Synthetic Near-Field Rock Motions in the New Madrid Seismic Zone

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Participants

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David Rogers, Ph.D., P.E. (geologist)
Robert Hermann, Ph.D. (seismologist)

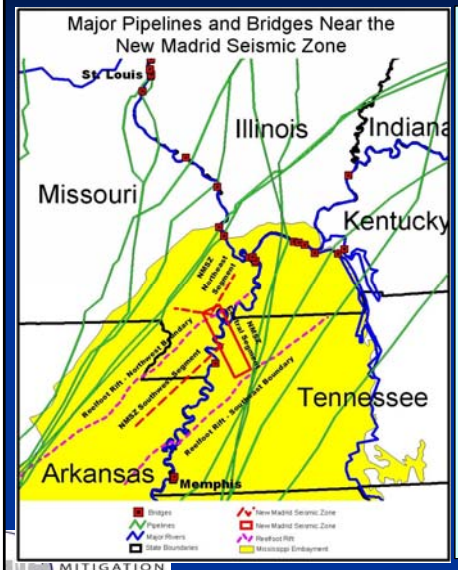
Outline of Presentation

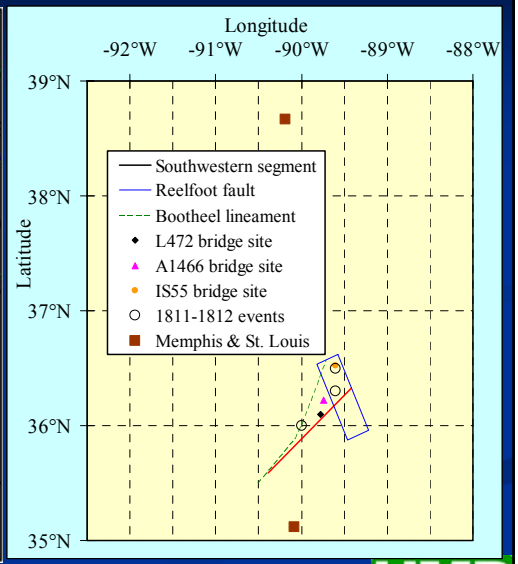
- Objectives
- Overview of Study Area
- Characteristics of Near-Field Motions
- Generation of Synthetic Near-Field Rock Motions
- Discussion of Results
- Simulated vs. AASHTO & NCHRP 12-49 Spectra
- Comparison with other Simulation Methods
- Concluding Remarks

Objectives

- To provide rock motion time histories at three bridge sites within the NMSZ for various combinations of moment magnitude and fault mechanism
- To evaluate near-field characteristics in the NMSZ
- To compare the spectra of the simulated motions with those of the AASHTO and the NCHRP 12-49 project
- To compare the results of the composite-source method with those of the finite-fault and the point-source models

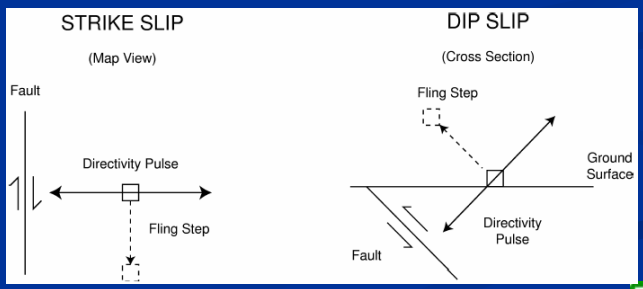
Overview of Study Area

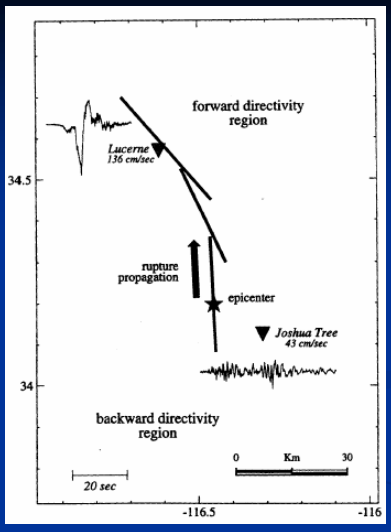




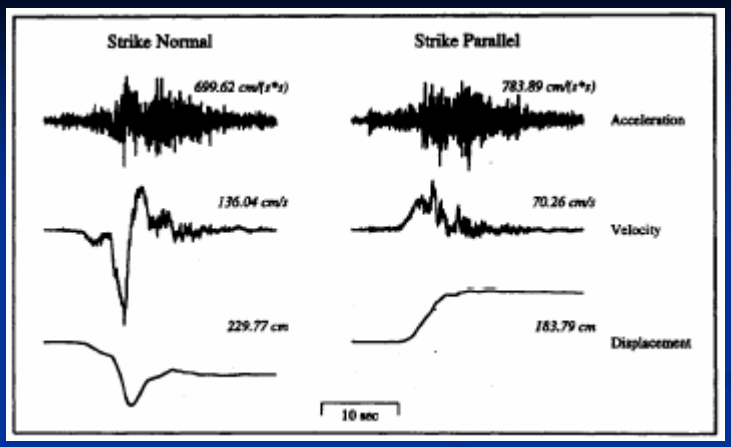
Characteristics of Near-Field Motions

- **Forward Directivity:** rupture towards the site and is characterized by a two-sided velocity pulse(s) in the fault-normal direction
- **Fling Step:** characterized by one-sided velocity pulse in the same direction as the slip on the fault





1992 Landers earthquake in Southern California (Strike-Slip Earthquake)

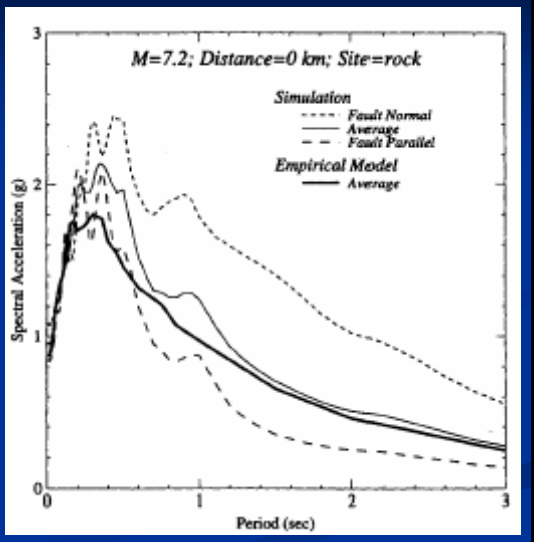


1992 Landers earthquake - Lucerne Records

Fault-normal: *double-sided velocity pulse; small permanent displacement*
Fault-parallel: *single-sided velocity pulse; large permanent displacements*

Effects of Forward Rupture Directivity

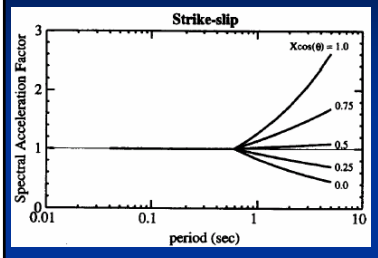
- Increase the amplitude of intermediate and long period ground motion
- Fault-normal component is larger than fault-parallel component at intermediate and long periods

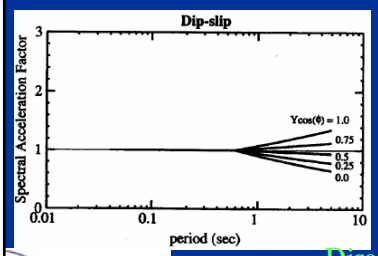


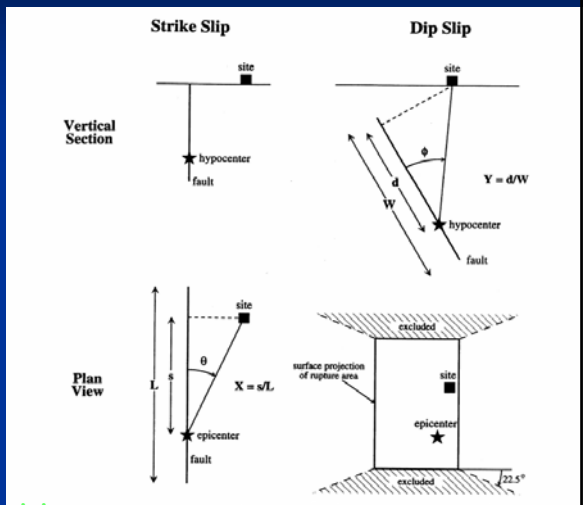
after Somerville et al. (1997)

Parameters of Forward Rupture Directivity

after Somerville et al. (1997)





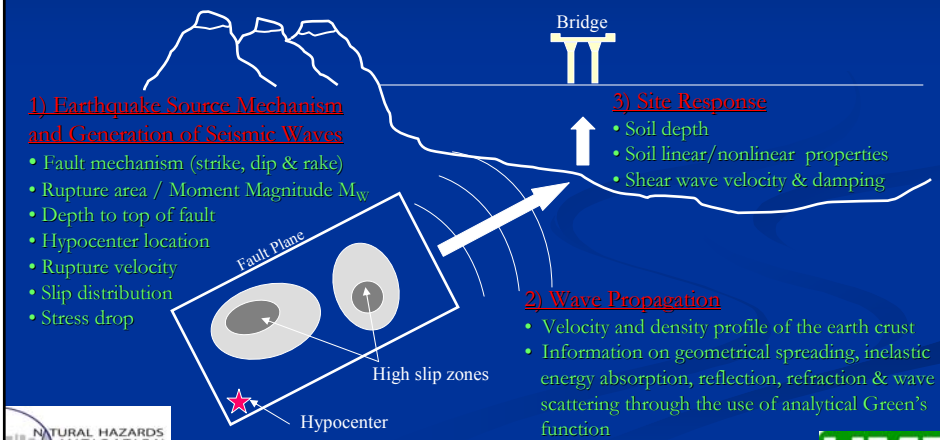


Directivity parameters: X cos θ for strike-slip faults

Y cos Φ for dip-slip faults

Generation of Synthetic Near-Field Ground Motions in the NMSZ

Earthquake Processes & Key Parameters



Seismic Source Parameters

Best-estimates & uncertainties

Rupture Area

$\log A = -3.42 + 0.90\ M_W$ $\quad\quad$ $s = 22\%\ (26\%)$

s is the standard deviation for strike-slip (reverse) faults

after Wells & Coppersmith (1994)

Fault	Best-estimate mechanism	Best-estimate rupture area
Southwestern segment (strike-slip fault)	Strike = 226.5° dip = 90° rake = 180°	L = 120 km, W = 18 km *for M_W 7.5,* L = 56 km, W = 13.6 km *for M_W 7.0,* L = 27 km, W = 10 km *for M_W 6.5*
Reelfoot fault (reverse fault)	Strike = 156.1° dip = 32° rake = 90°	L = 82 km, W = 28 km *for M_W 7.5,* L = 44 km, W = 18 km *for M_W 7.0,* L = 22 km, W = 11 km *for M_W 6.5*

Seismic Source Parameters

Best-estimates & uncertainties

Depth to top of the fault
1 km or 5 km

Rake angle of slip on fault
150, 180 or -150 °

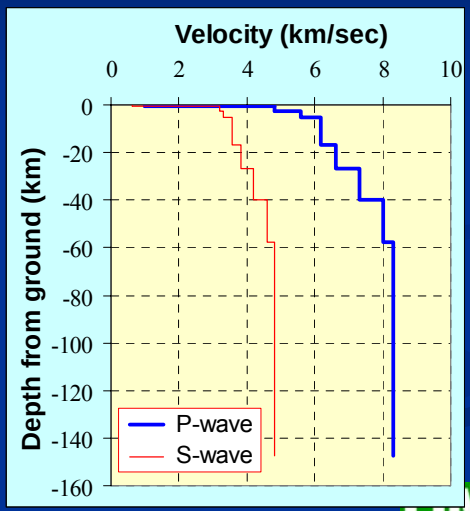
Stress drop
100, 150 or 200 bars

Rupture velocity
80% or 85% of V_S

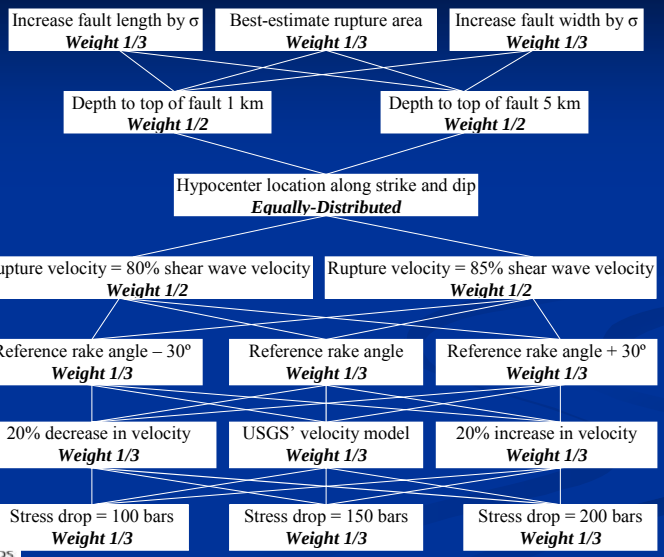
Wave Propagation Parameters

Best-estimates & uncertainties

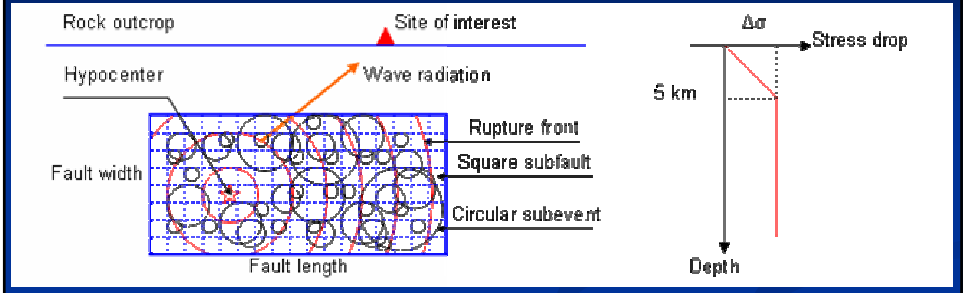
Velocity model of the earth crust
Chiu et al. (1992)
20% variation



Logic Tree of Uncertain Parameters



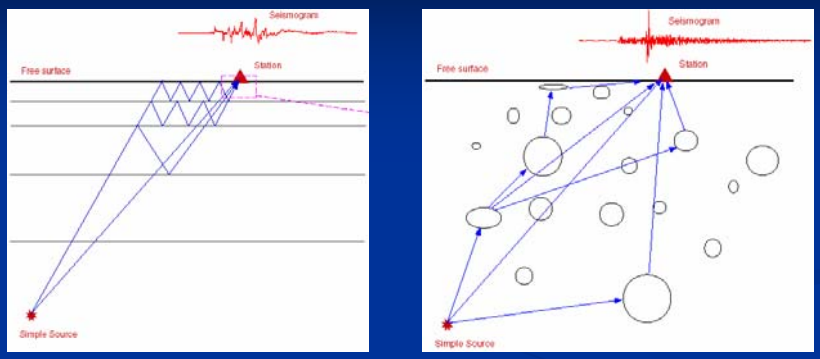
The Composite Source Model



Earthquake Source

The source of a strong earthquake is taken as a superposition of the radiation from a significant number of circular subevents with a constant stress drop. Rupture initiates at the presumed hypocenter and propagates radially at a constant rupture velocity. Each subevent is triggered when the rupture front reaches the center of the subevent. The subevent then initiates the radiation of a displacement pulse.

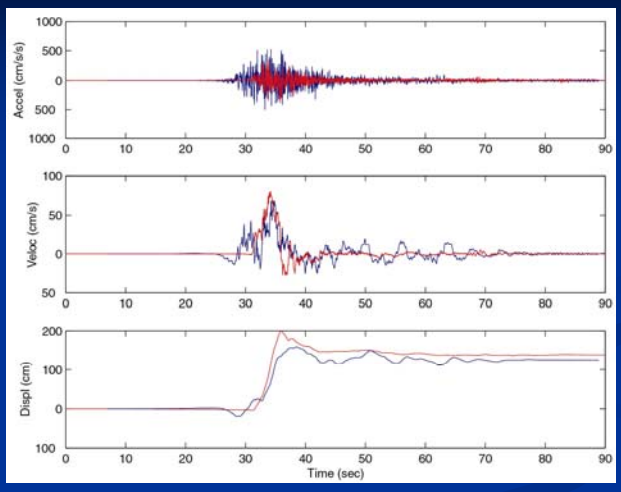
The Composite Source Model



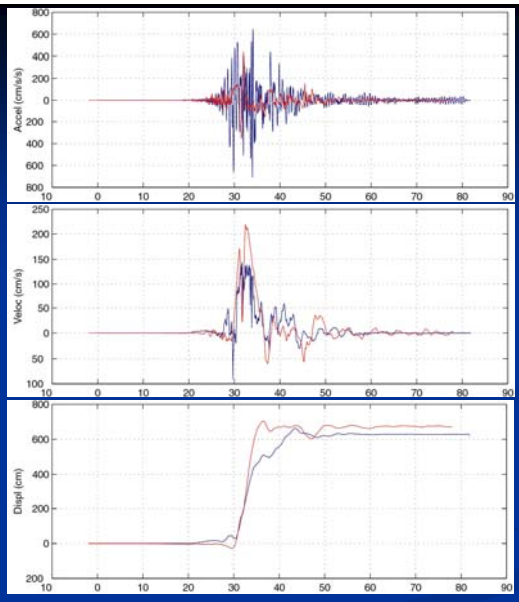
Wave Propagation & Wave Scattering

The generated displacement pulse propagates through a flat multi-layered earth crust. The wave propagation process is modeled with synthetic (analytical) Green's functions in both short- and long-period ranges. The short-period component is modified to account for the effects of random lateral heterogeneity of the earth by adding scattered waves.

The Composite Source Model Validation



Observed (red) vs. synthetic (blue) ground motions at station SKR (east horizontal component) during 1999 Kocaeli earthquake (strike-slip)

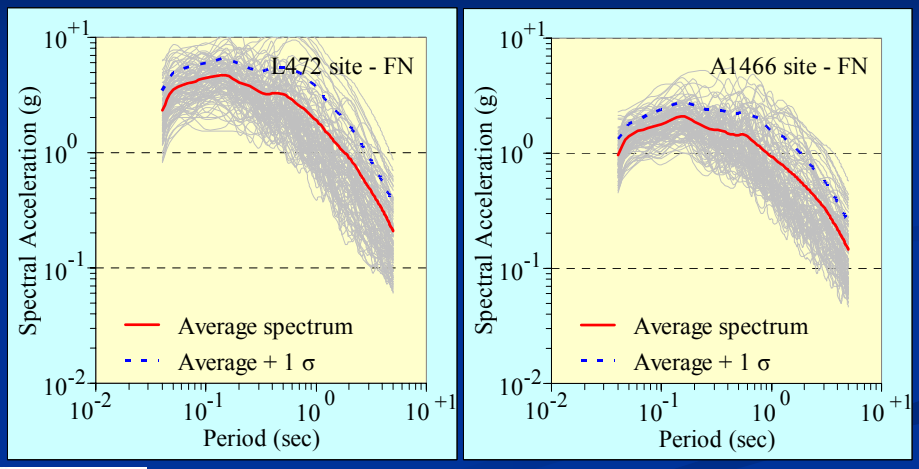


Observed (red) vs. synthetic (blue) ground motions at station T052 (NS component) during 1999 Chi-Chi earthquake (reverse)

Discussion of Results of the Maximum Considered Earthquake (MCE) or M_W 7.5

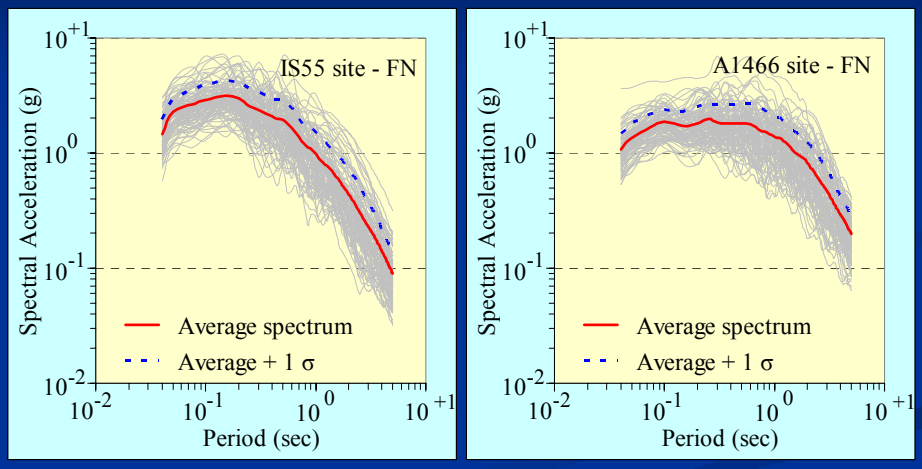
Total Uncertainty

Southwestern segment



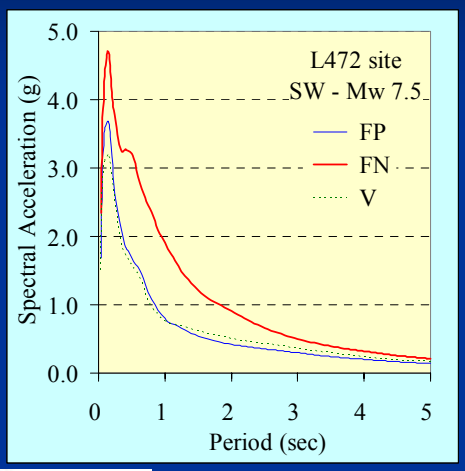
Total Uncertainty

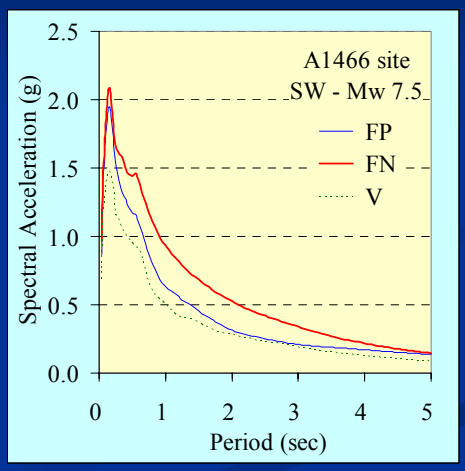
Reelfoot fault



Average Response Spectra

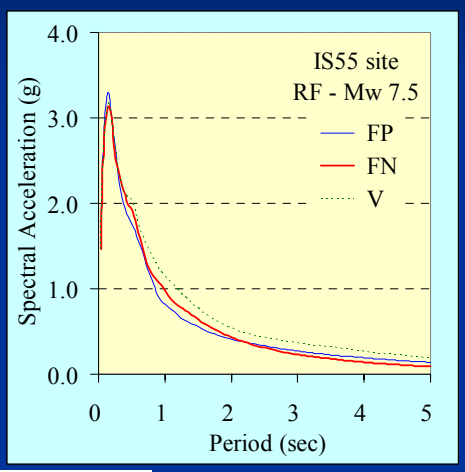
Southwestern segment

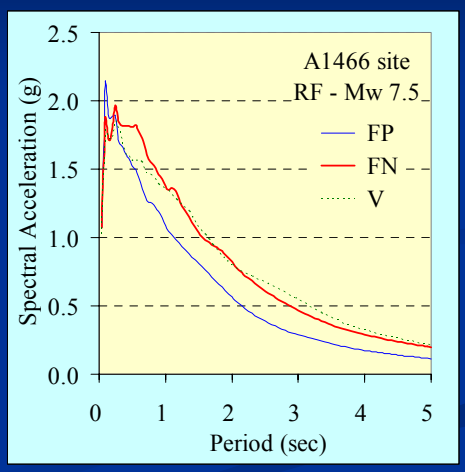




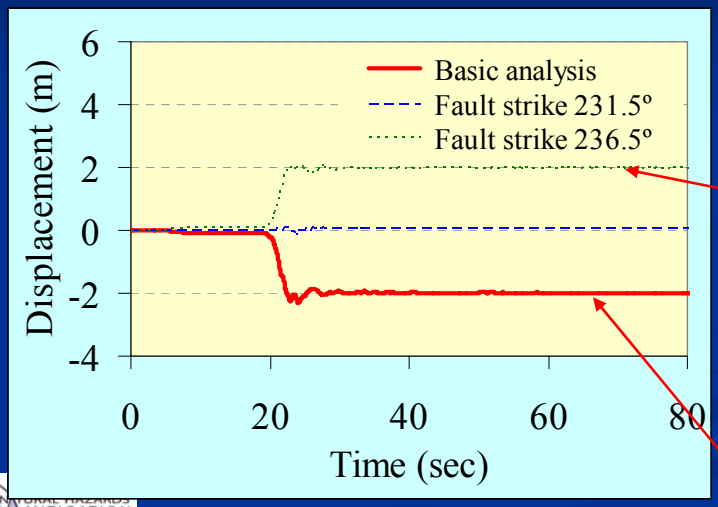
Average Response Spectra

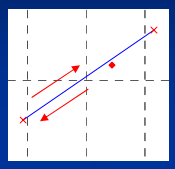
Reelfoot fault



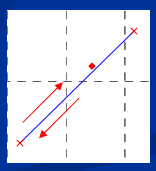


Influence of Fault Mechanism on the Fling Step at L472 site



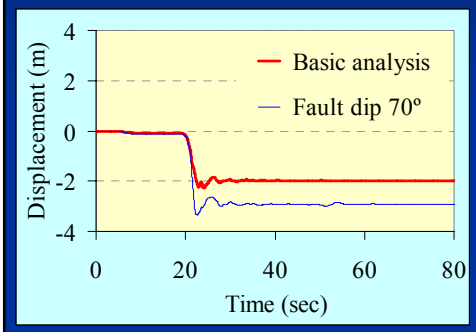


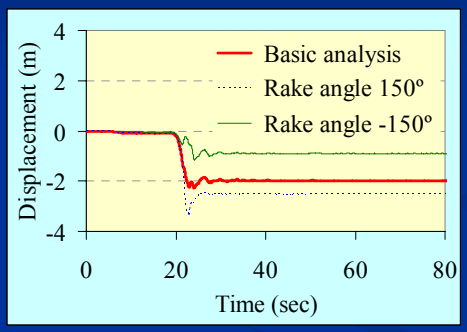
Fault strike 236.5°



Fault strike 226.5°

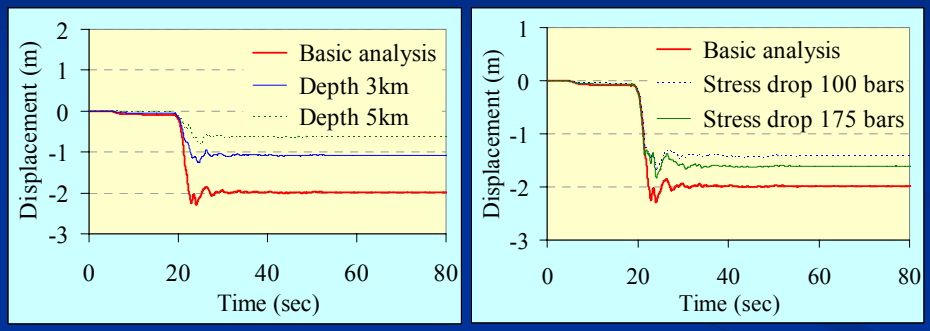
Influence of Fault Mechanism on the Fling Step at L472 site





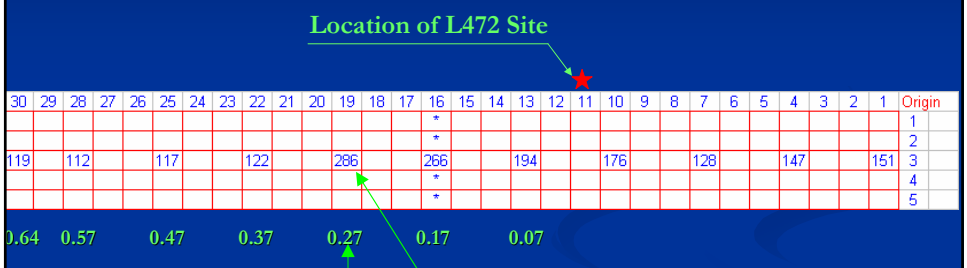
For basic analysis:
Fault dip 90°
Rake angle 180°

Influence of Depth to top of Fault and Stress Drop on the Fling Step at L472 site

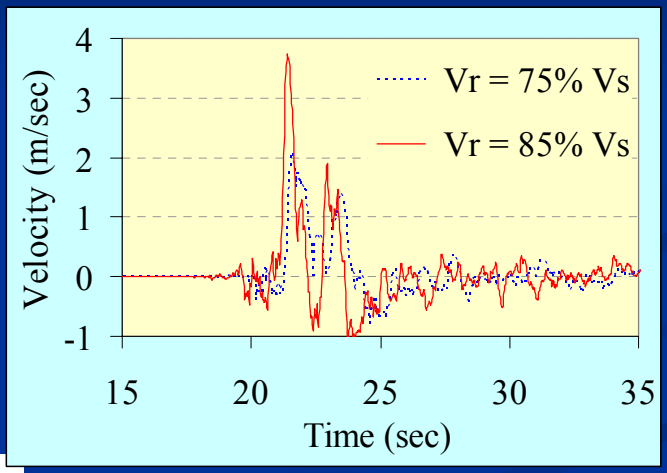


For basic analysis:
Depth 1km
Stress drop 150 bars

Influence of Hypocenter Location on Peak Rock Velocity at L472 Site



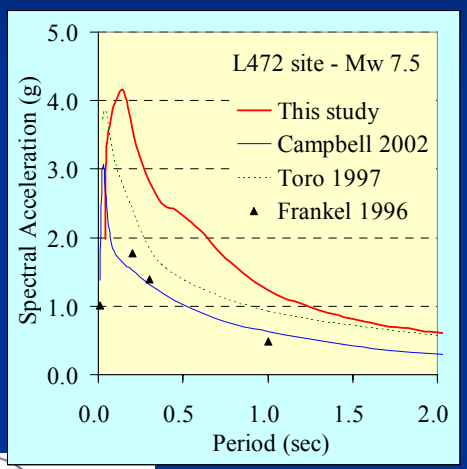
Influence of Rupture Velocity on Velocity Pulses at L472 Site

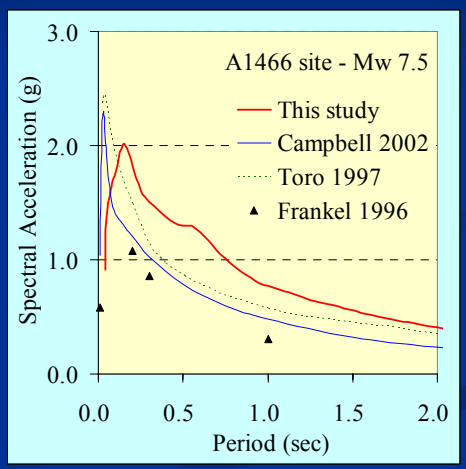


Validation of Synthetic Rock Motions

Comparison with Attenuation Relations

Southwestern segment

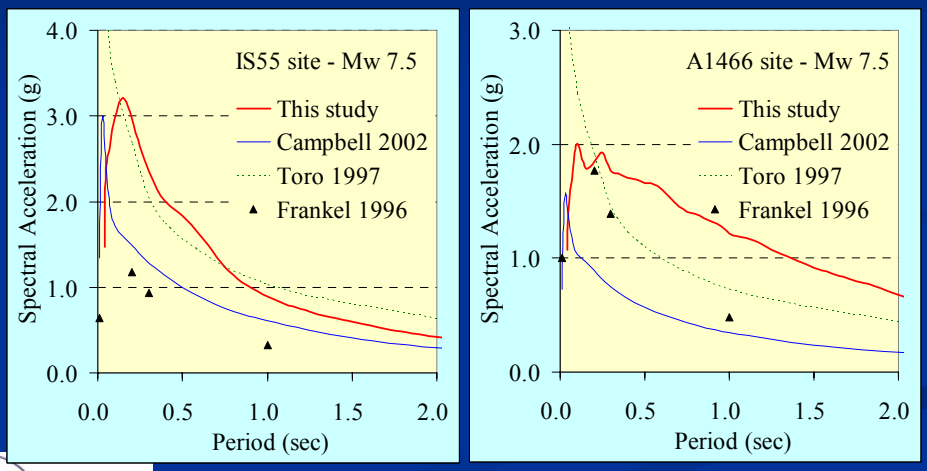




Validation of Synthetic Rock Motions

Comparison with Attenuation Relations

Reelfoot fault



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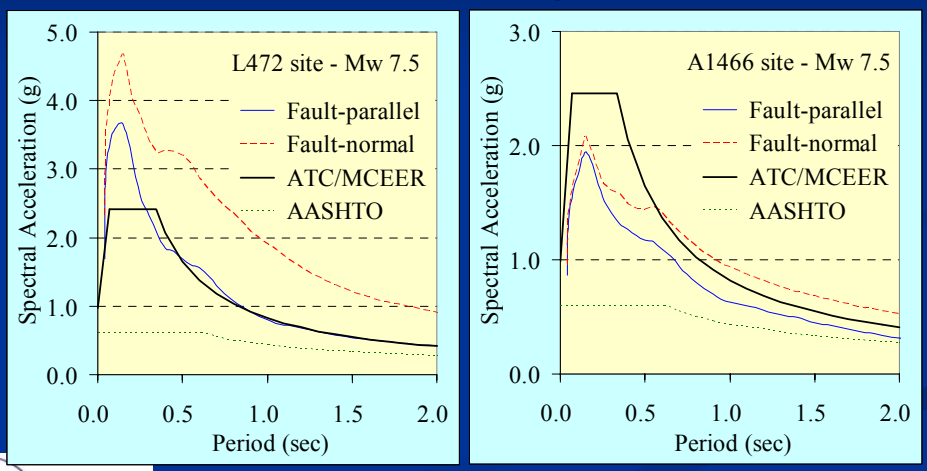
Validation of Synthetic Rock Motions

Comparison with NCHRP & AASHTO Guidelines

Southwestern segment



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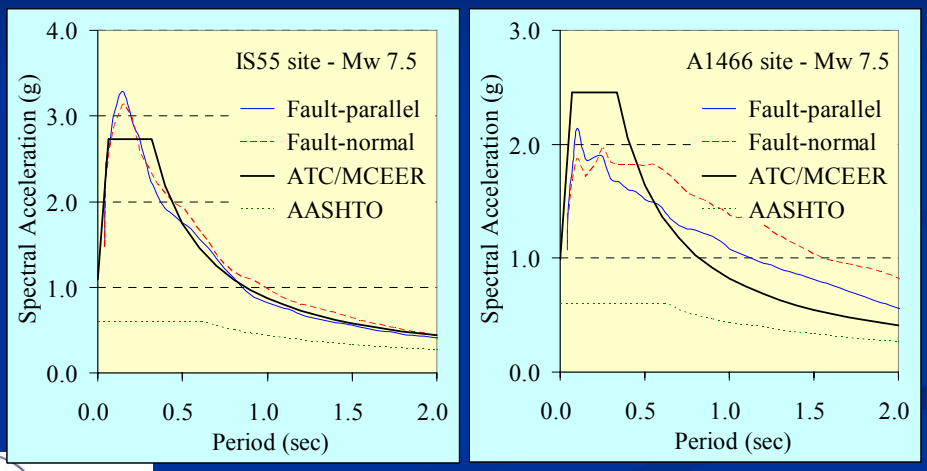

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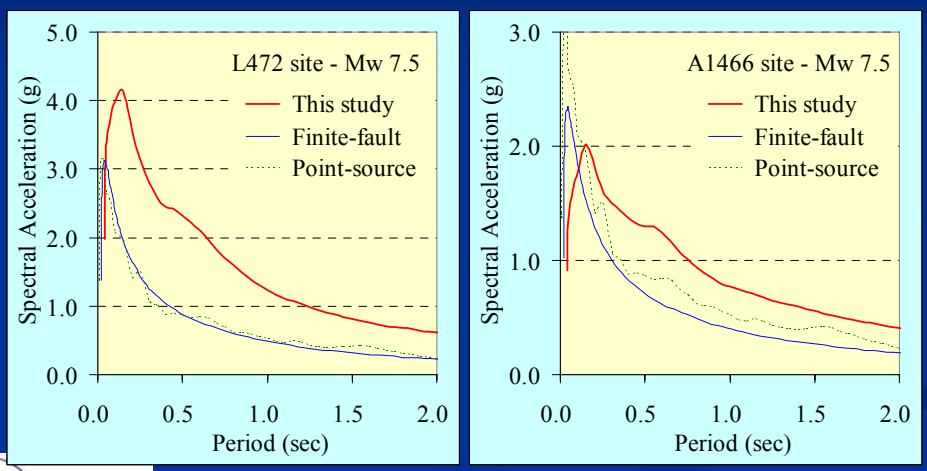
Validation of Synthetic Rock Motions

Comparison with Finite-Fault & Point-Source Models

Southwestern segment



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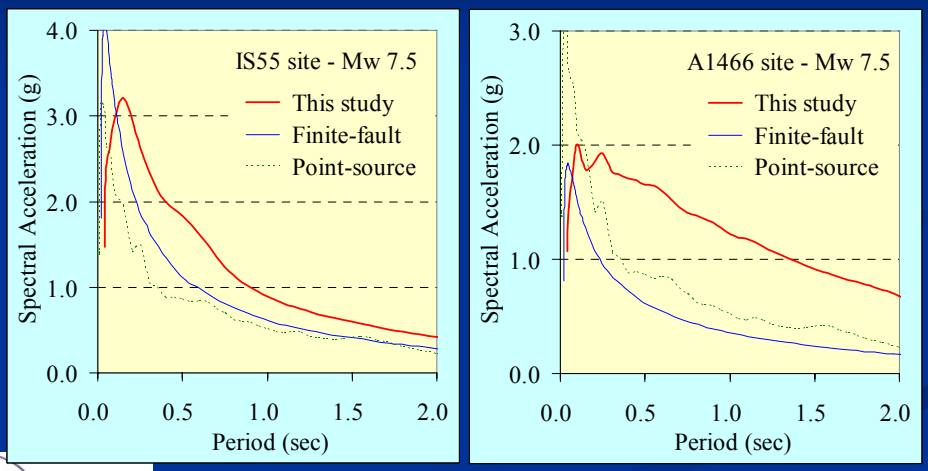


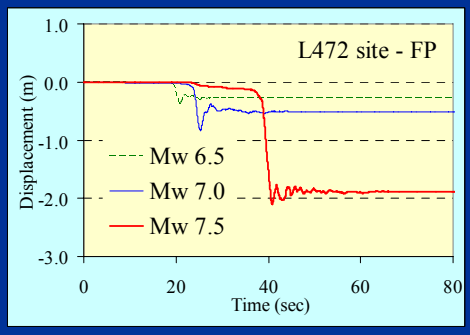
Near-Field Characteristics of the Selected Motions

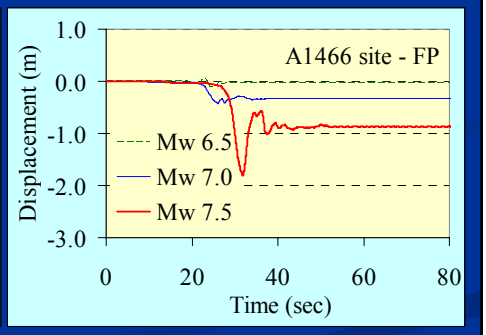
Selection criteria of rock motions

1) Fit the average response spectra
2) Fling step in the direction of the slip on the fault
3) Velocity pulse in the fault-normal direction
4) Realistic peak rock accelerations
   (within 75%-125% of Toro et al., 1997)

Near-Field Characteristics of the Selected Motions

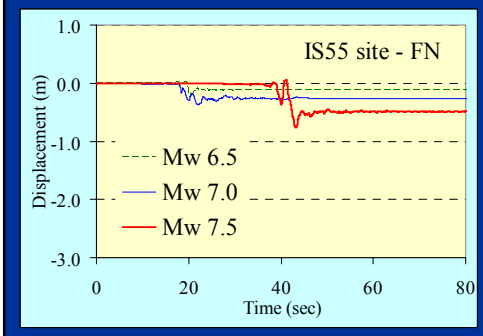
Fling step from the southwestern segment

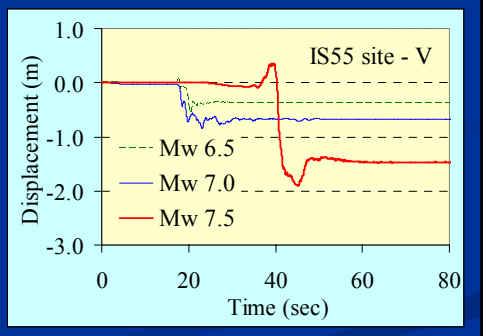




Near-Field Characteristics of the Selected Motions

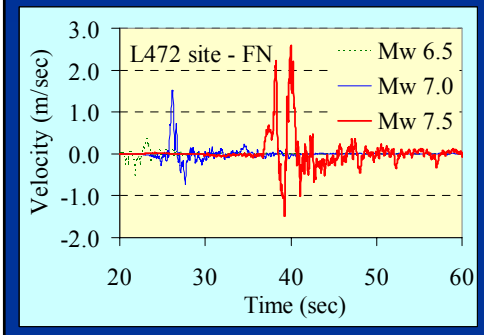
Fling step from the Reelfoot fault

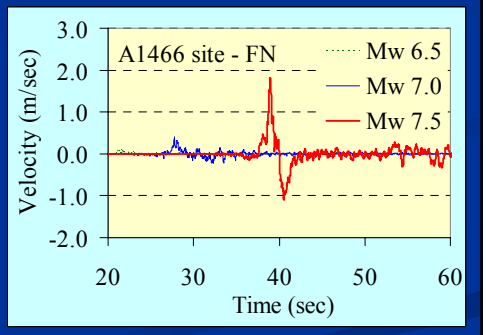




Near-Field Characteristics of the Selected Motions

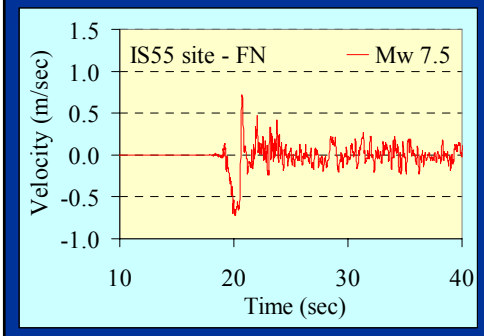
Velocity pulse from the southwestern segment

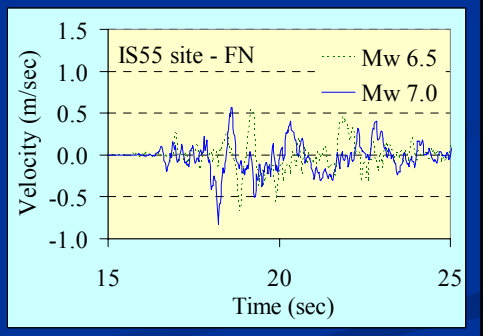




Near-Field Characteristics of the Selected Motions

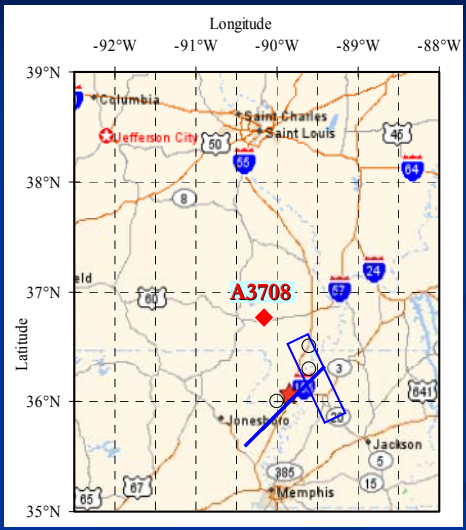
Velocity pulse from the Reelfoot fault





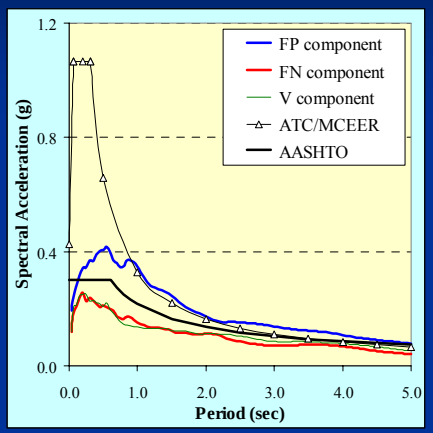
St. Francis River Site (Far-Field)

A3708 site is about 50km from the Reelfoot fault and 87km from the southwestern segment

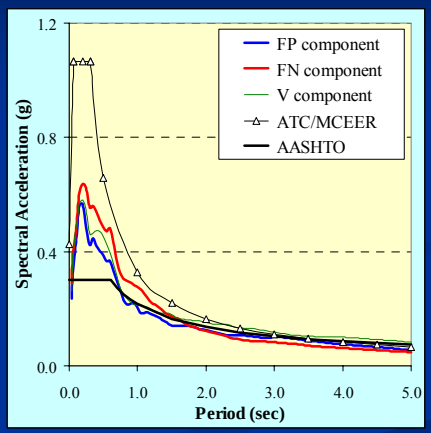


Far-Field Rock Motions

Comparison with NCHRP & AASHTO Guidelines



Southwestern segment



Reelfoot fault

Average of 20 simulations

Concluding Remarks

- The uncertainty of near-fault motions increases with moment magnitude and decreases with distance to fault
- The southwestern segment (strike-slip) contributes more to the total uncertainty than the Reelfoot fault (reverse) due to its forward rupture directivity effects
- The vertical component associated with the Reelfoot fault is stronger than that of the southwestern segment
- Fling step is dependent on the fault mechanism (strike, dip and rake), depth to top of the fault and stress drop

Concluding Remarks

- Velocity pulses are dependent on the hypocenter location along the strike and rupture velocity
- The simulated spectral accelerations are higher than those of the attenuation relations, point-source or finite-fault models due to forward rupture directivity effects, particularly for M_W 7.5 for strike-slip faults
- Velocity pulses associated with M_W 7.5 are very large as compared to M_W 7.0 or 6.5 that may impose special seismic demands for structures very close to active faults

Concluding Remarks

- In comparison with ATC/MCEER spectra, the near-field motions in the proximity of the faults (<5 km) are generally higher, and those around 10km are similar in long period components but smaller in short period components.
- The far-field rock motion is on the average less than what ATC/MCEER specified in their recommended guidelines.