Water retention curves of nonwoven geotextiles during drainage

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ABSTRACT: A series of water retention tests were performed for five nonwoven geotextiles of different materials and manufacturing processes. The van Genuchten model was applied to both the water retention curves obtained from these tests and to previously published data. Method of estimating water retention curves of the drainage process using the saturated hydraulic conductivities of nonwoven geotextiles were investigated. The water retention curves during nonwoven geotextiles drainage are *S*-shaped and are similar to those of soil material. Furthermore, the results also show that the nonwoven geotextile water retention curves can be estimated by the van Genuchten model. This study suggests that drainage phase water retention curves and unsaturated hydraulic conductivities can be estimated by only testing the permeability of saturated nonwoven geotextiles.

Keywords: nonwoven geotextile, water retention curve, air entry value, hydraulic conductivity

1 INTRODUCTION

Nonwoven geotextiles used in construction have many applications related to seepage and flowing water, such as slope protection, horizontal drainage from embankments, scour prevention and filtration. When nonwoven geotextiles are used to protect slopes against rainfall, measurements of water retention properties and unsaturated hydraulic conductivity are required. These properties and parameters are used to evaluate the seepage of rainwater into the slope and the water flow on the surface. When nonwoven geotextiles are used as horizontal drainage in embankments, the nonwoven geotextile undergoes a range of different conditions, from unsaturated to saturated. As such, the unsaturated hydraulic conductivity of a nonwoven geotextile is required to evaluate its drainage performance. However, although the unsaturated hydraulic conductivity of nonwoven geotextiles has been investigated, a straightforward evaluation method has not been established (e.g. Iryo & Rowe 2003, Nahlawi et al. 2007, Morris 2000). Conversely, many mathematical models of water retention and hydraulic properties have been proposed for unsaturated soil materials. Mathematical models of unsaturated hydraulic conductivity and unsaturated seepage flow using water retention properties have also been established for soil materials. As these models can be applied to nonwoven geotextiles using material parameters, they offer an effective method of evaluating nonwoven geotextile seepage and permeation in unsaturated conditions.

In this paper, a series of water retentivity tests were performed for five different types of nonwoven geotextiles and water retention curves during drainage were obtained. The van Genuchten water retention curve model (VG model) (van Genuchten 1978 & 1980) for soil materials was applied to the test results. Based on the test results and other published data, this method was used to estimate water retention curves during drainage using the saturated hydraulic conductivities of nonwoven geotextiles, k_{ws}. Moreover, calculations of nonwoven geotextile unsaturated hydraulic conductivities were also conducted.

2 MODEL OF WATER RETETION CURVE AND UNSATURATED HYDRAULIC CONDUSTIVITY

The VG model, one of the most widely-used water retention curve models, is expressed by the following equations (van Genuchten 1978 & 1980):

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left\{1 + (-\alpha \cdot s)^n\right\}^{-m} \quad (1)$$

$$m = 1 - \frac{1}{n} \quad (2)$$

where S_e is effective saturation, θ is volumetric moisture content, θ_s is saturated volumetric moisture content, θ_r is residual volumetric moisture content, s is suction, α is a scaling parameter in units of $1/s$, and n and m are non-dimensional fitting parameters ($n > 1$, $0 < m < 1$).

An unsaturated hydraulic conductivity model based on Eqs. (1) and (2) is established in Eq. (3). A combination of Eqs. (1), (2), and (3) is widely used to model unsaturated groundwater seepage flow.

$$k = k_{ws} S_e^{\xi} \left\{1 - \left(1 - S_e^{1/m}\right)^m\right\}^2 \quad (3)$$

where ξ is a fitting parameter, equal to 0.5 (Mualem 1976) or 2 (Burdine 1953) for unsaturated soils.

3 METHODS AND MATERIALS

The water retentivity test for nonwoven geotextile drainage was carried out using a suction method in which a water head difference was directly applied to the specimen. Figure 1 shows a schematic of the test apparatus. The bottom plate drainage tube is connected to a drainage container on a high-precision electronic balance with a minimum value of 0.001 g. The total amount of drainage was calculated using mass change measurements. To prevent evaporation of water from the drainage container, the water surface was covered with olive oil. To prepare for the test, filter paper, membrane filter (ADVANTEC, Cellulose Acetate Type, pore size of 0.20 μm), and nonwoven geotextiles with 60 mm diameters were immersed in pure water and then deaired by applying a maximum vacuum pressure of −95 kPa for a minimum of 24 h. After the drainage tube was saturated, three sheets of filter paper and one sheet of membrane filter were installed on the bottom plate. One sheet of nonwoven geotextile was placed on top. To maintain contact between the membrane filter and the nonwoven geotextile, a weight corresponding to 0.5 kPa confining pressure was installed on the nonwoven geotextile. During the test, the upper part of the apparatus was open to the atmosphere and thus the nonwoven geotextile pore air pressure was maintained at atmospheric air pressure ($u_a = 0$). The water head difference (Δh, $\Delta h > 0$) between the olive oil surface and the centre of the nonwoven geotextile was applied to the nonwoven geotextile, where the resulting pore water pressure is expressed as $-\gamma_w \Delta h$. By raising the apparatus using the hoisting stage, the water head difference increased incrementally from 1 cm to 50 cm, corresponding to pore water pressures of –

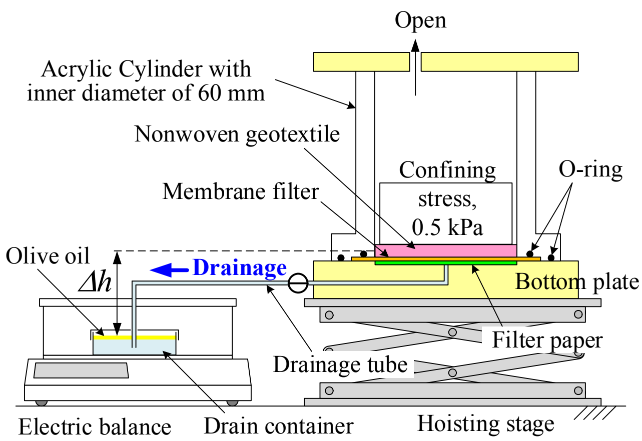

Figure 1. Apparatus of gravity drainage column test.

Table 1. Specifications and characteristics of nonwoven geotextiles subjected to water retention tests.

	Sample A	Sample B	Sample C	Sample D	Sample E
Material	Polyester short fibre	Polyester short fibre	Polyester long fibre	Polyester long fibre	Polypropylene long fibre
Production method	Needle-punching and binder	Needle-punching	Spun bonding	Spun bonding	Needle-punching and spun bonding
k_{ws}	1.8×10^{-2} m/s	3.4×10^{-3} m/s	2.3×10^{-3} m/s	1.7×10^{-3} m/s	1.8×10^{-3} m/s
Thickness	3 mm	1.7 mm	0.75 mm	3 mm	4 mm
Mass (from product catalogue)	125 g/m^2	300 g/m^2	100 g/m^2	300 g/m^2	400 g/m^2

Table 2. Specifications and characteristics of the nonwoven geotextiles extracted from previous studies.

	Sample F	Sample G	Sample H	Sample I
Material	Polyester short fibre	Polyester short fibre	Polyester short fibre	Polypropylene short fibre
Production method	Needle punching	Needle punching	Needle punching	Needle punching
k_{ws}	5.0×10^{-2} m/s	4.0×10^{-3} m/s	4.0×10^{-3} m/s	2.7×10^{-3} m/s
Thickness	2.3 mm	1.8 mm	2.3 mm	3.7 mm
Reference	Bouazza et al. 2006	Bouazza et al. 2006	Nahlawi et al. 2007	Morris 2000

0.1 kPa to –5 kPa, respectively. Finally, the pore water was drained from the nonwoven geotextile. After the amount of drainage per hour fell to below 0.01 g, corresponding to approximately 0.01% water content, the test advanced to the next stage.

Five types of nonwoven geotextiles of different materials, manufacturing processes, k_{ws} values, and thicknesses were used. In addition, published data regarding four types of nonwoven geotextiles (Bouazza et al. 2006, Nahlawi et al. 2007, Morris 2000) were used for comparison. Tables 1 and 2 show the specifications and properties of the nonwoven geotextiles. The saturated hydraulic conductivity values in Table 1 were obtained from constant head permeability tests (JIS A 1218) of well-deaired nonwoven geotextiles. According to the testing standards, JGS 0931-2009 and ISO 11058:2010, the specimen is submerged in water containing a wetting agent, gently stirred to remove air bubbles, and left to saturate for a minimum of 12 h. In this study, the wetting agent was not used in the water retentivity or permeability tests as it may affect the results. Instead, nonwoven geotextiles were saturated by deairing for 24 h.

4 TEST RESULTS AND DISCUSSION

Figure 2 shows water retention curves and the relationship between s and Se of nonwoven geotextiles

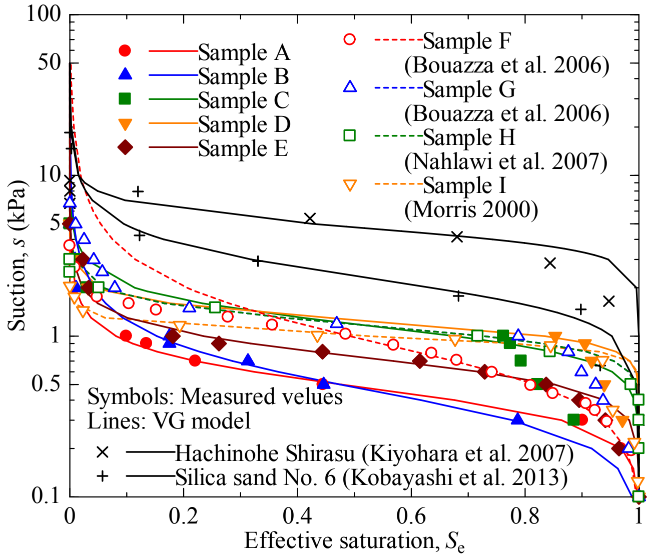

Figure 2. Relationship between effective saturation and suction for all samples.

drainage, where s was calculated as $u_a – u_w = –u_w$. The curves shown in Figure 2 were obtained by fitting the VG model to the data (Eqs. (1) and (2)). Published test results of sandy soils, silica sand No. 6 and Hachinohe Shirasu, extracted from Kobayashi et al. 2013 and Kiyohara et al. 2007 are also shown. The water retention curves of nonwoven geotextiles are *S*-shaped, similar to those of soil materials. Moreover, the VG model provides high-quality fits for nonwoven geotextiles as it does for soil materials. The air entry value, *AEV*, of nonwoven geotextiles was between 0.2 and 1 kPa, which is less than values for sandy soil (1–5 kPa).

Figures 3(a) and 3(b) show the relationships between VG parameters α and n, obtained from VG model fitting, and k_{ws} of nonwoven geotextiles. As shown in Figure 3(a), increases in k_{ws} correspond with decreases in α. The relationship between k_{ws} and α can be approximated by the curve shown in Figure 3(a). α is also correlated to the reciprocal of *AEV* (van Genuchten 1978). *AEV* values of 0.33–1 kPa can be obtained using this relationship and are similar to the range of *AEV* values shown in Figure 2 (0.2–1 kPa). However, there is no significant relationship between n and k_{ws}. Although Sample I has an n value of 11, values of n for other the other samples range between 3 and 7.

Relationships between α and n, and k_{ws} (Figures 3(a) and 3(b)) are approximated by following equations:

$$\alpha = 10.638 \times k_{ws}^{0.378} \tag{4}$$

$$n = 0.537 \tag{5}$$

As shown in Figure 3(a), Eq. (3) approximates the relationship between α and k_{ws} for all samples except Sample B. n is assumed to have a constant value of 0.537.

The accuracy of the water retention curves was estimated using k_{ws} and Eqs. (1), (2), (4) and (5). Figure 4 shows the relationship between s and S_e for the test results as well as the calculated curves. As a

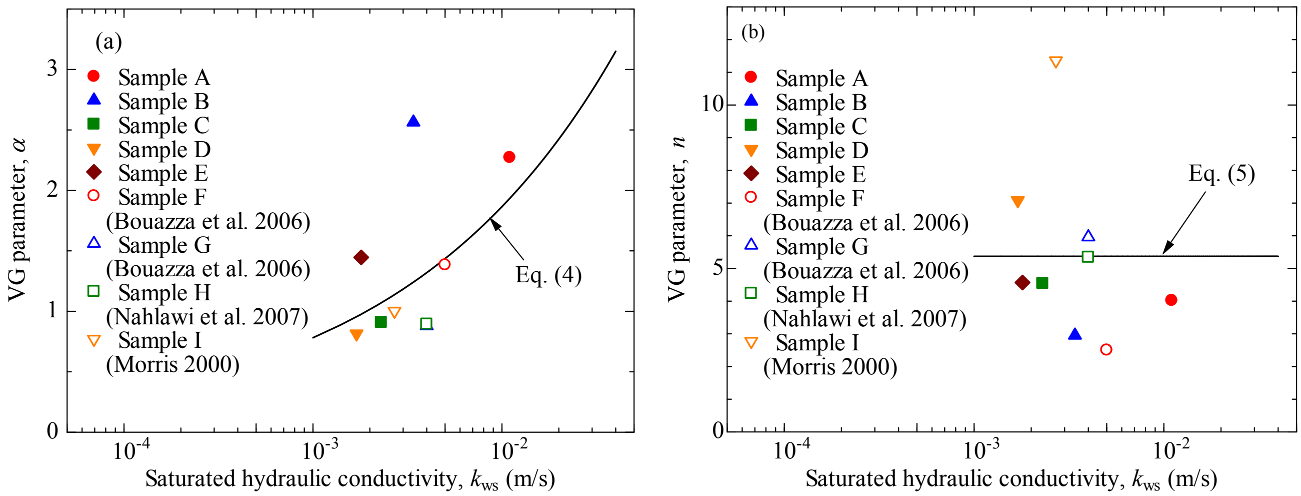

Figure 3. Relationships between saturated hydraulic conductivity and α and n for all samples.

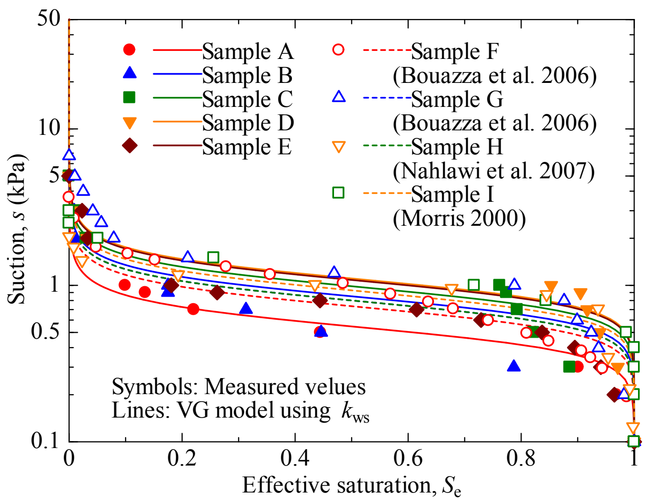

Figure 4. Nonwoven geotextile water retention curves estimated using VG parameters.

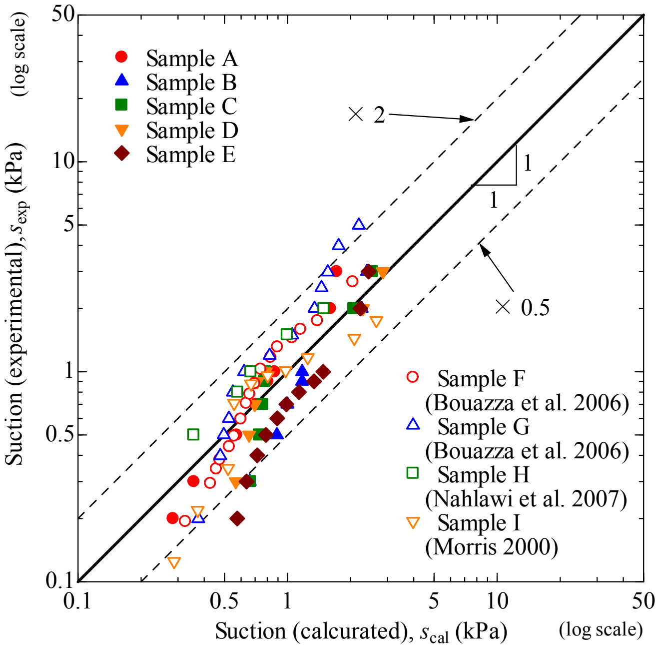

Figure 5. Comparison of experimental and calculated suction values.

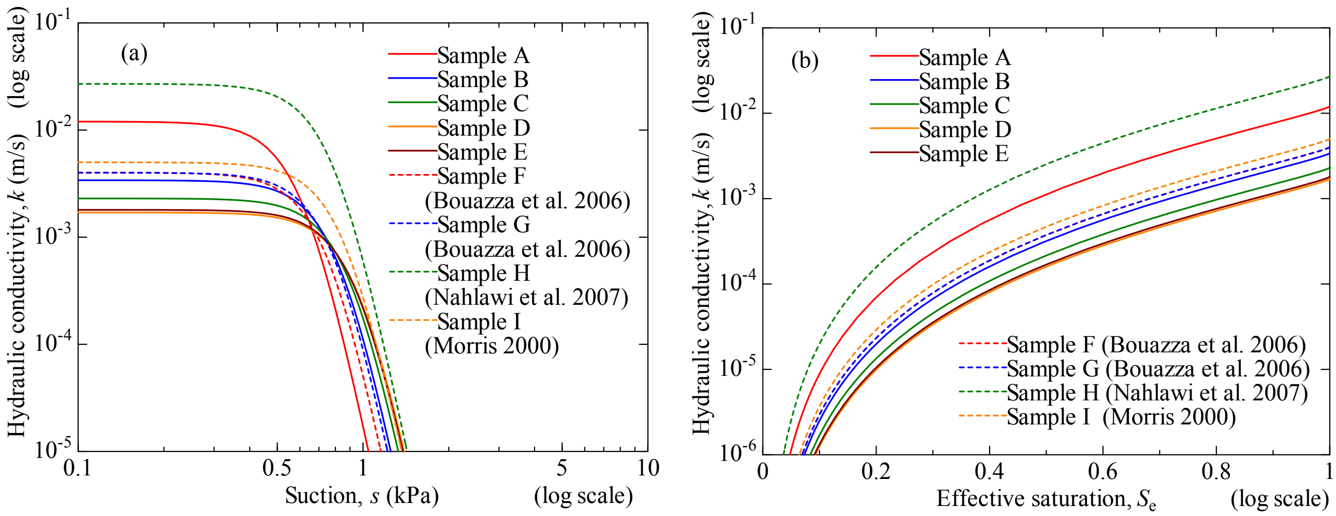

Figure 6. Unsaturated hydraulic conductivity estimated using saturated hydraulic conductivity.

constant value is assumed for n, the slope of these curves is constant in the range where the value of suction is greater than *AEV*.

Figure 5 shows a comparison between experimental and calculated values of suction for the water retention curves. Experimental values, s_{exp}, and calculated values, s_{cal}, corresponding to the same relative saturations are compared. The calculated values are 0.5 to 2 times the experimental values. In general, suction is expressed on a logarithmic scale; thus, the above error is negligible. The observed differences in Samples B and I are within this range, despite the fact that their VG parameters differ from those of other samples (Figures 3(a) and 3(b)). By only testing the permeability of saturated nonwoven geotextiles, water retention curves can be generated.

Figures 6(a) and 6(b) show calculated nonwoven geotextile unsaturated hydraulic conductivities. The value of relative saturation, S_e, calculated using k_{ws} and Eqs. (1), (2), (4) and (5) was substituted into Eq. (3), where $\zeta = 0.5$ was used. These results show that the unsaturated hydraulic conductivity of nonwoven geotextiles can be estimated using exclusively the saturated hydraulic conductivity.

5 CONCLUSIONS

A series of water retentivity tests were carried out for five different types of nonwoven geotextiles to obtain water retention curves of the drainage process. The VG water retention curve model was applied to the test results and previously published data. Additionally, methods of estimating water retention curves of the drainage process and unsaturated hydraulic conductivities of nonwoven geotextiles were investigated. The main conclusions are as follows:

1. The water retention curves of nonwoven geotextiles were *S*-shaped, similar to those of sandy soils. Furthermore, these curves can be estimated using the VG model.
2. The *AEV* ranged between 0.2 and 1 kPa for the nonwoven geotextiles in this study, less than values for sandy soils.
3. The values of α for nonwoven geotextiles ranged from 1 to 3. Increases in k_{ws} correspond to larger values of α. From this relationship, values of α can be estimated using k_{ws}.
4. Values of n ranged between 3 and 7 and showed no clear relationship with k_{ws}.
5. Water retention curves of the drainage phase and unsaturated hydraulic conductivities for nonwoven geotextiles can be estimated using only permeability tests.

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