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The influence of the drainage particle contact area on soil-nonwoven geotextile filtration behavior

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ABSTRACT: Seepage rate and clogging potential assessments for a soil-geotextile filtration system are presented in this paper. An ASTM Gradient ratio test apparatus was modified to carry out the tests. A drainage layer formed by steel beads was placed at the downstream of a geotextile to simulate the granular drainage layer in the field. The experimental results show: (1) For the steel bead sizes used in the experiment, the lower the opening area, the lower the flow seepage rate. However, the final flow seepage rate was not proportional to the opening in the interface between the geotextile and steel beads. (2) When steel beads were used to form the downstream drainage layer, the clogging potential increased with the reduction in the open area between the geotextile and drainage material, indicating that a 100 % opening underestimates the clogging potential of the filtration system. (3) Beads of different sizes can be formed into drainage layers with the same sized open area; however, the GR values exhibit minor changes when the size of the open area remains the same.

1 INTRODUCTION

A filtration system is composed of several layers of different sized granular particles downstream of the soil to prevent excess soil particle loss and allow a proper degree of water flow. In recent years, geotextiles have been used widely as a substitute for mineral aggregate in filtration applications. Geotextiles are placed beneath rig-rap to replace several granular filter layers in erosion control for inland waterways or coastal erosion protection (John, 1987). Geotextiles wrapped around free-draining stone or aggregate to form a trench drain channel in drainage applications is one of the typical applications (Fig. 1). However, being much thinner than a granular filter, synthetic filters require careful assessment of their retention performance (to prevent excess soil loss) and clogging (to allow the proper degree of water flow) associated with their use. When experimental approach is used as the basis for design methodologies or as a performance evaluation of site-specific soil, comprehensive simulation of the field boundary conditions becomes essential in ensuring the applicability of the test results.

The gradient ratio test is one of the methods used in the laboratory for evaluating the clogging potential of a soil-geotextile system. A screen beneath the geotextile is used in the ASTM type apparatus to support the soil and geotextile specimen. Because cross sectional areas of mesh wire are very small and water will flow through the screen support without restraint, the test set-up arrangement can be interpreted as a free drain condition downstream of the geotextile. However, in most of the previously mentioned engineering applications, a layer or full granular particle space is placed downstream of the geotextile to act as a protective cushion or drainage channel (Fig. 1). The geotextile has direct contact with the granular particles so that the contact areas could reduce the number of pores for water flow. Flow channel blocking by the downstream particles may alter the flow direction and/or deter fine particles from passing through the geotextile specimen. A test set-up modification to assess the flow rate and clogging potential of the soil-geotextile filtration system due to the downstream blocking effect is the central aim of this paper.

The drainage layer consists of steel beads instead of a support screen. These beads were placed underneath the geotextile specimen to simulate drainage aggregates. The boundary of the filtrameter is similar to field conditions, allowing the flow rate and clogging potential of a soil-geotextile filtration system to be monitored properly. A schematic diagram of the apparatus is shown in Fig. 2

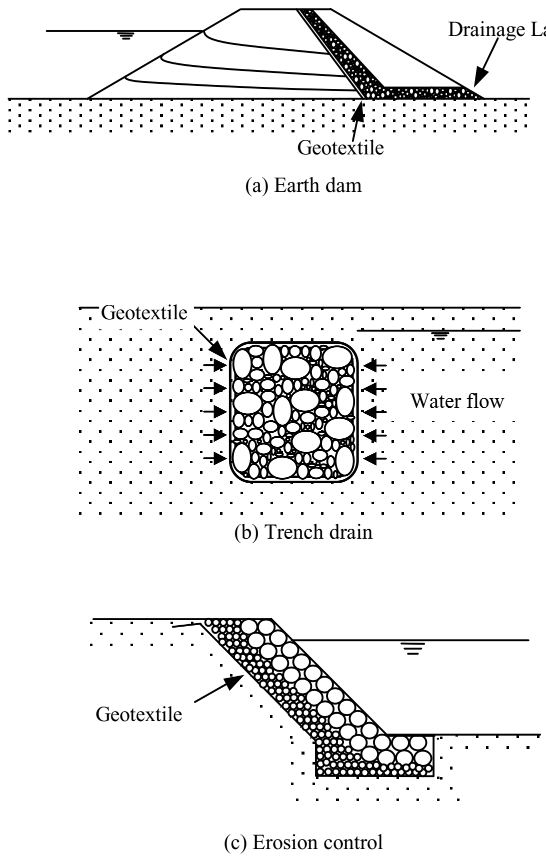
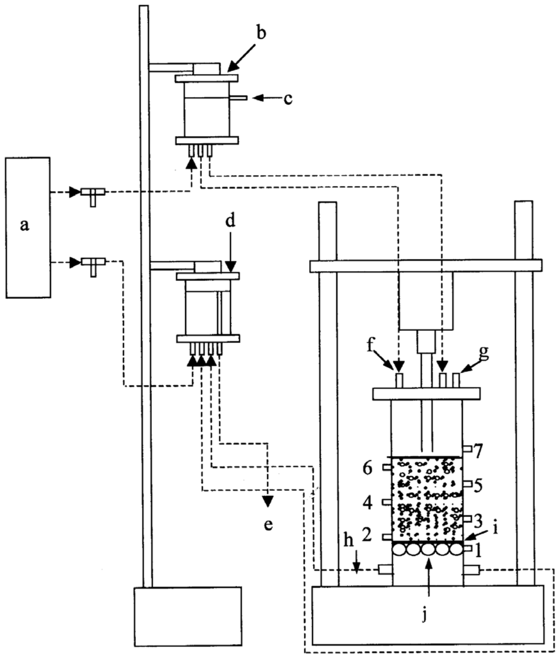


Figure 1. Geotextile in filtration and drainage applications



a	water supply	f	water inlet
b	inflow CHD	g	vent valve
c	water out flow port	h	water outlet
d	outflow CHD	i	geotextile
e	water outflow port	j	steel beads

Figure 2. Schematic diagram of test apparatus

Table 1. Particle size distribution data

Sieve No.	4	10	20	40	60	100	170	200	pan
Size(mm)	4.76	2.00	0.84	0.42	0.25	0.149	0.088	0.074	0
Percent passing by weight(%)	100	90	65	45	30	20	15	13	0

Table 2. Properties of geotextiles

Geotextile	I	II
Polymer	Polyester	
Fabric	Needle punching method	
Unit density (g/m^2)	250	450
Thickness (mm)	1.4	2.5
Permeability (cm/sec)	0.1	0.08

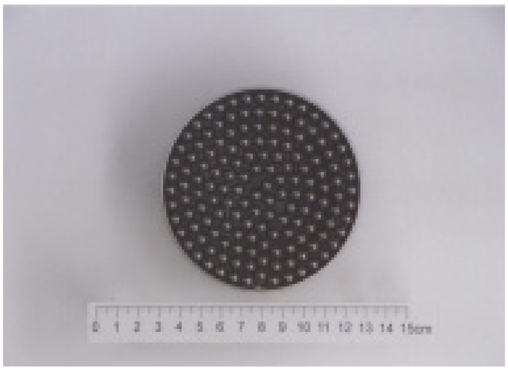


Figure 3. Drain layer of 7-mm steel beads

Table 3. Details of filtration test

Test	Bead diameter (mm)	Opening rate (%)	i=1				i=5			
			I_{if}	I_{pf}	GR/GR_{100}	Q/Q_{100}	I_{if}	I_{pf}	GR/GR_{100}	Q/Q_{100}
R 1-1	7	30	0.58	0.56	1.33	0.48	0.65	0.64	1.26	0.38
R 1-2	11	50	0.58	0.56	1.28	0.58	0.69	0.67	1.21	0.46
R 1-3	14.2	68	0.68	0.66	1.19	0.74	0.74	0.73	1.11	0.66
R 1-4	15.85	68	0.65	0.61	1.20	0.71	0.72	0.72	1.12	0.66
R 1-5	19	64	0.67	0.63	1.23	0.71	0.72	0.68	1.16	0.59
R 1-6	25.4	82	0.72	0.68	1.14	0.84	0.77	0.74	1.08	0.80
R 1-7	31.8	68	0.64	0.62	1.21	0.68	0.73	0.72	1.16	0.65
R 1-8	–	100	0.76	0.72	1.0	1.0	0.81	0.79	1.0	1.0
R 2-1	7	30	0.50	0.46	1.35	0.48	0.66	0.63	1.19	0.37
R 2-2	11	50	0.54	0.52	1.25	0.60	0.68	0.66	1.15	0.50
R 2-3	14.2	68	0.63	0.59	1.14	0.80	0.72	0.69	1.08	0.69
R 2-4	15.85	68	0.61	0.58	1.16	0.76	0.71	0.69	1.09	0.66
R 2-5	19	64	0.60	0.58	1.22	0.72	0.70	0.68	1.10	0.60
R 2-6	25.4	82	0.64	0.62	1.11	0.84	0.74	0.70	1.06	0.77
R 2-7	31.8	68	0.61	0.58	1.18	0.76	0.70	0.69	1.09	0.64
R 2-8	–	100	0.64	0.64	1.0	1.0	0.79	0.77	1.0	1.0

2 TEST PROGRAM

2.1 *Soils used for the tests*

The soil used had a specific gravity of G_s=2.68, density of ρ= 1.786 g/cm^3, d_{50}= 0.5 mm, e_{max}= 0.638, e_{min}= 0.395, with the particle size distribution data shown in Table 1.

2.2 *Geotextiles*

Two needle-punched nonwoven geotextiles made of polypropylene were used as the filter. The properties provided by the manufacturer are shown in Table 2.

2.3 *Steel beads used to simulate drainage aggregate*

Single-sized steel beads were bonded together and encircled by a 96 mm diameter steel ring to form the drainage layer, as shown in Fig. 3. The geotextile specimen was then placed above the drainage layer and attached to the filtrameter. Steel beads with 7 mm, 11 mm, 14.2 mm, 15.85 mm, 19 mm, 25.4 mm, and 31.8 mm diameters were chosen in this test program to simulate various drainage material sizes. Under the soil filled in the filtrameter, the open areas between the beads and geotextile were 30 %, 50 %, 68 %, 68 %, 64 %, 82 %, and 68 %, respectively. An unfended steel ring used to make the opening rate 100 % was adopted to simulate the free drain condition. Specific details, together with some test results are given in Table 3. The contact areas between the geotextile and steel beads were measured by placing a piece of the specimen on top of painted steel beads. Under the soil specimen load, the geotextile was imprinted at the contact areas. The open area was obtained by subtracting the painted areas from the total circular area. The opening rate was defined as the ratio between the open and total areas.

In the table, I_{if} and I_{pf} are indexes used to evaluate the flow changes between the initial and final stages and between the peak value and final stages, defined by

$$I_{if} = \frac{Q_f}{Q_i} \quad (1)$$

$$I_{pf} = \frac{Q_f}{Q_p} \tag{2}$$

where Q_f, Q_i and Q_p are the system flows at the final, initial stage and peak, respectively.

3 EXPERIMENTAL TEST RESULTS

3.1 *Flow rate of the filtration system*

Hydraulic gradients of 1 and 5 were applied to the filtration system. Tests were terminated at 120 hours of elapsed time as the flow rates reached relative equilibrium values for the tests.

At the beginning of the tests, fine particles carried out by the flow can be seen by the turbidity of the outflow water. About 30 minutes later, the flow rates reached peak values and then gradually decreased. Typical flow rate curves with the elapsed time are shown in Fig. 4. Experimental results reveal that the final flow rates of the filtration system increased with increased opening rate percentage as shown in Figs. 5 and 6. However, the relationships between the flow rate and opening rate for both needle-punched nonwoven geotextiles were not linearly proportional. The flow change indexes, I_{if} and I_{pf}, decreased with decreasing opening rate, signifying that steel beads significantly deter the outflow water (Figs. 7 and 8).

3.2 *GR values*

The GR values of the experimental tests are presented in Fig. 9. The ratios of GR values between drainage layers and free drain

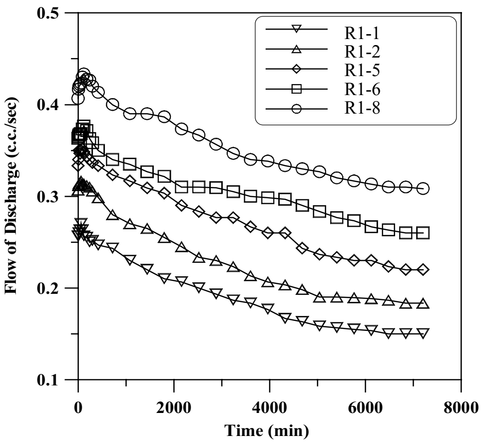


Figure 4. Flow rate of drain layer with geotextile 1

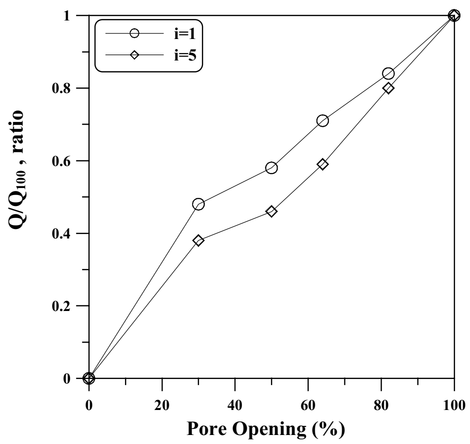


Figure 5. Flow rate vs. opening rate (geotextile 1)

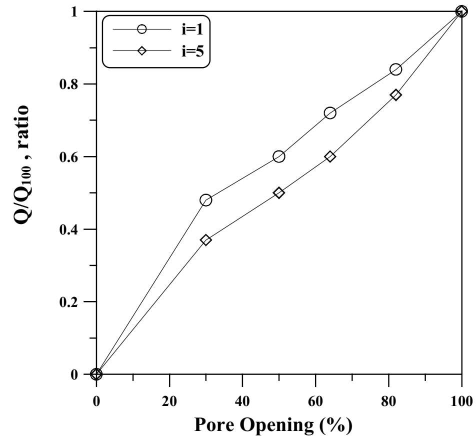
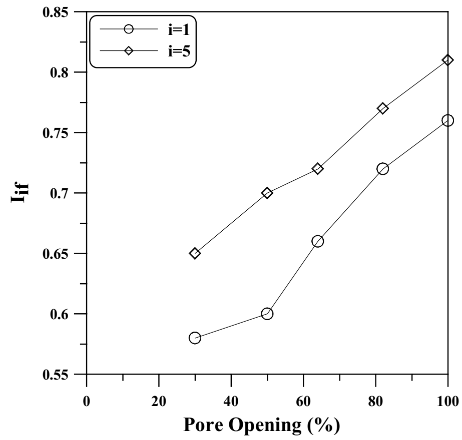
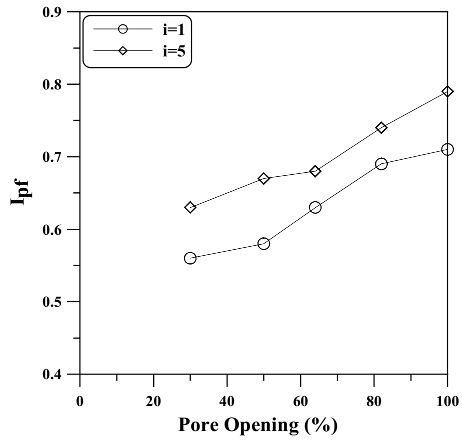


Figure 6. Flow rate vs. opening rate (geotextile 2)



(a) I_{if}



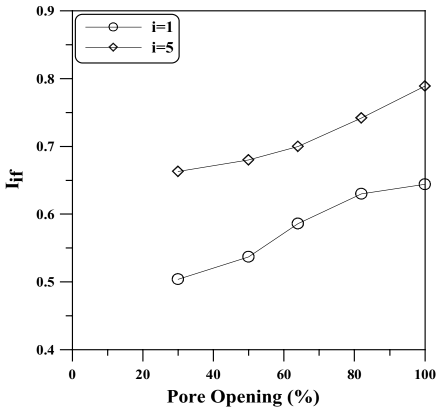
(b) I_{pf}

Figure 7. Flow change index vs. opening rate (geotextile 1)

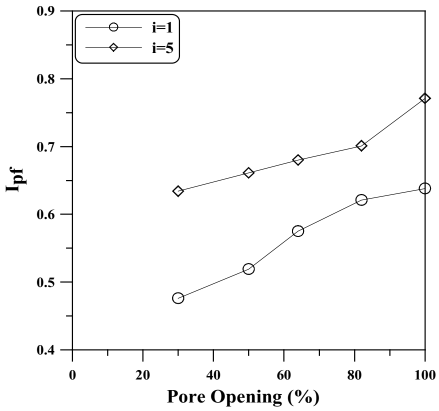
are shown in Fig. 10. The test results reveal that the GR values increase as the percentage of blocked flow channel area increases. This indicates that the steel beads increase the clogging potential of a soil-geotextile filtration system.

3.3 *Different bead sizes having the same opening rate*

In the formation of a drainage layer, the beads fitted into the steel ring must be whole, so that 14.2, 15.85, and 31.8 mm diameter beads will form the same opening rate of 68 %. The experimental results revealed that the discrepancy in the flow rates and flow change indexes I_{if} and I_{pf} among the three bead sizes is insignificant. The GR values for both tested geotextiles

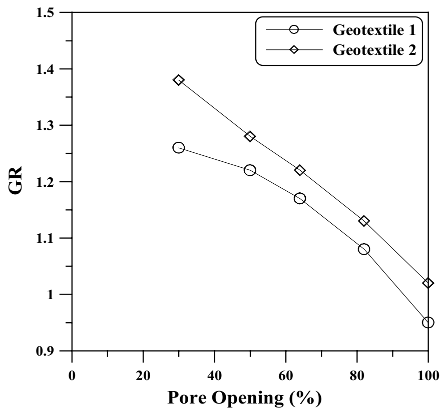


(a) I_{if}

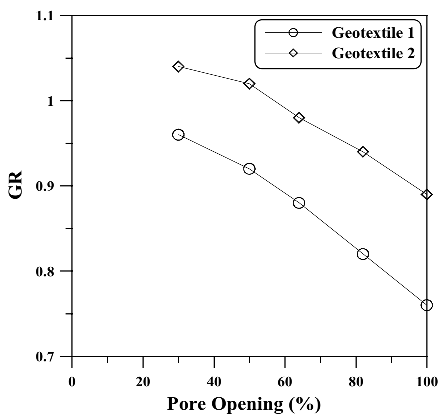


(b) I_{pf}

Figure 8. Flow change index vs. opening rate (geotextile 2)



(a) i=1



(b) i=5

Figure 9. GR values vs. opening rate

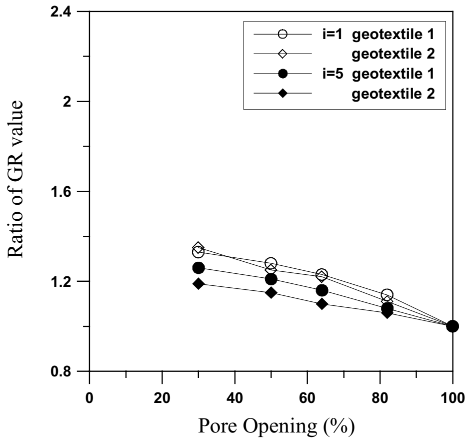


Figure 10. Ratios of GR values between drainage layers and free drain condition

with different hydraulic gradients have less than a 2 % variation among the filtration systems formed using three different bead sizes. This phenomenon indicates that the clogging potential of the filtration system is influenced by the pore opening rather than by the bead size.

4 CONCLUSIONS

The experimental results show: (1) A drainage layer formed by steel beads deters the water flow and the lower the open area the lower the flow seepage rate. However, the final flow seepage rate is not proportional to the open area in the steel bead-geotextile interface for the steel bead sizes used in this experiment. (2) When steel beads are used to form a downstream drainage layer, the clogging potential increases with the reduction in the open area, indicating that a 100 % open experimental result underestimates the clogging potential of a filtration system. (3) Beads with different sizes can be formed into drainage layers with the same open area; however, the GR values and flow rates will have only minor changes as long as the open area remains the same. This shows that the open area instead of the bead size should be the main concern in assessing the clogging potential and flow rate of a filtration system.

5 REFERENCES

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