COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

INTERNATIONAL COMMISSION
ON LARGE DAMS

ICOLD Bulletin No. 194
TAILINGS DAM SAFETY

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As vice chair representing:

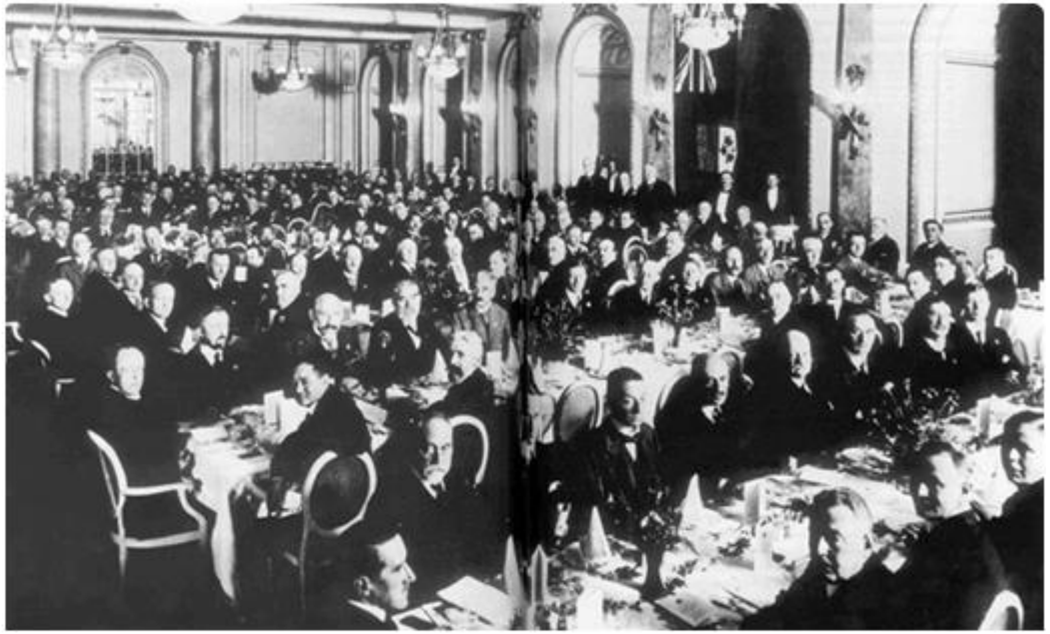
ICOLD - Committee L Tailings Dams and Waste Lagoons

Purpose of todays presentation

- Introduce ICOLD and its work related to tailings
- Background to why tailings dams are important - failures
- Overview of how the world have reacted
- Overview of the ICOLD Bulletin 194 and most important messages

Who/What is ICOLD/CIGB

- The International Commission on Large Dams (Commission Internationale des Grands Barrages), founded in 1928 is an **international, non-governmental** organization dedicated to the sharing of **professional information and knowledge** of the design, construction, maintenance, and impact of large dams.
- National Committees from more than **100 countries** with approximately **10 000 individual** members.
- ICOLD members are essentially practising engineers, geologists and scientists from governmental or private organizations, consulting firms, universities, laboratories and construction companies.
- ICOLD is an **independent professional body**.



Committee L – Tailings dams and Waste Lagoons

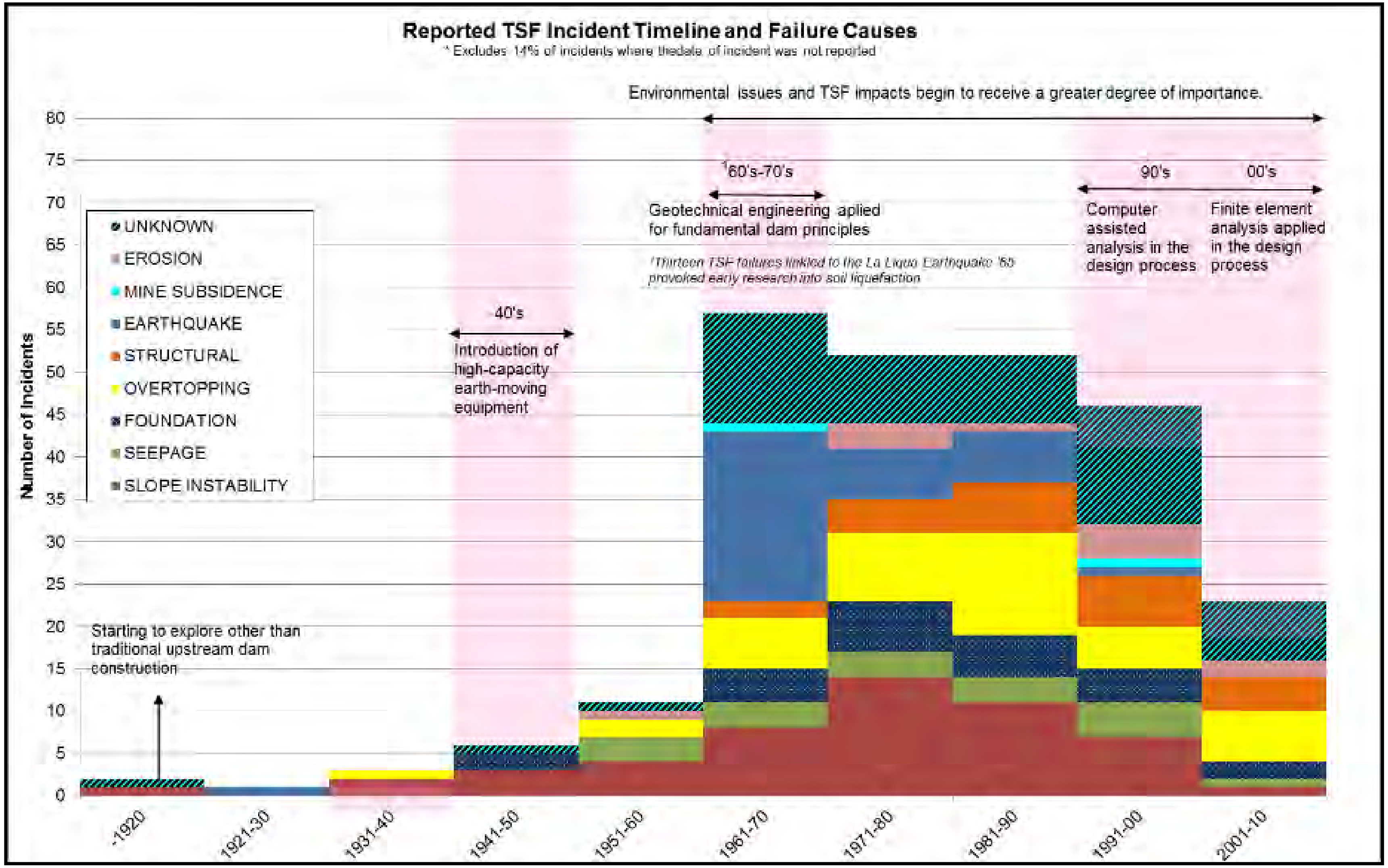
ICOLD Committees (29)

A	COMPUTATIONAL ASPECTS OF ANALYSIS AND DESIGN OF DAMS (2020-23)
B	SEISMIC ASPECTS OF DAM DESIGN (2020-23)
C	HYDRAULICS FOR DAMS (2021-25)
D	CONCRETE DAMS (2021-24)
E	EMBANKMENT DAMS (2020-23)
F	ENGINEERING ACTIVITIES WITH THE PLANNING PROCESS FOR WATER RESOURCES PROJECTS (2014-22)
G	ENVIRONMENT (2020-22)
H	DAM SAFETY (2021-24)
HWS	HISTORICAL WATER STRUCTURE (Water Heritage) (2021-24)
I	PUBLIC SAFETY AROUND DAMS (2022-25)
J	SEDIMENTATION OF RESERVOIRS (2020-23)
K	INTEGRATED OPERATION OF HYDROPOWER STATIONS AND RESERVOIRS (2015-23)
L	TAILINGS DAMS & WASTE LAGOONS (2020-23)
LE	LEVEES (2018-2024)
M	OPERATION, MAINTENANCE AND REHABILITATION OF DAMS (2020-23)
N	PUBLIC AWARENESS AND EDUCATION (2021-24)
O	WORLD REGISTER OF DAMS AND DOCUMENTATION (2021-24)
P	CEMENTED MATERIAL DAMS (2020-25)
Q	DAM SURVEILLANCE (2017-22)
RE	RESETTLEMENT DUE TO RESERVOIRS (2021-2024)
S	FLOOD EVALUATION AND DAM SAFETY (2020-24)
T	PROSPECTIVE AND NEW CHALLENGES FOR DAMS AND RESERVOIRS IN THE 21st CENTURY (2020-23) (AD HOC Committee)
TRS	TROPICAL RESIDUAL SOILS (2020-23)
U	DAMS AND RIVER BASIN MANAGEMENT (2021-24)
V	HYDROMECHANICAL EQUIPMENT (2016-22)
X	FINANCIAL AND ADVISORY (AD HOC Committee)
Y	CLIMATE CHANGE (2021-23)
Z	CAPACITY BUILDING AND DAMS (2021-24)
ZX2	YOUNG ENGINEERS

ICOLD Bulletins related to tailings dams

- No. 45: Manual on Tailings Dams and Dumps (1982)
- No. 74: A Guide to Tailings Dam Safety (1989)
- No. 97: Tailings Dams - Design of Drainage (1994)
- No. 98: Tailings Dams and Seismicity (1995)
- No. 101: Tailings Dams Transport, Placement and Decantation (1995)
- No. 103: Tailings Dams and Environment (1996)
- No. 104: Monitoring of Tailings Dams (1996)
- No. 106: A Guide to Tailings Dams and Impoundments (1996)
- No. 121: Tailings Dams Risk of Dangerous Occurrences
  Lessons Learnt from Practical Experiences (2001)
- No. 135: Improving Tailings Dam Safety (2011)
- No. 153: Sustainable Design and Post-Closure Performance of Tailings Dams (2013)
- No. 181: Technology Update (2021)
- No. 194: Current **Bulletin on Tailings Dam Safety** (*2018*-2023)

Why are we worried about Tailings Dams?



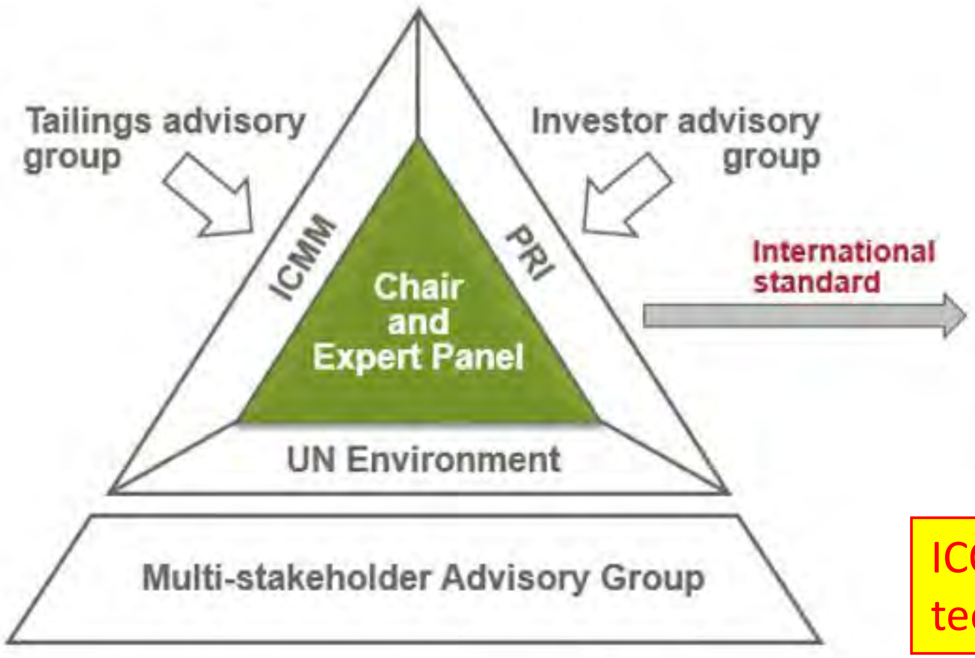
- Average 4 significant tailings dam failures every year around the world
- At least 1/year is responsible for deaths and major environmental impact
- A range of failure modes
- Likelihood of failure higher than water dams and potential consequences much greater

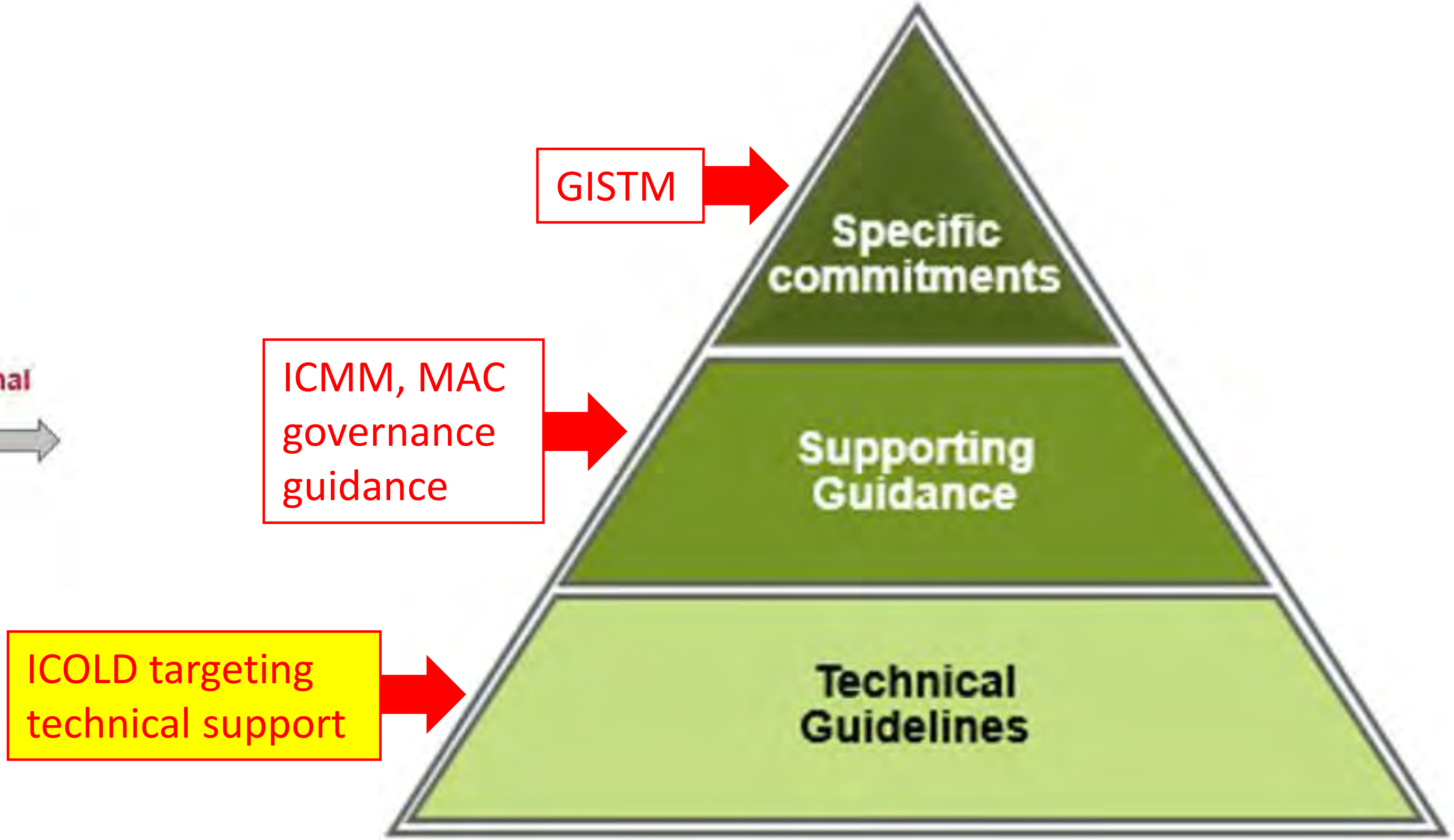
World Response to tailings dam failures

- **Professional Body Guidelines**
  - International Commission on Large Dams - **ICOLD**
  - Australian Commission on Large Dams - **ANCOLD**
  - Canadian Dam Association - **CDA**
- **Industry Guidelines**
  - International Council on Mining and Metals - **ICMM**
  - Mining Association of Canada - **MAC**
- **Global Tailings Review (**Principles for Responsible Investment **- PRI,** United Nation Environment Program **– UNE and ICMM)**
  - Global Industry Standard on Tailings Management – **GISTM** (Aug 2020)
- **Regulators**
  - Legislation and Regulation (for ex. in Brazil)

ICOLD Symposium 2019 (Ottawa): ICOLD - GISTM

Presentation by Michael Davies, Teck





Available to ICOLD Members

https://www.icold-cigb.org/GB/publications/bulletins.asp

COMMITTEE ON TAILINGS DAMS (2018-2022)

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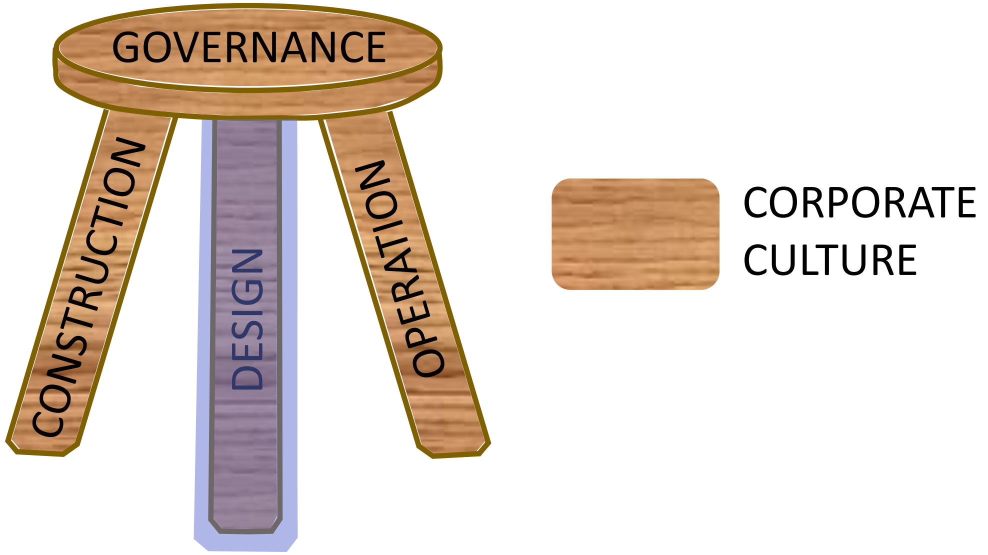
Bulletin 194 – Tailings Dam Safety – Outline

1. Introduction
2. Tailings Storage Facility Governance
3. Closure
4. Dam Consequence Classification
5. Site Characterization
6. Tailings Characterization
7. Design
8. Risk Management
9. Dam Failure/Breach Analysis
10. Emergency Preparedness and Response Planning
11. Construction
12. Operations
13. References
14. Definitions

Appendix A Shear Strength and Deformation Behaviour
Appendix B Stability Analysis Framework for Tailings Dams with Contractive Soils



Overview of Bulletin (ICOLD 2022)
https://youtu.be/4q0ldq5HLxw

Consequence Classification

Similar to GISTM

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.
Significant	1-10	none	Limited loss or deterioration of environmental values. Potential contamination of livestock/fauna water supply. Moderate area of impact and restoration possible.	Limited effects and disruption of business and livelihood. 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. Moderate economic loss.
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 to 20 km^2. Restoration possible within a moderate time frame.	Many 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. Losses.
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 moderate to long time frame.	A high number of 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.
Extreme	> 1000	> 100	Catastrophic loss of critical environmental values including rare and endangered species of high significance. - Very large areas of potential impact. . Restoration or compensation in kind impossible or requires a very long time.	A large number of 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 communities and very high social readjustment costs.

Flood Design – Inflow Design Flood (IDF)

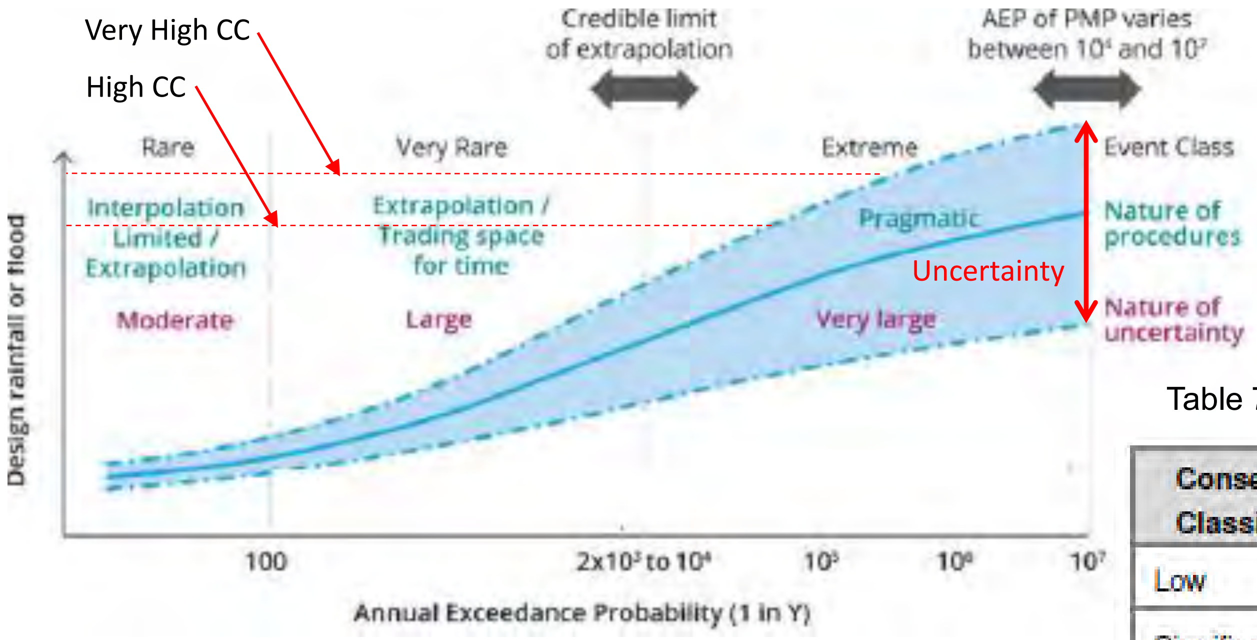


Figure 7.2 Limits of uncertainty for large floods (Nathan et al, 2019)

Table 7.2 Suggested **minimum** flood design criteria for operating & active care phases

Consequence Classification	Flood Criteria -- Annual Exceedance Probability (AEP)[1] Operations and Active Care Closure
Low	1/200
Significant	1/1,000
High	1/3rd between the magnitude of the 1/1,000 flood and the PMF
Very High	2/3rd between the magnitude of the 1/1,000 flood and the PMF
Extreme	PMF

Note: 1) The criteria presented is guidance for suggested minimum criteria.

Seismic design

Table 7.3 Suggested **minimum** seismic design criteria

Consequence Classification	Seismic Criteria[1] Annual Exceedance Probability[2] or Maximum Credible Ground Motion[3]
	Operations and Active Care Closure
Low	1/200
Significant	1/1,000
High	1/2,475[4]
Very High	1/5,000 or 50th percentile MCE[1,3]
Extreme	1/10,000 or 84th Percentile MCE[1,3]

Notes:

1) The selection of the probabilistic or deterministic (scenario-based) design earthquake ground motions should consider the seismic setting and the reliability and applicability of each method.
2) The criteria associated with annual exceedance probabilities (AEP's) presented are guidance for suggested minimum criteria. Each facility should be assessed for the potential to increase the design criteria to further reduce risk.
3) MCE is based upon a deterministic seismic hazard assessment that considers a range of scenarios.
4) The selection of an AEP of 1/2475 as a minimum design earthquake for High Hazard is based on the typical design earthquake for buildings in certain building codes, the application of this value for dam safety in multiple countries, and its inclusion in the GISTM.

Consider higher values for risk reduction and closure

Comments:

- Recommend site-specific seismic hazard assessment
- Seismic stability requires understanding of potential for liquefaction and post earthquake residual strength
- ICOLD does not support the use of pseudo-static analysis

Stability Analysis

Stability Condition	Target Minimum Factor of Safety
Static Conditions	1.5
Post-Liquefaction Conditions	1.1

- **Key** element of the safety evaluation of tailings dams
- Most often based upon Factor of Safety (FOS) values calculated using **limit-equilibrium (L-E) analyses**. This is adequate where all materials (foundation and structural zones) are **dilative** over the life of the facility **(detailed discussion in Appendix A)**
- Need to consider **drained & undrained** situations
- Need to assess **residual strength** post seismic for **contractive** materials **(Appendix B)**
- **Minimum FOS** assuming leading international practice has been adopted with respect to: site characterization, selection of parameters and design methodology
- Alternatively, stability analyses can be carried out using advanced numerical models – **non-linear deformation analyses** (NDA) based on stress-strain relationships

Dilative

Contractive

Stability Analysis

- **Upstream tailings dams must be analyzed for liquefaction**
- Seismic and static triggers are present
- Closure must assume liquefaction can occur
- ICOLD addresses this in detail

https://youtu.be/QEduIBYY6Xw

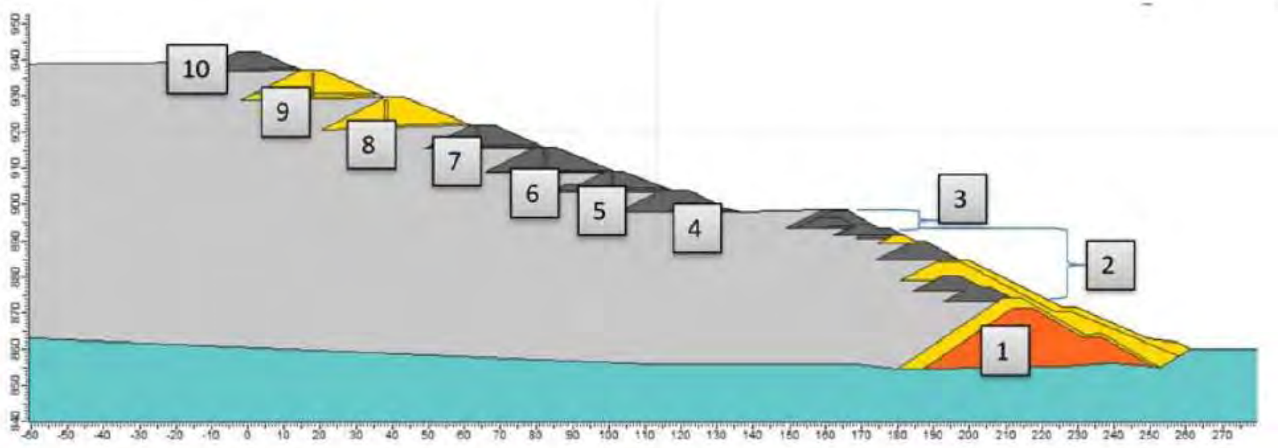


Figure 19: Dam I Cross-section, Showing Raisings and Stages of Construction[8]

Brumadinho Failure – 2019, From panel report

Tailings Storage Facilities in Central Asia

- **Tajikistan**
  - 13 Tailings Storage Facilities
  - 10 Active
- **Kazakhstan**
  - 121 Tailings Storage Facilities
- **Kyrgyzstan**
  - 56 Tailings Storage Facilities
  - 13 Active
  - 50 greater than 30 years old
- **Uzbekistan**
  - 33 Tailings Storage Facilities

- **Total: 223**

- Upstream constructed tailings dams?
- Regulations provide limited technical guidance
- ICOLD Tailings Dam Safety Bulletin can supplement local regulations

Conclusion

- ICOLD have developed a **comprehensive guideline** covering all aspects of tailings dam safety considerations
- The guideline particularly focusses on **technical aspects** to underpin other industry initiatives
- Particular attention to factors & methods affecting **stability assessment**
- This is **ICOLDs contribution** to help eliminate tailings dam failures such as Samarco & Brumahdino
- A **supplement** to regulation, not replace

Thank You for your attention