Case History: Application Of Geosynthetics in A Tailings Storage Facility Rockfill Buttress Construction Project

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Abstract

The objective of this paper is to present the application of geosynthetics in the buttressing of a gold tailings dam in 2022 in an undisclosed location in Free State, South Africa. Several geosynthetic materials were involved in the project such as geogrids, non-woven geotextiles, HDPE drainage pipes, and a geo-composite drainage. Drainage of the saturated in-situ clay was achieved using sub-soil drains consisting of a slotted HDPE pipe wrapped in non-woven geotextile for filtering function. Biaxial geogrid reinforcement was used to protect the subsoil drain from crushing under the weight of the overburden rockfill. Non-woven geotextile and geocomposite drain were used as a separator and filter material between the tailings and rockfill. The application of geosynthetics in this project was successful as the products proved functional post-construction based on available monitoring data.

Keywords: *filtration, separation, geogrid, geotextile, geocomposite, buttress.*

1.0 Introduction

One of the key components to the safe operations of an upstream tailings storage facility (TSF) is ensuring that the margins of safety against credible failures are sufficient using slope stability analysis. Knight Piesold (KP), as an Engineer of Record, undertook a slope stability analysis of a gold TSF in an undisclosed location in Free State, South Africa in 2021. The results indicated marginal and non-compliant factors of safety for drained and undrained failure modes in accordance with international standards and guidelines such as the Australian National Committee on Large Dams (ANCOLD). The following was observed from multiple site visits by KP: (1) seepage noted through the tailings slope face with large wet patches visible on the slopes below the first bench, (2) the in-situ foundation consisted of soft saturated clay with dense reed growth and groundwater springs noted in the paddocks of the critical areas, and (3) increasing pore pressures as indicated by the installed vibrating wire piezometers. These factors, in conjunction with the slope stability analysis, necessitated the design and construction of a rockfill buttress to improve the margins of safety and minimize the risk of a TSF failure.

The stability component of the buttress design involved sizing of a rockfill mass at the toe of the TSF to function as passive weight and retain the tailings from potentially sliding outward. Due to the visible seepage on the slopes and the soft, saturated foundation, other components to the design including drainage, filtering, separation, protection, and reinforcing using geosynthetic products were required. This paper discusses how various geosynthetics were designed and installed in the buttress construction project in 2022.

2 Geosynthetic Component in The Project

2.1 Subsoil HDPE Drainage

The 2021 field geotechnical investigation which consisted of cone penetration testing with pore pressure measurements (CPTu) and multiple site visits indicated that a saturated clay foundation and the buttress construction loads could increase the pore pressure posing a risk to the TSF stability and safety of the site project team. The design considered the use of sub-soil drains to intercept groundwater in the clay and transport it to a discharge point downstream in the solution trench, creating a drainage path for excess pore pressures generated during and post-construction.

The subsoil drain design layout was such that the pipe is installed from the toe of the starter wall, extends diagonally across the paddocks, and discharges at the solution trench. The drain consisted of two 160 mm diameter HDPE slotted pipes laid in a trench at minimum fall of 1% and wrapped in a 200 g/m^2 non-woven geotextile. Each pipe unit was 6 m long and had 4 opened slots of 15 mm diameter at strategic points on the circumference, with this detail repeating every 300 mm along the pipe length, as shown in the typical detail in Figure 1. The opened slots increase the catchment surface area of the pipe along its length, maintaining a high potential for seepage capture over the length of the pipe from the surrounding soil.

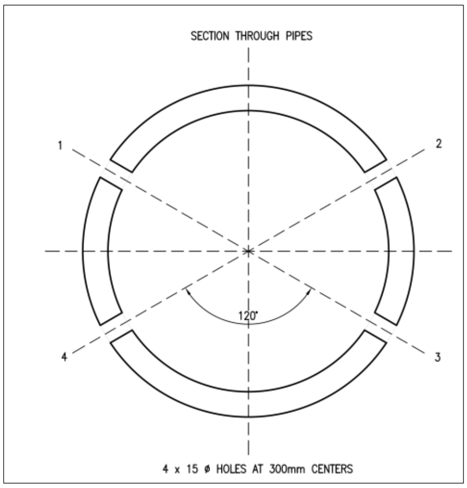

Figure 1: Section through the perforated HDPE drainpipe.

The non-woven geotextile wrapped around the pipe was to prevent the surrounding filter sand in the trench, which was required to comply with filter design criteria with the surrounding clay, from migrating into the pipe through the slots, thus, assuming the dual role of a separator and a filter media. Filtration is simply defined as the restraining of soil particles subjected to hydrodynamic forces while allowing the passage of fluids into or across a geotextile.

The filter sand between the geotextile and the in-situ clay was designed to comply with filter criteria and prevent clogging of the geotextile by the fine clay particles. To maximize the seepage capture of the drain at heights above the slotted pipes, it was decided to construct a geocomposite drain consisting of two non-woven geotextiles separated by a geonet drainage core and this was connected to the slotted pipes as shown in Figure 2 (left). The role of the geocomposite drainage medium was to intercept seepage from higher areas in the trench and transport it down to the slotted pipes through the drainage core.

Post construction total monthly flow rates are measured by the operator of the TSF, and these typically range from 18 litres / minute in the dry season to 60 litres / minute in the wet season. Figure 2 (right) shows the drainpipe outlet post construction and flow can be seen from the outlet on the left side.

Figure 2: HDPE drainpipes, (left) typical drawing section, (middle) site installation, and (right) post-construction monitoring.

2.2 Biaxial Geogrid Reinforcement

To protect the drainpipes and geocomposite drain from potentially crushing as well as settlement under the weight of the overburden rockfill during and post-construction, 2 monodirectional geogrids cross laid, strength class 100 x 100 kN/m, were designed and installed. The geogrid performs a reinforcing function by increasing the stiffness of the soil layers where it increases the confining stress on the surrounding soil, thus, increasing the load distribution efficiency and reducing the stresses at depth. For this project application, the geogrids were placed over the subsoil drainpipe trench; the geogrid was placed such that it spans 5 m either side of the centerline of the trench as shown in Figure 4 and over the length of the trench under the buttress footprint.

The concept of reinforcement membrane effect (Gourc & Villard, 2018) was borrowed for this design where the subsoil drains trench acts as localized weak zone / void in the foundation. The tensile geogrid reinforcement was then required in more than one direction along the length and cross section of the trench; thus, the strips were placed in varied orientations relative to the trench centerline. It is assumed that the reinforcement acts as a tensioned membrane supporting the full overburden rockfill pressure over the span of the trench void (Bonaparte & Christopher, n.d) as shown in Figure 3. As the rockfill weight pushes down on the localized weak void represented by the trench it causes vertical deformation over the span of the trench, however, the geogrid mobilizes its tensile strength and limits the vertical deformation, and the underlying drainage is protected from crushing under the weight of the rockfill. As the pipes are slotted, it does not have the same stiffness as a solid and thick HDPE pipe; in addition, due to the soft clay, the drainpipes would settle under the weight of the rockfill and lose the 1% fall which will affect flow; thus, requires the extra protection from the geogrid.

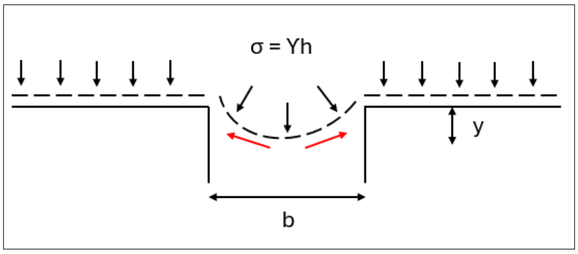

Figure 3: Tensioned membrane effect demonstration over a void of width b *(Bonaparte & Christopher, n.d)*.

In terms of quality assurance on the installation of the geogrid, it was ensured that the geogrid was placed as evenly as possible and taut on the surface, with minimum undulation and unevenness. A minimum overlap of 500 mm over geogrid strips was maintained to ensure continuous distribution of the biaxial tensile strength over the length of the trench.

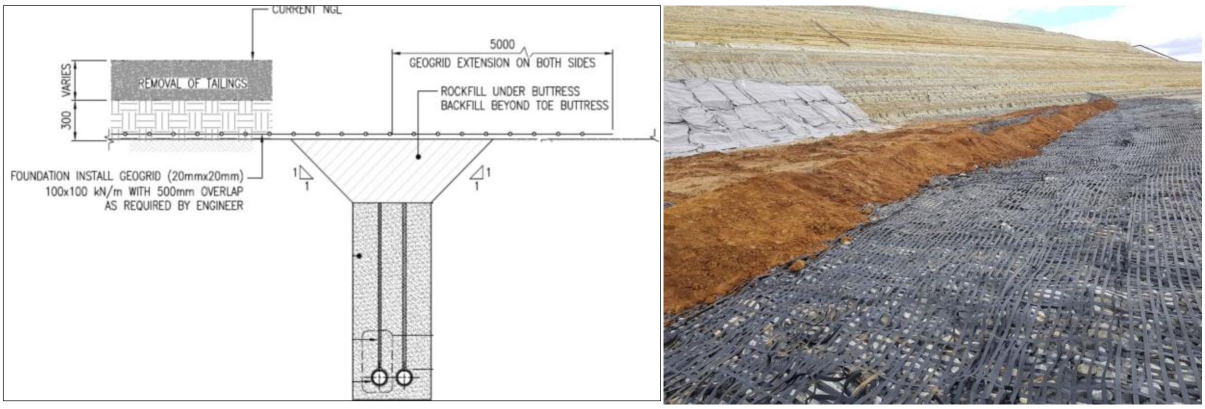

Figure 4: Installation biaxial geogrid over the soft subsoil drain excavation.

2.3 Filter, Drainage, and Separator Media on TSF Slopes

From the 2021 CPTu investigation it was noted that there was an elevated phreatic level within the TSF as shown in Figure 5, and this was supported by the wet patches and seepage on the face of the tailings below the first bench. The degree of seepage and wetness, however, varied over the 760 m length of the TSF, and the areas were divided into critical and non-critical; the critical areas had visible sloughing and seepage flow from the tailings, while the non-critical areas showed light saturation in the foundation with little to no seepage from the tailings. As such, the slope filter medium for these two zones was designed and constructed to fit the conditions.

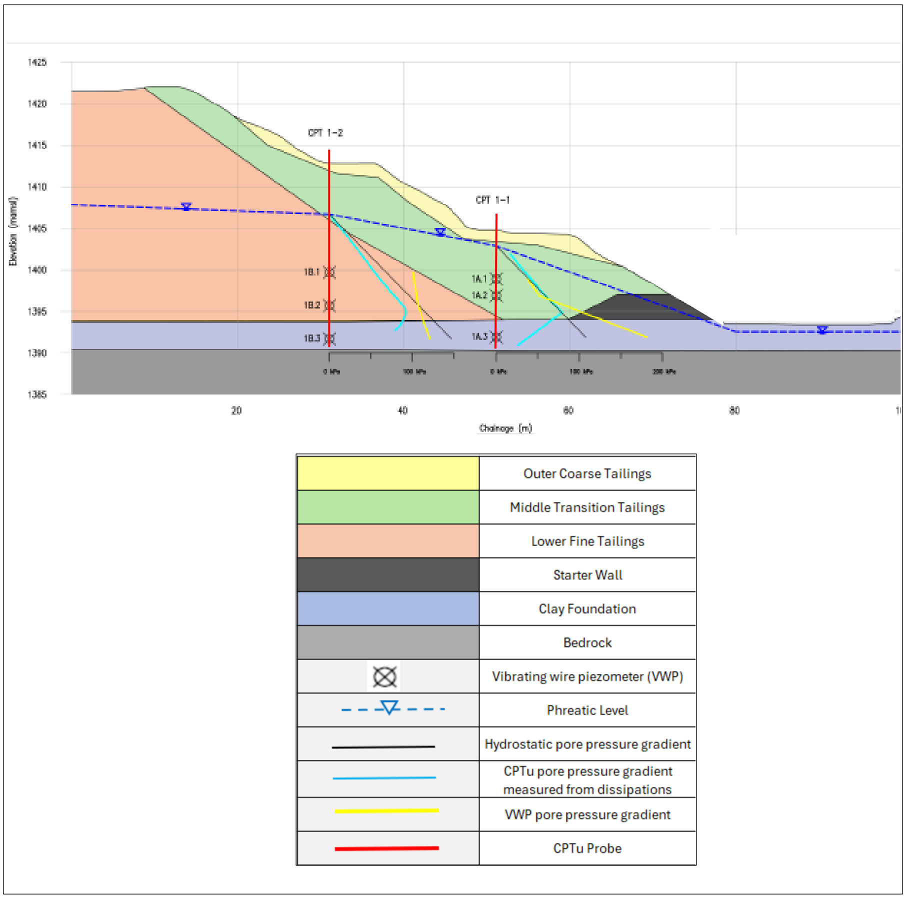

Figure 5: Elevated phreatic level within the TSF critical section.

2.3.1 Geocomposite Drainage Blanket for Non-Critical Seepage Slopes

In the non-critical slopes of the TSF, the choice of a geocomposite drainage blanket consisting of a drainage core protected on both sides by non-woven geotextiles was selected. This geocomposite drain was designed such that it performs the following functions:

- The upstream geotextile acts as a filter for the tailings, allowing seepage water and surface runoff to pass through to the drainage core while retaining the fine particles,
- The downstream geotextile acts as a protector for the core from the weight of the rockfill whilst still allowing any potential runoff from the rockfill to freely drain into the core,
- The drainage core acts as a water transportation medium and collects water from upstream and downstream, channeling to the base of the buttress where it is collected into the underlying subsoil drain.

The key property considered for the drainage core was the through flow in-plane at 200 kPa confining pressure. By specifying the required flow at 200 kPa it allows for the geocomposite drain to still be serviceable even under the high loads of the rockfill weight, which ensures long-term drainage functionality. Table 1 summarizes the properties that were required for the drainage core of the geocomposite.

Table 1: Geocomposite Drainage Design Properties.

Property	**Test Method**	**Unit**	**Minimum Required Value**
Thickness at 2 kPa	EN ISO 9863-1	mm	5.0
Through flow in-plane at 200 kPa at i = 1.0	EN ISO 12958	l/m/s	0.5
Tensile strength	EN ISO 10319	kN/m	18.0

The geocomposite strips were installed on the tailings slope up to the design level in the non-critical seepage areas and the rockfill was then placed onto the material, as shown in Figure 6. To minimize undulation of the material, the sheets were held down on the slope both by using large diameter rocks and site-made steel rods to anchor and hold the sheet down. A minimum overlap of 500 mm between individual strips was maintained to ensure continuity. The material was covered within the same day that it was laid on the slope to minimize UV sunlight exposure which undermines the fibres of the material when exposed for extensive period.

Figure 6: Geocomposite drainage blanket laid on the TSF slopes in the non-critical areas.

2.3.2 Filter and Separator Geotextile for Critical Seepage Slopes

In the critical areas of the TSF, due to the large degree of wetness on the face of the tailings slope, sloughing, and visible seepage, a 300 mm sand filter medium with a non-woven 750 g/m^2 geotextile was designed and installed. This design choice was influenced by the fact that there were several areas where the tailings had sloughed and formed shallow holes on the TSF slope, which required sand material for filling these holes back to original profile. As the rockfill and the filter sand would not be natural compatible filters for each other, the 750 g/m^2 had a dual role of filtering and separating these two dissimilar materials. An additional consideration to the suitability of this geotextile was considered; it should not puncture and tear under the load of the rockfill which would result in cross mixing of the sand and rockfill. Thus, higher static puncture resistance and thicknesses were considered when specifying this geotextile.

Figure 7 shows the installation of the non-woven geotextile between the rockfill and filter sand on the slope of the TSF in the critical seepage areas. The filter sand was first placed in 300 mm thick layer directly against the tailings, then the 750 g/m^2 geotextile is draped over the sand layer followed by the placement of rockfill on top of the geotextile. This detail was installed up to design level 6 m above ground over the extent of the critical area. To ensure continuity of drainage, the filter sand and geotextile were installed such that they are linked to the subsoil drain, so any seepage collected by the surface system ultimately ends up in the subsoil drain and is transported from there to the solution trench.

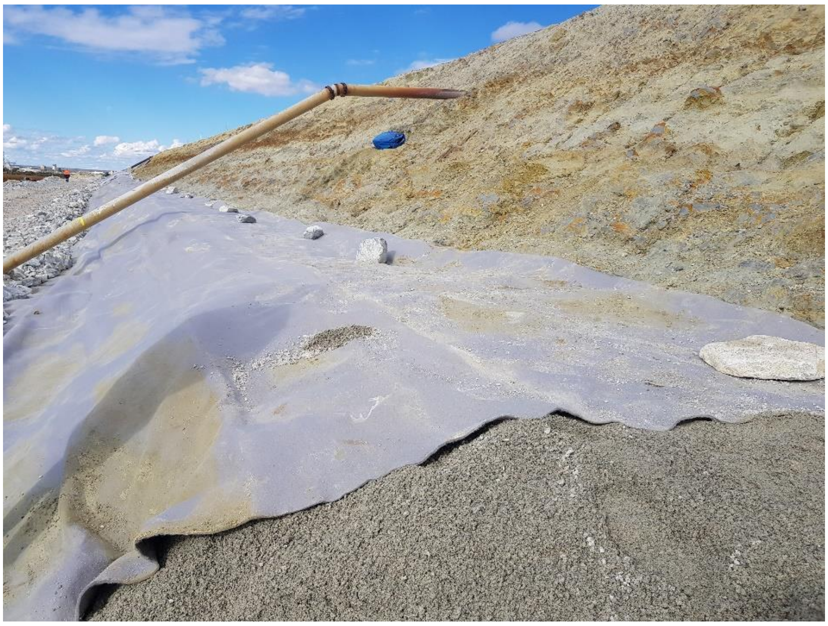

Figure 7: Installation of the 750 g/m^2 non-woven geotextile between the filter sand and the rockfill.

3.0 Conclusions

The aim of this paper was to present a case history of the application of geosynthetics in a buttress construction project undertaken in 2022 by Knight Piesold to improve the stability of a TSF. In addition to improving the stability of the TSF using rockfill mass at the toe, other key considerations of the project were subsoil drainage, protection of underdrains through geogrid reinforcement, filtration, drainage, and separation on the TSF slopes. To address the drainage of the saturated clay foundation, twin HDPE slotted pipes of 160 mm diameter were laid in an excavated trench from the toe of the TSF to the discharge point at the solution trench. As the overburden rockfill would impose significant compression pressures on the underlying drains and potentially cause the pipes to settle and misalign from the 1% fall, it was required to provide a protection detail for the drain. Two monoaxial geogrids, cross laid to form a 100 x 100 kN/m biaxial grid, were used with the design premise that they will achieve tensioned membrane effect over the span (cross section and length) of the subsoil drain trench and mobilize their tensile strength to limit vertical deformations in the trench and protect the pipes.

For the non-critical seepage areas on the slopes the geocomposite drainage blanket was installed to aid with filtration and drainage functions, where the seepage water is transported to the base of the buttress into the subsoil drainage system. The critical seepage areas were addressed with a filter sand layer overlain by a thick 750 g/m^2 geotextile, which offered filtration and separation between the sand and rockfill.

There has been on-going post-construction monitoring at the TSF by Knight Piesold and it has been found that the systems are all still functioning as envisaged. The primary indicator of this is that the HDPE subsoil drain outlets are monitored for flow monthly by the operator of TSF and on review, the outlets are producing flow monthly. The continued measured flow rates also indicate that the pipes have not crushed or misaligned from their design fall. This project is an example that geosynthetics can prove to be viable alternatives to typical civil and geotechnical material even in tailings storage facility related work, however, the right design basis is required to ensure that the right products are specified for use.

References

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