BRIEF OVERVIEW OF
SEISMIC THREAT POSED BY THE NEW MADRID SEISMIC ZONE

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EARTHQUAKES

- **4 million earthquakes occur every year; or about 11,000 each day**
- **About 6,200 quakes are strong enough for people to notice**
- **About 800 damaging quakes between Magnitude 5.0 and 5.9 each year**
- **About 120 destructive quakes with Magnitudes 6.0 to 6.9 each year**
- **Despite improved building codes, about 15,000 people are killed each year**

QUAKES KILL PEOPLE

- **In 1556, 830,000 people were killed in Shensi, China**
- **180,000 killed near Kansou, China in 1920 quake**
- **9,500 people were killed and 30,000 injured in Mexico City in September 1985 by a M8.1 earthquake 350 km away!**
- **In 2003, 43,819 people were killed by earthquakes worldwide**
- **Geology beneath site is just as important as quake magnitude**

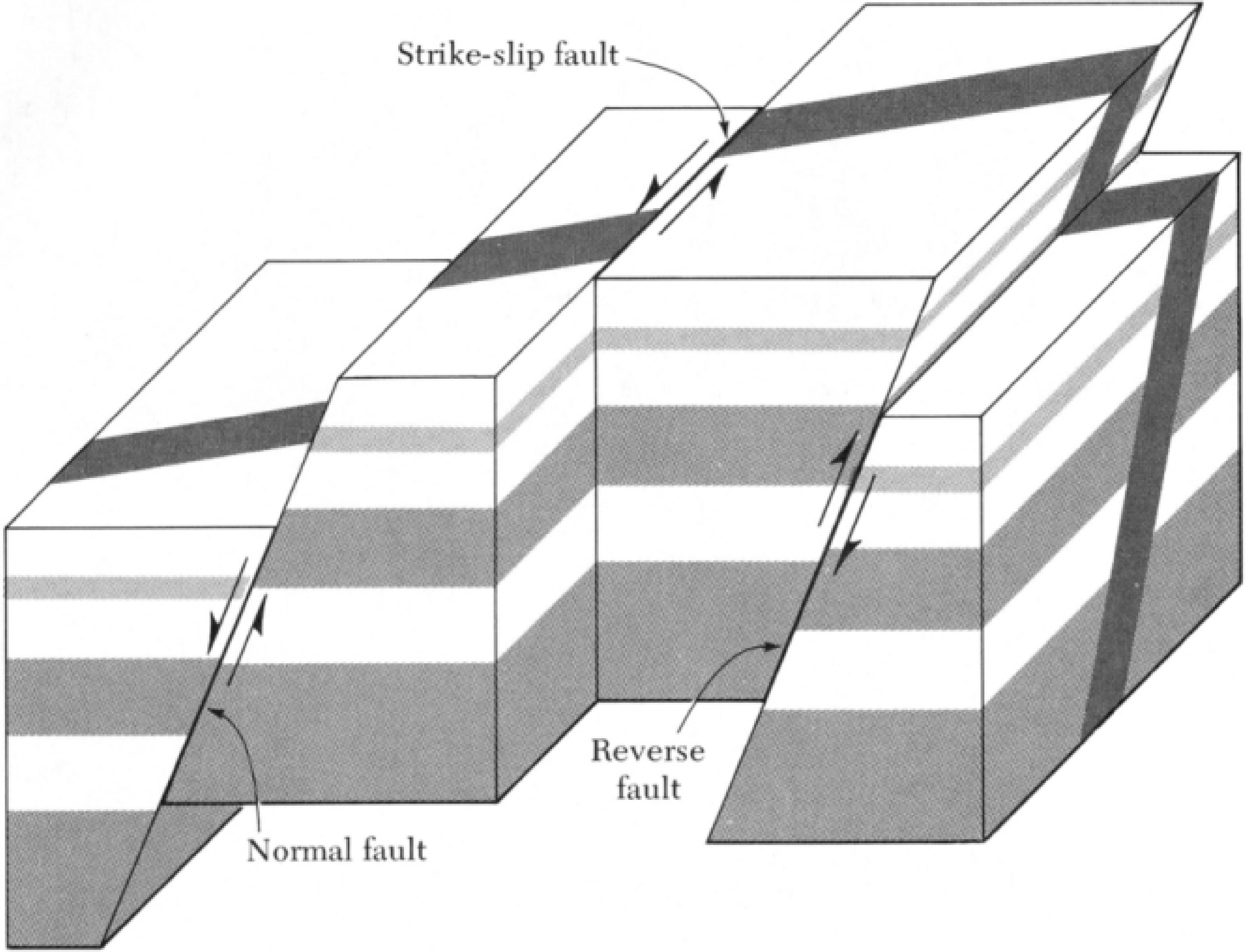
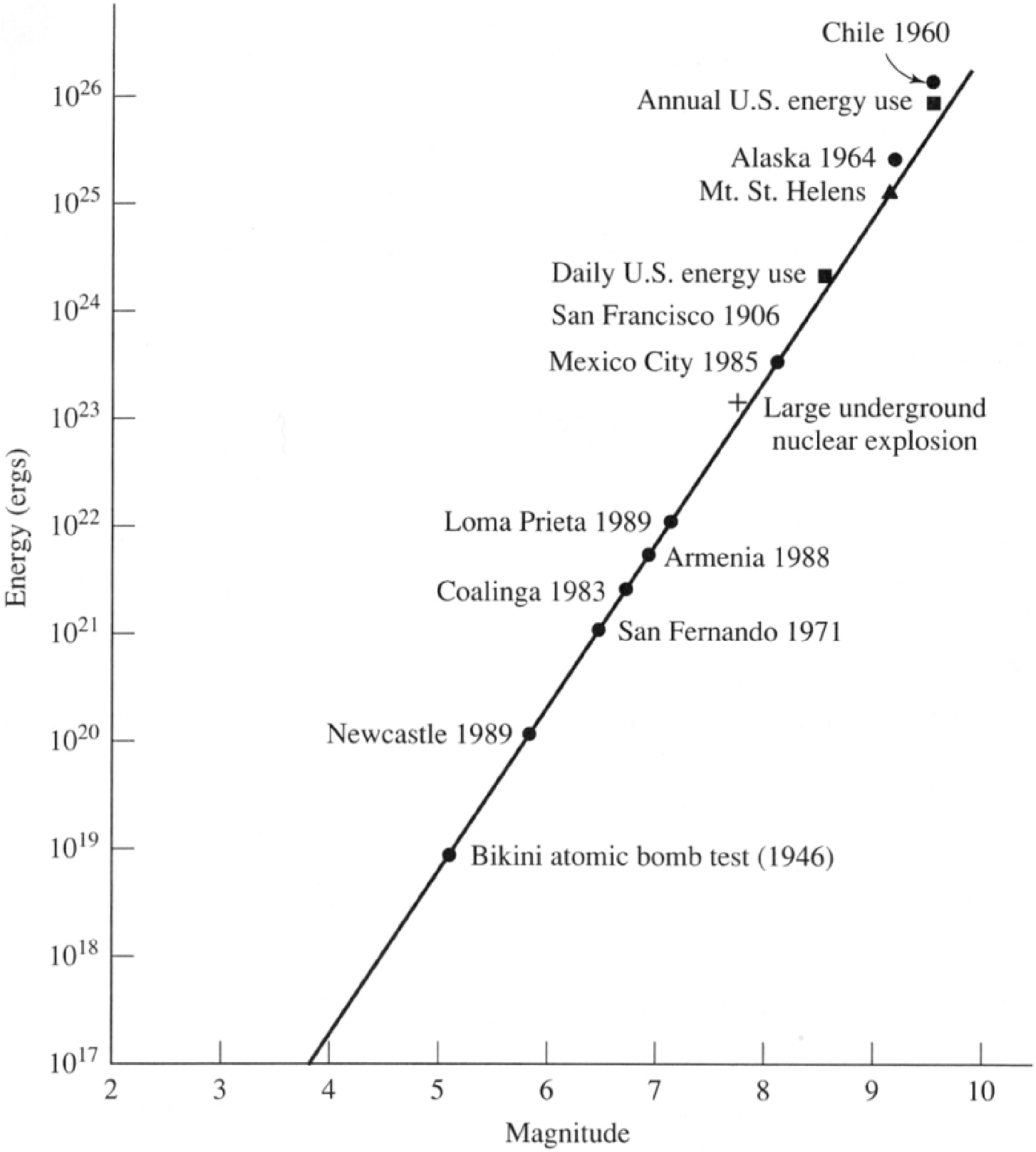
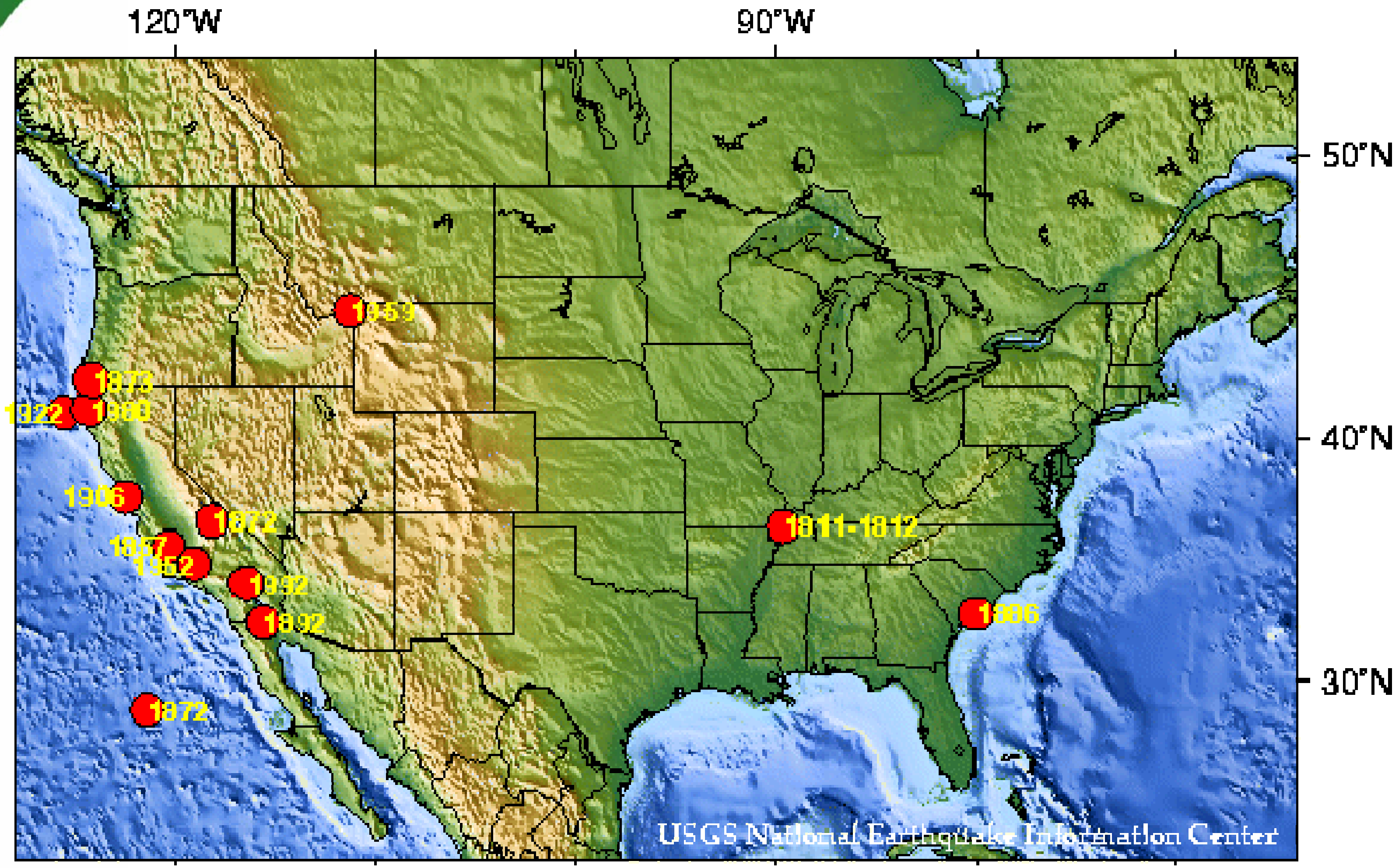


Diagram showing the three main types of fault motion.

Earthquake Magnitude versus Energy Release

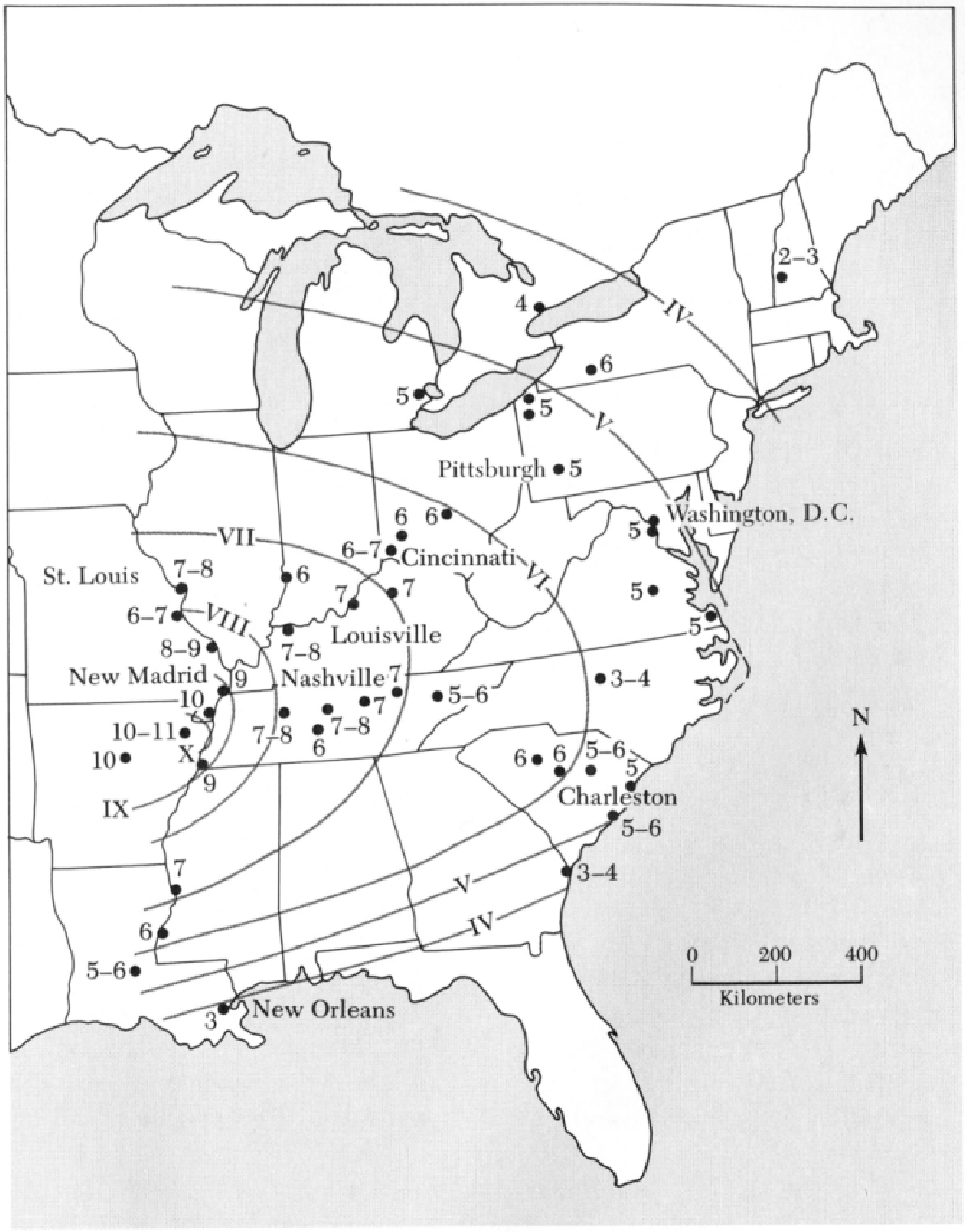


- **Modern earthquake magnitudes are based on energy release using a logarithmic scale**
- **Each numerical magnitude is about 33X the energy release of preceding numerical value**

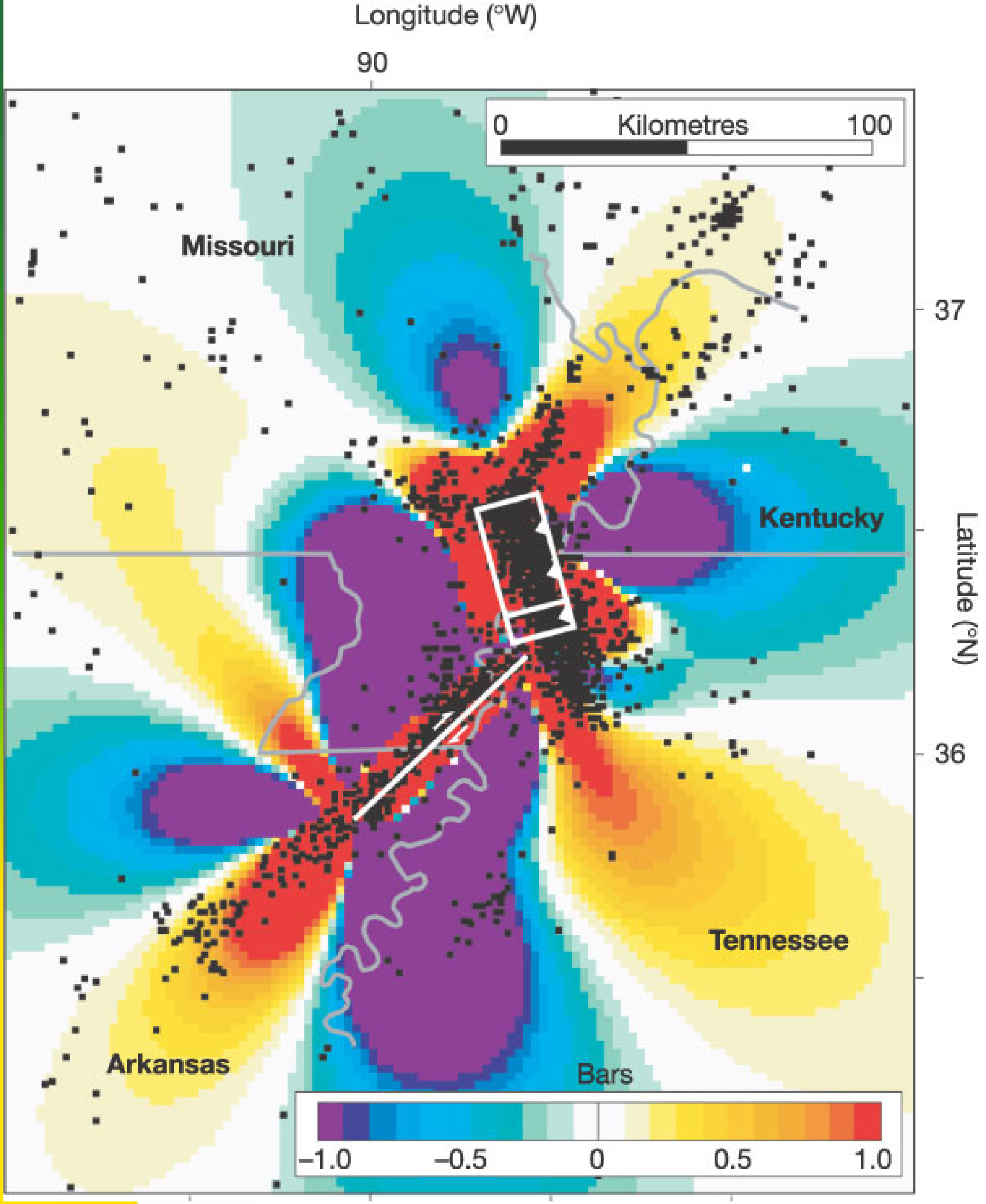


USGS National Earthquake Information Center

- In 1663 the European settlers experienced their first earthquake in America. From 1975-1995 there were only four states that did not have any earthquakes: Florida, Iowa, North Dakota, and Wisconsin. The most damaging earthquakes have occurred in California, Nevada and Alaska. Should we be concerned in the Midwest?



- **Isoseismal lines for the December 16, 1811 M_s 8.6 New Madrid earthquake**
- **Felt over an area greater than 1 million square miles**
- **Extensive damage to masonry in Cincinnati**
- **Rang church bells in Boston**
- **Most people lived along rivers in Midwest and no inhabitants west of the Mississippi**



NEW MADRID STRESS FIELD

- **Solution for distribution of the elastic stress field in the crustal basement at a depth of 12 km for earthquakes felt in late 1811 and early 1812**

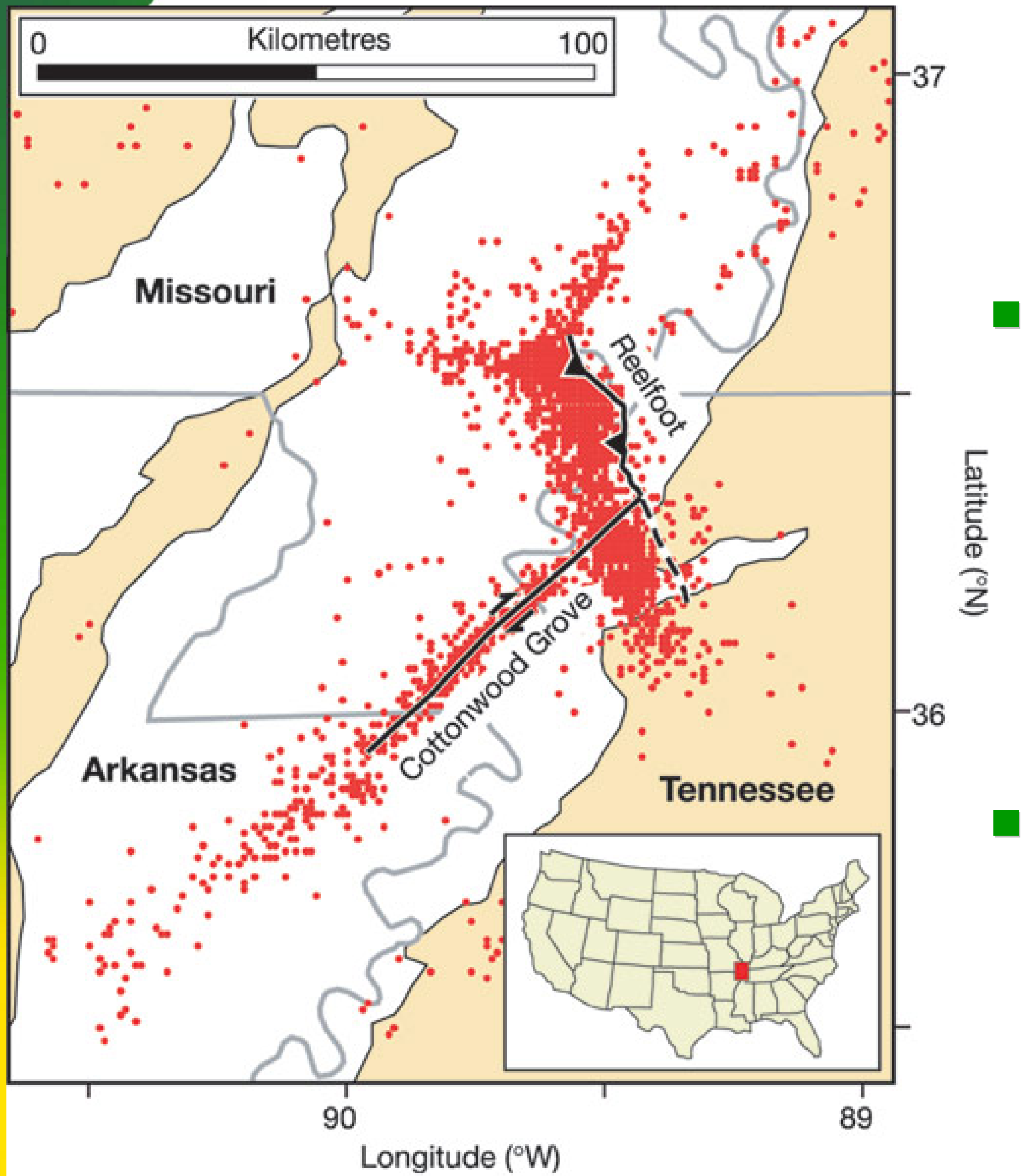
NEW MADRID SEISMIC ZONE

- 2000 quakes in New Madrid Seismic Zone in 1811-12; four with M> 7.5
- Felt over 1 million square miles!
- Chimneys toppled in Cincinnati, Ohio, 560 km away
- Raised and lowered vast tracts of land as much as 20 feet, temporarily reversing flow of Mississippi River
- Ground fissures and massive liquefaction over a zone measuring 240 x 80 km!

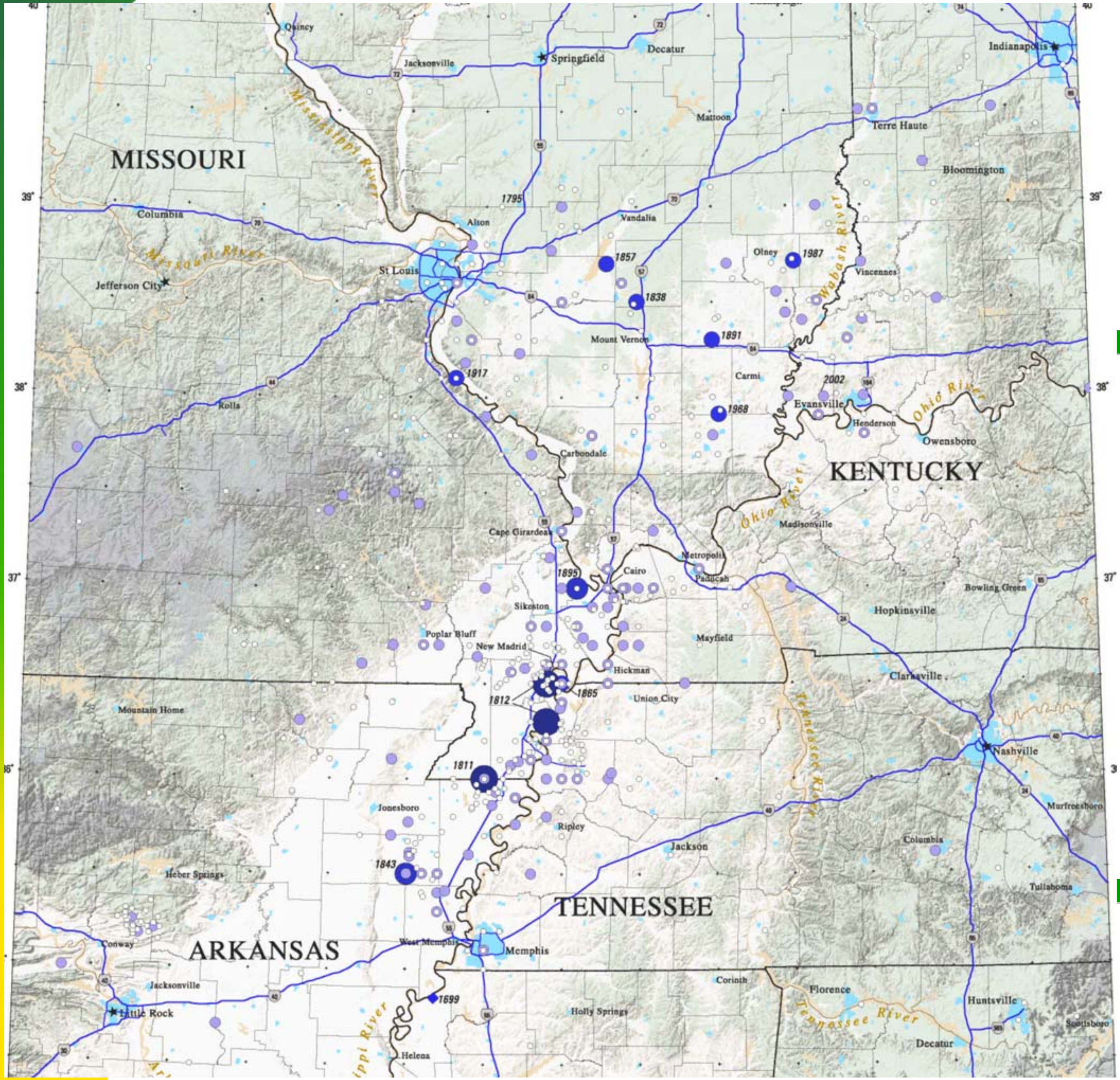
POST 1812 SEISMICITY in NEW MADRID SEISMIC ZONE

- **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**

ACTIVE SEISMICITY



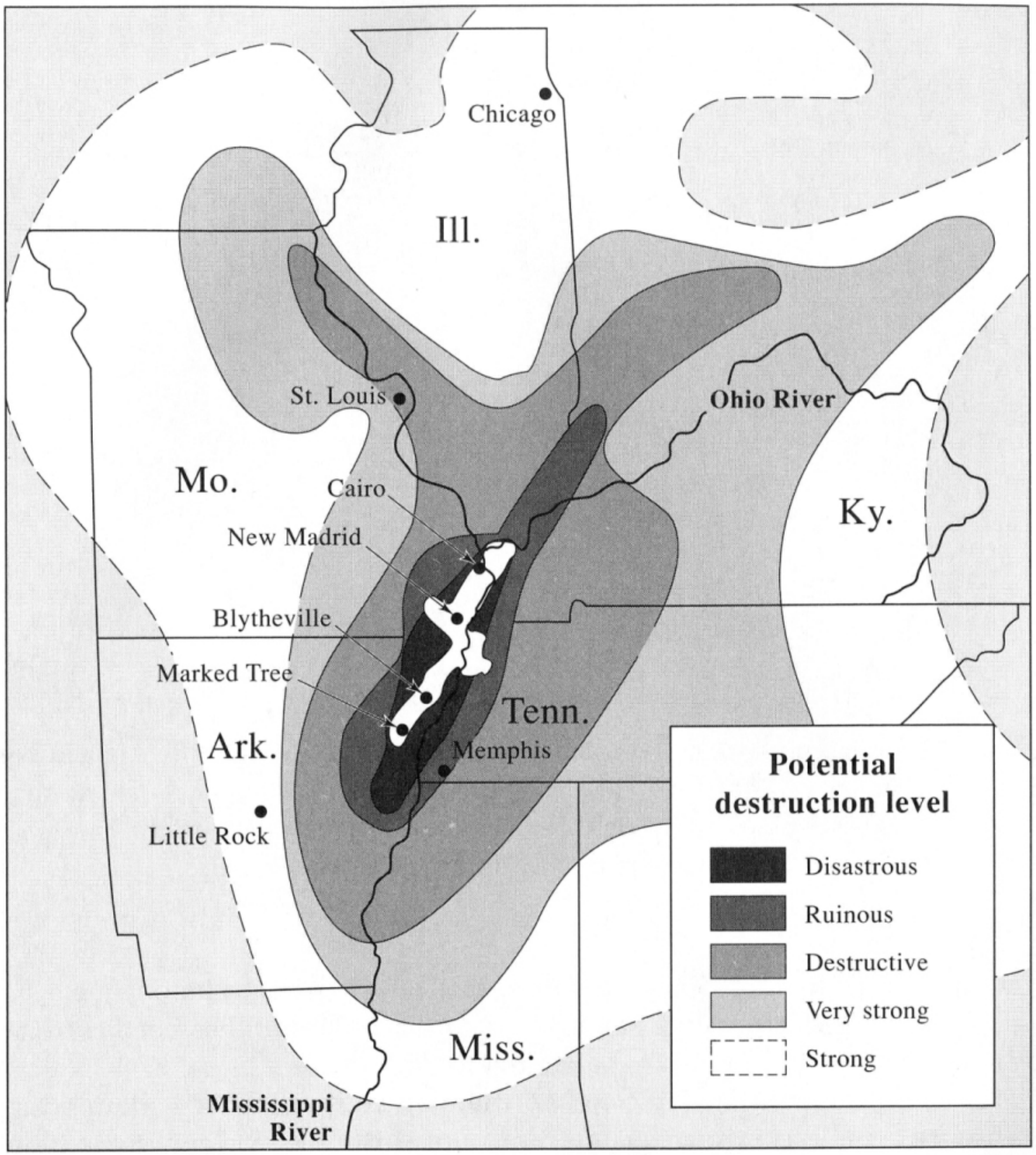
- Epicenters recorded between 1974-96 describe a seismically active zone of complex intraplate tectonics
- Right lateral strike slip and blind thrust faulting occur in the same region



OTHER SEISMIC SOURCES

- Not all of the region's quakes emanate from the recognized New Madrid Zone
- Other sources likely

DAMAGE POTENTIAL



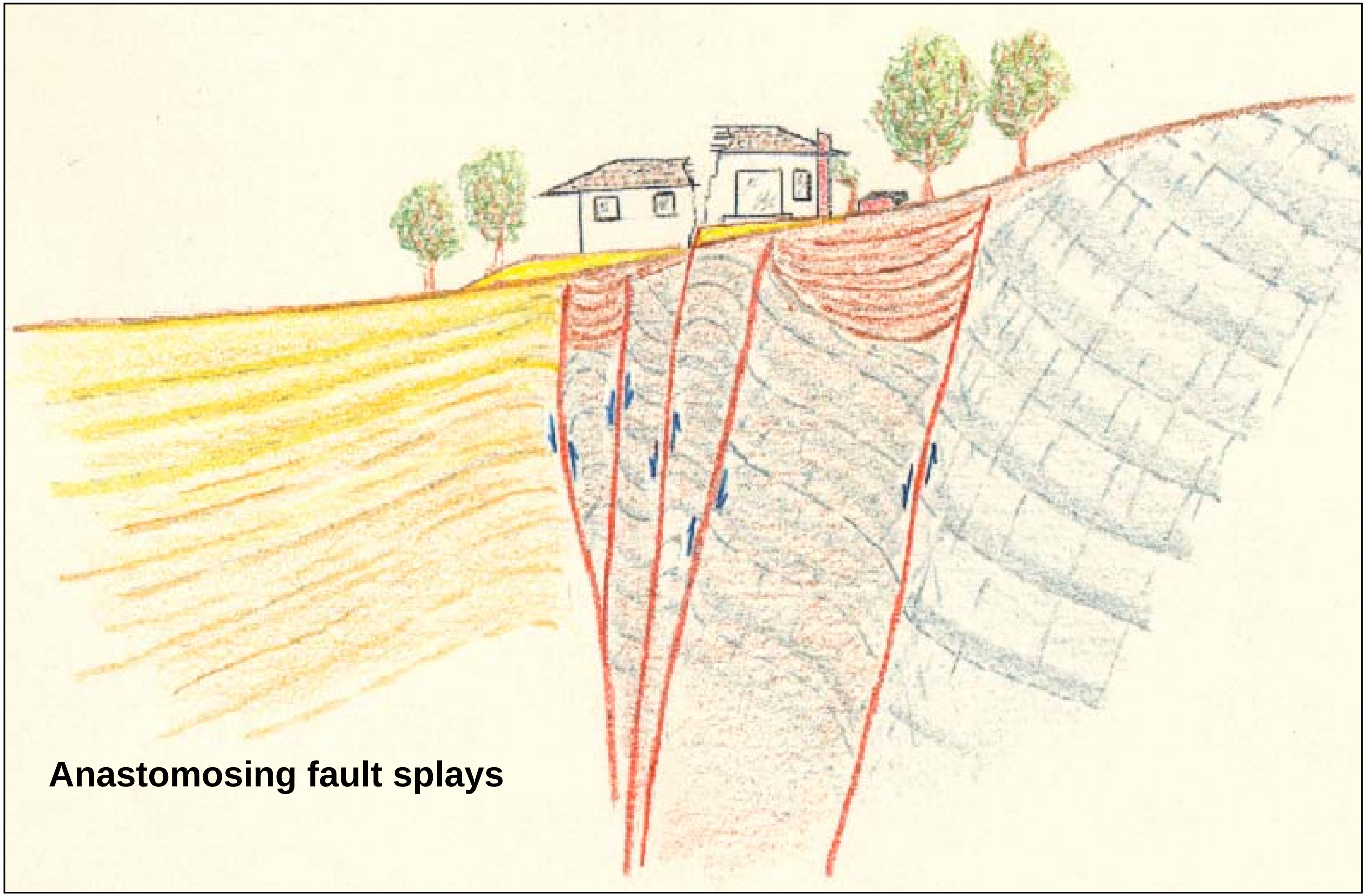
Published damage predictions for the New Madrid Seismic Zone have focused on the near field area, in the upper Mississippi Valley

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

EARTHQUAKE MECHANISMS THAT COMMONLY IMPACT STRUCTURES

- Surface fault rupture hazards
- Ground waves and fling effects
- Topographic enhancement of seismic energy
- Dynamic consolidation of soils
- Liquefaction and lateral spreading
- Site amplification effects
- Long period motion and resonant frequency effects
- Out-of-phase structural response

SURFACE FAULT RUPTURE HAZARDS

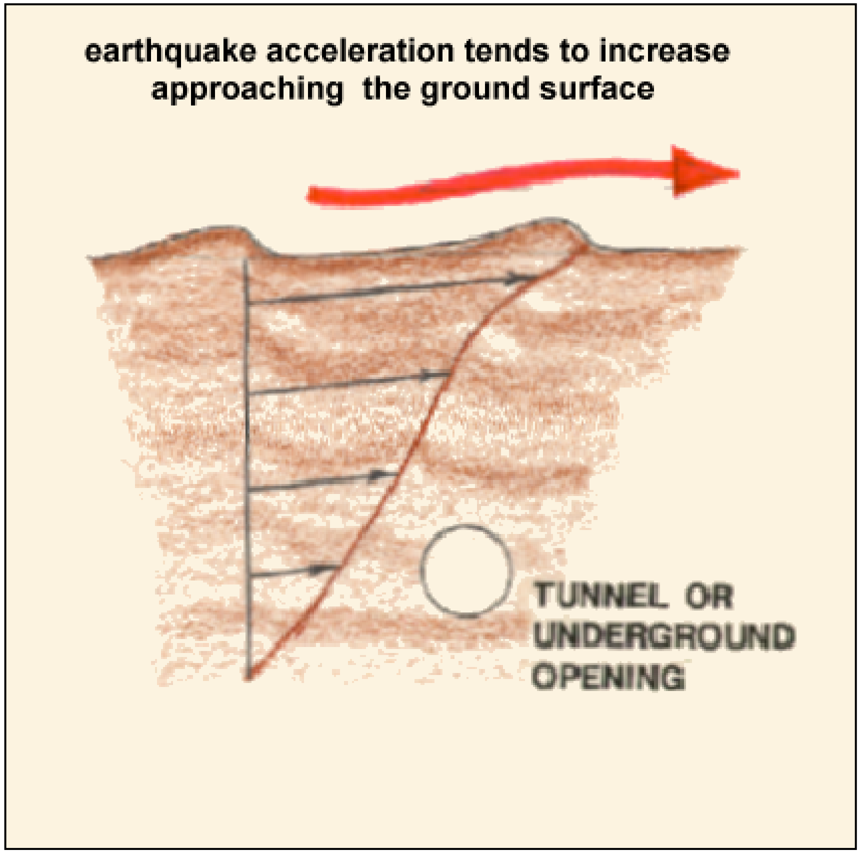


- Major active faults usually extend up to the ground surface, where they can pose a threat to structures. Only about 2% of earthquake-induced structural damage is caused by surface fault rupture. Various fault strands identified near the ground surface may be active, dormant or ancient, as shown above.

SURFACE RUPTURE

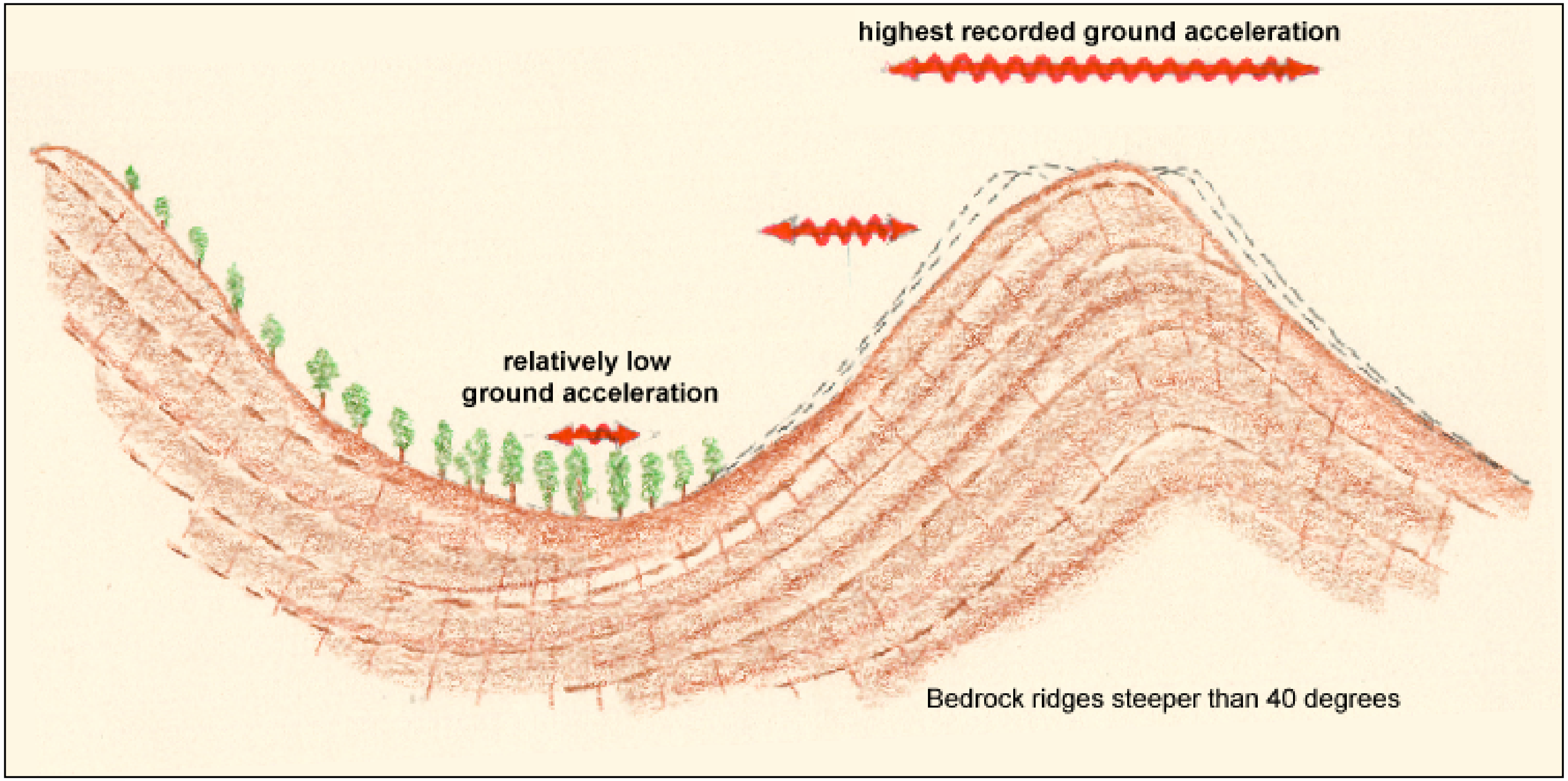
- Only a small percentage of earthquakes actually cause noticeable surface fault rupture
- Sometimes it is rather discrete (upper left)
- On other occasions it can be very abrupt and graphic (lower left)

FREE BOUNDARY/ GROUND WAVE EFFECT



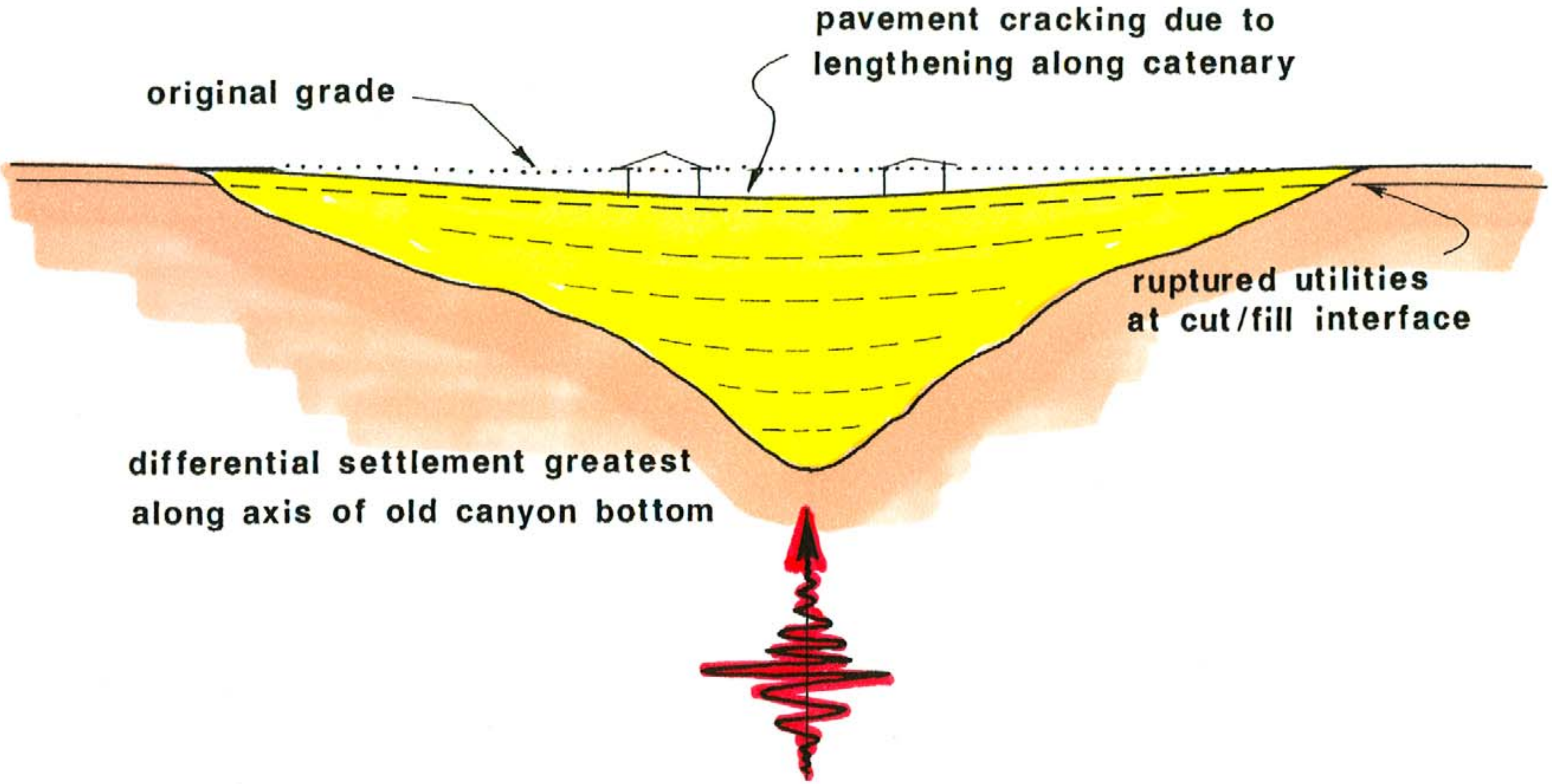
- As the seismic wave train propagates upward and along the Earth’s surface, the peak ground accelerations will tend to increase at the ground surface because there is no confinement. Tunnels and underground openings usually record much lower values of acceleration due to their increased confinement.

TOPOGRAPHIC INFLUENCE ON SITE RESPONSE

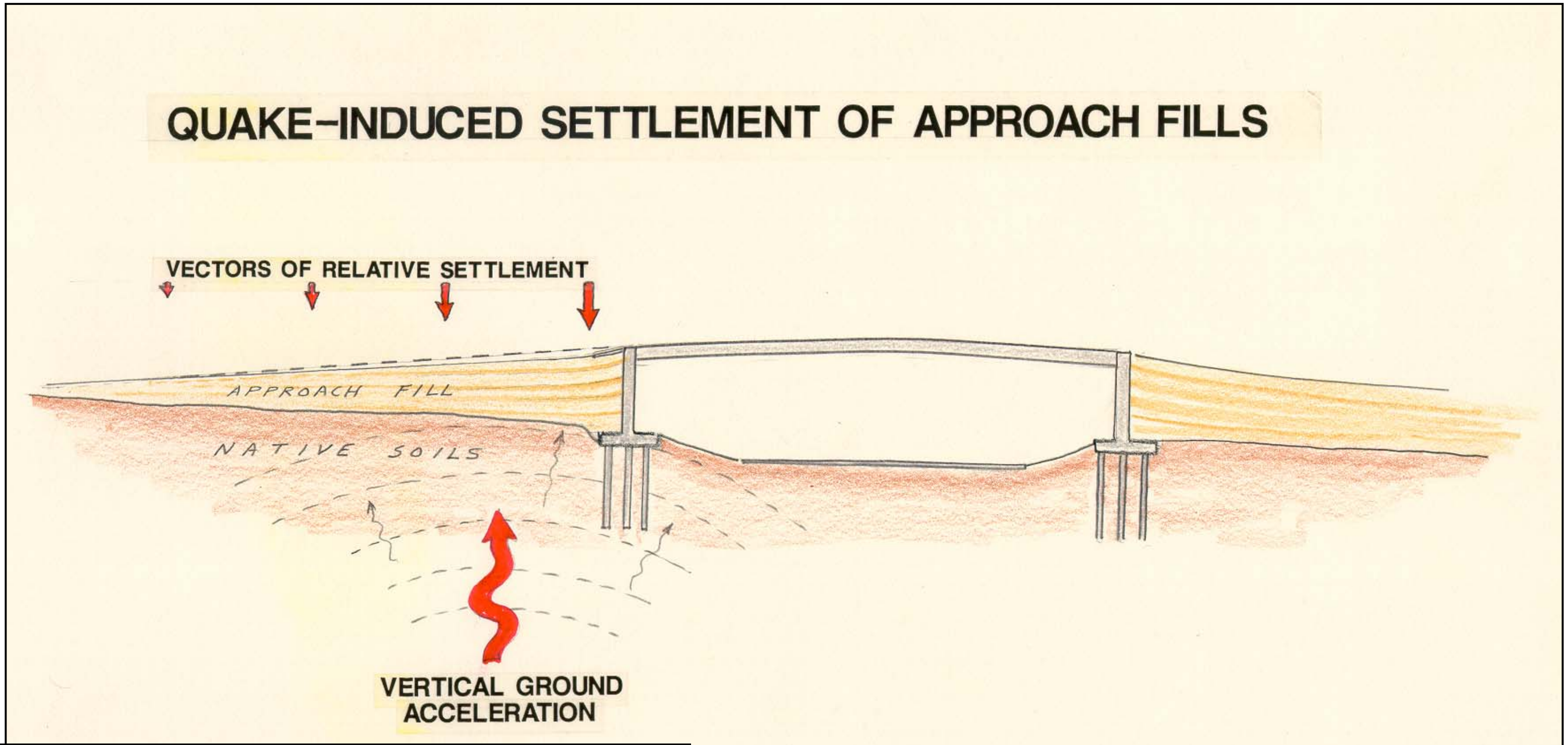


- **Steep-sided bedrock ridges usually experience much higher accelerations during earthquakes because they are less laterally constrained. In the October 1989 Loma Prieta earthquake the PGA of 0.77g was recorded in the valley bottom at Corralitos. Estimates of PGA values for the adjoining ridges were in excess of 1.30g.**

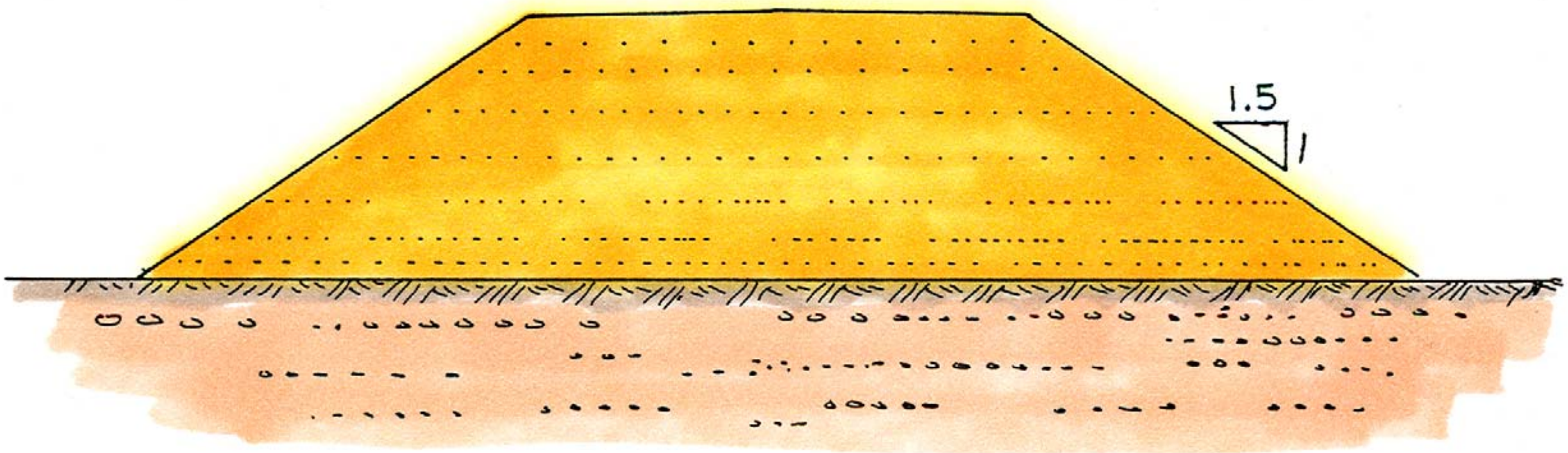
DYNAMICALLY-INDUCED SETTLEMENT OF A VALLEY FILL

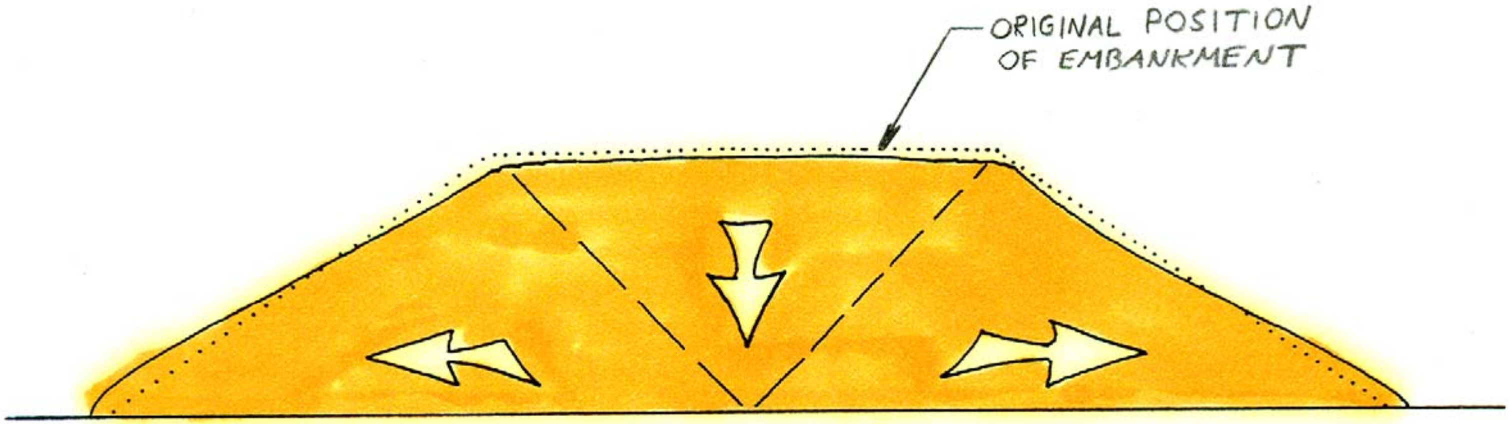


- **Fill embankments tend to consolidate and settle under dynamic loading in the near-field zone**



- Regardless of the compactive effort engendered to filled ground during placement, these materials tend to compress during earthquake-induced shaking, often causing abrupt settlement of the approach fills at the abutments.





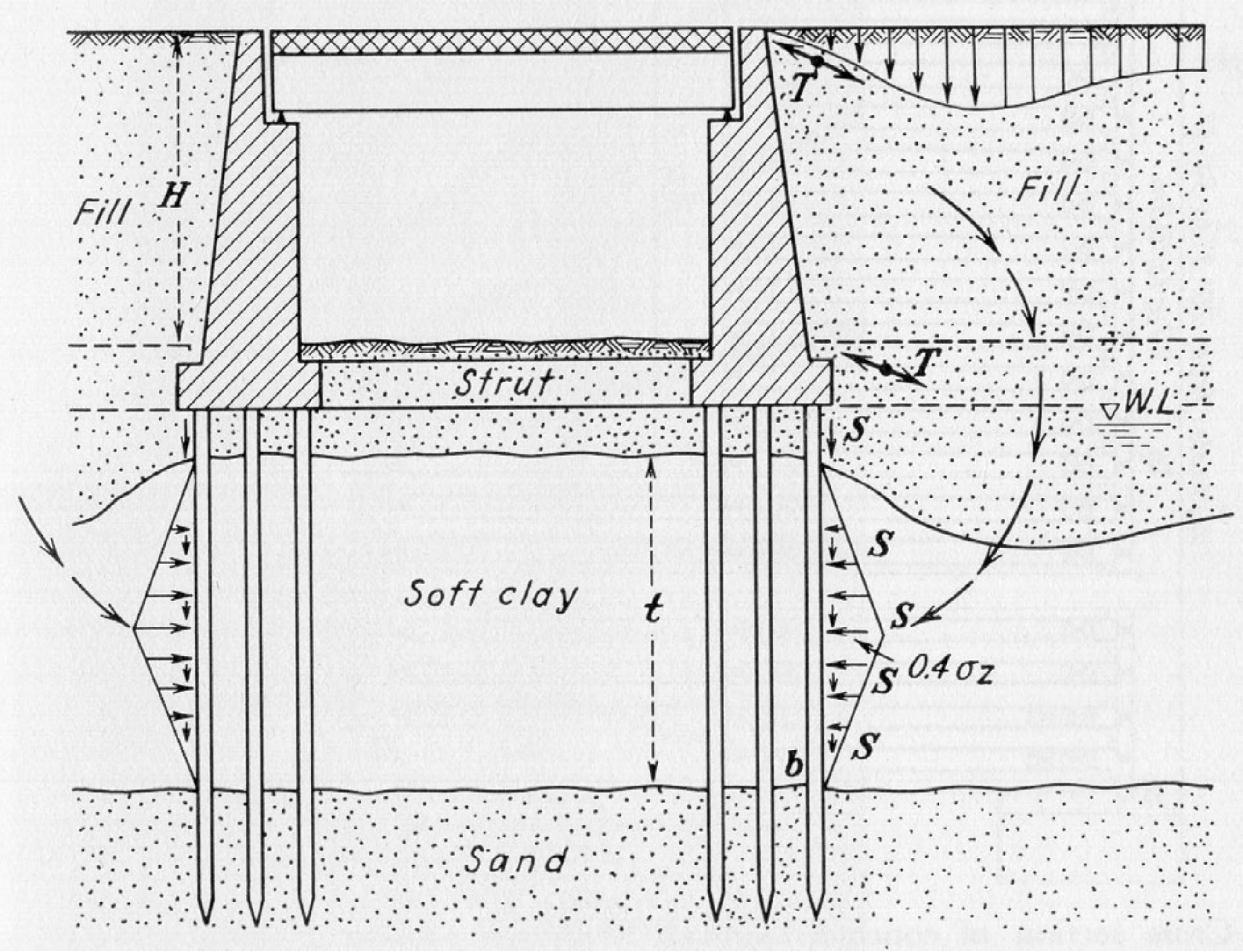
- **Mechanism of seismically-induced settlement of bridge approach fill prisms**

QUAKE-INDUCED SETTLEMENT

- Approach fills for pile supported bridges commonly exhibit grievous differential settlement
- Impacts traffic flow and any entrained utilities, like fire mains
- These examples are from Aug 1999 Chi Chi earthquake in Taiwan

APPROACH FILL SETTLEMENT

- Seismically-induced settlement and lurching of approach fills for the Cayumapa River Bridge near Valdivia, Chile, which occurred during the M9.5 May 1960 earthquake
- Replacement structure being constructed in lower view, using Geofoam



- **Tschebotarioff (1973) presented case studies of pile supported bridges that failed because of approach fill settlement**.

SETTLEMENT OF APPROACH FILL

- **Crib wall supported approach fill for pile supported bridge. As fill consolidated, crib wall deformed and supporting piles deflected inward, towards channel. Taken from Tschetarioff (1973).**

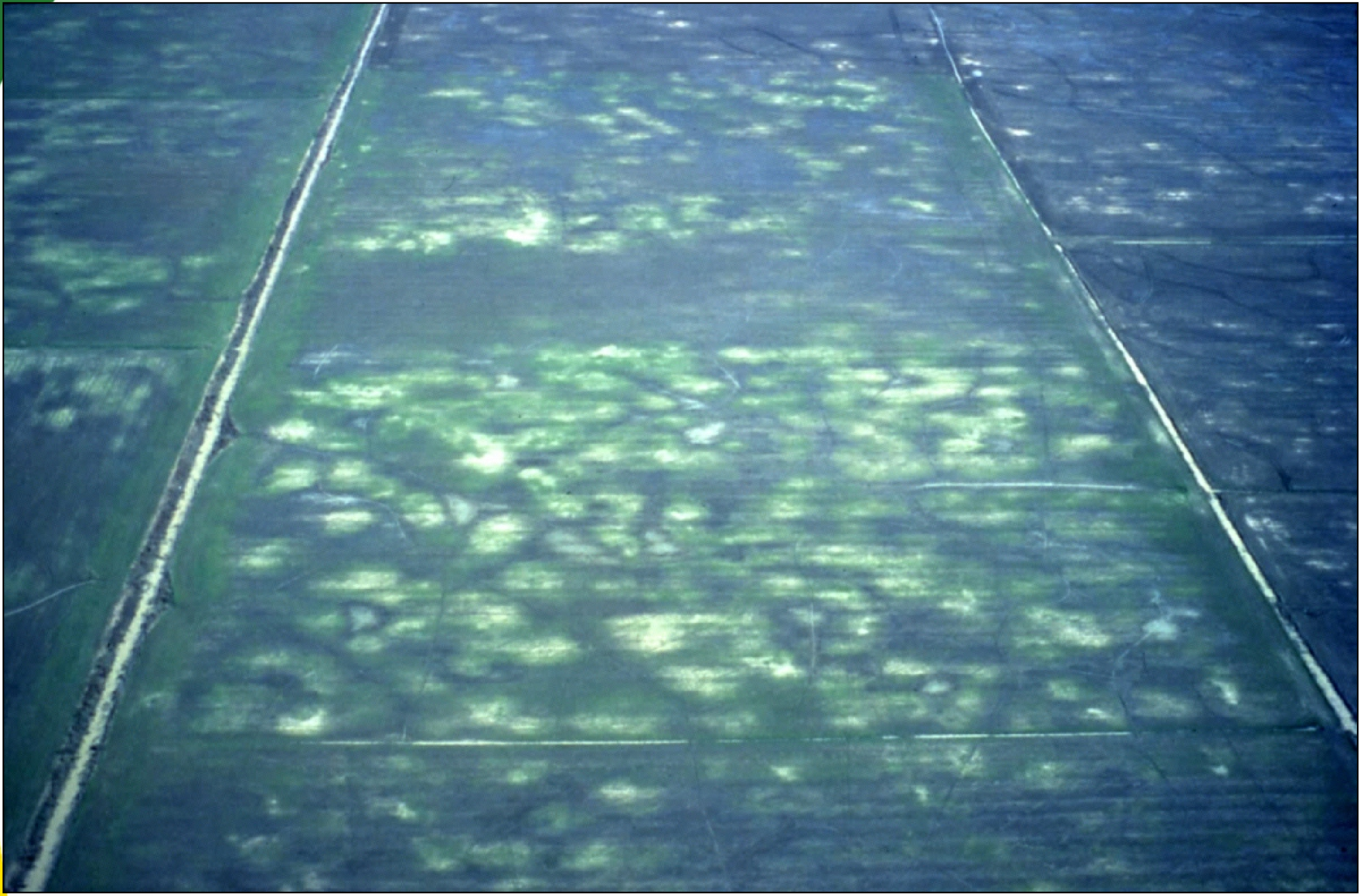
LIQUEFACTION

- 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

LIQUEFACTION

Liquefaction is a failure mechanism by which cohesionless materials 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.

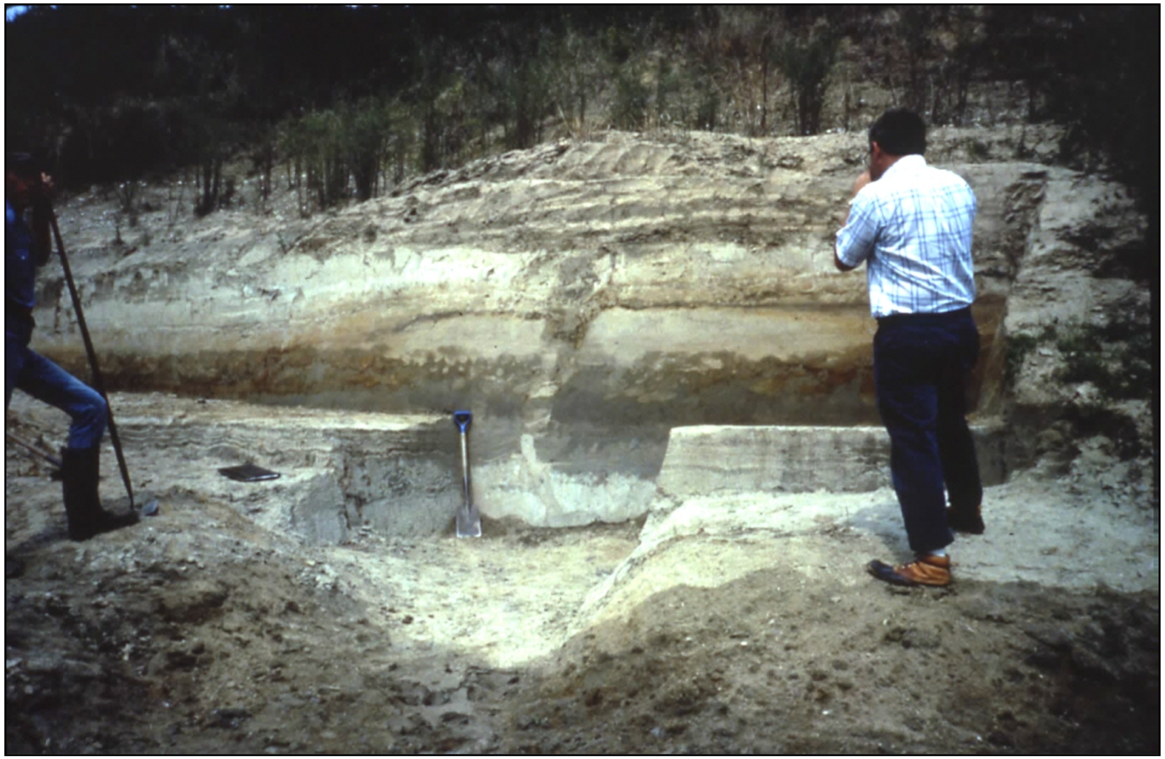
- Recent sand blows dot the landscape surrounding New Madrid, MO, testifying to massive liquefaction



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

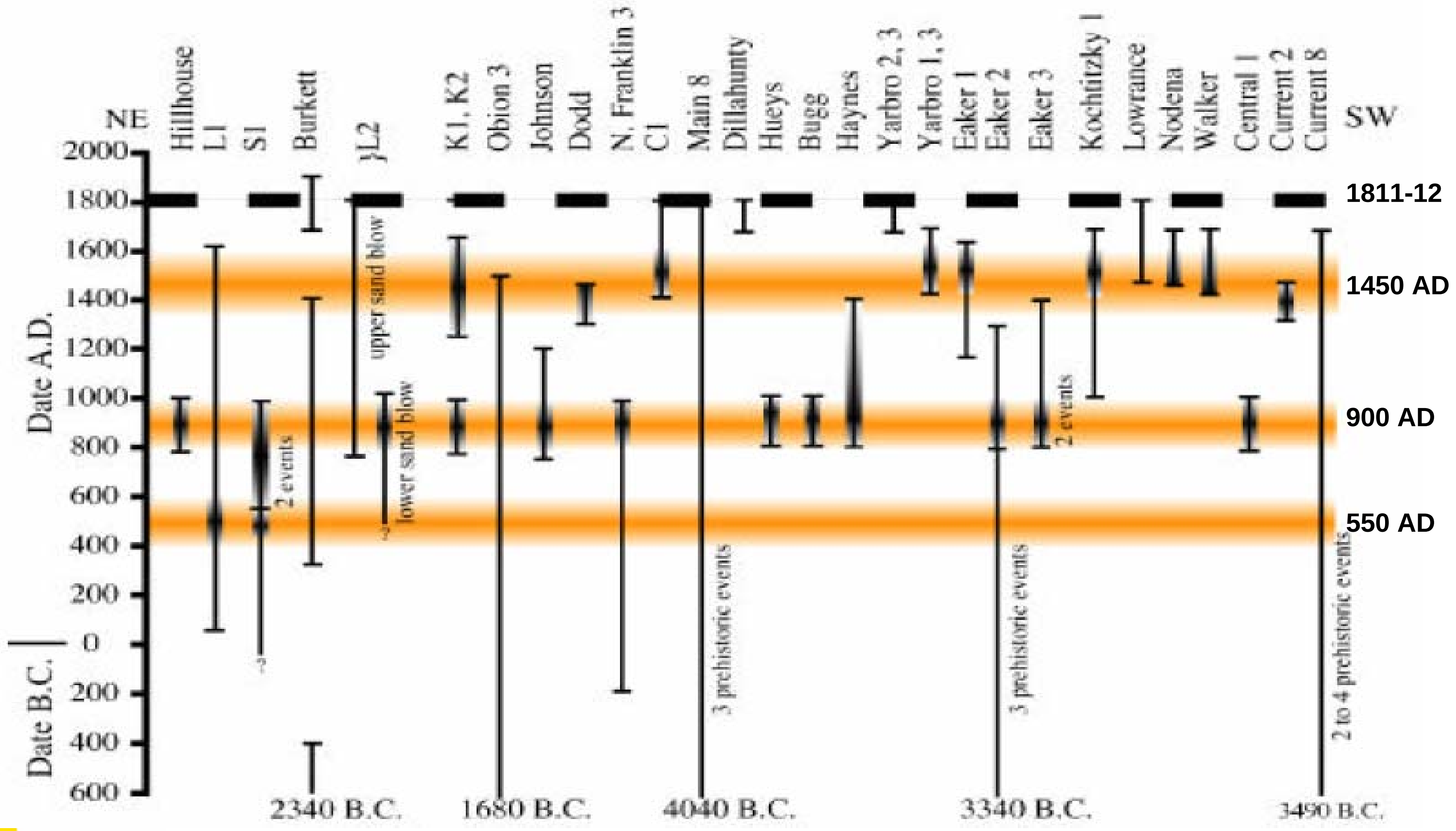
- Farm lands west of Big Lake, AR reveal a series of linear fissures which disgorged liquefied sand from beneath a silt cover.

PALEOLIQUEFACTION STUDIES



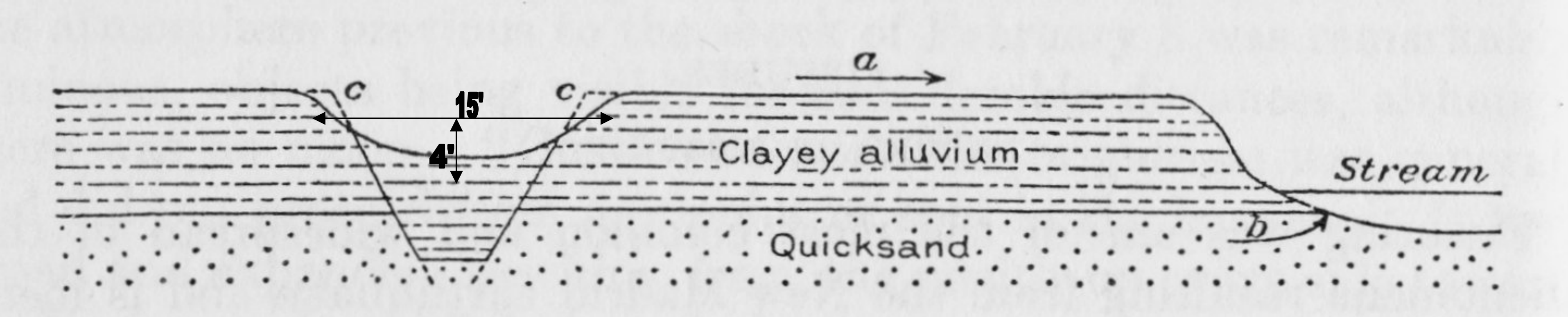
- C14 dating of organics caught in sand boils and dikes are used to date past earthquakes. Three M7.5 to M8 paleoevents have been conclusively dated: ~1450, ~900 and ~550 AD.

Paleoliquefaction Assessments

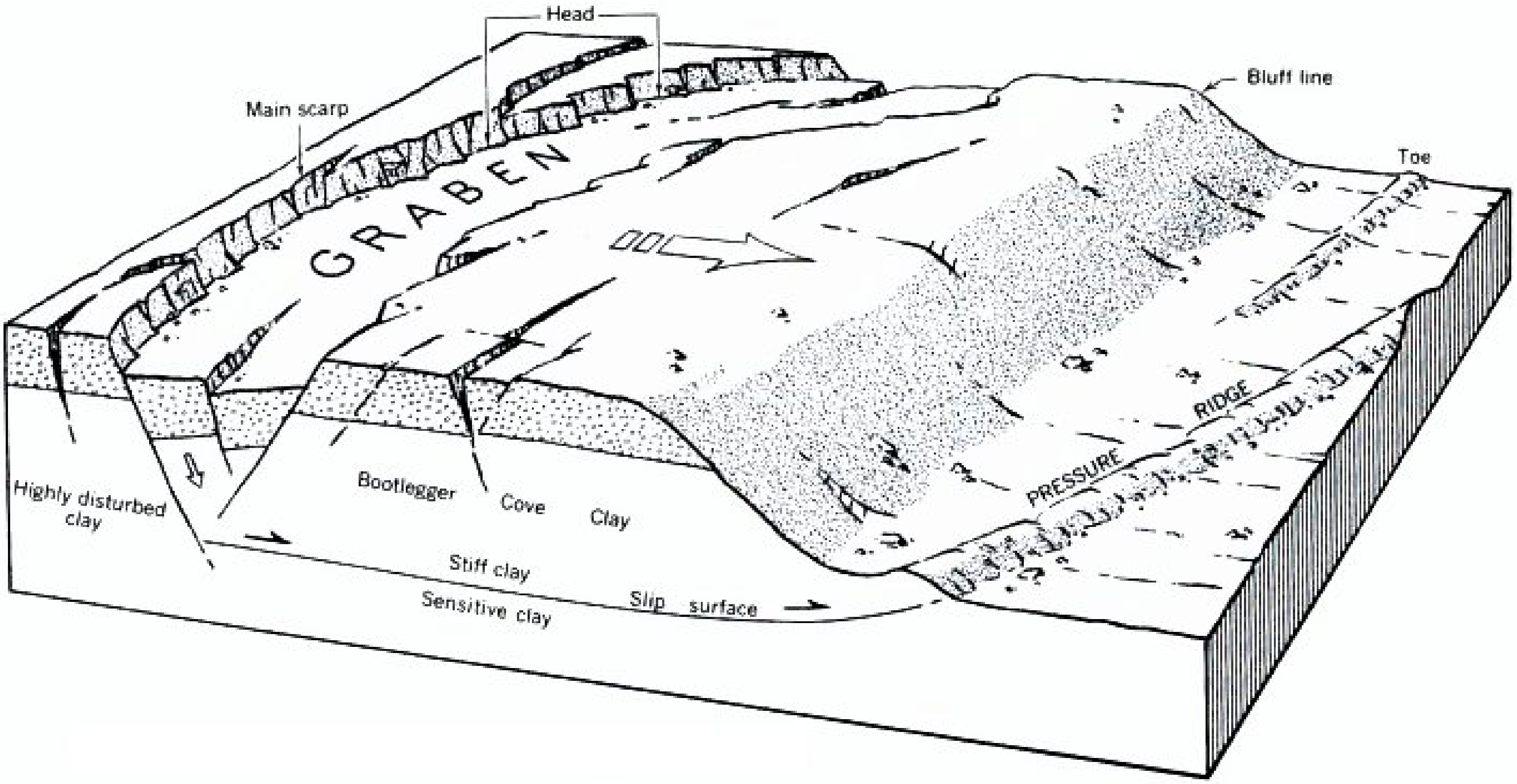


Shaded orange lines show most probable ages of major earthquakes in the NMSZ prior to 1811-12 (shown as dashed line)

Liquefaction of Confined Horizons Causes Lateral Spreads

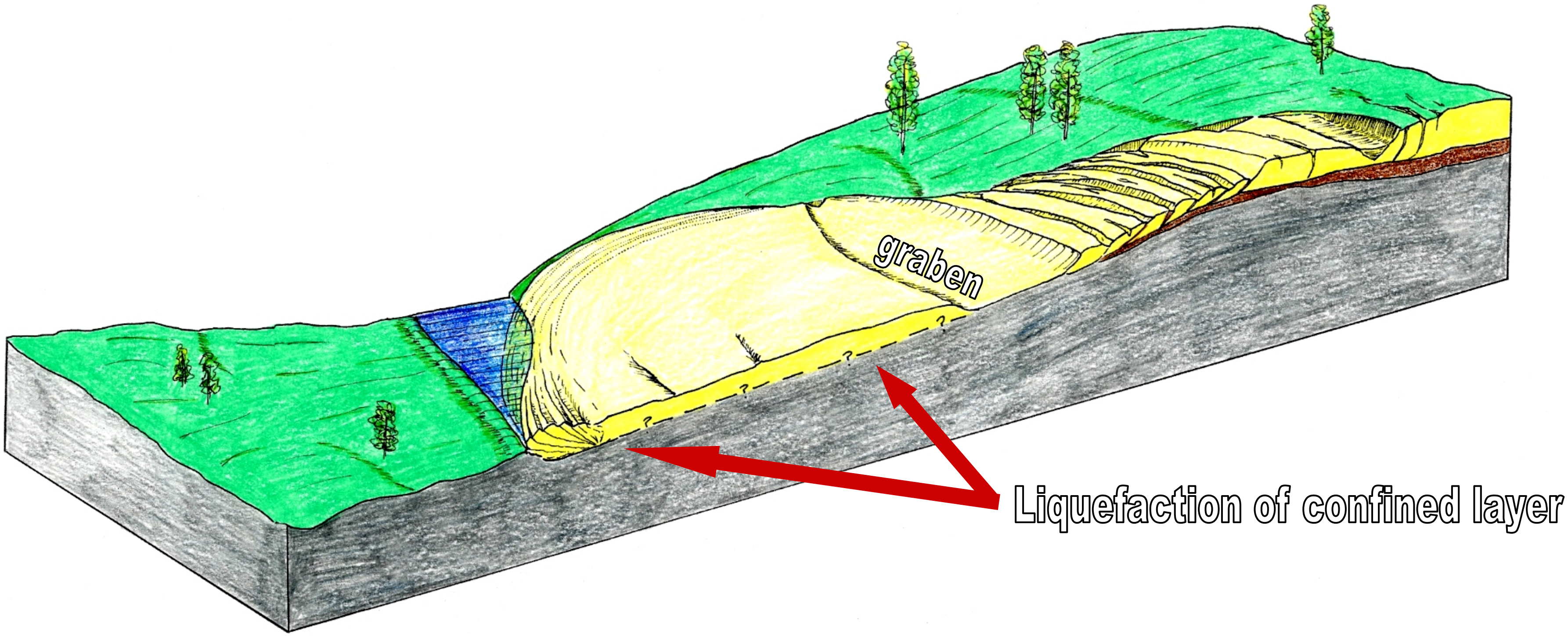


- **Lateral spreads** were initially recognized and identified by USGS geologist Myron Fuller while studying the effects of the 1811-12 New Madrid earthquakes between 1905-12. Fuller made the sketch above, noting that: *“The depth of the openings was not usually very great, probably being in most cases limited to the hard clayey zone extending from the surface down to the quicksand which usually underlies the surface soil at depths of from 10 to 20 feet.”*



Block diagram of a lateral spread which evolved from post-1964 earthquake evaluations in Alaska by Walt Hansen in USGS Professional Paper 542-A (1966)

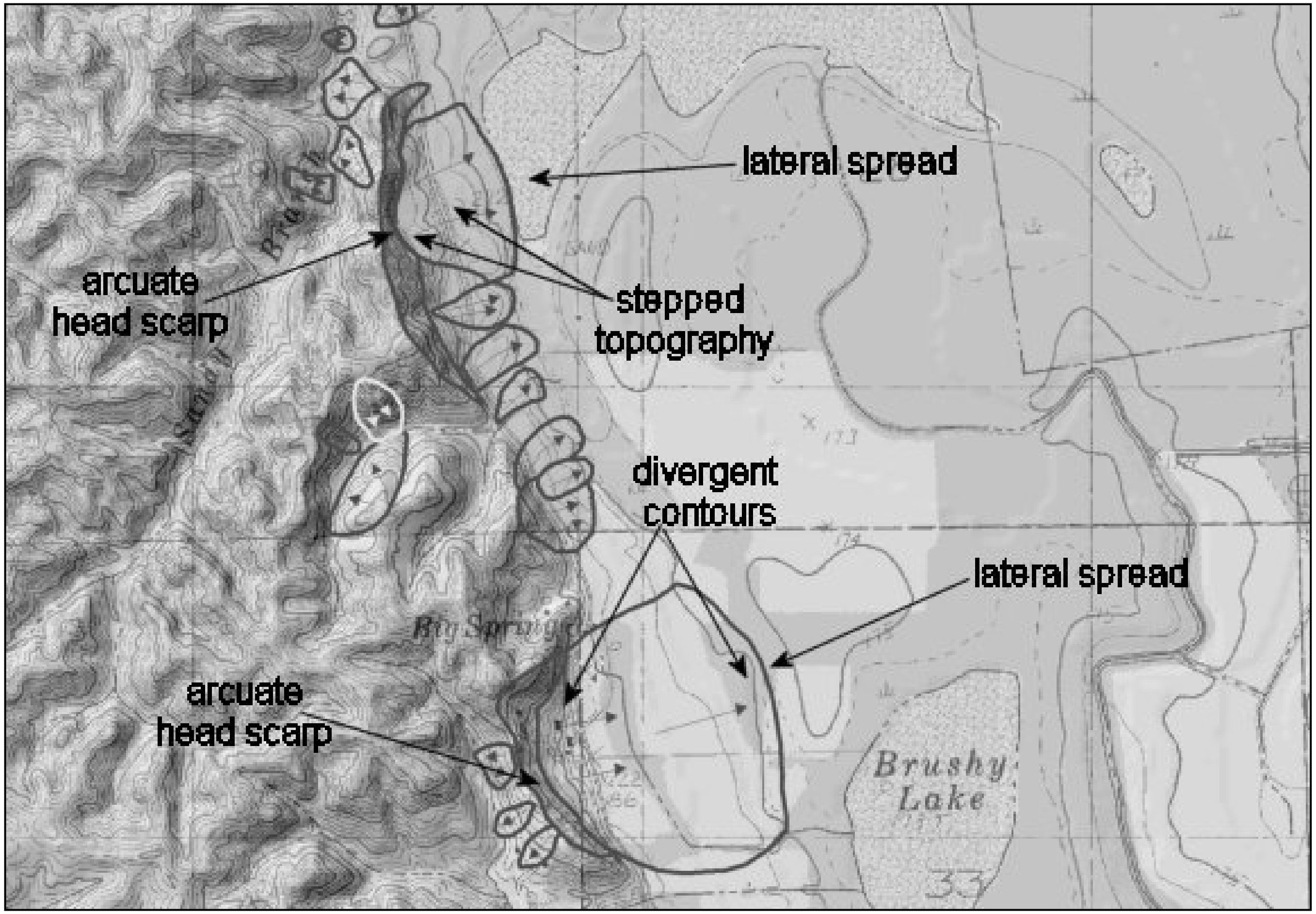
LATERAL SPREADING



- Lateral spreads can exhibit different length-to-depth ratios, depending on soil sensitivity. Liquefaction occurs along discrete horizons which are confined, allowing lateral translation of rafted material, usually towards open channels or depressions.

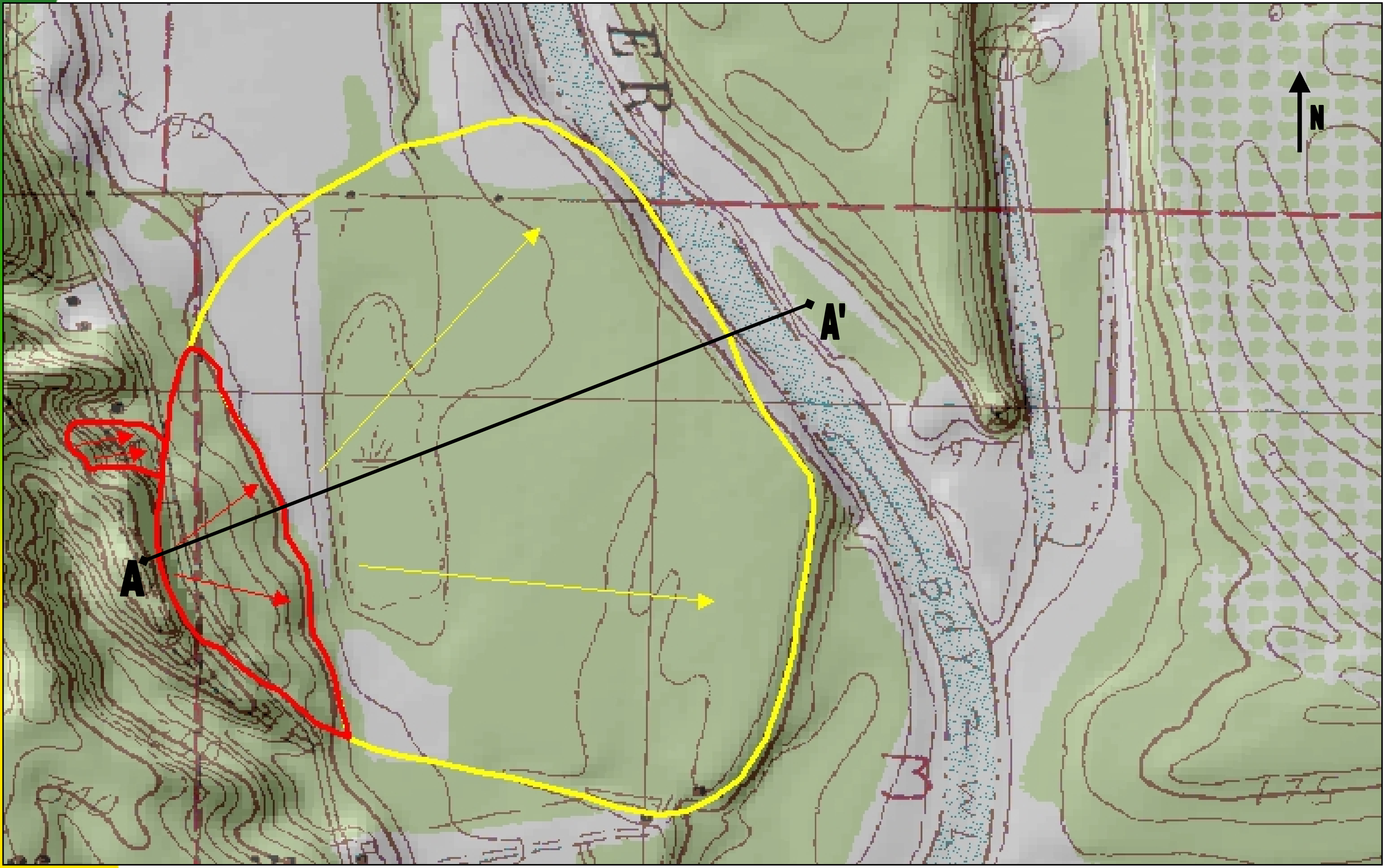
Topographic Expression of Lateral Spreads Near Helena, Arkansas

- **Divergent contours**
- **Stepped topography**
- **Headscarp evacuation grabens**
- **Arcuate headscarps**

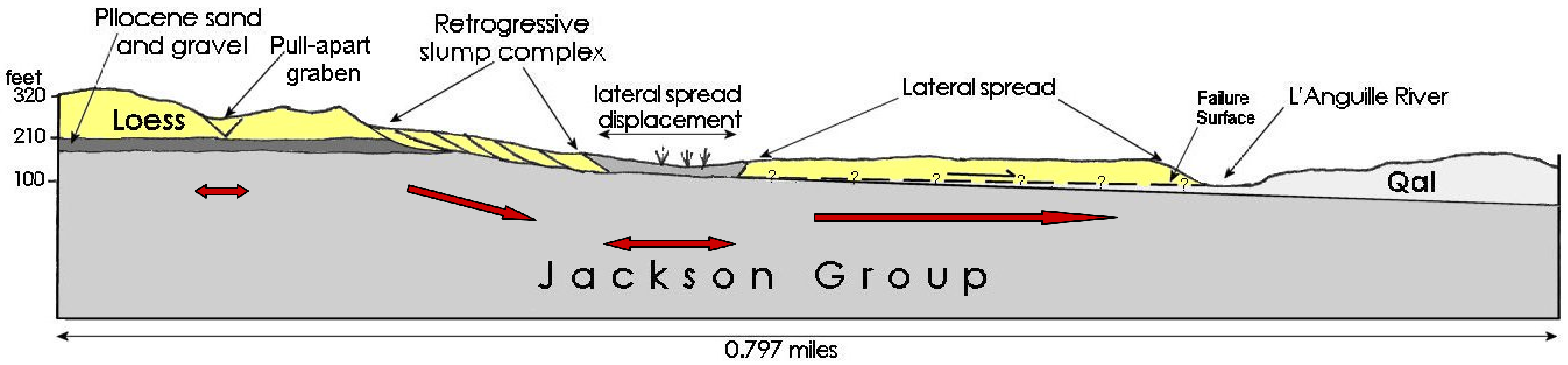


UMR

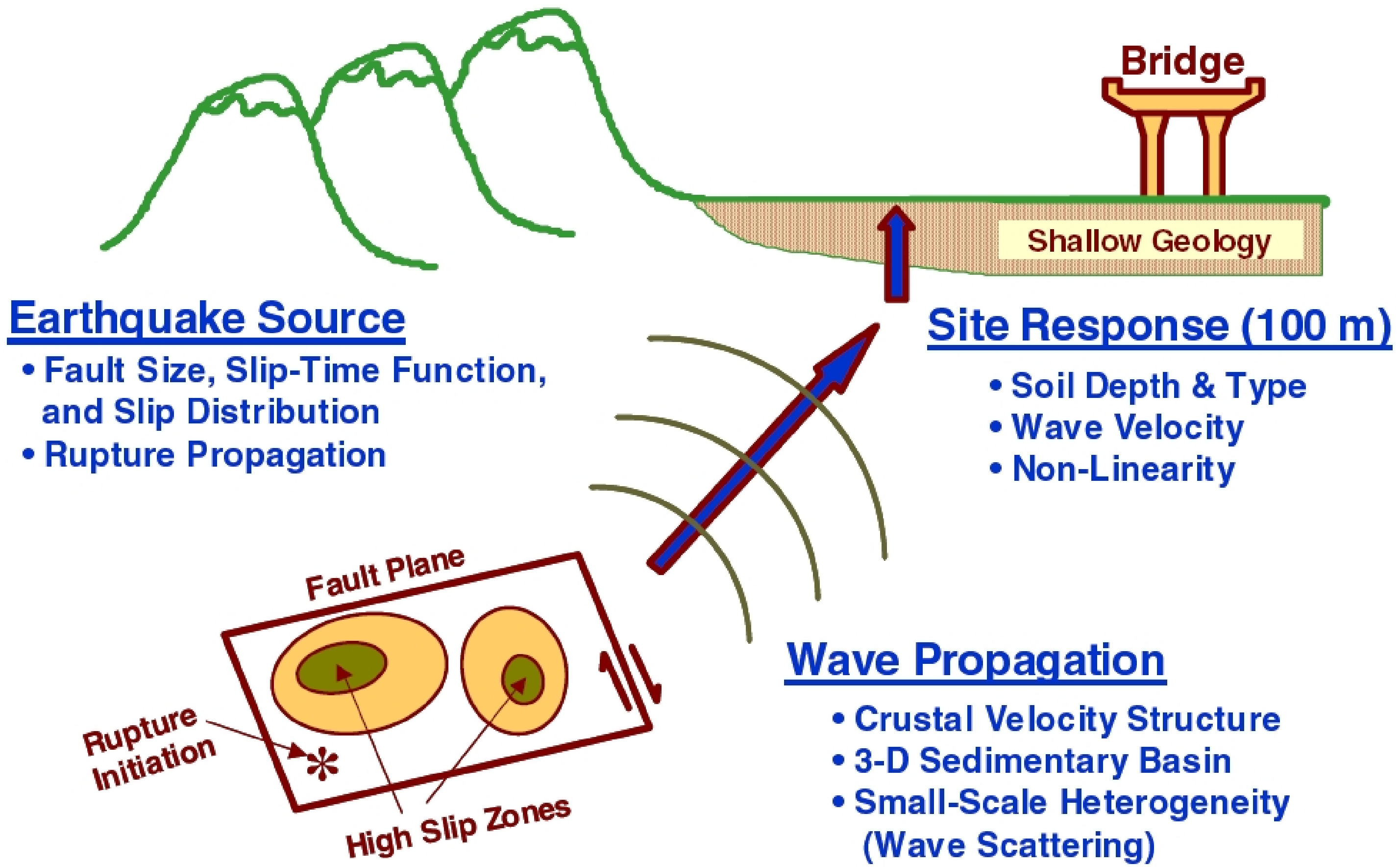
Jeffersonville Lateral Spread Along Crowley's Ridge ~ 25 km north of Helena, Arkansas



Cross-section through Jeffersonville Lateral Spread and Crowley's Ridge



The Jeffersonville Lateral Spread feature appears to have been triggered by the 1811-12 New Madrid earthquake sequence, with the ground translating easterly into the L'Anguille River, near its mouth with the St. Francis River. The eastern escarpment of Crowley's Ridge is peppered with similar features.



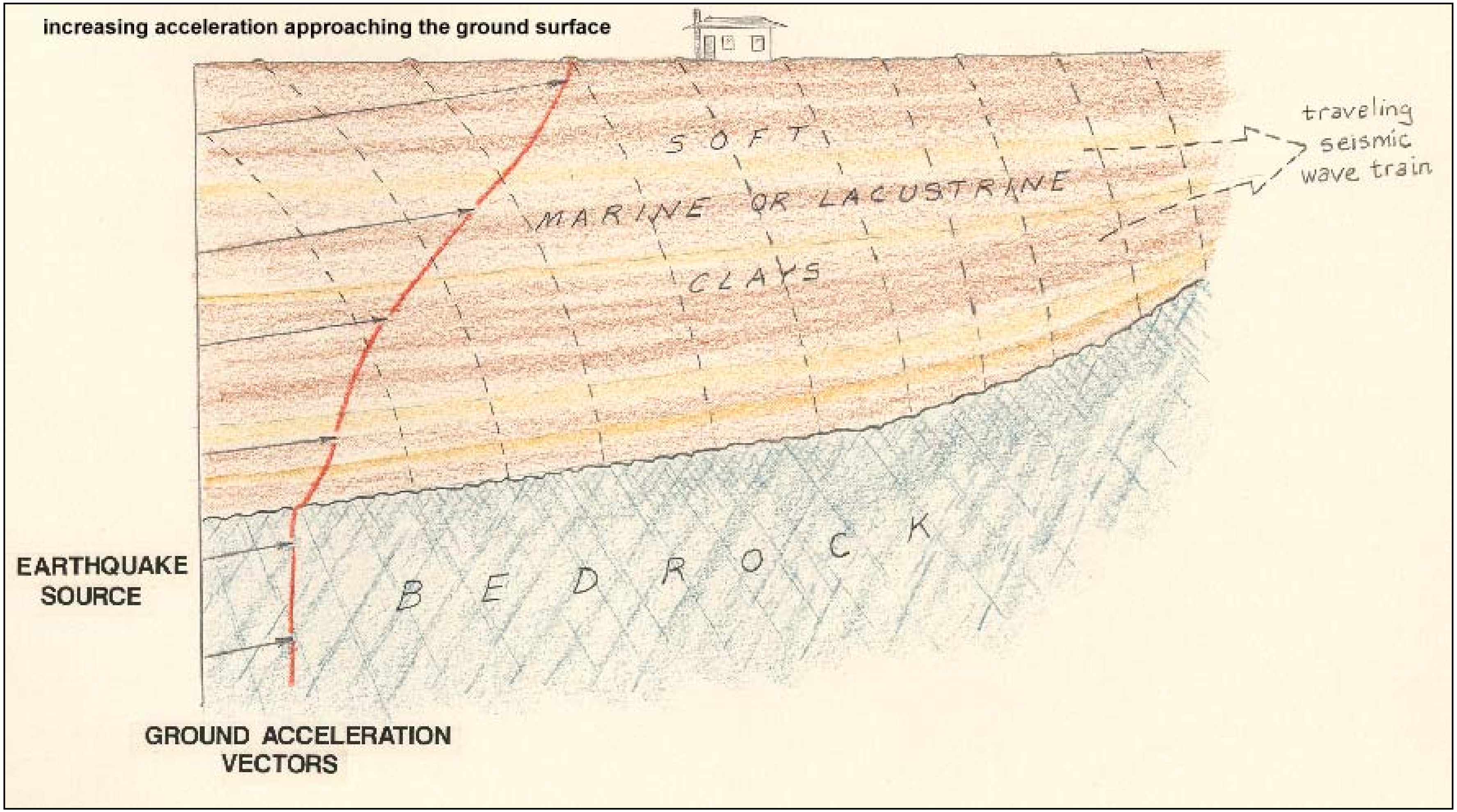
Earthquake Source
- Fault Size, Slip-Time Function, and Slip Distribution
- Rupture Propagation

Site Response (100 m)
- Soil Depth & Type
- Wave Velocity
- Non-Linearity

Wave Propagation
- Crustal Velocity Structure
- 3-D Sedimentary Basin
- Small-Scale Heterogeneity (Wave Scattering)

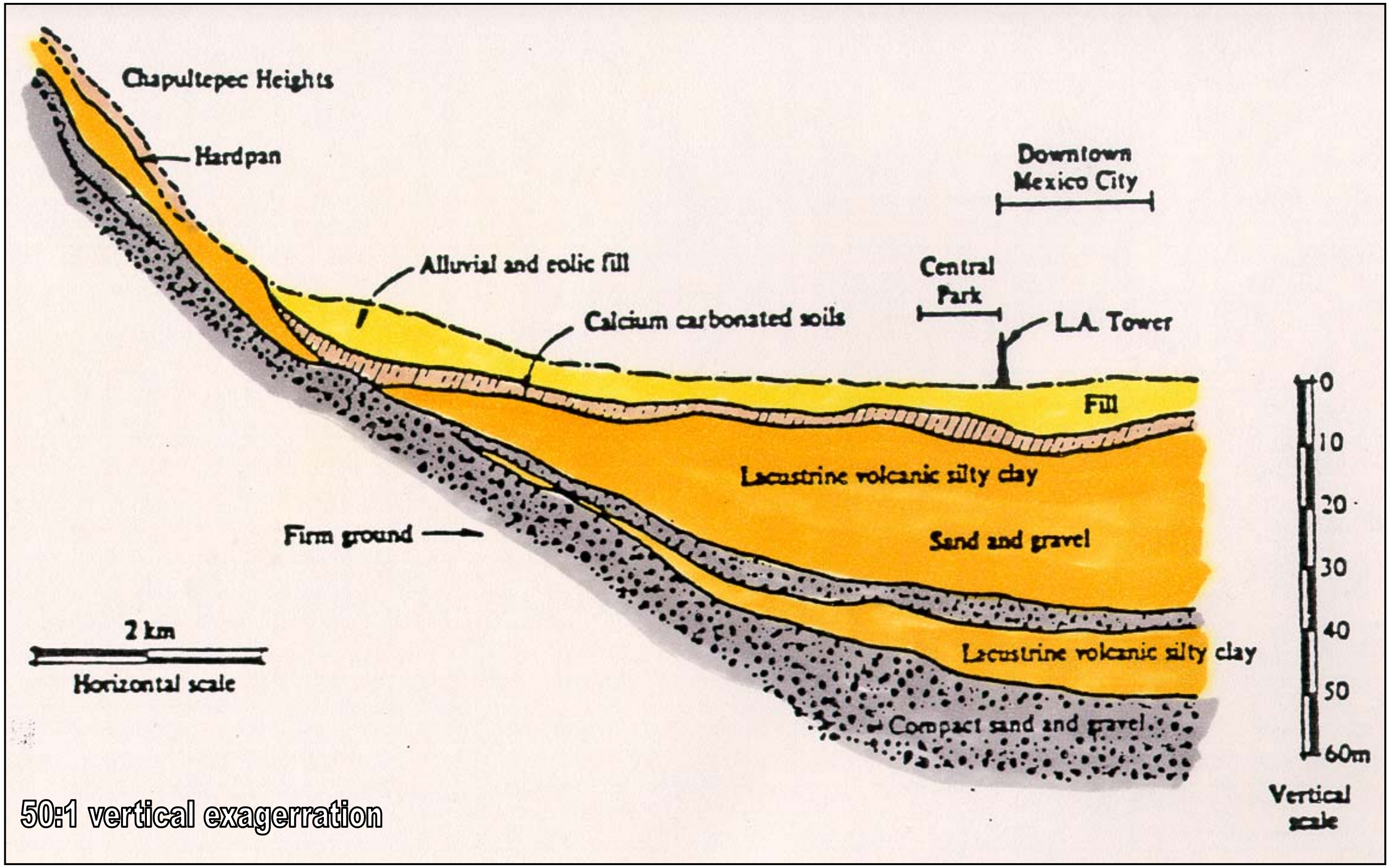
- **The type, depth and size of earthquake combine with geophysical properties of the underlying geology to affect seismic site response**

WHAT IS SITE RESPONSE ?



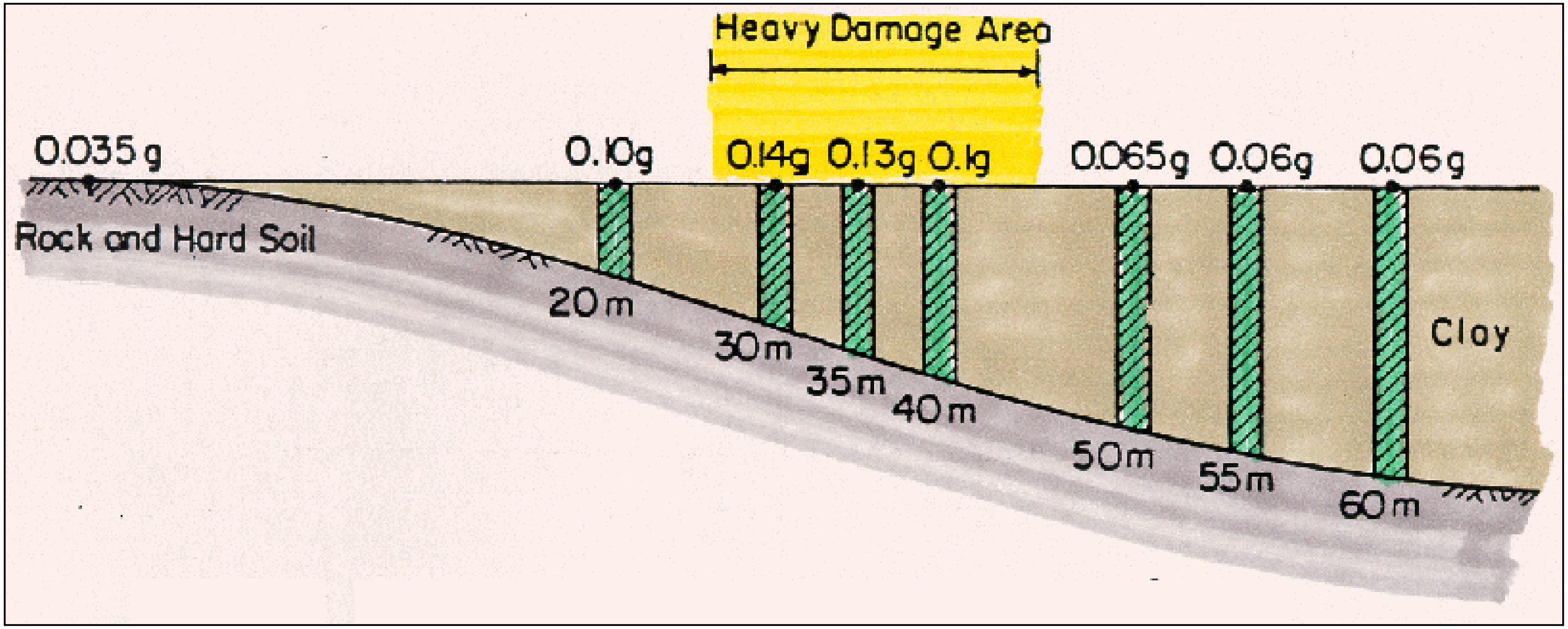
- Site response is used to describe the fundamental period of vibration generated by a typical earthquake at any particular site. If soft unconsolidated sediments overlie resistant bedrock an impedance contrast develops at this boundary which causes incoming seismic energy to be absorbed at a rate faster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

SOFT SEDIMENTS UNDERLYING MEXICO CITY



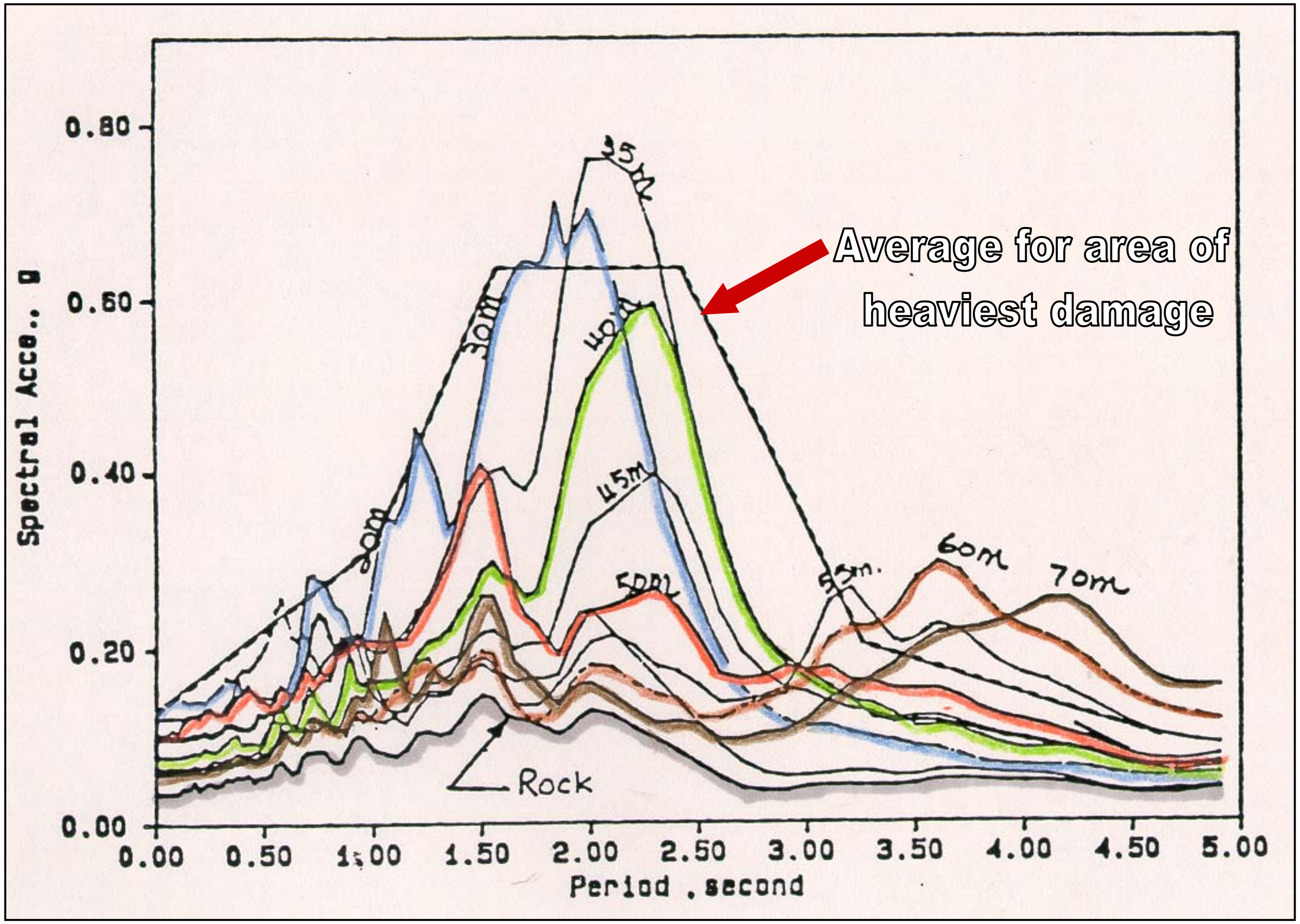
- Generalized geologic cross section of the southern margins of the lacustrine basin underlying Mexico City. The lacustrine sediments were covered with fill as the city developed. These soft materials amplified the incoming seismic wave train from a M.8.1 earthquake located 52 km off the coast of Michoacan Province, some 350 km from Mexico City!

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 epicenter was 350 km from Mexico City and 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.

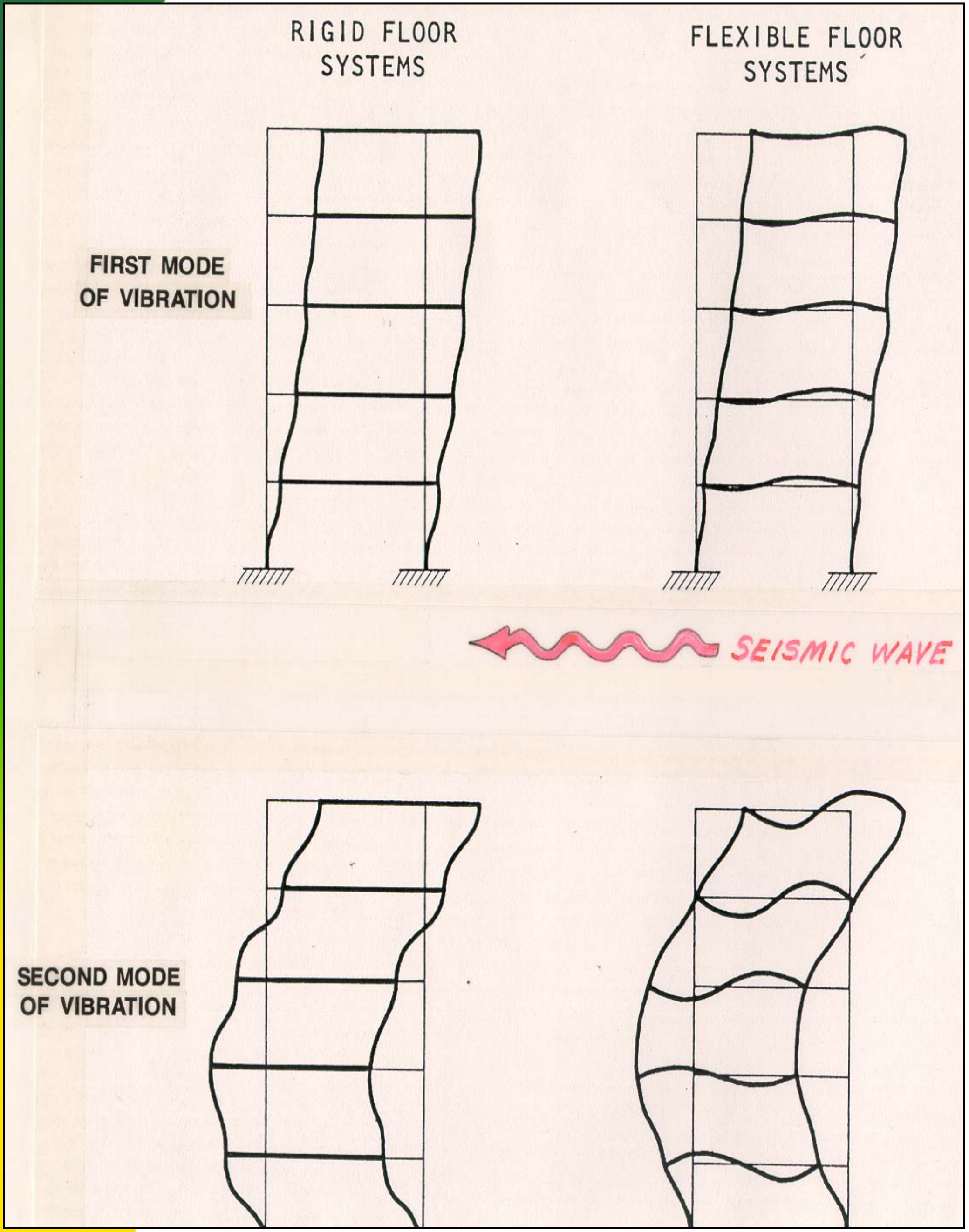
VARIANCE OF RESPONSE SPECTRA WITH SEDIMENT THICKNESS IN MEXICO CITY



Average for area of heaviest damage

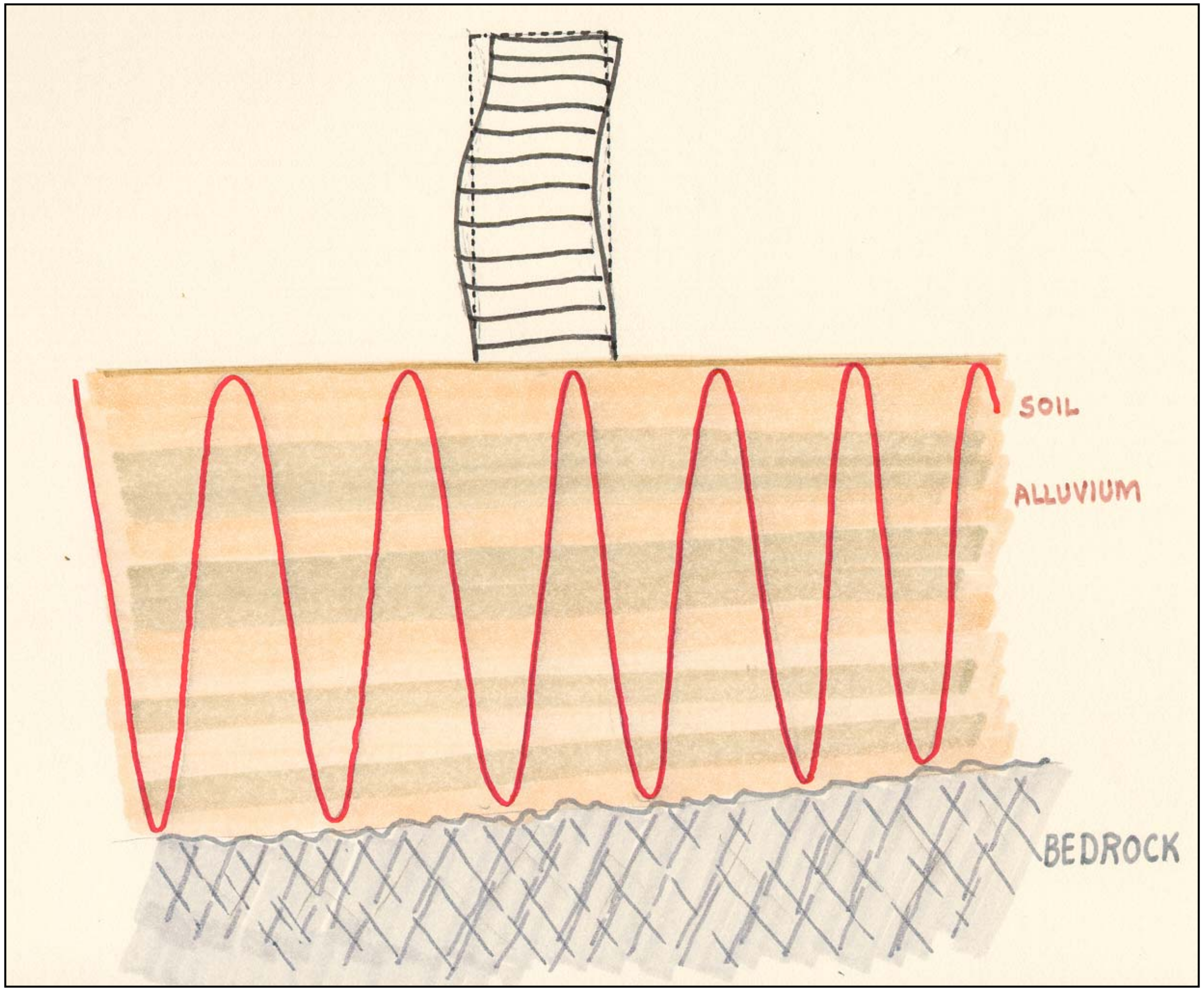
- **Response spectra calculated for different thicknesses of soft sediments in southern Mexico City, between downtown and Chapultepec Heights. Note impact of 30 to 45 m thickness.**

MODES OF VIBRATION



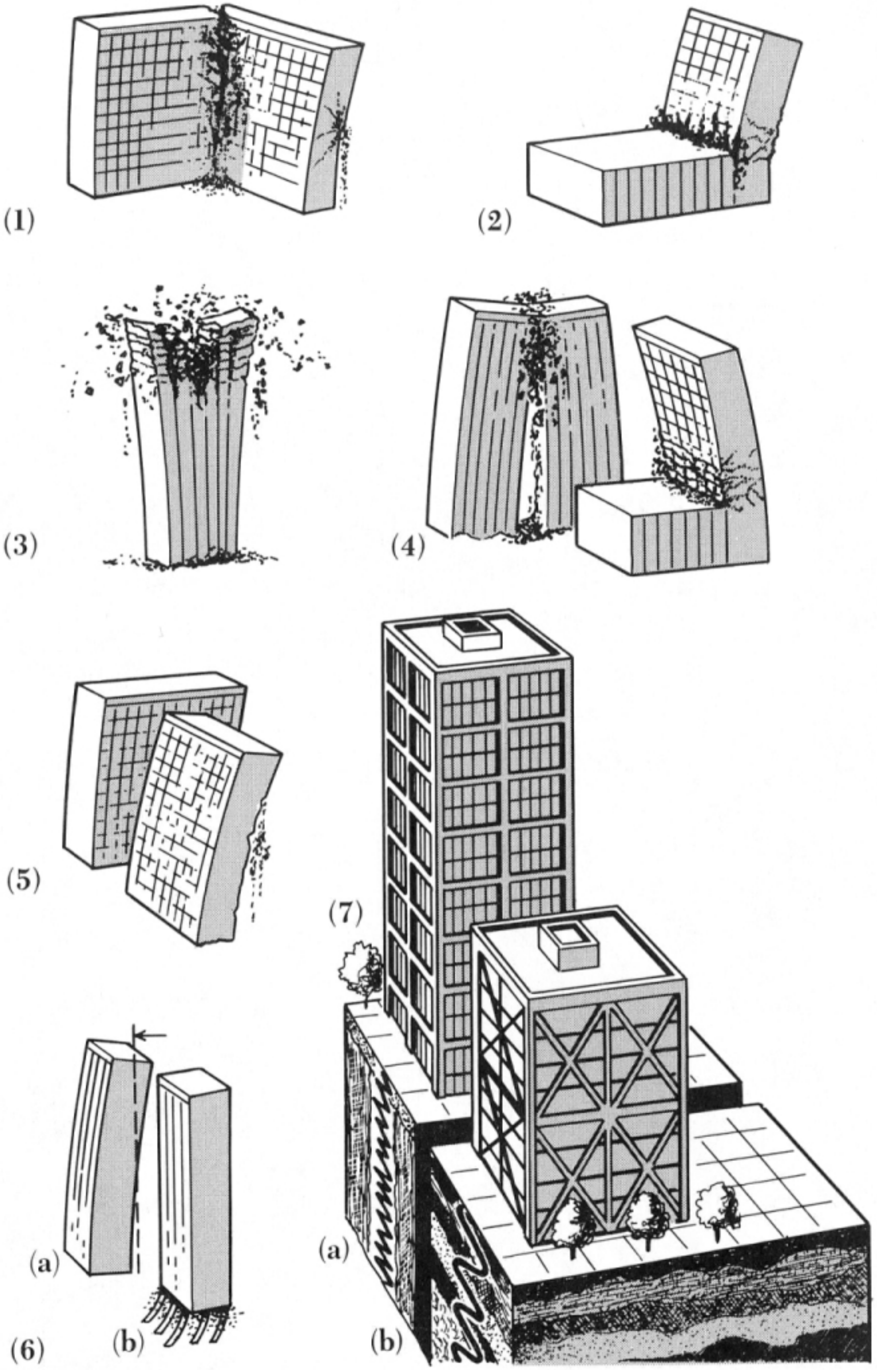
- All structures posses fundamental modes of vibration which depend on their skeletal make-up: including material type, shear panels, connections, span distances and symmetry.
- This fundamental mode is known as the “first mode of vibration” and it generally controls the seismic design of most symmetrical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

SITE RESPONSE VERSUS STRUCTURAL RESPONSE

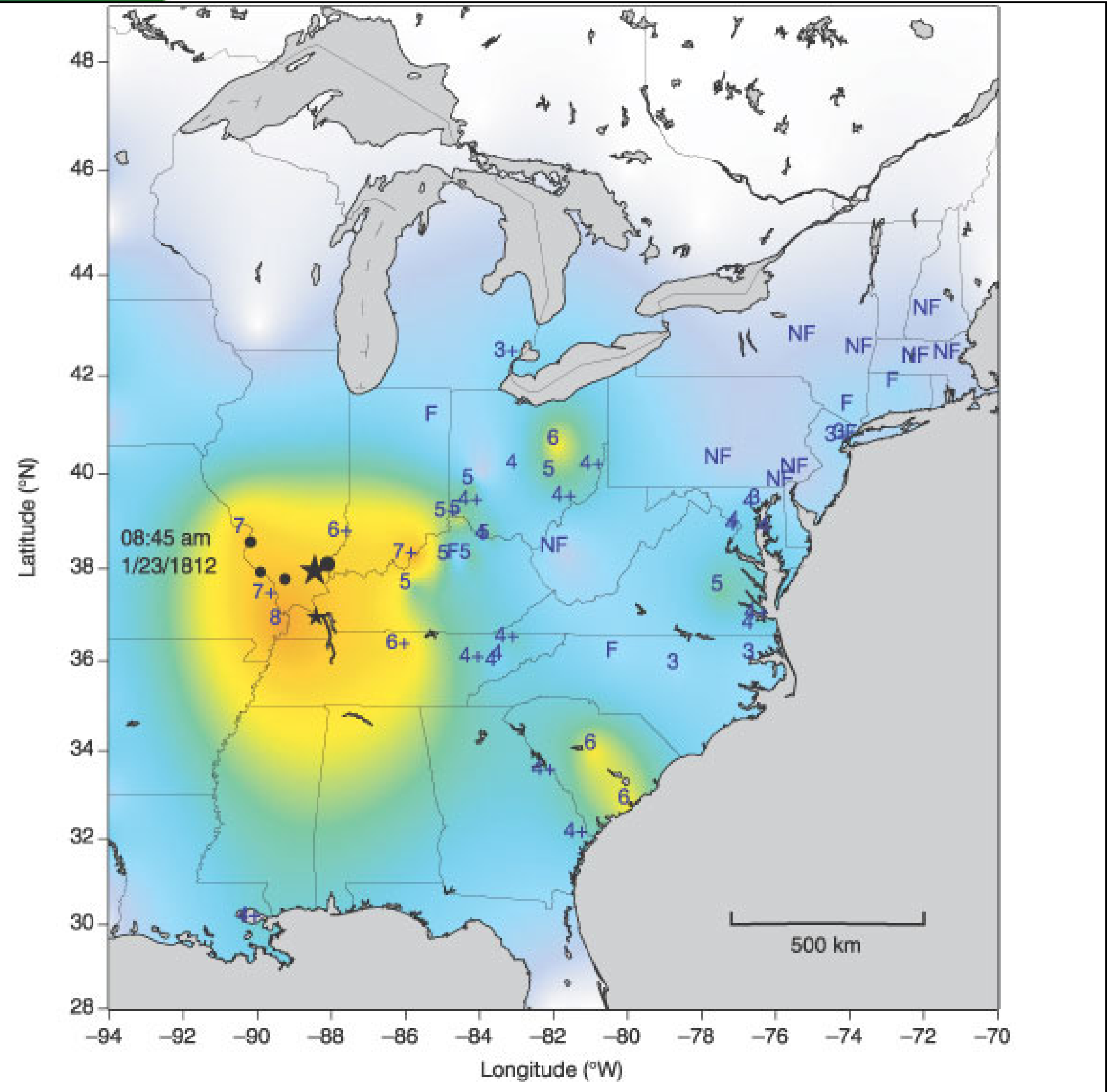


- The fundamental period of vibration of any structure depends on its design and construction details. If the site period and structural period converge, a resonant frequency results which may be an order of magnitude greater than the natural site period, and the structure will be severely damaged or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

OUT-OF-PHASE MOTION



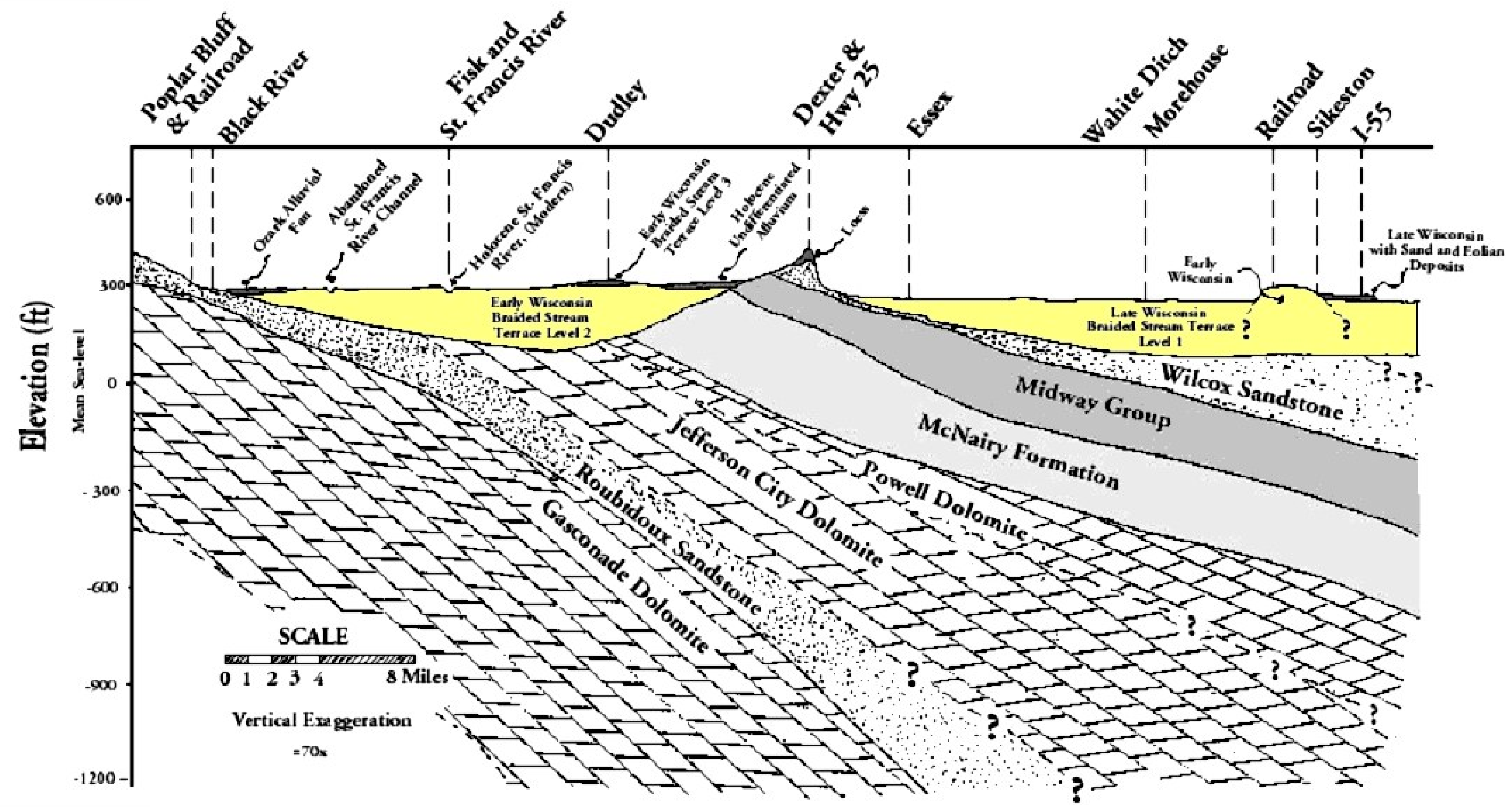
- **Adjacent structures can react differently to seismic excitation, depending on focal aspects of incoming energy, long period motion, site amplification, and degrading structural response as frames become damaged**



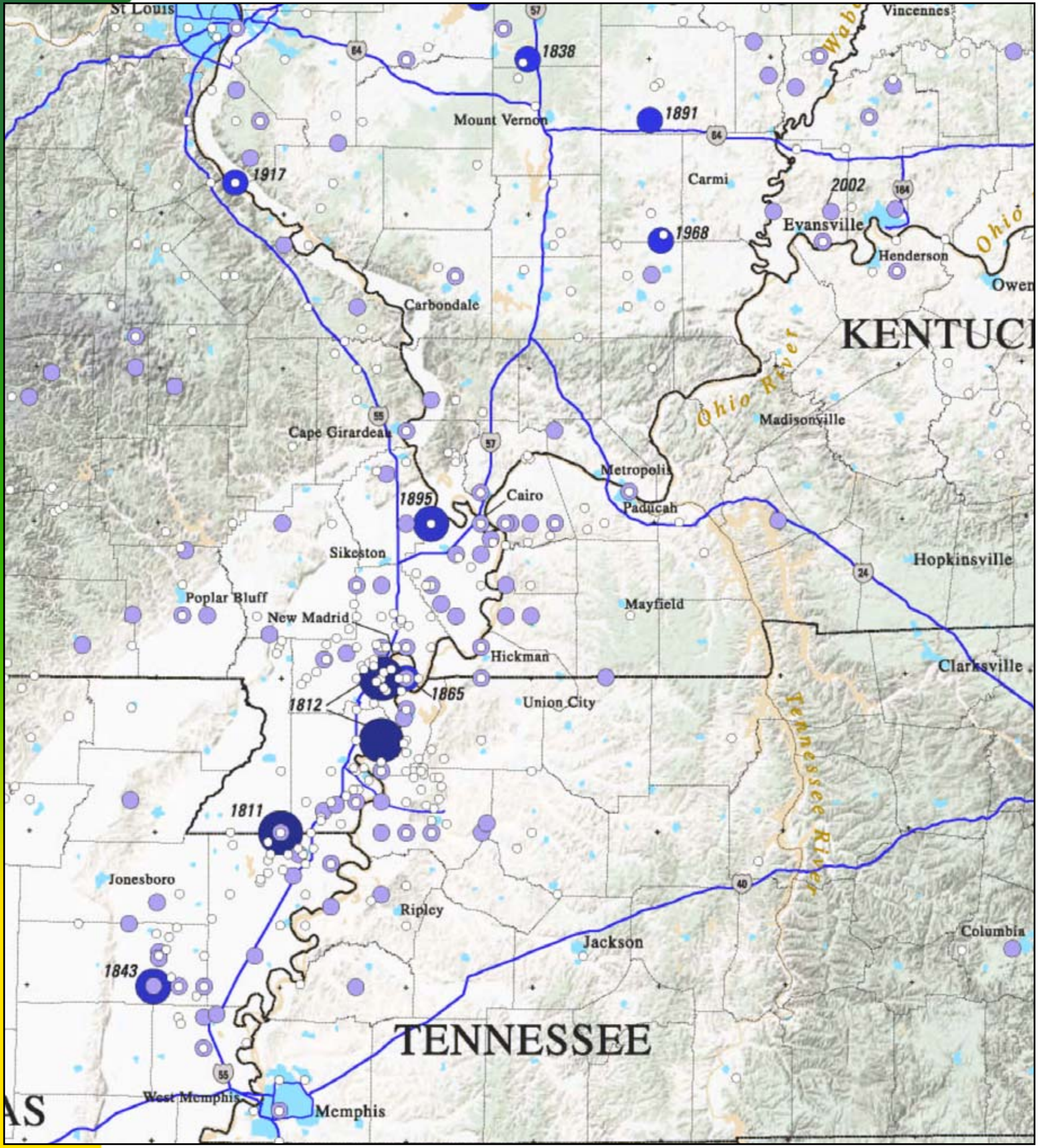
Perceived shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Potential damage	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
Peak acceleration (% of *g*)	<0.17	0.17–1.4	1.4–3.9	3.9–9. 2	9.2–18	18–34	34–65	65–124	>124
Peak velocity (cm s^{-1})	<0. 1	0.1–1. 1	1.1–3. 4	3.4–8. 1	8.1–16	16–31	31–60	60–116	>116
Instrumental intensity	I	II–III	IV	V	VI	VII	VIII	IX	X+

- **Recently, the destructive effects of the 1811-12 New Madrid events has been attributed to site amplification effects, since most of the inhabited areas were in Holocene channels along major drainages.**
- **This is a revised map illustrating shaking severity for the January 23, 1812 event, thought to have been something between M7.5 and M8.0**

Geology Northern Mississippi Embayment



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



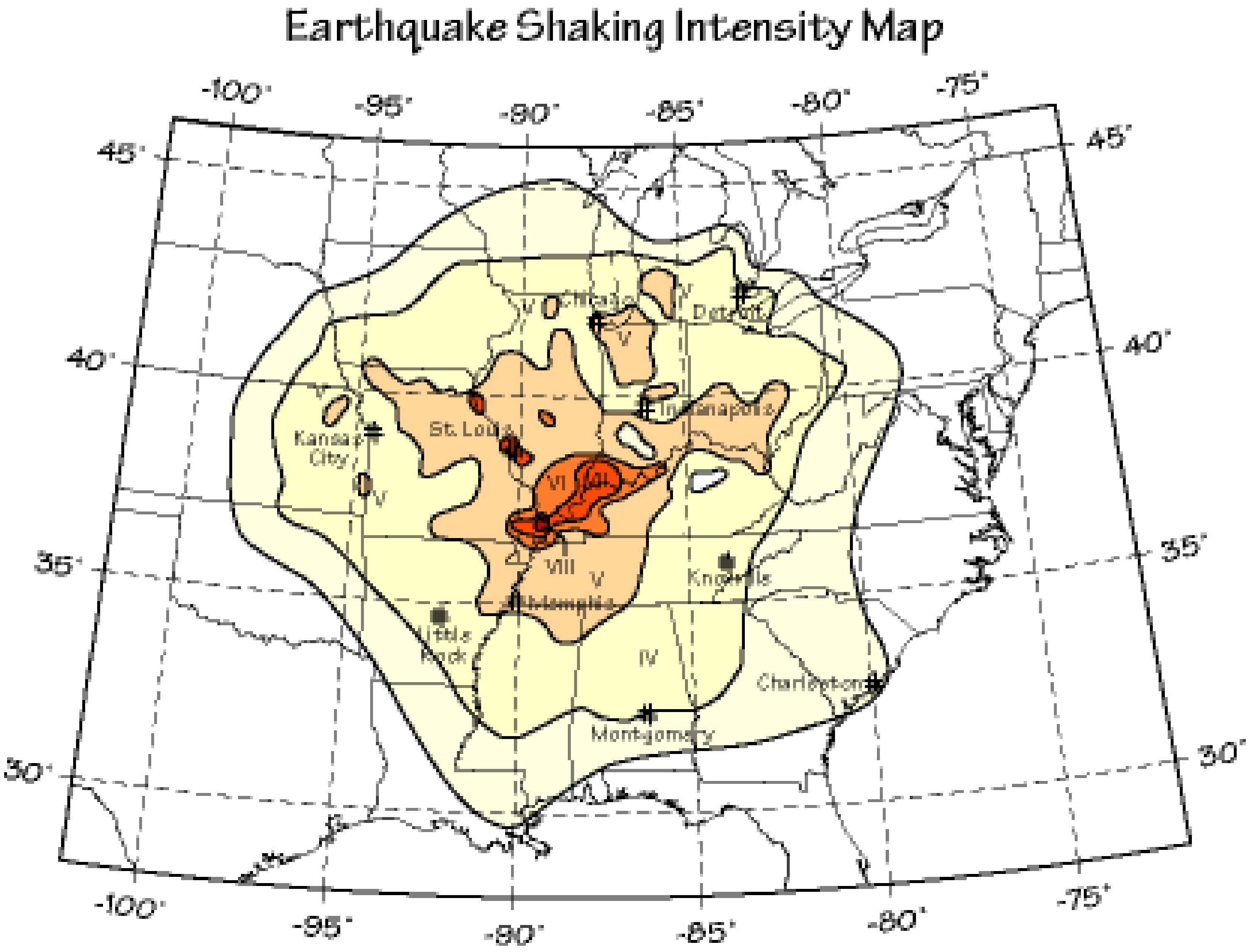
WHAT IS THE DESIGN EARTHQUAKE?

- >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

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



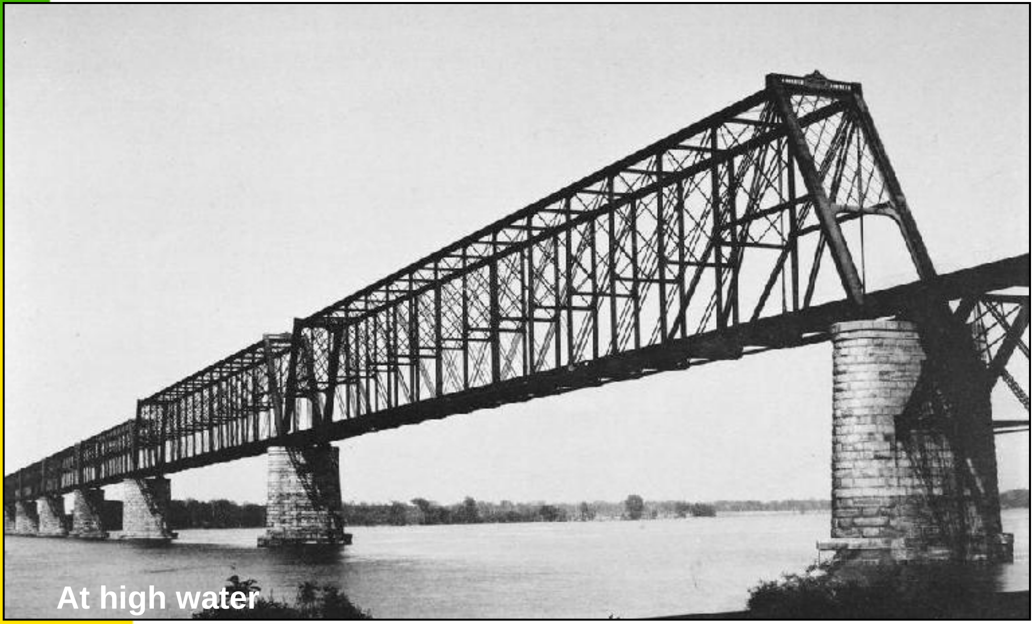
- **1895 M6.6 Charleston, MO earthquake**

1895 M6.6 Charleston, MO Quake

- **October 31, 1895 Magnitude 6.6 Earthquake near Charleston Missouri. Modified Mercalli Intensity VIII**
- **Largest earthquake to occur in the Mississippi Valley region since the 1811-1812 New Madrid earthquake sequence. The estimated body-wave magnitude of this event is 5.9 and the surface-wave magnitude estimate is 6.7.**
- **People in 23 states felt this earthquake which caused extensive damage. to a number of structures in the Charleston region, including schools, churches, and homes. Structural damage and liquefaction were reported along a line from Bertrand, MO to Cairo, IL. The most severe damage occurred in Charleston, Puxico, and Taylor, Missouri; Alton, and Cairo, Illinois; Princeton, Indiana; and Paducah, Kentucky.**
- **The earthquake caused extensive damage (including downed chimneys, cracked walls, shattered windows, and broken plaster) to school buildings, churches, private houses, and to almost all the buildings in the commercial section of Charleston, MO. That's the reason the epicenter was assumed to be near Charleston.**

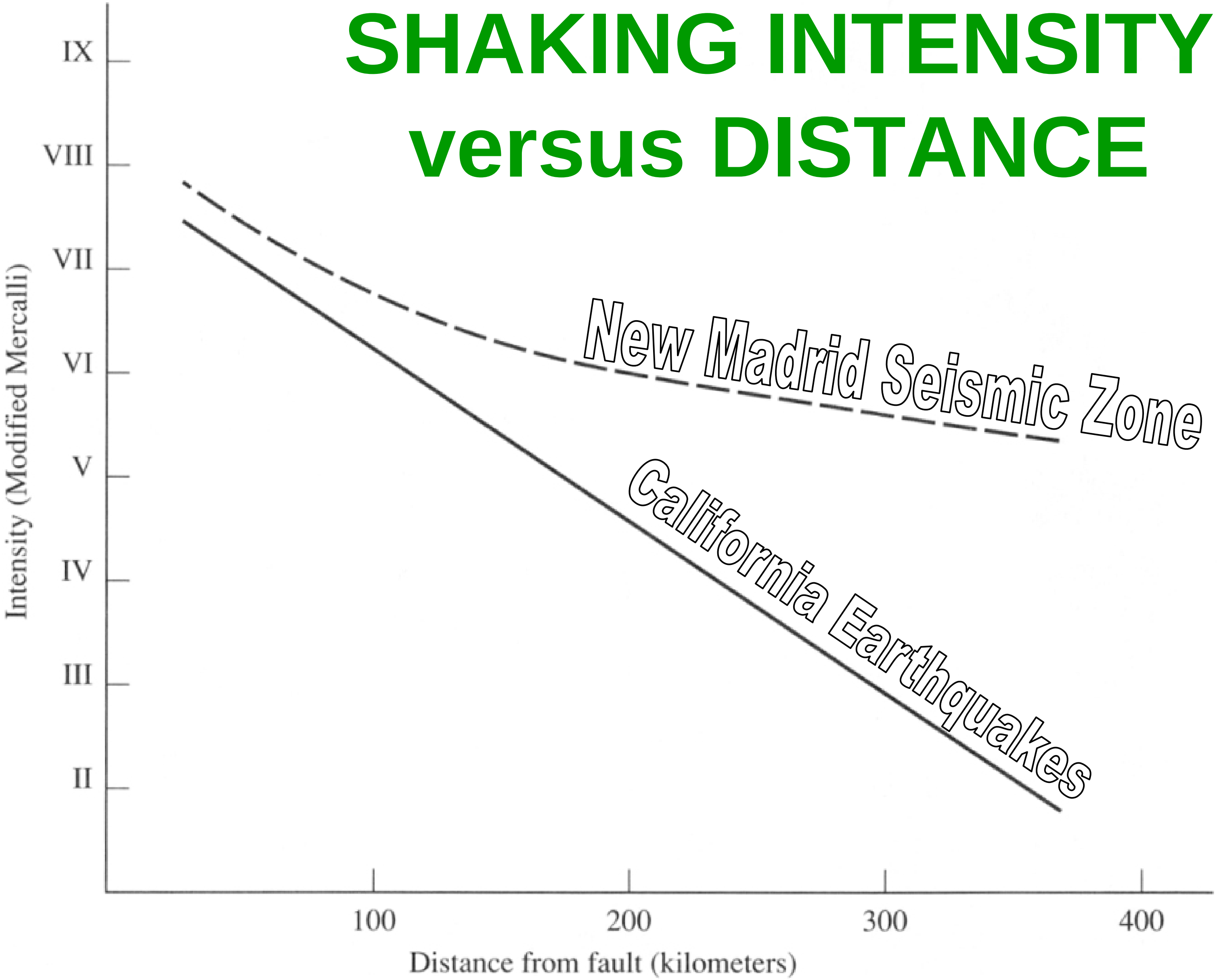
Illinois Central Bridge at Cairo, IL


At low water

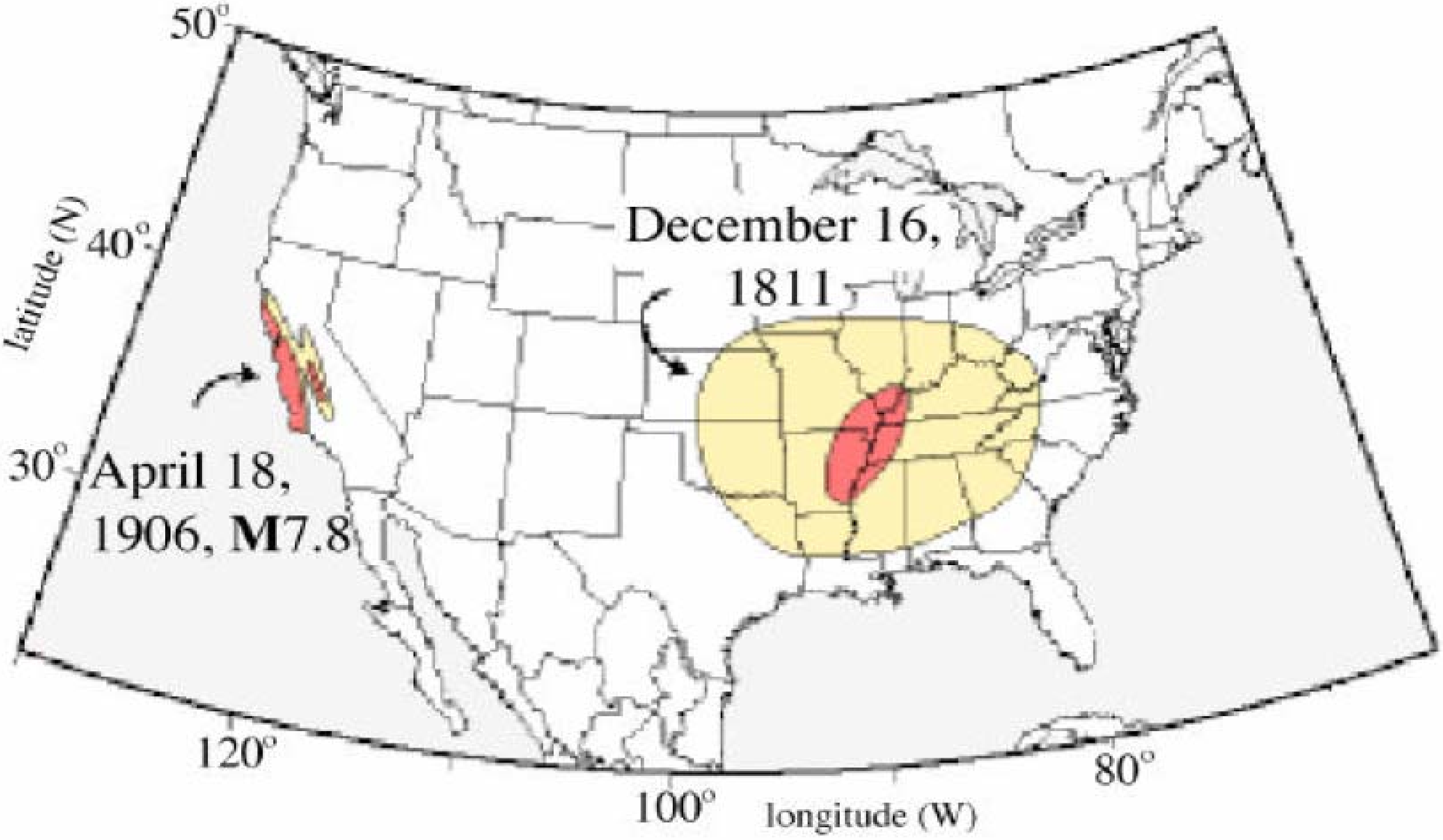

At high water

- The Illinois Central Railroad bridge across the Ohio River at Cairo, IL was the longest iron or steel bridge in world when completed in 1889 (4 miles).
- One of its masonry bents was cracked and severely damaged during Oct 1895 Charleston, MO quake

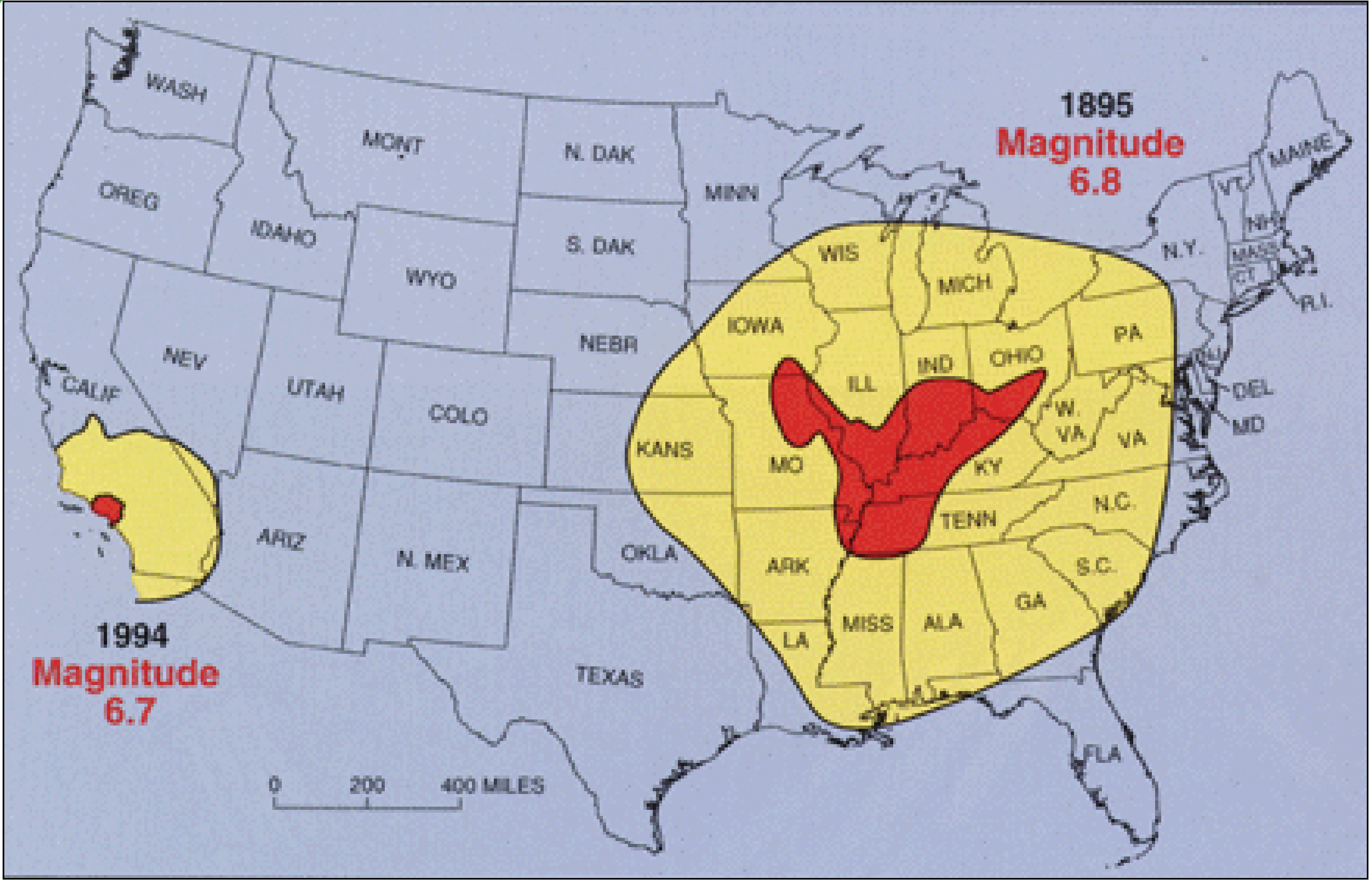
SHAKING INTENSITY versus DISTANCE



Midwest quakes are less frequent, but much more lethal than California quakes because there is <u>less damping</u> of seismic energy.



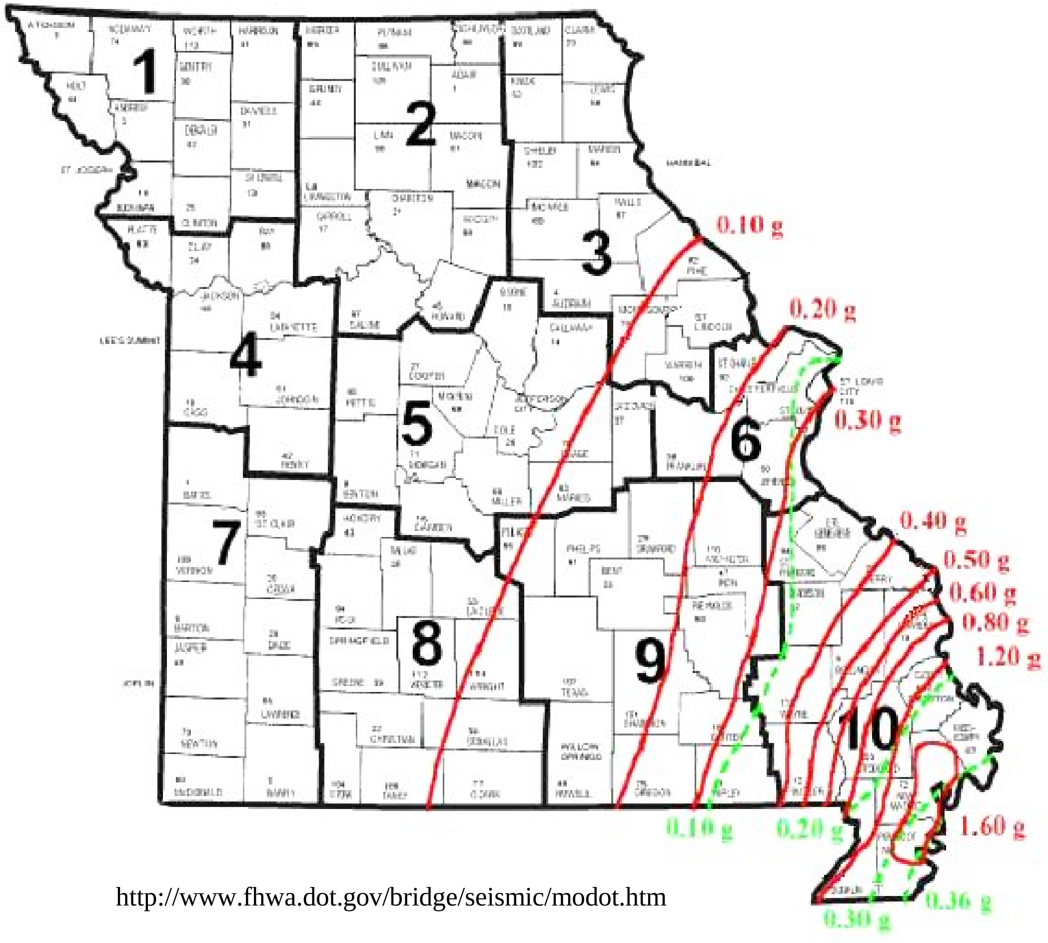
Areas affected by earthquakes of similar magnitude - the December 1811 M_s8.0 New Madrid and M_s8.3 1906 San Francisco earthquakes. The red zones denote areas of minor to major damage. The three largest New Madrid quakes affected more than 10X area San Francisco quake, deadliest in US history.



- **Areas affected by earthquakes of similar magnitude – the M6.8 1895 Charleston, MO and M6.7 1994 Northridge earthquakes.**

Current and Proposed MODOT Standards for Seismic Design

- **Green lines** are current ASSHTO design parameters using USGS 10% PE (1988)
- **Red lines** are proposed design parameters using USGS 2% PE (1996)



http://www.fhwa.dot.gov/bridge/seismic/modot.htm

SCREENING ANALYSES

- **Risk assessment** is perhaps the most nefarious aspect of our profession. If we wanted to know the 100 year recurrence frequency flood, we would need 1000 years of flow records.
- We have a significant risk of future destructive earthquakes in the Midwest. But, our probabalistic models are based solely on data gathered from the New Madrid Seismic Zone, ignoring other likely sources.
- **Screening analyses** allow us to identify the structures with the greatest risk-consequence of failure and prioritize bridges based on seismic vulnerability.

EXAMPLE SCREENING ANALYSIS

- A preliminary site response evaluation was undertaken on three bridge sites along the Missouri River, located between 215 and 257 km from the New Madrid Seismic Zone.
- In our lifetimes, the most likely earthquake to impact these structures would be a repeat of the M6.6 Charleston, MO quake of 1895, which has a recurrence frequency of 70+/- 15 years (overdue since 1980).

TECHNICAL APPROACH

- **Model one-dimensional equivalent linear site response and liquefaction susceptibility at the bridge sites.**
- **Liquefaction potential assessed through a two part qualitative and quantitative analysis.**
- **Generate artificial time histories using Boore's (2001) SMSIM code for base rock input motions.**
- **Simulation of seismic wave propagation through the surficial materials using the program DEEPSOIL by Park and Hashash (2003).**

Missouri River Bridges with High Quality Geotechnical Data

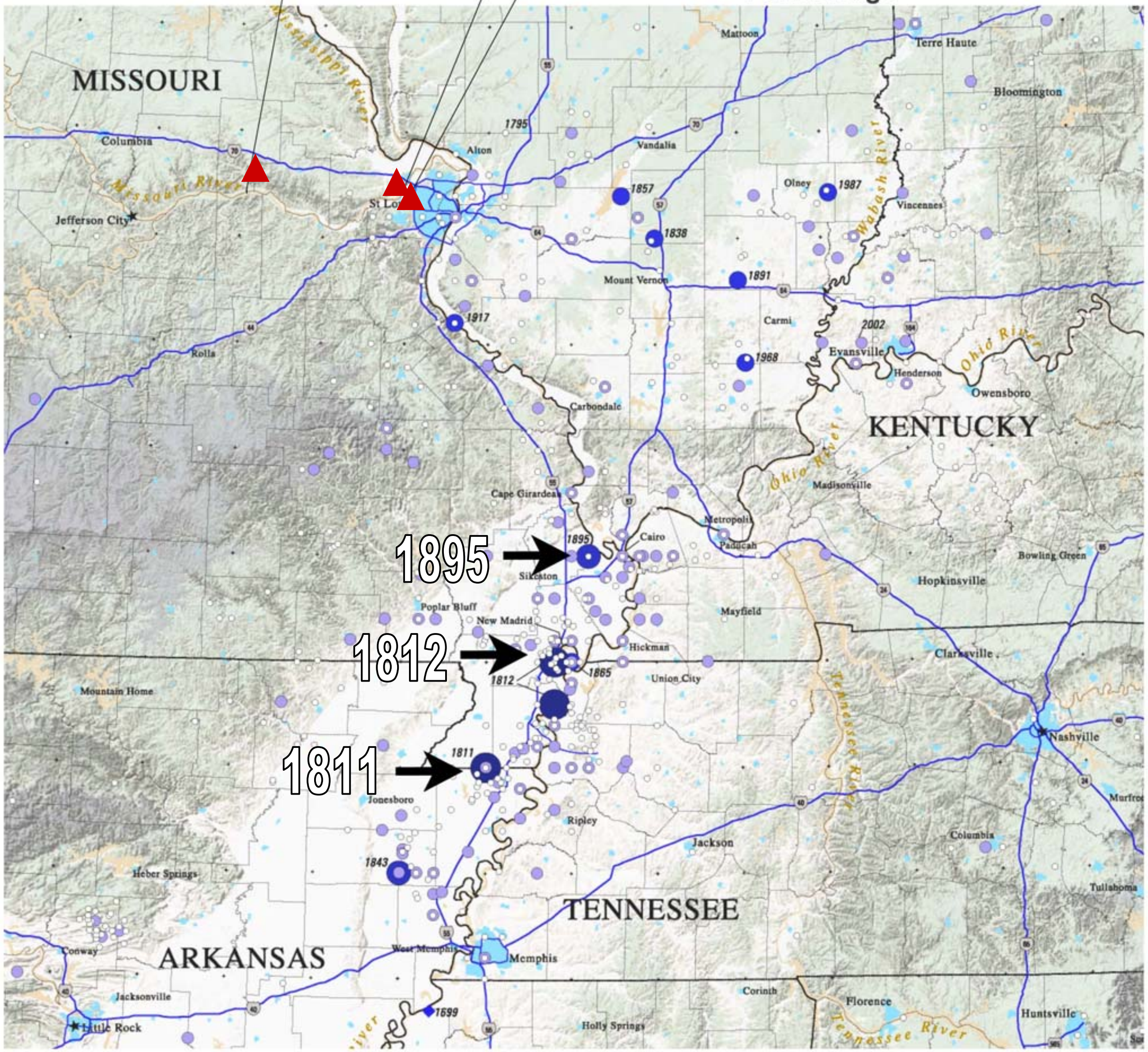
- **Page Extension Missouri River Bridge explored in 1996. 215 km from NMSZ**
- **Page Extension Creve Coeur Lake Memorial Park Bridge explored in 1996. 215 km from NMSZ**
- **Proposed State Route 19 replacement for Hermann, Missouri Bridge explored in 1999. 257 km from the NMSZ**

Bridge Locations With Respect to the New Madrid Seismic Zone

Hermann Replacement Bridge

Page Extension, Missouri River Bridge

Page Extension, Creve Coeur Lake Memorial Park Bridge



1895

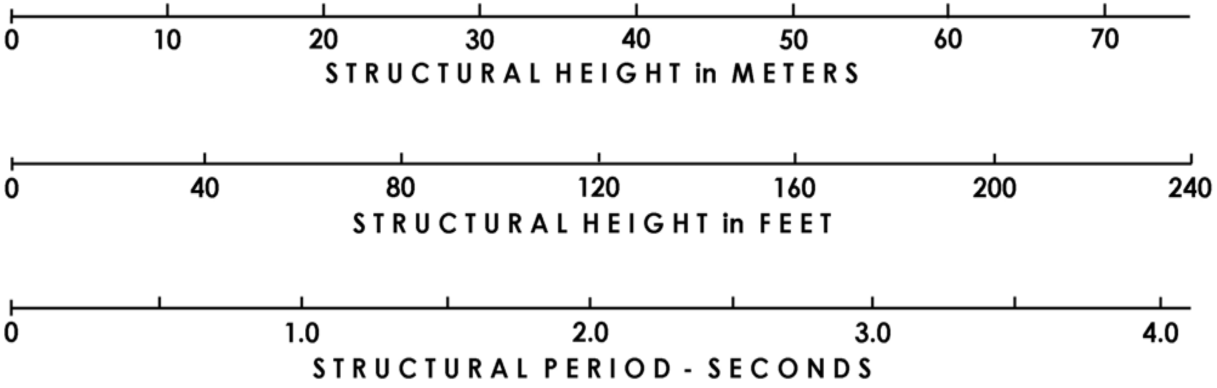
1812

1811

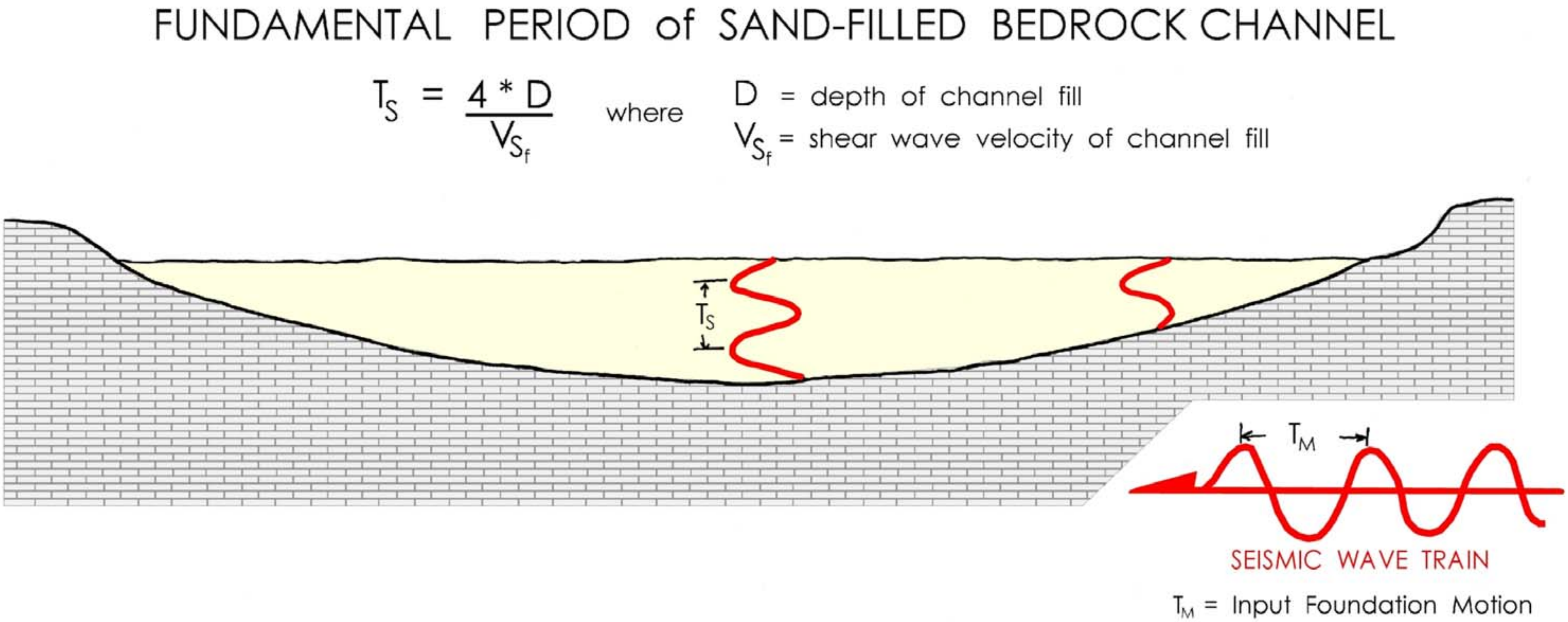
LENGTHENING of SEISMIC WAVE TRAIN with DISTANCE from SOURCE

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

FUNDAMENTAL PERIOD vs STRUCTURE HEIGHT

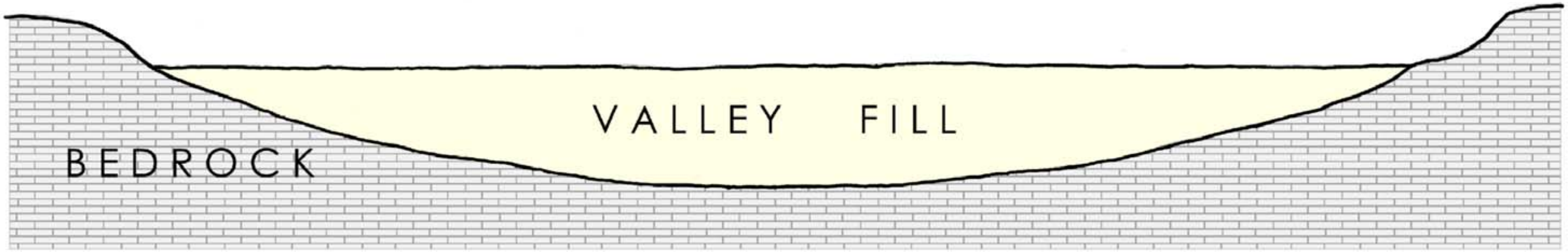


- **Long period motions (T > 1.0 second) of great import when evaluating structures > 160 km from the quake hypocenter**



- **We can estimate the fundamental site period with some basic data. The period will change with location in a parabolic shaped channel.**

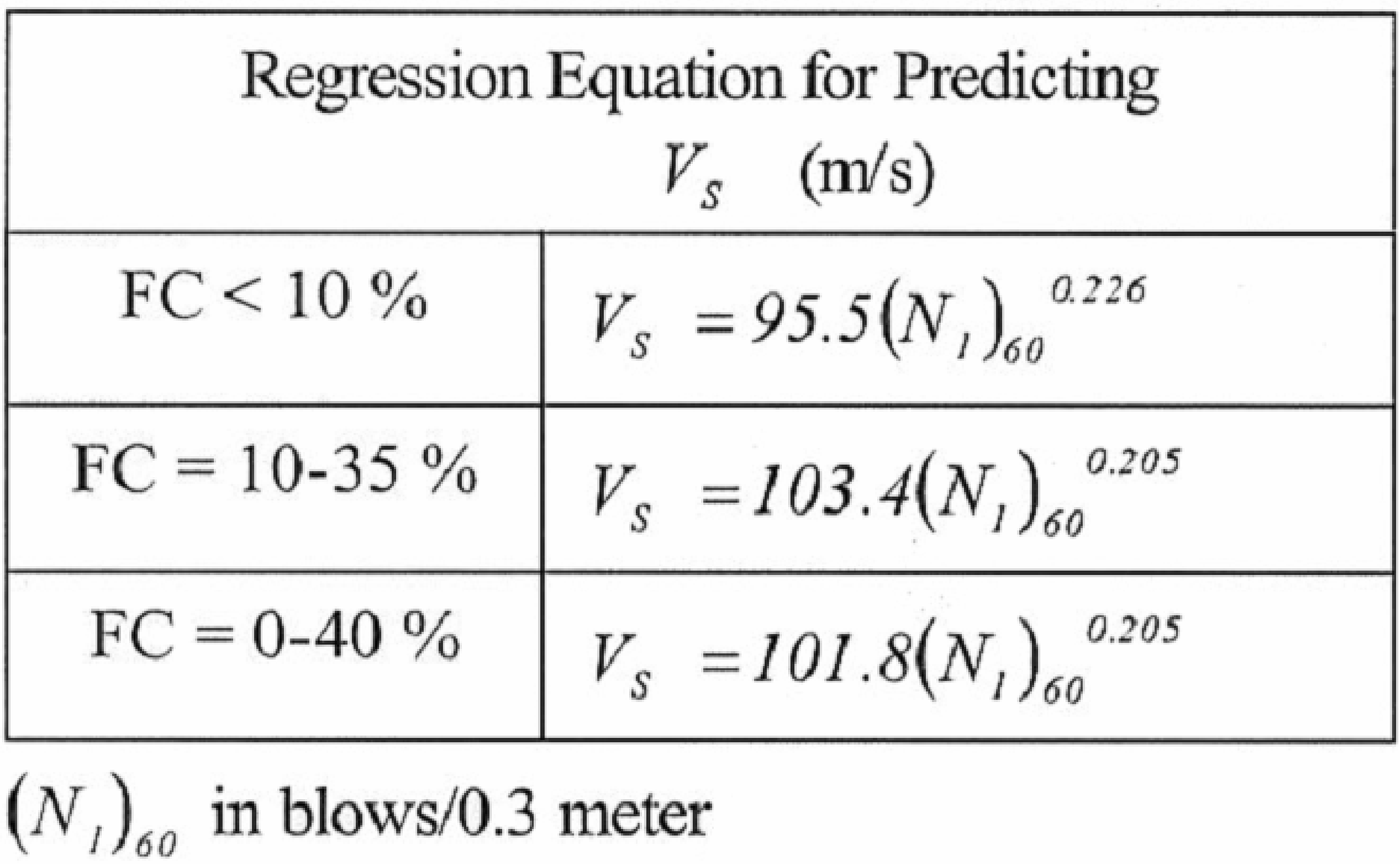
IMPEDANCE



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

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

Estimating V_s from $(N_1)_{60}$

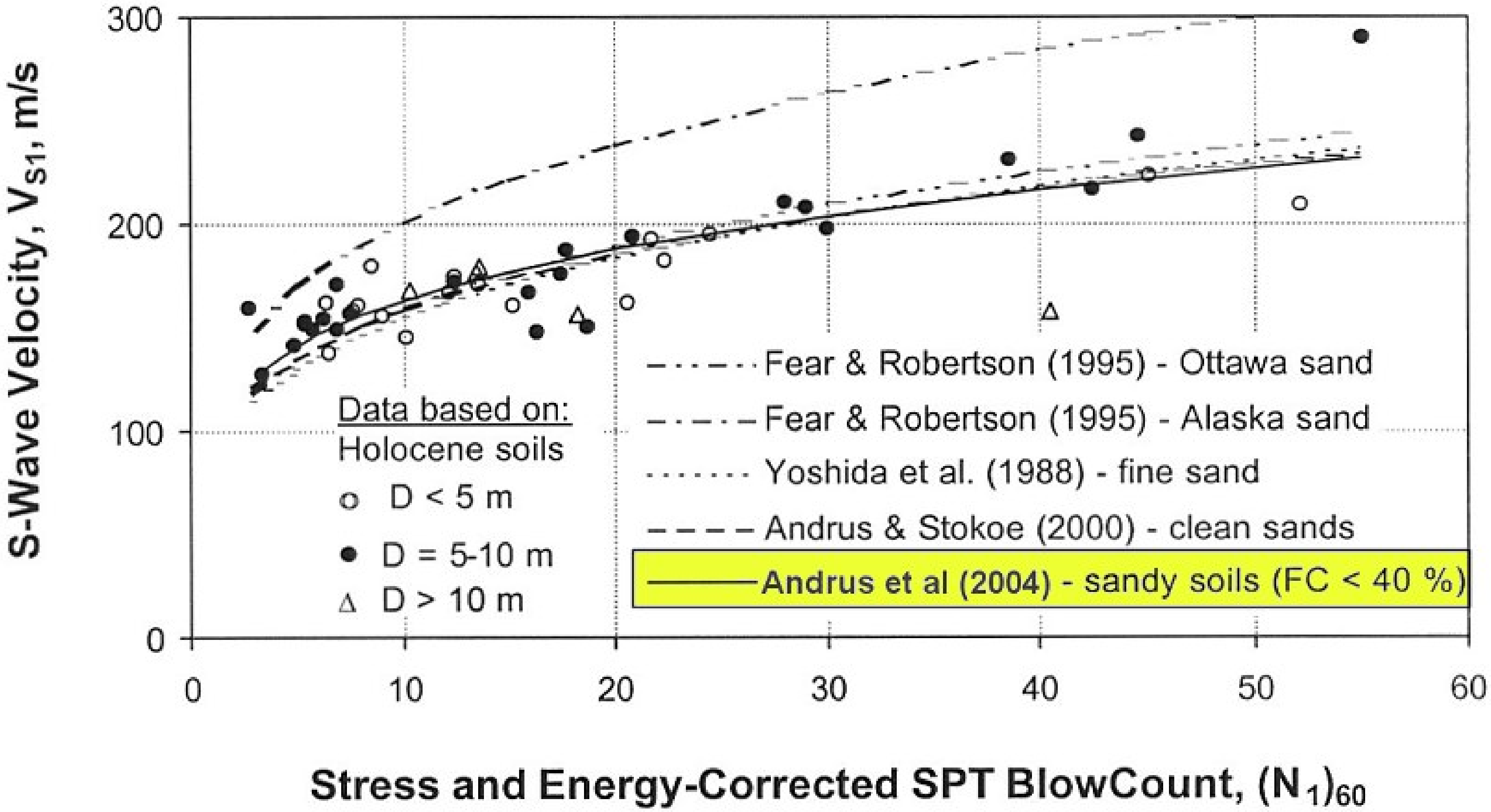


Regression Equation for Predicting V_s (m/s)	
FC < 10 %	$V_s = 95.5(N_1)_{60}^{0.226}$
FC = 10-35 %	$V_s = 103.4(N_1)_{60}^{0.205}$
FC = 0-40 %	$V_s = 101.8(N_1)_{60}^{0.205}$

$(N_1)_{60}$ in blows/0.3 meter

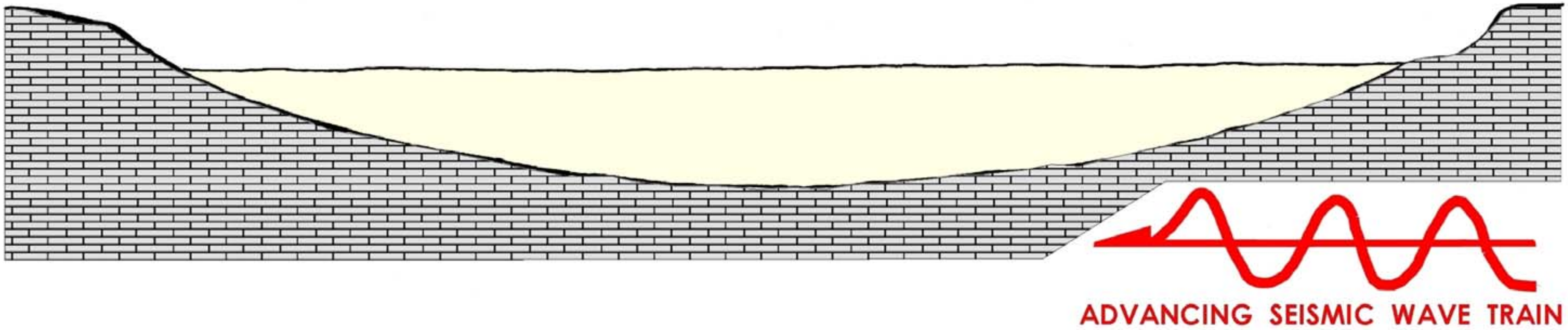
Andrus et al., 2004

SHEAR WAVE VELOCITY CORRELATIONS



Andrus et al., 2004

LATERAL INCOHERENCE

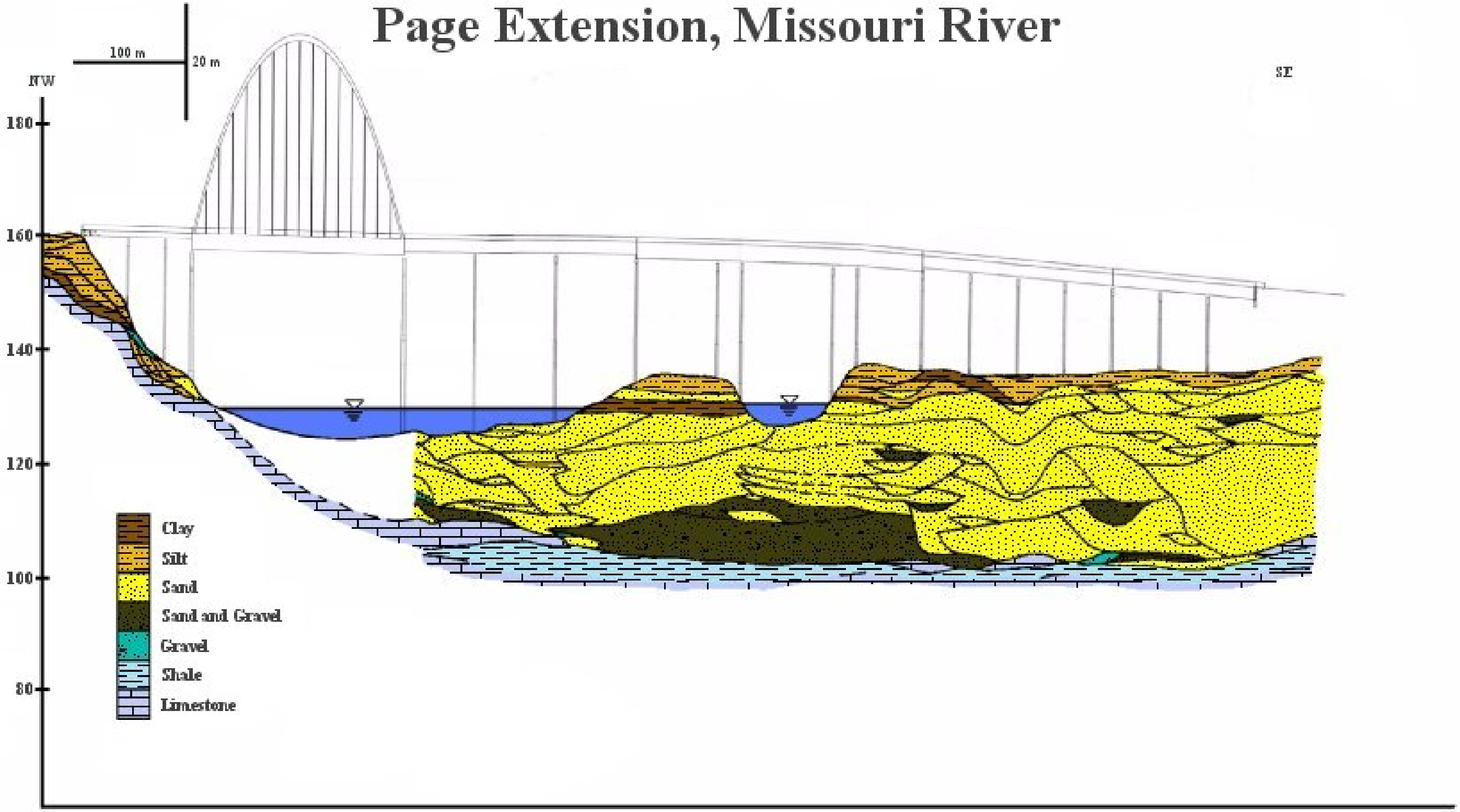


- If we attempted to model the dynamic system created by the channel's interaction with an extremely long bridge structure, we would have to consider lateral and vertical incoherence of the foundations. This is usually performed in a full-blown dynamic analysis, not in a screening analysis.

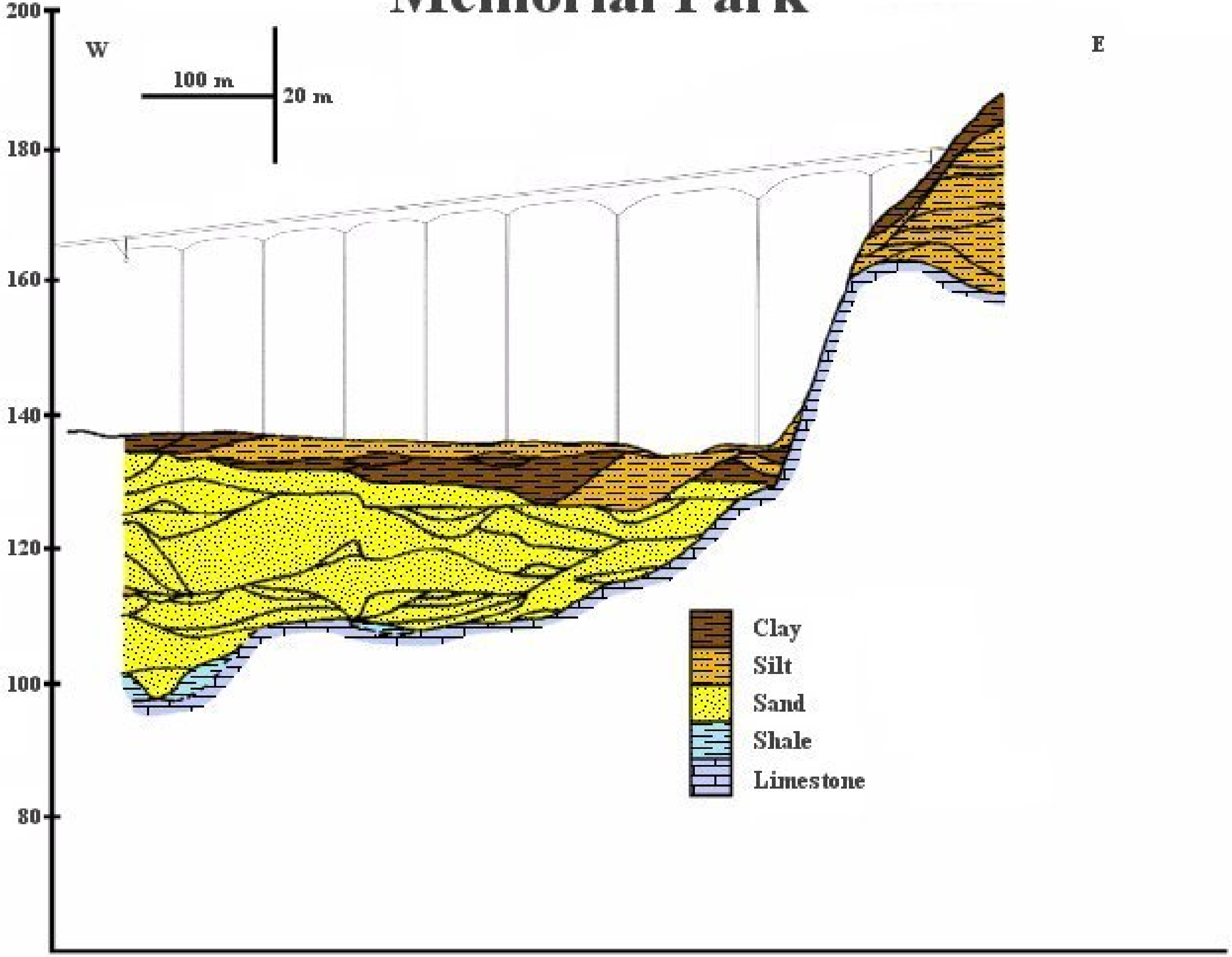
UNDERLYING GEOLOGY

- **The Missouri River bridges are founded on up to 31 m of unconsolidated loess, channel sands, silts, and oxbow clays/silts.**
- **Channel fill is unconsolidated Holocene age material; mostly saturated channel sands with low relative density**
- **Underlying bedrock is stiff Paleozoic age limestone, dolomite, and shale.**
- **All three bridges cross asymmetric channels, with bedrock on one abutment and unconsolidated sediment beneath the other.**

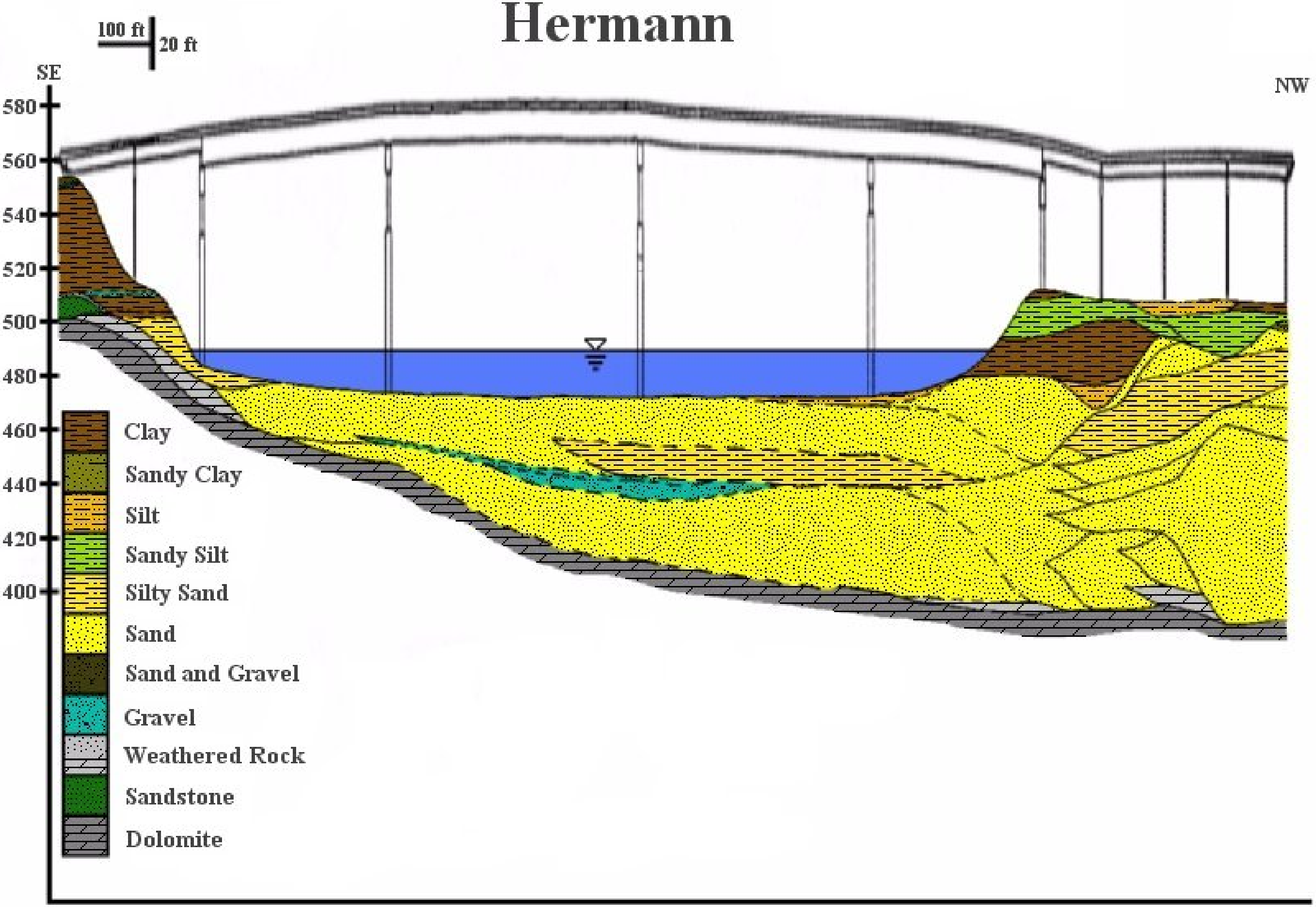
Page Extension, Missouri River



Page Extension, Creve Coeur Lake Memorial Park



Hermann


100 ft
20 ft
SE
NW
580
560
540
520
500
480
460
440
420
400
Clay
Sandy Clay
Silt
Sandy Silt
Silty Sand
Sand
Sand and Gravel
Gravel
Weathered Rock
Sandstone
Dolomite

Generation of Artificial Time Histories

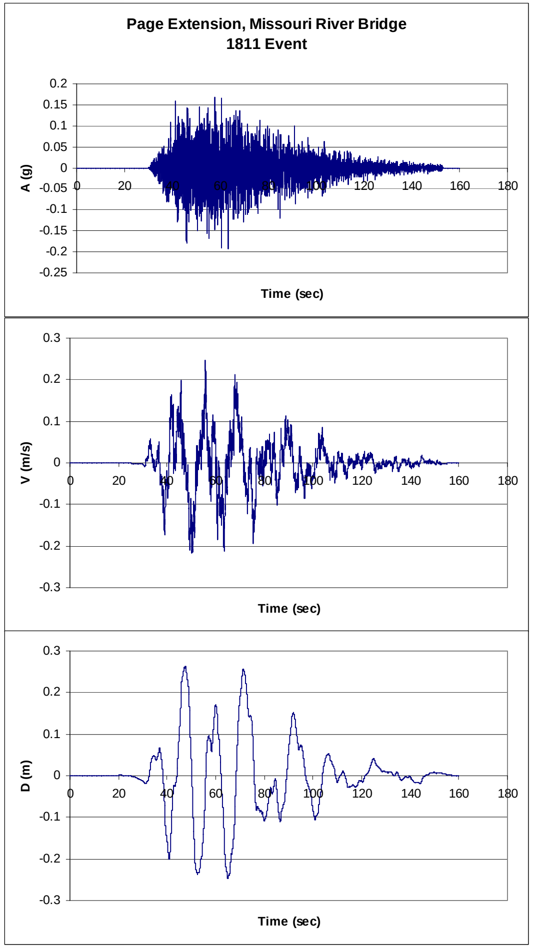
- **Artificial time histories were generated using SMSIM code developed by Dave Boore of the USGS and modified by Bob Herrmann at St. Louis University for Midwest deep soil sites.**

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 USGS 96 source (modified)	Mid-Continent Deep Soil (new)

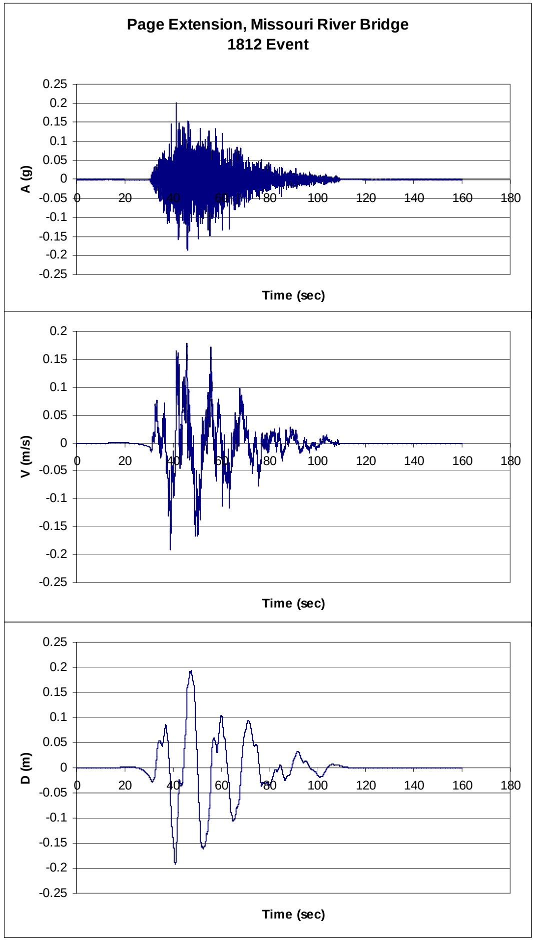
ARTIFICIAL TIME HISTORIES FOR SCREENING ANALYSES GENERATED FOR THREE HISTORIC EVENTS EMANATING FROM THE NEW MADRID SEISMIC ZONE:

- 16 Dec 1811 M_s8.6 = M7.3 event
- 7 Feb 1812 M_s 8.0 = M7.5 event
- 31 Oct 1895 M_s 6.8 = M6.6 event

Page Avenue Missouri River Bridge Artificial Time Histories


Page Extension, Missouri River Bridge
1811 Event

1811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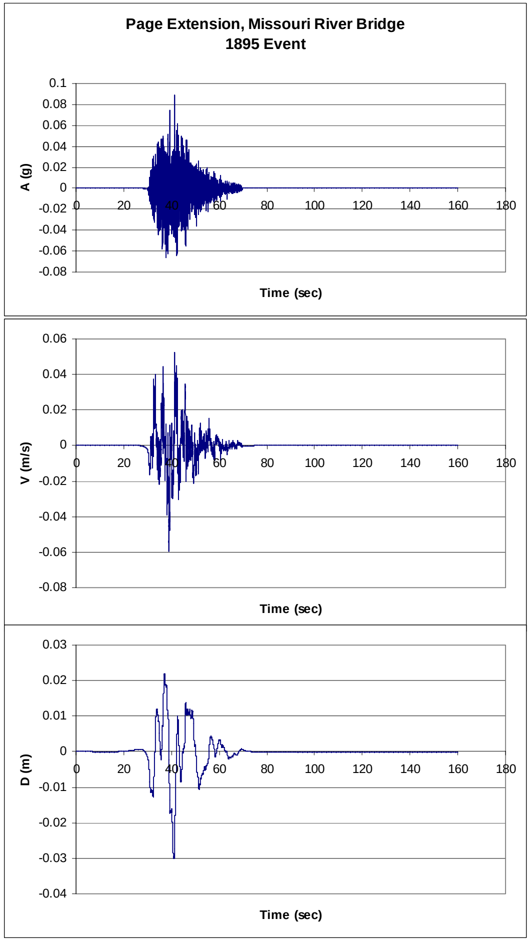
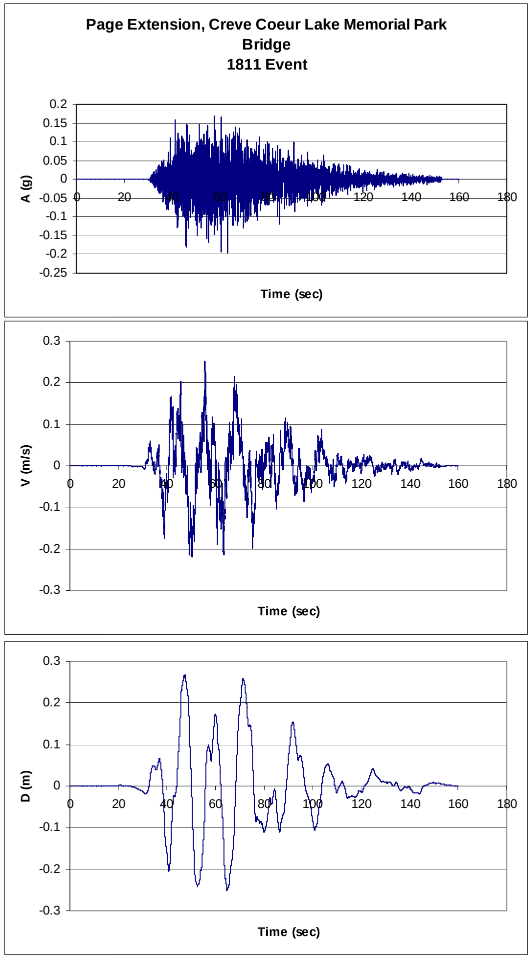
1812 Event

1812

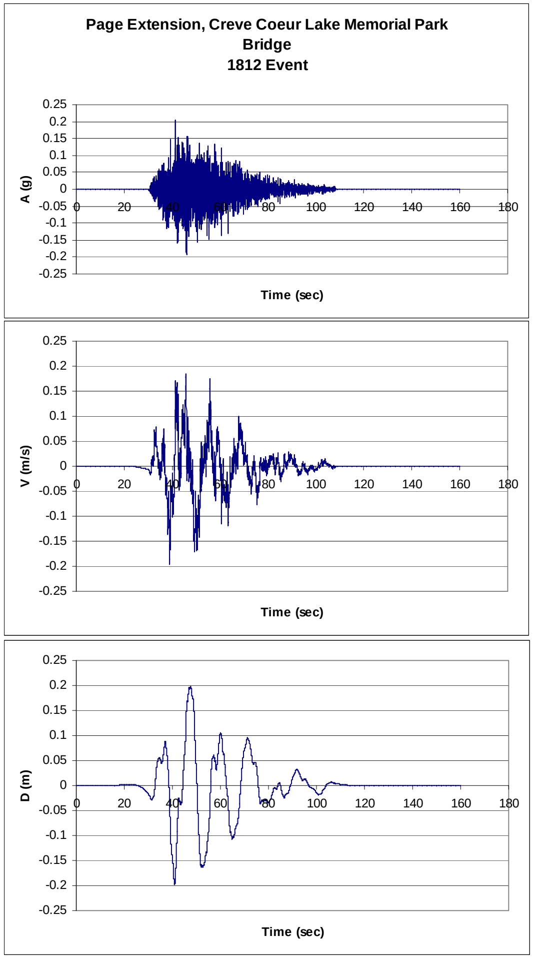

Page Extension, Missouri River Bridge
1895 Event

1895

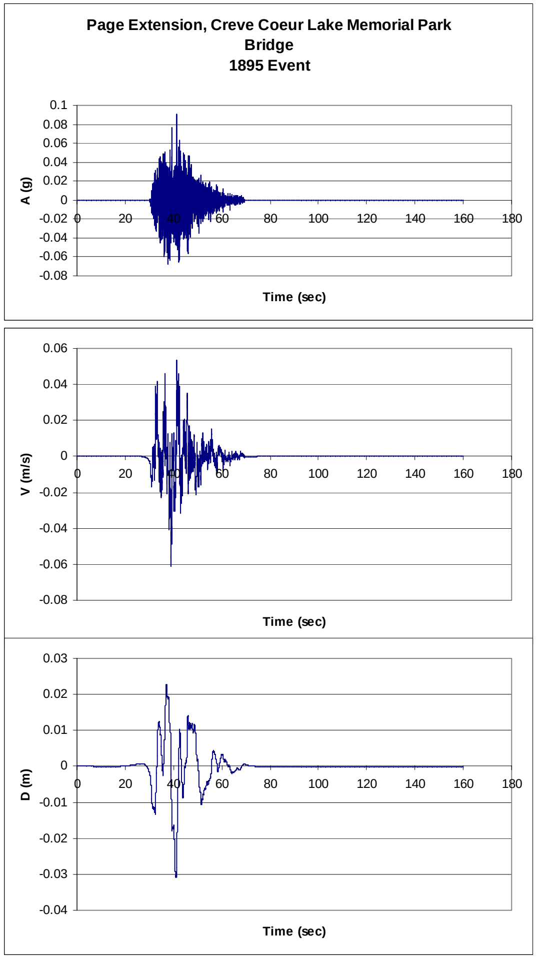
Creve Coeur Lake Bridge Artificial Time Histories



1811

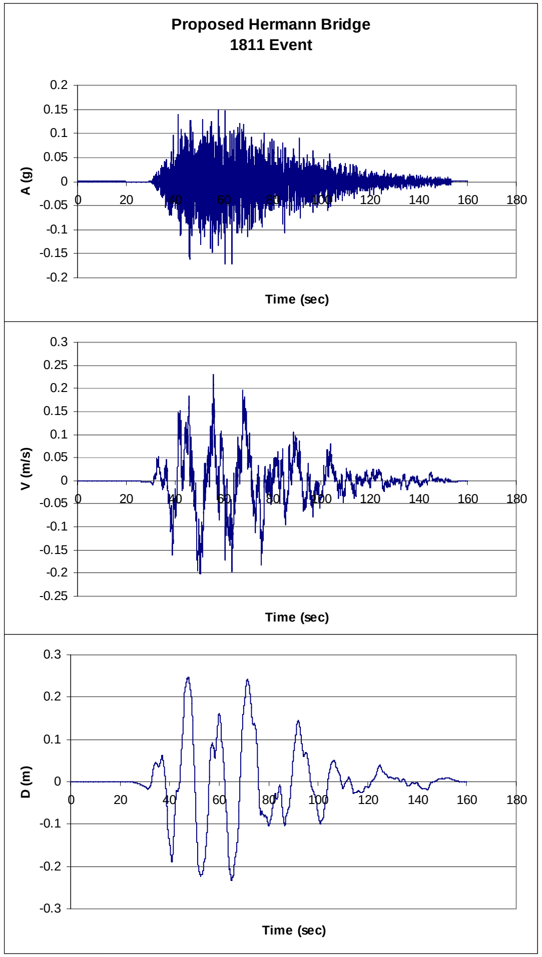


1812

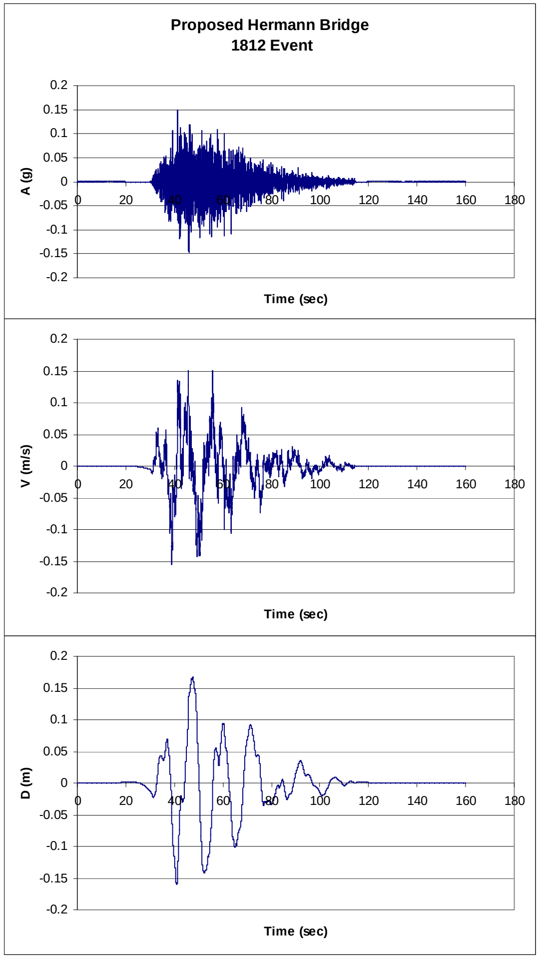


1895

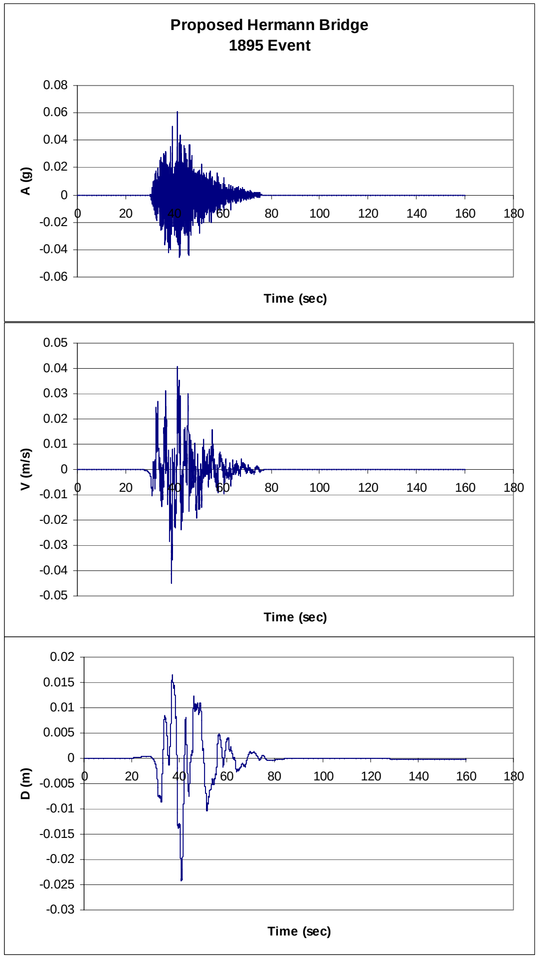
Hermann Bridge Site
Artificial Time Histories



1811



1812



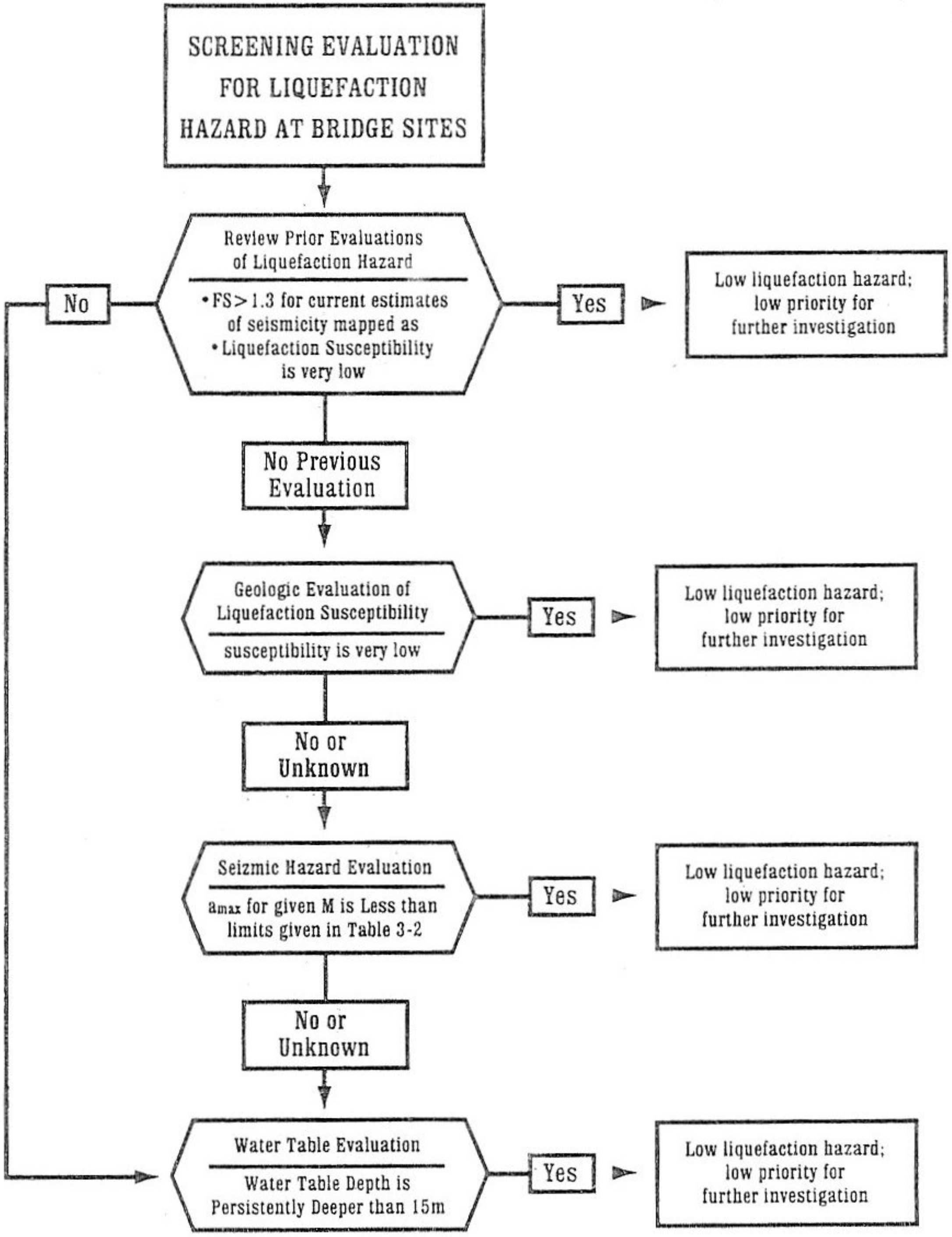
1895

Screening Analysis for Liquefaction Potential

- Recommend using:

  T. L. Youd,1998, *Screening Guide for Rapid Assessment of Liquefaction Hazard at Highway Bridge Sites*: Technical Report MCEER-98-0005
- It employs a Qualitative Analysis; and
- A Quantitative Analysis
- Good idea to include both

Qualitative Liquefaction Analysis Flow Chart from MCEER 98-05



GEOLOGIC EVALUATION

Type of Deposit	<500 yr	Holocene	Pleistocene	Pre-Pleistocene
River Channel	Very High	High	Low	Very Low
Flood Plain	High	Moderate	Low	Very Low
Alluvial Fan	Moderate	Low	Very Low	Very Low
Delta	High	Moderate	Low	Very Low
Lacustrine	High	Moderate	Low	Very Low
Colluvium	High	Moderate	Low	Very Low
Glacial Till	Low	Low	Very Low	Very Low

Youd (1998)

SEISMIC EVALUATION

Earthquake Magnitude	Soil Profile Type I and II (Stiff Sites)	Soil Profile Type III and IV (Soft Sites)
	Very Low Hazard for	
M < 5.2	Amax < 0.4g	Amax < 0.1g
5.2 < M < 6.4	Amax < 0.1g	Amax < 0.05g
6.4 < M < 7.6	Amax < 0.05g	Amax < 0.025g
7.6 < M	Amax < 0.025	Amax < 0.025

Youd (1998)

Soil Profile Descriptions from AASHTO (1996)

WATER TABLE EVALUATION

Groundwater Table Depth	Relative Liquefaction Susceptibility
< 3 m	Very High
3 m to 6 m	High
6 m to 10 m	Moderate
10 m to 15 m	Low
> 15 m	Very Low

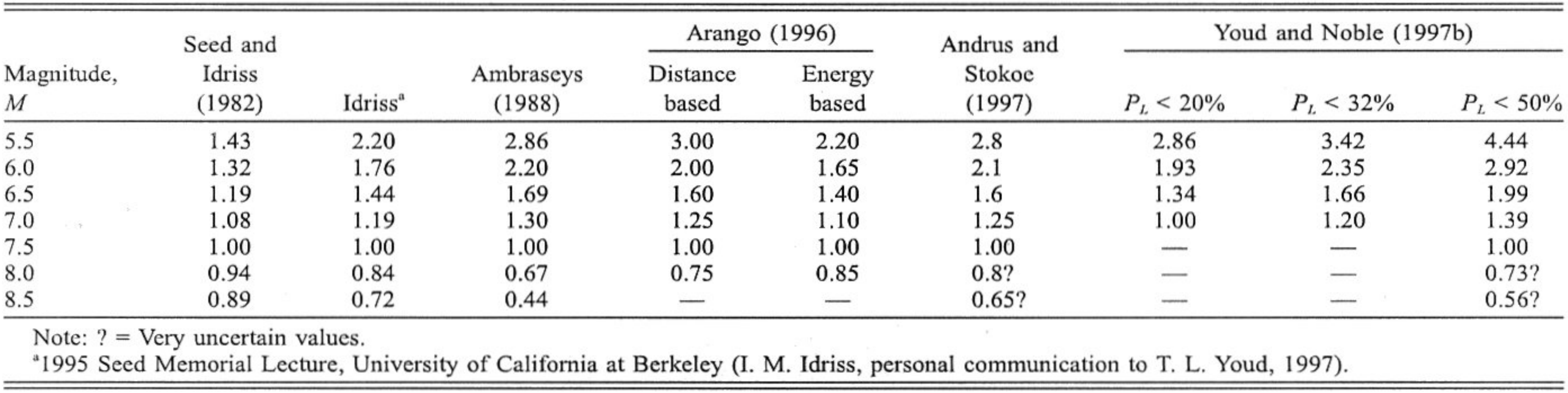
Youd (1998)

QUANTITATIVE ANALYSIS

Youd et al. (2001)

- Based on T. L. Youd et al., 2001, *Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils*: ASCE Journal of Geotechnical and Geoenvironmental Engineering
- Cyclic Stress Ratio (CSR) vs. Cyclic Resistance Ratio (CRR) (normalized for M 7.5)
- Factor of Safety (includes a magnitude scaling factor)

MAGNITUDE SCALING FACTORS for calculating liquefaction factor of safety can be estimated from published charts



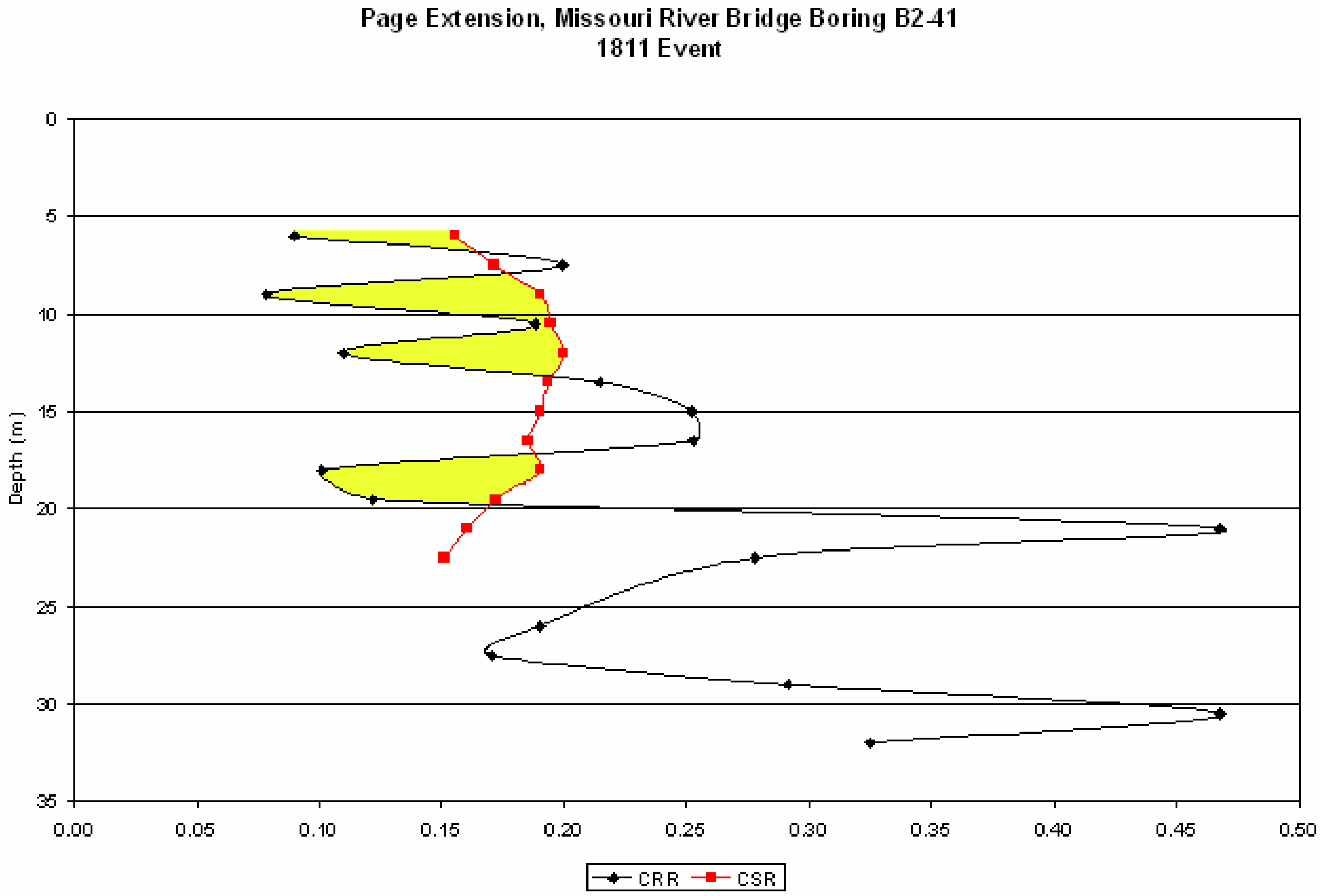
Magnitude, M	Seed and Idriss (1982)	Idriss[a]	Ambraseys (1988)	Arango (1996)		Andrus and Stokoe (1997)	Youd and Noble (1997b)		
				Distance based	Energy based		$P_L < 20\%$	$P_L < 32\%$	$P_L < 50\%$
5.5	1.43	2.20	2.86	3.00	2.20	2.8	2.86	3.42	4.44
6.0	1.32	1.76	2.20	2.00	1.65	2.1	1.93	2.35	2.92
6.5	1.19	1.44	1.69	1.60	1.40	1.6	1.34	1.66	1.99
7.0	1.08	1.19	1.30	1.25	1.10	1.25	1.00	1.20	1.39
7.5	1.00	1.00	1.00	1.00	1.00	1.00	—	—	1.00
8.0	0.94	0.84	0.67	0.75	0.85	0.8?	—	—	0.73?
8.5	0.89	0.72	0.44	—	—	0.65?	—	—	0.56?

Note: ? = Very uncertain values.

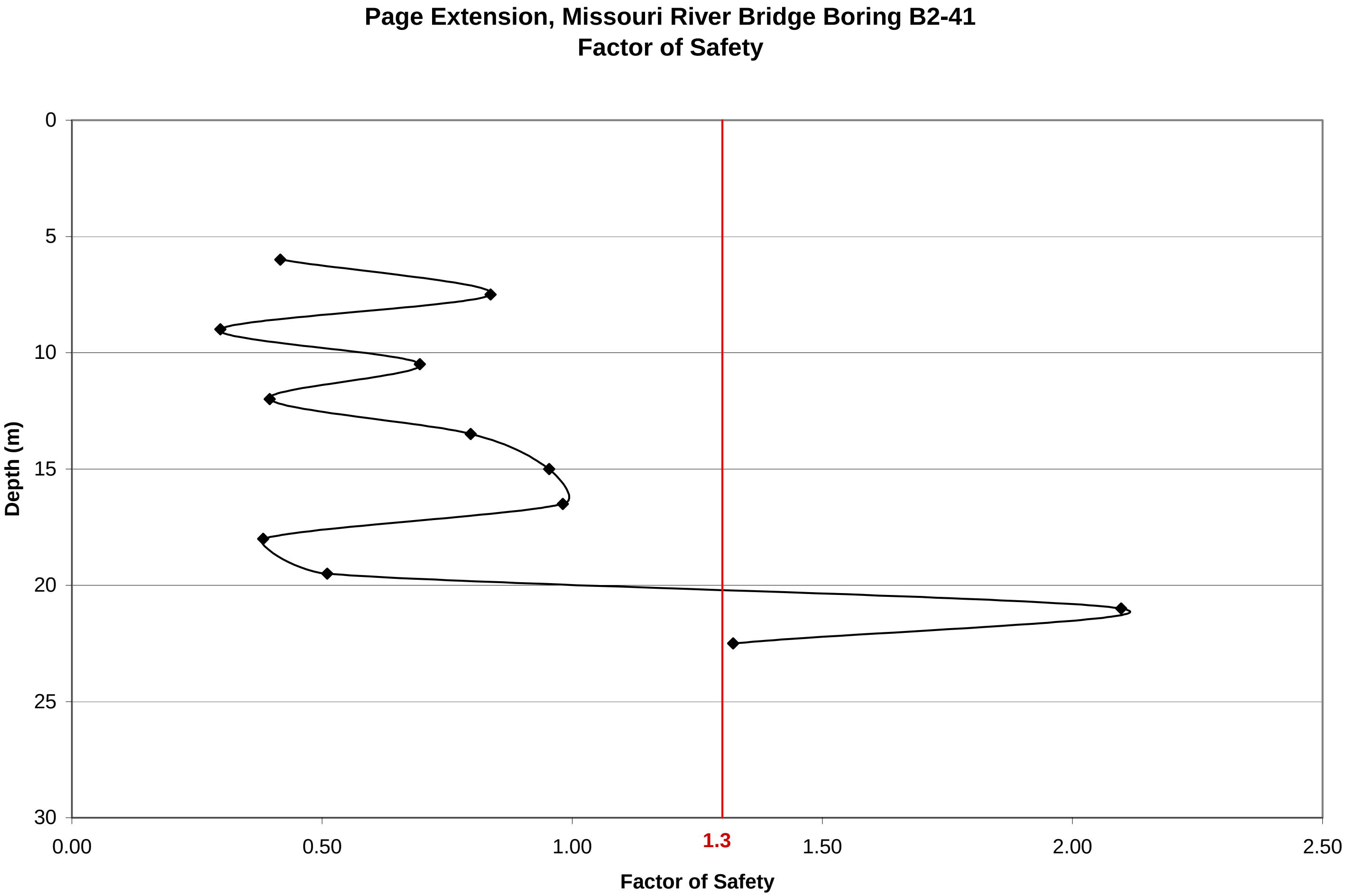
[a] 1995 Seed Memorial Lecture, University of California at Berkeley (I. M. Idriss, personal communication to T. L. Youd, 1997).

taken from Youd et al. (2001)

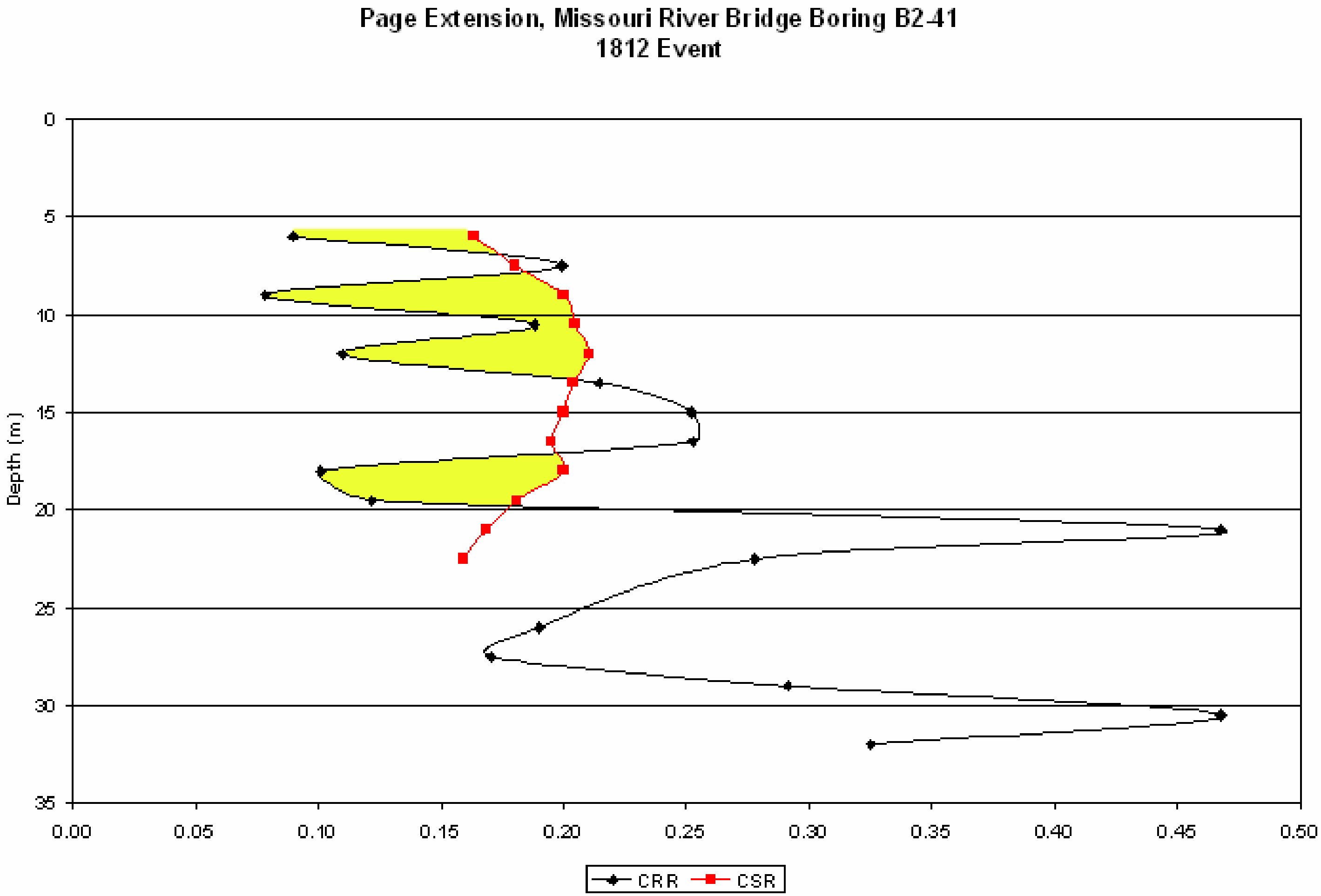
Page Ave. Missouri River Bridge CSR vs. CRR



Page Ave. Missouri River Bridge Liquefaction Factor of Safety

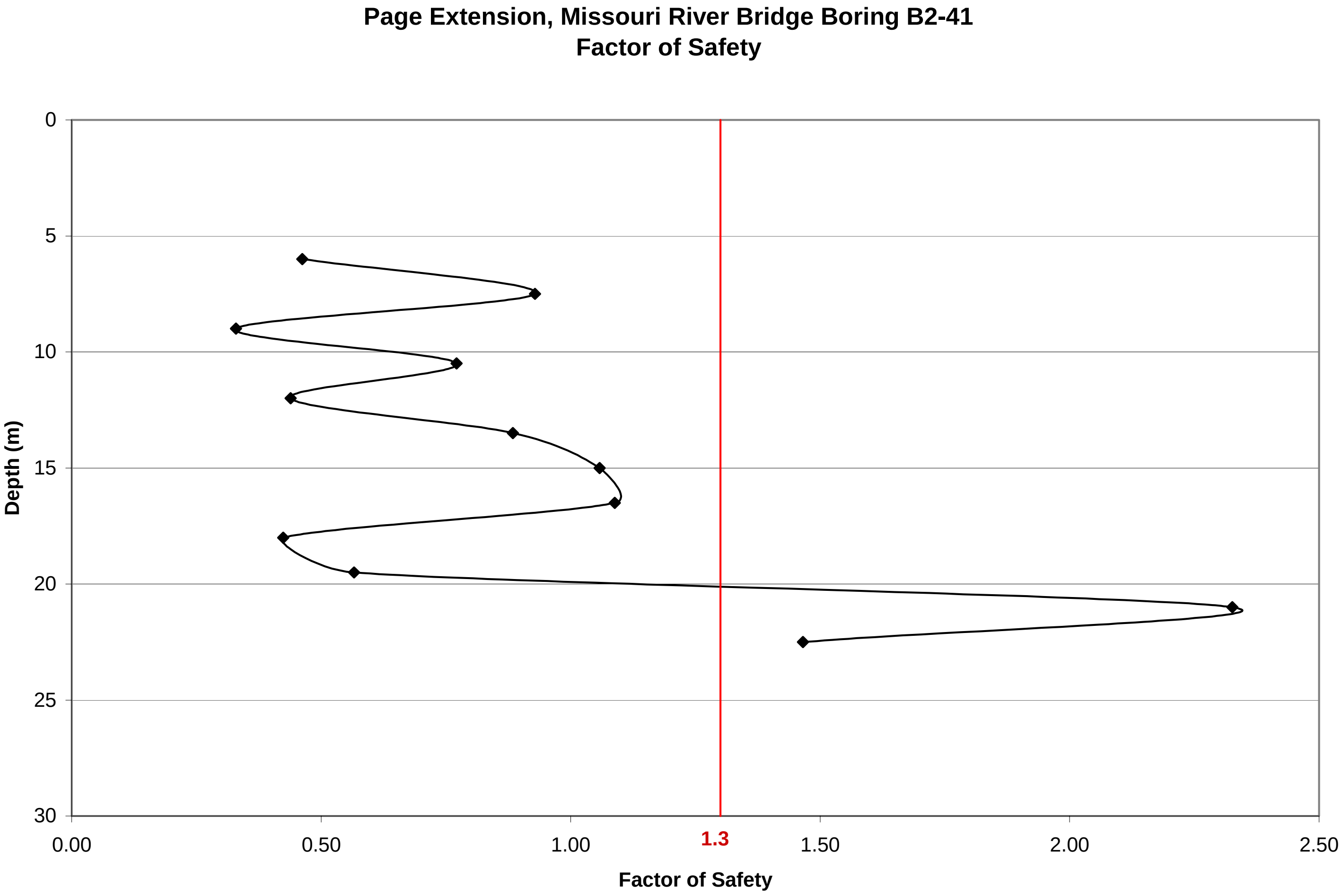


Page Ave. Missouri River Bridge CSR vs. CRR

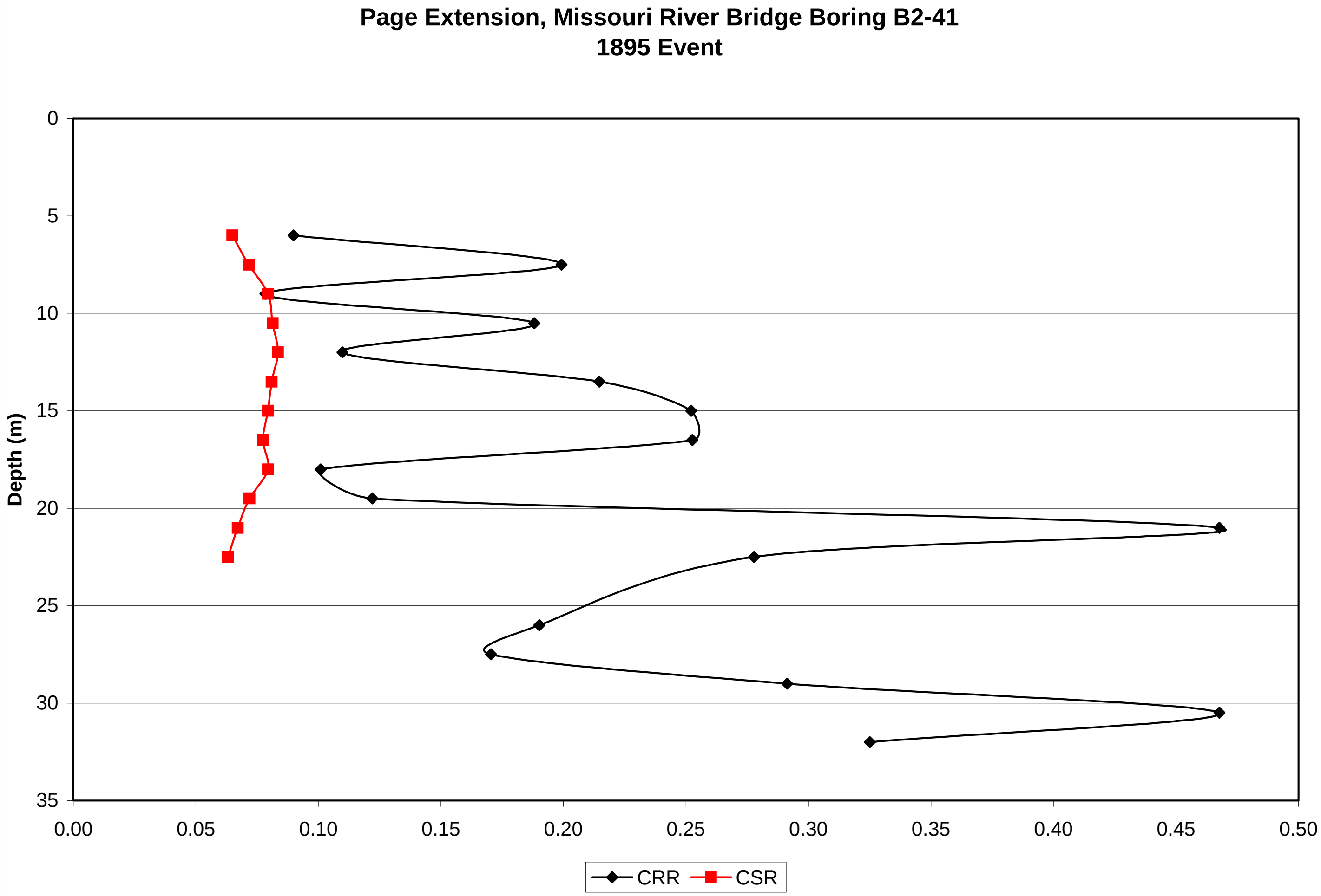


$M_s 8.6$

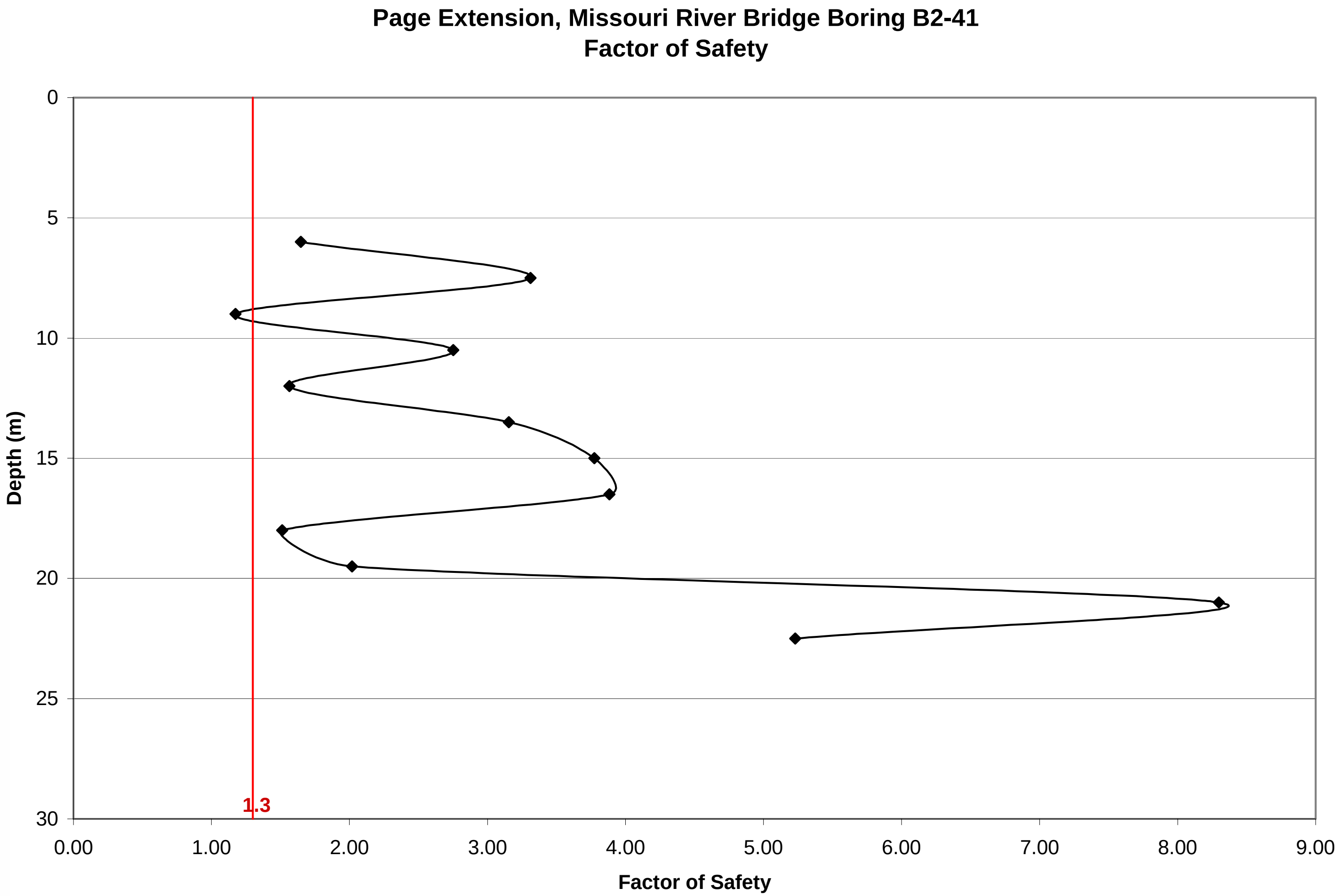
Page Ave. Missouri River Bridge Liquefaction Factor of Safety



Page Ave. Missouri River Bridge CSR vs. CRR



Page Ave. Missouri River Bridge Liquefaction Factor of Safety



M_s8.6

1D Seismic Site Response Equivalent Linear Approach

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

Main Features Include:

- **a) 1-D non-linear time domain wave propagation analysis method**
- **b) 1-D equivalent linear frequency domain analysis method**

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Youssef Hashash and Duhee Park

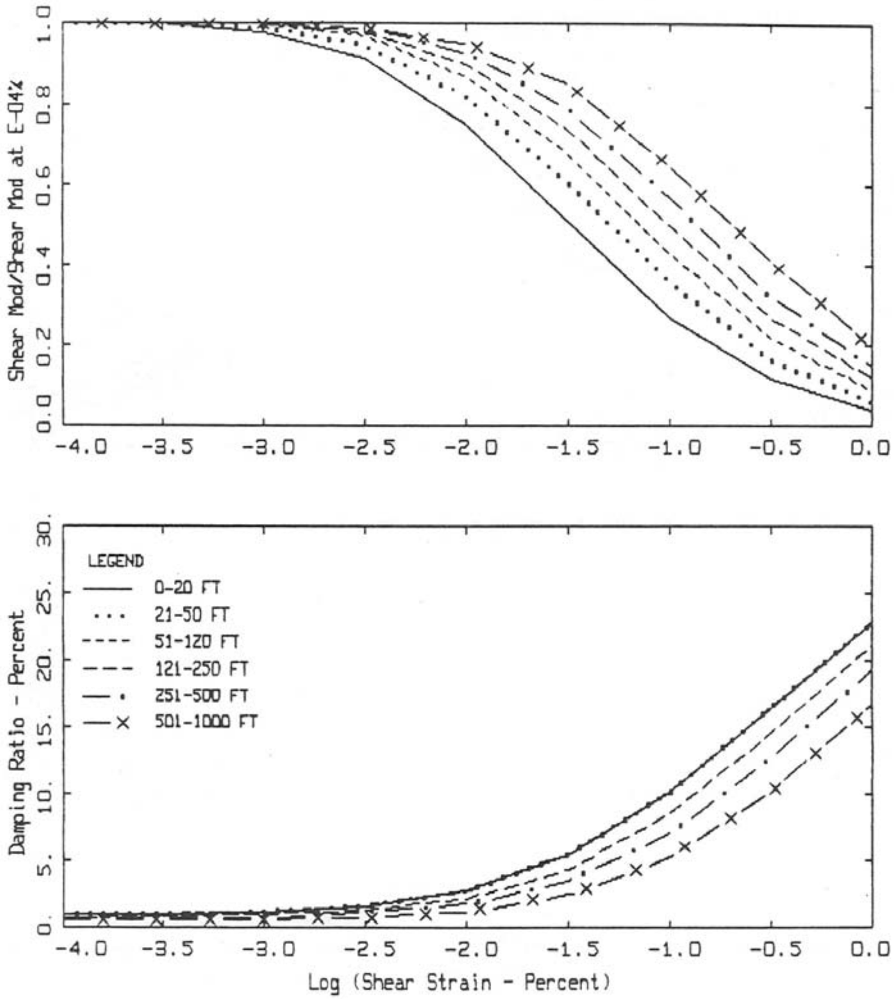
Sponsored in part by project GT-3 Mid-America Earthquake Center NSF Grant EERC-9701785.

Developed by: Youssef Hashash and Duhee Park
User Interface: Daniel Turner
Help Manual: David Asfar

For future updates check staff.uiuc.edu/~hashash or contact hashash@uiuc.edu

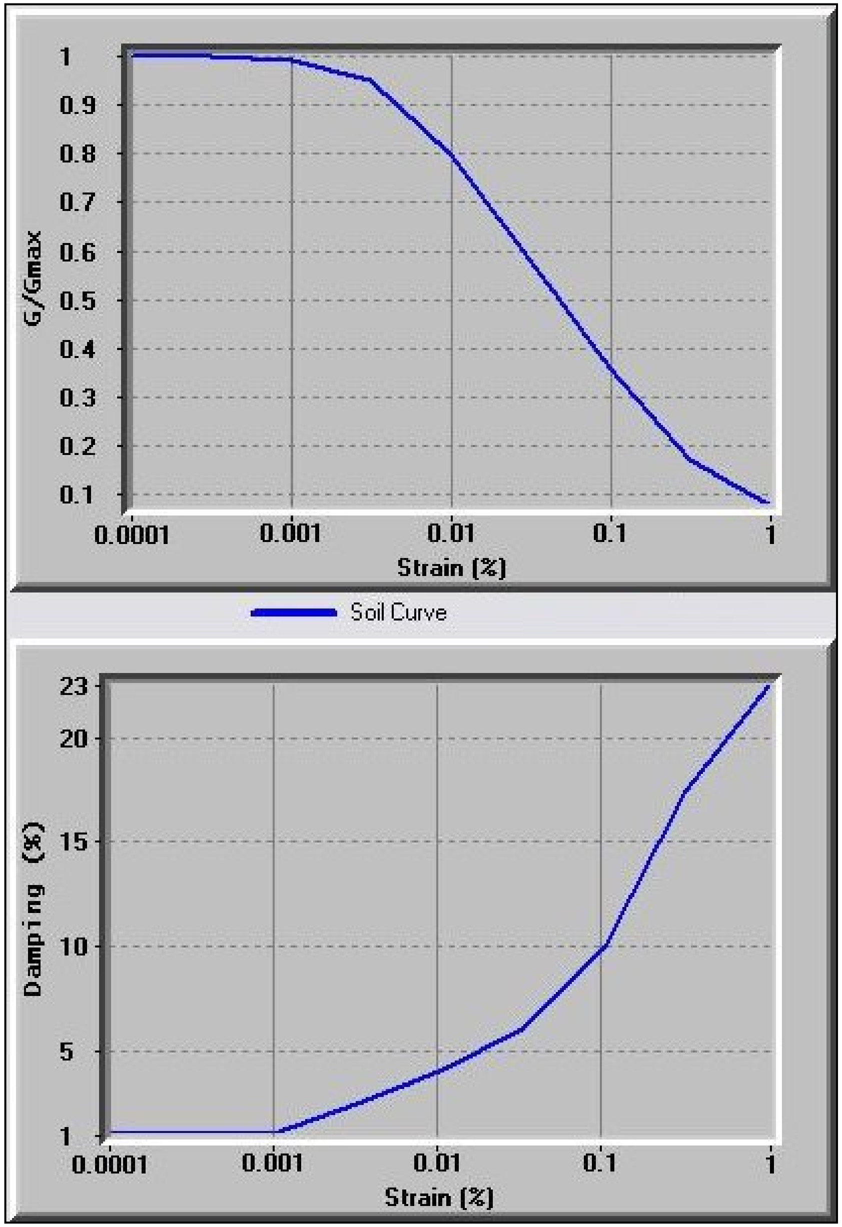
EPRI GENERIC MODULUS REDUCTION CURVES

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

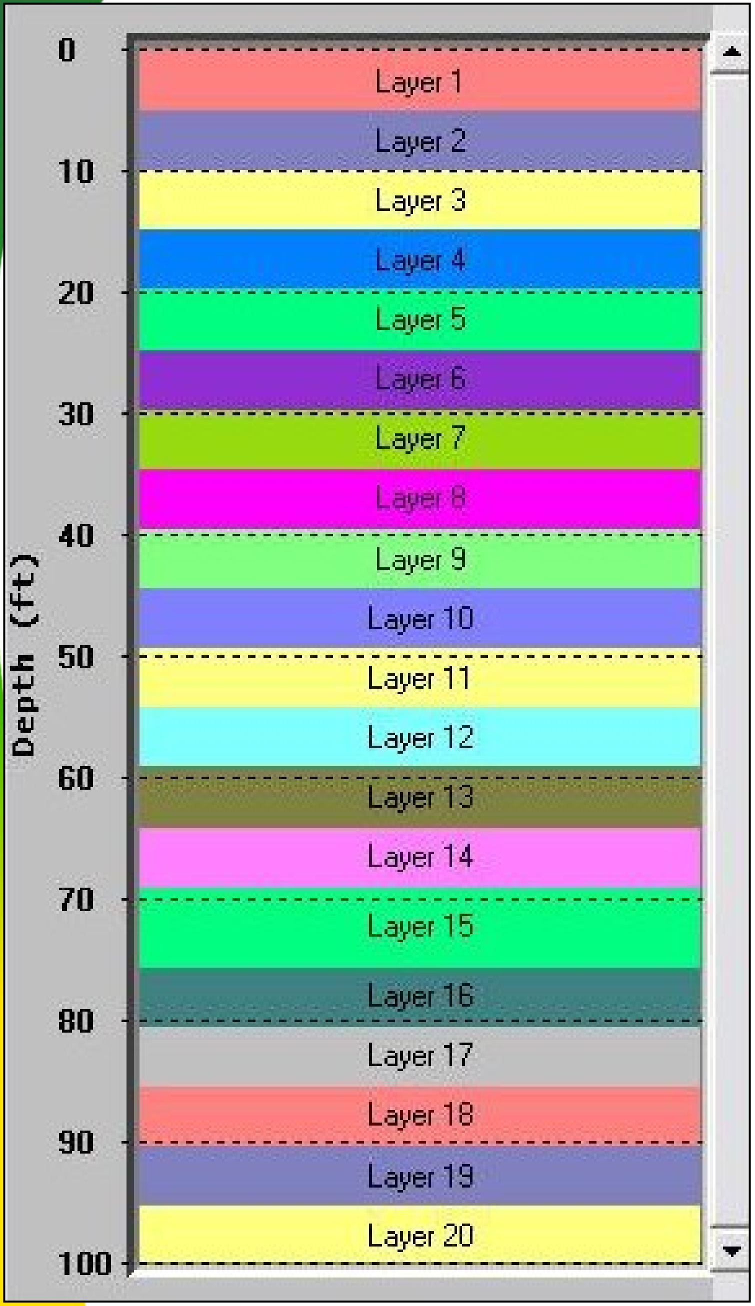


EPRI (1993)

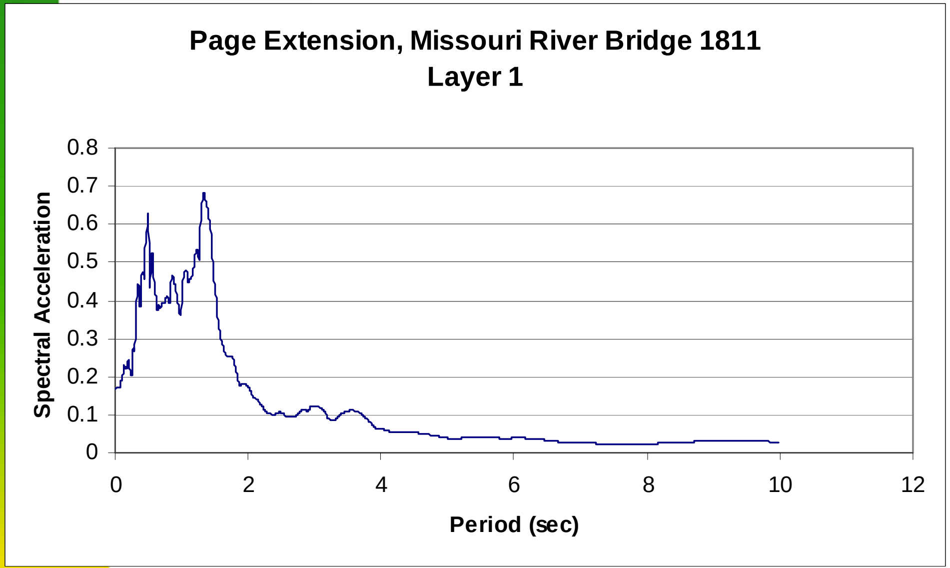
EPRI Curves Approximated

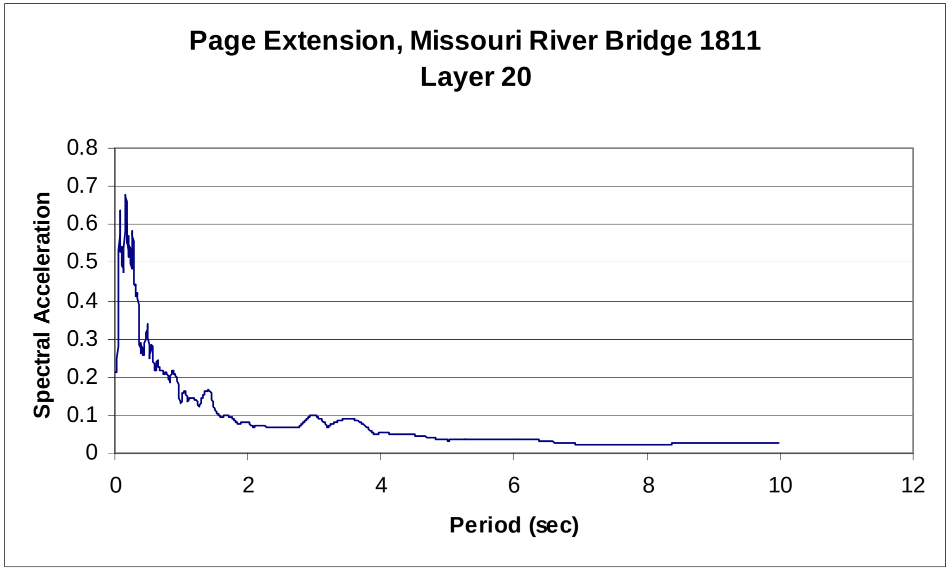


Soil Parameter Input Interface using DEEPSOIL 1-D wave propagation analysis



Page Ave. Missouri River Bridge M8.6 1811 NMSZ Event

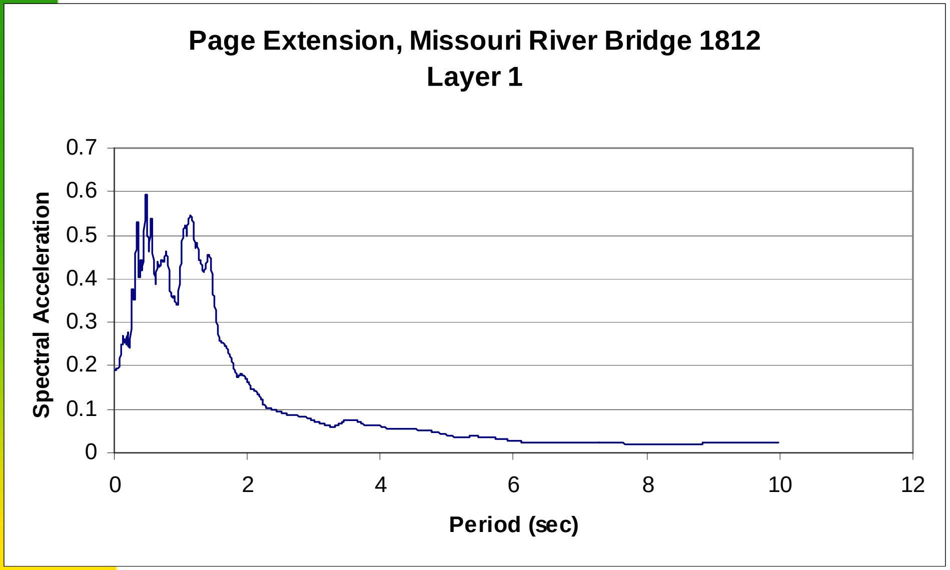


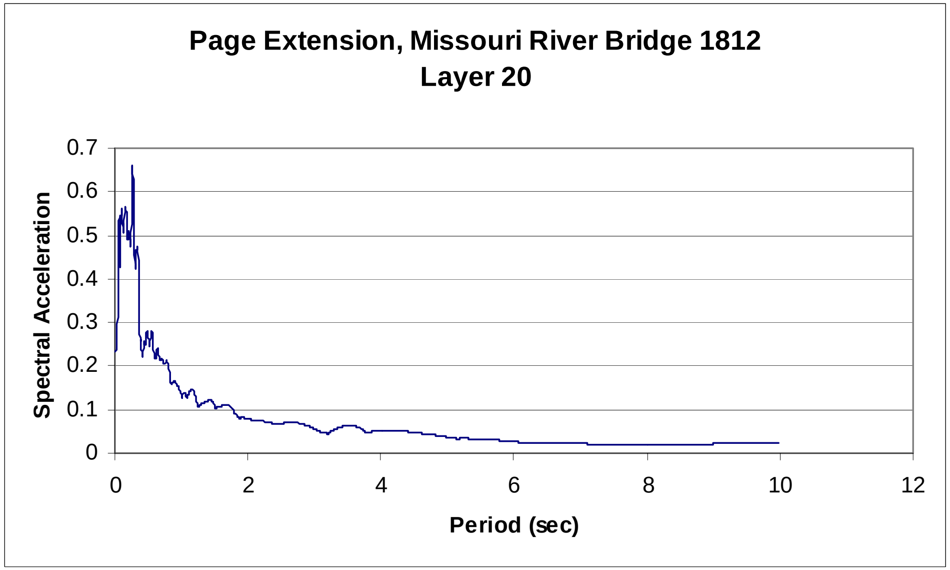


At ground surface

At bedrock interface

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

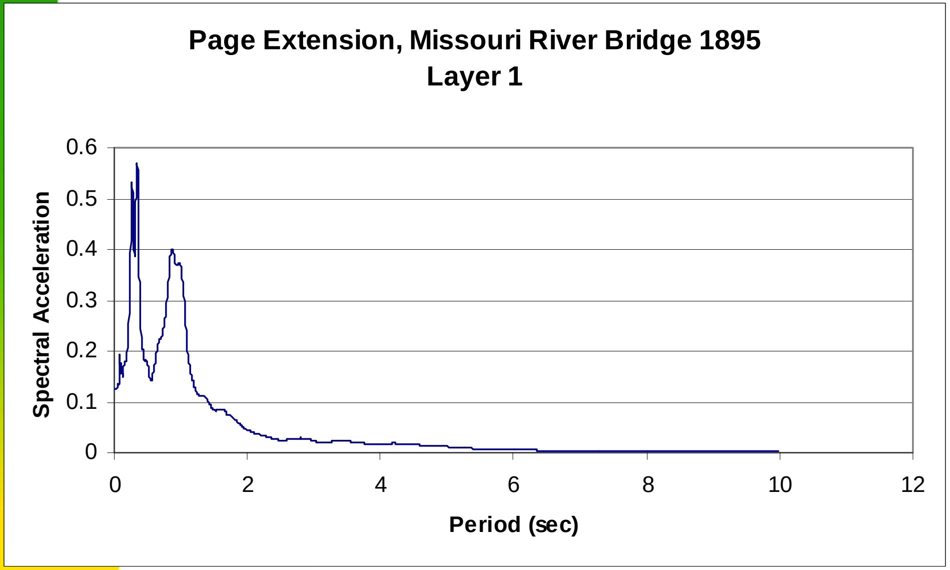


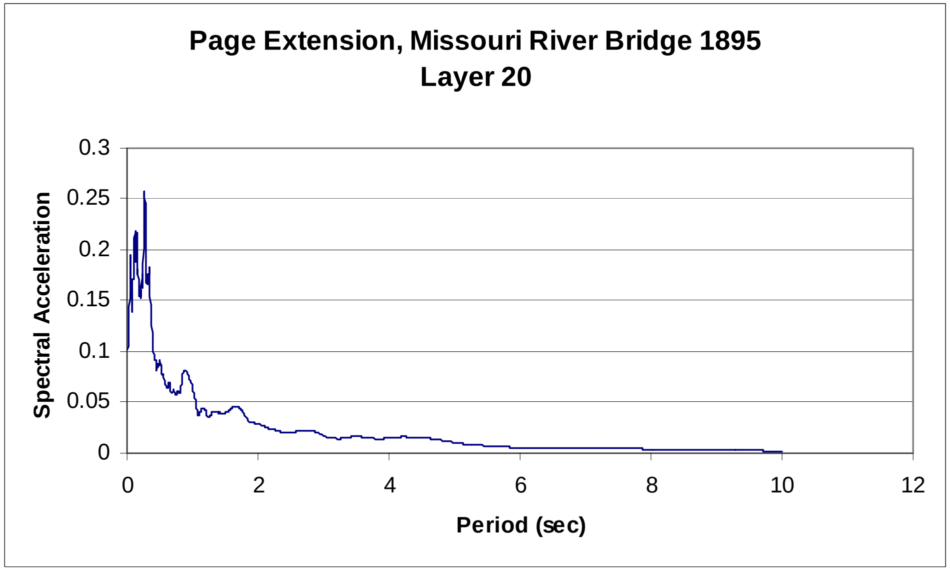


At ground surface

At bedrock interface

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





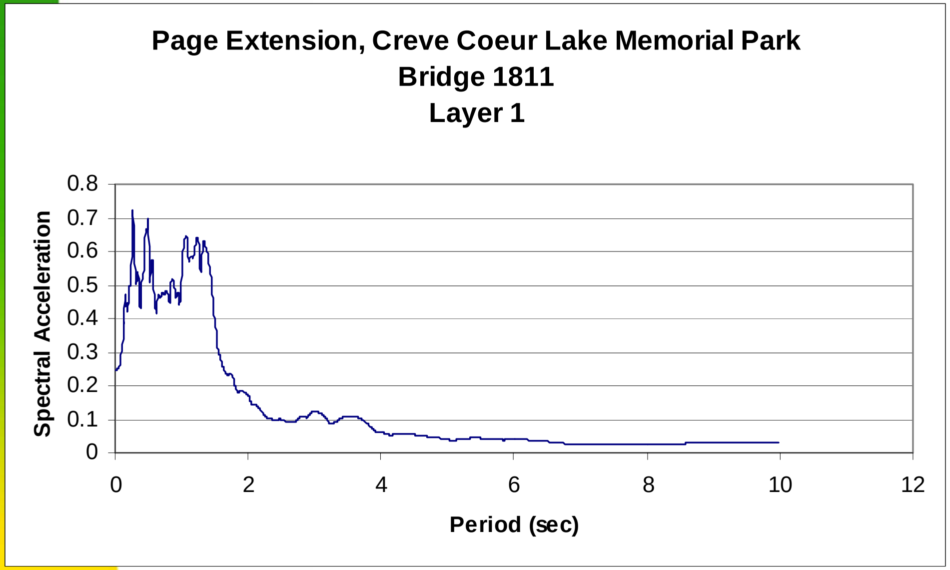
At ground surface

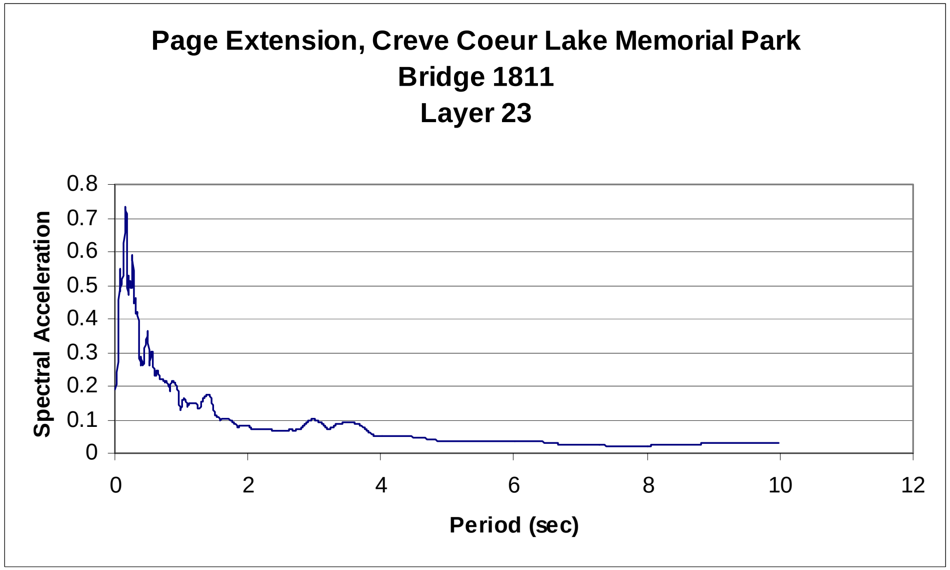
Increases to 0.58 g

At bedrock interface

a_{max} = 0.22g

Page Ave. Creve Coeur Lake Memorial Park Bridge
M8.6 1811 Event

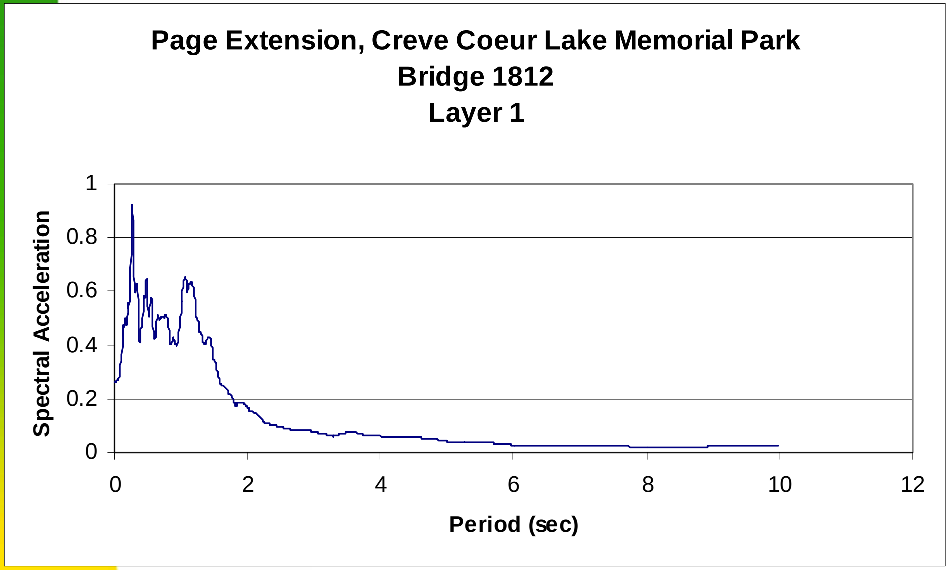


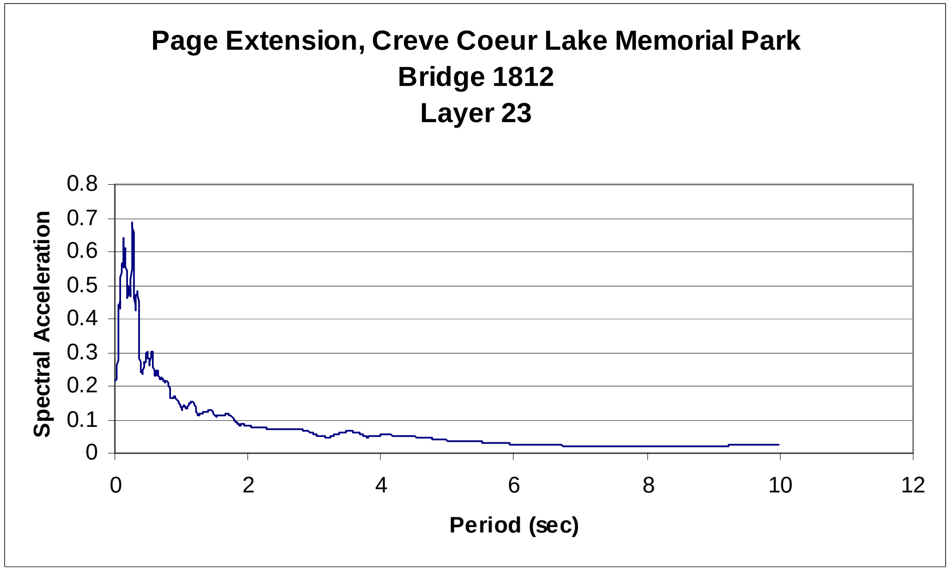


At ground surface

At bedrock interface

Page Ave. Creve Coeur Lake Memorial Park Bridge M8.0 1812 Event





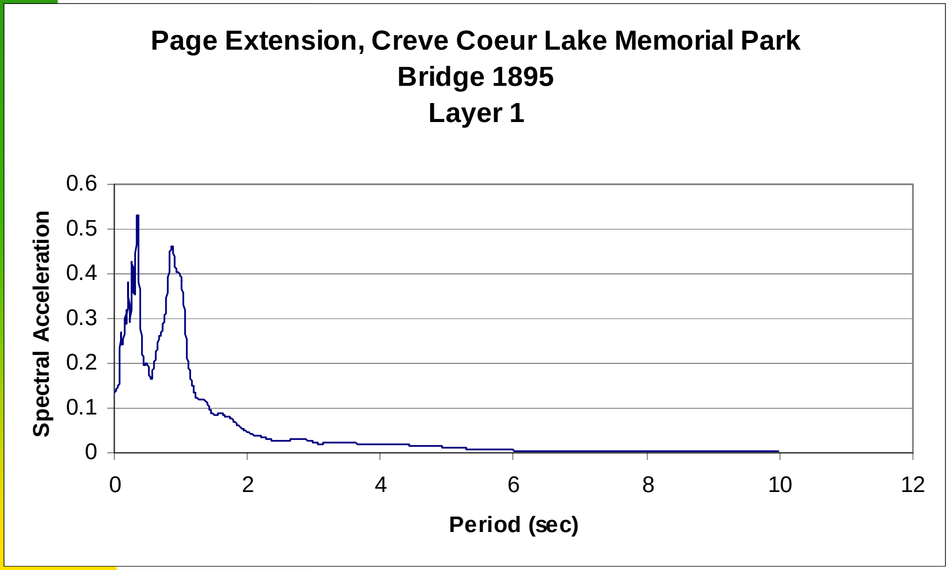
At ground surface

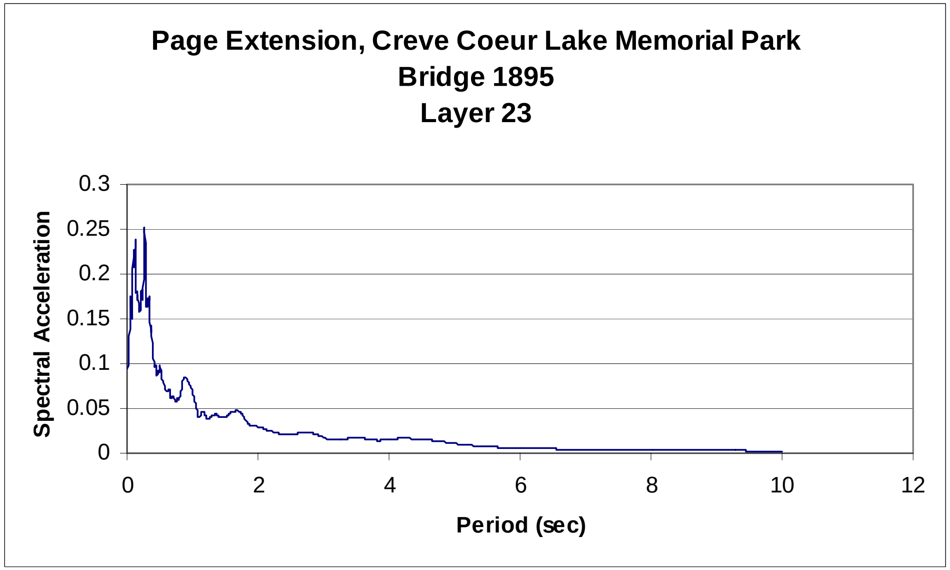
Increases to 0.90 g

At bedrock interface

a_{max} = 0.70g

Page Ave. Creve Coeur Lake Memorial Park Bridge M6.6 1895 Event





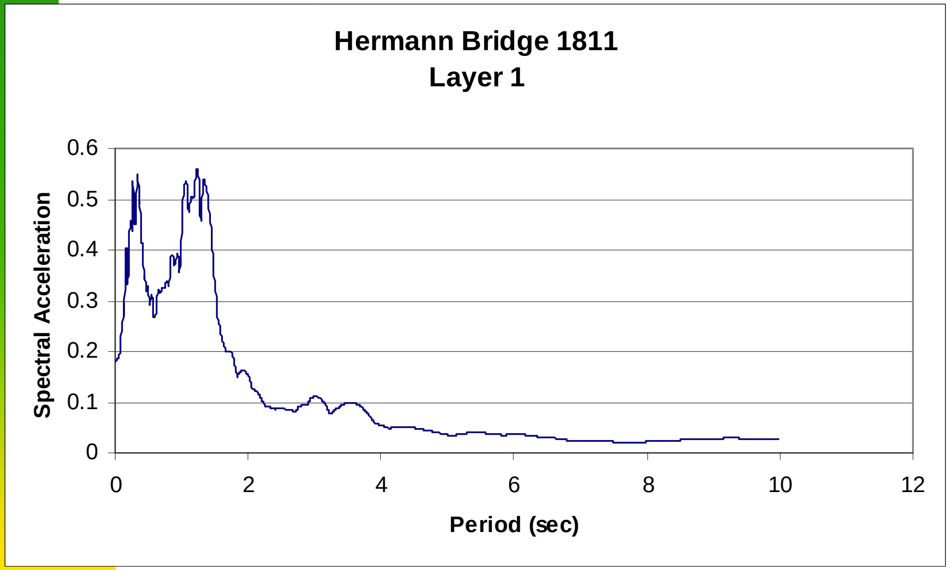
At ground surface

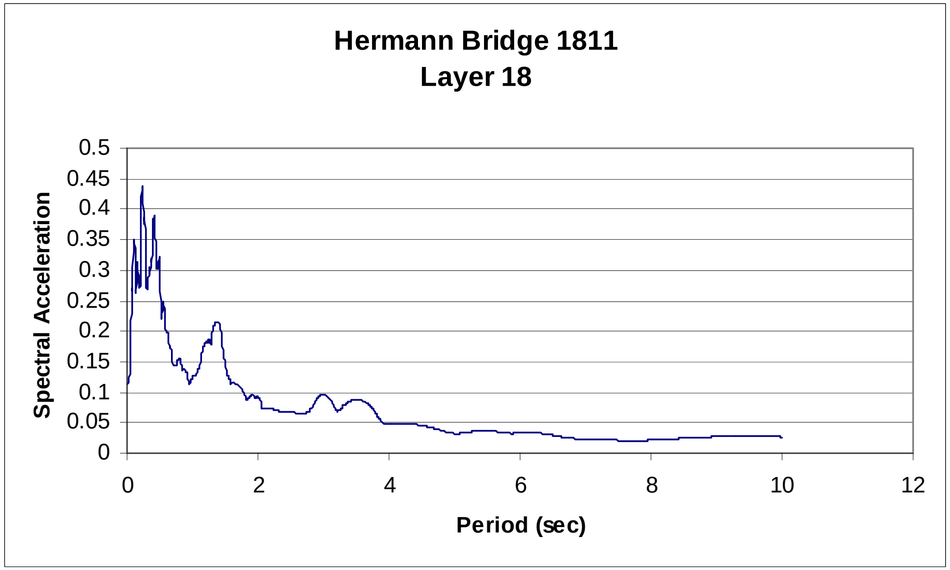
Increases to 0.53 g

At bedrock interface

a_{max} = 0.24g

Hermann Bridge Site
M8.6 1811 Event





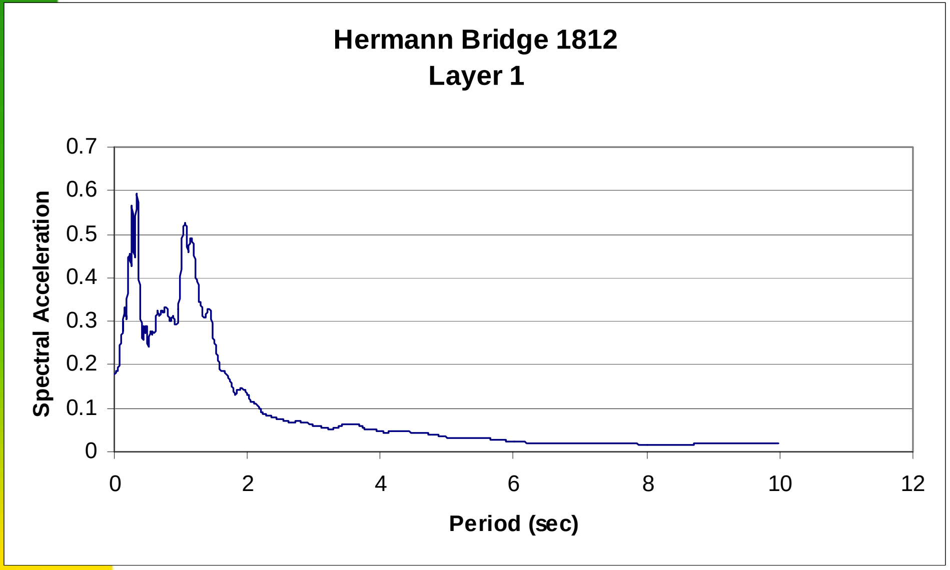
At ground surface

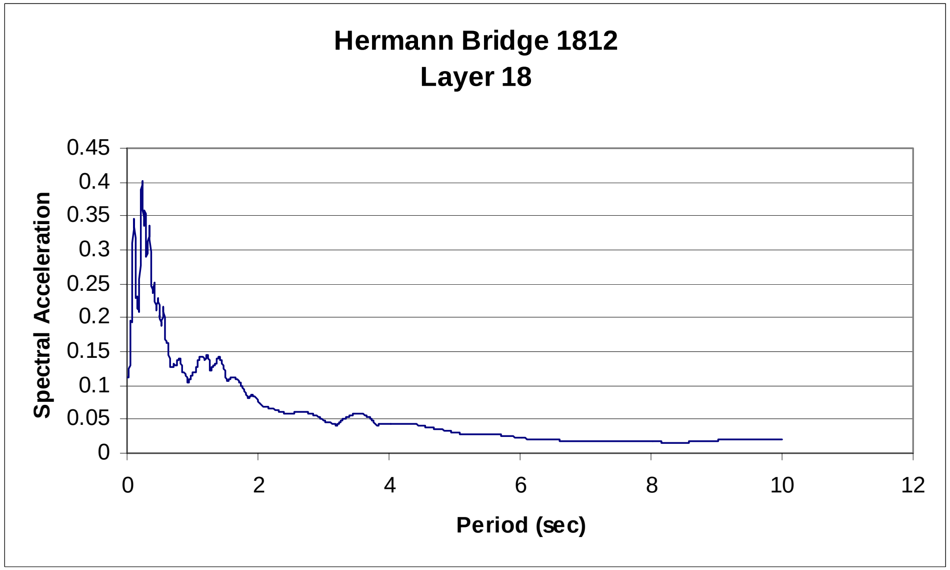
Increases to 0.56 g

At bedrock interface

a_{max} = 0.44g

Hermann Bridge Site
M8.0 1812 Event





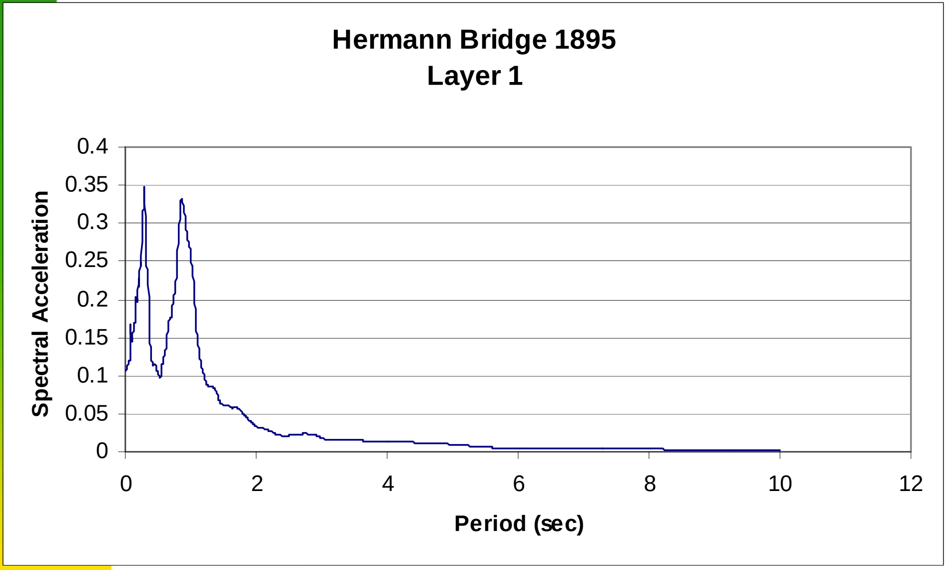
At ground surface

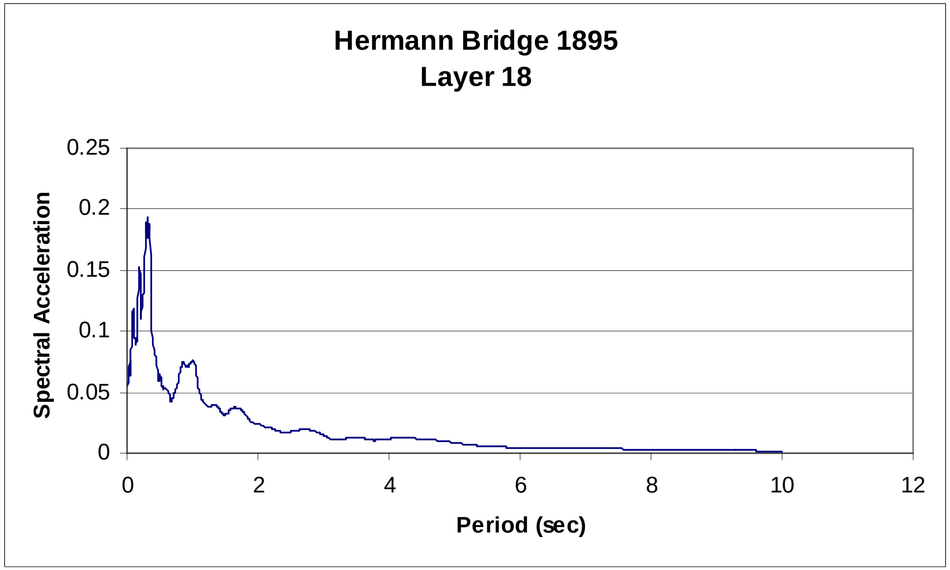
Increases to 0.60g

At bedrock interface

a_{max} = 0.39g

Hermann Bridge Site
M6.6 1895 Event





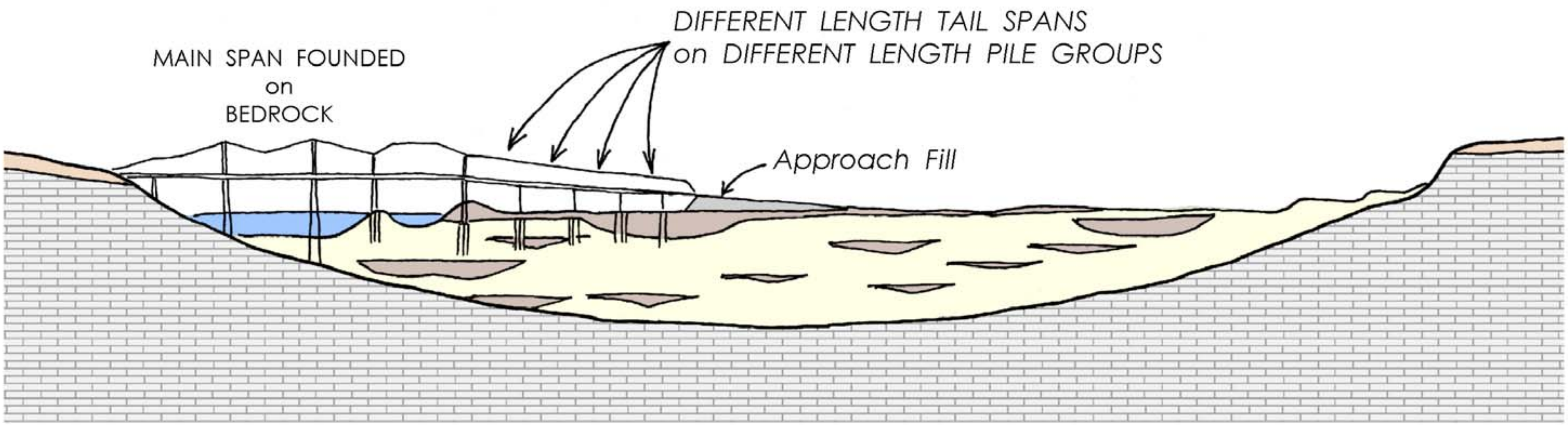
At ground surface

Increases to 0.35g

At bedrock interface

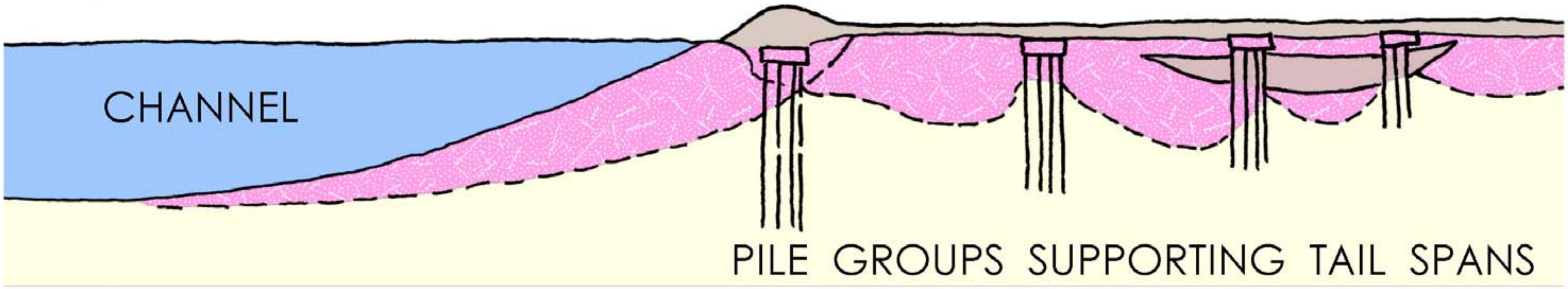
a_{max} = 0.19g

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

ZONES COMMONLY SUSCEPTIBLE to LIQUEFACTION



- **Simply supported tail spans would appear to be most vulnerable part of existing highway bridges**
- **Site amplification causes long period motions to peak between 1.0 and 1.5 seconds**
- **We can expect liquefaction of foundations (areas shown in pink)**

CONCLUSIONS

- **Widespread liquefaction likely in M6.6 or greater events at great range (~250 km)**
- **Liquefaction so severe (deep) and continuous in M7.5+ events that localized failure/tilt of supporting pile groups can be expected**
- **Lateral spreads can be expected near channels in those areas subject to severe liquefaction. These would destroy any pile supported structures**
- **Long period motions will cause significant site amplification locally, which could trigger collapse of simply supported spans at great range (~250 km)**
- **Two-dimensional effect of bedrock channels not considered in these screening analyses. This could make matters worse locally.**

About the Presenter

J. David Rogers, Ph.D., P.E., R.G. is the Karl F. Hasselmann Chair in Geological Engineering at the University of Missouri-Rolla. He can be contacted at rogersda@umr.edu

- J. David Rogers served as Chair of the Building Codes Committee of the Association of Engineering Geologists between 1990-97 and was AEG representative to the International Conference of Building Officials while the 1991, 1994 and 1997 Uniform Building Codes and 2000 International Building Code were developed.
- He has taught short courses on seismic hazards for the University of California, FEMA, California Geological Survey and the Southern California Earthquake Center.