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Thickened tailings deposition for closure

SRK Consulting tailings experts discuss how higher solids concentrations at later stages of the operation for existing conventional TSFs can reduce post-operational earthworks and time to final closure

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A conventional tailings storage facility at the Stratoni operation in Greece

As the mining industry transitioned through a downturn on lower commodity prices and unstable macro-economic conditions, miners have sharpened their focus on innovative concepts, while minimising expenditure. Tailings management, perceived by many as simply a cost burden, is a key area potentially targeted for savings.

Tailings storage facility (TSF) water management is one of the most important drivers when designing tailings disposal strategies, and post-operational water management of the tailings surface is also one of the most challenging aspects of successful closure. However, site operators often select convenient, short-term disposal methods, giving minimal consideration to future closure objectives or costs.

TSFs are normally the largest disturbed area at a mine and therefore incur the highest rehabilitation cost, along with waste rock dumps. Profits over mine life can be eroded by closure delay if a strategic closure plan isn't progressively implemented.

The transition from TSF operations to closure has numerous challenges to be dealt with to achieve specific closure objectives and create a stable facility. For example, conventional paddock-style TSFs sometimes cannot be closed immediately after operations because the tailings top surface is soft and unconsolidated with a large, centrally-ponded area lacking sufficient strength to sustain an engineered cover right after decommissioning the facility. These facilities often require a significant amount of borrowed fill material to attain a final shape compatible with site-closure objectives.

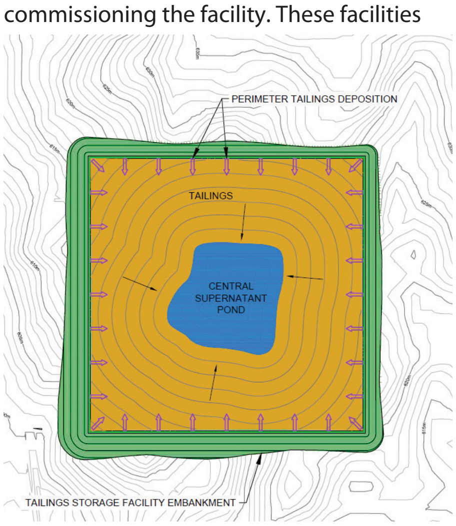

Figure 1: Schematic TSF with conventional perimeter tailings deposition and central supernatant pond

Appropriately dealing with these challenges often translates into low confidence when applying conventional closure strategies, such as covers and capping layers, to support early conceptual closure plans for ongoing financial assurance assessment. Additionally, operators can encounter large capital expenditure and delays during closure.

Owners and designers of conventional TSFs can benefit from dewatering techniques to assess the feasibility of integrating thickened tailings into current conventional disposal system shifting from perimeter discharge to central discharge. Key opportunities include improved TSF water recovery and enhanced storage capacity, along with potential closure advantages.

Post-operational earthworks and closure timelines can be significantly reduced by modifying the tailings disposal strategy as operations wind down by using thickened tailings to create a convex-shaped, water-shedding final landform (via central discharge), limiting post-operational surface reshaping and borrow material. This may considerably reduce closure implementation time and overall site rehabilitation, as tailings would initiate the consolidation process as the convex shape is attained.

There are challenges to be assessed before embarking on a thickened tailings-centred closure strategy; mostly around retrofitting the plant and TSF from a conventional configuration. These challenges include slurry characterisation, including central discharge, assessing thick tailings deposition impact on the existing beach, and supernatant water management plan adjustment.

The 'deposition for closure' concept using thickened tailings is explored through a case study currently in the early stages of implementation at a gold mine in Ghana. This case considers technical, environmental, operational, closure and regulatory aspects.

DEPOSITION FOR CLOSURE STRATEGY OVERVIEW

Full-perimeter discharge is a common conventional TSF disposal method. It creates a concave-shaped surface leading to a centrally-located supernatant pond remaining at end of operations (Figure 1).

The transition from operations to closure requires changing the water containment specifications for the facility, with closure objectives focused on limiting water on the tailings surface post operations. A common solution is a cover above the final tailings surface, shaped to shed clean run-off water towards a controlled spilling zone. To construct the cover, a significant amount of fill material (waste rock, borrow) is required. The steeper the beach slope, the more material required.

The alternative –the subject of this paper – involves re-shaping the TSF during operations using tailings to create the final landform with the inclusion of central discharge. This is done by modifying the deposition strategy so thickened tailings are disposed in targeted areas late in the mine life, as op-

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posed to uncontrolled deposition to simply fill the basin.

Strategic deposition (central and perimeter locations) can deliver considerable cost savings in the long term if the site-specific conditions are conducive. Implementation can significantly reduce post-operational earthworks and construction requirements, and reduce final rehabilitation timing is critical.

Tailings would typically be deposited radially around the TSF from a slightly eccentric location, creating a beach grading towards the dedicated spilling outlet. Depending on the TSF shape and configuration, tailings may need discharging from strategic locations around the perimeter to achieve a consistent beach slope that effectively conveys water towards a low point or controlled spilling zone. From there, water is released into the natural drainage system (Figure 2).

An extensive cover layer, typically composed of fill material and growth media, would still usually be required for isolation and environmental purposes, however, the underlying tailings surface formed to the desired shape means the cover material would be a thin layer of fill.

The controlled water-shedding surface would also limit potential overtopping and minimise rainfall infiltration from a pond into the tailings mass, which promotes faster drawdown of the phreatic level inside the tailings mass and limits future seepage.

The water-shedding surface significantly reduces the lag period between final deposition and cover placement. The central area (the pond's usual location) is normally less consolidated than the rest of the TSF and therefore more susceptible to settlement. As the pond is displaced away from the central position, consolidation of this area is promoted by self-weight, and it can effectively reach the same consolidation level as perimeter zones in a shorter timeframe.

Thus, generally, the final cover could be placed in a shorter timeframe after operations, as the tailings beach would be dryer and more consolidated.

Further, earlier access and vehicle trafficability may therefore be attained, compared to a conventional central pond scenario (from perimeter deposition), which will take a longer time post deposition to achieve uniform consolidation across the TSF top surface.

EXISTING OPERATIONS ADOPTING A SIMILAR CONCEPT

While this specific 'deposition for closure' strategy is not common practise, there are operations that have already, or are in the process of, modifying tailings disposal at conventional facilities, despite limited public information available. While there are varying approaches, the general concept of strategically depositing thickened tailings, with closure in mind, is consistent.

The Tanami and Union Reefs gold operations in Australia both incorporated thickened tailings disposal towards the end of operations to reshape TSF landforms and minimise rehabilitation earthworks. As with the Ghanian's case study, Tanami implemented central thickened discharge in the basin of the paddock facility to change the overall tailings-surface slope to a convex profile to maximise capacity and form a shedding surface to fast-track closure. In contrast to the Tanami strategy, Union Reefs intended to simply change the basin profile from upstream sloping to downstream sloping, thereby maximising capacity. The top surfaces of both facilities were reformed through strategic tailings deposition so runoff was directed to a controlled spilling outlet amenable to long-term management (Robins, 2004).

The Kimberley Diamond Mines operation in South Africa used the deposition of thickened tailings for rehabilitation of old slimes dams in the latter stages of mining to maximise tailings storage capacity, while generating a final landform profile more amenable to closure. Low rainfall meant a key focus was to minimise water use, thus, additional benefit of thickened tailings was realised. The overall benefits of this change were worth the dewatering costs, including installing the new thickener and positive displacement pumps at the treatment plant (Robins, 2004).

More recently, the Prestea gold mine in Ghana implemented a central discharge strategy to maximise tailings storage leading into closure. The tailings were thickened to approximately 45% (w/w) and deposited from an elevated central platform, using

The Tanami gold mine incorporated thickened tailings

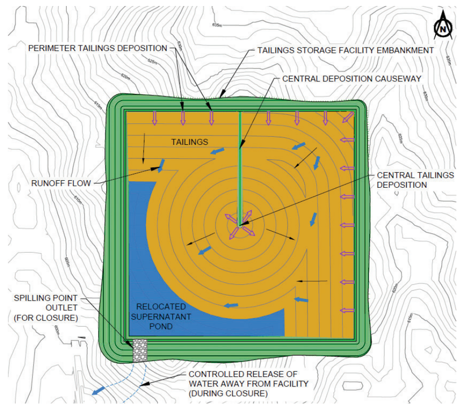


Figure 2: Schematic TSF with revised deposition strategy by means of which central and perimeter tailings discharge creates a water-shedding surface directing runoff towards a controlled spilling outlet

waste rock to construct the access spine across to the center of the facility. This strategy created challenges with pond-water management, as surface water was not directed to a controlled spilling outlet, with the existing perimeter embankments not designed or constructed to retain ponding water.

The Peña Colorada iron ore mine in Mexico is currently in the process of commissioning thickened tailings discharge to replace conventional deposition to maximise the disturbed footprint, establishing a steeper beach slope (for capacity) and reducing the volume of water pumped back to the plant. Challenges have included high seismicity and rate of rise at which the underlying conventional tailings were placed. This will likely result in significant tailings settlement and potentially to the thickened tailings beach slumping into the conventionally deposited tailings after a seismic event (Moreno, Thompson and Hore, 2014).

In general, the existing cases have implemented the change because of the perceived benefits, focused on closure savings rather than only operational improvements. Each operation has considered it financially viable over the long term to compensate for the initial investment, a contentious view for mature operations.

However, there are potential risks related to implementing thickened tailings deposition and due consideration of these is critical; it is important to understand site-specific conditions and TSF operational history to design a landform that successfully evolves towards closure.

KEY CONSIDERATIONS OF MODIFYING DISPOSAL STRATEGY

- **Tailings composition and characterisation:** Characterisation of slurry should be conducted early and before the significant investment involved in changing disposal system.

It's critical the thickened tailings product chemical composition is understood prior to implementing a direct water-shedding strategy. Adopting a water-shedding tailings upper surface is only feasible if the upper exposed portion of the tailings is chemically benign and stable, and will not affect the receiving environment.

Typically, the intent would still be to place a cover layer of suitable fill material above the tailings surface for long-term closure. However, there will likely be an intermediate period during cover placement when tailings would be exposed to oxidation and, as runoff contacts the tailings before exiting the facility, there is an environment and watercourse contamination risk.

Tailings would need to be non-acid forming and have very low heavy-metals leaching potential – below regulatory standards – to promote clean excess water runoff. Where multiple streams of tailings are produced, it would be possible to select the most geochemically benign tailings stream as a covering layer.

- **Geotechnical stability and conventional/thickened tailings interface:** When perimeter discharge is used as the disposal strategy with the intent of creating a central supernatant pond, the containment embankments are not necessarily required to be water retaining. However, if a modified disposal strategy is adopted to produce a convex water-shedding tailings surface, water may temporarily pond against outer embankments. The embankment stability needs assessment – a higher phreatic surface is likely, through adjacent ponding or saturated tailings. Depending on shear strength of the fill material and the existing downstream slope angle, mitigation, such as a downstream buttress or elevated drains, may be required.

Depositing fresh, thickened tailings over a conventional tailings deposit leads to several considerations around tailings-layer interaction that need evaluating, particularly in relation to geotechnical stability (static and dynamic) of the composite landform. A secondary consideration is beach deformation from differential settlement, which could influence the tailings surface's final, long-term shape.


Photo: WWL

The density of the slurry is one factor in planning for closure

Another consideration is the existing tailings consolidation state, which is largely driven by its previous deposition strategy. The forming beach stability is critical, as potential thickened tailings slumping into the softer (conventional) tailings may trigger a surge in pond levels, particularly in high seismicity areas. Limiting the rate of rise could be imposed to mitigate this risk.

A CPTu programme for representative geotechnical profiles of the existing conventional deposit would be required and, from these, evaluation of potential stability and/or liquefaction concerns. Results from CPTu campaign could help in defining the state of the current deposit, as it could behave dilative or contractive upon loading it with an extra thickened tailings cap. A Soil Behavior Type chart from CPTu defining a region with critical state greater than zero could be used as a screening tool to determine areas with potential stability issues (Robertson, 2010), then design disposal strategies that enhance beach consolidation.

- **Disposal strategy:** Change of disposal strategy to central thickened discharge introduces additional complexity – cycling between central and perimeter deposition for the desired beach shape must be managed. It is important to focus on integrating current best practices, operator capabilities and infrastructure (operational decant systems, pipelines etc) where possible. This limits the capital expenditure (excluding dewatering equipment) in terms of purchasing new and/or relocating infrastructure, and increases the confidence of operators in managing the revised strategy and smoothing the transition.
- **Existing closure plan:** Depending on the extent of the change, modification of the approved closure plan may be required. As plans are commonly approved in the early operational stages, changing to thickened tailings deposition may provide an opportunity to introduce a more efficient reclamation plan, updated for the current improved TSF status and condition; that may enable earlier relinquishment.

IMPLEMENTATION OF TAILINGS DEPOSITION FOR CLOSURE STRATEGY

Switching from conventional to a thickened tailings strategy should be staged and carefully consider key criteria discussed above.

Below is a logical sequence for safe implementation of the proposed closure strategy. Each stage should progressively reduce input uncertainty for following stages, with costs progressively spent on investigation – from simple characterisation through actual strategy implementation.

- **Characterisation of the slurry:** Slurry characterisation must include early geochemical, rheological and geotechnical assessment.

As discussed, geochemical slurry characterisation is fundamental to assess the chemical stability of the tailings cover on exposure to wet/dry cycles, as the primary aim is to redirect clean runoff. Characterisation includes acid-forming potential, salt-wicking potential and heavy-metal leachability.

Rheological slurry characterisation allows establishment of a credible range of beach


Photo: PSEI

A thickened tailings disposal system

slopes achievable at a certain thickening rate. This influences the final landform shape and informs the disposal strategy for shifting from concave to convex. A rheogram for selected thickening rates is important, as is a 'yield stress versus solids concentration' assessment for beach-slope modelling. Applying in-line flocculation should also be explored.

Closure-specific geotechnical assessment should include permeability (saturated and unsaturated), consolidation properties and shear strength to estimate the thickened and conventional tailings interaction.

Full slurry characterisation feasibility for this closure strategy provides confidence in more detailed investigations, such as geotechnical basin profiles, key structures mapping (ponds and spillways), and spillway discharge flow routing.

- **Design of the thickening system:** Slurry characterisation facilitates thickening system design, integrating the thickener, transport system and disposal strategy. The link between these disciplines is the tailings rheology, and the objective is a suitable, final landform shape. Beach angle selection for a sustainable convex shape influences the thickening target and, in turn, defines inputs for pumps, pipeline and tailings discharge element design.
- **Deposition trials to verify beach slope target:** Success in strategy implementation depends on achieving certain beach angles and overall profiles. As the strategy focuses on operating mines, deposition trials to observe beach formation variability are possible, from which disposal strategies can be defined to assist the operator in full implementation. Assumptions made during previous stages can also be validated.
- **Geotechnical investigation and access causeway construction:** The central thickened discharge method requires the deposition pipeline to extend to the facility center, and therefore construction of a purpose-built central deposition causeway above existing tailings for access.

At this point, a current tailings geotechnical investigation (including CPTu) and stability assessment of thickened/conventional tailings interaction should enable causeway design.

With a conventional perimeter deposition, there will be a central supernatant pond, and therefore tailings nearer the center are likely to have relatively low shear strength. This could lead to slumping of dumped material (often waste rock or tailings) when constructing the causeway.

However, experience is well developed – causeway construction would be similar to building supernatant pool walls. Prior to causeway construction, perimeter discharge would be adjusted to temporarily move the pond away from the proposed causeway alignment, allowing this beach area to consolidate by negative pore pressures driven by desiccation

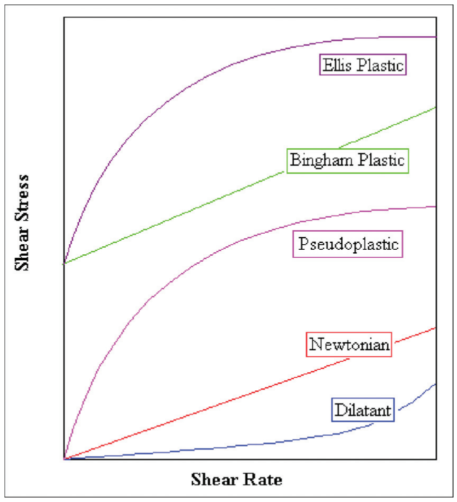
- **Commissioning central thickened discharge:** Trial deposition would enable development of guidelines for the required landform shape, for refinement throughout the operating life. The deposition strategy should include detail on safe migration of the operating pond towards final decanting points. Then, achieving a target design beach angle is secondary. Once the pond is positioned, the operational aim is to consistently achieve the target beach profile.

During early thickened tailings deposition stages, the potential central tailings area low shear strength may encourage consolidation and differential settlement resulting in tailings surface deformation. Regular beach surveillance would monitor tailings beach development (in comparison to design surface), identifying low zones requiring extra filling to promote consistent tailings beach grading towards the spilling outlet. These low points can be filled by extending deposition pipes from existing spigots into the middle of the low-lying areas. Operational practice and target elevations could be adjusted according to the survey.

- **Water management:** Tailings deposition should be controlled to maintain the supernatant pond around the future spilling point, creating a low point. Once deposition has ceased and landform design is attained, the pond should be temporarily shifted from the outlet point to promote desiccation and allow for light-equipment access to install the cover and a suitably designed spillway. A sedimentation pond might be required after operations to prevent tailings being washed through the outlet and to capture sediment prior to water release into a natural surface water stream as the TSF surface is being stabilised.

Embankment breaching through spillway construction converts the TSF from a water-retaining structure to a water-shedding facility; the freeboard then constitutes the distance between the maximum design water elevation in the spillway and the embankment crest elevation. Runoff water would be evacuated through the spillway and ponding would be limited to transient pooling as water discharges.

A local drainage network review is required to determine the optimal location for water release, and allow linkage to a stream network, avoiding any downstream infrastructure or villages. If the mine continues operation, the existing infrastructure (ponds, roads, pipes and control instrumentations) would need consideration when locating post-closure spilling point for run-off release.



A rheogram is important for selected thickening rates

Photo: ResearchGate

CONCLUSIONS

A sustainable tailings management system requires integrating daily operations to the assessment of tailings disposal costs associated with closure long-term rehabilitation. Attempts at closing conventional TSFs operated with a central pond may lead prolong implementation periods and earthworks to meet agreed landform shapes.

Implementing a modified 'deposition for closure' approach using thickened tailings towards the end of operations to create a water-shedding surface, allows controlled management of excess water during operations and closure. The surface transformation from concave to convex using tailings would considerably reduce the borrow-fill material quantities required during closure construction, by limiting the surface re-shaping required to create a closure profile.

Furthermore, it reduces the lag between end of deposition and start of cover placement. Another benefit is transition to thickened tailings at conventional facilities can maximise storage capacity without increasing the footprint. These factors translate to reductions in cost and time expended.

These benefits need to be weighed against the cost of dewatering and pumping high-density materials. While there are numerous potential advantages in applying a 'deposition for closure' strategy to a project, it's critical to assess various site-specific challenges to modify existing tailings disposal methods in a staged approach before committing to a new strategy. ■

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