From Dynamic Rupture Modeling to Ground Motion

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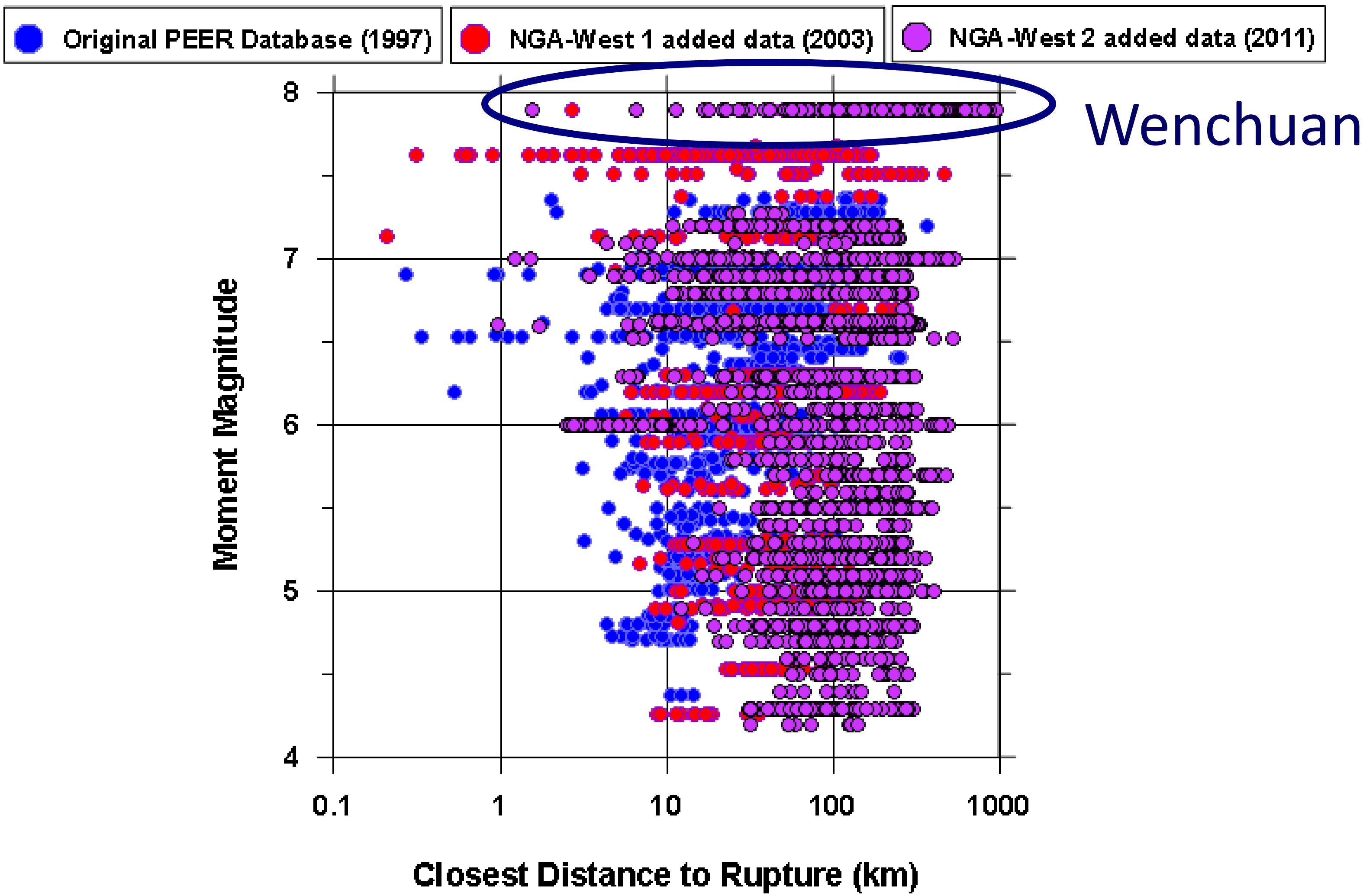
Introduction

- Empirical models
  - Fitting simple parametric equations to data
  - But need to extrapolate for most engineering applications
- Finite-Fault Numerical simulations
  - Physics-based
  - Validation against data
    - Data for validation is the same as available for empirical models
    - Site effects differences cause difficulties
  - Need to define distributions for model inputs
    - Involves extrapolation for engineering applications

Difficulties with Empirical Data

- Data sets still sparse in the key magnitude-distance ranges
- Bad properties of data sets
  - Uneven sampling of earthquakes
    - 1 to >200 recordings per event
  - Censoring of data
    - Smaller ground motions not sampled (triggering issue)
  - Limited bandwidth (long period) in older data
  - Correlation of independent parameters
    - Magnitude – distance
    - Rupture depth and focal mechanism
    - Site condition (VS30) and depth to rock
  - Correlation of dependent parameters
    - Correlation through Event term
    - Correlation through Site term

Rrup vs Magnitude



Use of Numerical Simulations in U.S. Engineering Practice

- WUS (crustal)
  - Sparse use of simulations
- Subduction
  - Common use of simulations used for M8-M9
- EUS (stable)
  - Wide use of point source models with an effective point source distance
  - Some use of finite-source models

Numerical Simulations

- Physics-based hazard using finite-fault simulations with 3-D velocity structure is one focus of SCEC
  - Accounts for site-fault specific geometries and complex crustal structure
  - No need for simplified distance metric
  - Can sample large suite of earthquakes, not just those with strong motion data
- Why don’t we use finite-fault models more in engineering applications?

NGA Project (2001-2008)

- Goal: develop empirical model but with constraints on scaling from simulations
  - Only use simulations for relative scaling, not absolute level of ground motion
- Analytical simulations considered
  - Hard-rock ground motions using finite-fault seismological simulations (1-D crustal structure)
  - 1-D site response amplification factors using equivalent-linear method
  - 3-D basin response for the Los Angeles Region

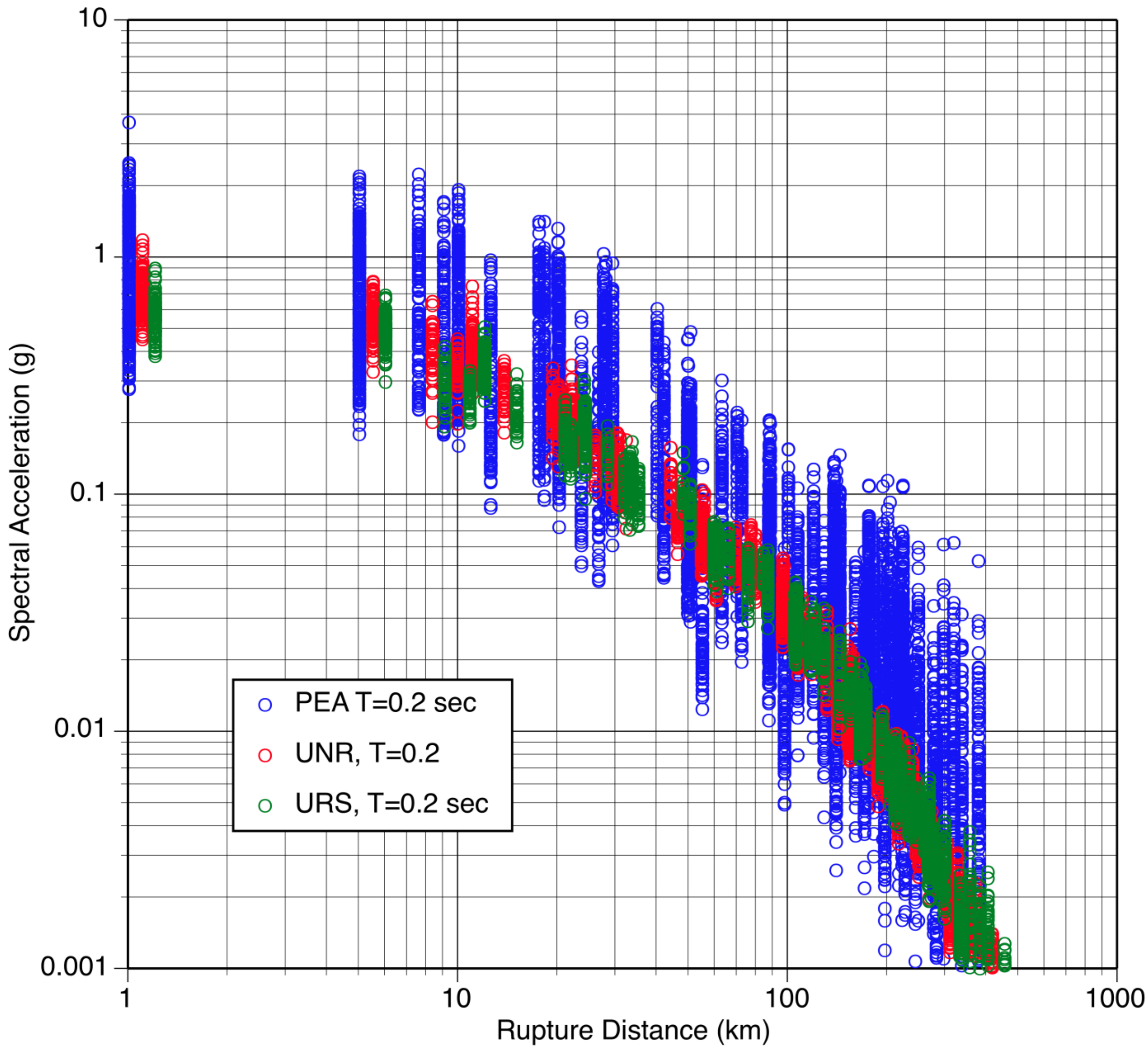
Use of Kinematic Simulations

- Constraints
  - Magnitude scaling from M7 to M8.5
  - Short distance scaling (1 to 10 km)
  - Large distance scaling (70 to 200 km)
  - Long period scaling (3 to 10 seconds)
  - Static stress-drop scaling
  - Shallow vs Buried rupture scaling
  - Hanging wall scaling

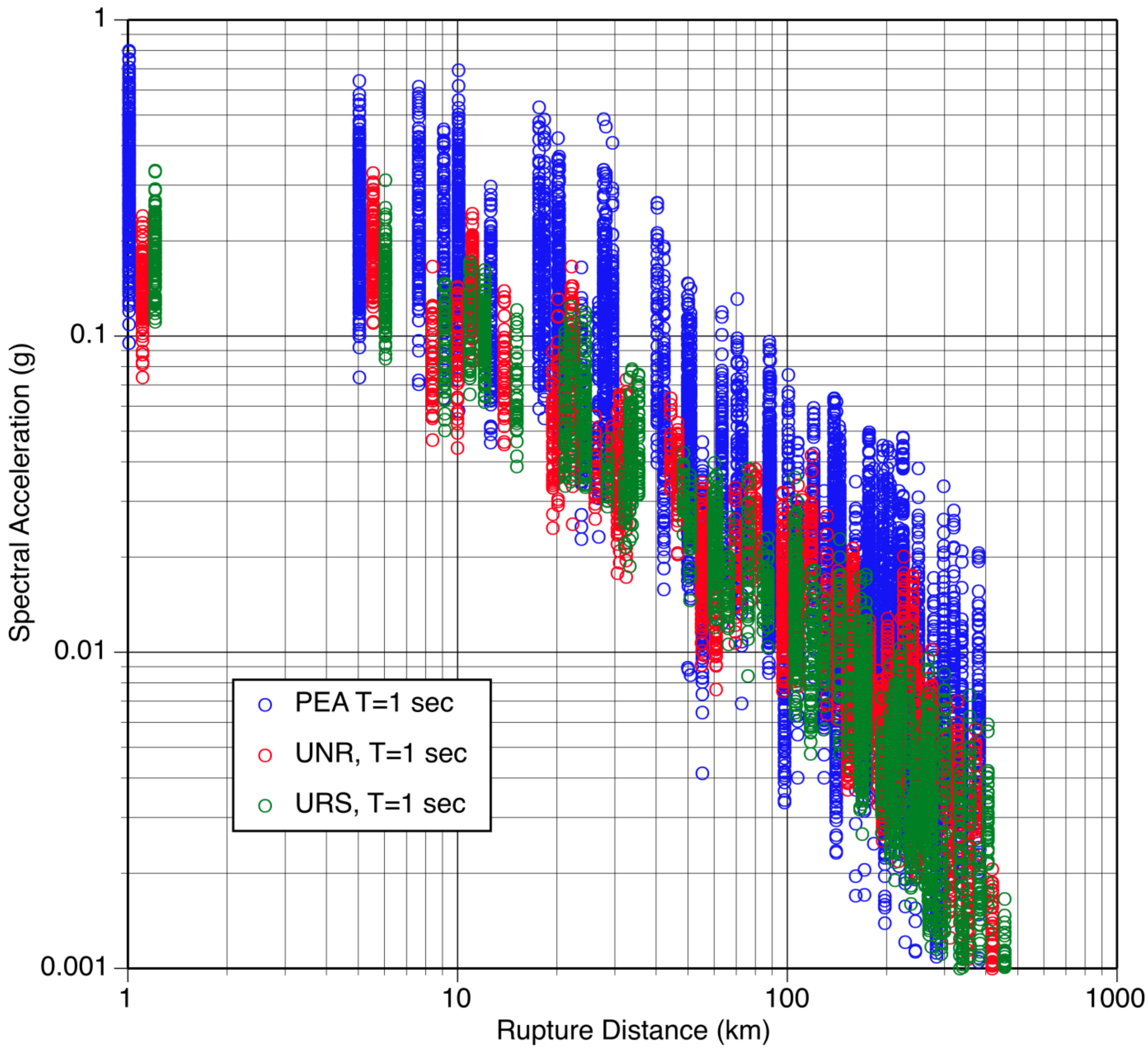
Kinematic Simulation Methods Used in NGA project

- Three Kinematic Finite-Fault Simulations
  - Pacific Engineering and Analysis (Silva)
  - University of Nevada, Reno (Zeng)
  - URS (Somerville / Graves)
- Each model was validated against empirical data (dist < 50 km, except Landers)
  - 1979 Imperial Valley
  - 1989 Northridge
  - 1992 Landers
  - 1994 Northridge
  - 1995 Kobe
  - 1999 Chi-chi
- Multiple Realizations for each scenario, sampling range of source inputs
  - PEA: 15 or 30 realizations
  - UNR:12 realizations
  - URS: 12 realizations

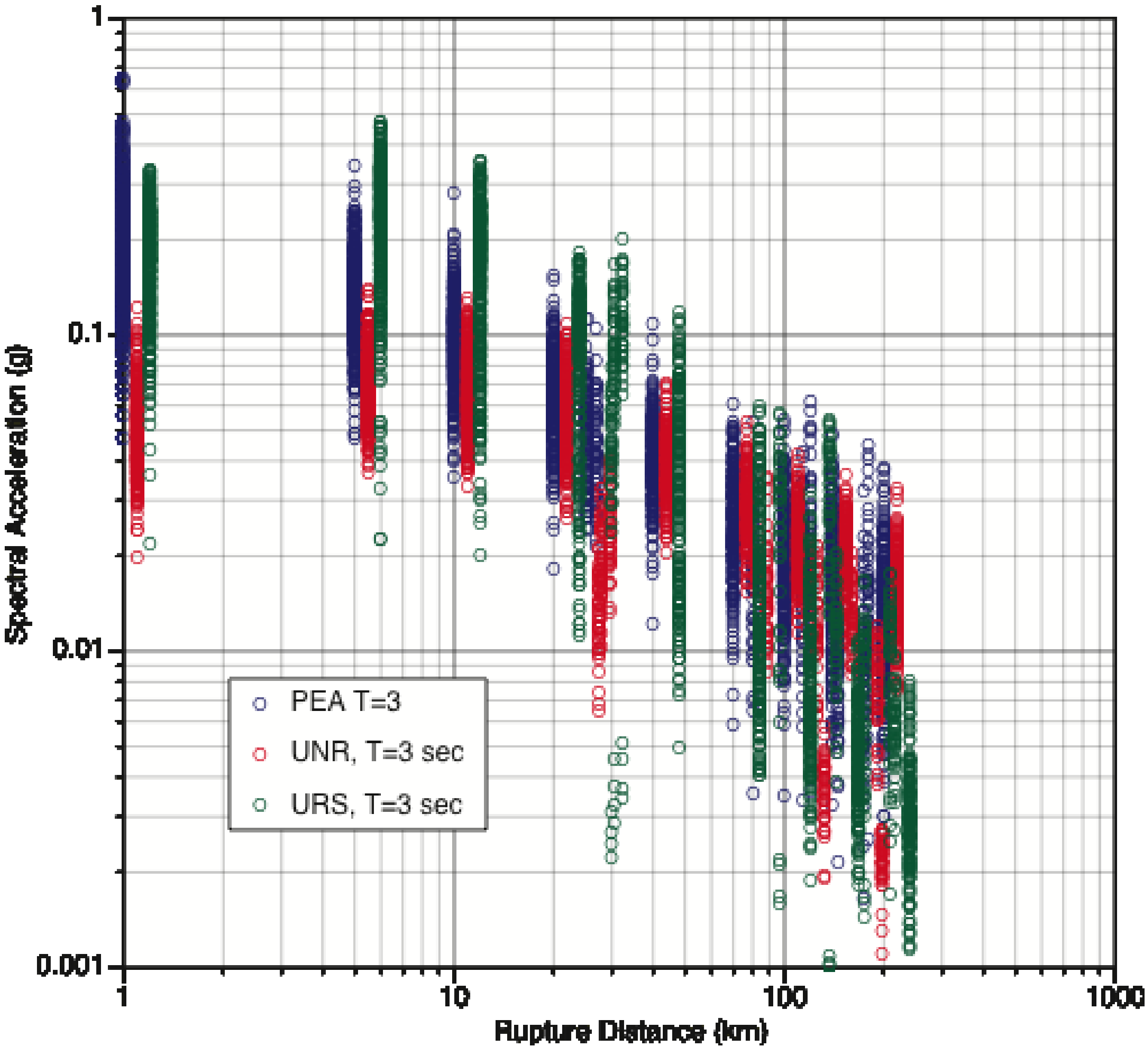
Scenario SA: M6.5, SS (T=0.2 sec)



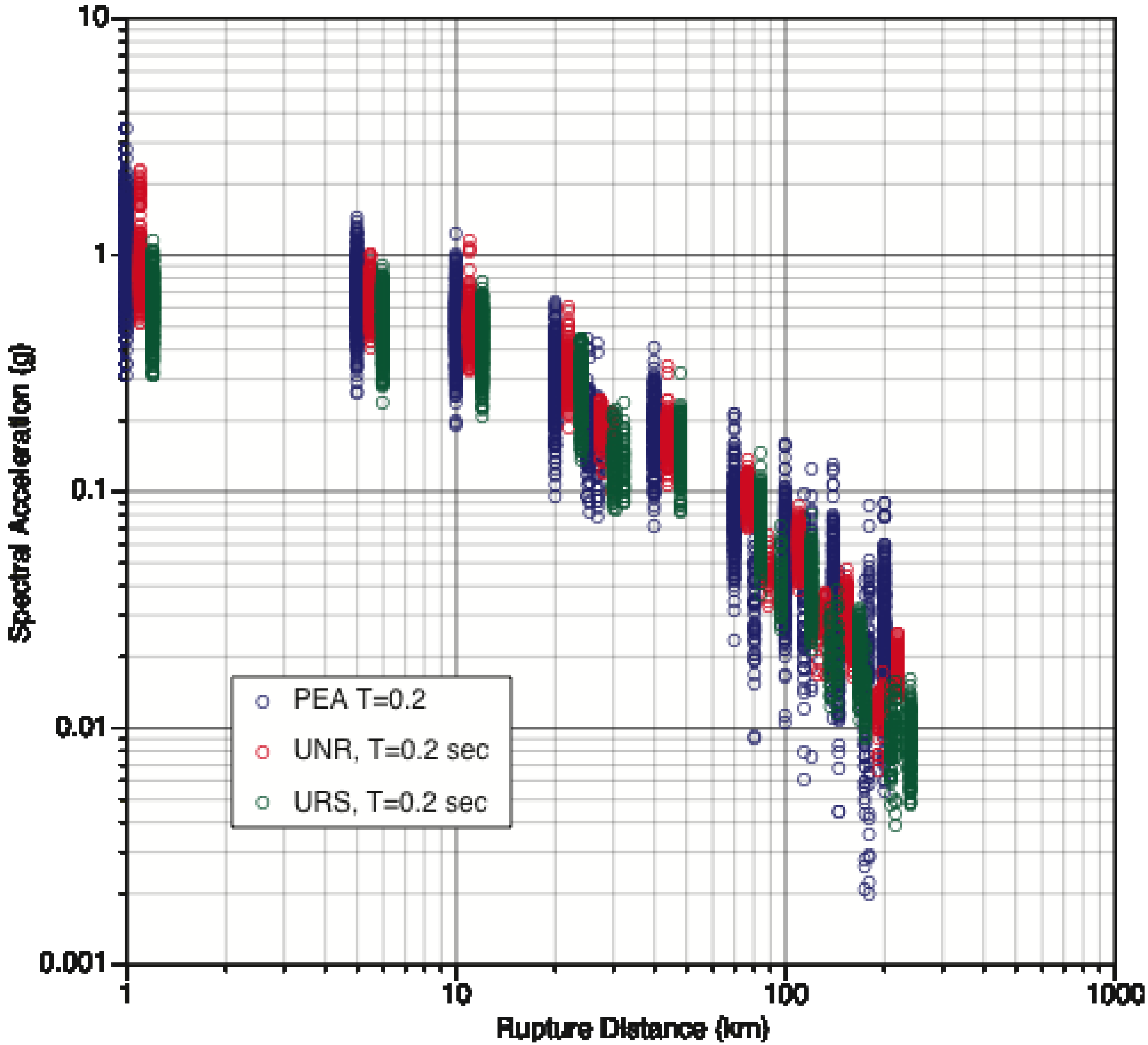
Scenario SA: M6.5, SS (T=1 sec)



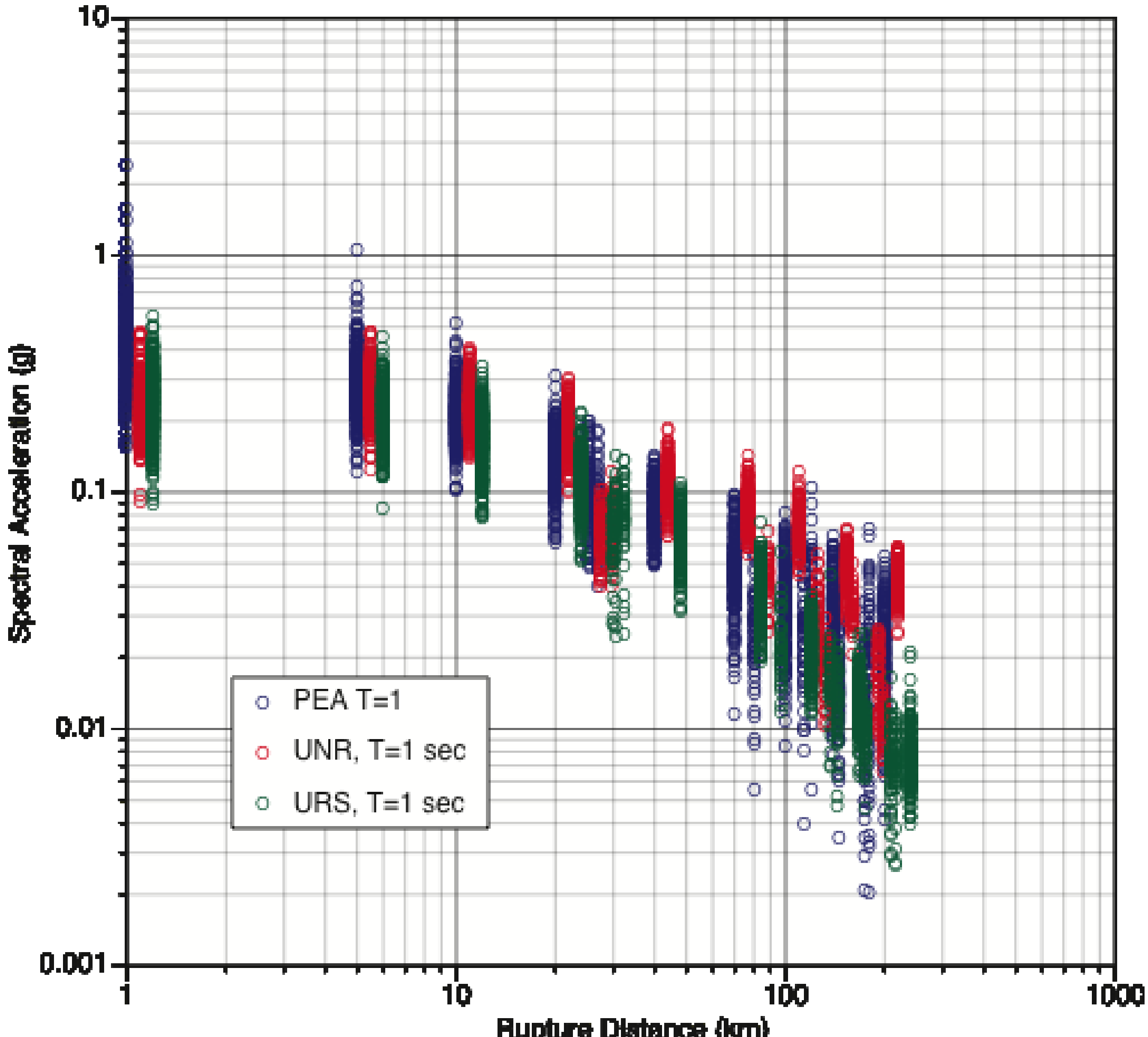
Scenario SA: M6.5, SS (T=3 sec)



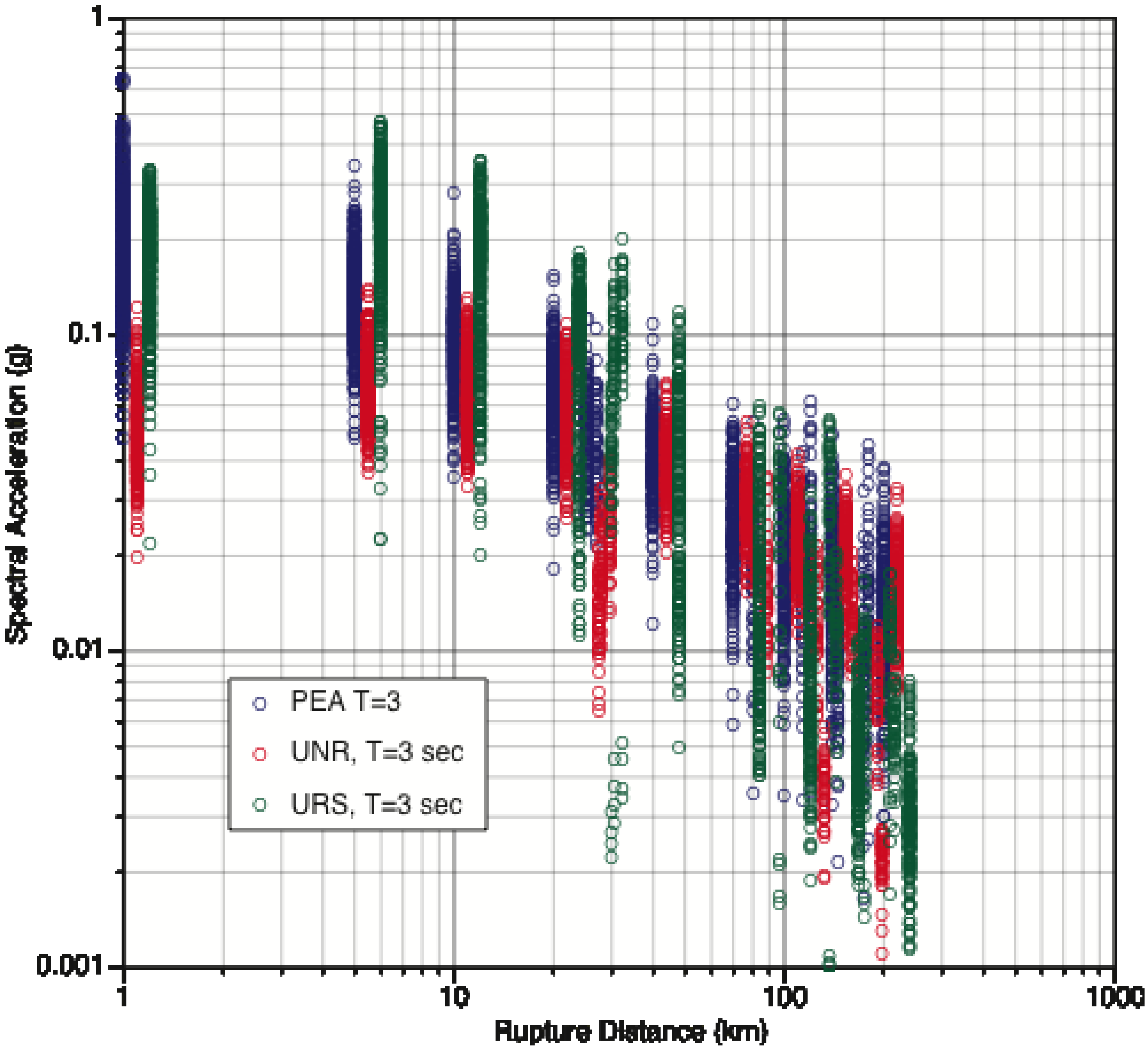
Scenario SH: M7.8, SS (T=0.2 sec)



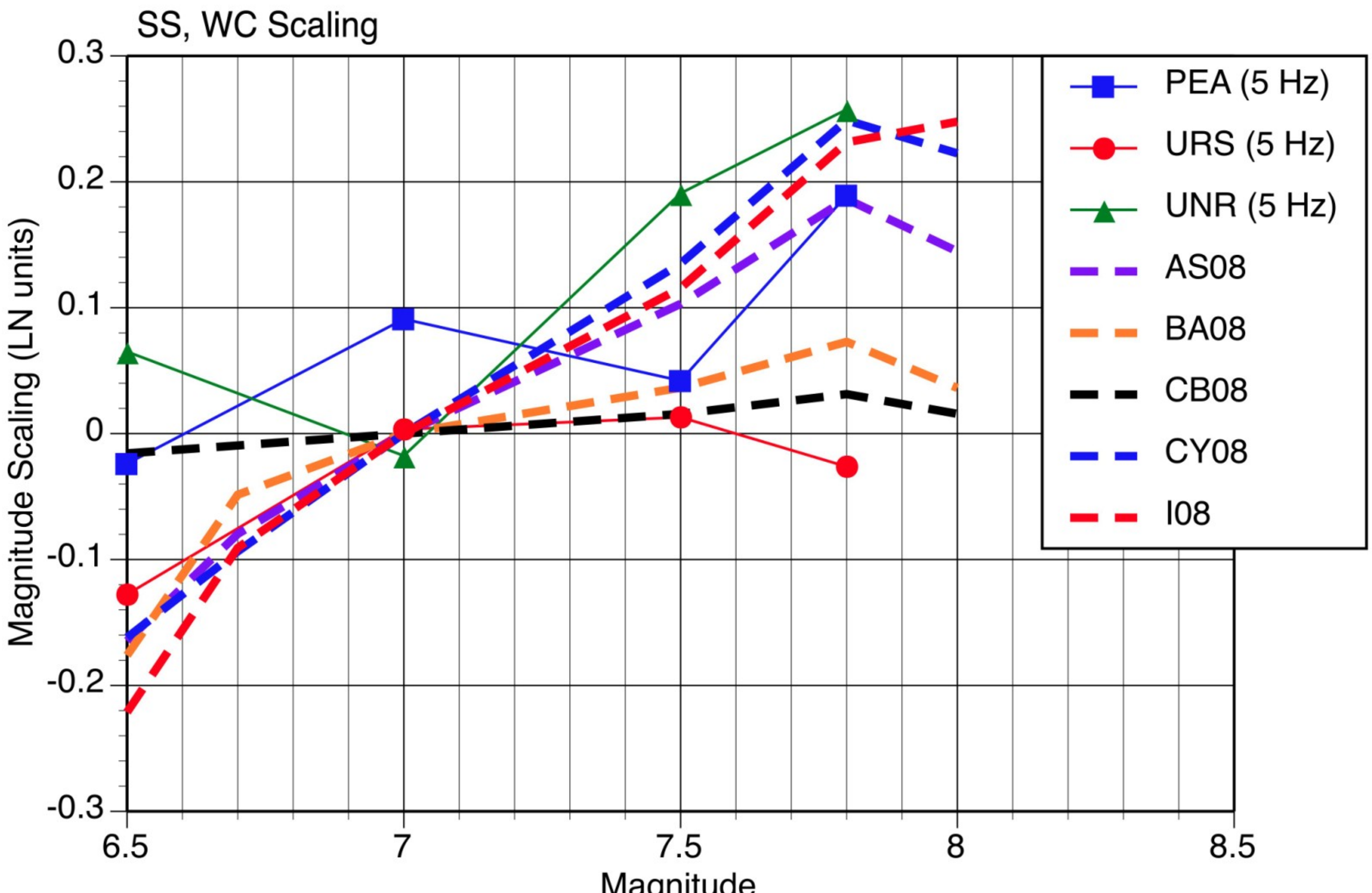
Scenario SH: M7.8, SS (T=1 sec)



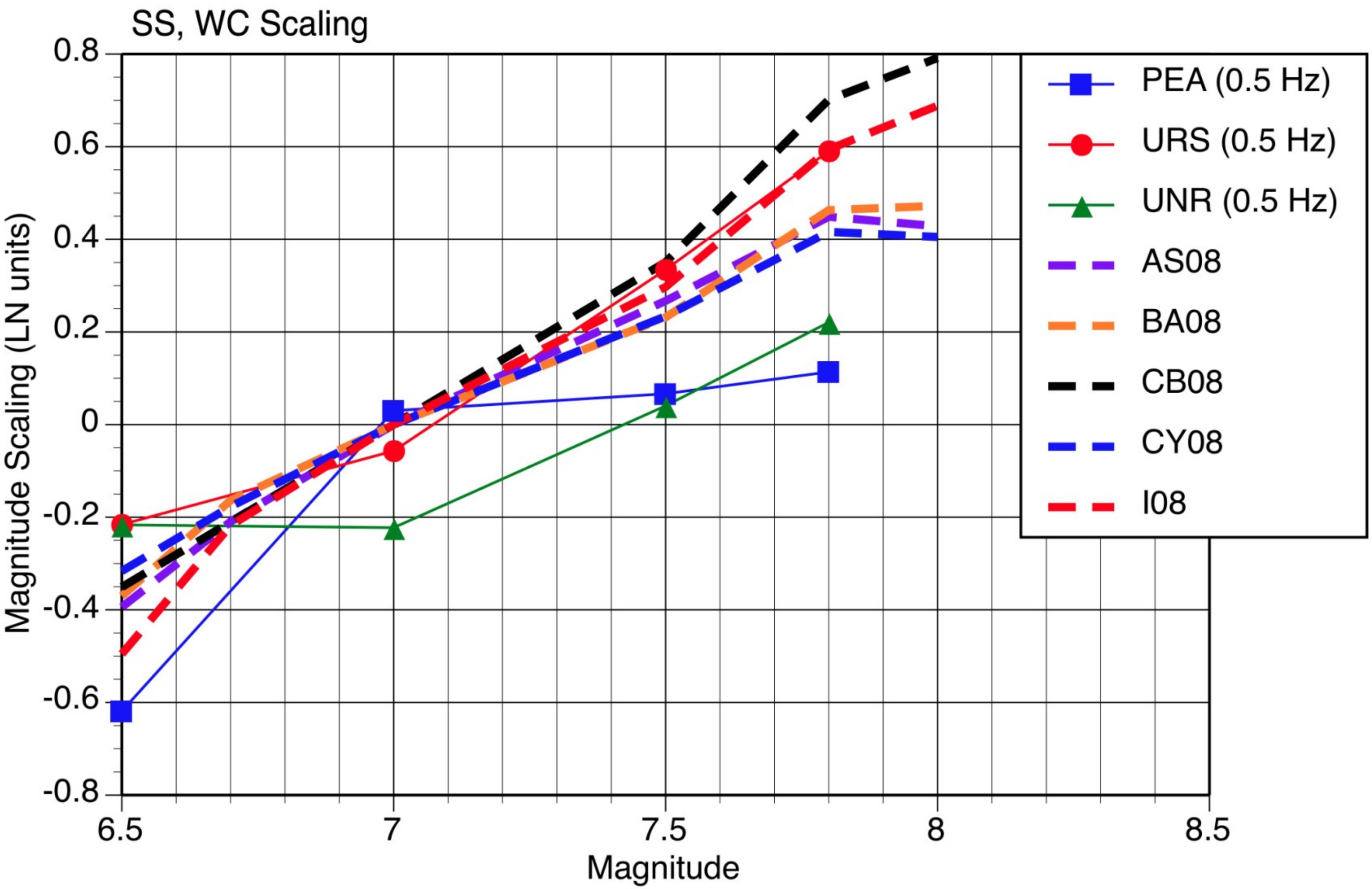
Scenario SH: M7.8, SS (T=3 sec)



SS, WC Scaling, T=0.2 sec
Rrup=0-5 km



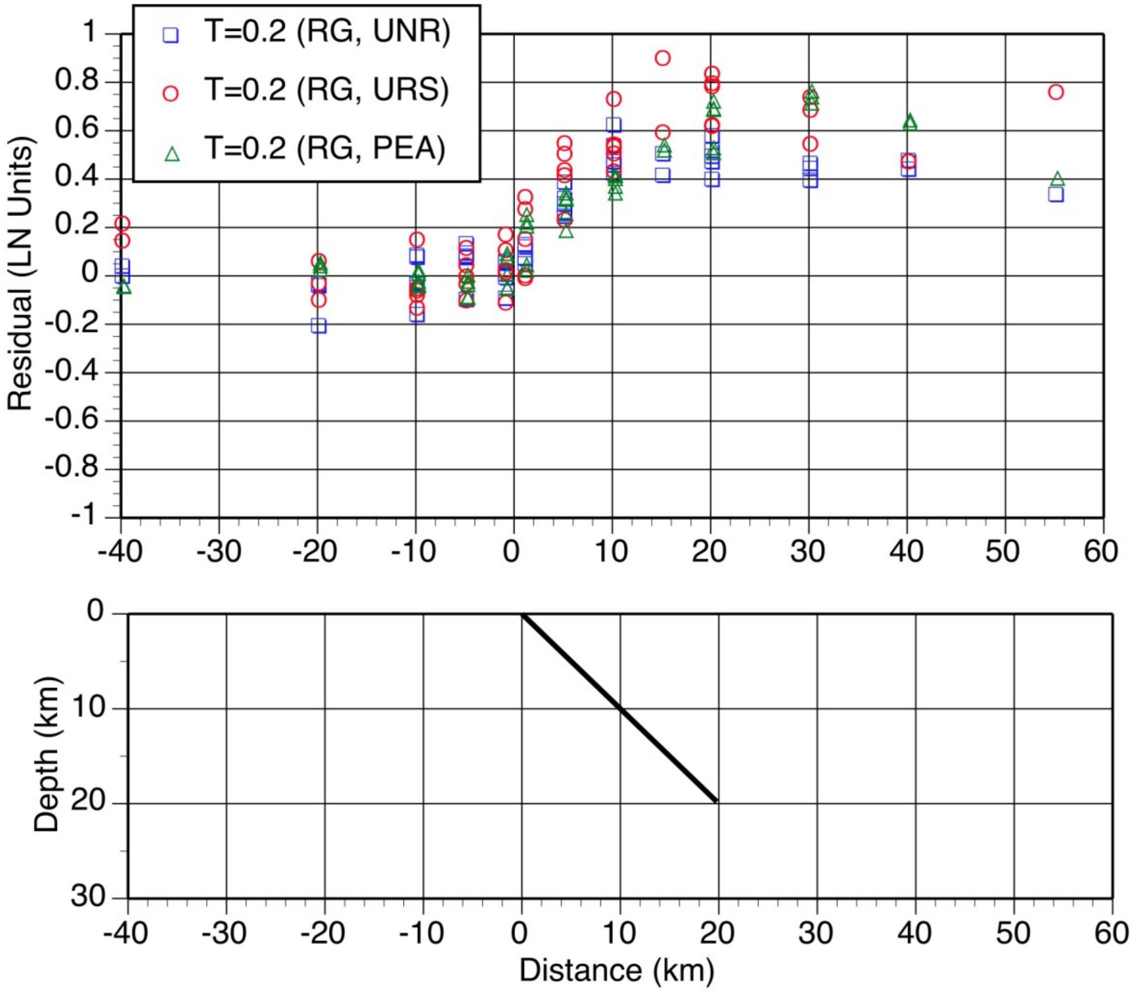
SS, WC Scaling, T=2 sec
Rrup=0-5 km



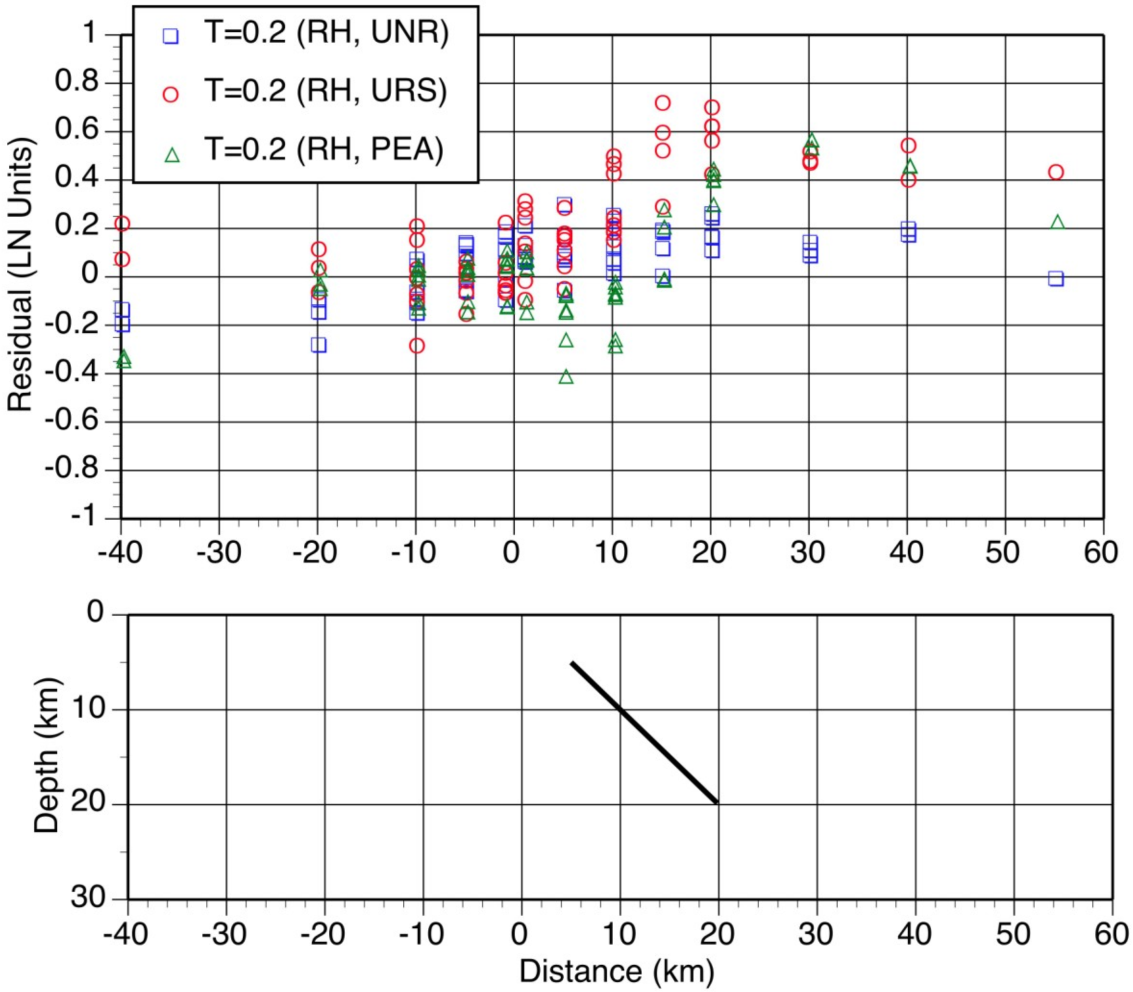
Use of Results

- Not used for NGA models to constrain large magnitude scaling
- Saturation at large magnitudes from empirical data is consistent with some of the simulation results

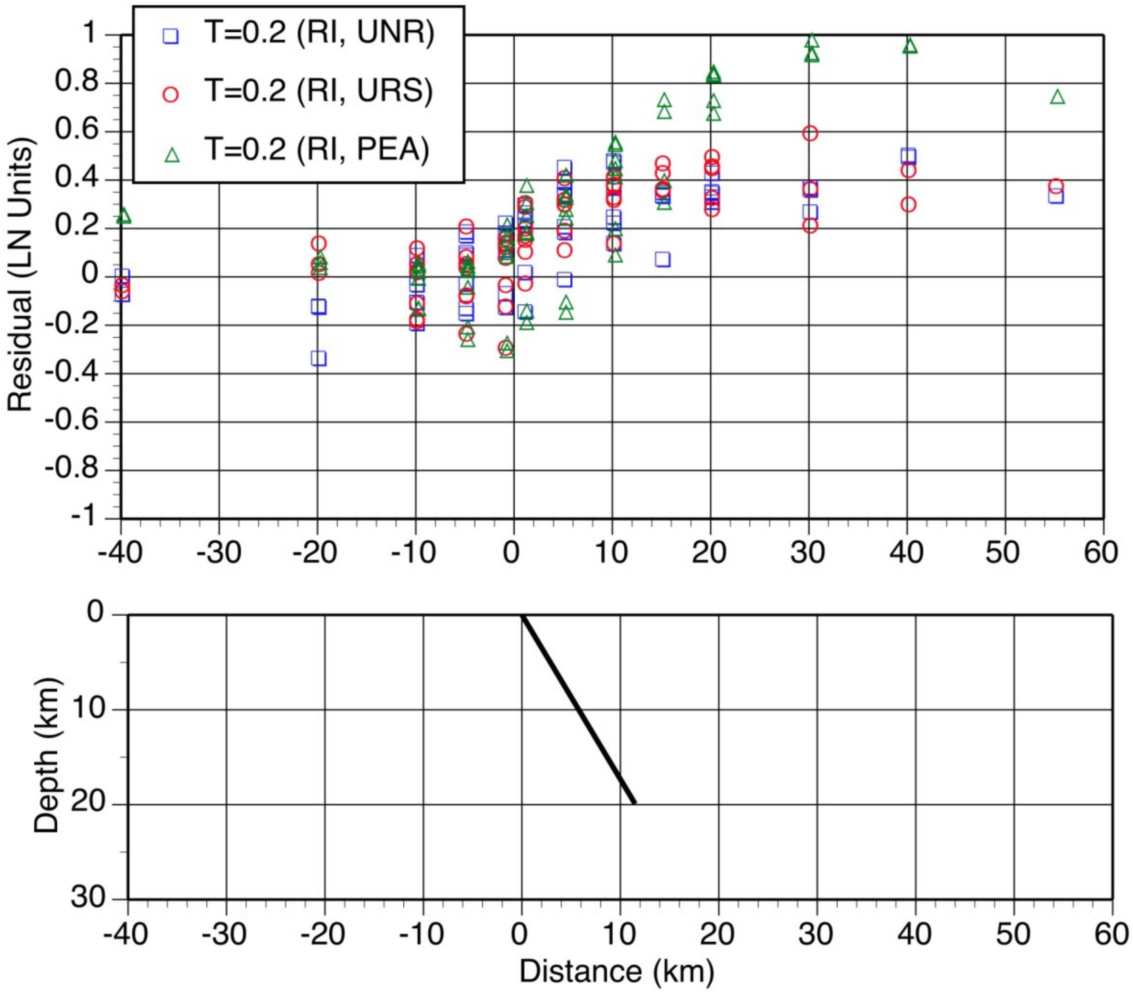
M7.0, Dip=45, ZTOR=0



M7.0, Dip=45, ZTOR=5



M7.0, Dip=60, ZTOR=0



Use of HW results

- Used to justify inclusion of HW scaling
  - Very sparse in empirical data, but systematic trends seen in simulations, consistent between different simulation methods
- Used to constrain or justify inclusion of scaling with dip and depth of rupture

Dynamic Rupture Simulation Applications for PG&E

- Source models for kinematic simulations
- Branch fault realizations
- Ground motions from dynamic simulations

Inputs to Kinematic FF simulations

- Correlations for kinematic inputs addressed through dynamic rupture models
  - Check sensitivity of correlations to the dynamic rupture inputs
  - Correlations applicable to both subshear- vs supershear need to addressed
- Methods for developing dynamic rupture inputs
  - Broad community review methods (collaborate with SCEC)
    - SCEC ground motion committee review
  - Check variability produced by dynamic rupture input methods with variability from empirical data

Source Models for Kinematic Simulations

- Objective
  - Develop a library of source models that capture correlations of kinematic source parameters
- Scope
  - Inputs
    - Initial stress distribution
  - Dynamic rupture runs
    - 50 realizations of M6.5-M7.5 Strike-Slip earthquakes
    - 50 realization of M6.0-M7.0 reverse earthquakes, dip=45
  - Develop model of joint pdf of source parameters
- Schedule
  - Updated input method by May 2012
  - Trail application by Dec 2012
    - Evaluate method (compare variability of source parameters and ground motions)
  - If needed, revise input method by Mar 2013
  - Complete dynamic simulations by Sep 2013
  - Develop statistical model of source parameters (joint pdf) by Feb 2014

Fault Branching Effects on Ground Motions

- Recorded ground motions from fault branching
  - Very few recordings available near branching ruptures
    - 1979 Imperial Valley - station E06 (may be 4 other stations as well)
    - 1995 Kobe– Kobe Univ site
- Dynamic rupture simulations
  - Use simulations to compute differences between fault branching case and typical case (captured by empirical model)
    - Estimate scale factors to apply to empirical GMPEs
  - Check sensitivity to small changes in inputs or details of how fault branch is set up numerically

Strike-Slip Branch Faulting

- Objective
  - Evaluate probability of rupture onto branch faults (SS case)
    - Focus on branch fault rupture of more than 10 km
    - Dependence on main fault magnitude, main fault and branch geometry, and regional stress
- Cases
  - Main flt – branch fault angles of 15-30 degrees
  - Magnitudes – M6.5 to M7.5
- Schedule
  - Complete by Sep 2013

Use of Ground Motions from Dynamic Rupture Simulations

- Validation
  - Show that the simulations are consistent with observed ground motions
- Two methods:
  - Validate against past earthquakes
  - Validate against well constrained part of empirical GMPEs

Validation

- Validation against observed Ground motion
  - For stable results, should have about 20 validation earthquakes
    - Source parameters are optimized for each earthquake
  - Check observed and predicted spectral acceleration (0.2 to 30 Hz), PGA, and PGV
    - Average misfit should be unbiased
    - Standard deviation of misfit should be better than empirical GMPEs
- Validation against GMPEs
  - Provides a check of forward method (how are inputs to simulations are developed)
  - Use only well constrained part of the GMPE (e.g. M6.5-7.0, 10-40 km)

Ground Motions from Dynamic Ruptures for RV & NML

- Objective
  - Compare ground motions from dynamic rupture simulations with kinematic simulations (and empirical models)
- Scope
  - Extend dynamic ruptures simulations up to 5 Hz for distances limited to 15 km
  - Validation with 20 eqk
  - Method for defining inputs
  - Dynamic rupture simulations for RV & NML M6.0-M7.0 earthquakes
    - Sites on HW and FW
- Schedule
  - Dec 2014?