DESIGNER'S FORUM

The design of geonets in landfill leak-detection systems

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OF ALL THE VARIED APPLICATIONS in which geonets serve, their use in waste-containment leak-detection systems (LDSs) probably is their most natural. These systems must provide two important functions in liner structures:

1. Allow leakage from an overlying primary liner system to be monitored (hence the term LDS)
2. Minimize the head acting on an underlying secondary liner system.

While most regulatory attention is focused on the first role, the latter actually is more important for environmental protection. This paper reviews the natural role of a geonet in LDS systems, presents the equations required for their proper design, and reviews construction and operational considerations.

LDS-design objectives

The LDS system must be designed to satisfy the following objectives:

- provide rapid detection of a major breach in the primary liner system (a maximum detection time of 24 hours commonly is required)
- limit the head acting on the secondary liner to less than the LDS thickness.

Unfortunately, regulators commonly focus on the first objective and on the leachate quantity drained by the LDS system. However, it is important to remember that the second objective will be met, regardless of flow rate, if the LDS is not saturated. This is ensured by defining an action leakage rate (ALR) that is less than the saturated flow of the LDS.

If the ALR is exceeded, then the facility must implement supplemental efforts to limit the generation of leachate in the refuse and/or increase the rate of its removal from the primary collector system. Leachate generation can be reduced by minimizing the size of the active working face and by increasing runoff from interim covers that use tarps. The removal rate can be advanced by increased or continuous operation of leachate-recovery pumps.

Leak-detection design

Geonets provide the most efficient material for rapid detection of leaks in an overlying liner system. Because of limited field capacity and high transmissivity, the geonet minimizes the time lag between leak occurrence and detection time. LDSs constructed of sand or gravel have significant liquid-storage potential that can delay leakage detection in the primary liner.

Travel time

The travel time of liquids that drain through the LDS is estimated by assuming that the system is saturated. Given this assumption, the apparent velocity of flow in the drainage net, v, can be estimated from Darcy's Law as follows:

Equation 1: $Q = kIA = (kt)Iw = \psi Iw = vA = vwt$

or Equation 2: $v = \psi I/t$

where ψ is the transmissivity of the geonet, A is the cross sectional area of the net ($A = w \times t$, where w is the width, and t is the thickness, of the geonet or geocomposite), and I is the flow gradient. The thickness of the geonet or geocomposite is determined under design load (at least twice the anticipated service load). **Figure 1** presents the

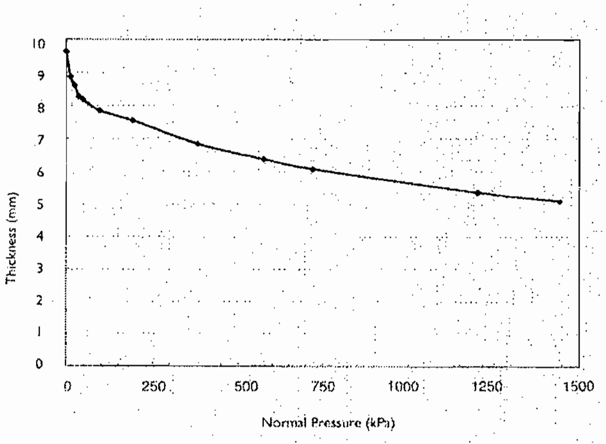
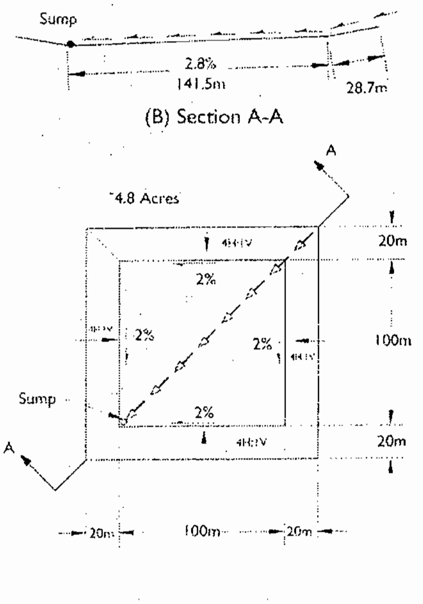


Figure 1. Geocomposite thickness under a range of normal loads.



(B) Section A-A

(A) Plain View

Figure 2. Common landfill-cell profile.

curve of thickness for a geocomposite under a range of normal loads.

The drainage geonet's design transmissivity must be obtained from laboratory transmissivity-test data (ASTM D 4716), which typically is provided by the manufacturer, and divided by a factor of safety (typically 10.0). For the LDS, the product of the long-term reduction factors for intrusion, compressive creep, biological and chemical clogging proposed by R.M. Koerner is 4.7–16 (1997). The recommended safety factor of 10 is equal approximately to the average value of the above range.

The transmissivity test must be performed with normal loads and boundary conditions that replicate field-service situations. For LDS testing, the lower boundary of the geonet typically is the geomembrane. The upper boundary is either another geomembrane or a filter-fabric/soil-barrier layer that forms part of a composite-primary liner system. In the case of a composite primary, the upper boundary in the transmissivity test must include both the filter geotextile and a soil layer to properly simulate intrusion into the upper boundary and the resulting loss of transmissivity.

The true velocity of flow, v_{true}, is calculated by dividing the apparent velocity by the porosity, n, of the geonet. Because of the volume of flow space occupied by the drainage-geonet ribs, v_{true} actually is greater than the apparent velocity calculated above. Here, porosity is the volume of the voids divided by the geonet's total volume. Typical porosity values for geonets range from 0.3 to 0.8.

Figure 2 (p. 20) shows a common landfill-cell geometry, or profile. The maximum travel time, T, for this system can be calculated by applying Equation 2 as follows:

Equation 3: $T = T_1 + T_2 = L_1/v_1 + L_2/v_2$

or Equation 4: $T = L_1/\{\psi_1 I_1/t_1 n_1\} + L_2/\{\psi_2 I_2/t_2 n_2\}$

where the transmissivities, ψ, are obtained from a manufacturer's chart such as **Figure 3** (p. 22); the geonet's thickness is obtained from a manufacturer's chart, such as the example in Figure 1; the geonet porosity, n, is provided by the manufacturer; and I is the flow gradient in the field. All geonet properties should be determined at normal loads that reflect field-service levels.

For the conditions on Figure 2, we can assume that the following properties reflect field-service conditions for the geonets represented on Figures 1 and 3:

- $\psi_1 = 3.2 \times 10^{-4} m^2/sec$,
- $\psi_2 = 1.8 \times 10^{-4} m^2/sec$ (FS=10),
- n1 = n2 = 0.6,
- $t_1 = t_2 = .006$ m at a design normal load of 750 kpa (15,000 psf).

By using these values, the travel time for the example cell is determined to be approximately 16.7 hours. This analysis is conservative, since our goal in the next design phase will be to ensure that the LDS does not become saturated.

Action leakage rate

The ALR is a fraction of the flow rate that would be generated if the LDS became saturated. For the geometry of the example used above, the saturated-flow rate can be calculated by modeling the LDS as one-fourth of a confined aquifer drained by a fully penetrating well. Therefore, the max-

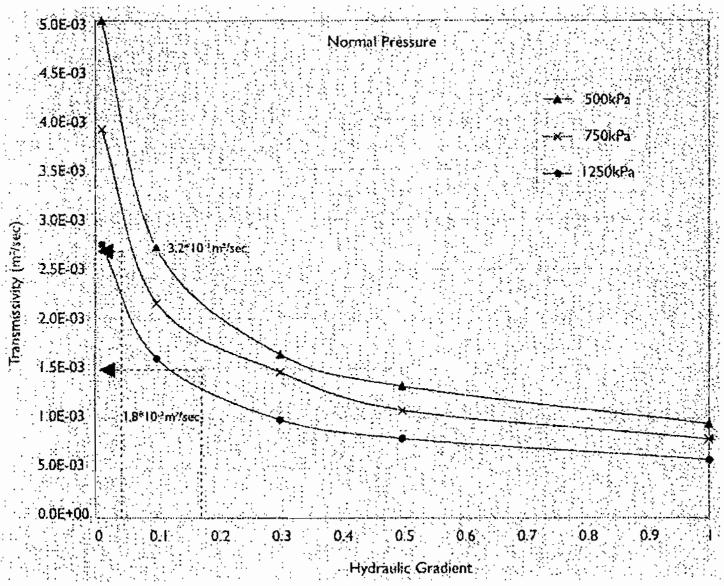


Figure 3. Manufacturer-supplied transmissivity chart

Photo 1. The geonet in the LDS of this landfill not only ensures rapid leak detection, it actually lowers the leakage rate.

imum saturated flow into the LDS sump can be estimated as follows:

Equation 5:

$Q = 0.25 \times [2 \pi \psi \Delta h / \ln(R/R_{sump})]$

(McWhorter and Sunada 1981)

where Δh is the head loss (2.8 m), R is the radius of the drain field (100 m), and R_{sump} is the radius of the sump area (0.5 m). The 0.25 factor reflects that only one- fourth of an equivalent circular field drains to the sump. Maximum saturated flow into the LDS sump on Figure 2 then can be estimated as follows:

Equation 6:

$Q = 0.25 \times [2\pi 3.2 \times 10^{-4} \times 2.8/\ln(100/0.5)] = 2.65 \times 10^{-4}$ m³/sec

or approximately 6040 gallons per day. For the 4.8-acre cell, this amounts to 1260 gal/acre/day (gad). The actual value selected for the ALR must be less than the estimated maximum saturated flow into the LDS sump. If the value is too low, the facility will risk being forced into a heightened monitoring/operational mode or even facing closure each time the ALR is exceeded. Picking a value that is too high will increase the cost of the LDS recovery-pump system, since it must be sized to handle the ALR-flow rate. Typical ALR values range from a low of 20 gad for liner systems with a composite-primary liner to as much as 200 gad for those that include only a single primary liner.

Recent studies sponsored by the U.S. Environmental Protection Agency (EPA) show that, for systems with a composite-primary liner that includes a compacted-clay liner and a geomembrane, actual peak flows measured in LDS systems range from 0–114 gad initially and drop to 0–63 gad during cell operation (Othman et al. 1998). For systems with a composite primary liner that includes a GCL, the flows measured in LDS systems range from 0–86 gad initially to 0–15 gad during operation. These flows can include construction water draining from the LDS and pore water from the consolidating primary clay liner, in addition to leakage through the primary liner. The results indicate that most LDS systems currently installed are not saturated and effectively are limiting the head acting on the secondary liner system.

The same study clearly showed the value of a composite primary liner in lowering flow rates to the LDS. Those cells with only a geomembrane primary liner had a range of peak initial-flow rates to the LDS of 0–367 gad and operational peak-flow rates of 0–254 gad. Limited post-closure data indicates a significant drop in the long-term flow rate to the LDS after placement of the final cover. This study also demonstrates the need to actually calculate the ALR, rather than using "rules of thumb" to set it.

Head-reduction design

The LDS's most important environmental role is to limit the head acting on the secondary composite-liner system. As discussed in the previous "Designer's Forum" (August, *GFR*, pp. 21–23), the leakage through a penetration, Q (m³/sec), in a geomembrane can be estimated with the following equations (Giroud et al. 1992):

for good contact, Equation 7:
$Q = 0.21\, h^{0.9} a^{0.1} k^{0.74}$

for poor contact, Equation 8:
$Q = 1.15\, h^{0.9} a^{0.1} k^{0.74}$

where a is the area of individual penetration (m²) 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.

The area of penetration is limited by a comprehensive construction-quality assurance (CQA) program. In liner systems, the permeability typically is less than 1×10^{-7} cm/sec. Therefore, the designer's role is limited to ensuring that the head acting on the secondary barrier system is minimal.

For municipal solid-waste landfills, Resource Conservation and Recovery Act (RCRA) Subtitle D limits the allowable head to less than 30 cm. With standard CQA and a 1×10^{-7} cm/sec liner system, this implies typical liner leakage of approximately 0.84

gad (assuming good contact and six penetrations at 1 cm² each per acre). The data presented by Othman et al. indicates that many primary liners are performing below this level, which is no doubt due to poor liner/clay contact and the impact of geomembrane wrinkles (1998).

The addition of an LDS system allows the designer to limit the design head to something less than the thickness of the geonet component. For a typical geonet, this means that the maximum head acting on the geomembrane is less than its thickness of approximately 8 mm. If the field conditions originally considered in Equation 7 are applied and this value is substituted into the equation, the predicted total leakage is reduced to less than 0.03 gad.

The elimination of wrinkles in the liner system obviously is of great importance in LDS construction. A wrinkle that may be acceptable in a single composite-liner system with an allowable 30 cm head clearly is not acceptable beneath a LDS system that is trying to achieve a 6-mm maximum head. Therefore, the CQA program for LDS systems must provide decisive measures to minimize geomembrane wrinkling. Typically, such measures include limiting the amount of liner that is allowed to be installed before placement of the geonet and primary liner system. This forces the construction of the full liner-system section across the facility, as opposed to the current practice of layered construction.

Summary

Geonets provide the correct balance of low water-storage capacity and high-flow transmissivity for the design of LDS systems. Contrary to its name, the leak-detection system goes well beyond monitoring the performance of the primary liner system. The system's ability to reduce the head that acts on the secondary liner system, thereby lowering the leakage rate, should be considered its more important role. Its capacity to do so even when subjected to significant leakage from the primary liner system must be recognized.

This role is particularly important since, for political reasons, it is almost impossible to empty a waste-containment cell once it is completed. Therefore, the designer's emphasis should be on preventing future leaks and not simply on detecting them. Geonets are essential for accomplishing this goal. **GFR**

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