ABSTRACT: Light structures such as highways, railroads, runways, and other life line structures, constructed over expansive soils may be severely damaged due to high swell-shrinkage behaviour of these soils owing to fluctuating water content. In India, these soils cover as high as 20% of the total land area, and black cotton soils come under this category. Expansive soils are considered to be unsafe with reference to safety of the structure in serviceability aspects, and needs to be tackled in a well engineered manner, if it should be used as a foundation soil. Several ground stabilization and ground improvement techniques are in use to control the swelling potential of such soils. The use of compressible inclusion such as EPS geofoam is a new and innovative solution, in which a layer of geofoam is placed over an expansive soil subgrade to mechanically stabilize it, and control swelling pressures. The present study attempts to understand the effectiveness of EPS geofoam in controlling swelling pressures. Swelling pressures are measured in the laboratory with and without placing EPS geofoam above black cotton soil, in conventional one-dimensional oedometer apparatus. The influence of two parameters of EPS geofoam, viz., its thickness and compressive modulus, on the measured reduction of swelling pressure is systematically studied, under controlled conditions. From the experimental results, it is observed that the swelling pressures are substantially reduced, as the thickness of EPS geofoam increases. The compressive modulus of EPS geofoam is also observed to influence the measured swelling pressures significantly; a higher reduction can be achieved using lower modulus.

INTRODUCTION
Soils that exhibit volume change from variations in water content are referred to as expansive or swelling soils. In India, expansive soils cover about 20% of the total area. The tendency of expansive soil to increase in volume due to infiltration of water is resisted by a structure resting on the soil and as a consequence, vertical swelling pressure is exerted on the structure. Swelling pressures develop if the soil is not allowed to swell freely. The magnitude of swelling pressure depends on the degree of expansion permitted. When a little soil expansion is allowed, the swelling pressure may be decreased considerably relative to the case of no expansion. If the swelling pressure exerted by soil is not controlled, it may cause uplifting and distress in structure.

LITERATURE
Soil stabilization techniques are widely used for stabilizing expansive soils. Physico-chemical stabilization techniques, such as using lime, cement, flyash, enzymes, or other chemicals to control swelling in expansive soil have been practiced and are not uncommon to geotechnical engineers [1]. In these techniques, uniform mixing of the stabilizers with soil must be ensured, to achieve increased benefits. Mechanical stabilization of soil (without altering chemical properties) includes controlled compaction [2], prewetting [3], mixing with sand [2, 4], use of cohesive non-swelling soil [5], and reinforcing the soil using geosynthetics [6, 7]. Expanded polystyrene (EPS geofoam) can also be used to reduce swelling pressures, due to its compressive behavior [8]. EPS geofoam has some advantages over conventional methods of stabilization, such as reduced time of construction, reduced immediate settlements and increased durability.

Recent studies focused on the influence of placing EPS geofoam between rigid vertical wall and backfill, consisting of swelling soil, through laboratory tests on small-scale models. It was observed that both lateral and vertical swelling pressures reduced significantly due to EPS geofoam inclusion in soil [9]. Previous research on this material revealed the potential reduction in swelling pressure using sand and EPS geofoam above bentonite soil specimen. It was observed that geofoam of thickness higher than 10% of the total thickness, proved more effective in reducing swelling pressure compared to that achieved using a sand layer [7].

The use of EPS geofoam to control swelling pressures is not gained momentum in the field applications due to limited experimental results and confidence in research findings. In order to verify and supplement the data available in the literature, further studies highlighting the influence of various physical parameters of geofoam on the swelling pressure are warranted.

Therefore, the studies on the influence of two parameters of EPS geofoam, viz., thickness and modulus, on the measured swelling pressure, are the objectives of the present work.

EXPERIMENTAL STUDY
Black cotton soil from Ahmednagar district in Maharashtra is used for the experimental study. Table 1 summarizes the physical properties of the black cotton soil. The soil is
oven-dried before using in experimental study. The soil sample specimen for swelling pressure tests is compacted to achieve maximum dry unit weight with 20% moisture content in 75 mm diameter and 25 mm height oedometer ring. The thickness of soil sample is kept as 25 mm for all the tests.

### Table 1 Physical properties of soil used

<table>
<thead>
<tr>
<th>Black cotton soil</th>
<th>CH</th>
</tr>
</thead>
<tbody>
<tr>
<td>USCS soil classification</td>
<td>CH</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>61</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>31</td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>30</td>
</tr>
<tr>
<td>Optimum water content (%)</td>
<td>20</td>
</tr>
<tr>
<td>Maximum dry unit weight (kN/m³)</td>
<td>16.2</td>
</tr>
<tr>
<td>Free swell index (%)</td>
<td>85.7</td>
</tr>
</tbody>
</table>

The EPS geofoam of nominal density of 10 kg/m³ and 20 kg/m³ are chosen for the study. The pressure versus deformation curves of two samples of EPS10 and EPS20 respectively, are shown in Fig. 1. The tests are conducted by loading the samples of 100 mm diameter and 100 mm height at 10% strain rate [10]. The mean compressive modulus values of five samples of EPS10 and EPS20 are 1373 kPa and 2477 kPa, respectively. Compressive stiffness is the single most important behavioral characteristic of any compressible inclusion and Young's modulus is the material stiffness parameter of primary interest [11]. Therefore, compressive modulus of EPS geofoam is determined to study its influence on swelling pressure of geofoam stabilized soil. In the present study, swell-load method is used for evaluating the swelling pressures, as swelling pressures obtained by swell-load method are higher than those obtained by constant volume method [12, 13].

To determine swelling pressures for each sample, consolidometer/swell-load method is used [14]. Fig. 2 shows the test setup used for determining swelling pressure. The specimen is saturated under a seating pressure of 5 kPa. After no swelling is observed for 24 hours, the specimen is loaded incrementally, and allowed to compress under each load increment. The loading pressure under which the soil sample compressed to its original volume is the measured swelling pressure.

### RESULTS AND DISCUSSION

The percent swell under a seating pressure of 5 kPa was studied for all the samples, with reference to time. The details of soil samples used in the study are as follows:

- a) Black cotton soil sample 25 mm thick (BC)
- b) Black cotton soil sample 25 mm thick, with 4 mm EPS geofoam of density 10 kg/m³ (BC10-4)
- c) Black cotton soil sample 25 mm thick, with 4 mm EPS geofoam of density 20 kg/m³ (BC20-4);
- d) Black cotton soil sample 25 mm thick, with 8 mm EPS geofoam of density 10 kg/m³ (BC10-8)
- e) Black cotton soil sample 25 mm thick, with 8 mm EPS geofoam of density 20 kg/m³ (BC20-8).

The percent swell behavior for all the above samples are compared and presented in Fig. 3. The percent swell is ratio of swell observed to the initial soil thickness i.e. 25 mm. It is noted that percent swelling increases steeply in the initial stages, and is almost constant after almost 4000 minutes. The maximum measured swelling varied between 3.0 to 3.2%, for all the samples. This can be justified as black cotton soil of same initial dry density, initial water content and thickness is used in all the samples.

The compression of samples under each load increment is shown in Fig. 4. The percent change in sample height is determined by considering the total initial thickness of soil and EPS geofoam. It is observed that the measured swelling pressure reduces substantially by placing EPS geofoam, a compressible material above the soil layer.

Fig. 5 represents the effect of compressive modulus of EPS geofoam and its thickness on swelling pressure. For EPS geofoam of same modulus, the swelling pressure reduces with increase in thickness of geofoam from 4 mm (16% of soil thickness) to 8 mm (32% of soil thickness). In the case of EPS geofoam of same thickness, the swelling pressure shows a decrease with increase in compressive modulus of EPS geofoam.
increases with increase in compressive modulus from 1373 kPa to 2477 kPa. Table 2 shows the swelling pressure values obtained for each sample.

### Table 2 Swelling pressure results

<table>
<thead>
<tr>
<th>Soil sample</th>
<th>Swelling pressure (kPa)</th>
<th>Reduction in swelling pressure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>70</td>
<td>---</td>
</tr>
<tr>
<td>BC10-4</td>
<td>14</td>
<td>80</td>
</tr>
<tr>
<td>BC10-8</td>
<td>7.5</td>
<td>89.3</td>
</tr>
<tr>
<td>BC20-4</td>
<td>29</td>
<td>58.6</td>
</tr>
<tr>
<td>BC20-8</td>
<td>19</td>
<td>72.8</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

In this study, the swelling characteristics of black cotton soil are studied. EPS Geofoam of thickness 4 and 8 mm and density of 10 and 20 kg/m$^3$ are used to understand their influence on the reduction of swelling pressures of black cotton soil, through laboratory swell-compression tests in oedometer. Following are some of the major conclusions of the study.

Black cotton soil, used in the presented study, exhibited a swelling pressure of 70 kPa. This swelling pressure is reduced considerably by placing EPS geofoam above the soil sample.

The thickness of geofoam plays an important role in the reduction of swelling pressures. Higher is the thickness of EPS geofoam, lesser is the swelling pressure of geofoam stabilized soil.

Compressive modulus of geofoam also influences the measured swelling pressure. EPS geofoam of lower modulus is more effective in minimizing the swelling pressures of expansive soils.

**REFERENCES**


