CHALLENGES IN THE CONSTRUCTION OF A LINED VALLEY FILL COPPER LEACHING FACILITY SILVER BELL MINING, LLC – MARANA, ARIZONA (24)

Expositor	Día	Hora	Sala
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In 2012, Asarco LLC (Asarco) identified the need for additional leaching capacity at its Silver Bell mine in Tucson, Arizona. Due to spatial constraints and site environmental conditions, it was determined that a lined leaching facility would be necessary to prevent contamination of the underlying aquifer. In 2015-2016, Asarco, LLC constructed a double lined valley fill copper leaching facility at Silver Bell Mine in Marana, Arizona, USA. This paper focuses on the considerations incorporated into the design of a lined leaching facility as well as the challenges that were encountered during the construction phase of the project. Some of the considerations in the design of the facility included the placement of the liner system on 2:1 slopes, the necessity of mid slope seams, bedding preparation and solution collection piping system design. The challenges during construction focus mainly on the prevention of liner slippage, placement of liner during hot weather and its effect on the liner and detection of liner leaks prior to commissioning and other challenges not considered in the design phase.

Keywords: *copper leaching; liner; leach pad construction.*

Introduction

In 2012, the Silver Bell mine, owned by Asarco LLC (Asarco) identified the need for future additional leaching capacity. The Silver Bell mine, located west of Marana, Arizona is surrounded by the Ironwood Forest National Monument, limiting its capability for expansion. Due to spatial constraints and site environmental conditions, it was determined that a lined valley fill leach pad would be designed to meet aquifer protection permit standards required by the state of Arizona.

The design consisted of a double liner system which included an 80mil textured linear low-density polyethylene (LLDPE) liner over a geosynthetic clay liner (GCL) over a 15 cm thick layer of 2.5 cm minus Bedding Fill. Slopes of the valley were graded to 2 horizontal-to-1 vertical (2H:1V) or flatter. Within the leach pad area, 4.8 km of solution collection pipes were supported by 9.5 mm minus acid resistant rock pipe bedding fill and overliner drain fill (ODF) consisting of a 0.6 m thick layer of 38 mm minus graded acid resistant rock fill.

This paper will focus on the key considerations that, through previous experience, were included in the design by the engineering firms involved. Considerations in the design concentrated on adequate friction coefficient in the placement of GCL and LLDPE liners on steep slopes. In addition, the grading design required slope lengths in excess of the length of rolls of LLDPE liner. This required consideration of mid slope seams in the design. The prevention of collapse of the solution collection piping under a 150 m heap height was another design concern. Pipe failure modelling was conducted to determine the appropriate pipe rating.

Despite extensive design and technical review, unanticipated challenges were encountered during the construction phase of the project. Construction challenges included the placement of liner on steep slopes during summer. Small wrinkles in the liner would expand and contract causing liner slippage prior to placement of ODF to provide stability. Liner tension was experienced necessitating an alternative method of anchoring the liner and placing of ODF on slopes. Selection of material to be used as ODF had to be non-degrading in the presence of acid to maintain structural support of solution collection piping. To alleviate concerns of heavy equipment puncturing or tearing the liner, a leak location survey was performed over the entire lined area of the leach pad. This survey accurately detected leaks which were then repaired prior to commissioning. The first phase of the leaching facility went into operation in December 2016.

Initial grading of leach pad area

Engineering and Design Phase Considerations

From prefeasibility through issuance of final plans and specifications, the engineering firms involved in the design of the leaching facility addressed many considerations from optimized grading of the area to ore characterization, geotechnical stability and environmental protection. Some the key challenges involved the site terrain and the necessity of designing a facility placed on the steep slopes of the valley.

The design criteria included:

1. Three phase leach pad, with Phase 1 consisting of a 0.4 km^2 area.

2. Local hauling/regrading earthworks: 382,000 m^3.
3. Slopes: nearly flat to slopes more than 2 horizontal-to-1 vertical (2H:1V).
4. Double Liner System: 80mil textured linear low-density polyethylene (LLDPE) over geosynthetic clay liner over 15 cm thick layer of 2.5 cm minus Bedding Fill.
5. Solution Collection Pipes: 4.8 km of perforated high density polyethylene (HDPE) pipe.
6. Pipe Bedding Fill: 9.5 mm minus acid resistant rock fill around HDPE collection pipes.
7. Overliner Drain Fill (ODF): 0.6m thick layer of 38 mm minus graded acid resistant rock fill.

Grading Design

The grading design incorporated continuous slopes up to 137 m long.

Areas with slopes between 2H:1V and 2.5H:1V were necessary to optimize the capacity of the facility and cut/fill balance. A prepared bedding for liner placement required the identification of suitable onsite material. A 15cm layer of crushed and screened 2.5 cm minus material recovered during ODF production was used for bedding fill.

Deployment of liner on long steep slopes.

Liner Design

Environmental regulations required the placement of a 30 cm thick clay layer exhibiting permeability of no more than $1x10^{-6}$ cm/s. Due to the lack of onsite sources of clay, an equivalency demonstration allowed for the substitution of a geosynthetic clay liner (GCL). The selected upper liner was an 80 mil LLDPE liner.

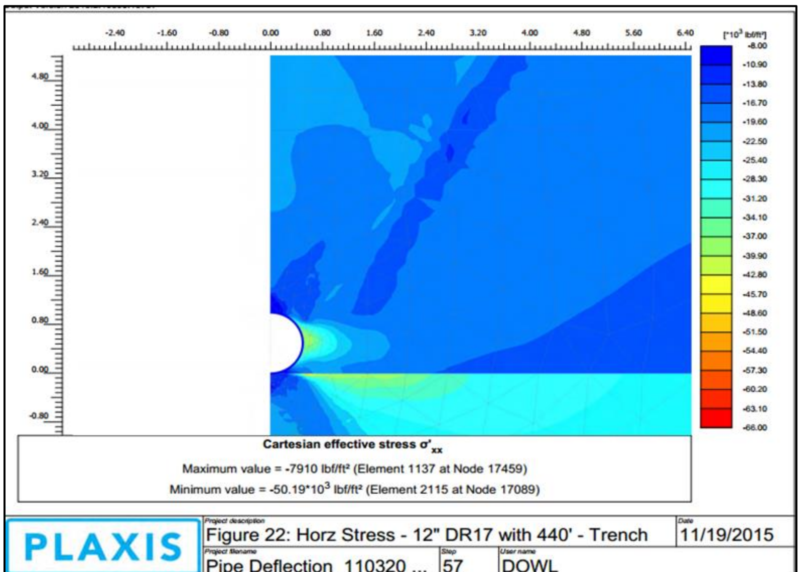
The original design called for LLDPE liner rolls up to 137 m in length for placement on long slopes as steep as 2:1. Due to slope geometry, the liner design was modified to include mid slope seams. Concerns with this design included reduced strength at horizontal seams on end-to-end LLDPE panels going up slopes, and long slope lengths without benches to break up the loading. To the extent possible, horizontal seams were minimized on slopes, and if installed, were staggered from adjacent panels' seams. Due to the rolling nature of the slopes, angled seams and horizontal seams could not be avoided entirely. The long 137 m design slopes were re-designed to be shorter and flatter to minimize the long panel lengths and to minimize the potential for liner movement during ODF placement.

Solution Collection Piping System

To prevent solution head build up on the liner, a solution collection and drainage system underlying the ore pile was required. At total build out, the leach pad will be 150 m high. To prevent pipe collapse under such weight, pipe deflection modeling using the finite element analysis program Plaxis was conducted. Though compaction of the ODF near the pipe increases the risk of damage to the liner,

studies have shown that it is imperative for structural integrity of the pipe (Smith, 2004). For heap facilities, the ODF also needs to remain as permeable as possible even under compression from high loads and degradation due to leaching.

Pipe Support Fill placement around collection pipes is a key factor in bridging external loads and preventing pipe collapse. Based on the conclusions of this modeling, trenches for the deepest parts of the heap were added to the design as well as hand compaction of pipe support fill under the solution collection pipe drain system.



Finite Element Analysis results exhibiting pipe deflection on unsupported pipe.

Overliner Drain Fill

Extensive pre-construction studies and testing was performed for on- site waste rock, and other source to find a suitable material for ODF.

Solution collection piping with ODF placement over liner and pipe

The purpose of ODF to protect the solution collection piping system and LLDPE liner from damage during placement of ore and for the life of the pad with ever increasing loads. A suitable source of ODF needed to be acid resistant

to prevent breakdown over time causing external loading support loss on the collection pipes, and pipe collapse. On-site pit waste rock composed of Alaskite was found to provide the best combination of acid resistance, gradation

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and cost savings. Pipe Support Fill was screened from the Alaskite ODF material during crushing. At locations of collection pipe tees, eccentric reducers were included in the design to maintain intimate contact between the pipe and subgrade and eliminate voids under pipes that could create load concentration points. Geogrid fabric was also placed within the ODF over tees to provide additional strength and load distribution at structural weak points.

Construction Challenges

As with any major project, unanticipated challenges were encountered during the construction phase of the project. These challenges were met and overcome by the dedicated engineers, contractors and construction managers on the project.

<u>Liner Movement</u>

Probably the greatest challenge encountered during the construction of the facility was the unanticipated movement of the liner down the slopes prior to anchoring with ODF. The liner installation phase of the project started in June 2016. During the day, the liner would heat up to temperatures in excess of 77°C. Changes in temperatures caused high expansion (due to heat) and contraction (due to cooling). Air pockets under small wrinkles in the liner would

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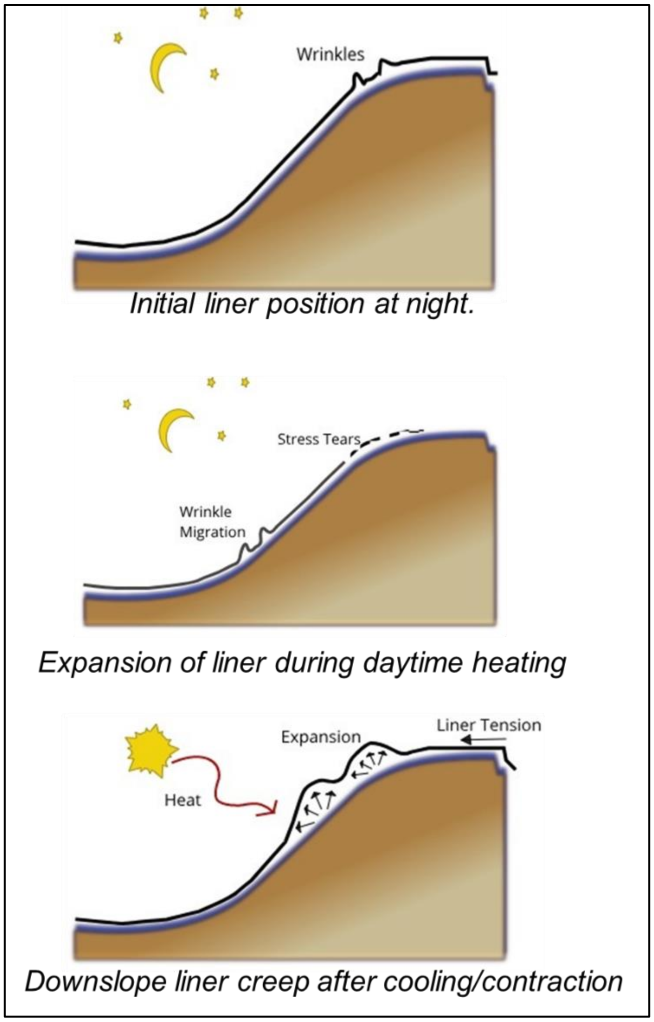
expand during the day and cause wrinkles that were larger than acceptable as well as cause a "trampoline" effect near the top of the slope. This "trampoline" effect reduced the amount of geomembrane in contact with the GCL. Because the liner was secure in the anchor trench, the air expanded in the heat in between the GCL and geomembrane which reduced the surface contact needed to stay within the friction safety factor. When 8 cm diameter holes were cut in the geomembrane, significant amounts of hot, high pressure air was observed escaping out of each hole. At night the wrinkles would cool and contract further down the slope causing the liner to creep down to the toe of slopes. In as little as 3 days, all excess liner was at the toe of the slope and the liner anchored at the top of the slope was in tension, a condition that will cause liner failure. Due to the contractor's work phasing and the lag in crushing/screening of ODF material, lined slope areas initially sat uncovered for over a month while the expansion/contraction process continued.



Top liner sections moved in areas where temporary anchoring was not sufficient.

In areas where top anchoring was sufficient, the liner movement created trampoline effect in areas where grading low spots were resent. Initially, ODF placement was performed during the day.

Evidence of liner failure at anchor trench.

Wrinkles in excess of 15 cm were removed prior to ODF placement. In one steep 2H:1V slope section, the liner experienced significant movement and ODF placement on steep slope sections was temporarily suspended. The liner continued to move and thinning and tension tears occurred at the top, uncovered portions of the slope. Other steep 2H:1V slope sections showed some signs of movement, but not as significant. .
Slope geometry may have added to liner movement in the section with significant Movement.

Night time ODF placement

Liner Movement Investigation/Resolutions

Liner samples were collected and tested at various orientations, moisture conditions, and loading to confirm design stability evaluations. Testing indicated that lower friction between the LLDPE and GCL resulted when the textured LLDPE was dragged for long distances over the GCL (i.e., combing of the GCL fibers). The combed GCL decreased the peak friction strength by 11% in testing. A smooth Geomembrane was tested and showed no difference in strength so the combing effect was isolated to the GCL properties. Evaluations also indicated that textured LLDPE experienced an increase in peak friction strength and a decrease in residual strength at extreme temperatures.

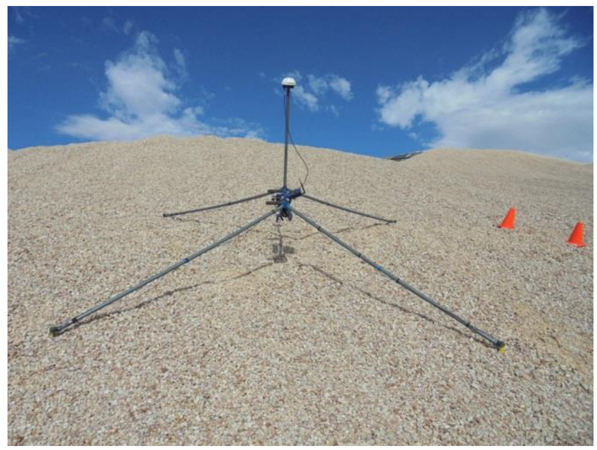
Three test panels were performed at night (27°C liner temperature) on slopes of 1.9H:1V to 2.6H:1V, with an average slope of 2.0H:1V. Test panels were 15 m wide, 30 m long and un-anchored on all sides. ODF was pushed up-slope in a 0.6 m lift using D6 and D8 dozers. Dozers pushed full blade loads of material, which represented the lowest factor of safety conditions determined in slope stability engineering evaluations. Total liner movement of 60 mm or less was noted on the test panels during ODF placement. After ODF placement, brake tests were performed by backing the dozers down slope and stopping quickly, which resulted in very little liner movement. The observed liner movement occurred during ODF placement, which stabilized after the ODF was in-place. Measurements indicated that in some instances, the LLDPE liner moved up-slope as small wrinkles were pushed up by ODF placement. The fourth test panel was performed where ODF was pushed all the way up to the top of the slope. The maximum slope on this test was 2.1H:1V. The test panel results were used to determine ODF placement criteria for the remainder of the project:

- ODF placement at night, or with liner temperatures less than 30°C.
- LLDPE was placed using slip-sheets to prevent combing of the GCL fibers during placement.
- Liners were not installed in the anchor trenches until after ODF was placed. This allowed the air to expand and contract as needed without expanding in the void between the liners.
- All liner wrinkles greater than 10 cm were cut/removed and repaired.
- Initially, ODF was pushed in 15 m wide strips spaced 45 m apart to avoid compounded dozer loading. After favorable results on the fourth test panel, spacing was later reduced to 23 m.
- If tension was noted in the liner, the top and/or sides of the LLDPE along the placement area were cut to relieve tension (GCL was left un-cut). LLDPE liner was then re-welded after ODF placement was complete.
- ODF placement up slopes was limited to D6 low ground pressure (LGP) equipment only.
- To the extent possible, ODF placement was to be performed within 3 days of liner placement on slopes greater than 3.3H:1V during hot weather. As liner placement progressed into the cooler time of the year, the timeframe was relaxed.
- During placement quality assurance personnel continuously monitored liner for movement, wrinkles and/or tension and need for corrective action.

- One area of the leach pad where earthwork had not been completed was regraded to 2.5H:1V slope and the length of the slope was reduced to 75 m.
- In one area with 1.8H:1V slope, ODF thickness was increased to 0.8 m.

Using the above approach, ODF placement was completed for the remainder of the project without significant liner movement. The section of 2H:1V slopes that had experienced significant liner movement was repaired as follows:

- ODF was stripped from the slope until the leading edge of the liner failure was exposed.
- LLDPE liner in thinned areas was cut and thickness measured using a digital caliper.
- Damaged and thinned LLDPE liner was removed.
- GCL liner was inspected for movement, integrity and saturation. GCL did not show signs of movement, and saturated GCL was removed.
- New LLDPE and GCL was placed, leaving the top edge of LLDPE un-welded to allow for tension relief during ODF placement.
- ODF was pushed up-slope using the new placement criteria.
- Below and within the slippage area, newly mined ore was placed to create a buttress to prevent potential additional liner movement until future ore placement/leaching.
- Within remaining sections steeper than 2.5H:1V, 36" diameter HDPE sections were placed within the ODF, leaving the liner exposed to allow for surveying to monitor for movement.



Leak Testing

Leak detection testing was performed over the entire leach pad using the dipole method according to ASTM standard D7007. Copper wires were installed between the GCL and LLDPE. Water was sprayed to wet the ODF. The locations of leaks were determined when an electrical circuit was completed between the wetted ODF and copper wire under the LLDPE. Some of the limitations in this test method included:

- Testing the ODF required large volumes of water from water trucks which were limited in access after ODF was placed. *Typical tear/leak discovered with testing.*
- Some leak repairs were difficult to perform in areas where the LLDPE liner was under tension due to liner movement.
- Leak repair also required equipment removal of ODF, which created potential for additional liner damage/repair.
- Areas where liner was not in contact with subgrade (i.e., wrinkles) could not be tested with this method.

Overall, the testing was successfully able to determine the location of leaks and enable repair prior to commissioning.

Leak location equipment

Conclusion/Lessons Learned

Critical considerations in the design and construction of valley fill leach pads should include:

- Short lengths of slope up to 2H:1V can safely be incorporated with proper design and installation.
- A thicker layer of ODF on steeper slopes can offset costs of cutting back slopes and can be utilized as long as the liner temperature and wrinkles are managed, GCL combing is eliminated, and the design at the base of the slope includes a smooth transition..
- Limit slope lengths to less than the length of LLPDE roll length. If longer, consideration should be given to staggered seams.
- Consider the use of white liner to extend the amount of time that geomembrane can be left exposed prior to ODF placement.
- Solution collection piping support is critical to prevent pipe collapse. Use of nondecrepitating rock as ODF with compaction under pipe to support pipe.
- Temperature and time of year is a major consideration in the liner and ODF installation phase. In hot climates, installation should occur during cooler times of the year to minimize tension or wrinkles in the liner and maintain maximum contact with the underlying surface.
- Slope geometry has a significant effect on liner stability. Slopes should be as uniform as possible (both horizontally and vertically) and designed to prevent locations of steep, incised valleys.
- Leak detection testing using the dipole method is an effective means to detect tears and holes in a liner post placement.

References

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