JP GIROUD, INC.

TECHNICAL NOTE

USE OF STRIPS OF HIGH-TRANSMISSIVITY GEOCOMPOSITE IN LEACHATE COLLECTION SYSTEMS

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1. INTRODUCTION

This technical note shows that leachate collection systems can be constructed parallel strips of high-transmissivity geocomposite associated with a layer of sand. It will be seen that, if this type of leachate collection system is properly designed, it meets the same performance and regulatory requirements as usual leachate collection system entirely constructed with a layer of geocomposite.

A leachate collection system is typically constructed on a slope defined by its angle, β, and its length, L, measured horizontally from the crest to the toe of the slope (Figure 1). In this technical note, the area covered by the leachate collection system is referred to as “the slope”, even in the case of the very gentle slope (e.g. 2%) at the base of a landfill. The hydraulic gradient for flow along the slope is $\sin\beta$.

2. TYPICAL LEACHATE COLLECTION SYSTEM USING A GEOCOMPOSITE

In the case of a leachate collection system constructed with a geocomposite, the geocomposite typically covers the entire surface area of the slope. This type of leachate collection system is referred to herein as a continuous layer.

The geocomposite is characterized by its hydraulic transmissivity, $\theta_{measured}$, measured under conditions that best simulate the conditions at the site. Thus, the normal load applied on the geocomposite during the hydraulic transmissivity test must be at least equal to the normal load at the site and must be applied for at least 100 hours to allow for a large fraction of time-dependent mechanisms to take place. Also, the hydraulic gradient used in the hydraulic transmissivity test must be at least equal to $\sin\beta$ (and greater than 0.1 because hydraulic transmissivity measurements for hydraulic gradients less than 0.1 may be inaccurate).

The hydraulic transmissivity used in design is the "long-term-in-soil hydraulic transmissivity", $\theta_{LAYER\text{-}LTIS}$, defined by the following equation (Koerner 1998; Giroud et al. 2000a):

$$\theta_{LAYER-LTIS} = \frac{\theta_{LAYER-measured}}{\Pi\left(RF\right)} = \frac{\theta_{LAYER-measured}}{RF_{IN}^{LAYER} \times RF_{CR}^{LAYER} \times RF_{CC}^{LAYER} \times RF_{BC}^{LAYER}} \qquad (1)$$

where: $\theta_{LAYER\text{-}measured}$ = hydraulic transmissivity of the geocomposite measured in a hydraulic transmissivity test that simulates as much as possible the conditions at the site; $\Pi\ (RF)$ = product of reduction factors that account for mechanisms that reduce the hydraulic transmissivity of the geocomposite, but were not (or not totally) simulated in the hydraulic transmissivity test; RF_{IN}^{LAYER} = reduction factor for geotextile intrusion in the case of a geocomposite used to form a continuous layer; RF_{CR}^{LAYER} = reduction factor for creep in the case of a geocomposite used to form a continuous layer; RF_{CC}^{LAYER} = reduction factor for chemical clogging in the case of a geocomposite used to form a continuous layer; and RF_{BC}^{LAYER} = reduction factor for biological clogging in the case of a geocomposite used to form a continuous layer. 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 highly 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 a geonet or a geocomposite is subjected to a large compressive load, under which some products may experience structural collapse. The reduction factor for compressive creep in this case would be infinite, i.e. a product that may collapse is not suitable for the considered application. 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.

The factor of safety of a leachate collection system constructed with a continuous layer of geocomposite is given by the following equation:

$$FS_{\theta-LAYER} = \frac{\theta_{LAYER-LTIS}}{\theta_{LAYER-required}} \tag{2}$$

where: $\theta_{LAYER\text{-}required}$ = hydraulic transmissivity required to ensure that the leachate thickness in the geocomposite is less than the thickness of the geocomposite, i.e. to ensure that there is no head buildup in the geocomposite. (Note: leachate thickness is measured perpendicular to the slope, whereas the more familiar leachate depth is measured vertically. For practical purposes, the leachate thickness is approximately equal to the leachate depth and the leachate head.) A value of 2.0 or greater is generally used for the factor of safety.

As indicated by Giroud et al. (2000a):

$$\theta_{LAYER-required} = \frac{q_h\, L}{\sin \beta} \tag{3}$$

where: q_h = leachate impingement rate, i.e. the rate at which leachate percolates vertically through the waste and other media overlying the leachate collection system.

Example 1. A leachate collection system that consists of a continuous layer of geocomposite is to be located on a 2% slope with a horizontal length of 50 m. The normal load at the site is expected to be approximately 720 kPa (15,000 psf). The leachate impingement rate is expected to be 3.5×10^{-8} m/s (3230 gallons per acre per day). The hydraulic transmissivity of the geocomposite measured under a load of 720 kPa (15,000 psf) and a hydraulic gradient of 0.1 is 5×10^{-4} m^2 /s. What is the factor of safety?

Assuming that RF_{IN}^{LAYER} = 1.2, RF_{CR}^{LAYER} = 2.0, RF_{CC}^{LAYER} = 1.5, and RF_{BC}^{LAYER} = 2.0:

$$\Pi\left(RF\right) = 7.2$$

Equation 1 gives:

$$\theta_{LAYER-LTIS} = \frac{5\times10^{-4}}{7.2} = 6.94\times10^{-5}\,\text{m}^2/\text{s}$$

Equation 3 gives:

$$\theta_{LAYER-required} = \frac{\left(3.5\times10^{-8}\right)\left(50\right)}{0.02} = 8.75\times10^{-5}\,\mathrm{m^2/s}$$

Equation 2 gives:

$$FS_{\theta-LAYER} = \frac{6.94\times10^{-5}}{8.75\times10^{-5}} = 0.79$$

This factor of safety is not adequate. If the slope configuration (L, β) cannot be changed, then a geocomposite with a higher hydraulic transmissivity is required.

3. LEACHATE COLLECTION LAYER USING GEOCOMPOSITE STRIPS

In the case of the typical leachate collection layer discussed in Section 2, the geocomposite covers the entire slope. Alternatively, parallel strips of high-transmissivity geocomposite associated with a layer of sand can be used to convey the same amount of leachate (Figure 2). The leachate collected between the strips is conveyed laterally by the sand toward the strips. The lateral slope in the sand is small. The hydraulic gradient that results from this small slope can be neglected with respect to the hydraulic gradient that results from leachate thickness difference. Essentially, the leachate flow is driven by the head difference due to the fact that the leachate thickness in the sand is maximum at mid-distance between the geocomposite strips. This 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 most regulations, a maximum leachate head of 0.3 m (1.0 ft) is prescribed, which for practical purposes is equivalent to a maximum leachate thickness of 0.3 m (1.0 ft). In summary, the design of a system of parallel strips of high-transmissivity geocomposite 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 slope without pressure buildup in the geocomposite (i.e. with the thickness of leachate in the geocomposite smaller than the thickness of 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.

The condition that expresses that the geocomposite strips should have sufficient hydraulic transmissivity to convey all of the leachate collected over the entire surface area of the slope without pressure buildup is obtained by adapting Equation 3 as follows:

$$\theta_{STRIP-required} = \left(\frac{q_h\, L}{\sin \beta} \right) \left(\frac{B+S}{B} \right) = \left(\frac{q_h\, L}{\sin \beta} \right) \left(1 + \frac{S}{B} \right) \tag{4}$$

where: B = width of geocomposite strip; and S = spacing between two adjacent geocomposite strips.

The “long-term-in-soil hydraulic transmissivity” of the geocomposite used in the strips, $\theta_{STRIP-LTIS}$, is defined by the following equation (Koerner 1998; Giroud et al. 2000a):

$$\theta_{STRIP-LTIS} = \frac{\theta_{STRIP-measured}}{\Pi\left(RF\right)} = \frac{\theta_{STRIP-measured}}{RF_{IN}^{STRIP} \times RF_{CR}^{STRIP} \times RF_{CC}^{STRIP} \times RF_{BC}^{STRIP}} \tag{5}$$

where: $\theta_{STRIP-measured}$ = hydraulic transmissivity of the geocomposite used in the strips measured in a hydraulic transmissivity test that simulates as much as possible the conditions at the site; Π (RF) = product of reduction factors that account for mechanisms that reduce the hydraulic transmissivity of the geocomposite used in the strips, but were not (or not totally) simulated in the hydraulic transmissivity test; RF_{IN}^{STRIP} = reduction factor for geotextile intrusion in the case of a geocomposite used to form a continuous layer; RF_{CR}^{STRIP} = reduction factor for creep in the case of a geocomposite used to form a continuous layer; RF_{CC}^{STRIP} = reduction factor for chemical clogging in the case of a geocomposite used to form a continuous layer; and RF_{BC}^{STRIP} = reduction factor for biological clogging in the case of a geocomposite used to form a continuous layer. Guidance regarding values of the reduction factors is provided by Koerner (1998) and Giroud et al. (2000a, 2000b).

The factor of safety with respect to hydraulic transmissivity of a leachate collection layer constructed with a continuous layer of geocomposite strips is given by the following equation:

$$FS_{\theta-STRIP} = \frac{\theta_{STRIP-LTIS}}{\theta_{STRIP-required}} \tag{6}$$

The maximum leachate thickness in the sand, assuming zero slope in the direction of the flow, is given by the following equation (Giroud et al. 2000a):

$$t_{\max} = \frac{S}{2}\sqrt{\frac{q_h}{k_{SAND}}} \qquad (7)$$

where: k_{SAND} = hydraulic conductivity of the sand.

From Equation 7, the required hydraulic conductivity of the sand is:

$$k_{SAND-required} = \frac{q_h\ S^2}{4\ t^2_{\max allowed}} \qquad (8)$$

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

The factor of safety of the sand is given by:

$$FS_{SAND} = \frac{k_{SAND-LT}}{k_{SAND-required}} \qquad (9)$$

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

$$k_{SAND-LT} = \frac{k_{SAND-measured}}{RF_{CC}^{SAND} \times RF_{BC}^{SAND}} \qquad (10)$$

where: $k_{SAND\text{-}measured}$ = hydraulic conductivity of the sand measured in the laboratory; RF_{CC}^{SAND} = reduction factor for chemical clogging of the sand; and RF_{BC}^{SAND} = reduction factor for biological clogging of the sand.

The factor of safety of the sand, FS_{SAND} , should be greater than the factor of safety of the geocomposite strips, 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_{CC}^{SAND} than for RF_{CC}^{STRIP} and for RF_{BC}^{SAND} than for RF_{BC}^{STRIP} due to the fact that the porosity of sand is much smaller that the porosity of geocomposite.

Example 2. A leachate collection system is to be located on a 2% slope with a horizontal length of 50 m. The normal load at the site is expected to be approximately 720 kPa (15,000 psf). The leachate impingement rate is expected to be 3.5 × 10^{-8} m/s (3230 gallons per acre per day). This leachate collection system is designed using 2 m wide strips of high-transmissivity geocomposite. The strips are parallel with an edge to edge spacing of 2 m. The hydraulic transmissivity of the geocomposite measured under a load of 720 kPa (15,000 psf) and a hydraulic gradient of 0.1 is 1.8 × 10^{-3} m^2 /s. The measured hydraulic conductivity of the sand is 1.0 × 10^{-5} m/s. The thickness of the sand layer is 0.5 m and the prescribed maximum leachate head is 0.3 m. What is the factor of safety?

In fact, two factors of safety will be calculated, one for the geocomposite strips and one for the sand.

Equation 4 gives:

$$\theta_{STRIP-required} = \left[\frac{\left(3.5\times10^{-8}\right)\left(50\right)}{0.02}\right]\left(1+\frac{2}{2}\right) = 1.75\times10^{-4}\,\mathrm{m^2/s}$$

Assuming that RF_{IN}^{STRIP} = 1.2, RF_{CR}^{STRIP} = 1.2, RF_{CC}^{STRIP} = 1.5, and RF_{BC}^{STRIP} = 2.0 leads to:

$$\Pi\left(RF\right) = 4.32$$

Equation 5 gives:

$$\theta_{STRIP-LTIS} = \frac{1.8\times10^{-3}}{4.32} = 4.17\times10^{-4}\,\mathrm{m^2/s}$$

Equation 6 gives:

$$FS_{\theta-STRIP} = \frac{4.17\times10^{-4}}{1.75\times10^{-5}} = 2.38$$

Since the thickness of the sand layer is 0.5 m and the prescribed maximum leachate head is 0.3 m, the value of $t_{\mathrm{max}allowed}$ is 0.3 m. Equation 8 gives:

$$k_{SAND-required} = \frac{\left(3.5\times10^{-8}\right)\left(2\right)^2}{4\left(0.3\right)^2} = 3.89\times10^{-7}\,\mathrm{m/s}$$

Assuming that RF_{CC}^{SAND} = 2.0 and RF_{BC}^{SAND} = 4.0, Equation 10 gives:

$$k_{SAND-LT} = \frac{1\times10^{-5}}{(2.0)(4.0)} = 1.25\times10^{-6}\,\text{m/s}$$

Equation 9 gives:

$$FS_{SAND} = \frac{1.25\times10^{-6}}{3.89\times10^{-7}} = 3.21$$

The factors of safety are acceptable.

4. MAXIMUM ALLOWABLE SPACING BETWEEN GEOCOMPOSITE STRIPS

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

Based on Equations 4 to 6, the maximum value of *S* that ensures that the geocomposite strips can convey all of the collected leachate is:

$$S_{\max} = B\left[\frac{\left(\dfrac{\theta_{STRIP-LTIS}}{FS_{\theta-STRIP}}\right)\sin\beta}{q_h\,L} - 1\right] = B\left[\frac{\left(\dfrac{\theta_{STRIP-measured}}{FS_{\theta-STRIP}\times RF_{IN}^{STRIP}\times RF_{CR}^{STRIP}\times RF_{CC}^{STRIP}\times RF_{BC}^{STRIP}}\right)\sin\beta}{q_h\,L} - 1\right] \tag{11}$$

Based on Equations 8 to 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:

$$S_{\max} = 2\,t_{\max allowed}\sqrt{\frac{\left(\dfrac{k_{SAND-LT}}{FS_{SAND}}\right)}{q_h}} = 2\,t_{\max allowed}\sqrt{\frac{\left(\dfrac{k_{SAND-measured}}{FS_{SAND}\times RF_{CC}^{SAND}\times RF_{BC}^{SAND}}\right)}{q_h}} \tag{12}$$

Example 3. A leachate collection system is to be located on a 2% slope with a horizontal length of 50 m. The normal load at the site is expected to be approximately 720 kPa (15,000 psf). The leachate impingement rate is expected to be 3.5×10^{-8} m/s (3230 gallons per acre per day). This leachate collection system is designed with 2 m wide strips of high-transmissivity geocomposite. The hydraulic transmissivity of the geocomposite measured under a load of 720 kPa (15,000 psf) and a hydraulic gradient of 0.1 is 1.8×10^{-3} m^2/s. The measured hydraulic conductivity of the sand is 1.0×10^{-5} m/s. The thickness of the sand layer is designed to be 0.5 m and the prescribed maximum leachate head is 0.3 m. What is the maximum spacing between strips with a factor of safety of 2.0 for the strips and a factor of safety of 3.0 for the sand?

Assuming that RF_{IN}^{STRIP} = 1.2, RF_{CR}^{STRIP} = 1.2, RF_{CC}^{STRIP} = 1.5, and RF_{BC}^{STRIP} = 2.0 leads to:

$$\Pi\left(RF\right) = 4.32$$

Equation 5 gives:

$$\theta_{STRIP-LTIS} = \frac{1.8\times10^{-3}}{4.32} = 4.17\times10^{-4}\,\mathrm{m^2/s}$$

Equation 11 gives:

$$S_{\max} = \left(2.0\right)\left[\frac{\left(\dfrac{4.17\times10^{-4}}{2.0}\right)\left(0.02\right)}{\left(3.5\times10^{-8}\right)\left(50\right)} - 1\right] = 2.76\,\mathrm{m}$$

Assuming that RF_{CC}^{SAND} = 2.0 and RF_{BC}^{SAND} = 4.0, Equation 10 gives:

$$k_{SAND-LT} = \frac{1\times10^{-5}}{\left(2.0\right)\left(4.0\right)} = 1.25\times10^{-6}\,\mathrm{m/s}$$

Equation 12 gives:

$$S_{\max} = 2\,\left(0.3\right)\sqrt{\frac{\left(\dfrac{1.25\times10^{-6}}{3.0}\right)}{3.5\times10^{-8}}} = 2.07\,\mathrm{m}$$

Therefore, the leachate collection system can be constructed with a maximum spacing between strips of 2.07 m. In this example, $S_{\max}$ is governed by the sand (Equation 12) and not by the geocomposite strips (Equation 11).

The above calculations can be checked by using the same equations as in Example 2, but with S = 2.07 m instead of 2.0 m.

Equation 4 becomes:

$$\theta_{STRIP-required} = \left[\frac{\left(3.5\times10^{-8}\right)\left(50\right)}{0.02}\right]\left(1+\frac{2.07}{2}\right) = 1.78\times10^{-4}\,\text{m}^2/\text{s}$$

Assuming that RF_{IN}^{STRIP} = 1.2, RF_{CR}^{STRIP} = 1.2, RF_{CC}^{STRIP} = 1.5, and RF_{BC}^{STRIP} = 2.0 leads to:

$$\Pi\left(RF\right) = 4.32$$

Equation 5 gives:

$$\theta_{STRIP-LTIS} = \frac{1.8\times10^{-3}}{4.32} = 4.17\times10^{-4}\,\text{m}^2/\text{s}$$

Equation 6 becomes:

$$FS_{\theta-STRIP} = \frac{4.17\times10^{-4}}{1.78\times10^{-4}} = 2.34$$

Since the thickness of the sand layer is 0.5 m and the prescribed maximum leachate head is 0.3 m, the value of $t_{\max allowed}$ is 0.3 m. Equation 8 becomes:

$$k_{SAND-required} = \frac{\left(3.5\times10^{-8}\right)\left(2.07\right)^2}{4\left(0.3\right)^2} = 4.17\times10^{-7}\,\text{m/s}$$

Assuming that RF_{CC}^{SAND} = 2.0 and RF_{BC}^{SAND} = 4.0, Equation 10 gives:

$$k_{SAND-LT} = \frac{1\times10^{-5}}{\left(2.0\right)\left(4.0\right)} = 1.25\times10^{-6}\,\text{m/s}$$

Equation 9 gives:

$$FS_{SAND} = \frac{1.25 \times 10^{-6}}{4.17 \times 10^{-7}} = 3.0$$

A factor of safety of 3.0 is obtained, which confirms the calculations made above in the first part of Example 3.

5. EQUIVALENCY BETWEEN STRIP SYSTEM AND CONTINUOUS LEACHATE COLLECTION SYSTEMS

One may be in a situation where a geocomposite has been specified to construct a continuous leachate collection system, i.e. a leachate collection system where the geocomposite covers the entire surface area of the slope. It is interesting to have a methodology to rapidly determine if an alternative leachate collection system is equivalent to the designed system without redoing the design. The methodology presented below can be used to determine if an alternative leachate collection system that consists of parallel strips of high-transmissivity geocomposite is equivalent to a typical leachate collection system that consists of a continuous layer of geocomposite.

Combining Equations 2, 3 and 11 gives:

$$S_{\max} = B\left[\frac{\left(\dfrac{\theta_{STRIP-LTIS}}{FS_{\theta-STRIP}}\right)}{\left(\dfrac{\theta_{LAYER-LTIS}}{FS_{\theta-LAYER}}\right)} - 1\right] \tag{13}$$

Here it is assumed that the same factor of safety is used for the layer and for the strips:

$$FS_{\theta-STRIP} = FS_{\theta-LAYER} \tag{14}$$

Combining Equations 13 and 14 gives:

$$S_{\max} = B\left(\frac{\theta_{STRIP-LTIS}}{\theta_{LAYER-LTIS}} - 1\right) \tag{15}$$

Combining Equations 1, 5 and 15 gives:

$$S_{\max} = B\left[\frac{\left(\dfrac{\theta_{STRIP-measured}}{RF_{IN}^{STRIP}\times RF_{CR}^{STRIP}\times RF_{CC}^{STRIP}\times RF_{BC}^{STRIP}}\right)}{\left(\dfrac{\theta_{LAYER-measured}}{RF_{IN}^{LAYER}\times RF_{CR}^{LAYER}\times RF_{CC}^{LAYER}\times RF_{BC}^{LAYER}}\right)} - 1\right] \tag{16}$$

In general, the reduction factors are different for the strips and the continuous layer. If it is assumed that the same reduction factors are used for the strips and the continuous layer, then Equation 16 becomes:

$$S_{\max} = B\left(\frac{\theta_{STRIP-measured}}{\theta_{LAYER-measured}} - 1\right) \tag{17}$$

The second value of S_{max} can be obtained by combining Equations 2, 3 and 12:

$$S_{\max} = 2\, t_{\max allowed}\sqrt{\frac{\left(\dfrac{k_{SAND-LT}}{FS_{SAND}}\right)}{\dfrac{\theta_{LAYER-LTIS}\,\sin\beta}{FS_{\theta-LAYER}\,L}}} \tag{18}$$

Combining Equations 1, 10 and 18 gives:

$$S_{\max} = 2\, t_{\max allowed}\sqrt{\frac{\left(\dfrac{k_{SAND-measured}}{FS_{SAND}\times RF_{CC}^{SAND}\times RF_{BC}^{SAND}}\right)}{\dfrac{\theta_{LAYER-measured}\,\sin\beta}{\left(FS_{\theta-LAYER}\times RF_{IN}^{LAYER}\times RF_{CR}^{LAYER}\times RF_{CC}^{LAYER}\times RF_{BC}^{LAYER}\right)L}}} \tag{19}$$

It is important to note that, in Equation 19, the reduction factors in the denominator are the reduction factors for the continuous layer of geocomposite (not the reduction factors for the strips). This is because Equation 19 is related to lateral flow in the sand, which does not depend on the strips. The reduction factors for the geocomposite layer are present in Equation 19 only because, in the equivalency approach, the case of the leachate collection system constructed with a continuous geocomposite layer is used as a reference.

An important assumption of the equivalency calculations presented above is that the specified geocomposite has been properly selected. Clearly, when an alternative system is equivalent to a specified system, the alternative system is adequate only if the specified system is adequate. The equivalency approach is useful only to check if a specified system can be replaced by an alternative system, but it does not eliminate the need for design. As shown above, equivalency calculations can be performed without knowing the leachate impingement rate, q_h , whereas it is necessary to know the leachate impingement rate to perform design. If the impingement rate is known, it is possible to check if the specified system is adequate by calculating its factor of safety using Equations 2 and 3 (see Example 1). If the impingement rate is unknown, it is possible to calculate the maximum impingement rate for which the considered design is valid. This can be done by using the following equation derived from Equations 1, 2 and 3:

$$q_{h\max} = \frac{\theta_{LAYER-measured} \ \sin\beta}{\left(RF_{IN}^{LAYER} \times RF_{CR}^{LAYER} \times RF_{CC}^{LAYER} \times RF_{BC}^{LAYER}\right)\left(FS_{\theta-LAYER}\right)\left(L\right)} \qquad (20)$$

Example 4. A leachate collection system is to be located on a 2% slope with a horizontal length of 50 m. The normal load at the site is expected to be approximately 720 kPa (15,000 psf). The geocomposite to be used for the leachate collection system is specified to have a hydraulic transmissivity of 5×10^{-4} m^2/s measured under a load of 720 kPa (15,000 psf) and a hydraulic gradient of 0.1. An alternative solution using 2 m wide strips of high-transmissivity geocomposite is considered. The hydraulic transmissivity of the high-transmissivity geocomposite is 1.8×10^{-3} m^2/s measured under a load of 720 kPa (15,000 psf) and a hydraulic gradient of 0.1. The measured hydraulic conductivity of the sand is 1.0×10^{-5} m/s. The thickness of the sand layer is 0.5 m and the prescribed maximum leachate head is 0.3 m. What is the maximum spacing between strips for the alternative solution to be equivalent to the specified solution?

It is assumed that the same factor of safety is used for the two solutions and the same reduction factors are applicable to both geocomposites. Equation 17 gives:

$$S_{\max} = \left(2.0\right)\left(\frac{1.8\times10^{-3}}{5\times10^{-4}} - 1\right) = 5.2 \text{ m}$$

To calculate the second condition (i.e. the condition expressed by Equation 19), the following values are assumed for the reduction factors for the sand, RF_{CC}^{SAND} = 2.0 and RF_{BC}^{SAND} = 4.0, and the following values are assumed for the reduction factors for the continuous layer of geocomposite, RF_{IN}^{LAYER} = 1.2, RF_{CR}^{LAYER} = 2.0, RF_{CC}^{LAYER} = 1.5, and RF_{BC}^{LAYER} = 2.0. The factor of safety is taken as 2.0 for the geocomposite and 3.0 for the sand. Equation 19 gives:

$$S_{\max} = 2\,(0.3)\sqrt{\frac{\left(\dfrac{1\times10^{-5}}{3.0\times2.0\times4.0}\right)}{\dfrac{\left(5\times10^{-4}\right)(0.02)}{(2.0\times1.2\times2.0\times1.5\times2.0)(50)}}} = 3.29\,\text{m}$$

In this example, $S_{\max}$ is governed by the sand (Equation 19) and not by the geocomposite strips (Equation 17).

This example can also be treated by assuming different values for the reduction factors for the continuous layer of geocomposite and for the geocomposite used for the strips. The following values of the reduction factors are assumed:

RF_{CC}^{SAND} = 2.0 and RF_{BC}^{SAND} = 4.0, for the sand
RF_{IN}^{LAYER} = 1.2, RF_{CR}^{LAYER} = 2.0, RF_{CC}^{LAYER} = 1.5, and RF_{BC}^{LAYER} = 2.0, for the continuous layer of geocomposite,
RF_{IN}^{STRIP} = 1.2, RF_{CR}^{STRIP} = 1.2, RF_{CC}^{STRIP} = 1.5, and RF_{BC}^{STRIP} = 2.0, for the strips

Equation 16 gives:

$$S_{\max} = (2.0)\left[\frac{\left(\dfrac{1.8\times10^{-3}}{1.2\times1.2\times1.5\times2.0}\right)}{\left(\dfrac{5\times10^{-4}}{1.2\times2.0\times1.5\times2.0}\right)} - 1\right] = 10.0\,\text{m}$$

There is a significant difference between the value of 5.2 m obtained with Equation 17 (where reduction factors are the same for the continuous layer of geocomposite and for the geocomposite used for the strips) and the value of 10.0 m obtained with Equation 16 (where reduction factors are different for the continuous layer of geocomposite and for the geocomposite used for the strips). However, in both cases the value of S is controlled by the other equation, which does not depend on the reduction factors for the strips.

Finally, the equivalency calculations performed above are valid only if the impingement rate is smaller than a maximum value calculated using Equation 20 as follows:

$$q_{h\max} = \frac{\left(5\times10^{-4}\right)\left(0.02\right)}{\left(1.2\times2.0\times1.5\times2.0\right)\left(2.0\right)\left(50\right)} = 1.39\times10^{-8} \text{ m/s}$$

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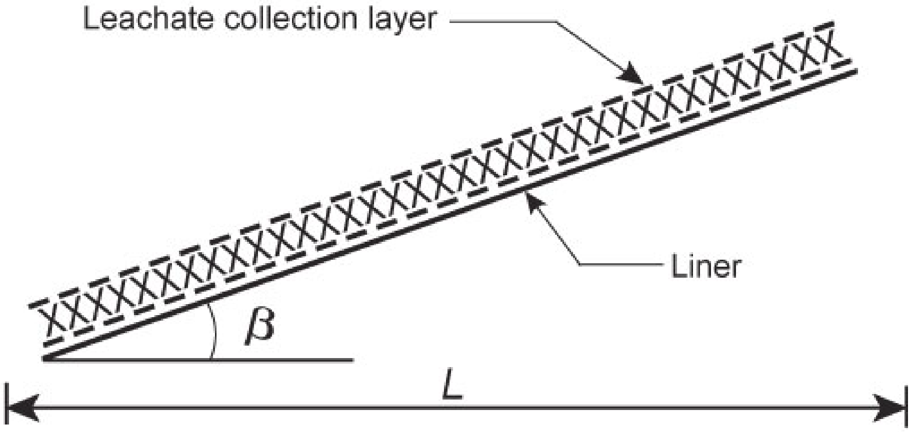

Figure 1. Definition of slope

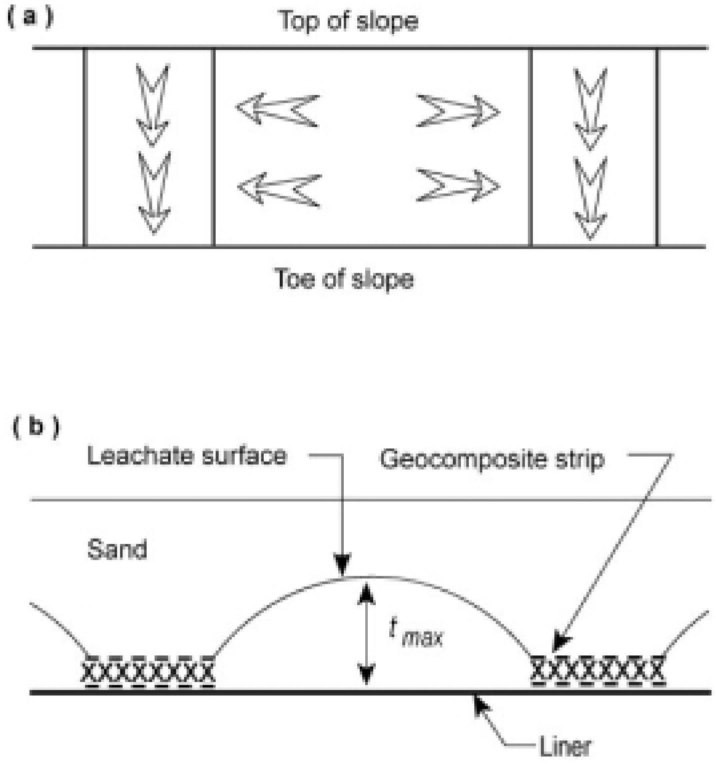

Figure 2. Leachate collection system constructed with geocomposite strips: (a) plan view with arrows showing the direction of leachate flow; (b) cross section perpendicular to flow direction, showing maximum leachate thickness.