BRIEF OVERVIEW OF
SEISMIC THREAT POSED TO STRUCTURES IN THE ST. LOUIS METRO AREA

J. David Rogers, Ph.D., P.E., R.G., C.E.G.
Karl F. Hasselmann Chair in Geological Engineering
Natural Hazards Mitigation Institute
University of Missouri-Rolla

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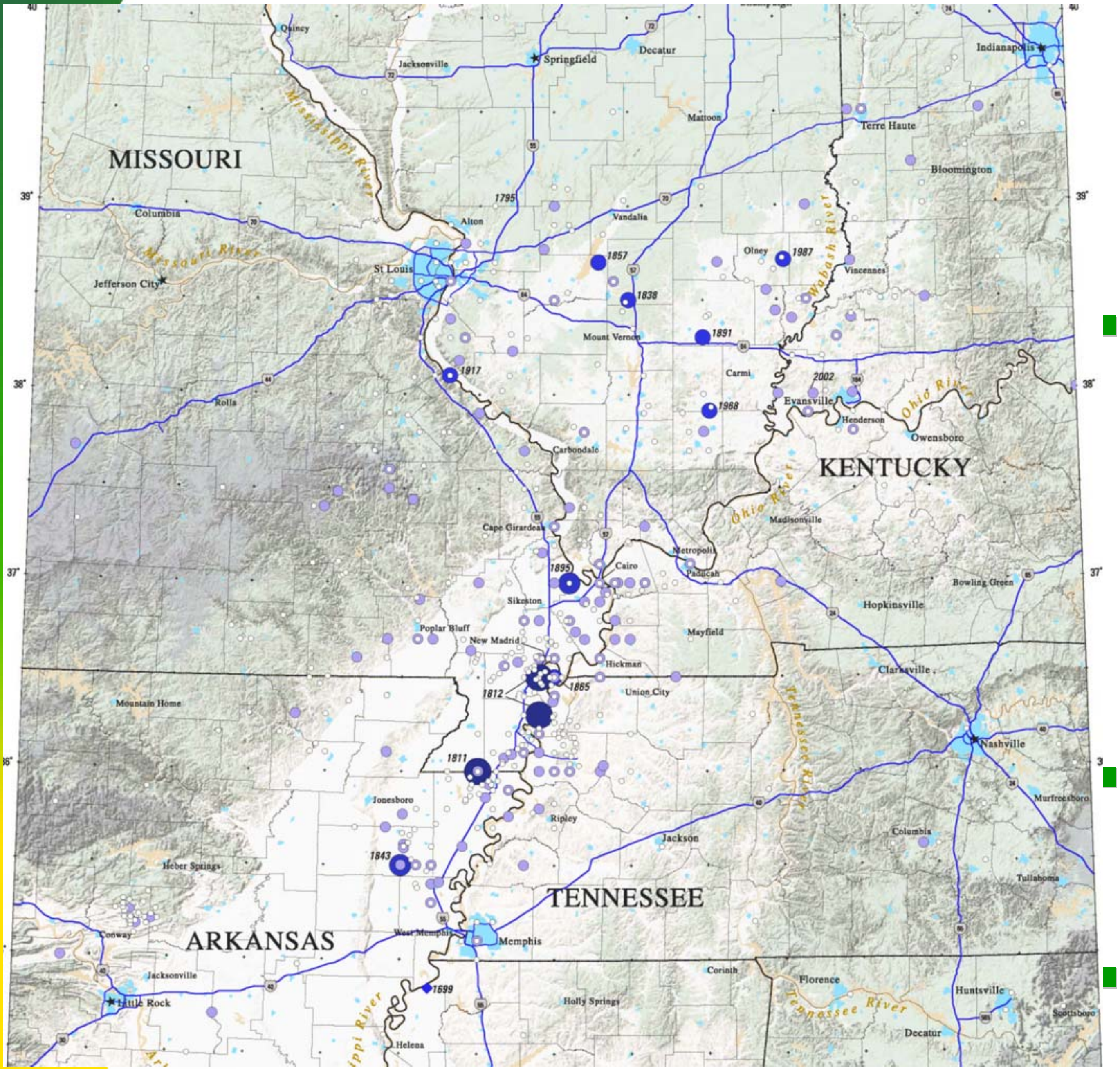

MIDWEST SEISMIC SOURCES

- **Not all of the region's quakes emanate from the New Madrid Seismic Zone**
- **Wabash Valley Seismic Zone**
- **South Central Illinois**

POST 1812 SEISMICITY in NEW MADRID SEISMIC ZONE

- M6.3 quake in Marked Tree, AR in 1843; did considerable damage to Memphis, 60-70 km east
- M6.6 quake in Charleston, MO in 1895; Felt in 23 states, 30 km of sand blows
- M5.4 in Wabash Valley (Dale, IL) in 1968; also felt in 23 states; light damage in St. Louis
- M5.0 in Wabash Valley west of Vincennes, IN (Olney, IL) in 1987
- M4.6 near Evansville, IN in 2002

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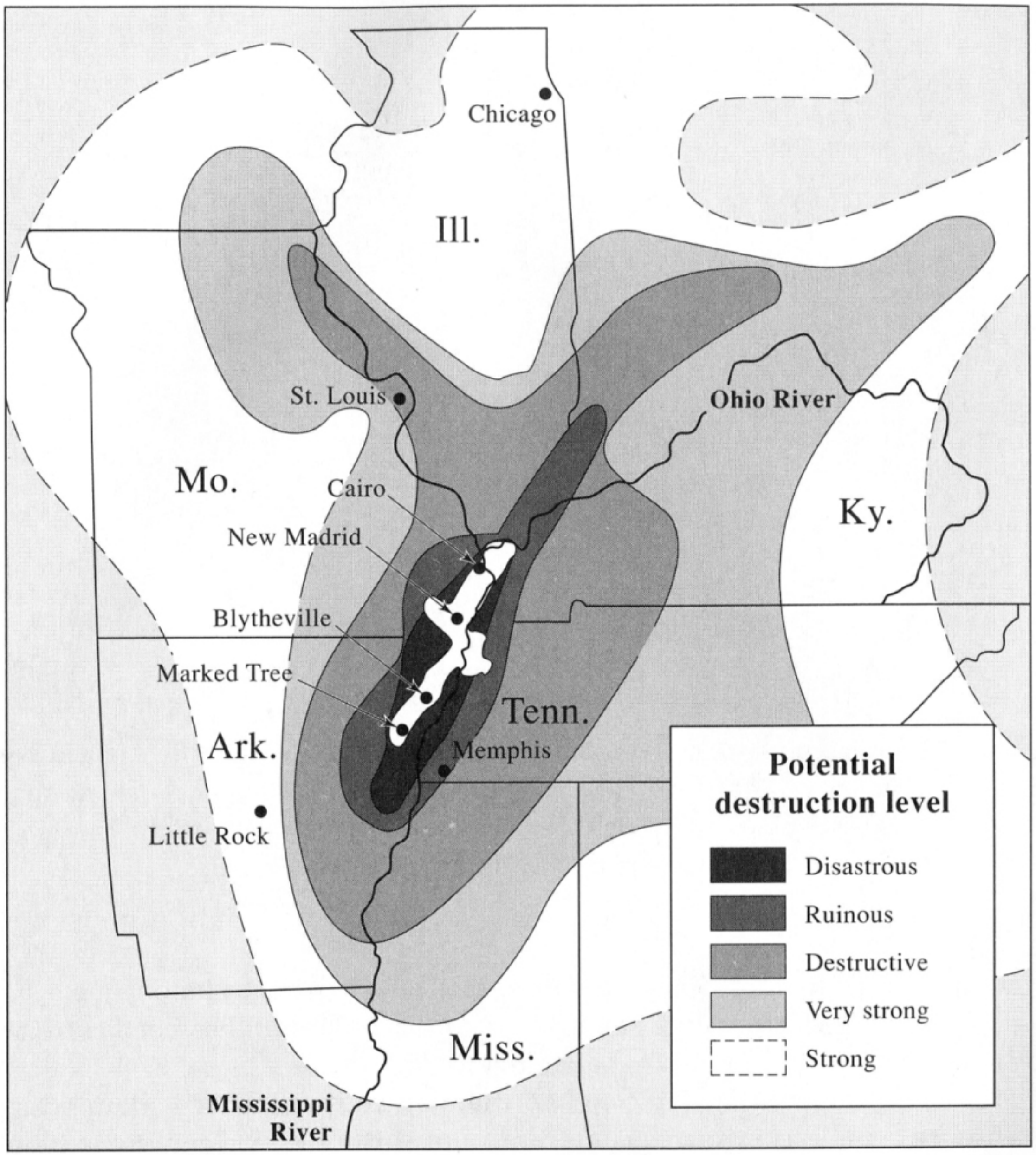

DAMAGE POTENTIAL

Published damage predictions for the New Madrid Seismic Zone have focused on the near field area, in the upper Mississippi Valley

These are based on synthetic motion time histories with assumed soil cover; not on site specific characteristics or dynamic properties of structures.

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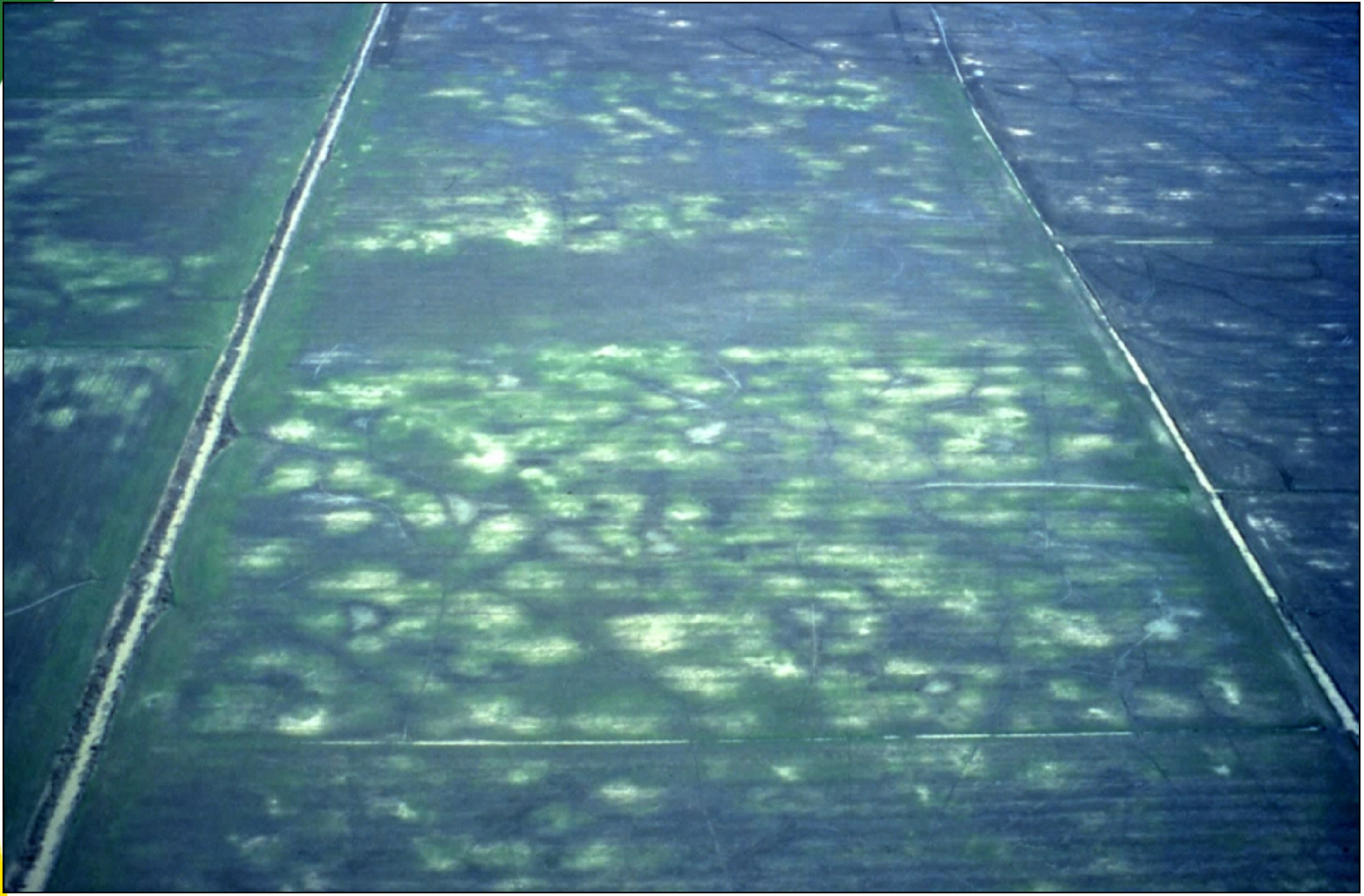
LIQUEFACTION or "QUICK SAND"

Liquefaction is a failure mechanism by which cohesionless materials (sand and silt) lose shear strength when the pore pressure is excited to a level equal to the effective confining stress. Usually limited to the upper 50 feet and typically occurs in silt, sand and fine gravel.

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



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

- **Farm lands west of Big Lake, AR reveal a series of linear fissures which disgorged liquefied sand from beneath a silt cover.**

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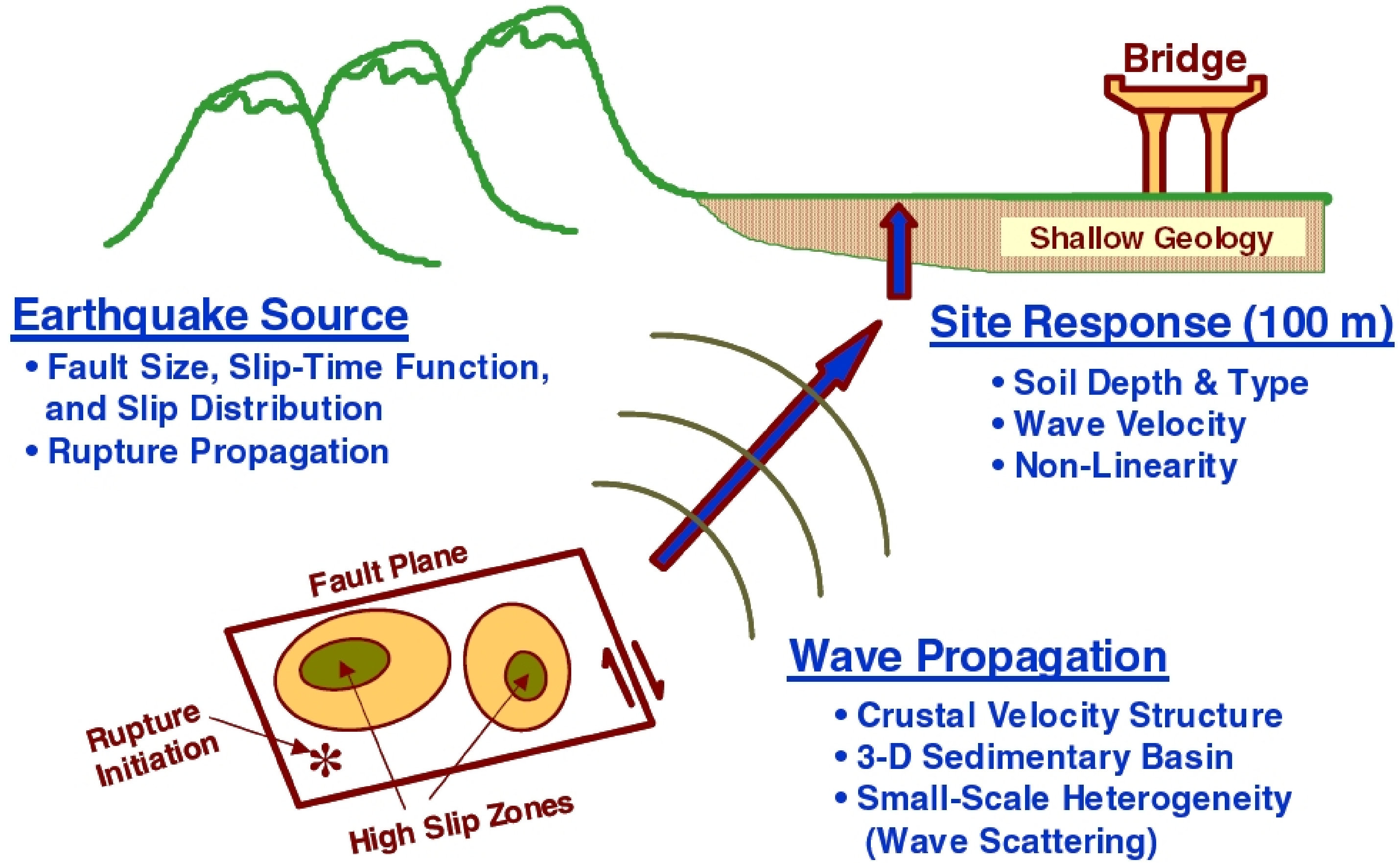
LIQUEFACTION

- 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



- **The type, depth and size of earthquake combine with geophysical properties of the underlying geology to affect seismic site response**

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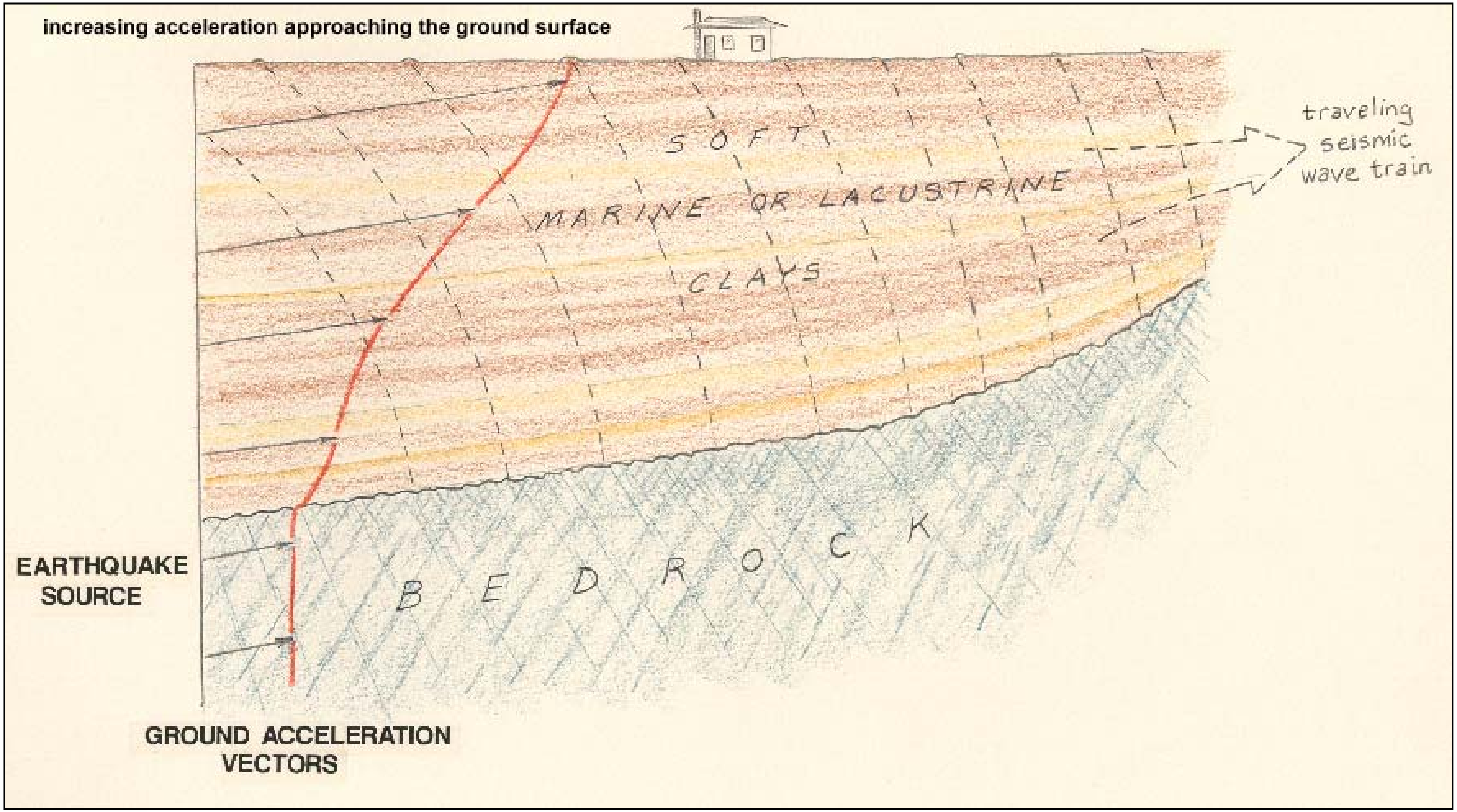
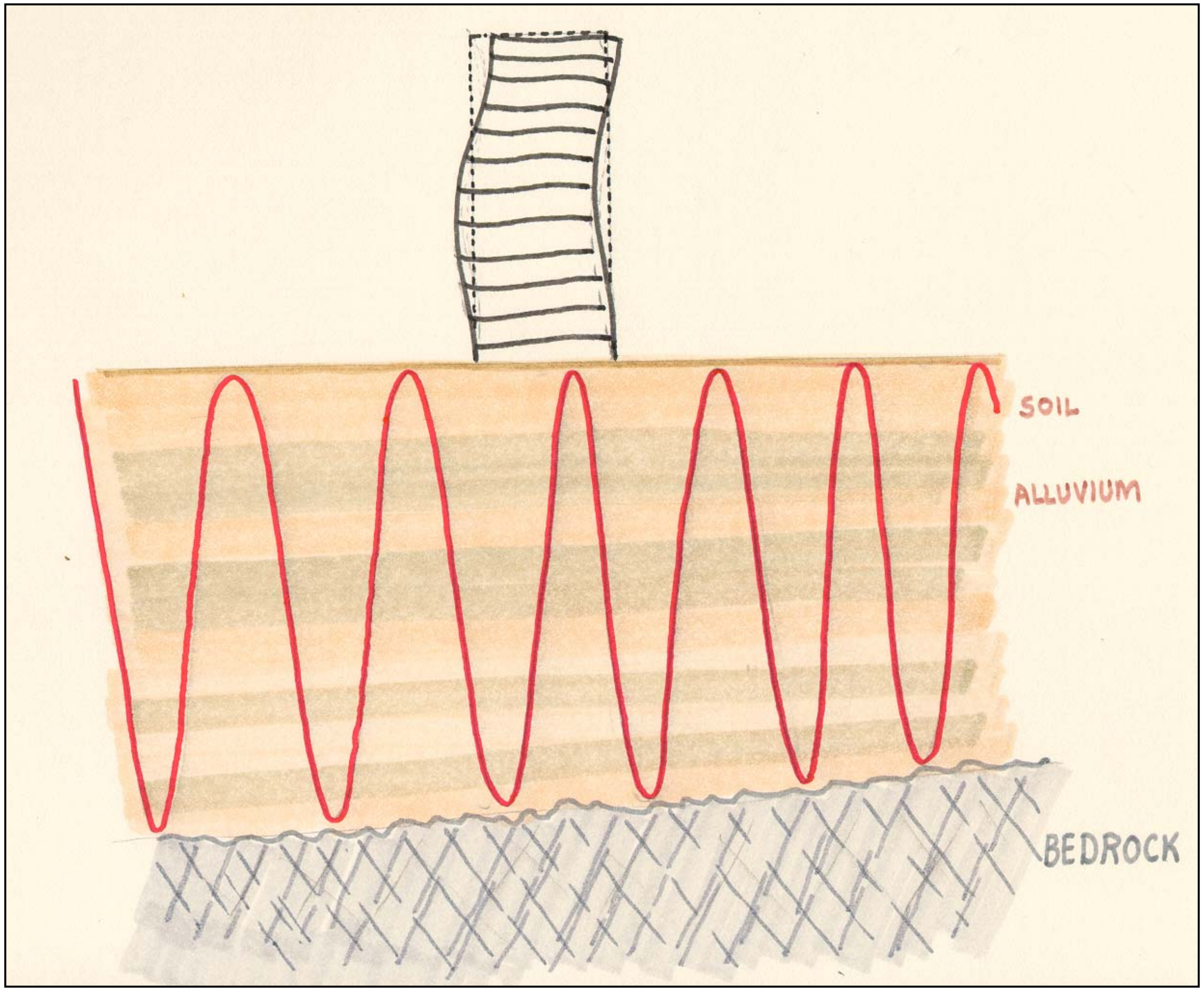
WHAT IS SITE RESPONSE ?



- **Site response is used to describe the fundamental period of vibration generated by a typical earthquake at any particular site. If soft unconsolidated sediments overlie resistant bedrock an impedance contrast develops at this boundary which causes incoming seismic energy to be absorbed at a rate faster than it can be transferred through the upper layers, causing significant amplification of ground motions.**

SITE RESPONSE VERSUS STRUCTURAL RESPONSE



- The fundamental period of vibration of any structure depends on its design and construction details. If the site period and structural period converge, a resonant frequency results which may be an order of magnitude greater than the natural site period, and the structure will be severely damaged or destroyed.

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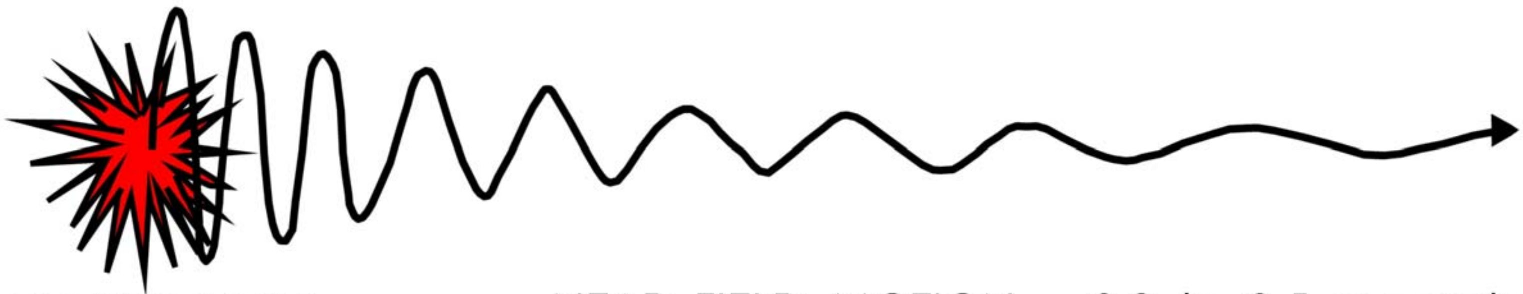
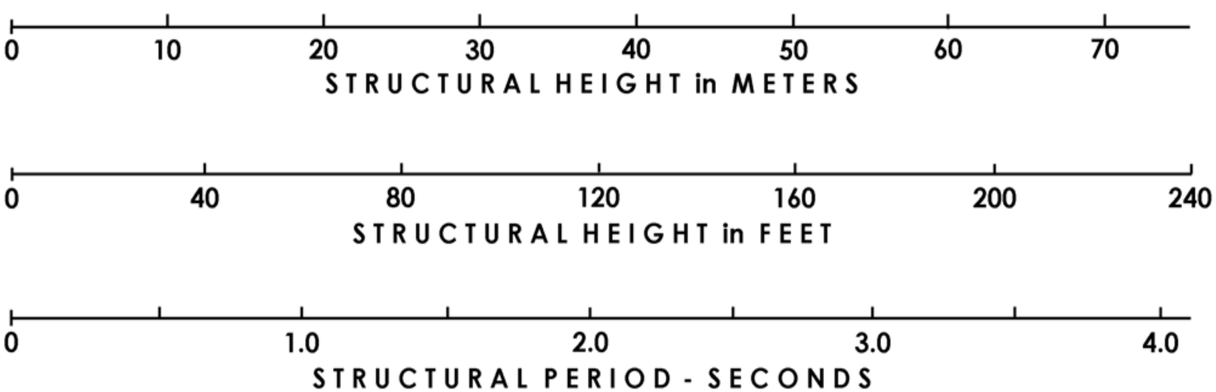
LENGTHENING of SEISMIC WAVE TRAIN with DISTANCE from SOURCE



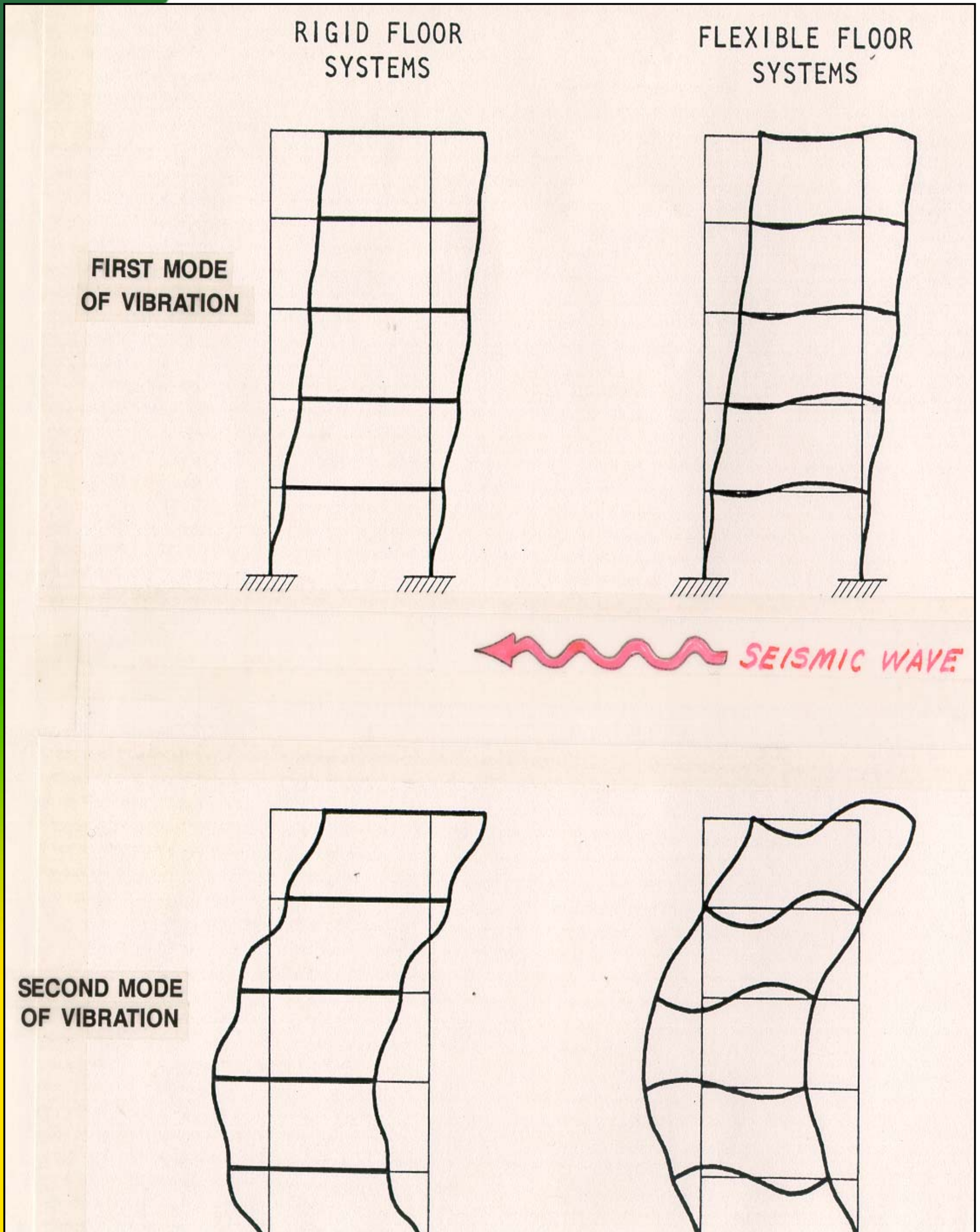
EARTHQUAKE SOURCE

NEAR FIELD MOTION ~ 0.3 to 0.5 seconds
LONG PERIOD MOTION > 1.0 seconds

FUNDAMENTAL PERIOD vs STRUCTURE HEIGHT



- **Long period motions (T > 1.0 second) of great import when evaluating structures > 160 km from the quake hypocenter**



MODES OF VIBRATION

- All structures posses fundamental modes of vibration which depend on their skeletal make-up: including material type, shear panels, connections, span distances and symmetry.
- This fundamental mode is known as the “first mode of vibration” and it generally controls the seismic design of most symmetrical structures.
- Secondary modes of vibration become increasingly important in complex structures with asymmetrical form or stiffness, or structures with damaged frames.

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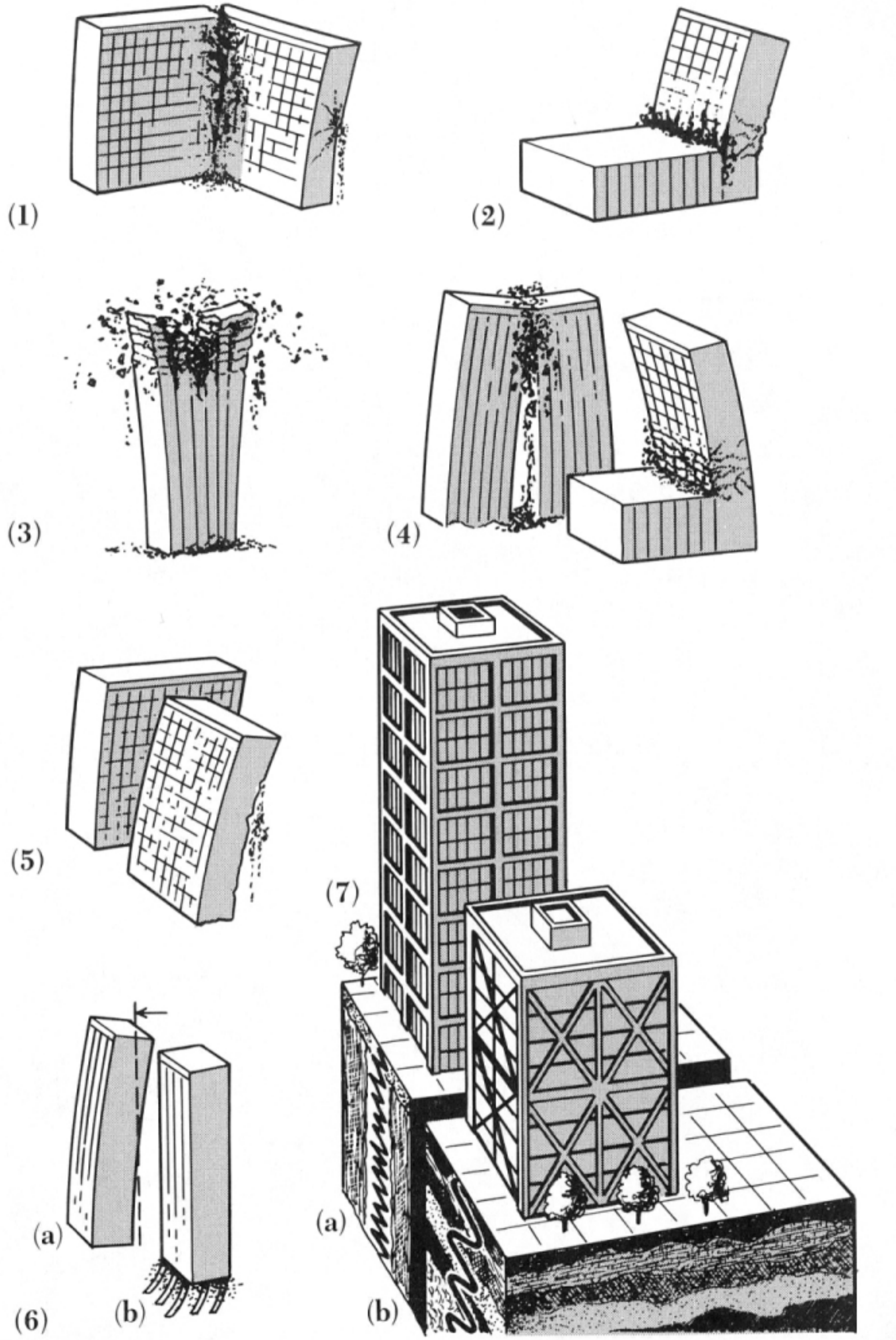
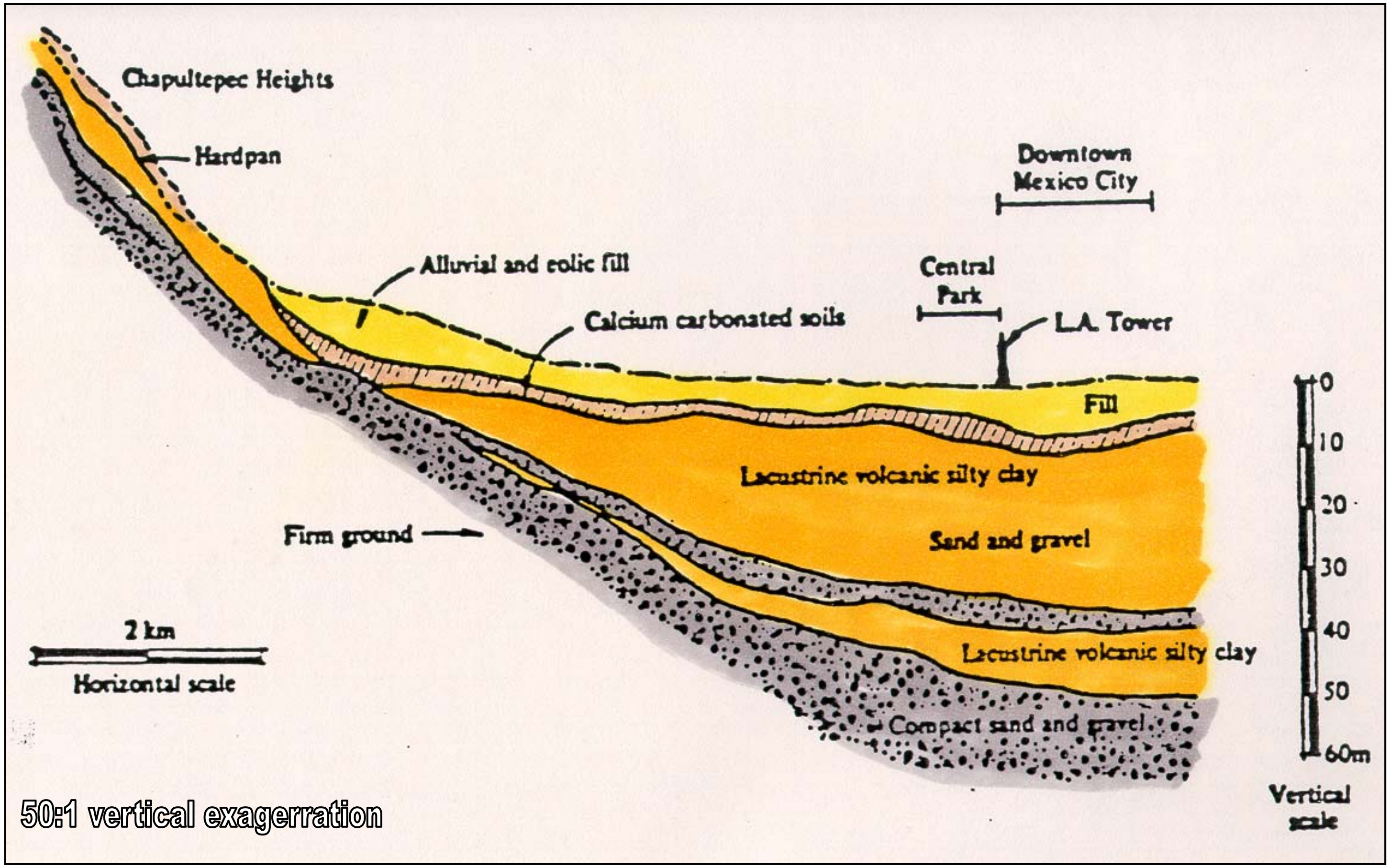


OUT-OF-PHASE MOTION

- **Adjacent structures can react differently to seismic excitation, depending on focal aspects of incoming energy, long period motion, site amplification, and degrading structural response as frames become damaged**

SOFT SEDIMENTS UNDERLYING MEXICO CITY



- **Generalized geologic cross section of the southern margins of the lacustrine basin underlying Mexico City. The lacustrine sediments were covered with fill as the city developed. These soft materials amplified the incoming seismic wave train from a M.8.1 earthquake located about 350 km from Mexico City!**

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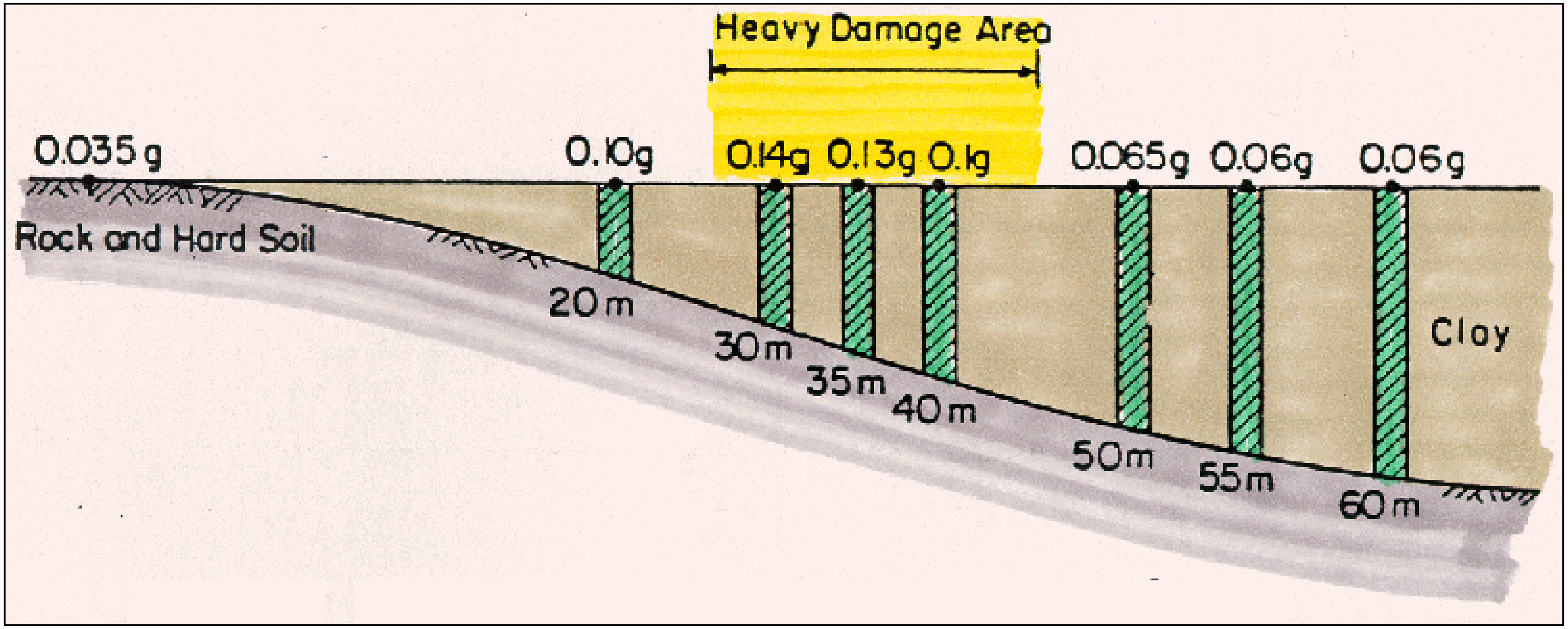
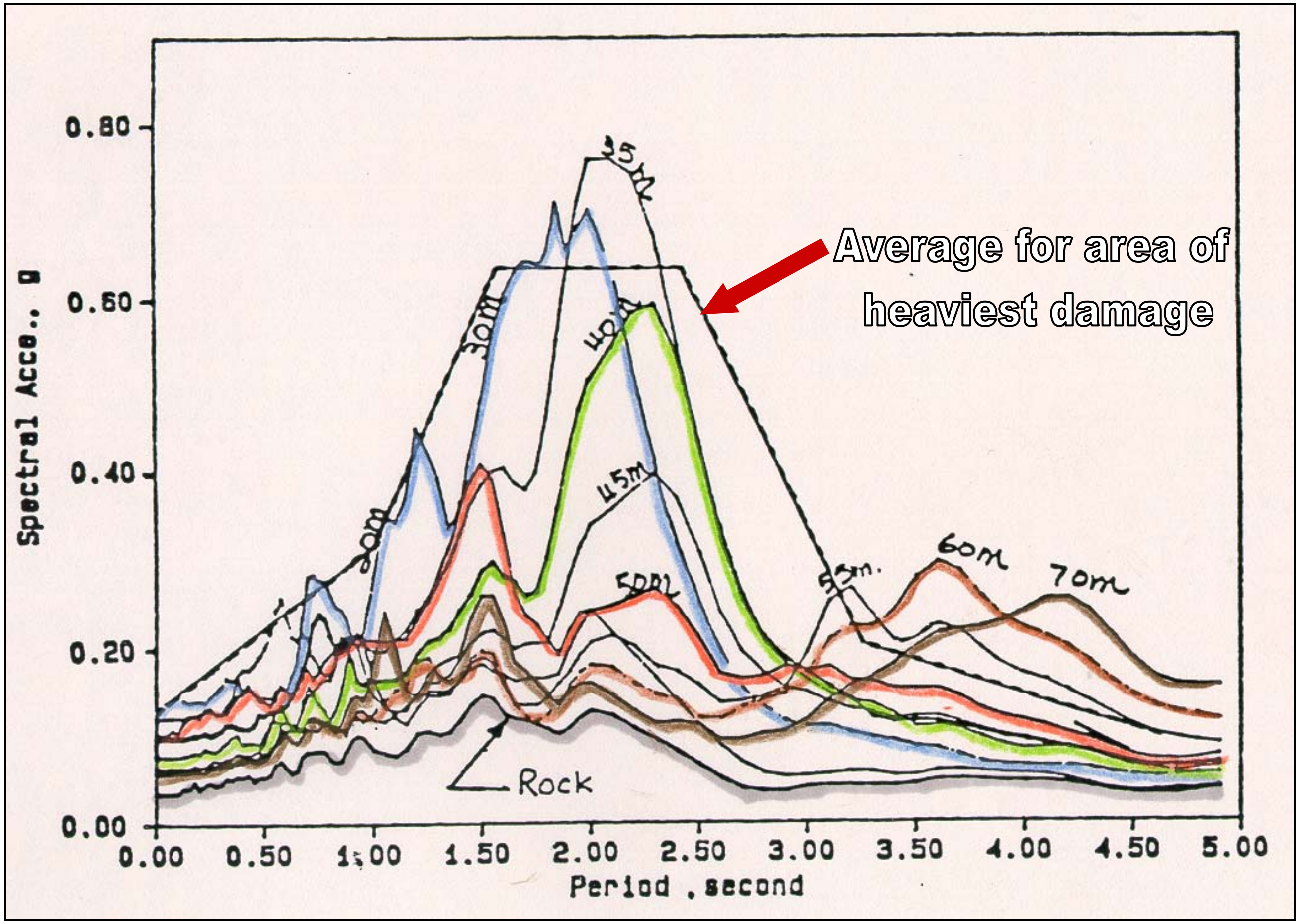
ZONE OF HEAVIEST DAMAGE DURING 1985 MEXICO CITY EARTHQUAKE



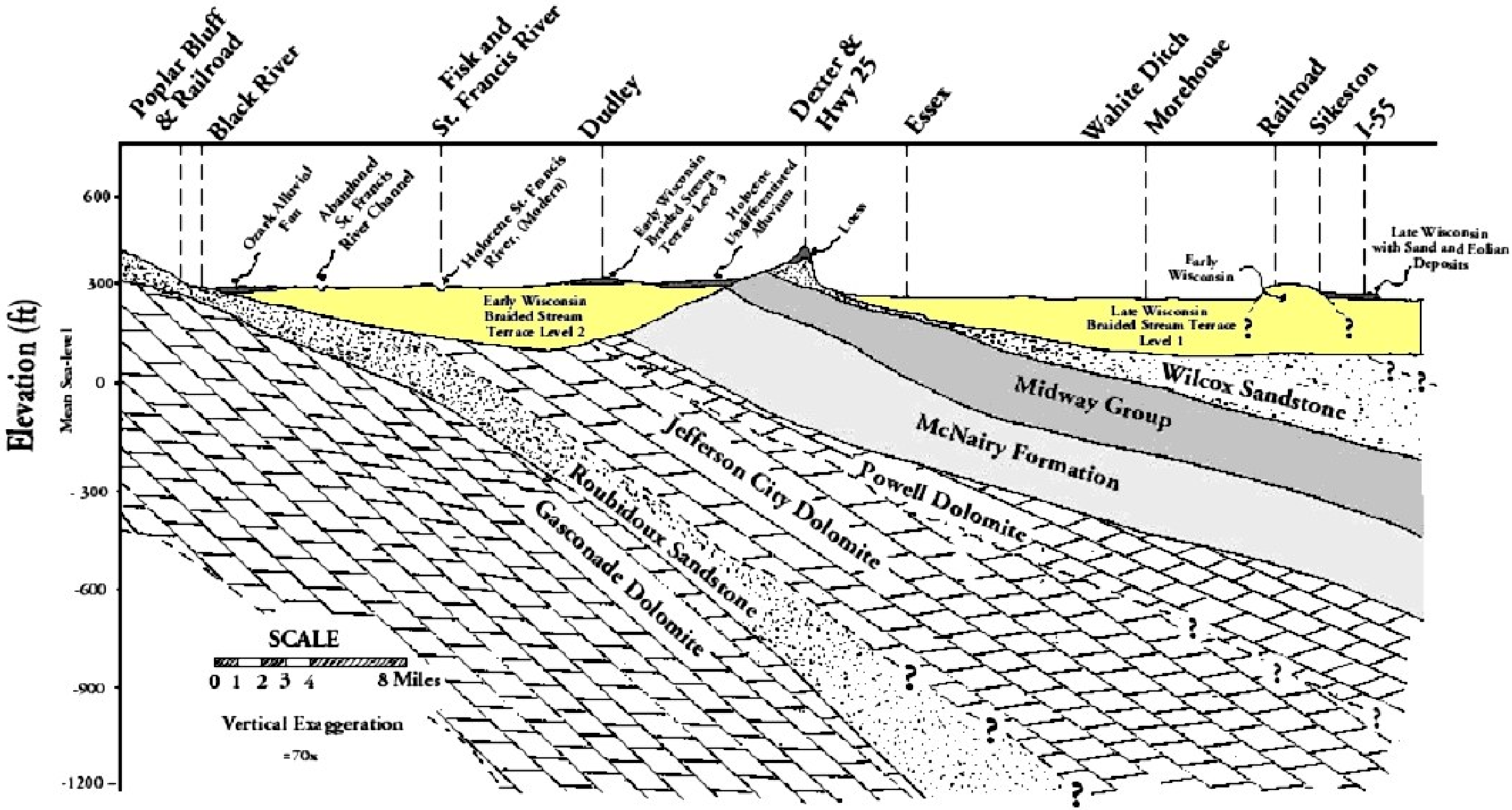
- Computed distribution of peak ground surface accelerations for typical soil profiles in Mexico City, bounding the zone that experienced severe damage during the 1985 M. 8.1 Michoacan earthquake. The earthquake shaking lasted close to 3 minutes. More than 500 buildings within the highlighted zone were severely damaged and 100 buildings between 6 and 22 stories high actually collapsed; killing 9,500, injuring 30,000 and leaving 100,000 homeless.

VARIANCE OF RESPONSE SPECTRA WITH SEDIMENT THICKNESS IN MEXICO CITY



- Response spectra calculated for different thicknesses of soft sediments in southern Mexico City, between downtown and Chapultepec Heights. Note impact of 30 to 45 m thickness.

Geology Northern Mississippi Embayment



Impedance contrasts within the Wisconsin age river channels (yellow) likely pose the greatest seismic threat to structures in the Midwest.

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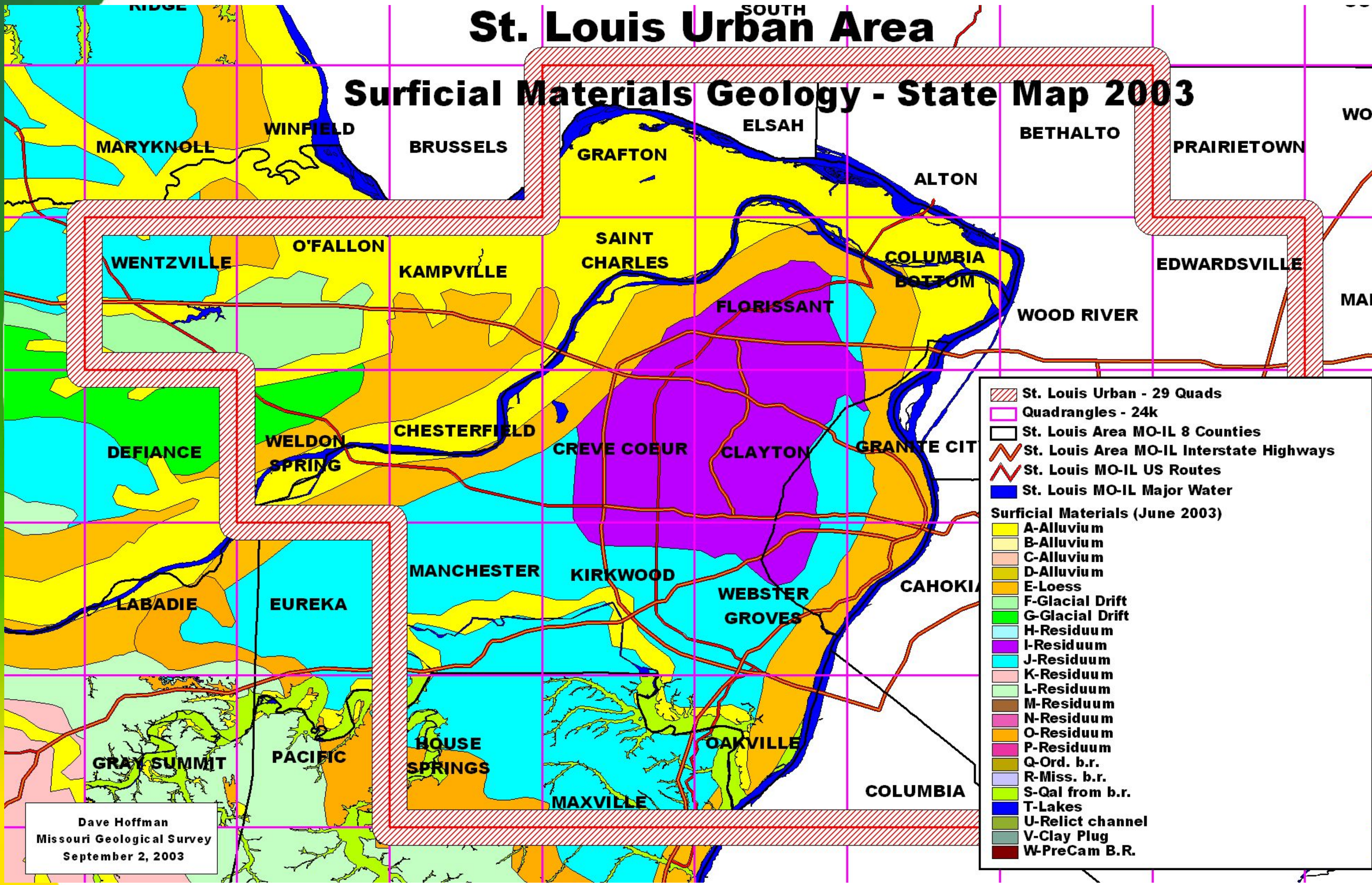

- **Geologic map of surficial materials in St. Louis area, west of Mississippi River**

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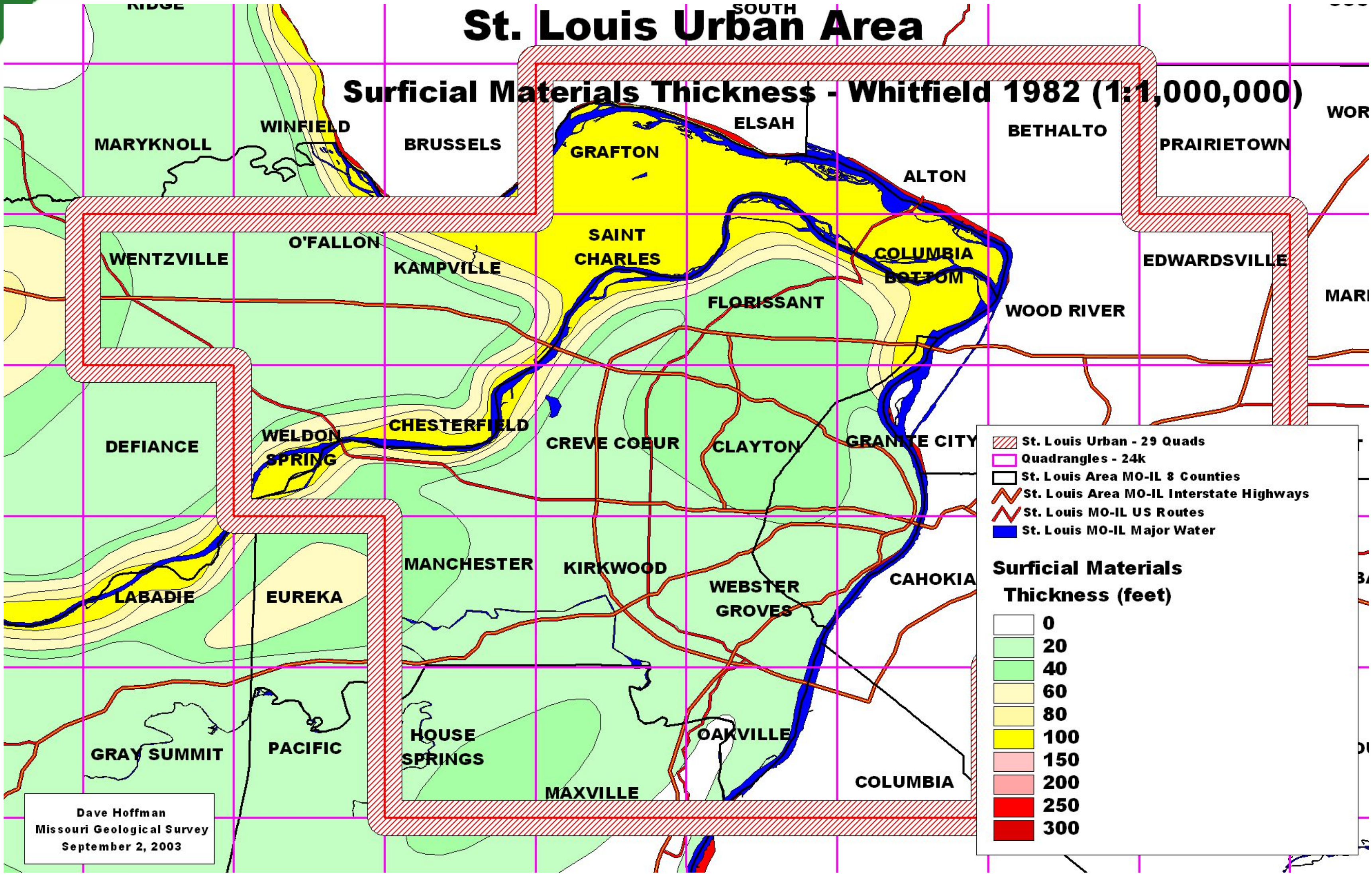
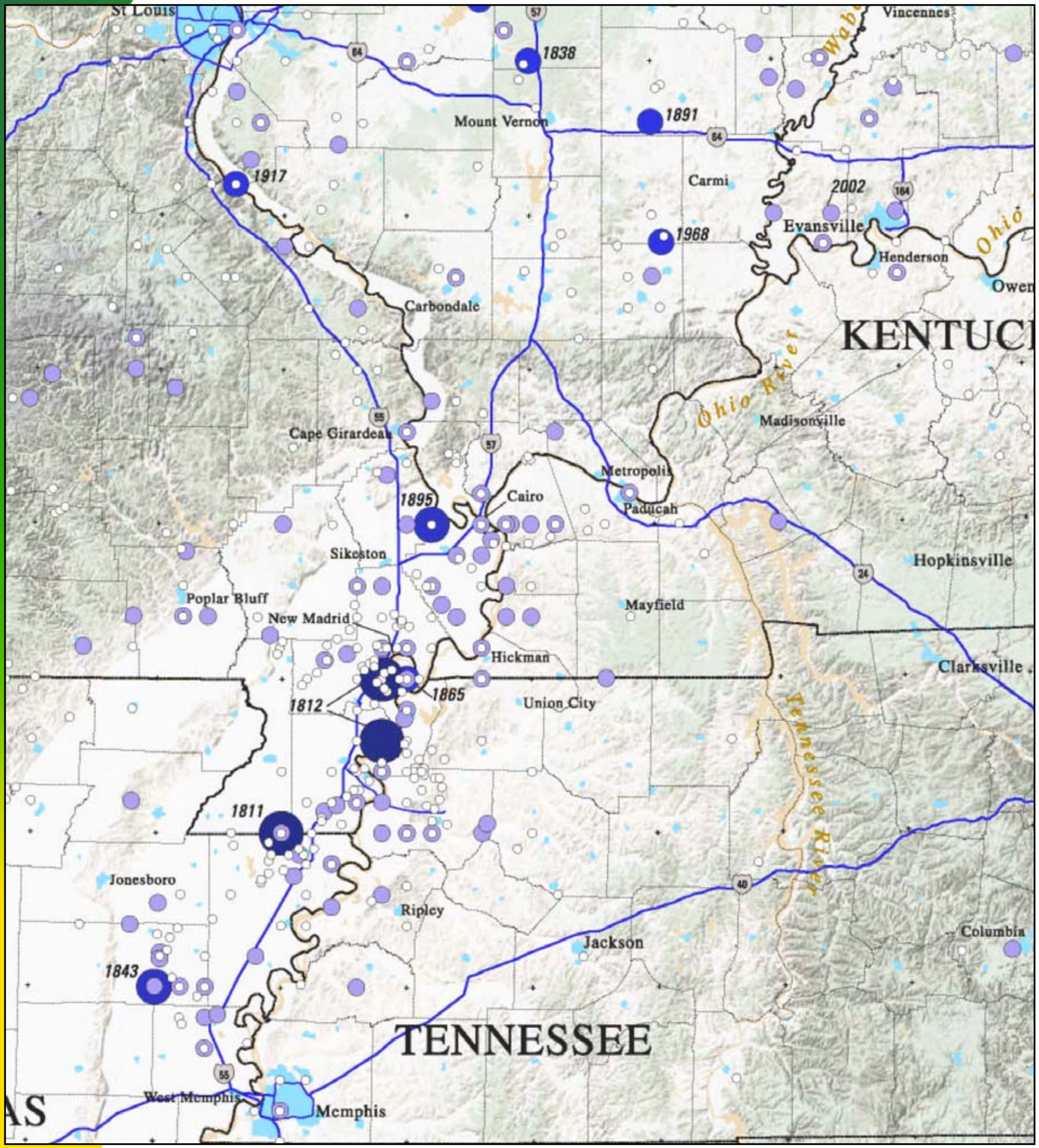


- Depth to bedrock varies between 0 and about 100 feet in St. Louis, west of the Mississippi River

WHAT IS THE DESIGN EARTHQUAKE?



- >M7.5 in ~550
- >M7.5 in ~900
- >M7.5 in ~1450
- M7.5+ in 1811
- M8.0 in 1812
- M6.3 in 1843
- M6.6 in 1895
- M5.4 in 1968
- M5.0 in 1987
- M4.6 in 2002

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Recurrence Intervals for New Madrid Earthquake Events*

Magnitude	Recurrence Interval
4.0	14 Months
5.0	10 – 12 Years
6.0	70 – 90 Years
7.0	254 – 500 Years
8.0	550 – 1200 Years

* based on existing data; always subject to update and revision

MOST LIKELY QUAKE

- In our lifetimes, the most likely earthquake to impact St. Louis would be something similar to the Magnitude 6.6 Charleston, MO quake of 1895, which has a recurrence frequency of 70+/- 15 years (overdue since 1980).
- It could emanate from either the New Madrid Zone, the Wabash Valley Fault Zone, or from south central Illinois

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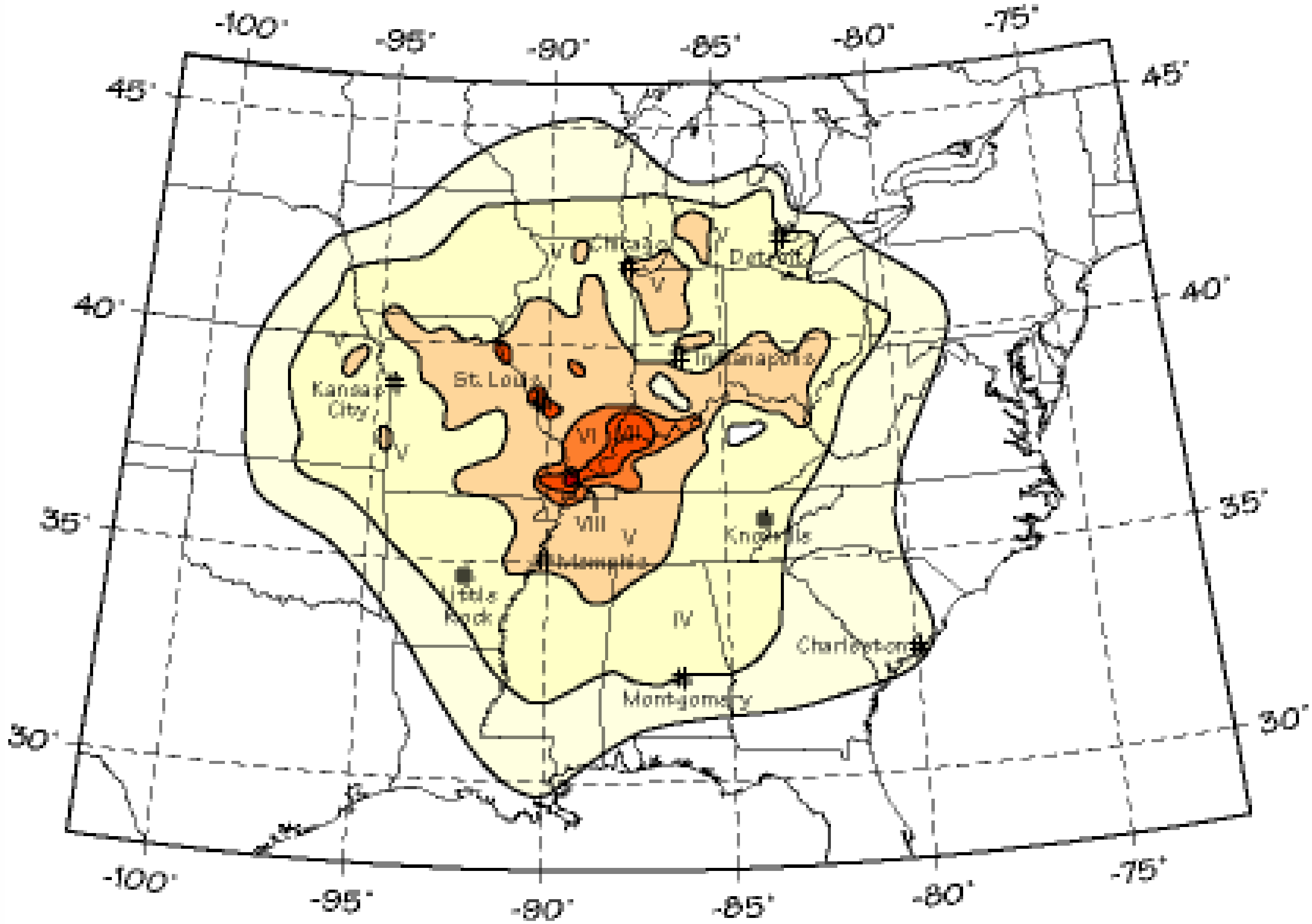
Earthquake Shaking Intensity Map



- **1895 M6.6 Charleston, MO earthquake**

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SCREENING ANALYSES

- A series of site response evaluations were made on the Page Avenue Extension bridges in western St. Louis, located:
  - About 115 km from the south central Illinois area which spawned the 1857 M 5.1 1857 quake
  - about 215 km from the 1895 M 6.6 Charleston, MO quake in the New Madrid Seismic Zone.
  - About 223 km from the location of the 1987 M 5.0 Olney, IL quake in the Wabash Valley Fault Zone

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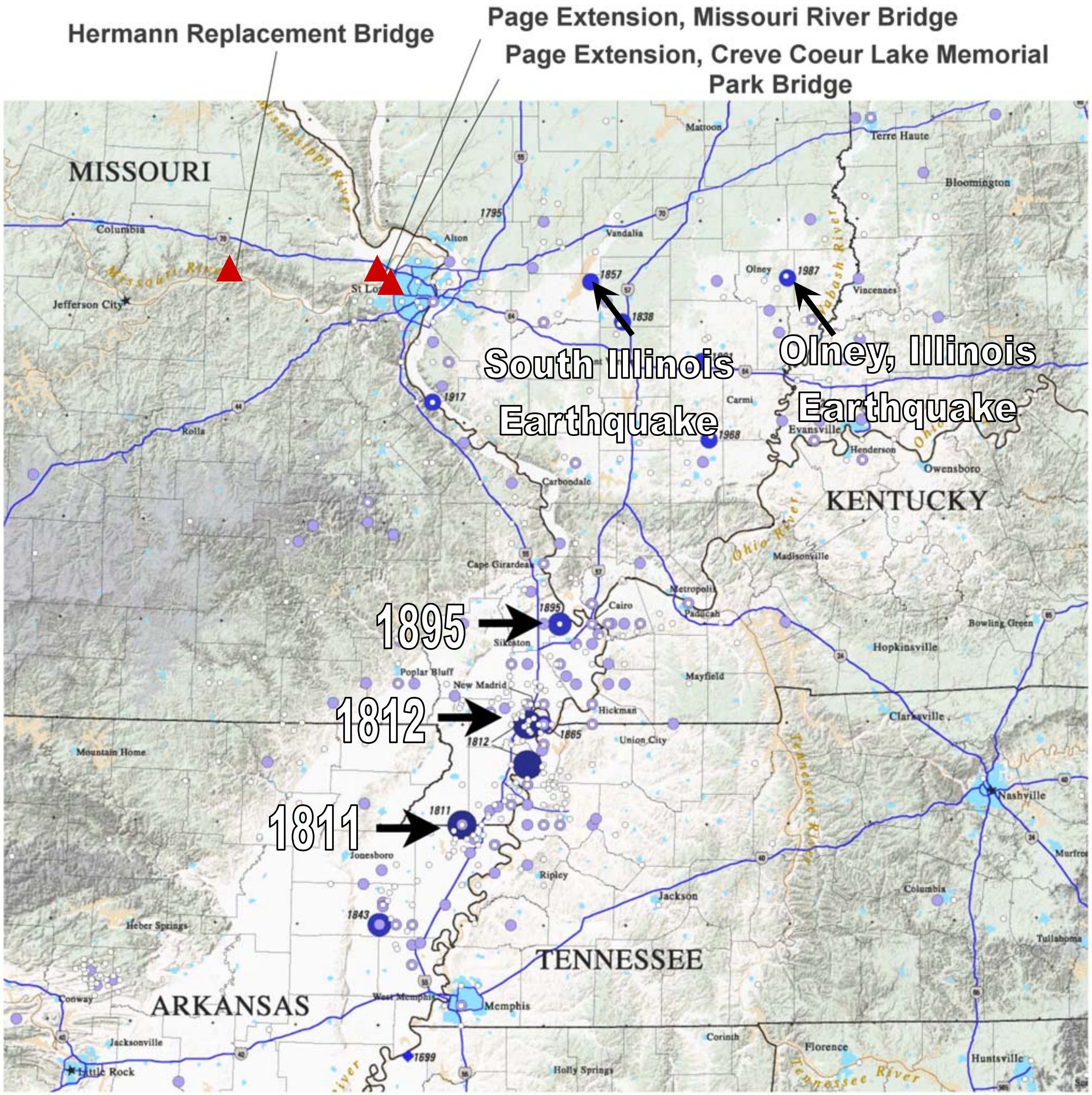
Bridge Locations With Respect to the New Madrid Seismic Zone



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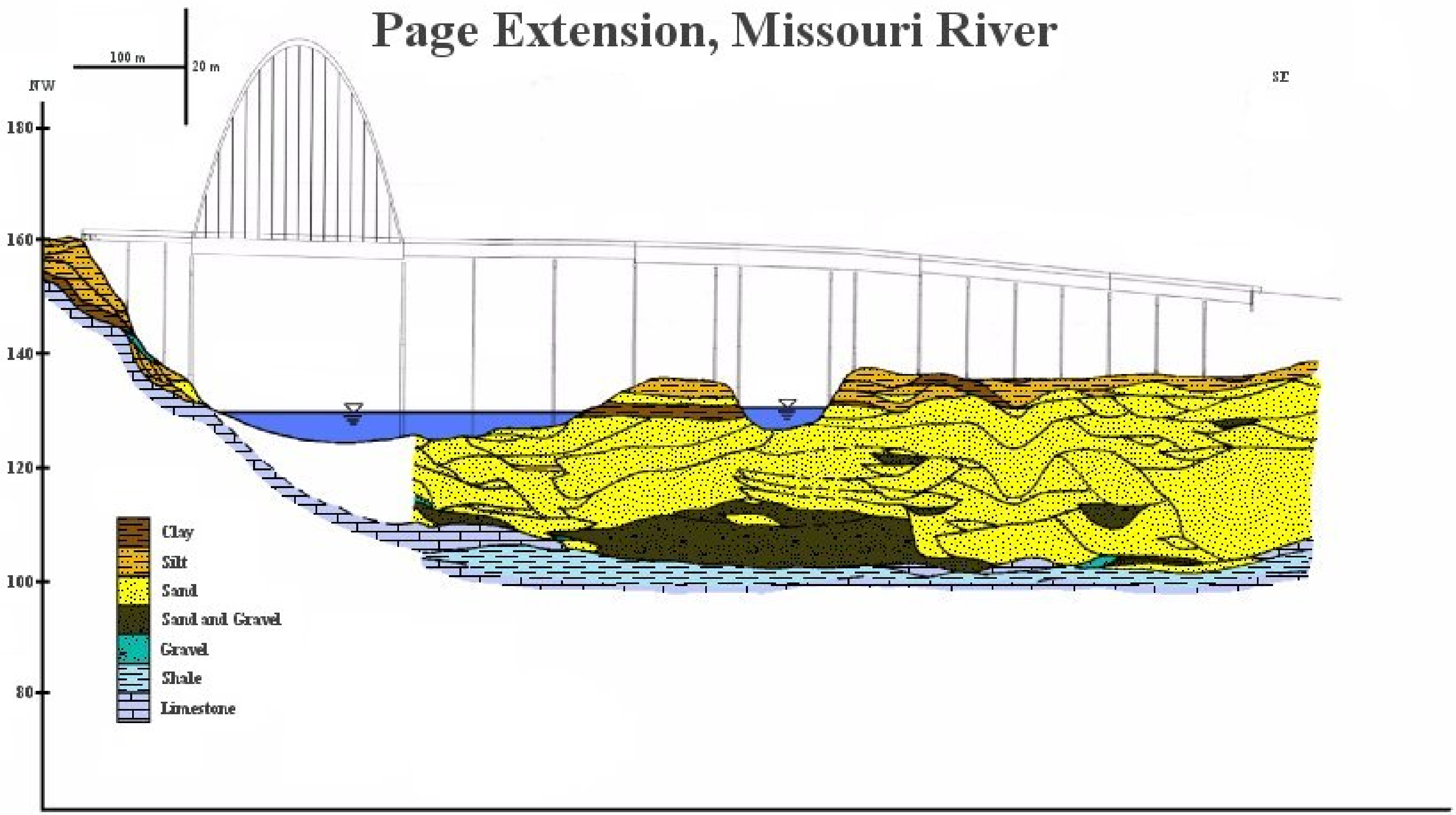
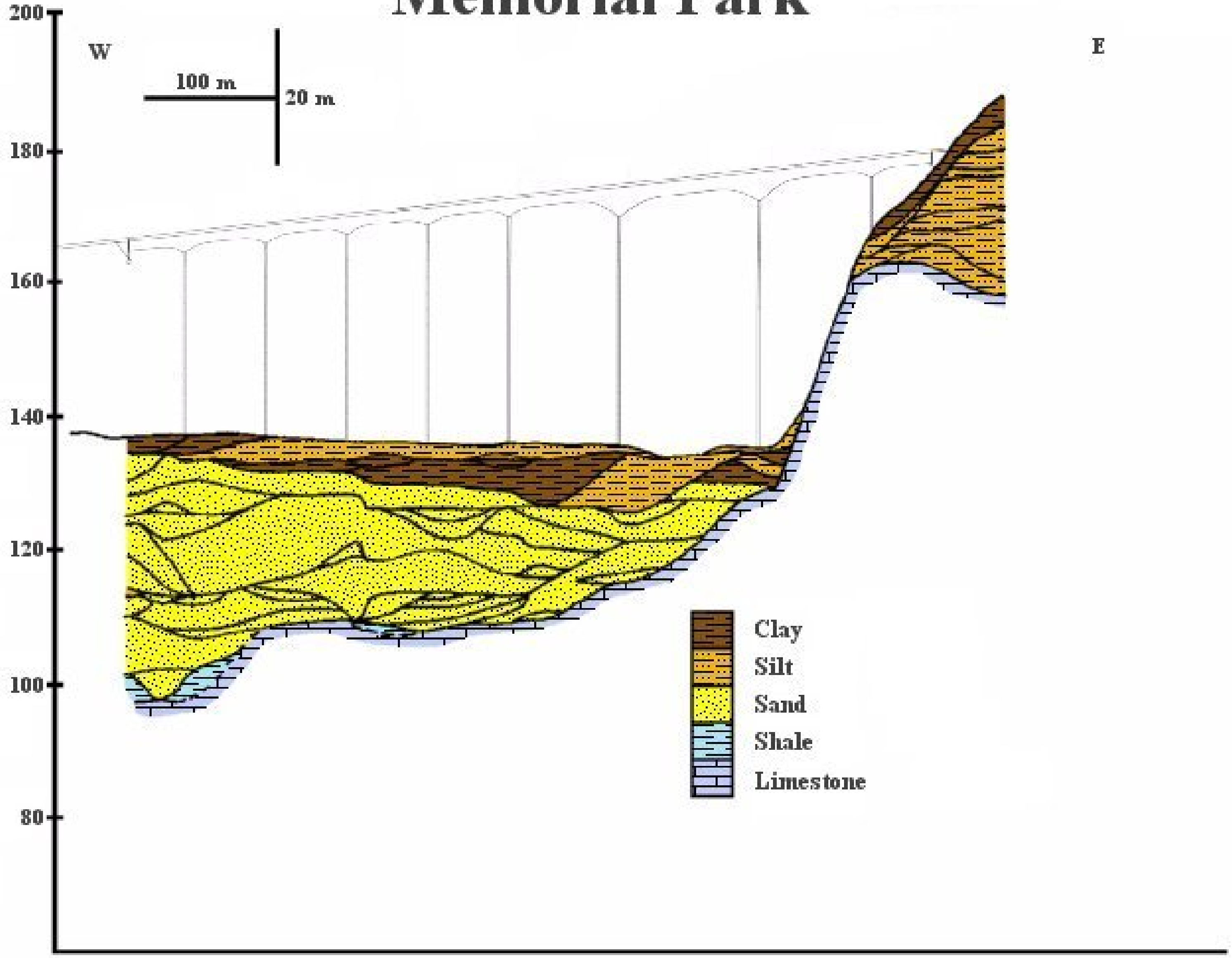


The Missouri River channel filled with up to 31 m of unconsolidated alluvium, mostly sands

Page Extension, Creve Coeur Lake Memorial Park



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ARTIFICIAL TIME HISTORIES FOR WERE GENERATED FOR THREE HISTORIC EVENTS IN THE NEW MADRID SEISMIC ZONE:

- **16 Dec 1811 M_s8.6 = M 7.7 event, at distance of 312 km**
- **7 Feb 1812 M_s 8.0 = M 7.5 event, at distance of 261 km**
- **31 Oct 1895 M_s 6.8 = M 6.6 event, at distance of 230 km**

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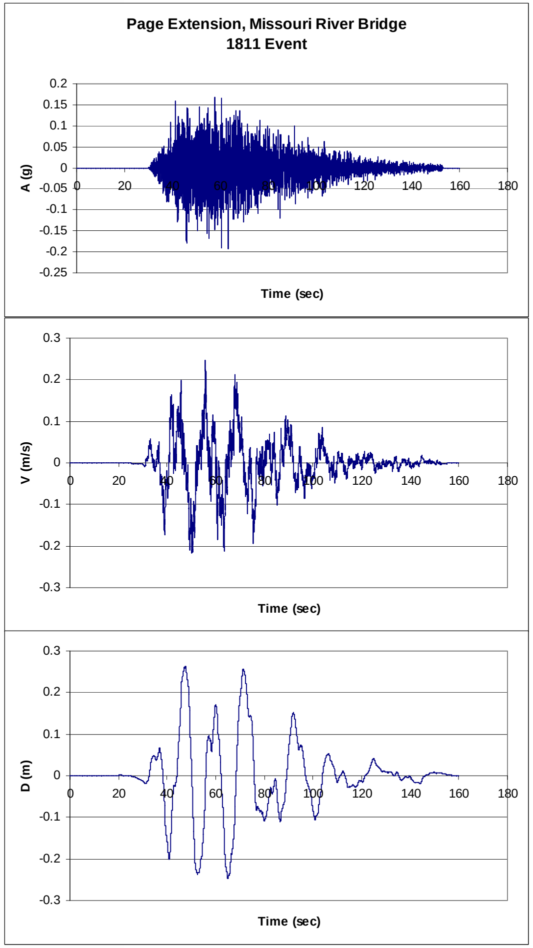
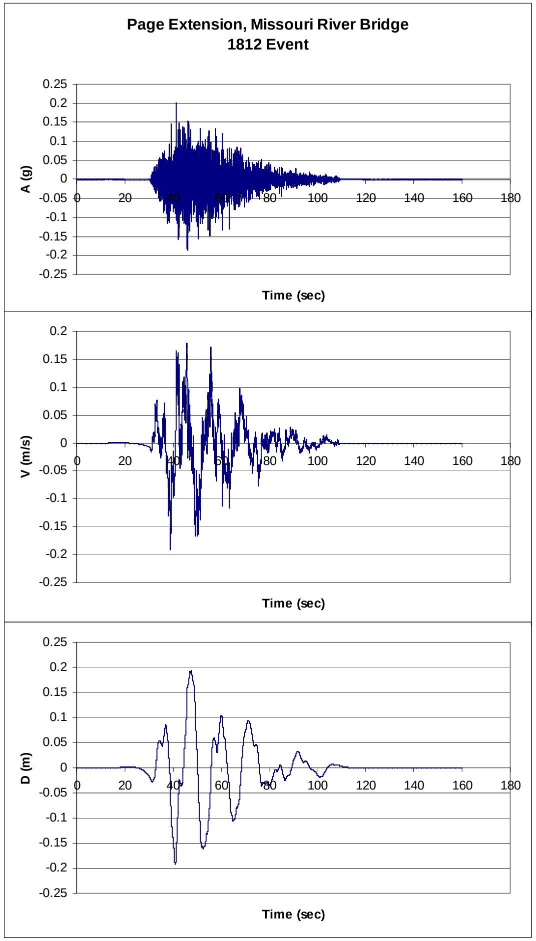
Page Ave. Bridge Artificial Time Histories for Quakes in NMSZ



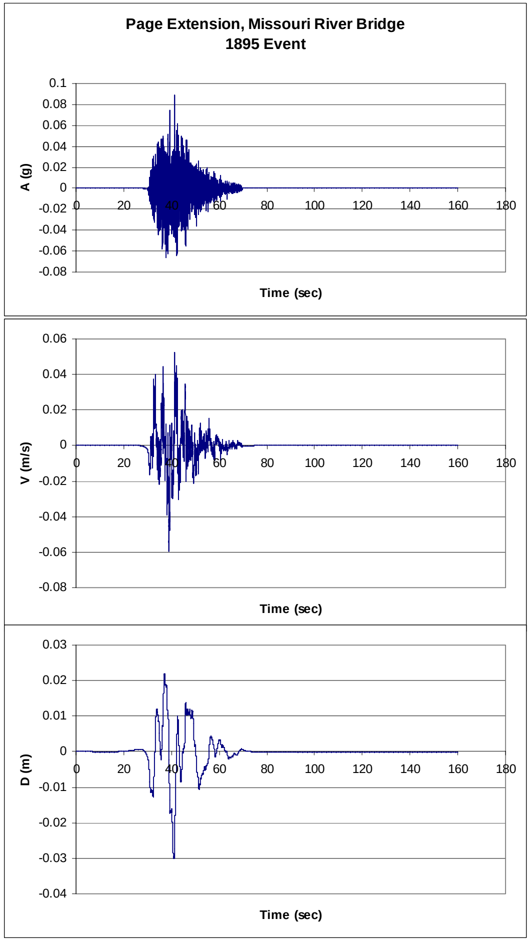
1811

312.5 km distance



1812

261.4 km distance



1895

230.5 km distance

ARTIFICIAL TIME HISTORIES WERE ALSO GENERATED FOR A SERIES OF LIKELY EARTHQUAKES EMANATING FROM SOUTH CENTRAL ILLINOIS AND THE WABASH VALLEY FAULT ZONE:

- M 6.0 and 6. 8 quakes at 115 km distance in south central Illinois (site of 1857 quake)
- M 6.0 and 6.8 quakes at 223 km distance in Olney, Illinois (site of 1987 quake)

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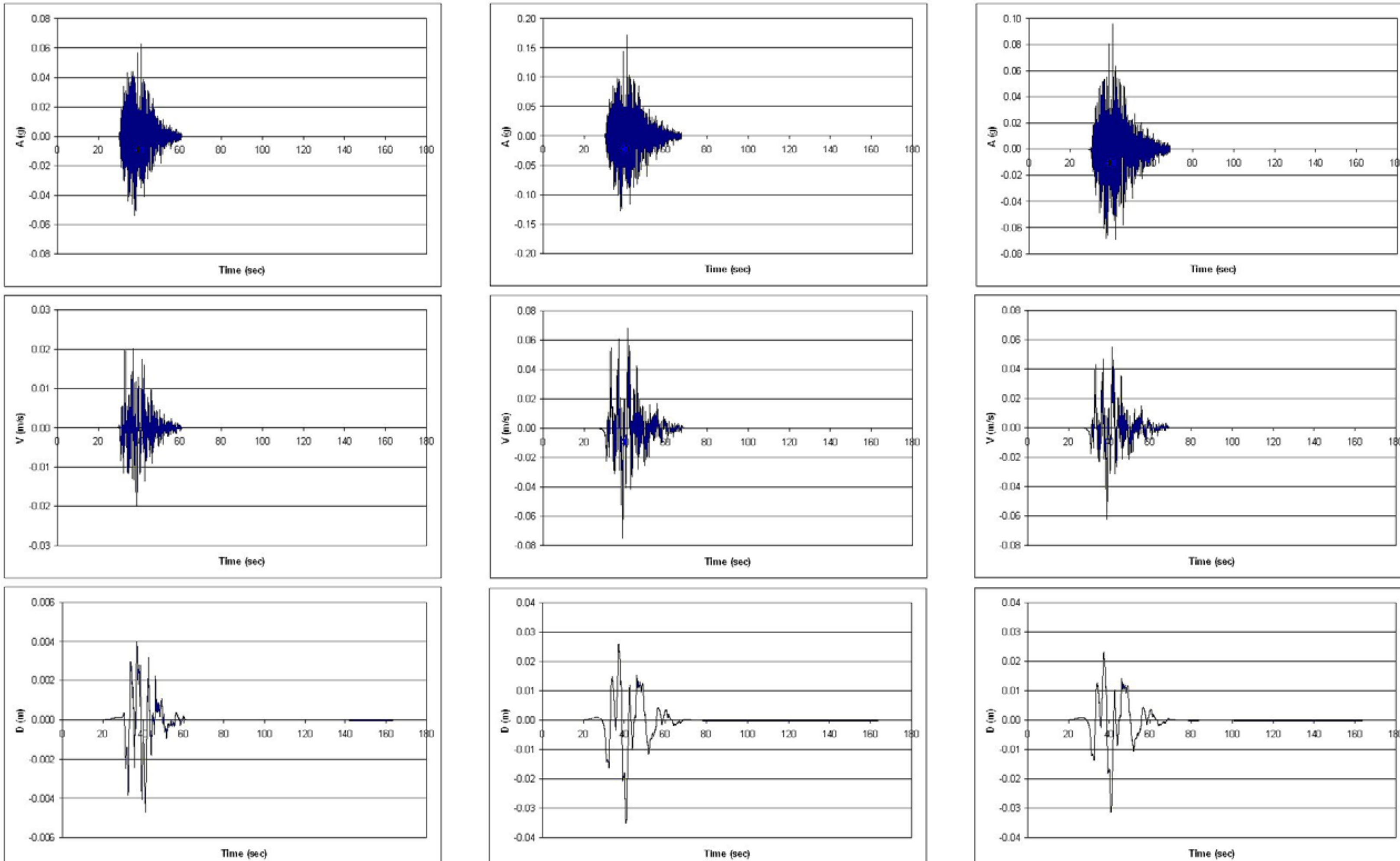
Page Ave. Bridge Artificial Time Histories for Quakes in Illinois



Magnitude 6	Magnitude 6.8	Magnitude 6.8
115 km distance	115 km distance	223 km distance

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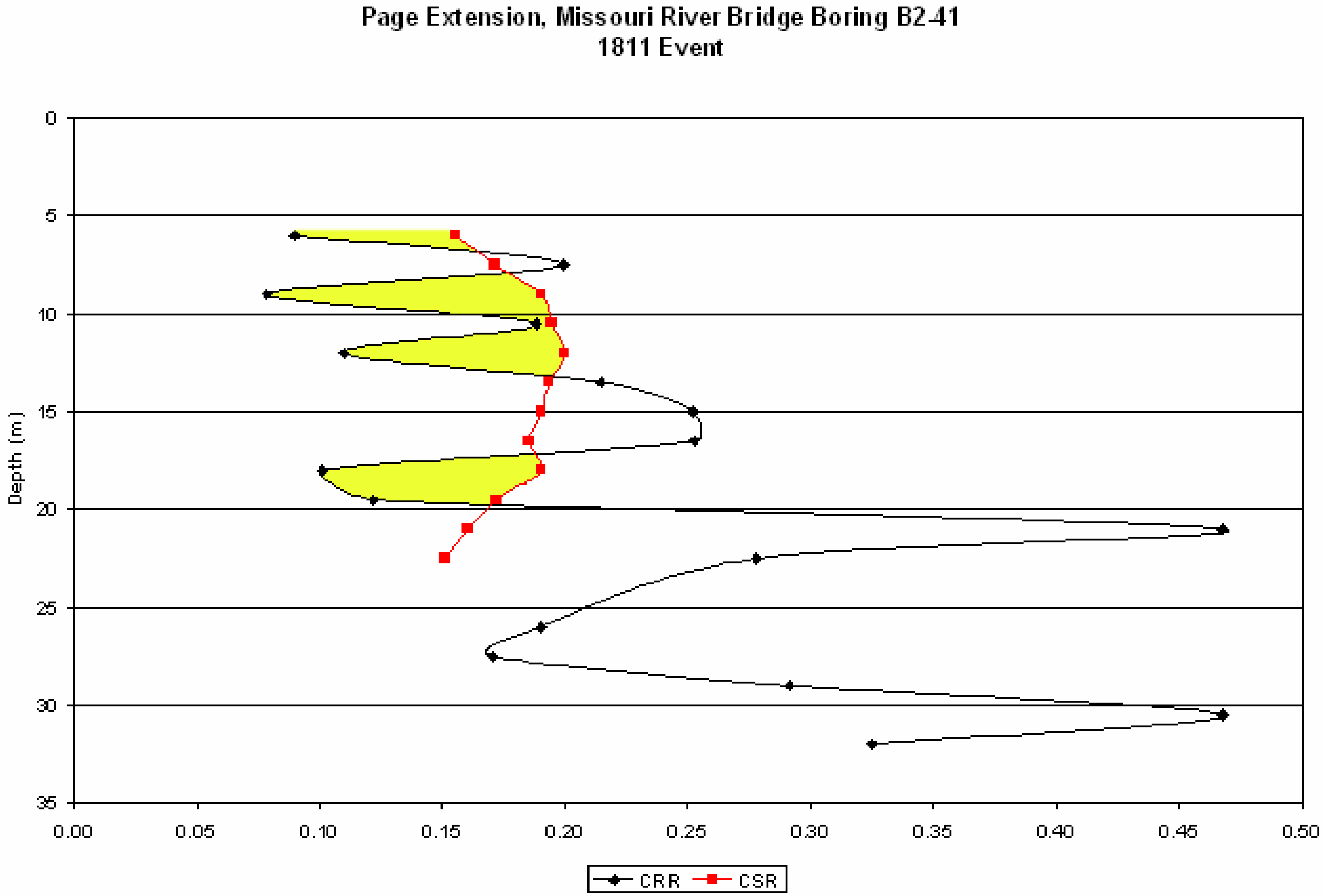
Page Ave. Extension Missouri River Bridge
M 7.3 New Madrid Seismic Zone event
Cyclic Stress Ratio vs. Cyclic Resistance Ratio



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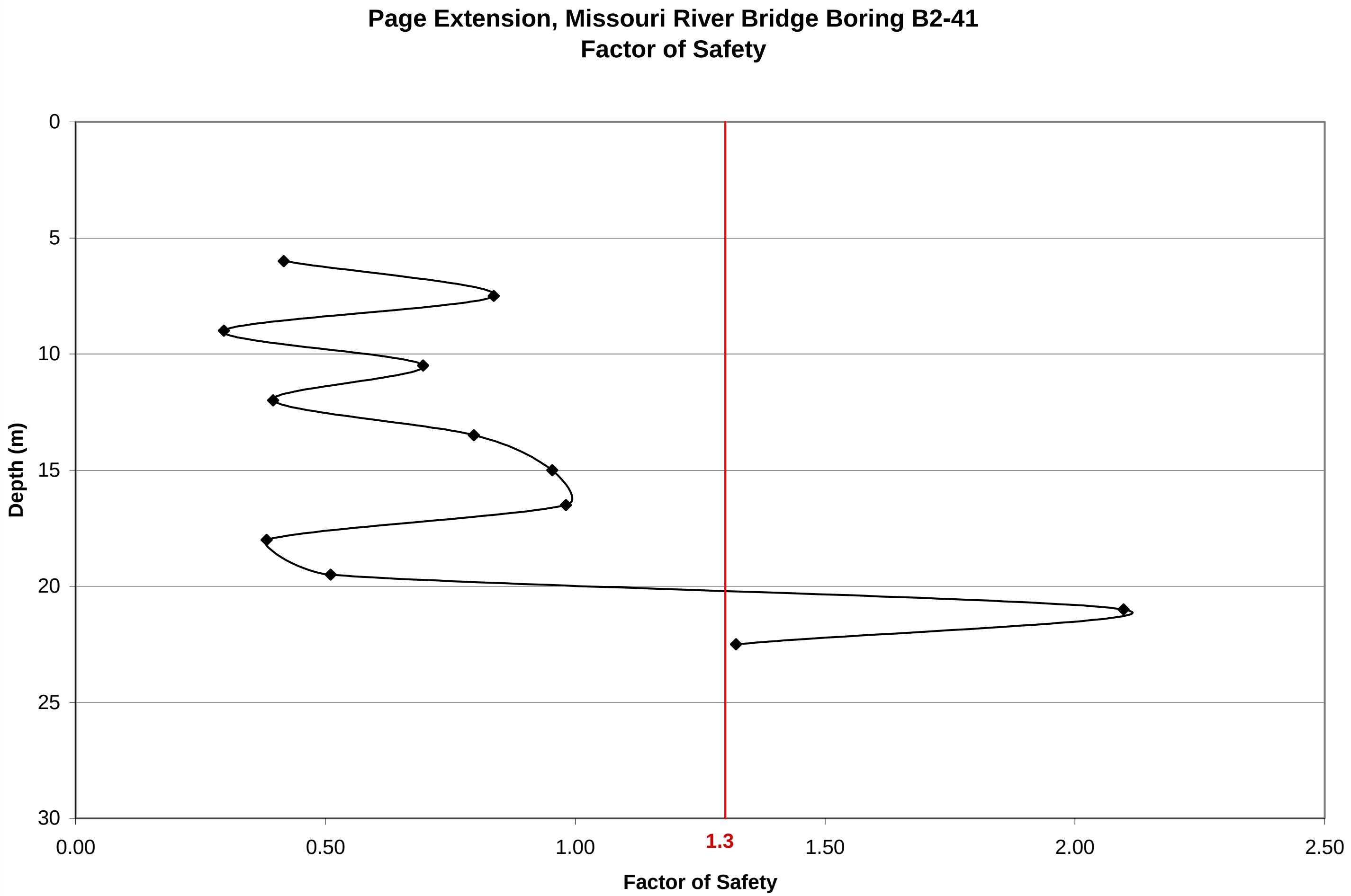
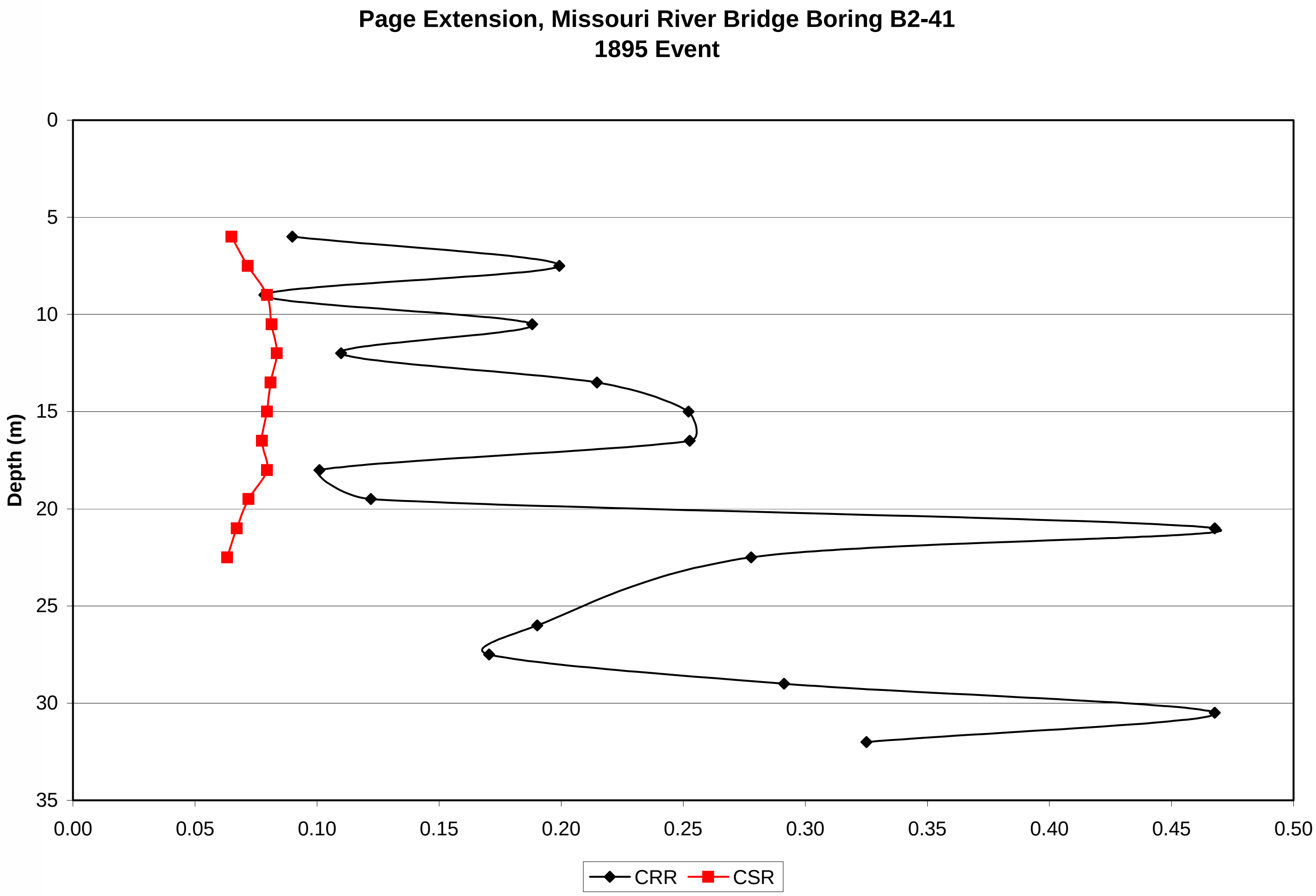
1811 $M8_s.6$

Page Ave. Missouri River Bridge Liquefaction Factor of Safety 1812 M 7.5 NMSZ event



Page Ave. M 6.6 NMSZ event

Cyclic Stress Ratio vs. Cyclic Resistance Ratio



M_s6.8

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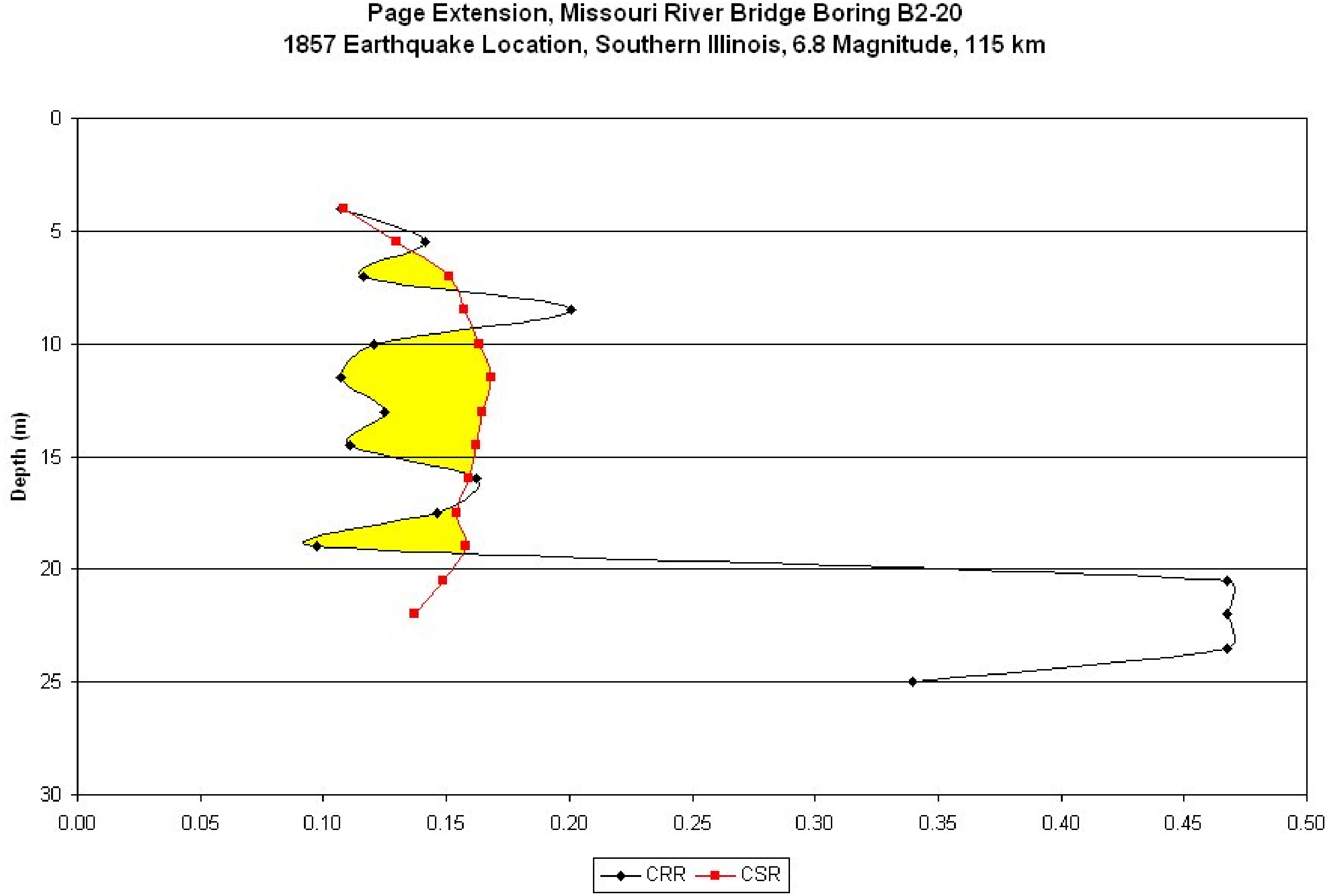
Page Ave. M 6.8 SCI event

Cyclic Stress Ratio vs. Cyclic Resistance Ratio



M_s6.8 – 115 km distance

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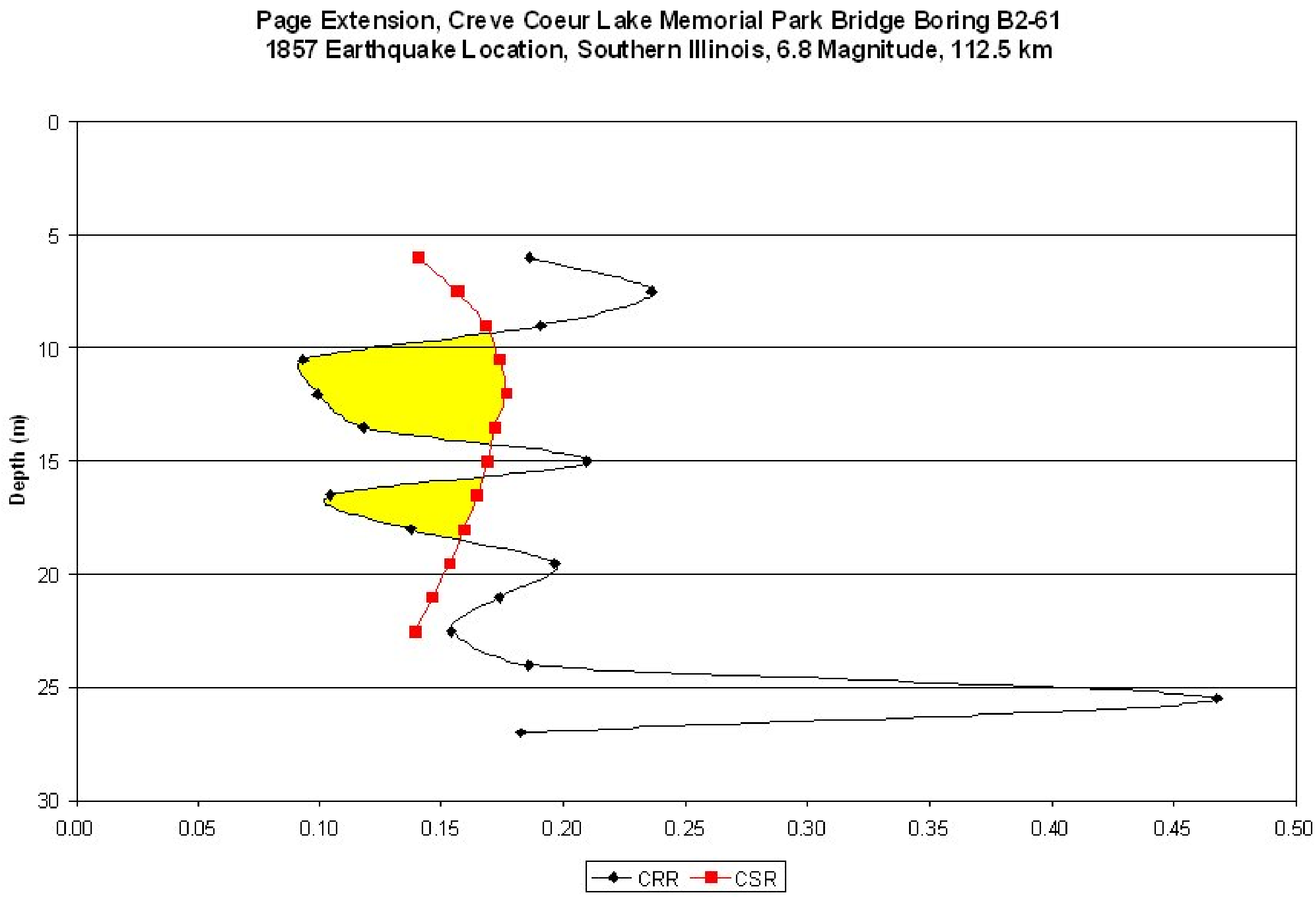
Creve Coeur Bridge M 6.8 SCI event

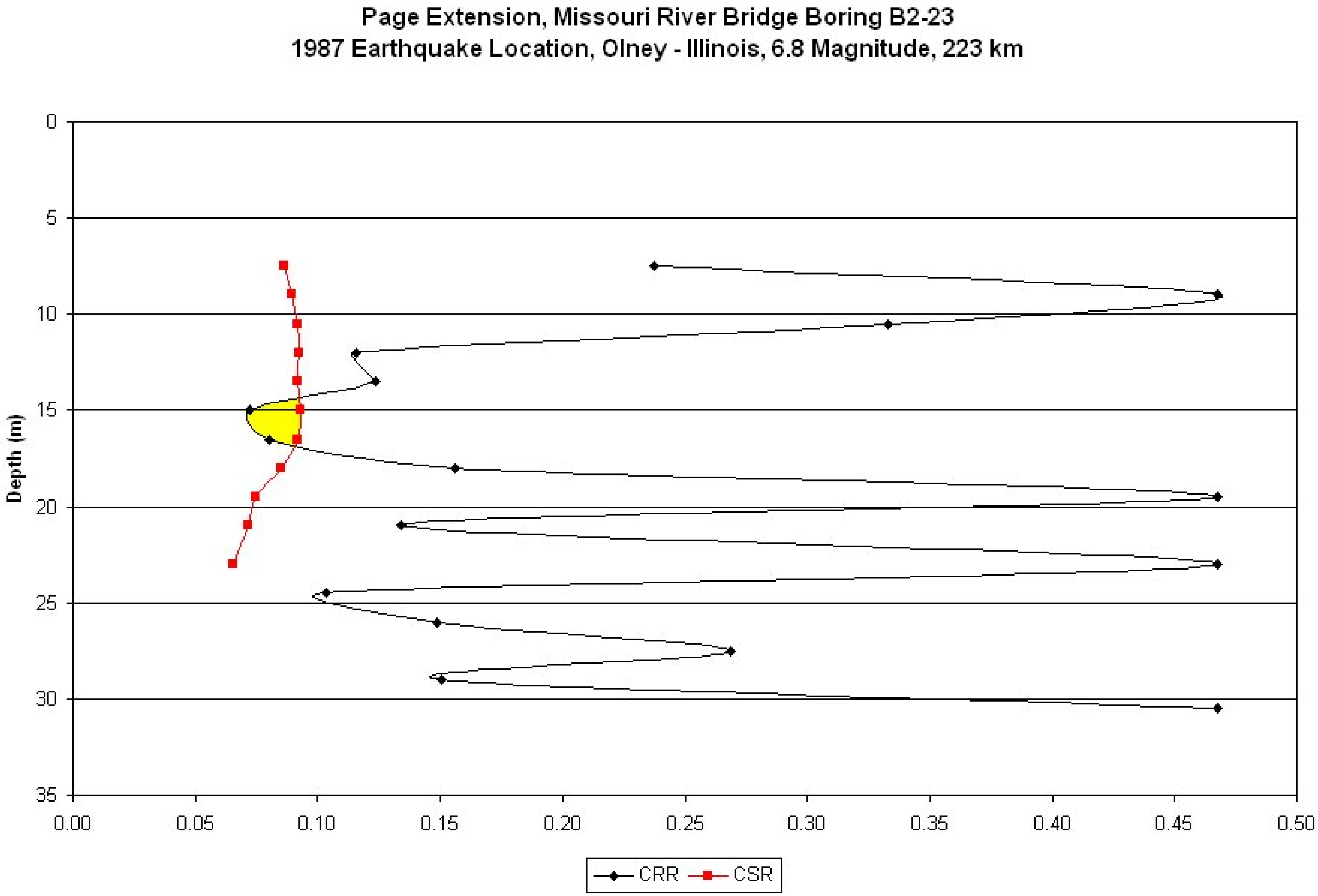
Cyclic Stress Ratio vs. Cyclic Resistance Ratio



M 6.8 – 112.5 km distance

Page Ave. M 6.8 WVFZ event

Cyclic Stress Ratio vs. Cyclic Resistance Ratio



M_s6.8 – 223 km distance

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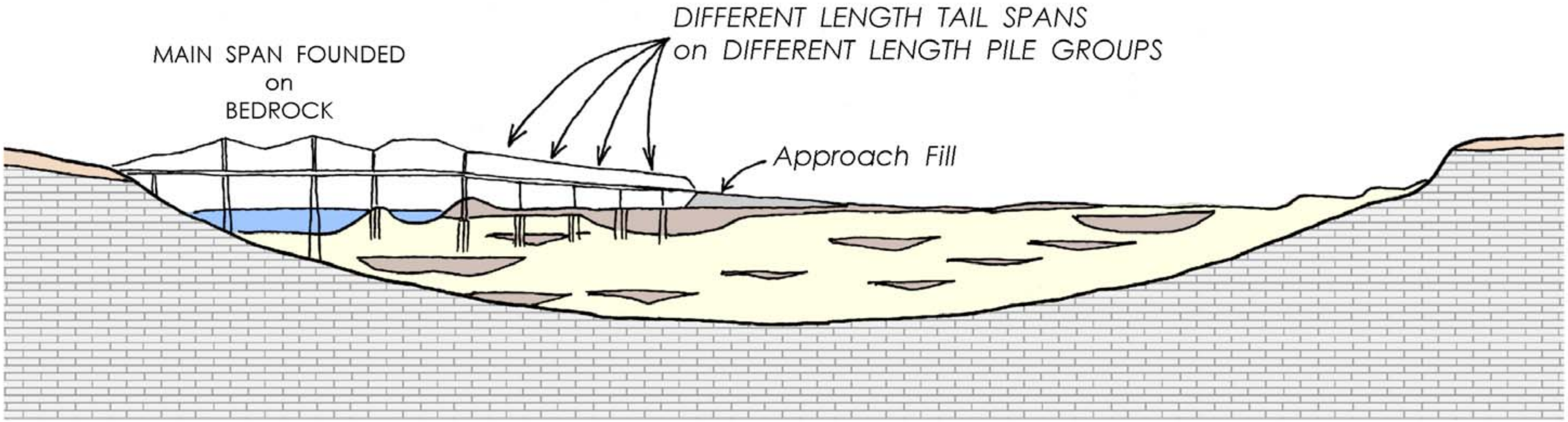
ELEMENTS of a TYPICAL CHANNEL CROSSING



- Asymmetric channel section; Missouri river on far south side of parabolic shaped channel
- Main spans supported on stiff caissons to rock
- Tail spans supported on pile groups of differing length
- Soft pockets on old oxbows can be problematic
- Widespread liquefaction and lateral spreads likely near channels

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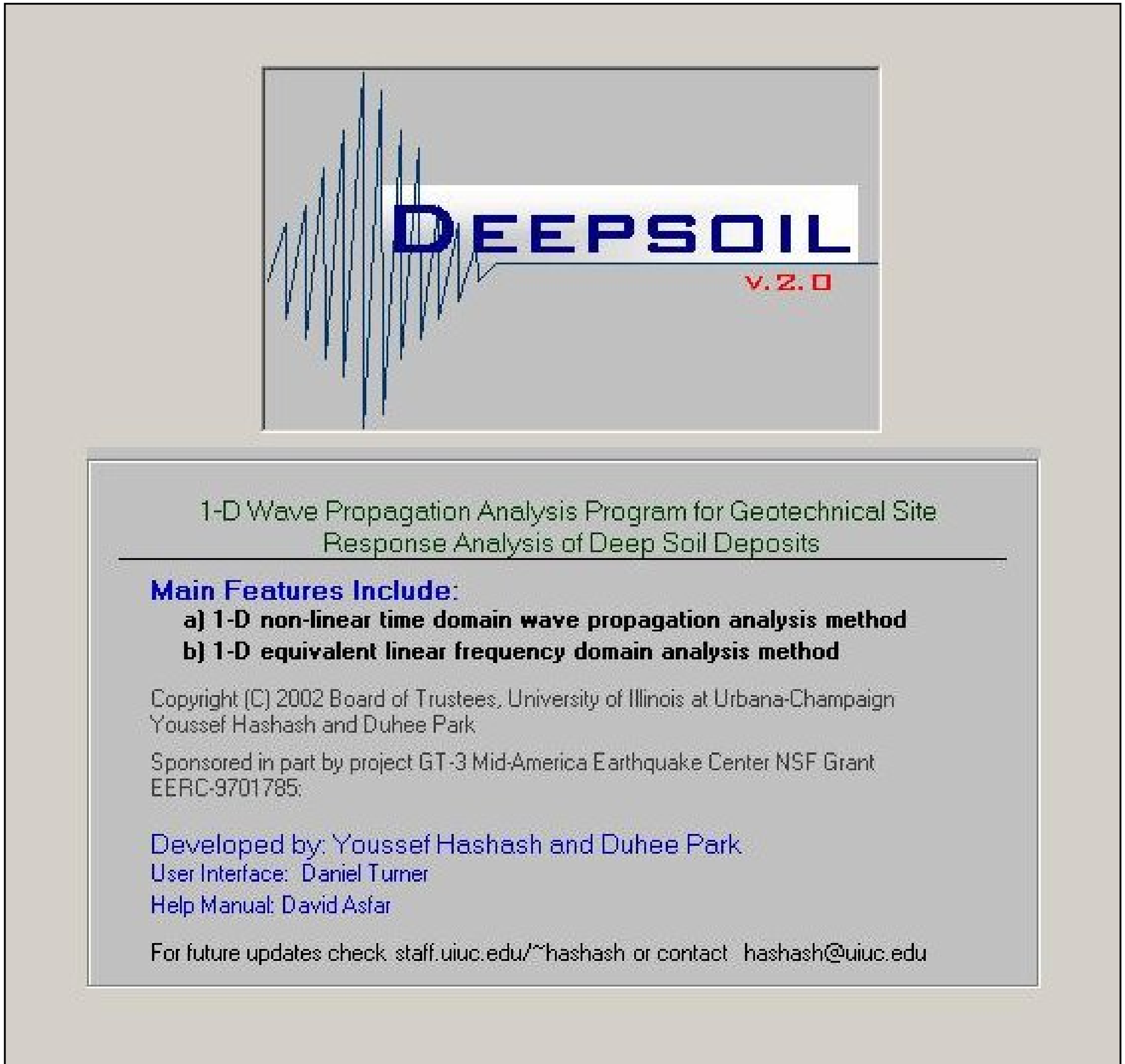
1D Seismic Site Response Equivalent Linear Approach



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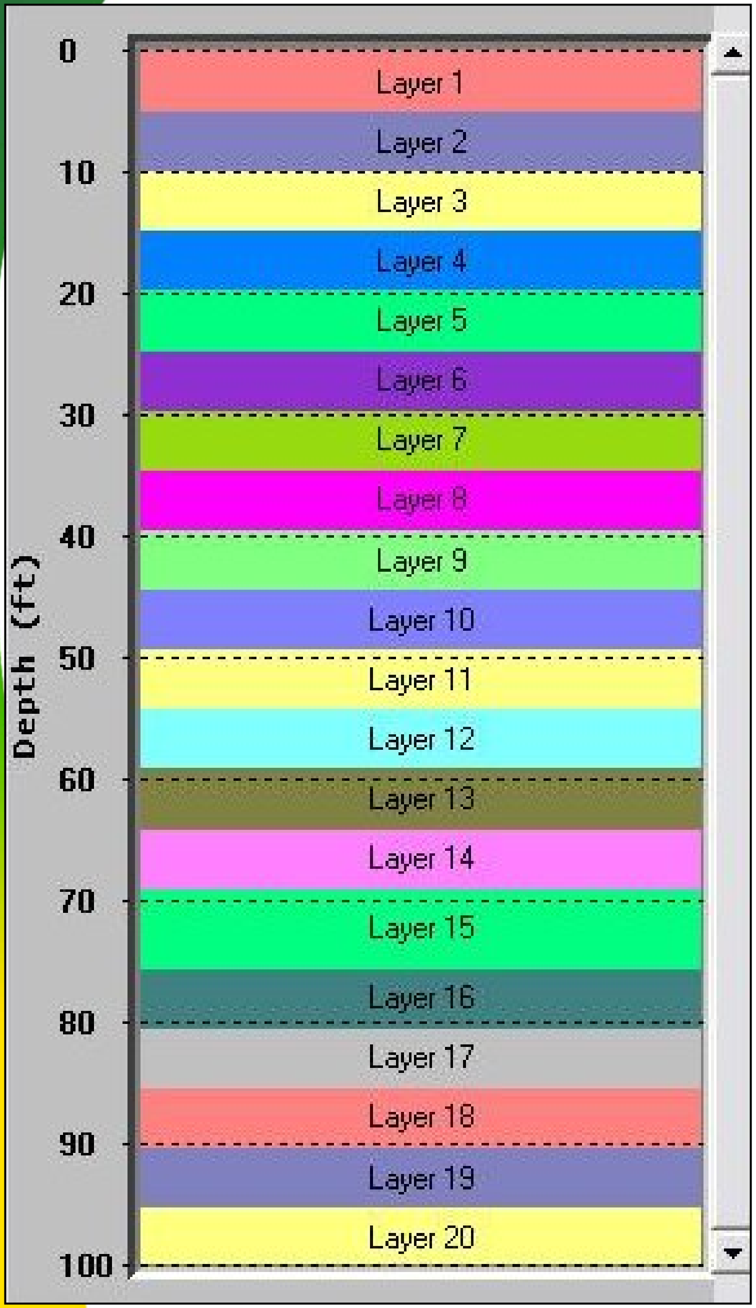

Soil Parameter Input Interface using DEEPSOIL 1-D wave propagation analysis

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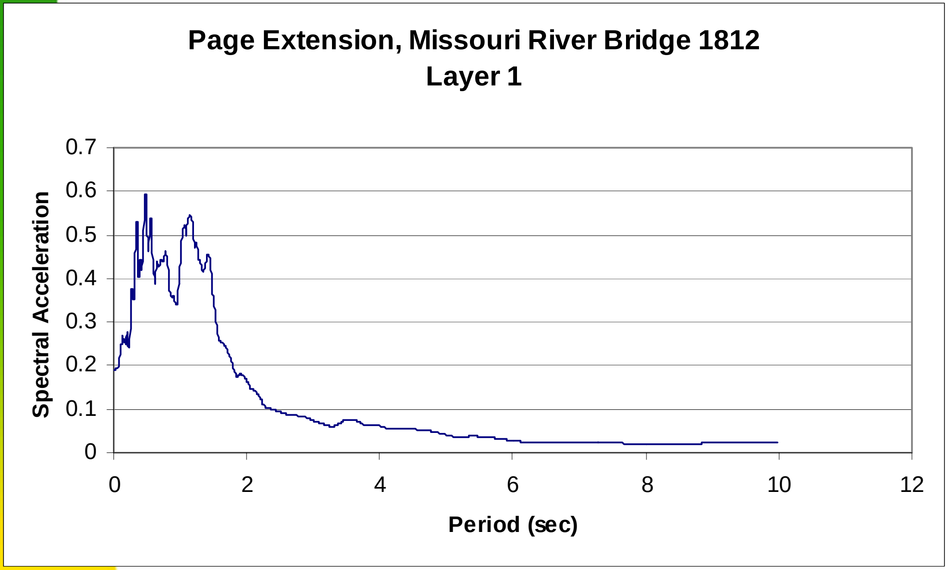
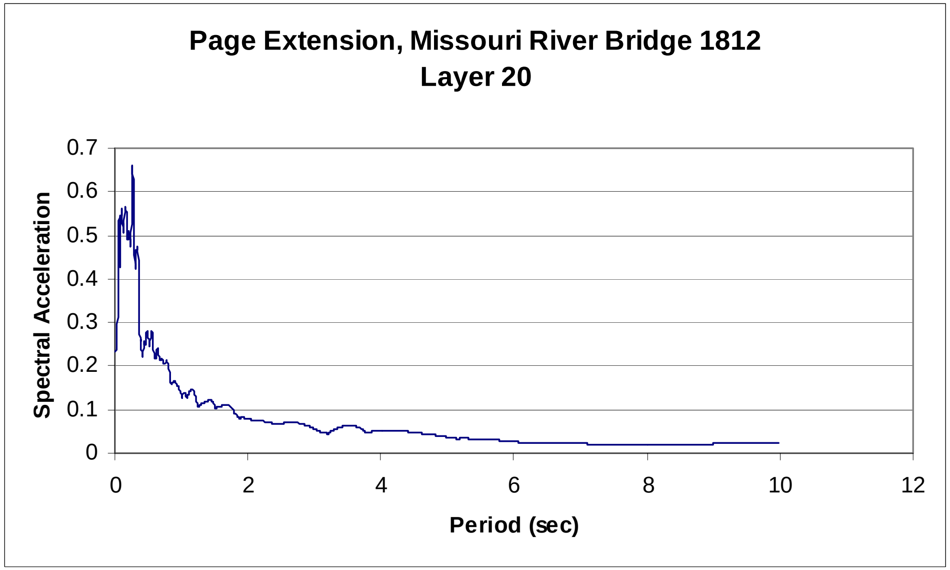
Page Ave. Missouri River Bridge M8.0 1812 NMSZ Event





At ground surface

At bedrock interface

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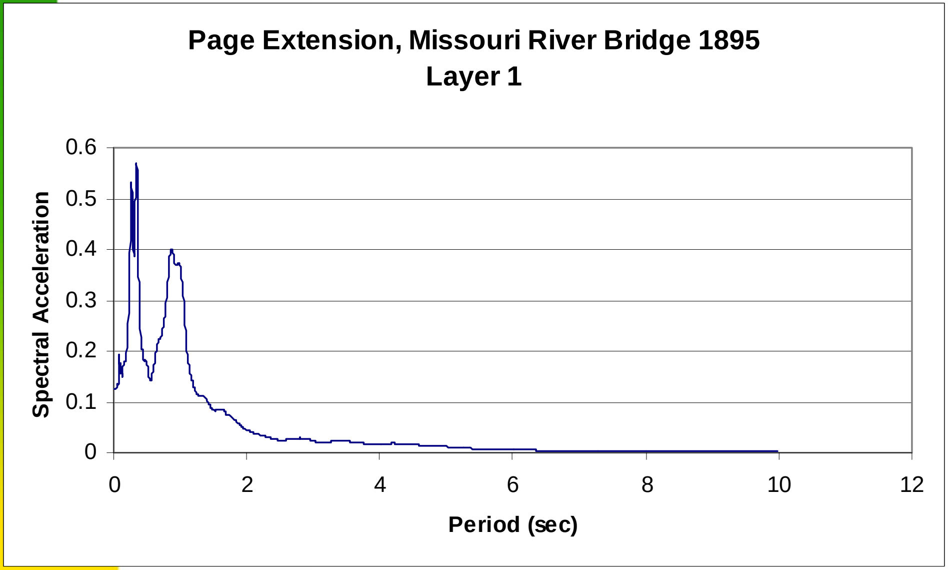
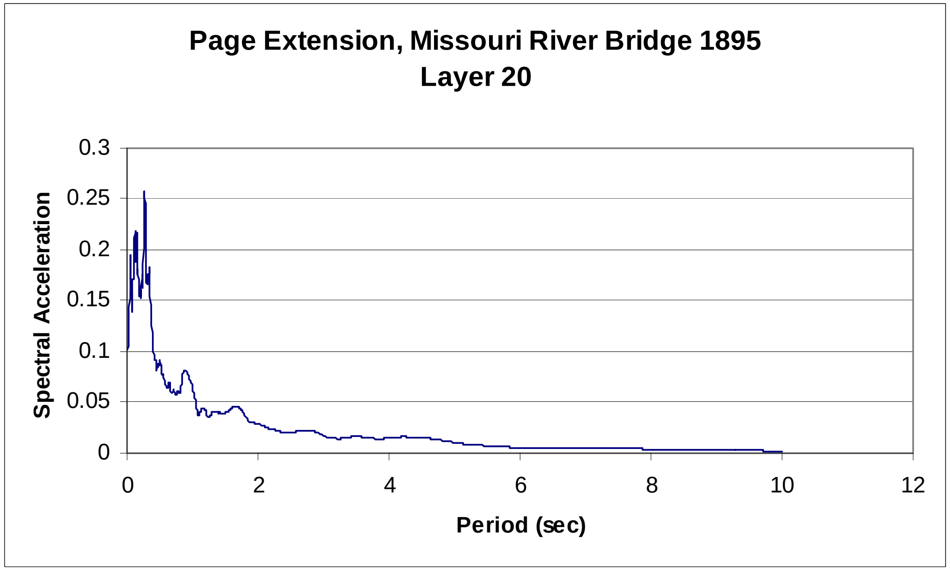
Page Ave. Missouri River Bridge M6.6 1895 NMSZ Event





At ground surface

Increases to 0.58 g

At bedrock interface

a_{max} = 0.22g

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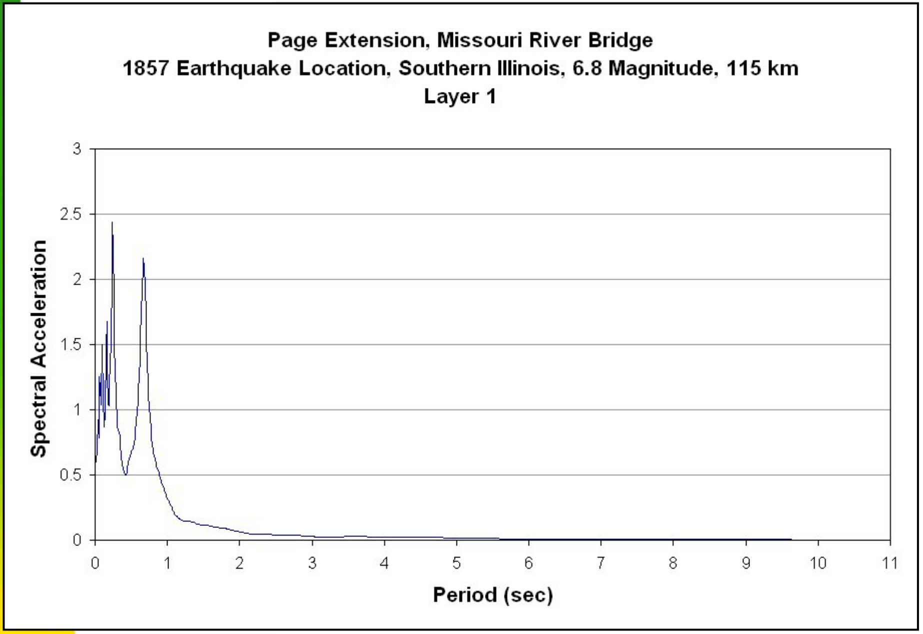
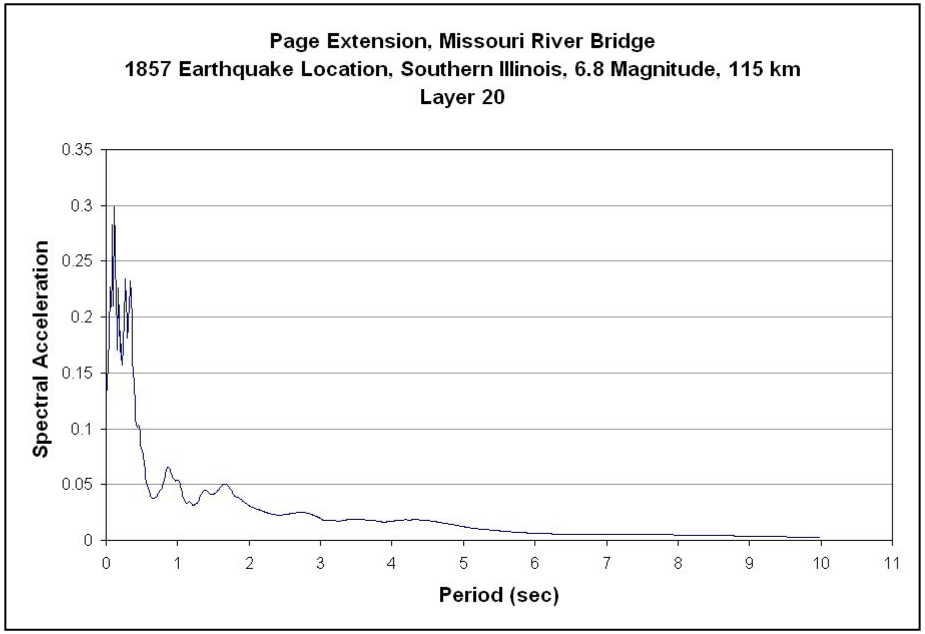
Page Ave. Missouri River Bridge M6.8 115 km distance

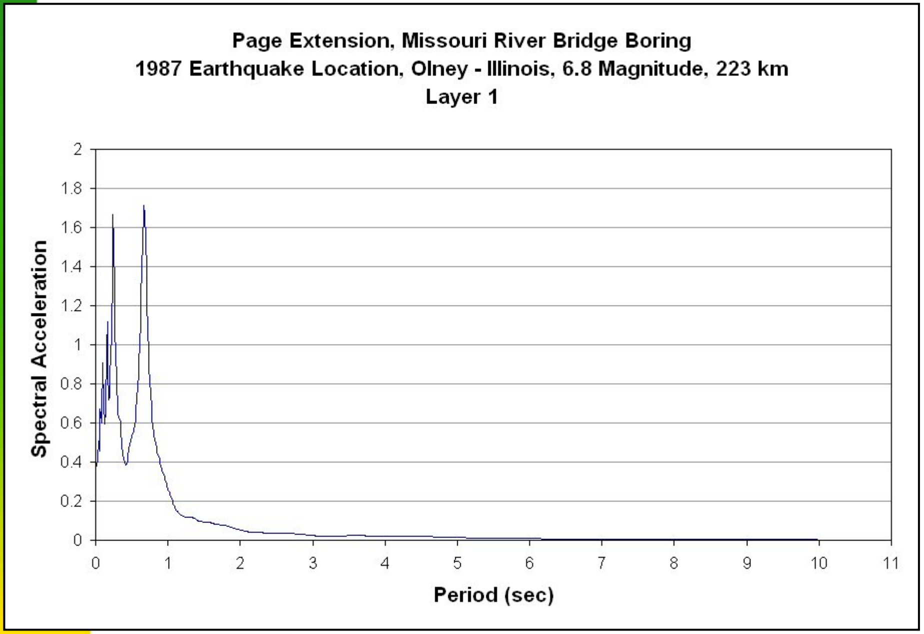


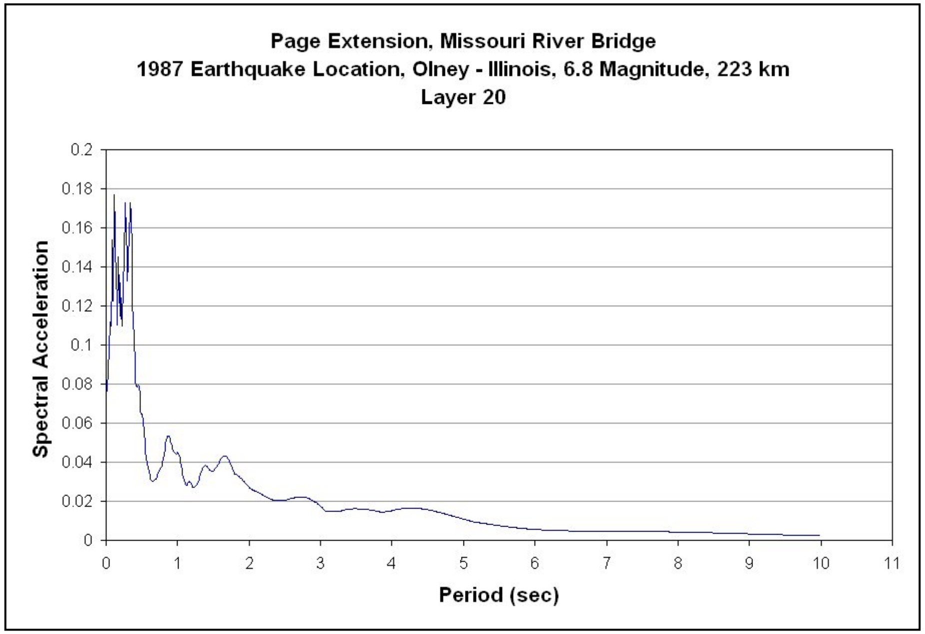


At ground surface

At bedrock interface

Page Ave. Missouri River Bridge M6.8 223 km distance





At ground surface **At bedrock interface**

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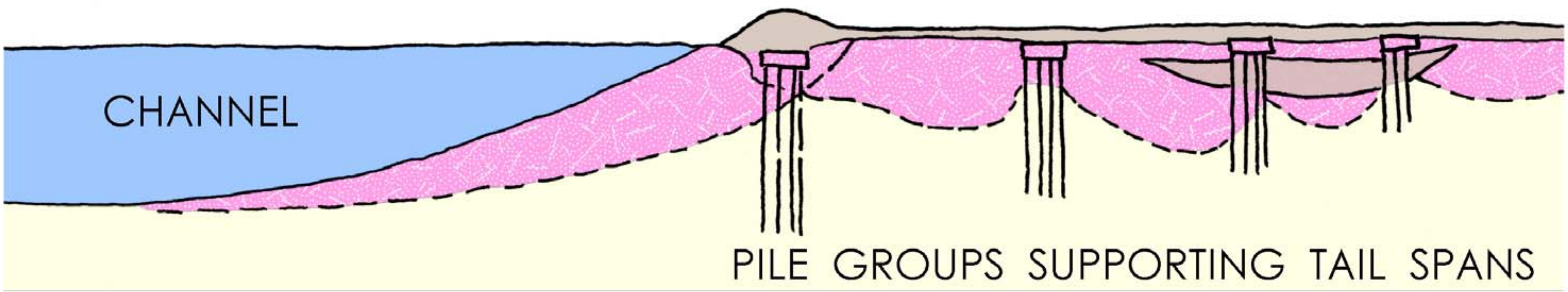
ZONES COMMONLY SUSCEPTIBLE to LIQUEFACTION



- Simply supported tail spans probably most vulnerable component of long span highway bridges
- Site amplification causes long period motions to peak between 0.75 and 1.5 seconds; same period as bridges
- We can expect liquefaction of foundations (areas shown in pink)

CONCLUSIONS

- **Significant site amplification likely in deep valley fills, such as Mississippi and Missouri River channels**
- **Widespread liquefaction likely in Magnitude 6.6 or greater events at great range (155 miles/250 km)**
- **Liquefaction likely to be severe (deep) and continuous in Magnitude 7.5+ events**

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Online Posting

- This lecture will be posted online for easy downloading at:

www.umr/edu/~rogersda/nmsz