Geosynthetics 2009
February 25-27 2009, Salt Lake City, Utah

Post-Construction Landfill Liner Failure and Lessons Learned

Richard Thiel, P.E., Vector Engineering, Inc, Grass Valley, CA, USA

ABSTRACT
A relatively small rural landfill was designed with a PVC/GCL composite liner system overlain by 300 mm of gravel. One end of the project contained a slope having an inclination at 4(H):1(V) for a length of approximately 58 m. Three months after construction the PVC liner had ripped along the crest of the slope, and the gravel and PVC had slid on top of the GCL along the entire slope length. The GCL was exposed about half way down the slope. The failing interface was clearly between the PVC and the GCL. The lessons learned from this project were (a) to conduct slope stability testing and analyses for interim and construction conditions in addition to final fill conditions, and (b) interface direct shear testing should have interfaces sprayed with water during the setup, and not just count on flooded conditions to allow water to travel to the interface. Neither of these lessons is particularly new to the industry, showing the value of having a project peer-reviewed by designers experienced with the nuances of geosynthetics design and construction.

1. INTRODUCTION

A relatively small rural landfill was designed with a composite liner system to be constructed well in advance of waste placement. The landfill expansion was designed to tie into a previous landfill cell. The lining system consisted of the following elements, from bottom to top:

- Prepared subgrade on firm well-graded native soils
- Needle-punched fabric-supported GCL, with a nonwoven geotextile on its upper side facing the overlying geomembrane
- 1 mm thick smooth PVC geomembrane
- 300 mm of granular drainage soil

The geometry of the landfill was very simple: a relatively flat bottom area, and at one end of the project there was a slope having an inclination at 4(H):1(V) for a length of approximately 58 m.

Because of the low waste volumes received at this rural landfill, the completed construction would be expected to remain exposed for a period of several years. Being in a northern climate, the site could expect snow and freezing conditions every winter.

Landfill construction was performed using conventional methods of subgrade preparation, smoothing, geosythetics deployment and seaming, and placement of gravel with thickened roads and spreading with an LGP dozer (D6). At one point during gravel hauling, dumping, and spreading on the floor some slippage and tearing of the geomembrane was noted. The incident was attributed to the haul trucks operating on a ridge line, and turning too tightly. The damaged area was repaired, the haul roads were rerouted to the valleys, and all spreading was pushed in an uphill direction, even on the relatively gentle 4% and 8% flanks of the bottom ridge-and-swale pattern.

After experiencing that small failure, for which the Contractor took full responsibility, the Contractor decided to take extra caution when placing gravel on the 4:1 slope. Instead of placing and spreading gravel in the traditional manner of dumping at the toe and pushing upslope with a dozer, the Contractor elected to place all of the gravel using a “telebelt” (Figure 1). The telebelt could extend approximately 36 m, and place the desired gravel thickness relatively precisely at all slope locations using a cantilevered conveyor belt using a remote control joystick. By using the telebelt from both the bottom and the top of the slope, no piece of construction equipment was ever required to get on the slope, and the exact thickness of gravel (300 mm) was able to accurately be placed everywhere in a gentle manner. Note that this method of placement, while not extremely rare, is not common because it is substantially more expensive than the traditional method of dumping and dozer-spreading. The Contractor decided to absorb the extra cost of doing the work in this manner rather than take a chance of creating any potential slippage after his experience in the more gently sloping bottom area.

The project was completed at the end of November. Just over three months later, in March, it was noted that from one day to the next the PVC liner had ripped a few hundred feet along the crest of the slope. The gravel and PVC had slid and exposed the GCL about half way down the slope. It had snowed and then rained that previous day and evening.

The failing interface was clearly between the PVC and the GCL. The exposed GCL appeared unstressed and undamaged.

Figure 1. Placing gravel onto PVC with telebelt on 4:1 slope.

The author was consulted by the Contractor after the failure to help ascertain why the slope had failed. The author had very limited design information available, and had not been involved during construction. During this investigation the author was only able to make one site visit, and conduct only a limited amount of testing before the parties were satisfied with the results discussed in this paper. Thus, while this case history is not fully comprehensive in its investigation, the limited amount of information that was gathered may prove useful to others designing veneer systems.

2. FIELD VISIT AND LABORATORY INVESTIGATION

The engineer had originally performed shear strength testing for the PVC/GCL interface. The normal loads used in the test program, however, were directed to evaluate the stability of the filled landfill, and were much too high to use for an evaluation of the veneer condition that existed at the time of construction or immediately after.

After consultation with the author, the engineer performed additional testing using samples of the exhumed GCL with fresh pieces of PVC. The GCL samples were carefully cut out, wrapped on a plastic pipe core, wrapped with plastic, and placed in sealed bags to preserve their moisture content. In the laboratory, the GCL samples were sandwiched against the PVC, and this was placed between native subgrade soils and gravel to simulated field conditions. The sandwich was hydrated under 4.8 kPa (100 pounds per square foot [psf]) below water for 24 hrs, and sheared at 0.1 mm/min. The tests were performed with a 30 cm by 30 cm square direct-shear box designed specifically for low-normal loads, and the boxes were calibrated to account for machine-friction. The resulting frictional shear strength of approximately 36 degrees peak and 35 degrees post-peak was much too high to be able to predict the failure (Figure 2).

Another sample was similarly prepared, and then froze to see if perhaps the freezing condition would affect the shear strength. After freezing, the sample was quickly placed in the shear box and sheared at 5.0 mm/min. Similar results were achieved, which again would not have predicted the failure.

In June the author was requested by the Contractor to visit the site. The failed slope was fully visible, with exposed GCL on the upper half. The exposed GCL was dry because of the arid site conditions. It was clear that the slope had failed from crest-to-toe as evidenced by the presence of bunched-up wrinkles in the PVC at the toe (Figure 3), and bulging and open cracks is the soil cover at the toe (Figure 4). The author shoveled through some of the gravel at the edge of the failed PVC, and lifted the edge of the PVC to observe how the interface looked where it had been protected from meteoric conditions. The surface condition of the exposed un-ripped PVC appeared to be excellent in all cases. The GCL was observed to be normally hydrated (defined by the author as softened to the point that it could be deformed with thumb pressure, but was in no way very soft or oozing), as one would expect from extended contact with the subgrade.

Very little bentonite was observed on the top of the GCL's upper NW geotextile. The bottom side of the PVC was observed to have a thin film of moisture (Figure 5).

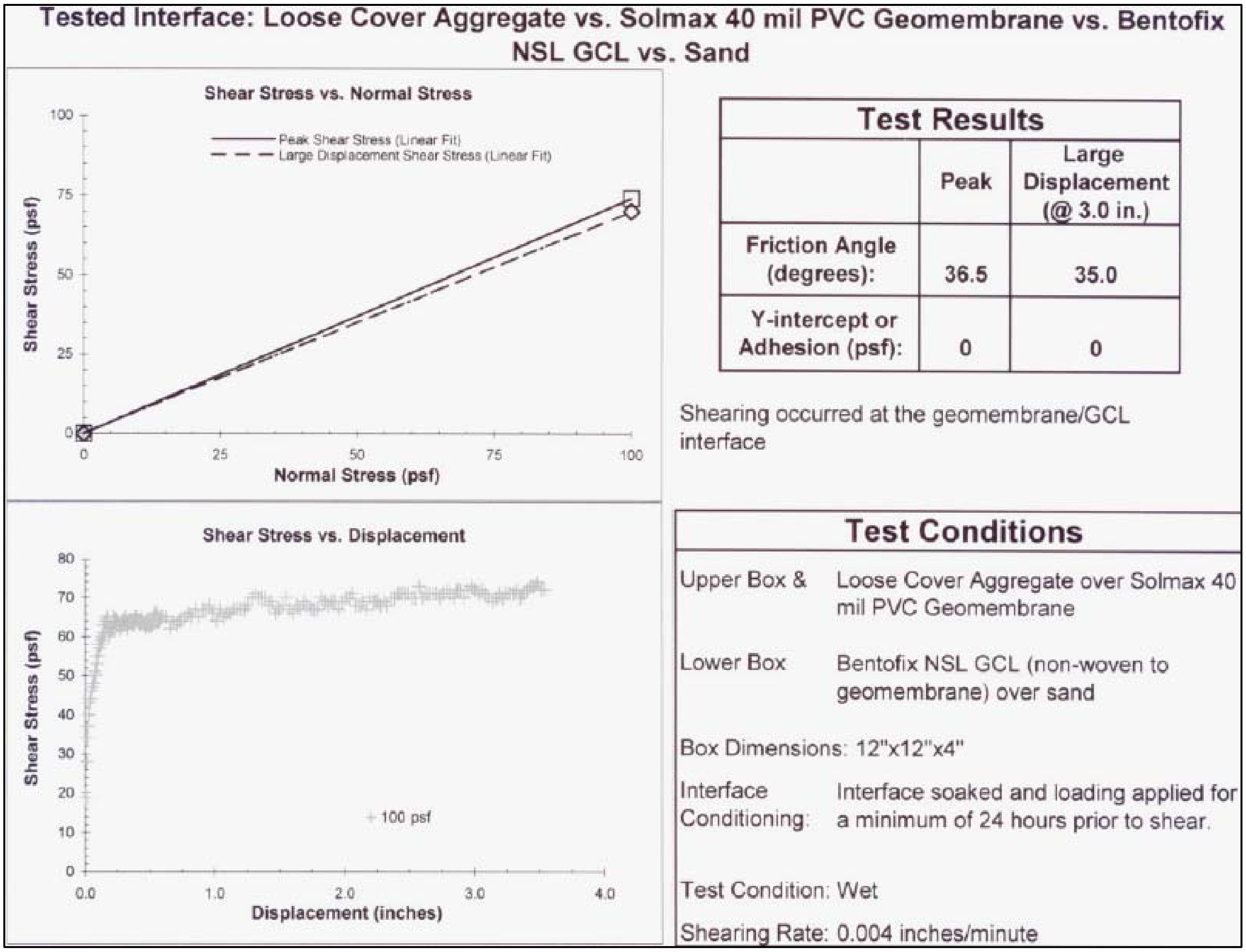


Figure 2. Direct shear test: Interface dry for test assembly, and then submerged after assembly.

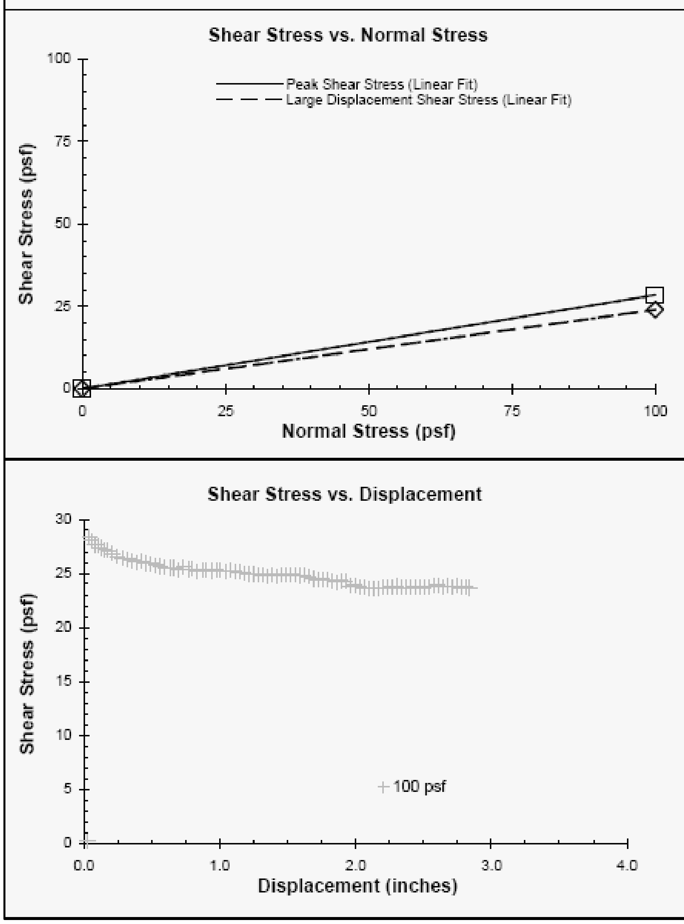
Figure 3. Bunched-up wrinkles in PVC at toe of 4:1 slope.

Figure 4. Deformed and cracked cover soils near toe of slope.

Figure 5. Standing on exposed GCL (obscured with sandy gravel cover) and lifting edge of torn PVC. Clean white GCL can be seen been raised edge of torn PVC. Condensation water was noted on bottom side of PVC.

The last observation led the author to immediately commission the same laboratory used by the designer to perform a single-point shear test at 4.8 kPa (100 psf) normal load where the interface was sprayed with water immediately prior to shearing (a very common procedure when performing interface shear testing during the design phase). Using the same laboratory, equipment, and technician would remove inter-laboratory variations in test values. The test was performed with virgin materials with insignificant pre-hydration or consolidation, and sheared at 5.0 mm/min. Although other test parameters could have been used, these were the parameters chosen by the author given that he only had this single test opportunity on this project. The measured shear strength was a peak secant friction angle of 15.9 degrees and a post-peak angle of 13.5 degrees (Figure 6). These results, showing peak and post-peak frictional strength parameters straddling the slope angle, are indicative of a high probability of failure. These results also show what a large difference there is between a dry PVC/geotextile interface versus a wet one.

Tested Interface: Solmax 40 mil PVC Geomembrane vs. Bentofix GCL (representative)



Test Results

	Peak	Large Displacement (@ 2.8 in.)
Friction Angle (degrees):	15.9	13.5
Y-intercept or Adhesion (psf):	0	0

Shearing occurred at the geomembrane/GCL interface

Test Conditions

Upper Box & Bentofix GCL soaked prior to mounting

Lower Box Solmax 40 mil PVC Geomembrane

Box Dimensions: 12"x12"x4"

Interface Conditioning: Both GCL and geomembrane were sprayed with water prior to loading. Interface was sheared immediately after loading.

Test Condition: Wet

Shearing Rate: 0.2 inches/minute

Figure 6. Direct shear test results: Interface sprayed with water before test assembly.

3. DISCUSSION

The relatively high friction angles achieved in the first round of forensic testing by the engineer were undoubtedly due to the presence of a dry interface between the PVC and the GCL. This condition existed even through the GCL from the field was pre-hydrated through months of subgrade contact, and in spite of having the test sandwich submerged under load for 24 hours. This suggests that even though a GCL may become largely hydrated, it may also preclude free water from getting to the interface in a direct shear test.

Common observation shows how quickly free-water condensation occurs on the underside of a piece of plastic that is placed on the ground. This is even more true if the plastic is exposed through a day-night cycle. Almost every geomembrane placed in the landfill industry is exposed for at least one day-night cycle. It is extremely rare that a deployed geomembrane is covered with soil the same day that it is deployed. And thus designers, installers, and contractors accept it as a fact that virtually any time a geomembrane is deployed on earthen materials, free moisture will occur at the interface between a deployed geomembrane and its underlying subgrade.

When performing direct shear testing, it is essential that the test set-up reflects field conditions as closely as practical. The two preceding paragraphs lead to the following conclusions:

- The presence of free water is almost guaranteed in the field conditions at the geomembrane interface with underlying earthen subgrades.
- Sandwiching a GCL against a geomembrane in a dry state, loading, and then hydrating may have a very low likelihood of allowing any free water to reach the geomembrane interface.
- Laboratory direct shear testing with geomembranes against surfaces that will have access to soil moisture should always be sprayed with water before assembling them in the shear box.

The limited amount of field observation and laboratory testing performed for this case study suggests how critical the difference between wetting and not wetting the interface can be in a test program. This same lesson was learned in the 1988 failure of the Kettleman Hills hazardous waste repository (author's personal discussions with designers).

4. LESSONS LEARNED

There were two main lessons learned in this project for people who regularly practice in this industry.

1. Projects need to evaluate stability for construction conditions; not just final operational conditions. In this case, this would have meant evaluating the slope stability for the veneer system by performing interface shear strength testing at the appropriate low normal loads.
2. Direct shear tests involving clays or GCLs against geomembranes need to have the geomembrane interface sprayed with water before the test materials are assembled. Simply flooding the assembled test "sandwich" may never allow the interface to become wet. Under field conditions a deployed geomembrane will have condensation water on its bottom surface within a matter of hours, and thus spraying the interface with water is representative of field conditions. There can be a large difference in shear strengths between a dry interface and a wet one.

Neither of the two lessons described above are unusual or new in the geosynthetics and landfill lining industry. For designers who do not regularly practice in this field, it is useful to engage the peer-review services of someone who regularly practices in this field. In fact, this principle applies to any area of professional practice.