Centrifuge Modelling to Study Dynamic Friction at Geosynthetic Interfaces

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Abstract: The dynamic friction behavior of different geosynthetic interfaces involving geotextiles, geomembranes and geonets has been studied. A shake table apparatus and a geotechnical centrifuge have been used in the tests to determine the effects of parameters such as the nature and orientation of the geosynthetic material, the frequency of vibration and normal stress at the interface. The simulation of high prototype stresses on the geotechnical centrifuge can be utilized to perform dynamic tests on models of large scale earth structures containing geosynthetic interfaces.

1 INTRODUCTION

The dynamic shear strength at interfaces involving geosynthetic layers is an important criteria in the design of structures such as landfill liners and retaining walls against dynamic loadings (e.g. earthquakes and blasts). The angle of friction at geosynthetic-geosynthetic interfaces can be significantly lower than that at soil-geosynthetic interfaces and the friction angle of soils and usually determines the critical conditions for sliding types of failure. To date most of the research on geosynthetic interface friction has been limited to static cases. However many regulatory agencies around the world currently require structures such as landfills and retaining walls to be designed for earthquake type dynamic loadings.

The paper presents an experimental study of the dynamic friction at geosynthetic interfaces, including geotextile, geomembrane and geonet. A shake table apparatus was used to provide horizontal acceleration to the interfaces and some tests were performed on a 100 g-ton centrifuge to simulate large prototype stress conditions. The effects of frequency of vibration and normal stress on interface friction were studied.

2 INTERFACE FRICTION

The interface friction angle under static conditions have been studied by various authors [Mitchell et al (1990), Stark and Poeppel (1994)] using direct shear devices, ring shear apparatus and pull-out boxes. However very little research has been reported in the literature on the dynamic interface friction properties of geosynthetic liner materials. Kavazanjian et al (1991) and Yegian and Lahlaf (1992) have used shake table apparatus to study dynamic friction behavior for geosynthetic materials under different frequencies, stresses and surface conditions.

3 THEORY

The horizontal acceleration of the shake table, a_t provides a frictional force, F to the block with weight W, as shown in the freebody diagram in Figure 1. 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, $\phi_d = \tan^{-1}(a_b/g)$.

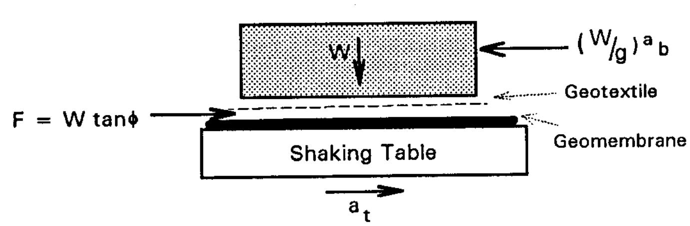
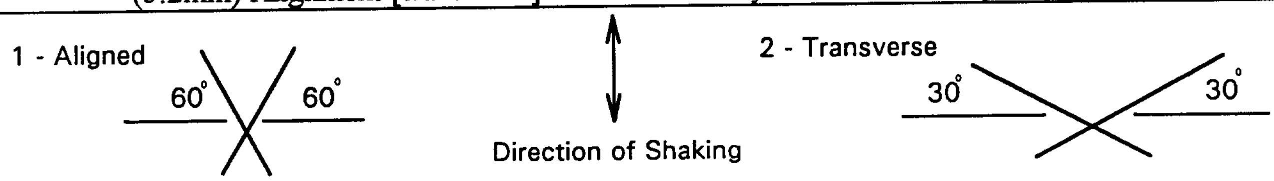


Figure 1. Freebody diagram

Table1. Description of the interfaces

Interfaces	Geosynthetic A (on table)	Geosynthetic B (on block)
I	Smooth HDPE Geomembrane Gundline HD 60 mils (1.5mm)	Non-woven Geotextile Polyfelt TS 700 8 oz/yd^2 (270 g/m^2)
II	Smooth HDPE Geomembrane Gundline HD 80 mils (2.0mm)	Non-woven Geotextile Polyfelt TS 700 8 oz/yd^2 (270 g/m^2)
III	MDPE Geonet Tensar NS 1405 205 mils (5.2mm) Alignment: [aligned][1]	Non-woven Geotextile Polyfelt TS 700 8 oz/yd^2 (270 g/m^2)
IV	MDPE Geonet Tensar NS 1405 205 mils (5.2mm) Alignment [transverse][2]	Non-woven Geotextile Polyfelt TS 700 8 oz/yd^2 (270 g/m^2)



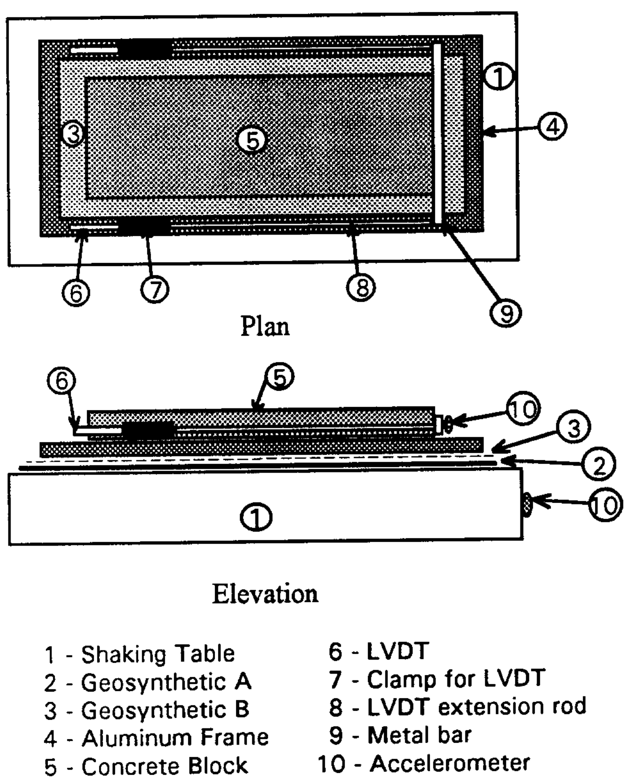


Figure 2. Experimental setup

4 TESTING PROGRAM

Dynamic tests were performed on four different interfaces. A fifth interface involving a textured geomembrane and a geotextile was also tested but was found to have an extremely high friction angle and hence does not appear to be a critical case in design. The interfaces are described in Table 1. The dynamic friction angles were determined on the basis of the shake table acceleration that induced sliding between the interfaces. A servo-hydraulic shaker was used for the dynamic experiments and the centrifuge tests were performed on the 100 g-ton centrifuge at Rensselaer.

4.1 Experimental setup

The setup used in the tests is shown in Figure 2. Geosynthetic A (geomembrane or geonet) was attached to the shake table surface. Geosynthetic B (geotextile) was laid flat over surface A with a concrete block placed on top. The instrumentation used in the tests consisted of two accelerometers to measure the accelerations at the two geosynthetic surfaces and two LVDT's (Linear Variable Differential Transformers) to measure the relative displacement (slip) between the surfaces.

4.2 Test procedure

A sinusoidal horizontal acceleration was provided to geosynthetic A by means of the shake table. The amplitude of vibration was varied using a dynamic signal analyzer. For low amplitudes of accelerations the geosynthetics moved together and the accelerations measured on the block and on the table were the same. However, as the accelerations increased, a point was reached where the entire frictional resistance at the interface was mobilized and sliding between the geosynthetics began to occur. From this point on the magnitude of block acceleration is lower than the table acceleration. Additional details of the test procedure are given in Zimmie et al (1994).

4.3 Centrifuge testing

Interface I was tested at 5 different g levels: 1g, 5g, 10g, 20g and 40g. A prototype frequency of 5 Hz was simulated following the scaling relations for frequency (i.e. at N·g centrifugal acceleration a model frequency of N·f Hz is necessary to simulate a prototype frequency of f Hz at 1g). The normal stress on the interfaces was applied by using a concrete block (2.1 kPa stress at 1g), thus simulating higher prototype stresses at higher g-levels.

5 RESULTS & DISCUSSIONS

The acceleration records for the two geosynthetics were used to obtain the corresponding amplitudes of accelerations on the geosynthetics at the same instants of time proceeding from very low amplitudes of acceleration (about 0.04g) to extremely high amplitudes (up to 4g).

Figure 3 shows the plots from such tests performed on geotextile-geomembrane interfaces I and II. The initial steeper portion of the curves indicate equal table and block accelerations, i.e. amplitudes of acceleration for which no sliding occurred. The flatter portion of the curve indicates that slip is occurring and the block acceleration is lower than the table acceleration. The dynamic friction angle can be computed from the acceleration at the break in the curve. The values for ϕ_d are found to be 12.4° for Interface I and 21.8° for Interface II. Test results are shown in Table 2.

Table 2. Dynamic friction angles for interfaces tested

Interfaces	Dynamic Friction Angle
I	12.4°
II	20.3°
III	17.2°
IV	22° - 35°

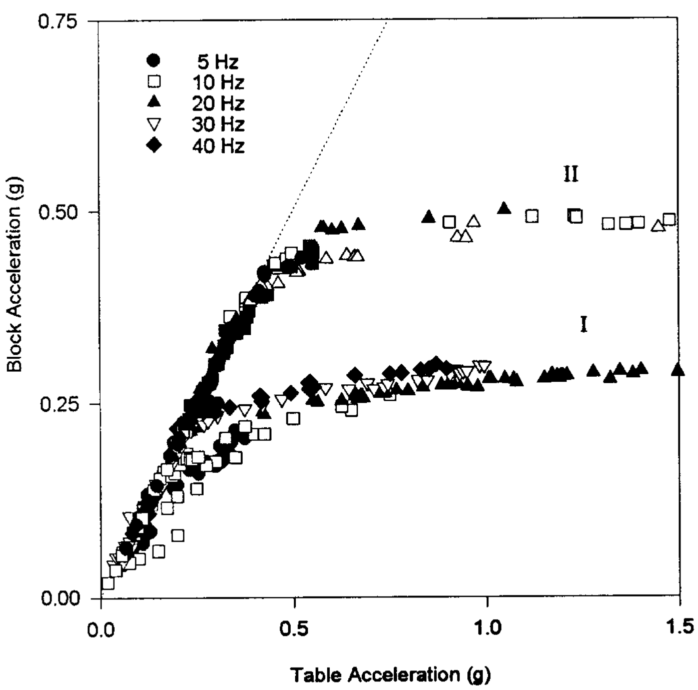


Figure 3. Acceleration plots for Interfaces I & II at 1g

The plots show no variations in behavior with changes in frequency of vibration. However there is a substantial difference between the friction angles computed for the two interfaces. Since the interfaces were composed essentially of the same material, with only the thickness of the geomembrane different, it is not understood at this point what may have caused the difference.

The influence of normal stress on the interface friction angle was studied and no apparent effect was noticed for the range of stresses employed. Much higher values of stress were simulated on the centrifuge in other tests discussed later.

Interfaces III and IV both consist of a geonet and a geotextile. The orientation of the geonet was varied with the long direction of the mesh aligned in the direction of table acceleration for Interface III and transverse to the acceleration for Interface IV. Figure 4 shows the plots obtained from tests on Interfaces III and IV. Interface III has a friction angle of 17.2°, which is lower than that for Interface IV. Interface IV (geonet in transverse direction) exhibited interlocking between the geonet and the geotextile, i.e. stick-slip frictional behavior. As a result the accelerations appear to be more random in nature as shown in Figure 4, and it is difficult to determine an exact value of the dynamic friction angle. From a practical standpoint, it is unlikely that Interface IV would be a critical interface in a landfill. It can be seen that the frequency of vibration and the magnitude of normal stress have no influence on the friction behavior at the geotextile-geonet interface for either orientation.

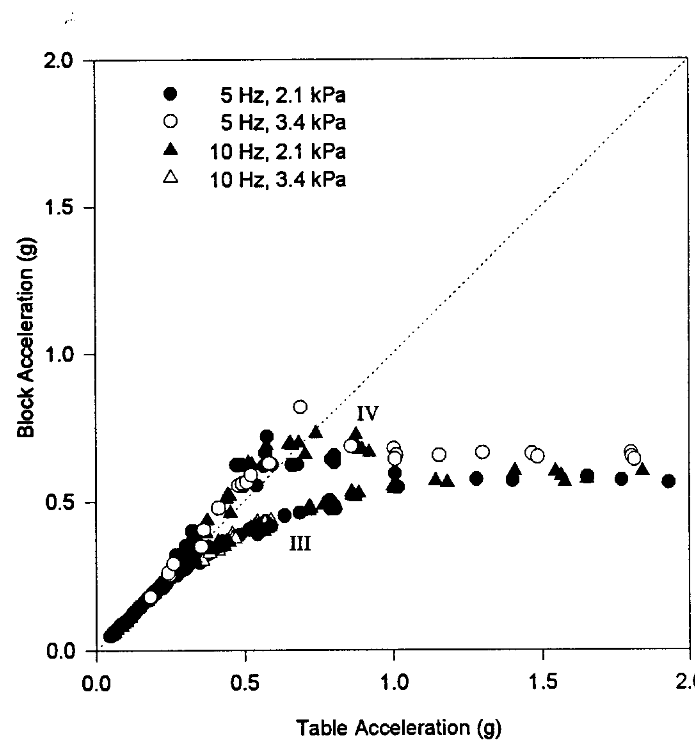


Figure 4. Acceleration Plots for Interfaces III & IV at 1g

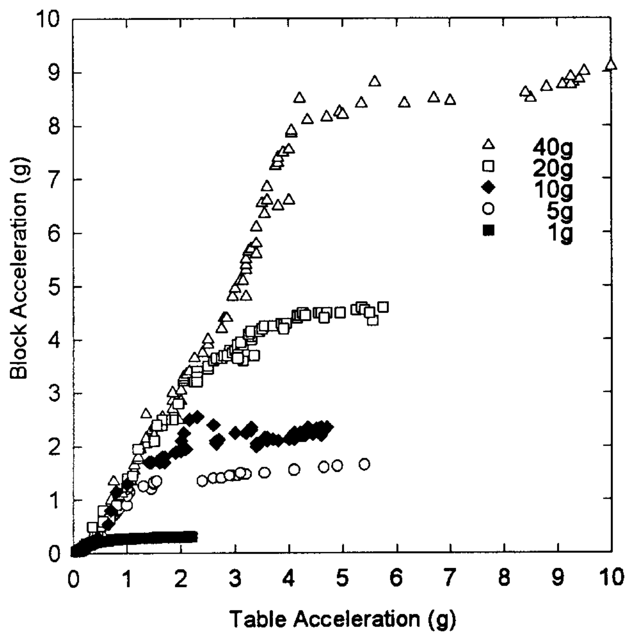


Figure 5. Acceleration Plots for tests on Interface I at different g levels

The plots from the centrifuge tests performed on Interface I are shown in Figure 5. The plots for each g level show the same trend shown in tests at 1g. In each case the slip at the interface is found to occur at approximately the same prototype acceleration and hence very similar values for the dynamic friction angle are obtained. These results are shown in Table 3.

5 CONCLUSIONS

A procedure for determining the dynamic friction angle at geosynthetic interfaces has been presented. Some interfaces commonly used in geotechnical structures have been used in the tests. It has been found that the dynamic friction angle does not depend on the frequency of vibration. Also, for most interfaces normal stress (at least for low values) does not influence the friction angle substantially. However the situation can be different for some interfaces and hence more tests employing higher normal stresses are necessary. The results from the shake table tests on the centrifuge are important since they demonstrate scaling of interface friction at high g levels. This enables simulation of prototype stress conditions in structures such as landfills and retaining walls.

All tests reported here were performed using a concrete block placed above the interface supported on a shake table. It is recognized that the response of a rigid block and table setup will not be exactly same as that of a more compliant mass system (e.g. soil or landfill waste) and hence tests using soil in contact with the interfaces will be a necessary extension to the present series of experiments. The application of a centrifuge will be useful in such cases to simulate prototype normal stresses on the interfaces.

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Table 3. Dynamic friction angles at different g-levels and under different normal stresses for Interface I

g level	Normal Stress (KPa)	Model frequency (Hz)	Model acceleration at slippage (g)	Prototype acceleration (g)	Dynamic Friction Angle
1	2.1	5	0.215	0.215	12.1°
5	10.5	25	1.10	0.22	12.4°
10	21	50	2.1875	0.21875	12.3°
20	42	100	4.50	0.225	12.7°
40	84	200	8.75	0.21875	12.3°