Geosynthetics, J. Kuwano & J. Koseki (eds)
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Use of geocomposite strips in leachate collection systems

Zhao, A.
Tenax Corporation, USA

Giroud, J.P.
J.P. Giroud Inc., USA

Keywords: leachate collection system, geocomposite, strips, design equations, case history

ABSTRACT: A leachate collection system can be constructed with parallel strips of geocomposite (placed at regular intervals) embedded within a continuous layer of sand. The design of such a system should meet two conditions: (i) the geocomposite strips should have sufficient hydraulic transmissivity to convey all of the leachate collected over the entire surface area of the leachate collection system without pressure buildup in the geocomposite; and (ii) the thickness of leachate in the sand layer should be smaller than the thickness of the sand layer or smaller than a prescribed thickness, whichever is smaller. This paper presents design equations for calculating the required hydraulic transmissivity for the geocomposite and the required hydraulic conductivity for the sand layer. This paper also provides design equations for calculating the maximum allowable spacing between the strips. Finally this paper presents a case history using the design concept and methodology described in the paper.

1 INTRODUCTION

Leachate collection systems typically consist of a layer of drainage material that entirely covers an area, such as the entire side slopes of a landfill cell, or the entire base of a landfill cell, or an entire landfill cell area. Such systems are herein referred to as conventional leachate collection systems. An alternative solution is presented in this paper where parallel strips of geocomposite (placed at regular intervals) are embedded within a continuous layer of sand.

The methodology developed by the second author for the design of the alternative solution described above includes equations adapted from equations used for the design of conventional leachate collection systems. Therefore, it is useful to summarize, in the following section, some of the equations used for the design of conventional leachate collection systems.

2 EQUATIONS FOR DESIGNING CONVENTIONAL LEACHATE COLLECTION SYSTEMS

In a conventional leachate collection system, the leachate thickness varies as shown in Figure 1; and, generally, only the maximum leachate thickness is calculated.

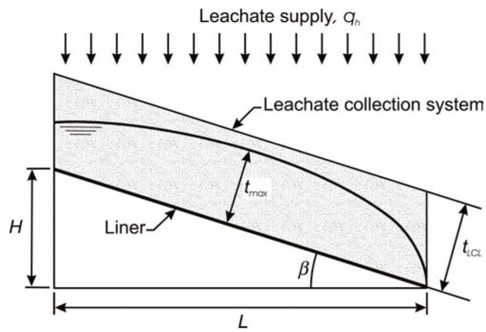

Figure 1. Conventional leachate collection system.

The maximum leachate thickness in a leachate collection system, t_{max}, is given by the following equation (Giroud & Houlihan 1995):

$$t_{max} = \frac{\sqrt{4(q_h/k) + \tan^2\beta} - \tan\beta}{2\cos\beta} L \quad (1)$$

where q_h is the rate of leachate supply per unit surface area measured horizontally (i.e. the rate at which leachate percolates through the overlying waste and soil layers and impinges onto the leachate collection system), k is the hydraulic conductivity of the leachate collection system material, β is the slope angle, and L is the length (measured horizontally) of the leachate collection system.

In the special case where the slope is zero, Equation 1 becomes:

$$t_{\max} = L\sqrt{\frac{q_h}{k}} \tag{2}$$

In the special case where the thickness of the leachate collection system, t_{LCL}, is small (i.e. less than one tenth of the height, H, shown in Figure 1), which is always the case with geocomposites, Equation 1 becomes:

$$t_{\max} = \frac{q_h L}{k \sin\beta} \tag{3}$$

Since hydraulic transmissivity is the product of hydraulic conductivity by thickness, Equation 3 gives:

$$\theta_{\text{req}} = \frac{q_h L}{k \sin\beta} \tag{4}$$

where θ_{req} is the required hydraulic transmissivity of the leachate collection system, i.e. the hydraulic transmissivity required to ensure that the leachate thickness in the leachate collection system is less than the thickness of the leachate collection system (to ensure that there is no head buildup in the leachate collection system).

3 LEACHATE COLLECTION SYSTEM USING GEOCOMPOSITE STRIPS

3.1 *Description*

The leachate collection system considered in this paper consists of parallel strips of geocomposite (placed at regular intervals) embedded within a layer of sand (Figure 2). The layer of sand covers the entire surface area of the leachate collection system. Therefore, leachate is collected over the entire area of the leachate collection system, which is a typical regulatory requirement.

3.2 *Assumption*

For the development of the design method presented in this paper, it is assumed that the slope in the direction of the strips is small (i.e. less than 5%). This limits the use of the design method to geocomposite strips installed at the base of landfills. Geocomposite strips could be installed on steeper slopes, but the design method would need to be different from the method presented herein.

3.3 *Leachate flow*

Since the longitudinal slope is small, it can be inferred that the leachate collected between the strips is conveyed laterally by the sand toward the strips (Figure 2a). The lateral slope in the sand is zero or close to

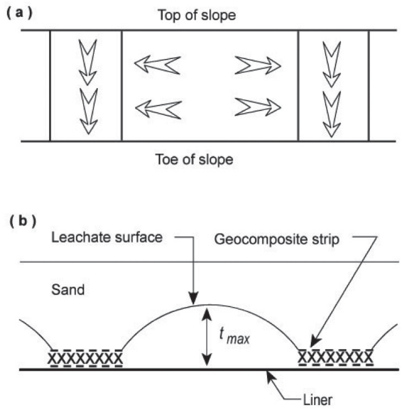

Figure 2. Leachate collection system constructed with geocomposite strips: (a) plan view with arrows showing the direction of leachate flow; (b) cross section perpendicular to flow direction, showing the maximum leachate thickness.

zero. Therefore, the hydraulic gradient in the sand results essentially from the difference between the leachate head maximum value at mid-distance between the geocomposite strips and its minimum value at the edges of the strips.

3.4 *Requirements*

The system described above must meet the same performance and regulatory requirements as conventional leachate collection systems. Two main requirements must be met: (1) there must be no pressure buildup in the components of the leachate collection system (i.e. the thickness of leachate in the leachate collection system must be smaller than the thickness of the leachate collection system); and (2) the head of leachate in the leachate collection system must be smaller a prescribed value. These requirements apply to both the geocomposite and the sand.

3.5 *Geocomposite strip requirements*

Since all of the collected leachate ends up in the geocomposite strips, the geocomposite should have sufficient hydraulic transmissivity to convey all of the leachate collected over the entire surface area of the leachate collection layer without pressure buildup. This condition is expressed by adapting Equation 4 as follows:

$$\theta_{\text{req}} = \left(\frac{q_h L}{\sin\beta}\right)\left(\frac{B+S}{B}\right) = \left(\frac{q_h L}{\sin\beta}\right)\left(1+\frac{S}{B}\right) \tag{5}$$

where B is the width of geocomposite strip, and S is the spacing between two adjacent geocomposite strips.

The factor of safety of the geocomposite is given by the following equation:

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$$FS_\theta = \frac{\theta_{\text{LTIS}}}{\theta_{\text{req}}} \tag{6}$$

A value of 2.0 or greater is generally used for this factor of safety.

The geocomposite is characterized by its hydraulic transmissivity, θ_{measured}, measured under conditions that best simulate the conditions at the site. The hydraulic transmissivity used in design is the "long-term-in-soil hydraulic transmissivity", θ_{LTIS}, defined by the following equation (Koerner 1998; Giroud *et al*. 2000a):

$$\theta_{\text{LTIS}} = \frac{\theta_{\text{measured}}}{RF_{\text{IN}}^{\text{GCP}} \times RF_{\text{CR}}^{\text{GCP}} \times RF_{\text{CC}}^{\text{GCP}} \times RF_{\text{BC}}^{\text{GCP}}} \tag{7}$$

where θ_{measured} is the hydraulic transmissivity of the geocomposite measured in a hydraulic transmissivity test that simulates as much as possible the conditions at the site, $RF_{\text{IN}}^{\text{GCP}}$ is the reduction factor for geotextile intrusion in the geocomposite, $RF_{\text{CR}}^{\text{GCP}}$ is the reduction factor for creep of the geocomposite, $RF_{\text{CC}}^{\text{GCP}}$ is the reduction factor for chemical clogging of the geocomposite, and $RF_{\text{BC}}^{\text{GCP}}$ is the reduction factor for biological clogging of the geocomposite. Tables of typical values of the reduction factors are provided by Koerner (1998) and Giroud *et al*. (2000a). A procedure for determining the reduction factor for creep developed by Giroud *et al*. (2000b) is presented in the GRI-GC8 standard (2001). This procedure is recommended because it makes it possible to obtain an objective value of the reduction factor for creep, rather than using tables of typical values. This is especially important when the geocomposite is subjected to a large compressive load, under which some products may experience structural collapse. For the other reduction factors, the tables of typical values should be used, as no procedure for determining reduction factors other than for creep has been developed.

3.6 Sand requirements

The maximum leachate thickness in the sand (Figure 2b), assuming zero slope angle in the direction of the flow, is given by the following equation derived from Equation 2:

$$t_{\max} = \frac{S}{2}\sqrt{\frac{q_h}{k_{\text{SAND}}}} \tag{8}$$

where k_{SAND} is the hydraulic conductivity of the sand.

The maximum leachate thickness in the sand must be smaller than the thickness of the sand layer or smaller than a prescribed thickness, whichever is smaller. In many regulations, a maximum leachate head of 0.3 m is prescribed, which is practically equivalent to a maximum leachate thickness of 0.3 m (since head and leachate thickness are equivalent when the slope angle is small).

Therefore, the required hydraulic conductivity of the sand is given by the following equation derived from Equation 8:

$$k_{\text{SAND-required}} = \frac{q_h S^2}{4\, t^2_{\text{max allowed}}} \tag{9}$$

where $t_{\text{max allowed}}$ is the minimum of the sand layer thickness and the prescribed maximum leachate thickness.

The factor of safety of the sand is given by:

$$FS_{\text{SAND}} = \frac{k_{\text{SAND-LT}}}{k_{\text{SAND-required}}} \tag{10}$$

where $k_{\text{SAND-LT}}$ is the long-term hydraulic conductivity of the sand, given by:

$$k_{\text{SAND-LT}} = \frac{k_{\text{SAND-measured}}}{RF_{\text{CC}}^{\text{SAND}} \times RF_{\text{BC}}^{\text{SAND}}} \tag{11}$$

where $k_{\text{SAND-measured}}$ is the hydraulic conductivity of the sand measured in the laboratory, $RF_{\text{CC}}^{\text{SAND}}$ is the reduction factor for chemical clogging of the sand, and $RF_{\text{BC}}^{\text{SAND}}$ is the reduction factor for biological clogging of the sand (Giroud *et al*. 2000a).

The factor of safety of the sand, FS_{SAND}, should be greater than the factor of safety of the geocomposite, FS_θ, because of greater variability in hydraulic property measurements for sand than for geocomposites manufactured with high level of quality control. Also, higher values should be considered for $RF_{\text{CC}}^{\text{SAND}}$ than for $RF_{\text{CC}}^{\text{GCP}}$ and for $RF_{\text{BC}}^{\text{SAND}}$ than for $RF_{\text{BC}}^{\text{GCP}}$ due to the fact that the porosity of sand is much smaller that the porosity of the geocomposite.

4 MAXIMUM ALLOWABLE SPACING BETWEEN GEOCOMPOSITE STRIPS

An approach to the design of leachate collection systems with geocomposite strips consists in calculating the maximum allowable spacing between strips. This approach is helpful for design engineers trying to achieve economical design.

Based on Equations 5 and 6, the maximum value of S that ensures that the geocomposite strips can convey all of the collected leachate is:

$$S_{\max} = B\left[\frac{\left(\dfrac{\theta_{\text{LTIS}}}{FS_\theta}\right)\sin\beta}{q_h L} - 1\right] \tag{12}$$

Based on Equations 9 and 10, the maximum value of S that ensures that the leachate thickness in sand will be less than the maximum allowed value is given by:

$$S_{\max} = 2 t_{\max\,\text{allowed}} \sqrt{\frac{\left(\frac{k_{\text{SAND-LT}}}{FS_{\text{SAND}}}\right)}{q_h}} \qquad (13)$$

Since two values are calculated for $S_{\max}$, the smallest must be used.

5 EXAMPLE OF APPLICATION

The original permitted leachate collection system design for a landfill in the northern United States, consisted of a 0.6-m-thick layer of sand with a hydraulic conductivity of 1×10^{-4} m/s. The lower 0.3 m of the sand was for drainage and the upper 0.3 m was intended as a protective layer.

The owner and the regulatory agency were then presented with an alternative design for the leachate collection system on the landfill base. The alternative design consisted of 2-m-wide strips of drainage geocomposite. These strips were placed 4 m apart, and 4-m-wide panels of nonwoven geotextile having a mass per unit area of 200 g/m^2 were sewn in between (Figure 3).

The geocomposite consisted of a triplanar geonet laminated on both sides with a nonwoven geotextile having a mass per unit area of 200 g/m^2. The hydraulic transmissivity of the geocomposite was 5×10^{-3} m^2/s under a normal stress of 500 kPa. Finally, 0.3 m of sand was placed over the entire area, as the second component of the alternative design. This leachate collection system met the design criteria and regulatory requirements (Landis *et al.* 2005).

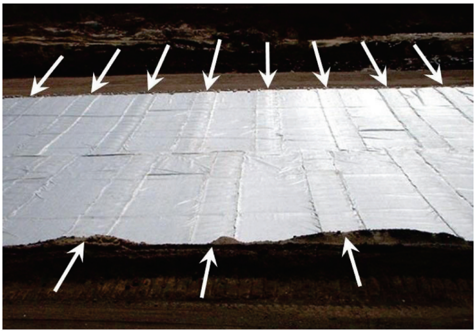

Figure 3. Leachate collection system constructed with 2-m-wide geocomposite strips (shown using arrows), with 4-m-wide panels of nonwoven geotextile sewn in between.

6 CONCLUSIONS

Innovative leachate collection systems that consist of strips of high-transmissivity geocomposite (placed at regular intervals) overlain with a continuous layer of sand can be designed to meet the same performance and regulatory requirements as conventional leachate collection systems, i.e. leachate collection systems entirely constructed with a geocomposite or a layer of granular material. Design equations provided in this paper allow the determination of the required hydraulic transmissivity and the maximum allowable spacing for the geocomposite strip drains, and the required hydraulic conductivity of the sand layer. The strip drain leachate collection system eliminates the need to tie adjacent panels of geocomposite together, thereby reducing both installation cost and waste of geocomposite material due to overlapping.

The design method presented in this paper is limited to small slope angles (i.e. slopes less than 5%). The development of a design method for steep slopes is underway.

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