Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Centrifugal Model Tests to Determine the Tensile Force of Geotextile and Geomembrane Used on the Side Slope of a Waste Landfill

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ABSTRACT: Geomembranes are installed on the bottom and sides of a landfill to protect the surrounding ground and water from being polluted by the leachate from the waste. Geotextile is also placed over the geomembrane to protect it from mechanical damage. In order to evaluate the tensile forces of geotextile and geomembrane which are used on the slope, centrifugal model tests were conducted in the laboratory. This paper presents the results of these centrifugal tests and compares them with the calculated values based on the ordinary ultimate force equilibrium method. The authors have also proposed a modified method of calculation.

1 INTRODUCTION

A liner system composed of geomembrane and geotextile is installed on the bottom and the side slope of a waste landfill. The liner prevents contamination of the surrounding ground and ground water by leachate from the harmful substances within the landfill. To design how much volume the anchorage requires, it is very important to estimate the amount of force created in the system.

Tensile force in the geotextile is caused by friction between the waste and the geotextile which is a result of the compression of the disposed waste. Many methods of calculating the tensile force of the geotextile and the geomembrane have been presented by researchers. Koerner (1994) presented a method based on the friction forces transmitted between the materials. B.Frederic (1995) presented an analytical method by using the static equilibrium of the liner system and the transmission of stresses into the different layers. H.Kanou (1997) presented a calculation method of the thermal stress.

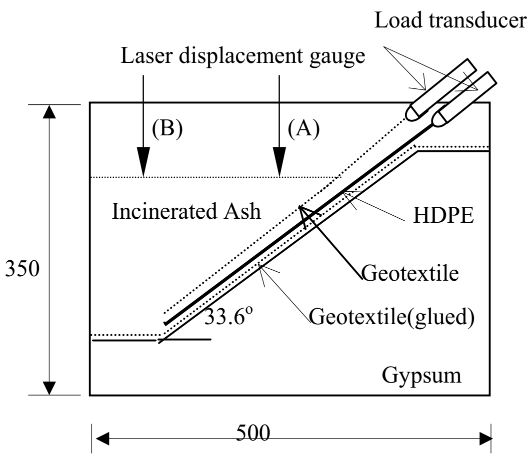

Figure 1 Configuration of model waste landfill

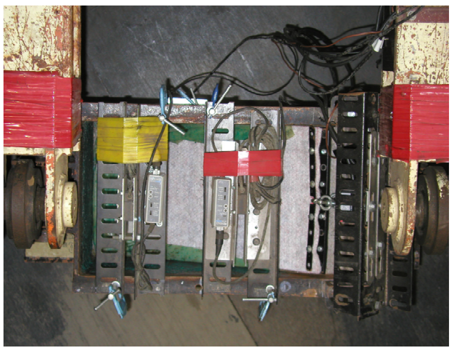

Figure 2 Set up of the model waste landfill

2 CONFIGURATION

The experiments in foundation engineering have been conducted as in-situ tests or small modeled tests in the laboratory. Because of the cost and time requirements of in-situ tests, centrifugal model tests are used. In the centrifugal test, the size of the model is 1/n in prototype and the model is run to n times gravitational acceleration G in a centrifuge. The stresses in the model are the same as would be seen in the landfill.

The model landfill was placed in a steel container having a length of 50 cm, a width of 26 cm and a depth of 35 cm. The foundation and slope of the model landfill were made of gypsum. The slope of the model landfill was 1:1.5(V:H) with a height of 17 cm. Stapled non-woven geotextile was then glued to the surface of the model landfill which was then covered by an HDPE geomembrane with a thickness of 1.5 mm. A protective layer of stapled non-woven geotextile was spread over the geomembrane (Figure 1) which was then covered on the surface by incinerated ash. The model was accelerated to about 38 G in centrifuge. The forces induced within the top layer of geotextile and geomembrane were measured through load transducers of 196 N and 490 N which were fixed at the top of slope. The displacement of surface ash was measured by a laser displacement gauge set at the top of the container (see Figure 2).

3 MATERIALS AND TESTING PROCEDURE

3.1 *Materials*

Smooth surface HDPE geomembrane was used. Its thickness, tensile strength and elastic modulus at 20^o Celsius are listed in Table 1. Non-woven stapled geotextile was used for protecting the geomembrane. The geotextile unit area mass, tensile strength and elastic modulus are shown in Table 2.

Table 1. Mechanical properties of HDPE

Thickness (mm)	Tensile strength (kN/m^2)	Elastic modulus (kN/m^2)
1.5	40000	484000

Table 2. Properties of stapled nonwoven geotextile

Unit area mass (kg/m^2)	Tensile strength (kN/m^2)	Elastic modulus (kN/m^2)
1.2	330	656

Ash from incinerated municipal waste was used to represent the landfill waste. The water content of the ash was between 50% and 59%. The friction angle of incinerated ash was 54.07^o. In order to calculate the tensile force of the geotextile, the shear test was conducted between the ash and the geotextile. The result of direct shear resistance between the ash and geotextile is shown in Figure 3. With increased relative displacement, the coefficient of friction increases and shows a peak when the relative displacement is 20 mm.

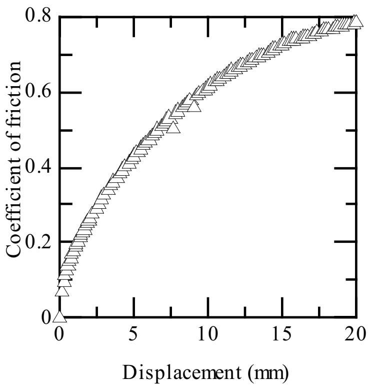

Figure 3 Relation of relative displacement to coefficient of friction $(\sigma_v = 39.2kN/m^2)$

3.2 *Testing procedure*

Incinerated ash was poured into model landfill. Its wet density was approximately 750 kg per cubic meter. Tensile force measurements were taken with the incinerated ash with a varied height of 0 mm, 50 mm, 100 mm, and 150 mm respectively. Acceleration of the centrifuge was increased at a rate of 5 G/min to a maximum of 38 G, a 150 mm height in the model is equivalent with a 5 meter height of waste landfill in the prototype. The tensile force T_{GT} of geotextile, the tensile force T_{GM} of HDPE, the surface settlement of ash, and the acceleration were recorded by computer at each 5 G interval in acceleration.

4 RESULTS

The results of testing are shown in Figure 4(a), 4 (b), 5, 6 and Table 3. As the weight of the ash was increased due to increasing acceleration, it compressed and the relative displacement between the ash and the geotextile is generated. This also resulted in downdrag forces of the geotextile. As shown in Figure 4(a) and (b), increasing the gravitational acceleration created increases in the tensile forces of geotextile and geomembrane. Tensile forces also increased as the height of the incinerated ash was increased. The tendency of the graph depicting the increases in tensile force of geotextile, as a result of gravitational acceleration, and the tendency of the graph representing the increases in tensile force of geomembrane are almost identical (Figure 5). Because of this similarity it was very important to evaluate the tensile force of the geomembrane.

The natural condition of the incinerated ash is very loose. However, it is rapidly compressed as soon as centrifugal acceleration begins and the spaces between the particles of ash decrease. Figure 6 clearly shows the how quickly the compression takes place from 0 G to 10 G. It also shows the decrease in the compression value at acceleration over 10 G.

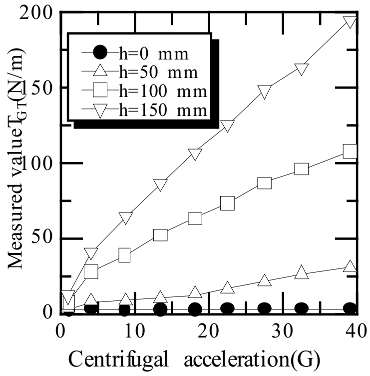

Figure 4(a) Top geotextile

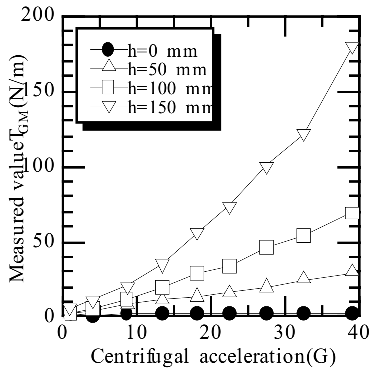

Figure 4(b) Geomembrane

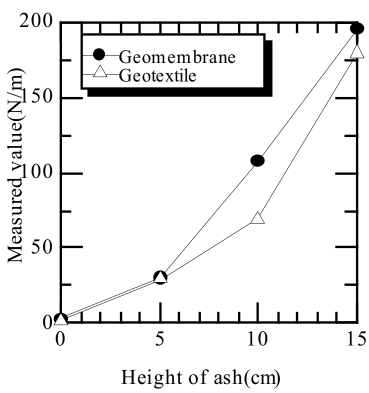

Figure 5 Relation of the height of ash and the tensile force of material

Table 3. The tensile force of geotextile and geomembrane excepting for the weight of testing material Unit: N/m

H=5 cm		H=10 cm		H=15 cm	
T_{GT}	T_{GM}	T_{GT}	T_{GM}	T_{GT}	T_{GM}
30	29	108	69	195	179

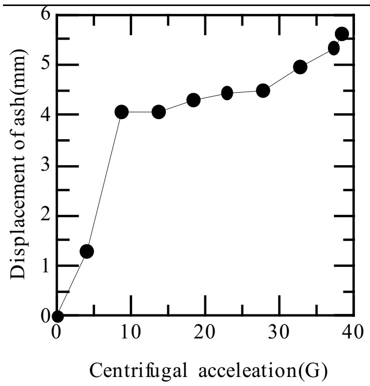

Figure 6 Relation of centrifugal acceleation and surface displacement of ash

5 CALCULATION

5.1 *Ordinary calculated method*

The following equations were derived based on ultimate equilibrium theory:

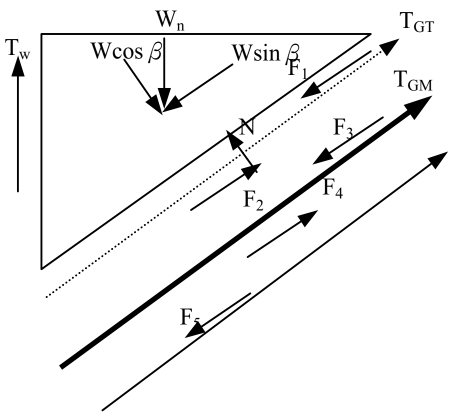

Figure 7 Force equilibrium model

$$W_{net} = W = W_n - T_w \tag{1}$$

$$T_w = \sigma_h * \tan\phi * H * b$$
$$= \tfrac{1}{2} * \gamma_n * H(1-\sin\phi) * \tan\phi * H * b \tag{2}$$

$$F_1 = W\cos\beta\mu_1 \tag{3}$$

$$F_2 = W\cos\beta\mu_2 \tag{4}$$

$$T_{GT} = F_1 - F_2 \tag{5}$$

$$T_{GM} = F_3 - F_4 \tag{6}$$

In this tests β =angle of slope is 33.6° ; μ_1 = coefficient of friction between the ash and geotextile is 0.7816; μ_2 = coefficient of friction between geotextile and geomembrane is 0.2221; W_n = weight of ash under a centrifugal acceleration of n G; ϕ = friction angle of ash is 54.07° ; γ_n = unit weight of ash under centrifugal acceleration of n G.

The results of calculation at n=38G were shown in Table 4 according to equations (1) to (5).

In the ultimate equilibrium method, it was assumed that the ash was a rigid body and could move freely on the slope. It was also assumed that the ash would maintain the same displacement throughout the slope. The shear testing results proved to be different from the assumed condition. The calculated results based on the assumed condition proved to be from 7 to 10 times that of the observed testing results.

Table 4 The calculated tensile force of top geotextile

	H=5cm	H=10cm	H=15cm
γ_n (kg/m^3)	740	730	720
F_1 (N)	69	275	608
F_2 (N)	20	78	173
T_{GT} (N)	49	197	435
Unit tensile Force(N/m)	188	758	1673

5.2 *Modified method*

In actuality the displacement of ash differed at every location on the slope with the top of the slope exhibiting the largest displacement, friction at this point could completely act between ash and geotextile. At the base of the slope, the ash met with resistance from the foundation which restricted the displacement resulting in minimal forces of friction at this location.

If the slope were divided into three sections as shown in Figure 8, the ash displacement ΔL_A at point A relative to geotextile would be the displacement value L_A of ash deduced the development value $\varepsilon \bullet L'$ of the geotextile. That is to say:

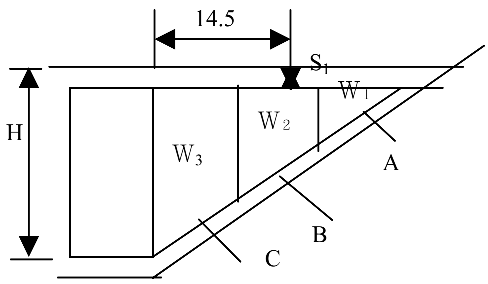

Figure 8 Divided method of slope

$$L_A = \sqrt{s^2 + (1.5s)^2} = 1.8s \tag{8}$$

$$\varepsilon = \frac{\sigma}{E_1} = \frac{T_{GT}}{E_1 * bt} \tag{9}$$

from equation(8),(9) $$\Delta L_A = \frac{5*1.8*s}{6} - \varepsilon * L' \tag{10}$$

$$\Delta L_C = \frac{1.8s}{6} - \varepsilon * L' \tag{11}$$

Where ε = strain of material; E_1 =modulus of elasticity of geotextile; L'= length between calculated point and top of material; ΔL_A = relative displacement of point A; ΔL_C = relative displacement of point C;

On the basis of the calculation results, the relative displacement at point A proved to be the greatest, however the weight of section W_1 was only 1/5 that of section W_3. According to the direct shear test shown in Figure 3, the coefficient of friction would reach its maximum when the tween ash and geotextile was larger than 20 mm. The relative displacement at point C is only 0.95 mm, therefore its coefficient of friction had not reached the maximum, and in fact it had only reached about 23 % of the maximum friction coefficient. Taking this into consideration and using the equations derived from the Ultimate Equilibrium Theory from Figure 7, the following calculations have been made.

$$W_i = F_{1i} \sin\beta + N_i \cos\beta \tag{12}$$

$$F_{1i} = N_i \mu_{1i} \tag{13}$$

from equations (12), (13) and $F_1 = \sum_{i=1}^{m} F_{1i}$,

$$F_1 = \sum_{i=1}^{m} \frac{\mu_{1i} * W_i}{\mu_{1i} \sin\beta + \cos\beta} \tag{14}$$

$$F_2 = \sum_{i=1}^{m} W_i * \cos\beta * \mu_{2i} \tag{15}$$

$$F_3 = F_2 \tag{16}$$

$$T_{GT} = F_1 - F_2 \quad (17) \qquad T_{GM} = F_3 - F_4 \quad (18)$$

When m was 3, the calculation results were shown according to equations (12) to (18) in following Table 5 and Figure 9.

Table 5. The calculated values of geotextile

	H=5 cm	H=10 cm	H=15 cm
μ_{11}	0.5257	0.7020	0.7816
μ_{12}	0.3869	0.5288	0.6310
μ_{13}	0.1739	0.1201	0.1778
F_1 (N)	30	124	329
F_3 (N)	19	78	174
T_{GT} (N)	11	46	155
Unit width force(N/m)	42	177	596

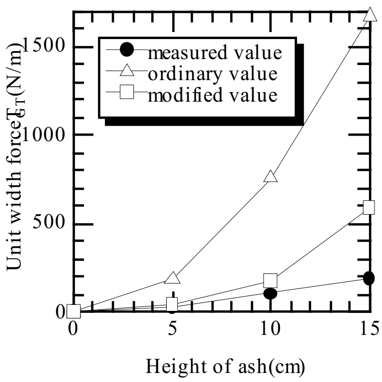

Figure 9 Relation of the calculated to the measured values of tensile force of top geotextile

According to ordinary ultimate force equilibrium method, a geomembrane sandwiched between geotextiles of equal quality could not create any tensile force. However through experimentation it is clear that tensile force was created in the geomembrane. The elongation ΔL of geomembrane can be estimated by strain ε times length L of geomembrane. Therefore

$$\Delta L = \varepsilon * L = \frac{\sigma_{GT}}{E_2} \bullet L = \frac{T_{GM}}{E_2 A} = \frac{(W * \cos\beta\mu_2 - F_4)}{E_2 * b_H t_H} * L$$

An under geotextile was glued to a plaster foundation. The rigidity of the geomembrane was very high, and the relative displacement between the geomembrane and the under geotextile was very low. Therefore the friction force between the geomembrane and the under geotextile was so small as to be considered negligible, that is $F_4 = 0$. According to the calculation result, the development value ΔL of the geomembrane is only 0.015 cm. Table 6 and Figure 10 show the results of this calculating method. These calculated values, however, when compared to the actual test results, proved to be 3-5 times larger.

Further testing after one week revealed that the consolidation and compression of the test material decreased. The relative displacement between ash and geotextile also became smaller. This resulted in test values, after one week's time, to be less than those taken during the initial experiment.

Table 6: Tensile force of geomembrane

	H=5 cm	H=10 cm	H=15 cm
γ (kg/m^3)	740	730	720
F_3 (N)	19	78	174
Unit width force (N/m)	77	300	668

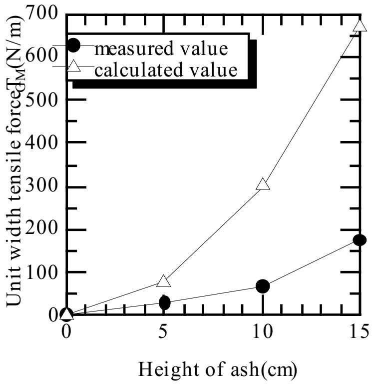

Figure 10 Comparison of the calculated to the measured of tensile force of geomembrane

6 CONCLUSIONS

(1) The modified method of calculating, discussed here, can estimate tensile force better and more accurately than the ordinary ultimate equilibrium method.

(2) The tensile forces of geotextile and geomembrane placed on the slope of a waste landfill could be accurately measured by a centrifugal model tests.

(3) The displacement value of testing material must be considered when calculating the tensile forces of geotextile and geomembrane used on the slope of a waste landfill if calculating with the ultimate equilibrium method.

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