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6TH VICTOR DE MELLO LECTURE

GEOTECHNICAL RISK, REGULATION AND PUBLIC POLICY

to
9th Portuguese – Brazilian Geotechnical Congress

Full paper, presentation and lecture available at
http://www.victorfbdemello.com.br/en/de-mello-lectures-2/

In Memoriam

Through engineering, Victor devoted his life to the betterment of the people not only of Brazil, but also the world at large. The central theme of this Lecture is public safety. I like to think that Victor would have approved of it.

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REPORT OF THE INDEPENDENT REVIEW PANEL ON FILL SLOPES

GEO REPORT No. 86

J.L. Knill, P. Lumb, S. Mackey,
V.F.B. de Mello, N.R. Morgenstern & B.G. Richards

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

The Hong Kong Slope Safety System

- catalogue slopes
- apply suitable prescriptive design measures
- develop soil testing procedure
- check designs proposed for construction
- characterize regional soils and geology
- perform slope stabilization measures on priority slopes
- risk quantification
- issue landslide warning
- provide advanced emergency disaster services
- public education on slope safety

(Malone 1997)

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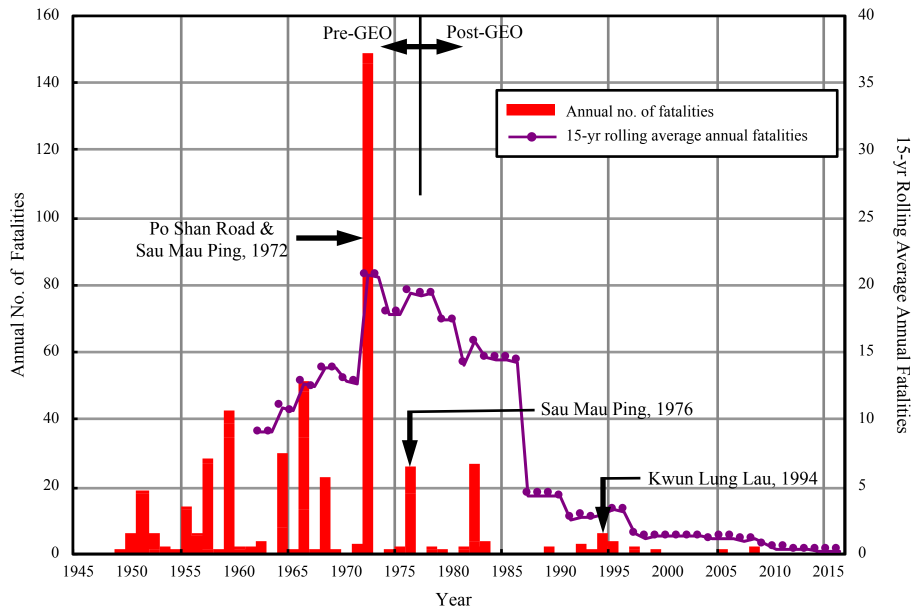

Known Landslide Fatalities in Hong Kong (1948-2016) (Wong 2017)

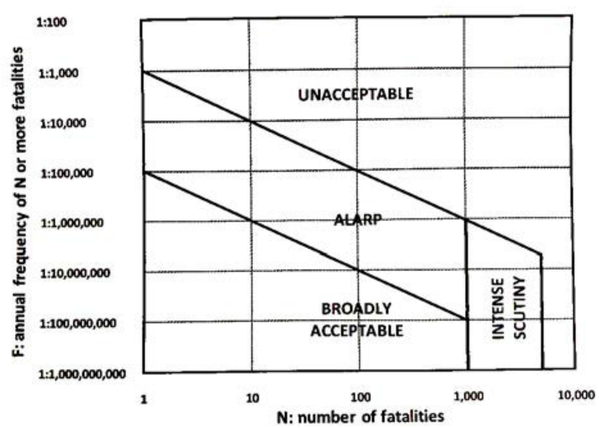

Figure 3. Societal risk tolerance criteria for landslides in Hong Kong (GEO 1998).

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Risk Communication

Tappenden, K.M., 2014. The district of North Vancouver's landslide management strategy: role of public involvement for determining tolerable risk and increasing community resilience. Natural Hazards, Vol. 72, p. 481-501.

A community task force approach was evaluated in terms of four criteria for successful public involvement:

1. Representative participation
2. Early involvement
3. Information availability
4. Impact on policy

The DNV has received international recognition for their Natural Hazard Management Program, of which the Landslide Management Strategy forms an important part. In 2011, the DNV received the United Nations Sasakawa Award for Disaster Risk Reduction, and in 2012, when the United Nations published the handbook "How to Make Cities More Resilient", the DNV was recognized as an example of innovation and community engagement.

Sample Entries for a Maturity Matrix for Assessing Community Engagement

Elements	Level I	Level II	Level III
Dam or levee safety reviews	No activity	Standards-based only	Introduction of additional review criteria (e.g., failure mode analysis)
Other programs related to conventional dam/levee safety activities	*Each tool is defined at different levels to show progression from minimum activity (Level I) through best industry practice to full community member and stakeholder engagement and collaboration (Level V)*		
Emergency action plans	No activity	EAPs developed internally by owner	EAPs developed with input from emergency management agency
Specific tools related to emergency planning response, including development of community preparedness measures, warning and evacuation procedures, and recovery plans	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		
Floodplain management	No floodplain management plans	Floodplain management plans in place	Floodplain management plans accommodate shadow floodplain associated with catastrophic dam or levee failure
Specific tools such as those related to land-use planning and floodplain management, including initiatives for financial incentives and zoning reform	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		

National Research Council, 2012. Dam and Levee Safety and Community Resilience: A Vision for Future Practice

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Sample Entries for a Maturity Matrix for Assessing Community Engagement (continued)

Level IV	Level V	Examples of Possible Outcomes
Application of quantitative risk assessment by using criteria developed by owner or regulator with input from community members and stakeholders	Application of quantitative risk assessment by using criteria that reflect the community's societal values	Community is fully apprised of current level of risk
EAPs developed with input from community members and stakeholders and emergency management agency and shared with selected community representatives	Community collaboration with owners or operators to develop integrated EAPs that reflect community values	Community collaboration results in EAPs that minimize consequences of defined emergencies by incorporating community values and the potential for community resilience
Floodplain management plans integrated into community comprehensive or general plans	Floodplain management plans fully integrated into dam and levee owners' planning processes	Full participation by both community and dam and levee owners in floodplain management facilitates adoption of complementary resilience-enhancing measures

National Research Council, 2012. Dam and Levee Safety and Community Resilience: A Vision for Future Practice

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Water Dams

1) Buffalo Creek Dam, West Virginia, USA

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Water Dams

2) Teton Dam, Idaho, USA

Water Dams

3) Brinded (2000)

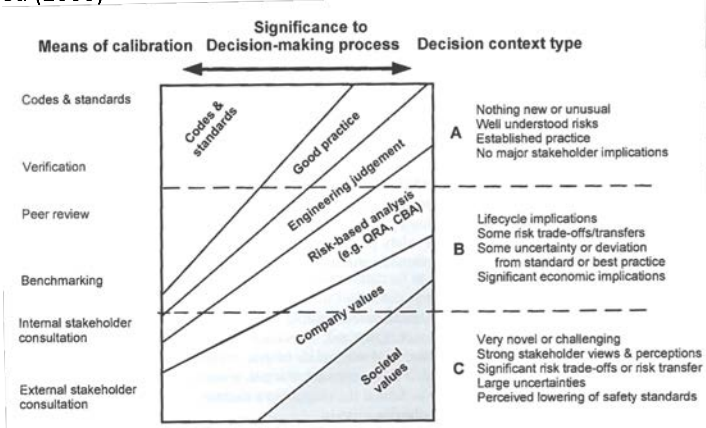

Figure 3-2. Risk decision framework (UKOOA), (Brinded, 2000)

Note: QRA – quantitative risk analysis
CBA – cost–benefit analysis

Risk Analysis

As summarized by France and Williams (2017), the evolution of risk analysis has strengthened the dam safety community in many ways by:

i. recognizing in a formal manner the many ways that a dam can fail and the consequences of the failures;
ii. using risk as a tool for prioritizing risk reduction actions, particularly for dam portfolio analyses; and
iii. focusing monitoring programs and remediation efforts on the highest risk dams and potential failure modes.

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Quantitative Risk Analysis (QRA)

As observed by Bowles (2007):

"From the outset… it is emphasized that judgements about the adequacy of dam safety, which are fundamentally judgements about public safety, are intrinsically value judgements and not technical matters, although they should be informed by sound technical information."

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Oroville Dam Safety Incident (2017)

"Although the practice of dam safety has certainly improved since the 1970s, the fact that this incident happened to the owner of the tallest dam in the United States, under regulation of a federal agency, with repeated evaluation by reputable outside consultants, in a state with a leading dam safety regulatory program, is a wake-up call for everyone involved in dam safety. Challenging current assumptions on what constitutes "best practice" in our industry is long overdue"

(Independent Forensic Team Report 2018)

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The following points are extracted from the summary of the IFT report of the Incident which led to the mandatory evacuation of at least 188,000 people on February 13, 2017:

- The inherent vulnerability of the service spillway design and as-constructed conditions reflect lack of proper modification of the design to fit the site conditions.
- Almost immediately after construction, the concrete chute slab cracked above and along underdrain pipes, and high underdrain flows were observed. The slab cracking and underdrain flows, although originally thought of as unusual, were quickly deemed to be "normal" and as simply requiring on-going repairs.

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- The seriousness of the weak as-constructed conditions and lack of repair durability was not recognized during numerous inspections and review processes over the almost 50-year history of the project.
- Over time, a number of factors contributed to progressive deterioration (see Report for details).
- Due to the unrecognized inherent vulnerability of the design and as-constructed conditions and the chute slab deterioration, the spillway chute slab failure, although inevitable, was unexpected.
- Once the initial section of the chute slab was uplifted, the underlying poor-quality foundation materials were directly exposed to high-velocity flows and were quickly eroded.

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- Although the poor foundation conditions at both spillways were well documented in geology reports, those conditions were not properly addressed in the original design and construction, and all subsequent reviews mischaracterized the foundation as good quality rock. As a result, the significant erosion of the service spillway foundation was also not anticipated.
- In limiting service spillway discharge to reduce the likelihood of powerhouse flooding, the additional dam safety risk associated with use of the emergency spillway was not appropriately considered. Once the emergency spillway was allowed to overtop, this additional risk was soon realized and the evacuation order became a necessary precaution.

Whether precautionary or performance-based, or even utilizing subjective judgements based on experience, it is essential that the risk assessment process be constrained by evidence and its evaluation to a higher degree than is currently the case.

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(Independent Forensic Team 2018)

(Independent Forensic Team 2018)

The following are recommended:

i) Design Basis Memorandum (DBM)

The DBM contains the design criteria for all aspects of the facility and the methods of analysis. It should contain enough detail to support a forward projection of all observational performance data once the project is complete and in service. Such an analysis should be undertaken to provide a reference basis for in-service expectations.

ii) Construction Record

Experience reveals that when problems occur, the record is everything. Construction recordings should be expanded to develop a comprehensive GIS-based retrievable system that will document all aspects of construction history chronologically, as well as any written or photographic documents associated with the specific components.

iii) Quality Assurance (QA)

The role of QA is to document whether the facility has been constructed as intended. This is much more than simply collecting as-built drawings and some corroboration of laboratory procedures. More extensive reporting is needed tied to the expanded Construction Record.

iv) Deviations

Deviation from the design/specifications are common. Major deviation may result in a formal design change which would be captured in the QA report and changes to the DBM. However minor deviations may accumulate. To avoid the risks associated with normalization of deviation, a Deviation Accountability Report (DAR) should be implemented to validate the acceptance of the deviations.

Implementing the above and carrying the related documentary references and criteria through the future dam safety evaluation process should contribute to improve reliability, accountability and transparency, and thereby strengthen the safety cultures associated with the long-term performance of water dams.

Safe Tailings Dams

1) Grizzly Gulch Tailings Dam, South Dakota, USA

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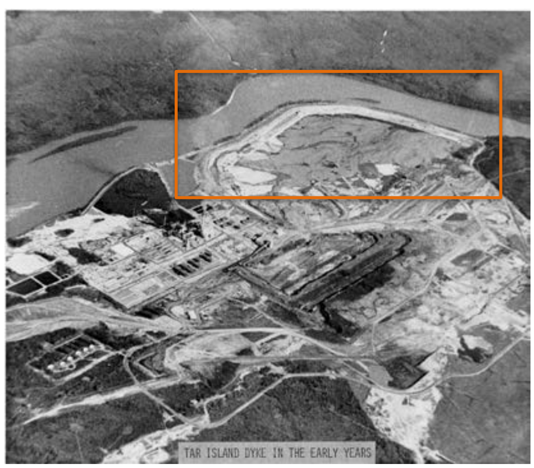
Safe Tailings Dams

2) Tar Island Dyke, Alberta, Canada

- First to be built
- First to discover MFT and beach slopes
- First to discover that flume to field can come with issues
- First to experience pressures of no in-pit space available
- First to be increased without overburden and be built with modified upstream construction, hydraulically placed sand
- First to experience flow or static liquefaction from fast overboarding
- First pond to be reclaimed



(McRoberts et al. 2017)

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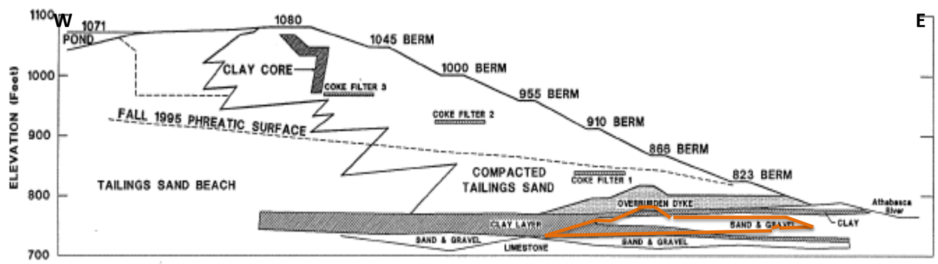
Safe Tailings Dams

2) Tar Island Dyke, Alberta, Canada

1964: Initial planning had a plan for a 40 ft. (12 m) high overburden dyke
1967: Increased to a 75 ft. (23 m) high overburden dyke
1973: A further height increase required to contain hydraulic fills to 1000 ft. (elev. 305 m)
Today: Final elevation of 1080 ft. (329 m), ultimately 320 ft. (98 m)



(McRoberts et al. 2017)

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1. The standard of care associated with mine waste retention structure was too low.
2. The standard of care associated with mine waste retention structures should move towards those of water-retaining structures.
3. Establishing the standard of care is the responsibility of senior mine management who should set design objectives, risk management policy, and the associated levels of safety.
4. Consultants should involve Failure Modes/Effects Analysis or equivalent risk analyses at an early state of project development.
5. Regulatory Agencies should devote more concern to the details of corporate policy regarding mine waste management procedure as opposed to being risk driven.
6. ICME (now ICMM), as the industrial interface, should contribute to improved risk management by drafting model corporate policy codes of practice and model regulations for consideration by individual corporations and regulatory agencies.

(Morgenstern 1998)

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- Each owner is cognizant of its responsibilities to provide a tailings management consistent with the MAC guidelines.
- Each owner has staff qualified in the management of tailings dams.
- Owners retain consulting engineers for design and construction supervision who are well-known for their expertise in tailings dam design with special reference to the circumstances associated with the oil sands industry; the designer acts as the Engineer-of-Record at least for design; senior internal review of design submissions is expected.
- Designs rely on the detailed application of the observational method for risk management.
- Designs are reviewed by the Alberta Dam Safety Branch, the regulator, who have staff well-versed in dam design and construction.

(Morgenstern 2010)

- An annual report is submitted to the regulator by the owner, supported by the Engineer-of-Record, that the dam is behaving as intended; if not, actions that have been or need to be taken are indicated.
- In accordance with CDA Guidelines, approximately every five years the owner retains an engineer, other than the Engineer-of-Record, to undertake an independent assessment of dam safety.
- Each owner retains an Independent Geotechnical Review Board, comprised of senior specialists, to provide on-going third-party review of geotechnical issues of significance to the operation. One of the major responsibilities of such Boards is to review all aspects related to safety of tailings dams over the life cycle from design, construction, operation and closure.

(Morgenstern 2010)

Image courtesy of Mining Association in Canada
Tailings Management Component of the *Towards Sustainable Mining* Program presentation

Image courtesy of Mining Association in Canada
Tailings Management Component of the *Towards Sustainable Mining* Program presentation

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Image courtesy of Mining Association in Canada
Tailings Management Component of the *Towards Sustainable Mining* Program presentation

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Responding to the Crisis

1) Prescriptive Recommendations
- "Ban upstream dams, particular subjected to seismic loads."
- "Ban clay foundations."
- "Require a Factor of Safety of at least 1.5 during operations."

No set of simple prescriptions will resolve the crisis. As emphasized by McRoberts et al. (2017): "One of the most important learnings can be seen in failure of other structures in the world. This is that a highly integrated team effort and success of an individual structure relies on the operational discipline of planning, technology, operations, geotechnical engineering and regulatory bodies."

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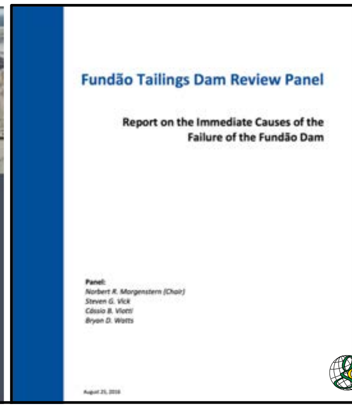
Responding to the Crisis

2) Response of Governments

- Response in British Columbia to the Mount Polley Incident (2014)
- Response in Brazil to the Samarco Incident (2015)



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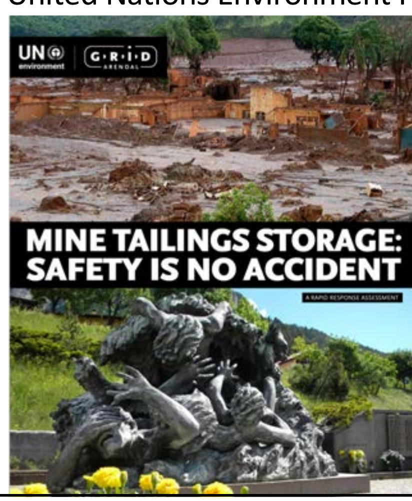
Responding to the Crisis

2) Response of Governments

- Response of United Nations Environment Programme (UNEP)



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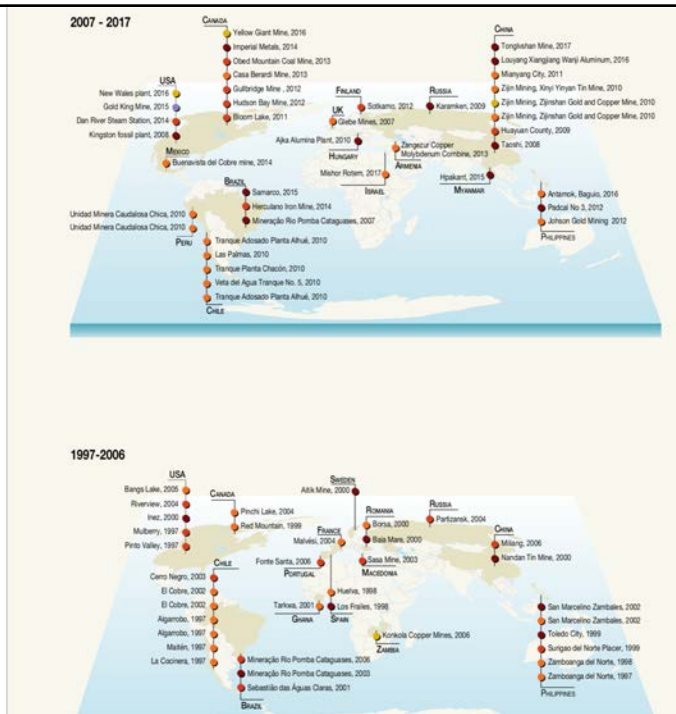

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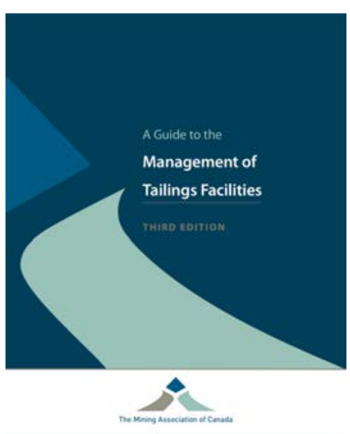
Responding to the Crisis

3) Response of Mining Association of Canada (MAC)

- Revised guide to the Management of Tailings Facilities, 3rd edition, November 2017



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In the new edition, new guiding principles are introduced to include:

- risk-based approaches
- BAT and BAP for tailings management
- the roles of independent review
- design and operating for closure
- revised roles and responsibilities.

This new Guide provides an outstanding document to influence the organization and governance protocols needed to ensure safe tailings management from the conceptual stages through to closure.

Responding to the Crisis

4) Response of International Council on Mining and Metals (ICMM)

- Golder Associates, 2016. Review of Tailings Management Guidelines and Recommendations for Improvement to ICMM.

Before engaging in the review that concentrated on governance issues, the study team reflected on learning from recent high-profile failures and concluded:

"… if one were to focus on these and other such case histories through consideration of a greater number of failure and investigation results over the last 20 or so years, and ask the question is there anything missing form existing standards and guidance documentation that if known and applied could have forestalled such events, then the answer might be as follows:

"Existing published guidance and standards documentation fully embrace the knowledge required to embrace such failures. The shortcoming lies not in the state of knowledge, but rather in the efficiency with which that knowledge is applied. Therefore, efforts moving forward should focus on improved implementation and verification of controls, rather than restatement of them."

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- Accountabilities, responsibilities and associated competencies are defined to support appropriate identification and management of tailings storage facilities risk.
- The financial and human resources needed to support continued tailings storage facility management and governance are maintained throughout a facility's life cycle.
- Risk management associated with tailings storage facilities, including risk identification, an appropriate control regime and the verification of control performance.
- Risks associated with potential changes are assessed, controlled and communicated to avoid inadvertently compromising facility integrity.
- Processes are in place to recognize and respond to impending failure of facilities and mitigate the potential impacts arising from a potentially catastrophic failure.
- Internal and external review and assurance processes are in place so that controls for facilities risks can be comprehensively assessed and continually improved.

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Position Statement

- ICMM, 2016. Preventing Catastrophic Failure of Tailings Storage Facilities.

Basic Causes of Tailings Incidents

			Basic Causes		
Name	Year	Place	Engineering	Operations	Regulators
Tyrone	1980	New Mexico, USA	✓		
Ok Tedi	1984	Papua New Guinea	✓		
Stava	1985	Italy			✓
Omai	1995	Guyana	✓		
Golden Cross	1995	New Zealand	✓		
Marcopper	1996	Philippines	✓		
El Porco	1996	Bolivia	✓		
Pinto Valley	1997	Arizona, USA	✓	✓	
Los Frailes	1998	Spain	✓		
Inez	2000	Kentucky, USA	✓	✓	
Kingston	2008	Tennessee, USA	✓		
Keephills	2008	Alberta, Canada	✓		
Obed	2013	Alberta, Canada		✓	✓
Mount Polley	2014	British Columbia, Canada	✓	✓	
Samarco/ Fundao	2015	Minas Gerais, Brazil	✓	✓	

Stava

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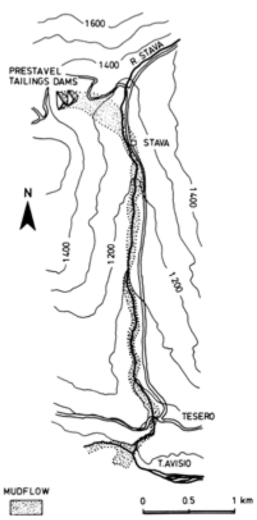
Position of Tailings Dams and the Mud Flow's Course



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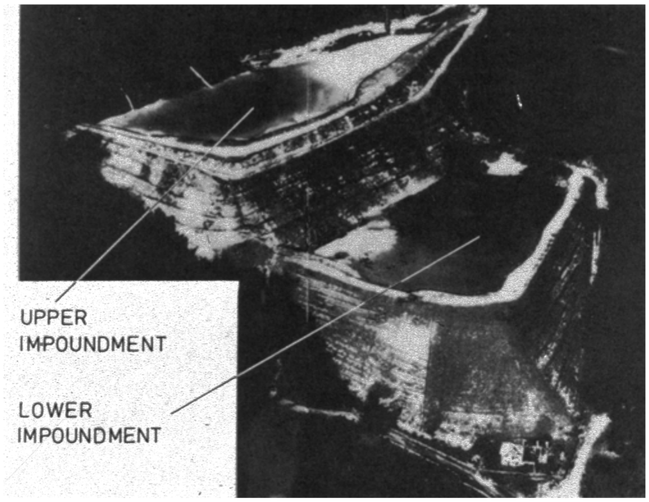

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Pinto Valley

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Keephills Ash Lagoon

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Obed Mountain Coal Mine

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Dominant Cause of Failures

The most important finding is that the dominant cause of these failures arises from deficiencies in engineering practice associated with the spectrum of activities embraced by design, construction, quality control, quality assurance and related matters. This is a very disconcerting finding.

There is an unwritten covenant in our professional practice with the assumption on the part of an operator that, given reasonable resources, and on the part of the regulator that, given technical guidelines and a modicum of inspection, the engineering team can be relied upon to produce a tailings storage facility that will perform as intended. The experience summarized here leads to the conclusion that this covenant is broken.

The conclusions in the ICMM-sponsored study of tailings management guidelines (Golder Associates 2016) and the recommendations embraced in the Tailings Governance Framework issued by ICMM (2016) are not adequate to resolve the crisis.

Performance-Based, Risk-Informed Safe Design, Construction, Operation, and Closure (PBRISD)

Stage 1: (Conceptual)

1. Qualified Operator
2. Establish Independent Review Board
3. Uncertainty Assessment
4. Potential Problems Analysis (PPA)
5. Multiple Account Analysis (MAA)

Stage 2: (Feasibility)

1. Engineer-of-Record (EoR)
2. Designer
3. Design Basis Memorandum (DBM)
4. Risk Assessment
5. Quality Management
6. Documentation

Stage 3: (Construction and Operations)

1. Operations

Stage 4: (Closure Implementation)

Guidance

It is the primary responsibility of the proponent to put forward an acceptable waste management plan that meets these standards. The evolving crisis related to trust and confidence, discussed here, has also revealed a high rate of technical deficiencies as a significant factor in the failures that have been documented. It is tempting to conclude that increased prescriptive measures controlling the engineering works are required. However, the intrinsic complexity and diversity of the undertakings reduces the reliability of this perspective. Instead, the underlying principle for the tailings management system advocated here (PBRISD) is accountability. This is achieved by multiple layers of review, recurrent risk assessment and performance-based validation from construction through closure.

The regulator also has a vital role. It is the responsibility of the regulator to review the proposed waste management plan and indicate how it is to be validated. This will involve some combination of inspections concentrating on quantified performance objectives, receiving review board reports and other measures deemed necessary. The regulator is also the custodian of prescribed regional practice.

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Recommendations

In order to turn the system recommended here into a reality, it is necessary to expand the skeleton outline into a guidance document that would help individual operators in developing a tailings management system for their specific operations based on PBRISD. The principles involved in PBRISD are entirely consistent with the ten principles that are the foundation of ICMM's Sustainable Development Framework. In addition, supporting the adoption of PBRISD can be regarded as a natural extension of the action already taken by ICMM in their 2016 Position Statement.

This Lecture concludes with the recommendation that ICMM support the tailings management system based on PBRISD, as outlined here, and fund the development and publication of a guidance document that would facilitate its adoption in mining practice.

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Acknowledgements

I would like to recognize the valuable discussions on these matters with numerous colleagues in both professional practice and academic studies over the years. They are too numerous to list in detail, but important to remember. In the short term, the preparation of this Lecture and publication owes much to the organizational and communication skills of Vivian Giang to whom I am grateful.

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