DESIGNER'S FORUM

Composite drains for side slopes in landfill final covers

By Gregory N. Richardson and Aigen Zhao

FINAL-COVER DESIGN FOR LINED landfills presents the designer with challenges related to soil erosion and slope stability. The previous "Designer's Forum" (May, 1998, pp. 22–27) focused on using synthetic erosion-control mats to limit erosion on landfill final-cover elements, including down chutes, swales and side slopes. This column will concentrate on the design of geosynthetic-drainage composites to ensure landfill final-cover slope stability. This topic has been the subject of academic studies by the Geosynthetics Research Institute (GRI), Philadelphia, and of GRI director Dr. Bob Koerner's keynote presentation at the recent Sixth International Conference on Geosynthetics in Atlanta.

This column is the first of a two-part series on the design of drainage layers within final covers that will review concerns expressed by Dr. Koerner and provide simple methods for properly designing lateral-drainage systems within landfill final-cover systems. This first article evaluates the design of lateral-drainage layers, which are required to provide stability to the 3H–4H: 1V side slopes common in contemporary municipal-landfill final covers.

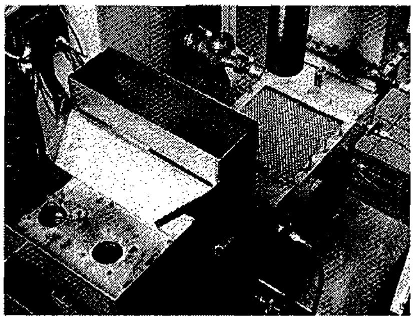

Photo 1. Transmissivity test equipment can be adjusted for a range of normal loads and boundary conditions.

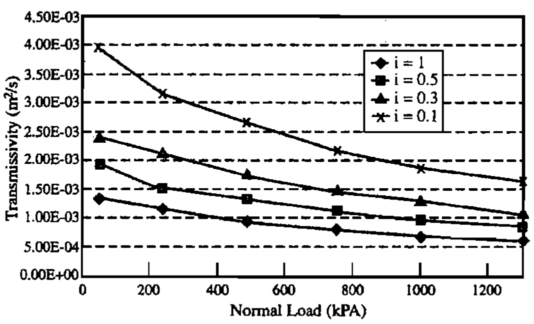

Figure 1. Transmissivity data for a geonet laminated with an 8 oz/yd^2 nonwoven on each side, tested with ASTM D 4716 under in-soil environment.

In this situation, the drainage layer must prevent pore-water pressures from developing immediately above the barrier system. Limiting infiltration is not the primary concern—stability is. The August "Designer's Forum" will address lateral-drainage system design for the flatter 5–8% portions of the landfill, where the drainage layer must minimize the head acting on the liner system to limit infiltration.

Problem statement

Final covers on RCRA Subtitle D landfills must limit infiltration through the cover to a rate less than the leakage rate of the liner system (U.S. Environmental Protection Agency 1993). The U.S. Enviromental Protection Agency (EPA) interpreted this requirement by mandating that final covers include a composite barrier consisting of a 18-in.-thick compacted-soil barrier with a permeability of less than $1x10^{-5}$ cm/sec, covered by a geomembrane (Federal Register, June 26, 1992). A nominal 6-in. erosion-control layer placed over the geomembrane completed the minimum regulatory profile.

In reality, this thin erosion-control layer is ill-suited for survival and never incorporated alone. A typical layer must provide sufficient water-storage capacity to allow the cover vegetation to survive periods of drought. Except for arid and semi-arid regions of the country, this usually requires a 1.5–2-ft layer of vegetative support soil covered with a 6-in. topsoil layer.

The presence of a barrier layer within the final cover can cause a build up of pore-water pressures above, or landfill gas (LFG) pressures beneath, the barrier, thus risking sliding failure (see "Designer's Forum," March, 1997, pp. 15–17). Both types of pressure reduce the contact or effective stress acting on veneer interfaces, which reduces the final-cover sliding stability.

In order to ensure the stability of the veneer layers that form the final cover, the designer must confirm that:

1. The interface friction between any two cover layers is adequate.

2. Pore-water pressures from water which infiltrates the cover does not reduce the contact stresses between the geomembrane and the overlying soil.

3. LFG pressures beneath the final cover are vented adequately.

This article will review a design of geocomposite-drainage layers that satisfies these three design considerations.

Geocomposite drains

Geocomposite-drain systems are composed of a core drainage net with a geotextile laminated on one or both faces and are designed for in-plane flow over a large surface area. The critical engineering properties of the composite include its flow capacity (or transmissivity) under design loads and boundary conditions, and its internal shear strength. A laboratory transmissivity test (ASTM D 4716), using the equipment setup shown in **Photo 1**, is performed to evaluate the geocomposite-flow capacity. This equipment allows a range of normal loads and boundary conditions, i.e., soil vs. rigid membrane, to be applied to the geocomposite face. The head acting across the 12-in.^{2} sample can be varied to create a range of gradients that simulate field-slope conditions.

Figure 1 shows typical data produced by this transmissivity test. The test was conducted on a geocomposite, which consisted of a geonet laminated with 8-oz/yd^2 (272 g/m^2) nonwoven geotextile on both sides, under an in-soil environment. Be aware that the transmissivity of the geonet core is not representative of the geocomposite as a whole. If the end product is a composite, transmissivity-test data must be obtained from a geocomposite. The geotextile portion of the geocomposite functions as a filter and separator and, therefore, should meet the filtration and retention criteria specific to the on-site soil.

Geocomposite-shear strength is controlled by the strength of the lamination between the geotextiles and the core drainage net. A nonwoven geotextile typically is laminated to a polyethylene geonet by a thermal process. Lamination strength can be verified with the direct-shear test (ASTM D 5321), but commonly is achieved and field-verified by a minimum-specified ply-peel adhesion strength (ASTM D 413). A minimum-ply adhesion of 1 lb/in. or 454 gm/in. commonly is specified.

Geocomposite-drain design

Interface friction

Geocomposite drains have proven to be very stable in slope applications, due to the high interface friction that the geotextiles have with textured geomembranes and soils. If the geotextile used in the drain is a needle-punched nonwoven, the interface-friction angle can be assumed conservatively to equal ⅔ of the adjacent soil's internal angle of friction (Martin, Koerner and Whitty 1984). Alternatively, the interface friction of heat-calendered nonwovens can be measured in the laboratory with the direct-shear test (ASTM D 5321).

Pore-pressure reduction

If surface water infiltrating down through the vegetative layer is not drained off, it will generate detrimental pore-water pressures above the barrier layer. An accurate prediction of the maximum water infiltration rate is the greatest uncertainty in pore-water drain design.

For many of us, the extreme weather generated by El Niño has made this prediction easier. The resulting high precipitation and mild weather have produced saturated conditions in the vegetative layer of many U.S. regions that we previously would not have anticipated. In fact, the authors feel that, with the exception of arid and semi-arid regions, the designer should assume that the vegetative layer will become saturated during the final-cover service life. Such an assumption simplifies the analysis since, under saturated conditions, the gradient, *i*, is equal to one (unit gradient) and the infiltration velocity is equal to the permeability of the soil.

R. Thiel and M.G. Stewart first presented the design of a pore-water pressure drain that underlies a saturated vegetative layer at the Geo '93 conference in Vancouver, British Columbia, Canada. The rate of water infiltration into the geocomposite drain can be determined readily, since the water moves down under a unit gradient such that the infiltration velocity is equal to the permeability of the vegetative layer. Typical permeabilities for such systems range from 5×10^{-3}–5×10^{-4} cm/sec. Tighter soils do not allow root penetration and looser soils do not provide adequate water storage.

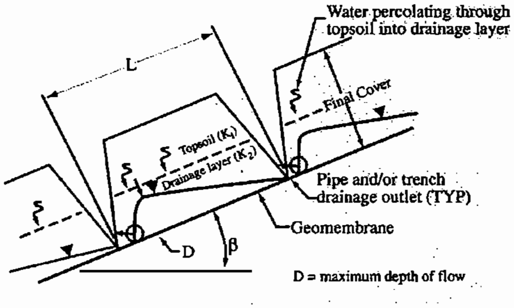

Figure 2. Schematic of head buildup in the drainage layer (Thiel and Stewart 1993)

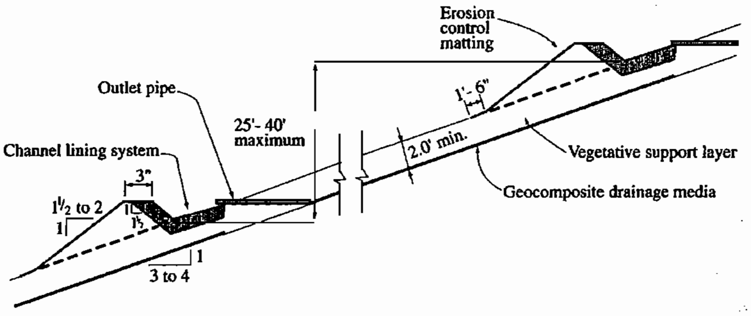

Figure 3. Computer-aided design (CAD) of a side-slope swale in a landfill final cover

Figure 2 shows the basic model developed by Thiel and Stewart. The quantity of water, Q_{in}, that infiltrates into a drainage-composite unit with length L is determined by:

$$Q_{in} = K_{veg}\ L\ 1$$

The drainage-layer flow capacity is determined for the use of Darcy's Law as follows:

$$Q_{out} = KiA = Ki\,(t \times 1) = [K_t]\ i$$

where t is the thickness of the drainage layer and K_t is defined as transmissivity (flow within the drainage layer), Ψ. The transmissivity of a geocomposite-drainage layer is obtained from laboratory testing, as described above. It is important that Ψ be obtained at normal stress levels, boundary conditions and gradients that reflect actual field conditions. Additional reduction factors for compressive-creep deformation of the drainage core, biological and chemical clogging of the geotextile, etc., also should be considered.

A factor of safety for the drainage capacity, FS_{dc}, of the geocomposite-drainage layer can be defined as follows:

$$FS_{dc} = Q_{out}/Q_{in} = \Psi\ I/K_{veg}L$$

It is important to understand the impact of both Ψ and L on the hydraulic factor of safety. Design implementation of this equation typically is integrated into the side-slope swale systems commonly used to limit surface erosion (Thiesen and Richardson 1998). The geocomposite-drainage layer is designed to drain into each swale but, to ensure that L will be defined by the actual spacing of the swales, it must not be installed continuously across a single ditch. These two functional requirements can be accomplished by using the swale details shown on **Figure 3**. The authors recommend that a minimum FS_{dc} of 2.0 be used in design.

The required-transmissivity range is easy to estimate based on typical slopes of 4H:1V–3H:1V, a vegetative soil permeability of 1×10^{-3} cm/sec, 25–40-ft (7.6–12.2 m) vertical spacing of the swales, and a minimum factor of safety of 2.0. Using these assumptions, the required transmissivity range is 1.6×10^{-3}–4×10^{-3} m²/s—a surprisingly small range that should serve as a good guide for designers to check their values against.

LFG-pressure dissipation

LFG is generated during the degradation of the putricible fractions of MSW(municipal solid waste). The actual rate of gas generation for a given landfill is dependent on the waste composition, waste-moisture content, etc., such that the design engineer will have to make an assumption for the gas-generation rate. For lined landfills that do not recirculate leachate, the gas-generation rate can be assumed conservatively to equal 0.1 scf/year/lb of MSW. The gas-generation rate, Q_{gas} (scf/yr/ft^2), immediately beneath the final cover can be estimated conservatively as follows:

$$Q_{gas} = \{[\text{weight of waste}] \times 0.1\} / [\text{final-cover surface area}]$$

The design of the geocomposite drain for gas removal then can be calculated using the same equations previously used for surface-water infiltration.

The gas flow into the geocomposite, Q_{ing}, is determined with the following:

$$Q_{ing} = Q_{gas}(L \times 1)$$

Though the geocomposite gas-flow capacity should be evaluated with gas flows in the laboratory, such tests are exceptionally rare. A lower estimate for the drainage-geocomposite gas-flow capacity can be calculated by multiplying the water transmissivity by 100, a conversion based on an assumption of laminar flow and the ratio of the intrinsic viscosities. Koerner, Bowe and Martin confirmed this relationship for geotextiles (1984).

The assumption of laminar flow is valid for low-flow gradients and permits Darcy's Law to be used. It allows the factor of safety in gas flow to be defined as follows:

$$FS_{gas} = Q_{out}/Q_{in} = \psi\,gas\,i \,/\, Q_{gas}\,L$$

It is important to remember that the unit weight of LFG (0.075 pcf) must be used when calculating the head used in evaluating the gradient, *i*, (change in head/flow distance), and that the flow direction is upward.

It is more difficult to establish a "typical" range of required gas transmissivities since the volume of waste affects the calculation and varies from site to site. However, assuming approximately 150 ft (46 m) of waste, Q_{gas} can be calculated to equal approximately 1000 scf/year/ft^2 (1×10^{-5} m^3/sec/m^2). For typical slopes of 4H:1V-3H:1V and a vertical spacing of swales from 25 to 40-ft (7.6–12.2 m), the flow gradient will range from 1.7 to 3.4. The required gas transmissivities are then equal to 1.5–5.8 cm^2/sec for a safety factor of 2. The equivalent water transmissivities would equal 1.5–5.8 x 10^{-2} cm^2/sec. Thus it appears that a composite drain which serves as the pore-water pressure-relief system would also be an adequate gas-venting material, assuming that the gas is vented or collected at distances equal to the surface-swale spacings.

Summary

Though the design of geocomposite drains for final covers requires very simple design calculations, it is dependent on the quality of laboratory-transmissivity data. The designer should ensure that the data properly reflects the normal loads, boundary conditions and flow gradients associated with the actual field installation. The next "Designer's Forum" will focus on designing the lateral-drainage system to minimize the head acting on the barrier system for the 5–8% tops common to landfills. GFR

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