Permeability reduction of soil-geotextile system induced by clogging

Rédution de perméabilite de systerne de soil-geotextile induite en obstruant

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ABSTRACT: The permeability reduction in the soil-filter system due to the clogging phenomenon is evaluated. An extensive research program is performed using two typical weathered residual soils which are sampled at Shinnae-dong and Poi-dong area in Seoul. Two separate simulation tests with weathered residual soil are performed: the one is the filtration test (cross-plane flow test); and the other is the drainage test (in-plane flow test). Needle punched non-woven geotextiles are selected since it is often used as a drainage material in the field. The compatibility of the soil-filter system is investigated with emphasis on the clogging phenomenon. The hydraulic behaviour of the soil-filter system is evaluated by changing several testing conditions. Also, experimental results of the permeability reduction are compared with the results obtained from the theoretical model which can monitor the spatial variation of the permeability with time.

RĚSUMĚ : La réduction de perméabilite du systeme de sol-filtre du au phénoméne obstruant est évaluée. Un programme de recherche étendu est éxecuté en utilisant deux sols résiduels superficiels par les agents typiques qui sont échantillonnés à la region de Shinnae-dong et de Poi-dong à Seoul. Deux essais de simulation séparés par la direction de ecoulement dans le system de sol-filtre sont réalisés: celui est l'essai de filtration (essai d'écoulement tranversale) et l'autre est l'essai de drainage (essai d'écoulement longitudinale). Des geotextiles non-tisses perforés par aiguille sont choisis puisqu'elle est souvent utilisée comme materiel de drainage dans le domaine. La compatibilite du systeme de sol-filtre est étudiée avec l'accent sur le phénomène obstruant. Le comportement hydraulique du systeme de sol-filtre est évalué en changeant plusieurs conditions d'éxecution. En outre, des résultats éxperimentaux de la réduction de perméabilite sont compares aux resultats obtenus a partir du modele theorique qui peut surveiller la variation de la coefficient de perméabilite avec du temps.

1. INTRODUCTION

Main function of the geotextile is to protect fine particles being transported from the base soil and to relieve the excess pore water pressure induced by movement of fine particles. When a geotextile which is installed for drainage purpose is clogged or piped, these may lead to instability of geotechnical structures such as tunnel, retaining wall, and dam. To evaluate filter efficiency in geotechnical area, soil characteristics should be figured out in advance. In this research, Korean weathered residual soil is selected as test material because this soil is most frequently encountered in the Korean peninsula. In this research, experimental study is performed to evaluate hydraulic behavior and particle transport in a soil-geotextile system caused by the cross-plane flow as well as the in-plane flow. Also, a model is proposed to simulate particle transport and permeability reduction phenomenon in the soil-geotextile system due to clogging.

2. TEST APPARATUS AND MATERIALS

The in-plane permeameter used in this test was a modified one to the in-plane permeameter described by ASTM test standard D4716. A simplified schematic diagram of the test equipment and setup is presented in Figure 1. By utilizing the water head regulator, different hydraulic gradients can be applied to each of the soil samples located in cells. Manometer ports that are located at the side and at the bottom of cell are used to monitor the pressure head distribution at six locations. The spacing between ports 1 and 2 is 70 mm and port 3 is 80 mm away from port 2. Ports 4, 5 and 6 are located at, respectively, 20 mm, 40 mm, 80 mm above the top surface of geotextile. The soil sample is divided into three cells. The cross-plane permeameter, illustrated in Figure 2, consists of one cell with a 60 mm × 80 mm cross section and 150 mm in height. The spacing of each manometer is 20 mm apart to compare with the results of the in-plane permeameterTest samples were obtained from Shinnae-dong and Poi-dong in Seoul. Each of the samples represents typical weath-

Table 1. Properties of soil sample

Soil sample	Shinnae-dong	Poi-dong
O.M.C (%)	10	16
Porosity	0.358	0.409
$\gamma_{d(max)}$(kN/m^3)	18.64	16.68
Percent passing #200 sieve (%)	14.23	47.36
G_s	2.65	2.74
USCS	SW-SM	SC

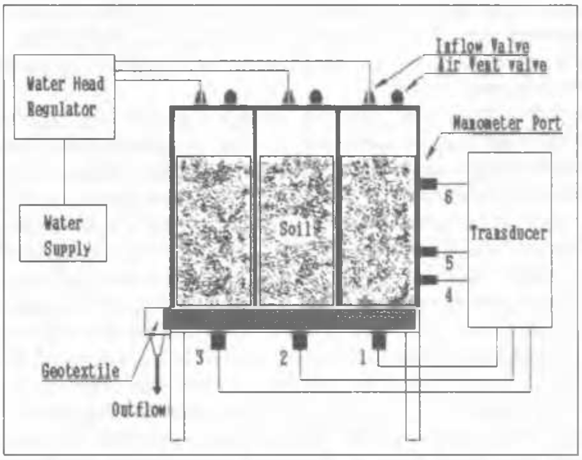


Figure 1. Schematic diagram of the in -plane permeameter test

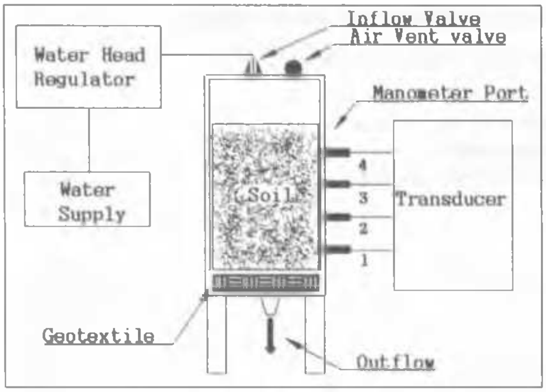


Figure 2. Schematic diagram of the cross-plane permeameter test

ered residual soil type in Korea. Laboratory experiments were performed. The results for each test are shown in Table 1. (Park, 1999) The particle size distribution curve was determined through wet sieve analysis and hydrometer test, and the results are illustrated in Figure 3.

3. PROPOSED MODEL

A series permeability reduction model is developed by modifying the reduction model proposed by Reddi et al. (2000) to simulate the permeability reduction in the soil-filter system with respect to space as well as time. As shown in Figure 4, the filter layer is divided into three elements along the flow path assuming one-dimensional (in-plane) flow problem. Each of the geotextile-filter is subject to the different pressure head. By analyzing the depositions of fine soil particles contained in influent which is eroded from the base soil, the effluent concentration out of the filter is computed. C_{o1} is the influent concentration for the filter element 1 and the calculated effluent concentration C_{o11} becomes the influent concentration for the next filter element 2 along with the concentration C_{o2} coming from the base soil. For the filter element 3, the same procedure is carried on as shown in Figure 4

4. LABORATORY TEST RESULT

Two types of nonwoven geotextiles which are most widely used in drainage and filtration applications are chosen for this study. The first one denoted NP-1 in this paper was thinner and had a smaller mass per unit area than the other one called NP-2. The basic characteristics of geotextiles used are listed in Table 2. A theoretical method proposed by Faure et al. (1986) was used to calculate the pore size distribution with the change of geotextile thickness. The results are presented in Figure 5 with their respective opening size. The O_{95} could decrease up to, respectively, 22.74% and 45.18% by the compressive strain of 33.76% and 61.03% in case of the NP-1.

The transport of fine particles through the base soil matrix during drainage may influence the variation of pressure along the soil sample height and the geotextile filter. So, the pressure head distributions obtained from testing results are compared to the ideal case that the pressure head decreases linearly with depth. As illustrated in Figure 6 (a), pressure distribution along the soil sample height is similar to the typical one which shows the clogging/blinding phenomenon in the soil-geotextile system in case of the cross-plane flow. The gradient ratio calculated using the measured pressure value from port 1, port 4, and port 6 is 1.5 at equilibrium state. This value indicates that test result belongs to zone 2 in Figure 6 (b). It can be judged that the clogging or blinding effect occurs in the Shinnae-dong soil-filter system. Also, the zone of clogging or blinding is extended into the base soil with time.

Table 2. Properties of geotextiles tested

Properties	NP-1	NP-2
Denier	4.50	5.45
Density	1.38	1.37
Permeability in cross-plane(cm/sec)	0.36	0.42
Transmissibility (m^2/sec)	2.0×10^{-5}(10kPa) 1.1×10^{-5}(300kPa)	2.8×10^{-5}(10kPa) 1.9×10^{-5}(300kPa)
A.O.S (μm)	75	50
Mass (g/cm^2)	300	600

Figure 7 (a) and (b) show the permeability reduction curves of each experimental result. The figure shows that the tendency of permeability reduction increases as the applied hydraulic gradient increases. For the Poi-dong soil-filter system, the curves of permeability reduction ratio are similar to those for the Shinnae-

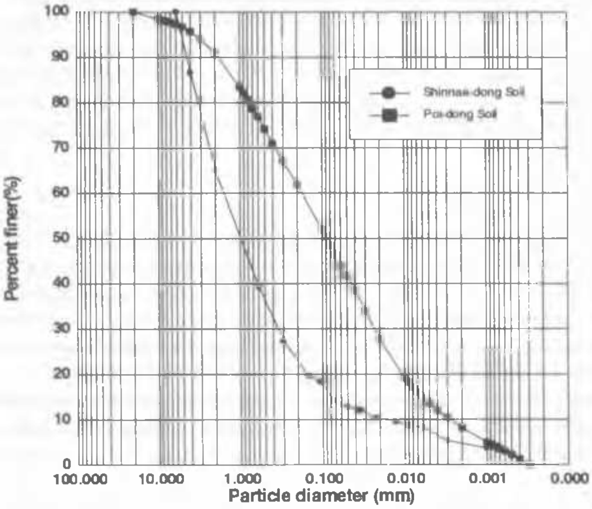


Figure 3. Particle size distribution curve for tested materials

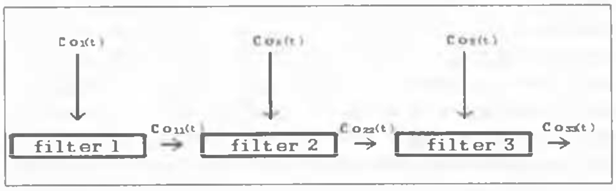


Figure 4. Schematic of filter elements

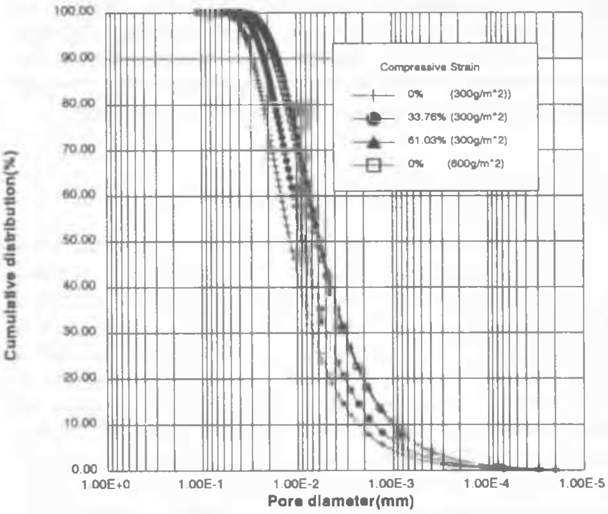
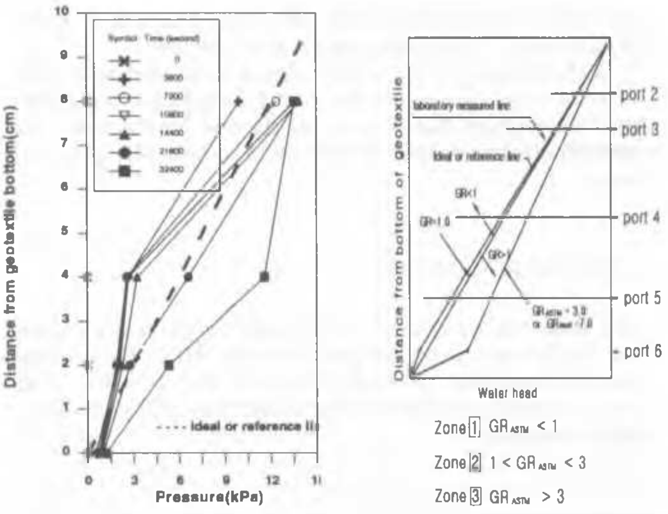


Figure 5. Pore size curves of geotextile filter with variation of compressive strain



(a) (b)

Figure 6. Pressure variation along the sample height: (a) Pressure variation in the Shinnae-dong soil-filter system; (b) Schematic unified interpretation of the gradient ratio test

dong soil-filter system under the variations of hydraulic gradients. However, the permeabiliy reduction was much less. It means that the Shinnae-dong soil-filter system is more liable to clogging or blinding which could be the cause of the decrease of permeability.

The permeability reduction of the soil-filter system in filtration is evaluated as shown in Figure 8 (a) and (b). The behaviour of filtration and anisotropy of the geotextile filter can be investigated by comparing with the test result of the in-plane flow. The permeability reduction ratios of each experimental test show a tendency to decrease with increasing pressure head. The permeability reduction of the cross-plane flow becomes more significant compared to the in-plane flow. The figures show that due to the anisotropy of geotextile filters (smaller permeability in the cross-plane flow), the clogging or blinding phenomenon is more significant in the cross-plane flow. This phenomenon is even more serious in the Poi-dong soil-filter system as shown in Figure 8 (b).

Permeability reduction curves predicted by the proposed model are shown in Figure 9 and 10. Three curves of permeability reduction ratio with time, for each of three elements, are presented to show the spatial variation of the particle transport and deposition process. Model prediction shows that most soil particles are accumulated at the last (third) element of the geotextile filter; most particles pass through the filter element 1 and 2 and deposition occurs at the filter element 3 since the rate of the particle accumulation is higher than that of the particle transport within the filter element 3, specifically at higher hydraulic gradient. The figures also show that the permeability reduction ratio at the element 2 approaches to that of the element 3 as the hydraulic gradient is lower. It means that the lower the hydraulic gradient, the shorter does the soil particle move.

5. CONCLUSION

The conclusion of this study can be summarized as follows :

1) The Shinnae-dong soil shows the higher erodibility than the Poi-dong soil. This is most likely due to the fact that the Shin-

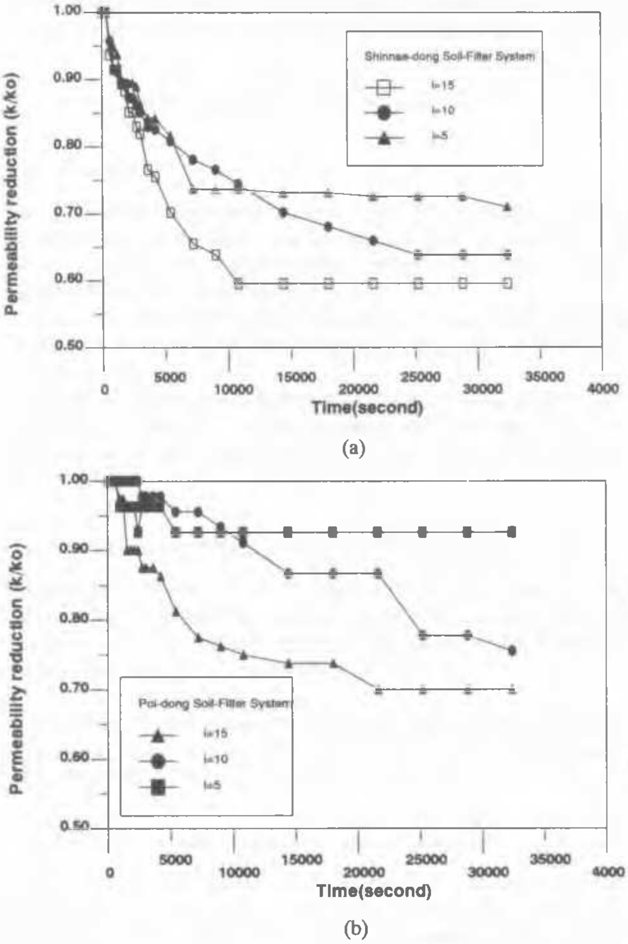


Figure 7. Permeability reduction curves of the in-plane flow: (a) Shinnae-dong soil-filter system; (b) Poi-dong soil-filter system

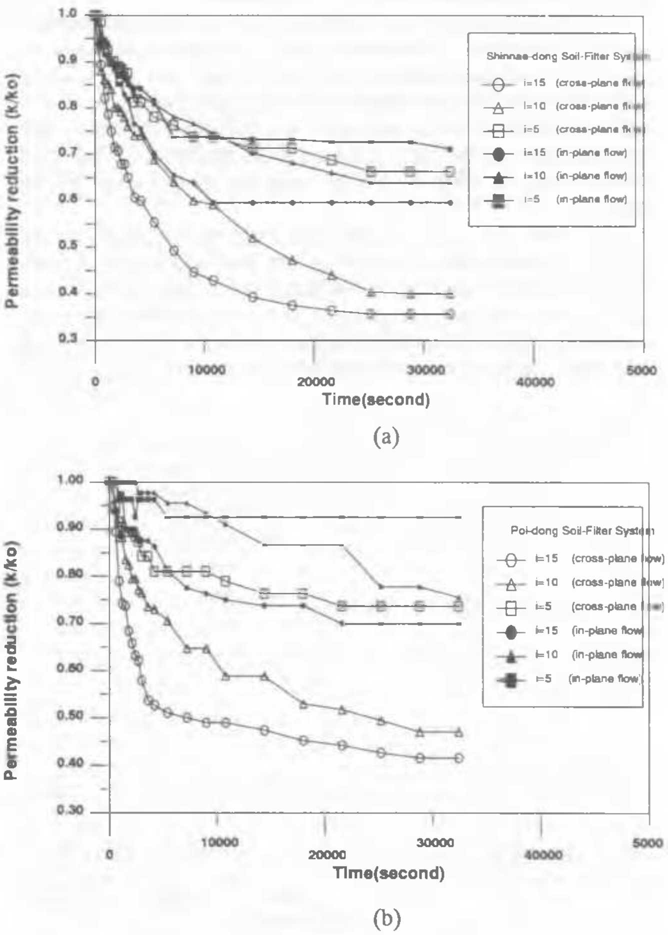


Figure 8. Permeability reduction curves: (a) Shinnae-dong soil-filter system; (b) Poi-dong soil-filter system

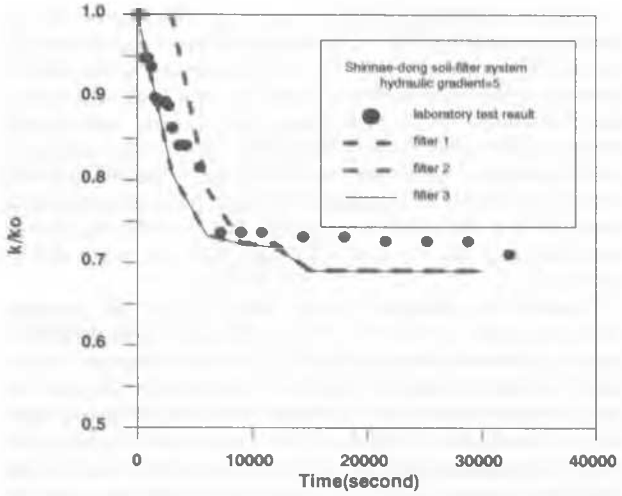


Figure 9. Comparisons of experimental results with model predictions(i=5)

nae-dong soil, which behaves as single grained structures, is unstable; Poi-dong soil is more stable by the nature of cohesiveness. Therefore, the permeability reduction in the Shinnae-dong soil-filter system was more significant than the Poi-dong soil-filter system.

2) The particle transport and the hydraulic behaviour of the soil-filter system are controlled by several factors: the erosion rate of the base soil, the deposition process in the filter, the interaction between soil particle and pore structure of filters and the applied hydraulic gradient. Expecially in the in-plane flow, the particle transport and deposition along the filter is the critical factor affecting the behaviour of the soil-filter system.

3) With the increase of the hydraulic gradient, the permeability reduction increases. The retaining ratio, the gradient ratio and the generated residual pressure both in the filter and the soil are found to be key factors to identify the clogging potential.

4) In case of the Shinnae-dong soil, the maximum erodible particle size that can be transported from the base soil ranges from 450 to 500μ m. That in the Poi-dong soil ranges from 180 to 200μ m.

5) The particles larger than the maximum pore diameter of the filter will accumulate on the top of the filter and induce a blinding. The ratio of these coarse particles to the total soil particles deposited in the filter ranges from 20% to 40%. Blinding effect was more significant in the filtration test than in the drainage test.

6) Filter clogging was more significant in filtration than in drainage. It is due to anisotropy in the filter structure and in the mobilization tendency of the fine particle along the filter.

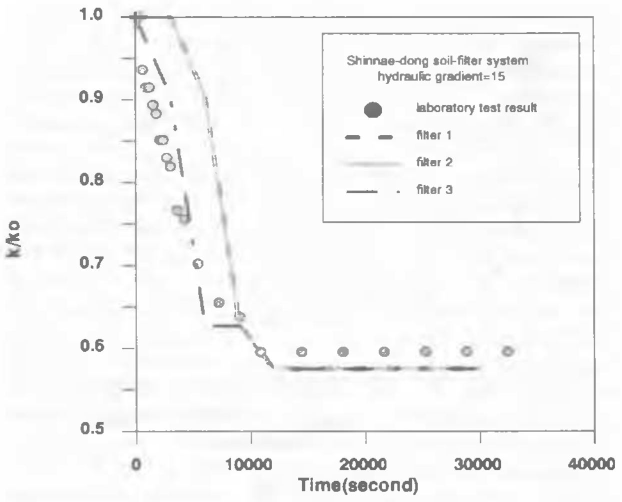


Figure 10. Comparisons of experimental results with model predictions(i=15)

7) Model prediction fits the experimental result reasonably well. At initial time, the permeability at each filter section was different. The clogging mostly occurs at the last filter section. The permeability comes close of each filter section with elapse of time.

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