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EVALUATION OF INTERFACE SHEAR RESISTANCE OF GEOSYNTHETIC LINER SYSTEM FOR KETTLEMAN LANDFILL MODELS

Mu-Hsiung Chang

Fugro (Hong Kong) Limited Consulting Engineers, 11/F Park Commercial Centre, 2-12 Shelter Street,
Causeway Bay, Hong Kong

ABSTRACT

Direct shear and tipping board tests were performed to evaluate the shear resistance of interfaces between various geosynthetics and between geosynthetic and soil. The geosynthetic materials were candidates of the model liner system for the study of the 1988 Kettleman landfill slope failure. Modifications of test apparatus and procedure were made in consideration of the sheeting-like liner materials and the low stress state (< 5kPa) of the models. In order to avoid erroneous reading due to roller friction, the conventional direct shear box was modified such that the shear resistance of liner interface was measured at the upper plate of shear box. Various potential factors had been considered and their effects on the interface shear resistance were investigated. It was found that the shear resistance of geosynthetic liner interface was very sensitive to the surface cleanliness. The increase in surcharge loading time could significantly increase the interface shear resistance. Due to prolonged or multiple shearing, the polished geosynthetic surface reduced both peak and "residual" interface shear strengths. However, this effect tends to decrease and become insignificant at a greater shear distance (e.g., 25-50cm). Temperature apparently had an effect on the interface shear resistance when the temperature was low (e.g. < 20°C). Results of the study provided an experimental basis for estimating the interface shear resistance of the model liner system. The study also demonstrated the direct shear and tipping board apparatus discussed herein provided effective tools for evaluation of the interface shear resistance under low stress conditions.

INTRODUCTION

On 19 March 1988, a slope failure occurred in the 30m high waste fill in Disposal Unit B-19 at Kettleman Hills Landfill, California, USA, resulted in significant displacements of the waste fill of about 11m and settlements up to 4.5m. Significant tears in the liner system underlain the waste fill were observed due to the sliding. Kettleman Hills Landfill is a Class I hazardous-waste treatment-and-storage facility. The Disposal Unit B-19, a 14.6ha oval-shaped storage area, was constructed with a composite liner system complying the requirements of 1986 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act [1], which mandates leachate-collection systems and both geomembrane and compacted-clay barriers. Figure 1 illustrates various components of the base liner system used in the landfill. The failure had been investigated by several parties [2][3][4][5][6][7][8]. The paper discussed herein presents the results of shear strength evaluation of various interfaces of the liner system used in the physical models for the Kettleman landfill failure study [7].

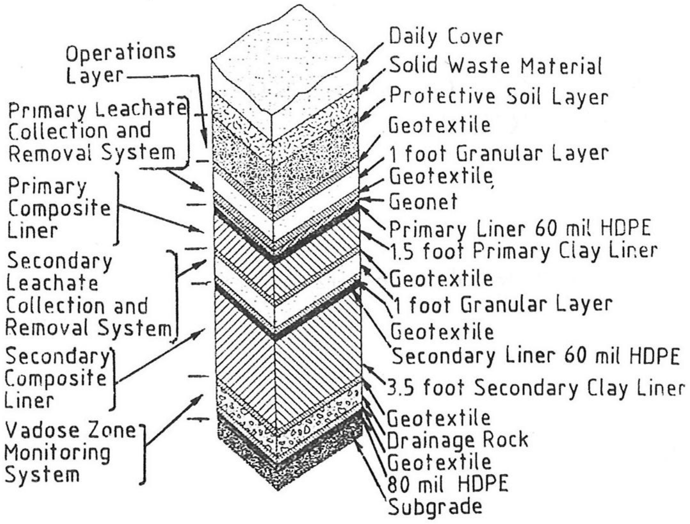

Fig. 1 - Kattleman Landfill Base Liner System
(After Byrne et al. 1992)

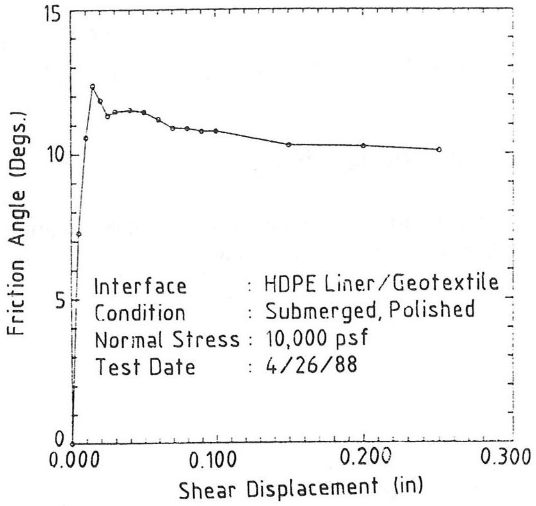

Fig. 2 - Direct Shear Test Results for HDPE/Geotextile Interface
(After Mitchell et al. 1990)

MODEL LINER MATERIALS

Based on field investigation and laboratory testing, three critical liner interfaces of the in-situ liner system were identified, i.e., geotextile/geomembrane, geonet/geomembrane, and geomembrane/compacted clay, [2][3][5][6]. The measured angle of shear resistance was about 8° for geosynthetic liner interfaces and the undrained shear strength was about 25-50kPa for the geomembrane/clay interface. Figure 2 shows a typical test result for the geosynthetic liner interface, indicating a relatively small shear displacement was required to mobilize the peak strength.

In the model study of the Kettleman landfill failure, a 1:150 liner scale was adopted and a double-layered (single interface) liner system was used in the models [7]. Similarity conditions between the model and the prototype were set up based on Rocha [9], which required the angle of shear resistance and the scaled shear force-shear displacement relation of the model liner interface should be the same as those for the in-situ liner system. Five liner material candidates had been considered and various combinations of the materials were tested for the suitability as the model liner system. The liner materials considered included: (a) 0.025mm mylar sheet; (b) 0.1mm polyethelyne (PE) sheet; (c) 0.25mm vinyl sheet; (d) 1.5mm high density polyethelyne (HDPE) geomembrane; and (e) wax paper. The HDPE geomembrane used in this study was the same material as in the in-situ landfill liner system.

TEST APPARATUS AND PROCEDURE

Direct shear and tipping board tests were adopted for evaluating the shear resistance of geosynthetic liner interfaces under low model stress conditions (< 5kPa). The direct shear test provides a more accurate measurement in the peak and residual strengths as well as the shear displacement. The force-displacement curve of the test can be obtained. The tipping board test is relatively simple to perform. However, the test cannot provide shear displacement information.

Direct Shear Tests

Due to the sheeting-like liner material and the low model stress conditions, the existing Karol-Warner direct shear box had to be modified to facilitate the measurement and to enhance the test accuracy. Figure 3 shows a schematic illustration of the modified direct shear apparatus used in this study.

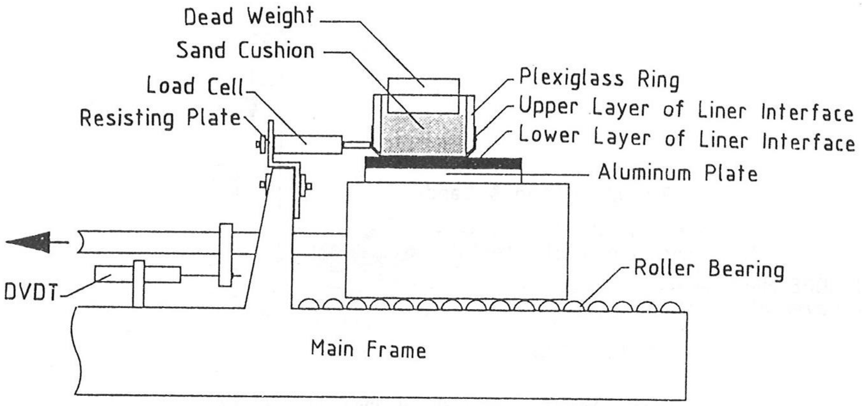

Fig. 3 - Schematic Illustration of Direct Shear Test Apparatus

The modifications of the device included the following aspects:

(1) The bottom plate of the shear box was replaced by a solid steel platen on which a 100mm x 100mm square sample of a lower layer interface material was attached. The top plate of the shear box was replaced by a 76mm-dia. plexiglass ring. The lower end of the top plate was sharpened to form a 45° angle and was attached with an upper layer interface material. The plexiglass ring was filled with sand to form a cushion for the overlying dead weights.

(2) The shear resistance was measured at the top plate to by-pass the effect of roller friction induced at the bottom plate of the box. The roller friction was estimated to be approximately 30-40% of the geosynthetic interface strength under the model stress conditions. The measurement point of shear resistance was located at 3.2mm above the shear plane of the box. The estimated eccentricity of the contact resultant was less than 1.5% and 5% across the shear area for interface friction angles of 10° and 30°, respectively, which were considered to have negligible effects on the measured interface shear strength.

It was found that the shearing velocity had essentially no effect on the measured interface shear resistance for a speed of up to about 1.5 mm/min. In order to measure the peak strength and the associated shear displacement, a slower speed of 0.011 mm/min was used in the initial (pre-peak) stage and a faster speed of 0.914 mm/min was adopted for the rest of shearing process. In order to overcome the limitation of shear distance of the device (i.e., approx. 15mm per shear), a large shear distance was achieved by continuously replacing the top plate of the shear box back to its original position at the end of one shearing.

Tipping Board Tests

The arrangement of the tipping board device is shown in Figure 4. A lower layer interface material was attached onto the board. The plexiglass ring with an attached upper layer interface material, same as the top plate of the direct shear device, was placed on the tipping board. A sand ballast of 4-6cm in thickness provided a normal stress of approximately 0.5-0.75kPa, which was used for all the tipping board tests. The contact resultant was estimated to fall within the central 1/3 of the contact area for the expected interface friction angle of about 10° and the eccentric effect was considered to be minimal.

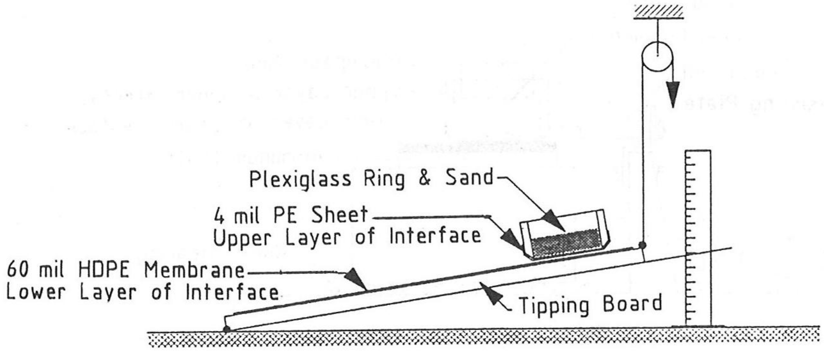

Fig. 4 - Schematic Illustration of Tipping Board Device

In order to detect both peak and residual friction angles, the test procedure was arranged as follows: (a) lifting up the board very slowly at one end of the tipping board until the movement of the plexiglass ring was observed; and (b) lowering down the board immediately, but gently, so that the plexiglass ring could come to rest smoothly. The first recorded tilt angle at the onset of a slide corresponded to the peak interface friction angle and the tilt angle at the cease of a slide corresponded to the "residual" interface friction angle. As discussed in the following, the interface shear resistance decreases with the increase of the shear distance. The "final" residual shear resistance of the geosynthetic interfaces tested could be reached at a large shear distance of about 25-50cm.

TEST RESULTS

Five primary factors were anticipated to have an influence on the measured interface shear strength and their effects were investigated. The factors included: (a) interface cleaning procedure; (b) taping of liner joints; (c) interface surface polishing; (d) surcharge loading time; and (e) temperature.

A normal test condition was determined and the results of tests under the normal condition were used as references for comparison with other test conditions. The normal condition included: (a) water-cleaned geosynthetic surface (i.e., C_1 - procedure); (b) new upper and lower layer liner materials (i.e., no surface polishing); (c) normal stress less than 5kPa; (d) no surcharge loading time; and (e) temperature ranged between 20-24°C.

A typical result for the PE sheet/HDPE geomembrane interface tested under the normal condition is shown in Figure 5. The result indicates the peak strength of the geosynthetic interface can be mobilized at a relatively small displacement (i.e., on the order of 10^{-2}mm) and then followed by a drop in strength to an "initial" residual state. However, the shear strength is decreasing gradually for a large shear distance of approximately 25 to 50cm before a "final" residual state can be reached. In this study, the residual strength refers to the "initial" state unless otherwise specified. Generally, the shear force-shear displacement relation of the geosynthetic liner interfaces tested under this study is geometrically similar to those of the critical interfaces in the field liner system.

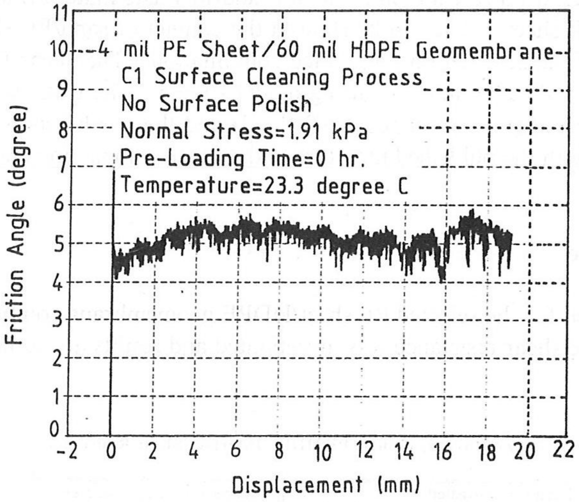

Fig. 5 - Typical Direct Shear Test Results for PE/HDPE Interface

The aims of the laboratory testing were to select proper interface materials for use in the model liner system and to investigate the effect of potential factors on the interface strength. Accordingly, the first part of the test program included screening tests for various liner interface combinations and the second part included a detailed investigation of potential factors on the selected interface combination from the screening tests.

Screening Tests

Results of the screening tests are summarized in Table 1. The tests were conducted under the condition similar to the normal condition mentioned previously, except for the interface cleaning procedure where the geosynthetic surfaces were cleaned by dry cotton cloth only (i.e., C_0 - procedure). The results indicated that the combinations of PE sheet/HDPE geomembrane and wax paper/HDPE geomembrane had measured angles of shear resistance most similar to the values for the critical interfaces of the in-situ liner system (i.e., $\phi \approx 8°$). However, the wax paper/HDPE geomembrane interface exhibited a much greater time-dependent effect on the interface strength due to surcharge loading. Accordingly, the PE sheet/HDPE geomembrane interface combination was selected for the model liner system.

Tab. 1 - Shear Resistance of Various Liner Interface Combinations

Interface combination	ϕ_{peak} (deg.)	ϕ_{res} (deg.)	d_{peak} ($\times 10^{-2}$mm)
Mylar sheet / Vinyl sheet	20	18	25 to 75
Wax paper / Vinyl sheet	12.5	9.5	7 to 20
Wax paper / HDPE geomembrane	11	8	2 to 13
Wax paper / Wax paper	≥ 10	9.5	17
PE sheet / Vinyl sheet	12.5	10	38 to 50
PE sheet / HDPE geomembrane	11	8.5	2 to 10
PE sheet / PE sheet	10	6.7	5 to 8
Mont. #0 sand / Wax paper	14.5	12.5	50 to 75
Mont. #0 sand / PE sheet	13	11	12 to 25
Mont. #0 sand / Mont. #0 sand	37	37	250 to 500

The preliminary tests were also conducted to confirm that the critical interface during a slide (i.e., slip surface) would be confined within the liner system, and no shear failure would be occurring on the contact between the model fill sand (i.e., a representation of in-situ landfill waste material) and the upper layer of the model liner system (i.e., PE sheet). The results showed the contact of sand/PE sheet had higher shear resistance than the strength of the selected liner interface combination. The shear failure at the sand/PE sheet contact was thus considered to be unlikely during model sliding. The tests were also performed on the shear strength of the test sand (i.e., Monterey No.0 Sand) and the results showed the angle of shear resistance of the sand agreed with the published literature under loose compaction and low confining stress conditions [10].

Tests for PE/HDPE Interface

A detailed study was conducted for the selected PE sheet/HDPE geomembrane combination. The effect of various factors on the interface shear resistance was investigated and results are summarized in Table 2.

Tab. 2 - Summary of Investigation on PE/HDPE Interface Shear Resistance

Factor investigated	$\Delta\phi_{peak}$ (degree)	$\Delta\phi_{res}$ (degree)
Surface cleaning process		
C0 - dry cotton cloth	+2 to +7	+2 to +6
C3 - liquid soap and water	0 to -1	-1 to -2
C5 - dust contaminated surface	+3 to +9	+2 to +10
Scotch taping	+6 to +11	+1 to +8
Surface polish		
1-sided (new/polished)	0 to -2	0 to -2
2-sided (polished/polished)	0 to -2.5	0 to -3
Time under sustained loading		
Δt = 0.5 day	+4	+1.5
Δt = 1.0 day	+5.5	+2
Δt = 1.5 days	+6	+2
Δt = 2.0 days	+6	+2
Temperature		
(5 to15) °C	≅ +0.2°/°C	≅ +0.3°/°C
(20 to 40) °C	≅ 0	≅ 0

The cleanliness of geosynthetic surface has a significant effect on the interface strength tested under low stress conditions. The angle of shear resistance of the PE sheet/HDPE geomembrane interface depends to a great extent on the surface cleaning procedure. For the surface cleaned by dry cotton cloth (C_0 - procedure), the interface angle of shear resistance can increase by 2-7° as compared with the normal test condition (i.e., C_1 - procedure, cleaned with water). For the surface cleaned by liquid soap and water (C_3 - procedure), the interface angle of shear resistance decreases up to 2°. On the other hand, the angle of shear resistance increases up to 10° for the originally dust-contaminated geosynthetic surface (i.e., C_5 - procedure).

Scotch taping was applied on the joint between HDPE geomembrane pieces. The results indicate the taping significantly increases the measured interface strength up to about 11°.

The polishing of liner interface was considered in two cases: (a) Single-Sided Polish - new upper liner layer (PE sheet) and polished lower liner layer (HDPE geomembrane), a condition applied for the combination of new PE sheet and polished HDPE geomembrane at the onset of a slide; (b) Double-Sided Polish - both polished upper and lower liner layers, a condition for the model liner system during shear where both PE sheet and HDPE geomembrane surfaces are polished. As shown in Figure 6, surface polishing decreases the interface angle of shear resistance up to 2° for single-sided polish case. For double-sided polish case, the decrease can be up to 3°. Generally, a shear distance of 25-50cm is required for the PE sheet/HDPE geomembrane interface to reach a "final" residual state. Besides the general trend, the results indicate a relatively large scatter (approx. ±1°) in the measured interface angle of shear resistance, which might have been due to the cross-effect by other factors, e.g., surface cleanliness.

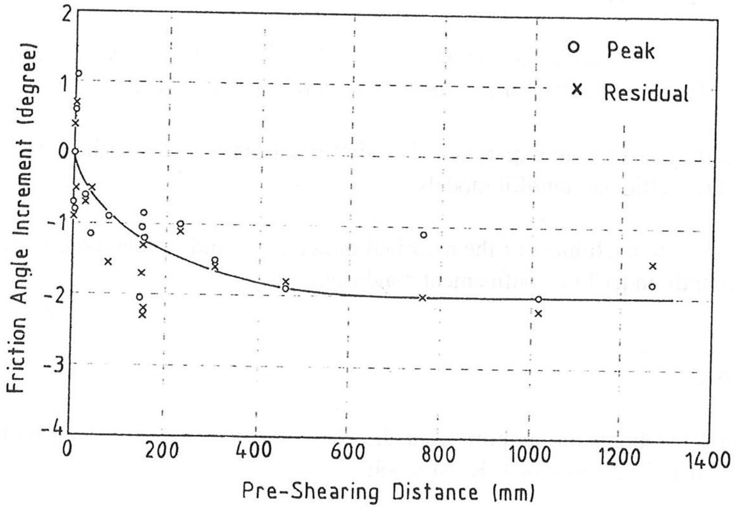

Fig. 6 - Effect of Single-Sided Polishing on PE/HDPE Interface Shear Resistance

The surcharge loading on the model liner system has a pronounced effect on the liner interface strength. The results show both the peak and residual strengths increase with the increasing loading time. Maximum increases in strength are about 6° and 2° for the peak and residual cases, respectively, with a loading time greater than 1 to 1 1/2 days.

As shown in Figure 7, the angle of shear resistance of PE sheet/HDPE geomembrane interface is relatively insensitive to the room temperature greater than 15-20°C. For temperature below the above range, the interface strength decreases with the decreasing temperature. The angle of shear resistance decreases 2° and 3° for the peak and residual cases, respectively, for the room temperature dropped from 15 to 5°C.

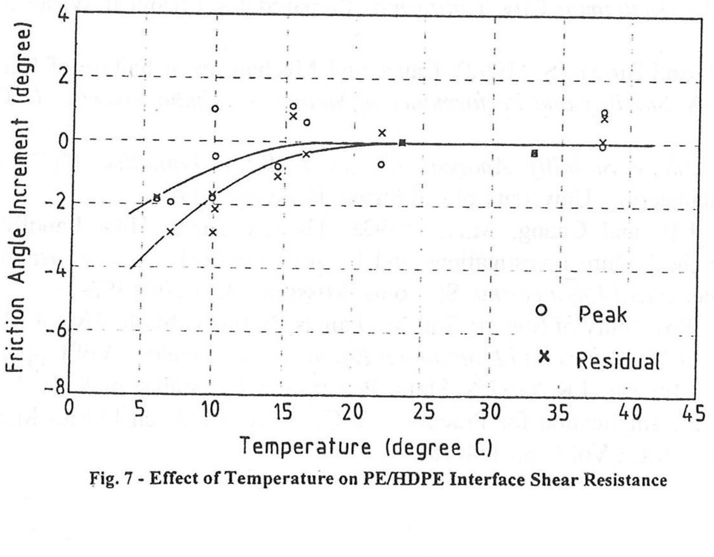

Fig. 7 - Effect of Temperature on PE/HDPE Interface Shear Resistance

CONCLUSIONS

The study had been conducted to investigate the shear resistance of various geosynthetic interfaces of the liner system used in the Kettleman landfill models. Conclusions of the study can be drawn as follows:

(1) The shear resistance of geosynthetic liner interface under low stress states is very sensitive to various factors, including: surface cleanliness, surface polishing, surcharge loading time, and temperature.

(2) The results of the study provided an experimental basis for estimation of interface shear resistance of the liner system for the Kettleman landfill models.

(3) The study demonstrates the usefulness of the modified direct shear and tipping board devices for study of liner interface strength under low confinement conditions.

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