

Landfill closure: A lesson in crisis management

Set in the beautiful coastal lands of the eastern Chesapeake Bay, the small landfill had served Somerset County, Maryland from 1977 to 1997. The site was flat, sandy, with groundwater near the surface. As with all municipal solid waste (MSW) landfills of this age, no liner or leachate collection system was present beneath the waste. The state's Code of Maryland Regulations (COMAR), issued by the Maryland Department of the Environment (MDE), required a low permeability layer, such as a geomembrane, in the final closure cap to limit infiltration.

Figure 2 shows the contours and site boundaries. The cell's shape was reminiscent of Oklahoma, which complicated the closure design with the tight property boundaries. The side slopes were intended to be as steep as 3H:1V (33%).

This article reviews the design and construction problems that were encountered during the closure of this landfill. More importantly, this paper discusses the solutions to these problems and recommends simple means of avoidance for such problems.

Interim closure activities

The landfill stopped receiving waste in early 1998, when the first cell opened at the county's new lined landfill (part of the same site). For this 31 acre closure, COMAR requires that a minimum of 24 in. of soil be placed over the waste as an interim cover until the landfill closure cap is installed. The soil separates the waste from the overlying geomembrane. COMAR requirements also stipulate that the final landfill slopes be less than 3H:1V. County labor was used to final grade the waste contours and for placement of the interim soil cover. While the county generally achieved the interim closure requirements, several small areas of the side slopes of the landfill's "panhandle" portion exceeded the 3H:1V maximum slope.

As this occurred, the Maryland Environmental Service (MES) prepared the final closure design. The designed final cover incorporated the following layers (top-down) over the interim soil cover:

- 6 in. thick topsoil layer vegetated with regional grasses
- 18 in. vegetative support layer

- Geosynthetic drainage composite consisting of a drainage net with an 8 oz./yd.² nonwoven bonded to the upper surface
- 20 mil PVC geomembrane barrier
- 8 oz./yd.² cushion geotextile

The United States Environmental Protection Agency's (EPA) Hydraulic Evaluation of Landfill Performance (HELP) model was used to size the drainage composite. The interface friction angle was estimated from a technical paper (Hillman and Stark 2001) to be 23°.

The impact of these design assumptions is discussed later in this paper.

The engineer's cost estimate for completion of closure was \$1,794,017. With the design approved by MDE, the final closure was bid in April 2001. The contractor, who was then constructing the county's first lined landfill cell, submitted the winning bid of \$1,993,873. This contractor was awarded the contract and given a Notice to Proceed with the closure project, effective July 30, 2001.

Construction problems

Construction progressed quickly, with the balance of 2001 being used to install gas wells, the cushion geotextile, and the 20 mil PVC and single-sided geocomposite drainage layer. Cover soil placement commenced too, simultaneous with development of a soil borrow pile. Placement of the vegetative support soil began on the flatter slopes of the "pan" portion of the landfill and was moving towards the steeper slopes of the panhandle.

Due to the highly restricted access at the base of the landfill on all sections except the east face, the contractor attempted to place vegetative support soil on the side slopes in a top-down fashion. This allowed vegetative support soil placement without first constructing the entire perimeter access road system. To access the western-most portion of the site, the contractor elected to place soil on the crest of the panhandle to serve as a base for off-road trucks

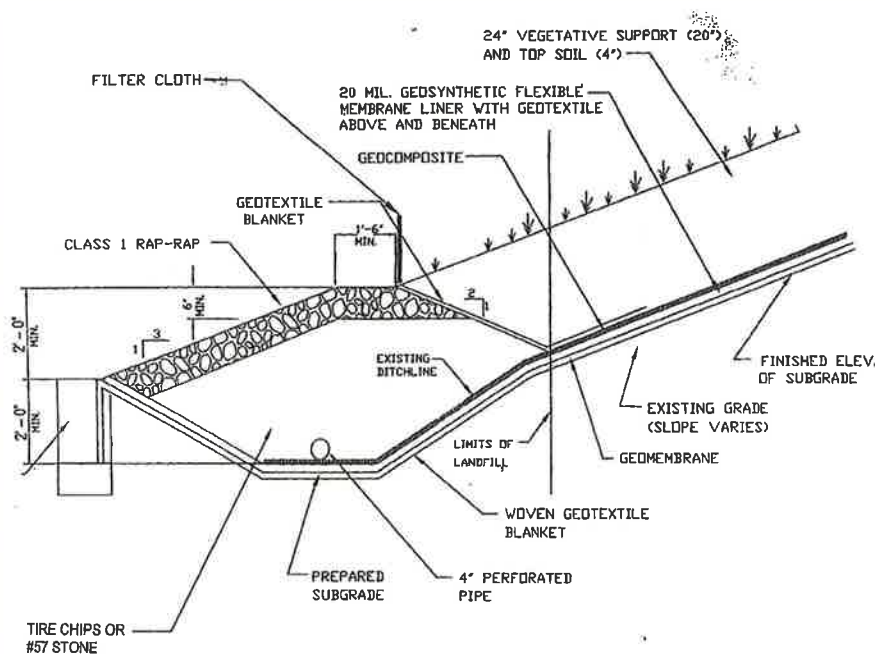


Figure 1. Original gravel drain at toe of slope.

and other heavy equipment. When this was complete, the contractor planned to push soil downslope. The ridge of the panhandle was covered with approximately 4 ft. of cover soil material to allow dump trucks to back out onto the ridge of the panhandle. During the process of extending this roadway, a portion of the roadway slid off of the top of the slope and moved downward. **Photo 1** shows the slide and indicates that the failure interface was between the PVC geomembrane and the overlying drainage composite. Shortly thereafter, on the southwest portion of the site, another slope failure occurred when the contractor was using off-road equipment on the side slope of the landfill without first completing the perimeter road system in this area.

As a result of these slope failures all construction work halted on the project in November 2001.

Both the contractor and MES brought in geotechnical consultants to evaluate the stability of the final cover under the actual field conditions. Several factors were thought to play a major role in the failure:

- The slope was steeper than the 3H:1V (33%) assumed maximum.
- The interface friction between the PVC geomembrane and the drainage composite was only 18.4° with a minimal adhesion of 10 psf.
- The top-down construction eliminates the toe buttressing of the soil veneer and lowers the sliding factor of safety.

In discussions with the county and the contractor, it became evident that the steeper slopes were due to inadequate grad-

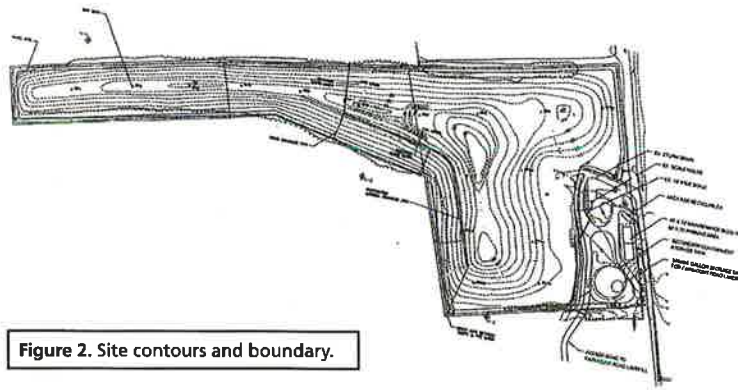


Figure 2. Site contours and boundary.

ing prior to cover soil placement. Immediately prior to commencement of the closure cap construction, MDE had required additional soil to be placed in certain areas of the site where MDE determined that the required 24 in. of final cover soil had not been fully placed. The county used its own staff and equipment to place this additional soil. The entire slope area of the landfill areas should then have been regraded by the contractor to meet the maximum 3H:1V slopes stipulated in both COMAR and the approved construction documents.

To bring the side slopes into compliance, MSW could have been removed, transported and disposed of in the new lined landfill or in flatter areas on the old landfill. The contract specifically included funds to compensate the contractor for this activity. The slopes could also have been brought closer into required grade compliance by reducing the thickness of the interim cover, but MDE denied a variance from the 24 in. thickness requirement.

The error in the assumed interface friction angle (23°) was traced to a significant difference in measured peak and residual

friction angle between the project's first guiding reference (Hillman and Stark 2001), or "Reference 1," and actual data obtained from testing the interface. Reference 1 indicated peak and residual secant friction angles of 23 and 18°, respectively, for a 17 kPa normal load that simulates what was achieved under the final cover. Direct shear testing (ASTM D 5321) of the actual PVC geomembrane and drainage composite yielded peak and residual interface friction angles of 18.4 and 9.6° respectively.

The lesson here is clear: always require the contractor to provide direct shear testing of critical interfaces to ensure that the minimum interface shear strength assumed in design is actually achieved in the field. Published interface strength values should be used only as a guide in the initial design of a system.

The ability to construct the side slopes of the panhandle bottom-up was compromised by both the tight property lines and the presence of a large gravel drain at the toe of slope. This detail is shown in Figure 1. The property line was only 5 ft. from the edge of riprap for much of the perimeter.



Photo 1. Initial slope failure.



Photo 2. UV degradation of drainage composite.



Photo 3. Invasive grass in exposed geotextile.



Photo 4. Perimeter roadway.



Photo 5. Final cover today.

The contractor did not believe that it was possible to construct and then remove a construction road around the base with this drain present.

Involuntary UV testing

Reflecting the worst fears of all design engineers, the dispute regarding the stability of the final cover as designed brought a halt to construction with nearly all geosynthetic materials already deployed. Over 20 acres of drainage composite was deployed but not covered or otherwise protected. In the following 24 months, the original contractor was removed from the project and MES assumed direct control of construction. The result of 24 months of direct exposure to the sun was dramatic on the geosynthetic materials. This provides a graphic lesson.

As a result of the delay in completing the construction, all of the exposed geotextile forming the top of the drainage

composite had completely lost its integrity. The fabric was easily torn by hand and easily removed from the geonet core. Those areas immediately adjacent to the hot air seams were particularly quick to deteriorate (Photo 2). The geonet cores of the drainage composite were joined by white nylon ties on 5-ft. centers. Once the geotextile deteriorated, the direct sunlight quickly made the ties brittle and weak. Soon the drainage composite panels were no longer tied together; they acted independently. All exposed drainage composites had been damaged by the ultra violet (UV) light. They were removed and disposed of in another portion of the closed landfill.

The removal process was complicated by the presence of invasive grasses that had rooted tightly to the drainage composite (Photo 3). All of this vegetative material had to be removed by hand prior to the placement of new materials.

The 20 mil PVC geomembrane had been exposed too, as the drainage composite deteriorated and came apart. Portions of the PVC geomembrane suffered a significant number of small holes from wind and vector damage. The PVC geomembrane itself was tested to quantify the loss of physical properties that had resulted from the exposure. The following tests were performed on samples of PVC recovered from the field: volatile loss (ASTM D1203), dimensional stability (ASTM D1204), tear resistance (ASTM D1004), puncture resistance (ASTM D4833), hydrostatic resistance (ASTM D751), and basic tensile properties (ASTM D882 Method A). Surprisingly (at least to the authors), the PVC still met all original project specifications and could be salvaged! Nearly 5.9 acres of PVC geomembrane were replaced with the reason for replacement typically being the presence of a large number of small holes in a given section, or the inability to redeploy the material without destroying it. Replacement was simply easier and less costly than repair.

Redesign of side slopes

Both MES and Somerset County wanted the materials used to tolerate the actual slopes that existed on the panhandle. This meant that localized slopes of up to 22 (40%) had to be tolerated. Three key design changes were made to the side slopes

to achieve stability:

- Both Reference 1 and a GFR Designer's Forum article (Stark and Richardson 2000) showed that a PVC geomembrane had a significantly higher interface friction angle with a nonwoven geotextile as compared to a geonet. Thus, an improvement in interface friction could be obtained by using a drainage composite material that has a nonwoven geotextile bonded to both faces of the geonet. This had only a nominal cost impact and increased the peak friction angle from 18.4 to 23.9° with a significant apparent adhesion of 45 psf. The transmissivity of the drainage composite was also increased based on a more appropriate unit-gradient infiltration analysis to replace the HELP model evaluation.

- Past experience with evaluating "lumpy" slopes has shown that the factor of safety against veneer failure can be maintained if the maximum surface slope angle is maintained despite the lump. This produces a localized area of increased cover thickness that acts as a buttress. The presence of the steeper lump does not reduce the veneer stability as long as the original maximum slope is maintained below the lump. This means that field inspectors must verify both the minimum thickness of the overlying soil layer and its slope.

- The simplest change was to incorporate a permanent access road at the base of the slopes such that bottom-up construction could be used. Photo 4 shows the roadway incorporated in the revised detail at the base of the slopes. As an additional benefit, the damaged drainage composite that had been removed from the cover was placed in layers beneath the roadway. This provided inexpensive disposal and reinforced the sands beneath the roadway.

These three simple changes allowed the side slopes of the panhandle portion of the landfill to be easily completed. Photo 5 shows the final cover as it exists today. Most of this cover was placed during what was for the region its wettest summer since 1948. In general, there were more rain and rain clean-up days than actual construction days. The stability of the slopes under conditions of near total soil saturation was well demonstrated.

The only plus to the rain was accelerated vegetation of the slopes.

Lessons learned

After the successful completion of the final cover, the authors feel that both technical and contractual lessons were learned from this project. The technical lessons are clearer and consist of the following:

- When access to the base of a slope is limited, the design should incorporate either a means of access for the contractor or sufficient slope stability that allows top-down construction. When bottom-up construction is required, it should be clearly required in the specifications.
- When the slope height is less than 40 ft., the sliding factor of safety can be maintained by specifying a maximum slope that must be maintained on the top of the completed final cover.
- Interface friction between critical elements should be confirmed by testing actual materials to be used in construction before material placement on site is allowed to commence.

The technical hurdles to achieve suc-

cessful construction of this final cover are minor when compared to the legal battles that ensued. On this project, the contractor was under contract directly to the county. Previous projects between the county and the contractor had been successful and led to a hesitance on the part of the county to force action from the contractor. Because of this, MES was forced to watch as weather completely destroyed over \$113,000 worth of geosynthetic materials. Prior placed materials and construction efforts were also destroyed as a result of the 24-month delay in the completion of the construction. MES incurred a cost of over \$354,000 to repair damages to the site that occurred after the contractor abandoned the project in 2001. In the end, it was apparent that the contractor had no intention of completing the final cover for the original bid price. Once the contractor was removed from the project, MES was able to complete the revised final cover in a timely and routine fashion. Because of this project, MES will no longer provide construction support

on projects that it cannot directly enforce contractual requirements.

Acknowledgements

Jeffery Pitts was the MES construction manager who made the field components of the project work. Hallaton Inc. installed and then repaired the geosynthetic components on the project. **GFR**

Gregory N. Richardson, Ph.D., P.E., is president of G.N. Richardson & Associates, www.gnra.com.

William E. Chicca works for the Maryland Environmental Service (MES), www.menv.com.

References

- Hillman, R.P., and Stark, T.D. 2001. "Shear strength characteristics of PVC geomembrane-geosynthetic interfaces." *Geosynthetics International*, vol. 8, no. 2.
- Stark, T.D., and Richardson, G.N. 2000. "Flexible geomembrane interface strengths." *Geotechnical Fabrics Report*, vol. 18, no. 3.



"BLANKETING NATURE WITH NATURE"

WESTERN EXCELSIOR MANUFACTURES A FULL LINE OF PRODUCTS DESIGNED TO BE EROSION CONTROL SOLUTIONS

- *ROLLED EROSION CONTROL PRODUCTS
 - 100% ROCKY MOUNTAIN EXCELSIOR
 - 100% WEED FREE STRAW
 - 100% COCONUT
 - STRAW COCONUT BLENDS
 - 100% SYNTHETIC
- *SEDIMENT CONTROL LOGS AND WATTLES
 - 100% ROCKY MOUNTAIN EXCELSIOR
 - 100% WEED FREE STRAW
- *HYDRAULIC MULCH
 - 100% WOOD FIBER
 - WOOD FIBER / CELLULOSE BLEND

AVAILABLE ACROSS THE COUNTRY IN A VARIETY OF SIZES AND CONFIGURATIONS INCLUDING RAPID DEGRADABLE AND 100% BIODEGRADABLE.

WESTERN EXCELSIOR PRODUCTS ARE DESIGNED TO MEET YOUR NEEDS AND PROVIDE EROSION CONTROL SOLUTIONS

WESTERNEXCELSIOR.COM
1-800-833-8573