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Influence of Wetting on the Interface Frictional Behavior Between Geomembrane / Soil and Geomembrane / Geotextile Systems

by

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Introduction

Land disposal is the most common choice for handling solid and hazardous wastes. Since the cost of land disposal of these wastes is well below the other available options, efforts are being made all over the world to improve the construction and operation techniques for landfills and to reduce ecological damage by preventing the discharge of landfill leachate into the environment. The main component of a landfill is the leachate collection system. This system typically consists of different types of geosynthetic material and soil. An in-depth understanding of the interface friction along various interfaces in a composite synthetic/soil component system will assist in the development of a better slope design and consequently increase the control over stability problems in various geotechnical applications such as canal liners, liquid containment (pond) liners, and solid waste containment (landfill) facilities.

Calculation of the frictional resistance along different interface material depends on various properties such as the physical characteristics of the material being tested, the type of testing apparatus (Lopes et al., 1993), the degree of polishing, the relative orientation of the layers to the direction of the shear stress application, and the probable wetting of the geosynthetic present at the interface (Mitchell et al., 1990). Geosynthetic wetting may occur due to rainfall during construction, water ponding due to the vicinity

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of the leachate collection sump, thermal effects leading to the collection of water on the underside of the liner during initial liner placement, and moisture concentration due to condensation of clay. This paper investigates the influence of geosynthetic wetting on frictional resistance along the most critical interfaces found in a multi-liner landfill. These interfaces are most often between geomembranes and nonwoven geotextiles, geomembranes and sand, and nonwoven geotextiles and sand.

Review of the Literature

Numerous studies have been performed to determine the interface frictional behavior between a wide variety of soil and geosynthetic materials using direct shear apparatus (Richards and Scott, 1985; Williams and Houlihan, 1986; Takasumi et al., 1991; Druschel et al., 1991; Bemben et al., 1993; Lopes et al., 1993 and Sharma et al., 1993). However, this published data is highly site specific and, therefore, cannot be applied to any other design (Giroud, 1991 and Lopes et al., 1993). The variations in measured strength parameters in liner systems indicate the desirability of similar test programs for proposed new facilities to establish design parameters (Mitchell et al., 1990).

A slope failure occurred on March 19, 1988 in a 27.45 m high, 60,000 m^2 hazardous waste landfill in Kettleman City, California, U.S.A. that resulted in the displacement of the surface of the waste fill up to 10.68 m laterally and 4.27 m vertically. Mitchell et al. (1990) and Seed et al. (1990) reported that the failure of the Kettleman landfill was mainly due to low frictional resistance between various geosynthetic material (i.e., the HDPE liner, geonet, geotextile) and the compacted clay liner. Different interface material was tested under a variety of conditions including dry and submerged. Interface friction was found to be affected considerably by the presence of water. Though the effect of geosynthetic wetting on interface *friction was studied by a few other researchers* (Mitchell and Seed, 1990; Bemben et al., 1993), there is not enough data available to clearly understand the influence of wetting on interface properties. According to ASTM D 5321-92 when determining the coefficient of friction between soil and geosynthetics or geosynthetics and geosynthetics by direct shear method under geosynthetic wet conditions, the geosynthetic specimen should be soaked in water for at least 24 hours prior to the test period. In the present study, however, the condition of geosynthetic wetting was simulated by brushing the top surface of the geosynthetic with a small quantity of water. This approach was taken due to the authors' strong belief that the material used in current experimental work will not absorb a measurable quantity of water and in the field a complete soaking condition might not occur.

Scope

From the literature review, it is apparent that additional research is needed to evaluate the influence of probable geosynthetic wetting on frictional resistance along various interfaces in a multi-liner system. A study has been undertaken to evaluate the effect of wetting on the angle of interface friction along the most commonly occurring interface conditions found in a multi-liner landfill. These include geomembrane liner and sand, geomembrane liner and nonwoven geotextile, and nonwoven geotextile and sand. Partially fixed direct shear tests, described by Takasumi et al. (1991), were found to be appropriate in evaluating the interface strength parameters for these interface conditions.

Testing Material

Direct shear tests were performed to evaluate interface friction along different interface conditions. In all the tests, saturated, compacted clay was used in the lower box and dry sand was used in the upper box. The properties of these soils are described in Table 1.

The different geosynthetic materials used in the present study includes HDPE smooth and rough geomembranes, flexible smooth and rough geomembranes, and nonwoven needle-punched geotextiles. The properties of these synthetic materials adopted directly from the manufacturer's published literature are given in Table 2. The effect of geosynthetic wetting on frictional resistance was studied by keeping the geosynthetic dry as well as wet under different interface conditions. Complete dryness was achieved by heating the sample in an oven at 95°F for approximately 30 minutes. The condition of probable geosynthetic wetting found in the field was simulated by brushing the geosynthetic with water.

TABLE 1.
Properties of the Soils

Clay	Sand
Natural water content = 30%	D_{60} = 0.65 mm. D_{10} = 0.52 mm
Liquid Limit = 41%	G_s = 2.65
Plastic Limit = 24%	Shape = Subangular to angular

TABLE 2.
Properties of the Geosynthetic Materials

Property	Geomembranes				Nonwoven Geotextile
	HDPE Smooth	HDPE Rough	Flexible Smooth	Flexible Rough	
Thickness mm (mils)	1.0 (40)	1.0 (40)	1.0 (40)	1.0 (40)	2.4 (95)
Specific Gravity	0.94	0.94	0.929	0.929	--
Tensile Strength at Break (kN/M)	28	15	28.34	34.99	0.934 (Grab Tensile), 17.1 (Wide Width)
Puncture Resistance (kN)	0.13	0.20	0.18	0.18	0.423
Elongation at Break	--	--	--	--	60% Grab Tensile, 65% Wide Width

Equipment

The testing apparatus consisted of a 100 mm (4 in) square box with a strain controlled, displacement system operating at 0.0024 mm/min to 1.22 mm/min. To measure shear forces, a load cell of 113.5 kg (250 lb) capacity was used. LVDTs were used to measure horizontal and vertical displacements. All the readings were electronically recorded. In all the tests, normal stresses ranged from 15 to 30 kPa, the typical range of stresses on most landfill covers and lining systems occurring during construction. All the tests were carried out at the strain rate of 1.22 mm/min. The different interface conditions used in the present experimental program are shown schematically in Fig. 1a and 1b.

Results

A total of 65 tests were conducted to verify the effect of geosynthetic wetting on interface friction along different geomembrane/geotextile and geomembrane/sand systems. Repeated tests not only indicated the same shear stress-strain behavior but also reproduced the test results within an order of 1 to 3% error.

Figure 2 shows the results of direct shear tests on HDPE smooth geomembranes and sand for the interface condition of dry and wet. It is evident from Figs. 2a and 2b that the peak as well as residual shear stresses were reduced by half due to interface wetting. The amount of reduction varied with the applied normal stress. In all tests, peak shear stresses were recorded for shear strains less than 1%.

Results from direct shear tests on the smooth HDPE geomembrane and nonwoven geotextile system (Fig. 3) showed similar variation as to that observed in the smooth HDPE geomembrane and sand system. For tests conducted under interface wet condition, water was pushed from the interface to the outer edge of the clamped membrane. In these tests, wetting of the membrane had a significant influence on the interface friction behavior.

Direct shear tests on rough HDPE geomembrane and sand systems (Fig. 4) suggest that the effect of geosynthetic wetting on the angle of interface friction was almost negligible for the normal stresses of 15 kPa and 23 kPa but significant for 31 kPa. The roughness of the membrane and fiber of the geotextile seemed to cause the material to interlock under high confining stress. Upon shear, these materials then behaved in a manner similar to that of sand. When water is present, it appears that this interlocking does occur.

For the interface condition present in a rough HDPE geomembrane

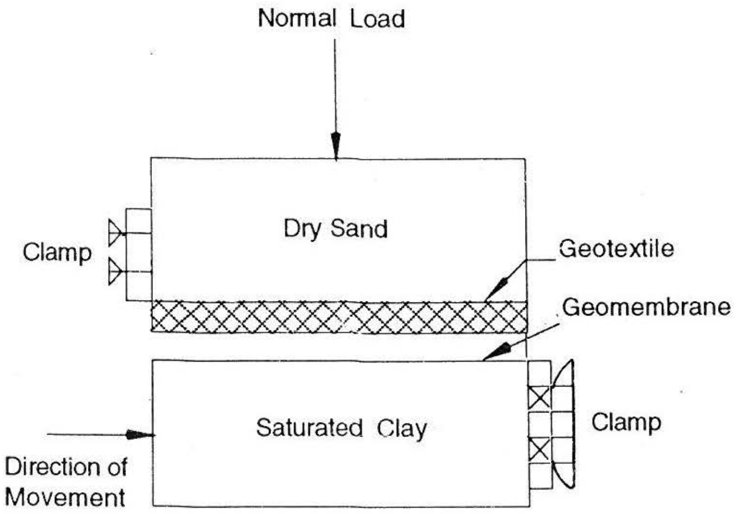


FIGURE 1a. Interface between Geomembrane and Geotextile

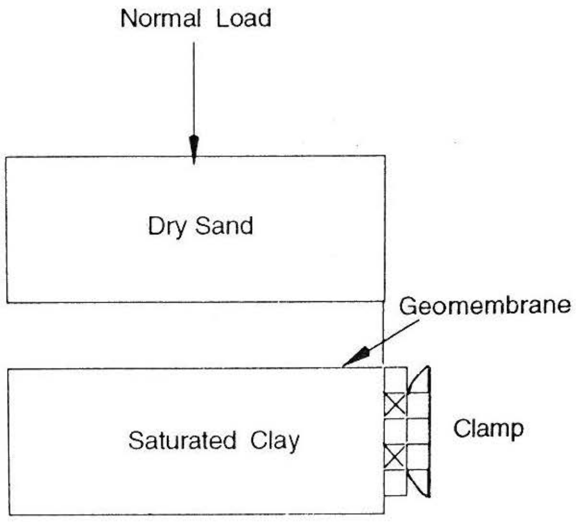
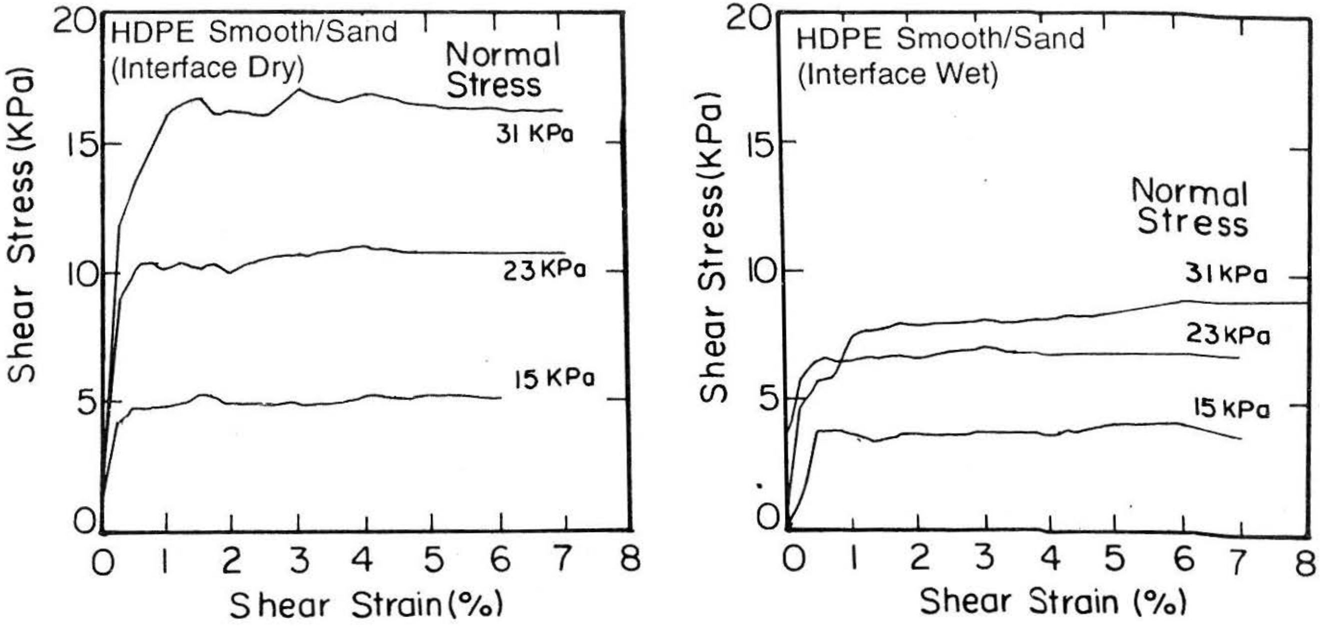
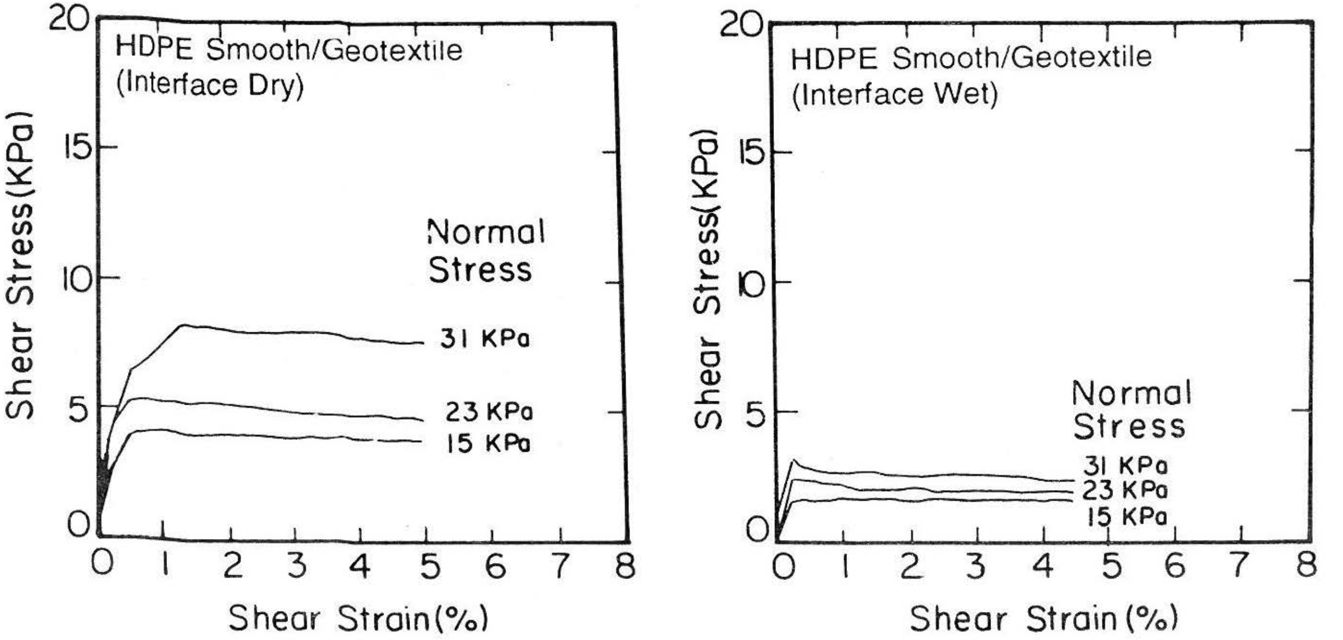


FIGURE 1b. Interface between Geomembrane and Sand



(a) (b)

FIGURE 2. Direct Shear Test Results on HDPE Smooth/Sand



(a)

(b)

FIGURE 3. Direct Shear Test Results on HDPE Smooth/Geotextile

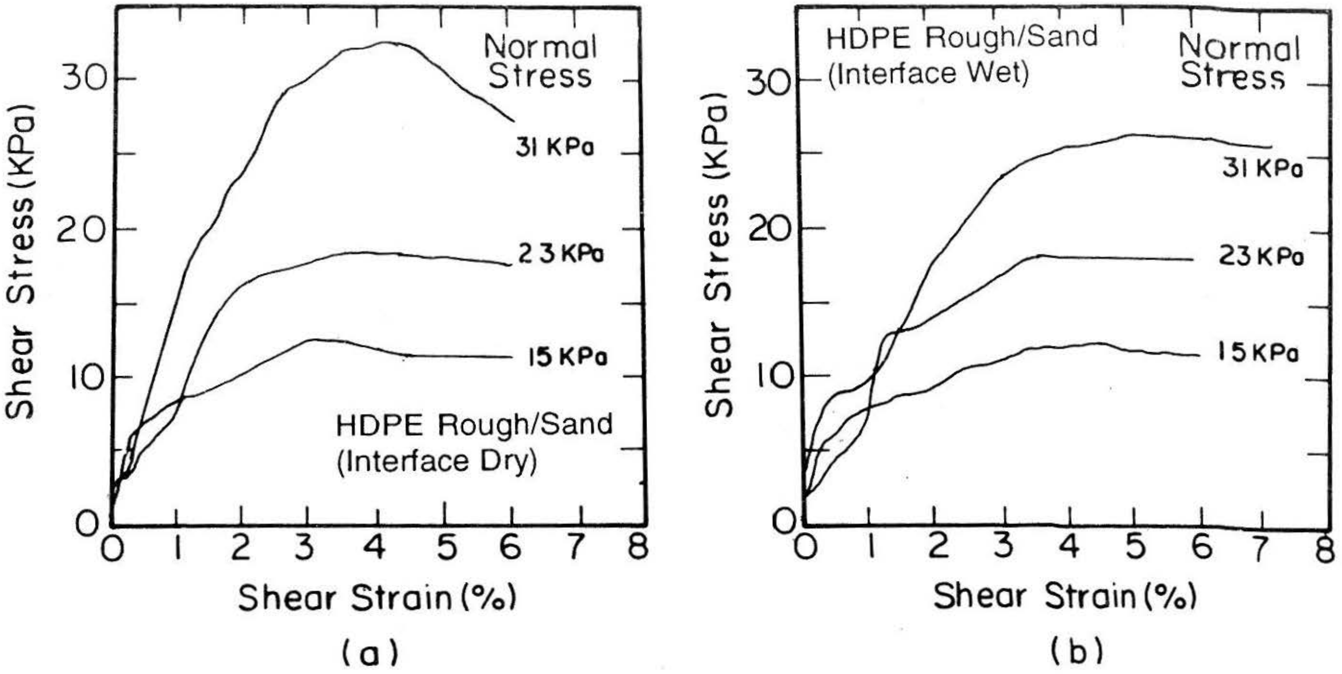


FIGURE 4. Direct Shear Test Results on HDPE Rough/Sand

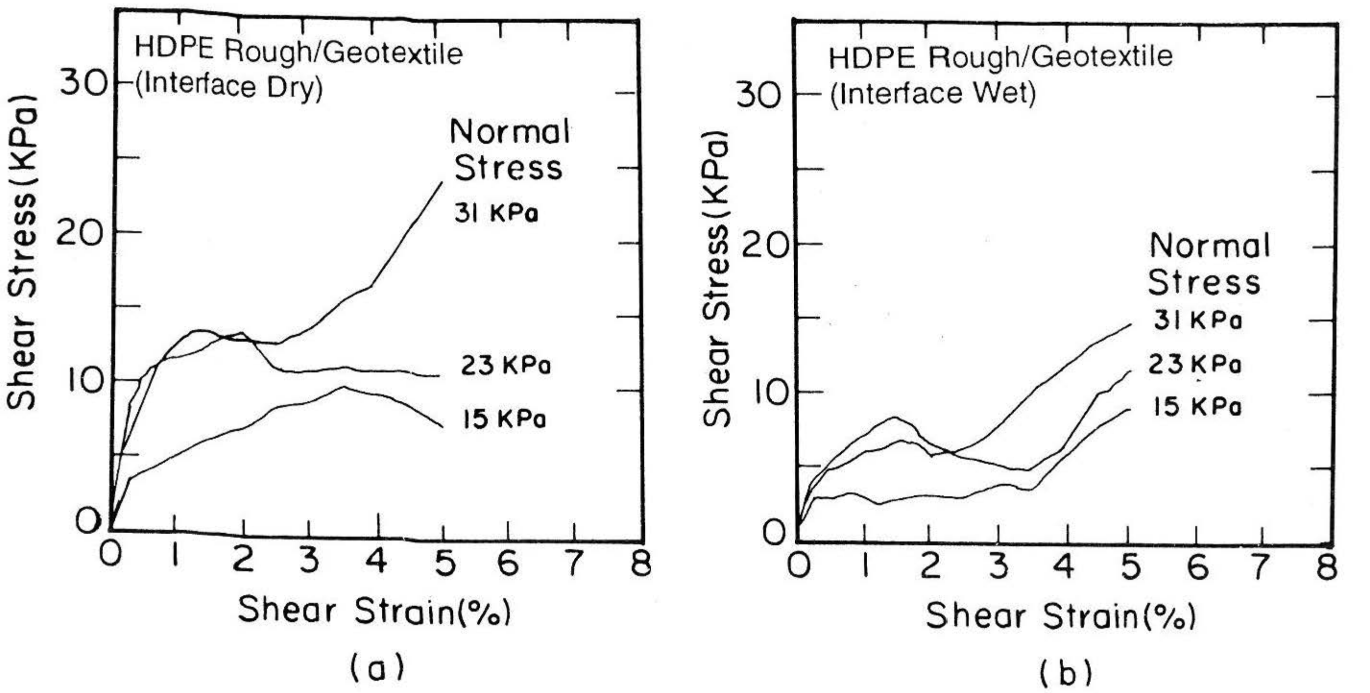
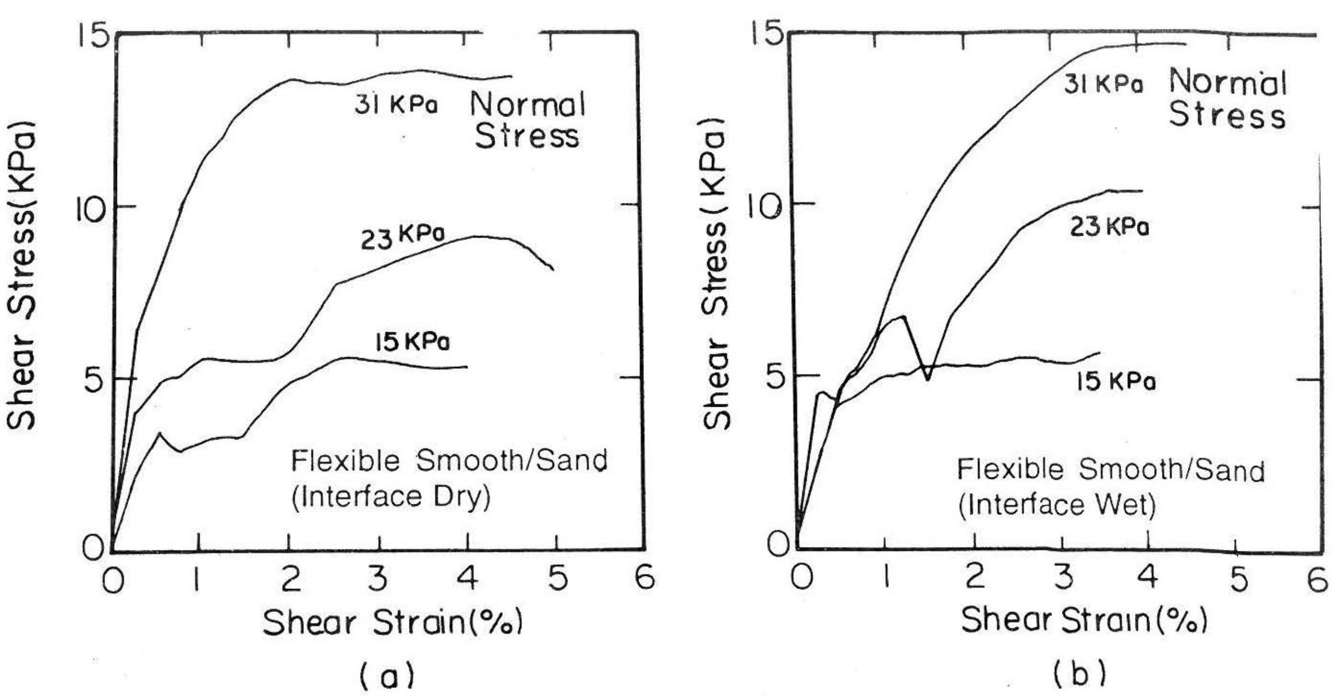


FIGURE 5. Direct Shear Test Results on HDPE Rough/Geotextile



(a)

(b)

FIGURE 6. Direct Shear Test Results on Flexible Smooth/Sand

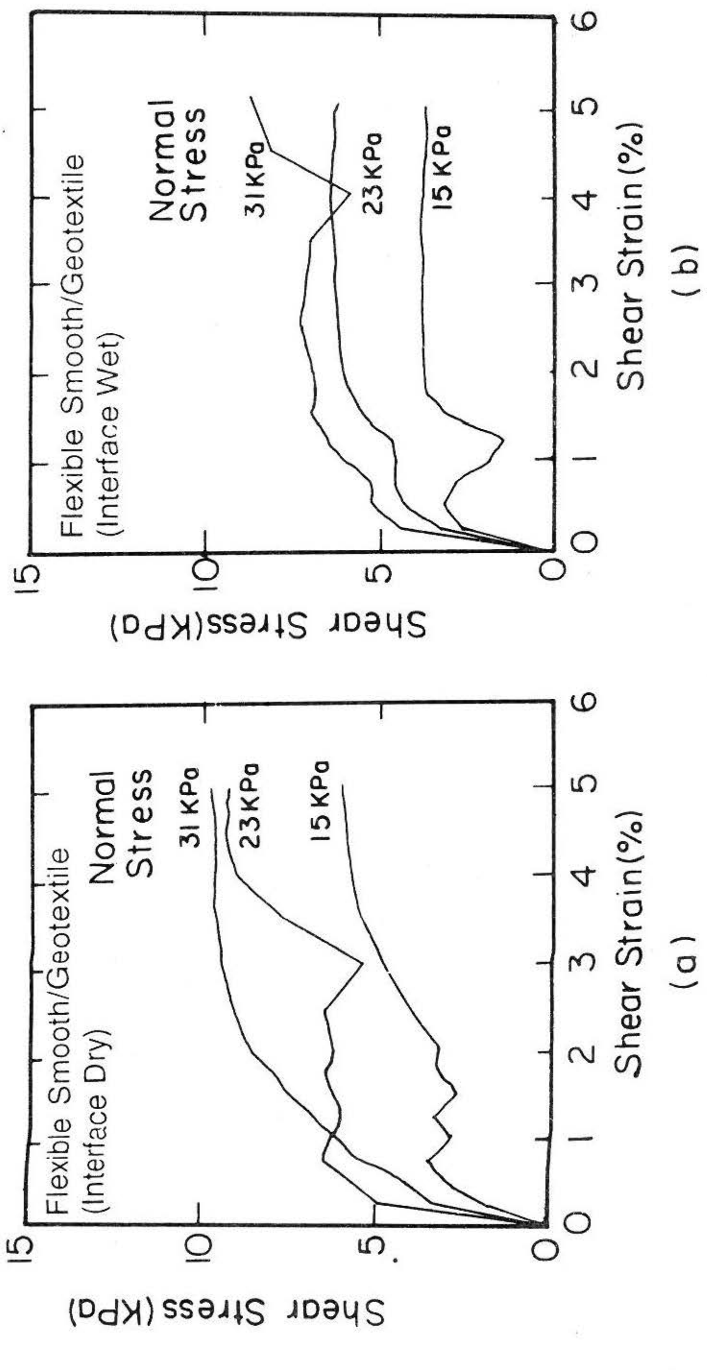


FIGURE 7. Direct Shear Test Results on Flexible Smooth/Geotextile

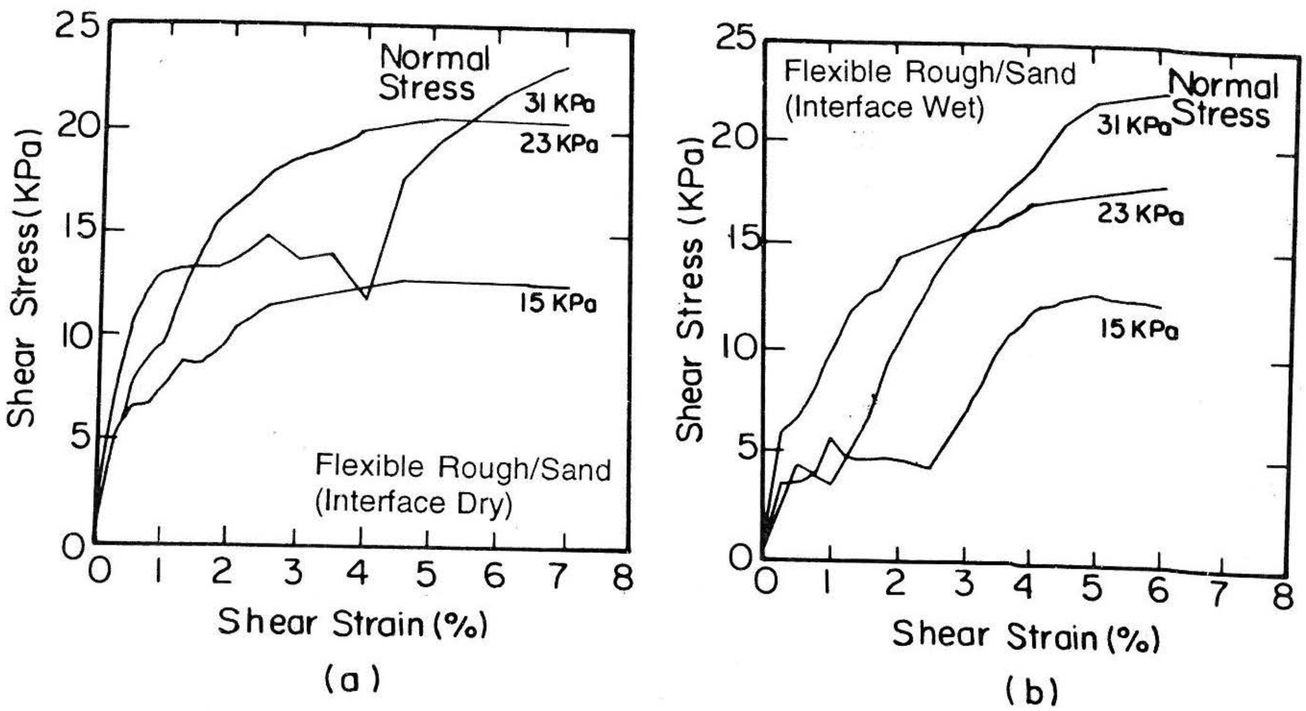


FIGURE 8. Direct Shear Test Results on Flexible Rough/Sand

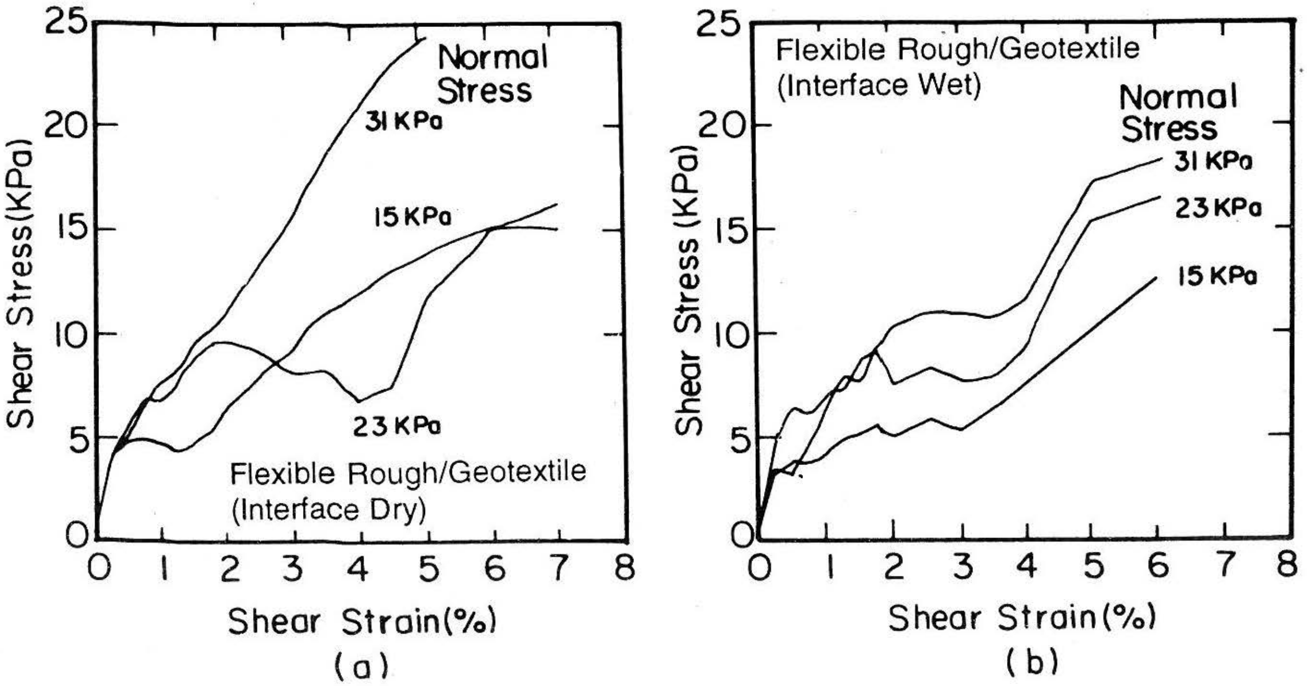


FIGURE 9. Direct Shear Test Results on Flexible Rough/Geotextile

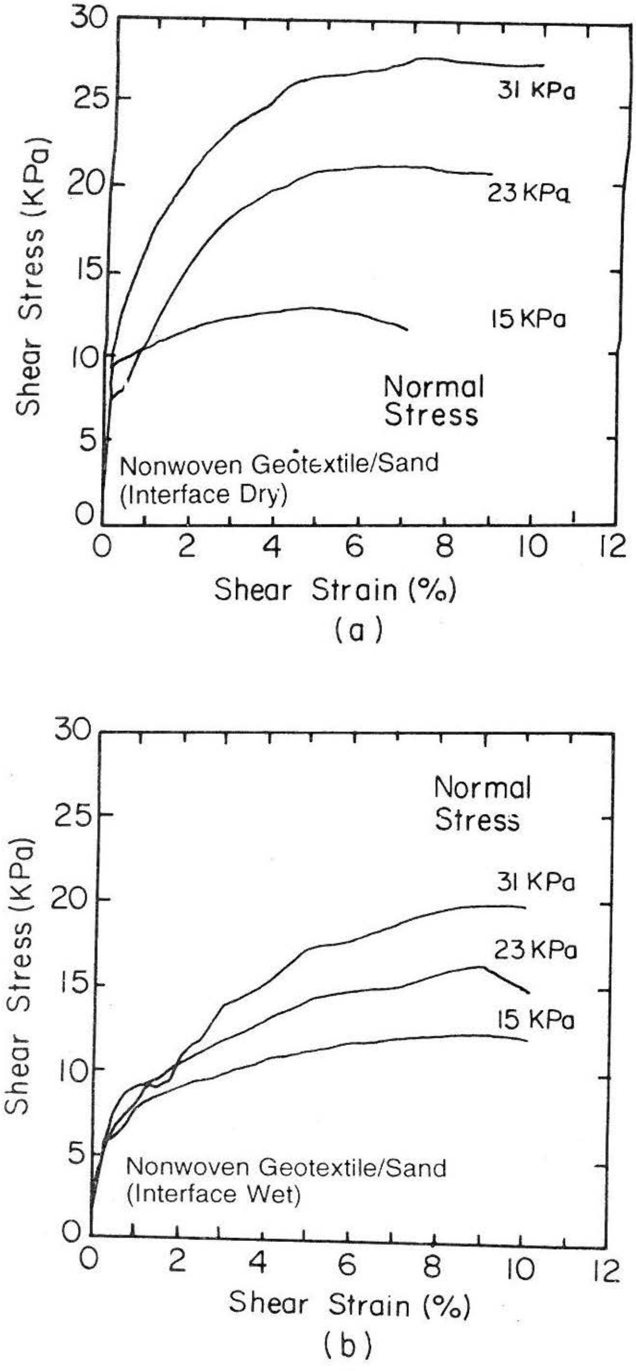


FIGURE 10. Direct Shear Test Results on Nonwoven Geotextile/Sand

and geotextile system under wet interface condition (Fig. 5a) at the normal stress of 31 kPa, shear stress reached its peak at a strain of 1.5% followed by a small drop and then a sharp rise in its value till the sample failed. This behavior occurred primarily due to the stretching of the geotextile. A small, permanent, residual deformation was also observed at the clamped end of the geotextile at the end of the test.

Shear stress-strain curves for rough HDPE geomembrane and geotextile systems (Fig. 5) under wet interface conditions displayed a different behavior as that observed in the rough HDPE geomembrane and sand system (Fig. 4). The presence of water at the interface between the geomembrane and geotextile may create a bond between the membrane and geotextile allowing the fabric to stretch irrespective of the condition of normal stress.

Figures 6 and 7 portray the results of direct shear tests performed on the smooth flexible geomembrane and sand and the smooth flexible geomembrane and nonwoven geotextile systems. All these results show a similar behavior to that observed for the smooth HDPE geomembrane and sand system. They exhibit a random behavior, though, when compared to the findings for the smooth HDPE geomembrane and geotextile system. Penetration of the membrane into the flexible clay base may explain this variation. Depending on the amount of membrane deformability, shear stress varied with applied normal stress. At high normal stresses, the membrane was significantly deformed into the underlying soil resulting in a significant change over the shear-strain.

Test results for rough flexible geomembrane and sand and rough flexible geomembrane and nonwoven geotextile systems (Figs. 8 and 9) display similar behavior to that of tests on the rough HDPE geomembrane systems. As observed in the case of smooth flexible membranes, rough flexible membrane test results also portrayed a random behavior. These findings gave less peak/residual shear values as compared to those for the rough HDPE membrane experiments. The interface behavior of smooth or rough flexible membranes is influenced by the amount of penetration of these membranes into the clay block. The rigid base below the membrane can lead to different results.

Direct shear test results on nonwoven geotextile and sand systems are presented in Fig. 10. The presence of water along the interface not only reduced the amount of shear but also shifted the peaks significantly.

Discussions and Conclusions

In the present study the effect of the presence of water on the interface friction behavior along different interface conditions was studied through a series of direct shear tests. In all the tests in order to represent the actual field conditions in a multi-liner landfill, saturated, compacted clay was used in the lower box and crystal silica sand was used in the upper box of the direct shear apparatus. Even though ASTM 3080 standard test method for direct shear specifies that the soil sample be consolidated before shear, the tests were conducted under unconsolidated, undrained conditions with the idea that the developed pore pressures and rate of consolidation within the clay sample due to interface wetting would be very slow (Mitchell, 1990).

Among all the tested membranes, smooth HDPE membranes appeared to be influenced significantly by the presence of water along the interface. A considerable amount of shear reduction occurred both for the membrane and sand and the membrane and geotextile systems. However, rough HDPE membranes behaved like a dense sand and were not subjected to a remarkable change in the interface friction due to interface wetting. At high normal stress, the nonwoven geotextile bonded with the rough membrane. This bonding resulted in the stretching of the geotextile during the shear. A small, permanent, residual deformation was noted along the clamped edge of the geotextile.

Flexible membranes portrayed a random behavior as compared to the HDPE membrane tested. This occurred mainly due to the membrane deformation into the flexible clay base under high confining stress. Reproducibility of the test results for flexible membranes became a problem due to the nonuniform membrane penetration into the underlying clay.

Based on the testing program undertaken, the following conclusions were drawn:

1. The presence of water along different interfaces not only reduces the shear stress but also significantly alters the shear-stress strain behavior.

2. The influence of wetting was significant for smooth membranes (both hard and flexible) and nonwoven geotextiles as compared to rough membranes and geotextiles.

3. Rough HDPE geomembrane and geotextile systems portray a very different interface frictional behavior as compared to smooth HDPE geomembrane and geotextile systems. This is predominantly due to the stretching of the geotextile with respect to the rough membranes.

4. Direct shear tests with flexible membranes produced different shear stress-strain behavior at difference confining conditions. This was due mainly to the deformation of the geomembrane into the flexible clay base. Depending on the amount of deformability, shear stress varied with the applied normal

stress.

In summary, the influence of wetting of the geosynthetic interface has very different effects on different materials. For smooth membranes and sand and smooth membranes and geotextile systems, the presence of water reduced the interface frictional resistance. However, the shear stress-strain behavior of flexible versus rigid membranes was quite different. The rough, rigid and/ or flexible membrane and sand or geotextile system showed quite a different effect of wetting. The rough, rigid membrane and geotextile test results indicated little or no influence of wetting on interface frictional resistance. The stress-strain behavior of rough membranes with geotextiles was totally different from the result found with smooth membranes and geotextiles.

In conclusion, the influence of wetting on interface friction behavior should not be generalized because every interface system behaves differently. Since the data discussed in this paper is limited, further study should be undertaken to verify the influence of wetting/soaking along different soil-geosynthetic interface conditions.

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