**GeoAmericas 2024**
5th Pan-American Conference on Geosynthetics
**April 28 - May 1, 2024**
Toronto

# Water Retention Characterization of Non-Woven Geotextiles: An Application for Wicking Materials

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**Abstract.** Non-woven geotextiles are commonly used in soil embankments for separation, filtration, and drainage purposes. While these conventional geotextiles can effectively drain gravitational water from saturated embankments, they often struggle to drain capillary water when the embankments are unsaturated—a typical state during their service life. This inefficiency can lead to water accumulation, potentially resulting in moisture-induced damage. To overcome this, a new geotextile, termed "wicking non-woven geotextile," has been introduced. This material is engineered to drain capillary water from unsaturated embankments more effectively. This paper aims to offer a thorough review of the unsaturated behavior of geotextiles, discussing characterization methods and experimental techniques. Furthermore, we will present the results of a capillary rise test, which will help determine the geotextile-water retention curves (GWRC) for a wicking geogrid composite

## 1. Introduction

Geotextiles are permeable planar polymeric textile layers that can be manufactured using woven or nonwoven fabric styles. Non-woven geotextiles are commonly employed for various purposes in soils, including ensuring adequate flow in the in-plane direction for drainage, acting as separation materials to prevent the mixing of dissimilar soils, and serving as filtration materials to prevent the migration of fine particles during saturated conditions [1–6]. Geotextiles primarily excel at draining water in saturated soil conditions [6]. However, they face a significant limitation when it comes to water drainage under unsaturated conditions [7], which are the prevailing conditions in the majority of soil embankments. This limitation can lead to instability problems. For instance, even a slight increase in moisture content before reaching full saturation can cause a decrease in the resilient modulus of a railroad's subgrade subjected to cyclic loading [8, 9].

To address this limitation, wicking geotextiles were introduced to the market to effectively drain both free and capillary water from unsaturated soils. The available material is typically a woven wicking geotextile with hydrophilic and hygroscopic properties. An outstanding characteristic of wicking geotextiles is their ability to retain and transport

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moisture due to their high hydraulic conductivity under high suction levels (unsaturated conditions) [10].

Developing water retention curves for geotextiles is crucial for modeling and understanding the transient water flow in unsaturated earthen systems incorporating geotextiles [11]. This paper provides a comprehensive background on the unsaturated behavior of conventional non-woven geotextiles compared to wicking geotextiles. It also reviews common experimental techniques used to measure geotextile water retention curves and presents the results of a capillary rise test performed on a newly proposed wicking geogrid composite to determine its hydraulic behavior under unsaturated conditions.

## 2. Background

When conventional geotextiles are placed in unsaturated soils, they exhibit a phenomenon known as the capillary-break effect. This occurs when the flow of water is impeded because of the installation of large-pored layers, such as coarse-grained soil (gravel or sand) or nonwoven geotextiles below a fine-grained soil layer [2]. Water accumulates near the interface between the geotextile and the fine-grained soil until it reaches a breakthrough point. The breakthrough point refers to the point where the hydraulic conductivity of the geotextile equals that of the surrounding soil [12]. Conventional geotextiles, with their low hydraulic conductivity under negative pore water pressure, are incapable of effectively draining moisture from water surface infiltration and capillary water rise resulting from a high water table [13–15]. Figure 1 illustrates the capillary-break effect using the hydraulic conductivity functions of two geomaterials.

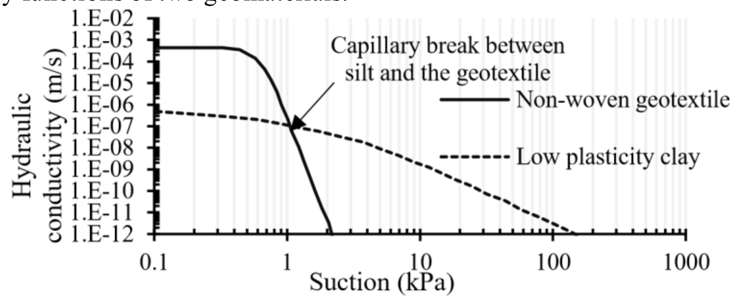


**Fig. 1.** Hydraulic conductivity functions of two geomaterials, adapted from McCartney et al. (2005).

### 2.1 Geotextiles with enhanced lateral drainage

The aforementioned interaction between conventional geotextiles and unsaturated soils has led to the development of geotextiles with enhanced lateral-drainage capabilities. These geotextiles are effective for drainage under unsaturated conditions and are called wicking geotextiles [14].

So far, the application of wicking geotextiles has been studied in transportation infrastructure. Guo et al. (2019) presented a conceptual drainage design using the wicking geotextile. The wicking geotextile was extended to the atmosphere to allow evaporation of the drained water. Unlike conventional drainage systems that result in excess water accumulation in the overlying soils, both gravitational and capillary water can be absorbed by the wicking fabric from surrounding soils, transported along the wicking fibers to the facing of the road slopes, and eventually evaporate to the ambient atmosphere. Under unsaturated conditions, the relative humidity in the soil is high because of the presence of capillary water and water infiltration, whereas air in the atmosphere typically has a relative humidity lower than 50%. The suction in the air can reach 14MPa [16]. The relative humidity gradient between the buried section of the geotextile within the embankment and the exposed end at the embankment slopes served as the driving force for water flow [1]. If properly designed, the atmosphere can function as a natural pump that operates 24 hours a day and 365 days a year to dehydrate embankments [17]. As a result of wicking geotextile installation, a relatively dry zone is formed within the embankment, increasing the stiffness of the soilgeotextile composite and improving the embankment performance [10, 18].

The effectiveness of the drainage system incorporating the wicking fabric has been validated through several successful case studies on field applications in Canada and the United States; the Beaver Slide highway in Alaska, Saint Louis County roadway in Missouri [19], and Texas County highway in Texas [20].

### 2.2 Unsaturated properties

The water retention characteristics and hydraulic conductivity functions are crucial hydraulic properties of geotextiles under unsaturated conditions. In unsaturated soil mechanics, the water retention curve (WRC) represents the water storage capacity of a geomaterial and is obtained by illustrating the relationship between water content ($\theta$) and suction ($\psi$) [2]. The WRC can be represented by both drying and wetting paths. The drying path typically reflects the material's ability to retain and transport water. Initially, a saturated geotextile subjected to increasing negative pressure will not allow air to enter the pores and desaturate it until the suction level reaches the air entry value (AEV). After reaching the AEV, the water content decreases with increasing suction until it reaches the residual conditions when little water is present in the pores, effectively blocking water flow. On the other hand, during the wetting path, an initially dry geotextile subjected to decreasing suction levels will not allow water to enter the pores until it reaches the water entry value (WEV) [11]. Figure 2 illustrates that these two paths (drying and wetting) exhibit hysteresis phenomena. The wetting path remains relatively flat within high suction levels due to air entrapment in the large pores, preventing water from saturating the material [11].

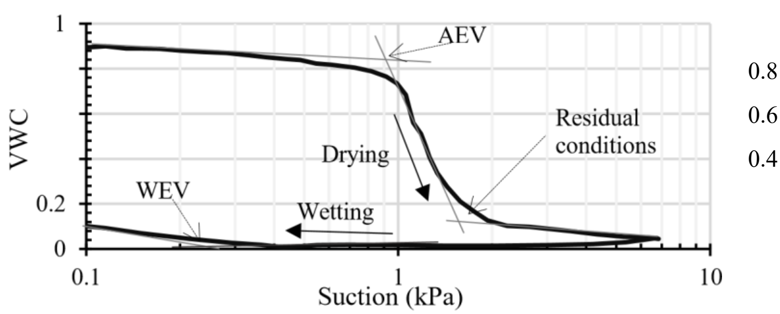


**Fig. 2.** Variation of water-retention on drying and wetting paths, adapted from Bouazza et al. (2006).

## 3. Experimental methods to measure the GWRC

The constitutive function $\theta(\psi)$ of geotextiles is determined experimentally. There are primarily two approaches to measure the GWRC (Geotextile-Water Retention Curves): suction control methods and moisture control methods. Suction control methods involve measuring the specimen's water content at different suctions. Commonly used tests for this approach include the capillary rise test, the hanging column test, the pressure plate test, and the salt concentration test. Conversely, moisture control methods require measuring suction at different water content levels. Common instruments employed for assessing the suction of geotextile specimens when they are stabilized at a specific hydraulic condition include thermocouple psychrometers, filter paper, and tensiometers. Researchers have specified the use of each method for a certain suction range and complexity [21–23]. This paper focuses on reviewing the common physical techniques available as suction control methods. These techniques mainly involve imposing increasing or decreasing suctions on an initially dry sample for the wetting path or an initially saturated sample for the drying path.

### 3.1 Capillary rise test

The capillary rise test primarily involves suspending geotextile samples vertically, with widths ranging from 50 to 100 mm and lengths between 500 to 1000 mm, while submerging their ends in water [24]. Initially saturated samples are wrapped with plastic sheets to prevent evaporation. These samples are left hanging for a duration of 1 to 4 days until equilibrium conditions are achieved. It is worth noting that time does not significantly influence the test results, as indicated in the literature [21]. In the literature, researchers have monitored the height of water rise over time for initially dry samples, providing an estimation of the water entry value (WEV) in the in-plane direction [13, 25]. Additionally, in-plane water retention curves for both wetting and drying paths are obtained by measuring the volumetric water content at different heights above the water surface. This is accomplished by cutting the strips into 20- or 50-mm segments and weighing them before and after oven drying to calculate the volumetric water content and plot the relationship $\theta(\psi)$ [26]. Furthermore, the capillary rise test has also been conducted with inclined samples at various angles, a variation known as the tilted capillary rise test [27].

### 3.2 Hanging column test

The hanging column test, initially designed to measure soil water retention characteristics [28], has been adapted for assessing the water retention properties of geotextiles [29]. In this procedure a geotextile specimen is positioned on a saturated porous ceramic plate under a seating load, establishing hydraulic equilibrium and facilitating contact between the two porous materials. The porous ceramic plate is connected to a manometer tube, which, in turn, is linked to a reservoir. To impose a suction value on the geotextile specimen, the porous disk's level is adjusted above the water level in the manometer tube beneath the plate. The geotextile specimen responds by either absorbing or adsorbing water to equilibrate with the water in the porous plate as the reservoir level varies. After achieving equilibrium at a specified suction level (typically 24 hours), the specimen is removed and weighed to measure its water content at the target suction [30, 31]. This testing technique is suitable for suction heads of approximately two meters or less [13]. Stormont reports that several days to weeks were required to measure a GWCC.

### 3.3 Pressure plate test or axis translation technique

The pressure plate test (or axis translation technique) is an alternative controlled suction method. In this technique, a known air pressure is imposed on the sample that has been placed in contact with a saturated porous ceramic plate of an air entry value higher than the applied [31]. The air pressure forced water to get out of the cell, and when equilibrium conditions are reached, the samples are taking from the apparatus to measure the corresponding water content. Equilibrium conditions are reached when no more water is out from the cell to the beaker at a specific suction. This method was mostly used to measure the geotextile clay liners (GCL)' water retention curves [32]. The disadvantage of using this technique for GCL systems is the lack of adequate contact between the specimen and the porous disc/membrane, which results in significant scatter in the retention data (Southen and Rowe, 2007). Other authors designed a controlled outflow capillary pressure cell to measure the water retention curve of non-woven geotextiles, this setup has the ability to accommodate for large testing samples and has air and water pressure transducers to monitor and record suction and water outflow using a computer-controlled data acquisition system (DAS) [31, 33]. Recently Lin 2019 used the traditional pressure plate cell to measure the water retention curves of woven geotextiles and in order to ensure a good contact between the woven geotextile and the ceramic plate, the author proposed to add a thin layer of soil slurry to ensure continuous flow between the geotextile and the porous ceramic plate.

## 4. Experimental application

Capillary rise test is performed to measure the water retention characteristics of a newly proposed wicking geogrid composite. Measured data is curve fitted using two methods, the Fredlund and Xing equation [34] and the modified the Van Genuchten equation [35], shown in equations 1 and 2, respectively.

$$\theta_i = \theta_s \left[1 - \frac{\ln\left(1+\frac{\Psi}{h_r}\right)}{\ln\left(1+\frac{10^6}{h_r}\right)}\right] \left\{\frac{1}{\ln\left[e + \left(\frac{\Psi}{\alpha_f}\right)^{n_f}\right]}\right\}^{m_f} \tag{1}$$

$$\theta_i = \frac{(\theta_s - \theta_r)}{\{1 + (\alpha \Psi_i)^q\}^p} + \theta_r \tag{2}$$

### 4.1 Materials and methods

A wicking geogrid composite that comprises a biaxial polypropylene geogrid heat bonded to a polyester wicking non-woven geotextile is used in the present investigation. This material has been tested for its tensile properties [36] and in this paper, it will be tested for its unsaturated hydraulic properties. The geotextiles hydraulic properties provided by the manufacturer are presented in Table 1.

Drying capillary rise tests were conducted following the experimental method described above. Samples measuring 100 mm in width and 1000 mm in length were cut from a roll as received from the manufacturer. These samples were saturated by immersing them in distilled water for 24 hours. After saturation, excess water was removed, and the samples were wrapped in plastic sheets to prepare them for vertical hanging. The test was repeated four times to ensure the repeatability of the results. The tested samples were then left hanging vertically for 7 days to reach equilibrium conditions.

**Table 1.** Hydraulic properties provided by the manufacturer

| | |
|---|---|
| Permittivity | 1.62 $sec^{-1}$ |
| Flow rate | 4940 $l/min/m^2$ |

| | |
|---|---|
| Wet front water movement (983 min/ 0 gradient) | 2301 mm |
| Apparent Opening Size | 0.2 mm |

### 4.2 Results

Figure 3 displays the measured data from four repeated capillary rise tests. The data from these repeated tests exhibit a relatively consistent distribution. The water content decreases as suction increases, indicating that higher suction values result in drier test samples. These results are primarily influenced by the equilibrium between gravity flow and capillary rise, as described by Lin (2019).

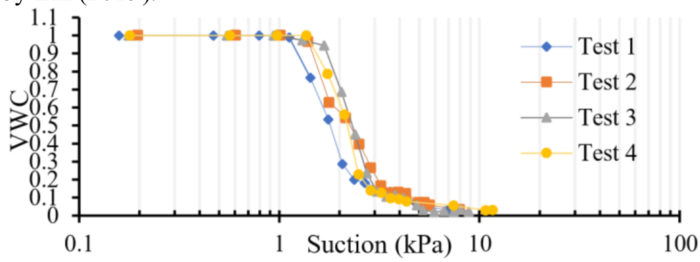


**Fig. 3.** Capillary tests' measured data on the wicking geogrid composite.

Each test was fitted to both the modified Van Genuchten and the Fredlund and Xing equations. Figure 4 illustrates the average GWRC and the unsaturated hydraulic properties resulting from the four tests using both curve-fitting methods. Notably, both methods produced similar results, with an AEV (Air Entry Value) of 1.4 kPa and residual conditions around 4 kPa. These findings are relatively higher than those observed in the majority of conventional geotextiles [37]. This suggests that in drying conditions, wicking geotextiles exhibit a superior ability to retain and transport water compared to conventional geotextiles.

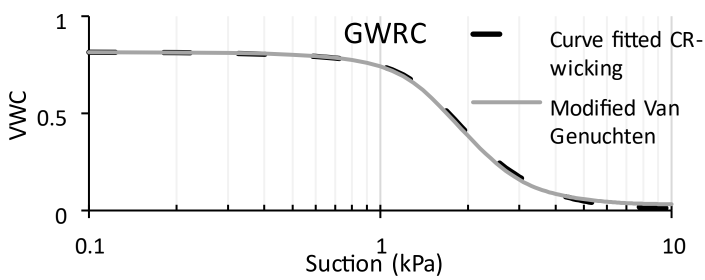


**Fig. 4.** Curve fitted results using both Van Genuchten and Fredlund and Xing methods.

## 5. Conclusion

This paper examines the unsaturated hydraulic behavior of conventional geotextiles versus wicking geotextiles. Conventional geotextiles have a limited ability to dehydrate unsaturated soil embankments, leading to significant stability problems. On the other hand, wicking geotextiles, with their hydrophilic and hygroscopic properties, can effectively wick moisture away from unsaturated embankments, thereby preventing the capillary break effect. The paper delves into the operational mechanism of wicking geotextiles and the methods of characterization. It emphasizes water retention properties as key parameters for understanding transient water flow in unsaturated geomaterials. Moreover, it focuses on physical techniques for measuring the water retention curves of geotextiles. The paper also showcases an application using a newly introduced wicking geogrid composite. A capillary rise test is conducted to determine the water retention curves of this material. The gathered data is then fitted to two established models. The findings indicate that the air entry value (AEV) and the residual conditions of the wicking geogrid composite are notably higher than most conventional geotextiles. This underscores its capacity to retain and move water in unsaturated scenarios.

## 6. Acknowledgements

This research is funded by an NSERC Alliance grant in partnership with Titan Environmental Ltd. The authors are grateful for Mr. John Bartczak, of the Jamieson Structures Laboratory at McGill University for their help in building the experimental setup.

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