Empirical-Stochastic Ground Motion Prediction for Eastern North America

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Types of Source Models for ENA

- Single-Corner Frequency Model (e.g., Frankel et al., 1996; Toro et al., 1997)
- Double-Corner Frequency Model (e.g., Atkinson and Boore, 1995; Silva et al., 2002)
- Hybrid-Empirical Model (e.g., Atkinson, 2001; Campbell, 2003)
- Finite-Source Model (e.g., Somerville et al., 2001)

- The objective of this study is to revise the 2003 Campbell attenuation relationship for ENA, using Hybrid-empirical model, combining single and double source spectra , and changing magnitude-dependent stress drop in the WNA and ENA regions which have different seismological parameters.

- Empirical refers to the empirical attenuation models developed in WNA (a host region) and Hybrid refers to models that transform attenuation relationships to ENA (a target region) by using seismological parameters.

Hybrid-Empirical Model

Earthquake Source Spectra

Geometrical Attenuation Factor

$$\frac{Y_{ENA}}{Y_{WNA}} = \frac{E_{ENA}(f_c)}{E_{WNA}(f_c)} \times \frac{A_{ENA}(f)}{A_{WNA}(f)} \times \frac{G_{ENA}(R)}{G_{WNA}(R)} \times \exp[R(\gamma_{WNA} - \gamma_{ENA}) + \pi f(\kappa_{WNA} - \kappa_{ENA})]$$

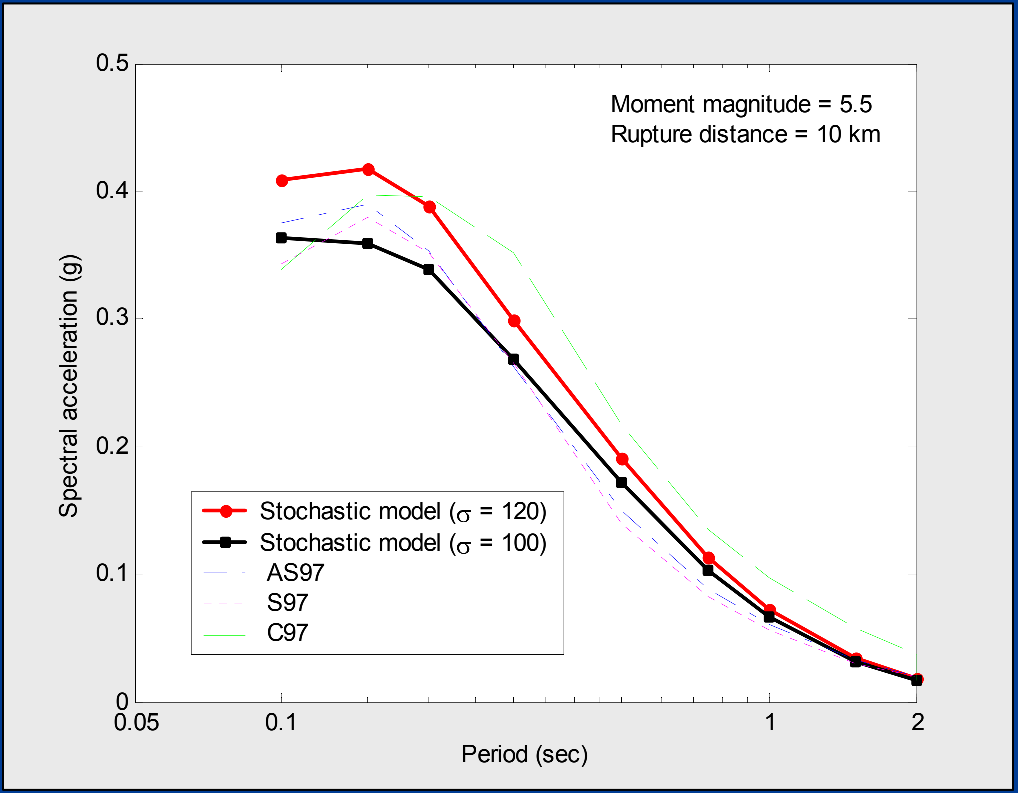
Filter Function of the Transfer Media and Local Site Conditions

Crustal Amplification Factors

Hybrid-Empirical Attenuation Relationships

- The 2001 Atkinson relation
  - Sadigh et al., 1997 from WNA
  - Elimination of Source Model
- The 2003 Campbell relation
  - Four Attenuation Relationships from WNA
  - Single-Corner Source Model
  - Constant Stress drop of 100 bars for WNA
- The 2005 Tavakoli-Pezeshk relation
  - Three Attenuation Relationship from WNA
  - Single-Corner Source Model at Long Distances
  - Double-Corner Source Model at Short Distances (< 30km)
  - Magnitude-Dependent Stress drop for WNA

Effect of Magnitude-Dependent Stress Drop in WNA

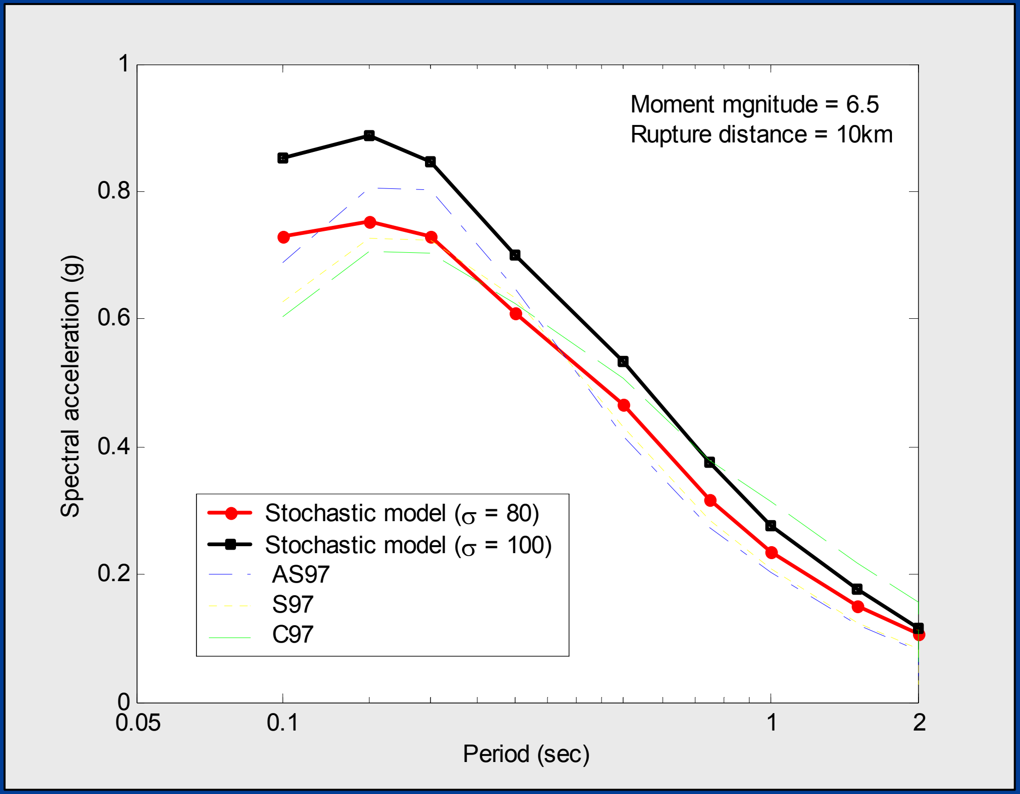


AS97 - Abrahamson and Silva (1997)

S97 - Sadigh et al. (1997)

C97 - Campbell (1997)

Effect of Magnitude-Dependent Stress Drop in WNA



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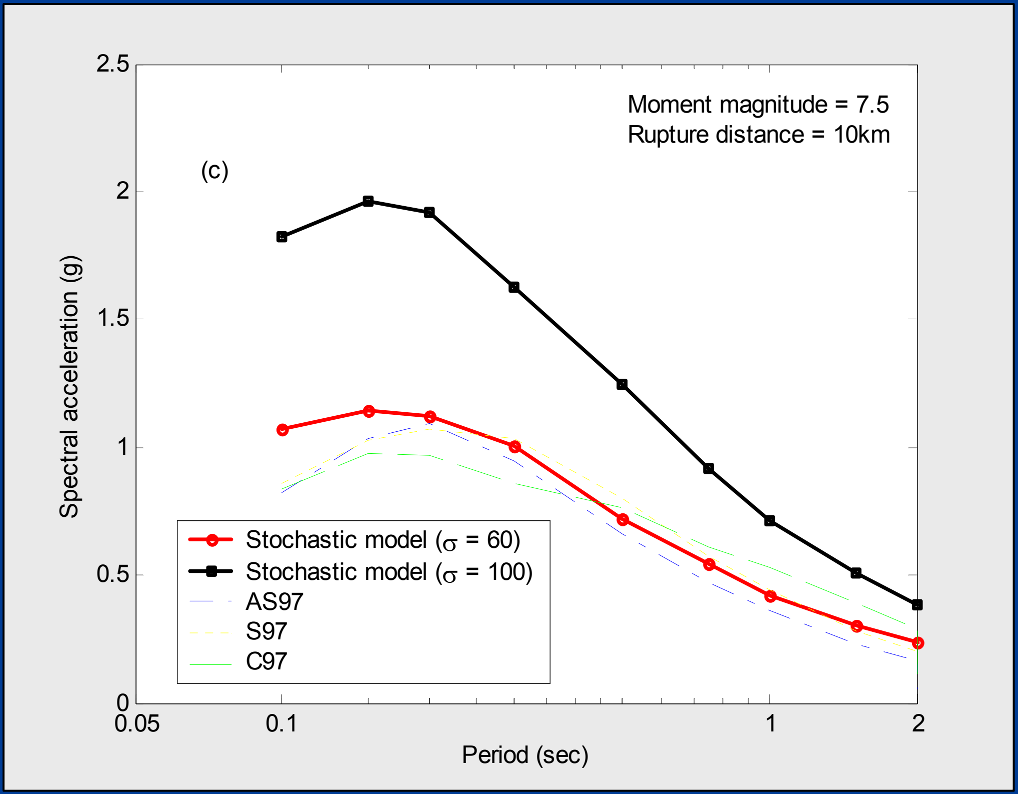

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Shape of Source Spectra and Model Parameters

- Source Spectra
  - Shape
  - Corner Frequencies

Atkinson and Boore (1995)

$$S(M_0, f) = \left[\frac{1-\varepsilon}{1+\left(\frac{f}{f_a}\right)^2} + \frac{\varepsilon}{1+\left(\frac{f}{f_b}\right)^2} \right]$$

- Model Parameters
  - Geometrical Spreading
  - Quality Factor
  - Path Duration
  - Site Amplification
  - Site Diminution (Kappa)

$$\gamma_{ENA} = 0.00122 f^{0.64}$$

$$\gamma_{WNA} = 0.00499 f^{0.55}$$

New Information to Incorporate into Ground Motion Simulation

- We considered the effects of near field saturation, focal depth, and stress drop on ground motions.
- We used the double corner-frequency source model to consider the effect of finite-fault modeling at short distances and large magnitudes.
- We used the single corner-frequency source model for the far-field ground motions.
- We used three empirical attenuation relationships from WNA.
- A composite functional form of the attenuation model for ENA based on the existing attenuation relationships in WNA.

Attenuation Relationship Developed for ENA

$$ln(Y) = f_1(M_w) + f_2(r_{rup}) + f_3(M_w, r_{rup})$$

Magnitude Scaling

$$f_1(M_w) = C_1 + C_2 M_w + C_3 (8.5 - M_w)^{2.5}$$

Distance Scaling

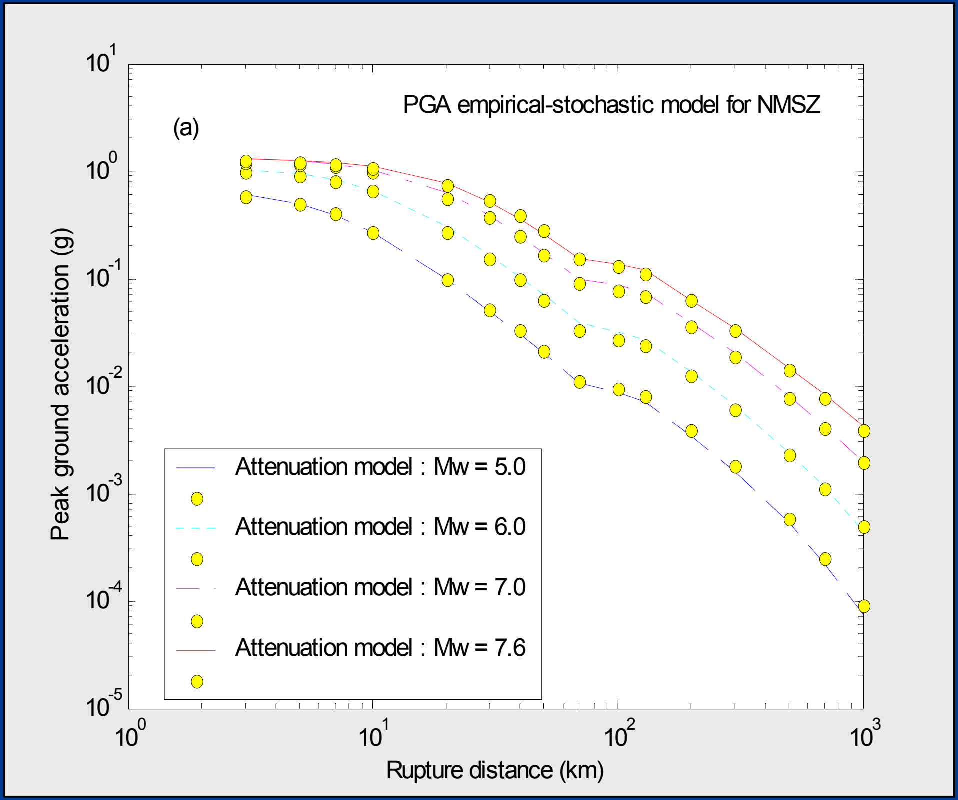
$$f_2(r_{rup}) = \begin{cases} C_9 ln(r_{rup} + 4.5) & r_{rup} < 70km \\ C_{10} ln(\frac{r_{rup}}{70}) + C_9 ln(r_{rup} + 4.5) & 70 < r_{rup} < 130km \\ C_{11} ln(\frac{r_{rup}}{130}) + C_{10} ln(\frac{r_{rup}}{70}) + C_9 ln(r_{rup} + 4.5) & r_{rup} < 130km \end{cases}$$

Magnitude-Distance Scaling

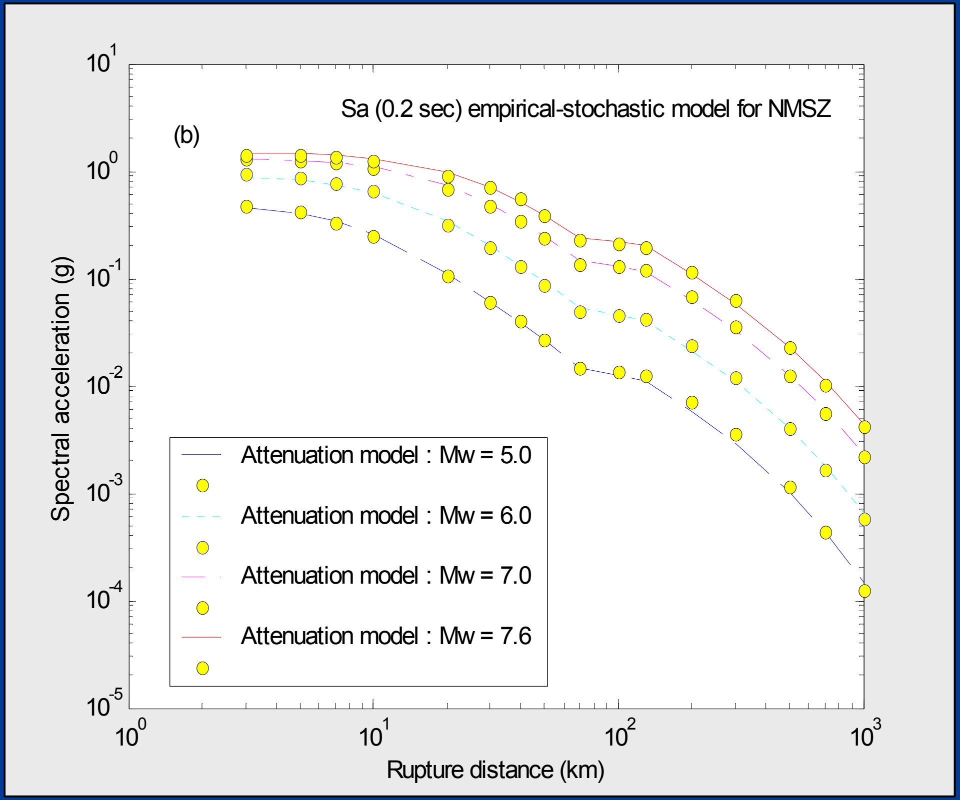
$$f_3(M_w, r_{rup}) = (C_4 + C_{13} M_w) lnR + (C_8 + C_{12} M_w) R$$

$$R = \sqrt{r_{rup}^2 + \left(C_5 exp\left[C_6 M_w + C_7 (8.5 - M_w)^{2.5}\right]\right)^2}$$

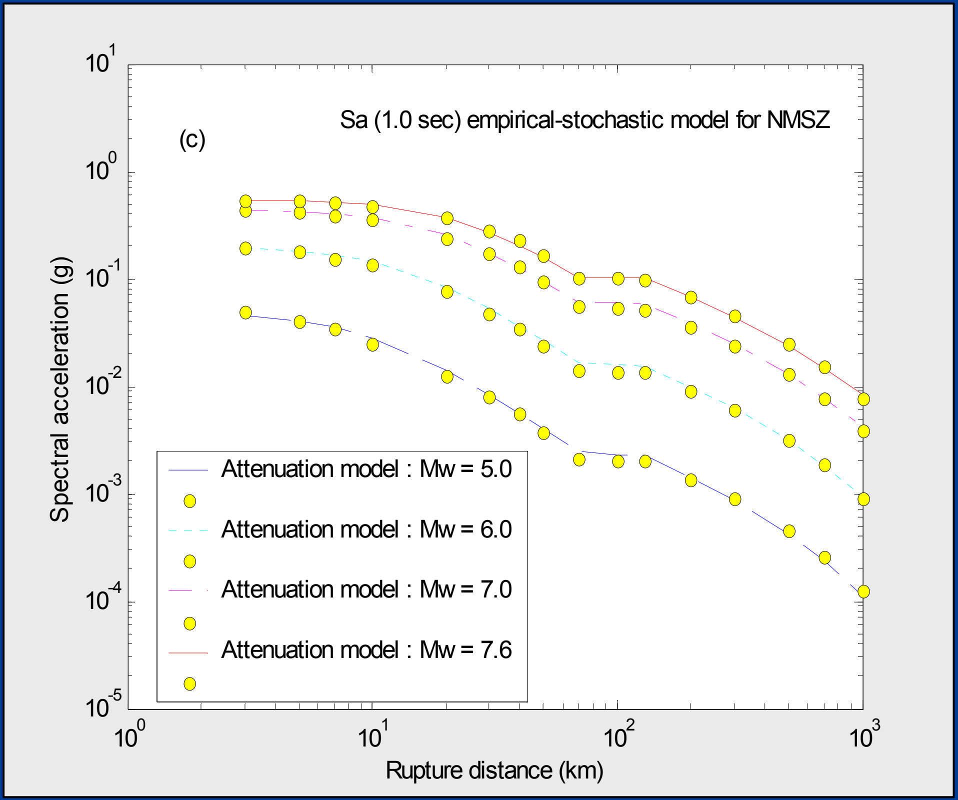
Empirical-Stochastic attenuation relation developed in this study for the ENA/NMSZ



Empirical-Stochastic attenuation relation developed in this study for the ENA/NMSZ



Empirical-Stochastic attenuation relation developed in this study for the CUS/NMSZ

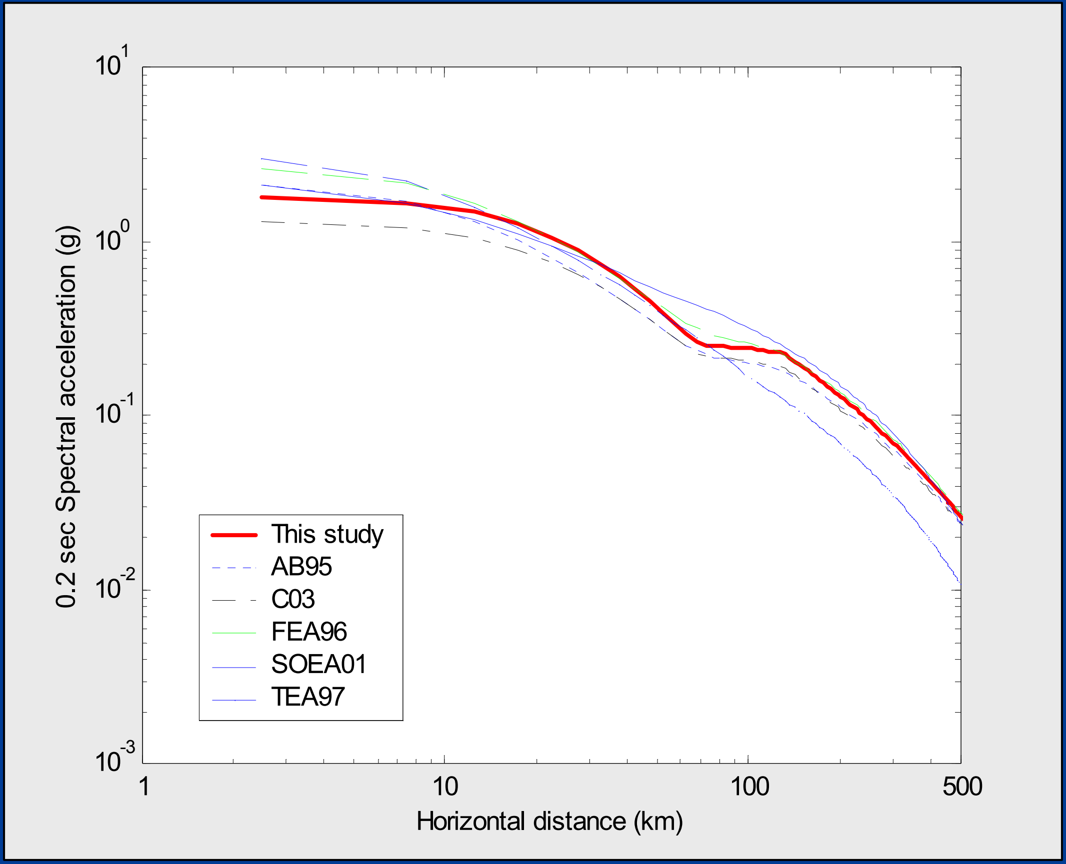


Optimization Using Hybrid Genetic Algorithm (HGA)

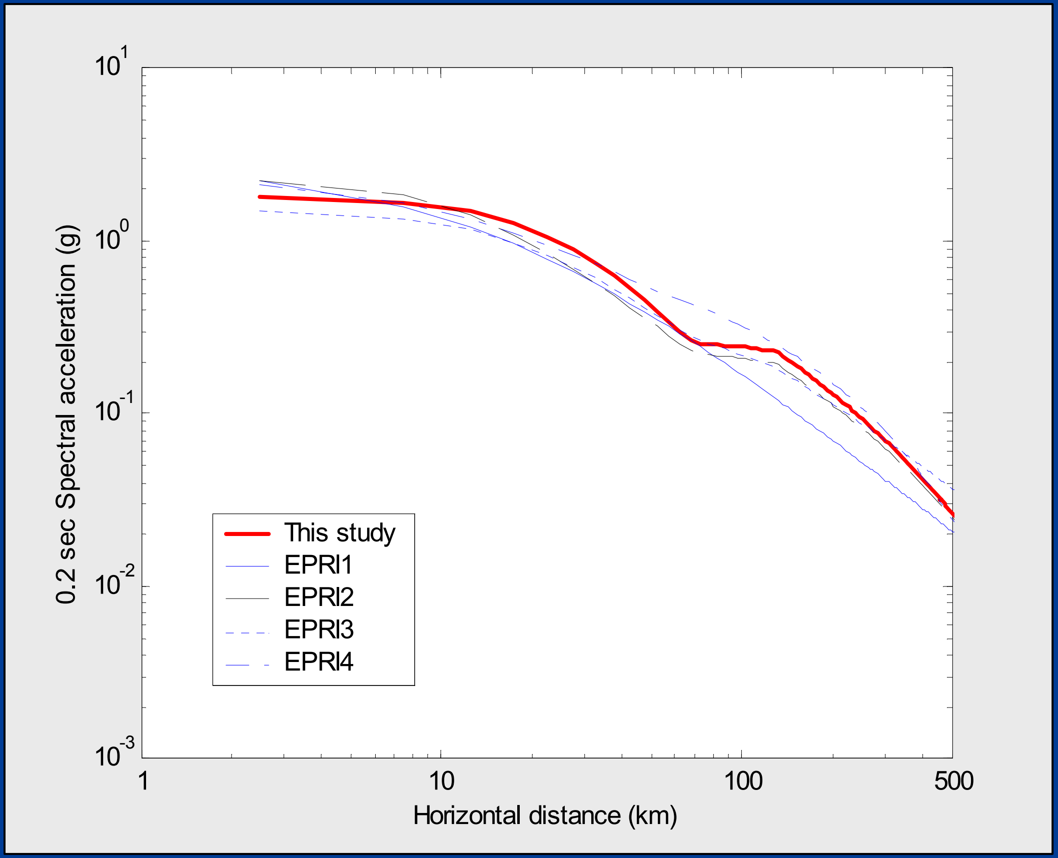
$$l(\theta|Y_{ij})=\min\left\{[Y_{ij}-f(x_{ij},\theta)]^{t}[Y_{ij}-f(x_{ij},\theta)]\right\}$$

- HGA is a directed stochastic search technique (a derivative-free approach) that is able to provide an optimal solution to compute the vector of the model parameters in attenuation relationships.
- A HGA consists of initialization, evaluation, reproduction/selection, crossover, and mutation.
- The HGA can be applied to complex attenuation models with several variance components.

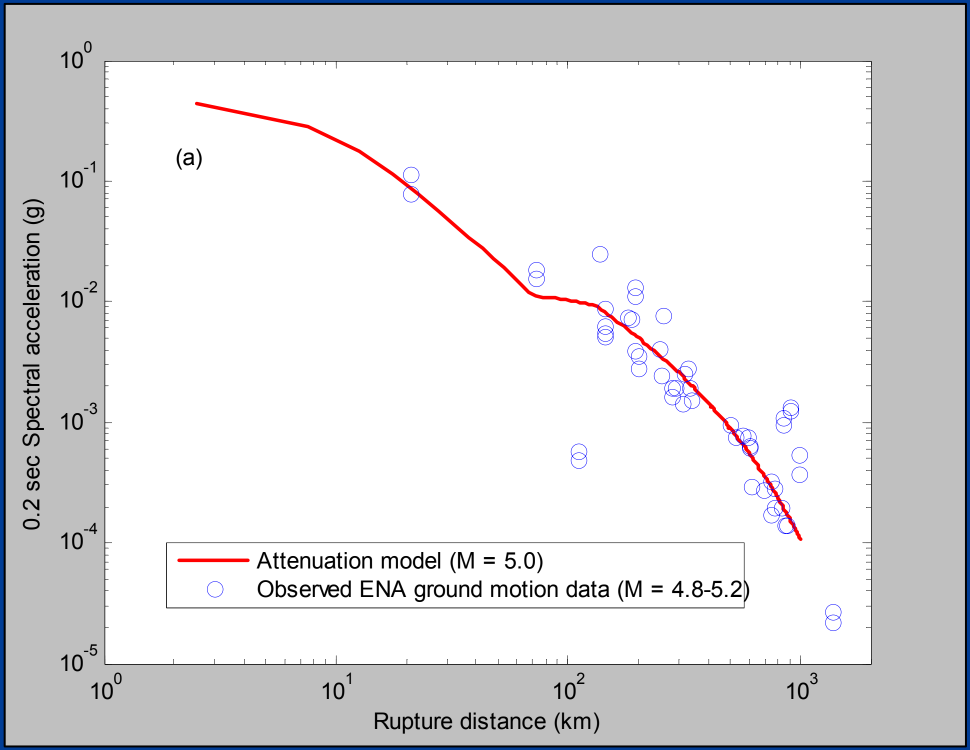
Comparison of Results with Other Attenuation Relations for ENA



Comparison of Results with Other Attenuation Relations for ENA

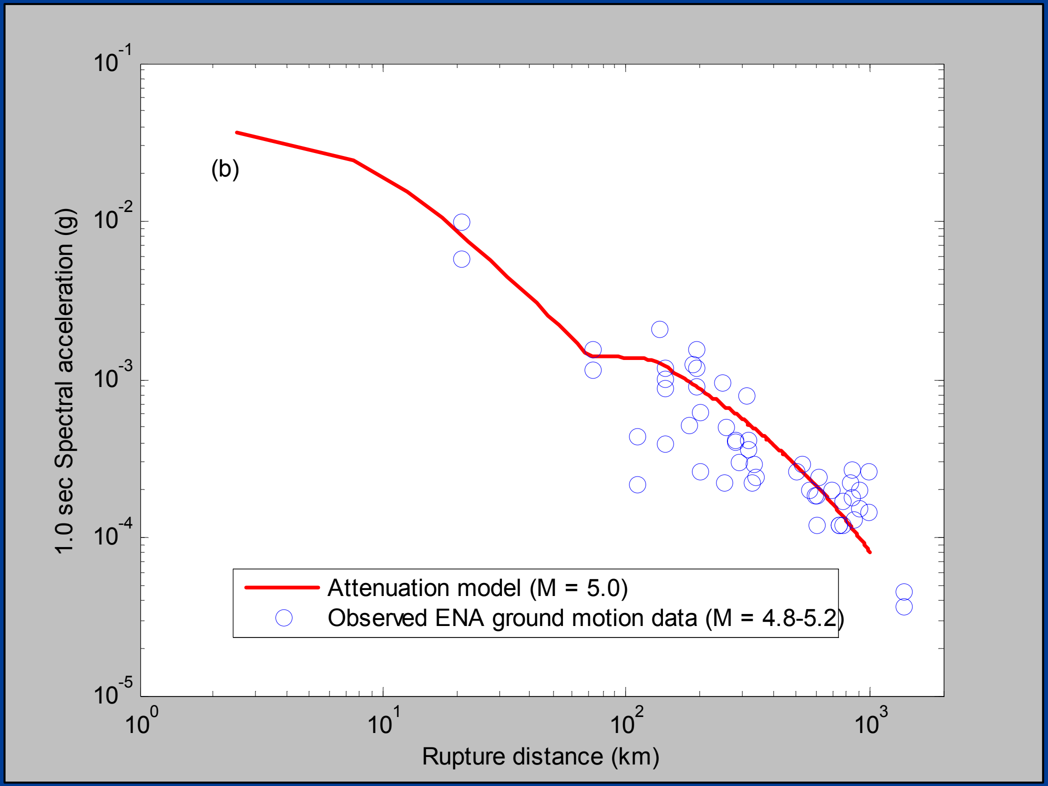


Comparison of Results with Observed Ground Motion Data for ENA



Data from Kafka and Atkinson (2005)

Comparison of Results with Observed Ground Motion Data for ENA



Conclusions

- Consider both double and single corner source spectra for WNA and ENA.
- Consider the HGA to estimate the epistemic and aleatory uncertainties.
- Consider the effects of near field saturation, focal depth, and stress drop on ground motions.
- Consider the effect of finite-faults using the finite-fault stochastic models.
- Consider the effects of rupture propagation and directivity to define finite-fault source model for near-field ground motion characteristics in ENA.