EVALUATION OF SLIDING EFFECT ON ANCHORAGE

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ABSTRACT

The anchorage of the geomembrane on side slope is very important item for designing landfill liner systems. The anchorage must restrain the geomembrane strictly not to be slipped down. But at the same time, it is well known that the geomembrane should not be strictly restrained for the release of the stress.

After the analyzing the data obtained from two field tests, authors found that at first sliding anchorage can reduce the stress of the geomembrane, so, the need for the resistance of the anchorage can be reduced. And authors show that the pulling out of geomembrane with only 20mm length from the concrete anchorage can reduce the one forth of the thermal stress, which is the main factor of the geomembrane on the side slope.

For designing anchorage, it is first considered to keep the weight or the total resistance for the slipping safe. Then, it also should be considered to keep some sliding length of the geomembrane at the anchorage.

INTRODUCTION

Geomembrane in Japan has been used for a landfill liner since 1980. A landfill has often been constructed in the valley site because of lack of flat area in Japan. So, the landfill must have a lot of area on a steep side slope. And the geomembrane is put and exposed without cover soil because cover soil can not be stable at the steep side slope.

The first used geomembrane for a landfill liner was made from EPDM rubber, which has been used in popular as a liner of a pond. It was very flexible and has low modulus. The section area of the concrete to anchor of an EPDM membrane was 300mm square. At the end of 1980's, the second geomembrane, which was made from EPDM mixed with Polypropylene was developed and applied. It is now called Thermoplastic Olefin (TPO) and has relatively high modulus. The section area of the concrete anchorage was same as the case of an EPDM membrane. The lifting problem of the anchorage concrete occurred when it was installed at winter season. So, for avoiding lifting problem of the anchorage concrete, the cut size of the anchorage concrete was enlarged and 400mm square. At the beginning of 1990's, HDPE membrane was imported and applied. It has very high tensile strength and high modulus. And the same problem occurred. So, designers adopted much larger size of the anchorage concrete for a HDPE membrane. Thus, the design of the anchorage has been decided only for avoiding the pulling up problems. In order to evaluate the anchorage resistance, the first field test was conducted by The Landfill System Technologies Research Association of Japan in 1995. And it was showed that the resistance of the anchorage filled with concrete is much stronger than one of the anchorage filled with the soil and the resistance for pulling up is nearly same with the weight of the anchorage concrete.

On the other hand, in most cases of U.S.A. or European countries, the geomembrane is protected by cover soil and the anchorage is designed as a siding anchorage for reducing the stress of the membrane.

By the way, it should be also important to evaluate the stress of the edge of the geomembrane that connects to the anchorage. It was decided to carry out the real scale experimentation. The Japan Association Membrane Methods with the NEDO financial support conducted this field test. The stress, the strain and the temperature of the components were measured as long as the filling height reached to 5m. After analyzing the data, the value of the stress by compaction was separated by taking the value of the thermal stress from the total stress. And it was showed that the thermal stress is much larger than the stress by the compaction.

Thus, two large-scale field tests were conducted in order to evaluate the anchorage resistance and the stress of the geomembrane on the side slope.

This paper presents another field test results conducted by Utsunomiya University and the relationship between the anchorage resistance and the stress of the geomembrane.

THERMAL STRESS FIELD TEST

The thermal stress creating at the end of the geomembrane was measured after the test site of the large-scale compaction field test that mentioned before.

1) TEST METHOD

(A) PRPPERTIES OF GEOMEMBRANES AND GEOTEXTILES

The properties of the geomembrane and the geotextile made of staple fibers that were used for the field test are shown in Table 1 and Table 2.

Table 1 Properties of HDPE Geomembrane

Kind of Geomembrane	HDPE	EPDM
Thickness (mm)	1.5	1.5
Surface	Flat	Embossed
Tensile Strength(MPa)	32.1	9.8
Young Modulus at 20C (MPa)	484	10.7
Friction Coefficient(Sand)	0.43	0.90
Friction Coefficient(G.T.)	0.12	0.57

Table 2　Properties of Geotextile

Thickness(mm)	10
Weight per unit area (gf/m^2)	1300
Color	White
Tensile Strength(kN/m)	29.3
Elongation at Break (%)	100
Friction Coefficient(Sand)	1.02

(B) MODELED SIDE SLOPE (AT THE FIELD TEST)

The modeled side slope was made by digging of the ground with a depth of 5m. The modeled side slope has 34 degree angle (H: L=1:1.5) as shown in Figure.1 and Figure.2. On the shoulder of the slope, the foundation for measuring the force was made by H steel and concrete

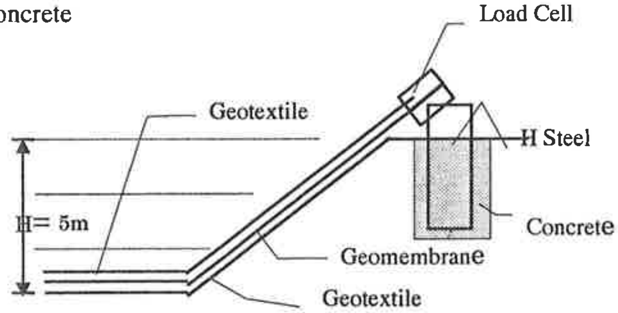

Figure. 1 Cut Design of the Field Test Model

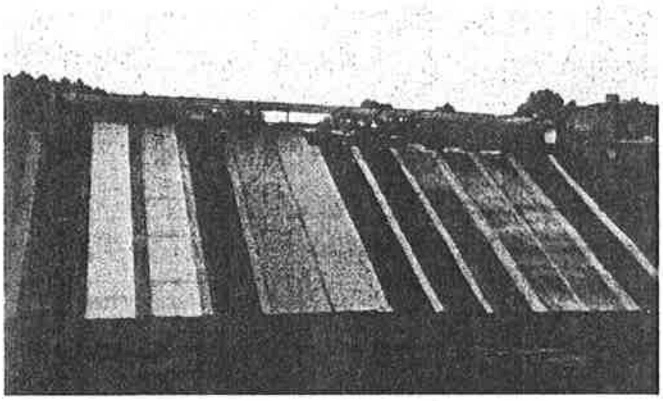

Figure.2 Photo of the Field Test Model

The geotextile was placed over the soil surface of the side slope. Then, two HDPE panels and one EPDM panel with 1m width were placed on the geotextile. Over one of two HDPE spread slope, geotextile was placed again. The upper end of the geomembrane and the geotextile was connected to the jaw and load cell, which was fixed to H shape steel. The thermal couples were adhered on the surface of the geomembranes. The cable from load cells, strain gages, thermal couples are connected to the switch box of the data logger.

(C) MEASURING METHOD

The tensile force, the strain and temperature were measured every 5 minute. The data were recorded in the hard disk of the computer.

2) RESULTS AND DISCUSSION

Variations of surface, temperature and tensile stress of HDPE, EPDM and HDPE covered by the geotextile was shown in Figure 3 – 5 with colapsed time. For better understanding, the axis of the temperature is reversed.

The stress variations seem to be the same. So, it is clear that the temperature affected measured stress. Therefore, this measured stress is thought to be a thermal stress. The surface temperature of the geomembrane at starting the measurement in the evening 7th September, was 62.7 degree incase of HDPE without G.T., 34.2 degree in case of HDPE with G.T. and 55.6 degree in case of EPDM without G.T. The surface temperature decreased to 20 degree at 2 hours. The thermal stress created and increased gradually with decrease of the surface temperature. The surface temperature did not increase so highly on 8th and 9th, because it were cloudy. In the morning of 10th September, the thermal stress decreased with the increase of the surface temperature. The changes of the surface temperature and the stress in measuring period are 47.5 degree and 1.72 MPa in case of HDPE, 17.9 degree and 1.04 MPa in case of HDPE with G.T, 38.7 degree and 0.057 MPa in case of EPDM.

So, it was clarified that a white G.T. has the effect to decrease the temperature of the membrane surface but, the increasing trends of thermal stress with decrease of temperature are almost same in each case, beside the value of the thermal stress was different.

The relationship between the surface temperature and the measuring stress of the first day and the fifth day was indicated in Figure 6 in case of HDPE without G.T., Figure 7 in case of HDPE with G.T. and Figure 8 in case of EPDM without G.T.

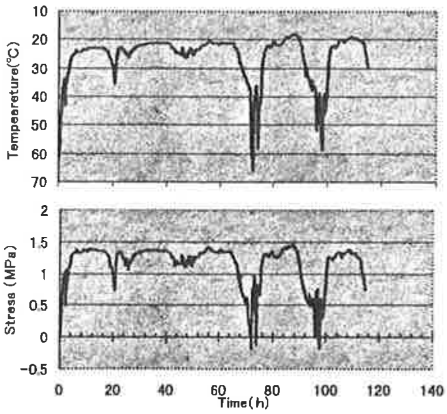

Figure.3 Stress and Temperature (HDPE)

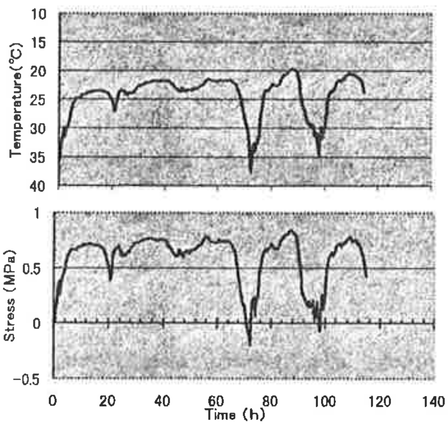

Figure.4 Stress and Temperature (HDPE+G.T.)

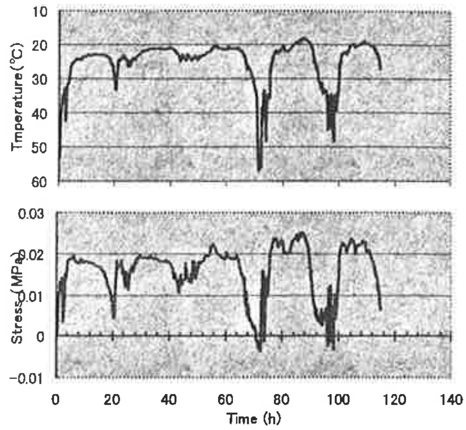

Figure.5 Stress and Temperature (EPDM)

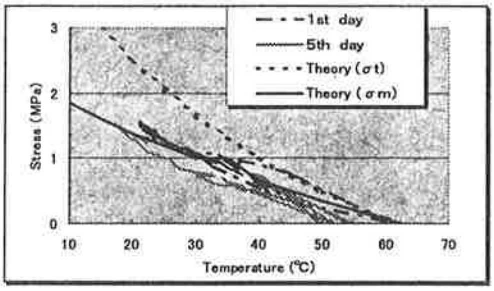

Figure.6 Stress versus Temperature (HDPE)

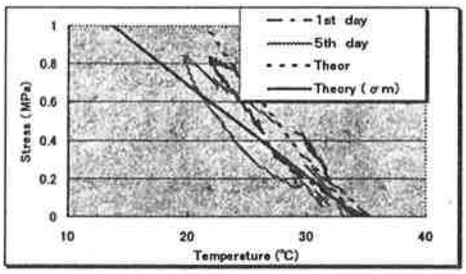

Figure.7 Stress versus Temperature (HDPE with G.T.)

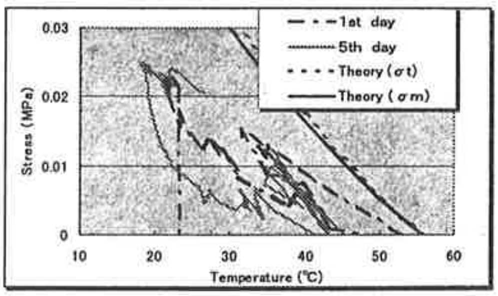

Figure.8 Stress versus Temperature (EPDM)

The stress curve when the temperature was decreasing was above that when the temperature was increasing. The slope of curves of the first day and those of the fifth day were relatively equal but the stress of the fifth day was below the stress of the first day. The reason of this small decrease is thought to be a creep.

The theoretical curve calculated based on the complete restrain model expressed as Equation (1) is also indicated in from Figure 6 to Figure 8. The complete restrain model is such that the both edges completely anchored without a pullout of the geomembrane and is conducted by the authors*2. And the elastic theory curve of the elastic model including pullout as equation (2) is indicated in Figure 6 – 8,too. The authors also conducted the elastic theory.

$$\sigma_{ab} = \int_{t_a}^{t_b} \Delta\sigma = -\int_{t_a}^{t_b} \beta \cdot E_0 10^{-\alpha t}\, dt \qquad (1)$$

$$\sigma_t = \sigma_m + \frac{2}{3 \cdot L_2}\left(\frac{t_g}{\gamma_t \cdot \sin\theta \cdot \cos^2\theta \cdot \mu}\right)^{0.5} \sigma_m^{1.5} \qquad (2)$$

E: secant modulus at o degree ($8.1\text{x}10^7$1kgf/cm^2)

α: temperature factor of secant modulus (0.0102)

t_a: temperature at starting measurement

L_2: length of exposure part of geomembrane (0.7m)

μ: friction coefficient

σ_m : theoretical value of stress at the edge

σ_t: Theoretical value of the stress by Equation (1)

β: expansion coefficient (1/degree)

According to Figure 6 and Figure 7, the values of the complete restrain theory, as Equation (1) is larger than the value of the test result. And the values of the pullout theory, as Equation (2) is almost same as the test result.

3) CONCLUSION

The stress of the geomembrane at the top of the side slope can be measured and it was as large as 1.5MPa in the case of HDPE. This stress was dominated thermal stress.

The theoretical estimation that introduced by the authors from elasticity- pulling out relationship theory can evaluate the test results.

FIELD PULLOUT TEST OF ANCHORAGE

The pullout test of anchorage was conducted for evaluating the effects of the size, the shape and the restrain conditions against the pulling up resistance of the concrete anchorage. The field test was conducted at Yatsugi site where the thermal stress field test was also conducted in 1998.

1) TEST METHOD

The property of the geomembrane and the geotextile is the same as mentioned before in 3.1.1.

The modeled anchorage of concrete at field tests were by digging a trench by hydraulic shovel as Figure 9. And the base footing was made with a H steel and a steel board having a thickness of 10mm.

Ditches were made with scoops. The width of the ditch was about 60 cm and the length and the depth was 50 cm. The wooden panel boards were set in the ditches.

Then, G.T. was placed in the ditch and the Geomembrane was placed on the G.T. At the part of the corner, the HDPE geomembrane was curved and placed for fitting the ditch shape. Then, ready mixed concrete was poured into the ditch. After aging for 3 days, the wood board was displaced.

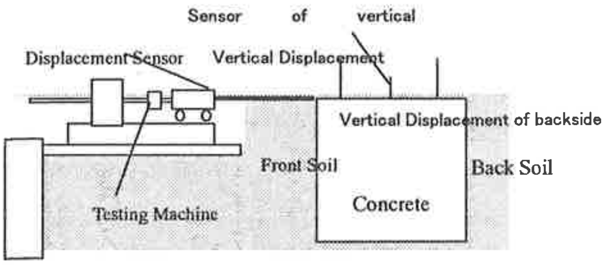

Figure.9 Making the Anchorage Models

The other end of the geomembrane was jointed with the jaw of the testing machine. This testing machine was made of the shaft, the mortar, sliding box with the jaw and the 4.9kN load cell. The length between the concrete anchorage and the jaw was adjusted to 100mm.

All sensor was connected to the data loggers and personal computer. The data was record in the hard disk. The pulling speed of the machine was 3mm/min.

2) TEST RESULUTS AND DISSCUSION

The movement of the concrete anchorage was recognized from the vertical displacement of the both edges of the top surface of the concrete. The average of the vertical displacements of the front edge and the back edge indicates the lifting up movement of the center of the gravity and the difference between the vertical displacements and the front edge and that of the backside edge was indicates the rotation of the concrete. For instance of section area of 500mmx 500mm, the relationship between the horizontal displacement of the geomembrane end and the pull out force was indicated in Figure 10. And the relationship between the vertical displacement of the edges of top surface of the concrete and the pull out force was indicated in Figure 11.

The photo for a explanation is shown in Figure 12. According to Figure 11, the vertical displacement at the front edge was occurred when the pull out force reached at 4.5kN. At this time, the displacement of the edge was about 15mm as shown in Figure 10. After that, the vertical displacement and pull out force was increased linearly.

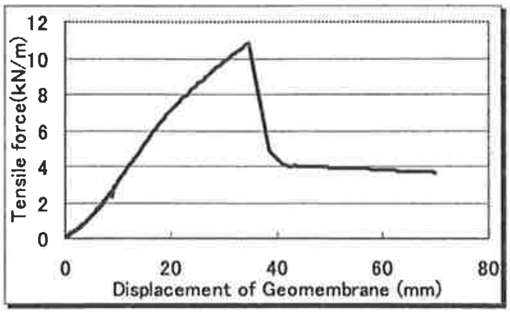

Figure.10 Displacement of G.M. and Tensile Force

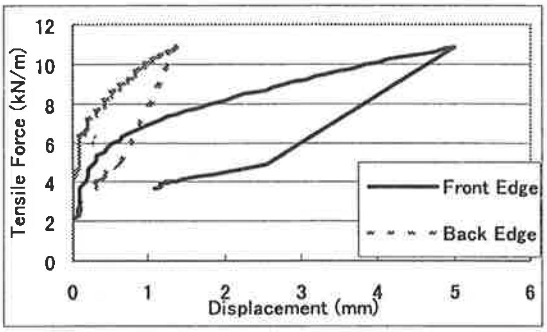

Figure.11 Vertical Displacement and Tensile Force

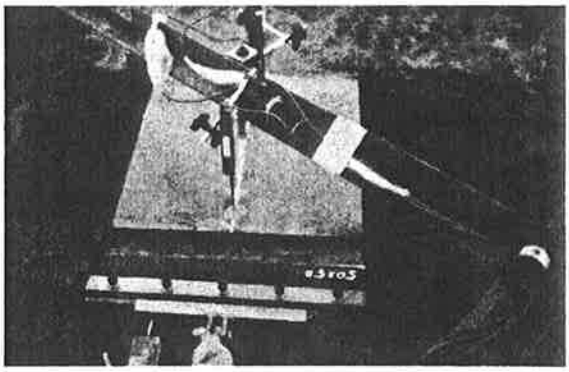

Figure.12 Photo of 500mm square case testing

When the pull out force reached to 10.8kN, it dropped suddenly with a sound. In this case, shear failure found. Therefore, it was thought that mode of the failure of anchorage should be peeling off the membrane from the concrete surface.

From the test results for the different size concrete anchorage, the relationship between the weight of the concrete anchorage and the pull out force at starting the lift up of the concrete anchorage was indicated in Figure 13. The relationship between the weight of the concrete and the maximum tensile force was also indicated in Figure 13.

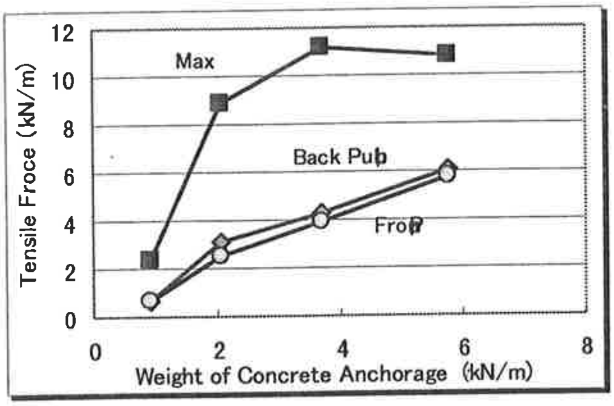

Figure.13 Weight and Lifting-Up Force

From the test results, the relationship between the weight of the concrete and the force of lift up should be liner. The most important point is that at the end of the geomembrane, some horizontal displacement is needed at the end of the geomembrane when the concrete anchorage is going to be lifted up.

3) CONCLUSION

The tensile force of geomembrane can lift the concrete anchorage. The vertical displacement occurred when the force is almost large as same as the concrete weight. And some displacement of the geomembrane was needed near the edge of the concrete.

STRESS REDUCITON EFFECT

As mentioned before, sliding of the geomembrane from the terminal restrain can reduce the stress of the geomembrane. At the field test with a section area of 500mm square, about 50mm horizontal displacement of the geomembrane at 100mm point far from the end of the concrete anchorage was measured.

Figure 14shows the relationship between the tensile force and horizontal displacement of the geomembrane is almost linear.

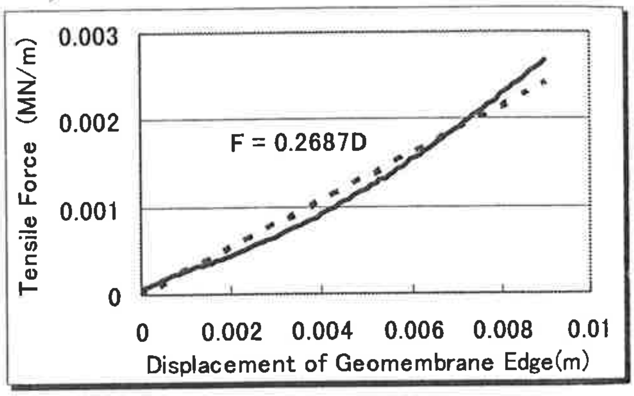

Figure.14 Horizontal Displacement of Front Edge and Tensile Force (500mm Square Case)

This displacement should be of the geomembrane and summation of the strain induced by pull-out force. From the point of stresses, the stress measured (σ_E) should be elimination the reduction stress (σ_s) by pulling out from the stress without pulling out reduction (σ_m), which is calculated by Equation (2). This relationship can be indicated as Equation (3)

$$\sigma_m = \sigma_E + \sigma_s \qquad (3)$$

According to the relationship between displacement and tensile force as shown in Figure 14, if the section area is A, the reduction stress by pulling out (σ_s) can be indicated as Equation (4).

$$F = 0.2687D = A \cdot \sigma_E \qquad (4)$$

So, the displacement is caluculated by the estimated tress as Equation (5).

$$D=\frac{A\cdot\sigma_E}{0.2687}=\frac{0.0015\cdot\sigma_E}{0.2687}=5.58\cdot10^{-3}\cdot\sigma_E \quad (5)$$

The displacement is the pulling out length from the anchorage which can reduce the stress. The reduction stress (σ_s) can be calculated by the Equation (6).

$$\sigma_S=E\cdot\varepsilon=E\cdot\frac{\Delta L}{L_2}=\frac{E\cdot D}{L_2}=\frac{4.38\cdot10^{-0.0102t}\cdot\sigma_E}{L_2} \quad (6)$$

E: Modulus of HDPE

t: Temperature

L_2: Length of exposure part of geomembrane

Thus, Equation (7) can be derived.

$$\sigma_m=\sigma_E+\frac{4.38\cdot10^{-0.0102t}\cdot\sigma_E}{L_2} \quad (7)$$

The Equation (7) means that estimated stress (σ_E) after sliding out should be effected by not only the temperature (t) and the length of exposure part of the geomembrane8(L_2). Therefore, the length of exposure part (L_2) effects both reducing the thermal stress by pulling out from the soil as shown in Equation 2 and reducing stress by sliding out of the anchorage as shown in Equation 7. So, the relation between estimated stress and the temperature is shown in Figure 15 with a parameter of L_2. The model is based on the case of HDPE thermal stress, which is equal to the value in Figure 6.

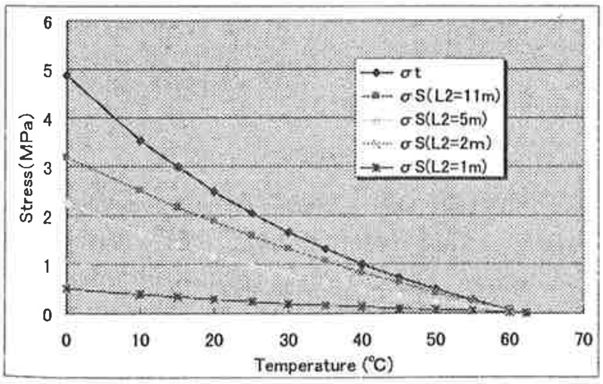

Figure.15 Estimated Stress Reduced by Pulling Out from Anchorage (HDPE/ 500mm Square Case)

From the Figure 15,it can be seen that when the length of exposure part of the geomembrane is decreasing, the stress is also decreasing.

FINAL CONCLUSION

The designing of the anchorage is very important for the liner system of landfill with steep side slope. For avoiding of slipping down of the geomembrane, it was thought that the weight of the concrete anchorage must be larger than the force induced within the geomembrane. But, it is more effective to reduce the induced force by permitting a small displacement of slipping out from the anchorage. Especially, in this paper, HDPE geomembrane was focussed, because it has high elastic and then much effect of sliding out. It is also found that the tension of the geomembrane on the side slope decreases with the increasing of the filling height. In this case, the length of the exposure geomembrane is getting shorter, and this leads to more effective reduction of the force by sliding out.

At last, some methods that should be effective for sliding out can be though, for example, using cushion between soil and concrete etc.

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