SHAKING TABLE TESTS FOR GEOSYNTHETIC INTERFACES

A. M. Lahlaf
GEI Consultants, Inc., Winchester, MA, USA
(formerly Northeastern University, Boston, MA, USA)

M. K. Yegian
Chairman, Civil Engineering Department
Northeastern University, Boston, MA, USA

ABSTRACT

In recent years significant progress was made in the field of geosynthetics. Recent research efforts have been targeted mainly at investigating the behavior of geosynthetic-geosynthetic and geosynthetic-soil systems under static loads.

This paper presents the results of a research program undertaken to investigate the dynamic interface shear strength properties of geosynthetic systems using shaking table tests. Tests were performed on geomembrane-geotextile and geomembrane-geomembrane interfaces for both dry and wet conditions.

The results indicate that during dynamic tests, there is a limited shear stress, hence a limited acceleration, that can be transmitted from one geosynthetic to another. Beyond this acceleration, relative displacement is initiated between the two geosynthetics. These limiting accelerations corresponding to different geosynthetic interfaces are presented. Also, for the geosynthetics used, there was no appreciable difference between the dynamic interface friction angles measured at the onset of sliding and those from static tests. Therefore, shaking table tests can be adequately used to provide values for dynamic as well as static interface friction angles. It was also found that handling of the geomembrane has a significant effect on the measured static and dynamic friction angles. A mere touch of the geomembrane surface placed enough perspiration on it that the friction angle was lowered significantly. The orientation of the geomembrane with respect to the direction of motion of the shaking table, the normal stress, and the frequency of motion were found to have no effect on the measured dynamic friction angles. Wetting of the geosynthetic interface was found to slightly reduce the dynamic friction angle. Finally, the applicability and limitations of using a shaking table to measure dynamic friction properties of geosynthetics are discussed.

INTRODUCTION

Significant progress was made in the field of geosynthetics during the last decade. Recent research efforts have been targeted mainly at investigating the behavior of geosynthetic-geosynthetic and geosynthetic-soil systems under static loads, while the dynamic behavior of such systems is not yet adequately addressed. The results of extensive static tests on the interface shear strength properties of geosynthetics have been reported in the literature. Investigations of the dynamic interface shear strength properties of geosynthetics have been limited.

This paper presents the results of a research program undertaken to investigate the dynamic interface shear strength properties of geosynthetic systems using shaking table tests. The shaking table tests consisted of subjecting a concrete or a steel block, the base of which was covered with a geosynthetic that was resting freely on another geosynthetic fixed to the table, to a periodic motion. The calculation of the angle of internal friction between geosynthetics was based on measurements of the accelerations of the block. Tests were performed on geomembrane-geotextile and geomembrane-geomembrane interfaces for both dry and wet conditions.

While the concept of using a sliding block to determine the dynamic interface shear properties is in essence a simple one, a thorough understanding of the nature of sliding friction in general, and the factors affecting it is an essential component toward developing a better understanding of the dynamic interface shear properties of geosynthetics. The subject of friction between moving bodies has received great attention from researchers for a long time. Deresiewicz (1986) reported that in 1699 Guillaume Amontons introduced the idea that the frictional force is proportional to the normal force. Also, one of the earliest comprehensive testing programs was undertaken by Charles Augustin Coulomb in 1785. He determined that factors that can affect sliding friction include: the nature of the materials in contact and their coating, the surface area, the normal force, the time of contact before motion begins, and the relative velocity. More recent research indicates that additional parameters such as temperature (West and senior, 1962), and sliding distance (Sung and Suh, 1979) can also affect sliding friction. In this research some of the factors listed above were investigated, and the results are reported.

Finally, in this paper the applicability and limitations of using a shaking table to measure dynamic friction properties of geosynthetics are discussed.

TEST APPARATUS

Figure 1 shows a schematic of the shaking table facility used to evaluate the dynamic interface properties between geosynthetics.

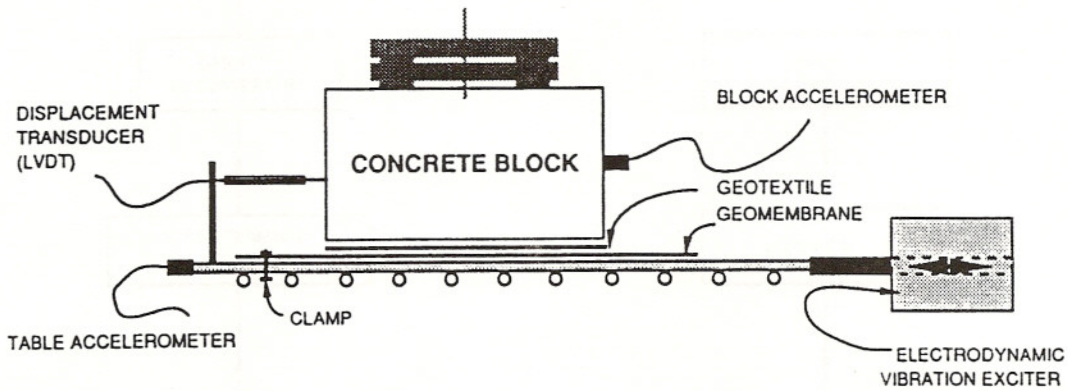

Figure 1. Shaking Table Apparatus

The shaking table apparatus consisted of a vibration exciter connected to a rigid aluminum table, which was mounted on frictionless linear bearing pillow blocks, and moving on two stainless steel guide rails. The vibration exciter has a capacity of 1.11 KN (250 lb), a stoke of 2.54 cm (1 in.), and a usable frequency range of 5000 Hz. The dimensions of the table are 91 cm (3 ft) in the direction of motion, and 81 cm (2.65 ft) in the transverse direction. The results presented herein correspond to a periodic excitation of the vibration exciter.

A concrete block with weights placed on top of it, rested on a segment of a geotextile which in turn rested on a large piece of geomembrane that was fixed to the shaking table. When a wet condition was required, the block-geosynthetic system was placed in a tub full of water and fixed to the shaking table.

The acceleration of the table and that of the block were measured simultaneously by piezometric accelerometers. The output signals from the accelerometers were fed through charge amplifiers. The displacement of the block relative to the table was recorded using a linear variable displacement transducer (LVDT) attached to the shaking table.

For data acquisition, the outputs of the two accelerometer-amplifiers units and the LVDT were fed into a personal computer via a screw terminal board as shown in Figure 2. Upon conversion of the signals from analog to digital, the data was retrieved and analyzed by commercially available software.

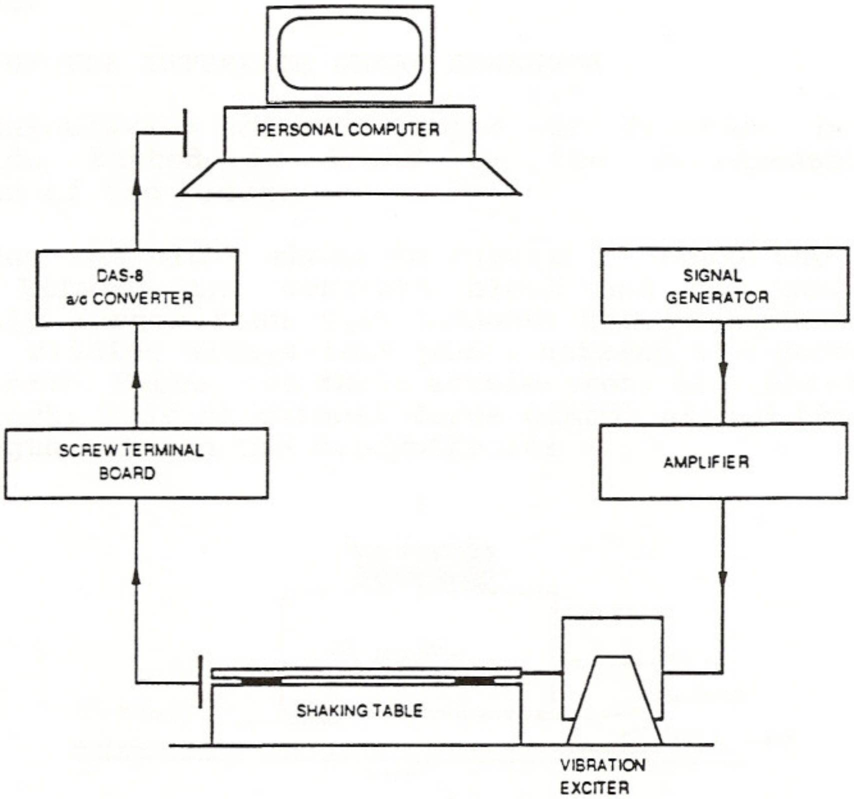

Figure 2. Schematic of Test Apparatus and Data Acquisition System.

The geosynthetics used in this research consisted of a hard smooth high density polyethylene (Gundle HD60), and a nonwoven geotextile (Polyfelt TS700).

TESTING PROCEDURE

After the desired geosynthetic interface was selected, the concrete block and the weights were placed atop it. The vibration frequency was set to 2 Hz, and the incoming current to the vibration exciter from the signal generator was set to cause the table to move with a certain acceleration. Measurements of the 3 channels were recorded immediately after the table started its motion. The measurements were made for a duration of 4 seconds. The sampling frequency for the 3 channels was 100 Hz, i.e., 100 samples per second.

After one test was finished, the data was stored for later analysis. The incoming current to the vibration exciter was increased so as to increase the acceleration of motion of the table, and another test was performed. This procedure was repeated for each test.

For the tests where the table acceleration was large enough to cause sliding of the block, the block was repositioned at the start of each test.

EVALUATION OF THE INTERFACE SHEAR STRENGTH

The calculation of the angle of friction between the geosynthetics tested is based on the measurement of the acceleration of the block.

Consider the block shown in Figure 3. Since the frictional resistance between the concrete block and the geotextile is significantly larger than that between the geomembrane and the geotextile, sliding always took place between the geotextile and the geomembrane. Hence, the table accelerates, it transmits a force F to the block. This frictional force cannot exceed the interface shear strength between the geosynthetics

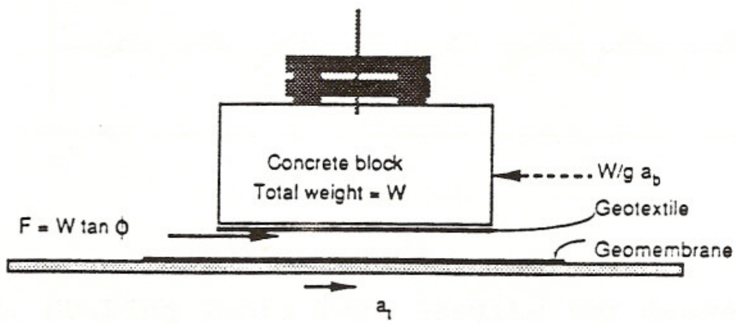

Figure 3. Forces Acting on the Block.

$$F = W \tan\phi \qquad (1)$$

where
W is the weight of the block and added weights
f is the interface friction angle between the geosynthetics.

The force F causes the block to move with an acceleration given by

$$W \tan\phi = \frac{W}{g} a_b$$

or

$$a_b = \tan\phi \, g \qquad (2)$$

Equation 2 implies that during tests where the table acceleration is smaller than the limiting block acceleration given by equation 2 the block and the table move together ,i.e., the table and the block accelerations are equal as shown in Figure 4. When the acceleration of the table exceeds the limiting block acceleration, however, relative displacement between the block and

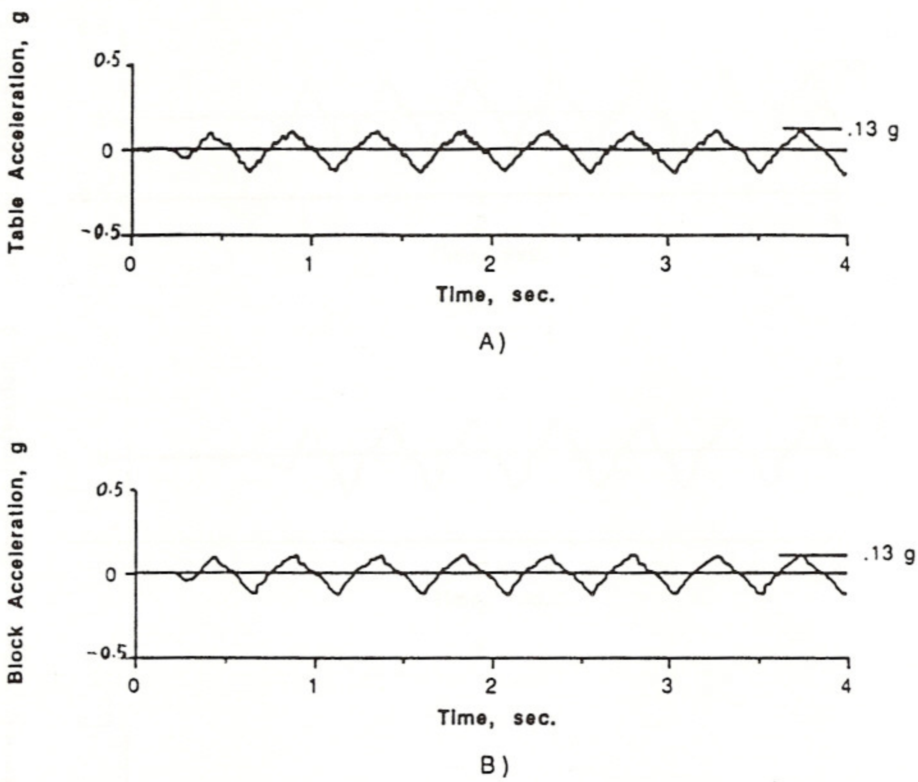

Figure 4. Shaking Table Test Results for Geomembrane-Geotextile Interface, Dry Condition,
A) Table Acceleration Record with a Peak Value of 0.13 g.
B) Block Acceleration Record with a Peak Value of 0.13 g.

the table is induced as shown in Figure 5. Thus, measurement of the limiting acceleration of the block can provide the dynamic interface friction angle between the geosynthetics.

$$\phi = \arctan\left(\frac{a_b}{g}\right) \tag{3}$$

TEST RESULTS

Geomembrane-Geotextile Interface

Tests similar to those presented in Figures 4 and 5 were performed for values of peak table acceleration ranging from 0.10 g to 0.40 g. The tests were conducted for a dry geomembrane-geotextile interface condition with a normal stress of 1.2 psi (8.5 KPa), and a frequency of excitation of 2 Hz.

A plot of the peak block acceleration versus the peak table acceleration is shown in Figure 6. The solid lines shown in Figure 6 represent the least square fit of the data. A number of

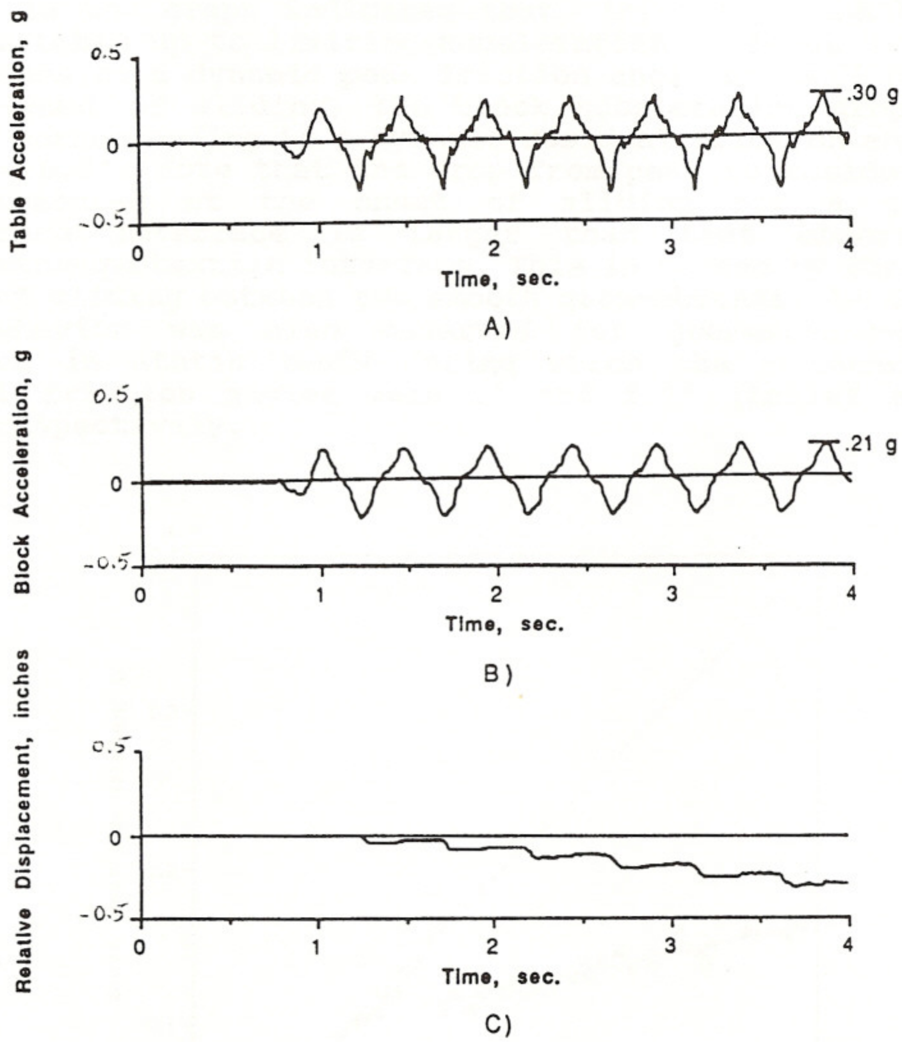

Figure 5. Shaking Table Test Results for Geomembrane-Geotextile Interface, Dry Condition,
A) Table Acceleration Record with a Peak Value of 0.30 g.
B) Block Acceleration Record with a Peak Value of 0.21 g.
C) Relative Displacement.

significant observations can be made from these and other similar results. The initial segment that has a slope angle of about 45° confirms that the block initially moves with the table (no sliding occurs between the geomembrane and the geotextile) up to a limiting table acceleration of about 0.20 g. This corresponds to a block acceleration, a_b = 0.20 g, or a friction angle of $\tan^{-1}$ (0.20) = 11.3°. Immediately after sliding of the block is initiated, the block acceleration invariably drops slightly. This reduction is attributed to the residual shear strength of the geomembrane-geotextile system (Mitchell et al. 1990, Yegian and Lahlaf, 1992). The block acceleration associated with the interface residual strength is about 0.19 g. This corresponds to a friction angle of $\tan^{-1}$ (0.19) = 10.7°. These numbers are very similar to those segment in the graph indicates that, initially, the block moves with the table up to limiting acceleration of about 0.14 g. This corresponds to a dynamic peak friction angle of $\tan^{-1}$ (0.14) = 8°. At the onset of sliding, the block acceleration drops to about 0.11 g, corresponding to a dynamic residual friction angle of $\tan^{-1}$ (0.11) = 6.3°. Note that the drop from peak to residual friction angle measured at the onset of sliding for a geomembrane-geomembrane interface is larger than that observed for a geomembrane-geotextile interface. This is caused by the stick-slip nature of sliding between two smooth geomembranes. In fact, stick-slip behavior was also observed for geomembrane-geomembrane interface in static tests during which the measured peak and residual friction angles were 8° and 5.7° (Lahlaf and Yegian, 1991), respectively.

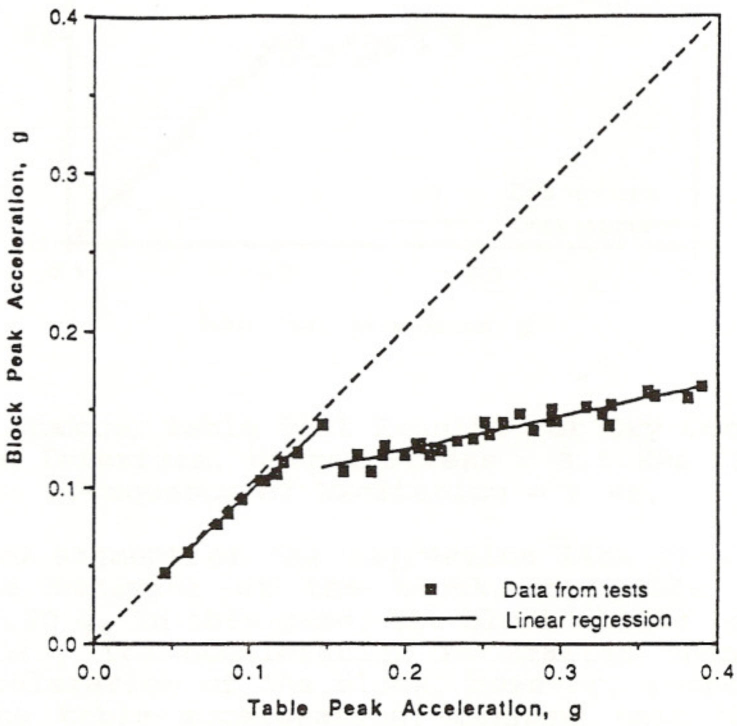

Figure 6. Shaking Table Test Results for Dry Geomembrane-Geotextile Interface, Normal Stress = 8.5 KPa (1.2 psi), Frequency of Excitation = 2 Hz.

Similar to the observation made for the geomembrane-geotextile interface, once sliding occurred along the geomembrane-geomembrane interface, the measured block acceleration increased with increasing table acceleration. When the table acceleration was 0.40 g, the measured block acceleration was about 0.16 g, corresponding to a friction angle of 9.1°.

obtained for the same geosynthetic interface from static interface strength tests obtained by Yegian and Lahlaf (1992).

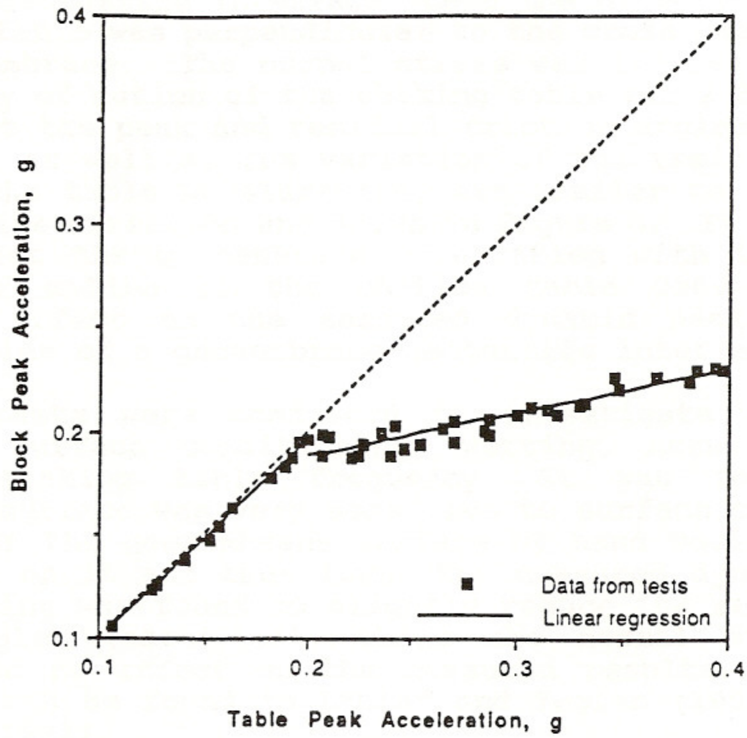

Figure 7. Shaking Table Test Results for Dry Geomembrane-Geotextile Interface, Normal Stress = 8.5 KPa (1.2 psi), Frequency of Excitation = 2 Hz.

The second segment of the regression line shown in Figure 6 represents the behavior of the block for table accelerations greater than 0.20 g. In this case, the block slides relative to the table; therefore, its acceleration is smaller than that of the table. The acceleration of the block, however, increases slightly with increasing table acceleration, meaning that the frictional force, F, transmitted by the block to the table is a function of the table acceleration. This leads to an increase in the residual friction angle, from 10.7° to 13° within the range of table accelerations of 0.20 g to 0.40 g. Such an observation has also been made during other shaking table tests on model retaining walls by Lai (1979) and Jacobson (1980).

Geomembrane-Geomembrane Interface

The results of dynamic tests on a geomembrane-geomembrane interface, conducted under a normal stress of 1.2 psi (8.5 KPa) and an excitation frequency of 2 Hz, are shown in Figure 7. The first

Factors Influencing the Dynamic Interface Friction Angle

To determine if the geomembrane orientation has an influence on the measured dynamic friction angles, tests were conducted on a geomembrane-geotextile interface where the direction of motion of the shaking table was perpendicular to the cross machine direction of the geomembrane. The normal stress was 1.2 psi (8.5 KPa) and the frequency of motion of the shaking table was 2 Hz. The results indicate that the peak and residual friction angles obtained from these tests, as well as the variation of the residual angle with respect to the table acceleration, are similar to those obtained for the machine direction and shown in Figure 6. It is, therefore, concluded that the geomembrane orientation with respect to the direction of motion of the shaking table does not have any appreciable effect on the measured dynamic peak and residual friction angles of a geomembrane-geotextile interface.

Other tests were conducted to investigate the effect of geomembrane surface conditioning, wetting, normal stress, and effect of shaking table frequency. It was found that the geomembrane surface was very sensitive to surface conditioning. A mere touch of the geomembrane surface by hand would place enough perspiration on it and thus lower the measured dynamic interface angles. Wetting was found to slightly reduce the measured dynamic friction angles (about 1°), while the normal stress and the frequency had no effect on the measured results. Details about these tests can be found in Lahlaf and Yegian (1991), and Yegian and Lahlaf (1992).

CONCLUSION

Previous investigations of interface shear strength of geosynthetics have been focused mainly on the static behavior. In the research reported in this paper, dynamic interface shear strength properties of geosynthetics were investigated. For this purpose, shaking table tests were successfully utilized. Shaking table tests offer the advantage of using large representative samples of geosynthetics, especially if field samples need to be tested. It was shown that shaking table tests can provide both static and dynamic friction angles between geosynthetics. During such tests the influence of normal stress, and frequency of motion can be easily studied. In addition, tests can be performed using actual time histories, where not only the response of the system on top of the geosynthetic interface is obtained, but also any change in the frequency characteristics of the transmitted motion is detected.

There are, however, some limitations associated with shaking table tests. These include factors such as: difficulty of achieving a perfectly horizontal table; data acquisition problems and noise in the measured responses; difficulty in adapting the testing procedure for geosynthetic-soil systems because of problems such as densification of soil during testing; and difficulty of achieving very high normal stresses.

Current research is underway at Northeastern University to devise tests for geosynthetic-soil systems, and to improve the shaking table apparatus to allow tests at high normal stresses.

ACKNOWLEDGEMENT

The work described in this paper was partially funded by the Stone and Webster Corporation and the National Science Foundation. This support is greatly appreciated. The authors also extend their gratitude to Polyfelt, Inc., and Gundle Lining Systems, Inc. for contributing the geosynthetics used in this research.

REFERENCES

Deresiewicz, H. (1986), "Amontons and Coulomb, Friction's Founding Fathers", Proceedings of the Workshop on the Use of Surface Models to Predict Tribology Behavior, Columbia University, New York, pp. 56-60.

Jacobson, P. N. (1980), "Translational Behavior of Gravity Retaining Walls During Earthquakes", M. E. Report 80-9, University of Canterbury, New Zealand.

Lahlaf, A. M., and Yegian, M. K. (1991), "Dynamic Interface Shear Strength Properties Between Geomembranes and Geotextiles", Report No. CE-91/08, Civil Engineering Department, Northeastern University.

Lai, Cho sim (1979), "Behavior of Retaining Walls Under Seismic Loading", M. E. Report 79/9, University of Canterbury, New Zealand.

Mitchell, J. K., Seed, R. B., and Seed, B. H. (1990), "Kettleman Hills Waste Landfill Slope Failure. I: Liner-system Properties", Journal of Geotechnical Engineering, ASCE, Vol. 116, No. 4, pp. 647-668.

Sung, N-N., and Suh, N. P. (1979), "Effect of Fiber Orientation on Friction and Wear of Fiber Reinforced Polymeric Composites, Wear, Vol. 53, pp. 129-141.

West, G. H., and Senior, J. M. (1962), "Frictional Properties of Polyethylene", Wear, Vol. 19, pp. 37-52.

Yegian, M. K., and Lahlaf, A. M. (1992), "Dynamic Interface Shear Strength Properties of Geomembranes and Geotextiles", Journal of Geotechnical Engineering, ASCE, Vol. 118, No. 5, pp. 760-779.