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The study of the durability about the triple liner system – The loading tests about slope hydraulic barrier function in the sea area landfill sites

Satoh, T.
Civil Technical Department of Osaka branch, Toyo construction Co., Ltd., Japan

Akai, T.
Technology Research Institute of Osaka Prefecture, Japan

Ishida, M.
Civil Engineering Company, Taiyo Kogyo corporation, Japan

Nomura, T.
Kinjo Rubber Co., Ltd., Japan

Kamon, M.
Graduate School of Global Environmental Studies, Kyoto University, Japan

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ABSTRACT: We have developed hydraulic barrier sheet is called triple liner system (TLS). TLS is used polyurethane elastomer as an intermediate material between double sheets of geomembrane (polyurethane elastomer thickness 10 mm – 20 mm and the geomembrane sheet are PVC t = 3 mm or LLDPE t = 1.5 mm). We had already verified that the TLS had low conductivity (less than 10^{-13}–10^{-14} cm/s) and high flexibility and the other basic peculiarity in the laboratory tests. In this study, we have carried out the puncture tests and loading tests to investigate the durability of TLS. In these tests, we have imaged that TLS is set on the uneven base ground surface of the slope in the sea area landfill site and the waste load are loaded on TLS under this condition. In the results, we have recognized that the high durability of TLS was compared with the combination of geomembrane sheets and nonwoven geotextile. And it is seemed that the effect of the stress dispersion by the polyurethane elastomer as an intermediate material between the geomembrane sheets is contributed to the high durability of TLS. We have thought that the effect of the stress dispersion was caused by non-linearly elastic and the high flexibility of the polyurethane elastomer as an intermediate of TLS.

1 INTRODUCTION

In the slope hydraulic barrier of sea area landfill sites, hydraulic barrier are designed and constructed used by double geomembrane sheets and buffer material or low permeability layer between them to keep the barrier function. Because slope in the sea area landfill sites are normally composed rubble mound breakwater and there are possibility that the uneven ground surface of slope damage the geomembrane sheets. Therefore the size of uneven surface on the slope in sea area landfill sites is prescribed (the permissible range from the design ground level is less than ±40 cm) WAVE 2000.

But it is so difficult to get safety against the damage of geomembrane sheets because the damage of geomembrane sheets are influenced by the construction condition as follows that,

- It is difficult to get the high leveling accuracy of base ground surface in sea area.
- Shape and Size of the rubble cusp are variously changed on uneven ground surface.

Therefore study of the relation between the shape variation of rubble cusp on uneven ground surface and the damage of geomembrane sheets has been carried out (Kano et al 2004). And the suitable specification about nonwoven geotextile to protect against the damage of geomembrane sheets on uneven ground surface has been studied (Akai et al 2003).

We have developed the hydraulic barrier sheet is called triple liner system (it is referred to as TLS after this) as shown Figure 1. (Kamon et al 2002).

TLS is used polyurethane elastomer as the intermediate material between double geomembrane sheets, and this polyurethane elastomer as nonlinear material has low conductivity (less than 10^{-13}–10^{-14} cm/s) and high flexibility (maximum tension strain more than 200%). Therefore TLS has triple liner structure and this system has high hydraulic barrier function in itself only (Kamon et al 2002). And TLS have been already checked the basic performance about barrier function and flexibility in the laboratory tests (Kamon at al 2002).

In this study we have carried out puncture tests (ASTEM 1996) and loading tests to investigate the durability of TLS against the damage in the cause of the local pressure generated by uneven ground surface and upper load in sea area landfill site. Especially because it is difficult to estimate the durability of the

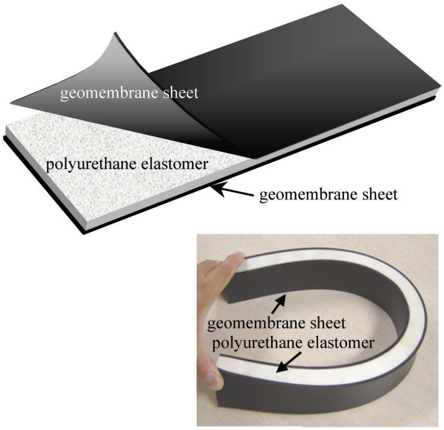

Figure 1. Three-layers structure of TLS.

slope hydraulic barrier on uneven base ground of sea area landfill site by puncture test only, we have carried out loading test that the uneven base ground was modeled by No. 4 crushed stone.

In this paper we have tried to estimate the durability of TLS compared with hydraulic barrier structure used by geomembrane sheets and nonwoven geotextile.

2 TEST APPARATUSES AND TEST CASES

2.1 *Puncture test*

Puncture tests have been carried out in conformity by ASTM (1996) (solid steel rod, diameter 8 mm and test speed 300 mm/min). Figure 2 shows view of puncture test apparatus (fixture and probe). In this study we carried out the puncture tests of 30-sheet combinations pattern with 8 kinds materials. Table 1 shows the puncture test cases of 30-sheet combinations pattern. And Table 2 shows explanation of the 8 kinds material used in these tests. In these tests we have investigated puncture resistance and relation between the puncture resistance and the puncture displacement against sheet combination that seems to use in sea area landfill site. And also we have tried to estimate durability of TLS by comparing with the other sheet combinations.

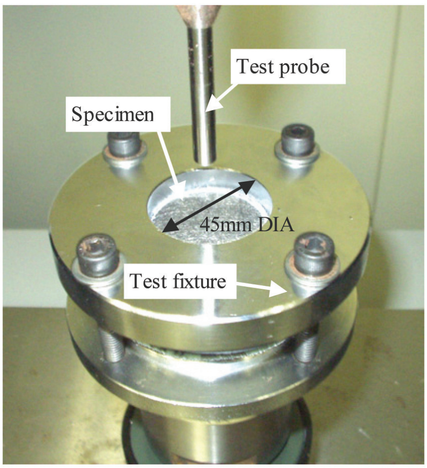

Figure 2. View of puncture test apparatus.

Table 1. Puncture test cases.

No.	The sheets combination	
A-1	GT45	single
A-2	GT60	
A-3	GT45 × 2	double
A-4	GT60 × 2	
A-5	Ps	single
A-6	Ls	
A-7	Ps × 2	double
A-8	Ls × 2	
B-1	PU1 · Ps	TLS only
B-2	PU1 · Ls	
B-3	PU2 · Ps	
B-4	PU2 · Ls	
C-1	GT45 + Ps + GT45	single geomembrane sheet between nonwoven geotextiles
C-2	GT60 + Ps + GT60	
C-3	GT45 + Ls + GT45	
C-4	GT60 + Ls + GT60	
C-5	GT45 + Ps × 2 + GT45	double geomembrane sheets between nonwoven geotextiles
C-6	GT60 + Ps × 2 + GT60	
C-7	GT45 + Ls × 2 + GT45	
C-8	GT60 + Ls × 2 + GT60	
D-1	GT45 + PU1 · Ps + GT45	single TLS between nonwoven geotextiles
D-2	GT60 + PU1 · Ps + GT60	
D-3	GT45 + PU2 · Ps + GT45	
D-4	GT60 + PU2 · Ps + GT60	
D-5	GT45 + PU1 · Ls + GT45	
D-6	GT60 + PU1 · Ls + GT60	
D-7	GT45 + PU2 · Ls + GT45	
D-8	GT60 + PU2 · Ls + GT60	
E-1	GT45 + Ps + GT45 + Ps + GT45	layer structure of sheet and nonwoven geotextiles
E-2	GT45 + Ls + GT45 + Ls + GT45	

Table 2. Explanation of the 8 kinds material.

GT45	nonwoven geotextile/the unit area weight of 450 g/m^2
GT60	nonwoven geotextile/the unit area weight of 600 g/m^2
Ps	PVC geomembrane sheet: thickness 3 mm
Ls	LLDPE geomembrane sheet: thickness 1.5 mm
PU1· Ps	TLS PVC geomembrane sheet: thickness 3 mm Polyurethane elastomer: thickness 10 mm
PU2· Ps	TLS PVC geomembrane sheet: thickness 3 mm Polyurethane elastomer: thickness 20 mm
PU1· Ls	TLS LLDPE geomembrane sheet: thickness 1.5 mm Polyurethane elastomer: thickness 10 mm
PU2· Ls	TLS LLDPE geomembrane sheet: thickness 1.5 mm Polyurethane elastomer: thickness 20 mm

We have used the unwoven geotextile which unit area weight of 450 g/m^2 and 600 g/m^2. And especially the unit area weight of 600 g/m^2 unwoven geotextile is normal spec in sea area landfill site.

In the test case of C and E sires, we glued sandpaper on round the circular specimen surface of the geomembrane sheet by instant glue in order to prevent slipping the contact surface between the geomembrane sheet and the nonwoven geotextile during puncture test.

2.2 *Loading test*

Figure 3 shows the view of loading test apparatus and Figure 4 shows the outline of loading tests apparatus. The loading test apparatus has been composed with (inner size: length 50 cm × width 25 cm × depth 25 cm), air cylinder and guide frames. In the loading test, first No. 2 crushed stone are put into the container and leveled in about 9 cm height. And next TLS or other test specimen (the combination of geomembrane and nonwoven geotextile) is spread on the model ground surface. And the crushed stone are put on the test specimen again and leveled in about 9 cm height as shown Figure 5.

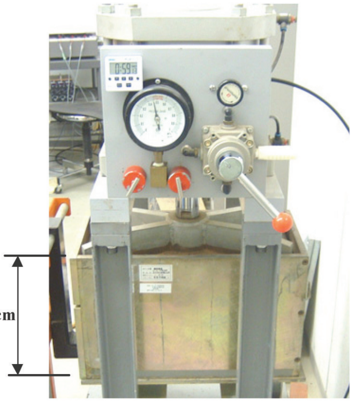

Figure 3. View of the loading test apparatus.

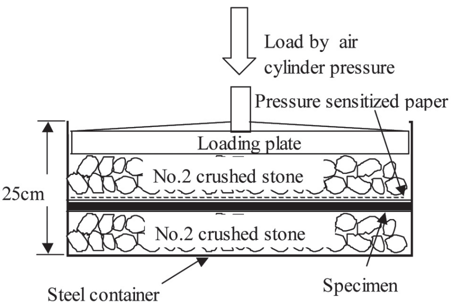

Figure 4. Outline of the loading tests apparatus.

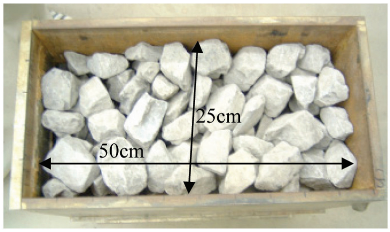

Figure 5. Model uneven ground layer used No. 2 crush stones.

The loading has been loaded on the surface of the second crushed stone layer. In these tests the crushed stone was used No. 2 crushed stone (grain size: 40 mm–60 mm) because we have tried to investigate the durability about TLS under more severe condition. The grain size of this crushed stone is bigger than other kind of crushed stone used for the slope ground therefore this crushed stone shape the big uneven ground surface.

The unit weight of the crushed stone layer was 1.35 gf/cm^3 in the target. But In these tests the average unit weight of the crushed stone layer was 1.48 gf/cm^3.

On the other hand the loading tests were carried out with 294 kPa load that was estimated at the point of depth 15 m in sea area landfill site. The loading time interval was set in one hour, because the settlement of this crushed stone layers has been almost zero in one hour.

In the loading tests, we have investigated the durability of the hydraulic barrier structure used by nonwoven geotextile, geomembrane sheet and TLS. We have carried out the loading tests against the combination of TLS, geomembrane and nonwoven geotextile.

In this study nonwoven geotextile was used in unit area weight of 450 g/m^2 in order to investigate the durability of TLS or geomembrane sheet itself. And geomembrane sheet were used PVC and LLDPE sheet.

The pressure sensitized paper were spread on the specimen (it is referred to as model hydraulic barrier after this) in order to investigate the local pressure and distribution of the local pressure on their surface. Table 3 shows the test cases and sheet combination.

3 TESTS RESULT

3.1 *Puncture test result*

Figure 6 shows the relation between puncture resistance and puncture displacement about No. A-7, B-1, and D-1. No. A-7 is case of the double geomembrane sheets, No. B-1 is TLS (polyurethane elastomer thickness 10 mm) case and No. D-1 is case of the nonwoven geotextile and TLS combination.

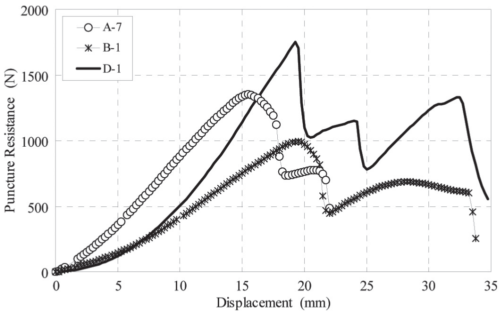

Figure 6. Relation between puncture resistances and puncture displacement (No. A-7, B-1, D-1).

In the maximum puncture resistance of these cases, No. D-1 (nonwoven geotextile and TLS combination) was biggest in three cases, and No. A-7 was 1.4 times as big as No. B-1.

ASTM (1996) describes that the puncture resistance should be read from the greatest force resistance on the recording instrument during the test. But in the durability of the slope hydraulic barrier, it is important to consider the puncture displacement too.

Figure 7 shows the relation between puncture resistance and puncture displacement in the specimen breakage with No. C-5,6,7,8 and No. D series. In the puncture displacement, the combination of TLS and nonwoven geotextile (No. D series) are longer than the combination of nonwoven geotextile and double geomembrane sheets (No. C-5,6,7,8). And it seems that the combination of TLS and the nonwoven geotexitle is effective about the flexibility function against landfill site deformation rather than the double geomembrane sheets and nonwoven geotextile combination.

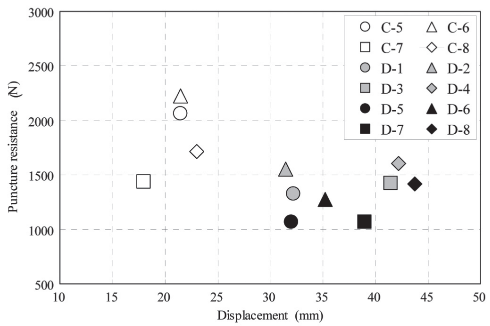

Figure 7. Relation between puncture resistances and puncture displacement in the specimen breakge (No. C-5, 6,7,8 and No. D series).

The puncture resistance of all test cases are greater than 1000 kN, and it seems that the puncture resistance of all sheet combinations are satisfied against the regulation value against protection mat of landfill site (IGSJ 2000) and requirement value against base ground used by No. 4 crushed stone (Akai et al 2003)

3.2 *Loading test result*

Table 3 shows the loading test results. This table shows that extent of damage on the model hydraulic barrier surface after these tests and the maximum contact pressure on each model surface during loading.

Table 3. Loading test case and result.

		Tests resule		
No.	Sheet combination	Nonwoven geotextile	Max. local pressure (MPa)	Damage level
B-1	PU1 · Ps	–	78.3	1
B-2	PU1 · Ls	–	79.3	1
B-3	PU2 · Ps	–	62.6	1
C-5	GT45 + Ps × 2 + GT45		49.7	2
C-7	GT45 + Ls × 2 + GT45		143.7	3
D-1	GT45 + PU1 · Ps + GT45		12.6	1
D-3	GT45 + PU2 · Ps + GT45		18.1	1
D-5	GT45 + PU1 · Ls + GT45	the unit area weight 450 g/m^2	69.5	1
D-7	GT45 + PU2 · Ls + GT45		59.8	1
E-1	GT45 + Ps + GT45 + Ps + GT45		110.43	3
E-2	GT45 + Ls + GT45 + Ls + GT45		80.6	2

We have classified the damage condition of all model hydraulic barriers after these tests as follows that,

1. Level 1: normal condition
2. Level 2: the condition that there is possibility of the damage on the model surface
3. Level 3: the condition that the model surface has been damaged.

Level 2 means the case that there is the trace or the hollow of pushing crushed stone edges into the nonwoven geotextile or into the geomembrane sheet surface and there is the possibility of the damage on the model surface.

Level 3 means the case that there is the damage or the penetrated hole on the model hydraulic barrier surface.

The test cases of TLS only (No. B-1 to B-3) and combination cases of TLS and nonwoven (No. D-1,3,5,7) were all Level 1 as shown Table 3.

Figure 8 shows the condition of TLS surface after loading test in B-1. There was no damage of TLS surface though the marks of the several crushed stones pushed have been put on the TLS surface.

On the other hand, in the combination cases of the geomembrane and nonwoven geotextile, damage level

Figure 8. Condition of TLS surface after loading test (No. B-1).

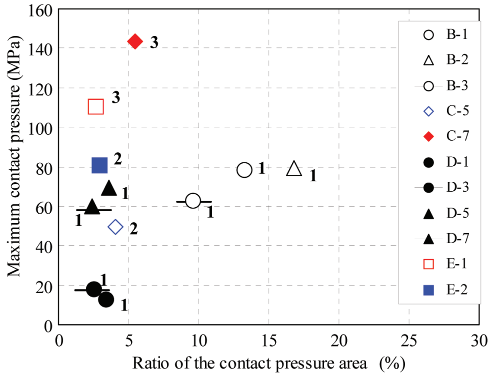

Figure 10. Relation between the maximum contact pressure and the ratio of contact pressure area in all test cases.

were level 2 or level 3. And it seemed that the durability of these combination cases are not higher than TLS only cases

Figure 9 shows 3-D contour of the contact pressure on the model hydraulic barrier surface in No. B-1 (the TLS only case) and No. E-1 (combination case of the geomembrane and nonwoven geotextile). And the damage level of No. B-1 was level 1 and was level 3 as shown Figure 9.

It seemed that the contact pressure area of No. E-1 were relatively smaller than No. B-1 and the contact pressure were higher than No. B-1. From these results, it was assumed that the relation the contact pressure and contact pressure area would be caused the damage. And then we have checked the contact pressure area and the maximum contact pressure in all test cases and we have tried to investigate the relation between the maximum contact pressure and contact pressure area ratio (the model surface area versus contact pressure (more than 1 MPa) area).

Figure 10 shows the relation between the maximum contact pressure and the ratio of the contact pressure area in all test cases. And the damage level of each test was indicated into Figure 10.

In the test case of No. C and No. E series (the combination of geomembrane and nonwoven geotextile), we have recognized that the ratio of contact pressure area were about 5%, the maximum contact pressure were more than 60 MPa and the damage level were more than level 2.

In the No. B series tests (TLS only and No. D series (TLS only cases and the combination of TLS and nonwoven geotextile), the ratio of the contact pressure area were about 5% and the maximum contact pressure were more than 60 MPa, however the damage level were level 1. And when the maximum contact pressure was about 80 MPa, the ratio of the contact pressure area had been increased from 15% to 20% and the damage level were level 1. In other words, it assumed that when the local pressure has increased by the cause that the uneven ground cusps have shoved into TLS surface, the polyurethane nonlinear elastomer (thickness: 10 mm–20 mm) as intermediate protecting layer has dispersed the local pressure. Therefore it seemed that there was no damage of TLS by this dispersion mechanism of TLS.

From these results of the loading tests, it seems that it is expected that the thickness 10 mm intermediate protecting layer have the sufficient durability.

On the other hand the combination case of the geomembrane sheets and nonwoven geotextile dose not have the dispersion mechanism by themselves and it seemed that the durability of the model hydraulic

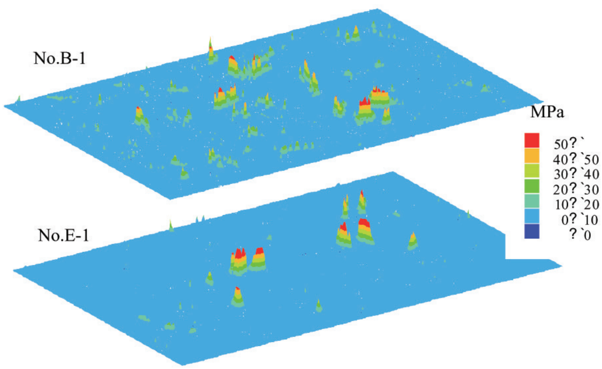

Figure 9. 3-D contour of contact pressure on the model hydraulic barrier surface in No. B-1 and No. E-1.

barrier have been influenced by the damage resistance of them. Therefore the geomembrane sheets (PVC and LLDPE) have been damaged by the contact pressure more than their damage resistance.

4 CONCLUSION

In this study, we have recognized the conclusion as follows that

- From puncture tests result, it seems that the combination of TLS and the nonwoven geotexitle is effective about the flexibility function against landfill site deformation rather than the double geomembrabe sheets and nonwoven geotextile combination.
- Puncture resistance of all test cases are greater than 1000 kN, and it seems that the puncture resistance of all sheet combinations are satisfied against the regulation value against protection mat of landfill site and requirement value against base ground used by No. 4 crushed stone
- When the local pressure has increased by the cause that the uneven ground cusps have shoved into TLS surface, it assumed that the polyurethane nonlinear elastomer (thickness: 10 mm–20 mm) as the intermediate protecting layer has dispersed the local pressure
- It seemed that there was no damage of TLS by the dispersion mechanism of TLS
- The combination case of the geomembrane sheets and nonwoven geotextile dose not have the dispersion mechanism by themselves and it seemed that the durability of the model hydraulic barrier have been influenced by the damage resistance of them.
- The geomembrane sheets (PVC and LLDPE) have damaged by the contact pressure more than their damage resistance.

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REFERENCES

ASTM standards (1996). Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products: *ASTM D4833-88 pp 1269-1272*.

Akai, T. et al, (2003). Protection capability of nonwoven geotextile applied protection mat of waste disposal site at the sea, *Geosynthetics Engineering Journal 18, pp 13-16 (in Japanese)*.

International Geo-synthetic Society of Japan (2000). Landfill Design and Construction Handbook-Water Cutoff Technology, *IGSJ (in Japanese).*

Kano, S., Morohoshi, K. and Oda, K. (2004). Puncture resistance of Waterproof Sheets Applied at Costal Confined Waste Disposal Site. *Technical Note of National Institute for Land and Infrastructure Management No.142, March (in Japanese).*

Kamon, M., Akai, T. and Matsumoto, A. (2002). New development of triple liner system with polyurethane elastomer between double geomembrane sheets, *Proceeding of the International Conference on Geosynthetics, IFAI, 1: pp 561-56*.

Waterfront Vitalization and Environment research Center, (2000). Manual of Design, Construction and Management at a costal disposal site. *Tokyo: Waterfront Vitalization and Environment research Center (in Japanese).*