COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

INTERNATIONAL COMMISSION
ON LARGE DAMS

ICOLD Bulletin No. 194
TAILINGS DAM SAFETY

Andy Small, Chair – ICOLD Tailings Committee

Representing:

ICOLD - Committee L Tailings Dams and Waste Lagoons

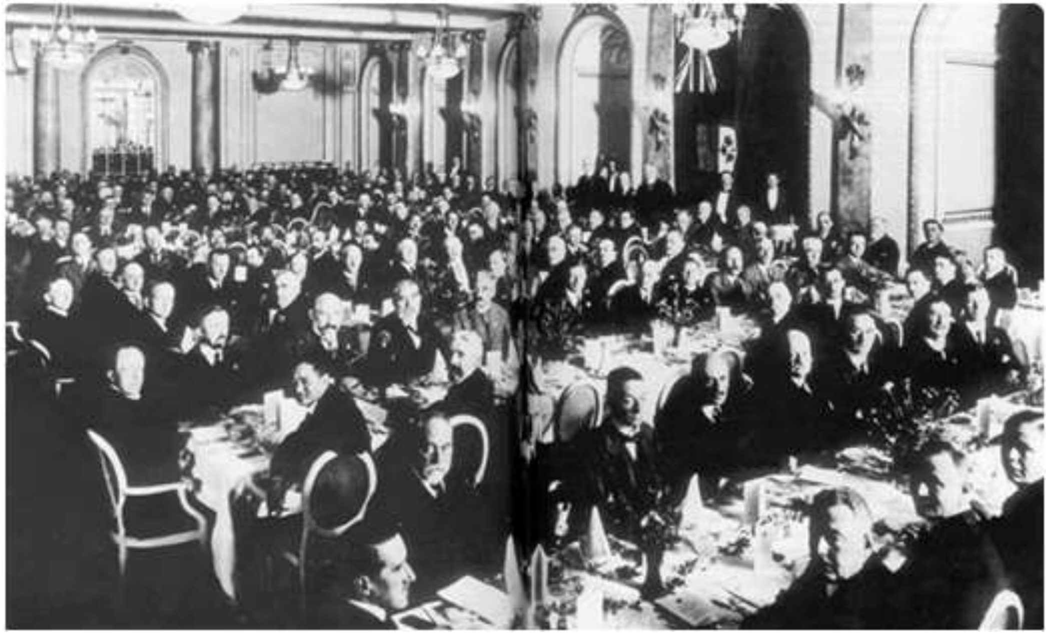
Who/What is ICOLD/CIGB

- 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**.



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)
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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)
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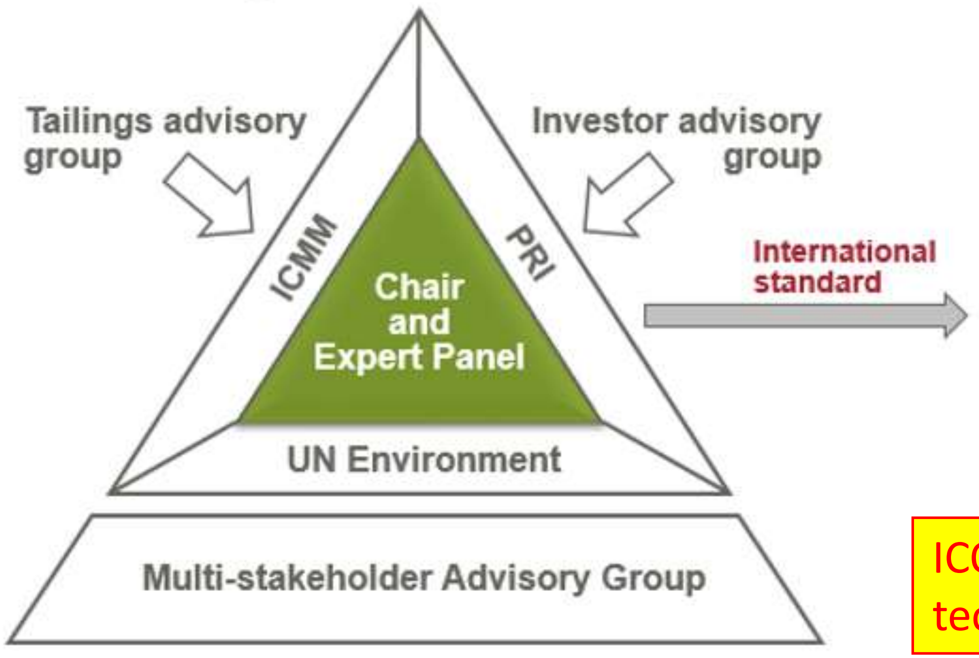
V	HYDROMECHANICAL EQUIPMENT (2016-22)
X	FINANCIAL AND ADVISORY (AD HOC Committee)
Y	CLIMATE CHANGE (2021-23)
Z	CAPACITY BUILDING AND DAMS (2021-24)
ZX2	YOUNG ENGINEERS

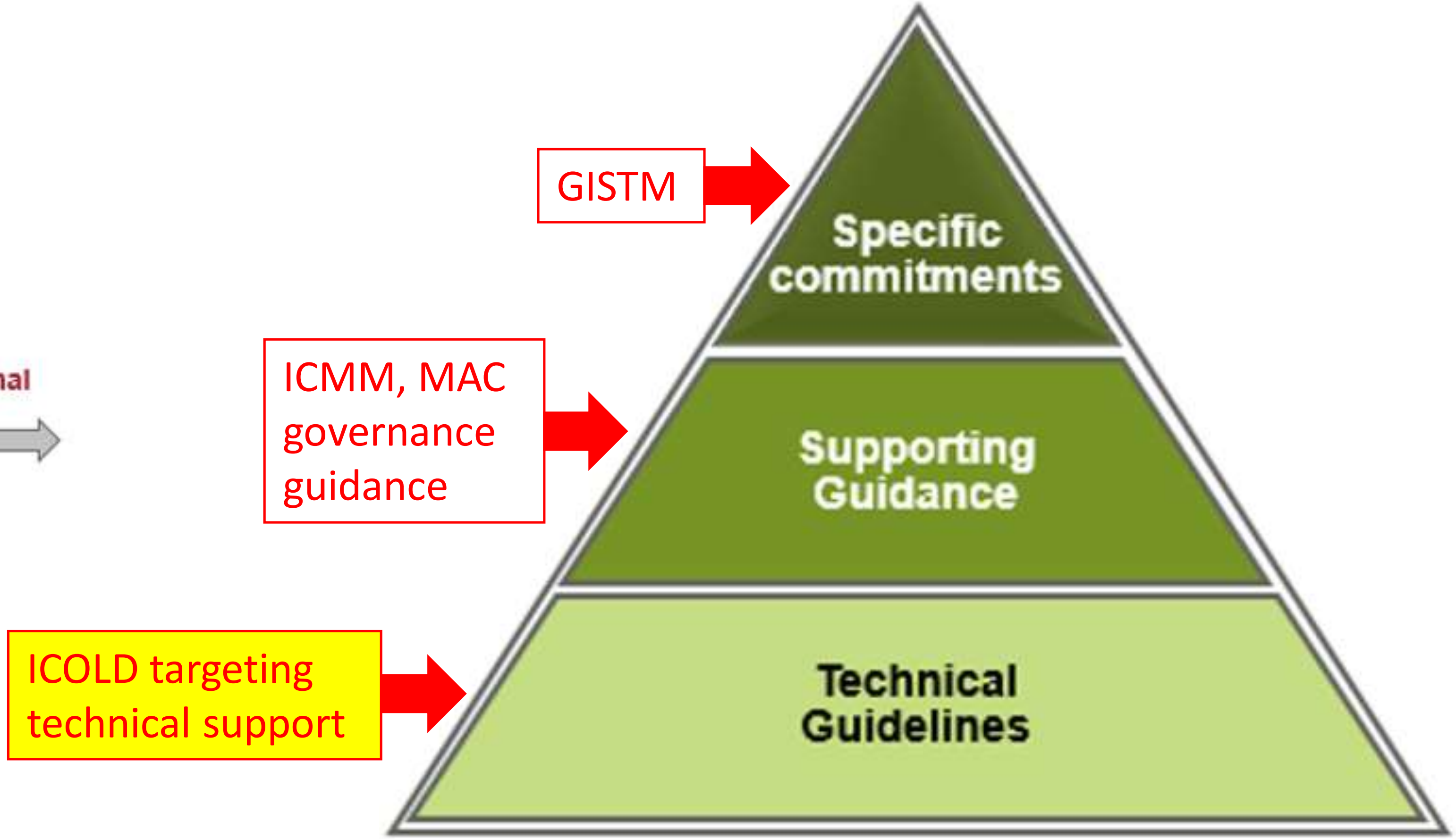
Bulletins related to tailings

- 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**

ICOLD Symposium 2019 (Ottawa): ICOLD - GISTM

Presentation by Michael Davies, Teck





Available to ICOLD Members

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

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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

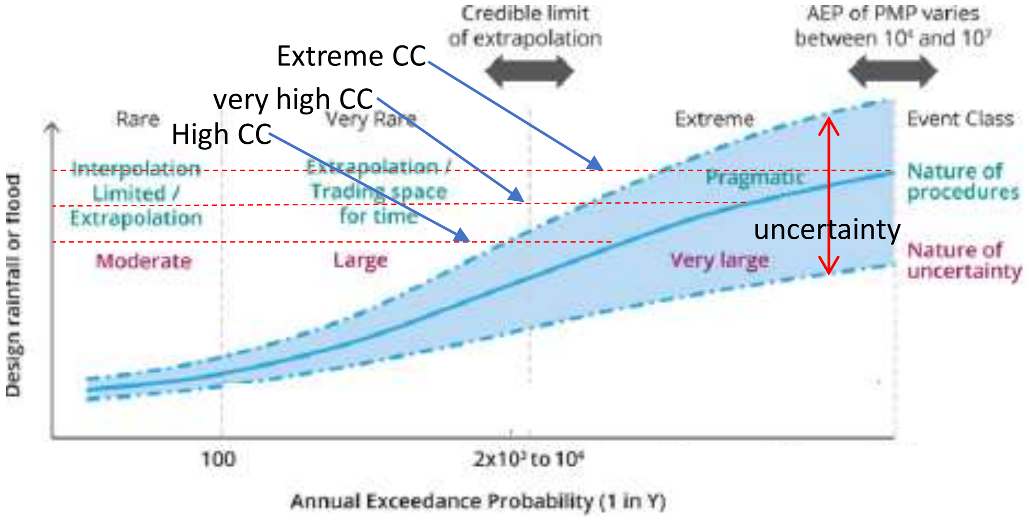

Table 7.2 Suggested **minimum** flood design criteria for operating & active care phases

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

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.

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 materials comprising the foundation and the structural zones of the tailings dam are expected to be **dilative** over the full range of operating conditions 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.

Tailings Storage Facilities in Central Asia

- Tajikistan:
  - 13 Tailings Storage Facilities
  - 10 Active

- Kyrgyzstan
  - 56 Tailings Storage Facilities
  - 13 Active
  - 50 greater than 30 years old

- Uzbekistan:
  - 16 Tailings Storage Facilities

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

Stability Analysis

- **<u>Upstream tailings dams must be analysed for liquefaction</u>**
- Seismic and static triggers are present
- Closure – assume liquefaction can occur
- Ignoring liquefaction stability ➔ unsafe
- Failures in Brazil in 2015 and 2019 followed regulations, ignored liquefaction stability
- ICOLD stability addresses this in detail

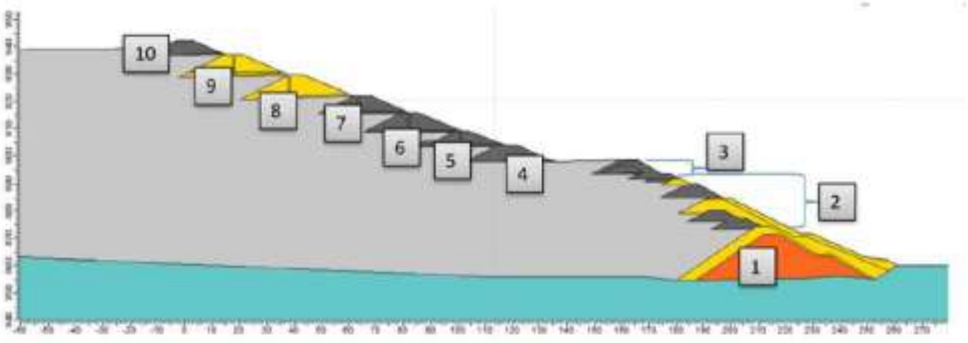

Figure 19: Dam I Cross-section, Showing Raisings and Stages of Construction[8]

https://youtu.be/QEduIBYY6Xw

Brumadinho Failure – 2019
From panel report

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
- Supplement regulation, not replace

Thank You for your attention