Assessments of Long-Term Drainage Performance of Geotextiles

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ABSTRACT
Drainage performance of nonwoven geotextiles was examined in consideration of the values for reduction factors and these values are tempered by the site-specific conditions. Two types nonwoven geotextiles- typical and hybrid types-, which are widely applied as drainage materials to the civil engineering fields in Korea were used to compare the drainage performance. For this case, the flow rate of these geotextiles were decreased with reduction factors but the degree of decrease for hybrid type geotextiles were very lower than those of typical type nonwoven geotextiles. Allowable flow rates of geotextiles were mainly influenced by the reduction factors of soil clogging and creep reduction of voids. Hybrid type geotextiles have more stable and excellent drainage performance than typical type geotextiles

RÉSUMÉ

1. INTRODUCTION

Various types of geosynthetics are used for several civil engineering structures. Especially, nonwoven geotextiles are widely used for drainage purposes under various conditions.
Geotextiles have the functions of protection/reinforcement, separation, drainage, filtration etc. Among these functions, drainage function of geotextiles is the provision for directing the runoff that occurs from precipitation or overland flow in such a way as to prevent contact with refuse or interference with landfill operations
In general, drainage materials as geotextiles for the above system allow the adequate liquid flow into the in-plane direction with limited soil loss. But for the waste landfills, there are many reduction factors that influence the flow rate of geotextiles such as soil clogging, creep reduction of voids, intrusion of voids, chemical clogging, biological clogging etc.
Besides this, marvel stones to be used as drainage materials of leachates over 50 mm diameters will cause to occur to the intrusion phenomena of geotextiles. These intrusion phenomena of geotextiles are the causes to decrease the drainage efficiencies in waste landfills.
Drainage performance of nonwoven geotextiles is estimated by the transmissivity and therefore, it would be needed to modify the ultimate transmissivities of geotextiles to consider these reduction factors.
In this study, two types nonwoven geotextiles- typical and hybrid types- that are widely applied as drainage materials to the civil engineering fields in Korea were used to compare the drainage performance.
And reduction factors to affect the allowable flow rate of geotextiles were applied to examine the drainage function of geotextiles.

2. THEORETICAL BACKGROUND

2.1 Transmissivity

Transmissivity is evaluated by the amounts of water to be passed through the geotextile specimen flow under the confined normal stress and the specific hydraulic gradient in accordance with ASTM D 4716.
The principal transmissivity mechanism of smart geotextiles in this study is analyzed by equation [1]~[4].
If water flows along the surface of geotextiles horizontally and the amounts of water-in should be equal to those of water-out, flow rate of water, q, for drainage system could be written by equation [1] from Darcy's law.

$$q = K_p \times i \times A = K_p \frac{\Delta h}{L} \times w \times t \qquad [1]$$

And transmissivity of geotextiles for drainage in *Figure 4* is as following:

$$\theta = K_p \times t = q \frac{L}{\Delta h \times w} = \frac{q}{i \times w} \qquad [2]$$

, Where θ : transmissivity of geotextile
i : hydraulic gradient
K_p : in-plane permeability
q : flow rate
L , t : length and thickness of geotextile,

respectively

Δh : total water head lost

A, W : cross section area and width of geotextile

If water flows radially through the geotextile and is collected around the outer perimeter of the device, the theory is adapted as follows:

$$q = K_p \times \frac{dh}{dr}(2\pi \times r \times t) \quad [3]$$

And the amounts of radial drainage are calculated by the following equations:

$$2\pi(K_p \times t)\int_{h_1}^{h_2} dh = q\int_{r_1}^{r_2}\frac{dr}{r}$$

$$\theta = \frac{q\ln(r_2 / r_1)}{2\pi\Delta h} \quad [4]$$

, Where r_1 : inner radius of geotextile test specimen

r_2 : outer radius of geotextile test specimen

2.2 Long-Term Drainage Performance

For problems dealing with through or within a geotextile, such as filtration and drainage applications, the formulation of the allowable values takes the following equations.

$$q_{alow} = q_{ult}\left(\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right) \quad [5]$$

$$q_{allow} = q_{ult}\left(\frac{1}{\prod RF}\right) \quad [6]$$

, Where qallow = allowable flow rate,

q_{ult} = ultimate flow rate,

RF_{SCB} = reduction factor for soil clogging,

RF_{CR} = reduction factor for creep reduction of void space,

RF_{IN} = reduction factor for adjacent materials intruding into geotextile's void space,

RF_{CC} = reduction factor for chemical clogging,

RF_{BC} = reduction factor for biological clogging, and

ΠRF = value of total reduction factors.

From total reduction factor, ΠRF of the equation [6], we can calculate the allowable flow rate to affect the drainage performance of geotextiles.

3. EXPERIMENTAL

3.1 Preparation of smart geotextiles

The smart geotextiles of 3-layer structure, which have the adaptative drainage function under confined loading condition, were manufactured by needle punching method. Three different punching patterns were applied to manufacture these geotextiles as ↑, ↑ and ↓ punching mechanism. Table 1 shows the specifications of the smart geotextiles – SMGT 1, 2, 3 and 3 types of geonet composites – GNC-1, -2, -3 etc. - having the same thickness as smart geotextiles were used as comparison materials for drainage function and Figure 1 showed the cross sectional morphology of smart geotextiles and geonet composites.

Table 1. Specifications of smart geotextiles

Geosynthetics For Drainage		Thick-ness (mm)	Com-position	Drainage Layer
Smart Geo-textiles	SMGT 1	1.2	Non-woven /Drainage Layer /Non-woven	* (Waste) PP or PET Fibers * 20-1,000 Deniers Accumulation of web
	SMGT 2	1.4		
	SMGT 3	1.7		Pre-punched Nonwovens
Geonet Com-posites	GNC 1	6.2	Non-woven /Drainage Core /Non-woven	2-Layer HDPE Core
	GNC 2	7.2		
	GNC 3	8.0		

(a)

(b)

Figure 1. Photograph of smart geotextile

3.2 Tests of drainage properties

Radial in-plane flow test apparatus in accordance with GRI Test Method as shown in Figure 2 was used to evaluate the transmissivity, in-plane pearmeability of smart geotextiles and geonet composites. The size of test specimen is 100cm^2 and confining load ranges to be applied to the specimen are 1~240 kg. Transmissivity of smart geotextiles and geonet composites under confined loading conditions were evaluated by equation [4]. Before testing, specimens were immersed in the distilled water to eliminate the vapors in the specimens.

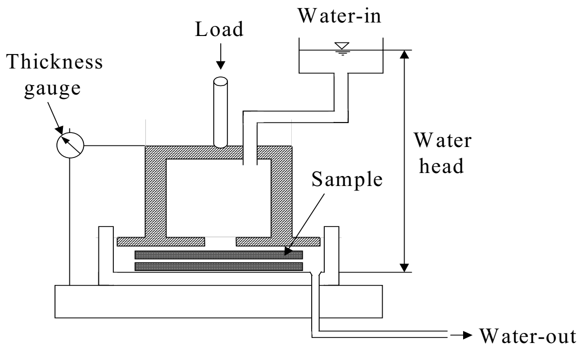

Figure 2. Schematic diagram of radial transmissivity apparatus

4. RESULTS AND DISCUSSION

4.1 Thickness and in-plane permeability

In general, the thickness of the geotextile is decreased by the compressive stress for installation within the soil structure. For this case, transmissivity of the geotextile would be the function of thickness and it is very important to evaluate the variation of thickness with the compressive stress.
The relationship between thickness and compressive stress would be written as equation [7] by using the variation constant of the geotextile,

$$T/T_0 = (\sigma/\sigma_0)^{-a} \quad [7]$$

, Where T_0, T : thickness of geotextile with/without compressive stress, respectively
a : variation constant of geotextile
σ_0, σ: initial and compressive stress of geotextile, respectively (σ_0=0.04 kg/cm^2)

Figure 3 shows the schematic diagram of intrusion phenomena by the confined loading of smart geotextile and geonet composite. In here, the upper nonwoven of geonet composite shows the considerable intrusion by the confining load whereas smart geotextile shows a bit of intrusion. This is closely related to the variations of thickness with compressive stress.

From this equation, the variation constant, *a*, will be larger with the thickness of the geotextile and therefore, another variation constant, *b*, should be introduced to equation [7] to compensate the variation constant, *a*.
Therefore, the variation of thickness with compressive stress could be written as following:

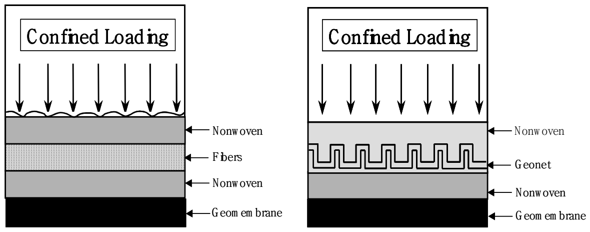

Figure 3. Schematic diagram of intrusion for smart geotextiles and geonet composites under confined loading

$$T = T_0 - a\ln\frac{\sigma}{\sigma_0} = T_0\left(1 - \ln\frac{\sigma}{\sigma_0}\right) \quad [8]$$

$$b = a / T_0$$

Figure 4 shows the relative decrease of thickness with compressive stress of geosynthetics by using equation [8]. Geonet composites showed more significant decrease of thickness with confined loading due to the considerable intrusion of upper nonwovens than smart geotextiles. The constants of equation [8], T_0, a_T, b_T and correlation coefficient, R^2 for smart geotextiles and geonet composites were represented in Table 2. In-plane permeability with thickness of smart geotextiles and geonet composites was shown in Figure 5.
From this, it is seen that the linearity between thickness and in-plane permeability for smart geotextiles and geonet composites should be obtained with compressive stress.

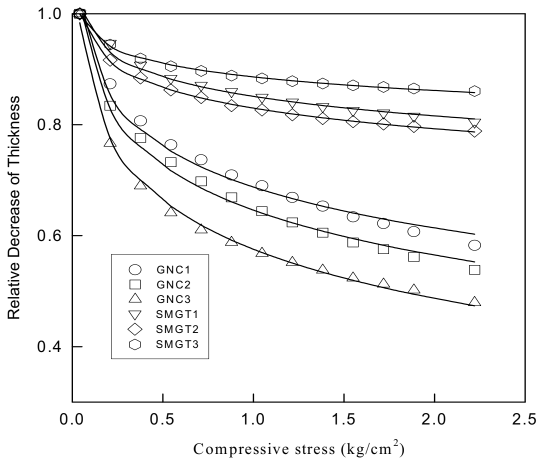

Figure 4. Relative decrease of thickness with compressive stress for smart geotextiles and geonet composites

Figure 6 shows the relationship between relative decrease of in-plane permeability and compressive stress of smart geotextiles and geonet composites.
Smart geotextiles showed the lower decrease of in-plane permeability than geonet composites as described in the case of relationship between thickness and compressive stress.
From this, it is seen that this is due to the intrusion by the difference of structural compositions between smart geotextiles and geonet composites.

4.2 Transmissivity and compressive stress

Transmissivity is a kind of parameter to determine the drainage properties of geotextiles and this is the function of the multiplication thickness by in-plane permeability of geotextile. In-plane permeability of geotextile to be derived from the equation [8] is as following:

$$K_p = K_0 - a_K \ln\frac{\sigma}{\sigma_0} = K_0\left(1 - b_K \ln\frac{\sigma}{\sigma_0}\right) \quad [9]$$

$$b_K = a_K / K_0$$

, where K_0 : initial in-plane permeability
K_p : in-plane permeability under confined loading
a_K, b_K : variation constants of geotextile

From the equation [2] and [9], transmissivity of geotextile could be written as following:

$$\begin{aligned}\theta &= T \times K_p \\ &= T_0\left(1 - b\ln\frac{\sigma}{\sigma_0}\right) \times K_0\left(1 - b_K \ln\frac{\sigma}{\sigma_0}\right) \\ &= (T_0 \times K_0)\cdot\left(1-(b+b_K)\ln\frac{\sigma}{\sigma_0} + b\cdot b_K \ln^2\frac{\sigma}{\sigma_0}\right) \\ &= \theta_0\left(1-(b+b_K)\ln\frac{\sigma}{\sigma_0} + b\cdot b_K \ln^2\frac{\sigma}{\sigma_0}\right)\end{aligned} \quad [10]$$

where θ_0 , θ : transmissivity with/without confined loading of geotextile, respectively

Table 2. Parameters to be related to thickness of smart geotextiles and geonet composites

Geosynthetics For Drainage	Coefficients to be Related to Thickness			
	T_0	a_T	b_T	R^2
GNC1	3.4634	0.3585	0.1035	0.9853
GNC2	4.3138	0.4946	0.1147	0.9923
GNC3	2.7448	0.3564	0.1298	0.9964
SMGT1	7.8463	0.3939	0.0502	0.9852
SMGT2	9.8557	0.5285	0.0536	0.9992
SMGT3	12.7900	0.4526	0.0354	0.9982

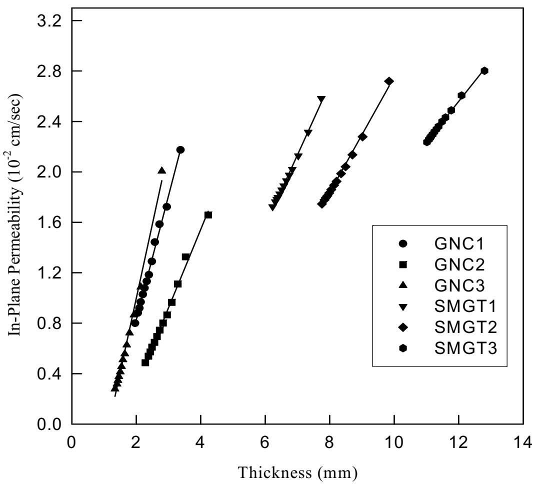

Figure 5. Thickness and in-plane permeability with compressive stress for smart geotextiles and geonet composites

For equation [8], the value of ($b \times b_k$) is (0.02～0.03) and this value is smaller than ($b + b_k$), (0.3～0.4).
Therefore, the 3rd term of equation [8] could be negligible to be simplify this equation if the value of (σ/σ_0) is not larger than (0.02～0.03).
Finally, transmissivity of geotextile would be written as follows:

$$\theta = \theta_0\left(1 - b_\theta \ln\frac{\sigma}{\sigma_0}\right) \quad [11]$$

, Where b_θ : variation constant of the geotextile

Figure 7 shows the relationship between transmissivity and compressive stress and solid line indicates the theoretical values of the equation [9] in the condition of the initial compressive stress, σ_0=0.04 kg/cm^2.
In here, the errors between experimental and theoretical values of transmissivities for GNC-1 were larger than those of the other materials. It means that is the 3rd term of equation [8] should not be negligible because of the larger (σ/σ_0) values.
But the errors between experimental and theoretical values of transmissivities for GNC-1 will be smaller if the initial compressive stresses are larger than 0.04 kg/cm^2.
This means that the 3rd term of equation [8] should be negligible and the initial compressive stress should be larger to be applied the equation [9] to the analysis of transmissivity of the geotextile.

Table 3 shows the parameters to be related to in-plane permeability and transmissivity of smart geotextiles and geonet composites.

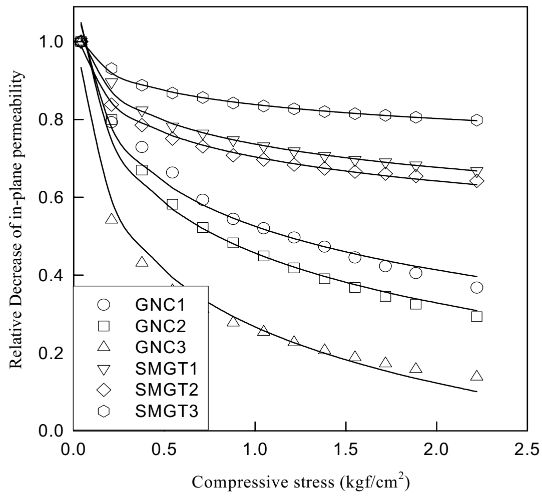

Figure 6. Relative decrease of in-plane permeability and compressive stress for smart geotextiles and geonet composites

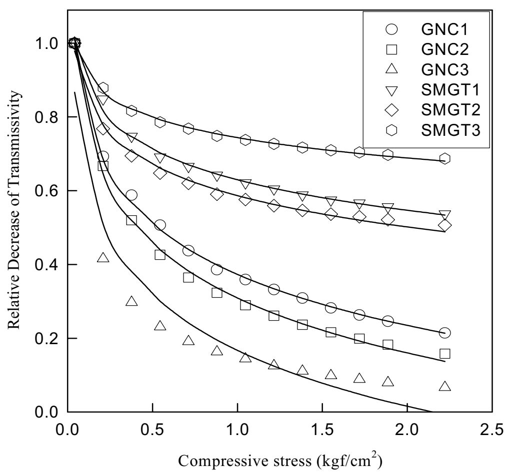

Figure 7. Relative decrease of transmissivity and compressive stress for smart geotextiles and geonet composites

4.3 Long-Term Drainage Performance

Table 4 shows the ultimate flow rates of geotextiles in accordance with ASTM D4716.
For typical type nonwoven geotextiles, the ultimate flow rates, transmissivities, were decreased with the weight and this is due to the increase of fiber compactness and needle punching densities with the increase of the geotextile weight. On the other hand, the ultimate flow rates of hybrid type geotextiles were increased with the weight. It was thought that the fiber compositions of the drainage layer were more parallel with the weight and therefore the planar flow rate could be increased.

Table 4. Ultimate flow rates of geotextiles

Geotextiles	Ultimate Flow Rates ($\times 10^{-4}$ m/s)
SMGT-1	1.026
SMGT-2	1.317
SMGT-3	1.682
GNC-1	0.765
GNC-2	0.688
GNC-3	0.463

Table 5 shows the reduction factors to affect the allowable flow rates of geotextiles for drainage. In here, soil clogging and creep reduction in voids are very important factors for drainage performance of geotextiles. For both geotextiles, there are almost no changes for soil clogging but the numbers of other reduction factors for typical type geotextiles were larger than those of hybrid type geotextiles. For soil clogging, the reason why the reduction factors of hybrid type geotextiles were larger than typical type geotextiles is due to the special composition and structure of hybrid type geotextiles. Table 6 shows the total reduction factor and the allowable flow rate of geotextiles for drainage. Total reduction factors of hybrid type geotextiles were decreased with weight whereas those of typical type geotextiles were increased. Therefore, there are no significant changes of the allowable flow rates among the hybrid type geotextiles.

Table 5. Reduction factors of geotextiles for drainage

Reduction Factor / Geotextiles	Soil Clogg-ing	Creep Re-duction of Voids	Intrusion into Voids	Chemical Clogging	Biological Clogging
SMGT 1	2.3	2.1	1.1	1.1	1.1
SMGT 2	2.4	2.0	1.0	1.1	1.1
SMGT 3	2.4	2.0	1.0	1.1	1.1
GNC 1	2.2	2.2	1.2	1.3	1.3
GNC 2	2.2	2.2	1.2	1.4	1.3
GNC 3	2.3	2.1	1.3	1.4	1.4

Table 3. Parameters to be related to in-plane permeability and transmissivity of smart geotextiles and geonet composites

Geotextiles	In-plane permeability				Transmissivity			
	K_0	a_K	b_K	R^2	θ_0	a_θ	b_θ	R^2
GNC 1	0.023	0.003	0.155	0.982	0.741	0.146	0.198	0.998
GNC 2	0.017	0.003	0.177	0.986	0.699	0.151	0.216	0.997
GNC 3	0.019	0.004	0.223	0.979	0.485	0.123	0.253	0.930
SMGT 1	0.026	0.002	0.085	0.993	2.023	0.239	0.118	0.994
SMGT 2	0.027	0.002	0.090	0.996	2.618	0.328	0.125	0.992
SMGT 3	0.028	0.001	0.052	0.996	3.581	0.286	0.080	0.997

Table 6. Total reduction factor and allowable flow rate of geotextiles for drainage

Geotextiles	Total Reduction Factor	Allowable Flow Rate ($\times 10^{-3}$ m/s)
SMGT 1	6.4	1.6
SMGT 2	5.8	2.3
SMGT 3	5.8	2.9
GNC 1	9.8	0.8
GNC 2	10.6	0.6
GNC 3	12.3	0.4

5. CONCLUSION

1. The variations of thickness with compressive stress of smart geotextiles were smaller than those of geonet composites. This is due to the difference of intrusion by compressive stress between smart geotextiles and geonet composites.
2. The decrease of in-plane permeability and transmissivity with compressive stress of smart geotextiles showed the same tendency as the case of variations of thickness.
3. Total reduction factors to affect the allowable flow rate of typical type nonwovens were larger with weight and the allowable flow rates were decreased. On the other hand, hybrid type geotextiles showed the reverse trends for both values to compare with typical type geotextiles.

From this result, it was seen that hybrid type geotextiles have more stable and excellent drainage performance than typical type geotextiles.

6. REFERENCES

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