New Findings Regarding the Seismic Threat Posed by the New Madrid, South Central Illinois and Wabash Valley Fault Zones on Structures in the St. Louis Metro Area

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and

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OVERVIEW

- Preliminary site response evaluation of two highway bridges spanning the Missouri River, west of St. Louis.
- Three seismic source zones were considered: New Madrid Seismic Zone (NMSZ), Wabash Valley Seismic Zone (WVSZ) and South-Central Illinois Seismic Zone (SCI).
- The latest probabilistic assessment predicts a Magnitude 6.0 earthquake has a 25 to 40% chance of occurrence in the next 50 years.
- These screening analyses focused on the likely effects and ground motions for earthquakes of Magnitude 6.0, 6.3, 6.5 and 6.8; not on the M 7 to 7.8 events of 1811-12.

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TECHNICAL APPROACH

- Artificial time histories obtained using SMSIM code of Boore (2001) for input of baserock motions.
- Seismic wave propagation through surficial materials accomplished using the program DEEPSOIL v. 2.5 [Park and Hashash, 2003].
- Products: 1) Peak Horizontal Ground Acceleration; 2) Response Spectrum, and

  3) Spectral Amplification
- Liquefaction Screening the two part qualitative and quantitative analysis recommended by Youd et al., 2001.

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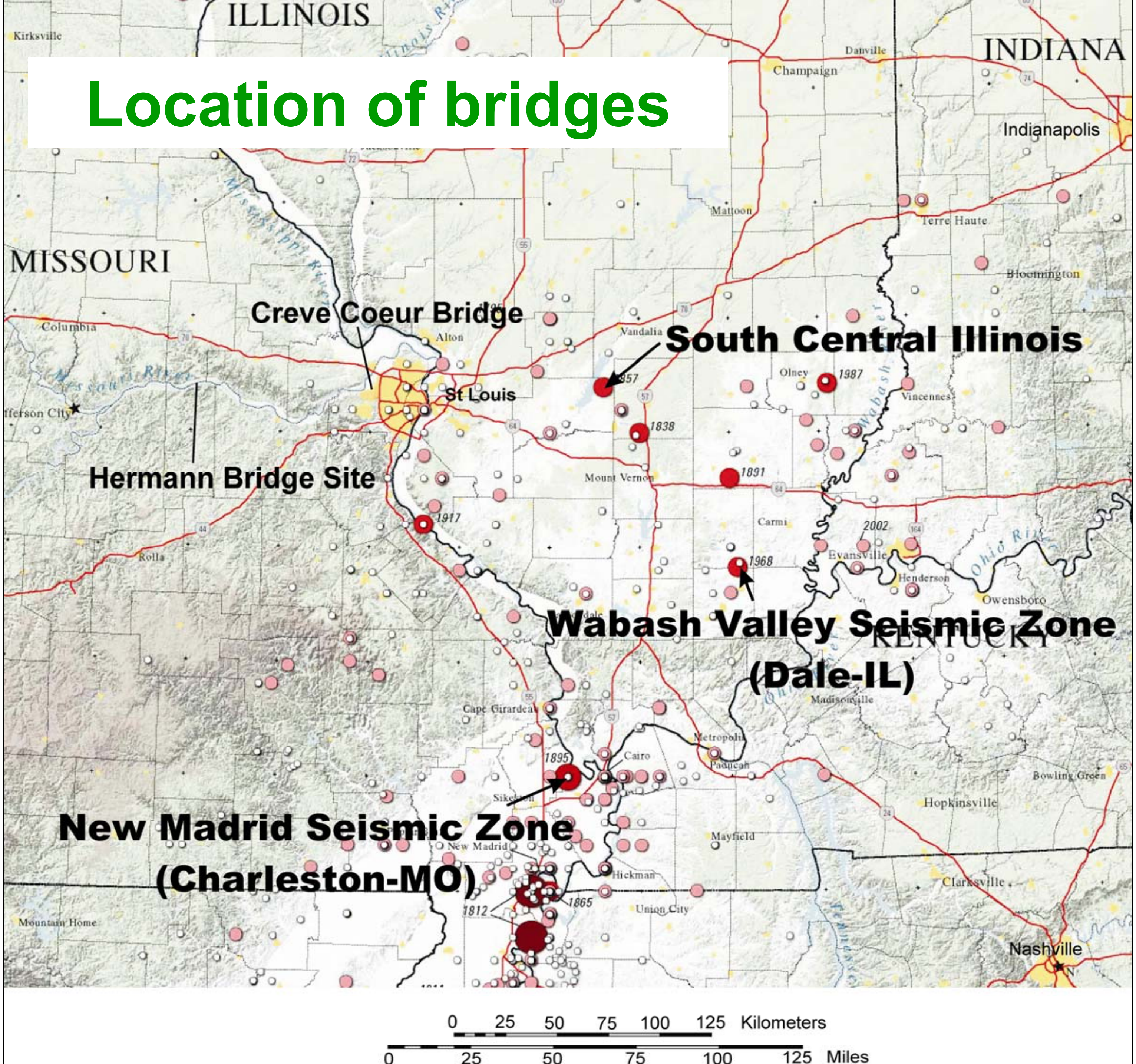
Location of bridges



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Assumed earthquake source distances

	Creve Coeur Bridge	Hermann Bridge Site
South Central Illinois	110 km	195 km
Wabash Valley Seismic Zone	195 km	275 km
New Madrid Seismic Zone	210 km	260 km

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Creve Coeur Bridge-Page Extension

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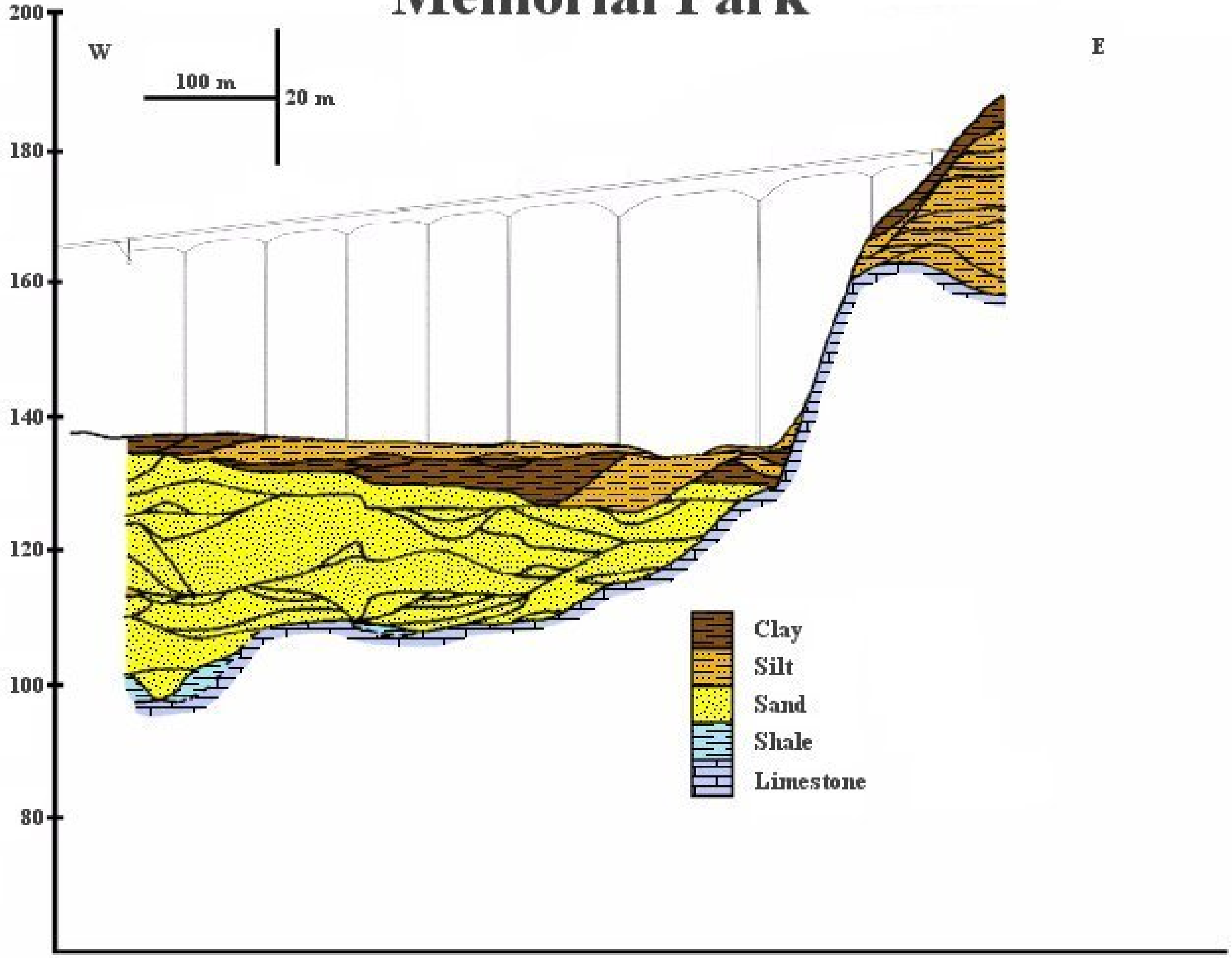
Page Extension, Creve Coeur Lake Memorial Park

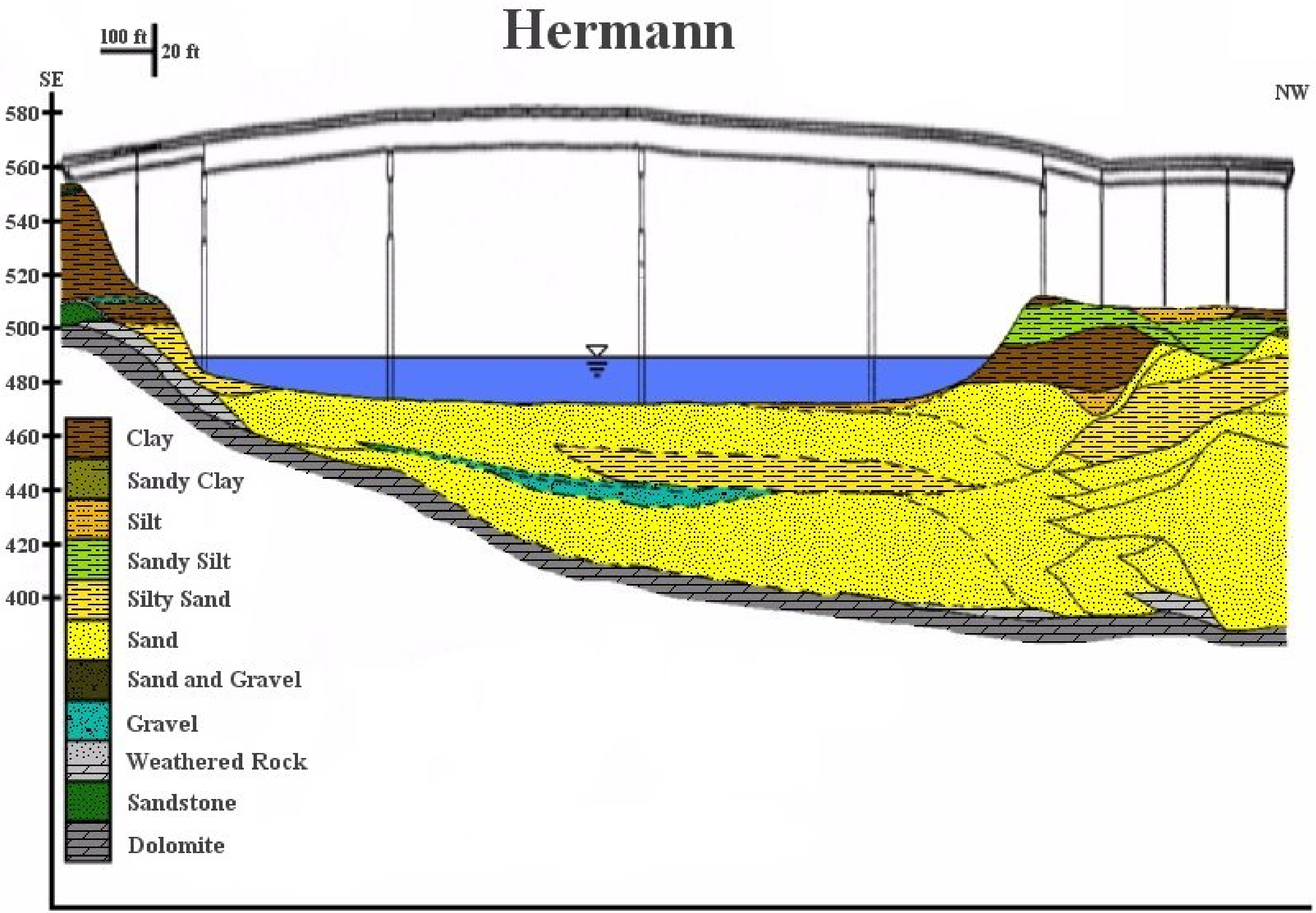


Creve Coeur Bridge-Page Extension

Hermann Bridge

Proposed replacement bridge

Original bridge



Main channel hugs the south bank, against the cliffs

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Generation of Artificial Time Histories

- **Artificial time histories were generated using SMSIM code developed by David M. Boore, USGS, and modified by Robert B. Herrmann, Saint Louis University, for deep soil sites in the Midwest.** http://www.eas.slu.edu/People/RBHerrmann/MAEC/maecgnd.html

Model	Name	Site Effect
1	Atkinson-Boore 1995 (AB95)	ENA Hard Rock
2	USGS 1996	Generic B-C Boundary
3	USGS 1996 (modified)	Mid-Continent Deep Soil (new)
4	Mid-America Deep Soil AB95 source (modified)	Mid-Continent Deep Soil (new)
5	Mid-America Deep Soil USGS96 source (modified)	Mid-Continent Deep Soil (new)

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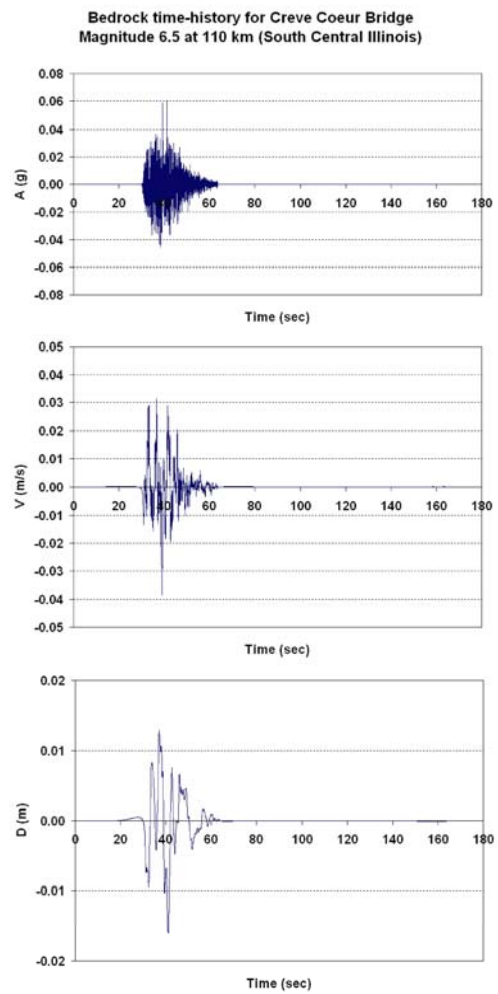
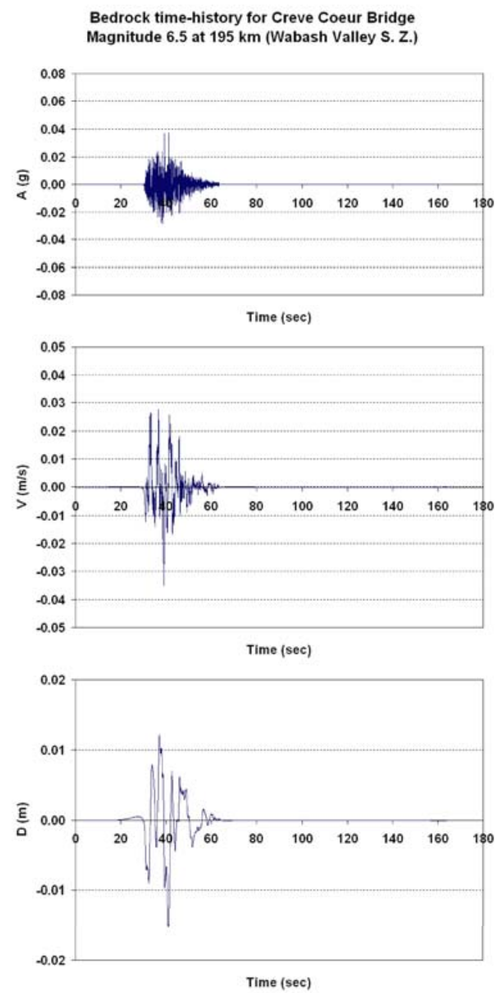
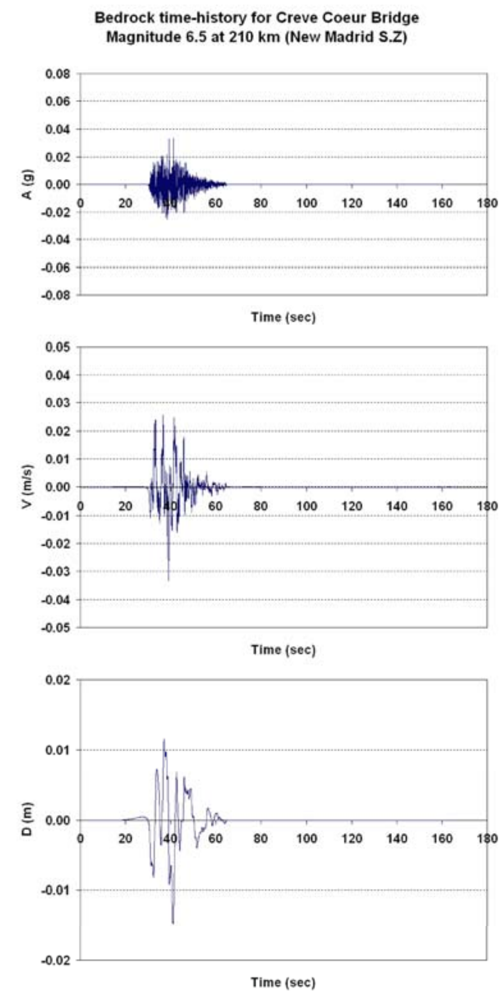
Creve Coeur Lake Bridge
Artificial Time Histories from 3 sources





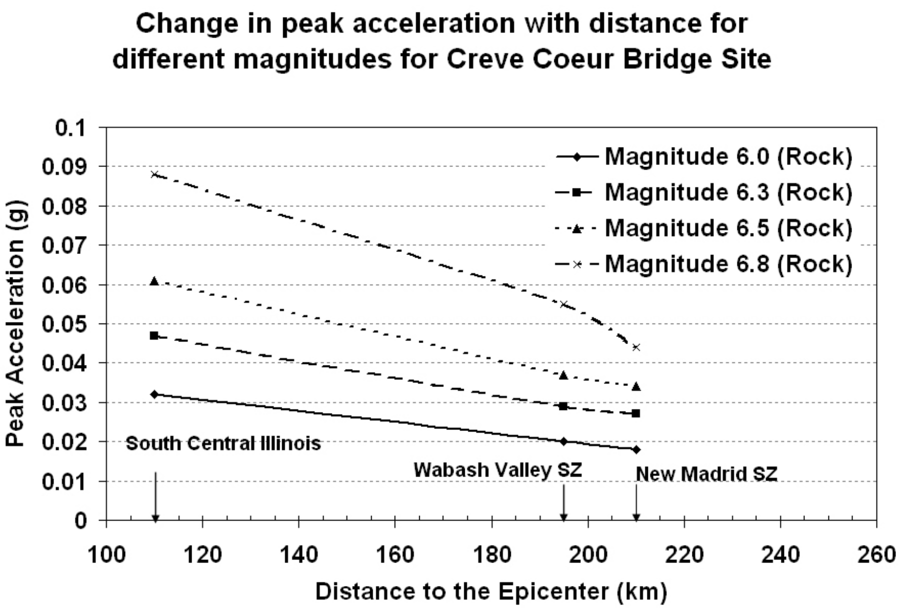


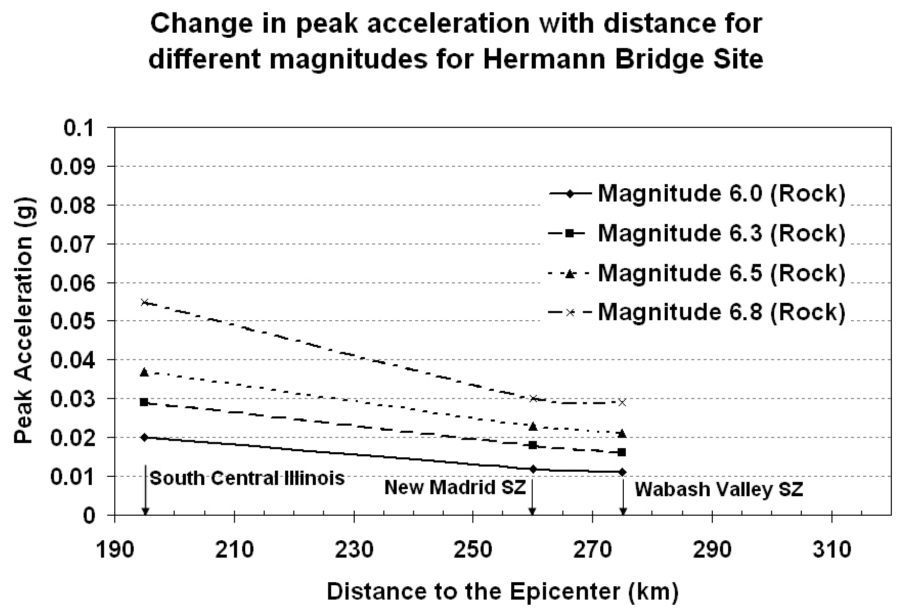
South Central Illinois
Distance = 110 km
$M_o = 6.5$ $a_{max} = 0.06g$

Wabash Valley Seismic Zone
Distance = 195 km
$M_o = 6.5$ $a_{max} = 0.038g$

New Madrid Seismic Zone
Distance = 210 km
$M_o = 6.5$ $a_{max} = 0.034g$

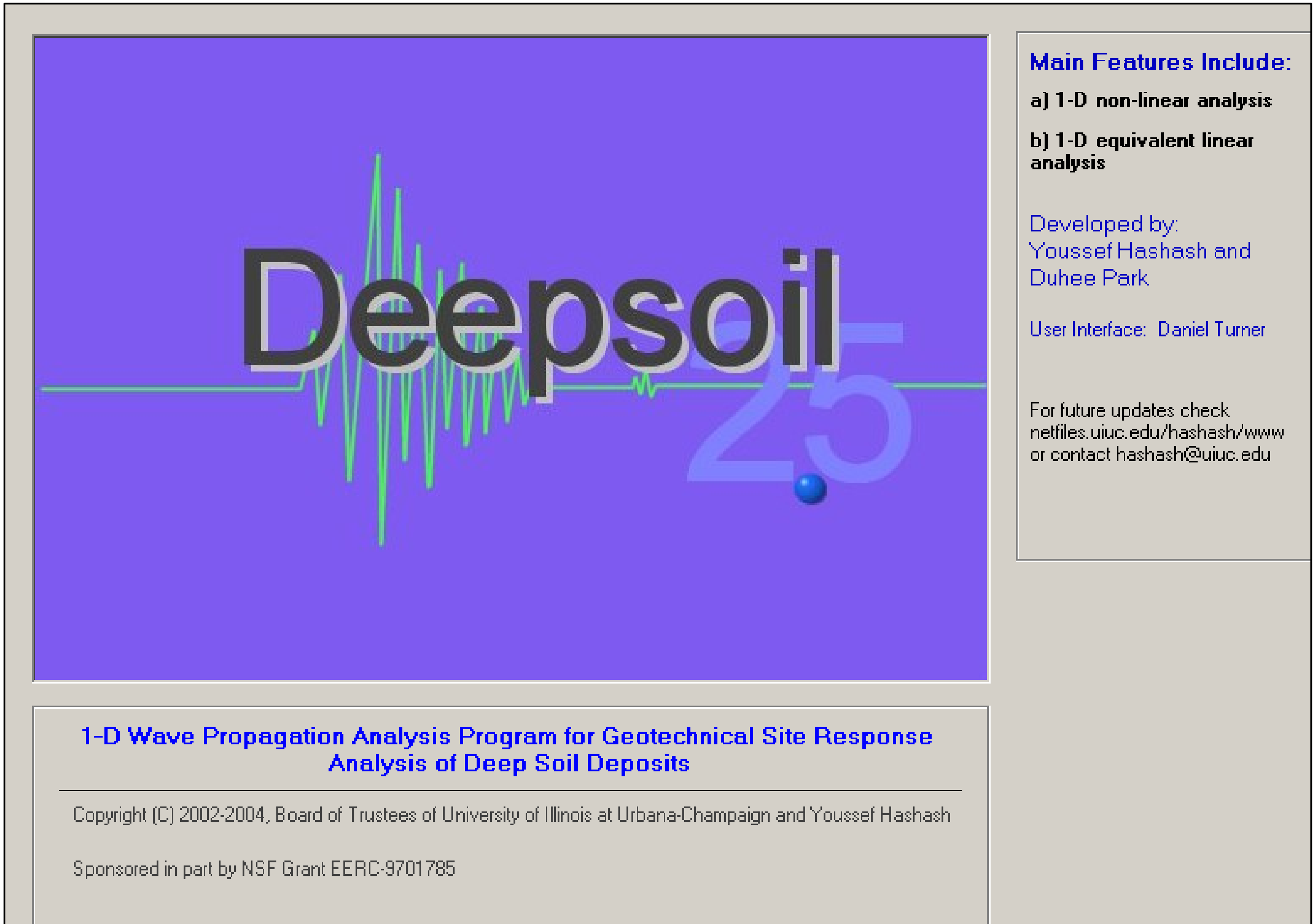
Charts Showing Epicentral Distance vs SMSIM Peak Rock Acceleration





Note nonlinearity at distances > 200 km when Magnitudes exceed 6.8

1D Seismic Site Response Equivalent Linear Approach



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Equivalent-linear approach (ELA):

- ELA adequately estimates motions for ground motion less than 0.2g of input rock accelerations (Idriss, 1990).
- Produces larger spectral accelerations at intermediate periods (~0.5 sec) and smaller accelerations at shorter periods (~0.1 sec), compared to non-linear analysis (Dickmen and Ghaboussi, 1984)

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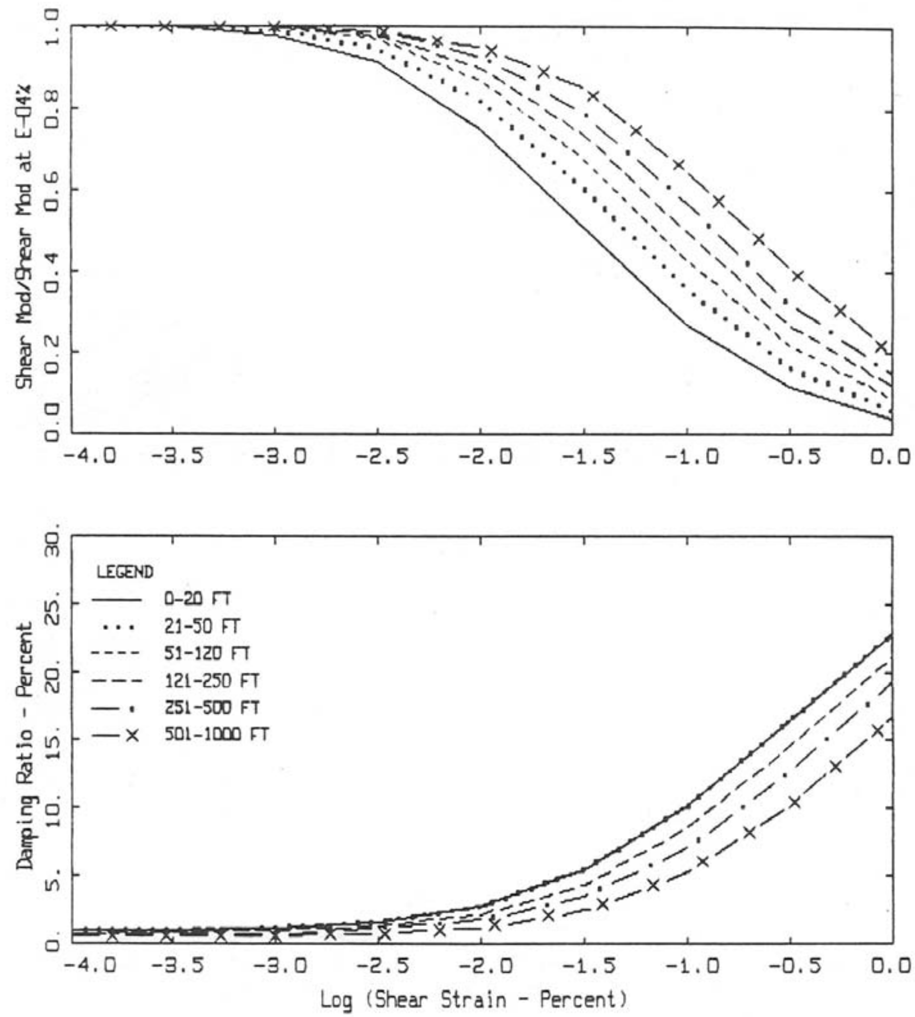
EPRI Generic Modulus Reduction Curves

- Soil parameters correlated from Corrected SPT blow counts.
- Dynamic soil parameters estimated to fit modulus reduction and damping curves presented in EPRI (1993)



EPRI (1993)

RESULTS

- Results are presented in two ways:

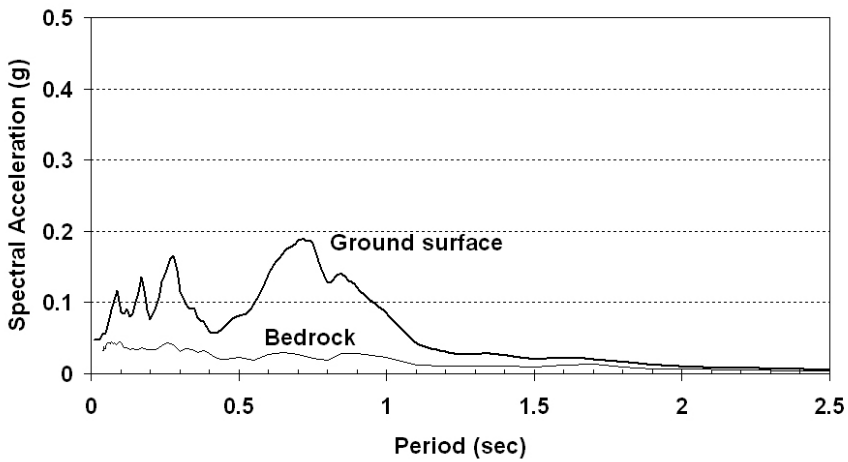
a. The site response of each profile (absolute response)

b. The response of each profile relative to a reference basement rock profile (relative response)

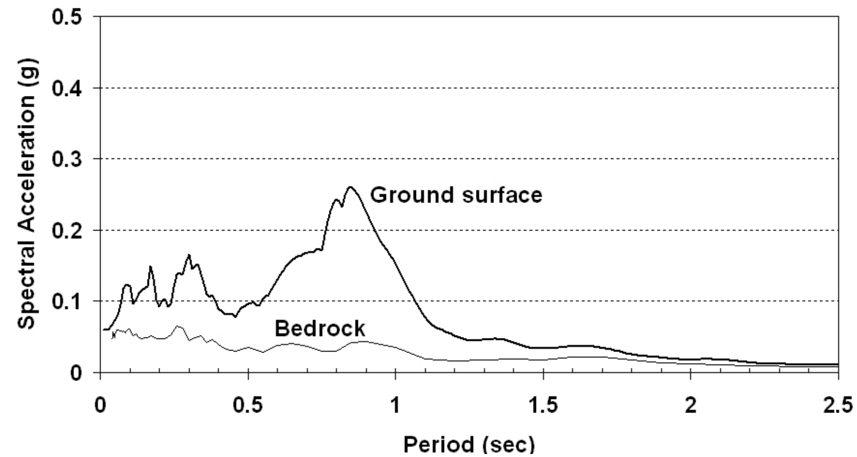
- Amplification spectra: The ratio of soil profile site response to its basement rock site response
- The amplification spectra is a reliable indicator of potential site amplification; which may necessitate more rigorous site-specific dynamic analyses

Response Spectra for Creve Coeur Lake Bridge from Wabash Valley Seismic Zone

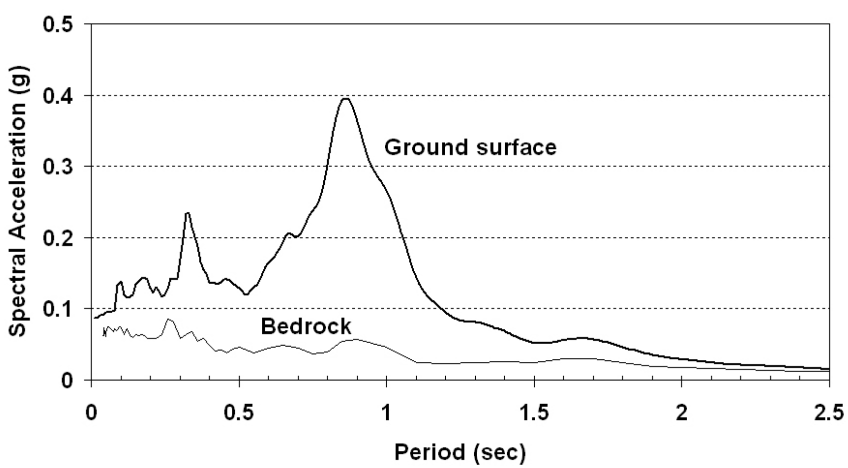
Rock and Ground surface spectral accelerations for Creve Coeur Bridge Magnitude 6.0 event at 210 km



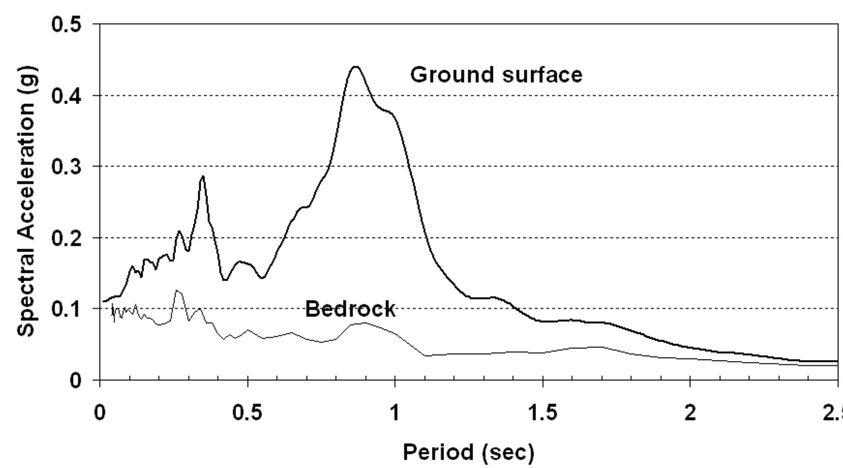
Rock and Ground surface spectral accelerations for Creve Coeur Bridge Magnitude 6.3 event at 210 km



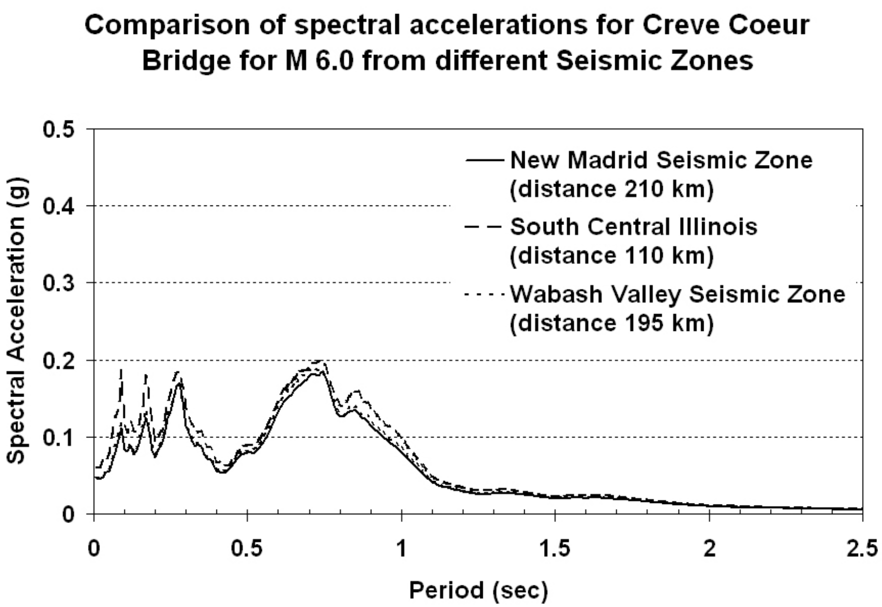
Rock and Ground surface spectral accelerations for Creve Coeur Bridge Magnitude 6.5 event at 210 km

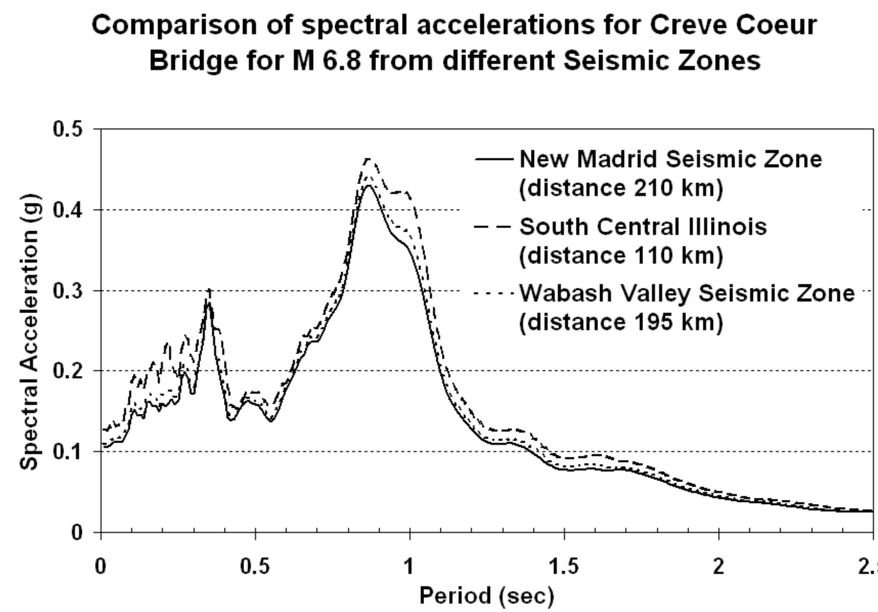


Rock and Ground surface spectral accelerations for Creve Coeur Bridge Magnitude 6.8 at 210 km



Creve Coeur Lake Bridge: Site Response from different Seismic Sources





Note the dramatic shift in site response between Magnitude 6.0 and 6.8: 1) Increase in peak site period; 2) increase in spectral acceleration; and 3) small difference in attenuation (unique to Midwest).

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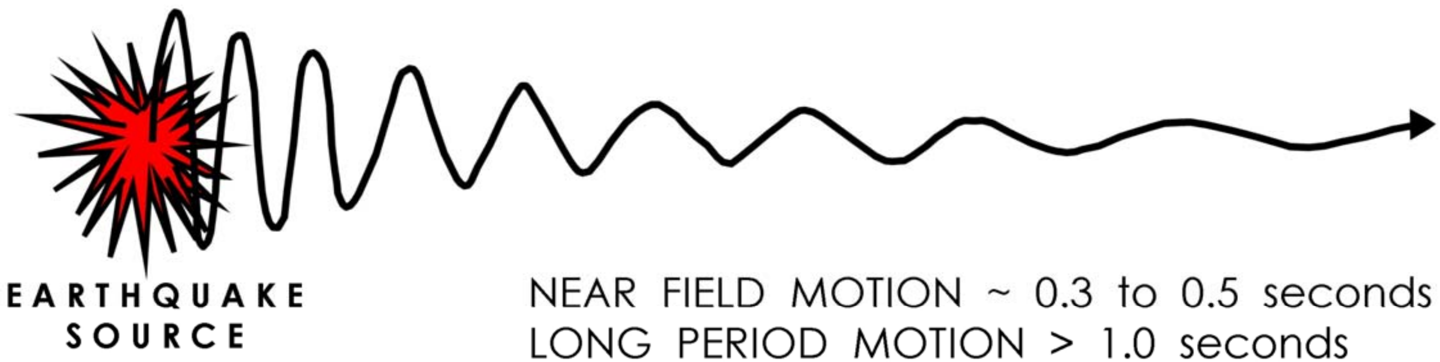
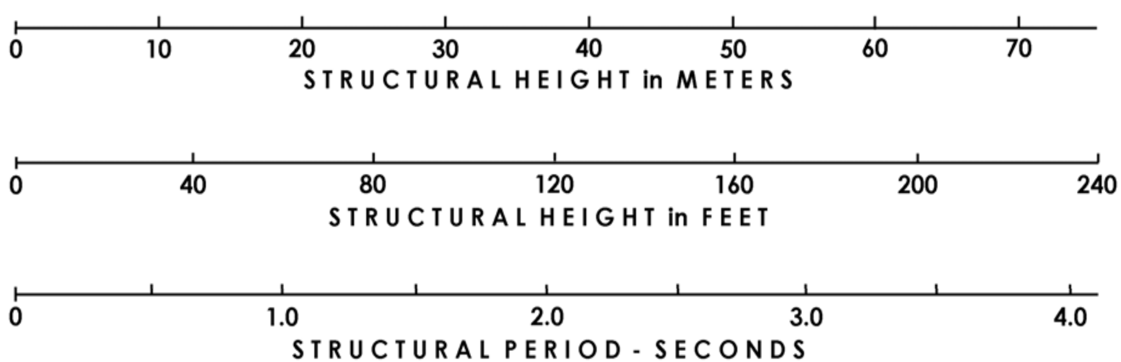
LENGTHENING of SEISMIC WAVE TRAIN with DISTANCE from SOURCE



FUNDAMENTAL PERIOD vs STRUCTURE HEIGHT



- **Long period motions (T > 1.0 second) become important when evaluating structures > 150 km from the quake hypocenter**

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What Causes Amplification of Ground Motion

- **Resonance** within the soil column overlying much stiffer basement rocks
- **Impedance Ratio** between the rigid basement rock and the unconsolidated soils lying over them
- **Conservation of energy** of the incoming seismic wave train (e.g. wave energy arriving at a much higher rate than can be propagated through the soft soil cover)

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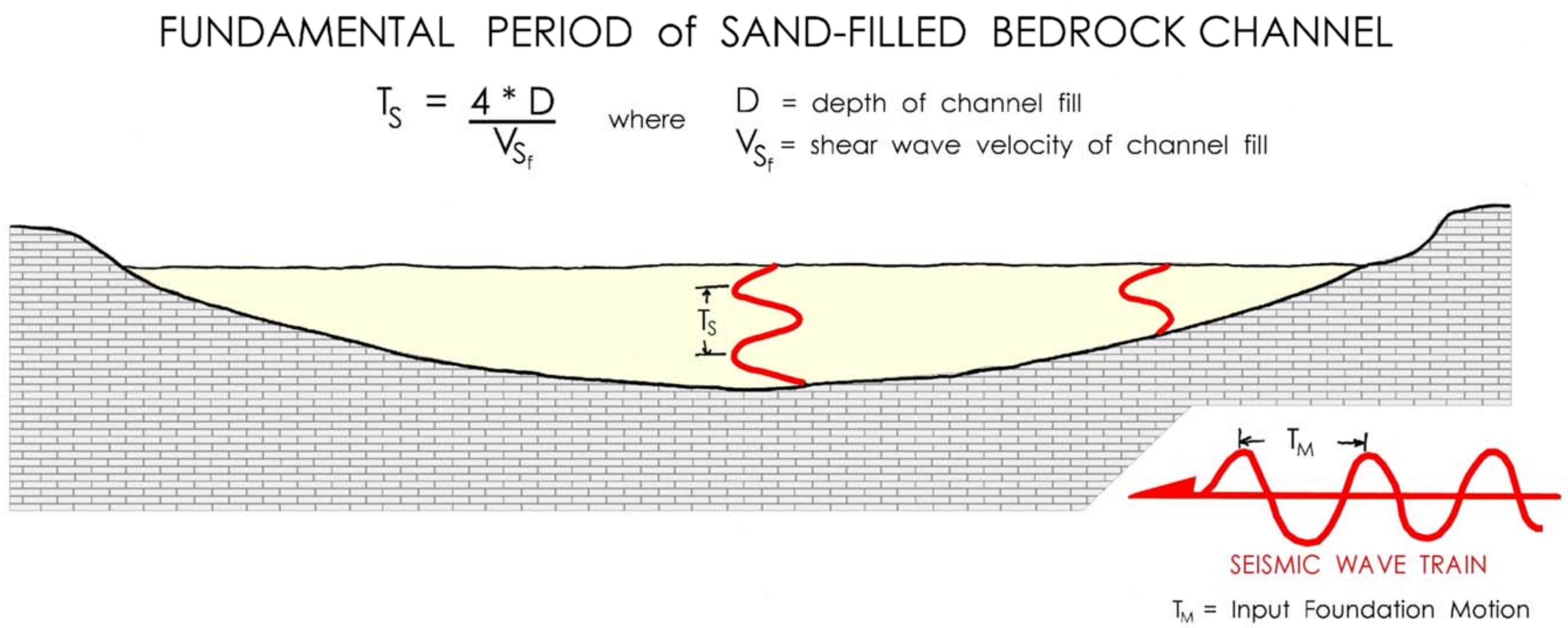
Resonance within the soil column



- **If the frequency of the seismic wave is approximately equal to the characteristic frequency of the overlying soil deposit, site amplification will occur, increasing the amplitude of the ground motion significantly at the characteristic frequency/period.**

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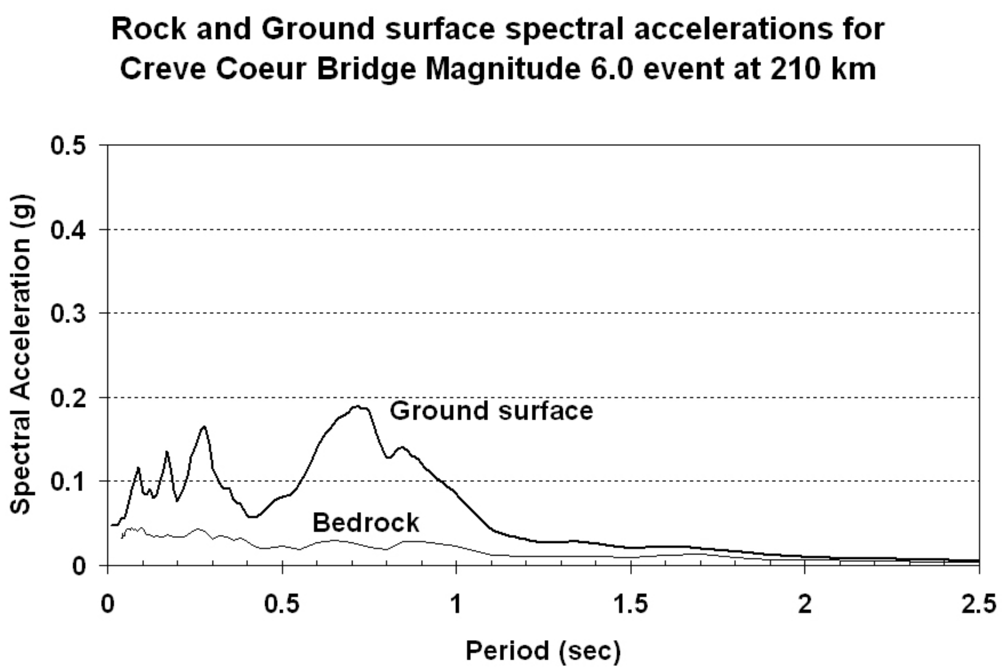
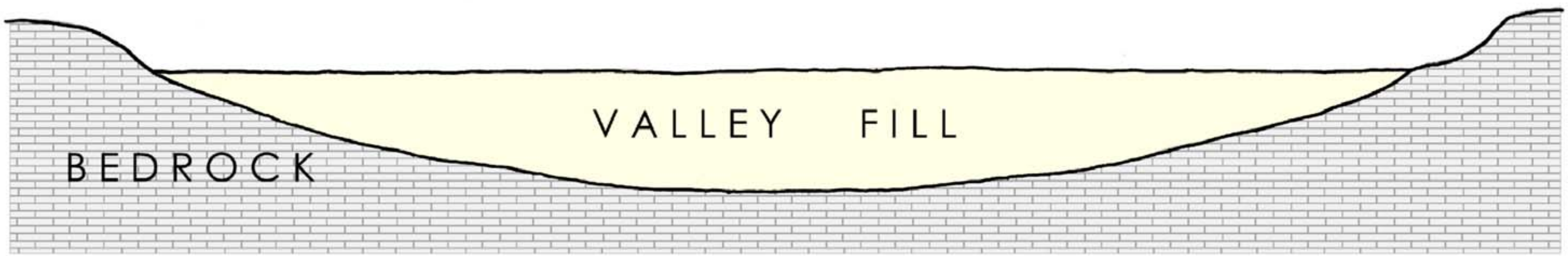


Characteristic Site Period for Creve Coeur Bridge

- Average V_s = 182.6 m/sec
- Average thickness = 35 meters
- Average Characteristic Period

$$T_c = 4 * 35/182.6 = 0.76 \text{ sec}$$

IMPEDANCE



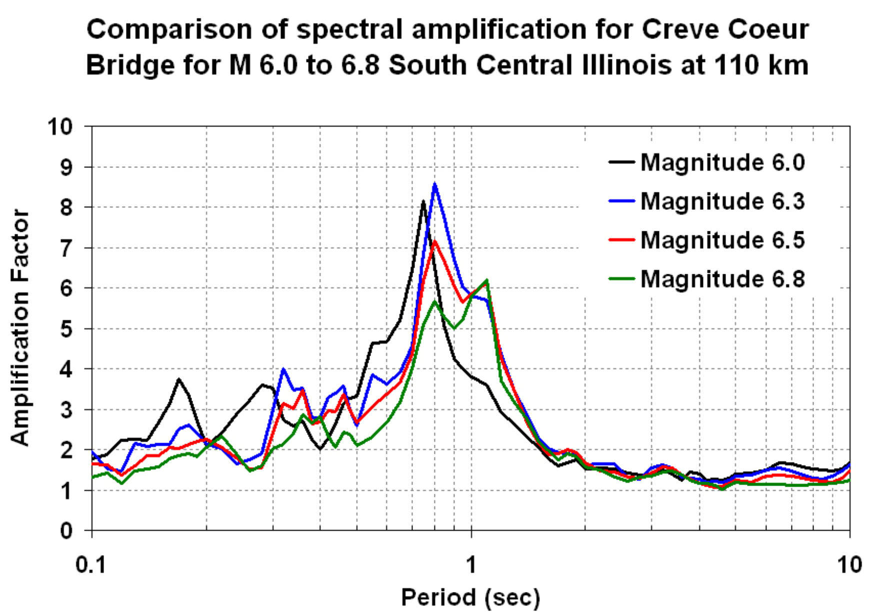
$$\text{IMPEDANCE RATIO} = \frac{\rho_{\text{FOUNDATION}} * V_{S\ \text{BEDROCK}}}{\rho_{\text{VALLEY FILL}} * V_{S\ \text{VALLEY FILL}}}$$

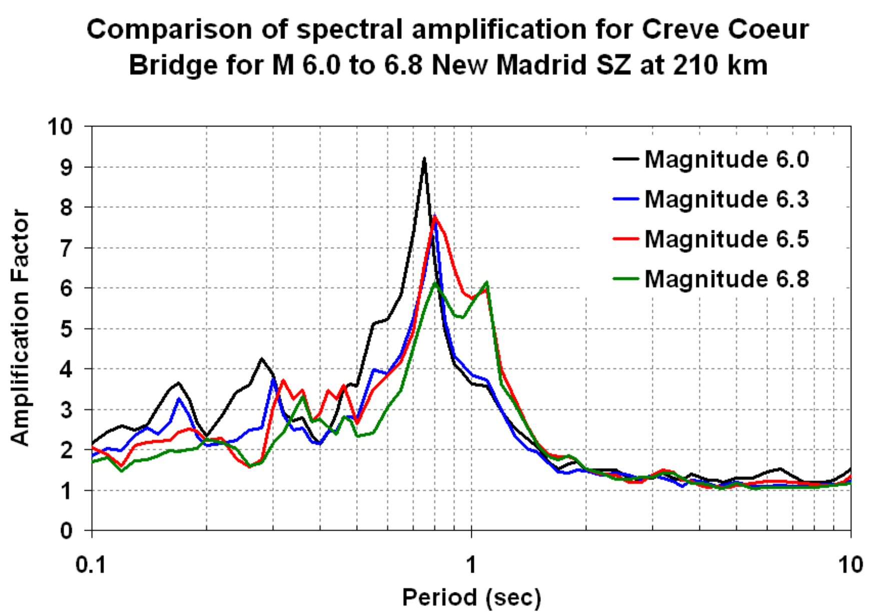
- **Site amplification** is a function of the **Impedance Ratio** between the valley fill and the underlying basement rock.
- Amplification increases as the impedance ratio between two layers increases.

Conservation of Energy

- Energy flux = $\rho * V_s * \acute{u}^2$
- Since ρ and V_s decrease as waves approach the ground surface, the particle velocity must increase.
- Seismic energy is absorbed by the softer, more deformable materials.

Creve Coeur Lake Bridge
Amplification Spectra





South Central Illinois
110 km

New Madrid
210 km

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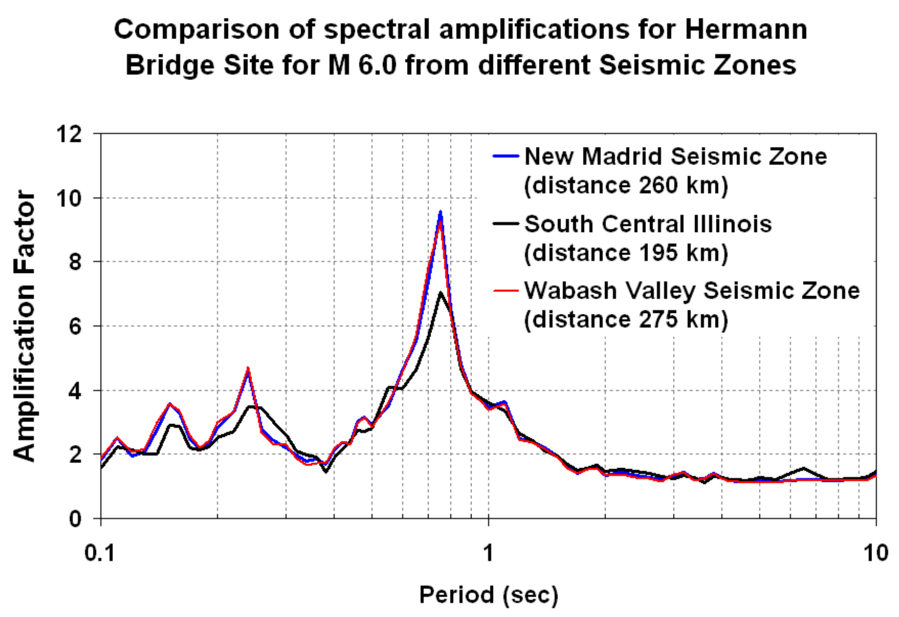
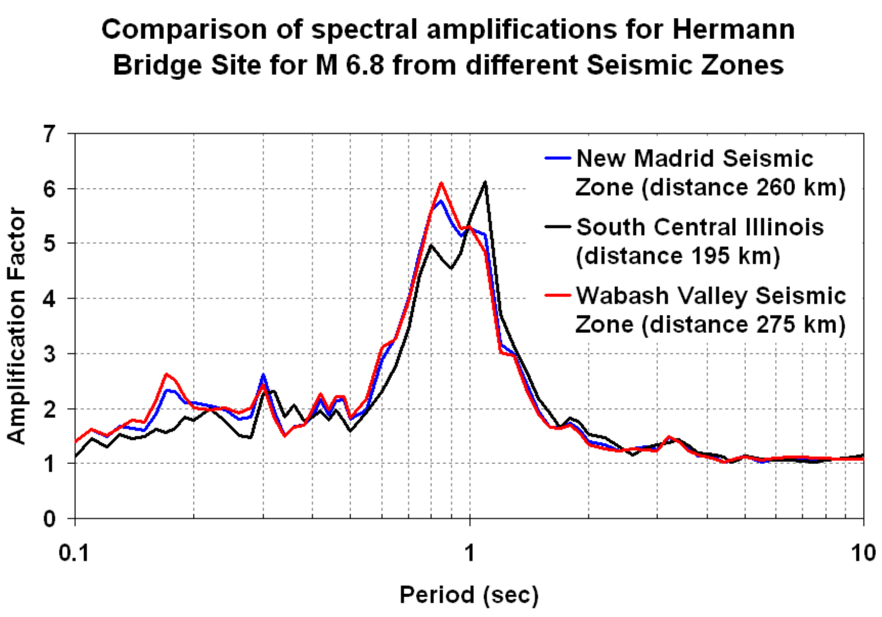
Hermann Missouri River Bridge Amplification Spectra





M 6.0

M 6.8

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Significant Site Amplification Predicted

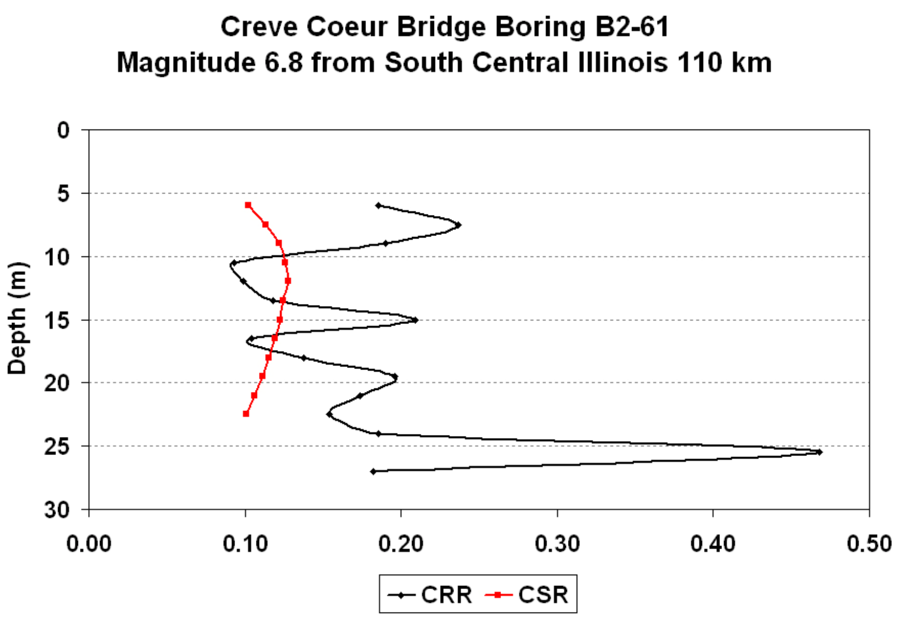
- Amplification Factors for Creve Coeur Bridge (for distances 110, 195 and 210 km) varies between 6x to 9.5x for Magnitudes 6.0, 6.3, 6.5 and 6.8.

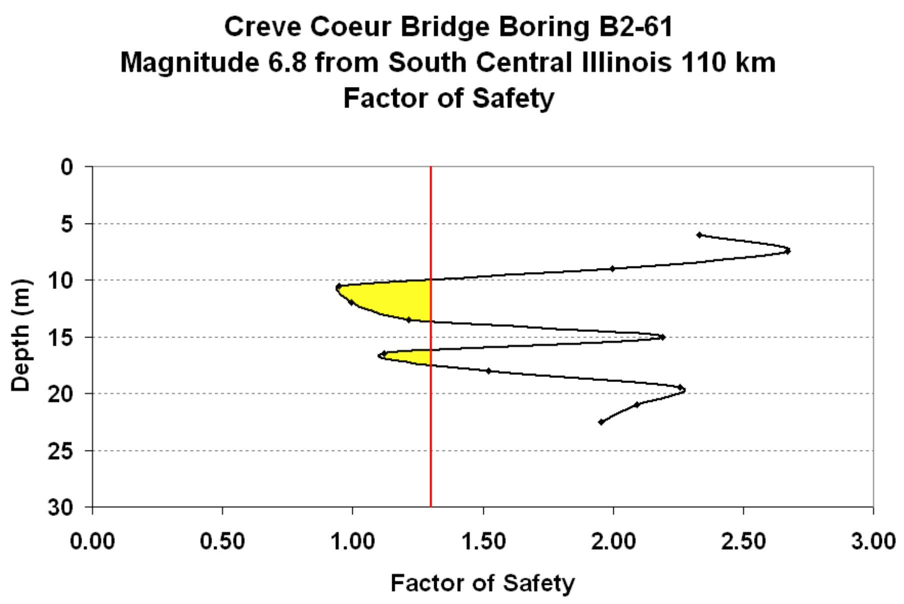
- Amplification Factors for Hermann Bridge Site (for distances 195, 260, and 275 km) varies between 5x to 10x for Magnitudes 6.0, 6.3, 6.5 and 6.8.

Quantitative Liquefaction Screening Analysis Youd et al. (2001)

- Cyclic Stress Ratio (CSR) vs. Cyclic Resistance Ratio (CRR) (at Magnitude 7.5)
- Factor of Safety (includes a magnitude scaling factor)

Creve Coeur Bridge Liquefaction Screening for M 6.8 event emanating from South Central Illinois

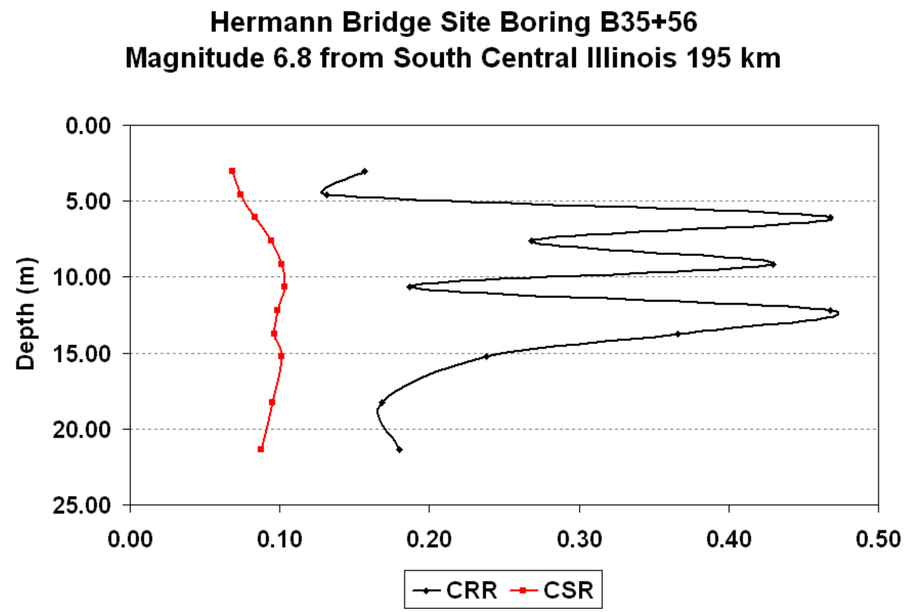


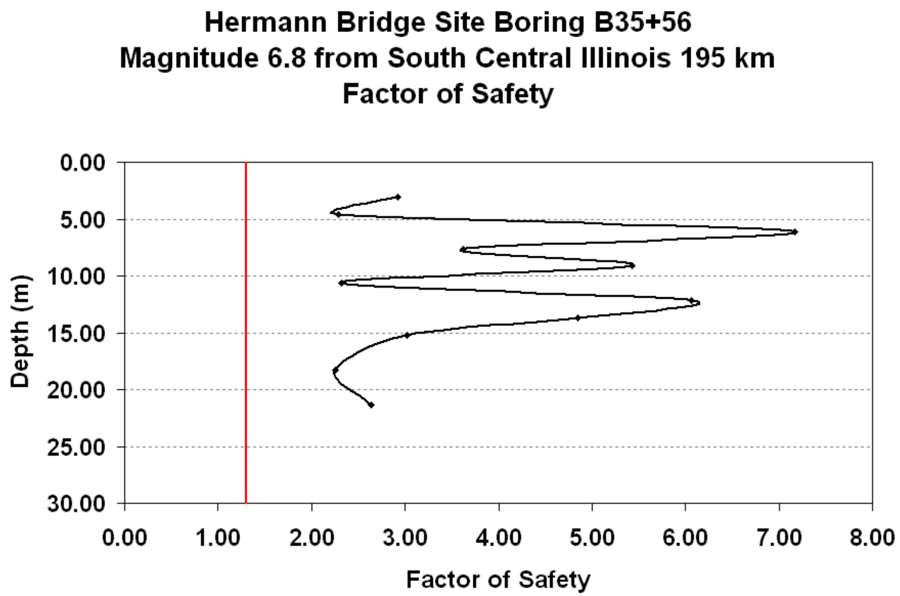


CSR vs. CRR

Factor of Safety

Herman Bridge Liquefaction Screening for M 6.8 event emanating from South Central Illinois





CSR vs. CRR

Factor of Safety

CONCLUSIONS - 1

- The most likely earthquake we can expect in the next 50 years in the Midwestern United States is something between Magnitude 6.0 and 6.8
- This earthquake could emanate from any of three seismic zones, with the most likely being the New Madrid SZ, which is exhibiting crustal strain accumulation of 1 to 2.7 mm/yr
- Preliminary results indicate that the bridges we analyzed would be subjected to long period motions, which may pose a significant threat to simply-supported tail spans founded on friction piles.
- The peak spectral accelerations range from 0.15g to 0.5g for M6.0 to M6.8 earthquakes, respectively.
- Large amplifications can be expected at both bridge sites. Amplification of the ground motion is in the range of 5 to 10X.

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CONCLUSIONS - 2

- A surprising result was similar site amplification was predicted for earthquakes at distances of 110 to 210 km, because little wave energy attenuation occurs in the stiff Paleozoic bedrock.
- Widespread liquefaction predicted at the Creve Coeur Bridge site for ≥ M 6.8 event, but only localized liquefaction for M 6.3-M 6.7 events.
- The screening analysis did not predict any liquefaction at the Hermann Bridge site.
- Soil softening (liquefaction) may cause a decrease in response spectra values for periods < 1 sec.
- However, soil softening may cause an increase in response spectra values for periods >1 sec.

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