INCREMENTALLY RAISED INCLINED ASPHALT CORE TAILINGS DAM

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SUMMARY

SRK designed an 171m high incrementally raised tailings dam for the Frieda River project located in Papua New Guinea. The facility will store approximately 1Billion tonnes of tailings and waste, and will generate approximately 80 Mw of power. The site receives approximately 8 m of rain per annum and seismic accelerations associated with the maximum credible earthquake are 1.19 g. The high rainfall and remoteness of the site dictated a rockfill embankment with an impermeable zone. Typical of tailings dams, the facility will be incrementally raised, and as such, a standard vertical asphalt core was not considered a feasible alternative. Therefore, SRK designed the embankment with a 2m thick inclined core and filter/transition zones, which have been designed with consideration for long term closure of the facility.

ABSTRACT

The Frieda River project is a greenfields mining project located in a challenging landscape in northwest Papua New Guinea. The complex nature of the site dictated that the tailings dam be a rockfill structure to ensure constructibility, longevity and availability of materials. The highly sulphidic nature of the tailings and waste requires that it must be stored underwater to limit environmental impacts. As such, the requirements of the dam are more typical of a water dam than a conventional tailings dam. However, as typical for tailings storage facilities, the embankmentmust be incrementally raised over the life of the operation.The embankment was designed with an inclined asphalt core and robust filter/transition zones, which allow the embankment to be incrementally raised and facilitate long-term closure of the facility.

1. INTRODUCTION

The Frieda River Project as currently envisaged will mine a large copper porphyry deposit that lies in rugged jungle-covered upland terrain of Sanduan (West Sepik) province, Papua New Guinea (PNG). SRK Consulting (SRK) was commissioned by Frieda River Limited to develop the design of themine waste, plant tailings and hydroelectric power integrated storage facility (ISF).

The ISF design requirements and challenging site conditions dictated the design of the ISF containment embankment.The complex nature of the site dictated that the embankment be a rockfill structure to ensureconstructability, longevity and availability of materials. The impermeabilisation of the embankment includes an inclined asphalt core and robust filter/transition zones, which allow the embankment to be incrementally raised and facilitate long-term closure of the facility.

2. PROJECT BACKGROUND

Frieda River represents one of the largest undeveloped copper-gold deposits in the world. TheFeasibility Study for the project was completed in May 2016 which contemplated a plant feed of 40 M tonnes per annum and mine life of 17 years.This equates to a total tailings and mine waste storage requirement of approximately 800 million m^3.

Mine waste and plant tailings generated from the mining operation will be deposited and stored subaqueously in the ISF.Additionally, the river flow through the facility will be used to generate hydroelectric power. The ISF features a 171 m high zoned rockfill embankment with upstream asphalt core, two diversion dams, a 36 m high cofferdam, two diversion tunnels, a decant system, a hydropower intake and conveyance system, and a side-hill spillway.

2.1 Location

The Frieda River Project lies in rugged jungle-covered upland terrain of Sanduan (West Sepik) province, PNG – Figure 1. The site is located approximately 70 km south of the Sepik River, and approximately 500 km upstream of the coast. The area is remote, with no road access or power supply.

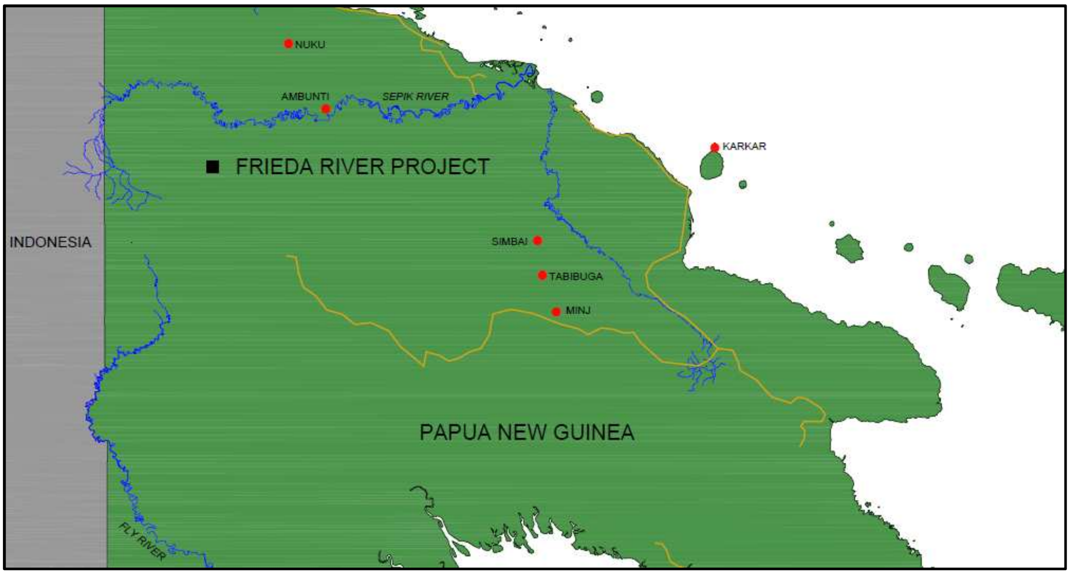

Figure 1- Frieda River Site location

The site is located in a mountainous region characterised by steep topography, and deeply incised valleys. The elevation is highly variable, from approximately RL 100 m at the ISF toe to approximately RL 650 m at the mine itself – Figure 2. Dense tropical vegetation covers much of the area. Landslides are common, and many of the hill slopes are covered by landslide material.

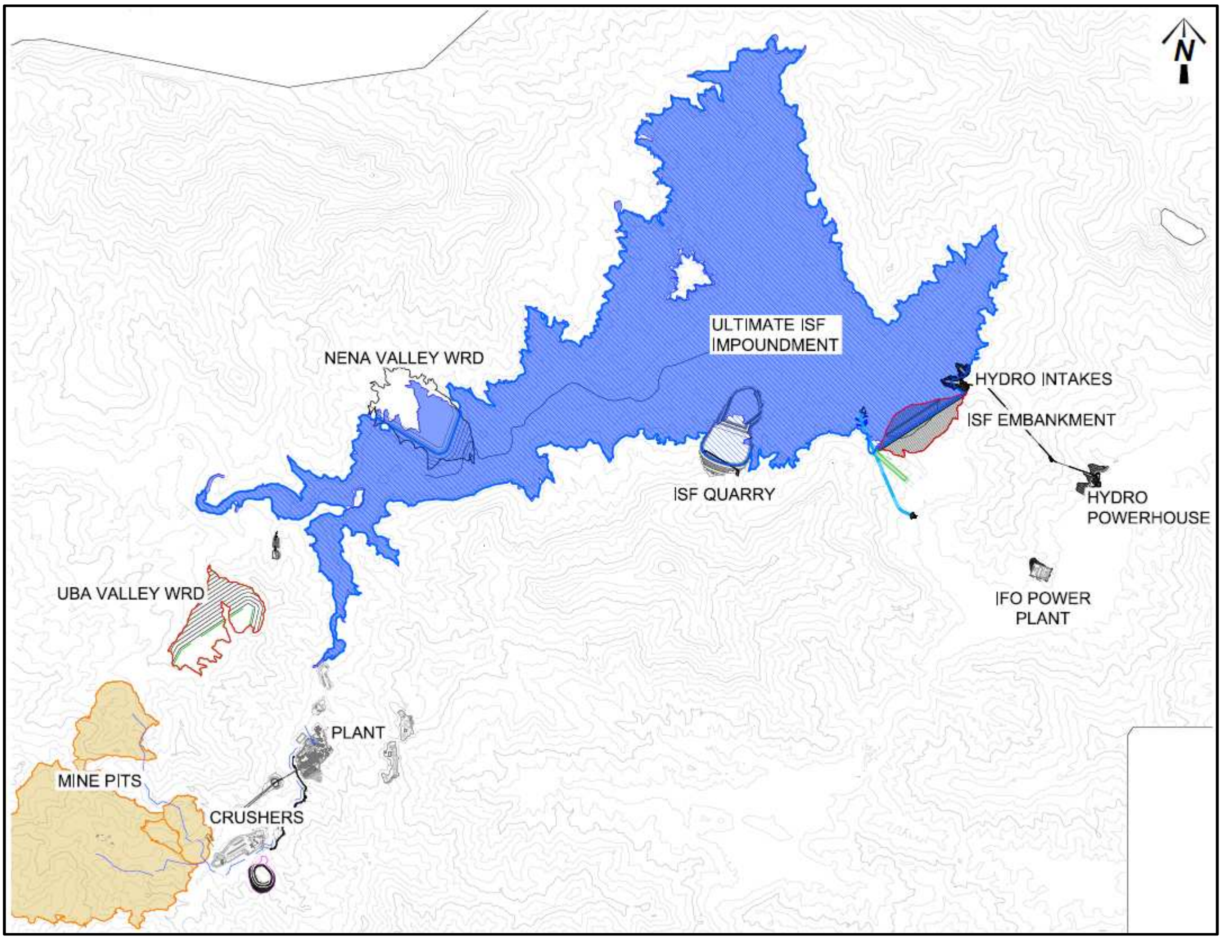

Figure 2 – Proposed Project Layout

The current proposed location for the ISF is on the lower Nena River, several kilometres upstream of its confluence with the Frieda River, which flows northwards, exiting the highlands to meet with the regional Sepik River, 35-50 km from the Project site.

2.2 Site conditions

2.2.1 Foundation conditions

The site is located within a complex geological setting that presents variable conditions. Geotechnical investigations to date indicate that the ISF embankment site is underlain largely by well-foliated phyllite (strong to very strong), with schistose phyllite (weak), fissile well-foliated phyllite (moderate) and banded phyllite (very strong) encountered locally. Numerous small diorite intrusions and larger intrusions were also encountered.

Weathering on the left abutment is deeper than on the right abutment. Soil-like materials extend to around 25 m on average in the left abutment and around 9 m in the right abutment. Significantly weathered rock extends down to bedrock at 65 m on the left abutment and 25 m on the right abutment.

2.2.2Climate and hydrology

The site climate classifies as wet tropical. Average annual rainfall in the surrounding mountainous areas is in the order of 8,000 mm. As a result of the mountainous terrain, the climate is dominated by local weather effects rather than by synoptic scale monsoonal effects. One of these is the movement of the inter-tropical convergence zone, so the rainfall pattern exhibits very weak seasonality.

The ISF catchment is approximately 258 km^2 with anaverage inflow to the facility of approximately 50 m^3/s, while the peak runoff from the 24 hr probable maximum precipitation (PMP)(920 mm) is in the order of 9,500 m^3/s.

2.2.3Seismicity

The PNG region is located in one of the most tectonically active and complex regions of the worldcharacterized by the oblique convergence of the Indo-Australian and the Pacific Plates at a rate of about110 mm/year. The ISF site is located on the southern margin of the New Guinea Mobile belt; a zone characterized by faulting and intense folding caused by the oblique collision of the Pacific and Indo-Australian plates.

Site-specific probabilistic and deterministic seismic hazard assessments were undertaken to determine design ground motions. The resulting design acceleration for the maximum credible earthquake (MCE)was 0.91g.

2.3 Design objectives

The primary design objective of the ISF is to safely store tailings and waste produced by the mining and milling operation. Geochemistry testing indicated that the tailings and waste are likely to be net acid forming. Exposure of the tailings or waste to oxygen would likely lead to mildly acidic conditions that would result in elevated metals release, copper in particular. Sub aerial deposition (above water) of the tailings and formation of tailings beaches could lead to the release of metals. Therefore, the preferred disposal strategy for tailings is subaqueous (below water) deposition. As such, the facility is designed to contain water similar to a water storage dam, rather than a tailings dam where water storage is generally not good practise.However, similar to a typical tailings dam, the embankment needs to be raised incrementally over the life of the facility, and the facility then needs to be closed.

3. DAM TYPE SELECTION

3.1 Dam type options

Initially, four dam type options were considered, namely rockfill, zoned earthfill, roller compacted concrete (RCC) and hardfill. Rockfill was identified as the most suitable option for a number of reasons, primarily as there is readily available competent diorite immediately upstream of the proposed embankment location. The other options were discounted due the remoteness of the site and the difficulty of transporting large amounts of bulk product to the site, the construction concerns due to the wet conditions, and the proposed construction schedule and costs.

3.2 Impermeable element

Various methods were considered to provide the impermeability for the embankment including asphalt core (inclined and vertical), synthetic liner (HDPE, PVC or bituminous geomembrane liner (BGM)), and concrete and asphalt facing. The option selected consists of a rockfill embankment with an inclined asphalt core.

The incremental construction and loading of the embankment results in the embankment sagging or displacing in the downstream direction. The higher density of the tailings/waste loading means that the displacements can be quite large (metres), and as such the impermeable zone needs to be able to accommodate these displacements.

Asphalt was selected for its plastic properties and its ability to deform with the slope without significant cracking occurring. In addition, the asphalt has the ability to self-repair under the effects of the water pressures, and allows for all-weather construction (assuming heating of the laid asphalt and rain protection at the point of placement). Other benefits of asphalt in dams include low permeability, stability under a range of loading conditions, resistance to aging,and good connection that can be achieved between the asphalt and the plinth[1].

Asphalt is commonlyused as the impermeable element in dams in the form of either a core (in the interior of the dam supported on both sides) or as a facing (on the upstream face of the dam). A an asphalt core is generally 60-100cm thick and is constructed in layers [2]. Alternatively, a facing is typically6-8cm thick and is constructed by rolling up and down the face of the dam [3]. A core was selected as the impermeable element for the ISF embankment to provide robustness against potential deformations and to facilitate safe construction for the 171m high embankment.

The preference for an inclined asphalt core rather than a vertical asphalt core was primarily based on the incremental raising requirement, as discussed in Section 4.3.

4. DAM DESIGN

The ISF embankment is designed as a zoned rockfill dam with an impermeable zone at the upstream face. The embankment shown in Figure 3 includes the following main features:

- Foundation excavation
- Filter and transition zones
- Impermeable inclined asphalt core zone
- Rockfill shell.

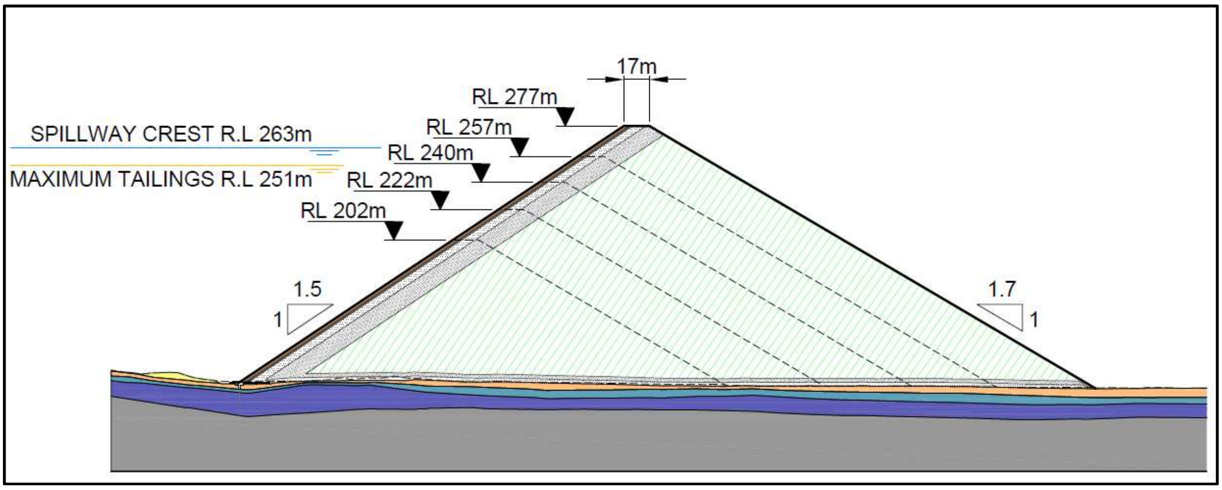

Figure 3 – Embankment section

4.1 Foundation preparation

As discussed in Section 2.2.1, weathering of the foundation on the left abutment is deeper than on the right abutment, with soil-like materials extending to around 25 m and 9 m on the leftand right abutments, respectively. The completely weathered, soil-like material has low strength (≤1 MPa) and is at, or above, optimum density in situ. This material should be removed or excavated to a depth of approximately 20 m. It is assumed that at this depth the weathered material would be unsaturated with sufficient shear strength.

4.2 Zoning

The upstream inclined core zone, shown in Figure 4, consists of low strength cast concrete curbing,similar to that used for concrete faced rockfill dams, upstream shoulder material, inclined asphalt core, filter and transition zones.

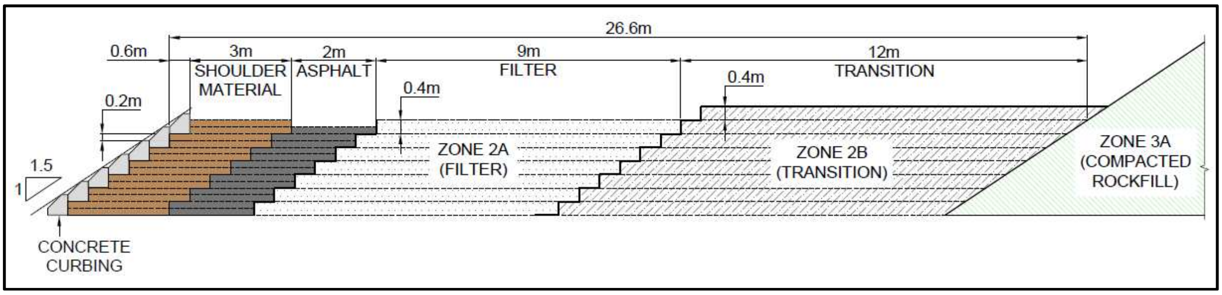

Figure 4 – Upstream inclined core zone

The impermeable asphalt zone is thick (2 m) and is similar to a core rather than a facing, despite being located on the upstream face. The asphalt core is inclined by a series of steps, and is compacted between the filter material on the downstream side and the shoulder material on the upstream side.

The upstream shoulder material that serves two purposes, namely providing confinement to compact the asphalt during construction, and acting as a filter plugger in the event of significant displacement. The upstream shoulder material will need to have a reasonable portion of its matrix as a sand or larger for compaction, as well as having mobile fines. The curbing provides the required containment to allow compaction of the adjacent shoulder material.

The ISF embankment has been designed with filter layers to inhibit tailings piping and to restrict/ manage seepage flows should the asphalt zone deform or degrade. Horizontal transition layers will be constructed along the foundation of the embankment where required to inhibit foundation piping and pass seepage flows.

4.3 Impermeable zone

The design requirement for the impermeable zone was to minimise seepage losses through the embankment during operations while catering for closure and the potential for the material to degrade. It is expected that an impermeable zone may degrade during closure due to seismic displacements. Assuming that the impermeable zone will be compromised over the very long term, the tailings against the face of the embankment will ultimately become the control on seepage. However, tailings will only be effective as a barrier if the tailings are backed-up by a suitably graded filter zone. Locating the asphalt on the face means that the associated filter zone will be immediately against the tailings in the event that the asphalt is degraded or damaged over the long term

A central asphalt core option is a more conventional design which could be constructed using equipment and procedures that are very well-established and readily available in the large dam contracting community. However, the central core alternative as a whole is not well-suited to staged construction. It would be necessary to initiate and raise the central core alternative over a much wider base area, increasing starter embankment and early raise costs. The wider construction footprint would also entail greater exposure to risks from the slopes above the construction area. In addition, a central core wouldrequireincreased containment grouting and plinth constructionas a result of the faulting parallel to the embankment crest and associated deep weathering.

SRK elected to proceed with the upstream core design as it is more amenable to phased construction. In SRK's experience, the cost and schedule advantages of phased construction are extremely important to mining projects, and outweigh any of the other considerations discussed above.

4.4 Constructability

The construction of the ISF embankment requires the placement of rockfill, filter and drainage zones, and the asphalt zone. The placement of these materials will occur at different rates, having different challenges and requiring different equipment. The design assumed that the placement of rockfill, filter and drainage zones for the starter and the final embankment walls would be executed in the same manner. Due to the considerable loads that the stored waste rock and water would exert on the embankment, each material has to meet specific standards with regard to density, strength, permeability, compressibility and resistance to deformation. Rockfill has been placed under similar (wet) conditions in places such as Colombia, Panama, Dominican Republic, Thailand, Malaysia and Indonesia.

Erosion, sediment transport and slope stability are major concerns when vegetation is stripped off and as such the design caters for sediment management(ponds, diversion drains, matting and shotcreting), and theslopes will be excavated top-down, nailed, meshed and shotcreted.

For construction of the filter and transition zones, it is proposed to use a fleet of 40 t articulated trucks to deliver the borrowed material or excavated river gravels to a crusher and to dump the engineered fill on the embankment crest. The filters will be expanded up the abutments progressively with lined drainage on the upstream side of each discrete panel to divert sediment and run-off from impacting and contaminating the filters / transition material.

The asphalt placement would follow the low strength concrete curbing that would be formed ahead of the paving operation. The asphalt material would be delivered to the asphalt paver on the embankment crest. The material would be handled into the asphalt pavers by loader and compacted by plat drum rollers. The asphalt would be placed in two to three layers per day.

5. CONCLUSIONS

The Frieda River Project site is very challenging and required an innovative solution to contain the tailings and waste during operation and closure. The engineering studies indicated that arockfillembankment with an inclined asphalt core design was the most viable option for the site.

Further studies are required to increase the confidence in the site location and demonstrate the constructability of the asphalt under site construction in the proposed configuration.

6. KEYWORDS

Rockfill, inclined, asphalt, core, tailings.

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