



# EQEN Program Structural Aspects

**Dr. Robert L. Hall**



**Concrete Dams**

**Numerical & Physical Modeling**

**Back Analysis of Performance of Dams -Taiwan**

**Database Development**

**Outlet Works**

**Retaining Walls**

**US Army Corps of Engineers**

**Engineering Research and Development Center**



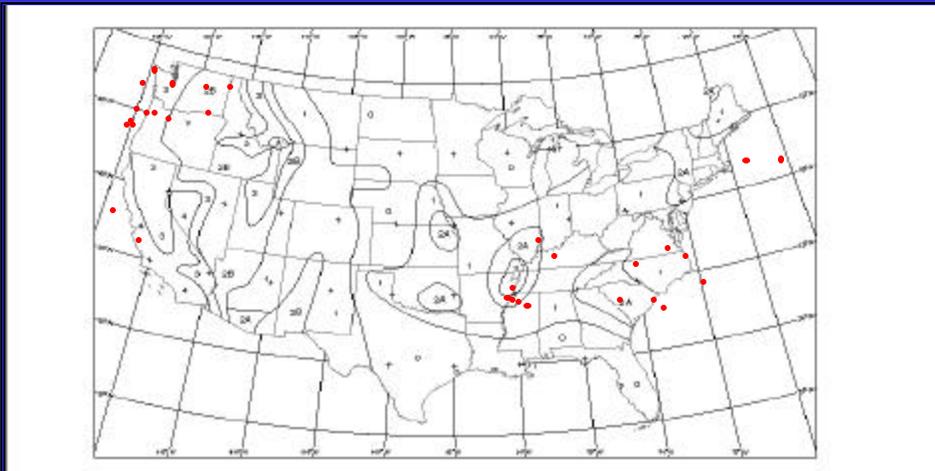
# Earthquake Engineering: Concrete Dams

Accurate evaluation of seismic performance for concrete dams requires development of numerical procedures that account effectively for the most critical factors controlling response



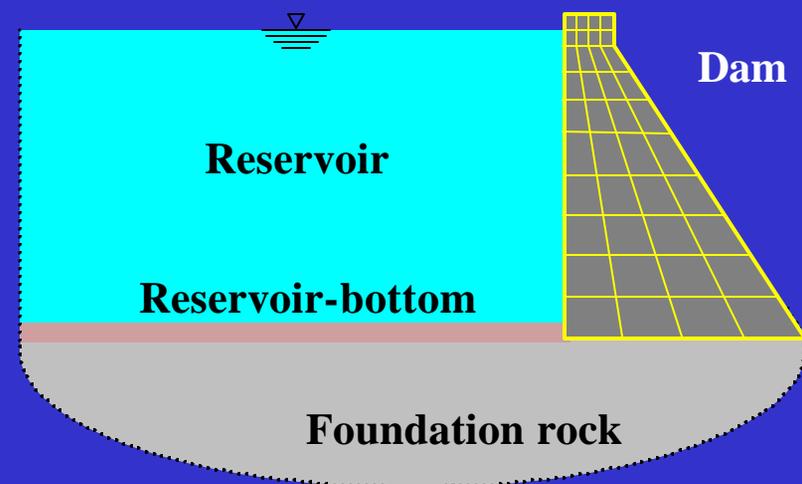
## Objective

Develop, implement and validate numerical procedures for dynamic analysis of concrete dams subjected to seismic excitation



# Problem

- The prediction of the seismic performance of concrete dams constitutes a challenging problem governed by
  - Three-dimensional geometry
  - Spatial variability of seismic input
  - Intensity and frequency characteristics
  - Material constitutive behavior
  - Presence of lift and contraction joints
  - Interaction phenomena



# Problem (cont.)

- Different approaches can be used to generate a “solution” to the problem, ranging in complexity and modeling capabilities.

Static analysis

Eigenvalue analysis

Linear dynamic analysis

Nonlinear dynamic analysis



# Products

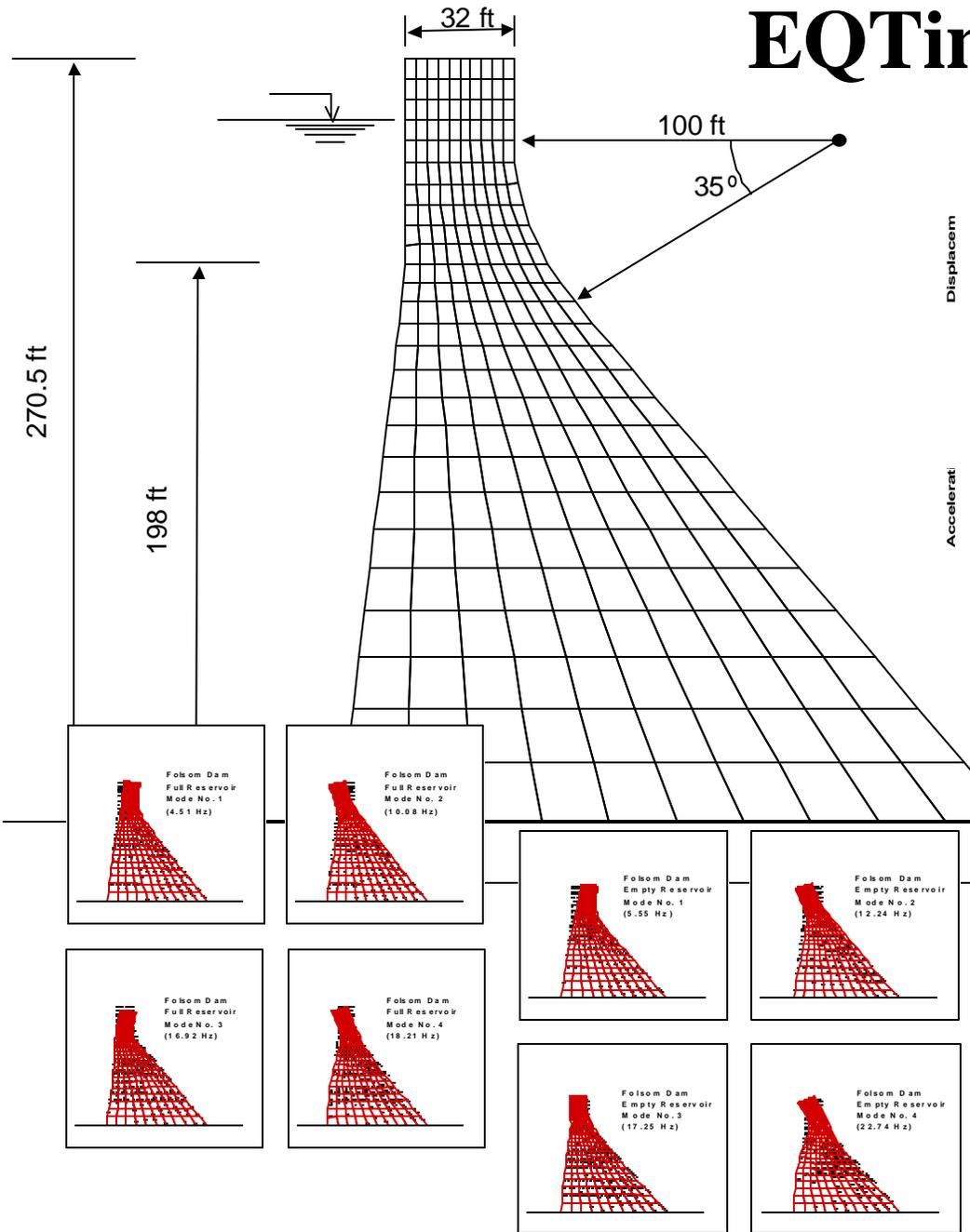
A family of computer codes for nonlinear transient analysis of dam-reservoir-foundation systems under seismic excitations

**EQTime2D**

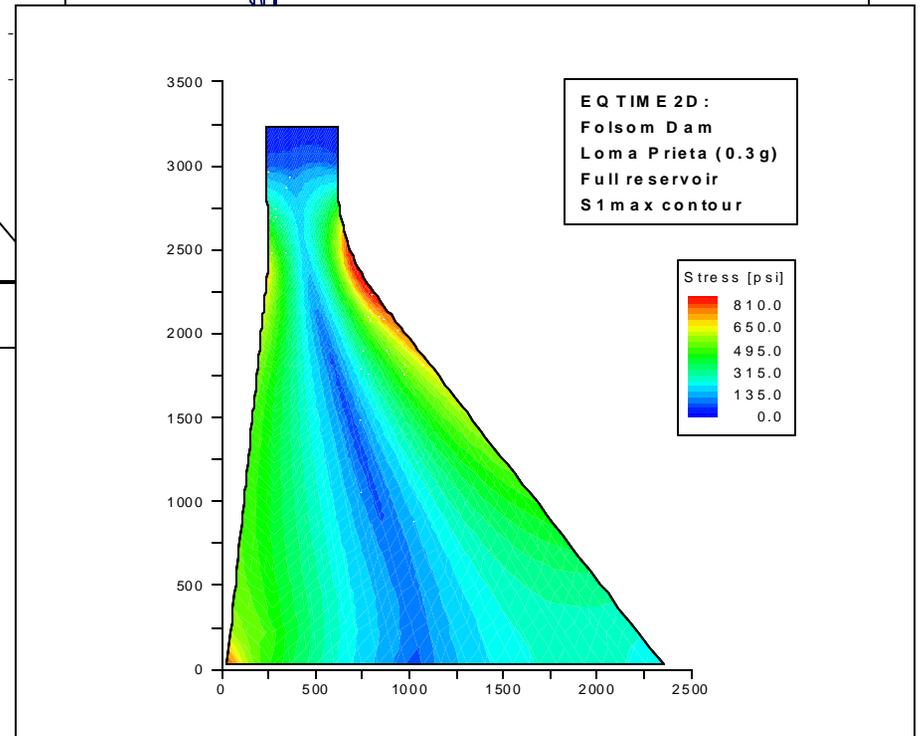
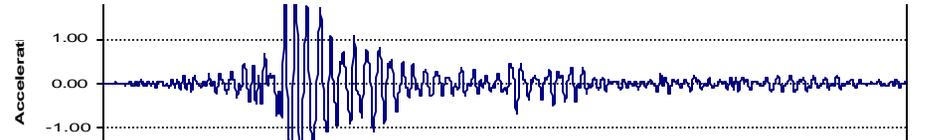
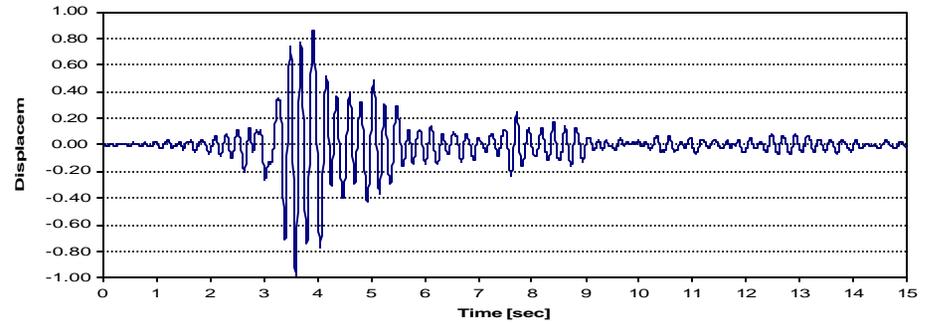
**EQTime3D**

- **2D model**
- **Platform for evaluation of models and solution strategies**
- **3D model**
- **Final analysis tool**

# EQTime2D: Folsom Dam, CA



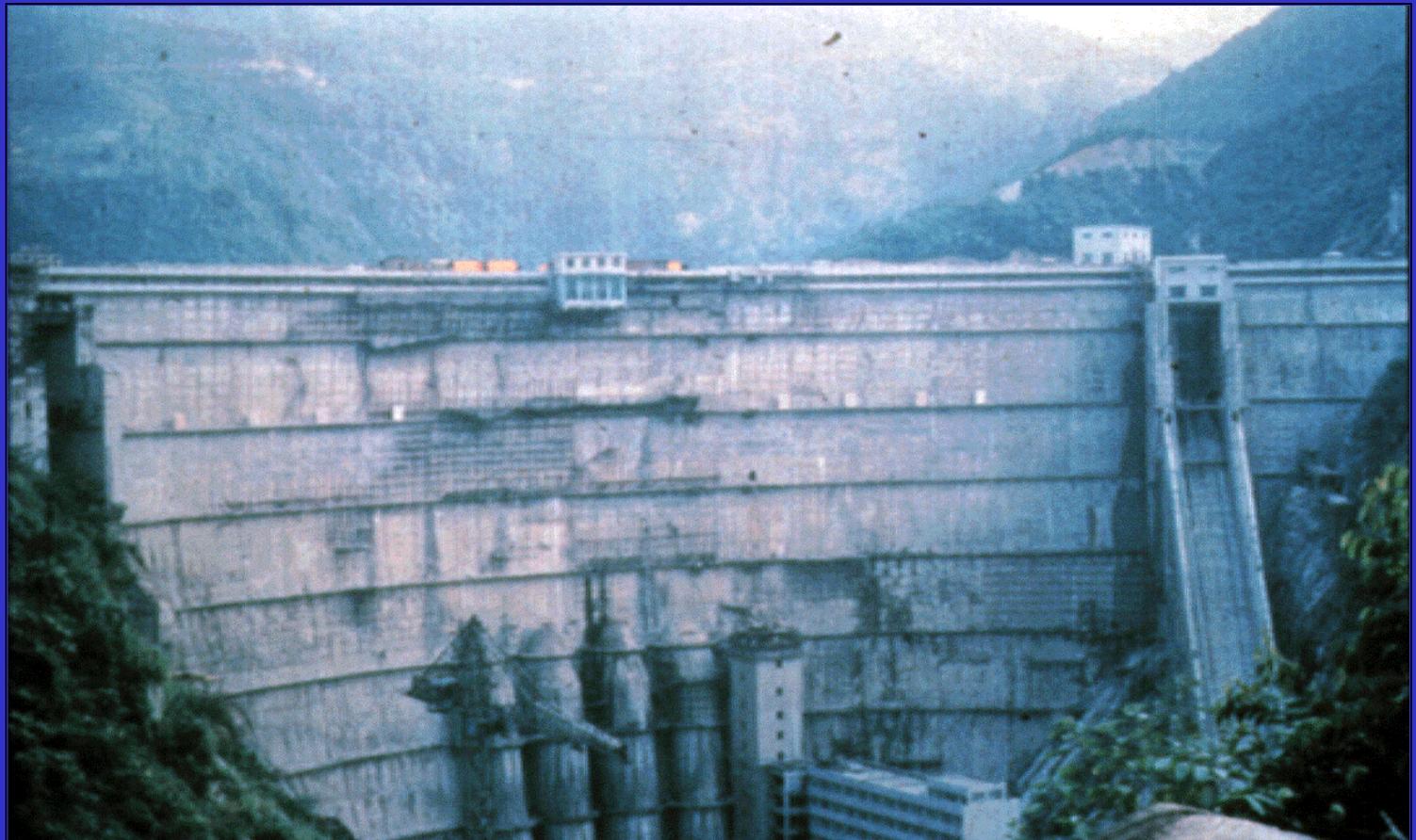
Crest horizontal displacement - Loma Prieta (0.3g) - Full reservoir



# Validation - Dongjiand Dam, China

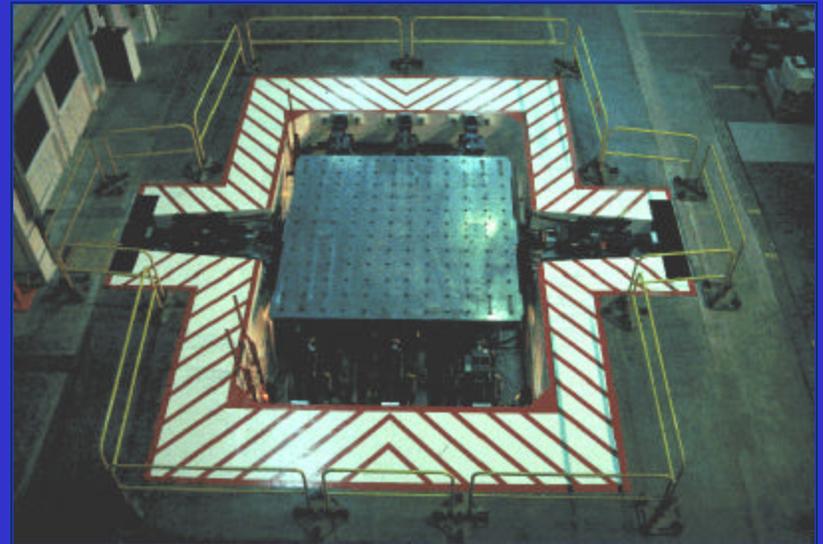
## Database Development

- Experimental Performance of Dams
- Actual Performance of Dams



# Shake Table Experiments

- To simulate the dynamic behavior of a monolith of Koyna Dam (earthquake-induced cracking pattern)
- To observe and identify response characteristics and failure mechanisms under various types of excitation signals
- To provide data for validation and calibration of analytical models.

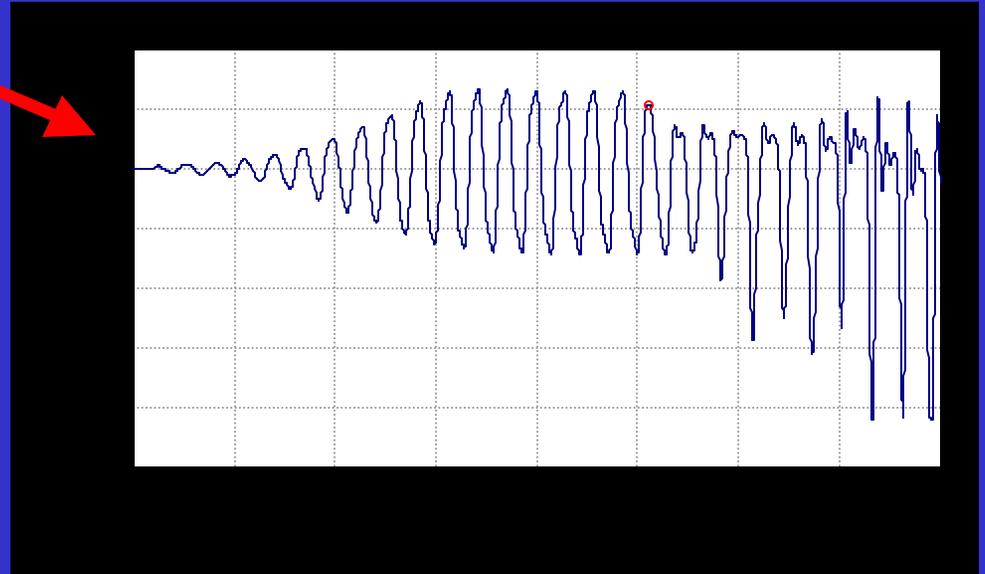


*CERL Shake Table*

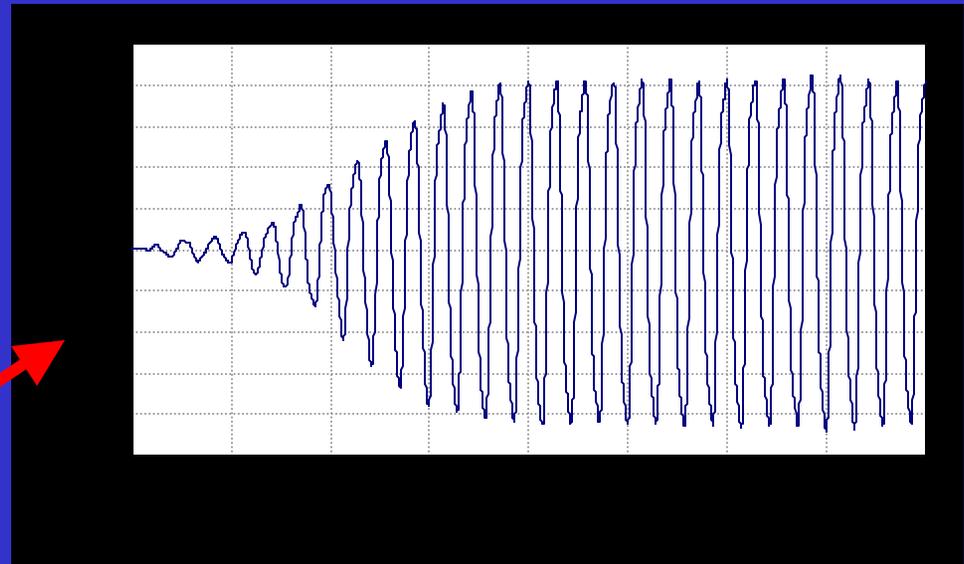


# Shake Table Results (Strain Gage Data)

•  $\sim 0.16 \sin(2\pi(14)t)$

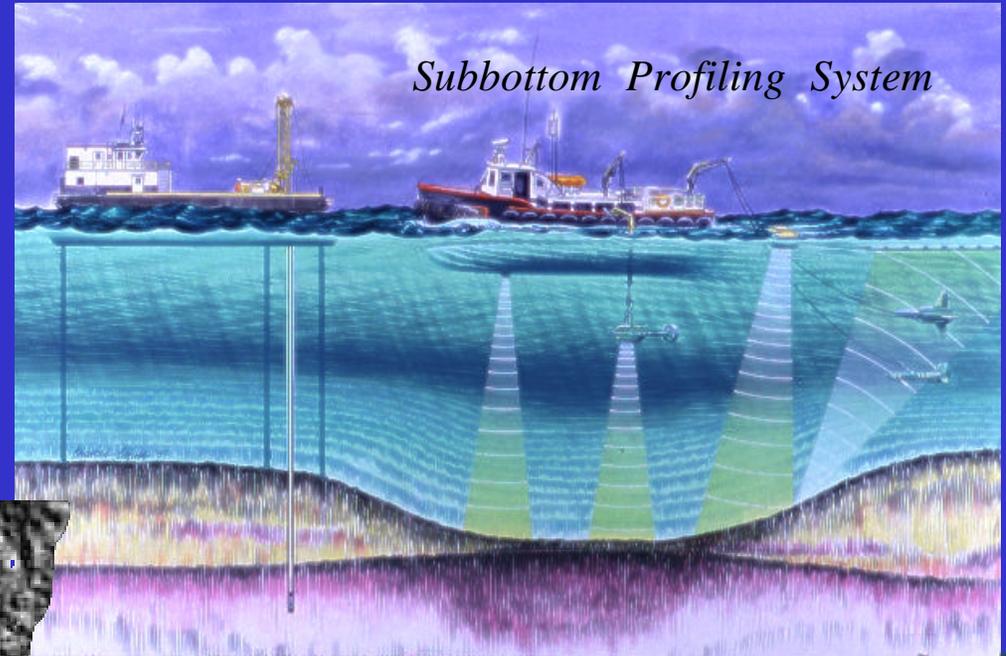


•  $\sim 0.12 \sin(2\pi(14)t)$

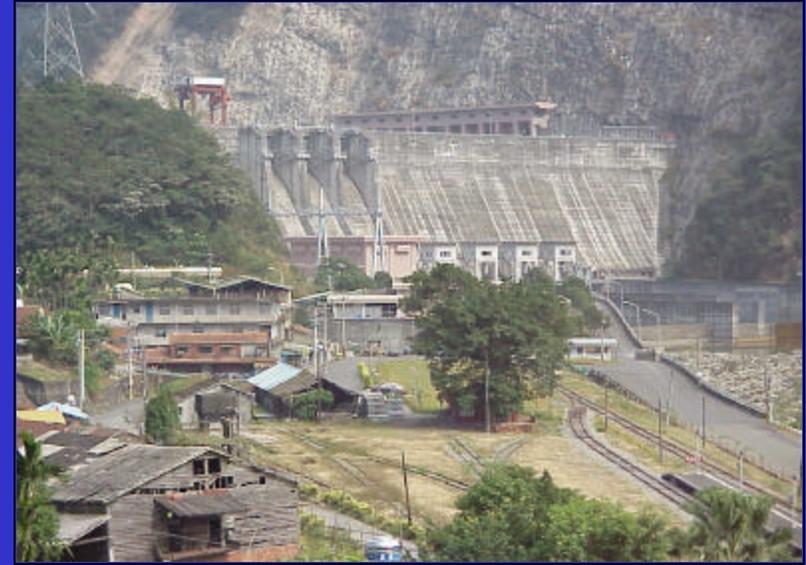


# Breakthrough in Concrete Dam Research - Subbottom Absorption

- 2-D Time Domain Model
- Guidance



# Back Analysis of Taiwan Dams



Performance of Dams During  
Large Earthquakes

Nice to learn in another's backyard

# Potential Savings

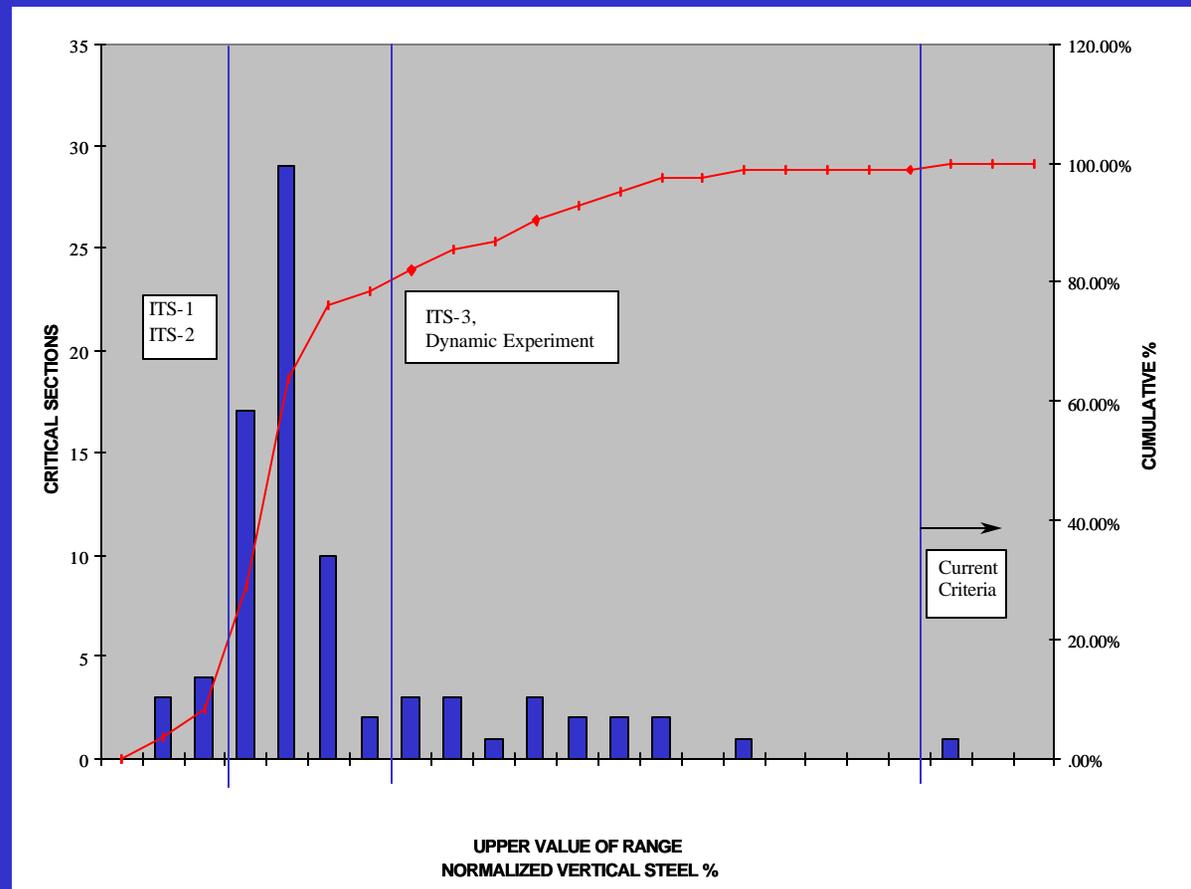
- **72 Towers have been identified as being located in seismic zone 2 or above, almost all are very lightly reinforced.**
- **The cost of retrofitting an existing tower has been estimated to be between \$5 million and \$100 million.**
- **Proper estimation of ductile capacity has a large potential payoff.**



*Gathright Tower, VA*

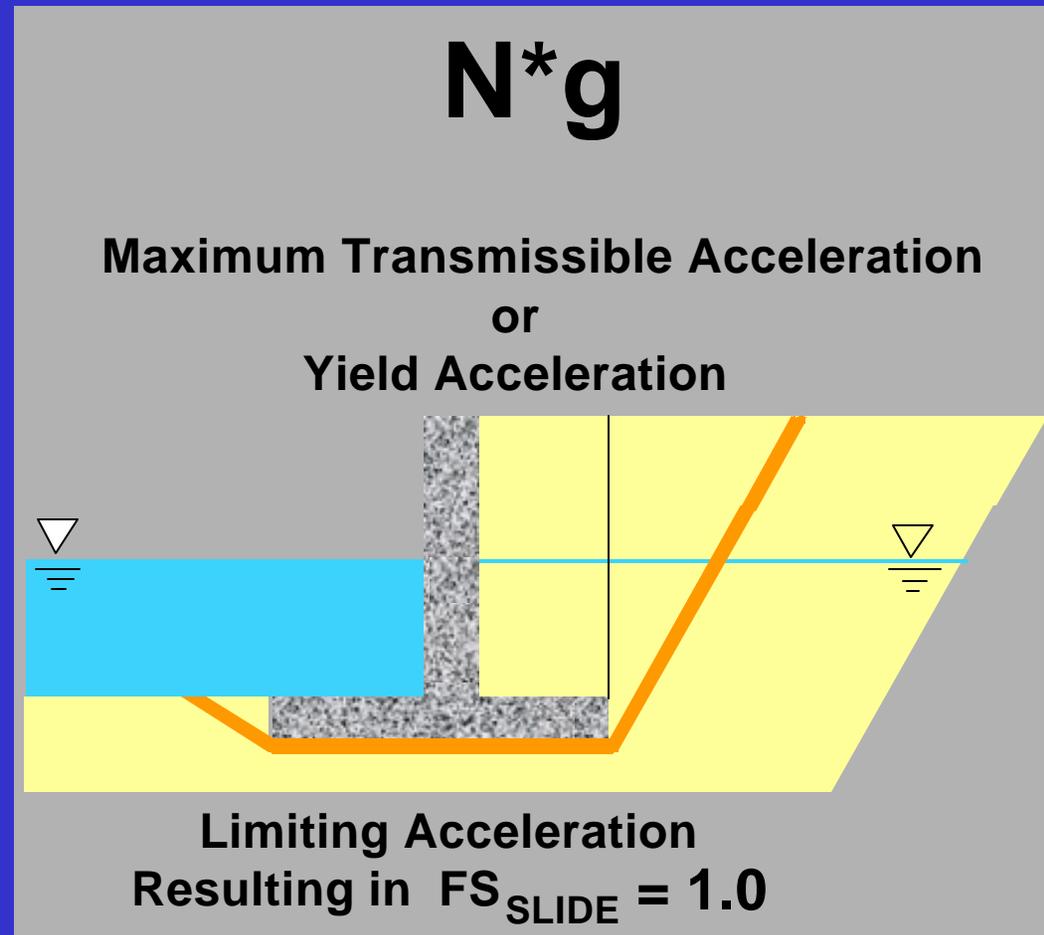
# Inventory of Existing Towers

- Used to design Intake Tower Substructure (ITS) experimentation.
- ITS experimentation was conducted and demonstrated significant ductility in a single crack failure mode.
- Based on experimentation, the Displacement Based Analysis technique was selected as a promising analysis method.



# Seismic Design of Cantilever Retaining Walls

- Development of CSLIP Computer Program



CSLIP – windows based program for computing seismically-induced deformations in retaining walls, for performance based designs

# Technical Reports

- **Roller-Compacted Concrete Dams**
- **Measurements of Reservoir Bottom Absorption**
- **Uplift Pressures for Concrete Dams**
- **Dynamic Response of Intake Towers**
- **General Ductility of Gate Piers**
- **Experimental Study of Dongjiang dam for Dam-Water-Foundation Interaction**
- **Measurement and Prediction of Dam-Water-Foundation Interaction at Longyangxia dam**
- **Experimental Study of 1/20th Scale of Koyna Dam**
- **Guidance for Including Effects of Reservoir Bottom Absorption**

# Summary Of Accomplishments

- **EC 1110-2-6050 Response Spectra and Seismic Analysis for Concrete Hydraulic Structures**
- **EC 1110-2-6051 Time-History Analysis of Concrete Hydraulic Structures**
- **EC 1110-2-285 Structural Analysis and Design of Intake Structures for Outlet Works**
- **EQ-Time 2D**
- **Internet Based Data Base**

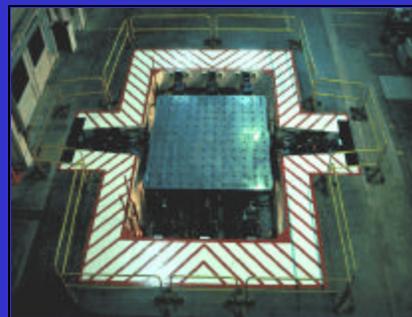
# Earthquake Engineering Research Program

## Concrete Dams - Summary

- Hydrodynamic loads on concrete dams – field procedures
- Roller-compacted concrete – seismic properties & construction procedures
- Nonlinear analysis code for cracking
- Nonlinear analysis for monolith to monolith interaction
- Nonlinear analysis for sliding on lift joints
- Comprehensive code for reservoir-foundation-structure analysis
- Software to translate FEM output into moments, shears, and thrusts
- Software to interpret time history analysis results



*CERL Triaxial Earthquake  
Shock Simulator*



*Folsom Dam, CA*



# Infrastructure Engineering and Management Research Thrust Area

## Earthquake Engineering Program

*End of Presentation  
Questions*

*D. E. Yule*

**US Army Corps of Engineers  
Engineering Research and Development Center**

