TRAP-DOOR TESTS WITH SLOW DEFORMATION FOR BENTONITE MIXED SOIL LINER

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ABSTRACT

In Japanese landfills, the bentonite mixed soil (BMS) has been often used for the material of their liners. The BMS is made by adding about 10 % bentonite into a natural soil, and the compacted BMS liner has a low permeability. Its permeability is required to be lower than 10 nm/s by the regulations of Japanese government.

In landfills, it is afraid that the foundation of the liner may experience subsidence with increasing the waste weight filled in the landfill. And it is also afraid that the foundation above the groundwater collection pipes has a cavity with the erosion by sucking out of soils around the pipes. The BMS liners on such foundations will be sure to be deformed. If the deformation of the BMS liners becomes large, the liners have cracks in it. It can be also thought that the permeability of the deformed liner will increase and the original performance won't be able to accomplish. However few papers concerning those deforming behaviors are reported until now. In the past papers, the authors reported about the deformation behaviors of the BMS liner in the modeled tests that it was quickly deformed at a rate of 1 mm/min. In this paper, they report about the deformation behaviors of the BMS liners in the cases that the trap-door settles at a rate of 1 mm/day.

From these studies, it was found that the results of slow deformation didn't differ from the case of fast deformation tests too much. And it was also found that the deformation ability of BMS liners was not so high, and was reconfirmed that the liner has a limit amount of vertical deformation against cracking.

Keywords: Bentonite mixed soil liner, subsidence, deformation rate, trap-door

INTRODUCTION

In landfills, the barrier system is necessary to prevent the leachate from infiltrating into the ground water around the landfill. In Japan, the barrier system consisting of geomembrane and compacted clay liner has been mainly used since 1998. And the quality of the used clay liner is required to have a permeability of less than 10 nm/s and a thickness of larger than 50 cm. However , since it is difficult to get a natural clay with such low permeability, the compacted clay soil liner that is made by mixing the bentonite with natural soils obtained in the area close to landfill site (BMS)[1] has been used in Japan.

The foundation of landfill liners may experience a compression or deformation due to increase of the overlaid waste weight. When the underground water collection pipes installed in the foundation were deformed by the overburden pressure of the waste or the soils around the pipes had the erosion by sucking, the spaces between the foundation and the overlaid bentonite mixed soil liners (BMS) are formed. Then the soil liner would deform to fill the open spaces. If the deformation was big, the soil liner would fail[2),3)] .

In this study, the authors investigated the deformation behaviors of the BMS liners in the tests that the trap-door settled at a rate of 1 mm/day, and compared the results[4), 5), 6)] from the tests conducted at a rate of 1 mm/min reported former.

MATERIALS & METHODS

Bentonite mixed soil liner

Bentonite: The bentonite used in this study is sodium one produced in U. S. A.. Its characteristics are shown as follows.

Density = 2.86 g/cm^3, Free swelling = 38 ml/2g, pH = 9.8, Liquid Limit = 581 %, Plastic Limit = 38 %

Sand: The sand used as parent material of BMS is the fine crushed rock. The characteristics of the sand are shown in Table 1. It has a maximum particle size of 9.5 mm and well graded soil. The sand is classified as Sand with Fine-soil(SF) according to the Method of Japanese Classification of Geomaterials for Engineering Purpose.

In the compaction test, the sand is compacted into a mold with a inside diameter of 10 cm and a volume of 1,000 cm^3 in three equal layers by dropping a hummer with a mass of 2.5 kg. Blowing number is 25 for each layer. The maximum dry density(ρ_{dmax}) of 2.11 g/cm^3 and the optimum water contents(w_{opt}) of 9.6 % are obtained.

Table 1 Particle size and density of the sand

Gravel (%)	33.4
Sand (%)	50.5
Silt (%)	7.1
Clay (%)	9.0
Max. Particle Size (mm)	9.5
D_{60} (mm)	1.6
D_{30} (mm)	0.3
D_{10} (mm)	0.008
Uniformity Coefficient Uc	200.0
Coefficient of Gradation Uc’	7.0
Particle density (g/cm^3)	2.70

Bentonite mixed soil: BMS was formed by adding 10 % in dry mass of bentonite into the sand. From the result of compaction tests, ρ_{dmax} of 1.88 g/cm^3 and W_{opt} of 10.7 % were obtained.

For the deformation tests, the BMS was compacted statically using oil jack to be a degree of compaction (Dc) of 95 %, and the BMS liner samples were trimmed with the size of W800 mm*L200 mm*D100 mm. Their water contents were 10.7 – 15.0 %.

Procedure of deformation test

Figure 2 shows the cross section of the deformation test equipment. The equipment is made by the steel container, the inside size in that is W800 mm*L200 mm*D350 mm. The container has a trap-door (Iron plate, the width is 300-500 mm) at its bottom, and the height of the door is controlled by a jack placed under the door.

In the container, the compacted BMS liner (t=100 mm) is placed on the bottom and is overlaid by protective sand (t=200 mm). The airbag placed on the sand functions to apply uniformly distributed pressure on the compacted BMS liner through the protective sand. The amount of subsidence of BMS liner is measured through the displacement gauge tied to a thin steel plate settled on the top and bottom center of the BMS liner.

In the slow deformation tests, the trap-door was lowered by the jack with increasing the value of the displacement gauge in 1 mm per 24 hours. During the tests, the airbag had pressured the BMS liner with 107.8 kN/m^2.

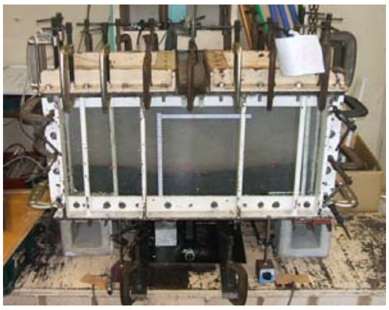

Figure 1. Side view of the deformation test equipment

<u>**Case of the deformation tests**</u>

In the deformation tests, the thickness of the BMS liners was fixed to 100 mm. And three types of span (width of trap-door) were prepared such as 300 mm (No.1), 400 mm (No.2) and 500 mm(No.3). Since these span had been used in the fast rate deformation tests[4), 5), 6)] previously, the results in these experiments could be compared with them.

Table 2 shows the condition of these tests.

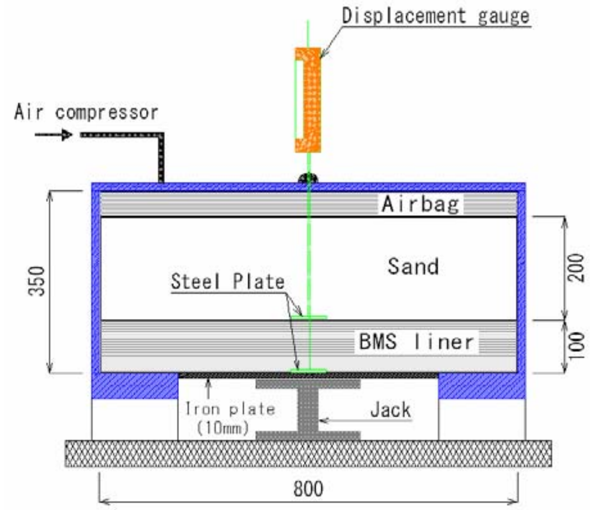

Figure 2. Cross section of the deformation test equipment

Table 2. Condition of the slow rate deformation tests

No.	Thickness of BMS liner [mm]	Span [mm]	Water content [%]	Degree of compaction [%]
1	100	300	16.3	95.7
2	100	400	17.2	94.0
3	100	500	16.5	95.5

RESULT

Figure 3 and 4 show the side view after deforming and the displacements of the BMS liner with trap-door in case of No.3 test, respectively. When the subsidence at the top surface of the BMS liner reached to 12 mm, the share crack (A, B) had taken place in the middle height of the BMS just above the edge of the trap-door. These cracks had grown both upward and downward with increasing the subsidence. When the center of the BMS liner subsided by 14.5 mm, Crack A had reached the top surface of the BMS liner. And when the displacement gauge showed 18.5 mm, Crack B had reached the bottom surface of the one.

On the other hand, when the center of the BMS liner subsided by 18 mm, the bending crack (C, D) had taken

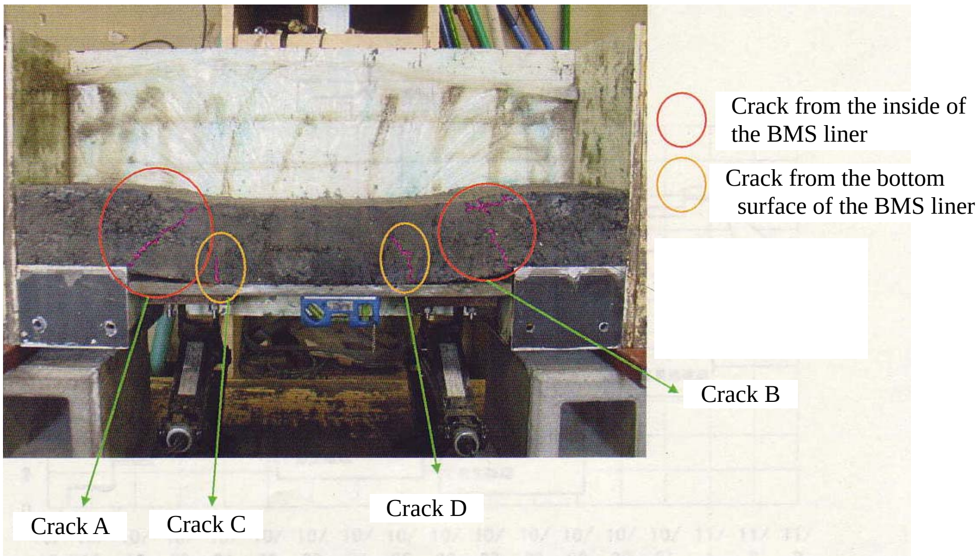

Figure 3. The appearance of cracks after finishing the deformation test (Case No.3)

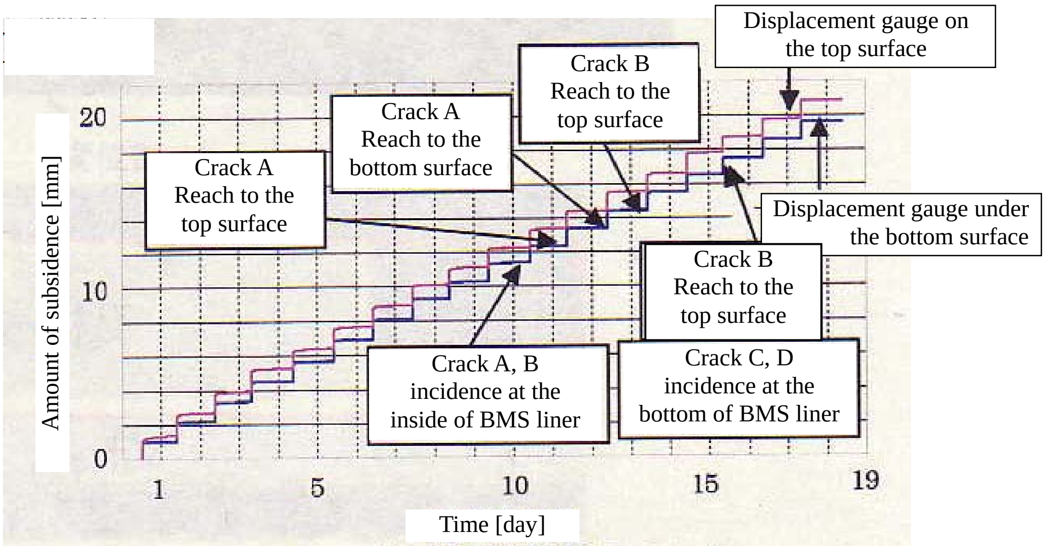

Figure 4. The relationship of the amount of the subsidence and the measurement time (Case No.3)

Table 3. Summary of the deformation test results and comparison with ones of fast rate deformation tests

Deformation Speed	No.	Thickness of BMS liner [mm]	Span [mm]	Density of BMS liner [g/cm^3]	Shear/Span ratio	Applied pressure*2 [kPa]	Subsidence*2 [mm]	Type of crack
Slow (1 mm/day)	1	100	300	1.77	1.5	156.8	8	no crack
	2	100	400	1.74	2.0	107.8	11	Shear
	3	100	500	1.77	2.5	107.8	12	Shear
Fast (1 mm/min.)	A2*1	100	300	1.84	1.5	88.3	12	Shear
	B7*1	100	400	1.88	2.0	58.8	23.7	Bending
	B9*1	100	500	1.84	2.5	29.4	12.8	Bending

*1 These numbers are quoted from the paper[4), 5),6)] reported by us before.
*2 These values are at the moment that the BMS liner had experienced some cracks.

place around the bottom center of the BMS liner. Then those cracks had been growing upward with increasing the deformation.

From the above results, it was found that the failure of the BMS liner in case of No.3 (That has a thickness of 100 mm and a span of 500 mm) mainly caused in the form of share crack.

Similarly, in the case of No.2, the shear cracks appeared when the displacement gauge on the top surface showed 11 mm (See Table 3) and the bending crack appeared after that. The shear crack proceeded toward top and bottom inside the BMS liner with increasing the deformation. And it reached to the top surface when a displacement gauge showed 15mm and to the bottom surface when that showed 18 mm.

In the case of No.1, under a applied pressure of 107.8 kPa, the amount of subsidence of the BMS liner did not proceed over 4 mm and the BMS liner experienced no cracks. Therefore the pressure was raised up to 156.8 kPa. As the result, the value of the subsidence became 8 mm. However the subsidence did not increase any more. The reason why the BMS liner did not experience a crack is thought such that the bending stress and the shear stress were smaller than the bending strength and shear strength of the compacted BMS. Their bending and shear stress are induced by the applied pressures against the modeled BMS liner with a thickness of 100 mm and a span of 300 mm, that Shear/Span ratio is 1.5(Deep beam).

DISCUSSION

The trap-door tests in this paper were carried out under the condition of a slow rate of 1 mm/day to investigate the ability of BMS liner following the deformation of the foundation at that time. Table 3 shows these results, and also shows the results of a fast rate of 1 mm/min tests reported[4), 5), 6)] by the authors. From Table 3, it is found that the applied pressure of the slow rate deformation tests had a greater value than that of the fast rate tests at the moment that the BMS liner had experienced some cracks. And the main type of crack was different between the slow rate tests and the fast rate tests. The reason is thought as follows. The shear strength and the bending strength are much affected by the strain rate and the trigger-strength is different.

In Table 3, the amounts of subsidence on the top surface of the BMS liner under an overburden pressure of 107.8 kPa are 11 mm and 12mm for 400 mm in span (No. 2) and 500 mm in span (No.3), respectively. This suggests that the lager the span become, the lager the amount of subsidence before cracking become. In the beam theory, if the strength of the beam wasn’t considered, the deflection at the center of the beam becomes larger with increasing the length of span. Therefore the beam theory will be applicable to the analysis of the trap-door tests.

Figure 5 shows the relationship between the span and the applied pressure at the moment that the BMS liner just has failed, however the results with the span of 300 mm under slow rate had no crack.

From Figure 5, in the deformation test with a fast rate of 1 mm/min (This test had been conducted by mean of stress-controlled), it can be regarded that the applied pressure when the BMS liner just have experienced some cracks becomes smaller as the span becomes wider. In comparison with the applied pressure to the BMS liner with equal span length, it is found that the value for the slow rate tests are larger than that for the fast rate tests when the BMS liner just have experienced some cracks. This is thought that the strength of the BMS liner became large by rearrangement of the soil particles in the slow deformation.

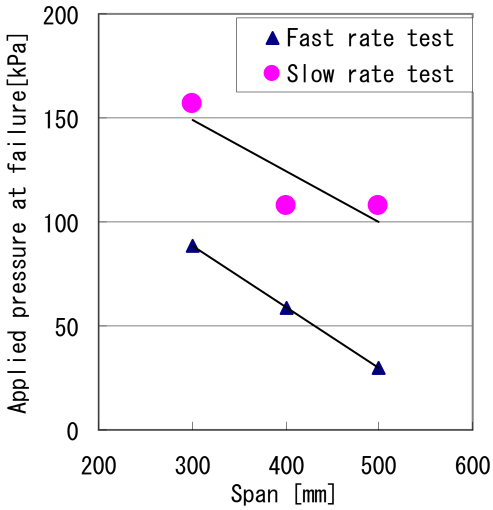

Figure 5. Relationship between the span and the overburden pressure at failure

SUMMARY

The main results obtained from this study are as follows.

(1) In the slow rate deformation tests, the BMS liner has been mainly failed by the shear cracks.

(2) When the BMS liner was deformed under the constant overburden pressure, the amount of vertical subsidence at the center of the liner until some cracks experience becomes larger with increasing the span length.

(3) For the equal span length, the overburden pressures when the BMS liner just has failed in slow rate tests are larger than those of the fast rate tests.

(4) Therefore it is thought that the landfill would be able to design safety according to using the result based on the fast rate deformation test.

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REFERENCE

1) D. E. Daniel and R. M. Koerner (1995): Waste Containment Facilities – Guidance for Construction, Quality Assurance and Quality Control of Liner and Cover System, ASCE Press, pp.61-62

2) S.C.Cheng, J.L.Larralde and J.P.Martin (1994), Hydraulic conductivity of compacted clayey soils under distortion or elongation conditions, Hydraulic Conductivity and Waste Contaminant Transport in Soil, pp.266-283

3) B. V. S. Viswanadham and S. Senguputa (2005): Deformation Behaviour of Compacted Clay Liners of Landfills in a Geocentrifuge, Proc. of the 10th International Waste Management and Landfill Symposium, CD-ROM No.367

4) S. Usami, K. Kudo, S. Imaizumi, H. Kato and K. Shibata (2006): Deformation performance of bentonite mixed soil liner used to landfill and proposal for landfill design, Proceedings of the 17th Annual Meeting of the Japan Society of Waste Management Experts, pp.935-937 (in Japanese)

5) H. Kato, S. Usami, S. Imaizumi, K. Kudo and S. Matsuyama (2007): Experimental study and analysis on deformation of bentonite mixed soil liner,

Proceedings of the 11^{th} International Landfill Symposium, Sardinia, CD-ROM

6) Y. Shinozaki, S. Imaizumi, T. Yoshinao and K. Kudo (2007): Deformation tests of bentonite mixed soil liner with applied pressure, Proceedings of the 4^{th} Annual Meeting of Kanto Chapter of the Japanese Geotechnical Society, pp.343-345