Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

A Critical Review on Stabilisation of Expansive Soils With Compensating Materials

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Abstract. Expansive soils are mostly found in semi-arid and arid regions, and these soils suffer significant volume change when exposed to seasonal moisture fluctuations. Further, this volume change may cause extensive damages to the engineering structures and also the cost of damages increases every year. Practicing geotechnical engineers used different treatment methods to enhance the engineering performance of these soils. However, the placement of compensating materials in expansive soil deposits was found to be attractive for shallow stabilisation due to its construction feasibility and economic aspect. Extensive research has been carried out for the past 60 years for understanding the mechanisms of compensating materials in controlling the volume change of expansive soils. The engineering solutions to these soils consider various factors like the thickness of expansive soil, swell pressure, active zone profile, and properties of compensating material. This article reviews some of the essential aspects of the physical and engineering properties of different compensating materials and also the placement conditions followed in practice.

Keywords: expansive soil; swell pressure; cohesive non-swelling soil; soil replacement; chemically stabilised soil.

1 Introduction

For ensuring the stability of the civil engineering structures, the sub-structures are constructed over different types of soils. However, some soils in their natural state may not be suitable for construction purposes, and such soils are identified as problematic. Moreover, these soils require special treatment before using it as a foundation material. Due to the detrimental volume change experienced by the expansive soils upon moisture intake, they are identified as problematic soils. Expansive soils are residual soils derived from the parent materials of igneous (basalt) and sedimentary (limestone, sandstone and shale) based rocks when subjected to chemical weathering at the high alkaline environment (Seiple, 1968; Donaldson, 1969). In India, almost 20% of the land area is covered by expansive soil deposits and mostly found in the states of Maharashtra, Madhya Pradesh, Karnataka, Telangana, Andhra Pradesh, Tamil Nadu, Rajasthan and Gujarat (Katti, 1978; Rao, 2000; Kumar et al. 2020). The unpredictable volume change of expansive soils may disturb the service life of the structures if not addressed and treated properly.

Several methods were developed and followed as mitigation measures. However, methods such as moisture control, pre-wetting of soil, surcharge loading, placement of compensating materials (removal and replacement technique), compaction control and chemical modification gained popularity (Chen, 1975; Nelson and Miller, 1992). Among the mitigation methods, removal and replace technique (placement of compensating) is one of the attractive solutions for lightly loaded structures due to material availability, field workability and economic considerations. Hence, a detailed review was carried to bring out the significance and limitations of the different compensating materials in mitigating the volume change of expansive soils.

2 Different Types of Compensating Materials And Their Mechanism In Controlling The Volume Change of Expansive Soils

2.1 Gravel material

Holtz (1959) suggested the soil replacement as a retrofitting technique for Mohawk and Welton canal, constructed over expansive soil. Lightly compacted gravel and sand were used as a compensating material. Since it is a remedial measure, the material was placed over the partially swollen sample, and the compensating material not only provides the surcharge effect but also it minimises the differential movement. However, the placement conditions such as density index and thickness of the compensating material was not detailed for expansive soils with varying degree of soil expansion.

2.2 Sand material

Satyanarayana (1969) and Moussa et al. (1985) suggested sand as a compensating material to control the volume change. It works on the principle that during monsoon, the wet sand consumes less volume, and hence it accommodates the excess volume change of underlying expansive soil. Similarly, during the shrinkage process of expansive soil, the excess voids are compensated by bulking nature of sand in a partially saturated condition. The swell potential of expansive soil stabilised with sand as cushion material showed maximum reduction when sand was placed at a lesser density index. A recent study by Kumar (2020) also reported similar observations and showed that the swell reduction was mainly due to the reduction in the void ratio of the sand upon inundation. Earlier observations showed that sand cushion could be used for low and medium swelling soils; however, the placement conditions were not generalised. Besides, the compensating materials like gravel and sand are not encouraged due to its higher hydraulic conductivity, and it may establish a water reservoir over the expansive soils.

2.3 Non-swelling soil

Based on the field observations, Chen (1975) reported that a structure resting on 5 feet (1.5 m) of granular soil (SP - SC) followed by expansive soil did not result in any distress. However, the mechanism behind the control of swell was not precise, i.e. whether the seepage water did not reach the expansive soil or it was because of the uniform heave of expansive soil that did not result in any distress of the structure. Chen

(1975) suggested to use non-swelling soils with liquid limit of 30% to 50% and the finer fractions (<75 µm) ranging from 5% to 50%. Besides, he also suggested that material should be impervious, and the relative compaction of the compensating material should be in the range of 90 to 100% of standard Proctor density. The thickness of the non-swelling soil ranges from 3 to 5ft (about 0.9 to 1.5 m). Nelson and Miller (1992) also supported the observations reported by Chen (1975).

2.4 Cohesive non-swelling soil (CNS)

The continuous works of Katti (1978) and his co-workers proposed cohesive non-swelling (CNS) soil as a compensating material and showed that the swelling was controlled due to the development of cohesive forces in the CNS material. This method is also extended to field applications for lightly loaded structures such as canal lining and pavement construction. Based on the laboratory and field investigations, Katti (1978) proposed the specifications, field conditions and thickness of CNS material to minimise the heave of expansive soil during saturation. The term cohesive non-swelling could be used only when the compensating material meets the specifications proposed by Katti (1978), and other materials as non-swelling soils. The CNS should be compacted to standard Proctor condition, and the measured swell pressure of the CNS should be less than 10 kPa. The thickness of the CNS material was decided based on the measured swell pressure. IS-9451: 1994 also suggested the specification proposed by Katti (1978) for swell control in expansive soils in particular for canal applications. Recently, Kumar et al. (2018) suggested CNS material as a compensating material in the retrofitting works of the distressed industrial building.

2.5 Chemically stabilised soil (CSS)

Practically, it is not easy to obtain the soils with the exact specification of CNS material in the vicinity of the construction site (location), and this makes the designer to choose alternate methods (Katti, 1978). Later researchers tried to get compensating materials using industrial wastes like fly ash and rice husk ash by using directly or blending with cement or lime as a cushion (Sivapullaiah et al. 2004; Sahoo et al. 2008). Few experiments were conducted to study the possibility of using native expansive clay as CNS material by mixing with suitable admixtures and called this material as chemically stabilised soil (CSS) cushion (Katti, 1978; Katti and Katti, 1994).

Rao *et al*. (2008) recommended the use of lime admixed fly ash as cushion material. They also suggested that the thickness of the cushion should be half the depth of active zone for efficient functioning. Murthy and Praveen (2008) suggested that the expansive clay blended with 0.5% $CaCl_2$ and 8% rice husk ash can also be used as alternate to natural CNS material.

3 Cyclic Swell-Shrink Behaviour of CNS/CSS Stabilised Expansive Soil

Several laboratory studies were performed to bring out the wet-dry effects on expansive soil stabilised with compensating materials. Rao (2000) reported that CNS was effective only during the first cycle of wetting, and its efficacy was lost in the subsequent wetting cycle. A recent study by Kumar (2020) also reported similar observations where CNS was used as a compensating material. Few studies were also carried out on natural, cement/lime stabilised murrum as a CNS material and subjected to wetting and drying cycles (Sahoo et al. 2008; Sahoo and Pradhan, 2010). Rao and Rao (2010) performed swell-shrink studies to evaluate the suitability of cement and lime stabilised fly ash as cushion material. They found that the cement stabilised fly ash cushion was more effective than the lime stabilised fly ash cushion in controlling the swell-shrink movements.

4 Depth of Active Zone

Due to the cyclic process of precipitation and evapotranspiration, the water content fluctuates at the surface level of expansive soil deposit, and it decreases or increases with depth according to the environmental condition (summer and winter). Nelson et al. (2001) defined the active zone as the zone of soil that contributes to the heave due to soil expansion at any particular time. The selection of the method of treatment to the expansive soils depends on the depth of active zone and swell pressure. It is essential to evaluate the active zone for a given site because almost 60-80% of volume change occurs in the top 50% of active zone depth (Rao et al. 1988; Fityus et al. 2004).

The depth of active zone changes with time and also it depends on the soil profile, hydraulic conductivity and other environmental factors. In places, where the soil profile is stratified, the depth of the active zone can be determined by plotting w/w_L (w is the water content and w_L is the liquid limit) or plasticity index (I_P) versus depth (Nelson and Miller, 1992). Typically, in India, the depth of active zone was found to be 3.5 to 5 m in Madhya Pradesh, 1.5 m in Maharashtra and NIT Warrangal campus, Telangana (Murthy and Praveen, 2008; Soni, 2009). The maximum depth of the active zone was found in the place Colorado (USA), and it was obtained as 16 m (Holtz, 1969).

4.1 Thickness of soil removal in the active zone

Ardani (1992) has developed guidelines for the thickness of removal of soil, which was proposed and followed by the Colorado department of highways. Here, the thickness of removal is optimised based on the plasticity index of soil, and the same is summarised in Table 1. Further, the sub-excavated soil should be compensated with impervious materials.

As discussed in the above section, the process of removal of soil in the active zone itself controls the volume change before placing the compensating materials (Rao et al. 1988; Fityus et al. 2004). Therefore, it is more meaningful if the replacement of soil is decided based on the active zone, rather than depending on plasticity, the thickness of the clay layer and swell pressure. In general, it is complicated to evaluate the active zone profile for the given site, and this makes uncertainty in heave measurement (Coduto, 2013).

5 Laboratory Constraints In Understanding The Behaviour Of Expansive Soil Stabilised With Compensating Material

Swell-consolidation and constant volume methods are mostly used for the determination of swell pressure of layered soil (ES + CNS/ CSS/ Sand). Fredlund (1969) reported that the swell pressure of expansive soil (ES) from the swell-consolidation method should be corrected for compressibility of filter paper, porous stone and apparatus. In a layered soil system, the compressibility of compensating material is entirely different from the expansive soil. So far, no studies were reported to show how to account the corrections for layered soils, which poses different compressibility behaviour in saturated conditions. A recent study by Kumar (2020) showed that the swell pressure of ES + CNS was found to be higher than the swell pressure of ES alone. The higher swell pressure might be due to the rigid behaviour of CNS material (comparatively with expansive soil) and sidewall friction, which offer more resistance against the applied pressure. Besides, it is also challenging to simulate environment-dependent active zone profile in laboratory conditions.

Table 1. Thickness of removal of soil in the active zone based on plasticity index

Plasticity index (%)	Thickness of removal (ft)
10 - 20	2
20 - 30	3
30 - 40	4
40 - 50	5
>50	6

6 Summary and Conclusions

This paper explores the development of different compensating materials to overcome the detrimental volume change of expansive soil induced upon inundation. It is clear from the above review that the placement of compensating material is successful in controlling the volume change and still followed by the many practising engineers across the world. Further, the natural compensating materials are ineffective during wet-dry cycles. Besides, it is also evident from the above discussion that mechanisms of compensating materials in controlling the volume change differ among the researchers, and it might be due to limited field trials. Therefore, better understandings of compensating materials could be established by performing many field trials with the support of instrumentation results.

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