SITE-AMPLIFICATION MAPS FOR THREE QUADRANGLES IN THE ST LOUIS AREA, MISSOURI AND ILLINOIS

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In 2005 USGS-CEUS office organized a St. Louis Area Seismic Hazard Mapping Project Technical Working Group (SLAHMP-TWG).

The SLAHMP-TWG convenes four times a year to discuss mutual goals and assignments for the 5-year NEHRP earthquake hazards program (EHP) study, focusing on evaluating relative seismic risks and ground shaking hazards posed to the St. Louis Metropolitan area.

The study area encompasses about 4,000 km$^2$ across 29 USGS 7.5-minute quadrangles.
Our pilot feasibility study has selected three 1:24,000 scale quadrangles: 1) Granite City, 2) Monks Mound and, 3) Columbia Bottom, encompassing downtown St Louis and the area immediately to the east and north, including the Mississippi River floodplain.

These seismic hazard maps are based on accurate assessments of site-amplification that incorporate considerations of actual geologic conditions underlying these areas.
What information do we need to estimate site amplification?

1) Characterize the bedrock properties below the surficial materials

2) Characterize the bedrock acceleration

3) Characterize the shallow geology overlying the bedrock
   Surficial geology maps
   Depth to Bedrock

4) Characterize the properties of the surficial materials (soil cap)
   Physical soil properties
   Dynamic soil properties (Shear modulus and damping, Shear-wave velocity)
Shear wave velocity of the weathered bedrock interface

- Frequency
- Shear-wave velocity (m/sec)

- 400-600
- 600-800
- 800-1000
- 1000-1200
- 1200-1400
- 1400-1600
- 1600-1800
- 1800-2000
- 2000-2200
- 2200-2400
- 2400-2600
Data below surficial materials

- We used 2000 m/sec for the weathered bedrock shear-wave velocity as suggested by Bob Hermann, St. Louis University.
- We have selected 50 m thickness of the weathered bedrock.
- We used 2800 m/sec for the half-space below the weathered bedrock.
What do we need to know to estimate the amplifications?

1) Characterize the bedrock properties

2) Characterize the bedrock acceleration

3) Characterize the shallow geology
   - Surficial geology maps
   - Depth to Bedrock

4) Characterize the soil properties
   - Physical soil properties
   - Dynamic soil properties (Shear modulus and damping, Shear-wave velocity)
## Earthquake time-series on Rock used in Amplification analysis

<table>
<thead>
<tr>
<th>Year</th>
<th>Mw</th>
<th>Dist</th>
<th>Earthquake</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>M7.3</td>
<td>194 km</td>
<td>Landers, CA</td>
<td>200, 290</td>
</tr>
<tr>
<td>1999</td>
<td>M7.1</td>
<td>184 km</td>
<td>Duzce, Turkey</td>
<td>E, N</td>
</tr>
<tr>
<td>1999</td>
<td>M7.6</td>
<td>183 km</td>
<td>Chi Chi, Taiwan</td>
<td>N, W</td>
</tr>
<tr>
<td>1999</td>
<td>M7.1</td>
<td>194 km</td>
<td>Hector Mine, CA</td>
<td>360, 90</td>
</tr>
<tr>
<td>2002</td>
<td>M7.5</td>
<td>200 km</td>
<td>Atkinson and Beresnev</td>
<td></td>
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<tr>
<td></td>
<td>M8.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2002</td>
<td>M7.0</td>
<td>200 km</td>
<td>Boore’s SMSIM Code</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M7.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Acceleration-time histories

Atkinson and Beresnev, 2002
Distance = 200 km, Mw = 8.0

1999 Duzce Earthquake
Distance = 184 km, Mw = 7.3

SMSIM v2.2 Distance = 200 km, Mw = 7.5

Hector Mine, CA Earthquake
Distance = 194 km, Mw = 7.1
6 different earthquakes are selected. With the components, 14 different scenarios were used in the analysis.

The amplification depends on the amplitude and frequency of the ground motion.

Distribution of site amplification are built at a particular amplitude and frequency.

The real ground motions are “scaled” to input rock motions at ten different shaking levels (0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8 and 1.0g).
What do we need to know to estimate the amplifications?

1) Characterize the bedrock type
2) Characterize the bedrock acceleration
3) Characterize the shallow geology
   Surficial geology maps
   Depth to Bedrock
4) Characterize the soil properties
   Physical soil properties
   Dynamic soil properties (Shear modulus and damping, Shear-wave velocity)
Geology Interpretation
Data Points

Legend
- Depth to Bedrock Data
  - Sources
- WELL_TYPE
  - City of St Louis Water Division
  - Engineering Boring
  - IL Division of Highways
  - ILDOT
  - ISGS Wetlands Section
  - Interpretations
  - Mega CD
  - MoDOT borehole
  - Private boreholes
  - Stratigraphic well
  - URS Isopleth
  - US Army Corp. of Eng.
  - USGS
  - Water well

UMR

3 1.5 0 1.5 3
Kilometers

COLUMBIA BOTTOM

WOOD RIVER

GRANITE CITY

MONKS MOUND
Estimation of Top of Bedrock Elevations

Legend
Top of Bedrock Elevation Prediction Map in meters
Filled contours:
- 47 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120
- 120 - 130
- 130 - 140
- 140 - 163

COLUMBIA BOTTOM
WOOD RIVER
GRANITE CITY
MONKS MOUND

4 3 2 1 0 4
Kilometers
Depth to Bedrock

Legend
Depth to top of Bedrock in meters
- 0
- 0.1 - 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - 60
- 60.1 - 70
- 70.1 - 80

COLUMBIA BOTTOM
GRANITE CITY
MONKS MOUND

Kilometers
What do we need to know to estimate the amplifications?

1) Characterize the bedrock type

2) Characterize the bedrock acceleration

3) Characterize the shallow geology
   Surficial geology maps
   Depth to Bedrock

4) Characterize the soil properties
   Physical soil properties
   Dynamic soil properties (Shear modulus and damping, Shear-wave velocity)
Shear Modulus and Damping
EPRI (1993)
Compilation of shear-wave velocity profiles

- Five main sources are used:
  - University of Missouri Rolla
  - United States Geological Survey
  - Illinois State Geological Survey
  - Missouri Department of Natural Resources
  - Local Private Companies

- Total of 76 shear wave velocity measurements are used.
Local Vs Analyses

Total of 9 sites were selected for the assessment of the uncertainty in determining Vs for various surficial geology and for the generation of the local characteristic Vs profiles.
Floodplain (Alluvial) deposits

Characteristic Profiles

\[ V_s = 134 \text{ m/s} \]
\[ \sigma = 33 \text{ m/s} \]

\[ V_s = 180 \text{ m/s} \]
\[ \sigma = 30 \text{ m/s} \]

\[ V_s = 218 \text{ m/s} \]
\[ \sigma = 34 \text{ m/s} \]

\[ V_s = 250 \text{ m/s} \]
\[ \sigma = 50 \text{ m/s} \]

\[ V_s = 256 \text{ m/s} \]
\[ \sigma = 50 \text{ m/s} \]

\[ V_s = 286 \text{ m/s} \]
\[ \sigma = 53 \text{ m/s} \]
Characteristic Profiles

Loessal Upland deposits

- $V_s = 179 \text{ m/s}$
  - $\sigma = 51 \text{ m/s}$

- $V_s = 241 \text{ m/s}$
  - $\sigma = 86 \text{ m/s}$

- $V_s = 325 \text{ m/s}$
  - $\sigma = 116 \text{ m/s}$

- $V_s = 442 \text{ m/s}$
  - $\sigma = 167 \text{ m/s}$

- $V_s = 481 \text{ m/s}$
  - $\sigma = 211 \text{ m/s}$
Amplification calculations

- Uncertainties are present in all components of the site-amplification calculation.

- Uncertainties present due to:
  - Variations in the shear-wave velocity
  - Variations in density values and dynamic soil properties
  - Estimation of the depth to the top of bedrock
  - Differences in time-histories.

- These may cause large differences in amplification calculations when combined.
Amplification calculations

- State-of-the-art completely probabilistic approach is applied.
- This approach is the same approach taken by Chris Cramer for Memphis Seismic Hazard Maps.
- The properties of sediments are selected randomly
  - From a suite of Vs profiles.
  - From dynamic soil properties.
  - From estimated thickness distributions.
  - From suite of acceleration-time histories.
Amplification uncertainty analysis

- For each frequency and amplitude, the process of randomly choosing a ground-motion record and scaling it, randomly choosing a set of sediment properties, and calculating the response to the scaled input motions is repeated by 100 times.

- SHAKE91 is used to calculate the response.
Amplification uncertainty analysis

- The amplification factor distributions are represented by mean values and their standard deviations.
- These amplification distributions are calculated on a grid for every 0.005 degree for loess and 0.01 degree for alluvium.
- Total of approximately 1000 grid points.
Grid points

Legend
- Data on loess every ~0.5 km
- Data on alluvium every ~1 km
Amplification distribution in Alluvium
Amplification Distribution in Loess
Site-Amplification Sensitivities

- We have conducted an uncertainty and sensitivity analysis for the site-amplifications generated.
- The Monte Carlo randomization procedure used in generating the site-amplification distributions provides an estimate of uncertainty.
- We examined the sensitivity to a specific parameter by fixing the Monte Carlo choices for all parameters.
Input ground motion sensitivity
Thickness of weathered bedrock sensitivity
Shear wave velocity of weathered bedrock sensitivity
This preliminary study calculated the amplification distributions for the St Louis Metro area for different ground motion shaking levels. These amplification distributions are calculated in order to estimate hazard in a “fully probabilistic” approach.
Conclusions - 2

- Calculations indicate that the greatest sensitivity comes from the choice of the input time-series, at all levels of ground motion.

- The thickness and shear wave velocity of the weathered bedrock below the soil profile has little impact on amplification and uncertainties.
Conclusions

- Other uncertainties in site-amplification include:
  - The choice of soil-response program
  - Dynamic pore pressure changes
  - Site-specific dynamic soil properties

- Site-amplification uncertainties may range between 20-50% because of the choice of the various input parameters.
Acknowledgments

- We would like to thank St Louis Earthquake Hazard Mapping Program Technical Working Group for their technical oversight and much of the needed data.

- Special thanks to Professor Chris Cramer at the University of Memphis for his recommendations and ongoing review of the hazard mapping process.