Study on use of chemically stabilized native expansive soil as cohesive non-swelling material

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Abstract. The growing infrastructural need requires extensive construction activities in various parts of the world. The problems posed by the expansive soils have caught the attention of the academia and industry at several work sites. Several remedies were suggested by various researchers like replacement of soils, physical, hydraulic & chemical modification of the local problematic soils, inclusion of cushion materials and other reinforcing materials etc. Among the various methods, inclusion of cushion materials under the foundations seemed to be economical and simple. Availability of cohesive non-swelling (CNS) materials to be used as a cushion at some work sites could not be very easy. This study utilizes the local expansive material stabilized with chemical and industrial wastes to prepare a suitable CNS material. Model tank studies with varied thickness of the CNS cushion prepared from this study was placed on the expansive soil were performed to find the efficacy of the CNS material in arresting the heave of the expansive soil. Four cycles of wetting and drying was carried out to check the stability of CNS materials under continuous swelling and shrinking. Results obtained from the model test results indicate that the CNS material prepared from the native expansive soil seem to be an effective CNS material that arrests considerable amount of heave when the thickness of the native CNS material was half of the soil thickness.

Keywords: Expansive Soil, Swelling, Shrinking, Cohesive non-swelling soil and compression.

1. Introduction

Expansive soils pose severe threat to the stability of the structures founded on them due to their volumetric changes with the variations in the moisture content. These problems received universal attention due to serious economic losses faced by several world nations [1, 2]. The findings of research community all around the world offered the civil engineering with several remedial measures to reduce the impact of the damages caused by expansive soil deposits [3–8]. Various remedial measures and foundation techniques were developed like replacement of soil [9,10], placing adequate surcharge [9], controlling the moisture variations [11], altering the design of superstructure [2,12], physical and
chemical modifications of soil [13–22], using a sand cushion [23–25] & Cohesive Non-Swelling (CNS) material cushion [3,26–28], using under-reamed piles [29,30], piled raft [31,32] & recently granular anchor piles [33–35] etc.

Usage of the cushion materials have got more prominence among various remedial measures in view of the inherent economical constraint on their application [2]. Earlier, the sand cushion was adopted in various situations but its paradoxical behavior under different site conditions led the prominence of CNS cushion in alleviating the heave of expansive soil promulgate. However, exact material meeting the requirements of CNS materials [3] may not be easily available at several site conditions [36] which makes this technique non-viable in many circumstances. Various researchers felt the need for conversion of the existing local expansive soil artificially into a CNS material by means of some suitable admixture [2,26,37–39]. Sastry [37] investigated the suitability of expansive soil mixed with several admixtures like lime, lime + fly ash, lime + rice husk ash, lime + cinder ash as a CNS material and suitable outcome was observed. Gurumurthy [38] prepared an artificial CNS material by mixing the local rice husk ash with lime and cement and observed that these materials arrest the heave better than a few of normal CNS material. Similar researches were found that other waste materials stabilized with suitable admixtures can be used as a CNS material [40–42]. Kate and Katti [26] suggested the use of 2% lime or gypsum or 60% natural sand in the local expansive soil to attain the CNS material characteristics. Murty [43] used various proportions of Calcium Chloride (CaCl₂) on rice husk ash to attain the characteristics of a CNS material. The CaCl₂ or the rice husk ash could be used directly on the native expansive soil in order to reduce its plasticity and swelling characteristics besides increasing the strength of soil that was a result of the cation exchange reactions and pozzolanic reactions [44].

In this present paper, a native expansive soil was converted into a CNS material by using lime and fly ash as admixtures. The index and engineering characteristics were studied on the modified material and model tank studies were conducted with different CNS-Soil thickness ratios and the heave under saturated conditions was measured. The effect of repeated wetting and drying cycles on the heave was also undertaken at the laboratory conditions.

2. Materials

2.1 Soil
The soil was collected from the Airport region, Tirupathi, Andhra Pradesh, India. The differential free swell index test performed on the soil shown that the soil was of high swelling nature though the material falls under the category of clayey sand. The properties of the soil determined as per the IS code procedures were presented in table 1.

Table 1. Properties of expansive soil

| Test Parameter                          | Result |
|----------------------------------------|--------|
| Specific gravity                       | 2.71   |
| Gradation:                             |        |
| Gravel, G (%)                          | 0.0    |
| Sand, S (%)                            | 54.6   |
| Fines (%)                              | 45.4   |
| Atterberg’s Limits:                    |        |
| Liquid Limit, LL (%)                   | 79.6   |
| Plastic Limit, PL (%)                  | 27.2   |
| Plasticity Index, PI (%)               | 52.4   |
| IS Soil Classification                 | SC     |
| Differential Free Swell Index, DFSI (%)| 220    |
| Compaction Characteristics:            |        |
| Optimum Moisture Content, OMC (%)      | 13.0   |
| Maximum Dry Density, MDD (kN/m³)       | 18.1   |
Unconfined compressive strength, UCS (kN/m²)  124  
Undrained Cohesion, c_u (kN/m²)  62  

Oedometer results:
Swelling Pressure @OMC (kN/m²)  180  
Compression Index @OMC  0.153  
Compression Index @LL  0.415  

2.2 Lime
Locally available commercial hydraulic lime was used in the study.

2.3 Fly ash
Fly ash was taken from the Rayalaseema thermal power plant (RTPP), Muddhanur, Kadapa.

3. Experimental Methodology

3.1 CNS material
As per table 1, the selected local soil is ineffective as a CNS material. So, to convert the native soil into CNS material, 5% lime was added to reduce the plasticity. Further varied proportions of fly ash (5, 10, 15, 20 and 25%) was added along with 5% lime. The LL, PL & PI, compaction characteristics and UCS of the soil mixed with lime and varied proportions of fly ash were investigated as per relevant IS codes. These properties were compared with the requirements of CNS material proposed by Katti [3] and the optimum admixture content was identified.

3.2 Oedometer studies
The material passing the 425 microns sieve was mixed with optimum admixture content as discussed in the section 3.1. Oedometer specimens were prepared at OMC & MDD and were allowed to swell under saturated conditions at the seating pressure [45] and then loaded as per the IS code procedure [46] to measure the compression index value. Another series of oedometer tests on native soil at liquid limit were conducted to measure its compression index.

3.3 Model tank studies
The efficacy of the CNS material prepared from the native soil using admixtures was studied using fabricated cylindrical tank made of galvanized iron (GI) with diameter 30cm and height 60cm, filled with sand, compacted and levelled to a height of 10cm. Expansive soil material passing through 4.75mm IS sieve was used to carry-out the tank studies. A schematic diagram of the experimental setup was shown in figure 1. A specimen of 15cm diameter and 15cm long was prepared at its OMC & MDD and placed at the center of tank on the top of levelled sand bed. CNS material as obtained from section 3.1 was placed on the top of the expansive soil prepared at its OMC & MDD at varying thickness of \( t_c/t_s \) of 0, 0.25 and 0.5, where \( t_c \) being the thickness of CNS material and \( t_s \) being the thickness of expansive soil. The gap between the specimen and the tank walls was filled with sand to serve as a medium for faster saturation of specimen. Using a heave stake placed on the top of specimen and a dial gauge of least count 0.01mm, the heave was measured while the specimen is saturated. The specimen is allowed to swell completely to measure the heave potential of the soil when \( t_c/t_s = 0 \). For the other \( t_c/t_s \) ratios also, a similar period was allowed to measure the heave in the soil. Upon completion of heaving, the material was allowed to drain completely and the specimen was air dried initially, later which was completely oven dried at a temperature of 105-110°C. This corresponds to one cycle of wetting and drying. The heave was measured for a total of 4 cycles of wetting and drying cycles. The experimental test setup was shown in figure 2.
4. Test results and discussion

4.1 CNS material
The expansive soil used in this study possesses high swelling nature besides having excessive plasticity. For preparing a CNS material, addition of 5% lime and further the varying proportions of fly ash not only reduces plasticity but also the swelling nature because of the mineralogical changes expected to occur due to the Cation exchange [44]. Hence various tests were performed at varied proportions of fly ash along with 5% lime mixed expansive soil and checked with the tentative limits of a suitable CNS material proposed by R. K. Katti [3].

4.1.1. Atterberg’s limits and Free Swelling Index. The LL, PL and PI variations of the expansive soil mixed with 5% lime and varied proportions of fly ash were shown in figure 3. The figure 3 depicts that the addition of admixture reduced the LL and increased the PL reducing the plasticity (PI). The values of LL, PL and PI fall in the range of the tentative values provided for the CNS material by R. K. Katti for admixture content above 20% (5% Lime and 15% Fly ash). However, for the admixture content more than 30% ends up making the material fall out of the range of limits proposed. For the current study, an admixture content of 25% i.e., 5% Lime and 20% Fly ash was chosen for further studies. The differential free swelling index (FSI) for the mixtures of soil with various admixture contents specified earlier were presented in figure 4. Figure 4 depicts that the FSI values were reduced by about 50% for admixture contents more than 20% (5% Lime and 15% Fly ash). For chosen admixture content of 25%, FSI reduced by about 55%.
4.1.2 Compaction Parameters and Unconfined Compressive Strength. The OMC and MDD of the selected soil mixed with 5%L and 20% fly ash and native expansive soil alone were found by performing the light compaction test as per IS:2720 part 7 [47]. The values of OMC & MDD for the expansive soil were found to be 13% and 18.1 kN/m$^3$ and for the CNS material the values were 16.8% and 17.0 kN/m$^3$. The Unconfined Compressive Strength (UCS) of the native expansive soil and the prepared CNS material were found for the specimens prepared at the MDD. The stress vs. strain graph was presented in figure 5. The UCS values of the expansive soil and the CNS material (after 28 days curing in desiccator) were found to be 124 and 232 kN/m$^2$ respectively. From figure 5, it can be observed that the UCS value of the prepared CNS material was very much improved when compared to the native expansive soil which helps in better foundation design.
Figure 5. Variation of stress-strain curve with addition of admixture

4.2 Swelling Pressure and Compression Index.

The oedometer specimens were prepared at corresponding MDD& OMC for native expansive soil alone and the prepared CNS material in order to find the variation of swelling pressure and the compression index. The swelling pressure was found to be about 180 kN/m² and 10 kN/m² for the expansive soil and the CNS material respectively. The variation of void ratio with increase in the load was studied to estimate the compression index whose values were found to be 0.153 and 0.060 respectively. The void ratio versus applied pressure (for specimens prepared at OMC) for the expansive soil and the CNS materials were presented in figure 6. The void ratio versus applied pressure for expansive soil specimen prepared at LL was presented in figure 7. The CNS specimen was not prepared at LL for studying the compressibility as obtaining the actual density at which CNS material shall be compacted in reality would be very critical. Based on the test results of the admixture stabilized expansive soil specimens, it can be understood that this material can confidently be used as a CNS material.

Figure 6. e vs. log(p) curves for native soil and the prepared CNS material at OMC
4.3 Model studies – wetting and drying cycles
The previous section studies confirm the use of stabilized native expansive soil as a CNS material. The efficacy of CNS material placed in different thickness in arresting the heave produced by the soil in a model test tank were conducted. The heave results for 4 cycles of wetting and drying were presented in figure 8, 9 and 10 respectively for the $t_c/t_s$ ratios of 0, 0.25 and 0.50.

Figure 8. Heave-time plot for $t_c/t_s = 0$

Figure 9. Heave-time plot for $t_c/t_s = 0.25$

Figure 10. Heave-time plot for $t_c/t_s = 0.50$

Figure 11. Heave-time plot for cycle 2

Figure 8, 9 and 10 depicts that the heave is considerably higher in the second wetting and drying cycle as compared to first cycle. This could be attributed to the initial moisture present in the specimen.
which could have inhibited some part of swelling as compared to a dry specimen in second cycle. With increase in number of cycles of wetting and drying it was observed that the actual heave was a little less as compared to the previous cycles (except for cycle 1). As the \( t_{c}/t_{s} \) ratios increased, the amount of heave also found to be reduced as could be understood from the more depth of CNS layer available to arrest more amount of heave. Figure 11 presents the heave-time plot for all the \( t_{c}/t_{s} \) ratios for cycle 2 providing a better understanding of the efficacy of the CNS layer. It could be observed that about 20\% and 54\% of heave reduction was obtained with \( t_{c}/t_{s} \) ratios being 0.25 and 0.50 respectively. Similar observations were made by R. K. Katti [3] and C Lavanya and A Srirama rao [42] with varying thickness of CNS material was adopted. This confirms that the native expansive soil locally stabilized with admixtures could be a good CNS material.

5. Conclusions
The utilization of CNS materials as a cushion under the foundations of lightweight structures shall be universally well accepted, particularly in cases of foundations occupying a vast area as in cases of pavements, canal linings and floorings, etc. Availability of a good CNS material readily at the worksite shall be scarce making the end-user rely on alternate methods. This study could be a solution to that problem which suggests the utilization of native expansive soil with local stabilization using admixtures. This not only offers a solution to the unavailability of good materials but also the utilization of industrial wastes in large amounts. A solution was proposed to convert the local expansive Clayey Sand into a CNS material using lime and fly ash as the admixtures. The index and engineering properties found for the material were observed to be satisfying the requirements of a CNS material. The efficacy of this material was also studied using model test tanks with varied thickness of CNS material above the expansive soil subjected to 4 consecutive wetting and drying cycles. With the addition of CNS cushion, a reduction in heave of about 54\% when the thickness of the CNS cushion is almost half of the expansive soil thickness. Practically, this accounts for half of the thickness of the active zone in the field. The heave reduction obtained with \( t_{c}/t_{s} \) ratio was about 20\% which could be treated as not very effective. Hence it is concluded that at least half the thickness of the active zone should be converted into CNS materials using admixtures while adoption this technique to actual field problems.

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