Capping waste rock at a Superfund site

An innovative design tackles pollution at a mining operation's waste repository.

The Gilt Edge mine is located in the northern Black Hills of South Dakota on private lands southeast of the town of Lead. Historically, the site was mined for gold beginning in 1876 with operations that extracted sulfide bearing gold ores from irregular geological deposits. In the 1880s, stamp mills were erected, and in the 1890s cyanide mills were constructed to work the gold ore. Underground mining ended in 1940. Production of gold resumed in 1988 with large scale surface mining.

Acid rock drainage (ARD) and surface/groundwater contamination was first detected in 1993. In response to environmental lawsuits, mining ceased in 1997. In the spring of 1999, Brohm Mining Corp. abandoned the site. The Gilt Edge Mine became a Superfund site and was added to the U.S. National Priorities List (NPL) in December 2000.

One of the major causes of contamination at the site is ARD originating from approximately 20 million cubic yards of sulfidic waste rock and spent heap leach ore deposited in a valley fill known as Ruby Gulch. As part of the remedial action, a cap system was required for the waste rock repository to reduce the rainwater infiltration and subsequent generation of ARD water that was costing millions of dollars per year to treat.

The U.S. Bureau of Reclamation (Reclamation), Denver, Colo. was retained by the U.S. Environmental Protection Agency (EPA), Region 8, to provide technical assistance to the State of South Dakota and the EPA for closure and reclamation of the Gilt Edge mine. As part of the overall remediation effort, a final cap system for the Operable Unit 3 : Ruby Waste Rock Repository was designed to cover approximately 26 ha (65 acres) of spent ore and waste rock to minimize the formation of ARD from the dump area due to water infiltration.

Photo 1. Structured 80-mil LLDPE on slope between benches. Note the smooth surface prior to placement of geotextile and drainage layer.

R. K. Frobel & Assoc. Consulting Engineers, Evergreen, Colo. was retained as a subconsultant by Reclamation to provide technical assistance with the geosynthetics cap design, specifications, construction quality assurance and review of the overall closure plan for the Ruby Waste Rock Repository.

The cap system design utilizes a structured geomembrane with integral drain layer to form the barrier over the 26 ha (65 acres) of waste rock. Due to the 550-m (1800-ft.)-long slope length of the waste rock and in consideration of the stability of the cap system, the entire slope length was reconfigured into a series of nine benches each 8 m (25 ft.) in width with backslopes and subsurface/surface drainage to perimeter ditches or letdown channels sized to convey the flow from a 100 year storm event. The perimeter ditches were lined with a geocomposite lining system designed to withstand extreme installation stress. The cap system geosynthetics materials and installation methodology provided an innovative long term solution for reducing water infiltration and generation of ARD.

Design considerations

The Ruby Waste Rock Repository reshaping

The original slopes on the lower east-west surface of the original Ruby dump were 3:1 with slope lengths between existing benches in excess of 50 m (164 ft.). The crest of the dump contained 1:1 slopes that required restructuring for stabilization. It was recommended that Reclamation reshape the entire 550-m (1800-ft.)-long dump surface and reduce the slopes to 3.5:1. This resulted in moving over 775,000 m^3 (1,000,000 $yd.^3$) of material. Thus, all slopes were cut to a maximum 3.5:1 or 16 degrees to enhance slope stability, provide better constructability and provide for less surface erosion potential on the final vegetative soil layer. Also, final design for the reshaped slopes incorporated a maximum 12 m (40 ft.) vertical height between benches

Ronald K. Frobel, P.E., David B. Paul, P.E., and Michael J. Gobla, P.E.

and 8-m (25-ft.)-wide benches. This resulted in maximum slope lengths of 46 m (150 ft.) for design purposes of slope stability, material roll size, constructability and erosion potential.

In the final slope design, a total of nine benches were incorporated on the dump slope and each bench was sloped back into the dump section at 8% prior to placement of the bedding material to facilitate lateral subsurface drainage on top of the geosynthetics, enhance slope stability at the base of each slope and allow for the construction of lateral surface drainage ditches in the cover material at each bench.

Due to the reshaping of the waste rock dump surface, filling of large depressions and shaping of the top and toe terrace areas (< 3% slope), approximately 6.8 ha (17 acres) of terrace or flat area and approximately 19.2 ha (48 acres) of slope and slope bench area were established for placement of the Ruby cap.

Geomembrane cover system

The final cover system designed for the Ruby Waste Rock Repository is as follows from top to bottom:

- 75-m (6-in.)-thick processed/amended topsoil seeded with native grasses
- 900-mm (36-in.)-thick processed/amended soil and rock
- 450-mm (18-in.)-thick processed, crushed 1-in. minus rock
- 335 g/m^2 (10 oz./yd.^{2}) nonwoven geotextile heat set one side
- 2.0 mm (80 mil) LLDPE structured geomembrane with integral drain layer
- 300-mm (12-in.)-thick roller compacted processed 1 in. minus ore base layer
- Waste rock dump working surface

The geomembrane/geotextile system was selected to provide the requisite barrier layer to prevent water infiltration into the Ruby Waste Rock Repository; thus, it will prevent future generation of ARD. The primary barrier is composed of the geomembrane with integral top surface drainage.

Based on the site conditions, construction considerations, slopes, base layer soil, longevity requirements, acidic nature of interface soils and survivability during installation, a 1.5 mm (60 mil) minimum high density polyethylene (HDPE) geomembrane was originally considered. After investigating the characteristics of the processed ore and the interface friction potential against a roller compacted processed ore surface, it was also decided to incorporate either a heavily textured surface or a structured texture surface that would provide high interface friction against the roller compacted ore. In consideration of additional toughness, resistance to installation stress, subsidence, dimensional stability, ease of installation and durability, a 2-mm (80-mil)-thick LLDPE geomembrane was selected as opposed to a more rigid and less conforming HDPE. The LLDPE polymer provides a more flexible material for installation purposes and potential settlement considerations. It conforms better to the base layer—fewer wrinkles—during construction. To insure the roughest possible surface, a minimum requirement for surface roughness was part of the technical specifications for the geomembrane in addition to the performance requirement for a minimum δ = 28° interface friction angle with the compacted ore base layer. Historical large scale direct shear tests have shown friction angles for 1 in. minus angular soil to be in the range of δ = 26–30°

Figure 1. Typical slope/bench section for the final cover system, including lateral subsurface drainage pipe.

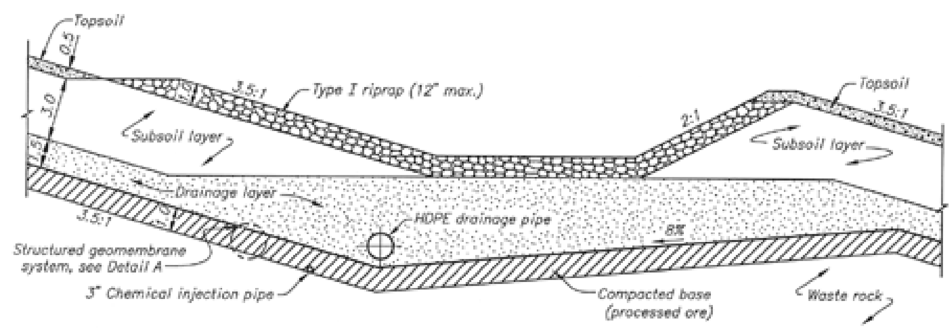


Photo 2. Processed ore base layer being vibratory roller compacted.

Photo 3. Placement of overlying drain layer using an LGP dozer equipped with GPS for layer thickness control.

for blown film texture and in excess of δ = 35° for structured (moulded surface) high profile HDPE or LLDPE.

Minimum physical/mechanical specifications generally followed those specified in the Geosynthetic Institute Standard GRI GM-17 with the exception of asperity height, which was increased to 0.38 mm (15 mils).

The Gilt Edge specifications also required that the contractor submit third party large scale conformance testing for direct shear on all slope interfaces conducted in accordance with ASTM D 5321. The requirement that a minimum post peak large displacement interface friction angle of δ = 28° between all geosynthetic materials interfaces and geosynthetic/soil interfaces was specified for all slope areas. Minimum test parameter requirements of normal loads, soils properties, placement, moisture conditions and test speeds were also specified.

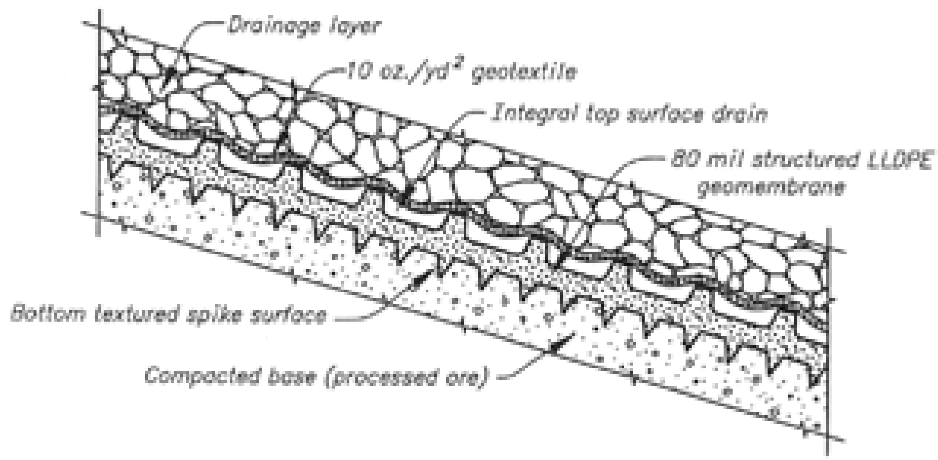
Heap leach pad processed ore—base bedding layer

In the original Reclamation closure plan for the Gilt Edge Mine, it was decided to reuse and remove/replace as much of the on-site material as possible in a final mass balance. In this regard, the existing heap leach pad (HLP) processed and oxidized spent ore was to be used as the bedding material for the geosynthetic barrier layer for the Ruby Waste Rock Dump cap system. Thus, the on-site processed ore was investigated for soil interaction considerations when designing the cap system and required the review of the following characteristics:

• Gradation, maximum particle size and angularity
• Internal shear resistance (stability on slopes)
• Density as a base layer (consolidation characteristics)
• Smoothness as a base layer (roller compaction characteristics)
• Interface shear resistance against geosynthetics

Interaction of the soil with geosynthetics needed to be addressed to determine the interface layer stability of the soil against the geomembrane under wetted surface conditions. Also, interaction during construction must be considered so that the processed ore material in contact with the geomembrane does not displace or damage the geomembrane during placement of cover soils. To this end, high interface shear strength and good adhesion characteristics are important considerations.

Figure 2. Detail of the cap system's complexity.



The processed ore material is generally classified as a poorly graded gravel with clay and sand (GP-GC). Although some of the gradation curves indicate presence of some 38–75 mm (1.5–3.0 in.) material (usually less than 1%), the majority of the spent oxidized ore can be considered 38 mm (1.5 in.) minus with 90% passing 38 mm (1.5 in.) sieve and over 80% passing the 25 mm (1 in.) sieve. Thus, consideration for screening the material to 25 mm (1 in.) minus was eliminated from design due to cost considerations and the fact that the potential for damage to the geomembrane system would be minimal with a roller compacted base surface and careful placement of geomembrane and cover soils above the system.

Photo 4. Typical slope area showing open rough cut ditch, ore base, geomembrane system and overlying drain layer—prior to final ditch lining.

Drainage considerations—cover soils

A free draining layer was required at the geomembrane/soil interface to prevent possible build up of seepage forces during high rainfall events and saturated cover soil as well as during spring thaw of the cover system. As seepage forces result in the most frequent failures of slope covers, the following design considerations were addressed:

- Cover soils will be highly variable and may be finer than desired
- Cover soils are saturated (worse case condition for infiltration into drain layer)
- Subsurface drainage at the toe of all slopes must be adequate and open to drains
- Fine soil sediments may accumulate at toe of slopes above drain system
- Potential for freezing of drain layer and soils immediately above geomembrane
- Design factor of safety for the geosynthetic drain flow rate must be > 1.5

It was assumed that the final cover at some point in its life will approach saturation due to weather conditions. If water flow in the soil layer immediately above the geomembrane is blocked, pore pressures will develop and adversely affect the slope stability.

Coarse aggregate drain layer

The soil material to be placed immediately above the geomembrane system on all slope areas must be free draining, consistent in gradation and mechanical properties, stable and screened to 25 mm (1 in.) minus to help protect the geomembrane system during cover materials placement. Due to state requirements, borrowed material from a nearby highway cut was incorporated. The following were selected as candidate materials for the 45-mm (18-in.)-thick layer directly above the geomembrane system:

• Phyllite—a GW crushed and screened to 1 in. minus
• Trachyte—a GW screened to 1 in. minus (material available at the Gilt Edge site)
• Deadwood formation—a GW crushed and screened to 1 in. minus
• Porphyry/latite—a GW crushed and screened to 1 in. minus

All of the above materials were sampled and tested for mechanical characteristics, permeability and shear strength against the proposed geomembrane cover systems. In general, the Trachyte and Porphyry/Latite exhibited the best soil partical shape (angular) and stability under load and soaking. Also, these two materials exhibited the best interface strength characteristics when tested against the top surface of the geomembrane system. The Phyllite was noted to have subangular flat particle structure, which tended to break down upon soaking and loading and also exhibited the highest percentage of fines and lowest permeability. The Deadwood Formation material was also noted to be subangular and flat in particle structure but was not noted to break down upon soaking and under load. The final material that was crushed and screened for the drain layer consisted of a combination of Trachyte and Porphyry/Latite. The remainder of the materials from the highway project were designated for the upper 600 mm (24 in.) soil layer in the cap system.

Selected geosynthetic materials

The prime earthmoving contractor selected by the government for remediation work was Delhur Industries, Port Angeles, Wash. The geosynthetics subcontractor/installer was Comanco Environmental Corporation, Tampa, Fla.

The geosynthetic materials submitted by the contractor and approved for installation on the Ruby Waste Rock Dump cap system were as follows:

Slopes and benches

• 2-mm (80-mil)-thick LLDPE structured geomembrane with integral drain structure on top and spike grip texture on the bottom surface
• 335 g/m^2 (10 oz./yd.^{2}) nonwoven polypropylene geotextile

Terraced areas

• 2-mm (80-mil)-thick LLDPE smooth geomembrane
• 335 g/m^2 (10 oz./yd.^{2}) nonwoven polypropylene geotextile

Perimeter ditches

• 1.0-mm (40-mil)-thick LLDPE geomembrane/geotextile composite with 670 g/m^2 (20 oz./yd.^{2}) geotextile bonded to both sides of the LLDPE

Subsurface lateral drains

• 3800 m (12,500 ft.) of 300- and 450-mm (12- and 18-in.) geopipe for subsurface bench drains

The structured LLDPE geomembrane is manufactured by continuous horizontal flat die extrusion into profiled rolls. The machined rolls provide the final structured surface which in this case is a 2-mm (80-mil) core thickness with a 3.8-mm-high-studded drain surface on the top side and 3.8-mm-high-spiked friction surface on the bottom side. The 6.9-m (22.5-ft.)-wide rolls of

Sidebar 1. A number of project points noted in this article are available online for further study. A good starting point is either a standard search in Google (www.google.com) or a visit to www.geosynthetica.net. The following information is directly available through the latter source:

• GRI Specifications GM13 and GM17.

• Complete CQA plan for use in the field. Online source includes demo field logs and other ready-to-use documents.

• IAGI HDPE installation specifications.

• An article: "Electrical Leak Location Surveys—What are they Finding?" by Nosko et al.

• A stone/geotextile calculator from GeoFabrics.

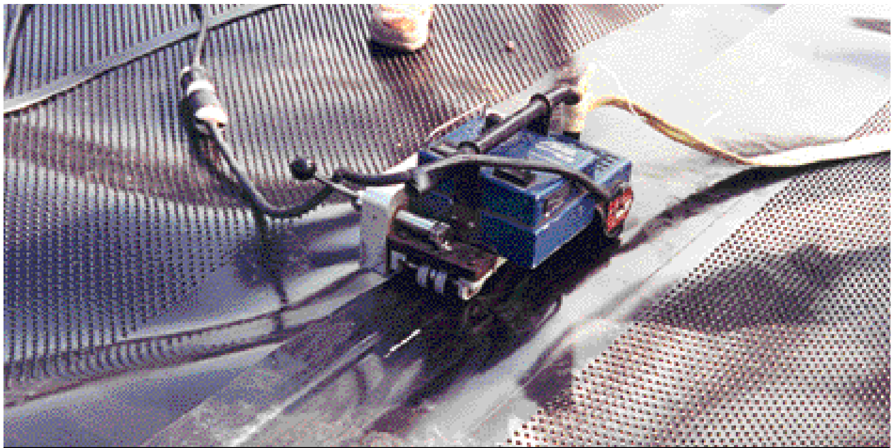


Photo 5. Structured LLDPE double fusion weld at smooth edge overlaps.

finished product include a smooth edge on both sides of the roll for ease of thermal welding in the field. Due to the molded structure, core thickness does not vary as with blown film textured sheet, thus mechanical properties of the sheet are not affected. CQA thickness measurement is limited to spot edge check only and does not require frequent core thickness measurements. In addition, the consistent high profile texture insures optimum interface friction characteristics at any point on the sheet surface.

The top surface integral drain structure consists of 2.5-mm-diameter studs 3.8 mm in height and spaced on a diamond pattern of 12.5-mm (0.5 in.) spacing. A filter/protection geotextile is required to be placed on the drain profile. The geotextile was heat-set on one side (placed against the drain structure) to reduce intrusion into the drain. Large-scale flow rate testing with this configuration, overlying soils and expected normal loads resulted in planar flow rates in excess of 0.54 m^2/s (2.6 gpm/ft.).

Installation

Once the slopes and benches were cut to final grade, the processed ore material was placed and roller compacted over the entire dump surface. Actual in place ore layer thickness was in excess of 450 mm (18 in.) in order to provide enough material to smooth the rough cut and rocky soils of the final graded working surface. Ore material roller compaction was accomplished just prior to geomembrane placement to prevent weather damage and maintain a tight surface.

The structured LLDPE geomembrane was custom configured in roll lengths to accomodate variable slope lengths. Runout on the 8-m (25-ft.)-wide benches was required to be a minimum of 1.5 m (5 ft.). The 6.9-m (22.5-ft.)-wide roll goods were deployed from each bench downslope using requisite deployment equipment, including spreader bar and four-wheel drive lift. Once positioned, the slope seams were aligned and welded at the smooth edge overlaps using a double wedge welder. All slope seams were QC-tested by air channel. Butt welds of the structured geomembrane were not allowed on slopes, and all end of roll butt welds were required to be a minimum of 1.5 m (5 ft.) from toe of slope at each bench. All bench seams were welded with a 50-mm (2-in.)-wide solid wedge. Due to the melt temperature and flow of the LLDPE polymer, butt welds were accomplished without grinding smooth the structure as recommended by the manufacturer. Consistent QC destructive field and laboratory results were obtained on this type of weld.

Once the structured geomembrane was placed, the overlying nonwoven geotextile was positioned and thermally welded at all overlaps. It was noted that the LLDPE exhibited minor wrinkling with surface temperature changes, and in fact the high profile spike surface adhered to the smooth ore surface without displacement. Once the geomembrane was placed, seamed and accepted by CQA, the light color geotextile was immediately placed to prevent any possible temperature variations and movement of the LLDPE geomembrane prior to placement of overlying drainage aggregate.

The 25 mm (1 in.) minus drain layer was placed in a 450 mm (18 in.) lift over the entire geomembrane system slopes and benches. Placement was generally from bottom to top of slope, and thickness of the layer was maintained by using an onboard GPS system mounted on the LGP dozer. No movement of the underlying geomembrane system was noted during drain layer placement.

The comprehensive CQA Plan included four full-time site inspectors and an on-site CQA engineer. The CQA Plan required the testing of the entire dump surface by electrical leak location methods after drain layer placement. This requirement was designed to detect damage caused by placement of the overlying drain layer. Leak location testing was completed under separate contract by Leak Location Services Inc. (LLSI) of San Antonio, Texas. Only minor backhoe damage on one bench was detected after testing the entire dump surface.

Perimeter ditch lining

Due to the fact that the ditches (designed to carry a 100 year storm event) are cut into the rock sides of the valley and could contribute to surface leakage in some areas, a lining system was required. The lining system was designed to withstand extreme installation stress in cold weather over rough rock cuts and during placement of Type I and II riprap. To this end, the 1 mm (40 mil) LLDPE polymer sheet was protected by 670 g/m^2 (20 oz./$yd.^2$) geotextile bonded to both sides. The 8.5-m (28-ft.)-wide geocomposite was overlapped within the channel and the primary cover system was overlapped a minimum of 1.5 m (5 ft.) on the composite ditch liner. Due to the location at the perimeter of the dump, any infiltration would be minimal and thus the composite system was required to be overlapped down gradient without mechanical thermal seaming to the primary cap system. Installation of the geocomposite continued into the winter months of 2002.

Summary

The entire 26 ha (65 acre) Ruby Waste Rock Repository cap system geosynthetics and drain layer was installed in under 60 working days with few installation difficulties and virtually no discrepencies in material or installation, which is considered unheard of for projects of this size.

Aside from the excellent cooperation and scheduling between all parties involved, the following are considered contributing factors to the overall sucess of the project:

- Prime contractor with requisite experience in federal contracts and large earth moving projects
- Installation subcontractor with requisite experience in specified materials and large projects
- Extensive CQA plan implementation by the federal government

• Geomembrane material selection:
-Highly flexible structured LLDPE (installation and conformance)
-Integral drain layer (no need for separate geonet drain layer)
-High surface friction profile (high interface shear and adhesion)
-Smooth edge sheet (rapid field seaming with consistent quality)
-Custom manufactured roll lengths
-Toughness against installation stress
-Consistent sheet quality
• Geocomposite material selection:
-Wide width three layer composite (one roll install)
-Extreme toughness against installation stress
-Cross ditch installation, cutting, positioning
-Resistance to placement of large ditch riprap.

The combination of desirable geosynthetics material properties and extensive contractor/subcontractor experience and cooperation resulted in a project completion within extreme climatic-induced time constraints and with very little material or installation difficulties or deficiencies. Phase 1 and Phase 2, described above, were completed in 2002 at an estimated cost of $17.5 million. Phase 3—final soil cover and revegetation—will be completed in 2003 at a cost of approximately $3.5 million. GFR

References
R.K. Frobel & Associates. 2000. *Preliminary Report—Task 1 and 2, Technical Assistance with Geomembrane Design and Construction - Gilt Edge Mine, South Dakota*. March.
R.K. Frobel & Associates. 2000. *Interim Design Review—Task 3 - Gilt Edge Mine Reclamation - Ruby Waste Rock Dump Cap System Design Considerations*. April.
SGI Testing Services, LLC. 2002. *Final Test Report No. SGI1105*. February.
United States Bureau of Reclamation. 2000. Technical Memorandum. *Earth Sciences and Research Laboratory Physical Properties Test - Brohm Mine, Gilt Edge, South Dakota - Report No. 8340-00-07*. January.
United States Bureau of Reclamation. 2000. *Closure Plan for Gilt Edge Mine, Lawrence County, South Dakota, USBR Technical Service Center Final Report*. February.
United States Bureau of Reclamation. 2000. Technical Memorandum. *Earth Science and Research Laboratory Physical Properties Test Results - Gilt Edge Mine, South Dakota - Report No. 8340-00*. August.

Ronald K. Frobel, P.E., is principal of R.K. Frobel & Associates Consulting Engineers, Evergreen, Colo.
David B. Paul, P.E., is a construction project manager for the U.S. Bureau of Reclamation, Denver, Colo.
Michael J. Gobla, P.E., is a design engineer for the U.S. Bureau of Reclamation, Denver, Colo.

Project information

Contractor (earthmoving): Delhur Industries

Subconsultant: R.K. Frobel & Associates

Subcontractor: Comanco Environmental Corp.

Technical assistance: U.S. Bureau of Reclamation (Denver, Colo.)

Geocomposite manufacturer: Huesker Inc.

Geomembrane manufacturer: AGRU America Inc.

Geotextile manufacturer: Tenax Inc.

Sidebar 2. Further article-applicable resources available through www.geosynthetica.net include:

• Paper: "Stress Cracking—What It is and How to Avoid It."

• Comprehensive list of abstracted papers and technical documents on the subjects of waste capping, membrane installation, etc.

• Paper: "A Review of Interface Friction and Its Importance" by Rob Swan, SGI.

• Material specifications for the project's geosynthetics: LLDPE structured geomembranes, non-woven polypropylene geotextiles, LLDPE smooth geo-membranes, thick LLDPE geomembrane/geotextile composites, and geopipe.

More material and educational articles are also available at www.gmanow.com.