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Interface resistances among soil and geosynthetic materials for final cover of a hazardous landfill in Thailand

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ABSTRACT: Stability of landfill final cover is controlled mainly by interface resistances among soil and geosynthetic materials, e.g., geonet, geotextile, geomembrane and geosynthetic clay liner (GCL). The present study aims to determine the interface resistance of various materials used in construction of the final cover of a hazardous landfill in Rayong Province (Eastern part of Thailand). Soil used as waste covering layer and protective layer is a coarse sandy soil existing in the area. The friction angles obtained from direct shear tests are about 36° and 42° for samples with dry density of 1.5 and 1.9 t/m^3, respectively. A test setup was arranged to determine resistances among several possible interfaces existing in the final cover. Interfaces between soil and various geosynthetic materials were about only 70 – 80% of the soil friction angle. The interface resistance between geomembrane – geomembrane was the lowest (10°). Fortunately, the case was not actually relevant to the actual landfill. As a consequence, the most critical sliding may occur at the interface between Geotextile – Geomembrane which provided friction angle of no more than 12°. To improve this, it was decided to use the rough surface geomembrane which helped increasing the interface resistance and accommodating the slope with inclination of 1:3 (V:H). The interface resistance between geotextile – geonet obtained from the laboratory test was high due to application of confinement. In actual application, due to much less contact area (depending on aperture and opening ratio of Geonet) during installation, mechanical binders (wires) was required to temporarily fix the geonet to geotextile. Use of Geocomposite was proven to be much more convenient.

1 INTRODUCTION

The regulatory requirements for solid and hazardous waste landfill covers require installation of a liner system to protect the landfill from infiltration of surface water. Similar to the leachate collection system, liners of the final cover consist of a combination of geosynthetic materials and natural or processed soil. Geotextile, geomembrane and geonet are widely used as essential components of liner system in waste landfills. The frictional characteristics of interfaces between geosynthetic-geosynthetic and geosynthetic-soil are therefore important factor in designing of the liner's structure such as side slope stability.

This paper presents a series of test results to determine the interface frictions between geosynthetics – geosynthetics and geosynthetics –sand. The influences of density of sand and different types of geosynthetics are presented.

Possible interfaces in the final cover can be varied depending on the functioning of the cover. In general, the final cover may compose of the components as depicted in Figure 1.

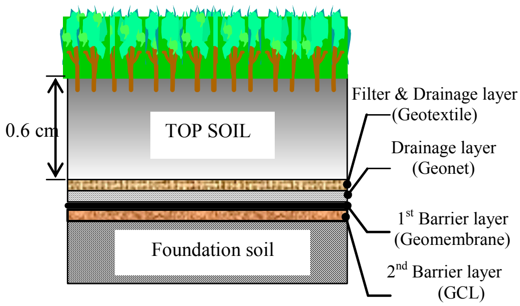

Figure 1 Schematic section of final cover

2 EXPERIMENTAL STUDY

The possible interface as shown in Figure 1 shall be tested in the laboratory so that the resistance will be obtained for stability analysis of the final cover. Figure 2 schematically shows the setup of the direct shear box (20 cm×20 cm) used for interface testing. The tested geosynthetics were fixed to the upper and lower boxes. They were confined through compacted sand in the upper and lower boxes, respectively. The upper box was slightly shorter than the lower one, in order to provide free moving space. In each series of tests, the vertical stress of 0.5, 1.0 and 2.0 kg/cm^2 were applied before shearing. Air-dried sand was first compacted in the lower box. After installing the lower and upper geosynthetics, compacted sand was then prepared in the upper half of the direct shear box. Two densities of compacted samples were prepared; i.e., γ_d = 1.5 and 1.8 kg/cm^3 (D_r = 65% and 75%). Vertical load was applied directly using the weight balance, while horizontal load was measured using a load cell install between AC motor and the shear box.

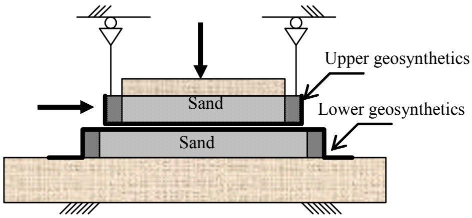

Figure 2 Schematic drawing of testing equipment

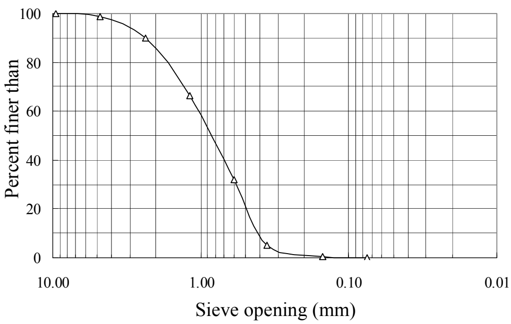

Figure 3 Grain size distribution of tested

Table 1 Summary of interface tests done in the study

	Sand	GT	GN	GM
Sand	O	O	O	O
GT		O	O	O
GN			O	O
GM				O

GT = Geotextile, GN = Geonet, GM = Geomembrane

The coarse sandy soil existing nearby the construction site was used as the tested material (Figure 3). It was adopted because the sand will be used for both foundation and top soils in the actual construction. Its D_{50} and G_s are 0.9 mm and 2.60 respectively.

Although not all interfaces between geosynthetics were existed in the final cover, the present study conducted all interface properties as summarized in Table 1. Frictions between sand against all geosynthetic materials were also tested. The basic physical properties of geosynthetics used are;

- Geotextile: Non-woven
  Thickness = 1.9, 3.2 mm
  Mass = 250, 400 g/m^2
- Geomembrane : HDPE, thickness = 1.5 mm
- Geonet : HDPE, thickness = 4 mm

3 EXPERIMENTAL RESULTS

3.1 *Friction resistance between sand and geosynthetics material*

Figure 4 shows plot between the maximum shear stress and vertical (normal) stress obtained from tests on compacted sands at various values of overburden stress. The friction angles (ϕ) defined according to the equation shown below was about 36° and 42° for medium loose and dense samples respectively.

$$\tan\phi = \frac{\tau_{\max}}{\sigma_v'} \tag{1}$$

The values of sand friction angles were given for the purpose of reference. Table 2 summarizes the friction resistance between sand and geosynthetic materials. The ratio of friction angle, $\phi_{soil}/\phi_{interface}$ was about 0.7 – 0.8 for all of the interface tested.

Table 2 Interface friction angle between sand and geosynthetics

Type	Loose Sand $\phi_{soil}/\phi_{interface}$	Dense Sand $\phi_{soil}/\phi_{interface}$
GT	0.79	0.74
GM	0.78	0.71
GN	0.75	0.69

GT = Geotextile (1.9 mm), GM = Geomembrane, GN = Geonet

3.2 *Interface resistance between geosynthetic materials*

Tests were conducted on various interfaces; i.e., geotextile – geotextile, geotextile – geomembrane and geotextile – geonet. Figure 5 shows an example of typical relationships between the shear stress and shear deformation obtained from tests with *GT-GM*. The shear resistances of the interfaces between geo-

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synthetics exhibit a strong normal stress dependency.

For similar normal stress, the geotextile – geotextile interface provides the highest resistance, while the geomembrane – geomembrane gives the least one. The friction characteristic of the interface between geosynthetics is rather a pattern of cohesionless. Namely, without normal stress, frictions between interfaces of geosynthetic materials are almost zero (Figure 6). Table 3 summarizes the friction angles between geosynthetics derived from Figure 6. The interface between geomembrane – geomembrane gives the minimum friction angle of about 9 degrees. While the geotextile – geotextile interface provides the maximum friction angle of almost 20 degrees.

Table 3 Interface friction angle between interfaces of geosynthetics

Type	GT	GM	GN
GT	19.8 ^{O}	12.0 ^{O}	16.9 ^{O}
GM		9.9 ^{O}	14.3 ^{O}
GN			13.1 ^{O}

GT = Geotextile (1.9 mm), GM = Geomembrane, GN = Geonet

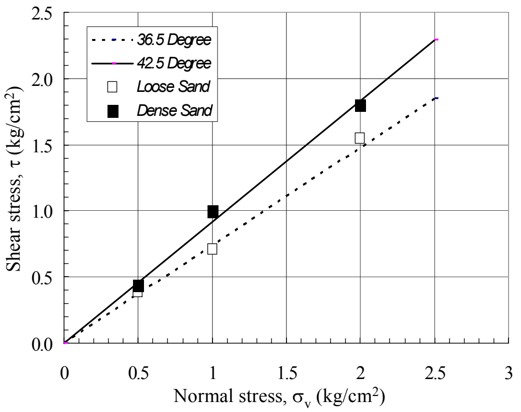

Figure 4 Friction angles of sand samples

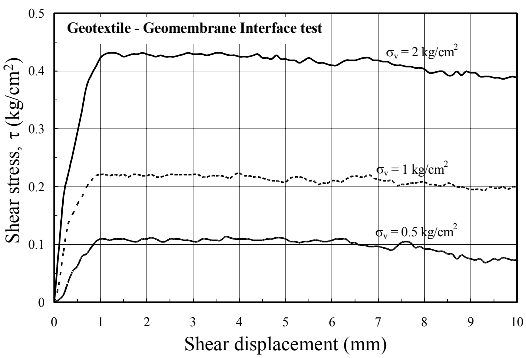

Figure 5 Shear stress and shear deformation relationship between GT – GM

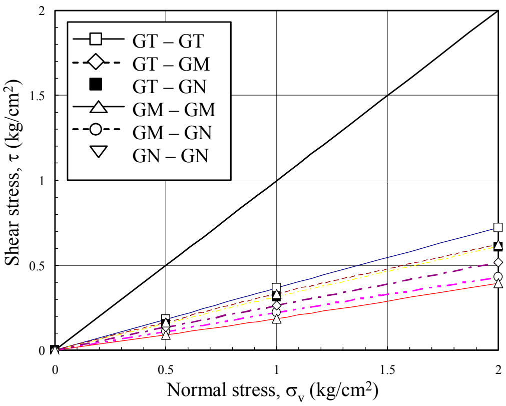

Figure 6 Shear stress vs. normal stress obtained from interface tests

4 STABILITY OF LANDFILL COVER

The slope of the existing cap varies in the range of 2.8:1 to about 3.3:1. The friction angles from the above mentioned interface tests were used to compute the stability of slope. The most critical sliding mechanism is expected to be either the sliding of geotextile on geomembrane or the sliding of the geomembrane on GCL (geotextile).

The safety of factor against sliding was computed using the assumption shown in Figure 7. It is assumed that the passive wedge (resistance) is developed at the toe of the slope. The material properties, apart from shear strength, are as following; thickness of cover soil = 0.6 m, length of slope = 80 m and inclination of slope = 2.8:1 (= 19°)

The basic assumption and parameters used in computing sliding stability are summarized in Figure 7. The factor of safety against sliding along the interface can be obtained through the following equations (Koerner and Daniel, 1996, Thiel and Stewart, 1993).

$$a(FS)^2 + b(FS) + c = 0 \qquad (2)$$

where:

$$a = (W_A - N_A \cos\beta)\cos\beta$$

$$b = -[(W_A - N_A \cos\beta)\sin\beta\tan\phi + (N_A \tan\delta + C_{in})\sin\beta\cos\beta + (C_{soil} + W_P \tan\phi)\sin\beta]$$

$$c = (N_A \tan\delta + C_{in})\sin^2\beta\tan\phi$$

$$W_A = \gamma h^2 (L/h - 1/\sin\beta - 0.5\tan\beta)$$

$$N_A = W_A \cos\beta$$

Based on the above equation for simplified slope stability analysis, the factors of safety against sliding between interfaces were computed. The results are summarized in Table 4. The following conclusion can be drawn.

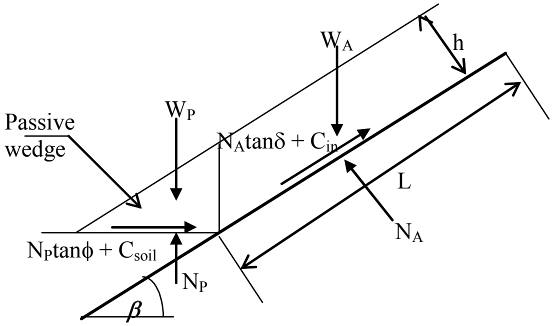

Figure 7 Basic assumption adopted in calculation of sliding stability of the final cover

Table 4 Factor of safety (FS) based on Interface friction angle between interfaces of geosynthetics (β = 19°)

Type	GT	GM	GN
GT	1.42	0.99	1.25
GM		0.88	1.11
GN			1.05

GT = Geotextile (1.9 mm), GM = Geomembrane, GN = Geonet

(a) Factor of safety between geomembrane and geomembrane is the least. However, this kind of interface does not really occur in the field. The shear resistance of the overlapping geomembrane occurred during installation shall be compensated by thermal bonding of the overlapping sheet.
(b) Similarly to (a), the interface between geonet and geonet does not occur in the field. This is therefore not the case to be considered.
(c) As a consequence, the interface between geotextile (GT) and geomembrane (GM) may impose difficulty in maintaining the stability of the final cover. This interface may be directly found between GT and GM and indirectly existed between geosynthetic clay liner (GCL) and GM (see Figure 1).

To solve the problem, the rough geomembrane was used. Though no test conducted based on the rough surface geomembrane, Stark et al. (1996) and Triplett and Fox (2001) suggested that the rough surface geomembrane can provide additional friction angle between interfaces of about 4 – 5 degrees to the smooth surface geomembrane. By adopting this assumption, the factor of safety against sliding between the interface of geomembrane and geotextile can be increased to about 1.3.

Attention should be given to the following point when the geosynthetic clay liner (GCL) is used in the final cover. Since the residual strength of the GCL is very low (ϕ = 4.7°, Triplett and Fox, 2001), it is very important to ensure that the safety factor obtained by using the peak strength of interface is always smaller than that obtained by using the peak strength of the GCL. This is done to confirm that the peak strength of the GCL shall never be exceeded. Namely, failure shall occur at the interfaces rather than inside the GCL. Furthermore, the use of Geocomposite (where geotextile is mechanically or thermally bonded to the geonet) gives more engineering advantages than using the conventional geonet – geotextile. Although test result and computation result do not indicate any trouble of such interface, there are a few difficulties in installing such interface in the actual construction.

5 CONCLUSION

The direct shear tests were conducted using the actual materials (soil and geosynthetics) that will be used in the construction of final cover of a hazardous waste landfill in Rayong Province of Thailand. It was found that the interface between the geotextile and geomembrane provided the minimum friction resistance. By conducting a simplified slope stability analysis, this interface gave very low factor of safety. The decision had been taken to use the rough surface geomembrane instead of the smooth surface one. Furthermore, the using of geocomposite is recommended.

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