Figure 1 View across the basin of Marula's new tailings dam, which is under construction

Challenges and opportunities with lined tailings dams

Linda Spies
Senior Geotechnical Engineer
SRK Consulting
lspies@srk.co.za

Tailings are currently classified by South African environmental legislation as potentially hazardous waste. When assessed against the legislated Waste Acceptance Criteria, platinum tailings are often classified as requiring a high-density polyethylene (HDPE) liner as a pollution-control barrier. This relatively new requirement brings environmental benefits, but does complicate the design, construction and operation of a tailings storage facility (tailings dam).

Traditionally, tailings dams in South Africa have been built on top of the in situ soils, which may have acted as a natural drainage medium for the tailings dam. Among the new challenges to be faced in tailings dam design and construction, then, is that all drainage must now be artificially added. Also, the stability of the tailings dam needs to be assessed in new ways to consider different possible failure mechanisms, and management of stormwater during construction must be carefully planned.

This article presents a case study that highlights how some of these challenges were addressed in a tailings dam project at Implat's Marula Platinum Mine, where an HDPE liner was included in the design.

LINERS FOR SOUTH AFRICAN TAILINGS DAMS

Under the regulations of the National Environmental Management Act (NEMA, Act 107 of 1998), waste such as tailings is assessed in terms of Waste Acceptance Criteria for Disposal to Landfill. In accordance with these regulations, various mineral residue deposits are found to require some type of geomembrane liner, and therefore a liner is being included in the construction of a growing number of new tailings dams.

The protection of water resources and the prevention of contamination are being prioritised, in preference to the traditional philosophy of mitigating the spread of contamination and pollution clean-up. A lining under a tailings dam prevents polluted leachate from seeping into the groundwater, and also allows more water in the tailings system to be captured and returned to the plant. This is particularly useful in a water-scarce country such as South Africa.

However, since the tailings dam industry has not always included liners in its design or construction, there is still much to learn, even by seasoned tailings consultants and contractors. Although there are proposed amendments to the regulations, which could see a possible

This article is a shortened version of a paper that the author presented at the SAIMM Tailings Storage Conference held in February 2020.

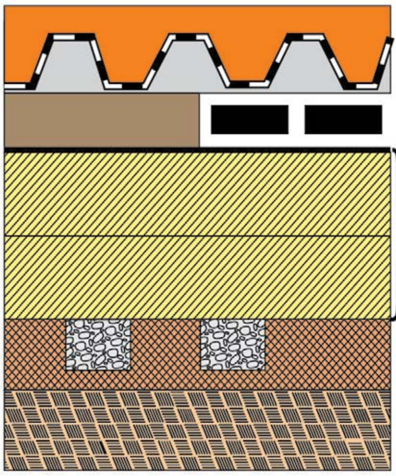

Figure 2 Class C landfill engineering requirements (NEMA Reg 636)

future relaxation of the regulations on a case-by-case basis following a risk-based approach, such regulations have yet to be promulgated into law. In the meantime, the current regulations apply to the disposal of tailings in the same way they apply to the disposal of any other waste to landfill.

NEW TAILINGS DAM FOR MARULA MINE

Marula Platinum Mine near Burgersfort in Limpopo Province is constructing a new tailings dam to accommodate the mine's future tailings production. With a footprint of 77 hectares, the new tailings dam is planned to abut the existing unlined facility, which is approaching the end of its life. It will rise to a maximum height of 47 m and is planned for a design life of 20 years.

The site for the new tailings dam inclines gently, at an approximate slope of 1:60, downwards toward the north-west. The geology of the site comprises part of the Eastern Limb of the Bushveld Igneous Complex (BIC). Typically, the top 1.5 m of the soil profile consists of topsoil and firm-to-stiff clay of residual norite – also known as black turf or black cotton soil. Beneath this, soft gabbro-norite rock is encountered. About 500 m to the west of the new facility is the Moopetsi River.

Since the new tailings dam will receive tailings from the same source as the existing tailings dam, its design is based on material properties derived from in situ and laboratory testing of the tailings on the existing tailings dam. Various studies were undertaken, which show that the Marula tailings classify as Type 3 waste, according to NEMA Regulation 635 (2013). This is due mainly to the tailings leachate having elevated nitrate ($N0_3$) levels.

According to Regulation 636, a Class C landfill barrier system, or a barrier of equivalent performance, is required for disposal of Type 3 waste. The components that make up a standard Class C barrier system consist of a 1.5 mm thick HDPE geomembrane over a 300 mm thick clay liner as barrier components, and geotextile or fine material to preserve the integrity of the barrier components. The system also includes vital drainage installed both above and below the barrier components.

DESIGN CHALLENGES

Drainage

As soon as a low-permeability barrier system is introduced as part of a tailings dam design, drainage needs to be carefully considered. It is generally the drains that add to the cost of a lined tailings dam design, rather than the cost of the liner material itself.

The above-liner drains draw down the phreatic surface, which is loosely equivalent to the water table, for structural stability purposes. They also reduce the head on the liner, thus reducing the seepage gradient, and decrease the liquefaction potential of the tailings material. Above-liner drains need to be designed for protection from stormwater damage. The design must also ensure that the fine tailings that are first deposited over the drains do not cause them to blind, as this would render them useless for the remainder of the tailings dam's life.

The under-liner drains mitigate against construction issues related to water trapped beneath the liner forming "whales" or softening the foundations. They also provide a leakage-detection layer and, due to the abutment of the new tailings dam against the existing tailings dam, they drain seepage from the existing dam.

Various alternatives were considered for the drainage above and below the liner. The final drainage design consists of a herringbone structure of drains on a 50 m

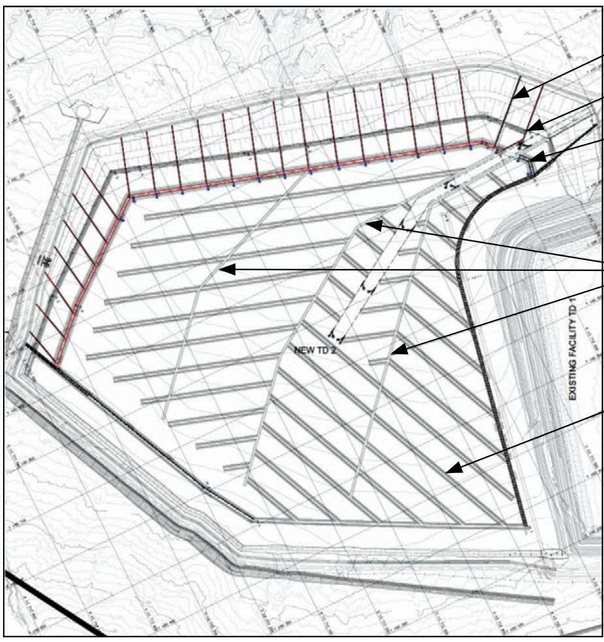

Figure 3 Above-liner drain layout

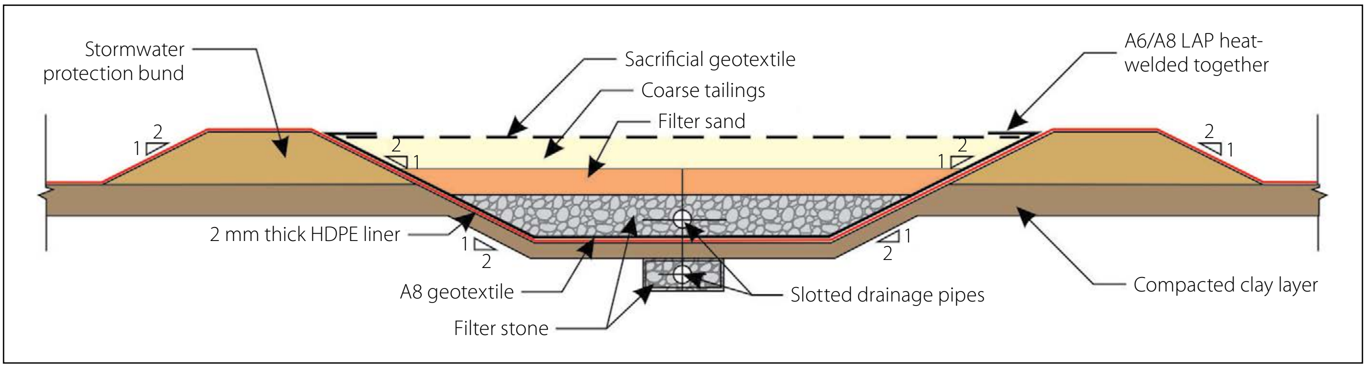

Figure 4 Section through a typical drain

spacing. Steady-state finite element seepage models confirmed that this spacing reduces the head on the liner to 5 metres. This reduces the seepage gradient and hence possible seepage across the liner.

Robust blanket and toe drains were included in the above-liner drainage. These are the primary drains responsible for drawing down the phreatic surface under the outer slope, which is required for structural stability of the tailings dam. The outlets from the blanket and toe drains are separate from the rest of the basin drainage, also on a 50 m spacing. This means that, in a worst-case scenario where some of the inner basin drains become blocked, the blanket and toe drains could continue to operate independently.

The herringbone drains across the basin of the tailings dam collect into three major arterials, which serve as outlets to these drains. In addition to reducing the head on the liner, these drains attempt to mimic the basal drainage observed through piezocone test work on the existing tailings dam. There, downward seepage in the tailings basin can flow (to a limited extent) into the in situ soils, which act as a natural drainage medium for the flows. In the lined tailings dam, however, drains that will permit equivalent flows need to be artificially added.

In a typical drain, there are 0.5 m high bunds, covered with the liner, on both sides of the drain to protect it from stormwater damage. Sacrificial geotextile, which is removed before deposition, temporarily covers the drain and also protects it from stormwater damage. A layer of coarse tailings is included as the top-most filter layer of the drain to prevent the sand layer of the drain from blinding were the finest tailings material to be deposited directly over it. A substantial geotextile (A8) is included in the drains between the lowest gravel filter layer and the geomembrane. This is to protect the geomembrane from being punctured by the gravel, and to limit strains in the geomembrane, which would reduce its service life.

Liner design

The liner design selected for this project consists of an HDPE geomembrane 2 mm

Figure 5 Construction of underdrains through the new tailings dam's starter wall

Figure 6 The Marula return water dam which is also being lined with HDPE as part of this project

thick overlying a compacted layer of clay 300 mm thick. The geomembrane exceeds the stipulated Class C landfill 1.5 mm thickness, and was chosen as it would be more robust and resistant to damage during installation and until the liner was covered everywhere with a protective layer of tailings. A double-sided textured liner was chosen beneath the crest of the tailings dam to improve the interface friction between the liner, the underlying clay and the overlying tailings.

Ensuring dam stability

The stability of a tailings dam is commonly determined using limit equilibrium methods. The dam and its underlying soil horizons are considered as one "combined structure" when undertaking slope stability analysis. A factor of safety (FoS) of more than 1.5 against large-scale slope failure is considered acceptable (under steady-state drained conditions) for the stability of the combined structure. If there are significantly weaker layers within the tailings dam or its underlying soil horizons, the failure slip circle will generally pass through these weaker layers.

In the mine's existing tailings facility, which is unlined, the black turf horizon presents a weak layer with a friction angle of 21°. In the case of the new lined facility, the weakest layer is the interface of the soils/tailings with the liner. This interface is taken to have a friction angle of 16°, based on specific shear interface testing which was undertaken on samples of the actual materials from site and the actual chosen liners. An overall outer slope of 1:4 is required to achieve an FoS of at least 1.5, which is flatter than the slope of 1:3 used in the existing facility. The flatter slope means a reduction in the airspace available for material storage within the sloped areas of the lined tailings dam compared with the unlined tailings dam.

The use of a double-sided textured liner beneath the crest of the tailings dam is also expected to improve the interface friction above the conservative design value of 16°. This will increase the level of confidence in the expectation that the material properties on site are at least as good as the design properties.

The geometry or width of the coarser, more permeable tailings, i.e. the outer desaturated zone, is known for the existing tailings dam from the results of piezocone test work undertaken there. By ensuring that the boundary conditions for the existing and new tailings dams are as similar as possible, knowledge of the tailings behaviour, i.e. the width of the outer desaturated zone on the existing tailings dam, can be inferred and applied to the new tailings dam.

QUALITY OF CONSTRUCTION

The success of a lined facility in limiting the seepage of leachate relies on all components of the facility being constructed to the highest standard. The liner is manufactured to high quality standards and micrometre accuracy, and is passed through numerous tests in accordance with GRI-GM13 before even leaving the factory. Once construction starts, much of this quality assurance can be lost if the same diligence is not applied during the installation process.

Each roll of liner that arrives on site comes with its own quality certificate, so it can be traced to a particular production batch at the factory if there is a problem during the site inspections. A panel layout is generated for the deployment of the liner panels, with each position in the layout carefully numbered. Many kilometres of welded seams between the panels need to be inspected and tested, and records need to be kept relating back to the panel layout. Such onerous quality assurance requirements during construction require a trained and meticulous workforce of quality inspectors.

PROTECTING AGAINST STORMWATER DAMAGE

The timing for the construction of this project is such that a large portion of the liner installation may need to be constructed during the rainy season. Stormwater can flow very rapidly over the liner as it does not have the roughness of the natural vegetation, and it can pond on top of the liner as it cannot infiltrate into the natural soils. High-speed stormwater flows and ponding of water can cause significant damage to the above-liner drainage system.

In addition to the drain-specific measures that have been taken to protect the drains from stormwater damage, a permanent stormwater cut-off trench has been included on the upslope eastern and southern sides of the facility. It is also likely that temporary cut-off trenches will be needed upslope of sections of the basin to protect the liner works as they are proceeding. In addition, intermediate penstocks have been included in the design near the lowest point of the basin to assist with decant of ponding stormwater during construction.

Figure 7 Rolls of HDPE stockpiled on site awaiting installation

SEQUENCING OF CONSTRUCTION

The sequencing of construction works around the installation of a liner is complex but important. Once the liner has been laid, traffic cannot be allowed to pass over it as this can damage the liner. Even pedestrian traffic must be limited and labourers educated: simply dropping a cigarette or a pen knife onto the liner can have serious consequences. With the herringbone drains spaced every 50 m, the liner and the drains have to be constructed concurrently; the liner cannot be trafficked over later to place drainage materials over it.

It is important to note that the liner cannot all be laid at once. Rather, placement of the liner will depend on the rate of the drain construction. The contractor either has to order shipments of liner in batches, which increases the risk that materials are not available on site when required, or they must store large quantities of liner on site for a long time. There are about nine months between the first liner and last liner being laid in the Marula tailings dam project programme.

Deterioration of the liner is a risk if it is stored for a long time exposed to the elements. Rolls of black liner can heat up considerably if ventilation is not allowed through the stacks of liner; the upper exposed surface of a liner was recorded to heat up to 83–86°C at midday at various sites in Limpopo. It was found that if the liner was covered with a thin layer of soil or tailings (about 100 mm), its temperature and the number of associated wrinkles reduced significantly. Getting a layer of tailings over the Marula tailings dam's liner as soon as practical is a priority.

COMMISSIONING

Although the project is not yet at the commissioning phase, there are areas that will require careful attention at that stage. For instance, protection of the drains against blinding is a challenge when commissioning any tailings dam. In a lined tailings dam, there are many more drains that need to be protected, so this activity needs to be that much more rigorous. There is also a need to remove the sacrificial geotextile covering every drain before depositing over it. The geotextile has not been designed as a filter layer, but instead is in place to protect the other filter layers from eroding.

In conclusion, the requirement for liners under new tailings dams clearly brings benefits that should be embraced, including the opportunity for mines to become more water-efficient within the tailings system. However, the requirement adds considerable complexity to dam design and construction which will involve a steep learning curve. □

Project team	
Client	Marula Platinum, Implats Group
Contractor	Fraser Alexander Construction
Consultant	SRK Consulting