

Water Retention Behavior of Wicking and Conventional Non-Woven Geotextiles

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Abstract

Non-woven geotextiles are widely used in soil embankments for separation, filtration, and drainage. Although soil embankments often remain in unsaturated conditions during their service life, conventional non-woven geotextiles are primarily designed for saturated conditions. As a result, their water retention capacity is often overlooked or tested within a limited suction range due to their hydrophobic nature and low hydraulic conductivity. To overcome these limitations, wicking non-woven geotextiles have been developed with hydrophilic and hygroscopic properties. This study evaluates the unsaturated behavior of wicking geotextiles relative to conventional non-woven geotextiles across the full suction range encountered in unsaturated soils. Laboratory tests, including capillary rise and hanging column, were conducted to establish and compare the geotextile-water retention curves of both materials. The results highlight the superior capacity of wicking geotextiles to retain and transport water under unsaturated conditions.

Introduction

Non-woven geotextiles are widely used in transportation embankments due to their ability to perform key functions such as filtration, separation, and drainage. Their design primarily focuses on performance under saturated conditions, where they facilitate the removal of gravitational water [1]. However, conventional non-woven geotextiles often exhibit reduced effectiveness fail to perform effectively in unsaturated soils, which are prevailing conditions in transportation embankments [2]. In such conditions, these materials tend to act as capillary barriers rather than facilitating moisture movement. This capillary-break effect impedes water flow across the geotextile, ultimately causing a buildup of moisture that can compromise both soil stability and system performance[3], [4].

To overcome the limitations of conventional geotextiles, wicking geotextiles have been developed. These materials possess hydrophilic and hygroscopic properties, enabling them to

efficiently drain both gravitational and capillary water from unsaturated embankments [5]–[7]. Unlike conventional geotextiles, which restrict moisture movement, wicking geotextiles create a continuous pathway for moisture transport under unsaturated conditions [6], [8]. [6], [7]. Field and laboratory studies have validated their effectiveness, showcasing improvements in embankment stability and durability by reducing moisture accumulation and capillary water [6], [9]–[11].

A critical aspect of evaluating geotextile performance in unsaturated conditions lies in understanding their water retention behavior. Water retention curves (WRCs) provide a quantitative relationship between suction (ψ) and volumetric water content (θ), offering insights into the drying and wetting characteristics of the material [12]. The drying path highlights the geotextile's ability to retain and transport water as suction increases, with key parameters such as the air entry value (AEV) identifying the transition from saturation to desaturation [13]. Figure 1 illustrates the wetting and drying paths of a non-woven geotextile [13]. Common experimental techniques used in the literature to determine WRCs include capillary rise tests [14]–[17] and hanging column tests [18]–[20]. These methods are suitable for characterizing the WRC within a suction range of 0–10 kPa. However, when geotextiles must be evaluated for their unsaturated behavior in soil embankments, where suction levels can reach several hundred kPa, other methods are required to assess the WRC over a broader suction range. One such method is the pressure plate test [19], [21], which is widely adopted for this purpose. These experimental methods impose varying suction levels on the geotextile and measure the corresponding water content.

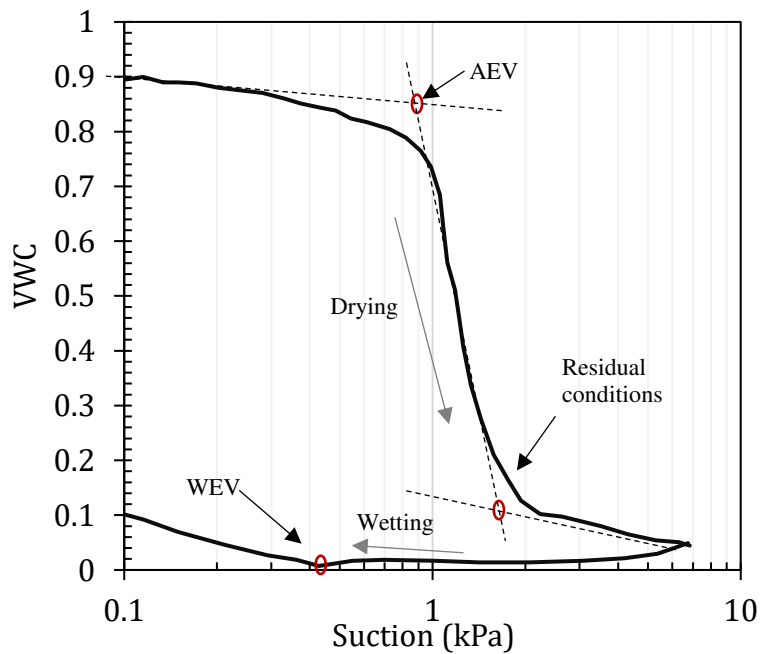


Figure 1: Geotextile water retention on drying and wetting paths, adapted from Bouazza et al. (2006).

Wicking geotextiles are installed horizontally at a zero gradient within soil embankments, with their ends exposed to the atmosphere [2]. These geotextiles absorb moisture from unsaturated soil in the cross-plane direction, causing wetting along this axis. The absorbed moisture then migrates in-plane due to the humidity gradient between the exposed and buried sections, results in drying within the in-plane direction. Finally, evaporation drives drying in the cross-plane direction. This process involves distinct but interconnected wetting and drying mechanisms. Despite its significance, the unsaturated behavior of geotextiles in these directions remains insufficiently studied in the literature. Previous studies have distinguished between cross-plane and in-plane testing of the unsaturated behavior of non-woven geotextiles [22], [23]. Understanding these directional differences is critical for wicking geotextiles, as their moisture transport efficiency depends on multidirectional transport capacity

This study investigates the unsaturated hydraulic behavior of a newly developed wicking geotextile, termed “WickGrid”, and compares it with conventional non-wicking geotextiles. The WickGrid is composed of a hydrophilic, chemically treated nonwoven geotextile bonded to a high-strength polymeric geogrid[24]. The WickGrid has not yet been tested for unsaturated behavior. This study utilizes capillary rise and hanging column tests to produce comprehensive water retention curves and assess the material's performance in both the in-plane and cross-plane directions. The findings aim to highlight the superior moisture management capabilities of wicking geotextiles compared to conventional geotextiles.

Methodology

This study evaluates the unsaturated properties of a wicking non-woven geotextile and a conventional non-woven geotextile. Capillary rise and hanging tests are performed to develop and compare the geotextile-water retention curves (GWRC) along the drying path in the in-plane and cross-plane directions.

Materials

This study investigates two types of geotextiles: a conventional non-woven geotextile and a chemically treated version referred to as a wicking non-woven geotextile. For the capillary rise test, rectangular samples measuring 10 cm × 100 cm are prepared, while circular samples with an 8 cm diameter are used for the hanging column test. The capillary rise test is conducted in quadruplicate for each material, requiring four samples per geotextile type. The hanging column test is performed once for each geotextile, requiring one sample per geotextile type. Before testing, all samples are saturated by submerging them in distilled water for 24 hours, as specified by ASTM D6637 standards. After saturation, excess water is carefully removed. Manufacturer-provided saturated hydraulic properties are presented in Table 1.

Table 1 : Hydraulic properties of geotextiles

<i>Material</i>	Reference	<i>property</i>	<i>value</i>
Conventional non-woven geotextile	ASTM D 4751	AOS (mm)	0.075
	ASTM D 4491	Permittivity (s ⁻¹)	1.39
Wicking non-woven geotextile	ASTM D 4751	AOS (mm)	0.2
	ASTM D 4491	Permittivity (s ⁻¹)	1.62

Experimental program

Two laboratory tests are performed to obtain the geotextile water retention curves for suction values ranging from 0 to 10 kPa in both cross-plane and in-plane directions. The tests include the capillary rise test and hanging column test. The capillary rise test characterizes the water retention curve along the in-plane direction for suction values ranging from 0 to 10 kPa. The hanging column test determines the water retention curve in the cross-plane direction within the same suction range of 0 to 10 kPa.

Capillary rise

Geotextiles are tested for in-plane water retention using the capillary rise method. Samples measuring 100 mm in width and 1000 mm in length are immersed in distilled water for 24 hours to ensure saturation [14], [25]. Excess water is removed, and the samples are wrapped in plastic sheets to prevent evaporation before being prepared for vertical hanging. Four replicate tests are conducted for each geotextile type to ensure result reliability. The vertically hung samples are left for seven days to reach equilibrium, as literature indicates that equilibrium conditions are not significantly time-dependent. [8]. In-plane water retention curves for the drying path are obtained by measuring the volumetric water content at different heights above the water surface. This is achieved by cutting the samples into 20- or 50-mm segments and weighing them before and after oven drying. These weight measurements are then used to calculate the volumetric water content and plot the relationship $\theta(\psi)$ [17].

Hanging column

During the hanging column test, the geotextile specimen is placed on a saturated porous ceramic plate under a seating load, ensuring hydraulic equilibrium and proper contact between the two porous materials. The ceramic plate is connected to a manometer tube, which is further linked to a water reservoir. To impose a specific suction value on the geotextile specimen, the height of the porous ceramic plate is adjusted above the water level in the reservoir. This adjustment creates a pressure differential, causing the geotextile specimen to adsorb water

across its cross-section until equilibrium is reached with the water in the ceramic plate. Typically, equilibrium is achieved after 24 hours at a given suction level. Once equilibrium is attained, the specimen is carefully removed and weighed to determine its water content at the target suction level [18], [19].

Results and discussion

The results of the capillary rise test and hanging column test are presented and discussed in the following sections, as illustrated in Figures 2 and 3.

Capillary rise test

The capillary rise test results for non-wicking and wicking geotextiles are displayed in Fig.2Figure 2, illustrating the unsaturated behavior in the in-plane direction. The plotted data represent average values of the four specimens for each geotextile type, calculated by averaging the volumetric water content (VWC) at each targeted suction level.

The drying process is influenced by both gravitational drainage and capillary action. Initially, saturated samples drain water downward due to gravity. As drying progresses, capillary action counterbalances gravitational forces, leading to equilibrium.

The non-wicking geotextile maintains a volumetric water content (VWC) of approximately 82% at nearly zero suction levels for seven days during the drying phase. The water content remains stable until the suction level reaches the Air Entry Value (AEV) of about 0.5 kPa, equivalent to a 5 mm head level. Beyond this point, the VWC sharply declines to 6% at a suction level of 1.4 kPa, marking the residual condition where minimal moisture remains. In contrast, the wicking geotextile initially exhibits a VWC of approximately 80% during the drying phase, like the non-wicking geotextile. This VWC remains stable until the AEV of 1.6 kPa, a significantly higher threshold than that of the non-wicking geotextile, indicating enhanced water retention capability. Beyond this AEV, the decline in VWC is less pronounced, tapering off to 6% at a suction level of 5 kPa. This behavior highlights the wicking geotextile's ability to retain higher moisture levels across the 0 to 10 kPa range of suction levels compared to the non-wicking geotextile in the in-plane direction.

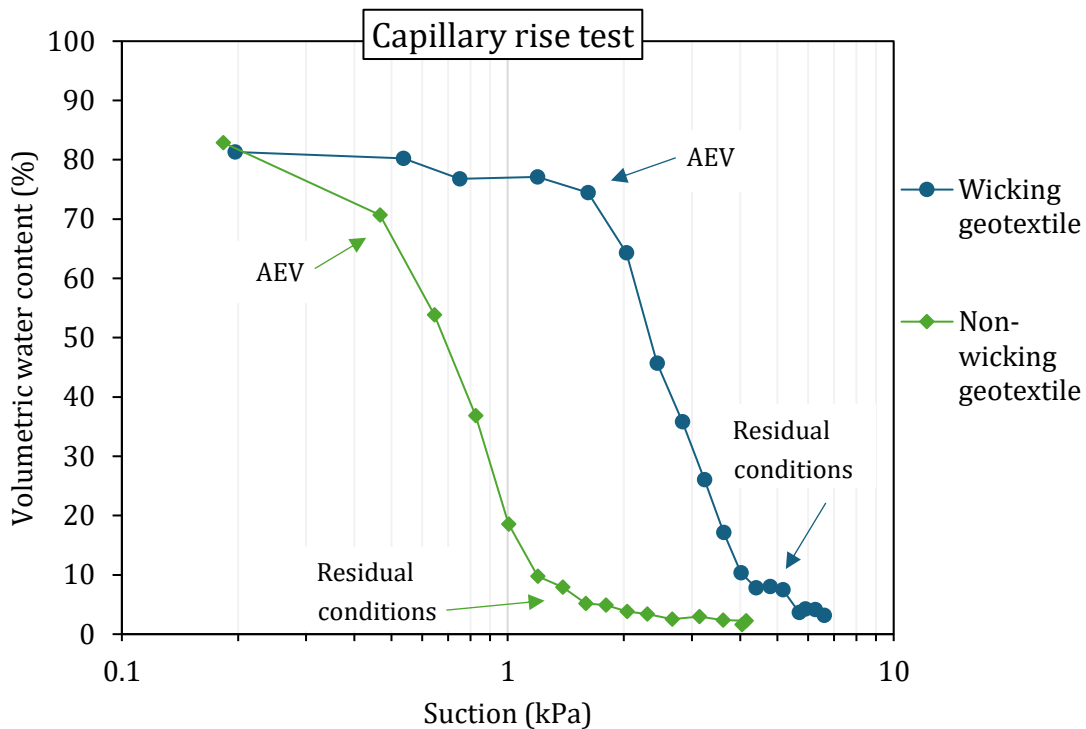


Figure 2 : Capillary rise tests results

Hanging column test

The hanging column test results for non-wicking and wicking geotextiles are displayed in Fig.3, demonstrating the drying behavior of the geotextiles in the cross-plane direction. The initial saturated sample is placed on the saturated porous disk, the specimen loses moisture due to suction increase as the porous disk is moved above the water tank level.

The non-wicking geotextile maintains a volumetric water content (VWC) of approximately 72% at nearly zero suction levels during the drying phase. The water content remains stable until the suction level reaches the Air Entry Value (AEV) of about 0.7 kPa, equivalent to a 7 mm head level. Beyond this point, the VWC greatly declines to 1.8% when reaching the suction level of 2 kPa, marking the residual conditions level. The wicking geotextile initially exhibits a volumetric water content (VWC) of approximately 77% in the drying path at 0 suction, close to the non-wicking geotextile. This VWC stabilizes at this level until the Air Entry Value (AEV) of 0.7 kPa is reached, like the non-wicking geotextile. Beyond this AEV, the VWC decreases to reach 5.5% at a suction level of 2 kPa. The results for the drying path in the cross-plane direction show similar unsaturated properties as AEV and residual conditions, for both wicking and non-wicking geotextiles. This indicates that the wicking geotextile will dry as fast as the non-wicking does in the cross-plane direction.

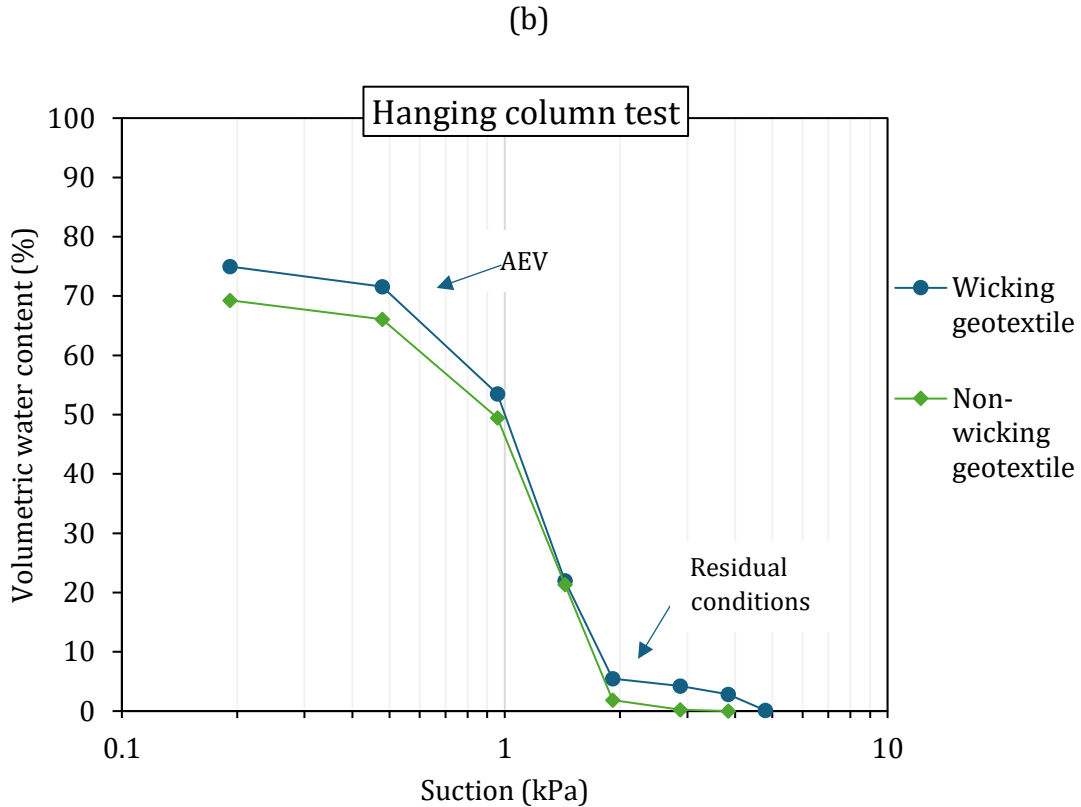


Figure 3 : Hanging column tests results

Conclusion

This study provides a comprehensive assessment of the water retention curves of both wicking and conventional non-woven geotextiles using capillary rise and hanging column tests conducted across both in-plane and cross-plane orientations. The findings highlight the distinct advantages of wicking geotextiles in unsaturated conditions, emphasizing their enhanced capacity for water retention and transport.

The capillary rise test results underscore the superior hydrophilic properties of wicking geotextiles. They maintain a higher volumetric water content (VWC) within the 0 to 10 kPa suction range compared to conventional non-wicking geotextiles, with a significantly higher air entry value AEV in the in-plane direction. This indicates their ability to retain and transport moisture effectively under low suction levels.

The hanging column test revealed that, in the cross-plane direction, both geotextile types exhibited similar drying paths, with comparable AEV values and residual moisture conditions. Overall, the results establish the wicking geotextile as a promising material for applications in unsaturated conditions, offering enhanced capabilities for lateral drainage material. These findings contribute to advancing the design and application of geotextiles in transportation embankments and other infrastructure subjected to unsaturated conditions.

References

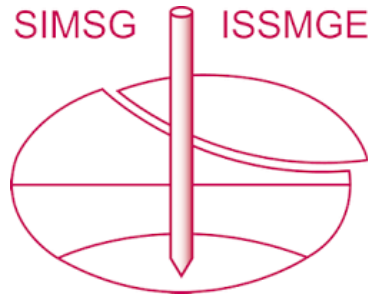
- [1] R. M. Koerner, *Designing with geosynthetics-Vol.1*, Vol.1. Xlibris Corporation, 2012.
- [2] N. Lu and W. J. Likos, "Rate of Capillary Rise in Soil," *J. Geotech. Geoenvironmental Eng.*, vol. 130, no. 6, pp. 646–650, 2004, doi: 10.1061/(asce)1090-0241(2004)130:6(646).
- [3] M. J. Lima, M. M. Azevedo, J. G. Zornberg, and E. M. Palmeira, "Capillary barriers incorporating non-woven geotextiles," *Environ. Geotech.*, vol. 5, no. 3, pp. 168–175, 2018, doi: 10.1680/jenge.16.00038.
- [4] J. C. Chai, *Geotextiles used in drainage*. Elsevier Ltd, 2016. doi: 10.1016/B978-0-08-100221-6.00013-9.
- [5] J. G. Zornberg, M. Azevedo, M. Sikkema, and B. Odgers, "Geosynthetics with enhanced lateral drainage capabilities in roadway systems," *Transp. Geotech.*, vol. 12, pp. 85–100, 2017, doi: 10.1016/j.trgeo.2017.08.008.
- [6] J. Guo, J. Han, X. Zhang, and Z. Li, "Evaluation of moisture reduction in aggregate base by wicking geotextile using soil column tests," *Geotext. Geomembranes*, vol. 47, no. 3, pp. 306–314, 2019, doi: 10.1016/j.geotexmem.2019.01.014.
- [7] C. Lin, X. Zhang, J. Galinmoghadam, and Y. Guo, "Working mechanism of a new wicking geotextile in roadway applications: A numerical study," *Geotext. Geomembranes*, vol. 50, no. 2, pp. 323–336, 2022, doi: 10.1016/j.geotexmem.2021.11.009.
- [8] C. Lin, "Use of Wicking Geotextile To Dehydrate Road Embankments," 2019.
- [9] X. Zhang and B. Connor, "Evaluate H2RI Wicking Fabric for Pavement Application-Year 2," 2015, [Online]. Available: <https://scholarworks.alaska.edu/handle/11122/10380%0Ahttps://digital.lib.washington.edu/researchworks/handle/1773/43553>
- [10] M. Subgrade Stabilization, St. Louis County, *Tencate Geosynthetics*. 2013. [Online]. Available: <https://www.tencategeo.us/en-us/resources/Case-Studies/Case-study-explorer//UhiT/Subgrade-Stabilization-St-Louis-County-MO>
- [11] M. Azevedo and J. G. Zornberg, "Capillary barrier dissipation by new wicking geotextile,"

Adv. Unsaturated Soils, pp. 559–565, 2013.

- [12] J. G. Zornberg, A. Bouazza, and J. S. McCartney, “Geosynthetic capillary barriers: Current state of knowledge,” *Geosynth. Int.*, vol. 17, no. 5, pp. 273–300, 2010, doi: 10.1680/gein.2010.17.5.273.
- [13] A. Bouazza *et al.*, “Water retention of nonwoven polyester geotextiles,” *Polym. Test.*, vol. 25, no. 8, pp. 1038–1043, 2006, doi: 10.1016/j.polymertesting.2006.07.002.
- [14] J. Lafleur, M. Lebeau, Y.-H. Faure, Y. Savard, and Y. Kehila, “Influence of matric suction on the drainage performance of polyester geotextiles,” in *Annual conference; 53rd, Canadian Geotechnical Society; Geotechnical engineering at the dawn of the 3rd millenium*, 2000, pp. 1115–1122.
- [15] H. Nahlawi, A. Bouazza, and J. Kodikara, “Capillary Rise in Unsaturated Nonwoven Geotextiles,” vol. 2, no. March, pp. 281–289, 2008.
- [16] J. C. Stormont and C. E. Morris, “Characterization of Unsaturated Nonwoven Geotextiles,” in *In Advances in Unsaturated Geotechnics.*, 2000, pp. 153–164.
- [17] C. Lin, Y. Guo, X. Zhang, and J. Galinmoghadam, “Reexamination of traditional testing techniques for determining WRCs of woven geotextiles in full suction range,” *Geotext. Geomembranes*, no. April, 2023, doi: 10.1016/j.geotexmem.2023.04.007.
- [18] R. Graça, M. Almeida, and L. Villar, “Determination of water retention curves for one residual soil and two distinct non-woven geotextiles,” *MATEC Web Conf.*, vol. 337, p. 01015, 2021, doi: 10.1051/mateconf/202133701015.
- [19] M. A. Knight and S. M. Kotha, “MEASUREMENT OF GEOTEXTILE-WATER CHARACTERISTIC CURVES USING A CONTROLLED OUTFLOW CAPILLARY PRESSURE CELL,” *J. Geotech. Geoenvironmental Eng.*, vol. 8, no. September, pp. 790–800, 2001.
- [20] J. C. Stormont, K. S. Henry, and T. M. Evans, “Water retention functions of four Nonwoven polypropylene geotextiles,” *Geosynth. Int.*, vol. 4, no. 6, pp. 661–672, 1997.
- [21] J. M. Southen and R. Rowe, “Evaluation of the water retention curve for geosynthetic clay liners,” *Geotext. Geomembranes*, vol. 25, no. 1, pp. 2–9, 2007, doi: 10.1016/j.geotexmem.2006.10.002.

- [22] C. B. Pickles and J. G. Zornberg, "Hydraulic Classification of Unsaturated Nonwoven Geotextiles for use in Capillary Barriers," *Second Pan Am. Geosynth. Conf. Exhib.*, no. May, pp. 408–420, 2012.
- [23] U. Al-Anbaki, "Hydraulic Interaction of Soil and Nonwoven Geotextiles under Unsaturated Conditions Bochum," RUHR-UNIVERSITÄT BOCHUM Usama, 2019.
- [24] J. Jarjour and M. Meguid, "Investigating the effect of temperature and water freezing on the response of geogrid composite," *Geosynth. Int.*, pp. 1–10, 2023.
- [25] K. S. Henry and R. D. Holtz, "Capillary rise of water in geotextiles," in *Proceedings of International Symposium on Ground Freezing and Frost Action in Soils*, 1997, pp. 227–233.
- [26] ASTM D6836-16, "Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge," ASTM international, West Conshohocken, PA, 2016.

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