Effect of Geocomposite Drainage Layer on Water Balance of Evapotranspirative Cap Lysimeters

Milind V. Khire\textsuperscript{1} and Ramil G. Mijares\textsuperscript{2}

\textbf{ABSTRACT:} It has been reported that a geotextile layer present in the geocomposite drainage layer acts as a capillary break when it is used to construct a lysimeter to study field-scale water balance performance of earthen caps. Numerical modeling was carried out to evaluate the capillary barrier effect in a soil column underlain by a geocomposite drainage layer. The numerical modeling carried out using the UNSAT-H model indicates that the capillary break introduced by a non-woven geotextile in lysimeters is significant only when the equivalent hydraulic conductivity of the cap soils is in the range of $10^{-3}$ to $10^{-4}$ cm/s. For cap soils having equivalent hydraulic conductivity $\leq 10^{-5}$ cm/s, the capillary barrier effect due to geotextile is insignificant.

\textbf{INTRODUCTION}

Evapotranspirative (ET) caps which contain only soil layers have been tested in the field since 1980s for long-term capping of municipal solid waste (MSW) landfills as well as radioactive waste sites. Since then, ET caps have been widely used in arid and semi-arid climates and are being tested and permitted in sub-humid and humid climates on a case by case basis. Often the performance of ET caps is evaluated by constructing a lysimeter to collect the percolation that infiltrates through the cap. Based on the magnitude of the annual percolation collected in the lysimeter, the ET cap is approved, disapproved, or redesigned.

The lysimeter usually contains a geocomposite drainage layer (GDL) installed at the base of the ET cap to collect and drain the percolation to a measuring or monitoring device(s). Often the geotextile (GT) present in the GDL is non-woven. Previous published studies indicate that non-woven geotextiles have soil water retention function that is similar to those of coarse-grained soils such as gravels and sands. Hence, it has been indicated that non-woven geotextile layer acts as a capillary break. If it acts as a capillary break, it allows greater storage of moisture in the soil layers above the geotextile before the percolation breakthrough occurs. In addition, a capillary break can reduce the total percolation by enhancing ET.

\textbf{OBJECTIVES}

The key objectives of the study presented in this paper are to evaluate: (1) the effect of a geocomposite drainage layer used in lysimeters on the water balance of the earthen cap; and (2) compare the capillary barrier effect due to the presence of a geotextile in lysimeters to that due to

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the waste layer that is present in actual caps.

In this numerical study, the effect of GDL consisting of a non-woven geotextile on the soil water storage of the cap was evaluated by numerically simulating three ET caps. 1-D cylindrical columns having 30 cm diameter and 90-cm height were simulated as lysimeters or actual caps using UNSAT-H.

**NUMERICAL MODELING**

Commercially available finite-difference model UNSAT-H (Fayer 2000) was used in this study. UNSAT-H numerically solves a modified form of Richards’ equation to compute the flow of water through both saturated and unsaturated soil. This model has been routinely used for water balance modeling of earthen caps (Khire et al. 1997; Khire et al. 2000). For this study, one-dimensional simulations were carried out using UNSAT-H Version 3.0.

A schematic of the conceptual model used in the numerical simulations is shown in Fig. 1. For the lysimeter, the lower boundary consists of a 4-mm thick GDL layer. For an actual cap, the cap was underlain by a 30 cm thick waste layer. Additional simulations with thicker waste layer were created. However, thicker waste layer did not influence the percolation and soil water storage of the simulated cap.

![Figure 1. Conceptual model used to simulate the lysimeter with a geocomposite drainage layer.](image-url)
Material Properties

Table 1 summarizes the saturated and unsaturated hydraulic properties of the soils used to simulate the lysimeter presented in Fig. 1. Hydraulic properties of the municipal solid waste (MSW) reported by Kazimoglu et al. (2006) were assumed to represent the waste layer in the actual cap. Kazimoglu et al. (2006) did not report the unit weight of the MSW used in their study. However, they mentioned that the waste was obtained from Lyndhurst Landfill in Australia. Stoltz and Gourc (2007) published similar waste retention curves for loosely compacted MSW having a dry unit weight equal to 0.57 g/cm³.

<table>
<thead>
<tr>
<th>Soil/Material</th>
<th>$\theta_s$ (cm³/cm³)</th>
<th>$\theta_r$ (cm³/cm³)</th>
<th>$\alpha$ (cm⁻¹)</th>
<th>$n$</th>
<th>$K_s$ (cm/s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotextile</td>
<td>0.82</td>
<td>0</td>
<td>0.066</td>
<td>3.99</td>
<td>1.5 x 10⁻¹</td>
<td>Park and Fleming (2006)</td>
</tr>
<tr>
<td>OK 110 Fine Sand</td>
<td>0.42</td>
<td>0.03</td>
<td>0.016</td>
<td>6.5</td>
<td>6.4 x 10⁻³</td>
<td>Mukherjee (2008)</td>
</tr>
<tr>
<td>SM Soil</td>
<td>0.42</td>
<td>0.02</td>
<td>0.005</td>
<td>1.48</td>
<td>2.7 x 10⁻⁴</td>
<td>Khire et al. (2000)</td>
</tr>
<tr>
<td>SM-ML Soil</td>
<td>0.35</td>
<td>0.02</td>
<td>0.012</td>
<td>1.123</td>
<td>9.0 x 10⁻⁶</td>
<td>Khire et al. (2000)</td>
</tr>
<tr>
<td>Waste</td>
<td>0.58</td>
<td>0.14</td>
<td>0.15</td>
<td>1.6</td>
<td>1.0 x 10⁻³</td>
<td>Kazimoglu et al. (2006)</td>
</tr>
</tbody>
</table>

Fig. 1 does not show the actual cap. In the actual cap, the GDL was replaced with a 30-cm thick waste layer. Fig. 2 shows the soil water characteristic curves and the hydraulic conductivity functions for the geotextile and the waste presented in Table 1. The soils presented in Table 1 are adopted from Khire et al. (2000) and Mukherjee (2008) and have been used by Khire and Mijares (2008) and Mijares et al. (2010). Fig. 2(b) shows that the unsaturated hydraulic conductivities of the non-woven geotextile have about the same magnitudes as that of MSW at matric suctions greater than about 20 cm.

Fig. 3 shows the unsaturated hydraulic conductivity of the three soils and the geotextile. In order for capillary barrier effect to occur, the hydraulic conductivity of the overlying finer-grained porous material needs to be greater than the underlying porous material (Khire et al. 2000). Fig. 3 shows that the unsaturated hydraulic conductivity of the geotextile is less than the overlying OK110 sand at matric suctions greater than about 20 cm. At 20 cm suction, the hydraulic conductivity of OK110 sand is relatively high (~ 6 x 10⁻³ cm/s). Fig. 3 also shows that when SM-ML soil is used as the soil for the cap, at about matric suction equal to 70 cm, the hydraulic conductivity of the GT drops below that of the SM-ML soil. The hydraulic conductivity of the SM-ML soil at 70 cm suction is about 10⁻⁷ cm/s, which is relatively low. Hence, while capillary barrier effect may occur for both soils, its effect on percolation would be relatively small when SM-ML soil is used.
Fig. 2. Soil water characteristic curves (a); and hydraulic conductivity function (b) for the simulated lysimeters and actual caps.
Initial and Boundary Conditions and Numerical Control Parameters

A constant unit flux boundary was applied at the ground surface (Figure 1) for the lysimeter as well as the actual cap. The constant unit flux was 5.3 mm/hr, 0.22 mm/hr, and 0.0075 mm/hr for the OK110 fine sand, the SM soil, and the SM-ML soil, respectively. The flux values were

![Graph showing hydraulic conductivity functions](image)

Fig. 3. Unsaturated hydraulic conductivity functions of geotextile and the cap soils to demonstrate the capillary barrier effect.

selected such that no runoff would be generated for the simulated cap. A unit gradient boundary condition was imposed on the lower boundary of the model domain for the lysimeter as well as the actual cap. However, the unit gradient boundary used for the actual cap was applied to the bottom of the waste layer. Fayer et al. (1992) and Khire et al. (1997) have used this boundary condition for lysimeters. Khire and Mijares (2008) and Mijares et al. (2010) have used the same lower boundary condition for simulations with waste layer. Initial conditions were specified using matric suctions corresponding to an average degree of saturation of about 40%. Spatial discretization of the model domain was optimized by conducting sensitivity analysis. This was done by repeatedly refining the nodal spacing until insignificant changes in simulated water balance parameters were achieved. The nodal spacing between the nodes located near the upper and lower boundaries was relatively small (1 mm) to ensure as little numerical error as possible. For all numerical analyses, mass balance errors were less than 1%.
RESULTS

Fig. 4 presents the cumulative percolation and soil water storage for OK 110 sand subjected to a constant unit flux equal to 5.3 mm/hr at the upper boundary. The predicted cumulative percolation and soil water storage for OK110 with a geotextile or with waste are almost identical. However, without GT, the soil water storage is relatively low and percolation onset is early. Due to the relatively low unsaturated hydraulic conductivity of GT or waste when it is relatively dry, the soil water storage of OK110 sand builds up high enough to increase the degree of saturation of the GT or the waste high enough to increase their hydraulic conductivities which results in percolation. Thus, Fig. 4 shows the evidence of capillary break created by non-woven GT or waste layer when the overlying soil is a relatively permeable soil such as OK110 sand.

![OK110 Fine Sand](image1)

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Fig. 5 presents the cumulative percolation and soil water storage for SM soil subjected to a constant unit flux equal to 0.22 mm/hr at the upper boundary. The predicted cumulative percolation and soil water storage for SM soil with a geotextile and with waste are slightly different. The percolation onset for the lysimeter with GT is slightly early compared to the waste. However, without GT, the soil water storage is relatively low and percolation onset occurs much earlier. Fig. 5 shows the evidence of capillary break created by non-woven GT or waste layer when the overlying soil is a relatively permeable soil such as the SM soil.

![SM Soil](image2)
Fig. 5. Simulated cumulative percolation and soil water storage for SM soil.

Fig. 6 presents the cumulative percolation and soil water storage for SM-ML soil subjected to a constant flux equal to 0.0075 mm/hr at the upper boundary. The predicted cumulative percolation and soil water storage for SM-ML soil with a geotextile, without geotextile, and with waste are about the same. Thus, while Fig. 3 shows the capillary barrier effect is possible based on the differences in hydraulic conductivities of the SM-ML soil and the GT or the waste interface, due to relatively low hydraulic conductivity of the SM-ML soil, the capillary barrier effect does not yield lower percolation or greater soil water storage. Thus, capillary barrier effect is less pronounced when the soils used for the cap have relatively low hydraulic conductivity.

SUMMARY AND CONCLUSIONS

This numerical study demonstrates that capillary break is introduced when the soil used for constructing the cap is underlain by a non-woven geotextile or municipal solid waste. While a geotextile or a waste layer both create a capillary break, the capillary barrier effect impacts the percolation collected by the lysimeter and the soil water storage of the cap only when hydraulic conductivity of the cover soils is $10^{-4}$ cm/s or more.

ACKNOWLEDGEMENTS

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Fig. 6. Simulated cumulative percolation and soil water storage for SM-ML soil.

REFERENCES


