

SHEAR RESISTANCE ON EPS GEOFOAM BLOCK SURFACES

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ABSTRACT

Direct shear tests were conducted in order to quantify the shear resistance at geofoam-geofoam, geofoam-geosynthetics, and geofoam-soils interfaces. EPS geofoam samples were obtained from the surfaces of blocks with nominal densities of 10, 15, 20 and 30kg/m³. Five geotextiles, five geomembranes and three soils were tested. Applied normal stresses varied from as low as 5 kPa to approximately the yield stress of the geofoam blocks. Results are presented in the form of failure envelopes having a bilinear shape as a good first order approximation. At relatively low normal stress levels, the shear resistance obtained is a purely “frictional” phenomenon while at higher normal stress levels it can be considered as purely “adhesional”. The apparent angle of friction at geofoam-geofoam, geofoam-geotextile, geofoam-geomembrane and geofoam-soil interfaces ranges from 35° to 43°, from 21° to 34°, from 16° to 46° and from 22.5° to 55.5°, respectively. The effect of geofoam density on the apparent friction angle between geofoam blocks and geosynthetics or soils is insignificant. The maximum shear resistance on any type of contact surface tested is a relatively small percentage (15% to 35%) of the shear strength of the geofoams.

KEYWORDS: EPS geofoam, geotextiles, geomembranes, soils, interface, shear resistance, direct shear

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INTRODUCTION

Major applications of expanded polystyrene (EPS geof foam) products include construction of light-weight embankments or fills, improvement of slope stability, reduction of lateral earth pressures on retaining structures, protection of utilities and thermal insulation of foundations and highway or airport pavements. Due to the nature and size of such construction projects, geof foam blocks are placed in contact to each other as well as in contact with other materials such as geosynthetics, soils, coarse aggregates and concrete. Accordingly the internal and/or the overall stability of a structure may be governed by the interaction mechanisms at the interfaces between geof foam blocks or geof foam blocks and other materials. However, pertinent information is very limited in available literature.

Kuroda et al. (1996) processed data from shaking table tests and computed an apparent friction angle equal to 31° between geof foam blocks with nominal density of 20kg/m^3 . Hotta et al. (1996) have recommended the use of a design value of about 27° for the apparent friction angle between geof foam blocks and soils. Horvath (1995) summarized the results of other investigations and reported that the apparent friction angle between geof foam blocks ranges between 27° and 35° and is independent of nominal density and applied normal stress. GRC (2001) reports that according to results obtained by Sheeley (2000), the apparent angle friction at dry or wet interfaces between geof foam blocks with nominal densities of 20kg/m^3 and 30kg/m^3 under normal stresses up to 25kPa ranges from 37° to 40° . Finally, for normal stresses up to 25kPa , the same source (GRC, 2001; Sheeley, 2000) reports apparent friction angle of 45° at the interface between geof foam and rough HDPE, which is reduced to about 39° for normal stresses of about 45kPa , 16° at geof foam-smooth HDPE interfaces, and 35° at geof foam PVC interfaces.

The information presented herein is part of an extensive experimental investigation of the mechanical properties and behavior of commercially produced EPS geof foam blocks. Scope of this presentation is to offer additional information on the shear resistance at the interfaces between geof foam blocks as well as between geof foam blocks and geotextiles, geomembranes and soils.

MATERIALS AND EXPERIMENTAL PROCEDURES

The shear resistance at the interface between EPS geof foam blocks, EPS geof foam blocks and geosynthetics and EPS geof foam blocks and soils was quantified by conducting direct shear tests. Commercially produced EPS geof foam blocks measuring $2.5\text{m} \times 1.0\text{m} \times 0.5\text{m}$ were obtained for the purposes of the investigation reported herein. The blocks had a nominal density of 10, 15, 20 and 30kg/m^3 . Samples obtained from these blocks are referred to in this text using the symbol EPS and the nominal density (i.e. EPS 20). Typical results of unconfined compression tests on 50mm cube samples at a strain rate of $10\%/minute$ are presented in Figure 1 and average values for yield stress, compressive strength and initial modulus of elasticity are summarized in Table 1. These results are in very good agreement with the range of values expected for EPS geof foam (Horvath, 1995; Duskov, 1997; PES, 1997; BASF, 1998). Presented also in Table 1 are shear strength values which were obtained by direct shear testing of relatively thin (10mm) samples and are within the range of values reported in available literature (Horvath, 1995; BASF 1998).

The interface shear resistance between EPS geof foam blocks and geosynthetics was measured for five different geotextiles and five different geomembranes. The geotextiles group included one nonwoven needle punched product, two nonwoven thermally bonded products and two woven products. The geomembranes group included three HDPE products, one PVC product and one PP product. These products were selected in order to cover a relatively wide range of frequently used products in terms of polymer type, manufacturing process and surface roughness. Brief descriptions of these geosynthetics are presented in Table 2.

The soils tested were a laboratory prepared clay, a medium sand and a fine gravel. The soil classified as clay was prepared by mixing kaolinite (liquid and plastic limits equal to 43 and 26, respectively) with distilled water and

curing for 24 hours. As placed in the shear box, the clay had void ratio of 1.1, water content of 35% and cohesion equal to 14kPa. The sand used had subangular grains with sizes between 0.60mm and 0.85mm, was placed in the shear box at a void ratio of 0.65 and had an angle of internal friction, as measured by direct shear testing, of 46° at this void ratio. The fine gravel had angular grains with sizes between 4.75mm and 9.52mm, was placed in the shear box at a void ratio of 0.72 and had an angle of internal friction of 49°, as measured by direct shear testing, at this void ratio.

Interface shear resistance was measured by conducting direct shear tests using 100mm and 300mm square shear boxes. All EPS geofoam samples were cut and shaped using hot wires, as shown in Figure 2. In order to simulate field conditions, all samples were obtained from the outer surfaces of the EPS blocks. Thus, the as-produced roughness and shape of the EPS block surfaces was retained. Shown schematically in Figure 3 is the configuration of samples in the direct shear box. When testing for shear resistance at the interface between EPS geofoam blocks, the interface did not coincide with the shear plane defined by the two parts of the shear box because of the compressibility of the geofoam samples. To overcome this deficiency, the upper EPS geofoam sample was reduced in length, in the direction of shearing, by an amount equal to the maximum displacement between the two parts of the shear box. The applied shear rate was 1.0mm/min for all tests conducted. The applied normal stresses ranged from as low as 5 kPa to approximately the yield stress of each EPS geofoam. With the exception of shear resistance tests on EPS geofoam-clay interfaces, all tests were conducted with dry interfaces. The results obtained are presented herein in the form of failure envelopes (applied normal stress-maximum shear resistance). For most, if not all, of the failure envelopes obtained, a bilinear shape is a good first order approximation.

SHEAR RESISTANCE AT EPS GEOFOAM INTERFACES

Presented in Figure 4 are the failure envelopes obtained from direct shear tests at the interfaces between geofoam blocks. It can be observed that the shear resistance increases in proportion to the increase of the applied normal stress up to a “limit” value of the normal stress and remains practically constant thereafter. Accordingly, the first segment of the bilinear failure envelope indicates a purely “frictional” phenomenon and the second segment a purely “adhesional” phenomenon. The observed limiting value of the applied normal stress ranges from 17kPa to 80kPa, increases with increasing geofoam nominal density, and corresponds to about 30% to 60% of the measured yield stress in unconfined compression.

The initial segment of the failure envelope indicates that the apparent friction angle increases with increasing nominal density and attains values equal 35°, 36°, 40° and 43° for EPS10, EPS15, EPS20 and EPS30, respectively. Compared to results obtained by other researchers, the values for EPS20 and EPS30 are higher by a few degrees. The second (final) segment of the failure envelopes yields values which increase with increasing nominal density and range from 11.5kPa to 77.7kPa. Accordingly, the maximum shear resistance which may develop at the interface between geofoam blocks corresponds approximately to 15% to 35% of the shear strength of the geofoam blocks. This indicates the need to use binder plates in order to avoid relative movement between adjacent geofoam blocks.

SHEAR RESISTANCE AT EPS GEOFOAM-GEOSYNTHETICS INTERFACES

The results presented in Figure 5 indicate that, for most of the geotextiles and geomembranes tested, the bilinear failure envelope is a good first order approximation. In some cases, it appears that the experimental data could be fitted better by a failure envelope which would have a transitional, curved, part between the purely frictional and the purely adhesional segments. However, the bilinear interpretation was selected for the purposes of this presentation. It should be noted that the results presented in Figure 5 are limited to interfaces between the geosynthetics and EPS20 in order to exclude the possible effects of geofoam nominal density.

For relatively low applied normal stresses (at least up to 40kPa), which are most common in light-weight fill applications, the interaction mechanism between EPS20 and geotextiles is observed to be purely frictional. The apparent friction angle has values between 21° and 34° depending on the roughness of the geotextile surface. As expected, the differences in frictional behavior between the two thermally bonded nonwoven geotextiles (GT2 and GT3) are negligible. However, the measured apparent friction angle of these geotextiles is significantly lower (25° versus 32°) than the angle obtained for the needle punched geotextile (GT1). A similar observation can be made for the woven geotextiles, which are manufactured using different weaving patterns yielding relatively smooth (GT5) and relatively rough (GT4) surfaces. Finally, it can be observed that, for relatively low normal stresses, the shear resistance at the interface between geotextiles and EPS 20 geofoam is lower than at the interface between EPS20 geofoam blocks (21° to 34° versus 40°).

Similar to geotextiles, the interaction mechanism at the interface between EPS20 and the various geomembranes tested is purely frictional for relatively low applied normal stresses. However, significant differences can be observed depending on geomembrane type (polymer type). The HDPE geomembrane with smooth surface yields an apparent friction angle of 16° while the PVC geomembrane with smooth surface yields more than twice this value (37°). An intermediate value of 23.5° was obtained for the PP geomembrane. The disadvantage of smooth HDPE geomembranes can be overcome by increased surface roughness. It can be observed that when HDPE geomembranes with rough surface (textured or with micro spikes) were tested, the apparent friction angle obtained a value of 46°. These values, are in very good agreement with data obtained by Sheeley (2000) and reported by GRC (2001). It should be noted that the HDPE geomembranes with rough surfaces were the only geosynthetics tested which exhibited an apparent friction angle at the interface with EPS20, which was larger than the apparent friction angle between EPS20 blocks (46° versus 40°).

The second linear segment of the failure envelopes obtained for all geosynthetics tested is characterized by adhesion only with values ranging between 23kPa and 33kPa, which correspond to 18% to 26% of the shear strength of EPS20. On the average, these values are similar to those obtained for the interface between EPS20 blocks (20%). The limiting value of the applied normal stress, separating the frictional from the adhesional segments of the failure envelopes, ranges from 33kPa to 82kPa and corresponds to 37% to 90% of the yield stress of EPS20.

In order to investigate the effect of geofoam nominal density on the shear resistance at the interfaces with geosynthetics, direct shear tests were conducted using EPS15 and EPS30 in contact with geotextile GT1 (nonwoven needle punched) and geomembrane GM5 (PVC smooth). The results obtained are presented in Figure 6 together with the results obtained for EPS 20. It can be observed that an increase of EPS geofoam nominal density from 15kg/m³ to 30kg/m³ has a negligible effect on the value of the apparent friction angle which characterizes the initial segment of the failure envelopes. The limiting applied normal stress which separates the purely frictional from the purely adhesional segments of the failure envelope increases with increasing geofoam nominal density and corresponds to 44% to 53% of the geofoam yield stress. Similarly, the adhesion value or the maximum shear resistance increases with increasing nominal density and attains values from 18% to 26% of the shear strength of the EPS geofoam blocks.

SHEAR RESISTANCE AT EPS GEOFOAM-SOIL INTERFACES

Presented in Figures 7 and 8 are the results obtained for the shear resistance at the interface between EPS geofoam blocks and soils. The existence of the transitional part in the failure envelope between the segments indicating purely frictional and purely adhesional behavior is apparent in practically all cases. However, for reasons of uniformity and simplicity the failure envelopes are approximated by a bilinear shape. The maximum shear resistance that may develop at the interface between EPS20 and clay (Figure 7) is low, corresponds to approximately 45% of the maximum shear resistance between EPS20 blocks and is approximately equal to the shear strength of the clay under quick loading conditions (12kPa). However, when the soil is a sand or a gravel with subangular and angular grains, respectively, the maximum shear resistance corresponds to about 160% of the maximum shear resistance between EPS blocks and to about 30% of the shear strength of the geofoam itself. For relatively low applied normal stresses, up to 30kPa, the apparent friction angle values at the interface between EPS20 and sand or gravel are relatively high and are approximately equal or exceed the apparent friction angle between EPS20

blocks (38.5° and 55.5° versus 40°). As shown in Figure 8, an increase of the nominal density of the EPS geof foam blocks from 15kg/m^3 to 30kg/m^3 has a negligible effect on the apparent friction angle at the interface with sand. The value of the limiting normal stress separating the purely frictional from the purely adhesional segments of the failure envelope increases with increasing nominal density as does the maximum shear resistance that may develop at EPS20-sand interfaces.

DISCUSSION

When EPS geof foam blocks are used as light-weight fill, the applied normal stresses frequently do not exceed 25kPa to 30kPa or the equivalent of approximately 1.5m of soil. It has been recommended that, to minimize creep, the applied normal stresses should not exceed 50% of the yield stress of the geof foam used (Horvath, 1995; 1998; Hillman, 1996; Duskov, 1997). More recently, it has been suggested that, in order to prevent any deformations due to creep, the initial elastic deformation should not exceed 0.5% (Duskov and Houben, 2000). Based on the information presented in Figures 4 through 8, it can be observed that the interaction mechanism at all interfaces tested is purely frictional for applied normal stresses which frequently exceed the value of 30kPa. Based on the typical property values of the EPS geof foams tested during this investigation (Table 1), it can be stated that the forementioned criterion of maximum allowable elastic deformation of 0.5% corresponds to applied normal stresses which do not exceed 30kPa for any of the EPS geof foams.

Considering, for example, the results obtained for EPS 20, which is a material frequently used in construction, for an applied normal stress of 20kPa, and for purely frictional shear resistance at the interfaces, it can be easily computed that the shear resistance between geof foam blocks will be 18kPa, at the interfaces between geof foam and various polypropylene geotextiles will range from 8 to 14kPa, at the interfaces between geof foam and smooth HDPE, PP and PVC geomembranes will range from 6 to 15kPa, at the interface between geof foam and rough HDPE geomembranes will be approximately 21kPa and at the interface between geof foam and clay, subangular sand and angular gravel will be 8kPa, 16kPa and 29kPa, respectively. Each of these shear resistance values is a small percentage (5% to 23%) of the shear strength of EPS20. Accordingly, any shear failures will appear at interfaces between geof foam blocks or between geof foam blocks and other materials. Since it is frequently recommended that special binder plates be used between geof foam blocks, similar consideration should be given to interfaces between geof foam blocks and other construction materials. Furthermore, these values indicate that the resistance at interfaces between geof foam blocks is exceeded only by the resistance at interfaces between geof foam blocks and soils with angular grains or very rough geosynthetics.

SUMMARY

Based on the results of the limited experimental investigation reported herein, the following conclusions can be advanced:

1. The shear resistance at the interface between EPS geof foam blocks, EPS geof foam blocks and geosynthetics, and EPS geof foam blocks and soils is dependent on the magnitude of the applied normal stress.
2. As a first order approximation, failure envelopes have a bilinear shape, with an initial segment indicating purely frictional behavior and a final segment indicating purely adhesive behavior. It is recognized that a transitional segment (combined frictional and adhesive behavior) may exist.
3. For relatively low normal stresses, characteristic of light-weight fill applications, the shear resistance at all interfaces tested is purely frictional. The shear resistance at the interface between geof foam blocks can be exceeded only by the shear resistance at interfaces between geof foam blocks and soils with angular grains or geosynthetics with very rough surface.
4. Further consideration should be given to interface shear resistance under high normal stresses in order to generate appropriate design information for such applications.

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Table 1. Properties of EPS geofoam blocks

Property	Geofoam			
	EPS 10	EPS 15	EPS 20	EPS 30
Nominal density (kg/m ³)	10	15	20	30
Mean density (kg/m ³)	9.97	15.07	19.90	31.97
Density range (kg/m ³)	8.87 – 12.78	13.85 – 18.74	17.90 – 23.04	26.80 – 37.30
Yield stress (kPa)	26.5	65.5	89.0	186.0
Compressive strength (kPa) (at 10% axial strain)	36.5	78.0	100.0	210.0
Initial modulus of elasticity (kPa)	1250	3040	3980	6033
Shear strength (kPa)	80.2	123.5	129.4	220.2

Table 2. Description of geosynthetics used for testing

Geosynthetic	Thickness (mm)	Weight (gr/m ²)	Description
GT1	3.27	350	Nonwoven, needle punched geotextile, PP staple fibers
GT2	0.45	125	Nonwoven, thermally bonded geotextile, PP continuous filament
GT3	0.62	190	Nonwoven, thermally bonded geotextile, PP continuous filament
GT4	0.40	100	Woven geotextile, 1.5mm wide PP tapes, negligible open area, negligible asperities on surface
GT5	1.10	330	Woven geotextile, 1.9mm and 2.3mm PP tapes, negligible open area, 0.2mm asperities due to weaving
GM1	0.75	750	HDPE geomembrane, smooth surface
GM2	1.50	1505	HDPE geomembrane, textured surface, up to 0.4mm asperities
GM3	1.00	980	HDPE geomembrane, smooth surface with 0.55mm micro spikes on a 3mm mesh
GM4	0.66	795	PP geomembrane, smooth surface, 0,15mm asperities due to internal reinforcement
GM5	2.00	1320	PVC geomembrane, smooth surface

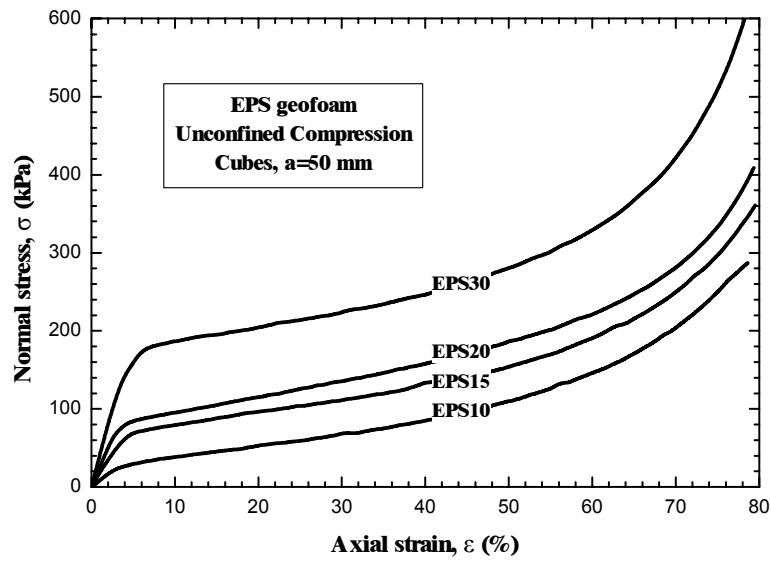


Figure 1. Typical unconfined compression stress-strain curves for EPS geofoam blocks

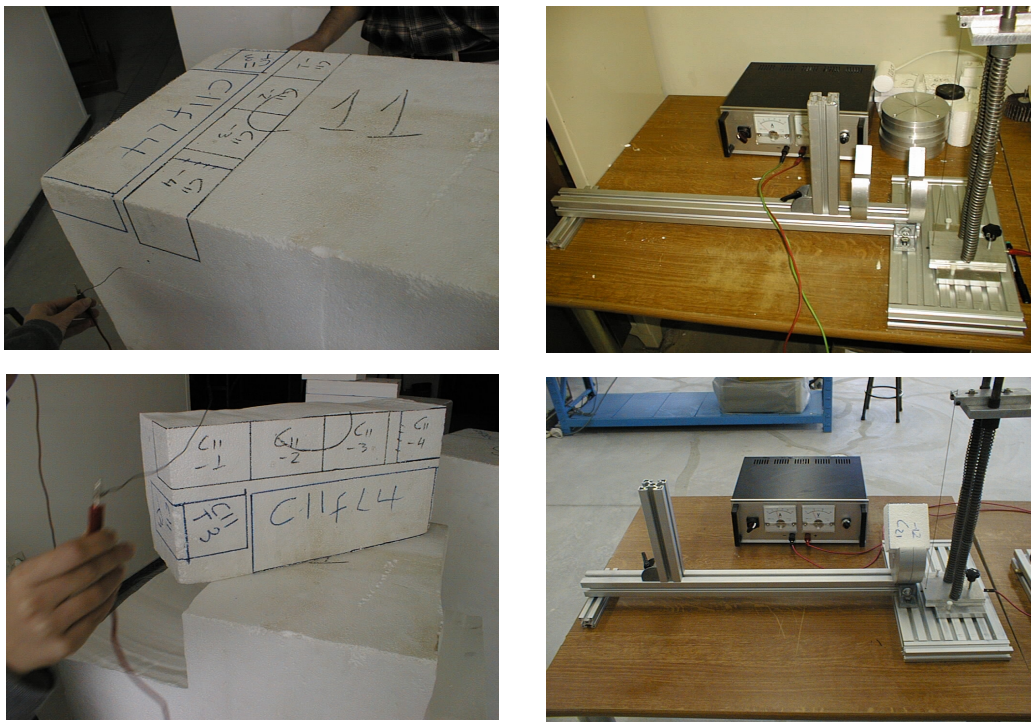


Figure 2. Sample cutting and forming equipment

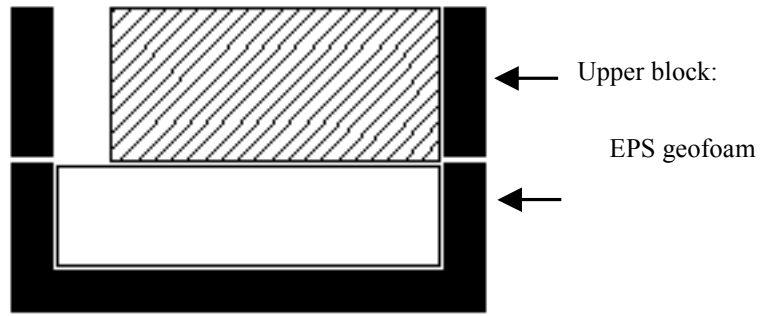


Figure 3. Sample configuration in direct shear box

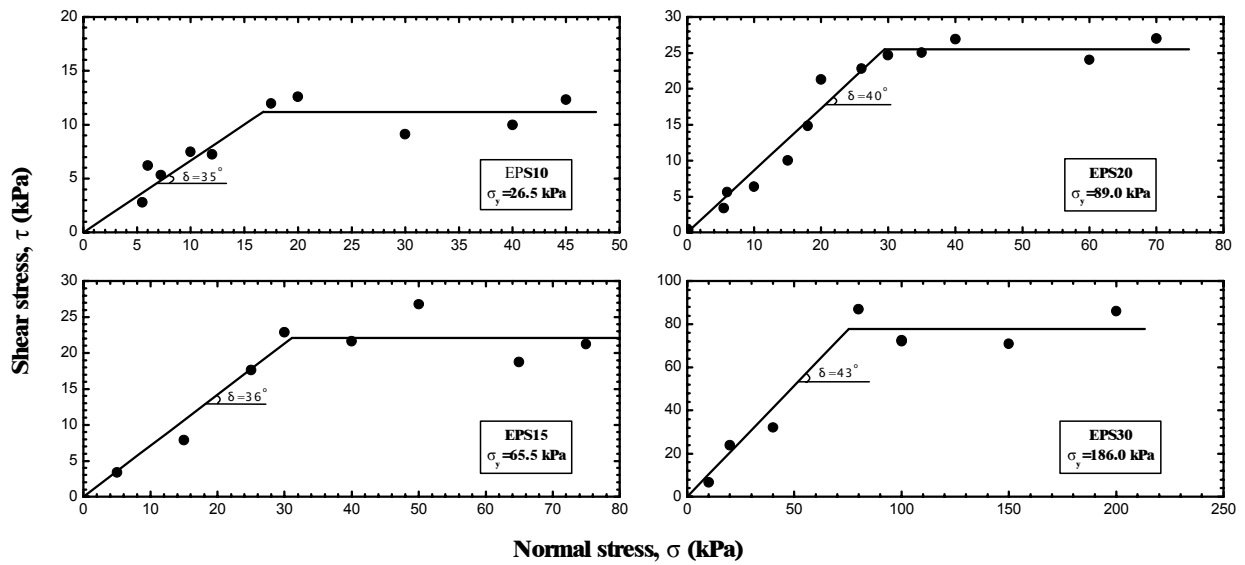


Figure 4. Shear resistance at the interface between EPS geofoam blocks

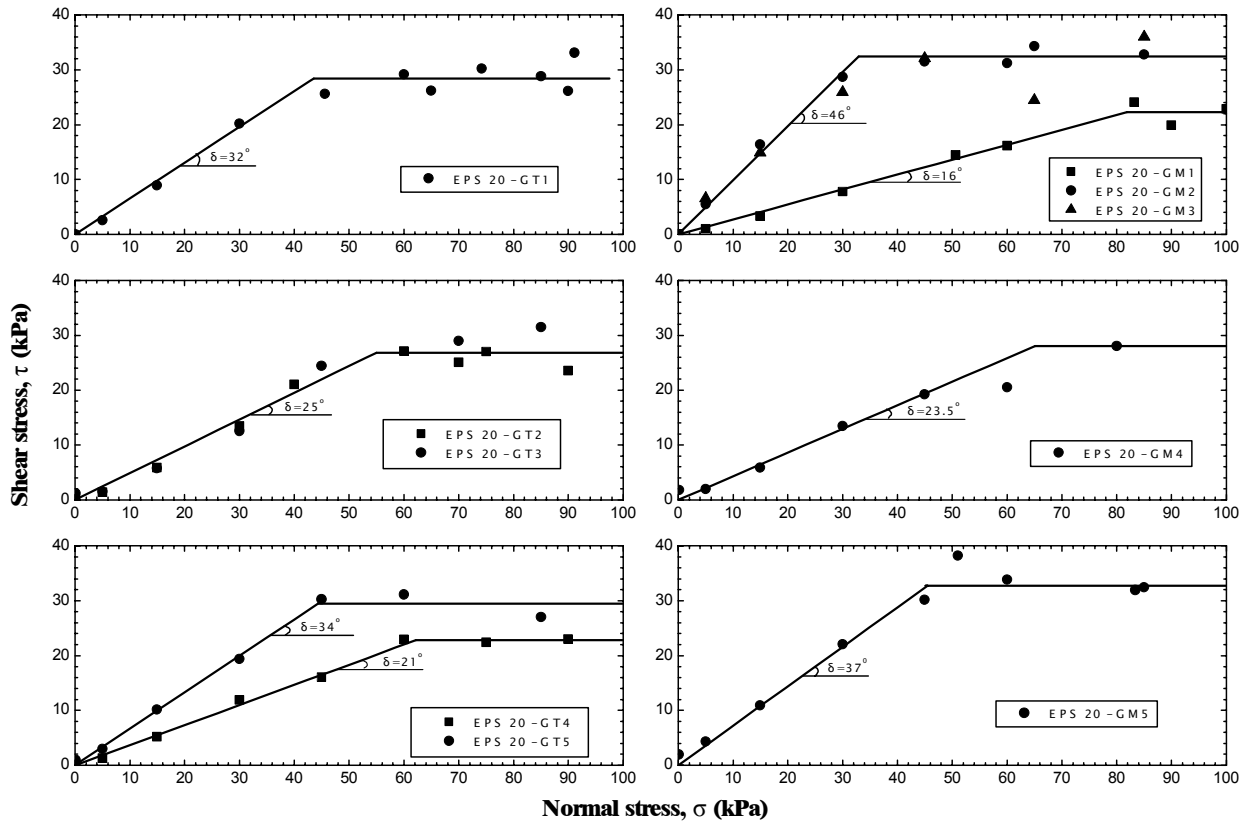


Figure 5. Shear resistance at the interface between EPS geofoam and geosynthetics

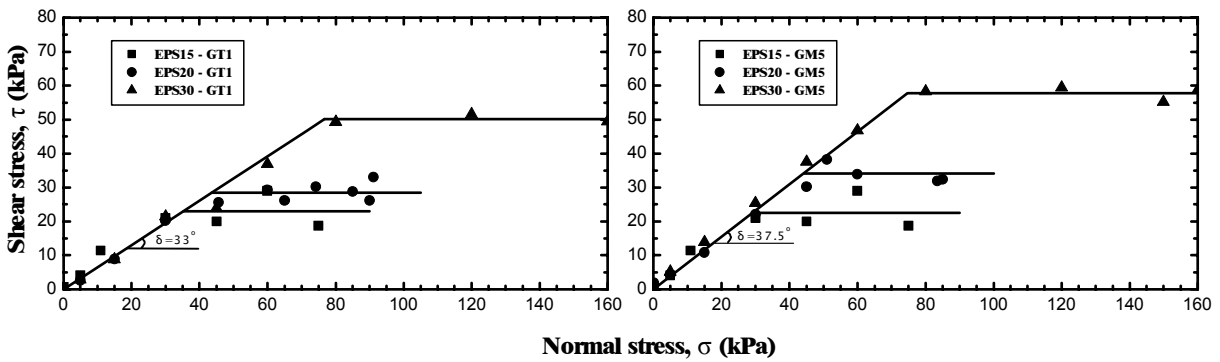


Figure 6. Effect of nominal density on shear resistance at the interface between EPS geofoam and geosynthetics

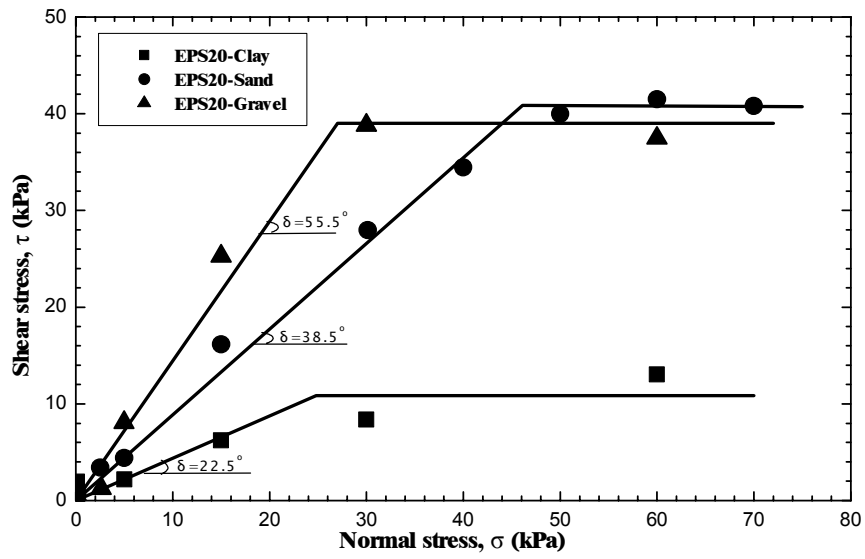


Figure 7. Shear resistance at the interface between EPS geofoam and soils

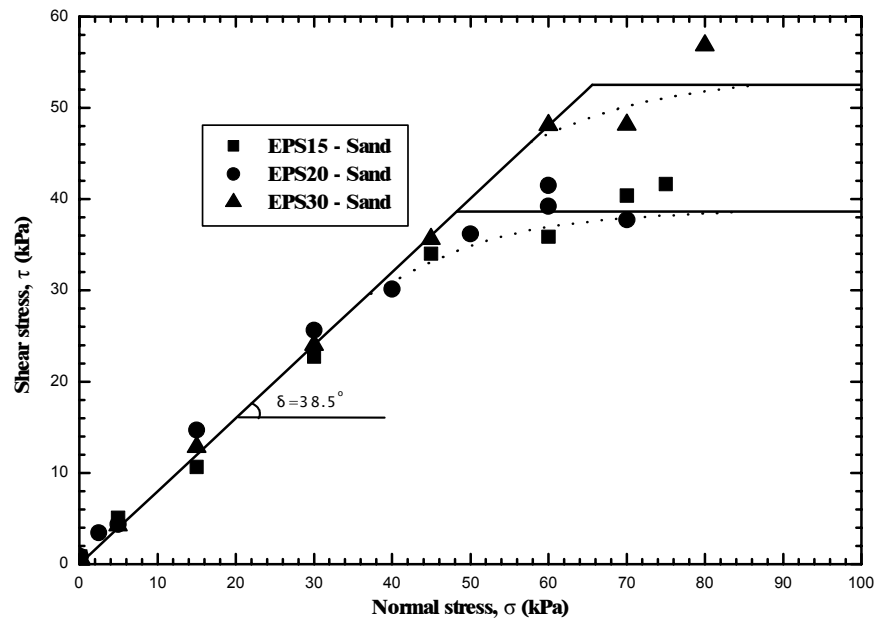


Figure 8. Effect of nominal density on shear resistance at the interface between EPS geofoam and sand