Numerical modeling of 1D infiltration on unsaturated interfaces between soil and geosynthetics

Modélisation numérique de l'infiltration 1D sur des interfaces non saturées entre le sol et les géosynthétiques

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ABSTRACT: Capillary barriers developed on unsaturated interfaces soil-geosynthetics have been studied for different engineering applications. However, the breakthrough of water depends of matric suction at the unsaturated interface under infiltration. The threshold suction for breakthrough of water is function of different parameters as initial moisture content, type o geosynthetic and interface geometry. To provide the understanding of capillary barriers behavior under infiltration, the use of numerical modeling can be an encouraging tool, since it allows an intensive parametric study of infiltration into unsaturated interfaces soil-geosynthetics. This study consists on the 1-D numerical modeling of a physical infiltration column conducted in laboratory to investigate the hydraulic behavior of interfaces soil-geosynthetics. Three different nonwoven geotextiles characterized by Stormont and Morris (2000), Bathrust *et al.* (2009) and Lima (2014) were simulated using finite element software. The numerical modeling was used to evaluate the effect of the shape of water retention curves (WRCs) on the development of capillary barriers at soil-geosynthetic interfaces. Results showed a good agreement between numerical and physical 1-D infiltration models and the development of capillary barriers during infiltration was observed.

RÉSUMÉ : Les barrières capillaires développées sur des interfaces non saturées sol-géosynthétiques ont été étudiées pour différentes applications techniques. Cependant, la percée de l'eau dépend de l'aspiration matricielle à l'interface insaturée sous l'infiltration. Le seuil d'aspiration pour la percée de l'eau est fonction de différents paramètres comme teneur en humidité initiale, type o géosynthétique et géométrie d'interface. Pour mieux comprendre le comportement des barrières capillaires sous l'infiltration, l'utilisation de la modélisation numérique peut être un outil encourageant car elle permet une étude paramétrique intensive de l'infiltration dans des interfaces non saturées sol-géosynthétiques. Cette étude consiste en la modélisation numérique en 1-D d'une colonne d'infiltration physique réalisée en laboratoire pour étudier le comportement hydraulique des interfaces sol-géosynthétiques. Trois différents géotextiles caractérisés par Stormont et Morris (2000), Bathrust *et al.* (2009) et Lima (2014) ont été simulés à l'aide de logiciels à éléments finis. La modélisation numérique a été utilisée pour évaluer l'effet de la forme des courbes de rétention d'eau (WRC) sur le développement des barrières capillaires aux interfaces géosynthétiques du sol. Les résultats ont montré une bonne concordance entre les modèles numériques et physiques d'infiltration 1-D et le développement de barrières capillaires pendant l'infiltration.

KEYWORDS: Numerical modeling; Nonwoven Geotextile; Capillary Barrier; Unsaturated Soil; Infiltration.

1. INTRODUCTION

Most design manuals recommend the use of granular soil as backfill of geosynthetic reinforced soil structures in North America and Europe (Portelinha and Zornberg 2014). Nonetheless, in practice contractors use local fine-grained soil as backfill materials in order to save money and avoid environmental problems in disposing the local soil. As a result, the use of local fine-grained soil in a unsaturated condition can lead to a development of capillary barrier when geotextiles are used.

The capillary barrier is a mechanism used to block the water flux and it is formed when materials with different porosity and permeability are put together in an unsaturated condition. Although nonwoven geotextiles are not classified as porous medium material, it is known that they have a porous matrix, and so, its behavior is similar to granular soils. The capillary barrier development has been suggested as a low cost system in different engineering applications, such as: agriculture, landfill cover, mining, drainage of paving structures and others. However, hard work has been put in order to avoid the capillary barrier development. For instance, in case where the geotextile is used as a filter for drainage purpose.

On saturated conditions, the nonwoven geotextile has high permeability, similar to a coarse soil. Nevertheless, when subjected to unsaturated conditions this material become highly impermeable, even more than fine-grained soils (Stormont and Morris 2000, McCartney and Zornberg 2010). Moreover, many studies have shown that nonwoven geotextile act as a moisture barrier instead of a drainage material due to capillary barrier effect (Iryo and Rowe 2004, Iryo and Rowe 2005, Bathurst *et al.* 2009, Portelinha and Zornberg 2014, Thou *et al.* 2015, Thou *et al.* 2016).

This paper consists of four numerical modeling of a one dimensional column using four different nonwoven geotextiles characterized by Bathurst *et al.* (2009), Stormont and Morris (2000), Lima (2014) and Portelinha and Trovato (2014) with the objective of evaluate the development of capillary barrier into unsaturated interface of soil-geosynthetic. Firstly, the numerical modeling is calibrated by comparing the water front progression of a physical model studied by Portelinha and Trovato (2014). Then, further analyses are performed using the others geosynthetics to better understand its capability to block water from reach the free boundary surface.

2. MATERIALS PROPERTIES

The water retention curve (WRC) and conductive of the clayey sand soil used in the physical test by Portelinha and Trovato (2014), and the geosynthetics used in the analyses were adjusted to van Genuchten (1980) fitting parameters. The clayey sand used by Portelinha and Trovato (2014) has about 38% of fine grains (clay and silt) and 62% of granular soil (sand).

Table 1 present the sand clayey soil fitting parameters while Table 2 present the nonwoven geotextiles parameters. Note that the soil used in this study is a lateritic soil, and so, the shape of the WRC needs to be adjusted by two ranges of suction using the van Genuchten (1980) model. The hydraulic conductivity of all materials were adjusted using the van Genuchten-Mualem model.

Table 1 - Van Genuchten (1980) fitting parameters of clayey soil

Path	Suction	θs	θr	α (kPa-1)	n
Wetting	<200 kPa	0.256	0.375	0.14	4.74
Wetting	>200 kPa	0.022	0.256	0.0001	2.63
Drying	<200 kPa	0.215	0.35	0.313	5.3
Drying	>200 kPa	0.0183	0.215	0.0001	1.796

Table 2 – Van Genuchten (1980) fitting parameters of nonwoven geotextile

Author	θ_s	θ_r	α (kPa^{-1})	n	k_s (m/s)
Bathurst *et al.* 2009	0.800	0.120	14.70	16.8	1.4x10^{-3}
Stormont and Morris 2000	0.615	0.000	3.18	6.9	6.6x10^{-3}
Lima 2014	0.887	0.001	0.65	7.0	4.0x10^{-1}
Portelinha and Trovato 2014	0.82	0.001	0.2	3	5.3x10^{-3}

Plotting the hydraulic conductivities of all materials (Figure 1) in the same graph it is possible to have a better view of how the materials chosen for this study behave in unsaturated conditions.

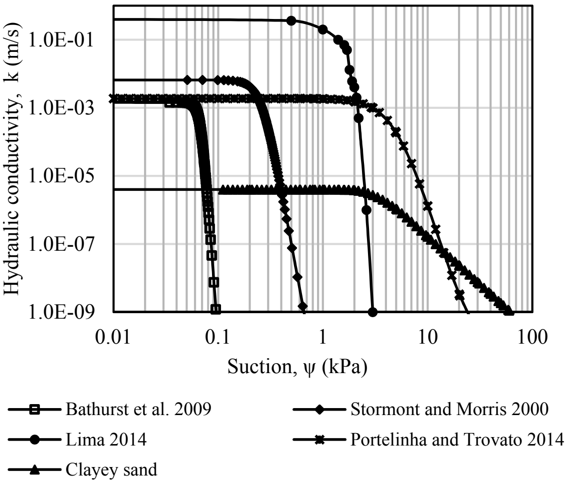


Figure 1 – Comparison of hydraulic conductivities of all materials (soil and nonwoven geotextile) used in the present study.

3. NUMERICAL CALIBRATION

Portelinha and Trovato (2014) performed a series of column infiltration tests using a clayey soil and a nonwoven geotextile. One of the column tests (Figure 2) was chosen to use as a reference in order to calibrate de numerical modeling. The initial conditions were of all subsequent transient analyses were set to 38.0 kPa suction based on the water content of 90% compaction of the clayey sand soil. As the clayey sand saturated permeability (k_{sat}) was 1.4x10^{-6} m/s, on the physical test, Portelinha and Trovato (2014) applied an infiltration of about 1.0x10^{-6} m/s on top of the column, which is about 1.4 times less the permeability of soil. While the test was running, volumetric water content was measured over time until a steady state condition was reached.

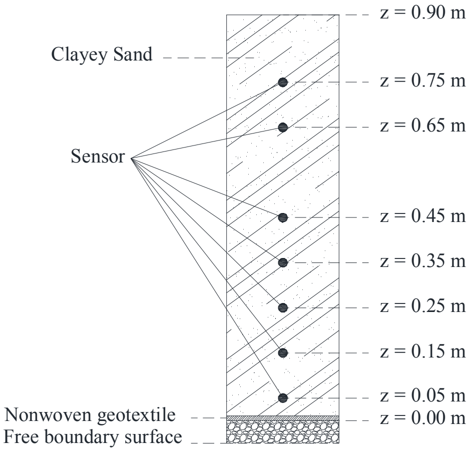


Figure 2 – Layout of Portelinha and Trovato (2014) infiltration column.

Figure 3 shows results from the column test and the numerical analyses. It is clear that with exception of the first sensor near to top of the column, results were quite consistent. Approximately 3% difference was observed on the volumetric water content between test result and numerical prediction. The reason for such a difference between results on the first sensor near the top could not be explained. It is supposed that water may have accumulated around those sensors. Just a few results were presented for better avaliation.

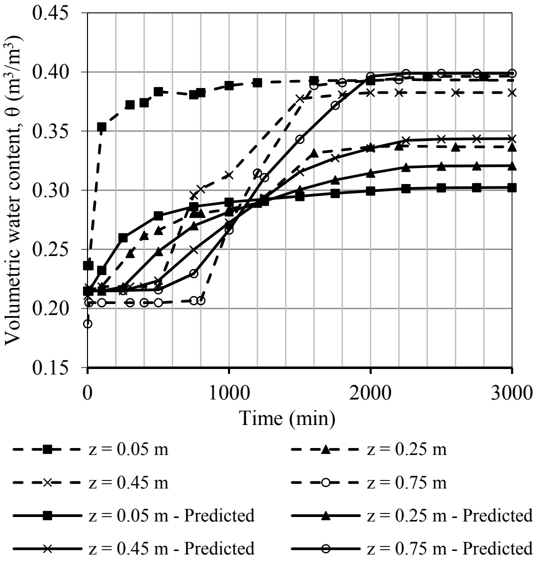


Figure 3 – Comparison of experimental results and numerical results of the front infiltration into the column over time.

Note that the profile of pore water pressure remained constant from 2000 minutes to 3000 minutes. Because of that, it can be inferred that steady state condition has been reached in the transient analyses.

Taking the pore water pressure development along the height of the column for different times (Figure 4), it can be seen that no positive pore water pressure build up on top of the geotextile (z = 0.00 m).

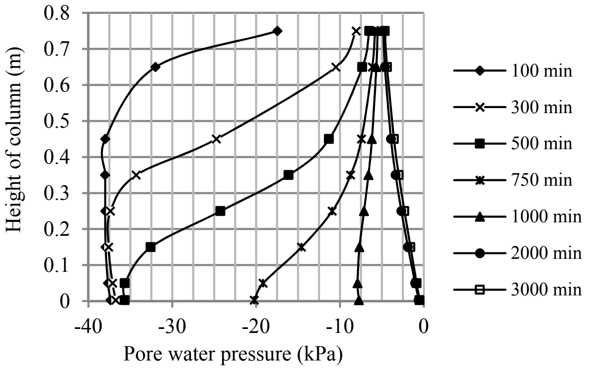


Figure 4 – Profile of pore water pressure along the height over time.

4. NUMERICAL MODELING RESULTS

As the results from numerical simulation were considerable close to physical testing and no positive pore water pressure developed above geotextile. Other characterized geotextiles were searched throw the literature to evaluate when pore water pressure would increase above geosynthetic characterizing a capillary barrier mechanism.

More three analyses were performed using the others geotextiles presented in Figure 1. The advance of wetting front and profile of pore water pressure will be presented in the following figures.

The height of the column needed to be changed in order to allow the model to accumulate water on top the geosynthetic studied without let water flow out of the column throw the top. So, the height was changed from 0.90 m to 1.20 m in the model. Figure 5 presents the new configuration.

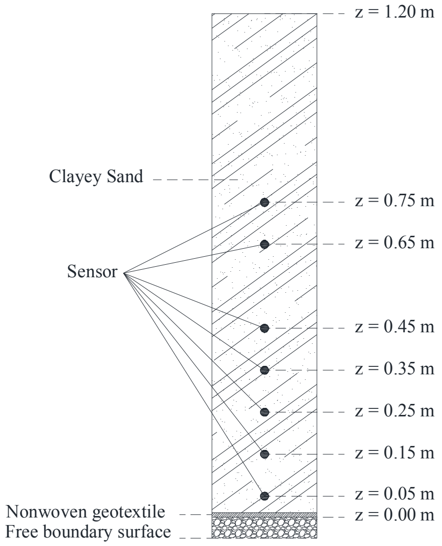
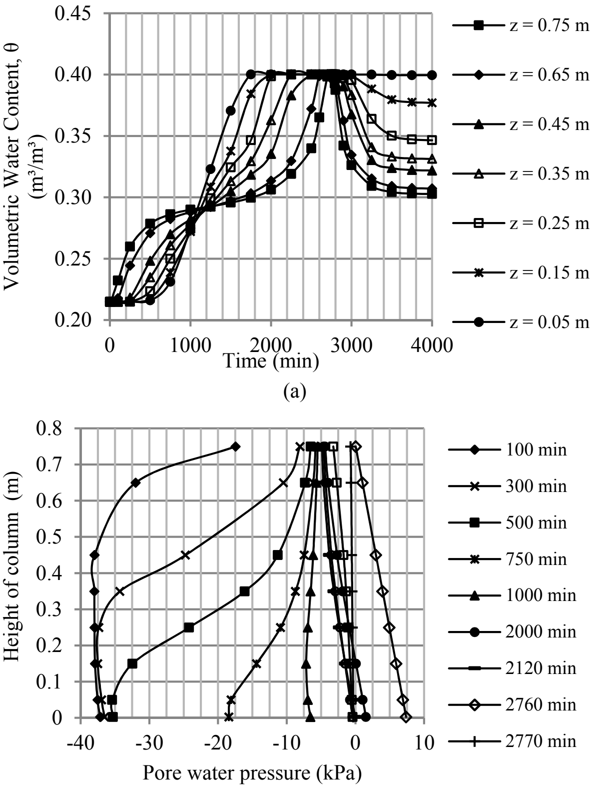


Figure 5 – New model used to evaluate the development of positive pore water pressure above geotextile.

The following results refer to the nonwoven geotextile characterized by Bathurst *et al.* (2009), Stormont and Morris (2000) and Lima (2014). Note that for each analyses required a different duration until steady state was reached.

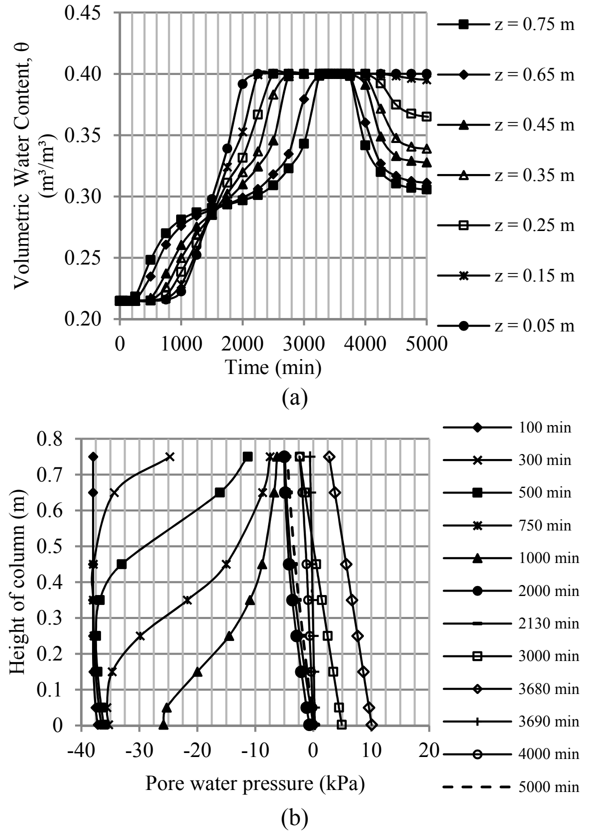
In Figure 6 and Figure 7 is clear that the geotextile acted as a capillary barrier since the volumetric water content raised to the saturated volumetric water content and there was an increase in pore water pressure above the geotextile (Height = 0.0 m) of approximately 7.5 kPa and 10 kPa for the Stormont and Morris (2000) and Bathurst *et al.* (2009) geosynthetic, respectively.



(a)

(b)

Figure 6 – (a) Advance of wetting front over using Stormont and Morris (2000) geosynthetic (b) Profile of pore water pressure along the height using Stormont and Morris (2000) geosynthetic.

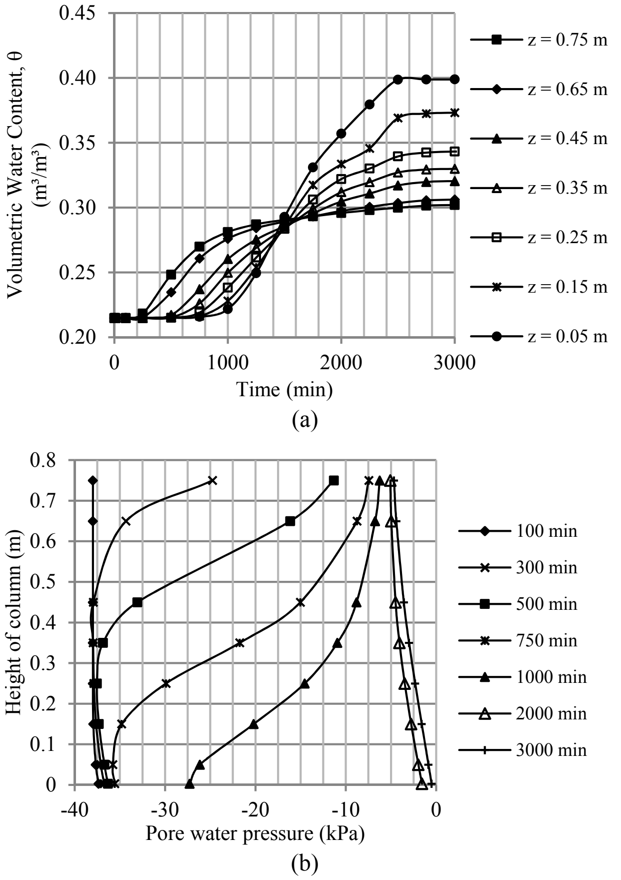


(a)

(b)

Figure 7 – (a) Advance of wetting front over using Bathurst *et al.* (2009) geosynthetic (b) Profile of pore water pressure along the height using Bathurst *et al.* (2009) geosynthetic.

In contrast, the geotextile characterized by Lima (2014) had no positive pore water pressure above it (Figure 8). Thus, the geotextile characterized by Lima (2014), as well as the geotextile used in the physical experiment (Portelinha and Trovato 2014), did not act as a capillary barrier.



(a)

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Figure 8 – (a) Advance of wetting front over using Lima (2014) geosynthetic (b) Profile of pore water pressure along the height using Lima (2014) geosynthetic.

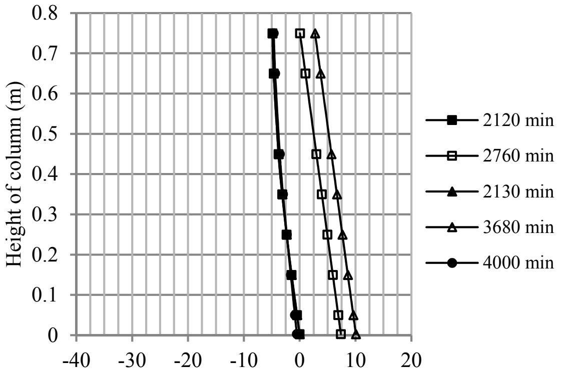

Figure 9 – Profile of maximum pore water pressure along height of column for the three nonwoven geotextiles studied. (Stormont and Morris 2000 represented by squares; Bathurst et al. 2009 represented by triangles; Lima 2014 represented by circles).

Figure 9 shows the time from the beginning of water accumulation on top of each geosynthetic until the time that water crossed the capillary barrier. Note that the time for the breakthrough of the capillary barrier was higher for nonwoven geotextile characterized by Bathrust *et al.* (2009), which was 3680 minutes in total.

5. CONCLUSIONS

A series of numerical analyses were conducted to investigate the hydraulic behavior of 1-D columns with different nonwoven geotextiles placed on its bottom. The following conclusions are presented:

- Numerical modeling agreed relatively well with the volumetric water content measured during a physical laboratory testing. A difference of about 3% of volumetric water content was noticed
- The nonwoven geotextile characterized by Bathrust *et al.* (2009) experienced a positive pore water pressure of 10 kPa before breakthrough of capillary barrier. While Stormont and Morris (2000) nonwoven geotextile experienced 7 kPa.
- No positive pore water pressure was developed on top of geosynthetic characterized by Lima (2014). So, it was concluded that there was no capillary barrier development.
- It may be affirmed that there is a geosynthetic with a WRC between the nonwoven geotextile characterized by Lima (2014) and Stormont and Morris (2000) that is classified as a limit for capillary barrier development.

6. ACKNOWLEDGEMENTS

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