ABSTRACT: Expanded Polystyrene (EPS) geofoam is an interesting area in the field of geotechnical engineering. In the present study an attempt has been made to understand the behavior of shear strength parameters of EPS geofoam through direct shear tests. Direct shear test has been carried out on EPS geofoam of four different densities i.e. 0.15, 0.2, 0.22 and 0.30 kN/m$^3$ under four different normal stress values of 15, 30, 45 and 60 kN/m$^2$. The dimensions of the specimen used in the investigation are having length 100 mm, width 100 mm and height 50 mm. The test results show that with the increase in density of EPS geofoam, cohesion value increases whereas marginal increase in angle of internal friction of material is observed. Shear factor ‘z’ has introduced to know the effect of normal stresses and relationship of cohesion and density of EPS geofoam has also developed.

1 INTRODUCTION

EPS geofoam is characterized by very low density (nearly 100 times lesser than soil) with potentially high compressibility, good flexural strength and high rupture strength in shear. The weakest plane in the failure of EPS geofoam under fill load was found to be at the interface between EPS geofoam blocks and between EPS geofoam block and interfacing material in the contact. For any construction material, basic engineering properties of EPS geofoam are required to perform analysis and design. The friction factor or interface friction coefficient is the ratio of the resisting shear stress to the applied normal stress which is an important parameter for assessing the stability of the structure containing EPS geofoam. Interface friction coefficient can be derived from the results obtained from the laboratory testing. The evaluation of the interface strength parameter should consider different materials and field applications. The test should be conducted at representative normal stresses. Wagner (1986) investigated interface strength behavior of geofoam of density 22 kg/m$^3$ by using two test methods tilt test and direct shear test. He reported the interface friction coefficient from tilt test whereas the peak and residual interface friction coefficient from direct shear. Kuroda et al. (1996) conducted shaking table test to calculate interface friction coefficient value of geofoam to geofoam of density 20 kg/m$^3$ under both static and dynamic loading conditions. They investigated interface strength using geofoam of density 20 kg/m$^3$. Miki (1996) conducted direct shear test to determine interface friction coefficient between geofoam to geofoam and geofoam to sand using density of geofoam 20 kg/m$^3$. The investigation of geofoam to sand show decrease in the value of interface friction coefficient due to increase in the thickness of sand layer below geofoam. Negussey (1997) reported that the interface friction between geofoam and sand is comparable to the angle of internal friction of sand alone. Sheeley and Negussey (2004) investigated interface strength behavior of geofoam by conducting large scale direct shear test by using density of geofoam 18 and 29 kg/m$^3$. The investigation consist of interface strength between geofoam to geofoam in both dry and wet condition, geofoam to cast in situ concrete and geofoam to geomembrane (both HDPE and PVC). They have reported geofoam to geofoam interface strength was found to be equal in both dry and wet condition. They reported
Geofoam to cast in situ concrete interface shows higher peak and residual strengths due to adhesion bond developed between them, whereas geofoam to geomembrane interface strength was found to be very low. Barrett and Valsangkar (2009) conducted shear resistance tests on geofoam blocks with no connection, block connected with barbed connector plates and blocks connected with polyurethane adhesive.

It has been found that extensive study has been carried out in the direction of interface characteristic EPS geofoam with construction and geosynthetics materials whereas no study has been found in the direction of obtaining shear strength parameter of EPS geofoam. The present study aims to investigate the shear strength parameter EPS geofoam with different densities of the material locally available in India.

2 INVESTIGATION

A series of direct shear tests were performed to investigate the shear strength parameters i.e. cohesion and angle of internal friction of EPS geofoam with various densities.

The effect of normal stresses on the shear stresses were examined, the shear factor has also been calculated which is the ratio of shear stress at failure to the applied normal stress.

A relationship of cohesion and density which are the important parameter of the EPS geofoam material has been developed.

3 EQUIPMENT AND TEST PROCEDURE

Direct shear test setup is used with modified shear box of size 100 mm x 100 mm x 75 mm to find out strength characteristics of EPS geofoam. 5 mm thick steel plate with slots are provided at the top and bottom of the specimen to hold the specimen in the shear box. Four different densities of EPS geofoam 0.15, 0.20, 0.22 and 0.30 kN/m$^3$ were used to find shear strength parameters. The specimens of EPS geofoam were taken from the same sample of specified density and cut into 100 mm x 100 mm x 50 mm as shown in Figure 1. Different colour was used to distinguish between different densities. The test was conducted for four different normal stresses 15, 30, 45 and 60 kPa for each density of EPS geofoam. The complete test assembly and placement of EPS geofoam test specimen are shown in the Figure 2.

4 RESULTS AND DISCUSSION

4.1 Shear stress –strain behavior

The shear stress-strain behavior EPS geofoam with different densities is given in Figure 3. The graphs show that there is continuous increase in the value of shear stress with respect to increase in the shear strain for all the densities. It was also observed that shear stress increases with the increase in the density of EPS geofoam material. Figure 4 shows the EPS geofoam specimens after test.
Figure 3. Shear stress and displacement behavior of EPS geofoam density (a) 0.15 kN/m$^3$, (b) 0.20 kN/m$^3$, (c) 0.22 kN/m$^3$ and (d) 0.30 kN/m$^3$.

Figure 4. The observed shear in the EPS geofoam test specimens with densities (a) 0.15 kN/m$^3$, (b) 0.20 kN/m$^3$, (c) 0.22 kN/m$^3$ and (d) 0.30 kN/m$^3$.

4.2 Shear strength parameter

Figure 5 shows the relationship between maximum values of shear stress versus normal stress for various densities of EPS geofoam. The results show for all the densities, the cohesion parameter is predominant. The angle of internal friction is having very low values. There is considerable increase in the value of cohesion for the density of EPS geofoam 0.30 kN/m$^3$ over other densities. Table 1 shows the values of cohesion and angle of internal friction for all the densities.

![Figure 5](image)

Table 1. Shear strength parameter of EPS geofoam.

<table>
<thead>
<tr>
<th>Density of EPS geofoam (kN/m$^3$)</th>
<th>Cohesion (kPa)</th>
<th>Angle of internal friction (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>30.75</td>
<td>3.0</td>
</tr>
<tr>
<td>0.20</td>
<td>36.00</td>
<td>4.0</td>
</tr>
<tr>
<td>0.22</td>
<td>40.25</td>
<td>4.5</td>
</tr>
<tr>
<td>0.30</td>
<td>59.75</td>
<td>6.0</td>
</tr>
</tbody>
</table>

4.3 Shear factor ‘z’

The shear factor, a dimension less parameter of EPS geofoam is the ratio between shear stress at failure to the applied normal stress. The variation of shear factor with normal stress is shown in Figure 6. The shear factor for all the densities
showed a decreasing pattern as the normal stress is increased. The magnitude of decrement is relatively high from 15 kPa to 45 kPa of normal stress after that the decrement is little. The shear factors of the EPS geofoam with the densities are calculated and given in the Table 2.

![Graph showing the relationship between shear factor 'z' and normal stress](image1)

**Figure 6. Relationship between shear factor ‘z’ and normal stress.**

**Table 2. Shear factors for different normal stress with respective density.**

<table>
<thead>
<tr>
<th>Applied normal stress (kPa)</th>
<th>Density of EPS geofoam (kN/m³)</th>
<th>Shear Factor ‘z’</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.15</td>
<td>2.084</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>2.534</td>
</tr>
<tr>
<td></td>
<td>0.22</td>
<td>2.756</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>4.083</td>
</tr>
<tr>
<td>30</td>
<td>1.092</td>
<td>1.275</td>
</tr>
<tr>
<td></td>
<td>1.424</td>
<td>2.118</td>
</tr>
<tr>
<td>45</td>
<td>0.750</td>
<td>0.890</td>
</tr>
<tr>
<td></td>
<td>0.996</td>
<td>1.438</td>
</tr>
<tr>
<td>60</td>
<td>0.580</td>
<td>0.687</td>
</tr>
<tr>
<td></td>
<td>0.755</td>
<td>1.108</td>
</tr>
</tbody>
</table>

4.4 C- line

From the experiments it is found that the cohesion of the EPS geofoam is a major factor contributing to the shear strength. The obtained cohesion value was plotted against the density of EPS geofoam to get C line as shown in Figure 7. Regression analysis is carried out for EPS geofoam densities ranging from 0.15 to 0.30 kN/m³ and fit in to a straight line equation \( C = m \cdot x - b \). Where ‘C’ is cohesion, ‘m’ is slope of the line, ‘x’ is the density of geofoam and ‘b’ is constant.

![Graph showing the relationship between cohesion and density of EPS geofoam](image2)

**Figure 7. Relationship between cohesion and density of EPS geofoam.**

5 CONCLUSIONS

In the present study, the behavior of EPS geofoam was observed under shear loading to calculate the shear strength parameters and some important relationships are developed. The conclusions of the study are as follows.

1. From the direct shear test results no peak value of shear strength were observed in all the densities of EPS geofoam. Shear strength parameters of EPS geofoam was increased with the increase in the density of geofoam.
2. Cohesion value increases significantly whereas marginal increase in the angle of internal friction was observed with increase in the density of EPS geofoam.
3. Cohesion and angle of internal friction values are achieved maximum for density of EPS geofoam 0.30 kN/m³. The cohesion value is 59.75 kPa and angle of internal friction is 6°.
4. The shear factor for all the densities of EPS geofoam showed a decreasing pattern as the normal stress is increased. The magnitude of decrement is relatively high from 15 kPa to 45 kPa of normal stress after that the decrement is marginal.
5. The obtained relationship between cohesion and density of EPS geofoam is very useful for estimating the approximate value of the cohesion.

REFERENCES


