Risk Analysis

HOW DID WE GET HERE AND WHERE ARE WE GOING?

Steven G. Vick
1. The purpose of risk analysis is to improve dam safety
   • diagnostic – improved understanding of dam and its vulnerabilities
   • efficiency – allocating resources to maximize risk reduction

2. The purpose of risk analysis is not
   • to calculate a number
   • to prove the dam is safe
   • to avoid dam safety modifications
Potential failure mode analysis (PFMA)

• based on detailed, site-specific failure mode description and propagation

Flow through the dike embankment across the Zone 1/ foundation interface. This could result in the Zone 1 materials eroding and being carried through the open joints to an unprotected exit downstream. (Failure would result if backward erosion (piping) through the Zone 1 materials reached the reservoir source. An ever increasing flow potential could then progressively enlarge the flow channel downstream of the point of erosion initiation in the core to an extent large enough to carry continually increasing flows).

• informally categorizes failure modes according to “significance”

• stresses understanding of failure modes in monitoring and operation (diagnostic)

<table>
<thead>
<tr>
<th>Category I</th>
<th>Highlighted Potential Failure Modes</th>
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<tbody>
<tr>
<td>Category II</td>
<td>Potential Failure Modes Considered but Not Highlighted</td>
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<td>Category III</td>
<td>More Information or Analyses needed to Classify</td>
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<td>Category IV</td>
<td>Potential Failure Mode Ruled Out</td>
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</table>
Failure modes and effects analysis (FMEA)

Qualitative

- rank-ordered likelihoods
- relative, not absolute measures
- applicable for individual dam

Quantitative

- broad probability ranges for likelihood
- descriptive consequence categories
- allows for comparison among dams
Probabilistic risk analysis (PRA or Event Tree)

- detailed treatment of failure mode
- decomposes failure sequence into component events/conditions
- reduces overconfidence bias for event probabilities
- allows for comparison among dams
- can be used with f-N criteria for life loss and tolerable risk
- order-of-magnitude uncertainty bounds
US Bureau of Reclamation (USBR)

Design  Dam safety (SEED)  Risk (RIDM)

failure statistics (internal erosion)  FMEA  PRA/tolerable risk guidelines

1976 Teton (internal erosion)  1979 (Jimmy Carter)

Corps of Engineers (USACE)

Design/dam safety

Risk (RIDM)


FMEA and PRA (adapted from USBR)

2005 Katrina
Federal Energy Regulatory Commission (FERC)

Dam safety regulation (3000 dams)  Risk (RIDM)


PFMA
Mining Industry (tailings dams)

- 1970
- 1980
- 1990
- 2000
- 2010

- Nuclear industry
- FMEA
- Design/permitting
Organizational cultures

<table>
<thead>
<tr>
<th>characteristic</th>
<th>USBR</th>
<th>USACE</th>
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<tr>
<td>organizational structure</td>
<td>amorphous entrepreneurial</td>
<td>hierarchical top-down</td>
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<tr>
<td>goals and objectives</td>
<td>flexible</td>
<td>procedural</td>
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<tr>
<td>adaptability to change</td>
<td>reinvented twice</td>
<td>est. 1775 by G. Washington</td>
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<tr>
<td>RIDM implementation</td>
<td>serves as model</td>
<td>transition</td>
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<td>primary mission</td>
<td>risk-based dam safety</td>
<td>design</td>
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<tr>
<td><em>organizational crisis</em></td>
<td><em>Teton</em></td>
<td><em>Katrina</em></td>
</tr>
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Dam Safety Mission Statement:

"To ensure Reclamation dams do not present unreasonable risk to people, property, and the environment."
USACE post-Katrina
“12 Actions for Change”

- Employ integrated, comprehensive and systems based approach
- **Employ risk-based concepts in planning, design, construction, operations, and major maintenance**
- Continuously reassess policy for program development, planning guidance, design and construction standards
- Employ dynamic independent review
- Employ adaptive planning and engineering systems
- Focus on sustainability
- Review and inspect completed works

- **Effectively communicate risk and reliability with the public and within the Corps**

- **Assess and modify organizational behavior**
  - Manage and enhance technical expertise and professionalism
  - Invest in research
USACE – current (2014)

Dam Safety Policy and Procedures (regulation no. 1110-2-1156):

**Risk Informed Corporate Approach.** The USACE dam safety program will be managed from a risk-informed USACE-wide portfolio perspective applied to all features of all dams on a continuing basis.
The classic homunculus
The design homunculus

deductive reasoning (analysis-based)

FMEA

permit

PMF

FS
MCE

design standards
criteria

guidelines

analysis
The risk homunculus

*inductive reasoning (evidence based)*

*a different way of thinking*

*a different way of seeing the world*
Oroville Dam

service spillway structural failure, Feb. 7, 2017
- design capy = 150,000 cfs
- failed at 54,500 cfs (36%)

emergency spillway (30’ concrete gravity) headward erosion, Feb. 11, 2017
- design capy = 300,000 cfs
- erosion at 12,600 cfs (4%)
Oroville Dam

emergency spillway – 2004 PFMA

We have recently re-evaluated the Oroville Dam emergency spillway, FERC Project No. 2100, with regard to dam and project safety. The safety of the emergency spillway was reviewed during a FERC Potential Failure Mode Analysis (PFMA) session held on September 15, 2004. The PFMA session is part of our dam safety evaluation and at the session, it was determined by FERC, the licensee, and consulting dam safety engineers that operation of the emergency spillway would not threaten the Oroville Dam.

so far (April 2017):
• dam has not been threatened

but:
• 188,000 residents evacuated (= PAR)
• $275 million repair costs

system defined in overly restrictive way
Mt. Polley PFMA

Independent (third-party) Dam Safety Review, 2006

“[Failure] mode:
Shear failure of the slope, including failure through the foundation, due to self-weight of structure and elevated water levels in the containment structure”

failed by undrained shearing through the foundation, 2014

“In terms of potential slope stability concerns relative to the modes of failure deemed possible...there are no real dam safety issues.”
Tailings Dam example

- the imperative of dam raising
- internal erosion symptoms
- lack of interpretation
- “normalization of deviance”

Diagnostic application of FMEA
- acknowledge internal erosion as the dominant failure mode
- define internal erosion failure pathways in detail
- provide framework and context for collecting and connecting the dots:
  - seepage observations and measurements
  - piezometer locations and data analysis
- living document to track changes in risk over time
Exposure period and inventory

\[ p_{n,t} = [1 - (1 - p_i)^{nt}] \]

1. **for any individual dam that retains water**
   
   - the cumulative probability of failure increases exponentially with time: for any nonzero \( p_i \), as \( t \to \infty \) \( p_{n,t} \to 1.0 \)
   
   - base-rate failure frequency: \( p_i = 1.7 \times 10^{-3} \) /dam/yr for BC tailings dams
     
     \( \sim 1 \times 10^{-4} \) /dam/yr for water dams

2. **for a portfolio of dams that retain water**
   
   - the probability of one or more failures increases exponentially with the number of dams in the inventory
Future directions

1. Risk-based thinking and methods will continue to become embedded in dam safety practice

2. Methods will be adapted to organizational needs

3. Organizational change will embrace risk-based thinking and methods

4. A broad spectrum of risk-based methods will be included in engineering curricula

5. Bayesian statistics, AI, neural networks will be applied to likelihood assessment
Future directions

6. Tailings dam risks and consequences will be the mining industry’s Achilles’ heel, challenging the concept of tolerable risk.
Summary

• risk-based methods were conceived to remedy the mismatch between design-based safety assessment and the actual causes of failures

• risk analysis is a way of thinking, not a procedure

• to be successful, risk-based thinking needs to be embedded in organizational values and culture