

An Investigation of Geofam Interface Strength Behavior

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Abstract

Use of EPS (expanded polystyrene) geofam as an ultra lightweight fill for construction over areas of soft ground has increased in recent years. An investigation of the interface friction between geofam and construction materials that are commonly used with geofam are presented in this paper. The interfaces studied included geofam to geofam, in dry and wet conditions. Geofam to cast in place concrete as well as geofam to geomembrane interfaces were also tested. Interface strengths between geofam and HDPE as well as PVC geomembranes were determined. The effect of geofam surface degradation due to extended exposure to sunlight on interface strength and adhesion bonding with cast in place were evaluated using field samples and samples degraded by accelerated weathering in the laboratory. The results indicate material density; sample size, stress level and surface moisture do not have significant influence on geofam to geofam interface strengths. A strong adhesion bond developed between geofam and cast in place concrete. Both the peak and residual strength for geofam and cast in place concrete surfaces were much greater than for geofam to geofam interfaces. Degradation due to exposure to sunlight and accelerated weathering in the laboratory reduced the strength of adhesion bonding between geofam and cast in place concrete. The interface strength between geofam and geomembranes was found to be much lower than any of the geofam interfaces.

Introduction

EPS Geofam is a very low density solid with potentially high compressibility, good flexural strength and high rupture strength in shear. The

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weakest plane of failure within a geofoam fill under load is at the interface between geofoam blocks and between geofoam blocks and interfacing materials. As for any construction material, basic engineering properties of geofoam are required to perform analysis and design. The friction factor or interface friction coefficient is the ratio of the resisting shear to the applied normal stress and is an important design parameter for assessing the stability of structures that contain geofoam. Interface friction coefficients can be derived from results of laboratory testing. The evaluation of interface strength properties should consider different materials and field conditions to be expected in actual applications. Tests should be conducted at representative normal stresses. Effects of moisture, discoloration and dusting due to extended exposure to sunlight need to be examined.

Kuroda et al (1996) performed a series of shaking table tests to determine geofoam to geofoam interface strengths and to evaluate the effectiveness of binder plates under static and dynamic loading. Geofoam of 20 kg/m^3 density was used. A 1 cm thick slice of geofoam board was glued to the surface of a shaking table having a 1.5 by 1.0 m area. Blocks of EPS foam, with dimensions 0.25 by 0.50 by 1.00 m were stacked in 4 layers on the glued geofoam. Normal loads of either 7.4 kPa or 14.7 kPa were applied. Accelerations of 10 to 20 Gal (0.10 to 0.20 m/s^2) 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 geofoam layers and the test was repeated. The presence 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 400 Gal (4 m/s^2). 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 interface of the glued slice at the base and also at the normal load interface at the top. Coefficients of friction were determined to range from 0.2 to 0.4 and were lower than the value of 0.6 derived from traction test. The binder plates were 150 mm by 150 mm with 25 mm deep rectangular and saw-toothed protrusions and are larger than binder plates used in the United States. The number of binder plates used per geofoam surface area far exceeded the amount used in actual geofoam fill construction.

Miki (1996) presented interface friction coefficients for geofoam to geofoam, and geofoam to sand based on direct shear tests. 20 kg/m^3 density geofoam was used for both types of interface tests. For the interface of sand and geofoam, the friction coefficient was found to change with the sand thickness underlying the foam. For a few millimeters of sand below the geofoam, the friction coefficient was nearly 0.7. The interface friction coefficient decreased to approximately 0.55 for sand layers greater than 35 mm. For geofoam to geofoam interfaces subjected to normal stresses in the range of 0 to 50 kPa, a constant interface friction coefficient 0.64 was reported.

Wagner (1986) investigated the interface strength properties of Type II (22 kg/m^3) (ASTM-C-578) geofoam. Two different test methods were used to

determine peak and residual interface friction coefficients. The first method involved a tilt test using a geofoam block and a geofoam board. The angle at which the foam block began to slide was measured and a coefficient of friction of 0.54 was determined. No additional normal load was applied other than the weight of the sliding geofoam block. The second method involved performing direct shear tests. A pair of 430 mm by 290 mm by 200 mm blocks were cut from a large block using a hot wire saw. The blocks were installed in the direct shearing device and two hydraulic jacks applied a normal load. The base of the shear box traveled at a displacement rate of 1 mm/sec. The upper shear box was restrained and the resulting reaction force was monitored with a proving ring. Tests were performed at normal stresses of 11, 23 and 30 kPa. Peak and residual interface friction coefficients of 0.63 and 0.52 were obtained from these tests.

The Norwegian Road Research Laboratory (1992) suggested an interface friction coefficient of 0.7 for both geofoam-to-geofoam and for geofoam to granular soil interfaces. The UK Transportation Research Laboratory (Sanders and Seedhouse, 1994) recommended a geofoam to geofoam interface friction of 0.5. No test data was given from either source. Construction of geofoam fills typically feature a reinforced concrete slab for protection and load distribution. There are no reported studies of interface strength between geofoam and cast in place concrete. The UK guidelines, among others, recommend use of geomembranes as protective cover on geofoam fills in place of a concrete slab. There are also no reported studies or suggested values for interface friction coefficients between geofoam and geomembranes. Construction specifications often mention a limit on duration of geofoam exposure to sunlight out of concern for surface discoloration and dusting due to UV degradation. There are no reported investigations on the possible effect of UV degradation on interface friction behavior. Geofoam fills are not protected from rainfall during construction and may remain submerged for extended periods while in service. Possible differences in interface strength between dry and wet geofoam surfaces have not been examined. Some manufacturers and manufacturer interests (AFM Corporation, 1994) advocate the use of double barbed galvanized steel binder plates between geofoam layers. The benefits of using binder plates (or timber fasteners) between geofoam to geofoam interfaces have been questioned (Transportation Research Laboratory (1994)). More evidence is needed to resolve these conflicting positions.

Results of geofoam to sand interface strength tests were previously reported (Negussey, 1997). Direct shear tests were performed on 100 mm EPS samples and sand. The investigation determined that the interface friction is comparable to the friction angle of the sand alone. During shearing sand grains embed into the geofoam and failure at the interface plane occurred in the sand.

There has so far been very limited study of interface strength between geofoam to geofoam as well as geofoam to other typically used construction materials. The investigation reported in this paper was aimed at generating

additional information on geofabric interface friction behavior considering several of the factors mentioned above. A more detailed investigation of interface shear characteristics of geofabric can be found in (Sheeley, 2000).

Investigation

A series of direct shear tests were performed to investigate shear strengths between geofabric to geofabric surfaces, geofabric to cast in place concrete and also geofabric to geomembrane interfaces. Both dry and wet geofabric to geofabric interfaces were tested. The effect on interface strength of discoloration and dusting due to ultraviolet degradation was examined by testing field samples as well as samples that were subjected to accelerated weathering in the laboratory. The effects of geofabric density, normal stress level and sample size on interface strength were examined. Tests were also performed to evaluate the advantages of using binder plates to improve interface resistance. Samples of geofabric that had been exposed to sunlight for over three months were obtained from a construction site. Because the geofabric had been exposed beyond the time allowed in the specification, the contractor proposed to pressure wash the degraded surface. Tests performed on pressure washed geofabric and cast-in-place concrete interfaces are compared to corresponding results for fresh and degraded geofabric to concrete interfaces.

Materials

EPS manufacturers provided Type VIII (min. 18 kg/m^3) and Type IX (min. 29 kg/m^3)(ASTM-C-578) geofabric blocks for the investigation. For fresh geofabric to geofabric interface strength tests, finished skin rather than hot wire cut surfaces were used. Rectangular boards were cut to the dimensions of the carrier box and were then placed in a weatherometer for different durations of exposure to UV lighting. A cycle of 8 hours of UV exposure and 4 hours of condensation was used. At selected time periods, samples were removed from the weatherometer to obtain different levels of degradation. Samples were exposed to a maximum of 250 hours of UV lighting. A contractor provided both surface degraded and pressure washed samples of geofabric from a large construction site. All geofabric test specimens were cut to desired dimensions using a hot wire saw. Concrete mix was poured in a 100 mm by 100 mm by 25 mm cast placed over a geofabric base. The concrete was cured for a minimum of 28 days and the form was removed. Concrete was also cast on field-degraded, pressure-washed and artificially-weathered geofabric surfaces in the same way. Each concrete mix had the same proportion of water to sand and cement (950 g concrete:120 g water). The thickness of rough and smooth HDPE and also PVC membranes used for interface tests were 1.5 and 0.8 mm, respectively. Double-sided galvanized steel binder plates of 100 mm by 100 mm area and 1 mm thickness were used. The binder plates had eight 15 mm deep triangular projections per side.

Equipment and Procedures

Most of the interface shear strength tests were performed using a modified direct shear machine. The interface contact areas were 100 mm by 100 mm. Geofoam samples of 25 mm nominal thickness were cut to fit in the 125 mm by 150 mm opening of the carriage box as the lower unit of the test interface. The area of the lower unit was larger than the contact area. The nominal thickness of the top unit was also 25 mm. The two halves were installed and a loading platen was placed over the top. The loading platen base had parallel ribs that penetrated into the geofoam. The ribs were 1.4 mm in depth and were aligned normal to the direction of shearing to prevent slippage at the platen interface. Normal load was applied by dead weight suspended on a hanger. The hanger was supported on the top platen. Constant normal stress in the range of 14 to 48 kPa was applied before shearing. The top geofoam, hanger and dead weight assembly remained fixed while the carriage box containing the lower geofoam was pushed at a rate of 1.2 mm/min. Horizontal reaction was provided by a blade and load cell assembly attached to a fixed stub through a guide bushing. The upper half of interface test samples were restrained in the shearing direction but were not otherwise laterally confined. Water was poured into the carriage box while preventing the base geofoam from floating. With the base geofoam fully submerged, the upper geofoam and loading platen were installed. The water level was above the interface during shearing. For tests involving binder plates, the plates were installed between the upper and lower geofoam halves. The top geofoam was placed within an upper half of a direct shear box for binder interface testing in forward and reverse shear thrust. The carriage box was tied to return with the drive screw on load reversal. The load cell and shear box were coupled to register forces in forward and reverse directions. A dummy spacer with end grip fixture was installed in the base carriage to secure a geomembrane. The configuration of the upper half and the application of normal load for tests involving binder plates or geomembranes was the same as for other interface tests. After curing, the geofoam base and concrete block were placed in the carriage. The dimensions of the concrete were nominally the same as the upper half of geofoam to geofoam interface samples. The loading platen was placed over the concrete and a hanger and dead weight, as in the other tests, applied normal load. The travel of the carriage box and magnitude of the shear force were monitored by a displacement transducer and load cell.

A large direct shear-loading device was built to enable testing samples of up to 500 mm by 500 mm in contact area (Fig. 1). A 38 mm diameter jackscrew was aligned to apply horizontal thrust. Rotation of a four-spoke hand wheel was translated to linear motion of the jackscrew at a thrust bearing support. A second support sleeve and key restrained the jackscrew from rotating. The supports were mounted on the top flange of an I-beam. The lower flange of the I-beam was bolted to a large tabletop. A load cell and loading platen were mounted to an adapter at the forward end of the jackscrew. A spring-loaded displacement transducer at the rear end of the jackscrew monitored the forward movement of

the shaft. At the far end of the table ahead of the jackscrew, a reaction wall was bolted securely to the tabletop and restrained the lower geofoam block. The 500 mm by 500 mm size of the lower geofoam was the same for all tests. Samples of different contact area were tested by changing the size of only the top geofoam block. A loading platen was placed over the top block and additional weights were added to apply normal stress of either 12 or 26 kPa. The handle was then rotated manually to induce displacement of the top block at a steady rate of about 10 mm/min. The large direct shear device was used to investigate fresh geofoam to geofoam interface strengths only. Samples having interface contact areas ranging from 100 mm by 100 mm to 500 mm by 500 mm were tested.

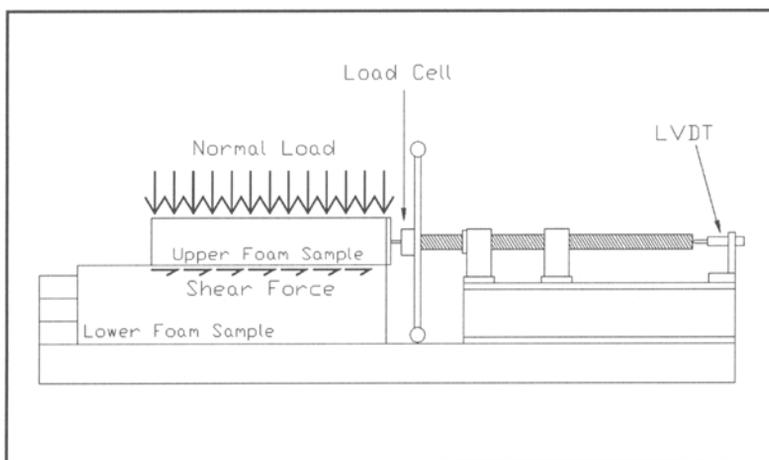


Figure 1. Cross Section of Large Direct Shear Machine

Results

Results of interface shear strength tests on dry Type VIII and IX geofoam are shown in Figs. 2a through 2d. The normal stress levels over which the tests were performed cover values that would be expected to occur in field applications. Each of the shear stress and displacement curves manifest peak resistance and a tendency towards residual strength. At the same stress levels, peak and residual strengths for both geofoam densities were about the same. There is therefore no significant change of interface friction of geofoam on account of density. Results of a similar set of tests but on wet geofoam interfaces are shown in Figs. 2c and 2d. Again, both peak and residual strengths are evident. The magnitude of peak and residual shear strengths, at corresponding stress levels, for wet geofoam interfaces are not much different than for dry conditions. These results are further summarized in Fig. 2e and 2f for Type VIII and Type IX geofoam, respectively. In each figure, the average curves for peak and residual conditions decrease slightly with normal stress. The minimum residual friction

factor is not lower than 0.6 and the peak friction factor is generally higher than 0.8. Hence a friction factor of 0.6 is a lower bound and is reached after mobilizing peak resistance. At lower normal stresses of about 25 kPa or less and typical of stress levels commonly applied on geofoam fills, the interface friction factors are higher and generally above 0.7 and 0.9 for residual and peak conditions, respectively. Previously suggested interface factor values of 0.5 to 0.7 are generally on the conservative side, especially in cases where safety factors are further applied.

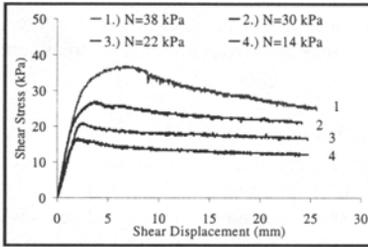
The results of interface strength tests that were performed with and without the presence of binder plates are shown in Fig. 2g. On first loading, no appreciable advantage in using binder plates was evident. Resistance at a binder plate to geofoam interface was provided by two separate mechanisms. The first was the interface resistance between the metal surface and geofoam. The second was the passive resistance to the penetrating projections that have flat faces normal to the direction of shearing. These two mechanisms in combination did not provide a better interface strength than a geofoam to geofoam interface. On reverse loading and reloading the interface strength resistance for the binder plate reduced to about half the peak value in first loading and then increased to match the resistance curve for the geofoam to geofoam interface. This is because the binder plate projections created a gap in forward advance. When the shear loading was reversed, the projections encountered reduced resistance and most of the interface strength was developed between the metal and geofoam surfaces. The same situation developed on reloading. The flat segment at zero shear stress for both cases was due to gaps that formed on horizontal compression by the shear load. Even if the binder plates were found to provide enhanced interface resistance much greater than the geofoam interface, their practical usefulness is very questionable. No more than two to four binder plates are installed per geofoam block of 1.2 by 2.4 m and more often 1.2 by 4.8 m contact area. At a given normal stress, the proportion of shear resistance provided by the binder plates can be shown to be a significantly low proportion of the amount contributed by the larger geofoam to geofoam contact surface. The evidence of reduced resistance on shear reversal for binder plate to geofoam interfaces implies binder plates have questionable performance in large displacement cyclic loading. The findings in this investigation support the suggestion of Sanders and Seedhouse (1994) not to use binder plates in normal geofoam fill construction.

Interface strength results for geofoam to geomembrane materials are shown in Fig. 2h. The friction coefficient for rough HDPE and geofoam surfaces is in the range of 1 at normal stresses of 25 kPa or less and reduces to about 0.8 at about 45 kPa. Smooth HDPE and geofoam interfaces resulted in a low friction factor of about 0.25 regardless of normal stress level. There is not much difference in evidence between residual friction factors of less than 0.5 for rough PVC and 0.4 for smooth PVC. The friction factor for rough PVC decreases only slightly with normal stress. These results indicate that the interface resistance

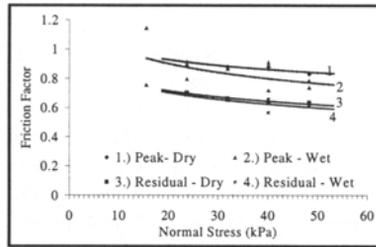
between geofoam and geomembranes, with the exception for rough HDPE, is considerably lower than for geofoam to geofoam interfaces. These results suggest need for careful consideration in using geomembrane cover in seismic areas and on sloping geofoam surfaces.

The results of interface strength tests between cast in place concrete and Type VIII geofoam surfaces are shown in Fig. 3a and 3b. These include results for fresh geofoam, geofoam exposed to artificial UV lighting in the laboratory as well as field sunlight exposed and pressure washed geofoam surfaces. The fresh geofoam and concrete interface developed a strong adhesion bond that resulted in a shear resistance of over 70 kPa at a normal stress of 32 kPa. As the adhesion bond broke, the shear resistance dropped sharply to a residual value of almost 50 kPa. Once formed, geofoam to concrete adhesion bonding was difficult to separate. When separated, the concrete contact surface was rough and small pieces of geofoam broke off to remain attached with the concrete block. The high residual shear resistance is in part due to the roughness of the concrete surface. A strong adhesion bond did not develop between cast-in-place concrete and geofoam degraded by extended exposure to UV lighting in the laboratory. Both the peak and residual strengths for these degraded geofoam interfaces are much lower than for fresh geofoam and cast-in-place concrete. Pressure washing of the field degraded geofoam surface re-established the interface strength performance to the level of the fresh surface. The plot of friction factor against UV exposure in Fig. 3b shows a decrease in the friction factor with increasing time of UV exposure. The friction factor for geofoam exposed to 90 days of sunlight in the field is about 2 and improved to about 2.5 on power washing. The strong adhesion bond and high residual interface strength that was evident for cast-in-place concrete and geofoam has not been recognized in design practice of geofoam fills. Even with extreme degradation, as was achieved under accelerated weathering of lab samples, the friction factor for degraded geofoam to cast-in-place concrete did not reduce below values for fresh geofoam-to-geofoam interfaces.

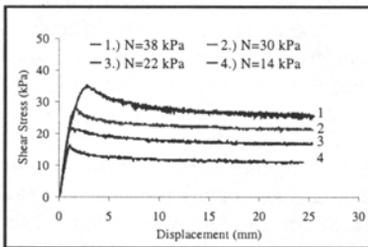
All of the results and observations above were based on tests performed with a modified direct shear machine. Results from tests made using a large direct shear apparatus are shown in Fig. 3c and 3d for Type VIII geofoam at normal stresses of 12 and 26 kPa, respectively. Shear displacements to peak resistance increased with sample size. For the largest sample, and especially at the lower 12 kPa normal stress, the shear displacement occurred in jumps associated with strain build-up and sudden energy release. Displacements were being monitored at the rear of the jackscrew and not relative to the test sample. Relaxation with each jump is manifested with reduction of stress and with the jump not showing as displacement. Fig. 3e and 3f summarize the sample size effects at 12 and 26 kPa normal stresses. These results show no significant sample size effects on interface shear strength of geofoam. The peak and residual friction factors of 0.90 and 0.65 derived from the large direct shear test apparatus are in good agreement with those obtained from tests with the modified direct shear machine.



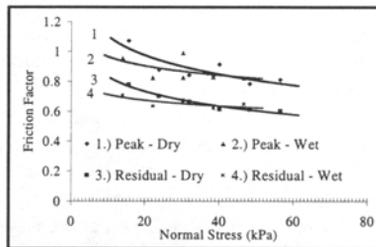
a) Dry Type VIII Geofoam Interfaces.



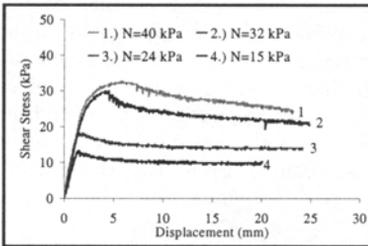
e) Type VIII Geofoam Interfaces.



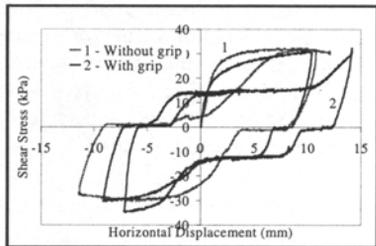
b) Dry Type IX Geofoam Interfaces.



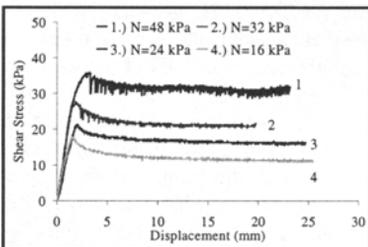
f) Type IX Geofoam Interfaces.



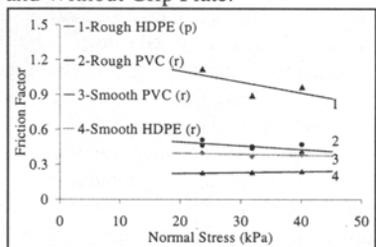
c) Wet Type VIII Geofoam Interfaces.



g) Reversible Direct Shear Test, With and Without Grip Plate.



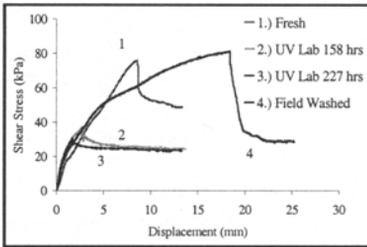
d) Wet Type IX Geofoam Interfaces.



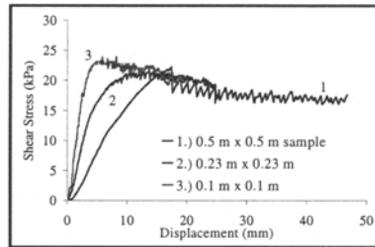
h) Geofoam / Geomembrane Interfaces.

Figure 2. Interface Shear Test Results (1) for Types VIII and IX Geofoam.

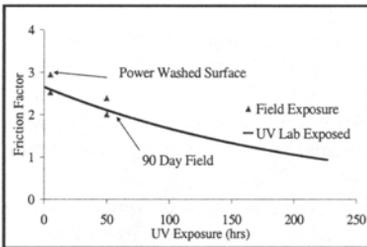
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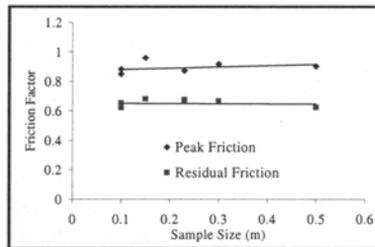
a) Geofoam and Cast In Place Concrete Interfaces at 32 kPa Normal Stress.



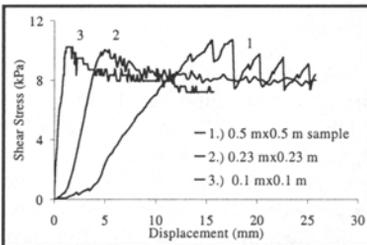
d) Geofoam Interface Strengths at Normal Stress of 26 kPa.



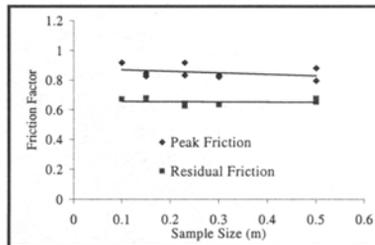
b) UV Exposed Geofoam and Cast in Place Concrete Interfaces.



e) Geofoam Interface Strengths at Normal Stress of 12 kPa.



c) Geofoam Interface Strengths at Normal Stress of 12 kPa.



f) Geofoam Interface Strengths at Normal Stress of 26 kPa.

Figure 3. Interface Shear Test Results (2) for Type VIII Geofoam.

Conclusions and Summary

- Geofoam interface shear strengths were investigated for small and large samples in the range of working stresses used in practice and for different densities and interfaces.
- Geofoam to geofoam interface shearing developed peak and residual strengths.
- The effect of density on interface strength of geofoam was negligible.
- Binder plates did not provide increased shear resistance in one directional loading and had reduced resistance in reverse loading and re-loading.
- There was no significant difference between wet and dry interface strengths in the range of normal stresses used in practice and for short-term exposure to water.
- A strong adhesion bond developed between geofoam and cast-in-place concrete interfaces and both peak and residual interface strengths were higher than geofoam to geofoam interfaces.
- The interface strength between geofoam and geomembrane surfaces was low. Substitution of a concrete load distribution slab with a geomembrane would result in a much weaker interface.
- UV degradation diminished the peak interface strength between geofoam and cast in place concrete. Power washing effectively removed the degradation and improved the adhesion bond strength.
- Peak and residual interface strengths for geofoam to geofoam interfaces were relatively independent of sample size and working stress level.

Acknowledgment

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