145 Ann Street, Level 9
Brisbane, Queensland 4000
Australia
ghd.com

Feasibility study of co-disposal of tailings and mine waste rock

A. Wanninayake[1] and T. Dixon[2]

1. Technical Director - Tailings, GHD, Perth Western Australia 6000. Email: Ajitha.Wanninayake@ghd.com
2. Senior Tailings and Dams Engineer, GHD, Vancouver British Columbia V5T 1M6. Email: Tyler.Dixon@ghd.com

Keywords: Tailings, Co-disposal, Waste rock, Co-mingling, Mining, Acid rock drainage

ABSTRACT

Alternative tailings disposal methods have gained much attention due to their advantages over conventional slurry tailings storage facilities. Co-disposal of tailings and mine waste rock is one of the leading methods of alternative disposal methods. However, application of this technology has been mostly limited to small-scale and research projects until recently. This paper discusses the use of co-disposal technology in a large-scale mining project in Western Australia.

An options assessment was performed to evaluate alternative tailings disposal methods against conventional slurry deposition, and co-disposal of tailings and mine waste rock was selected as the preferred option for tailings management. A feasibility study was completed for the selected co-disposal option that involved co-mingling of tailings with mine waste rock and construction of alternating layers of waste rock and tailings. Geotechnical and geochemical characteristics of tailings and waste rock, site topography and subsurface conditions, climatic conditions, construction and operational benefits, life cycle costs and safety in design were evaluated during the study.

Suitable mixing ratios of waste rock and tailings were assessed relative to the mine waste production schedule to maintain rock to rock contact ensuring improved static and dynamic stability of the co-disposal facility. Containment of potentially acid forming waste rock was incorporated in the design by including tailings in the waste rock dump.

Preliminary designs were completed for the co-disposal waste rock dump facility and slope stability and deformation analyses were performed for the design. The co-disposal facility will be developed to a detailed design during the next phase of the project.

Introduction

Project overview

A large-scale mining project, located in Western Australia, is envisaged to be an open-pit mine with a concentrate production rate of 5 Mt/annum and a 28-year mine life. The project Pre-Feasibility Study (PFS) identified a reduced-capital development option. The pilot process testing showed favourable results for the manufactured tailings, specifically greater than expected quantities of the dry and coarse tailings stream (referred to as grits) from the vertical roller mill (VRM). For this reason, the project evaluated different tailings storage options prior to proceeding with a definitive feasibility study. The evaluation comprised a thorough review of waste disposal techniques and completing a trade-off study by way of multicriteria analysis (MCA).

Site overview

The project is located in an area where the climate can generally be described as temperate with distinctly dry and warm summers. The monthly average temperature ranges from a low of 6°C in August to a high of 25°C in January. Seasonal fluctuations show a noticeable difference between summer and winter, with the warmest months being December to February and the coolest months being June to August. Typically, the wetter months occur during the winter while the dry months occur during the summer, however, some high rainfall events do occur as summer storms. The mean annual evaporation is approximately1200 mm.

The project site is characterised by undulating topography comprising sand dunes, ridges, and natural depressions. The depressions are generally structurally controlled by faults while prevailing wind patterns control the sand dunes. No significant drainage features are present across the site.

The project site is also recognised to be in a low to moderate seismic activity region.

Summary of waste streams

Waste for the project will be comprised of waste rock and tailings. Waste rock is divided into two streams, non-acid forming (NAF) rock particles and soils and potentially acid forming (PAF) rock particles. The tailings generated from the process plant are divided into three streams as described below:

- Dry non-magnetic grits are the coarse by-product of the VRM and rougher magnetic separator (RMS) components of the process plant. This stream produces a dry, benign, and uniformly graded sand material.
- Intermediate magnetic separator (IMS)+Cleaner magnetic separator (CMS) tailings underflow is the finer by-product of the VRM that goes through additional processing. The by-product is a slurry that is pumped through IMS and CMS to produce non-magnetic IMS and CMS tailings, respectively. The non-magnetic IMS+CMS tailings are then re-combined at the tailings thickener and the underflow produces a stream of filtered/paste-like, benign, fine tailings.
- Sulphide tailings are the by-product of all waste streams that include sulphide containing waste. These tailings will be managed separately.

The dry non-magnetic grits and IMS+CMS tailings are combined into an agglomerated tailings stream that will be co-disposed with mine waste in the Waste Rock Dumps (WRDs).

Sulphide tailings will be stored in a separate lined conventional impoundment Tailings Storage Facility (TSF).

- The overall process, with tailings streams, is presented in Figure 1.

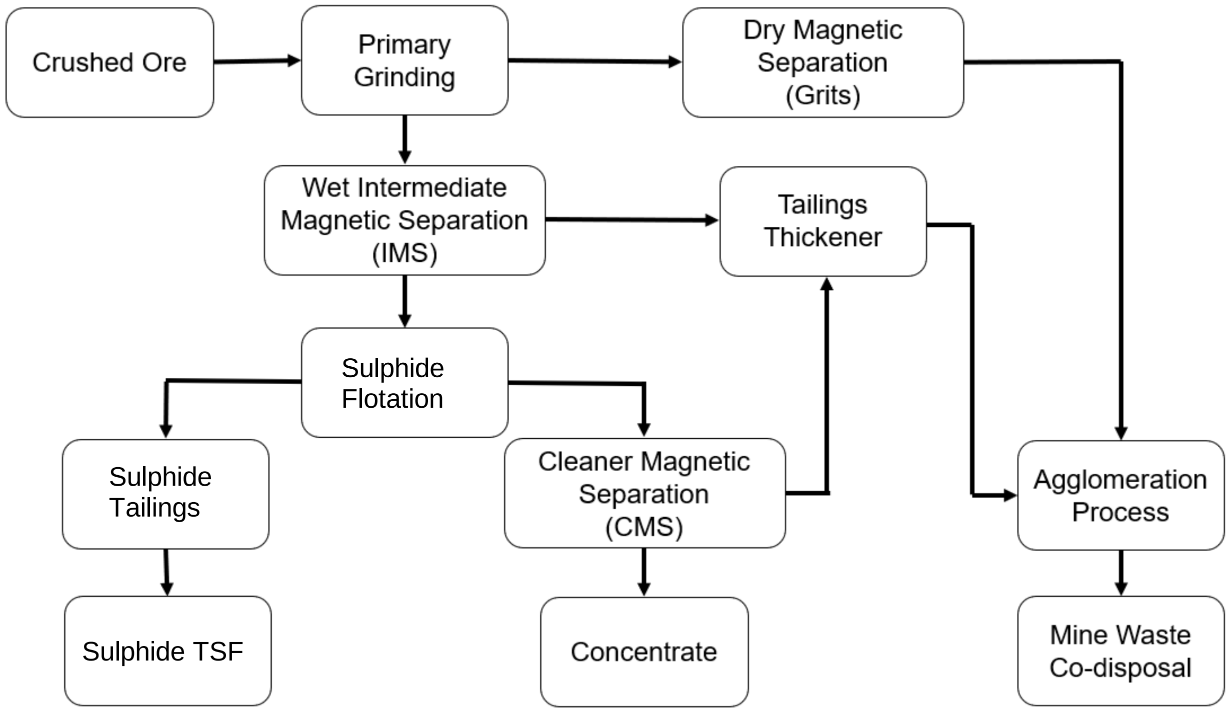

Figure 1 ***Simplified tailings processing block flow diagram***

Summary of waste production rates and tailings volumetrics

The volumes of expected NAF waste rock and agglomerated tailings are provided in Figure 2. The ratio of NAF waste rock to agglomerated tailings, by volume, is expected to be approximately 7:1 during initial start-up construction activities and averaging 2.3:1 thereafter. Tailings production inputs are provided in Table 1

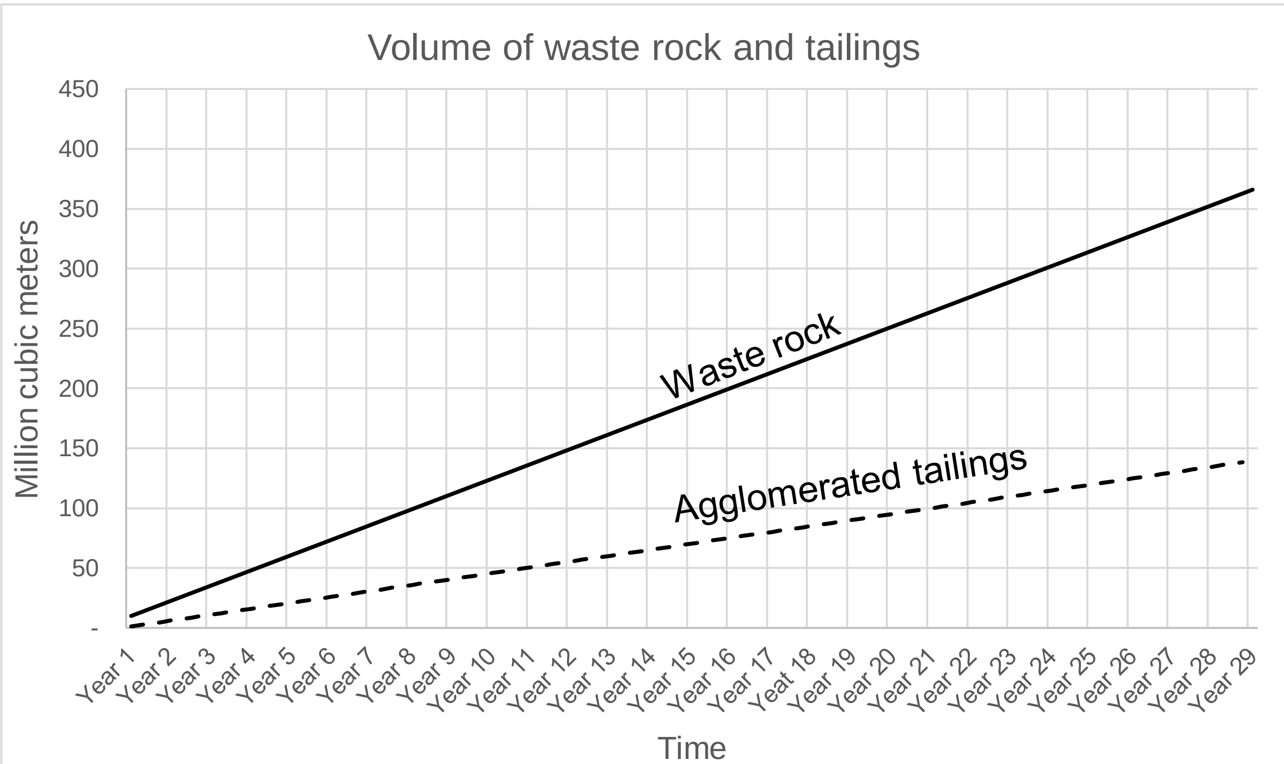

Figure 2 ***Waste rock and agglomerated tailings production volumes***

Table 1 Tailings streams production data

	Dry non-magnetic tailings (grits)	IMS+CMS tailings underflow	Agglomerated tailings
Solids mass flow (t /h)	769	458	1227
Water mass flow (t /h)	16	206	222
Total mass flow (t /h)	785	664	1449
Total mass flow (Mt/year) (Based on 8,000 operation h/year)	6.3	5.3	11.6
Solids content (%)	98	69	85
Moisture content (%)	2	45	18
Solids specific gravity	3.01	3.25	3.10
Slurry specific gravity	2.89	1.92	2.35
Volume (m^3/h)	271	346	617
Volume (Mm^3/year) (Based on 8,000 operation h/year)	2.2	2.8	4.9

Summary of tailings properties

Based on laboratory testing, in accordance with Australian Standard 1726, the agglomerated tailings have been classified as SAND-SILT MIXTURE with non-plastic fines (SM), and the grits are classified as poorly graded SAND with little to no fines (SP). The tested Standard Maximum Dry Density (SMDD) and Optimum Moisture Content (OMC) of agglomerated tailings are 1.97 t/m^3 and 13%, respectively; while the grits achieved a SMDD of 1.93 t/m^3 and an OMC of 15.5%, respectively. The Particle Size Distribution (PSD) of agglomerated tailings and grits are shown in Figure 3.

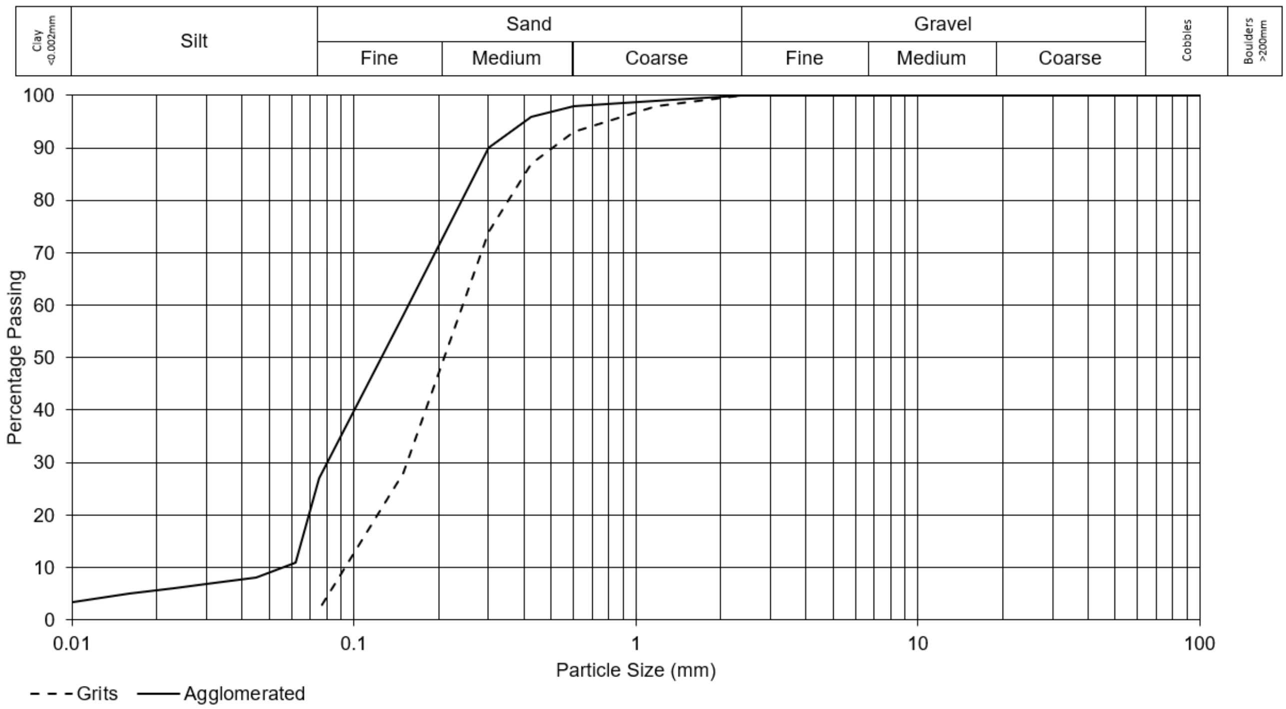

Figure 3 Tailings particle size distribution

Triaxial, Oedometer and California Bearing Ratio (CBR) tests were conducted on agglomerated tailings to inform the feasibility design of the co-disposal WRD.

Options assessment

Objective

The objective of the options assessment was to evaluate different storage options for waste rock and tailings, accounting for the relative proportions and properties of different tailings streams, and to assess potential optimisations by combining waste streams for improved geotechnical performance. Conceptualised options were developed and then assessed using multicriteria analyses.

Overview and approach

The options assessment commenced with a period of information gathering and sharing among the owner, the tailings consultant, the mining consultants, the processing consultants, and other stakeholders. The owner provided guidance and offered position statements consistent with best available practices and encouraged the adoption of emerging technologies. Through this consultation process three conceptualised options were proposed for further study which were:

- a conventional wet TSF
- dry stacking tailings
- combinations of tailings and waste rock co-disposal methods.

The options assessment was then carried out through a two-step MCA, described below.

Key criteria and constraints

The key criteria driving the options assessment were:

1. Storage capacity: will containment and storage of the tailings be feasible?
2. Ease of production, material handling, and deposition: does the option provide simpler production, material handling, and deposition?
3. Geotechnical engineering: does the option face any geotechnical risks?
4. Water and environment: does the option face any water / environmental risks?
5. Operations and processing: are there any operation and processing risks associated with the option?
6. Upfront costs: relative to other options based on a comparative order of magnitude.
7. Ongoing costs: relative to other options based on a comparative order of magnitude.
8. Permitting and approvals risk: will there be any complexity for approvals for this option?

The key constraints were:

1. Storage capacity
2. Footprint constraints
3. Visual impacts and height restrictions
4. Start-up costs and initial start-up risks
5. Closure planning and long-term risks

Options study

Summary of storage concepts

Based on the pre-feasibility studies the approximate general arrangement and footprints available for waste storages were known. Then, through the consultation process, it became clear that spatial constraints and volumetrics of waste materials were critical inputs for the key criteria. Therefore, any storage concept relied on co-disposal to manage at least a proportion of the tailings waste streams. Three combinations of storage options were studied as depicted in Figure 4. The combinations were:

1. Option 1: Conventional TSF and wet storage of IMC+CMS tailings and co-disposal of grits and excess IMS+CMS tailings at WRD1 considering a) blended and b) layered co-disposal methods.
2. Option 2: Dry stack of agglomerated tailings and co-disposal of agglomerated tailings at WRD1, considering a) blended and b) layered co-disposal methods.
3. Option 3: Co-disposal of agglomerated tailings only, considering a) blended co-disposal at the WRD only and b) layered co-disposal methods at the WRD only, c) blended co-disposal at both locations, and d) layered co-disposal at both locations.

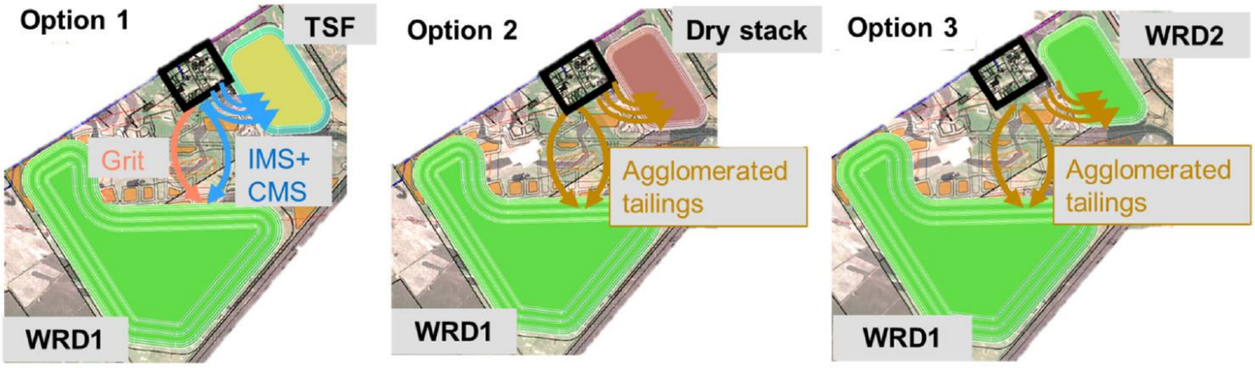

Figure 4 Waste storage options

Co-disposal

In this study co-disposal is a generic term used to describe the handling and disposal of different waste materials together at the same location. This study then considered further subclassifications identified as blended co-disposal and layered co-disposal, which are techniques sometimes referred to as co-mingling, co-placement, or co-deposition.

Blended co-disposal is the process when waste rock and tailings are transported separately and blended together during placement in such a way that the tailings ingress into the waste rock void space to generate a composite material. Layered co-disposal is the process when waste rock and tailings are transported separately then placed and compacted in alternating layers.

A necessary requirement of the blended co-disposal technique is to have the shear strength performance of the WRD governed by the properties of the waste rock. To achieve this intent the waste rock particles shall remain in contact whilst tailings fill the void space. The waste rock to tailings mix ratio for the blended co-disposal technique was assumed to be the product of a 60% void filling efficiency and a waste rock porosity of 0.3, which is equivalent to 18% of the waste rock unit volume and a 5.55:1 waste rock to tailings ratio (by volume). The assumed void filling efficiency is consistent with ideal mix ratios of greater than 4:1, preferably 5:1, as supported in findings by Gowan, Lee, and Williams (2010), Wickland (2006), Khalili, Wijewickreme, and Wilson (2010), Wijewickreme, Khalili, and Wilson (2010), and S. Bainbridge et al. (2022).

A comparison of either co-disposal method is given in Table 2.

Table 2 Comparison of blended and layered co-disposal methods

Advantages	Disadvantages
1. Blended co-disposal	
– Clast supported (at mix ratios of 5:1 or greater) – Increased physical stability performance as the rock particles will be in contact – Reduction in potential ARD of mine waste rock due to low ingress of oxygen into tailings filled voids – Reduces overall waste storage footprint – Lowers overall environmental and long-term risks – Dust suppression efficiency	– Requires test fills to determine an appropriate mechanical blending methodology – Added equipment costs to achieve blending – Tailings ratio is limited by waste rock porosity and ‘rock-to-rock’ contact requirements – Success of blending is highly dependent on waste rock PSD and porosity – Efficiency is susceptible to different waste production rates

Advantages	Disadvantages
2. Layered co-disposal	
– Reduction of ARD of mine waste rock due to tailings layers covering rock. – Less requirement for mechanical blending of tailings and waste rock More constructable as opposed to mechanically blending the material – Flexible design can accommodate different waste production rates – Efficiency is less susceptible to different waste production rates – Independent of waste rock PSD and porosity	– Includes connected zones or layers of lower shear strength material (tailings), hence stability would be influenced by tailings layers – Requires civil equipment fleet for additional construction work front (placement and compaction). – Tailings as-placed and compacted moisture content will be a critical element – may require moisture conditioning or evaporation ponds or other drying methods – Requires CQC and CQA – Decreases available storage of waste rock

Advantages and disadvantages of primary storage options

Throughout the options assessment, in consultation with the owner, the owner's other consultants, and other stakeholders, a number of advantages and disadvantages were identified for each of the options and summarised in Table 3.

Table 3 A comparison of advantages and disadvantages for primary waste storage options

Advantages	Disadvantages
1. Conventional wet TSF as the primary storage option with co-disposal at the designated WRD.	
– Confined storage area provides a contingency for upset conditions (eg, tailings with high water contents) and space for evaporation	– Total volume of IMS + CMS tailings is expected to exceed the maximum available capacity of TSF storage; therefore, alternative storage would be required later in the mine life – Additional handling methods would be required for co-disposal of the grits – Greater long-term risks due to difficulties closing wet storage facilities – Greater short-term risks associated with breach of the TSF embankments – Greater CAPEX costs – May require dust suppression measures for grits
2. Dry stack TSF as the primary storage option with co-disposal at the designated WRD	
– Potential lower OPEX – Simplified tailings storage area – Lower short-term risk as embankment breach risks would be mitigated – Lower long-term risk (than a wet TSF) as closure would be less costly – Reduces wet TSF storage to sulphide tailings only, lower overall project risk	– May be vulnerable to upset conditions (eg, tailings with high water contents) – Total volume of agglomerated tailings is expected to exceed the storage capacity for the dry stack area, therefore, alternative storage would be required later in the mine life – Requires a minimum density for geotechnical stability – Low erosion resistance without rock cover – Reprofiling for final landform design will be required – Susceptible to liquefaction – Potentially high Capex – Limited in height, therefore greater storage area required and longer conveyor distances – Lower process plant annual operating hours due to TSF mechanical equipment availabilities – Dust suppression measures would be required

Advantages	Disadvantages
3. Co-disposal only, utilizing both storage areas available	
– Simplicity in combining waste rock and tailings into one facility. – Good final environmental outcome limiting long term environmental and owner risks through a high-density compacted structure – Truck haulage providing flexibility to create zones within the WRD that meet the required characteristics for geotechnical stability, drainage, seepage, and final landform for mine closure commitments – Volume efficiency reducing the project disturbed footprint as grits and tailings will fill a portion of the voids in the fresh rock and WRD has potentially less height constraints. – Operating procedure would be flexible through truck, dumping and bulldozer combinations. – Dust suppression efficiency through combining dry grits and wet tailings. Wetter products may better penetrate the fresh rock voids. – Low CAPEX option. – No impact on process plant availability due to flexibility in truck fleets. – Reduces wet TSF storage to sulphide tailings only, lower overall project risk. – Option to include blended and layered co-disposal methods.	– May be more susceptible to upset conditions. – Blending techniques are not developed and proven – Tailings streams require mixing to average – moisture content prior to co-disposal. This requires extra handling. – The height of the storage facility will increase if excess tailings cannot be stored elsewhere (eg, in pit backfill). – High OPEX option, due to low Capex expenditure and diesel prices, until electrification for emission reduction. Trolley assist or conveying extensions will reduce OPEX. – Truck load capacity will depend on material characteristics (eg, slumping)

Multicriteria analyses

Methodology

A two-step analysis was performed by completing two MCAs in sequence for the co-disposal and tailings storage options discussed. A multistep process was undertaken to allow for ease of comparison between co-disposal methods and primary storage options as one may have influence over the other. For example, the first step was an MCA to evaluate which co-disposal method was preferred, which was given a weighting factor that was then input into the second MCA for primary storage considerations.

For both MCAs options were assessed against elements that together made up a single key criterion. Each option was then given a score between 1 to 5 for each element and the average score across all elements made up the overall score for that particular key criterion. For example, the key criterion of 'ease of production, material handling, and deposition' was the combined average scores for the elements: tailings delivery / deposition methodology, blending / mixing / agglomeration process, and variable production rates. Following scoring, the key criteria were given a weighting based on a consensus of the level of importance to the overall outcome.

MCA results

The hierarchy for the MCA scoring was as follows:

1. Very negative outcome
2. Negative outcome
3. Neutral outcome
4. Favourable outcome
5. Very favourable outcome

The results of the MCA favoured Option 3 as the primary storage option and the layered co-disposal method. Then extra advantages were realised when considering utilising both blended and layered co-disposals methods, as will be discussed next.

Integrated waste landform definitive feasibility design

General

The envisaged design concept emerged from co-disposal waste rock dumps to two integrated waste landforms. The concept is comprised of strategically placed agglomerated tailings and waste rock zones that take advantage of qualities of each material. By doing so the concept optimises the overall site-wide waste storage capacity, provides operational flexibility, lowers short-term and long-term foreseeable risks, and more easily facilitates closure objectives.

Design concept

The selected design concept is integrated waste landforms that include the following elements:

- A perimeter shell comprised of non-acid forming, unblended, waste rock.
- Alternating layers of compacted agglomerated tailings and blended co-disposal tailings/waste rock.
- Internal waste rock columns, and
- Internal potentially acid-forming waste rock encapsulation cells.

The design concept is shown in Figure 5.

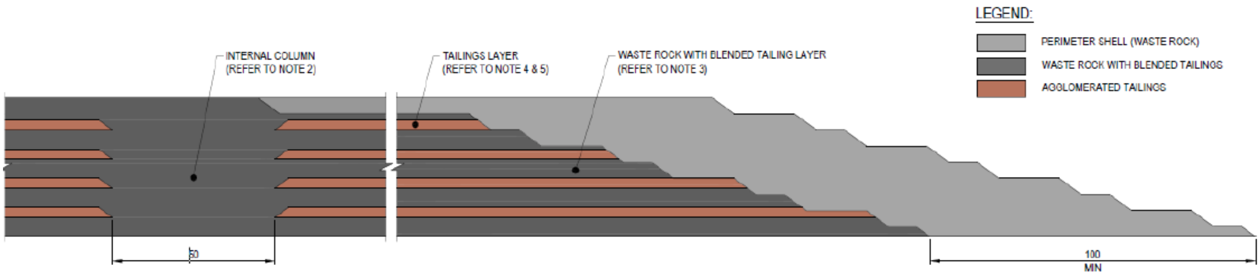

Figure 5 *Typical schematic cross section (PAF cells not included*

Envisaged advantages of the co-disposal concept

Optimised waste storage and operational flexibility

Within the layered and blended co-disposal regions, the blended tailings/waste rock layers are between 5-6 m placed in 1 m thick layers, and the agglomerated tailings layers are between 3-5 m placed in 0.5 m thick layers considering compactability. Increase in density of agglomerated tailings due to compaction and dissipation of pore water pressure through internal waste rock columns will help reducing liquefaction risk. Each zone between rock columns is in a grid pattern with spacing between 100-200 m. This arrangement maximises operational flexibility and provides optimised storage capacity of the tailings waste stream.

PAF management

Tailings are lower permeability than waste rock and have a higher degree of entrained moisture. By including tailings in layers and in the void spaces of the waste rock the landform and composite material will have a reduced vertical transmissivity, thus reducing diffusion and advection and the ingress of oxygen throughout the landform. This will result in a reduced flux of both air and water, which will reduce the propensity for PAF waste rock to generate acid.

Short-term and long-term foreseeable risks

Many of the risks associated with a ‘conventional’ tailings storage would be reduced or mitigated by implementing this design concept. At a high level, the risks and their mitigating factors are summarised below:

– Embankment failure and dam breach: Eliminates the hazard from release of tailings due to a potential embankment breach. Embankment failure is design dependent.
– Geotechnical slope instability: The perimeter shells provide buttressing and can be adapted (batter slopes and dimensions) to suit variable conditions, as necessary, reducing the hazard. Waste rock particle contact, within the blended co-disposal layers, provide additional internal shear resistance improving overall geotechnical stability.
– Geotechnical instability of the foundation: Construction can be staged to allow for consolidation of foundation soils and dissipation of pore pressures and the perimeter shell can be adapted to provide restoring forces, reducing the hazard.
– Liquefaction: Internal agglomerated tailings will be compacted to a suitable relative density to achieve a non-liquefiable mass. The perimeter shell and blended layers are not expected to be susceptible to liquefaction. The landform is not expected to impound water and the waste rock columns provide shortened drainage paths to mitigate against perched water tables.
– Earthquake induced deformation: Deformations as a result of an earthquake may be possible, but large deformations would be tolerable, reducing the overall hazard.
– Variable rate of waste streams: Construction may be staged throughout the landform to provide for optimum operational flexibility. Tolerances of layering thickness provides additional flexibility.
– PAF cell acid generation: Tailings layers will reduce the conditions that typically lead to acid formation by limiting the ingress of oxygen and reducing seepage flux, in addition to the PAF cell design.
– Closure planning and sustainability: Closure planning and rehabilitation at lower levels can begin before the end of mine life. Slopes can be flattened and revegetated during construction, improving the long-term sustainability.
– Post mine land-use: More options are viable for a post mine land-use than a conventional wet TSF or dry stack.

Conclusions

By incorporating tailings with waste rock into an integrated waste landform, the favourable properties of each material type were used to their advantage for an optimal waste storage design. The agglomeration process combines dry grits with wet IMS+CMS tailings to produce a tailings mixture which is close to the optimum moisture content facilitating handling and compaction. Adding agglomerated tailings to fill rock voids reduces oxygen ingress resulting in less potential for acid rock drainage.

The results of the options assessment and multicriteria analyses indicated that co-disposal of agglomerated tailings and waste rock would provide an effective integrated mine waste landform whilst addressing potential risks associated with other disposal methods and provide advantages during operations and closure.

The concept design was developed to a definitive feasibility level however further study is required during detailed design and during construction. This will include confirmation of the geotechnical properties of the waste materials, a comprehensive geotechnical investigation of the foundation, field trials for optimal blending techniques and compaction methods, development of material handling procedures and a strategy for coordination between mine waste production and tailings production streams.

Acknowledgements

The authors would like to express their gratitude towards the owner of the project and the project team for their support throughout the study and this paper. The authors would also like to thank Daniel Maher, Milan Thiaga, John Phillips, Sina Kazemian, Caroline Holmes, Louise Thomas, and Andrew White for their significant contributions, guidance, and review.

REFERENCES

Bainbridge, S, Steele, J, Samlets, J, and Walker, D, 2022. Design approach for a co-managed tailings and waste rock facility in British Columbia, Canada. *Proceedings Tailings and Mine Waste 2022*, pp 48 - 58. (Tailings and Mine Waste: Denver)

Gowan, M, Lee, M, and Williams, D J, 2010. Co-disposal techniques that may mitigate risks associated with storage and management of potentially acid generating wastes, in *Proceedings Mine Waste 2010* - A.B. Fourie and R.J. Jewell (eds), (The Australian Centre for Geomechanics, Perth)

Khalili, A, Wijewickreme, D, and Wilson, G W, 2010. Mechanical response of highly gap-graded mixtures of waste rock and tailings. Part I: monotonic shear response. Canadian Geotechnical Journal, 47: 552-565.

Wickland, B E, 2006. Volume change and permeability of mixtures of waste rock and fine tailings, PhD thesis, University of British Columbia, Vancouver.

Wijewickreme, D, Khalili, A, and Wilson, G W, 2010. Mechanical response of highly gap graded mixtures of waste rock and tailings. Part II: undrained cyclic and post-cyclic shear response.