A diverse approach in geosynthetic barrier systems to ensure environmental compliance of existing TSF’s

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Abstract

Following the publication and implementation of Global Industry Standards for Tailings Management (GISTM), on new and existing Tailing Storage Facilities (TSF), the growing demand for environmental compliance and innovative barrier systems are constantly on the rise. This paper aims to present the design considerations and challenges of a diverse multi-layered barrier system that has been proposed to underlie the buttressing of an existing TSF. The design for the barrier system follows the waste classification of the tailings – Type 1 and slag – Type 3, of which the slag material will be used to construct the buttress surrounding the TSF. Given the site topography and geology, various tests were conducted along with advanced stability modelling, to render a safe and suitable design. As part of the barrier design requirements, consideration was further given to improve the existing drainage systems on site, to accommodate the increased catchment area following construction of the buttress.

Keywords: *TSF, barrier, GISTM, slag, tailings*

1 Introduction

The global market for Tailing Storage Facilities (TSF) is currently experiencing significant growth due to the increasing demand of minerals and number of mining operations, and as such, mining owners have become deeply invested in seeking sustainable solutions that are both cost effective and environmentally compliant. Considering the implementation of the Global Industry Standard for Tailings Management (GISTM, 2020) to South African TSFs, mining owners are further encouraged to assess current stability conditions of existing TSFs and to take remediation measures in ensuring compliance with GISTM regulations.

Furthermore, the waste management framework published in the National Environmental Management Waste Act, (NEM:WA, 2008), emphasizes environmental compliance in respect to the concentration of pollutants and the receiving environment; thus requiring barrier systems to be tailored in achieving a low ratio of leakage to concentration of pollutants.

Consequently, this has left manufacturers and design engineers constantly challenged in providing innovative solutions for new TSFs and to improve current conditions of existing TSFs, that conform with the stringent mining regulations and environmental requirements. Geosynthetics has grown as part of the global trend due to its sustainable use, and increased footprint in the mining industry as part of basal lining for TSFs. Its performance in comparison to traditional barrier systems is continuously proven and well documented.

2 Project Background

An undisclosed site, consisting of two tailing dams, has undergone a thorough stability analysis of which the Factor of safety (FoS) was found to fall below current mine owned regulations and the respective FoS requirements. To further improve the FoS and the stability conditions of the TSF, the mining owner has resorted to buttress the facility as there are no space limitations, and the slag material (by-product from the mining operations) that will be used to construct the buttress, is readily available on site.

Given that the facility is existing, a barrier system has been installed at foundation level to limit groundwater contamination, and from the As-built drawings available, the following barrier details were noted, as presented in Table 1. The barrier systems are deemed to be serviceable based on groundwater monitoring on site and leakage measurements below the barrier system.

Table 1: Existing Barrier Systems

	Tailings Dam 1- *(Built in 2000)*	**Tailings Dam 2 - (*Built in 2012)***
Status	Dormant (No active deposition)	Active
Primary Barrier	1mm HDPE Geomembrane over a 300mm in situ Compacted Clay Liner (CCL), with a 450mm CCL below leakage collection system	2mm textured Geomembrane over a 10mm Geosynthetic Clay Liner (GCL), with a 300mm CCL
Secondary Barrier	None	1.5mm textured HDPE Geomembrane over a 300mm CCL

Note: CCL is sourced from residual soil present in the area, well known for its high PI (more than 30) and low shearing resistance.

3 Supplementary Barrier Systems

In accordance with waste classification Regulation (GN R634, 2013), the tailings classify to be Type 1 waste and the slag Type 3 waste, thus requiring Class A and Class C barriers respectively. Due to the lack of information available on the existing barrier design and the sensitive nature of the site, an innovative approach was taken in combining the new and existing barrier systems, with minimal disturbance. Hence, the Class A barrier system is achieved by installing the new liner as the primary liner and having the existing liner as the secondary liner.

Further challenges encountered were the accessibility of suitable clay material and the limited space between the TSF and toe wall, making it less workable for major construction operations. Thus, the use of a Geosynthetic Clay Liner (GCL) was preferred over a Compacted Clay Liner (CCL), of which the construction would have caused damage to the existing liner, and the compaction would have been challenging if inadequate.

3.1 Class A and Class C barriers

The Class A and Class C barrier systems were designed to operate independent from each other with separated waste streams, as the footprint of the buttress would result in a considerable cost if the Class A barrier system were to extend throughout.

As indicated in Figure 1, the presence of the existing toe wall is considered as the boundary between the Type 1 waste from the TSF and the Type 3 waste from the slag of buttress. The new Class A barrier system will be implemented at the toe of the TSF to the top of the starter berm, whereas the Class C barrier system will be implemented from the top of starter berm and extend for the full footprint of the buttress.

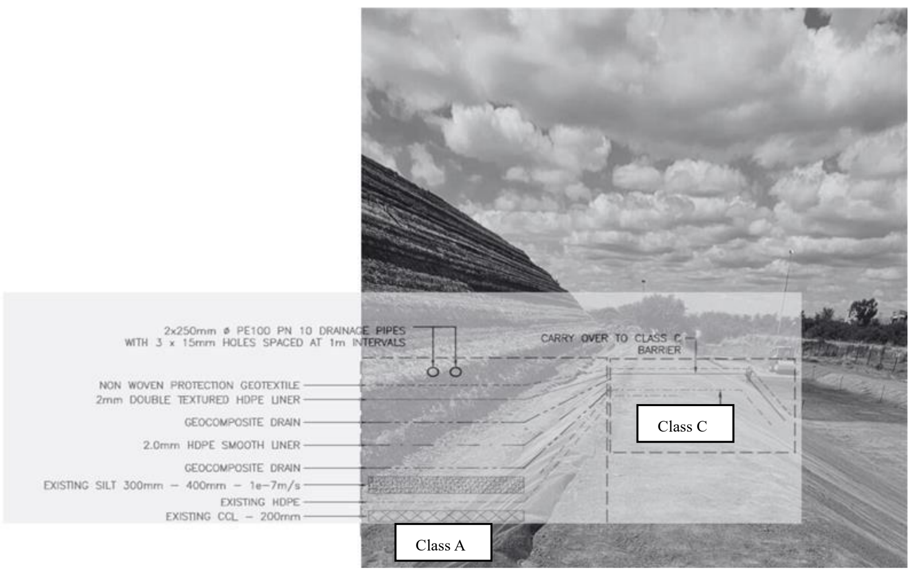

Fig. 1. New Class A and Class C barrier systems.

3.1.1 Class A barrier

The use of a GCL in the initially proposed Class A barrier design has been omitted as it has shown to have a low chemical compatibility with the leachate from the tailings, and from the laboratory tests conducted, the swell Required Minimum Distribution (RMD) calculation as per Benson and Meer (2009) indicated that the presence of divalent cations (Mg and Ca) would have compromised the reaction of the montmorillonite of the GCL, thus preventing swelling and resulting in a higher permeability.

Therefore, the final Class A barrier design as shown in Figure 1, consists of two 2mm HDPE geomembranes with a leak detection – geocomposite drain (equivalent to R636 specifications) between the geomembranes. The geocomposite drain specified does not include a geotextile backing for drainage purposes and will be connected to a solid HDPE pipe for future monitoring. As part of the design considerations for the Class A barrier system, a hydraulic design - seepage analysis was conducted in the dormant TSF. The analysis was considered a worst-case scenario of phreatic surface, plus a 1:50 year 1 day storm applied to calculate the total run-off from the tailings, of which the existing toe wall was deemed sufficiently high (500mm) to contain the flow.

3.1.2 Class C barrier

On the principle of containing the Type 1 waste upstream of the toe wall with the Class A barrier system, the Class C barrier system is developed as a single barrier to contain the Type 3 waste from the slag only. For a sufficient tie in, the HDPE geomembrane from the Class A barrier will overrun into the Class C barrier and will be placed on top of a GCL, covered with a geotextile. The preferred choice of using the GCL rather than a double HDPE was for stability as otherwise a double geomembrane with a drainage layer in between would have resulted in a much lower shear interface friction angle, with a wider footprint for the buttress.

A 1 500 g/m^2 polyester continuous filament protection geotextile has been specified to limit the amount of strain induced by the buttress material (D_{max} 24mm) onto the underlying geomembrane, of which in accordance with (Hornsey, 2023) emulates a 2 200 g/m^2 polypropylene geotextile. To further analyze the strain effects in the Geomembrane, a test pad was constructed as illustrated in Figure 2.

Fig. 2. Test pad under construction to monitor damage and strain in the Geomembrane.

From the test results obtained, after a 24-hour period with a load of 500kPa (full height of the buttress), the amount of strain generated in the geomembrane, using the (Tognon et al., 2000) method, calculated to be 1.5% which is below the threshold value of 3%, at which the geomembrane would exhibit stress cracking potentials (Seeger et al., 2003).

4 Permeability of founding materials

As the GCL was deemed to not perform as expected due to chemical compatibility, the permeability of the underlying in situ material became of critical importance in the design of the Class C barrier system. An ideal foundation should be impermeable to lowly permeable, to prevent an excessive amount of seepage in the event that leakage does occur. To form part of the Material Quality Assurance (MQA), double ring infiltrometer tests were conducted on various sections of the buttress footprint to determine the saturated hydraulic conductivity of the subgrade. The tests were conducted on various sections of the TSFs as the site contained a blend of in situ materials; mainly Residual Norite – Black Turf and Hillwash, containing traces of G5 material.

4.1 Double ring infiltrometer tests

The double ring infiltrometer test method is an adaption of Parr and Bertrand (1960), widely used to determine the infiltration rate of soils, which further enables the designer to calculate the permeability of the in-situ material. The permeability for different soil types is classified in Table 2.

Table 2. Soil classification based on values of saturated hydraulic conductivity K (Czech standard, CSN 721020)

Permeability	**Approx. range of saturated hydraulic conductivity (m s^{-1})**	**Soil Types**
Highly impermeable	< 10^{-10}	clays with low and medium plasticity, clays with high and extremely high plasticity
Impermeable	From 10^{-8} to 10^{-10}	gravel loams, gravel clays and sandy clays, loams with low and medium plasticity
Lowly (poorly) permeable	From 10^{-6} to 10^{-8}	sandy loams, loamy sands and clayey sands, loamy gravels and clayey gravels
Permeable	From 10^{-4} to 10^{-6}	sands and gravels, containing fine-grained fraction (5-15%)
Highly permeable	> 10^{-4}	sands and gravels without or with very low fine-grained fraction (<5%)

The test apparatus consists of two concentric metal rings as shown in Figure 3, which are driven into the soil about 5cm deep with a wooden piece and rubber hammer. Although measurements are only read from the inner cylinder by means of a measuring tape as shown in Figure 4, it is necessary to fill the outer cylinder to add a confining pressure to the inner cylinder and to ensure that the infiltration is downwards into the soil and not lost laterally.

Fig. 3. Double Ring Cylinders

Fig. 4. Tape measure on inner cylinder

Measurements were taken once the soil was fully saturated, after a 24-hour period and recorded in intervals of 10 – 360 minutes until a steady state of permeability was achieved.

4.1.1 Challenges

A few challenges were encountered when conducting the double ring infiltrometer tests, that created difficulty in taking accurate readings:

- Inclement weather conditions – excessive wind, heat and rain
- Overnight thunderstorms during a 24-hour test run
- Vibration of construction equipment due to ongoing earthworks

Given the above factors, the tests were redone until stable conditions were achieved. The resulting permeability for both the Hillwash and Residual Norite were analyzed based on the known (Philip, 1957) infiltration equations and were found to be in the order of 10^{-6} to 10^{-8} m s^{-1} which classifies as "Lowly Permeable" and meets the design criteria for the suitable subgrade conditions.

5 Drainage

The drainage was divided between the Class A and Class C barrier systems to cater for separated seepage and infiltration of the TSF and the slag buttress. The use of HDPE pipes was considered to assure long term durability and are drilled with holes designed to retain the D_{min} of the buttress material to ensure bridging would occur. Due to the importance of drainage surrounding the TSFs, a FoS between 5 and 10 was used with slope of more than 1% to ensure no silting up within the pipe and to allow for camera inspection and jet-rodding. One drainage system will run within the toe wall above the Class A barrier and the other one will be at the low point of the buttress as the foundation is sloped inward at 2% to ensure no water is discharged outside the barrier system.

6 Conclusion

The increase in mining operations has driven the need for TSFs and innovative barrier systems worldwide. The Global Industry Standard for Tailings Management (GISTM) and other applicable standards require new and existing TSF's to comply with current mining regulations and environmental compliance. Often existing TSFs are deemed non-compliant with current stability requirements and require remediation measures, such as the construction of a buttress, to further improve the stability of the TSF. Additional testing and measures may be essential in scrutinizing the compatibility of the lining and in-situ materials contained in the barrier system.

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