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The friction characteristics of geomembrane with incinerator residue

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ABSTRACT: Waste landfill sites for dumping incinerator residue commonly use geomembranes as the liner. It is very often that the sites are built in valleys where side slopes are so steep that cause the residue or the geomembrane slide down. In order to investigate the effect of the friction characteristics of geomembrane with incinerator residue, a series of interfacial friction tests as well as tensile tests of geomembrane are performed. From test results, an example of stability analysis is presented for two possible failure types of landfill sites.

1 INTRODUCTION

Landfill sites commonly use geomembranes as a barrier at the bottom for intercepting water. However, if the design is not appropriate, the liner will fail due to slippage along the interfaces of various materials or tensile failure in geomembranes, etc. In addition, incinerated residue dumped directly on geomembranes might cause scratches and reduce the tensile strength of geomembranes.

According to a report that investigated sixty-three waste landfill sites in Taiwan, several defects that are found include:

(a) geomembranes contact directly with wastes
(b) geomembranes have tensile or anchorage failures
(c) inappropriate cover soil for geomembranes
(d) poor grading job before placing geomembranes
(e) Unsuitable covering work

The above defects are due primarily to inappropriate protection of geomembranes (Fig. 1). Hence, this paper aims to investigate the effect of the friction characteristics of the interface between geomembrane and incinerator residue by a series of direct shear tests. After performing the direct shear tests, the geomembrans are tested by tensile tests to find out if there is significant change in the tensile strength. The results from the tests are then used in a stability analysis on two possible failure types of landfill sites.

Figure 1. A solid waste landfill site.

2 MATERIAL PROPERTIES

2.1 *Incinerator residue*

The residue obtained from an incinerating plant is composed of metal, glass, ceramics, and a small amount of paper. The residues before and after dried are shown in Figure 2: wet residue is dark gray with bad smell. Dried residue chunks would break apart if shake lightly. The grains are in irregular shape and have very rough surface. Large grains are adhered by many small grains. Some grains even look very porous.

The specific gravity of the residue is determined by the ASTM method. The range is 2.57~2.73 (mean value 2.60). The water content is 23.4~25.7% (mean value 24.5%). The grain size distributions are shown in Figure 3. The seven curves on the figure all have similar distributions, i.e., most of the grains are between #4 ~ #100, and less than 2% of minus #200. The curve from averaging the seven curves is shown in Figure 4. The residue is classified as a well graded sand (SW) according to the Unified Soil Classification System.

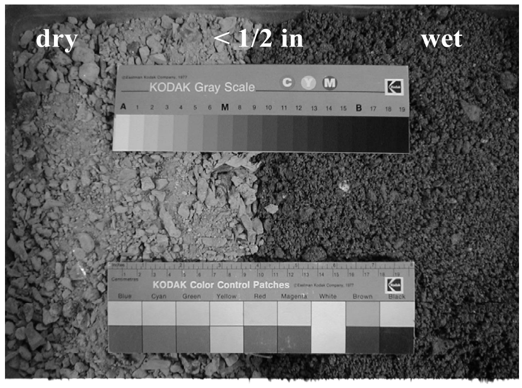

Figure 2. The appearance of the incinerator residue (left: dry, right: wet).

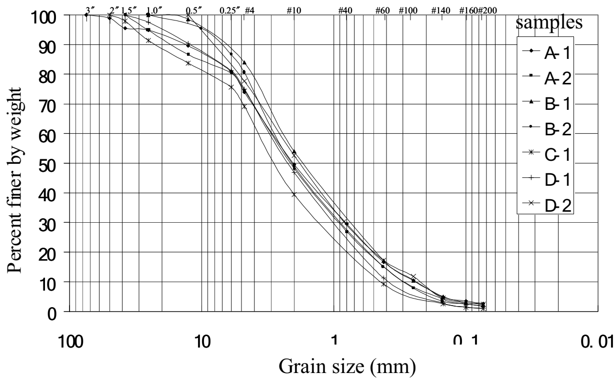

Figure 3. The grain size distributions of the incinerator residue.

Because the height of the direct shear box is 10 cm, the maximum diameter of the residue retained is 0.5 inches (1.27 cm, less than 1/6 of the height). According to the equivalent weight method, the sizes larger than 0.5 inches are scaled down and replaced by the sizes between 0.5 inches ~ #4, This modified grain size distribution is still classified as SW; hence its engineering property should not have much difference.

Besides, the results of compaction tests show that the maximum dry density is 1.32 g/cm^3, and the minimum dry density is 1.0 g/cm^3.

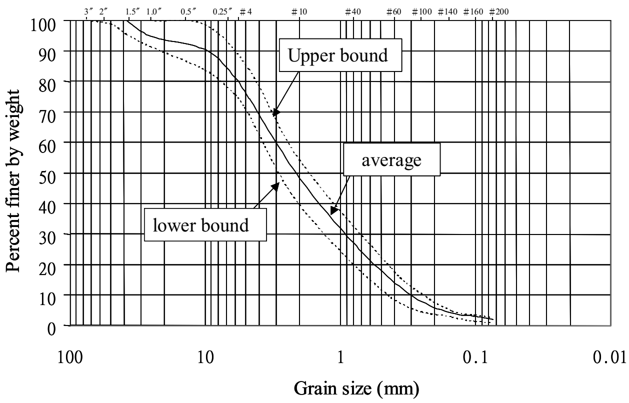

Figure 4. The grain size distributions from averaging the seven curves.

2.2 *Sand*

The sand used in this study contains 99.8% of quartz and classified as SP. It has specific gravity 2.65, maximum dry density 1.66 g/cm^3, and minimum dry density 1.41 g/cm^3.

2.3 *Geomembrane*

The geomembrane is a 2-mm thick HDPE with smooth surface. Its ultimate strength is 41 kN/m. The result of the tensile test is shown in Figure 5.

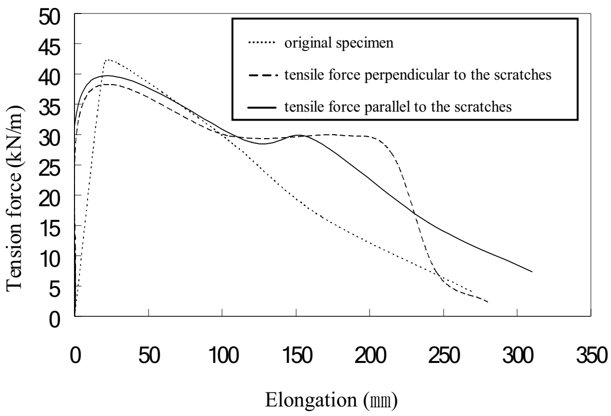

Figure 5. The tensile test results of a geomembrane.

3 TEST RESULTS AND DISCUSSIONS

3.1 *Effect of water on interfacial friction*

The friction angles between the residue and the geomembrane are higher than those between the sand and the geomembrane (Tables 1-2). This is not difficult to understand because the residue is a well-graded material with angular shape, irregular and rough surface. However, the sand is more uniform, with regular shape and less rough surface than the residue.

As to the water, its effect on the friction of residue/geomembrane is not so significant as to sand/geomembrane. This phenomenon can be explained by examining the scratches on the geomembrane after the test. As mentioned earlier, the residue is non-homogeneous with various components such as metal, glass, ceramics, etc. The grains of the residue would penetrate into the geomembrane when subjected to normal force. As the shear box was moving, the scratches were then induced. On the other hand, the sand is rounded shape and hence less likely to damage the geomembrane surface.

Since the residue might be pressed into the geomembrane, the interfacial friction is not only due to the surface friction, but also to the penetration of the grains. This passive resistance can increase the friction angle more than that reduced by the water. However, water affects the interfacial friction of sand/geomembrane. The friction angle can drop off as high as eight degrees. Moreover, the relative density increases the friction angle for both the sand and the residue, but also decreases the adhesion. Hence, increasing the relative density will not necessarily increase the factor of safety in stability analysis, as will be explained later.

Table 1. The results of direct shear test on residue/geomembrane

Relative density (%)	Water content (%)	Peak strength		Residual strength	
		c_a (kPa)	δ (°)	c_a (kPa)	δ (°)
60	0	5.52	19.1	1.50	15.4
	20	7.08	19.9	7.45	14.4
80	0	2.04	24.6	0.50	19.3
	20	1.50	25.7	2.00	19.9

Table 2. The results of direct shear test on sand/geomembrane

Relative density (%)	Water content (%)	Peak strength		Residual strength	
		c_a (kPa)	δ (°)	c_a (kPa)	δ (°)
60	0	0.14	17.2	2.50	13.0
	11.6	0.00	9.3	0.00	8.0
80	0	0.40	18.2	2.00	14.3
	11.9	10.60	10.8	10.50	8.7

3.2 *Choice of shear strength parameters*

From the result of the direct shear test between two materials, the force versus displacement curves dropped off after the peak strength (Fig. 6). Hence, whether to choose the peak strength or the residual strength in design should depend on the location. For example, on a side slope, the material on geomembrane might slide down a certain distance that makes the interfacial resistance drop to residual strength. In this case, choosing the peak strength in design will not be appropriate because of overestimation. But, at the bottom of a landfill site, since it is not likely to have significant relative displacement between two materials, then choosing the peak strength in design will be suitable.

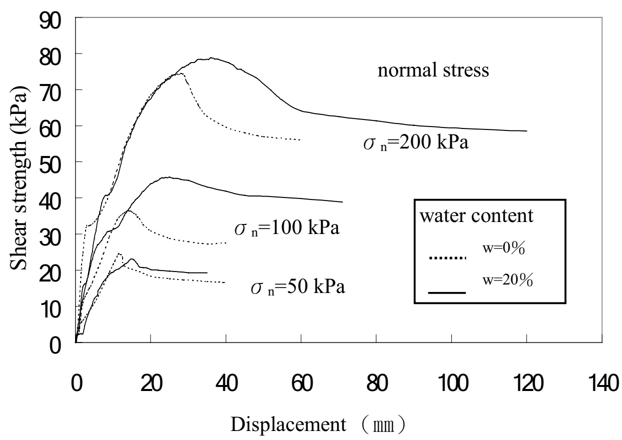

Figure 6. The results of direct shear test on the interface of residue and geomembrane

3.3 *The tensile strength of geomembrane*

To investigate if the tensile strength of the geomembrane will have a significant change after direct shear testing that induced scratches, comparisons are made in Table 3. The tensile strength is 41.7 kN/m before the test, and reduces 1.1~6.4 kN/m after the test. The ratio is 2.5~15% of the original strength.

Moreover, the behaviors are different as compared in Figure 5. The curve of original specimen is less steep before the peak but drops quicker after the peak than the scratched samples. It also can be seen that the curves of the scratched samples drop off in two stages instead of suddenly. From this observation, it can be concluded that the tensile strength of the geomembrane will decrease and the behavior becomes more ductile.

Table 3. The tensile strength of the geomembrane (Lin, 2000)

	Relative density (%)	Normal stress*** (kPa)	Tensile strength (kN/m)
Before test	—	—	41.7
After test	80	200 *	38.7
		200 **	37.0
		100**	39.0
		50**	40.6
	60	200**	35.3
		100**	37.1
		50**	39.2

* tensile force perpendicular to the scratches
** tensile force parallel to the scratches
*** normal stress used in direct shear test

4 STABILITY ANALYSIS

For the case that dumping incinerator residue directly on geomembrane, two kinds of instability might occur:

Type 1: the residue slides down along the geomembrane due to insufficient friction (Fig. 7).

Type 2: the geomembrane is under high tensile stress due to the friction forces on its top and bottom (Fig. 8).

An example of stability analysis is shown below.

A landfill site has a side slope of 18.4° (V:H = !:3), and the slope face is 100 m. The thickness of the residue is 1 m high. The tensile strength of the geomembrane is 41 kN/m.

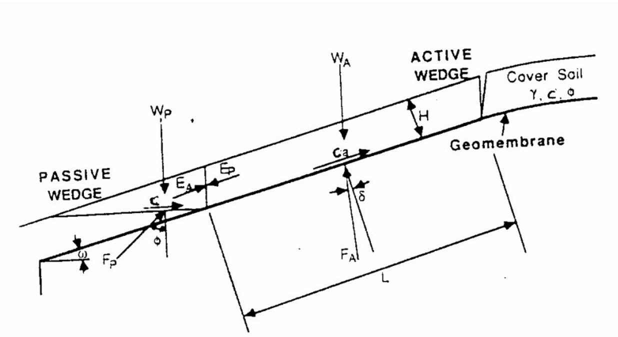

Figure 7. The free body diagram of a side slope when cover material above a geomembrane (Koerner & Hwu, 1991).

4.1 *Analysis of type 1*

The sliding mass is divided into two parts: the active wedge along the slope and the passive wedge at the bottom (Fig. 7). The equation of the equilibrium is shown below:

$$(FS)^2\left[0.5\gamma LH\sin^2(2\omega)\right]-(FS)\begin{bmatrix}\gamma LH\cos^2(\omega)\tan(\delta)\sin(2\omega)\\ +c_aL\cos(\omega)\sin(2\omega)+\gamma LH\sin^2(\omega)\tan(\phi)\sin(2\omega)\\ +2cH\cos(\omega)+\gamma H^2\tan(\phi)\end{bmatrix}$$

$$+\left[(\gamma LH\cos(\omega)\tan(\delta)+c_aL)(\tan(\phi)\sin(2\omega))\right]=0 \quad (1)$$

where γ = the unit weight of the residue; c, ϕ =the strength parameters of the residue; c_a, δ = the strength parameters along the interface; ω = slope angle; L = the length of the slope face; H = the thickness of the residue; and FS = the factor of safety.

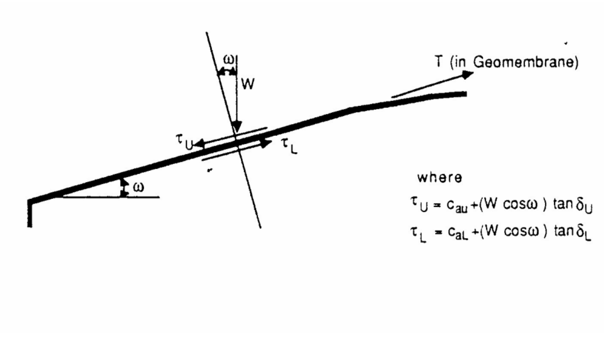

Figure 8. The friction forces on the two sides of a geomembrane (Koerner & Hwu , 1991).

It needs to mention that the above equation does not consider seepage and seismic loads.

The factors of safety considering both peak strength and residual strength are presented in Table 4. The factors of safety obtained from the residual strength are about 50~90% of those obtained from the peak strength. It ca be seen that the adhesion contributes a lot in the factor of safety. Additionally, the factors of safety for the cases with higher relative density are less than those of lower relative density. This is because the adhesion decreases as shown in Table 1.

Table 4. The results of stability analysis of type 1 (Lin, 2000)

Relative density (%)	Water content (%)	Factor of safety			
		$c_a \neq 0$		$c_a = 0$	
		Peak strength	Residual strength	Peak strength	Residual strength
60	0	2.6	1.3	1.1	0.9
	20	3.1	2.9	1.2	0.8
80	0	2.0	1.3	1.5	1.2
	20	2.1	1.8	1.3	1.2

4.2 *Analysis of type 2*

The tensile force per unit length of the geomembrane is expressed in Equation 2:

$$\frac{T_{reqd.}}{W} = \left[(c_{aU} - c_{aL}) + \gamma H\cos(\omega)(\tan(\delta_U) - \tan(\delta_L))\right]L \quad (2)$$

where T_{reqd}. = required tensile force of the geomembrane; c_{aU}, δ_{aU}= interfacial strength parameters at the top of the geomembrane; and c_{aL}, δ_{aL}= interfacial strength parameters at the bottom of the geomembranem, and W= the width of the geomembrane.

The factor of safety is defined as:

$$FS = T_{allow}/T_{reqd}. \quad (3)$$

where T_{allow}= allowable tensile force of the geomembrane.

The results of the stability analysis assuming no adhesion are shown in Table 5. It can be seen clearly that the tensile force in the geomembrane depends on the difference of the friction forces acting on the two sides of the geomembrane. The more difference in friction force, the higher the tensile force will be induced in the geomembrane.

Table 5. The result of the stability analysis of type 2 (Lin, 2000)

δ_U (°)	δ_L (°)	Tensile force (kN/m)	Factor of safety
19.1	18.2	19.1	2.14
	10.8	169.7	0.24
15.4	18.2	*	*
	10.8	92.4	0.4
19.9	18.2	36.2	1.1
	10.8	184.9	0.2
14.4	18.2	*	*
	10.8	72.0	0.6

* no tensile force induced

5 CONCLUSIONS

From the test results, the incinerator residue is a frictional material. Increasing its relative density can increase its shear strength by more than 30%. Besides, the friction angle at the interface of residue/geomembrane increases as the relative density of the residue is higher. On the contrary, increasing the relative density of the residue may decrease the interfacial adhesion and therefore can not increase the stability. However, the water content of the residue has insignificant effect on its friction angle. The reason is attributed to the grains being pressed into the geomembrane. On the contrary, the friction angle drops off several degrees for wetter sands.

From the interfacial friction tests, the curves of shear strength versus displacement show peaks in strength and strain softening behavior. This strain softening characteristics needs to consider when choosing parameters for stability analysis. In addition, the results of tensile tests show the difference in tensile force of the geomembranes, before and after sheared, are about 3~15%. This factor needs to be taken into account in designing when the residue will dump directly on the geomembrane.

Finally, directly dumping incinerator residue on a geomembrane liner will not only damage the liner, but also may induce tensile stress in the geomembrane. The stability analysis presented in the example is necessary when designing.

6 REFERENCES

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