ADVANCES IN ENSURING TAILINGS DAM SAFETY

Duncan Grant-Stuart[1],
Knight Piésold (Pty) Limited (South Africa)

PRESENTER: DUNCAN GRANT-STUART

ABSTRACT

Recent widely publicised and catastrophic tailings dam failures resulted in a request to 684 Mining Houses by the Church of England Pension Fund for full disclosure of the status of their Tailings Dams (or tailings storage facilities – TSF's). The Church of England Letter, as it has come to be known, prompted the International Council on Mining and Metals (ICMM) to publish the Global Industry Standard on Tailings Management (GISTM) in August 2020. The GISTM provides a framework for safe management of Tailings Dams while allowing operators flexibility in how to achieve this goal. The ICOLD Sub-Committee L (Tailings Dams and Waste Lagoons) has prepared a new Bulletin which will be submitted to the ICOLD Central Committee in November 2021 to provide Technical Guidelines in support of the GISTM's Management Principles.

1. INTRODUCTION

To a large extent tailings dams were unregulated throughout the first half of the 20th century, and inevitably the early methods of tailings dam construction led to failures with varying degrees of consequence. The introduction of legislation relating to tailings dams has primarily been driven by the occurrence of failures of these facilities. Records of tailings dam failures prior to the 1960's are sparse, but the Aberfan coal fines dump tragedy in Wales in 1966 focussed the world's attention on the safety of mine residue deposits and tailings dams. Southern Africa has had its share of tailings dam disasters, with the worst being listed below:

1970: Mufulira in Zambia, where an inrush of tailings into underground workings resulted in 89 fatalities

1974: Bafokeng Mine in the North-West Province of South Africa, where a failure of the tailings dam caused a 40km mud flow which engulfed a shaft resulting in 12 fatalities underground.

1978: Arcturus in Zimbabwe, where overtopping after heavy rain resulted in one fatality and extensive environmental damage

1993: Saaiplaas, in the Free State province of South Africa, where a failure resulted in the release of 140 000 m^3 of tailings

1994: Merriespruit, also in the Free State province of South Africa, where a failure following heavy rain resulted in 17 fatalities

Each failure of a tailings dam, and the emergence of previously unforeseen or ignored environmental impacts from tailings dams in general, has resulted in the strengthening of legislation regulating the siting, design, construction, operation, management and closure of tailings dams.

In 1978 the Chamber of Mines' "Guideline for Environmental Protection – The Design, Operation and Closure of Metalliferous and Coal Residue Deposits" was published and provided the first structured guideline for the design and operation of tailings dams in Southern Africa. It was subsequently updated in 1983 and again in 1996.

In 1998 The South African Bureau of Standards published SABS 0286 (now SANS 10286) "Code of Practice: Mine Residue". This document, although not legally binding or prescriptive, provides guidelines for the siting, design, construction, operation, management, surveillance and closure of tailings dams in Southern Africa.

With effect from 2001 the South African Department of Mineral Resources (DMR) requires the owner of a mine residue deposit to have a Mandatory Code of Practice for the facility. The Code of Practice documents areas of responsibility for any mine residue deposit and by law must be updated on a continual basis.

Today tailings dams in South Africa are required to be constructed and operated in accordance with several different Acts of Legislation, some of which may at times appear to be contradictory. There is no single Statute, Act or Regulation in South Africa dealing specifically with the construction, operation and decommissioning of Mine Residue facilities.

Recent amendments to the Water Act (Act 36 of 1998) and the National Environmental Management Act (Act 107 of 1998) have placed increased onus on the owners, operators and designers of tailings dams to prevent environmental degradation and ensure the safety of persons and property in their proximity.

Perhaps the legislation most pertinent to Tailings Dams is Government Notice R704 of the National Water Act dated June 1999 (commonly referred to as GN 704) which, inter alia, requires that a mine must:-

- Ensure that contaminated water must be kept separate from clean water and must not be allowed to spill into a clean water system more than once every fifty years
- Operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level
- Prevent water containing any substance which is likely to cause pollution of a water resource from entering any water resource
- Ensure that water used in any process at a mine or activity is recycled as far as practicable

2. GLOBAL INDUSTRY STANDARD ON TAILINGS MANAGEMENT

In August 2020 the International Council on Mining and Metals (ICMM) published the Global Industry Standard on Tailings Management (GISTM) which is based on the following 15 Principles:

1. Respect the rights of Project-Affected people and meaningfully engage them in all phases of the tailings facility lifecycle, including closure
2. Develop and maintain an interdisciplinary knowledge base to support safe tailings management throughout the tailings facility lifecycle, including closure
3. Use all elements of the knowledge base – social, environmental, local, economic and technical to inform decisions throughout the tailings facility lifecycle, including closure
4. Develop plans and design criteria for the tailings facility to minimise risk for all phases of it’s lifecycle, including closure and post closure
5. Develop a robust design that integrates the knowledge base and minimises the risk of failure to people and the environment for all phases of the tailings facility lifecycle, including closure and post closure
6. Plan, build and operate the tailings facility to manage risk at all phases of the tailings facility lifecycle, including closure and post closure
7. Design, implement and operate monitoring systems to manage risk at all phases of the tailings facility lifecycle, including closure
8. Establish policies, systems and accountabilities to support the safety and integrity of the tailings facility
9. Appoint and empower an Engineer of Record
10. Establish and implement levels of review as part of a strong quality and risk management system for at all phases of the tailings facility lifecycle, including closure
11. Develop an organisational culture that promotes learning, communication and early problem recognition
12. Establish a process for reporting and addressing concerns and implement whistleblower protections
13. Prepare for emergency response to tailings facility failures

14. Prepare for long term recovery in the event of catastrophic failure
15. Publicly disclose and provide access to information about the tailings facility to support public accountability

2.1 Consequence Classification

The GISTM provides for categorisation of Tailings Facilities into 5 levels, based on the consequence of failure of the facility. The categories are:

- Low,
- Significant,
- High,
- Very high, and
- Extreme.

The consequence category is derived from the number of people potentially at risk, the potential loss of life, impact on environment, disruption to health, social and cultural aspects as well as infrastructure and economic loss. Establishment of the consequence classification requires a Dam Breach Analysis (DBA) to determine the inundation area, flow arrival times, duration of flooding and depth of flow. The DBA does not take account of probability of failure and is based on credible failure modes, which may vary during the life of a tailings facility. The Consequence Classification is used to determine design criteria for the facility.

3. ICOLD BULLETIN ON TAILINGS DAM SAFETY

The ICOLD Bulletin has been prepared to document technical practices recommended for the planning, design, construction, operation and closure of tailings dams, with the overarching goal of promoting the safety of these structures. It draws on existing ICOLD Bulletins and internationally accepted guidelines such as ANCOLD (2019), CDA and MAC to support the GISTM (2020) and provide technical guidance for tailings dam safety.

It is recognized that many countries have National guidelines and standards in place regulating tailings and mine waste storage facilities which may differ from the proposals outlined in this Bulletin. The intention of the ICOLD bulletin is not to contradict existing standards but to provide a benchmark against which counties may evaluate their standards and assist in the development of a common international approach to ensuring the safety of tailings dams in the future.

3.1 Dam Failure Assessment

A dam failure analysis should be undertaken to provide an indication of how the dam could fail and whether the consequences of such a failure could be large scale (catastrophic) or not. This is an important consideration for dam classification, emergency planning, and for determining the level of dam breach analysis that should be undertaken.

3.2 Dam Breach Analysis

The purpose of a dam breach analysis (DBA) is to determine the potential consequences of a breach of the dam. If the failure analysis indicates that there would be limited runout then simplified methods for the dam breach analysis may be appropriate. Conversely, if the dam failure analysis indicates that catastrophic consequences could occur, then a detailed dam breach analysis is required.

The outflow of tailings from a breach in a tailings dam is controlled by the viscosity and mobility of the tailings, and the volume of water on the dam. Tailings deposits are frequently loose and saturated and therefore susceptible to static and dynamic liquefaction, which if not constrained may flow. Tailings may also contain potentially toxic constituents and the environmental effects of tailings outflows can be expected to be considerably higher than for water dams.

The delineation of the inundation zone following a dam breach enables the Consequence Classification of a tailings dam to be determined.

3.3 Consequence Classification

The Consequence classification given in the ICOLD Bulletin replicates that of the GISTM, with some minor grammatical changes to clarify areas where interpretations may differ. The Consequence Classification is shown in Table 3-1 below.

Table 3-1. Consequence Category

Dam Failure Consequence Classification	Incremental Losses				
	Population at Risk[1]	Potential Loss of Life[2]	Environment[3,4]	Health, Social & Cultural	Infrastructure and Economics [5]
Low	none	none	Minimal short-term loss of environmental values. No expected impact on livestock / fauna drinking water. Limited area of impact and restoration feasible in short term.	Minimal effects and disruption of business and livelihood. No measurable effects on human health. No disruption of heritage, recreation, community or cultural assets	Low economic losses: area contains limited infrastructure or services - <US$1M.
Significant	1-10	none	Limited loss or deterioration of environmental values. Potential contamination of livestock/fauna water supply. Potential area of impact < 5 km2. Restoration possible in < 5 years.	Limited effects and disruption of business and livelihood (up to 500 people affected). No measurable effects on human health. Limited loss of regional heritage, recreation, community, or cultural assets.	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes. - <US$10M
High	10-100	1 - 10	Significant loss or deterioration of critical environmental values. Potential contamination of livestock/fauna water supply. Potential area of impact 5 km^2 – 20 km^2. Restoration possible but difficult and could take > 5 years	500 - 1,000 people affected by disruption of business, services, or social dislocation. Significant loss of regional heritage, recreation, community, or cultural assets. Potential for Some short-term human health effects.	High economic losses affecting infrastructure public transportation, and commercial facilities, or employment. Moderate relocation / compensation to communities. <US$100M
Very High	100-1000	10 to 100	Major loss or deterioration of critical environmental values including rare and endangered species of high significance. Potential area of impact >20 km^2. Restoration or compensation possible but very difficult and requires a long time (5 years to 20 years).	> 1,000 people affected by disruption of business, services, or social dislocation for more than one year. Significant loss of national heritage, recreation, or community facilities or cultural assets. Significant long-term human health effects.	Very high economic losses affecting important infrastructure or services (e.g. highway, industrial facilities, storage facilities for dangerous substances), or employment. High relocation/compensation to communities. <US$1B
Extreme	> 1000	> 100	Catastrophic loss of critical environmental values including rare and endangered species of high significance. - Potential area of impact > 20 km^2. Restoration or compensation in kind impossible or requires a very long time (>20 years).	> 5,000 people affected by disruption of business, services, or social dislocation for years. Significant National heritage or community facilities or cultural assets destroyed. Potential for Severe and/or long-term human health effects	Extreme economic losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances or employment. Very high relocation /compensation to

Dam Failure Consequence Classification	Incremental Losses				
	Population at Risk[1]	Potential Loss of Life[2]	Environment[3,4]	Health, Social & Cultural	Infrastructure and Economics [5]
					communities and very high social readjustment costs. > US$1B

3.4 Use of Consequence Category to Determine Design Criteria

Error! Reference source not found.3-2 provides the suggested flood and seismic criteria corresponding to the failure consequence classification described in Table 3-1. These criteria are recommended for use during the operating and active care periods of a tailings facility.

Table 3-2. Flood and Seismic Design Criteria

Consequence Classification	Flood Criteria	Seismic Criteria
	Annual Exceedance Probability for Operations and Active Care Closure	
Low	1/200	1/200
Significant	1/1,000	1/1000
High	1/3rd between 1/1,000 and PMF	1/2475
Very High	2/3rd between 1/1,000 and PMF	1/5000 or 50th percentile MCE
Extreme	PMF	1/10000 or 84th percentile MCE

Since most tailings dams are likely to become permanent landforms that will remain in perpetuity, higher stability criteria are recommended for the passive care closure phase. This normally equates to the PMF and MCE for flood and seismic loading respectively.

3.5 Slope Stability Assessment

Slope stability assessments are key to the safety evaluation of tailings dams and are commonly based on Factors of Safety calculated by limit-equilibrium analyses. Alternatively, advanced numerical models (finite element analyses) may also be used. Target factors of safety for limit-equilibrium stability analyses for two critical loading conditions, namely long-term static conditions and post-peak (strain softened) conditions are:

Long-term static: 1.5
Post-peak: 1.1

Higher factor of safety targets could be adopted for a project to account for the following considerations:

- Closure conditions
- High degree of uncertainty in material properties or pore pressure conditions
- Concerns over excessive deformations associated with sensitive/strain-weakening soils
- Complex geological conditions that are difficult to fully define for design
- Potential for changes to soil properties or loading conditions with time
- To address uncertainty

3.6 Risk Management

Risk is defined as the combination of the likelihood and consequences of identified hazards. Risk assessment is a fundamental process to assist in safe tailings dam management from early stages of planning throughout life cycle. The use of structured risk evaluation process, such as Failure Mode and Effects Analysis (FMEA) to identify potential risks leading to failure is an important step in early planning for a tailings dam and can be used to guide the design process and the construction and operating phases.

The tolerable levels of risk considering the consequences of failure should be part of the design basis and a risk management plan should be prepared at the planning phase and be updated regularly.

The plan should:

- Eliminate or avoid risk to the extent practicable
- Minimize the likelihood of an unwanted event
- Respond to and minimize the consequences of an unwanted event

3.7 Management of Change

The construction period for a tailings dam is the full service life of the facility, and may extend over a period of several decades. During this period there are likely to changes in personnel, ownership, operator, material properties, deposition (construction) method and, perhaps most importantly, legislation regarding handling of tailings. A change management system that includes evaluation, review approval and documentation of all changes should be included and implemented in the Tailings Management System.

3.8 Closure

Closure of a TSF (ICOLD, 2013) is defined as "*the planned final cessation of tailings disposal and the modification/engineering of the tailings dam with the objective of achieving long-term physical, chemical, ecological and social stability and a sustainable, environmentally appropriate after-use"*.

Closure design is required in the early stages of assessment and initial project planning of a tailings dam and must consider all alternatives which may impact on sustainable closure. It should include input from a broad spectrum of specialists covering all aspects of mining operations including surface and groundwater hydrologists, geochemists, biologists, social planners, community relations planners, etc. Sustainable closure design considerations include geotechnical, geochemical, physical, hydraulic, ecological and social stability.

Successful closure is often more difficult to achieve at the end of a facility's life when pre-existing conditions may limit the options and financial resources that could have been available. Planning for closure from the very start of mine concept development will result in reduced risk throughout the life cycle (ICMM, 2008).

Progress from cessation of mining to final closure can occur over a broad time period. The various stages include:

- Closure works such as removal of infrastructure, landscaping and vegetating,
- Active care comprising monitoring and maintenance, and
- Passive care when maintenance requirements are reduced to a level consistent with the designated long-term land use and when ownership of the site may be transferred.

3.9 Site Characterisation

The objective of site characterization is to identify and mitigate conditions that impact and/or would be impacted by the TSF.

The characterization activities are iterative, with continual improvement of the site understanding as the project develops from planning through to closure. The site characterization covers a wide range of aspects including the following conditions:

- Social and Environmental setting
- Physiography
- Climate and Hydrology

- Geological and geotechnical conditions
- Hydrogeology
- Seismicity

A comprehensive site characterization requires a broad mix of professionals similar to those required for closure design.

3.10 Tailings Characterisation

The physical characteristics of tailings can have a significant impact on the performance and structural integrity of a tailings dam. Therefore parameters such as particle size distribution, permeability, consolidation characteristics and shear strength need to be understood to predict and manage performance of the facility over its life. The rheology of a tailings slurry must also be characterized to design the transport systems.

ICOLD Bulletin 181 (ICOLD, 2020) has classified tailings into five broad types depending on their physical properties, primarily particle size and plasticity. This classification system provides a useful framework for predicting generalised behaviour of tailings during the early design process such as initial settled density, beach slopes, hydraulic conductivity, coefficient of consolidation, void ratio etc. These parameters can be used for initial planning activities such as preliminary sizing of facilities, identification of potential challenges, risk assessments, but they do not take the place of a full characterization of tailings properties based on site-specific data.

Geochemical characterization of tailings is required to determine the potential for acid rock drainage (ARD) (also known as acid and metalliferous drainage (AMD)) and metal leaching. These are naturally occurring processes that can be accelerated in mine wastes due to the increased total surface area exposed to oxidation. Acid generation occurs when minerals containing sulphide and elemental sulphur are exposed to the weathering effects of oxygen and water. Metal leaching is associated with acidic drainage due to high metal solubility under acidic conditions.

3.11 Laboratory and In-Situ Testing

Hydraulically deposited tailings will naturally exhibit some degree of segregation, which presents challenges in obtaining undisturbed samples for laboratory testing that are representative of in-situ conditions. Cone penetration testing with pore pressure measurements (Piezocone or CPTu) and shear vane tests and Standard Penetration testing (SPT's) are recognised as the most reliable means available to characterise in-situ behaviour.

Using both in-situ and laboratory testing to estimate in-situ parameters provides a balanced methodology whereby tailings parameters can be estimated.

4. EMERGENCY PREPAREDNESS AND RESPONSE PLANNING

An emergency at a tailings dam is any event or situation that could compromise dam safety, the safety of individuals in the vicinity or the ability of the facility to fulfil the function for which it was intended. Frequently, an emergency is the result of a combination of circumstances that require active intervention by operators, management and external resources. Emergencies could be initiated either by natural causes beyond the control of the operator or by operational non-conformances.

Depending on the severity of the event and risk associated with it, reporting and intervention will need to be escalated to the appropriate level. This escalation should be linked to and guided by a Trigger Action Response Plan (TARP).

Levels of severity of an incident on a tailings dam can be prioritized into various risk categories. A typical risk level framework is:

Alert Level 1: When active intervention is potentially required the Emergency Response team are notified. It is not yet an emergency situation but has the potential to become one.

Alert Level 2: An imminent emergency is occurring that could lead to failure of the dam. Active intervention and external notification are likely required. Emergency mitigative measures are implemented.

Alert Level 3: A failure is either occurring or has occurred. Full emergency response and crisis management actions are implemented.

5. OPERATION, MAINTENANCE AND SURVEILLANCE MANUAL

An Operation, Maintenance and Surveillance (OMS) Manual should be completed prior to commissioning of a tailings dam and updated throughout it's life. The OMS Manual should specifically highlight all requirements for operation and response actions that must be met to ensure the ongoing safety of the dam.

The Operation Plan should include, as a minimum:

- Description of the TSF, expected nature of the tailings, production rate, life of mine plan, dam type, dam raising schedule, etc.
- Roles and responsibilities of key personnel and organization chart
- Dam consequence classification and key design criteria (geotechnical, water management, environment)
- Deposition plan: spigot discharge locations, beach management, etc.
- Water management: requirements for managing diversions, pond size/location, reclaim and discharges, freeboard management, decant systems, pump barges, etc.
- Environmental controls: eg. seepage collection, water discharges, dust control, etc.
- Surveillance requirements for dam inspections
- Risk assessment register
- Summary of preventative controls
- List of Critical Controls and trigger action response plans
- Maintenance requirements for pumps, pipelines, channels, etc.
- Training requirements for key staff
- Summary of the emergency preparedness and response plan (EPRP) and links to the document.
- Document management plan

The OMS Manual should specify the minimum level of operator training and should typically be updated every two years as a minimum to remain current.

6. CONCLUSION

The implementation of the GISTM and new ICOLD guidelines will impact on the management and operation of many existing TSF's in Southern Africa, which to date have been designed, constructed, operated and managed according to far less stringent legislation. Compliance with the GISTM is mandatory only for the current 28 members of the ICMM, however financial institutions and insurers are likely to look increasingly toward the standard of management of tailings storage facilities when assessing dealings with mining houses.

The new ICOLD Bulletin will provide technical guidelines to assist in the development of a common international approach to ensuring the safety of tailings dams in the future.

7. REFERENCES

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