Astryn FPP;0]

The Use Of An Exposed Reinforced Flexible Polypropylene Geomembrane To Cap A Landfill.

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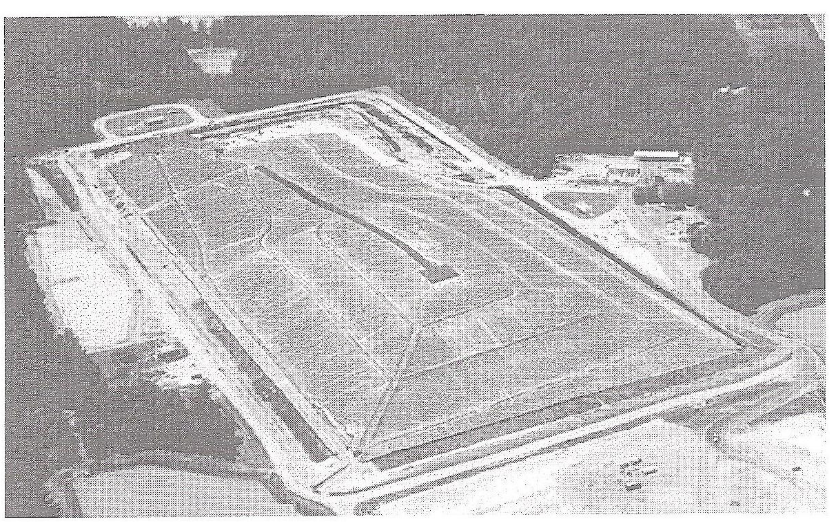
Abstract

A 42-acre 36 mil (0.9 mm) thick reinforced flexible polypropylene exposed geomembrane cap (EGC) has been installed to close two cells at Delaware Solid Waste Authorities southern site. This paper reviews the properties of the geomembrane which made this cap possible, and some of the design and construction challenges the cap presented.

DSWA Exposed Geomembrane Cap



Introduction

During 1997-1998 Delaware Solid Waste Authority (DSWA) installed an exposed geomembrane cap (EGC) on a 42-acre (17 hectares) landfill with a total height of approximately 100 feet (30 m), comprising Cells 1 and 2 at the Southern Solid Waste Management Center (SSWMC) in Sussex County, Delaware. The EGC consists of a 36 mil reinforced flexible polypropylene geomembrane overlying a protective layer of soil, which is placed over solid waste. Figure 1. The protective cover soil, topsoil, and vegetation components of the Subtitle D cap system are not included in the EGC. Elimination of these materials from the design saved on construction costs. In 1992, DSWA demonstrated the EGC concept on test cells at the DSWA's Central Solid Waste Management Center (CSWMC) in Kent County, Delaware.

The concept for the exposed geomembrane cap system originated as a low-cost cap system to provide quick and easy access for landfill mining. DSWA considers landfill mining as a viable option for closing a landfill, including incineration of the recovered combustible waste and reuse of the landfill footprint. This cap system provides for easy mining in the future. It also satisfied the criteria to limit leachate production. In terms of operations, the EGC will reduce maintenance associated with vegetation and erodible soils, compared to a conventional Subtitle D cap.

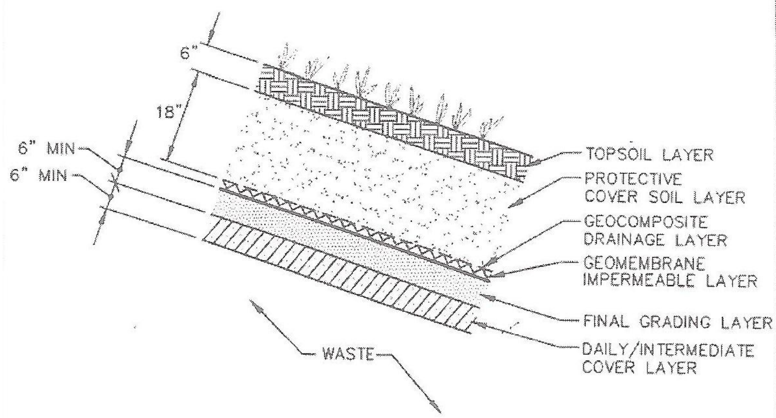


FIGURE 1. TRADITIONAL FINAL CAP

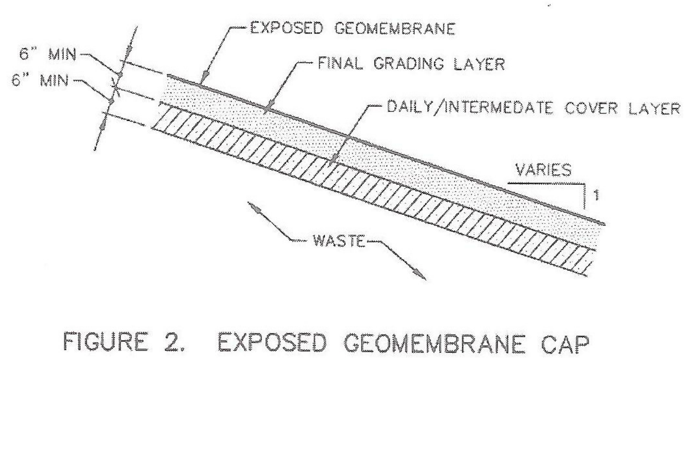


FIGURE 2. EXPOSED GEOMEMBRANE CAP

Alternatively, the EGC can easily be converted into a traditional cap system that meets the requirements of the Delaware Regulations Governing Solid Waste (DRGSW) for Subtitle D landfills. The typical cross section for traditional final cap system under DRGSW is presented in Figure 2. The target design life for the EGC is 20 years. An evaluation of the EGC will be conducted at that time. If the EGC is still in acceptable condition and well-maintained, the DSWA anticipates that the cap could be permanent.

This first of its kind installation presented unique design, build and installation challenges. The DSWA selected GeoSyntec Consultants (GeoSyntec) of Columbia, Maryland to design the cap system, Stevens Geomembranes to supply the green reinforced flexible polypropylene membrane and Environmental Liners to fabricate and install the geomembrane. Barbella Environmental Technology was the general contractor. Montell USA Inc. supplied the flexible polypropylene resin for Stevens Geomembranes to produce the membrane.

The type of geomembrane selected for this cap system was critical to the design. In the initial stages of the design, several types of geomembranes were considered including: polyvinyl chloride (PVC), high density polyethylene (HDPE), flexible polypropylene (FPP), reinforced chlorosulfinated polyethylene (i.e. CSPE-R or Hypalon), reinforced flexible polypropylene (FPP-R), and reinforced ethylene interpolymer alloy (EIA-R).

Reinforced polypropylene (FPP-R) was selected for the EGC because of its resistance to ultraviolet (UV) light, high tensile strength and its ability to withstand large temperature changes. Typical landfill cap geosynthetic materials, polyvinyl chloride (PVC) and high density polyethylene (HDPE) were eliminated for use on this project. PVC was not considered because of a low UV resistance, low tensile strength, potential for down slope creep and low puncture resistance. Aside from low UV resistance. HDPE was rejected for the same reasons, as well as its high coefficient of thermal expansion and contraction.

FPP-R typically has a polyester scrim reinforcement that provides the necessary strength and low elongation to resist wind uplift, down slope creep and puncturing. The high tensile strength allows greater distances between anchor trenches. The scrim also provides low thermal expansion and contraction coefficient.

The two geomembrane resins that were considered to be acceptable for the design were FPP-R and EIA-R.

Geomembrane Selection Requirements

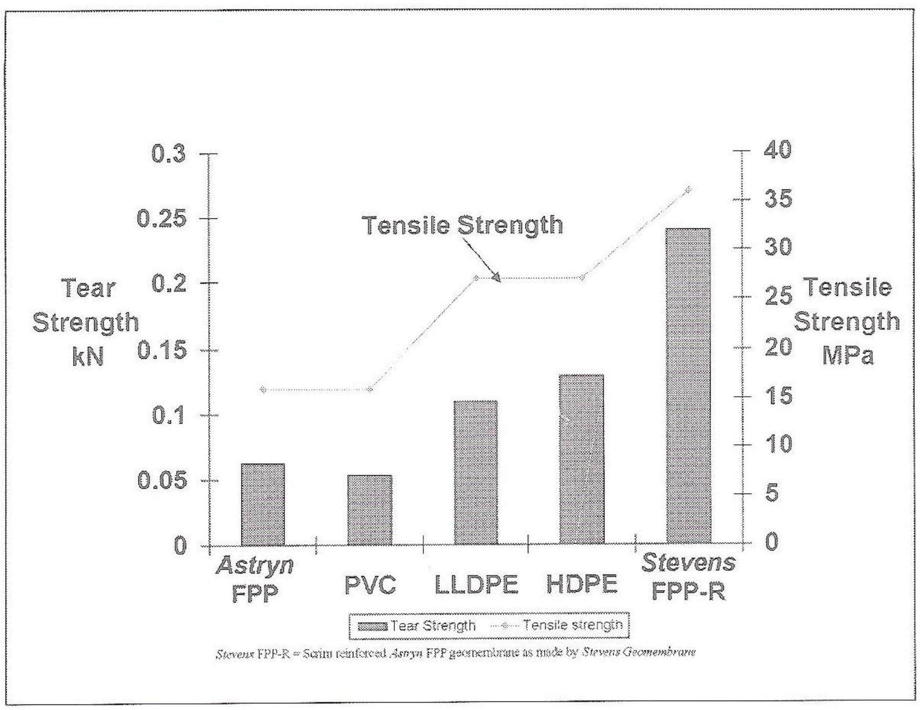
Tensile Strength

A geomembrane used for an EGC must have sufficient tensile strength to resist the tensile loads imposed by wind uplift. The wind speed used for this design is 80 miles per hour (130 kilometers per hour), based on the local building code. Use of an unreinforced geomembrane with additional anchorages was considered. Several types of anchorage were considered for the unreinforced geomembrane, including sandbags, tires, and concrete-filled bags all placed at regular intervals on the geomembrane. The only long-term effective solution to wind uplift was considered to be geomembrane anchor trenches. Due to the relatively low strength of unreinforced geomembranes, anchor trenches would be required approximately every 12 ft (4 m) of elevation of the landfill while a reinforced geomembrane needed anchor trenches/cover terraces every 40 ft (12 m). The cost for constructing the additional anchor trenches exceeded the benefits of using a less expensive unreinforced geomembrane. Thus only geomembranes that had reinforcement were considered to have acceptable tensile strength.

Tear Initiation

The use of a textile scrim reinforcement in FPP dramatically increases the tear strength (Figure 3) as well as acting like a rip stop fabric to prevent tear propagation. This is especially important in exposed applications. Geomembranes made from flexible polypropylene have excellent resistance to tear initiation and tear propagation. In the event of a tear, the tear will not readily propagate even when under tensile stresses such as those experienced on side slopes.

Figure 3
Geomembrane Tensile Strength versus Tear Strength



Exposure to Ultraviolet Light, Heat, and Wind

The properties of the geomembrane component of the EGC must not be easily affected by exposure to ultraviolet light, heat, and wind. Geomembranes with plasticizers which could leach out over time were considered unacceptable. This eliminated PVC from consideration.

Since flexible polypropylene has only been available for eight years there is limited real time exposure data. The geomembrane for this EGC needed to last 20 years through numerous freeze thaw cycles and exposure to the sun. Geomembrane manufacturers often provide 20-year warranties on their materials, but there is limited real time data regarding the stability and longevity of any materials in an exposed landfill application. A white flame retardant compound of flexible polypropylene has performed well in industrial single ply roofing applications, where its been used for over eight years.

The DSWA had two landfill test cells at the CSWMC. Both one-acre (0.4 hectare) cells were capped with a black unreinforced flexible polypropylene (FPP) geomembrane that was exposed for 40 months. The FPP EGCs on the test cells performed up to all expectations. The data in Figure 4 reports the properties of the 1.0mm black unreinforced FPP geomembrane. The geomembranes mechanical properties remained virtually unchanged following 40 months of exposure. Geomembrane temperatures can reach over 70℃ during the summer. During the winter snow coverage and ice formation were experienced. After this exposure the unreinforced flexible polypropylene geomembrane maintained its physical properties.

Figure 4

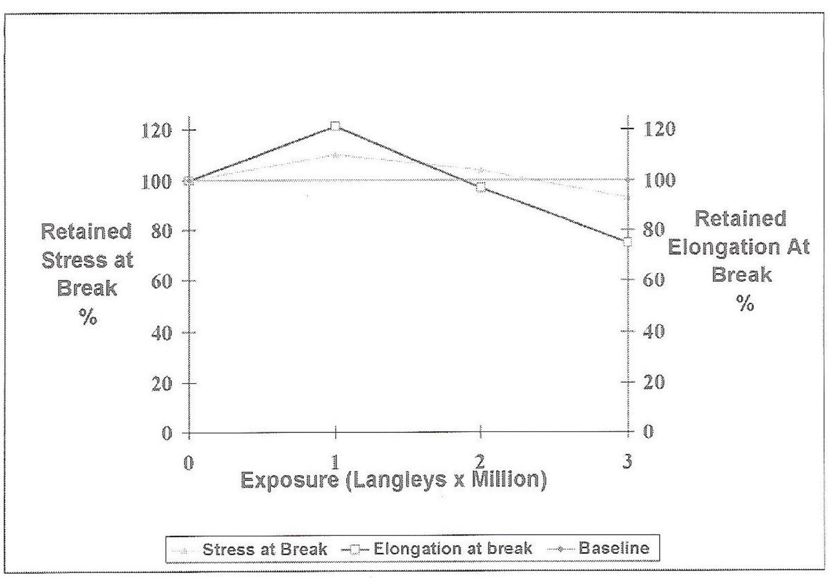
Black unreinforced FPP geomembrane mechanical properties following 40 moths of exposure

Property	*% Change from control sample after 28 months*	*% Change from control sample after 40 months*
Strength at break	-4	-2
Elongation at break	+2	-7
Tear resistance	+7	-10

Carbon black pigmented geomembranes made from Astryn flexible polypropylene resins from Montell containing high-performance UV stabilization additives have excellent resistance to UV degradation (Figure 5). Colored flexible polypropylene geomembranes do not usually contain carbon black, rather they use different UV absorbers. Different test results are obtained for different colors. Light colored membranes generally perform the best and dark ones the worse, except black which performs well, as shown in Figure *5.*

Figure 5

Astryn FPP EMMAQUA Accelerated Weathering Test Results



A number of accelerated weathering tests are available to determine the relative UV resistance of a geomembrane. EMMAQUA accelerated weathering testing is accepted as the best test for predicting real life performance of a geomembrane, provided the actual commercial geomembrane structure and thickness is used. Correlating test results to real life performance in different geographic locations is possible as natural sunlight intensity is well known in many locations (Figure 6). The EMMAQUA (equatorial mount with mirrors for acceleration with water) test method employs Fresnel reflecting solar concentrators that use ten flat mirrors to uniformly focus sunlight onto a geomembrane mounted in the target plane. High quality mirrors provide an approximate intensity of eight suns with the spectral balance of natural sunlight in terms of ultraviolet integrity. The specimens, located at the focal line of the mirrors, lie under a wind tunnel along which a deflector directs cooling air across the sample. Samples are sprayed with deionized water in accordance with established schedules, to simulate dew and rain. This simulates the wet/dry cycle, which can cause migration of plasticizers and additives from some geomembranes.

Figure 6

Correlating EMMAQUA Test Results to Indicative Real Time Exposure in Different Geographic Locations

Location	*Annual Solar Radiant Exp. MJ/M^2*	*Rainfall (mm)*	*Summer Avg. Maximum Temperature °C*	*Winter Avg. Minimum (Years)*	**Indicative Real Time Exposure*
Phoenix Arizona USA	8004	255	39	8	15
Miami Florida USA	6500	1685	34	13	19
Columbus Ohio USA	5110	794	29	-7	24

Three million Langleys of EMMAQUA testing confirms that considerable UV exposure has negligible effects on the mechanical properties of 1mm thick black geomembranes made from properly stabilized Astryn flexible polypropylene (Figure 5). Tensile strength and elongation remain virtually unaltered even after accelerated sunlight doses corresponding too many years of solar radiation in various locations (Figure 6).

Xenon weather-o-meter testing is the method used to differentiate the relative performance of different additive and pigment formulations in flexible polypropylene. Xenon weather-o-meters are a convenient and reliable tool for pigment and UV additive formulation screening. The xenon weather-o-meter test exposes the geomembrane to light from a water-cooled xenon lamp that operates at calibrated light intensity and wavelength (0.35 W/M2 at 340 nm) per test method ASTM G26. The geomembrane samples are periodically sprayed with water to simulate rain and dew and the geomembrane temperature is kept at 60℃ to 80℃, depending on the test protocol. The xenon lamp produces a light which is close in spectrum and intensities to natural sunlight. However the high temperature also accelerates thermally induced degradation. Thus the xenon weather-o-meter tests both the effect of UV and thermally induced degradation. The test results are difficult to corrclate to real life outdoor performance where average exposure temperatures are much lower, and degradation is primarily caused by UV exposure.

Geomembrane Color

Since the cap is exposed, and because the landfill is the highest point in Sussex County, the 42-acre EGC is seen by some residents. To make it aesthetically appealing, DSWA selected a light green color for the reinforced polypropylene geomembrane. The color was unique, and was selected to blend in with the green landscape of the site.

The geomembrane was manufactured by Stevens Geomembranes. As the color selected was new xenon weather-o-meter accelerated weathering tests had to be done to determine the best stabilizer and pigment system. Stevens Geomembranes conducted 4,000 hours of xenon weather-o-meter testing followed by a severe bend stress test. The excellent results in xenon testing coupled with Stevens Geomembranes experience with similar colors, which have been tested at EMMAQUA for over 3 Million Langleys. allowed them to offer a 20 year warranty on the geomembrane.

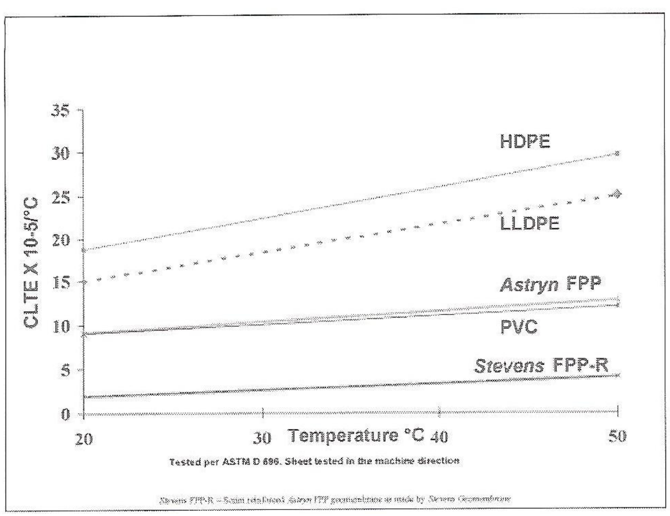
Thermal Expansion

Expansion and contraction of the geomembrane over long periods of time could lead to down slope creep of the geomembrane, thus creating additional stress at the anchorages. Low thermal expansion provides less potential for stress on the cap when it shrinks during cold weather. It also allows the installation of less slack in the cap during installation and thus there is. Only geomembranes with very low coefficients of thermal expansion and contraction were considered to be acceptable for the EGC. Polyester scrim reinforced geomembranes have the lowest thermal expansion.

A low coefficient of linear thermal expansion (CLTE) reduces stress on seams caused by thermal contraction, often the cause of stress cracking in the seam areas of other polymer geomembranes. Pronounced wrinkling caused by exposure to the sun is another source of stress cracking that is minimized by the use of an FPP-R membrane.

Scrim reinforced flexible polypropylene (FPP-R) exhibits only 14 percent of the maximum dimensional change measured in HDPE (Figure 7).

Figure 7
Coefficient of Linear Thermal Expansion



Repairability

Repairability of the weathered membrane is important. Should the membrane be damaged it must be repairable after years of exposure. This ruled out CSPE-R which cures with time. After curing CSPE is not repairable by heat welding.

Geomembranes made from Astryn flexible polypropylene resins can he repaired by heat welding after years of exposure. The repair processes are simple and generally require only surface preparation, such as cleaning off dirt or other contaminants, and heat welding with a hand held hot air gun and roller.

The area to be repaired must be thoroughly cleaned. Due to flexible polypropylenes softness, dirt can become embedded in the surface of the geomembrane making a good weld difficult without proper surface cleaning. Usually a wash with a high strength aqueous industrial cleaning solution will properly clean the surface. If required wiping with ethyl acetate or an organic solvent wipe has proven effective to remove oxidized material. The surface of the geomembrane needs to be thoroughly dried before welding.

Multi-Axial Stress Strain

The ASTM D 5617 multi-axial stress strain test best simulates the out-of-plane stress and strain found in the field (Figure 8 and 9). The performance of FPP-R in this test is comparable to HDPE, and is desirable for an EGC where the amount of subsidence is unpredictable but any subsidence will be visible.

On the other hand unreinforced flexible polypropylene has relatively low modulus and high extensibility, giving it high conformance characteristics. It elongates and conforms to the substrate at low levels of stress. This high working strain is desirable when designing for large movements under load, such as in a landfill cap subjected to large levels of subsidence, a temporary cover or where there may be seismic movement.

Figure 7
Coefficient of Linear Thermal Expansion

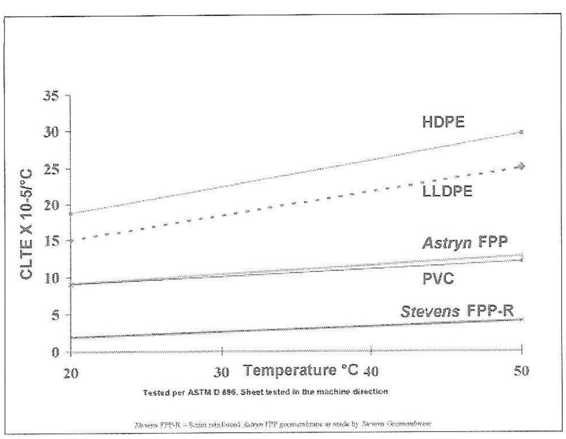
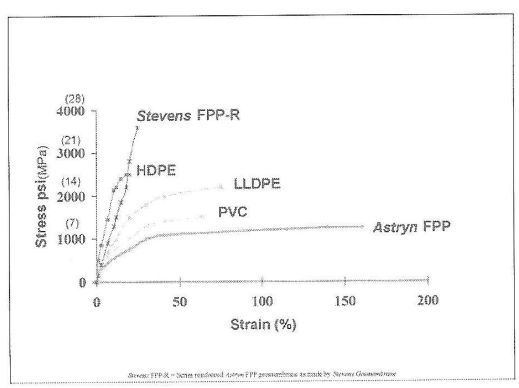


Figure 8
Comparative Multiaxial Stress/Strain Properties of Various Geomembranes



Toughness

The EGC needs enough toughness to resist installation stresses, animal traffic and airborne debris. Because the geomembrane is exposed, it may be susceptible to damage by extreme weather, such as large diameter hailstones. Occurrences of hailstones of 2-in. *(5-cm)* diameter and larger have been recorded in Sussex County. Therefore, it was desirable to have a geomemnbrane with high puncture resistance. The puncture resistance of FPP-R, as measured by the critical cone height test (Figure 10 and 11), CBR puncture (Figure 12), and index puncture tests (Figure 10) is outstanding. Even at temperatures below — 40°C flexible polypropylene remains flexible and has excellent impact resistance (Figure 13). This is a temperature at which PVC becomes brittle. This property is important when the product has to be handled or installed under cold weather conditions.

Regulatory Approval

This use of an EGC is being conducted with the cooperation of the state regulatory agency, Delaware Department of Natural Resources and Environmental Control (DNREC). The permit application for the EGC was submitted in April 1996 to the Delaware DNREC. It was approved as a long term intermediate cover. The ability to easily convert the exposed cap to a traditional Subtitle D buried cap, should unexpected problems arise, provides little risk in permitting this 'alternative cover" design.

DNREC requires that the EGC be examined for any damage monthly, monitored for performance and the geomembrane to be tested for signs of degradation annually. A sacrificial strip of FPP-R geomembrane will be attached to the south face and any other key areas. Pieces of the FPP-R strip will be retrieved yearly and the surface will be examined under a microscope to check for the onset of crazing. Microscopic crazing is the first sign of membrane degradation.

Construction

The earthwork and LFG components of construction were initiated in early 1997. Construction of the geomembrane component of the EGC occurred from September 1997 to June 1998. Consideration was given to the constructability of the design. Because heavy equipment might damage the EGC it could not operate on the membrane. The anchor trenches were designed at locations beneath the cover terrace/berms. The panels were made in long strips so all horizontal (cross slope) welds ate located under the anchor trenches so they will not experience any stress.

The project required a great deal of coordination between the geomembrane installer and the general contractor to alternate work in a given area. Subgrade preparation first, then placing the geomembrane, then back filling the anchor trench, then installing the cover terrace/berm membrane (Figure 14). The filling of the anchor trenches with sand was slow. This low pressure vehicle used to back fill the anchor trenches carried relatively small loads and had to travel a long distance on the anchor trench, which has only one *way* access.

The FPP geomembrane rolls are 6 feet wide. They are fabricated into custom-sized panels in Environmental Liners' environmentally controlled factory, assuring consistently high quality seams, These- custom sized panels allow high geomembrane installation rates. The prefabricated panel seam integrity was tested in the factory, reducing construction quality assurance (CQA).

During construction the LFG surface collectors were turned off. These collectors, when operating, create a negative pressure under the membrane. The negative pressure prevents wind uplift. With the surface collector system off, and no anchor trenches installed, high winds sometimes lifted the geomembrane. The movement caused some of the LFG valve stems, which protrude above the EGC, to break. Opening the surface LFG collector valves as soon as the membrane was in place eliminated this problem. With the EGC in place, the surface collectors on and the ballast tubes positioned there is little movement of the FCC. The LFG surface collectors create a negative pressure under the geomembrane and suck it down to the surface of the landfill.

Field seaming of flexible polypropylene was fast and easy due to FPPs broad wedge welding seaming temperature window (Figure 15). A light weight Comet welder was used for the hot wedge seams between panels. Hot air welds, done by hand, were required for all the detail work and to attach the anchor trench/berm covers and seal all LFG collection penetrations. Typical destructive weld test results were within 90% of the parent material. All field seams were 100% air lance tested for integrity.

Construction proceeded through a number of severe winter storms with wind speeds up to 94 MPH, During one storm some damage to the membrane resulted but was easily repaired even after the membrane had been exposed to the elements for 4 months.

As the surface of the landfill side slopes were not of constant slope the EGG tended to bridge between the high points. Sand ballast tubes were used to help the EGG conform to the side slope topography, which was not of constant slope.

Storm Water Management

A major concern *was* for the management of storm water runoff from the EGG. Because there is no soil and/or vegetative layer above the EGG to retard runoff, the volume and rate of storm water runoff for thc EGG is much greater than for a traditional final cap. In effect, water shedding is significantly improved compared to a subtitle D design as there is little head or driving force for the water to penetrate any small leaks.

This site's flat topography and high water table necessitated the use of berms and down chutes to direct and control storm water drainage volumes and velocity. The down chutes convey storm water runoff collected in the cover terraces/berms into two holding ponds, totaling ever 15 acres in area. The bottom portion of cells 1 and 2 drain to a perimeter ditch that also conveys storm water into the holding ponds.

The cover terrace/berm design which worked best is shown in Figure 14. More details about the storm water management and land fill gas collection (LEG) system design are contained in an earlier paper by Germain et al.[1]

Maintenance - Cap Access

Maintenance and inspection of the EGC is expected to be much easier than for a traditional final cap system. Because there is no exposed soil on the EGG, there will be none of the typical maintenance problems associated with erosion of the cover soils and mowing of the vegetation. In addition, unlike a traditional final cap system where the geomembrane is buried and damage to the geomembrane may be undetected, visual inspection of the geomembrane component of the EGG will be performed as part of routine operations. Holes or minor damage observed on the geomembrane can be easily patched by operations personnel with hot-air seaming devices.

Vehicular access is provided via an access road which goes to the top of the landfill. The up slope side of the access road was designed with a drainage ditch which conveys storm water runoff to a cover terrace/berm.

To date one small (~30 Ft^2) area of the EGG received minor damage suspected to be from birds. It was patched by heat welding a new piece of FPP-R membrane over it. There was no problem in heat welding the membrane which had been exposed to the environment for four months.

Landfill Gas Collection

The gas collection system's design and the spacing of pipes had to eliminate the chance for localized entrapment of gas between the surface of the landfill and the EGG. The existing LFG collection system was modified and expanded to minimize the accumulation of gas beneath the geomembrane. In addition to standard vertical LFG collection wells, perforated horizontal collector pipes located approximately 2 ft (0.6 in) below the exposed geomembrane were installed to collect LFG which bypasses the vertical LFG wells. These horizontal collectors were spaced along the side slopes and crest of the landfill. The trenches for the horizontal collector pipes were back filled with aggregate and were overlain by a geocomposite gas collection layer to extend the zone of influence of each horizontal collection pipe.

In a traditional final cap system, a permeable gas collection layer is often placed beneath the geomembrane to allow LEG to migrate to a collection point. Because there is no soil overburden on the EGG, the gas migrates freely to a horizontal surface collectors or to where the influence of the vertical wells creates negative pressure at the landfill surface. The locations where LEG will not migrate freely beneath the geomembrane are at the cover terraces, access road, and the down chutes for storm water runoff. At these locations, a geocomposite gas collection layer was installed beneath the geomembrane.

The LFG collection system is working well. The negative pressure exerted by the horizontal collector pipes has the additional benefit of holding the geomembrane in intimate contact with the landfill surface. This reduces wind uplift and movement of the membrane. During construction, when the horizontal collectors were turned off, the membrane could lift up as much as 8 feet.

Wind Uplift Resistance

Design of the exposed geomembrane cap system for resistance to wind uplift is a function of the tensile characteristics of the geomembrane, the landfill geometry and location, and the design wind speed. The analysis for geomembrane wind uplift followed the procedures presented by [2]Giroud et. al., 1995. The forces for geomembrane tear and pullout at the anchor trenches were calculated based on the uplift force of the wind and the length of exposed geomembrane. The uplift force of the wind is based on the design wind speed of 80 miles per hour (130 km/hour). The maximum force on the exposed geomembrane was calculated to be approximately 200 lb/in (35 kN/m). The reinforced polypropylene geomembrane selected has a tensile strength at break 20 times greater than this.

Leachate Minimization

The state of Delaware typically receives 44 inches of rain each year. Even with effective operating practices and a grass covered earthen cap on a landfill, much of that rain can infiltrate through the cover.

At the Southern Solid Waste Management Center (SSWMC), Cell 1 was capped with 24 inches of soil and vegetated in 1988, and Cell 2 stopped receiving waste in January 1997. The two cells form a single mound that generated over 14,000 gallons of leachate per day. More details on leachate minimization are covered in a Solid Waste Technologies article.3

The EGG will minimize rainwater infiltration dramatically reducing leachate generation.. Since placement of the cap leachate generation has started dropping, though its to early to make an conclusive statement regarding the effectiveness of the EGG.

Costs

The final cost for this first FCC project was on par with a traditional subtitle D cap. Design modifications resulted in added expenditures. Lessons learned from construction and operation of this project should result in future EGCs which are more economical than a traditional subtitle D cap.

Conclusion

An exposed geomembrane cap (FCC) made from 36 mu reinforced flexible polypropylene has been installed as a long term tcmporary final cover at DSWA's 42-acre southern site. The EGC is working as envisioned. The cap has weathered eight months of storms with peak wind speeds of 94 MPH and precipitation of 4.5 inches in one day. The storm water diversion system is performing well. A number of minor changes were implemented which have improved the performance of the EGC.

A reinforced flexible polypropylene geomembrane has the properties necessary to make this EGC design possible. Long term monitoring will confirm the durability and performance of the EGC.

Therefore EGCs promise to be a viable and economical alternative to the traditional subtitle D cap prescriptive design. EGCs arc especially suited for sites where t is difficult to maintain a soil cap, sites with steep side slopes, seismically active sites. etc. as there is no potential for the cover soil sliding. Also sites, such as this one. where soil most be imported

Acknowledgements

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