Proceedings of the 6th International Mining and Industrial Waste Management Conference, 29, 30 & 31 October 2018 – Legend Golf and Safari Resort, Limpopo

Design of Zinc Tailings Storage Facility

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Abstract

One of the largest diversified natural resource companies required a tailings storage facility (TSF) as part of the new Zinc mine in the Northern Cape, South Africa. The concept design incorporated a spigot deposition system, but due to footprint and cost limitations, the final design was changed to a centerline and upstream constructed, cyclone deposition method, which provides an acceptably stable outer zone, built from cyclone underflow (coarse tailings) with cyclone overflow (finer tailings) stored in the internal basin. A concrete penstock tower was provided to decant supernatant and rain water, through to the return water dam. Although the area experiences extreme evaporation, the water balance still indicated that sufficient capacity will be required in the return water system to remove water from the TSF within reasonable timeframes without spillage to the environment. This paper discusses some of the design aspects and challenges faced during the design process.

Keywords: *Tailings Design, Water Management, Geotechnical.*

1 Introduction

Knight Piésold Consulting (KP) was appointed by the Main Contractor for the Detail Design and Construction Supervision of the Engineering, Procurement and Construction (EPC) of a 112 Ha TSF near Aggeneys, in the Northern Cape, South Africa. Due to the fast track nature of the project, the Detail Design had to be completed in 3 months, to enable start of construction in April 2017.

Some of the design components are discussed in this paper, as well as some of the lessons learnt during the design and review process.

2 Design Criteria

The main design criteria for the TSF are presented in Table 1.

Table 1. Design Criteria.

Description	**Criteria (Rounded)**
Capacity (ROM Feed)	4 Mtpa
Solids to TSF	440 tph
Solids SG	3.39
Slurry to TSF	820 tph
% Solids	53
TSF capacity required	45 Mt (12 years)
TSF Storage capacity	34.5 Mm³ (44m high at 983 mamsl)
TSF footprint	112 Ha
Annual Rainfall (avg)	200 mm
Annual Evaporation (avg)	3 694 mm
Construction method	Cyclone wall building (split 35% UF: 65% OF)
Minimum freeboard	2 m
Maximum rate of rise	3.3 – 4.1 m per year (Cyclone U/F outer wall deposition) 2.5 - 4.6 m per year (Cyclone O/F, inside deposition)
Overall outer slopes	1:3 (V:H)
Individual slopes between berms	1:2.5 (V:H)
Minimum Factor of Safety	1.5 (Static) 1.1 (Pseudo-static / seismic)
Design flood	1:50 year RI, 24 hr duration: 29.9 mm (June) – 104.9 mm (Feb) 1:100 year RI, 24 hr duration: 35.1 mm (June) – 127.1 mm (Feb)
RWD capacity	20 000 m³
RWD outlet flowrate to process plant	210 m³/h
Slurry Pipeline – overland	DN 300 HDPE-lined steel pipe, (292 mm ID)
Slurry Pipeline – distribution	HDPE PE100 355 OD SDR 11 (288 mm ID)
Cyclones	250 mm diameter, every 36 m 8 Banks of 10 cyclones each
Tailings	Silty sand - 55 % > 63 micron
Slurry Density	Delivered density - 1.6 t/m³ (53.66 % solids by mass)
Coarse tailings in-situ density	1.5 t/m³
Fine tailings in-situ density	1.3 t/m³
Cohesion	0 kPa
Friction angle	29 °

HDPE Liner	Smooth in basin Textured on walls and in drains
Cohesion	0 kPa
Friction Angle - Textured	30 °
Friction Angle - Smooth	18 °

3 Design Components

The design components included:

- Geotechnical Investigation, foundation and materials study
- Hydrogeology study
- Waste classification testwork on the tailings
- Starter and toe walls
- A clean water diversion channel
- An HDPE lining for the TSF
- The decant system consisting of decant towers, one main tower and one intermediate structure, and a decant pipe.
- Access to the decant towers
- Tailings geotechnical testwork
- The tailings deposition pipelines around the TSF and deposition piping feeding the cyclone banks
- A cyclone deposition plan and wall building sequence
- A drainage system and underflow wall drain system consisting of slotted HDPE piping and a filter system
- Sumps where the drainage outlet pipes exit underneath the starter wall
- HDPE piping from sumps to the silt trap and from silt trap to the return water dam (RWD)
- Toe drains around the outside of the TSF
- An unlined storm water dam (SWD), which can spill into the RWD
- An HDPE lined RWD and a bottom outlet to the gravity feed water line to the plant.
- An emergency spillway for the RWD
- Access roads onto the TSF and a gravel access road from the main tar road (N14)
- Fencing and access gates
- Monitoring boreholes
- Temperature measuring devices for monitoring of liner

The following components will be discussed in further detail below:

- Geotechnical Conditions
- Starter wall / liner configuration
- Decant tower construction
- Water Management

3.1 Variable Geotechnical Conditions

The geotechnical investigation was conducted by means of test pit excavations and borehole drilling. The soil profiles generally consist of residual soils to very soft rock gneiss with nodular to hardpan calcrete in the upper portion of the soil horizon, overlain by aeolian sand. The conditions varied significantly as presented in Figure 1. Some test pits could be excavated to end of reach of the excavator, while other could only be excavated a few 100 mm. Blasting was required for portions of the diversion channel. The RWD had to be relocated due to poor excavatability of the initial planned position.

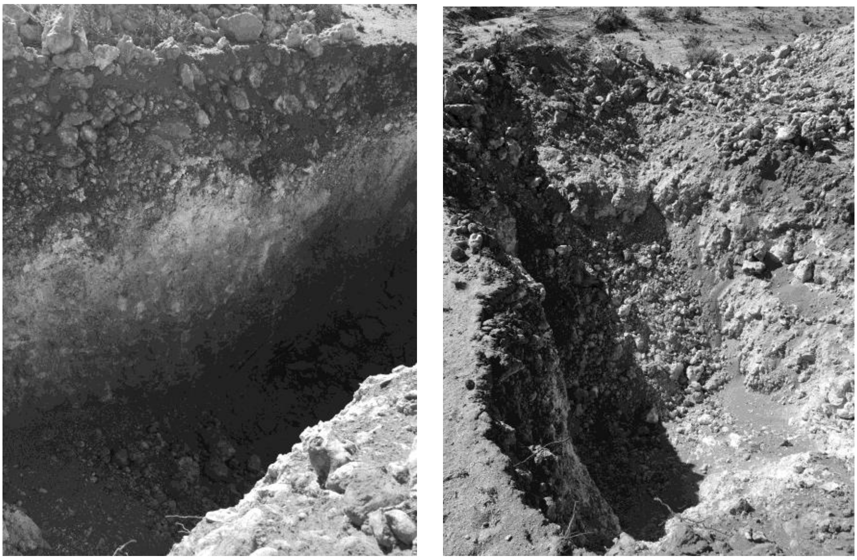

Figure 1. – Variability of test pit profiles

The ground conditions at the two boreholes (for the decant positions) were highly variable and it was expected that decant tower could be founded at 3 m depth. Eventually the tower position was moved 11 m south to find competent bedrock for the foundation.

3.2 Starter wall / liner configuration

The TSF layout is presented in Figure 2. The topography slopes at approximately 1:100 (V:H) from north to south over a distance of 860 m.

A main internal starter wall was constructed to an elevation of 946 mamsl on the South side of the TSF, transitioning to 947 mamsl on the North side, to contain the initial overflow tailings deposited into the facility for the first 12 months. The wall is a minimum of 1.5 m high, but up to 6 m high on the South side. An external toe wall of 1.5 m height was constructed 60 m downstream of the starter wall as presented in Figure 3. Coarse underflow tailings from the cyclones will be placed in a 60 m wide outer wall, between the toe wall and the starter wall, while fine overflow tailings will be placed inside the starter wall.

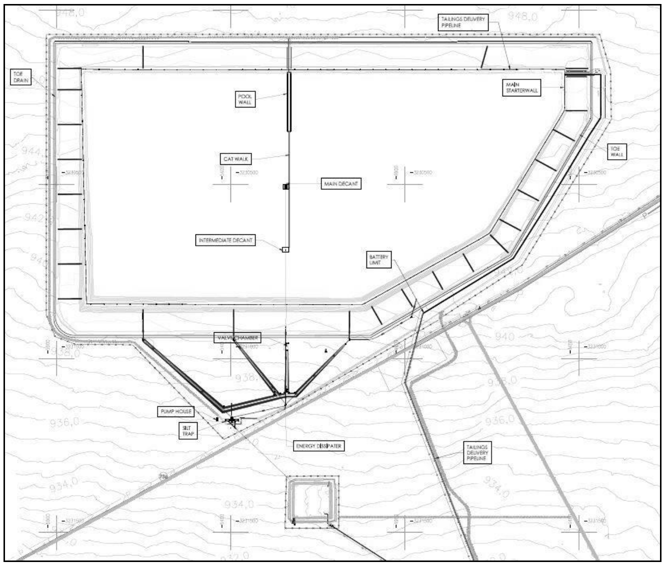

Figure 2. TSF Layout

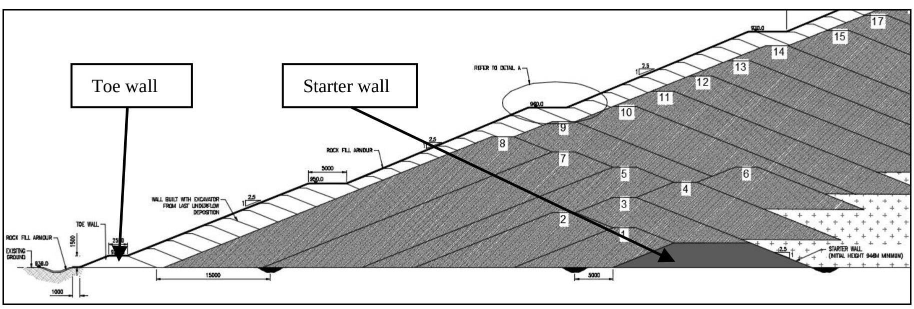

Figure 3. TSF Wall building (future) cross section

Drains were provided upstream of the starter wall, 5 m downstream of the starter wall and one 15 m upstream of the toe wall. The starter wall is 10 m wide on top to allow for access. The wall was constructed with nodular calcrete or very soft rock gneiss in layers not exceeding 300 mm and compacted to at least 95 % Mod AASHTO of maximum dry density at ± 3 % OMC. The cross section of wall is presented in Figure 4.

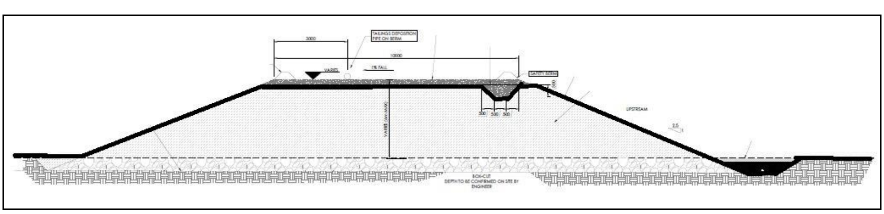

Figure 4. TSF Starter wall cross section – liner over wall

The liner was placed over the starter wall, through an anchor trench and covered with a minimum 200 mm thick protection layer of screened sand, mixed with 13 mm aggregate from the borrow pit. A geotextile was placed on top of the liner for protection. A geotextile protection sheet was also placed underneath the liner for the entire section shown in Figure 3.

Stability analyses for this configuration resulted in factors of safety (FoS) in excess of the required minimum 1.5 for safe long term (after closure) and short term (during operation) FoS and 1.1 under seismic conditions.

Although the FoS is sufficient, placing the liner over the starter wall creates significant construction and operational difficulties:

- Compacting the side slopes of the walls to the required compaction and smoothness proved to be difficult and an additional sand layer had to be placed on the side slopes as presented in Figure 5.
- The “road building” material placed on top of the wall, was difficult to keep in place and additional geotextile material had to be used to envelope the material and the liner had to swept a number of times as shown in Figure 6.
- In areas the geotextile underneath the liner also slipped down the embankment due to wind uplift of the liner, while the geotextile was not welded at the top. The areas were opened up and repaired.
- The cyclones and associated piping has to be moved around on top of the wall and the overflow pipes, into the basin of the TSF, lies on the liner covered slopes. The slopes are not expected to be covered in the first year, therefore continuous movement of pipes poses a significant risk to the liner.

Figure 5. TSF Starter wall compaction

The advantage of placing the liner over the starter wall was:

- The liner installer did not have to establish twice and therefore there is a cost saving to this option. The double establishment could however be avoided with proper construction planning and sequencing, especially on such a large project.

It is highly recommended for future projects, to install the liner below the starter wall, if drainage conditions allow for it. It initially was proposed to make the boxcut for the starter wall, between 1 m and 0.5 m, depending on geotechnical conditions, provide a compacted cushion layer, below and above the liner, and then build the starter wall on top of the liner, as presented in Figure 7. However, due to logistical reasons, this option was not accepted, in favour of the liner being installed over the starter wall.

Figure 6. TSF Starter wall cleaning

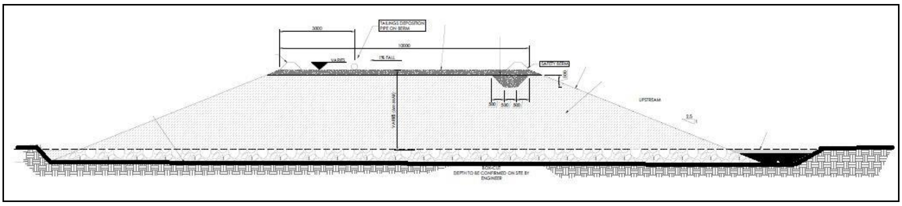

Figure 7. TSF Starter wall with liner underneath

In terms of stability, it does not make a significant improvement for the scenario where the internal drains (inside the starter wall) are functioning properly, but for the scenario of a failed internal drain, the liner over the starter wall creates a “bath tub” inside the starter wall. In this project’s case, a 6 m high wedge of undrained material behind the starter wall. Detail seepage and stability analyses still needs to be done for this scenario, but preliminary analysis showed that the stability improves with the liner underneath the starter wall. If the internal drain is blocked due to operational problems, seepage can still take places through the compacted starter wall, which is assumed to have a hydraulic conductivity of 1.00E^{-06} m/s.

In terms of construction and eventually operation, the liner is protected with a cushion layer and an embankment and movement of the pipes should pose a much lower risk of damage to the liner.

3.2 Decant Tower Construction

The Main Contractor proposed an innovative idea for building the 25 m high concrete decant tower. Instead of form work, pre-cast air valve chambers were used to build the 3 stage decant tower as presented in Figure 8. The reinforcing and internal HDPE drainage pipe were then fixed in 2 m lifts and then the cavity was filled with 30 MPa concrete. The base of the tower is 7.5 m x 11 m and 4 m thick (including 2 m mass concrete), founded on rock.

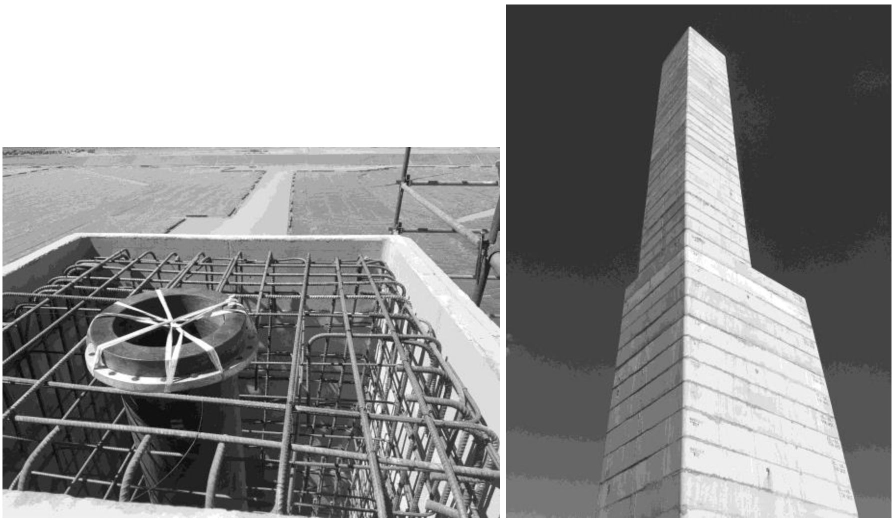

Figure 8. Concrete decant tower

3.3 Water Management

For an arid, desert type environment, it was surprising to find that the storm water from the catchment area (685 Ha) north of the TSF required a 2 km long, 3 m bottom width trapezoidal diversion channel, ranging from 1.9 m to 3 m deep to cater for the maximum storm flow rate of 40 m^3/s. The channel was provided with a reno mattress protected outlet.

The final wall side slopes will be cladded with a mortar layer and rockfill, and therefore the run-off is regarded as clean water. The run-off will be collected by an open toe drain downstream of the toe wall and diverted to an unlined storm water dam (SWD). The SWD will cater for the 1:100 year event and is provided with an overflow into the return water dam (RWD).

The size of the clean water SWD is driven by the area of the side slopes that have been re-habilitated. Phase 1 of the SWD has a capacity of 18 000 m^3, but a total volume of 42 000 m^3 will eventually be required (based on assumed parameters, which will be verified during operation).

Rain and process water will be collected in the TSF pool, decanted through the decant tower, through an energy dissipater, a silt trap and collected in a double lined RWD. The water will gravity feed to the process plant through a steel pipeline at 210 m^3/h, which was the limit set by the process plant. After a storm event, it is good practice to remove the excess pool water on the TSF as soon as possible. These two factors governed the size of the RWD. Finding the optimum size of the RWD, was a balance between limiting the number of days to decant water off the TSF (a stability and safety concern), while considering the budget constraints of the Lump Sum contract.

4 Importance of Review Process

This project is another example, to prove that sufficient review cycles, as per accepted project management principles (PMBOK® Guide – Fifth Edition (2013)), is very important and could save time and cost during construction and eventually operation.

Due to the fast track nature of the project, the detail design had to be completed in 3 months. Although there was a DWS approved conceptual design and a set of tender drawings, done prior to KP's appointment, some of the concepts changed considerably to optimize the cost of the project. KP's design team also did not get the opportunity to discuss the previous designs with the original design team, therefore the design intent was not clear for all the conceptual design components. To meet the construction and payment milestones of the lumpsum contract, construction started before the detail design was fully completed and therefore items like the footprint of the TSF was frozen early during the design process.

The detail design should have gone through another review, before implementation. Although several external reviews from 3rd parties took place, some of the design components could not be changed, as they were being constructed already. If changes were possible, at least the following items could have been modified:

- The liner should have been taken through under the starter walls as discussed in Section 3.
- The shape of the footprint should have been changed to avoid low slopes on the under-drainage system and drainage channels on the north and south sides of the TSF. The main driver for the current shape was constructability of the walls and liner installation, but with minor changes in the footprint, the drain pipes and channels would have had increased slopes, reducing the risk of blockage, while reducing the depth of some of the excavations, thereby saving time and cost.

References

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