UNIQUE INFLATED POND COVER USING REINFORCED FLEXIBLE POLYPROPYLENE

Richard Thiel, P.E.; Thiel Engineering, Inc.; USA

ABSTRACT

A 1.1-acre (0.45 ha) leachate pond has been successfully covered with a removable, inflated geomembrane. The cover is kept inflated with a 1 horsepower (0.75 kW) fan supplying only 3-tenths of an inch of water column of pressure (0.01 psi, or 75 Pa). The maximum height along the center of the inflated geomembrane is controlled by steel cables. The geomembrane is anchored to a perimeter concrete block with a removable anchorage. An automatic backup generator and fan are installed in case of a power outage or mechanical breakdown.

A geomembrane material was selected for the cover that would be appropriate for the performance conditions of exposure, stress, chaffing, and operational wear from repeated installations and removals. The selected material was a reinforced 30-mil (0.76 mm) flexible polypropylene. The material was selected for its strength, toughness, durability, and ease of repair. The cover has performed well over two winters experiencing high winds, intense rain, snow, and freezing conditions. The cost of this installation has already been fully recovered by the avoided leachate treatment costs. The cover has been successfully removed and reinstalled.

INTRODUCTION

In the calendar year of 1998, the Coffin Butte landfill near Corvallis, Oregon constructed a new leachate treatment infrastructure to supercede its outdated practice of agronomic irrigation onto hay fields. The new infrastructure consisted of a direct-osmosis treatment plant, a concentrate-solidification plant, and a 4-million gallon (15,000 m^3) leachate surge pond. Because of the limited capacity of the new treatment plant and its relatively high operational cost, it was highly desirable to cover the leachate surge pond to minimize the collection of rainwater into the leachate.

The traditional way to cover a pond is with a floating cover. However, an innovative inflated-cover concept was pursued and eventually implemented. The perceived advantages of the inflated cover compared to a floating cover were a) the ability to take the cover on and off for winter and summer operations, b) lower cost, and c) defects and holes in the inflated cover would have an insignificant effect on its environmental function. There are many civil design and construction elements to this project that would be of interest to anyone designing such a system. The scope of this paper is necessarily focused, however, on the geomembrane selection and performance in line with the theme of the conference and proceedings to which this paper forms a part.

DESIGN CONCEPT AND APPROACH

The pond inside crest dimensions were approximately 400 feet x 120 feet (122 m x 36.6 m). A schematic plan and cross-section illustrating the initial design concept are shown in Figure 1. The initial design concept for the inflated pond cover was as follows:

- Cover the pond with a geomembrane anchored around the perimeter.
- Provide an insert to the geomembrane to allow a fan to blow in air to inflate the geomembrane.
- Install cables across the pond to take the majority of the stress caused by inflation, as well as forces induced by wind.

DESIGN FORCES

Air pressure. A propeller or blower fan would be used to pressurize the cover system. A design goal was established to operate the cover with an average air pressure in the range of 0.1 to 0.3 inches of water (25-75 Pa). This level of pressure would be enough to counteract the self-weight of the geomembrane plus rain. More pressure than this would require greater structural considerations for total uplift and tension on the cables.

Uplift force. The uplift force is simply the air pressure times the area. A factor of safety was used to account for wind-induced airfoil effects. The uplift was designed to be counteracted by the weight of the concrete perimeter footing.

Cable tension. All of the uplift force caused by the air pressure against the geomembrane cover was assumed to be transmitted to the cables. The tributary area for each cable was assumed to be the half-distance to the neighboring cables times the cable span. The cables were assumed to be uniformly loaded, and the well-known cable formulae were applied as follows:

$$H = \frac{w L^2}{8h} \tag{1}$$

$$V = \frac{w L}{2} \tag{2}$$

$$T = \frac{w L}{2} \sqrt{1 + \frac{L^2}{16 h^2}} \tag{3}$$

$$L' \approx L + \frac{8 h^2}{3L} \tag{4}$$

where: H = horizontal component of cable tension at anchorage; w = uniform load per unit length along the cable; L = horizontal cable span; h = vertical height of cable arc above anchor points; V = vertical component of cable tension at anchorage; T = cable tension; L' = actual cable length.

The operating tension in the cables for this project were calculated to be on the order of 7,000 lbs (31 kN). The effect of the horizontal and vertical forces exerted by the cables on the eye bolts and perimeter foundation had to be considered.

External wind forces. These were not explicitly calculated, but were allowed by a factor of safety in the uplift and cable forces.

Snow loads. No design provisions were included for snow loads. Snow would potentially collapse the cover. As long as this was understood by the operator, snow-induced collapse would not be considered a "failure" of the cover system. Management of rare snow loading would be accommodated by operations, as discussed later.

DESIGN DETAILS

The following details had to be considered to allow construction and operations of the cover system:

- Perimeter weight. The dead weight of the entire system, and in particular the perimeter concrete foundation, had to be designed to counteract the vertical uplift caused by the air pressure and potential wind-induced airfoil uplift.
- Geomembrane anchorage. A design goal was to provide a removable anchorage for the geomembrane around the perimeter so that the geomembrane could be pulled off of the pond periodically and reinstalled. Reasons for wanting to remove the geomembrane included

pond cleaning and enhanced spray evaporation during the summer months. Figure 2 illustrates the design for the perimeter anchorage.

- Cable anchorage. One-inch diameter galvanized steel eye-bolts were designed to resist the cable tension. The eye-bolts were epoxy-set into the concrete perimeter block. Turnbuckles were used between the cable ends and the eye bolts to allow fine tuning of the cable length.
- Fan insert. The design included a portion of the concrete perimeter wall raised high enough to allow a 2-foot (0.6 m) square propeller fan to be inserted into the wall. A subsequent backup blower fan was included in the system by connecting its outlet to a hole in the concrete wall with sheet-metal air ducting.
- Pressure control. Pressure control was designed into the system by providing several large holes in the concrete end wall fitted with slide gates.
- Stormwater runoff. A perimeter french drain was installed just outside of the perimeter foundation to collect and convey stormwater runoff from the cover. (See Figure 2)
- Access to pond interior. Pipe inlets, outlets, and instrumentation were designed to go either under or through the concrete perimeter foundation.
- Method to uncover the pond. A series of ropes were installed at the quarter, half, three-quarter, and full distance across the short dimension of the cover to allow it to be pulled back into a series of accordion-pleats for summer maintenance and pond cleaning.

GEOMEMBRANE SELECTION

In an attempt to provide an extremely low cost cover, an initial attempt was to use a quite inexpensive tarp material to cover the pond. The landfill operators have a lot of experience using a lightweight polyethylene tarp for temporary cover on the landfill that is available in panels up to 60,000 sq ft (0.56 ha) in area. The material consists of two 3-mil (0.08 mm) plies of polyethylene film adhesively bonded together, with nylon reinforcement threads spaced 0.4 inch (10 mm) each-way between the two plies. The cost to purchase and deploy this material over the pond was estimated at approximately $10,000 US. It was thought that even if the material only lasted a year or two, it would have some salvage value for use in the landfill, and its low cost would be worth more frequent replacements compared to a more expensive geomembrane.

Figure 3 is a photograph of the author standing on the inflated cover with the light weight material in use. Imagine that the support is only 6 mils (0.15 mm) of polyethylene (with the nylon reinforcement), and a pressure of only 0.2 inch water (0.0072 psi, or 50 Pa)! (Quite a demonstration of faith in geosynthetics and fluid mechanics.)

Indeed, the material initially appeared to perform quite well, surviving wind and rainstorms. Everything appeared to work in accordance with the design calculations. In a relatively short period of time, however, the durability of the tarp came into question. The tarp would expand, contract, and move due to temperature changes and wind. Even clouds passing by the sun would cause enough temperature change to result in the cover tarp "breathing". All of this movement of the cover tarp resulted in chaffing against the cables that, in a few months time, caused large tears in the tarp. While the cover could handle numerous holes without a problem, 12-foot (4 m) long tears resulted in deflation. The only way this lightweight material could be repaired was by sewing, and these types of repairs did not last very long. Ultimately, the low durability and poor repairability of this lightweight material proved it completely unmanageable and inappropriate for this application. With this lesson learned, a more discriminating process was followed to select a replacement material. What was needed was a real geomembrane, not just a tarp.

Available geosynthetic materials were researched that would provide good durability and performance. Research conclusions coincided with the suggestions received from many geosynthetic industry representatives, which was to use reinforced polypropylene (PP-R). The following statements regarding the advantages of PP-R led to its selection:

- It has a very high tensile strength of about 200 lbs/inch (35 kN/m). This is 10 times the strength of the lightweight tarp first used.
- It has a high tear strength of 100 lbs (ASTM D751 – Tongue Tear). The reinforcement is very dense (9 heavy reinforcement fibers per inch (25 mm), each way) that are thermally encapsulated in the polypropylene (versus 2.5 fibers per inch (25 mm) in the tarp which were held in place by a glue). This is a significantly stronger tear strength than unreinforced materials like polyethylene.
- It has excellent resistance to UV light, heat, and cold, and is typically manufactured for long-term, exposed applications. The material maintains excellent flexibility and strength well below freezing temperatures, and maintains its strength on clear, hot sunny days due to the internal reinforcement.
- It has a low expansion/contraction coefficient (only 14% that of polyethylene), which will reduce the movement of the liner below the cables.
- It has excellent repairability, even after long exposed aging. Repairs can be made with a hot-air gun and a roller. PP has a very wide temperature window for making good welds (from 230-480 °C, compared to 280-380 °C for HDPE). Other materials such as HDPE require specialized welding equipment and trained operators.
- Welds are very strong. In shear, the welds typically achieve greater than 90% of the parent material strength. The material can be wedge-welded, or welded with a hot-air gun. The shear strength of a pull-tab during installation is very important. Being able to achieve nearly 200 lbs/inch (35 kN/m), even in the presence of abrasions, nicks, and gouges, makes taking the cover on and off much more feasible than less durable materials.
- The material has a very high toughness rating for impacts, and high durability when nicked or gouged. Polyethylene, for example, rips very easily when scratched.
- The material is very flexible, yet it does not stretch much due to the strong internal reinforcement.
- The material is about 9% lighter than water, and so it readily floats.

- Although the cost for PP-R is significantly more expensive than the lightweight product (ultimately about five times the installed cost), most, if not all, of the cost will be made up over time because it will last much longer.
- The toughness of the material will allow it to be pulled back and forth over the pond every winter and summer to allow use of a spray evaporation system or for pond maintenance. One of the reasons this can be done is that patches can be welded on this tough material to allow attachment of hardware (e.g. "D" rings) for attaching ropes and cable guides that can be used to pull the cover. Rubsheets (also called doubler strips) could also be welded where chaffing would be expected.
- It is noteworthy that the PP-R cover would do just fine under an inflation pressure of 0.2 inch water (50 Pa) with no cables. The average force on the liner perimeter, with no cables, would only be 30 lbs/inch (5.2 kN/m), which is much less than its rated value of 200 lbs/inch (35 kN/m). The use of cables is still recommended, however, to a) maintain and control the cover shape, b) to take stress off the perimeter anchorage, and c) to take the force of wind gusts.

The PP-R material is available in gages ranging from 20 to 45 mils (0.5-1.1 mm). The same reinforcement is used for all of the gages. Thicker-gage material would tend to have better long-term resistance to UV radiation. Consequently, the manufacturer warranties began at 10 years for the 20-mil (0.5 mm) material, increased to 15 years for the 30-mil (0.76 mm) material, and capped at 20 years for the 36-mil (0.91 mm) and thicker material. For this project, a 30-mil (0.76 mm) material was selected as a compromise between weight, cost, and expected durability.

CONSTRUCTION AND INSTALLATION

The following construction steps were followed, given that the double-lined pond was pre-existing:

- Inlet and discharge pipes to and from the leachate pond that would be installed underneath the permanent foundation were trenched into place.
- The concrete perimeter foundation was cast in place. This included the raised wall at one end for the fan, pressure-control holes, and a 2-foot (0.6 m) diameter pipe access portal to the leachate pond to lower pumps and instrumentation.
- The stormwater french drain was installed.
- Three geomembrane panels were factory fabricated from detailed layout drawings and shipped to the site. The fabrication included doubler strips, cable pocket guides, and pull tabs.
- The geomembrane was deployed with the aid of two loaders, one on each side of the pond, which pulled the geomembrane the long way over the pond. The geomembrane material was supplied in three pre-fabricated panels that were welded together during deployment. The cables were threaded through the pocket guides, and ropes tied to the pull tabs, as the material was deployed.

- Once the anchored position of the geomembrane was established, holes were drilled into the concrete foundation to allow epoxy setting of the eye bolts at the proper locations to hold the cables. The turnbuckles were used to attached the cable ends to the eye bolts.
- The primary propeller fan was installed in the raised perimeter wall block out. Later, a backup fan and generator were added to the project.
- All of the vents were closed and the cover was inflated.
- After inflation, the pressure was adjusted using slide-gates on the vent holes. The final cover profile was established by adjusting the cable lengths. A lower profile would result in less wind forces, but much greater tensions in the cable. Ultimately, a peak height of approximately 20 feet (6 m) was established in the center of the cover. Figure 4 is a photo of the completed installation.

OPERATIONS

The following protocol has been followed for operations:

- Inflation: Close all vents and turn on both fans.
- Pressure control: When desired operating pressure is reached (approximately 0.2 inch water (50 Pa)), use only one fan and adjust vents to meet equilibrium.
- Restoring a downed-cover: This is only problematic if the geomembrane is covered on top with rainwater. In this case, pumps are simply placed in the low spots as the cover is reinflated. Eventually the pumping and air pressure overcome the weight of the water.
- Removing and reinstalling cover: This has been performed by attaching ropes to pull-tabs at quarter-points on the cover and pulling the cover across the narrower pond dimension. It takes approximately 25 laborers half a day to remove or reinstall the cover.
- Snow: Snow events are rare for this site. If a snow event is forecast, a propane heater is run in front of the fan intake. This method has been successful in preventing snow accumulation on the cover. This issue might be more problematic at sights that experience more significant snow events.

PERFORMANCE AND OBSERVATIONS

The following lessons were learned from this project:

- An inflated cover can be a practical solution.
- Geomembrane durability is a key operational parameter. Reinforced flexible polypropylene was determined to be the most cost-effective, functional solution for this application.
- This system has performed very well under strong winds. The reinforced geomembrane and cable system move very little.
- Precautions are needed for snow loading.

- The cover system can reasonably be removed and reinstalled within one day for each process.

ACKNOWLEDGEMENTS

Thanks and acknowledgements are due to the following parties for making this project a success: Valley Landfills Inc., the owner, for supporting and encouraging this novel idea; Larry Well for first giving the author the seed of an idea to pursue such a project; Jacob Berman who provided practical design consultation; Texas Environmental Plastics whose industry networking and installation brought the project on line; Colorado Lining Systems whose responsive and expert fabrication made the job possible; and Cooley Engineered Membranes whose excellent geomembrane material made this project a success.