

Buttress Dams

Best Practices in Dam and Levee Safety Risk Analysis

Part E – Concrete Structures

Chapter E-5

July 2019



US Army Corps
of Engineers®



Outline

- Objectives
- Key Concepts
- Load Carrying Mechanism and Types
- Case Histories
- Seismic Considerations
- Takeaway Points



Objectives

- Understand the mechanisms that affect buttress dam failure.
- Understand how to construct an event tree to represent buttress dam failure.
- Understand how to estimate nodal probabilities and probability of breach.



Key Concepts

- Buttress dams constructed mainly in early 20th century when labor was cheap and materials were expensive.
- Buttresses saved on concrete but light structures required upstream sloping water barriers – water force acting downward needed for stability.
- Designed to carry load in stream direction, but did not consider (seismic) loading in cross-stream direction.
- Cracking or yielding of reinforced concrete members does not equal dam failure

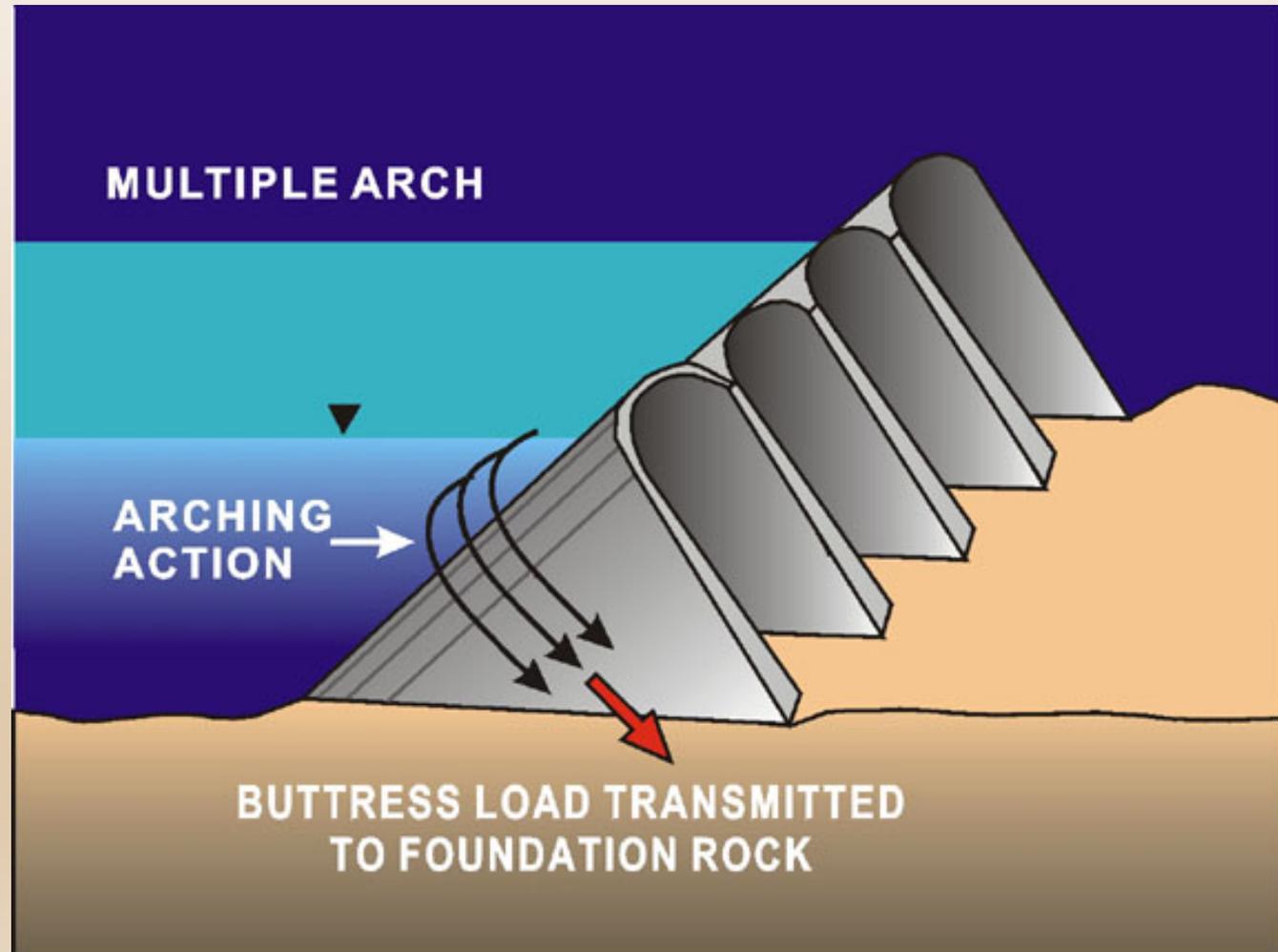


Load Carrying Mechanism and Types



Buttress Dams

- Early 20th century
- Expensive materials
- Cheap labor
- Sloped upstream face needed for stability

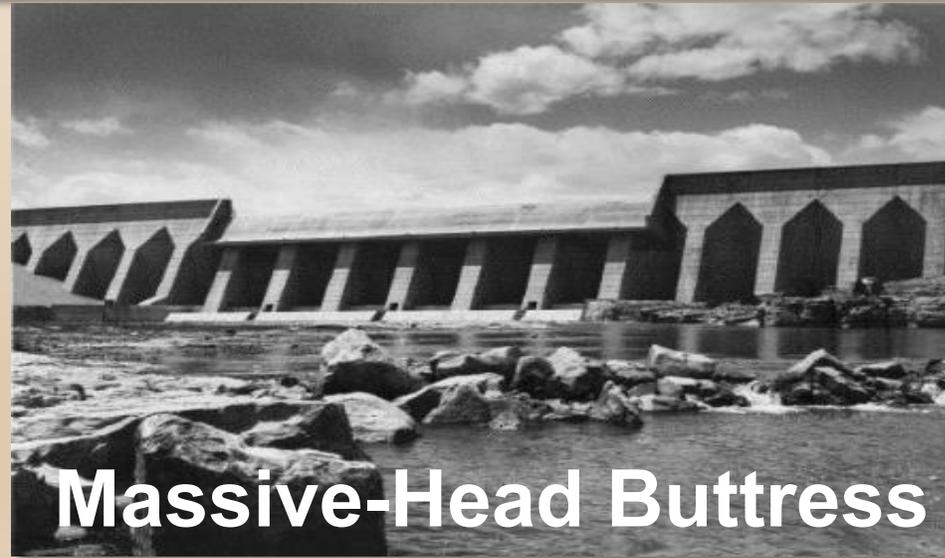


Slab and Buttress

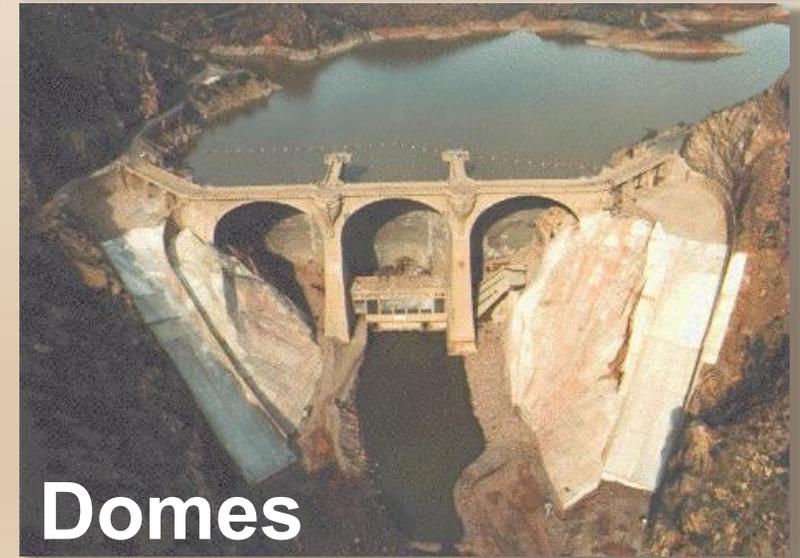


Also known as an Amburesen Dam

Multiple Arch



Massive-Head Buttress

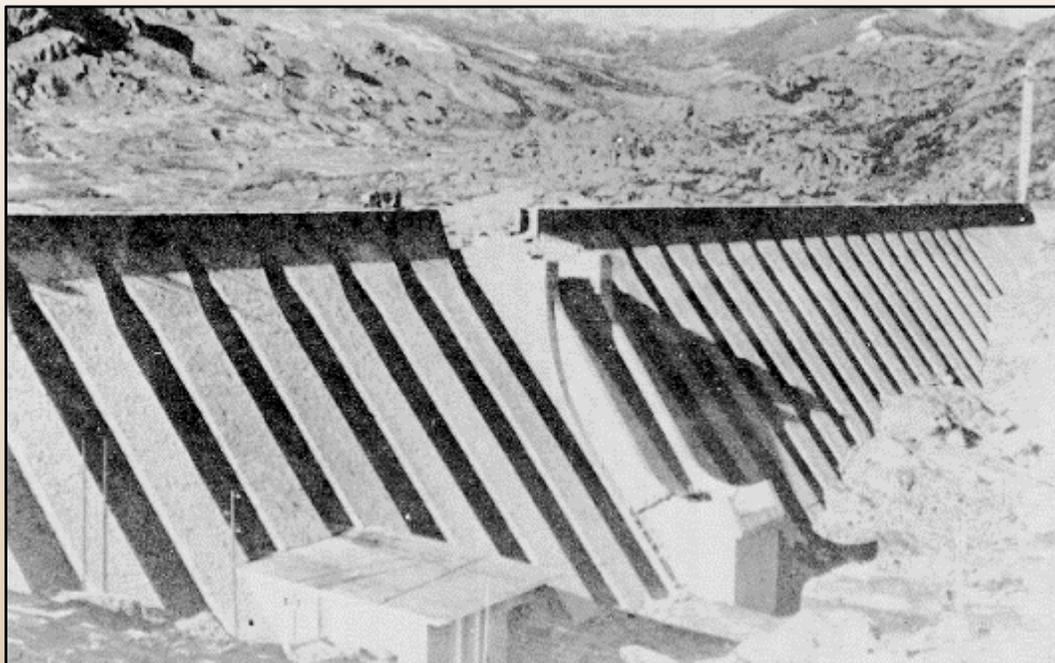


Domes

Case Histories



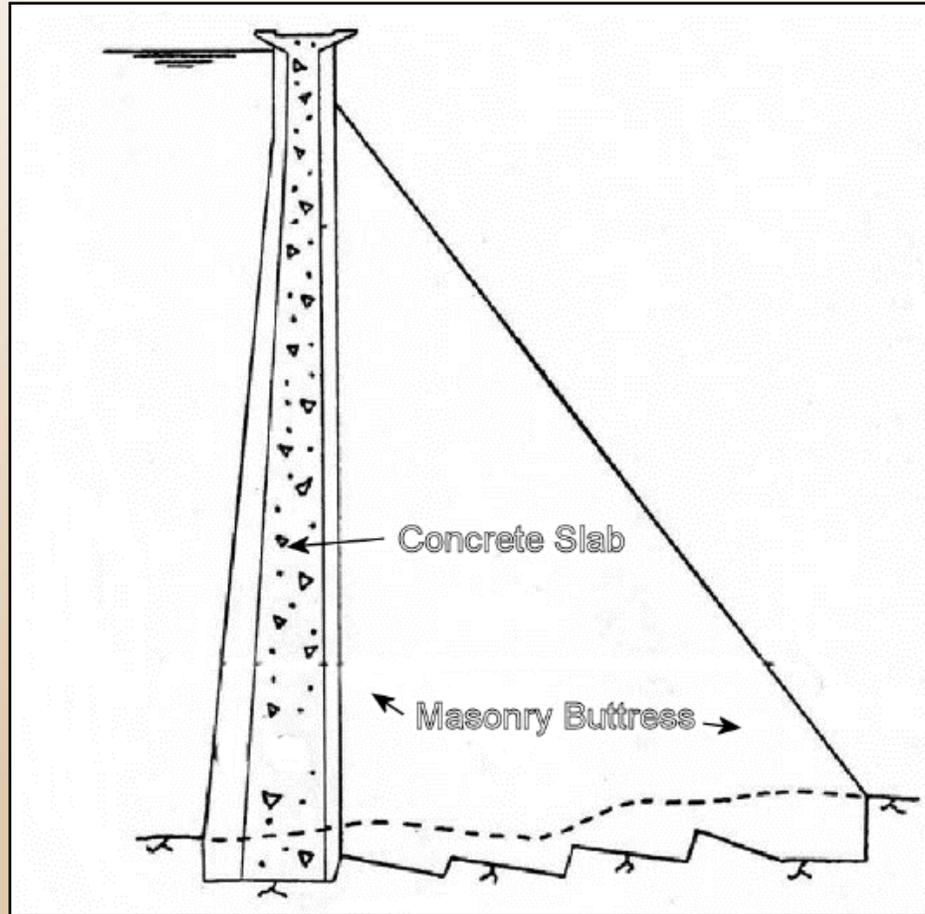
Vega de Tera Dam, Spain



- 112' high buttress dam completed 1957
- Winter shutdown, little attention to lift joints
- Failed January 10, 1959
- 144 fatalities



Vega de Tera Dam, Spain



But not much slope on u/s face!

- Buttresses cement mortared masonry.
- Grouting in 1956 to control leakage.
- Reservoir full in 1958. Empty in October 1958.
- In January 1958, heavy rains filled reservoir.
- 17 buttresses failed in rapid succession.
- Failure initiated between masonry and concrete on sloping portion of foundation.
- Modulus of masonry = 140,000 lb/in².
- Official cause of failure attributed to large deformations due to low modulus masonry.

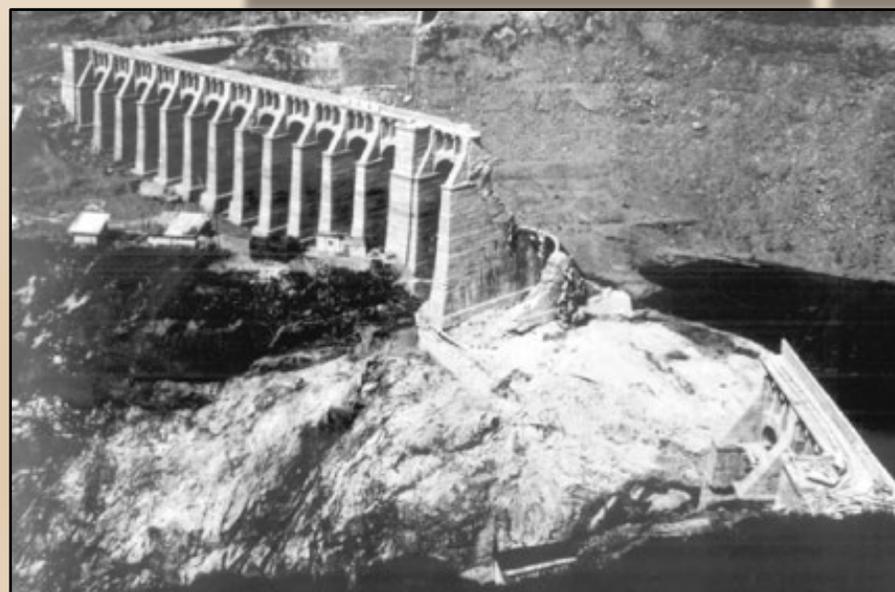
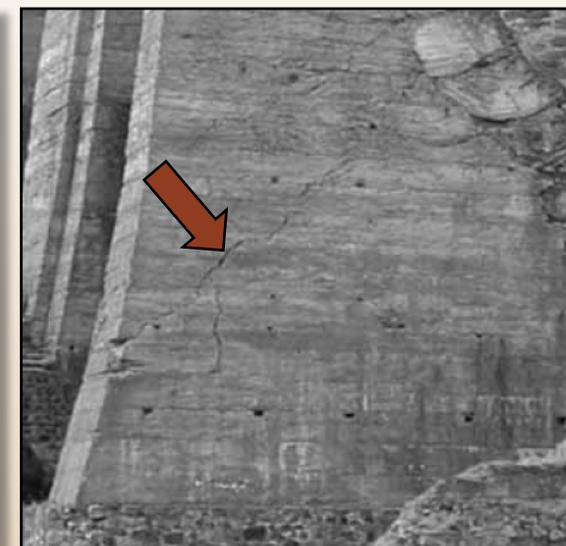
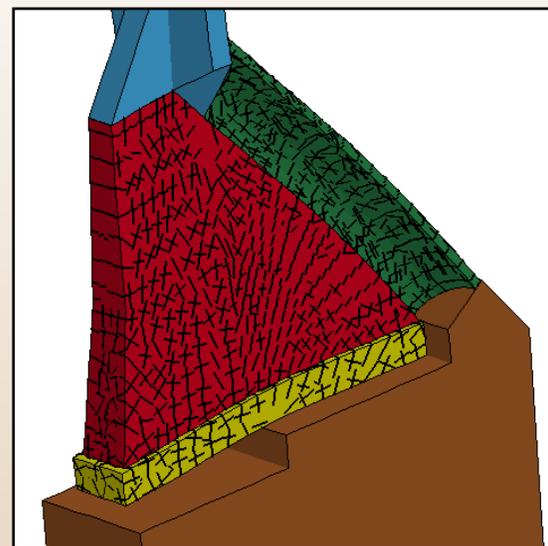
Gleno Dam, Italy



- 164-ft high multiple arch
- 52-foot high masonry plug constructed in deep central gorge (lime mortar instead of specified cement mortar)
- Original design called for gravity dam; design changed and dam built prior to approval
- Poor concrete quality
- Dam survived nearly full for 2 months
- Failed October 22, 1923
- 100-foot high wave, widespread destruction in Dezzo River Valley
- 356 fatalities

Gleno Dam Failure

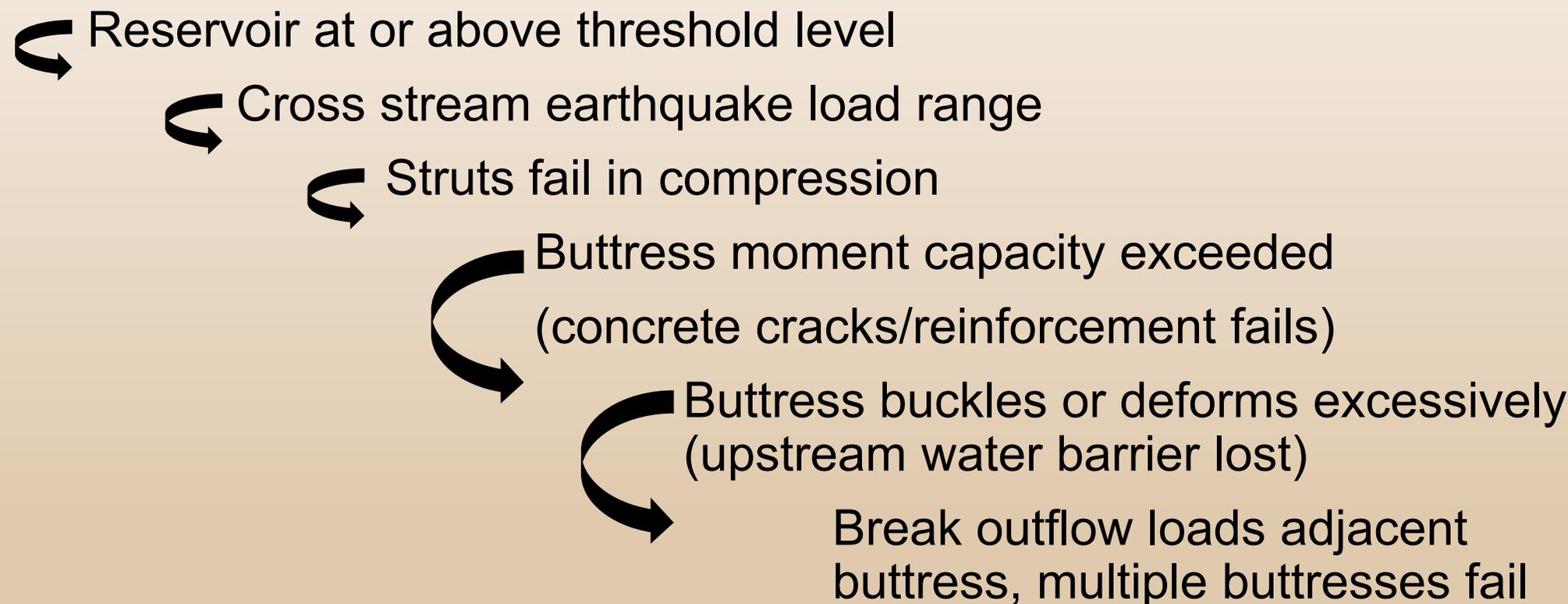
- Official inquiry indicated the masonry plug was not stiff enough nor did it extend far enough downstream to carry the buttress loads.
- With complete loss of contact over the front 35 foot of foundation (representing the downstream portion of the masonry plug), the finite model depicted here fails catastrophically!
- FE model predicted cracking matched observed cracking



Seismic Considerations

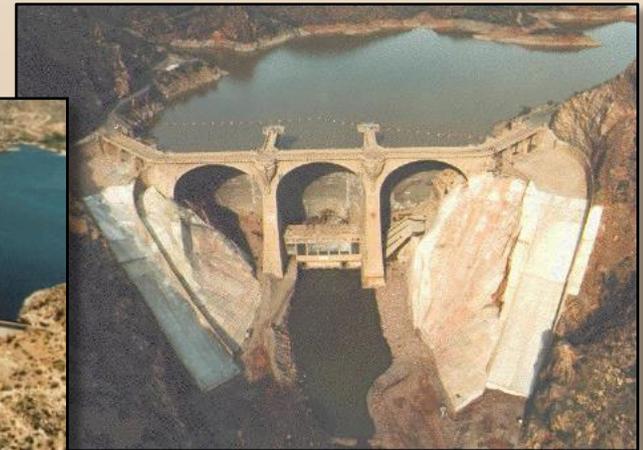
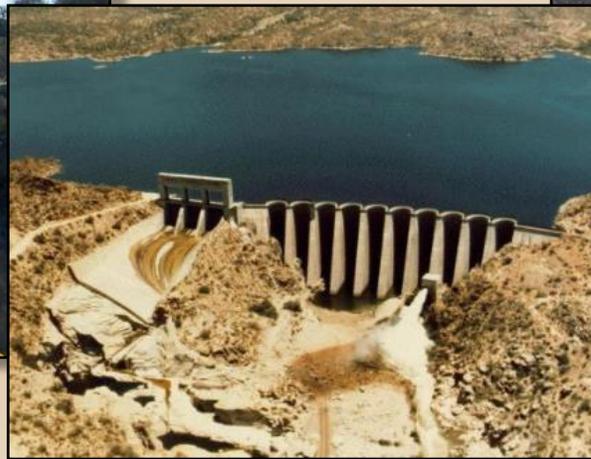


Typical Event Tree for Seismic Evaluation



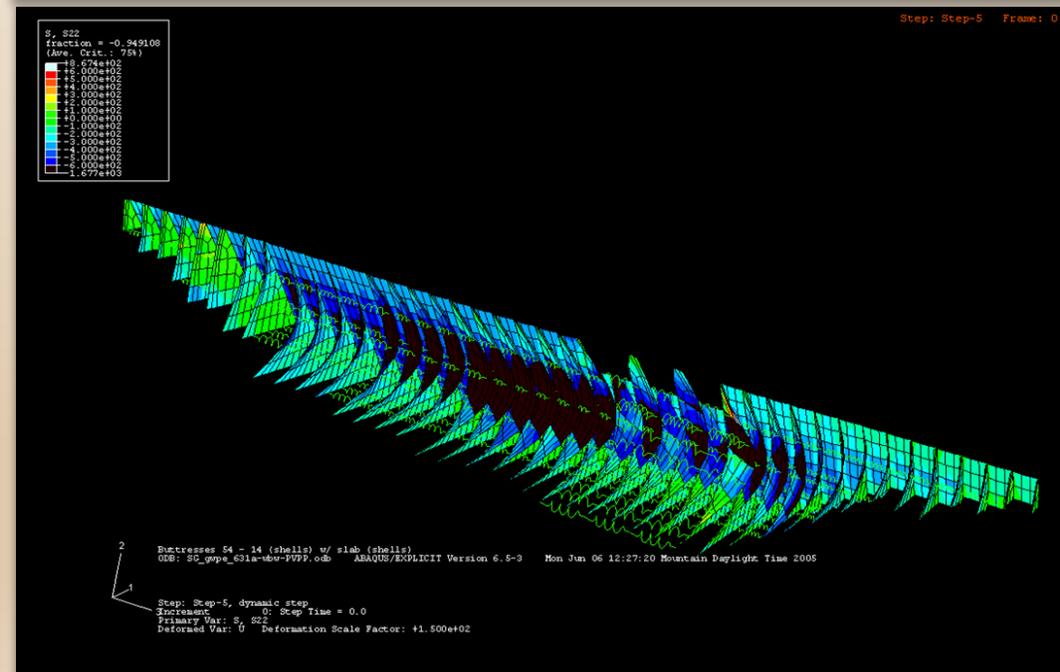
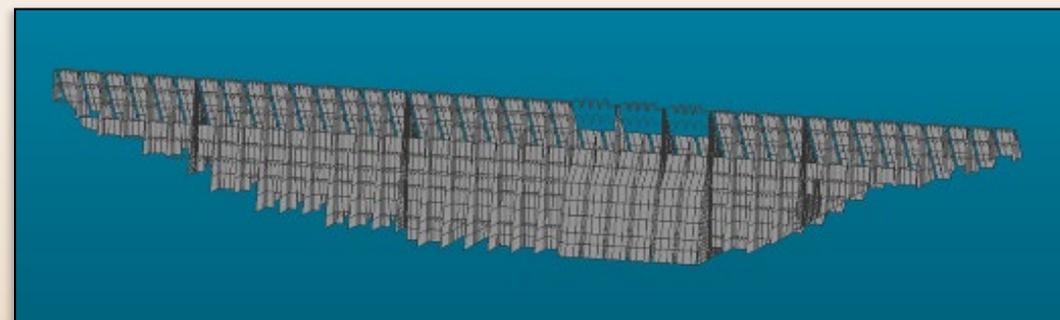
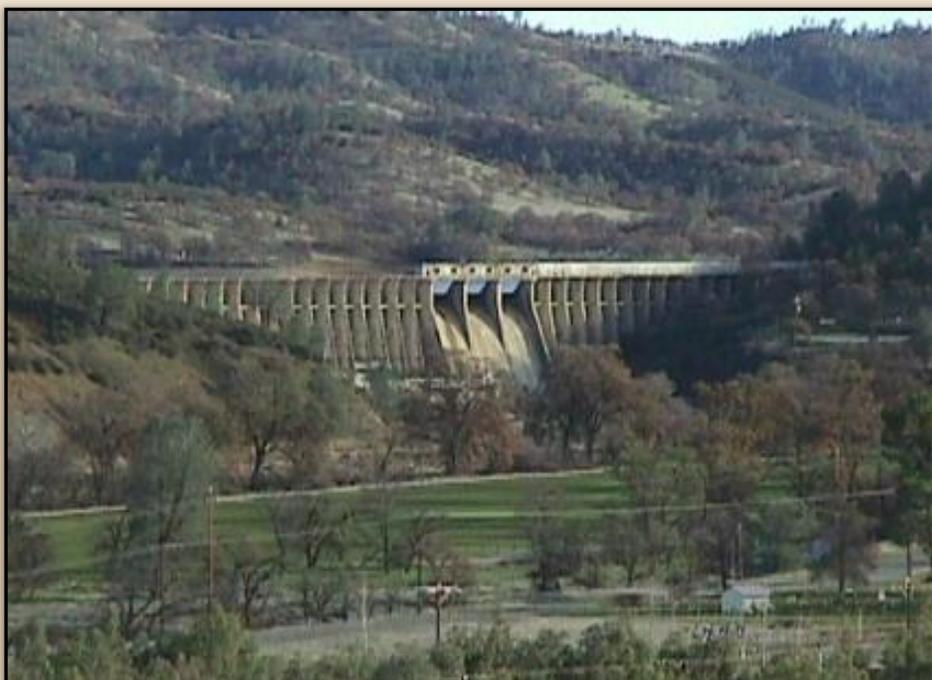
Water Barrier Evaluation

- Note that the previous event tree did not address the upstream slabs/corbels, arches, or domes.
- This would be a separate potential failure mode that should be evaluated using reinforced concrete principles (covered in another chapter).



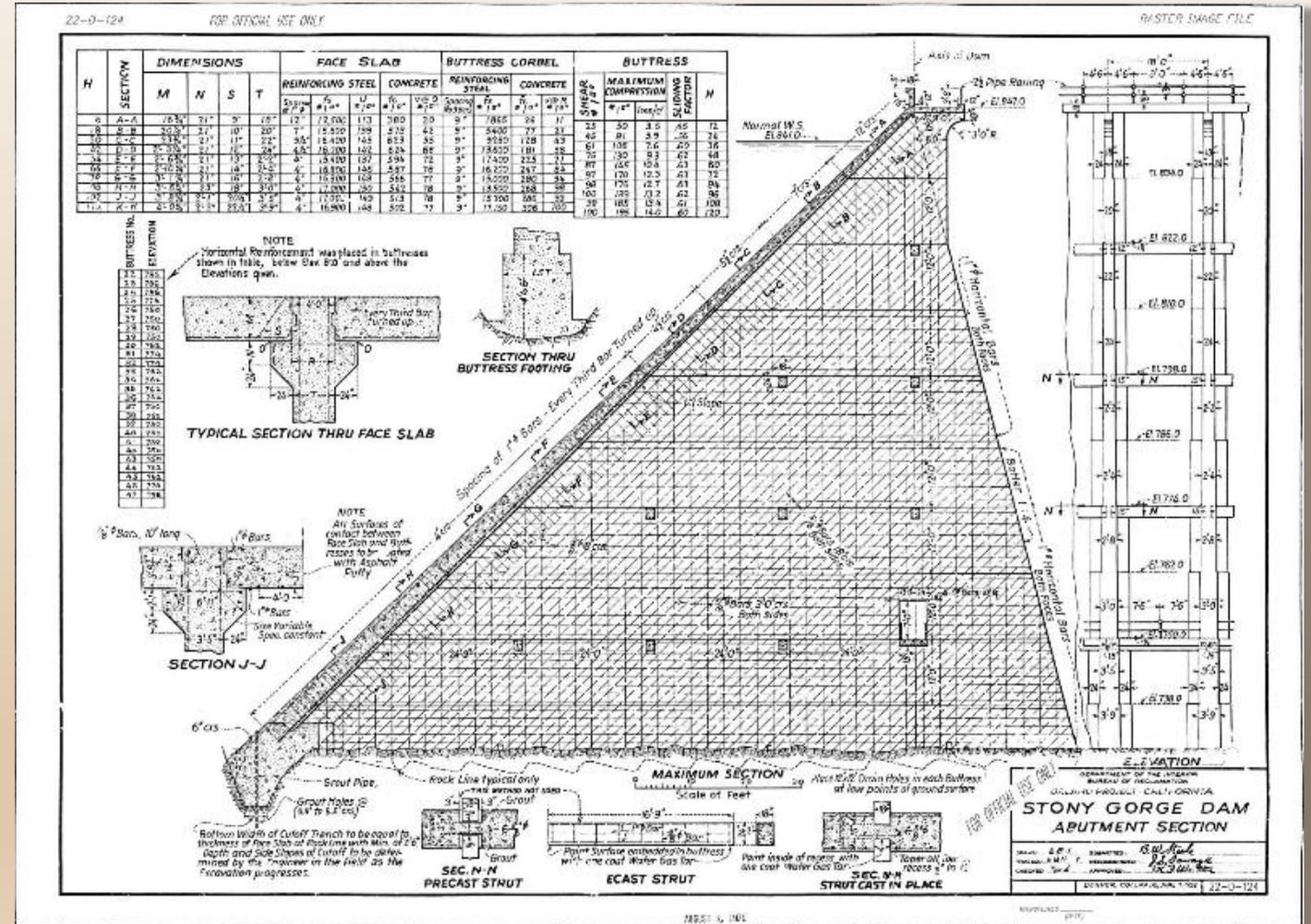
Seismic Analysis

- Buttresses weak in **cross-canyon** direction.
- Entire dam must be modeled to include “**racking**”



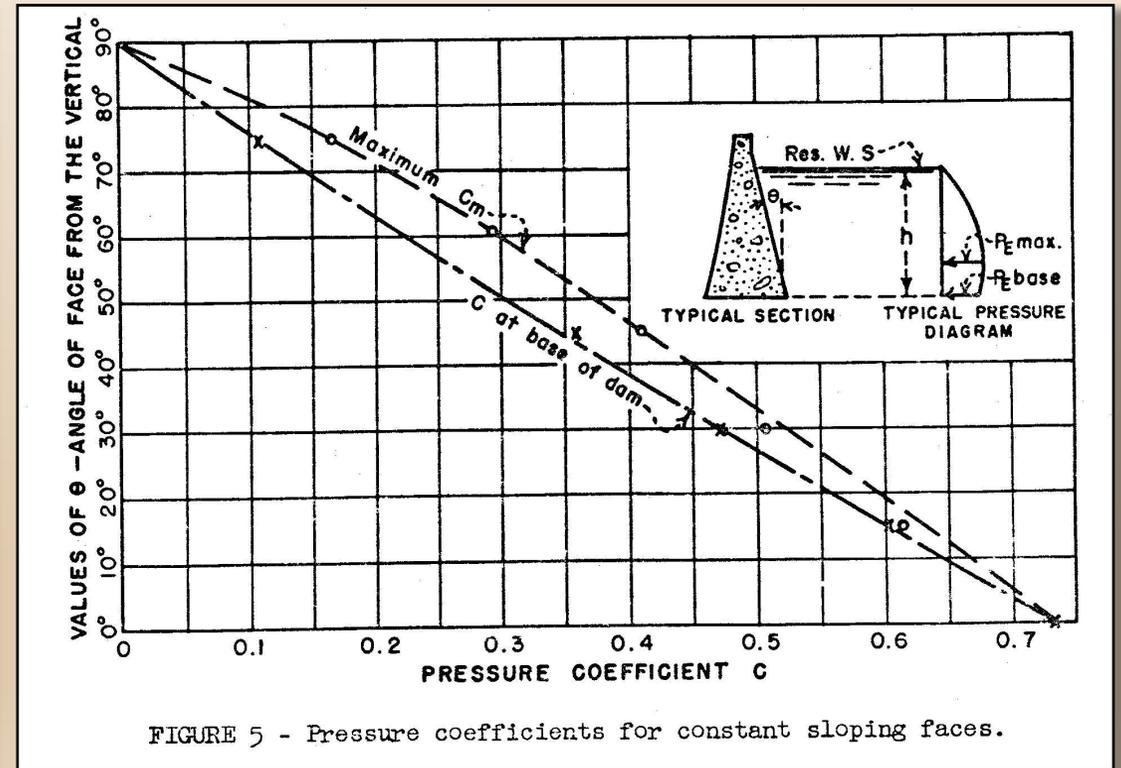
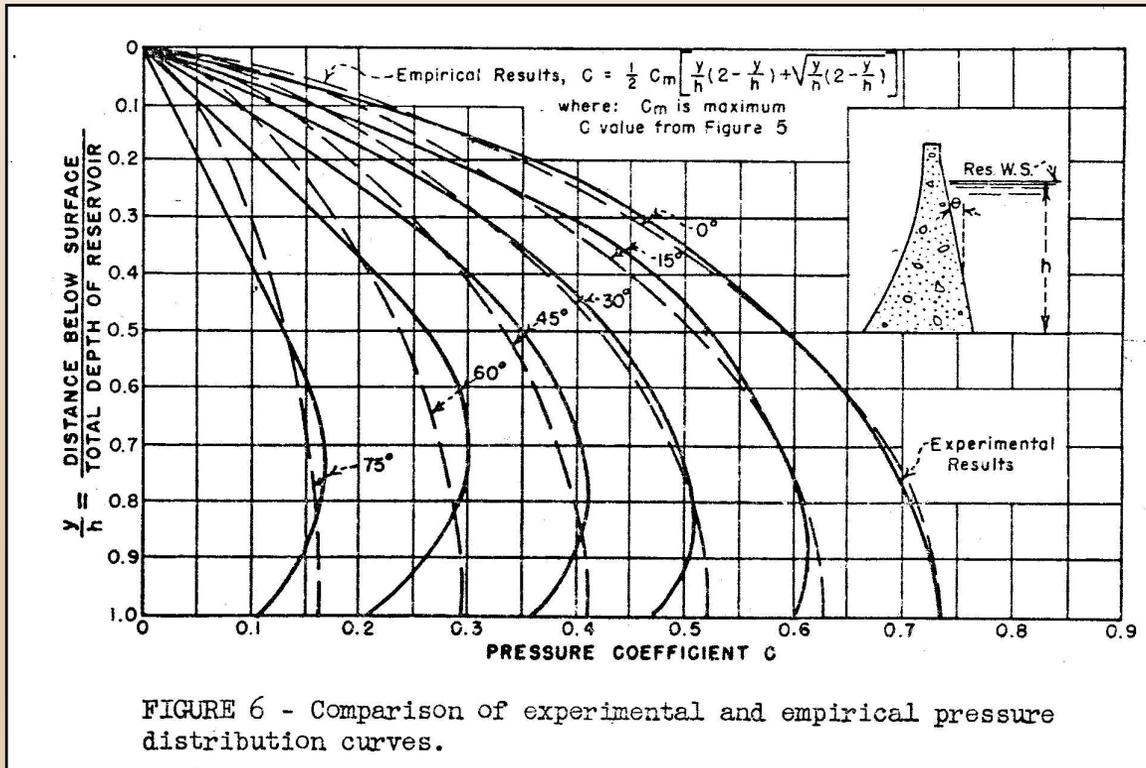
Reinforcing Steel Considerations

- Most buttress dams are getting old, concrete spalls or cracking can lead to corrosion
- Also no air entrainment (freeze-thaw susceptibility) and reinforcement not up to current standards



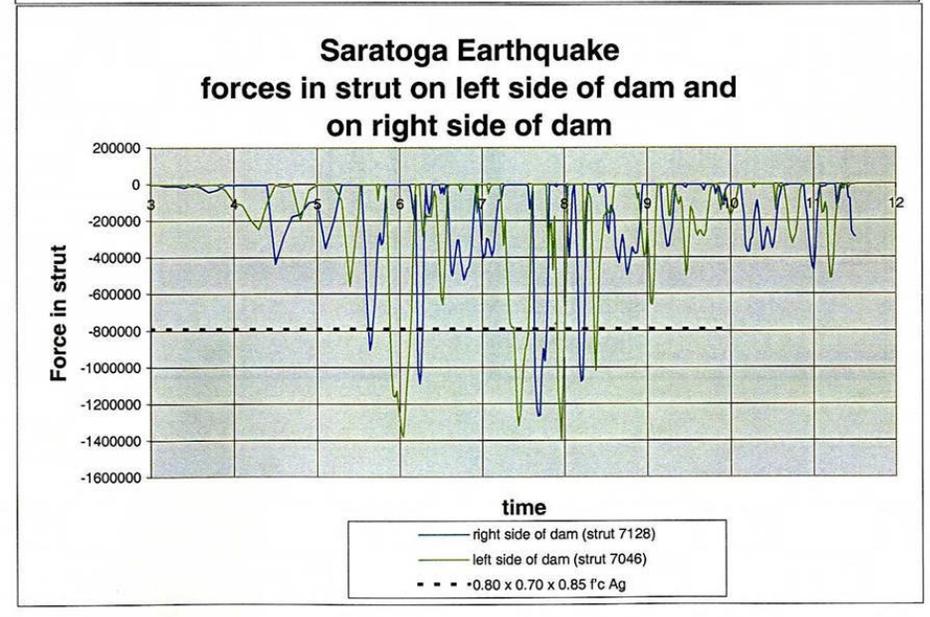
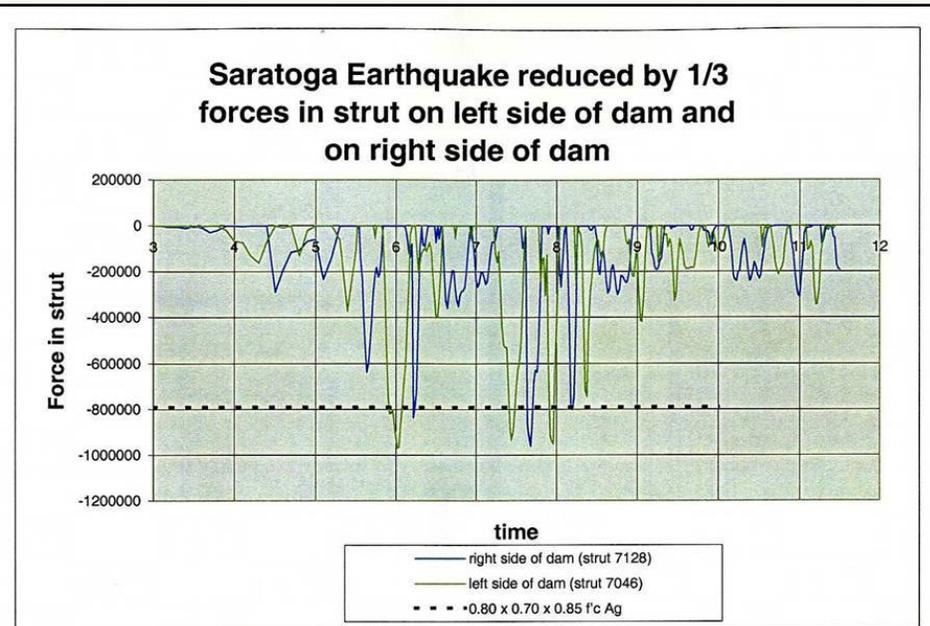
Hydrodynamic Interaction

The hydrodynamic forces in **stream direction** are reduced by the sloping face (the water will tend to ride up along the face). Zanger approach (below) can be used with directional masses, or fluid elements if available.



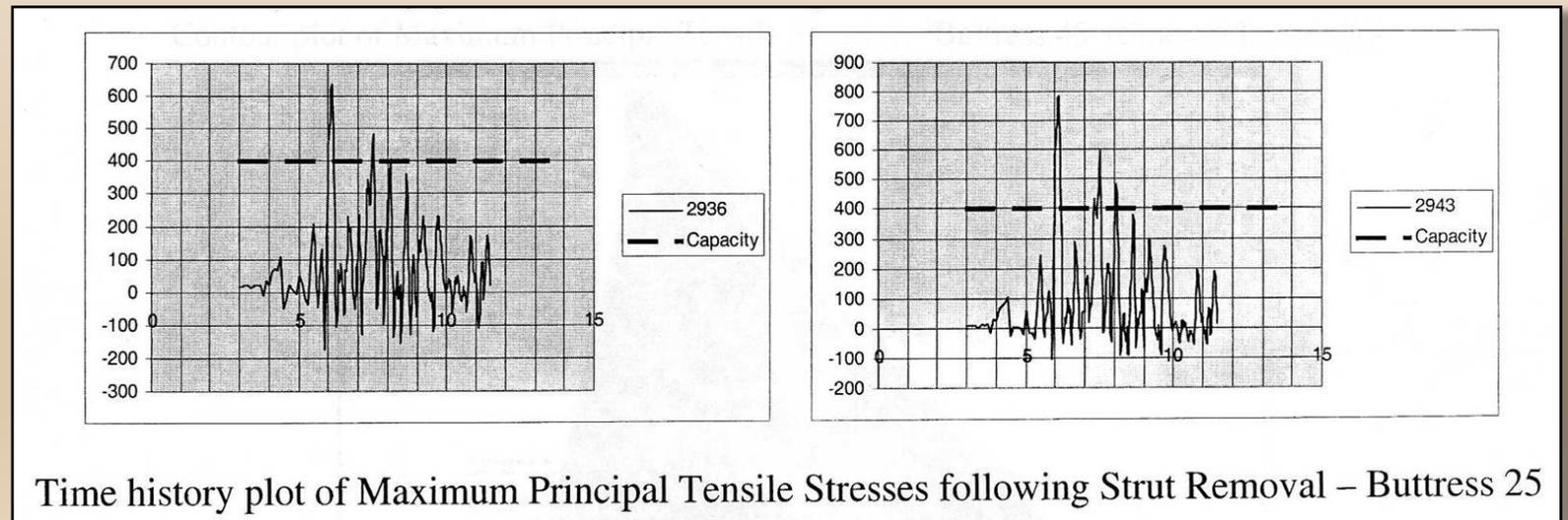
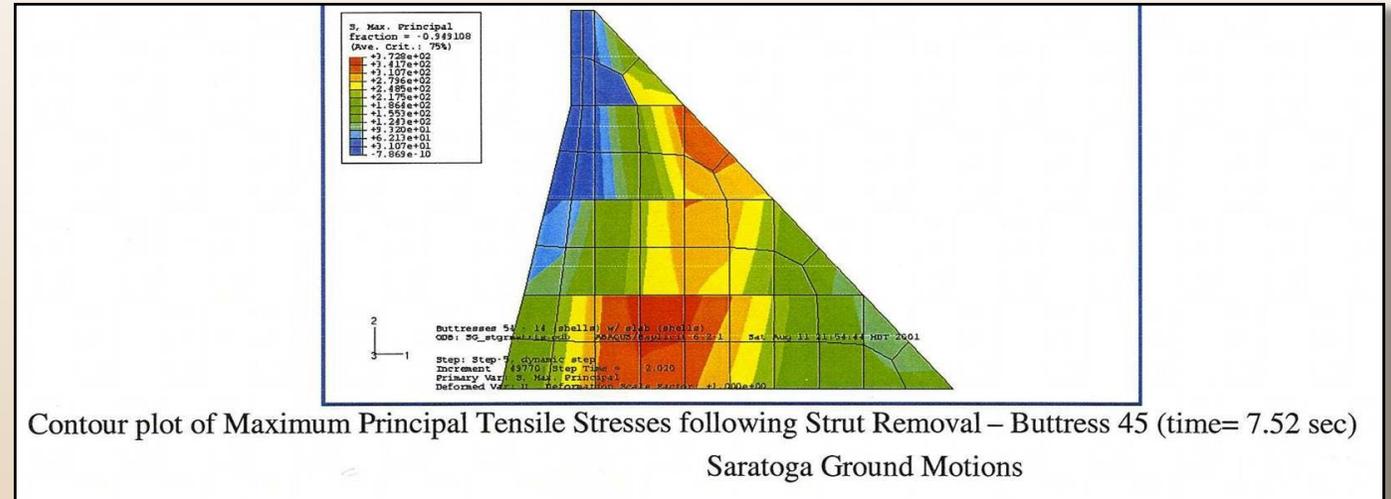
Struts

- Some buttresses have struts between buttresses for lateral support
- As buttresses move in earthquake, load accumulates across dam and can overload end struts (push over analysis)
- Crushing stress in struts normally controls over buckling



Buttresses

- Some buttresses have struts between buttresses for lateral support.
- As buttresses move in earthquake, load accumulates across dam and can overload end struts (push over analysis).
- Crushing stress in struts normally controls over buckling.



Moments

- As a result of buttress dams varying in thickness and reinforcement from base to crest, the response of the dam and seismically induced moments in the buttresses will vary.

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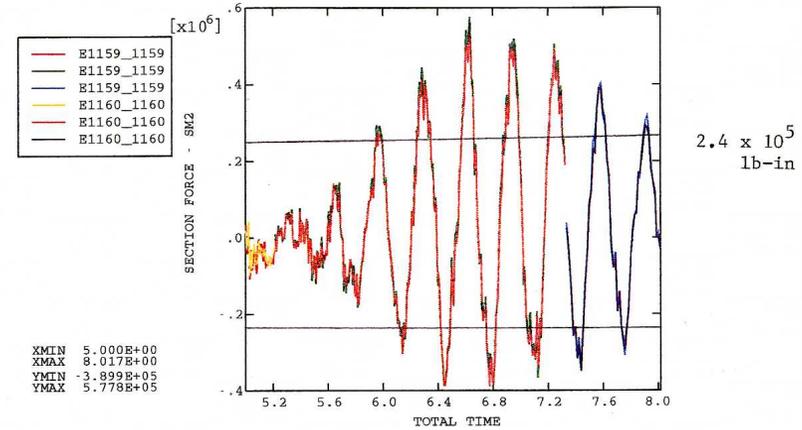


Figure 25a-1 Buttress thickness = 32 inches

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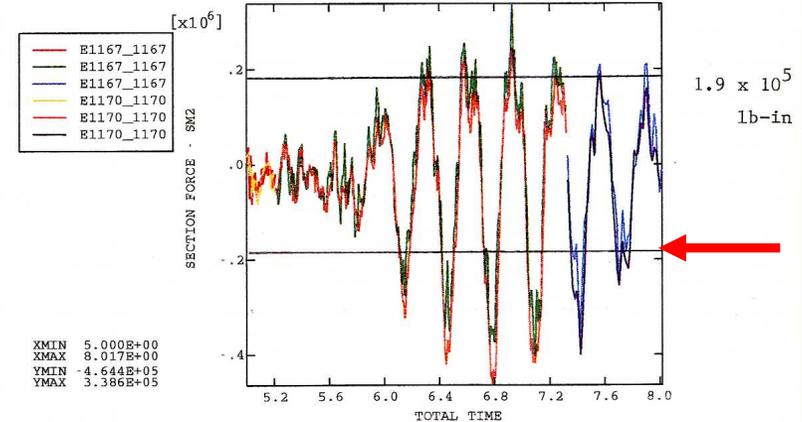


Figure 25a-2 Buttress thickness = 26 inches

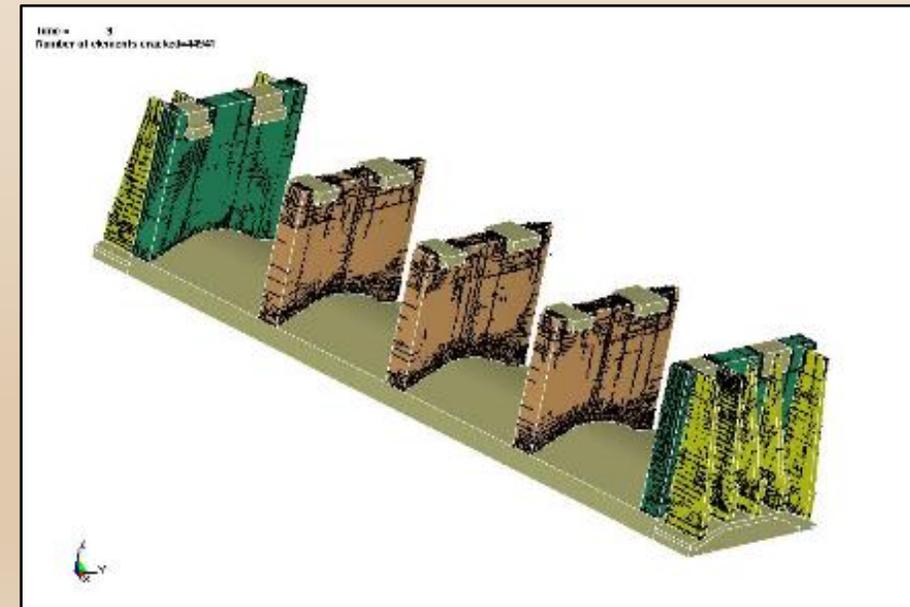
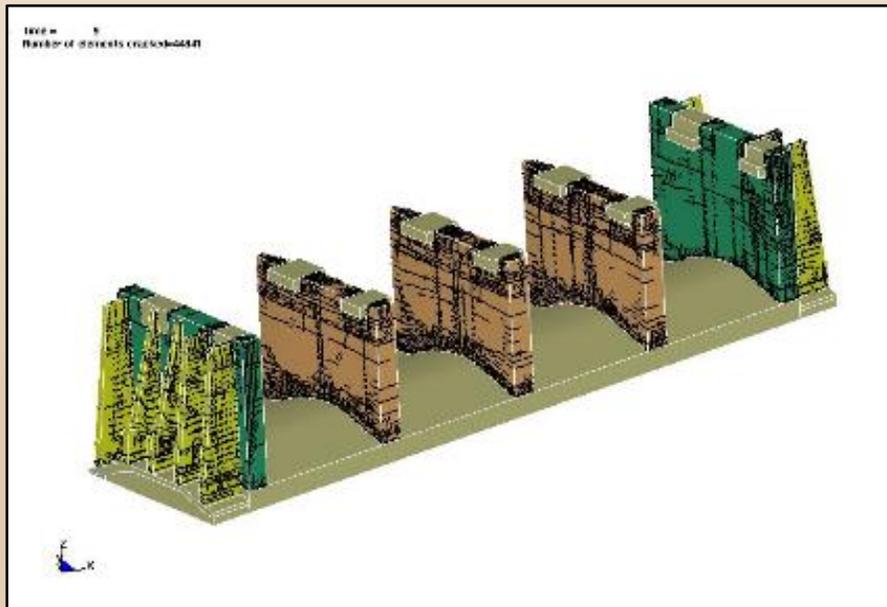
Capacity

Moment Time History Figures



Nonlinear Structural Analysis

- Some nonlinear finite element programs have concrete cracking and steel reinforcement models that can be used to examine the potential for cracking, yielding, excessive deformation and failure directly. However, remember these are just models and careful scrutiny of the input assumptions and output is necessary.



Takeaway Points

- Designed to carry load in the stream direction.
- Vulnerable to cross-stream seismic loads.
- Finite element analyses of entire structure are needed to capture response.
- Reinforced concrete risk concepts can be used to examine probability of nodal estimates.
- Careful consideration of the concrete quality, joint treatment, and reinforcing details are required.
- Level of analysis for estimating performance should reflect with the level of study needed for the risk analysis and decision-making.



Questions or Comments?



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