What will a Magnitude 6.0 to 6.8 Earthquake do to the St. Louis Metro Area?

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Friday February 3, 2006

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OVERVIEW

- The latest probabilistic assessment predicts a Magnitude 6.0 earthquake has a 25 to 40% chance of occurrence in the next 50 years.
- Three seismic sources exist in the Midwest: New Madrid Seismic Zone (NMSZ), Wabash Valley Seismic Zone (WVSZ) and South-Central Illinois Seismic Zone (SCI).
- We performed screening analyses focusing on the likely ground motions for earthquakes of Magnitude 6.0, 6.3, 6.5 and 6.8.

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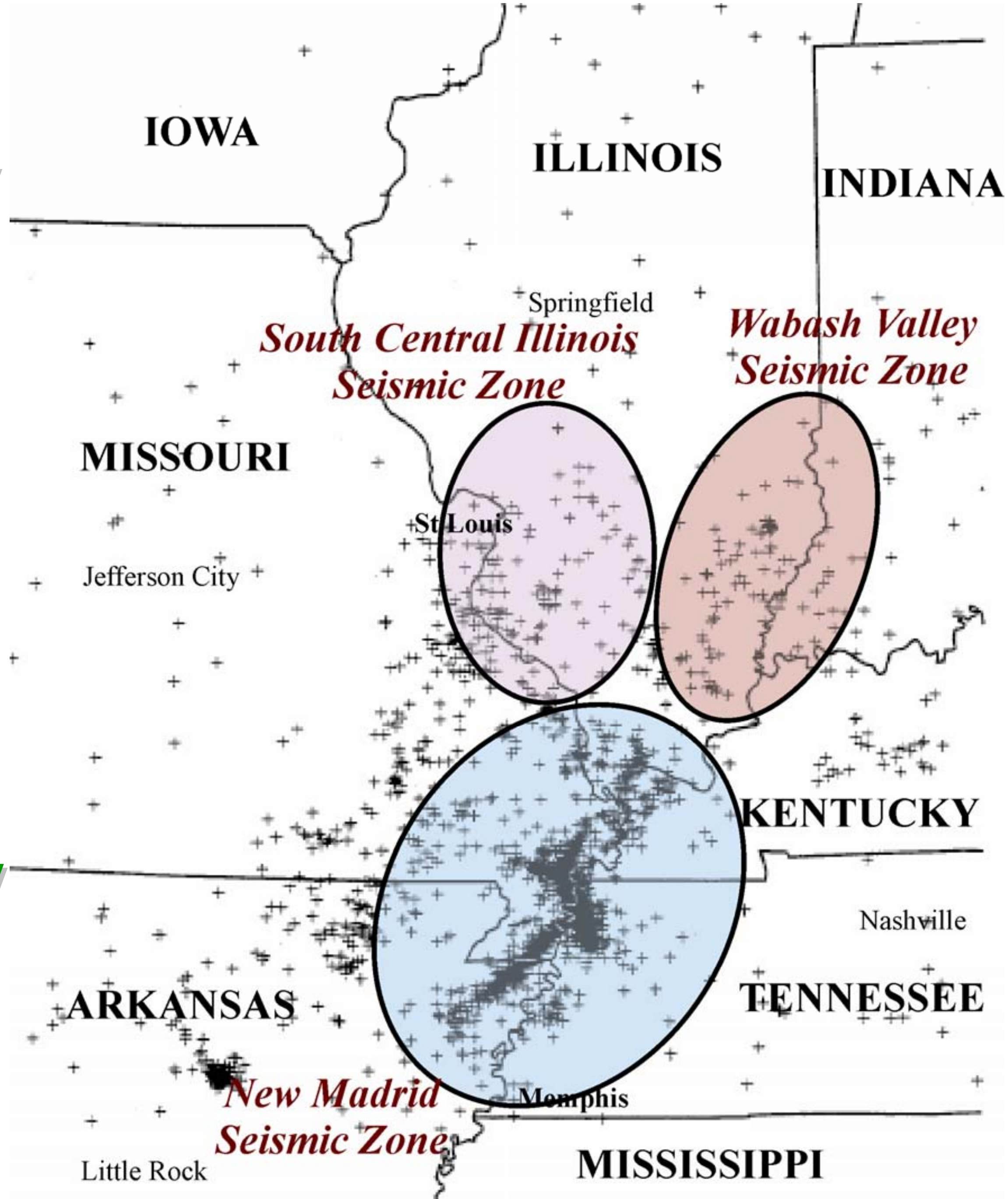
Seismicity of the Region more complex than previously thought



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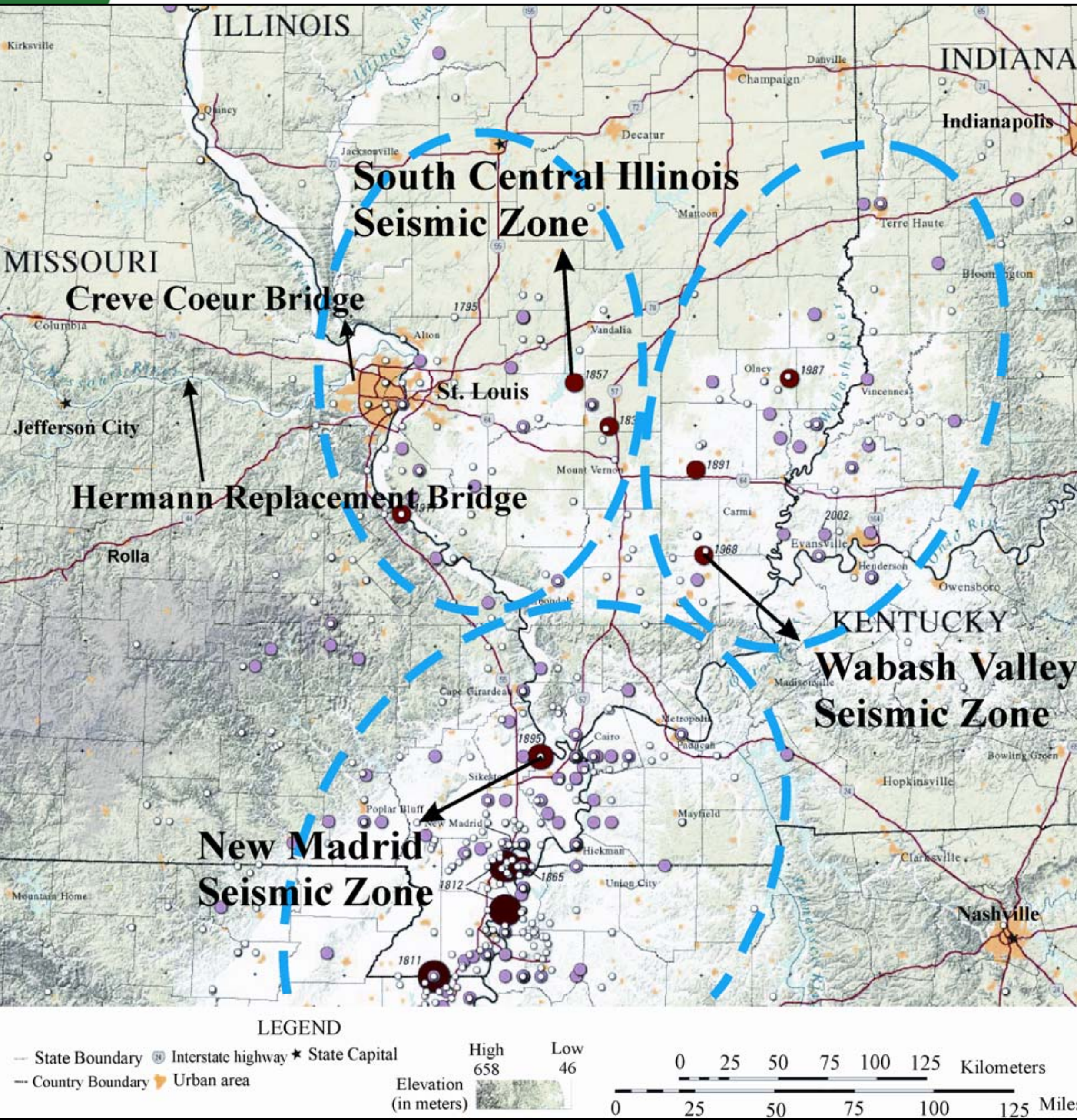
Bridge locations and seismic zones



	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

Creve Coeur Bridge-Page Extension

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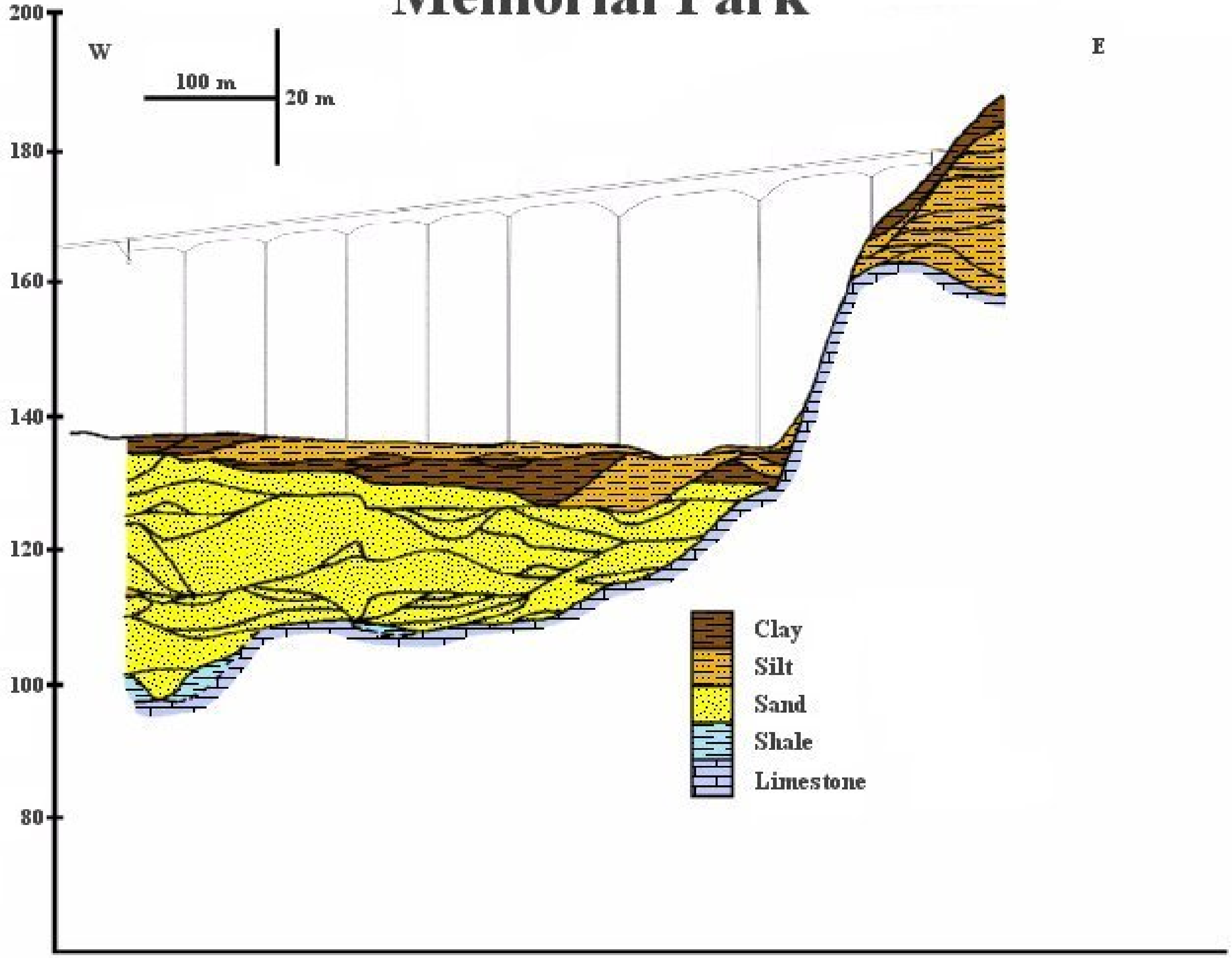
Page Extension, Creve Coeur Lake Memorial Park



Creve Coeur Bridge-Page Extension constructed in 2002-04

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New Hermann Bridge

Proposed replacement bridge

Existing span

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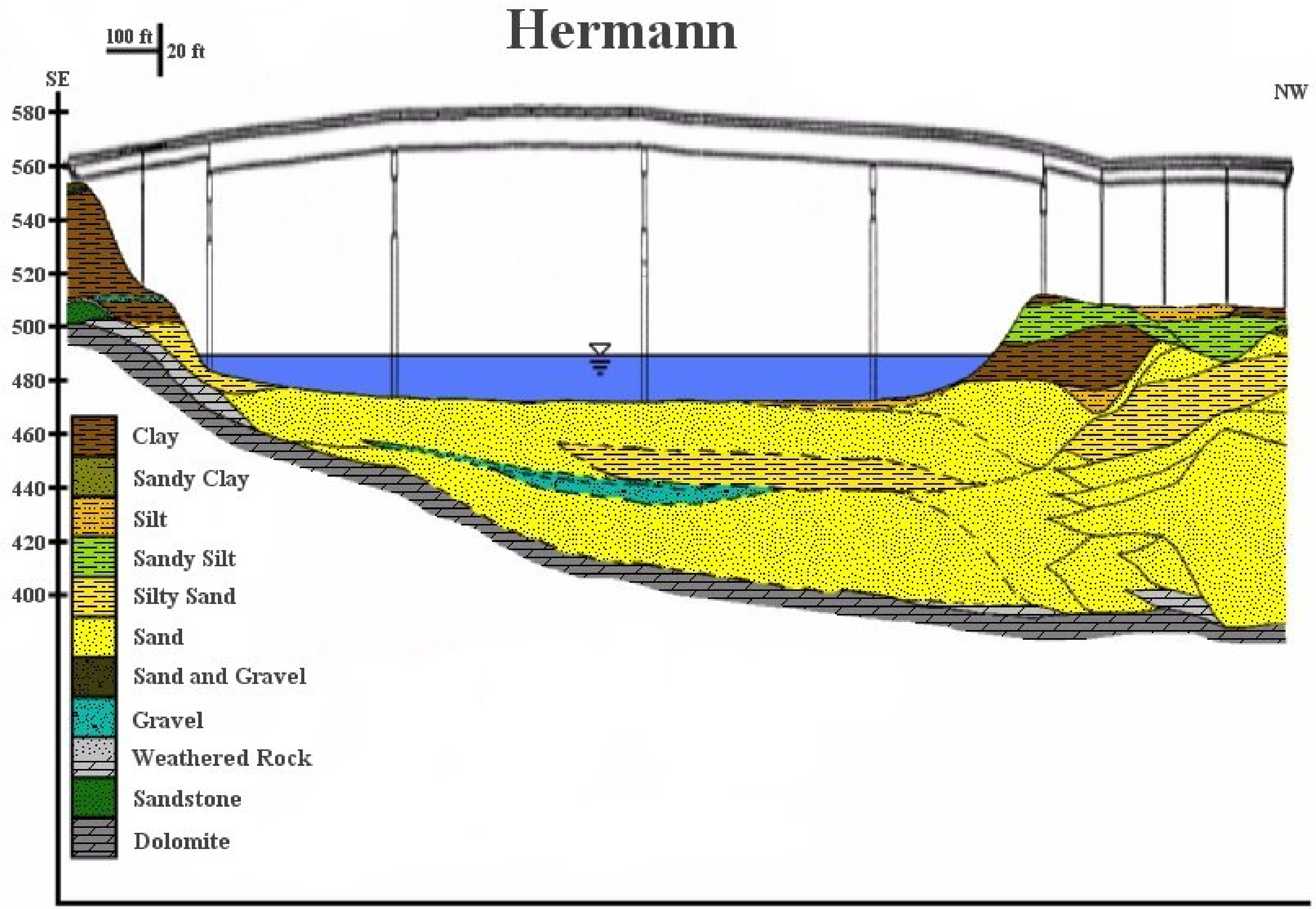
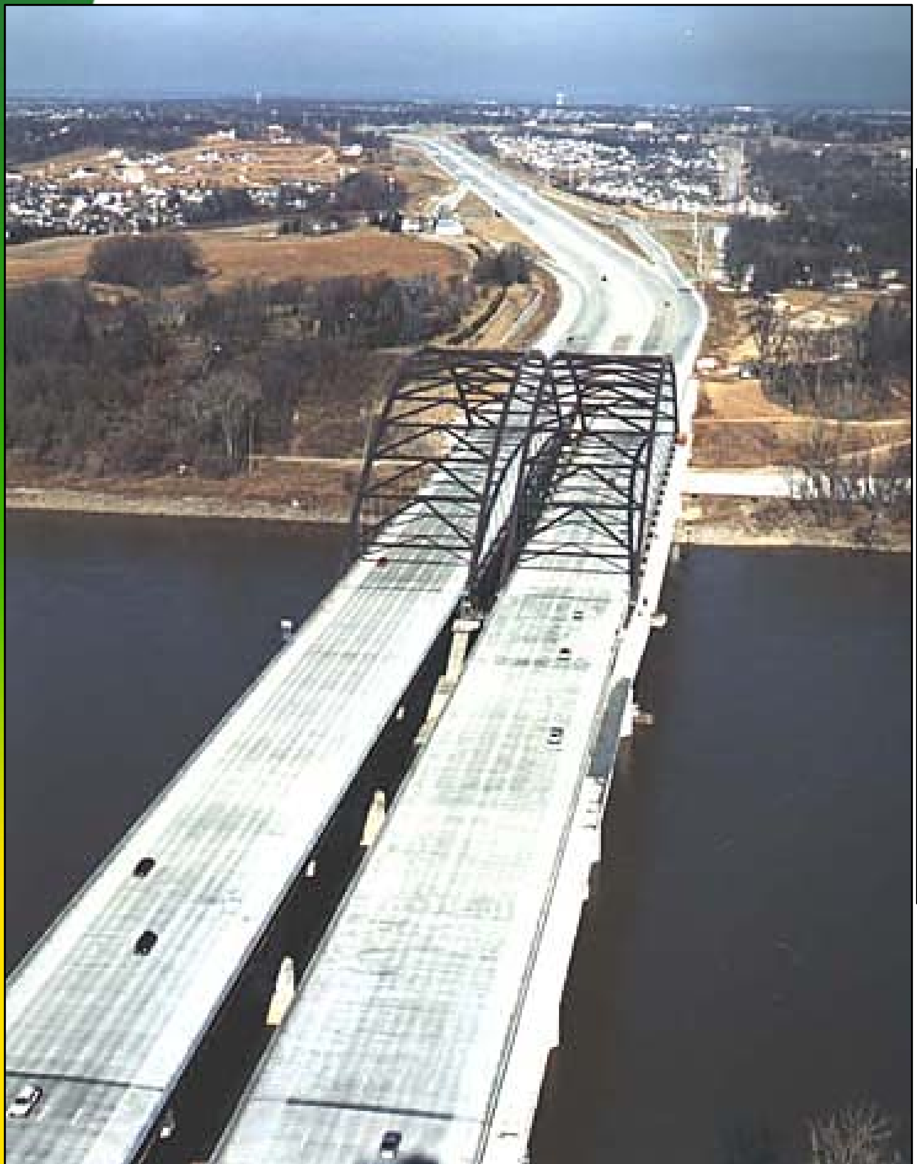


Main channel hugs the south bank, against the cliffs

Missouri River Bridge



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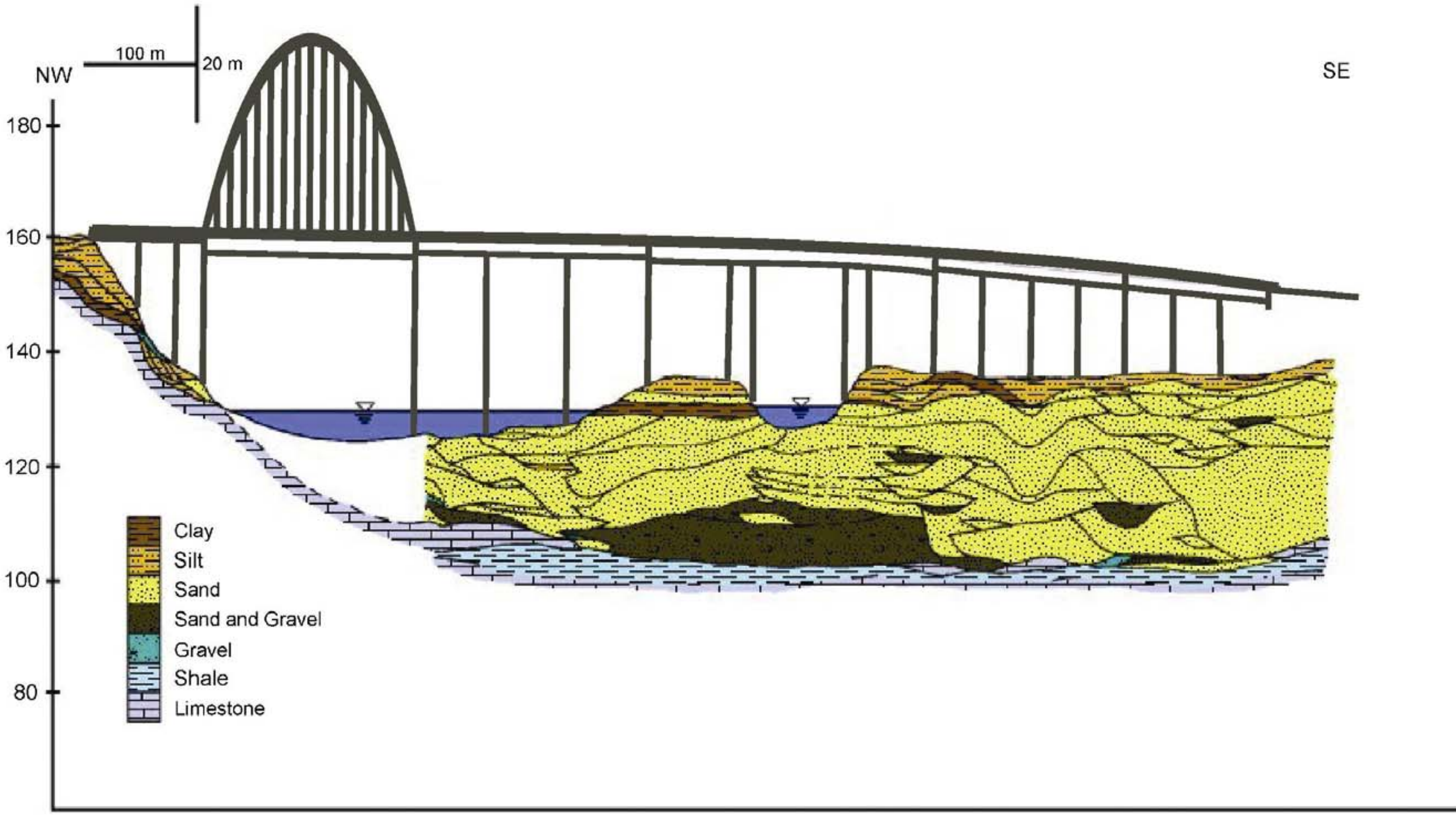
Route D Missouri River Bridge



Main channel hugs the north bank

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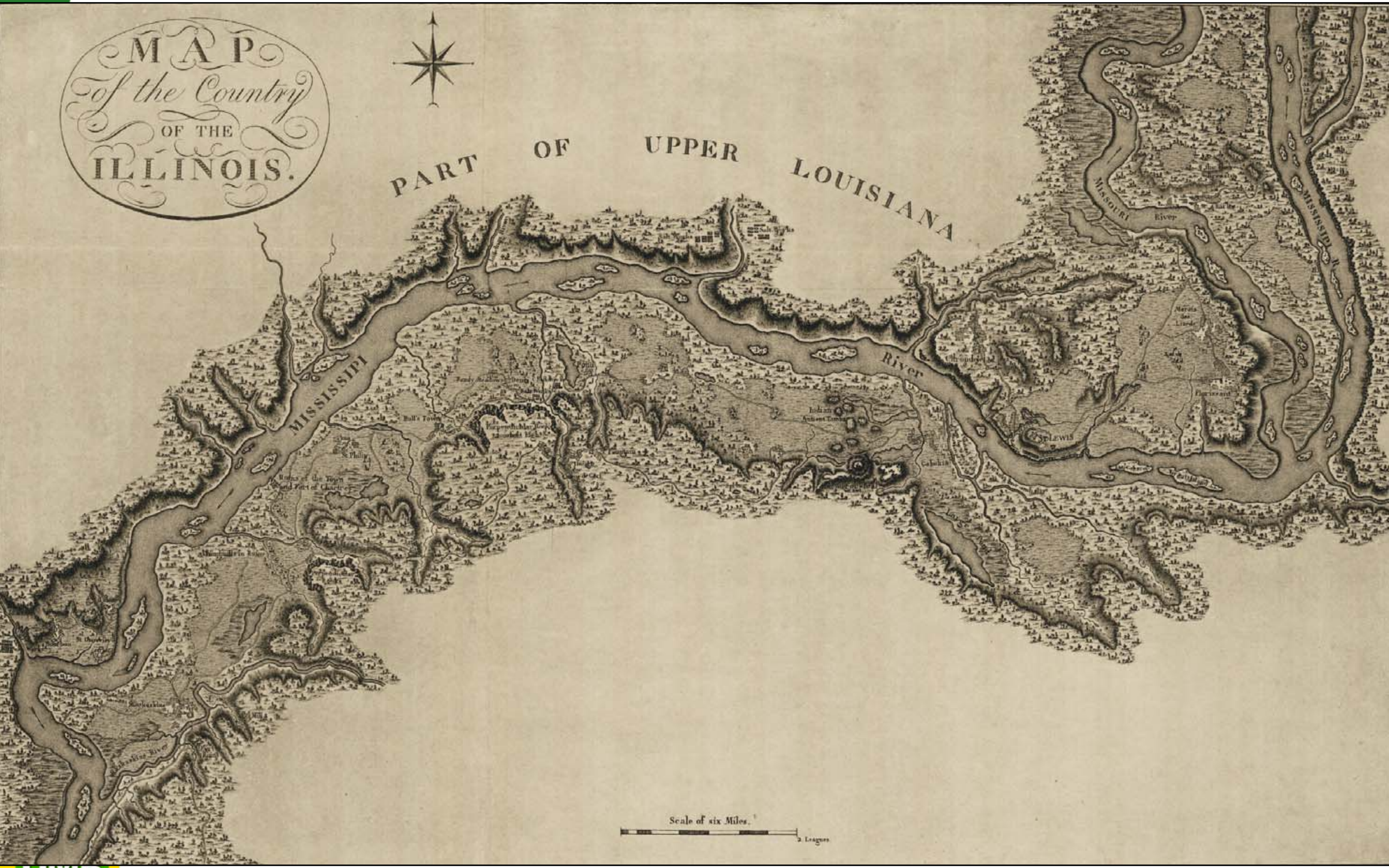
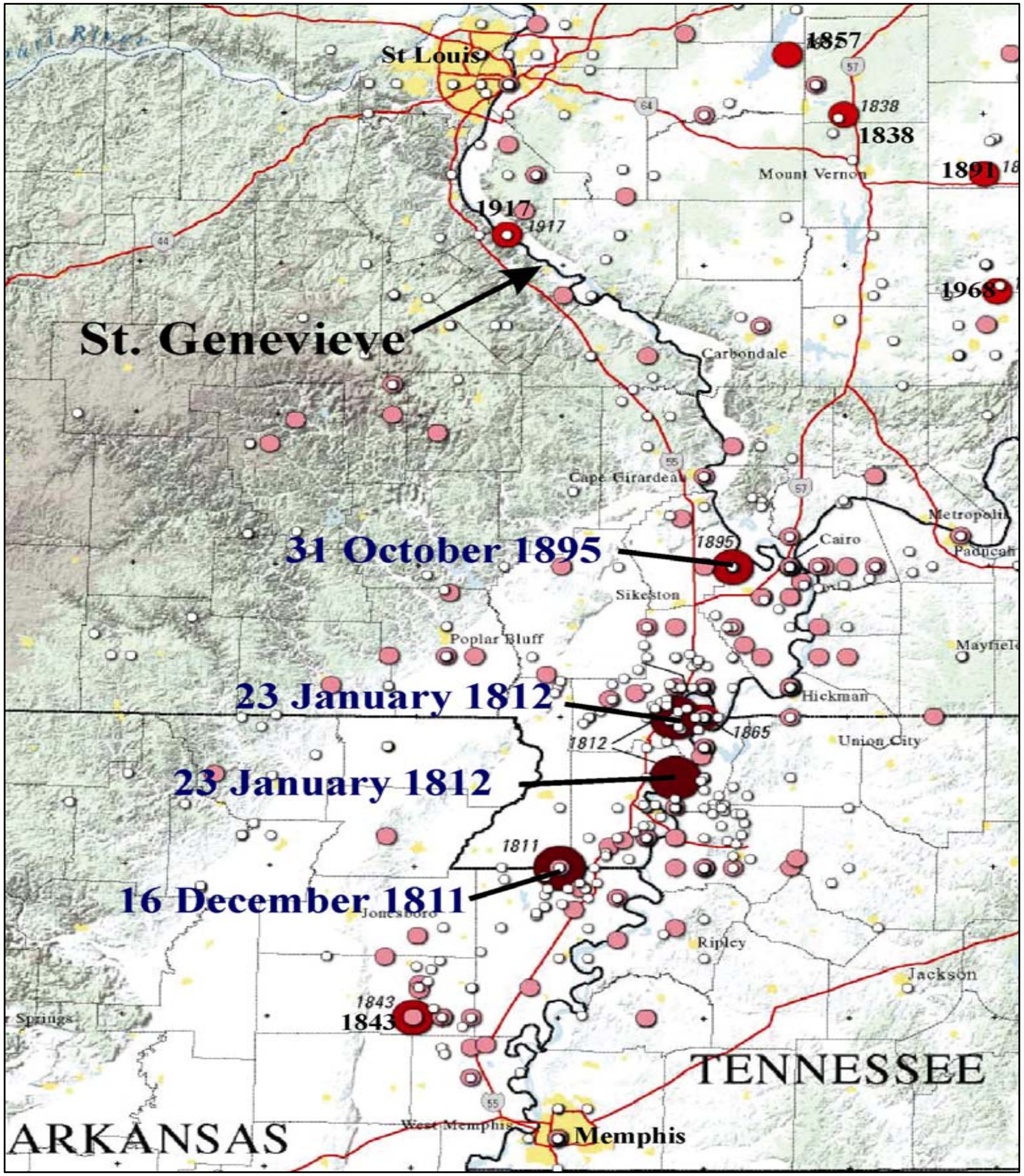
Historical Insights: Callot's 1796 Map



The town of St. Genevieve was originally built on the Mississippi River flood plain. It was relocated to the bedrock bluffs after the flood of 1795

Proximity of St. Genevieve to the big New Madrid area earthquakes of 1811-12



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2000 earthquakes that decimated the region in 1811-12 did not cause any damage to St. Genevieve

As Fred Flintstone said: bedrock is the place to be

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Is the St. Louis area at risk for a moderate size earthquake? The kind that occur every 70+/- 15 years?

Estimating quake effects

- Artificial time histories obtained using SMSIM code of Boore (2001) for EQ rock motions.
- Seismic wave propagation through soil cover estimated using DEEPSOIL v. 2.5 (Park and Hashash, 2003).
- Products: 1) Peak Horizontal Ground Acceleration; 2) Response Spectrum, and 3) Spectral Amplification
- Liquefaction Screening using the two part qualitative and quantitative analysis recommended by Youd et al. (2001).

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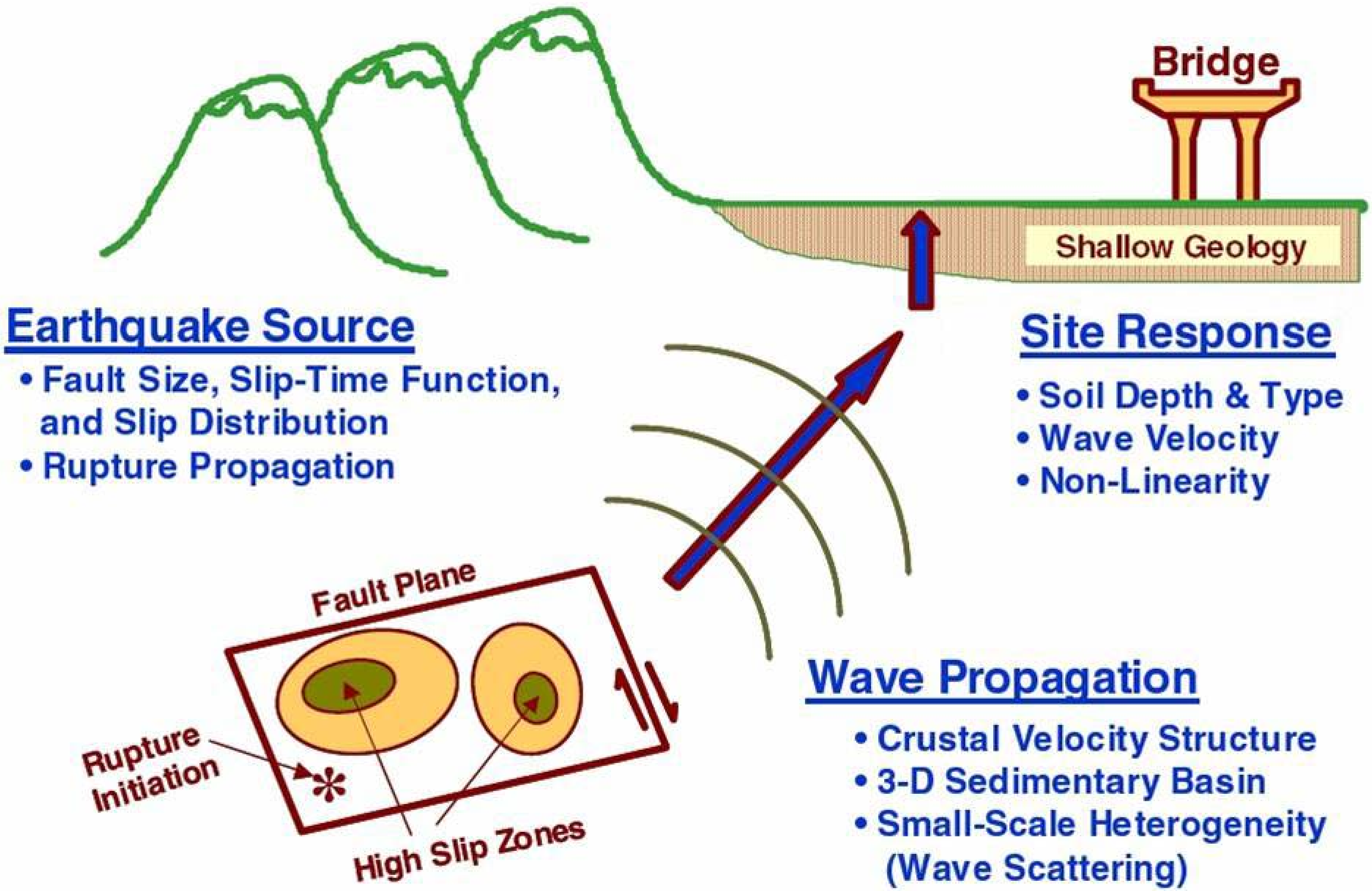
Technical Approach



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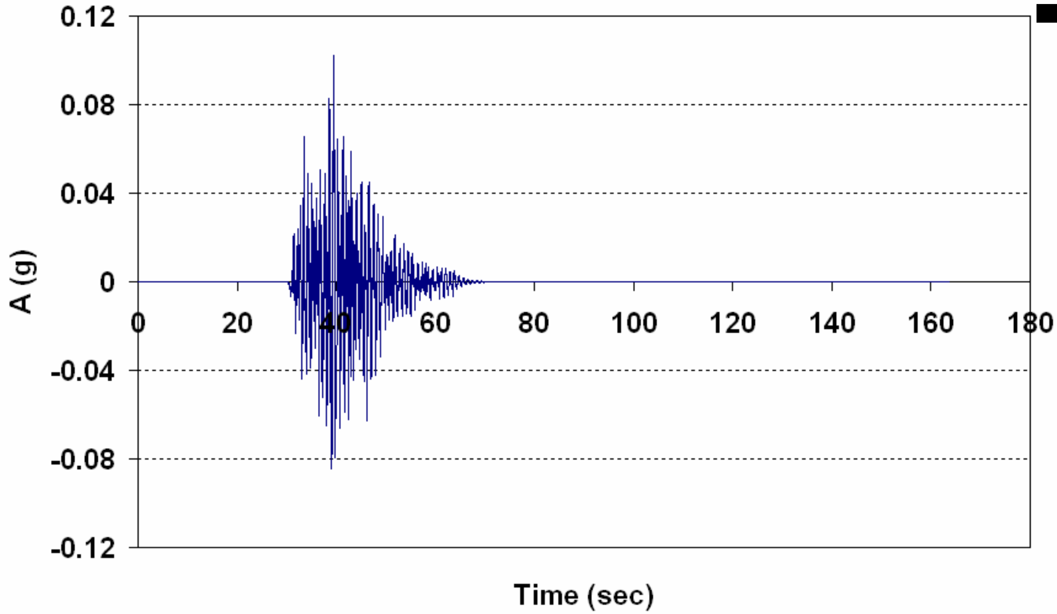
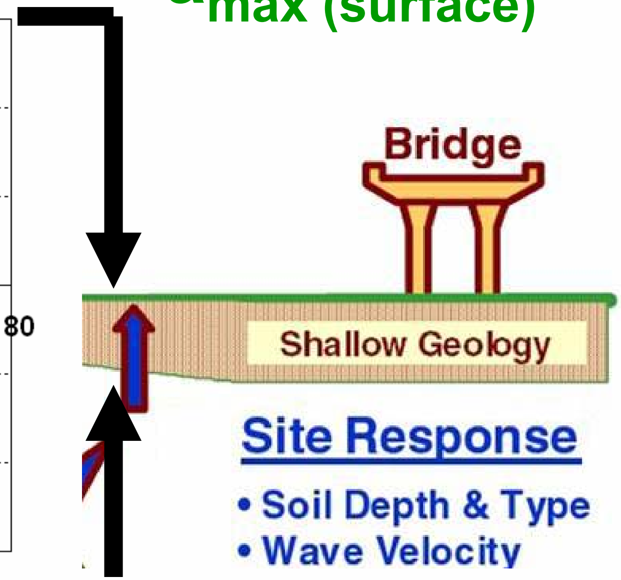
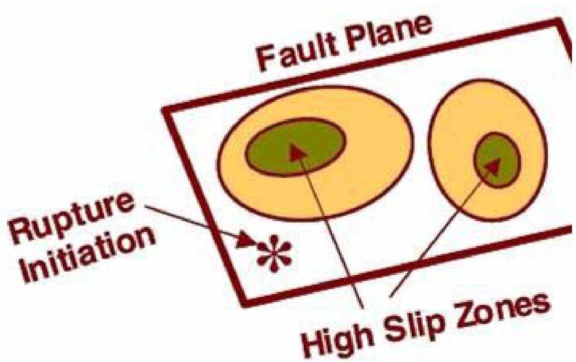
Surface acceleration-time history for Creve Coeur Bridge Magnitude 6.5 at 110 km (SCI)

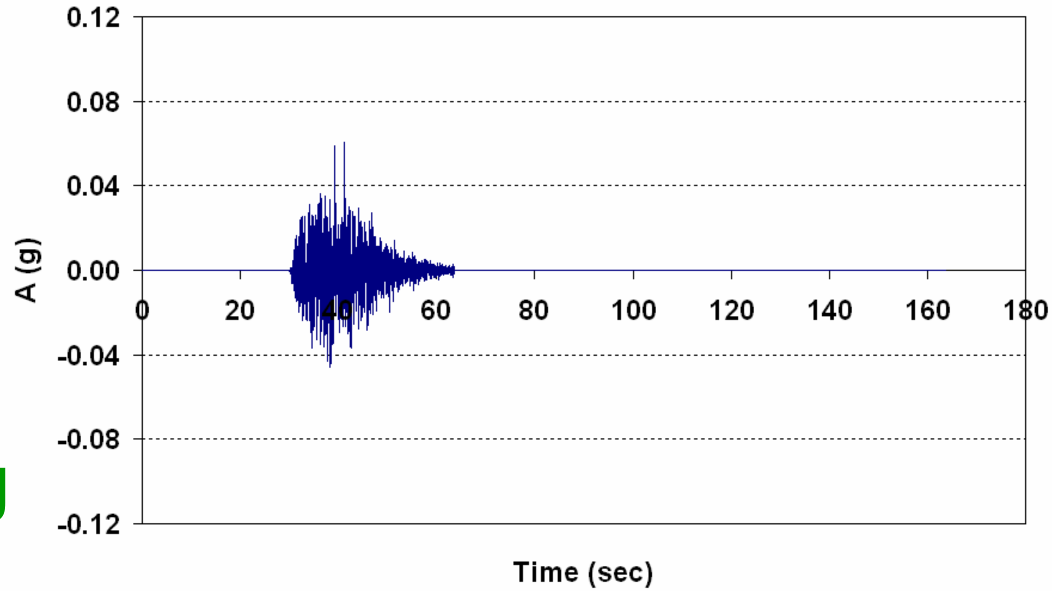


$$a_{max\ (surface)} = 0.102g$$



:celeration-time history for Creve Coeur Bridge Magnitude 6.5 at 110 km (SCI)





$$a_{max\ (rock)} = 0.061g$$

RESULTS

- Results are presented in two formats:

a. The absolute site response of each site profile

b. The relative response of each profile, comparing ground surface to underlying bedrock

- 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

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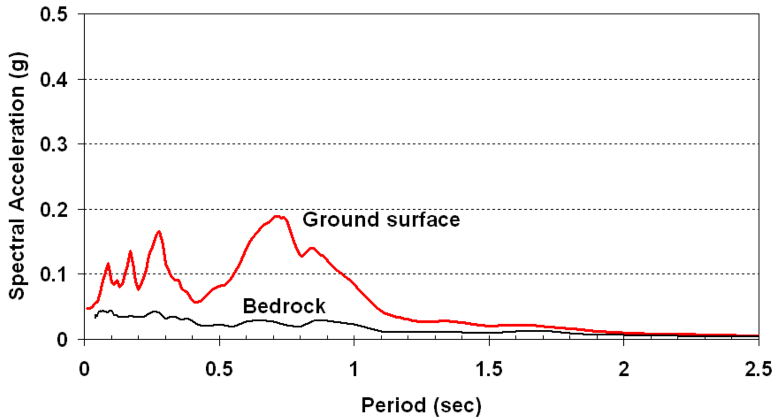
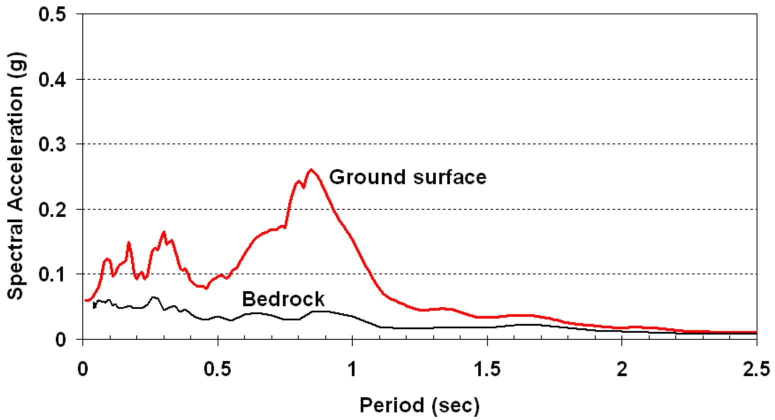
Response Spectra for Creve Coeur Lake Bridge from Wabash Valley Seismic Zone

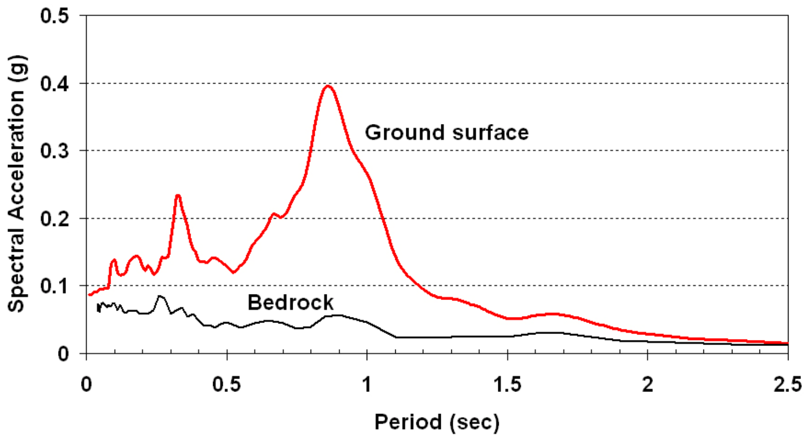
Rock and Ground surface spectral accelerations for
Creve Coeur Bridge Magnitude 6.0 event at 210 km



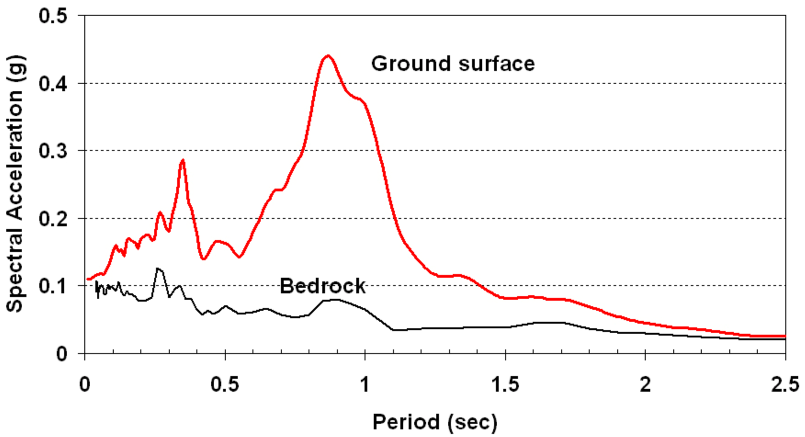
Rock and Ground surface spectral accelerations for
Creve Coeur Bridge Magnitude 6.3 event at 210 km



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



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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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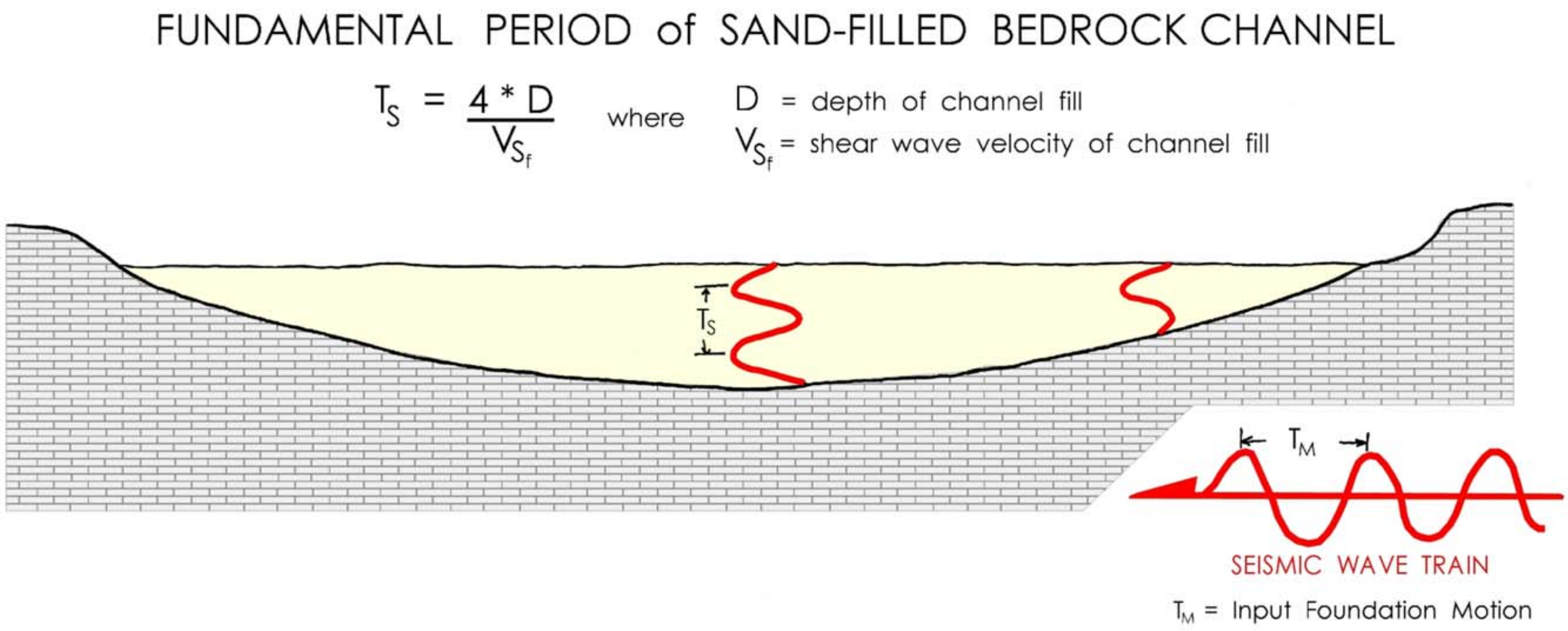
Resonance of the "soil column"



- **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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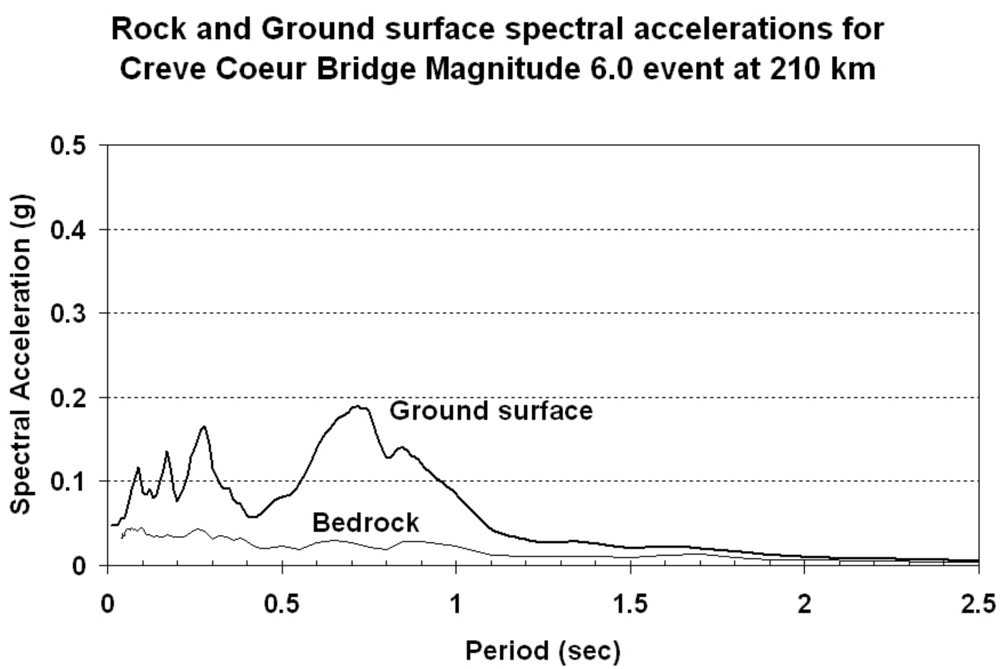

Characteristic Site Period for Creve Coeur Bridge

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

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

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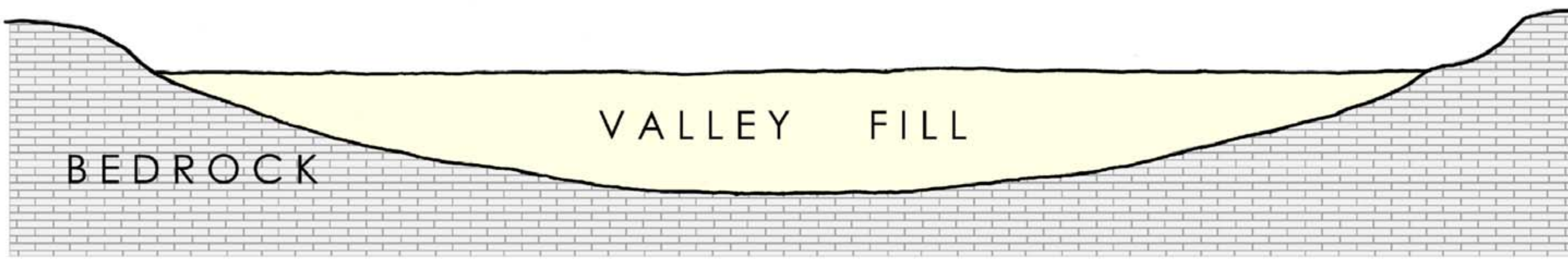
IMPEDANCE

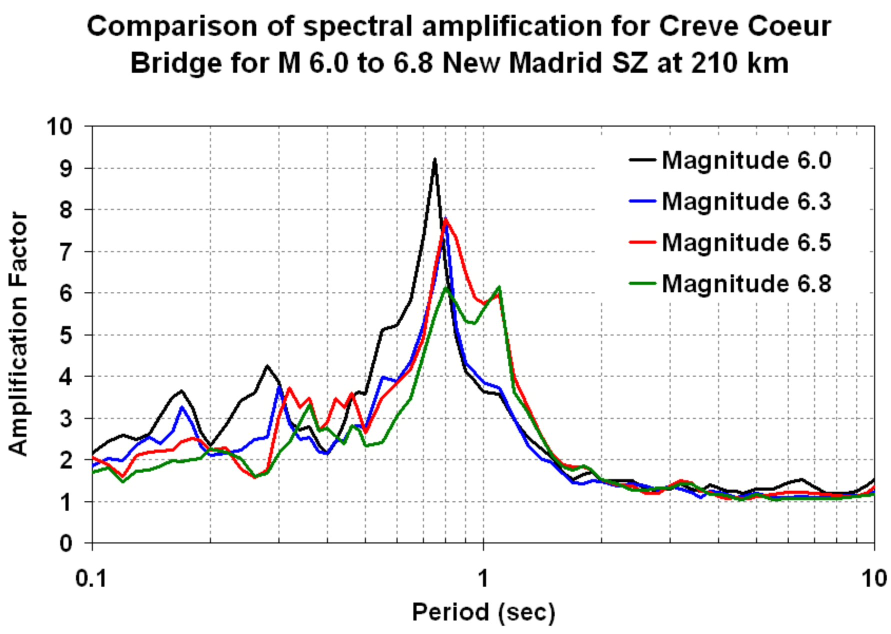


$$\text{IMPEDANCE RATIO} = \frac{\rho_{\text{FOUNDATION}} * V_{S\ \text{BEDROCK}}}{\rho_{\text{VALLEY FILL}} * V_{S\ \text{VALLEY FILL}}}$$

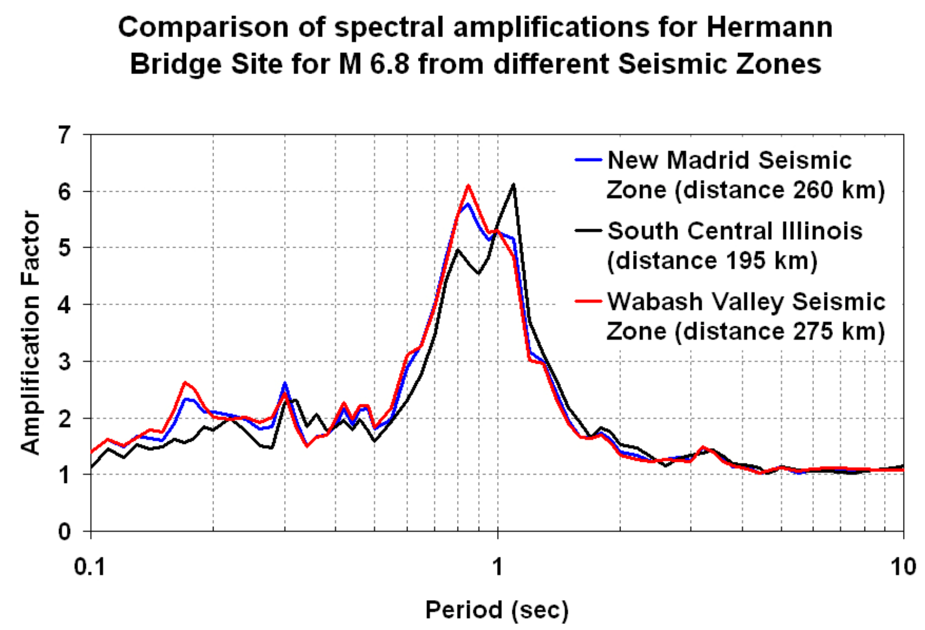
- **Site amplification is a function of the Impedance Ratio between the valley fill and the underlying basement rock.**
- **Amplification increases as the impedance ratio between two layers increases. Impedance Ratios in Midwestern US channels are among the most excessive examples identified anywhere in the world.**

Amplification of the Ground Motion

Creve Coeur Bridge



Hermann Bridge



New Madrid 210 km

Note the drop in amplification as magnitude increases

Comparison M 6.8 from all sources

Note the similar amplification factors

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Significant Site Amplification Predicted along Missouri River Valley

- **Amplification Factors** for Creve Coeur Bridge (at 110, 195 and 210 km) varies between **600% and 950%** for Magnitudes 6.0, 6.3, 6.5 and 6.8.

- **Amplification Factors** for the Hermann Bridge Site (at 195, 260, and 275 km) varies between **500% and 1000%** for Magnitudes 6.0, 6.3, 6.5 and 6.8.

LIQUEFACTION or "QUICK SAND"

Liquefaction is a failure mechanism by which sandy or silty materials lose shear strength when the pore pressure is excited to a level equal to the confining stress. Usually occurs within 50 feet of the ground surface.

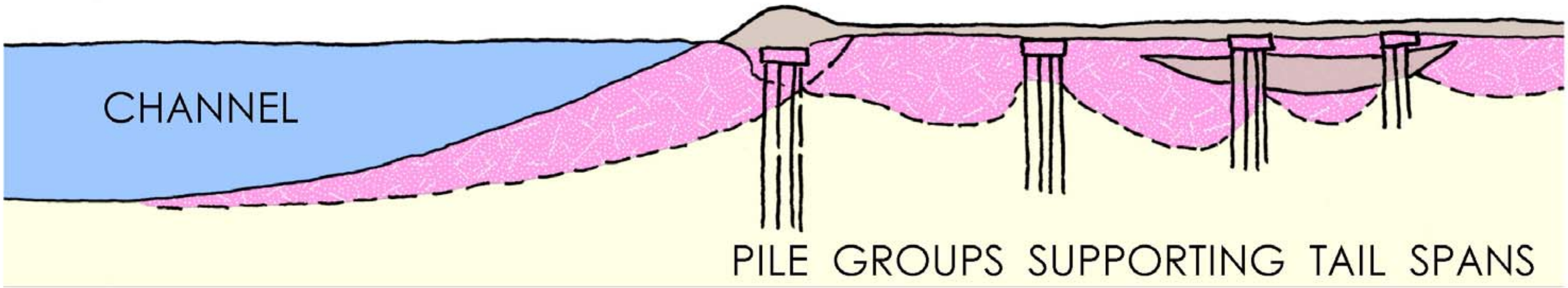
- Recent sand blows dot the landscape surrounding New Madrid, MO, testifying to massive liquefaction

- **Enormous tracts of land in NE Arkansas exhibit evidence of paleoliquefaction – on a grandiose scale**

LIQUEFACTION

- Bridge failures during April 1991 M7.5 Costa Rica earthquake
- Though supported on steel and concrete piles respectively, these bridges both failed due to liquefaction of foundation materials, which tilted the piles

ZONES COMMONLY SUSCEPTIBLE to LIQUEFACTION



- **Simply supported tail spans would appear to be most vulnerable part of Missouri's highway bridges**
- **Site amplification causes long period motions to peak between 0.40 and 1.6 seconds; bad for bridges**
- **We can expect extensive liquefaction of foundations for Magnitudes > 6.6 (areas shown in pink)**

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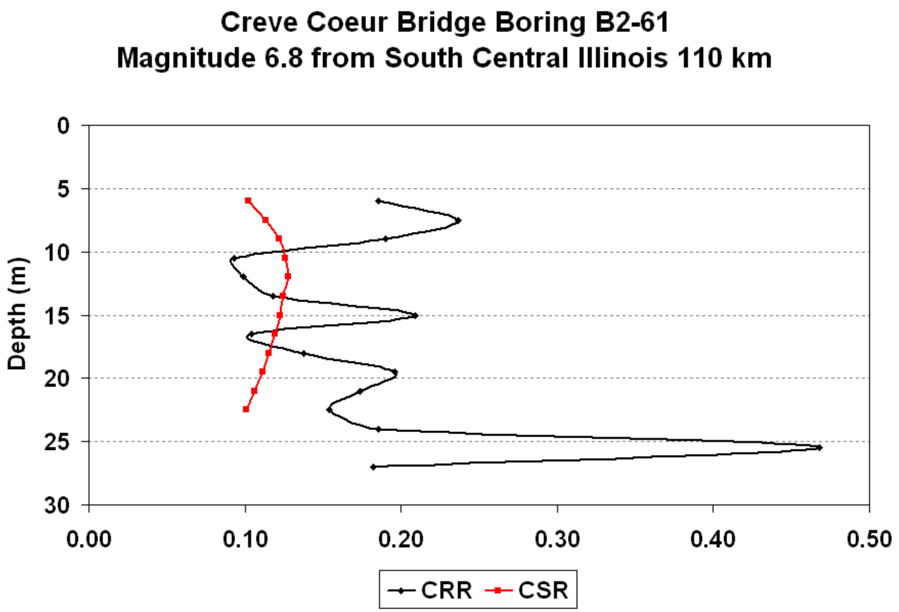
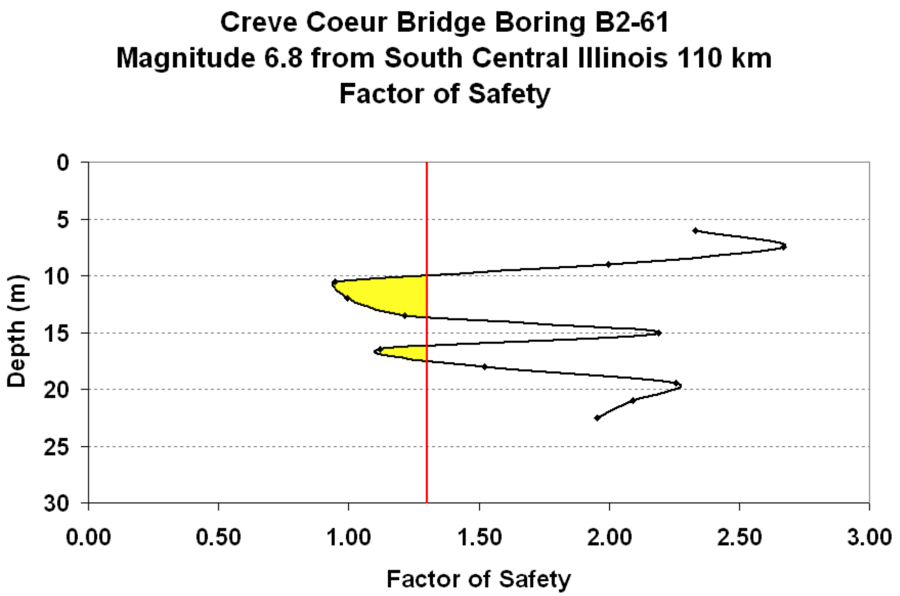
Creve Coeur Bridge Liquefaction Screening for M 6.8 event emanating from South Central Illinois





CSR vs. CRR

Factor of Safety

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CONCLUSIONS - 1

- Earthquakes could strike St. Louis from any one of three seismic zones; over a range of azimuths
- Significant site amplification can be expected when the soil cover is greater than about 46 ft. Most of St. Louis lies on less than 20 ft of soil cover.
- The threshold for widespread liquefaction at distances >200 km is about Magnitude 6.7

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CONCLUSIONS - 2

- The river bridges would be subjected to long period motions, which could pose a significant threat to simply-supported tail spans founded on friction piles.
- Large amplifications can be expected at both bridge sites. Amplification of the ground motion is in the range of 500% to 1000%.
- 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.

CONCLUSIONS - 3

- Widespread liquefaction predicted at the Creve Coeur Bridge site for ≥ M 6.8 event, but only localized liquefaction for M 6.3 to M 6.7 quakes.
- 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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