Overview of Seismic Issues in California

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PG&E

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Issues

- Seismic issues from owners perspective
- Source Characterization
  - Faults
  - Background zones
- Ground Motion
- Fault Rupture

Seismic Issues from Owner Perspective

- Safety requirements
  - Regulators
- What is the performance of a dam?
  - Evaluate performance vs “safe”
    - Probability of dam failure
      - Probabilistic loading (ground motions, fault rupture)
      - Probabilistic capacity (Fragility of dams)
  - Seismic Reliability
    - What is the reliability?
    - Is there a need to improve performance beyond regulatory requirements for safety?
  - Main technical need is for fragility studies of dams

Performance-Based Approach

- Evaluate the actual performance of the dam during earthquakes
  - Consider a range of ground motions (not just a single eqk)
  - Use best estimates of dam properties and response, not conservative assumptions used in design criteria
  - Quantify uncertainty in the best estimates
  - “Fragility curves”
- Consider the probability of different ground motions
  - Seismic hazard curves
    - Ground motion lower than design criteria
    - Ground motions larger than design criteria
- Combine ground motion and dam response into a risk calculation
  - Probability of different failure models of the dam
    - Quantifies the probability of PFMA

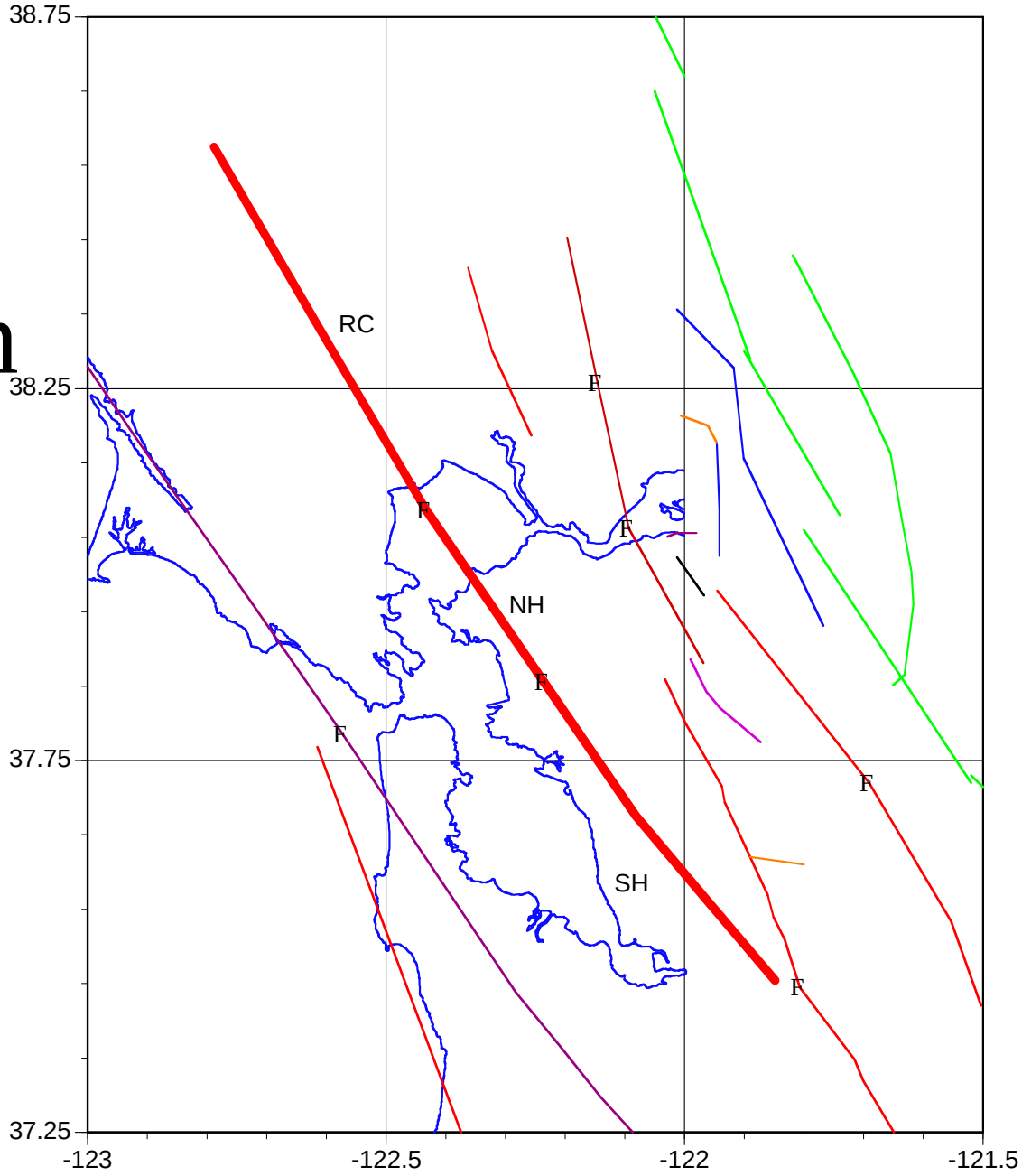
Dam Fragility

- Response of the Dam
  - Compute response parameters based on dynamic analysis of dam
    - Strains, deformation, liquefaction
- Performance of the Dam
  - Given the response of the dam, what is the chance of a failure mode occurring?
    - Use expert judgment (group of experts)
    - Key issue is to avoid conservatism
      - Difficult for engineers

Key Source Characterization Issues

- Faults
  - Segmentation (impacts M and rates)
  - Renewal models (impacts rates)
- Source zones
  - Selection of a deterministic background eqk
  - Spatial smoothing of seismicity for PSHA

Hayward Fault Segmentation



Fault Segmentation

- 1970s
  - 1/4 to 1/2 of fault length
- 1980s
  - Single segment ruptures (full length of segment used)
- 1990s
  - Multiple segment rupture
    - Landers Earthquake
- Current
  - Identified segmentation points
    - Narrow range of characteristic magnitudes
    - Consider multi-segment ruptures
  - Unknown segmentation points
    - Broad range of characteristic magnitudes

Renewal Models

- Accounts for time since last large (characteristic) earthquake
- Statistical models available
  - CV of about 0.5
  - Fault interaction still unresolved
- Data Needs
  - Most faults do not have reliable dates of last characteristic earthquake

Renewal Models

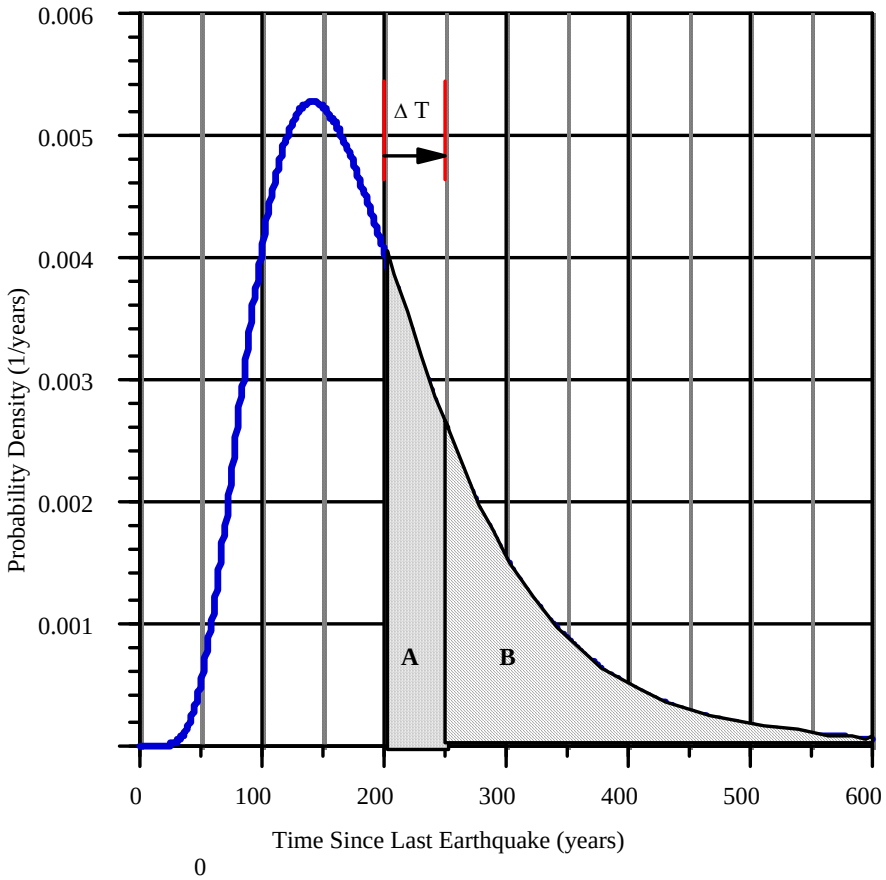


Figure 10. Computation of the conditional probability for the rewnel model.

Renewal Models

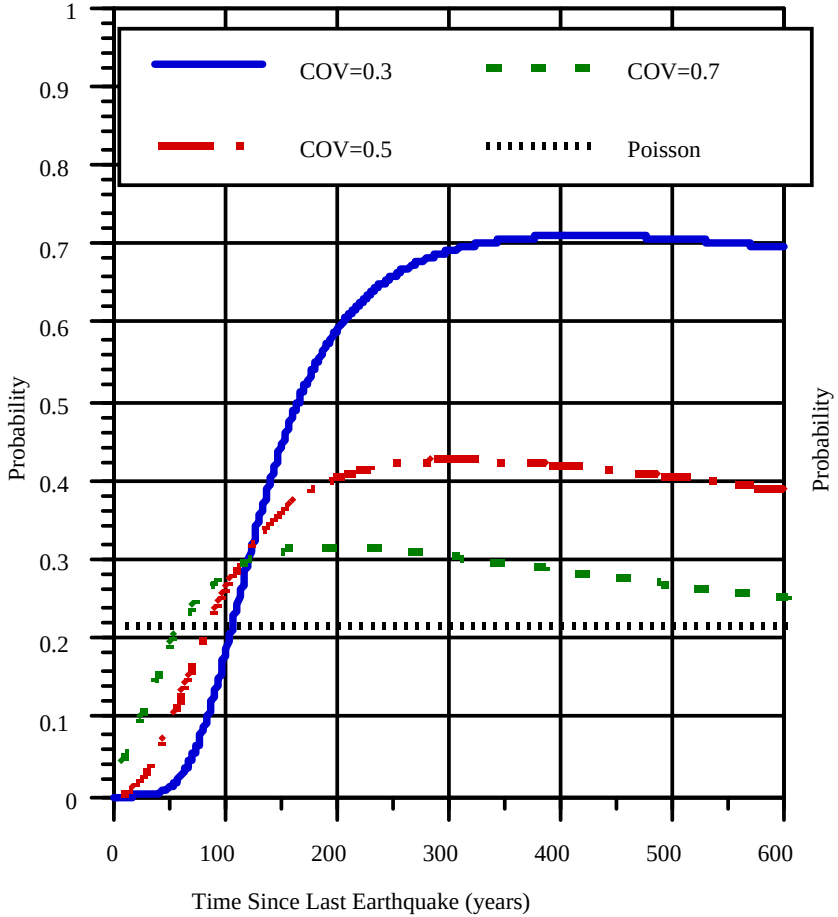


Figure 11. Sensitivity of the conditional probability for the renewala model for a 50 year exposure period.

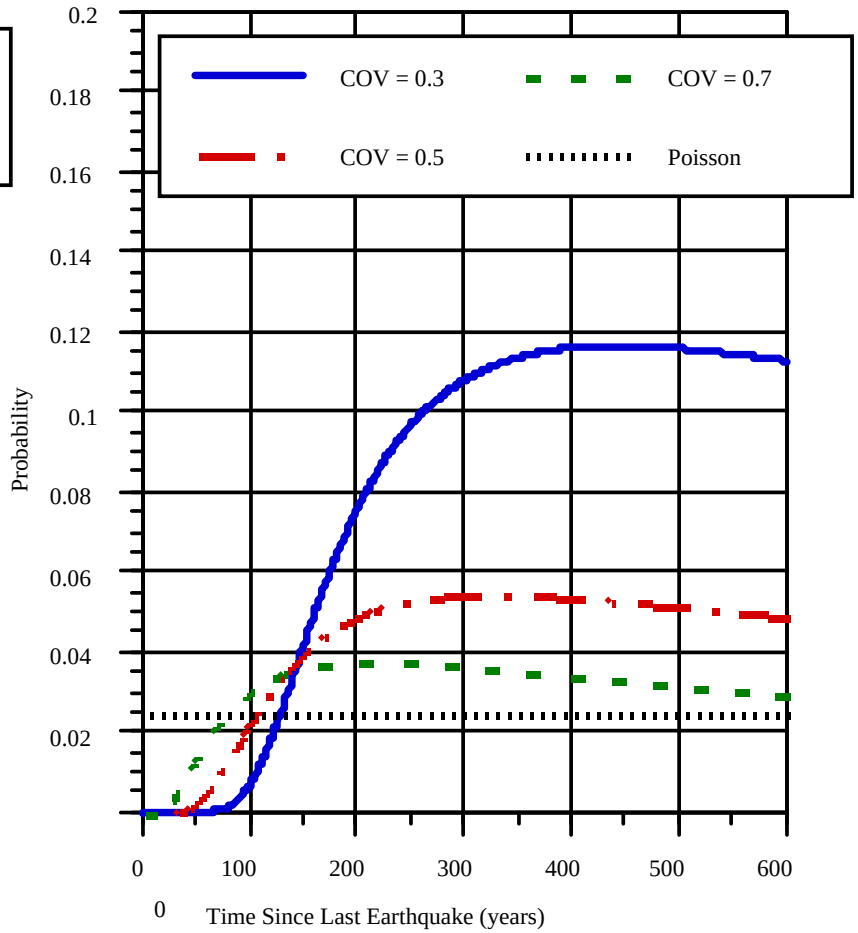
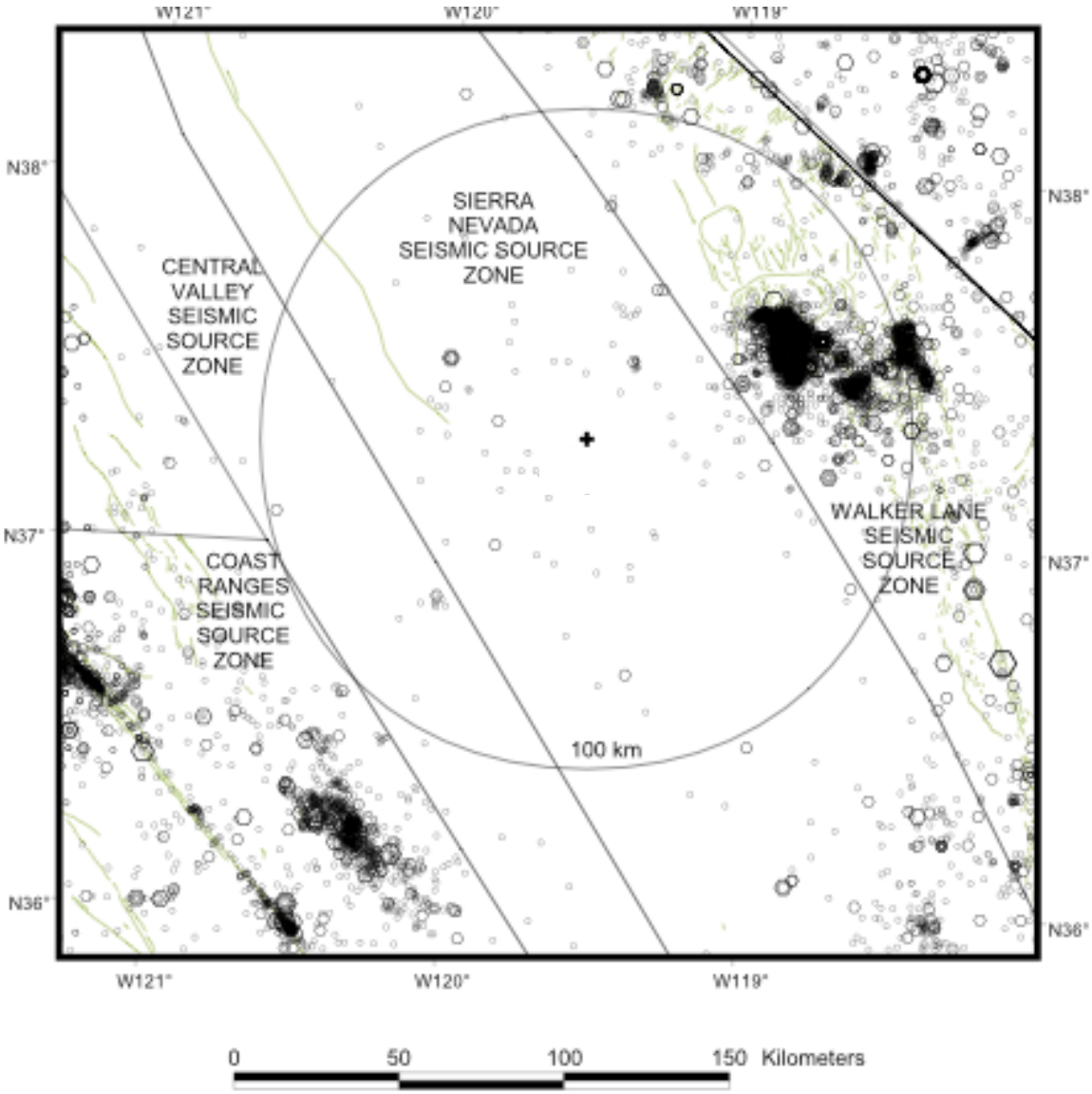


Figure 12. Sensitivity of the conditional probability for the renewala model for a 5 year exposure period.

Source Zones

- Deterministic approach
  - What magnitude / distance to select?
  - Negotiated with regulator
    - Typically M5.5 to 6.25 at distance of 5 to 20 km
- Probabilistic approach
  - Well suited to background earthquakes
  - Main issue is how much spatial smoothing?
    - Need method for testing the smoothing
      - Too much?
      - Too little?
  - Mmax is not critical as long as > 6

Seismicity 1857-2004



Example: Testing of Seismicity Smoothing

- Seismicity within 50 km of site
  - 40 earthquakes with M>3
- Seismicity within 17 km of site
  - 0 earthquakes with M>3
- If assumed uniform
  - P(zero eqk within 17 km) = (1-(17/50)^2)^40 = 0.007
  - Less than 1% chance that model could produce observed rate within 17 km of site
  - Need alternative smoothing
    - Set rate such that prob of 0 eqk in 17 km is 10%, 30%, 50%

Testing Smoothing

- Start with broad smoothing
- Compare the statistics of the observed spatial distribution with the spatial distribution from multiple realizations of te model
  - Nearest neighbor pdf
  - Separation distance pdf
- If rejected with high confidence (e.g. 95% or 99%) then reduce the smoothing and repeat
- In general, US practice leads to too much smoothing.

Ground Motion Models for CA

- Shallow Crustal Earthquakes
  - NGA models
  - Use and misuse of VS30
- Subduction Earthquakes
  - Poor state of models
- Ground motion parameters for Dams
  - Beyond spectral values

NGA Models:
Main Changes from Previous Models

- Use of Vs30
- Standard deviation independent of magnitude for most models
- Non-linear site response
  - Impacts both median and standard deviation
- Hanging wall and Footwall factors
- Additional predictive parameters
  - Depth to Top of Rupture
  - Depth of Soil
  - Dip (HW factor only)
- Models are much more complex

Generic Rock and Vs Based Models

- Generic Rock categories
  - Many previous studies had incorrect classification of site
  - Vs30 approx 550 m/s for A&S 1997 generic rock
- Expect a reduction in the ground motion model to account for Vs30 differences
  - If increase Vs30 from 550 to 750m/s
  - 12% decrease for PGA
  - 25% decrease for T= 1 sec

Style-of-Faulting Factor

- Previous models included larger ground motion for reverse faults
  - Low short period ground motions from Chi-Chi reduces the SOF factor for reverse
  - C&B only include SOF factor for rev for buried ruptures
- Normal faulting SOF factor is not well constrained
  - Ranges from 0 to 20% reduction as compared to SS

Additional Parameters

- Buried reverse
  - CB08
- Top of rupture
  - AS08, CB08, CY08
- Depth of soil
  - Depth to VS=1.0 km/s (Z1.0)
    - AS08, CY08
  - Depth to VS=2.5 km/s (Z2.5)
    - CB08
- Other Parameters
  - Dip, rupture width used only to taper HW effects

Summary of NGA model Changes from Previous Models

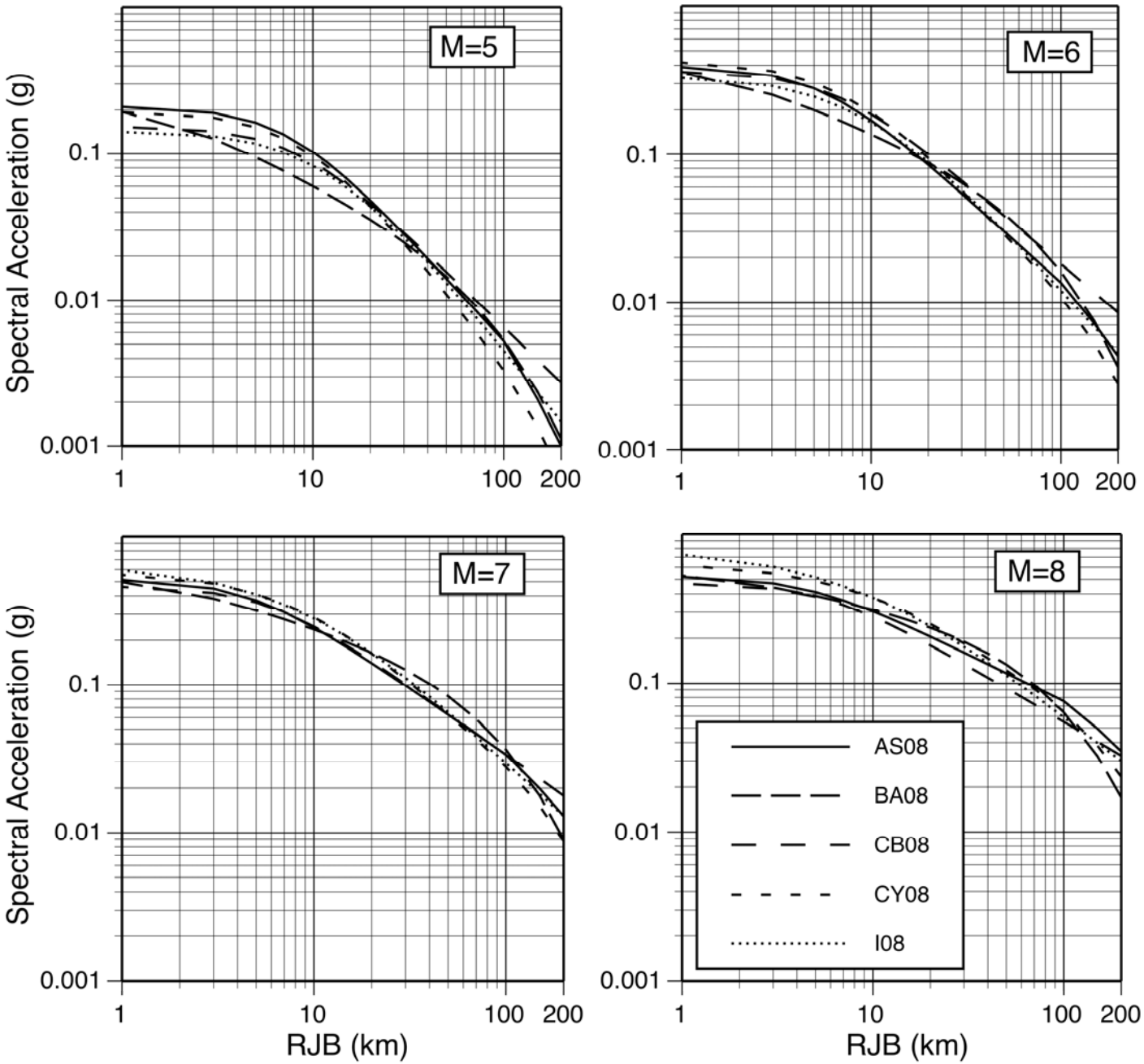
- Decrease in median on rock (Vs=760) for strike-slip earthquakes, particularly at large magnitudes
- Increase in median for buried reverse fault on hanging wall side
- Increase in the sigma for large magnitudes, decrease in sigma for small magnitudes (M<6)
  - At high GM levels, some models give smaller sigma for soil than for rock sites due to non-linearity
- SOF factor more complicated, not just reverse vs strike-slip
- HW included in most models, (JB distance implicitly includes HW) and more complicated
- Models applicable (controlled extrapolation) out to 200 km and for M up to 8.5 SS

Dist Scaling

PGA

SS

V_{S30}=760

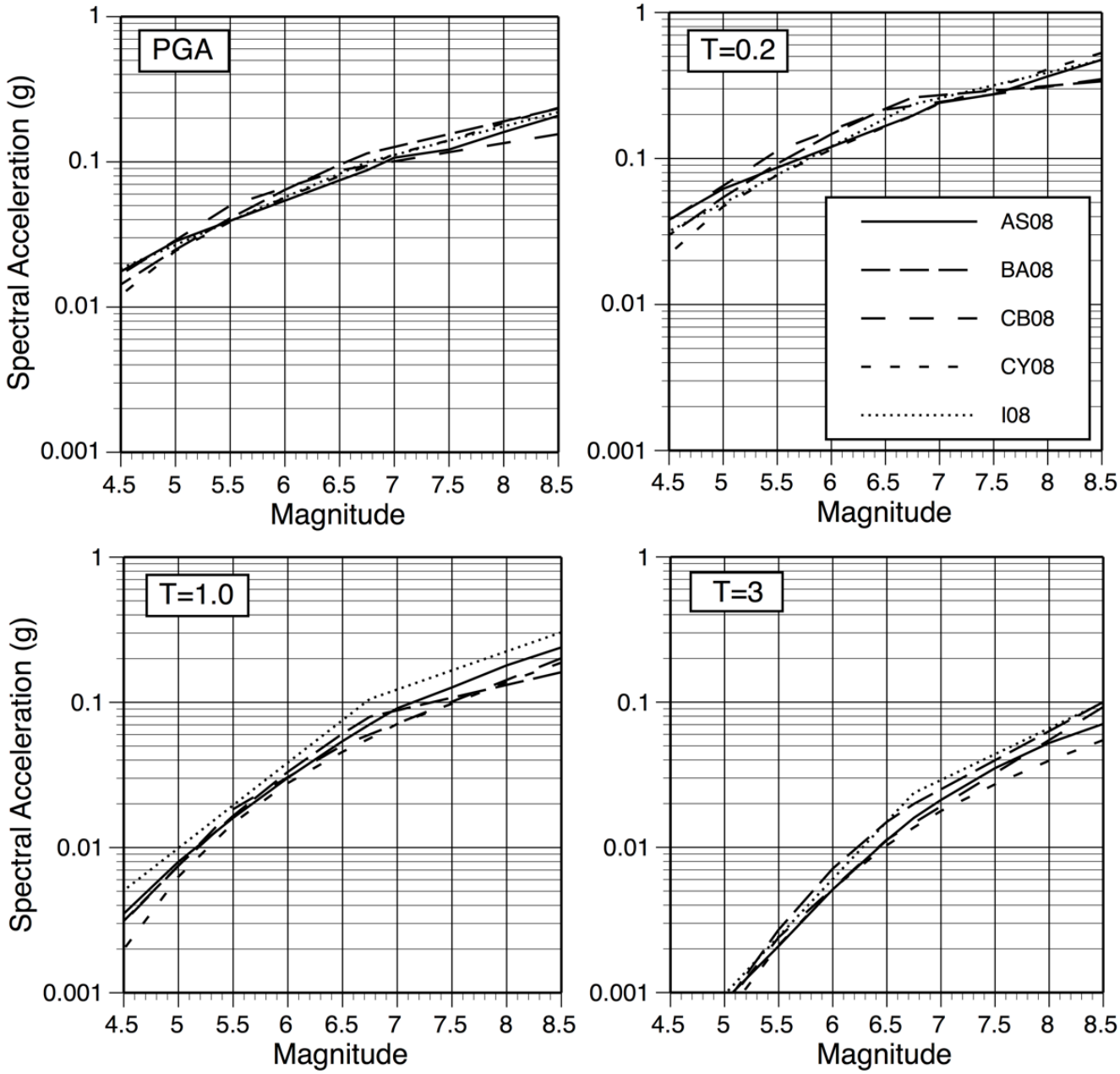


Mag Scaling

SS

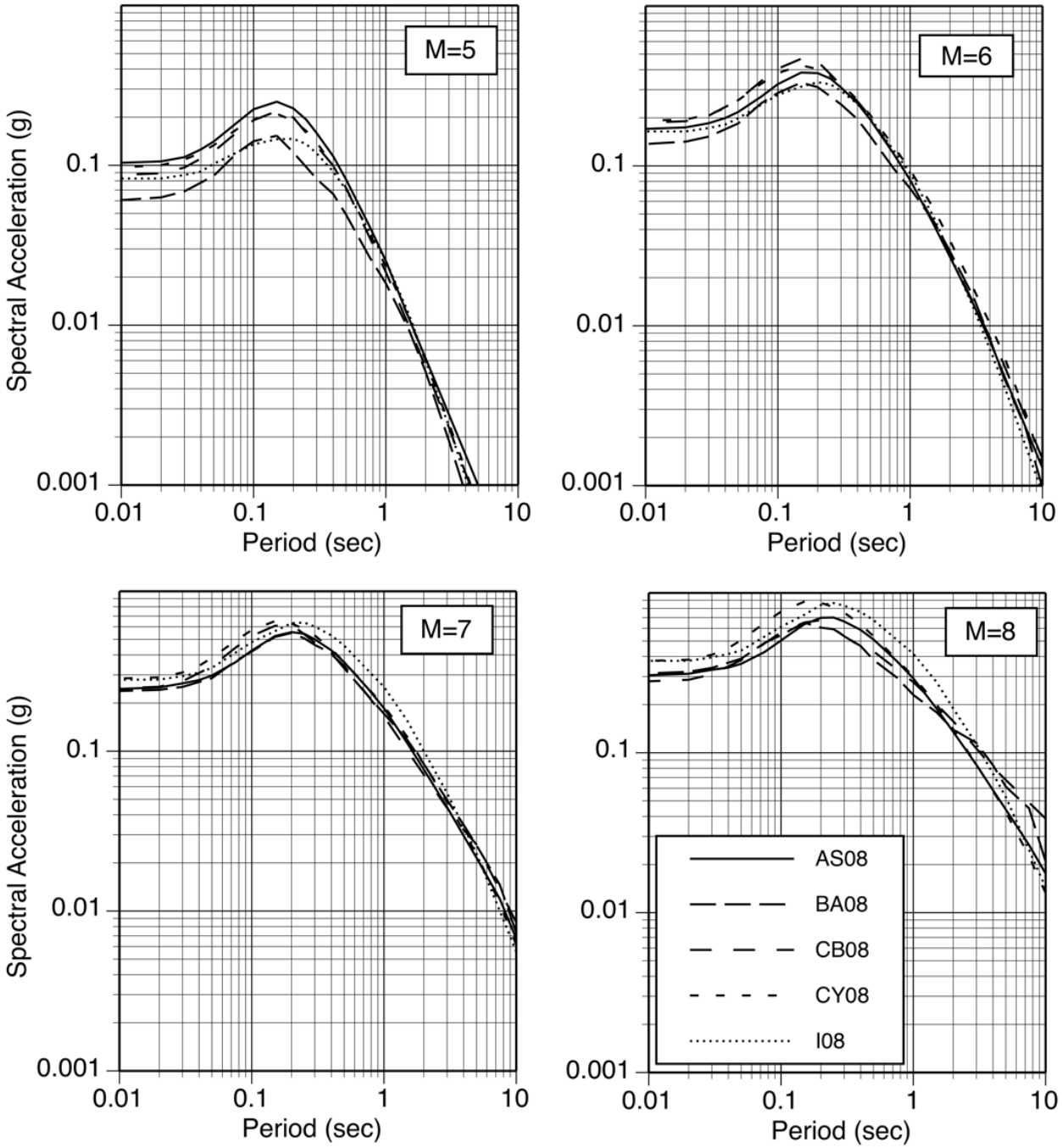
V_{S30}=760

R_{JB}=30 km

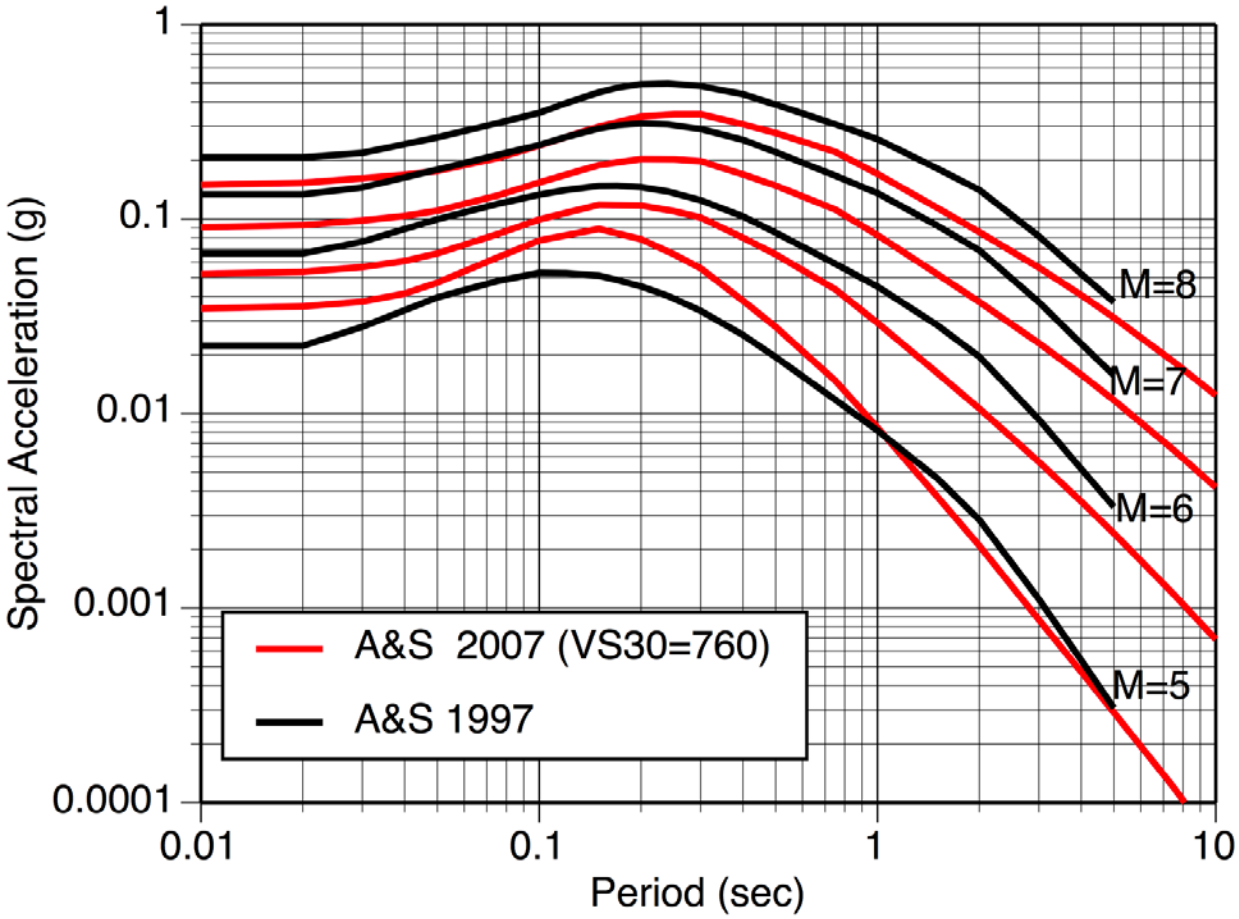


Rock Spectra

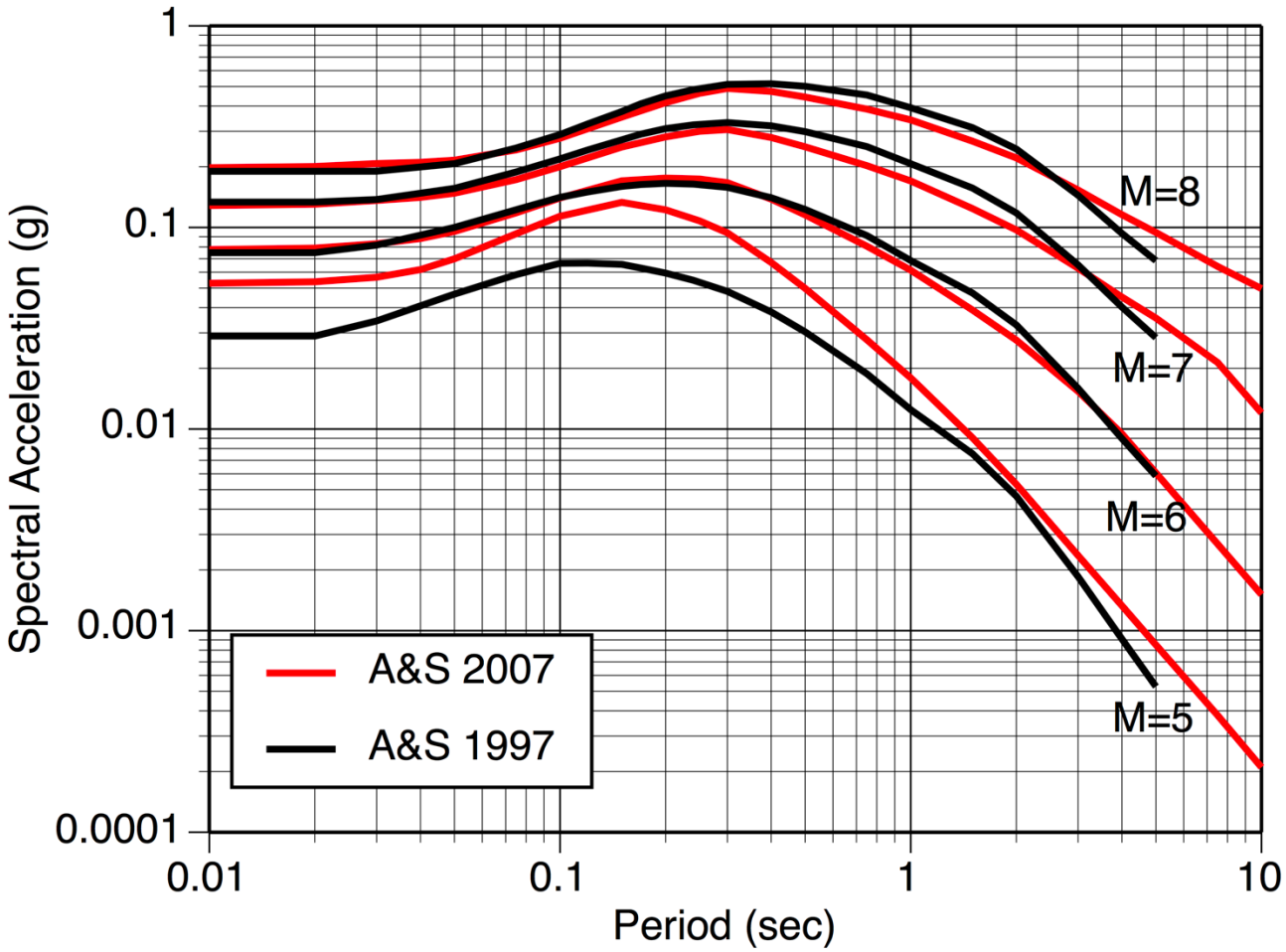
R_{JB}=10 km
V_{S30}=760



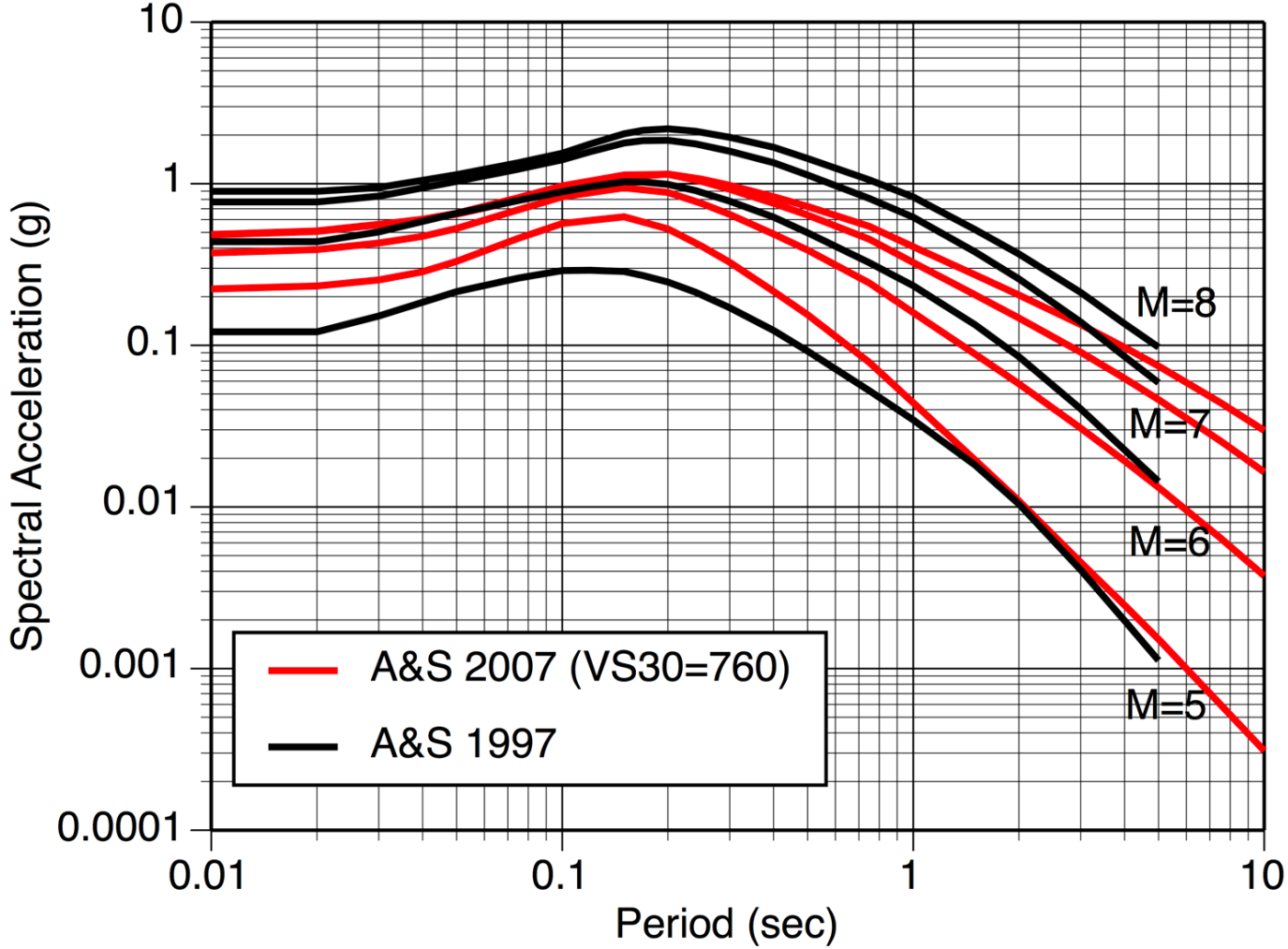
RJB=30 km, VS30=760



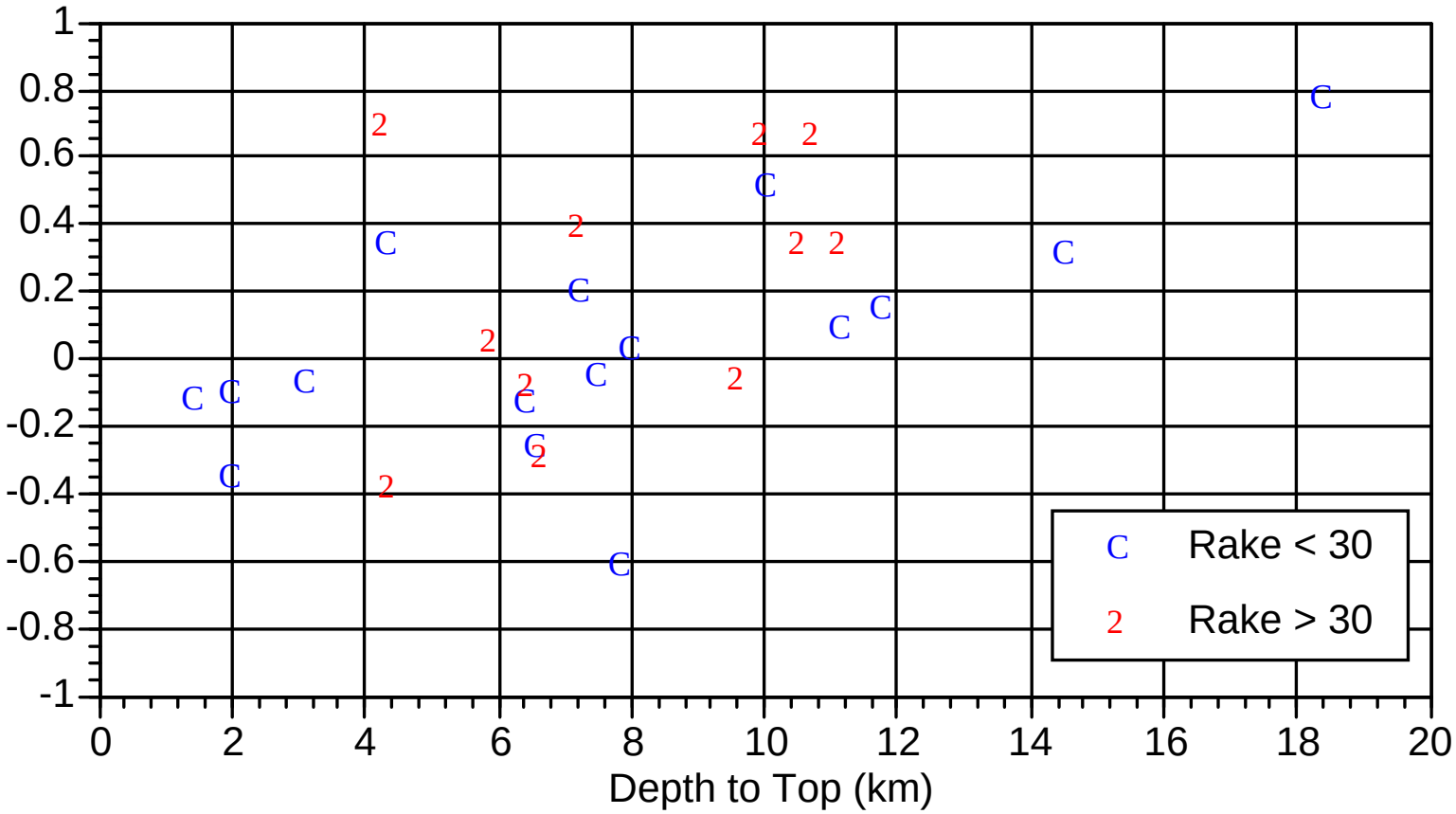
RJB=30 km, VS30=270



RJB=1 km, VS30=760

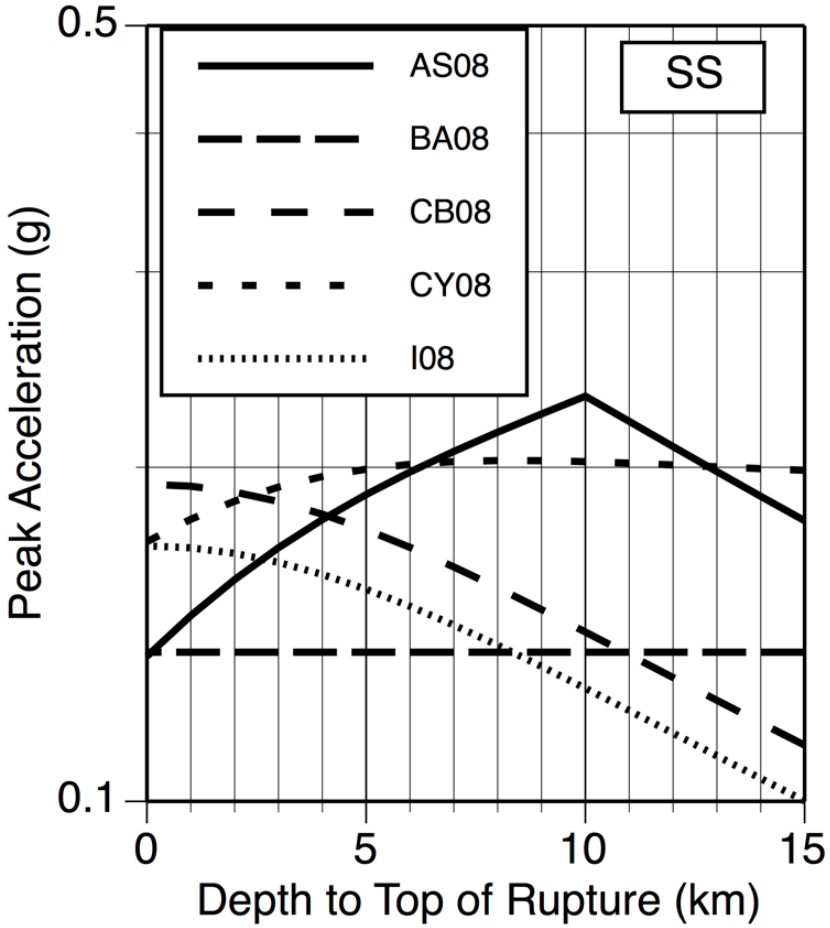


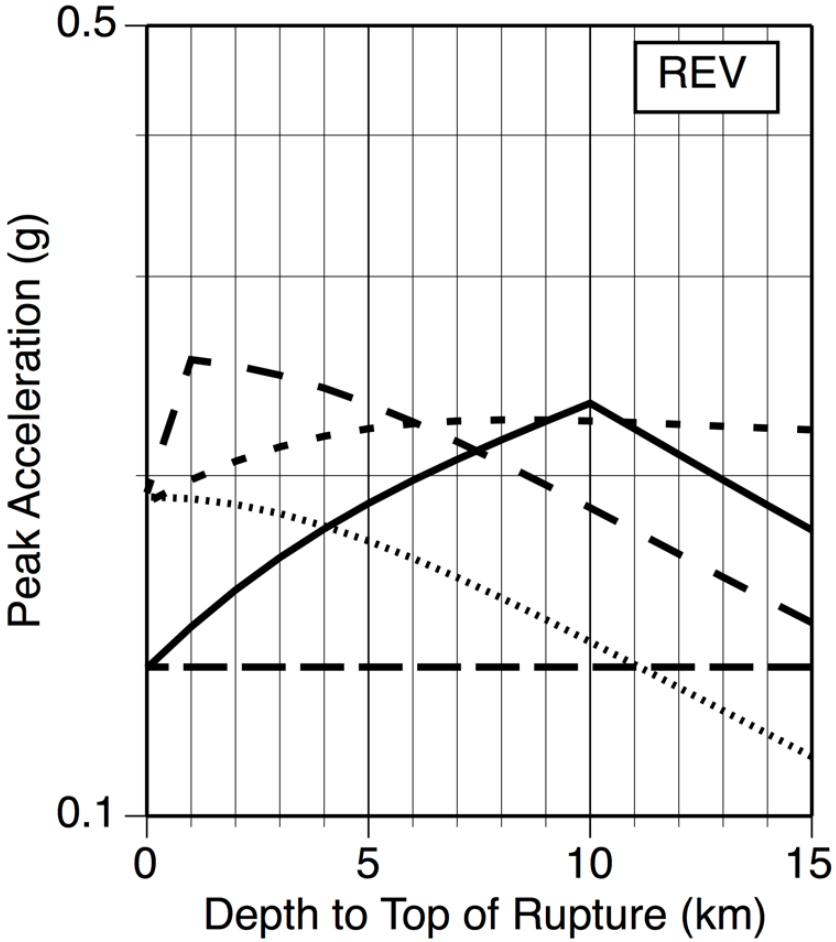
Buried Rupture Effect for PGA M5-M6



Rupture Depth Scaling

(M=6, R_{JB}=10 km)



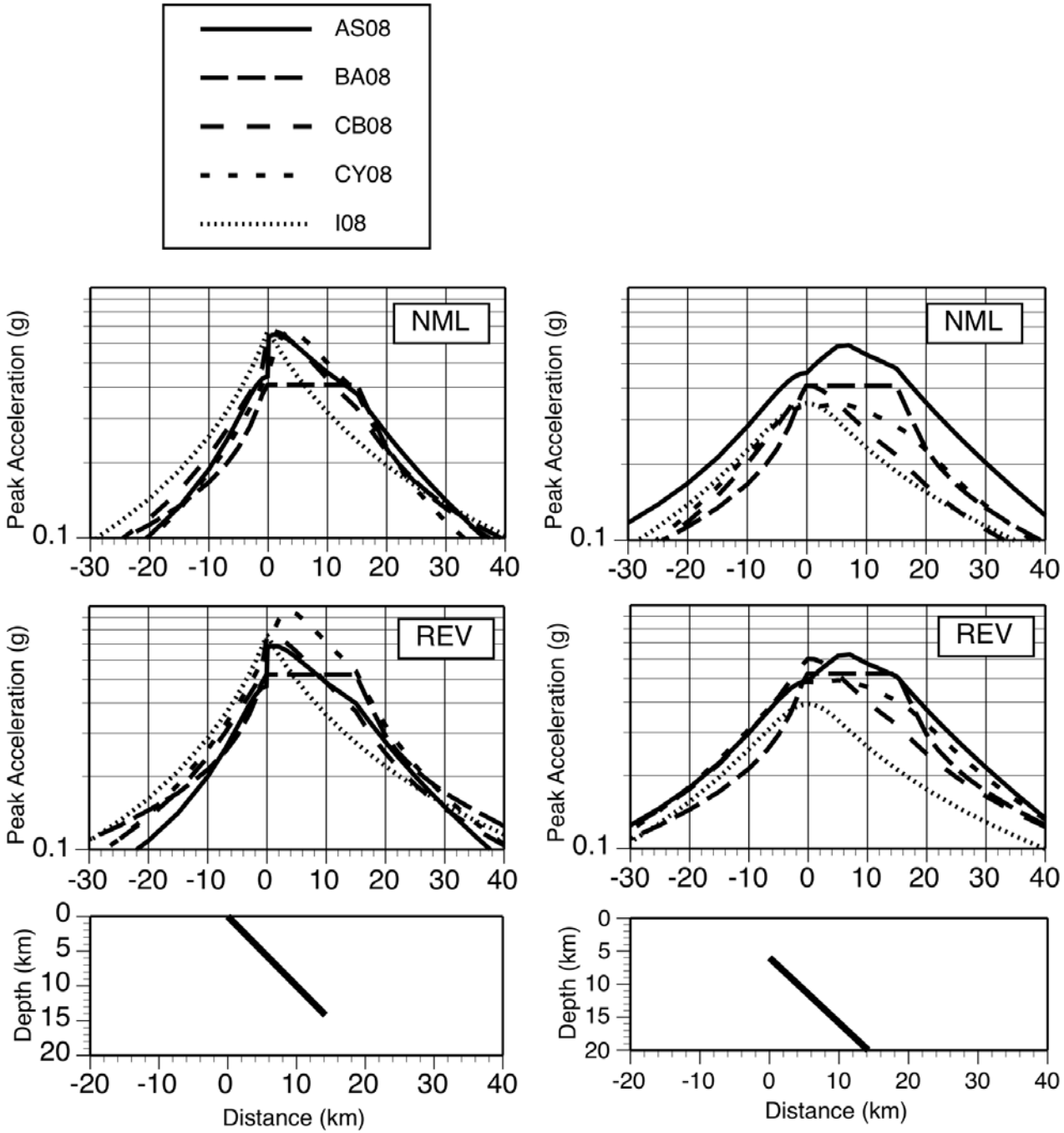


Buried Rupture and Style-of-Faulting

- Buried rupture effect has replaced most or all of the SOF for Rev
  - More REV eqk are buried
  - Effects are correlated

HW Scaling

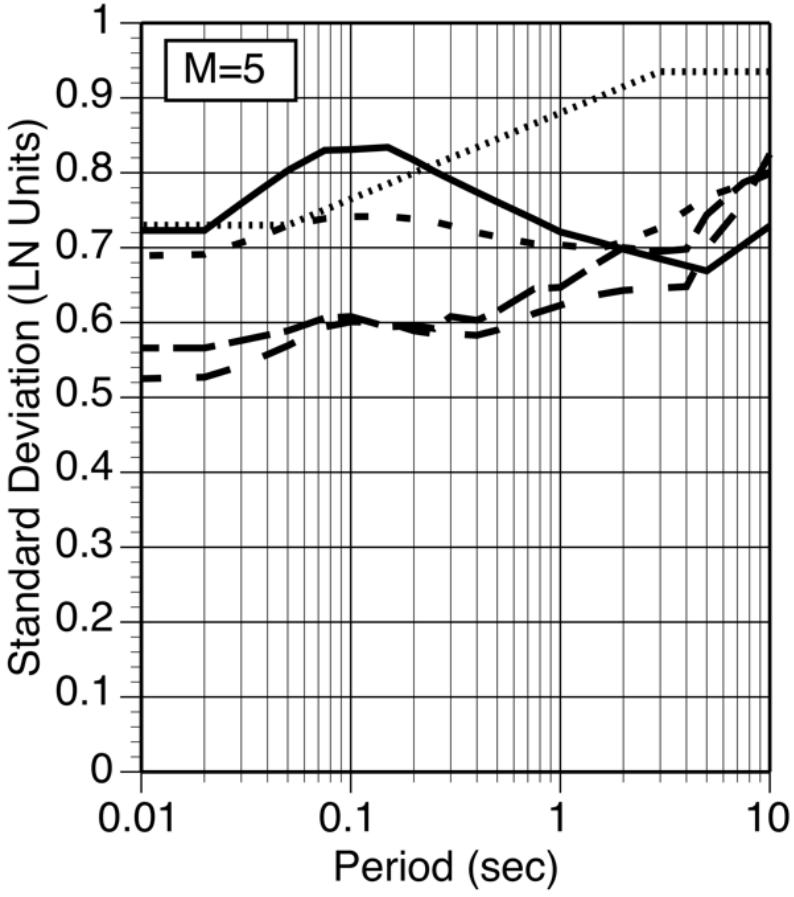
M=6.7
V_{S30}=760

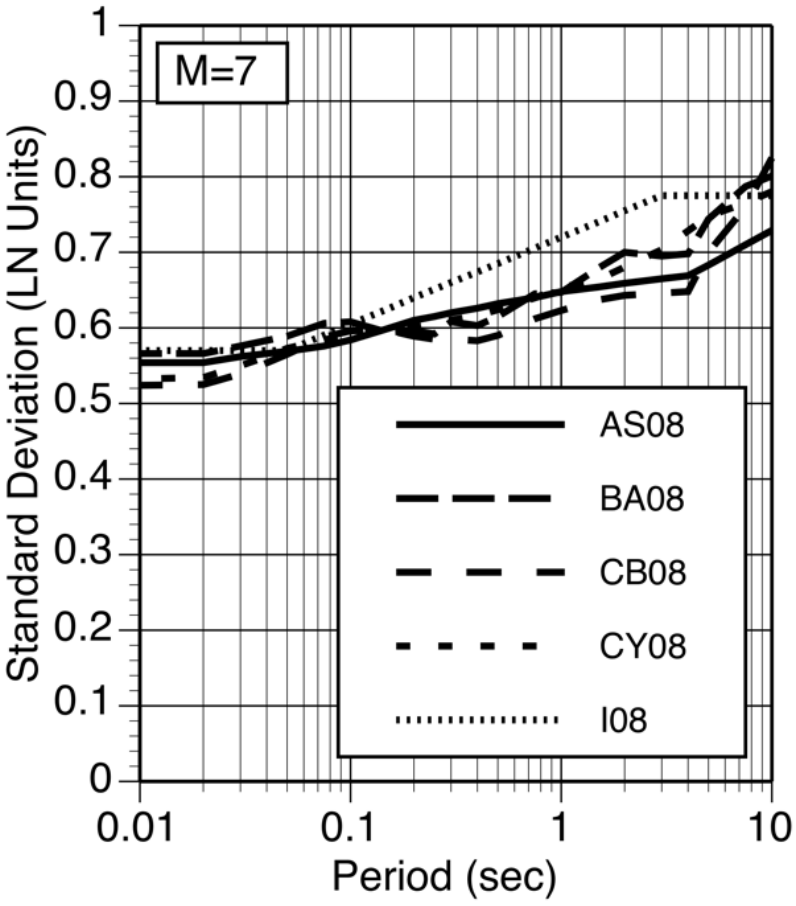


Hanging Wall Effects

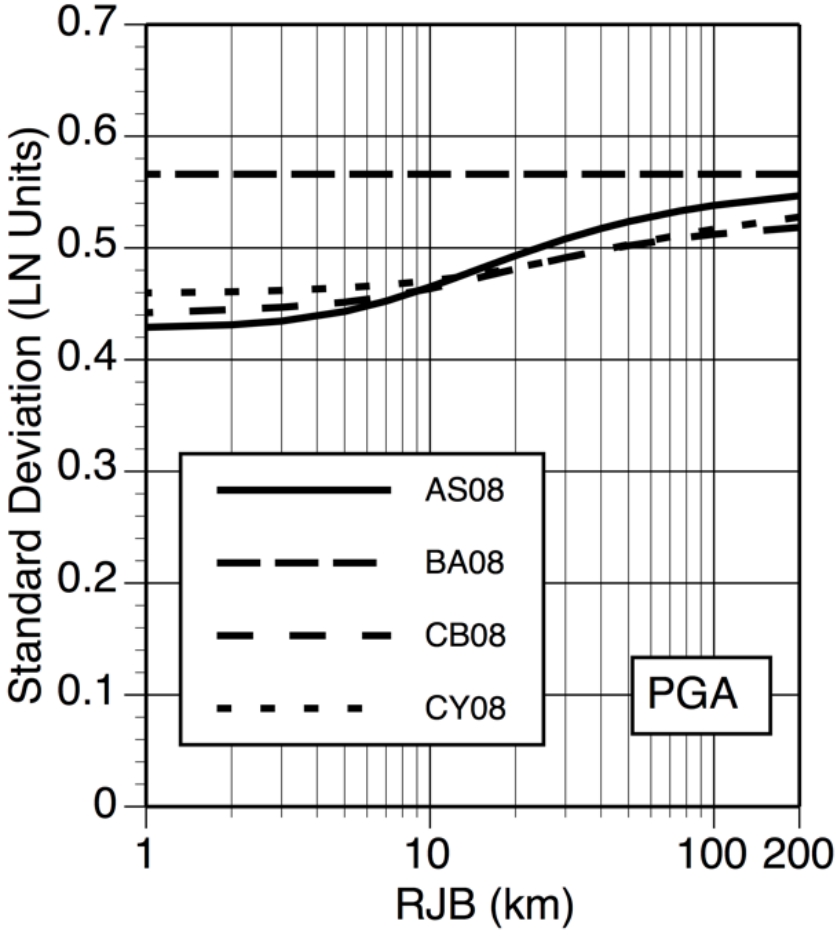
- HW scaling not well constrained in NGA models
  - Mag scaling
  - Dip scaling
  - Style-of-faulting dependence
- Similar for dip=45, M7, RV
- Key Issues
  - Normal faulting (dip=60)
  - Non-vertical strike-slip

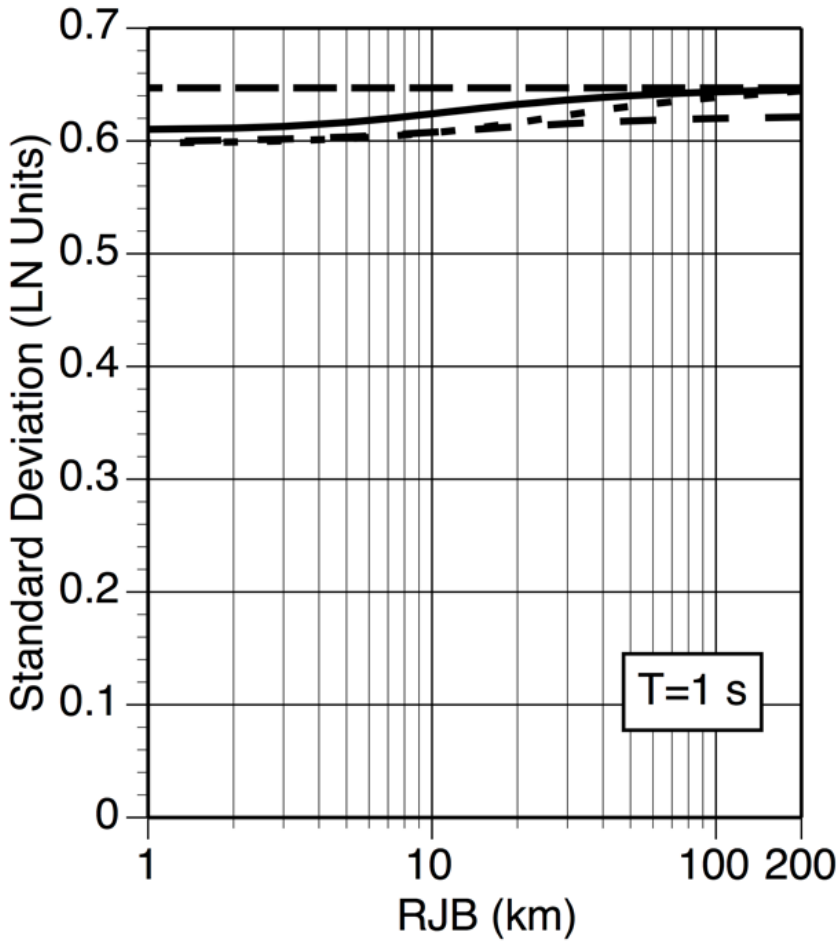
Standard Deviation (RJB=30 km, VS30=760)





Standard Deviation (M=7, VS30=270)

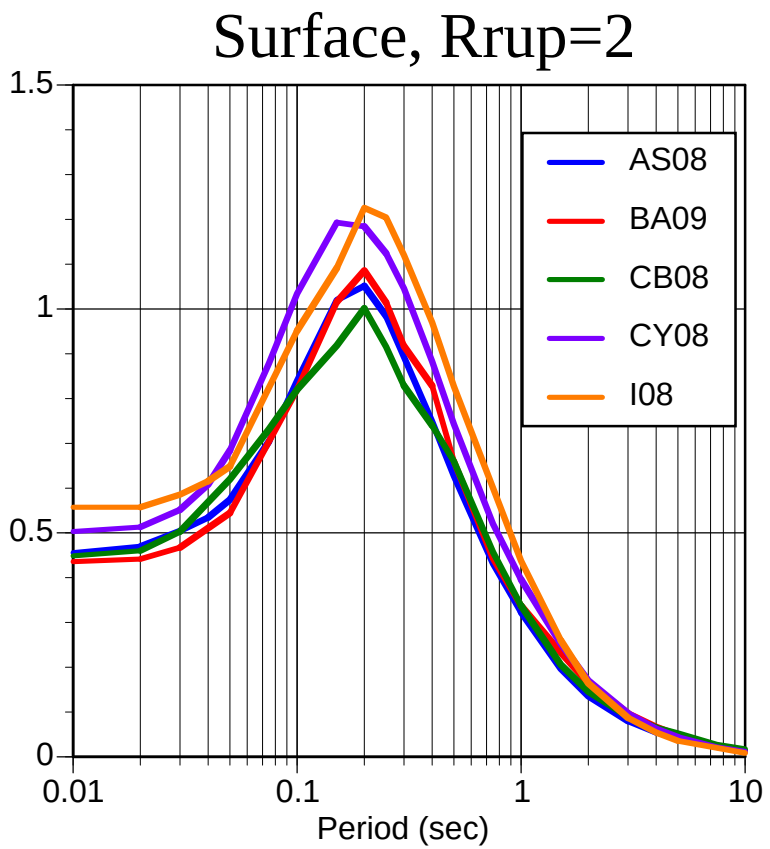


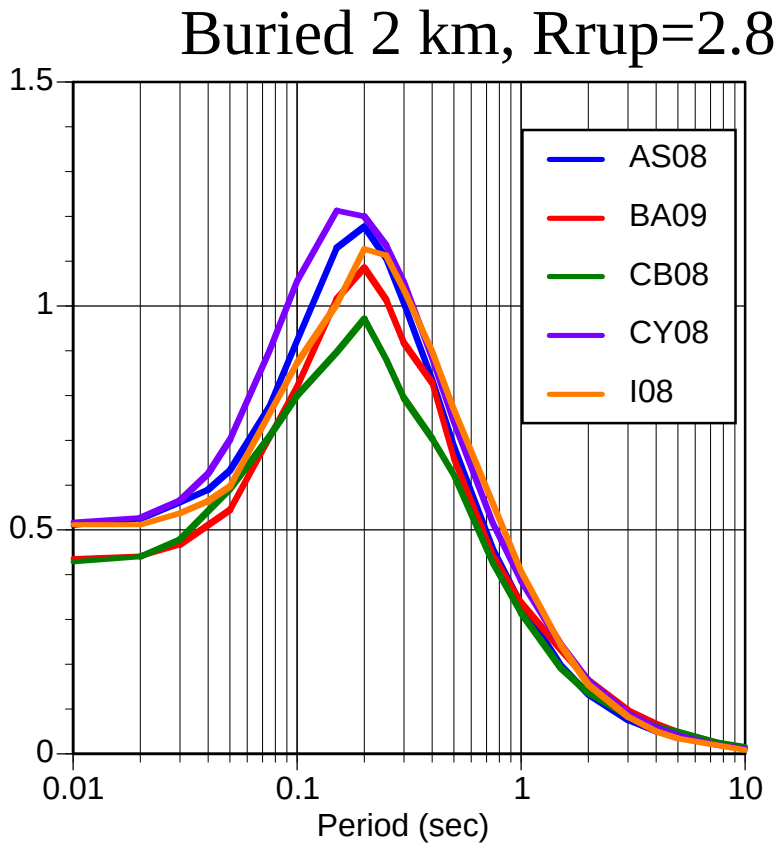


Epistemic Uncertainty

- Issue:
  - NGA developers worked together and started with a common database
  - Does the range of the NGA models capture the epistemic uncertainty?
- Current Models
  - USGS (2008) added additional epistemic uncertainty to the NGA models
    - 0.4 ln units for M>7 at short distances
    - Reduced factor for other M,R bins

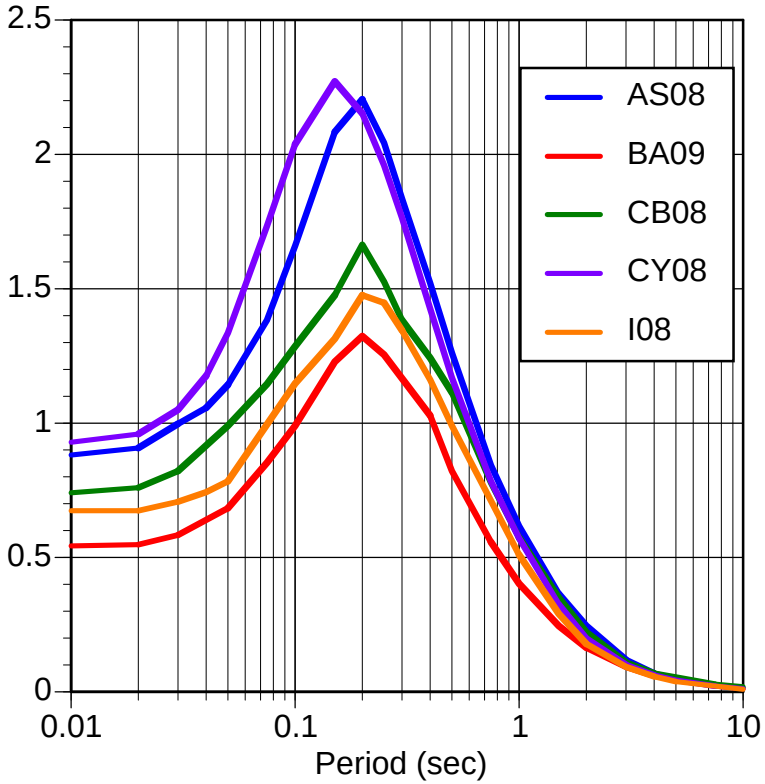
Rock Spectra
M7, SS



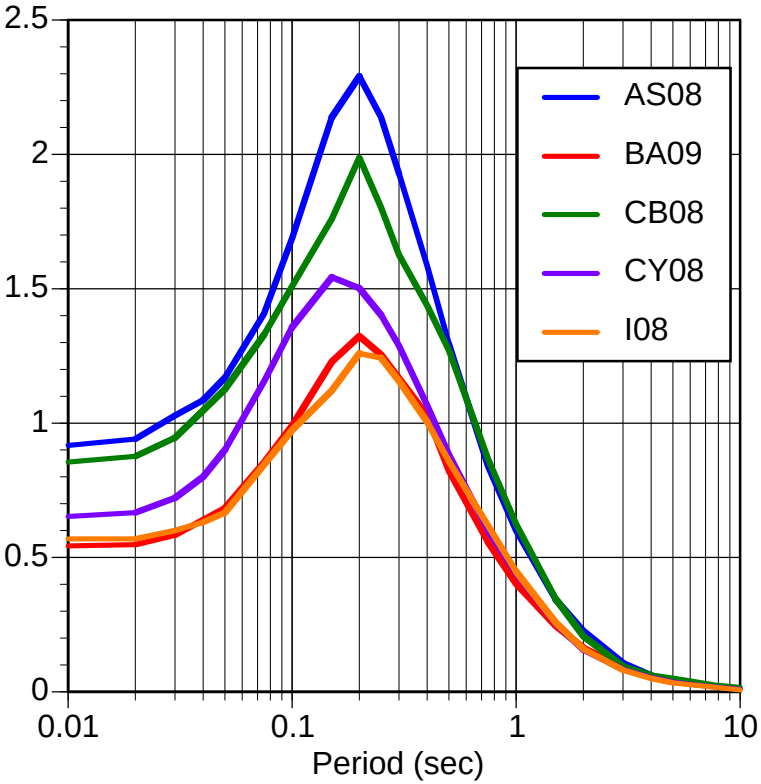


Rock Spectra
M7, RV, 45 dip, HW

Surface, Rrup=1.4 km



Buried, Rrup=2.8 km



Epistemic Uncertainty

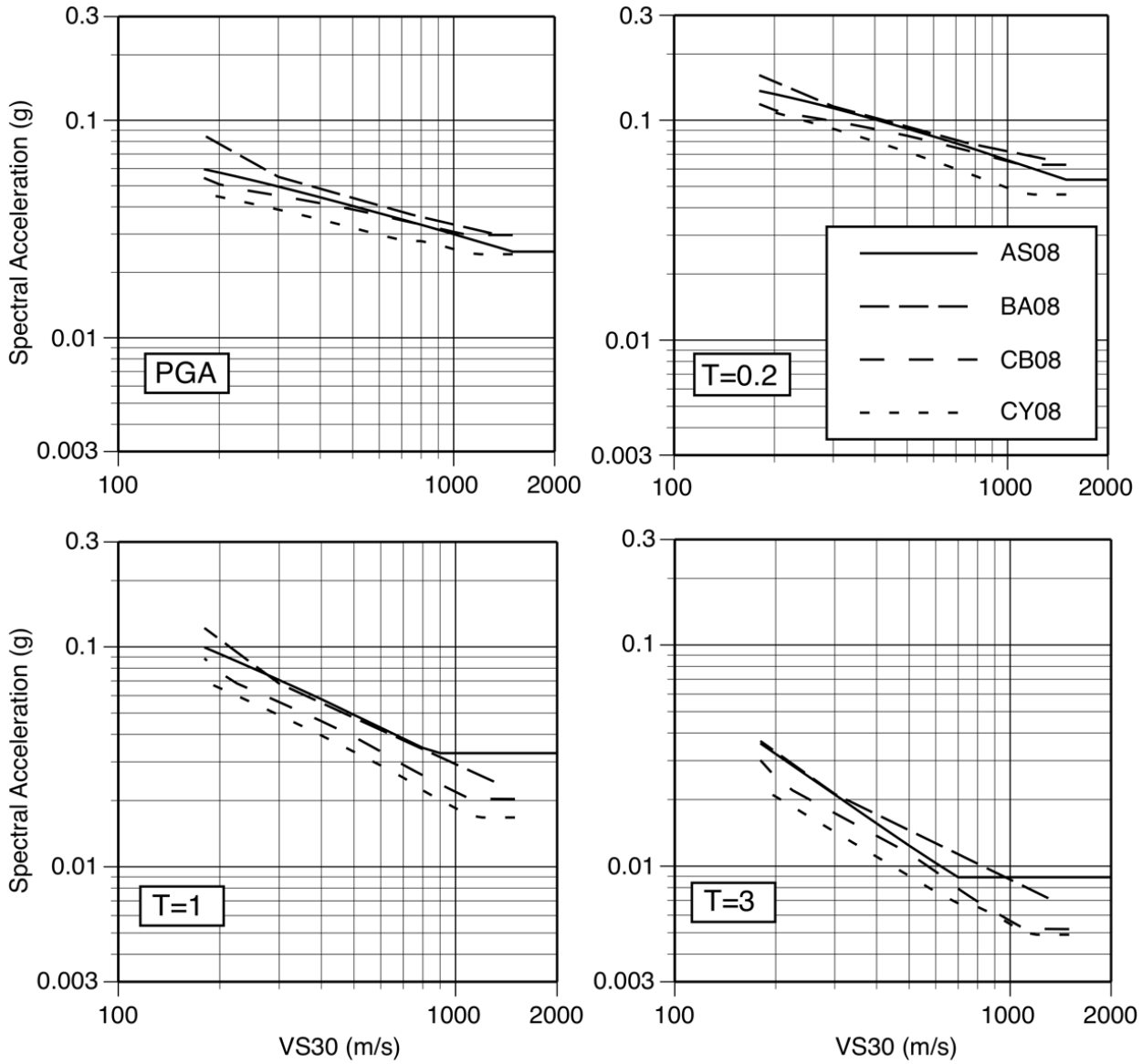
- Ongoing Work
  - New method for estimating epistemic uncertainty
    - Constraints from the data (number of eqk and recordings)
    - Range of medians from the models
    - Add additional epistemic uncertainty
      - Range of model combined with epistemic = constraints
  - PEER is addressing epistemic uncertainty in 2009

Use and Misuse of VS30

- VS30
  - Not the fundamental physical parameter
  - For typical sites, VS30 correlated with deeper Vs profile
    - Most soil sites are in alluvial basins (deep soils)
    - Need soil depth for shallow soil sites
- Proper Use
  - Clear hand-off between ground motion and site response
    - Consistent definition of “rock”
  - Use for deep soil sites that have typical profiles
- Misuse
  - Replace site-specific analysis for any profile (not typical as contained in GM data base)

V_{S30} Scaling

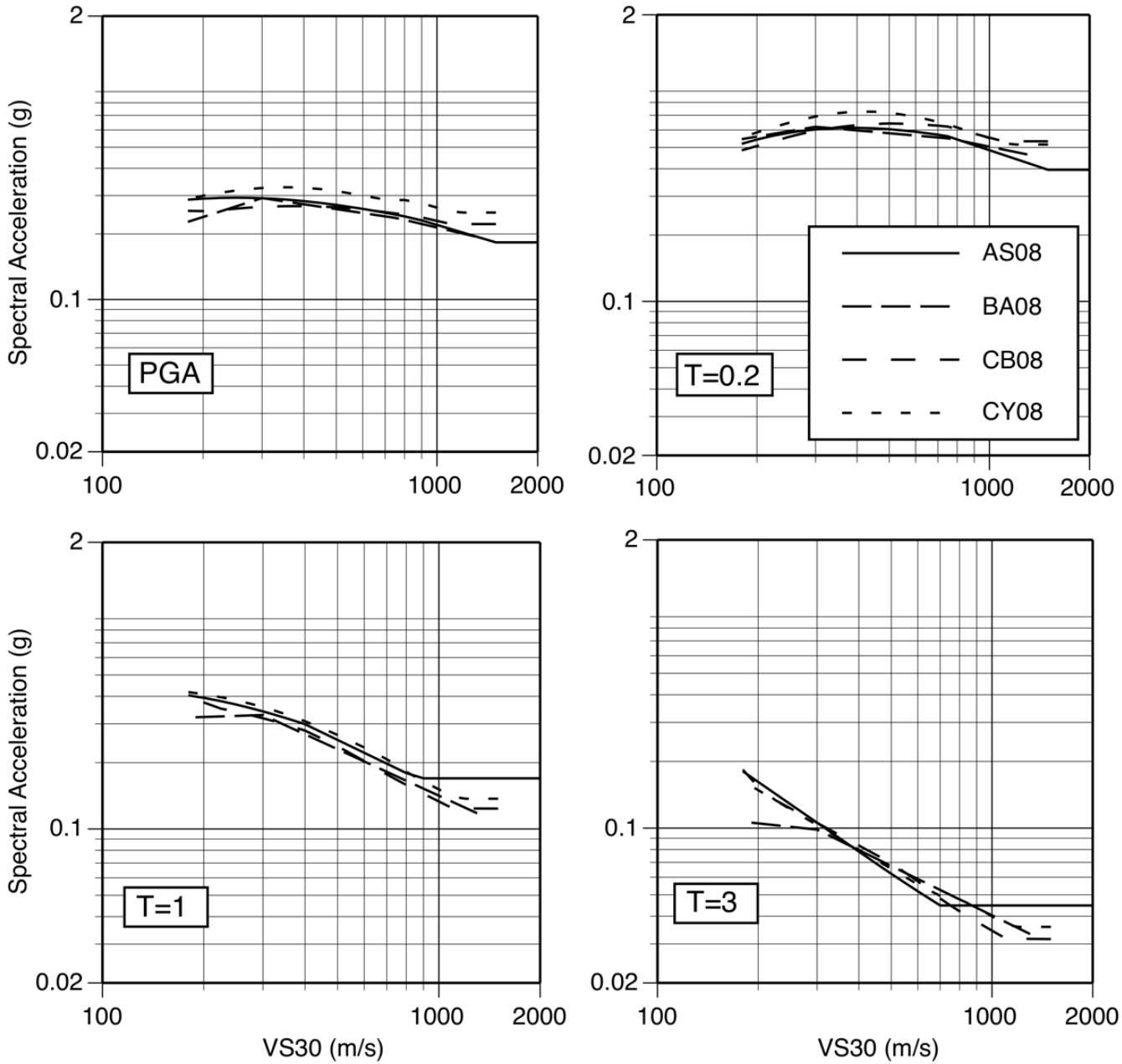
M=7,
R_{JB}=100 km



V_{S30} Scaling

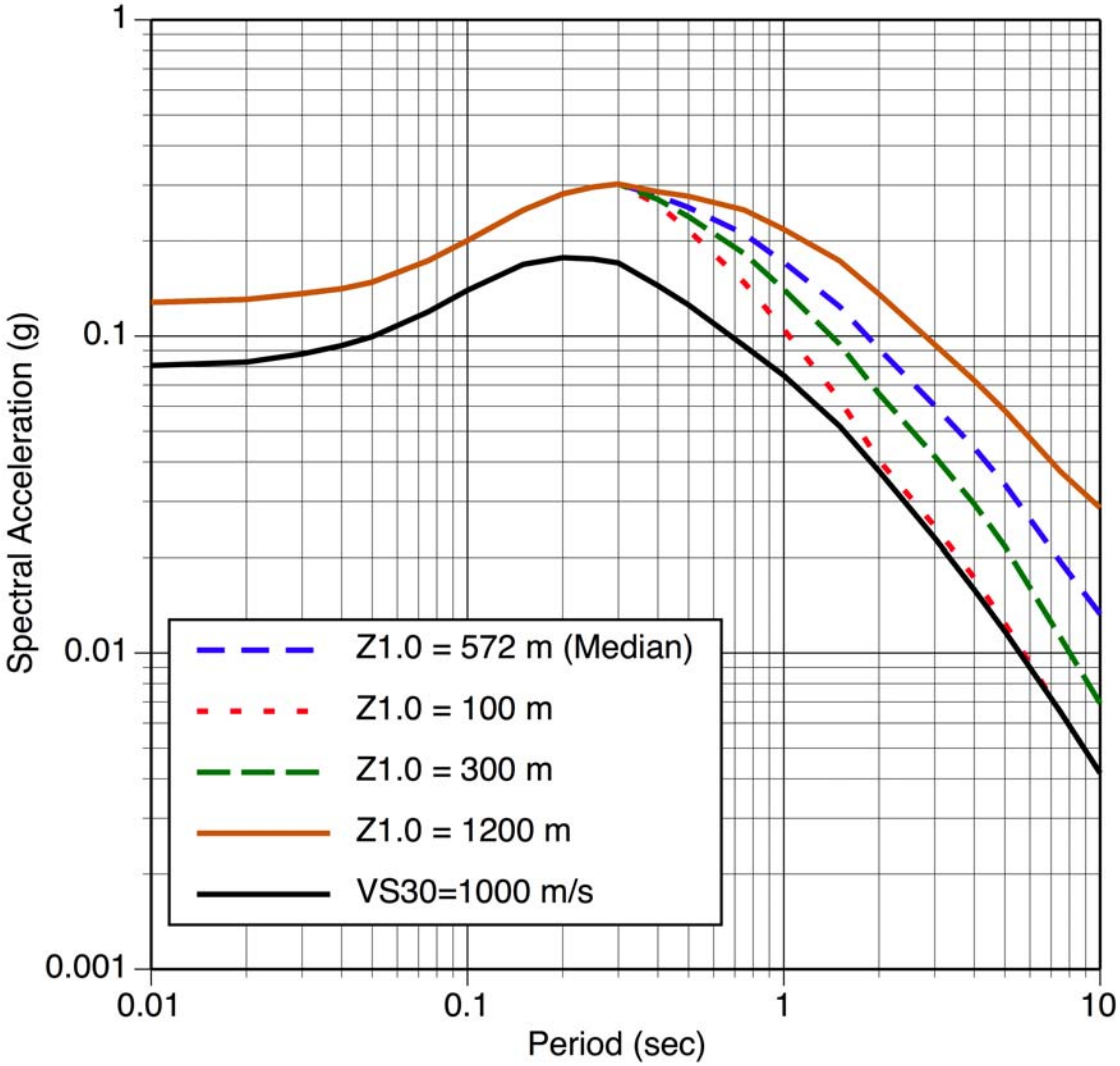
M=7

R_{JB}=10 km



Effect of Soil Depth (Basins)

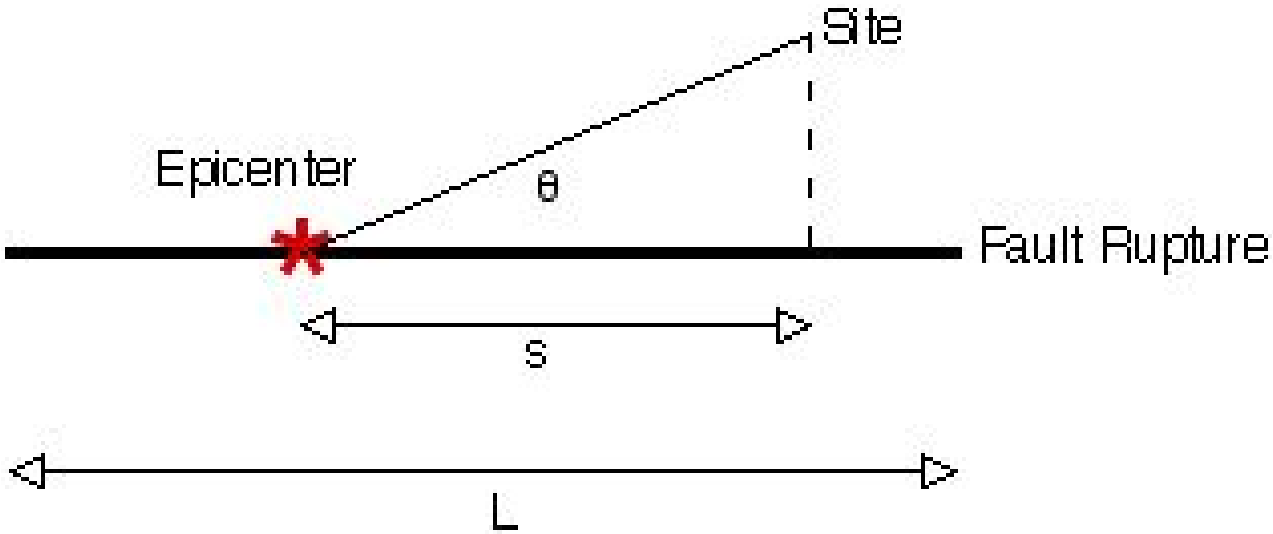
AS08 model



Directivity

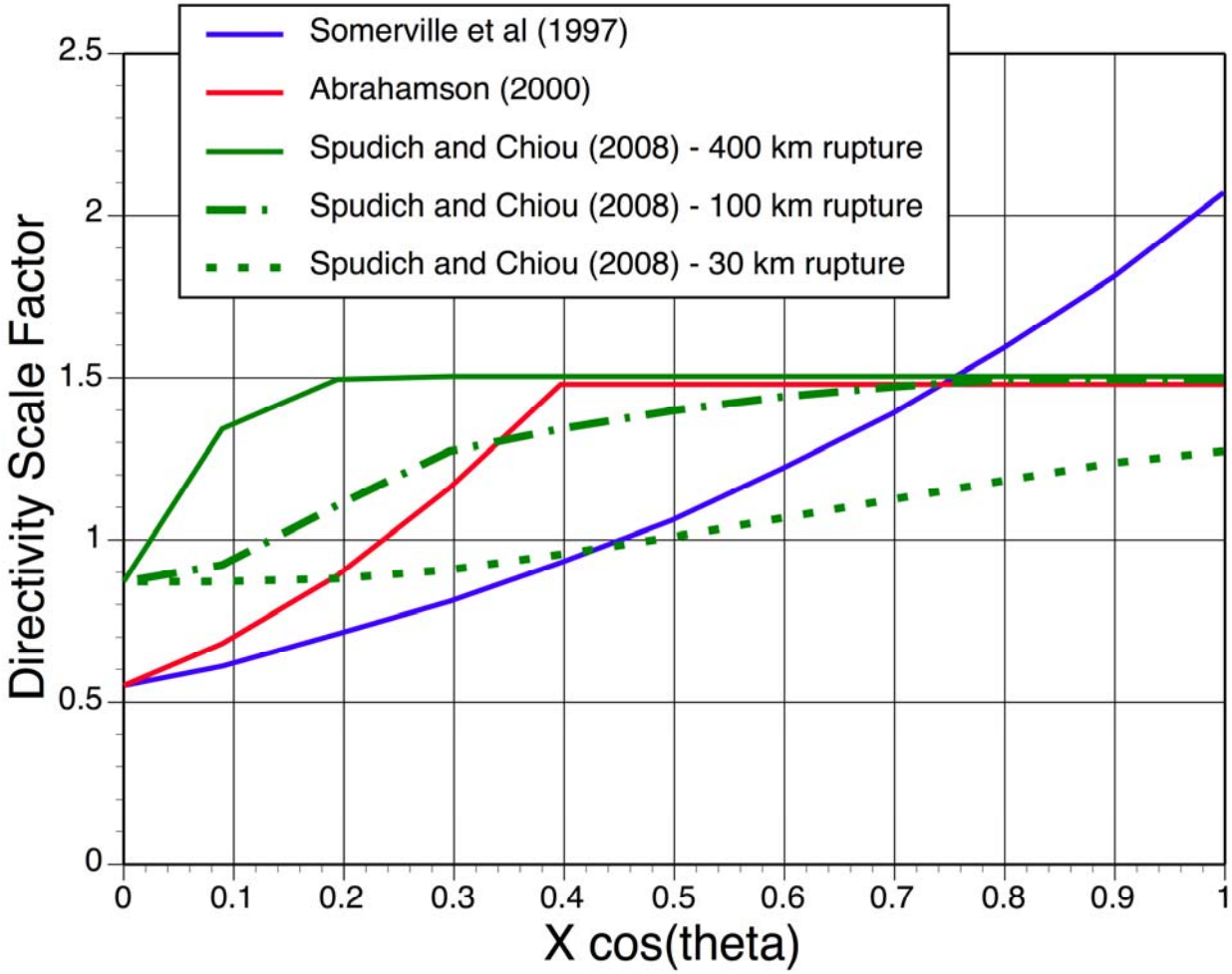
- Current Models
  - Somerville et al (1997)
  - Abrahamson (2000)
  - NGA: Spudich and Chiou (2008)
    - Applies seismological parameters
      - Radiation pattern
      - Rupture velocity
    - less directivity scaling for M< 7.25
    - Similar scaling for M>7.25

Directivity Parameters for Strike-Slip Faults Used by Somerville et al (1997)



$X = s/L$

Directivity for T=3 sec



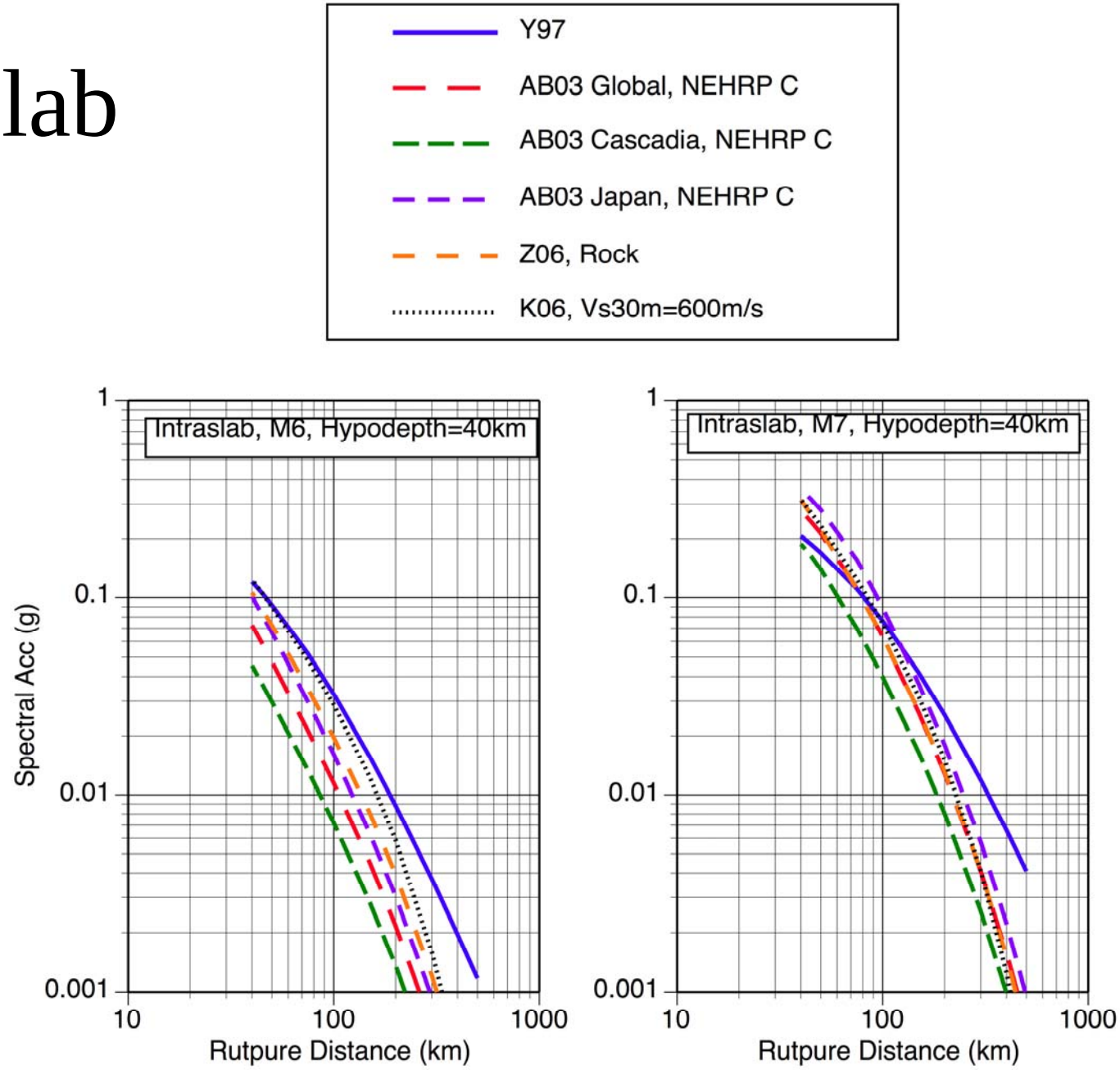
Vertical

- NGA models have not been developed for vertical
  - Initial model (Yilmaz and Abrahamson, 2008) shows a reduced V/H ratio for large magnitudes
  - Strong impact from unusually low verticals for the Chi-Chi mainshock
  - Expect NGA vertical models in 2009
- V/H model
  - Campbell and Bozorgnia (2004)

Subduction Models

- Current Models
  - Youngs et al (1997)
  - Atkinson & Boore (2003)
  - Gregor et al (2006)
    - Finite-fault simulation, Megathrust only
  - Zhao et al (2006)
  - Kanno et al (2006)
    - Combined interface and shallow crustal

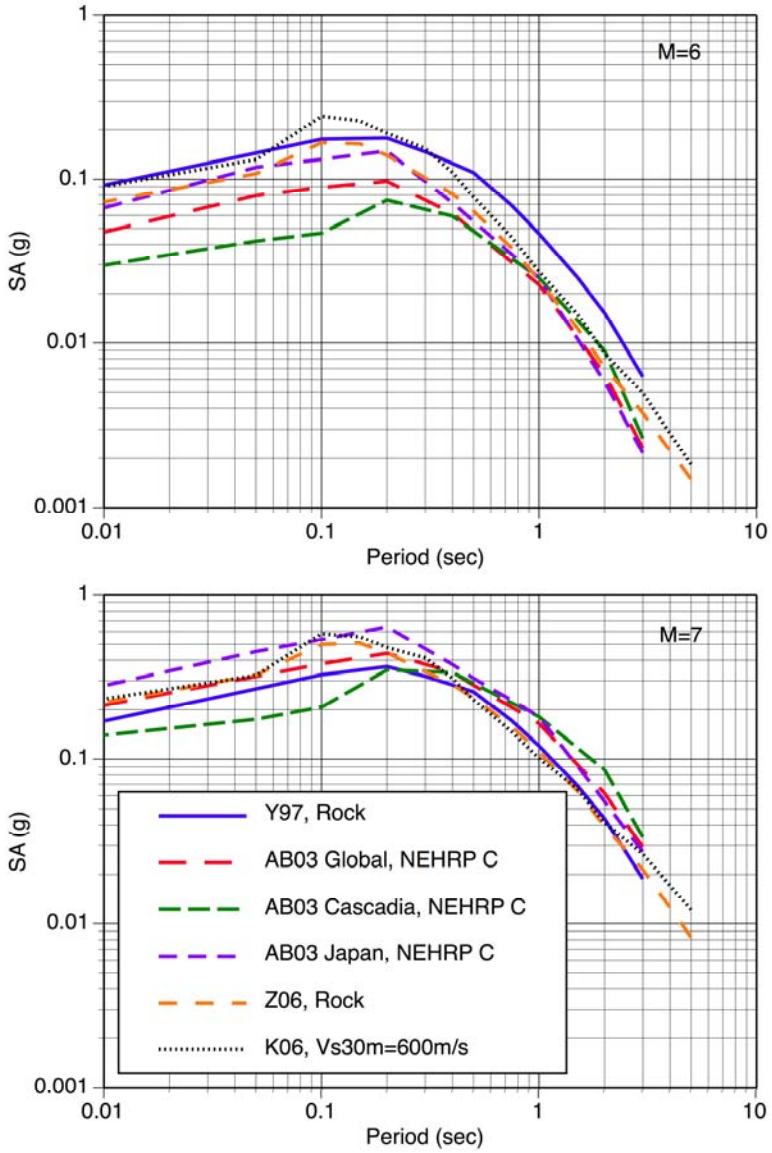
Intra-Slab PGA



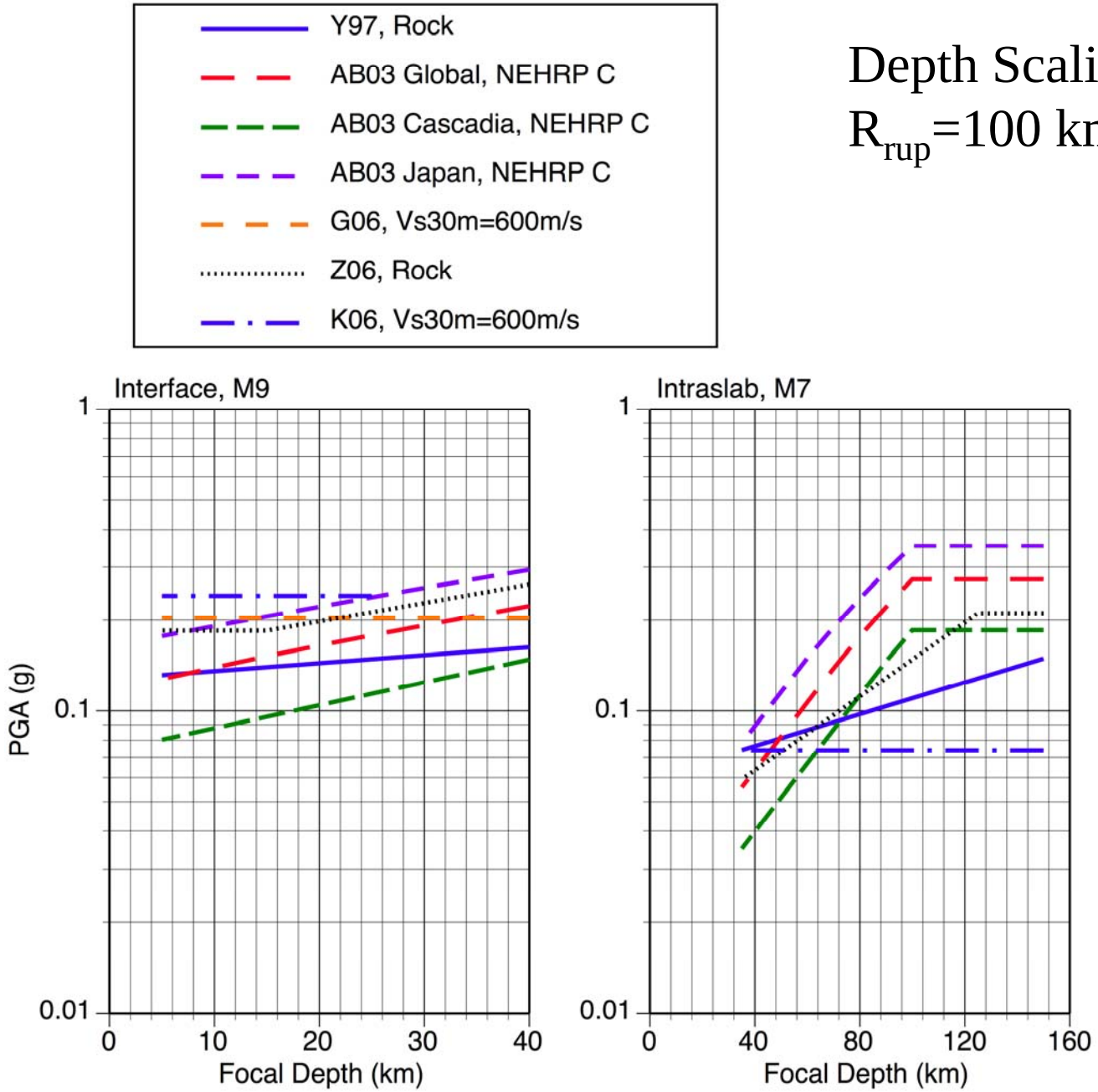
Intra-slab

R=50 km

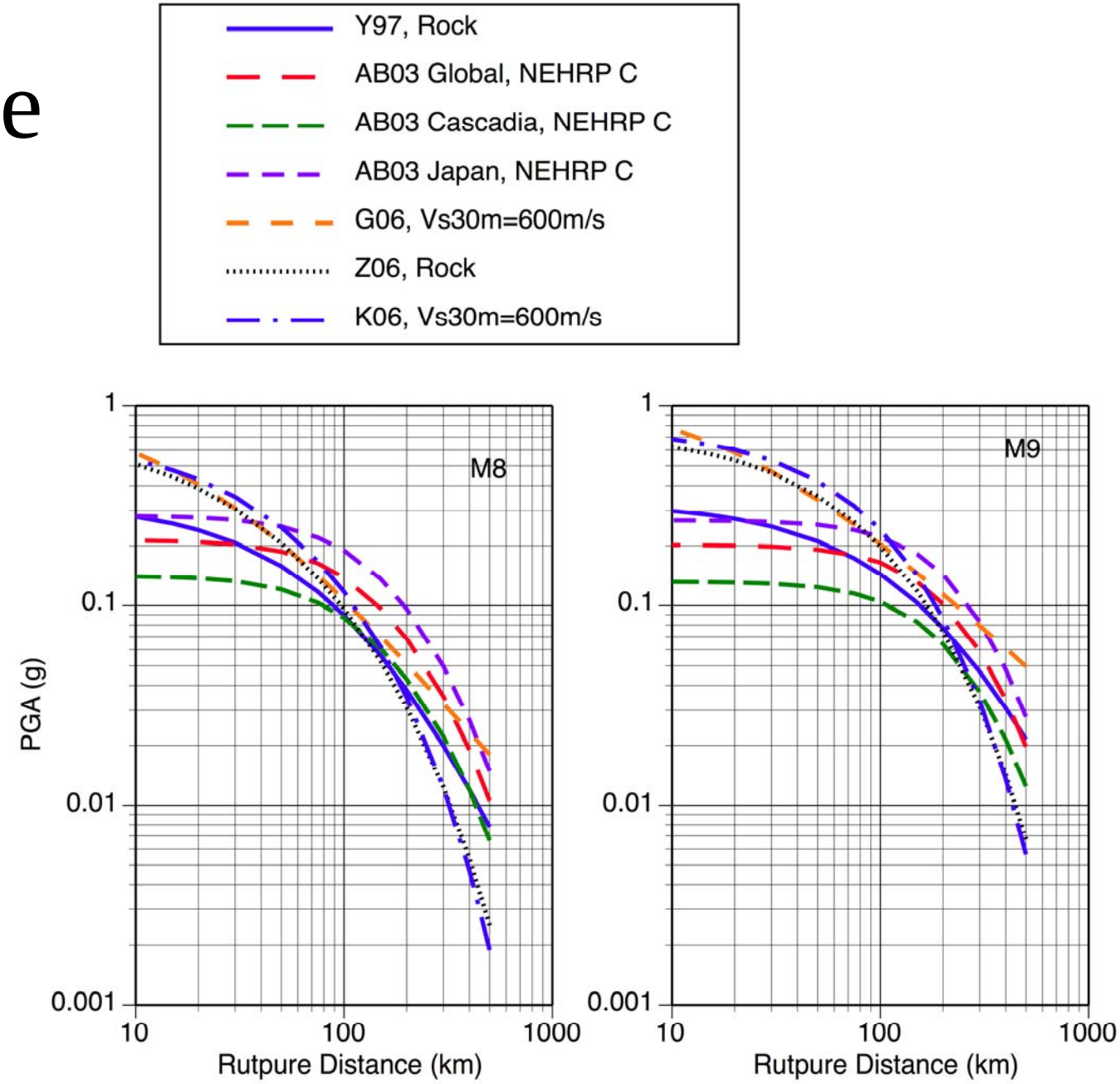
H=40 km



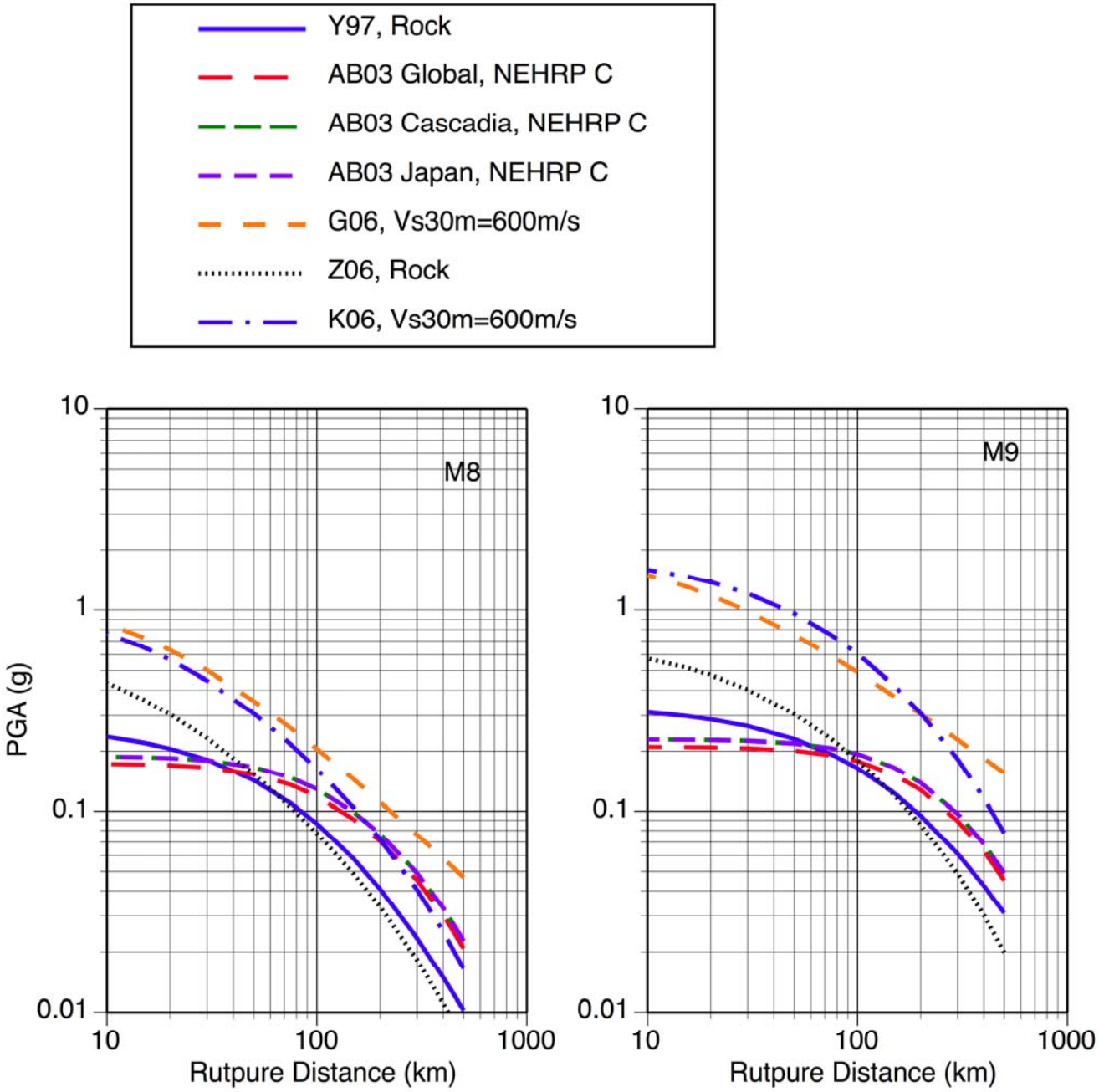
Depth Scaling
R_{rup}=100 km



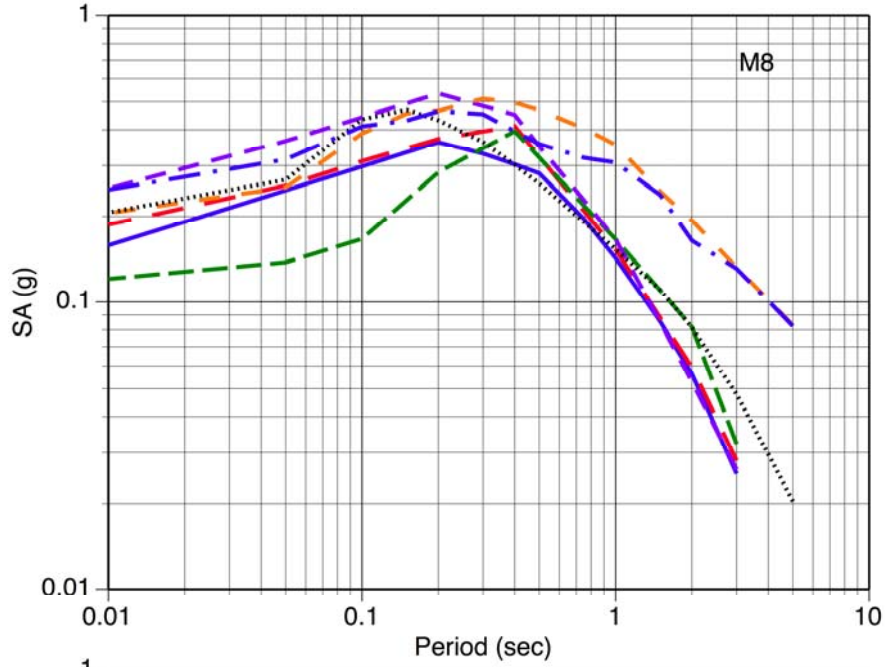
Interface PGA



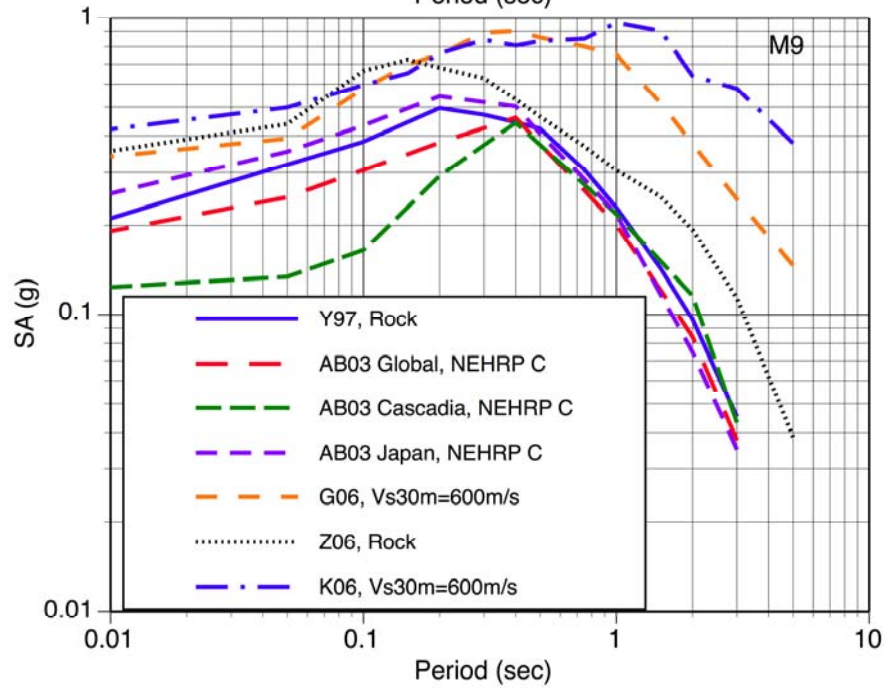
Interface T=1 sec



Interface
R=40 km

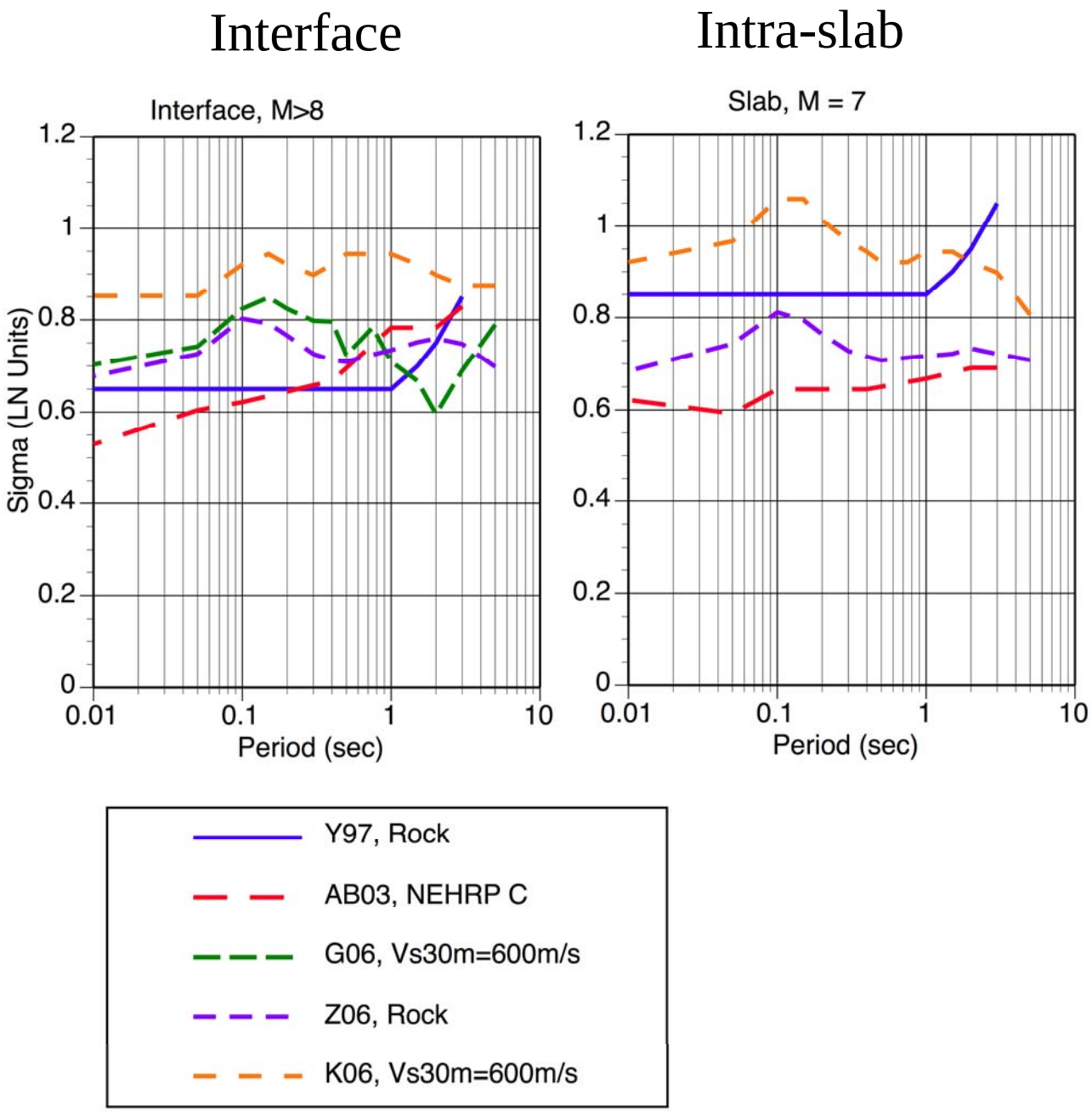


M8



M9

Standard Deviation



Subduction GM Models

- Current models are in bad shape
- BCHydro sponsoring ongoing work for a new subduction models
  - Starting from scratch, not based on existing models
  - Preliminary results show good agreement between earthquakes in different subduction regions
  - Initial model results in 2009
- PEER/GEM
  - Plan for follow up with more complete update in 2011

Role of Numerical Simulations

- Stochastic point-source models
  - Widely used in engineering practice (CEUS)
- Finite-fault models
  - Emphasis of seismological research
  - Moving to wider application of simulations
  - Cybershake (SCEC)

Issues for Finite-Fault Simulations

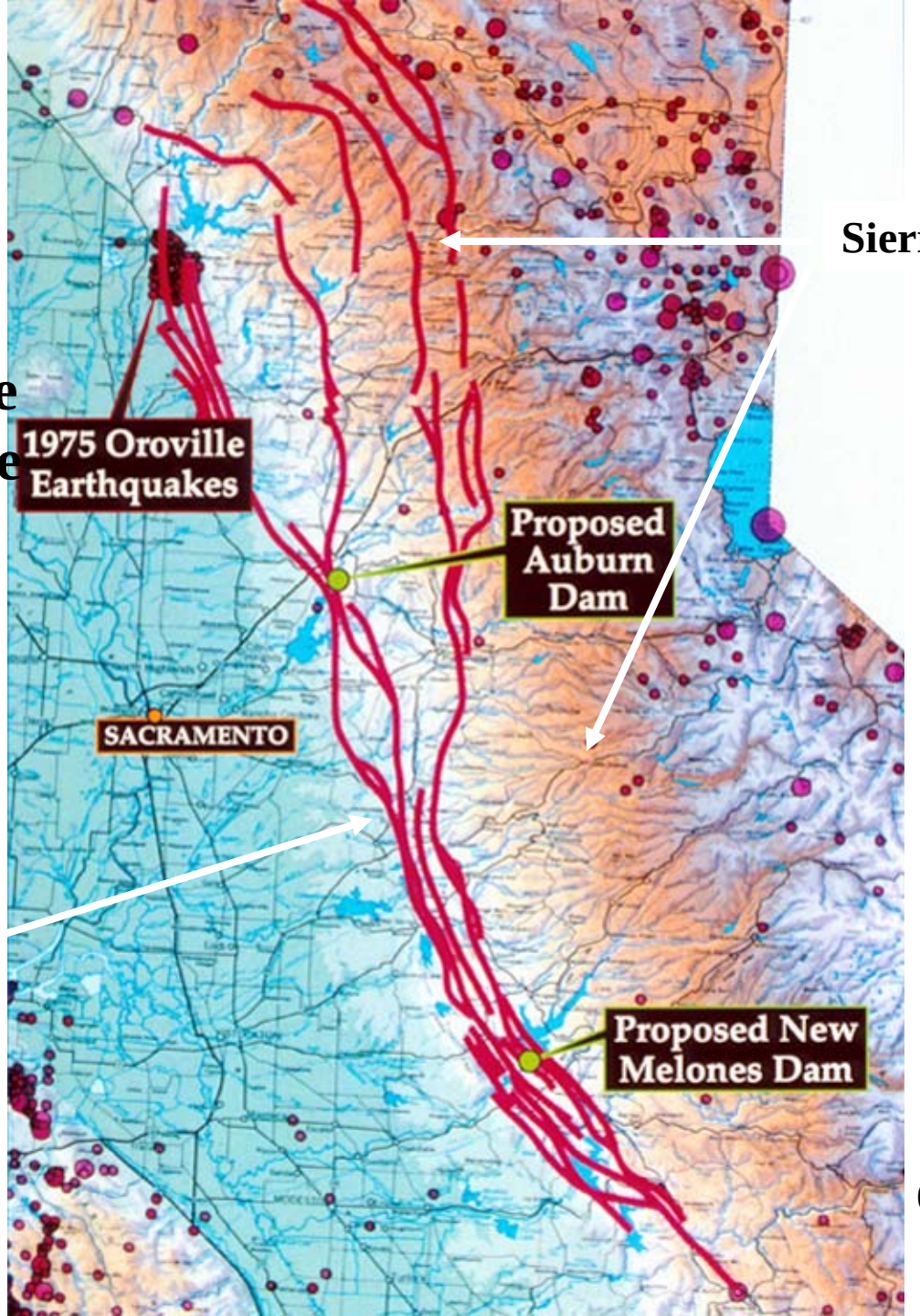
- Past studies show large range from different modelers
- Key Issues
  - Need to consider the correlation of the large number of source parameters
    - Hypocenter, slip amplitude , rise-time, rupture velocity, rake
  - Need a standard computational platform with multiple modules
    - SCEC broadband platform
    - Allows evaluation of alternative approaches using a single platform
    - Allows for QA of simulations

Finite-Fault Simulations

- Dynamic rupture models
  - Model verification by Dec 2008 (SCEC/USGS)
  - Use verified dynamic rupture models to generate a library of earthquake sources
  - Source parameters are correlated based on physics of the dynamic rupture
- Kinematic simulations
  - Develop equivalent kinematic source models based on the library of dynamic ruptures
  - Conduct simulations using broadband platform

Auburn and New Melones Dams, California 1974 - 1980

Oroville earthquake 1975 suspected to be reservoir induced



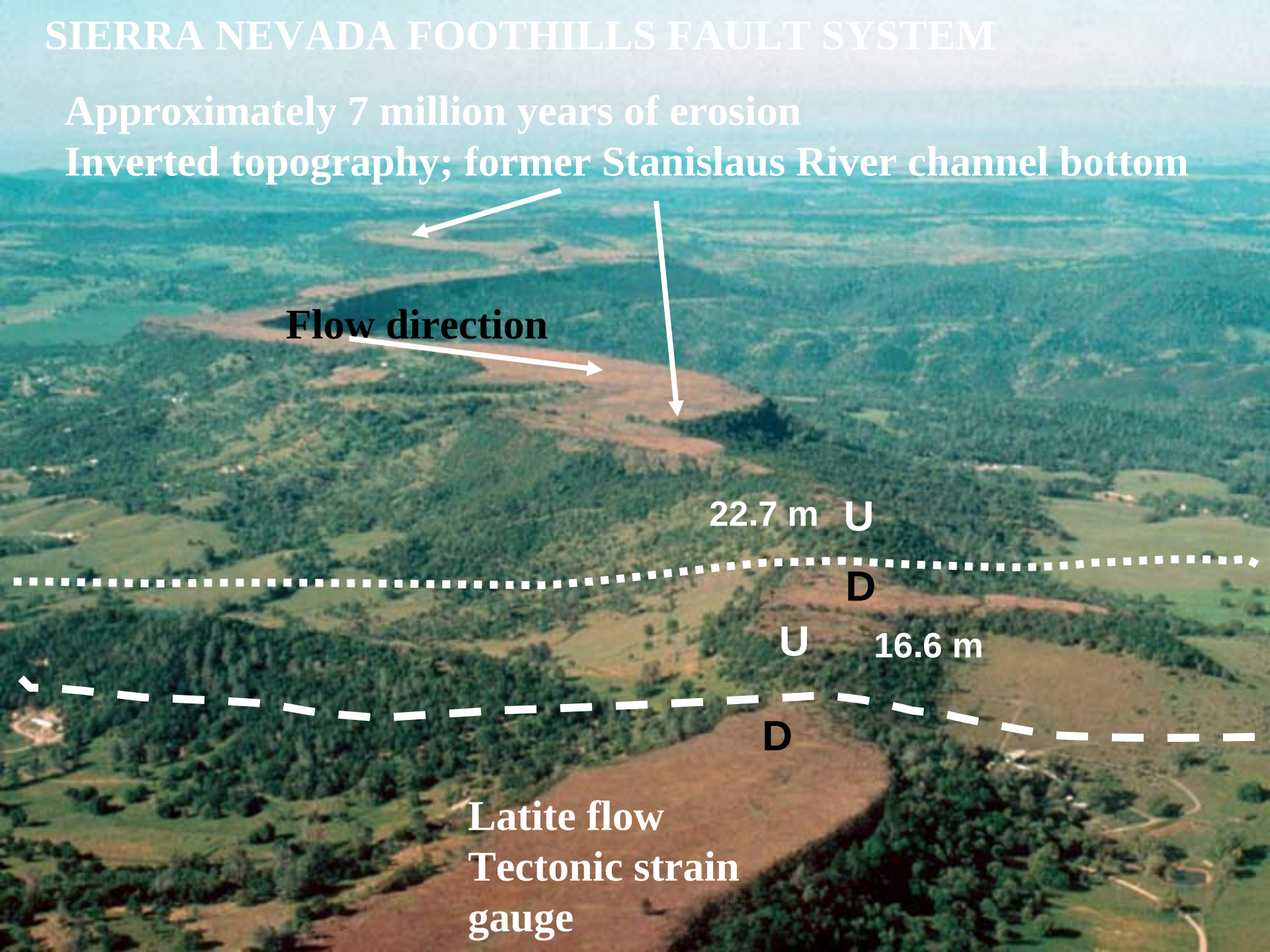
Sierra Nevada

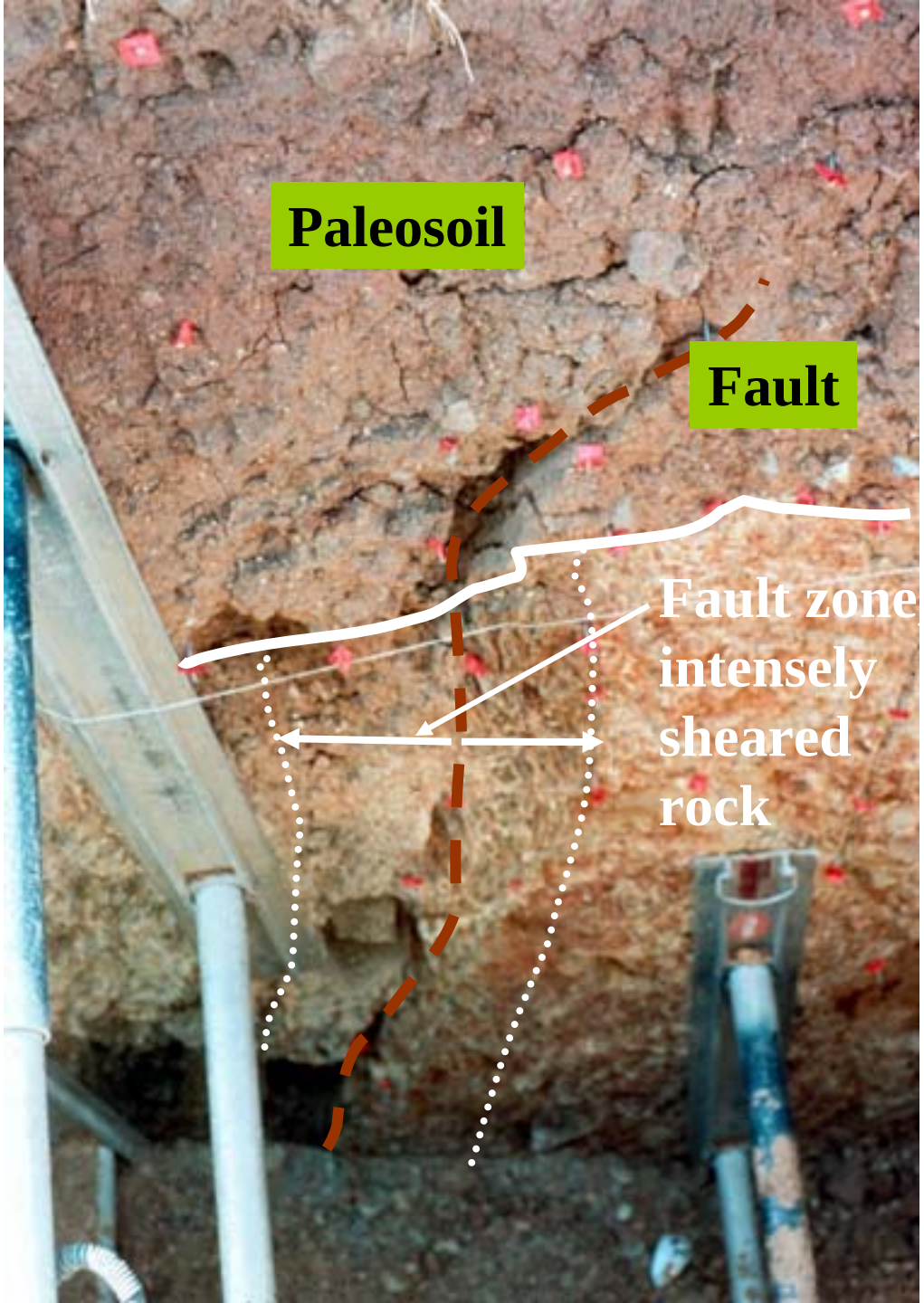
Western Sierra Foothills Fault System

Scale:

0 km 100

SIERRA NEVADA FOOTHILLS FAULT SYSTEM





Paleosoil/
weathered
bedrock
contact

Proposed Auburn Dam Model

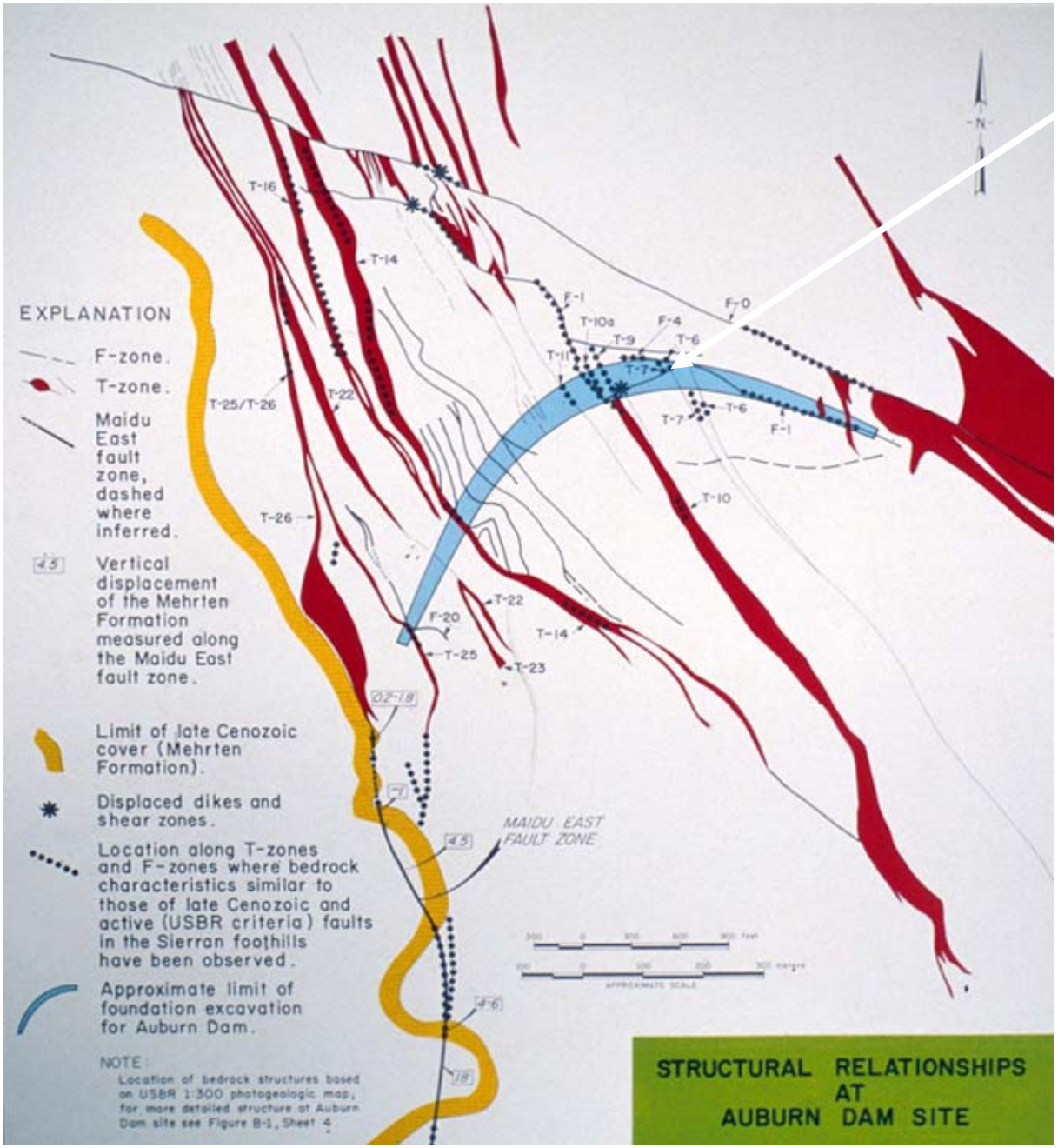
Crest Length: 1258 m

Thickness at Crest: 12.1 m

Thickness at Base: 60 m

Height: 212 m

Faults traverse Auburn Dam foundation



Footprint of dam

Auburn Dam Abandoned

- Surface fault rupture issue causes Auburn Dam Project to be cancelled by Secretary of Interior Andrus
- Surface fault rupture effects could not be accommodated by thin-arch concrete dam
- Lack of design team flexibility to accommodate new earthquake information and modify design
- California Division of Dam Safety opposed thin-arch dam at proposed site

Site of New Melones Dam
Under construction
View downstream
Rock-fill type dam
Trend of Bear Mountain fault zone

Faulted and sheared foundation rock
Rock-fill
Wide clay-core
Mitigates piping

New Melones Dam Completed

- Surface fault rupture potential overcome
- Surface fault rupture effects accommodated by rock-fill dam, with thick clay core
- Dam completed on schedule

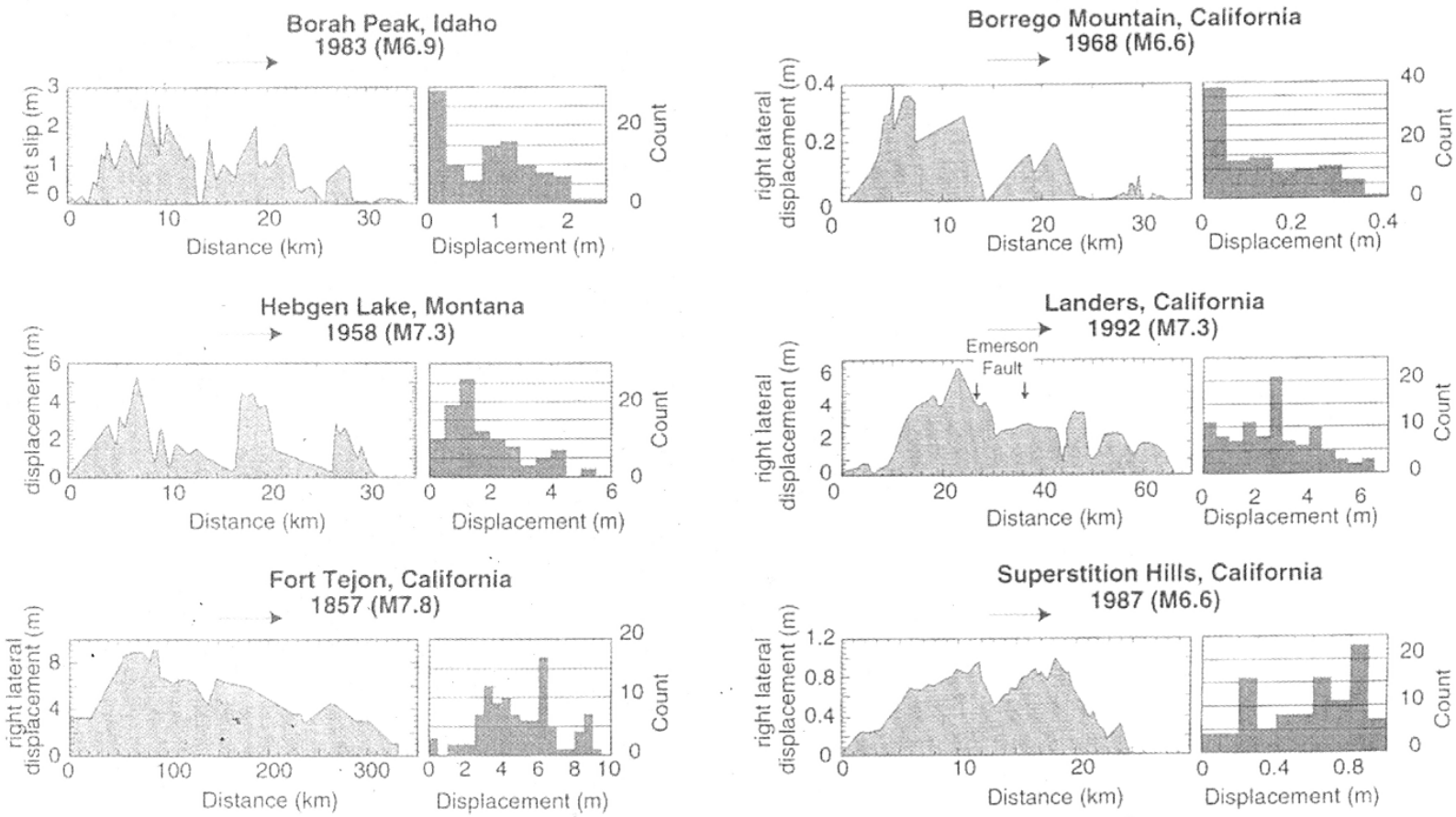
Fault Rupture

- Rupture hazards
  - Main Fault Rupture
  - Secondary ruptures
- Models for fault rupture
  - Analogous to ground motion
  - Typically use empirical models based on global data
    - Wells and Coppersmith (1994)
  - Shortcoming with global models
    - Fault rupture is highly characteristic for a site
  - Statistical models for secondary rupture for SS available
    - NML and RV not complete

Global Models

- Model for average displacement
  - Log(AD) = -6.32 + 0.9M
  - Sigma = 0.28 (log10 units)
- Model for variability of displacement along strike
  - Sigma = 0.27
- Total variability at a point (ergodic assumption)
  - Sigma = 0.39

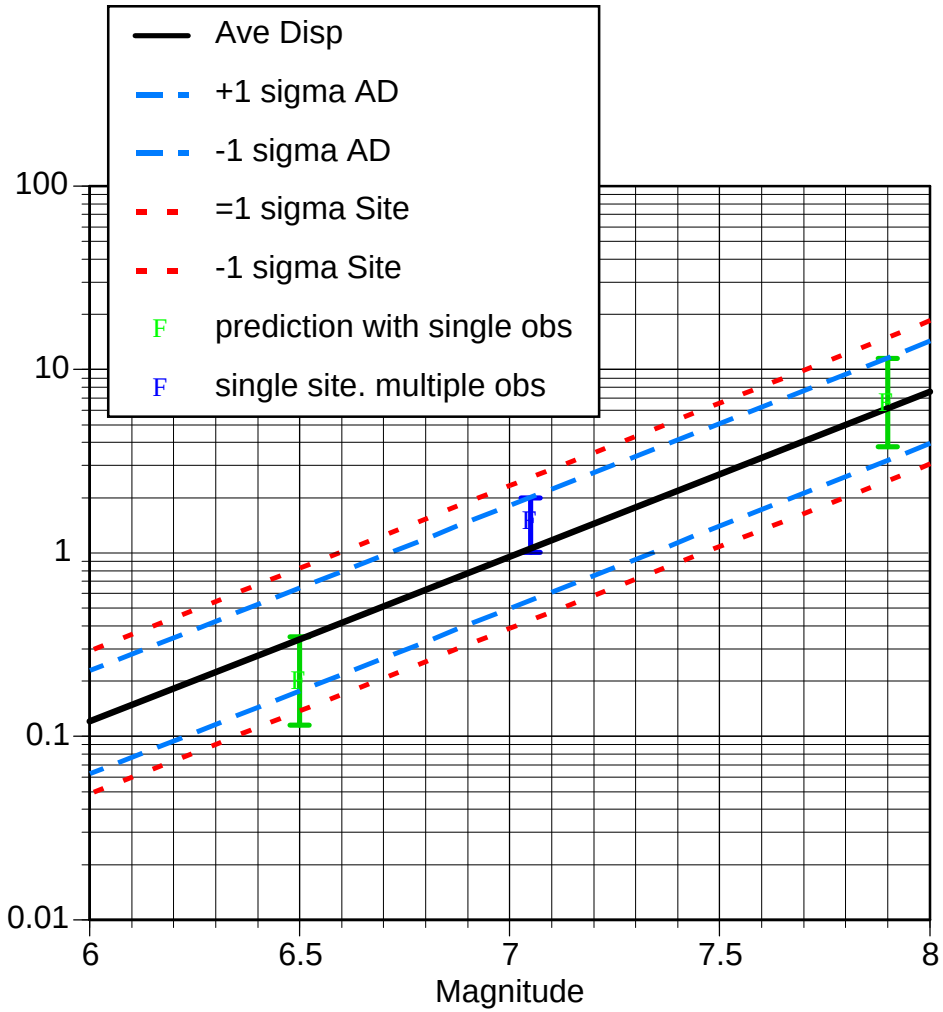
Along Strike Variability



Single Site Data

- Sites with observations of multiple displacements (typically 3)
  - Sigma = 0.17
  - Much smaller than predicted by global models
    - Sigma = 0.39 for global model
  - Implies characteristic slip at a point

Fault Rupture Models



N	Epistemic Uncertainty in Median
0	0.35
1	0.17
2	0.12
3	0.10

Summary: Needs for Performance-Based Approach

- Seismic hazard
  - Science for ground motion is well developed
    - Improvements to ground motion models is ongoing
    - Fault rupture hazard benefits greatly from site observations
- Dam fragility
  - Very little work has been done on dam fragilities
    - Most of work on newer dams
    - Many dams in CA are old
  - Requires an efficient way to evaluate the dam for a large range of ground motions
    - Building industry is addressing this topic