Response of Geosynthetics Under Earthquake Excitations

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ABSTRACT

The seismic response of a geosynthetic interface system is investigated using shaking-table tests. Under harmonic type excitation, results show a limited shear stress, and therefore, acceleration transferred through the interface. Beyond this "yield" acceleration, relative displacement or slip deformation occurs along the geosynthetic interface. Similarly, under earthquake-type excitation, a reduced acceleration is transmitted through the geosynthetic interface. However, the yield acceleration is not constant and varies from one pulse to another. In the vicinity of the predominant frequency of the ground motion, the spectral acceleration of the transmitted motion is deamplified. This deamplification is a function of the peak ground acceleration of the base motion and the frequency content. Beyond a peak acceleration of 0.2g, the geosynthetic interface (HDPE/Polyfelt) acts as a base isolation and absorbs the wave energy through relative displacements or slip. Relative displacement is also investigated on a horizontal geosynthetic interface using three different earthquake-type motions. The maximum slip deformation during an earthquake can be larger than the permanent displacement along a geosynthetic interface, and should be considered to ensure the integrity of the landfill liner system.

INTRODUCTION

Seismic response of landfills and waste containment facilities continues to receive increased attention in geotechnical engineering practice. The US Code of Federal Regulation (1992), title 40, which went into effect in October 1993, requires that all new municipal solid waste landfill (MSWL) facilities be designed for a level of earthquake acceleration associated with 10% chance of exceeding in 250 years. The USGS has prepared a seismic hazard map of the United States and Puerto Rico which provides the probability based estimates of the peak ground accelerations. The regulation requires seismic safety evaluations of landfills planned in regions called "Seismic Impact Zones" where the PGA from the hazard map is greater than 0.1g.

During the past two decades, the geotechnical and earthquake engineering practice in the design and analysis of embankments and dams experienced significant advances. Yet our understanding of the seismic response of municipal landfills and waste containments incorporating geosynthetics is limited. The reasons for this limitation include:

1-Limited number of case history performances -although the Northridge earthquake has provided some data.

2-A lack of good knowledge of the static and dynamic behavior of waste materials and geosynthetic interfaces.

3-Insufficient understanding of the dynamic response of landfill/geosynthetic systems.

4-Lack of reliable performance criteria that define acceptability of designs.

Notwithstanding these difficulties, geotechnical engineers often adopt many of the current procedures utilized in seismic analysis of embankments to analyze the seismic response of landfills and waste containments. Some of these existing procedures and practice may very well be applicable to landfills. However, research results have demonstrated that the presence of geosynthetics in landfills introduces important differences between the seismic response of a landfill and that of an embankment (Yegian and Lahlaf, 1992 and Kavazanjian et al., 1991). Research on the seismic response of landfills is growing fast. Results from these investigations continue to improve our understanding of the seismic response of landfills and waste containments.

For the past few years, the authors have been conducting research on the dynamic shear properties of geosynthetic interfaces, and more recently on the seismic response of geosynthetic/geosynthetic as well as geosynthetic/soil systems commonly used in landfills. This paper presents some of the results from our experimental research on geosynthetics. The purpose of the paper is to demonstrate the important effects of geosynthetic interfaces upon the earthquake-induced ground motions transmitted to a landfill, and the seismic response of the landfill to these motions.

SHAKING TABLE TESTS ON GEOSYNTHETICS

Figure 1 shows a schematic diagram of the shaking table facility used to investigate the dynamic interface behavior between two geosynthetics and between geosynthetics and soils. Typically, a geomembrane is taped on the surface of the table upon which a 20.3 cm x 25.4 cm

(8"x10") plexiglass box is placed. The box has no top or bottom plates which allow the placement of soil and lead weights to increase the normal contact stress.

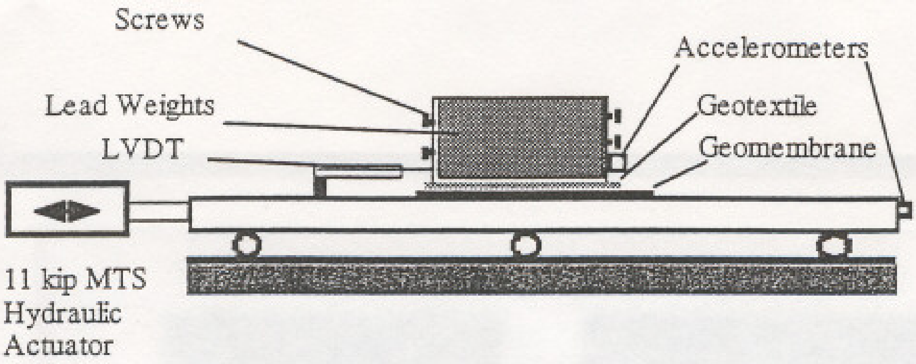

Fig. 1 Schematic Diagram of the Test Setup for Investigating the Dynamic Shear Properties Between Geomembrane/Geotextile Interface.

To test a geomembrane/geotextile interface, the sand in the box is replaced by a piece of geotextile, and the lead weights again placed over the geotextile for added normal stress. In this test, a piece of polyfelt TS 700 (Nonwoven, continuous filament, needle punched geotextile) is placed on a smooth geomembrane (60 MIL-HDPE). The 11 kip hydraulic actuator of the table is capable of generating harmonic excitations as well as earthquake-type motions. During a test, both accelerations of the table and the lead block, as well as the relative displacement between the block and the table (slip along the interface), measured by the LVDT, are recorded by a data acquisition system (Labtech notebook), and then analyzed in a spreadsheet.

SEISMIC RESPONSE OF GEOMEMBRANE/GEOTEXTILE INTERFACE

Yegian and Lahlaf (1992) described the dynamic response of geosynthetic interfaces under harmonic excitations. They concluded that there is a limiting shear force, hence acceleration that can be transmitted from a geomembrane to a geotextile. Beyond this limit, relative displacements "slip" will occur along the geosynthetic interface. Further research by the authors using earthquake-type excitations has demonstrated that the presence of geosynthetics in landfills has an important effect on:

1-the peak ground acceleration (PGA) transmitted,

2-the nature of the time history record transmitted and,

3-the relative permanent displacement along the geosynthetic interface.

This paper details these findings.

1- Effect of Geosynthetics on the Peak Ground Acceleration (PGA)

Figure 2 shows typical shaking table test results of table and block peak accelerations. The horizontal axis represents the peak acceleration of the table when its motion is harmonic with frequencies of 2, 5 and 10 Hz. The vertical axis shows the recorded block peak acceleration that is transmitted trough an HDPE/Polyfelt (TS 700) geotextile interface.

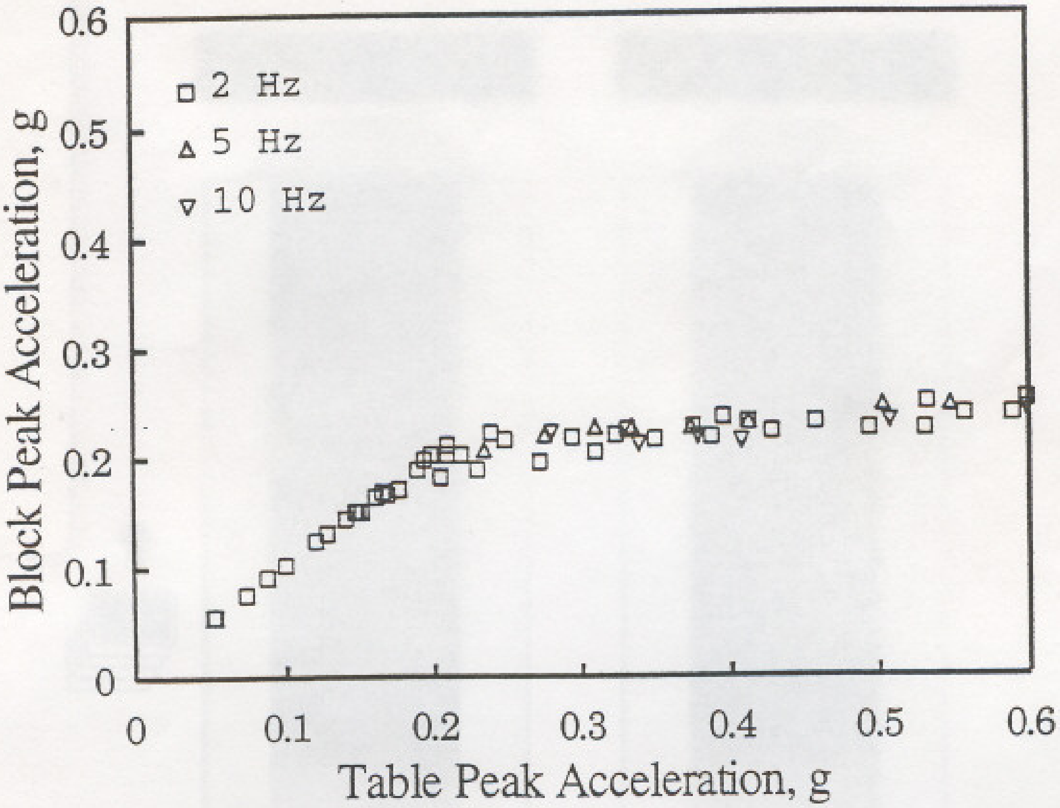

Fig. 2 Recorded Block Peak Acceleration Versus Table Peak Acceleration for HDPE Geomembrane/Geotextile Interface.

The results demonstrate that for a table peak acceleration less than 0.2g, the block and table have the same acceleration, and no sliding along the interface is observed regardless of the frequency of motion. Beyond a table acceleration of 0.2g, the block acceleration is less than that of the table. Therefore, the shear stress transmitted through the HDPE/geotextile interface is limited. Yegian and Lahlaf (1992) provided the following expression for the maximum shear resistance:

$$\tau = \sigma \tan(\varphi_d) \qquad (1)$$

where σ is the normal stress, φ_d is the dynamic interface friction angle equal to arctan(a_b/g) and a_b is the block peak acceleration. From the above results, the friction angle at the emergence of sliding along the HDPE/Polyfelt interface is 11.3° (or arctan 0.2).

Figure 3 shows a typical acceleration record of the block for a table peak acceleration of 0.3g at an excitation frequency of 2 Hz. During this test, the geosynthetic interface could transmit only about 0.21g and thus slip occurred along the interface. From Figure 2 it can be observed that slip deformations will occur between the geotextile and the geomembrane when the table peak acceleration is greater than 0.2g. This leads to the conclusion that in "seismic impact zones", where the peak accelerations are greater than 0.2g, relative displacements are to be expected along a horizontally placed HDPE/geotextile interface. The magnitude of this displacement will depend upon the peak ground acceleration below the geomembrane.

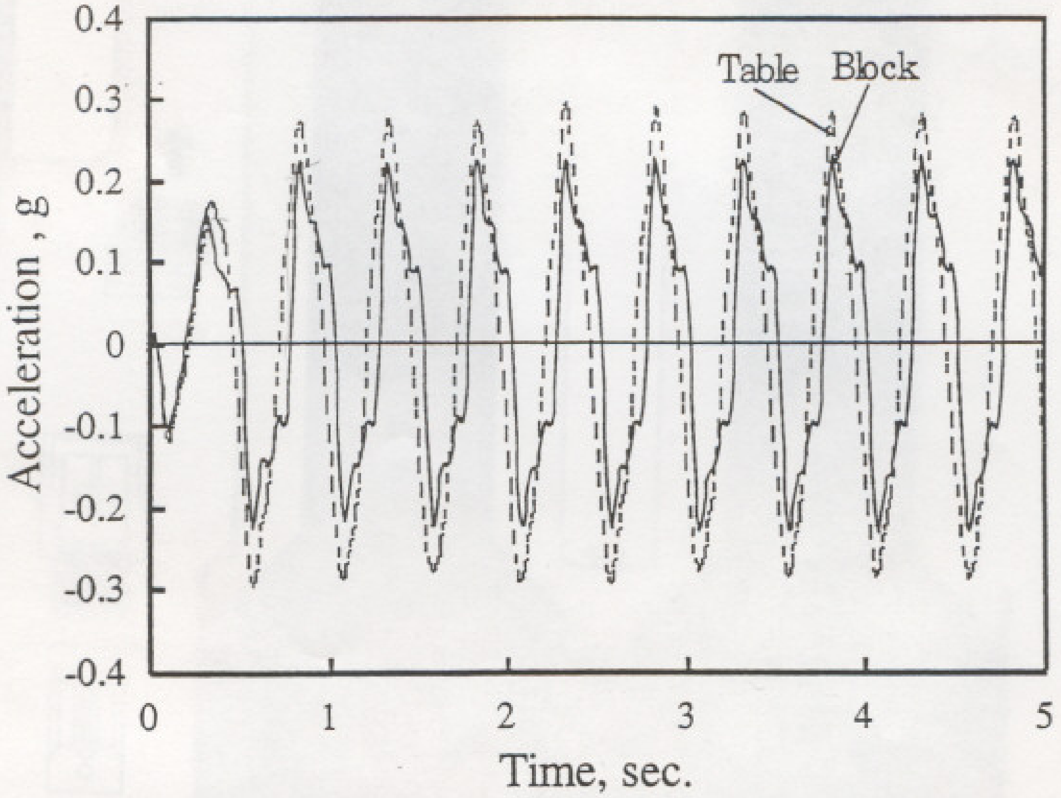

Fig. 3 Recorded Block and Table Accelerations Versus Time for the Geomembrane/Geotextile Interface.

Figure 4 shows recorded slip deformations for a table acceleration of 0.3g, as shown in Figure 3 . It is noted that the results shown are for horizontally placed geosynthetic interface. For inclined interfaces, the limiting acceleration will be significantly smaller than 0.2g and hence, for a given base acceleration, the slip will correspondingly be larger. The authors are currently investigating the seismic response of inclined geosynthetic interfaces.

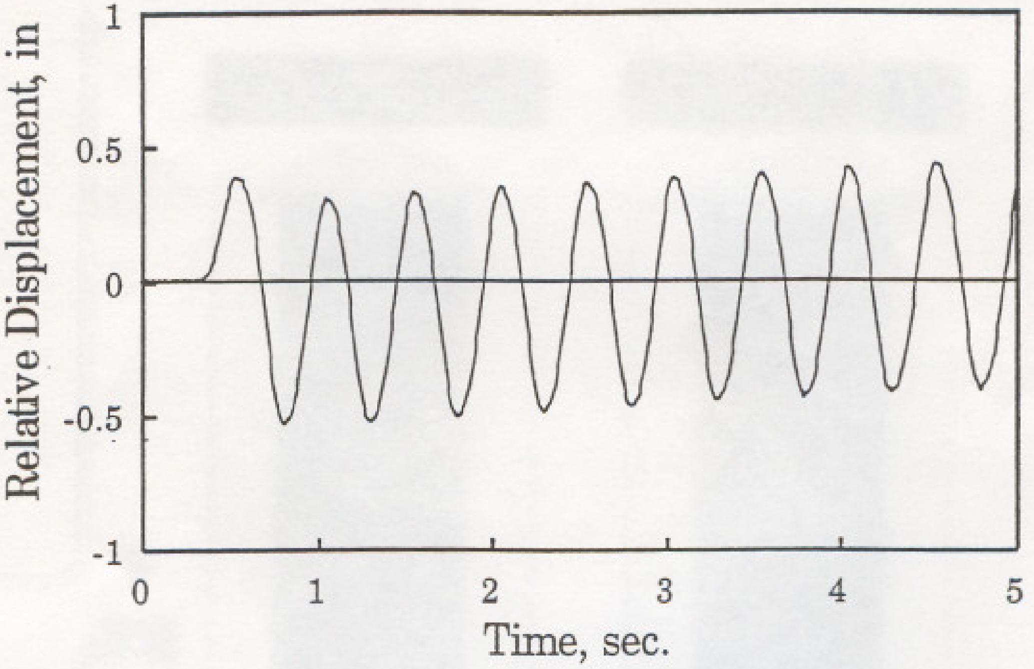

Fig. 4 Recorded Relative Displacement (slip) Versus Time along the Geomembrane/Geotextile Interface.

To further understand the slip potential along a geosynthetic interface, shaking table tests were conducted using recorded ground motions from recent earthquakes. Figure 5 shows the table acceleration when excited with the record from the 1988 Armenia earthquake, scaled to a peak value of 0.4g. The response acceleration of the block placed on the HDPE/geotextile interface is also shown in Figure 5. Again, it is clear that the HDPE/geotextile interface could not fully transmit the 0.4g acceleration. However, unlike the case of the harmonic excitation of the table, with the Armenia record, the limiting block acceleration varied from 0.15 g to 0.23g during the excitation.

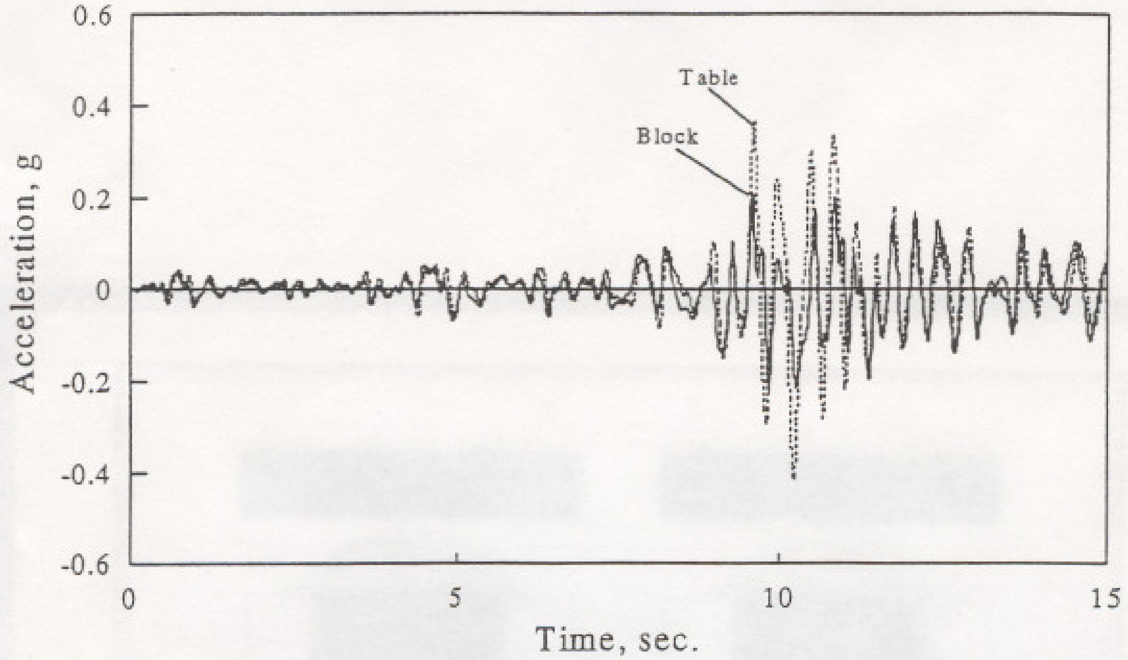

Fig. 5 Table & Block Accelerations Versus Time for the 1988 Armenia Earthquake with HDPE/geotextile Interface.

Figure 6 shows the recorded slip along the geosynthetic interface for the scaled Armenia record. The magnitude of the maximum slip is 4.3 cm (or 1.7 inches). It is noted that the permanent slip (2.0 cm or 0.8 in) under this earthquake motion is smaller than the maximum slip. These slip values are small since the interface tested was horizontal.

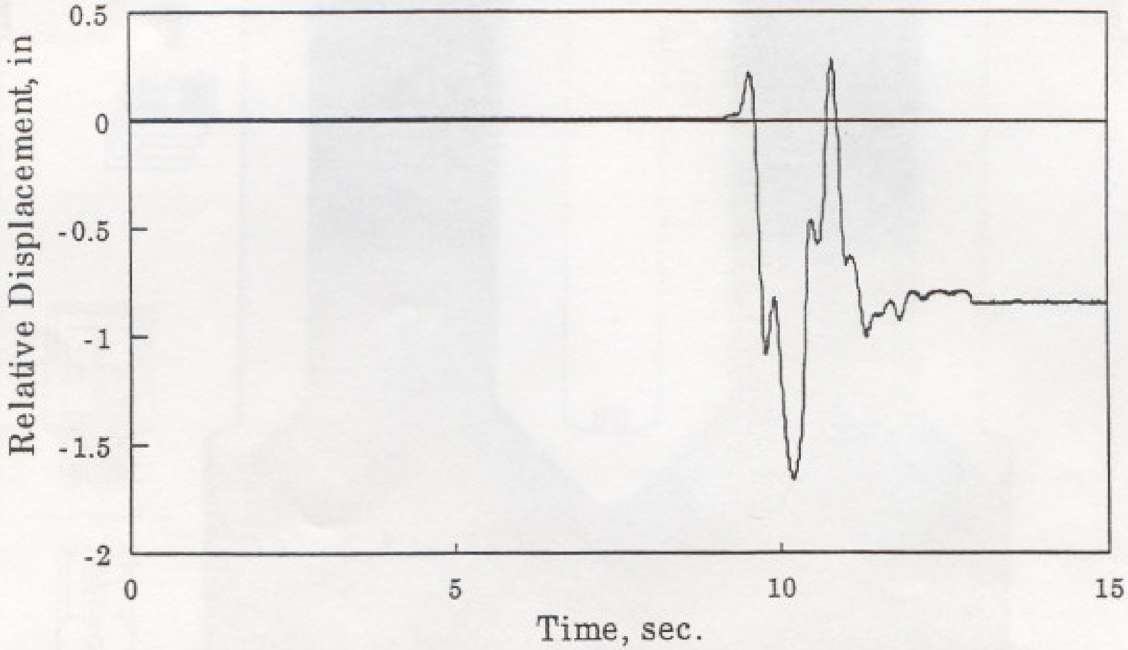

Fig. 6 Relative Displacement Versus Time for HDPE/geotextile Interface for the 1988 Armenia Earthquake Motion.

2- Effect of Geosynthetics on Frequency Characteristics of the Transmitted Motion.

The results obtained using the Armenia earthquake record (Figure 5) showed that the yield acceleration beyond which slip was initiated, varied from one pulse to another. To further understand the effect of geosynthetics upon the frequency characteristics of the motion transmitted through the interface, response spectra of the table and the block motions were calculated. A response spectrum provides the dynamic response of a series of single-degree-of-freedom systems with varying natural periods, subjected to a specific base motion. A comparison between the response spectrum of the table (Armenia record) and that of the motion transmitted through the geosynthetic interface is shown in Figure 7. From this figure, it is observed that when the peak table motion was 0.4g (spectral acceleration at period T = 0 sec.), the peak acceleration transmitted to the block was as stated earlier 0.23g. The results also indicate that the presence of the geosynthetic interface reduces the maximum spectral acceleration from 1.74g to 0.92g. Hence, the presence of the geosynthetic interface, which has weaker shear strength than the surrounding soil or landfill material, causes absorption of energy through slip; in fact acting as a base isolator. Such effects and potential benefits of using geosynthetics as base isolator have also been described by Kavazanjian et al. (1991) and Yegian and Lahlaf (1992).

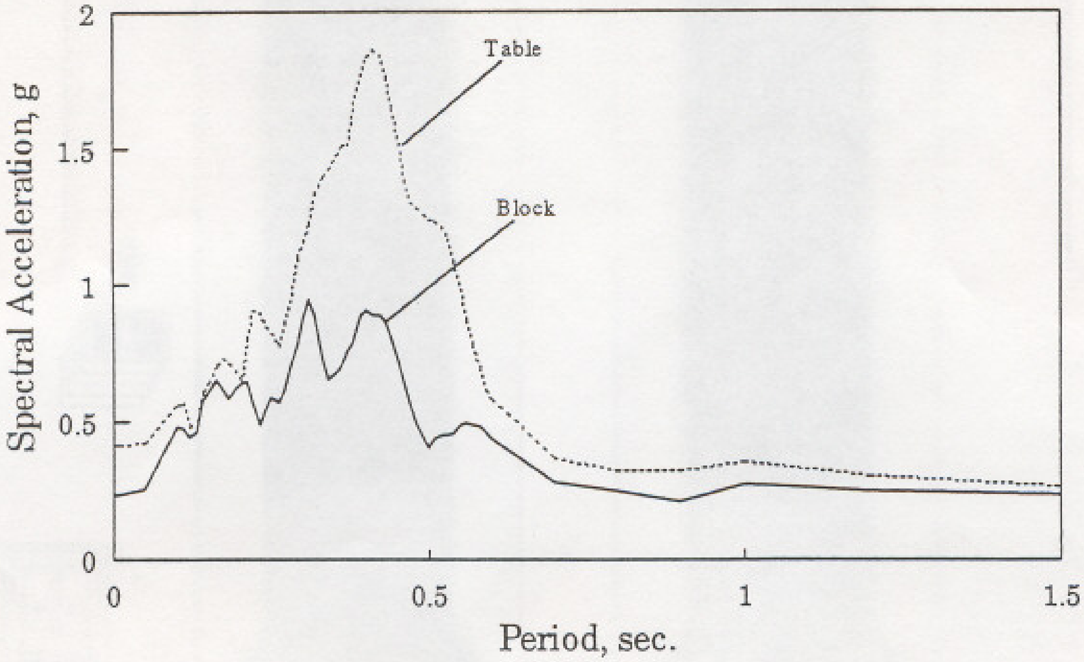

Fig. 7 Response Spectra of the Table Motion and that Transmitted Through the HDPE/Geotextile Interface (block) for the 1988 Armenia Earthquake Motion (5% damping).

Additional test results were obtained using the 1988 Saguenay, Canada and 1990 Manjil, Iran earthquakes to investigate the geosynthetic interface response under earthquake records of different frequency characteristics. The 1988 Saguenay earthquake has very high frequency motions, whereas the Manjil record obtained in Lahijan is characterized by longer period motions due to the presence of a deep deposits of alluvium.

Figures 8 to 11 show the shaking table results from these two additional records, which again show that yielding can occur at an acceleration as low as 0.2g. Furthermore, the slip displacement pattern from these additional two earthquakes are quite different. This is further discussed in the next section.

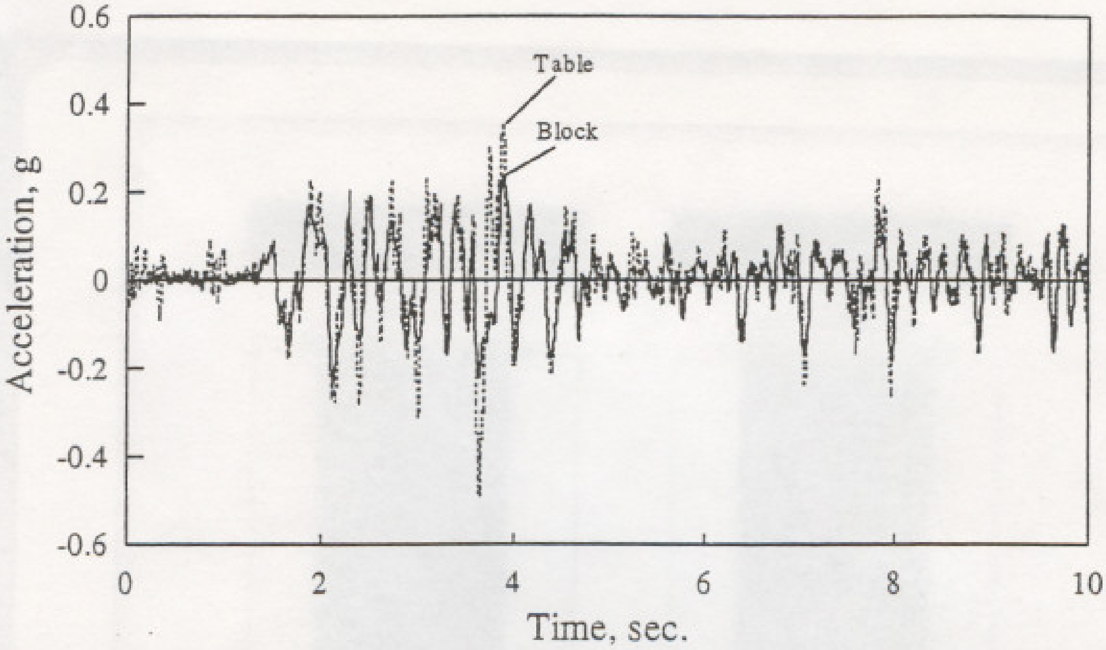

Fig. 8 Table & Block Accelerations Versus Time for the 1988 Saguenay, Canada Earthquake with HDPE/Geotextile Interface.

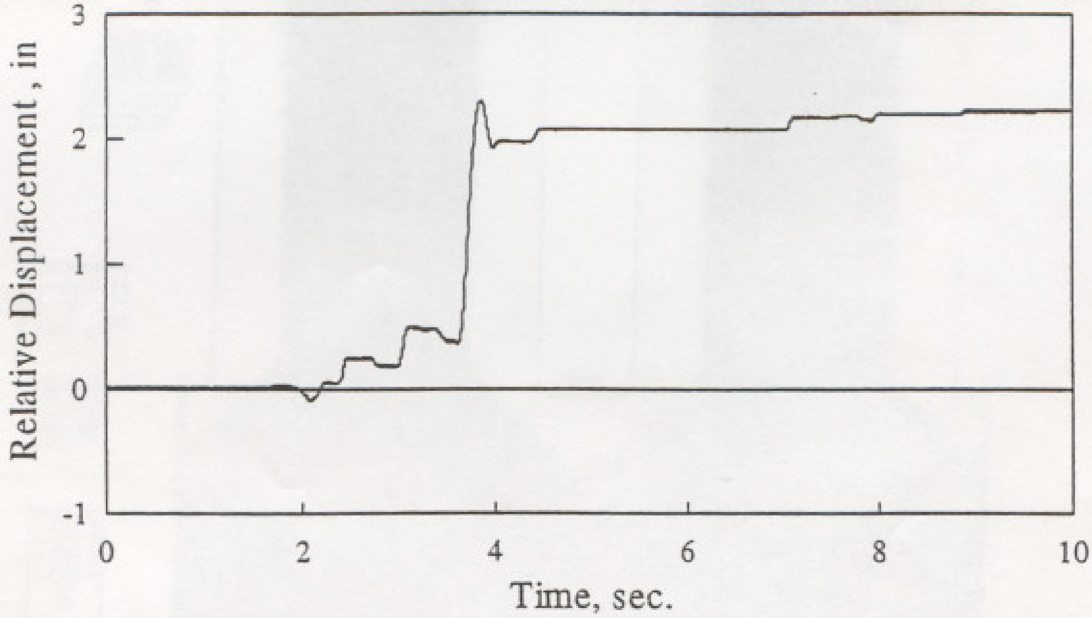

Fig. 9 Relative Displacement Versus Time for HDPE/Geotextile Interface for the 1988 Saguenay, Canada Earthquake Motion

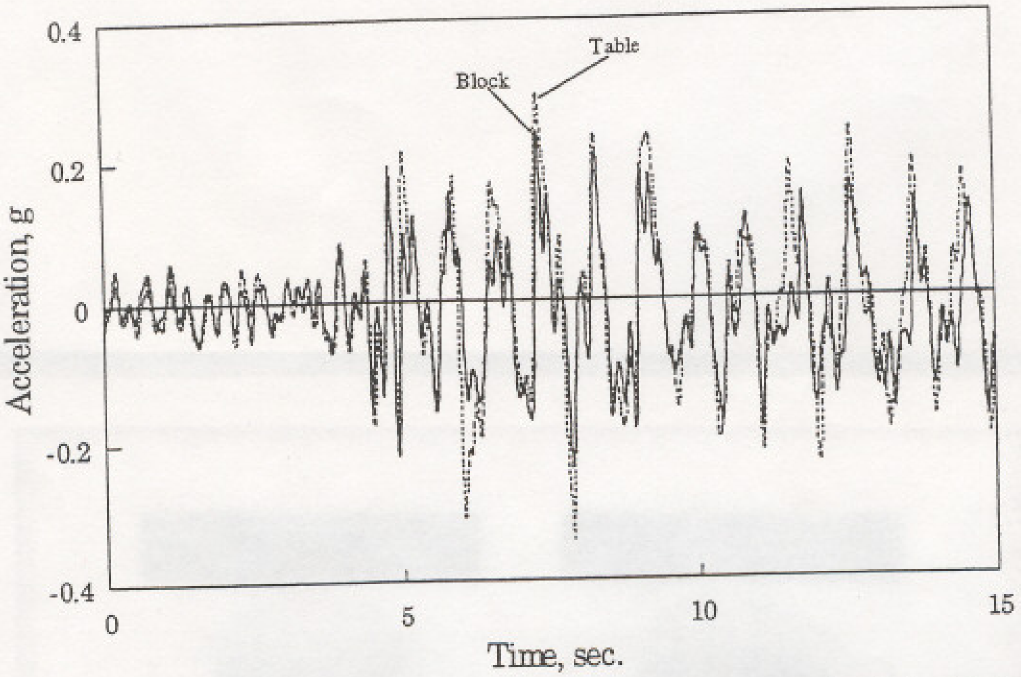

Fig. 10 Table & Block Accelerations Versus Time for the 1990 Manjil, Iran Earthquake with HDPE/Geotextile Interface.

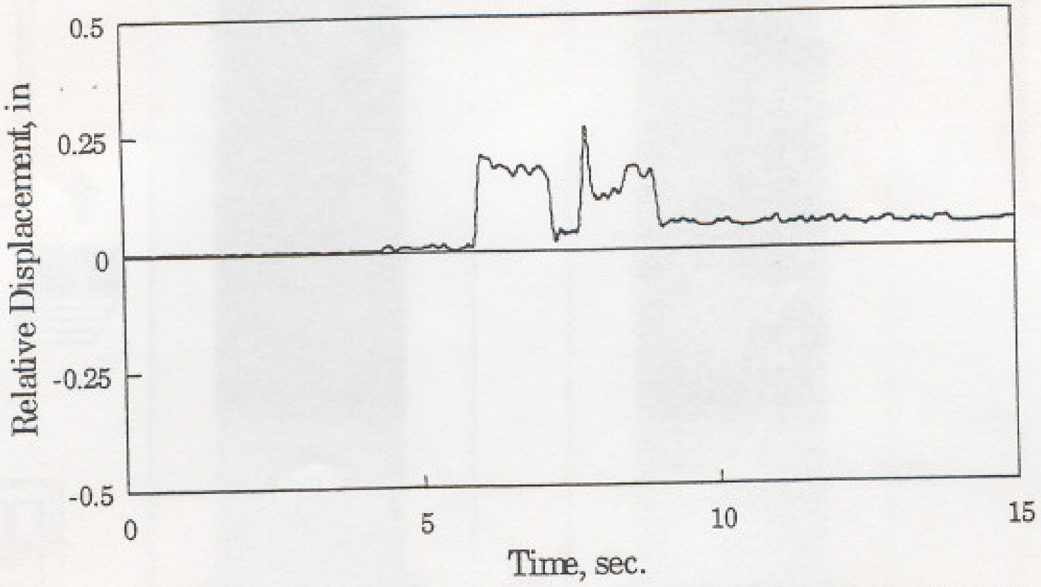

Fig. 11 Relative Displacement Versus Time for HDPE/Geotextile Interface for the 1990 Manjil, Iran Earthquake Motion

Comparisons of the response spectra of the recorded motions from those two additional tests are made in Figures 12 and 13. The results again show that the geosynthetic interface transmits only limited energy thus, reducing the spectral accelerations of the ground motion. The magnitude of this reduction varies from one period to another and also is dependent upon the nature of the earthquake motion.

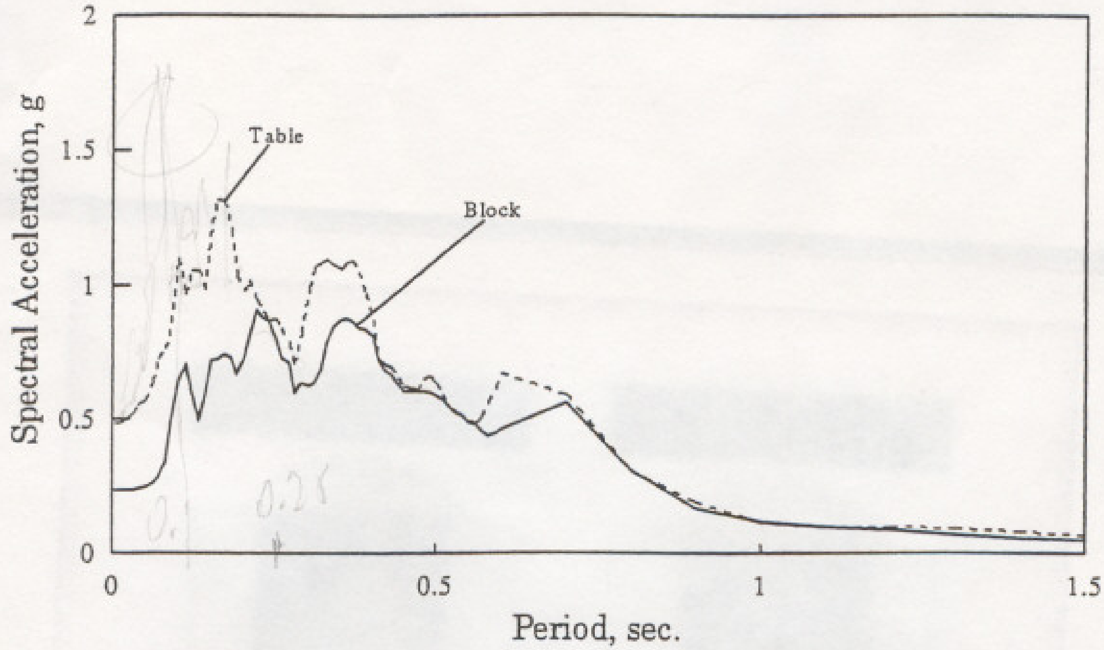

Fig. 12 Response Spectra of the Table Motion and that Transmitted Through the HDPE/Geotextile Interface for the 1988 Saguenay, Canada Earthquake Motion (5% damping)

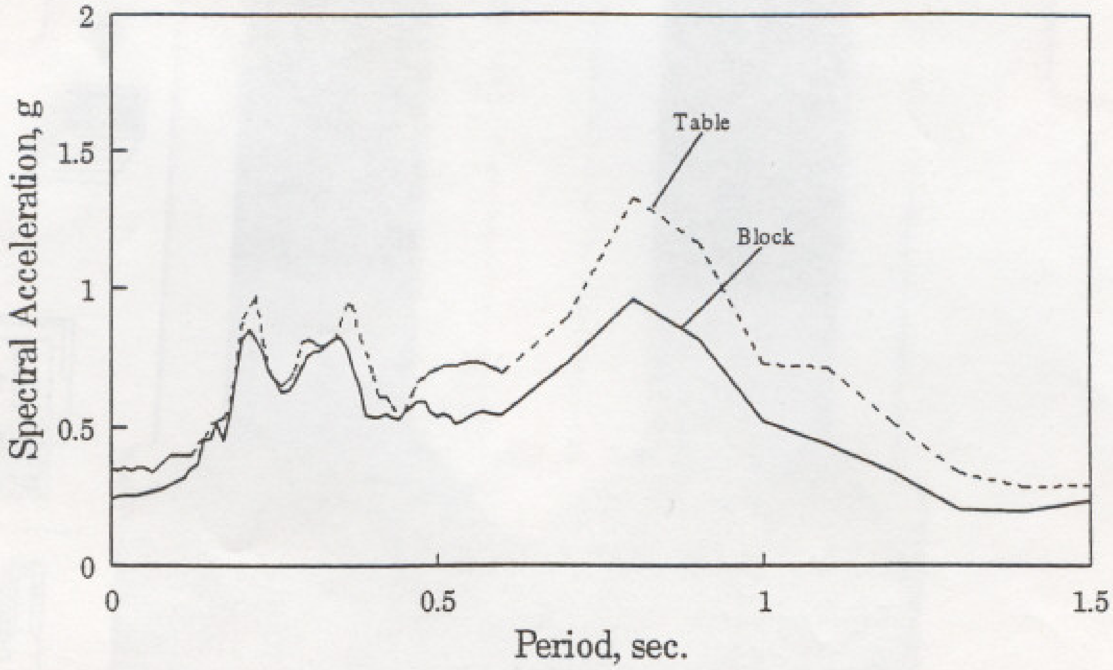

Fig. 13 Response Spectra of the Table Motion and that Transmitted Through the HDPE/Geotextile Interface for the 1990 Manjil, Iran Earthquake Motion (5% damping).

3-Slip Along Geosynthetic Interface

In the previous sections, it was demonstrated that ground motion characteristics (both peak accelerations and frequency contents) transmitted through a geosynthetic interface is significantly influenced by the peak acceleration and frequency content of the base motion. Figures 6, 9 and 11 show how the slip deformations along the geosynthetic interface are influenced by the ground motion record. The magnitude and pattern of the maximum and the permanent slips are different for each of the three records. Such differences are attributed to the level of PGA and the frequency content of the motion. It is also observed that the slip under a single pulse can be larger than the permanent slip. Thus, if one is interested in assessing the effect of slip upon the integrity of a geosynthetic, maximum slip deformation becomes as important as permanent slip. A stick-slip behavior is manifested along the geosynthetic interface. The shear force transmitted through the interface momentarily increases at the time of reversal of direction of motion.

CONCLUSIONS

Shaking table tests were conducted to investigate the seismic response of an HDPE/Polyfelt geotextile interface. The following observations and conclusions are presented:

1-Under harmonic excitation, there is a limiting acceleration that the geosynthetic interface can transmit. Beyond this acceleration, slip deformations along the interface are induced.

2-Under earthquake-type excitations, this limiting acceleration is not constant, and the response of the geosynthetic interface is quite complex. Yet, the following observations are made:

a-The geosynthetic interface reduces the level of the acceleration pulses of the ground motion.
b-The magnitude of the reduction in the acceleration pulses varies with the peak acceleration of the ground motion as well as with frequency content of the motion.
c-The spectral accelerations of the transmitted motion are reduced specially in the range of the predominant frequency of the ground motion.
d-The geosynthetic interface acts as base isolator absorbing the wave energy through interface slip.
e-The magnitude and pattern of the maximum and the permanent slips depend on the level of PGA and the frequency characteristics of the earthquake time history.

3-Slip deformation in one direction along a horizontally placed geosynthetic interface can be larger than the accumulated permanent slip deformation. Thus, in seismic design of landfills (unlike in earth-dams and embankments) maximum slip as well as permanent slip deformation should be important specially if one is concerned about the integrity of the liner system.

ACKNOWLEDGMENT

The authors gratefully acknowledge the National Science Foundation for the support of their research on the "Dynamic Shear Properties of Geosynthetics Interfaces" and the "Seismic Response of Geosynthetic/Soil Systems".

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