

GEOCOMPOSITE DRAINS FOR LANDFILL FINAL CLOSURES: THE CHALLENGE AND SOLUTION

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SUMMARY: The design of final covers for lined landfills presents the designer with challenges related to soil erosion and slope stability. To ensure the stability of the cover slope, the designer must confirm that the interface friction between any two adjacent layers of the cover system is adequate to resist seepage forces and the reduction in shear strength resulting from landfill gas pressure. This paper demonstrates the critical problem of the long-term slope stability of landfill capping drainage systems in conventional final covers that include a geomembrane barrier and presents an innovative geotextile/geonet/geomembrane cover composite. This cover composite eliminates the weakest interface between geocomposite and the liner. With significant cost and performance advantages, the authors are hopeful that this alternative closure system will gain in more widespread usage for this application.

1. INTRODUCTION

The general long-term care of landfill final cover becomes very problematic when a combination of significant slopes and geomembranes are present together. Significant research and post analysis of failed final covers has led to a more rigorous method of designing geocomposite drains to perform in these types of applications. This method, which has been previously published by the authors through the use of actual failure cases (Richardson et al. 2002), demonstrates the catastrophic failure mechanisms present in conventional landfill final covers. Inadequate lateral drainage capacity can dramatically reduce its long-term ability to eliminate seepage forces. These seepage forces will result in a slope failure during periods of extended rain. Such failures have proven to be very costly. Based on first hand observations of long term failure mechanisms in final cover drainage composites, the authors developed a drainage composite that mechanically binds the geomembrane to the drainage composite. This allows long-term mechanisms that can be devastating to current designs to actually lead to increased factor of safety using the drainage/membrane composite.

This paper demonstrates the challenges of the long-term slope stability of landfill capping drainage systems in conventional final covers that include a geomembrane barrier. This paper then describes the structure of the new cover composite and presents its in-plane hydraulic

performance and shear strength result. Furthermore, this paper demonstrates installation details such as seaming and drainage of the composite. Cost data is also presented to compare the installed cost of the next generation drainage composite as compared to today's costs for conventional drainage composites placed over geomembranes.

2. LONG-TERM STABILITY PROBLEM

With the exception of arid and semi-arid regions, the final cover will at some point in its life approach saturation due to weather conditions. Assuming full saturation, the maximum seepage force in the cover soil layers using the infinite slope model shown on Figure 1 is given as follows:

$$F_{seep} = \gamma_w d \sin \beta$$

Where β is the slope angle and d is the vertical thickness of the soil cover and γ_w is the unit weight of water.

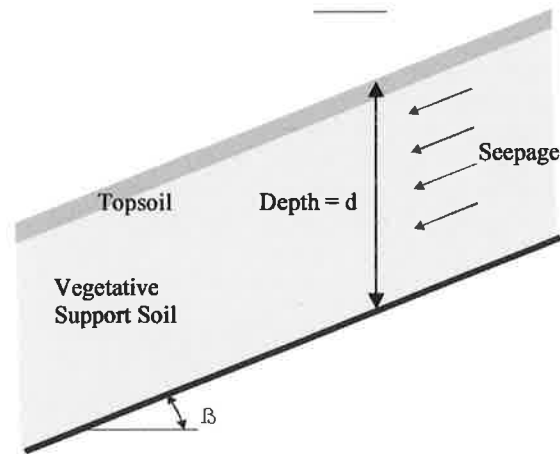


Figure 1. Infinite slope model

If the transmissivity of the underlying lateral drainage system is inadequate, then the infiltrating water will begin to flow parallel to the slope and the seepage forces will reduce the stability. If the cover soil fully saturates and the drain layer is inadequate, then the slope stability factor of safety is given as:

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{\gamma_b d \cos \beta \tan \delta}{\gamma_b d \sin \beta + \gamma_w d \sin \beta} = \frac{\gamma_b \tan \delta}{\gamma_{sat} \tan \beta} \approx 0.5 \frac{\tan \delta}{\tan \beta}$$

Where γ_{sat} is the saturated unit weight of the soil, γ_b is the buoyant unit weight of the soil, and δ is the interface friction angle.

When such seepage forces are eliminated by a functioning high flow capacity geocomposite, the slope safety factor, FS, becomes:

$$FS = \frac{\tan \delta}{\tan \beta}$$

For common 4H: 1V side slopes and $FS = 1.5$, this requires a minimum interface friction angle of 20.5° when the cover soil is not saturated and 36.8° when it is saturated. The 20.5° interface friction angle is easily achieved due to the “velcro” stick between nonwoven geotextiles and most textured geomembranes. The 36.8° interface friction angle actually exceeds the shear strength of common soils used in landfill cover systems and demonstrates that seepage forces must be prevented by the use of an adequately designed lateral drainage system.

The design of the pore water pressure drain underlying a saturated cover soil layer was first presented by Thiel and Stewart (1993). The rate of water infiltration into the geocomposite drain can be readily calculated under a unit gradient since the infiltration velocity is equal to the permeability of the vegetative layer. Typical permeability values for vegetative systems range from 1×10^{-3} to 1×10^{-5} cm/sec.

For geocomposite lateral drains, Giroud et al. (2000) has shown that the maximum liquid thickness, t_{max} , is given as follows:

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

Where L is the slope length, q_h is the vertical percolation rate or soil permeability in the saturated case, and k is the permeability of the lateral drainage composite. This equation is appropriate when the thickness of the geocomposite is less than 20 mm over the range of slopes common to most landfills. This equation should not be used with thicker natural drainage layers. This allows the required transmissivity for a geocomposite drain to be directly solved for as follows:

$$\theta_{required} = \frac{q_h L}{\sin \beta}$$

The transmissivity specified must be significantly greater than $\theta_{required}$ to account for in-service factors than reduce the flow capacity of the geocomposite. The long-term-in-soil transmissivity, θ_{LTIS} , is determined by the following equation (Girould et al. 2000):

$$\theta_{LTIS} = \frac{\theta_{measured}}{RF_{in} \cdot RF_{cr} \cdot RF_{cc} \cdot RF_{bc}}$$

Where θ_{LTIS} is the long-term-in-soil hydraulic transmissivity of the drainage geocomposite, $\theta_{req'd}$ is the required transmissivity based on design needs, $\theta_{measured}$ is the transmissivity measured in accordance with ASTM 4716 or GRI-GC8 (2001), and RF are service reduction factors. The following four reduction factors were initially introduced by Koerner (1998):

RF_{in} = reduction factor for elastic deformation, or intrusion of the adjacent geotextiles into the drainage channel.

RF_{cr} = reduction factor for creep deformation of the drainage core and/or adjacent geotextile into the drainage channel.

RF_{cc} = reduction factor for chemical clogging and/or precipitation of chemicals in the drainage core space.

RF_{bc} = reduction factor for biological clogging in the drainage core space.

More recent work by Giroud et al. (2000) has defined additional long-term service factors that include the following:

RF_{IMCO} = reduction factor for immediate compression, i.e. decrease of hydraulic transmissivity due to compression of the transmissive core following immediately the application of stress;

RF_{IMIN} = reduction factor for immediate intrusion, i.e. decrease of hydraulic transmissivity due to geotextile intrusion into the transmissive core following immediately the application of stress;

RF_{CD} = reduction factor for chemical degradation, i.e. decrease of hydraulic transmissivity due to chemical degradation of the polymeric compound(s) used to make the geocomposite;

RF_{PC} = reduction factor for particulate clogging, i.e. decrease of hydraulic transmissivity due to clogging by particles migrating into the transmissive core;

Each service reduction factor corresponds to a mechanism that reduces the hydraulic transmissivity of the geocomposite in the field. If one of these mechanisms occurs during the hydraulic transmissivity test in the laboratory to the same extent as in the field, then the corresponding reduction factor is equal to 1.0.

The recently published GRI-GC8 standard (2001) requires the transmissivity to be measured under simulated conditions for 100-hour duration. Creep reduction factor RF_{cr} is determined from 10,000-hour compressive creep data. In the absence of 10,000-hour creep data, designers must assess the applicability of the geocomposite with respect to structural stability under sustained loads.

The above reduction factors do not include consideration of the impact of vegetative root penetration of the lateral drainage composite. This uncertainty, regarding the impact of vegetation on the stability of conventional final cover systems, was the genesis of the new final cover system presented in this paper.

3. FINAL COVER COMPOSITE

The inevitable threat of vegetative root penetration into the lateral drainage composite forced a re-evaluation of the final cover geosynthetics. Additionally, the authors had been concerned with the following shortfalls of conventional final cover systems:

- The lower geotextile used to increase interface friction with the liner on drainage composites causes nearly an order of magnitude reduction in transmissivity.
- Conventional geosynthetic final cover systems require a specialized installer, which limits the ability of the owner to incrementally construct final cover.

With these goals in mind, it was obvious that a final cover composite would require the geomembrane to be integral with the drainage composite and act as its lower drainage surface.

Figure 2(a) and (b) show the final cover composite developed to meet the above goals. The key performance specifications of the new geosynthetic are as follows:

- 0.7 mm (\cong 30 mil) thickness polyethylene geomembrane,
- transmissivity (gradient = 0.1, normal load = 48 kPa, seating time = 100 hours) equals 1×10^{-2} m²/sec

- transmissivity (gradient = 0.33, normal load = 48 kPa, seating time = 100 hours) equals $6.5 \times 10^{-3} \text{ m}^2/\text{sec}$
- geomembrane interface friction angle with silty sandy soil 27 degrees (peak) and 23 degrees (residual), measured at normal loads of 7, 14 and 28 kPa.
- a unit weight of approximately 1200 g/m^2 .

This single geosynthetic composite is intended to replace the drainage composite and separate geomembrane now commonly used in closure systems. Final closure of RCRA D facilities is commonly done using 0.76 mm (30 mil) HDPE geomembranes without the addition of a lateral drainage system. The new composite final closure geosynthetic provide the lateral drainage system that ensures both stability on slopes and a reduced head on the liner. The latter translates into a significant reduction in the potential infiltration through the final cover. In both performance and cost, the new composite final closure geosynthetic is superior to the simplified regulatory final cover.



Figure 2(a) Landfill final cover composite



Figure 2(b) Landfill final cover composite – a close look

3.1 Seaming

A 75 mm smooth edge is provided on both edges of the final cover composite to allow for seaming. Three methods of seaming the composite have been evaluated as follows:

- Wedge welding the geomembrane edges followed by sewing or Lysterizing the geotextiles together produces a very conventional union, but requires an installer familiar with geomembrane welding.
- Sewing the geomembrane and geotextiles together in a common prayer seam that keeps the seam above the flow elevation of the fluids, but may not be as gas tight as the other two seaming methods.
- Taping the geomembrane together and sewing or Lysterizing the geotextiles together.

The last alternative is slightly more costly than the other two in materials, but it offers simplicity of installation that many owners may find attractive. A 75-mm wide tape is under evaluation that provides approximately 3.5 kN/m peel strength to the polyethylene geomembranes and has a greater shear strength than the geomembrane itself. This seam can be applied without specialized equipment or training and is as effective as the wedge welding in seam strength and integrity.

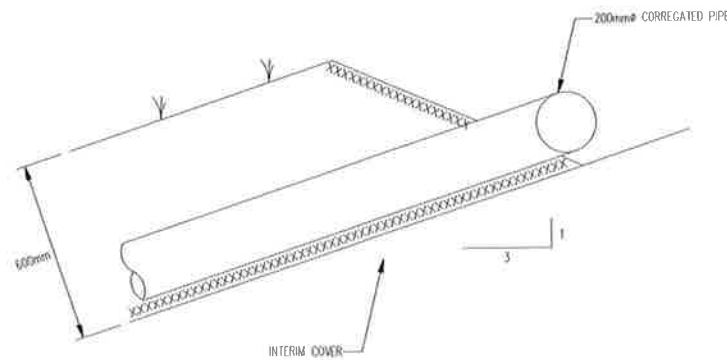
3.2 Final cover drainage details

Integrating the final cover composite into final cover slope designs actually allowed for construction simplicity and economy. Final covers on long slopes are incrementally constructed between surface water swales as the waste mound grows in height. As shown on Figure 3, gravel drains collect the surface water every 40 to 50 meters to prevent excessive erosion of the surface soils. Conventionally, the lateral drainage layer is also drained at the same location as the swales. In recent years, many final cover designs have consolidated the surface water and lateral drainage from the composite into a single drainpipe.

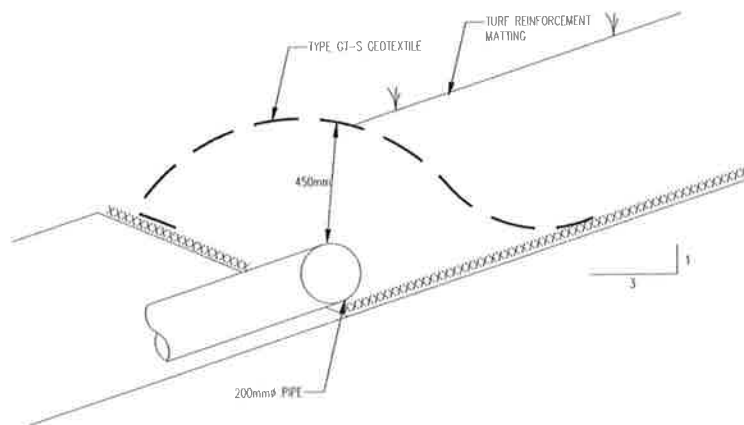


Figure 3. Gravel Drain

Figure 4 shows the design concept for such a consolidated system using the new final cover composite material. Figure 4a shows the upper termination of a final cover increment. The new final cover composite is wrapped over the lower vegetative support soil to limit erosion and to form a lateral drainage swale. Figure 4b shows how the final cover section is extended vertically. Note that both the surface water and the infiltration water are collected by the final cover composite and are collected in the same pipe. This pipe conveys the waters laterally to either a down chute or a down pipe buried within the waste. Note that this concept does not use swales to collect surface water, but instead relies on gravel drain type drop inlets. Figure 3 shows what such covers look like once completed. Note that a turf reinforcement mat is used to protect the gravel drain until vegetation is established. Additionally, a geotextile is now wrapped over the gravel to further limit the potential for clogging prior to development of vegetation.



4(a) Interim Termination of Final Cover



4(b) Surface Water/Composite Drain

Figure 4. Collection of Surface Water and Seepage Waters

3.3 Landfill gas considerations

The final cover section shown in Figure 4 does not include a collector for LFG. This collector may include active gas wells, a surface gas collection layer or spaced gravel drains placed shallow in the waste. Design of these features is beyond the scope of this paper, but their necessity must be noted.

4. COST CONSIDERATIONS

Final covers that include a geomembrane barrier constructed by the first author over the past three years have ranged in unit cost from \$270,000 to \$320,000 per hectare. This cost does not include placement of 300-mm of interim soil cover as part of operations or construction of an active gas collection system. It does commonly include the cost of passive landfill gas vents. Table 1 presents three cost summaries that include 1) conventional final cover constructed by contracting out work, 2) alternative final cover constructed by contracting out work, and 3) alternative final cover incrementally constructed with facility equipment and staff.

Table 1. Final Cover On Slope Installation Costs

Final Cover Component	Conventional	Alternative Contracting out	Alternative Owner install
1) Geomembrane, delivered to site	4.09	6.03	6.03
2) Geocomposite drain	4.52		
3) Geomembrane installation	1.61	2.15	0.54
4) Geocomposite installation	1.61		
5) Pipes and gravel drains	4.84	4.84	4.84
6) Soil (450-mm soil + 150-mm topsoil)	7.53	7.53	3.22
7) Soil placement	3.22	3.22	1.08
8) Erosion control mat	0.54	0.54	0.54
9) Seeding	0.54	0.54	0.54
TOTAL COST \$USA/m ²	\$28.52	\$24.86	\$16.79
TOTAL COST \$USA/hectare	\$285,200	\$248,600	\$167,900

The last alternative demonstrates the advantage of a final closure system that can be incrementally constructed by the operator. Both soil and drain placement are greatly simplified if the final cover is incrementally constructed. Placement of both geosynthetics and soil are difficult on very long slopes that result from delaying the closure process.

In the USA, an additional cost saving in bonding the closure is obtained by incrementally closing in small areas. Any waste surface requiring final closure must be financially bonded to pay for closure if the operation fails financially. Incremental construction of the final cover minimizes this expense.

5. CONCLUDING REMARKS

The geocomposite geomembrane/lateral drainage element offers owners the opportunity to construct their final covers incrementally at a unit cost that is almost one half of current closure costs. More importantly, the integration of the geomembrane and the final cover drainage

composite together eliminates the potential for future slope stability problems resulting from root penetration and clogging of the drainage composite. Given both cost and performance advantages, the authors are hopeful that this alternative closure system will gain in more widespread usage for this application.

REFERENCES

- ASTM D4716 (2001) Standard Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using Constant Head.
- GRI-GC8 (2001) Standard Guide for Determination of the Allowable Flow Rate of a Drainage, Geocomposite, Geosynthetics Research Institute.
- Giroud, J.P., Zornberg, J.G., and Zhao, A. (2000) Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers. *Geosynthetic International*, Vol. 7, Nos. 4-5, pp, 285-380.
- Koerner, R.M. (1998) Designing with Geosynthetics, Prentice Hall, New Jersey.
- Richardson, G.N. and Zhao, A. (2002) Lessons Learned From the Failure of a Landfill Capping System, *Proceedings of the 7th International Geosynthetics Conference*, Edited by Delmas, Gourc & Girard, International Geosynthetics Society, Nice, October, pp.
- Richardson, G.N., Giroud, J.P and Zhao, A. (2002) Lateral Drainage Update – Part 1, Designers Forum, *Geotechnical Fabrics Report*, IFAI, St.Paul, MN, January/February, pp. 18-21.
- Richardson, G.N., Giroud, J.P and Zhao, A. (2002) Lateral Drainage Update – Part 2, Designers Forum, *Geotechnical Fabrics Report*, IFAI, St.Paul, MN, March, pp. 12-17.
- Thiel, R.S., and Stewart, M.G. (1993) Geosynthetic Landfill Cover Design Methodology and Construction Experience in the Pacific Northwest. *Proceedings Geosynthetics '93*, Vancouver, IFAI, pp. 1131-1144.