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Lining an impoundment and dam at a gold mine located over 14, 000 feet in elevation in the Andes Mountains of Chile, South America. High sloping canyon walls formed the sides of the impoundment, with a rock-filled dam located downstream. The dam is 200 ft high and is constructed from mine overburden rock. A dual geomembrane liner and geonet leak-collection system provided a seal to inhibit seepage through the porous rock fill.

Geomembrane and GCL mining usage tests

Remote mountainous sites in Chile and Colorado supply test pad locations to evaluate geomembrane and GCL field performance for mining applications.

By Phillip Crouse, Brian Jacobs, Patrick Corser and John Redmond

GEOMEMBRANES AND GEOSYNTHETIC CLAY liners (GCLs) are used for a variety of solid waste landfill and mining applications. The use of geosynthetic products in solid waste landfills is well-documented, and their use continues to be studied by numerous researchers. Most recently, efforts are being made to determine the efficiency and requirements of puncture-protection layers over geomembranes, as well as the potential for installation damage to GCLs when they are subjected to potentially damaging coarse-grained sands and gravels used as drainage media (Heerten et al., 1991, Zanzinger et al., 1998, Richardson et al., 1998, Fox et al., 1998).

These same geosynthetic products can also be exposed to potentially damaging soils in mining applications. In this application, the designer and contractor often must rely on geosynthetic requirements used for landfills that may be overly conservative or inappropriate for geosynthetics in mining applications. Alternately, a test pad can provide good design criteria for the site-specific function of the geosynthetic product without relying totally on standards used in the landfill industry.

High in Chile's Andes Mountains, Montgomery Watson, Pasadena, Calif., built its first large test pad to simulate the performance of a geomembrane and geotextile cushion installed on the face of a rock-fill dam. The company's second large test pad was built in the Rocky Mountains of Colorado at a tailings reclamation project. There, researchers evaluated the installation damage caused to a GCL by heavy equipment.

The test pads were constructed using the same material, equipment and techniques employed at the project sites. After the pads were constructed, they were loaded with on-site heavy earthmoving equipment and monitored by Construction Quality Assurance (CQA) personnel. After loading, the geosynthetics were exhumed, examined, then tested to determine what changes in their material properties might have occurred.

The geosynthetics in both projects performed well in the test pads without evidence of significant damage or loss of strength.

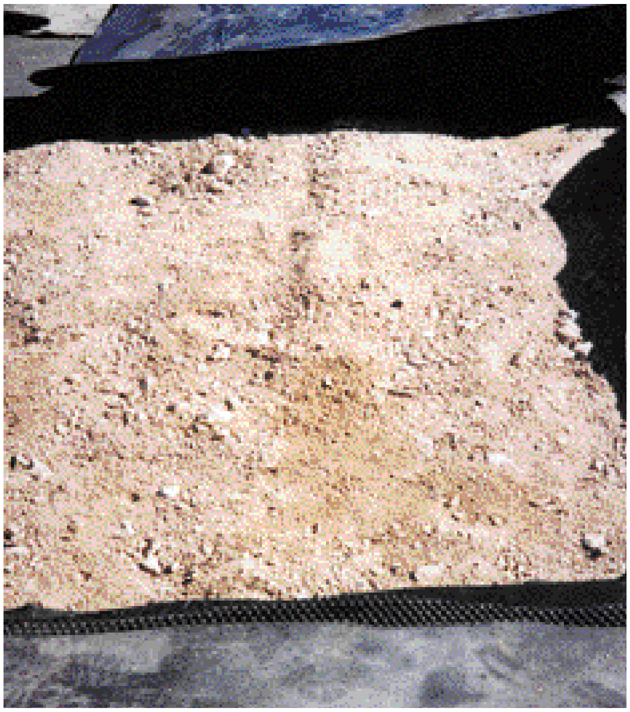

Photo 1: Uncompacted bedding.

Subsequently, the geosynthetics were installed in full scale under the auspices of an independent CQA team, and they continue to perform well since the completion of the projects.

Test pad using a geomembrane and geotextile cushion

Approximately 6.0 million sq. ft of high-density polyethylene (HDPE) geomembrane was used to line two tailing impoundments at an active gold mine located in the Andes mountains. High sloping canyon walls formed the sides of the impoundment, and two rock-fill dams framed the upper and lower portions of the canyon. The upper and lower dams are approximately 200 ft high and were constructed from mine overburden rock, with upstream slopes of 3H:1V and 2H:1V, respectively. A dual geomembrane liner and geonet leak-collection system provided a seal to inhibit seepage through the porous rock-fill.

To provide puncture resistance for the geomembrane on the 2H:1V slope of the lower dam, the mine proposed using a bedding layer of coarse sand, topped with a geotextile cushion, then the primary geomembrane liner. The sand was readily available from alluvial and colluvial deposits at the bottom of a nearby gulch; however, the material included a fraction of gravel- and cobble-sized rocks up to two inches in size.

Taking into account the anticipated pressures on the liner system at the base of the dam, the firm selected a 14-oz/sy nonwoven needle-punched geotextile to provide the protective cushion layer between the proposed sand and the liner system. Since the bedding layer would be tracked and walked by bulldozers, some irregularities would exist in addition to its semi-loose state that could easily be simulated in a test pad.

Material components

The approximately 30 ft wide and 30 ft long test pad was constructed using the materials and procedures anticipated for the dam face lining system.

The upstream face of the dam was comprised of the following layers, listed from bottom to top:

Rock-fill subgrade: Waste rock from mining operations, sand to boulder-sized

Bedding layer: Well-graded sand and gravel containing approximately 15 percent particles between 1 and 2 in.

- Puncture protection: 14-oz/sy nonwoven geotextile
- Secondary liner: 60-mil smooth HDPE geomembrane
- Leak collection: Geonet
- Primary liner: 80-mil smooth HDPE geomembrane (exposed)

Table 1 presents the particle-size gradations for the bedding layer used for the test pad. The physical properties of the geomembrane and geotextile are presented in **Tables 2 and 3** respectively.

Test pad construction and loading

A 275 Komatsu bulldozer spread a 24-in.-thick veneer of subgrade soil over level natural ground and tracked it in place. Laborers hand-raked the pad to remove rocks larger than 2 in. They also performed the same raking on the dam. One side of the test pad was compacted with a self-propelled smooth-drum vibratory roller. The opposite side of the pad was left in a semi-loose condition. **Photos 1 and 2** show the uncompacted and compacted bedding material, respectively.

TABLE 1. PARTICLE SIZE GRADATIONS

Percentage of total by weight passing

Standard Size	2.0 in.	1.0 in.	#4	#40	#200
Bedding Layer	100	85	64	47	11

TABLE 2. GEOMEMBRANE PHYSICAL PROPERTIES (M.A.R.V.)

Property	60-mil HDPE	80-mil HDPE
Yield Strength	132 lb/in	176 lb/in
Yield Strain	12%	12%
Break Strength	228 lb/in	304 lb/in
Break Strain	600%	600%

TABLE 3. NON-WOVEN NEEDLE-PUNCHED GEOTEXTILE PHYSICAL PROPERTIES (M.A.R.V.)

Property	Geotextile
Weight	14 oz/sy
Thickness	155 mils
Grab Tensile	390 lb
Grab Elongation	60%
Puncture	210 lb

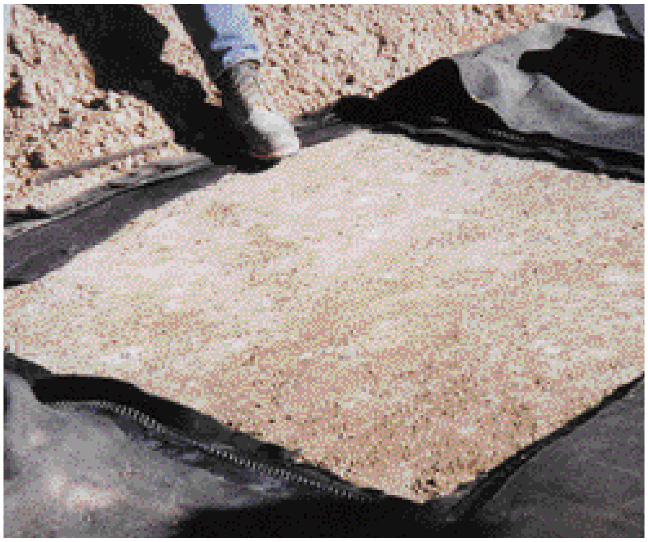

Photo 2: Compacted bedding.

After the remaining liner materials were installed, a 6-oz/sy nonwoven needle-punched geotextile cushion was placed over the exposed 80-mil HDPE to provide protection from treads. After construction, an 80-ton loaded International Haul Pack truck (model 210 M) was parked on the test pad. The truck simulated pressure that would be placed on the liner by the tailings and liquid stored in the impoundment at its full depth, and was used only on the test pad. Other heavy equipment was not permitted on the unprotected liner during construction.

The truck applied a surcharge pressure between 60 and 80 lbs/sq. in. to the liner system, based on its tire pressure. This was within the expected range of service pressures on the liner system planned for the upstream face of the rock-fill dam. Soil was stockpiled on the areas adjacent to the truck to prevent rutting when the truck was driven on and off the pad.

The truck was left on the pad overnight and driven off the following day. Workers then cut large samples from the portions of the liner located beneath each truck tire. These samples were then examined and tested by CQA personnel. **Figure 1** illustrates the test pad and cross section showing the liner system.

Exhumed geomembrane and testing

Upon visual examination, the primary 80-mil geomembrane over both the compacted and uncompacted bedding layer remained unscathed. Several small dimples were observed on the secondary 60-mil geomembrane closest to the bedding layer. Samples from both the compacted and uncompacted areas had these dimples, although the sample from the uncompacted bedding layer had several more dimples than its counterpart on the compacted subgrade.

CQA personnel cut five one-inch-wide specimens from each of the eight samples with a die-cutter, then tested them with an on-site field tensiometer to determine their tensile strength. Four additional specimens were cut directly from the dimpled material exhumed from the uncompacted side of the test pad and then tested.

The tensile test results of the 44 specimens cut from the test pad samples were compared with the CQA conformance samples that were collected at the manufacturer's plant before the material was shipped to the site. The conformance samples were tested using ASTM D 638 at an independent geosynthetic testing laboratory. It should be noted that the conformance tests are index tests and were used for quality control and quality assurance of the manufactured sheet material installed at the site. The results, though not completely comparable with field tests, provided a reference to gauge whether the tensile strength of the exhumed geomembrane was adversely impacted by the subgrade.

Conformance samples were obtained from the different lots at a frequency of one sample per every 60,000 sq. ft of geomembrane. The tensile strength at yield of the 80-mil geomembrane ranged from 207 to 222 lb/in. based on 10 samples. The tensile strength at yield of the 60-mil geomembrane ranged from 149 to 169 lb/in. based on 27 samples.

The tensile-strength test results of the 44 specimens cut from the exhumed samples are graphically illustrated in **Figure 2.** The CQA conformance test results are also shown on the figure for comparison purposes. The tensile strength of the exhumed geomembrane samples were within approx-

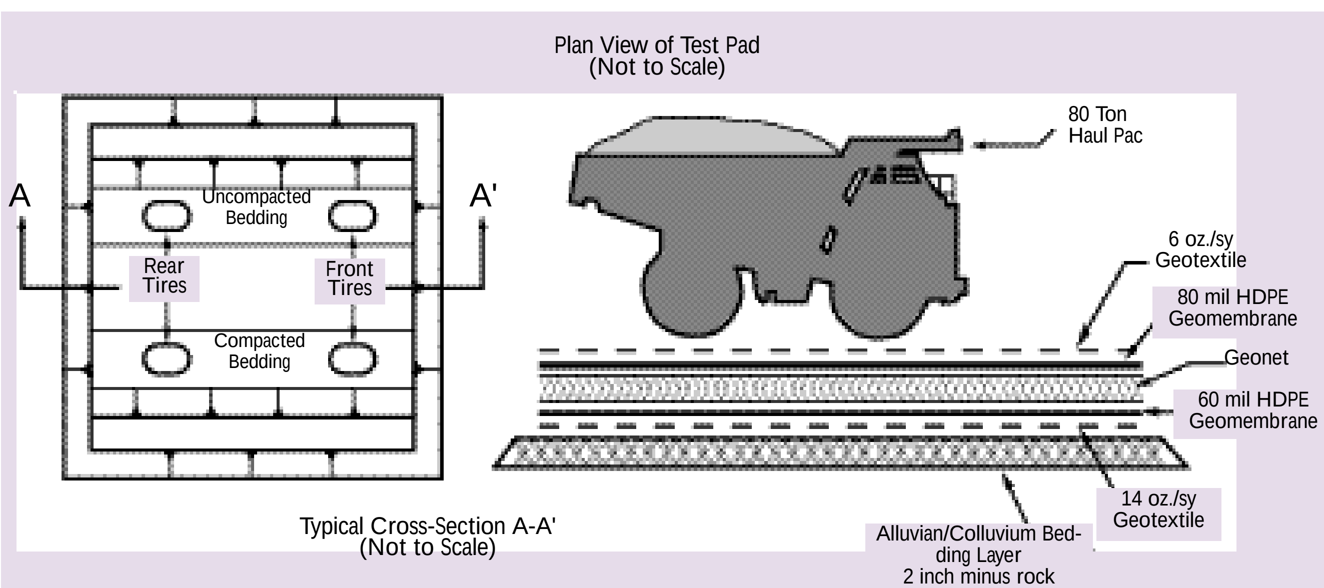

Figure 1: Test pad using a geomembrane and geotextile cushion.

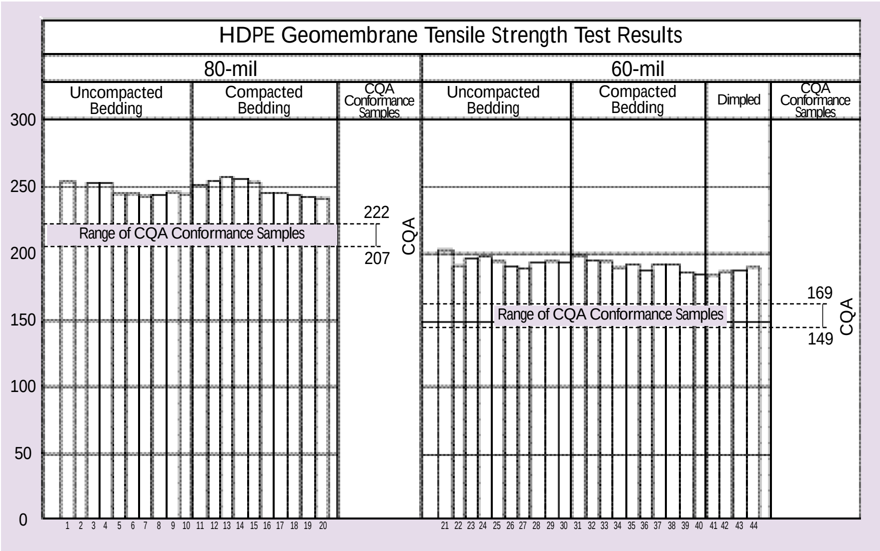

Figure 2: Results of tensile strength tests.

imately 20 percent of the conformance test results, indicating that the tensile behavior of the geomembrane was not adversely impacted by the coarse sand bedding material. Additionally, the tensile strength trend of the exhumed material was higher than the conformance test results. Most likely, this was due to the different aspect ratios of the test specimens. The larger aspect ratio of the specimens tested in the field may have minimized the Poisson effect (i.e., contraction within the central region) giving it a stronger load extension response as compared to the smaller aspect ratio of the specimens tested in the laboratory using ASTM D-638 (Koerner, 1994).

The tensile strengths of the dimpled samples were slightly less than the other samples, but still above the CQA conformance range. Dimples or indents are local deformations that can develop concentrated stress and strain in a geomembrane and should be avoided for landfill lining systems (Heerten et al., 1991). Although small dimples occurred in the secondary geomembrane, the adverse effects were anticipated to be small for the following reasons:

- The liner would be loaded slowly as tailings accumulated in the impoundment
- The primary geomembrane was unscathed
- Tensile strengths were above the CQA conformance test results.

After reviewing the test results with the designer, owner and the CQA manager, participants agreed to place the proposed bedding soil on the rock fill subgrade, followed by the geotextile cushion layer and geomembrane liners. The liner system on the dam face has performed well since construction without leakage or required repairs.

Test pad using a GCL with soil/rock cover and equipment loading

The second test pad was constructed at a tailings-reclamation project in the Colorado Rockies. The project design required the company to use a 16-acre earthen cap with a low-permeability GCL to reduce infiltration into the tailings. The tailings had been deposited along a mountain slope, creating a bench with side slopes between 2H:1V and 3H:1V. The crest of the pile extended approximately 100 ft above the existing ground surface at its highest point.

The design required a GCL to be placed over the regraded tailings, with a geonet/geotextile composite drainage layer under 1.5 ft of a rock fill. The contractor proposed two methods of cover placement. On the near-level surfaces, rock cover would be transported to the site by over-the-road belly dumps and unloaded at the edge of the fill area, then spread over the geosynthetics with a D-6 bulldozer. On the 3H:1V sloped areas, the contractor proposed using scrapers to haul the rock cover from a nearby stockpile and place it on the slope. This would provide a much shorter push distance (less than 50 ft) compared to pushing rock cover from the bottom of the slope to the top (more than 300 ft). A heavily loaded scraper traveling and braking across the slope could create potential damaging stresses in the underlying geosynthetics. Moreover, rocks in the cover could puncture the geocomposite and GCL in addition to other installation damages. Therefore, a test pad was constructed to evaluate this proposed construction method.

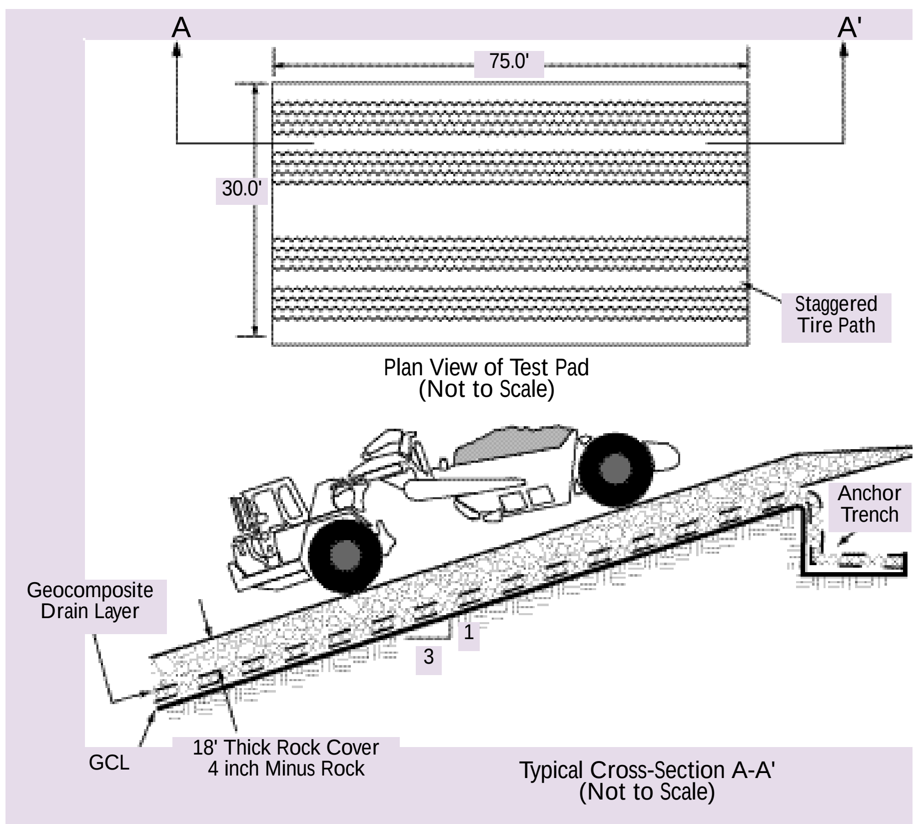

Figure 3: Test pad using a GCL.

TABLE 4. PARTICLE SIZE GRADATIONS

Percentage of total by weight passing							
Standard Size	4 in.	3 in.	2 in.	1 in.	#4	#40	#200
Cover	100	89	55	31	9		
Subgrade	100	100		85	75	56	32

TABLE 5. GCL AND GEOCOMPOSITE PHYSICAL PROPERTIES

(M.A.R.V.) Property	GCL	Geocomposite
Bentonite Mass/Area	14 oz/sy	
Grab Tensile	120 lbs	580
Internal Shear	25 degrees	
Peel Strength	15 lbs	
Non-woven Geotextile Weight	3.2 oz/sy	7.1 oz/yd^2 (two layers)
Woven Geotextile Weight	6.0 oz/sy	

Material components

The approximately 30-ft-wide and 75-ft-long test pad was constructed using the materials and procedures anticipated for the cover system. Since the tailings surface had not yet been prepared, the test pad was constructed on a natural 3H:1V slope similarly to the eventual slope of the cover. Unlike the fine-grained tailing sands, the natural slope was composed of a well-graded mix of cobble-sized rounded rocks, gravel, sand and clay. Although a much coarser subgrade than the fine-tailings sand, it would provide a worst-case result of installation damage.

The test pad composition, by layer:

- **Subgrade:** Well-graded mix of cobbles less than 4 in., gravels, sand and clay (USCS: SC-SM)
- **GCL:** Needle-punched reinforced material manufactured with woven (thermally treated) and nonwoven geotextiles
- **Geocomposite drainage layer:** Geonet sandwiched between two nonwoven 7 oz/sy geotextiles
- **Rock cover:** 4-in. and smaller

The test pad configuration is illustrated in **Figure 3. Table 4** presents the particle-sized gradations for the subgrade and cover rock used for the test pad. The physical properties of the GCL and the geocomposite drainage layer are presented in **Table 5**.

The test pad was constructed on a 3H:1V mountain slope under the direction of the design engineer and CQA team. Before deploying the geosynthetics, workers rough-graded the subgrade with a D-6 bulldozer, mainly to remove large boulders and topsoil. After preparing the subgrade, they deployed two GCL and geocomposite panels and anchored them in a trench 3 ft deep by 2 ft wide on the up-slope side of the pad. The GCL panels were overlapped approximately six in., with free bentonite between the seams, and left in a dry state. The geocomposite was then installed over the GCL followed by an 18-in.-thick lift of the proposed soil/rock cover material spread by the bulldozer and track-walked as illustrated in **Photo 3.**

Following construction, workers repeatedly loaded the test pad by driving a 75-ton fully loaded Caterpillar 631 scraper over it. The scraper traveled down the slope of the test pad to a haul road at the bottom that circled around and returned to the top of the slope. During each pass, the scraper applied its brakes to apply additional dynamic stresses to the underlying geosynthetics. The scraper traveled across the pad five times, staggering its tracks each time to load the entire width of the test pad.

Testing exhumed GCL

Immediately after loading the test pad, workers examined the rock cover to determine if the downward forces of the scraper caused the pad to slide. Indications of movement, such as tensile cracks or bulging, were not observed. The rock cover appeared intact, with only small ruts created by the tread of the scraper tire.

After examination, the rock cover was removed **(Photo 4)**, exposing the underlying geosynthetics. The teeth on the bucket of the backhoe removing the rock cover caused some damage to the underlying geocomposite. It is recommended that a "screed" be attached to the teeth of the bucket. This has worked well in other published field studies (Richardson and Johnson, 1998). After the initial damage caused by the backhoe bucket, the remaining rock cover was removed primarily by hand to prevent further damage.

The geocomposite and GCL were carefully examined by the design engineer and CQA team for signs of damage and then carefully removed from the pad. The project team believed that a visual examination, without extensive laboratory testing, would be adequate to determine installation damage. Other field studies have performed laboratory testing, including tests for grab tensile strength, grab peel strength, thickness, mass per unit area and water content. However, these tests observed significant variability in the test results, providing only general trends in material property changes after loading. Only the bentonite mass per unit area was determined to be a sensitive indicator of installation damage; however, this is most noticeable if the GCL is hydrated (Fox, et al., 1998). Since the test pad GCL was loaded in a dry condition, the test would not have provided good information.

The geocomposite remained in good condition and did not reveal signs of tensile strain or other damage from the overlying rock cover. The GCL was intact and in good condition, with only small dimples from the underlying subgrade. The GCL was carefully exhumed and examined to detect any further evidence of bentonite migration or tearing in the geotextile confining layers. Based on the visual examination, the GCL appeared to remain in good condition after being loaded by the scraper, as shown in **Photo 5.**

Based on the test pad results, the contractor was allowed to use the proposed method placing the rock cover with scrapers. Construction was performed in this sequence:

- Scrapers hauled the rock cover from a stockpile located above the tailings to the slope's crest and unloaded the material as they drove from the crest to the slope's toe.
- Empty scrapers used a haul road built around the pile to return to the stock pile and repeat the cycle.
- After the scrapers dumped their loads, a bulldozer spread the rock cover over the geocomposite and GCL liner

Photo 3: Spreading rock cover over geosynthetics

Photo 4: Removing rock cover

system.

This cycle continued from one end of the pile to the other, until the entire slope was covered.

Because the scrapers transported the rock cover closer to the fill area, placement was very rapid and the tailings were capped in one construction season.

Conclusions

The geosynthetics in both projects performed well in the test pad without evidence of significant damage or loss of strength. These site-specific tests demonstrated that geosynthetics, though they are thin and sensitive products, can be successfully used in mining and reclamation applications. However, the following shortcomings should be kept in mind when using a site-specific test pad to determine geosynthetic durability:

- The test pad simulates only short-term conditions.
- Test pads should not be substituted for design recommendations and factors of safety.
- Design life, leakage consequences and cost of mitigation should be taken into account when evaluating test pad results.

Given these shortcomings, the two site-specific test pads provided some insight that, with appropriate protection, geosynthetics can be fairly durable when faced with well-graded coarse-grained soils and heavy loads. The actual performance of the geosynthetics used at these two projects demonstrates the importance of providing feedback to the industry, so allowing test and design methods to continue to be updated and improved so that the use of geosynthetics in mining and other non-landfill applications can be addressed.

Photo 5: Top of GCL after loading.

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