CYCLIC RESPONSE OF CLAY-GEOMEMBRANE INTERFACES AND THEIR IMPACT ON THE SEISMIC RESPONSE OF LINED LANDFILLS

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ABSTRACT

This study presents the results of cyclic shear tests on HDPE geomembrane/clay soil interfaces at strains < 1 % and investigates the effect of such interfaces on the seismic performance of landfills. Laboratory cyclic shear tests were performed on both textured and smooth HDPE geomembrane materials overlying a silty clay material.

INTRODUCTION

Recent RCRA Subtitle D regulations (40 CFR Part 258) established the requirements that MSW landfills must not be sited where they can be damaged by active ground faulting (258.13) and that they must be designed to resist the effect of regional earthquakes (258.14). Seismic design quidance developed by EPA (Richardson, et al., 1995) requires that, at a minimum, these facilities be designed to resist accelerations resulting from an event having a 90 percent probability of not being exceeded in 250 years.

The dynamic response of geomembrane/geotextile interfaces was previously investigated by Yegian et al. (1992) using a harmonic excitation shake table. 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 or slip will occur along the geosynthetic interface. In a proceedings of a workshop on research priorities for seismic design of a solid waste landfills (USC, 1994), it was noted that low shear strength interfaces may have a beneficial effect on the seismic response of a landfill in a manner similar to that of frictional base isolation systems for buildings. Yegian et al. (1995) more recently investigated the effect of irregular excitation on the response of geomembrane/geotextile interfaces. They showed the following: (1) that the magnitude of the reduction in the acceleration pulses varied with the peak acceleration of the ground motion (PGA) as well as with frequency content of the motion, (2) spectral accelerations of the transmitted motion are reduced especially in the range of the predominant frequency of typical ground motions, (3) 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, and (4) the geosynthetic interface acts as a base isolator absorbing the wave energy through interface slip. Kavazanjian and Matasovic (1995) used non-linear dynamic response analysis that a potential benefit of low shear strength geosynthetic interfaces is a reduction of the peak acceleration response of the landfill.

CYCLIC LOADING ON A GEOMEMBRANE/CLAY INTERFACE

Shear tests were conducted to analyze the performance of the HDPE geomembrane/soil system interface under both static and cyclic loading. The laboratory program involved testing both textured and smooth HDPE geomembrane materials. The geosynthetic textured geomembrane materials tested were from three manufacturers (Gundle, STL and NSC). In addition Gundle's smooth HDPE geomembrane was also tested. Both static and cyclic shear tests were performed using a direct shear machine having a pneumatic loading system to apply the normal stress. The machine was fitted with a 102 mm (4 in.) diameter shear ring to perform the testing and shear loads were applied using a hydraulic actuator. Constant amplitude cyclic loads were applied at a frequency of 0.5 cycles per second. Cyclic load and displacement data were logged using a personal computer (PC) interface card which recorded 50 data points per second.

The clay liner material used was a white clayey sand whose properties are presented in Table 1.

Table 1 - Summary of Laboratory Test Material Properties

% Passing No. 200 Sieve	45.8%
Liquid Limit	24%
Plastic Limit	17%
Plasticity Index	7%
Maximum Dry Unit Weight (ASTM D698)	1.97 Mg/m^3 (123.4 pcf)
Optimum Water Content	11.5%

The clayey sand test specimens were compacted at approximately the soils optimum moisture content of 11.5 % to a relative compaction of 98 %. The compacted soil sample was placed in the top ring of the direct shear device. The lower ring was filled with rigid metal and porous discs. The liner coupon was attached with flat head screws to the top surface of the bottom ring. In this position, the geomembrane covered the rigid metal and porous discs. The upper and lower shear rings were placed together sandwiching the soil and liner and creating the interface to be tested. This "sandwich" with the soil over the liner coupon, was then consolidated. Consolidation was performed by applying a vertical consolidation load through a porous stone and loading cap on the soil sample. A loading hanger, pulled down by a pneumatic piston, applied the load to a top cap which transfers the force to the interface. The system was allowed to soak and compress over night under a consolidation load of 193 kPa (28 psi), 359 kPa (52 psi), 414 kPa (60 psi), 828 kPa (120 psi). The change in specimen height was monitored and recorded.

After the consolidation was complete, a cyclic loading was applied. A hydraulic actuator applied the lateral shear loading to the liner/soil interface by acting on the top shear ring. The upper shear ring was moved a preset deformation. The single amplitude deformations used in this study were 0.18 mm (0.007 in.), 0.30 mm(0.012 in), 1.01 mm (0.04 in), and 2.03 mm (0.08 in). The specimen was cycled at 0.5 Hz for 10 cycles at each displacement level, starting with the smallest displacement and ending with the largest. The specimen was allowed to rest at its null location for 30 minutes between each of the four displacements. The load and displacement was monitored and recorded during the cyclic loading.

The static test sequence was performed using loading in only one direction. The loading rate for the static test was 0.01%/min. Results from the static tests (adhesion Ca, residual phi angle, and void ratio) are presented in Table 2.

Table 2 - Summary of Static Direct Shear Test Results

Interface	Ca kPa(ksf)	Phi(residual) (degrees)
Gundle HDPE(smooth)/Soil	5.8(0.12)	10.9
Gundle HDPE(textured)/Soil	25.4(0.53)	24.4

A summary of results from cyclic testing on both smooth and textured Gundle liner material are presented in Figure 1 . The results are plotted for a constant vertical stress as shear stress ratio/vertical stress (i.e. stress ratio) versus deformation. A review of the data by the authors shows that for a smooth liner material the effect of deformation level, vertical stress and the number of cycles on the stress ratio is minimal. In addition, stress ratio is effectively constant at 0.2 for the conditions investigated. This value of stress ratio corresponds to an angle of friction between the HDPE/clay interface of 11.3 degrees. This value is in agreement with results from static tests as presented in Table 2.

For the textured liner material the effect of the number of cycles of load application based on the authors observation of the data is minimal. The effect of increasing vertical stress is to move the curve from the top to the bottom of the range. The level of the stress ratio achieved increases with increasing deformation.

This data strongly suggests that the use of static interface shear strengths for smooth and textured geomembranes for dynamic analysis is conservative.

CYCLIC RESPONSE OF LANDFILLS

The response of landfills with geosynthetic interfaces under seismic loading can be investigated using either a limited number of computer models which incorporate slip elements or the SHAKE program. For programs which use slip elements information presented in Figure 1 can then be used directly. In contrast, a more common procedure is to use the SHAKE program to estimate the response of the landfill. This program requires information on the variation of shear modulus with shearing strain for the interface. To incorporate the interface data from Figure 1 equivalent "slip" elements must be developed or a true non-linear dynamic analysis must be used. To develop this information for SHAKE it was assumed that the deformation presented in Figure 1 occurred in a 1 ft (0.3 m) thick layer. The resulting shearing strain can then be calculated as the deformation divided by the layer thickness.

Plotting the secant shear modulus (G) from data presented in Figure 1 for both smooth and textured HDPE liner material versus the logarithm of the shear strain as a function of the vertical effective stress results in modulus degradation curves as presented in Figure 2. The G_{max} values at 0.001% shearing strain was estimated using an empirical equation by Hardin (1978). A review of Figure 2 shows that texture of the geomembrane does not appear to significally affect the shear modulus degradation curves. The effect of increasing vertical effective stress is also shown to increase the shear modulus for all shearing strain levels between approximately 0.001% thru 1.0%.

A normalized modulus degradation curve for both smooth and textured HDPE liner/clay interfaces is presented in Figure 3 as G/Gmax versus the logarithim of the shearing strain. At strain levels below approximately .01 % curves are relatively flat indicating that the interface is undergoing basically elastic behavior. Above a strain level of approximately .01 % the G/G_{max} versus shearing strain curve undergoes degradation which indicates that the interface is undergoing plastic behavior.

RESPONSE OF LANDFILL UNDER SEISMIC LOADING

To evaluate the effect of an HDPE liner/clay interface on the seismic behavior of a landfill, a case study was investigated utilizing the idealized soil layers (Layer No. 1 and 2) as presented in Figure 7. Layer profile No. 1 consisted of a typical soil/waste column without a HDPE geomembrane/clay interface. In contrast, Layer profile No. 2 consisted of the same soil/waste column with a soft layer (HDPE geomembrane(smooth and textured)/clay interface) located at the bottom of the waste. The computer program SHAKE91 was used in this model study (Idriss and Sun, 1992). The approximate modulus degradation curve used for the soft layer was based on Figure 3 for smooth and textured geomembrane/clay interfaces. An earthquake time history (1987 Whittier Earthquake, Los Angeles-Obregon Park) with a peak horizontal acceleration of 0.43g was input at the top of the rock layer. The shear wave velocities of the MSW shown in Figure 4 were estimated from Idriss et al. (1995). The shear wave velocity is a function of the shear modulus (G) and the density (ρ) of the material as given by the below

(2) Case Study - Assuming cyclic deformations occurred over a 1 foot thick layer of material.

a. An approximate modulus degradation curve of G/Gmax versus the logarithim of the shearing strain exists for both smooth and textured HDPE geomembrane/clay interfaces assuming a 1 ft. thick layer. The general shape of this relationship is approximately that previously identified for clayey soils.

b. For the idealized soil/waste columns studied under small strains, the fundamental period occurs between 2 to 2.5 seconds. This fundamental period is approximately the same for the conditions of either a geomembrane layer and without a geomembrane layer at the soil/waste interface.

c. For all the cases studied, the soil/waste column with and without a geomembrane/clay interface amplifies the acceleration level at the top of a 100 foot fill by a factor of 3.8 from that inputed at the basement rock level.

d. The small levels of shearing strain (0.15%) experienced at the bottom geomembrane/clay interface for the case studied did not fully mobilize the available strength of the contact. Therefore the bottom liner/clay interface studied does not appear to provide a slip surface and therefore does not modify earthquake response for the conditions modelled (Mag=6.1,a=0.43g). If the strain at the liner interface had been larger then the strength of the contact system would probably have governed the mechanical behavior.

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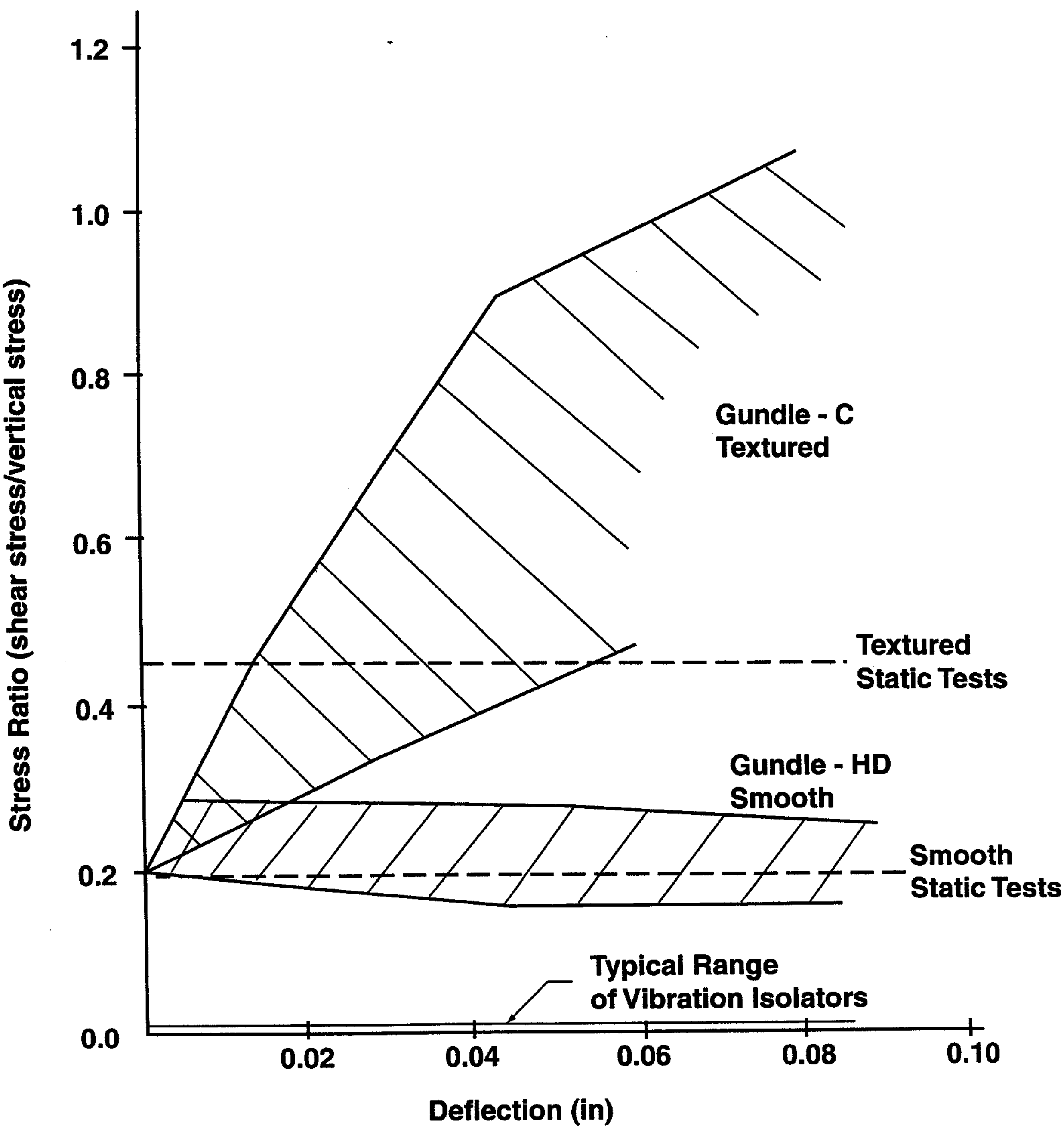

Figure 1 - Stress Ratio versus Deformation

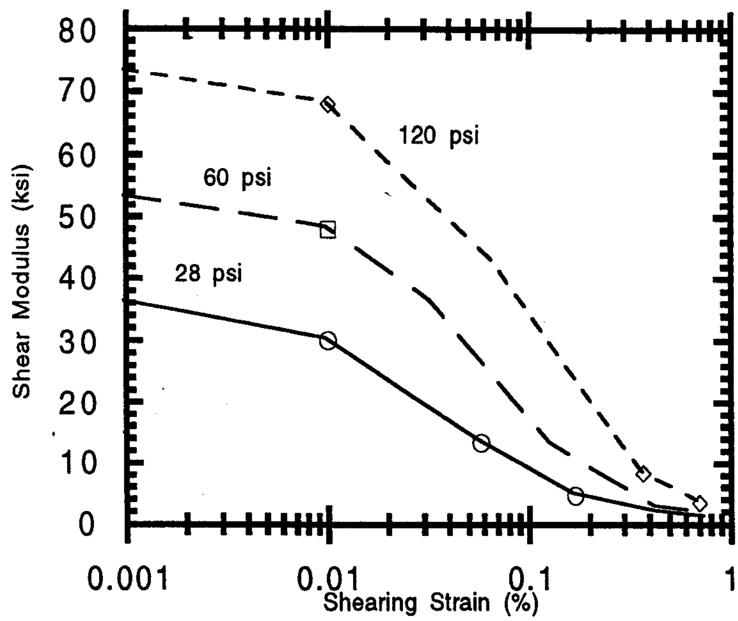

Figure 2 - Summary of Estimated Modulus Reduction Curves, Geomembrane over 1 foot thick Clay Layer

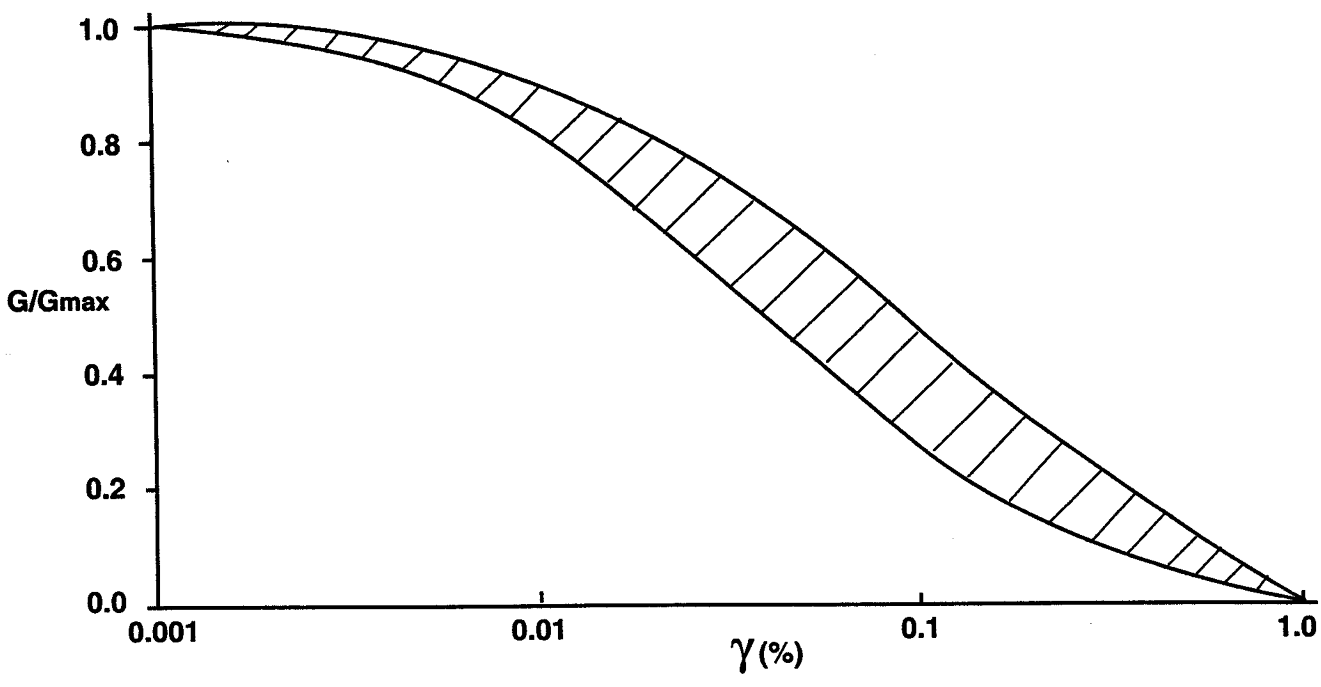

Figure 3 - Normalized Modulus Reduction Curve for HDPE Liners/Clay Interfaces Assuming a 1 foot thick layer.

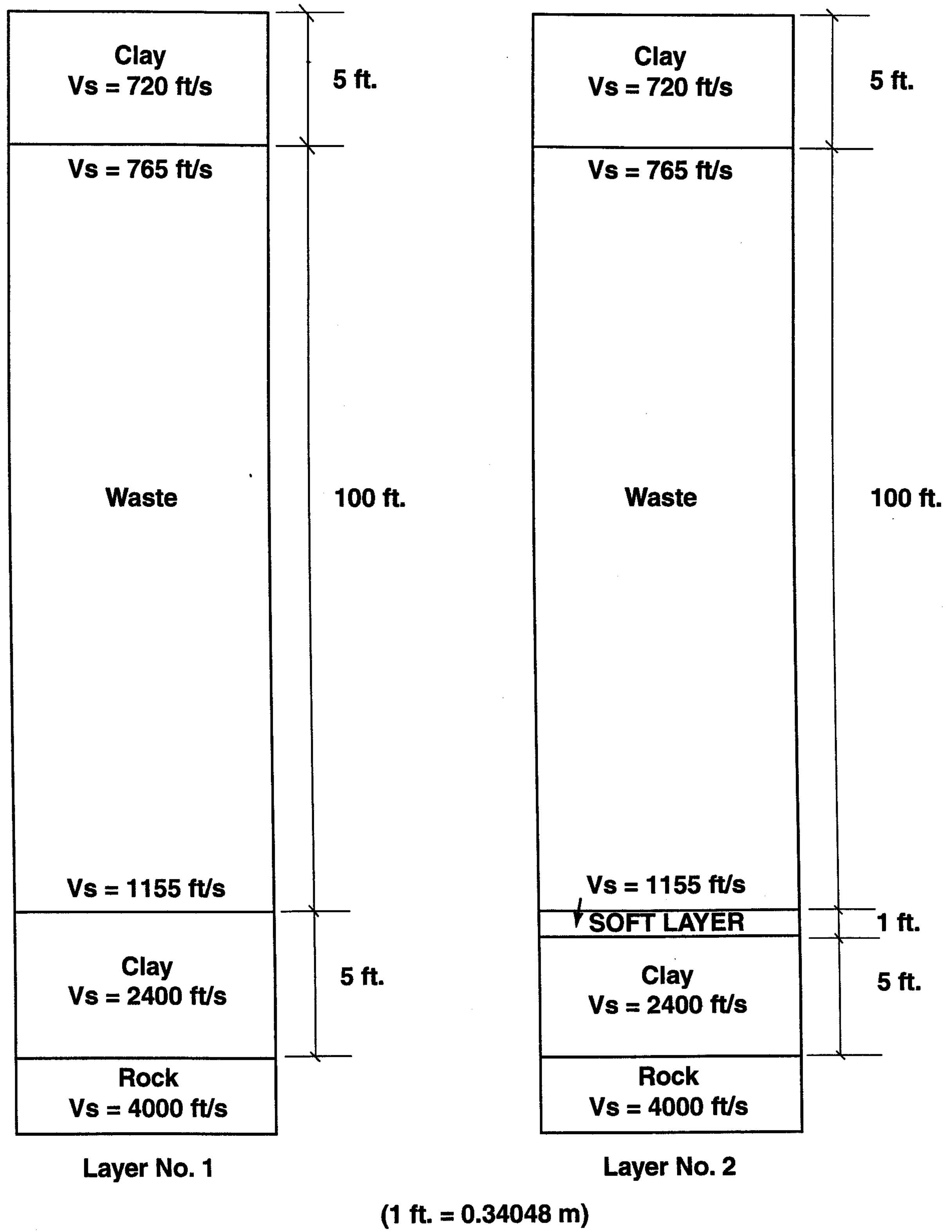

Figure 4 - Case Study Idealized Soil Layers

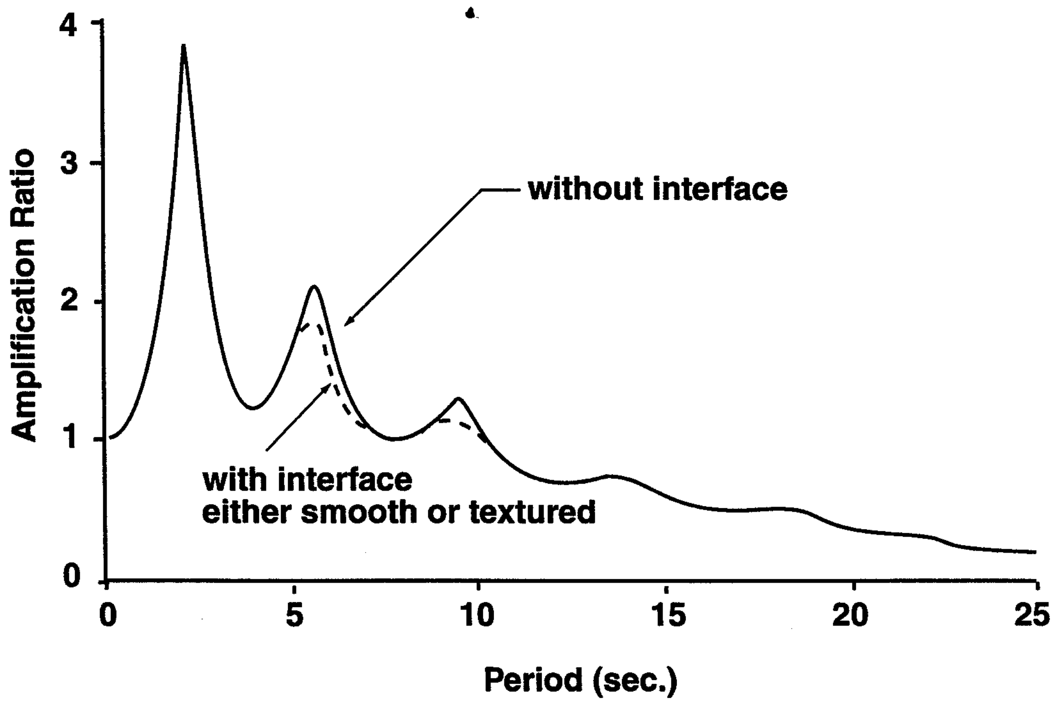

Figure 5 - Amplification Ratio versus Period for condition without and with (geomembrane / clay) Interface Conditions.