Special Session organized by the World Bank

World Bank's Technical Notes

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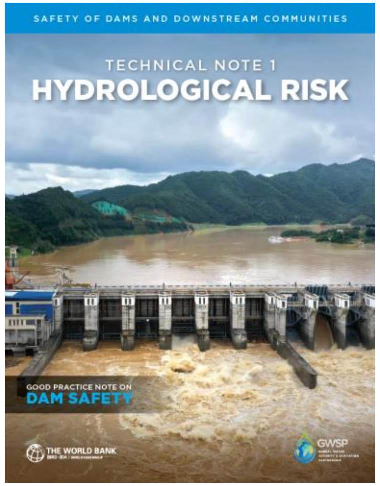
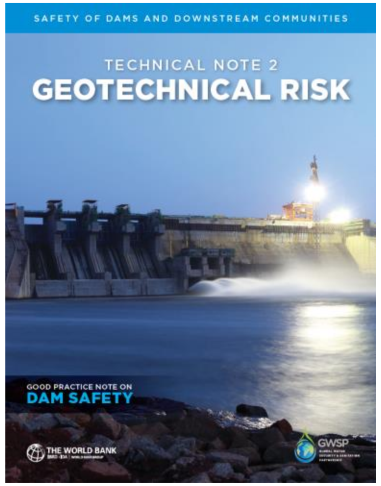
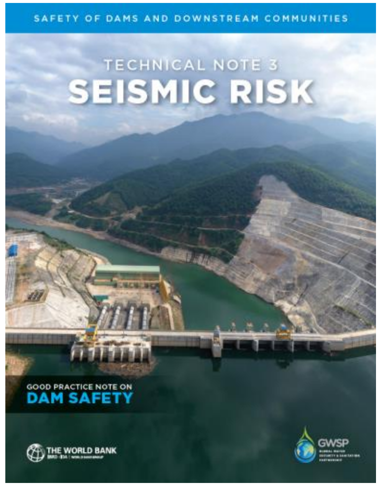
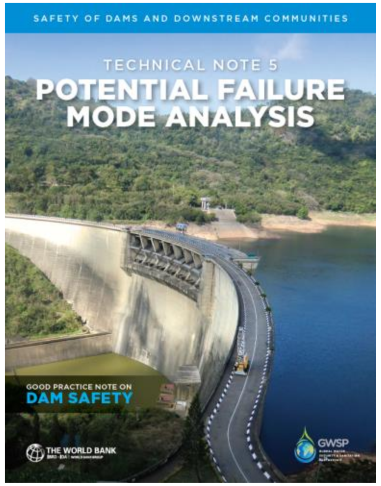
World Bank

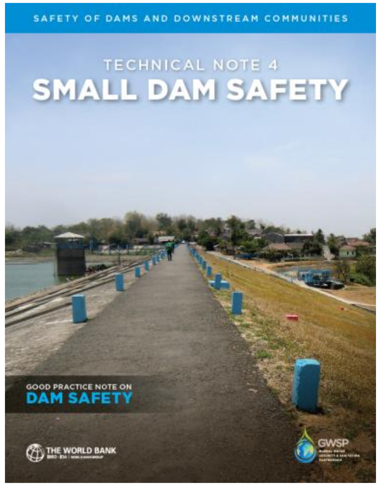
Seven Technical Notes

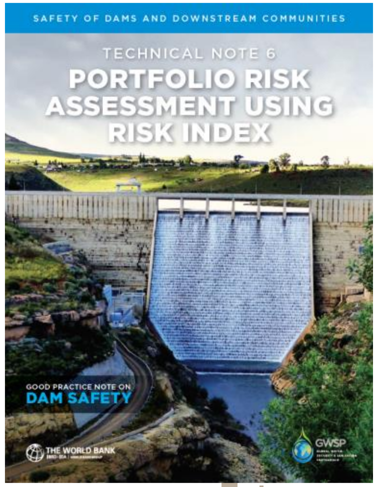


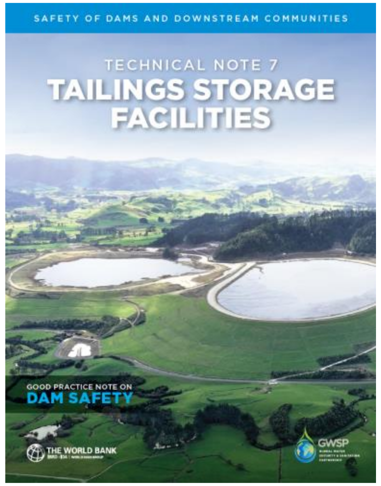












Objectives of the Technical Notes

1. To provide the minimum level of technical detail for specific topics, so that non-specialists can use it;
2. To provide guidance to the World Bank task teams and clients regarding particular dam related issues and recommended risk mitigation and management measures;
3. To raise awareness and inform specific studies and investigations to be carried out during project preparation and implementation.

TN 1 – Hydrological Risk that may affect dam safety

1) Data management
2) Watershed and river system models
3) Probabilistic characterization of floods
4) Other methods for flood characterization
5) Sedimentation
6) Ecological flows
7) Unusually large flood-handling requirements
8) Impacts of climate change
9) Managing hydrological risk

TN 1 – Hydrological Risk

Hydrological Risk and Dam Safety Assurance for Life Cycle

- **Planning, feasibility study and Design:**
  - Establishing adequate size / layout of spillway, outlet works and energy dissipating facilities to secure to safe discharge capacity (design flood and check flood)
- **Construction:**
  - Ensuring that during the construction period inflows can be safely passed through or around the construction site and safety of cofferdams, ensuring downstream safety and avoiding delay and cost increase.
- **Operation:**
  - Ensuring that the dam can safely handle all inflows expected during the operational phase of dam life cycle along with adequate reservoir operation /downstream warning procedure

TN 1 – Hydrological Risk

Incorporation of Resilience Enhancement Approach and Adaptive Management Measures to reduce Hydrological Risk

Topic	Remarks	What to do
Resilient Infrastructure Design	**(a) structural measures:** suitable types of spillway / outlet works, operational system, auxiliary spillway (redundancy), installation of fuse plugs/gates, increasing freeboard, etc. **(b) non-structural measures:** optimal reservoir operation, installation of an early warning system, preparation of emergency preparedness plans, etc.	Consider options for enhancing infrastructure's resilience throughout the life cycle of the dam.
Adaptive Dam System Management	Flood forecasting system allowing early reservoir drawdown. Temporary or permanent lowering of Full Supply Level.	Include reservoir operational system and procedures on flood forecast and water releases in the O&M Plan and in the EPP.
Update of Hydrological Database	Periodical review and update of hydrological study / flood management Periodical review of reservoir operating rule curves	Include provisions for hydrological data update and adaptive management in the O&M Plan.

TN 2 – Geotechnical risk

1) Geological Hazards
2) Geotechnical Threats to the Dam
3) Foundation Conditions
4) Dam Types
5) Investigation
6) Geotechnical Baseline
7) Geotechnical Risk Register
8) Instrumentation and Monitoring

TN 2 – Geotechnical risk

Geotechnical Risk and Complex Foundations

- Near horizontal bedding planes or shears are present in the foundation that stability calculations indicate have a reasonable likelihood of sliding under design loads.
- Joints in foundation rock are open or infilled with erodible material.
- Soft, compressible foundation material is present.
- Foundation material is soluble
- Foundation material has the potential to liquefy during earthquakes.
- The dam is constructed on a landslide.
- Active faults are present in the dam foundation.

TN 2 – Geotechnical risk

Potential Failure Modes and Preventive Measures for Embankment Dams

Potential Failure Modes

- Leakage along crack or defect through core leading to erosion of core and dam failure.
- Internal erosion and formation of pipe through core connecting to reservoir.
- Internal erosion of core material into abutment defects leading to collapse of the core.

Preventive Measures

- Place Impervious fill material that is resistant to internal erosion.
- Durability, compressibility and permeability of the fill material to limit settlement and control seepage.
- Avoid or care in the use of dispersive soils.
- Check foundation material strength and potential defects.
- Avoid steps and sharp changes in grade in foundation that could initiate cracks in the dam core.
- Appropriate design of filter and drainage materials to prevent piping and control drainage of seepage.
- Employ sound construction practices that prevent defects in the dam, e.g. avoid segregation that creates near-horizontal preferential seepage paths.
- Prevent preferential paths for seepage and erosion at the abutments.

TN 3 – Seismic risk

1) Earthquake Intensity Levels for Dam Design
2) Choosing Probabilistic or Deterministic Seismic Hazard Assessments
3) Seismic Design Method for Embankment Dams
4) Seismic Design Method for Concrete Dams
5) Active features crossing dam or reservoir site
6) Liquefaction and Cyclic Softening Risk
7) Defensive Design Measures
8) Reservoir Triggered Seismicity
9) Seismic Instrumentation
10) Dams in High Seismic Zones

TN 3 – Seismic risk

Earthquake Intensity Levels for Dam Design

Earthquake Level being Considered	New or Existing	Performance Requirement	Hazard Category	Return Period of Design Earthquake
Safety Evaluation Earthquake (SEE)	New and Existing Dams	The dam must not suffer catastrophic failure or uncontrolled release of its reservoir that presents a life safety risk downstream. Significant damage to the dam or economic loss may be tolerated	High	Typically 10,000 years
			Medium or Significant	Typically 2.500 to 3,000 years
			Low	Typically 500 years to 1,000 years
Operating Basis Earthquake (OBE)	New and Existing Dams	Little or no damage occurs. Dam operation should continue without interruption	High or Medium	150 years to 500 years
			Low	150 years

TN 3 – Seismic risk

Defensive Seismic Design Measures

Embankment Dams

1) Filter and drainage improvements to prevent piping
2) Embankment geometry features to counter seismic deformations
3) Downstream filter buttress or drainage berm to control seepage
4) Improved embedded structures
5) Treatment of potentially unstable reservoir slopes

Concrete Dams

1) Avoid active faults for dam site
2) Geometry of interface to improve sliding resistance
3) Concrete with high tensile / compressive strength with u/s filet
4) Drainage increase to manage post-earthquake seepage
5) Shear transfer keys to lock blocks again
6) Avoid prominent crest features

Appurtenant Structures

1) Operable Low level discharge and spillway for post-earthquake use
2) Locate discharge equipment clear of rockfall risk
3) Consider amplified ground motions at dam crest. Strengthen gate lifting equipment.
4) Robust independent backup power and communications systems
5) Testing of hydro-mechanical equipment, including backup systems
6) Consider free overflow discharge if outlets are unreliable

TN 4 – Small Dams Safety

1. Objective and Scope of This Note
2. ESF Safety Requirements for Small Dams
3. General Information on Small Dams
4. Legal and Regulatory Aspects of Management of Irrigation System & Small Dams
5. Technical Requirements for Small Dams
   A. Safety of Small Dams
   B. Operation and Maintenance Requirements
   C. Surveillance and Monitoring of Small Dams
   D. Improving Construction Quality
6. Lessons Learned for Community Participation in Irrigation Management and Small Dam Safety
7. Environmental and Social Impacts
8. Recommendations

Typical Issues of Small Dams

- Chronic lack of financial and human resources for proper planning and design.
- Inadequate investigation and design during planning and construction.
- Inadequate supervision and quality control of construction works, such as use of unsuitable materials.
- Lack of as-built documentation.
- Unrecognition/ underestimation of safety-related signals/ occurrences.
- Inadequate or no maintenance; in many cases, lack of surveillance due to shortage of financial and human resources

General Guidance with Proportionality Considerations

Dam Safety Requirements	Large Dams	Small dams (small size, no complexity, negligible risk)
Independent Panel of experts	Required; three or more experts.	Independent review; could be one expert.
Dam Safety Plans	Required; four plans at specific schedule along project cycle.	Simplified; operator training sessions.
Bidders Pre-qualification	Required	Track record evidence.
Periodic safety inspection	Required	Desirable

Considerations to Local Communities Participation

- Awareness creation for dam safety among key stakeholders
- Identify and empower the entity, such as local community organization, water user associations, etc. responsible for surveillance, maintenance and operation
- Train responsible staff to enhance their understanding of safety-related tasks, and to serve as “trainers of trainees” for the community-level trainings
- Prepare a concise and clear description of duties and checklists including basic surveillance, emergency response and notification.
- Allocate budget to remunerate surveillance staff.

What can communities do?	With basic training	With some additional training
Surveillance	X	
Routine observations	X	
Seepage measurements (especially for long embankments)		X
Basic maintenance tasks		X
Respond to simple and clear emergency protocols		X

TN 5 – Potential Failure Mode Analysis

1. Definitions and origin of the PFMA
2. Objectives and applications of the PFMA
3. Critical assessment of the PFMA after the Oroville incident

    A-Standard Potential Failure Mode Analysis

        Scope of work

        Methodology of the PFMA Workshop

        Duration and Deliverables

    B-Simplified PFMA

        Individual Dam

        Portfolio of Dams

Definition of Potential Failure Modes Analysis (PFMA)

- Potential Failure Modes Analysis (PFMA) is a process to systematically identify, describe and evaluate ways a dam and its appurtenant structures could fail under postulated loading conditions.
- Qualitative Risk Assessment
- Since 2002, Potential Failure Modes Analysis (PFMA) has been introduced as part of 5-year inspections under the Federal Energy Regulatory Commission (FERC) regulations for non-federal hydropower dams in the US. The FERC Guidelines, Chapter 14 provides detailed description of the PFMA process.

https://www.ferc.gov/sites/default/files/2020-04/chap14.pdf

Objectives of PFMA

PFMA can be used both during design and operation of dams to:

- Identify potential failure modes;
- Identify additional defensive measures;
- Identify key parameters and provide instrumentation;
- Prepare or enhance dam safety plans.

Follows the general principles of FERC’s PFMA process but optimizes time and resources for client countries’ contexts.

- Considering quantity and quality of information available.
- May or may not be followed by a full-fledged PFMA.

PFMA Process

1. Joint site visit and workshop with a qualified facilitator
2. Brainstorm and Develop a master list of Potential Failure Modes
3. Identify Adverse and Favourable Factors
4. Screen All Potential Failure Modes (Initiating Events/Sequence/Consequences)
5. Identify Credible Failure Modes
6. Planning for Prevention /Mitigation Measures
7. Monitoring and additional needs for Data collection & Analysis
8. Documentation of Findings and recommendations

Scenario/Monitoring/Risk Reduction Opportunities/Data & Analysis

TN 6 – PRA using Risk Index

1. General
2. Risk Index Method in Three Steps
   A. Step One: Classification of Dam Risk
   B. Step Two: Select relevant measures for indexing risk
   C. Step Three: Assigning Weights to Risk Indexes
3. Safety assessment for a portfolio of dams
4. Risk assessment for individual dam
5. Required Cautions for Using Risk Index Approach

Annex A: Risk Classification System of Existing Dams in Canada (Quebec Province)

Annex B: India Risk Indexing Scheme under the Bank Financing

Annex C: Fatality rates with and without adequate warning

Risk Indexing (RI) Process

- The RI is <u>not</u> related to actual probability of failure.
- The approach is called a Risk <u>Index</u> because it provides an <u>indication</u> of potential levels of risk.
- The RI tool is not a measure of risk but provides a relative indication of potential levels of risk.
- Risks are quantified as deficiencies in the current physical state or condition of the dam.

Typical Risk Indicators

Risk (R) = Risk Category (RC) * Potential Hazard (PH)

Score for Technical Characteristics (TC) +	Score for Existing Condition (EC) +	Score for Dam Safety Plan (SP)
Technical Characteristics (TC), calculated by summation of respective points for dam height, length, construction material, foundation type, age, design flood return period, etc.	Existing Condition of Dams (EC), calculated by points for reliability of spillway, reliability of outlet structures, seepage, deformation/settlement, slope deterioration, sluice gate/hydro-mechanical maintenance, etc.	Dam Safety Plan (SP), calculated by points for existence of project documentation, organization structure/dam safety staff qualification, dam safety inspection/monitoring procedure, operational rules, dam safety reports with analysis and interpretation, etc.

Brazil Water Resources Council (CNRH) Normative Resolution No. 143 (2012) on Dams Classification Criteria

Safety Assessment for a Portfolio of Dams

- RI methods are best suited to assess risk of a portfolio of dams.
- The results typically include:
  - risk profile as baseline conditions
  - identification of higher risk dams and prioritization of remedial measures
  - improvement of dam safety management, intensified monitoring and surveillance
  - comparison of risk profile before and after project, and
  - development of a business and budget plan

Cautions to Risk Indicators

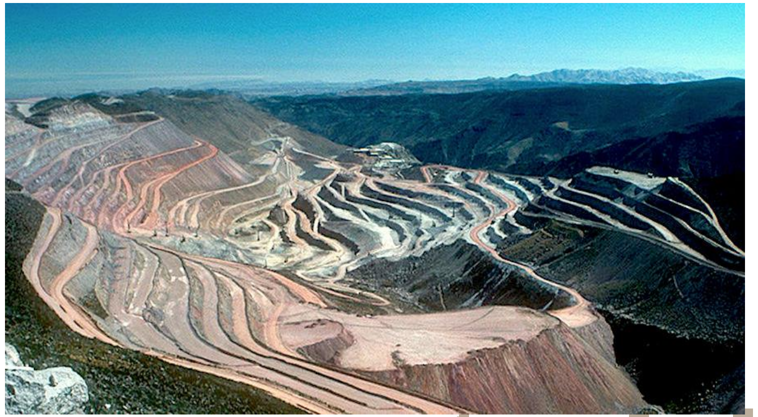
- RI is a basic tool for preliminary level risk analyses for portfolios of dams and initial screening of risky dams.
- Consistent application of RI for portfolio of dams is critical with adequate manual and training.
- In the higher risk cases, or whenever deemed appropriate, more detailed risk analyses, such as PFMA, are required.

TN 7 – Tailing Storage Facility

Tailings Dams & Water Storage Dams

Component	Tailings Dam	Water Dams
Stored Material	Tailings and Mine Waste	Water
Operation Life	5-40 years	100+ years but as required by society
Construction Period	Over lifetime of mine	1-3 years
Engineering Level	Medium-High	High
Quality Assurance	Critical, good for starter dam, variable for raises	Critical
Consequence of Failure	Significant Environmental Contamination	Water-inundation damage

Adapted from McLeod & Murray, 2003



Considerations to Reduce Risk

- Follow regulatory guidance documents.
- Conduct investigations to understand geological and geotechnical site conditions.
- Use experienced specialists in design and construction and operational management.
- Implement best practices in design and management.
- Ensure quality assurance during construction.
- Monitor the structure with instrumentation.
- Dam safety training for all staff involved in the project.

Thank you!

Good Practice Note on Dam Safety: https://hdl.handle.net/10986/35484

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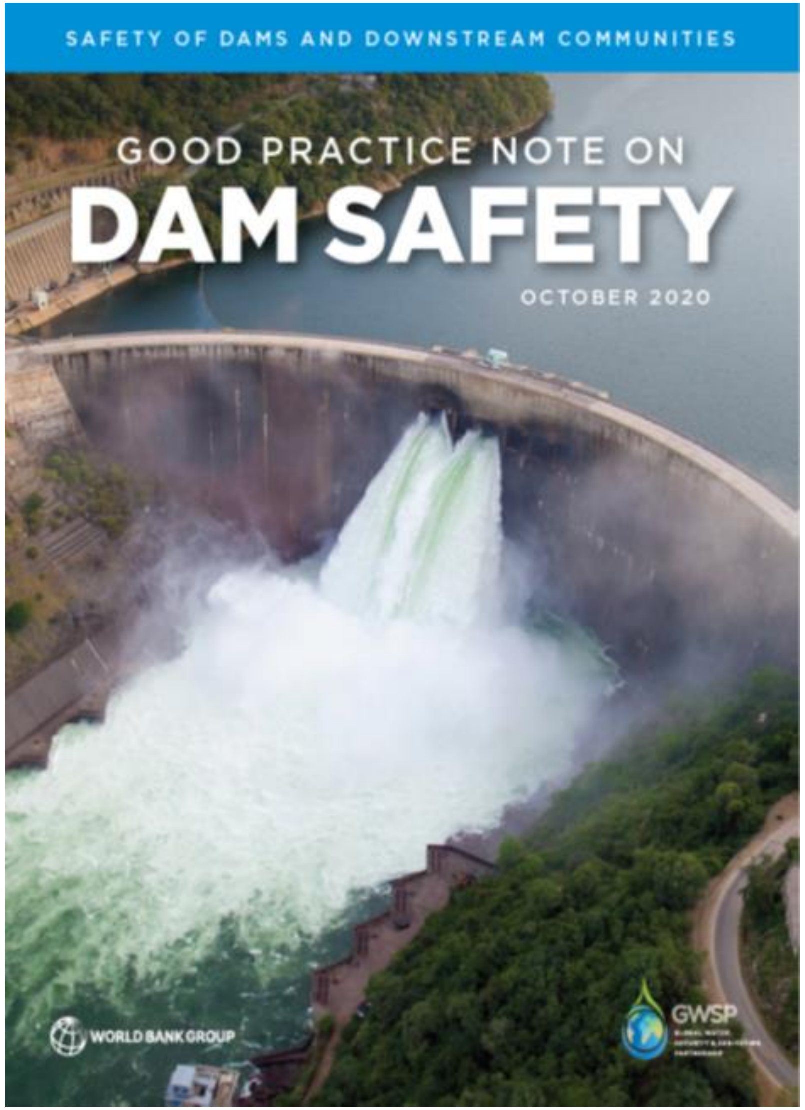

WORLD BANK GROUP Water

GWSP GLOBAL WATER SECURITY & SANITATION PARTNERSHIP