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Exposed geomembrane covers: Part 1 - geomembrane stresses

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During the late 1980s and early 1990s, many mixed-waste disposal areas owned by the U.S. Department of Energy were given an interim closure using exposed geomembrane covers (EGCs). These interim covers were necessary because Congress had failed to promulgate regulations that clearly defined the performance criteria, mainly acceptable radiation emission release levels, for the final covers. **Photo 1** shows one such closure at the DOE reservation at Oak Ridge, Tenn. Still, the use of similar interim exposed geomembrane covers in MSW landfills was not envisioned under the 1993 RCRA Subtitle D regulations that govern municipal landfills. ß258.60 simply indicates that final closure must occur within one year of the final placement of waste in an area.

***Photo 1**. An interim closure using exposed geomembrane covers at the Department of Energy reservation in Oak Ridge, Tenn.*

EGCs might have remained exclusively in the DOE arena if three factors had not emerged in the past five years in MSW landfills:

1) The lateral expansion mode of operation of most MSW landfills creates interim slopes that may be exposed for many years prior to receiving additional wastes,

2) NPSE air quality regulations increasingly force control of landfill gas (LFG) emissions from operational landfills, and

3) The move to "leachate recirculation" or bioreactor landfills results in accelerated settlements of the waste.

These factors make EGCs an attractive solution to MSW landfill closure problems that are now becoming apparent. One of the first Subtitle D facilities to use an EGC was the 1996 closure of 40 acres at the Delaware Solid Waste Authority (DSWA) using an EGC (Germain, et al. 1996, Gleason, et al. 1998). The author is aware of other EGCs in the design stage in Virginia and Florida. This article will review key design considerations for EGCs.

Long-term vs. interim role for EGC

As shown in **Photo 1**, an EGC may be an integral part of the long-term final cover for the landfill. In this application, considerations for stability of the final cover may require the use of a high-interface friction geomembrane and a surface-water drainage layout based on long-term needs. Here the EGC is simply phase 1 of a two- phase construction of the final cover. Interestingly, this phased approach to final closure also provides significant cost savings to the owner. Delay of placement of the drainage layer and vegetative layer postpones the cost of these sub-systems. Estimating the cost of these delayed sub-systems at $55,000/acre, a delay of only 10 years represents a cost savings of approximately 50 percent, or approximately $28,000/acre. Germain estimates that DSWA saved approximately $35,000/acre by using an EGC interim closure.

An EGC may also be simply a long-term interim cover over a slope that will receive future waste. In this application, the geomembrane is not a component of the final cover, and greater flexibility exists in its selection. Interface friction may not be a concern, except for ballast features described later in this article.

Design for wind uplift

Discussions in the provided references cover such environmental concerns for the EGC as hail damage and thermal stresses. This topic will be covered in greater detail in Part 3 of this series. However, the primary selection criteria for the geomembrane will be its ability to resist the significant wind loads it will be exposed to during its service life. Guidelines for evaluating the wind-uplift force have been provided by both Wayne and Koerner (1988) and Giroud et al. (1995). Both of these papers rely on the earlier work performed by Dedrick (1975).

The wind uplift pressure, S_e, for a given wind velocity can be conservatively expressed as follows:

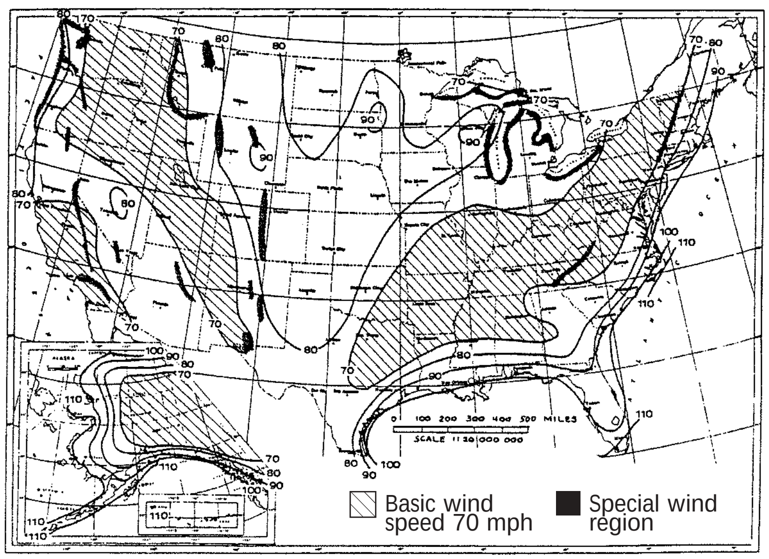

Figure 1. *Maximum design wind velocities.*

$$S_e \text{ (Pa)} = 0.6465\, V^2 \text{ (m/s)}$$
$$S_e \text{ (psf)} = 0.00124\, V^2 \text{ (ft/s)}$$

This force decreases with increasing site elevation. A general guideline for design wind velocities is provided in **Figure 1**. Designs based on lesser wind velocities would have to provide for field inspection of the EGC if the design velocity is exceeded in service.

The more important modifications to the wind forces relate to the impact of the slopes of the landfill. **Figure 2** shows that the above wind-uplift forces can be reduced by an average factor of 0.7 for an EGC placed on side slopes.

Geomembrane tension due to wind uplift

As I have reminded readers in the past, J.P. Giroud has been a man possessed to define the impact on geomembranes of all forces known to man, and wind uplift is no exception. Giroud et al. (1995) presents two solutions for tension in a geomembrane due to wind uplift: one for the simpler condition of a linear modulus for the geomembrane, and a second solution for a non-liner modulus. Both solutions are correct for large displacements/strains of the geomembrane and are based on the mode shown in **Figure 3**.

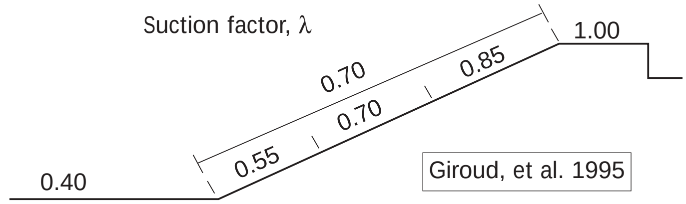

***Figure 2**. Slope modification factor, l.*

The simpler linear modulus solution will serve most designers who wisely choose to limit the design strains in the EGC geomembrane. For this case, Giroud solves for the strain in the geomembrane as

$$\frac{S_e L}{2J\varepsilon} = \sin\left[\frac{S_e L}{2J}\left(1+\frac{1}{\varepsilon}\right)\right]$$

where J is the tensile stiffness of the geomembrane, S_e is the uplift pressure, and L is the length between restraints. Lacking an explicit solution for this equation, Giroud developed a simple numerical solution. The normalized tensile stiffness of the geomembrane ($S_e L/J$) is calculated and the strain is then obtained from **Figure 4**. The tension in the geomembrane, T, is given by εJ.

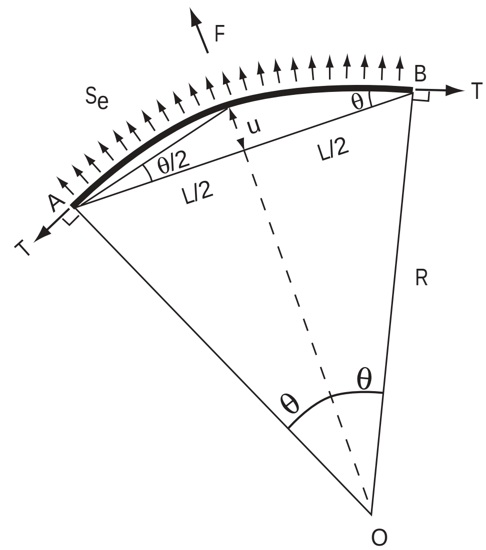

***Figure 3**. Giroud EGC Membrane Model.*

An interesting variation on the above solution is the classical beam solution for a "flexible" beam, e.g. cable, supporting a uniform load. This model is shown in **Figure 5**. The horizontal force at the points of anchorage are given by

$$P=\left[\frac{w^2 l^2 EA}{24}\right]^{1/3}$$

where w is the applied load (previously S_e), l is the unsupported length, E is the elastic modulus of the geomembrane, and A is the area per unit width. The vertical reaction at each end of the beam, V, is equal to $wl/2$ and the total reaction at each end is $(P^2 + V^2)^{0.5}$.

Figure 6 presents a comparison of tensions in a 60-mil HDPE geomembrane, calculated using both Giroud's membrane model and the classic beam model. The solutions are very close and offer an excellent means of check for the designer.

Both solutions determine the maximum vertical displacement of the geomembrane between the restraints. The beam theory solution calculates the maximum vertical displacement, Δ, as

$$\Delta = l\left[\frac{3wl}{64EA}\right]^{1/3}$$

Giroud solves for the displacement using the simple geometry shown in **Figure 3** and obtained

$$u = \frac{L}{2}\tan(\Theta/2)$$

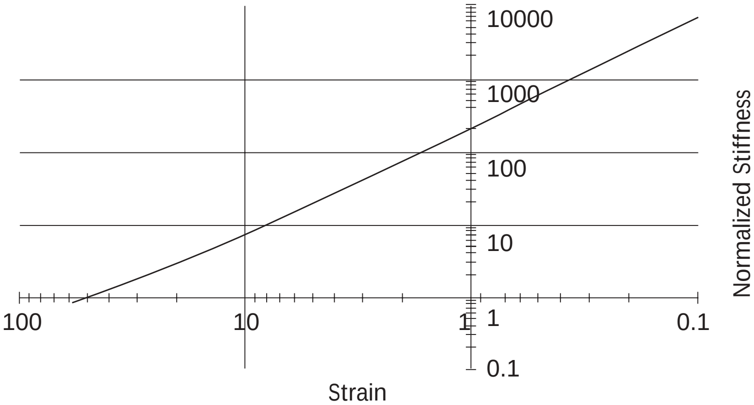

***Figure 4**. Normalized Tension Stiffness vs. Strain (Ref. Table 4 Giroud, et al. 1995).*

where *u* and Δ are equivalent. Note that both *L* and *l* denote the total distance between restraints. For strains from less than 5 to 8 percent, the above equations yield very similar predictions for vertical displacement.

It is recommended that these solutions be used only over the 'elastic' portion of the geomembrane tensile-stiffness curve. This curve should be established using ASTM D-4595. For HDPE, the above solutions are adequate to approximately 5 percent strain. For strains beyond these levels, Giroud's more rigorous solution should be used.

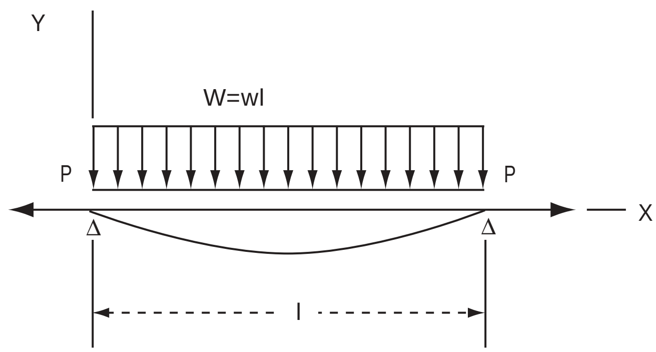

***Figure 5**. Flexible Beam Model.*

Geomembrane restraint

The two constant modulus solutions also provide reaction forces at the ends of the geomembrane that must be resisted by some device. For Giroud 's solution, the angle the geomembrane makes at the point of restraint is given by

$$\Theta = \sin^{-1}\left(\frac{S_e L}{2T}\right)$$

This allows determination of the vertical and horizontal components of the geomembrane tension T. The beam solution produces these components directly.

With typical wind-uplift forces on the order of 6-15 psf (0.3—0.72 kPa), the vertical reaction can become very large. For a 60-mil HDPE geomembrane, the unsupported length will be limited by the strength of the geomembrane. Limiting the tension in a 60-mil HDPE geomembrane to 115 lb/inch (20 kN/m), the maximum unsupported length would range from approximately 38 to 15 feet. At high wind velocities, the need for a reinforced geomembrane becomes obvious. Vertical reaction forces for the HDPE geomembrane are approximately 1400 lbs/ft and require more than an occasional sandbag.

EGC restraints are typically existing design features of the final cover that can be used due to their weight. Features such as roads, swales, down chutes, gas collection lines, and surface water berms make excellent candidates for EGC restraints. The DSWA cover relies on side-slope swales and toe and top-of-slope berms to hold the ESC down. Part 2 of this article will explore alternative means of anchoring the EGC.

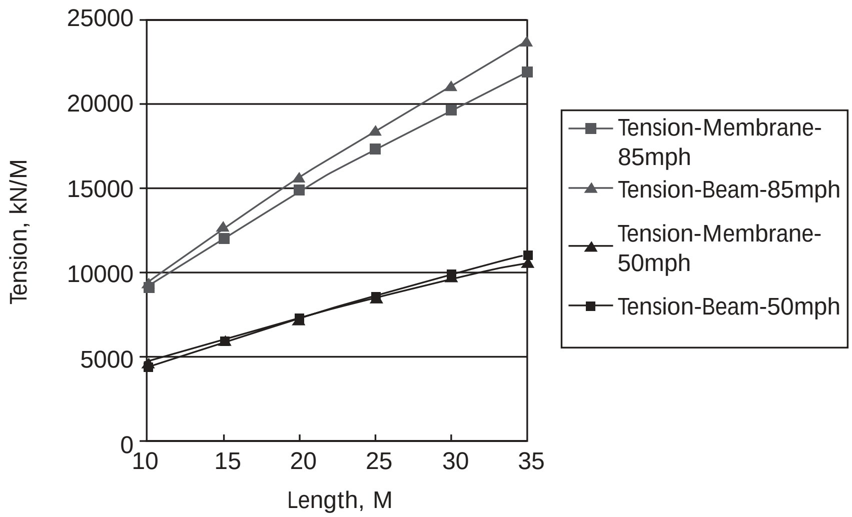

Figure 6. *Beam vs. Membrane Model.*

Summary

The use of EGC will increase dramatically if wet-cell MSW landfills become the rule and not the exception. It is always encouraging to see the strong role played by geosynthetics in the evolution of landfill technology. The author would like to acknowledge review comments provided by Matt Adams, J.P. Giroud, and Ann Germain. GFR

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