New Considerations in Tailings Harvesting for Backfill

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Abstract

The sudden failure of the dormant iron ore tailings storage facility (TSF) near Brumadinho, Brazil, on January 25, 2019, the tragic loss of 270 lives, and subsequent regulatory, societal, and mining industry responses hold important implications for the planning and operation of tailings harvesting at surface, for mining backfill. This paper describes some of the new responsibilities for tailings harvesting schemes, with particular focus on the risks, safety, and stability of TSFs as harvesting takes place. GISTM 2020, ICMM 2021 and several associated publications require more detailed scrutiny of risk, free prior and informed consent (FPIC) for stakeholders, renewed attention to assessment of potential liquefaction, slope stability, management of surface water, risk-informed design and new environmental, health and safety precautions for operators.

Key words: tailings harvesting, backfill, GISTM, risk-informed design, liquefaction, free prior and informed consent

Introduction

Although there have been several recent high-profile tailings failures, these are unrelated to tailings harvesting operations. However, tailings harvesting of dormant tailings structures for the purpose of backfilling introduce risks to the tailings structure that must be carefully identified, assessed, and managed. Renewed attention is required for the assessment of potential liquefaction, slope stability, management of surface water, risk-informed design and new environmental, and health and safety precautions for operators of tailings harvesting schemes, just as is required for any responsible mining operation.

Backfill material from tailings may be sourced directly from the metallurgical process plant instead of from an existing tailings deposit. In the case of the former, without any disturbance of an existing TSF, no risk is introduced to a tailings structure and thus backfill obtained without tailings harvesting is not applicable to the information in this paper.

New risks for harvesting schemes from GISTM and new tailings management publications

Several recent publications have been introduced since 2020 that redefine legislation, industry guidelines, standards, and procedures for tailings management. These include the Global Industry Standard on Tailings Management (GISTM 2020), the Tailings Management: Good Practice Guide (ICMM 2021) and the SME Tailings Management Handbook (SME 2022). Tailings harvesting operations represent new risks that must be managed in accordance with these guidelines.

GISTM 2020 was developed to provide a global framework for safe tailings facility management while affording operators flexibility as to how best to achieve this goal. The framework applies to all phases of a TSF lifecycle, including closure, which clearly also applies to any tailings harvesting operation. Compliance with GISTM is an ICMM member company commitment, with greater uptake encouraged by the industry as a whole. At the time of writing, the three primary proponents of GISTM were in the process of contacting non-compliant mining companies to determine their response to GISTM. Those not responding are to be targeted with letters to shareholders, boards of directors and management.

The Tailings Management Good Practice Guide (ICMM 2021) was informed by the requirements of the GISTM and has similar objectives. It was developed by the Tailings Working Group of ICMM and is intended to support the safe and responsible management of tailings across the global mining industry, with the ultimate goal of eliminating fatalities and catastrophic events.

The Society for Mining, Metallurgy and Exploration (SME) Tailings Management Handbook (SME 2022) was developed with input and collaboration from more than 100 authors with a breadth of expert tailings knowledge. It was written with the intent to support education and competency-building of tailings management professionals and to provide context and further detail of the requirements of the GISTM and the ICMM guidelines.

Together, these publications provide valuable guidance against which tailings management may be assessed. ICMM members must have become compliant with GISTM standards by August 5, 2023, for Extreme, Very High or High dam safety consequence tailings facilities and by August 5, 2025, for all other facilities (GISTM 2020). This compliance requirement in a tailings harvesting context necessitates the need for further assessment of risk when developing a tailings harvesting design basis.

Review of historical harvesting challenges

Formal mine backfilling has been in use since at least 1933 with records from Mount Isa in Australia showing lead jig wastes conveyed to the underground stopes for stabilization (Grice 1998). Informal backfill may be as old as mining itself. The utility of backfill as an underground stabilization technique has grown over the past four decades along with a widespread increase in need for stabilization and safety in underground mining. In many cases, existing tailings deposits provide a ready source of aggregate for paste fill mixes as they can be transported into the mine underground workings hydraulically. With ever increasing tailings harvesting volume requirements, operational challenges including equipment access, weather, water control and geochemical reactions, which cause difficulties for harvesting operations.

Figure 1. Tailings harvesting operation (adapted from Chapter 8 in SME Tailings Management Handbook).

The heterogenous nature of tailings deposition may cause operational challenges when excavating material. Typically, tailings are deposited from perimeter spigots or discharge locations, with the coarsest material being deposited near the perimeter and the finest material near the centre due to natural gradation from slurry settlement. Harvesting of finer tailings may be more challenging, as the tailings become progressively less stable and less able to support equipment. Mechanical harvesting is usually undertaken by front end loader or backhoe excavator in conjunction with truck transportation. To overcome the instability of untrafficable fines material, finger roads made from geotextile or other materials for strength may be required (Lee and Pieterse, 2005). Saturation of tailings can further reduce the strength of the material and may not meet moisture content requirements for paste production in the plant. Therefore, any excavation should only consist of unsaturated tailings, and dewatering systems may be required to obtain these conditions (Grice et al., 2007).

Hydraulic mining presents an alternative harvesting method that does not require the use of mechanical excavation. Instead, hydraulic mining uses high pressure jets of water to erode the tailings face. The resulting slurry formed from the combination of the pressurized water and tailings sediment is then moved through a network of trenches to a series of sluice gates, and the desired tailings tonnage is extracted through additional processes (Boswell et al., 2013). Therefore, the use of hydraulic mining to extract tailings could be beneficial in untrafficable tailings deposits as there is no requirement for tracked or wheeled equipment that requires higher strength tailings deposits. Hydraulic mining presents many other useful benefits which are not the subject of this paper. Instead, the reader is referred to the above reference.

Figure 2. A typical hydraulic tailings remining operation (Boswell et al., 2013).

Winter excavation, along with the challenges of screening and handling tailings in frozen conditions, is very difficult. Saturated tailings material may contain ice clumps that are detrimental to blending and may be difficult to excavate. Ice buildup around the working face can cause safety concerns by concealing ponded water under layers of snow and ice. These challenges are typically overcome by excavating, blending, and stockpiling the winter tailings supply over the non-winter months (Lee and Pieterse, 2005). A similar but opposite problem to a frozen surface layer can occur when the surface layer dries out completely, and in the presence of dissolved salts can form a hard crust that must be screened out or crushed to be used for paste fill (Grice et al., 2007).

The process of drainage and excavation can cause sulphide tailings to oxidize by removing fully saturated conditions. The acidic water that is produced can be detrimental to excavation equipment and can alter the cementation process at the mixing stage (Grice et al., 2007). Any prospective tailings backfilling source should be tested before harvesting begins for acid rock drainage (ARD) potential, as well as the risk of metal leaching (ML) usually in alkaline conditions. The overall assessment practice has evolved into MLARD assessment.

New harvesting precautions considering tailings development over the last decade
Recent events in the tailings industry in Canada and elsewhere have greatly increased scrutiny on the mining industry. Failures such as Mount Polley and Brumadinho typically arise from a combination of causes, with water being a key element. It is important to understand current stability and how tailings harvesting processes are affecting stability during and after their completion. During tailings harvesting activities, any impacts on tailings dam stability need to be carefully monitored. Some of these impacts include (but are not limited to):

- ponding
- seepage
- side slope stability
- static and seismic liquefaction potential
- internal erosion (piping) and sinkholes
- loss of freeboard and overtopping
- spillway failure (blockage or erosion)

As both a GISTM 2020 and ICMM 2021 requirement, every TSF owner must have an Engineer of Record (EoR) appointed for each TSF. The EoR is responsible for monitoring the safety of the TSF during multiple lifecycle phases. During tailings harvesting, the EoR must closely monitor data and determine risk to the TSF, with focus on the following 15 components:

1. Monitoring the phreatic water levels and pore pressures in the structure.
2. Assessing drainage and piping concerns.
3. Determining if there will be a requirement for re-grading as random low spots from the tailings harvesting will result in water accumulation (pooling) with potential to cause adverse events.
4. Possible clearing of snow from harvesting areas in advance of freshet.
5. Determining if all slopes and planned slope geometries are safe.
6. Defining tailings and foundation conditions, and geotechnical and hydrotechnical properties.
7. Identifying whether any layers or zones are liquefiable.
8. Determining the static liquefaction potential of tailings with recent laboratory testing and cone penetration testing (CPTs) on site.
9. Seismic liquefaction analysis and seismic stability analysis.
10. Monitoring freeboard levels and climate.
11. Determining that there is sufficient capacity to contain flood and storm events and that the condition of the TSF meets latest legislation requirements.
12. Ensuring that the spillway has sufficient capacity and is not obstructed in any way.
13. Updating the Emergency Preparedness and Response Plan (EPRP) and the Operation, Maintenance and Surveillance (OMS) Manual.
14. Determining how changes to the structure including vegetation removal will affect slope stability and emissions.
15. Determining how any construction events will affect stability, seepage and liquefaction of the tailings.

Figure 3. Harvesting tailings operation (Adapted from Chapter 8 in SME Tailings Management Handbook).

The tailings material needed for backfilling operations is typically sourced from dormant tailings structures. Dormancy is defined as the period between the cessation of operations and the start of closure and reclamation activities (Boswell et al., 2020). Tailings in a dormancy state in which closure is neither anticipated nor implemented introduces several risks that must be considered before any harvesting operation is to begin. These risks as described by Boswell et al. include:

1. Planning risks
   - No plan at all
   - Starting too late
   - Short sighted mine planning
   - A lack of integrated planning
   - Inflexibility of plans
2. Risks arising from decision making based solely on financial information.
   - Lack of awareness and foresight of mining commodity cycles
   - Reliance on net present value instead of Life Cycle Costing
   - Shortage of funds and materials (eg, crushed rock)
   - Avoiding expensive Sustaining CAPEX
   - "Mothballing" to avoid decommissioning and closure
   - Mine bankruptcy or foreclosure
3. Regulatory risks
   - Poorly defined closure acceptance process
   - Non-holistic regulation
   - New risks arising from imposed regulations/interventions
   - Disallowed discharge of water
   - Jurisdictional conflicts and/or gaps in addressing closure
4. Technical risks

The need for a harvesting plan that accompanies and compliments a closure plan is apparent to reduce the dormancy risks listed. The main technical risk associated with tailings harvesting of dormant structures is the risk of static liquefaction. Static liquefaction occurs when saturated or partially saturated granular material experiences a rapid loss of strength due to an undrained loading response resulting from a trigger. Triggers include excessive rainfall, rapid loading as a result of high rate of rise, or loss of resistance as a result of excavation or erosion of the downstream toe (Boswell et al. 2019). Tailings harvesting could inadvertently trigger static liquefaction in susceptible tailings by excavation causing a loss of resistance, stockpiling of tailings backfill on the structure causing rapid loading, or even vibration from harvesting equipment. Therefore, it is critical to responsibly design a tailings harvesting operation to include defences against static liquefaction. These defences that are relevant to a harvesting operation as described by Boswell et al. include:

- identifying all potential triggers for liquefaction
- incorporating substantial drainage in the design
- pursuing Best Available Technology (BAT) and Best Applicable Practice (BAP).
- performing a comprehensive Failure Modes and Effects Analysis (FMEA) and formally reducing liquefaction risk
- understanding the critical role of deposition history in determining tailings behaviour and bearing history in mind as design defences are developed
- monitoring closely for any changes
- ensuring continuity of responsibility through to Closure

The critical role of surface water management

A surface water management plan considering each phase of harvesting is critical to the success of a tailings harvesting operation. It is key to merge any road access designs and ongoing harvesting operations into a "living" surface water management plan for the facility. A drainage design considering all low points in the harvesting operations with sufficient grade to direct flow away from the perimeters of the facility and towards the spillway/decant/pump station is required. Throughout the harvesting operation, inflow design flood (IDF) conveyance and freeboard must be reviewed and accommodated. The unplanned creation of voids which can later trap surface water should be carefully avoided. Also, snow loading should be considered and managed as part of the surface water management. The transition between seasons should also feature in surface water management planning.

Factors influencing working face selection

When beginning a harvesting excavation cut in tailings material, the working face selection is critical. Substantial errors and risks may be introduced when the working face is not analysed, assessed, and planned. CPT data should be acquired first to assess the slope stability and liquefaction potential of the work area. These data will determine cut depths and slope angles as well as inform the rate of excavation. Local geotechnical instrumentation should be closely monitored before and during the initial excavation to confirm that the phreatic surface is responding to the excavation as predicted.

The working face must be properly dewatered to reduce operational challenges, increase safety for workers, and increase slope stability of the excavation. A full drainage design must be incorporated into the grading design such that the working area can accommodate all the seepage flows introduced from the excavated tailings face as well as the IDF. A progressive harvesting operation should not leave standing pockets of water on the tailings surface as this introduces geotechnical and safety risks. If the harvesting cut cannot be naturally graded to a collection sump, then local pumping systems may be required during operation, including possible satellite pumping.

A new working face excavation will expose granular tailings to the environment. The tailings will dry out and may generate substantial quantities of dust. During dry and windy days, dust can become a major problem for a harvesting operation and can cause damage to equipment from abrasion, reduce visibility for operators, become a safety hazard for workers, generate community and stakeholder complaints, and even pose risk to the mine's social license to operate. In most jurisdictions, there are environmental requirements imposed on mining operations to limit mine dust. Therefore, dust should be supressed as much as possible by applying water, chemical agents, or other covers such as straw or gravel mulch to the exposed tailings material (Makarov et al., 2021). Additionally, only the minimum area of overburden or vegetation should be removed from a tailings harvesting area at a time, so that the exposed tailings surface is kept to a minimum, thereby reducing dust potential. This applies equally well to reduction of surface water emissions.

Checklist for harvesting design

A tailings harvesting design basis memorandum (DBM) should be prepared to consider the many elements that must be properly understood, analyzed and planned for. This includes the collection of tailings data, operational requirements, geotechnical elements of the TSF, water management, and procedural documents. A tailings harvesting DBM checklist is therefore a key document for operators to ensure a successful and risk-reduced tailings harvesting program. A typical DBM checklist is provided in Table 1.

Table 1. Design basis memorandum checklist for harvesting operations

Category	Sub Category	Comments
Characterization of Tailings	Residual Ore Grade	Potential and timing for reprocessing, depending on grade
	Particle Size Distribution	Influences blending requirements and paste recipe
	Moisture Content Range	Affects blending requirements and paste recipe; affects excavation
	Trace Elements and Contaminants	Both metal leaching and acid rock drainage are of concern (MLARD)
Vegetation Cover	Clearing/brushing specification	Must consider timelines and any legislation requirements
Topography	LiDAR	LiDAR surfaces for computing volumes; Drone survey may also be used
	Surface Profile	Initial condition surface profile needed for volume reconciliation
Backfill Feed Requirements	Tonnage	Strongly influences mining plan and grading
	Recipe Specifications	Determines tailings property specifications for recipe
Surface Hydrology	Drainage	Reduce stored water on tailings facility to as low as possible
	Flood Determination (IDF)	Determine inflow design flood
Geotechnical Stability and Fabric of TSF	Liquefaction Potential	Cone penetration testing campaign to determine liquefaction potential
	Microfabric (McRoberts 2023)	Grain size, shape, packing
	Mesofabric (McRoberts 2023)	Layering of fines, climate impacts
	Macrofabric (McRoberts 2023)	Earthfill construction, depositional methods
Mining Plan		Includes haul diagram, logistics and selection of mining equipment
Grading Plan		Geometric profile and volume of cuts and fills required to meet tonnage
Equipment Selection		To meet tonnage, cost and vibration specifications
Process Affected Water Management Plan	Sump Design	To meet drainage volumes and pump capacity volume
	Berming	To contain and separate process affected water
	Access Roads	Requires culvert/drainage plan, aggregate source
Geotechnical Instrumentation		Piezometers to measure pore water pressure, monitoring wells to measure water table and to collect water samples
Key Procedures	HSE	Detailed health and safety plan
	Organizational Chart	Detailed organizational chart with responsibilities
	Communication Chart	Detailed contact list for operating site
	Emergency Response and Preparedness Plan	Includes periodic practice drills with local stakeholders

FPIC for stakeholders

GISTM 2020 Principle 1 emphasizes respecting the rights of project affected people and duty to meaningfully engaging them throughout all phases of a tailings facility lifecycle, including harvesting and closure. To demonstrate conformance to this international guideline and leading practice framework, operators should obtain and maintain FPIC. To obtain FPIC, consent must be secured through cooperation and consultation with the project affected peoples (GISTM 2020).

In many cases, tailings harvesting will decrease tailings landform volumes and can potentially remove them entirely if a harvesting program is suitable for the entire structure. Therefore, long-term tailings landform risks such as liquefaction, acid generation, and slope instability can be greatly reduced. A harvesting program could also introduce disturbances to the community of interest such as increased emissions, dust, increased traffic and a possible influx of new workers. These factors should be incorporated into management plans to control emissions and impacts from the project and should be communicated with project stakeholders in advance of commencement of harvesting operations.

Conclusions

There is no doubt that the preparation of tailings harvesting plans has become increasingly complex since the publication of GISTM 2020. This paper has described the risks of harvesting without consideration of recent changes to regulations, guidelines and leading practice. It also outlines the value of careful advanced planning, itemizes focus areas for attention, includes a list of operational precautions and provides checklists for inclusion in a typical tailings harvesting plan and design basis memorandum.

The well-worn adage is still true for tailings harvesting: those who fail to plan, plan to fail.

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Acronyms

BAP	Best Applicable Practice
BAT	Best Available Technology

CPT	Cone Penetration Test
DBM	Design Basis Memorandum
EPRP	Emergency Preparedness and Response Plan
EoR	Engineer of Record
FMEA	Failure Modes and Effects Analysis
FPIC	Free Prior and Informed Consent
GISTM	Global Industry Standard on Tailings Management
ICMM	International Council on Mining and Metals
IDF	Inflow Design Flood
OMS	Operation, Maintenance and Surveillance Manual
SME	The Society for Mining, Metallurgy and Exploration
TSF	Tailings Storage Facility