TAILINGS HISTORY:
2016 & 2017

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Robertson Geoconsultants

Tailings and Mine Waste 2017
Overview

• The Failures
  • Luoyang, China
  • Mishor Rotem, Israel
  • Mulberry, Florida
  • Tonglvshan copper mine, China

• The Successes
  • ICMM Guidelines
  • BC Regulatory Update
  • APEGBC Foundation Guidelines
  • NRC Research Program
  • Unesco Statement
  • MEND Report
Luoyang, China
Aluminum Facility
Held 2 M tonnes
1.5 km perimeter
The Failure

• 8th August 2016
• Dam “shut down” and villagers evacuated ahead of dam burst
• 2 m cubic meters of “aluminum production byproducts” released
Flow From Dam
Failure Flow
Mishor Rotem, Israel
Phosphate Factory
Side View
The Failure

• 30\textsuperscript{th} June 2017
• Overtopping or piping
• 60-m high wall collapsed
• 100,000 cubic meters acidic wastewater flowed to riverbed
• 20-km long flow path to
• Pool several kilometers from the Dead Sea.
Blog Comment

• I’m curious about the apparent erosion all along the sides of the now absent pond. Is that a result of the rapid draining, or did the erosion cause the breach? Was there enough fetch in the pond to have produced waves that ate away at the dam?
• [I agree, that is a very odd feature. I am surprised if it resulted from drawdown.]
Mulberry, Florida
Phosphate Tailings
The Failure

- 14-m wide sinkhole
- 840,000 cubic meters released
Tonglvshan copper mine, China

• “A tailings dam failure at Tonglvshan copper mine in Huangshi in China’s Hubei province resulted in two deaths in March 2017.”
THE SUCCESSES

Tailings History: 2016 & 2017
INTERNATIONAL COUNCIL ON MINING AND METALS (ICMM)

REVIEW OF TAILINGS MANAGEMENT GUIDELINES AND RECOMMENDATIONS FOR IMPROVEMENT

Submitted to:
International Council on Mining and Metals (ICMM)
35/28 Portman Square,
London W1H 6LR,
United Kingdom
ICMM Member Companies

African Rainbow Minerals: member since 2009
Anglo American: founding member
Anglo Gold Ashanti: founding member
Antofagasta Minerals: member since 2014
Areva Mines SA: member since 2011
Barrick: member since 2008

BHP Billiton: founding member
Codelco: re-joined in 2011
Freeport-McMoRan: founding member
Glencore: member since 2014
Goldcorp: member since 2009
Gold Fields: member since 2007

Hydro: member since 2011
JX Nippon: founding member
Lonmin: member since 2004
Mitsubishi Materials: member since 2002
MMG: member since 2009
Newmont: founding member

Polyus Gold: member since 2015
Rio Tinto: founding member
South32: member since 2015
Sumitomo Metal Mining Co.: member since 2002
Teck: member since 2006
Findings
Knowledge vs Implementation

• Existing guidance and standards embrace the knowledge required to prevent failures.
• The shortcoming lies in the efficacy with which that knowledge is applied.
• Therefore, focus on:
  • improved implementation
  • verification of controls.
Recommendations

Minimum Requirements

• Life of facility plan
• Operating plan
• Resource plan
• Risk Management
• Engineer of Record
• Independent review
• Corporate commitment
Findings
ICMM Member Company Documents

- Some corporate documents comprehensive and examples of good practice.
- The majority have documents that substantially follow good practice.
- A minority adopt a surrogate that partly follows good practice.
Recommendations
For ICMM Member Companies

- TSF classification system
- Change Management Process
- Formal communication between EOR and mine owners
- Risk assessment
- Independent peer review.
Path Forward
My simple summary

• ICMM company documents:
  • Most have corporate guidance documents
  • The documents vary in comprehensiveness

• Therefore all members should:
  • Adopt a tailings management framework
  • Implement assurance control to verify framework is used.
Guidance Document

Health, Safety and Reclamation Code for Mines in British Columbia

Version 1.0

Updated July 2016
Clear Responsibility

• Mine Manager
• TSF Qualified Person
  • Report to Mine Manager on Tailings Management
• Engineer of Record
  • A person, not a firm
  • May be employee of mine
• Independent Tailings Review Board
• Inspectorate
# Minimum Design Criteria

<table>
<thead>
<tr>
<th>Dam Class</th>
<th>Annual Exceedance Probability – Floods²</th>
<th>Annual Exceedance Probability - Earthquakes</th>
<th>Minimum Static Factor of Safety</th>
<th>Downstream Slope No Steeper Than</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1/3 between 1/975 and PMF</td>
<td>1/2475</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Significant</td>
<td>1/3 between 1/975 and PMF</td>
<td>1/2475</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>High</td>
<td>1/3 between 1/1000 and PMF</td>
<td>1/2475</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Very High</td>
<td>2/3 between 1/1000 and PMF</td>
<td>½ between 1/2475 and 1/10,000 or MCE</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Extreme</td>
<td>PMF</td>
<td>1/10,000 or MCE</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 3-2 Minimum Design Criteria for Tailings Dams

Note: 1) Adapted from CDA Dam Safety Guidelines, 2013. Further context and guidance provided there.

2) The Code required that a facility that stores the inflow design flood use a minimum event duration of 72 hours.
SITE CHARACTERIZATION FOR DAM FOUNDATIONS IN BC

APEGBC PROFESSIONAL PRACTICE GUIDELINES

V1.0
<table>
<thead>
<tr>
<th>Design Stage</th>
<th>General Objectives of Design Stage</th>
<th>Typical Site Characterization Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scoping level design</td>
<td>Develop options for siting and design</td>
<td>Work is primarily based on existing information and table-top evaluations, but it typically includes a site visit for general reconnaissance of site conditions and mapping. Site geologic and other public information is used to develop an initial characterization of the potential site foundation conditions.</td>
</tr>
<tr>
<td>Prefeasibility design</td>
<td>Compare options to select the preferred site and design</td>
<td>Work typically includes terrain and bedrock mapping, some site-specific intrusive investigations, lidar, test pits, and geophysics.</td>
</tr>
<tr>
<td>Feasibility design</td>
<td>Support financing and environmental assessment estimates</td>
<td>Work includes a wide range of investigation methods, including intrusive investigations, in situ testing, geophysics, and laboratory testing. Extent of site investigations is increased to the level required for the complexity of the site.</td>
</tr>
<tr>
<td>Detailed design</td>
<td>Issue for construction drawings and specifications Address permitting requirements</td>
<td>It may be necessary to conduct additional site characterization to support aspects of the detailed design.</td>
</tr>
</tbody>
</table>
Development of improved monitoring system and technical guidelines for tailings dams

Rob Hui, Lawrence Charlebois, Colin Sun
National Research Council - Energy, Mining and Environment

September, 2017
MINE TAILINGS STORAGE: SAFETY IS NO ACCIDENT
Known mining accidents the last decade

2007 - 2017

- **Very serious tailings dam failures**
  Multiple loss of life (~20) and/or release of ≥ 1,000,000 m³ total discharge, and/or travel of 20 km or more.

- **Serious tailings dam failures**
  Loss of life and/or release of ≥ 100,000 m³ semi-solid discharge.

- **Other tailings dam failures**
  Engineering/facility failures other than those classified as very serious or serious, no loss of life.

- **Other tailings-related accidents**
  Accidents other than those classified under the first three categories of dam failures.

- **Non-tailings (or unknown type) failure**
  Non-tailings incidents - groundwater, waste rock, etc.

Source: Center for Science in Public Participation, Wise Uranium Project.

An analysis of tailings dam failures indicates that while the overall number of failures has decreased, the number of serious failures has increased in the last three decades.
Recommendation 2
Establish a UN Environment stakeholder forum to facilitate international strengthening of tailings dam regulation.

- **Knowledge, technology, innovation & people**
  - Establish an accessible public-interest, global database of mine sites, tailings storage facilities and research.
  - Fund research into mine tailings storage, failures and management of active, inactive and abandoned mine sites.
  - Compile and review existing regulations and best practice guidance.
  - Encourage innovation in the reuse and recycling of mine tailings.
  - Encourage the development of technological solutions to eliminate the main causes of failures.

- **Failure prevention**
  - Expand mining regulations to include independent monitoring and the enforcement of financial and criminal sanctions for non-compliance.
  - Regularly publish disaster management plans.
  - Increase gender diversity and broaden skill sets on company boards.
  - Establish independent waste review boards to conduct and publish independent technical reviews prior to, during construction or modification, and throughout the lifespan of tailings storage facilities.
  - Avoid dam construction methods known to be high risk.
  - Ensure any project assessment or expansion publishes all externalized costs, with an independent life-of-mine sustainability cost-benefit analysis.
  - Require detailed and ongoing evaluations of potential failure modes, residual risks and perpetual management costs of tailings storage facilities.
  - Enforce mandatory financial securities for life of the mine.
  - Ban or commit to avoid riverine disposal and avoid submarine disposal unless justified by independent review.

- **Crisis response**
  - Establish a global financial assurance system for mine-sites.
  - Fund a global insurance pool.

- **Benefits**
  - Establishes a basis for improved regulation and consistent best practice.
  - Assists in educating people to make informed decisions.
  - Reduces the volume of tailings stored and potentially creates additional business opportunities.
  - The path to zero failures (IEEIRP 2015).

  - Clarifies responsibility for tailings dam performance.
  - Provides transparency on disaster planning.

  - Improves governance and corporate social responsibility.
  - Reduces risk of dam failure by providing independent expert oversight.
  - Reduces risk of failure by eliminating less stable methods of dam construction.
  - Protects the environment from less controlled waste disposal.

  - Ensures best practice in tailings management, monitoring and rehabilitation.
  - Addresses unmet liabilities from major tailings dam failures.

Note: Some of these important actions are already being undertaken or partially implemented in a number of jurisdictions. The aim is to ensure best practice is enacted at all mine sites where tailings are stored.
This work was done on behalf of the Mine Environment Neutral Drainage (MEND) Program and sponsored by: The Mining Association of Canada (MAC) and MEND

October 2017
### Table 5.2  Typical Relative Operating Cost per tonne of Tailings Storage for Different Tailings Dewatering Technologies (capital and closure costs not included)

<table>
<thead>
<tr>
<th>Dewatering Technology</th>
<th>Typical Processing &amp; Transport Cost ($/t)</th>
<th>Typical Dam &amp; Water Management Cost ($/t)</th>
<th>Typical Total ($/t)</th>
<th>Range of Cost ($/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unthickened (conventional)</td>
<td>$0.20</td>
<td>$1.00</td>
<td>$1.20</td>
<td>$0.50 to $2.50</td>
</tr>
<tr>
<td>Thickened</td>
<td>$0.30</td>
<td>$1.00</td>
<td>$1.20</td>
<td>$0.50 to $2.50</td>
</tr>
<tr>
<td>High-density thickened</td>
<td>$0.50</td>
<td>$0.90</td>
<td>$1.50</td>
<td>$0.75 to $2.50</td>
</tr>
<tr>
<td>Paste</td>
<td>$1.50</td>
<td>$0.50</td>
<td>$2.00</td>
<td>$2.00 to $8.00</td>
</tr>
<tr>
<td>Filtered</td>
<td>$5.00</td>
<td>$0.20</td>
<td>$5.20</td>
<td>$4.00 to $12.00</td>
</tr>
</tbody>
</table>

**Notes:**
1. Costs are very site- and project-specific and the costs shown are only for indicative purposes to illustrate the relative range of costs for the different dewatering technologies.
2. Tailings cost per tonne typically decreases with larger tonnage operations due to economies of scale.
3. Capital and closure costs not included.
My Conclusions

- Rate of failure not about to decrease
- Failure cannot be blamed on lack of guidelines
- Failure Root Cause often insufficient money
  - Poor orebodies
  - Insufficient budget
- Failure stems primarily from human factors:
  - Management inattention
  - Inexperienced designers
  - Unsupervised operators
  - Inept regulators.
- Technical Factors important – but we have the technology.
Perspectives on the Future

• Filter Press vs Conventional Covers vs Water Covers?
• Responsibility for Perpetual Surveillance & Maintenance?
• Who is the Responsible Engineer for Mine Closure?
• The Role of International Bodies (ICMM, UNESCO)?
• Mine Economics & Tailings Failure
• The Cost of Insurance for Tailings Failure