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Dynamic shear behaviour of geosynthetic interfaces

Comportement à cisaillement dynamique des interfaces géosynthétiques

Anirban De & Thomas F. Zimmie – *Department of Civil Engineering, Rensselaer Polytechnic Institute, Troy, N.Y., USA*

ABSTRACT: The dynamic friction behavior of geosynthetic interfaces was studied using shaking tables and direct shear devices. The dynamic friction angle was found to change with the number of cycles of shear loading. In certain cases dependence on normal stress was also observed. The results from this study are expected to be useful in the design of landfill liner systems for seismic stability.

RESUME: On a étudié le comportement du frottement dynamique des interfaces géosynthétiques en utilisant des tables branlantes et des cisailles. On s'est aperçu que l'angle de friction dynamique changeait en même temps que le nombre de cycles du cisaillement de charge. On a également observé dans certains cas une dépendance de contrainte normale. On espère que les résultats de cette étude pourront servir à la conception et à la mise au point d'un système de gaine pour les dépotoirs en vue d'obtenir une stabilité sismique.

1 INTRODUCTION

The worldwide shortage of landfill space has led to the need to increase capacity by building landfills with steeper side slopes. Further, the coefficient of friction of different landfill components is one of the most important parameters for stability analyses. Most modern landfills are required to be built with composite liner systems, including various geosynthetic layers, e.g. geomembranes, geotextiles and geonets. In such cases the frictional characteristics of the liner components often control the stability of the slopes. Recently, many regulatory authorities have required landfills to be designed to withstand seismic excitation, in view of concern about earthquake damage to landfills. Hence, the coefficients of dynamic friction of geosynthetic components of landfills have become extremely important parameters in design.

Considerable research has been done to study the frictional behavior of geosynthetic materials under static conditions. However, currently there is very limited guidance for designers with regard to dynamic friction coefficients. At present, most designers assume that the static and dynamic friction angles are equal, primarily for lack of better data. Thus, from a theoretical and practical standpoint, it is necessary to establish an understanding of this very important parameter.

2 EXPERIMENTAL APPROACH

This paper presents some of the results of a research project to understand the dynamic frictional behavior of geosynthetic layers, as they apply to landfill liners and covers. A series of experiments were performed on a range of geosynthetic materials using a wide variety of apparatus. Shaking table tests were conducted both in a normal laboratory environment (1-g), as well as at higher acceleration levels, using a 100 g-ton geotechnical centrifuge, simulating a high stress environment. The results from these tests were compared with static and dynamic test results obtained from shear tests performed on a large scale direct shear device. The correlation between shake table results and cyclic direct shear tests demonstrate very interesting features about dynamic frictional behavior. The cyclic behavior of geosynthetics were found to be highly dependent on the type of geosynthetic material, as well as on other parameters.

Geosynthetic interfaces commonly appearing in landfill liner systems were chosen to be tested in this research. Results from tests on four interfaces, involving three geosynthetics, are presented in this paper and the details are provided in Table 1. A full description of all interfaces tested and the results obtained from the study are presented in De (1996).

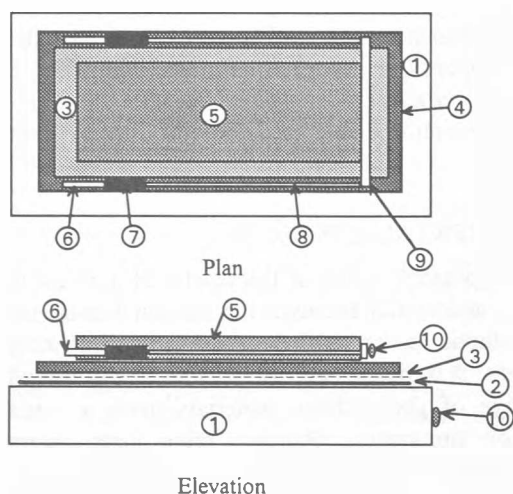
Table 1. Description of geosynthetic interfaces

Interface	Upper Geosynthetic	Lower Geosynthetic
A	Geotextile: Polyfelt TS 700	Smooth Geomembrane: Gundline HD 60 mils
B	Smooth Geomembrane: Gundline HD 60 mils	Smooth Geomembrane: Gundline HD 60 mils
C	Smooth Geomembrane: Gundline HD 60 mils	Geonet (longitudinal): Tensar NS 1405
D	Smooth Geomembrane: Gundline HD 60 mils	Geonet (transverse): Tensar NS 1405

3 TESTS USING SHAKING TABLE APPARATUS

Shaking table tests were performed on pairs of geosynthetics with one geosynthetic mounted on the shaking table surface and the other geosynthetic laid over it with an overlying solid block providing the normal stress. The accelerations in the geosynthetics were measured by accelerometers. The relative displacement between the two layers were monitored by means of two linear variable differential transducers (LVDT's).

Figure 1 shows the experimental setup used in the shaking table experiments. Detailed descriptions of the apparatus and the theory have been presented by Zimmie et al (1994a&b) and De (1996).



- 1 - Shaking Table
- 2 - Geosynthetic A
- 3 - Geosynthetic B
- 4 - Aluminum Frame
- 5 - Concrete Block
- 6 - LVDT
- 7 - Clamp for LVDT
- 8 - LVDT extension rod
- 9 - Metal bar
- 10 - Accelerometer

Figure 1. Experimental setup

The coefficient of friction of the geosynthetic interface being tested may be calculated on the basis of the measured acceleration of the block, a_b , at the time sliding is first initiated. Figure 2 shows a freebody diagram of the block under shaking table excitation.

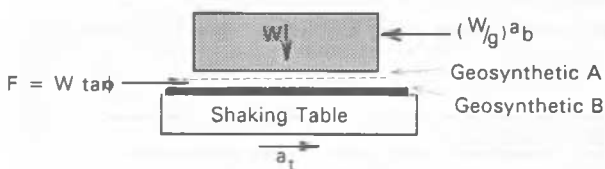


Figure 2. Freebody diagram

The horizontal acceleration of the shake table, a_t , provides a frictional force, F to the block with weight W . As the table acceleration is increased, there will exist a limiting value of acceleration, a_b up to which the block will move with the table.

The limiting value of frictional force will be a function of the dynamic friction angle, ϕ_d and can be obtained by equating the forces in the free body diagram. From this the dynamic friction angle at the interface can be expressed as,

$$\phi_d = \tan^{-1}(a_b/g).$$

Tests were conducted wherein the shaking table received sinusoidal excitation of gradually increasing amplitude. This excitation was transferred to the block, until relative displacement (slip) occurred between the block and the table. These tests were performed at frequencies of excitation varying from 5 Hz to 20 Hz, in different experiments. The details regarding these experiments have been presented in Zimmie et al (1994a), and these results show that the coefficient of friction is independent of frequency, for the range tested. The values of dynamic friction angle obtained from the shaking table tests are shown in Table 2.

Table 2. Dynamic friction angles observed on shaking table tests

Interface	Dynamic friction angle
A	12°
B	14°
C	12°
D	12°

4 TESTS USING SHEAR DEVICES

Monotonic and cyclic tests on geosynthetic interfaces were conducted using the Direct Shear Device for Geosynthetics. The cyclic tests were run under stroke-controlled conditions using an MTS control unit. For each cycle of sinusoidal excitation, the same amplitude of displacement was attained. This amplitude was fixed beforehand at a magnitude greater than the displacement required to mobilize the maximum shear strength in the sample.

During testing, the normal force, the shear force and the displacements in the normal and shear directions were measured. The ratios of the maximum shear force and the normal force at any cycle during the cyclic testing provides an instantaneous value for the coefficient of dynamic friction. Thus, values of dynamic friction angle at different cycles during the testing can be calculated.

Tests were conducted on 305 mm square specimens. The specimens were mounted on two solid aluminum plates with the top plate fixed and the bottom one connected to the actuator that induced movement.

Cyclic tests were performed using sinusoidally varying controlled stroke input under different values of normal stress. The frequency of excitation was 0.25 Hz for all the tests presented here. Although this frequency is at the low end of the frequencies associated with common earthquakes, this should not influence the results, since, as mentioned previously, the interface friction behavior was shown to be independent of the frequency of excitation.

In the case of interface A (geotextile/smooth geomembrane) the maximum shear force for each cycle shows a tendency to decrease with the number of cycles. This drop is quite sharp for the first few cycles.

From the values of maximum shear force and normal force for each cycle, the variation of the dynamic friction angle with numbers of cycle of stroke controlled loading can be plotted. As explained before, the friction angle was calculated from the maximum shear force and the normal force in each cycle.

Figure 3 shows this relationship for Interface A. It can be seen that at the beginning of the test (for the first few cycles) the friction angle had a value of about 12.5°. This value is very close to the static friction angle observed in the current research (Zimmie et al (1994)) as well as by other researchers (Yegian and Lahlaf (1992)). However, as cycles of loading continue, the value of dynamic friction angle decreases continuously. This means the geosynthetic interface offers reduced resistance to sliding. For this particular interface, the value of dynamic friction angle drops significantly for the first 25 cycles, after which the drop continues at a much reduced rate.

This drop in shear resistance, and therefore, in friction angle is most likely due to polishing of the smooth geomembrane surface by the geotextile. This has also been observed by other researchers such as

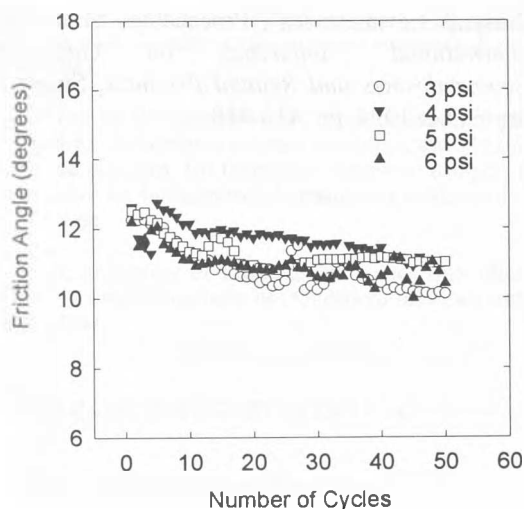


Figure 3. Variation in friction angle with number of cycles for Interface A

Mitchell et al (1990) and Yegian and Lahlaf (1992). Further evidence of this is presented in De (1996) in the form of photographs of the sections taken under an optical microscope. Even though the change is relatively small (on the order of 15%), designers should be aware of this and may wish to consider such drops in friction angle when doing slope stability analyses.

Figure 4 shows similar plots for interface B which is composed of a smooth geomembrane over a smooth geomembrane. While such an interface is not commonly found in landfill liners, it is a component used in base isolator systems and thus was included in this research. Here the maximum shear force tends to increase rapidly for the first few cycles. This means the interface offers increasing shear resistance as the number of cycles increase.

The change in the dynamic friction angle is from 10.5° to 19.5°. The dynamic friction angle obtained from the shaking table tests was found to be about 14° for the same interface. The results from cyclic direct shear tests showed no dependence on normal stress.

Figures 5 and 6 show the variation in dynamic friction angle with the number of cycles for geonet in two different orientations over smooth geomembrane. In the longitudinal orientation the strands of the geonet are at an angle of 25° to the direction of sliding, whereas in the transverse direction the angle is about 62°. Further details about the orientations are presented in De (1996).

For both orientations it can be seen that the relationship of friction angle versus number of cycles is dependent on the normal stress, with the lower normal stress leading to the largest increase in friction angle with numbers of cycles. The dynamic friction angle for either orientation was about 10° for the first cycle of loading. After 50 cycles, the value was between 18°

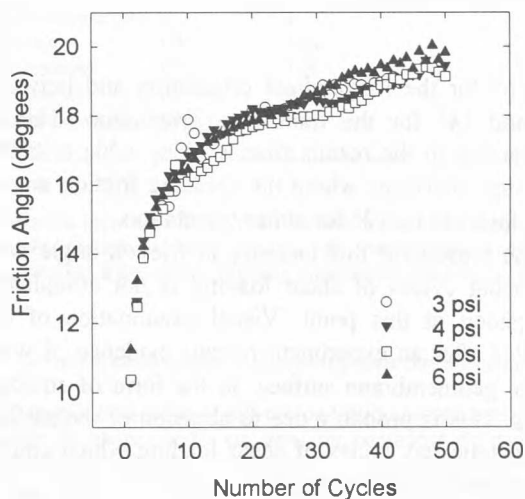


Figure 4. Variation in friction angle with number of cycles for Interface B

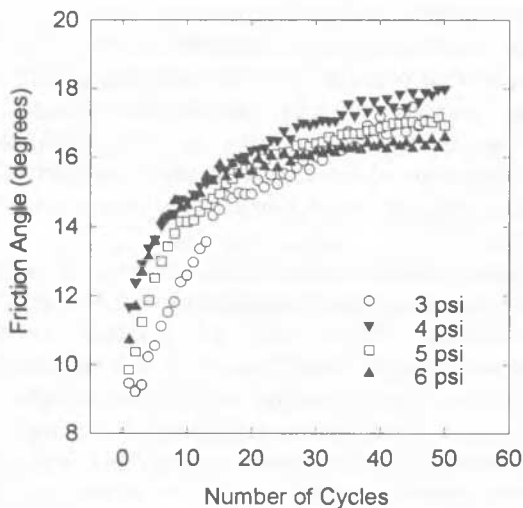


Figure 5. Variation in friction angle with number of cycles for Interface C

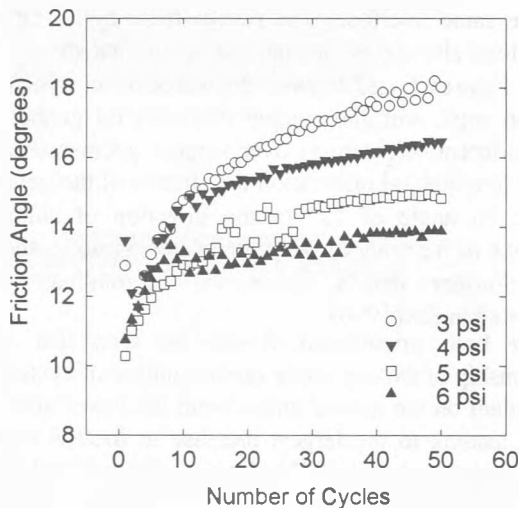


Figure 6. Variation in friction angle with number of cycles for Interface D

and 16° for the longitudinal orientation and between 18° and 14° for the transverse orientation. This is comparable to the results from shaking table tests for the same interfaces where the dynamic friction angles were found to be 12° for either orientation.

The reason for this increase in friction angle with increasing cycles of shear loading is not completely understood at this point. Visual examination of the samples after an experiment reveals evidence of wear on the geomembrane surface, in the form of striation marks. This is probably due to abrasion of the surface during repeated cycles of shear loading which causes the increase in friction angle.

Designers should be aware of the possibility of an increase in friction angle during seismic excitation. For a conservative liner or cover design, it may be desirable to ignore the increase in friction angle, and

use the lowest value of interface friction angle. In cases where geosynthetic materials are used for the purpose of base isolation, the increase in friction angle probably should be taken into account.

5 CONCLUSIONS

Results from shaking table tests and cyclic direct shear tests on four geosynthetic interfaces have been presented. Cyclic direct shear tests indicate that the dynamic friction angle appears to change with the number of cycles of shear loading. It is important to take this kind of change into account when designing facilities with such interfaces. The results from shaking table tests appear to match those from direct shear tests for the interfaces tested.

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