DESIGNING AND SPECIFYING LANDFILL COVERS

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This article describes a case history that illustrates a number of important design, specification, and bidding issues for landfill covers. The case history involves a landfill near Somerset County, Maryland in the beautiful coastal lands of the Chesapeake Bay. The landfill operated from 1977 to 1998 until the first cell of the adjacent new lined landfill opened. The closed site consists of about 30 acres. The landfill site is flat, sandy, with groundwater near the surface. The landfill is unlined and does not posses a leachate collection and removal system below the waste and thus installation of a final cover system is important to reduce groundwater contamination. The Code of Maryland Regulations (COMAR), issued by the Maryland Department of the Environment (MDE), require a minimum of 24 in. of interim soil cover prior to final closure. COMAR also require slopes to be 3H:1V or less and a low permeability layer, i.e., a geomembrane, in the final cover system to reduce infiltration.

This article reviews the initial design, specification, bidding, construction, and the remedial measures for this final cover system. Afterwards, the article provides recommendations so the problems encountered are avoided in future projects.

The initial design for the final cover was prepared by Maryland Environmental Services (MES). MES is an Independent Agency of the State of Maryland that is a self-supporting, not-for-profit public corporation that provides engineering services to governmental and private sector clients. The agency competes with private sectors firms for a variety of projects including

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water and wastewater treatment, solid waste management, composting and organic products marketing, recycling and marketing of recovered materials, dredged material management and recycling, and hazardous materials cleanup and engineering. One main competitive advantage for MES is that it has sovereign immunity from legal claims. MES was created in 1970 and employs over 560 people.

MDE is an Executive Department of the State of Maryland and reports to the Governor. MDE is the regulatory body that approves landfill liner and cover system designs prepared by MES and private consultants. Thus, one state agency approved the design of another state agency for this landfill cover without any external review. This lack of external review is not recommended, especially when the design will be submitted for outside bid. If a state agency will perform the construction activities, external review may not be as critical because the state can assume responsibility for design errors.

INITIAL CONSTRUCTION PROBLEMS

Before final cover construction commenced, MDE identified areas of the landfill that did not posses the required 24 in. of interim soil cover. To comply with MDE’s request for 24 in. of interim soil cover, Somerset County personnel placed additional soil cover which resulted in the slopes being even steeper. The landfill is shaped like a sauce pan with a long handle. The oversteepended portions of the landfill are located along the panhandle as shown in Figure 1. As placement of soil cover was occurring by Somerset County, MES prepared the final design based on a slope inclination of 3H:1V. Thus, the design did not reflect field conditions from the beginning.

The construction contract included a pay item for “closure excavation” of 1,000 cubic yards and a budget of $8,250. Clearly, this small volume and budget was not intended for the contractor to remove the recently placed interim soil cover, remove waste to flatten the slope to 3H:1V, dispose of the waste, and replace the interim soil cover to achieve a 3H:1V slope in the oversteepened areas. In fact, the remediation did not involve any slope flattening. The slope toe could not be moved outward to reduce slope inclination because adjacent properties are within 1 to 5 feet of the geosynthetics anchor trench. MES sought a variance for the 24 in. thickness of interim soil cover layer to reduce slope inclination but the request was denied by MDE. Thus, MES instructed the contractor to proceed without providing any guidance to accommodate the oversteepened slopes or sufficient funds to remove the oversteepened waste.

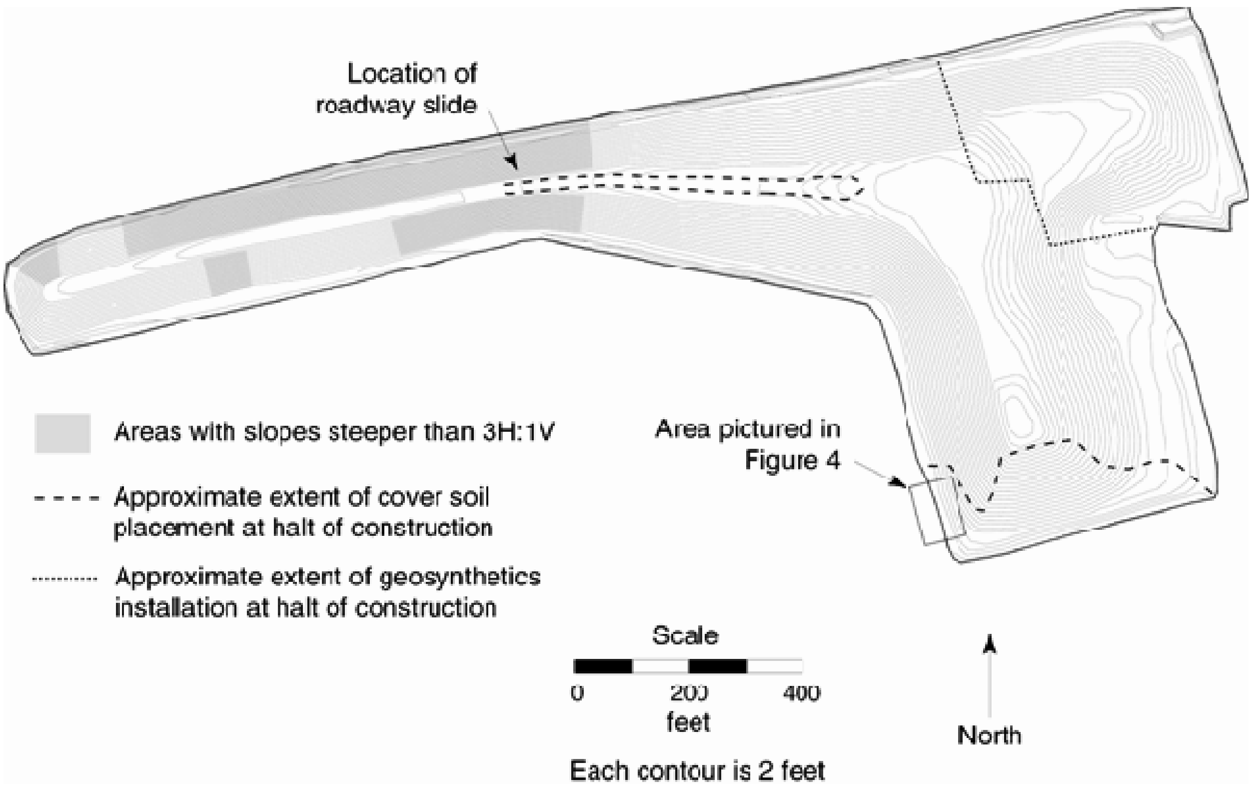

Figure 1: Plan view of landfill slopes steeper than 3H:1V after placement of additional soil by Somerset County to achieve the required 24 in. thickness of intermediate soil cover

INITIAL CONSTRUCTION ACTIVITIES

Because access along the north side of the panhandle prevented creation of an access road, the contractor started placing vegetative cover soil over the drainage composite on the crest of the panhandle from the east towards the west (see Figure 2). Geosynthetic placement started at the west end of the panhandle and moved to the east along the panhandle. Thus, the panhandle is the area that was ready first for vegetative cover soil placement which is the reason the contractor started placing vegetative cover soil there instead of another location. Upon reaching the western end of the panhandle, the contractor intended to place material down the western most slope and then install cover soil from the bottom to the top of the slope along the north and south sides of the panhandle. Before proceeding too far down the panhandle, a portion of the roadway slid off the narrowest portion of the panhandle (see arrow in Figure 2). The slide movement clearly occurred at the geonet/PVC geomembrane interface and tore the single-sided drainage composite. The single-sided drainage composite tore because the length of each roll was sufficient to allow one end to anchored on the south side of the panhandle and the other end to be anchored on the north side of the panhandle. This resulted in no ties being needed to tie together different rolls of the drainage composite on the panhandle.

In an effort to keep the project moving while MES pondered the problem, the contractor moved to the southern most portion of the landfill, i.e., the bottom of the sauce pan, where installation of the geosynthetics had been completed and because geosynthetics were being installed in the northeast corner. The contractor installed the sideslope anchor detail shown in Figure 3 along the southern slope toe towards the west side of the "pan". An access road across the southern portion of the landfill was located just above the top of the anchor trench detail because the designer substituted tire chips for the Class 1 rip-rap (#57 stone) shown in Figure 3 and because the crest width is only 1.5 feet (see Figure 3). The tire chip substitution was made to access funds from the shredded tire program to facility project funding and occurred after the slope stability calculations were complete because the unit weight for the buttress material in the stability calculations is 116 pcf instead of about 30 pcf. The substitution of tire chips resulted in a compressible foundation for an access road and a low unit weight material acting on the geonet/PVC geomembrane interface. The small crest width and compressible material necessitated that the access road be primarily founded on the slope. With a small access road created slightly above the sideslope anchor detail, the contractor started placing soil from the bottom to the top of the south slope. As fill was being placed up the south slope, tension started developing at the top of the landfill and some of the plastic ties holding the drainage composite together started failing. As a result, soil placement did not reach the top of the south slope and the drainage composite started pulling apart (see Figure 2). Afterwards, soil placement and the anchor trench detail were started along the west side of the pan. Before construction was halted, soil was placed a distance of about 30 to 40 feet west from the southern corner. The soil placement proceeded slightly ahead of the anchor trench detail only for the last portion of the west side constructed. This resulted in the access road on the west side not being continuously supported by the tire chips. However, the vegetative cover was being placed parallel to the slope toe first and not up the west slope yet.

Figure 2: Aerial view of panhandle and southern slope

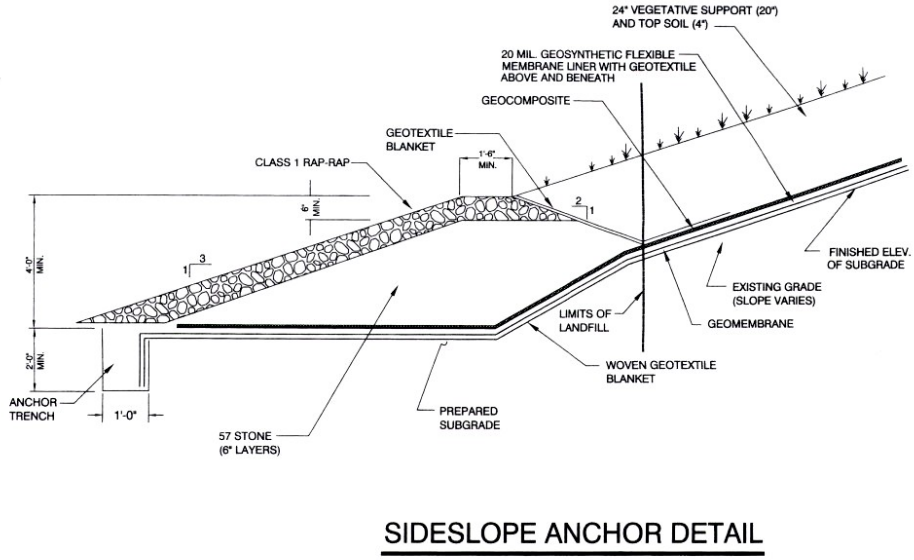

Figure 3: Sideslope Anchor Detail prepared by MES

As construction progressed from the southwest corner towards the steepest portion of the west slope (see Figure 1), wrinkles started developing in the single-sided drainage composite at the slope toe (see Figure 4) and plastic ties along the top of the western slope started failing. Movement was again occurring at the geonet/PVC geomembrane interface which suggested a design problem to the contractor. Minor wrinkling of the single-sided drainage composite started before the end of work on a Friday and the majority of the wrinkles occurred over the subsequent weekend when no construction equipment was present. The photograph in Figure 4 was taken on the following Monday morning. Therefore, the majority of the slope movement was not caused by vehicle loading; instead it appears that progressive failure over the weekend contributed to the magnitude of observed movement. The potential for progressive failure is enhanced when the interface friction (16.0 degrees) is less than the average slope inclination (18.0 degrees) (Stark and Poeppel 1994). It is recommended subsequently that the interface friction angle should always exceed the slope angle even with the presence of a toe buttress. The slide on the panhandle occurred quickly and thus progressive failure was not a large factor because the slope angle (22 to 23^0) significantly exceeds the back-calculated friction angle for the geonet/PVC geomembrane interface, i.e., 16^0. In addition, the laboratory direct shear testing (ASTM D5321) of the geonet/PVC geomembrane interface conducted after problems developed show a peak geonet/PVC geomembrane interface friction angle of 18 degrees. Thus, the design assumption of a geonet/PVC geomembrane interface friction angle of 23 degrees from a seminar presentation is the main issue leading to the failure of the cover system.

Figure 4: Toe of west slope showing wrinkles in single-sided drainage composite that developed over weekend

The geocomposite material necessary to create the wrinkling shown in Figure 4 was derived from the separation of butt-seams at the top of the west slope over the weekend and/or elongation of the geonet and geotextile due to the tensile forces induced along the slope. The separation of butt-seams at the top of the west slope also identified that sliding was occurring on the geonet/PVC geomembrane interface along the entire west slope length. The observed failure mode is representative of a global failure, not a localized failure such as might be induced by a heavy piece of equipment on the slope. The observed failure mode also illustrates the ramifications of installing a weak interface on a steep slope, which is that every material above that weak interface can move downslope, even if the overlying material exhibits high shear strength. In short, the good material will simply be "along for the ride" and thus a careful evaluation of the interface strengths should be undertaken prior to construction.

Upon uncovering the large wrinkles shown in Figure 4 and because of the prior experience on the panhandle, the contractor concluded the geonet/PVC geomembrane interface was inadequate to support placement of cover soil under any circumstance and ceased work. After substantial legal posturing, the County terminated the contractor so MES could redesign the cover system and complete the cover system at an additional cost of $1.4 million over the contract price of $2.0 million. During the legal posturing, MES adamantly refused to redesign the cover system and blamed the contractor. After the contractor was terminated, MES quickly redesigned and constructed the cover using MES equipment and personnel. The contractor was paid for all of his work and had every intention to complete the project, but realized that cover soil could not be placed up the 50 foot high oversteepened slopes using the original design. The termination of the contractor is unfortunate because the contractor had performed other successful projects for Somerset County, but the designer would not admit the problem and allow the project to be redesigned until the contractor was removed.

INITIAL DESIGN AND SPECIFICATIONS

The original MES design includes two unbounded nonwoven geotextiles, a 20 mil PVC geomembrane, and a single-sided drainage composite as shown in Plan Sheet C-9 in Figure 5. The unbonded geotextiles are designed to provide cushion between the geomembrane and the interim soil cover and the overlying geonet, respectively. The presence of an unbonded, non-woven geotextile between the geonet and the PVC geomembrane gives the appearance of a double-sided drainage composite, but it is not, as is shown in Figure 5. The design consists of a single-sided drainage composite, two unbonded geotextiles, and a PVC geomembrane. Fortunately the unbonded non-woven geotextile underlying the geonet was removed from the design in the first addendum to the contract bid package dated April 27, 2001 because a pay item was not included for this geotextile. The inclusion of this unbounded geotextile/geonet interface would have resulted in an even lower interface friction angle than the geonet/PVC geomembrane because the geonet cannot embed in the geotextile as it can into the PVC geomembrane. The inclusion of this unbounded geotextile/geonet interface, the lack of a pay item for the unbonded non-woven geotextile, and the subsequent deletion of this unbonded geotextile suggests that the strength of various interfaces was not well understood. It is possible that the design was just adapted from another site that probably did not have the extreme site access and oversteepened slope problems present at this site. This is reinforced by the following project chronology: (1) Construction Drawings dated April 4, 2001, (2) letter soliciting bids dated April 10, 2001, (3) slope stability design calculations dated April 19, 2001, and (4) first Contract Bid Addendum dated April 27, 2001. Therefore, the slope stability calculations were conducted AFTER the construction drawings were prepared and bids were solicited. In addition, the slope stability analyses were performed before the Bid Addendum removed the unbonded geotextile below the geonet but the stability analyses do not consider the geonet/unbonded geotextile interface.

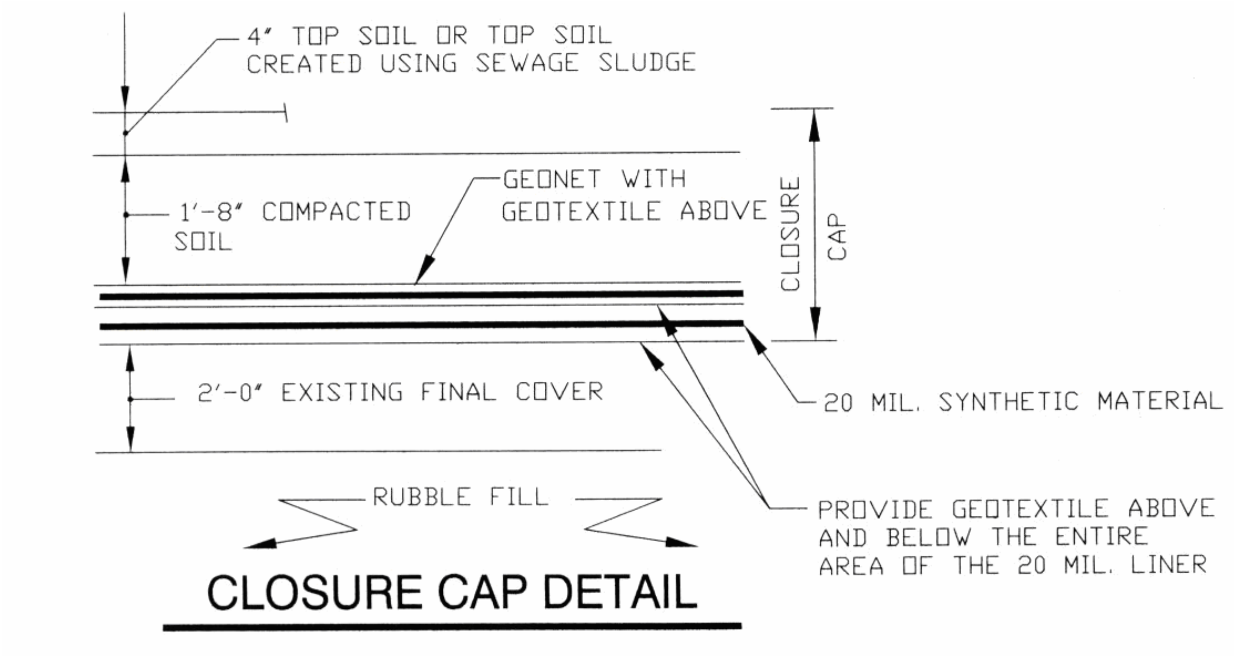

Figure 5: Original final cover system design from Plan Sheet C-9 with unbonded nonwoven geotextile below the drainage net.

The cover system actually bid and initially attempted to be constructed by the contractor is shown in Figure 6. Figure 6 shows the unbonded, nonwoven geotextile removed from below the geonet with all other components shown in Figure 5 remaining the same. Figure 6 shows that sliding occurred on the geonet/PVC geomembrane interface.

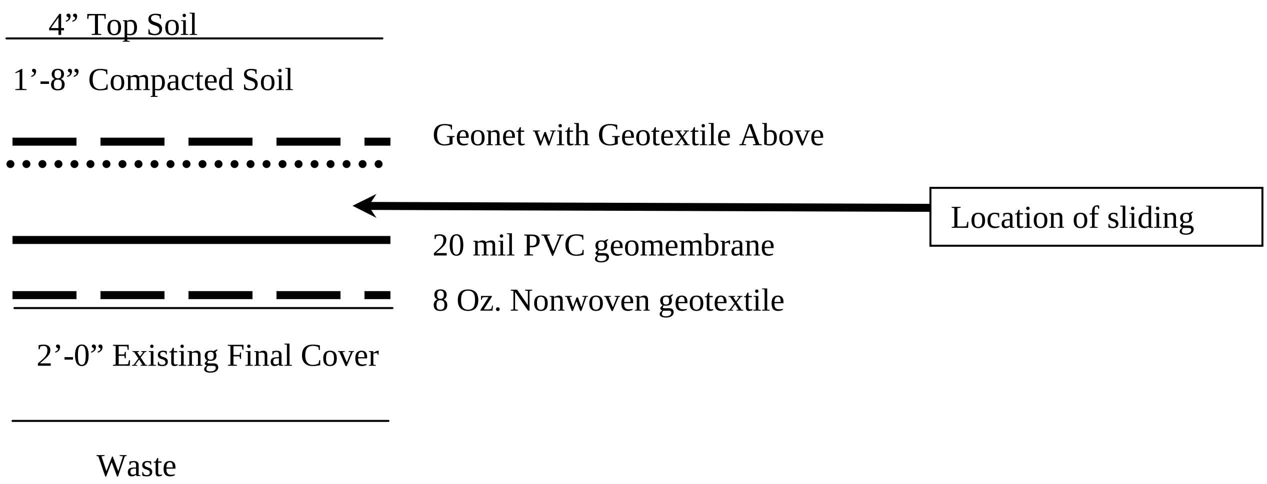

Figure 6: Final cover system bid by contractor

Another limitation of the slope stability analyses is the selection of the interface strength parameters. The MES calculation sheets label the analysis and strength parameters from “Geosynthetics for Advanced Solutions Seminar” dated 3/13/2001 as shown in Figure 7. This fact should be a warning to individuals who conduct short courses to understand that attendees will utilize, and possibly mis-use, the information presented. This seminar used to be offered by GSE Lining Technology, Inc. (the first author participated in one of these seminars) and it is doubtful that GSE used a PVC geomembrane in developing their recommendation of 23^0 for the “FML/geocomposite” interface presented in the seminar notes. Thus, the designer used a seminar presented interface friction angle and the friction angle probably is meant for a different type of geomembrane. It is recommended that seminar presenters inform attendees not to use any of the presented interface strength parameters for design purposes. Richardson and Chicca (2005) suggest that MES used data from Stark and Hillman (2001) to develop the design interface friction angle of 23^0 but this paper had not been published prior to April 19, 2001 which is the date of the calculation sheets (see Figure 7). In addition, Hillman and Stark (2001) present interface data for the faille side of a 30 mil PVC geomembrane and not the smooth side of a 20 mil PVC geomembrane. This difference in PVC geomembrane thickness is significant because less embedment of a geonet occurs, and thus interface friction, with a thinner PVC geomembrane. Thus, even if MES somehow had an advance copy of Hillman and Stark (2001), MES did not recognize the different interface friction angles for geotextiles/PVC geomembrane and geonet/PVC geomembrane interfaces and the different PVC geomembrane thickness and texture in Hillman and Stark (2001).

The improper selection of the friction angle for the geonet/PVC geomembrane interface is especially important in Maryland because the MDE only requires a factor of safety 1.3 and not 1.5 for final cover slopes. Thus, the calculations performed by MES using "Seminar" values of interface friction angle only utilize a factor of safety of 1.3. This small factor of safety proved problematic on this project. It is recommended that the MDE raise the required static factor of safety for landfill covers from 1.3 to 1.5, which is the value used in many other states.

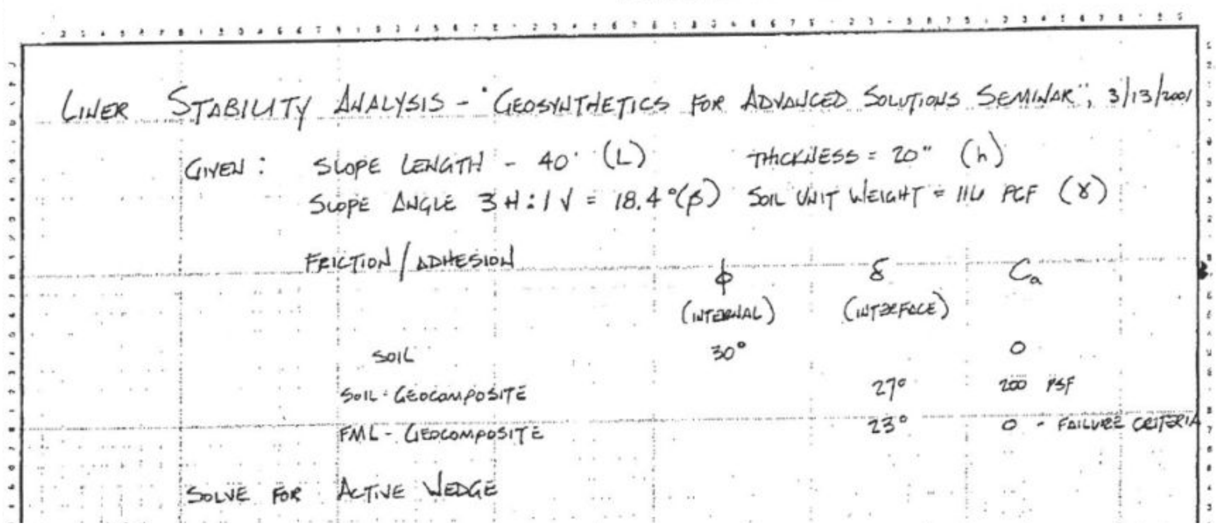

Figure 7: MES calculation sheet

REMEDIAL DESIGN

The main hurdle in the remedial design is the slopes could not be regraded to achieve a 3H:1V inclination. This necessitated an interface friction angle that could accommodate slopes as steep as 2.5H:1V or 22 degrees. To accommodate this steep slope, a double-sided drainage composite replaced the single-sided drainage composite. This meant that the remedial design returned to the initial design, except that the geotextile between the geonet and geomembrane is bonded to the geonet. This is a standard design; unfortunately the initial design did not recognize the importance of the second geotextile being heat bonded to slope stability. As noted by Richardson and Chicca (2005), Hillman and Stark (2001) show that a non-woven geotextile/PVC geomembrane interface is significantly stronger than a geonet/PVC geomembrane interface. At this point, the designer should have recognized the need for site-specific interface strengths.

The second main feature in the cover system redesign is the sideslope anchor detail shown in Figure 8. The redesign allows a sufficiently wide access road for construction vehicles and limits the thickness of the tire chip layer to 12 in. instead of the entire thickness of the toe detail as suggested by the contractor.

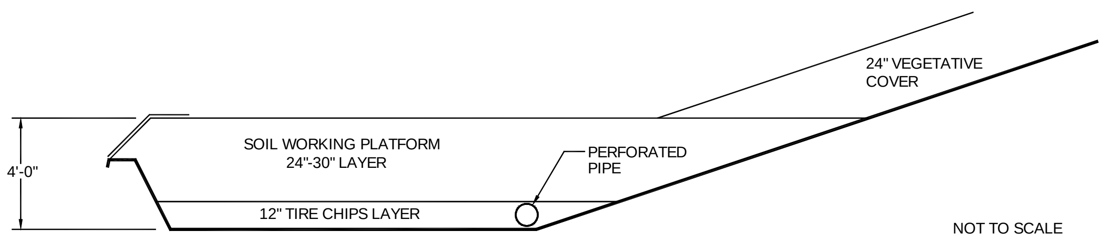

Figure 8: Remedial sideslope anchor detail

PERFORMANCE OF PVC GEOMEMBRANES

The good news from this troubling case is the performance of the 20 mil PVC geomembrane. After 24 months of ultra-violet (UV) light exposure, the 20 mil thick PVC geomembrane still met all of the original project specifications (PGI 2004) and did not require removal. The exposed PVC geomembrane was tested for volatile loss (ASTM D 1203), dimensional stability(ASTM D 1204), puncture resistance(ASTM D 4833), hydrostatic resistance(ASTM D 751), and basic tensile properties (ASTM D 882 Method A) and the test results exceeded the

PVC Geomembrane Institute (2004) specification for new PVC geomembranes. This is in agreement with other case histories showing the long-term durability of PVC geomembranes in a variety of environments, e.g., Stark et al. (2001 and 2005). Conversely, all of the single-sided drainage composite was damaged by the ultra violet (UV) light exposure over the 24 months of exposure and had to be removed.

LESSONS LEARNED AND RECOMMENDATIONS

The technical and construction related lessons and recommendations generated from this challenging project include:

- External review should be required for designs that are created and approved by different state agencies if the design will be submitted for outside bid. If a state agency will perform the construction activities, external review may not be as critical because the state can assume responsibility for design errors.

- Design entities should not "recycle" designs from prior sites and assume that the design will be suitable for another site. Each site should be considered independently and the necessary design steps repeated for each site.

- New slope stability analyses should be conducted whenever the design changes or slope inclinations increase. In this case the stability analyses represent a 3H:1V slope with a nonwoven geotextile between the geomembrane and geonet as well as a rip-rap toe buttress. It turned out that none of these assumptions represented the field conditions.

- Published or seminar presentation values of interface friction angle should not be used for final design. Appropriate, shear tests utilizing the actual materials involved should be conducted on the potentially weak interfaces prior to geosynthetics shipment and construction to confirm the design required interface strength. In addition, the slope angle should not exceed the minimum interface friction angle to prevent the onset of progressive failure.

- Finally, the State of Maryland should consider the benefits of raising the required static factor of safety for landfill covers from 1.3 to 1.5, which is the value used in many other states. The many variables encountered in the design process, e.g., variations in geosynthetic interface strengths, uncertainty in the intensity of the design storm event, and variations in slope geometry and construction operation, e.g., different access scenarios, material substitutions that impact the engineering properties of the materials, and equipment, suggest that a higher factor of safety should be utilized for short-term and long-term conditions for landfill covers.

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