LARGE MODEL TESTS ON THE BENTONITE MIXED SOIL LAYER UNDERGOING LOCAL SETTLEMENT (Part 2)

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ABSTRACT

In Japan, bentonite mixed soil (BMS) which is made by mixing the bentonite into sand about 10 to 15 % in dry mass in order to have a hydraulic conductivity of less than 10 nm/s is widely used as soil barrier layer of landfill. The BMS layer may experience local settlement of the base ground. In case of large local settlement, the BMS could crack to lose the integrity of the barrier system. The authors constructed six large models of BMS layer in the field which had a thickness of 0.5 m, a width of 1.5 m and a length of 3.0 m. Among them, four models were underlaid with a geonet having a mesh size of 10 mm and different tensile strength. As results it is found that the crack appeared on the bottom surface of the BMS layer at the edge of the cavity and progressed upward at an angle of about 60 degree to the horizon. The models underlaid with geonet had also cracked but did not progress to the top surface while those without geonet had a crack reaching the top surface. It is also found that at the site where the width of crack appeared on the top surface was less than 2 mm an inflow quantity became a little after a few days.

Keywords: Bebtonite mixed soil, Local Settlement, Crack, Geonet, Permeability

INTRODUCTION

In Japan, bentonite mixed soil (BMS) which is made by mixing the bentonite into sand about 10 to 15 % in dry mass in order to have a hydraulic conductivity of less than 10 nm/s is widely used as soil barrier system on the bottom and side slope in landfill. Beneath the bottom barrier system, collection pipes for ground water are also placed. The fine soil surround the pipe may flow into the pipe under heavy rainfall. This causes the cavity in the base ground over the pipe and leads the local settlement of soil barrier system. In case of large local settlement, the BMS layer could crack to lose the integrity of the barrier system.

Up to today, Camp S., et al (2007), Edelmann L., et al (1996), Gourc J.P. (2008) and Viswanadham B.V.S. and Sengupta S. (2005) have studied about problems relating to occurrence of cracks of impervious soil layer due to a deformation. The authors (Kudo K. and Imaizumi S. (2012)) have also conducted the trap door tests and infiltration tests for the small model of BMS layer with a thickness of 10 cm and a length of 80 cm to simulate deformation behavior of a BMS layer subject to local settlement. They found that (1) the BMS layer had a crack at the bottom surface when the trap door lowered by about 10 mm and the crack reached the top surface at a fall of about 20 mm, (2) the BMS layer which experienced a fall of 10 mm did not function as barrier system and (3) the BMS layer underlaid with a geonet maintained a function as barrier even when it experienced a fall of 45 mm, though it had also crack.

In this study, because the thickness of 0.5 m of BMS layer is a standard in Japan, the authors constructed 6 large models of BMS barrier system in the field which had a thickness of 0.5 m, a width of 1.5 m and a length of 3.0 m. Then they conducted tests on local settlement to observe the behavior of the BMS barrier system. They also conducted infiltration tests on just the site subject to deformation. At some testing site, a geonet having a mesh size of 10 mm and different tensile strength was placed beneath the BMS layer to confirm its effectiveness to maintain the barrier function.

MATERIALS USED

Bentonite mixed soil (BMS)

The BMS was made by mixing the sodium bentonite into rock-crushed sand with a maximum particle size of 5 mm at a ratio of 10 % in dry mass. From the compaction test using a mold with an inside diameter of 10 cm and a volume of 1,000 cm3, a hummer with a mass of 2.5 kg and a blowing number of 25 for each three layer, the optimum water contents (w_{opt}) of 19.1 % and the maximum dry density (ρ_{dmax}) of 1.60 g/cm^3 are obtained.

Figure 1 shows a variation in hydraulic conductivity obtained for the specimen with a compaction degree of 100 % using a flexible-wall permeability apparatus. The measured hydraulic conductivity indicates stable values of about 10 nm/s beyond an elapsed time of 40 hours, which satisfies the Japanese standard of less than 10 nm/s as clayey barrier system.

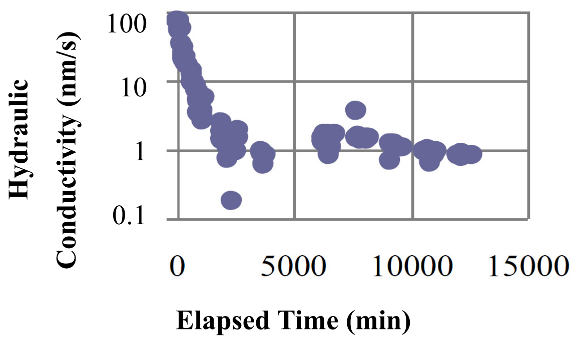


Figure 1 Variation of measured hydraulic conductivity

Geonet

Two types of geonet, made of High Density Poly-Ethylene (HDPE), were used to place beneath the BMS layer. Tensile strength of these geonet were estimated as 6,552 N/m (N24) and 5,146N/m (N248) from the tensile test conducted at a rate of 1 mm/min under a room temperature of 23 degrees C.

MODEL OF BENTONITE MIXED SOIL BARRIER SYSTEM

Types of model and structure

Six models of BMS barrier system were constructed continuously as shown in Figure 2. The size of each BMS layer is, as diagrammatically shown in Figure 3, 3.0 m in length, 1.5 m in width and 0.5 m in thickness. Two models have no geonet beneath the BMS layer though two models have N24 geonet and two models have N248 geonet. The base ground of the model was stabilized by adding cement into site soil mainly composed of sand. The ditch with a size of 1.2 m x 1.5 m and different depth, that is 0.1 or 0.2 m for the each model, was made on the top surface of the stabilized base ground. Round pipes with a diameter of 50 mm and a length of 2 m were placed in the ditch then the space was filled with sand. The geonet was placed over the sand and its ends were stuck by steel pin. Table 1 shows the condition of 6 models.

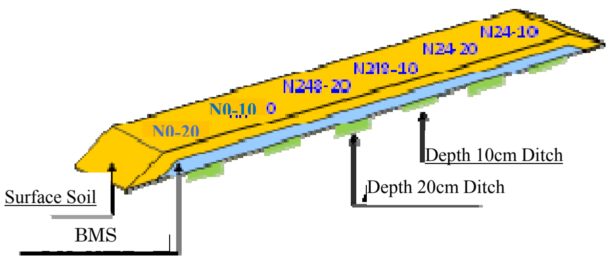


Figure 2 Schematic Drawing of Test models

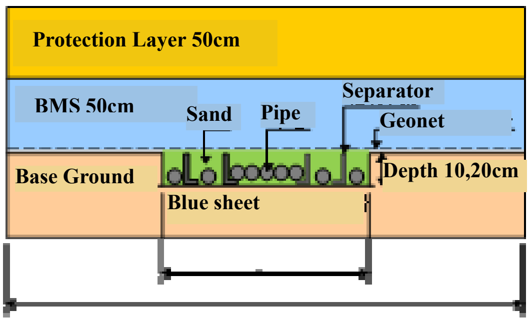


Figure 3 Schematic Drawing of BMS Layer

Table 1 Condition of six BMS barrier system

Name of Model	No-20	No-10	N248-20	N248-10	N24-20	N24-10
Geonet	without	without	N248	N248	N24	N24
Septh of Ditch	20	10	20	10	20	10

Construction of the model

The BMS barrier system with a thickness of 0.5 m was constructed by compacting three BMS layers with 0.15 m or 0.20 m thick each. First the masses of sand and bentonite required for one layer were measured and mixed. Then tap water was supplied and kneaded for the BMS to become a water content of 17 %. It was spread on the stabilized base ground including the filled ditch. A light vibration-compactor with an ability of 10 kN was used to compact the BMS layer to become a degree of compaction of 100 %. The surface of compacted BMS layer was scratched by rake for the layers to stick together. These works were repeated three times. After completing the BMS barrier system, a 0.5 m thick soil cover was placed.

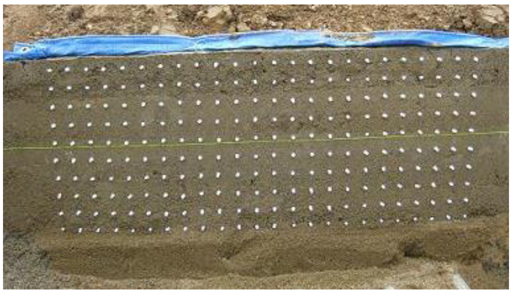


Figure 4 thumbtacks inserted into the surface of BMS

Figure 5 A view of constructed models of six BMS barrier system

Colored thumbtacks with a top of 5 mm in diameter were inserted into the side surface of the BMS barrier system in a 50 mm grid, as shown in Figure 4, for us to observe the deformation behavior easily. A transparent board made of Poly-carbonate with a thickness of 50mm was stood just in front of the side surface of the BMS barrier system. Figure 5 shows a view of constructed models of BMS barrier system in the field.

TESTS ON LOCAL SETTLEMENT

Procedures

In order to make a cavity beneath the BMS layer, following works were conducted.

1) The round pipes placed in the central area of 0.3 m of the ditch, where was enclosed by the wooden separators, were pulled out.

2) The sand filled in the above mentioned area was removed. Removal Ratio of Sand (RRS) was defined as a ratio of the width of the removed sand to the width of the ditch (=1.2 m), here RRS was 0.25.

3) Deformation behavior appeared on the side surface of the BMS layer was carefully observed and recorded on a video camera.

4) The wooden separators, round pipes and sand which were placed in the outer 0.15 m area were removed and the deformation behavior was observed.

5) Above works (4) was repeated till a RRS become 1.0.

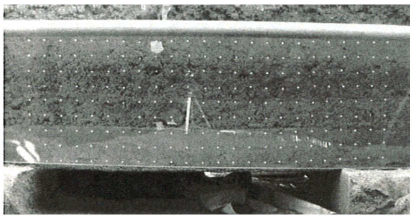
6) A vertical load up to about 44 kN was applied on the top surface of the cover soil placed on the BMS barrier system by a bucket of shovel loader. The deformation behavior of the BMS layer was also recorded.

Results and discussion

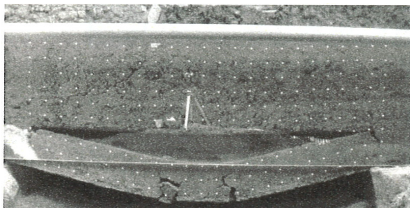
Figure 6 shows, as an example, the states of the BMS barrier system with increasing a RRS in case of tests on model N24-20, where the BMS barrier system had geonet N24 and a ditch of 0.2 m deep.

When the sand was removed by 87.5% of the whole width of the ditch, the crack do not appeared at the BMS barrier system.

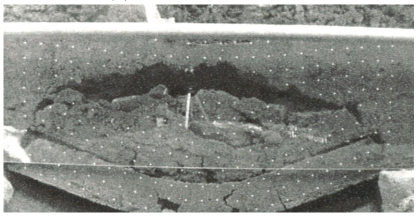
When the sand was fully removed, the crack appeared on the bottom surface at the edge of the cavity and progressed upward. The first compacted BMS layer failed as shown in Figure 6(b). After 3 minutes when the sand was fully removed, the crack reached the second compacted BMS layers and failed as shown in Figure 6(c). When a vertical load was applied, whole BMS barrier system failed as shown in Figure 6(d).



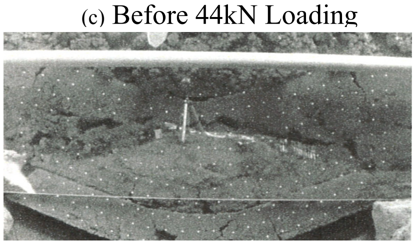
(a)Width of Ditch 1.05m



(b)Width of Ditch 1.2m



(c) Before 44kN Loading



(d) After 44kN Loading

Figure 6 States of N24-20 with increasing a removal ratio of sand

Figure 7 shows, as an example, the states of the BMS barrier system in case of tests on the model No-20, where no geonet was placed over a ditch of 0.2 m deep. When the sand was fully removed, the crack progressed up to 150 mm upward from the bottom and the first compacted BMS layer fallen down thoroughly.

Figure 7 State of No-20 on ditch width 1.20 m

Figure 8 shows, as an example, the states of the BMS barrier system in case of tests on the model N248-20, where the BMS barrier system had geonet N248 and a ditch of 0.2 m deep.

When the sand was fully removed, the crack progressed up to 450 mm upward from the bottom and the first and second compacted BMS layer fallen down.

Table 1 shows a summary of observed states of crack with increasing a RRS, where the maximum width of crack and differential settlement measured on the top surface of the BMS barrier system are also listed. From Table 1, the maximum width of crack seems to be wider as the ditch become deeper.

In the case without GN, BMS layer occurred shear cracks at the bottom surface by local settlement. However, in cases of with GN, cracks and deformation occurred on the top surface of BMS layer by bending rather than shear failure.

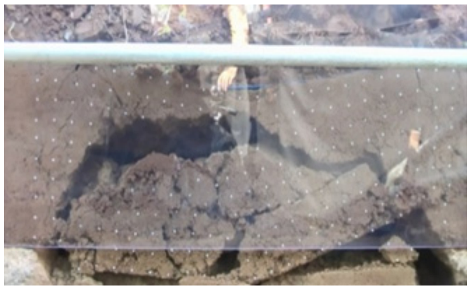


Figure 8 State of N248-20 on ditch width 1.20 m

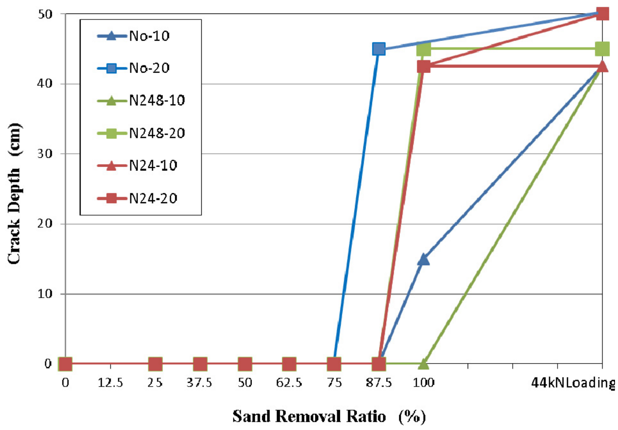


Figure 9 Progress of crack vs. Removal ratio of sand

Table 1 Summary of progress of the crack

Width of Ditch (m)	Sand removal Ratio(%)	The Crack Length from bottom of BMS layer					
		No-20	No-10	N248-20	N248-10	N24-20	N24-10
0.30	25.0	0	0	0	0	0	0
0.60	50.0	0	0	0	0	0	0
0.90	75.0	0	0	0	0	0	0
1.05	87.5	45	0	0	0	0	0
1.20	100.0	45	15	45	0	42.5	42.5
Loading 44kN		50	42.5	45	42.5	50	42.5
Angle of crack(Right,Left)		70,70	70,54	73,61	54,60	60,45	45,45
State of Surface of BMS	Max. Crack Width(mm)	40	10	60	8	20	10
	Settlement Width(mm)	1070	1130	1250	1300	1750	1280
	Max. Settle. Depth(mm)	180	90	195	80	195	110

Figure 9 shows a relationship between the removal ratio of sand and the progress of a crack from the bottom. It can be seen that as the ditch became deeper the crack appeared and progressed up to the top surface at lower removal ratio of sand. It is also found that the removal ratio of sand at of the crack appearing and progressing is larger in the model underlaid with a geonet than in the model without geonet.

TESTS ON INFILTRATION

Apparatus

Two types of cylindrical pipe made of HDPE with an inner diameter of 0.7 m and 0.3 m, and height of 0.95 m were used as a water tank. To measure the variation of water level in the pipe, a water level indicator shown in Figure 10 was made, which consists of perforated pipe with a diameter of 40 mm and a pole pasted on the surface with a tape measure having a diameter of 6 mm. The tip of the pole had a float made of expanded polystyrene having a diameter of 30 mm and a length of 70 mm.

Figure 10 A water level indicator

Testing sites

Nine testing sites were selected as shown in Figure 11. A large cylindrical pipe with an inner diameter of 0.7 m was used on site 1 to 5. A small cylindrical pipe with inner diameter of 0.3 m was used site A to D.

Among them, site 3 is the top surface of the BMS barrier system of which beneath no ditch was made, that is, between model N248-20 and model N248-10. Therefore, site 3 is a complete BMS barrier system.

The other eight (site 1, 2, 4, 5, A, B, C, D) are the sites where the BMS barrier system experienced some crack caused by local settlement tests. Site 1 and 2 situated on model No-10 that had no geonet and a ditch of 0.10 m deep, site 4 on model N248-10 that had geonet N248 and a ditch of 0.1 m deep and site 5 on model N24-10 that had geonet N24 and a ditch of 0.1 m deep are chosen such as the position where the width of crack recognized on the top surface was 1 mm or 2 mm.

Site A to D were chosen such as the position where the width of crack recognized on the top surface was more than 5 mm.

Procedures

A cylindrical pipe made of HDPE was stood on the testing site. Its bottom tip was buried into the BMS barrier system by about 50 mm. The space between the inner wall of the pipe and the BMS was filled up with putty as shown in Figure 12. A vinyl sheet was spread on the inner side of the pipe and on the top surface of the BMS barrier system. Then the pipe was filled with

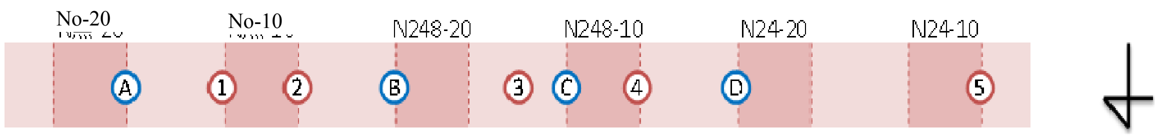


Figure 11 Schematic Drawing of Infiltration Sites

Φ700mm tank

Φ300mm tank

tap water. Water level indicator was stood in the pipe as shown in Figure 13, immediately after the vinyl sheet was removed. Change of the water level was noted with an elapsed time. The state of seepage around the pipe and/or beneath the BMS barrier system was observed.

Figure 12 Putty filled between wall and BMS

Figure 13 Setting a water level indicator

Results and discussions

Figure 14 shows variations of the water level with an elapsed time on 700mm diameter tank tests.

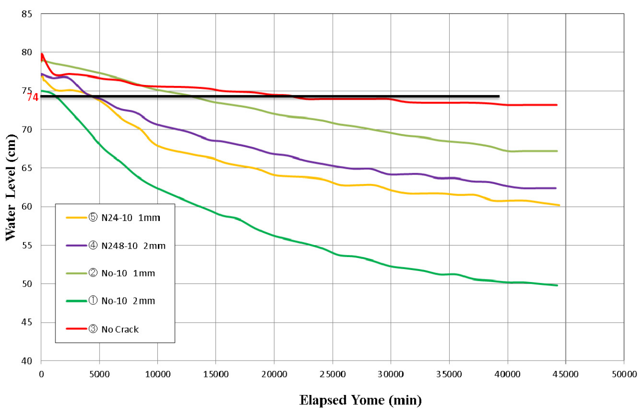


Figure 14 Variation of water Level on ϕ 700mm test sites

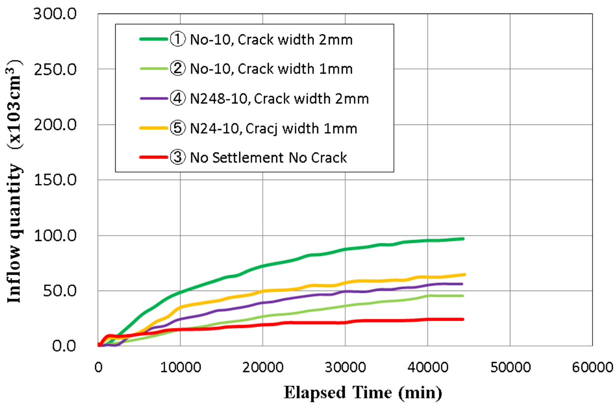


Figure 15 Variation of inflow quantity on ϕ 700mm test sites

Figure 15 shows a variation of the inflow quantity with an elapsed time on 700mm diameter tank tests, which was calculated by multiplying decrease in the water level by cross-sectional area of the pipe (=0.385 m^2).

In cases of site 1, site 2, site 4 and site 5, the inflow quantity shows almost stable beyond an elapsed time of about 44000 minutes (= 30days), though the inflow quantity at site 1 was largest and site 2 was the least. At these four sites, the width of the crack appeared on the top surface was less than 2 mm. At the all sites, it was also observed that the bentonite close to crack swelled to result in stopping the seepage through a crack.

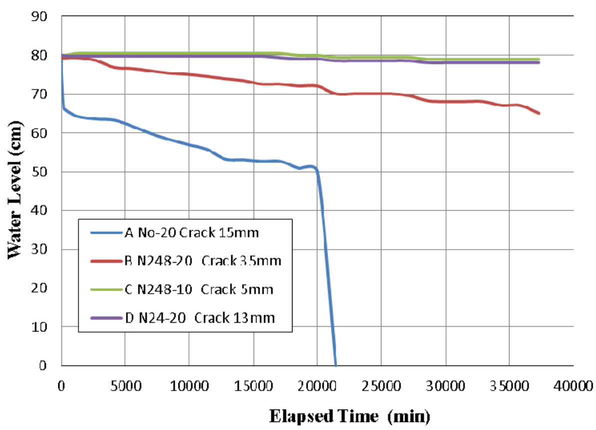


Figure 16 Variation of water Level on ϕ 300mm test sites

Figure 16 shows a variation of the water level with an elapsed time on 300mm diameter tank tests. In case of site A, the water level decreased rapidly until an elapsed time of 252 minutes. However, beyond an elapsed time of 252 minutes to until 20,000 minutes, the water level decreased gradually. And so, the water level decreased rapidly beyond an elapsed time of 20,000 minutes. This seems due to the fact that the water in the tank is frozen and melted.

From these facts, It is considered that as the crack did not pass through the BMS layer even if the width of the crack appeared on the top surface was as large as 5 mm, the permeation might stop by the swelling of the bentonite.

Relating to Figure 14, it is thought that the gradient of the water level as an elapsed time, that is Δh/Δt, is proportional to the hydraulic coefficient of the BMS layer and water head. Therefor a ratio of the gradient in case of cracked site to one in case site 3 under same water level may suggest a ratio of the hydraulic conductivities, called as permeability ratio.

Table 2 shows the gradient Δh/Δt under a water level of 74 cm. In the table, the permeability ratios are also listed. From the table, it is found that a permeability of BMS layer with cracks were several times higher than the complete section.

Table 2 Permeability ratio on water level 74 cm

Geonet	N24	N248	without	without	without
Depth of Ditch	10cm	10cm	10cm	10cm	none
Δh/Δt(nm/s)	150.4	92.5	40.5	253.6	13.3
Permeability Ratio	11.31	6.95	3.05	19.07	1.00

CONCLUSIONS

The main results of this study are summarized as follows:

(1) The crack appeared on the bottom surface of the BMS barrier system at the edge of the ditch and progressed upward at an angle of about 60 degree to the horizon.

(2) The BMS barrier system having deeper ditch occurred a crack at smaller removal ratio of sand.

(3) The testing sites underlaid with a geonet had also crack but did not progress to top surface, while the sites without geonet had a crack reaching the top surface.

(4) Drawdown stabilizes in about four weeks the start of the experiment, the crack were closed by bentonite swells when BMS layer top surface crack does not penetrates through to the bottom.

(5) Crack has penetrated, swelling of the bentonite cannot keep up with the seepage flow.

(6) Hydraulic conductivity of BMS layer crack occurs, large several times or more compared to the complete condition.

(7) From the above results, allowable settlement when there is approximately 1 m water level to BMS upper layer was considered to around 10cm when no underlaid with geonet to BMS bottom. Further, it was considered that about 20cm if it is underlaid with geonet.

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