Impact of geomembrane liners on the design and construction of tailings dams

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ABSTRACT: Tailings impoundments in recent time are becoming the largest geomembrane-lined fill structures in the world. Geomembrane liners were first used on large water storage dams in Europe as early as 1959 and subsequently on mining projects for tailings impoundments and evaporation ponds in the USA by the 1970's. Tailings impoundments typically store fine waste particles of earth fill materials from milling operations by open launder or pipeline slurry disposal around the perimeter limits. The hydraulically-deposited fine particles of sand, silt and clay-sized tailings form a tailings "beach" sloping downward from single or multiple disposal points to an interior water pool. The water pool is generally located away from the dam, where practical, with the pool water re-circulated back to the plant for reuse of the water in milling operations. Geomembrane-lined dams revolutionized the design and construction aspects of tailings dams by providing an impervious synthetic liner barrier on the upstream slope. The impervious liner barrier with adequate protection and filter control provides stable and fully drained conditions within the dam fill. This paper discusses the impact of geomembrane liners on the design and construction of downstream method tailings dams, including the use of co-disposal low cost mine waste rock fills, dump piles and depleted areas of open pit excavations in lined dam construction.

1 INTRODUCTION

The primary purpose for tailings impoundments in the mining industry is to store milling waste materials in the most economic and practical manner, while minimizing the environmental impact from operations to closure. This generally includes the slurry transport of tailings either by open launder channels and drop boxes for gravity flow or by pumping and pipelines to a selected impoundment site capable of storing the planned ultimate tailings tonnage. Tailings dams are constructed in phases with a startup dam to contain the settled tailings and associated water pool and storm runoff freeboard events at the lowest startup capital cost versus long-term operating costs.

Conventional or thickened (non-segregating) slurry transport of tailings solids and water is the most economic plant site operation and transport disposal method used in current practice. The tailings slurry transport allows the impoundment sites to be located more distant from the mine and mill plant areas, if it needed, for a better selection of remote disposal sites. However, most tailings dam sites are located within 1 to 5 km of the mine ore body primarily to allow use of the low-cost mine pit overburden stripping excavations as earth and rock borrow materials in dam construction.

Current disposal practice also includes the development of the tailings impoundment and dam within the mine waste piles for co-disposal, as well as within any depleted open mine pit excavations for reduced dam construction and mine disturbance costs at closure. Where mine site conditions are restricted in available land area or water supply, higher plant facility costs for paste or dry filter tailings disposal have been considered at a reduced tailings dam cost and smaller impoundment storage footprint.

This discussion will present an overview history of lined tailings impoundments and related geomembrane-lined structures, followed by a discussion on the impacts of the geomembrane liner on the design and construction of downstream method tailings dams.

2 HISTORY OF LINED TAILINGS IMPOUNDMENTS

The earliest non-synthetic lined tailings dams in the USA began in the mid 1850's during the Gold Rush era in the Sierras of Northern California. The dams were constructed with loose rock dump fills and lined on the upstream face with wooden timbers as water proofing to contain reservoir water and washed sediment tailings for gold placer sluicing operations. As the gold mining operations increased in size, the upstream dam facing for water proofing changed from timbers on hand-placed rock wall slopes in the late 1800's to steel, concrete, or asphaltic concrete on higher multiple lift loose rock dump dams in the 1910's to 1940's (Taylor 1977).

The transition from non-synthetic to synthetic geomembrane-lined dams began with small ponds and diversion canals in the 1940's and 1950's to large reservoirs by the 1960's. The first known geomembrane-lined reservoir dam of significant size is the 33 m high Sabetta Dam in Italy constructed in 1959 using a butyl rubber liner (Sembenelli et al 1998). One of the first geomembrane-lined tailings dams known to this author is the 30 m deep Sweetwater Dam Cell 1 in Wyoming, USA constructed in 1976 with scrim-reinforced chlorinated sulfonated polyethylene (CSPE) liner on the interior dam slopes connected to PVC liner on the impoundment bottom for subsequent hydraulic slurry disposal and containment of mill waste uranium tailing. Several smaller geomembrane-lined mining ponds have been constructed before 1976, including solution mining potash evaporation ponds in Utah, USA constructed in 1970 to 1974 using CSPE (exposed slopes) and PVC (salt covered bottom) liners. A high density polyethylene (HDPE) lined gold tailings impoundment cell constructed in the 1980's is shown in Figure 1.

Other related uses of geomembrane liners in reservoir and tailings dam construction included seepage barriers within the dam fill core and for prevention of downstream toe liquefaction during high seismic (earthquake) events. The first known use of geomembrane liners as a low permeability dam core zone is the TS Ranch Dam constructed in 1989 in Nevada, USA using very low density polyethylene (VLDPE) liner and bentonite-layered geosynthetic clay liner (GCL) in the cutoff trench. The geomembrane liner extended above the trench within the central core of the 20 m high dam for mine pit dewatering storage. Numerous tailings dams have been constructed with a partial or fully geomembrane-lined impoundment to present day. Several tailings dams have been constructed in Peru, in particular with geomembrane-lined upstream slopes since 1996, to enhance the dam stability and prevent liquefaction during any severe earthquake events.

Figure 1 – Geomembrane-lined gold tailings impoundment cell contained by a compacted earth fill tailings starter dam embankment in Nevada, USA in 1988.

Tailings dams have been constructed with mine waste stripping excavation materials starting generally in the 1950's at large copper mines, where rail cars or mine haul trucks dumped excavated earth and rock fill materials at the dam sites. Lined tailings impoundment containment within controlled mine waste dump piles has been a common practice at several open pit mines starting in Nevada, USA in the early 1990's. Open pit mines have not historically been used for lined tailings and solid waste impoundment disposal until recent times. A geomembrane-lined depleted rock quarry mine pit for solid waste disposal in Virginia, USA in 1998 is shown in Figure 2.

Figure 2 – Geomembrane-lined depleted open pit mine quarry being prepared for solid waste landfill disposal in Virginia, USA in 1998. Reference: Bristol Landfill Photo (1997), www.bristolva.org/WasteDisposal, Bristol, Virginia.

A geomembrane-lined depleted mine pit for gold tailings disposal in Northern Spain in 2004 is shown in Figure 3.

Figure 3 – Geomembrane-lined tailings impoundment for 2004 startup conventional tailings slurry disposal within a depleted open pit gold mine in 2004 in Austurias, Northern Spain.

3 GEOMEMBRANE LINED TAILINGS DAM DESIGN

3.1 *General*

The use of impervious geomembrane liners on the upstream face of tailings dams in combination with tailings beach disposal along the upstream face have significantly improved both the upstream and downstream slope stability conditions compared to conventional water storage dams (Breitenbach 2008). This section discusses the improved lined tailings dam design conditions for seepage control, stability, embankment geometry and co-disposal opportunities in waste piles. A geomembrane-lined downstream method construction tailings dam and impoundment is shown in Figure 4. This Figure shows that the perimeter pipeline tailings slurry disposal is above the geomembrane liner. An access road to an interior water pool is shown in the central impoundment area for floating barge pumping and water return pipeline back to the plant facilities for reuse.

3.2 *Seepage Control*

The good news about a properly designed and protected geomembrane liner system is that it becomes an impervious seepage barrier on the upstream dam face in combination with a relatively low permeability tailings beach fill cover subsequently placed above the liner surface over time. With the water pool located away from the dam after startup slurry disposal operations, the liner system and peripheral tailings beach cover ensure that the perimeter dam fills will remain fully drained during tailings disposal operations to closure.

Figure 4- Geomembrane-lined gold tailings impoundment contained by a compacted earth fill tailings dam embankment in South Caroline, USA, in 1987.

Tailings seepage control may include partially lined tailings impoundments or unlined impoundments with the startup dam upstream face fully lined. Partially lined impoundments focus mainly on limiting seepage into the low lying natural drainage areas at startup of operations, where the water pool may be in direct contact with pervious soils or exposed bedrock open fracture systems. Lined starter dam slopes generally include tie-in to a foundation cutoff trench or other types of seepage barriers, until the fine grained tailings beach can be developed for stable unlined dam raises above the starter dam crest level.

Where water pools are located in the dam area, seepage control in lined dams include an underlying composite fill zone consisting of underlying low permeability bedding fill and transition filter fill to prevent any piping through the dam fill. The underlying bedding fill zone is generally constructed with fine grained clayey fills or geosynthetic clay liners (GCL), as a backup containment system in case the geomembrane liner is inadvertently damaged from punctures or seam separations before it can be buried by the peripheral hydraulic tailings beach fill. Any slow leakage through a potential hole in the geomembrane liner would be minimized over time by the development of a low permeability “filter cake” zone in the drained tailings beach fill surrounding the liner opening.

The geomembrane liners are protected from the climate conditions after burial by tailings, however dam and foundation settlements beneath the liner system for continued tailings disposal and raised dam fill loads will cause some elongation of the geomembrane liner over time. The amount of anticipated elongation is generally well within the range of currently manufactured liners, and in particular the more flexible (less crystalline) geomembrane liners.

3.3 *Stability Analysis*

A leak proof geomembrane-lined slope can remain stable at very steep slope angles with the engineering concerns being the surficial movement of underlying fill materials from wave action, the surface drag movement of liners under gravity, temperature change and wave action forces, and the risk of subsequent liner tears that would cause wetting and slumping of materials on a steep dam slope.

Most of these steep slope concerns are further eliminated with the use of thick composite soil liners or thin synthetic GCL bentonite mats on slopes as steep as 1.5H:1V. Fully geomembrane-lined tailings dam slopes have drained effective stress conditions with no concern for rapid drawdown instability or liquefaction potential during severe earthquake conditions. The dam liner system may tie into foundation seepage barriers or underdrains, depending on site specific conditions for foundation stability and seepage control.

3.4 *Embankment Geometry*

A geomembrane lined dam with upstream zones of underlying composite soil liners and transition filter fill layers will allow the exterior slopes to become steeper compared to an unlined dam and remain stable. This assumes the foundation and ground water conditions are suitable to support the dam fill loads and granular fills are available for placement of controlled and compacted dam fill lifts.

In addition, a geomembrane lined upstream dam slope allows for flexibility in the selection of available impoundment and mine pit borrow materials for dam fill construction with less zone fill requirements in the central and downstream sections of the dam. The reduction in zoned fill requirements also makes the lined dam geometry more amenable to phased downstream dam raise construction.

3.5 *Co-disposal in Mine Waste Piles*

Geomembrane lined tailings dams have been successfully constructed and operated within mine waste tailings piles since the mid 1990’s. The liner system can be designed with flexibility to withstand high consolidation loads over time on the underlying less compacted waste dump fills. The waste pile zone directly beneath the impoundment liner system may have some borrow material selection, lift control and moisture conditioning requirements, depending on the ultimate thickness of the tailings beach loads.

The mine waste pile itself becomes the dam structure with the liner system containing a composite underlying soil and transition filter fill layer to the more coarse rock dump materials. The more fine mine waste rock materials are selectively placed adjacent to the filter zone with a transition to more coarse rock materials in thicker dump lifts in the downhill direction away from the impoundment liner system.

4 CONCLUSION

Geomembrane-lined large water storage dams have been constructed since the 1950’s with geomembrane lined tailings dams constructed since the 1970’s. The geomembrane liner allows fully drained high strength dam embankment conditions to develop with the upstream slope eventually covered by the tailings beach hydraulic fills.

The major benefits of geomembrane-lined tailings dams versus conventional unlined dams include: 1) an impervious barrier on the upstream slope for a significant improvement in startup dam seepage control; 2) fully drained dam fill conditions for upstream and downstream slope stability; 3) reduced risk of liquefaction during earthquake conditions; 4) reduced zone fill requirements for improved impoundment and mine waste fill borrow selection and in subsequent downstream dam raise construction; and 5) greater flexibility and reduction in dam construction costs by incorporating the lined tailings impoundment within co-disposal mine waste piles.

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