Design and construction of mine waste rock pile rehabilitation works at Cirque Mine, Mackenzie, British Columbia

Garry Davies
Senior Environmental Co-ordinator, Teck Mining Group, Kamloops, B.C.

Andy Haynes
Golder Associates Ltd., Burnaby, B.C.

Alistair Lowry
Golder Associates Ltd., Burnaby, B.C.

Abstract: Underground exploration work conducted at the Cirque Property, located some 280 km northwest of Mackenzie, B.C. between 1977 and 1991, created a stockpile of about 22,000 m^3 of acid generating waste rock. Originally two neutralization ponds were constructed immediately down gradient of the waste rock pile to allow collection, monitoring and treatment of acidic seepage and runoff. Cirque Operating Group wished to rehabilitate the waste rock pile and the treatment ponds as part of a rehabilitation plan for the property. A study was carried out to assess various options. A lined and covered containment cell option was selected on the basis of a Net Present Value analyses and consideration of other collateral benefits. The cell was constructed in two months during the summer of 2000. Fusion welded 1.5 mm thick PVC panels sandwiched between layers of non-woven geotextile were used for the cell liner and cover. A mixed organic cap was installed to cover the cell and promote revegetation. The finished cell measured approximately 105 m long, 60 m wide and 6.5 m deep.

Introduction and background

Exploration work was conducted at the Cirque Property, located some 280 km northwest of Mackenzie, B.C. between 1977 and 1991 and resulted in the construction of a 52 km long mine access road, an exploration camp and preliminary mine workings. In particular, the driving of a 1,277 metre long adit in 1989 produced approximately 22,000 m^3 of acid generating waste rock. It was stockpiled on the southern slope of a localized knoll, approximately 500 m from the adit portal. Two ponds were constructed immediately downhill of the waste rock pile to allow collection, monitoring and treatment of seepage and drainage water.

Even though the waste rock pile was relatively small, the Cirque Operating Group, the current operators and part owners of the Cirque property wished to implement a rehabilitation plan, commencing work in June 2000. As part of this plan it was necessary to rehabilitate the existing waste rock pile and its associated seepage ponds in order to minimise any future environmental impacts.

This paper comprises two main sections. Firstly, the key issues relating to the enhanced care and maintenance of the waste rock pile site are outlined. Several rehabilitation options are presented and appraised. An economic appraisal in the form of a net present value (NPV) analysis is presented that compares the capital and maintenance costs of the various rehabilitation options with the current maintenance costs. A recommended rehabilitation option is then identified.

Secondly, the engineering design of the recommended option is presented and on-site construction activities are discussed. The difficulties related to completing this work in a remote location, under poor weather conditions are identified.

Key Issues

The key issues relating to the rehabilitation of the waste rock pile were as follows:

Remote location and availability of suitable local borrow materials

Access to this remote site was limited to the Chowika barge loadout (approximately 120 km away), the Finbow airstrip (approximately 75 km away) and a forestry road along the west side of Williston Lake from Ingenika (approximately 100 km away). Consequently, the importation of plant, labour and materials had to be minimized. Possible local borrow sources in the vicinity were limited and clay was not available locally.

Temporary nature of existing facilities

The existing facilities at the Cirque property were built with the understanding that they would be temporary and would be replaced once the mine was developed. In particular, it was originally intended that the waste rock would be stored temporarily in an above ground pile and would ultimately be submerged in the tailings impoundment of the proposed mine facility.

Acid generating waste rock

The waste rock was known to be acid generating. It was known that the "rock types which envelope the deposit have a strong potential to generate acid. This particularly applies to the Devonian age Gunsteel and Alkie lithologies which contain disseminated pyrite" (Teck Corporation 1995). Collected acidic seepage was neutralized originally by lime dosing, but latterly by caustic addition. This caused the precipitation of dissolved metals such as zinc. The dosing occurred between the upper and lower ponds, with recycling until consent standards were met. Supernatant water was then pumped from the lower pond and discharged to a nearby creek.

Leaching process

In the absence of historical metal release data, and taking a conservative approach, it was assumed that oxidation of metals within the waste rock pile would continue without any flushing and unabated by depressed temperature, for approximately six months each winter. The stored products of oxidation would, therefore, tend to be flushed out of the pile over a two month period during the spring melt, giving rise to a "first flush" effect. The majority of oxidation products would be flushed out at this time and minimal precipitates would remain in the pile during the four summer months. This process would continue until all of the available metal precipitates had been leached from the waste rock within the pile, which may have taken many decades.

Seepage collection ponds

No quantitative water balance data existed for the volume of seepage and clean water flows collected in the existing ponds. Clean water collected in the ponds was limited mostly to incident precipitation as surface flows to the pond were generally excluded by the existing site grading and diversion swales.

Environmental objective

The environmental objective was to implement measures that reduced the generation of acidic drainage to levels not considered deleterious to the environment. It was further recognized that collection and treatment was an undesirable long term approach for environmental protection due to the remote location, potential for failure and high costs. The recommended rehabilitation measures had to, therefore, comply with the Ministry of Energy and Mines' Policy and Guidelines for Acid Rock Drainage (ARD) at Minesites in B.C., while being both technically and financially feasible.

Waste rock pile rehabilitation options

A number of ARD mitigation measures were considered, along with their salient environmental, technical and economic features. In order to allow an economic comparison of the various rehabilitation options in the form of a net present value (NPV) analysis, a "Do Minimum" option was also considered. The options considered are outlined in the following sections.

Option 1 – "Do minimum"

The "Do Minimum" option would involve re-working the surface of the waste rock pile to produce a pile with a smaller footprint and a domed surface to promote runoff. Proposed side slopes should be at 2:1 (H:V) for geotechnical stability. While it was recognized that contouring may not significantly reduce the total infiltration into the pile, it was expected to result in a reduction of flushed surfaces within the pile. Consequently, a greater proportion of the oxidation products should remain in the contoured pile as precipitates.

This option would also comprise the rehabilitation of the seepage collection ponds by regrading and relining them with 1.5 mm (60 mil) thick PVC geomembrane. Ancillary works would include general site grading and ditch/swale construction to divert clean flows around the waste rock pile and seepage collection ponds.

The estimated capital cost of this option was in the order of \$155k. In addition to this capital cost, the ongoing level of maintenance expenditure would be significant. Maintenance costs would include care-taking services, accommodation, travel, transportation and bulk fuel.

Option 2 - Underground disposal in existing adit

The existing adit was driven at an approximate 10:1 (H:V) decline and is 1,277 m long, with dimensions of roughly 4.6 m by 4.6 m. The water level in the existing adit was believed to be at or about 120 m from the portal i.e. some 12 m below the elevation at the portal. Inflow rates to the adit were also not certain, although inflow at the time of completion of driving operations was recorded at 35 litres/sec. It was assumed that this rate remained unchanged.

Given the above assumptions, it would be possible to place all of the approximately 22,000 m^3 loose volume waste rock within the lower, flooded portion of the adit. This would provide control of ARD due to lower oxygen availability and reduced leachate flushing mechanisms. Additional benefits of underground disposal include increased stability and reduction of both maintenance requirements and loss of productive land.

Disposal of the waste rock in the existing adit would require Ministry of Energy and Mines approval based on detailed study of the following issues (Ministry of Energy and Mines 1998):

- drainage input sources, volumes, rates and chemical loadings,
- rate and fluctuations in the final height of flooding,
- duration of exposure and consequent buildup of soluble weathering products,
- composition of materials above the final height of flooding and the expected metal and acidity discharge, and
- resulting drainage chemistry and locations and rates of discharge.

A budget estimate received from a mining and tunneling contractor indicated that the placement of the waste rock in the existing adit would take approximately 3 months and would cost in the order of $1.5 million. Future maintenance costs would be negligible.

Option 3 - In-ground disposal in prepared cell

This option would comprise the excavation of a storage cell, preparation of excavated surfaces and lining with a composite geosynthetic liner. The floor of the cell would be graded towards a collection sump that could be monitored from the surface by means of an inclined header pipe. The waste rock would be placed within the lined cell and an engineered geosynthetic/local borrow material cover placed over the top of the cell.

A PVC geomembrane was considered to be the most suitable for this installation given its impermeability, good chemical resistance and elongation properties, ability to be pre-fabricated off-site and relatively low cost.

Encapsulation of the waste rock and any sludge from the seepage collection ponds within such a lined cell would effectively reduce the supply of oxygen, inflow of runoff and movement of leachate, thus significantly mitigating the potential effects of ARD.

The capital cost of this option was in the order of $305k. It was estimated that future maintenance costs would be negligible.

Option 4 - Install impervious cover and rehabilitate seepage collection ponds

This option would include contouring the waste rock pile to improve runoff and covering the pile. In the absence of suitable local borrow material i.e. clay, which could be used as a low permeability soil cover, various geosynthetic alternatives were considered. These included Geosynthetic Clay Liner (GCL), PVC and HDPE covers.

Given that the proposed covered surface of the waste rock pile would become impervious, runoff from this surface would be "clean" and should be directed away from the seepage collection ponds by means of geomembrane lined ditches. Flow diverted in this manner would be discharged directly to the environment. Any remaining leachate within the pile would be collected at depth by means of a "French drain" and discharged to the treatment ponds.

The estimated cost of this option was in the order of $285k. The seepage collection ponds would remain and treatment of collected leachate would be required in the first few years following installation of the cover, resulting in slightly higher maintenance costs.

Appraisal of waste rock pile rehabilitation options and recommended option

In order to economically appraise the various options, a Net Present Value (NPV) analysis was carried out. The assumptions used in this analysis were as follows:

- Life of installed works = 30 years (2000 to 2029);
- Interest rates = 4%, 6% and 8% (for sensitivity analysis);
- 100% capital works replacement every 10 years for Option 1;
- No allowance made for capital works replacement for Options 2, 3 and 4;
- No residual value at end of life;
- Capital costs as discussed earlier; and,
- Maintenance costs as discussed earlier.

Given the above assumptions, the ranked results of the NPV analysis are shown in Table 1 below (1st = lowest cost and 4th = highest cost).

Table 1. Results of NPV Analysis

Option	**NPV @ 4% ($k)**	**NPV@ 6% ($k)**	**NPV@ 8% ($k)**
1 - "Do Minimum"	4th	4th	4th
2 – Underground Disposal in Existing Adit	3rd	3rd	3rd
3 - In-ground Disposal in Prepared Cell	1st	1st	1st
4 - Install Impervious Cover and Rehabilitate Seepage Collection Ponds	1st	2nd	2nd

Given the similarity between Options 3 and 4 in NPV terms and the level of accuracy of the capital and maintenance cost estimates used in the analysis, it was not possible to clearly identify the best option based solely on NPV terms. The collateral benefits of both of these options had to be considered in order to identify the recommended option.

The benefits of Option 3 over Option 4 include the fact that Option 3 would lead to removal of the seepage collection ponds and their associated treatment requirements and also would allow revegetation of the whole area.

In the light of the preceding discussion and appraisal of options, Option 3, In-ground disposal in a prepared cell was recommended.

Cell design

Required Cell Volume

The volume of the waste rock pile was originally estimated to be around 22,000 m^3 from the topographic survey and using an assumed underlying ground surface. As this material had been in place for about 11 years, some densification was likely to have occurred. Therefore, an allowance for bulking of about 5% was used.

A portion of the existing pond material was expected to be unsuitable for cell construction, due to softening or chemical alteration from the acidic leachate. It was assumed that this material would be placed within the cell along with the waste rock. It was estimated that such material would comprise as much as 20% of the excavated volume, or approximately 1,500 m^3.

It was unknown whether it would be necessary to excavate material from below the waste rock pile after removal of the waste rock. For design purposes it was assumed that about 1,500 m^3 would need to be excavated.

The total required cell volume was therefore estimated to be 26,000 m^3

Berm side slopes

The subsurface materials within the cell footprint were expected to be weathered, low strength schist. The berms forming the cell were therefore expected to be constructed from either in situ weathered schist or from compacted silty sandy gravel obtained from excavation of the in situ schist.

The criteria for the berm side slopes were as follows:

- provide acceptable short- and long-term factor of safety against instability;
- provide suitable gradients to allow compaction and surface preparation; and
- provide suitable gradient for placement of PVC liner.

The maximum gradient allowing construction of the outer batters with the equipment proposed for construction was considered to be 2.5H:1V. The maximum gradient allowing careful surface preparation for liner placement and for liner welding is 3H:1V, and this was therefore adopted for the internal side slopes.

The Geological Survey of Canada seismic zoning map indicated that the maximum horizontal ground acceleration for the site, based on a 10% probability of exceedance in 50 years, is 0.08g. A peak horizontal ground acceleration of 0.08g was used in the pseudo-static analysis.

The results of the stability analyses are summarised in Table 2.

Table 2. Summary of Stability Analyses

Load Case	Calculated Factor of Safety
Static	1.8
Pseudo-Static	1.6

The calculated factors of safety were considered to be acceptable.

Crest width

A crest width of 5 m was selected for the cell embankments to allow sufficient width for equipment access during liner installation, while including an allowance for the anchor trench.

Cell dimensions

The cell dimensions were selected in order to satisfy the following:

- match existing topography;
- provide sufficient cell volume;
- minimize excavation volume; and
- ensure an approximate cut/fill balance for embankment construction.

Cell construction

Embankment construction

Construction commenced on July 15, 2000. Unsuitable materials were removed from the base of the treatment ponds and loaded into tandem dump trucks for transport to the top of the waste rock pile where they were mixed with the waste rock.

The exposed weathered rock foundation was then track rolled with a Caterpillar D8 dozer.

Materials suitable for berm construction were excavated and placed in layers of about 0.5 m thickness to form the southern embankment for the cell. Each lift was compacted by at least four passes of a Caterpillar D8 dozer. The embankments were shaped with the dozer and a Hitachi EX200 excavator and by backblading with a

Komatsu WA250 wheel loader to achieve a surface suitable for liner placement.

Construction was impeded by intermittent rainfall, which made material placement and trimming difficult. Several springs were encountered at the north batter and in the excavation floor.

Inflows from the waste rock pile were intercepted by a trench and pumped to temporary lime treatment ponds to the east of the cell.

Seepage from the floor and collected rainwater were diverted by shallow drains to a sump in the cell floor, near the toe of the southern embankment. The water was then pumped from the excavation into a settling pond and discharged to a nearby watercourse. Pumping continued throughout the earthworks construction stage of the project.

Ramp construction

Material was placed in the cell using D8 dozer, a 20 tonne tracked excavator, a front-end loader, and two tandem trucks.

The very low friction angle between the geotextile and the PVC geomembrane meant that trafficking down the internal 3H:1V slopes with any of the equipment would exceed the shear resistance of the geomembrane and tend to drag and tear it.

It was also unacceptable to end dump waste rock from the embankment crest as the pile included a significant proportion of coarse rock that could puncture the geomembrane.

Ramps were therefore incorporated into the northeast and northwest corners of the cell, with a grade of 8H:1V. The ramps caused a minimal reduction to the capacity of the cell. Ramp construction is shown in Fig 1.

Fig. 1. Ramp Construction

Foundation preparation

Foundation preparation involved surface compaction with the dozer, excavator, or front-end loader. The wheel loader was then used to level the surface by backblading, as shown in Fig 2.

Fig. 2. Preparing Subgrade by Backblading with Front End Loader

A 4WD pickup truck was then used to track and smooth the surface, and final trimming and removal of sharp particles was performed by hand.

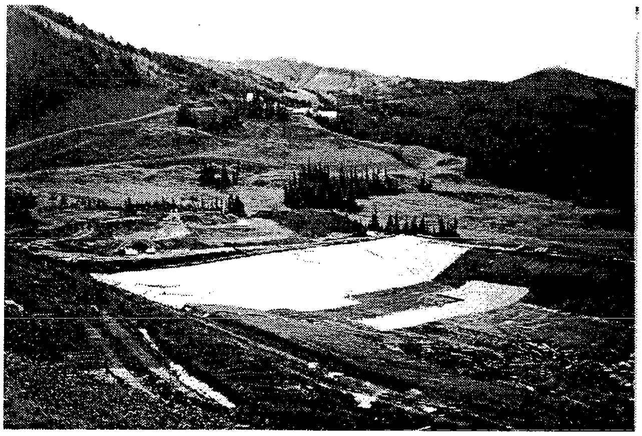
The entire floor area was then covered with a layer of 1.5 mm PVC to contain seepage and further improve the foundation conditions for the liner. The edges of adjacent panels were overlapped by about 300 mm. This secondary floor layer enabled placement of the geotextile and geomembrane in comparatively dry conditions, facilitating the welding of PVC panels.

Liner installation

A layer of 270 g/m^2 non-woven, needle punched geotextile was placed over the prepared subgrade and 1.5 mm thick PVC secondary layer on the cell floor and secured in an anchor trench. The geotextile sheets were welded with heat torches to prevent movement from occurring during PVC installation.

A single layer of 1.5 mm thick PVC geomembrane was then placed in panels over the geotextile and secured in the anchor trench. The secondary PVC floor layer, geotextile, and PVC floor liner are shown in Fig. 3.

Fig. 3. Secondary Layer, Geotextile, and PVC Floor Panels



Eleven PVC panels formed the floor liner and were continuously fusion welded. A mechanized welder was used for the majority of the seams. A heat gun was used where it was not possible to use the mechanized welder, or wherever patching was required.

The liner installation contractor tested seams and repairs with an air-lance, in the presence of the Site Engineer.

After testing and approval of the geomembrane, a layer of 270 g/m^2 non-woven, needle punched geotextile was placed over the PVC geomembrane.

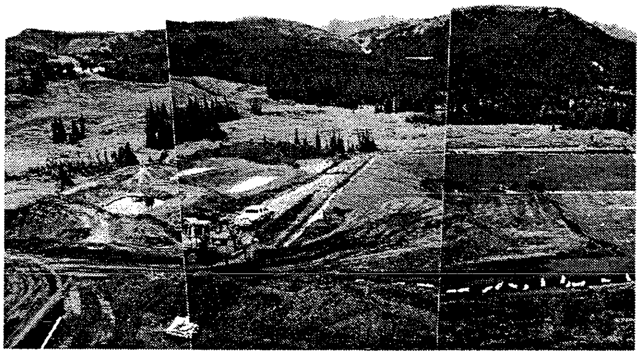
Sampling pipework

A 100 mm diameter PVC pipe was placed within the cell to allow subsequent sampling of leachate. Pipe connections were glued with PVC solvent cement, and the top was sealed with a screw-on PVC cap.

Waste rock placement

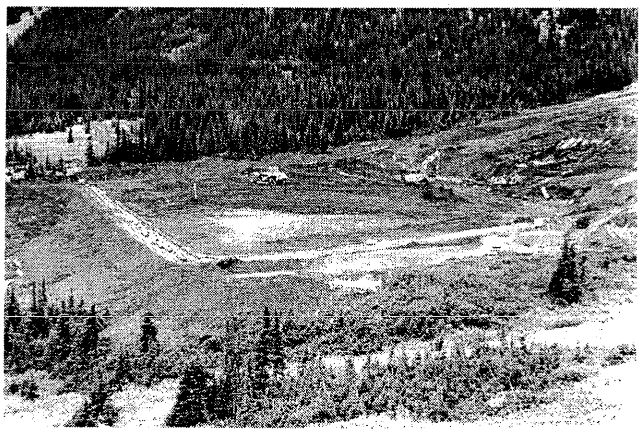
The placement of the material within the cell commenced on August 23, 2000. A layer of fine, weathered schist was placed to a thickness of about 0.3 m over the floor to reduce the risk of puncturing from coarse waste rock particles. Waste rock was then placed over this layer by end dumping from the access ramp with tandem trucks. The dumped material was spread with the Cat D8 dozer, as shown in Fig 4.

Fig. 4. Placing Waste Rock into Completed Cell



Waste rock placement continued until September 9, 2000. The cell near the completion of the waste rock placement is shown in Fig. 5.

Fig. 5. Placement of Waste Rock Nearly Complete



The sludge from the temporary lime treatment cells was removed and placed into the waste rock containment cell.

The upper surface of the waste rock was profiled to promote drainage of surface water, and back-bladed to achieve a smooth surface.

Cap installation

Installation of the cap commenced on September 9, 2000. A layer of 270 g/m^2 non-woven geotextile was placed over the entire cell area, including areas in which geotextile had been placed as subgrade improvement.

Ten panels of 1.5 mm thick PVC geomembrane were then placed to cover the waste rock fill. The panels were continuously joined with a mechanized fusion welder.

To enable placement of the 1.5 mm thick PVC geomembrane in cold weather, the PVC rolls were stored in a parachute and heated with kerosene space heaters until deployment.

To minimize the potential for wicking, the geotextile between the floor panels and the cap panels was folded back so that the two layers of PVC were in contact.

Placement of the cap was hindered by rain and snow, but was completed on September 13, 2000.

Cover layer

The PVC cap was then covered with a layer of 270 g/m^2 non-woven geotextile. The geotextile was generally placed directly onto the geomembrane, but some geotextile was placed over a thin layer of snow, as shown in Fig. 6.

Fig. 6. Placement of Cover Layer

A layer of fine, weathered schist and organic topsoil removed during cell excavation was then placed over the cell area. The thickness of the cover layer ranged from 0.45 m to 0.6 m.

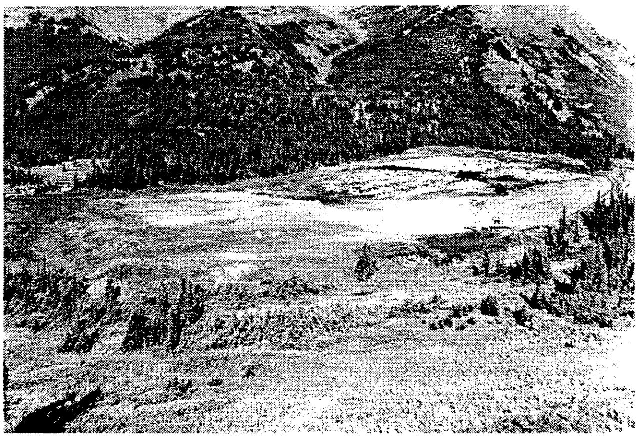
The surface of the cover layer was also graded by back-blading with the loader to promote surface drainage.

Reclamation works

The footprint of the previous waste rock pile was treated with lime.

The entire area of the previous waste rock pile, waste rock containment cell, and adjoining areas that were affected by the construction process were then seeded and fertilized. The containment cell area after the completion of seeding is shown in Fig. 7.

Fig. 7. Containment Cell After Seeding



Closure

The construction of the containment cell was hindered by poor weather throughout the project. Excavation of the previously existing upper and lower treatment ponds was made difficult by both the intermittent rainfall and seepage from the excavation floor. The rainfall and seepage also caused difficulties in embankment construction.

Cold conditions were encountered during the installation of the PVC cap. This made unrolling the panels difficult, as the PVC became significantly stiffer and less workable. The low temperatures were particularly problematic because of the thickness of the PVC used. Some of the panels were placed during, or shortly after light snowfalls, which also impeded their placement and welding.

Despite all of these factors the construction was completed before the onset of the 2000/2001 winter.

References

Teck Corporation, 1995. Cirque Project Prefeasibility Report.

Ministry of Energy and Mines 1998. Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in BC