Summary of USGS-KGS Meeting on Seismic Hazard Assessment in Western Kentucky

Compiled by Zhenming Wang

The U.S. Geological Survey national seismic hazard maps with 2 percent probability of exceedance (PE) in 50 years have been adopted as the preferred level for seismic safety regulations and design standards by Federal agencies such as the Federal Emergency Management Agency (FEMA), Environmental Protection Agency, Department of Energy, and Nuclear Regulatory Commission, as well as the American Association of State Highway and Transportation Officials, and became policy in their regulations. These maps predict very high ground motion in many counties in western Kentucky: peak ground acceleration (PGA) of 1.0 g or higher. This high ground-motion estimate has resulted in many problems in seismic safety regulation and design, and has affected everything in western Kentucky from building a single-family home to environmental clean-up at the superfund site of the Paducah Gaseous Diffusion Plant. For example, it would not be feasible for the U.S. Department of Energy to obtain a permit from Federal and State regulators to construct a landfill at a facility near Paducah if the USGS 2 percent PE in 50 years maps are used. The Structural Engineers Association of Kentucky also found that if the International Residential Code of 2000, which was based on the USGS maps, is adopted in Kentucky, constructing residential structures in westernmost Kentucky would be impossible without enlisting a design professional.

State and local governments and elected officials had asked the Kentucky Geological Survey to help them better understand seismic hazards, as well as geology and seismology in Kentucky, western Kentucky in particular. KGS had difficulty understanding why the USGS hazard maps predicted such high ground motion for western Kentucky; they had even more difficulty explaining the maps to users and policy-makers. Therefore, KGS has conducted research and asked the USGS for help. As a result, KGS Director Jim Cobb was invited to make a presentation at the USGS Science Earthquake Studies Advisory Committee meeting on June 3, 2004, in Memphis, Tenn. (Cobb, 2004). As a result of this presentation and subsequent discussions, a meeting was held in Lexington, Ky., on November 4, 2004, with representatives from KGS and USGS. This meeting, summarized in this publication, is part of the KGS effort to better understand and communicate the hazard maps to the public, decision-makers, and the engineering community, and to make these groups aware of the risk and decisions that may need to be made.

Attendees

USGS Staff:

Chris Cramer

Mark Petersen

Buddy Schweig

KGS Staff:

Jim Cobb

John Kiefer

Mike Lynch

Baoping Shi

Zhenming Wang

Ed Woolery

Other Attendees:

Lindell Ormsbee and Steve Hampson, both from the Kentucky Water Resources Research Institute at the University of Kentucky, also attended part of the meeting. Ormsbee is leading a research group dealing with the Paducah Superfund cleanup project funded by the U.S. Department of Energy. Seismic safety is one of the main concerns for that project.

Introduction:

Jim Cobb

Cobb welcomed everyone to the meeting, and opened the discussion by reiterating the problems KGS is having with the USGS 2 percent in 50 years maps. He noted that in meetings with Director Chip Groat and Geologic Division Chief Pat Leahy of the U.S. Geological Survey, it was repeatedly stated that "USGS does not set policy: but we create the maps." Unfortunately, the lines between setting policy and making maps have been blurred, and clarification is needed. Once the maps are adopted in the building codes, they become public policy, and help is needed to translate these maps to decision-makers, the public, and even to architects and engineers. With the 2 percent PE in 50 years map in print, readily available on the USGS Web site, and incorporated into the International Building Code and the International Residential Code, USGS's help is needed to explain the maps, if there are alternatives, and what these alternatives might be.

USGS Seismic Hazard Mapping in the Central United States:

Mark Petersen

Petersen gave a presentation on the development of the National Hazard Maps of 1996 and the 2002 update (Frankel and others, 1996, 2002). The maps were the result of 12 regional workshops, external review panels, open review of interim maps on the Internet, and three user-needs workshops. He noted that the maps are for an average hazard estimate and not a worst-case scenario. The USGS mappers used alternative attenuation relationships, fault models, and uncertainty estimates published in 2002. The Building Seismic Safety Commission (BSSC) determined the parameters to use for the design maps; i.e., 2 percent PE in 50 years. These parameters are average, although choosing this particular map is an engineering decision. It is an average map for the 2 percent probability of a particular ground motion's occurrence. Provisions of the National Earthquake Hazards Reduction Program (BSSC, 1998, 2001, 2004) were used as the basis for the American Society of Civil Engineers Suggested Standard 7 and the International Building Code. The National Hazard Maps are to be revised and released in 2007.

The tentative schedule for completing the 2007 maps is:

1. October 2005: Attenuation relation workshop
2. May 2006: Central United States workshop
3. Summer/fall 2006: External review panel and Applied Technology Council workshops
4. December 2006: First draft of maps on Web
5. June 2007: Final maps released.

By 2009 the maps are expected to be implemented in the International Building Code. Although these workshops would be open for comment, none of them will discuss the 2 percent in 50 years choice. That would be done at a BSSC workshop.

Next, Petersen reviewed the methodology of probabilistic seismic hazard analysis (PSHA).

The following steps are taken to calculate seismic hazard:

1. Determine the magnitude **m** and the distance **d** of an earthquake.
2. Calculate the ground-motion distribution for that **m** and **d.**
3. Calculate the hazard (annual probability of exceedance) that a particular ground motion will be exceeded for that earthquake.
4. Sum individual hazards for all expected earthquakes in the region to obtain the total hazard for that ground-motion level. (The total hazard curve is obtained by repeating steps 3 and 4 for a series of ground motions.)

Petersen worked through several examples of how to calculate the seismic hazard for a background earthquake of M6.5 with a recurrence time of 50 years at a distance of 15 km from the epicenter, and for a characteristic earthquake of M7.7 with a recurrence time of 250 years at a distance of 20 km from the epicenter. He explained how different sources could have an impact on the hazard calculations. He also showed the probability calculation and explained the meaning of ground motion with 10 percent PE in 50 years: there is a 10 percent probability of that ground motion or greater occurring in 50 years.

He also reviewed the concept behind deaggregation (a method based on the relative input of various sources) and showed the deaggregated results for Paducah. All the earthquakes used and contributing to the deaggregation can be obtained from the USGS Web site. Petersen then quickly went through models and graphs on M7.7 firm-rock attenuation relations. He presented a chart of scenario and design values for Memphis at firm-rock site conditions.

Petersen called the maps "average hazard estimates, not worst case." He indicated that the insurance industry uses these maps for rate-setting purposes. His comments prompted several in the audience to ask whether local officials knew that these maps are the average hazard estimates, not the worst case.

Petersen was asked whether the 2 percent PE in 50 years hazard is too conservative a choice, and if mapping of the 2 percent PE in 50 years is too conservative or too liberal. Petersen answered that engineers develop building codes, and the choice of 2 percent PE in 50 years is consistent with the nationwide design procedures put together by the Building Seismic Safety Council. Everyone agreed that the range of uncertainty among the ground-motion estimates is large and adds to the complexity of the problem.

Petersen also discussed performance goals and explained why 2 percent PE in 50 years was selected by the Building Seismic Safety Council:

collapse resistance $\geq$ collapse load

collapse resistance $\geq$ 1.5 x typical code resistance

collapse load = 2 percent PE in 50 years ground motion

1.5 x typical code resistance $\geq$ collapse load

typical code resistance $\geq$ 1/1.5 (2/3) x collapse load

A deterministic cap (1.5 x median ground motion) is being applied for some areas, such as California.

A discussion followed of just what the building codes really mean. John Kiefer noted that, in general, building codes are set for a minimum level to protect lives and prevent total collapse, not for a worst-case situation. In using the 2 percent PE in 50 years, however, we are looking at a very conservative value that, although not worst case, is approaching worst case. This is a somewhat contradictory position, but discussing it was considered beyond the scope of the meeting.

Petersen's presentation is included as Appendix A.

Some Issues in Seismic Hazard Assessment in Kentucky:

Zhenming Wang

Wang summarized the KGS approach to seismic hazard and risk assessment. KGS strongly believes that any decision should be based on good scientific research. The KGS staff has conducted a detailed analysis of the methodology and input parameters used in the 1996 and 2002 National Seismic Hazard Maps and communicated its findings to USGS in an e-mail from Wang, Ed Woolery, and Baoping Shi to Art Frankel, and in Wang (2002, 2003) and Wang and others (2003a, b). KGS has also communicated with Federal, State, and local government officials, professional organizations, and other institutions. Wang discussed the uncertainties in occurrence frequency, source location, and attenuation relation in the New Madrid Seismic Zone and made some comparisons with California.

Through research and communication, KGS has gained a better understanding of the methodology, input parameters used, and products of the 1996 and 2002 National Seismic Hazard Maps. Two specific sets of parameters—the location of the northern arm of the New Madrid Seismic Zone and the ground-motion attenuation relationship—that have a controlling effect on seismic hazard assessments for western Kentucky were identified. KGS, in cooperation with the University of Kentucky Department of Geological Sciences, operates a dense seismic network in western Kentucky to better constrain the arm of the New Madrid Seismic Zone and its eastern extent. KGS is also conducting research on ground-motion attenuation using a composite model and strong-motion data recorded from recent moderate earthquakes (M4 to 5).

Wang stressed the need to communicate the proper information to public policy-makers and to communicate the choices they can make based on a clear understanding of the science and the actual risk they face. For example, the ground motion with 2 percent PE in 50 years in Paducah is equivalent to the ground motion with an 80 percent confidence level from a characteristic earthquake of M7.7 in the New Madrid Seismic Zone. Additional use of 10, 5, and 2 percent PE in 50 years causes more problems in communication of seismic hazard.

Chris Cramer brought out the fact that the scarcity of data is one of the major problems we face in constructing the National Hazard Maps for the entire eastern United States. Also discussed was the uncertainty in ground-motion attenuation. Cramer also pointed out that there are other uncertainties that play into the calculation of each of the curves, increasing the total uncertainty even more.

Wang's presentation is included as Appendix B.

Discussion

Issues on Communication of the USGS Hazard Maps

Everyone agreed that how to communicate the seismic hazard assessment to the users and policy-makers is the biggest challenge. Probabilistic seismic hazard mapping is a confusing topic, since most people have difficulty understanding statistics.

Petersen noted that if the public and public policy-makers are shown all the data, including the data's uncertainty, they will simply be more confused. Use of 2 percent PE in 50 years adds another layer of confusion in communication. As Petersen and Wang demonstrated in their presentations for the New Madrid Seismic Zone, the meaning of the ground motion with 2 percent PE in 50 years is a ground motion with about an 80 percent chance of not being exceeded if a characteristic earthquake of M7.7 occurs. The meaning that has been communicated, however, is that there is a 2 percent probability of this ground motion or greater occurring one or more times in 50 years.

Petersen also noted that USGS wants to do a better job of communicating the hazard products and stated that USGS is revising its seismic hazard Web site and will welcome any comments or suggestions.

Wang pointed out that users and policy-makers need simple and understandable numbers: a level of ground motion and the associated confidence level (uncertainty). This was echoed by Mike Lynch. Lynch has first-hand experience of the difficulty in communicating seismic hazard to the general public and policy-makers.

Wang suggested that the USGS maps may need to incorporate those simple numbers, especially for the New Madrid area. Peterson thought this might be an effective way to communicate with the Kentucky end-users.

Issues Related to Kentucky Hazard Assessment

The Sources—Northern Boundary and Magnitudes of the New Madrid Seismic Zone. The actual location of the New Madrid Seismic Zone was discussed, and the KGS group emphasized that there is considerable question as to whether the New Madrid Seismic Zone actually extends into Kentucky at all, much less all the way to Paducah. Based on some very preliminary information from several recent earthquakes, their shallowness, and the nature of their signals, it would seem that the earthquakes in far western Kentucky are different from those in the New Madrid Seismic Zone and may represent an entirely different source.

The USGS group said that since all KGS had is a couple of earthquakes, such an assumption cannot be made on that basis. Cramer brought up a figure in Wang and others (2003a; Fig. 1) that shows seismicity, and commented on the uncertainty and problems with extending the seismicity to the north. There is a lot of seismicity to the north, but it is scattered, and a case can be made for extending the zone to the northeast or to the northwest. If it is extended to the northeast, how far, and in exactly what alignment? KGS agreed with Cramer, but again noted that the trend was different and could have a significant impact on directivity of ground motions. Woolery and Wang both pointed out that several studies, most of them by USGS staff (e.g., Hildenbrand and others, 1996; Harrison and Schultz, 2002), show northwest-trending structures and seismicity. Cobb noted that if the ground-motion contours are overlaid, the selection of a source is made even more complex. Shifting the alignment a small amount one direction or another makes a huge difference in where the ground-motion contours fall. All choices have a huge degree of uncertainty.

Everyone agreed that there is large uncertainty in where the northern extension of the New Madrid Seismic Zone falls. This should be one of the projects that USGS and KGS work on together.

The Attenuation Relationships. There are at least 13 ground-motion attenuation relationships for the central and eastern United States. All were developed from theoretical models, with or without the limited records from the few moderate to strong earthquakes that have occurred in the area. There are large differences in median ground motion and its standard deviation among these models, especially at near source (less than 50 km).

Wang said that the inherent uncertainties in the attenuation relationships make the hazard assessment even more complicated (uncertain). Shi announced that he had been working on attenuation relationship using a composite model.

Everyone also agreed that the ground-motion attenuation relationships have large uncertainty and that this is another important issue that needs to be addressed. Not only is it important for the hazard assessment for western Kentucky, but also for the national hazard mapping in the central and eastern United States, where real data are severely lacking.

Other Related Discussions. Petersen stated: "Paducah is always going to have a hazard and you might bump it up a little or down a little, but it will always have some significant level of hazard and maybe you need to move the plant to some other area in Kentucky." It was pointed out that the plant is already there and that the landfill really needs to be constructed near the plant. The reason Paducah was considered for a new $2 billion plant in the first place was because the old plant was already there.

Wang said that KGS also thinks there is an existing seismic hazard in western Kentucky because of its proximity to the New Madrid Seismic Zone. But the question is, how high is the seismic hazard and what level of hazard should be considered for mitigation and safety?

Petersen said that State or local jurisdictions in Kentucky should be able to select any level of hazard for their considerations. Wang pointed out that there will be some consequences for the State or local jurisdictions if they do so. This issue came up during the adoption and revision of the 2000 International Residential Code in Kentucky. Kentucky adopted IRC-2000, and it became KRC-2002 (Kentucky Residential Code). KRC-2002 was proposed to be implemented in January 2002, but implementation was suspended because of the severe problems it would cause in western Kentucky, especially in Paducah, where the code would require a site-specific study and structural design for all family homes. KGS worked with the Kentucky

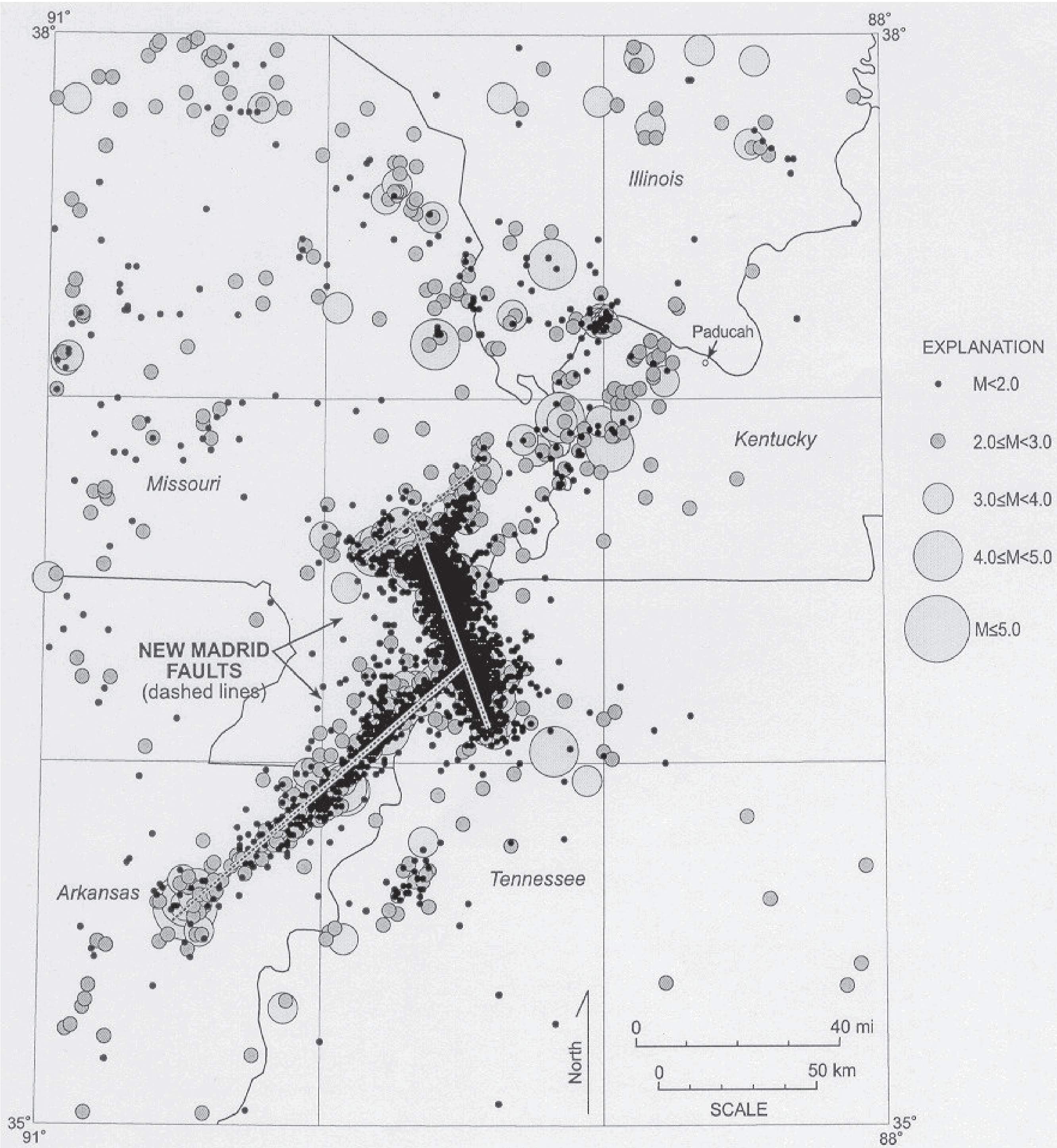

Figure 1. Locations of earthquakes in the central United States since 1974 (from the Center for Earthquake Research and Information).

Department of Housing, the Structural Engineers Association of Kentucky, the Home Builders Association of Kentucky, and others and recommended several hazard maps, including one produced by KGS in 1991 and the 1996 USGS hazard maps with 5 percent PE in 50 years. Many concerns were raised by Federal agencies (including FEMA) and private industries about using the maps recommended by KGS. The 1996 USGS hazard maps with 5 percent PE in 50 years were ultimately used because they were produced by a Federal agency (USGS). KRC-2002 has been implemented in Kentucky with the design ground motion for western Kentucky revised to that of the 1996 USGS hazard maps with 5 percent PE in 50 years.

Follow-Up Items

The following were discussed and agreed upon by both parties:

1. KGS will write a summary of the meeting based on the presentations given and the notes taken at the meeting. The summary will be sent to the USGS participants for their review and input. The final summary will be published by KGS.
2. KGS and the UK Department of Geological Sciences are conducting a seismic hazard assessment for the Paducah Gaseous Diffusion Plant. Cramer or Schweig will provide partial or overall review of the hazard assessment when it is done.
3. Because of the importance of the northern boundary of the New Madrid Seismic Zone, USGS and KGS will work together to conduct research and define that boundary as well as possible.
4. Ground-motion attenuation relationship is the other key issue for seismic hazard assessment for western Kentucky, as well as for seismic hazard assessment for the central United States. KGS will participate in the research and workshops organized by USGS as part of the planning and development process for the 2007 maps.
5. A joint KGS-USGS workshop in Paducah for engineers, contractors, planners, and decision-makers was discussed. It was agreed that although such a workshop was definitely worth doing, it needed to be carefully thought out or the participants would come away with the idea that everything was so uncertain that they might do just as well to ignore the science and just pick some numbers.

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Appendix A: Presentation by Mark Petersen

National Seismic Hazard Maps:

Issues for Kentucky

Mark Petersen

U.S. Geological Survey

http://eqhazmaps.usgs.gov

USGS
science for a changing world

USGS Seismic Hazard Maps (1996 and update in 2002)

- Consensus of experts: 12 regional workshops since 1994, external review panel, open review of interim maps on Internet, 3 user-needs workshops (w/ATC)
- Average hazard estimate, not worst case; used alternative attenuation relations, fault models, etc.; uncertainty estimates published in 1997, 2000, 2001

USGS science for a changing world

USGS Seismic Hazard Maps (1996 and update in 2002)

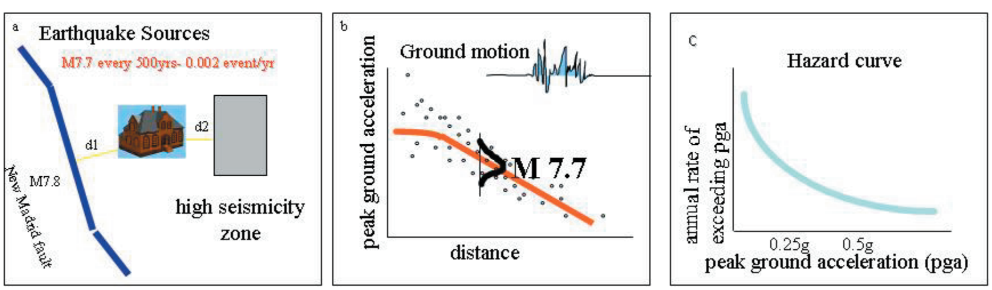
- Building Seismic Safety Council determined the parameters to use for design maps (e.g., 2% probability of exceedance in 50 years, 0.2 s SA)
- USGS applied parameters to maps for NEHRP Provisions
- NEHRP Provisions was used as the basis for ASCE7 standard and the IBC code
- ASCE7 is adopted by reference in the IBC and NFPA codes

USGS science for a changing world

USGS Seismic Hazard Maps (Tentative Update Schedule for 2007 Maps)

- October 2005: Attenuation relation workshop
- May 2006: CEUS workshop
- Summer/Fall 2006: External review panel, ATC workshops
- December 2006: First draft of maps on web
- June 2007: Final maps released
- 2009: Implemented in IBC 2009 code

PROBABILISTIC SEISMIC HAZARD METHODOLOGY



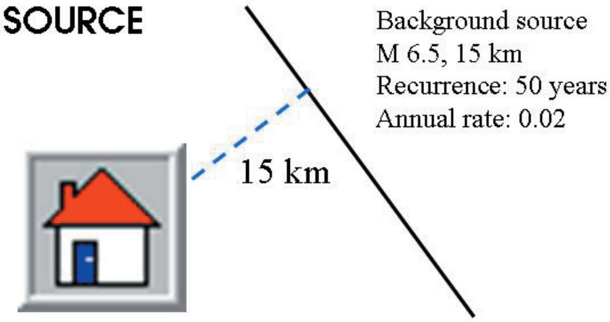
To calculate the hazard curve (annual rate of exceeding ground motions) :

1. Determine magnitude, m, and distance, d, of earthquake
2. Calculate ground motion distribution for that m and d.
3. Calculate the product:

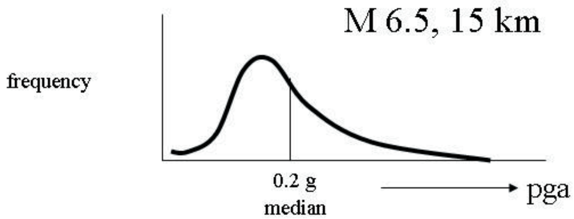
   annual rate of earthquake *probability that earthquake will exceed certain ground motion level

4. Sum these rates for all earthquakes in the model at each ground motion to get a hazard curve. This curve shows the rate of exceedance of each ground motion.

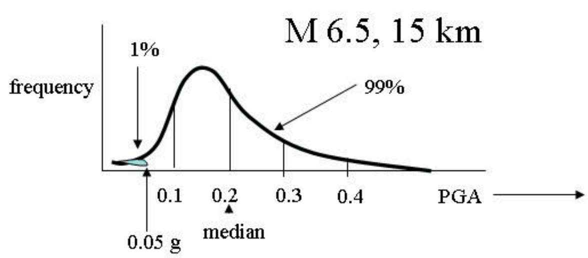
EARTHQUAKE SOURCE



GROUND MOTION



What is the annual rate that ground motion will exceed 0.05 g pga given M 6.5 earthquake occurs?

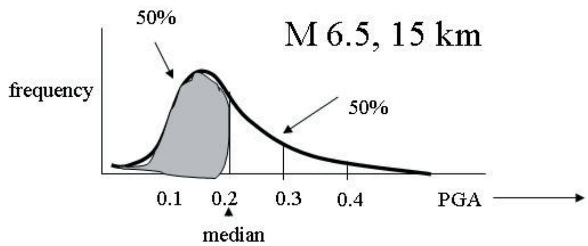


Almost all earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.05g

0.02 (ann. rate of M 6.5) * 0.99 (probability of exceeding 0.05) = 0.02

Ground motion:	0.05g
Rate of 0.05 g exceedance:	0.02

What is the annual rate that ground motion will exceed 0.2 g pga given M 6.5 earthquake occurs?

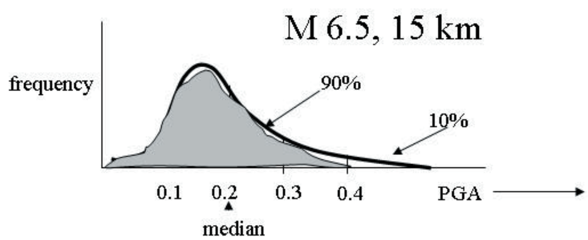


50% of earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.2 g

Rate of exceeding 0.2 g:
0.02 (ann. rate of M 6.5) * 0.5 (probability of exceeding 0.2) = 0.01

Ground motion:	0.05g	0.2g
Rate of 0.2 g exceedance:	0.02	0.01

What is the annual rate that ground motion will exceed 0.4 g pga given M 6.5 earthquake occurs?

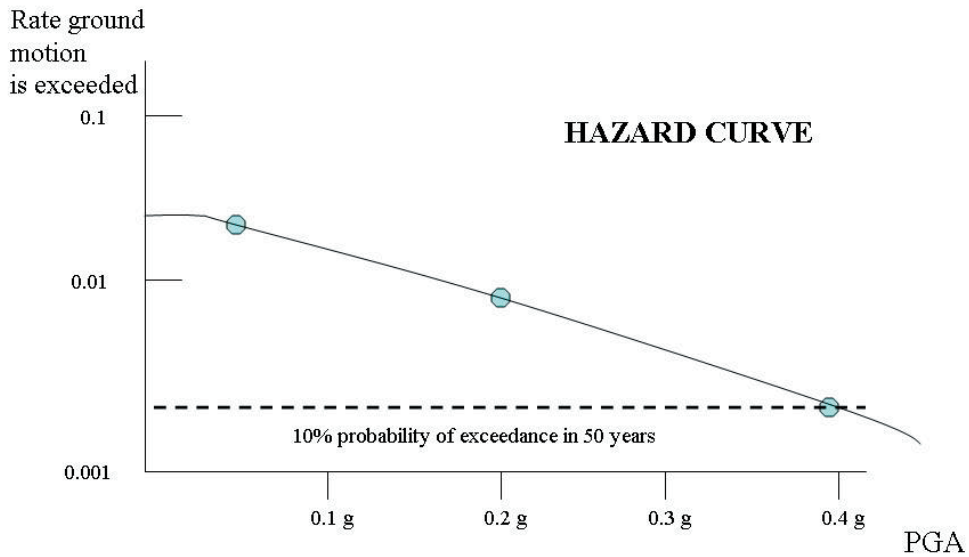


Only 10% of earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.4g

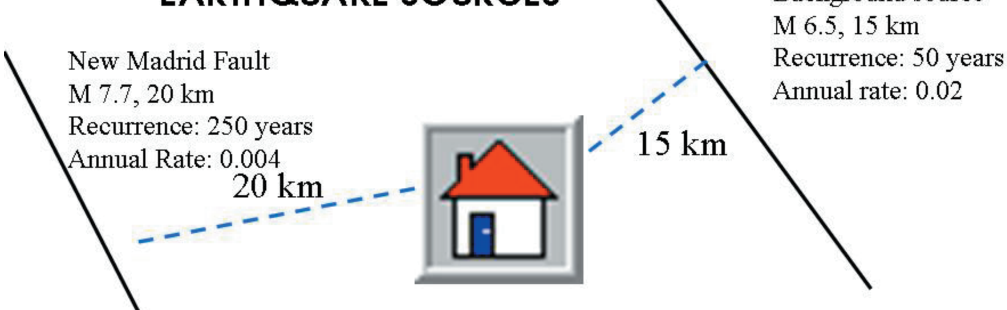
Rate of exceeding 0.4 g:
0.02 (ann. rate of M 6.5) * 0.1 (probability of exceeding 0.2) = 0.002

Ground motion:	0.05g	0.2g	0.4g
Rate of 0.4 g exceedance:	0.02	0.01	0.002

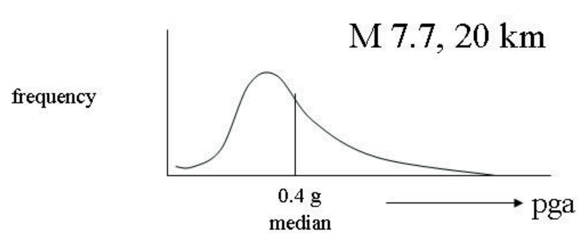
Ground motion:	**0.05g**	**0.2g**	**0.4g**
Rate of ground motion exceedance:	**0.02**	**0.01**	**0.002**



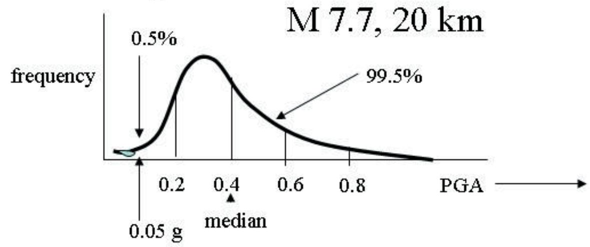
EARTHQUAKE SOURCES



GROUND MOTION



What is the annual rate that ground motion will exceed 0.05 g pga given M 6.5 and M 7.7 earthquake occurs?



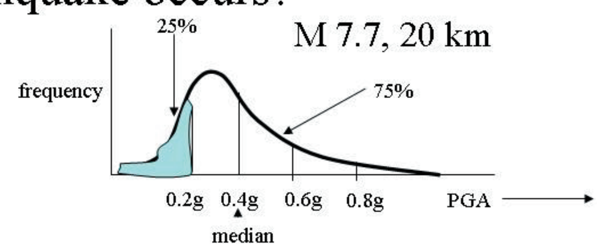
Almost all earthquakes M 7.7 at a distance of 20 km will cause ground motion that will exceed 0.05g

0.004 (ann. rate of M 6.5) * 0.995 (probability of exceeding 0.05) = 0.004

Ground motion:	0.05g
Rate of 0.05g exceedance:	0.02 + 0.004 = 0.024
	Fault 1 Fault 2

42 years

What is the annual rate that ground motion will not exceed 0.2 g pga given M 6.5 and M7.7 earthquake occurs?



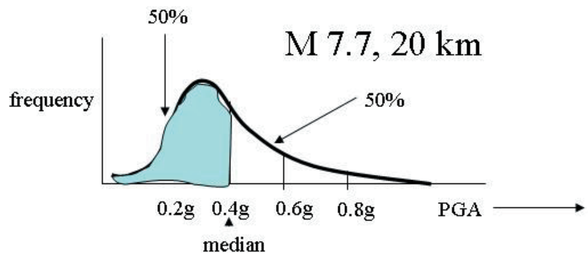
75% of earthquakes M 7.9 at a distance of 20 km will cause ground motion that will exceed 0.2g

0.004 (ann. rate of M 7.7) * 0.75 (probability of exceeding 0.2g) = 0.003

Ground motion:	0.2g
Rate of ground motion exceedance:	0.01 + 0.003 = 0.013
	Fault 1 Fault 2

77 years

What is the annual rate that ground motion will exceed 0.4 g pga given M 7.7 earthquake occurs?

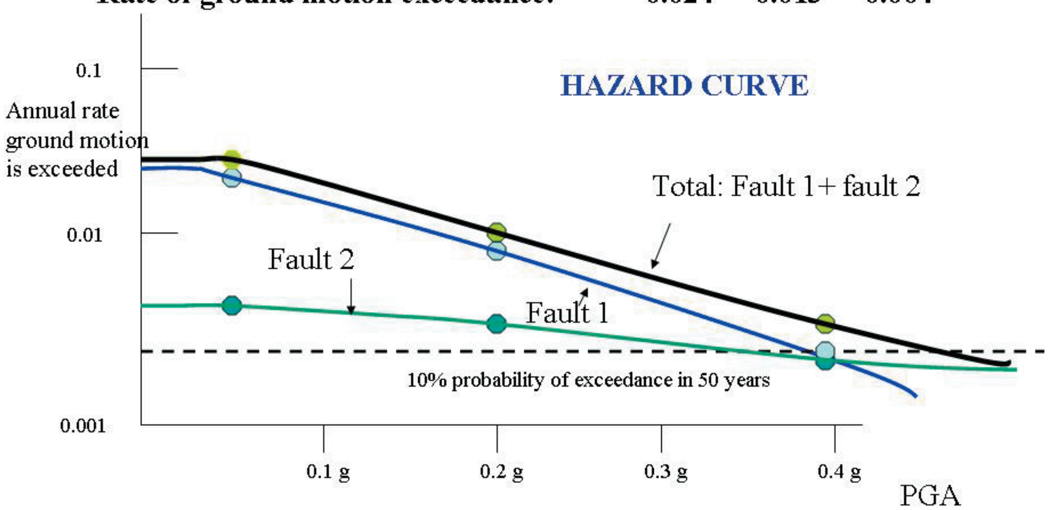


50% of earthquakes M 7.9 at a distance of 20 km will cause ground motion that will exceed 0.4g

0.004 (ann. rate of M 7.7) * 0.5 (probability of exceeding 0.4g) = 0.002

Ground motion:	0.4g
Rate of 0.4 g exceedance:	0.002 + 0.002 = 0.004
	Fault 1 Fault 2
	250 years

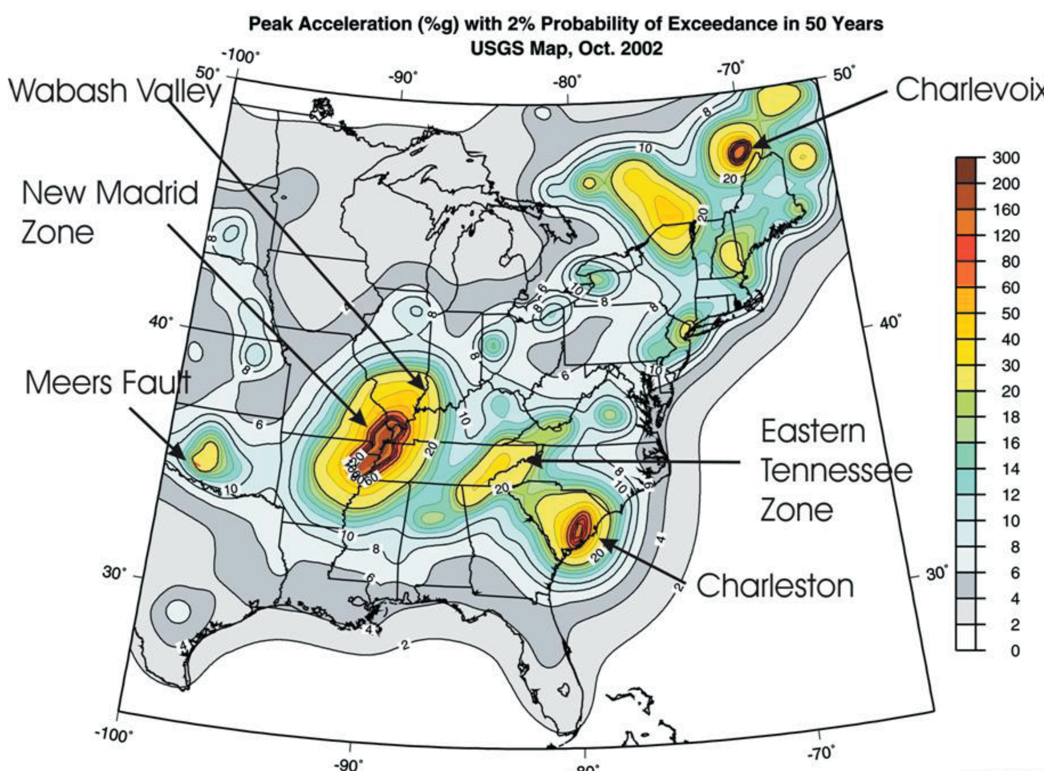
Ground motion:	**0.05g**	**0.2g**	**0.4g**
Fault 1	**0.02**	**0.01**	**0.002**
Fault 2	**0.004**	**0.003**	**0.002**
Rate of ground motion exceedance:	**0.024**	**0.013**	**0.004**

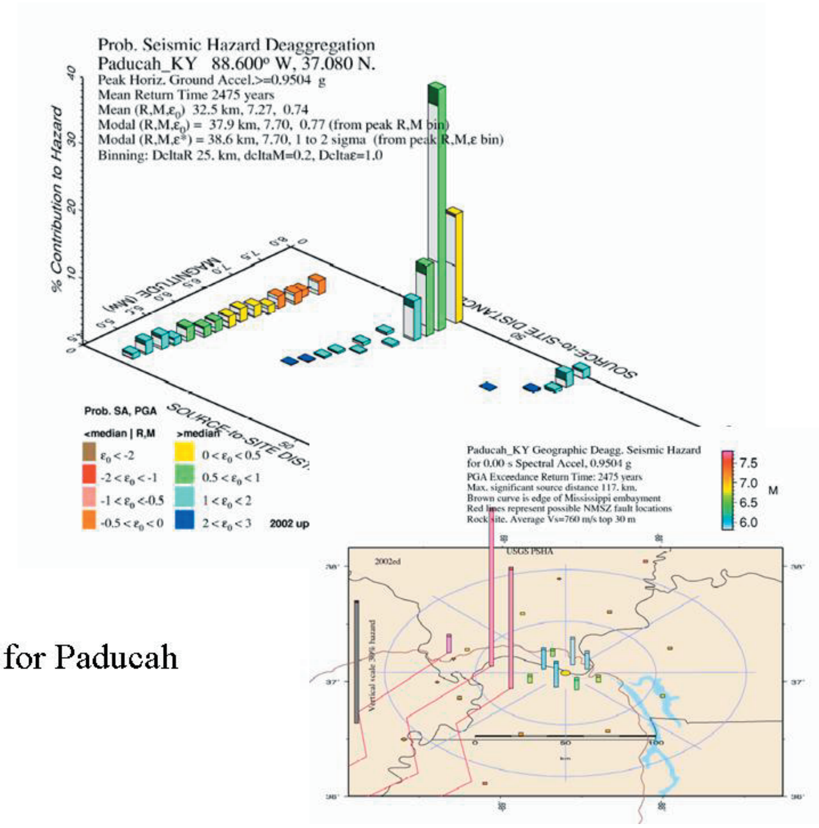


P=exp(-rate*time) probability of having no exceedances

P=1-exp(-rate*time) probability of having one or more exceedances

2002 National map hazard





Deaggregation for Paducah

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http://eqhazmaps.usgs.gov

Paducah Deaggregated Hazard

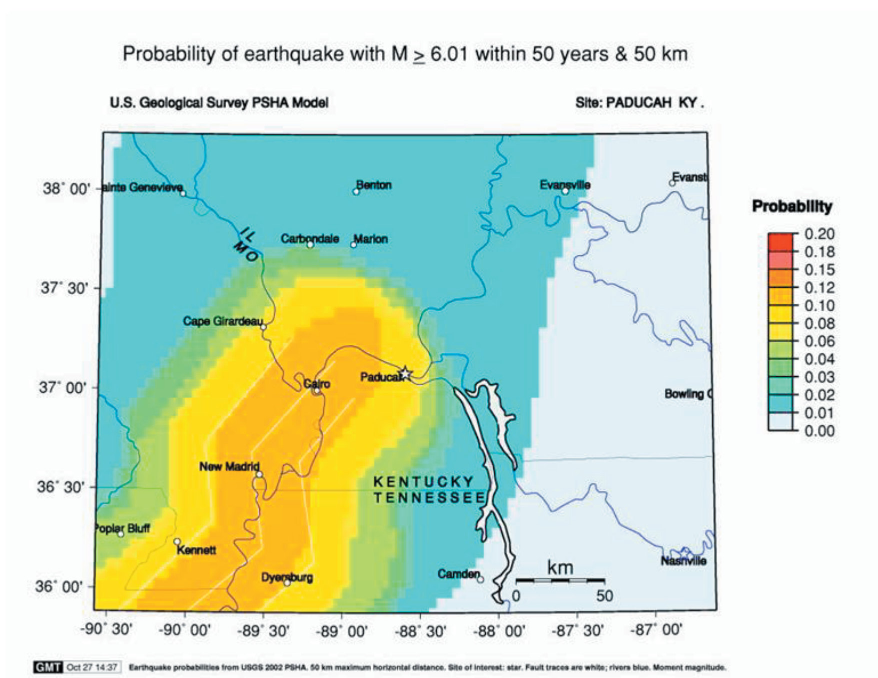
Principal sources

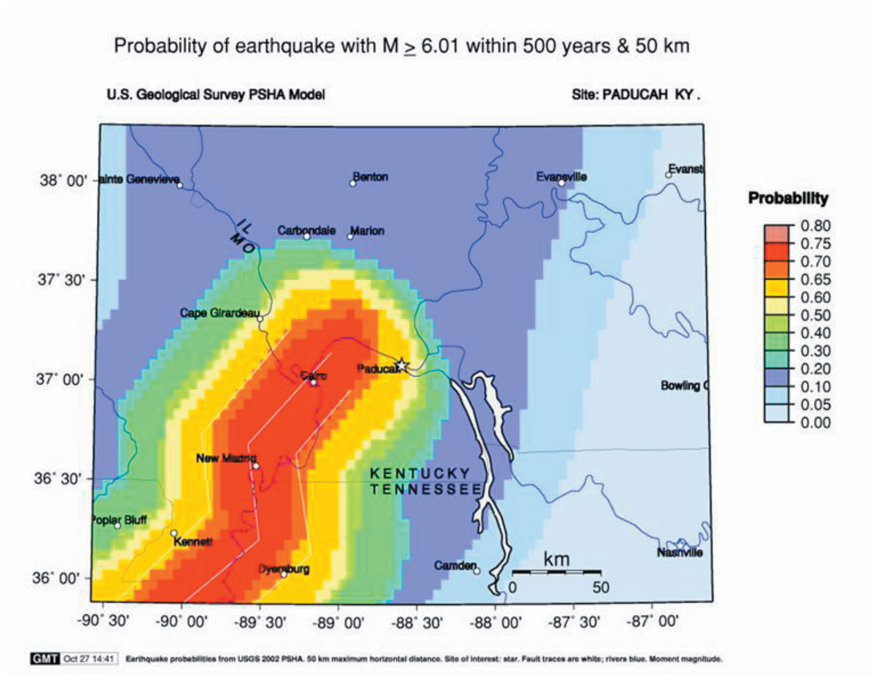
	Contrib.	R(km)	Mag	epsilon
NMSZ Mainshocks	72%	39 km	M7.7	e=0.81
CEUS gridded seism.	28%	14 km	M6.1	e=0.58

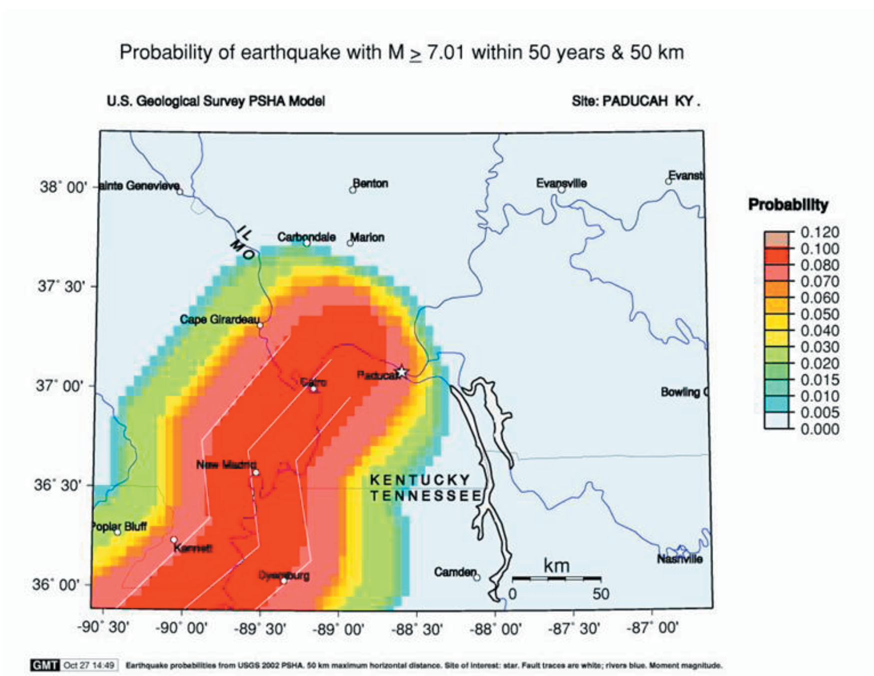
Individual fault hazard details if contrib.>1%:

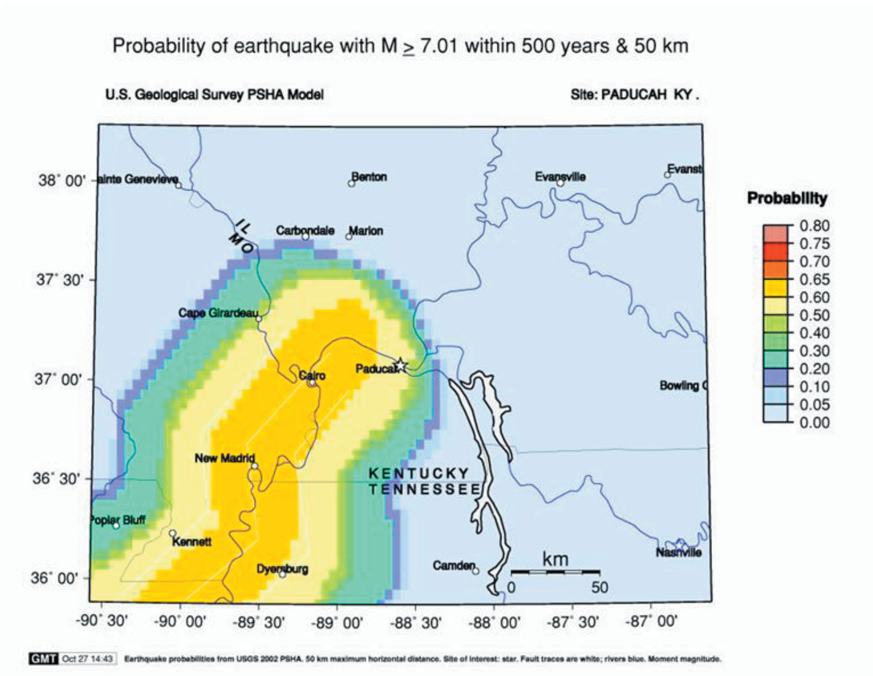
New Madrid western f	3.9%	68 km	M7.76	e=1.65
New Madrid eastern f	29.6%	33km	M7.70	e=0.59
New Madrid central f	38.8%	42km	M7.71	e=0.88

Probability maps




Probability of earthquake with M ≥ 6.01 within 500 years & 50 km
U.S. Geological Survey PSHA Model
Site: PADUCAH KY .
Probability
0.80
0.75
0.70
0.65
0.60
0.50
0.40
0.30
0.20
0.10
0.05
0.00
Benton
Evansville
Carbondale
Marion
IL
MO
Cape Girardeau
Paducah
Cairo
Bowling G
New Madrid
KENTUCKY
TENNESSEE
Kennett
Dyersburg
Camden
Nashville
km
0
50
38° 00'
37° 30'
37° 00'
36° 30'
36° 00'
-90° 30'
-90° 00'
-89° 30'
-89° 00'
-88° 30'
-88° 00'
-87° 30'
-87° 00'
GMT Oct 27 14:41
Earthquake probabilities from USGS 2002 PSHA. 50 km maximum horizontal distance. Site of interest: star. Fault traces are white; rivers blue. Moment magnitude.


Probability of earthquake with M ≥ 7.01 within 50 years & 50 km
U.S. Geological Survey PSHA Model
Site: PADUCAH KY .
Probability
0.120
0.100
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.015
0.010
0.005
0.000
Benton
Evansville
Carbondale
Marion
IL
MO
Cape Girardeau
Paducah
Cairo
Bowling G
New Madrid
KENTUCKY
TENNESSEE
Kennett
Dyersburg
Camden
Nashville
km
0
50
38° 00'
37° 30'
37° 00'
36° 30'
36° 00'
-90° 30'
-90° 00'
-89° 30'
-89° 00'
-88° 30'
-88° 00'
-87° 30'
-87° 00'
GMT Oct 27 14:49
Earthquake probabilities from USGS 2002 PSHA. 50 km maximum horizontal distance. Site of interest: star. Fault traces are white; rivers blue. Moment magnitude.



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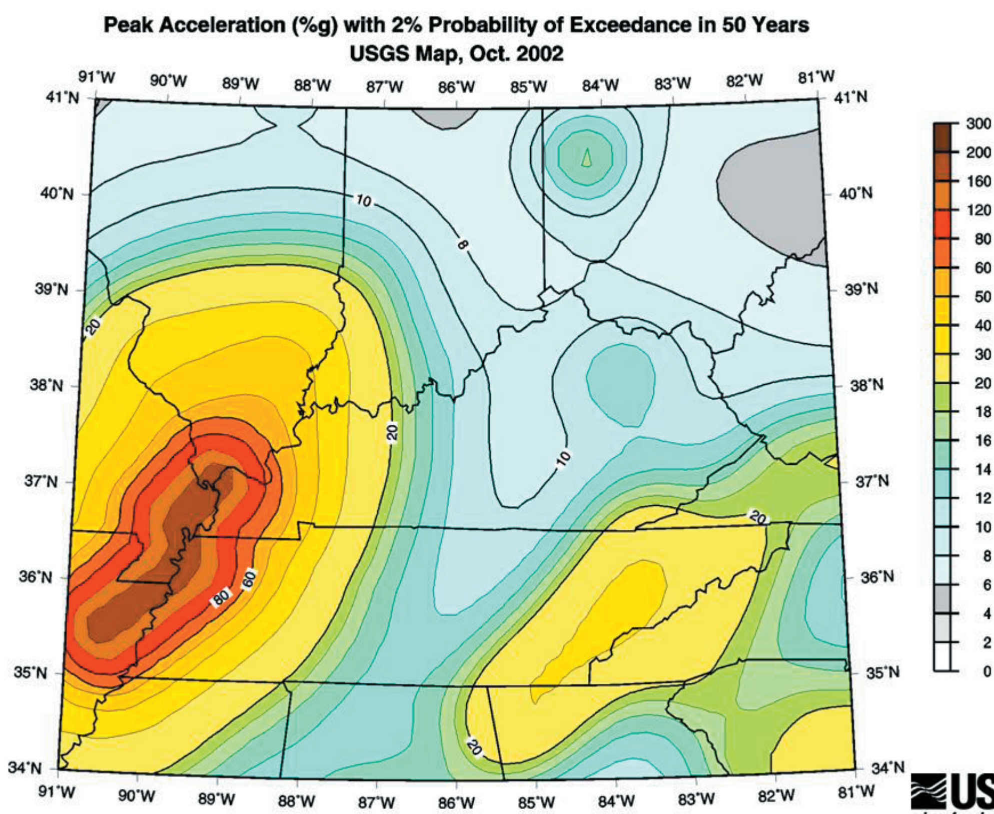
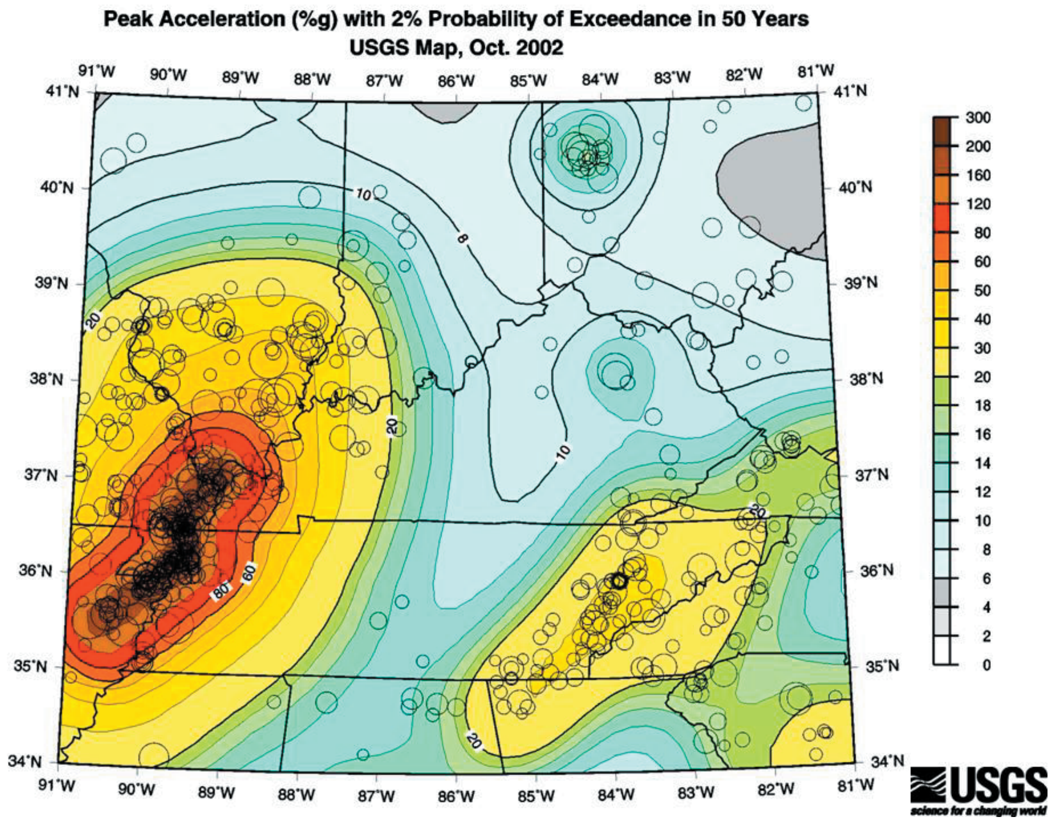
Earthquake Sources




Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002
91°W
90°W
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
41°N
40°N
39°N
38°N
37°N
36°N
35°N
34°N
300
200
160
120
80
60
50
40
30
20
18
16
14
12
10
8
6
4
2
0
USGS
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Attenuation relations

How do we estimate ground motions for large earthquakes near New Madrid?

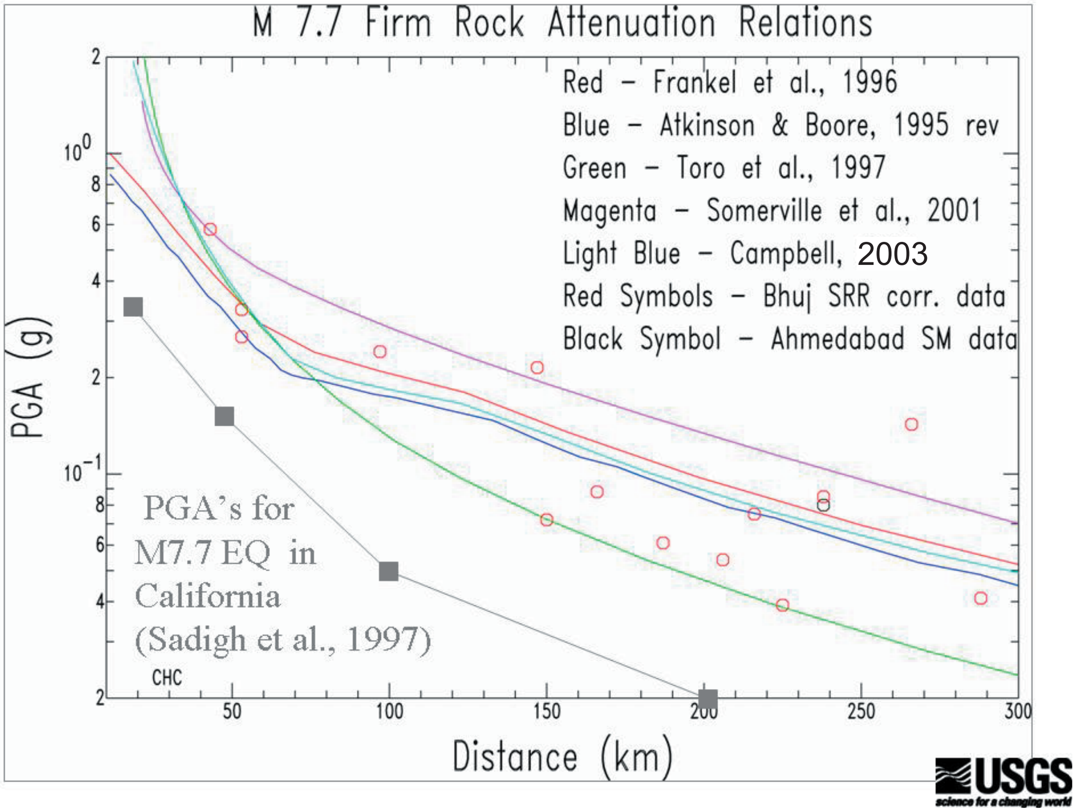
- use estimated magnitude to calculate ground motions from various attenuation relations: stochastic models using source parameters and derived for small earthquakes; constant stress drop with magnitude model validated with felt area vs. magnitude data; in 2002 added two corner frequency model, hybrid extended-source model, and semi-empirical model
- Atkinson and Boore (1998) compared predictions with regional ENAM data
- check with recorded ground motions of Bhuj, India earthquake

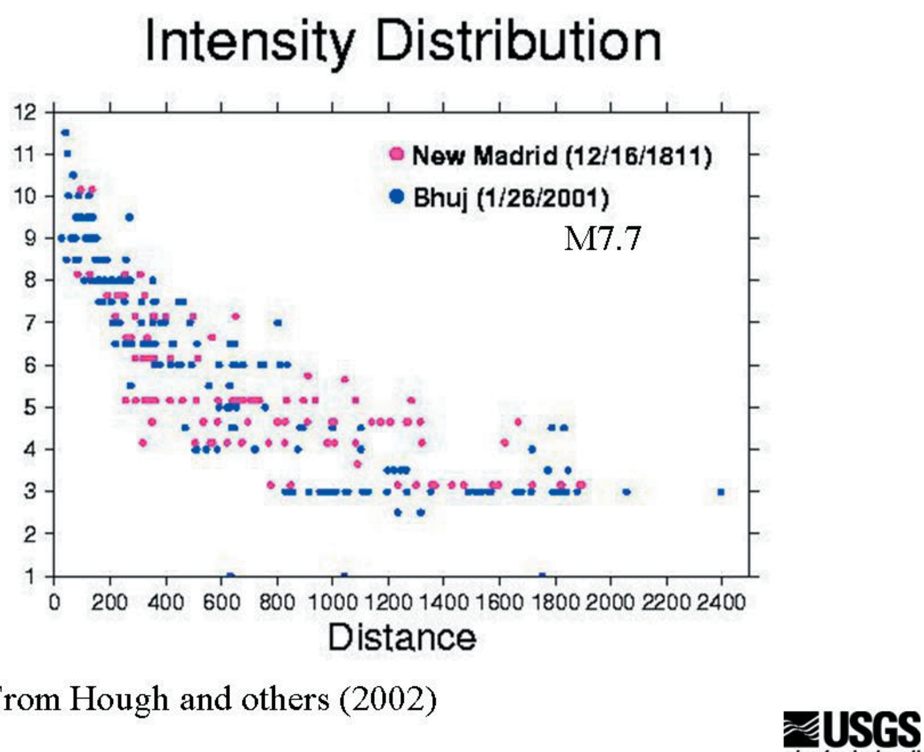
CEUS Attenuation relations used for 1996 and 2002 maps; describe median ground motions as function of distance and magnitude, as well as variability of ground motions

- Toro et al. (1997), adjusted to firm-rock site condition (Vs30= 760 m/s)
- Frankel et al. (1996)
- Atkinson and Boore (1995), adjusted to firm rock
- Somerville et al. (2001), adjusted to firm rock
- Campbell (2003), adjusted to firm rock

Higher ground motions (at high frequencies) for given magnitude, distance for CEUS earthquakes compared with WUS

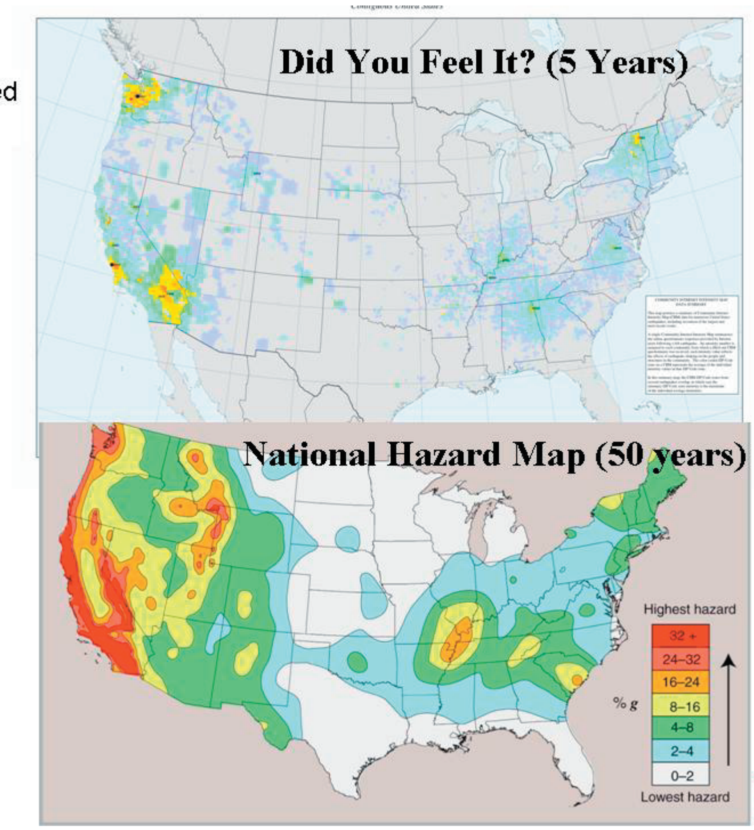
- Higher Q in crust: less attenuation with distance
- Higher earthquake stress drop: more high-frequency ground motion for specified moment magnitude
- Determined from instrumental analysis of small and moderate events in eastern North America and isoseismals of large historic events





From Hough and others (2002)

Slide composed by D. Wald

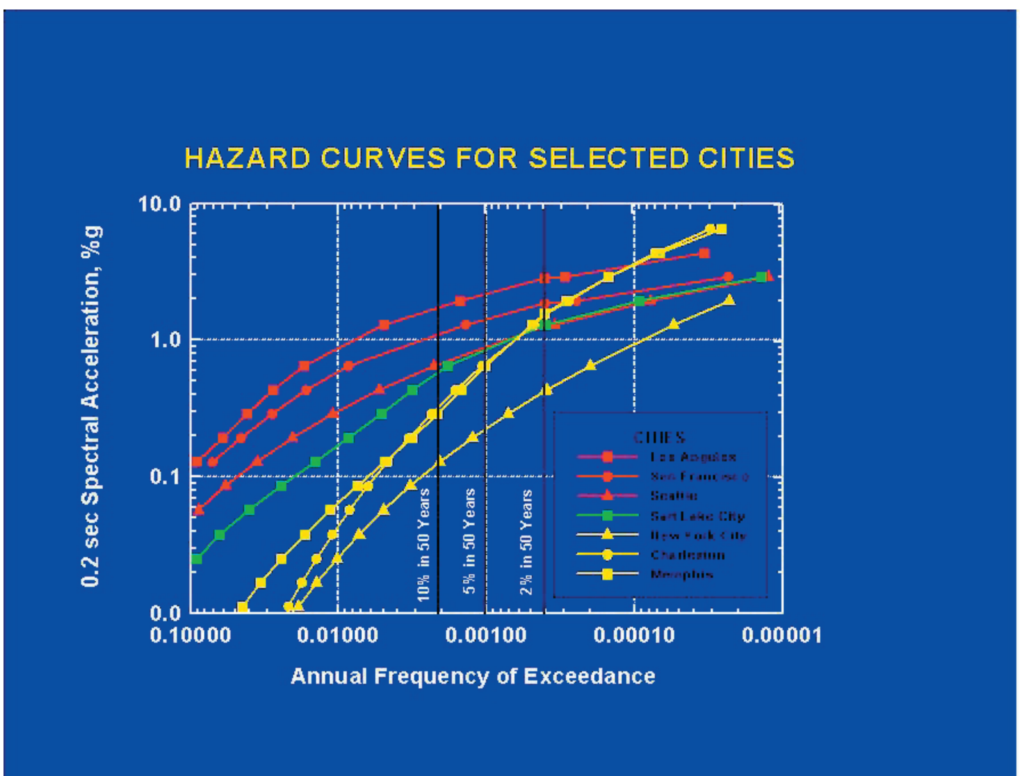


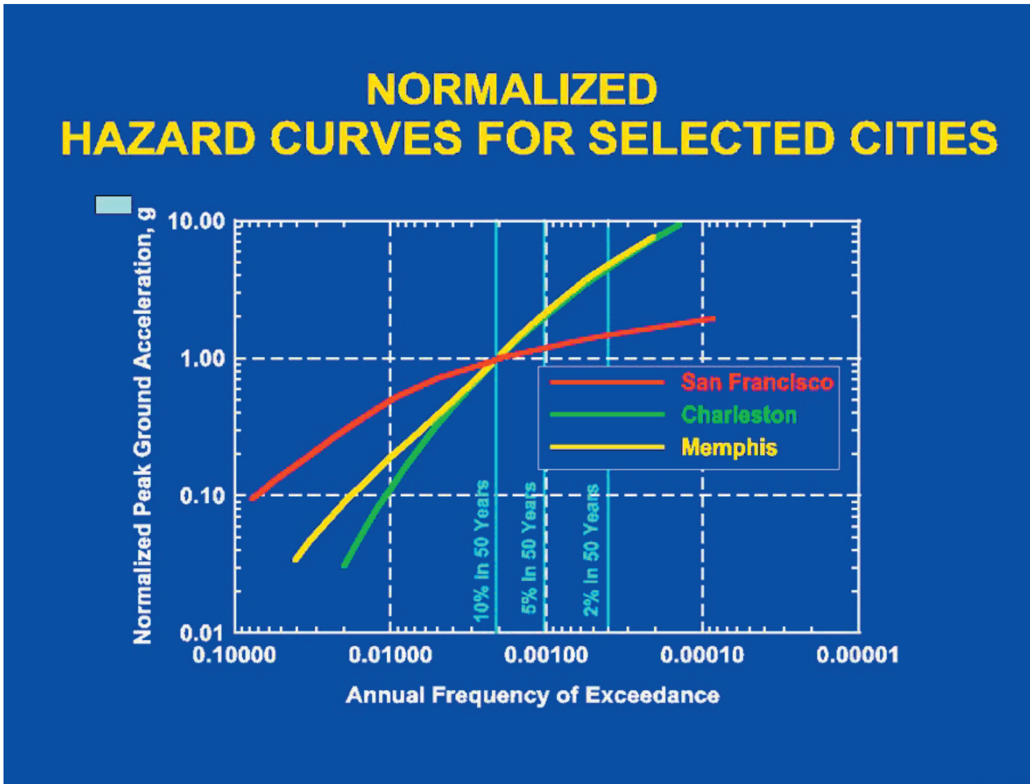
Scenario and Design Values for Memphis
(firm-rock site condition)

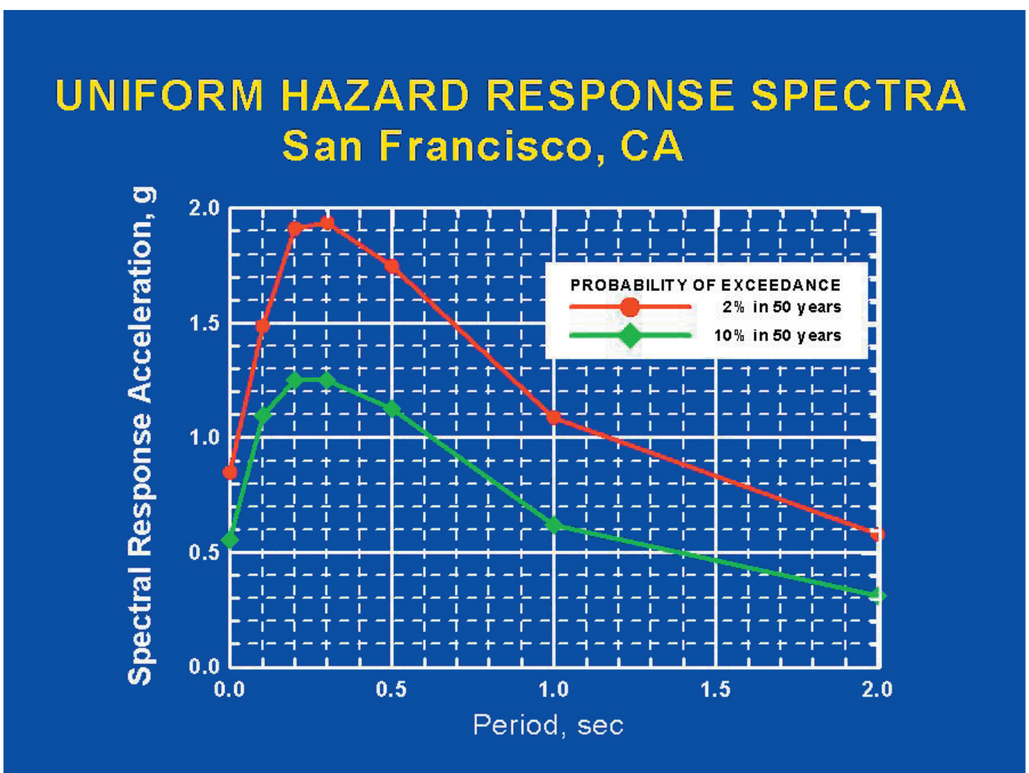
	PGA	5 Hz S.A.	1 Hz S.A.
Median ground motion expected for M7.7 on center of New Madrid Zone	0.30 g	0.60 g	0.16 g
Present code SBC	0.20 g	0.50 g	0.24 g
2000 IBC (BSSC design maps) 2/3 x 2% PE in 50 yr	0.45 g	0.92 g	0.27 g
Proposed by Tomasello: 10% PE in 50 yr	0.12 g (96) 0.22 g (02)	0.25 g (96) 0.35 g (02)	0.07 g (96) 0.09 g (02)

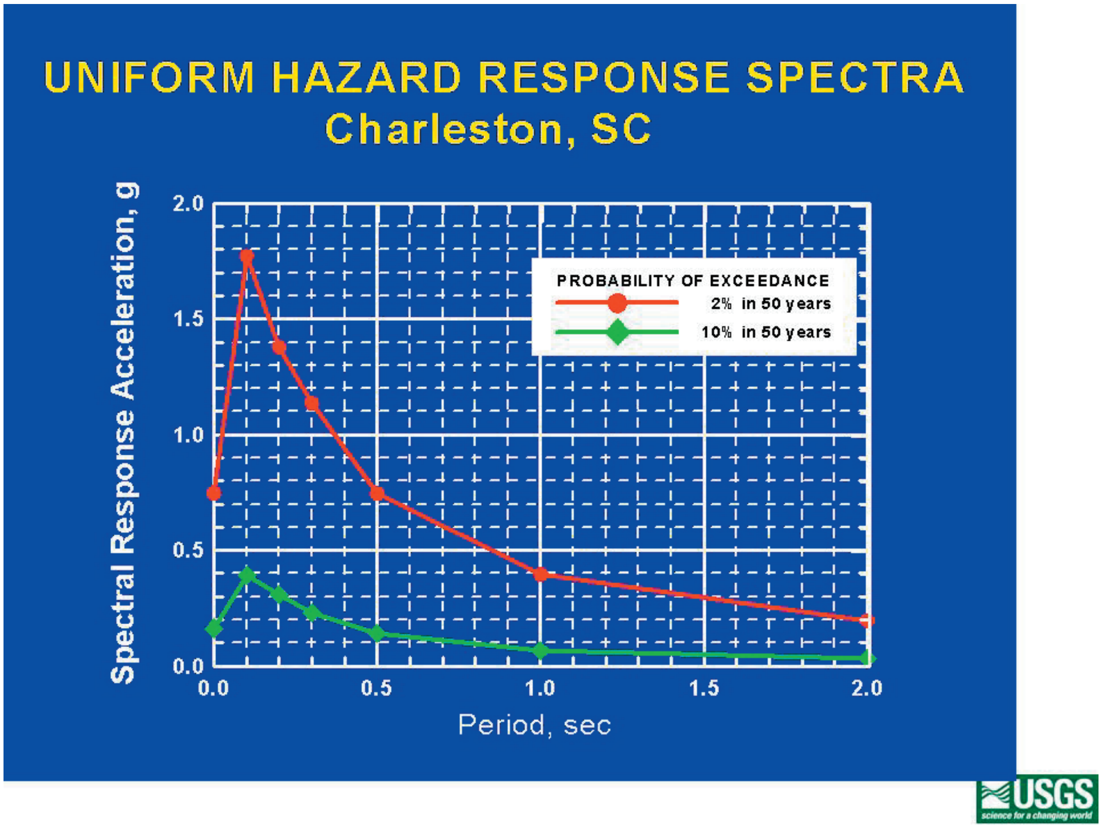
2000 IBC about equal to 74th percentile motion for scenario EQ

WHY 2% P.E. IN 50 YEARS?




NORMALIZED
HAZARD CURVES FOR SELECTED CITIES
Normalized Peak Ground Acceleration, g
10.00
1.00
0.10
0.01
0.10000
0.01000
0.00100
0.00010
0.00001
Annual Frequency of Exceedance
10% in 50 Years
5% in 50 Years
2% in 50 Years
San Francisco
Charleston
Memphis


UNIFORM HAZARD RESPONSE SPECTRA
San Francisco, CA
Spectral Response Acceleration, g
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
Period, sec
PROBABILITY OF EXCEEDANCE
2% in 50 years
10% in 50 years


UNIFORM HAZARD RESPONSE SPECTRA
Charleston, SC
Spectral Response Acceleration, g
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
Period, sec
PROBABILITY OF EXCEEDANCE
2% in 50 years
10% in 50 years
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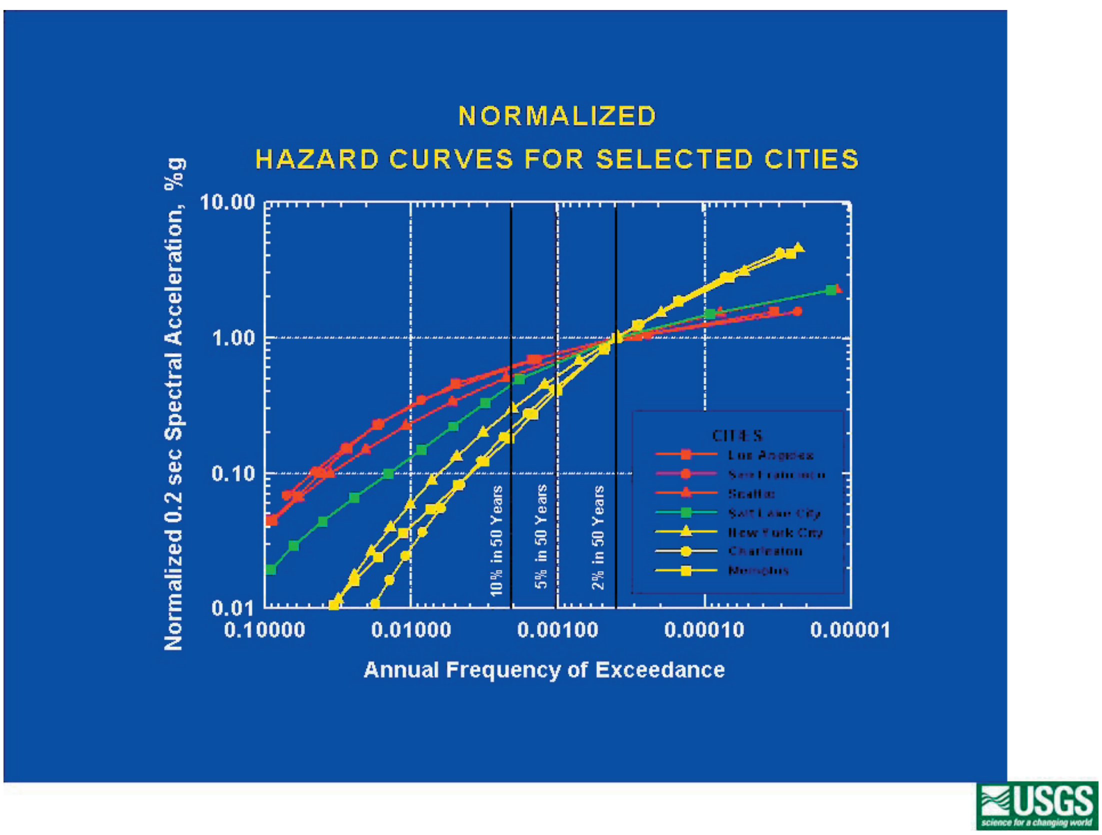
NORMALIZED
HAZARD CURVES FOR SELECTED CITIES
Normalized 0.2 sec Spectral Acceleration, %g
10.00
1.00
0.10
0.01
0.10000
0.01000
0.00100
0.00010
0.00001
Annual Frequency of Exceedance
10% in 50 Years
5% in 50 Years
2% in 50 Years
Los Angeles
Salt Lake City
New York City
Charleston
USGS
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DESIGN APPROACH

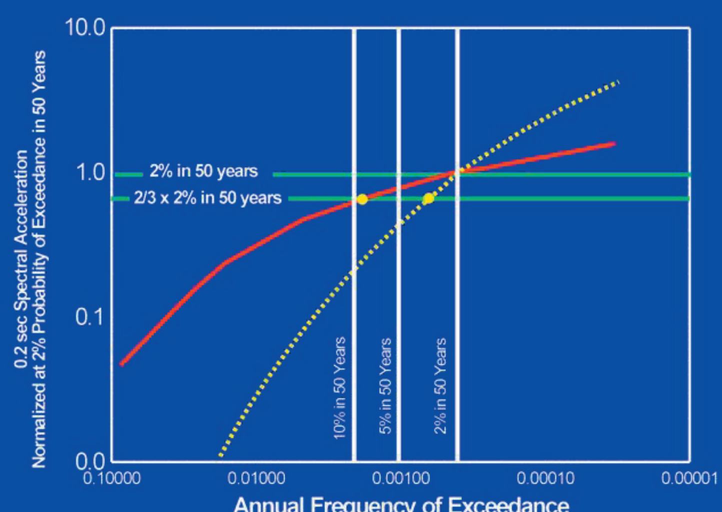
COLLAPSE RESISTANCE >= COLLAPSE LOAD

Collapse Resistance >= 1.5 x Typical Code Resistance
Collapse Load = 2% PE in 50 yrs GM

1.5 x Typical Code Resistance >= Collapse Load

Typical Code Resistance >= 1/1.5 x Collapse Load

Effect of Multiplying by 2/3



Deterministic Constraints

- In regions of high seismicity, such as coastal California, the hazard is typically controlled by large-magnitude events occurring on a limited number of relatively well defined fault systems
- Ground shaking calculated at a 2% in 50 years likelihood would be much larger than that which would be expected based on the characteristic magnitude of earthquakes on these active faults, because these faults can produce characteristic earthquakes every few hundred years.
- General rule is applicable in all regions.

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Constraints

- Near well-defined faults transition from probabilistic ground motion (GM) to deterministic GM
- Use the median GM times 1.5 (intended to approximate one sigma) as the deterministic GM for the maps

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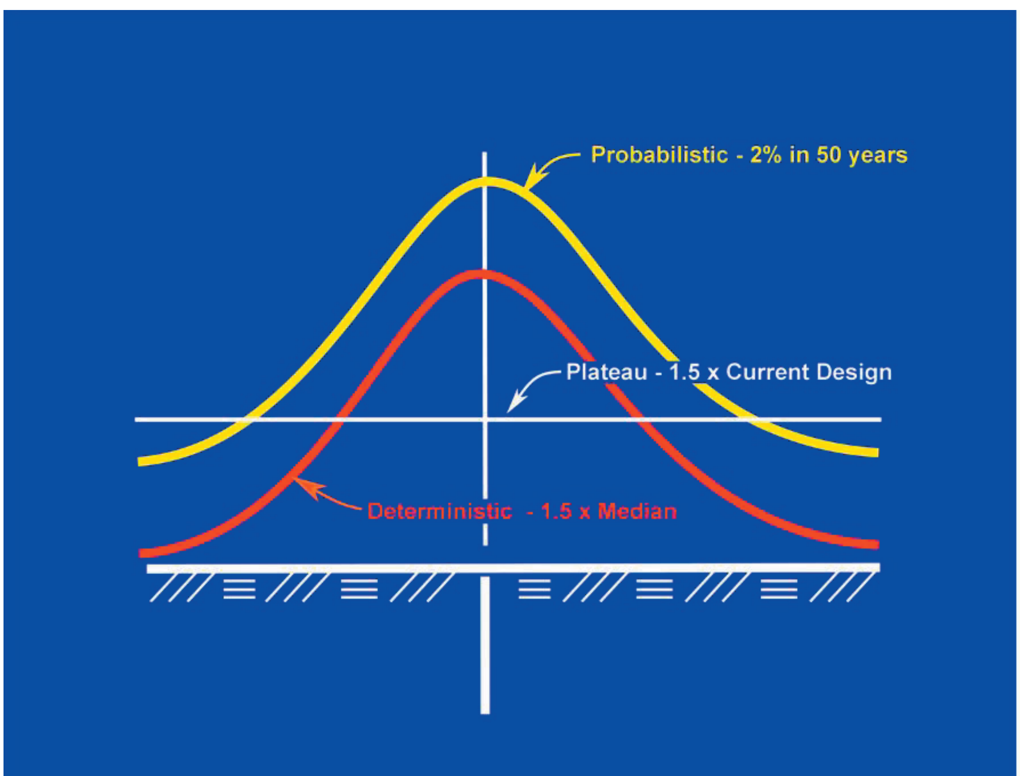
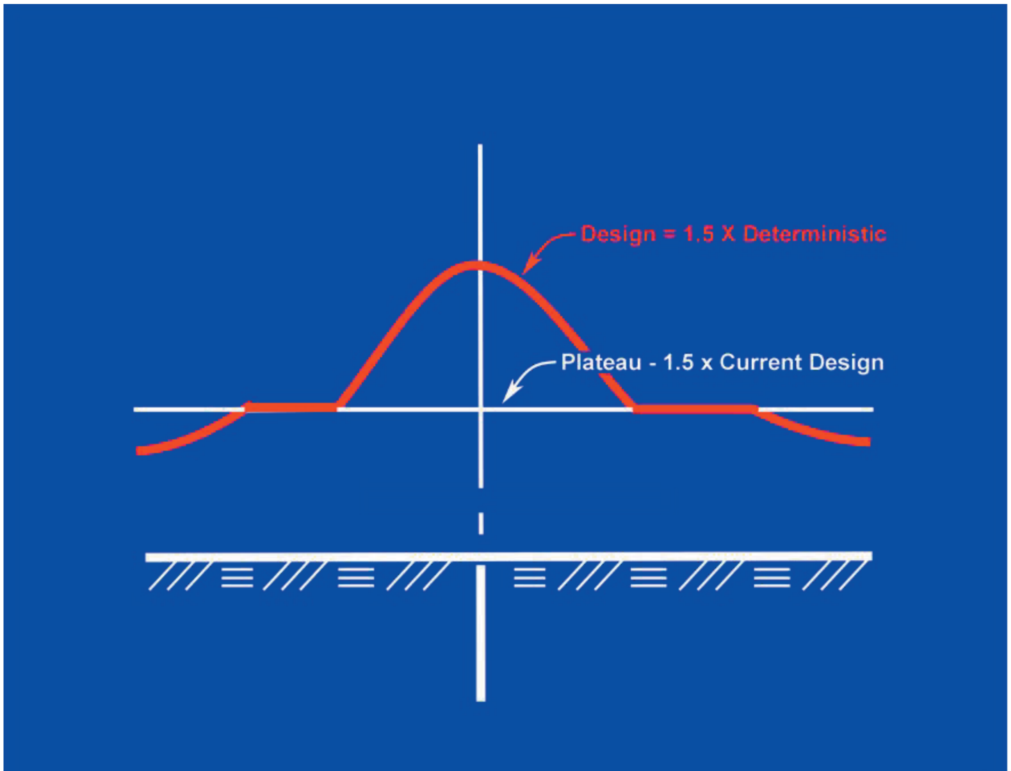
Constraints

- Use a plateau equivalent to current UBC Zone 4 design practice (x 1.5) as a transition from the probabilistic GM to the deterministic GM
- If the deterministic GM (x 1.5) exceeds the probabilistic GM, retain the probabilistic GM




Design = 1.5 X Deterministic
Plateau - 1.5 x Current Design

Appendix B: Zhenming Wang's Presentation

KGS Approach for Seismic Hazard Assessment in Kentucky

Zhenming Wang

Kentucky Geological Survey
University of Kentucky

USGS-KGS Meeting on Seismic Hazard
November 4, 2004
Lexington, KY

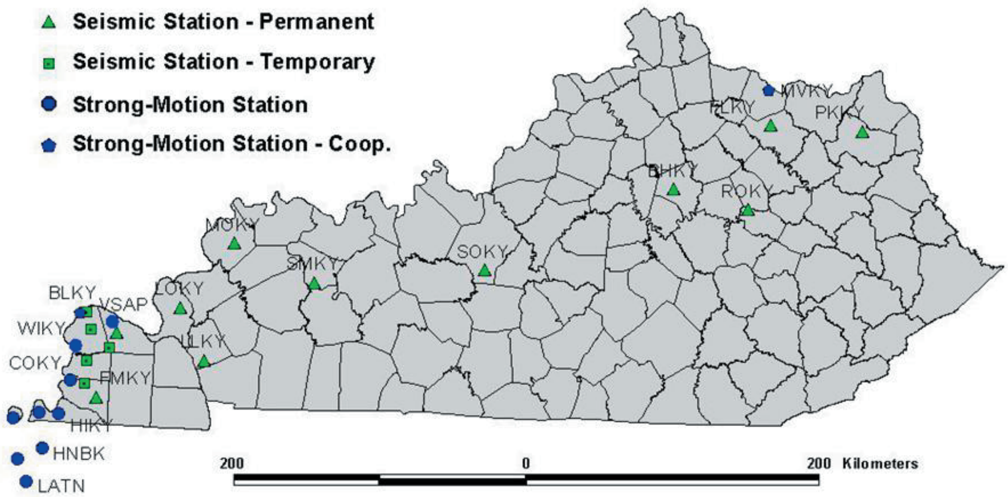
Outline

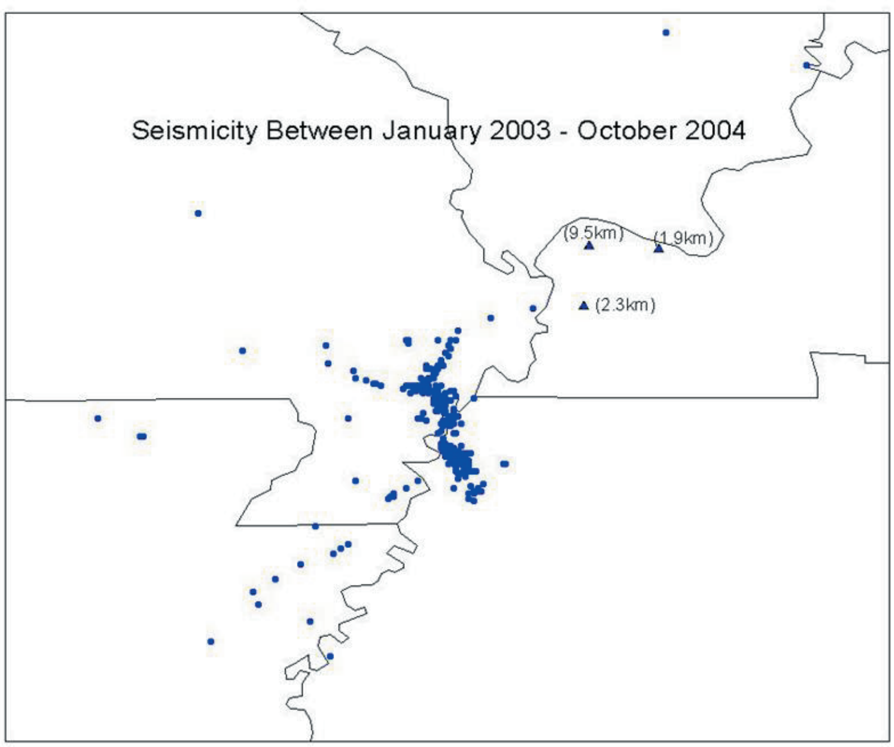
- KGS's approach in seismic hazard assessment
- Some issues with the National Hazard Maps

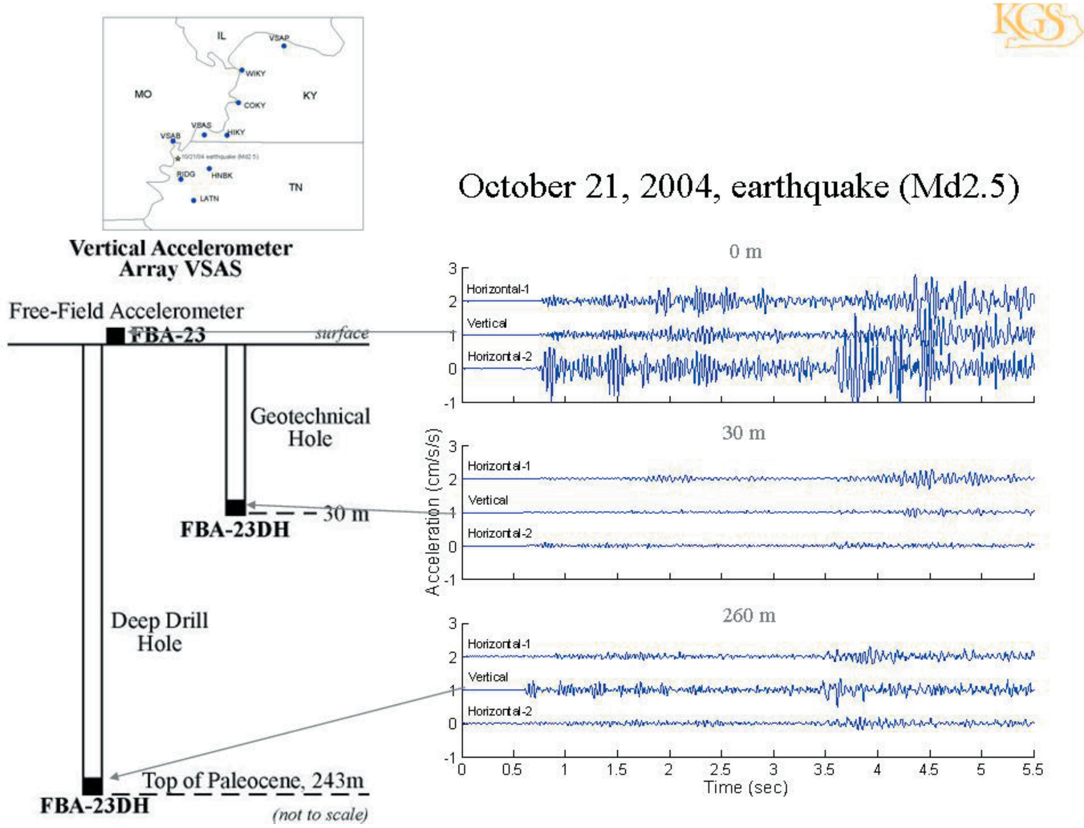
KGS's Approach

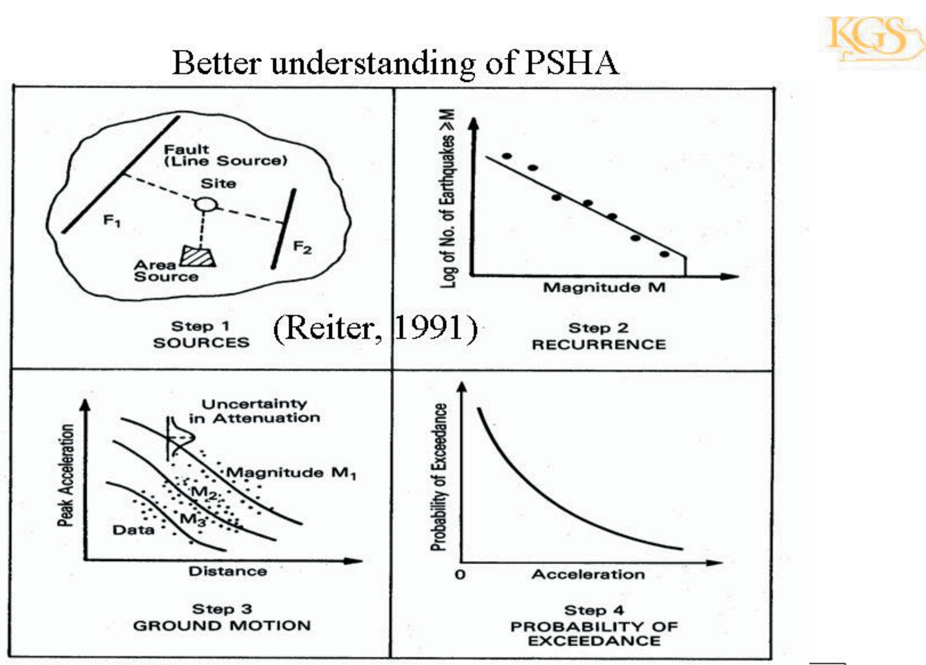
- Scientific Research
  - Enhancing the Kentucky Seismic and Strong-Motion Network
  - Detail analyses on
    - Methodology (PSHA)
    - Input database used in the national hazard mapping
    - Products
  - Strong ground-motion simulation using the composite source model
- Communication
  - Professional communities: SSA, EERI, AGU, AEG, GSA
  - Government agencies:
    - USGS, FEMA, DOE, NRC, USACE, EPA
    - KY-EPA, Dept. of Housing, Economic Development
  - Non-government organizations: BSSC, SEAOK

Kentucky Seismic and Strong Motion Network





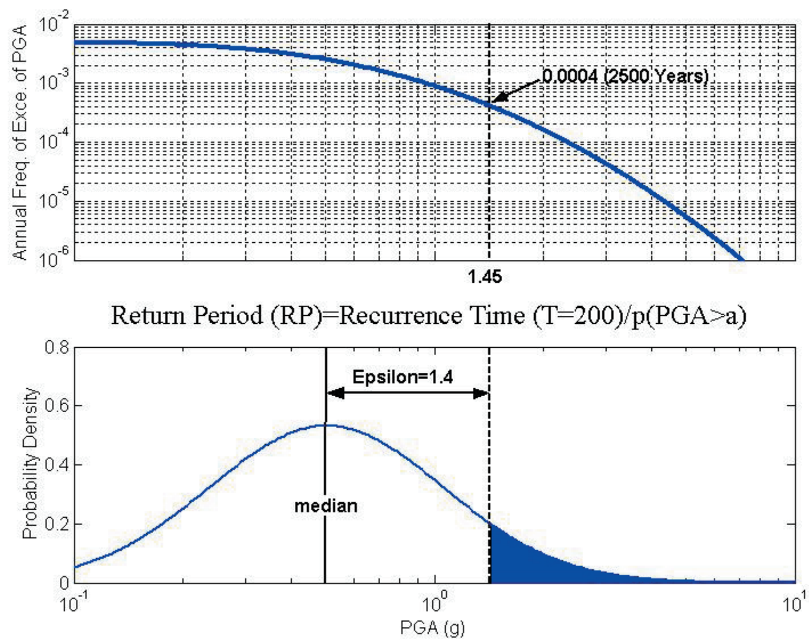




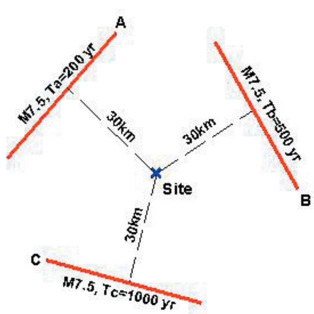
$$\gamma(y) = \sum v_i \iiint f_M(m) f_R(r) f_\varepsilon(\varepsilon) P[Y > y \mid m, r, \varepsilon]\, dm\, dr\, d\varepsilon$$

End result from PSHA: Hazard Curve

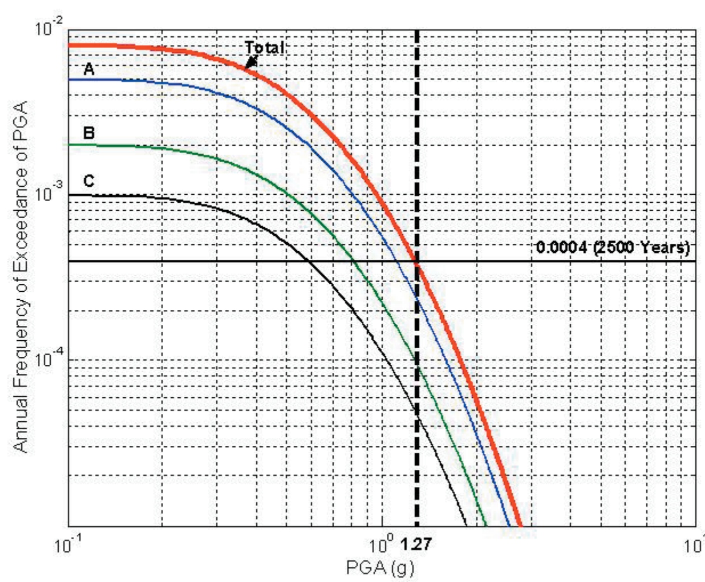
Hazard (PGA) curve at 30 km from M7.5 earthquake



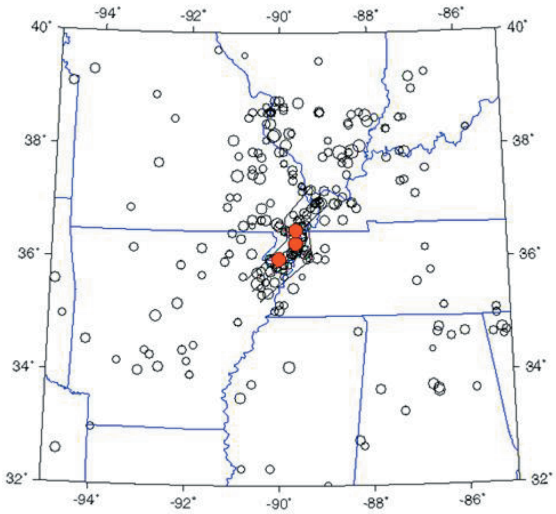
(Wang and others, 2003a)



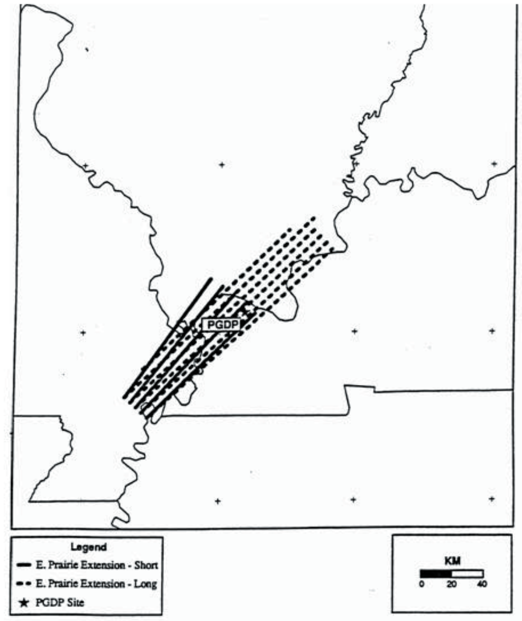
(Wang and others, 2003b)



Uncertainty in earthquake sources

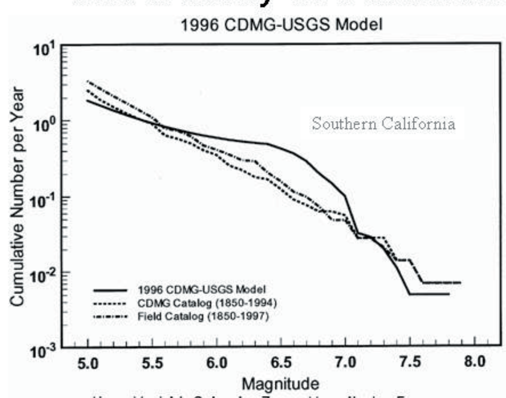


Fictitious fault (Frankel & others, 1996, 2002)
1/3 weight (Frankel & others, 1996)
25, 50, 25% (Frankel & others, 2002)

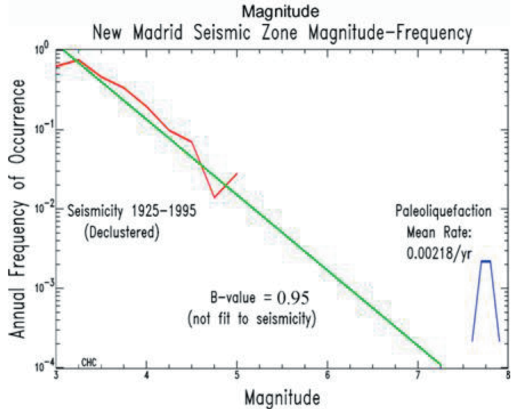


(REI, 1999)

Uncertainty in occurrence frequency

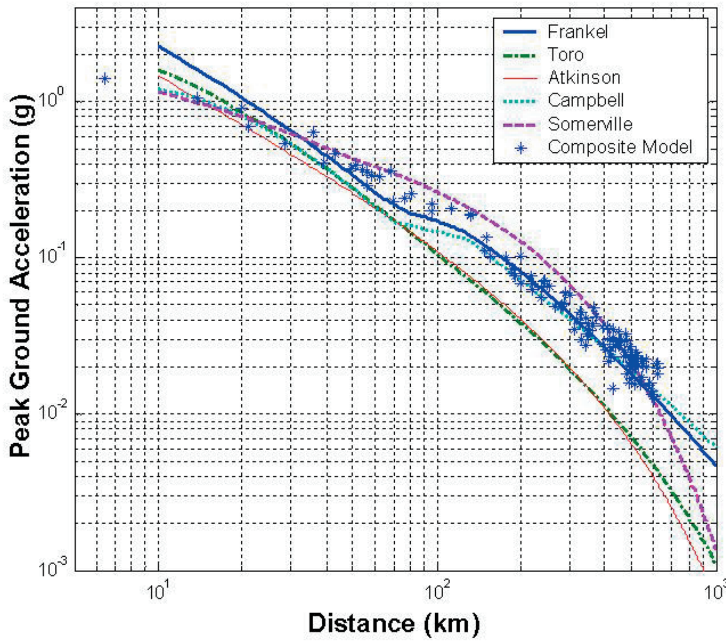


Seismicity in Southern California



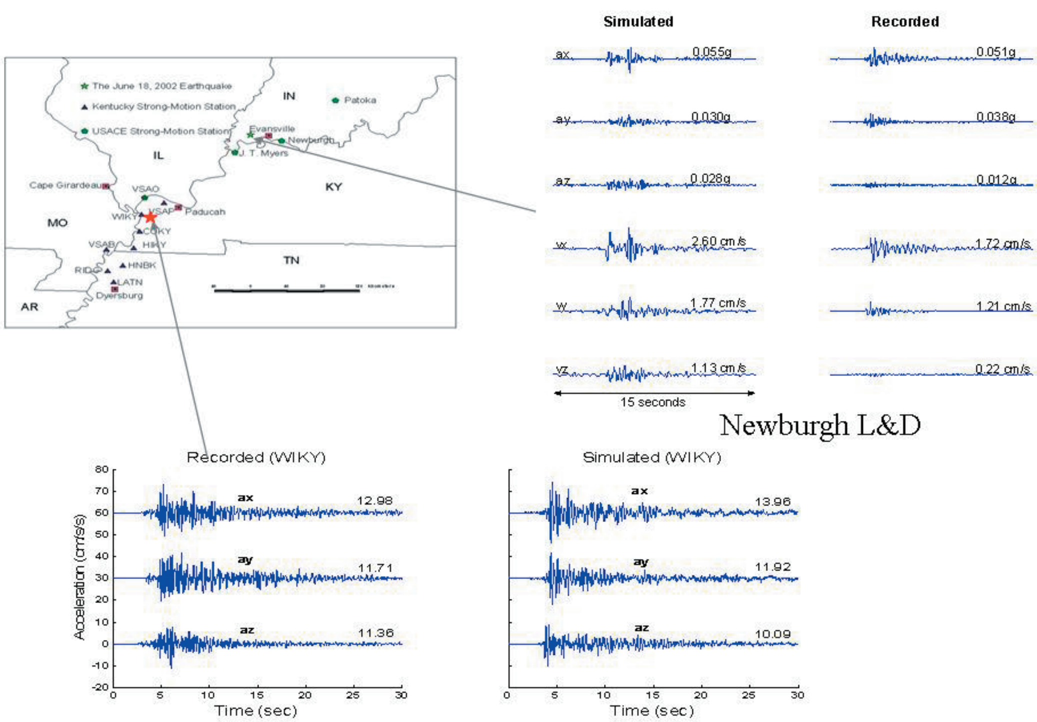
Seismicity in New Madrid Seismic Zone (Characteristic Earthquake)

Uncertainty in ground-motion attenuation



Ground-motion attenuation relationships for M8.0 earthquake

Composite source models



(Shi and others, in review)

- We understand:
  - Seismic risk mitigation policies, such as building codes, are complicated
  - Science (seismology), engineering, economic, and social issues
  - Role of geosciences - KGS
- We focus on:
  - Sciences (geology and seismology)
    - What do we know?
    - What information can we provide?
    - How should we communicate?

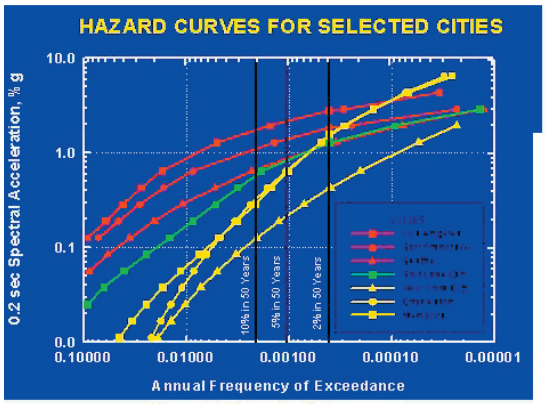
- "Uncertainty in seismic hazard estimates is a fact of life, even in California where seismic hazard input parameters are better known than in the CUS (the central United States)" (Cramer, 2001).
- Large uncertainty (source, frequency, and attenuation) is the fundamental issue in seismic hazard assessment for the CUS, and our job is to determine:
  - How to characterize it
    - Methodologies
    - Input parameters (source, frequency, and attenuation)
  - How to communicate it

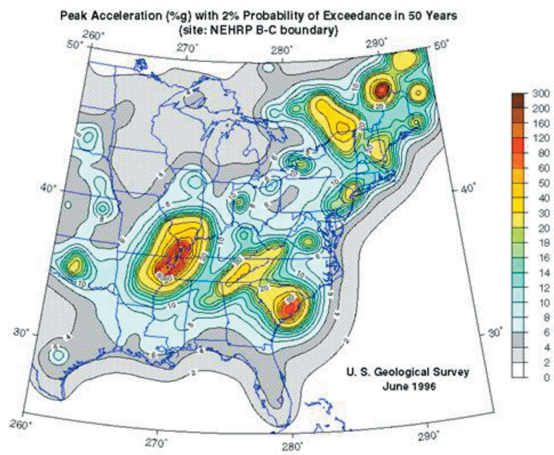
Issue #1: How to communicate?

What is the information policy-makers or engineers need?

– a level of ground motion (PGA, PGV, S.A.)

– and the associated confidence level





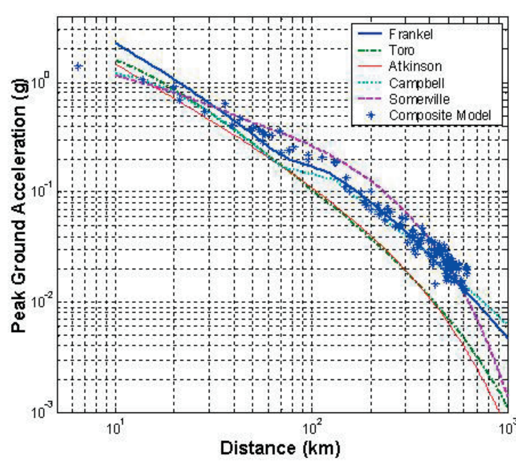
Issue #1: How to communicate?

1) What do we know in the CUS (western Kentucky)?

– Characteristic earthquake (M7.7)

– Recurrence time about 500 years (1811-1812, A.D. 800-1000, and A.D.1300-1600)

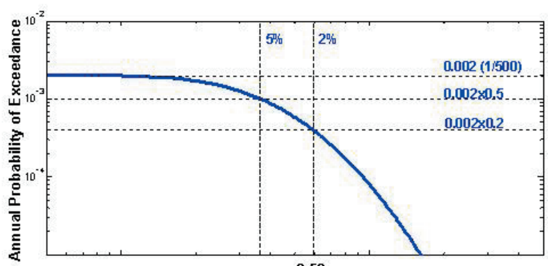
– Ground-motion attenuation (μ, σ_{ln})



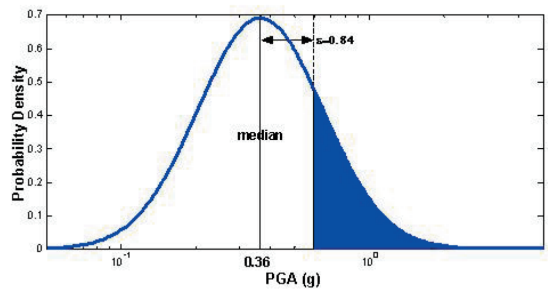
σ_{ln} = 0.6-0.8

Issue #1: How to communicate?

Hazard curve for the New Madrid Characteristic EQ



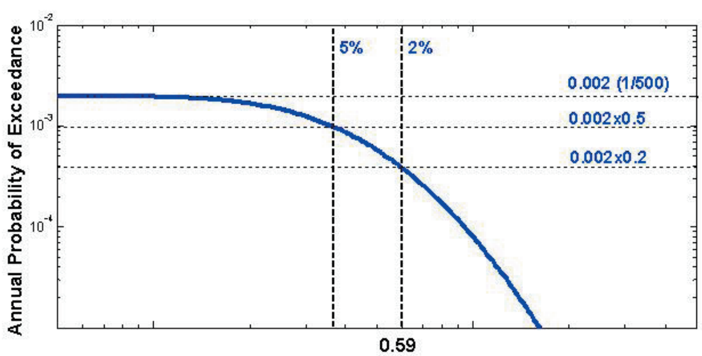
CUS (M7.7, T=500 yr)



(attenuation: Somerville and others (2001) at 40km)

Issue #1: How to communicate?

Hazard curve for the New Madrid Characteristic EQ

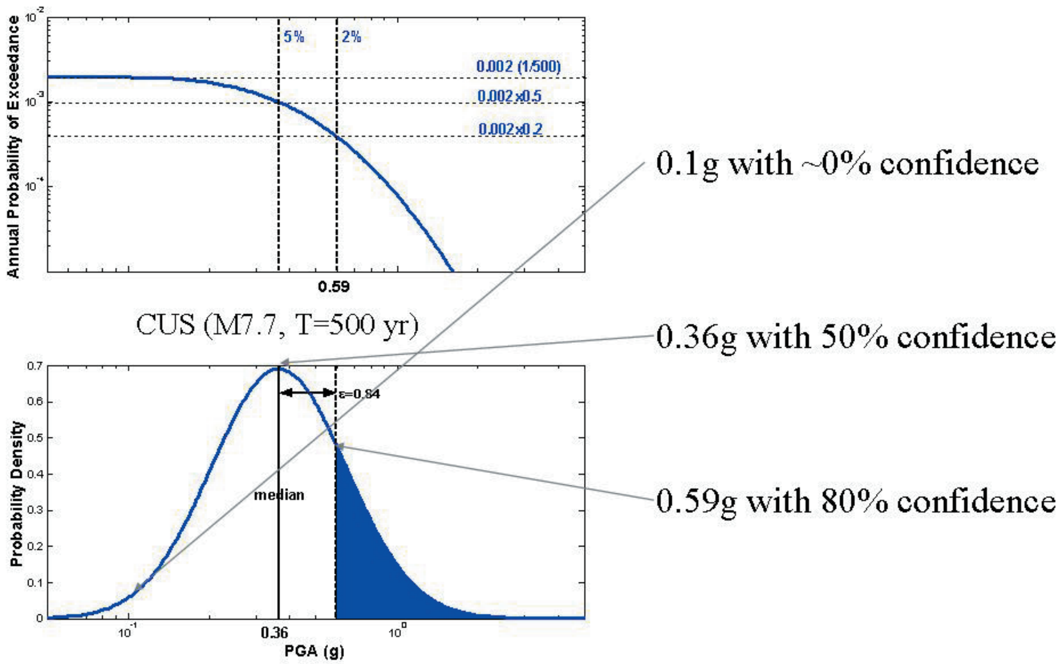


2% in 50 years means recurrence time of 2,500 years: 0.59g PGA
5% in 50 years means recurrence time of 1,000 years: 0.36g PGA
10% in 50 years means recurrence time of 500 years: <0.10g PGA

Do we communicate the information correctly?

Issue #1: How to communicate?

Our suggestion: Use original earthquake statistics

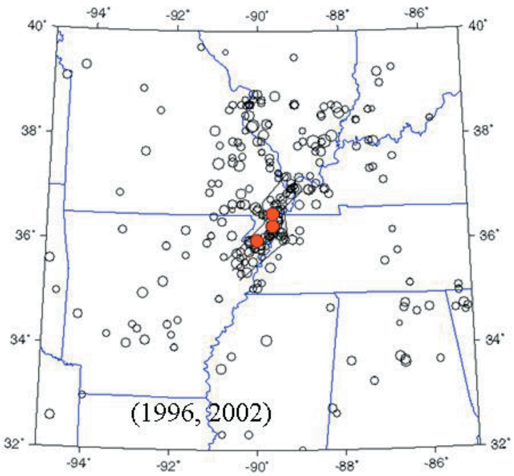


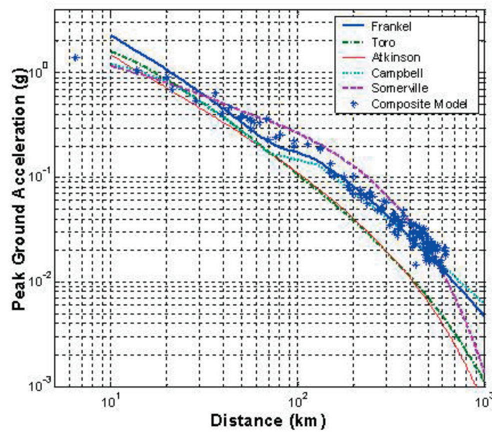
Issue #1: How to communicate?

- <u>One more confusion: X% PE in Y years</u>
  - What does 10, 5, or 2% PE in 50 years really mean?
    - No relationship with seismic hazard
    - Equation
      - X% PE in Y years = $1 - P^Y$
      - Return Period (RP) = $1/(1-P)$
    - 2%, 5%, and 10% in 50 years
      - 2% $=1-P^{50}$
      - P=0.999596 RP=2475 (years) ~ 2,500 years
      - 5% $=1-P^{50}$
      - P=0.998975 RP=975 (years) ~ 1,000 years
      - 10% $=1-P^{50}$
      - P=0.997895 RP=475 (years) ~ 500 years

Issue #2: The most important parameters for western Kentucky

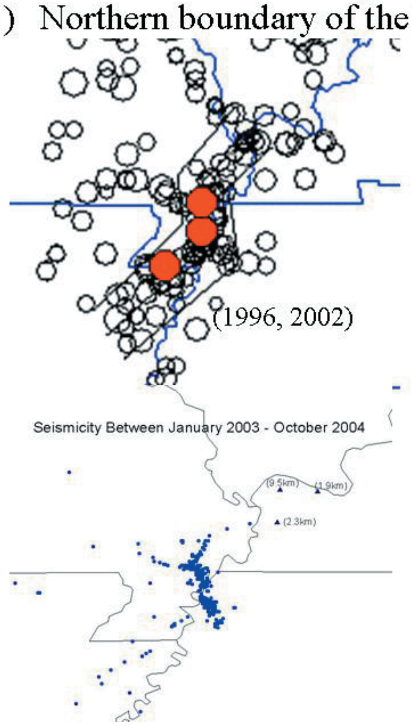
1) Northern boundary of the New Madrid Seismic Zone?
2) Ground-motion attenuation?

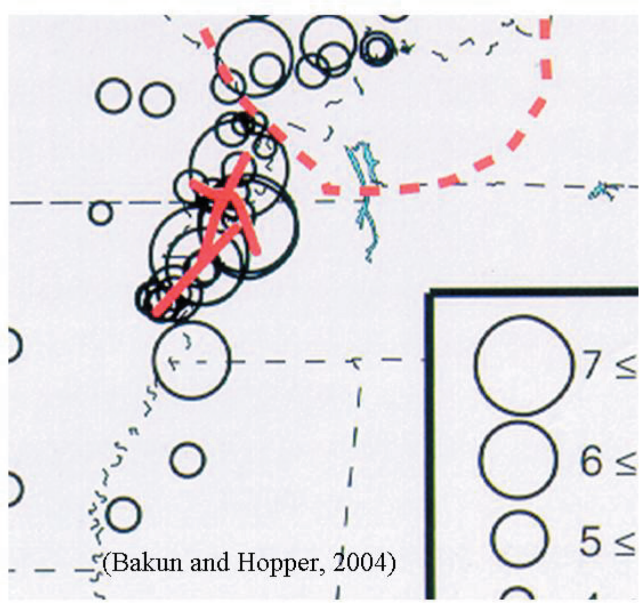




Issue #2: The most important parameters for western Kentucky

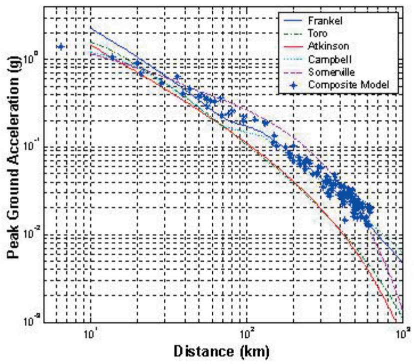
1) Northern boundary of the New Madrid Seismic Zone?





Issue #2: The most important parameters for western Kentucky

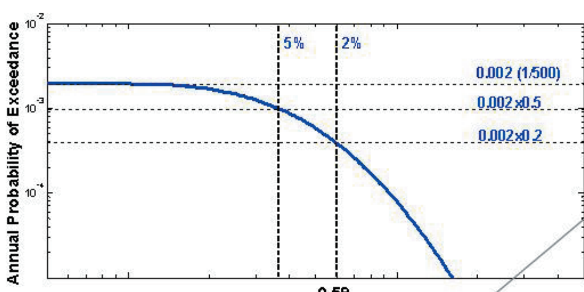
1) Ground-motion attenuation?



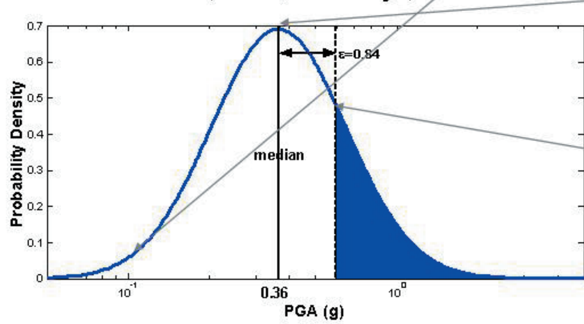
1) Large uncertainty (median and sigma)
2) Extremely high near-source (<30km)
3) Models (EPRI-2003)
    1) Single corner
    2) Double corner
    3) Hybrid
    4) Physical (Green's function)
        1) Somerville and others (2001) attenuation
        2) Composite source model

Issue #3: The hazard mapping methodology – PSHA

Hazard curve for the New Madrid Characteristic EQ



CUS (M7.7, T=500 yr)



For policy-makers:
- Level of ground motion
- Confidence level

0.1g with ~0% confidence

0.36g with 50% confidence

0.59g with 80% confidence