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Frictional Characteristics of Non-Woven Geotextile-Sand Interface

by

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ABSTRACT

The use of geotextiles is a recent innovation in soil stabilization. For soil reinforcement applications, adequate geotextile-soil friction is necessary. A high geotextile-soil friction will restrict displacements of soil around the geotextile and thus increase the strength of the soil itself. This paper presents the results of tests performed to determine the frictional behavior of the interface of sand and different types of non-woven geotextiles using a large direct shear testing machine.

INTRODUCTION

Geotextiles are fabrics made of synthetic materials in the form of cloth or mesh. Geotechnical engineering applications of geotextiles are separation, filtration and reinforcement or combinations of these. In the past, geotextiles were primarily used for separation and filtration. It is only quite recently that geotextiles are being employed in the design and construction of road bases, embankments and retaining wall backfills. It has been shown that the use of geotextiles improves stability and load capacity, and reduces settlements of foundations and earth structures (1, 2).

The reinforcement function of geotextiles is based on the ability of geotextiles to restrict the development of tensile strains in the soil caused by imposed external loads or deformations, increased effective self weight, or stress relief (1). The friction between geotextile and soil restricts the movement of the soil near the geotextile and, in effect, part of the load induced in the soil is carried by the geotextile. It is, therefore, necessary for a geotextile-soil interface to have adequate frictional strength.

The surface of a geotextile placed in a soil forms a plane of discontinuity which may cause slip or movement between the geotextile and the soil. Geotextile-soil friction is a factor that determines the occurrence of discontinuity between the soil and the geotextile and the effectiveness of the geotextile in reinforcing the soil. The frictional properties of geotextiles will depend, among others, upon the mode of their manufacture, material composition, and surface texture.

The purpose of this investigation is to assess the frictional behavior of the shear interface of sand and geotextiles using the direct shear test. Knowledge of this behavior is necessary for the design of geotextile-reinforced soil systems.

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MATERIALS AND EQUIPMENT

Large Direct Shear Testing Machine

A large direct shear testing machine designed at the Department of Transportation Engineering, Nihon University was used in measuring the frictional resistance between sand and geotextiles. The use of a large direct shear machine permits bigger specimens, loads and strains compared to those used in the standard direct shear tests of soils. The equipment consists of an upper box having a shear area of 1000 cm^2 (31.6 cm x 31.6 cm) and a height of 12 cm. Shear load is applied by pushing the upper box over a larger lower 47.8 cm x 40.5 cm box with a depth of 12 cm. The machine is capable of applying a shear displacement of up to 16.2 cm without loss of shear area allowing the residual shear force to be clearly established. It was found from previous research that the residual shear level of most geotextiles can not be reliably established until horizontal movements in excess of 10 mm have been induced (3). The shear force is applied by a variable speed electric motor through a positive buttress thread drive. The vertical load is applied through a vertical frame and lever system. Testing speed could be controlled up to 7 mm/min corresponding to a motor speed of 1200 rpm. Figure 1 shows the plan and section of the equipment.

Geotextiles

There are several types of geotextiles available for soil reinforcement. These types are: 1) Woven, 2) Non-woven, and 3) Mesh. For this investigation, only non-woven geotextiles were considered. Five geotextiles from three different manufacturers were tested. The properties of these geotextiles including the manufacturer's name, material composition and treatment are given in Table 1. All data were furnished by the manufacturers.

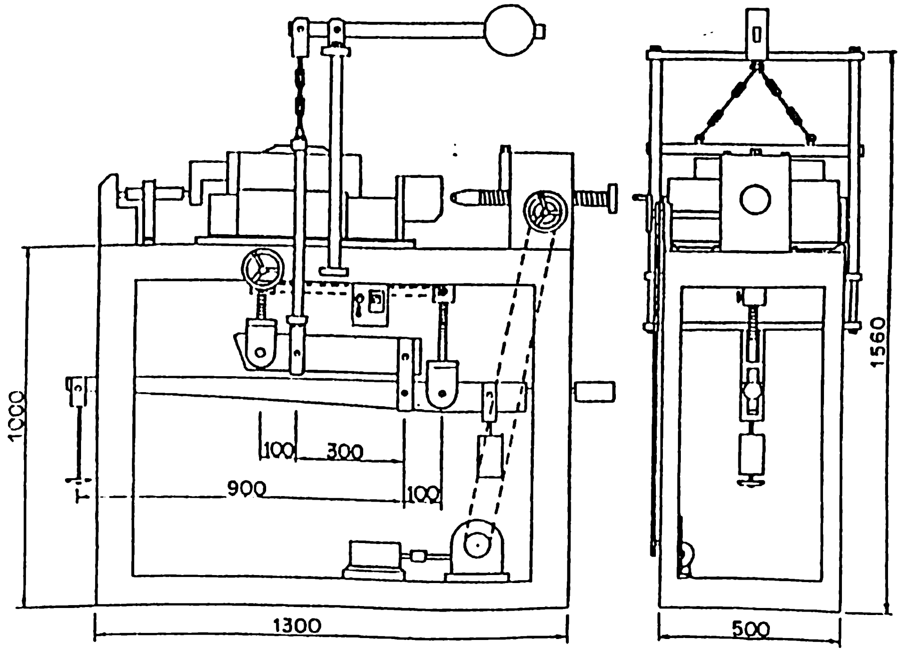


Figure 1. Large Direct Shear Testing Machine; all dimensions are in centimeter.

Sand

The soil used was the Toyoura sand, widely used in research and as a standard sand in Japan. The properties of this sand are listed in Table 2. Standard direct shear tests results for loose and dense Toyoura sand are given in Figure 2.

Table 1. Properties of Geotextiles Tested

GEOTEXTILE NO.	A	B	C	D	E
MANUFACTURER	Toyobo	Toyobo	Mitsui	UNICHIKA	UNICHIKA
PRODUCT NO.	T-4103 P105	T-4131 N105	R-90K	RP-110BKA	RN-4508KE
MATERIAL	POLYESTER	POLYESTER	POLYPROPYLENE	POLYESTER	POLYESTER
TREATMENT	HEAT-BONDED	NEEDLE-PUNCHED	–	–	NEEDLE-PUNCHED
UNIT WEIGHT (g/m)	95	135	500	110	420
THICKNESS (mm)	0.72	1.5	6.0	0.8	4.0
TENSILE STRENGTH (kg/5cm) LONGITUDINAL	30	40	26	30	80
TENSILE STRENGTH (kg/5cm) TRANSVERSE	20	30	16	–	–
TEAR STRENGTH (kg) LONGITUDINAL	2.5	8.5	22	4.0	30.0
TEAR STRENGTH (kg) TRANSVERSE	4.5	9.5	30	–	–

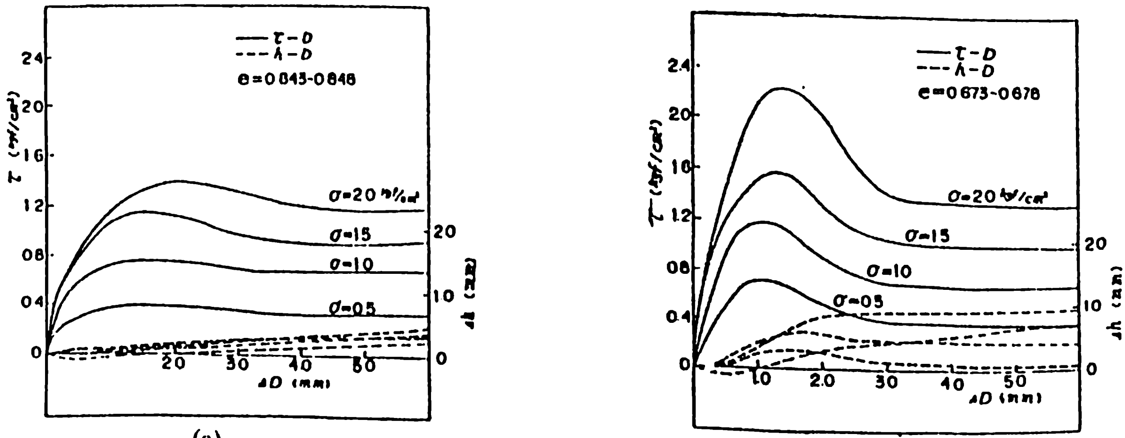
TESTING PROCEDURE

The lower box of the large direct shear machine was fitted with a stack of wooden boards and the geotextile was glued to the topmost wooden board using a commercial adhesive agent. The upper box was then placed in position over the geotextile. Sand was carefully poured in the upper box in three layers. For each layer, the sand was compacted and the top surface levelled.

A normal load was applied to the sand-geotextile system and the sand was allowed to settle. Application of the shear force commenced after settlement of the sand virtually ceased. A shearing displacement of 0.5 mm/min was used. Measurements were made of the shearing force, and horizontal and vertical displacements.

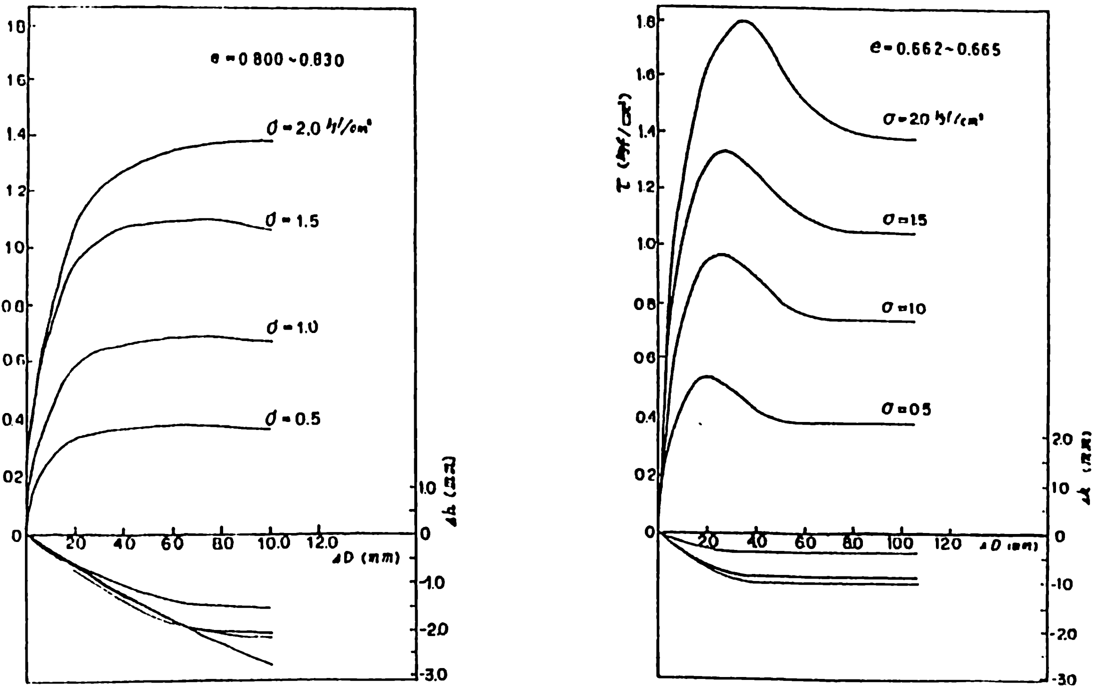
Two sets of tests were made for each type of geotextile. One test was for loose sand; another for dense sand. Loose and dense sand densities were attained by careful placement and compaction of the sand on the upper box.

To determine the angle of friction for each type of geotextile, normal loads of 0.5, 1.0, 1.5 and 2.0 kg/cm^2 were applied for each set of tests. Standard direct shear tests were also performed using the Toyoura sand so that comparisons can be made of geotextile soil friction to that of soil alone.



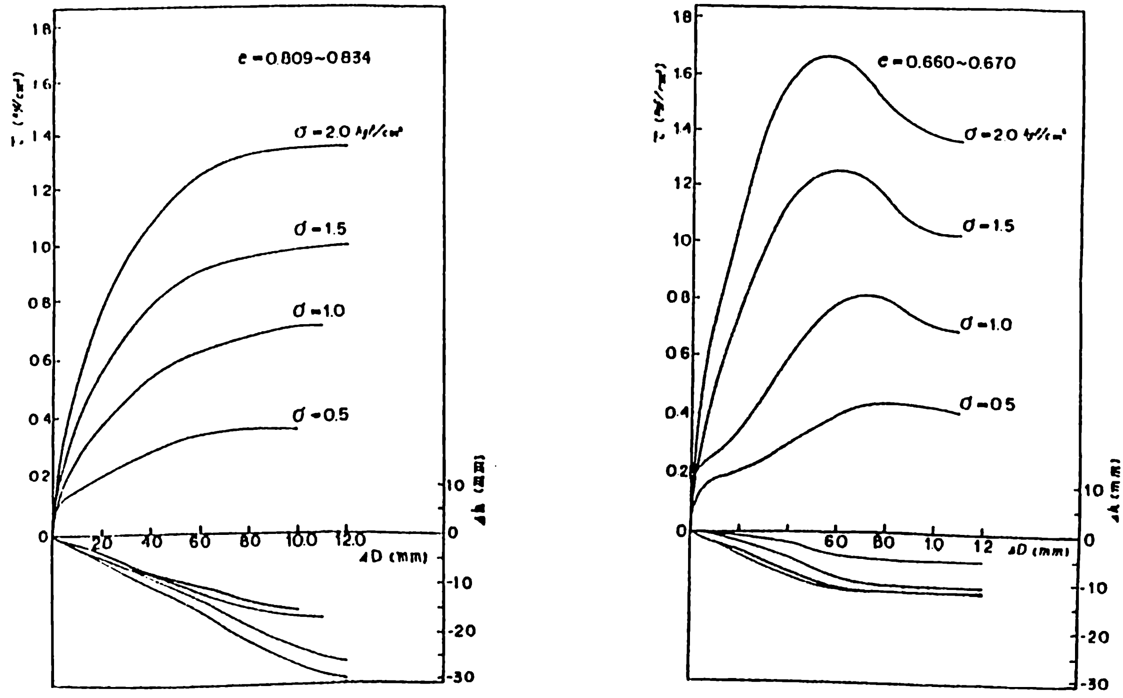
(a) (b)

Figure 2. Direct Shear Stress-Volume Change-Displacement Relationship of Toyoura Sand
a) loose, b) dense



(a) (b)

Figure 3. Shear Stress-Volume Change-Displacement Relationship of Geotextile A-Sand Interface
a) loose sand, b) dense sand



(a) (b)

Figure 4. Shear Stress-Volume Change-Displacement Relationship of Geotextile C-Sand Interface
a) loose sand, b) dense sand

Table 2. Properties of Toyoura Sand

SPECIFIC GRAVITY	2.67
GRAIN DIAMETER 10% PASSING (mm)	1.7
GRAIN DIAMETER 60% PASSING (mm)	3.0
COEFFICIENT OF UNIFORMITY	1.8
MINIMUM VOID RATIO	0.65
MAXIMUM VOID RATIO	1.00

TEST RESULTS AND DISCUSSIONS

The shearing stress-volume change-displacement curves obtained from the standard direct shear tests of loose (void ratio, e = 0.84 - 0.85) and dense (void ratio, e = 0.67 - 0.68) Toyoura sand are given in Figure 2. It can be seen from these results that loose Toyoura sand does not have a well defined peak strength while a densely compacted sand exhibits a sharp peak strength followed by a decrease of the stress to the residual strength level indicated by a steady value of shear stress. During shearing, the sand underwent large volume expansion in both the loose and dense states. The shearing behavior of Toyoura sand is typical of granular soils.

Typical tests results of direct shear tests on geotextile-sand friction for both loose and dense sand are shown in Figures 3-4. The shear stress-displacement curve of the interface of sand and geotextiles A and D are similar to that of sand itself. The interface of geotextiles B, C and E and dense sand exhibit a softening behavior at low normal stress levels. The change in the shape of the shear stress-displacement curve, indicated by a slight decrease or softening in shear resistance, for these geotextiles could be attributed to the local failure of the geotextiles. It should be noted that geotextiles B, C and E are much thicker than geotextiles A and D. Moreover, this phenomenon of local failure is more pronounced in geotextiles C and E which are 5.0 mm and 4.0 mm thick,

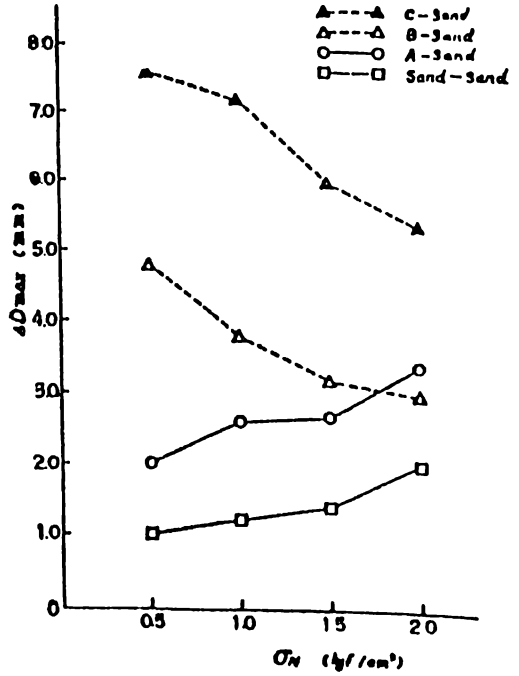


Figure 5. Displacement at Peak Stress for Different Normal Stress Levels

respectively, than in geotextile B which is only 1.5 mm thick. At higher normal stress levels the interface behavior of geotextiles B, C and E tend to resemble that of sand alone.

For dense sand, the displacement at peak stress for thin geotextiles (A and D) and sand alone is smaller at low normal stress levels and increases with increasing normal stress. For thicker geotextiles the opposite is true. These results are illustrated in Figure 5. It is possible, however, that for thick geotextiles the displacement at peak stress could increase with increasing normal stress after a certain level of normal stress.

The volume change-displacement relationship for the interface of all types of geotextiles and loose or dense sand exhibit decrease in volume during shearing. This is unlike that of sand alone which shows large volume expansion during shearing.

The angle of friction based on peak shear stress, ϕ_p, and on residual stress, ϕ_r, for soil alone and for geotextile-soil interface are given in Table 3. The angle of friction based on peak stress is determined by plotting normal stresses versus peak shear stresses for all normal stresses and passing a straight line through the plotted points. Angle of friction based on residual strength is determined by plotting normal stresses versus residual stresses. In many reinforcing applications, the friction between soil and geotextile is mobilized only after significant slip or relative movement between soil and geotextile has occurred. Thus, the residual soil-geotextile friction is essential for the evaluation of the reinforcing effect of geotextiles.

Table 3. **Comparison of Angle of Friction Based on Peak Stress and Residual Stress**

	ANGLE OF FRICTION BASED ON PEAK STRESS ϕ_p		ANGLE OF FRICTION BASED ON RESIDUAL STRESS ϕ_r	
	LOOSE	DENSE	LOOSE	DENSE
SAND-SAND	38	49	35	34
A-SAND	34	40	34	34
B-SAND	33	40	33	34
C-SAND	33	40	33	34
D-SAND	32	38	32	34
E-SAND	34	34	34	33

For comparison, the ratio of angle of friction, based on peak and residual strength, of interface behavior to that of soil alone may be computed. The range of values are as follows:

loose:

$$\frac{\phi_p(\text{geotextile-sand})}{\phi_p(\text{sand-sand})} = .84 - .90 \qquad \frac{\phi_r(\text{geotextile-sand})}{\phi_r(\text{sand-sand})} = .92 - .97$$

dense:

$$\frac{\phi_p(\text{geotextile-sand})}{\phi_p(\text{sand-sand})} = .69 - .82 \qquad \frac{\phi_r(\text{geotextile-sand})}{\phi_r(\text{sand-sand})} = .97 - 1.0$$

CONCLUSION

In this investigation the frictional behavior of non-woven geotextiles-sand interface was studied. Geotextiles studied in this research exhibited shear stress-displacement behavior that are essentially similar to that of sand alone in both the dense and loose conditions, except for the interface behavior of thick geotextiles and dense sand. Local failure of the thick geotextiles tested occurred during shearing with dense sand at low normal stress. The similarity of the frictional behavior of geotextile-sand interface to that of sand-sand friction can be attributed to the possible embedment of the sand grains in the surface of the geotextile such that sand-sand friction developed during shearing. The angle of friction based on residual strength of geotextile-sand interface are essentially the same as that of sand-sand. On the other hand, the ratio of the angle of friction based on peak strength of geotextile-sand to that of sand-sand are significantly different. The lowest value of this ratio is 0.69.

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