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EPS geofoam surface shear resistance

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ABSTRACT: The shear resistance at the interface between EPS geofoam blocks with nominal density from 15 to 35 kg/m^3 and between EPS geofoam blocks and other construction materials (five geotextiles, five geomembranes, three soils, pre-cast and cast-in-place concrete) was evaluated by conducting direct shear tests. The shear resistance at all interfaces tested is frictional with the exception of cast-in-place concrete where it is adhesional. The friction coefficient between EPS geofoam blocks ranges from 0.70 to 0.84 with an average of 0.80. Between EPS geofoam and other materials "strong" and "weak" interfaces are observed with friction coefficient values as low as 0.27 and as high as 1.20.

1 INTRODUCTION

Expanded polystyrene (abbreviated: EPS) geofoam products in the form of blocks are utilized for the construction of a variety of projects as light-weight fill or compressible inclusion. Due to the nature and size of such construction projects, geofoam blocks are placed in contact to each other as well as in contact with other materials such as geosynthetics, soils, coarse aggregates and concrete. The internal and/or the overall stability of a structure may be governed by the interaction at the interfaces between geofoam blocks or between geofoam blocks and other materials. In accordance with available literature, EPS geofoam types will be referred to in this text using the generic symbol EPS and the nominal density (i.e. EPS20) although it is believed that compressive strength should be established as the parameter differentiating EPS geofoam quality.

Pertinent information on surface shear resistance, usually quantified in terms of the friction coefficient, μ, is rather limited in available literature. Reported peak values for the friction coefficient between EPS geofoam blocks (EPS12 to EPS30) range from 0.85 to 1.13 while residual values range from 0.65 to 0.68 (Sheeley and Negussey 2000, Negussey et al. 2001). Lower values (0.51 to 0.64) have also been reported (Lin et al. 2001) for EPS12 and are recommended (0.5 to 0.7) by design guidelines (Refsdal 1985, Miki 1996, BASF 1997, Thelberg 2001) for all types of EPS geofoam. As reported by Sheeley and Negussey (2000), the friction coefficient between EPS geofoam blocks (EPS20 and EPS30) and HDPE geomembranes is 0.29 (smooth GMB) and 1.00 (textured GMB) and at the interface with PVC geomembranes is 0.70 (textured or smooth). At the interface with cast-in-place concrete the interaction mechanism is adhesional with an adhesion equal to 70 kPa for EPS30 (Sheeley and Negussey 2000). Finally, the interaction between EPS geofoam blocks (EPS10, EPS15, EPS20) and different sands has been investigated (Miki 1996, Negussey et al. 2001, Xenaki and Athanasopoulos 2001) and the friction coefficient was found between 0.55 and 0.85.

Scope of this presentation is to offer additional information on the shear resistance developing at the interface between EPS geofoam blocks as well as between EPS geofoam blocks and other construction materials frequently placed in contact with geofoam blocks in specific projects.

2 MATERIALS AND TESTING

Commercially produced EPS geofoam blocks measuring 2.5 m × 1.0 m × 0.5 m with nominal densities of 15, 20, 25, 30 and 35 kg/m^3 were obtained for the purposes of the investigation reported herein. All EPS geofoam samples were cut and shaped using hot wires and were obtained from the outer surfaces of the EPS blocks in order to simulate field conditions by retaining the as-produced factory roughness of the block surfaces. The mean density of all samples tested and results from unconfined compression tests on 50 mm cube samples are summarized in Table 1.

Table 1. EPS geofoam properties.

Property	EPS geofoam type				
	15	20	25	30	35
Mean density (kg/m^3)	15.1	19.9	24.1	29.3	34.7
Yield stress (kPa)	66	99	136	178	223
Compressive strength (kPa) (at 10% axial strain)	75	111	150	193	238

Interfaces with other materials were formed using five geotextiles (three nonwoven, two woven), five geomembranes (three HDPE, one PP, one PVC), three soils (gravel, sand, clay) and concrete (precast and cast-in-place). Brief descriptions of the geosynthetics used are given in the following Table 2 together with a summary of test results.

Table 2. Friction coefficients for EPS geofoam-geosynthetics interfaces.

Interface	Friction coefficient	Description of GSY
EPS15-GTX 1	0.62	Nonwoven, needle punched, PP staple yarns
EPS20-GTX1	0.65	
EPS30-GTX1	0.78	
EPS20-GTX2	0.48	Nonwoven, heat bonded, PP continuous filaments
EPS20-GTX3	0.44	Nonwoven, heat bonded, PP continuous filaments
EPS20-GTX4	0.38	Woven, 1.5 mm tapes, PP, smooth
EPS20-GTX5	0.62	Woven, 1.9 and 2.3 mm tapes, PP, rough (0.2 mm protrusios)
EPS20-GMB1	0.27	HDPE, smooth
EPS20-GMB2	0.80	HDPE, textured, 0.4 mm protrusions
EPS20-GMB3	0.61	HDPE, 0.55 mm micro spikes
EPS20-GMB4	0.48	PP, smooth, reinforced
EPS15-GMB5	0.62	PVC, smooth
EPS20-GMB5	0.65	
EPS30-GMB5	0.78	

The three types of soils used for testing were: (a) a laboratory prepared kaolinite clay (plastic limit 23, liquid limit 46, water content 33%) which, as tested, had an undrained cohesion of 14 kPa and a void ratio of 1.1, (b) a sand (subangular grains between 0.60 mm and 0.85 mm) which, as tested, had a void ratio of 0.65 and an angle of friction equal to 46° and (c) a fine gravel (angular grains between 4.75 mm and 9.52 mm) which, as tested, had a void ratio of 0.72 and an angle of friction equal to 49°.

Concrete was prepared with a water:cement:sand ratio of 0.22:0:24:0.54 by weight and was cast in wooden moulds with nominal dimensions 100 mm × 100 mm × 2.5 mm to provide samples which would fit in the lower half of the shear box used for testing. For testing cast-in-place concrete, the geofoam samples were placed on the wet concrete surfaces immediately after preparation. Concrete was cured for 28 days.

Interface shear resistance was measured by direct shear tests using a 100 mm square shear box. The rate of displacement was the same for all test and equal to 1.2 mm/min. The maximum relative displacement between the two units of the shear box was equal to 10 mm. The normal stresses applied had values ranging from 10 kPa to an average of 70% of the yield stress of the EPS geofoam type used. All information reported herein is in terms of the peak value for the friction coefficient since, in some cases, residual strength was not well defined due to limitations imposed by the maximum travel distance of the shear box carriage.

Shown schematically in Figure 1 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 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. Furthermore, for all tests conducted, the cross-section of the geofoam sample in the upper part of the shear box was modified, as shown in Figure 1b, in order to increase the reaction area on the vertical side of the shear box and, thus, reduce horizontal

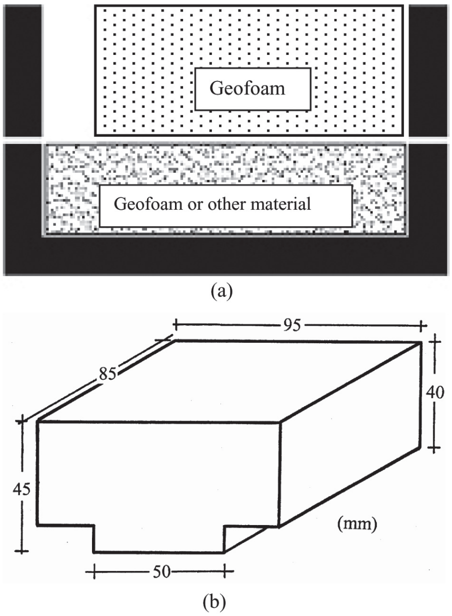

Figure 1. Direct shear testing: (a) cross-section of shear box, (b) upper geofoam specimen geometry.

normal stresses substantially below the yield stress of each geofoam.

3 RESULTS AND DISCUSSION

Summarized in Figure 2 are the results obtained for the shear resistance at the interface between EPS geofoam blocks. It can be observed that the interaction mechanism is frictional and that there is a variation of the friction coefficient value (0.70 to 0.84) between different EPS geofoam types (different nominal densities) without, however, any apparent trend. A linear fit through all data obtained yields a friction coefficient equal to 0.80. This average value is higher than values recommended in design guideline or measured experimentally by 13% to 40% (Refsdal 1985, Miki 1996, BASF 1997, Thelberg 2001, Lin et al. 2001). However, it is lower (by about 17%) when compared to the average of results reported by other investigators (Sheeley and Negussey 2000, Negussey et al. 2001).

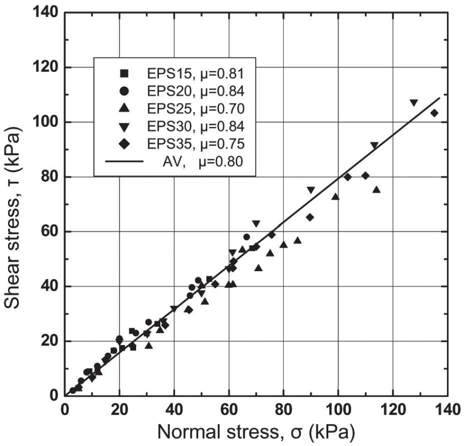

Figure 2. Shear resistance at the interface between EPS geofoam blocks.

Typical results obtained for the shear resistance at the interface between EPS geofoam blocks and geosynthetics are shown in Figure 3 and all results obtained are summarized in Table 2. It appears that manufacturing process, surface roughness and polymer type (especially for geomembranes) may all affect the magnitude of the friction coefficient. Relatively high friction coefficient values were obtained for the nonwoven needle - punched geotextile and the woven geotextile with rough surface (0.62 or higher). Interfaces with heat bonded nonwoven geotextiles yielded friction coefficient values significantly lower (by 30 to 35%) than the value obtained for the needle - punched geotextile. As expected, the smooth woven geotextile yielded the lowest value for the friction coefficient. The effect of polymer type is pronounced

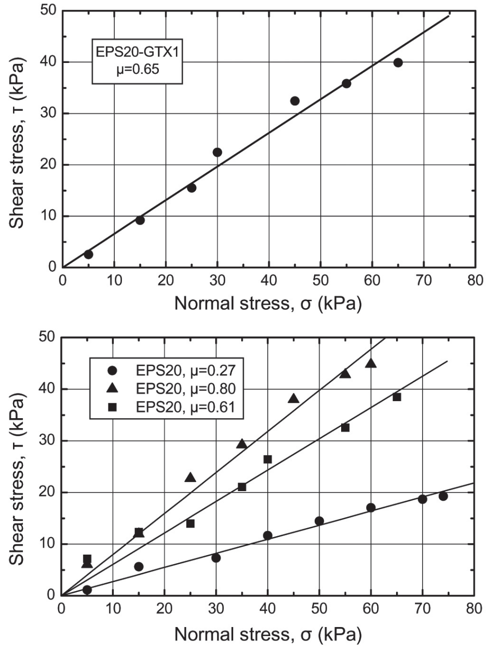

Figure 3. Shear resistance (typical results) at the interface between EPS geofoam and geosynthetics.

for geomembrane interfaces where smooth HDPE, PP and PVC geomembranes yielded friction coefficients of 0.27, 0.48 and 0.65, respectively. As observed for HDPE geomembranes, surface roughness improves significantly the friction coefficient values, as also reported by Sheeley and Negussey (2000).

Results obtained for the friction coefficient at the interface between EPS geofoam blocks and soils are summarized in Figure 4. At the interface with sand, the friction coefficient value is not affected by the nominal density of EPS geofoam and has a value which compares very well with values reported in the literature (0.77). Significantly weaker and stronger interfaces are formed when the EPS geofoam blocks are in contact with clay or gravel, respectively.

As shown in Figure 5, a strong bond develops between EPS geofoam blocks and cast-in-place concrete. This apparent cohesion, or adhesion, in approximately 40% (37% to 44% for the materials tested) of the compressive strength of the EPS geofoam. At EPS geofoam-precast concrete interfaces, the friction coefficient is slightly lower than that obtained for sand (0.69 vs 0.77).

4 CONCLUSIONS

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

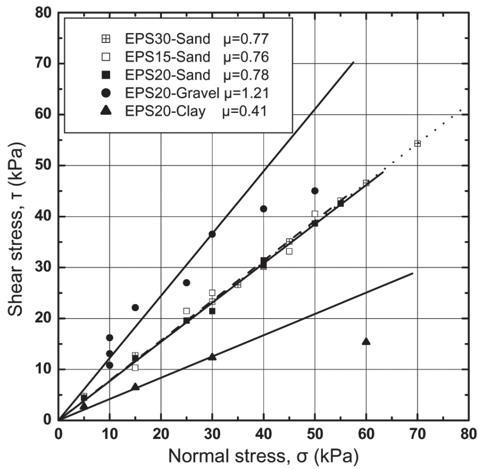

Figure 4. Shear resistance at the interface between EPS geofoam and soils.

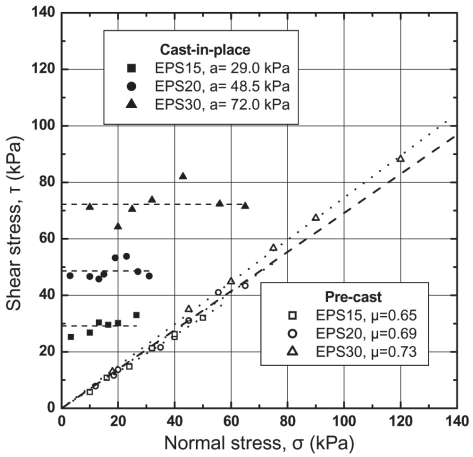

Figure 5. Shear resistance at the interface between EPS geofoam and concrete.

1. The shear resistance developing at the interface between adjacent EPS geofoam blocks or between EPS geofoam blocks and geotextiles, geomembranes, soils and precast concrete is purely frictional. It is adhesional at the interface with cast-in-place concrete.
2. The average friction coefficient value between EPS geofoam blocks (0.80) is comparable to the average value measured at geofoam-sand or geofoam-precast concrete interfaces and may be exceeded only if the geofoam blocks are in contact with very rough geosynthetics and angular soil or aggregate.
3. A strong bond, approximately equal to 40% of the compressive strength of the geofoam, develops between EPS geofoam and cast-in-place concrete.
4. EPS geofoam contact with clay and geosynthetics with smooth surface should be avoided since the interface is characterized by low values for the friction coefficient.

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