"MAXIMUM INTERFACE SHEAR STRENGTH; A CASE HISTORY FROM THE VISALIA LANDFILL"

This article discusses the design, specification, and testing of a liner system for a California landfill with steep slopes and seismic stability concerns. To address these concerns, the project engineer worked closely with geosynthetics vendors to ensure that his rigorous performance requirements with respect to interface shear strength could be achieved.

This collaborative effort between the engineer, geomembrane manufacturer, and CETCO resulted in a HDPE-GCL interface that met the design requirements in both the peak and residual conditions. Testing revealed that only CETCO's Bentomat DN GCL was able to achieve these high shear strength values.

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Maximum interface shear strength

A case history from the Visalia Landfill.

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The existing 127-acre Visalia Landfill, Tulare County, California, has been in operation for over 50 years and predates the requirements of the federal Resource Conservation and Recovery Act (RCRA) Subtitle D, Part 40. The landfill does not have a liner or leachate collection system. It is scheduled to close within the next two years.

The County of Tulare has permitted a second Waste Management Unit (WMU) to be compliant with current Subtitle D requirements. Both the new and existing WMUs are located on 631 acres owned by the County. The new landfill (WMU-2) will occupy a 115-acre footprint with an allowable waste height in excess of 300 ft. WMU-2 will have approximately 17,100,000 $yd.^3$ (13,070,000 m^3) of airspace and will be built in ten phases over the next 30 years. The subject of this paper is the design and construction of the first phase of WMU-2. The section in question is approximately 16 acres (6.5 ha).

The liner system

Design of the liner system was undertaken by EBA Engineering. It is permitted to accept a peak of 2,000 tons of refuse per day. The Visalia landfill accepts waste from only within the county, including six exclusive refuse hauler areas, unincorporated areas, and the cities of Visalia, Woodlake and Dinuba.

The state of California requires a Subtitle D composite liner system, consisting of a minimum 60 mil HDPE geomembrane underlain by two feet of compacted clay with a maximum hydraulic conductivity of 1×10^{-7} cm/sec. The absence of both a local source of low-permeability material and high quality drain rock, along with the associated high cost of importing these materials, dictated the use of a geosynthetic clay liner (GCL) and a geocomposite drain in the base liner design.

***Photo 1**. Arial photo of Visalia WMU-2 under construction.*

The original liner system consisted of the following components, from top to bottom:

- A 2 ft. thick protective operations soil layer
- A geocomposite drainage layer comprising the blanket leachate collection and removal system (LCRS) and consisting of a 5.7 mm (0.225 in.) thick HDPE geonet core heat-bonded to a geotextile filter fabric
- A double-sided textured 60-mil high-density polyethylene (HDPE) geomembrane
- A nonwoven, needlepunch-reinforced geosynthetic clay liner (GCL)
- A prepared subgrade

Calculations were performed to demonstrate the equivalency of a GCL to two feet of compacted. Data were provided to demonstrate that the GCL is compatible with the constituents in the Visalia Landfill municipal solid waste (MSW) leachate.

Regulation changes

Recent changes in the interpretation of the state's water code led the State Regional Water Quality Control Board to require double composite liners for new landfills and lateral expansions of existing landfills in California's Central Valley Region.

Subsequently, the liner system was redesigned to be a double composite system. The second composite liner system was incorporated with a 1 ft. thick soil separation layer. The primary function of the soil separation layer was to decouple the two liner systems and eliminate a weak interface between the systems. Additionally, this enhanced the constructability of the liner. **Figure 1** shows a cross-section of the final liner system design.

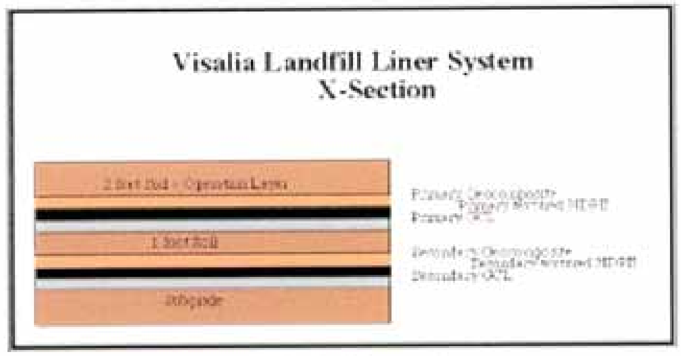

***Figure 1**. X-Section of Visalia liner system.*

Interface shear strength

Of primary concern were the interface shear strength requirements between the individual components of the liner system. Static and dynamic slope stability analyses were performed. They resulted in a minimum post-peak friction angle requirement of 17° between any liner component. The post peak interface shear measurements were made at two inches of horizontal displacement.

The peak internal friction angle of the GCL alone was required to be a minimum of 25 degrees when sheared at a normal load of 18,000 psf, representing the expected maximum stress on the liner when WMU-2 is filled. The GCL was also required to have a minimum peel strength of 30 lb., per ASTM D 4632, to enhance longterm creep performance and further guard against internal failure of the GCL. (See "Comparison" sidebar.) While some papers indicate there may be a correlation between GCL peel strength and GCL internal shear strength under large normal loads (Mackey and Von Maubeuge 1999), more investigation is required to accurately define the potential correlation.

***Photo 2.** Textured HDPE being installed over GCL with the use of a slip sheet.*

During the design phase, several "unconstrained" direct shear tests were performed on the entire liner system, meaning that components of the geosynthetic liner system were placed in the shear box apparatus without fixation to the upper half of the shear device. This technique allows the shearing plane to occur at the weakest interface between any of the components, including within the GCL, if lacking internal shear reinforcement. Interface shear testing of GCLs under large normal stress conditions representative of landfill liners can drive internal failure of the GCL if it does not possess adequate strength. This internal failure phenomenon was observed during the qualification testing of a particular GCL under consideration for this project. For this reason, interface shear testing is always recommended during the design phase of a project, especially when high normal and shear loads are expected.

***Photo 3**. The demand for higher waste heaps continues to fuel liner system design innovation.*

Specifications for the textured HDPE did not require a minimum asperity height, nor were there requirements for special texturing. The quality of texturing was considered a performance specification, so as to not limit manufacturers. However, all HDPE supplied to the project was required to be representative of the textured HDPE used in the contractor submittal testing. It should be noted that while there is evidence suggesting an association between maximum asperity height and peak interface shear strength, there is no strong correlation between asperity height and post-peak interface shear strength, particularly at high normal stresses. The authors did, however, observe that HDPE geomembrane sheet possessing a subjective overall higher degree of texturing (not simply a large asperity height) consistently produced higher post-peak interface strengths.

Ivy (2003) published test data showing the peak interface friction between textured HDPE and bi-planar geocomposite increasing from 24° to 29° as the textured HDPE asperity height increased from 11 mils to 31 mils. That is an increase in friction angle of over 20%. Furthermore, the large displacement friction angle of the interface with the greater asperity height geomembrane also increased over 20%. While this suggests that using a textured geomembrane with greater asperity height may increase interface shear friction angles, other geomembrane properties may be adversely affected, as mentioned by Ivy. It is evident that more investigation into this association is required.

Testing

Direct shear test parameters consisted of the following:

• The geocomposite, HDPE geomembrane, and GCL were used along with representative samples of site soils that had been remolded to 90% relative compaction at optimum moisture content per ASTM D1557.

• The GCL was allowed to hydrate under zero confining stress for 24 hours. The full normal load was applied to the specimen and consolidated for an additional 24 hours. This is believed to result in conservative shear strength test data, as the GCL is unlikely to fully hydrate under zero confining stress in the field. Should the GCL hydrate under zero confining stress in the field, further inspection and construction quality control/construction quality assurance (CQC/CQA) procedures would be required to ensure the integrity and shear strength of the GCL.

• The interface between the geonet composite and HDPE geomembrane was sprayed with water immediately prior to testing.

• The test was conducted at a shear rate of 0.04 in./min until a minimum displacement of 2 in.

The GCL (BentomatDN) did not experience internal failure during the interface shear testing program. It was accepted for use in the composite liner for the Visalia Landfill.

Interface shear testing of other liner system components were conducted by the contractor in accordance with specific testing criteria presented in the project specifications. EBA Engineering performed additional CQA interface testing for each lot of geosynthetics supplied for the project. This resulted in three additional testing programs being conducted, confirming that the materials delivered to the site achieved the interface shear requirements of the liner components.

Photo 4. *Thorough testing by manufacturers during product development and CQA personnel in the project design phase helped make the Visalia Landfill project, with its geosynthetic mix, a success.*

At the conclusion of the testing program, it was found that only one combination of GCL and geomembrane achieved the internal and interface shear strength requirements for this project. Interestingly, these materials were supplied from two separate manufacturers, each of whom committed to supplying products which were optimized for shear strength. This project is an excellent example of how geosynthetic shear testing was conducted in the design phase prior to the bidding process of the project to validate design parameters. The ultimate responsibility however, is left to the manufacturer of the geosynthetic products to produce a product (if possible) to meet the particular specification.

Conclusion

Liner installation began in late July 2003, and concluded in early November 2003. Particular attention was paid to minimize the amount of wrinkling in the HDPE in an effort to reduce potential pathways for leakage. This also created more opportunity for maximizing the interface shear characteristics of the HDPE/GCL interface.

This phase of the Visalia landfill expansion required specific geosynthetic products to meet an extremely difficult specification to assure stability of WMU-2. Standard products were simply not capable of meeting the specification. Engineers are perhaps becoming complacent with the term "site specific." While some design properties are more or less universal, most landfill liner designs do indeed have very unique and specific requirements as well. Manufacturers must understand the requirements of their customers and must continue to refine their geosynthetic products to meet these requirements. Likewise, designers need to understand the limitations of these products and must realize that special products may come at a premium. The Visalia landfill expansion was perhaps a unique example of how a designer and a team of manufacturers worked closely together to create an effective solution for a client. As more and more landfills are being permitted to be higher with more refuse being deposited in each cell, the attention on stability of these cells is paramount. Shear strength specifications are becoming more difficult to meet, requiring "special" geosynthetic solutions for these projects.

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Comparison of peel specifications per ASTM D4632 and ASTM D6496

It is becoming more common for engineers to specify GCLs possessing peel strength greater than the industry standard certified value of 15 lb., per ASTM D 4632, especially for landfill bottom liners expecting large normal stresses. However, a new ASTM peel strength method (D 6496) for GCLs has been implemented. Designers should be aware that the new test method involves different testing and reporting procedures and therefore yields different test results when compared to ASTM D 4632. If the new peel method had been specified for this project, the required peel strength would have been 5.03lb./in. This is equivalent to the ASTM D 4632 value of 30 lbs as originally specified.

Standard GCL Peel Value	*High GCL Peel Value*
ASTM 4632 – 15lb.	ASTM D 4632 –30 lb.
ASTM 6496 – 2.5lb./in.	ASTMD6496–5.03lb./in.

Project Information

Owner: Tulare County, Calif.
Design engineer: Damon Brown, EBA Engineering, Santa Rosa, Calif.
Installer: D&E Construction, Visalia, Calif.
GCL: Bentomat DN from CETCO, Arlington Heights, Ill.
Geosynthetic shear testing laboratory: SGI Testing Services, Norcross Ga.