International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
© 1988 Balkema, Rotterdam. ISBN 90 6191 820 0

Mobilization of soil-geofabric interface friction

K.Makiuchi & T.Miyamori
Nihon University, Japan

ABSTRACT: In order to assess frictional properties of soil-geofabric system, laboratory investigations were made on several types of fabrics in contact with cohesive and non-cohesive soils using a friction testing apparatus. This paper presents the concept of displacement-induced mobilizing process of frictional resistance on the interface between fabrics and soils. Results indicate that the mobilized friction parameters of fabric are mostly lower than those of soil itself and affected by surface texture and thickness of fabrics, and type, density and moisture content of soils.

1 INTRODUCTION

The use of geofabric in earthworks is now widely accepted as an additional tool for reinforcing unstable soil-structures. The surface of a geofabric placed in a soil mass forms a discontinuous plane causing a slippage or a movement on the interface. In the theoretical analysis and the rational design of a reinforced earth, to estimate the effect of geofabric-soil friction is necessary for a soil reinforcement application, and friction parameters such as the coefficient of friction must be determined as an essential and indispensable factor. Emphasis is placed, however, on the lack of basic geotechnical knowledge about this interface friction mechanism.

The objective of this study, therefore, is to investigate fundamental behaviour of the soil-goefabric system. The frictional resistance is largely dependent upon a shear displacement. According to the Coulomb-Navier's shear law, the friction is obtained in terms of a friction angle and an apparent cohesion. These friction parameters can be described as a function of relative displacement.

Frictional characteristics between soils and geofabrics will depend on the geofabric's material composition, treatment, thickness and surface texture, and also the soil's type and condition. In this test, five different types of woven and non-woven geofabrics are used for cohesive and non-cohesive soils with their conditions varied.

There are several kinds of friction testing methods[1) 2)] such as a pulling-out test. In this study an one-face test method was employed using a large shear testing apparatus.

2 APPARATUS

A large direct shear testing apparatus which consists of an upper and a lower boxes was used in measuring the friction between soils and geofabrics. The upper box has a cross-sectional area of 1000 cm^2 (31.6 x 31.6 cm), and its maximum available depth is 12 cm. The shearing is applied by pushing the upper box over the geofabric fixed to the larger lower box (47.8 cm long, 40.5 cm wide) with a height of 12 cm. Figure 1 shows the sectional view of the shear box.

The equipment is capable of giving a shear displacement of up to 62 mm without reducing the shear area. To apply horizontal shear loads, a variable speed electric motor is employed and the testing speed can be controlled 0 to 7 mm/min. Vertical

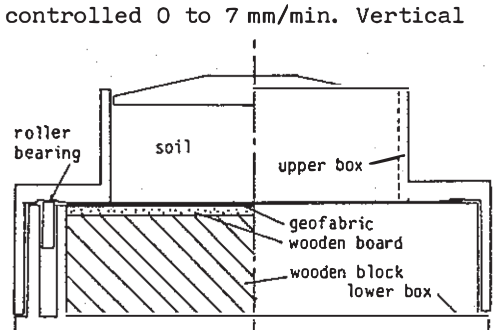


Fig.1 Cross-sectional view of the friction test apparatus

Table 1 Properties of geofabrics

	fabric	material	treatment	thickness (mm)	unit mass (g/m^3)
non-woven	N - 1	polyester	needle-punched & heat bonded	0.72	95
	N - 2	polyester	needle-punched	2.2	135
	N - 3	polypropylene	needle-punched	4.0	500
	N - 4	polyester	needle-punched & heat bonded	0.8	110
	N - 5	polyester	needle-punched	4.0	420
woven	W - 1	polyester	plain weave	0.25	160
	W - 2	polyester	plain weave	0.35	235
	W - 3	polyester	twill weave	0.70	450
	W - 4	polyester	triple weave	3.00	1100

Table 2 Properties of river sand

Soil particle density (g/cm^3)	2.67
Maximum grain size (mm)	2.0
Coefficient of curvature	1.75
Uniformity coefficient	0.72
Maximum void ratio	1.00
Minimum void ratio	0.65

Table 3 Properties of cohesive soil

Soil particle density (g/cm^3)	2.74
Maximum grain size (mm)	4.76
Liquid limit (%)	130.7
Plasticity index	28.8
Natural water content (%)	80-126

confining loads are imposed through a loading frame and a double lever system.

A conventional standard shear testing apparatus with a diameter of 60 mm and a thickness of 20 mm was also used for estimating frictional properties of the sand and the cohesive soil.

3 MATERIALS

For this investigation, five types of non-woven geofabrics and four woven geofabrics of different material components, treatment and thickness were tested. Basic material characteristics of these geofabrics are listed in Table 1.

The granular soil used was a poorly graded and sub-angular river sand from which the coarse and the fine particles were removed. The properties of the sand are shown in Table 2. The sand was tested in both air-dried and wetted conditions. The moisture content of the wet sand specimen was controlled about 9 %.

The cohesive soil used for the test was a volcanic ash soil (so-called Kanto loam). The physical properties of the cohesive soil are given in Table 3.

4 TEST PROCEDURE

The lower shear box was filled with a spacer of rigid wood of 10 cm height, and a hard wooden board of 2 cm thickness on which a test specimen, geofabric, was glued with a commercial adhesive agent was rested. The upper box was then placed in position over the geofabrics.

In the test for loose sand, the air-dried sand was lightly poured in the upper box. When testing the dense sands, both the air-dried and wetted sands were put into the upper box in five layers, and the sands were compacted by tamping.

The cohesive soil was compacted in the conditions of water content of 102 % and 3 layers, 225 tampings per layer of which the compaction effort was determined by Proctor's optimum moisture content.

After the loading plate was placed on it, a normal load was applied to the soil-fabric system till the soil was consolidated. Application of the shear force commenced after the vertical settlement was completed.

The rate of shearing was about 0.5 mm/min. Measurements were made of the horizontal and the vertical displacements, and the friction force exerted in the system during shearing.

To determine the friction angle and cohesion component for each type of geofabrics, normal stress of 50, 100, 150 and 200 kPa were applied for each set of tests.

Standard direct shear tests of 6 cm in diameter and 2 cm in thickness were also performed with both the sand and the cohesive soil in order that comparisons were made between the soil-geofabric interface friction and the internal friction of soil alone.

5 FRICTION-DISPLACEMENT RELATION

Figure 2 shows typical results of the friction-shear displacement relationships between soils and woven fabrics.

It is found that those relationships are markedly affected by combination of soils and fabrics, moisture and compaction conditions of soils, and confining stress level. Similar tendencies of the relation are also observed in the cases of other soil-fabric interfaces.

Loose dry dands :

In the cases of loose dry sand (density index: I_D = 0.46 - 0.57) - woven fabric interfaces as shown in Figs.2(a) and (d), the friction increases gradually with the displacement and a high confining stress delay the appearance of its peak friction. Thin woven fabrics and all non-woven fabrics show monotonous smooth curves and do not have a well defined peak value, whereas thick woven fabrics develop somewhat a sawtoothed pattern in the relations.

Dense dry sands :

As shown in Figs.2(b) and (e), the friction curve between woven fabric and densely compacted dry sand (I_D = 0.94 - 1.0) has obviously a sharp peak and then the friction decreases to the residual stress level indicated by a steady value after the displacement in excess of 3-5 mm.

It is interesting to note that friction-displacement relations exhibit smooth curves in the case of thin woven fabrics and non-woven fabrics[3]; while a friction curve of thick woven fabric-dense dry sand system fluctuates during shearing. This irregular variation of the curve becomes predominant with increase in thickness of geofabrics and stress level.

It is considered that this sawtoothed friction curve is caused by interlock-slip phenomena arising from the reiteration of forming and collapsing of bridging between the rough woven surface and sand particles, and of arching action of particles. Moreover, this phenomena seem probable from the performance of wave pattern occuring cyclically with a constant amplitude over a wide range of residual stress.

Several sharp mini-peal points of the friction curve develop over and over again until the friction reaches to its maximum value. From these figures it can be seen that each rising-up curve seems to have the same gradient, and the degree of fall of friction force is almost half of the mini-peak value.

Wet sand :

Figures 2(c) and (f) show the friction-displacement relation between woven fabric and dense wet sand of the moisture content of 9±1 % and the density index I_D = 0.86 - 0.94. These frictional resistance curves demonstrate the wave-shape pattern which is similar to those of the dense dry sands for both woven and non-woven fabrics.

Cohesive soil :

An example of friction curves for the woven fabric-cohesive soil system is illustrated in Fig.2(g). It may be seen that no obvious peak friction is given during shearing. Similar friction-displacement response is obtained for all geofabrics.

6 MOBILIZATION OF INTERFACE FRICTION

6.1 Determination of mobilized friction

Figure 3 shows a typical set of the confining normal stress and frictional stress relation. According to Coulomb-Navier's friction rule, a straight line through the plotted data can be obtained in good fitness, relevant to each displacement.

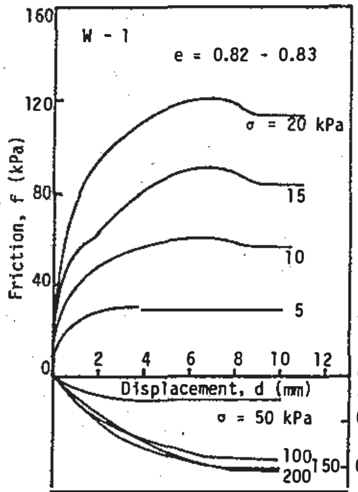
As parameters indicative of the frictional resistance of the system at a specified shear movement, both a friction angle, ϕ, and an apparent cohesion, c, are determined by the gradient, $\phi = \arctan(f/\sigma)$, and the intercept, respectively. It is observed from the test results that the intercept component, c, is negligible for all sand interfaces.

6.2 Mobilized friction parameters

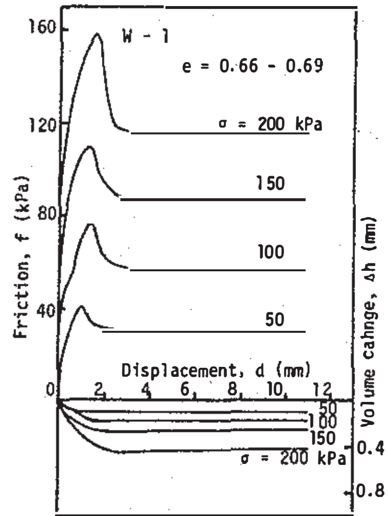
The friction angle and the cohesion intercept are expressed as a function of displacement. In the cases of sand-fabric interfaces shown in Figs.4(a) and (b), it is observed that denser the sand, sharper the friction curve, and higher the peak friction. Further observation reveals that the residual friction are almost equal, and the similar pattern can be obtained for other goefabric-sand systems.

As shown in the examples in Fig.4(c), both the angle and the intercept of cohesive soil increase in proportion to a displacement, without any ultimate value. This tendency is the same as all cases of fabric-cohesive soil interfaces.

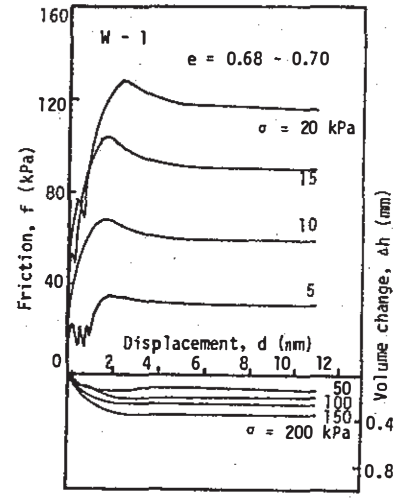
It is not reasonable to calculate the mobilized parameter of woven fabric-sand interfaces since their friction curves displays the sawtoothed fluctuation, therefore the friction angle at peak and residual states are illustrated in Fig.5. It is found that increasing of sand's void ratio, e = 0.80 to 0.65 reflects in increasing of the angle peak friction, $\phi \doteq 5 - 10°$; however no significant difference in the angles of residual friction is observed. It is also found that thicker the fabrics, higher the friction angle.



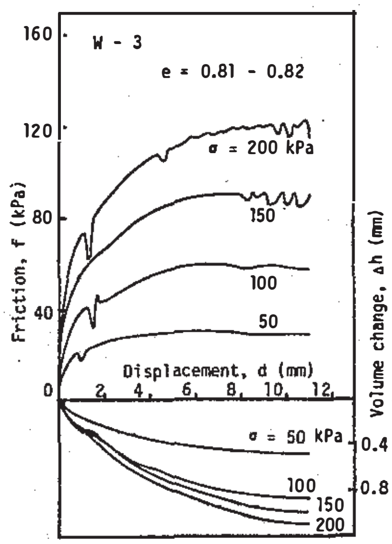
(a) Thin woven fabric/ loose dry sand



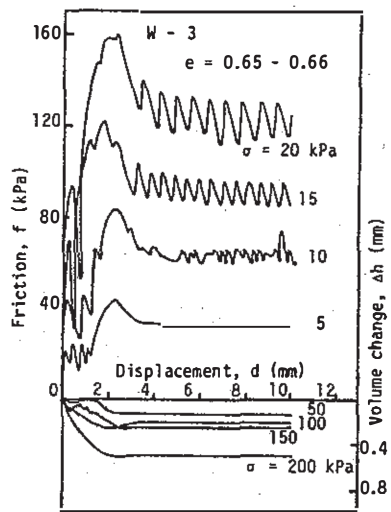
(b) Thin woven fabric/ dense dry sand



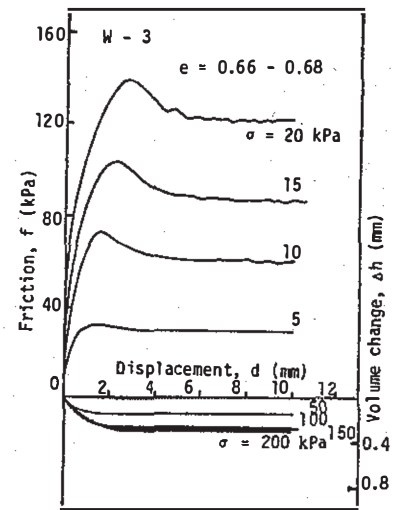
(c) Thin woven fabric/ wet sand



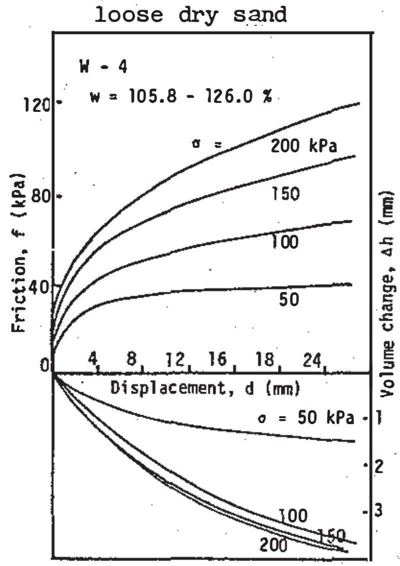
(d) Thick woven fabric/ loose dry sand



(e) Thick woven fabric/ dense dry sand



(f) Thick woven fabric/ wet sand



(g) Woven fabric/ cohesive soil

Fig.2 Friction-displacement-volume change relationships

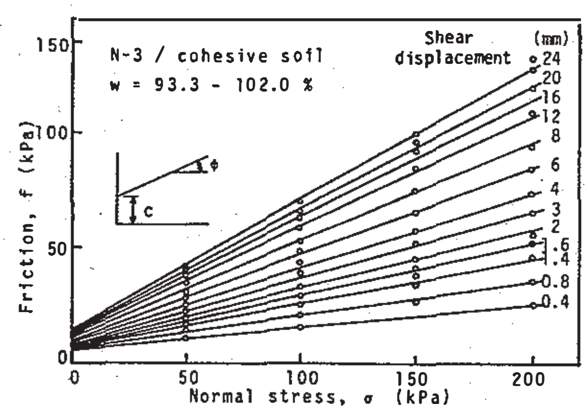
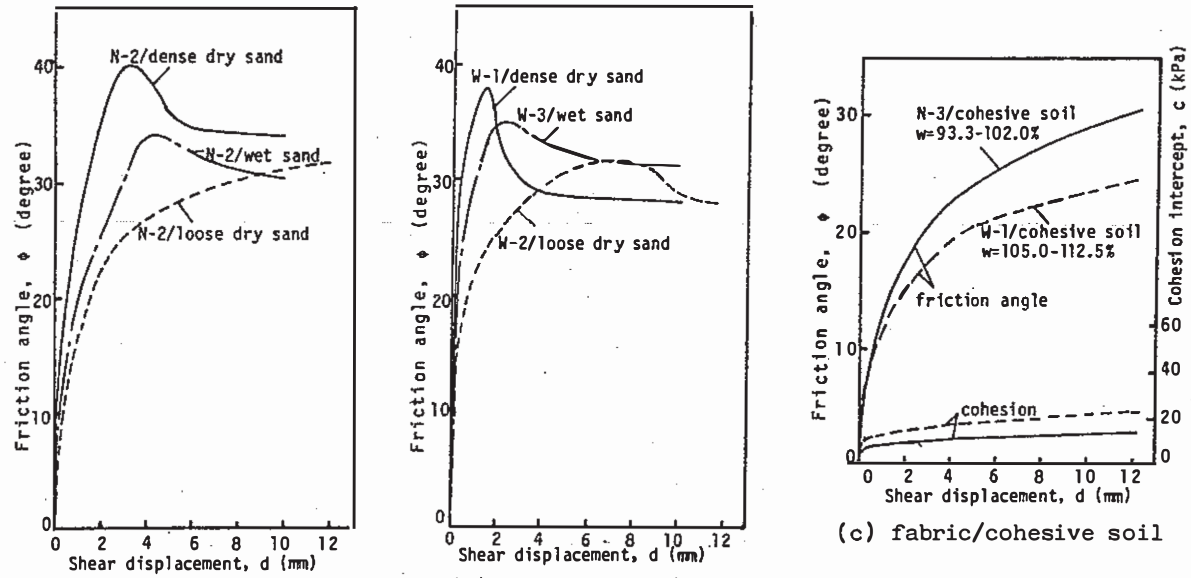


Fig. 3 Determination of mobilized friction parameters



(a) Non-woven fabric/sand (b) Woven fabric/sand (c) fabric/cohesive soil

Fig.4 Mobilization of friction parameters

6.3 Ratio of friction parameters

In an attempt to evaluate the mobilized frictional resistance of geofabrics at the specified deformation, the ratios of the mobilized friction of soil-fabric interface of ϕ (soil/fabric) to the mobilized internal friction angle itself ϕ (soil/soil) are calculated.

Figures 6(a) to (c) indicate the variation in the ratios for nonwoven fabric-sand interfaces. The ratio increases as a shear displacement develops. It appears that a dense sand or a thin fabric leads to an increase in the mobilizing ratio.

The ratios of friction parameters for woven and nonwoven fabrics adjacent to cohesive soil are illustrated in Fig.7. The ratios of friction angle are mobilized in the similar manner to the cases of sands. On the contrary, the ratio of cohesion intercept decreases markedly at the initial stage following the slight recovering with increase in deformation.

Figure 8 presents the ratio of friction angle at the peak and residual states for woven fabric-sand systems. The co-

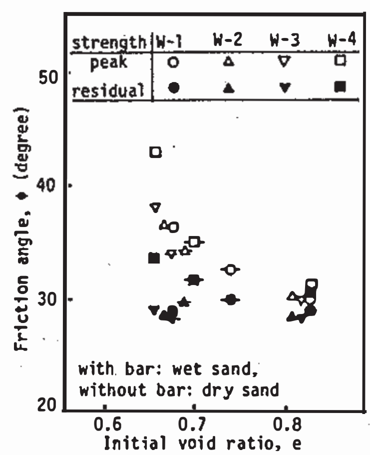
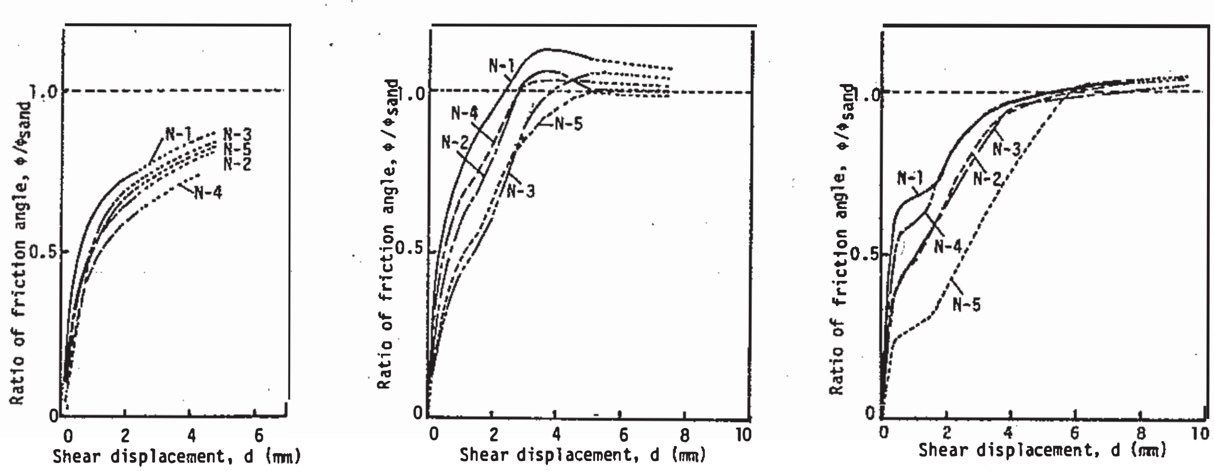


Fig. 5 Relation between void ratio and friction angle of woven fabric-sand interface



(a) Loose dry sand (b) Dense dry sand (c) Wet sand

Fig.6 Friction angle ratio of non-woven fabric – sand system

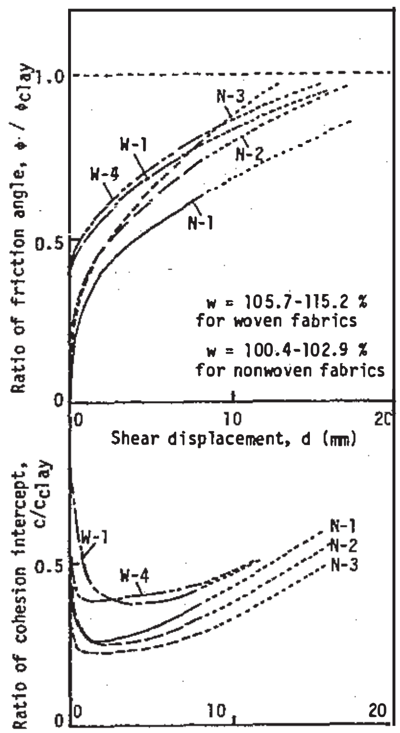


Fig. 7 Ratio of mobilized friction parameters for cohesive soil

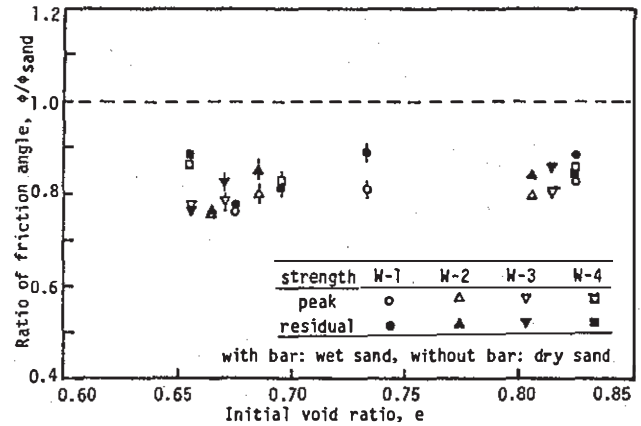


Fig.8 Relationships between void ratio and friction angle ratio of woven fabric

hesion component is zero in these cases. It is clearly demonstrated that the ratios are not influenced from the sand's moisture content and void ratio, and provides the value at range of 0.75 to 0.90. These values coincides with the reduction rate 80 to 90 % of the coefficient of friction of geotextiles which is now generally accepted in practice. However, it should be recognized that the ratio may be adopted under restrictions on peak or residual friction.

7 CONCLUSIONS

Displacement-induced mobilization process of frictional resistance was investigated using a geofabric - soil interface friction testing equipment. Results obtained in this study are summarized as follows.

1) Mobilized friction on the fabric-soil interface is much lower than that of soil itself in a range of small displacement, but increases as the displacement develops and approaches finally toward the friction value of the soil itself.

2) Denser the sand, higher the friction angle for woven and non-woven fabrics.

3) Increasing in moisture content of sand delays the appearance of peak friction of the interface.

4) A friction-displacement curve of woven-sand system displays an irregular sawtoothed fluctuation caused by interlock-slip phenomena. This behaviour is proportional to fabric's thickness, sand's density and confining stress level. This does not occur in the cases of non-woven fabrics and cohesive soils.

5) The ratio of mobilized friction angles for a woven fabric-sand interface, at both peak and residual states, has a constant value of 0.75 to 0.90, regardless of void ratio, moisture content and type of woven fabric.

6) Friction curves of cohesive soil-fabric systems demonstrates monotoneous increasing curves without any peak, and the ratios of mobilized friction parameters of woven fabrics are slightly higher than those of non-woven one.

REFERENCES

1) Myles, B. 1982. Assessment of soil fabric friction by means of shear. Proc. of 2nd Int. Conf. on Geotextiles., pp.787-792.
2) Nishigata, T. & I.Yamaoka 1986. Pull-out friction test of geotextiles. Proc.of 1st Sym. on geotextiles, pp.41-46, Japan Chapter I.G.S. (in Japanese).
3) Miyamori, T., S.Iwai & K.Makiuchi 1986. Frictional characteristics of non-woven fabrics. Proc. of 3rd Int. Conf. on Geotextiles, pp.701-705.