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Development of a safety case for a closed tailings storage facility in the tropics

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Abstract

Owners of tailings storage facilities (TSFs) must meet their legal obligations and adhere to current industry practice in relation to tailings dam safety. In the common law frameworks, this involves demonstrating that the TSF risks are eliminated whenever reasonably practicable and, if not, are reduced so far as is reasonably practicable. A similar requirement to reduce risks to as low as reasonably practicable (ALARP) is included in the non-mandatory Global Industry Standard on Tailings Management (GISTM).

Even in jurisdictions where legal and regulatory requirements do not explicitly mandate reducing risks so far as is reasonably practicable, and even if the owner does not adopt the GISTM, TSF owners should recognise that implementing practical risk controls aligns with current industry practice and thus falls within their duty of care.

The safety case provides a platform for a structured and logical argument that all reasonably practicable risk controls are either in place or are planned for implementation, making it a valuable tool for TSF owners to demonstrate their commitment to minimising risks.

This paper discusses the development of a safety case for a closed TSF with a permanent water cover in an equatorial tropical climate. The primary aims of the safety case were to outline plans for implementing reasonably practicable risk controls, address uncertainties that may necessitate additional controls in the future and demonstrate compliance with the GISTM.

Keywords: *governance, risk, safety case, GISTM, ALARP*

1 Introduction

This paper discusses the tailings storage facility (TSF) at a gold mine in the tropics, which was established by constructing a cross-valley embankment. Thickened tailings slurry was pumped from the processing plant and discharged into the upper reaches of the dammed river system. An operational spillway was built through a natural saddle, away from the embankment to manage the annual average rainfall of approximately four metres. Initially, the cross-valley embankment functioned as a conventional water dam until the tailings pipeline was relocated to allow deposition from both the embankment and the adjacent natural ground.

The TSF closure strategy involved submerging the stored tailings in situ by raising the operational spillway and constructing a larger, secondary spillway to handle extreme rainfall events. Submerging the tailings was chosen to limit oxidation and meet environmental requirements for surface and groundwater quality. The embankment and monitoring system were also upgraded as part of the closure works to improve stability and safety. The downstream face of the embankment was reinforced with an additional rockfill buttress, and the upper portion of the existing embankment clay core was reconstructed and raised to accommodate the permanent submergence of the tailings beach.

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Other closure options considered at the time included relocating some or all of the tailings to a mined-out pit, allowing for partial or full deconstruction of the TSF. However, risk assessments conducted for closure planning reasoned that although the quantified societal aggregate risk was outside the ANCOLD societal risk tolerability criteria, the in situ submergence of tailings presented the lowest overall safety risk, considering the significant risks associated with tailings relocation and TSF deconstruction.

The risk assessment also identified that local and transient groups of alluvial miners might attempt to recover remnant gold from the tailings post-closure, which was assessed as the highest post-closure risk for the TSF. Consequently, the closure design included measures to mitigate potential sabotage of the embankment aimed at releasing the reservoir to access the tailings. These measures included additional downstream face armouring, community mining trials to demonstrate the low concentrations of free gold in the tailings, and placement of large rockfill onto the submerged tailings beach directly upstream of the embankment crest.

The post-closure risk management plan incorporated site security and regular monitoring of the embankment to prevent unauthorised activities, which was expected to continue in perpetuity.

2 Demonstrating reduction of risks to as low as is reasonably practicable

The release of the Global Industry Standard on Tailings Management (GISTM) in 2020, and the preceding catastrophic tailings dams failures, spurred an increased focus on the risks associated with TSFs worldwide. The GISTM (Global Tailings Review 2020) includes the requirement to minimise TSF risks to as low as is reasonably practicable (ALARP), and for the Accountable Executive (an executive of the TSF owner organisation, accountable for the safety of the TSF) to approve and document the decisions.

The closure phase risk assessments, described in the introduction to this paper, focused on quantifying risks and comparing the aggregate risk to the ANCOLD societal risk tolerability criteria without considering reasonably practicable risk reduction measures.

Whilst these previous risk assessments were valuable in informing the selection of the TSF closure strategy, the risk assessment team did not intend to demonstrate that risks had been reduced to as low as reasonably practicable. In the context of the current risk assessment practice, comparison of the aggregate risk with tolerability criteria cannot be the sole basis of decision-making.

In 2021, the TSF owner initiated a risk assessment and management process to identify and implement reasonably practicable risk controls for the TSF. This process was based on the notion that only the risk reduction measures (controls), not the risk itself, could be reasonably practicable. Although the quantified risk profile of a tailings dam is useful for other, mainly comparative reasons, it was neither necessary nor sufficient for identification of all reasonably practicable risk controls for the TSF.

The TSF owner decided to document the outcomes and the reasoning for the implementation of reasonably practicable risk controls in a safety case to demonstrate to all stakeholders, with assurance, that all reasonably practicable risk controls have been, or will be, implemented. The Accountable Executive could then use the safety case to demonstrate compliance with the relevant GISTM requirements.

3 Facility overview

The TSF embankment is a zoned earthfill and rockfill embankment, with a wide central clay core, and a foundation grout curtain primarily targeting lower permeability bedrock zones.

The original embankment included an upstream and downstream clean rockfill shoulder with transition zones of rockfill containing fines against the clay core. River flows were managed during the construction by a diversion conduit through the dam base, which was closed at the end of the dam construction.

The closure upgrade works included construction of a downstream rockfill buttress, significantly flattening the overall downstream slope. Primary and secondary filter zones were introduced but only against the upper, reconstructed clay zone, and along the entire foundation of the downstream buttress. The majority of the embankment height (below the upper reconstructed clay core) included only a gravel transition zone with a geotextile. The operational spillway was raised by construction of a new concrete weir, and a reinforced concrete secondary spillway was introduced at a neighbouring saddle to increase the flood handling capacity of the TSF. Trash racks were included upstream of the spillways to reduce the risk of fallen trees around the reservoir blocking and impeding the function of the spillways.

The geotechnical investigations, assessments, design and construction of the TSF were well documented with relevant reports and details available. The risk assessment process accounted for the existence of information gaps and uncertainties. The TSF owner team and the Engineer of Record (EoR) monitor the embankment performance via a network of instrumentation, regular inspections, and water quality testing.

4 Safety case development

4.1 Guiding framework

The framework introduced by Herza et al. (2022) guided the development of the TSF safety case. The safety case is one method used in industries outside of tailings, including for water storage dams (McGrath et al. 2020), to demonstrate that risks have been reduced to ALARP or so far as is reasonably practicable.

4.2 Risk identification

4.2.1 Information gathering

The risk assessment team, comprising members of the EoR and TSF owner organisations, conducted thorough information gathering to define the TSF system and each of its elements and sub-elements; enabling them to identify and analyse potential failure modes.

They sourced digital documents from the TSF owner's computer servers, the original design engineer, and local site-based servers and hard drives. Additionally, they sourced and scanned hard copy files from the offices and storage rooms of the site buildings. This process proved invaluable as it revealed additional elements of the embankment, not captured within as-built drawings. For example, the risk assessment team discovered that the construction team had installed small collection pipes within the clay core to divert spring flows from the foundation and prevent flooding of the clay core during construction. The risk assessment team compiled and summarised all relevant information to inform the subsequent risk assessment workshops.

4.2.2 Failure mode analysis

Failure mode analysis (FMA) is a well-established method of identifying and documenting how losses of control over a 'system' may lead to a material unwanted event (failure). The objective of FMA is to identify the reasons and steps that result in an event that is defined as failure or failure of a system. Essentially, how something may go wrong and why.

A FMA workshop was conducted with members of the EoR and TSF owner organisations and an independent third-party involved in the previous risk assessments. The key objective was to identify the states or events (and underlying reasons) leading to the ultimate unwanted event of uncontrolled release of tailings and/or water. Finding the states and events leading to failure allowed for identification of potential risk controls along the failure pathways.

There are many tools used to conduct FMA, including event tree analysis (ETA), which utilises the logic of 'if this happens, what will happen next?' and fault tree analysis (FTA) where the focus is on 'what are the causes leading to this?' (ICOLD 2005).

Due to the decades-long history of risk analysis for water dams, ETA is typically relied upon due to the now well-understood failure mechanisms for water dams and the hazards that are typically applicable for water dams. This preference for ETAs has also translated to risk assessment for TSFs. However, use of ETAs requires a priori knowledge of all hazards and aspects of a TSF to predict the pathway to failure. Due to the acknowledged lack of data, which is a typical symptom of legacy mine sites, it was recognised that reliance on ETAs may result in missed hazards, or pathways to failure. As a result, FTA was adopted as the method to conduct the FMA.

4.2.3 Modified fault tree analysis

The FTA process starts with the unwanted event (also called the top event), and then identifies the states or processes necessary for the top event to occur using a top down, deductive method. The top event for the analysis was the defined unwanted event of uncontrolled release of tailings and/or water.

The objective of the FMA workshop was to develop a set of agreed modified fault trees for the TSF embankment to:

- Identify the progression and underlying reasons for an unwanted event occurring
- Identify (based on the above) existing/potential controls for those underlying reasons and identify knowledge gaps to be addressed for control assessment.

The objective was not to estimate probabilities of failure, and therefore the logical operators 'AND' and 'OR' typically seen in FTAs were not required. The outcome of this process was a set of physical bottom events, which were the fundamental causes leading to the top event (underlying hazards). Figure 1 show the first level branches under which further branches and ultimately 68 separate physical bottom events were identified.

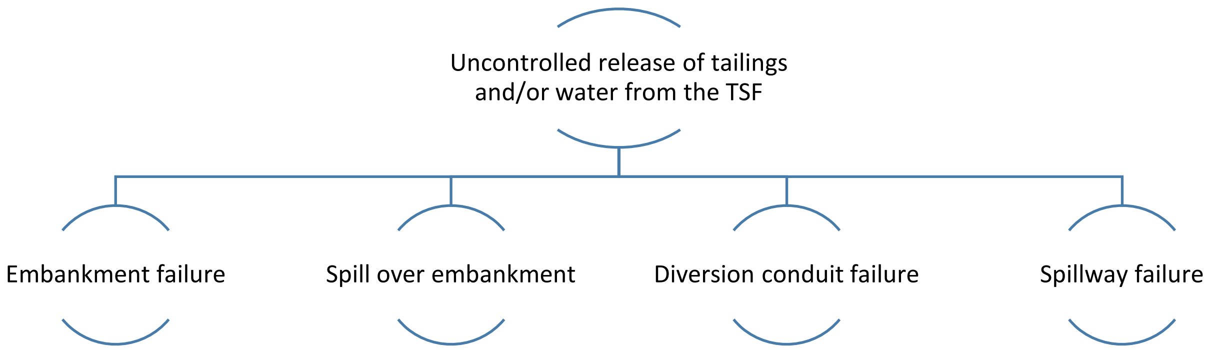

Figure 1 Tailings storage facility modified fault tree, with only the first level branches shown

It was reasoned that additional controls may be required for potential failures in processes and human actions leading to the identified physical bottom events. Separate 'people and process' fault trees were therefore developed beneath the physical bottom events considering the typical life stages of the TSF including investigation, design, construction, operation and maintenance.

Physically impossible bottom events, events with obviously negligible likelihoods and events for which controls do not exist were excluded from assessment at the FMA workshop.

4.2.4 Consequence assessment

The potential consequences of an uncontrolled release of tailings and/or water due to embankment failure were assessed by the design engineer as part of a dam break study and failure impact assessment. Acknowledging the complexities of completing dam breaks and impact assessments for all potential failure modes, a representative dam break scenario was adopted for the TSF embankment. The potential consequences of uncontrolled release of tailings and/or water by the other pathways shown in Figure 1 were not assessed, though the risk assessment team acknowledged the consequences would be lesser than for an embankment failure.

The consequence assessment outcomes were considered in the reasonably practicable elaboration, as well as for prioritisation of risk control actions outside of the process defined in the safety case.

4.3 Risk analysis

4.3.1 Risk control identification

A preliminary identification of controls for each of the bottom events and each failure path was completed during the FMA workshop. The fundamental controls were identified as the inverse states of physical and/or process, and people bottom events and then classified in accordance with the typical hierarchy of controls:

- elimination of hazards (elimination controls)
- modification of physical hazards to reduce the risk they present (modification controls)
- reduction of uncertainty associated with the various physical bottom events and thereby reducing the associated risk (engineering controls)
- procedural controls to increase the confidence in the management of the TSF being aligned with the design intent, in addition to increased confidence in control effectiveness verification activities.

Further consideration and identification of controls was then completed in preparation for a subsequent Risk Controls Assessment Workshop, at which each control was reviewed, updated and agreed upon by the workshop participants, including identification of additional controls. Each control was linked directly to the bottom events (hazards) in the fault tree using common numeral identification.

Using this workflow, all potential controls were identified for all bottom events that could result in the defined unwanted event.

4.3.2 Assessment against current practice

During the Risk Controls Assessment Workshop, the workshop participants negotiated an assessment of what constitutes ‘current practice’ for each control, as this is a key consideration for determining whether an action is reasonably practicable. If a gap against the assessed current practice was identified (e.g. unverified grading limits of internal zones), the workshop documented this as an action to be addressed.

Current practice is formed by standards, guidelines, and precedents that define the degree of skill, diligence, prudence, and foresight that a professional would reasonably and ordinarily be expected to demonstrate. The current practice in TSF management is evolving over time, and a consensus from a group of experienced practitioners in the relevant areas is required to define current practice for a given risk assessment.

4.3.3 Supporting studies and projects

The participants of the Risk Controls Assessment Workshop discussed and agreed upon further actions (next steps) that were deemed necessary to confirm or better understand the identified hazards or to define the appropriate risk controls. The TSF owner captured the next steps within the risk control implementation plan.

4.4 Risk evaluation

4.4.1 Assessment of risk control measures

The identified risk controls were assessed at the Risk Controls Assessment Workshop using the TSF owner’s criteria and TSF specific context to select what controls were reasonably practicable to implement. The same criteria could later be used to assist with prioritisation of the reasonably practicable controls implementation, recognising the limited resources of the TSF owner.

The TSF owner, as the accountable party, ultimately decides what is reasonably practicable for a given TSF at a given time and there is no pre-defined formula or procedure to follow. For example, what one would consider to be reasonably practicable for an operating TSF at an active mine, may not be reasonably practicable for a closed TSF at a rehabilitated mine site.

Therefore, the selection of criteria and appreciation of the TSF context must involve, if not being driven by, the TSF owner. In the case of the described TSF, the Risk Controls Assessment Workshop included a member of the operational mine management team who was at the site since project inception and who was responsible for the TSF safety. The criteria and aspects that were agreed to be considered by the assessment team for the reasonably practicable elaboration are presented in Figure 2. If any controls could not be assessed against any of the criteria and aspects, the required next steps to further define the controls were agreed and documented.

Hierarchy of Controls	•Recognising the hierarchy of the control allows the assessment of what is reasonably practicable to prioritise the most effective controls and avoid the time-consuming process of assessing each potential risk control measure independently.
Dominant Failure Mode	•A control that addresses the dominant (most probable) failure mode would have a greater effectiveness in reducing the overall risk profile. •A previously completed semi-quantitative risk assessment for TSF by the EoR identified the most probable failure mode to be piping through the embankment and along the buried conduits.
Consequences of uncontrolled release	•A control that addresses the uncontrolled release event with the higher consequences would have a greater effectiveness in reducing the overall risk profile. •The consequences of embankment failure were recognised by the risk assessment team as being significantly greater than for the other uncontrolled release events (e.g. spill over embankment, diversion conduit failure or spillway failure).
Current practice	•Assessment of current practice is a crucial step in the risk assessment process because it provides a defensible anchor point for decision makers. •Current practice is formed by standards, guidelines, and precedents that define the degree of skill, diligence, prudence, and foresight that a professional would reasonably and ordinarily be expected to demonstrate.
Introduced risks	•The implementation of a control should achieve a net reduction in risk. Some controls may introduce risks that outweigh the risk reduction benefits of the control itself, resulting in a net increase in risk.
Cost to implement	•An understanding of the overall cost to implement the risk control is important, especially in the overall context of a mine operator, their available finances, and the variety of risks required to be controlled across mining operations.
Time and resources to implement	•Limited resources are especially apparent in the tailings engineering industry with the resource supply being outstripped by demand of services, exacerbated by the GISTM requirements adopted as mandatory by many TSF owners.
Within current legal approvals	•The site is managed and maintained under certain legal agreements with the government. Activities outside of those approved under the agreements would require time and effort, and cost, to negotiate, and may not even be possible.
Alignment with mine closure solution	•The site has been closed under a Mine Closure Plan with certain activities completed to achieve the mine closure objectives (e.g. rehabilitation of waste dumps, borrow areas, access roads). Activities that do not align with the mine closure strategy will include issues similar to those regarding the governmental agreement.
Implementable with current company structure / personnel	•The site is managed and maintained with an established, small team. Actions that are not implementable within the current structure (e.g. major construction projects) would require additional resources that are not confirmed as available.
Verifiable	•The reliability, ability to be controlled by the TSF owner and having verifiable outcomes are other aspects that should be considered as part of the reasoning over practicability of a risk control measure.

Figure 2 Considerations for selection of reasonably practicable controls

4.4.2 Reasonably practicable elaboration

The aspects of risk controls used for the selection of the reasonably practicable risk controls and the summary of this decision-making for each identified control was agreed during the Risk Controls Assessment Workshop and documented in the safety case. The key considerations informing selection of reasonably practicable risk controls for the described TSF are provided in Figure 2. Using these considerations, each control was classified as being either reasonably practicable or not reasonably practicable or requiring additional actions to be assessed.

To align with the principle of hierarchy of controls, actions to eliminate a hazard were presented first, then modifications to the system to mitigate the risk presented by a hazard.

The controls and reasoning for whether they were found not to be reasonably practicable were documented together with further actions required to assess if a control was reasonably practicable, or to progress the control implementation.

5 Ongoing implementation of actions and safety case updates

5.1 Towards risk reduction to ALARP

The risks may be deemed to be reduced to ALARP when all reasonably practicable risk controls have been effectively implemented and their effectiveness is verified.

The safety case outlines the next steps that the TSF owner will follow in the journey towards reducing risks to ALARP and these steps include:

- detailing and scoping of the implementation of the reasonably practicable controls
- further actions (such as studies and assessments) that are required to assess whether other identified controls are, or are not, reasonably practicable.

Examples of the next steps included review of the probable maximum flood and emergency spillway hydraulic and structural capacity, review of the embankment ground model, updated stability analyses, and piping risk assessment focused on material compatibility and the influence of the buried conduits.

The next steps were being undertaken using the processes and procedures within the applicable management systems of the TSF owner. The TSF owner has committed to implementing the next steps in a timely manner, which is an important aspect of demonstrating committed progress towards reducing risks to ALARP.

5.2 Updating the safety case

The risk assessment and control process, documented in the safety case, shall be reviewed on a regular basis, or when there is a major change to the TSF or the site context. The minimum frequency should align with the GISTM requirements. For ‘High’, ‘Very High’ or ‘Extreme’ classification TSFs, the demonstration that risks are being reduced to ALARP is required at every Dam Safety Review or at least every five years.

Interim updates may also be conducted when the identified next steps are completed.

6 Conclusion

A responsible owner of a closed TSF in the tropics sought to confirm that the risks posed by their TSF are being eliminated where reasonably practicable, and where not, these risks are being reduced to ALARP. This confirmation was necessary to align with current industry practice and meet the requirements of the non-mandatory GISTM, released in 2020.

In 2021, the TSF owner initiated a risk assessment and management process focused on defining all potential risk controls and selecting those that are reasonably practicable for implementation. A modified FTA was adopted to identify the progression and underlying causes of an uncontrolled release of tailings and/or water from the TSF, along with the potential controls. Since the reasonableness of risk controls is a contextual, circumstantial, and temporal attribute, the risk assessment team – comprising members of the TSF owner and EoR organisations – formulated and assessed a unique set of criteria for each identified control in a workshop attended by personnel familiar with the site and its relevant constraints.

The risk assessment team decided to document the outcomes and associated reasoning for the implementation of reasonably practicable risk controls in a safety case, to demonstrate to all stakeholders that all reasonably practicable risk controls have been, or will be, implemented. The TSF risk would be reduced to ALARP once all reasonably practicable risk controls are effectively implemented, and their effectiveness verified. The safety case outlined the next steps that the TSF owner would follow in the journey towards achieving this goal, which were being progressively implemented at the time of writing.

The Accountable Executive could then use the safety case to demonstrate compliance with the relevant GISTM requirements.

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