Backfilling Depleted Open Pit Mines with Lined Landfills, Tailings Impoundments, and Ore Heap Leach Pads for Reduced Closure Costs

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ABSTRACT:
Landfills, tailings impoundments and heap leach pads are the largest and highest geomembrane lined fill structures in the world. The lined structures require large areas for storage and containment of solid wastes, precious or base metal mill waste tailings and ore heap fill materials. Municipal waste disposal landfills in modern times are considering the use of depleted open pit mines in remote areas away from the cities to allow for more efficient use of nearby city land space and natural resources. Lined tailings impoundments and leach pads could also be located within depleted mine pit excavations for reduced overall mine site disturbance.

This paper discusses the recent historic use and primary engineering concerns and benefits in lining, backfilling and operating depleted open pit mine excavations for containment of solid waste, tailings and ore heap fills.

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1. INTRODUCTION

The major mine disturbance areas related to open pit mining operations include the excavated mine pit limits, the surrounding mine waste dump piles from overburden (non-ore) stripping excavations, and the tailings impoundment or heap leach facilities. The tailings impoundments and leach pads are typically lined in modern times. A partial or complete backfilling of any depleted mine pit areas with these lined facilities, where practical, would significantly decrease the overall mine disturbance areas resulting in lower reclamation costs at closure. The post-mining backfill of open pit mine excavations with lined solid waste landfills is a relatively new concept as well, beginning in the late 1990’s.

The steep pit wall excavation slopes and the natural groundwater conditions above the mine pit bottom limits are the two greatest engineering design challenges to consider in lining and backfilling an open pit mine excavation. Several mine pits have been lined and backfilled for solid waste landfill and tailings impoundment slurry disposal operations in recent times. Several lined mine pit heap leach designs have been considered in the past, however there are no known lined mine pit heaps being constructed to the present day. An example of an active open pit mine with surrounding waste piles, tailing impoundment and leach pad facilities is shown in Photo 1.

This article will present case history examples of the recent lined and backfilled mine pits for solid waste landfill and tailings impoundment disposal, as well as the general engineering design considerations for potential backfilling of lined mine pits for waste disposal and ore heap leach operations.

2. Case Histories of Lined Facilities in Mine Pits

2.1 General

The open pit mines have historically been left in an open condition during operations to closure, unless unstable wall conditions warranted partial backfilling to complete the pit ore excavations. In some cases, the pit bottom limits were partially backfilled to above the natural groundwater level, where practical, to prevent ponding of water at closure or to stabilize waste dump slopes around the pit wall limits. Most open pit walls are constructed to a safety factor of 1 to extract as much ore from the ground with the least amount of stripping to expose the ore body.

The backfilling of mine pits with lined landfills, tailings impoundments and heap leach pads, where practical, would significantly reduce the mine disturbance area and related reclamation closure costs. In addition, mine pit backfilling makes efficient use of the excavated storage space with full facility containment within the natural ground versus constructing above ground dams, site grading fills and diversion channels for facility containment. Known case histories of lined mine pit facilities by this author are presented in this section.

2.2 Lined Landfills for Mine Pit Backfill

The lined landfill operations in the 1980's included numerous excavated cells constructed below ground level and lined with geomembrane liner, clay soil liner, or a combination of both geomembrane and clay liner as a composite liner system for the disposal of solid wastes. Excavated slopes were generally flattened as required for placement of the compacted low permeability clay soil liner. The excavated cell side slopes were steepened in the 1990's to present day, where geosynthetic clay liners (GCL) began to be accepted as an equivalent or better replacement to the clay soil liner. A steepened GCL and geomembrane lined valley wall slope with a flatter conventional clayey soil and liner at the base of the steep slope are shown in Figure 2.

The first abandoned open pit mine quarry excavation to be lined and backfilled with municipal solid waste was the Bristol landfill located in Bristol, Virginia. The open pit quarry included near vertical bedrock walls at more than 300 ft (100 m) high. A mine pit haul road ramp extended from the mine pit rim to the pit bottom for truck access and removal of excavated rock materials, until the mine operations ended sometime before 1990. The mine pit quarry was converted to a lined landfill operation by 1998, as shown in Figure 3 (1997 photo taken from www.bristol.org).

The near vertical rugged rock quarry pit walls were essentially the most extreme engineering challenge known to date for placement of the geomembrane liner system. The rock walls were pre-scaled of loose rock debris and covered with safety wire mesh screen in 1996 and 1997 to prevent rock fall during liner construction and for anchoring the liner system. A layer of geotextile fabric and HDPE geomembrane liner was placed on the lower pit side walls with plans to extend the pit wall liner upward in phases to maintain fully lined conditions above the rising active landfill surface. The mine pit floor was backfilled with a low permeability clayey soil for a conventional landfill bottom composite liner and overlying leachate drainage system.

2.3 Lined Tailings Impoundments for Mine Pit Backfill

Several underground mines have been backfilled with tailings backfill since the 1980's for economic, safety or mine closure reasons. Tailings backfill in completed underground mine workings included paste or thickened tailings materials mixed with cement and other stabilizing additives, which reduced the required amount of tailings to be stored in above ground impoundment facilities.

Numerous open pit mines, natural lakes and sea coast areas have been historically backfilled with unlined tailings disposal as well. More mines are adopting the use of compacted earth and rock fill dams with geomembrane liner systems in modern times for tailings disposal with long term containment and improved protection of baseline groundwater conditions. Lined tailings impoundment containment within mine waste piles has been a common practice at several open pit mines in Nevada since the early 1990's. However, open pit mines have not historically been used for lined tailings impoundment disposal until recent times. An example of a conventional above ground lined tailings impoundment contained by compacted earth fill dams in the mid 1980's is shown in Figure 4.

The first geomembrane lined mine pit backfilled with conventional tailings was the El Valle mine pit located in Austurias, Northern Spain. The gold mine pit was depleted of ore adjacent to other on-going nearby active mine pit operations by 2003. In 2004 the bottom portion of the 500 to 1,700 ft (152 to 518 m) deep mine pit was backfilled to above the existing groundwater conditions with a low permeability clayey waste rock site grading fill in preparation for geomembrane liner placement. The clayey mine waste materials were taken from local mine stripping operations to expose the deeper ore materials. The El Valle tailings impoundment at startup of tailings disposal operations is shown in Figure 5.

The clayey site grading fill in the mine pit bottom limits allowed for dry construction liner installation above the existing or dewatered mine pit ground water levels. Sufficient compacted clayey subgrade fill was placed adjacent to the steep pit walls at startup to allow for perimeter access roads and future lined tailings impoundment expansion raises. A woven geotextile fabric was placed between the geomembrane liner and the clayey rock and soil subgrade to cushion the liner from puncture on the occasional larger cobble sized rocks. The tailings impoundment liner consisted of a 60 mil (1.5 mm) HDPE liner. Tailings disposal within the geomembrane lined impoundment commenced in 2005 with conventional slurry tailings disposal.

2.4 Lined Leach Pads for Mine Pit Backfill

This author is aware of only one known lined mine pit leach pad operation to date that was constructed within the open pit limit. The lined pad was constructed in 1984 on a relatively small scale as a pilot test pad in southwest New Mexico, USA. According to mine personnel, the test pad was located in a depleted side pit wall bench area within a larger copper mine pit limit and lined with 80 mil (2.0 mm) HDPE liner. The geomembrane liner was covered with about 5 million tons of low-grade run-of-mine ore dump fill and included sufficient area downhill of the lined pad limits for gravity leach solution drainage to an external lined process pond sump. The pilot leach pad and open pit mine are shown in Figure 6.

Since the 1984 test pad construction, no known lined and backfilled mine pit leach pads have been constructed to date at the bottom of depleted open pit mine excavations. However, there are several copper mines in New Mexico and Arizona, USA considering this option, particularly where mine conditions indicate it is economic to construct for both operations and closure.

3. Liner Design Considerations for In-Pit Backfilling

3.1 General

The primary engineering concerns in lining, backfilling and operating a depleted open pit mine for containment of waste fill or ore heap materials include: 1) installation and protection of the liner below the natural ground water conditions; and 2) stabilizing any steep pit rock wall slopes that are near a safety factor of 1. The major benefits of backfilling with a lined facility include: 1) an overall reduction in required liner area for storage of materials; 2) minimal risk of spills with the elimination of above ground containment dams and watershed diversions (particularly in high seismic earthquake zones); and 3) a significant reduction in overall mine disturbance areas for less reclamation and closure costs. The in-pit liner containment becomes more practical and cost effective, if included early in the operation plans to allow use of nearby stripped mine waste materials for bottom pit site grading preparation and steep pit wall stabilization for liner placement.

The tailings impoundments and leach pad facilities are generally associated with open pit mining operations and located in close proximity to the excavated mine pit and stripped non-ore mine waste pile limits. As the open pit mine is developed, some mine sites have depleted open pit ore zone pockets or multiple open pit sites in close proximity to each other that may be amenable to lining and backfilling for tailings disposal or ore heap leaching. The overall steep pit wall slopes of 35 to 55 degrees with benches in most hard rock mining operations create an engineering challenge for liner systems. Waste rock materials from continued mine overburden stripping operations can provide economic site grading fill to stabilize the floor and pit walls for dry geomembrane liner installation with the liner system protecting the underlying groundwater conditions.

The pit wall stability would continue to improve, as lined backfill operations buttress and bury the exposed mine pit wall slopes. Each type of geomembrane lined facility has differing engineering concerns, as listed below.

3.2 Lined Landfill for In-Pit Backfill

The municipal solid waste landfills typically require a robust multiple liner system for leachate containment, collection and recovery operations. A drain fill cover and daily solid waste soil cover or temporary synthetic geotextile cover are common for solid waste disposal. Modern landfills within the last 10 years are beginning to apply irrigated water or recirculated leachate flows to the top surface or by deep well injection to accelerate settlement, waste bio-degradation, and methane gas collection (Breitenbach and Thiel 2005). This may require multiple cells and graded gravity flow to sump pump collection locations at the bottom of the landfill for recirculation throughout the life of the facilities.

Landfill liner systems prefer dry ground conditions with deep groundwater levels for no direct connection and transport of any leachate contamination away from the lined facilities. Therefore, most open pit mines would require some type of continuous groundwater dewatering and monitoring system beneath an in-pit liner or the option of mine waste site grading fill to raise the liner subgrade above the seasonal high natural groundwater level conditions.

In general, the lined solid waste landfill for in-pit backfill would include the following major engineering concerns: Dry and graded subgrade conditions beneath the liner system with separate drainage cells as required; Stable mine pit walls for liner stability and safe access to dispose of waste materials; Protection of the liner system from any differential subgrade settlement or puncture; Protection of the liner system from overlying waste material placement and puncture with adequate bottom and side wall drain fill or geotextile cover; Minimize hydraulic heads on the bottom liner system with a leachate collection and recirculation sump pump system; and Design deep sump well systems with redundancy and protection of the liner from the “pile driving affect” of vertical well down-drag forces during waste settlement (side wall wells along the liner slope are optional).

3.3 Lined Tailings Impoundment for In-Pit Backfill

The lined tailings impoundment may include storage of several types of tailings waste materials including conventional slurry disposal (about 45 to 55 percent solids to water by weight in a liquefied pipeline slurry discharge), thickened tails slurry disposal (about 60 to 70 percent solids to water for less water pool recirculation back to the plant), and other variations of dry filter and paste tailings transported by truck, conveyor or positive displacement pipeline pumping disposal to the lined impoundment.

Pipeline slurry disposal around the perimeter of the lined impoundment is the most common practice in the mining industry with milled and depleted waste tailings generally consisting of fine grained sand, silt and clay particles. The fine tailings materials form a perimeter sand and silt beach with settled solids forming a water pool in the interior. Decanted water from the water pool is recirculated back to the plant for reuse in operations. In general, the lined tailings impoundment for in-pit backfill would include the following major engineering concerns: Dry subgrade conditions for liner construction with any required dewatering as needed to maintain the operational tailings beach and water pool surface above the subgrade groundwater level at all times to closure; Liner subgrade backfill above bottom groundwater conditions or temporary dewatering is optional, until the lined tailings backfill is raised above the groundwater level; Stable mine pit walls for liner stability and safe access to dispose of waste materials; Protection of the liner system from any differential subgrade settlement or puncture; Partial drain cover above the liner to minimize hydraulic heads on the bottom liner system (optional for maximizing tailings drainage and consolidation) with a bottom leachate collection and recirculation sump pump system; and Design the optional deep sump well systems with redundancy and protection of the liner from vertical well down-drag forces during waste settlement (side wall wells along the liner slope are optional).

3.4 Lined Heap Leach Pad for In-Pit Backfill

The lined heap leach pad operations differ from solid waste landfills and tailings impoundments in that the liner backfill material is a crushed rock or run-of-mine ore fill placed in controlled lifts and leached to remove precious and base metals in solution for processing at the plant. The ore leaching process requires a fully drained granular ore material or an agglomerated fine grained material that allows percolation of solutions by gravity flow to a sump pump system. Some mines have the ability to provide a gravity solution collection tunnel from the pit bottom to an exterior pond system for pumping to the process plant.

The leach pad can tolerate some exterior hydraulic heads on the liner system (any liner leaks below the groundwater level would allow inflow of groundwater into the heap fill and collection sumps for full containment of solutions). However, any significant dilution of the collected process solutions by external groundwater inflow would be an operational concern in extracting the target metals. Leach pads also require large startup ore lift placement areas for maximizing active leach cycle time to recover the target metals in solution, ideally before the next ore lift can be placed for continued leaching. Copper mines can develop multiple interlift liner raises to optimize solution collection and pump return efficiency (reduce hydraulic head from the pit sump to the process plant). Gold and silver operations require rinsing of cyanide from the spent ore materials, and therefore generally do not operate with interlift liner systems.

In general, the lined heap leach pad for in-pit backfill would include the following major engineering concerns: Dry subgrade conditions for liner construction with any required dewatering as needed to maintain low external hydraulic heads on the bottom pad liner system; liner subgrade backfill above bottom groundwater conditions or temporary dewatering is optional depending on the performance of the liner system in preventing any groundwater inflow leaks mixing with the process solution; stable mine pit walls for liner stability and safe access ramps to stack ore materials in controlled lifts by conveyor or truck dumping; protection of the liner system from any differential subgrade settlement or puncture; protection of the liner system from overlying ore rock material placement and puncture with adequate bottom and side wall drain fill or geotextile liner cover; sufficient startup stack surface area for active leaching cycles (ore lift surface area will increase with each subsequent in-pit lift placement); partial drain cover above the liner to minimize hydraulic heads on the bottom liner system with a bottom leachate collection and recirculation sump pump system; and design the mandatory deep sump well systems with redundancy and protection of the liner from vertical well down-drag forces during waste settlement (side wall wells or tunnel gravity drainage systems optional for solution recovery).

4.0 Conclusions

Open pit mines have seen recent use of the below ground excavation limits for storage of solid waste landfill, tailings and ore heap leach fills. The primary engineering concerns in lining, backfilling and operating a depleted open pit mine for containment of waste or ore heap fill materials include: 1) providing dry construction conditions for installation and backfilling of the liner system below the natural ground water conditions; and 2) stabilizing typical 35 to 55 degree steep hard rock mining pit wall slopes that are near a safety factor of 1.

The major benefits of using lined facilities for mine pit backfill include: 1) the overall reduction in required liner area for storage of materials; 2) minimal risk of spills (particularly in high seismic earthquake zones) with the elimination of above ground containment dams; and 3) a significant reduction in overall mine disturbance areas for less reclamation and closure costs. The in-pit containment becomes more practical and cost effective, if included in the operation plans for early use of nearby stripped mine waste materials for site grading preparation and pit wall stabilization during the life of mine.

REFERENCES

Breitenbach, A.J. and Thiel, R.S. (2005), A Tale of Two Conditions: Heap Leach Pad Versus Landfill Liner Strengths, GRI-19 Geosynthetics 2005 Conference, Las Vegas, Nevada.

Bristol Landfill Photo (1997), www.bristolva.org/WasteDisposal, Bristol, Virginia.

Figure 1 – Active open pit copper mine operation showing a mine waste (non-ore) rock pile in the foreground with a heap leach pad and tailings impoundment in the background surrounding a relatively steep walled open pit excavation.

Figure 2 – Steep valley wall lined with composite geosynthetic clay liner (GCL) and geomembrane and valley floor being prepared with conventional compacted clayey soil liner in preparation for geomembrane liner installation.

Figure 3 – Bristol landfill liner construction in open pit quarry with conventional composite compacted clay and geomembrane across the valley floor. Note groundwater conditions shown in the bottom right side below the landfill liner system.

Figure 4 – Conventional above ground lined tailings impoundment contained by a compacted earthfill dam embankment in South Carolina, USA. Perimeter pipeline tailings slurry disposal is shown above the geomembrane liner with an interior water pool pumped in a water return pipeline back to the plant facilities for reuse.

Figure 5 – Lined tailings impoundment for startup conventional tailings slurry disposal within a depleted open pit gold mine in Northern Spain

Figure 6 – Lined leach pad constructed in lower left portion of open pit copper mine in 1994. A similar low grade ore heap is shown in the foreground adjacent to the mine pit wall limits.