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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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.
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.
Assumed earthquake source distances

<table>
<thead>
<tr>
<th>Seismic Zone</th>
<th>Creve Coeur Bridge</th>
<th>Hermann Bridge Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Central Illinois</td>
<td>110 km</td>
<td>195 km</td>
</tr>
<tr>
<td>Wabash Valley Seismic Zone</td>
<td>195 km</td>
<td>275 km</td>
</tr>
<tr>
<td>New Madrid Seismic Zone</td>
<td>210 km</td>
<td>260 km</td>
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</tbody>
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Creve Coeur Bridge-Page Extension
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
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

<table>
<thead>
<tr>
<th>Model</th>
<th>Name</th>
<th>Site Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atkinson-Boore 1995 (AB95)</td>
<td>ENA Hard Rock</td>
</tr>
<tr>
<td>2</td>
<td>USGS 1996</td>
<td>Generic B-C Boundary</td>
</tr>
<tr>
<td>3</td>
<td>USGS 1996 (modified)</td>
<td>Mid-Continent Deep Soil (new)</td>
</tr>
<tr>
<td>4</td>
<td>Mid-America Deep Soil AB95 source (modified)</td>
<td>Mid-Continent Deep Soil (new)</td>
</tr>
<tr>
<td>5</td>
<td>Mid-America Deep Soil USGS96 source (modified)</td>
<td>Mid-Continent Deep Soil (new)</td>
</tr>
</tbody>
</table>
Creve Coeur Lake Bridge
Artificial Time Histories from 3 sources

South Central Illinois
Distance = 110 km
\( M_o = 6.5 \quad a_{\text{max}} = 0.06g \)

Wabash Valley Seismic Zone
Distance = 195 km
\( M_o = 6.5 \quad a_{\text{max}} = 0.038g \)

New Madrid Seismic Zone
Distance = 210 km
\( M_o = 6.5 \quad a_{\text{max}} = 0.034g \)
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

Main Features Include:

1) 1-D non-linear analysis
2) 1-D equivalent linear analysis

Developed by:
Youssef Hashash and
Duhaa Park

User Interface: Daniel Turner

For future updates check
neifiles.uiuc.edu/hashash/www
or contact hashash@uiuc.edu

1-D Wave Propagation Analysis Program for Geotechnical Site Response
Analysis of Deep Soil Deposits

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Sponsored in part by NSF Grant EEIC-9701785
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).
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)
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).
Long period motions (T > 1.0 second) become important when evaluating structures > 150 km from the quake hypocenter.
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)
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.

\[ T_S = \frac{4 \times D}{V_{Sf}} \]

where

\( D \) = depth of channel fill
\( V_{Sf} \) = shear wave velocity of channel fill
Characteristic Site Period for Creve Coeur Bridge

- Average $V_s = 182.6$ m/sec
- Average thickness = 35 meters
- Average Characteristic Period
  \[ T_c = 4 \times \frac{35}{182.6} = 0.76 \text{ sec} \]
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 = $\rho V_s \dot{u}^2$

- Since $\rho$ 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

Comparison of spectral amplification for Creve Coeur Bridge for M 6.0 to 6.8 South Central Illinois at 110 km

Comparison of spectral amplification for Creve Coeur Bridge for M 6.0 to 6.8 New Madrid SZ at 210 km

South Central Illinois
110 km

New Madrid
210 km
Hermann Missouri River Bridge Amplification Spectra

Comparison of spectral amplifications for Hermann Bridge Site for M 6.0 from different Seismic Zones

- New Madrid Seismic Zone (distance 260 km)
- South Central Illinois (distance 195 km)
- Wabash Valley Seismic Zone (distance 275 km)

Comparison of spectral amplifications for Hermann Bridge Site for M 6.8 from different Seismic Zones

- New Madrid Seismic Zone (distance 260 km)
- South Central Illinois (distance 195 km)
- Wabash Valley Seismic Zone (distance 275 km)
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

Hermann Bridge Site Boring B35+56
Magnitude 6.8 from South Central Illinois 195 km

CSR vs. CRR

Factor of Safety

- CRR
- CSR

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.
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 $\geq M 6.8$ 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.
Thank You
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