

GEOTECHNICAL BENEFITS OF ENGINEERED TURF FINAL COVER SYSTEM

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INTRODUCTION

The Resource Conservation and Recovery Act (RCRA) was originally enacted in 1976 and initiated the regulatory framework under which Municipal Solid Waste (MSW) landfills would be designed, constructed and maintained. Regulations continued to advance throughout the 1980's at the state level and in 1991, the addition of RCRA Subtitle D and C established federal level requirements for MSW landfill siting, liners, leachate collection systems and final cover systems, among others.

Part 40 CFR 258.60 codifies RCRA Subtitle D final cover systems for MSW landfills. These requirements for a traditional final cover system are: (i) permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability of 1×10^{-5} cm/s, whichever is less; (ii) an infiltration layer of soil with a minimum thickness of 18 inches; and (iii) a vegetative layer of soil with a minimum of 6 inches to protect against erosion. For the purposes of this paper, a traditional cover system consists of the infiltration layer and vegetative layer underlain by a geomembrane. The regulations permit alternatives to the soil layers of a traditional final cover system as long as it maintains the minimum performance characteristics for permeability, infiltration and erosion.

More recently in 2014, adoption of Part 40 CFR 257 regulated the technical requirements for coal combustion residuals (CCRs) generated by electric utilities. This rule set minimum standards for CCR landfills and surface impoundments by placing them under the requirements of RCRA Subtitle D. Therefore extension of the rules established for traditional and alternative final cover systems of MSW landfills also cover CCR landfills and surface impoundments.

Recent developments and applications of engineered turf as a final cover system make it a viable and attractive alternative to traditional RCRA Subtitle D soil covers, particularly for CCR closure. The engineered turf cover system typically consists of a

structured geomembrane, an engineered turf protective layer and a thin layer (typically 1 inch thick, or less) of specified infill for ballasting, usually a clean sand as shown in Figure 1. This system eliminates the need for the 18-inch infiltration layer and the 6-inch vegetative layer. In addition to greatly reducing the need for borrow soils in constructing a cover; the reduction in soil mass has geotechnical benefits with regard to veneer stability, total and differential settlements. However, the use of an engineered turf final cover alternate raises unique questions that are not relevant to traditional systems such as durability under ultraviolet (UV) radiation and susceptibility to wind forces. Consideration of each of these topics is required prior to design and installation.



Figure 1. Typical engineered turf components.

The remainder of this paper presents comparisons between traditional and engineered turf cover systems to quantify the geotechnical benefits of the engineered turf under a given set of parameters. The issues specific to engineered turf (UV durability and wind uplift) are also addressed.

VENEER STABILITY

Evaluation of the benefit of a engineered turf cover system to veneer stability involves comparison with a traditional cover system through parametric study utilizing the equations of Giroud¹ for a slope of finite length.

$$FS = \left[\frac{\gamma_t(t - t_w) + \gamma_b t_w}{\gamma_t(t - t_w) + \gamma_{sat} t_w} \right] \frac{\tan \delta}{\tan \beta} + \frac{a / \sin \beta}{\gamma_t(t - t_w) + \gamma_{sat} t_w} \quad (1)$$

$$+ \left[\frac{\gamma_t(t - t^*) + \gamma_b t^*}{\gamma_t(t - t_w) + \gamma_{sat} t_w} \right] \left[\frac{\tan \phi / (2 \sin \beta \cos^2 \beta)}{1 - \tan \beta \tan \phi} \right] \frac{t}{h} + \left[\frac{1}{\gamma_t(t - t_w) + \gamma_{sat} t_w} \right] \left[\frac{1 / (\sin \beta \cos \beta)}{1 - \tan \beta \tan \phi} \right] \frac{ct}{h}$$

underlying geomembrane of: (i) 43 degrees for peak strength; and (ii) 38 degrees for large-displacement strength², as shown in Figure 3.

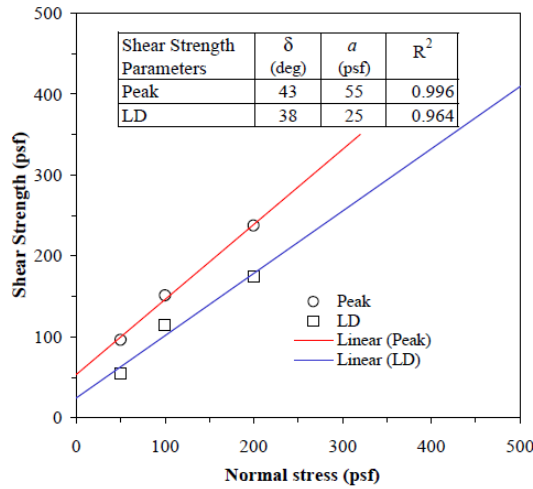


Figure 3. Interface shear test results for the engineered turf².

The comparison between the factors of safety for each system is given in Figure 4. As shown, the engineered turf has a factor of safety greater than the traditional cover system over the range of slope inclinations from 7 to 35 degrees. The increase in factor of safety for the engineered turf is largely attributable to the higher interface friction between the components of the engineered turf relative to the interface friction angles present with a traditional cover system. Also, the comparison given in Figure 4 considers a fully saturated condition, and therefore a worst-case scenario in terms of stability.

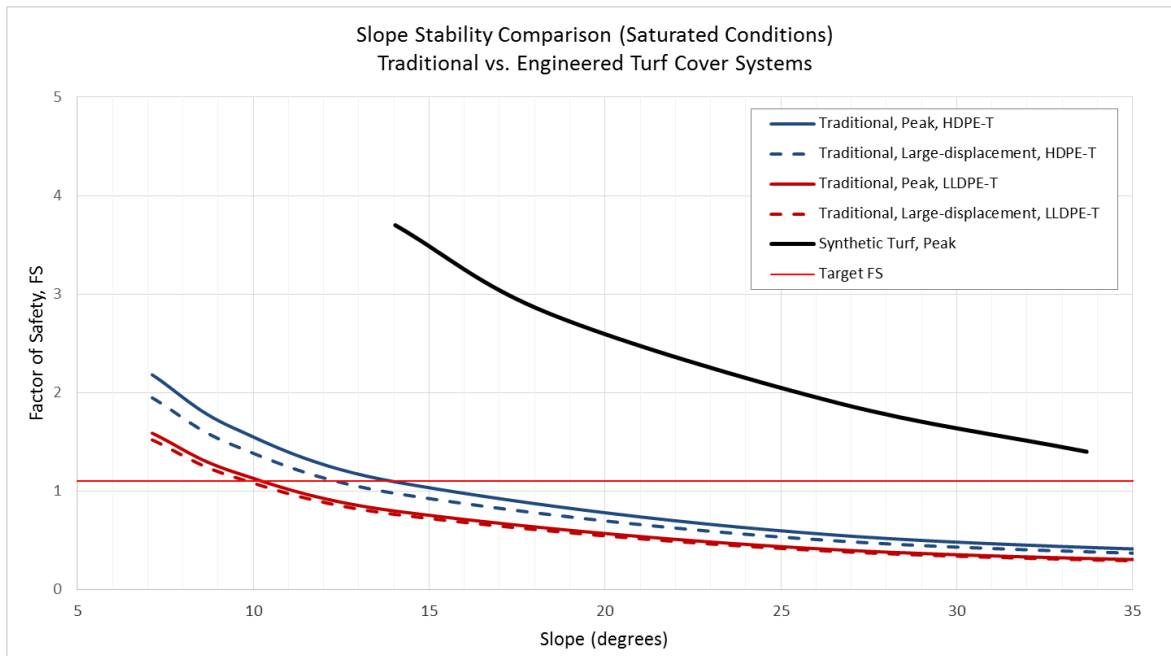


Figure 4. Comparison between engineered turf and traditional cover system FS as a function of slope angle.

SETTLEMENT

In order to compare the performance of engineered turf to a traditional cover in terms of settlement, the following analysis was performed using representative compressibility parameters for sluiced CCR within the framework for classical theory of consolidation for soils. For the purposes of this exercise, a hypothetical CCR impoundment was modeled, containing sluiced ash placed in 5 stages. Each stage is assumed to be 10 feet thick. Once a total of 50 feet in depth is reached, a surcharge load is placed on the surface which represents the weight of the cover system, either 2 inches of sand infill ballast as in the case of the engineered turf, or 2 feet of soil as in the case of a traditional cover system.

Total settlements are calculated as the sum of primary and secondary settlement. Equations for primary settlement based on the state of consolidation (i.e., normally or overconsolidated) are given below³.

$$S_p = C_{r\epsilon} H \log \left(\frac{\sigma'_{zo} + \Delta\sigma'_z}{\sigma'_{zo}} \right), \text{ when } \sigma'_{zo} + \Delta\sigma'_z < \sigma'_p; \quad (2)$$

$$S_p = C_{c\epsilon} H \log \left(\frac{\sigma'_{zo} + \Delta\sigma'_z}{\sigma'_p} \right) + C_{r\epsilon} H \log \left(\frac{\sigma'_p}{\sigma'_{zo}} \right), \text{ when } \sigma'_{zo} + \Delta\sigma'_z \geq \sigma'_p; \quad (3)$$

where:

S_p = primary settlement (in.);

$C_{c\epsilon}$ = modified compression index ($C_{c\epsilon} = C_c / (1 + e_o)$);

$C_{r\epsilon}$ = modified recompression index ($C_{r\epsilon} = C_r / (1 + e_o)$);

H = initial thickness of compressible layer (in.);

e_o = initial void ratio;

σ'_{zo} = initial effective overburden stress (psf);

σ'_p = pre-consolidation pressure (psf); and

$\Delta\sigma'_z$ = increase in effective vertical stress due loading (psf).

The calculation of secondary settlement uses the following equation.

$$S_s = C_{\alpha\epsilon} H \log \left(\frac{t_2}{t_1} \right) \quad (4)$$

where:

$C_{\alpha\epsilon}$ = modified secondary compression index ($C_{\alpha\epsilon} = C_\alpha / (1 + e_p)$);

H = initial layer thickness (in.);

e_p = void ratio at the start of secondary compression time;

t_1 = time (years) from loading to the end of primary consolidation; and

t_2 = time (years) at the end of analysis period.

The time where primary consolidation was considered to be completed was calculated as follows:

$$t_1 = \frac{T_v H_{dr}^2}{C_v} \quad (5)$$

where:

T_v = time factor (4.58 corresponding to 99.999% consolidation);

H_{dr} = height of the drainage path (ft); and

C_v = coefficient of consolidation (ft²/day).

The following consolidation parameters were used to represent the CCR materials within the impoundment:

$$e_o = 1.86$$

$$C_{c\varepsilon} = 0.060$$

$$C_{r\varepsilon} = 0.017$$

$$C_{\alpha\varepsilon} = 0.0005$$

$$C_v = 0.009 \text{ cm}^2/\text{s}$$

$$e_p = 1.72$$

$$H_{dr} = 5 \text{ feet for each stage of CCR placed} = 10\text{-ft thick stage}/2 \text{ drain paths}$$

The results of the calculations are shown in Figure 5. As shown the 50-foot thick deposit of sluiced CCR materials will settle approximately 2.34 inches under the weight of the traditional cover system. The engineered turf system is expected to cause settlements of 0.79 feet within the same 50-foot thick sluiced CCR deposit.

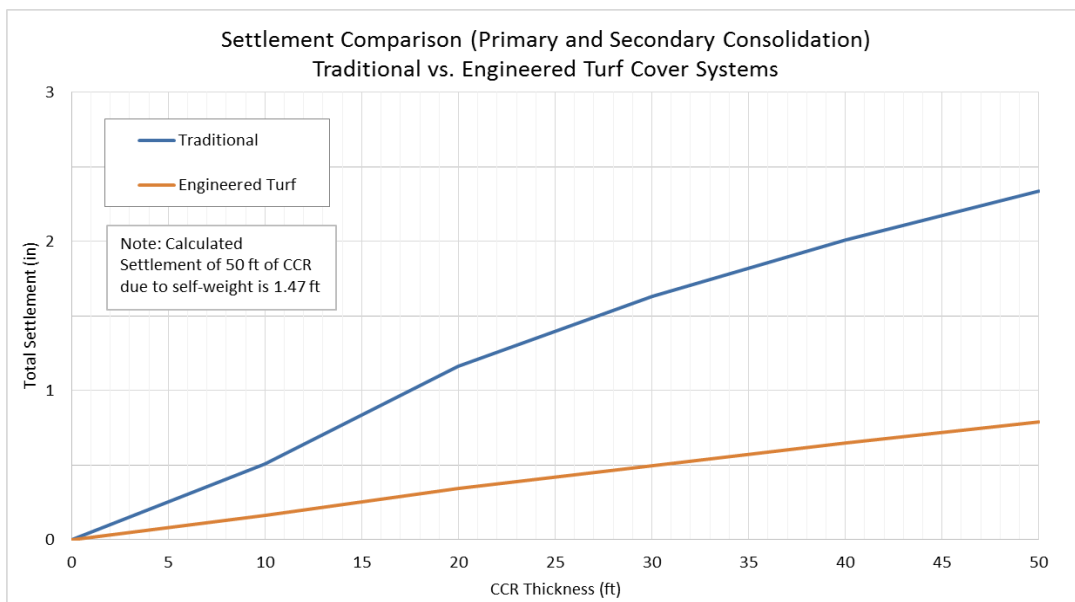


Figure 5. Comparison between engineered turf and traditional cover system total settlements for a hypothetical CCR impoundment.

Differential settlements within a CCR impoundment will place tensile strains into the engineered turf and the geomembrane component of a traditional cover system, if used. Both options will yield at approximately 11% tensile strain. However, the engineered turf option will experience small levels of tensile strain than a traditional cover system for a given length of void, if they develop under the cover. This is due to the reduction in weight carried by the geomembrane (i.e., engineered turf components plus sand infill, in lieu of 2 feet of cover soil). Therefore, assuming that the unit weight of the sand ballast is more or less equal to the unit weight of cover soil, the ratio of tensile strain induced between the two options will be approximately equal to the ratio of the loading. In this case, the ratio of loading is approximately a factor of 10. This ratio indicates that if 5% tensile strain is developed within the geomembrane used in a traditional cover system, the engineered turf will develop 0.5% strain under the same conditions.

ENGINEERED TURF ULTRAVIOLET (UV) DURABILITY

Since the engineered turf alternate is manufactured using polyolefins, it will be susceptible to degradation as a result of exposure to UV radiation once installed as a final cover. Within the buildup of the engineered turf cross section, the component most susceptible to this type of degradation is the HDPE grass blade component. The geotextile backing for the HDPE grass blades are covered by the ballasting sand, which is in turn partially shaded by the grass blades. The structured geomembrane component will be covered by the turf component and will not be exposed to UV radiation.

The UV durability of the HDPE grass blade part of the engineered turf has been investigated recently by Geosyntec⁴, Richgels⁵ and Watershed⁶. These investigations were based, in part, on field-aged samples of the engineered turf at a test facility in Arizona, where the highest levels of UV irradiance are found in North America. The field-aged samples have experienced approximately 10 years of exposure at the Arizona facility. In addition to the field data, laboratory data on the degradation of 1.5mm thick strips of HDPE were used to understand more advanced stages of exposure to UV radiation beyond the 10-year time frame covered by the field tests⁷. After pre-determined amounts of UV exposure, the field and lab samples are tested for tensile strength. Those results are compared to the tensile strength of control samples tested prior to UV exposure. The extrapolations of tensile strength loss based on Arizona-like UV exposure based on the field and lab data are shown in Figure 6.

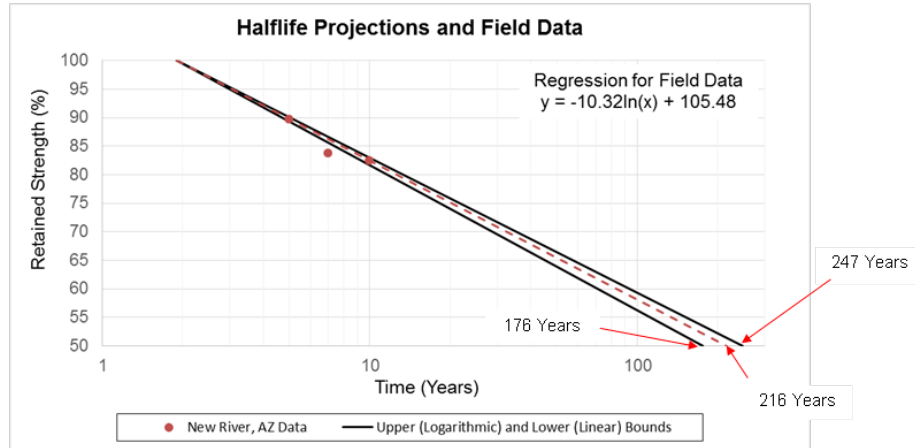


Figure 6. Anticipated half-life of the HDPE grass blade component of engineered turf⁴.

The results indicate that the half-life (i.e., the time required for the tensile strength of the grass blades to degrade to 50% of original strength due to UV exposure) of the HDPE grass blade is on the order of 100 years⁴. These projections will be updated as additional data from both lab and field studies become available.

ENGINEERED TURF UPLIFT FROM WIND FORCES

Since the engineered turf cover system has less mass per unit area than a traditional system and has interconnected backing, rather than consisting of discrete soil particles, it will have a greater tendency to be affected by aerodynamic forces due to wind. The Georgia Tech Research Institute performed a series of wind tunnel tests to experimentally determine the minimum thickness of ballasting soil required to counteract aerodynamic forces from wind speeds of up to 175 feet per second⁸. Two engineered turf configurations were tested, one representing the interior section and one representing the perimeter section of a large area. The tests confirmed that the perimeter section was more critical than the interior section.

The results for the perimeter section are shown in Figure 7. As shown, a relatively thin layer of sand is required to maintain stability of the engineered turf with a factor of safety of 1.0. Even for the most conservative case considering an interface friction coefficient of 0.50, less than 0.8 inches of sand is required at wind speeds of 175 mph.

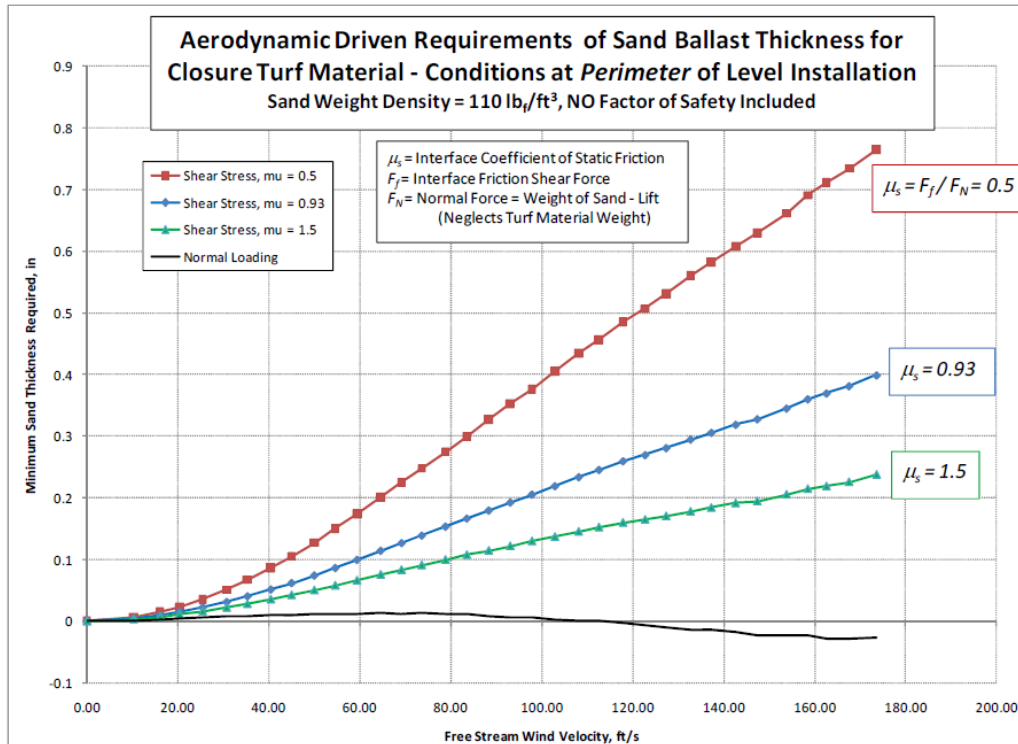


Figure 7. Minimum sand ballast required to maintain stability for a range of wind speeds⁸.

SUMMARY AND CONCLUSIONS

Part 40 CFR 257 and 258 outline the requirements for final cover systems for both MSW and CCR impoundments. Traditional cover system requirements include a 6-inch vegetative soil layer over an 18-inch infiltration layer which is in turn over a low permeability layer with values of 1×10^{-5} cm/s. The law also allows for alternative systems to be installed as long as the minimum performance characteristics of a traditional cover system are met. Recently, engineered turf alternates have been successfully used in lieu of traditional systems.

This paper demonstrates that engineered turf cover systems provide geotechnical performance benefits when compared with traditional cover systems, particularly when used to close CCR impoundments. Those benefits include superior performance with respect to veneer slope stability, total settlement, and tensile strain development due to void formation under the cover. In addition, engineered turf cover systems demonstrate satisfactory performance regarding exposure to UV radiation and aerodynamic forces due to wind.

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