

Seismic Analysis of Concrete Dams

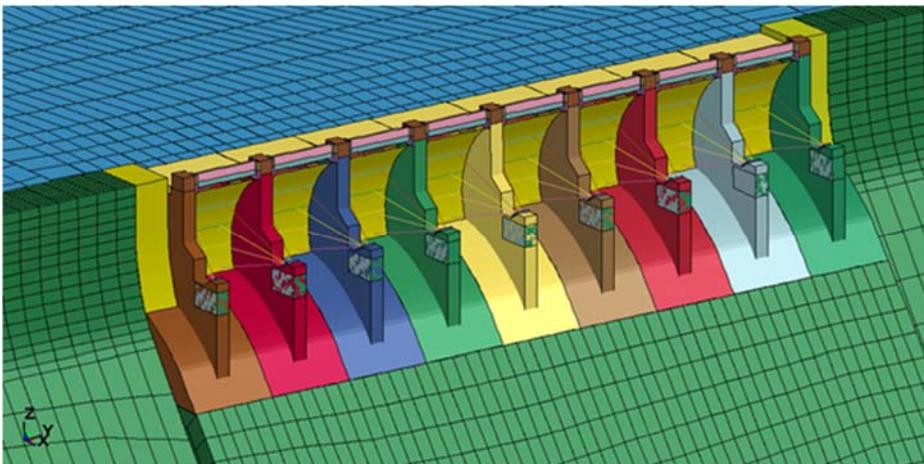
Two days, Thursday and Friday, April 6 and 7

Seismic analyses are becoming more detailed, more dependent on advanced modeling techniques, and more frequently inform critical dam safety decisions. However, the relative scarcity of data on the performance of dams subjected to extreme seismic events complicates the verification of these analytic tools and methods. It is prudent to solicit opinions among researchers and practitioners about the current state of practice in seismic analysis of dams to assess whether the results are consistent with observed performance and whether the right potential failure modes are being addressed.

The primary goals of the workshop are:

1. Solicit opinions among dam engineering researchers and practitioners about the current state of practice in seismic analysis of dams and to assess whether the results are consistent with observed performance, and whether the right potential failure modes are being addressed.
2. Discuss the most common types of analysis: how they should be used, i.e., their proper role in the decision process, and which analyses are appropriate to address the potential failure modes of a particular dam. Types of concrete dams include, but are not limited to, gravity dams, arch dams, slab and buttress dams
3. Evaluate accuracy of the analysis method used in seismic evaluation of concrete dams.
4. Identify the highest research priorities with consideration given to public safety and the needs of dam owners.

This workshop is not meant to be a presentation of papers. Participants will be encouraged to submit short statements identifying issues of particular concern followed by an open discussion among workshop attendees.



Folsom Dam finite element analysis

AGENDA

Thursday, April 6 (Marriott)

8:00 AM **Welcome**
(Mike Rogers, P.E. - MWH/Stantec)

8:05 AM **Introduction**
(Moderator: Phoebe Percell, P.E. - Reclamation)

- Introduction of Workshop
- Identification of Problems in analysis of concrete dams for seismic loads:
 - Current state of practice for the seismic analysis of concrete dams involves using advanced modeling techniques and frequently inform critical dam safety decisions. Scarcity of data on the performance of dams subjected to extreme seismic events brings into question how well these analyses can actually predict behavior and the validity and necessity of any seismic modifications.
- Objectives of the Workshop:
 - Solicit opinions among dam engineering researchers and practitioners about the current state of practice in seismic analysis of dams and to assess whether the results are consistent with observed performance, and whether the right potential failure modes are being addressed.
 - Discuss the most common types of analysis: how they should be used, i.e., their proper role in the decision process, and which analyses are appropriate to address the potential failure modes of a particular dam. Types of concrete dams include, but are not limited to, gravity dams, arch dams, multiple arch dams, slab and buttress dams.
 - Evaluate accuracy of the analysis method used in seismic evaluation of concrete dams.
 - Identify the highest research priorities with consideration given to public safety and the needs of dam owners.
- Summary of discussion sessions to be covered.

8:15 AM Session #1 – Case Histories and Seismic Potential Failure Modes

(Moderators: Larry Nuss, P.E. - Nuss Engineering, LLC)

Discussion: Case histories of concrete dams subjected to seismic events and the resulting performance of the dam.

- Presentation of case histories; shake-table and full-scale testing.
 - What can be learned for design, analysis, and evaluation?
- Typically accepted potential failure modes:
 - Seismic failures of concrete gravity, arch and buttress dams
 - Seismic failures of foundations
 - Progression of failure: overstress, cracking, movement
 - Distinction between failure and acceptable damage
 - Do these PFMs match the case histories? Any changes?
- Would current analysis methods capture these or unknown PFM?
 - Direction of cracking? Amount of sliding? Change in uplift?

Session Summary & Questions

9:15 AM Break

9:30 AM Session #2 – Field Investigations and Concrete Material Properties

(Moderators: Tim Dolen, P.E. - Dolen and Associates and Guy Lund, P.E. - Gannett Fleming)

Discussion: What field investigations, material testing, and special conditions and factors should be considered before proceeding with finite element analysis?

- Concrete and lift joint conditions: deterioration and cracking, AAR expansion, joint debonding, etc.
- Concrete coring to determine material properties and strength parameters; petrographic examination, etc.
- Testing methods and limitations.

Session Summary & Questions

10:15 AM **Session #3 – Field Investigations and Foundation Material Properties**
(Moderators: Dick Goodman, Ph.D. - U.C. Berkeley and Dom Galic, Ph.D., P.E.
- Reclamation)

Discussion: What field investigations, material testing, and special conditions and factors should be considered before proceeding with finite element analysis?

- Geologic investigations to identify rock blocks and other foundation discontinuities creating stability concerns
- Foundation deformation modulus and shear strength of dam-foundation contact and other potential failure planes and wedges
- Joint-controlled versus rock-mass controlled foundations
- Testing methods and limitations.

Session Summary

11:00 AM **Break**

11:15 AM **Session #4 – Results of 2016 USSD Monticello Workshop**
(Moderator: Phoebe Percell, P.E. - Reclamation)

Discussion: Summary of the Workshop results and general discussions from workshop participants.

- Overview of Monticello Blind Prediction Analysis Workshop hosted by the USSD Earthquake Committee during 2016 USSD Conference
 - General observations for participant results
- Validation
 - Comparison with observed and measured responses under static loading conditions.
 - Comparison against recorded motions.
 - Examples:
 - Mauvoisin Dam (Switzerland)
 - Pacoima Dam (California)

Session Summary & Questions

12:15 PM **Lunch**

1:15 PM **Session #5 – Linear Response History Analyses of Concrete Dams**
(Moderator: Anil Chopra, Ph.D. - U.C. Berkeley)

Discussion: What are the current methods used to analyze concrete dams and the factors affecting dynamic response?

Factors to be Considered

- “Semi-unbounded” size of fluid domain
- “Semi-unbounded” size of foundation rock domain
- Dam–Water Interaction; implications of added mass model; wave absorption at reservoir boundaries
- Dam–Foundation Rock Interaction; implications of ignoring mass of foundation rock
- Spatial variations in ground motion

Analysis Procedures

- Substructure method for analysis of dam-water-foundation systems with the latter two modeled as “semi-unbounded” domains.
- Direct FEM for analysis of dam–water–foundation systems with truncated versions of fluid and foundation domains terminating at absorbing boundaries
- Validation of Method 2 against Method 1

2:45 PM **Break**

3:00 PM **Session #6 – Response History Analyses of Concrete Dams with Nonlinearities**
(Moderator: Yusof Ghanaat, Ph.D., P.E. - Quest Structures)

Discussion: What are the nonlinear mechanisms of concrete dams? Which nonlinear mechanisms should be modeled?

- Purpose and need for nonlinear analysis
- Methods
 - Explicit vs. implicit
 - Constitutive vs. discrete modeling
- Modeling
 - Dam-water-foundation interaction and B.C’s
 - Contraction joints and shear keys.
 - Discontinuities at dam/foundation interface
 - Monolith interaction during sliding, considering irregularities along the sliding surface
 - Large deformation
 - Concrete nonlinear constitutive models
 - Reinforced concrete structures and components
- Compliant seismic input and topographic effects
- Evaluation and acceptance criteria

Session Summary & Questions

4:30 PM **Break**

4:45 PM **Day 1 Summary**
(Moderator: Hillery Venturini, P.E. - Reclamation)
Discussion: Additional discussions on topics of Day 1, as needed.

5:00 PM **Adjourn**

Friday, April 7 (Anaheim Convention Center)

8:00 AM **Introduction**
(Moderator: Jen Huggins, P.E. - Reclamation)

Discussion: Recap on discussion of Day 1, introduction to Day 2.

8:15 AM **Session #7 – Selection of Ground Motions to Represent Seismic Hazard**
(Moderator: Robert Youngs, Ph.D., P.E. - Amec Foster Wheeler)

Discussion: The seismic hazard at a site is typically quantified in terms of a response spectrum or response spectra derived from either a deterministic or probabilistic assessment. What approaches should be used to develop input motions for analysis of concrete dams?

- Representation of site hazard for analysis – use of UHS, scenario earthquake spectra, and CMS
- From UHS/CMS to 3 components of motion – correlations among components
- Alternative approaches for using CMS (e.g. how many? how broad?)
- Development of time histories – scaling versus spectral matching.

Session Summary & Questions

9:15 AM **Break**

9:30 AM **Session #8 – Accuracy of Analysis**
(Moderators: Jerzy Salamon, Ph.D., P.E. - Reclamation and Juan Quiroz, Ph.D., P.E. - MHW/Stantec)

Discussion: This session will focus on evaluation of accuracy in the structural analysis of concrete dams.

- Analysis process for concrete dams

- Physical models
- Mathematical models
 - Complexity
 - Limitations
 - Stress and strain measures in nonlinear analysis
- Analytical and numerical solutions
- Numerical methods
 - Complexity
 - Convergence
 - Estimation of accuracy
 - Mesh and time step adaptation
 - Efficiency of numerical methods
 - Comparison of analysis results using various numerical methods
 - Validation of solutions with observed and measured responses under static and seismic load conditions in lab and in field
- Questions
 - What level of mathematical model complexity is required to accurately predict behavior of the concrete dams during earthquake?
 - Is the complex analysis (dynamic solution with nonlinearities) able to accurately predict behavior of concrete dams? Can such models be used to quantify responses of the dams?
 - Challenges in interpretation of the non-linear analysis results in the engineering practice

Session Summary & Questions

11:00 AM Lunch

12:00 PM Session #9 – Research Priorities & Workshop Summary

(Moderators: Glenn Tarbox, P.E., MWH/Stantec & Mark Schultz, S.E., G.E., CA DWR/DSOD)

Discussion: The objective of this session is to provide an open discussion on the state of current research efforts, new areas of research, and ways to move forward.

- Discussion of previous research prioritization efforts (National Academy of Sciences, Boulder Workshop, USSD efforts, FEMA efforts, etc)
- Ongoing research efforts (USBR large-scale shake table tests, FEM verification studies, etc)
- Research ideas for improving computer models & predicting performance
- Research ideas for reducing dynamic response – tuned mass dampers,

base isolation etc.

- Group feedback on highest research priorities & path forward

1:30 PM Adjourn