

Lateral drainage design update—Part 1

Over the past 18 months, the authors have spent considerable time reviewing design concepts commonly used for lateral drainage systems. This effort resulted in a *Geosynthetics International* special issue (Volume 7, Nos. 4–6, 2000) devoted to liquid collection systems and a comprehensive design manual. This two part series presents highlights of these extensive works and will challenge a number of current concepts related to lateral drainage systems. Hopefully the reader will find the following interesting enough to obtain and review the original documents. While the concepts are presented in the context of landfill applications, the reader can easily adapt these same concepts to all lateral drainage applications.

Design rate of fluid supply

The conservative design of a lateral drainage system must begin with a realistic evaluation of the maximum rate that liquid will be entering the lateral drain. This rate is dependent upon both future extreme weather events and the materials placed over the drain. One of the most common methods used to evaluate both the design rate of fluid supply and lateral drain performance is to use the Environmental Protection Agency's HELP model. This water-balance model allows the designer to quickly evaluate the performance of a given barrier exposed to synthetic or historical weather data. Unfortunately, the HELP model does not provide a conservative design for lateral drainage systems. Soong and Koerner (1997) studied eight seepage induced landfill slope failures and found that the HELP model underpredicted the required hydraulic capacity of the lateral drains by factors ranging from 10 to 100! Their work suggests that the 24-hour time step employed by the HELP model and failure to correctly anticipate extreme weather events are the major sources of error. Koerner and Daniel (1997) present a detailed hand water-balance method intended to circumvent the 24-hour limitation of HELP.

An alternative design assumption preferred by the authors in all but arid regions is that the layer over the lateral drain is saturated such that a unit flow gradient exists in that layer. Using Darcy's Law, the flow velocity within a saturated material under a unit gradient equals the permeability of the material. This represents a design limit and is fortunately more definable than future extreme storm events. Thus, the authors recommend that, in non-arid regions, the design rate of fluid supply be taken as the permeability of the layer overlying the lateral drainage layer.

Maximum head in lateral drain

The maximum head, or mounding depth, of liquid within the lateral drain must be known for two reasons: (1) when acting on liner systems, this mounding depth is limited by the Resource Conservation and Recovery Act (RCRA) to less than 30 cm (12 in.), and (2) good design requires that the mounding depth be less than the thickness of the lateral drain, such that the flow within the drain is not confined. An exact solution for the mounding height was first published by McEnroe (1993) and is incorporated in the HELP model. While this solution is exact, it is very tedious to use and is subject to significant errors resulting from the number of significant digits used during the calculations. The authors recommend a simplified solution developed by Giroud, Zornberg and Zhao (2000) that is easily solved by hand and yet is within 1% of the McEnroe solution. Using Giroud's solution, the maximum liquid thickness within the lateral drain, t_{max} is given as follows:

$$\text{Eq. 1} \quad t_{max} = j \frac{\sqrt{\tan^2 \beta + 4q_h/k} - \tan \beta}{2 \cos \beta} L$$

where j is a correction factor, β is the slope angle, q_h is the fluid supply rate, k is the permeability, and L is the slope length.

The correction factor j is obtained from Figure 1 where:

Eq. 2

$$j = \frac{q_h}{k \tan^2 \beta}$$

It should be noted that the correction factor j is close to 1. Therefore, a conservative approximation of Equation 1 is obtained by replacing the correction factor j with 1.

For geonets, t_{max} becomes very small and Equation 1 can be reduced to the following:

Eq. 3

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

Note that this is the same equation as derived by Thiel and Steward (1993) for saturated final cover systems. The unit gradient assumption recommended as a limit for estimating q_h would simply replace q_h with the permeability of the soil immediately over the lateral drain, k_{soil} . The minimum required transmissivity, θ_{min} of the lateral drain, with a factor of safety equal to one, is equal to the product $t_{max} k$ for either solution.

Geonet equivalency to granular lateral drains

Many landfill regulations—e.g., hazardous waste landfill regulation 40 CFR 264.301(3)—require a minimum transmissivity for composite drainage media that is equal to that of a conventional granular drainage layer having a minimum thickness of 30 cm (12 in.) and permeability of 0.01 cm/sec. Thus, regulatory equivalency between natural and geocomposite lateral drainage systems is currently based on *equivalent transmissivity*. This concept is invalid. Giroud, Zhao and Bonaparte (2000) have shown that this practice is incorrect and non-conservative. An equivalency based solely on transmissivity will lead to selection of a geosynthetic drainage layer that may not provide adequate flow capacity and may result in the development of significant hydraulic pressures. Such hydraulic pressures can significantly impact the slope stability of landfill systems and the head acting on the underlying liner.

Equivalency between two lateral drainage systems must take into consideration the service flow gradients and maximum flow depth. A 30-cm (12-in.)-thick natural drainage layer can support larger gradients and maximum flow depth than a 6-mm-thick drainage geocomposite. Thus, a drainage geocomposite must provide a larger transmissivity to overcome these limitations. Giroud, Zhao and Bonaparte (2000) have shown that, to be equivalent to a natural drainage layer, the minimum transmissivity of the geocomposite must be greater than the transmissivity of the natural drainage layer. The minimum transmissivity of the geonet is obtained by multiplying the transmissivity of the natural drainage layer by an equivalency factor, E . For natural drainage systems having maximum flow depths of 30 cm (12 in.), E can be approximated as follows:

Eq. 4

$$E = \frac{1}{0.88} \left[1 + \left(\frac{t_{\text{prescribed}}}{0.88L} \right) \left(\frac{\cos\beta}{\tan\beta} \right) \right]$$

where $t_{\text{prescribed}}$ is the maximum liquid thickness prescribed by regulation. Equivalency values for common slope lengths and grades are presented in Table 1. Note that E increases with decreasing length of drainage and slope.

The equivalency defined by Equation 4 is based on equal unconfined flow volumes in the natural and geocomposite lateral drainage systems. However, the designer

Table 1. Values of the equivalency factor, E , between a geosynthetic liquid collection layer and a granular liquid collection layer when the prescribed maximum liquid thickness is 0.3 m (1 ft.), as a function of the slope, β , and the length, L , of the liquid collection layer.

Slope Length, L	Slope of the liquid collection layer, $\tan \beta$								
	0.02	0.03	0.04	0.05	0.1	1/4	1/3	1/2	1
m (ft.)									
15 (50)	2.43	2.00	1.78	1.65	1.39	1.24	1.21	1.18	1.15
30 (100)	1.78	1.57	1.46	1.39	1.26	1.19	1.17	1.16	1.15
45 (150)	1.57	1.42	1.35	1.31	1.22	1.17	1.16	1.15	1.14
60 (200)	1.46	1.35	1.30	1.27	1.20	1.16	1.15	1.15	1.14

should also realize that the very low heads associated with unconfined flow in a geocomposite lateral drain will result in a significant reduced head acting on the underlying liner system and therefore a reduced potential leakage. Thus equivalency here is based on equal flow properties and not equal leakage of the lateral drain and liner systems. Based on the leakage relationships developed by Giroud (1997), the leakage through a circular or square defect in the geomembrane component of a composite liner is proportional to $h^{0.9}$. Thus, a geocomposite drain with a maxi-

mum head of approximately 6 mm will have 34 times less leakage than a natural drain having a maximum head of 30 cm (12 in.). Equivalent flow and equivalent leakage are not synonymous.

Geonet and sand double drainage layers

Many states still require lateral drainage layers that consist of a geonet with an overlying sand "drainage" layer. These lateral drainage systems are commonly designed using the HELP model. The HELP program models these two systems as a single system having the same thickness and a weighted permeability given as follows:

Eq. 5

$$k_d = \frac{\sum k_i d_i}{\sum d_i}$$

where k_i and d_i are the permeability and saturated thickness of the i th layer respectively. (Note that it is not the total thickness of sand layer, but the saturated part thickness.) The average head, h , acting on the liner system is then calculated using one of the following equations:

Eq. 6

$$h = L \frac{\pi \sqrt{q_h/k_d}}{4 \cos \beta} \left[\frac{2 \sqrt{0.4}}{\pi} \left[\frac{q_h/k_d}{0.4 \sin^2 \beta} \right]^{2.1} \left(\frac{2 \sqrt{0.4}}{\pi} \right) \right]$$

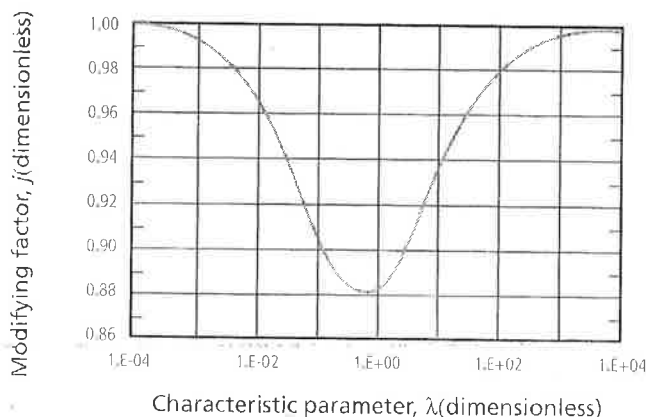
where $q_h/k_d \geq 0.4 \sin^2 \beta$

Eq. 7

$$h = L \frac{q_h/k_d}{2 \sin \beta \cos \beta}$$

where $q_h/k_d < 0.4 \sin^2 \beta$

Figure 1: Value of the modifying factor, j , as a function of the characteristic parameter, λ .



Note that this is an iterative solution since the weighted permeability, k_d , must be calculated only for the actual height of maximum flow, h , determined from Equations 6 or 7. Giroud (2001) has shown that (1) the weighted solution is incorrect, and (2) Equations 6 and 7 are incorrect. Additionally, Giroud (2001) solved for the maximum liquid thickness, t_{max} , under these same conditions and derived the following expression:

Eq. 8

$$t_{max} = t_1 + j_2 \frac{1 + \sqrt{1 + 4\lambda_2}}{2\cos\beta/\tan\beta} \left(L \frac{t_1 k_1 \sin\beta}{q_h} \right)$$

where

Eq. 9

$$\lambda_2 = \frac{q_h}{k_2 \tan^3 \beta}$$

The modifying factor j_2 is obtained from Figure 1 using λ_2 as λ . The significant difference between these two solutions is best shown by the example of a sand layer having a permeability, k_2 , of 10^{-3} cm/sec over a geonet drain having a transmissivity, θ_1 , of 1.4×10^{-5} m³/s-m

and a thickness, t_1 , of 4.5×10^{-3} m placed on a 19.2-m (63-ft.)-long slope, L , having a slope, $\tan \beta$, of 2%. Using the weighted permeability method, Equations 5 and 6 predict an *average* head of 23 cm (9 in.). Conversely, the Giroud solution of Equation 8 predicts a *maximum* head of 58 cm (22.8 in.). A design based on the 23-cm (9-in.)-average head may significantly underestimate the thickness of sand layer required and result in confined flow within the lateral drainage system. Confined flow is contrary to the assumptions made in deriving both of the above solutions and produces pore water pressures that can lead to stability problems. Thus, the weighted solution used by the HELP model is not conservative and should not be used for design of the dual lateral drainage layer systems.

Beyond the current technical errors in the HELP Model, the authors question the use of such dual lateral drainage layer systems since they promote maximum heads that are generally in violation of regulatory head limits. For the above example, the entire inflow to the system

could be contained within the geonet by simply increasing the service transmissivity to approximately 3×10^{-4} m³/s-m. By maintaining unconfined flow within the geonet, the head acting on the liner system is significantly reduced and the need for expensive gradation requirements for the overlying sand disappears. The use of expensive and environmentally deficient dual lateral drainage layer systems must be questioned.

Summary

Recent cover failures have clearly demonstrated that current final cover designs are underestimating the required transmissivity for lateral drainage layers. It is reasonable to assume that the leachate collection systems beneath the waste are also suffering this same fate. The authors echo the findings of Soong and Koerner (1997) that designs based on HELP model-generated heads are not conservative and conceal heads that may be significantly greater. Such large heads can easily lead to slope failures of final covers and increased leakage in liner systems.

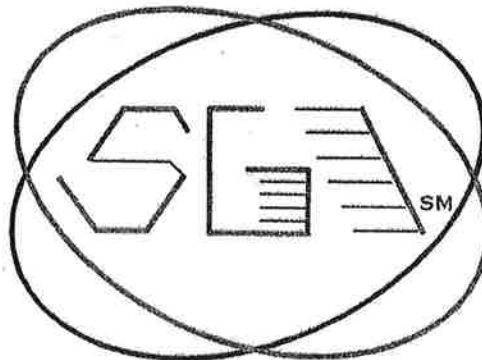
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The authors recommend that, in general, lateral drainage systems be designed by assuming that the design rate of fluid supply is equal to the permeability of the layer overlying the drain. While exceptions will occur, this method is always conservative and produces required values of service transmissivity that today's geonets can provide. The authors also recommend the use of Giroud's simplified solutions—Equation 1 for natural drainage systems and Equation 3 for drainage composites—to evaluate the maximum head acting within the lateral drain. These equations are readily solved by hand, avoid numerical problems of the McEnroe solution, and provide the designer with a better feel for the role of the various design variables.

Finally, the authors have also demonstrated that two established regulatory icons—equivalency based on transmissivity and dual layer lateral drainage systems—are non-conservative and can lead to solutions that result in excessive head acting on the liner system. It is hoped the regulatory community will let the mathematics control design and not tradition based on out dated design sections.

Part 2 of this series will take a hard look at current practices related to toe drains, leakage detection systems, and long-term service reduction factors. It will be as challenging as Part 1. **GFR**

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