Active LFG Control: An Unreliable Aid to Veneer Stability

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ABSTRACT
The potential for sliding failure of final covers and piggyback liners in municipal solid waste (MSW) landfills equipped with active landfill gas (LFG) control systems is demonstrated and the need for a contingency passive venting system is presented. Two final cover failures illustrate the potential failure scenario. Both failures occurred during the period that landfill active LFG control systems were shut down. In typical designs, the potential for positive pressures exerted by LFG had been neglected, e.g. no positive LFG pressures were anticipated. Design and construction of a contingency passive LFG venting system is then reviewed and demonstrated for final closure and piggyback liner applications. The contingency passive LFG venting system precludes entry of atmospheric air during active LFG extraction but allows for passive venting of LFG should positive pressures develop beneath the final cover.

1. INTRODUCTION

Modern MSW landfills commonly used veneered liner systems placed in part on slopes that have maximum angles ranging from 4 horizontal and 1 vertical (4H:1V or 14°) to 3H:1V (18.4°). A typical veneer final cover system profile is shown on Figure 1 and includes the following layers (top to bottom):

- A 45 to 60 cm thick vegetative support layer that protects the underlying geosynthetic layers and support a surface erosion resistant vegetative growth;
- A drainage geocomposite (DGC) that prevents development of seepage forces within the vegetative support layer and excess pore water pressures at the base of the vegetative support layer;
- A textured geomembrane (GM) barrier layer to limit surface water intrusion into the MSW and to contain LFG generated within the waste;
- An optional geosynthetic clay liner (GCL) to provide a composite barrier in conjunction with the geomembrane; and
- A soil layer that provides support for the overlying layers and may include the interim soil layer placed immediately over the waste.

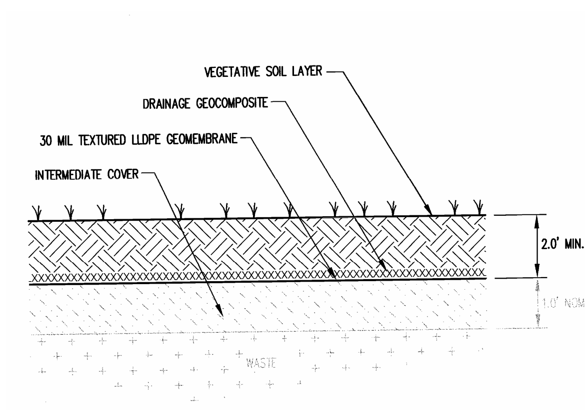

Figure 1 Typical Final Cover System

A typical piggyback liner system is a variation of the above with the addition of a second geomembrane and a leak detection system (See Figure 2). Significant writings have focused on the design of the various layers to resist sliding and to provide minimum factors of safety against sliding of 1.5 under static loading conditions and 1.0 under seismic loading conditions. Particular attention has been historically given to the influence of surface water infiltration on the stability of the final covers layers above the GM. This paper focuses on the impact of LFG pressure beneath the GM liner and demonstrates methods to ensure that it does not impact the stability of the overlying veneer liner system during its service life.

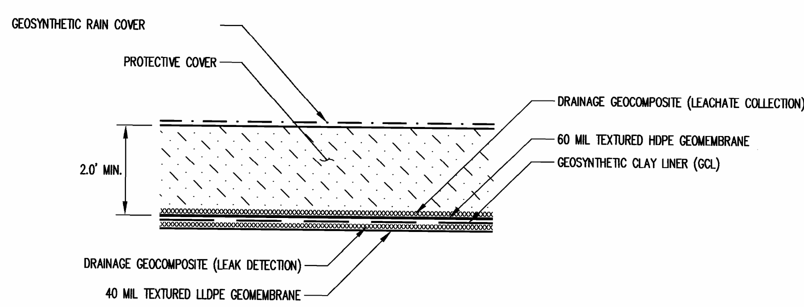

Figure 2 Typical Piggyback Liner System

2. STABILITY CONSIDERATIONS

2.1 Influence Of LFG On Sliding Factor Of Safety

The stability of the GM and overlying layers is influenced by the interface shear strength between the GM and underlying soil or GCL layer and the LFG pressure, P_{LFG}, acting immediately beneath the GM. This can be expressed as follows:

$$FS = \frac{(W - u_{LFG})\cos\beta\tan\delta + a}{W\sin\beta} \quad [1]$$

The variables in Equation 1 are defined as follows:

W = unit weight of final cover system above the GM (kN/m^3),
u_{LFG} = LFG pressure (kPa)
β = slope angle (degrees)
δ = interface friction angle (degrees)
a = Interface adhesion (kPa)

As the LFG pressure increases, the resistance to sliding due to interface friction decreases and the sliding factor of safety decreases to 1.0 immediately prior to failure. Figure 3 shows the LFG pressures (1-inch H_20 = 0.036 psi = 249 Pa) at a sliding factor of safety of one for two common slopes and a range of interface strength values. Typical interface shear strengths obtained for the soil – GCL – GM interfaces ranges from 24° to 30°with a nominal adhesion, commonly referred to as 'Velcro' effect, of 20 to 50 psf (960 to 2400 Pa). Allowable LFG pressures for 4H:1V slopes range from approximately 17 to 28 inches of H_20 (4200 to 6970 Pa) depending upon the level of adhesion developed. Similarly, Allowable LFG pressures for 3H:1V slopes range from approximately 10 to 20 inches of H_20 (2490 to 4980 Pa) depending upon the level of adhesion developed. The other fact apparent from Figure 3 is the important role played by the adhesion in maintaining stability. In all low normal load veneer barrier systems, the designer should select components that provide the maximum adhesion in addition to an acceptable interface friction angle.

Estimating the actual magnitude of LFG pressure that will develop in the absence of a LFG recovery system beneath a modern geosynthetic barrier system is difficult. Prosser and Janechek (1995) indicate that LFG pressures at the bottom of a MSW landfill can reach four (4) atmospheres (58.8 psi or 406 kPa) in the absence of a LFG recovery system. McBean et al (1995) suggest that with a good cover and liner system, high LFG pressures in the range of 10-30 inches H_2O (2490 to 9500 Pa) are reasonable. Comparing this latter range of potential LFG pressures to the limit LFG pressures presented in Figure 3 demonstrates that sliding failure is a certainty for all 3H:1V slopes and many 4H:1V slopes if LFG is allowed to accumulate and build in pressure beneath the barrier system.

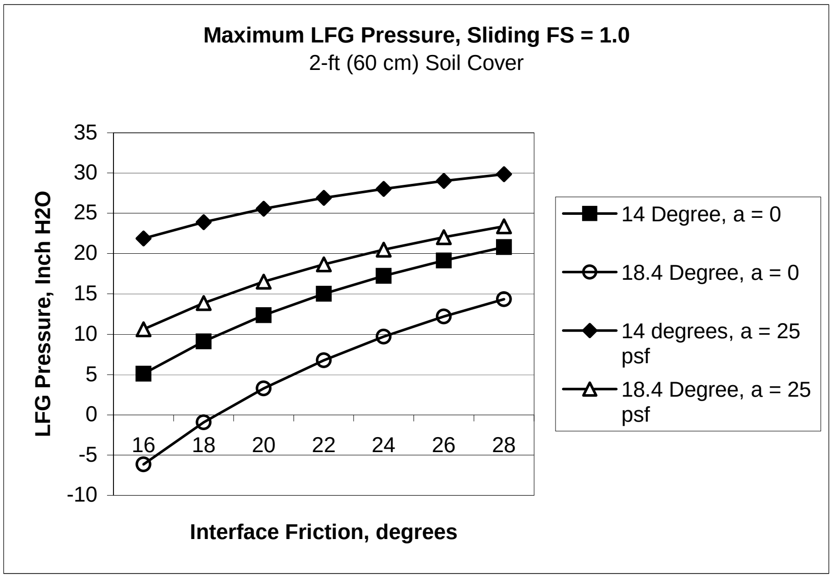

Figure 3 LFG Pressure at Limit of Sliding Stability, FS = 1.0

For landfills that incorporate an active LFG recovery system, the key question is how long can the recovery system be shut down before dangerous levels of LFG pressures develop. Active LFG recovery systems utilize large compressors to develop a vacuum to draw the LFG out of the waste. Such equipment must, at a minimum, receive annual maintenance that may require an extended shut down not to mention other unexpected shutdown events that commonly occur. Unless a parallel system is placed in service, the LFG pressure beneath the final cover or piggyback liner system will begin to increase. While the rate of increase is facility dependent, a good measurement of this rate was recently obtained after the final cover failure which will be discussed below in Section 3.2, GeoSyntec (2005). In this study and with a final cover in place, a single recovery well was removed from an active LFG recovery system and the subsequent increase in LFG observed. From an initial vacuum of 9-inch H_2O (-2240 Pa), it took only one hour to achieve a zero pressure. Over the next five (5) hours, the LFG pressure increased to 1.5-inch (374 Pa). Thus, over a 10-inch increase in LFG pressure required less than six (6) hours. This increase occurred despite the presence of adjacent LFG wells that remained in service and under the full operational vacuum. Conservative design would assume that full LFG positive pressures would develop in less than two (2) days if the entire active LFG system shuts down.

2.2 LFG Passive Relief/Collection System

The active LFG system relies on a regularly spaced network of gas well that penetrate vertically through the waste. On first thought, it would seem that excessive pressures beneath the veneer barrier system could be achieved by simply opening the well heads to the atmosphere. Unfortunately, an adequate passive LFG venting system is a very shallow system placed immediately beneath the veneer barrier as compared to the active LFG systems that penetrate deeply within the waste. Typical collection wells have solid sections of casing extending 20 feet below the veneer to limit air intrusion into the system which limits effectiveness in shallow regions. Additionally, the pressure gradients that generate flow in the active system are significantly greater than those occurring in a passive venting system.

Passive LFG systems are commonly empirically designed systems that rely on gravel "French drains" placed within the surface of the waste. The empirical nature of the design relates to the uncertainty about LFG generation rates at the landfill in question. Since LFG generation rates are influenced by the waste properties, the moisture content of the waste, cellulose content, and operational practices, accurately estimating the LFG generation rate is problematic. Fortunately, the design will be adequate even if a small positive pressure develops as shown on Figure 3. A typical empirically designed passive LFG system uses 60 cm by 90 cm gravel trenches placed into the waste placed perpendicular to the slope. Commonly, a 4-inch perforated pipe is placed within the trench and runs upslope to a vent that penetrates the liner. Horizontal spacing of the trenches varies from 30 to 40m such that a single vent services less than approximately 1-acre (0.4 hectare). This system is illustrated below in Section 4.2.

A more rigorous method for design of the passive LFG system was first presented by Thiel (1998,1999) that allows the designer to convert the water transmissivity characteristics of common geosynthetics into equivalent LFG flow properties. Thiel provides a rigorous design procedure that allows construction of the entire passive venting system without the use of the conventional gravel collector trenches. Richardson and Zhao (1998, 2000) also discuss the geosynthetic alternative and provide guidance for estimated LFG generation rates.

3. LFG INDUCED SIDE SLOPE FAILURE STUDIES

3.1 Failure During Construction

Figure 4 shows a sliding failure that occurred during construction of a 15-acre (6 ha) final cover on a 4H:1V side slope, Richardson (2000). The cover system was to include the following components, from bottom to top:

- Interim cover/structural layer immediately over waste;
- 1-ft (30 cm) thick LFG relief layer of fine sand;
- GCL having nonwoven face down, slit film face up;
- PVC geomembrane;
- 1-ft (30 cm) sand drainage layer;
- *1-ft (30 cm) vegetative soil; and*
- *0.5-ft (15 cm) topsoil.*

The last two layers were not placed at the time of failure. Failure occurred as sliding between the PVC geomembrane and the underlying slit film face of the GCL. Direct shear testing established that the interface shear strength between these two elements had a friction angle of 16° and an apparent adhesion, a = 11 psf (0.5 kPa). Given the sand layer had a density of 107 lb/ft^3 (17.3 kN/m^3), Equation 1 indicates that the drainage sand layer would be stable if the gas pressure acting beneath the PVC geomembrane was less than approximately 10 in-H_2O (2490 Pa).

Figure 4 Sliding of Geomembrane and Sand Drainage Layer During Construction

Figure 5[8] shows a small LFG 'whale' that developed in the PVC geomembrane immediately after failure. Twelve LFG probes installed beneath the PVC geomembrane after failure indicated an average LFG pressure of 6.6 inch-H_2O (1640 Pa) and a maximum LFG pressure of 16 inch-H_2O (4000 Pa). This indicated that the average factor of safety against sliding was close to 1.0 and that localized zones had factors of safety less than 1.0. With time, more of the saturated sands above the PVC geomembrane eroded and the LFG related stability problem worsened.

Given that this design incorporated a 1-ft (30 cm) thick LFG relief layer beneath the PVC geomembrane the failure was initially surprising. However, it was determined that the fine sand had saturated during construction and actually provided very little capacity for LFG transmission. It is critical that LFG relief layers be constructed of free draining materials since the LFG itself contains significant moisture. The existing fine sand relief layer was retained by adding supplemental strip drains spaced at 29-ft (8.8m) intervals running up the slope, Thiel (2007).

Figure 5 LFG 'Whale' Protruding Through Sand Drainage Layer

3.2 Failure Post-Construction

Just months after completion of the complete final cover system over a lined MSW landfill approximately 7-acres (2.3 ha) of final cover slid down the 3H:1V side slopes. The final cover system included the following components, bottom up:

- Prepared subgrade including 12-inch (30 cm) interim soil cover;
- Bentomat ST GCL with woven side up;
- 50-mil textured LLDPE with drainage spikes;
- 8 oz/sy (272 g/m^2) nonwoven geotextile; and
- 24-inch (60 cm) thick protective cover and topsoil.

Figure 6 shows that the sliding failure occurred between the GCL and the LLDPE geomembrane. When the failure was discovered, the active gas recovery system had been down approximately one week for maintenance.

Figure 6 GCL Exposed by Final Cover Sliding Failure

The sliding design of the final cover system was based on measured interface peak secant friction angles between the LLDPE geomembrane and the GCL of approximately 29°. This produces a factor of safety against sliding of Tan29°/Tan18.4° = 1.66. Referring to Figure 3, this would allow for a short term LFG pressure of approximately 15-inch H_2O without failure. Project specifications called for a minimum asperity height on the bottom texturing of 16 mils (0.4 mm) and CQA measurements of supplied liner showed 17 mils (0.43mm).

Post-failure testing of LLDPE liner samples obtained from the failure area indicated that the asperity height of the lower texturing was only 14 mils (0.35mm) as the result of dragging the geomembrane during installation. Direct shear testing using the as installed geomembrane over the GCL yielded peak secant friction angles ranging from 21.8° to 25.4° and averaging 23.5°. The actual factor of safety was thus reduced to Tan23.5°/Tan18.4° = 1.30. Referring to Figure 3, this would allow for a short term LFG pressure of approximately 9-inch H_2O (2240 Pa) without failure.

As previously discussed, shutting down a single LFG well at this site raised the LFG pressure at the well from an initial vacuum of 9-inch (-2240 Pa) to 1.5-inch (374 Pa) in less than 6-hours. It is not difficult to imagine that the shutdown of the entire system for a period of approximately one week would produce LFG pressures in excess of the 9-inch H_2O (2240 Pa) pressure that would lead to instability.

4. CONTINGENT PASSIVE VENTING SYSTEMS

4.1 Piggyback Liner Contingent Passive Venting System

A piggyback liner system places a veneered liner over the side slopes of an existing landfill. The example of this case is a piggyback landfill unit constructed in the valley formed by two existing unlined MSW landfills that have only a soil layer for final cover. The potential for LFG pressures beneath the piggyback liner system is significant since both of the existing landfills had only minimal provisions for LFG control.

In order to mitigate the potential build-up of LFG pressures beneath the piggyback liner system, a series of LFG collector trenches were installed immediately beneath the piggyback liner system on approximately 100 foot centers (Figure 7). The collector trenches were built using the cross section shown in Figure 8. In addition to serving an interim function to prevent sliding of the liner system (since eventually the new waste placed within the lined valley will prevent sliding of the liner system) the passive collector trenches are tied into header pipes outside the limits of the piggyback liner system and, thus, are included as part of the overall LFG control system for the landfill.

Figure 7 LFG Collector Trenches Installed in Surface of Existing Waste in Piggyback Landfill Application

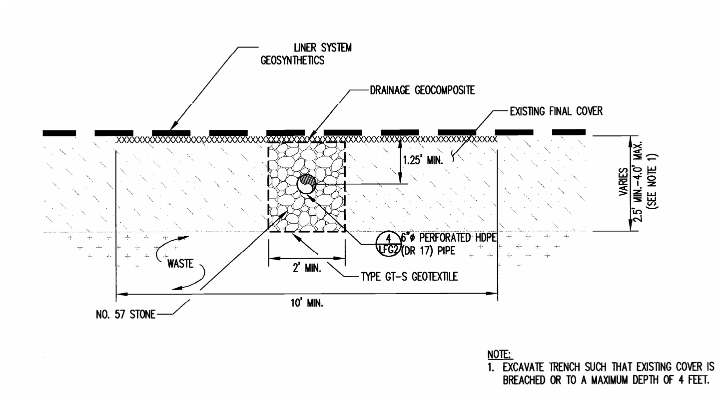

Figure 8 LFG Collector Trench Cross Section

4.2 Final Cover Contingent Passive Venting System

On a recent 3H:1V landfill closure, a contingent venting system was used to maintain veneer stability. The project was anticipated to collect LFG aggressively for use in a Landfill Gas to Energy (LFGTE) projects. The collection system included typical vertical extraction wells under vacuum to a flare system. However, the active system was supplemented with additional perforated collection piping around the anchor trench and perforated collection piping, installed parallel with the slope, placed in stone trenches as described in Section 2.2 above. The collection system was connected to each of the supplemental components, but a redundant relief system and vent (relief equal to design pressure of six (6) inches of H_2O) was also added. The relief system included a series of strips of DGC installed parallel with the slopes and placed below the cover GM. Relief vent are placed at a frequency of approximately two (2) per hectare as shown in Figure 9.

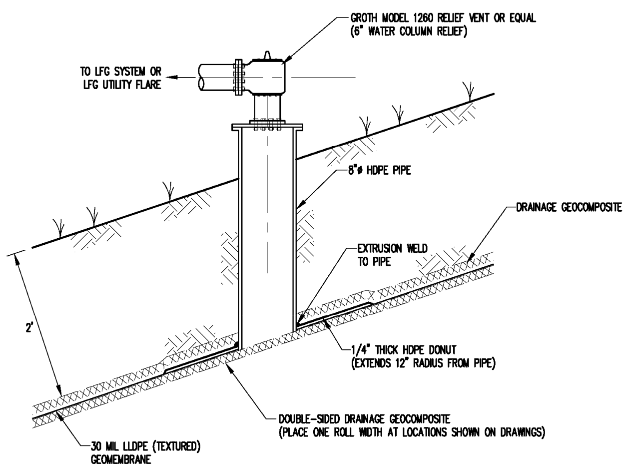

Figure 9 – Emergency Gas Relief Vent Cross Section

These vents are commonly used in oil and gas industry and generally consist of a weighted stainless steel plate and can be pre-set or field adjusted by simply adding additional weights (rings or washers) to the plate. The vent penetrates the cover GM and sits directly on the stone trench or DGC through a eight (8) inch HDPE pipe with a base plate. The vent simply bolts to the top as shown in Figure 10 below.

Figure 10 Emergency Gas Relief Vent

Since its installation, approximately one (1) year, these vents have been monitored quarterly under surface emission protocols and have been sealed satisfying air regulation requirements. These vents were also utilized effectively during final cover construction to aid in venting of the GM prior to and during soil cover placement to prevent “whales”.

4.3 Regulatory Considerations

When landfill sites are required to install active gas collection and control systems (GCCS) under the federal New Source Performance Standards (NSPS) there are certain restrictions that “by-pass valves” may not be included in the system. This provision essentially bottles up the LFG in complete contrast to the desires of the design engineer and as demonstrated above, can cause catastrophic failure of the veneer cover system. Therefore, the proposed relief valve system is offered as a compromise since the valve can be designed to only vent at a critical pressure considered in the design immediately below the GM and independent of the gas GCCS. Furthermore, the destruction of the LFG can continue if coupled with a solar vent flare that will only fire when gas is present, commonly used as an odor control measure today. These components can be addressed in the GCCS Design Plan as associated with the final cover components more specific to each landfill situation. The NSPS standards are currently under review and should consider these situations in their final form to better integrate the cover system design limitations with the intent of the air regulations.

5. SUMMARY

The primary lesson to be learned from the case studies presented in this paper is the need for all veneered barrier systems placed over waste to include a passive LFG venting system that precludes instability due to positive LFG pressures developing beneath the geomembrane. It is important to note that simply opening the well heads of an active LFG recovery system will not generally be adequate to prevent high positive LFG pressures developing beneath the geomembrane. The active wells are intended to reach deep into the waste mass and do not adequately vent LFG developing between the wells. Obviously, during operation of an active LFG recovery system, the contingent passive LFG venting system must be closed to the atmosphere. Examples have been presented for both manual and automated means of opening the passive LFG systems. For final covers, automatic means of opening the passive LFG system are recommended due to the lack of staff present during the post-closure period and the high probability of both scheduled shutdown of the active LFG system and crisis shutdown during natural catastrophes such as hurricanes. These passive vents can be designed to both satisfy the intent of air regulations and to ensure the immediate and long term stability of the veneer cover system.

A secondary point that designers should note is the potential for the interface friction of textured geomembranes to be significantly reduced by installation methods. If the geomembrane is dragged into place by the installer, samples of the installed geomembrane should be evaluated to determine if the asperity height of the texturing has been reduced. If it has or if visual scratching is observed, then direct shear testing with underlying interface should be performed.

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