Producing Broadband Synthetic Time Histories for Central and Eastern North America

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Outline:

- **Introduction**
- **Generation of Synthetics**
  - Engineering Approaches
  - Seismological Approaches
    - ✓ Stochastic Methods
    - ✓ Kinematic methods
- **The suggested Hybrid Broad Band Approach**
- **Sample Model Mw=6.5**
- **Case Study : Application for Seismic Analysis of a Bridge in Memphis**
- **Summary**

Introduction:
Generation of Synthetic Time Histories

- A promising solution in the absence of suitable real earthquake records in terms of M, R, and site characteristics are scarce

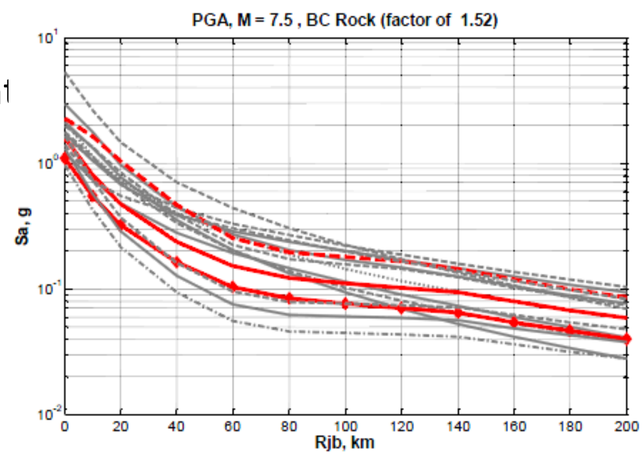
- **Applications:**

➢ **Time history analysis (Eng. viewpoint)**

- **Particular structures** (towers, power plants, dams, high tech facilities, base-isolated structures, and irregular buildings)
- **Dynamic nonlinear analysis** of structures is recommended by building codes

➢ **GMPEs (Seismological viewpoint)**

- Regions with historical seismicity while insufficient
- Complement of the available catalog



➢ **Goal:** Update GMPE **Pezeshk et al. (2011)** used by USGS

Figure is taken from Workshop on CEUS GMPEs for 2014 maps, Sanaz Rezaeian, Dec 12, 12, Berkeley, CA

Generation of Synthetic Time Histories (Cont.)

- **Synthetic Generation Approaches:**
- **Engineering:**

  More focused on the spectrum matching of generated seismograms with a target spectrum(like UHS from PSHA, etc.)
- **Seismological**
  - **Dynamic Models**

    Complicated

    Validate and simulate a scenario
  - **Kinematic Models**

    Low frequency in short distances
  - **Stochastic Methods**

    Point Source Stochastic (~SMSIM)

    Finite-Fault stochastic methods (~EXSIM)
  - **Hybrid Broadband (HBB)**

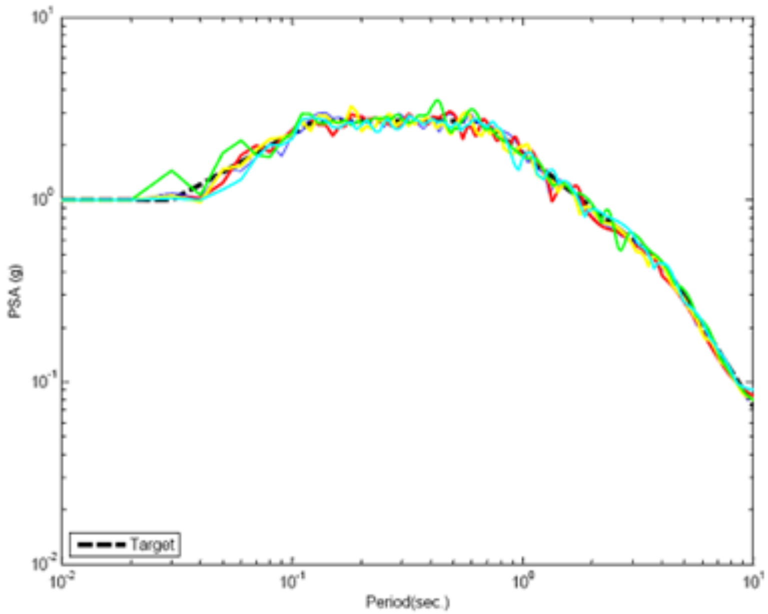
    Low Freq.: Kinematic model of EQ source & Deterministic model of wave propagation

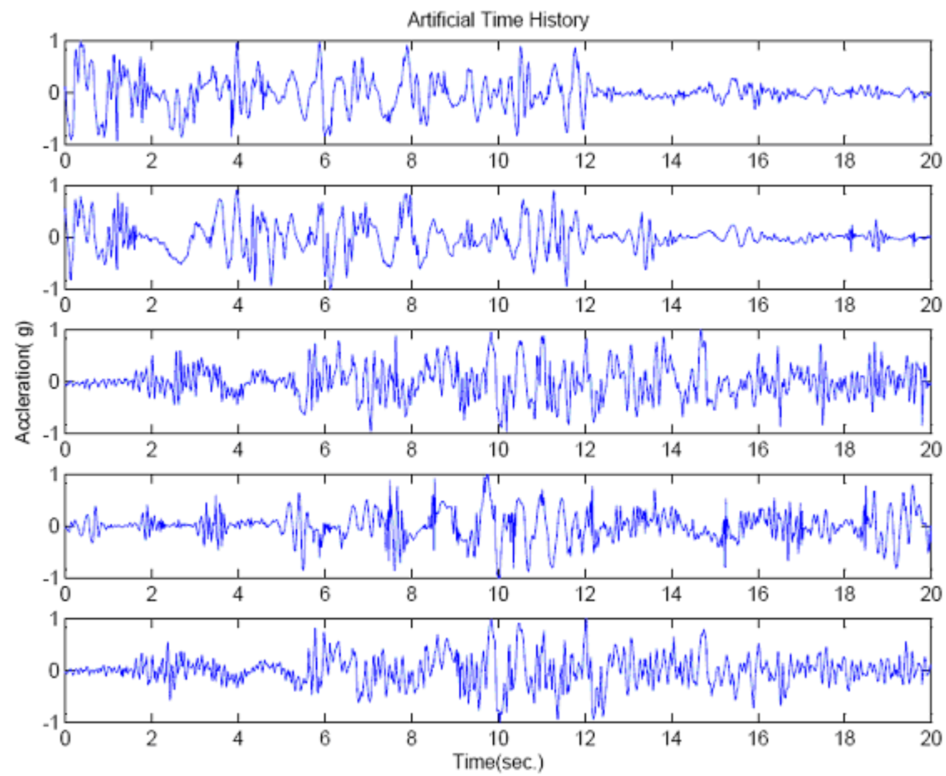
    High Freq.: Uses Stochastic Method

Engineering approach-Spectrum Matching

✓ Different techniques in time/freq. domain

Fourier/Wavelet/GA/ANN/PCA etc.





G. Ghodrati Amiri, A. **Shahjouei,** S. Saadat and M. Ajallooeian; (2011), *"Implementation of Genetic Algorithm, MLFF Neural Network, Principal Component Analysis and Wavelet Packet Transform in Generation of Compatible Seismic Ground Acceleration Time Histories,"* Journal of Earthquake Engineering (JEE); 15(1), 50-76

High freq. >> Stochastic

Low freq.>> Kinematic model of source and deterministic approach for path

❑ Part A: Stochastic Methods

3 Main parameters: **Source, Path, Site**

➢Part A-1: The source effect: $E(M_o, f)$

The most commonly used model of the earthquake source spectrum is the ώ-square model

$M_o f_0^3$=constant >> const. Stress drop ($\Delta\sigma$)

f_0=Corner freq.

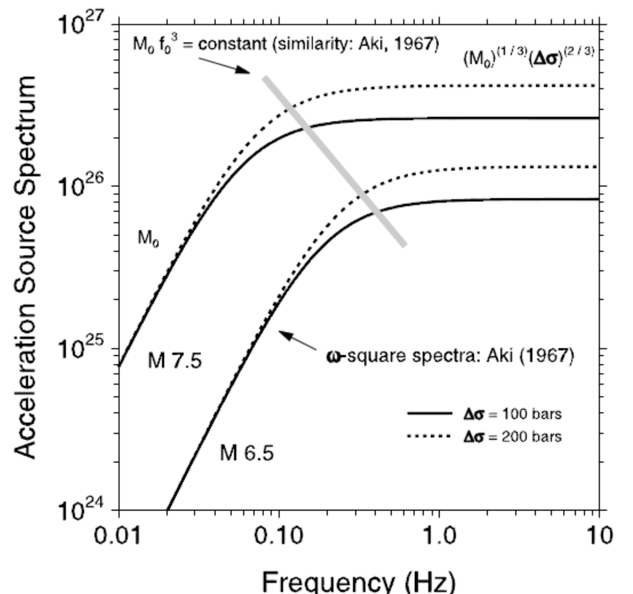
$f_0 = 4.9*10^6 \beta_s (\Delta\sigma/M_0)^{1/3}$

β_s: Shear wave velocity(km/s); $\Delta\sigma$(Bar); M_0(dyne-cm)

$F_{0:}$ Static Corner Freq., Dynamic Corner Freq., Single, Double

$E(M_0, f)=CM_0S(M_0, f)$ **>> $S(M_0, f)$: Disp. Source Spec.**

$S(M_0, f)=S_a(M_0, f)*S_b(M_0, f)$: shape of source spectral



➢ Part A-2: Path Effect, P(R, f)

$$P(R, f) = Z(R) \exp\{-\pi f R / Q(f)\, c_Q\}$$

Z(R): Geometrical spreading

Q(f): Seismic Attenuation=af^n

(Anelastic attenuation)

$$Z(R) = \begin{cases} \frac{R_0}{R} & R \le R_1 \\ Z(R_1)\left(\frac{R_1}{R}\right)^{p_1} & R_1 \le R \le R_2 \\ \vdots & \\ Z(R_n)\left(\frac{R_n}{R}\right)^{p_n} & R_n \le R \end{cases}$$

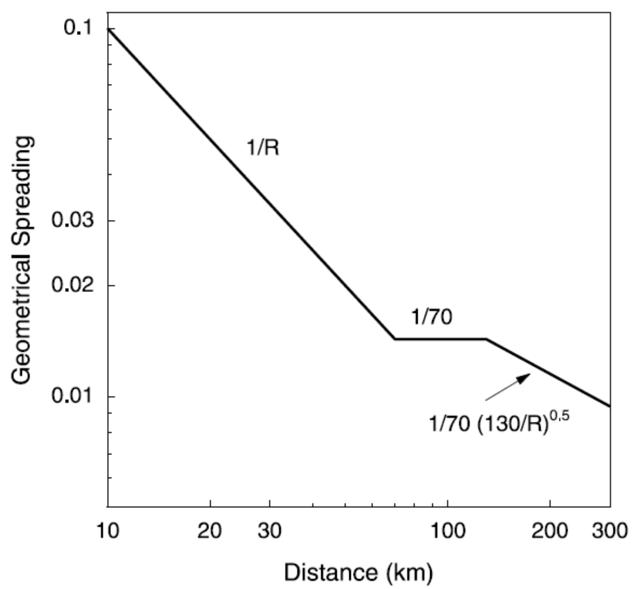
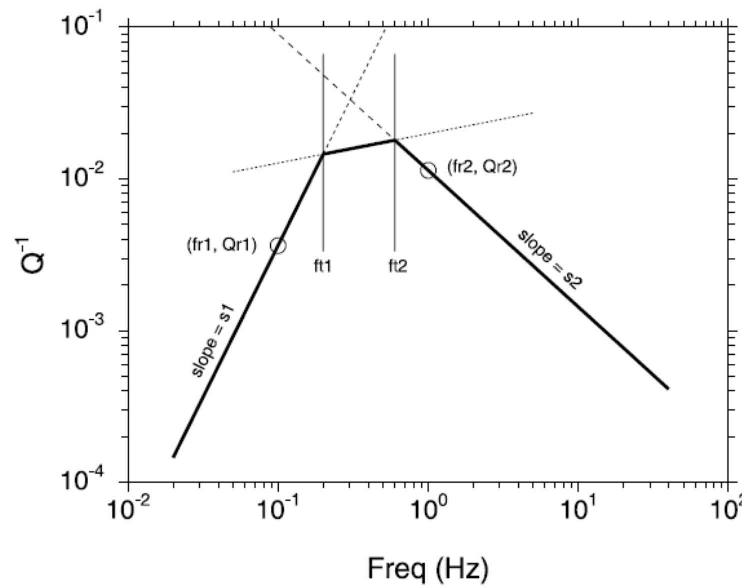


Figure 5
The geometrical spreading function used in applications in central and eastern North America by ATKINSON and BOORE (1995) and FRANKEL *et al.* (1996).



➢ Part A-3: Site Effect, *G(f)*

$$G(f)=A(f)*D(f)$$

A(f): Amplification factor > relative to source

D(f): Diminution function > path-independent loss of energy in high freq.> k_0 (kappa)

$$A(f(z)) = \sqrt{Z_s/\bar{Z}(f)} \qquad Z_s = \rho_s \beta_s$$

$$\bar{Z}(f) = \int_0^{t(z(f))} \rho(z)\beta(z)\, dt \bigg/ \int_0^{t(z(f))} dt$$

$$\bar{Z}(f) = \int_0^{z(f)} \rho(z)\, dz \bigg/ \int_0^{z(f)} \frac{1}{\beta(z)}\, dz$$

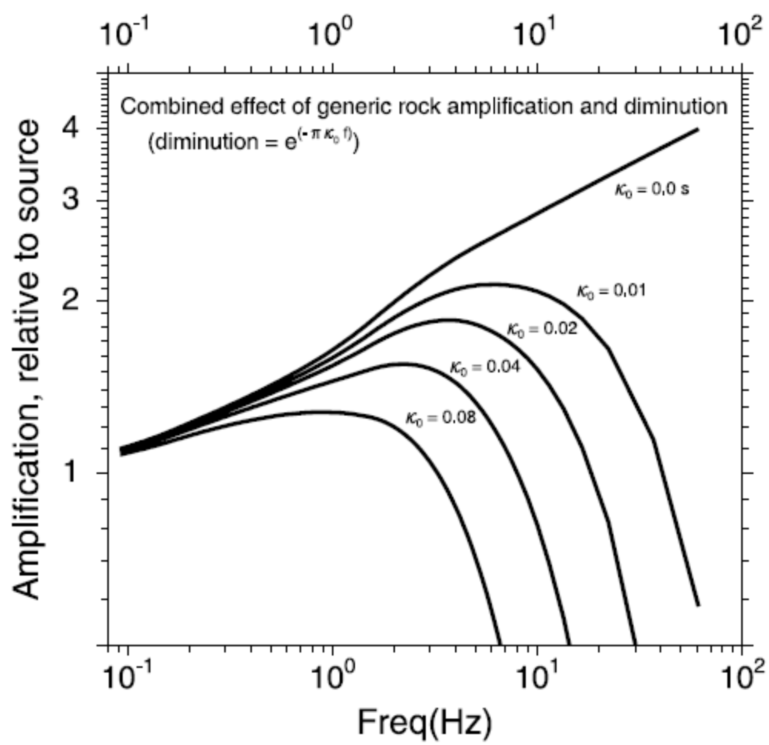
Two filters are in common use: the f_{max} filter

$$D(f) = \left[1 + (f/f_{max})^8\right]^{-1/2}$$

(Hanks, 1982; Boore, 1983), and the κ_0 filter

$$D(f) = \exp(-\pi\kappa_0 f) \ ,$$

Both Effects



Part A-4: Ground Motion Type, *I(f)*

Filtering:

$$I(f) = \frac{-Vf^2}{(f^2 - f_r^2) - 2ff_r\zeta i}$$

f_r: undamped natural freq.

ξ: damping

V: gain(for response spectra: V=1)

Low freq.>> Kinematic model of source and deterministic approach for path

❑Kinematic Models:

Need to define shaking scenarios (faulting, slip, rupture, etc.)

Engineering Application of shaking scenarios:

✓**Intensity measures:** PGA, PGV, PGD, SA

✓**Different intensity measures are required for different type of structure:**

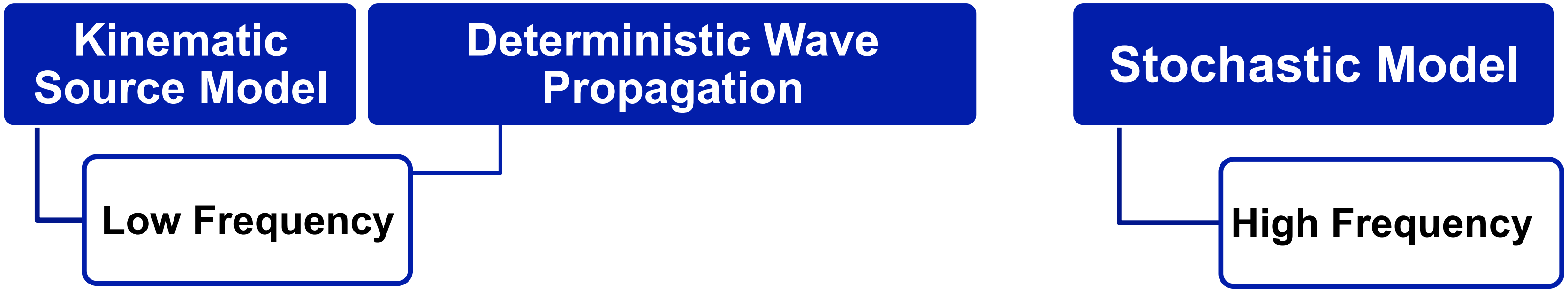
- **PGD**: related to low freq. (f<1 Hz), correlated to M & focal mechanism.>>
  long span bridges, displacement-based design approaches, and base-isolation devices.

- **PGV:** controlled by f_c and coherent low-intermediate freq. (1-3)Hz

- **PGA:** affected by high freq. that are strongly affected by small scale heterogeneities of rupture & propagation medium. >>
  buildings and tunnels

The Proposed Method

➢ **Technique: Hybrid Broadband (HBB) Synthetic Generation**



❑ Kinematic Models:

➢ **Need to define shaking scenarios (faulting, slip, rupture, etc.)**

➢ **Variability of kinematic parameters of Source (Site viabilities are excluded)**

- ✓ Rupture velocity
- ✓ Slip distribution
- ✓ Position of nucleation point (Hypocenter)
- ✓ Source-time function (STF)
- ✓ Rise time

Kinematic Source Modeling:

➢Set parameters and consider the correlations

- Estimate the rupture area based on Mw
- Calculate Average slip and slip velocity
- Distribute slip: Finite-Source Model as **Spatial Random Field Model** to characterize complexity (heterogeneities) in earthquake slip distribution >> ACF>> Asperity regions
- Define hypothetical Hypocenter
- Define the Soil layer density and wave velocities (P, S)
- Define Rupture (ratio, function etc.)
- Define Rise Rime (ration, value, function, etc.)
- Define Source Time Function (STF)

➢Consider source variability

- Uncertainties are considered in the method by applying random components

Deterministic Wave Propagation

- GFs for wave propagation <> *discrete wavenumber, finite-element method* (DWFE).
  - **Strength:**
    include complete response of the earth structure
    P, S waves and directivity in near-field are included in seismograms
  - **Weakness:** Anelastic attenuation can not be modeled

How does it work:

✓ **Calculate Green's function** in frequency, wavenumber, and depth domain. (fault geom. Independent)

✓ **Calculate traction Green's function** in frequency: traction on a defined fault surface for a set of observer location (independent of rupture model)

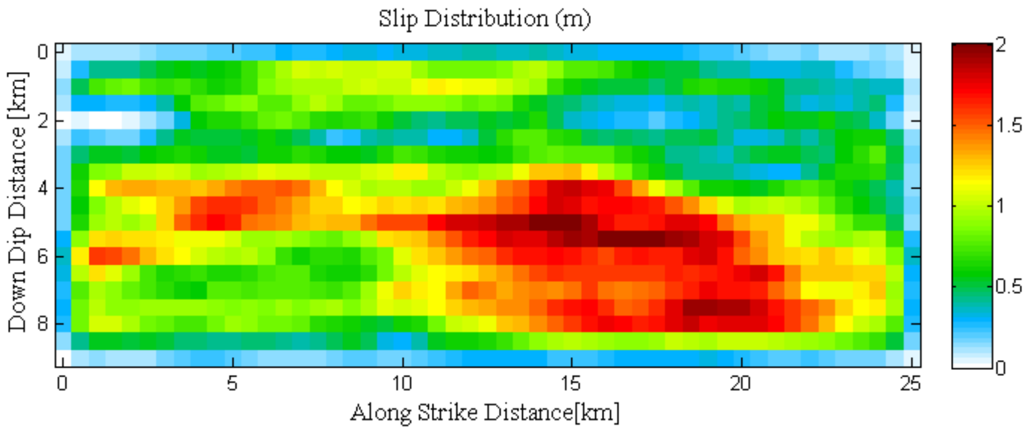
✓ **Apply representation theorem**: dot product of traction vector on a fault plane with slip & surface integral over the fault

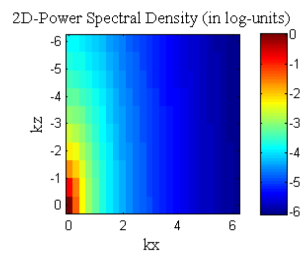
✓ **Transfer to time domain:** IFFT, and apply appropriate filter

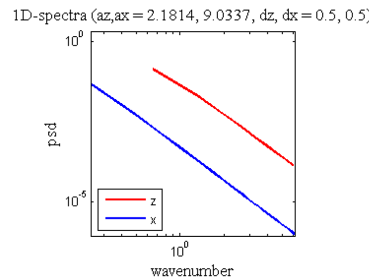
>> Long period synthetic at desired observers

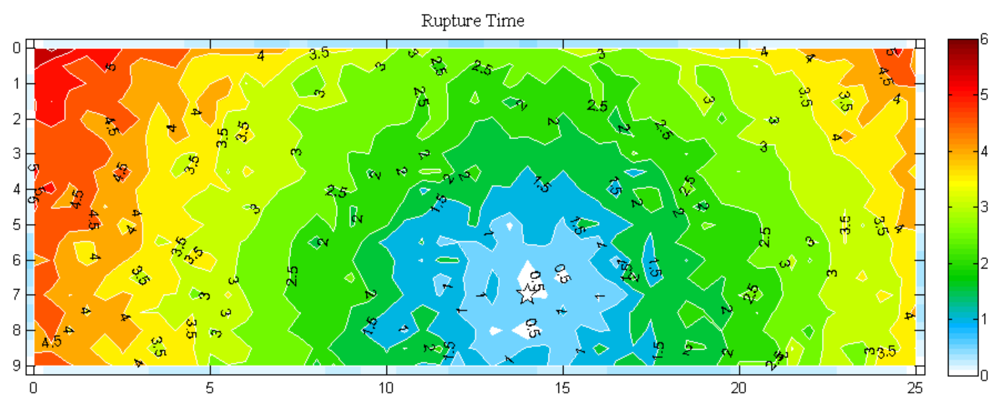
Sample Model Mw=6.5

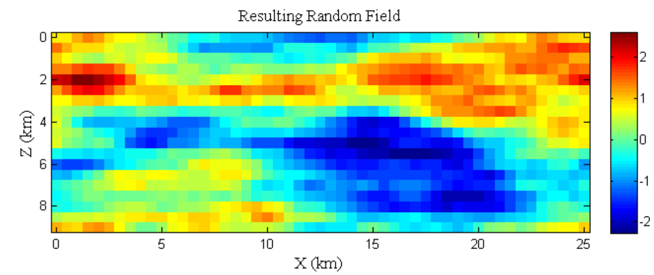
Fault Modeling









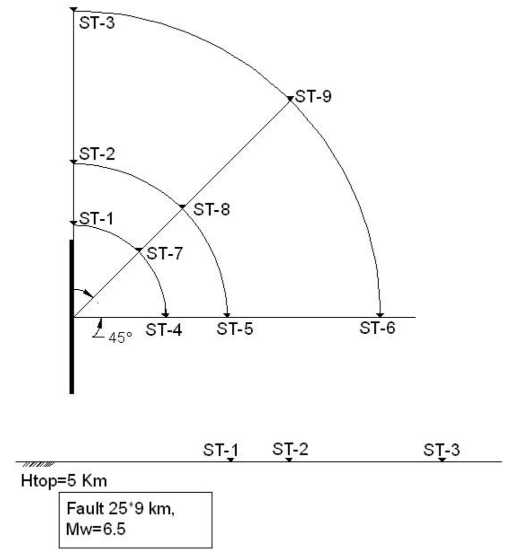


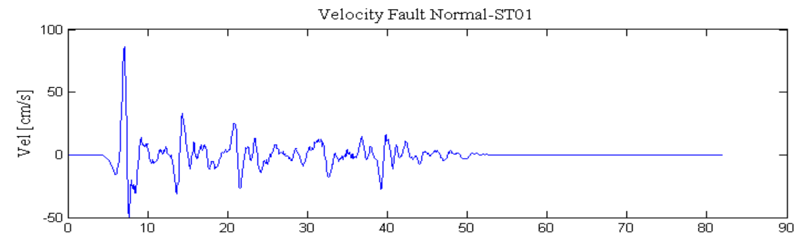
Mai, P.M., and G.C. Beroza (2002). A spatial random-field model to characterize complexity in earthquake slip, J. Geoph. Res., 107(B11), 2308, doi:10.1029/2001JB000588, 2002.

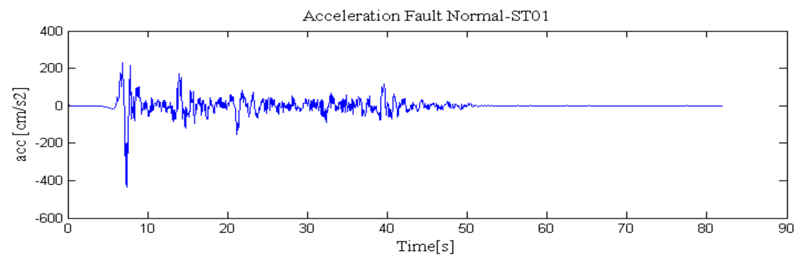
Modeling of Mw=6.5

Velocity model used in synthetic generations*

Z (km)	V_p (km/s)	V_s (km/s)	Rho (g/cm^3)
0.000	1.633	1	2.32
0.092	1.633	1	2.32
0.200	1.633	1	2.32
0.500	1.796	1.1	2.32
0.700	2.286	1.4	2.38
0.900	2.776	1.7	2.40
1.000	3.266	2	2.50
2.500	5.715	3.5	2.70
5.000	5.226	3.2	2.70
10.00	5.715	3.5	2.70

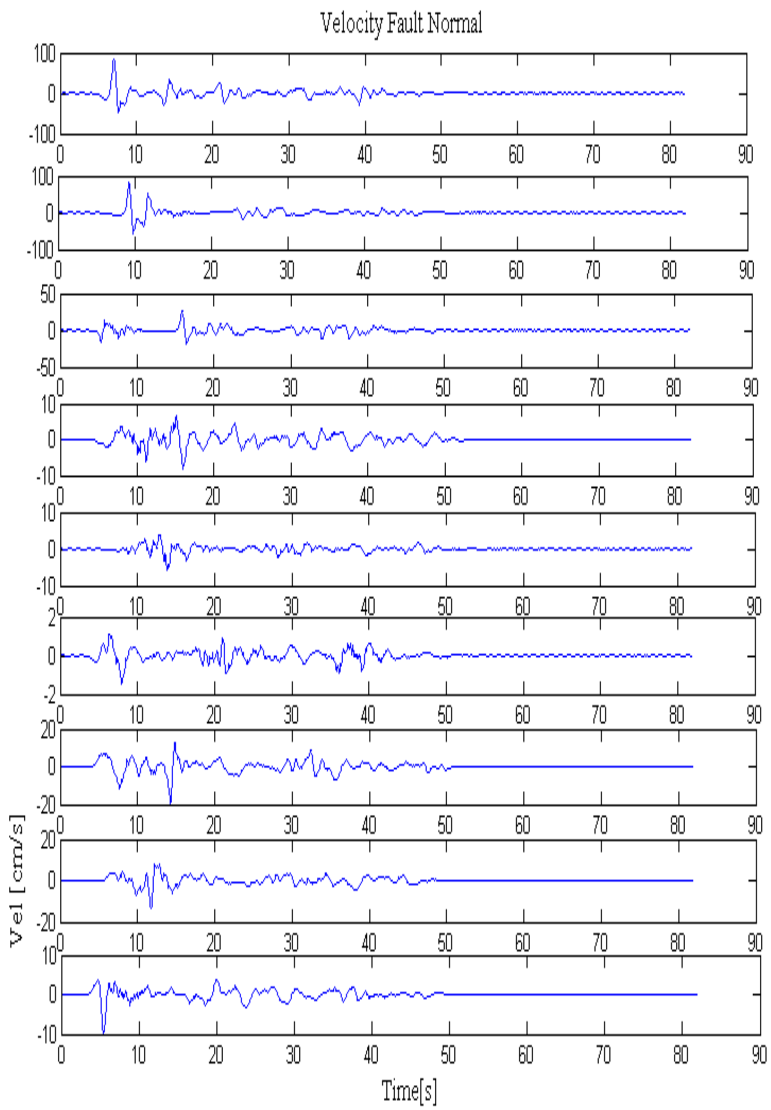


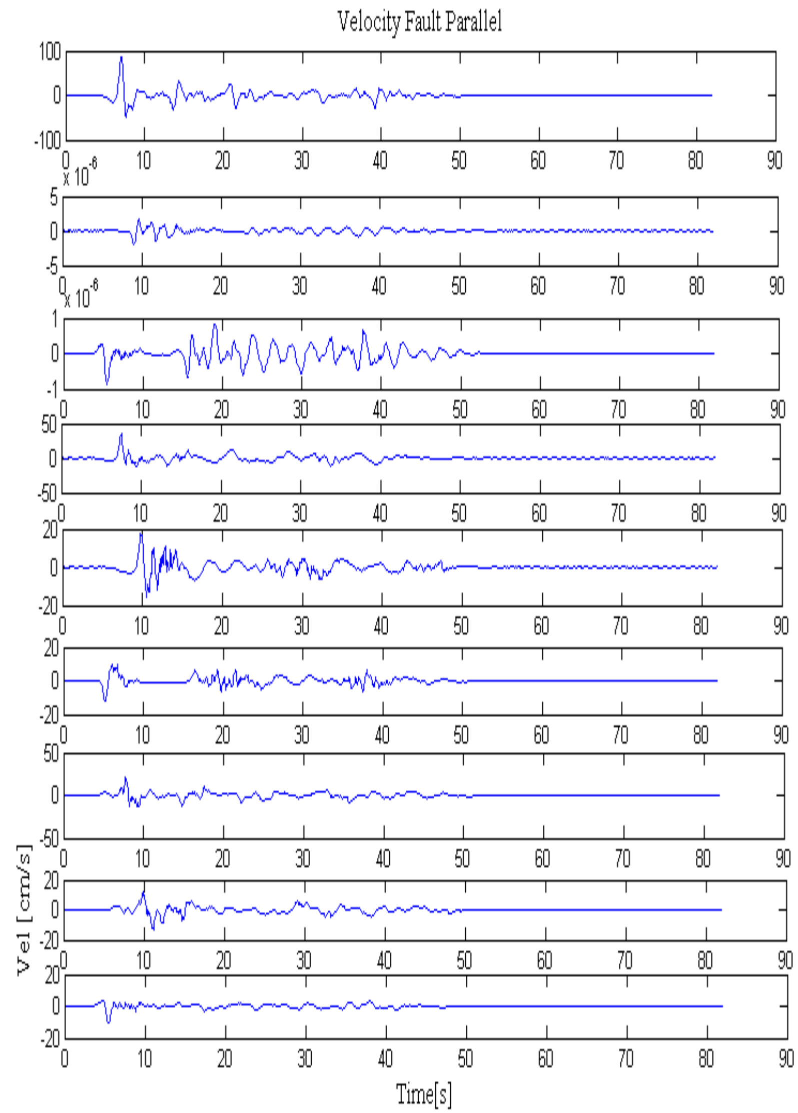




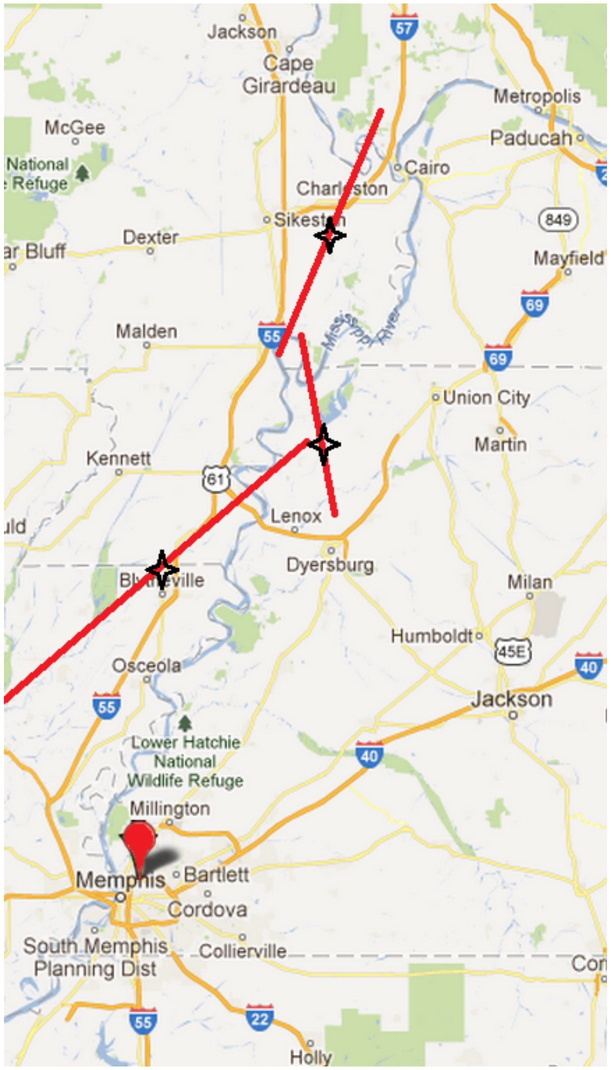
* Pezeshk, S., A. Zandieh, and B. Tavakoli. (2011). Hybrid empirical ground-motion prediction equations for eastern North America using NGA models and updated seismological parameters. , Bull. Seismol. Soc. Am 101(4), pp.1859-1870,

Velocity time histories generated for stations ST01to ST09 from top to bottom, respectively. Time origin is initiation of rupture at hypocenter.

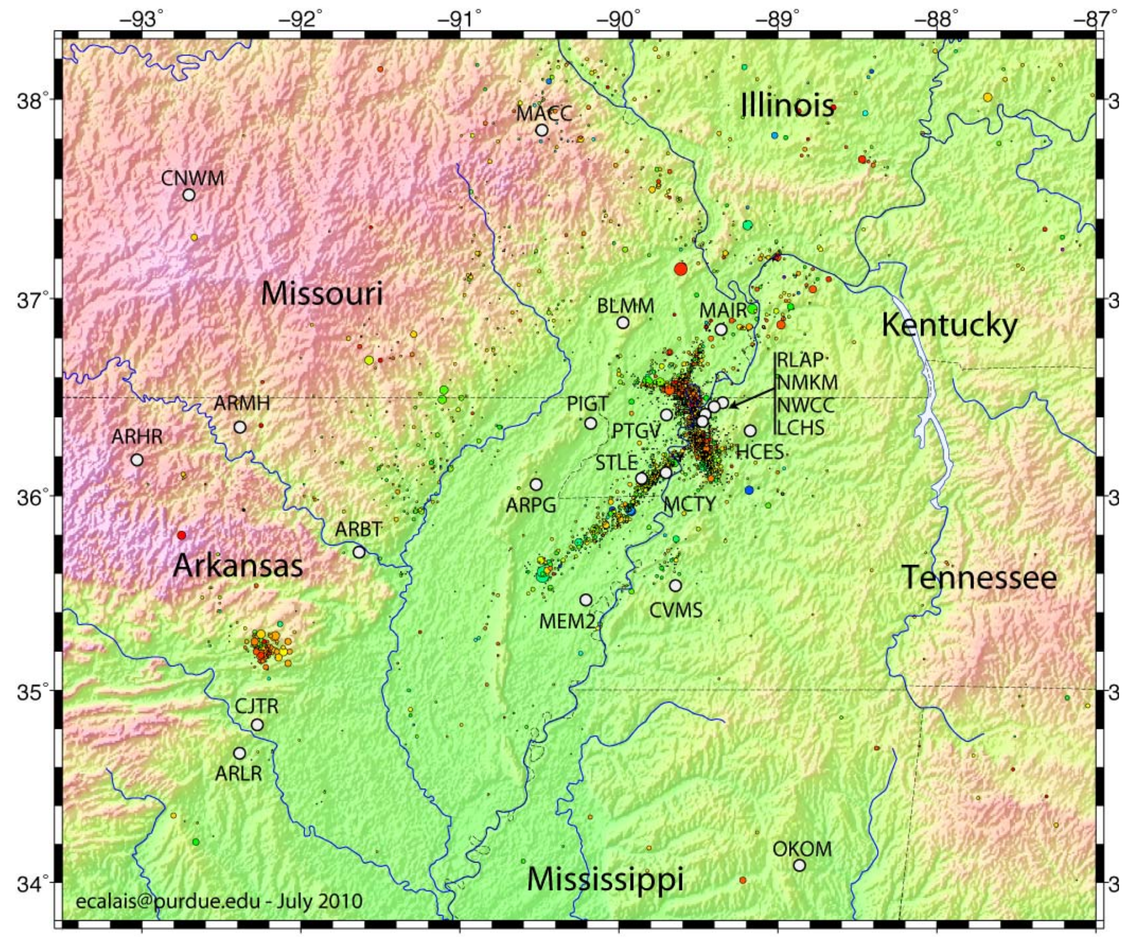




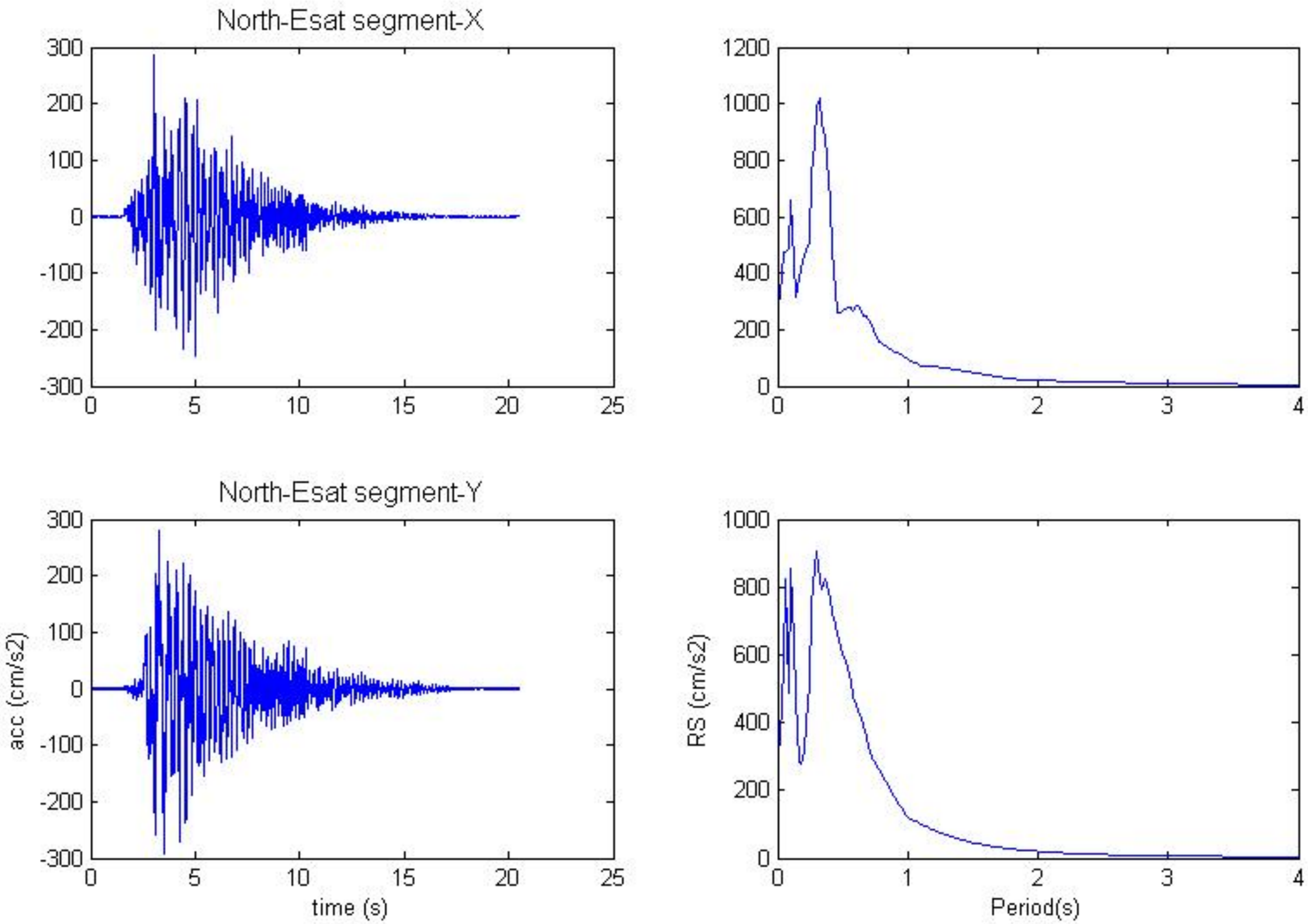
Case Study : Application for Seismic Analysis of a Bridge in Memphis



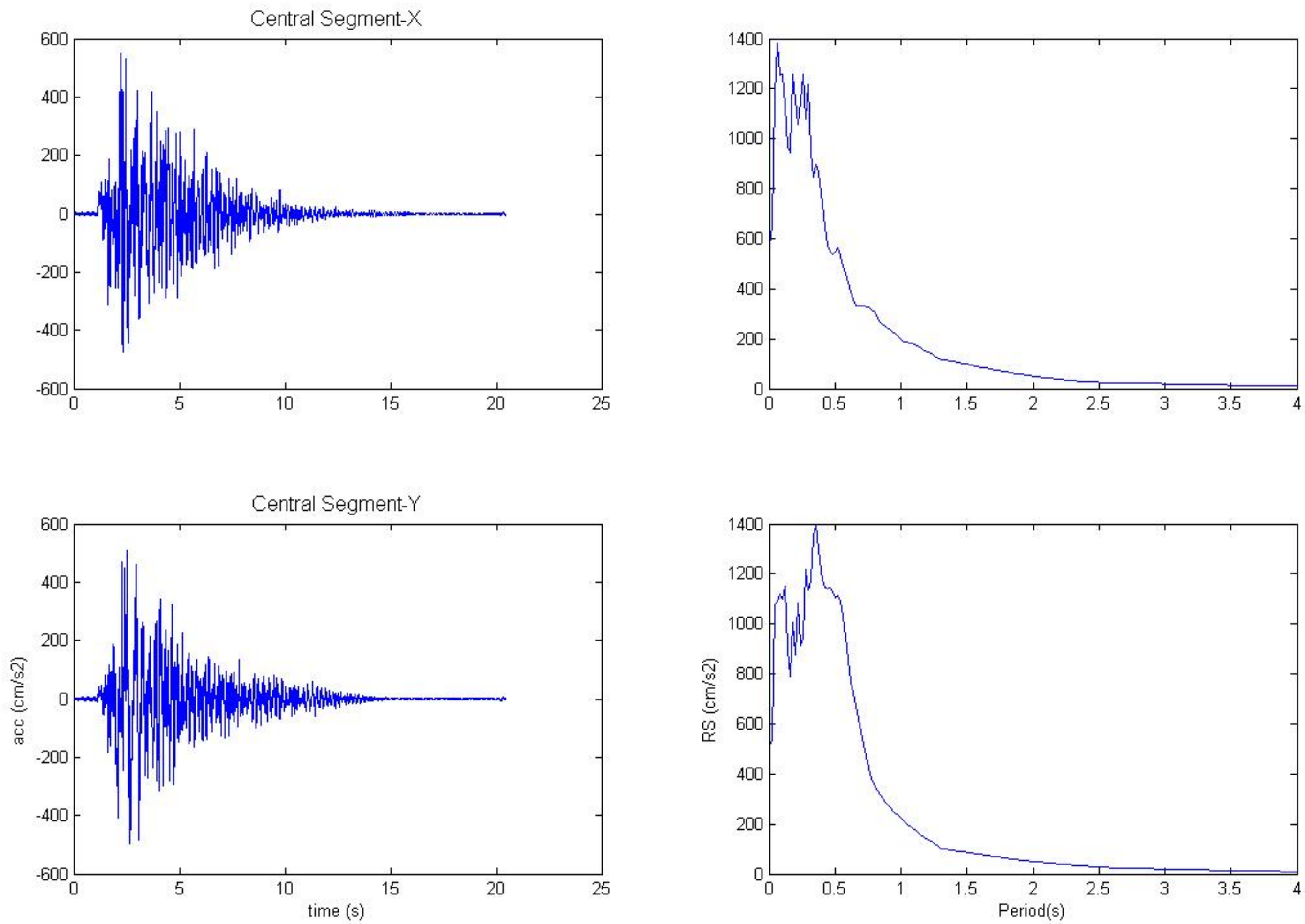
NMSZ



Synthetic from Mw=7.4 in North East part records at Memphis (~ 182 km)



Synthetic from Mw=7.4 in Central part records at Memphis (~ 145 km)



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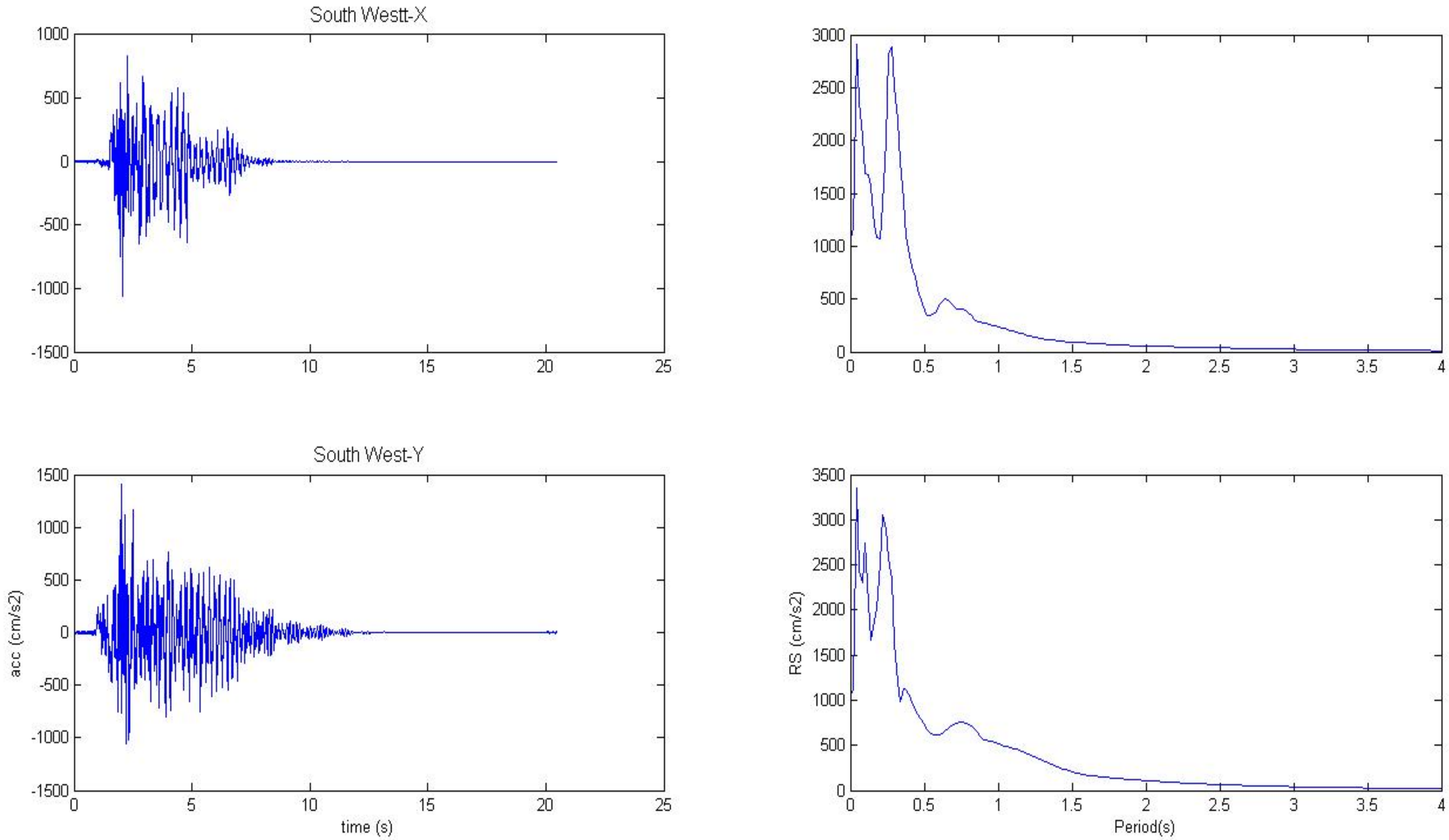
Synthetic from Mw=7.4 in South-West part
Records at Memphis (~ 90 km)



Summary:

- A HBB method is proposed for generation of seismic time histories in a broad frequency band (0-10 Hz) appropriate for the Central and Eastern North America
- Application: Time History analysis & Complement of the catalog for GMPE
- In HBB, for High Freq., we used Stochastic models and for long period we used the Kinematic model
- Wave propagations are modeled by generation Green's function
- Slip distribution on the fault rupture is calculated based on both the Von Karman auto correlation function (ACF) and fractal distribution
- We put some random components in all the processes in order to consider variability and uncertainties of the parameters
- The synthetics for magnitudes of *Mw*=5.5, 6.5 and 7.5 are generated as the complement of the available catalog
- Next step we will compare the synthetic's spectra with the NGA equations

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Thanks For Your Attention