Assessment and Communication of Seismic Hazard and Risk in the Central and Eastern United States: An Example from Kentucky

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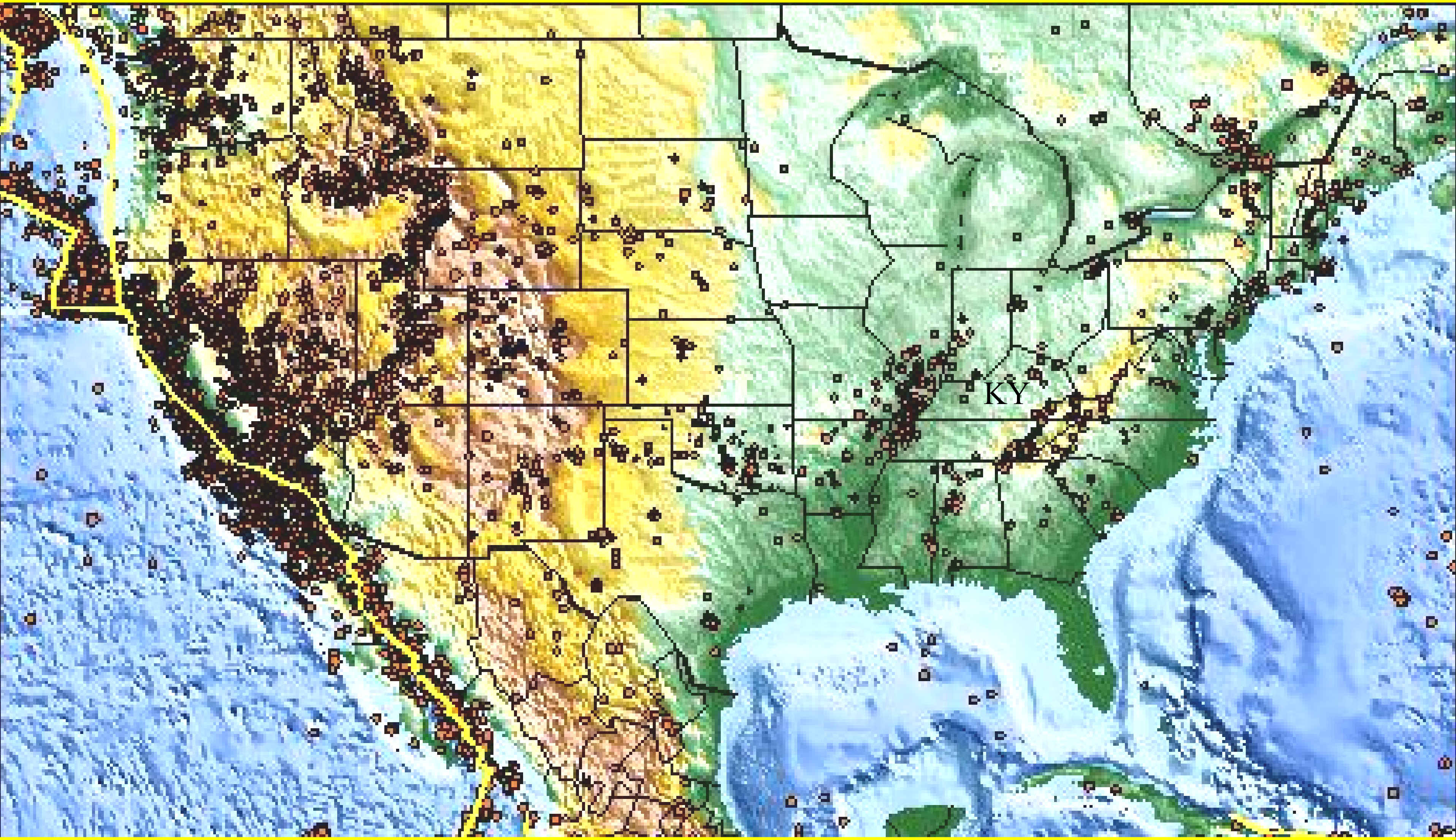
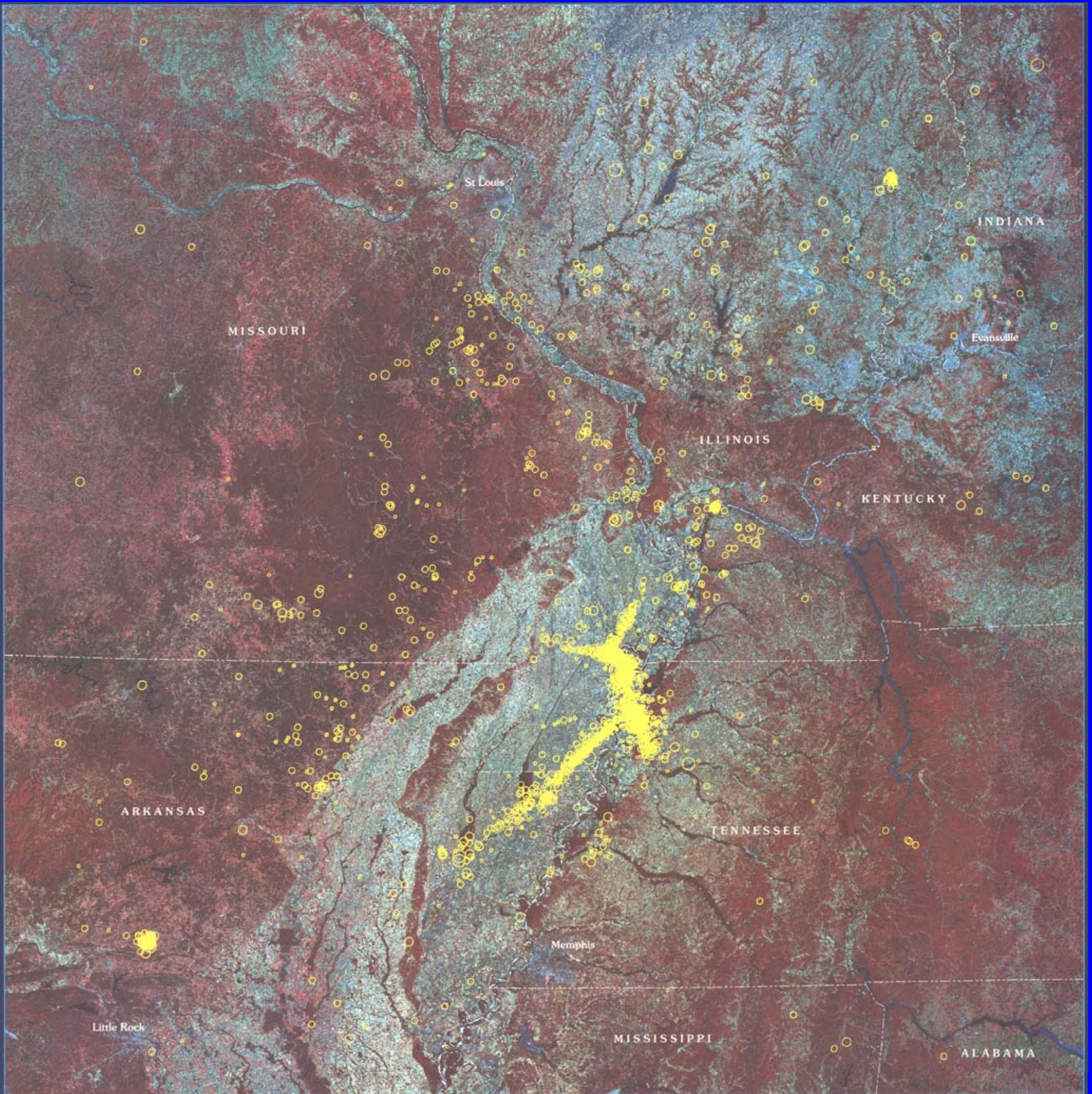
Outline

- Introduction - Earthquakes in Kentucky
- Problems in Seismic Hazard and Risk Assessment
- Seismic Risk
- Seismic Hazard
- Problems with the National Seismic Hazard Maps (PSHA maps)
- Conclusions

Earthquakes in the United States of America



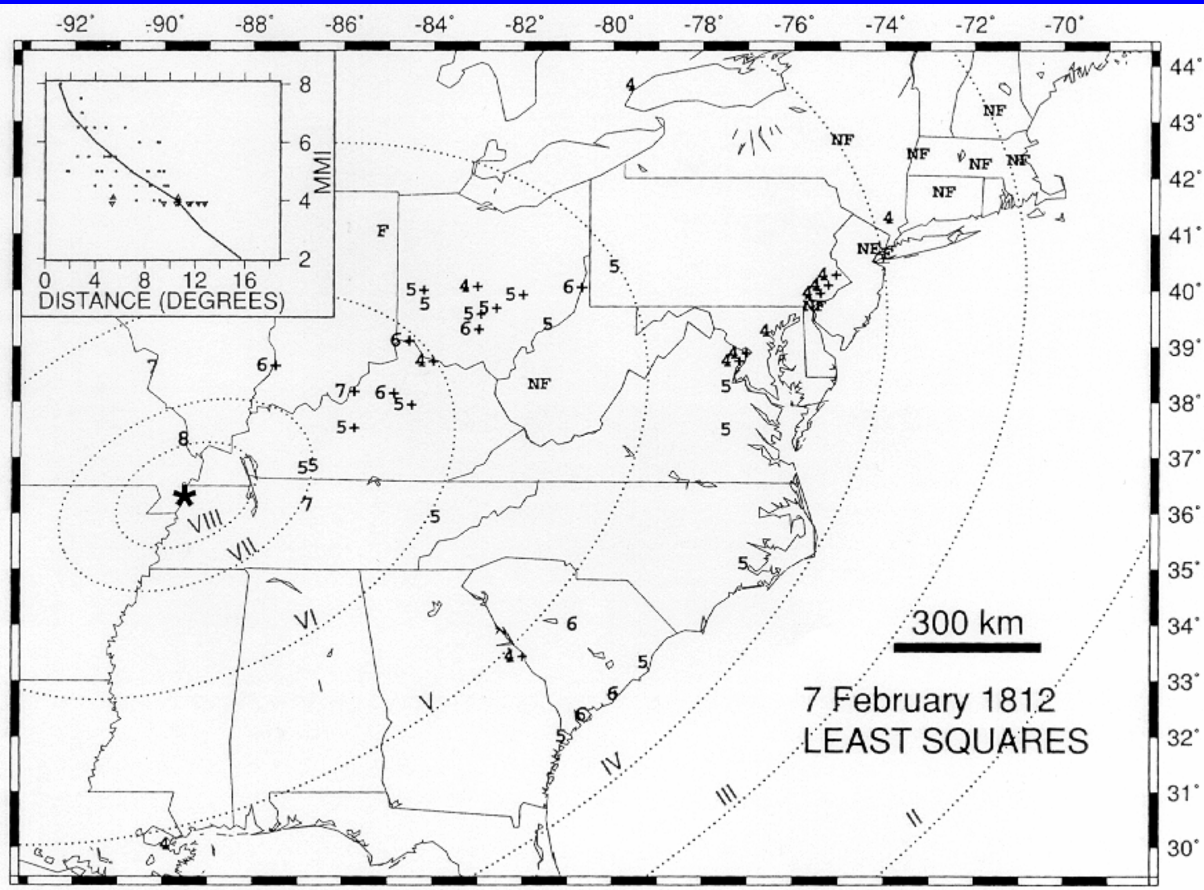


New Madrid Seismic Zone

1) At least three large earthquakes occurred in 1811-1812 (M7.0-8.0)

2) Two ~M6.0 (1886 and 1895)

3) Paleo-liquefaction: there were similar large earthquakes occurred in the past several thousands Years (~500 years recurrence interval)



(Hough et al., 2000)

Modified Mercalli Intensity Scale

INTENSITY	EFFECTS	AVE. PEAK ACCELERATION
VI	Strong 0.06–0.07g	Felt by all. Damage slight.
VII	Very Strong 0.10–0.15g	Everybody runs outdoors. Considerable damage to poorly designed buildings.
VIII	Destructive 0.25–0.30g	Considerable damage to ordinary buildings.
IX	Ruinous 0.50–0.55g	Great damage to ordinary buildings
X	Disastrous >0.60g	Many buildings destroyed.
XI	Disastrous	Few, if any, structures remain standing

(Simplified from Bolt, 1993)

- There is no question that there are seismic hazards and risk in the central US. But how high are the hazards and risk is a question because so little we know about them in the central US

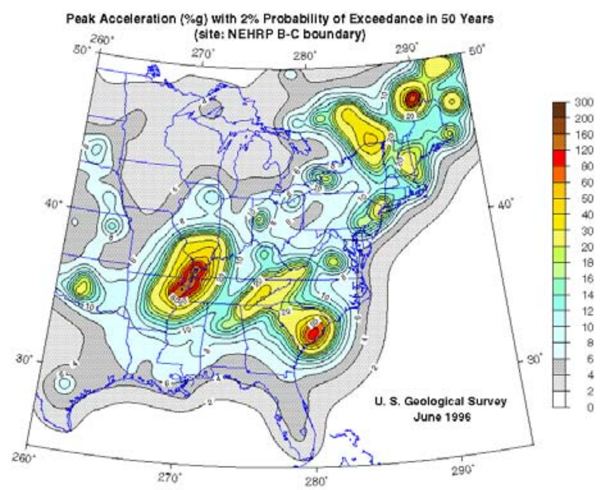
- What can we do with the hazards and risk?

- The best ways are to mitigate those hazards and to reduce the risk, including better seismic design of buildings and other structures.

- Seismologist role: providing the best information on the hazards and risk in the central US.

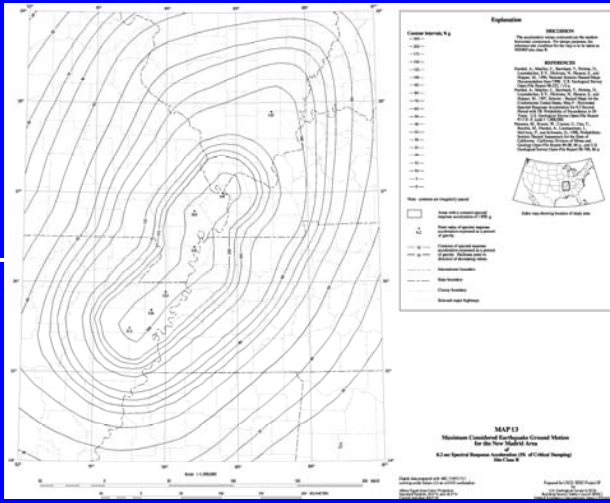
Development of Seismic Design Standard in US

The NEHRP* Hazard Maps
-USGS (PSHA)



BSSC – a group of engineers seismologists, and others

The NEHRP Design Maps
-FEMA (NIBS)

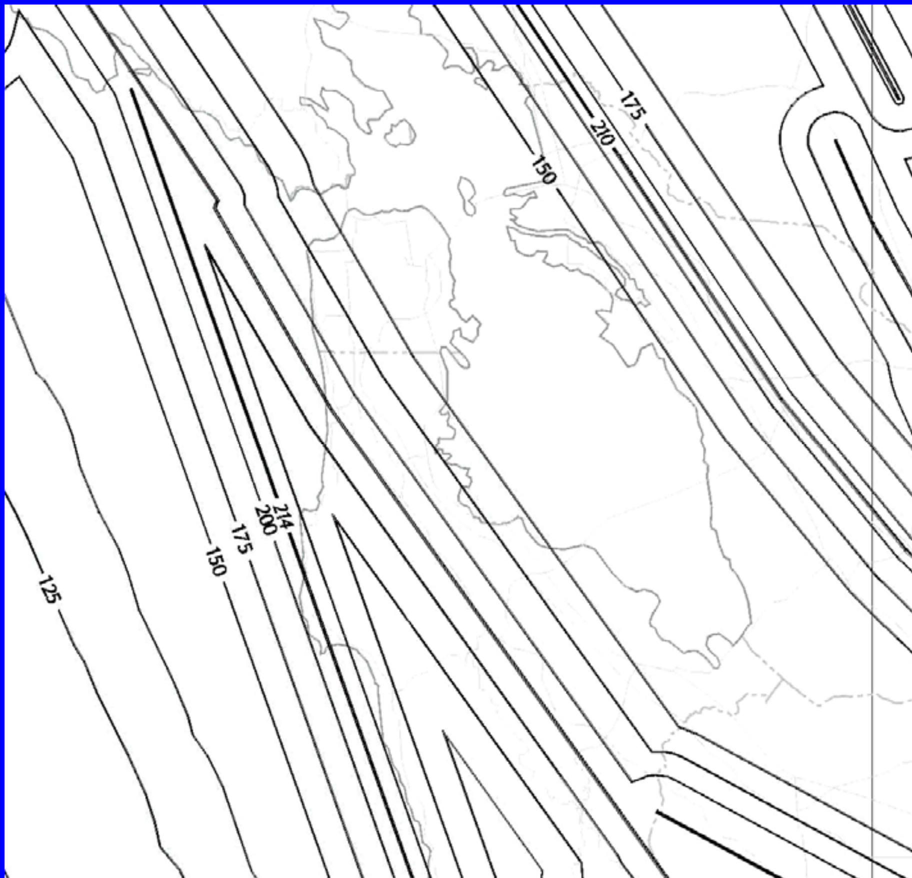


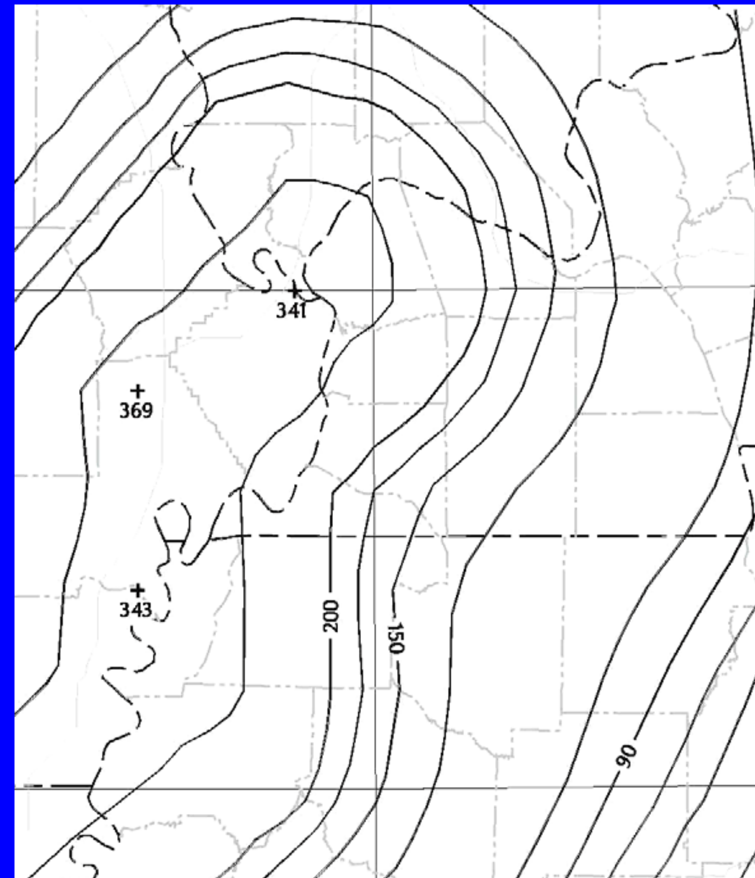
Federal regulations

State regulations (KBC-2002)

Other organizations

Design Ground Motion (0.2 s) in San Francisco and Paducah



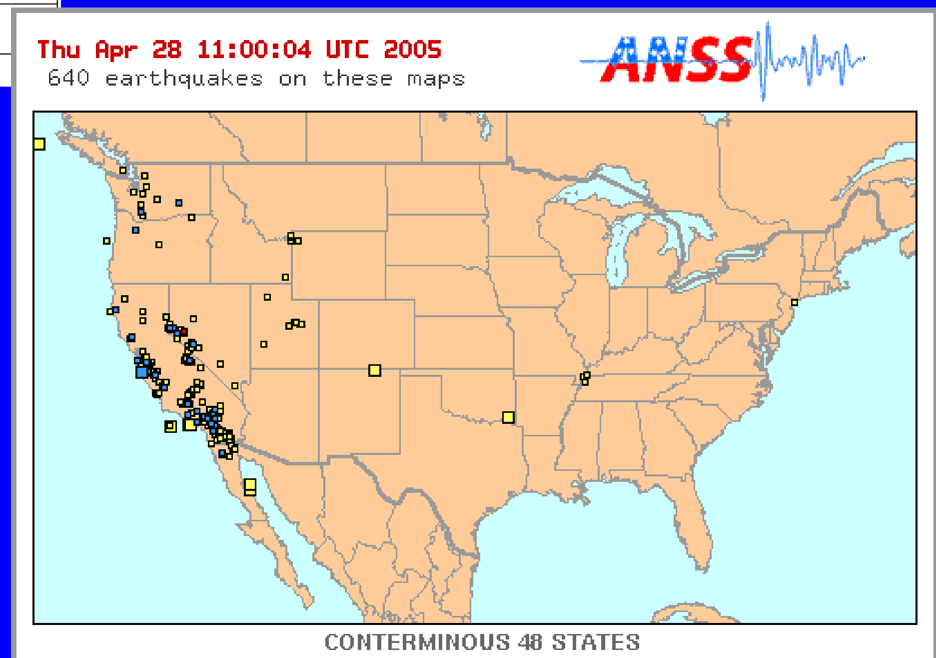


1) Mr. David Mast (a staff member from KY congressman Ed Whitfield office): Why can I not build a regular two-story house in Paducah?
2) SEAOK found that: impossible to construct residential structures in westernmost Kentucky without enlisting a design professional (IRC-2000).
3) DOE will not get permit from Ky-EPA to build a landfill at PGDP for clean-up.
4) One of the main reasons that Kentucky lost the centrifuge facility ($2B) to Ohio.

- Question: does it make sense if
  - You have to pay more for mitigating seismic hazards in Paducah than in San Francisco or Los Angeles?

- Answer: NO! (geology and seismology)

	California		West Kentucky	
Probability	(Deterministic)		2 % ~ 5% in 50 years	
Design (0.2 s)	<=1.0g (UBC-97)	<=0.7g PGA (CALTRAN)	>1.0g (IBC-2000)	>1.0g PGA (Bridge)
Geology	San Andreas fault >20 mm/y well defined		New Madrid faults <2 mm/y poorly defined	
Seismology	High M7.0-8.0: ~100 y M6.0-7.0: ~20-50 y		Low M7.0-8.0: ~500 y M6.0-7.0: ?	
Performance	Very well		?	



- There is a gap (confusion) in understanding of seismic hazard and risk between the assessors and users:
  - What is seismic hazard?
  - What is seismic risk?
  - How to assess and communicate them?

Hazard and Risk

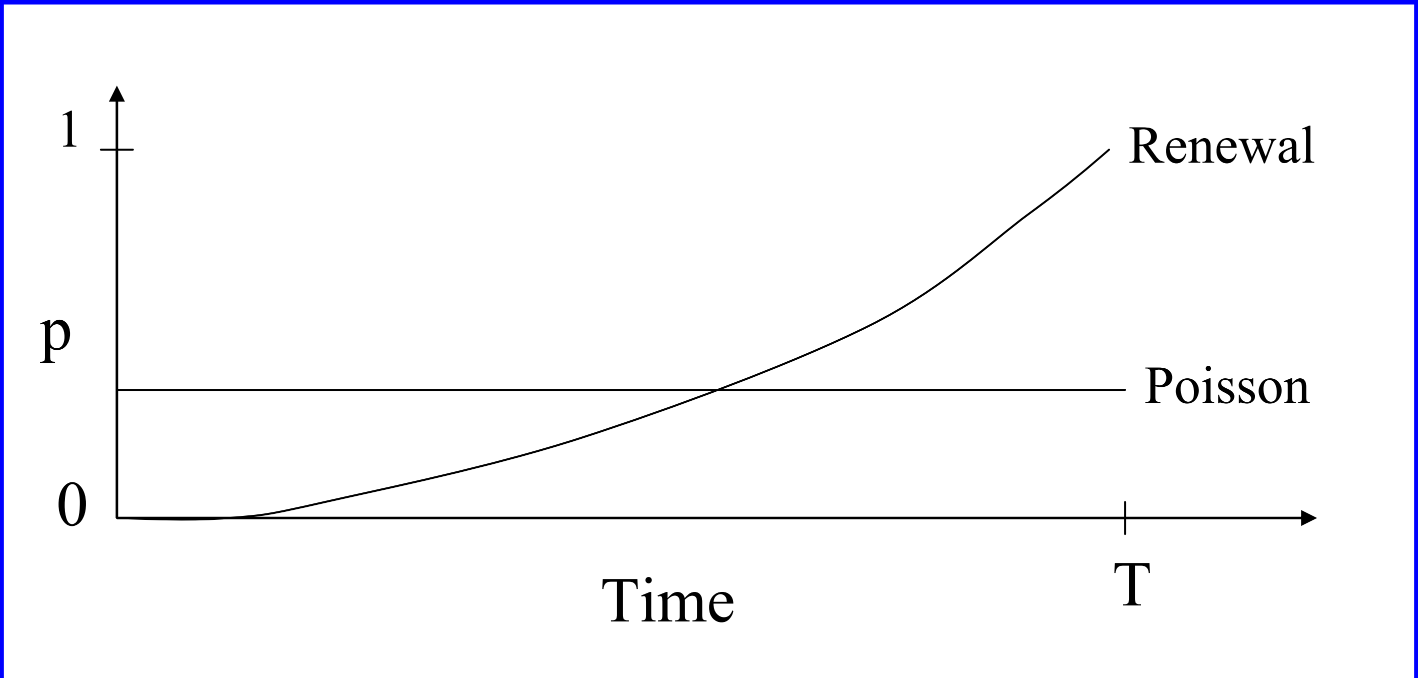
- Hazard and risk are two fundamentally different concepts
- **Hazard** is a phenomenon that has potential to cause harm (objective)
  - natural hazards: earthquakes, hurricanes, tornadoes, floods, and others
  - man-made hazards: car crash, chemical spill, train derailments, terror attack, and others
- **Definition of Risk** is very broad and subjective, and depends on the stakeholders, but it contains three elements:
  - Probability (likelihood)
  - A level of hazard
  - Exposure (asset and time)

Hazard and Risk

- Hazard Measurement:
  - Level of hazard (M8.0 earthquake, C-5 hurricane, car crash, 911 terror attach)
  - Its recurrence interval (500 years, 100 years, days [hours], ?)
- Risk Quantification:
  - Probability (likelihood) (1%, 5%, and 10%)
  - A level of hazard (loss) (M8.0, C-5, 911 event)
  - Exposure (time and asset) (10, 30, 50 years and a house, a city, a bridge)

- Seismic Hazard (objective)
  - Natural phenomena generated by the earthquake, such as surface rupture, ground motion, ground-motion amplification, liquefaction, and induced-landslide that have potential to cause harm
  - Measurement:
    - level of hazard (M6.0, MMI X [$100M loss], 0.5g PGA, 10m displacement)
    - and its recurrence interval (20, 100, 50, 500 years)
- Seismic Risk (subjective)
  - Probability (likelihood) of experiencing a level of seismic hazard for a given exposure (time and property)
  - Examples:
    - 0.3g PGA with 10% PE in 50 years
    - MMI VIII with 5% PE in 50 years
    - $100M loss with 2% PE in 50 years

- Seismic Risk Calculation
  - Assumption on earthquake occurrence (subjective)
    - Poisson model: time-independent and independent of the history of previous event
    - Renewal: occurrence probability increases with time
    - Others



Seismic Risk Calculation

- If earthquake occurrence follows Poisson model, then the probability of *n* earthquakes of given size in an area or along a fault during a time interval of *t* years (time exposure) is

$$p(n,t,\tau) = \frac{e^{-t/\tau}(t/\tau)^n}{n!}$$

- The probability of no earthquake of given size is

$$p(0,t,\tau) = e^{-t/\tau}$$

- The probability of one or more (at least one) earthquakes is

$$p(n \geq 1,t,\tau) = 1 - p(0,t,\tau) = 1 - e^{-t/\tau} \approx 1 - (1 - 1/\tau)^t$$

- Seismic Risk Calculation
  - Examples

$$p = 1 - e^{-t/\tau} \approx 1 - (1 - 1/\tau)^t$$

- p=2%, 5%, and 10% PE in 50 years (t), then τ (recurrence time) will be about 475 (~500), 975 (~1000), 2475 (~2,500) years for the Earthquakes (Events), respectively

- t=50 years and τ=100, 500, and 1,000 years, then p will be about 39%, 10%, 5% PE, respectively

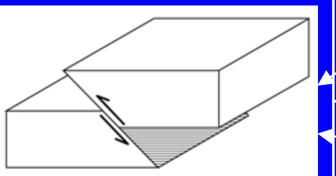
- τ=500 years and t=50, 75, and 100 years, then p will be about 10%, 14%, 18% PE, respectively

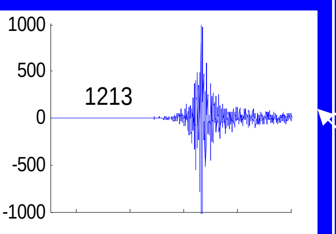
- Other Engineering Risk
  - Examples

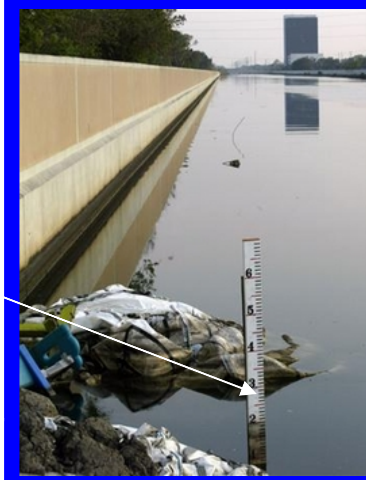
$$p = 1 - e^{-t/\tau} \approx 1 - (1 - 1/\tau)^t$$

    - Hydraulic Engineering (Flood)
      - p=1% PE in 1 year (t), then τ (recurrence time) will be about 100 years (100-year flood)
    - Wind Design
      - p=2% PE in 1 year (t), then τ (recurrence time) will be about 50 years (wind design)

Hazards and Risk Comparison



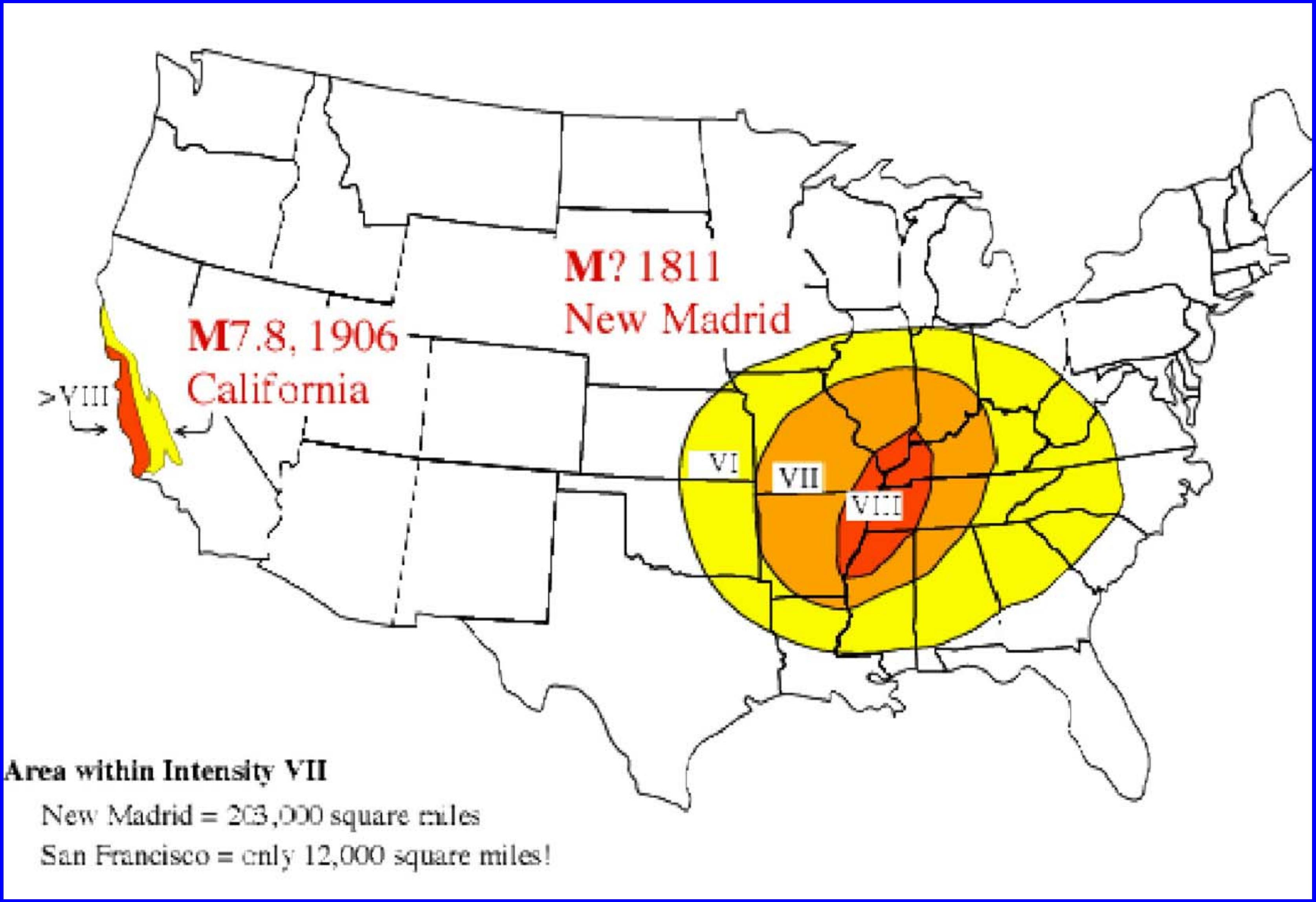




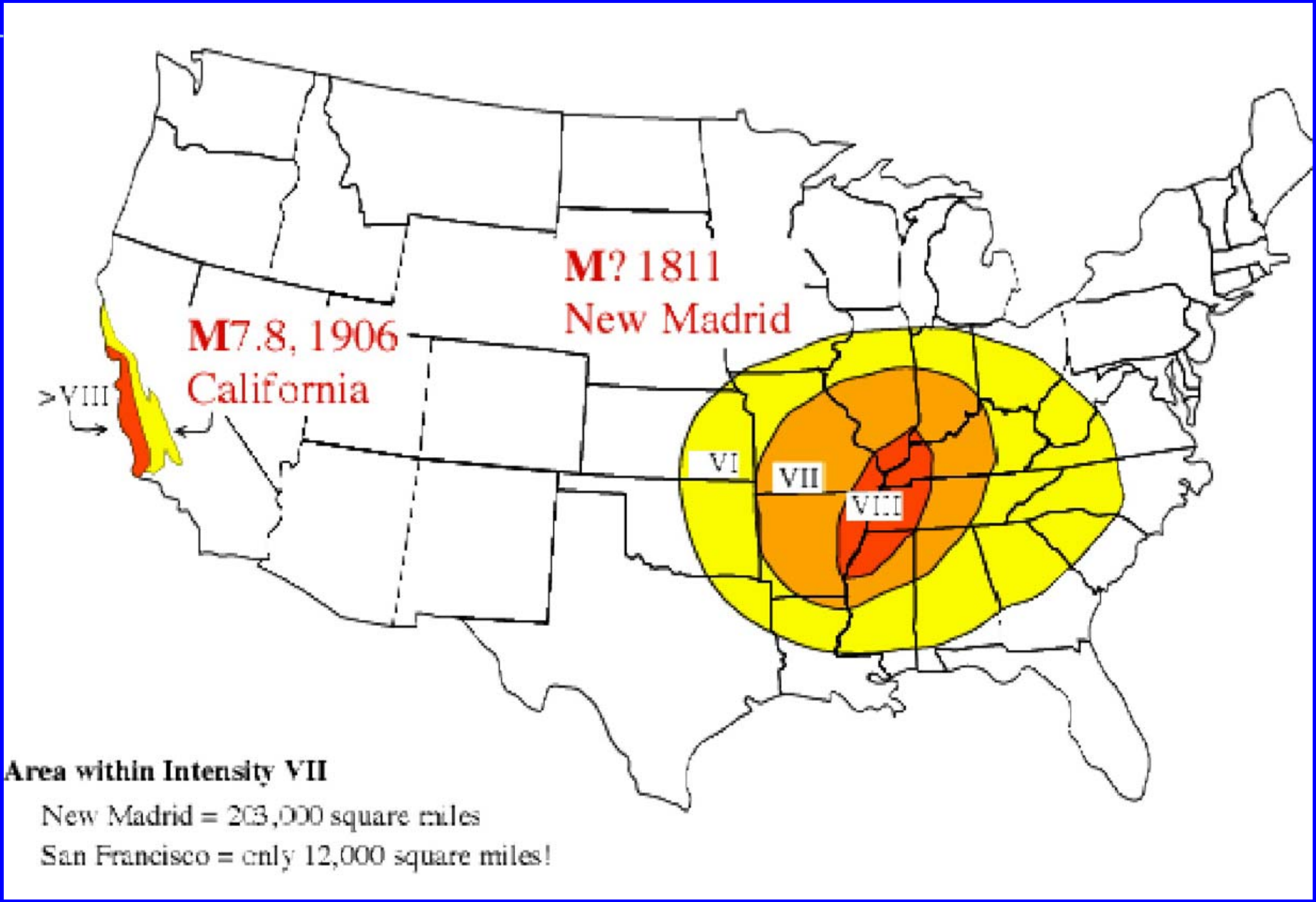
New Madrid earthquake	911 (NYC)	Event	Hurricane (Katrina)
~M7.7	?	Size	Category V
~500	~10?	τ (years)	~100?
~10% in 50 years/0.2% in 1 year	99% in 50 years/10% in 1 year	Risk (probability)	~39% in 50 years/1% in 1 year
PGA/MMI/ PSA	Comm./ Medical/	Hazard at a specific site	Flood level/Wind speed
$X	$~trillion	Loss	$75billions
x (?)	y (~3,000)	Fatality	z (~1,600)

(14%/75yrs.) (99.9%/75yrs.) (53%/75yrs.)

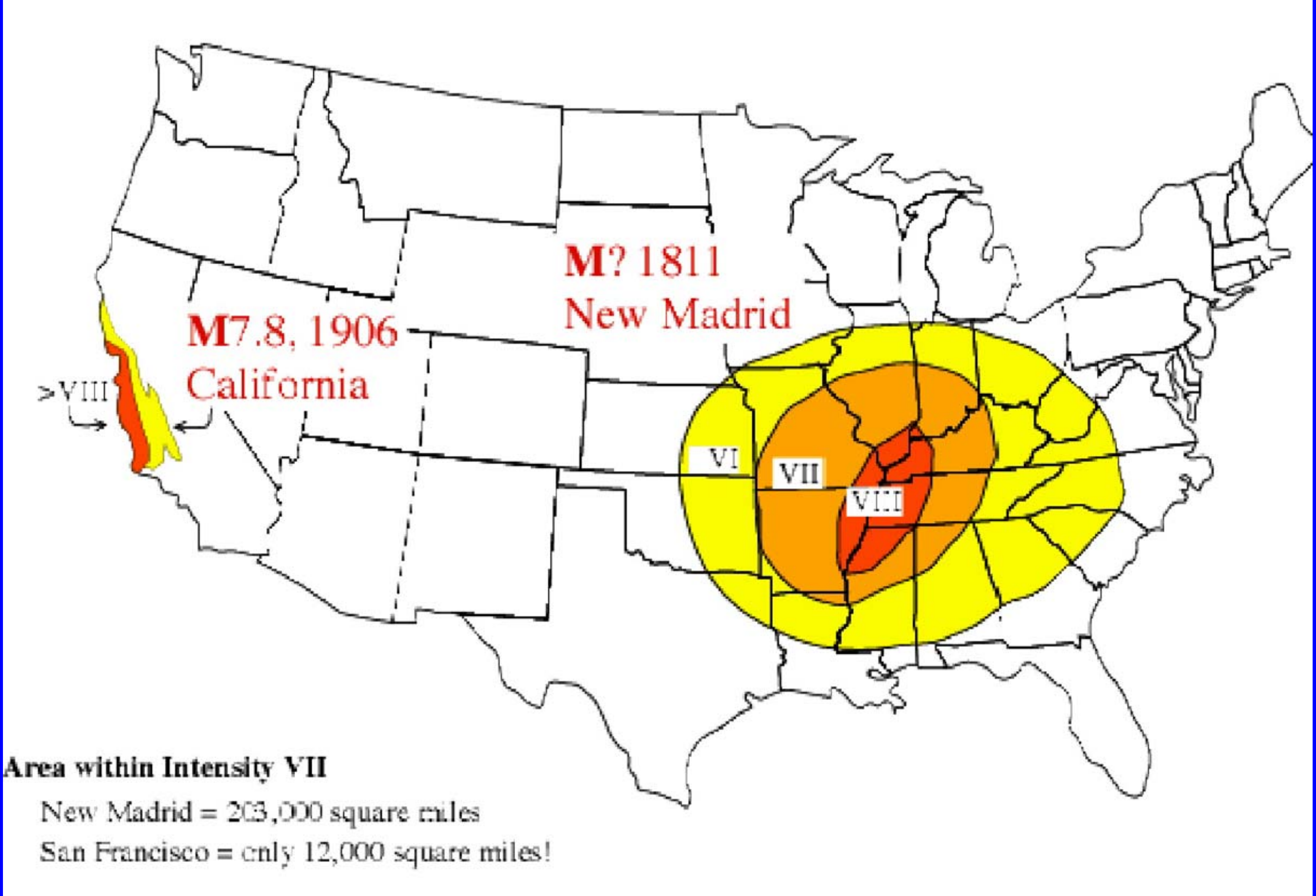
(different meanings for different users)



CUS has a higher seismic hazard?



California: ~100 years
New Madrid: ~500 years



Seismic Hazard:

CA: M7.8 /~100 years

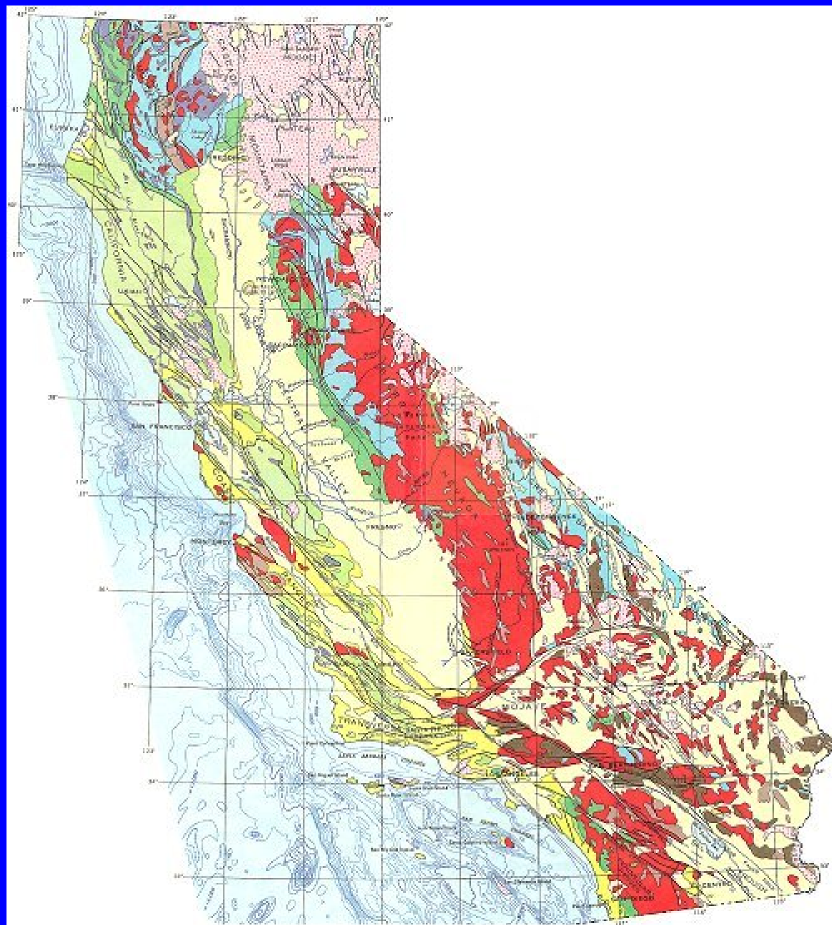
NM: M7.8/~500 years

If loss: $100B (same)

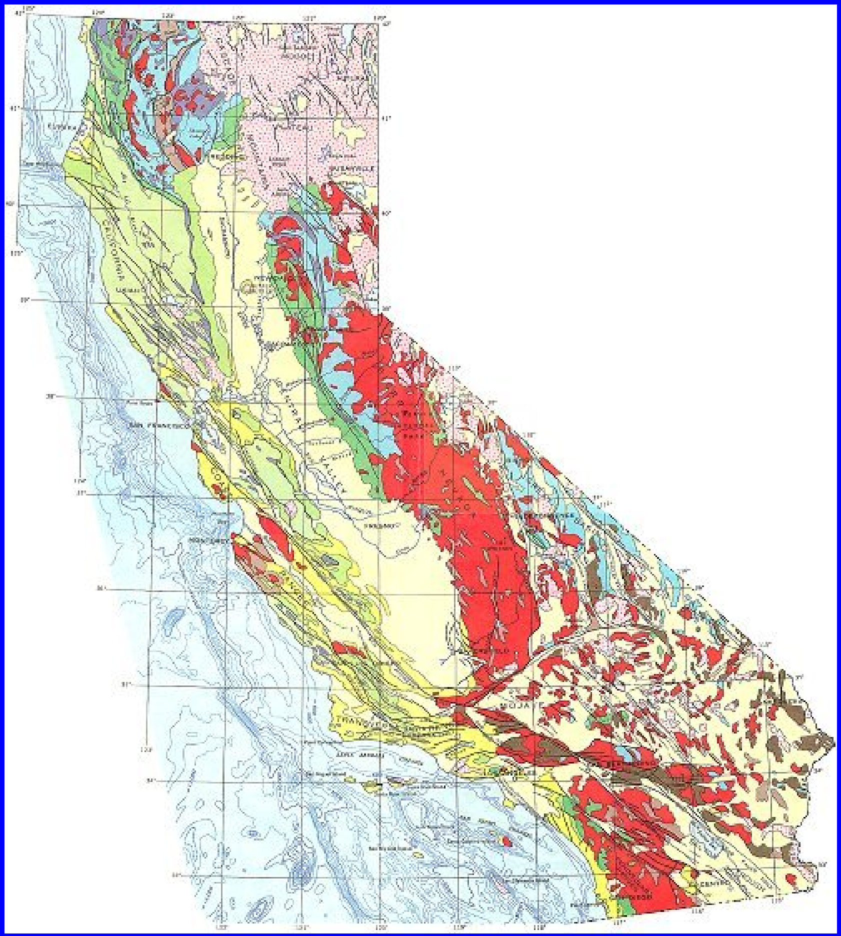
Seismic Risk:

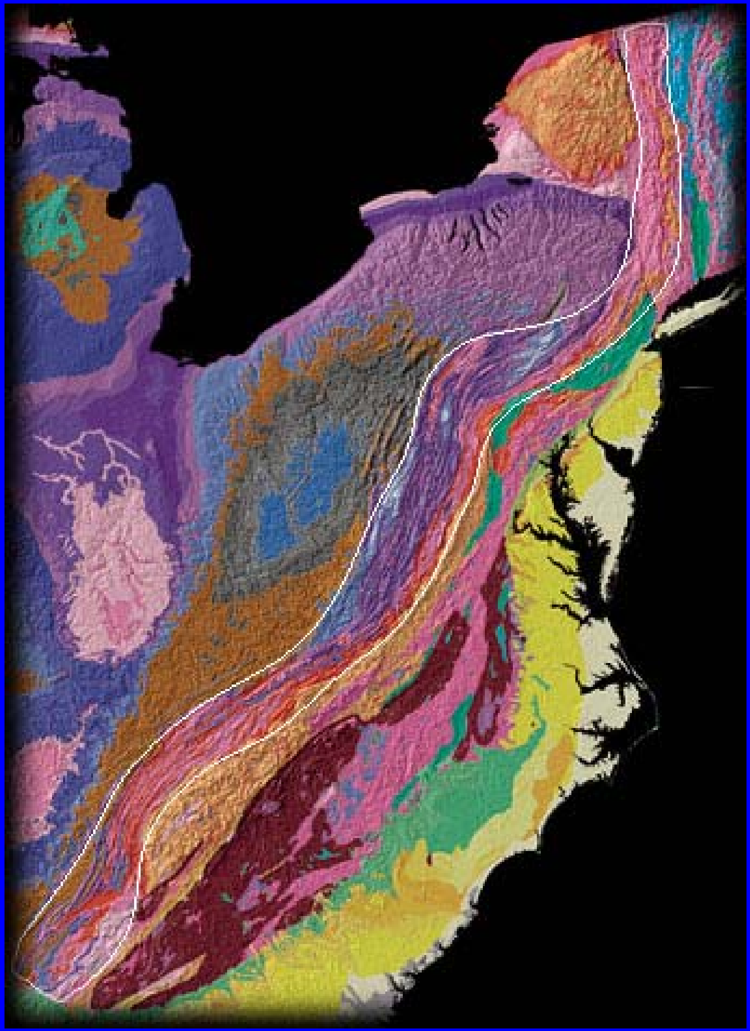
CA: M7.8 with 39% PE in 50 years

NM: M7.8 with 10% PE in 50 years



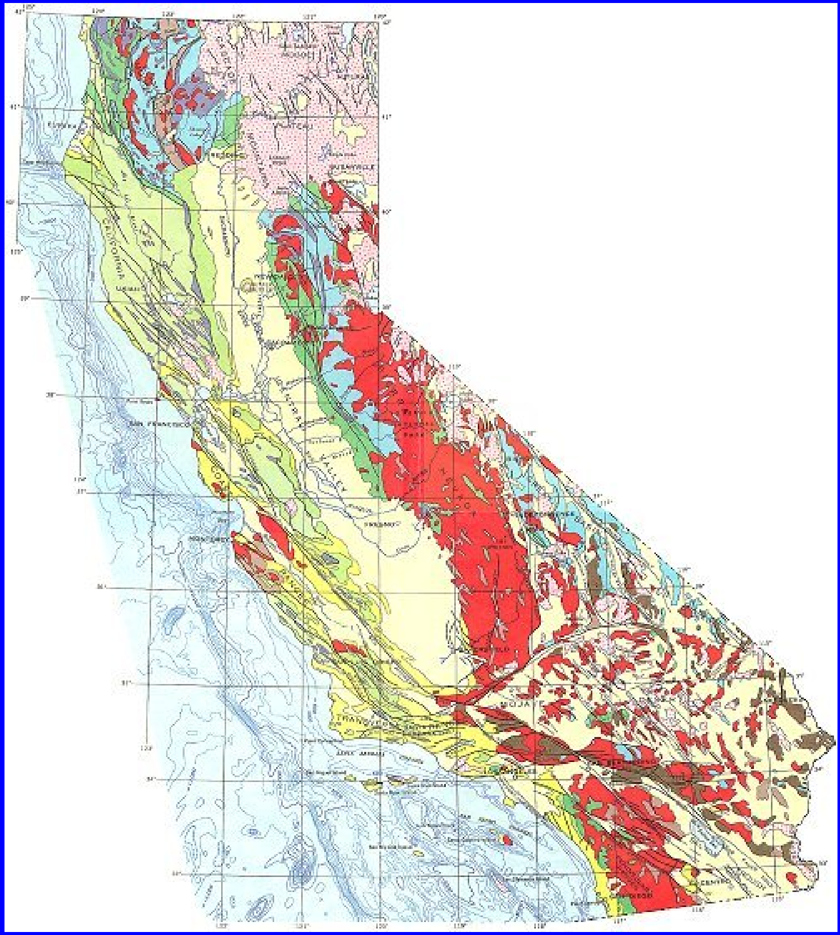
Appalachian Vs. San Andres
which has higher seismic hazard?



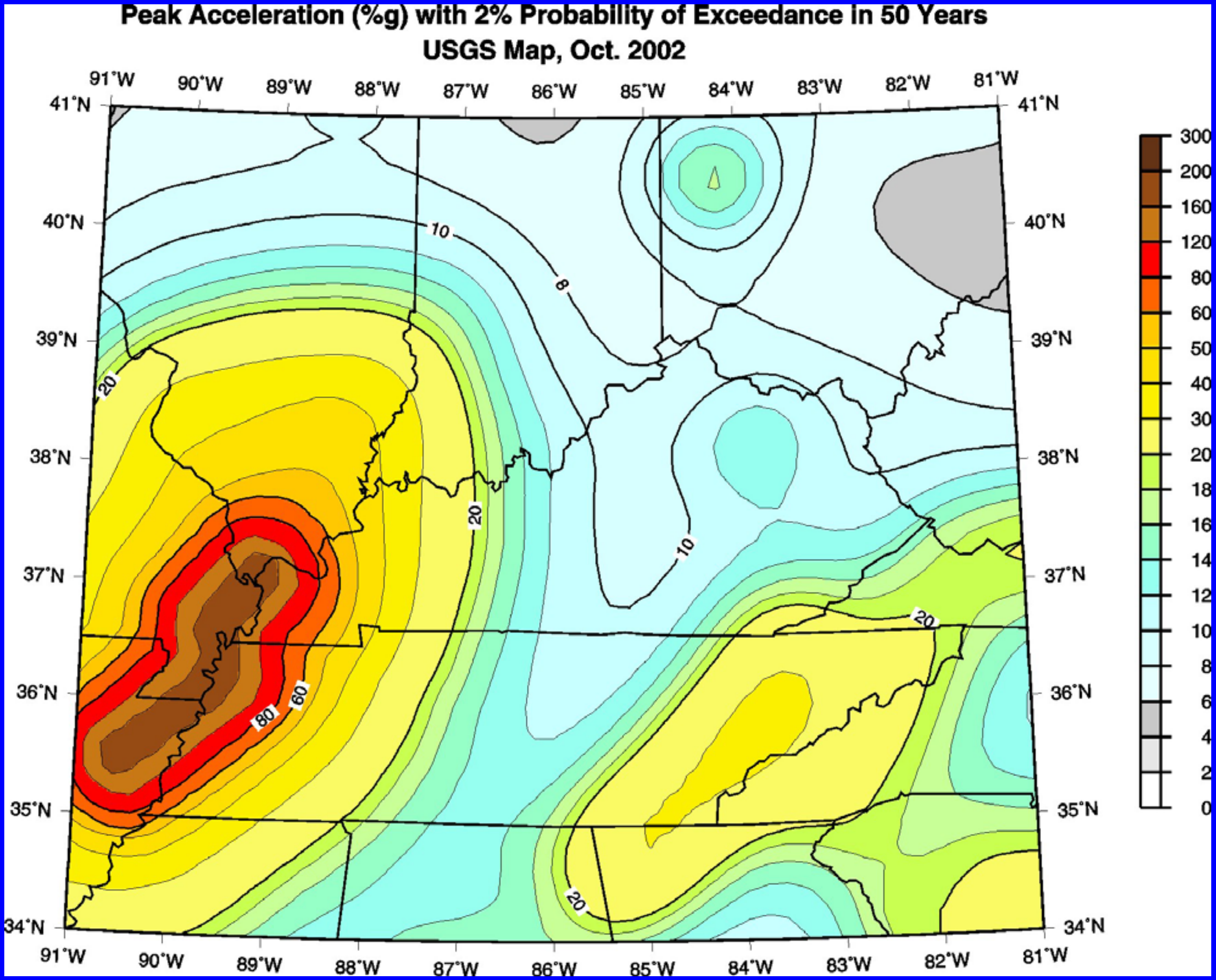


Appalachian Vs. San Andres:
which has higher seismic hazard?

Key Element: TIME (million vs. hundred)



Appalachian Vs. San Andres:
which has higher seismic hazard?
Seismic risk?: much higher for San Andres

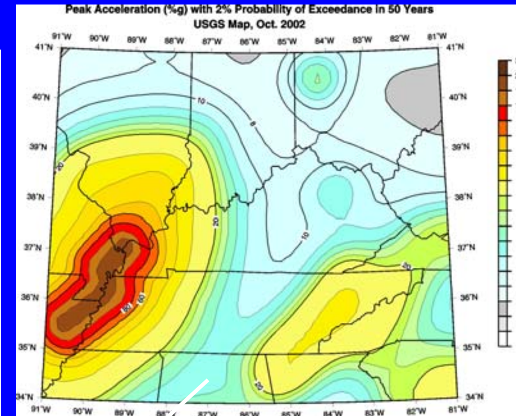


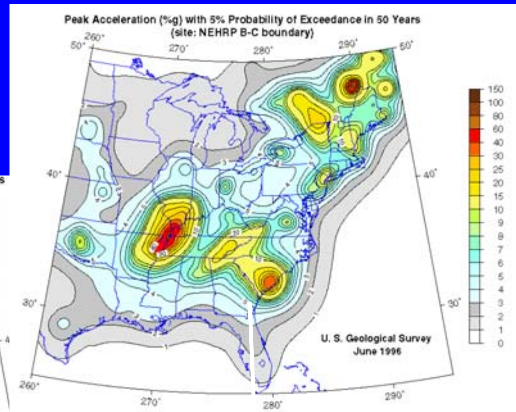
Problem #1:

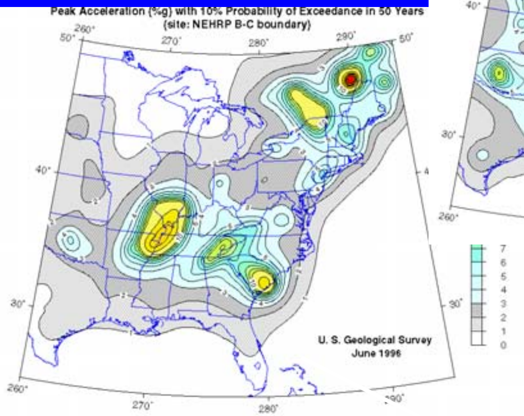
Is it a hazard or risk map?

By definition:
It is a risk map
(1)Poisson model
(2)General building Exposure (50 yrs)

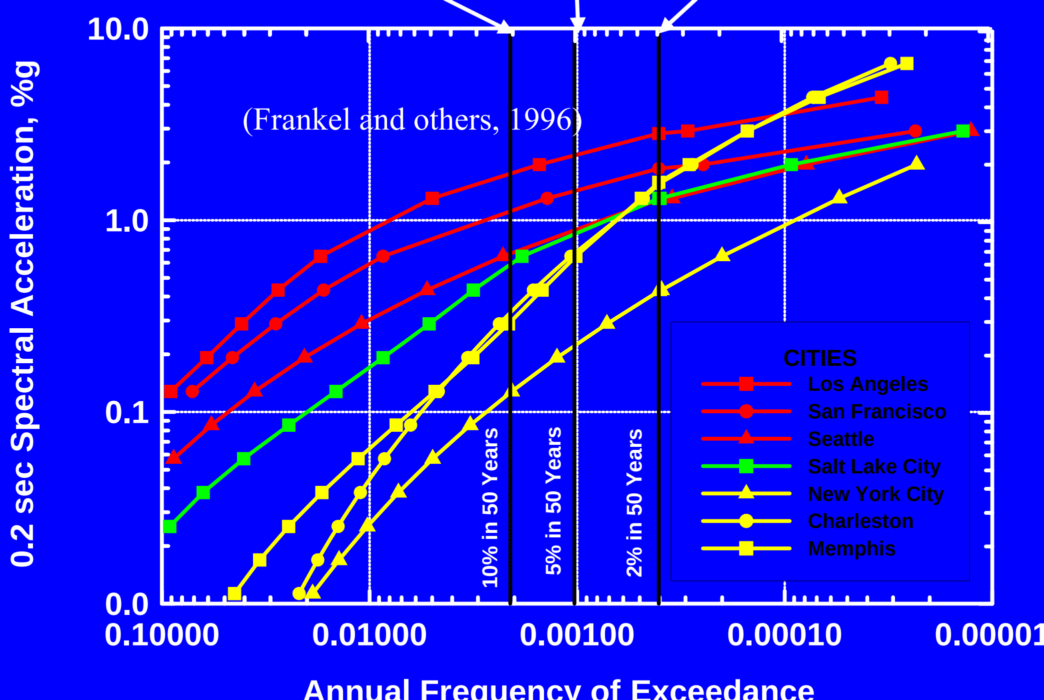
But: It has been Called as hazard map







HAZARD CURVES FOR SELECTED CITIES

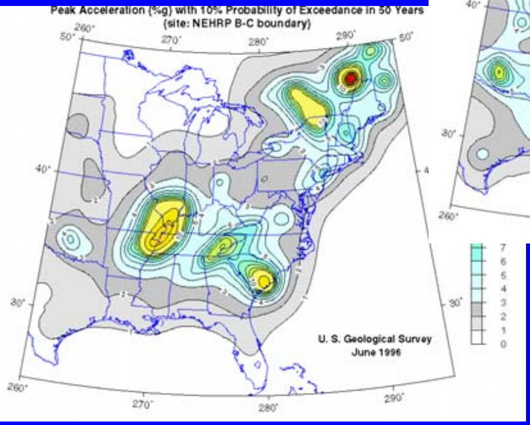


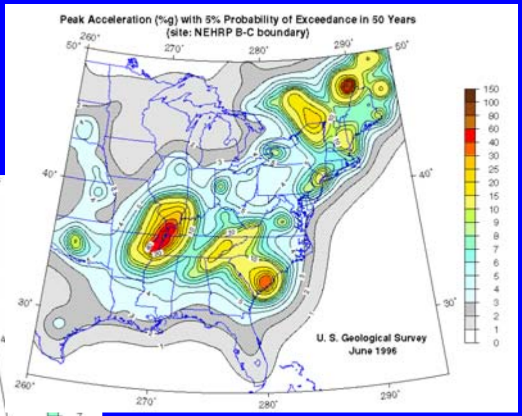
Probelm #2:

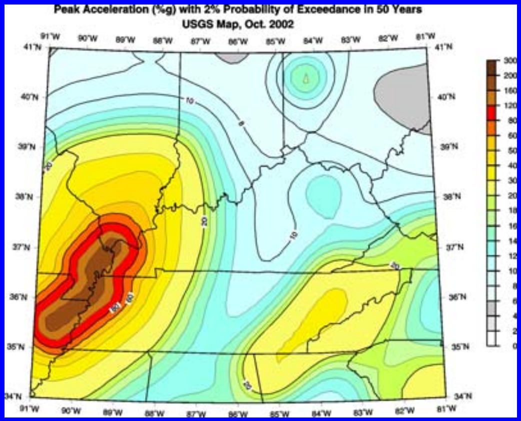
The national NEHRP mapping products are:

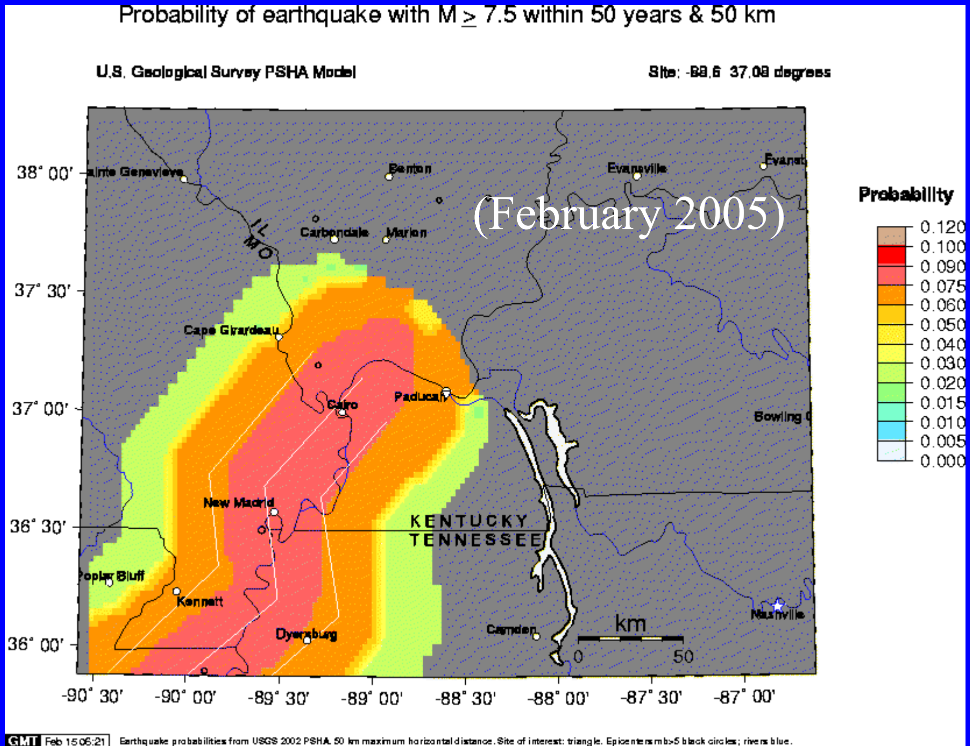
Hazard Curves

Or infinite maps







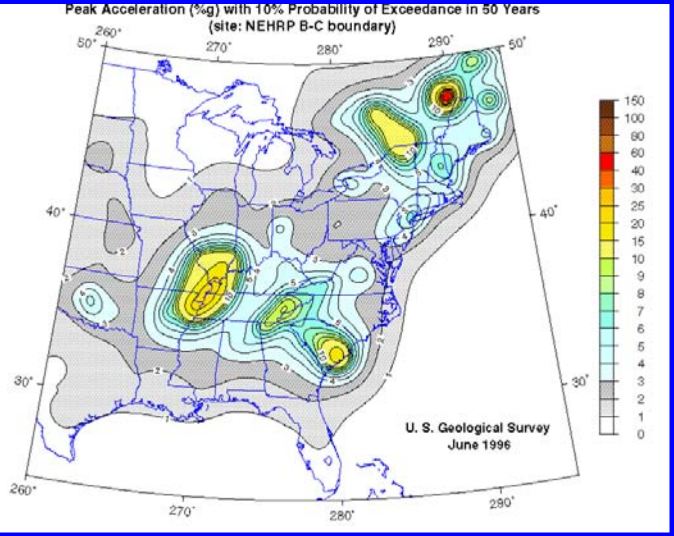


Problem #3:

10% PE in 50 years for earthquake (M7.5 or greater)

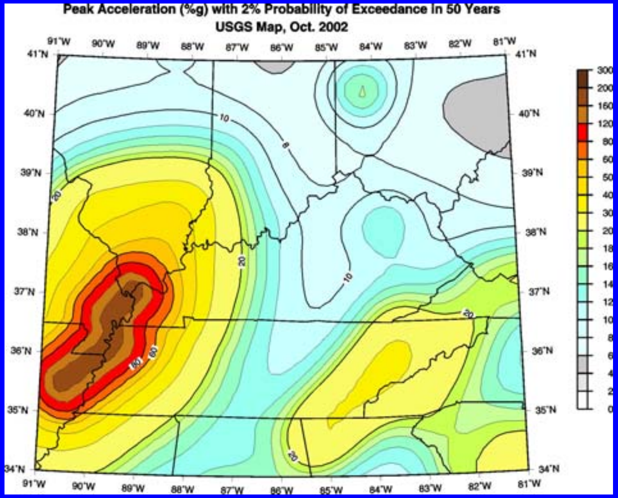
But there are 10, 5, 2,…, % PE in 50 years for ground motion for the Same earthquake

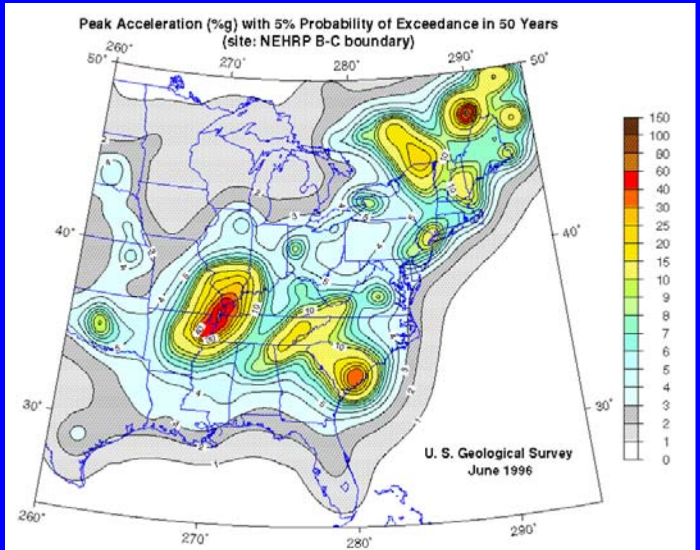
These problems result in difficulty in selecting a hazard level or risk for mitigation



(Memphis)

(Others)





(Kentucky and ASSHTO)

Conclusions

- Seismic Risk ≠ Seismic Hazard
  - Seismic Risk has three elements: probability, hazard level (earthquake with certain magnitude or ground motion generated by the earthquake), and exposure (life of buildings or other structures), is broad and subjective
  - Seismic Hazard is natural phenomena and has two elements: earthquake with certain magnitude or its effects (such as ground motions, generated by the earthquake) (how big) and its recurrence interval (how often)

Conclusions

- Seismic Hazard and Risk Comparisons between CA and CEUS show that
  - CEUS has lower seismic risk than CA
  - It does not make sense that Paducah has higher design ground motion than San Francisco
  - The difficulty in formulating mitigation policies is, at least in part, resulted from the problems in
    - How seismic hazard and risk are being defined
    - How them are being communicated and understood

Conclusions

- Geologists and Seismologists have to
  - Characterize Seismic Hazard and Risk clearly
  - And also communicate Seismic Hazard and Risk clearly

Thank You!