Dam and Downstream Community Safety Initiative

Preventing Loss of Life and Economic Damage from Natural Hazards Causing Extreme Dam Discharges in Viet Nam

Potential Failure Modes Workshop

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Delivered by

Collaboration of Water Resources University (WRU), GNS Science and Damwatch, in association with the Viet Nam Commission on Large Dams (VNCOLD)
Introduction and Description of Potential Failure Modes Analysis

1. Where we are at in the Dam and Downstream Consequence Project
2. Use of Failure Modes
3. Failure Modes Definitions
4. Examples of Failure Modes
5. Use of Failure Modes to Define Breach Hydraulics
Fundamental Project Objective:

Reduction in lives lost and economic damage from dam related disasters, because of:

– Improved dam management and safety practices
– Improved disaster risk management
Spillway Radial Gate Failure
At Folsom Dam, California
July 17, 1995

40,000 Cubic Feet
Per Second Discharge
Damage from South Fork Dam, USA

Originally built 1838-1853, failed in 1889 after 31-46 years of service
Project Components

Understanding natural hazards applying to catchment

Dam condition and management difficulties

Consequences of extreme discharge and disaster risk management to protect people
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What could happen?

- People
- Economy
- Lifelines
- Businesses
- Buildings
- $ Damage

Disaster impacts
Unintentional Release of Water

• Overtopping
• Seepage
• Misoperation
• Breaching failure
How Failure Modes Are Used

Identify Hazards
Identify factors that could result in failure (seismic, flood, landslide loading)

Potential Failure Modes Analysis

Consequence Assessment
Assess results of dam failure on downstream people, property and infrastructure.

Emergency Preparedness Planning; Disaster Risk Reduction

Standards for Dam Design & Reservoir Operation

Dam Surveillance & Monitoring
Relate potential failure modes to monitoring program
Potential Failure Mode Analysis (PFMA)

An examination of all of the ways that the dam might fail.

- Based on a review of:
  - existing data and information,
  - performance history
  - input from field personnel,
  - site inspection, and
  - engineering analyses.

- Requires discussion of:
  - dam characteristics,
  - failure causes, and
  - potential consequences of failure.
Failure Mode

• The means that cause a dam to have a sudden, rapid, and uncontrolled release of impounded water.

• Determined by which element or component failures must occur to cause loss of a system or subsystem that could result in dam failure.
Elements of a Failure Mode

Three elements of a potential failure mode are:

1. The Initiator
   – e.g. Reservoir level and/or load, Deterioration/ aging, Operation malfunction, Earthquake

2. The Failure Mechanism
   – including location and/or path (Step-by-step progression)

3. The Resulting Impact on the Structure
   – e.g. Rapidity of failure, Breach characteristics
Examples of Potential Failure Modes relating to Discharge Facilities

- Reduced spillway capacity (debris, gate malfunction, orifice flow under gates, fuse plug fails to erode, etc.) leads to overtopping erosion
- Mis-operation due to faulty instrumentation
- Cavitation or scour failure of spillway chutes or linings
- Overtopping of spillway walls leading to erosion
- Seismic failure of spillway piers and jamming or loss of gates
- Failure of large spillway gates releasing life-threatening flows
- Inadvertent opening from communications problem, buckling of radial gate arms (seismic or friction)
Examples of Potential Failure Modes for Concrete Dams

• Differential deformation (inducing stresses exceeding the structural capacity) leading to cracking and displacement

• Plugging of drains or unprecedented reservoir loads perhaps leading to the following:
  – Sliding along weak discontinuities in the foundation of concrete dams
  – Sliding on poorly bonded lift joints in concrete gravity dams

• Abutment slope failure

• Seismic cracking/sliding of concrete gravity dams, arch dams or buttress dams
Examples of Potential Failure Modes for Embankment Dams

- Internal erosion of embankments:
  - Due to lack of compatible filters
  - Along vulnerable paths including adjacent or into conduits or walls and into drains
  - Through flaws caused by differential settlement, arching, poor construction, etc.
  - Into geologic defects such as open joints or open-work gravel

- Seismic settlement or liquefaction, exceeds freeboard or allows seepage erosion through cracks

- Piping of alluvial material from beneath dam
Dam failures are most likely to happen for these reasons:

- **Inadequate maintenance** – Roots from trees can create seepage paths. Bushes harbor rodents, which can damage the dam.
- **Cracking** – Caused by movements such as the natural settling of a dam.
- **Seepage path** – Water passes through the dam and can cause damage.
- **Overtopping** – Water spilling over the top of a dam can cause damage.
- **Structural failure** – Caused by stress or instability from materials used in dam construction.
- **Piping** – When seepage through a dam worsens, forming sinkholes.
- **Transverse cracking** – Caused by shrinkage of embankment materials from severe drying and/or settlement in the embankment or foundation.
- **Stability failure** – The foundation or other features that hold the dam in place may collapse.

*Courtesy of Association of State Dam Safety Officials, USA*
Use of Failure Modes to Define Breach Parameters

• Define ultimate size of the break.
  – elevation at the top of the break.
  – elevation at the bottom of the break.
  – width at the bottom of the break.
  – side slopes of the break opening in the dam face.

• For overtop or piping mode determine elevation where the piping hole opens.

• Define the development time.
  – Length of time required for break to grow from initiation to ultimate size.
  – Identify the "critical" time, which begins with significant outflow and ends when the breach stops growing significantly. Reservoir may still contain a large volume of water when breach stops growing.
Next Steps

1. Site specific failure assessment of subject dam sites
2. Breach hydrograph determination
3. Dam break model development
4. Inundation mapping