October/November 2000
Volume 18, Number 8

Exposed geomembrane covers: Part 2 - geomembrane restraint

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In the previous Designer's Forum, design procedures were presented to evaluate the tension in exposed geomembrane covers (EGCs) due to wind-up lift loading. This article explores alternative means of providing anchorage to the EGC to resist such uplift forces. In general, this will involve attempting to use conventional features of a final cover, (e.g. roadways, swales, etc.) to provide a portion of the required restraint.

In addition to providing mass to act as a restraint, such features still must serve their primary functions. These functions include providing access for roadways and surface-water control for swales and down chutes. Thus, in many ways, the system of primary anchors used to resist wind uplift of the exposed geomembrane will mirror features of the completed final cover.

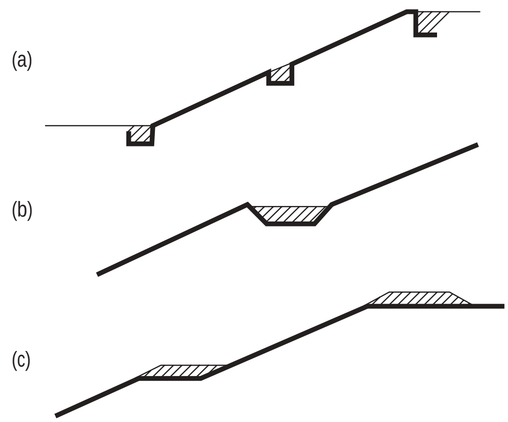

***Figure 1**: Examples of anchor trenches (a, b) and a bench (c).*

In this article, the various anchorage systems are subdivided into three categories: (1) horizontally oriented anchors, (2) vertically oriented anchors, and (3) secondary anchors. Horizontally oriented anchors use final cap features such as swales and roadways that are primarily horizontally oriented. Vertically oriented anchors use features such as down-chutes that are primarily vertically oriented. Secondary anchors generally do not reflect a final feature of the completed cap, but are interim points of anchorage. Thus, the final anchorage system may incorporate several categories of uplift anchorage.

Horizontally oriented anchors

Figure 1 shows three types of horizontally oriented anchors proposed by Giroud (1999). Two of these horizontally oriented anchors, *b* and *c*, modify side-slope swales or roadways to create uplift anchorage. The third, a, is a modified application of the standard anchor trench.

Anchor Bench — Drainage swale modifications probably are the most intuitive anchorage. They provide several specific alternatives for the designer that serve to illustrate the general design approach. **Figure 2** shows the general geometry of an anchor bench appropriate for a roadway or swale application. The EGC tensions, *T*, are calculated using the procedures discussed in Part 1 of this article. Using geometry, the EGC tensions can be resolved into forces vertical and horizontal to the horizon at the base of the anchor bench, as shown in **Figure 3**. The geomembrane tensions reduce the sta-

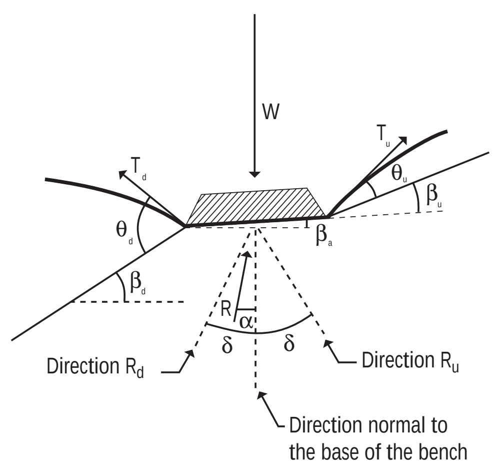

***Figure 2**: Forces acting on an anchor bench when the geomembrane is uplifted by wind action.*

bility of the bench anchor in two distinct ways: (1) the vertical components of the tension reduce the effective weight of the bench and therefore the base friction, and (2) the horizontal component of the lower EGC acts to pull the anchor off the bench.

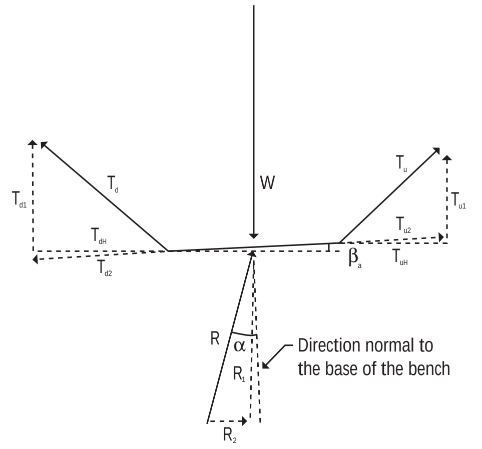

***Figure 3**: Decomposition of the forces acting on an anchor bench into vertical components (subscript 1) and components parallel to the base of the anchor bench (subscript 2).*

The latter is of particular concern if the tension in one of the EGCs is significantly larger than in the other. For this general case, Giroud (1999) shows how to determine the minimum anchor weight required in **Figure 4**.

In this equation, $W_{min}DOWN$ is the minimum weight if the EGC tensions drag the anchor down the slope, $W_{min}UP$ is the minimum weight if the EGC tensions drag the anchor up the slope, T_d is the tension in the geomembrane below the anchor, T_u is the tension in the geomembrane above the anchor, β_d is the slope angle below the anchor, β_u is the slope angle above the anchor, β_a is the slope angle immediately below the anchor, θ_d is the angle between the uplifted EGC and the slope below the anchor, θ_u is the angle between the uplifted EGC and the slope above the anchor, and δ is the interface friction angle between the anchor and the EGC. The minimum weight based on vertical uplift is given by

$$W_{minuplift} = T_d \sin(\Theta_d - \beta_d) + T_u \sin(\Theta_u - \beta_u)$$

However, Giroud showed that $W_{min}DOWN > W_{minuplift}$ and $W_{min}UP > W_{minuplift}$. This means that the sliding conditions govern for a bench anchor and not the pure uplift condition.

A key point in the construction of such bench anchors can best be made by looking at the two design details shown in **Figures 5a-5b**. The leading edge of the bench anchor will be lifted by the tension in the EGC, and must be stabilized in some manner to prevent raveling of the soil. **Figure 5a** shows the bench anchor detail used at the Delaware Solid Waste Authority EGC project (Germain, et al, 1996).

$$W_{min\frac{DOWN}{UP}} = \frac{\pm T_d \cos(\theta_d - \beta_d \mp \delta + \beta_a) \mp T_u \cos(\theta_u + \beta_u - \delta - \beta_u)}{\sin(\delta \mp \beta_a)}$$

***Figure 4**: Minimum anchor weight required.*

This design encapsulates the anchor soil in a geomembrane to contain it and prevent its loss. Alternative containment could use turf reinforcement mats (TRMs) or geogrid reinforcement. **Figure 5b** shows a bench roadway anchor detail that this author developed for caps at the Department of Energy's Oak Ridge facility. Here, containment of the edges is provided by gabions or timber cribbing.

Anchor Trench — An anchor trench provides passive earth pressure against the side of the trench to resist the resulting horizontal component of the EGC tensions. Koerner (1997) presents a good discussion of the horizontal restraint of conventional anchor trenches. The net horizontal resistance of the anchor trench is given as P_P-P_A. P_P is the passive resistance of the trench wall the anchor is being pulled into and P_A is the active force of the side the anchor is being pulled away from. The general equations for P_P and P_A for the anchorage trenches are as follows:

$$P_A = {}^1/_2\, \gamma^2 K_a d$$
$$P_P = {}^1/_2\, \gamma^2 K_p d$$

Where γ is the unit weight of the soil forming the trench, d is the depth of the trench, K_a = tan2(45- ϕ/2), K_p = tan2(45+ ϕ/2), and ϕ is the angle of shearing resistance of the soil forming the trench.

While P_A and P_P produce frictional forces on the side of the trench that resist uplift, these forces will be small in typical EGC applications. The resistance to uplift is provided primarily by the weight of soil within the trench. This weight must exceed $W_{minuplift}$ previously defined by Giroud.

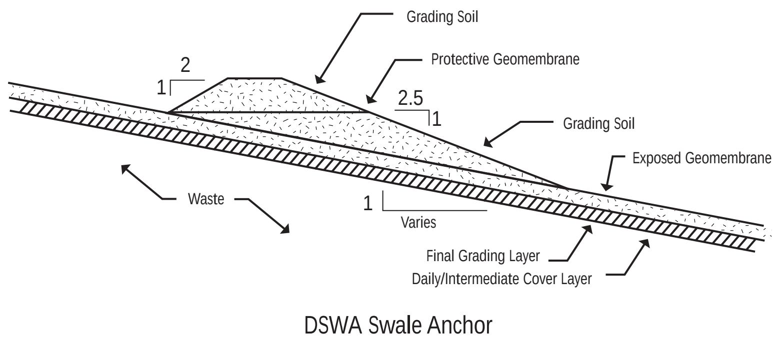

Figure 5a: *Detail of swale bench anchor used at the Delaware Solid Waste Authority EGC project.*

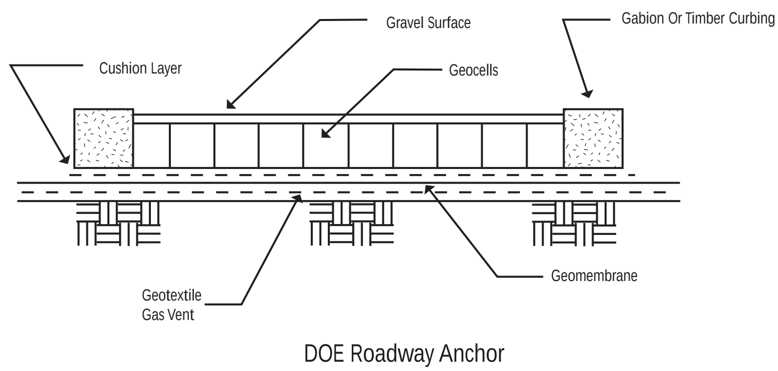

Figure 5b: *DOE roadway anchor.*

Care must be taken in design to ensure that the full weight of soil within the trench will contribute effectively to uplift restraint. Giroud suggests that the sides of the trench must be as vertical as possible, with a depth-to-width ratio of more than 0.25. This ensures that the pressure acting on the geomembrane on the bottom of the trench is as uniform as possible. An effective confinement of the soil in the trench must be ensured by the design.

Vertical anchors

Common vertical features on landfill side slopes include surface- water down-chutes and landfill gas (LFG) collection pipes. A ternative EGCs have been constructed to provide primary anchorage to the EGC geomembrane using these vertical features. This changes the orientation of the spans, e.g. horizontal vs. vertical, of the geomembranes and some design concerns.

Down-Chute Anchors — **Figure 6** shows a section through a drainage down-chute constructed in the early ’90s on the lateral perimeter of a mixed-waste landfill EGC cap. The minimum weight of down-chute required to hold down uplift forces from an EGC can be shown to equal

$$W_{min} = T_{left} \sin(\Theta_{left}) + T_{right} \sin(\Theta_{right})$$

T_{right} and T_{left} simply denote the ECS tension on either size of the down-chute. Since down-chutes form a channel to contain flow, the need for stabilization or reinforcement at the edge of the chute is not as difficult to achieve as for bench anchors.

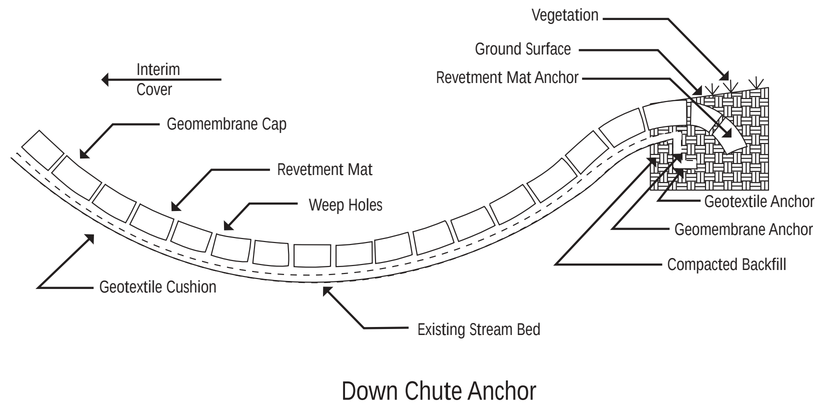

***Figure 6**: Section of a drainage down-chute.*

LFG Collection Trench Anchors — **Figure 7** shows restraint of the EGC achieved by attaching it to LFG collection trenches that run up the side slopes and are evenly spaced horizontally. As with horizontal anchor trenches, the LFG collection trenches will not be moved laterally by the horizontal forces from the EGC.

The minimum weight of the LFG collection trench can be calculated using the previous solution presented for down-chutes.

Note that this neglects the friction forces on the sides of the trench.

Secondary anchors

The previous anchorage systems are based on features of the final cover, that is, the EGC plus the lateral drainage, vegetative support, and vegetative layer. These anchorage systems lose their anchor role in the final cover, but retain their fundamental role.

Two distinct types of secondary anchors include both point and line anchors. The point anchors use commercially available earth anchors to provide restraint. To achieve a high load capacity (>1000 lbs.), these anchors are set in both the interim soil cover and the underlying waste. Costing less than $100 each, they can be installed in the field to tensile capacities greater than 10,000 lbs. The ability to fieldproof load the tensile capacity of the various point anchor systems is another benefit.

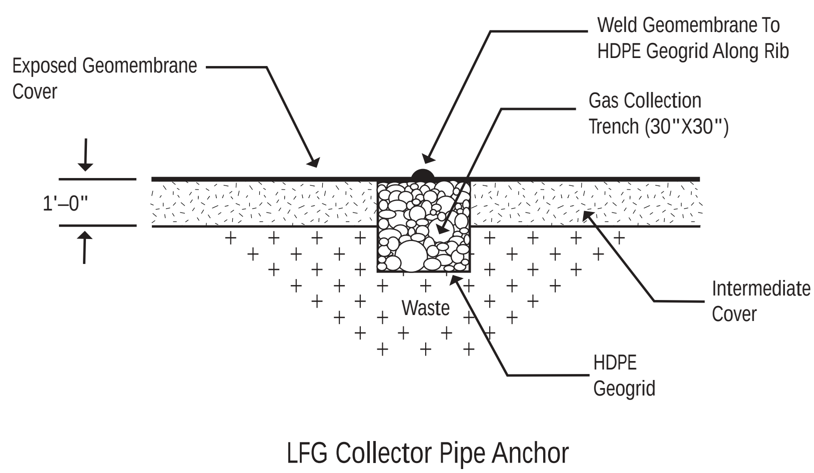

***Figure 7**: Restraint of EGC by attachment to LFG collection trenches.*

Remember that the primary markets for these point anchors are stabilized utility poles and wind restraints for mobile homes. The installation simplicity of the anchors reflects this market.

Secondary line anchors can be made by filling polyethylene pipes with water or grout, then cap-stripping the pipe to the EGC. These secondary line anchors provide supplemental uplift protection, but also provide a means of controlling surface-water flow over the EGC.

This control of surface water can be critical during the life of the EGC, since time of concentration of surface waters is minimal. These secondary line anchors are particularly helpful if a vertically oriented primary anchorage system is used, since they do not break up the slope. The secondary line anchors increase anchorage and provide interim swales.

Design factors of safety

The economical anchorage of an EGC requires the designer to utilize features of the final cap plus limited secondary anchorage systems. A minimum safety factor of 1.5 is recommended for bench anchors, 1.25 for trench anchors, and 1.0 for secondary anchors. All systems should be inspected if the design wind velocity is exceeded at the site. This inspection, and procedures for subsequent repairs, if required, should be part of the facility operations manual.

Summary

The author acknowledges the benefits of a decade of his own work on EGCs for the Department of Energy and the ongoing work by J.P. Giroud to define rigorously the requirements for such systems. One interesting device for providing restraint to an EGC not covered by this article is a suction vent. Placed in the upper portions of the slope, suction vents allow the wind to draw air from beneath the EGC to produce a suction force below the EGC. Unfortunately, recent federal regulations limit our ability to vent LFG directly into the atmosphere. For non-MSW landfill applications, such vents may be desirable. The third and final installment of the EGC series will examine the criteria for selection of the type of geomembrane to use with secondary line anchors.

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