Geotechnical and Wind Performance of Engineered Turf Landfill Cover

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ABSTRACT

The engineered turf cover is a relatively new landfill capping technology. It has been increasingly used in the last decade for closure of municipal and industrial solid waste landfills and other waste disposal facilities. Compared to traditional soil-geosynthetic covers, the engineered turf cover does not have protective and vegetative soil layers; therefore, there is no veneer slope failure that involves the soil mass and underlying geosynthetic components. The engineered turf cover consists of structured geomembrane and engineered turf, both of which are flexible geosynthetic materials and can tolerate tension and elongation due to differential settlement. Geotechnical performance of the engineered turf cover is discussed in the paper. Wind tunnel tests were conducted to investigate wind performance of the engineered turf cover. An example calculation is provided to illustrate the procedure of using the pressure coefficients obtained from the wind tunnel tests to estimate the factor of safety of the engineered turf cover against initiation of wind uplift.

INTRODUCTION

Since the first installation of engineered turf cover in the U.S. in 2009, the new landfill capping technology has been increasingly accepted by regulatory agencies and used by site owners for closure of municipal and industrial waste landfills and other waste disposal facilities, including coal combustion residuals (CCR) and industrial sludge impoundments [Abreu and Franklin 2014, O'Malley et al. 2017, Saindon 2019, SWANA 2017, Zhu et al. 2019]. The engineered turf cover consists of, from bottom to top, a structured geomembrane, an engineered turf, and a specified infill (see Figure 1).

The structured geomembrane is made of linear low-density polyethylene (LLDPE) or high-density polyethylene (HDPE). It serves as a hydraulic barrier to minimize infiltration of precipitation into the waste to the extent practical. It is the most critical component of the landfill cover system because it isolates the waste and protects human health and the environment. Selection of the structured geomembrane (i.e., geomembrane with textured surfaces, internal drainage studs, and/or friction spikes) is primarily based on interface friction angles and the maximum slope of a landfill.

The engineered turf is manufactured of PE synthetic turf fibers tufted into a double-layer woven geotextile backing, covering the structured geomembrane and protecting it from ultraviolet (UV) radiation exposure and wind uplift. Multiple colors of the engineered turf, including green, tan and a mixture of green and tan, can be selected for the landfill cover in order to better blend in with its surroundings. Outdoor UV longevity testing was performed on the turf fibers. Samples of the turf fibers exposed in the test field were collected during a period of 10 years and tested at an independent geosynthetics laboratory for tensile strength. The remaining tensile strength of the turf fibers was compared to the original tensile strength. Based on the test data, the number of years to reach 50% of the original tensile strength (i.e., the half-life) was projected to be over 100 years for the synthetic turf fibers [Geosyntec 2015].

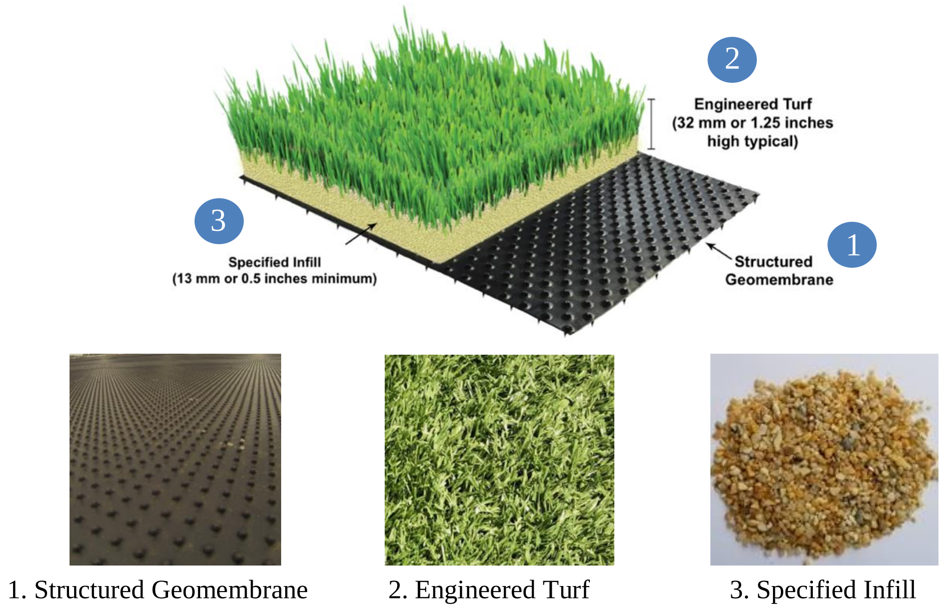

Figure 1. Illustration of engineered turf cover and system components.

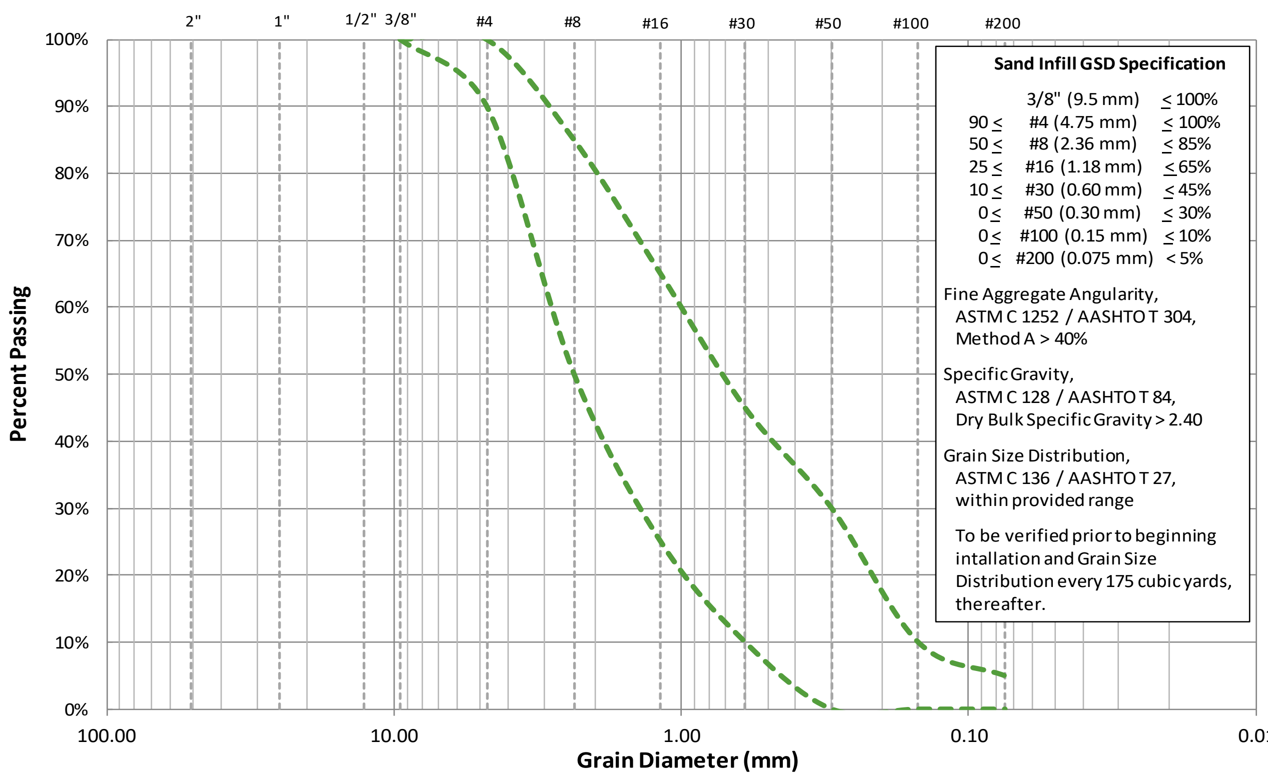

Figure 2. Engineered turf cover sand infill specification.

The specified infill, which is a minimum 0.5-inch (13-millimeter [mm]) thick sand layer filling the spaces between synthetic turf fibers, provides additional wind ballast of the structured geomembrane and UV protection of the geotextile backing of the engineered turf. It also improves trafficability on the cover as a result of increased surface friction. The sand infill specification (see Figure 2) has been developed based on the results of large-scale rainfall and channel erosion tests.

The specification includes requirements of the grain size distribution (GSD), angularity, and specific gravity in order to minimize potential sand movement during rainfall events. The acceptable GSD range is plotted on Figure 2. The actual grain sizes and color of the sand infill may vary from site to site depending on local sources (e.g., quarries).

GEOTECHNICAL PERFORMANCE OF ENGINEERED TURF COVER

Veneer Stability. One of the long-standing challenges with traditional soil covers is veneer-type soil slope instability that in some cases could result in failures (i.e., sliding) of the soil covers. Such failures have been documented in literature, a majority of which were attributed to internal drainage clogging and subsequent saturation of soil layers, as well as insufficient internal shear strength of soil materials and interface shear strength between the soil layers and underlying geosynthetic materials [Bonaparte et al. 2004, Nadukuru et al. 2017, Siebecker 2005, Stark and Newman 2010]. By replacing the overburden soil layers with an engineered turf and a thin layer of sand infill, the engineered turf cover essentially eliminates possibility of veneer slope failure associated with a traditional soil cover.

Stability of the engineered turf cover still needs to be evaluated by investigating the shear strength of two interfaces, i.e., the turf/geomembrane and geomembrane/subgrade interfaces, to prevent potential movement that could result in wrinkles of the engineered turf cover. Direct shear testing has been performed to evaluate the interface shear strength of the engineered turf

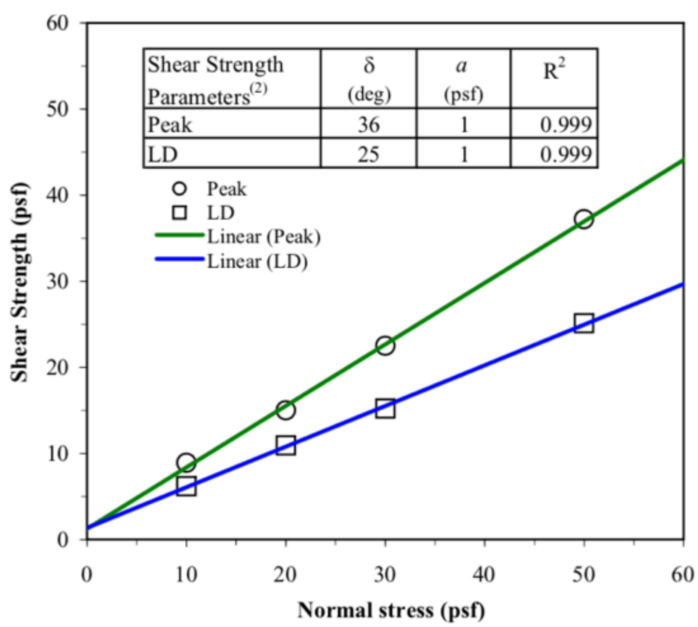

Figure 3. Direct shear results between engineered turf and structured geomembrane.

layer against the underlying structured geomembrane. For example, Figure 3 shows the direct shear test results of the interface between the engineered turf and a structured geomembrane with drainage studs on the top and friction spikes on the bottom. The test results indicate a peak interface friction angle of 36 degrees and a large displacement (LD) interface friction angle of 25 degrees.

The interface shear strength between the structured geomembrane and the subgrade depends on the subgrade materials at the project site. A site-specific direct shear testing should be performed using subgrade samples collected from the project site to obtain the interface friction angle of the structured geomembrane against the subgrade.

The interface shear strength values obtained from the direct shear testing are used by geotechnical engineers to evaluate whether the calculated factor of safety (FS) of the engineered turf cover meets a specified target FS for landfill cover slope stability. A simplified method to estimate the FS is to assume that the engineered turf cover slope is an infinite slope and there is no water pressure acting on the interface; therefore, the FS can be calculated using the following equation:

$$FS = \frac{tan\emptyset}{tan\beta} \quad (1)$$

where, $\emptyset$ is the interface friction angle and β is the angle of the slope upon which the engineered turf cover is installed. A more sophisticated method can be used to account for saturated conditions [e.g., Giroud et al. 1995a, Ohio EPA 2014]. Because the engineered turf does not have a soil layer that can hold water except for the thin layer of sand infill, no significant hydraulic head on the cover is expected. Therefore, the calculated FS under saturated conditions is not expected to be significantly different than dry conditions. A commercial slope stability analysis program can also be used to calculate the FS for the engineered turf cover slope.

Due to the advantage of cover slope stability, the engineered turf cover has been installed on landfills with side slopes as steep as 2.5H:1V to 2H:1V, including sites located in high seismic zones. A conventional landfill soil cover can be adversely affected by seismic activity. Tension in the soil cover can increase significantly during an earthquake, which leads to cracking and/or sliding of the soil cover and potential damage to the geosynthetic components due to down dragging from the soil layers. For the engineered turf cover, seismic stability is not a concern due to removal of overburden soil layers. The sand infill may move due to shaking of the ground, but it can be fixed quickly by replacing with new sand infill as part of the post-earthquake site maintenance.

Differential Settlement. Landfill settles due to compression and consolidation of waste and foundation soils. Settlement is expected to continue after the landfill is closed. Differential settlement caused by inhomogeneous waste can create local depression and surface cracks on a traditional soil cover because soil cannot tolerate much tension. The engineered turf cover, which consists of flexible geomembrane and engineered turf with high elongation properties, can tolerate much greater differential settlement than the traditional soil cover. For example, the elongation for a HDPE geomembrane can be 13% at yield and 200% at break; while the elongation for a LLDPE geomembrane can be 300% at break. An example of the stress-strain curve of the engineered turf is shown in Figure 4, indicating an average elongation of approximately 30% at yield in the machine direction (MD).

In the technical paper by O'Malley et al. [2017], a case study was presented where the engineered turf cover was installed as the final cover system to close a 70-acre (28–hectare) industrial ash and sludge impoundment. The engineered turf cover experienced significant differential settlement two years after closure as the waste underneath the cover was being dewatered. Due to its ability of tolerating large elongation, the engineered turf conformed with the shape of the depressed areas (see Figure 5). No detrimental impact on the integrity or overall performance of the cover was observed.

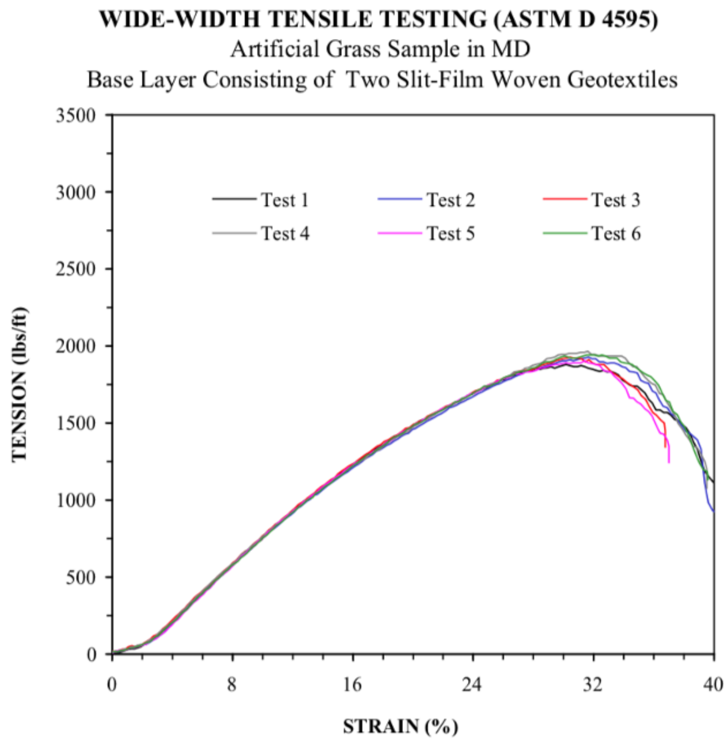

Figure 4. Tensile test results of engineered turf.

Figure 5. Differential settlement on engineered turf cover [O'Malley et al. 2017].

Repairs of local depression to correct grade reversal or local ponding of the engineered turf cover are easier and less costly than a traditional soil cover, because no soil layers need to be excavated and backfilled. A local depression on an engineered turf cover, if it occurs, can be repaired by a small crew using light equipment and tools. A flowable backfill can be pumped into the void under the engineered turf cover through holes cut into the geomembrane to raise the cover to original grades. After the slurry injection is complete, the holes in the geomembrane are patched and seamed with new pieces of geomembrane. At the end of the repairs, the engineered turf is repaired by a heat-bonded seam, and the sand infill is re-placed to cover the engineered turf.

WIND PERFORMANCE OF ENGINEERED TURF COVER

Wind tunnel studies have been performed to evaluate the wind performance of the engineered turf cover, ClosureTurf®, at the Iowa State University Aerodynamic and Atmospheric Boundary Layer Wind and Gust Tunnel. The tests were conducted on scaled landfill models constructed with a 3 horizontal to 1 vertical (3H:1V) slope on one end, a top deck, and a 4H:1V slope on the other end. Each model had two different slopes allowing rotation in the wind tunnel to test two different windward conditions. A velocity probe was used to record point-wise measurements of the upstream wind velocity. Pressure taps were used to measure wind pressures at fifteen locations along the model surface. The pressure taps were connected by flexible vinyl tubes to a pressure scanner module, where data were recorded. The geometry of one of the test models is shown in Figure 6 along with a photo showing the model inside the wind tunnel. Two types of engineered turf were tested, a standard turf referenced to as CT and a high-density turf referenced to as CT–HD.

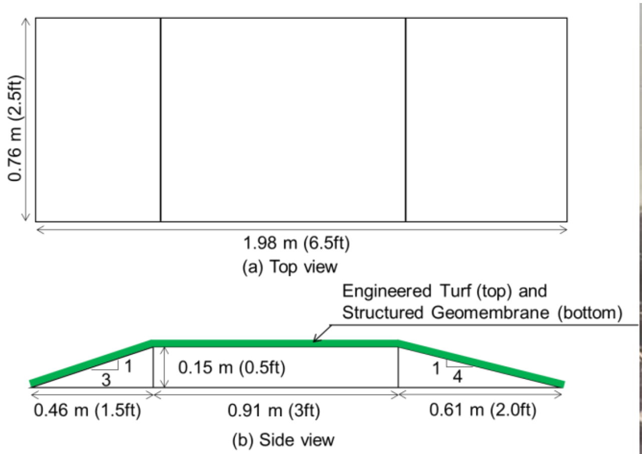

Figure 6. Engineered turf cover wind tunnel testing.

The wind tunnel test results are presented in the format of wind pressure coefficient, C_p. Profiles of C_p for the engineered turf cover interpreted from the wind tunnel test results are presented in Figures 7 and 8 for landfills with 4H:1V and 3H:1V slopes, respectively. Positive C_p corresponds to pressure acting toward the surface (i.e., downward pressure or compression) and negative C_p corresponds to pressure acting away from the surface (i.e., upward pressure or uplift). The horizontal locations of the measurement points, x, were normalized by the length of the model, L, as x/L in the plot.

The wind pressure coefficient can be used to calculate the wind load using the following equation [Giroud et al. 1995b, Wayne and Koerner 1988, Zheng et al. 2020]:

$$P = \frac{1}{2} \cdot C_p \cdot \rho \cdot U(H)^2 \tag{2}$$

where, P (pounds per square foot [psf]) is wind-generated pressure normal to the surface, ρ is the air density (ρ = 0.0024 slug/cubic foot [ft^3] at 59ºF and sea level), $U(H)$ (feet/second [ft/s]), is the upstream mean wind speed at the height of slope H (feet [ft]), and C_p is the wind pressure coefficient (dimensionless).

The results of the wind tunnel tests can be used in engineering practice to evaluate whether the landfill cover system has sufficient ballast to protect it from wind uplift under a selected design wind speed. An example calculation is provided in the section below.

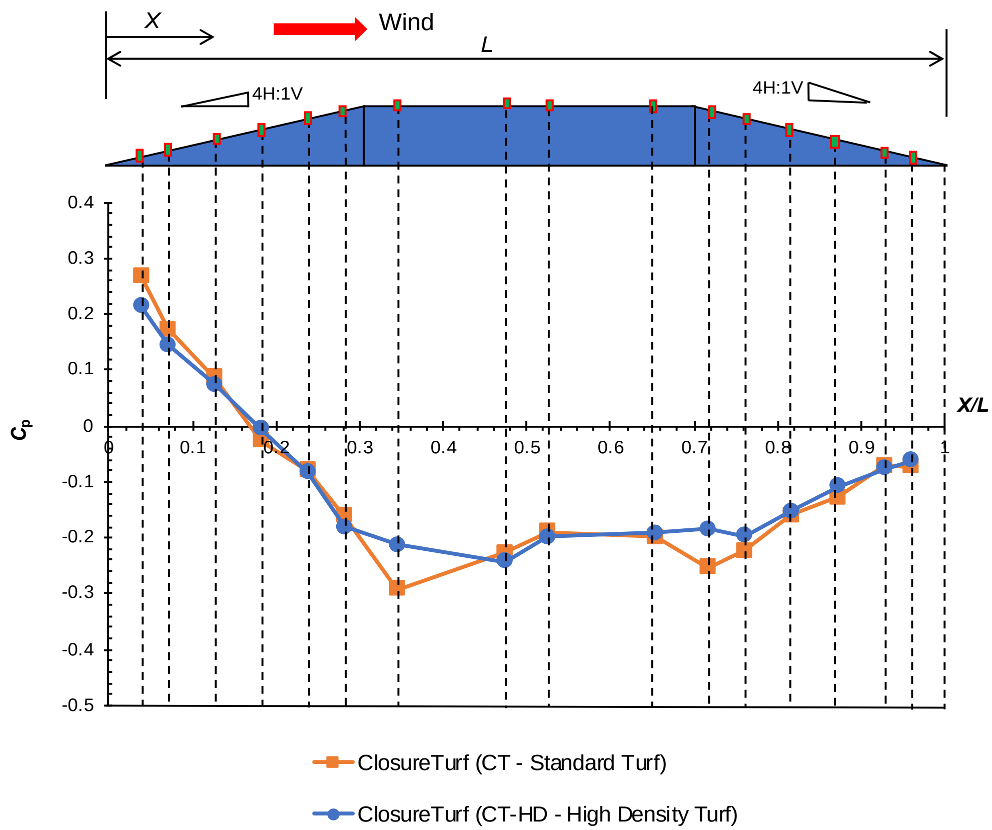

Figure 7. Wind pressure coefficient distributions of engineered turf cover with 4H:1V slope

Example: The landfill site is located in Atlanta, GA. It has a slope of 3H:1V with a maximum height of 100 ft. The maximum length of top deck is 200 ft with a maximum slope of 5%. The engineered turf cover is selected to close the site with the standard engineered turf CT and 50-mil structured geomembrane with friction spikes. The specified thickness of sand infill is 0.5 in. minimum, not to exceed 0.75 in.

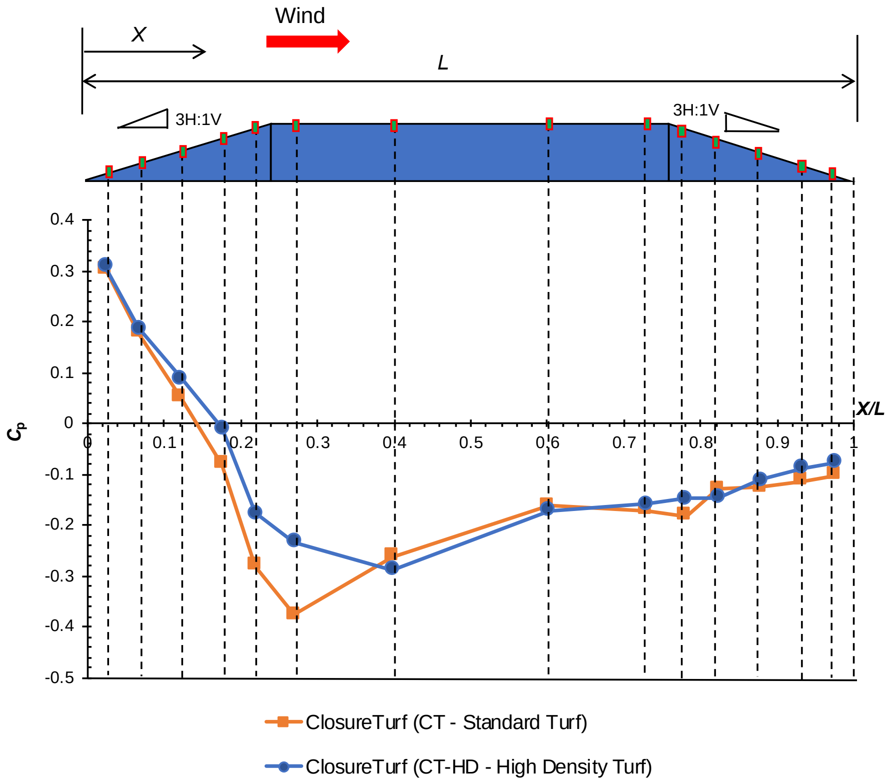

Figure 8. Wind pressure coefficient distributions of engineered turf cover with 3H:1V slope

For the purpose of illustrating the calculation procedure, the basic wind speed was assumed to be 78 mph (or 114.4 ft/s) for Atlanta, GA based on ASCE 7-16 (https://hazards.atcouncil.org/#/). This corresponds to the 3–second gust speed at 32.8 ft (or 10 m) elevation in open terrain, $U_3(32.8ft)$ or $U_3(10m)$, with a mean recurrence interval (MRI) of 25 years. The mean hourly wind speed at 32.8-ft (or 10-m) elevation, $U(32.8ft)$ or $U(10m)$, is calculated from $U_3(32.8ft)$ using a factor of approximately 1.5 for an open terrain [Vickery and Skerlj 2005]:

$$U(32.8\,ft) = \frac{U_3(32.8\,ft)}{1.5} = \frac{114.4}{1.5} = 76.3\,ft/s$$

Using U(32.8 ft) as the reference, the mean hourly wind speed at top of the landfill, $U(H)$ with H = 100 ft, is calculated using the Power-Law equation [Peterson and Hennessey 1978], with the exponent, α, being 0.14 based on the wind tunnel test results:

$$\frac{U(H)}{U(32.8\,ft)} = \left(\frac{H}{32.8}\right)^{\alpha}$$

$$U(H) = U(32.8\,ft)\cdot\left(\frac{H}{32.8\,ft}\right)^{0.14} = 76.3\times\left(\frac{100}{32.8}\right)^{0.14} = 89.2\,ft/s$$

The maximum mean wind uplift pressure is calculated using Eq. 2 with the maximum C_p value of 0.38 from Figure 8 for standard turf and a 3H:1V slope:

$$P_{max} = \frac{1}{2} \cdot C_{p,max} \cdot \rho \cdot U(H)^2 = 0.5 \times 0.38 \times 0.0024 \times 89.2^2 = 3.6\, psf$$

The weight of engineered turf cover per unit area is estimated to be about 5.4 psf with a 0.5-in thickness of sand infill. Therefore, the FS for the engineered turf cover against initiation of wind uplift is calculated to be 1.5 (i.e., 5.4 psf/3.6 psf) for the assumed landfill cross section. It should be noted that if a higher design wind speed is used and the maximum uplift pressure exceeds the weight per unit area of engineered turf cover, thicker sand infill and/or other measures (e.g., anchor trenches) can be used to further secure and ballast the cover in areas where the predicted FS is deemed to be insufficient.

REMARKS

The engineered turf cover technology is an alternative solution to the traditional soil covers for closure of landfills and other waste facilities. It provides geotechnical advantages with respect to landfill final cover veneer stability and differential settlement, besides other benefits including improved runoff quality and reduced post-closure maintenance. Performance of the engineered turf cover has been evaluated through extensive geotechnical, hydraulic, and wind tunnel testing. The engineered turf covers have been installed in regions with different climates. Some of the sites have experienced extreme weather conditions, including hurricanes, heavy rains, high winds, and freezing temperatures. Field observations demonstrate that the engineered turf cover has performed as an effective landfill final closure system.

ACKNOWLEDGMENT

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