Experimental Study on the Swelling Behavior of Expansive Soil Reinforced with Coir Geotextile

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Abstract. Structures constructed on expansive soils are experiencing a higher upward pressure due to swelling- shrinkage nature of expansive soil. India is having 15%-20% land with expansive soil and cause severe damages to the existing structure like pavement, dams, multi-storey building, retaining wall etc. This study investigated and identified the mechanisms by which swelling pressure can be mitigated in expansive clay soil. The single layer of coir geotextile used with the treatment of lime and silica fume. The coir treatment is made to enhance the efficiency of coir geotextile to reduce the swelling pressure of expansive soil subgrade. Chemical and microstructural component of expansive soil sample investigated by using X-ray Diffraction (XRD), Scanning Electron Microscope coupled (SEM), Fourier Transform Infrared (FTIR). With and without treatment of coir geotextile mat swelling pressure and heave analysis laboratory test has been carried out.

The experimental result analyzed which indicate that the lime treated coir geotextile mat significantly reduces the upward swell pressure and heave of expansive soil subgrade.

Keywords: Expansive soil, Swelling pressure, heave, Microstructural analysis, Coir geotextile, Lime, silica fume

1 Introduction

Expansive soils are characterized by their significant volumetric fluctuations, which tend to increase in volume as they add water to their voids and decrease in volume upon removal of that water. The resistance parameters (in particular, cohesion, specific gravity, and friction angle) of non-expansive soil and expansive soil of the same field have different properties. A large part of Central India and part of South India are covered with expansive soil. These soils have a high shrinkage and swelling behavior and low shear strength. Therefore, there is a need to improve these properties.

The expansive soil due to its dual swelling shrinkage nature pose problems to civil engineers for constructing structures like pavements, multi-storey building [1–3]. To mitigate the swelling pressure and heave phenomena of the expansive soil, various mechanical and chemical methods are proposed by the geotechnical engineers [4–7], however these methods are time consuming and increase construction time. In case of low-cost paved structure construction, natural fiber geotextile mat can be used as a separator layer. The stiffness and the load carrying capacity of the soil subgrade can be improved through increasing the frictional interaction between the subgrade and geotextile layer [8]. The coir geotextile are best suitable for paved structures applications due to high availability at low low-cost compared to its synthetic counterparts. Coir geotextiles are being used and extensive field trials are underway in India [9,10]. Naturally available coir fibers are biodegradable, environmentally friendly and available in abundance These coir geotextiles were made from the coir yarn which itself was made from the coir fibers extracted from the husk of coconut. As per the coir board of government of India, coir fibre produced in the year 2016-17 is 5,56,900 metric tons per year [11]. The coir geotextile mats are the most suitable natural fibre geotextile[12–14]. Although the coir geotextile is the biodegradable material and having low life however with the lime and silica fume treatment of the durability can be increase.

The primary focus of this paper is to evaluate the performance of coir geotextile mat as a reinforcement alternative with lime and silica fume treatment for the expansive soil subgrade. Several researchers studied the effect of geotextile on consolidation and swelling; however, the effect of natural coir geotextile on swelling pressure have not investigated much. This paper is a contribution towards this where the effect of coir geotextile was studied on both reinforced and unreinforced expansive soils. Since the chemical treatment of subgrade is highly complicated, in this study the soil subgrade is not treated directly but the coir geotextile layer with lime and silica fume used to increase the life of coir fibres, The constant volume swelling pressure test were conducted using coir geotextile mat with and without treatment, to propose the optimum treatment for coir geotextile needed to mitigate the upward swelling pressure and heave exerted by the expansive soil.

2 Properties of material

2.1 Index properties of expansive soil

The expensive clay soil used for the present study was collected from the Indore Madhya Pradesh India at a depth of 1.5m – 2m. The free swelling Index of the soil was 120%, which considered to be highly swelling. The liquid limit (LL) and plasticity index (PI) of the soil were 89% and 47% respectively, based on the LL and PL the soil is classified as silty clay of high plasticity (CH) as per the UCSC. The various index properties of expansive soil considered in the study are shown in the Table 1

Table 1. Index properties of expansive soil considered

S.No.	Property	Value
1.	Specific gravity	2.78
2.	Liquid limit (%)	89
3.	Plastic limit (%)	47
4.	Plasticity index (%)	42
5.	Shrinkage limit (%)	11
6.	USCS soil classification	CH
7.	Grain Size Distribution	
	Clay (%)	71.5
	Silt (%)	24.5
	Sand (%)	4.0
8.	Free swell index (%)	120

2.2 Microstructural characteristics of expansive soil

The microstructural and chemical components of the expansive soil was investigated using X-ray diffraction (XRD), Fourier transform infrared (FTIR) and scanning electron microscopy (SEM). The components are analyzed to assess the mineralogical composition of expansive soil present in study area.

Fig. 1. Expansive soil XRD Analysis pattern

The mineralogical properties of the expansive soil were translated by X-ray diffraction analysis (XRD). The analysis of the XRD pattern is shown in Fig. 1 and was performed with the Pananalytical X'pert Highscore Plus software. X-ray diffraction analysis data shows the quartz peak as a distinct peak. The position of 2θ; at 20.86°, 21.98°, 26.64°, 39.42°, 50.1°, 59.94° and 67.96° coincides with the quartz spectra. The at 2θ; lying peaks of about 5.76°, 19.7 °, 23.58° and 27.68° are the peaks for montmorillonite. The calcite has a peak of 29.44, 35.72, 39.42 and 48.62 and hematite has a peak of 24.42, 35.72 and 39.42. It was observed that 39.42° is the usual peak for quartz, hematite and calcite and the illite clay mineral diffraction peak was observed at 21.42 °. The XRD results showed that the quartz is present in larger quantities in expansive soils. However, the presence of montmorillonite, illite, hematite and calcite was also observed.

Fig. 2. FTIR spectra of expansive soil

The Fig. 2 present the FTIR spectra of expansive soil. The range from 500 cm^{-1} to 1200 cm^{-1} presented the presence of minerals, 1200 cm^{-1} to 3000 cm^{-1} organic substances and 3500 cm^{-1} to 4000 cm^{-1} clay minerals [15]. The characteristic bands of 3382, 3432, 3552, 3600, 3610 and 3698 cm^{-1} represent the vibration (stretching) of the hydroxyl groups (OH) of illite and kaolinite [16]. The other bands at 1008 and 1104 cm^{-1} are those of Si-O bonds and the bands at 714 and 528 cm^{-1} are due to the deformation vibrations of AlIV-OSi and AlVI-OSi The doublet peak at 798 and 782 cm^{-1} and a single peak at 694 cm^{-1} can be attributed to the quartz vibrations [17].

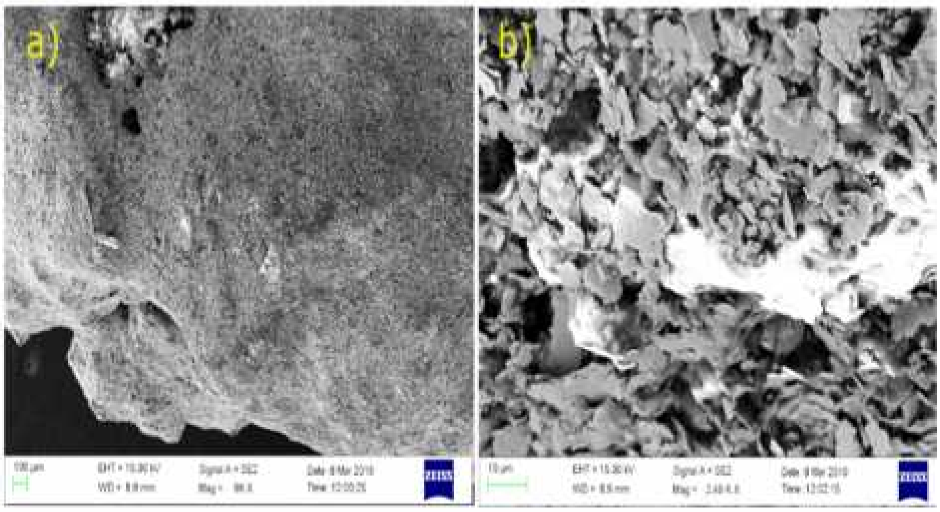

Fig. 3. (a) Surface texture of expansive soil (b) flaky texture of soil

The SEM image as presented in Fig. 3 (a) shows many cavities in the specimen which indicates the false void present in the soil. The SEM images presented in Fig. 3 (b) shows irregular wavy edges of the particles and the flaky, expanded, flared, "corn-flake" or "oak leaf" structure of montmorillonite[18,19] and also shows the flat-lying plates typical of illite.

2.3 Coir Geotextile

The coir geotextile used in the study were provided by the charankattu coir mfg. co. (pvt) Ltd. Kerla, India. Average length of coir geotextile used was maintained at around 20 mm, diameter of 20 µm and giving an average aspect ratio of 40. The coir geotextile was first treated with the lime and silica solution. The Fig. 4 present the image of (a) (a) coir geotextile b) lime treated coir geotextile and (c) silica fume treated coir geotextile.

Fig. 4. Normal coir (NC); b) Lime Coir (LC); c) Silica Coir (SC)

3 Experimental Program

In this present study, optimum moisture content, and maximum dry density, upward swelling pressure and heave of expansive soil is investigated. The coir geotextile layer with and without lime and silica fume treatment are placed at the top layer. In this paper normal coir geotextile, lime treated geotextile and silica fume treated geotextile is referred as NC, LC and SC respectively. To understand the swelling behavior of the expansive soil the constant volume swelling pressure test has been conducted for 28 days with the addition of 10 mm thick coir geotextile mat (with and without treatment) at the top. To increase the strength of coir mat, polypropylene fibre net is used. The initial moisture content and dry unit weight are essential factors affecting the swelling behaviors of expansive soil [1]. Hence, the specimen was prepared at the dry unit weight (17.65 kN/m3) and optimum moisture content (19.2 %) of expansive soil. The required amount of clay was compacted statically using lightweight proctor to achieve the field conditions. The solution of lime and silica fume mixed with water then this coir geotextile mat is dipped into solution for treatment. The dried coir geotextile layer is used for stabilizing the swelling pressure and expansion of soil.

4 Result and Discussion

The swelling pressure is defined as the pressure to maintain the volume of specimen constant while undergoing saturation in between two successive reading. The variation of the swelling pressure with and without coir geotextile reinforcement is shown in Fig. 5. This depicts that the swelling pressure in the expansive soil is exponentially increasing and it shows expansive clay soil exerts higher swelling pressure.

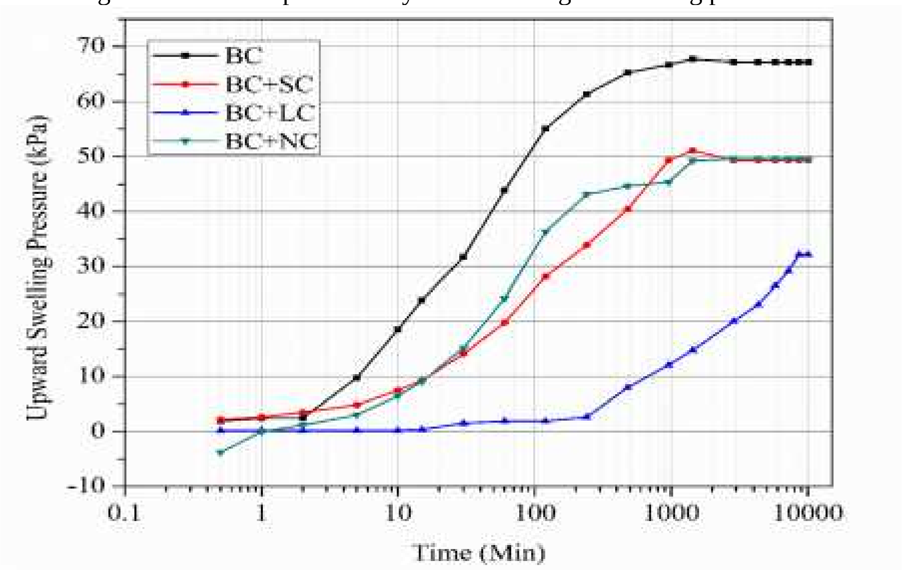

Fig. 5. Swelling pressure curve

In the initial state of experimental work it is observed that the free swelling index (120%) which shows higher swelling behavior. At the same time, it can be noted that with inclusion of coir geotextile layer without any treatment (NC) and with the silica fume treatment (SC) gives more or less similar swelling pressure exertion behavior, however it controls the swelling pressure up-to great extent. The inclusion of lime treated coir geotextile (LC), reduces the swelling pressure exponential and more than 50% reduction in the swelling pressure is observed. It also depicts that the swelling pressure of the expansive soil with or without coir geotextile mat changes at an exponential rate till 120 minutes and thereby gradually becomes constant due to saturation. The Fig 5 indicating the upward swelling pressure exerted by the clayey soil, however the lime treated coir geotextile mat with expansive soil gives a higher reduction in the upward swelling pressure. The upward swelling pressure reduces because coir geotextile due to its tensile strength take the pressure and as a result reduction in the upward swelling pressure observed. The frictional resistance between subgrade soil and coir geotextile is also a major reason of swelling pressure reduction.

Figure 6 depicts the expansion per minute of clayey soil with and without coir geotextile layer. It shows that initially, the expansion in clay rises exponentially, however after 30 min clay do not show any major change in the expansion/min. However, the inclusion of with and without lime treated coir geotextile, the expansion rate reduces at the higher rate and do not show higher rate of change in expansion while submerging into the water. During the initial process, clay having air voids and upon filling with water it develops pore pressure. As a result, the volume changes rapidly; however, after reaching the brink of saturation limit the expansion was minimal.

Fig. 6. Expansion (%/min) curve with time

It can be ascertained that expansive soil absorbs water and upon saturation, changes in swelling ratio without pressure can be roughly divided into three stages: (1) rapid expansion period. In general, this stage will be finished in 30 min after the expansive soil absorbs water and the swelling amount accounts for about 60% - 80% of the total. (2) Slow expansion period. In this stage, the expansion rate is slow compared to rapid expansion and will be finished in about 20 hours. (3) Stable expansion period. After expansive soil absorbs water and becomes saturated, its density is less, and the space between the soil enlarges. The time taken by the water to fill the space is more, so the expansion period lasts longer. But these changes is slight low hence the curve shown in Fig. 7 is relatively stable.

Fig. 7. Expansion % curve with time

5 Conclusion

The presence of clay minerals such as montmorillonite, illite and kaolinite are confirmed based on the microstructural characterization of the expansive soil subgrade which is responsible for the higher expansion. The results of the study on the potential use of coir geotextile to reduce the upward swelling pressure potential of expansive soils is presented. The use of coir geotextiles shows significant improvement in the swelling behavior of expansive clay soil. The expansive soils using coir geotextile mat with and without lime and silica fume can be used for controlling the swelling pressure of the expansive soil subgrade. The various coir geotextile mat with and without treatment has been analyzed. It has been observed that normal coir geotextile reduces the upward swelling pressure approximately 27% and recues the expansion/min rate. However, the silica fume treated coir geotextile gives almost same swelling pressure reduction behavior as untreated coir geotextile, hence silica fume treatment does not affect much on the performance of coir geotextile. The lime treated coir geotextile reduced the approximately 55% upward swelling pressure and 79% reduction in the expansion percentage. Hence lime treated coir geotextile can be considered as the more convenient solution to the swelling pressure and expansion rate reduction for field applications.

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