RECLAMATION

Managing Water in the West

Reclamation's processes for evaluating potential internal erosion concerns in embankment dams

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Significance of Internal Erosion in Embankment Dams

- **It's the leading cause of embankment dam failures**
  - **60 percent of all failures in the western United States are due to internal erosion**
  - **Nearly 50 percent of all worldwide failures are due to internal erosion**

- **It's the cause of the vast majority of incidents in Bureau of Reclamation embankment dams**
  - **Approximately 1 out of every 4 Reclamation embankments has experienced an internal erosion incident**
  - **The incidents have occurred in dams ranging in age from 1 to 94 years**

Many or Most Embankment Dams are not "Modern"

- Most Reclamation dams were built without key modern features such as internal filters/drains and did not incorporate current foundation treatment measures
- As such, they do not have the latest design features to safely protect against internal erosion
- However, it is financially impractical to modify all of our nearly 300 dams to bring them to current state-of-the practice

Technical Difficulties in Evaluating Internal Erosion Potential

- Internal erosion is an extremely complex process, with seepage traveling at different rates through heterogeneous natural or engineered soils which in turn have variable properties

- The spatial area involving internal erosion through an embankment and/or foundation is very large

- Internal erosion more likely to attack the “weak link” or vulnerable portion of a system

Technical Difficulties in Evaluating Internal Erosion Potential

- Seepage models (and existing instrumentation) can provide gradient information at certain locations, but typically model idealized conditions, typical permeabilities, and may not capture the critical flow path

- Similarly, laboratory tests can assess how small samples of potentially representative soils will behave, but are unlikely to represent the entire flow path within soils or possibly the critical area

Reclamation Approach to Evaluating Internal Erosion Potential

- Given the complexities involved in evaluating whether internal erosion poses a threat, we recognize that it is impossible to assess the likelihood of internal erosion with absolute certainty

- Rather than expend significant monies to reach a conclusion that won't be definitive or perhaps fully defendable, we use a number of prudent components of a dam safety program to help ensure our embankment dams are exposed to a low risk of failure due to internal erosion

Reclamation Approach to Evaluating Internal Erosion Potential

- Two general components to the approach could be described as:
  - Monitoring and engineering analysis
  - Risk evaluation

- "Monitoring and engineering analysis" consists of monitoring in the field and use of traditional engineering approaches and analyses

- "Risk evaluation" consists of development of failure modes and quantitative risk analysis

Monitoring and Engineering Analysis

- **This component of Reclamation's dam safety program includes:**
  - **A comprehensive monitoring program, consisting of both instrumentation and visual observations**
  - **Periodic use of geophysics, small camera surveys, and similar technologies to help understand why may be occurring within a dam or foundation**
  - **Limited laboratory testing**
  - **Limited use of numerical analyses**

Seepage Monitoring (Weirs, Piezometers, Visual Inspection)

- **Advantages:**
  - Can see changes in behavior (with time or with pool level)
  - Can verify whether behavior is within expected limits
  - Can detect sediment transport
- **Disadvantages:**
  - Not all seepage can be captured and measured
  - Piezometers may not be located in critical flow paths
  - Some internal erosion mechanisms can manifest very suddenly, with little advance warning
  - A dam can fail from internal erosion rapidly, between regularly scheduled visual observations

Special Tools/Techniques (Geophysics, Closed circuit TV surveys)

- **Advantages:**
  - **Non-invasive methods**
  - **Geophysics can identify anomalous areas**
  - **CCTV can get to otherwise inaccessible areas**
- **Disadvantages:**
  - **Geophysics frequently result in false positives**
  - **Verification borings usually needed to confirm geophysics**
  - **CCTV cameras can not always access important areas, particularly in small drain pipes with 90-degree bends**

Numerical and Physical Models (Seepage analyses, laboratory testing)

- **Advantages:**
  - **Can estimate representative behavior of system**
  - **Analysis helps predict gradients and velocities**
  - **Testing helps predict soil erodibility at various gradients**
- **Disadvantages:**
  - **Extremely difficult to model "weak link"**
  - **Both natural and engineered soils are quite variable, with permeabilities that can vary by orders of magnitude, which means gradients and velocities can vary greatly along a seepage path**
  - **Laboratory testing can only test a relatively small sample, while the entire field system is vast**

Risk Evaluation

- The disadvantages of some of the previous tasks or activities leads to the need for an additional component that attempts to utilize all available information and develop a sense for potential risks
- This second component of Reclamation's dam safety program includes:
  - Development and evaluation of potential failure modes, as related to internal erosion
  - Quantitative risk analysis to estimate the risks of failure from any credible internal erosion potential failure modes
  - Comparison of estimated risks to Reclamation's Public Protection Guidelines to see if actions are justified to better define or reduce risks

Potential Failure Mode Evaluation

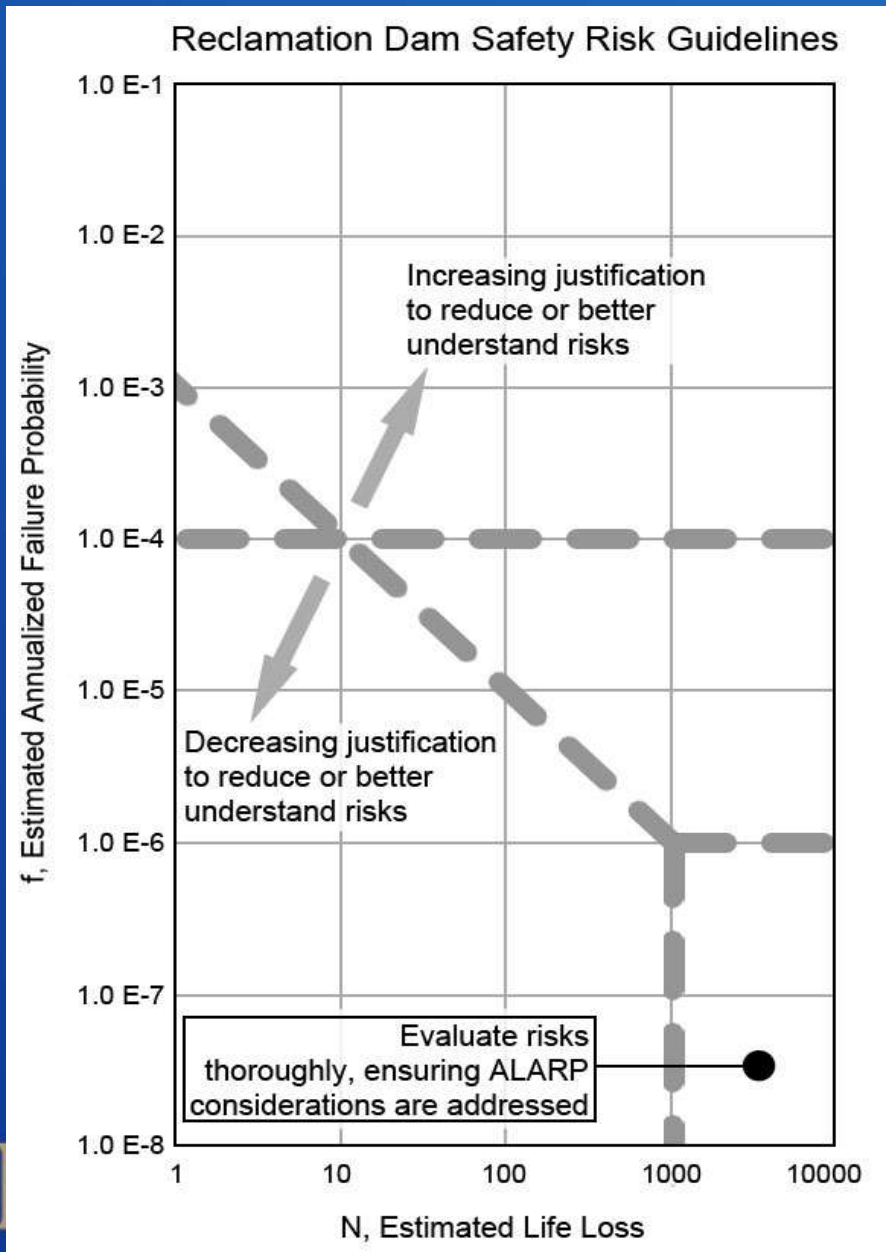
- **Advantages:**
  - Involves a team to get various viewpoints and experience
  - Necessitates a thorough review of records
  - Forces team to think about strengths and vulnerabilities
  - Leads to a well defined series of steps needed for failure
  - Provides the fundamental basis for risk analysis
- **Disadvantages:**
  - Available records are sometimes lacking
  - Some team members may be reluctant to share insights

Quantitative Risk Analysis

- **Advantages:**
  - **Logical extension of potential failure mode analysis**
  - **Involves a team to get various viewpoints and experience**
  - **Forces team to think about strengths and vulnerabilities**
  - **Leads to a thorough understanding of the potential internal erosion mechanisms by which a given dam may fail**
  - **Provides a relative risk estimate that can measure/compare the potential risks at a given dam**
- **Disadvantages:**
  - **Risk estimates are not "precise" or the "absolute truth"**
  - **Risk estimates alone are not enough – teams also need to "build the case" for the risks of potential failure modes**

Application to Guidelines

- Estimated risks are compared to established guidelines to assess whether additional actions are necessary
  - Allows various dams to be compared and prioritized
  - Allows risks to be compared to determine which dams require corrective actions



Final Thoughts

- A fundamental weakness with any efforts to assess the potential for internal erosion to develop stems from the difficulties in anticipating where the critical “weak link” will be in a spatially vast embankment/foundation system

- Even extensive modeling, testing, and instrumentation programs may not locate the critical meandering seepage pathway and locations of vulnerable soil conditions

Final Thoughts

- **The best chance at minimizing the development of internal erosion in an embankment dam is to have a comprehensive and integrated dam safety program that involves monitoring, periodic investigations, supplemental testing and analysis as needed, and an evaluation process involving the identification of potential failure modes and the estimation of potential risks of failure**

Final Thoughts

- **Ralph Peck said that reducing dam failures "depends on our ability to bring the best engineering judgment to bear on problems that are essentially non-quantitative, having solutions that are essentially non-numerical"**

- **Through the process of gathering data, reviewing performance, brainstorming failure modes, and estimating the likelihood of the various steps required to lead to failure; a team in fact develops and applies this type of judgment**

Thank you
for your attention