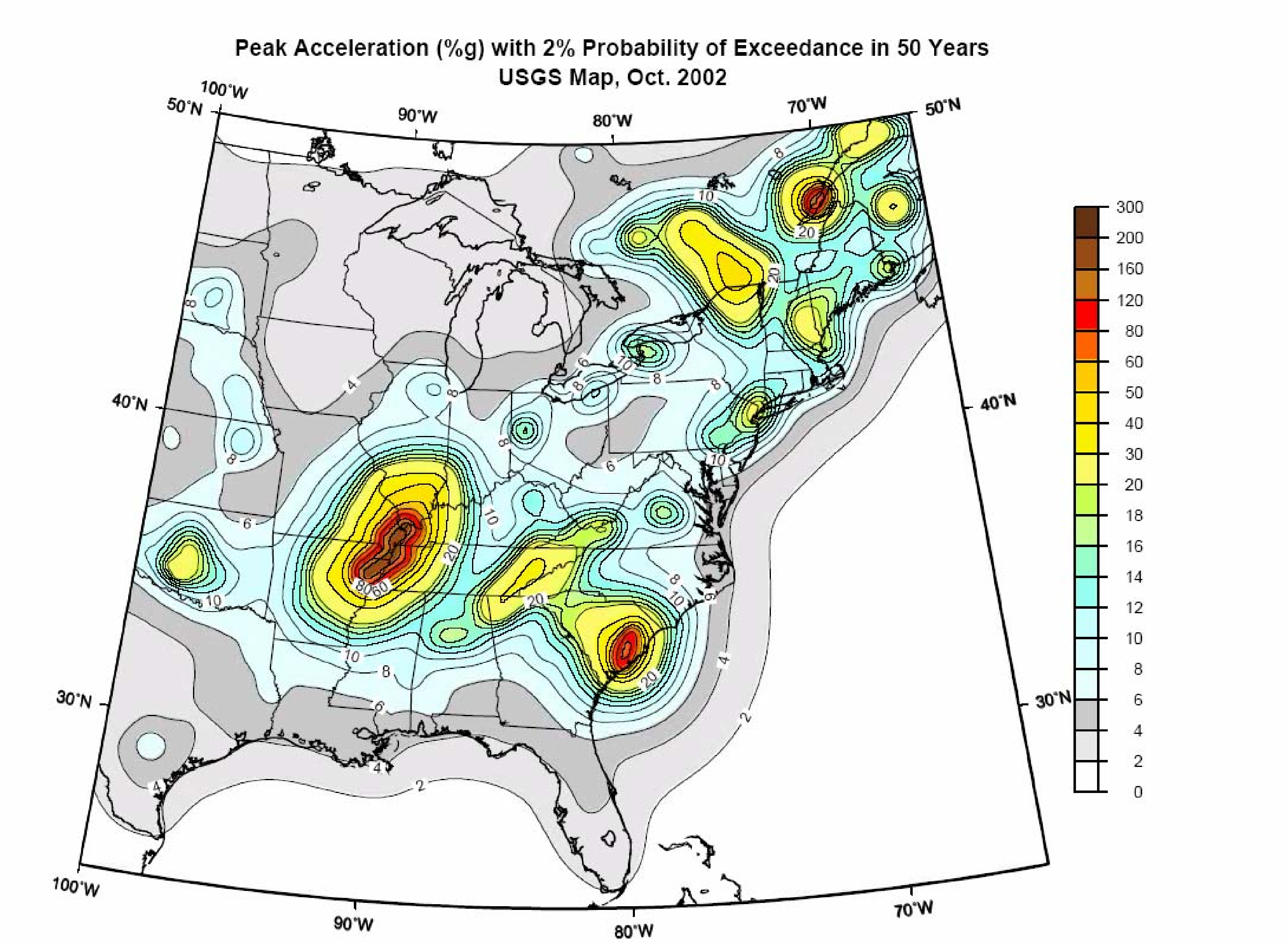
SEISMIC HAZARD ANALYSIS



Seismic Hazard Analysis

- Deterministic procedures
- Probabilistic procedures
- USGS hazard maps
- 2003 *NEHRP Provisions* design maps
- Site amplification
- *NEHRP Provisions* response spectrum
- UBC response spectrum

Hazard vs Risk

Seismic hazard analysis
describes the potential for dangerous, earthquake-related natural phenomena such as ground shaking, fault rupture, or soil liquefaction.

Seismic risk analysis
assesses the probability of occurrence of losses (human, social, economic) associated with the seismic hazards.

Approaches to Seismic Hazard Analysis

Deterministic

"The earthquake hazard for the site is a peak ground acceleration of 0.35g resulting from an earthquake of magnitude 6.0 on the Balcones Fault at a distance of 12 miles from the site. "

Probabilistic

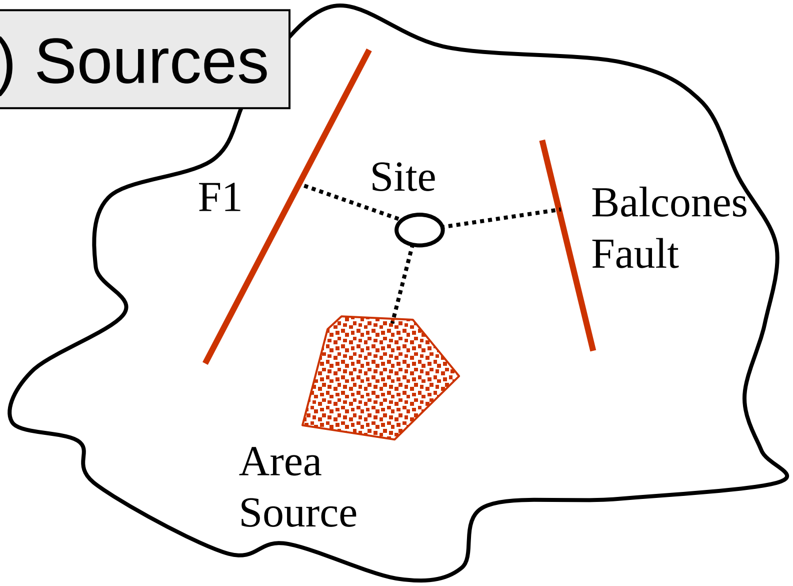
"The earthquake hazard for the site is a peak ground acceleration of 0.28g with a 2 percent probability of being exceeded in a 50-year period."

Probabilistic Seismic Hazard Analysis

First addressed in 1968 by C. Allin Cornell in "Engineering Seismic Risk Analysis," and article in the *Bulletin of the Seismological Society* (Vol. 58, No. 5, October).

Steps in Deterministic Seismic Hazard Analysis

(1) Sources

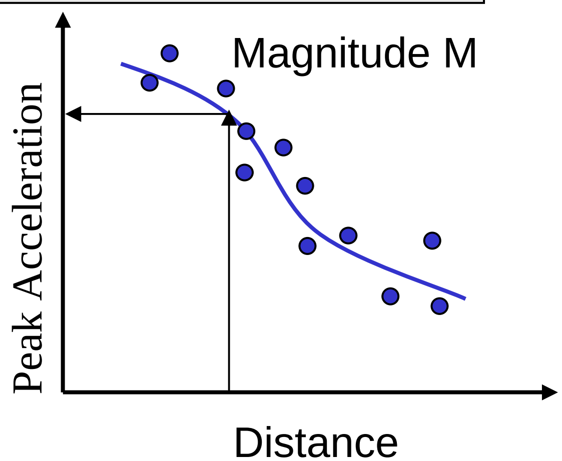


(2) Controlling Earthquake

Fixed distance R

Fixed magnitude M

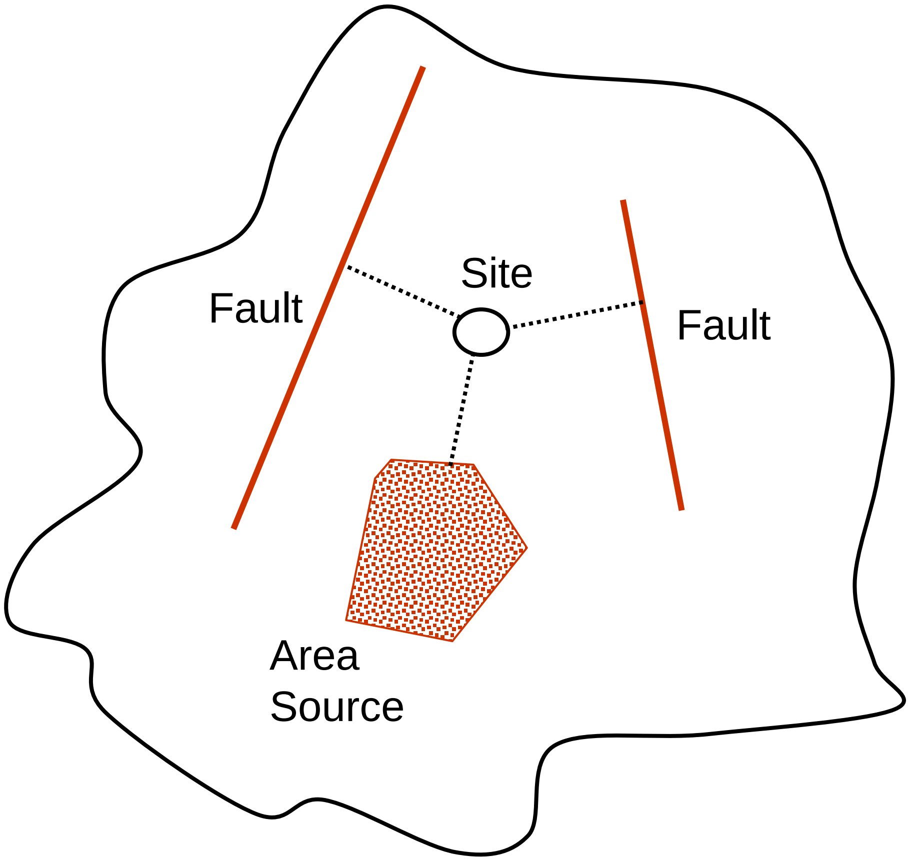
(3) Ground Motion



(4) Hazard at Site

"The earthquake hazard for the site is a peak ground acceleration of 0.35 g resulting from an earthquake of magnitude 6.0 on the Balcones Fault at a distance of 12 miles from the site. "

Source Types



- Fault
- Localizing structure
- Seismotectonic province

Source Types

Localizing structure: An identifiable geological structure that is assumed to generate or "localize" earthquakes. This is generally a concentration of known or unknown active faults.

Seismotectonic province: A region where there is a known seismic hazard but where there are no identifiable active faults or localizing structures.

Maximum Earthquake

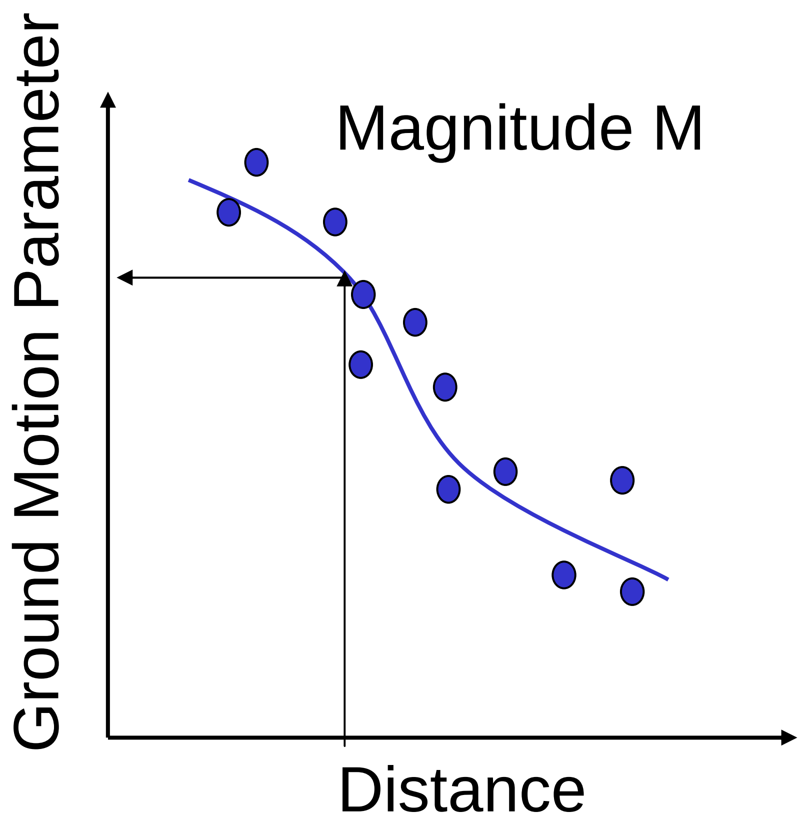
Maximum possible earthquake: An upper bound to size (however unlikely) determined by earthquake processes (e.g., maximum seismic moment).

Maximum credible earthquake: The maximum reasonable earthquake size based on earthquake processes (but does not imply likely occurrence).

Maximum historic earthquake: The maximum historic or instrumented earthquake that is often a lower bound on maximum possible or maximum credible earthquake.

Maximum considered earthquake: Described later.

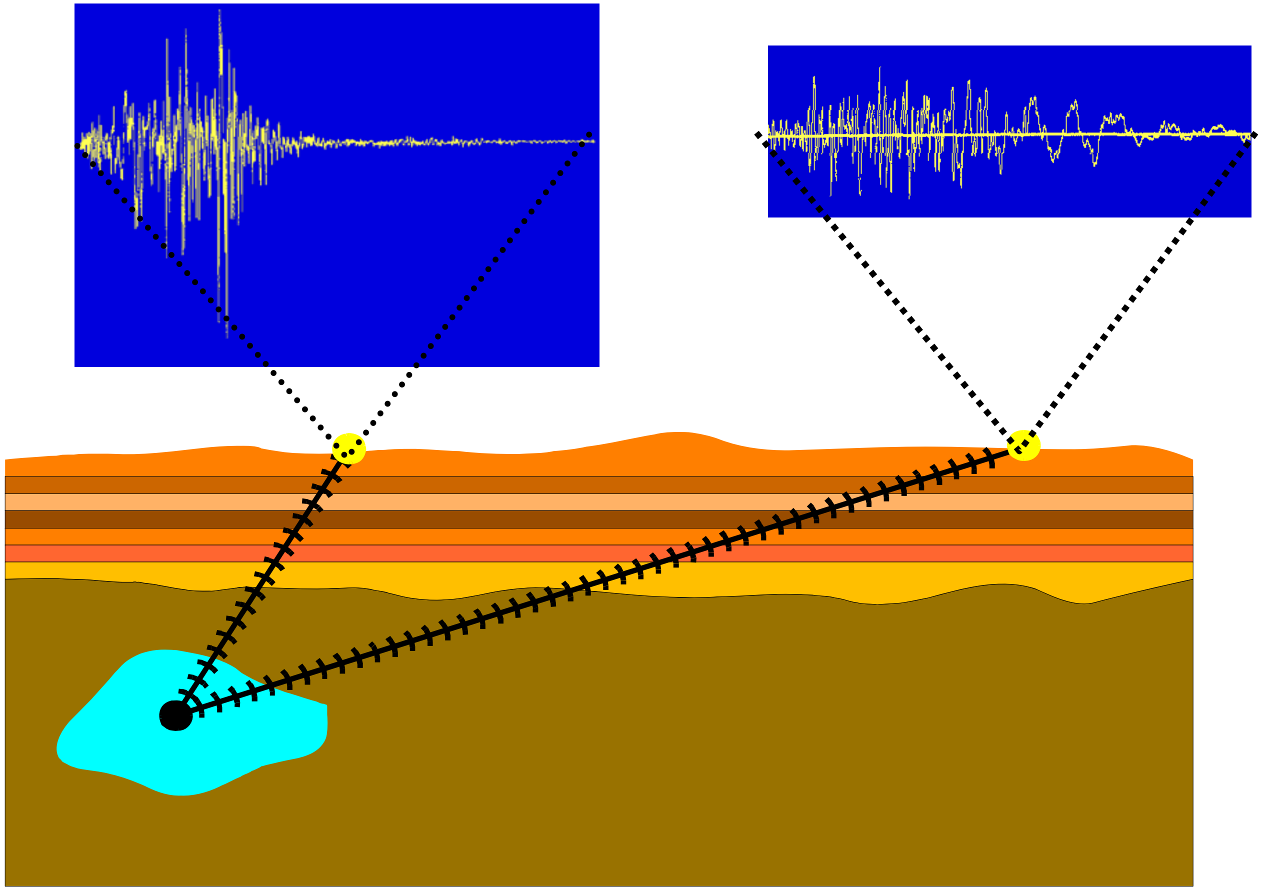
Ground Motion Attenuation



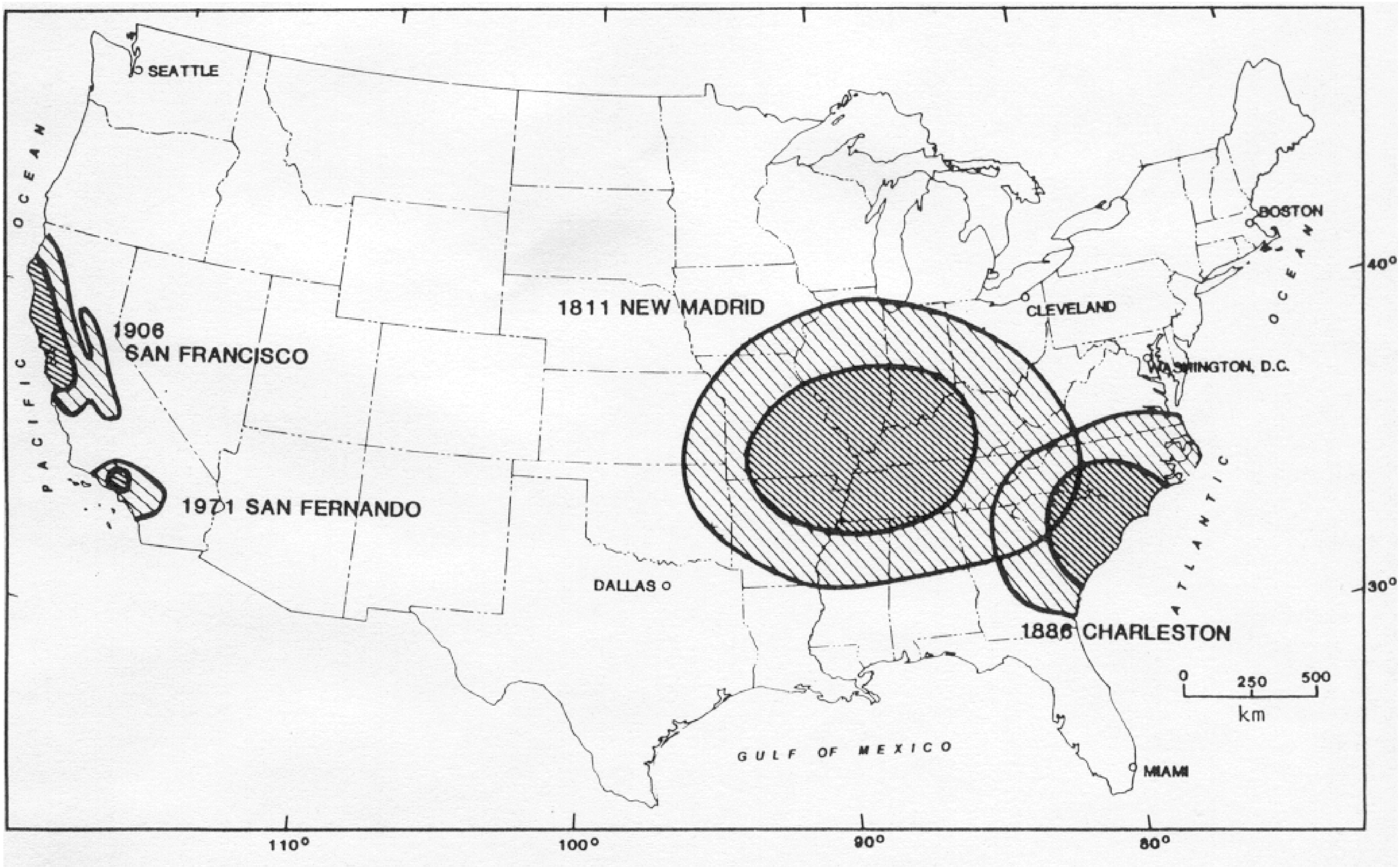
Reasons:

- Geometric spreading
- Absorption (damping)

Attenuation with Distance



Comparison of Attenuation for Four Earthquakes



Ground Motion Attenuation
Steps to Obtain Empirical Relationship

1. Obtain catalog of appropriate ground motion records
2. Correct for aftershocks, foreshocks
3. Correct for consistent magnitude measure
4. Fit data to empirical relationship of type:

$$\ln \hat{Y} = \ln b_1 + f_1(M) + \ln f_2(R) + \ln f_3(M, R) + \ln f_4(P_i) + \ln \varepsilon$$

Ground Motion Attenuation
Basic Empirical Relationships

$$\ln \hat{Y} = \ln b_1 + f_1(M) + \ln f_2(R) + \ln f_3(M,R) + \ln f_4(P_i) + \ln \varepsilon$$

$\hat{Y}$ Ground motion parameter (e.g. PGA)

b_1 Scaling factor

$f_1(M)$ Function of magnitude

$f_2(R)$ Function of distance

$f_3(M,R)$ Function of magnitude and distance

$f_4(P_i)$ Other variables

ε Error term

Ground Motion Attenuation Relationships for Different Conditions

- Central and eastern United States
- Subduction zone earthquakes
- Shallow crustal earthquakes
- Near-source attenuation
- Extensional tectonic regions
- Many others

May be developed for any desired quantity (PGA, PGV, spectral response).

Ground Motion Attenuation Relationships

Seismological Research Letters
Volume 68, Number 1
January/February, 1997

Earthquake Catalog for Shallow Crustal Earthquakes

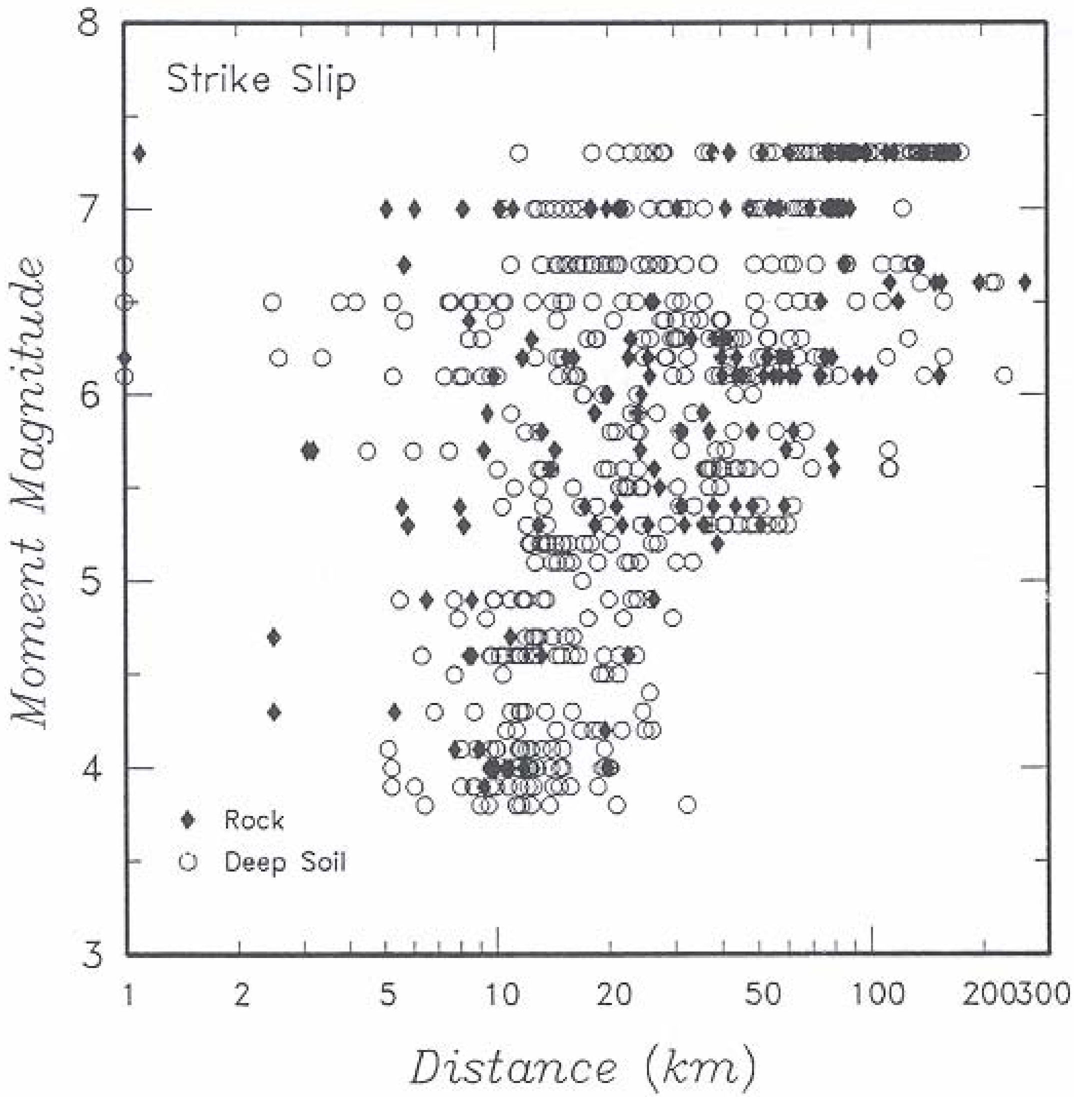
(Sadigh, Chang, Egan, Makdisi, and Youngs)

TABLE 1
List of Earthquakes Used to Develop Attenuation Relationships

Earthquake	Date	M	Fault Type[1]	Distance Range (km)	No. of Records[2]	
					R	DS
Kern County,CA	1952/07/21	7.4	RV	120.5–224.0	0	3
Port Hueneme, CA	1957/03/18	4.7	RV	14.1–14.1	0	1
Daly City, CA	1957/03/22	5.3	RV	9.5–9.5	1	0
Parkfield, CA	1966/06/27	6.1	SS	0.1–230.0	1	6
Borrego Mtn., CA	1968/04/09	6.6	SS	113.0–261.0	5	3
Santa Rosa, CA (A)	1969/10/02	5.6	SS	80.0–113.0	1	2
Santa Rosa, CA (B)	1969/10/02	5.7	SS	78.9–112.0	1	2
Lytle Creek, CA	1970/09/12	5.3	RV	19.7–76.0	5	2
San Fernando, CA	1971/02/09	6.6	RV	2.8–305.0	11	14
Lake Isabella, CA	1971/03/08	4.1	SS	8.9–8.9	1	0
Bear Valley, CA	1972/02/24	4.7	SS	2.5–2.5	1	0
Point Mugu, CA	1973/02/21	5.6	RV	25.0–25.0	0	1
Hollister, CA	1974/11/28	5.2	SS	39.0–39.0	1	0
Oroville, CA	1975/08/01	5.9	SS	9.5–35.8	2	2
Oroville, CA (R)	1975/08/02	5.1	SS	12.7–14.6	0	2
Oroville, CA (S)	1975/08/02	5.2	SS	12.4–15.0	0	2
Oroville, CA (A)	1975/08/03	4.6	SS	8.4–14.9	1	6

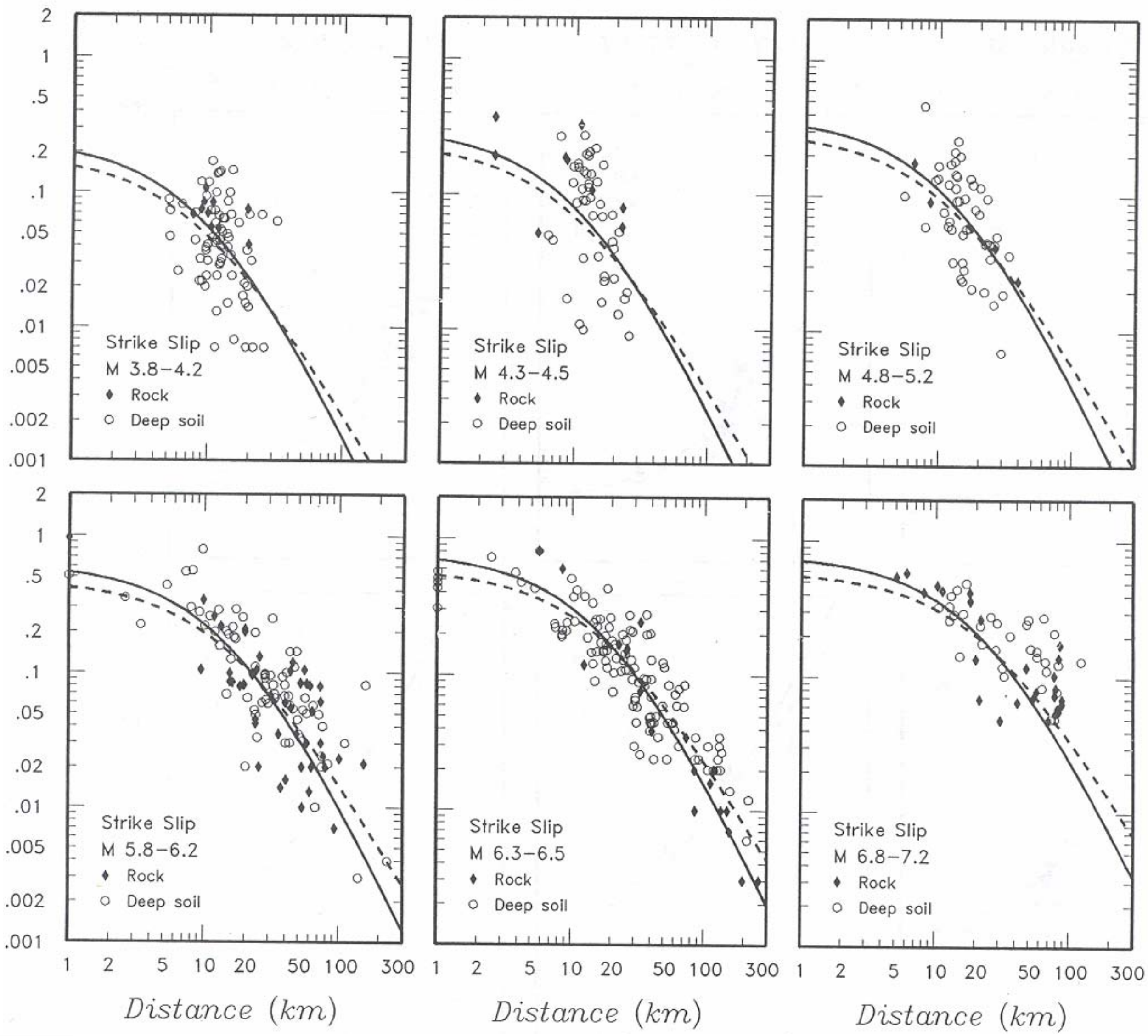
Earthquake Catalog for Shallow Crustal Earthquakes

(Sadigh, Chang, Egan, Makdisi, and Youngs)



Attenuation Relation for Shallow Crustal Earthquakes

(Sadigh, Chang, Egan, Makdisi, and Youngs)



Attenuation Relation for Shallow Crustal Earthquakes

(Sadigh, Chang, Egan, Makdisi, and Youngs)

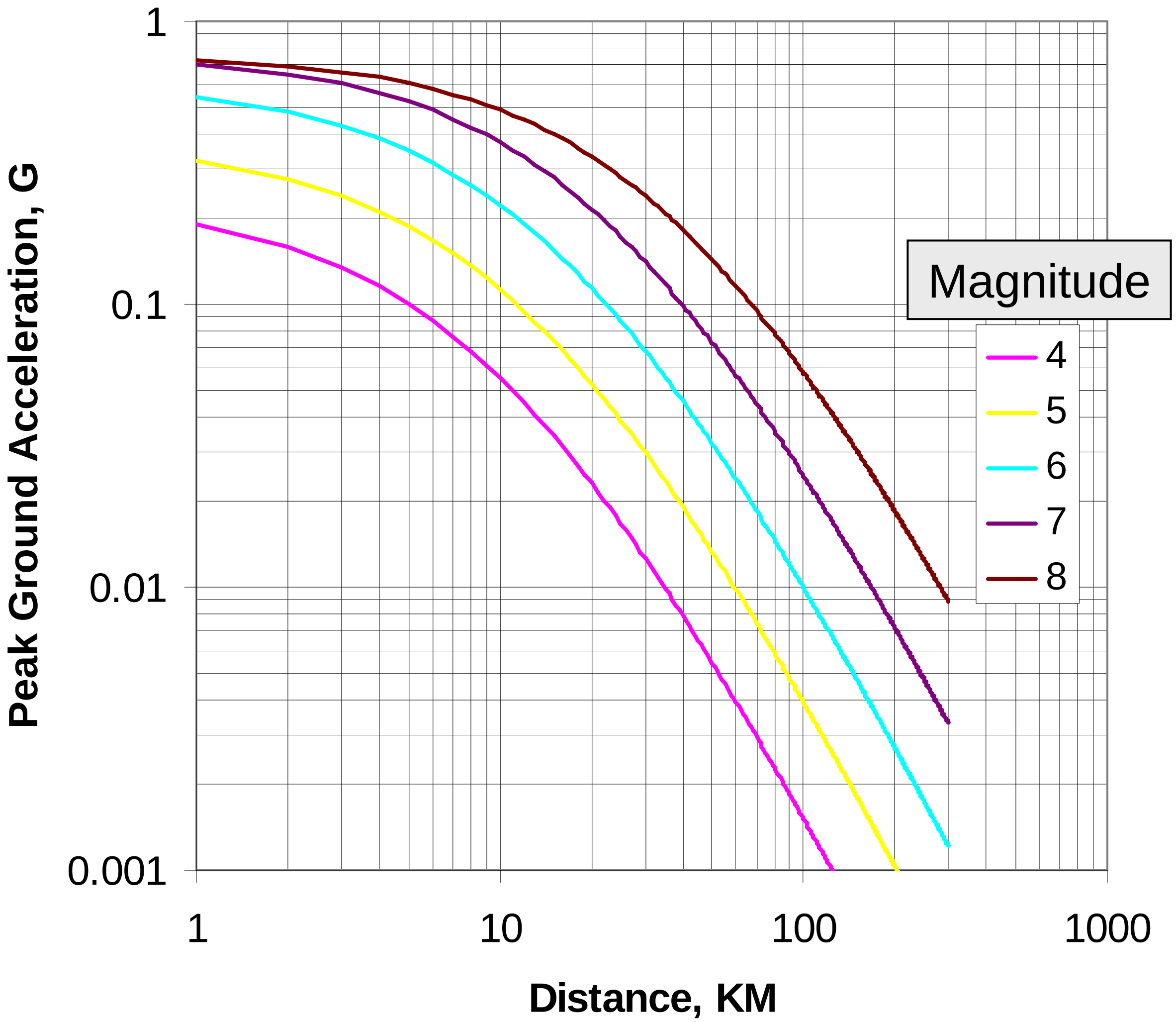
$$\ln(y) = C_1 + C_2 M + C_3 (8.5 - M) + C_4 \ln(r_{rup} + \exp(C_5 + C_6 M)) + C_7 (r_{rup} + 2)$$

T	C_1	C_2	C_3	C_4	C_5	C_6	C_7
PGA	-0.624	1.000	0.000	-2.100	1.296	0.250	0.000
0.07	0.110	1.000	0.006	-2.128	1.296	0.250	-0.082
0.1	0.275	1.000	0.006	-2.148	1.296	0.250	-0.041
0.2	0.153	1.000	-0.004	-2.080	1.296	0.250	0.000
0.3	-0.057	1.000	-0.017	-2.028	1.296	0.250	0.000
0.4	-0.298	1.000	-0.028	-1.990	1.296	0.250	0.000
0.5	-0.588	1.000	-0.040	-1.945	1.296	0.250	0.000
0.75	-1.208	1.000	-0.050	-1.865	1.296	0.250	0.000
1	-1.705	1.000	-0.055	-1.800	1.296	0.250	0.000
1.5	-2.407	1.000	-0.065	-1.725	1.296	0.250	0.000
2	-2.945	1.000	-0.070	-1.670	1.296	0.250	0.000
3	-3.700	1.000	-0.080	-1.610	1.296	0.250	0.000
4	-4.230	1.000	-0.100	-1.570	1.296	0.250	0.000

Table for Magnitude <= 6.5

Attenuation Relation for Shallow Crustal Earthquakes

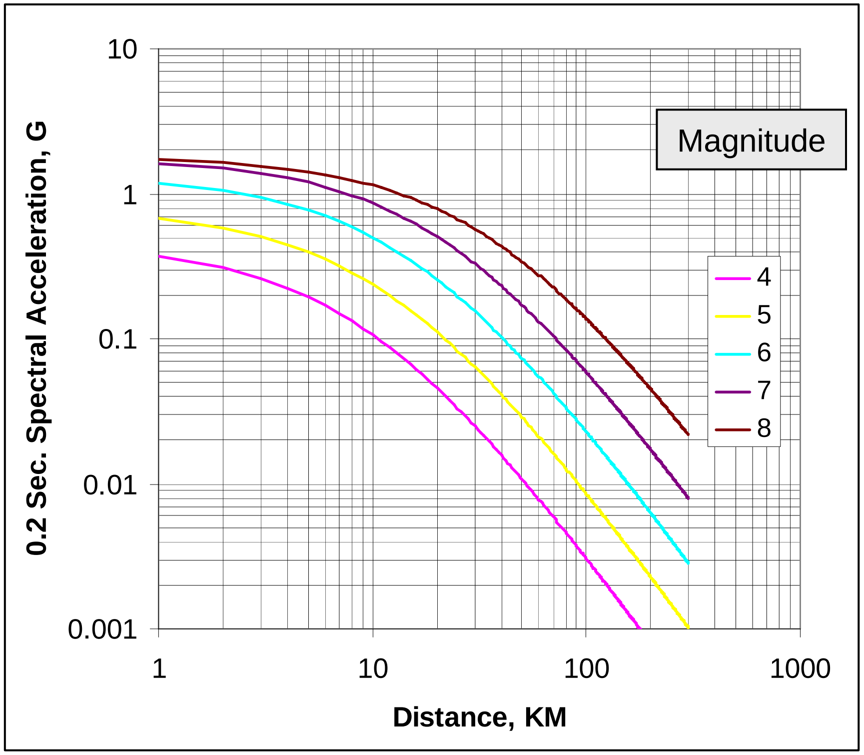
(Sadigh, Chang, Egan, Makdisi, and Youngs)



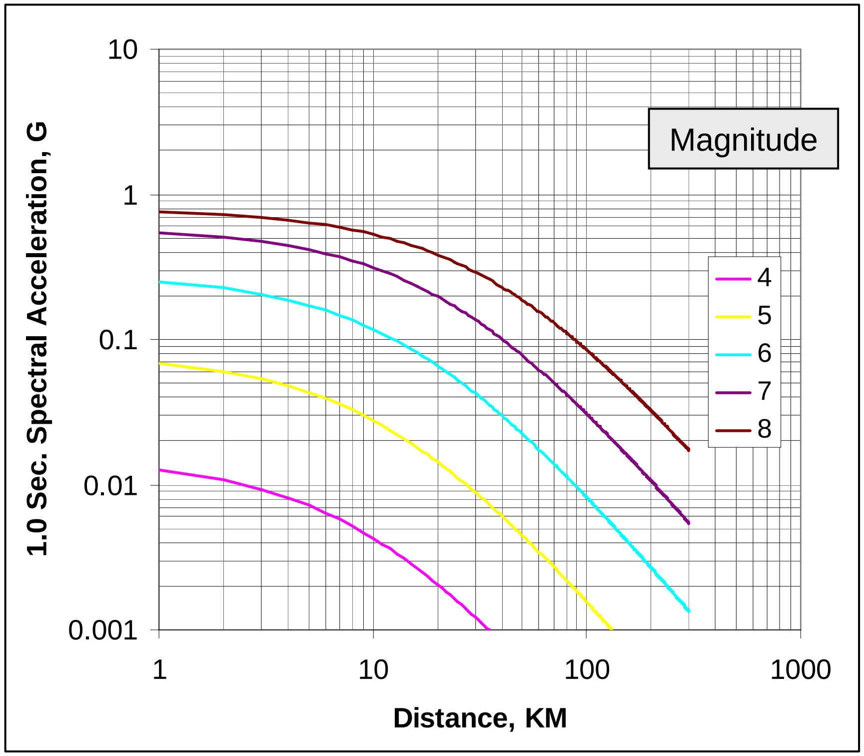
Attenuation Relation for Shallow Crustal Earthquakes

(Sadigh, Chang, Egan, Makdisi, and Youngs)

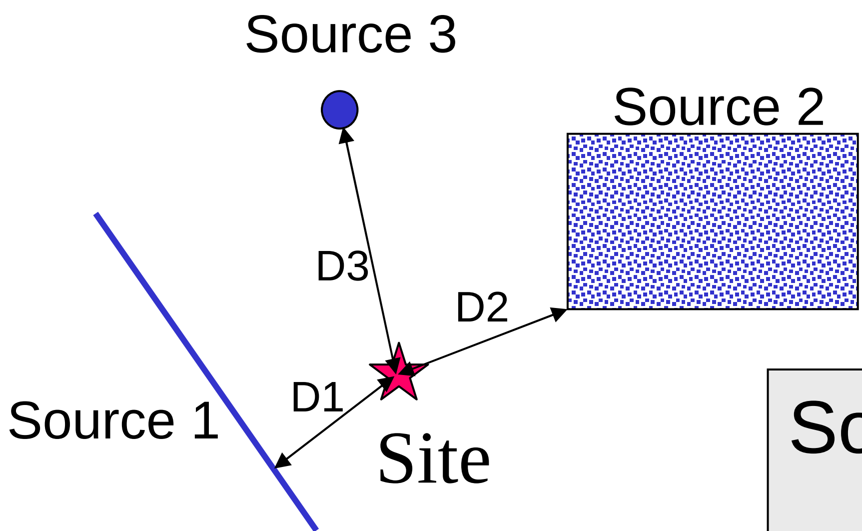
0.2 Second Acceleration



1.0 Second Acceleration



Example Deterministic Analysis (Kramer)

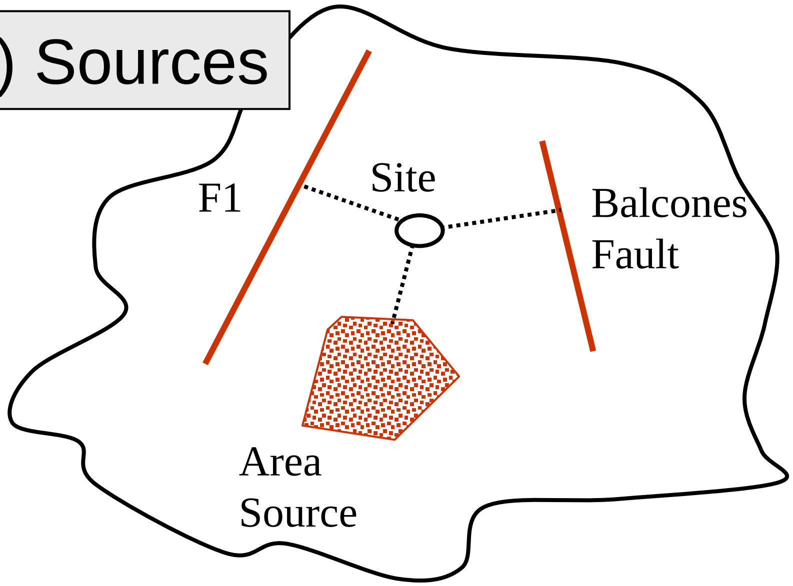


Source	M	D (km)	PGA (g)
1	7.3	23.7	0.42
2	7.7	25.0	0.57
3	5.0	60.0	0.02

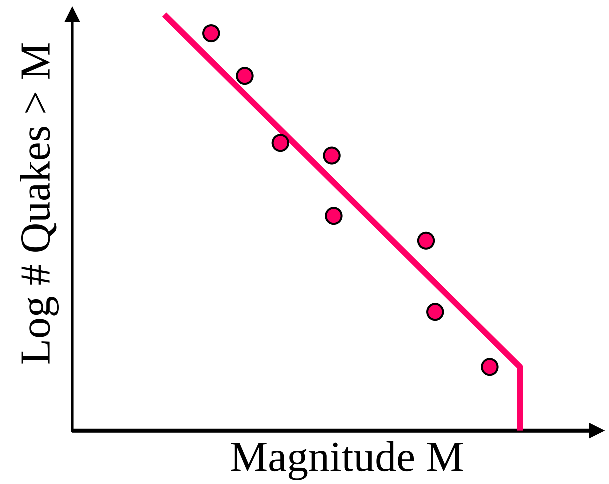
- M: Maximum on source
- D: Closest distance
- PGA: From attenuation relationship

Steps in Probabilistic Seismic Hazard Analysis

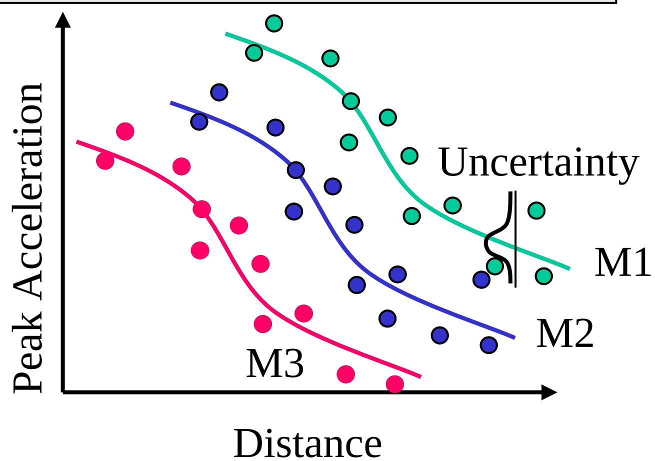
(1) Sources



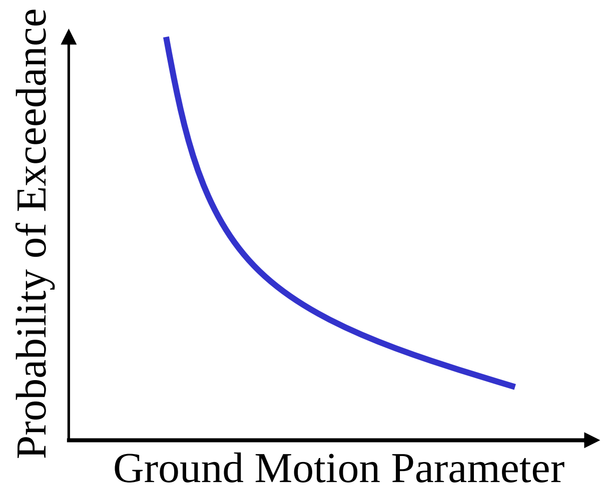
(2) Recurrence



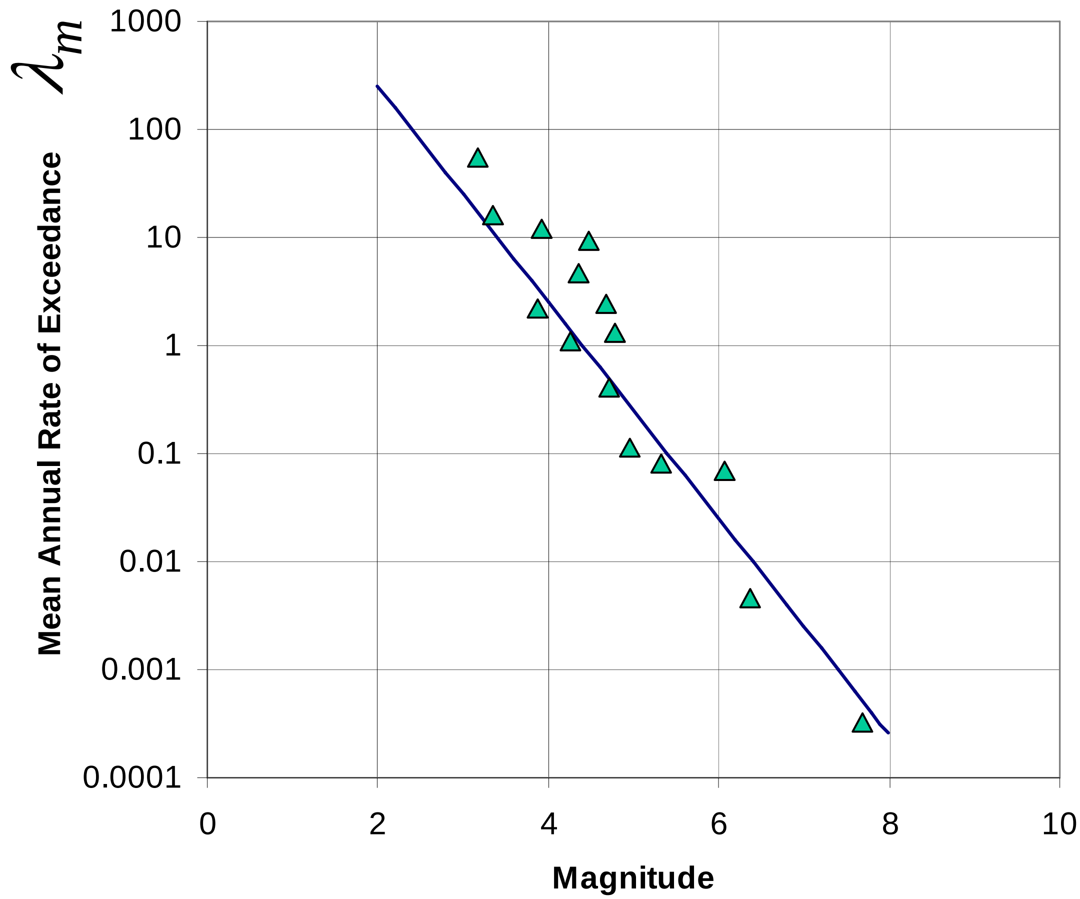
(3) Ground Motion



(4) Probability of Exceedance



Empirical Gutenberg-Richter Recurrence Relationship



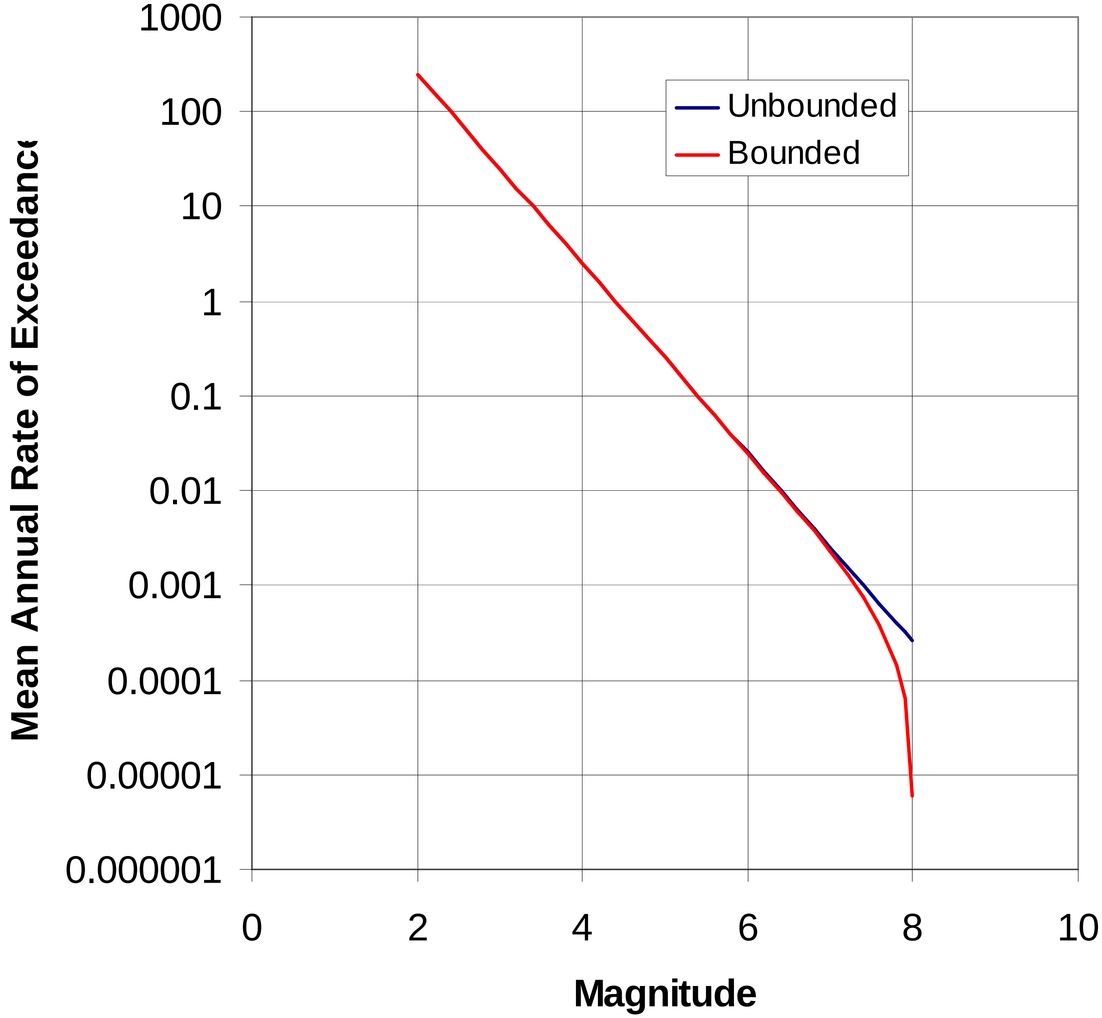
$$\log \lambda_m = a - bm$$

λ_m = mean rate of recurrence (events/year)

$1/\lambda_m$ = return period

a and b to be determined from data

Bounded vs Unbounded Recurrence Relationship



Uncertainties Included in Probabilistic Analysis

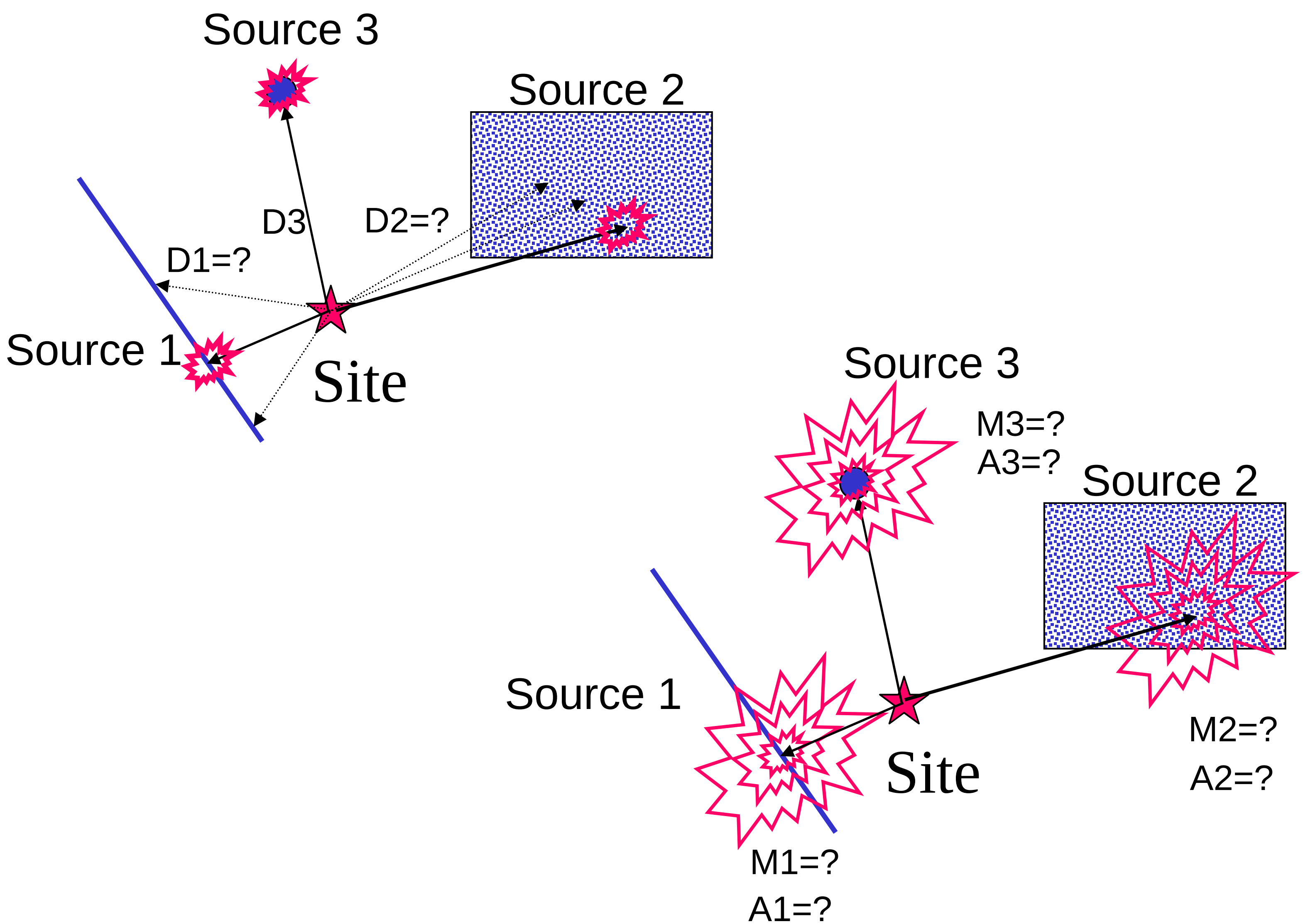
Attenuation laws

Recurrence relationship

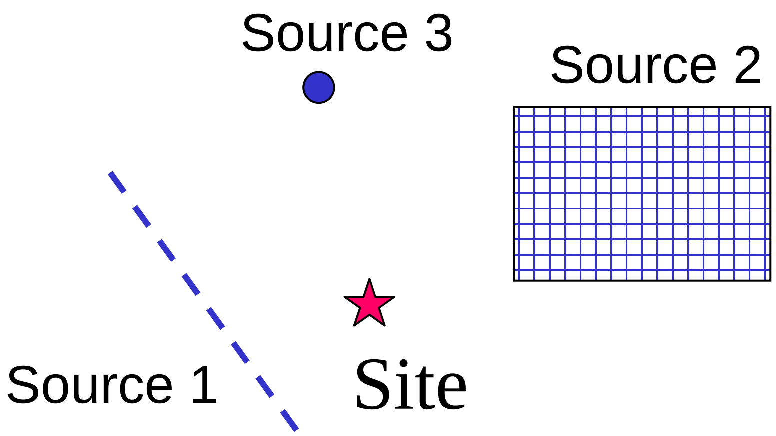
Distance to site

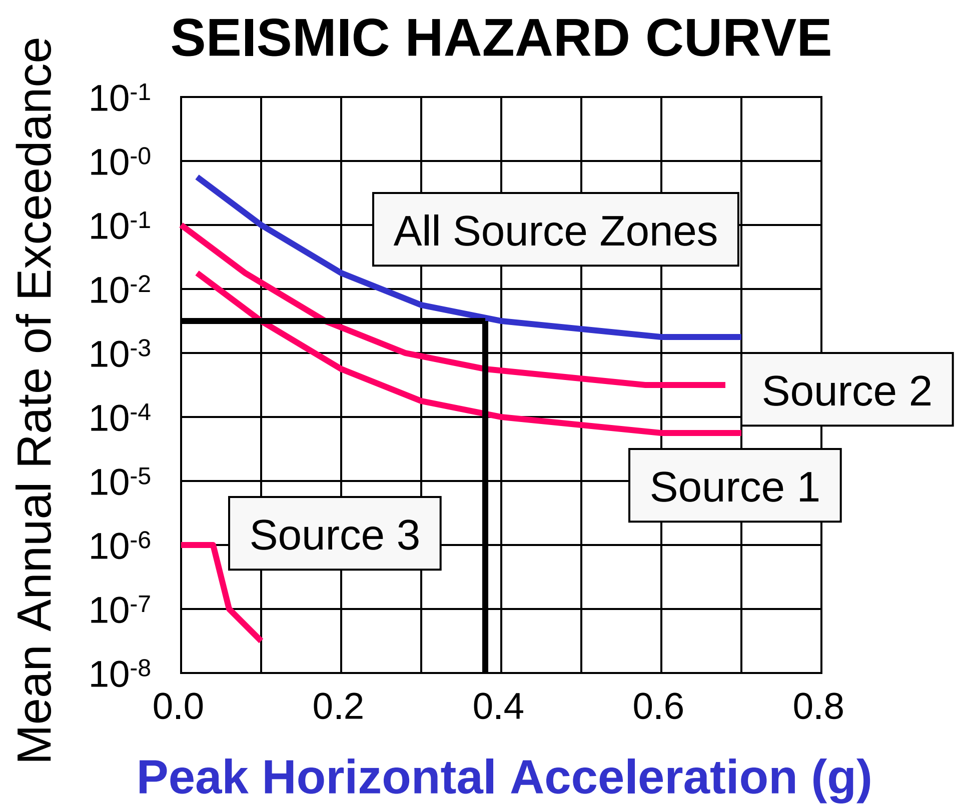
$$\lambda_{y*} = \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} v_i \; P[Y > y* | m_j, r_k] \; P[M = m_j] \; P[R = r_k]$$

Example Probabilistic Analysis (Kramer)



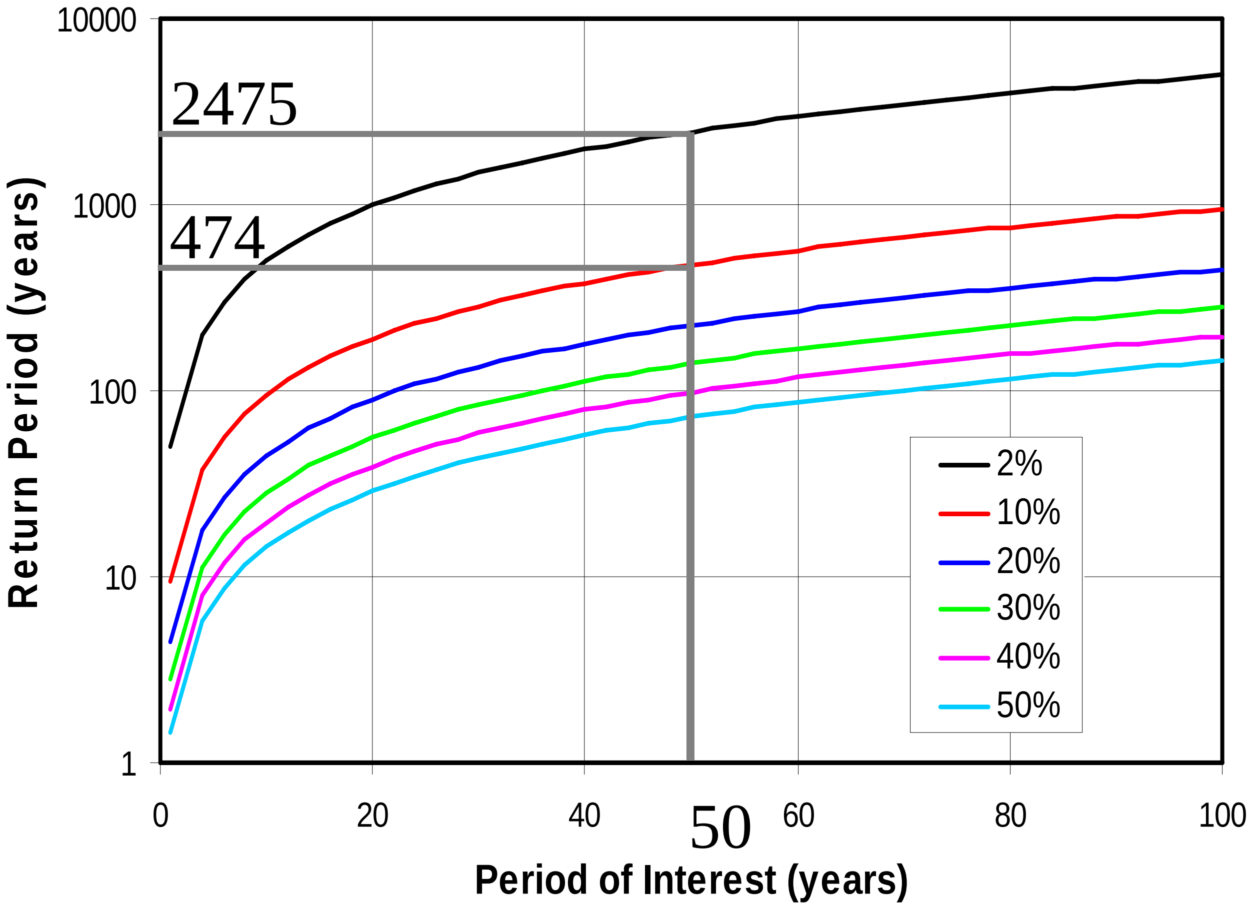
Result of Probabilistic Hazard Analysis





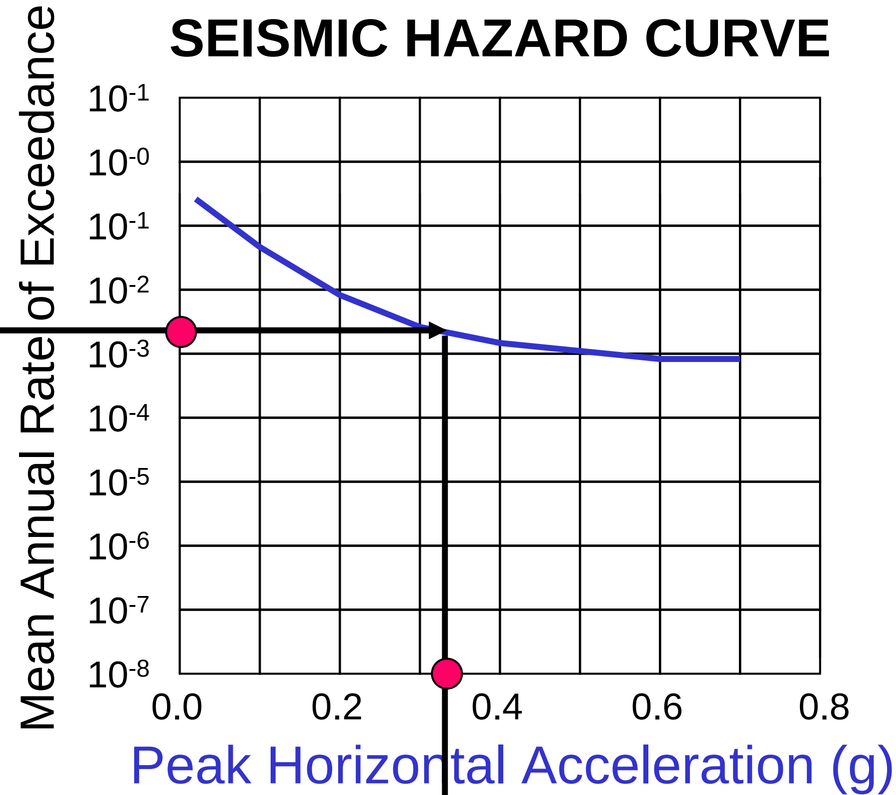
Relationship Between Return Period, Period of Interest, and Probability of Exceedance

Return period = -T/ln(1-P(Z>z))

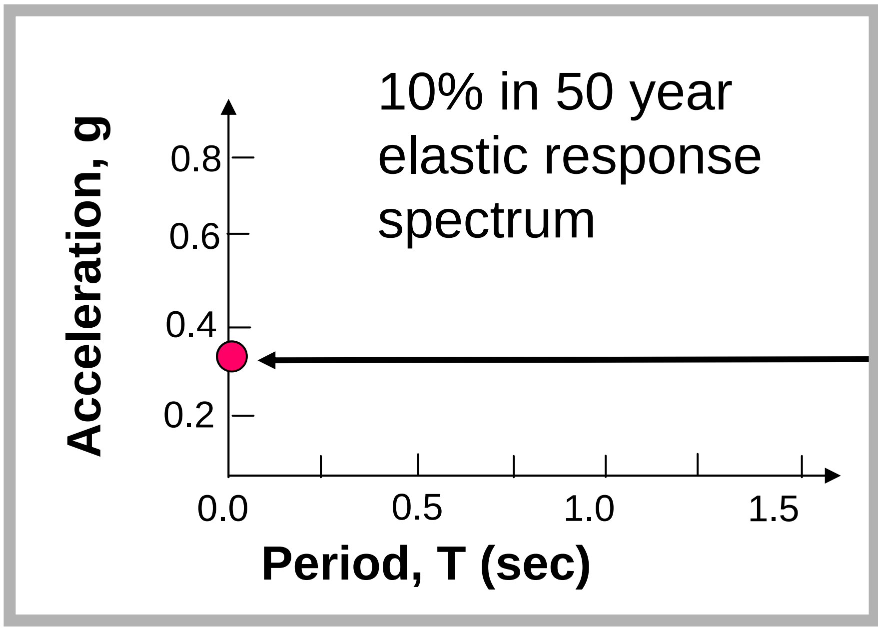


Use of PGA Seismic Hazard Curve

10% probability in 50 years
Return period = 475 years
Rate of exceedance = 1/475=0.0021

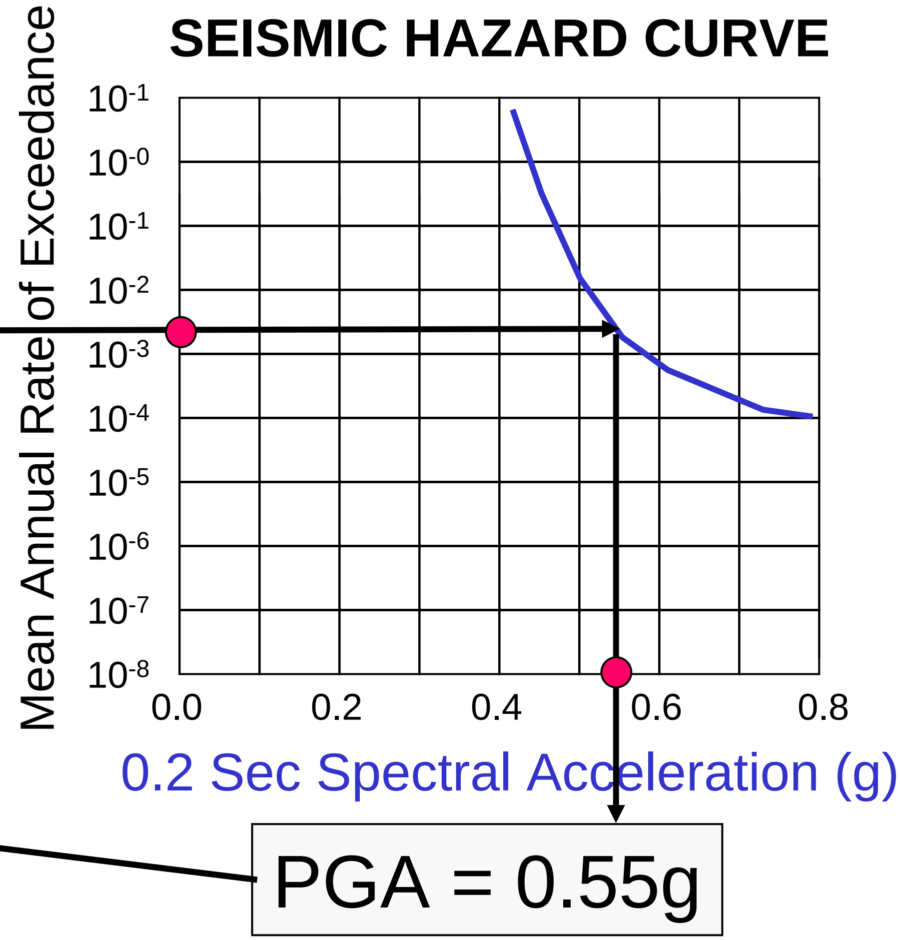


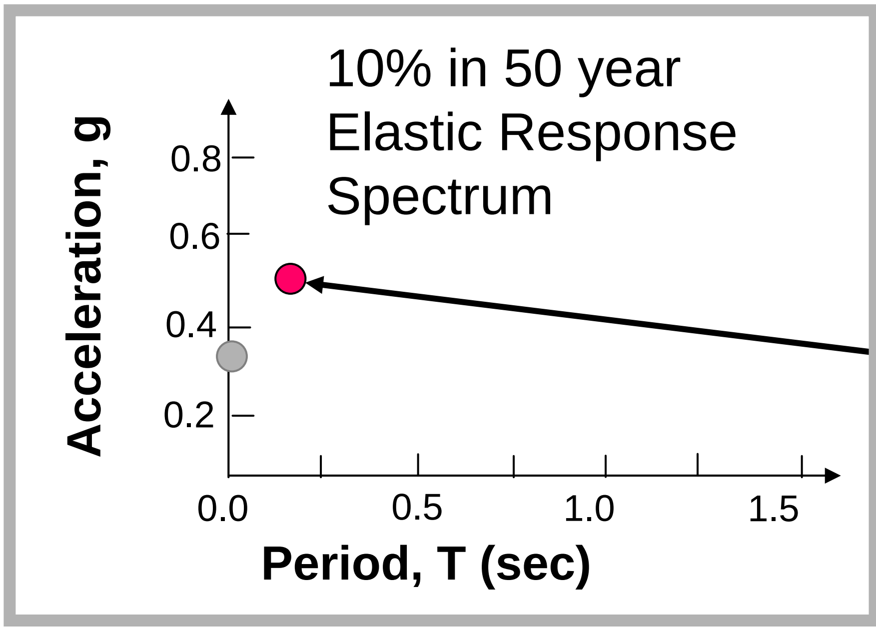
PGA=0.33g



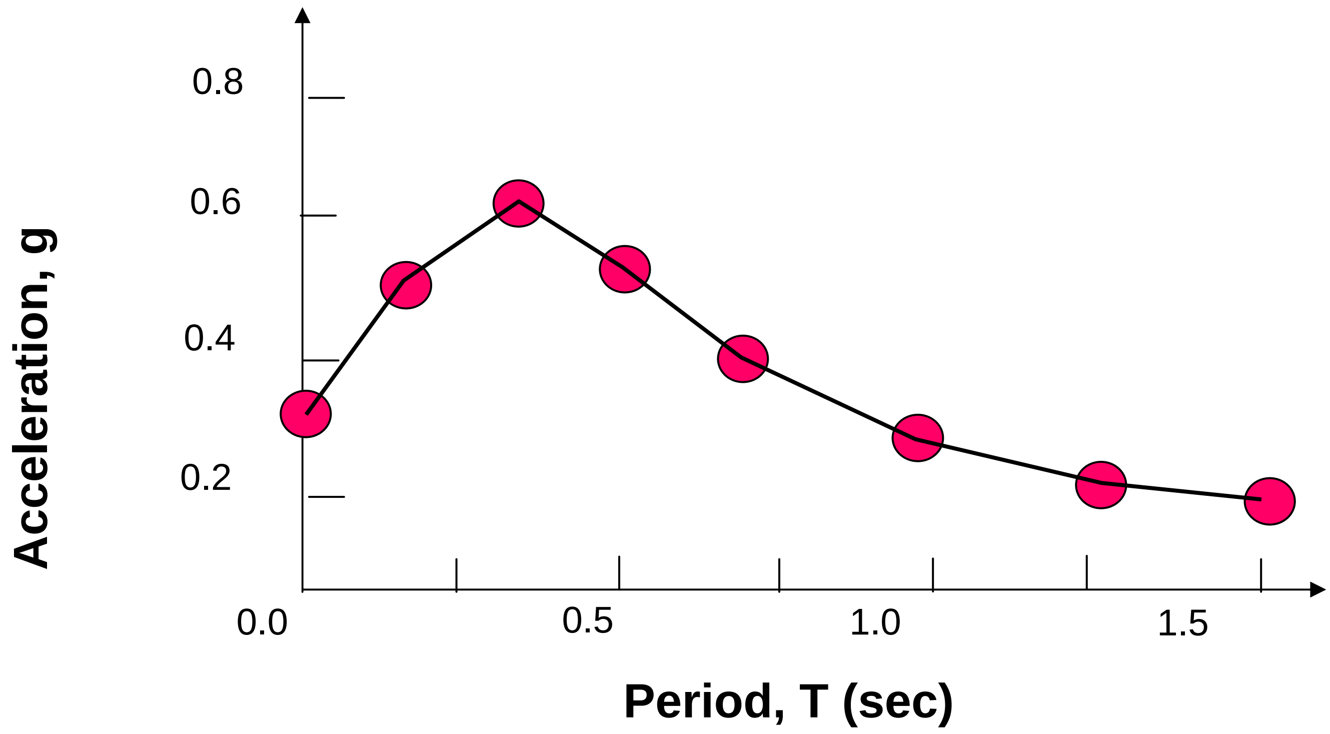
Use of 0.2 Sec. Seismic Hazard Curve

10% probability in 50 years
Return period = 475 years
rate of exceedance = 1/475=0.0021

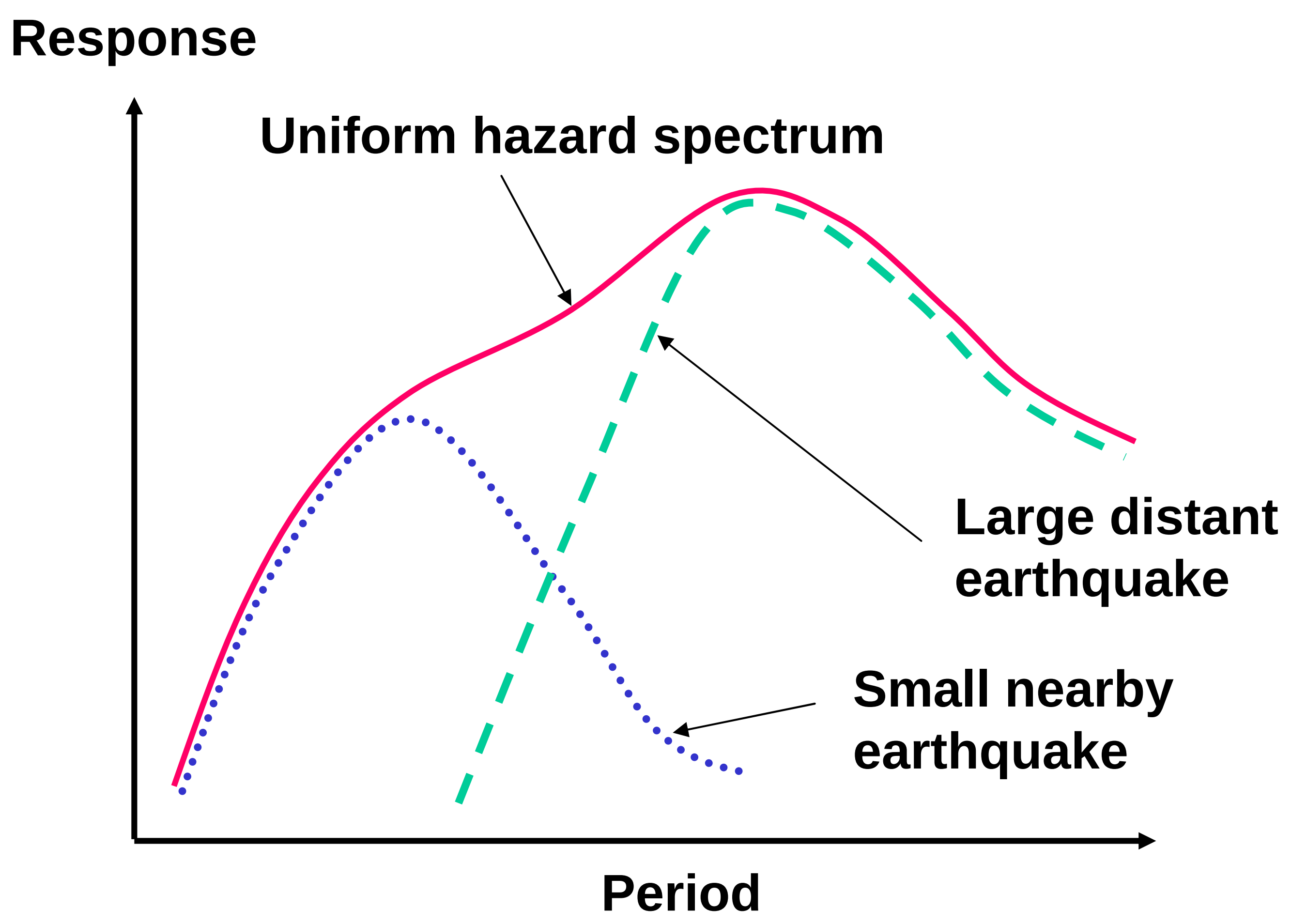




10% in 50 Year Elastic Response Spectrum



Uniform Hazard Spectrum



Uniform Hazard Spectrum

Developed from *probabilistic* analysis

All ordinates have equal probability of exceedance

Represents contributions from small local,
large distant earthquakes

May be overly conservative for modal response spectrum analysis

May not be appropriate for artificial ground motion generation

Probabilistic vs Deterministic Seismic Hazard Analysis

"The *deterministic* approach provides a clear and trackable method of computing seismic hazard whose assumptions are easily discerned. It provides understandable scenarios that can be related to the problem at hand."

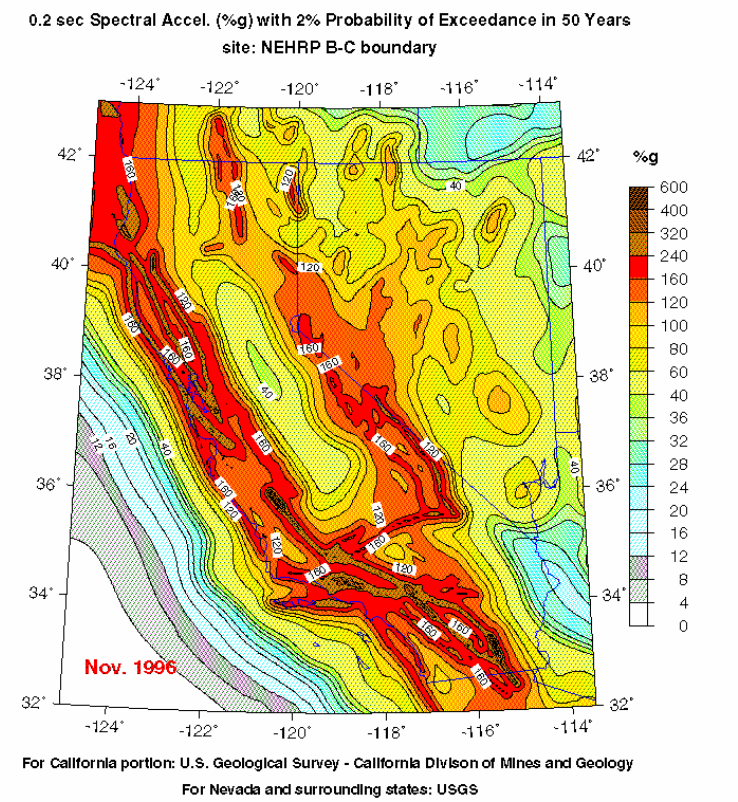
"However, it has no way for accounting for uncertainty. Conclusions based on deterministic analysis can easily be upset by the occurrence of new earthquakes."

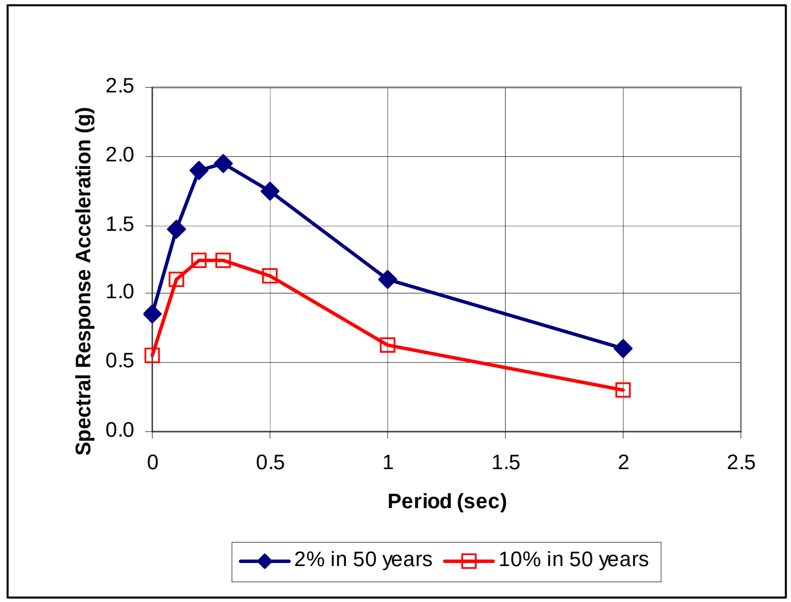
Probabilistic vs Deterministic Seismic Hazard Analysis

"The *probabilistic* approach is capable of integrating a wide range of information and uncertainties into a flexible framework."

"Unfortunately, its highly integrated framework can obscure those elements which drive the results, and its highly quantitative nature can lead to false impressions of accuracy."

USGS Probabilistic Hazard Maps (Project 97)





HAZARD MAP

RESPONSE SPECTRA

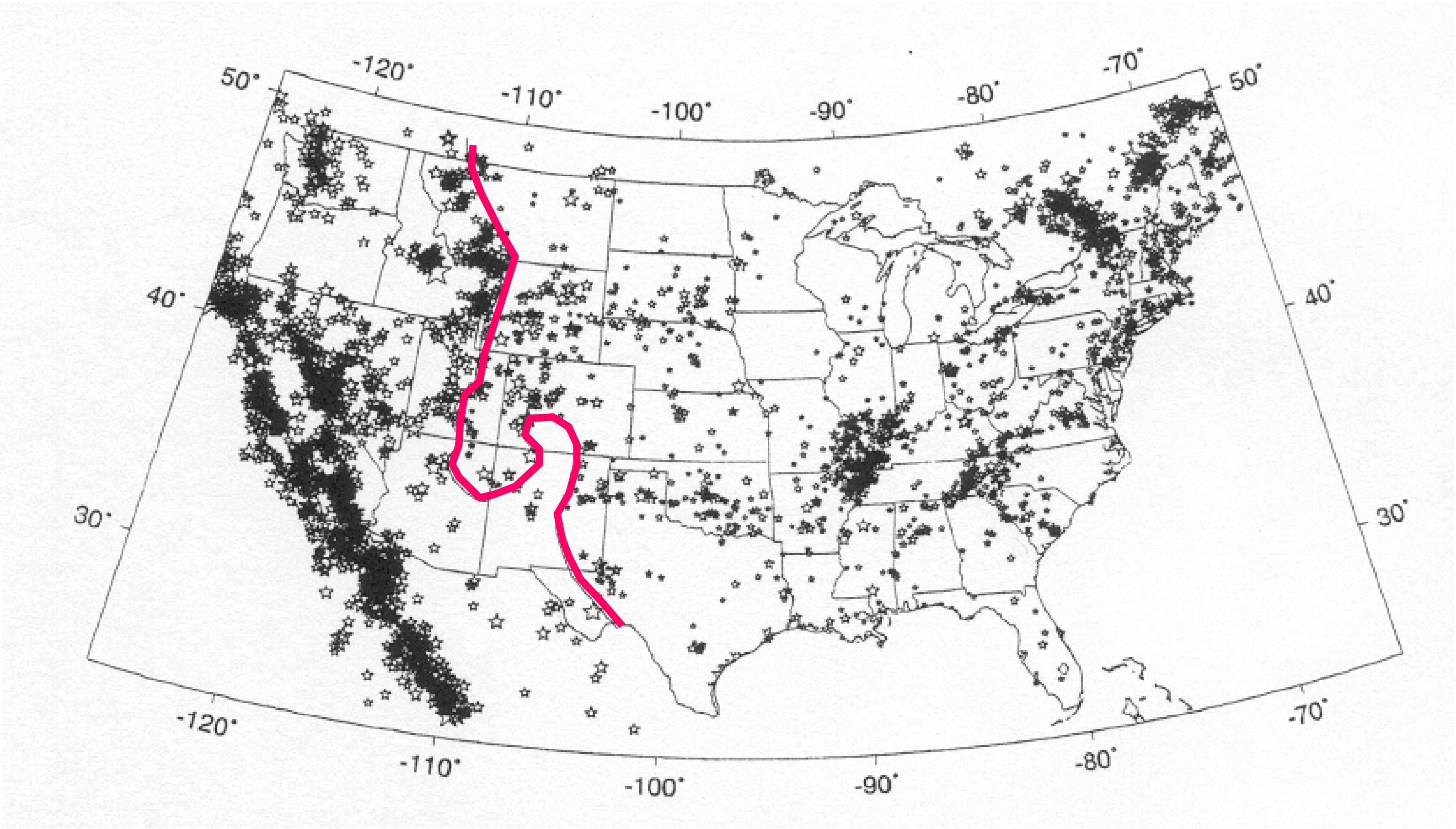
USGS Probabilistic Hazard Maps (and *NEHRP Provisions* Maps)

Earthquake Spectra, Seismic Design Provisions and Guidelines Theme Issue, Volume 16, Number 1, February 2000

Maximum Considered Earthquake (MCE)

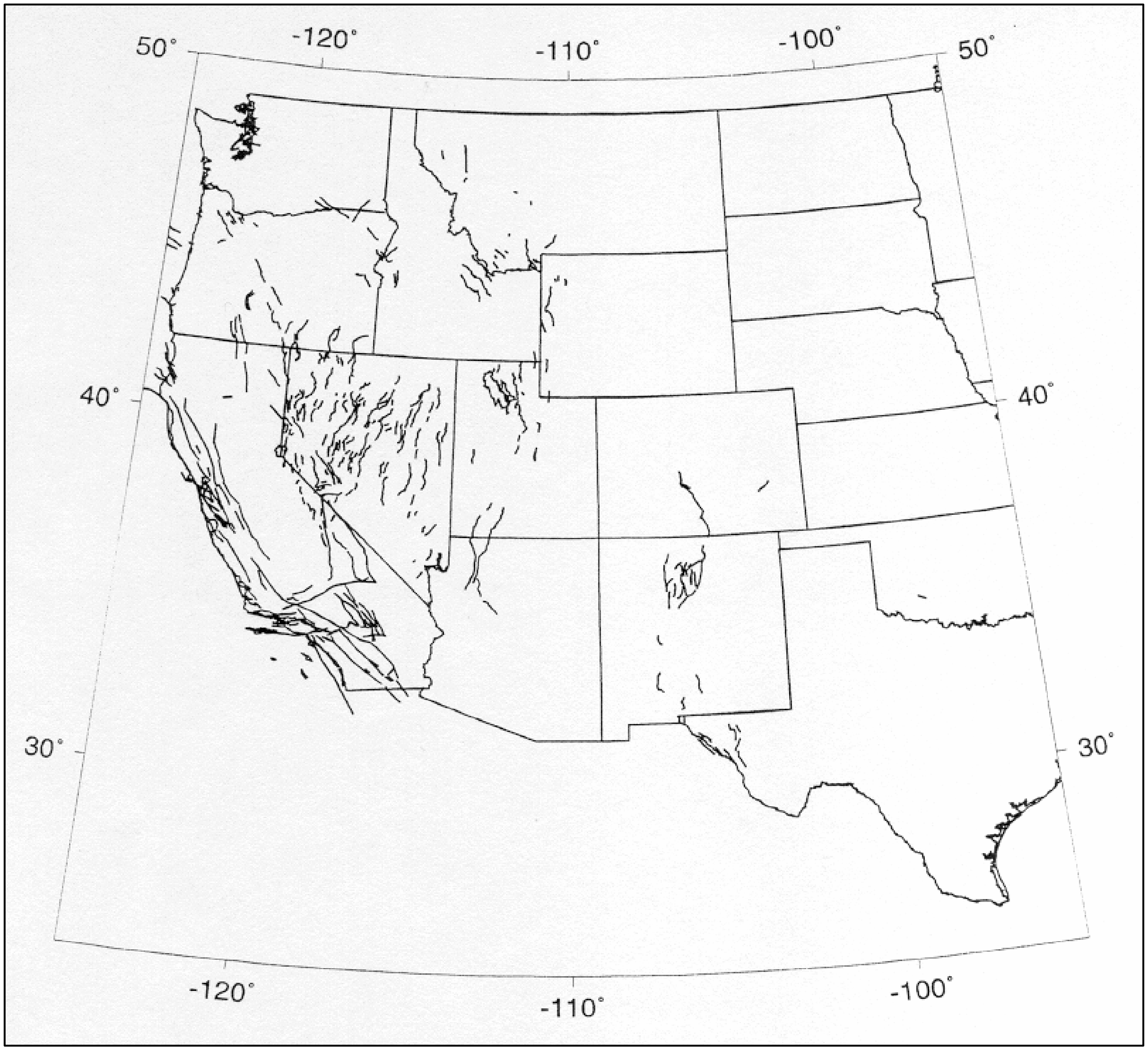
The MCE ground motions are defined as the maximum level of earthquake shaking that is considered as reasonable to design normal structures to resist.

USGS Seismic Hazard Regions

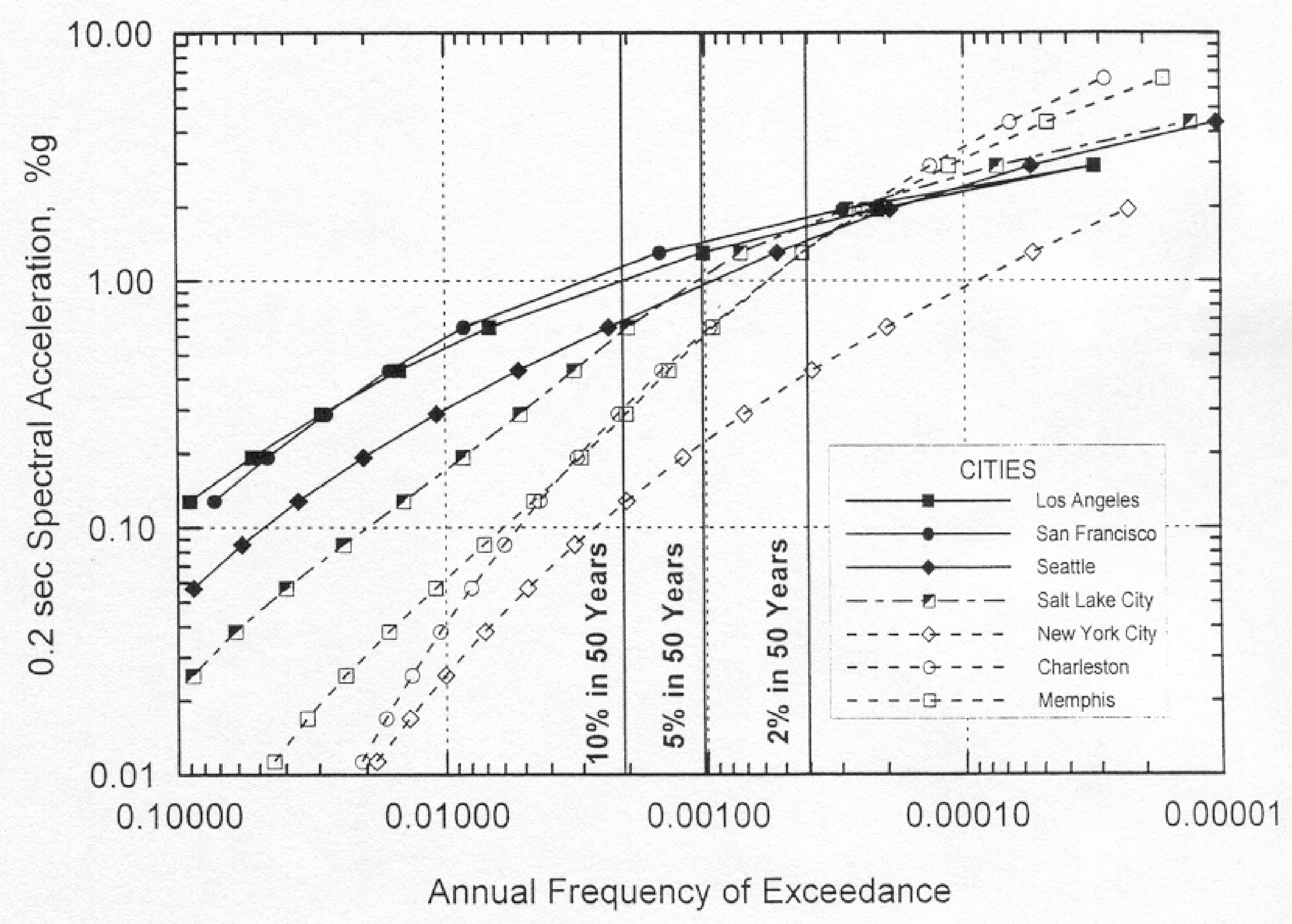


Note: Different attenuation relationships used for different regions.

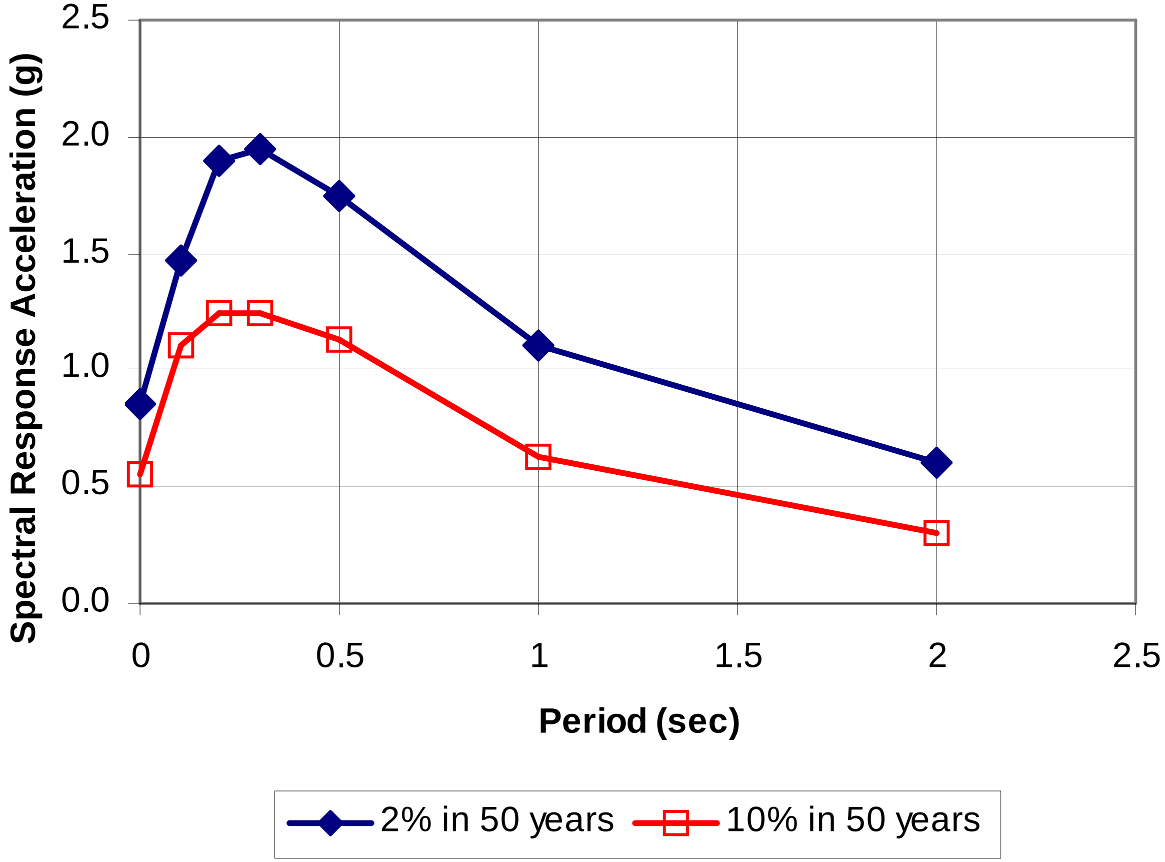
USGS Seismic Hazard WUS Faults



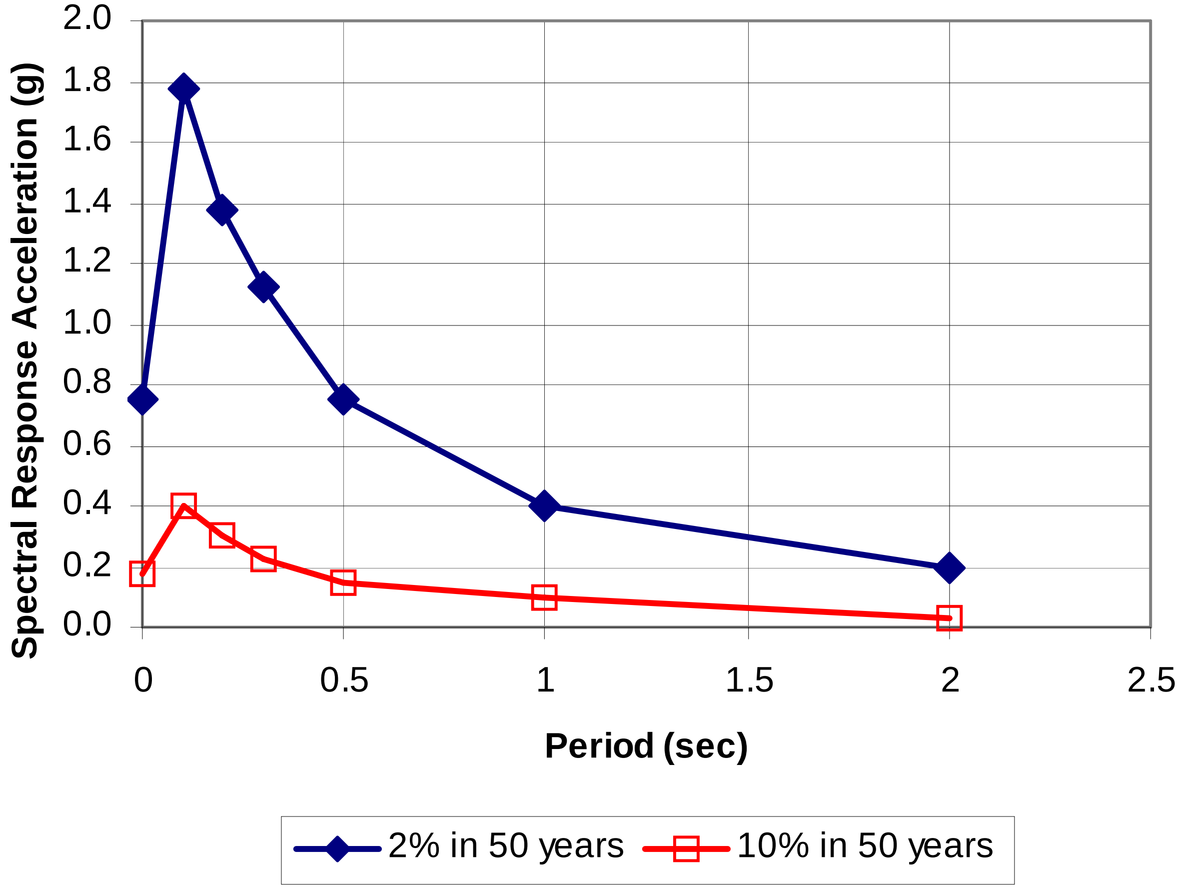
USGS Seismic Hazard Curves for Various Cities



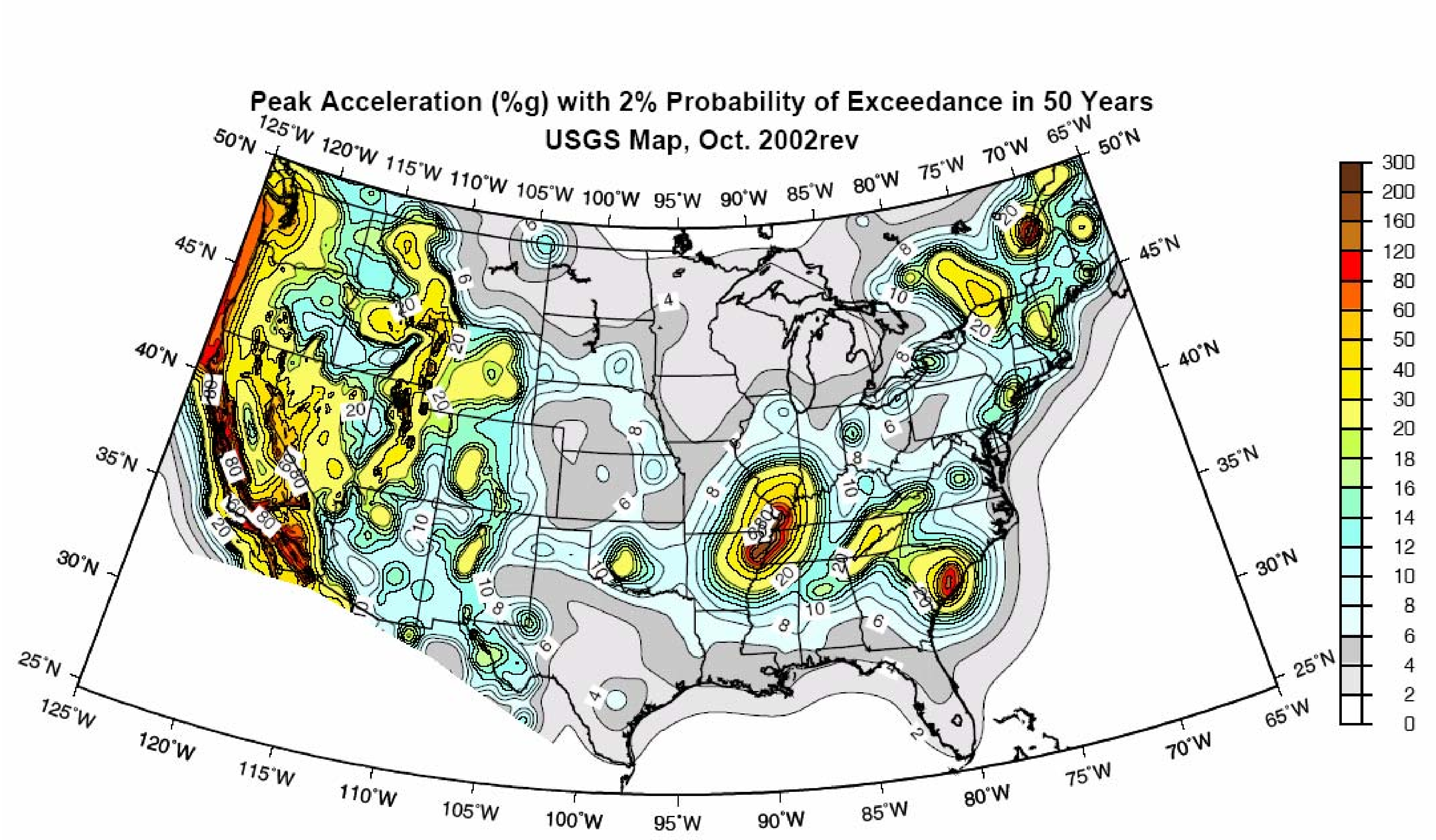
Uniform Hazard Spectra for San Francisco



Uniform Hazard Spectra for Charleston, SC

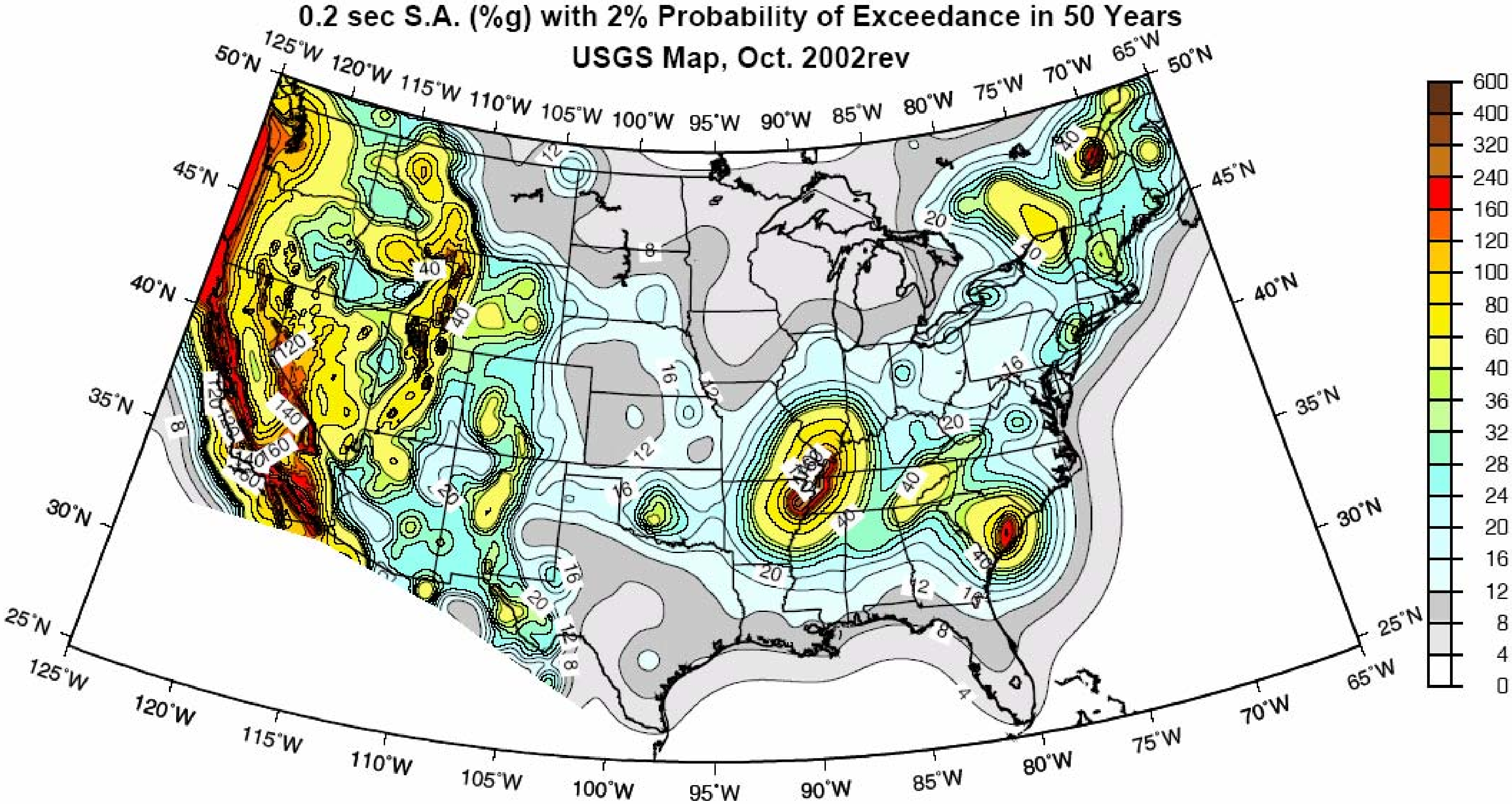


USGS Seismic Hazard Map of Coterminous United States

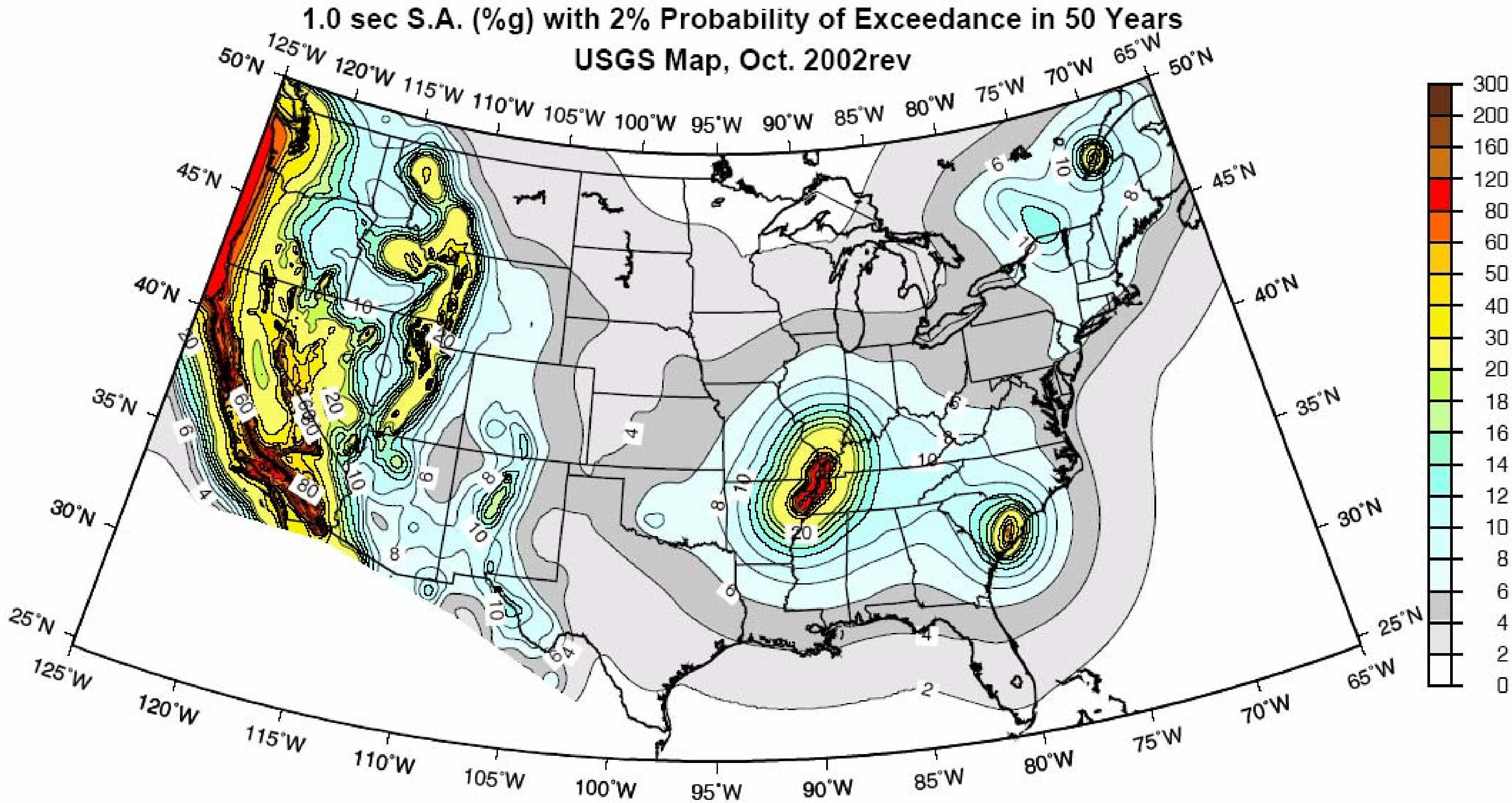


http://earthquake.usgs.gov/hazmaps/

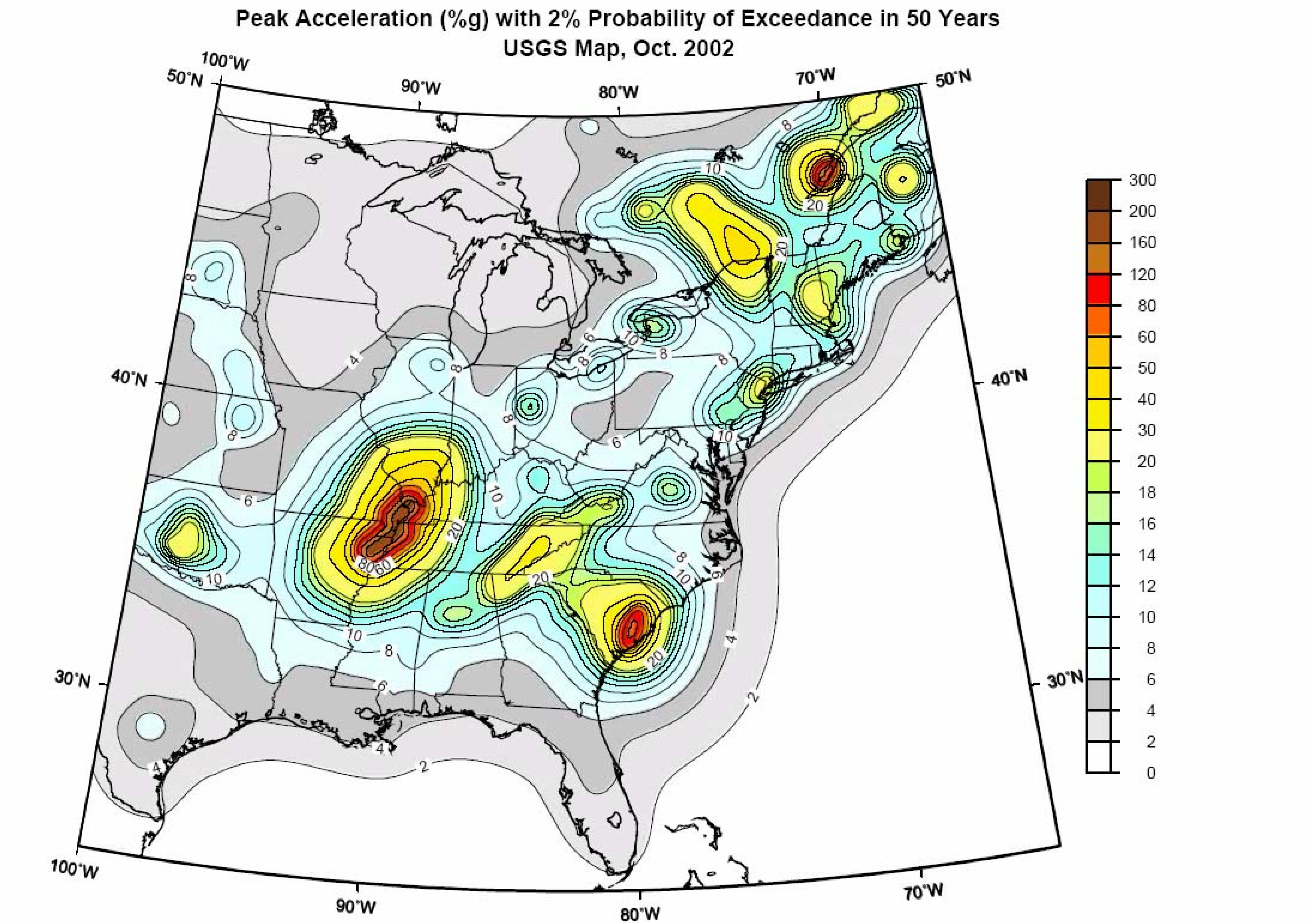
USGS Seismic Hazard Map of Coterminous United States



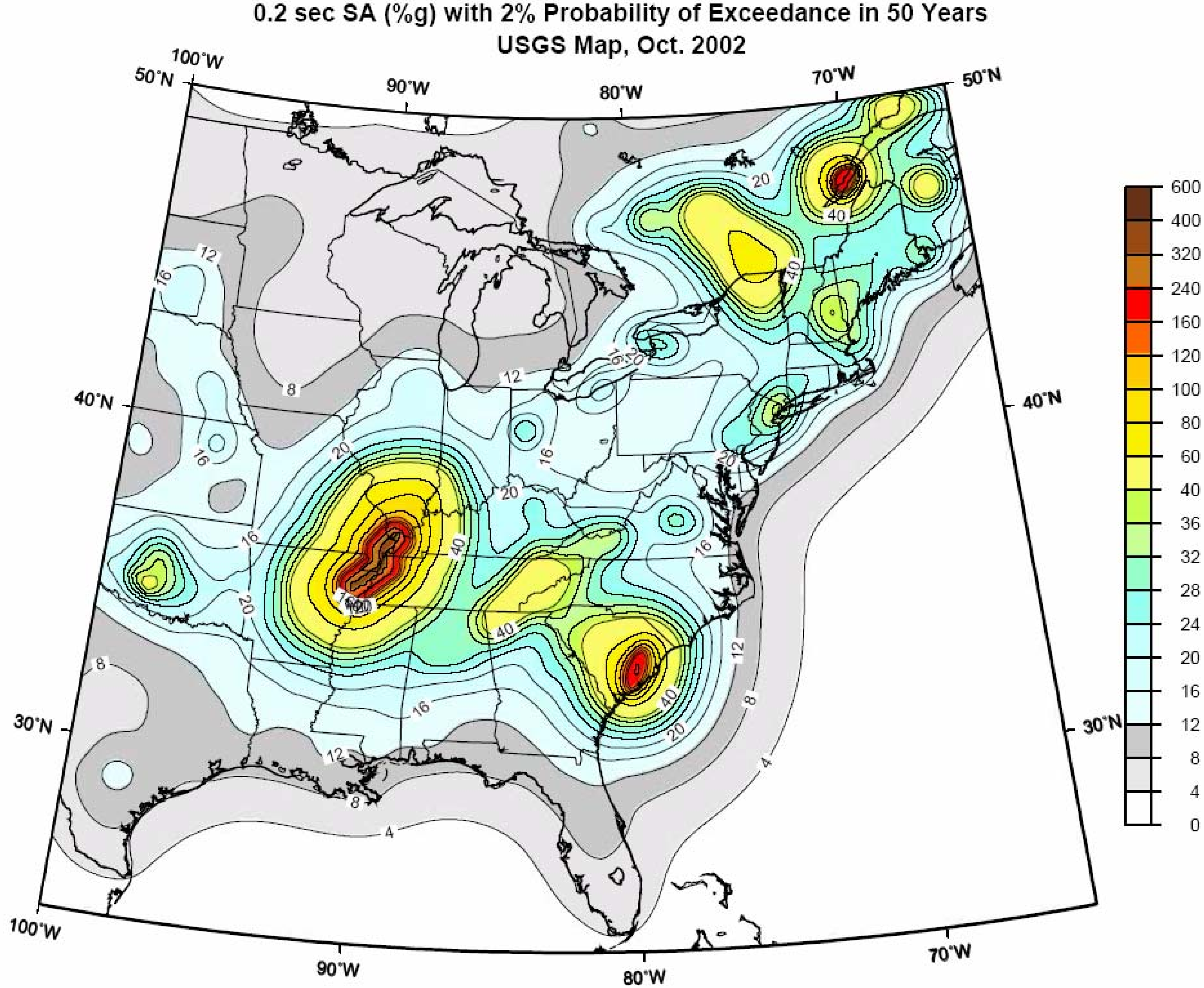
USGS Seismic Hazard Map for Coterminous United States



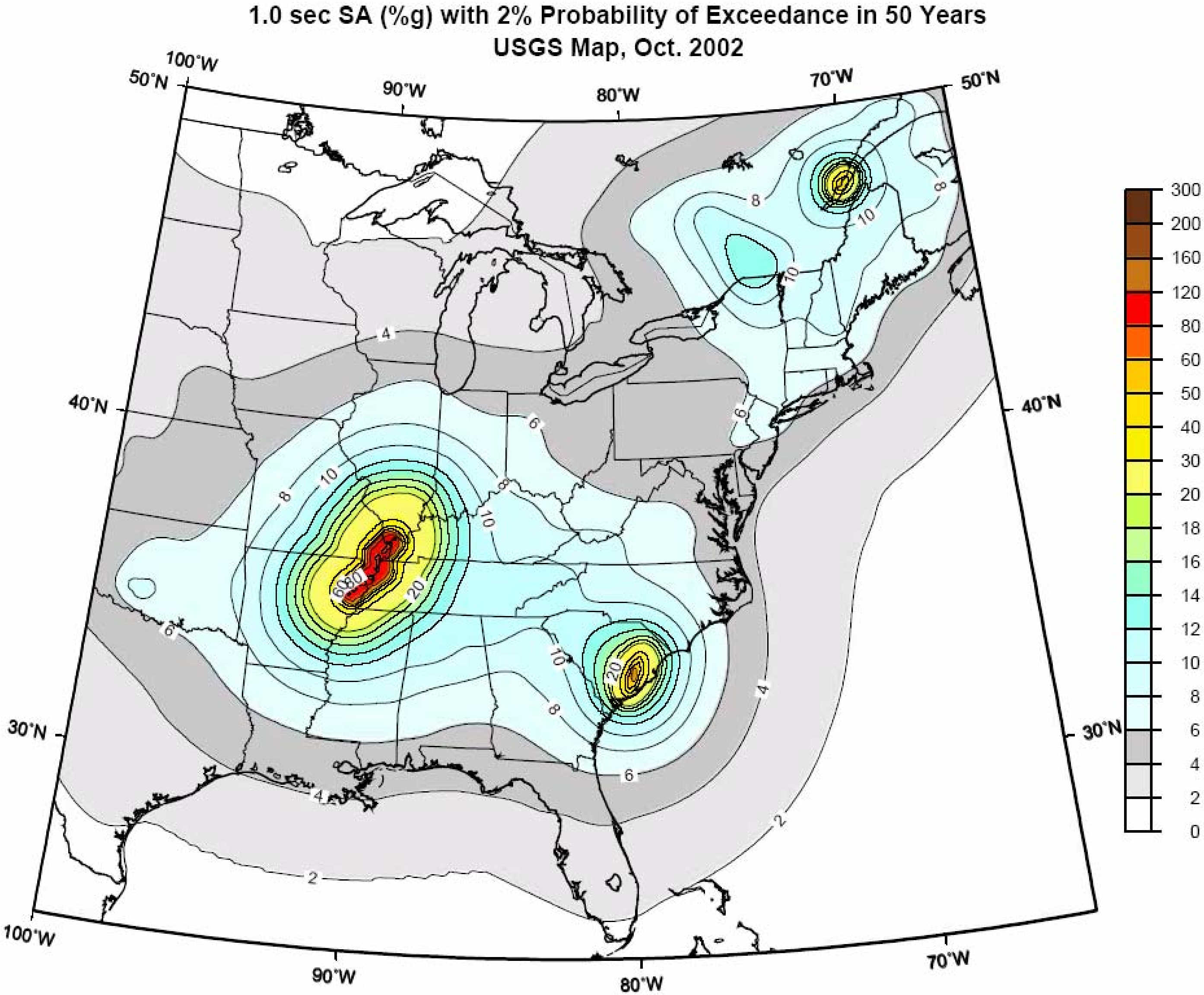
USGS Map for Central and Eastern United States



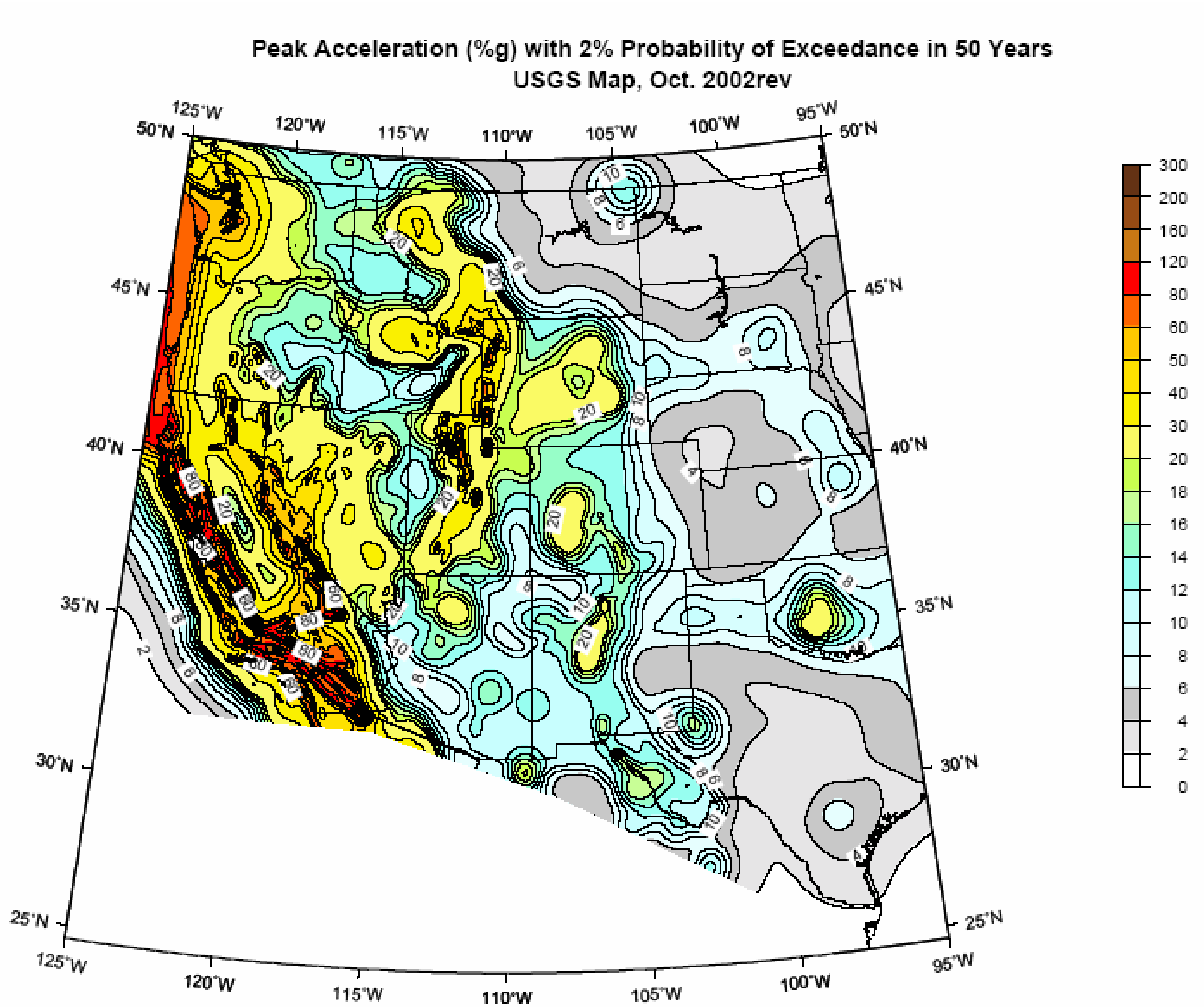
USGS Map for Central and Eastern United States



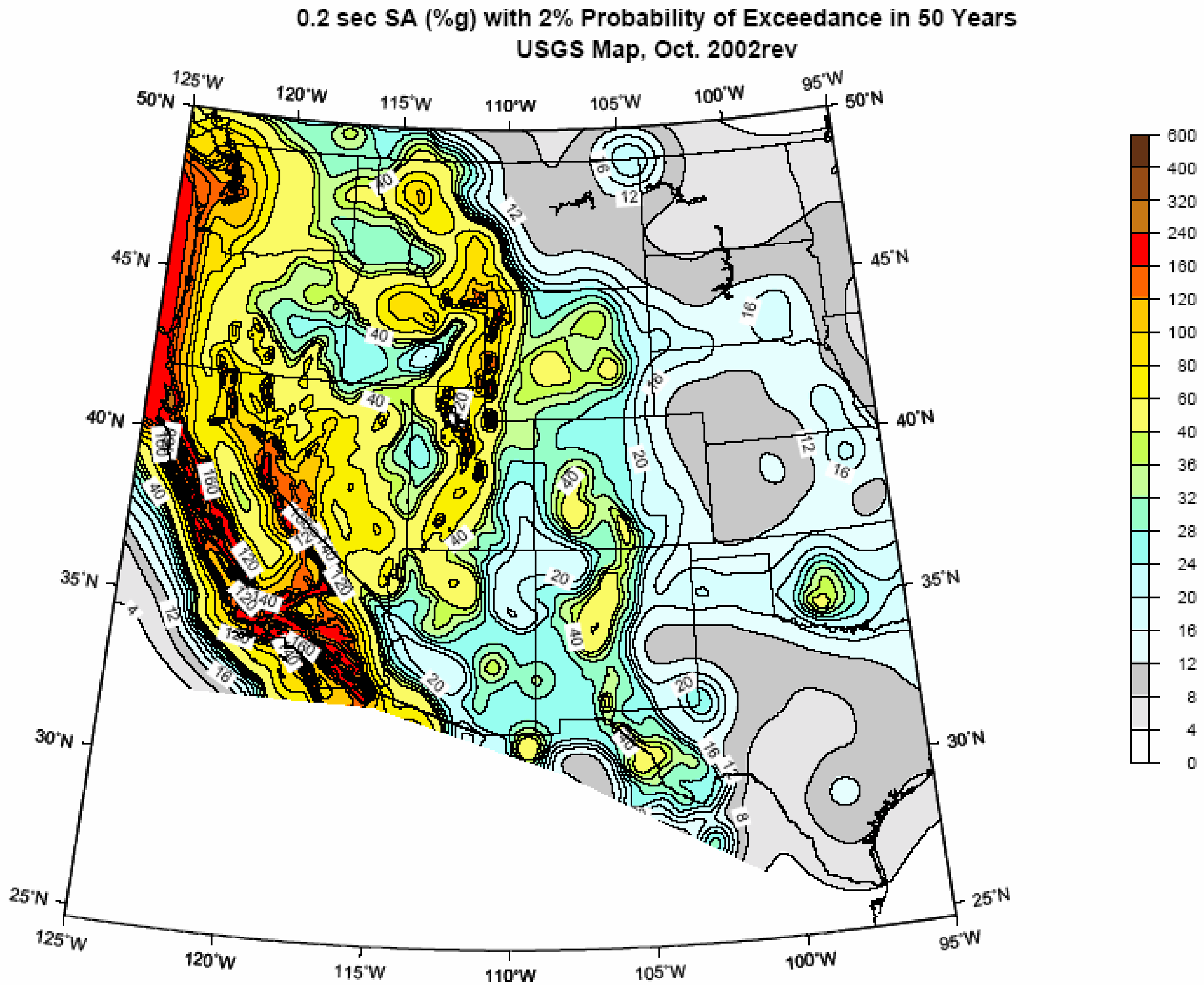
USGS Map for Central and Eastern United States



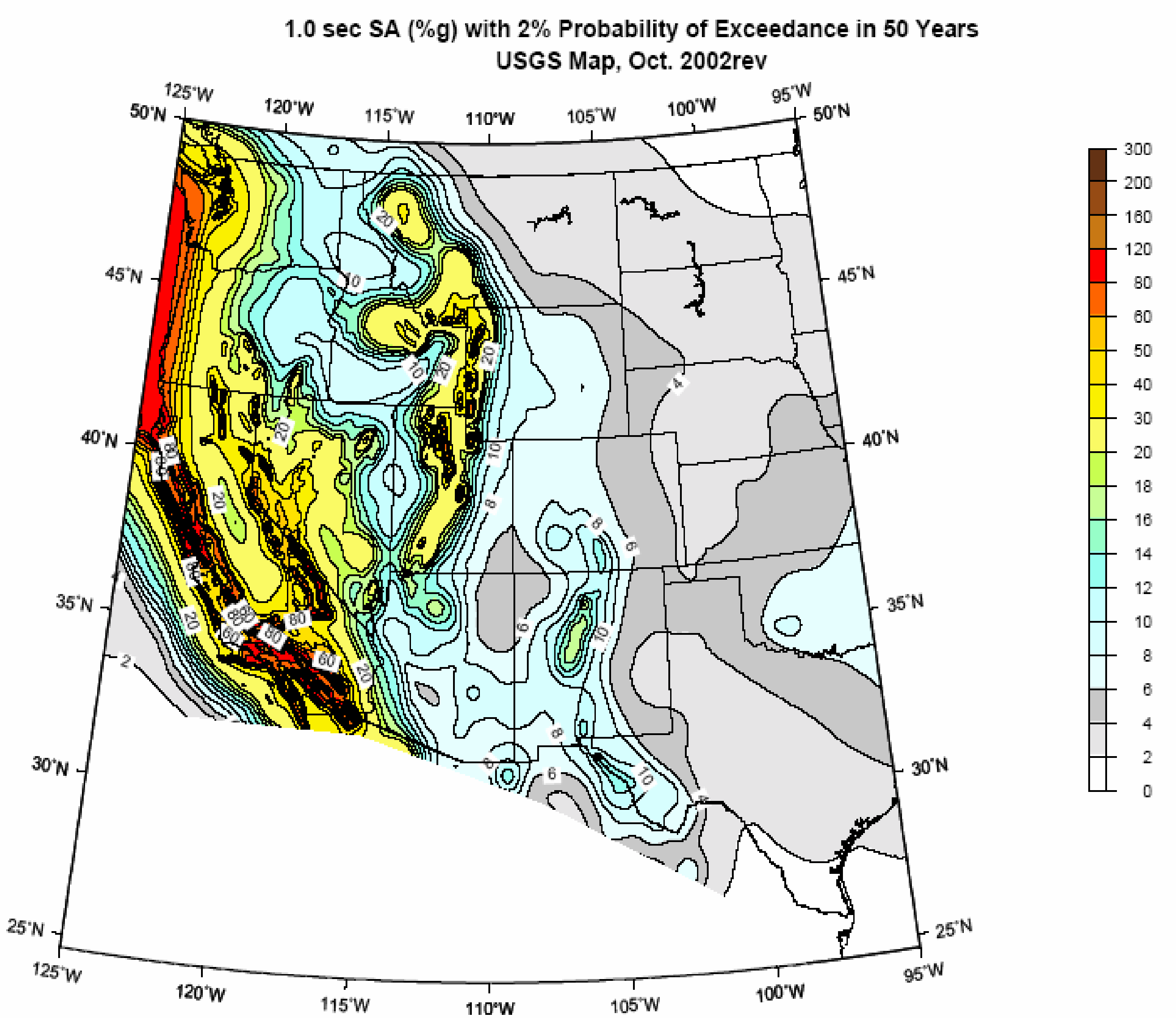
USGS Map for Western United States



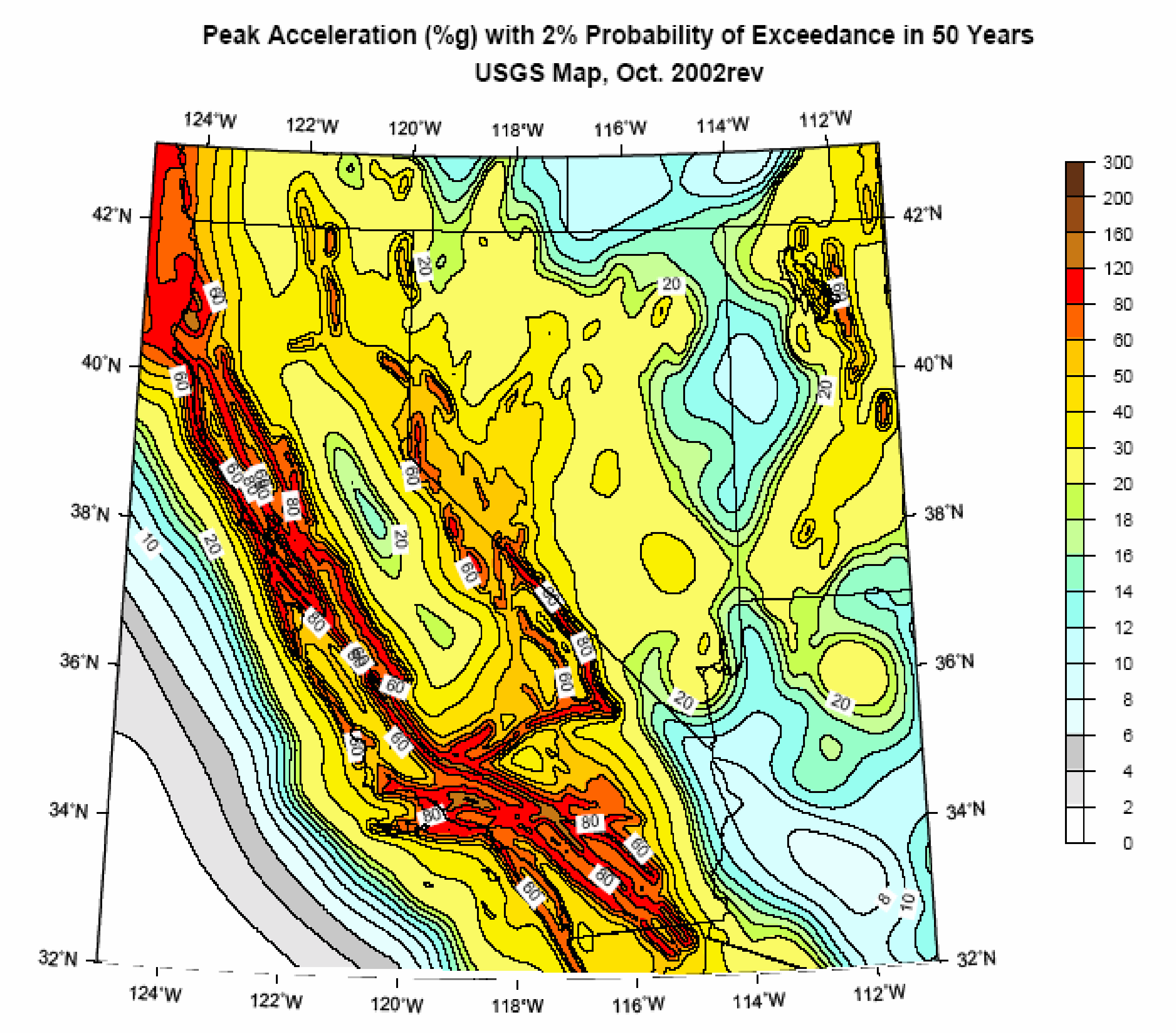
USGS Map for Western United States



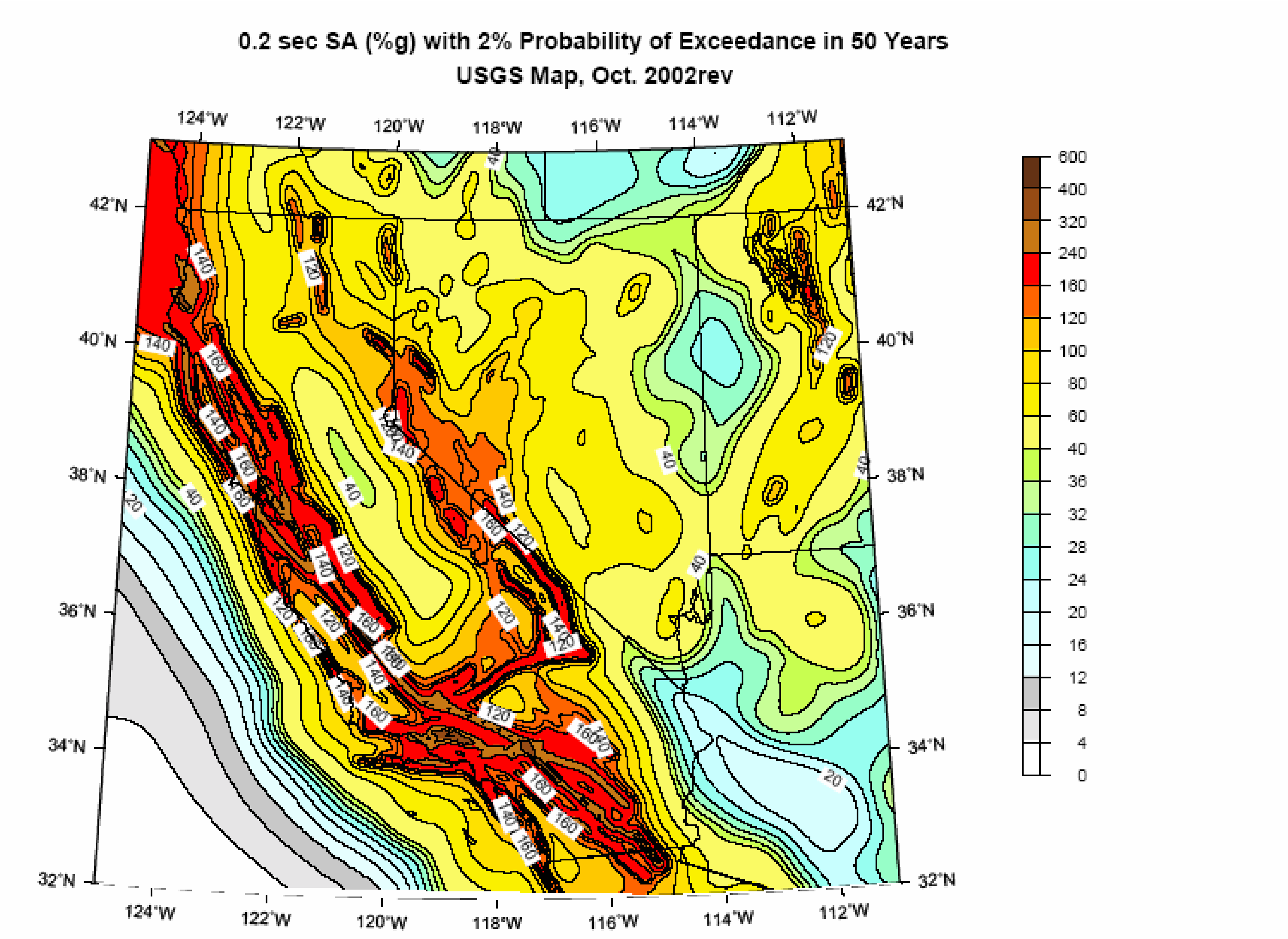
USGS Map for Western United States



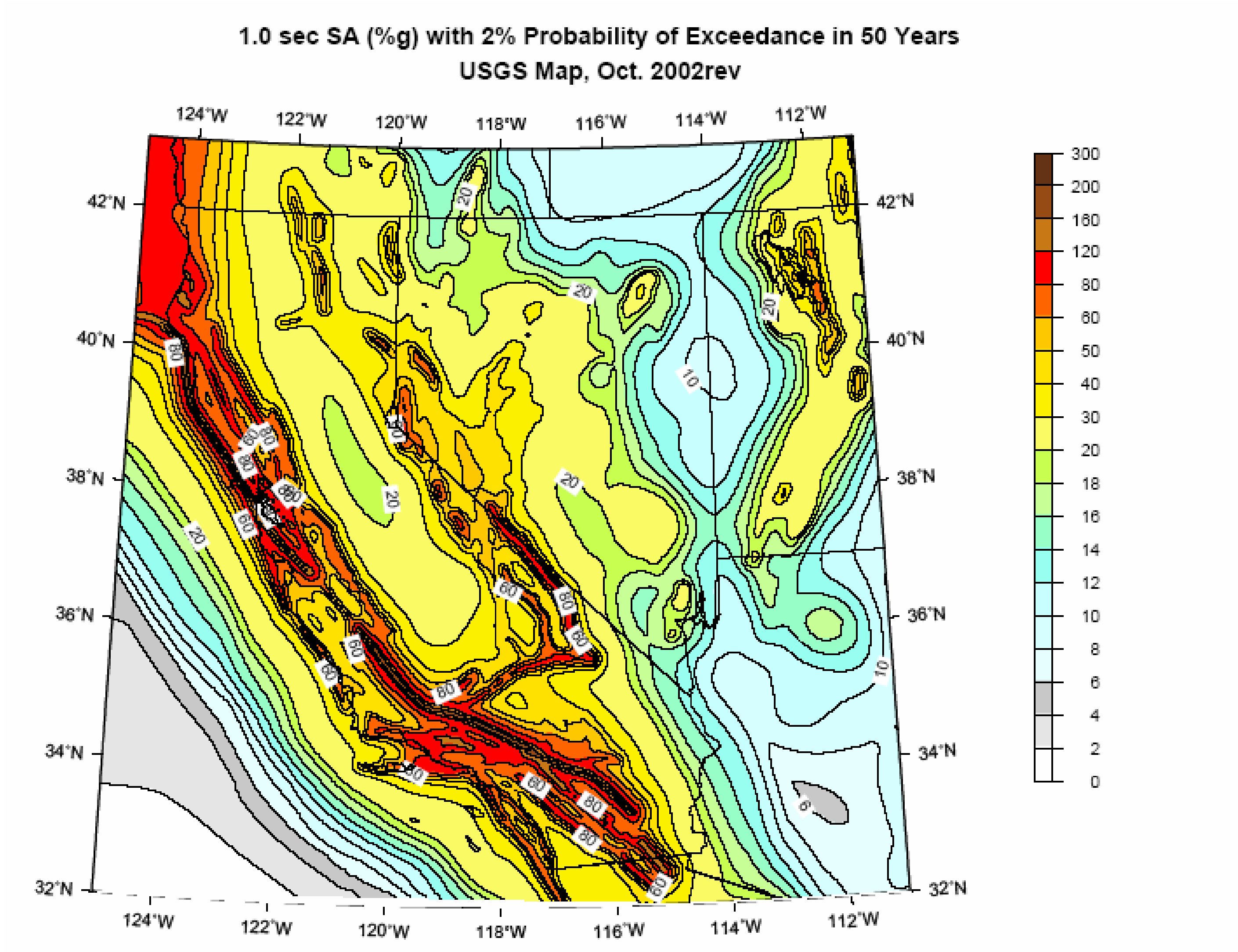
USGS Map for California



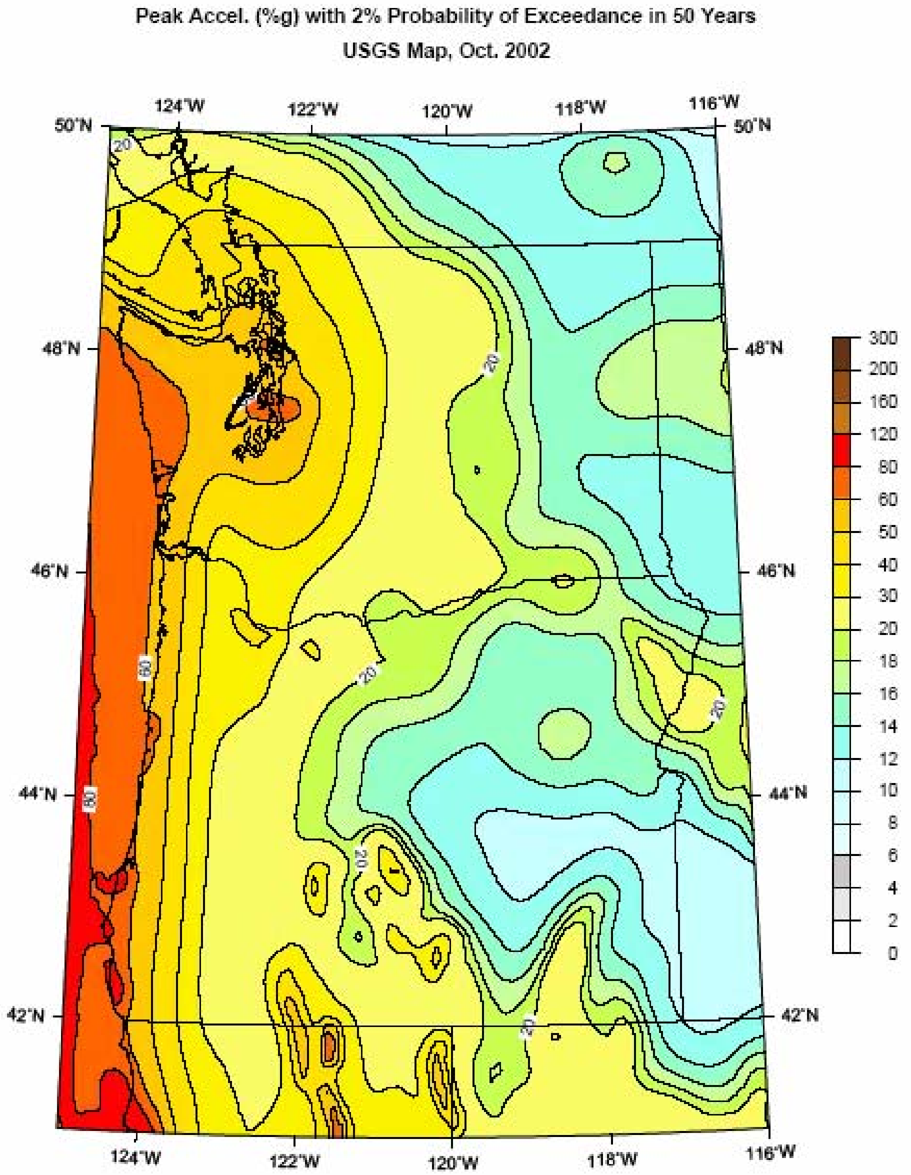
USGS Map for California



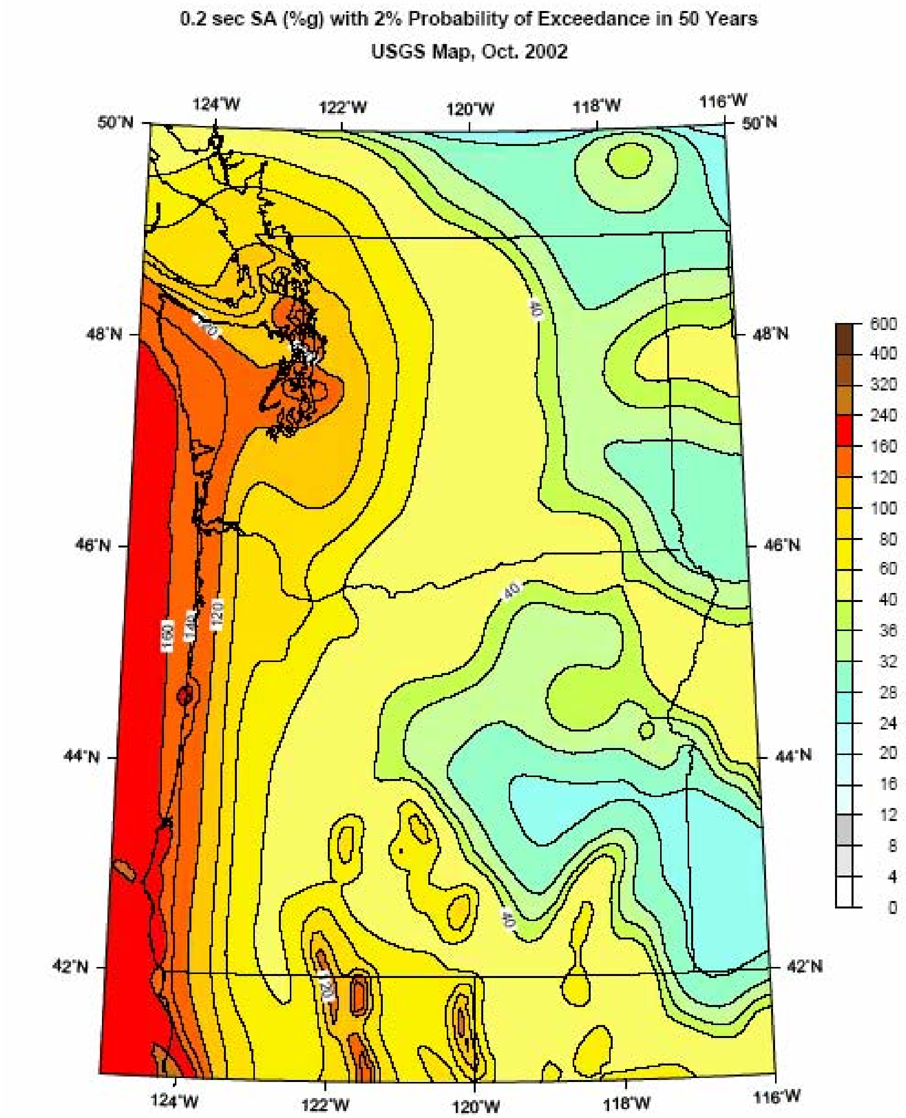
USGS Map for California



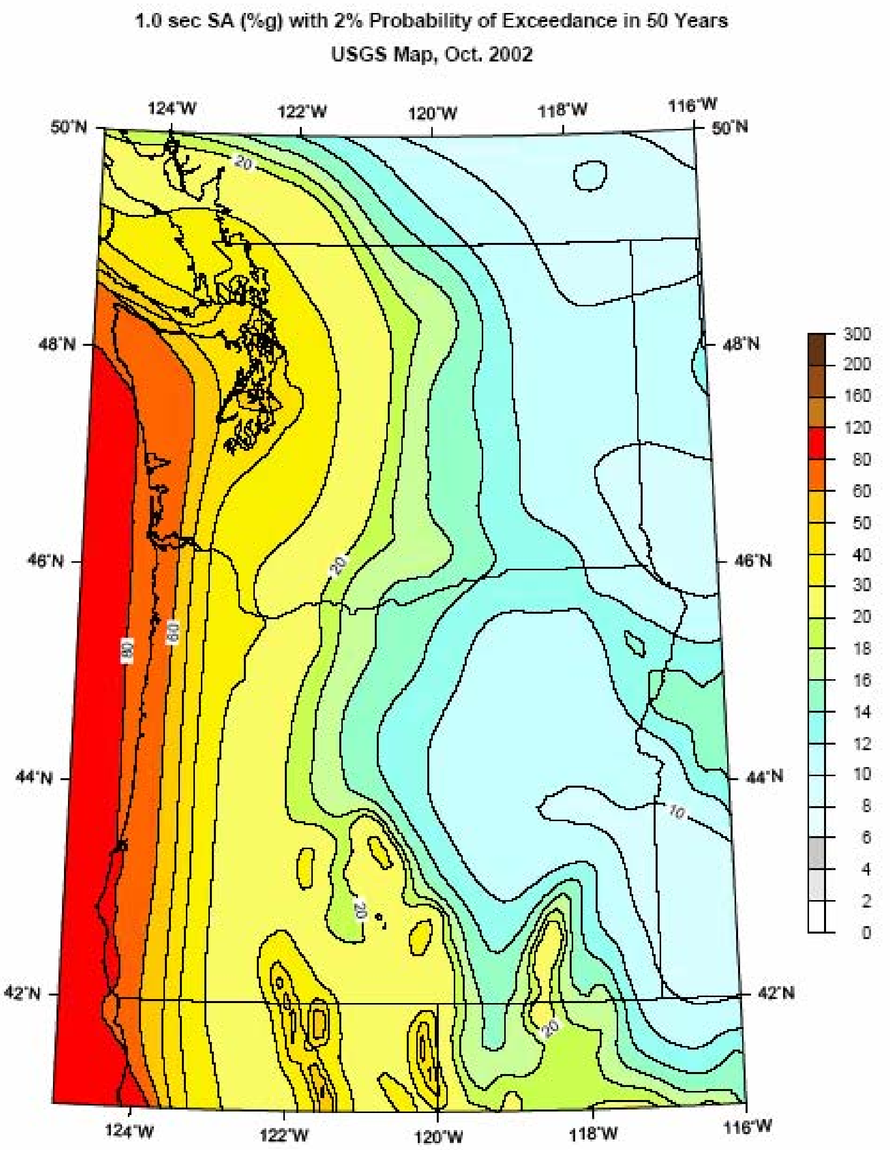
USGS Map for Pacific Northwest



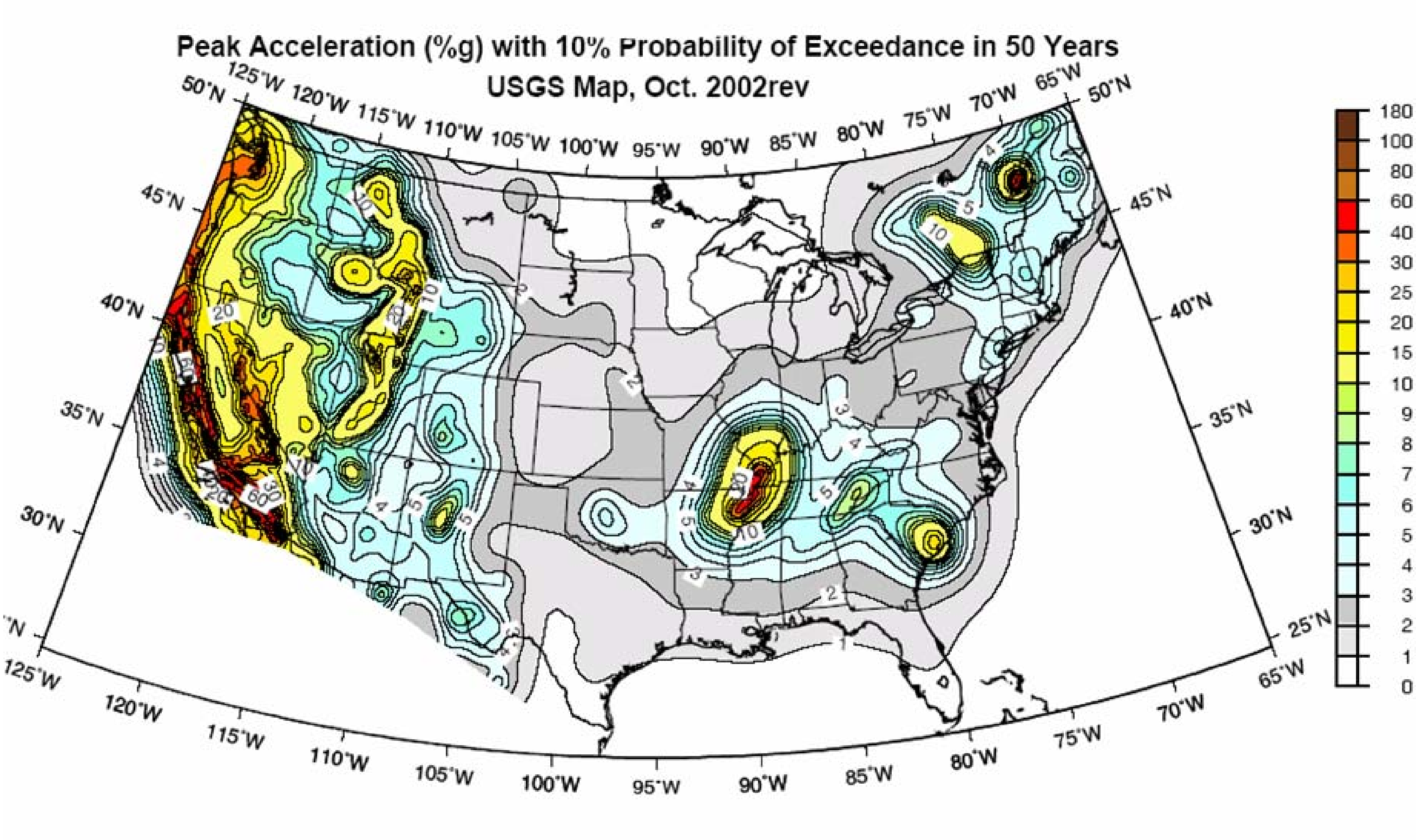
USGS Map for Pacific Northwest



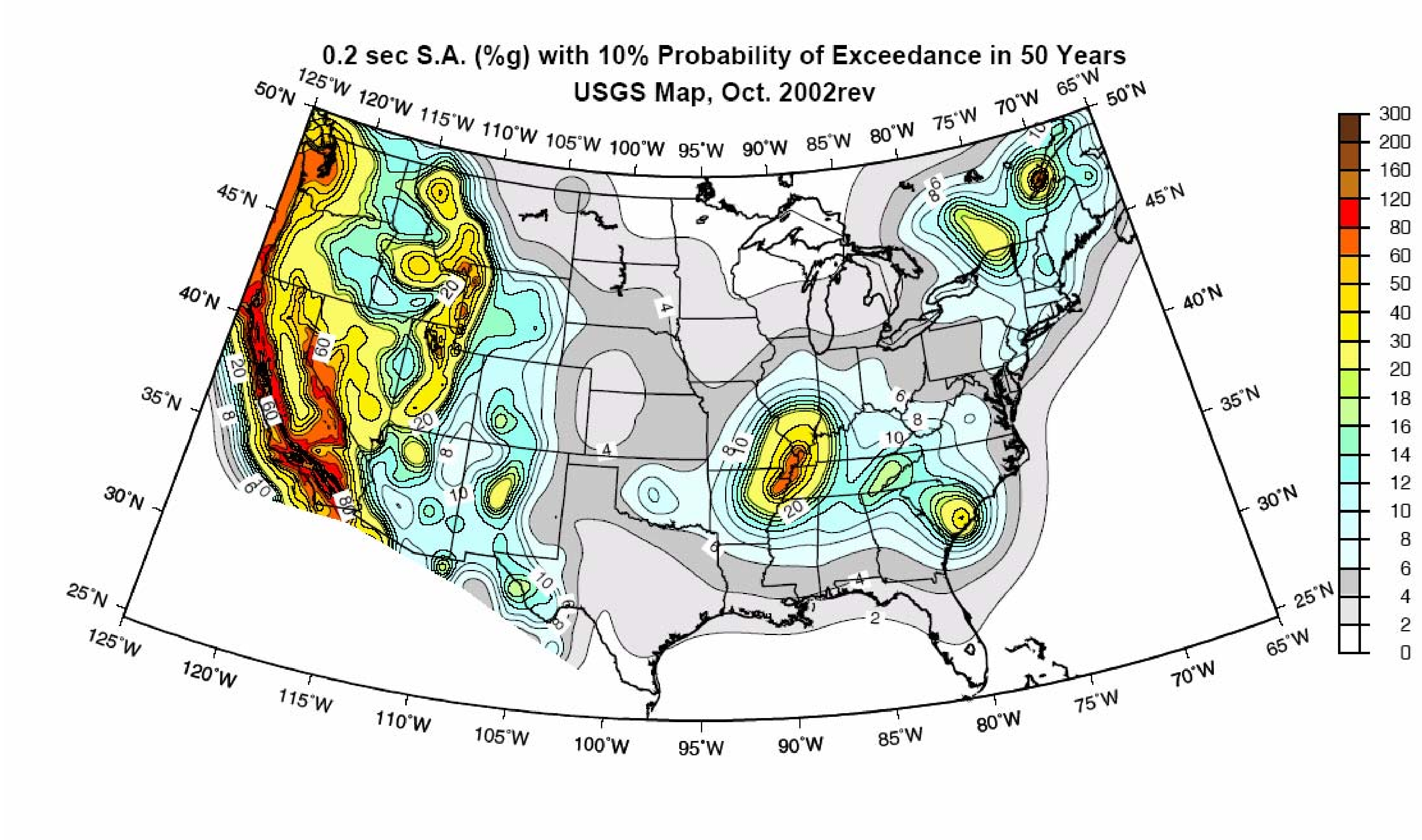
USGS Map for Pacific Northwest



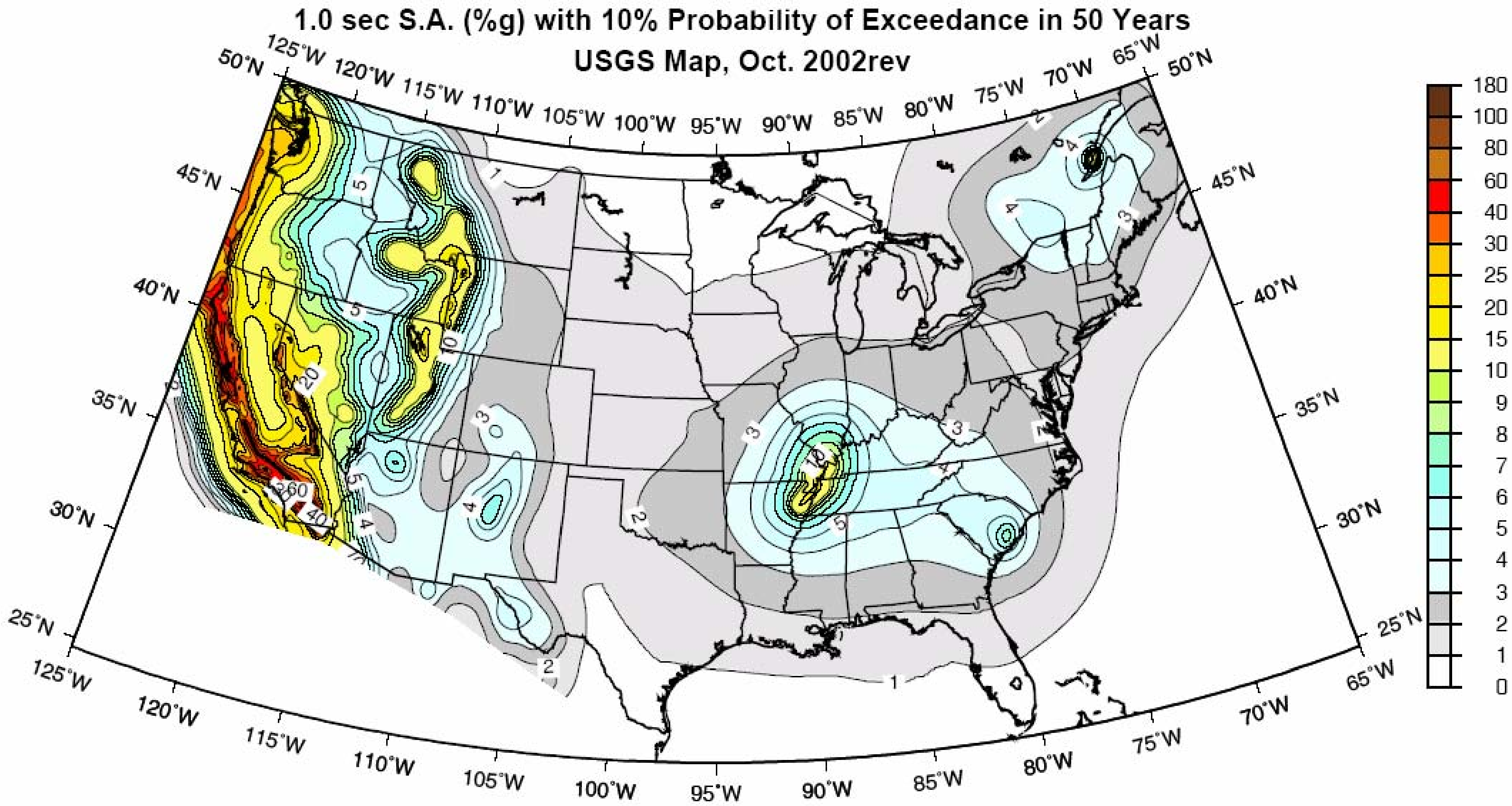
USGS Seismic Hazard Map of Coterminous United States



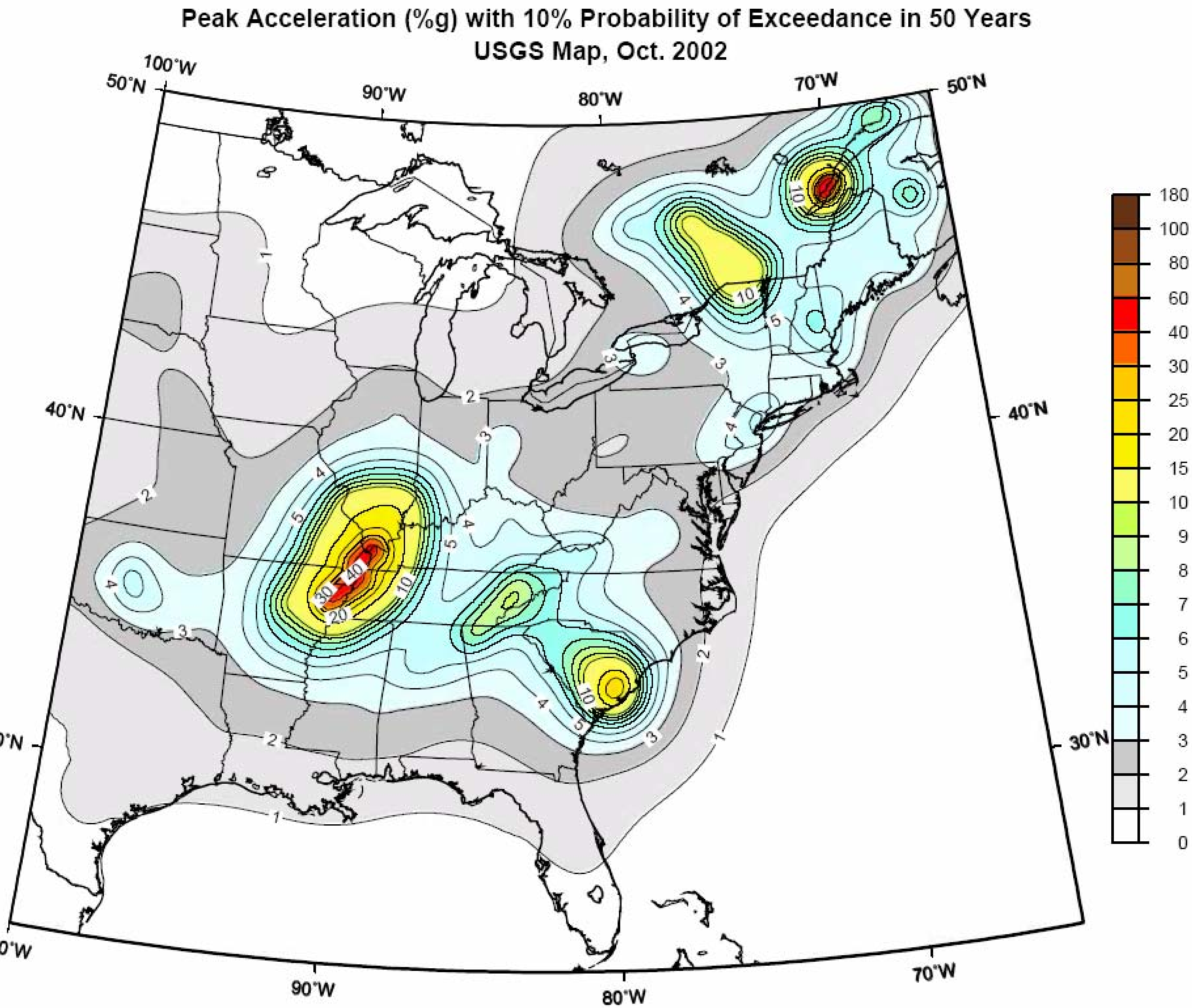
USGS Seismic Hazard Map of Coterminous United States



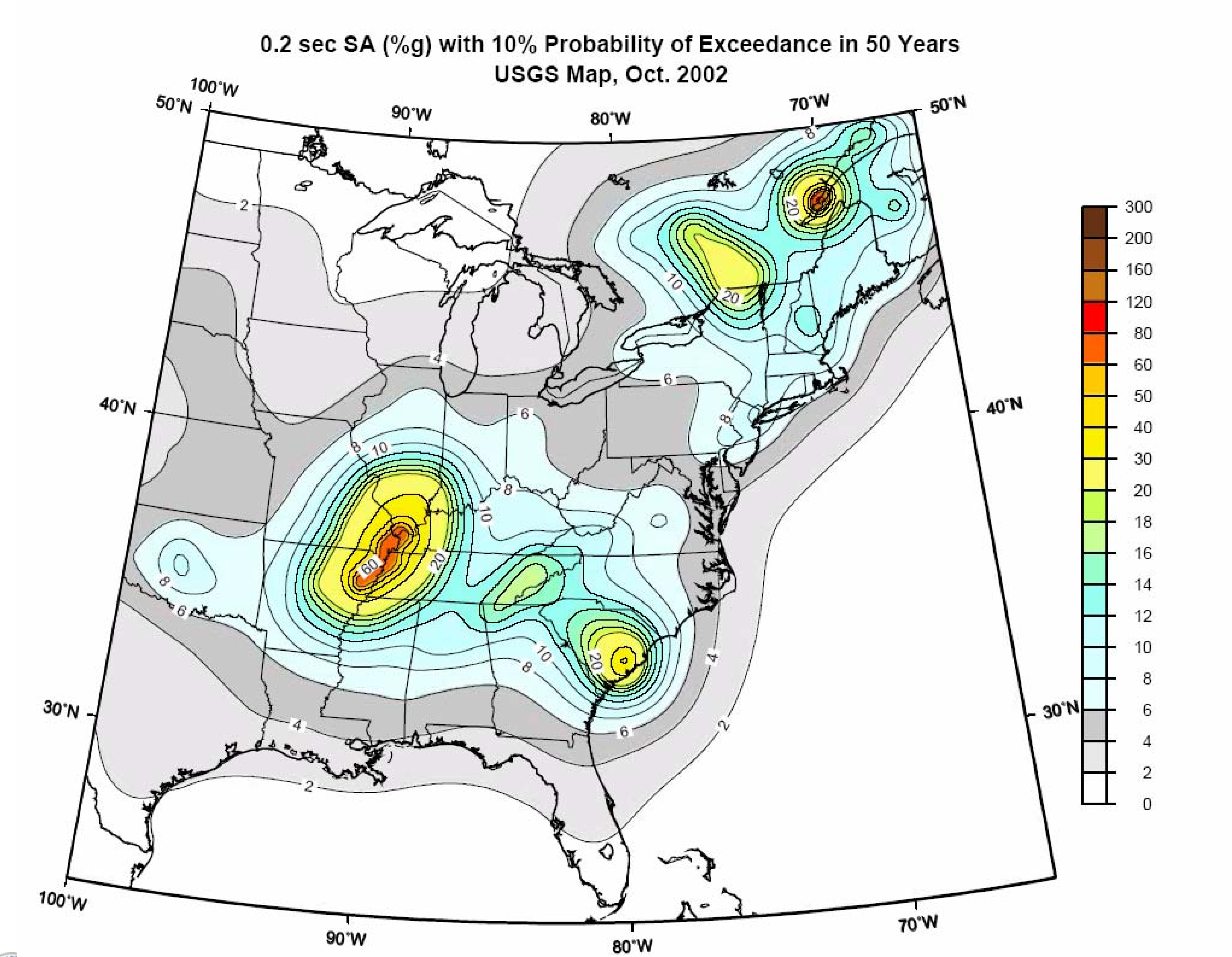
USGS Seismic Hazard Map of Coterminous United States



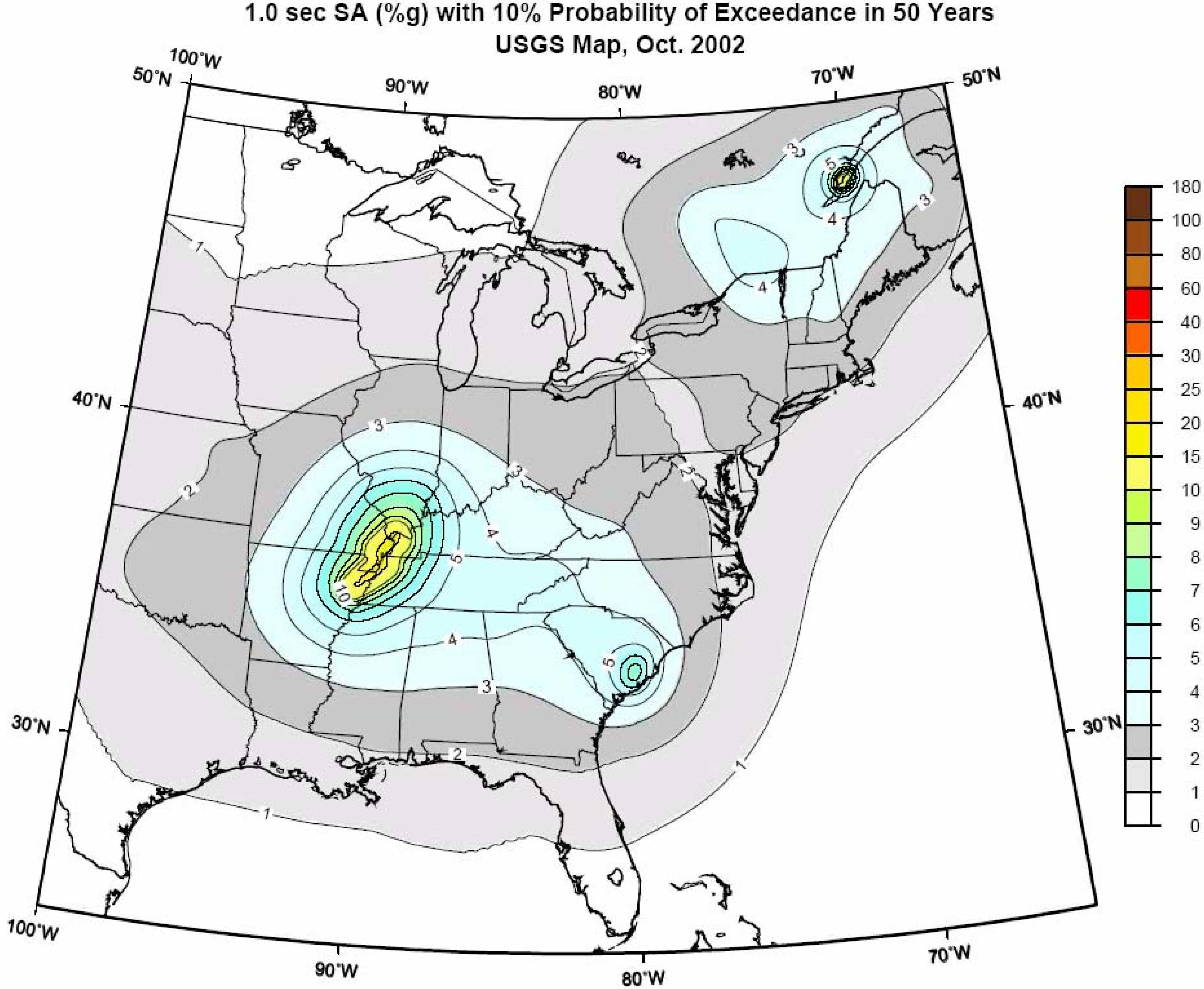
USGS Map for Central and Eastern United States



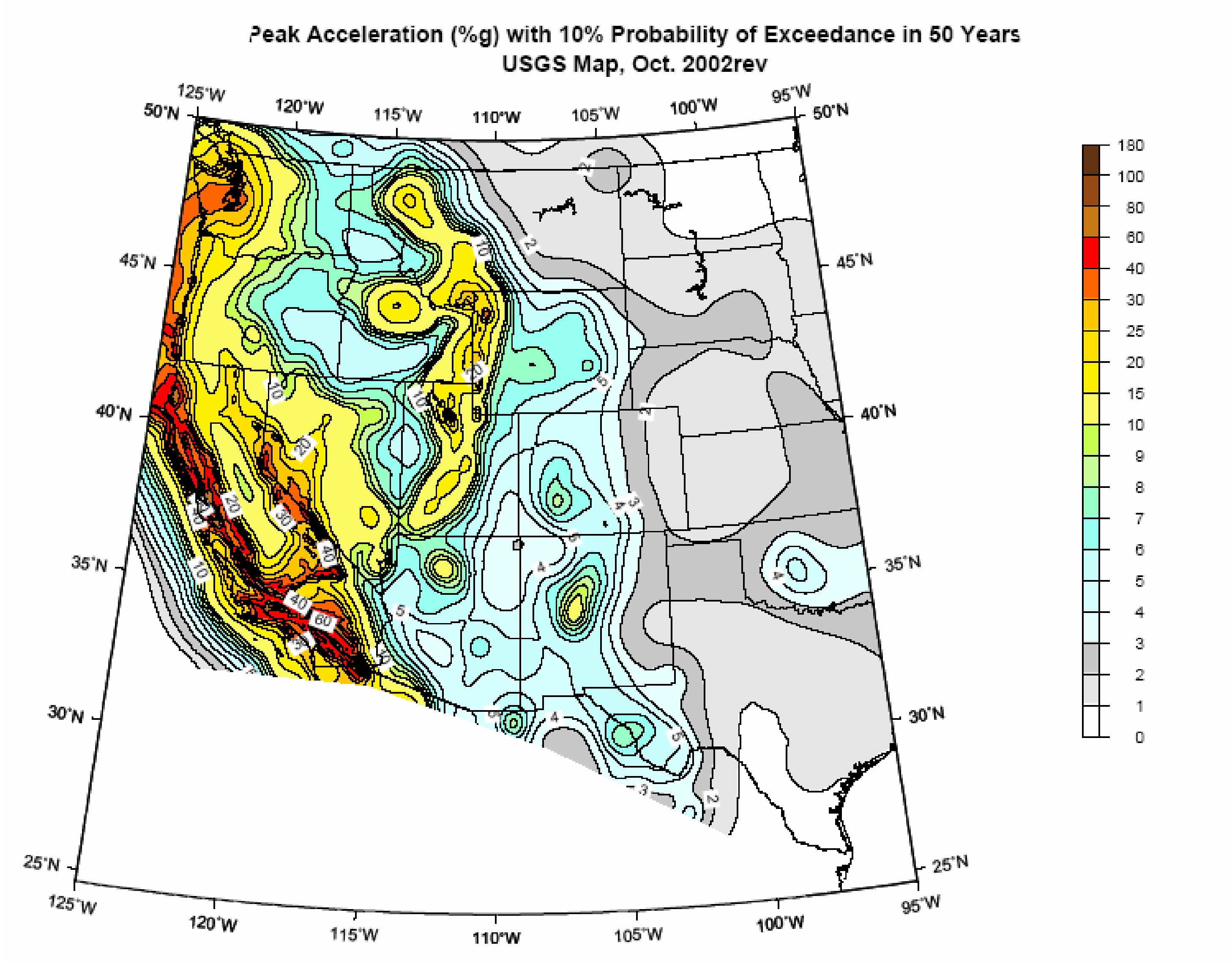
USGS Map for Central and Eastern United States



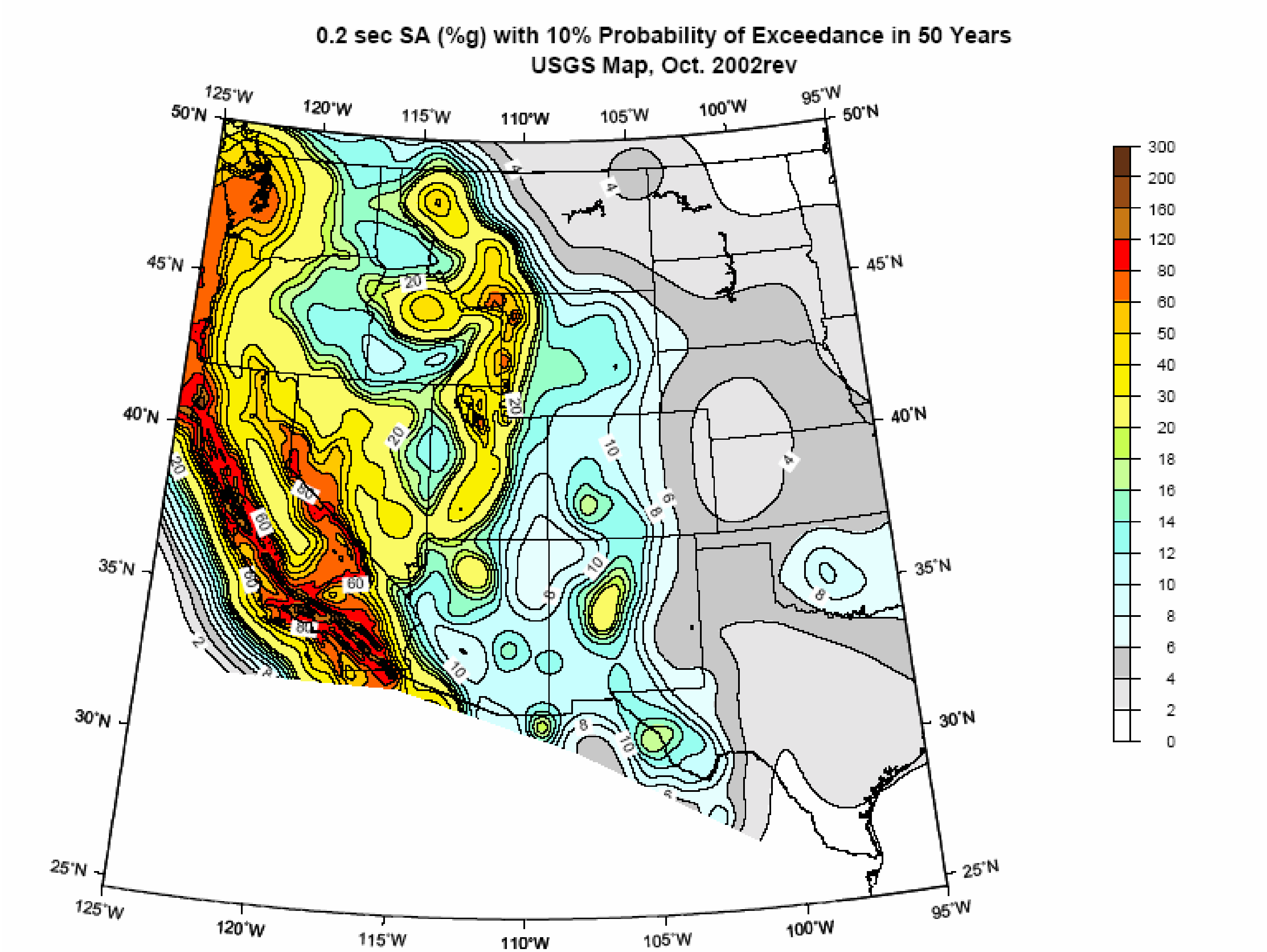
USGS Map for Central and Eastern United States



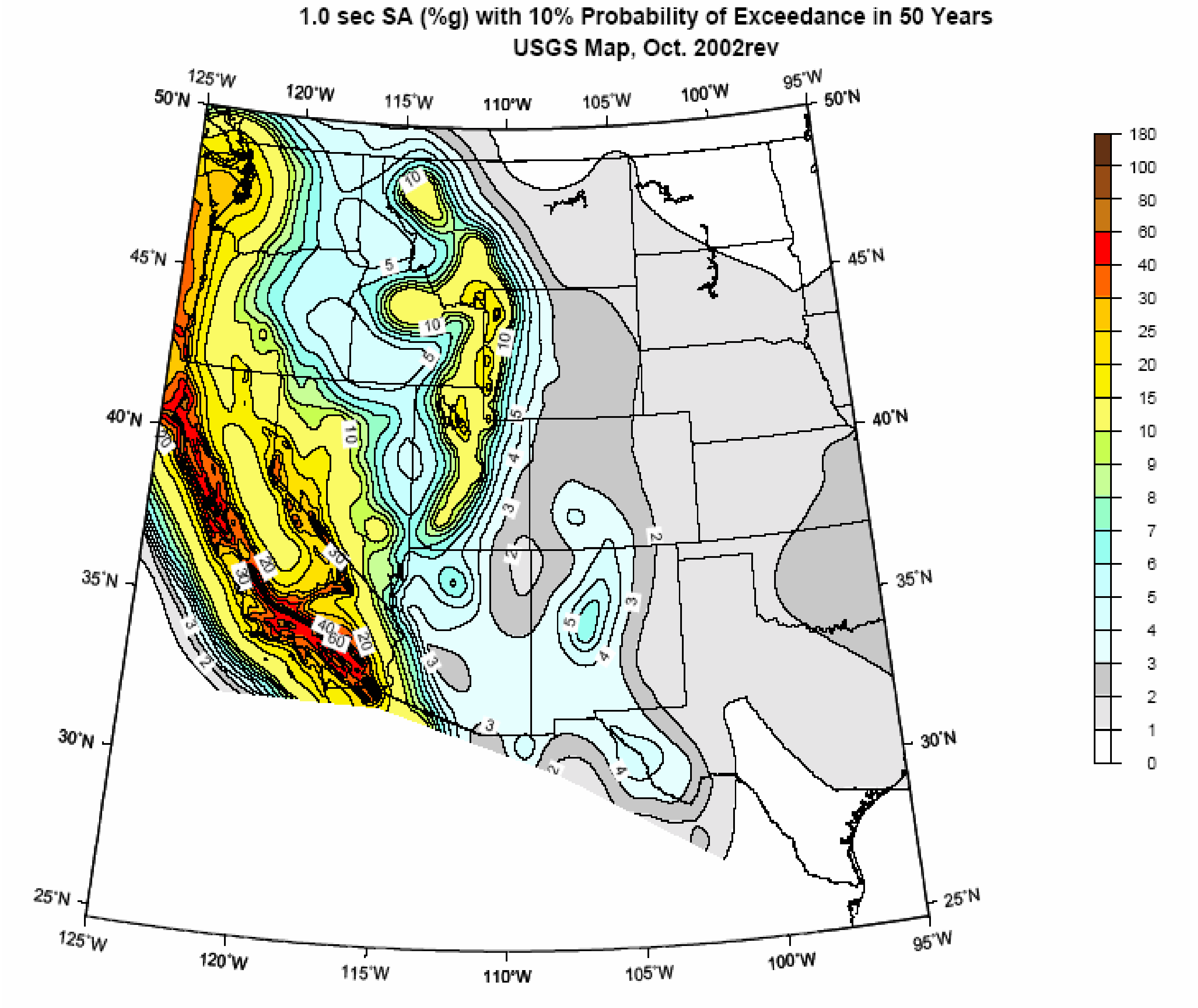
USGS Map for Western United States



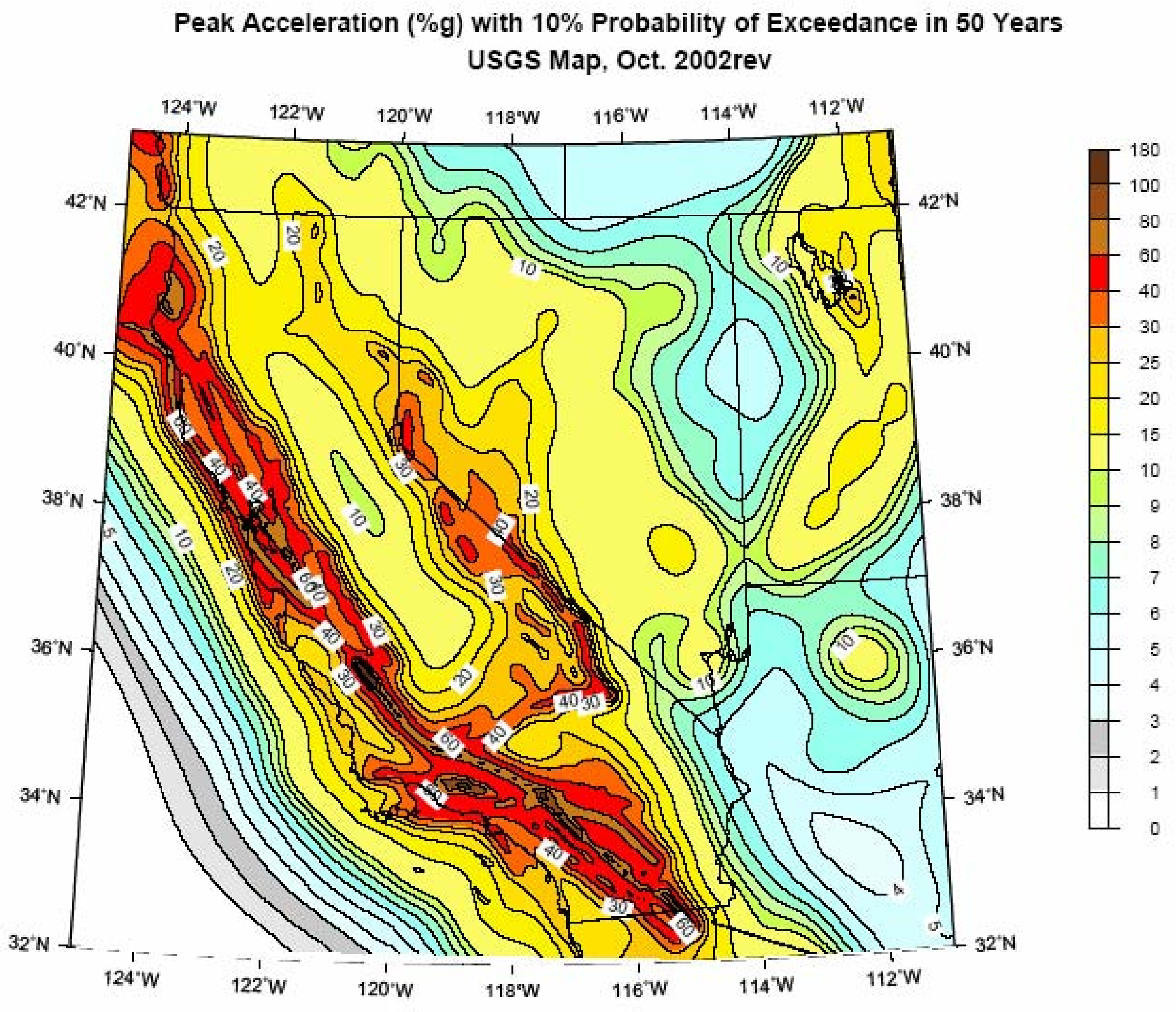
USGS Map for Western United States



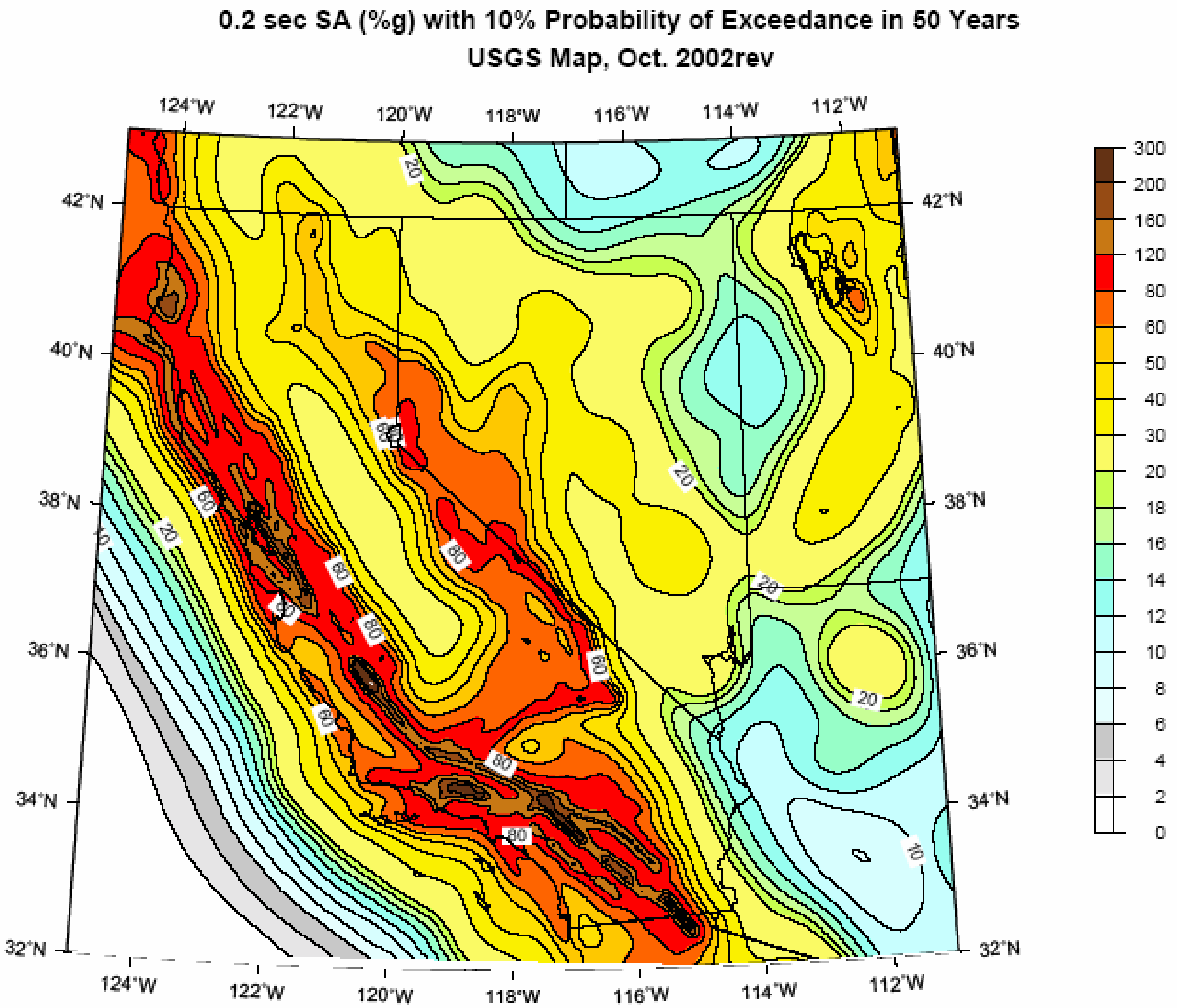
USGS Map for Western United States



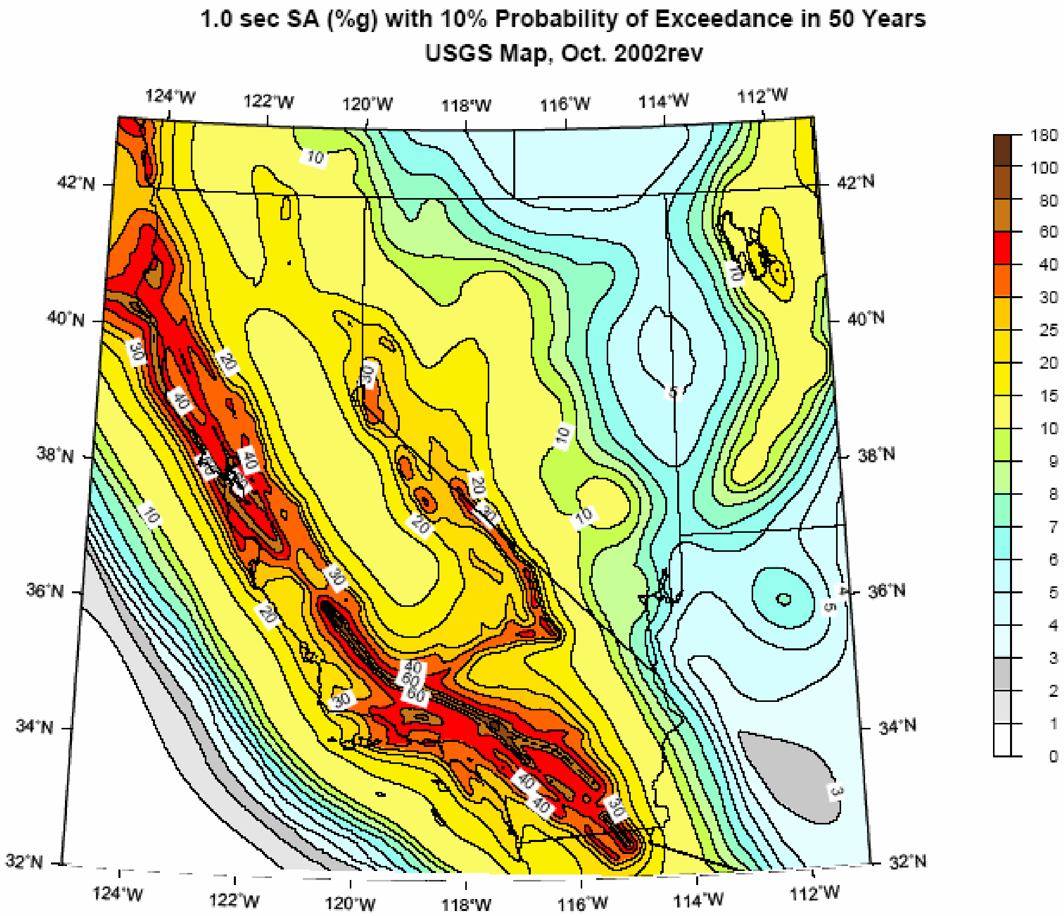
USGS Map for California



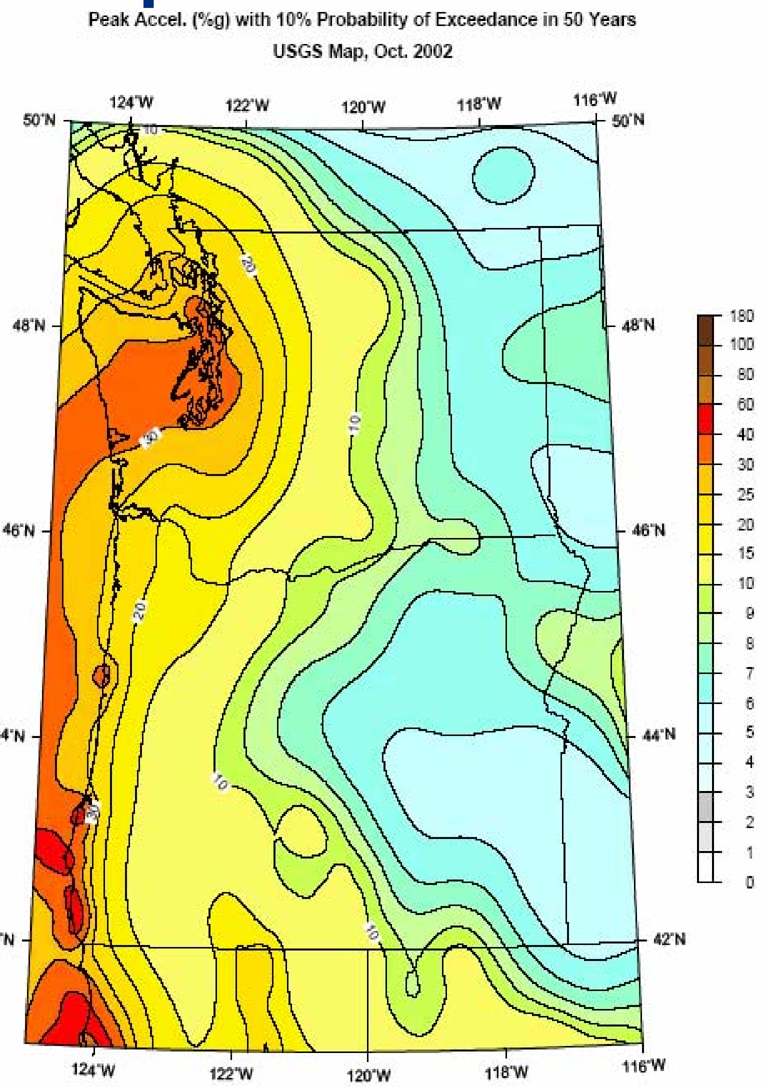
USGS Map for California



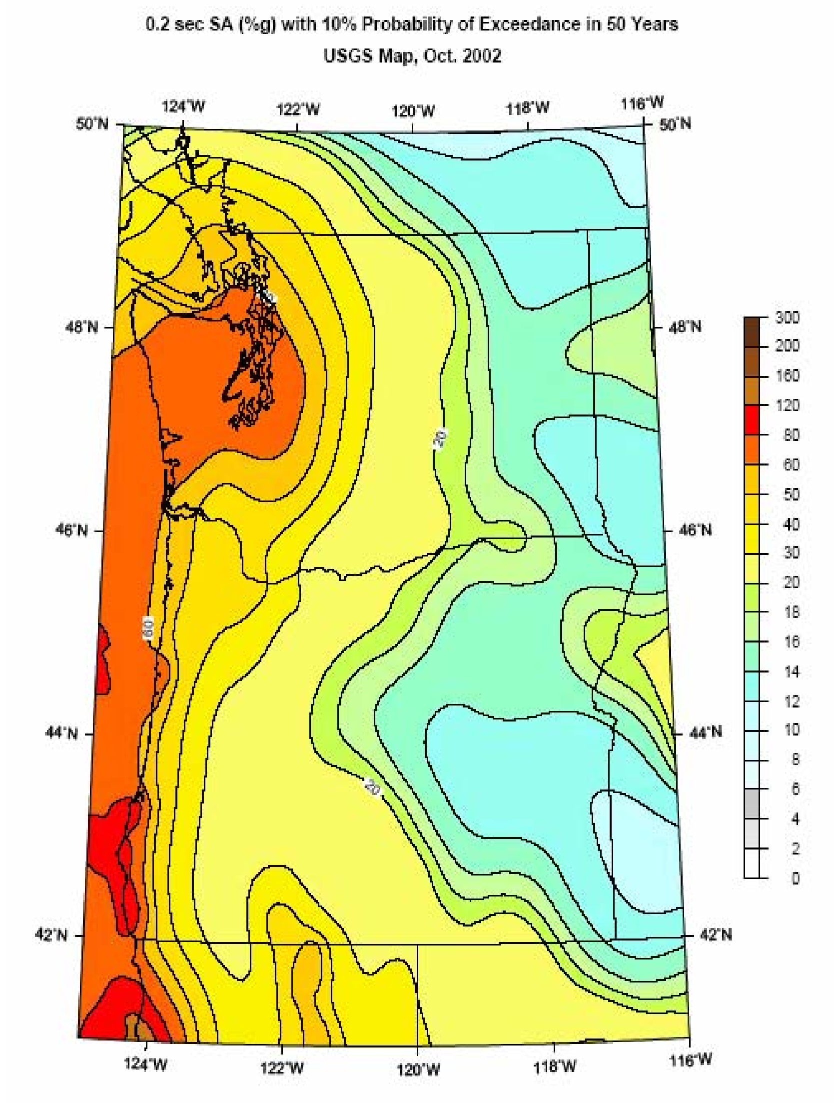
USGS Map for California



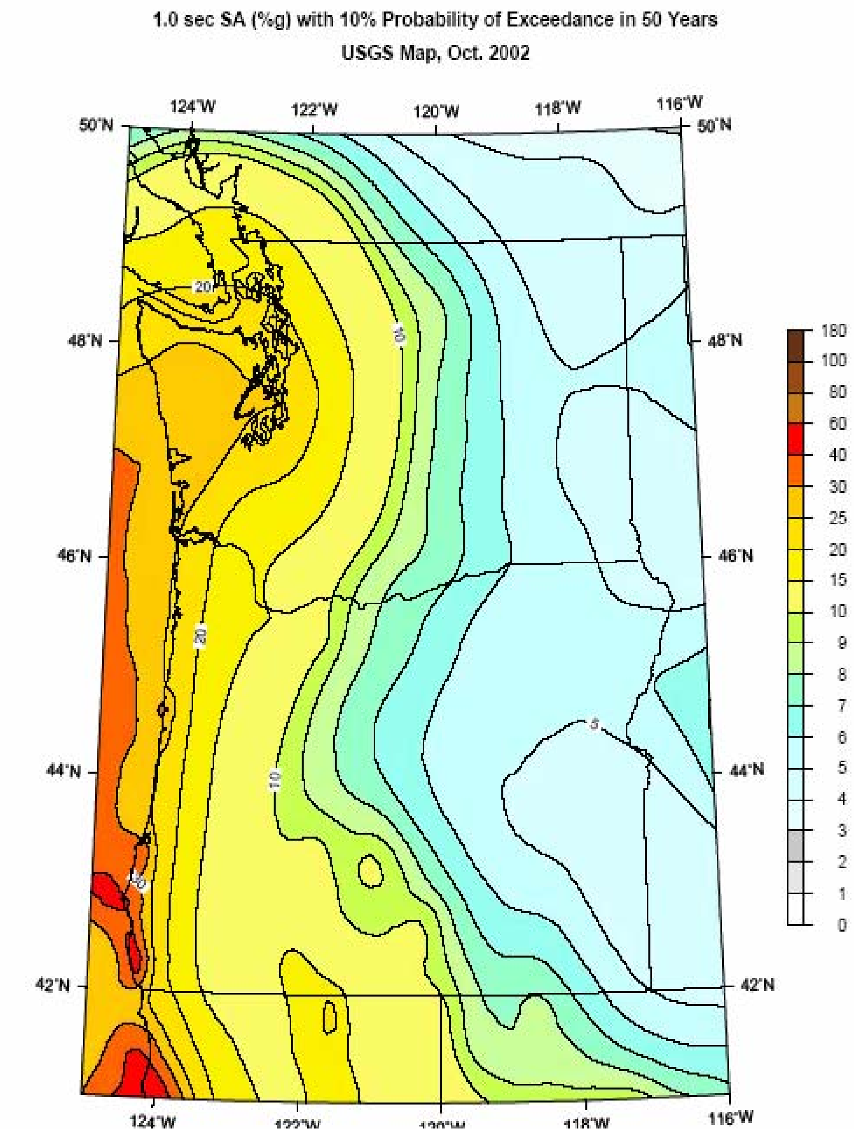
USGS Map for Pacific Northwest



USGS Map for Pacific Northwest



USGS Map for Pacific Northwest



USGS Website for Map Values

http://earthquake.usgs.gov/research/hazmaps/design/

```
   The input zipcode is 80203. (DENVER)
   ZIP CODE                         80203
   LOCATION                         39.7310 Lat. -104.9815 Long.
   DISTANCE TO NEAREST GRID POINT   3.7898 kms
   NEAREST GRID POINT               39.7 Lat. -105.0 Long.
   Probabilistic ground motion values, in %g, at the Nearest Grid
point are:
```

	10%PE in 50 yr	5%PE in 50 yr	2%PE in 50 yr
PGA	3.299764	5.207589	9.642159
0.2 sec SA	7.728900	11.917400	19.921591
0.3 sec SA	6.178438	9.507714	16.133711
1.0 sec SA	2.334019	3.601994	5.879917

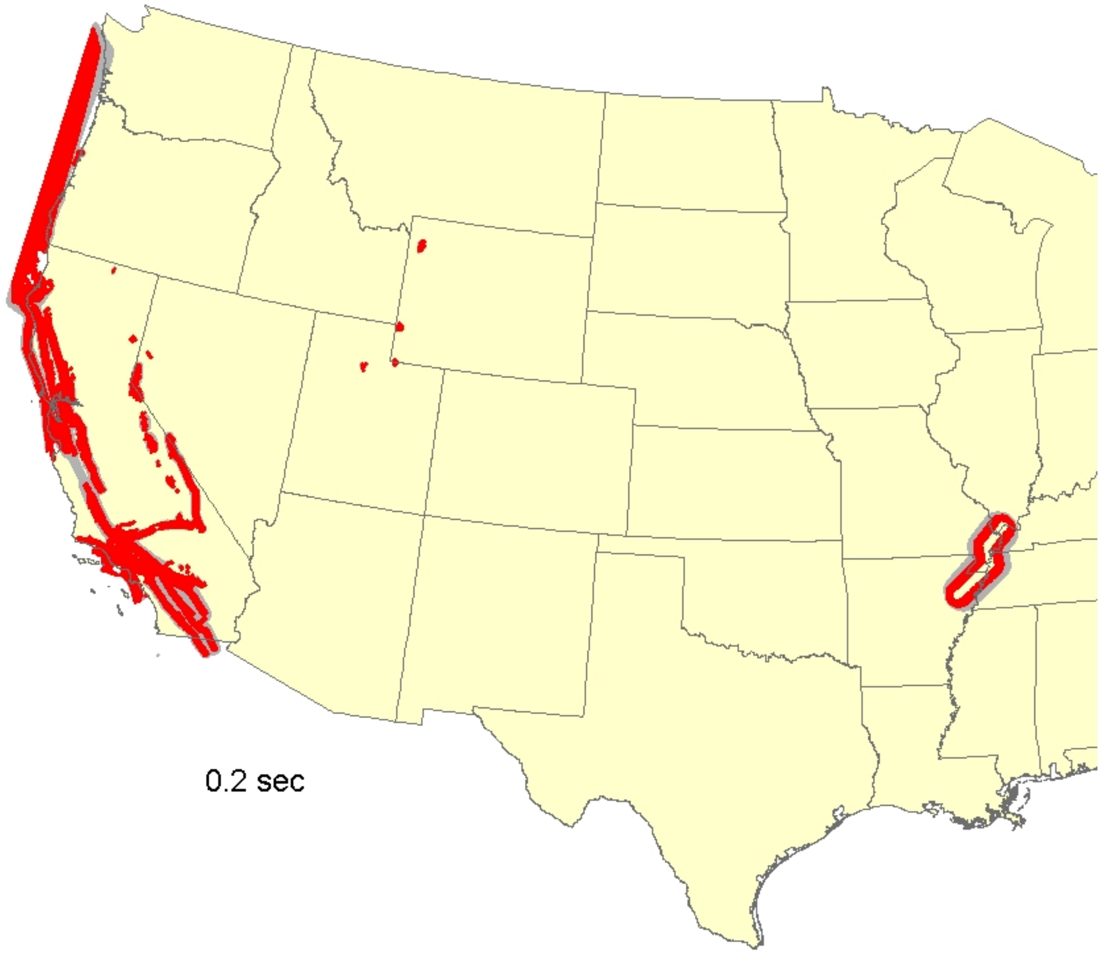
CAUTION: USE OF ZIPCODES IS DISCOURAGED; LAT-LONG VALUES WILL GIVE ACCURATE RESULTS.

Relative PGAs for the United States

2000 *NEHRP Recommended Provisions* Maps

- 5% damped, 2% in 50 years, Site Class B (firm rock)
- 0.2 second and 1.0 second spectral ordinates provided
- On certain faults in California, Alaska, Hawaii, and CUS *Provisions* values are deterministic cap times 1.5. Outside deterministic areas, *Provisions* maps are the same as the USGS maps.
- USGS longitude/latitude and zipcode values are probabilistic MCE. To avoid confusion, ALWAYS use *Provisions* (adopted by ASCE and IBC) maps for design purposes.

Location of Deterministic Areas



Deterministic Cap

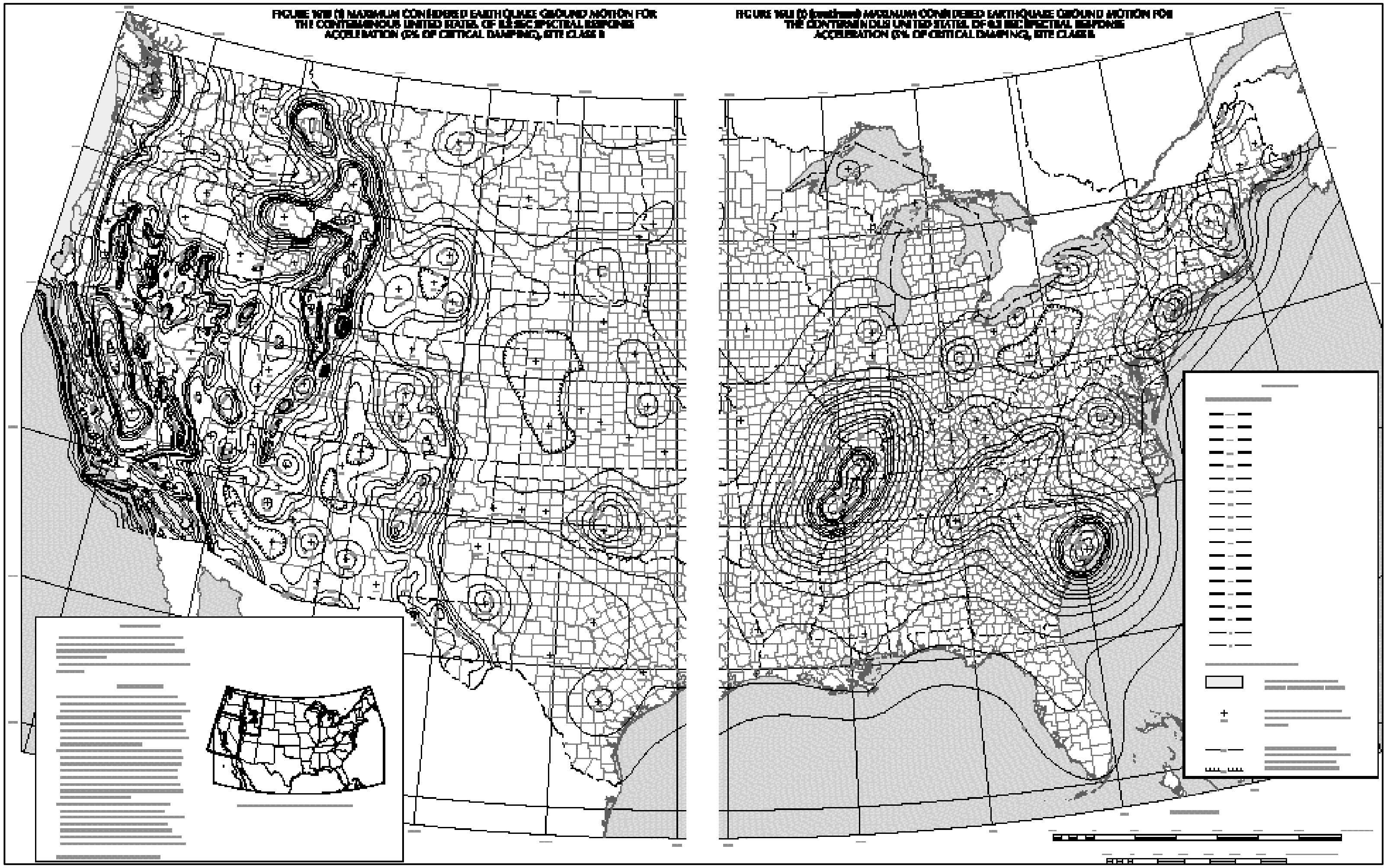
Applies only where probabilistic values exceed highest design values from old (Algermissen and Perkins) maps.

The deterministic procedure for mapping applies:

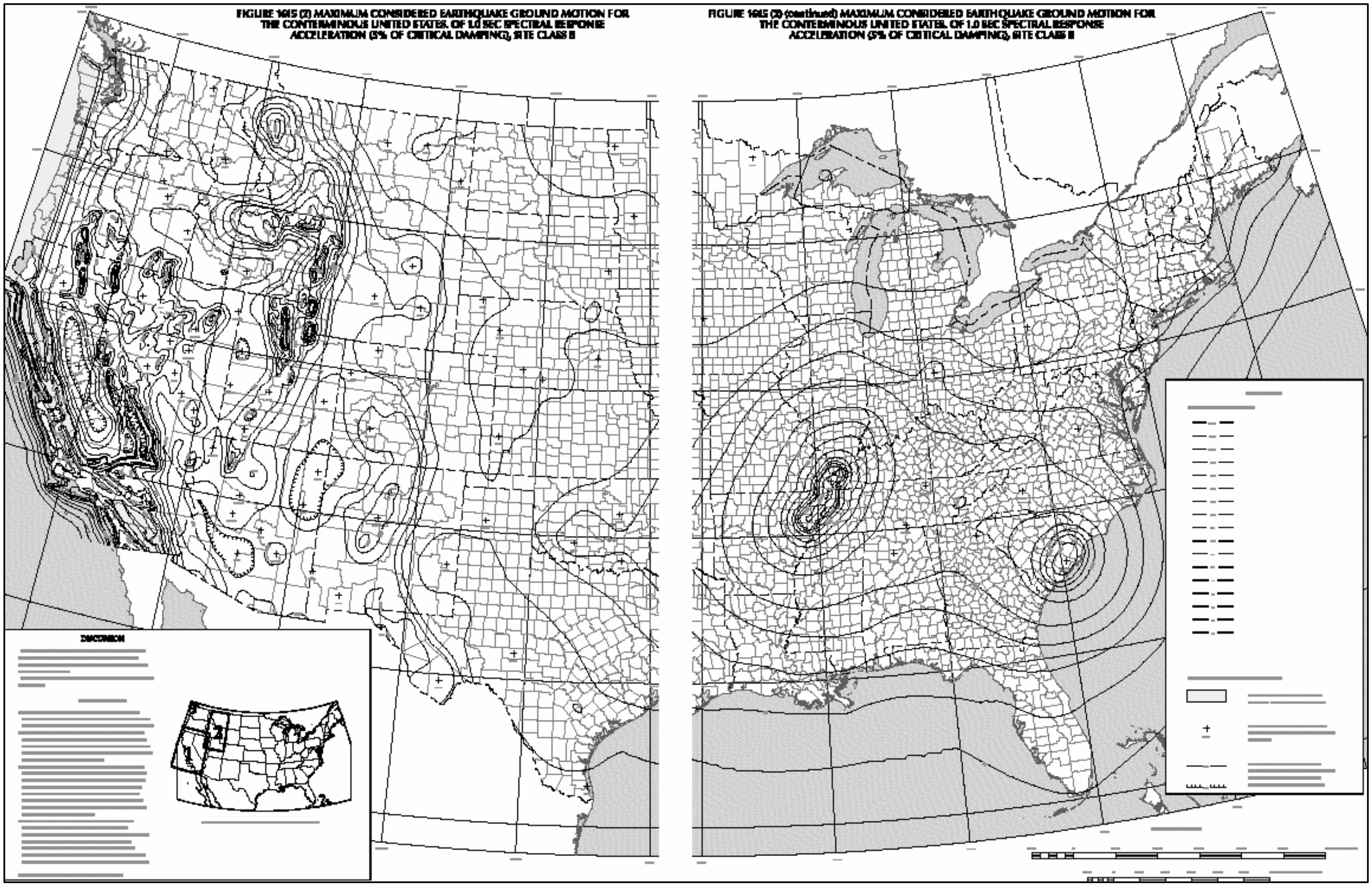
- For known “active” faults
- Uses characteristic largest earthquake on fault
- Uses 150% of value from median attenuation

Use deterministic value if lower than 2% in 50 year value

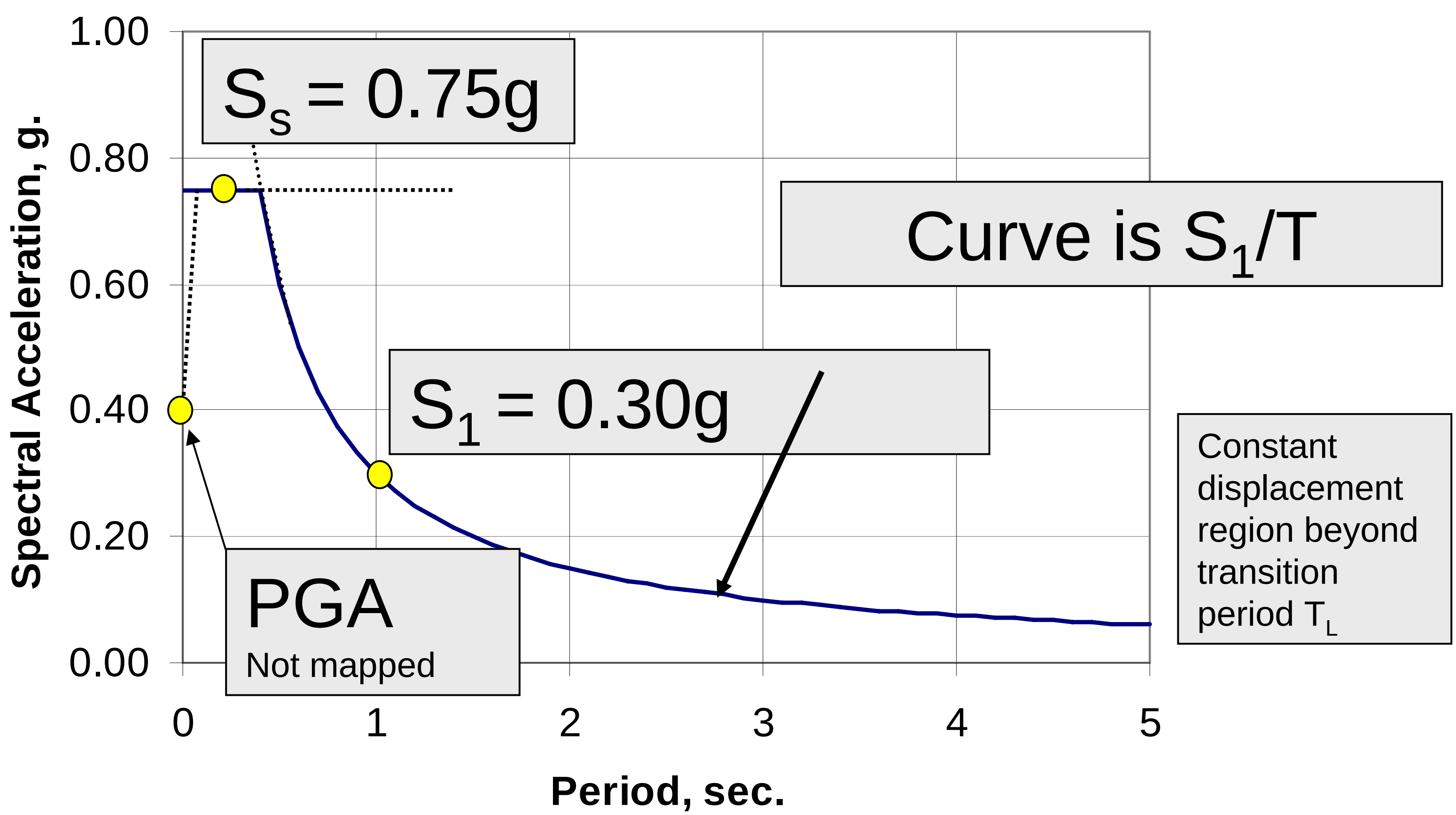
NEHRP Provisions Maps
0.2 Second Spectral Response (S_S)



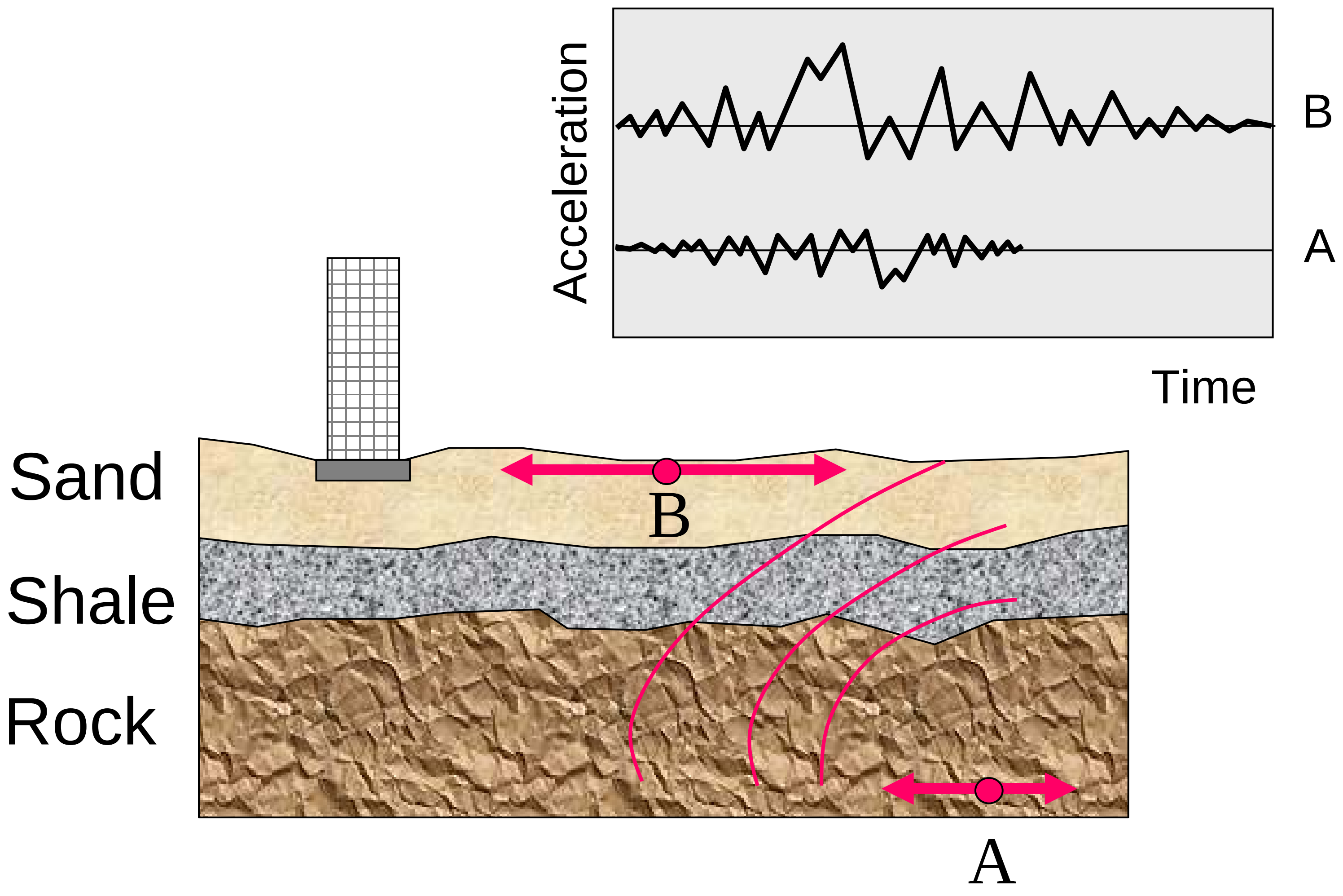
NEHRP Provisions Maps
1.0 Second Spectral Response (S_1)



2% in 50 Year 5% Damped MCE Elastic Spectra Site Class B (Firm Rock)



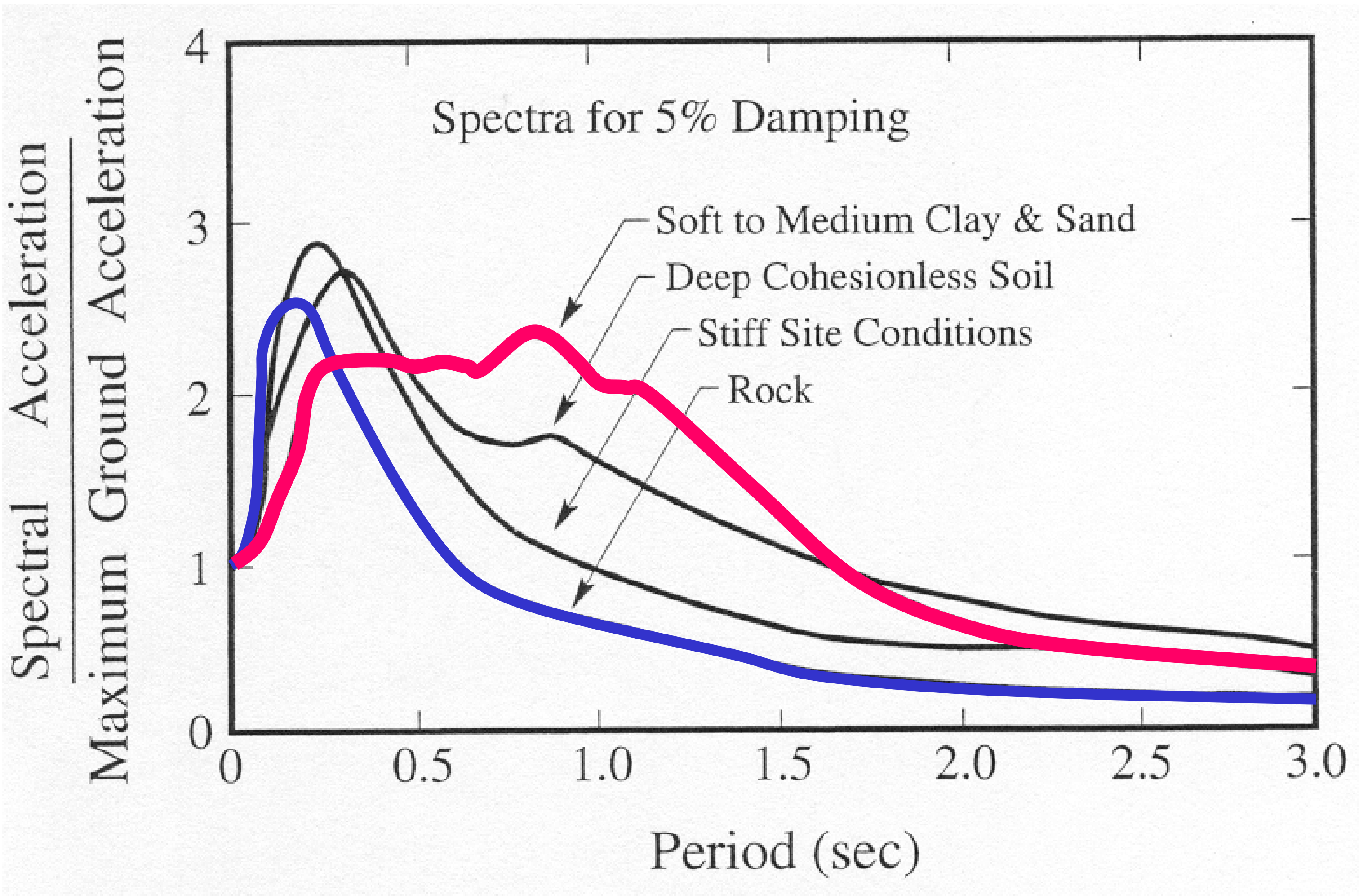
Site Amplification Effects



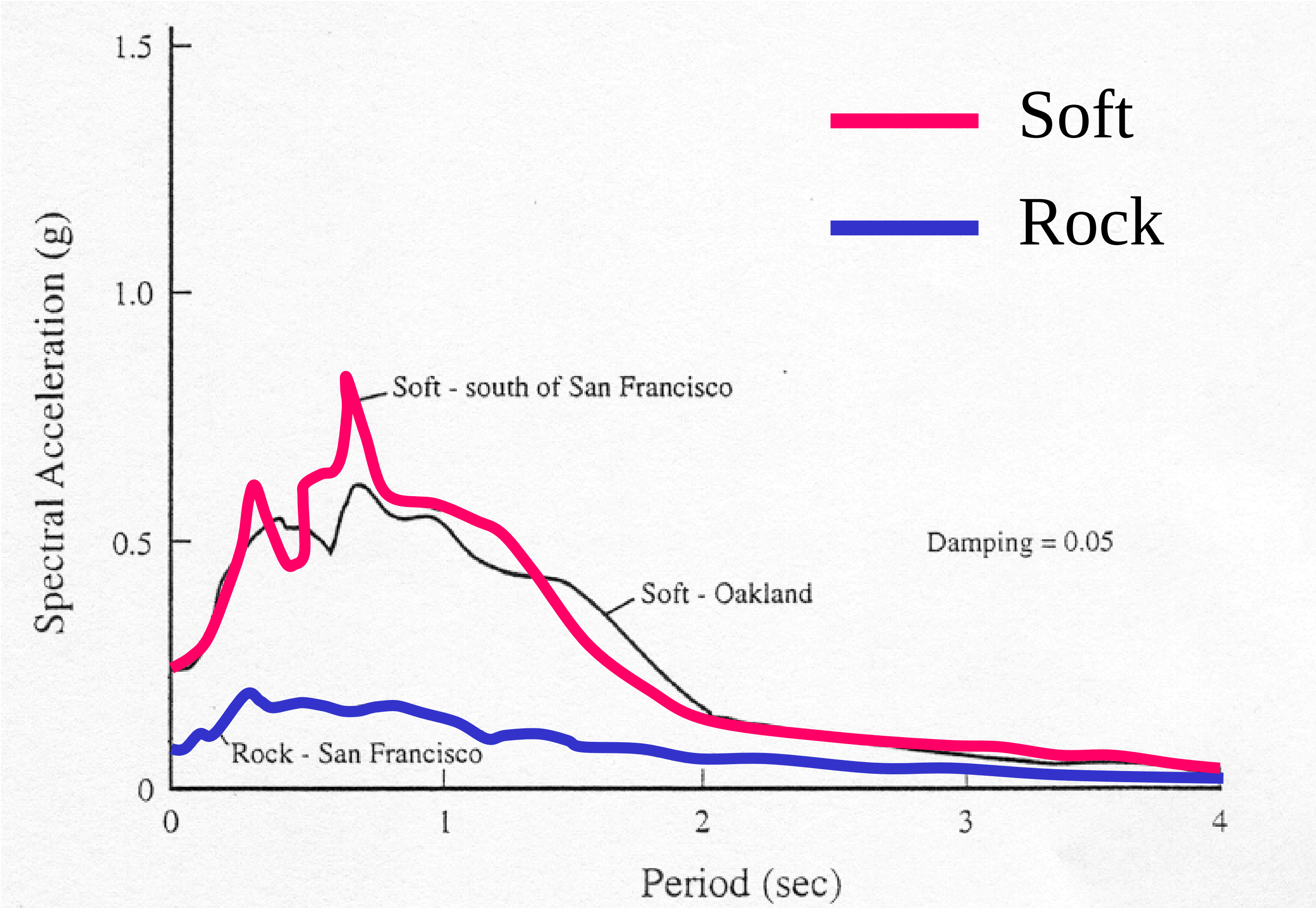
Site Amplification Effects

- Amplification of ground motion
- Longer duration of motion
- Change in frequency content of motion
- Not the same as soil-structure interaction

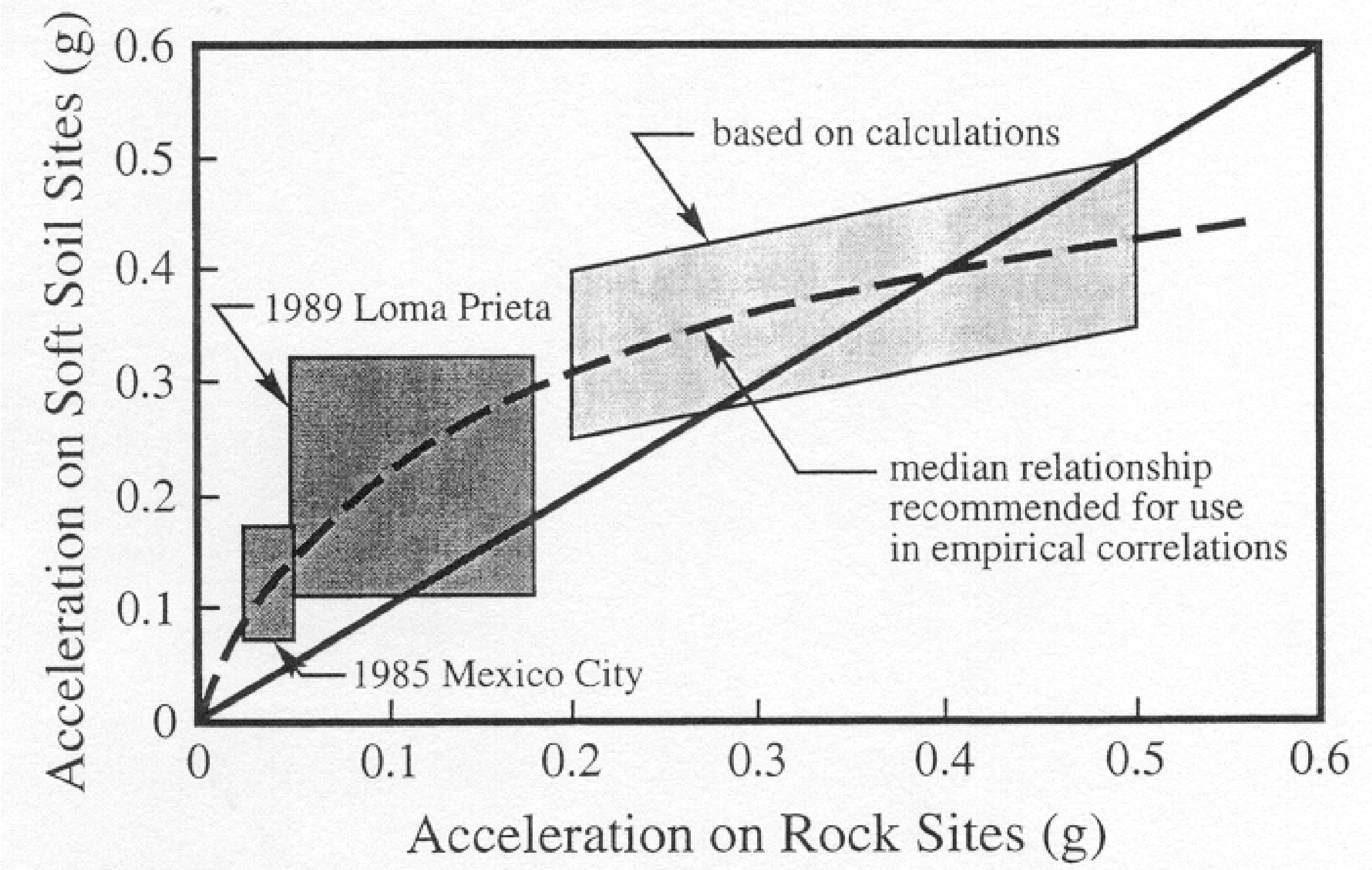
Site Amplification (Seed et al.)



Site Amplification: Loma Prieta Earthquake



Site Amplification: Loma Prieta and Mexico City Earthquakes



NEHRP Provisions Site Classes

A Hard rock $v_s > 5000$ ft/sec

B Rock: $2500 < v_s < 5000$ ft/sec

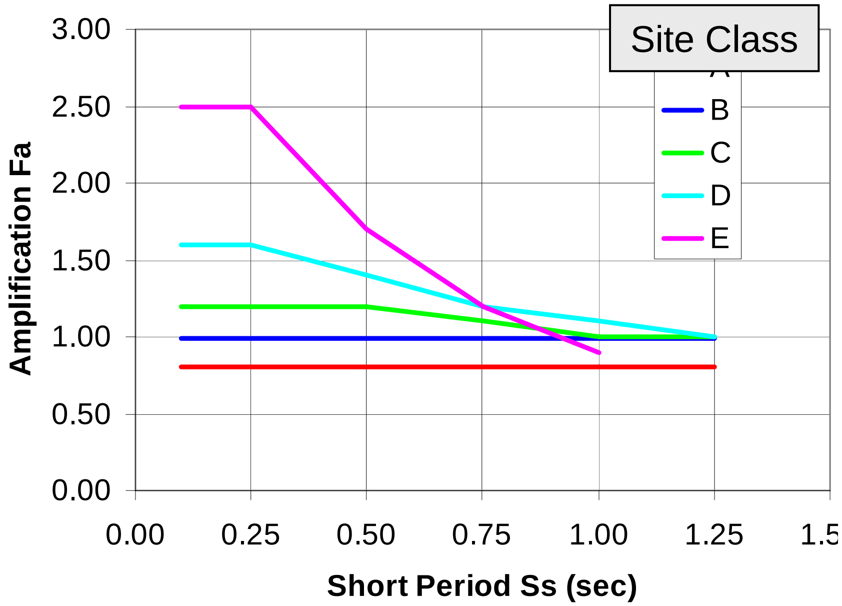
C Very dense soil or soft rock: $1200 < v_s < 2500$ ft/sec

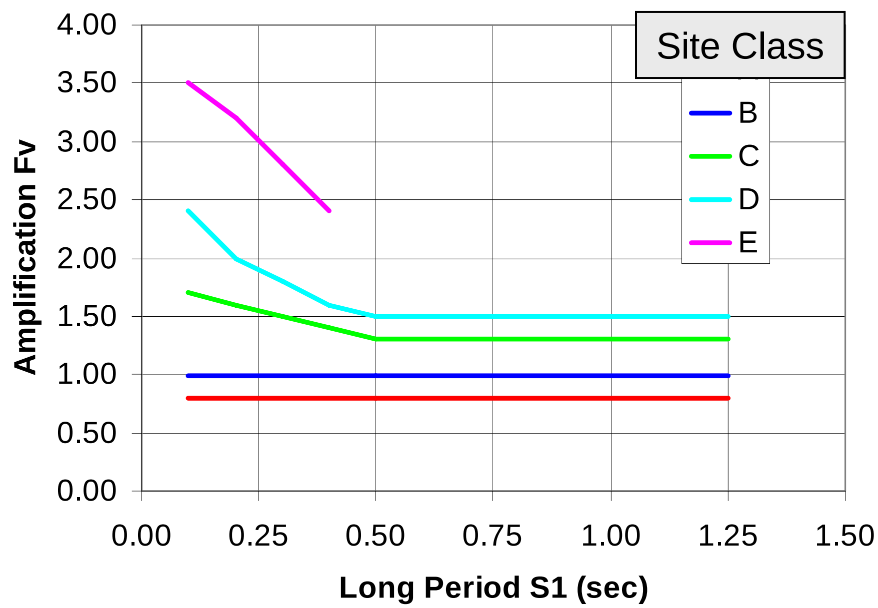
D Stiff soil : $600 < v_s < 1200$ ft/sec

E $V_s < 600$ ft/sec

F Site-specific requirements

NEHRP Site Amplification for Site Classes A through E

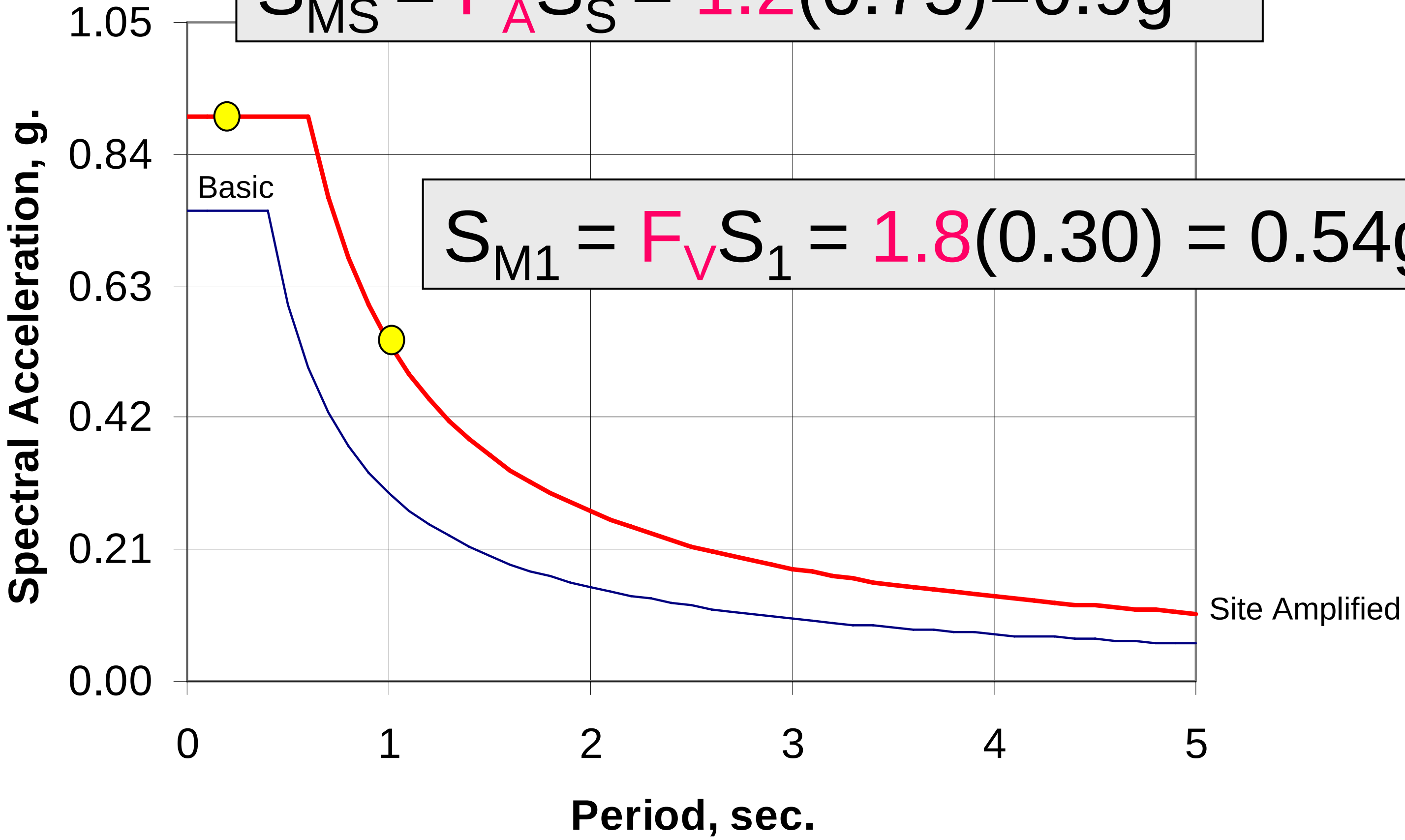




2% in 50 Year 5% Damped MCE Elastic Spectra Modified for Site Class D

$S_{MS} = F_A S_S = 1.2(0.75) = 0.9g$

$S_{M1} = F_V S_1 = 1.8(0.30) = 0.54g$



Scaling of *NEHRP Provisions* Spectra by 2/3 for "Margin of Performance"

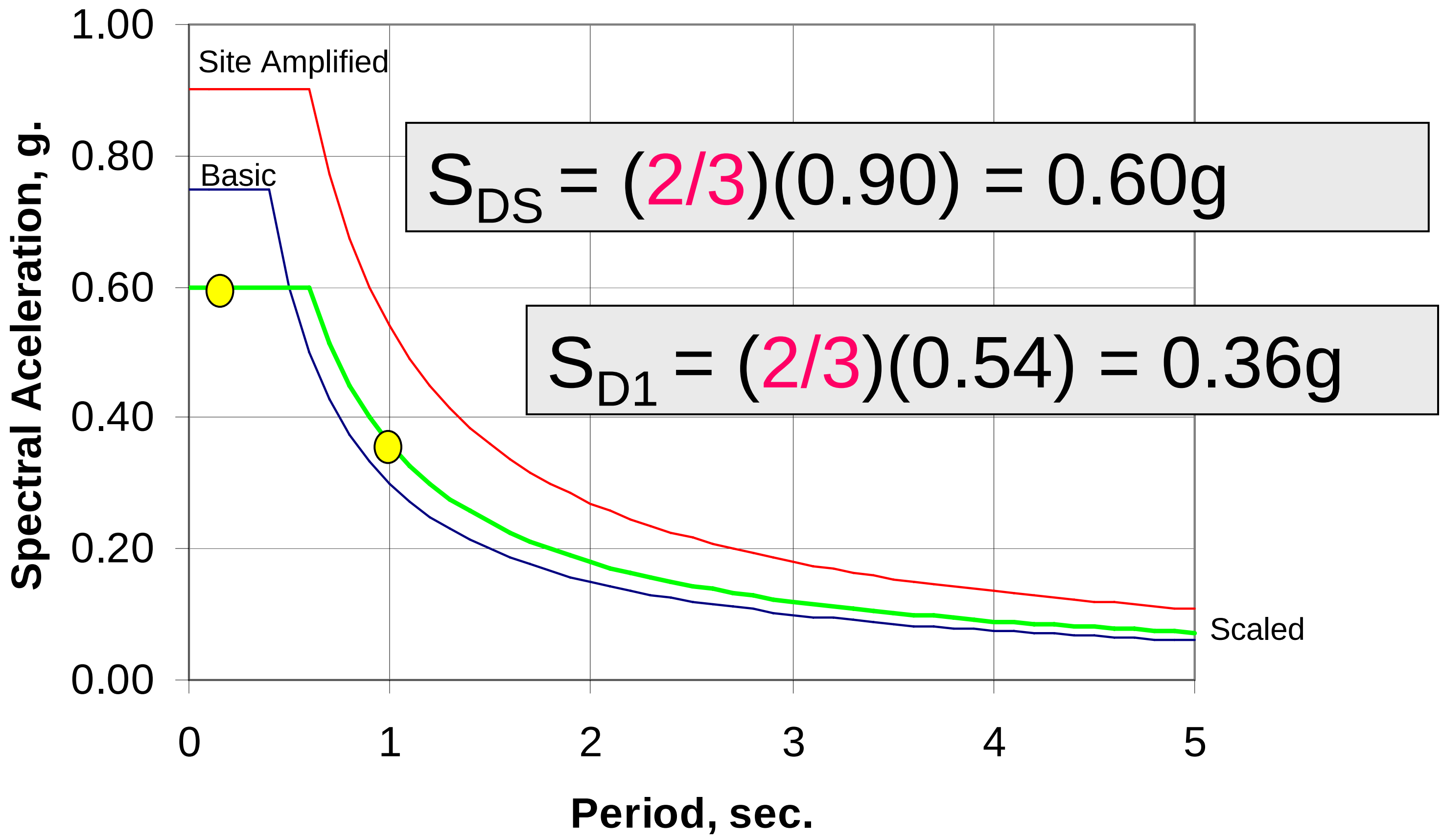
Buildings designed according to current procedures assumed to have margin of collapse of 1.5

Judgment of "lower bound" margin of collapse given by current design procedures

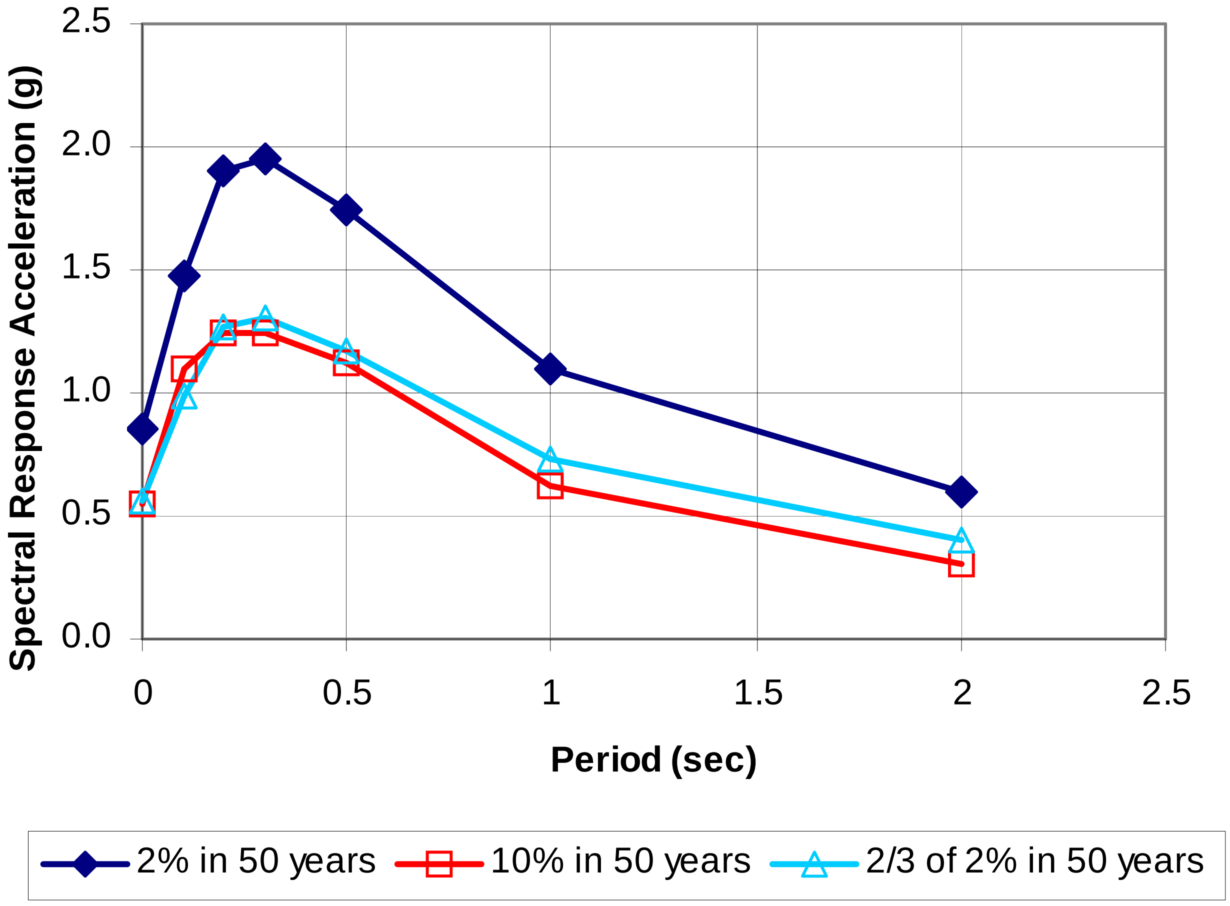
Design with current maps (2% in 50 year) but scale motions by 2/3

Results in 2/3 x 1.5 = 1.0 deterministic earthquake (where applicable)

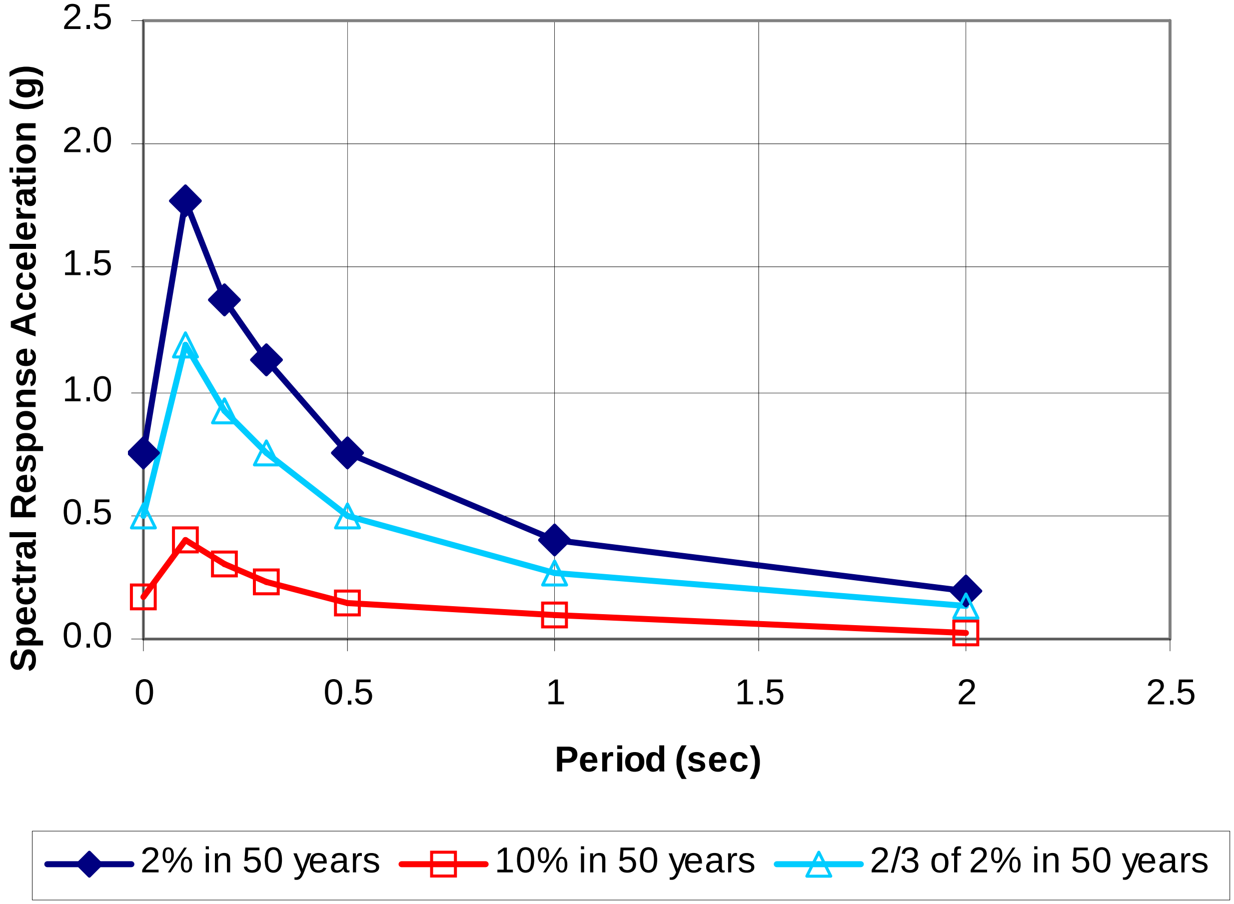
2% in 50 Year 5% Damped Elastic Design Spectra (Scaled by 2/3)



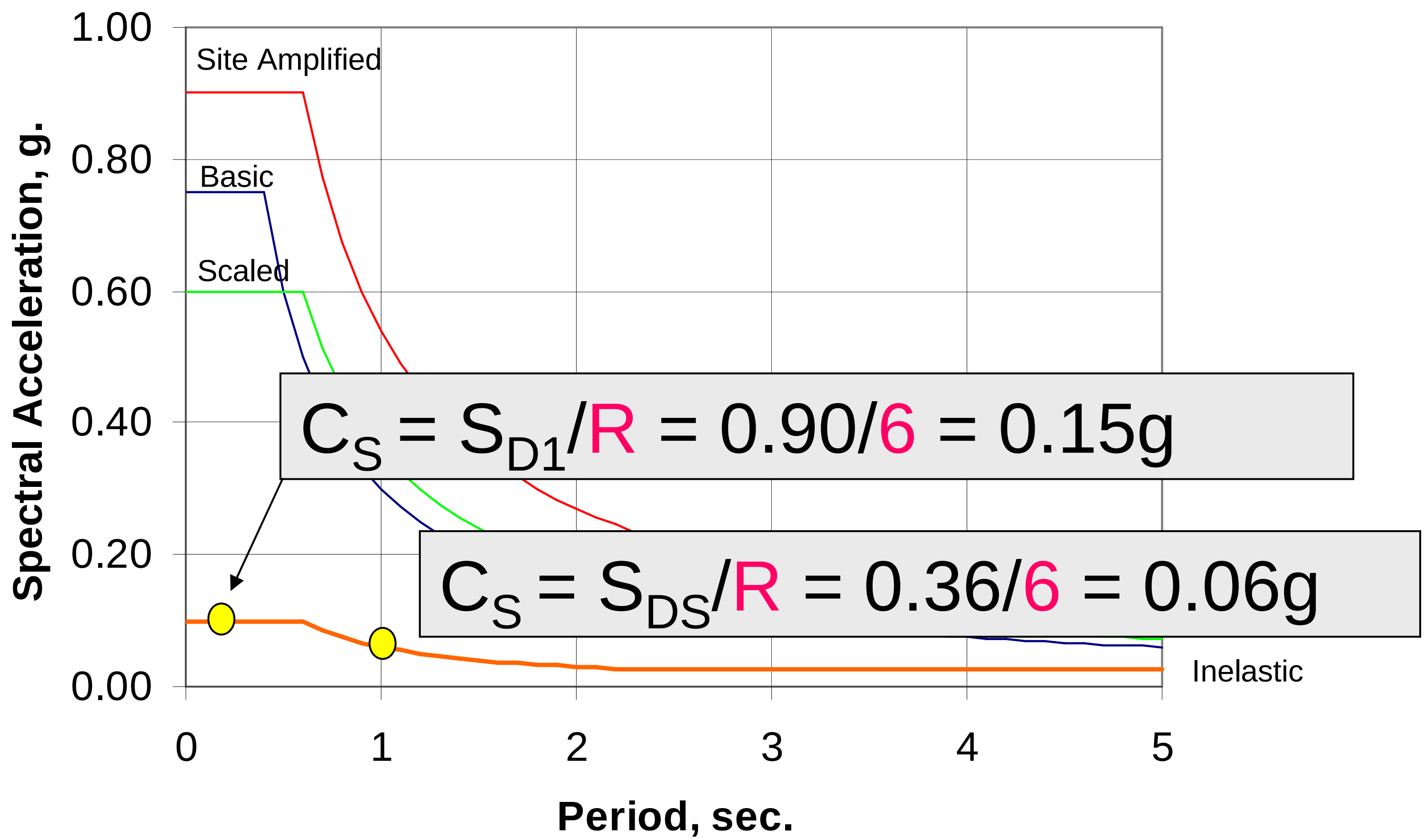
Effect of Scaling in Western United States



Effect of Scaling in Eastern United States



2% in 50 Year 5% Damped Inelastic Design Spectra (R=6, I=1) Site Class D



$C_S = S_{D1}/R = 0.90/6 = 0.15g$

$C_S = S_{DS}/R = 0.36/6 = 0.06g$

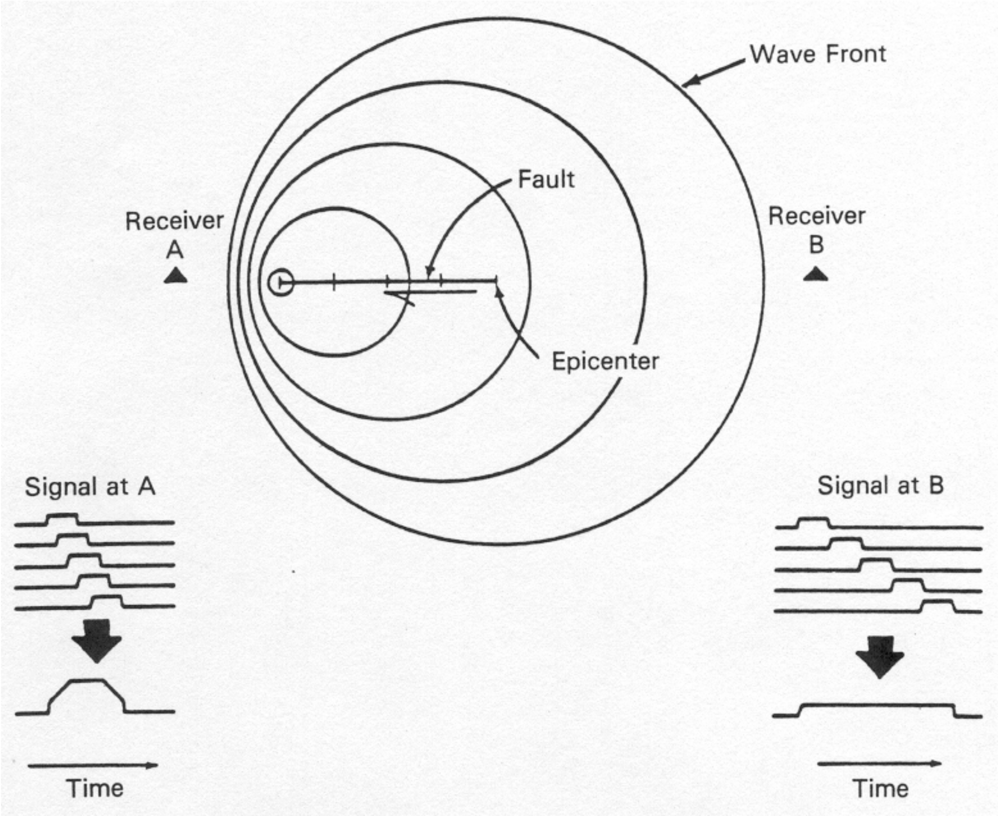
Basis for Reduction of Elastic Spectra by *R*

Inelastic behavior of structures

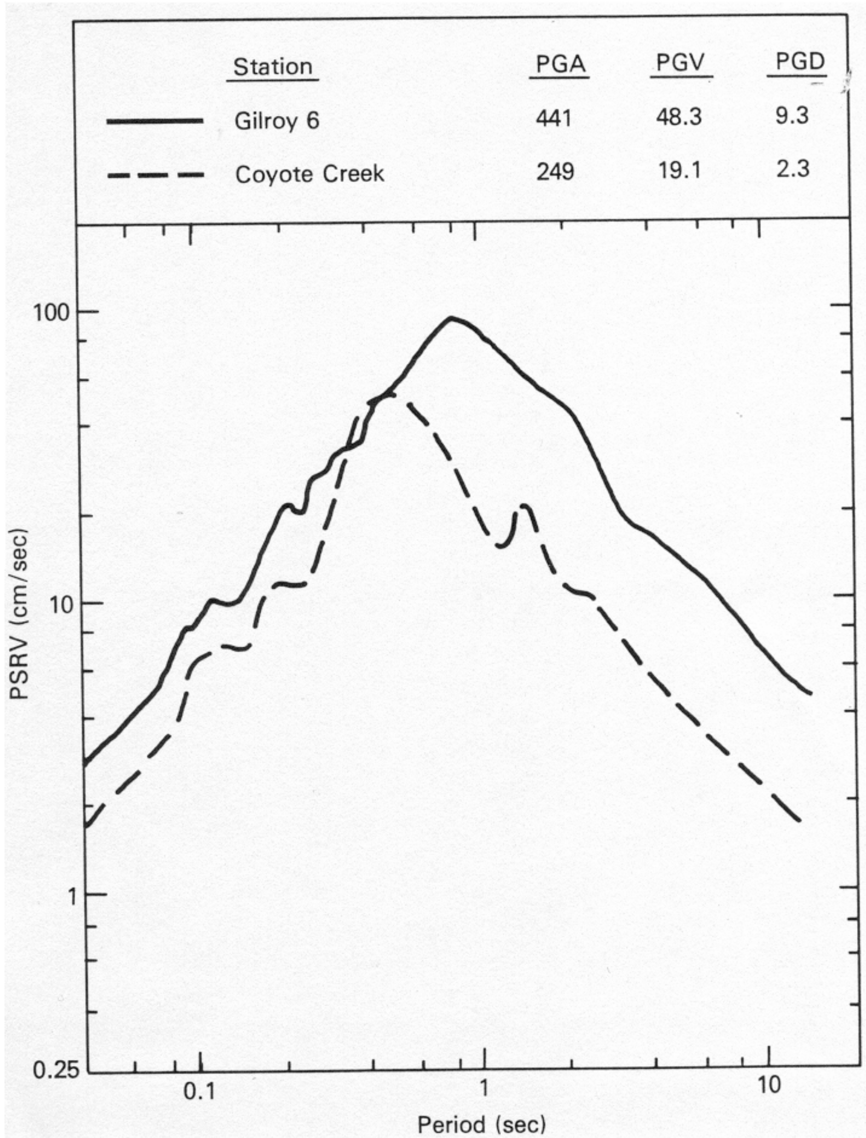
Methods for obtaining acceptable inelastic response are presented in later topics

Directionality and "Killer Pulse" Earthquakes

For sites relatively close to the fault, the direction of fault rupture can have an amplifying effect on ground motion amplitude.



Effect of Directionality on Response Spectra



ards

Effect of Directionality on Ground Motion