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LARGE-SCALE SHEAR TESTS ON INTERFACE SHEAR PERFORMANCE OF LANDFILL LINER SYSTEMS

M. Kamon[1], S. Mariappan[2], T. Katsumi[3], T. Inui[4] and T. Akai[5]

ABSTRACT: Interface shear performance of various landfill liner systems were evaluated for landfill stability by conducting large scale shear tests. Testing program covers the interfaces between 1) geosynthetics (geomembrane (GM) sheet (HDPE and PVC) and non-woven geotextile) and subsoil, 2) geosynthetics and compacted clay liner (CCL), and 3) GM and geotextile. The focus of this paper is placed on interface shear performance under both as installed condition (dry for geosynthetics and optimum moisture content for CCL or subsoil) and saturated / wet condition, since landfill liner system is often subjected to saturated / wet condition due to the higher water retention capacity of CCL as well as the contact to leachate and/or groundwater. For geotextile-GM interface, there is no significant effect on the interface shear strength. The saturated CCL-GM interface had lower shear strength compared to the interface under as installed condition, although the shear performances of CCL-geotextile interface under both conditions are similar to each other. For the interfaces between geosynthetics and subsoil, the frictional resistance of HDPE with textures surface had a significant drop from 23 to 15 degree in the saturated / wet condition.

Keywords: landfill liner, interface shear strength, water content, large-scale shear box test

INTRODUCTION

The liners and closure cover system of a modern municipal solid waste (MSW) landfill are constructed with layers of various geosynthetics, such as geosynthetic clay liner and/or geomembrane (hydraulic barrier), geonet (drainage layer), geotextile (filter) and geogrid (reinforcement). While geosynthetic clay liner and/or geomembrane function effectively as hydraulic barriers against leachate and infiltration, their interface peak and residual friction angles are lower than those of the soil alone. Such lower friction angle may present between geomembrane and other geosynthetics which could trigger much rapid failure during seismic loading conditions. The soil-geomembrane interface acts as a possible plane of potential instability of the system under both static and seismic loading (Ling and Leshchinsky 1997). Hence many researchers have discussed the interface shear strength of landfill liner materials (e.g., Stark et al. 1994 and 1996, Gilbert et al. 1996, Daniel et al. 1998, Palmeira et al. 2002, Chiu and Fox 2004, Fox et al. 2004, Gourc et al. 2004). The focus of this paper is placed on interface shear performance under both as installed condition (dry for geosynthetics and optimum moisture content for compacted clay liner and subsoil) and saturated/wet condition. Landfill liner system, which is initially constructed under optimum moisture condition (OMC), is eventually subjected to saturated/wet condition (SWC) due to the higher water retention capacity of CCL as well as the contact to leachate and/or groundwater. Thus, effect of the water content of the lining materials on the interface shear strength parameters should be carefully considered in the stability analysis of the landfill liner. This paper addresses a series of direct shear tests for the interface between 1) geosynthetics and 2) geosynthetic and soil under both OMC and SWC. Based on the test results, effect of the water content of the liner materials on the interface shear performance is discussed and summarized.

EXPERIMENTAL PROGRAM

Testing Apparatus

Figure 1 shows the large scale shear box apparatuses used in the test. Bottom shear box size of 350 x 600mm and top box size of 250 x 500mm were employed for the test. 100mm larger bottom box was set to allow 20% lateral displacement relative to top box length (500mm) during the shearing with the constant contact area of 250

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[1] Professor, Graduate School of Global Environmental Studies, Kyoto University, Japan. Email: kamon@mbox.kudpc.kyoto-u.ac.jp
[2] Former Graduate Student, ditto. Email: vanan.nexus@gmail.com
[3] Associate Professor, ditto. Email: tkatsumi@mbox.kudpc.kyoto-u.ac.jp
[4] Assistant Professor, ditto. Email: inui@mbox.kudpc.kyoto-u.ac.jp
[5] Senior Research Scientist, Technology Research Institute of Osaka Prefecture, Japan. Email: akai@tri.pref.osaka.jp

x 500 mm. Constant shearing speed of 1 mm/min was employed with the normal vertical loads of 100, 200 and 300 kPa, which is equivalent to up to 20m-height landfilling based on the assumption that the wet density of the reclaimed waste is 15 kN/m^3. Testing methods according to ASTM D3080-98, D5321-02 and D6243-98 were referred for the modifications of the shear box. To minimize the impact of the apparatus on the interface shear strength, the gap between the top and bottom boxes during shearing was kept 1mm.

Materials

Geosynthetics

Geosynthetics most typically employed in the landfill liner were studied, namely non-woven geotextile, PVC

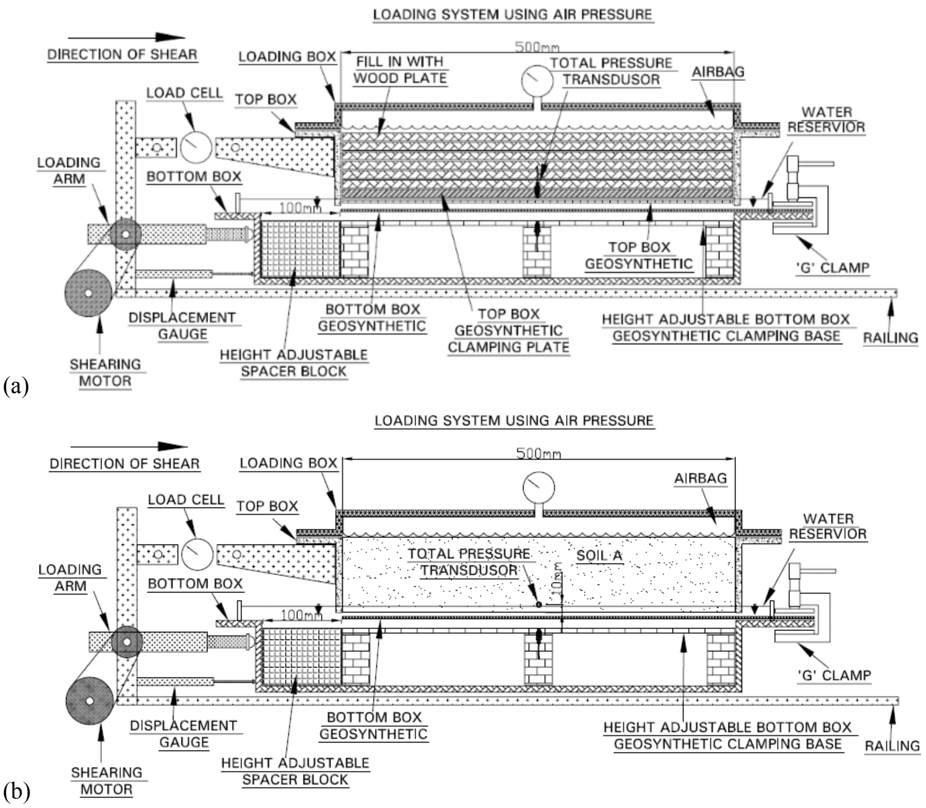

Figure 1. Direct shearing test apparatus for the interface between geosynthetics (a) and geosynthetics and soil (b)

Table 1. Properties of geosynthetics used in the test.

Materials		Geotextile	PVC sheet	HDPE sheet
Features		Non-woven type	Rear: Rough surface Front: Smooth surface	Smooth surface (Type-1) Blown film textured surface (Type-2)
Mass index	(g/m^2)	≥ 1,070 (JIS L1908)	≥ 1,940 (JIS L1908)	≥ 1,550 (JIS L1908)
Thickness	(mm)	10.0	1.5	1.5
Tensile strength	(N/mm)	≥ 16 (Weft, JIS L1908) ≥ 8 (Wrap, JIS L1908)	30 (JIS K6251)	544 (JIS K6251)
Elongation at break	(%)	≥ 55 (Weft, JIS L1908) ≥ 70 (Wrap, JIS L1908)	320 (JIS K6251)	790 (JIS K6251)
Tear strength	(N)	≥ 200 (JIS L1096)	N/A	289 (JIS K6252)
Penetration	(N)	≥ 1,000 (ASTM D4833)	N/A	≥ 539 (ASTM D4833)

Table 2. Physical properties of CCLs and native base soil

	Sand-bentonite mixture	Silt-bentonite mixture	Granite soil
Liquid limit (%)	47	69	–
Plastic limit (%)	23	35	–
Plasticity index	23	34	–
Particle density (Mg/m^3)	2.60	2.64	2.59
Maximum dry density (Mg/m^3)	1.90	1.68	2.06
Optimum water content (%)	10.5	17.5	9.0
Classification	Clay of low plasticity	Clay of high plasticity	Highly weathered granitic soil
Direct shear test			
Total cohesion (kPa)	77.0	43.1	31.4
Total friction angle (°)	34.3	35.8	45.5
CIU test			
Total cohesion (kPa)	5	4	5
Total friction angle (°)	15	22	30
Effective cohesion (kPa)	0	0	0
Effective friction angle (°)	33.5	28	35

Table 3. Summary of test cases and results.

Case	Material-1	Material-2	Dry/optimum moisture condition		Saturated/wet condition	
			Cohesion (kN/m^2)	Friction angle (°)	Cohesion (kN/m^2)	Friction angle (°)
Series 1: Geotextile-Geomembrane interface						
GT-H1	Geotextile	HDPE sheet (Type-1)	0.0*	7.6*	0.0*	7.3*
GT-H2	Geotextile	HDPE sheet (Type-2)	3.0	21.0	8.7	20.6
GT-PR	Geotextile	PVC sheet (Rear side)	11.3	18.6	6.1	18.2
GT-PF	Geotextile	PVC sheet (Front side)	26.3	16.9	0.0	22.3
Series 2: Soil-Geosynthetic interface						
SL-GT	Silt-bentonite mixture	Geotextile	0.0	15.2	0.0	19.0
SN-GT	Sand-bentonite mixture	Geotextile	0.0*	15.6*	0.0	20.6
GS-GT	Granite soil	Geotextile	0.0*	17.8*	9.9	18.6
SL-H1	Silt-bentonite mixture	HDPE sheet (Type-1)	0.0	15.3	0.0	5.2
SN-H1	Sand-bentonite mixture	HDPE sheet (Type-1)	0.0	13.7	0.0	6.1
GS-H1	Granite soil	HDPE sheet (Type-1)	0.0	15.6	0.0	19.8
SL-H2	Silt-bentonite mixture	HDPE sheet (Type-2)	0.0	24.1	0.0	9.1
SN-H2	Sand-bentonite mixture	HDPE sheet (Type-2)	0.0	24.5	0.0	10.9
GS-H2	Granite soil	HDPE sheet (Type-2)	0.0	23.0	26.8	15.2
SL-PR	Silt-bentonite mixture	PVC sheet (Rear side)	0.0	22.2	0.0	13.7
SN-PR	Sand-bentonite mixture	PVC sheet (Rear side)	0.0	19.7	2.4	10.5
GS-PR	Granite soil	PVC sheet (Rear side)	0.0	18.7	9.3	17.5
SL-PF	Silt-bentonite mixture	PVC sheet (Front side)	0.0	19.8	0.0	3.5
SN-PF	Sand-bentonite mixture	PVC sheet (Front side)	0.0	16.9	0.0	6.5
GS-PF	Granite soil	PVC sheet (Front side)	0.0	20.2	0.0	19.8

* Data have are published in Saravanan et al. (2006)

(polyvinyl chloride) geomembrane sheet and two different HDPE (high density polyethylene) geomembrane sheets (smooth surface HDPE sheet referred to "HDPE-1" and blown film textured surface HDPE sheet referred to as "HDPE-2"). The PVC geomembrane used has a rough rear and a smooth front. Both sides were subjected to the interface shearing. Basic properties of these geosynthetics are shown in Table 1.

Compacted clay liner and subsoil

Two different soil-bentonite mixtures were used as compacted clay liner materials; silt-bentonite mixture and sand-bentonite mixture. For these soil-bentonite mixtures, soil and sodium bentonite were mixed at dry mass ratio of 100:10 and compacted at optimum moisture content of 17.5% (silt-bentonite mixture) and 10.5% (sand-bentonite mixture). Compaction in the shear box was performed using a hand-held electric vibrating compaction machine. The compaction time was carefully calibrated for the minimum degree of compaction to reach more than 90 percent of the maximum dry density. As foundation soil, highly weathered granite soil compacted at its optimum water content of 9% was used. The basic physical and shear strength properties for these CCLs and granite soil are shown in Table 2.

Consolidated Isotropic Undrained (CIU) and small scale shear box tests were conducted on CCLs and compacted granite soil. The total cohesion, effective cohesion and friction parameters of the CCLs, along with the relevant shear box test results, are also listed in Table 2. A mixture of bentonite with sand shows similar cohesion to silt and bentonite mixture, however the sand mixture demonstrated higher frictional resistance from the CIU tests. The properties of highly weathered granite soil were sufficient to provide strong founding base.

Evaluation and Testing Cases

The interface test results indicate different kind of failures at different levels of relative displacement or horizontal strain. The maximum shear stresses ranged from 1 to 15% displacement relative to sample length or top shear box size of 500mm. In order to consistently analyze the relative displacement and shear stresses associated with failure, the maximum shear stress was a selection of either maximum shear stress, or the maximum shear stress reached within 8% of relative displacement. The selected shear stress consists of a combination of peak and hardening residual shear stress within 8% of relative displacement. Based on the selection criteria, the use of peak or residual interface strength is proposed to be assessed within the prescribed horizontal strain value of 8%. This is due to some of the test results presented in this paper have higher residual interface strength caused by horizontal strain hardening effect. Hence selection purely based on peak or residual interface strength in some cases could over or under estimate the interface resistance. Thus the selection of maximum shear stress within 8% horizontal strain was used as criteria in this research. The unit of 8% horizontal strain was selected as criteria of landfill liner failure limit, where potential geomembrane tearing which could lead to leachate pollution to the environment.

The selected shear stresses obtained were plotted against normal stresses to compute the failure envelope. To determine the total cohesion and total interface friction angle, best-fit linear plots were developed. The shear stress intersections were set to be through either axis or positive cohesion only. List of the test cases conducted and the interface shear strength parameters obtained are summarized in Table 3. Series-1 and 2 are designed to evaluate the effect of water content (OMC and SWC) on the interface shear performance between geotextile and geomembrane, and between geosynthetics and CCL / foundation soil, respectively. For SWC, the compacted soil samples were placed in a vacuum chamber with maximum negative pressure between 50 to 60kPa for 48 hours to achieve the degree of saturation around 90% in the shearing zone.

RESULT AND DISCUSSION

Interface shear strength parameters under both saturated/wet condition (SWC) and optimum moisture condition (OMC) are presented in Table 3. By comparing interface test results under OMC and SWC, following differences were found:

For the interface between geotextile and geomembrane in Series-1, the test results had very little different between OMC and SWC. Only in the case GT-PF (geotextile / front side of PVC geomembrane) 30% higher frictional resistance and no cohesion were observed under SWC. However, it can be concluded that there is no significant effect on the geotextile/ geomembrane interface shear performance in the case that the whole landfill liner is saturated/submerged.

For the silt-bentonite mixture interfacing with geomembrane, the parameters obtained were lower for SWC compared to OMC of about 62 to 195%. The HDPEs had frictional resistant lowered by 165 to 195% and PVC geomembrane by 62 to 88%. Figure 2 shows the shear stress profile with the horizontal displacement/ strain for the interface between silt-bentonite mixture and HDPE-1 under both OMC and SWC. For OMC, the peak shear stresses were observed at the 1 to 2% horizontal strain. For SWC, horizontal strain hardening effect was observed for all normal loads. These observations are also consistent with the silt-bentonite interfacing with HDPE-2 and PVC. For the silt-bentonite mixture interfacing with geotextile, 20% increment in frictional resistance was observed. The stress-displacement behaviors are similar to those of the interface with geomembranes.

For the sand-bentonite mixture interfacing with geosynthetics, the test results under SWC were similar to those of with the silt-bentonite mixture. However, the frictional contribution from the interfaces with sand-bentonite mixture was marginally higher than that of silt-bentonite mixture. In the initial prediction, sand-bentonite mixture was predicted to provide much higher frictional resistance as compared to silt-bentonite mixture. The test results were not as predicted due to the presence of bentonite in the sand and higher damages created on interfacing member during sharing by sand.

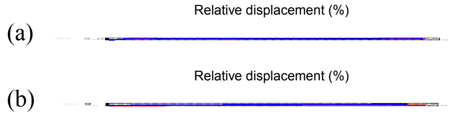

Figure 2. Stress-displacement curves for the interface between silt-bentonite mixture and HDPE-1: (a) OMC and (b) SWC.

Figure 3 shows the stress-displacement curves for the interface between sand-bentonite mixture and HDPE-1 under SWC. Unlike the silt-bentonite mixture, the peak shear stresses were followed by the horizontal strain hardening for all normal loads. This behavior was observed for the interfaces between HDPE-2 and PVC.

The saturated interfaces were lower for geomembranes compared to geotextile. The HDPEs had frictional resistant lowered by 125% and PVC geomembrane by 160 to 463%. In the case of geotextile, 25% increment in frictional resistance was observed, although horizontal strain softening behavior was clear only under SWC for relatively larger normal loads, as shown in Figure 4. These observations are similar to those for the silt-bentonite mixture.

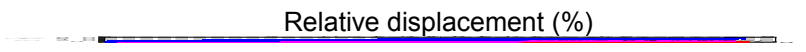

Figure 3. Stress-displacement curves for the interface between sand-bentonite mixture and HDPE-1 under SWC.

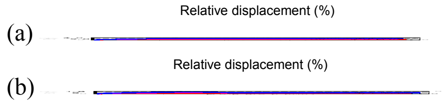

Figure 4. Stress-displacement curves for the interface between sand-bentonite mixture and geotextile: (a) OMC and (b) SWC.

Interface parameters of foundation granite soil with geotextile and geomembrane under SWC resulted in followings, compared to those under OMC;

- with geotextile: 4% higher.
- with smooth HDPE-1 geomembrane: 21% higher.
- with textured HDPE-2 geomembrane: 50% lower.
- with PVC geomembrane of both side: 2 to 7 % lower.

From the findings on granite soil, geotextile and smooth HDPE-1 geomembrane had higher frictional resistance compared to textured HDPE-2 geomembrane and PVC geomembrane under SWC. In the case of HDPEs, the frictional resistance of textured HDPE-2 geomembrane had significant drop from 23.0 degree under OMC to 15.2 degree under SWC, which is almost same to the frictional resistance of smooth HDPE (Type 1) geomembrane under OMC of 15.6 degree. As for PVC geomembrane only a drop of 2 to 7% was observed. Compared with CCLs, negative effect under SWC on the interface performance is less significant. This is probably because the presence of bentonite in CCLs affects the interface property a lot under SWC.

In all cases, geotextile had higher frictional resistance under SWC compared with OMC except the interface between geotextile and both sides of PVC geomembrane, where a significant drop of 30% in frictional resistance was observed between OMC and SWC.

CONCLUSIONS

This paper summarizes the interface shear performance of landfill liner components under as installed (optimum water content) condition and saturated/wet condition based on the test results of the modified large-scale shear test. The following remarks can be drawn:

1) Interface shear performance between geotextile and geomembrane sheet is not affected by wetting or submerging
2) Non-woven geotextile maintains or enhances the interface shear performance with both CCLs and foundation granite soil under saturated/wet condition.
3) The saturated/wet CCL-GM interface had much lower shear strength compared to the interface under OMC. The peak shear stresses were not clear and horizontal strain hardening effect was observed under SWC. Especially, the frictional resistance of textured HDPE-2 geomembrane under SWC had significant drop from the value under OMC.
4) For geotextile and geomembrane sheet, the frictional contribution from the interfaces with sand-bentonite mixture was marginally higher than that of silt-bentonite mixture.
5) Compared with CCLs, foundation granite soil is subjected to less significant influence on the interface performance under SWC. This is probably because the presence of bentonite in CCLs affects the interface property a lot under SWC.

However, detail mechanisms accounting for these different behaviors are still unclear and should be further studied.

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