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# Analysis of Filter Clogging in Drainage Tunnels
# 풍화 잔류토의 유동이 터널 배수재의 폐색에 미치는 영향 연구

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**개 요** : 본 논문에서는 실내에서 실시한 Filtration실험을 통하여 지하수 흐름하에서 이탈한 풍화 잔류토의 세립자가 흙-토목섬유 복합체를 통과하면서 발생하는 이동 (Transportation), 퇴적 (Deposition), 그리고 폐색 (Clogging)되는 과정을 분석하였다. 본 연구에서는 한국의 풍화 잔류토에 적합한 토목섬유 배수재의 새로운 설계기준을 제시함으로써 풍화 잔류토상에 축조되는 터널 구조물 시공시 광범위하게 사용되고 있는 토목섬유재인 부직포의 투수 및 배수특성과 세립토사에 의한 폐색 (Clogging)영향을 분석할 수 있게 되었다.

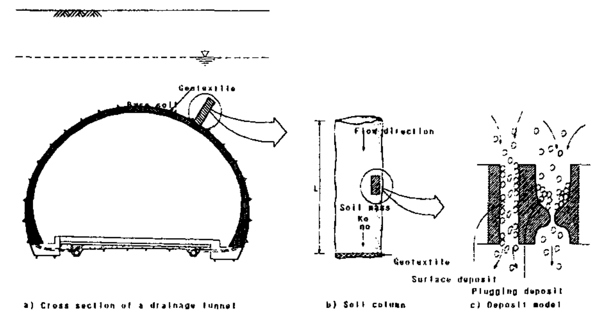
**주요어** : 토립자 유동, 한계 전단 응력, 토립자의 이탈, 이동, 집적, 폐색

## 1. Introduction

The objectives of this research are to evaluate hydraulic behavior and particle transport and filtration performance of the composite system of the weathered residual base soil and nonwoven geotextile filter layer, and to propose a new filter design concept for nonwoven geotextile which is used as filter (or drainage) material for a drainage tunnel in weathered residual soils.

The functions of filtration and drainage of geotextiles involve the movement of liquid through the geotextile itself. At the same time, the geotextile serves the purpose of retaining the soil on its upstream side. Both adequate permeability requiring an open fabric structure and soil retention requiring a tight fabric structure are required simultaneously. A third factor is also involved with the long-term soil to geotextile flow compatibility that will not excessively clog during the life time of the soil-geotextile composite system.

Filter clogging effects by fine particles may be evaluated not only by the soil retention in the geotextile layer, but also by the pressure drop or permeability reduction in the soil-geotextile composite system.



a) Cross section of a drainage tunnel
b) Soil column
c) Deposit model

Figure 1.1 Particle transport model of soil-geotextile system in a drainage tunnel

## 2. Preparation of Soil and Geotextile Samples

### 2.1 Soil Samples

Two types of typical Korean weathered residual soils are chosen for this research: the one is more like a cohesive soil sampled from the Poi-dong area (named 'P-soil' hereafter); the other is more or less a cohesionless soil from the Shinnae-dong area (named 'S-soil' hereafter) in Seoul. A series of soil classification tests is performed to confirm the stated properties and the main characteristics are summarized in Table 2.1.

Table 2.1 Index properties of the selected residual soils

| Soil sample | w (%) | LL (%) | PL (%) | PI (%) | FC* (%) | Gs | USCS |
|---|---|---|---|---|---|---|---|
| Poi-dong | 16.5 | 34.0 | 19.8 | 14.2 | 47.4 | 2.74 | SC |
| Shinnae-dong | 10.0 | NP | NP | NP | 10.1 | 2.63 | SW-SM |

Note: FC* = Fine Content (d < 0.074mm)
NP = Non Plastic

The compaction results for each soil sample is summarized in Table 2.2.

Table 2.2 Compaction results for the soil samples

| Soil Sample | OMC (%) | $\gamma_{dmax}$ (t/m$^3$) | Ws (g) | Ww (g) | $n_o$ (%) | $K_o$ (cm/sec) |
|---|---|---|---|---|---|---|
| P-soil | 16.5 | 1.76 | 791.68 | 130.63 | 41.63 | $1.8*10^{-4}$ |
| S-soil | 10.0 | 1.89 | 841.50 | 84.15 | 35.36 | $5.0*10^{-3}$ |

### 2.2 Geotextile Samples

Two types of nonwoven geotextiles which are most widely used in filtration applications are chosen for this study: one is the most frequently used filter material, 2.69mm thick and 311.2g/m$^2$, and denoted NW-1 in this paper; the other is 4.83mm thick and 551.0g/m$^2$, and named NW-2. Properties of the two different geotextiles are identified as shown in Table 2.3.

Table 2.3 Typical range of selected non-woven geotextile properties

| Geotextile Types | Thickness $t_g$, (mm) | Weight $\mu_g$, (g/m$^2$) | Porosity $n_g$, (%) | AOS ($\mu$m) | FOS ($\mu$m) | Permeability Kg, (cm/sec) |
|---|---|---|---|---|---|---|
| NW-1 | 2.69 | 311.2 | 91.4 | 180 | 103 | 0.21 |
| NW-2 | 4.83 | 551.0 | 91.5 | 170 | 100 | 0.39 |

## 3. Geotextile Filtration Testing Methods

Some filtation tests such as the gradient ratio test (GRT), the long-term flow test (LTFT), and the hydraulic conductivity ratio test (HCRT) are suggested to evaluate the compatibility of soil-geotextile composite system. The LTFT needs too much time (about 40 days) to get answer for clogging potential questions. The HCRT also needs much time and complicate interpretation methods. The GRT is a well-accepted method to evaluate the filtration performance of geotextile with cohesionless soils, such as sands and silts.

### 3.1 Gradient Ratio (Clogging) Test

The original gradient ratio test device and procedure were developed in 1972 at the US Army Waterway Experiment Station. In 1990, the American Society of Testing and Materials adopted a version of this procedure as a test method for geotextiles entitled, "Standard Test Method for Measuring the Soil-Geotextile Clogging Potential by the Gradient Ratio", and test equipment is shown in Fig. 3.1.

Two parameters of the ASTM test procedures were recently criticized by many geotechnical and geosynthetic engineers. First and foremost, it was felt that the location of the manometer nearest to the geotextile is so far from the geotextile surface that the test can not accurately determine the behavior at the soil-geotextile interface. Secondly, the ASTM can only test filtration behavior of soil-geotextile column in unidirectional, downward flow conditions.

The SAGEOS Geosynthetics Analysis Service of Canada modified the ASTM gradient ratio device as in Fig. 3.2. And they made a procedure by: (1) adding one additional manometer 6mm above the geotextile surface in an effort to more accurately measure the filtration phenomena at the soil-geotextile interface; and (2) testing the soil-geotextile system in the downward and upward flow directions.

But, both of the ASTM and SAGEOS procedures do not specify the application of normal stress on the geotextile, though the non-woven geotextile is so thin and compressible that a small application of vertival stress can affect the hydraulic behavior of the soil-geotextile system.

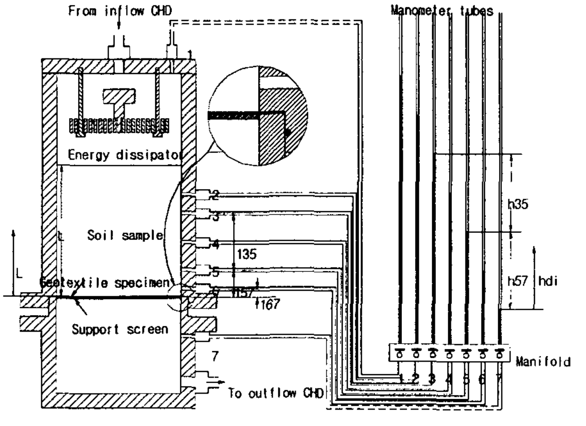


Figure 3.1 ASTM gradient ratio test device

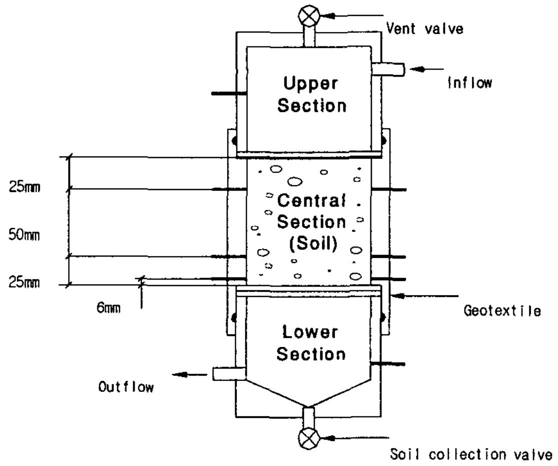


Figure 3.2 SAGEOS gradient ratio test device

### 3.2 The Modified KUGRC Filtration Testing Procedure

Based on the ASTM and SAGEOS gradient ratio testing procedures, a modified gradient ratio test procedure is designed and named as KUGRC (Korea University Geotextile Research Center) gradient ratio test procedure. As shown in Fig. 3.3, the modified KUGRC gradient ratio test device adapts the merits of the ASTM's and SAGEOS's device and procedure by: (1) adding an additional pressure measuring port 6mm above the geotextile surface in an effort to more accurately measure the filtration phenomena at the soil-geotextile interface; (2)adding a normal stress applying system from the bottom of geotextile to analyze the effects of the pressure-induced permeability change; (3) adding a load cell to measure the seepage force at the bottom of the geotextile; (4) and testing under the conditions of either constant flow velocity or constant hydraulic head.

The test procedure can be operated by two different controlling systems; One is the flow-controlled test, and the other is the pressure-controlled test. For the flow-controlled test, a computer-controlled pump drive is used to supply a constant flow rate of water into the soil column. And for the pressure-controlled test, a movable water tank is used to supply a constant hydraulic pressure into the soil column.

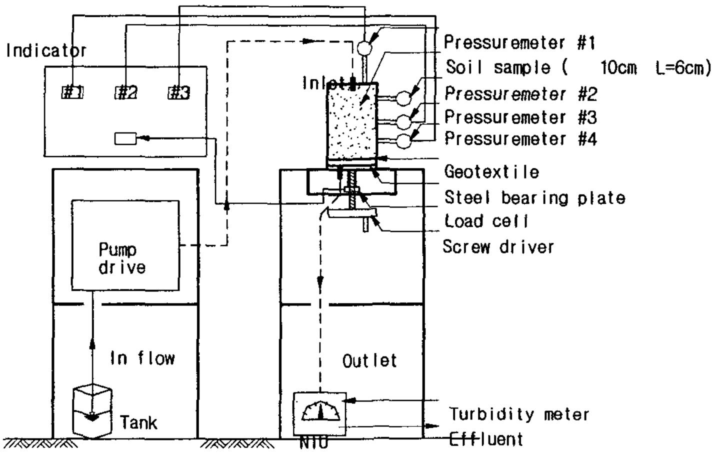


Figure 3.3 KUGRC computer-controlled constant flow test equipment

## 4. Test Equipment Set-Up

### 4.1 Cell Description

A permeability cell, illustrated in Fig. 4.1, consists of a stainless steel cylinder (A) with a 10cm inner diameter and 6.4cm in height. Both ends of the cylinder are machined to contain vitron O-rings (B) sealing the cell caps (C). The cell is held together by two threaded steel rods (D) fixed to the base plate. The fluid inlet (E) leads the water into the soil sample. The fluid outlet (G) allows collection of the effluent water for flow and concentration measurement. Three pressure ports (F) are located at different points on surface of the cell for measurement of water head distribution in the soil sample (I). The effluent water is collected in a 20ml glass bottle located in the turbidimeter (J). Turbidity of the effluent water ismeasured by a continuous flow turbidimeter (HF Scientific. Co.) which measures the turbidity of effluent water in terms of NTUs-nephelometric turbidity units. The particle concentration in the effluent is determined with the help of the correlation made between each soil suspension and NTUs. A magnatic stirrer is put into the bottle of the turbidimeter to prevent the settlement or attachment of fine particles on bottom or wall of the glass bottle. A stainless steel energy dissipator (H) is placed on top of the soil sample to prevent disturbance to the top of the soil from the concentrated high speed of water supply through inlet tube. A stainless steel bearing plate is placed below the geotextile filter and also to identify whether the seepage force developed from the soil sample is transferred to the bottom of the geotextile or not.

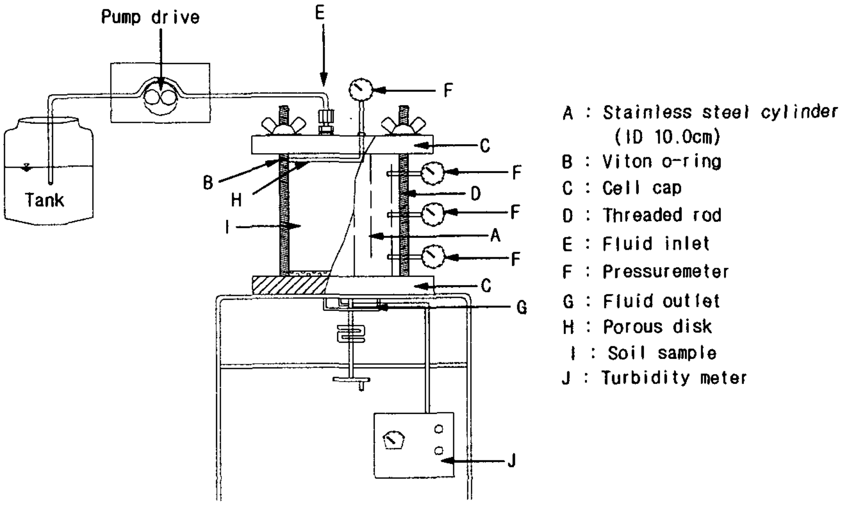


Figure 4.1 Schematic of the KUGRC permeameter cell

## 4.2 Testing Operation

Two different types of filtration test are performed. One is pressure-controlled test, and the other is velocity-controlled test. For the pressure-controlled tsts, three sets of water heads, $H_d$= 0.3, 0.6, and 0.9m (i = 5, 10, and 15, respectively) are applied. Also for the velocity-controlled tests, three different flow rates, q = 7, 14, and 21ml/min ( V = 0.2, 0.4 and 0.6cm/min, respectively) are selected. The range of suplying water heads and velocities is determined from the results of the pilot test and rapid velocity and pressure-increase tests.

The pressure-controlled test procedure requires measurements of water head and flow rate taken at different imposed hydraulic gradients across the soil sample for 24hours. The velocity-controlled test procedure requires measurements of hydraulic pressure developed inside of the soil-geotextile sample and a computer controlled pump drive is prepared to supply a constant flow rate of water into the soil sample.

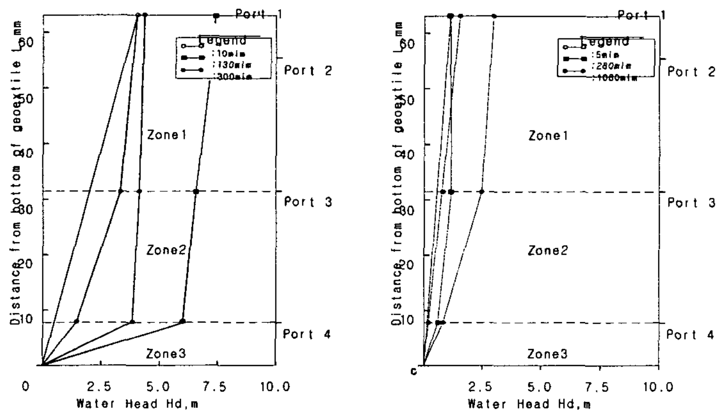
To confirm the performance of the equipment and measuring device, a series of pilot tests are performed.

## 5. Test Results and Discussions

Compatibility of soil-geotextile composition is analized in terms of the hydraulic head distribution in the soil sample and across the geotextile, the value of the gradient-ratio, the permeability reduction, and the mass ratio retained in geotextile layer.

### 5.1 Hydraulic Head Distribution

The hydraulic head distribution in the soil sample changes with the elapsed times due to the erodability of fines and soil-geotextile interactions. The typical variation of hydraulic heads with depth and time for the combination of the P-soil and NW-1 geotextile under flow rate q =7ml/min is shown in Fig. 5.1. Test results show that the head loss in upper 2/3part of the soil column is minimal, however, the head loss occurs dramatically in the bottom 1/3part of the soil column. This result indicates that lots of fine particles are eroded through the whole soil column and moved to downward according to water flow, and some of the fines are accumulated and make filter cake at the soil-geotextile interface and the others are finally passed out from the geotextile.



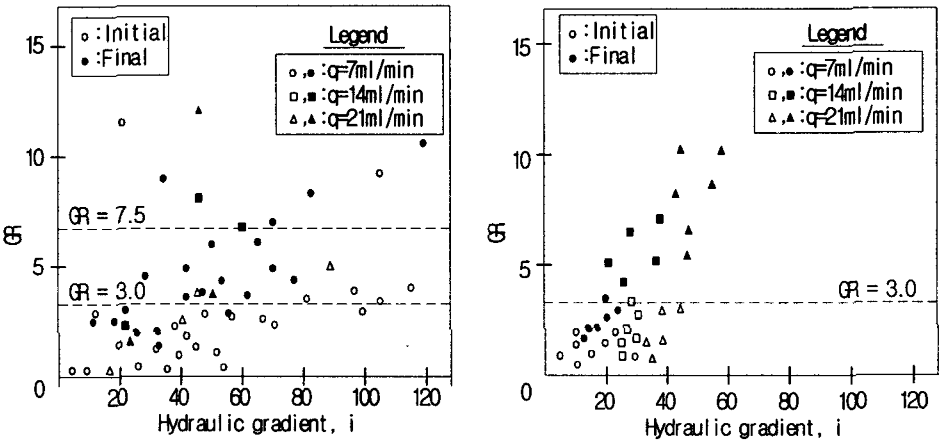
(a) P-soil
(b) S-soil

Figure 5.1 Typical variation of water head distributions in a soil column

### 5.2 Gradient Ratio

The GR values obtained from the experimental results for each soil-geotextile combination are plotted in Fig. 5.2. Fig.5.2 shows that most of the initial GR values do not show a unit value and the final GR values exceed the design criteria, GR=3.0. At the first peak concentration (t =10min), the initial gradient ratio does not indicate GR = 1.0 due to the non-homogeneity of the soil sample. At the second peak concentration (t =130min), water head in bottom layer of the soil sample increases sharply and the measured gradient ratio increases to GR = 10.4-12.4. At the end of the test (t = 300min), the water head starts to decrease but higher water head still remains in bottom layer of the soil column, and the value of gradient ratio still indicates as GR =9.0-9.4. The final values of GR for the P-soil and S-soil are GR=9.0-9.4, GR=3.7-8.7, respectively. This result indicates that the P-soil has more clogging potential than the S-soil. Judging from the existing design criteria given by the US Army, COE, both of the P and S-soil show poor compatibility with the thin non-woven geotextile, NW-1.

Application of the single GR value has limitation to evaluate soil-geotextile compatibility, because the initial GR value never shows a unit value due to initial turbulence effects and non-homogeneity of the soil sample. Therefore, based on the test results, it is recommended to use the ratio $GR_{final}/GR_{initial}$ to evaluate the long-term compatibility of the soil-geotextile system. The ratio $GR_{final}$ to $GR_{initial}$ of the P-soil ($GR_f/GR_i$ =2.7-3.4) is smaller than the S-soil ($GR_f/GR_i$ =3.2-3.7). This opposite result indicates that long-term compatibility of the S-soil with the thin nonwoven geotextile is not as good as the P-soil.



a) P-soil

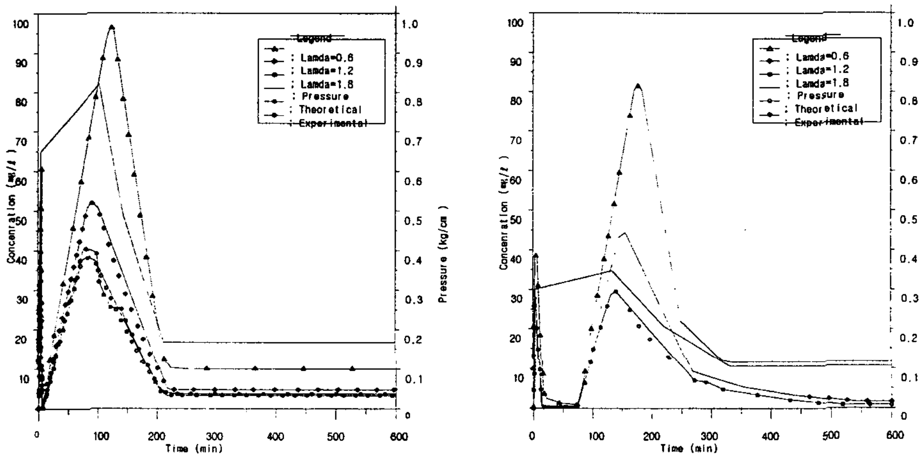
b) S-soil

Figure 5.2 GR values with hydraulic gradients

### 5.3 Evaluation of Particle Deposition Coefficient, λ

For both of the P and S-soil and geotextile sample, NW-1, as shown in Fig. 5.3, the measured effluent concentrations are coincided with the theoretically calculated using the deposition coefficient, $\lambda$ = 1.8min$^{-1}$.

From the sensitivity analysis of the deposition coefficient under the same erosion rate, it is found that the higher the deposition coefficient is, the smaller effluent concentration is achieved. This means that an increase in deposition coefficient in an accumulation of the fine particles at the interface of the soil and geotextile layer. For low values of the deposition coefficient, the particles eroded from the background soils are transported through the filter material, with causing insignificant accumulation of particles at the interface of the soil and geotextile layer.



(a) P-soil

(b) S-soil

Figure 5.3 Comparisons of experimental and theoretical concentrations for the velocity-controlled test

## 6. Conclusions

The following conclusions may be drawn from the interpretation of gradient ratio test data presented for the composite system of the non-woven geotextiles and the weathered residual soils used *in experiments*.

(1) Test results indicate that the initial GR-value never shows GR = 1.0 due to initial turbulence effects and non homogeneity of soil sample. Therefore, the ratio $GR_f/GR_i$ is recommended to evaluate long-term compatibility of soil-geotextile system.

(2) At the end of the filtration test, it is found that about 0.1% of the total soil mass is retained in geotextile layer, and 10% of them is washed out through the geotextile filter layer.

(3) For both of the P and S-soil and geotextile sample, NW-1, the calculated concentration using $\lambda = 1.8\text{min}^{-1}$ shows good agreement with the test results.

(4) Being confined by external pressure and clogged by fine particles, permeability of geotextile drainage layer is reduced to be one-third of the initial permeability of clean filter, especially in a drainage tunnel constructed in water-bearing weathered residual soil.

(5) At the first filling of ground water table after construction of a drainage tunnel, which exceeds the critical hydraulic pressure, $P = 0.12\text{-}0.15\text{kg/cm}^2$, the retained soil mass in the geotextile drainage is estimated to be 565~1130g/m and the passed soil mass is 10-20g/m in a 3m-radius drainage tunnel.

(6) It is observed that one thin layer of geotextile drainage filter is not enough to evacuate seepage water without restriction. To discharge the inflow water freely to the side-wall pipe, 10 to 15 layers of thin geotextile or a thick and stiff geosynthetic or a geocomposite layer is required.

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