilizing agent in the case of expansive soils. Figs. 9 and 10 respectively show the comparative effect of lime and fly ash on swell potential and swelling pressure [14].

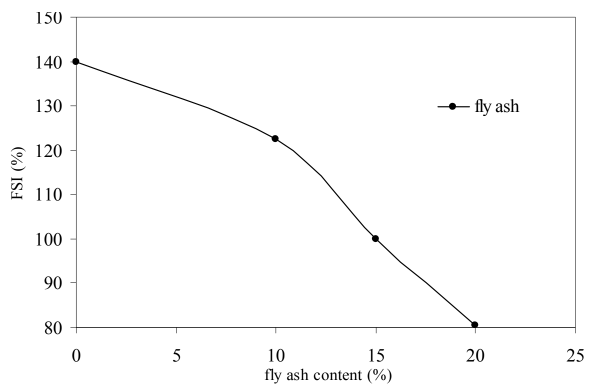

Fig. 8 Variation of FSI with fly ash content (%)

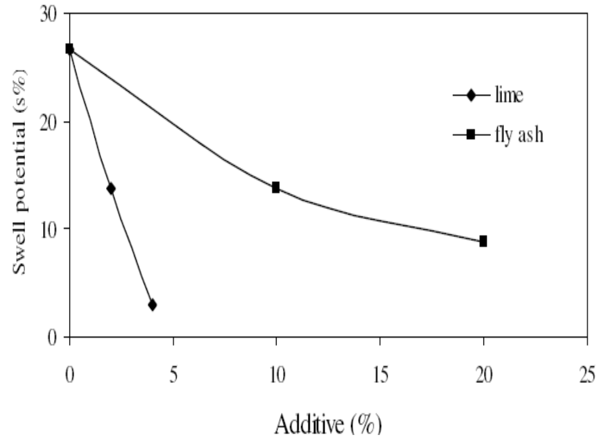

Fig. 9 Comparative effect of lime and fly ash on swell potential

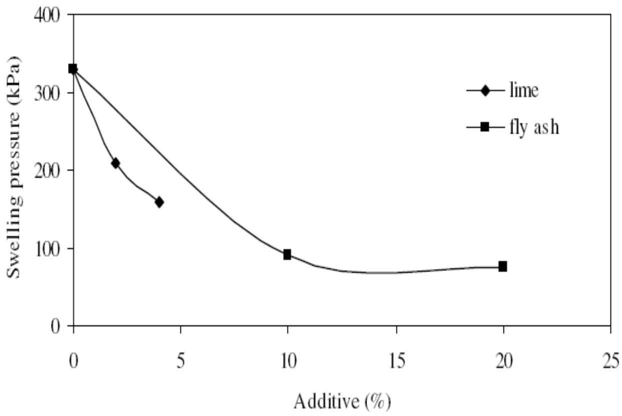

Fig. 10 Comparative effect of lime and fly ash on swelling pressure

Some innovative foundation practices have been recently devised using fly ash. Fly ash columns or FACs [19] and fly ash-stabilised clay cushion or FACC [20] are prominent among them. FACs are compacted columns of fly ash introduced into expansive clay layers. FACs was found to have reduced heave and improved bearing capacity. Fly ash-stabilised clay cushion is an innovative cushion technique suggested for expansive soils. It was found that heave and bearing capacity characteristics depended on the fly ash content in the cushion and also on the thickness of the cushion.

V. Conclusions

Expansive soils are highly problematic and civil engineering structures founded in them are severely distressed. Various innovative foundation techniques have been devised to ameliorate the problems posed by expansive soils. The chief of these innovative techniques are physical alteration, mechanical alteration and chemical alteration. Tension-resistant foundation techniques such as drilled and belled piers, under-reamed piles and granular pile-anchors (GPAs) have also been found to be quite effective in controlling heave of expansive clay beds.

Chemical admixtures such as lime, calcium chloride, cement and fly ash have been successfully used for modifying the properties of expansive soils in the technique of chemical alteration. Of these additives, lime is the most effective additive especially when volume reduction of expansive clays is the criterion. Cement is preferred when strength is the criterion. Swelling characteristics such as FSI, swell potential and swelling pressure can be significantly reduced at optimum percentages of the above additives. It was found that, at 20% fly ash content, FSI could be reduced to about 50% of the unblended expansive clay.

Fly ash columns (FACs) are a recent foundation technique suggested for ameliorating the problems posed by expansive soils. It was observed that heave of the composite ground (expansive clay improved by FACs) reduced and bearing capacity improved. Fly ash-stabilised clay cushion (FACC) is another innovative cushion technique for expansive clay beds. The load-carrying capacity of the expansive clay beds with FACCs was found to have increased. Suitable values of fly ash content and cushion thickness can be arrived at for the allowable heave and the required bearing capacity.

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