HEC-RAS Flood Model Project: Seismic Dam Failure Methodology

February 22, 2017

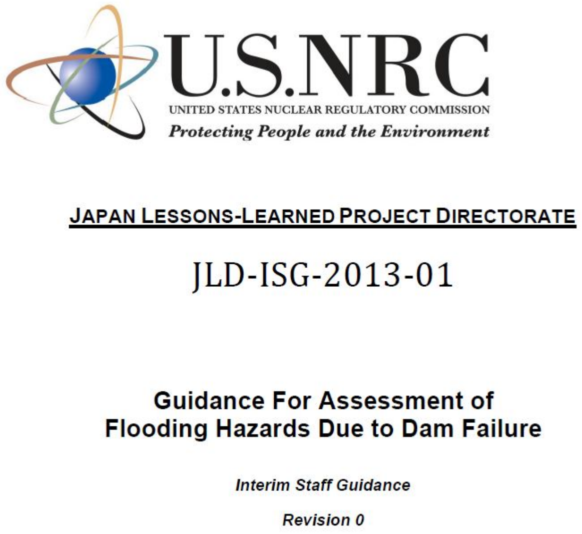
Outline

- Background Information
- Seismic Hazard
- Dam Stability Analyses
- Hydrologic & Hydraulic Models
- Single Dam Failures
- Multiple Dam Failures
- Results
- Schedule

Background

In the March 12, 2012, 50.54(f) letter submitted to licensees, re-evaluation of flood hazard is requested. Interim Staff Guidance, JLD-ISG-2013-01, provides guidance to perform flood hazard due to dam failure.

- TVA submits Updated Flood Hazard March 12, 2015.
- TVA re-evaluates stability of 27 upstream dams to current TVA dam safety standards for flood and seismic loading as outlined in JLD-ISG-2013-01.
- Assumptions of failure are made for additional upstream dams (conservative assumption for the flood hazard at nuclear power plants)


U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

JAPAN LESSONS-LEARNED PROJECT DIRECTORATE

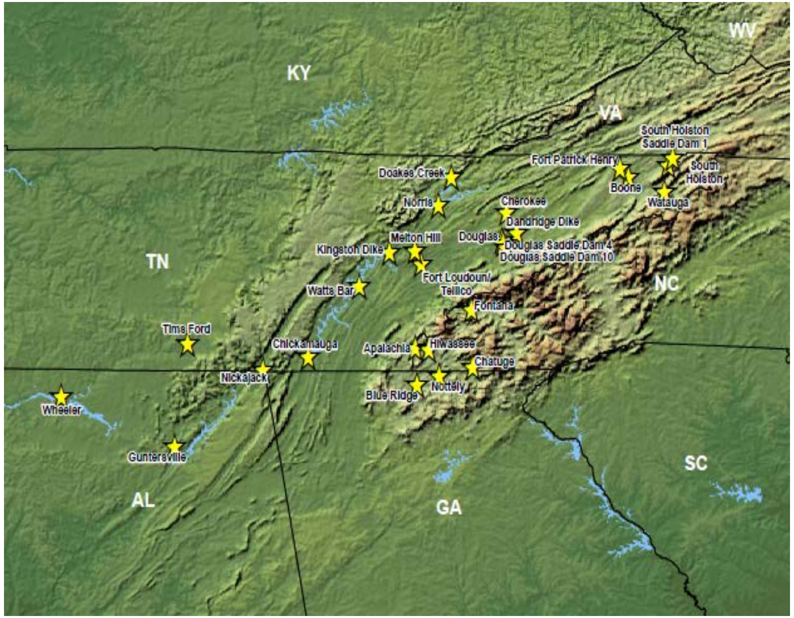
JLD-ISG-2013-01

Guidance For Assessment of Flooding Hazards Due to Dam Failure

Interim Staff Guidance

Revision 0

Updating Licensing Basis



Proposed Update

HEC-RAS model

Current dam stability methodology using probabilistic site-specific seismic hazard analysis for dam stability evaluation

Multiple dam failure considerations through deaggregation of seismic hazard

Current Basis

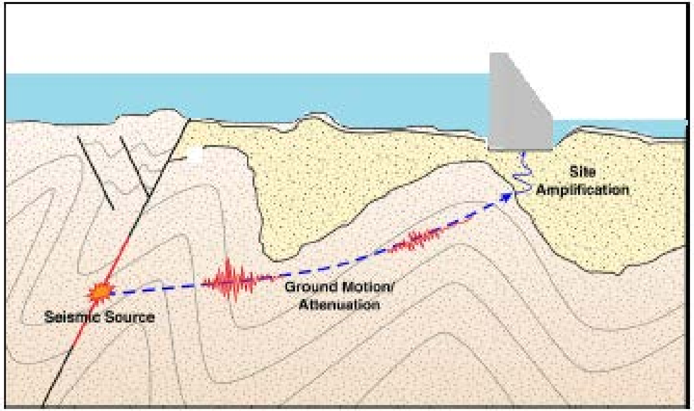
SOCH model

Deterministic nuclear power plant seismic input for dam stability evaluation

Multiple dam failure considerations using attenuation equations

Use of the completed updated flood hazard for seismic dam failures aligns with current standards for both dam stability and hydraulic analysis. Planned hydrology license amendment requests will require review criteria other than SRP.

Overview of Methodology



Detailed Analysis per JLD-ISG-2013-01

When dam failure is not assumed, detailed analysis of the dams are made.

Detailed analysis on 27 upstream dams/dikes

Seismic Source Model, CEUS-SSC [EPRI/NRC/DOE 2012]

Ground Motion Attenuation, Ground Motion Prediction Equations [EPRI 2004/2006]

Site Amplification, Site Response Analysis included detailed field investigation and laboratory test reports

Detailed Analysis of Seismic Capacity of the Dam, Post-seismic dam stability with detailed field investigation and laboratory reports [TVA Dam Safety Criteria]

Probabilistic Seismic Hazard Analysis

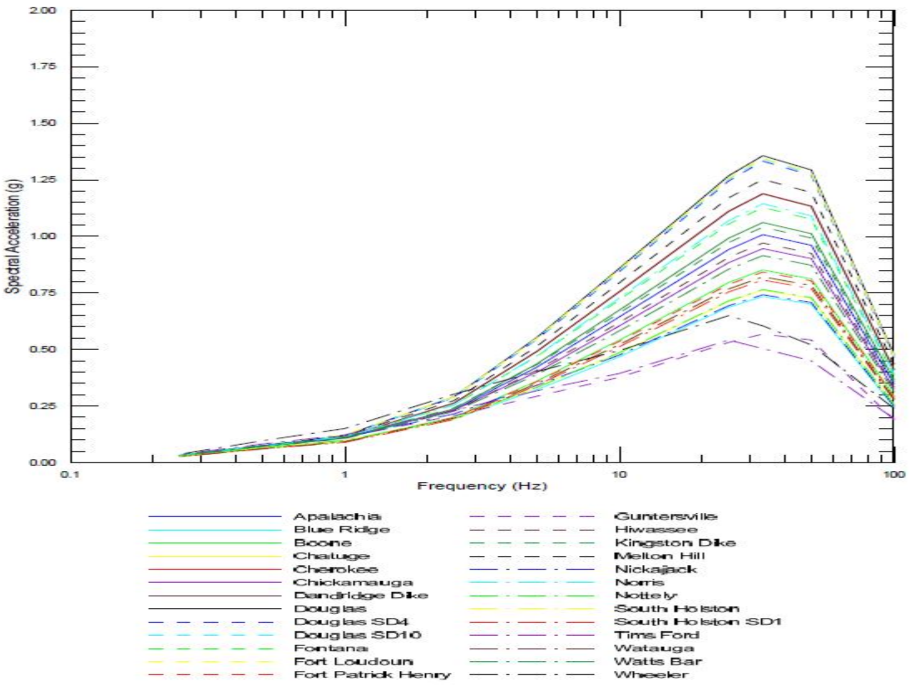
Inputs

Seismic source model: 2012 EPRI/DOE/NRC CEUS-SSC model

Ground motion prediction models: EPRI (2004, 2006)

Shown to the right are 10,000 year return period, 5% damped mean UHRS

No RLMEs located within about 200 km of the dam sites; however New Madrid fault system, Reelfoot Rift, and Charleston source added to model

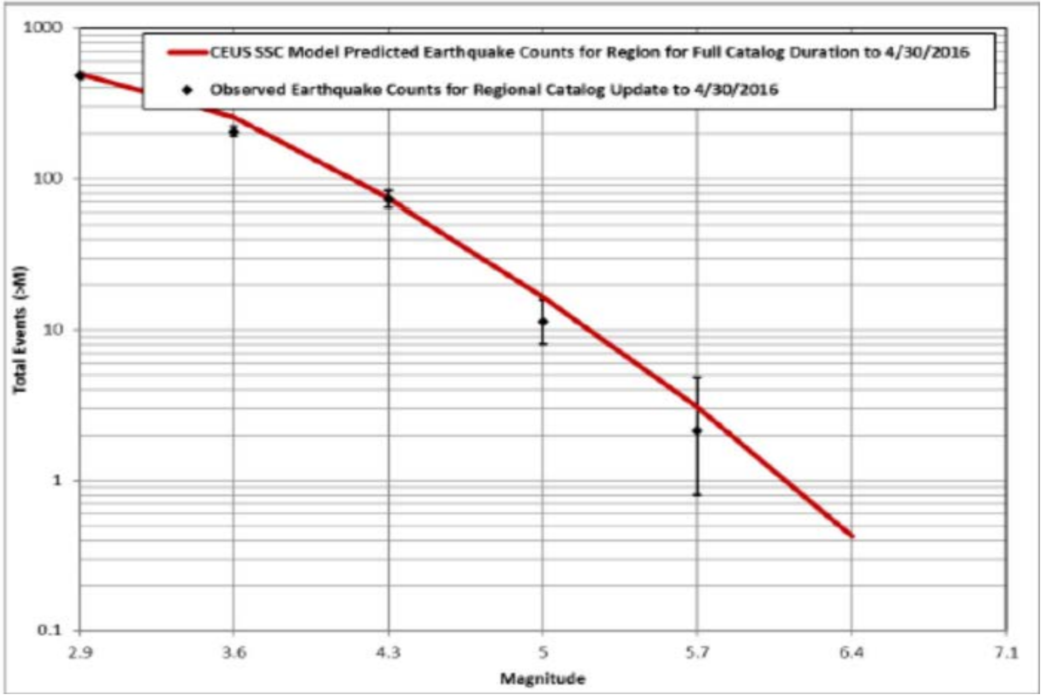


Seismic Source Catalog Updates

Seismic Source

Recently for seismic PRA work, catalog updates for the region have been completed

Plot to the right shows predicted vs. observed earthquake counts for catalog updates to 4/30/2016

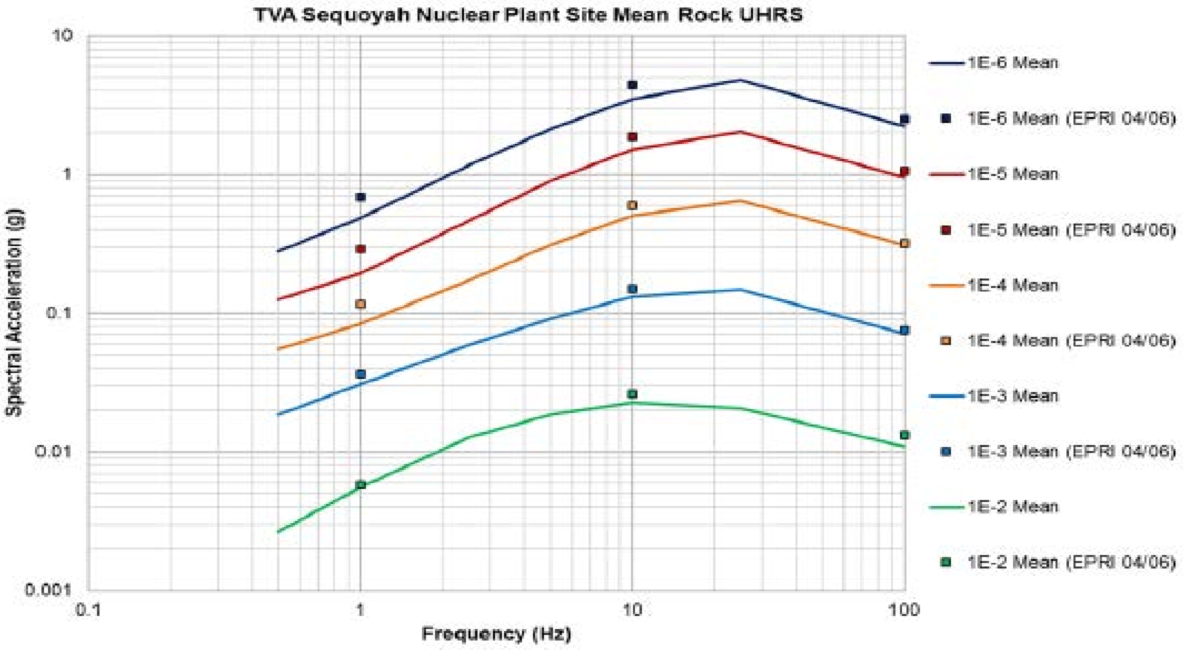


Ground Motion Model Update Comparison

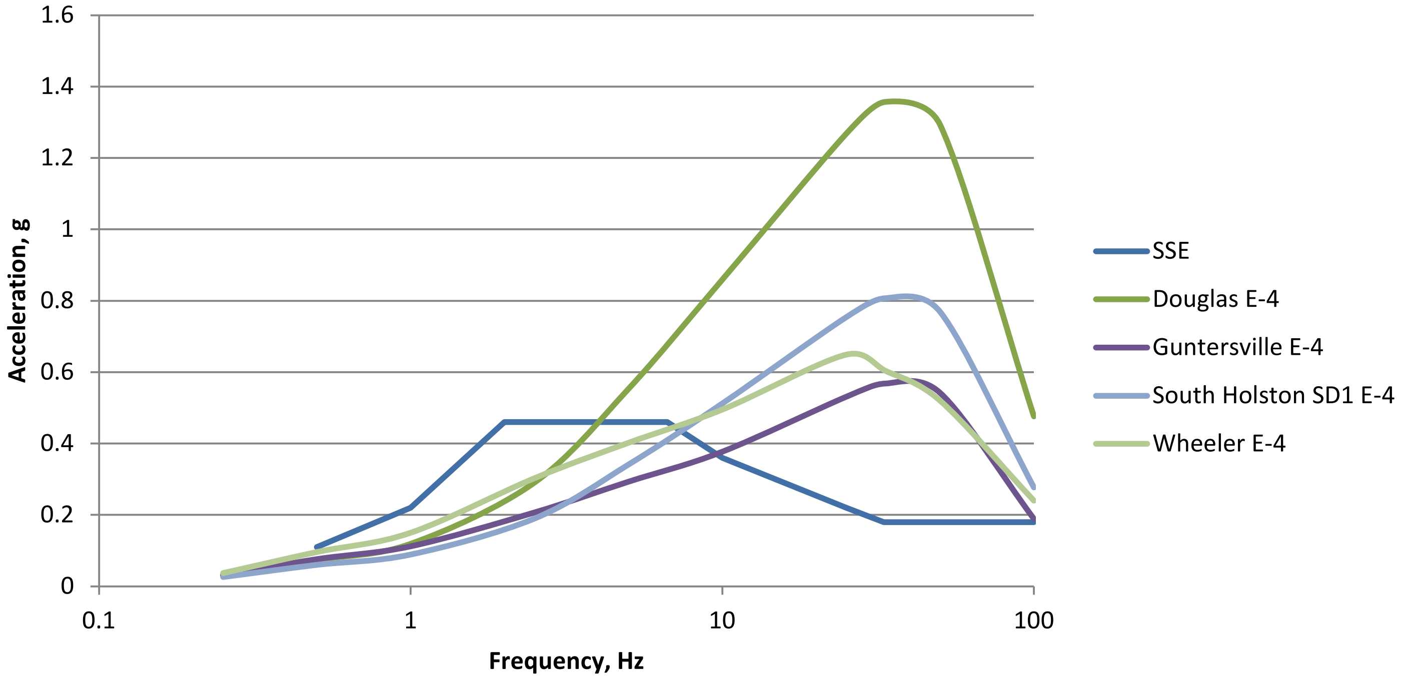
Ground Motion Models

EPRI 2013 vs. EPRI 2004/2006

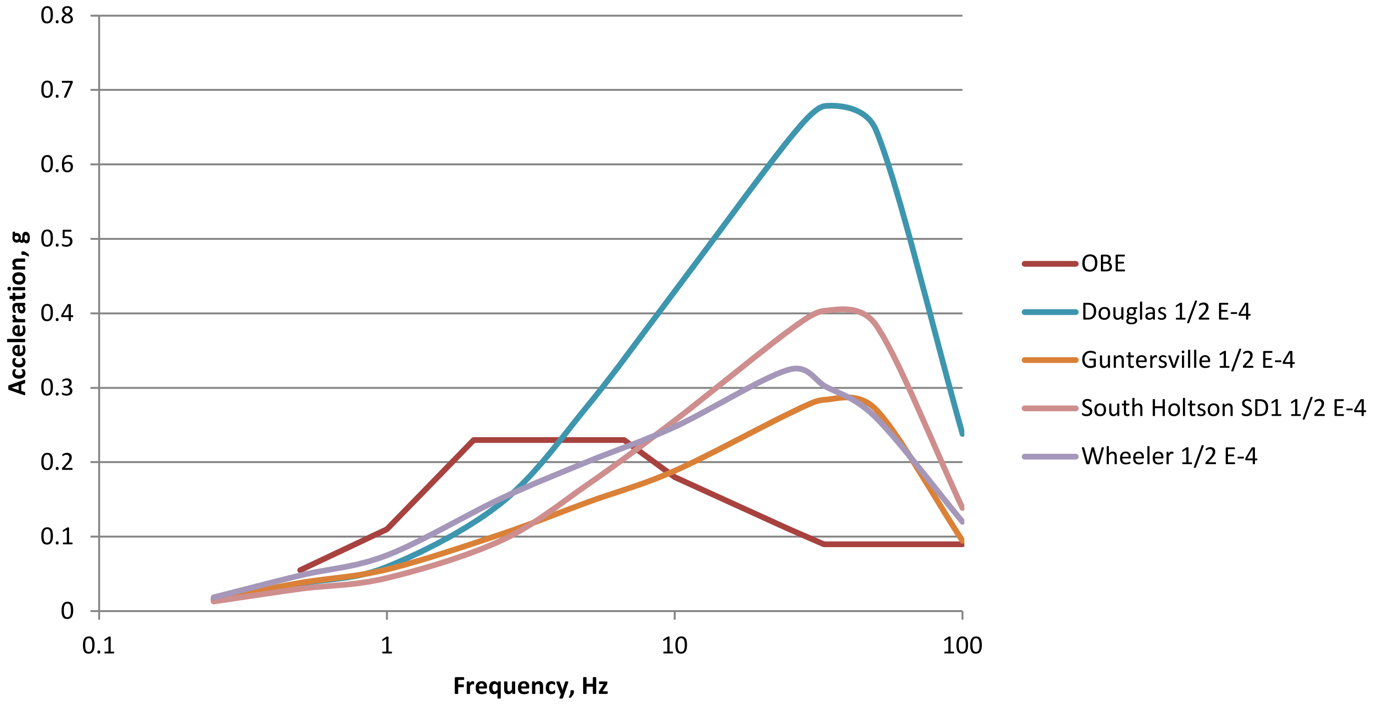
Recently for seismic PRA work, ground motion models comparisons have been completed



SSE comparison



OBE comparison



Controlling Earthquake

RG 1.208, Appendix D with following exceptions:

- Deagreggation at 1 and 10 Hz instead of 1 to 2.5 Hz and 5 to 10 Hz
  - 10 Hz spectral frequency of interest, concrete dam
  - 1 Hz spectral frequency of interest, earthen dam
- Modal magnitude and distance instead of mean magnitude and distance
  - 1 Hz controlling earthquake, distant large magnitude New Madrid
  - 10 Hz controlling earthquake, local moderate event in Eastern Tennessee Seismic Zone

Time histories

Time History Development

6 sets of time histories developed

3 sets for 1 Hz

3 sets for 10 Hz

Spectrally matched per SRP 3.7.1 criteria

Time History Use

1. Dynamic stability analyses of dams if founded on hard rock, or
2. Site response analysis to develop ground motions at foundation level beneath dam if dam not founded on hard rock

1 Hz Controlling Earthquake	1	1999	Chi Chi, Taiwan
	2	2002	Denali, AK
	3	1992	Landers, CA
10 Hz Controlling Earthquake	4	1987	Superstition Hills, CA
	5	2011	Mineral, VA
	6	1988	Saguenay, Quebec

Dam Site Response Analysis

- Site-specific exploration and testing completed
- Time history sets developed for each dam at frequency of interest
- Response analysis software used to perform the wave propagation analysis to define seismic response at dam foundation for condition other than hard rock
- V/H ratios from NUREG-6728, Table 4-5
- Foundations considered massless but with stiffness
- Hydrodynamic masses representing the upstream normal pool reservoir are computed and applied to upstream face

Dam Stability Analysis Concrete

Updated

2-D or 3-D finite element analyses of dams including modifications

Headwater and tailwater – normal pool

Dynamic analysis of seismic loading and reservoir effects performed to define "damaged state"

- Cohesion at rock-concrete interface neglected, conservatively
- Degradation of friction angle
- Silt pressure effect included
- Increased uplift due to degraded drains and base cracking

If damaged state, no rock-concrete tensile strength

Acceptance criteria – sliding FS=1.3 and Resultant within dam base

Current Licensing Basis

2-D rigid body analyses of critical locations prior to current modifications

Headwater and tailwater – 25 year flood and ½ PMF flood without tailwater reduction

Pseudo-static analysis with hydrodynamic pressures

- Silt pressure not considered
- Cohesion at rock-concrete interface applied
- Friction angle, no degradation
- Increased uplift due to degraded drains and base cracking not considered

Acceptance criteria – sliding FS=1.0 and resultant within dam base

Dam Stability Analysis Earthen

Updated

Pseudo-static method of seismic coefficient

Headwater and tailwater – normal pool

Dynamic analysis for applied ground motion with in-situ soil properties

Evaluation of liquefaction potential and reservoir effects

Post-seismic stability

- Stability FS $\geq$ 1.1
- If FS < 1.1, seismic deformation analysis is conducted
- Seismic deformation limited to $<$ 2 feet and ½ filter thickness
- Seepage evaluations included

Current Licensing Basis

Pseudo-static, standard slip circle method generally used

Headwater and tailwater – 25 year flood and ½ PMF without tailwater reduction

Amplification assumed based on nuclear plant studies (dam dynamic soil properties not available)

Hydrologic & Hydraulic Models

Updated

Hydrologic

Precipitation – 25 year flood updated with additional gauge data

Precipitation – 500 year flood

Hydraulic

HEC-RAS model

Debris fields not utilized

Current Licensing Basis

Hydrologic

Precipitation – ½ PMF (Vintage HMR)

Hydraulic

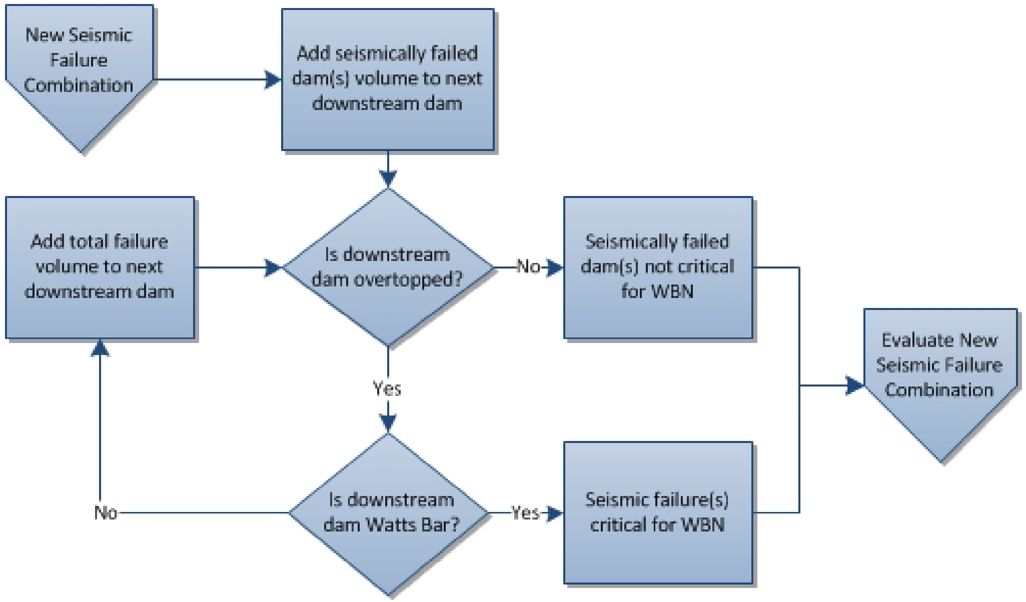
Simulated Open Channel Hydraulics (SOCH) model

Debris fields utilized

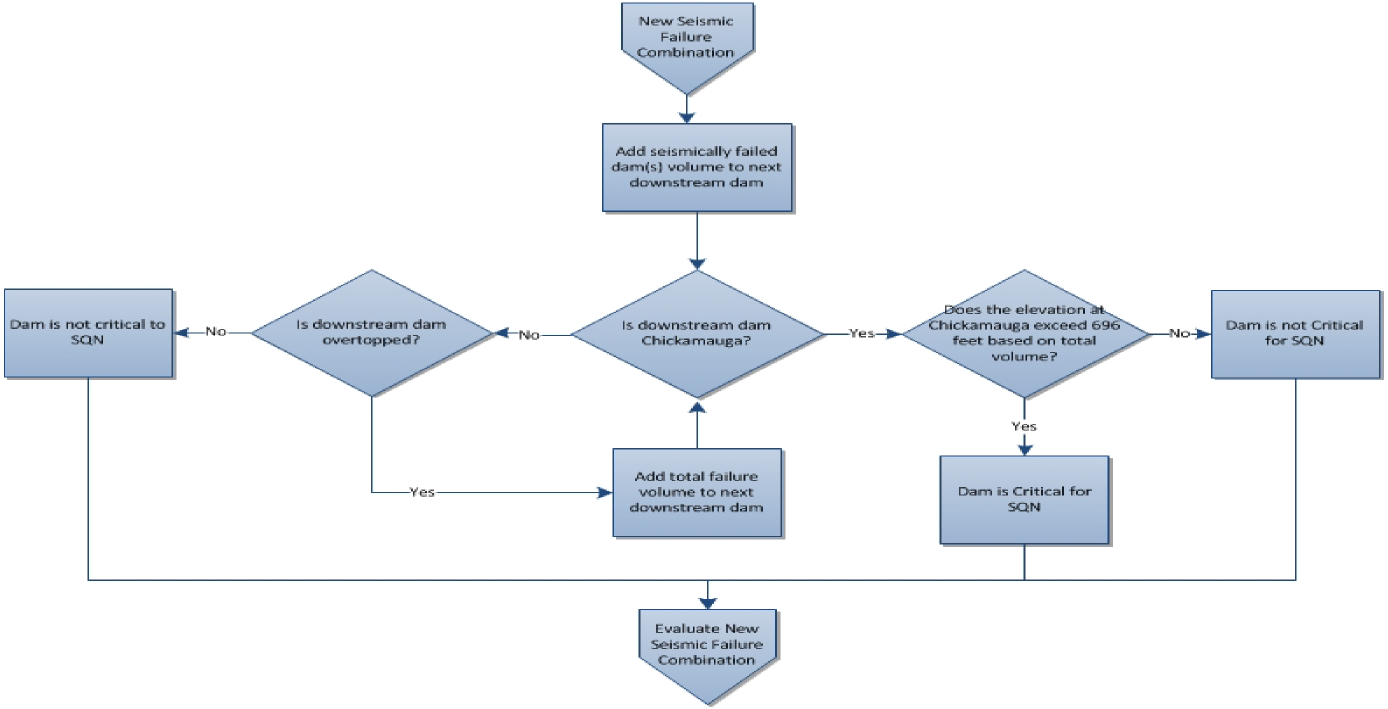
Simplified Screening

- Screening approach JLD-ISG-2013-01, Section 3
- Inconsequential dam failure combinations assessment based on reservoir volumes
- Entire volume transferred downstream to next reservoir, carried throughout system
- Outlet structures of stable dams assumed closed

Screening – Watts Bar



Screening - Sequoyah



Screening Results

- Possible Consequential Results (Single Failure)
  - South Holston
  - Watauga
  - Chatuge
  - Cherokee
  - Fontana
  - Norris
  - Nottely
  - Watts Bar

Seismic Single Dam Failure

Updated

One half 10^{-4} AFE ground motion + 500 year flood

Watts Bar

Chatuge

10^{-4} AFE ground motion + 25 year flood

No additional; above cases govern

Current Licensing Basis

OBE + ½ PMF

Norris

Cherokee

Douglas

Fontana

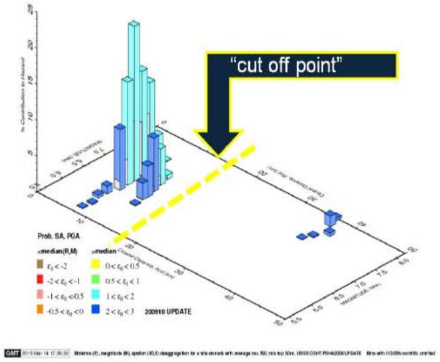
SSE + 25 year flood

Watts Bar

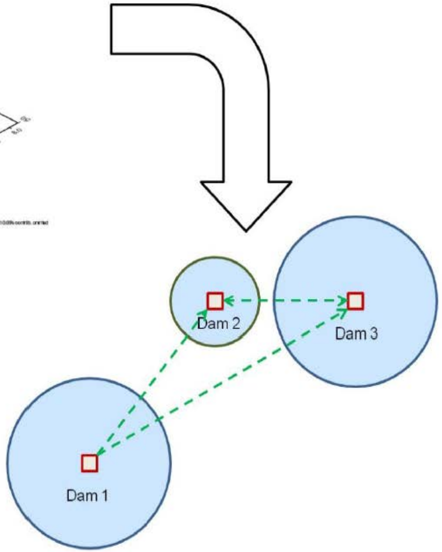
Considerations of Multiple Dam Failures From Single Seismic Event (Updated)

JLS-ISG-2013-01 Section 5.5

Seismic influence refinement completed through deaggregation of hazard.



Source: USGS

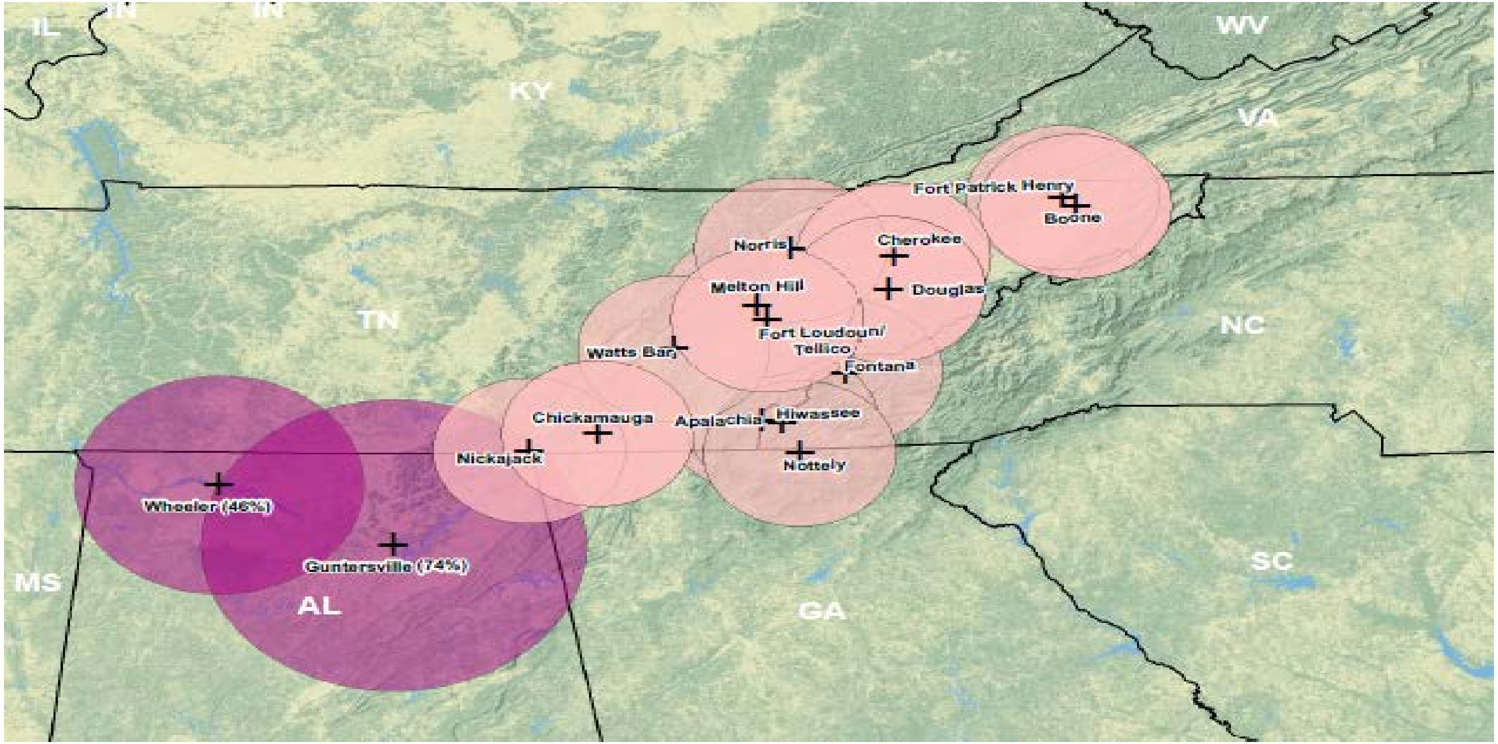


Frequency of Interest

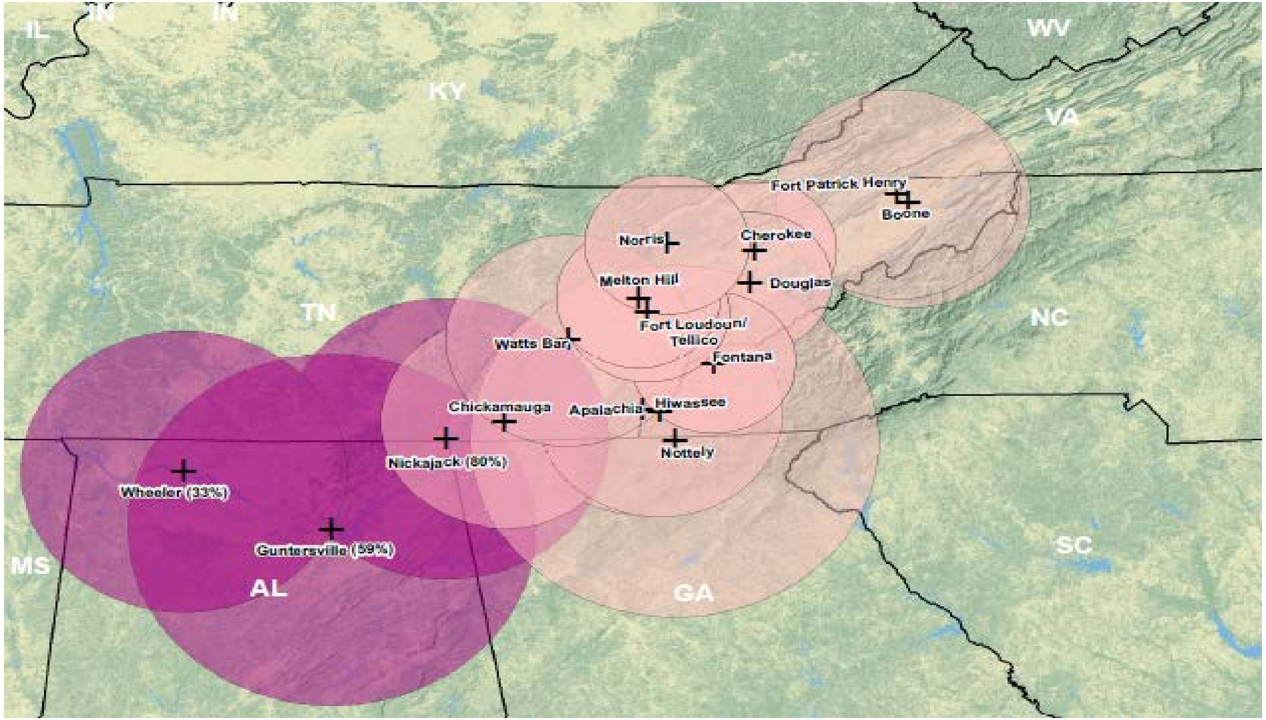
Concrete dams, 10 Hz

Earthen dams, 1 Hz

Seismic Influence Deaggregation 10 Hz at 10^{-4} AFE



Seismic Influence Deaggregation
10 Hz at one half ground motion 10^{-4} AFE



Seismic Influence Deaggregation 1 Hz at 10^{-4} AFE & 1 Hz at one half ground motion 10^{-4} AFE

- All dams evaluated have large portion of 1 Hz seismic hazard influenced by the New Madrid Fault Zone. Therefore, events contributing to the hazard of one dam are likely to be a major contributor to the hazard at all the other dams.

Multiple Dam Failure Combinations From Single Seismic Event

Updated

10^{-4} AFE eq + 500 year flood

Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Fontana, Melton Hill, Tellico and Watts Bar Dams

½ 10^{-4} AFE eq + 25 year flood

Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Melton Hill, Tellico and Watts Bar Dams

Current Licensing Basis

OBE + ½ PMF

Fontana and Tellico

Norris and Tellico

Fontana, Tellico, Hiwassee, Apalachia, Blue Ridge

Cherokee, Douglas and Tellico

SSE + 25 year flood

Norris, Cherokee, Douglas, Tellico

Results - SQN

FHRR+

Failure Combination	SQN Elevation (ft) Grade elevation 705
1/2 10-4 AFE eq + 500 year flood	
Douglas Centered (Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Fort Patrick Henry, Melton Hill, Tellico, Watts Bar)	705.3
10-4 AFE eq + 25 year flood	
Fort Loudoun Centered (Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Fontana, Melton Hill, Tellico, Watts Bar)	703.0

Current Licensing Basis

Failure Combination	SQN Elevation (ft) Grade elevation 705
OBE+1/2 Probable Maximum Flood	
Norris, Tellico	706.3
Fontana, Tellico	702.2
Fontana, Tellico, Hiwassee, Apalachia, Blue Ridge	706.3
Cherokee, Douglas, Tellico	708.6
SSE+25 year flood	
Cherokee, Douglas, Tellico, Norris	706.0

+FHRR shown only as an indication of expected updated results; HEC-RAS ineffective flow area issue requires addressing in updated

Results - WBN

FHRR+

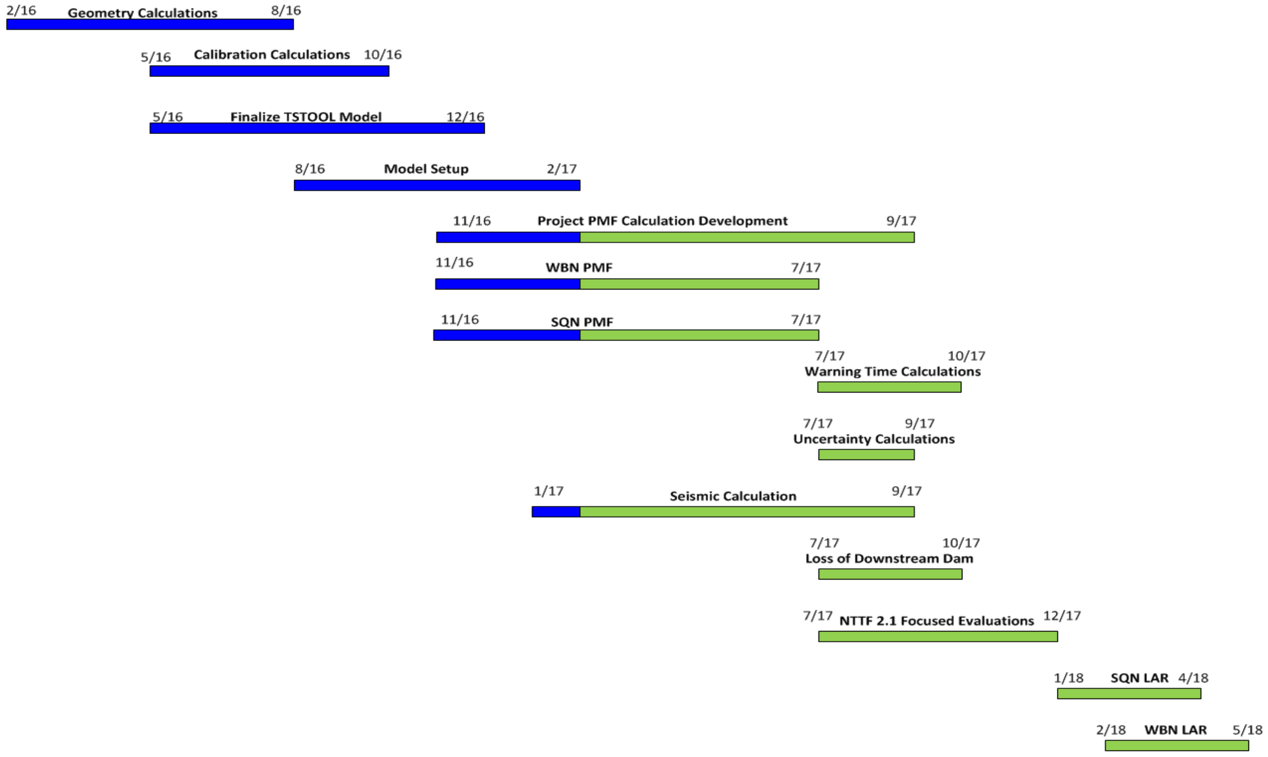
Failure Combination	WBN Elevation (ft) Grade elevation 728
1/2 10^{-4} AFE eq + 500 year flood	
Douglas Centered (Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Fort Patrick Henry, Melton Hill, Tellico, Watts Bar)	729.9
10^{-4} AFE eq + 25 year flood	
Fort Loudoun Centered (Apalachia, Blue Ridge, Chatuge, Fort Loudoun, Fontana, Melton Hill, Tellico, Watts Bar)	727.7

Current Licensing Basis

Failure Combination	WBN Elevation (ft) Grade elevation 728
OBE+1/2 Probable Maximum Flood	
Norris, Tellico	728.7
Fontana, Tellico	720.7
Fontana, Tellico, Hiwassee, Apalachia, Blue Ridge	722.0
Cherokee, Douglas, Tellico	729.1
SSE+25 year flood	
Cherokee, Douglas, Tellico, Norris	731.2

+FHRR shown only as an indication of expected updated results; HEC-RAS ineffective flow area issue requires addressing in updated

Schedule – Planned Path



TVA