

DESIGNER'S FORUM

Lateral-drainage systems over landfill barrier systems: Flat slopes

by Aigen Zhao and Gregory N. Richardson

THE JUNE/JULY DESIGNER'S FORUM ("Composite Drains for Side Slopes in Landfill Final Covers," pp. 22-29) presented design guidelines for geocomposite-drainage blankets that control pore-water pressure at the upper surface of the barrier layer, and landfill gas beneath the barrier on final-cover side slopes. Control of both pore water and landfill gases is essential for the stability of the final cover on typical 4H:1V or 3H:1V slopes; limiting infiltration plays a secondary role.

This column will address the design of this same drainage layer within the 5%-8% slopes common to the tops of the landfill and the 2%-8% slopes common to landfill-liner bottoms. In this location, slope stability is not a major concern, and limiting infiltration becomes the primary design objective. Infiltration for both applications is controlled by limiting the head acting on the barrier layer.

Application background

Leakage through a penetration in a geomembrane can be estimated with the following equation (Giroud, et al. 1992):

$$Q = 0.21 h^{0.9} a^{0.1} K^{0.74}$$

where a is the area of the penetration (cm^2) in the geomembrane component of the barrier, k is the permeability of the soil component of the barrier system (m/s), and h (m) is the head acting on the barrier. Be aware that this equation is valid only with the above SI units, and it assumes good contact between the geomembrane and the compacted-clay barriers.

The area of penetration is limited by a comprehensive construction-quality assurance program. The permeability of the soil component in a final-cover system typically is 1×10^{-5} cm/sec . Less permeable soils are avoided due to desiccation concerns. In liner systems, the permeability is typically less than 1×10^{-7} cm/sec . Therefore, the designer's role is limited to ensuring that the head which acts on the barrier system is minimal.

For barrier systems in municipal solid-waste (MSW) landfills, Resource Conser-

vation and Recovery Act (RCRA), Subtitle D limits the head acting on the liner to less than 30 cm, except immediately following a design-storm event. These same regulations do not limit the head acting on the final-cover barrier system, but do require that the infiltration through the final cover be less than the anticipated leakage through the liner system.

For side slopes, we ensure stability by verifying that the *drainage capacity* of the geocomposite-drainage layer was not exceeded. This limits the head to the small height of the drainage geocomposite and prevents pressure from building up within the drainage layer. For flatter barrier systems, including cover and liner, we must calculate the actual head acting on the barrier to demonstrate compliance and evaluate barrier leakage. The head acting on the barrier system is calculated using relationships developed by McEnroe (1993) for lateral-drainage layers.

The maximum head acting on the liner system is a function of the transmissivity of the lateral drainage layer, Ψ , the horizontal spacing of perforated drainage pipes within the lateral drainage layer, L , the slope of the barrier system, α , and the impingement rate, r , of liquid that vertically enters the lateral-drainage layer. The sawtooth-liner geometry assumed in McEnroe's solution is shown on **Figure 1** (p.22). Three impingement conditions are evaluated by McEnroe:

- Case 1: $r/k\sin.^2\alpha > 0.25$ —The slope/transmissivity capacity of the drainage layer controls the mounding height, as appropriate for flatter slopes.
- Case 2: $r/k\sin.^2\alpha = 0.25$ —A balance exists between the impingement rate and the slope/transmissivity capacity of the drainage layer.
- Case 3: $r/k\sin.^2\alpha < 0.25$ —The impingement rate controls the mounding height, as appropriate for typical side slopes.

Here, k is the permeability of the drainage layer. These three cases also are shown on **Figure 1**. Note that Cases 2 and



Photo 1. Geonet-composite drainage systems limit infiltration on the flatter slopes of landfill final covers.

3 also can be used to model a liner on an infinite slope that has collector pipes uniformly spaced down it. Case 1 conditions for the infinite slope require the slope length to be taken as the actual distance between the pipes, $2L$. A more thorough discussion of McEnroe's analysis is given by McBean, et al. (1995).

To simplify this evaluation for flatter slopes common to landfills, McEnroe's work can be reduced to the simple chart presented on **Figure 2** (p.22). It represents Case 1 conditions, with the exception of the 8% slope lines, which are Case 3 conditions. This indicates that the transition between "flat slopes" and "side slopes" typically occurs at a slope of approximately 8%.

McEnroe's equations were developed for natural-drainage layers with a thickness that greatly exceeds that of a geocomposite-drainage layer. Their application to drainage-geonet composites makes the assumption that the "head" acting on natural-drainage layers will be the same as pressure acting in the geocomposite-drainage layer, i.e., that Darcy's Law is applicable. Be aware that McEnroe's equations are based on a "free drainage" condition—i.e., the collection system has to be designed adequately so that there is no backwater effect over the barrier layer.

Figure 2 presents the minimum permeability for a 30-cm-thick drainage layer to limit head to less than 30 cm for the indicated uniform-inflow rates. Two distinct in-

flow rates have been evaluated:

- 10^{-6} cm/sec (12 in./year) represents typical Hydrologic Evaluation of Landfill Performance (HELP)-model infiltration rate for a final cover in non-arid or semi-arid portions of the country.
- 1×10^{-4} cm/sec is the typical permeability for a vegetative layer; therefore, it represents the seepage velocity if the final cover becomes saturated, i.e., unit gradient case.

These rates are discussed in greater detail below.

The design value of inflow must be this minimum k value multiplied by a factor of safety that reflects clogging and long-term performance concerns. For final covers, we recommend a minimum factor of safety (FS) of 8, while for leachate-collection systems, we recommend a minimum factor of safety of 20 to reflect the high clogging potential and high compressive creep under large normal loads. The above two safety factors are close to the sum of a drainage-safety factor of 2 and the product of reduction factors proposed by R. Koerner (1997).

Service loading

The most significant unknown for the designer to evaluate is the impingement rate or inflow of liquid that vertically enters the lateral-drainage layer. For cover systems in non-arid regions, this impingement rate can be taken as the permeability of the vegetative-layer system. This reflects an assumption of saturation and the resulting vertical flow gradient of one.

For the impingement rate of liquid that vertically enters the lateral-drainage layer over the liner system, we must estimate the drainage rate of leachate draining from the waste. Two methods exist for making this estimate:

1. The U.S. Environmental Protection Agency's (EPA) HELP model
2. Empirical rates based on historic leachate-generation rates.

The HELP model is limited in that it does not readily allow the operational/post-closure transition life of a landfill to be modeled—i.e., the geometry of the landfill model remains the same throughout the entire evaluation analysis. Because of this limitation, empirical rates commonly are used to evaluate the three key phases in the life of the lateral-drainage layer: during active placement

of the waste, after placement of interim cover, and after placement of the final cover.

Values for these phases can be estimated from regional landfill-service records, if available, and published typical leachate-generation values. It should be noted that recent evaluation of actual leachate-generation rates has shown that the HELP model can provide very good approximations to actual conditions (M.A. Othman et al., 1998).

Published typical leachate-generation values for non-arid regions show rates of 1200–2000 gallon/acre/day (gad), or an impingement velocity of $1.3\text{--}2.2 \times 10^{-6}$ cm/sec during active placement of waste, 200–600 gad once 12-in. of interim cover is placed, and 50–150 gad after placement of the final cover. The authors confirmed the reasonableness of these values through discussions with state solid-waste regulators in Florida, New York, North Carolina, and Virginia. (Comments from other states or operators would be greatly appreciated.)

Leachate-generation rates will be affected dramatically by the degree of leachate/stormwater separation inherent in the facilities-design and operational practices. The leachate-generation rates referenced above reflect typical design and operational efforts. Facilities that employ supplemental “rain sheets” may have less leachate, while those that are poorly designed and operated will have significantly more. The design is conservative for long-term flows if it is designed properly for short-term operational flows.

The reader by now should understand the basis for the two impingement rates assumed in Figure 1. The 1×10^{-4} cm/sec rate represents the impingement rate for a saturated final cover. The 1×10^{-6} cm/sec impingement rate approximately represents

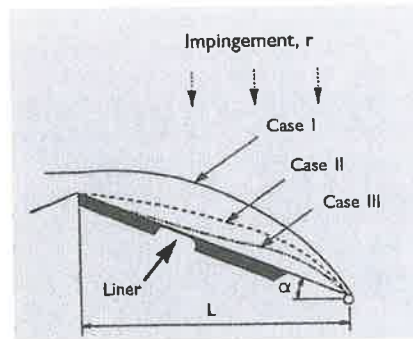


Figure 1. Sawtooth-liner geometry for McEnroe's final solution.

the infiltration into a final cover if it does not become saturated, or a leachate-collection system during initial waste placement.

Implications for geocomposite-drainage products

Figure 2 can be used to define the typical range of transmissivities required for geocomposite-drainage products for typical landfill applications. For final-cover applications where saturation is assumed, the range of minimum permeabilities is approximately 0.1–0.8 cm/sec. This represents required transmissivities of $2.4\text{--}19 \times 10^{-3}$ m²/sec (FS = 8.0). If final-cover saturation can be avoided, the required transmissivities drop dramatically to approximately $2.6\text{--}18 \times 10^{-5}$ m²/sec (FS = 8.0). The impact of cover saturation is quite significant.

Drainage composites in leachate-collection systems must be designed for both increased normal loads and increased clogging potential. Assuming FS = 20, the range of transmissivities required for the leachate-collection systems are $6\text{--}47.5 \times 10^{-3}$ m²/sec for an impingement rate of 1×10^{-4} cm/sec, and $6.5\text{--}45 \times 10^{-5}$ m²/sec for an impingement rate of

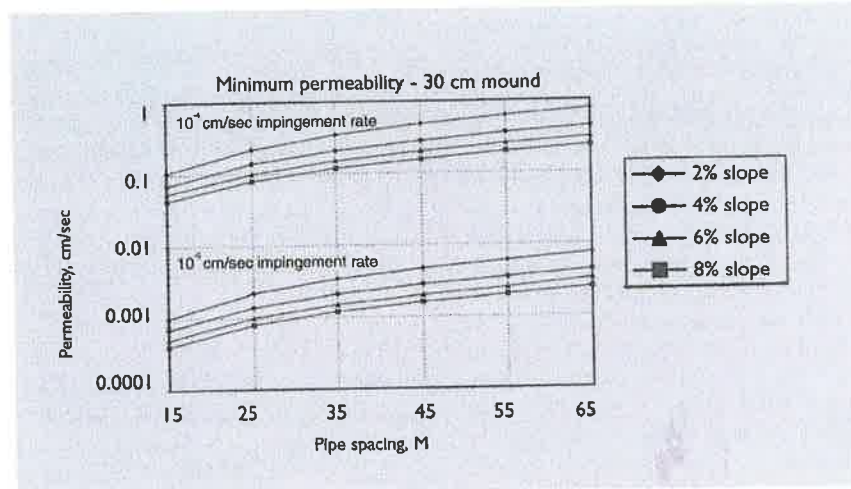


Figure 2. Minimum permeability for a 30-cm thick drainage layer to limit head to less than 30 cm for given uniform-inflow rates.

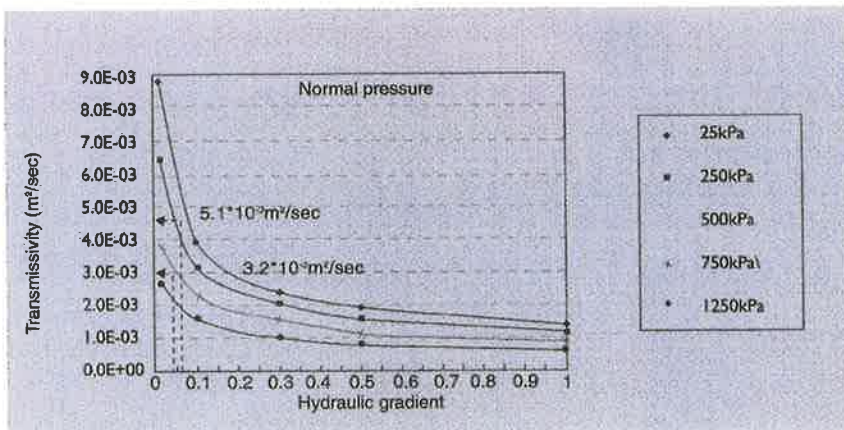


Figure 3. Laboratory transmissivity test data.

1×10^{-6} cm/sec. Based on the actual impingement rate, leachate-collection systems may require a very high capacity flow under high normal loads—a tough application. High-flow drainage composites or a combination of geocomposite with natural soil drains will be necessary in this case.

Design examples

Figure 2 can be used to quickly calculate the design transmissivity of a geocomposite-drainage component. For example, determine the required transmissivities for a geocomposite-drainage layer in a final cover with a 6% slope and pipe spacing of 35 meters. Assume typical infiltration—i.e., HELP model—and saturation.

From Figure 2, the minimum required drainage-layer permeabilities for the two cases are 0.0016 cm/sec and 0.16 cm/sec, respectively. With an overall safety factor of 8, the design permeabilities are 0.0128 cm/sec and 1.28 cm/sec respectively.

Required transmissivities, Ψ , are calculated by assuming an equivalent 30-cm thick drainage layer such that $\Psi = k \times$ thickness. The required transmissivities are 3.84×10^{-5} m²/sec and 3.84×10^{-3} m²/sec, respectively.

The normal load acting on the geocomposite-drainage blanket in this application is typically less than 25 kPa (500 psf). The geocomposite drain is selected according to laboratory transmissivity-test data, as shown on Figure 3. Care must be taken to ensure that the laboratory transmissivity tests utilize the correct range of normal loads (and seating time if creep is a concern) and the correct testing-boundary conditions that simulate field installation.

The transmissivity value under 25 kPa and gradient of 6% is 5.1×10^{-3} m²/sec $>$ 3.84×10^{-3} m²/sec. The design for the composite drain is acceptable.

In the second design example, determine the required transmissivity of a geocomposite as a primary leachate-collection layer over the liner with a 4% slope and pipe

spacing of 55 m. The minimum permeabilities are 0.0036 cm/sec and 0.36 cm/sec for an impingement rate of 1×10^{-6} cm/sec and 1×10^{-4} cm/sec, respectively. Required transmissivities, assuming an equivalent 30-cm thick drainage layer, are 2.16×10^{-4} m²/sec and 2.16×10^{-2} m²/sec, respectively. The normal load that acts on the geocomposite-drainage blanket in this application is assumed to be 750 kPa (15,000 psf).

Under the above normal load and a 4% gradient, the transmissivity determined from Figure 3 is 3.2×10^{-3} m²/sec. Therefore, if the design impingement rate is 10^{-4} cm/sec, the product represented by Figure 3 does not meet the flow requirement. An alternative product with higher flow capacity or a combination of high-flow geocomposite augmented by natural drainage soil may be needed. GFR

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