

# HEAP LEACH PAD DESIGN AND CONSTRUCTION PRACTICES IN THE 21<sup>ST</sup> CENTURY

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## INTRODUCTION

The mining industry has been using geomembrane liners for fill structures and ponds for more than 30 years, starting with brine solar evaporation ponds in Utah in the early 1970's. Geomembrane liners for heap leach operations have been around for more than 25 years, starting with gold and silver heap leach pads in Western Montana and Southern California in 1979. Geomembrane lined copper heap leach pads started in Mexico and Arizona as early as 1983, however the copper heap leach dump operations have gradually changed to geomembrane lined foundations and interlift liners within the last 5 to 10 years. An early geomembrane lined copper heap leach operation in Arizona is shown on **Photo 1**.

This article presents a general discussion of current leach pad design and construction practices, based on lessons learned over the past 30 years by engineers, contractors and mine operators in the mining industry.

## HEAP CONSTRUCTION

The construction of heap fills involves the placement of precious or base metal ore materials in controlled individual loose and relatively dry fill lifts stacked at the natural angle-of-repose. The heap ore lifts are typically stacked at 15 to 30 feet (5 to 10 meters) in thickness and leached to typical maximum heights in the range of 100 to 200 feet (30 to 60 meters). The highest heap stacks to date exceed 500 feet (150 meters) above the geomembrane lined pad foundation. A geomembrane lined leach pad with a stacked and leached ore heap in the background is shown on **Photo 2**.

Each ore lift surface is wetted uniformly during leaching by using irrigation drip emitters or sprinkler sprays. Leaching is generally conducted in 30 to 120 day or longer leach cycles with barren or recirculated alkaline (gold and silver) or acidic (copper) process solutions.

The maximum rock size of the granular ore materials range from large run of mine cobble and boulder rock fragments to fine crushed sand and gravel particles. The crusher operations may include agglomeration as needed to provide a more efficient distribution of fines (minus No. 200 sieve size material) for improved permeability and recovery of the target metals. The individual ore lifts are offset with benches along the exterior slope, as required for establishing the overall stable design slopes for operations.

## HISTORIC SLOPE STABILITY PERFORMANCE

The historic slope stability performance of geomembrane lined fill structures mainly concerns the downhill side of the heap stack on the outward sloping lined pad foundation. No known heap slope failures have occurred on the uphill side of lined pads to date. The past slope failures on geomembrane lined fill structures, such as solid waste landfills, heap leach pads, and cover fill caps, have shown that liner induced slides generally occur at the planar geomembrane liner interface contact with weaker underliner or overliner materials.

One of the earliest and most known geomembrane induced slope failure in the landfill industry was the Kettleman Hills landfill slope failure in Northern California in 1988 (Mitchell et al. 1990). Several other major landfill slope failures occurred between 1988 and 1997 in North America, Europe, Africa and South America (Koerner and Soong 1999).

The most known leach pad liner failure in the mining industry is Summitville in Southern Colorado. Although no known heap stack failures occurred at Summitville, there was a possibility that the exposed pad liner may have been damaged by an avalanche debris slide during early stacking operations. Several less known leach pad heap slope failures occurred between 1985 and 1993 at mine sites in North America, South America and Australia (Breitenbach 1997). The Northridge earthquake in Southern California in 1994 (Matasovic et al. 1995) and subsequent earthquakes in Chile and Peru in 1995 and 1996 gave some insight into the seismic behavior and stability of high fills on geomembrane liner systems.

The historic performance of fill structures on geomembrane liner systems indicates that translational (lateral movement) wedge slip failures generally occur along the planar liner interface contact with soils or geosynthetic materials. However, heap leach slope failures differ from landfill failures in that the slope failure generally occurs during the initial ore heap lift placement operations, rather than at the higher heap fill lift heights. The only exceptions for higher fills, concerning both lined heap leach pads and landfills, include either weak foundation conditions beneath the lined facility or excessive hydraulic conditions within the containment materials above the liner system.

The planar liner surface strength can be improved for heap stack stability in several ways, including stair-step pad grade construction on steep topography (subgrade slopes steeper than 5 percent) and installing textured versus smooth geomembrane liner in critical pad surface areas. An example of both of these slope strengthening practices is shown on **Photo 3**. The textured liner shown in the photo has a green tint color added by the manufacturer for blending visually with the surrounding terrain.

## **PAD LINER SYSTEM**

The most preferred pad liner system in current heap leach practice is the composite liner with an overlying drain cover fill (Breitenbach 1999). The primary purpose of the composite pad liner design is to prevent the loss of pad and pond process solutions from the lined facilities for both economic and environmental reasons. The composite liner consists of a low permeability subgrade soil in direct contact with the geomembrane liner, as shown on **Photo 4**.

The drain cover fill provides protection to the exposed geomembrane liner and is generally supplemented with drain pipes at controlled spacing. Relatively clean crushed ore materials are often used as the drain cover fill as much as practical. The drain cover fill and drain pipes provide both rapid drainage recovery of the pregnant solutions to the process pond and plant facilities, as well as maintaining low hydraulic heads above the pad liner. A protective drain cover operation is shown on **Photo 5**.

### **Underliner Bedding Fill Design**

The underlying fine-grained bedding fill provides a secondary containment barrier for leach solutions and also protects the overlying geomembrane liner from subgrade rock puncture. The bedding fill design generally includes the following: 1) a fine-grained low-permeability soil with a maximum minus 3/4-inch (19-mm) rock size; 2) a moisture content within optimum to two percent dry of optimum moisture content (ASTM D-698); 3) a compacted firm and smooth surface; and 4) a top surface graded to drain to solution collection systems for positive gravity drainage.

### **Geomembrane Liner Design**

A geomembrane liner beneath heap leach stack provides a primary containment barrier for leach solutions with proper liner selection and installation. The leach pad geomembrane liner selection must consider all engineering, construction, and operational aspects of the project for the most effective overall liner to prevent leakage.

Factors in design affecting the selection of the most suitable geomembrane liner at each project site include: 1) the liner type; 2) the liner thickness; 3) the surface roughness (smooth versus textured); 4) the initial loading conditions from the cover fill or first ore lift; 5) the final loading conditions from the

maximum heap height load; and 6) an adequate engineering construction quality assurance (CQA) program for acceptable liner installation, seaming and testing for strength and water tightness.

A geomembrane liner evaluation is generally performed by the engineer to select the most economical and functional liner to accommodate site specific conditions. An overall liner evaluation for selection typically compares the pros and cons of the various geomembrane liner types used in heap leach operations from a combined design, construction, and operation point of view. Some of the more important engineering aspects in liner selection include geomembrane liner resistance to rock puncture, adequate liner friction strengths for slope stability, elongation capacity to withstand foundation settlements under high heap loads, and long-term exposure to climatic conditions. The three most common types of geomembrane liners used in the past for heap leach pads include high density polyethylene (HDPE), linear low density polyethylene (LLDPE or VLDPE) and PVC geomembrane liners. The more flexible geomembrane liners are preferred in current practice to improve the liner strength and puncture resistance of the liner system.

### **Overliner Drain Cover Fill Design**

The general design requirements for overlying liner cover fills consider several aspects including: 1) the maximum rock particle size at the liner surface contact; 2) the rock particle shape; 3) the cover fill lift thickness; 4) adequate solution drainage; 5) available or planned equipment for placement and spreading; and 6) the type of geomembrane liner for withstanding initial dynamic construction traffic live loads and final heap dead loads. The cover fills are generally supplemented with perforated drain pipes for maintaining an order of magnitude higher permeability in the drain fill compared to the overlying ore heap fills. The supplemental drain pipes are designed and spaced by the engineer to transport the operational leach and storm infiltration flows, while maintaining low hydraulic heads on the composite liner system.

A secondary purpose for the drain cover fill is liner protection from exposure to the climate and biological or man made conditions. The climate conditions mainly include high winds, temperature fluctuations and exposure to sunlight (UV light). The biological or man made conditions generally include animal hoof or claw damage, equipment or foot traffic, and mine blast fly rock. The geomembrane liners are recommended to be covered on large pad areas as soon as practical with drain fill or ore materials to minimize the potential for stress-cracking, wind movement, folding, sun light degradation and other problems related to exposed liner conditions. Examples of liner exposure problems are shown on **Photos 6 to 9**.

### **WATER BALANCE LINER RAIN COATS**

A relatively new liner concept used in the Phillipines, Central America and South America since the early to mid 1990's in high rainfall areas is the use of liner rain coats on leached and spent ore slopes to minimize storm runoff flows from the heap stack to the lined collection ponds. This concept allows storm ponds to be sized for startup operation flow volumes, and potentially remain the same size with subsequent lined pad expansions. The liners are temporary for operations and are eventually removed for closure of the facilities. A liner rain coat on the exterior heap stack slopes is shown in **Photo 10**.

### **INTERLIFT LINERS**

Interlift liners have been used on copper heap leach pads mainly in South America starting in the mid 1990's for more economic metal recovery reasons. After the lower lifts have been stacked by conveyor or truck and leached, the spent ore top surface is typically smoothed and shaped to drain in preparation for placement of the interlift liner and drain system. The interlift liner may be designed to partially leak and releach the lower lifts, while more than 90 percent of the leach solution flow in the fresh ore lift is collected and routed through the drain system to the process ponds. Gold and silver heap leach operations require rinsing for closure, and therefore use lined on-off pads or expansion pads rather than interlift liners to continue heap stacking operations.

## CONCLUSIONS

The geomembrane lined heap leach pads for the 21<sup>st</sup> century have estimated operating time periods of 10 years or more compared to the more typical past gold and silver heap leach operational time periods of 3 to 5 years. Therefore this author believes the current design and construction practices should consider the long term durability of the geomembrane liner as the most important liner design consideration for high fills, which includes geomembrane liner stability and exposure concerns for compatibility with site specific conditions. Other major concerns (chemical compatibility, rock puncture, etc.) can easily be tested and verified in the laboratory under simulated worst-case conditions. Due to the excellent elongation properties of the flexible geomembrane liners, foundation settlement has been a lesser concern to date, but may need to be considered in the design of site grading foundation fills to maintain positive gravity drainage beneath the high fill loads.

The geomembrane liner surface generally has lower friction strength characteristics compared to the overlying fill and underlying foundation materials, thus the liner system requires special design and operational considerations to prevent instability

Geomembrane pad liners of all types are recommended to be covered with an overlying cover fill or ore materials for adequate long-term protection from exposure. The various geomembrane liner exposure problems may include ultra-violet (sunlight) sensitivity, thermal expansion and contraction with temperature changes, high wind and snow movement, equipment and foot traffic punctures, potential blast fly rock from the mine, and oversized rock roll-out onto the liner surface during haul road ramp construction and first ore lift placement. The geomembrane liners are relatively thin membranes and need all the cover fill protection the owner can afford. It is difficult to damage the geomembrane liner after it has been properly covered by suitable cover fill materials.

The success of lined heap leach projects can be directly attributed to an experienced team effort by the design engineer, followed by the construction liner fabricator/installer and testing personnel, and finishing with the operator of the facilities.

## REFERENCES

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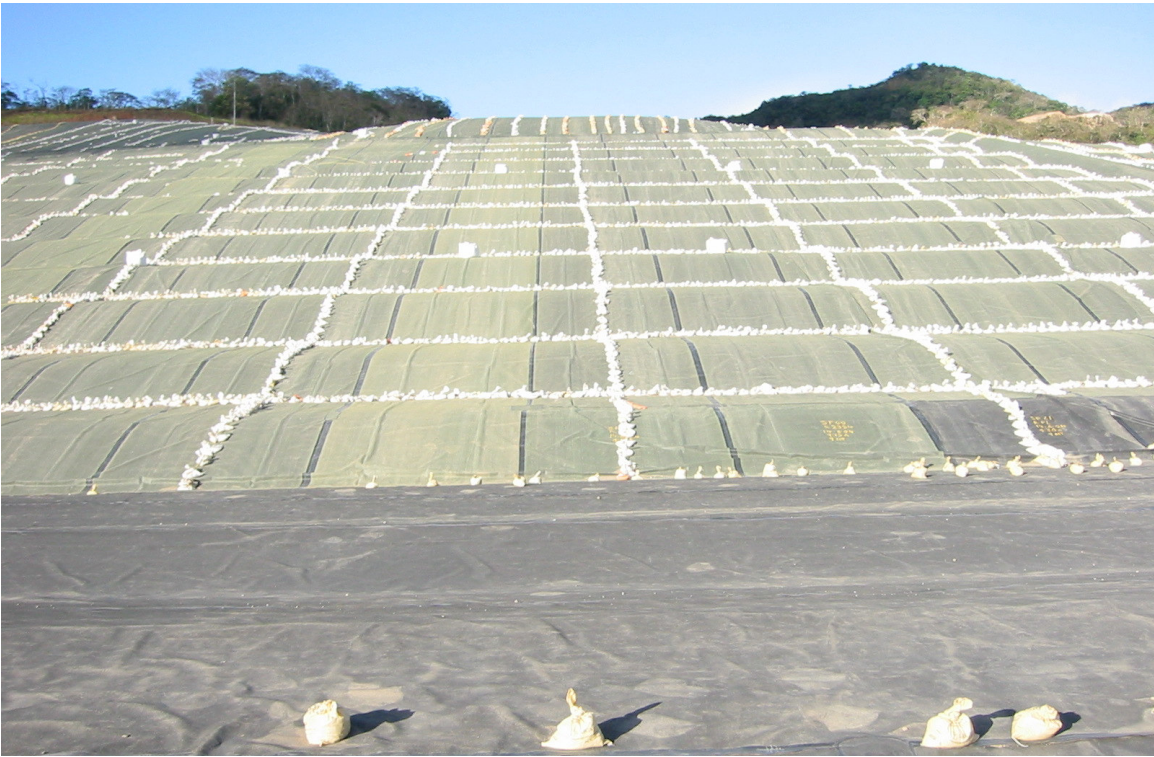
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**PHOTO 1 – GEOMEMBRANE LINED COPPER HEAP LEACH OPERATION IN ARIZONA**



**PHOTO 2 – GEOMEMBRANE LINED GOLD HEAP LEACH OPERATION IN MONTANA**



**PHOTO 3 – BENCHED LEACH PAD SURFACE AND TEXTURED LINER FOR STRENGTH**



**PHOTO 4 – COMPOSITE CLAYEY SOIL AND GEOMEMBRANE LINER SYSTEM**



**PHOTO 5 – DRAIN COVER FILL PLACEMENT ON THE PAD LINER SURFACE**



**PHOTO 6 – STRESS CRACK IN HDPE LINER OCCURED ON LARGE EXPOSED PAD AREA**



**PHOTO 7 – HAIL AND BLAST FLY ROCK DAMAGE CAN OCCUR ON EXPOSED LINER**



**PHOTO 8 – HIGH WINDS REQUIRE SAND BAGS TO HOLD LINER UNTIL COVERED**



**PHOTO 9 – LARGE BOULDER ROLLED ONTO GEOMEMBRANE LINER SURFACE**



**PHOTO 10 – HEAP SLOPE COVERED BY GEOMEMBRANE LINER RAIN COAT**