A Road Map for Seismic Analyses of Concrete Dam-Rock-Reservoir Systems

Presenters

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Outline

Introduction

Road Map

Verification

Validation

Calibration

Summary

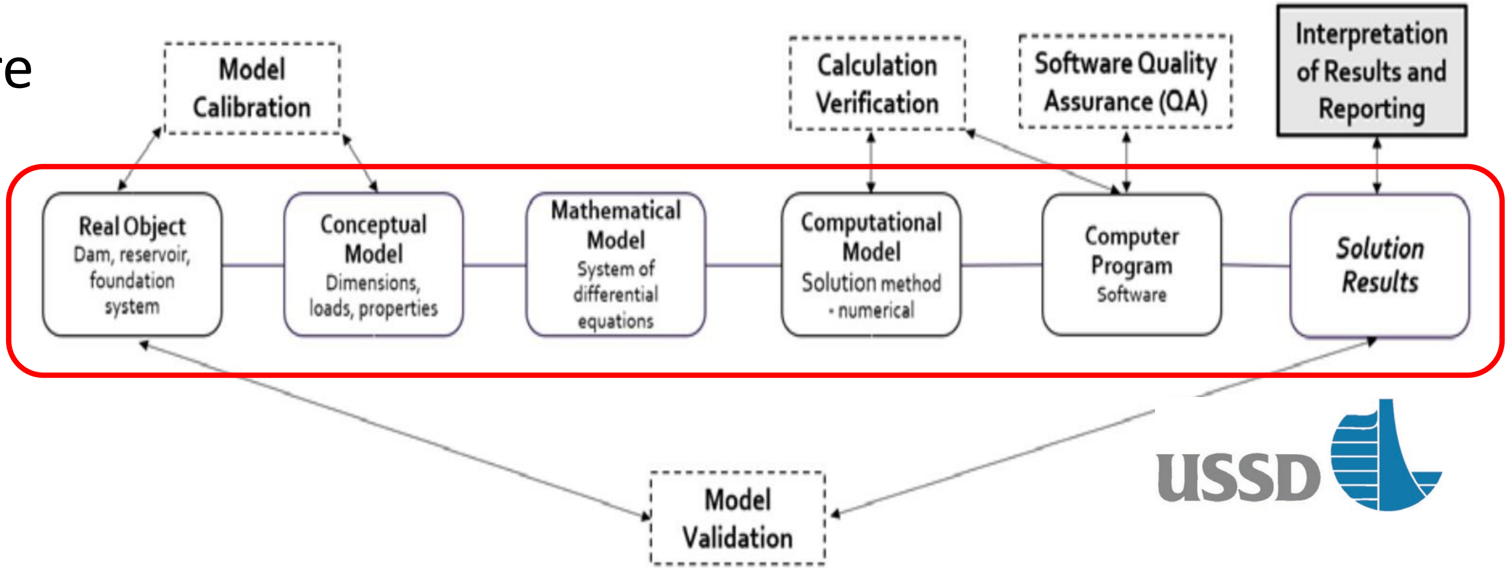
Motivation

- Advanced Structural Analysis (ASA) has become a primary tool in structural assessments of concrete dams
- Complex mathematical models are used in ASA of concrete dams
- The primary concern is the level of confidence in modeling and accuracy of the analysis results
- Our primary goal is to initiate and contribute to a discussion on developing unified guidelines (a road map) for conducting ASA of concrete dams and for verification and validation of such analyses

Road Map for Advanced Analysis of Concrete Dams

Road map for the ASA, as it applies to concrete dams

- ***Real Object* -** dam, reservoir, foundation
- ***Conceptual Model*** is a “virtual image” of the real object
- ***Mathematical Model*** - system of partial differential equations
- ***Computational Model*** - solutions of the mathematical model
- ***Computer Program* -** software
- ***Analysis Results***



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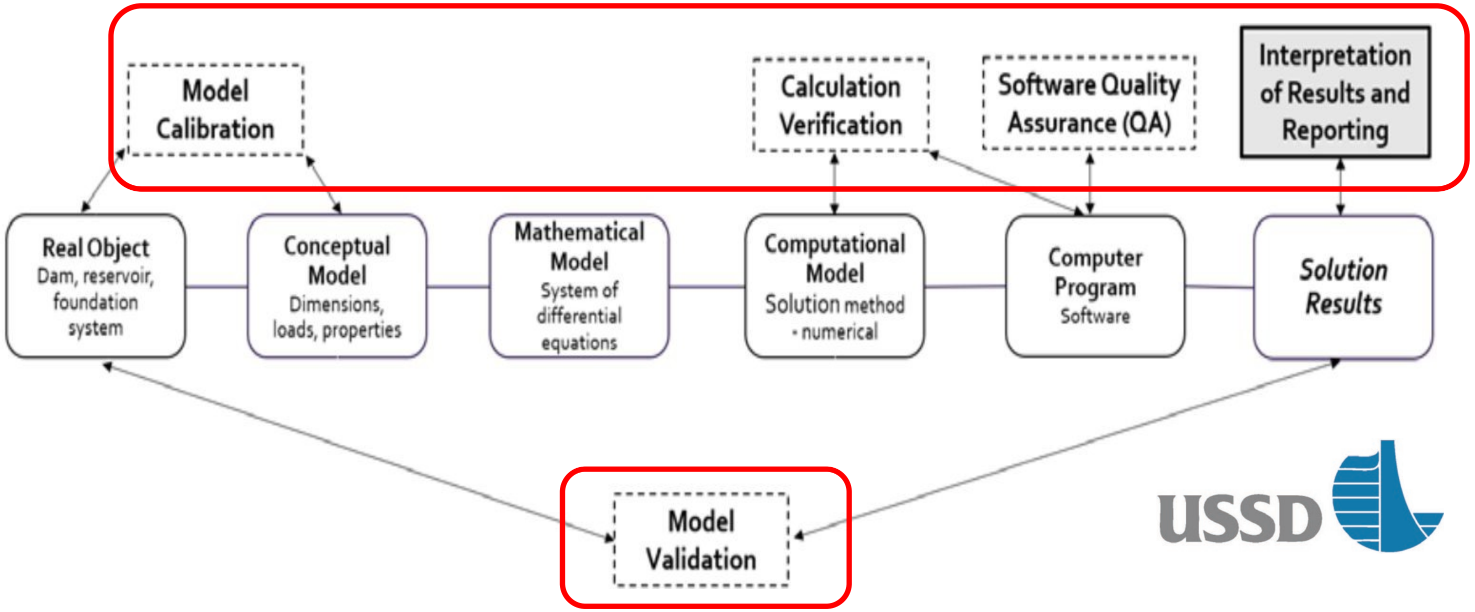
Road Map for Advanced Analysis of Concrete Dams

Confidence and credibility of the analysis is related to assessing accuracy in modeling and computational simulations

- ***Verification***
- ***Validation***
- ***Software Quality Assurance***
- ***Calibration***
- ***Interpretation of Results***



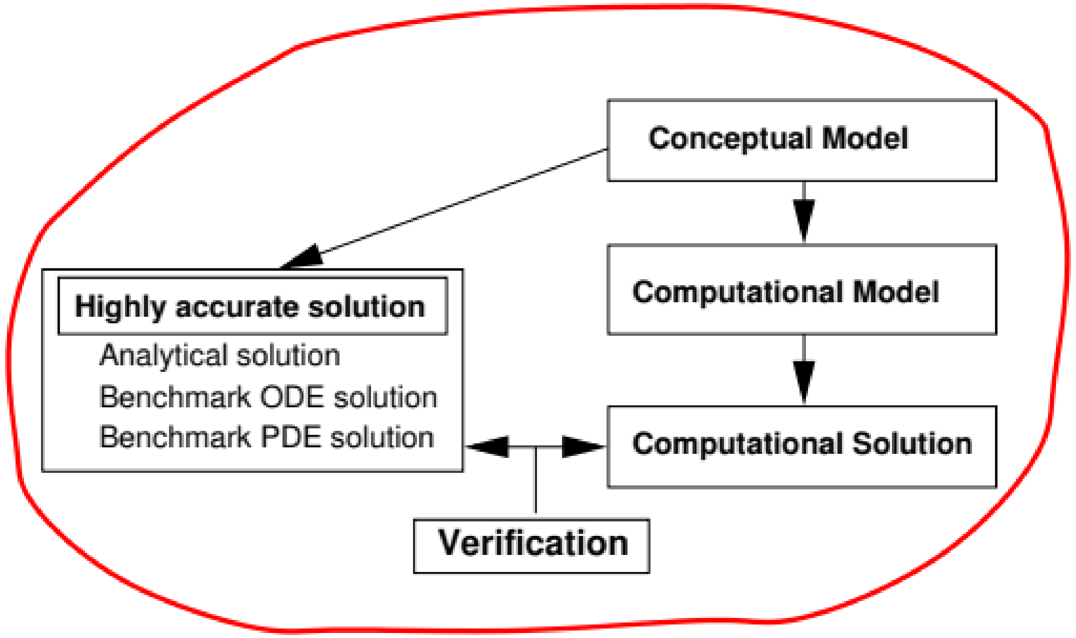
Verification Process

Process of determining that a model implementation accurately represents the developer’s conceptual description and specification

Mathematics, Computer Science issue

Verification provides evidence that the model is solved correctly

Identify and remove errors in computer coding
Quantification of the numerical errors in computed coding



Verification Process

Practical methods for verifying the ASA for concrete Dams

- Check the input parameters
- Check the computation results for symmetry, conservation of energy, general structure behavior, etc.
- Test submodels – each feature of the computational model is verified separately
- Compare submodel results with analytical solutions
- Compare the results with a suite of benchmark tests specific for concrete dam structures
- Compare software-to-software – conduct analyses with various software
- Evaluate discretization error
- Perform convergence tests
- Perform order-of-accuracy test
- Perform sensitivity studies – compare analysis results for a range of settings and a range of model parameters

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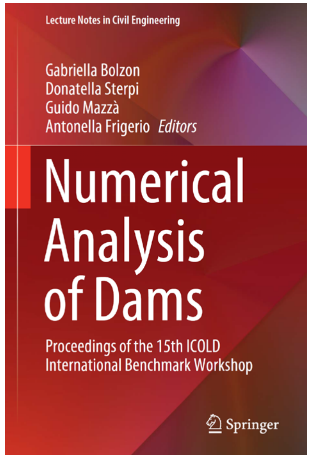
Illustration of Verification with Benchmark Test

Benchmark Workshops: ***Seismic Analysis of Concrete Pine Flat Dam***

- ICOLD 2019 - Milan, Italy [1]
- USSD 2018 - Miami, FL [2]



Reference [1]

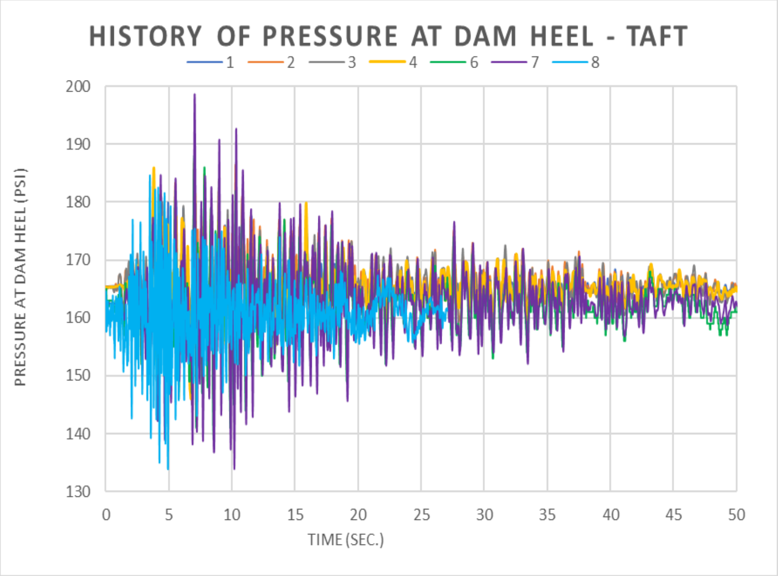
UNITED STATES SOCIETY ON DAMS
2018 CONFERENCE AND EXHIBITION

Workshop Organized by
The Committee on Concrete Dams and
the Earthquakes Committee

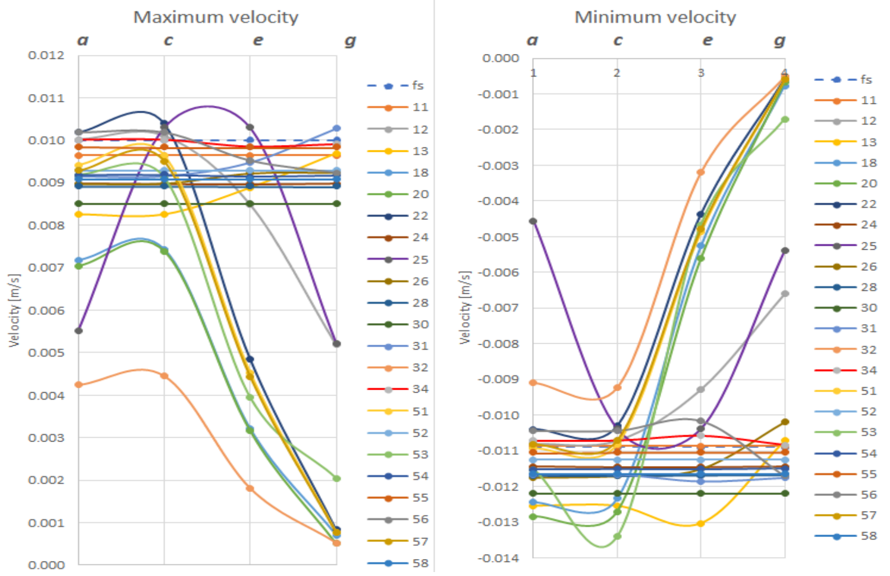
May 3, 2018 in Miami, FL

Formulation of the Case Studies for the
EVALUATION OF NUMERICAL MODELS AND
INPUT PARAMETERS IN THE ANALYSIS OF
CONCRETE DAMS

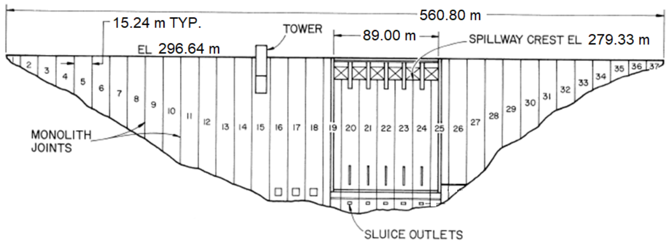
Reference [2]



Total hydrodynamic pressure at dam heel [2]



Peak velocity plots at Points *a, c, e,* and *g* for 22 contributions (dashed line is analytical solution) [1]



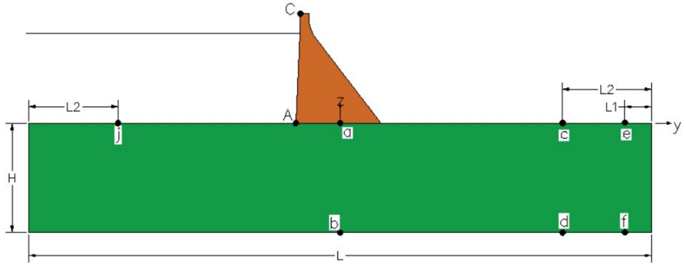
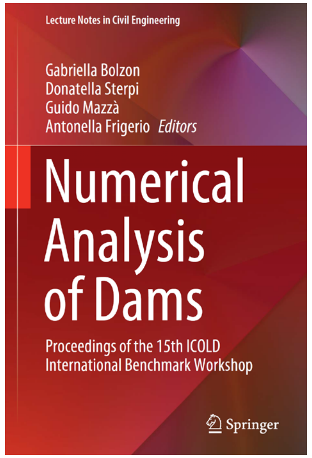
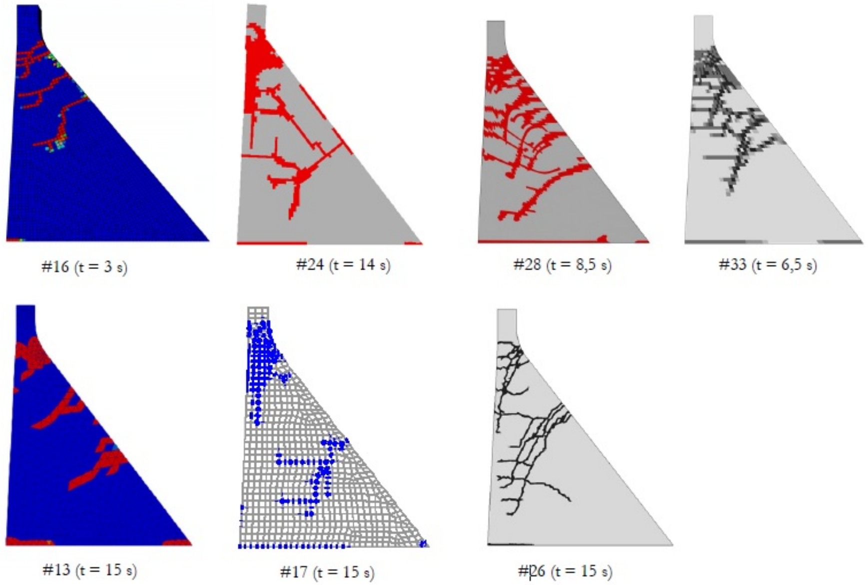
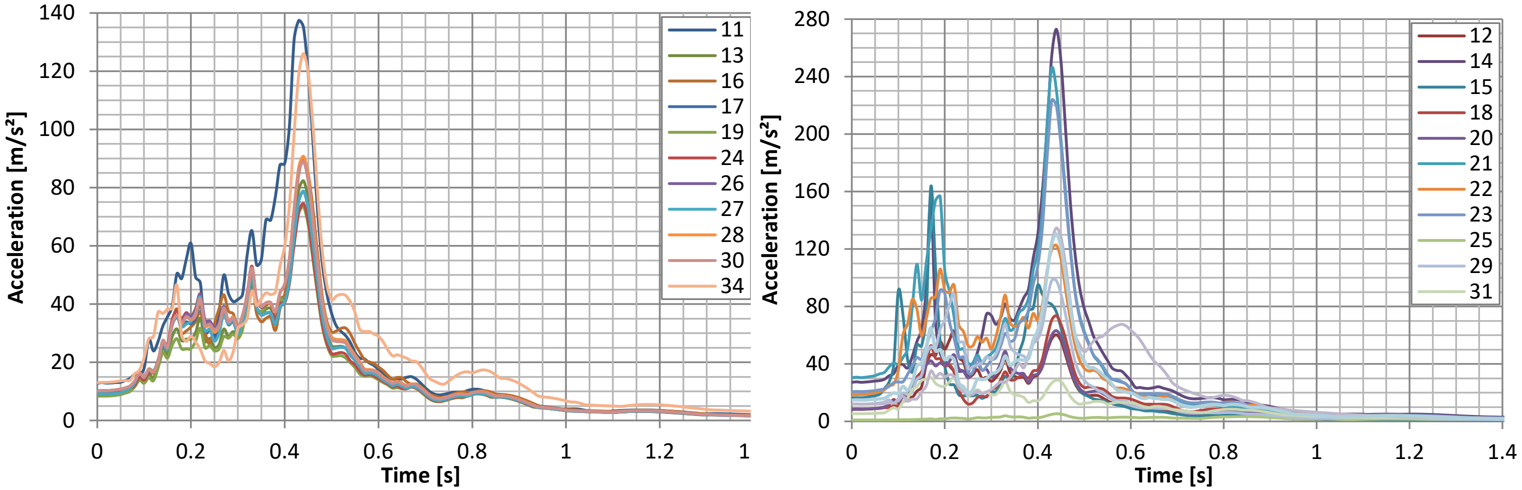


Illustration of Verification with Benchmark Test



15th ICOLD Benchmark Workshops: ***Seismic Analysis of Concrete Pine Flat Dam***





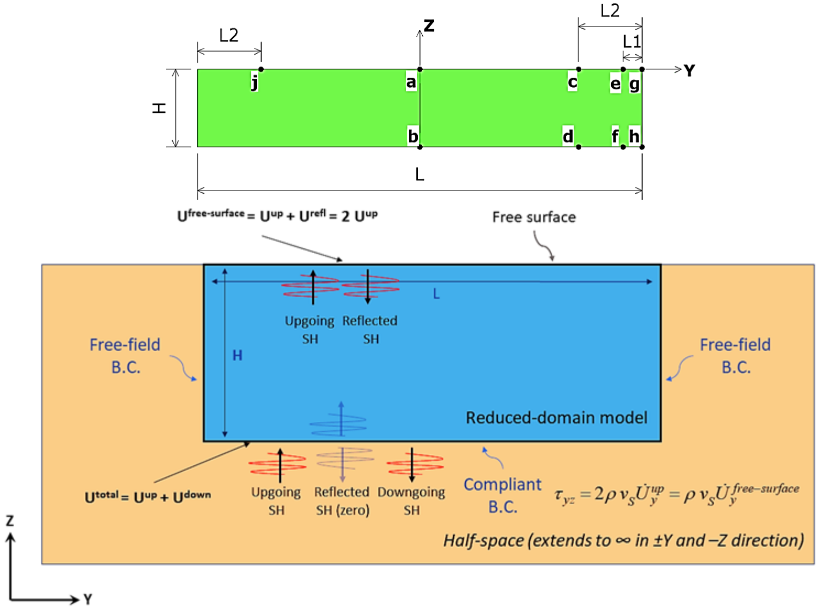
Free field BC

Non-reflecting BC

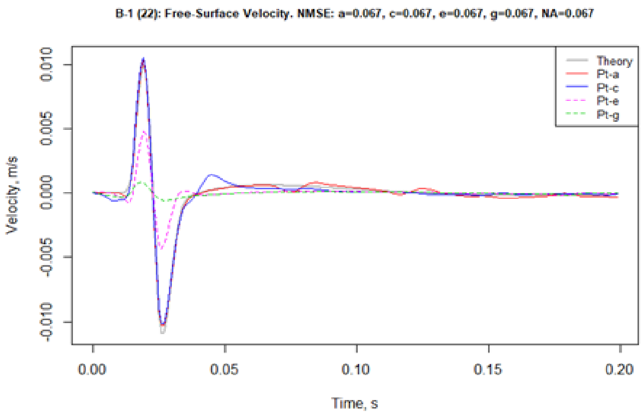
Horizontal accelerations at the dam crest [1]

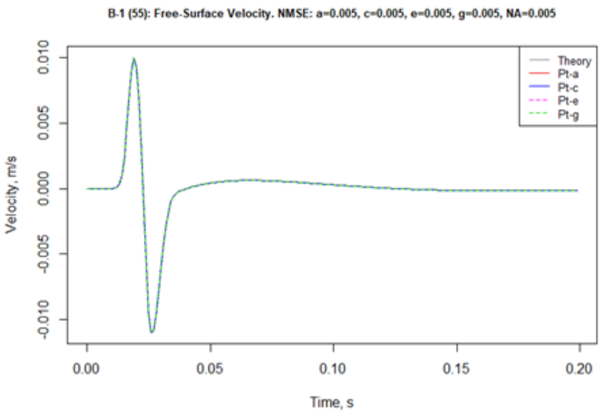
Damage profiles from 7 contributors [1]

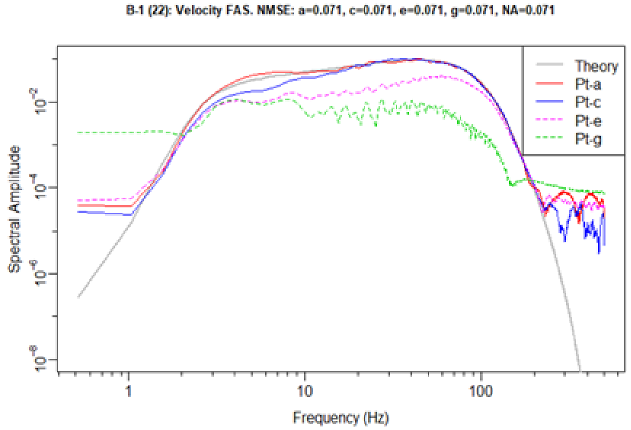
Illustration of Verification with Analytical Solution

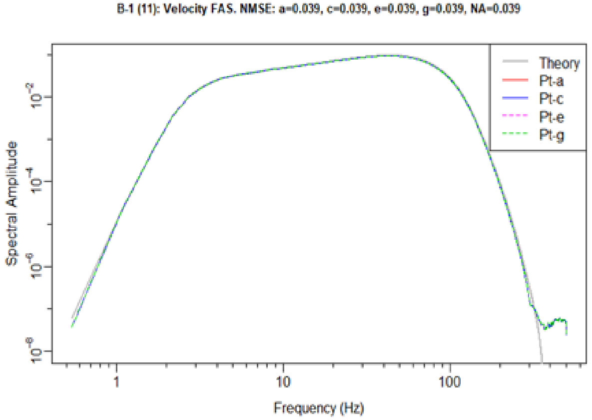


Far-field boundary condition [1]



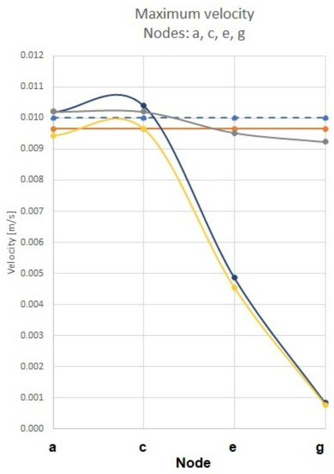


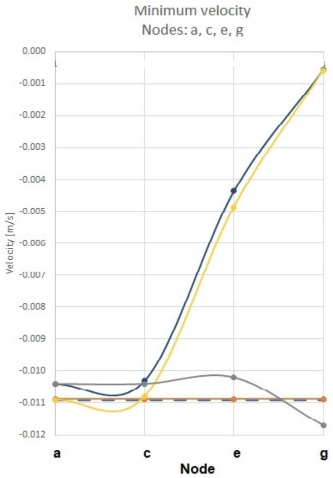




Non-reflective BC

Free field BC





"f" - free-field BC

"n" - nonreflecting BC

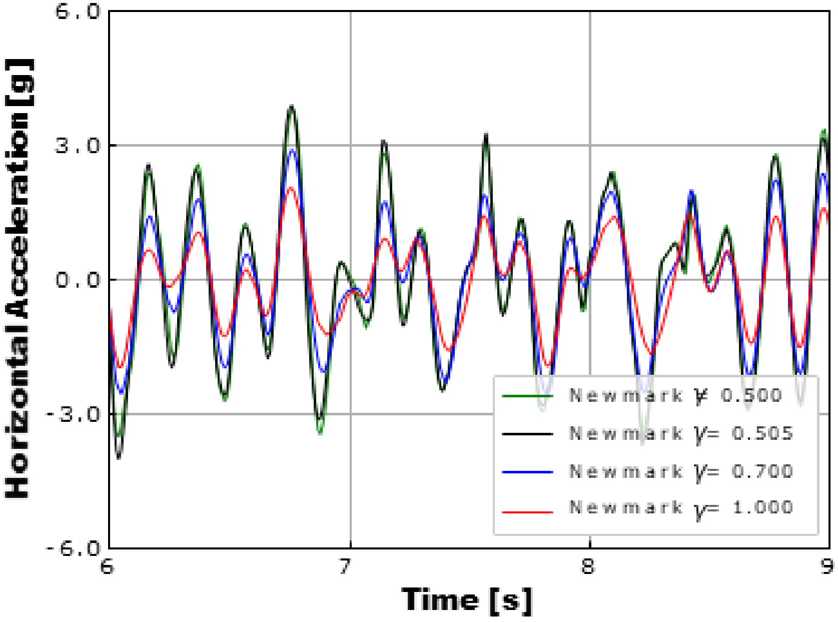
"theoretical" - dashed

- theoretical
- f
- n
- n
- f

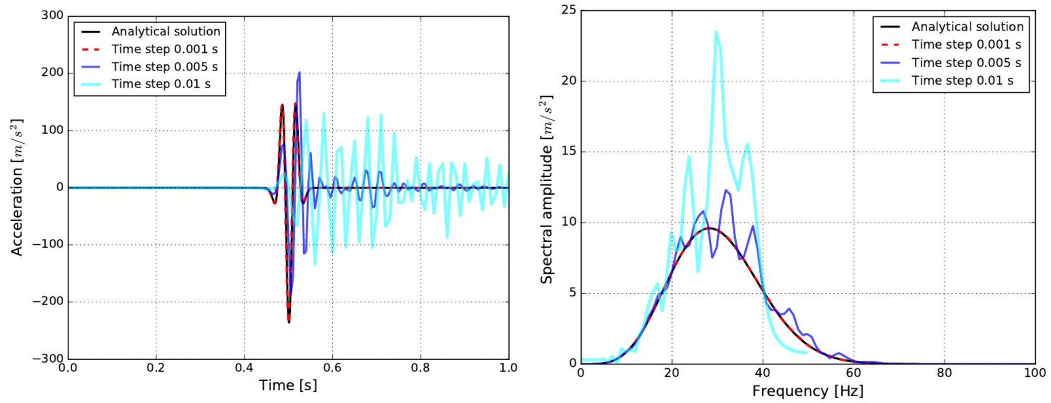
Max. and min. peak velocities at points *a*, *c*, *e,* and *g* of the foundation block.

Illustration of Verification

Effect of Numerical Damping



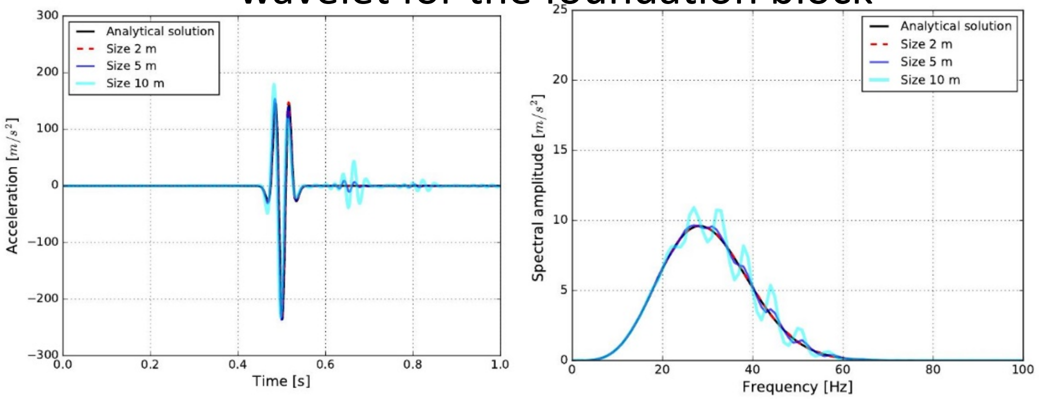
Influence of time step size on propagation of a Ricker wavelet for the foundation block



(a) Top acceleration

(b) Top spectrum

Influence of FE mesh size on propagation of a Ricker wavelet for the foundation block



(a) Top acceleration

(b) Top spectrum

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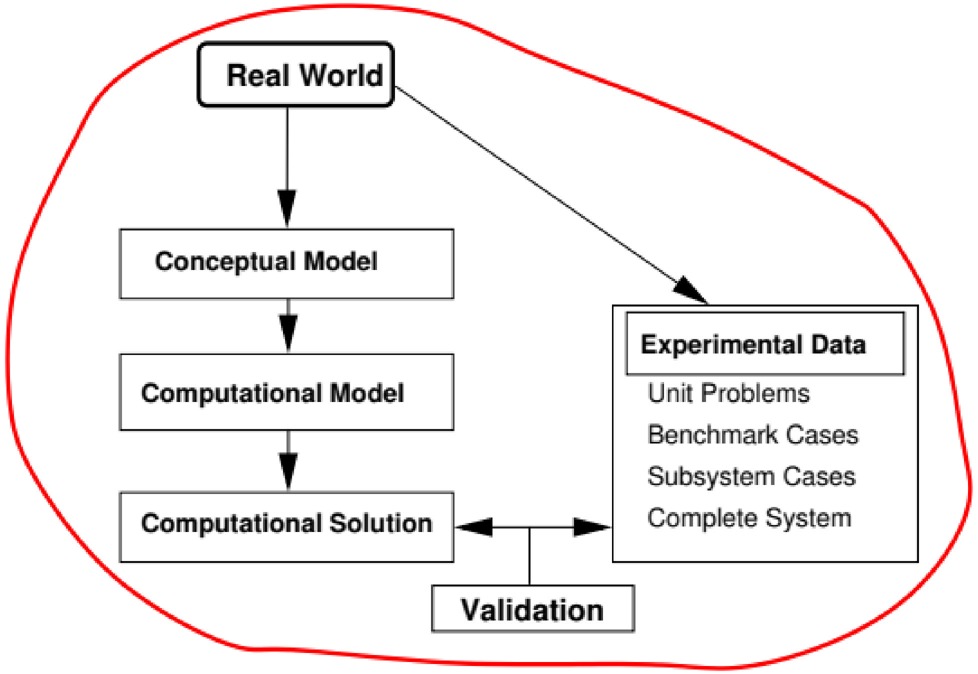
Validation Process

Process of determining the degree to which a model is accurate representation of the real world from the perspective of the intended uses of the model

Physics, Mechanics issue

Validation provides evidence that the correct model is solved



Tactical goal:

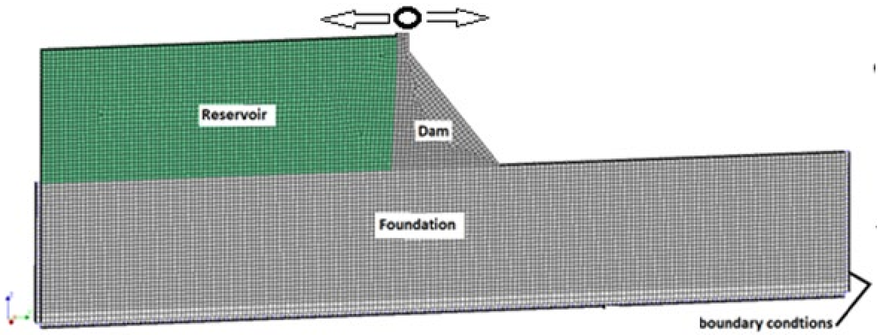
Identification and minimization of modeling uncertainties in the computational model

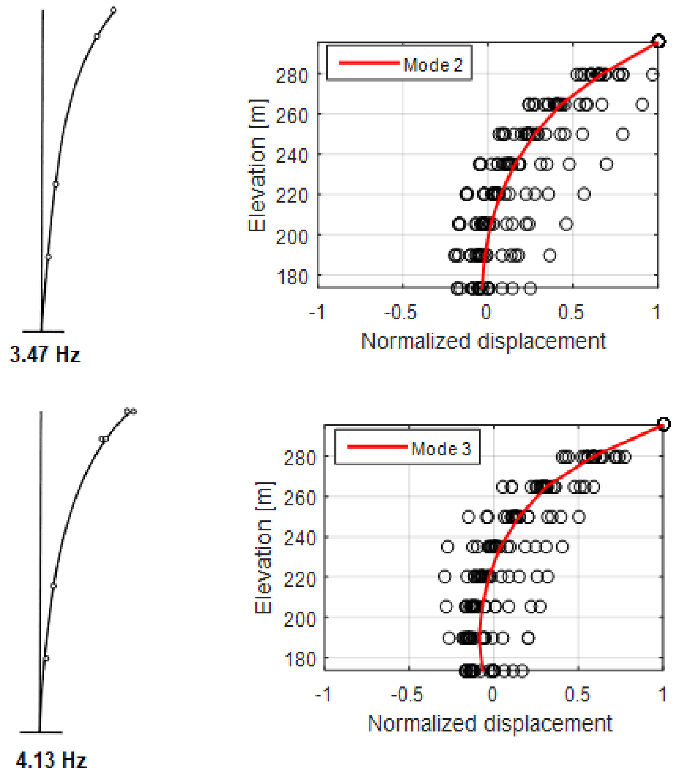
Strategic goal:

Increase confidence in the quantitative predictive capability of the computational model

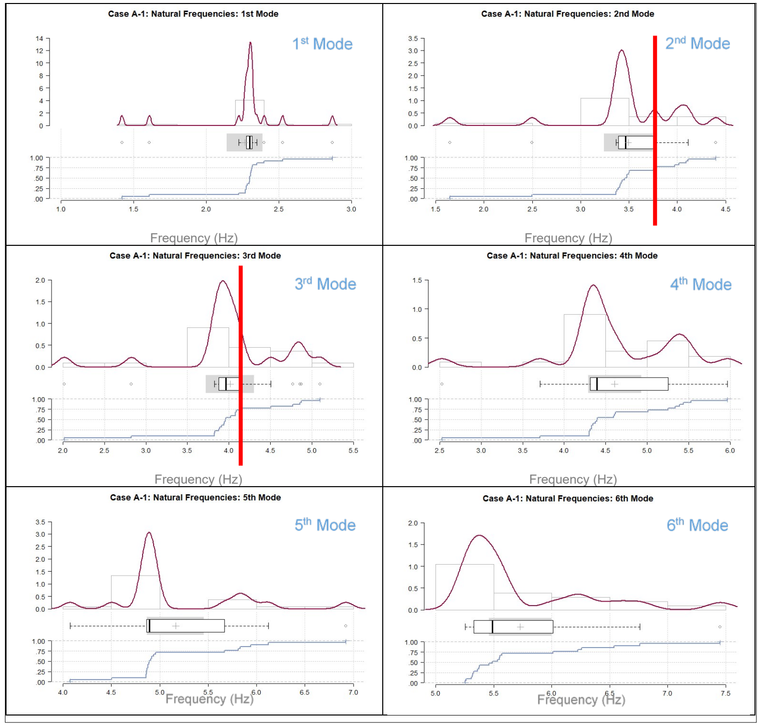
Illustration of Validation Process

Harmonic forced vibration field test of Pine Flat Dam [1]

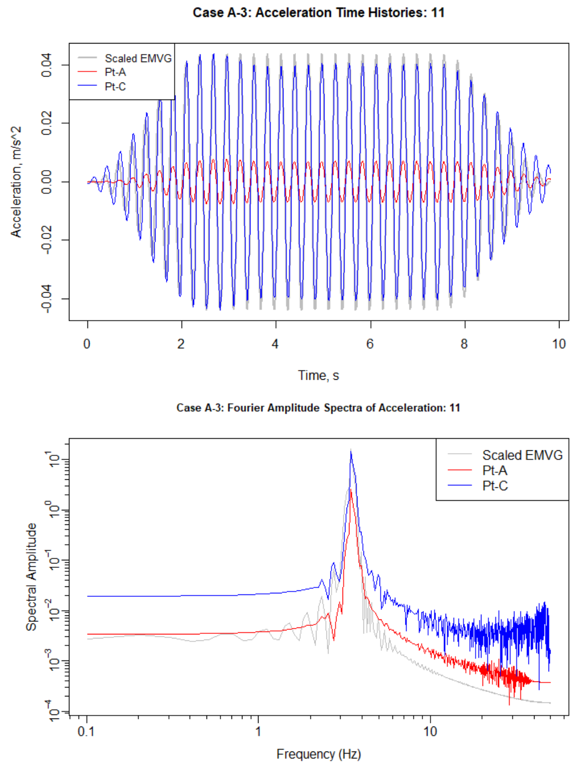




Mode shapes from 28 contributors



Natural frequencies



Acceleration at dam crest and heel dam

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Illustration of Calibration Process

Perform sensitivity studies – compare analysis results for a range of settings and a range of model parameters

Variations in Elastic Modulus of foundation rock [2]

E_1 = 3,000,000 psi ***E_2 = 10,000,000 psi***

Table D.1 - Natural Frequencies

Natural Frequency	Case D-1 (dam & foundation)	Case D-2 (dam & reservoir & foundation)
1	2.48	2.06
2	4.16	3.98
3	4.84	4.81
4	5.49	5.24
5	5.89	5.89
6	6.51	6.51

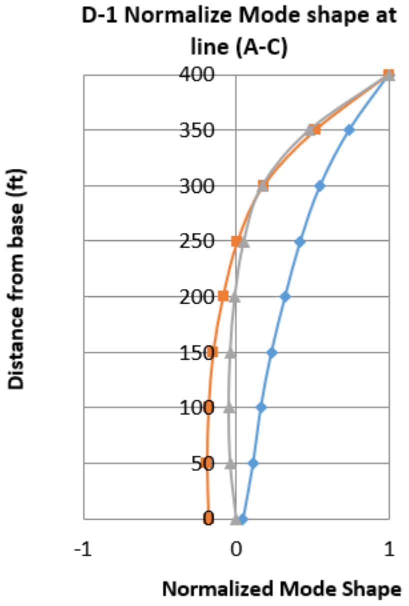
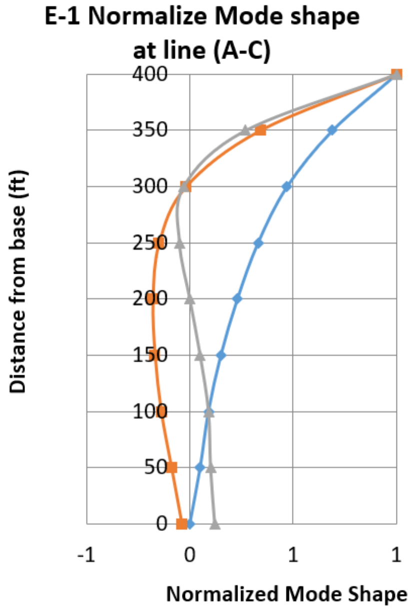


Table E.1 - Natural Frequencies

Natural Frequency	Case E-1 (dam & foundation)	Case E-2 (dam & reservoir & foundation)
1	2.91	2.43
2	5.58	5.02
3	6.94	6.90
4	7.89	7.72
5	9.96	9.48
6	10.28	10.28



Conclusions

- Accuracy the ASA for concrete dams is the primary interest in developing confidence in the analyses results
- Technical complexity and mathematical advancement of structural analyses of concrete dams require the analysts to have a high-level technical education, knowledge and experience in numerical solutions of structural problems, good skills in using the software, and expertise in concrete dams
- Engineering community will benefit from the unified guidelines (a road map) for conducting ASA of concrete dams

THANK YOU

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