EXPERIMENTAL STUDY ON SLOW AND FAST DEFORMATION OF BENTONITE MIXED SOIL LAYER

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SUMMARY:

For Japanese landfills, to prevent infiltration and diffusion of leachate in the peripheral ground and underground water, the barrier system consisting of geomembrane and compacted clay liner (CCL) has been frequently used since 1998. For the cohesive soil that is included in CCL, it is provided for in the regulation that the material shall have permeability coefficient of 10 nm/s or less and the layer thickness shall be 50 cm or more. However, because it is difficult to obtain the natural cohesive soil having such physical property in Japan, the bentonite mixed soil (BMS) is used for the CCL in Japan.

When designing landfills, there is a concern that, as the landfill operation progresses, the facilities may have a problem that the subgrade of the BMS layers is deformed by compression and consolidation due to increase of the waste disposed in the landfill. There is also a concern that the foundation above the groundwater collection pipes may be scoured or the pipes are deformed due to loading from upper layer, possibly leading to creation of space in the ground below the BMS layer. In these cases, the BMS layer should subside following the deformation of the subgrade. If the amount of the subsidence is large, the BMS layer can fail.

In this study, we implemented two testing methods for investigation of deformation of the BMS layer; fast deformation test and slow deformation test, and verified that these two methods are valid. This report describes how to put these methods to practical use when designing a barrier system of landfills.

1. INTRODUCTION

Landfills need the barrier system to prevent the leachate from penetrating 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. The quality of the clay layer to be used 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 natural clay with such low permeability, the BMS layer that is made by mixing the bentonite with natural soils obtained in the area close to landfill site (D.E. Daniel and R.M. Koerner; 1995) has been used for the compacted clay liners in Japan.
The foundation of landfill layers may experience a compression or deformation due to increase of the overlaid waste weight. When the underground water collection pipes installed in the foundation are deformed by the overburden pressure of the waste or the soils around the pipes is eroded by scoring, spaces are formed between the foundation and the overlaid BMS layers. Then the soil layer would deform to fill the open spaces. If the deformation is large, the soil layer would fail (S.C.Cheng et.al.; 1994, B.V.S. VISWANADHAM et. al.;2005).
In this study, we implemented two testing methods for investigation of deformation of the BMS layer; fast deformation test and slow deformation test. The fast deformation test used a beam loading equipment and slow deformation test used trap-door system. The following sections describe how to use these test equipment.

2. MATERIALS AND METHODS

2.1 Bentonite mixed soil (BMS) layer

2.1.1 Bentonite

The bentonite used in this study is a sodium type produced in the U.S.A. The physical properties of the material were as follows; Specific Gravity:2.86, Water Content:7.5 %, Free Swelling:38 ml/2g, pH:9.80, Liquid Limit:581 %, Plastic Limit:38 %, Plasticity Index:543, M.B.:49.0 ml/0.5g.

2.1.2 Sand

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

The sand was subjected to compaction test by using a mold with inside diameter of 10 cm and volume of 1,000 cm^3 and a hummer having a mass of 2.5 kg. The sand was compacted unsing non-repeating method into the mold in three equal thickness layers by blowing with the hammer 25 times per layer. As a result, the compacted sand reached the maximum dry density(ρ_{dmax}) of 2.11 g/cm^3 and the optimum water contents(W_{opt}) of 9.6 %.

Table 1. Particle size and density of the sand

Gravel (%)	33.4
Sand (%)	50.5
Silt (%)	7.1
Clay (%)	9.0
Max. Particle Pize (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
Specific Gravity （g/cm^3）	2.70

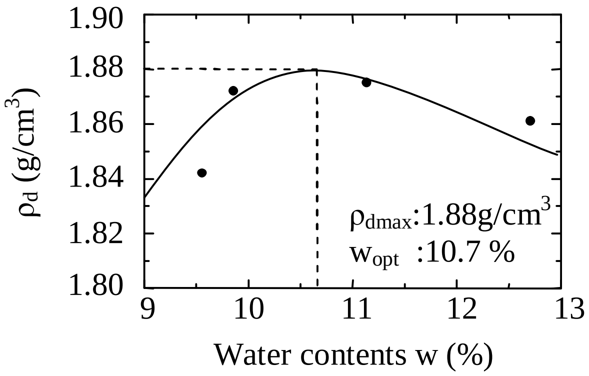

Figure 1. Result of compaction test of bentonite mixed soil

2.1.3 Bentonite mixed soil

Bentonite mixed soil was formed by adding 10 % in dry mass of bentonite into the sand and compacting it. The result of the compaction tests is shown in Figure 1. As a result, the compacted bentonite mixed soil having ρ_{dmax} of 1.88 g/cm^3 and W_{opt} of 10.7 % were obtained.

2.2 Equipment for deformation test

Figure 2 shows schematic cross-sectional view of the equipment for fast deformation test. The concrete foundation supporting the BMS layer has an open space on the top. The width and depth of the open space is changeable. The compacted BMS layer is covered with protective sand. The airbag placed on the sand is inflated to apply uniformly distributed adjustable pressure on the compacted BMS layer through the protective sand. The amount of subsidence of BMS layer is measured by using the displacement meter. The deformation tests were carried out following the steps described below.

(1) An air feed tube from compressor was connected to the airbag through the hole of steel plate cap.

(2) The airbag was inflated to apply pressure of 10 kN/m^2 statically, and an amount of vertical deformation of the BMS layer was measured at the center of the layer. When the amount of deformation measured every one minute became less than 1/100 of the width of the foundation's top open space, meaning that the deformation nearly stopped, additional pressure of 10 kN/m^2 was applied statically. This process was repeated until the layer showed cracks or penetration of failure.

(3) The state of progress of the deformation and the cracking of the BMS layers was observed and recorded on video-tape.

(4) When the BMS layer failed, the deformation test was finished.

(5) The test equipment was disassembled, state of deformation of BMS layer was measured and induced crack was recorded by camera.

Figure3 shows the schematic cross-sectional view of the equipment for slow deformation test. The equipment consists of the steel container, of which inside dimensions are 800 mm (width), 200 mm (length) and 350 mm (depth). The container has a trap-door (Iron plate, the width o 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 layer with a thickness of 100 mm is placed on the bottom and is overlaid by protective sand having a layer thickness of 200 mm. The airbag placed on the sand is inflated to apply uniformly distributed pressure on the compacted BMS layer through the protective sand. The amounts of subsidence of BMS layer are measured through the displacement gauges tied to a thin steel plate settled on the top and bottom center of the BMS layer.

For the slow deformation tests, the trap-door was lowered by the jack at a rate of 1 mm per 24 hours. During the tests, the airbag pressurized the BMS layer constantly at 107.8 kN/m^2.

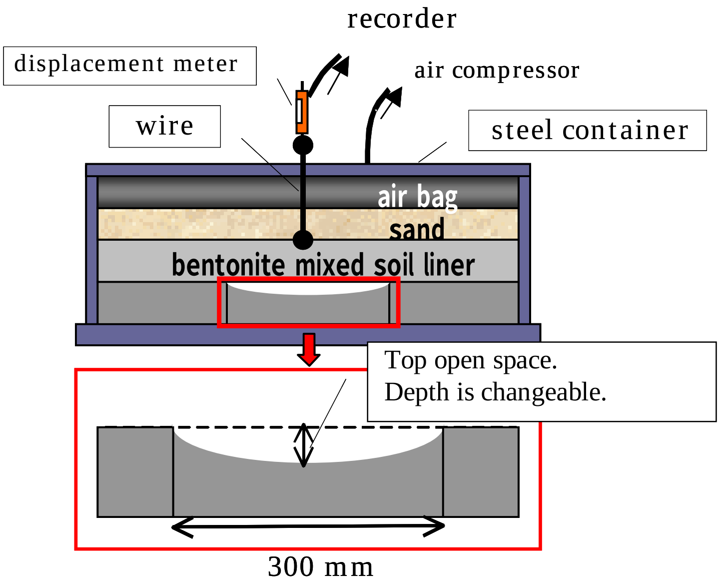

Figure 2 THE EQUIPMENT FOR FAST DEFORMATION TEST

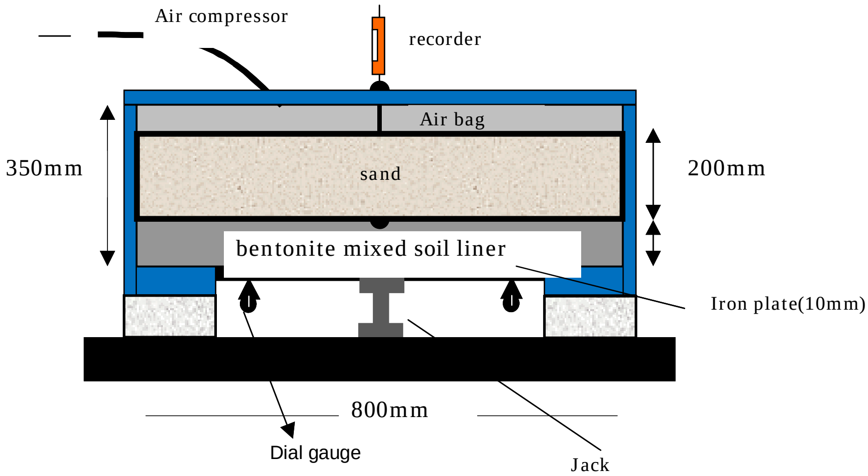

Figure 3 THE EQUIPMENT FOR SLOW DEFORMATION TEST

3.Result and discussion

3.1 Comparison of deformation test results

This section compares the results of fast deformation test and those of slow deformation test.

Figure 4 shows the cross-sectional view of the deformed layer at the end of the fast deformation test. For the fast deformation, only the shear crack occurred when the shear/span ratio was 1.5 or less. Bend crack occurred when the shear/span ratio was 2 or over.

Figure 4 Appearance of cracks at the end of the fast deformation test (Case No.F1)

Figure 5 shows the cross-sectional view of the deformed layer at the end of the slow deformation test. For the slow deformation test, only shear crack occurred and no bend crack occurred.

Figure 5 Appearance of cracks at the end of the slow deformation test (Case No.S3)

Table 2 collects the test results. For the slow deformation test, the subsidence increased from 8 mm to 12 mm with increase of the span. Only the shear crack occurred without regarding to the shear/span ration.
For the fast deformation test, no clear correlation was obtained between span and load and the one between span and subsidence because bend crack as well as shear crack occurred with the increase of shear/span ratio.

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*1	Applied pressure*2 [kPa]	Subsidence*2 [mm]	Type of crack
Slow (1 mm/day)	S1	100	300	1.77	1.5	156.8	8	no crack
	S2	100	400	1.74	2.0	107.8	11	Shear
	S3	100	500	1.77	2.5	107.8	12	Shear
Fast (1 mm/min.)	F1	100	300	1.87	1.5	107.8	14.5	Shear
	F2	100	400	1.88	2.0	58.8	23.7	Bending
	F3	100	500	1.84	2.5	29.4	12.8	Bending

*1 Shear/Span ratio means the value of span length divided by (2 x thickness of BMS layer).
*2 These values are at the moment that the BMS liner had experienced some cracks.

3.2 Analysis of test results

Figure 6 shows results of the tests using graph. As the span increases, both the fast and slow deformations show a tendency to decrease the pressure. This tendency indicates that it is possible to forecast the bearing capacity of the BMS layer. The bearing capacity of the ground is larger when the deformation is slow. This may be caused by recompaction after the deformation, by which the rigidity of the ground is made higher.

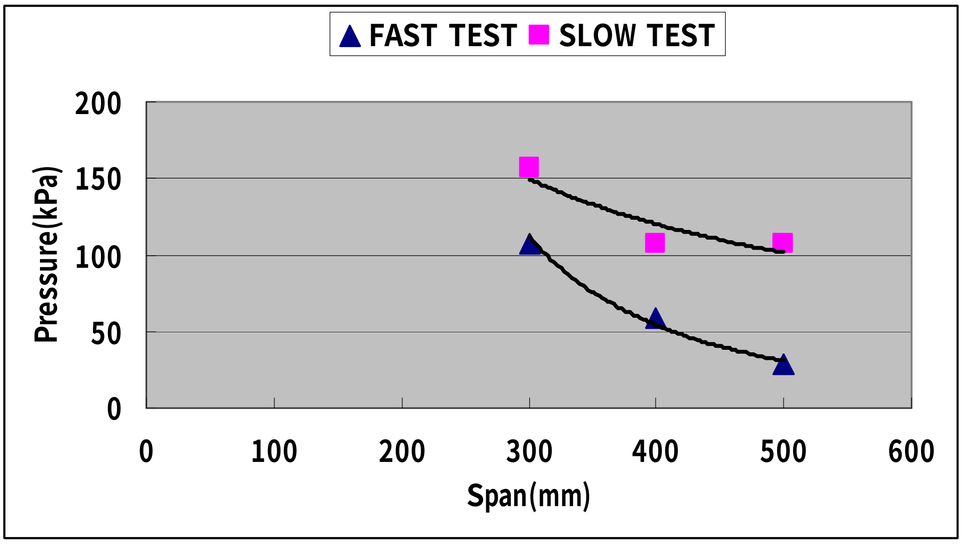

Figure 6 Relationship between the span length and the pressure applied at failure

Figure 7 shows relationship between the span and the subsidence. Result of the slow deformation test shows that the subsidence increases with the increase of the span. This correlation is not linear and may exist in a limited range of the span. On the other hand, for the fast deformation, where the BMS layer was set like a beam, the layer became easily fracturable when the span is 400 mm or over where the bend crack occurs. The shear/span ratio that does not cause the bend crack to occur was 1.5.

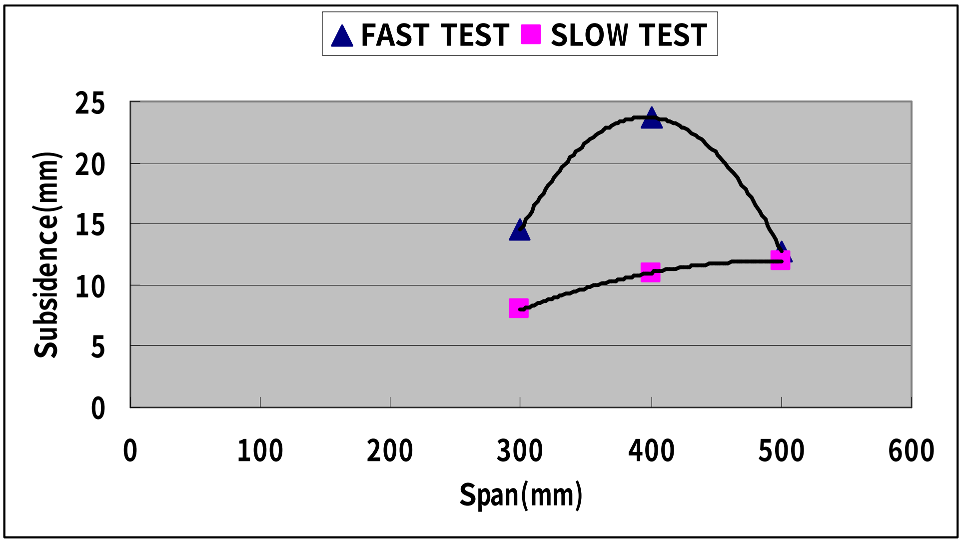

Figure 7 Relationship between span and subsidence

4. SUMMARY

The results of the fast and slow deformation tests can be applied to designing of landfills as described below.

(1) The fast deformation tests simulates the state that the ground runs off due to rain fall, and thus the results can be utilized for decision of excavation width of the ground below the BMS layer. As a result of this test, it was found that the bend crack does not occur when the shear/span ratio is 1.5 or less. If this result is applied to 500 mm thick BMS layer, the span with which the fracture occurs is 1.5 m. Therefore, the safe excavation width for actual construction is 1 m or less for this case.

(2) The slow deformation test was performed to investigate safety of BMS layer subjected to waste load after operation of landfill is completed. The results of the test show that non-uniform subsidence of 10 mm causes the crack to penetrate through the layer. Therefore, it is necessary to compact the layer during construction to prevent non-uniform subsidence.

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