The essence of material compatibility in advanced barrier systems of existing TSFs

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ABSTRACT

Following the implementation of Global Industry Standards for Tailings Management (GISTM) on new and existing Tailing Storage Facilities (TSF) in South Africa, the growing demand for environmental compliance and innovative barrier systems are constantly on the rise. Often, when developing advanced barrier systems for existing facilities, the main challenge emerges from adapting the new system with current site conditions and infrastructure. Therefore, emphasis should be placed on the compatibility and characteristics of surrounding materials, as barrier systems are generally governed by shear interface properties and tailored to suit the underlying subgrade, especially when soil importation is not a feasible option. To gain a better understanding of the material characteristics, various testing techniques are recommended and should be carried out in accordance with the application and function of the materials in the barrier system. Testing should be conducted on the new and existing materials to ensure that the design requirements and technical specifications are not compromised. This paper aims to highlight and present the various types of test methods that were considered in developing a diverse multi-layered barrier system that has been proposed to underlie the buttressing of an existing TSF. Furthermore, the existing drainage systems were overall improved to accommodate the increased catchment area following construction of the buttress.

Keywords: TSF; barrier systems; tailings; slag; buttress; GISTM

1 INTRODUCTION

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

As part of the barrier selection, a waste classification was conducted in accordance with the South African National Management Waste Act (NEMWA) GN 634 regulations, and the Tailings classified to be Type 1 waste and the Slag classified to be Type 3 waste, thus requiring Class A and Class C barrier systems respectively.

The barrier system selection and the waste classifications were based on the Total Concentration (TC) and Leachable Concentration (LC) of chemical elements contained in the waste stream as highlighted in Table 1.

Table 1. Waste Classification and Barrier Selection As per NEMWA GN R636.

Risk	Barrier Type
0 Excessively High -Risk Waste LC > LCT3 OR TC > TCT2	Disposal is prohibited. Waste required to be treated and retested prior to disposal
1 High Risk Waste LCT2 < LC ≤ LCT3 OR TCT1 < TC ≤ TCT2	Class A – Double liner with leachate collection and leachate detection system
2 Moderate Risk Waste LCT1 < LC ≤ LCT2 AND TC ≤ TCT1	Class B – Single liner system with leachate collection and under drainage monitoring system
3 Low Risk Waste LCT0 < LC ≤ LCT1 AND TC ≤ TCT1	Class C – Single liner system with finger drain and under drainage monitoring system
4 Inert Risk Waste LC ≤ LCT0 AND TCT0 for metal ions and inorganic anions AND all chemical substances are below the total concentration limits provided for organic and pesticides	Class D – No liner or drainage layers required

1.1 Class A and Class C Barrier Systems

A comprehensive study of the site allowed for an innovative approach in utilizing a unified system that satisfied both; the Class A and Class B barriers requirements in order to contain the two separated waste streams independent from each other.

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

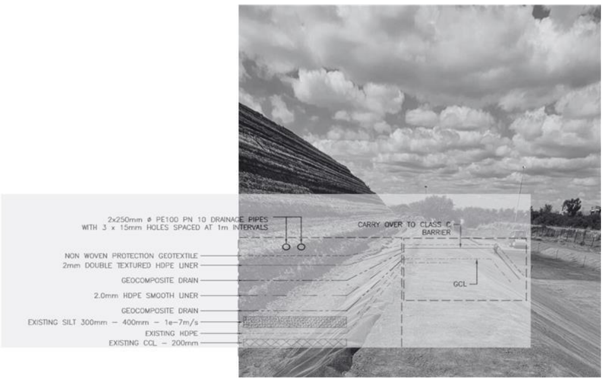

Fig 1. Unified Class A and Class C barrier systems.

1.2 Conformance Testing of Existing HDPE Liner

Having the existing HDPE liner as the primary liner of the new Class A barrier, conformance testing of the existing HDPE liner was paramount to the performance of the Class A barrier installation. `Material and ELL testing was conducted to assess the overall quality and repair work required on the existing HDPE liner. The material testing included the same criteria of MQA for the new HDPE liner.

1.3 Leachate Compatibility Tests with GCL

The use of the GCL was omitted from the initially proposed Class A barrier system following the swell index test as shown in Figure 2, of which the control swell was 29 and the swell with leachate was 8. It was found that the cations present in the leachate were highly reactive with the clay, thus preventing swelling and increasing the permeability to unacceptable values. This was confirmed at an early stage by using the ratio between monovalent and divalent cations (Benson, 2020).

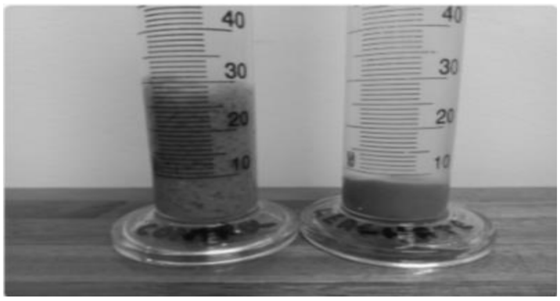

Fig 2. Control of 29 vs Swell with Leachate of 8

Therefore, it was considered to replace the GCL and to use two 2mm HDPE geomembranes with a leak detection in between, which showed to have equivalent performance to the primary barrier as per R 636 leakage rates.

During the project, a flexible wall constant head permeability test was carried out on the GCL using a representative sample of leachate. From the results obtained in Table 2, the permeabilities satisfied the design specifications and ensured a lower risk of contamination, should the leachate from the tailings dam leak into the Class C barrier system.

Table 2. Flexible wall constant head permeability test results

Sample ID	Co-efficient of Permeability (m/s)
No Leachate	3.8E-11
With Leachate (Old sample)	1.7E-11
With Leachate (New sample)	1.1E-11

1.4 Double Ring Infiltrometer Tests

Permeability testing of the in-situ material, particularly underlying the Class C barrier system, was conducted to further analyze the risk of contamination and amount of leakage, should a leak occur.

An ideal foundation should be impermeable to lowly permeable, to prevent an excessive amount of seepage. As part of the Material Quality Assurance (MQA), double ring infiltrometer tests were recommended on the footprint of the buttress to determine the saturated hydraulic conductivity of the subgrade. The tests were conducted on various sections due to the wide variation of in-situ soils contained on site; mainly consisting of Reworked Residual Norite – Black Turf and Hillwash, containing traces of sandy gravel material.

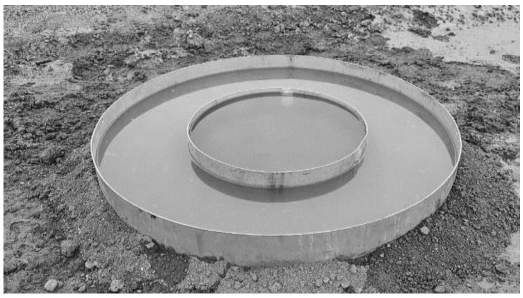

Fig 3. Double ring infiltrometer test apparatus

The double ring infiltrometer test, as illustrated in Figure 3, is an adaptation 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 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 1 x 10^{-6} to 1 x 10^{-8} ms^{-1} which classified to "Lowly Permeable" and satisfied the design criteria. 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.

1.5 HDPE Strain Test Pads

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 (Dmax 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 on site as illustrated in Figure 4.

Fig 4. Test pad under construction to monitor damage and strain in the Geomembrane

Due to the site topography and the wide variation of in-situ soils mainly consisting of Low Plasticity Clay (Hillwash) and Clayey Sand (Residual Norite), the level of strain generated in the geomembrane varied with the compaction of the subgrade.

Low Plasticity Clay (Hillwash)

The first test was conducted on the Hillwash with a load of 500kPa (full height of the buttress) over a 24-hour duration, and from the results obtained, using the (Tognon et al., 2000) method, the amount of strain generated in the geomembrane calculated to be 1.5% which falls below the threshold value of 3%, at which the geomembrane would exhibit stress cracking potentials (Seeger et al., 2003).

Clayey Sand (Residual Norite)

For the Reworked Residual Norite, three strain test pads were set up and conducted for varying compaction efforts of 85, 90 and 93% Modified Proctor as shown in Table 3. From the results obtained for three scenarios, the risks of a less dense surface could easily be identified and allowed for acceptable range to be agreed on should the contractor develop challenges in obtaining the specified density.

Table 3. Level of strain generated in HDPE geomembrane with varying compaction of Black Turf (Reworked Residual Norite)

Compaction (%)	Strain (%)
TP1 – 85	4.9
TP2 – 90	2.9
TP3 – 93	1.9

It was further specified that the contractor maintain a density of 93% Modified Proctor to eliminate the risk of failure and stress cracking.

2 DRAINAGE

The existing drainage systems were further improved with the new drainage system that was divided between the Class A and Class C barriers to cater for the additional seepage and infiltration of the TSF and slag buttress. The use of HDPE pipes were considered to assure long term durability, and drilled with holes designed to retain the Dmin 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 a slope of more than 1% to ensure no silting up within the pipe and to allow for camera inspection and jet-rodding. The drainage system was split to run within the toe wall above the Class A barrier and at the low point of the buttress with the foundation sloped inward at 2% to further ensure that no water is discharged outside the barrier system.

CONCLUSION

An existing TSF was rendered to be non-compliant and required to be buttressed to improve the FOS with the aid of an innovative barrier system. Addition testing became essential in scrutinizing the compatibility of the barrier system with the in-situ materials and current site conditions. With a limited amount of suitable clay available on site, the GCL was omitted from the Class A barrier and used in the Class C barrier. Permeability soil testing and HDPE strain test pads confirmed the design intent was met and not compromised.

REFERENCES

Philip, J.R. (1957). The theory of infiltration: 4 Sorptivity and algebraic infiltration equations. Soil Science, 84 (257-264).

Betrand, A.R., and Parr, J.R. (1960). Water infiltration into soils. Advances in Agronomy.

Moore, I.D., Rowe, R.K., and Togon, A. (2000). Geomembrane Strain Observed in Large-Scale Testing of Protection Layers. Journal of Geotechnical and Geoenvironmental Engineering.

Hornsey, W. (2013). Performance of Cushion Geotextiles for Liner Protection Applications. Geoafrica.

Benson, C.H., and Meer, S.R. (2020). Relative Abundance of Monovalent and Divalent Cations and the International Council of Mining Metallurgy, Global Industry Standard on Tailings Management.

Republic of South Africa. (2008). National Environmental Management Waste Act. National Norms and Standards for Disposal of Waste to Landfill GN R.636 (August 2013).