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ORIGINAL PAPER

Experimental Investigation of the Shear Behavior of EPS Geofoam

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Abstract

Geofoam has been used in a wide range of geotechnical engineering projects since 1960s; either as lightweight fill material (e.g. embankments and bridge approaches) or as compressible inclusion (e.g. retaining walls and culverts). In most of these projects, geofoam is installed either in direct contact with other geofoam blocks or other construction material. Successful design of these composite systems requires a good understanding of both the compression and shear behavior of the geofoam blocks as well as the shear strength of the interface. In this study, an attempt has been made to measure the shear strength parameters of expanded polystyrene (EPS) geofoam blocks of different densities as well as the interface strength parameters as these blocks interact with sand as well as polyvinyl chloride (PVC) material. A series of direct shear tests has been carried out on geofoam samples of three different densities, namely, 15, 22 and 35 kg/m^3. Shear test results on geofoam monoblocks showed that the increase in density results in an increase in the material cohesion, which is associated with a decrease in the internal friction angle. Most of the interface resistance was found to develop at small displacements. For geofoam–PVC interface, both the adhesion and angle of interface friction slightly increased with the increase in geofoam density. The measured geofoam–sand interface strength revealed a consistent increase in the angle of interface friction as the density of geofoam material increased. These experimental results can be used to guide engineers in estimating the interface parameters needed for both analytical and numerical analyses involving soil–EPS–structure interaction.

Keywords EPS geofoam · Direct shear tests · Friction angle · Interface strength · Adhesion

Introduction

Expanded polystyrene (EPS) was originally invented in Germany by BASF in 1950 [1]. It is an ultra-lightweight, rigid, closed cell foam which is significantly lighter than conventional backfill material [2]. Geofoam blocks have been successfully incorporated into various geotechnical engineering applications serving as lightweight fill material, vibration barrier, or seismic buffer for rigid structures [3].

Geofoam inclusions placed above buried pipes [4, 5] or behind retaining walls [6] are known to reduce earth loads on these structures leading to safer and economical design. Although geofoam blocks in these applications are generally subjected to compressive stresses, interaction with the protected structure and the surrounding ground can lead to the development of shear stresses particularly when geofoam is installed against the sidewalls of the structure. In most of these geotechnical engineering applications, EPS geofoam is installed in direct contact with other materials (e.g. soil, concrete, PVC, and steel). Therefore, understanding the shear behavior of both the geofoam material and interface strength is essential for successful design of these types of structures.

Several studies investigated the strength properties of geofoam monoblocks and the interface properties of geofoam as it interacts with either geofoam or other construction material. A schematic showing typical direct shear tests used in these investigations is shown in Fig. 1. For monoblocks, shear deformations generally develop along a horizontal shear plane that cuts through the material (Fig. 1a), whereas interface shear failure develops along the contact surface under a given normal load (Fig. 1b). Some of the experimental studies related to the shear behavior of geofoam interface

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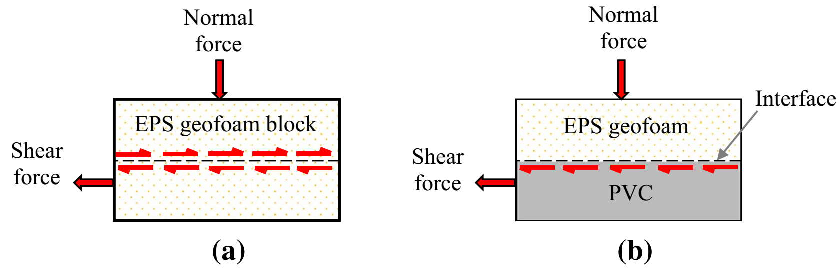

Fig. 1 Schematics of the direct shear test: **a** geofoam block, **b** geofoam–PVC interface

as well as the shear strength of geofoam blocks are summarized below.

Shear Behavior of Geofoam Interface

The interface shear behavior of EPS geofoam can be classified into three categories: (i) geofoam–geofoam; (ii) geofoam–sand; and (iii) geofoam in contact with other materials (concrete, steel, geotextiles, etc.). The relevant literature for these three categories is given in the following sections.

Geofoam–geofoam Interface

Wagner [7] used tilt tests to study the interface strength of two geofoam blocks with density of 22 kg/m^3. The results were compared with those obtained using direct shear tests. The measured geofoam–geofoam friction coefficient using tilt tests was found to be 0.54. Peak and residual interface friction coefficients measured using direct shear tests were found to be 0.63 and 0.52, respectively. The Norwegian Road Research Laboratory [8] recommended an interface coefficeint of 0.7 for geofoam–geofoam whereas the UK Transportation Research Laboratory [9] suggested a geofoam–geofoam interface coefficeint of 0.5. Kuroda et al. [10] performed a series of shaking table tests to determine geofoam–geofoam interface strength and evaluate the effectiveness of binder plates installed between block layers under static and dynamic loading. Normal stresses of 7.4 and 14.7 kPa were applied and the measured interface friction coefficients were found to range from 0.2 to 0.4. The effect of water on geofoam–geofoam interface properties was also studied by Sheeley and Negussey [11]. It was found that surface moisture, geofoam density and working stress level have a negligible effect on the characteristics of the geofoam–geofoam interface. Barrett and Valsangkar [12] conducted direct shear tests on geofoam samples with and without a barbed connector under different normal stresses. Results showed that barbed connector plates did not provide additional interface shearing resistance. Abdelrahman et al. [13] performed direct shear tests on geofoam–geofoam interface and found that the increase in normal stress and the decrease in geofoam density cause an increase in both the peak and residual friction coefficients. AbdelSalam and Azzam [14] showed that the presence of water significantly decreased the shear strength of geofoam–geofoam interface. A summary of some of the available friction coefficient values in this category is given in Table 1.

Geofoam–Sand Interface

Direct shear tests performed by Miki [23] revealed that interface friction coefficients for geofoam–sand interface range from 0.55 to 0.7 depending on the thickness of the sand below the geofoam. Negussey [24] measured geofoam–sand interface friction and found that the friction coefficient is similar to that of the sand material. Xenaki and Athanasopoulos [25] found that geofoam–sand interaction mechanism can be represented by three stages: purely frictional, frictional–adhesional, and purely adhesional depending on the applied normal stress. Direct shear tests were also conducted on geofoam–sand interface by AbdelSalam and Azzam [14]. No significant change in interface friction coefficient was observed under both dry and wet conditions. Some of the available values of coefficient of friction for geofoam–sand interface are summerized in Table 2.

Geofoam Interface with Other Material

Direct shear tests were performed by Sheeley and Negussey [11] on geofoam–cast in place concrete and geofoam–geomembrane interfaces. Results showed that geofoam–cast in place concrete provides more interface friction as compared to geofoam–geomembrane interface. Moreover, peak and residual responses were observed in both cases. A study conducted by Chrysikos et al. [19] showed that interface friction coefficient between geofoam and other material (i.e., soils, geotextiles, geomembranes, precast and cast-in-place concrete) ranges between 0.27 and 1.2. Similar study conducted by Padade and Mandal [21] evaluated the interface properties of geofoam in contact with other construction materials (e.g. jute geotextile, geogrid and fly ash). It was found that with the increase in geofoam density, adhesion values slightly increased while interface friction angle remain unchanged. A summary of selected interface coefficients for geofoam interacting with other material is given in Table 3.

Table 1 Selected geofoam–geofoam interface studies

Reference	Test/sample size (mm × mm)	Sample density (kg/m^3)	Coefficient of friction/friction factor
McAffee [15]	Ring shear test	15	0.90 (peak), 0.62 (residual)
Nomaguchi [16]	Monotonic and cyclic direct shear test	–	0.5
Sheeley and Negussey [11]	Direct shear test 100 × 100 to 500 × 500	18	0.9 (peak), 0.7 (residual) (dry)
	Direct shear test 100 × 100 × 25	20	0.85 (peak), 0.7 (residual) (dry)
			0.80 (peak), 0.65 (residual) (wet)
Negussey et al. [17]	Lower sample: 600 × 600 Upper sample: 175 × 375	18	0.94 (peak), 0.65 (residual)
		20	1.13 (peak), 0.68 (residual)
Atmatzidis et al. [18]	Direct shear test 100 × 300	20	0.83 (peak)
		30	0.93 (peak)
Chrysikos et al. [19]	Direct shear test	15 & 30	0.7–0.84 0.8 (average)
Barrett and Valsangkar [12]	Direct shear test 430 × 280 × 100	30	0.87–1.06 (peak), 0.74–0.86 (residual)
		15	0.60–0.99 (peak), 0.60–0.75 (residual)
Abdelrahman et al. [13]	Direct shear test 120 × 120 × 60	20	0.75–0.90 (peak), 0.55–0.63 (residual)
		30	0.65–0.82 (peak), 0.50–0.59 (residual)
Neto and Bueno [20]	Direct shear test	20	0.65 (peak), 0.51 (residual)
		30	0.75 (peak), 0.48 (residual)
Padade and Mandal [21]	Direct shear test 300 × 300 × 75	22	0.55 (peak), 0.53 (residual)
		30	0.57 (peak), 0.55 (residual)
Özer and Akay [22]	Direct shear 150 × 100	19	0.79 (peak), 0.72 (residual)
		29	0.98 (peak), 0.63 (residual)
AbdelSalam and Azzam [14]	Direct shear test 100 × 100 × 50	–	0.54 (dry)
			0.71 (wet)

Table 2 Selected geofoam–sand interface studies

Reference	Test/sample size (mm × mm)	Sample density (kg/m^3)	Coefficient of friction/friction factor
Miki [23]	Direct shear test	20	0.70 (sand layer thickness < 35 mm) 0.55 (sand layer thickness > 35 mm)
Negussey [24]	Direct shear test	–	Same as that of friction angle of sand alone
Xenaki and Athanasopoulos [25]	Direct shear test 100 × 100	10	0.67 (purely frictional) 0.34 (frictional–adhesional) 0 (purely adhesional)
		20	0.62 (purely frictional) 0.27 (frictional–adhesional)
AbdelSalam and Azzam [14]	Direct shear test 100 × 100 × 50	–	0.66 (dry)
			0.61 (wet)

Shear Behavior of Geofoam Monoblocks

Direct shear tests performed by Stark et al. [2] on geofoam samples of different densities showed that the cohesive strength is proportionally related to the material density. Similar conclusion was made by Padade and Mandal [26] based on direct shear tests performed on four different geofoam blocks having densities ranging between 15 and 30 kg/m^3. The increase in geofoam density resulted in significant increase in cohesion with slight increase in the angles of internal friction. Özer and Akay [22] conducted direct shear tests on EPS samples under a normal stress range of 10–40 kPa and found that the shear strength of the tested geofoam blocks is mainly dependent on its cohesion while interface shear strength is dependent on both adhesion and friction coefficient. AbdelSalam and Azzam [14] tested both dry and wet geofoam samples and concluded that the presence of water caused approximately 30% reduction in

Table 3 Selected geofoam–other material interface studies

Reference	Test/sample size (mm × mm)	Sample density (kg/m^3)	Interface	Coefficient of friction/friction factor
Sheeley and Negussey [11]	Direct shear test 100 × 100 × 25	–	Geofoam–cast in place concrete	2.36 (peak) 1 (residual)
			Geofoam–smooth geomembrane	0.7 (peak) 0.4 (residual)
Chrysikos et al. [19]	Direct shear test	–	Geofoam–other materials (i.e., soils, geotextiles, geomembranes, precast and cast-in-place concrete)	0.27–1.2
Padade and Mandal [21]	Direct shear test 300 × 300 × 75	15	Geofoam–geotextile	0.17
			Geofoam–geogrid	0.14
			Geofoam–fly ash	0.21
		30	Geofoam–geotextile	0.19
			Geofoam–geogrid	0.12
			Geofoam–fly ash	0.23
AbdelSalam and Azzam [14]	Direct shear test 100 × 100 × 50	–	Geofoam–concrete smooth (dry)	0.49
			Geofoam–concrete smooth (wet)	0.51
		–	Geofoam–concrete rough(dry)	0.96
			Geofoam–concrete rough (wet)	0.48

shear strength of the geofoam blocks under the same contact pressure. A brief summary of some of the available shear strength parameters of geofoam blocks is presented in Table 4.

The above studies provided some guidance in estimating the shear parameters of geofoam blocks as well as the interface strength between geofoam and different materials under a given test condition. However, the use of polyvinyl chloride (PVC) or high-density polyethylene (HDPE) pipes has been growing in geotechnical applications over the past few years and, to date, a little work has been done to evaluate the interface shear parameters for cases where geofoam is installed in contact with PVC material. The objectives of this study are to: (i) carry out experimental investigation to measure the shear behavior of EPS geofoam blocks that span a range of densities from 15 to 35 kg/m^3, and (ii) measure the interface strength parameters for geofoam blocks that are in contact with PVC material as well as sand material.

Experimental Program

A series of direct shear tests was performed to evaluate the shear strength and interface parameters of three different EPS geofoam materials. A total of 27 tests were conducted-nine tests on monoblocks and 18 interface shear tests. A brief description of the material properties and test procedure is given below.

Table 4 Selected geofoam monoblock studies

Reference	Test method/sample size (mm × mm)	Density (kg/m^3)	Shear strength parameters	
			c_a (kPa)	δ (°)
Stark et al. [2]	–	18.4	27.5	–
		28.8	50.0	–
Padade and Mandal [26]	Direct shear test 100 × 100 × 50	15	30.8	3.0
		20	36.0	4.0
		22	40.3	4.5
		30	59.8	6.0
Özer and Akay [22]	Direct shear test 100 × 100	18.5	26.6	10.0
		29.9	49.8	8.9
AbdelSalam and Azzam [14]	Direct shear test 100 × 100 × 50	20	12 (dry)	33 (dry)
		20	16 (wet)	19 (wet)

Material Properties

The material used in this study include EPS geofoam, PVC and silica sand material. The geofoam samples were cut from three large blocks of different densities, namely, 15 (EPS15), 22 (EPS22) and 35 kg/m^3 (EPS35). These densities cover the range of commonly used EPS materials in geotechnical applications [27]. The reported compressive strengths of these materials at 1% strain are 25, 50, and 98 kPa, respectively. The PVC samples (density = 1500 kg/m^3) were precisely cut to fit within the lower part of the direct shear box. As shown in Fig. 2, the tested monoblocks measured 99.5 mm × 99.5 mm × 40 mm whereas the geofoam and PVC samples used in the interface tests measured 99.5 mm × 99.5 mm × 20 mm. Fine-grained silica sand, passing #40 sieve and retaining on #100 sieve was used in this study. The properties of the PVC and sand material used in the experiments are summarized in Table 5.

Test Procedure

The shear box used throughout this study measures 100 mm ×100 mm × 50 mm and the tests were performed based on ASTM D5321-17 [31] under three different normal stresses, namely, 18, 36 and 54 kPa. Horizontal displacement was applied at the recommended rate of 0.9 mm/min. Horizontal reaction was measured using a load cell while horizontal and vertical displacements were monitored using linear variable differential transformers (LVDTs). Tests were terminated when a maximum displacement of 10 mm was reached. This displacement limit was dictated by the horizontal movement allowed by the direct shear apparatus. ASTM D3080-11 [30] specifications suggests that, if no peak response is observed, peak shear may be considered at 10% horizontal strain.

A total of 9 tests were performed on monoblocks that measure 99.5 mm × 99.5 mm × 40 mm. This represents three tests for each of the investigated density. Interface shear tests were performed on geofoam in direct contact with the PVC and the sand material. In the PVC interface tests, the geofoam was placed in the upper box while the PVC

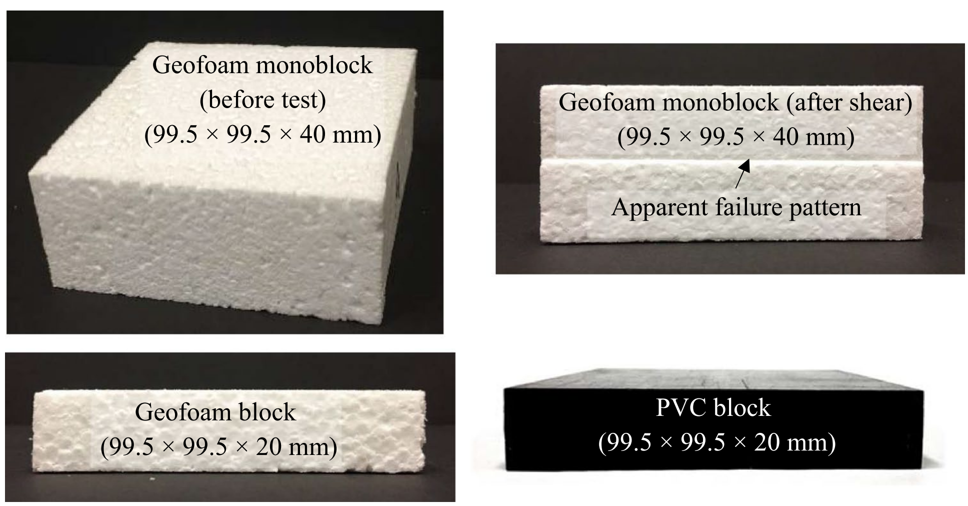

Fig. 2 Geofoam and PVC samples used in the experiments

Table 5 Properties of the PVC and sand used in the experiments

PVC material[a]		
Density	1500 kg/m^3	
Tensile strength	41,368 kN/m^2 (6000 psi)	
Water absorption	0.13%	
Coefficient of thermal expansion	3.3 × 10^{-5} 1 (°F)	
Silica sand		
Density	1.60 g/cm^3	[28]
Coefficient of uniformity (C_u)	1.9	[29]
Coefficient of curvature (C_c)	1.3	
Peak internal angle of friction (ϕ_{peak})	41°	[30]
Residual internal angle of friction ($\phi_{residual}$)	35°	

[a]Provided by the manufacturer

sample was placed in the lower box. This arrangement was adopted since the PVC block is considered incompressible compared to the geofoam under the applied loading and, hence, ensuring that the shear surface remains in line with the separation plane between the upper and lower parts of the box. Another advantage of this setup is that it minimizes the tilting that may be experienced if the lower block deforms unevenly during loading. Similar arrangement was used to study the geofoam–sand interface where the sand was placed in the lower part of the box and compacted to the target density (1.60 g/cm^3) before the overlying EPS block was placed. Adjustments were made to the setup before each test and a spirit level was used to ensure that the samples remain horizontal during the experiments.

Results and Discussion

The applied normal and shear loads as well as the corresponding displacements were measured for each of the performed test. The experimental results are used to develop the failure envelops and determine the shear strength parameters of the investigated conditions. It is noted that actual shear failure or rupture along the shear plane does not usually develop in EPS monoblocks, therefore, apparent failure, or excessive permanent deformation (see Fig. 2) is used to define the onset of monoblock shear failure in this study.

Shear Strength of Geofoam Monoblocks

For the three applied normal stress values (18, 36 and 54 kPa), the horizontal displacements and the corresponding shear stresses are presented in Fig. 3a through c for EPS15, EPS22, and EPS35, respectively. Shear stresses were found to increase with the increase in displacement and no apparent failure pattern developed up to the maximum applied displacement of 10 mm. The response of the geofoam can be characterized by two phases: (1) for displacement of up to 2 mm, shear stresses increased almost linearly with the increase in shear displacements. The maximum shear stress measured was found to be approximately 25, 30, and 40 kPa for EPS15, EPS22, and EPS35, respectively; (2) for displacement of more than 2 mm, shear stresses continued to increase at a slower rate reaching maximum values of 37, 42, and 54 kPa for EPS15, EPS22, and EPS35, respectively.

The measured normal and shear stresses are used to plot the Mohr–Coulomb failure envelops for the three investigated geofoam densities as illustrated in Fig. 4. The failure envelops are generally parallel with a gentle upward slope. The shear resistance is found to increase with the increase in geofoam density. As far as shear strength parameters, it has been reported [22] that since the horizontal shear plane induced by the shear box passes through the geofoam

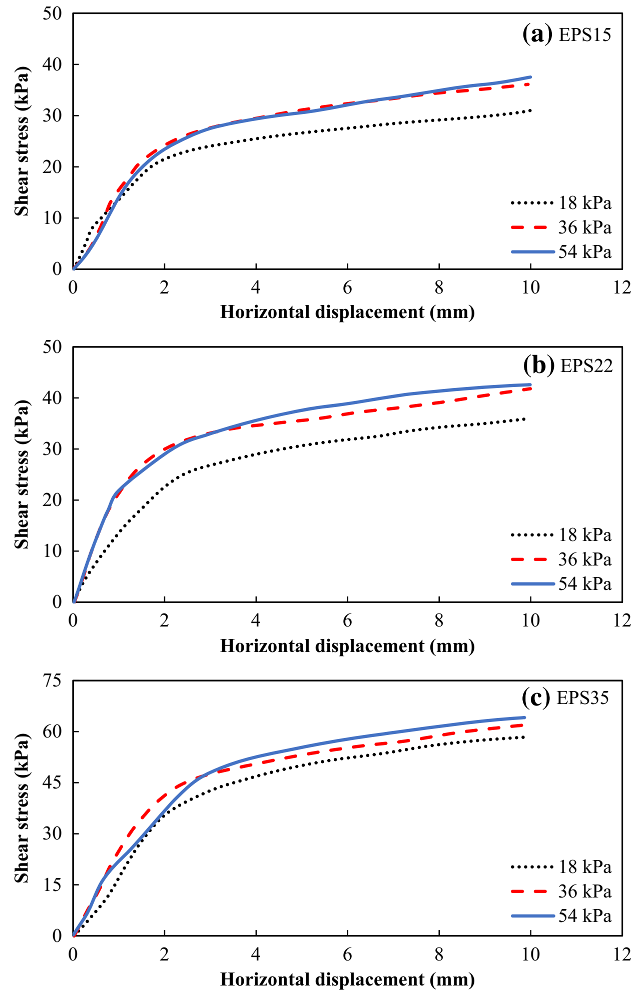

Fig. 3 Shear stress vs. horizontal displacements for monoblocks of different densities: **a** EPS15, **b** EPS22 and **c** EPS35

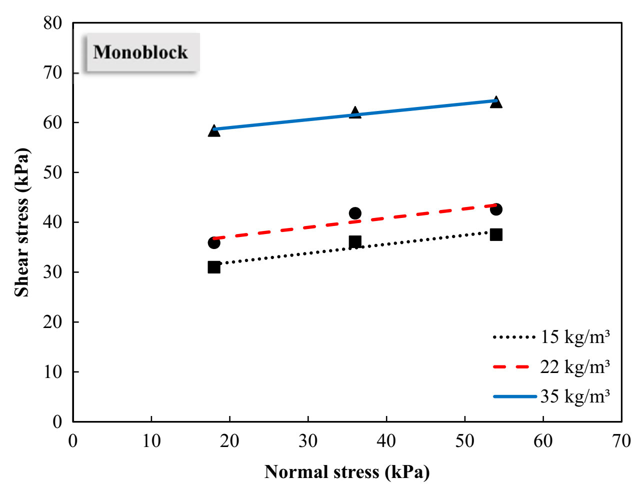

Fig. 4 Mohr–Coulomb failure envelopes of geofoam monoblocks

specimen, the shear resistance is directly related to the cohesion of the geofoam material. Figure 5 shows the changes in cohesion and friction angle for EPS monoblocks of different densities. The cohesive strengths were found to have an increasing trend with the increase in density. The cohesion values ranged from 28 kPa for EPS15 to about 56 kPa for EPS35 as illustrated in Fig. 5a. Conversely, the friction angles experienced a slight decrease from about 10.5° for EPS15 to 9° for EPS35 as shown in Fig. 5b. This validates the fact that shear strength of geofoam is mainly dependent on the material cohesion.

The recorded vertical compression of the geofoam blocks for different applied normal stresses is shown in Fig. 6. In general, EPS15 experienced more vertical compression as compared to EPS35 and the vertical compression increased with the increase in normal stresses. These results are consistent with the fact that the compression of geofoam is directly related to applied normal stress and inversely related to density of geofoam. The trend lines revealed that the rate of compression, reflected by the slope of the lines, was the highest for EPS15 and decreased with the increase in geofoam density.

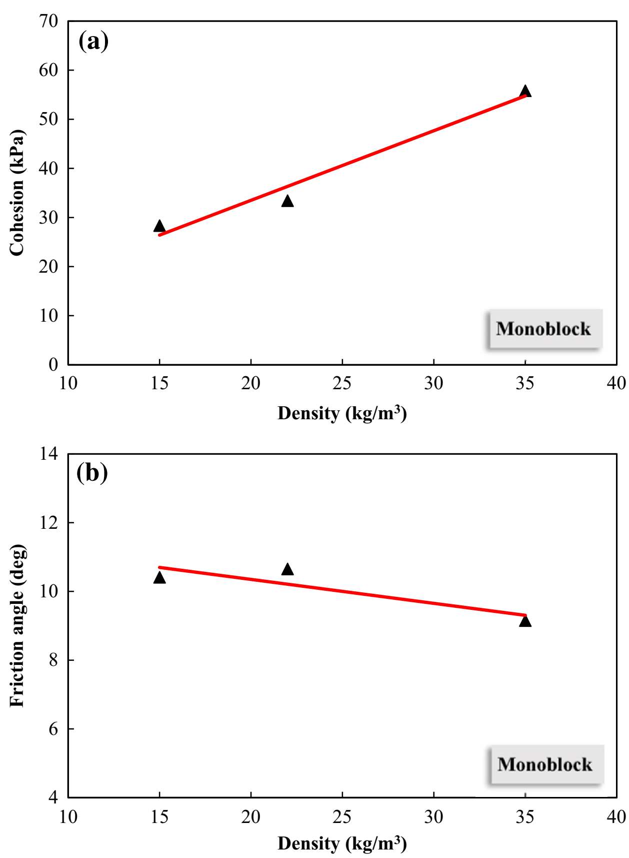

Fig. 5 Effect of geofoam density on **a** cohesive strength and **b** friction angle

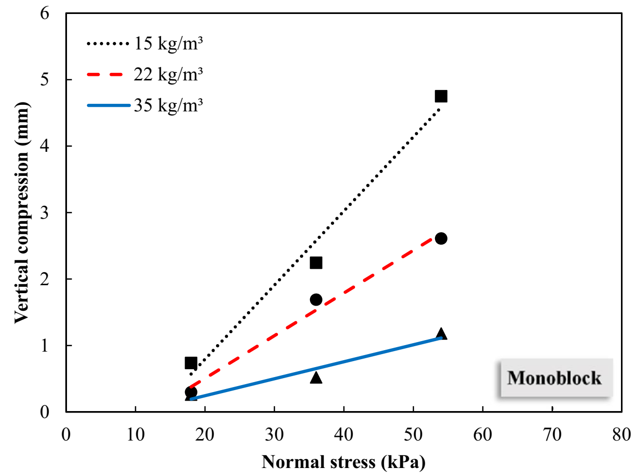

Fig. 6 Vertical compression measured of geofoam monoblock under different applied normal stresses

Another way to evaluate the effect of geofoam density on the shear strength of the tested blocks is to present the results using a normalized shear factor as shown in Fig. 7. The shear factor is defined as the ratio of shear stress at failure to the corresponding normal stress. Shear factors of greater than 1 indicate that shear resistance is more than the applied normal stress whereas shear factors of less than 1 means that shear resistance is smaller than the normal stress. As illustrated in Fig. 7, the shear factors decreased from about 1.7 to 0.7 for EPS15 and from 3.3 to 1.2 for EPS35 depending on the applied normal stress. These results confirm that for a given normal stress (e.g. 36 kPa), the shear stress at failure for both EPS15 and EPS22 is slightly higher than the applied normal stress with a difference in shear factor of about 10% between the two materials. EPS35, however, allowed shear stresses to reach up to 1.7 times the applied normal stress.

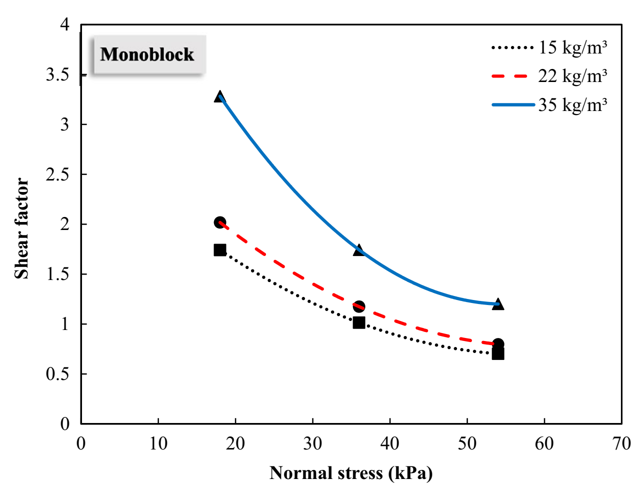

Fig. 7 Shear factors for different geofoam materials

Interface Strength Properties

In this section, the results obtained from direct shear tests performed to study the shear resistance of geofoam block interacting with PVC and sand materials are presented.

Geofoam–PVC Interface

The relationships between shear stresses and horizontal displacements for geofoam–PVC interface are shown in Fig. 8. The behavior is characterized by rapid linear increase in shear stresses at a very small displacements followed by either a plateau (for EPS15 and EPS22) or slow increase in shear stresses as the displacements increased up to 10 mm. For a given displacement (e.g. 2 mm), the average measured shear resistance was found to be 11, 14 and 18 kPa for EPS 15, 22 and 35, respectively. No peak or residual stresses were measured for the three investigated geofoam materials.

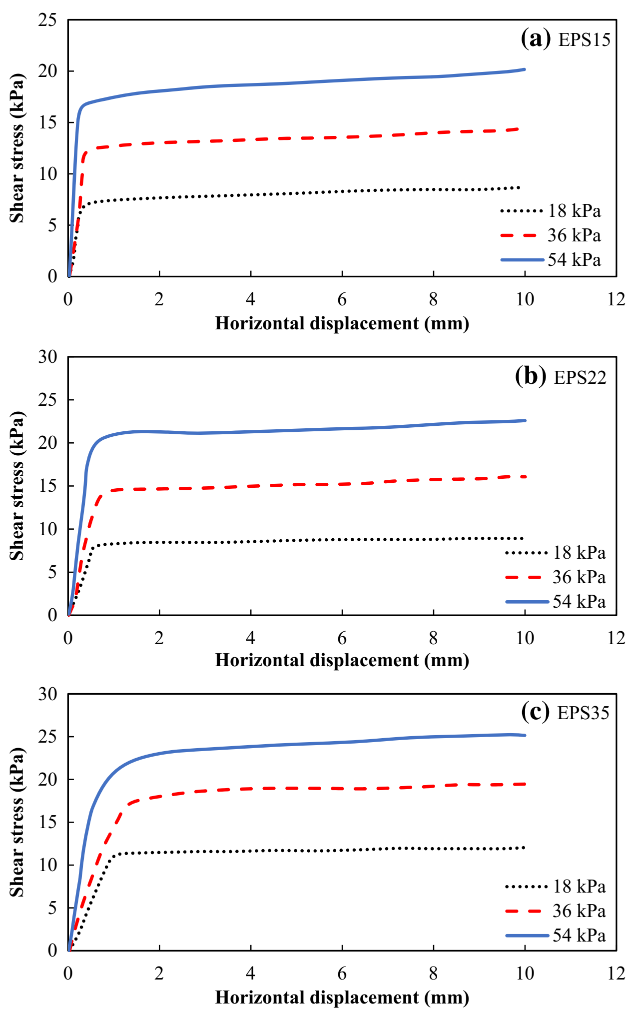

Fig. 8 Shear stress vs. horizontal displacemnts for geofoam–PVC interface: **a** EPS15, **b** EPS22 and **c** EPS35

The failure envelops for the geofoam–PVC interface tests are shown in Fig. 9. Shear stresses increased almost linearly with the increase in normal stresses. For all geofoam–PVC interfaces, linear failure envelopes were observed for the three different geofoam densities (Fig. 10) and both

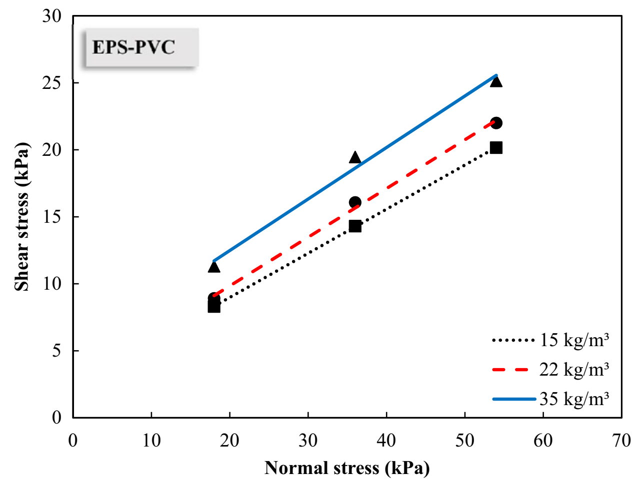

Fig. 9 Mohr–Coulomb failure envelopes for geofoam–PVC interface

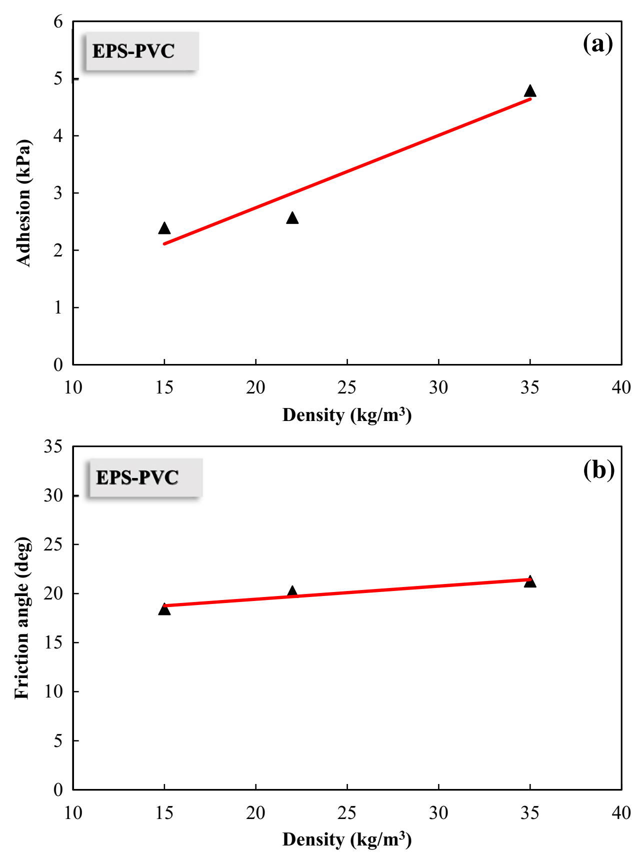

Fig. 10 Effect of geofoam density on the shear strength of the geofoam–PVC interface: **a** adhesion and **b** friction angle

the adhesion and angle of interface friction were calculated from these envelopes. For a given normal stress, the measured interface shear stress was found to increase with the increase in geofoam density. The slope of each line represents the interface friction angle whereas the intercept with the vertical axis represents the adhesion that develops at the PVC–geofoam interface. The relationships between the interface strength parameters and the geofoam density are shown in Fig. 10. Adhesion increased from about 2 kPa for EPS15 to 5 kPa for EPS35 (Fig. 10a). Friction angle did not change significantly with the increase in density and ranged between 18° to about 21° for the three investigated geofoam materials. This range of interface friction is higher than that measured for the monoblock.

Vertical compression during shear in this case was found to be small as compared to the monoblock with a maximum compression value of 2 mm for EPS15 as shown in Fig. 11. This is consistent with the thickness of the geofoam blocks used in interface tests, which is half of that of the monoblocks. Vertical compression decreased with the increase in density and the difference was more pronounced at high-applied normal stresses.

Geofoam–Sand Interface

The changes in shear stresses with the increase in horizontal displacements are shown in Fig. 12. Shear stresses increased rapidly with the increase in horizontal displacement up to about 2 mm. The average measured shear resistance at 2 mm displacement was found to be 24, 28 and 31 kPa for EPS15, EPS22 and EPS35, respectively. Slight reduction in displacements was measured in all cases as the displacement increased from 2 to 4 mm followed by a plateau for displacements more than 4 mm. The interface shear stress measured

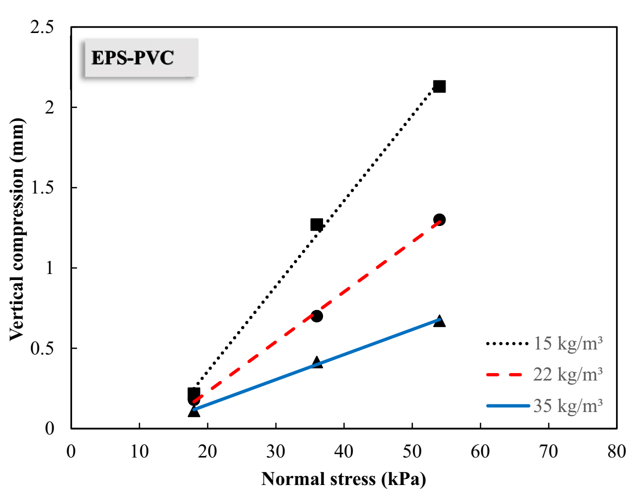

Fig. 11 Vertical compression measured for the geofoam–PVC interface test under different applied normal stresses

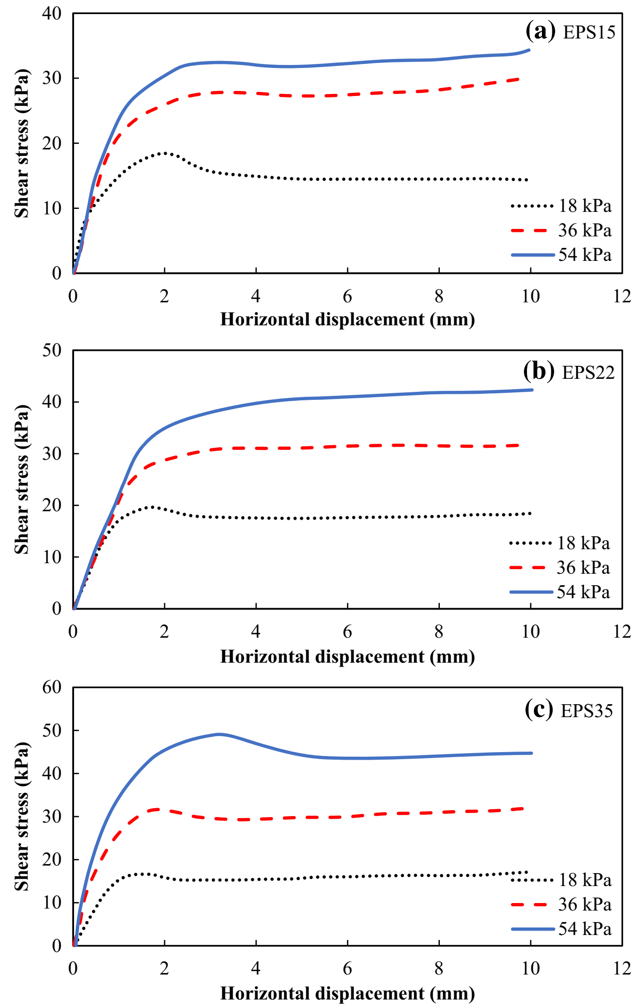

Fig. 12 Shear stress vs. horizontal displacements for geofoam–sand interface: **a** EPS15, **b** EPS22 and **c** EPS35

for the geofoam–sand interface was found to be generally higher as compared to that of the geofoam–PVC for the investigated range of normal stress and geofoam density.

Mohr–Coulomb failure envelops developing at the geofoam–sand surface are presented in Fig. 13. At low normal stress values, the difference between the shear stresses for the three geofoam densities is negligible. With the increase in normal stresses geofoam density started to affect the developing shear stresses that reached values of 32 kPa for EPS15 and 45 kPa for EPS35 at applied normal stress of 54 kPa. This may be attributed to the fact that at low normal stress, little interaction develops at the interface between the geofoam and the underlying sand layer, whereas at higher normal stress, sand particles penetrate into the geofoam surface resulting in much higher shear stress values.

Shear strength parameters for different geofoam densities are shown in Fig. 14. Adhesion values (Fig. 14a) were found to decrease from about 12 to 2 kPa as the density

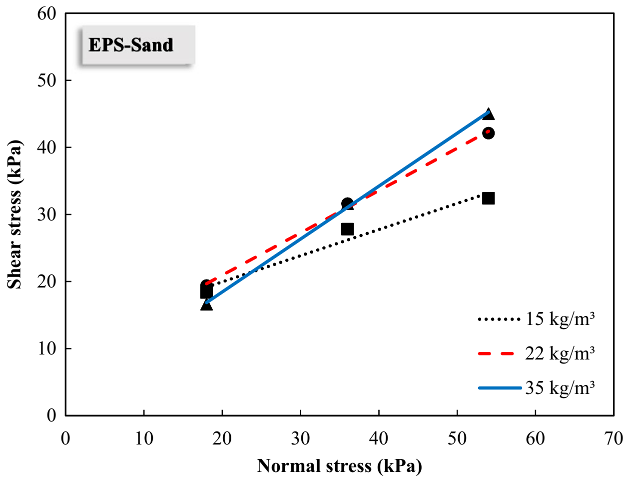

Fig. 13 Mohr–Coulomb failure envelopes for geofoam–sand interface

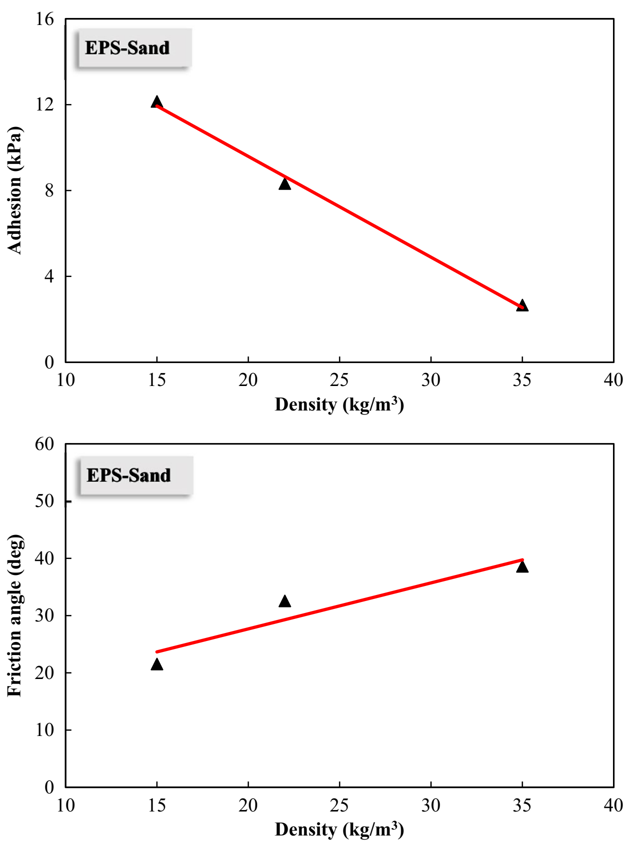

Fig. 14 Effect of density on the shear strength of the geofoam–sand interface: **a** adhesion and **b** friction angle

increased from 15 to 35 kg/m^3. This may be attributed to the fact that stiffer geofoam (EPS35) develops less interaction with the sand particles as compared to the soft samples (EPS15), which allows for the sand penetration across the contact surface. Friction angles (Fig. 14b) increased from 20° for EPS15 to 38° for EPS35. Post-test sample inspection revealed that the upper layer of the sand particles was pushed into the surface of the soft geofoam blocks (EPS15) during testing creating a rough surface. Less interaction with the sand material was observed for the stiffer geofoam blocks (EPS35).

Vertical compression developing during the geofoam–sand interface tests is shown in Fig. 15. For the same range of normal stresses, compression values were found to be larger than those measured for the case of geofoam–PVC but smaller than the compression of the monoblock. This is attributed to the compression experienced by the sand material during shear.

The above results suggest that the interface strength at the contact surface between a geofoam block and other material is highly dependent on the level of interaction that could develop at the interface. Stiff geofoam tends to produce small adhesion and friction angle when the geofoam is tested against material that has a smooth surface (e.g. PVC). Geofoam was found to develop more interaction with sand material resulting in higher adhesion and friction angle.

Conclusions

In this study, a series of direct shear tests was performed to measure the shear strength parameters of EPS monoblocks of different densities. In addition, interface shear tests were also performed to determine the shear parameters at the EPS–sand and EPS–PVC contact surfaces. Determining shear and interface properties of geofoam is essential for the analysis of geotechnical structures that involve geofoam interacting with other material. The experimental results presented in this study provides the shear parameters required

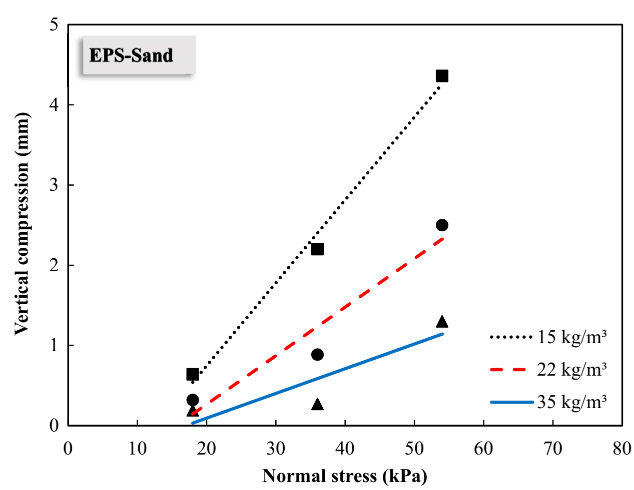

Fig. 15 Vertical compression measured for the geofoam–sand interface under different normal stresses

for numerical modeling of similar problems. The following conclusions have been drawn based on this experimental study.

1. Geofoam monoblocks experienced shear deformation with no actual failure under direct shear condition. Shear strength was found to be highly dependent on the material cohesion that increased from 28 to 56 kPa as the density increased from 15 to 35 kg/m^3. Internal friction angle, however, showed slight decrease from 10.5° to 9° with the increase in density.
2. Geofoam–PVC interface showed an increase in adhesion from 2 to 5 kPa with a slight decrease in interface friction angle (from 18° to about 21°) as the density of the geofoam increased from 15 to 35 kg/m^3. For geofoam–sand interface, however, adhesion values decreased from 12 to 2 kPa with the increase in EPS density. This is related to the fact that low density geofoam interacts better with sand particles under high normal stresses as compared to the high density geofoam material.
3. The measured compression for both the monoblocks and interface tests showed similar trends, however, the magnitude of compression was found to depend on the thickness of the tested geofoam sample. Monoblock samples experienced more compression as it has twice the thickness of that used in the interface tests.

Further experiments are needed to study the interface strength properties of geofoam with other construction material, including, concrete, steel and different types of backfill material.

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