INTERFACE FRICTION PROPERTIES OF EPS GEOFOAM

D. Negussey[1], N. Anasthas[2] and S. Srirajan[2]

ABSTRACT

Geofoam blocks must be capable of resisting lateral pressures and shear stresses that develop insitu. Hydrostatic pressure, lateral earth pressure, horizontal stresses due to dead loads and shear demand due to live load conditions must be resisted at block to block and also block to soil or concrete interfaces. An investigation of interface friction behavior of geofoam to geofoam contact surfaces is reported in this paper. EPS blocks of various densities from four manufacturers were tested. Tests were carried out on wet and dry interface conditions at different normal loads. Effects of interface type (factory skin surface or wire cut surface) on interface friction were examined. Tests were also performed at different displacement rates to examine rate effects on interface friction. Sand to geofoam interface tests were performed at different normal stress levels. The results of the investigation indicate that density and normal stress level do not significantly affect interface friction of EPS geofoam. Residual interface friction is slightly less for wet interfaces than dry interfaces for cut surfaces. Both peak and residual friction factors slightly decrease with increasing displacement rate. Interface properties of geofoam blocks with factory skin surfaces can be considered to be equivalent to hot wire cut surfaces. Sand to geofoam interface strengths are higher than geofoam to geofoam interface strengths.

KEY WORDS: density, displacement rate, EPS geofoam, friction, moisture, sand, shear, skin, stress

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INTRODUCTION

Expanded Polystyrene (EPS) geofoam is an ultra lightweight material with a list of geotechnical applications that has been increasing continuously over the last 30 years. In applications with EPS, blocks are stacked freely one over the other without bonding or an effective tie down system. The wide spread use of small binder plates to enhance interface strength between blocks has been shown to be ineffective, and in some cases counter productive, by Sheeley (2000). For the most part, lateral forces on EPS blocks must be resisted by geofoam to geofoam and geofoam to sand or concrete interface friction. The evaluation of interface friction for a project should consider the materials and conditions that would be expected in field applications.

Sheeley (2000) reported on a series of direct shear tests for various interface conditions. Tests were performed in a modified direct shear machine on samples of 100 mm x 100 mm interface area (Figure 1). EPS samples of 20 and 30 kg/m^3 densities and at different normal stress levels ranging from 13 to 47 kPa were tested. The interface conditions included dry and moist geofoam to geofoam, geofoam to sand base, with binder plate between geofoam, geofoam interfaced with cast in place concrete, geofoam to geomembrane and geofoam to geofoam with interface weathered by UV light. Table 1 summarizes the test results. Residual interface strength between geofoam and membrane interfaces was found to be notably lower than geofoam to geofoam or geofoam to concrete interfaces. Significantly higher interface strength developed due to adhesion bonding where concrete was poured over geofoam. The extent of adhesion bonding was compromised with surface degradation due to UV exposure.

Sheeley and Negussey (2000) reported on direct shear tests on large samples of up to 500 mm x 500 mm in interface area on a large custom-made direct shear machine. Tests were performed on samples of 20 kg/m^3 density geofoam. Samples with different interface area ranging from 100 mm x 100 mm to 500 mm x 500 mm were sheared at normal stress levels of 12 and 26 kPa. Sample size was found to have insignificant effect on the average peak friction factor of about 0.88 and the residual friction factor of 0.65 for all samples under both dry and wet conditions.

Negussey (1997) investigated the geofoam to sand interface with direct shear tests performed on 100mm x 100mm samples. The results showed that the interface friction is comparable to the internal friction angle of the sand. During shearing, sand grains embedded into the geofoam and failure at the interface plane was noted to have occurred in the sand layer.

Miki (1996) presented results for geofoam to geofoam and geofoam to sand interfaces from direct shear tests. EPS samples of 20 kg/m^3 density were used for both types of interface tests. For geofoam to geofoam interfaces subjected to normal stress levels of up to 50 kPa, a constant interface friction factor of 0.64 was obtained. The sand to geofoam interface friction was found to be a function of the thickness of the sand layer on which the geofoam was sheared. The sand to foam interface friction is 0.70 for sand thickness of about 3 mm and reduced to 0.55 for sand thickness of about 20 mm. For sand thickness above 20 mm the friction factor remained constant at 0.55.

Kuroda et al (1996) investigated geofoam to geofoam interface strengths and the effects of binder plates under static and dynamic loading. A series of shaking table tests were performed on EPS blocks of 20 kg/m^3 density. A geofoam board of 10 mm thickness was glued on a shaking table of dimensions 1500 mm x 1000 mm. EPS blocks with dimensions 250 mm x 500 mm x 1000 mm were stacked in four layers on the shaking table over the EPS surface. Normal loads of either 7.4 kPa or 14.7 kPa were applied. Accelerations of 0.10 to 0.20 m/s^2 (10 to 20 Gal) were induced at frequencies in the range of 0 to 20 Hz and a natural frequency of about 6 Hz was determined. Binder plates were installed between the layers and the test was repeated. The response of the binder plates was not found to affect the resonance frequency significantly. In subsequent tests, the geofoam began to spread apart when the acceleration exceeded 4 m/s^2 (400 Gal). The geofoam blocks were not observed to separate when the test was repeated with binder plates installed between blocks. However, sliding is reported to have occurred at the glued geofoam board interface and also at the interface between the normal load and the top geofoam layer. Friction factors are reported to range from 0.20 to 0.40 and lower than the value of 0.60 derived from traction testing.

This paper is part of the continuing research on interface strength at the Geofoam Research Center, Syracuse University (Sheeley, 2000; Sheeley and Negussey, 2000). Investigation on interface properties of EPS geofoam with regrind material is reported by Srirajan (2001) and Srirajan et al (2001). Interface strength under sustained shear loading is at present on going.

METHODOLOGY

A series of large direct shear tests were carried out to further investigate the strength between geofoam to geofoam interfaces. EPS blocks of various densities from four different manufacturers were tested at different normal stress levels. Differences in density and effects of normal stress level on interface friction were investigated. Tests were performed with wet and dry interfaces to examine the influence of surface moisture. The effects of interface type, wire cut surface or factory skin surface were examined. Tests were also performed at various displacement rates. A series of sand to sand and sand to geofoam tests were also performed to investigate the sand to sand interface properties more broadly.

TEST SPECIMENS

EPS geofoam blocks of 12, 15 and 20 kg/m^3 nominal density were tested. Geofoam boards of 175 mm x 375 mm x 25 mm were glued to wooden boards of the same size using a water-based adhesive. These glued pieces were the upper part of samples on which the desired nominal load was applied. The lower foam samples were 600 mm x 600 mm in bearing area and 200 mm thick. The upper samples were sheared on fresh surfaces of the larger lower blocks and each lower sample accommodated three upper samples. Only wire cut surfaces were tested with samples from manufacturers A, B, and C. For manufacturer D tests were performed with wire cut and factory skin surfaces with both wet and dry interface conditions. For tests with wet interface, a water height of 10 mm above the interface level was maintained on the bottom sample. Foam edge strips were glued along the top edges of the bottom sample to retain the water (Figure 2). For sand to geofoam interface tests samples from manufacturers B and C and dry silica sand were used. The area of contact for the geofoam sand interfaces was 100 mm x 100 mm.

EXPERIMENTAL SETUP AND PROCEDURE

The custom-made large direct shear machine (Figure 3) was used for all except for the geofoam to sand interface tests. The machine consists of a wooden base, a reaction wall, an I-beam carriage, a variable speed motor and transmission belt, a 38 mm jackscrew and support sleeves, a 2500 lb load cell and an LVDT. The reaction wall is bolted to the base to restrain the bottom foam sample. On the other end of the base, the I-beam is located centrally in a perpendicular offset to the reaction wall. The bottom flange of the I-beam is bolted to the base and the jackscrew is aligned to provide a horizontal thrust. The support sleeves are bolted on the top flange of the I-beam to guide and support the jackscrew. A key in one support sleeve restrains the rotation of the jackscrew. The DC motor is suspended from a bracket mounted on the top flange of the I-beam and the belt conveys the shaft rotation to advance the jackscrew. The load cell is mounted at the forward end of the jackscrew between the adapter and the loading platen. The LVDT at the back of the jackscrew registers horizontal displacement. The load cell and the LVDT were connected to a computer through a signal-conditioning box to record the test data.

The upper portions of samples were placed on the bottom geofoam block with the longer axis in the direction of shear displacement. Dead weights were placed on top of the upper sample to provide the desired normal stress. For high normal loads applied at the center of the upper sample, yielding was observed at the front edge as shearing took place. This was due to development of a non uniform contact stress on account of over turning moments. To overcome this problem, the load center was moved away from the front edge and high localized stresses. The dead weight center was shifted to the one third point of the upper sample length on the side of the load cell. The shear displacement was applied by the forward movement of the jackscrew through the support sleeves as actuated by the variable speed DC motor and belt system.

Additional tests were performed on sand alone with the same displacement rate and step loading levels to compare the sand internal friction strength to geofoam to sand interface strengths. The modified direct shear machine (Figure 1) was used. Geofoam board of 25 mm thickness was cut to cover the inside base area of the carriage box. The top box was placed on the geofoam board and filled with dry silica sand. Dead weights were suspended on a hanger that rested on the top platen. The top shear box, platen and dead weights were fixed. The carriage box was advanced at the maximum displacement rate for the machine of 1.5 mm/min to apply shear loading. The tests were started with a normal stress level of 27.5 kPa and then increased to 45 and 70 kPa in stages. For each test, the load cell registered the reaction of the stationary top plate. The LVDT record the displacement of the carriage box.

Test Series 1:

The first series of tests were performed to investigate the interface friction of EPS geofoam of various densities at different normal stress levels. EPS samples from three manufacturers (A, B, and C) were tested at six different normal stress levels ranging from 10 to 52 kPa. The tests were performed at a constant displacement rate of 25 mm/min on hot wire cut sample surfaces.

Test Series 2:

The second series of tests were performed to investigate the effect of moisture on interface friction. Wire cut samples of manufacturer B were sheared on wet interfaces at normal load levels of 10, 20 and 30 kPa. The water level of 10 mm above the interface was maintained while shearing at a displacement rate of 25 mm/min.

Test Series 3:

The third series of tests were performed to compare the friction factor obtained from wire cut samples with that obtained from factory finished skin surfaces. Samples with factory skin surfaces from manufacturer D were used. Wet and dry interfaces were sheared at a constant displacement rate of 25 mm/min at normal load levels of 10, 20 and 30 kPa.

Test Series 4:

The fourth series of tests were performed to investigate the effect of displacement rate on EPS geofoam interface properties. Wire cut samples from manufacturer C were tested at various displacement rates ranging from 2 mm/min to 30 mm/min. During each test, the displacement rate was changed from time to time during the residual shearing phase. Tests were performed at a normal load of 26 kPa on wet and dry hot wire cut interfaces.

Test series 5:

The fifth series of tests were performed in the modified direct shear machine to determine the interface friction between sand and geofoam. Wire cut samples from manufacturers B and C were tested.

A summary of the test series and sample sources is given in Table 2. A, B, C and D represent different manufacturers. All samples, except for series 1 and manufacturer A had the same resin source.

RESULTS

Results of test series 1 are shown in Figures 4 through 11. The normal stress levels were selected to cover the range of working stress levels that occur in the field. All the shear stress - displacement curves show a peak and residual strength. Figures 5, 7, 9, and 11 show peak and residual friction factors with normal stress for four EPS materials supplied by three manufacturers. The results show that normal stress does not have a significant effect on both peak and residual friction factors. At the same normal stress levels, the peak and residual strengths for the samples of source A1 (12 kg/m^3), B (15 kg/m^3), and C (20 kg/m^3) are about the same (Figures 5,9 and 11). However, both peak and residual strengths at a given stress level for the same density (12 kg/m^3) samples by the same manufacturer but different resin show difference (Figures 5 and 7). Thus the friction factor is affected more by bead type than density. Table 3 summarizes the average friction factors obtained from the above tests.

The results of test series 2 are shown in Figures 12 and 13. Figure 12 shows the shear stress - displacement curves for source B samples at normal stress levels of 10, 20 and 30 kPa under wet interface conditions. The results show peak and residual strengths developed during shear. Wet interface test results are compared with the corresponding results from dry tests (Figures 10 and 12) in series 1 in Figure 13. The interface friction factors are slightly less for wet interfaces. The difference is less than 2% at residual and 10% at peak strengths. However, higher differences were noted for residual at wet interfaces in test series 3. Tests were also performed to examine the effect of duration for which the interface remained wet. Samples that were tested after 24 hours of flooding showed the same results as those tested immediately after wetting the interface.

The results of test series 3 are shown in Figures 14 through 17. The shear stress - displacement curves obtained from tests performed on dry skin and cut interfaces on source D geofoam are compared as in Figure 14. The dry cut interfaces showed distinct peak and residual phases and the average peak and residual friction factors were 0.94 and 0.65, respectively. The skin interfaces showed less distinction between peak and residual strengths. Figure 15 indicates dry cut interfaces developed higher peak strengths than skin interfaces. Figure 16 compares the wet interface strengths of cut and skin surfaces. The average peak and residual friction factors for cut interfaces in wet condition were 0.89 and 0.55 and for the skin interface in wet condition were 0.67 and 0.62. The results show that dry skin surfaces tend to have lower peak strengths but about the same residual strength as dry cut surfaces. Friction factors for wet cut and skin interfaces are shown in Figure 17. Skin interface residual strengths are about the same as cut interfaces in wet condition.

The results of test series 4 are given in Figures 18 through 20. All tests on source C geofoam in the series were performed at a constant normal stress of 26 kPa. Displacement rate adjustments were made in the residual shear phases. Figures 18 and 19 show typical curves obtained for wet and dry interface tests wherein displacement rates were changed during the course of the tests. The results show that for both dry and wet interfaces, shear strengths slightly drop with increasing displacement rate. For displacement rate increases from 2 to 30 mm/min the residual and peak friction factors for dry interfaces reduced by less than 10% (Figure 20). At the lowest displacement rate of 2 mm/min the wet residual interface shear strengths were about 15% less than of the dry interface. However, residual wet and dry interface strengths were about the same at higher displacement rates.

Figures 21 through 23 show the results from test series 5. Figure 21 compares the shear strength of sand to sand and sand to geofoam interfaces at different normal stress levels. The shear stress - displacement curves for sand to sand and sand to geofoam interface tests are compared in Figures 22 and 23. The data obtained for sand to geofoam tests at the third normal stress level are not plotted. At the third load stage, the normal stress of 70 kPa was more than 50% of the compressive strength of the EPS sample and the top shear box and the sand deformed the bottom foam board and excessive shear loads developed. The average sand to sand and sand to geofoam interface friction factors were 0.68 and 0.85, respectively. Sand to geofoam interface strengths were observed to be slightly higher than the sand shear strength at these stress levels, as also previously noted by Miki (1996).

The results from this and previous investigations indicate that regardless of density, applicable normal stress levels or surface conditions a lower bound interface friction factor of 0.6 can be used for design. This implies, a 1.2 m by 2.4 m contact geofoam surface under a nominal 15 kPa normal stress would have a shear capacity of about 26 kN. In contrast, two 100 mm by 100 mm double barbed galvanized steel binder plates, as are often specified per geofoam block, would barely provide shear resistance of 1 kN (Sheeley, 2000). Binder plates develop even less capacity in reverse shear loading. To ensure availability of full interface shear capacity, geofoam to geofoam interface contact areas should be free of debris and metal plates. There is no rational basis for requiring metal binder plates for geofoam installation. A much better and less expensive way of developing additional shear capacity would be to introduce a shear key by rotating some geofoam blocks to disrupt the continuity of interface planes.

CONCLUSIONS

- Density and normal stress changes did not significantly affect interface friction factors for EPS geofoam.
- Bead type had some influence in both peak and residual friction factors.
- Both peak and residual friction factors of wet interfaces were slightly less than for dry interfaces. The peak friction reduced by about 10% whereas the residual friction values decreased by about 2%.
- The duration of surface ponding did not affect the interface friction factors observed on wet interfaces.
- Both peak and residual friction factors for dry interfaces and peak friction factors for wet conditions decreased with increasing displacement rate. Residual friction factors for wet surfaces did not show rate effects.
- Cut surfaces developed higher interface shear strength than skin surfaces. However, the residual strengths of cut and skin interfaces were about the same.
- Sand to geofoam interface strength compare favorably to geofoam to geofoam interface strength.

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Table 1. Summary of Interface Friction Factors (After Sheeley, 2000)

Interface	Peak Friction Factor	Residual Factor
Foam-Foam, 20 kg/m^3 (dry)	0.85	0.70
Foam-Foam, 20 kg/m^3 (wet)	0.80	0.65
Foam-Foam, 30 kg/m^3 (dry)	0.85	0.65
Foam-Foam, 30 kg/m^3 (wet)	0.75	0.65
Foam-Foam with grips (20kg/m^3)	Not Recommended	
Foam-Foam with grips (30 kg/m^3)	Not Recommended	
Foam-Sand base (ϕ=35°)	$\leq \phi$	$\phi_{residual}$
Foam-Cast in Place Concrete	2.36	1.00
UV Degraded Foam-Cast in Place Concrete	0.87- <2.36	0.71- <1.00
Foam-Textured HDPE Membrane	1.00	~ 1.00
Foam-Smooth HDPE Membrane	0.29	0.23
Foam-Textured PVC Membrane	0.60	0.44
Foam-Smooth PVC Membrane	0.70	0.40

Table 2. Summary of Test Program

Series	Sample Source	Resin Source	Nominal Density (kg/m^3)	Normal Load (kPa)	Displacement Rate (mm/min)	Surface Type	Interface Condition	Number of Tests
1	A	1	12	10,13,20,26,30,40	25	wire cut	dry	24
	A	2	12	10,13,20,26,30,40				
	B	1	15	10,20,26,30,40,52				
	C	1	20	10,13,20,26,30,52				
2	B	1	15	10,20,30	25	wire cut	wet & dry	6
3	D	1	18	10,20,30	25	skin & wire cut	wet & dry	12
4	C	1	20	26	2,16,23,30	wire cut	wet & dry	12
5	B & silica sand	1	15	27.5,45,70	1.5	wire cut	dry	1 (3S)*
	C & silica sand	1	20	27.5,45,70	1.5	wire cut	dry	1 (3S)*
	silica sand	NA	1800	27.5,45,70	1.5	NA	dry	1 (3S)*

* Test with 3 stages

Table 3. Summary of Average Friction Factors for EPS from Different Manufacturers

Source	Peak Friction Factor	Residual Friction Factor
A1	0.90	0.65
A2	1.16	0.74
B	1.00	0.65
C	1.13	0.68
D	0.94	0.65

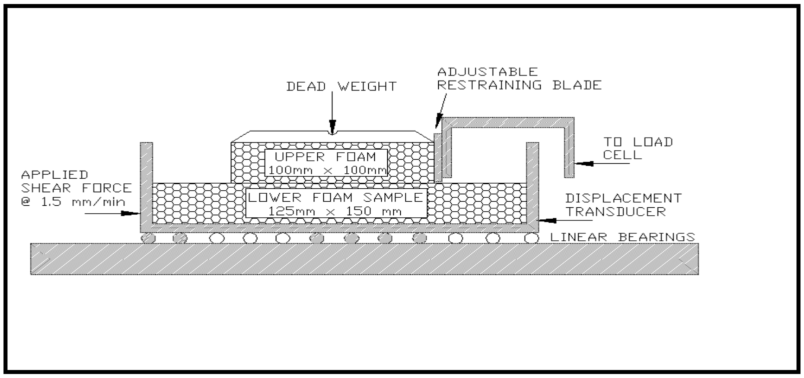


Figure 1. Diagram of Direct Shear Setup on Modified Direct Shear Machine (After Sheeley, 2000)

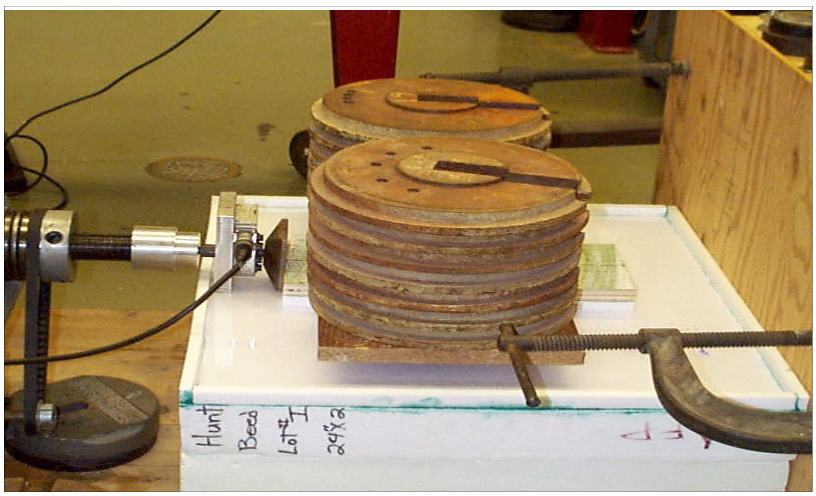


Figure 2. Photograph of Interface Friction Test on Wet Interface

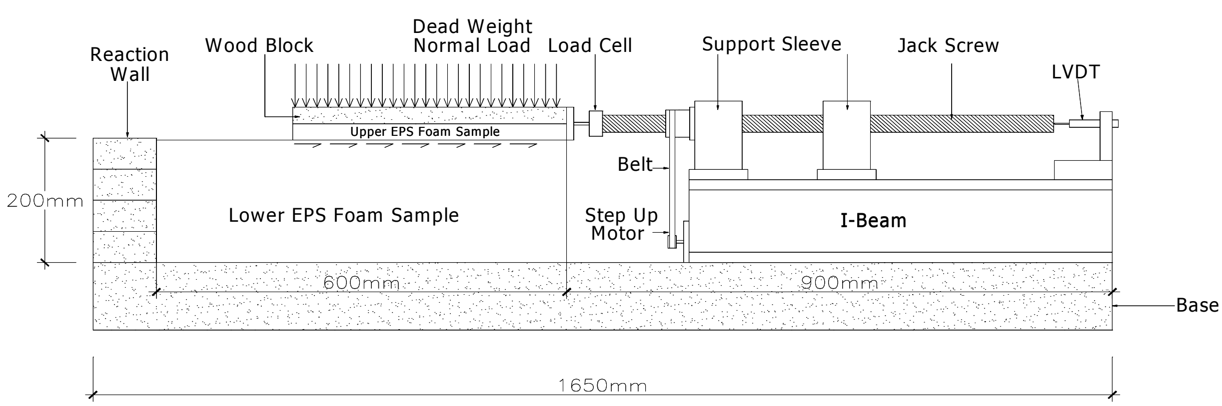


Figure 3. Custom Made Large Direct Shear Machine

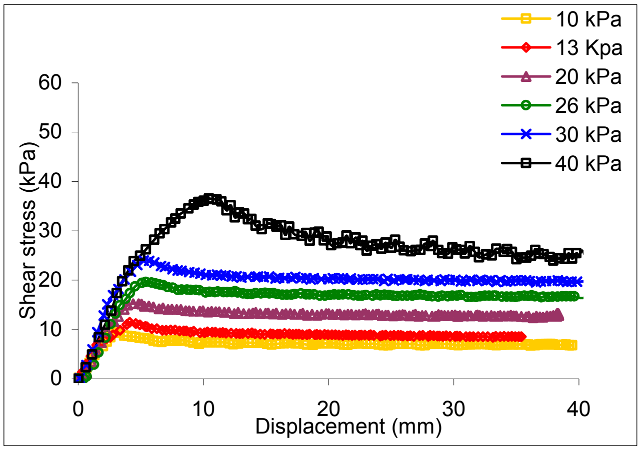


Figure 4. Shear Stress-Displacement Curves (SourceA1, Density = 12 kg/m^3)

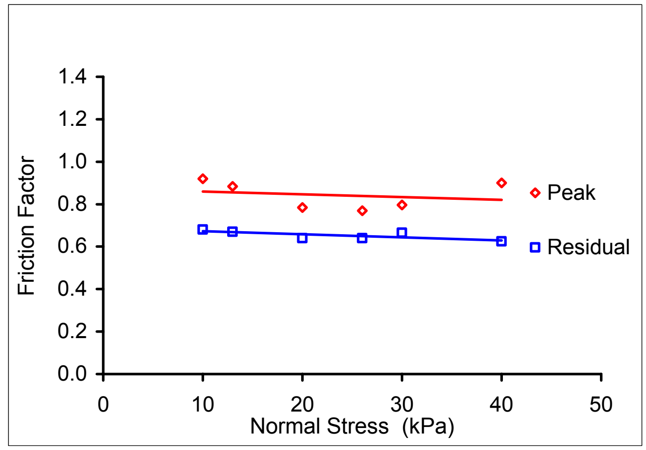


Figure 5. Friction Factors (Source A1, Density = 12 kg/m^3)

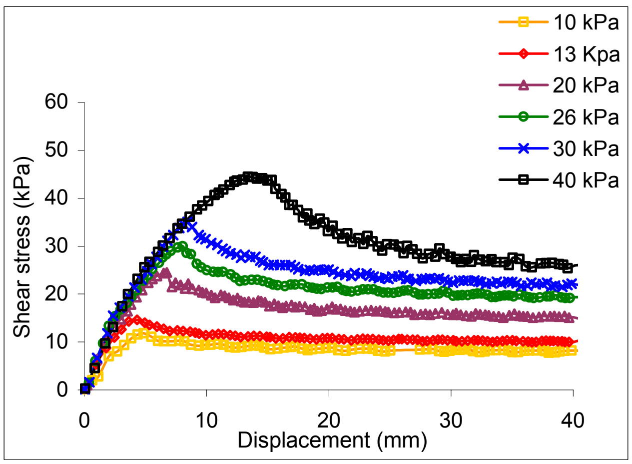


Figure 6. Shear stress-Displacement Curves (SourceA2, Density = 12 kg/m^3)

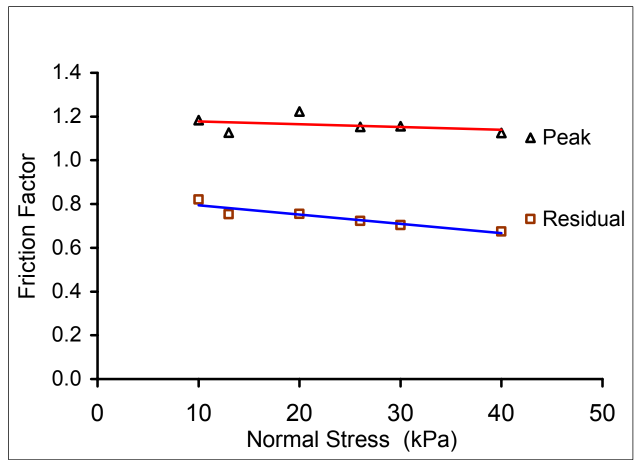


Figure 7. Friction Factors (Source A2, Density = 12 kg/m^3)

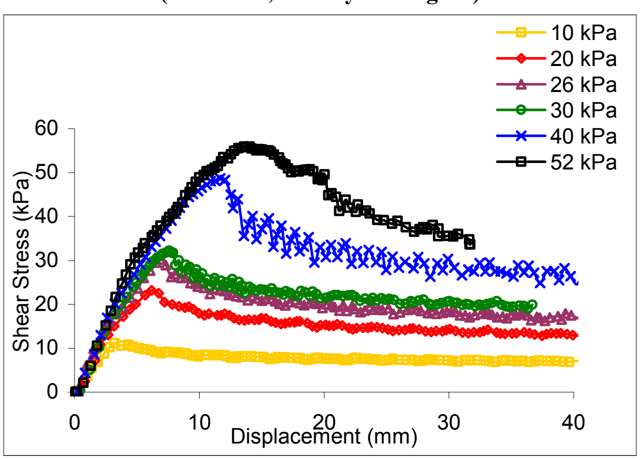


Figure 8. Shear Stress-Displacement Curves (Source B, Density = 15 kg/m^3)

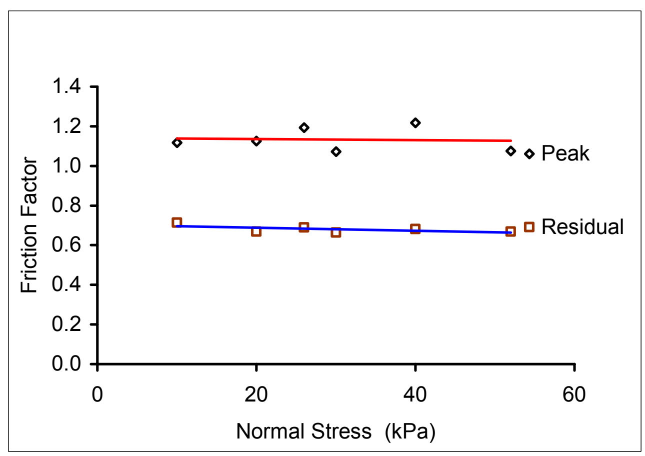
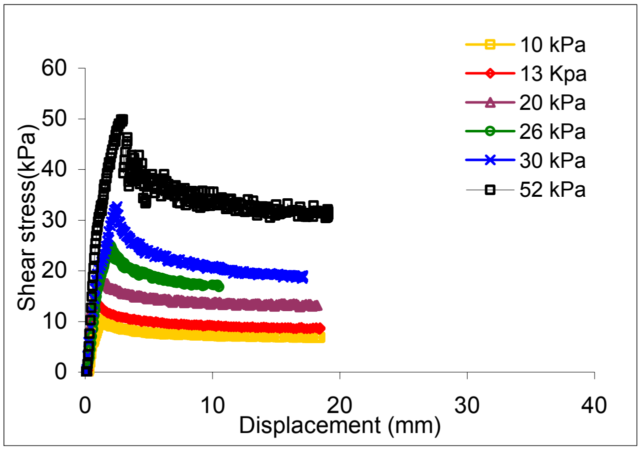


Figure 9. Friction Factors (Source B, Density = 15 kg/m^3)



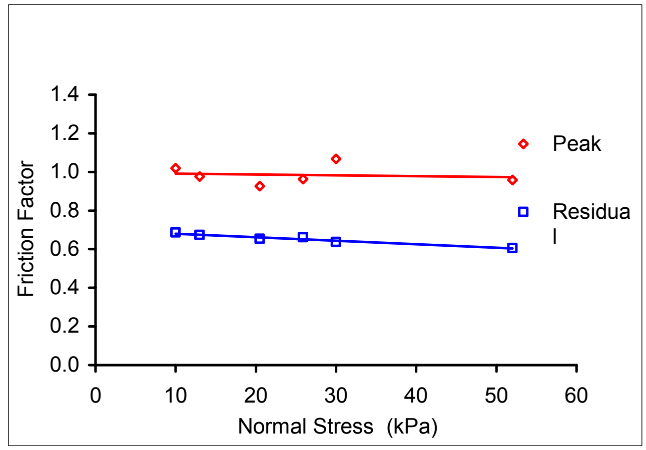
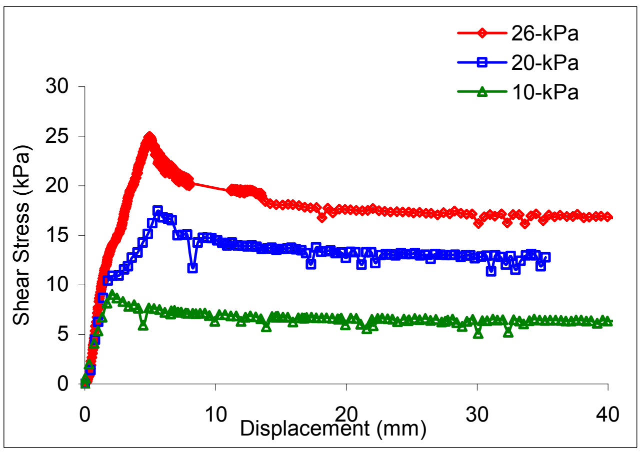


Figure 10. Shear Stress-Displacement Curves (Source C, Density = 20 kg/m³)

Figure 11. Friction Factors (Source C, Density = 20 kg/m³)



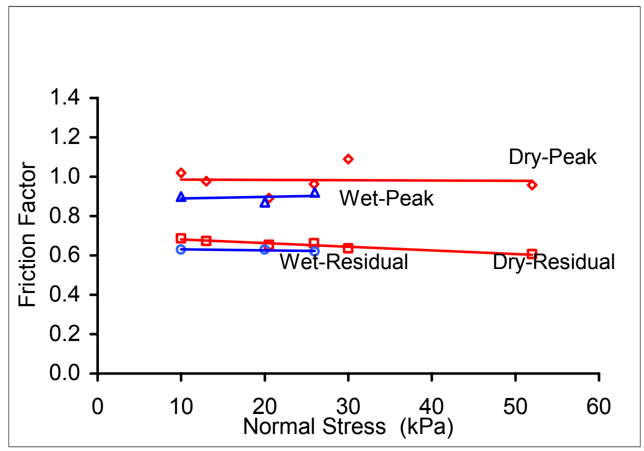
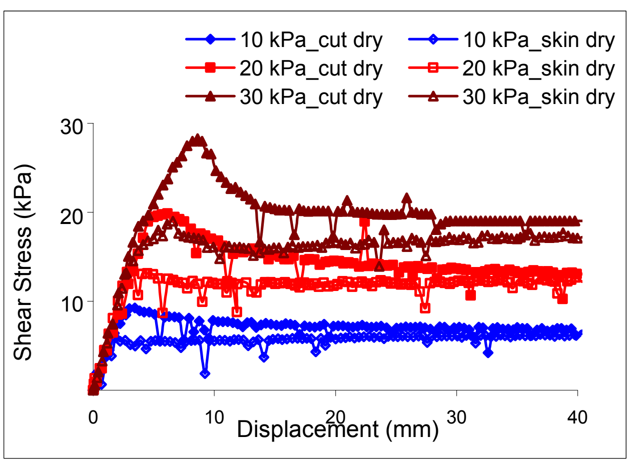


Figure 12. Shear Stress Displacement Curves for Wet Interfaces (Source B, Density = 15 kg/m³)

Figure 13. Friction Factor for Dry and Wet Interfaces (Source B, Density = 15 kg/m³)



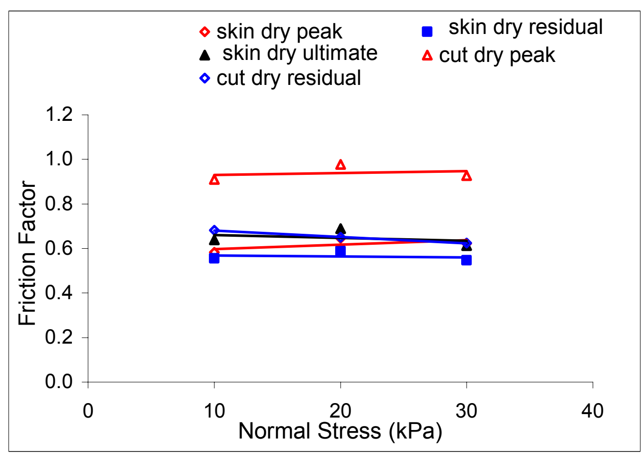


Figure 14. Shear Stress-Displacement Curves for Dry Skin Interfaces (Source D, Density = 18 kg/m³)

Figure 15. Friction Factor for Cut and Skin Dry Interfaces (Source D, Density = 18 kg/m³)

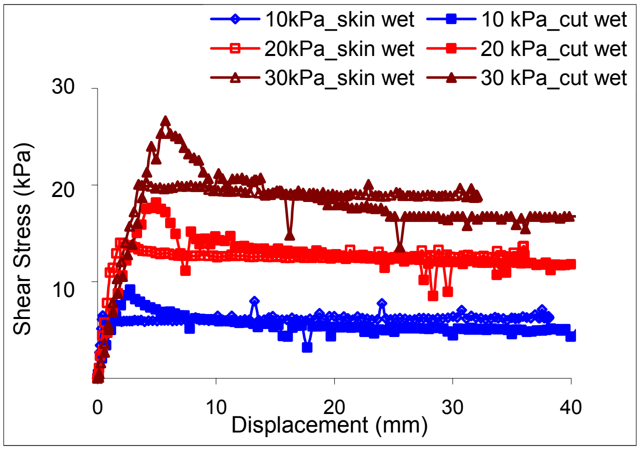


Figure 16. Shear Stress-Displacement Curves for Wet Skin Interfaces (Source D, Density = 18 kg/m^3)

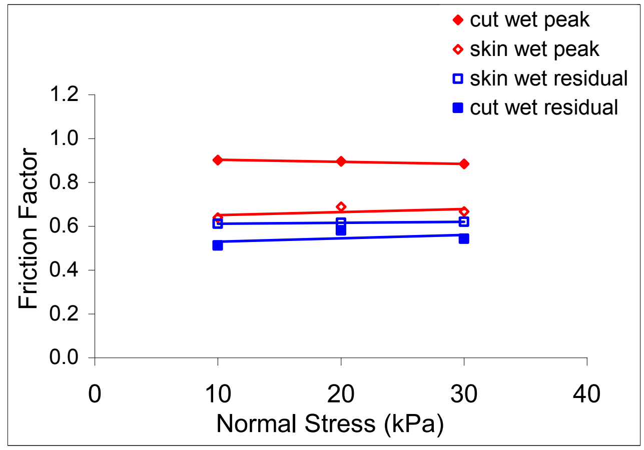


Figure 17. Friction Factor for Cut and Skin Wet Interfaces (Source D, Density = 18 kg/m^3)

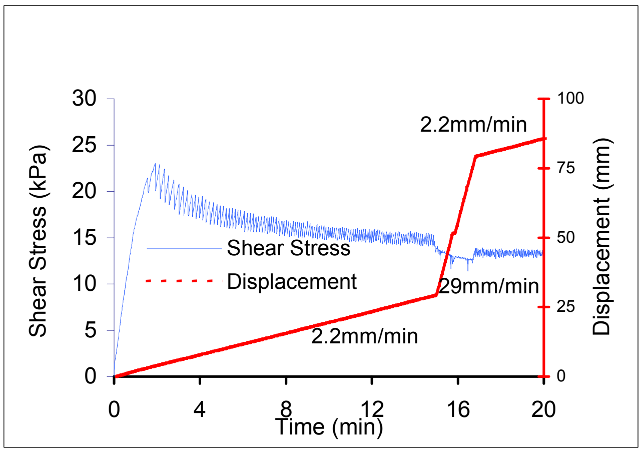


Figure 18. Shear Stress, Displacement vs. Time Curve (Wet Interface, Source C, Density = 20 kg/m^3)

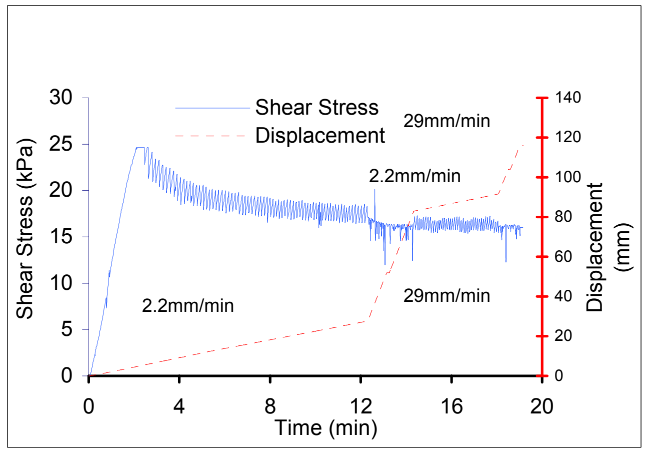


Figure 19. Shear Stress, Displacement vs. Time Curve (Dry Interface (Source C, Density = 20 kg/m^3)

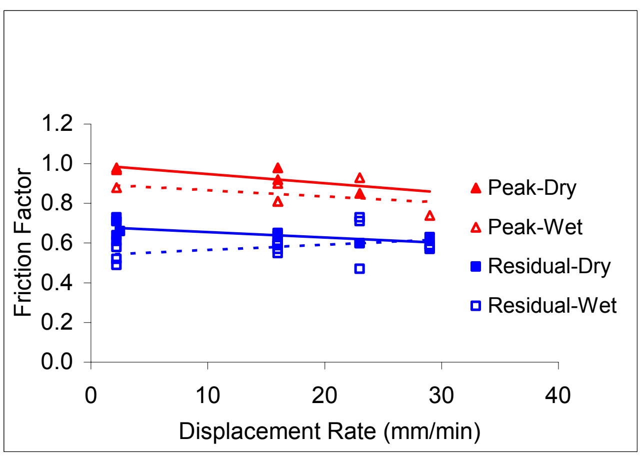


Figure 20. Interface Friction at Different Displacement Rates (Source C, Density = 20 kg/m^3)

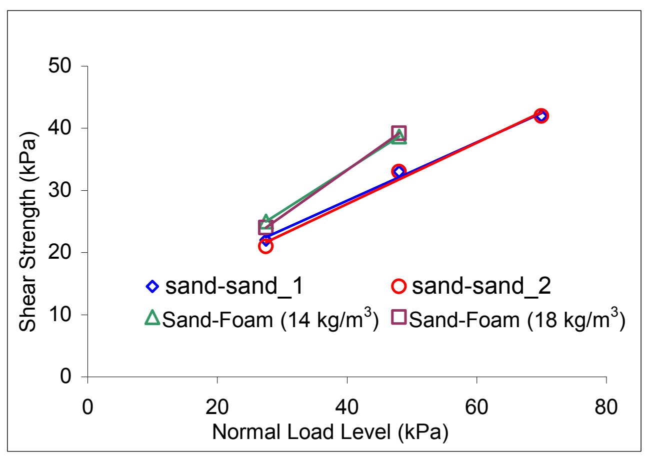


Figure 21. Sand to Foam Shear Strength vs. Normal Load

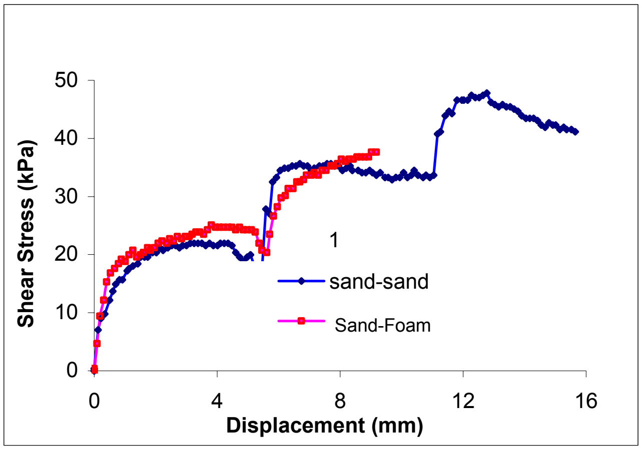


Figure 22. Sand to Foam and Sand to Sand Interface Strengths with Source B Geofoam of 14 kg/m^3 Density.

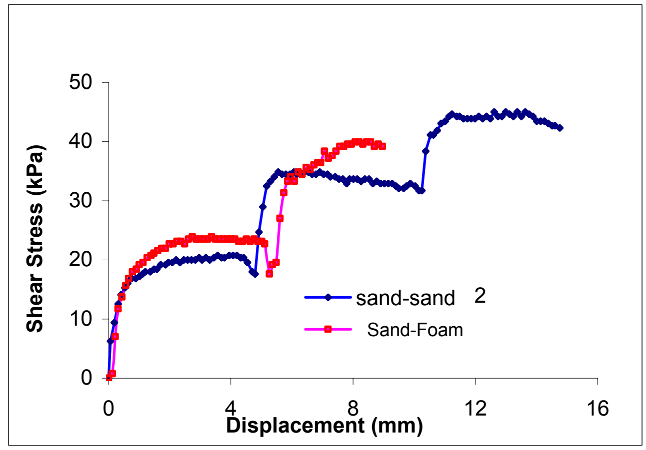


Figure 23 Sand to Foam and Sand to Sand Interface Strengths with Source C Geofoam of 18 kg/m^3 Density