

# TECHNICAL NOTE 7 TAILINGS STORAGE FACILITIES

GOOD PRACTICE NOTE ON  
**DAM SAFETY**



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FACILITIES**

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*Cover photo:* Tailings Storage Facilities at Waihi Gold Project, New Zealand © OceanaGold Ltd.

*Cover design:* Bill Praguski, Critical Stages LLC.

# Technical Note 7: Tailings Storage Facilities

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## Introduction

Tailings storage facilities (TSFs) are engineered structures that comprise the confining embankments (commonly referred to as *tailings dams*) and associated works and are designed to contain tailings (residue following extraction of valuable material from metal ore processing) and to manage associated water. A TSF contains mixed waste material from mining processes in liquid or slurry form and must be responsibly managed to prevent impacts on human health and safety, the environment, and other infrastructure. However, TSFs have historically suffered more problems than water storage dams. Internationally, TSFs have a historical long-term average of more than one major incident or failure per year.

To manage mining facilities responsibly, the TSF owner must understand the physical and chemical risks associated with the TSF and implement controls to reduce risks relating to potential health, safety, environmental, societal, business, and economic impacts in line with regulations.

International organizations, regulators and industries have developed guidelines to aid owners in the management of TSFs. These guidelines were used to develop this Technical Note. This Note contains

the minimum level of technical detail so that it can be used by nonspecialists. The key objective is to provide guidance early in project preparation so that safety aspects of a tailings facility are addressed over its life cycle. The Note is intended to raise awareness and inform specific studies/investigations, as appropriate, during project preparation. The material presented should be used to prepare terms of reference on such studies. It is expected that, reading the note, the task team will assess whether it is necessary to include tailings-specific expertise in the project team.

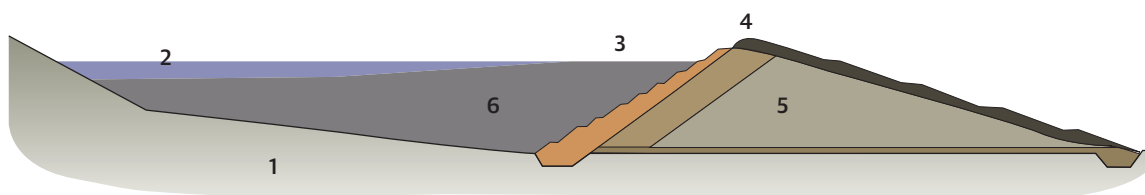
## Tailings Storage Facilities and Water Storage Dams

Water storage dams are assets built to store or convey water for irrigation, power generation, flood control, industrial processes, or recreational uses. TSFs are used for the storage and management of tailings solids and mine waste. The disastrous environmental and health consequences of TSF failure, and the length of time the potentially dangerous contents are stored, should mean that TSFs must be treated with even greater care than water storage dams and continue long after mine production has ceased. However, TSFs often attract less attention and financial resources because there is not a direct commercial incentive.

Tailings are frequently placed in slurry form with high initial water content. They can also be thickened to a paste or dewatered to an unsaturated condition, which reduces risks associated with a breach. The embankments forming TSFs can be constructed from earthfill or from tailings material. Although many design and safety evaluation principles used for conventional water storage dams will be applied to TSF, there are sufficient differences to warrant specific guidelines for them. Significant ways in which TSFs differ from water storage dams include:

- The embankments must be designed to store solids such as slurry and free water (figure 1).
- There are three main types of construction: upstream construction, downstream construction, and centerline construction (figure 2).
- The operating life may be quite short (about 10 to 20 years), but the tailings will be stored in the long term (more than 100 years). Closure of the TSF needs to create a permanent, safe, and

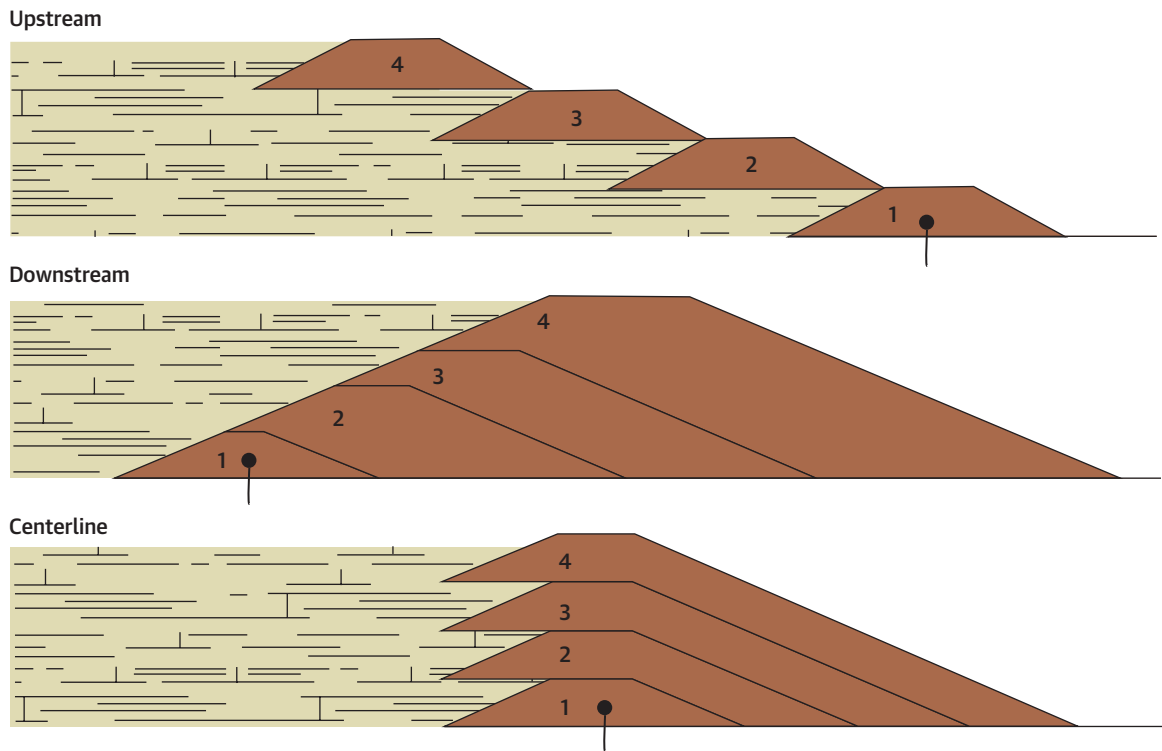
**FIGURE 1: Typical Components of a Tailings Storage Facility**



Source: OceanaGold-Waihi, New Zealand. Tailing Storage Facilities. <https://www.waihigold.co.nz/mining/waste-rock-and-tailings/tailings-storage-facilities/>

Note: 1 = natural ground; 2 = decant pond; 3 = beach; 4 = crest; 5 = zone embankment including starter dam; 6 = deposited tailings.

**FIGURE 2: Methods of Construction for Tailings Storage Facilities**



Source: Adapted from BHP. Tailing Dams. 2019. [https://www.bhp.com/-/media/documents/media/reports-and-presentations/2019/190607\\_esgbriefingtailingsdams.pdf?la=en](https://www.bhp.com/-/media/documents/media/reports-and-presentations/2019/190607_esgbriefingtailingsdams.pdf?la=en)

low-maintenance deposit that will not have long-term safety risks or environmental impacts for future generations. The TSF must be designed with closure in mind.

- Water management during operation is required to balance the total water gains from the tailings (water added for delivery as slurry), rainfall, and surface runoff against losses from drainage recovery, removal of ponded free water (referred to as decant), and evaporation. This is referred to as the water balance and is critical particularly when harmful materials are contained.
- Solids and water stored in TSFs may contain contaminants that can harm human health and the environment if not contained. In some cases, the TSF may have a geomembrane liner to provide secure containment.
- Seepage and dust may have a harmful impact on the environment.
- Construction is likely to occur in stages over several years. This can result in changes in tailings properties and material sources for embankment construction over time that depend on mining operations and mineral processing. To maintain safety, it also requires proper planning, active site supervision, and quality control.

- Construction may be undertaken by mine personnel and not necessarily with the level of engineering input and quality control used in the construction of water storage dams.
- Design inputs are variable; the filling rate, ultimate height, and overall storage may change in unforeseeable ways during construction and operation.
- There may be changes in designers and personnel responsible for construction and operation over the life of the TSF.
- Stability of the TSF changes over its life cycle and depends on several factors, such as design, construction staging, mining operations, and active management of the water balance.
- Characteristics of the stored tailings depend on how they are transported and deposited within the TSF. Often, discharge of the tailings results in the formation of a “beach” within the TSF consisting of coarser material being deposited near the discharge pipe outlet or spigots.
- Best Available Technology (BAT) is used for achieving performance objectives and managing risk. Selection of BAT includes considering a range of methods to determine how the mining material will be processed, how much water will be retained in the tailings, where to store the tailing, how the postclosure TSF land is appropriately taken care of, and whether the likelihood or consequences of the TSF failure is appropriately reduced through these methods of the TSF.

### **Risk Profile of Tailings Storage Facilities**

From a database inventory of 18,401 mine sites worldwide, the failure rate of tailings dams over the past 100 years is estimated to be 1.2 percent (Azam and Li 2010). This is about three orders of magnitude higher than the failure rate of water storage dams that is reported to be 0.001 percent (ICOLD 2001). The failure rate of TSFs is an average of one to two failures a year worldwide. Failures predominantly occur in small to medium-size dams that are up to 30 meters high and contain a maximum tailings volume of five cubic millimeters. The released tailings associated with failure are about 20 percent of those contained in the TSF. The rate of failure has not been reduced over time. Because of the consequences of failure, TSFs have the potential to result in some of the most significant environmental impacts in mining. This potential applies not only during operation, but long after closure of the mine or processing plant.

Because the focus of mining activity is production of the valuable mineral product, storage of tailings in a TSF is often not given the same attention as mine production activities. Temptations can be great to minimize cost first during mine operation and then not adequately fund closure of the TSF. Poor governance and commitment to dam safety, low investment, and insufficient technical input have been contributing factors in historical TSF failures and incidents. These incidents can have major consequences societally, environmentally, and economically.



Many lessons can be learned from historical TSF failures. The most common failure modes for TSFs are:

- Overtopping and overflow
- Slope instability
- Earthquakes
- Foundation failure
- Seepage and internal erosion

For TSFs constructed by upstream or centerline construction, or where conventional water storage dams are raised by upstream methods, potential failure modes (PFMs) that have been linked to failures include:

- Slope instability within the tailings under normal operating conditions. This instability can occur because of a loss of control of pore pressures resulting from a loss of control of the water management and ineffectiveness of drainage systems.
- Slope instability through low strength or contractive strata in the foundations or within the tailings for upstream construction. This may take the form of static liquefaction.
- Liquefaction of the tailings under seismic loading resulting in large deformations and loss of freeboard.
- Overtopping because of loss of control of the management of water ponded on the tailings.

These PFMs are quite different from water storage dams.

The main contributors to TSF failures include:

- Poor design
- Poor water management and lack of control of the water balance and failure to maintain adequate freeboard
- Substandard construction and supervision
- Poor governance and commitment to dam safety
- Insufficient resources; inadequate training; and lack of defined responsibilities, reporting structures, and understanding of the features that control safe operations and dam safety management

Downstream-constructed TSFs are more like conventional water storage dams and have a lower failure rate compared with centerline and upstream constructed embankments.

Following recent TSF disasters, some countries have moved to ban upstream construction.

Figure 3 shows the number of very serious and serious failures of TSFs. The failure levels are based on three severity variables that were created by the International Commission on Large Dams (ICOLD) (2011): (a) release, (b) runout distance of the tailings, and (c) deaths. The definition for the failure levels is as follows:

- *Very serious*. Having a release of at least 1 million cubic meters or traveled 20 kilometers (12.4 miles) or more, or multiple deaths (generally 20 or more)
- *Serious*. Having a release of 100,000 cubic meters (cubic meters) or loss of life

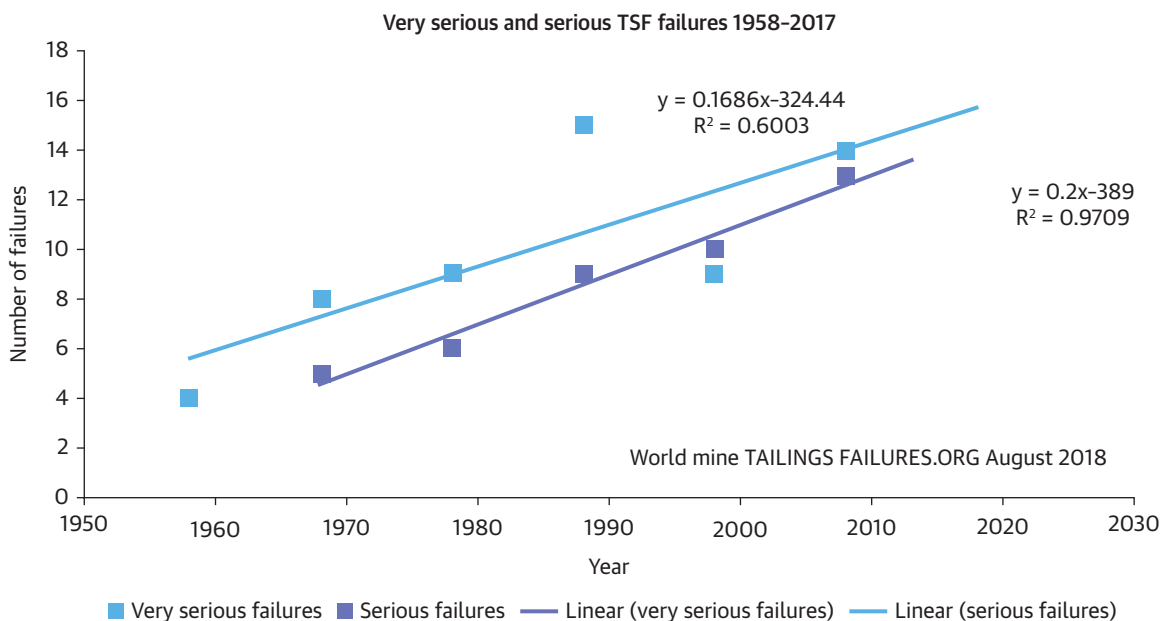
Annex B provides a recent tragic case study on the failure of Córrego do Feijão tailings Dam No. 1 located in Brazil.

### Available Guidance

International organizations, regulators, and industries have developed qualitative technical guidance documents to aid in the design, construction, and operation of TSFs.

A reference list of key technical guidance documents is included in Annex A. These documents include a large array of information that should be referred to as part of the development and management of TSFs. In some jurisdictions the requirements for design, construction, and operation are specified.

**FIGURE 3: Very Serious and Serious Failures of Tailings Storage Facilities**



Source: World Mine Tailings Failure. <https://worldminetailingsfailures.org/>

In some countries, the requirements are inadequate or outdated and standards can vary. Responsible TSF owners normally adopt international best practice in these situations. One of the following four guidelines can be a central reference document for the project involving TSFs:

- Australian National Committee on Large Dams (ANCOLD) (2012)
- International Council on Mining and Metals (ICMM), Principles for Responsible Investment (PRI), United Nations Environment Programme (UNEP) (2020).
- Mining Association of Canada (MAC) (2019)
- United Nations Economic Commission for Europe (UNECE) (2014)

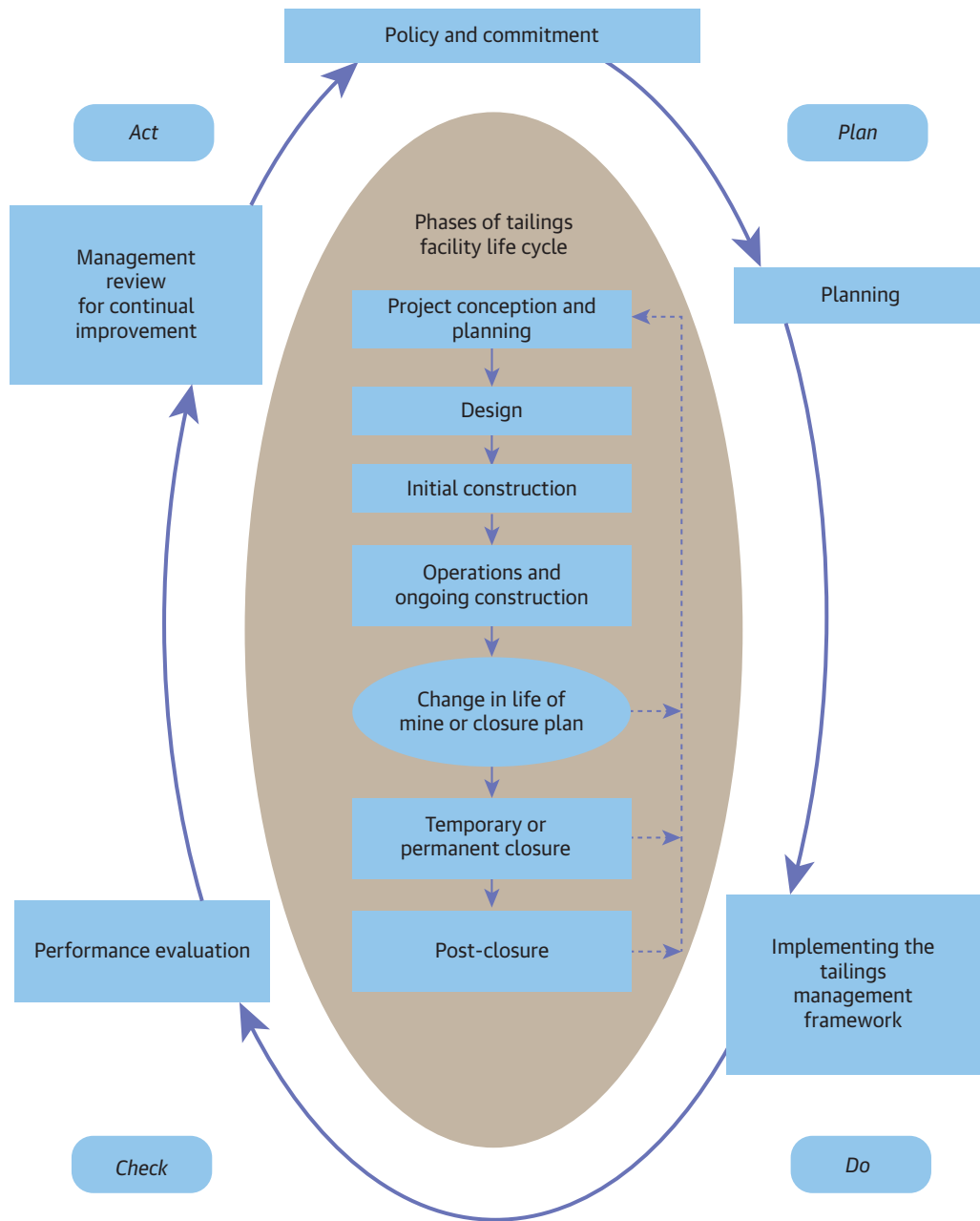
## Life-Cycle Management

It is important to have a tailings management framework through all phases of the life cycle of a TSF. The key elements include policy and commitment, planning, implementation, performance evaluation, and management review. Figure 4 shows an overview of how these elements are included over the life cycle. Tailings management should follow a “plan-do-check-act” model to allow for continual improvement. This model is consistent with other models for environment management systems.

The phases of the life cycle of a TSF are:

1. *Project conception and planning.* This is the initial planning and conception of a proposed mine and TSF, including the mine plan and plans for extraction processing. The phase needs to include rigorous decision-making tools to support selection of the location for the TSF and the implementation of BAT for tailings management.
2. *Design.* Design begins once the location and BAT for the TSF have been selected. It includes detailed planning and detailed engineering design of all aspects of the proposed mine and TSF.
3. *Initial construction.* This is the construction of structures and infrastructure that need to be in place before tailings deposition and storage commences. It includes, for example, removal of vegetation and overburden, and construction of starter dams, tailings pipelines, access roads, and associated water management infrastructure.
4. *Operations and ongoing construction.* Tailings are transported to and deposited in the TSF. TSFs may be raised or new tailings cells added according to the design. Depending on the overall mine plan, the operations and ongoing construction phase of a TSF may or may not coincide with the period of commercial operations of the mine.
5. *Standby care and maintenance.* The mine has ceased commercial operations and the deposition of tailings into the TSF is not occurring. The owner expects to resume commercial operations at some point in the future, so surveillance and monitoring of the TSF continue, but the TSF and associated infrastructure are not decommissioned and the closure plan is not implemented.

**FIGURE 4: Tailings Management Life Cycle**



Source: MAC 2017.

6. *Closure*. Closure begins when deposition of tailings into the TSF ceases permanently. The TSF and associated infrastructure are decommissioned and key aspects of the closure plan are implemented, including transition from operations to permanent closure, removal of key infrastructure such as pipelines, changes to water management or treatment, and recontouring or revegetation of tailings and any containment structures or other structural elements.

7. *Postclosure*. Postclosure begins when decommissioning work is complete, key aspects of the closure plan have been implemented, and the TSF has transitioned to long-term maintenance and surveillance. During postclosure, responsibility for a TSF could transfer from the owner to jurisdictional control.

NOTE: These definitions are strictly intended to describe key characteristics and activities of the TSF life cycle. There are also various legal definitions associated with the terms *closure* and *postclosure*, which may differ greatly among nations and regional jurisdictions.

The section on Planning for Closure and Retirement of a TSF provides additional details on each phase of the TSF life cycle.

## Key Roles

### Designer

The designer needs to be experienced in geotechnical engineering of tailings storage facilities, in particular their investigation, design, and construction.

The designer needs to understand how the TSF will be operated, including water management and sensitive geotechnical conditions that could quickly lead to failure of the TSF embankment.

Continuity of designer expertise throughout the design and construction is critical because the structure is evolving over time. Designers may be changed over the operational life of the TSF, but this must be managed carefully. TSF failures have occurred coincident with changes in design engineer. It is vital that the new designer has suitable expertise and experience and understands past design assumptions, decisions, and construction activities. Transfer of records and vigilance during the transition of engineers are particularly important. Conducting a PFM analysis workshop is recommended during the transition.

It is also recommended that the designer be responsible for ongoing review of the performance of a TSF during its life. This review involves providing support and advice to the personnel supervising construction and operating the TSF and undertaking annual inspections and performance and safety reviews.

### Engineer of Record

The owner needs to retain an engineer of record (EoR) to provide technical direction on behalf of the owner. The EoR verifies whether the TSF (or components thereof) has been:

- Designed in accordance with performance objectives and indicators, applicable guidelines, standards, and regulatory requirements; and
- Constructed, and is performing, throughout the life cycle in accordance with the design intent, performance objectives and indicators, applicable guidelines, standards, and regulatory requirements.

The designer often fulfills the role of the EoR, but on some large projects the EoR provides independent review.

## Independent Reviewer

An important part of managing the TSF throughout its life cycle is independent review by external experts. Third-party independent reviews should be completed at critical phases over the life cycle such as concept, feasibility studies, design, construction, and closure. This is a mandatory requirement in some jurisdictions. Periodic reviews should also be completed during operations. Most modern dam guideline documents provide recommendations for undertaking independent dam safety reviews. The same principles apply as for water storage dams. Such reviews are commonly referred to as *comprehensive dam safety reviews* and are undertaken every five years. Some owners appoint an independent review board (IRB) to review design, construction, and operation of a TSF. The IRB may report more frequently during design and annually when in operation.

## Components of Tailings Storage Facilities

There are many types and components of TSFs that depend on the method of containment, disposal, and closure. A tailings management strategy will describe the methods for transport, storage, and permanent retention of tailings and waste products. The type of TSF used in the management strategy depends on several factors such as site geology and seismic hazard, volume, and properties of materials available to construct the TSF, process type, tailings characteristics, available disposal area, climate, and long-term requirements. The main components of a TSF include the following.

Delivery of tailings to disposal site includes:

- Pipelines and pumps
- Channels/flumes
- Direct discharge
- Conveyed trucked (dry)
- Specialized transport or disposal systems

Transport, distribution, and discharge of tailings within the storage involves:

- Single or multiple discharge or spigoting discharge
- Spinning of tailings slurry to separate soils and liquid (referred to as *hydrocyclone*), often used when a significant portion of sand with the sand portion is used to construct upstream construction embankment dykes
- Thickened slurry with central discharge
- Codisposal with coarse rejects or waste rock
- Mechanical or solar drying and dry stacking

Deposition of tailings within the storage is:

- Deposition strategies for segregation of solids and liquids so that a beach slope forms for free water to drain to a designated area referred to as a *decant pond*
- Below the water line and tailings in a water environment (referred to as *subaqueous technique*) and results in a steeper settled slope
- Above the water line and on the ground or beach area so that tailings are exposed to the atmosphere (referred to as *subaerial technique*) and more commonly used than subaqueous technique

Containment of deposited tailings:

- Involves single-stage embankment construction
- Involves multistage raising, often using waste mining excavation rock or hydrocyclone coarse material as a construction material
- Is stacked, where dry tailings are placed and compacted for stable pile
- Involves waste dumps where material is carried to tip and dumped, resulting in a loose, potentially unstable pile
- Is placed within underground mine voids or open pits
- Is within lakes (lacustrine), rivers (riverine) or deep-sea disposal in a nonsensitive location

Water management and environmental protection measures are also included.

A staged construction is commonly adopted when constructing embankments for tailings containments. An initial embankment will be built first. This embankment typically has a short design life of one to three years. The design must consider future needs of the TSF through operation and closure; therefore, foundation cut-off drains, underdrainage, and linings for full height of the TSF must be designed and constructed for the initial embankment. Often, further exploration will discover more ore reserves at a mine and the required storage volume for tailings will increase. The designer needs to bear this in mind so that the design has flexibility to be expanded in the future if necessary. After the initial embankment is constructed, staged construction can be carried out using three methods (figure 2):

- Downstream, incorporating the initial embankment
- Centerline, where part of the raised embankment is built on tailings and the rest is downstream construction
- Upstream, where most of the embankment is built over the tailings beach

There is considerable flexibility, and mixed-design TSFs are not uncommon. A TSF may start as downstream, be raised by centerline, and then finally move upstream.

## Hazardous Materials Management

The potential for both chronic pollution and the acute risk associated with mine tailings deposits can remain for a long time. There are many cases in which tailings and waste deposited several centuries or even millennia ago still produce pollution in amounts that are harmful to the environment. This situation emphasizes the importance of appropriate design, construction, operation, maintenance, and careful consideration of closure of today's TSFs and waste dumps to avoid unacceptable risks or negative impacts in the future.

TSF management needs to include an environmental impact assessment (EIA) and environmental management plan (EMP) to demonstrate minimization of risks when dealing with hazardous materials.

An EIA should be completed in the conception and planning phases. The EIA needs to consider the following criteria:

- Location
- Site factors (climate, geology, hydrogeology, topography, and seismic hazard)
- Tailings characteristics
- Operation
- Management
- Closure concepts

Upon acceptance and approval of the EIA, an EMP should be completed to ensure that environmental impacts are minimized for:

- Communities downstream or nearby
- Water sources such as receiving watercourses, groundwater, water storage, and potable water supplies
- Air quality that can be affected by dust contaminants and fugitive gases
- Fauna and flora that support ecosystems
- Heritage sites

## Testing Tailings to Understand Environmental and Health Risk

Adequate knowledge and understanding of tailings' properties is essential to reduce the hazard related to them. Testing of tailings should provide an understanding of:

- Physical characteristics of the tailings as both slurry and solids, including allowance for partial segregation



- Material properties including bulk density, dry density, specific gravity, consolidation, strength, and permeability
- Chemistry for the free water that may be referred to as the processed liquor depending on composition
- Mineralogy/geochemistry
- Rheological properties such as stress-strain relationships and viscosity

Tailings and transport liquors can contain deleterious substances. Knowledge of the mineralogy and chemistry of the tailings is essential for proper environmental design. This understanding also aids in predicting material behavior during disposal. Chemical reactions that may occur in the storage area include:

- Oxidation of sulphides and creating acidic water
- Base exchange with cyanide compounds into insoluble forms to prevent volatilization of this very toxic chemical into the air
- Binding of toxic metals onto clay particles
- Release of harmful gases

### **Structural Stability**

Stability assessment of tailings facilities differs from that of water storage dams where:

- Embankment zones are typically thinner and smaller
- The embankment is constructed in stages over many years
- Upstream construction relies on the strength of tailings; the strength can vary based on consolidation and there is a potential for static liquefaction
- Pore pressures are a combination of seepage pressures and consolidation pressures

Limit equilibrium analysis is used to assess stability of the tailings embankment dam under static load conditions. Numerical modeling may be required if factors of safety are marginal. There are loading conditions that should be considered for stability analysis.

Drained conditions include:

- Long-term stability at ultimate design height
- Long-term post closure stability

Undrained conditions are:

- During construction, when geometry and pore pressures are changing
- Saturated contractive materials (including tailings and cohesionless foundations)
- New construction over existing slopes
- Renewed deposition over old impoundments
- Slope stability with toe excavation
- Static and earthquake-induced liquefaction
- Postseismic stability in which the earthquake is small enough to preclude liquefaction but large enough to induce undrained conditions
- Postseismic stability in which tailings or foundation liquefy

Seismic design considerations for tailings facilities are like those for water storage dams, but they also need to consider the tailings seismic performance. Refer to the *Technical Note on Seismic Risk* for further seismic guidance. Assessing the seismic performance of the TSF should consider the additional inertial loads and displacements from the tailings.

## Hydrological Safety

TSFs have a different storage capacity than water storage dams. Allowance needs to be made in consideration of dam safety and environmental spills where storage capacity is continually reduced by deposited tailings solids and fluctuating water volumes. The water quality of the stored liquor (free water) may also be unsuitable for release downstream.

Hydrological considerations in the design of tailings facilities include the following.

**Tailings Storage Capacity.** Capacity can be complicated by staged construction, uncertainty in the volume of tailings that will be produced, and the ultimate as-placed density the tailings will achieve.

**Minimum decant pond storage capacity.** The capacity of the decant pond needs to be sufficient to store the volume of water contained within the tailings slurry, which is released when tailings are initially deposited; interstitial water in the deposited tailings that is squeezed out as the tailings consolidate; direct rainfall and surface runoff that accumulates over wetter periods of the year and from extreme rainfall events; waves generated by wind; freeboard allowance; and the rate at which accumulated water can be removed for either use in the process plant, treatment, or possible direct release.

**Nonrelease TSF.** If the water quality is unsuitable for release under normal conditions, appropriate storage must be available to minimize the risk of a spill during heavy rainfall events or following large earthquakes. An emergency spillway should be included in the TSF design for the controlled release of

contents as part of risk management, or storage capacity should be provided for the worst possible conceivable situation.

**Spillway.** The design flood for a spillway design of a TSF is like the design flood for water storage dams. Refer to the *Technical Note on Hydrological Risk* for further details.

**Water balance.** Modeling the water balance will help understand the required freeboard to safely store accumulated water and assess the stability of the TSF during design. In operation, it can be refined and used to make timely adjustments for the safe operation of the TSF.

The water balance will determine the performance characteristics of a tailings drainage collections system. Characteristics include seepage flows and losses that must be managed during operations and closure.

Water balance modeling needs to consider variations in tailings properties, quantities, storage levels, and schedule of dam raises along with variations in climatic conditions.

**Stream management.** Tailings facilities are typically off-stream storage areas; it is preferred to separate the storage area from storm water runoff.

As with water storage dams, rainfall and runoff estimates should be completed as part of the water balance and minimum decant storage required. On-stream TSFs need to consider the runoff from the upstream catchments and the effect on freeboard when the inflow flood flows through the TSF.

**Seepage.** Seepage losses may not be significant for water balance; however, seepage can cause a significant impact on the environment if not properly captured. Seepage assessments like those of water storage dams should be completed in design to aid with stability analysis, understanding the rate of rise of the tailings, evaluating environmental impacts, and sizing the drainage collection systems.

Each TSF needs to have a unique water management plan. The following elements are required to be included in the water management plan:

- Hydrology/hydrogeology
- Design flood
- Water balance
- Surface water management plan
- Water release criteria
- Water treatment capability
- Containment balance and release
- Effluent criteria

## Hazard/Consequence Categories

There are two hazard<sup>1</sup>/consequence categories that need to be assessed for tailings facilities: dam failure and environmental spill.

Assessing the dam failure consequence level of a TSF is similar to a water storage dam. The highest classification from either the dam break or environmental spill assessments governs the hazard/consequence level for the project. The hazard/consequence level of a TSF is associated with the consequence of failure considering loss of life, environmental damage, economic damage, and societal impact. The classification methodology varies from country to country, and local guidelines should be used to assess the classification of the TSF in the specific country.

Because TSFs are always developing over their life cycle, the consequences of failure may change as the TSF develops or development takes place downstream. Thus, the classification of a TSF needs to be assessed over its life cycle and must be managed accordingly, should the classification change.

## Dam Safety Management

The fundamental dam safety objective is to protect people, property, and the environment. A dam safety management system provides an owner with a framework for dam safety management activities, decision making, and supporting processes. A dam safety management system should be developed for each TSF. Elements include:

- Governance
- People
- Operation and maintenance
- Surveillance and monitoring
- Intermediate (annual) dam safety reviews
- Comprehensive dam safety reviews
- Special inspections and dam safety reviews
- Emergency preparedness
- Identifying and managing dam safety issues
- Information management
- Audits and reviews

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<sup>1</sup> Whilst *hazard* is used as a threat or condition that may result from external cause (for example, an earthquake or flood) or potential source of adverse health and environmental effect in other sections of this Note, *hazard* is here used as a measure of consequences in case of dam failure and/or uncontrolled release of tailings as per dams engineering practice.

## Surveillance Programs

Surveillance programs consisting of instrument monitoring and visual inspections are important risk management practices for TSFs. A site-specific operations, maintenance, and surveillance (OMS) manual should be developed for each TSF. This manual should describe OMS requirements based on the TSF hazard/consequence classification, current engineering design standards, and site considerations. The OMS manual for TSF should include:

- A description of the embankment(s) forming the TSF
- A description of the tailings delivery system to the TSF
- A description of all monitoring procedures for inspections and instrumentation monitoring
- Alert and alarm levels for monitored parameters
- Procedures for reporting on noncompliance, incidents, and failures
- Corrective actions to be applied in the event of noncompliance and incidents
- An internal emergency plan
- Assessment parameters for effectiveness and suitability of the operation manual

Findings of the visual inspections and instrument monitoring should be used to reevaluate design inputs. Geotechnical inputs, such as estimated seepage and water pressures within the tailings, are often based on limited knowledge and the basis for design and expected performance. Surveillance data should be used to verify these design predictions, and if different, may require reanalyzing the TSF stability. Actual performance from the surveillance program versus design assumption should be checked throughout the TSF life cycle. Refer to the *Technical Note on Geotechnical Risk Assessment* for further guidance on surveillance.

## Emergency Preparedness

Emergency preparedness is important in the management of TSF to reduce life loss if an incident or failure were to occur. An Emergency Preparedness Plan (EPP) is a tool to reduce the risk of life loss and to document the owner's responsibility for sustainable development. The EPPs for TSFs should be like EPPs for water-retaining structures; however, emergency plans should be established for each phase of the TSF life cycle. As with water-retaining structures, internal and external emergency response plans should be prepared.

The EPP for a TSF should be established and tested:

- Before the start of operations
- If an incident or emergency occurs at the site or ancillary facilities

- When the emergency service organization or its senior personnel changes,
- When there is updated understanding of the TSF performance or new risks are identified
- If operational changes, mismanagement, structural problems, equipment modification, or natural events result in a threat that design limits will be exceeded
- At regular intervals, as set out in the emergency plans and for training purposes

The EPP for each TSF is expected to be different depending on the hazards, consequences, and site-specific components of each TSF, including:

- Plans of the TSF and safe access routes
- Identification of potentially affected stakeholders
- Purpose of the EPP including objectives and scope
- Emergency scenarios, risks, affected areas, and downstream hazards/consequences
- Hierarchy, coordination, and responsibility of each participant
- Communication organization and systems
- Emergency and notification procedures and systems
- Emergency response procedures for each scenario
- Internal and external equipment and resources as required for prompt intervention of the emergency
- Remediation procedures to return to normal operation
- Identification of potentially affected stakeholders
- Regular training requirements

### **Planning for Closure and Retirement of a Tailings Storage Facility**

TSFs should have a closure plan, preferably developed at the planning stage of a project. Although TSFs have a short active life, they should be planned, designed, constructed, operated, and closed considering the reality that they will be permanent structures. On closure, TSFs become engineered landforms, expected to remain physically and chemically stable for the long term. It is important to ensure that short-term financial or operational priorities do not prevail over better design and operational practices that would have lower long-term impacts, complexity, or risks.

Planning the closure of a TSF is intertwined with the original design and changes to the design that may occur during the life cycle. Planning should include:

- Risk assessment and preparation of a risk management plan
- Understanding topography
- Determining hydrogeology of surficial and bedrock units
- Determining soil conditions and geotechnical considerations
- Confirming regulatory requirements
- Design of the TSF, including any deviations from the plans throughout the
- operations and ongoing construction phase
- Determining physical and chemical characteristics of the tailings
- Assessing climate, including long-term climate change projections
- Confirming hydrology
- Preparing a tailings transport and deposition plan
- Preparing a water management plan
- Updating the OMS manual describing long-term surveillance and monitoring requirements
- Identifying existing infrastructure and infrastructure to be retained during closure and postclosure
- Assessing potential for revegetation
- Confirming availability of materials for reclamation

The development of the closure plan should cover the following topics:

- Progressive reclamation plan to address reclamation activities to be undertaken during the operations and ongoing construction phase of the life cycle
- Decommissioning plan to address activities to be undertaken during the closure phase
- Reclamation and revegetation plan
- Long-term maintenance and surveillance plan
- Emergency preparedness and response plan for closure and postclosure
- Plan to ensure continual control of documented information

As with other aspects of design and risk management of the TSF, the closure plan must be reassessed through the life cycle of the TSF. Long-term is considered more than 1,000 years, whereas most closed TSFs to date have been closed for only one or two decades. As more information is gained in postclosure behavior, the lessons learned should be applied to the closure plan of the TSF.

## Planning and Design

Figure 5 shows the process for planning and design of a tailings facility.

Assessing the alternatives for location is one of the first phases in project planning and conception. The location of the TSF is the foundation of the planning process and affects all subsequent decisions and planning. Considerations in the alternatives assessment include:

- Characteristics of the proposed mine
- Characteristics of tailings
- Availability and characteristics of impoundment construction materials
- Air and water management
- Environmental impacts

A screening-level assessment should be completed for each TSF site alternative that considers:

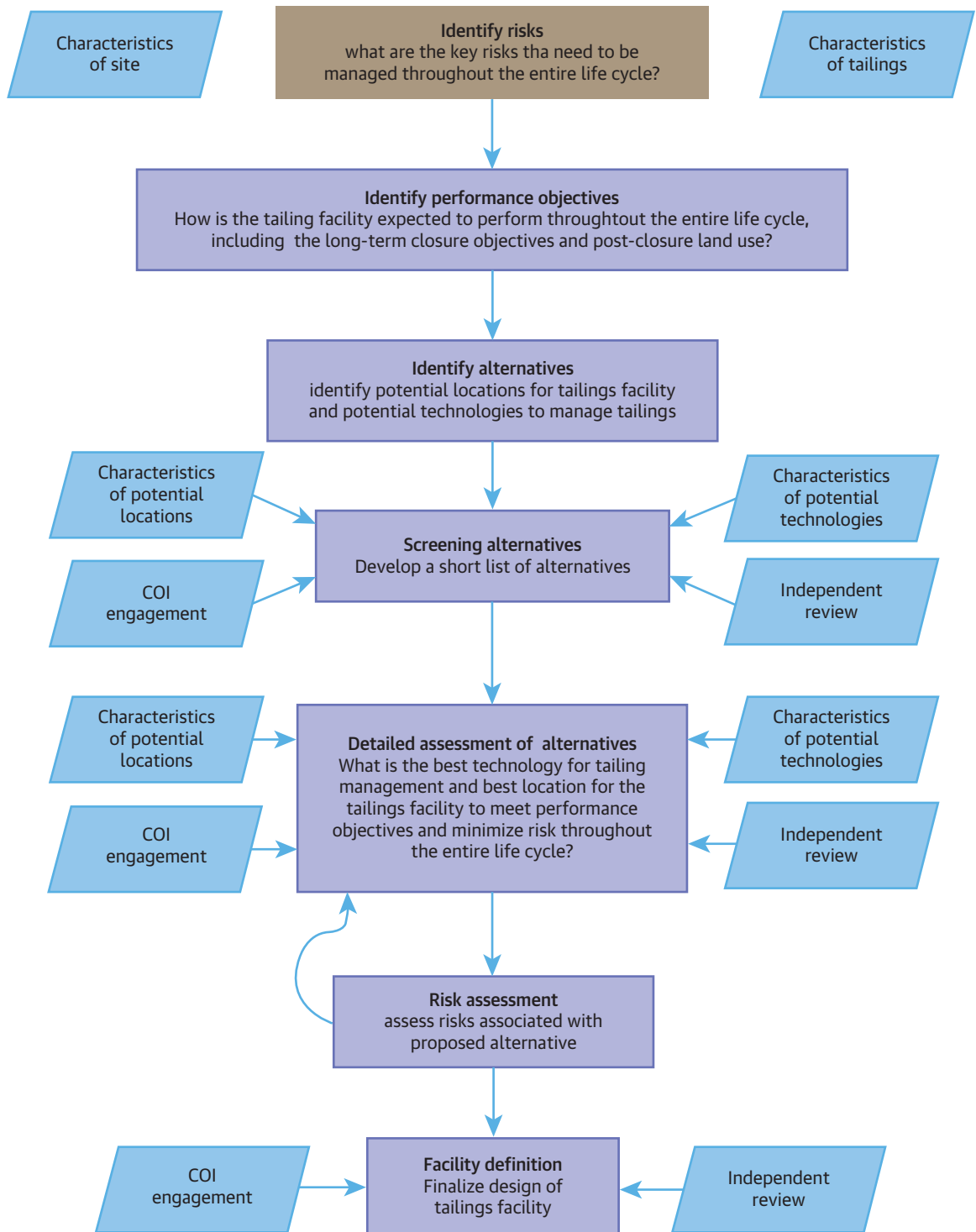
- Basic location information (that is, distance from mining operations, site topography, and surface area for storage of tailings)
- Existing planned infrastructure (mine and nonmine related)
- Flora and fauna that could preclude the TSF at that location
- Hazards including landslides, geological faults, geotechnical conditions, and hydrological conditions
- Social or cultural features
- Closure considerations
- Cost

A detailed assessment is completed after the screening assessment to rigorously evaluate the preferred alternatives identified in the screening assessment. The level of detail is less than a full engineering design but sufficient to understand and evaluate key factors that affect location, design, construction, operation, and closure. Considerations in detailed assessments include:

- Tailing management plan
- Closure plan



**FIGURE 5: Tailings Facility Planning and Design**



Source: MAC 2017.  
 Note: COI =Communities of Interest.

- Detailed topography using light detection and ranging
- Bedrock and hydrogeology
- Surficial geology and hydrogeology
- Hydrology within the footprint of the tailings facility
- Water management
- Natural hazards
- Terrestrial and aquatic environment
- Potential archaeology impacts
- Indigenous rights and cultural impacts
- Socioeconomic implications
- Cost

Once the alternative site is selected, a detailed engineering design is conducted by evaluating all of these factors.

### Construction

During construction, the objective is to create a safe, stable TSF that conforms to design intent, meets regulatory requirements, and meets the intended tailings and water management. Key aspects are initial construction and ongoing construction.

Initial construction involves:

- Construction of foundation, drainage, and first sections of embankment before operations
- Implementation of a quality management plan
- An EoR who ensures that design standards are being met
- Construction by the owner, contractor, or both

Ongoing construction involves:

- Construction of subsequent embankment lifts
- Continuation of a quality management plan
- An EoR to ensure that design standards are being met

- Change in personnel between initial construction and ongoing construction typically constructed by mine operators
- Verification of design assumptions against performance surveillance data

### Operations

During the operations phase, the objective is to store the tailings in a manner to minimize risks to the operations and environments during mining and long-term closure. Operations should be conducted so that they are:

- In accordance with the OMS manual
- In accordance with legal requirements
- Consistent to achieve the environmental objectives
- In alignment with the closure plan

### Closure

The main objective of mine closure should be long-term stabilization of the physical, chemical, ecological, and social condition of the TSF within a reasonable time to prevent degradation over time. Key objectives are:

- Remediation and containment after closure should not require any ongoing maintenance or expenditure other than the normal requirement for similar land use.
- The closed facility TSF should not pose an unacceptable human health and safety risk.
- The closed TSF should not pose unacceptable environmental risk.
- The TSF is to be left with appropriate and sustainable land and water use to meet the community objectives.

### Hazard/Consequence Assessment

Through the design and operations of a TSF, hazard/consequence assessments are to be completed to understand and manage risks. These assessments are to be updated when applicable over the life of the TSF. These assessments include:

- Environmental hazard assessment
- Dam break and hazard/consequence assessment
- Geotechnical and seismic assessments

## Operations, Maintenance, and Surveillance

The OMS manual is to be applied and updated over the life cycle of a TSF. The OMS should demonstrate:

- Commitment to develop, implement, review, and maintain a tailings policy
- Objectives for planning and strategic activities related to performance and risk management of tailings facilities
- That there is continual improvement of a tailings management system
- That internal controls and procedures are in place, maintained, implemented, and verified for the preparation, proper analysis, consideration, and disclosure of technical, scientific, environmental, and social information
- That effective, transparent, and appropriate levels of authority and competency are present for decision making
- That systems are in place to evaluate, recommend, and approve technical, management, environmental, social, and economic aspects related to tailings and water management
- That verifiable, clearly defined and updated critical controls and procedures are in place to manage risks

## Emergency Preparedness

EPPs are required to be developed for each site in coordination with relevant stakeholders.

EPPs should:

- Identify possible emergency situations that could occur during the initial construction; operations; and ongoing construction, closure, and postclosure phases of the life cycle of a tailings facility, and that could pose a risk to populations, infrastructure, and the environment
- Describe measures to respond to emergency situations and to prevent and mitigate on- and offsite environmental and safety impacts associated with emergency situations

## Essential Steps When Dealing with a Tailings Storage Facility

When managing a new or existing TSF, there are several steps to be considered to ensure that the TSF risks are being managed appropriately. Essential steps are presented in the following; further details are included in the planning and design section.

## Life-Cycle Assessment

A life-cycle assessment should be completed at the project conception and planning phase of a TSF. This assessment should consider project risks that can occur during the project lifetime. Best available technology should be used in the assessment. The assessment should consider the end-life

requirements—that is, final storage capacity required, long-term closure objectives, and postclosure land use. Based on the end-life requirements, alternatives should be identified and a screening level assessment should be conducted to determine feasibility and risks of each alternative. Considerations during the assessment include TSF needs, location information, infrastructure, hazards, consequences, environmental and social consideration, closure, and economics.

### **Downstream Hazard/Consequence Assessment**

After the screening level assessment is complete, a detailed assessment is required. The detailed assessment needs to consider the hazards/consequences that would occur downstream if the TSF were to fail. The hazard/consequence assessment is similar to that for water dams and assesses the loss of life, damage to the environment, and economic consequences in case of TSFs failures.

### **Detailed Design Monitoring and Surveillance**

Detailed design of TSFs is an ongoing process through the life of tailings facilities. Detailed engineering design needs to be completed with performance objectives, applicable guidelines, regulatory requirements, and closure in mind.

Detailed design is not only completed for initial construction but also needs to be continued over the life of the TSF. The design needs to continually be verified, updated, and assessed to ensure that the TSF meets performance objectives, guidelines, and regulatory requirements. Monitoring and surveillance data will provide data and fill potential information gaps regarding the performance of the TSF. The monitoring and surveillance data need to be assessed and incorporated into engineering design and assessment over the TSF life cycle.

### **Emergency Preparedness**

TSFs need to be designed, constructed, and operated with emergency preparedness in mind to reduce life loss if an incident or failure were to occur. An EPP is a tool to reduce the risk of life loss and to document the owner's responsibility for sustainable development. EPPs should be established for each phase of the TSF life cycle.

## Annex A: Guidelines and References

ANCOLD. 2012. *Guidelines on Tailings Dams Planning, Design, Construction, Operation, and Closure*. Hobart, Australia: ANCOLD.

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World Mine Tailings Failure. <https://worldminetailingsfailures.org/>

In addition to the ANCOLD, ICMM, ICOLD, ISO, MAC, PRI, UNEP, and UNECE which have produced the above and other useful references, there are other International organizations, regulators, and industries which have also developed qualitative technical guidance documents to aid in the design, construction, and operation of TSFs including but are not limited to:

- Australian Government, Department of Industry, Science, Energy, and Resources: Leading Practice Sustainable Development Program for the Mining Industry
- Canadian Dam Association
- Canadian Government, Environment and Climate Change Canada
- European Union, Directive and Best Available Techniques Reference Document
- International Cyanide Management Institute (ICMI): International Cyanide Management Code For the Manufacture, Transport, and Use of Cyanide In the Production of Gold
- South African Government, South Africa National Standards (SANS) 10286 1998
- United States Federal Emergency Management Agency
- Victoria State Government, Department of Jobs, Precincts and Regions (Earth Resources Section)
- Western Australia Government, Department of Mines and Petroleum

## Annex B: A Case History of TSF Failures: Córrego do Feijão, Brumadinho, Brazil

On January 25, 2019, Córrego do Feijão Tailings Dam No. 1, located near the town of Brumadinho, suddenly failed. The TSF failure caused a release of hazardous tailings, which immediately flooded the mining office and then flowed downstream to inundate the town of Brumadinho. The collapse of the TSF resulted in 177 deaths and 133 people missing.

### Overview of Failure

The sudden collapse of the TSF was captured on video: <https://www.youtube.com/watch?v=sKZUZ-Qytads>. The video shows a drill rig on the dam crest during the time of failure.

The failure released 11.7 cubic millimeters of hazardous tailings downstream. Flows reached a velocity of 120 kilometers per hour and flooded the mine office and town of Brumadinho, killing several mine employees and downstream residents. The flow reached the Paraopeba River, causing a large environmental impact and killing wildlife and vegetation.

An alarm system was installed at the dam; however, the failure happened too quickly for workers to evacuate and provide warning to the town downstream.

### No. 1 Dam

Córrego do Feijão Dam No. 1 is a TSF designed and constructed to store iron sinter tailings from the Córrego do Feijão mine. Map B.1 shows the location of the TSF in Brazil near the town of Brumadinho.

Mining production at Córrego do Feijão for iron ore commenced in 1963. Dam No. 1 was designed in 1975 and construction began in 1976. It is unknown where waste rock and tailings were deposited during this period. Dam No. 1 is the only TSF available for Córrego do Feijão.

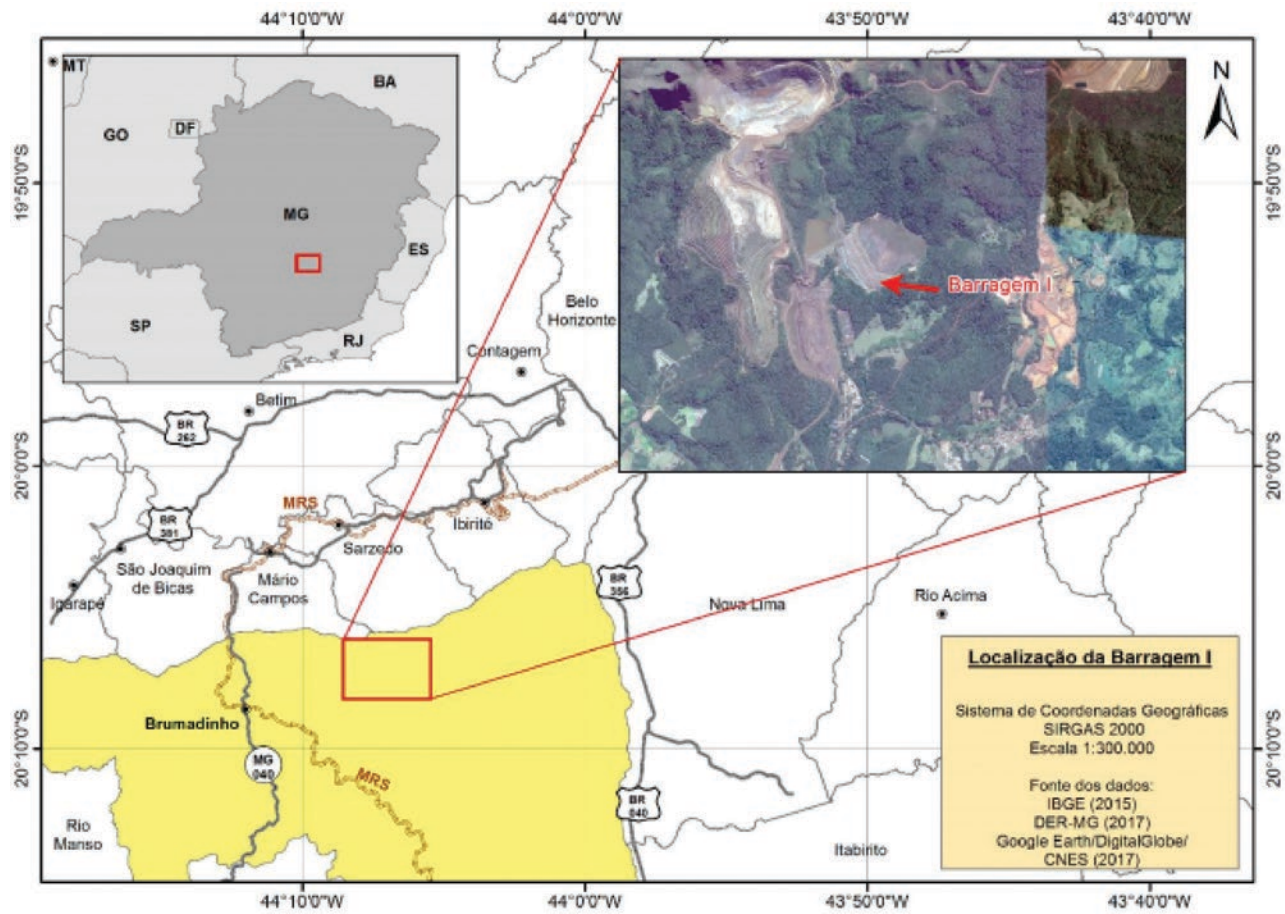
Table B.1 summarizes construction history of the TSF. Figure B.1 shows a cross-section of the embankment.

The initial dyke was constructed as an 18 meter-high homogenous embankment with a crest elevation at 874 meters above sea level (masl). The embankment had an upstream slope of 1V:1.5H and a downstream slope of 1V:1.75H with a five-meter-wide berm at an elevation of 864 masl. The embankment fill material was “ultra-fine ore” with a four-meter-thick laterite layer on the upstream slope and one-meter-thick laterite layer on the downstream slope. The initial dyke was designed by Christoph ERB. There is no record that an embankment drainage collection system was provided for the initial dyke.

The TSF was raised using upstream construction. The riser embankments varied in height and were constructed of compacted mine waste, silt, and clay. A second designer, TECNOSAN, was in place for the riser embankments (figure B.1).

There is no evidence of a drainage system installed on lifts 1 to 4. During the raise of the fourth lift, the factor of safety (FS) against stability was found to be less than 1.3 (the current standard of practice). At this point in construction, the dam axis was moved upstream, creating a large berm on the toe of the embankment.

MAP B.1 Dam Location



Source: Tüv Süd 2017.

TABLE B.1. Dam Construction History

Lift number	Year	Crest elevation (masl)	Dam height (m)
1	1976	874	18
2	1982	877	21
3	1983	879	23
4	1984	884	28
5	1986	889	33
6	1990	891.5	35.5
7	1991	895	39
8	1993	899	43

continued

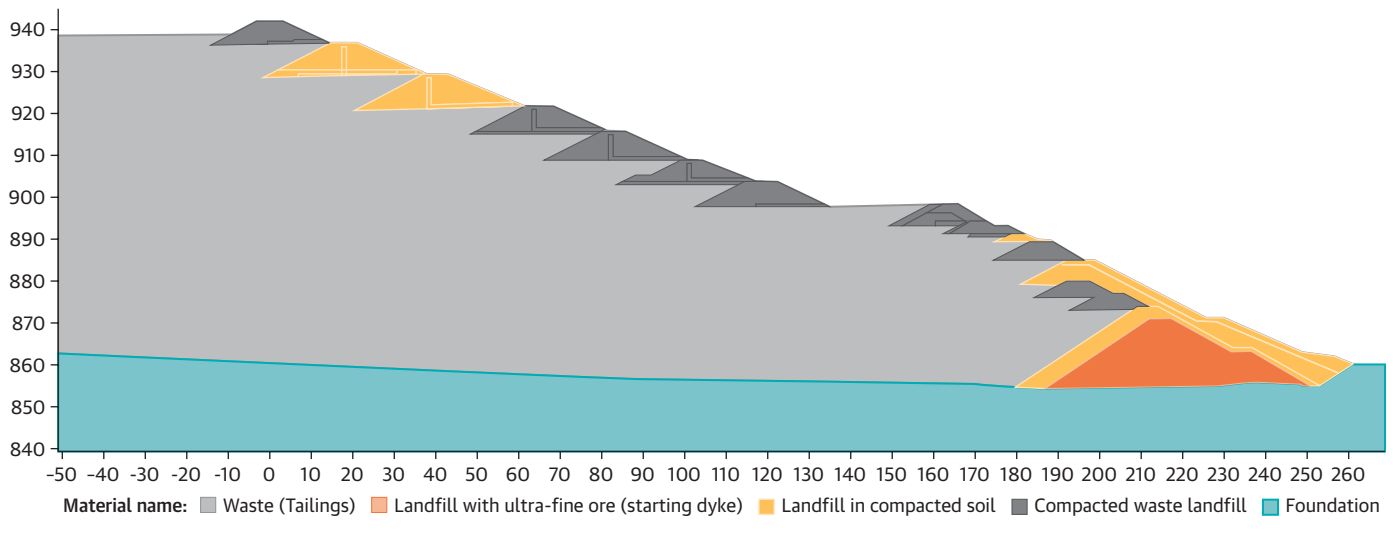


**TABLE B.1. continued**

Lift number	Year	Crest elevation (masl)	Dam height (m)
9	1995	905	49
10	1998	910	54
11	2000	916.5	60.5
12	2003	922.5	66.5
13	2004	929.5	73.5
14	2008	937	81
15	2013	942	86
Closure	2016	No longer receiving tailings	

Note: m = meters; masl = meters above sea level.

**FIGURE B.1. Dam No. 1 Cross Section through Section 4-4**



Source: Tüv Süd 2017.

The dykes above an elevation of 889 masl were also constructed with vertical and horizontal filters using the iron sinter feed (fine to medium-sized sand particles). The upstream and downstream slopes were changed to 1V:2.H and 1V:2.5H, respectively.

It is unknown why the height of the riser embankments varied, but the historical documents refer to “surges.” These surges may have motivated the raising of the embankment to a lower height and at a slower pace. The independent reviewer, Tüv Süd, noted that the second designer failed to account for the lack of bottom drain and this was a prudent dam safety measure not incorporated in the TSF design and construction. In 2016, the TSF stopped receiving tailings.

The original TSF was designed to have a total height of 87 meters and storage capacity of 12 cubic millimeters. The TSF had a total height of 86 meters and stored 11.7 cubic millimeters of tailings at the time of failure.

### Monitoring

Dam No. 1 had a surveillance program in place to monitor dam performance. The surveillance program included instrumentation monitoring, visual inspection, and maintenance activities.

Instrumentation installed at Dam No. 1 included:

- 93 piezometers
- 37 water level indicators
- 7 surface markers
- 53 flow-measuring points on drains
- 1 flowmeter
- 2 inclinometers
- 1 rain gauge

Instrumentation readings were taken monthly and visual inspections were conducted every two weeks.

Tüv Süd, the independent reviewer, performed the 2017 Dam Safety Periodic Review of Dam Safety (RPSB). The organization noted considerable flows from subhorizontal drains and several anomalies associated with cracks, water ponding within channels causing partially saturated slope section, and shoring of a downstream slope at 895 masl where there was a previous slip.

### Stability

Brazil has technical standards for dam safety and the stability of tailings dams. The most recent technical standard NBR-13028 was updated in 2017. The NBR-13028 requires a minimum long-term steady state stability FS of 1.5. This is consistent with international guidelines.

Dam No. 1 was initially designed to have a minimum stability FS of 1.3 at full height and storage capacity. This was Brazil's technical standard at the time for slope stability. The design considered the tailings to have drained strengths.

Tüv Süd performed the 2017 RPSB, which included a detailed stability assessment of the TSF. The assessment evaluated the downstream slope stability under static long-term conditions. Drained and undrained embankment strengths were considered. The stability assessment found that section 4-4, the steepest embankment section, was the most critical section regarding dam safety.

For the analysis with drained strengths, the embankment section 4-4 had a FS of 1.6, which meets NBR-13028 minimum FS of 1.5.

For the analysis with undrained strengths, the embankment section 4-4 had a FS of 1.09. The undrained strengths applied were to represent liquefied (static) conditions for the tailings. However, the applied strengths were peak rather than residual, which should be applied to understand the embankment stability following the occurrence of liquefaction. The Brazilian Dam Safety Standard does not call for a minimum FS for stability with static liquefaction.

Static liquefaction is an identified issue in tailings embankments. ICOLD 2011 states:

*If a loose and saturated tailings mass is formed as part of an upstream tailings dam or as the foundation of the dam structure, the tailings may liquefy... In several observed cases of liquefaction, there is a “trigger” effect like a blasting vibration, or from equipment passing, causing vibration, or any other load change that induces the on-set of the process of liquefaction.*

The 2017 RPSB evaluated and determined that only up to 2.6 percent of saturated tailings were susceptible to static liquefaction. This determination was based on whether the material was loose (low density) and exhibited contractive behavior (that is, collapse). The assessment used cone penetration test (CPT<sub>u</sub>) data. Tüv Süd acknowledged uncertainties (errors) in the interpreted parameters from the CPT<sub>u</sub> data.

The assessment of the TSF embankment performance was based on the drained analysis with a FS of 1.6. Results of the stability analyses using undrained strengths were considered to represent a very unlikely scenario associated with static liquefaction, which required a trigger. What was missed is that the majority of tailings were likely undrained and these results were representative of the TSF actual conditions without liquefaction.

The 2017 RPSB highlighted limitations of the stability analysis methods and the need for more-detailed analysis along with better characterization of the geotechnical parameters and water conditions within the tailings. The RPSB recommended completing a geotechnical investigation to install new piezometers, perform additional in situ testing, and obtain samples.

Tüv Süd recommended the adoption of measures that reduce the likelihood of static liquefaction triggering, including avoid inducing vibrations, prohibit blasting nearby, and avoid traffic of heavy equipment at the dam. In regard to other work for dewatering, the organization expressed that the operations are delicate and the drilling works pose risk to the tailings stability. It is noted the video of failure shows that a drill rig was present at the dam during failure. Further investigations are needed to determine the exact cause(s) of failure.

### **Contributions to Failure**

Dam failures are not typically a sudden event based merely on one factor, event, or error. Failures are often a result of a chain of events that begin as early as construction. As part of a dam safety program, an owner is required to continually assess and monitor the condition of structure. This section highlights

some of the potential contributing factors to the Dam No. 1 failure. These contributing factors are summarized from “Corrego Do Feijao Tailings Failure” (Bowker 2019).

Changes to the following components during the design and early life of the TSF would have likely affected the long-term performance:

- Selected construction method
- Tailing properties
- Embankment slopes
- Drainage system
- Remedial repairs
- Operations versus design

#### **Selected Construction Method**

The TSF was designed to be constructed using the upstream method. Upstream construction is the most economical construction method; however, it has greater design challenges and can be more delicate. Upstream construction requires greater detail in the drainage collection system and understanding of the tailings properties as they relate to the TSF stability. Operations are more critical in how tailings are deposited and maintaining a proper water balance. These challenges were not adequately acknowledged in the design and operations, as highlighted in the following factors.

Original construction documents for the TSF were unavailable; lack of these documents also contributed to the poor understanding of the structure.

#### **Tailings Properties**

The tailings deposits at Córrego do Feijão are sinter fines. During design of the TSF, the sinter fines were described as “easy draining.” Grain size testing in 2010 indicated that the fines content in the sinter tailings was greater than specified in the original design. Sinter fines are known to be subject to rapid absorption and slow discharge. Low permeable materials are not suitable for an upstream construction because they may build up pore pressures if continuously loaded with poor drainage. High pore pressures result in lower strengths and possible slope failure.

Also, the original specification was for materials with less than 60 percent sand. Best practice for upstream construction is for more than 60 percent sand to provide a more free-draining stable material.

#### **Embankment Slopes**

The original upstream design slopes were at 1.5H:1V, steeper than current recommended slopes of 3H:1V. The steeper slopes are less stable and put more reliance on the stored tailings for global stability of the TSF.

## Drainage System

The TSF did not include a proper drainage collection system to convey water from the stored tailings away so they can consolidate. Consolidation is a process in which water seeps out of the tailings to make them harder (stiffer) and stronger, making them more stable. Particular aspects missing in the TSF drainage system are:

- There were no drainage collection pipelines along the invert of the storage area, typically constructed with the initial dyke.
- No subsequent drainage collection pipes were installed within the stored tailings up to an elevation of 889 masl. These pipelines are provided at intermediate levels to provide a shorter drain pathway and ensure that the tailings consolidate.
- Embankments up to 889 masl did not include filter and drainage zones to protect against internal erosion and buildup of pore pressures. This is a conventional defensive design measure of water storage dams.

## Remedial Repairs

Dam No. 1 was the only TSF for the mine, which meant it was needed for disposing the tailings to maintain mine operations. Historically, avoiding interruptions to mining production and stopping operations of depositing tailings have been contributors to TSF failures.

## Operations versus Design

Operations of continuous deposition of tailings alone is typically not a problem. Problems and failures occur when pore pressures conditions within the tailings are not properly understood. The following outlines potential detrimental effects of such operations:

1. As new tailings are deposited, this applies a load to the underlying tailings.
2. The condition of the underlying tailings depends on drainage provided, the rate at which tailings are placed, how they are deposited (beach formation), and the water balance.
3. If there is insufficient drainage or time, the tailings are likely not consolidated, meaning they are in a similar state as when they were deposited, loose/soft, and of low strength.
4. The placement of additional tailings on top results in the buildup of pore pressures within the underlying low strength tailings.
5. Increased pore pressures result in lower strengths (undrained) and a greater chance of static liquefaction or slope failure to occur.
6. Static liquefaction results in minimal (referred to as *residual*) strengths for sudden large slope displacements.

Results of the stability analysis using drained strength did not reflect the actual long-term undrained condition of the tailings, at least in the lower tailings below 884 masl and within perched conditions.

Best practice now is to complete stability analysis for drained and undrained strengths and design for the lowest FS computed to assess the TSF performance.

### Lessons Learned

It is important to determine the cause(s) and learn from tragic failures like Córrego do Feijão Dam No. 1 TSF to prevent future failures. The cause of the failure is still under investigation, but there are several lessons identified from this event. As more information becomes available, owners are encouraged to bring these lessons learned into their management of existing and future TSFs.

Federal regulations are a minimum standard of safety for a TSF. Designing and operating TSFs to the minimum federal regulations does not necessarily mean the TSF is safe from failure. Dam safety should always be the highest priority when it comes to the design, construction, operation, maintenance, and closure of a TSF.

- Over the life of a TSF, the dam should continually be reassessed and remediated as necessary to meet current industry regulations and standards.
- The original design criterion with a minimum FS of 1.3 for stability did not meet current standard of practice.
- Dam No. 1 failed during its closure period, at a height and storage near the original design intent.
- The assessment of a TSF design and performance should be based on the lowest FS obtained from analysis using drained and undrained strengths. Recent reviews discounted the results analyses using undrained strengths as conservative. This determination was without fully accounting for uncertainties highlighted by their review, especially with potential perched conditions.
- Upstream construction has inherent risks that need to be managed throughout the TSF life cycle (that is, design, construction, monitoring, maintenance, operations, and closure).
- Deposition of the tailings was not consistent, described as “erratic,” over time and construction on the riser embankments. This inconsistency resulted in the beach having lenses of low permeable material. This is not consistent with the design intent.
- A proper drainage collection system is a critical component of TSFs to ensure that the tailings may consolidate and gain strength for long-term stability.
- A strong understanding of the tailings material properties is crucial for proper design and management of a TSF.
- Construction of the TSF was poorly documented for the lower portion of the TSF, lifts 1 to 6 (1990).

- There were two designers and many different contractors were used to construct the riser embankments. The contractor was identified as unknown For lifts 3 and 5.
- We are continually learning more about static liquefaction phenomena and failure mechanisms of dams and tailings facilities. Structures need to evolve with these standards. Historical design considerations should not be “grandfathered” as acceptable.
- Static liquefaction is an area of current research for TSFs. The proper assessment of static liquefaction and understanding its risks is critical for evaluating a TSF performance.

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