Paste 2026 – AB Fourie, M Horta, M Oliveira & S Wilson (eds)

doi:10.36487/ACG_repo/2655_62

Refinements to a dual mound central deposition tailings facility

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Abstract

Tailings facilities for central deposition of thickened tailings are formed with a central point or a series of central points for slurry deposition. Best practice is to develop a predicted tailings beach slope model for design of the facility, with the model informing the embankment layout, and tailings distribution and surface water management systems. Where the upstream raise method is allowed, designing for the life-of-mine layout is critical for the success of this raise method and the future closure of the landform.

Updates to the design tailings beach model should be expected throughout operation based on review of beach slope performance and these updates should inform refinements to the facility layout, both during stage operation and for future raise layouts. Perimeter embankment and internal refinements (e.g. for causeways) are typical throughout the life of the facility, to achieve the target storage capacity, accommodate changes to the beach profile and surface drainage, and the state of the tailings deposit.

The tailings deposition system may be modified to provide greater distribution of tailings deposition; reducing the volumetric flow rate from each outlet typically improves beach slope performance, in turn increasing storage capacity. The distribution system may also be modified to maximise use of available freeboard at the perimeter embankment.

Achieving the design beach geometry is critical for surface water management. A single decant area with appropriate water removal measures is favoured to limit dam failure risks associated with multiple, uncontrolled ponds. Adoption of a gravity decant system provides for passive release of water and pipe penetrations can be managed with controls to address failure modes associated with these penetrations. A passive system typically removes flood water faster than a pump-out system. An emergency spillway sized for an extreme rain event minimises the risk of overtopping.

Based on observations made over circa 19 years since the transition to central deposition and multiple stages of development, this paper describes design refinements made to a dual mounded central deposition tailings facility in a semi-arid climate that have improved operational performance, facilitated upstream raise construction, and established a runoff shedding landform that can be transitioned with limited works for long-term closure. It discusses how integration of tailings deposition and construction sequencing is critical to the success of the upstream raise method for central deposition facilities, and how the resultant landforms address best practice for geotechnical stability and surface water management during operation and at closure.

Keywords: *thickened tailings, central deposition, beach slopes, upstream raise, surface water, closure*

1 Introduction

Transitioning of the perimeter deposition tailings facility at the CSA Mine to central deposition commenced in 2007, following the millennium drought. Details of the transition are described in Accadia & Gassner (2018)

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and are summarised below. Including transitioning the layout for central deposition, a number of refinements have been made to the facility to improve its operational performance. Various design lessons, observed through monitoring the facility over 19 years since commencement of the transition, have informed subsequent stages of development and should inform the design of new facilities. Both the perimeter embankment and deposition causeway layout have been modified with each raise based on beach slope performance and surface drainage and modifying the embankment adjacent to the decant area to facilitate efficient raise construction. A number of modifications to the gravity decant system and decant dam have been made to improve the system for passive removal and collection of surface water.

2 Background

2.1 Historical development of the facility

The tailings facility was commissioned in 1965, with a cross-valley embankment and spigot arrangement along the embankment for initial up-valley deposition. A gravity decant system was installed with an outfall pipe through the embankment at the foundation with extensions of the pipe inlet during operation to stay ahead of the advancing tailings beach. Once the decant area reached what is now the perimeter of the facility, the decant pipe was decommissioned and there was a transition to perimeter deposition and a central pond for decant pumping via an earthen causeway. The pipe was decommissioned by pressure grout filling from the outlet.

From 2007, there was a transition to central deposition of thickened tailings. A western extension was initially developed for the deposition of tailings thickened to about 50% w/w (weight of solids over total weight of solids and water). Once the extension was filled and the old perimeter deposition layout of the eastern area had dried and desiccated sufficiently for access by earthmoving equipment, an upstream raise to the embankment was formed around the eastern area. The alignment of the upstream raise was configured to direct surface water to a decant area on the southern side of the facility, with gravity decant to an external decant dam. Removal of water from the central pond to the new decant area was achieved by excavation of a channel in the old tailings beach, forming filter berms across the channel and installing a flexible pipe through the perimeter embankment, with seepage control measures.

As the new tailings mound approached the perimeter by about 2013, the decant was upgraded to include a junction box at the upstream end of the pipe and the perimeter embankment was raised, with a decant chute installed on the upstream face to allow for the inlet to be raised ahead of the tailings surface. A second tailings mound on the western extension was integrated into the layout, with a perimeter embankment wrapping around both mounds, configured to direct drainage to the south-central decant area.

Including the initial transition layout over the old perimeter deposited tailings, the facility has been upstream raised in 4 stages (stages 7 to 10), each using tailings excavated from the 2 mounds to form the embankment raises, implementing conventional soil compaction methods.

2.2 Tailings generation and delivery

Tailings generated from the processing of copper ore at the CSA Mine is used for paste backfill of underground mine stopes and the remaining tailings is deposited in a surface facility. Thickened tailings is either pumped to a filtration plant to produce paste plant feed or is pumped to the tailings facility for central deposition. The typical particle density of tailings is about 2.9 g/cm^3 and the P_{80} (particle size for which 80% is finer) of the tailings is typically about 90 µm.

3 Tailings deposition learnings and improvements

3.1 Tailings thickening and beach slopes

Early design concepts adopted an average beach slope gradient of 1.5% based on the expected change in beach slope performance from perimeter deposition of low density slurry at about 30% w/w (measured at about 1 to 0.5%) to thickened tailings at about 50% w/w and published information at the time that indicated 2 to 1.5% beach gradients for the central deposition tailings facility at the nearby Peak Gold Mines site (Williams 2006).

Improvements to thickener performance over about 19 years of operation have seen additional dewatering of tailings to about 60% w/w. Beach slopes now vary from about 5% near the crest of the mounds to about 1% near the toe, with a concave profile. Deposition of up to about 60,000 dry tonnes per month, split over about 8 spigots, results in a volumetric flow rate at each outlet of about 3 L/sec. This low rate provides for relatively gentle flow and relatively steep beach development.

Factors that have led to occasional large erosion gullies in the beach and temporary periods of reduced performance include:

- periods of low density slurry
- higher flow rates when tailings is not being used for paste backfill
- inadequate spigot design
- inadequate frequency of spigot rotation
- breakaway of spigot pipes from delivery main, including due to inadequate valves
- prolonged pipeline flushing
- runoff from intense rain events.

Spigot design improvements, including for the latest stage layout and improvements to the rotation strategy for operation of spigots around the end of each causeway have limited the formation of large gullies and improved beach slope development, as described later.

Erosion events have led to deposition of sediment in the decant area which compromised freeboard at the perimeter embankment below the emergency spillway in earlier stage layouts. They have also led to sediment laden flow through the gravity decant system to the decant dam. A design improvement has been to allow contingency freeboard in the decant area, as described later. Designing for clean-out of sediment from the decant dam is also discussed.

3.2 Deposition causeways

Each stage raise for central deposition has comprised centreline raises to the causeways onto the west and east mounds, with each raise formed with compacted tailings. The causeways extend to almost the centre of each storage area and are set back from the centre to allow for beach perimeter drainage to the decant area. The lateral extent and elevation of the causeways for each raise are based on the design tailings beach model which has been progressively refined from operational performance review. Tailings deposition from the recently (Stage 10) raised causeway for the west mound are shown in Figure 1.

Figure 1 Tailings deposition onto west mound following Stage 10 raise construction

The centreline raise layout for the causeways has resulted in some differential settlement from construction partially onto the previous stage causeway and the tailings beach. A design improvement has been to include geosynthetic reinforcement layers in the compacted tailings causeways to limit cracks from differential settlement.

3.3 Spigot system

Various spigot arrangements have been trialled for the facility since the introduction of centrally deposited thickened tailings.

Tailings delivery pipelines extend to the end of each causeway, and, over last 30 to 40 m length of each, small diameter spigots are used to distribute thickened tailings slurry to develop the beach in a way that approximates the design model and maintains surface drainage to the decant area.

Short lengths of mine hoses that feed into PVC 'dropper pipes' with slots in the crown were initially used; however, to manage the risk of causeway erosion due to pipe dislodgement and direct flow onto the side slopes, the spigot system has been upgraded to comprise small diameter flexible (HDPE) pipes from the delivery main, also with slots in the crown. This approach has proven effective in limiting spigot maintenance and for better control of tailings beach development. Spigots at the recently raised east causeway are shown in Figure 2.

Figure 2 Tailings deposition spigots at the east causeway

3.4 Rate of rise

Maintaining a low rate of rise for tailings deposition followed by months of drying and desiccation has been required to facilitate upstream raise construction onto the centrally deposited tailings. This is achieved by a rotation strategy for deposition onto the mounds, with typical phases of up to 6 months on each mound before switching to the other mound. The average rate of rise across both mounds is about 1 m/year and with thin layer deposition and the prevailing evaporation, deposited tailings typically consolidate and drain to an unsaturated or partially saturated condition. Vane shear tests typically indicate the near surface tailings to be 'very stiff' after 3 months of drying. This enables access onto the tailings by earthmoving equipment for borrow excavation and raise construction, including wheel tractor-scrapers, as shown in Figure 3.

Figure 3 Open bowl scrapers on the east mound of the facility for tailings excavation

The rate of rise can be locally higher where available area is limited by construction activity occurring in other area of the facility, and the condition of the tailings continues to be reviewed via piezocone penetration test programs. Other than in the decant area, these have indicated an absence of phreatic surfaces in the mounded tailings deposits.

4 Embankment design and construction learnings

4.1 Perimeter embankment configuration

The perimeter embankment wraps around the 2 tailings mounds, as shown in Figure 4. It is configured based on the design tailings beach model, both in spatial layout to form a drain with the tailings beaches and in elevation to provide operational freeboard to limit overtopping by tailings and/or water. The authors are aware of other central deposition facilities where there has been no beach design to support the embankment layout, resulting in large variations in perimeter freeboard, drainage constraints and multiple pond areas. Risks of multiple pond areas without appropriate decant and spillway measures are described later, as well as the importance of additional freeboard in the decant area.

Figure 4 Westward view across the east and west tailings mounds during Stage 10 raise construction

4.2 Raise method

The upstream construction method is primarily adopted for the perimeter embankment, utilising tailings as the primary fill material, and mine rockfill for erosion protection, with a separating filter layer of non-woven geotextile on the downstream face and on the upstream face adjacent to the decant area.

The top-hat raise construction method is adopted for a portion of the perimeter embankment adjacent to the decant area, to limit the number of upstream raises onto the soft to wet tailings from intermittent ponding of water. For this method, the embankment is initially widened onto the soft tailings with robust foundation preparation measures, and subsequent raises are constructed onto the widened embankment. The widened embankment is sized based on the life-of-mine plan, to accommodate future raises without the need to construct upstream onto the tailings or downstream onto natural ground. It requires larger upfront capital expenditure to negate longer term risks. A small widening was adopted at Stage 7 to allow for a top-hat raise at Stage 8, and a larger widening was adopted at Stage 9 to allow for a top-hat raise at Stage 10, as shown in Figure 5.

Figure 5 Stage 10 top-hat raise construction over widened embankment adjacent to decant area

Widening of the embankment and top-hat raises adjacent to the decant area have allowed for extensions to the gravity decant chute on the upstream face of the embankment, thereby limiting the number of pipe penetrations through the perimeter embankment and associated design and decommissioning measures.

Transitions of the embankment between the upstream and top-hat raise methods have included geosynthetic reinforcement layers and filter curtains to limit the potential for cracks from differential settlement, arrest potential cracks and depressurise seepage.

Each raise has typically been less than 5 m high, which has been demonstrated by slope stability analyses to not require upstream toe berms. However, downstream buttressing has been required.

4.3 Buttresses

Mine rockfill was initially integrated into the tailings facility layout to avoid a standalone mine waste rock stockpile at the mine. A placement plan for mine rockfill was developed; however, this was later modified for the life-of-mine layout to prioritise rockfill to buttress portions of the perimeter embankment for slope stability. The site is in an intraplate tectonic setting with low earthquake risk, and assessments indicate only rare (very low probability) earthquakes could trigger liquefaction. The likelihood of static trigger mechanisms is also low; however, buttresses were designed for a scenario where liquefaction of susceptible tailings has occurred, consistent with industry best practice and in accordance with the principle of reducing the dam breach failure risk to ‘so far as is reasonably practicable’.

A key learning for this facility and others has been to consider the life-of-mine raise configuration for embankment slope stability, to identify opportunities for shear keys in the foundation of embankment raises and limit the size of buttresses.

4.4 Construction sequencing

The dual mound layout provides the ability to deposit tailings whilst undertaking upstream raise construction. For initial stage layouts for central deposition, raise construction was around one mound, followed by a resumption of tailings deposition on that mound and a temporary break in works to allow for beach drying at the other mound. Historically, about 3 months was the ideal gap between raising the embankment around each mound.

However, to provide for a continuous construction campaign, the latest stage raise was sequenced for completion of the embankment in 3 phases without breaks in the earthworks or tailings deposition. This was achieved by forming low height temporary bunds for both stormwater and deposition management to segment the larger eastern mound, whilst raise works initially occurred on the west mound, and then forming a dividing bund between the west and east mounds for the resumption of deposition on the west mound.

Although the construction and deposition sequencing strategy has worked for the facility, a more robust strategy would be to have separate tailings facilities that enable clear separation of areas for construction and tailings deposition.

4.5 Tailings borrow areas

The ability to excavate tailings from the impoundment area for embankment fill, primarily using wheel tractor-scrapers, has been possible due to implementation of a tailings deposition strategy. The strategy for thin layer deposition and rotation between the mounds has enabled the low-cost upstream raise construction method, limiting the disturbance footprint outside of the facility (e.g. for clay borrow) and gaining additional storage capacity from tailings borrow for future deposition.

Tailings borrow requires careful management to ensure drainage within the facility is maintained and future beach slope development is not compromised. Learnings have arisen from borrow areas being too close to the perimeter embankment and causeways, and drainage not being provided to the decant area. Excavations too close to embankments and inadequate drainage can lead to ponds, thick deposits of saturated tailings and dam failure risks related to seepage and overtopping. Poor beach performance can also result if borrow areas are not appropriately shaped, e.g. deposition into a deep 'scalloped' borrow pit can result in beach flattening and rapid use of perimeter embankment freeboard.

Design controls and monitoring measures are in place during construction and operation to maintain a minimum offset of borrow pits from the perimeter embankment to limit risks associated with ponds, for shaping of the borrow pit during construction to maintain drainage to the decant area and for carefully managed tailings deposition into borrow areas following completion of construction. The shaped borrow pit in the east mound during the Stage 10 raise works is shown in Figure 6.

Figure 6 Shaped east mound tailings borrow pit

5 Water management improvements

5.1 Surface drainage

Surface water is managed in a single decant area, where the gravity decant system and emergency spillway are located. The perimeter embankment and causeways are aligned for the drainage layout, and the tailings deposition strategy promotes drainage to the decant area.

Managing water in one decant area, a passive decant system and design measures in the adjacent embankment have controlled dam failure risks associated with pond water. Seepage from ponds in areas without appropriate water removal and design measures in the embankment can lead to internal erosion and/or slope instability. Embankment overtopping can also occur from ponds outside of designated decant areas. The authors are aware of other central deposition facilities where there have been multiple ponds adjacent to the perimeter embankment and overtopping incidents due to inadequate water removal measures. Multiple decant areas are not recommended without robust systems for passive and emergency release of surface water, including collection measures outside of the tailings facility.

5.2 Gravity decant system

Pump-out and gravity decant systems were originally considered for design. A pump-out system was adopted for the western extension; however, a large pond developed adjacent to the perimeter embankment, with the rate of water removal limited by available pump capacity. Large and sustained ponds adjacent to embankments that are not designed for water containment typically result in seepage and a higher risk of internal erosion and/or slope instability. Without an appropriately designed decant system and emergency spillway, the overtopping risk is also high. An appropriately designed gravity decant system can typically remove floodwater faster than pumps sized for return water and circumvents the need for operator intervention.

Following filling of the western extension, water removal options considered for transitioning the eastern area for central deposition were a decant tower with an access causeway and an inclined decant chute system, both with an outfall pipe through the embankment. A decant tower and access causeway was ruled out as this system typically constrains or is constrained by future embankment raises. The chute system was adopted for efficient inlet control and the ability to extend the chute on the upstream face of the embankment following top-hat raises adjacent to the decant area. Lids are placed progressively during operation to maintain the inlet slightly above the tailings surface, to control pond size and limit suspended solids in outflow.

During the Stage 7 transition to the dual mound layout, a gravity decant system with two decant chutes connected to a single outfall pipe via junction boxes was adopted to account for the expected change in the supernatant pond location. Once the pond was consistently around the eastern chute, the western chute was closed. The eastern chute was raised for the Stage 8 layout and at the end of stage filling, the chutes, junction boxes and the outfall pipe were decommissioned by grout filling. An upgraded system, with a single chute was installed at Stage 9 when the embankment was upstream raised onto the decant area and widened. The upgrade included a junction box with additional recess depth below the outlet to allow for some sediment accumulation, thereby reducing the risk of conduit blockage. It also included a new directionally drilled outfall pipe through the embankment, with various controls, including annulus grouting.

5.3 Emergency spillway

Compacted tailings is an economic choice for low-permeability embankment fill; however, appropriate measures are required for erosion control, including at the emergency spillway where high velocity outflow can erode fine grained fill rapidly.

From Stages 7 to 9, the emergency spillway was designed with a reinforced concrete outlet chute to limit erosion from the design flood. A 1 in 10,000 annual exceedance probability, critical duration rain event was initially adopted based on the assigned dam breach consequence category and local regulation. With the Stage 10 raise and an upgraded consequence category, the spillway design was modified with a rockfill buttress and rock armour for erosion control, with outflow capacity for a larger design event.

5.4 Decant dam

Keeping water off a central deposition tailings facility is critical for dam failure risk management, as supernatant and rainwater ponds form at the perimeter of the facility rather than centrally for a perimeter deposition layout. The decant dam for the tailings facility was formed when the western extension was developed, as flood storage capacity would be limited over the tailings surface. The dam was initially developed with 2 compartments, one lined for water decanted during normal operation and the other unlined for environmental containment of tailings contact water following a large rain event, i.e. to dilute water before a potential discharge to the environment via the dam’s emergency spillway. Prior to mounding of tailings over the eastern area of the tailings facility, a third compartment was constructed to upgrade the flood containment capacity.

Based on the initial consequence category and local regulation, flood containment was provided for a 1 in 10 annual exceedance probability, 72-hour design rain event. This was confirmed through a water quality prediction assessment to be the appropriate flood event for dilution of tailings contact water before an environmental discharge.

For the latest (Stage 10) layout of the tailings facility, the lined area has been retained and the unlined compartments of the decant dam have been combined and deepened for the updated drainage catchment and design rain data factored for climate change. During normal operation, gravity decant is to the lined area; however, it is diverted to the unlined area if heavy rain is forecast, as a higher outflow rate can be achieved to this area. The unlined area also receives discharges via the emergency spillway from the tailings facility. The 2 compartments are shown in Figure 7.

Figure 7 Lined and unlined decant dam compartments

An operational management strategy is in place to remove flood water as soon as possible from the decant dam to maintain the environmental flood capacity and to limit seepage losses.

Some tailings sediment has accumulated in the lined compartment of the decant dam over the circa 19 years of its operation due to tailings beach erosion events and suspended solids in decant water. This accumulation has slightly diminished available storage capacity and a key learning has been to consider clean-out methods in the design of the lined area of the decant dam.

6 Landform shaping for closure

A concept design for closure, considering a cover system over the non-acid forming tailings and reshaping of the perimeter embankment for further slope stability and erosion control has been developed. Due to the operational shape of the facility, the outer slopes of the landform will be of broadly convex shape due to the transition of the relatively gentle tailings beach profile to the steeper embankment slope.

Progressive closure measures have been limited to reshaping of some embankment slopes with weathered rockfill which has provided a growth medium for grass and small shrubs. This has proved effective against erosion where there is limited drainage onto the slope. With the convex profile of the final landform, broad drainage measures in the landform will likely be required to manage the increase in flow velocity at the transition between the upper surface and lower embankment slope gradients.

Shaping of the final layout is being planned to shed runoff in various directions rather than concentrating flow to the area of the operational decant and emergency spillway. At closure, additional fill is planned at the decant area to remove the depression and remove the emergency spillway.

Commissioning of another tailings facility towards the end of filling will allow for performance monitoring of the cover system and reshaped perimeter embankment, before an attempt is made to relinquish the landform.

7 Summary

Insights gained over 2 decades of design and monitoring for the central deposition tailings facility at the CSA Mine, including for its transition from perimeter deposition of low density tailings to central deposition of thickened tailings slurry have led to the adoption of various unique features and various incremental layout improvements. Key features, benefits, and learnings are:

- The tailings facility layout comprises 2 tailings mounds, 2 causeways, a perimeter embankment, a single decant area with gravity decant system and emergency spillway, and a decant dam.
- The causeways are formed with compacted tailings and are used to deposit thickened tailings centrally. The causeways are designed with ends offset from centre, and with the alignment of the perimeter embankment, provide for surface drainage to a single decant area. The centreline raise method has been adopted for the causeways and a learning is to include reinforcement measures to limit cracks from differential settlement.
- The perimeter embankment is also formed with compacted tailings and is primarily upstream raised onto the tailings beach. The embankment is sized with a nominal freeboard above the design tailings beach model. A learning is to include additional freeboard in the decant area to account for sediment accumulation from tailings beach erosion. Updates are made to the model as required based on beach slope performance for subsequent raises.
- Tailings deposition is via up to 8 spigots simultaneously to limit the volumetric flow of tailings onto the beach. Closely spaced small diameter flexible pipes with crown slots have proven to be the most effective means for depositing tailings onto the mounds, allowing for relative steep beach slopes whilst limiting gully erosion. Deposition occurs on one mound at a time, typically for up to 6 months. Rotation between the mounds limits the rate of rise and tailings liquefaction risk, and has enabled a sequenced strategy for upstream raise construction.
- Tailings for raise construction is excavated from the impoundment area. A learning is to maintain a buffer between borrow areas and the perimeter embankment and to maintain drainage to the decant area, as ponds and thick deposits of saturated tailings in borrow pits can lead to dam failure risks.
- The layout is configured with a single decant area and a gravity decant system is located adjacent to this area for passive release of surface water to an external decant dam. This approach limits dam failure risks associated with multiple ponds and with appropriate management of the inlet at the decant system, limits the size of the pond.
- The gravity decant system, comprising an outfall pipe installed via directional drilling, a junction box with a flexible pipe connection to allow for some settlement of tailings and a decant chute on the upstream face of the embankment is successfully used to remove surface water from the tailings storage area. It provides for rapid removal of flood water compared to pumping.
- An emergency spillway is also located adjacent to the decant area, sized for a very low probability design flood event. Robust erosion control measures have been adopted for the spillway chute and upgraded with stage raises to address scour risk.
- Widening of the perimeter embankment adjacent to the decant area allows for top-hat raises and extensions of the decant chute on the upstream face of the embankment. This approach limits upstream raise construction into the decant area and limits the number of pipe penetrations through the embankment that would otherwise be required for new decant systems.
- The decant dam is sized for storage of a nominal volume of decant water and runoff from a design flood event, supported by a geochemical water quality prediction assessment, to limit an environmental discharge via its emergency spillway. The capacity of the dam has been upgraded to account for climate change factored design rainfall data. A learning for decant dam design is to consider robust measures to facilitate clean-out of sediment without damaging geosynthetic lining systems.
- Rockfill buttresses for the perimeter embankment have been constructed to address tailings liquefaction risk, acknowledging the long-term slope stability limitation of the upstream method. A learning is to undertake slope stability analyses for the life-of-mine raise configuration and include shear keys in the foundation of upstream raises to limit the size of buttresses.

Life-of-mine planning measures and improvements with each stage raise have set up the dual mound facility for efficient operation and expected efficiencies for closure of the landform. The closure concept is for a landform that is covered with rockfill to limit erosion, sheds runoff in various directions and does not contain surface water or require an emergency spillway.

Acknowledgement

The authors thank Cobar Management Pty Ltd for permission to publish this paper and supply of aerial photographs and Metric PCM Pty Ltd for aerial photographs taken during the Stage 10 raise works.

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