Case history – geotechnical design of a tailings storage facility in Bolivia

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ABSTRACT
This paper presents the challenges in the design of a Tailings Storage Facility (TSF) for a gold mine in the Department of Potosi, Bolivia. Twenty (20) million tonnes of thickened tailings are to be contained within a small catchment area (1.3 km^2) bounded by broad bedrock controlled slopes, and covered by a thin layer of well graded colluvium. The main tailings dam will use phased centreline construction and be composed of an earth core dam with rock fill flanks. The dam will be up to approximately 110 m tall at closure. A unique aspect of the project was the need to match the water balance for the TSF to the planned staged construction, so as to remove the need for interim spillways until the facility is closed at the end of operations.

RESUMEN
Este papel presenta los retos del diseño de una Presa para Almacenamiento de Relaves Mineros (PARM) para una mina de oro en el departamento de Potosi, Bolivia. El propósito de la presa es contener aproximadamente 20 millones de toneladas de relaves espesos (thickened tailings) en una cuenca relativamente pequeña (1.3 km^2) delimitada por pendientes controladas por formaciones rocosas y cubierta por una capa delgada de material coluvial. El dique principal esta diseñado para ser construido mediante el sistema de línea central y estará compuesto por un núcleo de material impermeable y material rocoso en los flancos del dique. Al altura final de la presa será de aproximadamente 110 m. Un aspecto particular de este proyecto fue el balance de agua en todas las etapas para evitar la necesidad de construir vertederos de emergencia sino hasta el cierre final.

1 INTRODUCTION

Republic Gold Limited (Republic) is currently in the preliminary design stages for the Amayapampa Gold Project (the Project), located in the Bustillo Province, Department of Potosí in Bolivia (Figure 1).

Figure 1 Site Location Map

The proposed mine site is located in close proximity to the Village of Amayapampa in the high Altiplano on the eastern ranges of the Andes Mountains in the Bolivian Cordillera Oriental. The site is approximately 400 km from La Paz, and is accessed via paved and unpaved roads.

The mine will utilize open pit methodology and comprises the open pit, an ore processing plant, a TSF, Primary and Secondary Raw Water Supply dams and the associated infrastructure and buildings for the mine.

The mine is anticipated to produce approximately 7,500 tonnes per day (tpd) of raw ore and will produce thickened tailings with a 60% soilds content. Total taillings production over the currently feasible mine life will be close to 20 million dry tonnes or approximately 12 million cubic metres.

As part of the mine development process, WorleyParsons was contracted by Republic to provide a preliminary TSF design. The scope of the project comprised:

- an assessment of the technical feasibility of thickened discharge disposal;
- an assessment of previously identified TSF sites and identification of the preferred location;
- a geotechnical site characterization and assessment;
- design of a preliminary TSF layout;
- preparation of a TSF surface water management plan; and
- development of a preliminary acid generating materials management plan.

Based on the required storage volume, a TSF location was chosen approximately 2 km west of the proposed plant and 800 m northwest of the Amayapampa community. This location confines tailings to a small catchment area, bounded by broad rock slopes and covered by colluvium. Tailings will be retained by a large earthern core embankment dam, which at buildout will be approximately 90 m tall and 800 m long. The dam will be constructed in phases using centreline methodology and will not use tailings as a construction or foundation material. The dam was designed based on current best practices mandated by the World Bank (International Finance Corporation (IFC) 1996), the Canadian Dam Association (CDA 2007) and the International Commission on Large Dams (ICOLD 1996). The dam core will be largely constructed of clayey sand colluvium while waste rock from the mine will be used to form the rock shells. Granular filter layers will need to be manufactured by crushing.

Thickened taillings will be pumped to spigots around the outer perimeter of the TSF. Given the small watershed behind the dam, as well as the high evaporation rates at the site, relatively limited amounts of liquid tailings or water will be impounded behind the dam. This disposal method should also facilitate the development of a solid tailings consistency in time, which will allow placement of a dry cover at mine closure.

2 SITE CONDITIONS

2.1 Topography and Surface Drainage

The site is located in an area of rugged topography at an approximate elevation of 4,100 m above mean sea level (masl). Slopes in the area are generally steep, with local relief of up to 200 m and limited surface vegetation.

The proposed TSF Site is located approximately 800 m north-west of the Village of Amayapampa on the west side of the Río Irpa Kochi, at an approximate elevation of 4,000 masl. Topographic relief in the TSF site is around 70 m. The main drainage feature in the proposed TSF site is a quebrada (creek) which was noted to contain a minor flow at the time of the 2010 site visit.

The proposed site is bounded by elevated areas to the north, west and south and therefore generally provides natural containment for tailings storage. The site will require the construction of a main dam that at ultimate development will be approximately 100 m in height and 400 m in length. The axis of the main dam is proposed to be placed at the east end of the site, where the valley narrows and metamorphic bedrock provides natural abutments. Other supplementary saddle dams will be required to provide containment to the east and west.

The overall watershed draining into and including the TSF is estimated to be approximately 1.3 km^2.

2.2 Regional and Local Geology Overview

The Amayapampa region is characterized by a thin veneer of colluvium (gravity deposited material) covering sedimentary and weakly metamorphosed bedrock composed of sandstones, mudstones, siltstones, quartizes and shales (Vista Gold 2000). The proposed TSF site appears to be generally underlain by quartzitic sandstones.

Amayapampa is located in a region of folded rocks with associated thrust faults and minor cross faults and lies on the east limb of a northwest trending anticline (Vista Gold 2000). Although faulting was not observed in the proposed TSF area, faults may be present in the foundation rocks below surface.

Prominent metamorphic rock outcrops on the valley walls in the proposed TSF location suggest that adequate foundation conditions are present for the abutments and the base of the tailings dam.

No active landslides or evidence of geotechnical instability were apparent at the proposed tailings dam location.

2.3 Climate

The project is located in a region of great seasonal variations in precipitation and temperature. The temperature extremes vary between minus 4.0°C in winter to 25°C in summer. Annual precipitation ranges from 400 to 700 mm, with most of the precipitation occurring in the wet season between November and April. The waterbody evaporation potential is estimated at 1,400 mm per year.

2.4 Site Seismicity

Generally speaking, Bolivia is located in a seismically active area, experiencing earthquakes associated with the subduction of the Nazca tectonic plate beneath the South American plate. Slip along the dipping interface between the two plates generates frequent and often large interplate earthquakes between depths of approximately 10-60 km. Earthquakes can also be generated at depths greater than 600 km from internal deformation of the subducting Nazca plate (USGS 2010).

The largest recorded event within a 200 kilometre radius of the Site occurred in 1933, a magnitude 5.4 (Richter scale) quake located 45 kilometres to the north-west. The closest event occurred in 1991, a magnitude 3.1 quake located 20 km north of the site. Based on the seismic record, the maximum credible earthquake (MCE) for the project area was assessed as a agnitude 7.0 quake with an epicentre 45 km from the project area and having a return interval of approximately 60 years. A Peak Ground Acceleration of 0.15 g was used for the preliminary design.

3 FIELD RECONNAISSANCE

The field work conducted at the site consisted of reconnaissance of potential TSF locations, as well as a test pitting program.

The proposed TSF site comprises a small catchment area (1.3 km^2), bounded by broad bedrock controlled slopes covered with a thin layer of well graded colluvium. The topography lends itself to containing the anticipated 20 million tonnes (dry weight) of tailings, with additional capacity available, if needed. The main dam will be founded on apparent competent sedimentary bedrock and the saddle dams on the veneer of colluvium.

Because of the favourable site conditions, no significant geotechnical constraints are envisaged to developing the site.

3.1 Subsurface Conditions

The geotechnical investigation comprised 30 shallow test pits across the proposed TSF location to characterize the overburden and confirm the presence and properties of shallow bedrock. Soil and rock conditions encountered in the test pits were logged in detail and disturbed soil samples were collected for laboratory testing.

Generally speaking, the soil conditions encountered in the test pits comprised varying proportions of clayey sand colluvium overlying metamorphic bedrock. The colluvium was thickest at the base of the slopes and in and around the natural drainage features, as expected.
All test pits excavated were found to be dry and stable on completion.

The colluvial material was generally composed of a clayey or silty sand. Where encountered, this material ranged in thickness from 0.5 to more than 3.6 m below the existing ground surface (mbgs). In all test pits, the colluvium either extended directly to metamorphic bedrock, or beyond the depth of test pitting.

Metamorphic bedrock was encountered underlying the colluvium, or extending down directly from grade. The bedrock was generally laminated in layers up to 10 cm thick, dipping to the north or north east and was moderately strong to strong. The bedrock was generally observed to be sound or with sporadic fractures. Where encountered, these fractures were noted to occur in different directions with spacing of up to 0.5 m.
The subsurface lithology encountered in the test pits is summarized in Table 1.

Table 1 Encountered Subsurface Lithology.

Unit	Average Thickness (m)	Average Depth to Top of Unit (mbgs)
Topsoil	0.1	---
Colluvium[1]	2.0	0.1
Bedrock	---	0.2

[1]where encountered.

3.2 Laboratory Test Results

Thirteen representative colluvium samples were submitted for geotechnical testing, as summarized in Table 2.

Table 2 Laboratory Test Results

Characteristics	Range	Average
Moisture Content (%)	15.6 – 5.3	8.6
Liquid Limit (%)	36 – 13	25
Plastic limit (%)	27 – 10	19
Plasticity Index (%)	12 – 4	6
Fines (%)	44 – 19	33
Standard Proctor Density (kg/m^3)	---	1969
Optimum Moisture Content (%)	---	13.5
Permeability (cm/s)	---	7.4 x 10^{-6}

3.3 Assumed Soil Engineering Parameters

Table 3 presents the soil engineering parameters used in the analysis. These parameters were determined, based on the laboratory test results and on past experience.

Table 3 Assumed Soil Parameters

Soil Type	Colluvium	Rock Fill	Tailings
Unit Weight (kN/m^3)	21.5	21	20
Internal Friction Angle	32	40	25
Effective Cohesion (kPa)	10	0	0
Permeability(cm/s)	8 x 10^{-6}	---	---

4 WATER MANAGEMENT

The TSF is designed to contain all runoff from extreme rainfall events during construction and operation with controlled downstream discharge at facility closure. Since the drainage area is small (1.3 km^2), complete containment of the total runoff volume from the inflow design flood in the TSF impoundment is deemed the most economic method for flood management during construction and operation of the TSF. This removes the need to provide a spillway during mine operations, providing there is sufficient containment for the total runoff, although a spillway will be required prior to closure of the. Specific surface water management design criteria included containment of the 1 in 1,000 year extreme rainfall event during mine operation (CDA 2007) and provision of an emergency overflow spillway and channel to convey the probable maximum flood (PMF) at the conclusion of mining. A 1 m freeboard was also included in the dam design.

4.1 Hydrologic Design Criteria

Selection of the appropriate return period of the inflow design flood was done based on the assigned risk category for an embankment failure (CDA 2007). The Canadian Dam Safety Guidelines risk category was determined based on the region downstream of the site being currently sparsely populated, with any construction or mine camp structures anticipated to be located a reasonable distance away from the toe of the embankment and the economic damage to downstream infrastructure or habitation and to mine facilities (with the exception of the tailings embankment and associated structures themselves) expected to be low to moderate.

Considering the above, a low CDA risk category was assigned to this facility. In the Canadian Dam Safety Guidelines (CDA 2007), the flood return period for a tailings dam with a low to significant consequence category is between 100 and 1,000 years. Therefore, a return period of 1,000 years was assigned for the inflow design flood for the construction and operational phases of the TSF. Following closure, the TSF was designed to be capable of storing and/or conveying a probable maximum flood (PMF).

4.2 Inflow Design Flood

There are limited recorded flows in the region on watercourses with drainage areas comparable to that of the TSF. The inflow design flood was therefore derived from daily rainfall amounts recorded at a meteorological station located approximately 20 km west from Amayapampa for the complete years 2003 to 2007. The maximum annual daily rainfall data for this short rainfall record ranges from 28.4 mm (2005) to 47.8 mm (2007).

Based on these records, the estimated 100 year and 1,000 year maximum daily rainfall, using probability graphing, is 64.5 mm and 81 mm, respectively.

The inflow design flood was selected as the runoff resulting from a daily rainfall of 81 mm (1,000 year event). For the purpose of estimating runoff volumes, a runoff coefficient of 0.5 was used for the drainage area outside of the tailings deposition area and 100% runoff (coefficient = 1.0) was assumed for rainfall directly onto the areas of deposited thickened tailings.

4.3 Closure Spillway

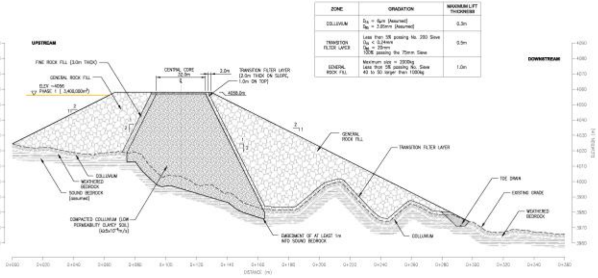
A spillway capable of conveying the outflow resulting from the Probable Maximum Flood (PMF) from the tailings impoundment is required at closure. The PMF for a drainage area of approximately 130 ha is estimated as 18 m^3/s, based on the method presented in Floods and Reservoir Safety (ICE 1978) and compared to an estimate based on modelling the runoff resulting from 5 times the 100 year rainfall event (322 mm rainfall and corresponding 21 m^3/s peak flow). This spillway will be located on the western side of the main TSF embankment dam.

5 TSF FACILITY DESIGN

5.1 General Concept

Based on the soil and rock conditions at the proposed TSF location, the nature of the tailings and the proposed quantities of tailings, a staged earthen core embankment dam design was selected. The core of the dam will consist of relatively impermeable compacted colluvium, flanked by appropriate filter layers and rock fill shells (Figure 2).

Figure 2 TSF Section – Phase 1



The dam will be constructed in stages, using a centerline construction methodology.

Given the seismically active location of the site and the uncertainty regarding the moisture content and shear strength of the produced tailings, the use of tails in dam construction was not considered in the design.

5.2 Design

The following assumed design data was used in the preliminary TSF design:

- Tailings solid content (after air drying and consolidation) = 80%;
- Tailings density = 1.6 t/m^3;
- Tailings placement by sub-aerial deposition around perimeter of TSF (as discussed later);
- Any collected seepage to be returned to the tailings impoundment or to the plant; and
- Tailings production rate: 7,500 dry tonnes/day.

The ultimate amount of tailings produced over the lifespan of the mine was forecast to range from 20 Mt (1 x 10^6 tonnes) to 25 Mt. Therefore, given the assumed tailings densities discussed above, an ultimate TSF capacity of 12.5 Mm^3 (1 x 10^6 m^3) to 15.6 Mm^3 is required.

5.3 Embankment Design

As discussed above, a staged earth-core embankment dam was considered appropriate to impound tailings on this project. The proposed TSF configurations by phase and volume are shown on Figure 2.

Based on the height of impoundment required (up to 100 m), and assumed favourable conditions in the bedrock and abutments, a centreline construction methodology was adopted for the design, with the centreline of the dam embankment extended vertically through all phases of construction. The initial phases of dam construction will therefore have a relatively wide cross-section to allow for construction of the additional stages.

The geotechnical investigation indicates that shallow bedrock is present throughout much of the proposed embankment dam envelope. However, seepage through fractures and/or faults in the underlying bedrock may be a concern if the tailings are acid generating. Therefore, several potential design features have been included to help minimize and collect seepage, as discussed below. The decision on inclusion of these features will be made following a bedrock coring investigation and in situ permeability testing.

5.4 Dam Zone Materials

The embankment core will be composed of the readily available low permeability colluvium material. If the colluvium proves easy to sort, finer graded colluvium will be placed on the upstream face of the core and coarser material on the downstream side of the core.

Sand and gravel filter materials will be derived from crushed local metamorphic rock, composed of clean, well graded granular soil, free of organics and other deleterious materials with a controlled gradation to prevent internal erosion of the core fill. Depending on the exact gradation of the core fill, as well as the gradation of the source material for crushing, multiple filter zones may be warranted.

Rock fill used for the bulk of the dam construction will be composed of sound, durable gravel, cobbles and boulders which are non acid generating. Use of angular rock will encouraged, although a certain degree of rounded rock is inevitable. This material should be relatively free of fines and hence free draining. A ready supply of suitable waste rock from the open pit excavation is expected to be available at a haul distance of approximately 2 km from the TSF.

5.5 Embankment Stability Analysis

The slope stability of various cross-sections of the proposed embankment dam has been analyzed with the Morgenstern-Price method of slices, utilizing the Slope/W Version 7 computer software. Pore-pressure distribution for the analysis was estimated using a piezometric line through the embankment, assuming a linear drop in head from full tailings storage level on the upstream side of the core to zero head at the transition and rock fill zones of the downstream side of the core.

Due to the use of thickened tailings, a situation involving a complete rapid drawdown of the reservoir is not envisioned and was not modeled.

The analysis was performed where the main dam is at its maximum height. The safety factor for a static condition was calculated to exceed 1.5, which is deemed adequate for the dam static stability. Therefore, the preliminary TSF design was considered acceptable. The dynamic analysis results are discussed in the following section.

Figure 3 Slope Stability Section of Downstream Face at Stage 3 (Impoundment Full)

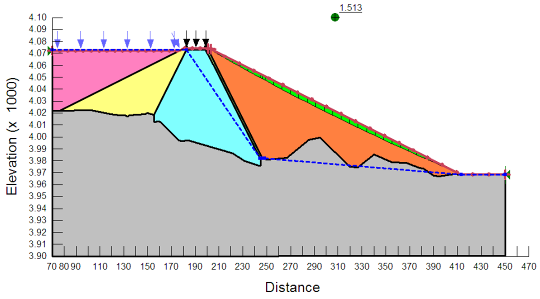
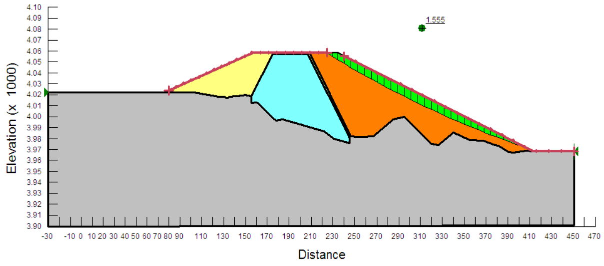


Figure 4 Slope Stability Section of Downstream Face at Stage 1 (Impoundment Empty)



5.5.1 Preliminary Seismic Assessment

A screening level pseudo-static analysis was used to assess the seismic stability of the tailings dam and to determine whether a more sophisticated dynamic analysis was warranted. If the Factor-of-Safety approaches 1, with the inclusion of a suitable seismic coefficient, the section may be potentially unsafe and may warrant further analysis related to the prospect of the foundation soils undergoing liquefaction. This pseudo-static analysis was again performed for the section where the dam is at its maximum height.

Adopting the assumed soil parameters discussed above and applying a seismic acceleration coefficient of 0.15, the preliminary embankment design has an acceptable Factor of Safety. This Factor of Safety will be confirmed in the detailed design phase using laboratory determined soil parameters.

Figure 5 Pseudo-static Slope Stability Section of Downstream Face at Stage 3 (Impoundment Full)

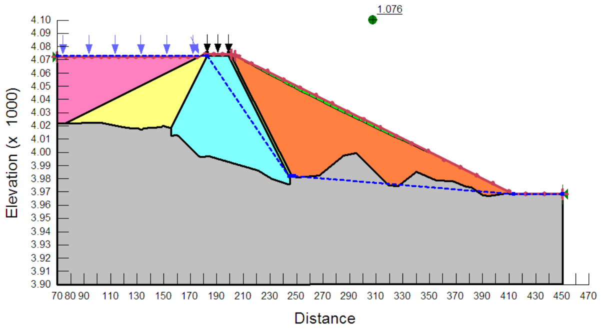
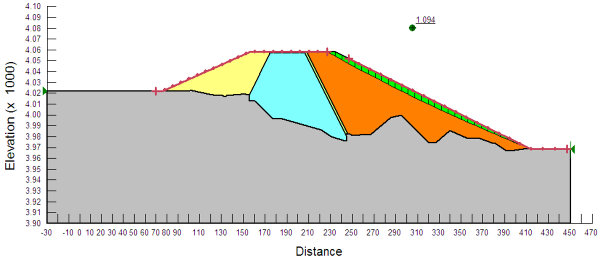


Figure 6 Pseudo-static Slope Stability Section of Downstream Face at Stage 1 (Impoundment Empty)



5.6 Seepage Control Measures

As a detailed investigation of the proposed dam foundation has not yet been completed, the foundation conditions have been assumed to consist of approximately 2 m of colluvium overlying weathered bedrock.

To reduce seepage under the core of the embankment, the preliminary design extends the core zone at least 1 m into sound, unweathered bedrock to serve as a seepage cut-off barrier. Loose, fractured or heavily weathered rock will also be removed in the abutments. Depending on the condition of the exposed rock subgrade and/or abutment sidewalls, construction of a grout blanket to infill voids may also be needed.

A grout curtain may be required if a significant amount of fracturing and/or faulting is present in the rock foundation or abutments underlying or adjacent to the core. This curtain would help seal off interconnected fractures and faults present in the native rock underlying and adjacent to the embankment which would otherwise serve as seepage conduits.

The need for a grout blanket and/or grout curtain will be determine following the detailed site investigation in the dam footprint.

Some degree of seepage, both through the embankment core and through the underlying rock foundation is anticipated. To collect this seepage, and to prevent internal erosion and potential piping failures, both in the embankment itself and in the underlying foundation, a filter blanket, embankment toe drain and collection pond will be constructed on the downstream side of the dam. Finger drains may also be required to collect and direct seepage.

A toe drain has been included at the downstream edge of the rock fill shell to collect any seepage through the embankment and to channel flows into the downstream collection pond.

All seepage collected from the filter blanket and toe drain will be collected in a downstream collection pond located at the downstream toe of the embankment. Seepage flows into this pond will be monitored for quantity and quality, as discussed below. Seepage water collected in the pond can either be returned to the plant or impoundment, or released to the environment once it has been treated to meet acceptable quality standards.

5.7 Closure Spillway

Prior to the end of Phase 3, a closure spillway capable of conveying the PMF is required. With the currently available rainfall data the PMF is estimated to be 18 m^3/s. The preliminary design comprises a 30 m wide spillway, cut into bedrock to a depth of approximately 1.5 m below the crest of the embankment. During extreme rainfall events this spillway will convey water out of the TSF to the Rio Khullka.

5.8 Monitoring

Monitoring of dams is essential to ensuring their long term performance and safety (ICOLD 1989). As well, as this is to be a staged dam, ongoing monitoring of dam performance during the initial stages may allow for further optimization in the design of future stages. Specification of a detailed instrumentation and monitoring system and schedule will be included as part of the detailed design process.

The monitoring program will comprise regular visual appearance and condition inspections, surface deformation measurements, internal pore pressure and phreatic surface measurements, seepage volumes and characteristics, groundwater chemistry in monitoring wells installed downstream of dam, seismic events and meteorological conditions.

6 CONCEPTUAL CLOSURE PLAN

The main objective of the TSF closure plan is to provide long term, secure and stable storage of the tailings within the facility. The closure plan should ensure that the stored materials are not susceptible to being transported from the facility by wind, or eroded by surface flows. Deleterious soluble substances within the tailings should also be prevented from migrating from the site by seepage.

The conceptual TSF closure plan incorporates a dry cover over the tailings material, and includes contingencies for addressing surface flow and groundwater seepage control measures for surface and subsurface impacts to water quality, and routine monitoring of pond, surface, and groundwater properties. A long term maintenance program for the control systems will also be required.

6.1 Drainage Plan

The downstream collection pond will be retained adjacent to the main dam of the TSF following closure. It will continue to collect surface runoff from within the catchment area of the TSF, including spillover of excess flows from any runoff interceptor ditches (provisional at this time). Potential overflows will be directed into a spillway with a design equal to the Probable Maximum Flood (PMF), attenuated somewhat by the routing of the flood inflows through the storage volume remaining within the TSF at closure.

After sufficient time has elapsed for substantial consolidation to take place in the tailings (in the order of 10 years), the remnant collection pond could then be filled in with colluvium and/or suitable waste rock.

6.2 Cover System

Based on our present knowledge of the physical and chemical properties of the tailings, a layered cover is proposed to cover the tailings at closure. The purpose of the cover is to minimize infiltration and hence the generation of groundwater flows in the tailings, both by direct shedding of water to the valley downstream of the main dam and by storing precipitation in the root zone where evapotranspiration can remove the stored water seasonally.

A multiple layer system was selected for the conceptual cover design. Although monolayer store and release covers have been shown to be effective on their own (Wels, et.al., 2001), the inclusion of a capillary barrier increases the available water storage and adds protection against drainage into the tailings during storm events (Scanlon, et.al., 2005). The conceptual cover system therefore consists of 150mm thick sand drainage layer directly atop the tailings to act as a capillary layer. This material will be overlain by a minimum 500 mm thick layer of colluvium to prevent wind and water erosion and to promote the establishment of vegetation. An additional 75 mm thick layer of organic topsoil may also be needed to nurture the growth of vegetation. Agricultural waste material may also be considered for this purpose.

We anticipate that the surface of the tailings will be sufficiently dry and firm within one to two years following the cessation of tailings deposition at the TSF to permit capping activities to proceed. The surface of the tailings may have consolidated to the extent that will permit trucks to haul and dump capping material over the surface of the TSF. If this is not the case, then capping material can be placed on the tailings beach as a working pad that can be extended into the tailings area, using the capping material. Trucks and spreading equipment can then operate from, and extend the working pad to include the total area of the tailings above the collection pond, which will temporarily remain in place as discussed above.

6.3 Long-Term Seepage

It is anticipated that the tailings will have undergone substantial consolidation by the end of the disposal operation and will continue to consolidate and hence, release pore water following closure. However, the volume of pore water in relation to surface flows, into which the pore water would be assimilated, is anticipated to be small. Therefore, the pH of the combined flow released to the spillway is expected to be within suggested limiting discharge criteria of 6-9.

In the event that adverse leachate conditions do develop, it would be necessary to examine a treatment regime to adjust the pH to be within the acceptable range for release. This might potentially involve the addition of lime prior to the release of drainage from the collection pond, or alternatively downstream, in a water quality monitoring pond.

Dry covers are generally effective in reducing infiltration into tailings materials; however, they do not suffice to completely eliminate infiltration (e.g. Meiers, et. al., 2005). The efficiency of the store and release cover will be strongly affected by the presence/absence of vegetation (Wels, et.al., 2001). Therefore, an active or passive treatment system may also be required to deal with post-closure outflows from the TSF.

7 CONCLUSIONS

The site selected for the TSF is satisfactory from both a design and an environmental protection perspective. The natural bowl shaped location provides containment with an outlet that can be readily plugged with an earth-rock dam founded on competent bedrock. The small catchment area (1.3 km^2) results in minimal runoff water to be retained or spilled, thereby minimizing risk of dam being overtopped. The foundation material is expected to be of relatively low permeability, based on site inspections and material testing. Hence, minimal underseepage is anticipated. The proposed location is also located within a reasonably short (<2 km) distance of the proposed pit and processing plant, allowing transport of tailings slurry by pipeline ease in obtaining construction material from the open pit excavation.

The proposed method of tailings deposition after thickening to a solids content of at least 60 percent, or approximately twice that of conventional “wet tailings”, lends itself well to the site topography, where subaerial exposure will facilitate drying and consolidation. This will result in increased storage capacity of the site and rendering the tailings to a “solid” state with time, which will facilitate post mining closure incorporating a dry cover. The method of thickened discharge deposition, combined with low precipitation and high evaporation, will normally preclude the accumulation of surface water with the TSF. However, a contingency plan for temporary pumping of excess water from the TSF to the process plant or to a downstream location should be planned. The thickened tailings method of deposition will also mitigate against the effects of any potentially adverse chemistry of the tailings, whether associated with the process chemicals, or possible generation of acidic conditions due to oxidation of sulphide constituents contained in the ore and host rock.

An earthern core embankment dam is considered appropriate to contain the thickened tailings. This dam will be constructed in stages using centerline construction methodology. Given the seismically active area, and the current uncertainty in the tailings properties, tailings have not been considered as dam construction materials. A suitable Factor of Safety exists for the preliminary dam design for both static and pseudostatic conditions.

The dam design will be optimized following a more detailed field investigation, consisting of a geotechnical and hydrogeological drilling program. This investigation is anticipated to include laboratory scale tests of the physical and rheological properties of the thickened tailings to assist in establishing the probable flow patterns and effect of drying and wet-dry cycles on consolidation and strength gain and susceptibility to dust generation. The dam design optimization will include selection of the most efficient upstream and downstream embankment slopes, following a detailed stability analysis, and determination of the necessary underseepage control mechanisms.

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