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Laboratory Tests into the Permeability of Bentonite Liners

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ABSTRACT
Bentonite liners are widely used in geotechnical engineering such as landfills, reservoir and waterproofing. When bentonite is in touch with water, it swells and causes a significant increase of permeability. This paper reports a series of permeability tests on bentonite liners. Six samples could be tested independently. An experiment setup similar to the Rowe cell was used for the experiments. Two types of Bentonite mat were used in the experiments such as powder from and granular from. The experiments were made with and without 30kN/m^2 normal stress and the diameters were varied as 75mm and 150mm. The permeability was tested under different conditions such as, after wet and dry cycles, after freezing and thawing cycles, and in overlapping region of two bentonites. Moreover, the effect of punctures was investigated by testing liners with a hole of about 8 mm diameter.

1. INTRODUCTION

Bentonite is being used in combination with geosynthetics to form a composite commonly known as a geosynthetic clay liner (GCLs), which has been in use in the landfill construction since 1988 (Koerner, 1999). They are used as a hydraulic barrier and/or contaminant layer for leachate, either in place of a composite layer or in addition to other layers in bottom landfill lining system. A fully hydrated sodium bentonite layer has a hydraulic conductivity of approximately 100 times lower than a typical compacted clay liner (CCL). A single GCL of less than 10mm provides superior hydraulic performance than 1m of typical compacted clay (Andrejkovičová, et.al., 2008).

Geosynthetic clay liners (GCLs), are widely used in landfill applications and have been subject to considerable recent research (Southen and Rowe, 2005; Barroso et.al., 2006; Dickinson and Brachman, 2006; Hurst and Rowe, 2006; Bouazza and Vangpaisal, 2006; Touze-Foltz et al., 2006) and GCLs are extensively used as part of composite liners in landfills (Rowe, 2005; Bouazza et.al., 2008; Saidi et.al., 2008; Brachman and Gudina, 2008a and Brachman and Gudina, 2008b). The potential for shrinkage of GCLs has attracted considerable attention by (Thiel et.al., 2006; Bostwick et.al., 2007 and Bostwick et.al., 2008).

2. MATERIALS AND TESTING PROCEDURE

2.1 Bentonite Mat

The bentonite mat used in the experiments is a flat, thermally and mechanically connected geocomposite with a thin layer of bentonite / fiber mixture between two layers of embedded geotextile. Both of the layouts are made up of polypropylene fibers connected together with thermal reinforcement to obtain high connection effect and shear strength. The bentonite used here is sodium bentonite containing at least 70% montmorillonite.

Dry bentonite mat has about 7mm thickness. The standard roll is about 30 m long and 4.95 m wide with a maximum roll weight of about 1000 kg. The average mass of individual components of bentonite mat and the properties obtained from the manufacturer are given in Table 1. Bentonite in granular form was used in the experiments 3-7 and bentonite in powder form was used in Experiments 1 and 2.

Table 1. Average masses and properties of bentonite mat used in the experiments

Average masses of bentonite mat	
Texture	125 g/m^2
Bentonite / Fiber mixture	5000 g/m^2
Coating	200 g/m^2
Total weight	5300 g/m^2
Properties of bentonite mat	
k value (DIN 18130)	$\leq 5 * 10^{-11}$ m/s
Inner shear strength when dry (ASTM D-3083)	35°
Inner shear strength when wet (ASTM D-3083)	25°
Tension strength in lengthwise (DIN 53857/2)	≥ 12kN/m
Tension strength in transverse (DIN 53857/2)	≥ 12kN/m

2.2 Test Method

The testing device is a modified Rowe cell for permeability tests with falling hydraulic head. The hydraulic head of the samples can be read from standpipe. The pressure head is maintained constant. Some water need be refilled into the system because of the sinking head in standpipe with time. The period of time between refilling the standpipe gives rise to some variations in the gradient. For the control of ventilation in every possible time, all of the pipes are made from Plexiglas. By means of compressed air, additional load at the sample in the Rowe cell can be applied. The normal stress can be read from a manometer.

2.2.1 Bentonite Mat with Powder Form (Experiment 1 and Experiment 2)

The experiments were made without applying normal stress in Experiment 1 and with 30 kN/m^2 normal stress in Experiment 2. Six parallel tests were carried out. In Tests 1-3 specimens with a diameter of 75 mm and in Tests 4-6 specimens with a diameter of 150 mm were used. Circular sample pieces were cut from the bentonite mat. Later these pieces were air-dried and placed between two water saturated filter plates in a Rowe cell. After installation, the sample was saturated for about 72 hours. During this time, water flow through the closed gate valve was prevented. After this saturation phase, a hydraulic gradient of i=80 was applied and the gate valve was opened. Water flow through bentonite mat from top to bottom was initiated. During this testing period, the gradient was changed between i=40 and i=80. The height of the sample after testing was measured.

2.2.2 Bentonite Mat with Granular Form (Experiment 3)

The experiments were conducted with a normal stress of 30 kN/m^2. There were 6 parallel tests with Tests 1-3 on specimens with a diameter of 75 mm and Tests 4-6 on specimens with a diameter of 150 mm.

2.2.3 Permeability after Wet-Dry Cycles (Experiment 4)

The experiments were carried out to determine the permeability of totally dry bentonite mat, which was saturated under 50kN/m^2 normal stress. There were 3 tests with specimens of 150 mm in diameter. Circular sample pieces were cut from the bentonite mat. Later these pieces were air-dried and placed between two water saturated filter plates in a Rowe cell. The sample was saturated for about 48 hours. During this time, flow of the sample through the closed gate valve was prevented. After this saturation phase, the samples with filter stones from Rowe cells were enlarged and were dried nearly at a temperature of about 40°C in an oven. After 7 days, the weight became constant. The process was repeated. Totally 5 wet-dry cycles were performed between two saturated filter plates in the Rowe cell. The gradient was changed between i=70 and i=80.

2.2.4 Permeability after Freezing-Thawing Cycles (Experiment 5)

The experiments were carried to determine the permeability of bentonite mat after 1 to 6 freezing-thawing cycles under 50kN/m^2 normal stress. There were 6 parallel tests on specimens with a diameter of 75 mm. The test method is described in ASTM D5084. Circular sample pieces were cut from the bentonite mat and were air-dried before being placed between two saturated filter plates in a Rowe cell. The sample was saturated for nearly 48 hours. During this time, flow of the sample through the closed gate valve was prevented. After this saturation phase, the samples were taken out from the device and for this type of test, a water tank was installed. In this testing arrangement, 6 samples with a diameter of 75 mm were tested. The samples stayed for 48 hours in a freezing chamber and 48 hours in room temperature afterwards. The experiment time was about 14 - 42 days.

2.2.5 Permeability in Overlapping Region of Two Bentonites (Experiment 6)

The experiments were conducted to determine the permeability of two bentonite mats in overlapping region under 50kN/m^2 normal stress. There were 3 parallel tests on specimens with a diameter of 150 mm. Circular sample pieces were cut from the bentonite mat and a circle segment with a width of 2.5 cm was separated. Two of these sample pieces were used. In the overlapping region, a bentonite paste with a water content of 150% was used. The bentonite quantity is 87g/m in dry mass and the overlapping region is about 10 cm in width with 2.5 cm untreated strip in width. The samples stayed under a normal stress of 50kN/m^2 and saturated for 72 hours. During this time, flow of the sample through the closed gate valve was prevented. After this saturation phase, the hydraulic gradient of i=80 was applied. The gate valve was opened and flow through bentonite mat from top to bottom obtained. During this testing period, the gradient was changed between i=48 and i=80.

2.2.6 Self-sealing Capacity of a Hole (Experiment 7)

These experiments were carried out to determine the permeability of bentonite mat with a hole of 8 mm in diameter in the middle of the sample piece under a normal stress of 50 kN/m^2. There were 3 parallel tests on specimens with a diameter of 75 mm. Circular sample pieces were cut from the bentonite mat and a hole with a diameter of 8 mm was punctured centrally. These pieces were air-dried and placed between two saturated filter plates in a Rowe cell. The samples stayed under 30 kN/m^2 normal stress and saturated for 72 hours. During this time, flow of the sample through the closed gate valve was prevented. After this saturation phase, hydraulic gradient nearly i=80 was applied and the gate valve was opened and flow through bentonite mat from top to bottom obtained. During this testing period, the gradient was changed between i=48 and i=83.

3. RESULTS

The permeability test results of bentonite mate in powder form without and with normal stress (Table 2-3), bentonite mate in granular form with normal stress (Table 4), after wet-dry cycles (Table 5), after freezing-thawing cycles (Table 6), overlapping region of two bentonites (Table 7), and self-sealing capacity of a hole (Table 8) are given below:

Table 2. Results of permeability of bentonite mat without normal stress (Experiment 1)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	75	0	19.88	28.620	1.4	3.1 E-11
2	75	0	22.81	32.850	1.4	8.0 E-11
3	75	0	18.94	27.270	1.4	1.4 E-10
4	100	0	16.93	24.380	1.5	9.4 E-11
5	100	0	20.74	29.870	1.5	4.9 E-11
6	100	0	21.95	31.605	1.5	5.7 E-11

Table 3. Results of permeability of bentonite mat with 0.3 bar normal stress (Experiment 2)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	75	0.3	23.74	34.185	1.2	3.8 E-11
2	75	0.3	24.91	35.870	1.2	2.2 E-11
3	150	0.3	24.91	35.870	1.2	4.5 E-11
4	150	0.3	24.91	35.870	1.2	3.1 E-11
5	150	0.3	22.05	31.750	1.2	3.0 E-11

Table 4. Results of permeability of bentonite mat with 0.3 bar normal stress (Experiment 3)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	75	0.3	27.96	40.260	1.2	1.6 E-11
2	75	0.3	27.96	40.260	1.2	1.6 E-11
3	75	0.3	25.80	37.155	1.2	9.5 E-12
4	150	0.3	27.96	40.260	1.2	2.4 E-11
5	150	0.3	27.96	40.260	1.2	9.6 E-12
6	150	0.3	27.96	40.260	1.2	1.3 E-11

Table 5. Results of permeability tests after wet-dry cycles (Experiment 4)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	150	0.5	25.94	37.350	1.1	2.0 E-11
2	150	0.5	25.94	37.350	1.1	1.3 E-11
3	150	0.5	25.94	37.350	1.1	1.7 E-11

Table 6. Results of permeability tests after freezing-thawing cycles (Experiment 5)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	75	0.5	13.93	20.055	1.1	6.2 E-12
2	75	0.5	16.85	24.270	1.1	4.0 E-12
3	75	0.5	15.99	23.025	1.1	1.4 E-11
4	75	0.5	42.06	60.570	1.1	2.0 E-11
5	75	0.5	35.02	50.425	1.1	2.5 E-12
6	75	0.5	30.95	44.565	1.1	4.2 E-12

Table 7. Results of permeability of two bentonites in overlapping region (Experiment 6)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	150	0.5	16.85	24.270	1.2	4.4 E-11
2	150	0.5	24.08	34.680	1.2	4.5 E-11
3	150	0.5	27.01	38.985	1.2	3.0 E-11

Table 8. Results of self-sealing capacity of a hole (Experiment 7)

Test no	φ (mm)	σ (bar)	Testing time D	mm	hp (cm)	k value (m/s)
1	75	0.5	31.94	45.990	1.1	4.7 E-11
2	75	0.5	31.94	45.990	1.1	6.6 E-11
3	75	0.5	31.94	45.990	1.1	6.0 E-11

4. CONCLUSIONS

- When bentonite is in touch with water, it swells and causes a significant increase of permeability. The results of a series of permeability tests on bentonite liners were given above and the mean and maximum values of k values in experiments are given in Table 9 below:

Table 9. The mean and maximum values of k values in the experiments

Experiment no	Mean value	Maximum value
Experiment 1	7.52E-11m/s	1.40E-10m/s
Experiment 2	3.32E-11m/s	4.50E-11m/s
Experiment 3	1.47E-11m/s	2.40E-11m/s
Experiment 4	1.67E-11m/s	2.00E-11m/s
Experiment 5	8.48E-12m/s	2.00E-11m/s
Experiment 6	3.97E-11m/s	4.50E-11m/s
Experiment 7	5.77E-11m/s	6.60E-11m/s

- As seen from Table 9 above, the obtained k values showed little variation for all these conditions when compared with the permeability of bentonit used in the experiments ($\leq 5*10^{-11}$ m/s).
- The maximum permeability was measured and the differences between the k values were the maximum where the bentonite liners were tested without normal stress in experiment 1.
- Another advantage is the self-healing capacity of the sodium bentonite with regard to damage caused by construction works.

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