

Development of U. S. National Seismic Hazard Maps and Implementation in the International Building Code

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(U.S. Geological Survey)

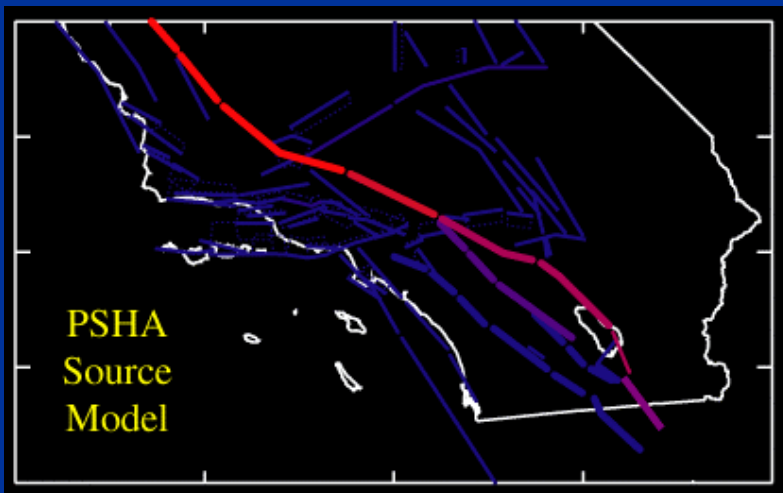
<http://earthquake.usgs.gov/hazmaps/>



Seismic hazard analysis has two model components:

(1) Earthquake-Rupture Forecast (ERF)

Probability of all possible fault-rupture events ($M \geq \sim 5$) for region & time span

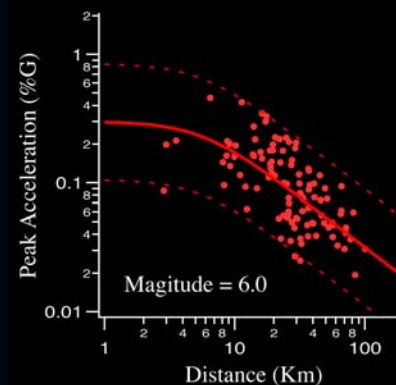


(2) Intensity-Measure Relationship (IMR)

Gives $\text{Prob}(\text{IMT} \geq \text{IML})$ for a given site and fault-rupture event

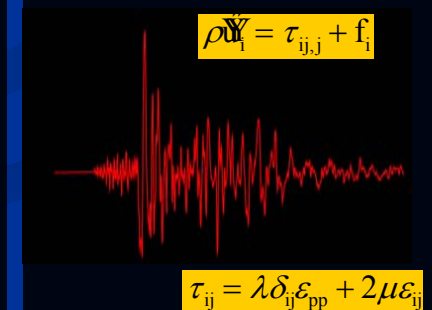
Attenuation Relationships

(traditional)
(no physics)

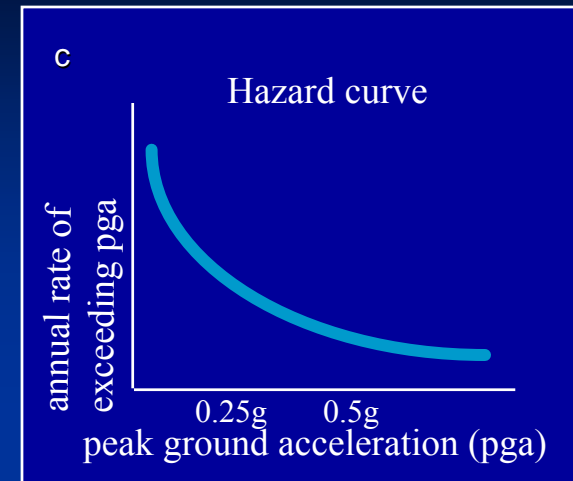
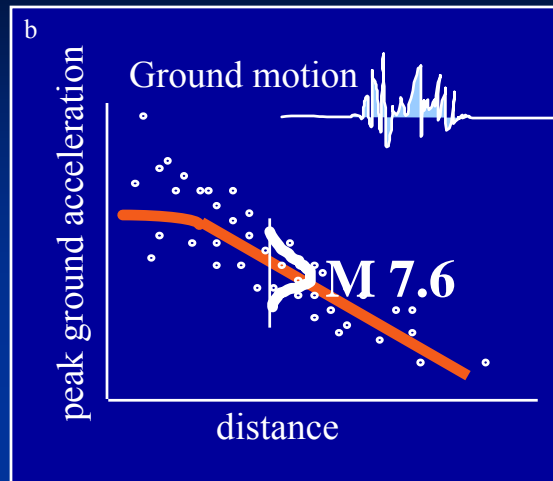
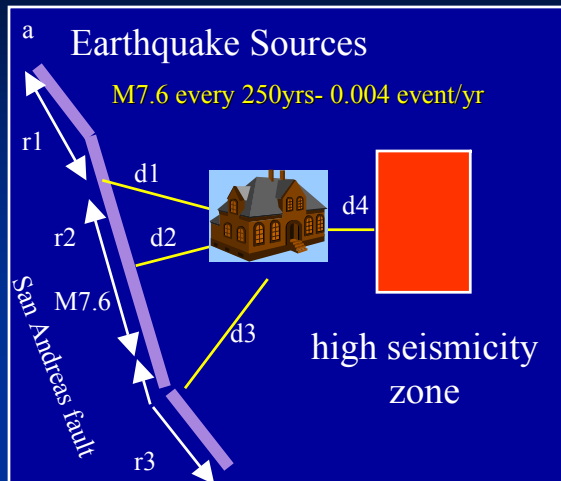


Full-Waveform Modeling

(developmental)
(more physics)



PROBABILISTIC SEISMIC HAZARD METHODOLOGY



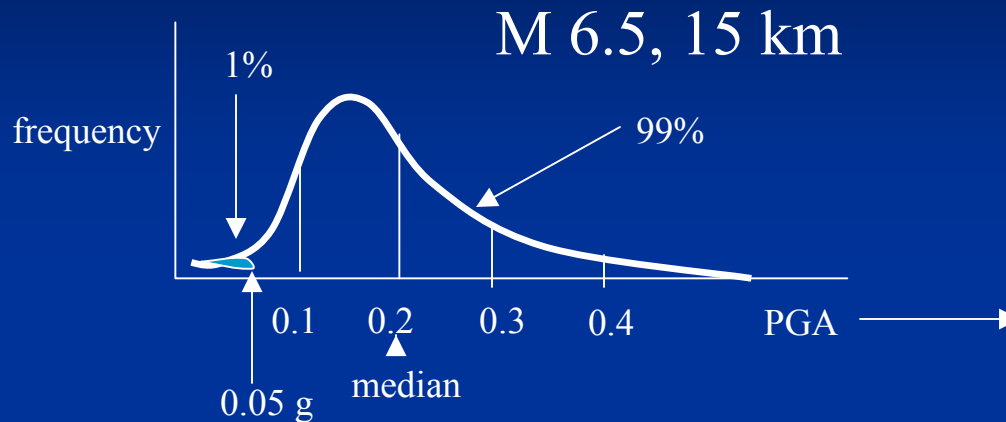
To calculate the hazard curve (annual rate of exceeding ground motions) we:

1. Determine magnitude, and distance, and rate 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.

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

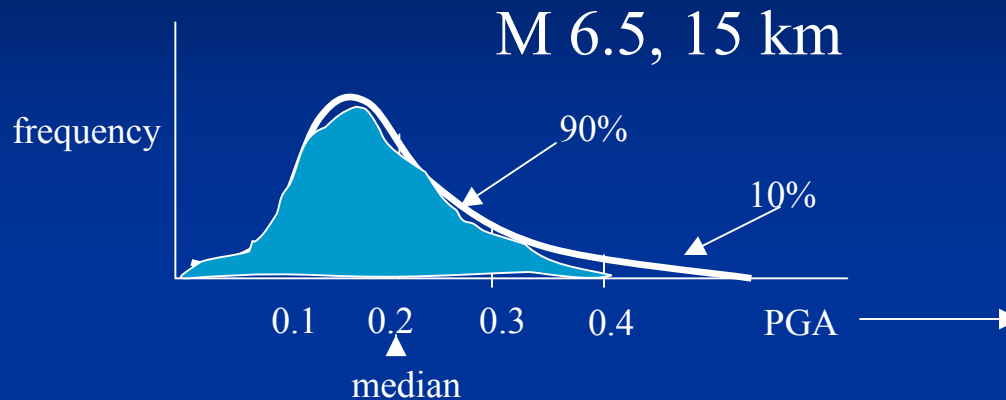


Almost all earthquakes M 6.5 at a distance of 15 km will cause ground motion that will exceed 0.05g

$$0.02 \text{ (ann. rate of M 6.5)} * 0.99 \text{ (probability of exceeding 0.05)} = 0.02$$

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

What is the annual rate that ground motion will exceed 0.4 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

0.4g

Rate of 0.4 g exceedance:

0.02

0.002

Ground motion:

0.05g

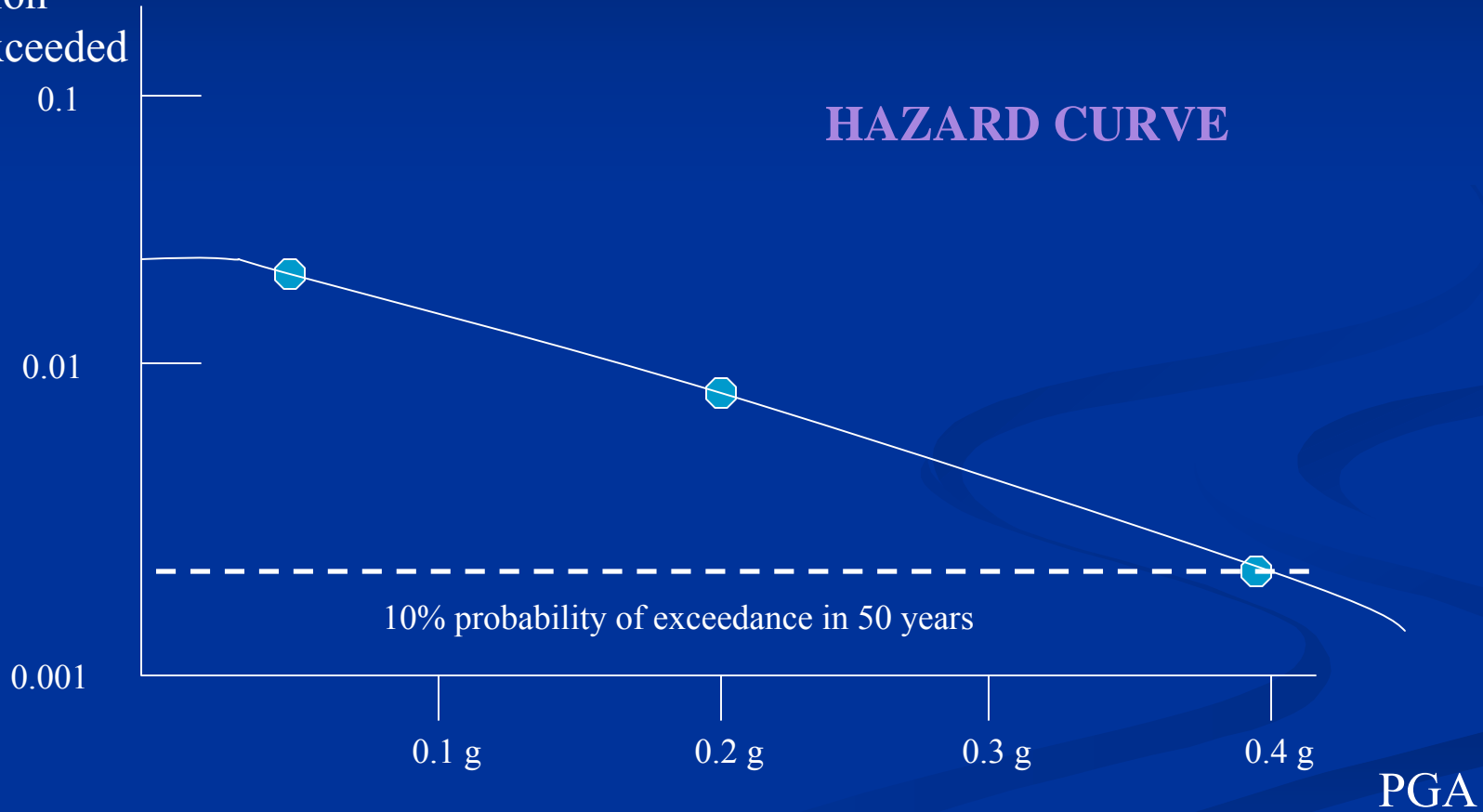
0.4g

Rate of Ground motion exceedance:

0.02

0.002

Rate ground
motion
is exceeded



DATA FOR DEVELOPING SEISMIC SOURCES

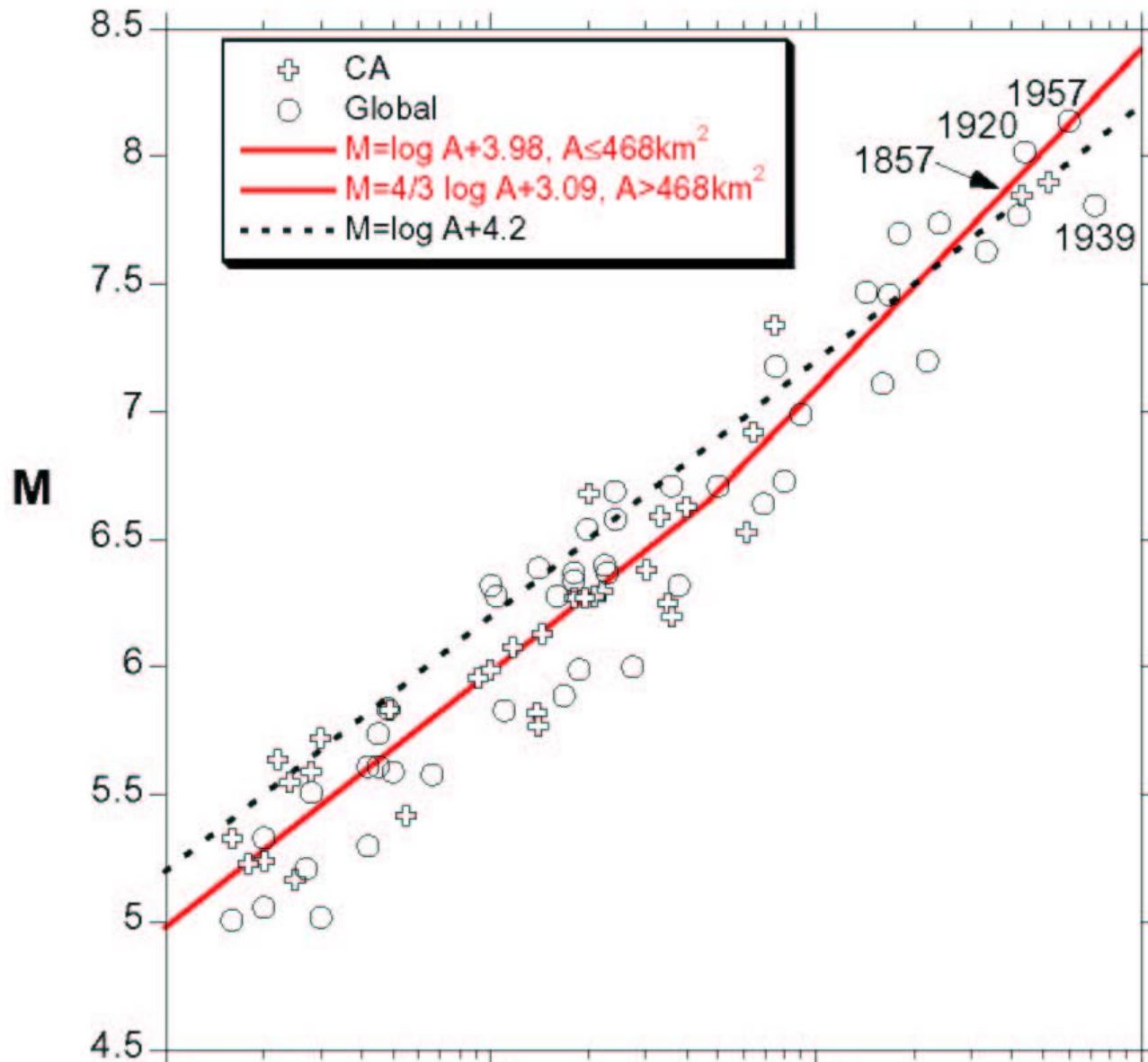
EARTHQUAKES

GEODETTIC DATA

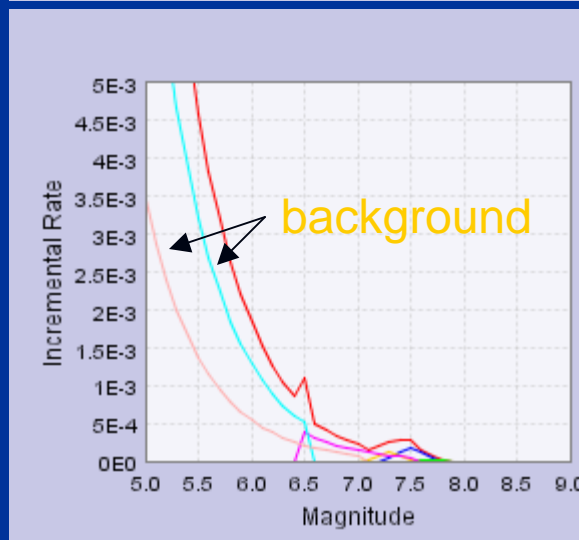
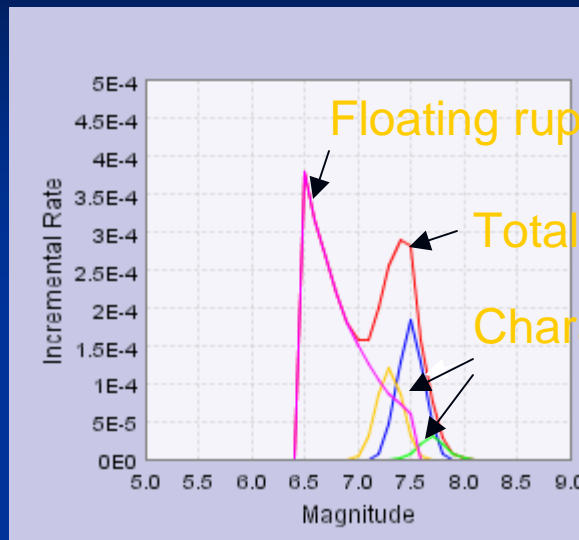
QUATERNARY FAULTS

Synthetic Aperture Radar Techniques
Paleo-tsunami studies
Paleo-seismology studies

From fault data we can estimate magnitude from potential Rupture area and recurrence from slip rate or paleoseismic data



USGS Magnitude-frequency model



Parameters

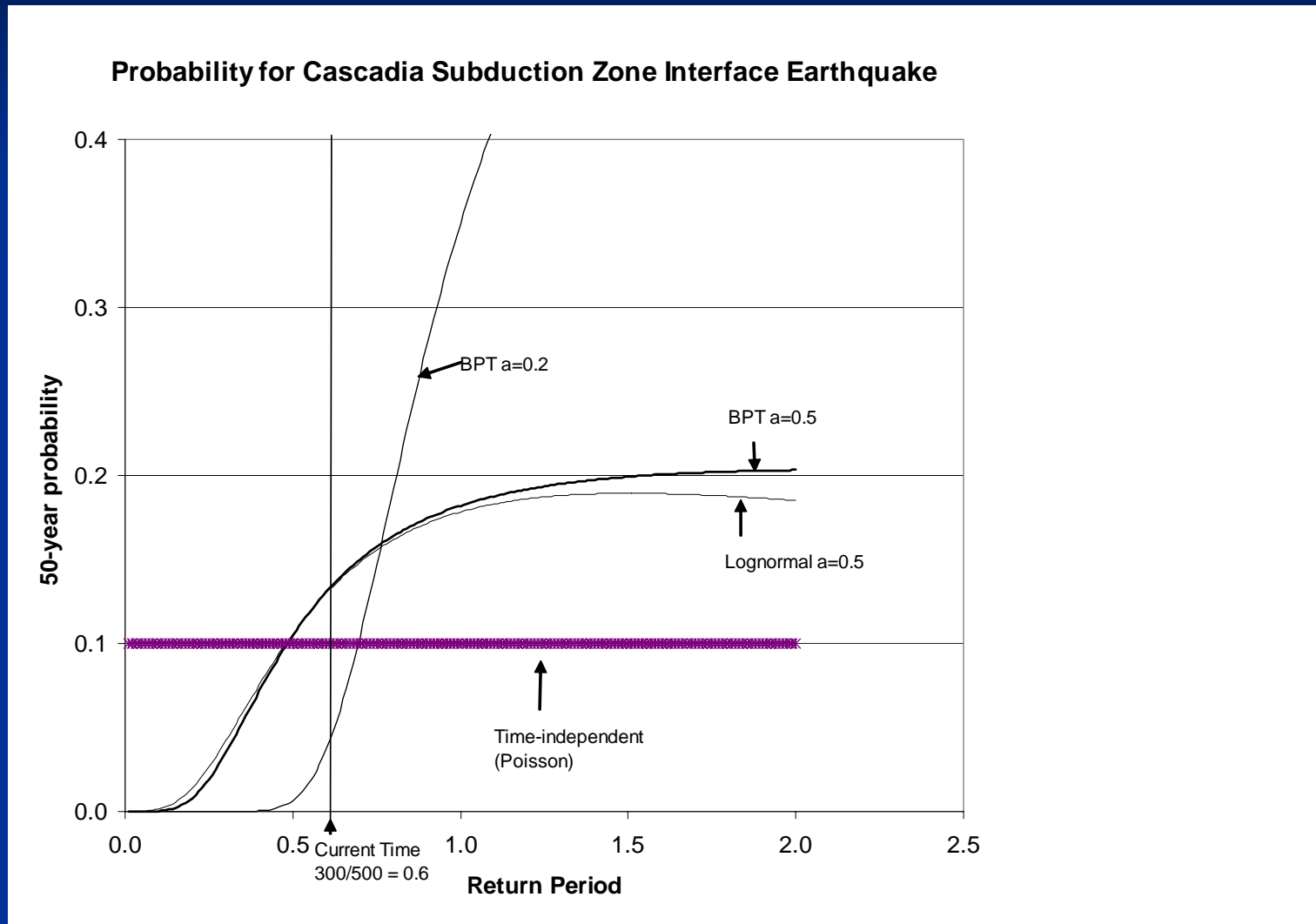
- Slip rate
- Characteristic or maximum magnitude
- Epistemic and aleatory uncertainty
- Ratio of Characteristic to Floating Rupture moment rate
- Minimum magnitude
- b-value

Moment rate $2E17/yr$ (2/3) split into three magnitudes
Moment rate $6.7E16/yr$ (1/3) used for floating ruptures (GR)
Moment rate $2E16/yr$ used for background earthquakes

Time-dependent hazard analysis

- Time dependent hazard considers the time since the last earthquake:
 - USGS has produced preliminary time-dependent maps for Alaska, California, Utah, and New Madrid region. These models are combinations of time-dependent and Poisson recurrence.
 - Currently, the USGS considers these maps as research products.
 - These products will be posted at our website.
 - For 2007 building codes the USGS will continue to use the Poisson maps.
 - The largest contribution of uncertainty in the 2002 report was due to the recurrence model used.

Time-dependent hazard maps



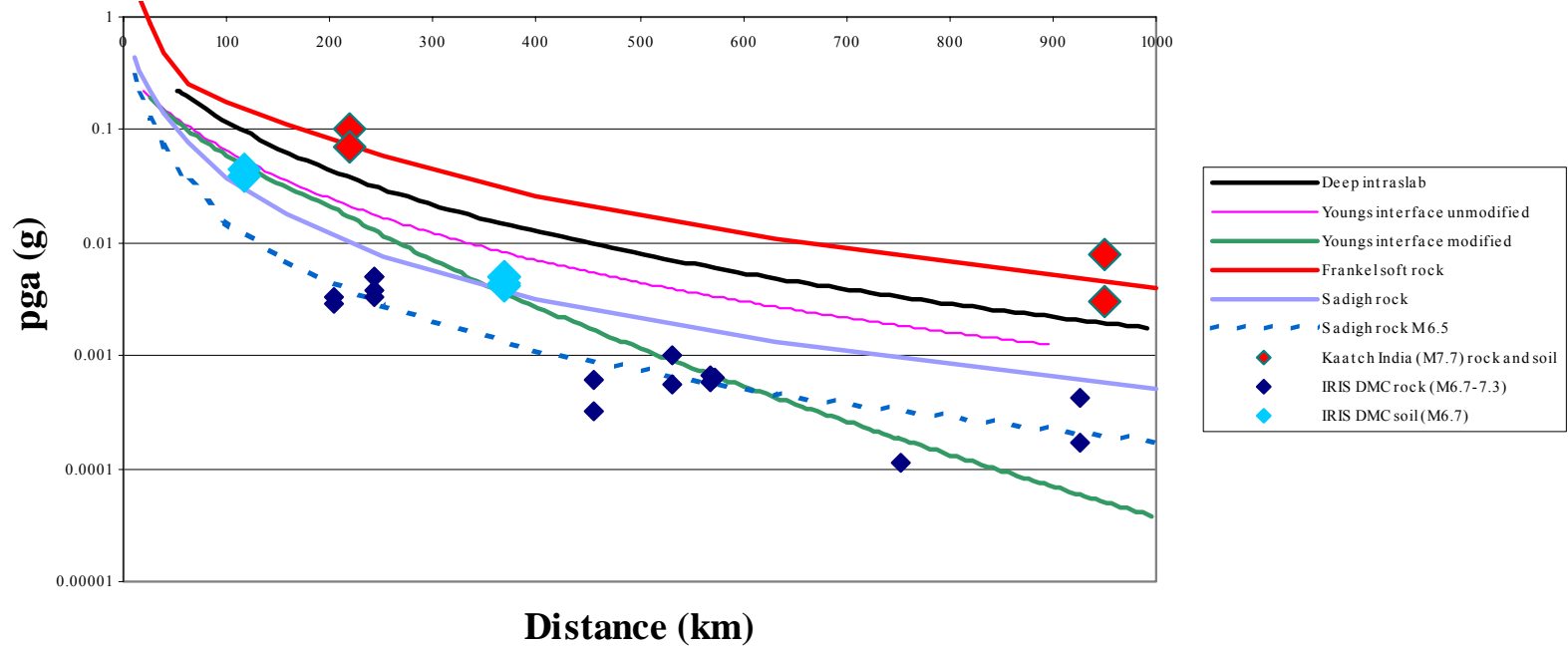
How do stress changes influence time-dependent earthquake probabilities?

- Time-dependent conditional probability *with stress changes*



Ground motion attenuation relations

M 7.5 comparsion of attenuation relations



General Functional Form of Crustal Interplate Ground Motion

Attenuation relations

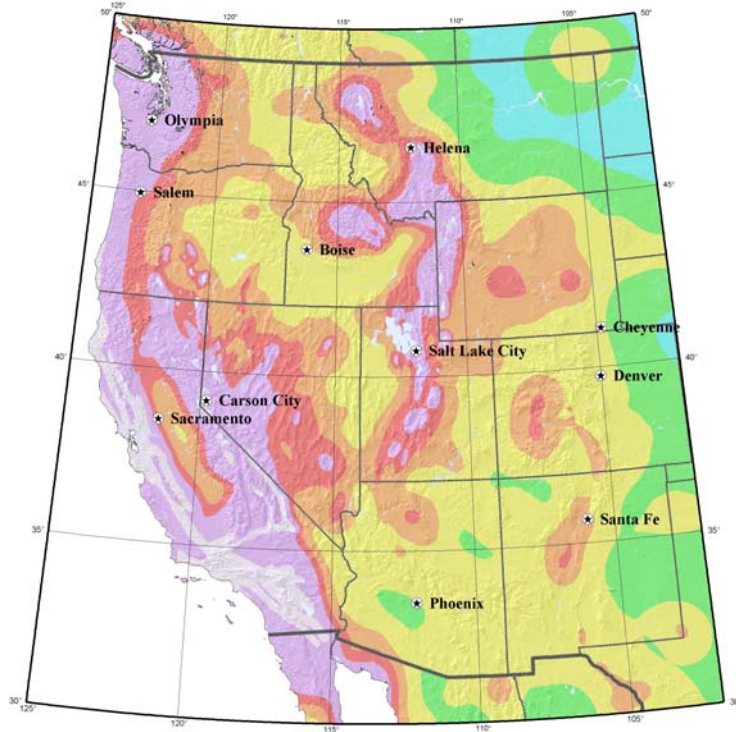
$$\ln Y = f_1(M) + f_2(R) + f_3(F) + f_4(HW) + f_5(S) + f_6(D) + \varepsilon$$

- $f_1(M)$ = magnitude scaling term
- $f_2(R)$ = distance scaling term
- $f_3(F)$ = style-of-faulting term
- $f_4(HW)$ = hanging-wall term
- $f_5(S)$ = shallow site conditions term
- $f_6(D)$ = shallow sediment and basin depth term
- ε = random error term

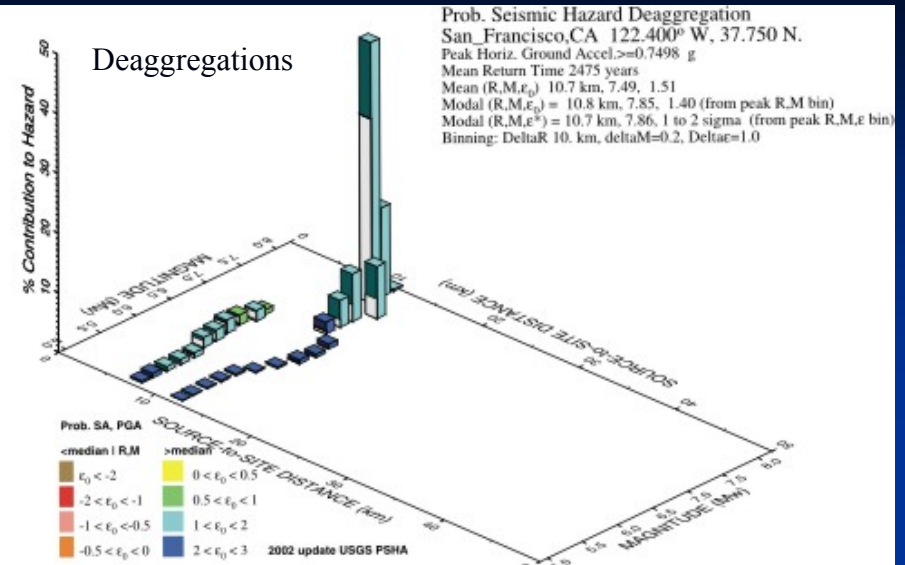
HAZARD PRODUCTS

<http://eqhazmaps.usgs.gov>

2002 Hazard Maps - PGA-rock
2% probability of exceedance in 50-years

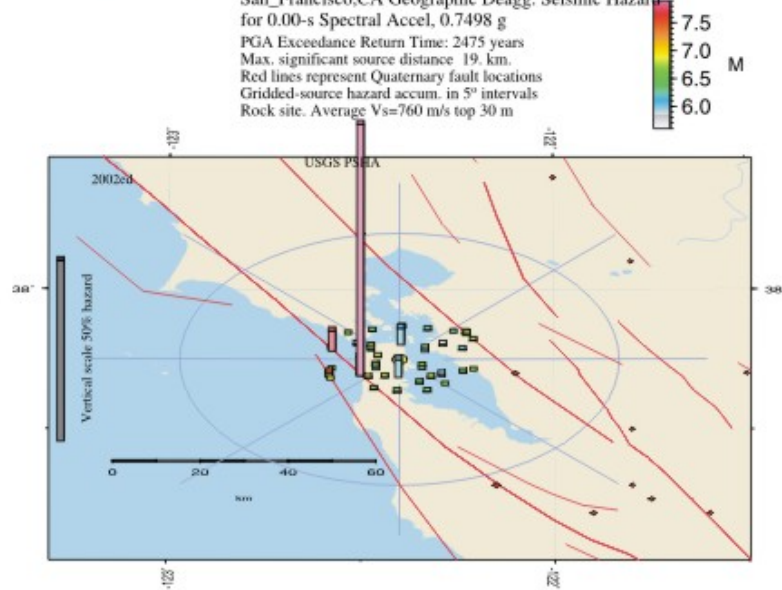


Purple-0.3g and greater
Yellow -0.1g and greater

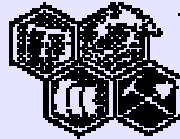


GMT 2004 Sep 1 16:05:51 Site Coords: 122.400 37.750 (yellow disk), Max annual ExceedRate: 2777E-09 (column height prop. to ExRate), Red diamonds: historical earthquakes, M=6

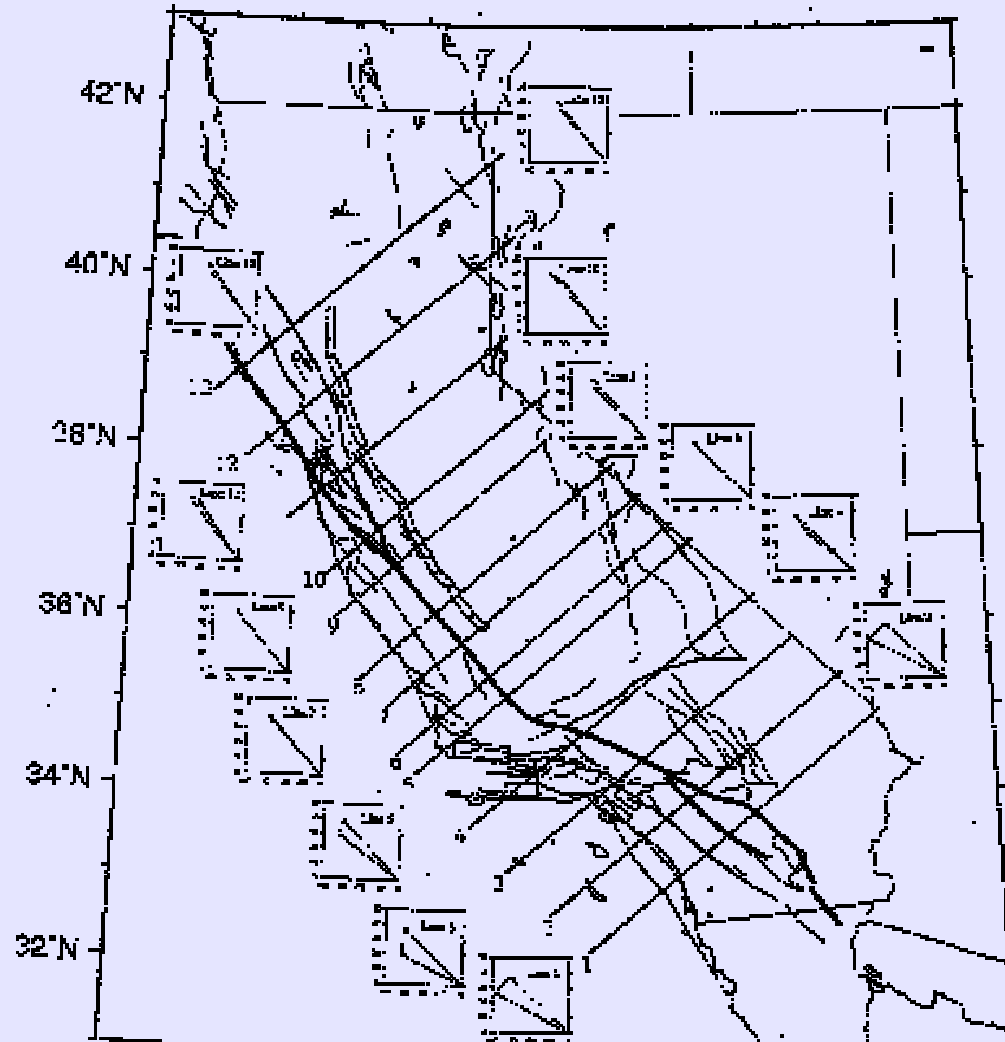
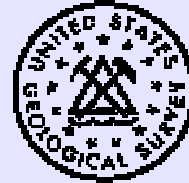
San_Francisco,CA Geographic Deagg. Seismic Hazard
for 0.00-s Spectral Accel, 0.7498 g
PGA Exceedance Return Time: 2475 years
Max. significant source distance: 19. km.
Red lines represent Quaternary fault locations
Gridded-source hazard accum. in 5° intervals
Rock site. Average Vs=760 m/s top 30 m



GMT 2004 Sep 1 16:05:51 Site Coords: 122.400 37.750 (yellow disk), Max annual ExceedRate: 2777E-09 (column height prop. to ExRate), Red diamonds: historical earthquakes, M=6



DEPARTMENT OF
CONSERVATION
DIVISION OF
MINES AND GEOLOGY



CA Historic versus Model Seismicity

using 2002 model

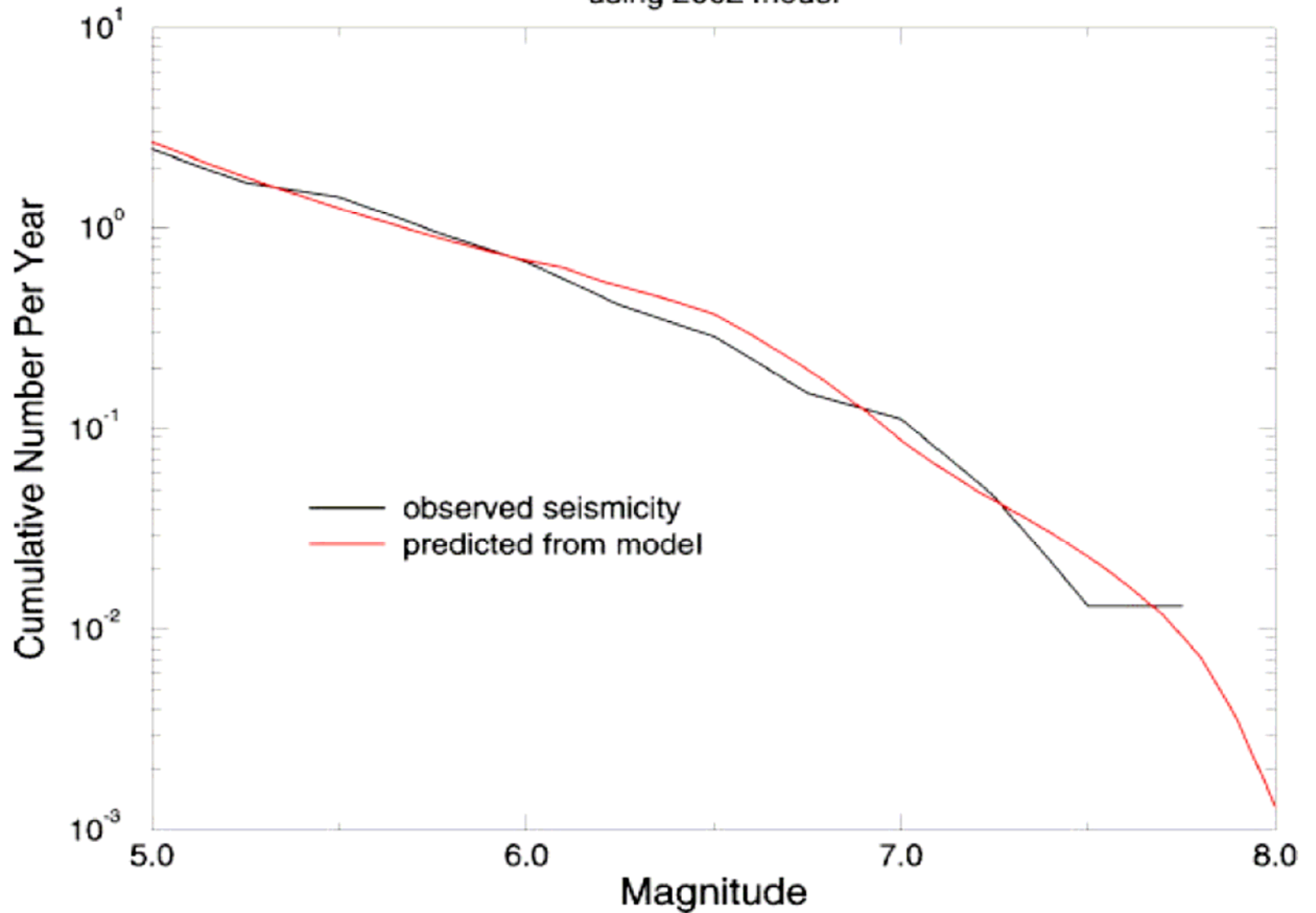


Figure 6. Comparison of predicted and historic seismicity rates for most of California.

How the Hazard Maps are used in the International Building Code

THE PROCESS OF INCLUDING SEISMIC HAZARD MAPS IN INTERNATIONAL BUILDING CODE

- **Building Seismic Safety Council and USGS worked together in an iterative process**
- **The end result was a series of USGS probabilistic maps and a series of MCE ground motion maps prepared in response to BSSC requests**

MCE MAPS

- **Maps of Maximum Considered Earthquake Ground Motion**
- **Based on probabilistic maps 2% probability of exceedance in 50 years, firm rock, 0.2s and 1.0 SA.**

PERFORMANCE GOAL

- **Minimize the risk to occupants,**
- **Increase the performance of higher occupancy structures,**
- **Improve the capability of essential structures to function, and**
- **Ensure a low likelihood of collapse for ground motions in excess of the design levels**

PROBABILITIES CONSIDERED

- **10% P.E. in 50 years**
- **5% P.E. in 50 years**
- **2% P.E. in 50 years**

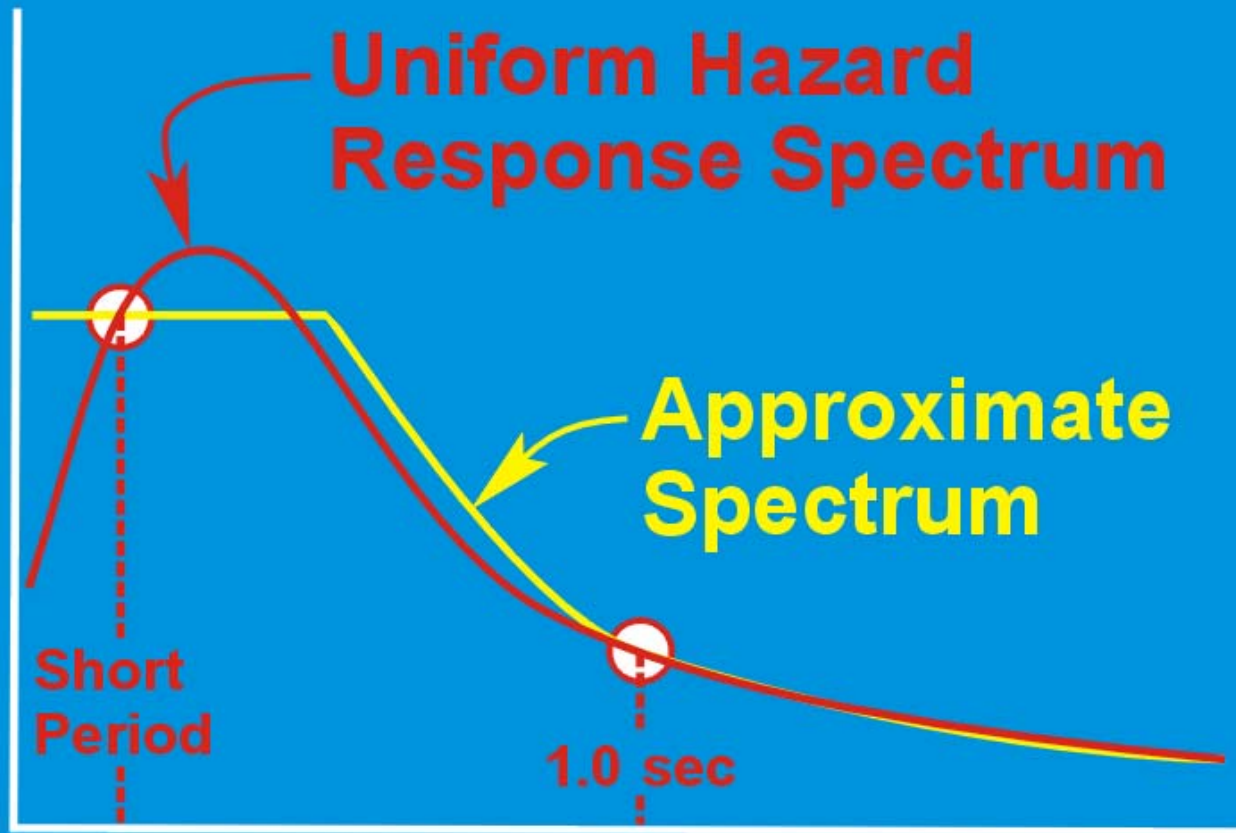
SITE CONDITION OF PROBABILISTIC MAPS

**B/C BOUNDARY - FIRM ROCK,
shear wave velocity of 760 m/sec
in the top 30 m (B/C Boundary)**

PARAMETERS CONSIDERED

- **PGA**
- **Spectral Accelerations**
0.1, 0.2, 0.3, 0.5, 1.0, and 2.0 sec

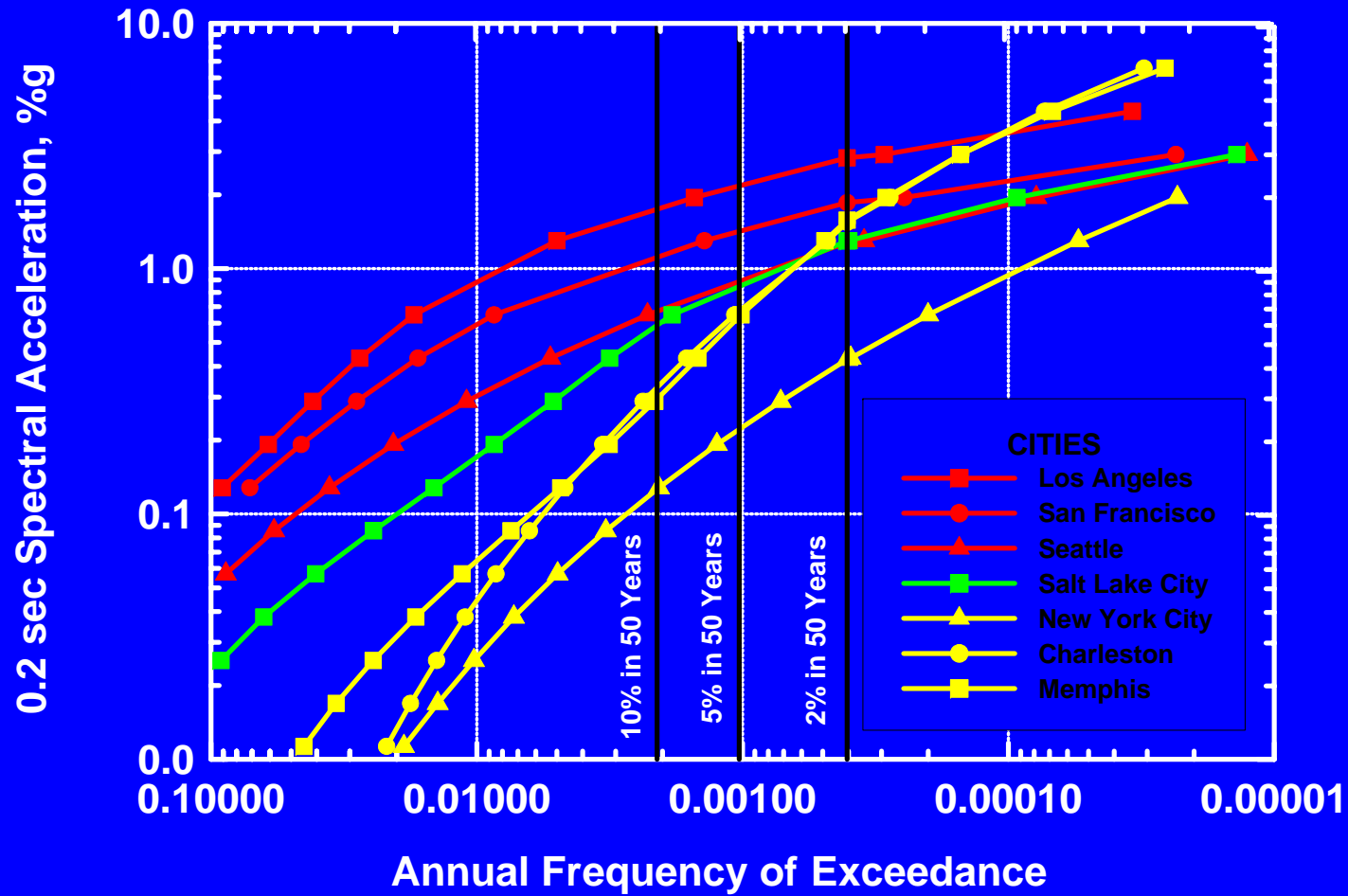
Spectral Acceleration



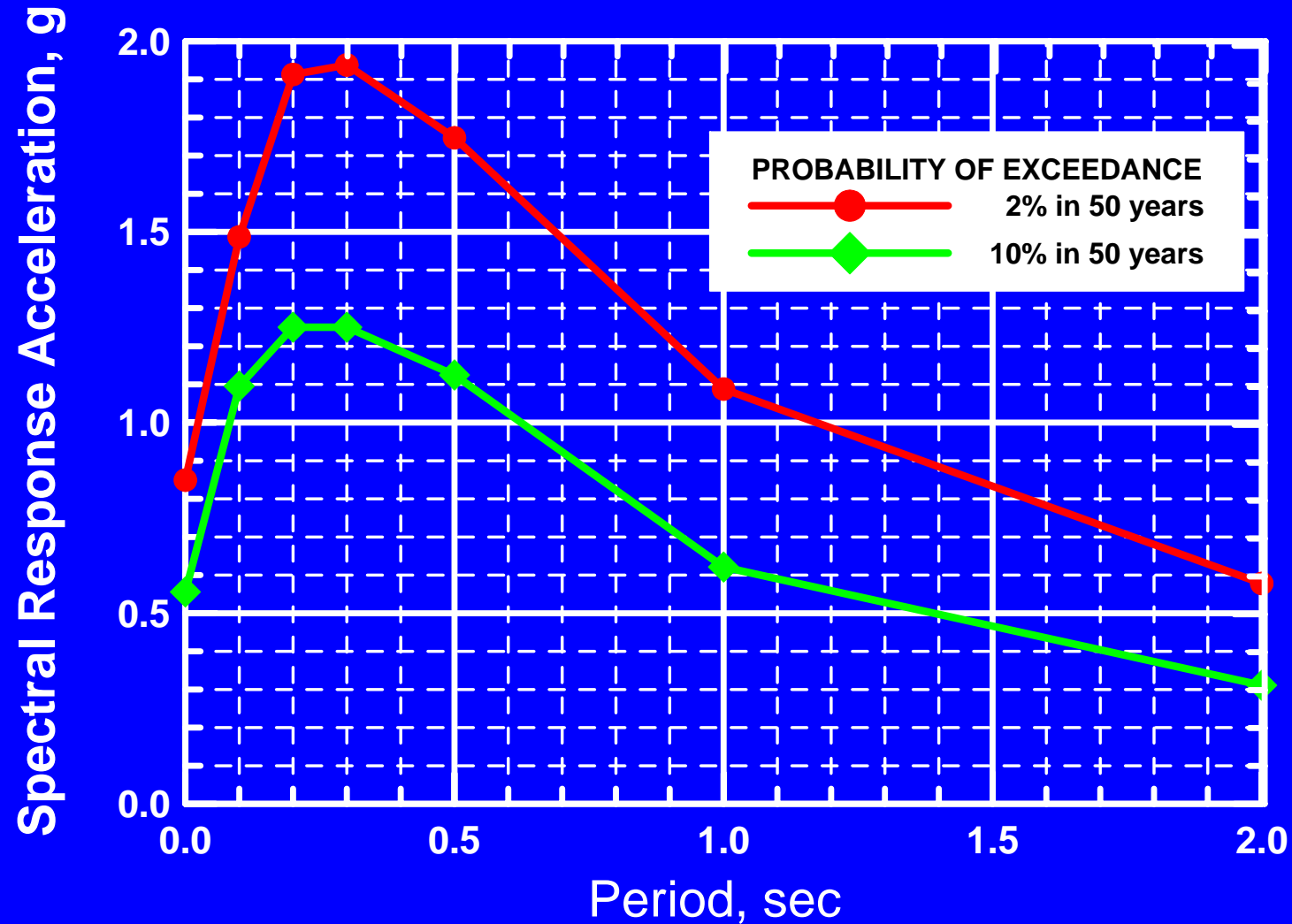
Natural Period

WHY 2% P.E. IN 50
YEARS?

HAZARD CURVES FOR SELECTED CITIES

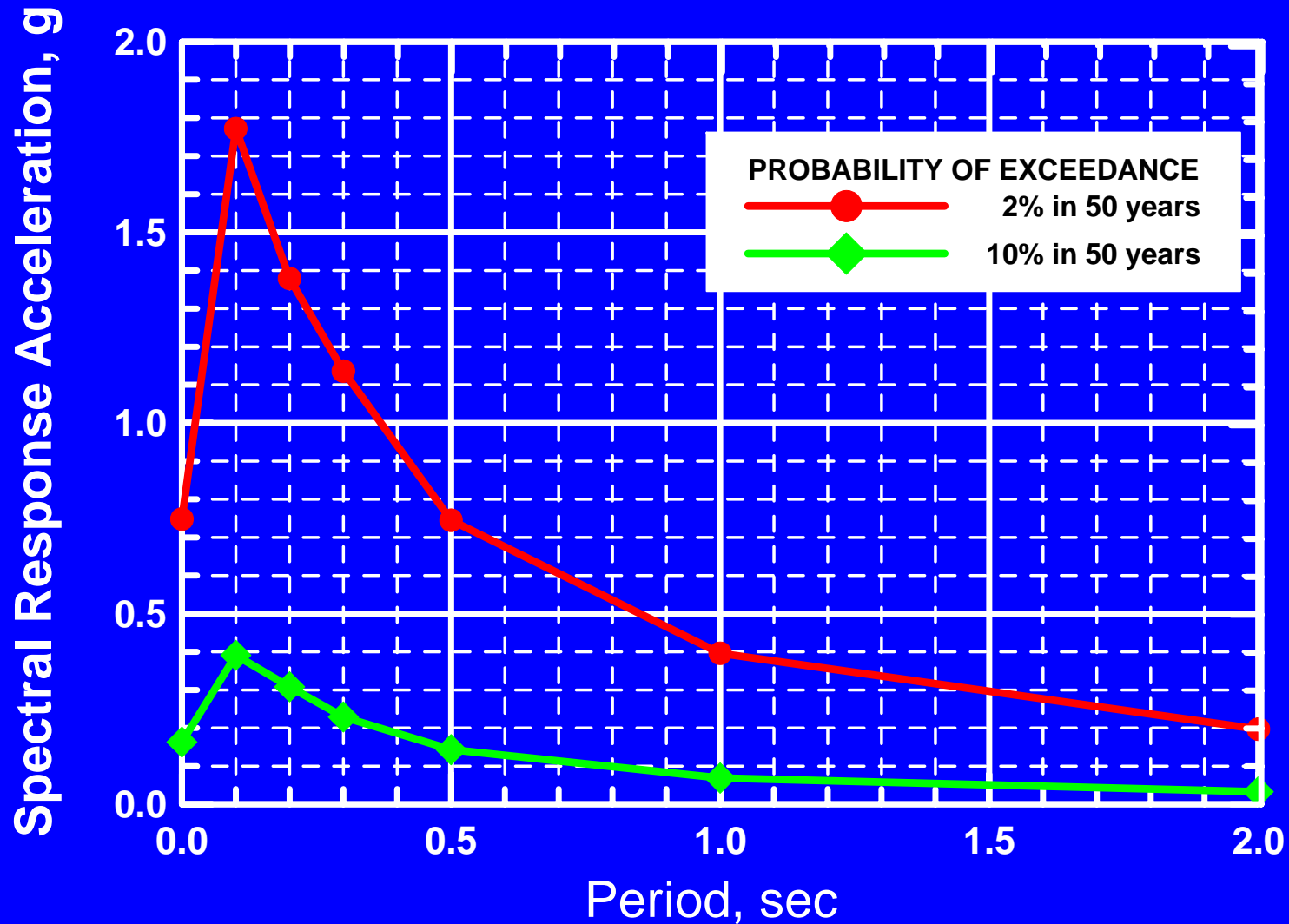


UNIFORM HAZARD RESPONSE SPECTRA San Francisco, CA



UNIFORM HAZARD RESPONSE SPECTRA

Charleston, SC

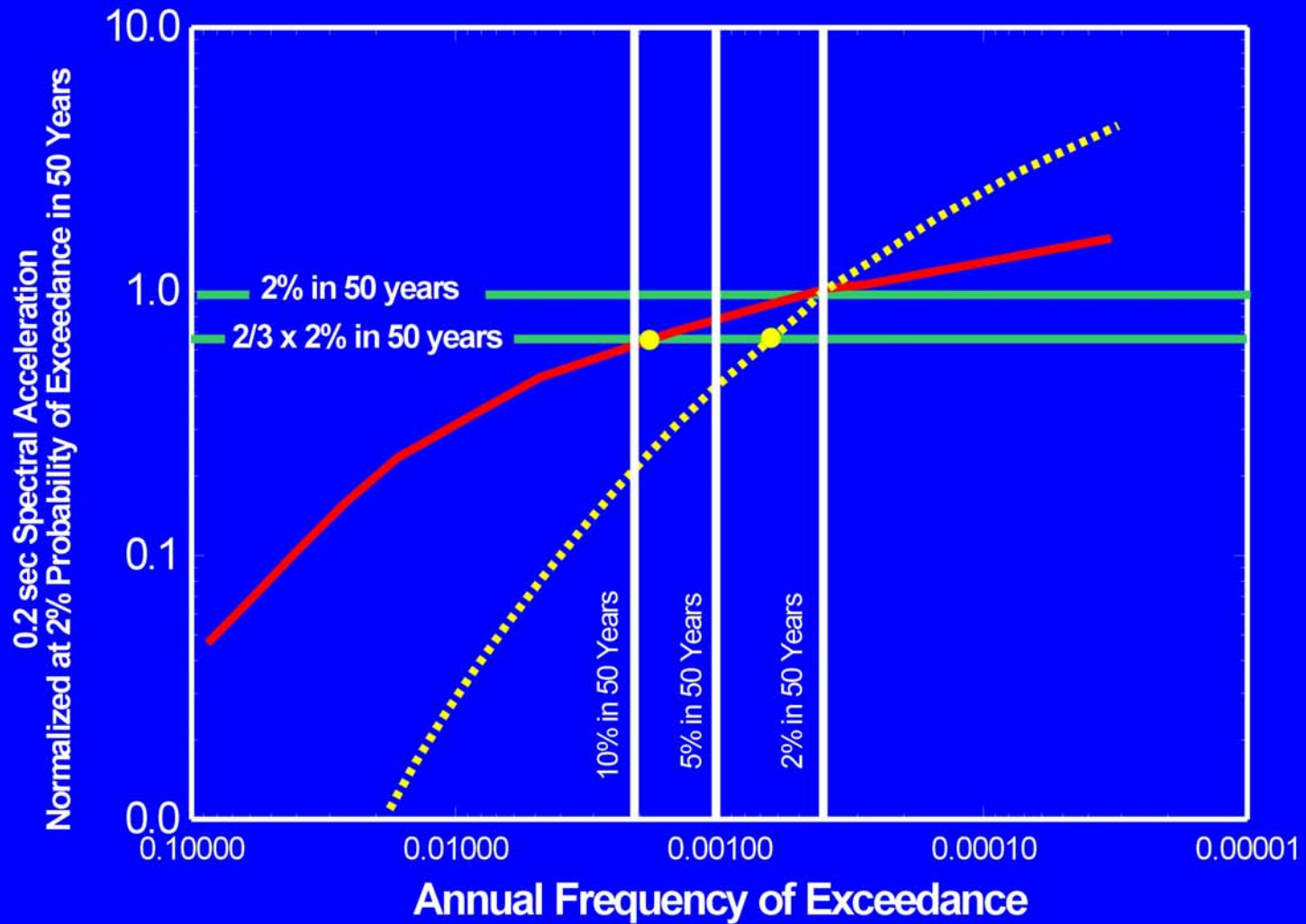


WHERE DID 2/3 COME FROM ?

- **Fundamental Design Requirement to Prevent Collapse**
Collapse Structural Resistance \geq Collapse Load
- **Conservative estimate of Collapse Structural Resistance**
Collapse Structural Resistance \geq 1.5 x Code Structural Resistance
- **Estimate of rare but possible ground motion for collapse conditions**
Collapse Load = 2% PE in 50 yr Ground Motion
- **Substituting into Design Requirement to Prevent Collapse:**
1.5 x Code Structural Resistance \geq 2% PE in 50 yr Ground Motion

Code Structural Resistance \geq 1/1.5 x (2% PE in 50 yr GM)
 \geq 2/3 x (2% PE in 50 yr GM)

Effect of Multiplying by 2/3



DETERMINISTIC CONSTRAINTS

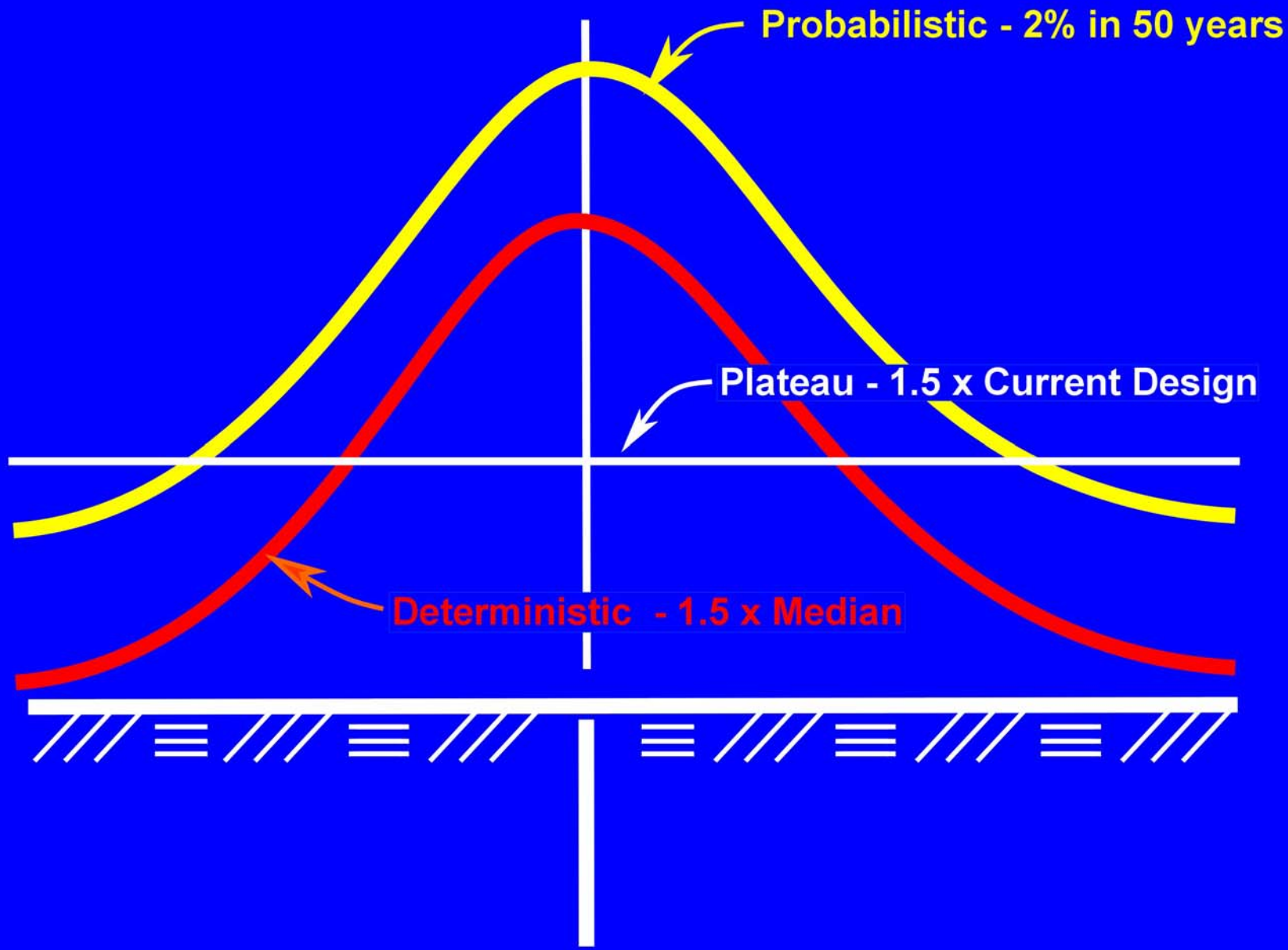
- In regions of high seismicity, such as coastal California, the hazard is typically controlled by large-magnitude events occurring on a limited number of relatively well defined fault systems
- Ground shaking calculated at a 2% in 50 years likelihood would be much larger than that which would be expected 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.

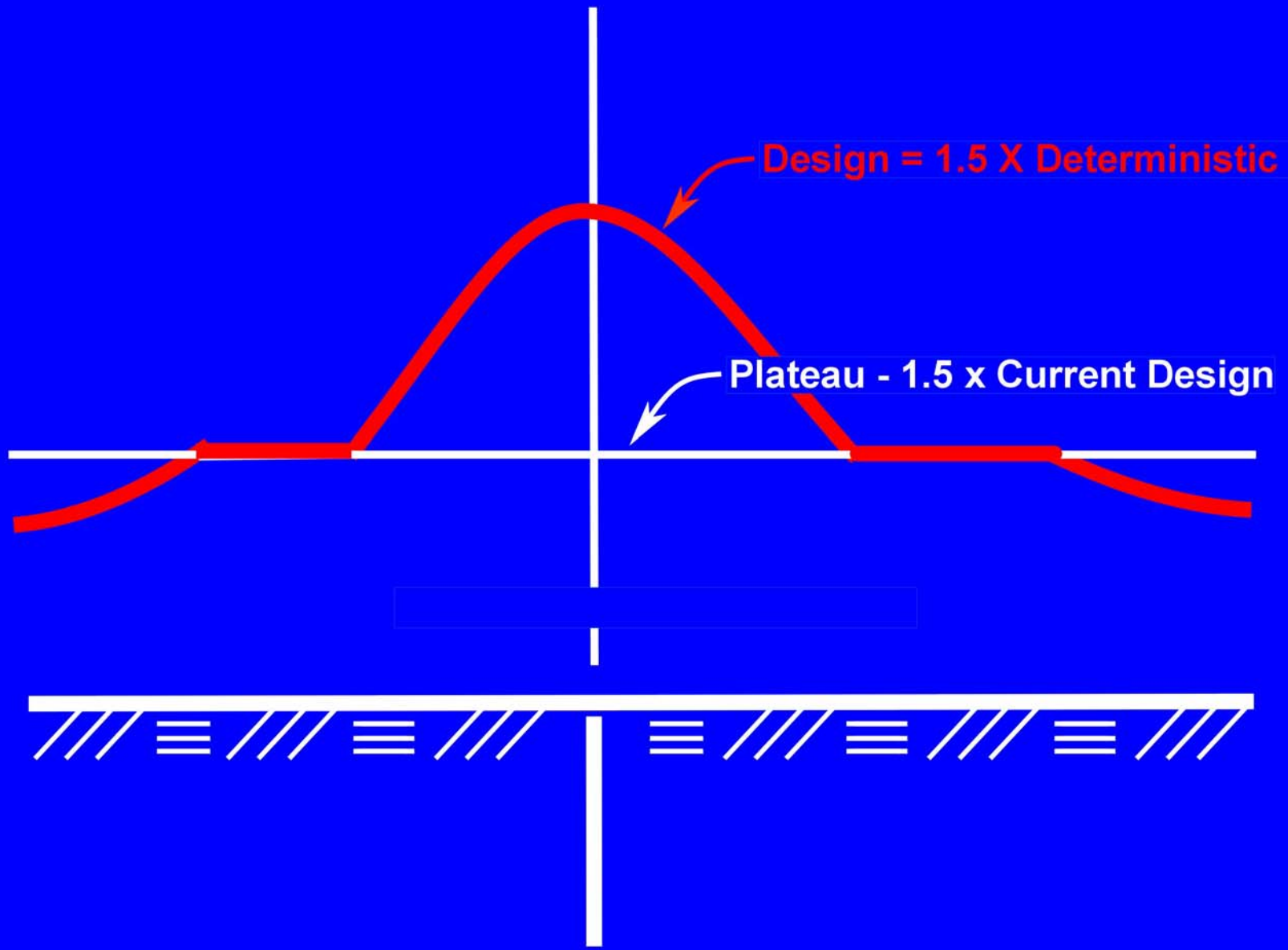
CONSTRAINTS

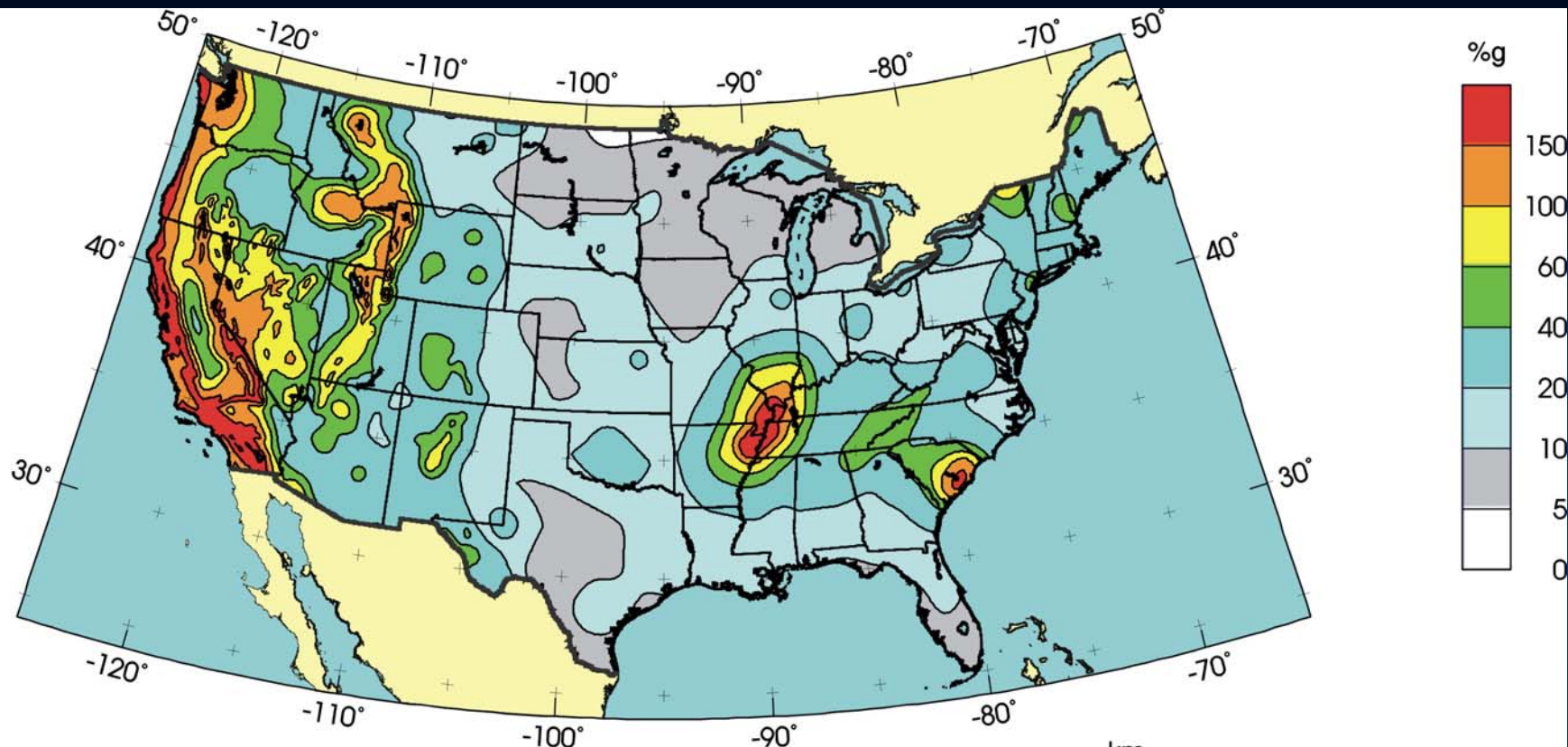
- **Near well-defined faults transition from probabilistic ground motion (GM) to deterministic GM**
- **Use the median GM times 1.5 (intended to approximate one sigma) as the deterministic GM for the maps**

CONSTRAINTS

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



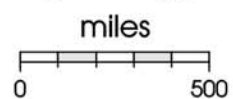
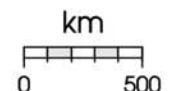




U.S. Geological Survey
National Seismic Hazard Mapping Project

Based on:

1. USGS Open-File Report 97-131 - F, 1997
2. USGS Open-File Report 96-532, 1996



Scale - 1:45000000
Albers Equal-Area Conic Projection
Standard Parallels 29.5°N and 45.5°N

**Horizontal Spectral Response Acceleration (%g) for 0.2 Sec Period (5% of Critical Damping)
With 2% Probability of Exceedance in 50 Years
Firm Rock - 760 m/sec shear wave velocity**

EXCEPTION FOR LOW-RISE REGULAR-SHAPED BUILDINGS

- Regular structures five stories or less in height with $T \leq 0.5$ sec
- Seismic Design Category D, E, or F
- Design ground motions (Site Class B) need not exceed
 - $T = 0.2$ sec $S_s = 1.5$ g ($S_{DS} = 1.0$ g)
 - $T = 1.0$ sec $S_1 = 0.6$ g ($S_{D1} = 0.4$ g)

Design/Hazard curve tool

International Building Code, Section 1615: Earthquake Loads - Site Ground Motion

File Project Name Help

Select Analysis Option **USGS Probabilistic Hazard Curves** Description

Select Geographic Region
Alaska

Select Edition
2003 International Building Code

Select Site Location - See Site Location Notes
 Latitude-Longitude : Recommended Zip Code

Latitude **61.2194** Longitude **-149.8882**
(72.0 to 48.0) (-200.0 to -125.0)

Design Parameters
Ground Motion Parameter MCE Ground Motion

Calculate Ss and S1 Calculate SM and SD Values

Design Spectra
Calculate Map Spectrum Calculate Site-Modified Spectrum
Calculate Site-Modified Design Spectrum View

Output for All Calculations
Bulk Mail Facility - 344 W 3rd Ave, Anchorage, AK 99501
Date and Time: 5/5/2005 9:33:58 AM
Alaska
2003 International Building Code
Spectral Response Accelerations Ss and S1
Latitude = 61.219400
Longitude = -149.888200
Ss and S1 = Mapped Spectral Acceleration Values
SiteClass B - Fa = 1.00, Fv = 1.00
Data are based on a 0.1 deg grid spacing.

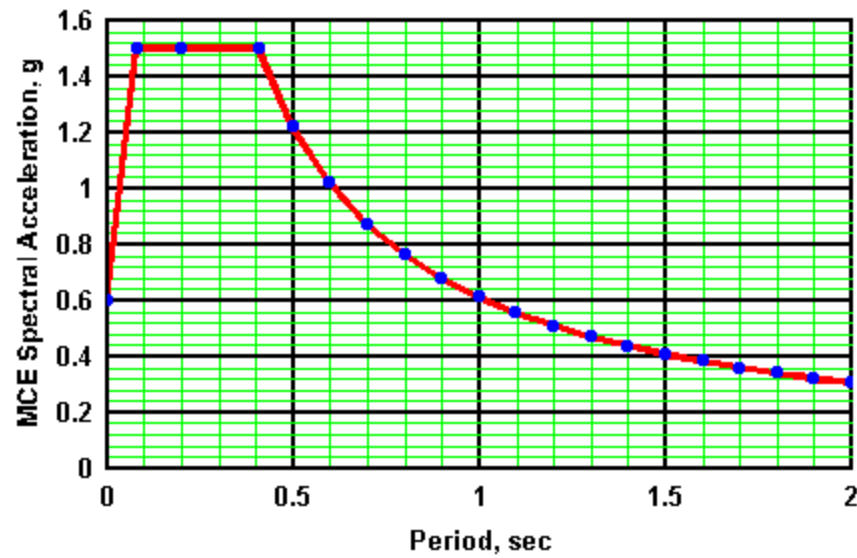
Period	Sa	
(sec)	(g)	
0.2	1.486	Ss, SiteClass B
1.0	0.550	S1, SiteClass B

Clear Output View Maps

CD available, Internet version available about
December, 2005

Response Spectrum Plot

Maximum Considered Earthquake Ground Motion
Site Class B $F_a = 1.00$ $F_v = 1.00$
Zip Code = 94111
Central Lat. = 37.798211 deg Central Long. = -122.398082 deg

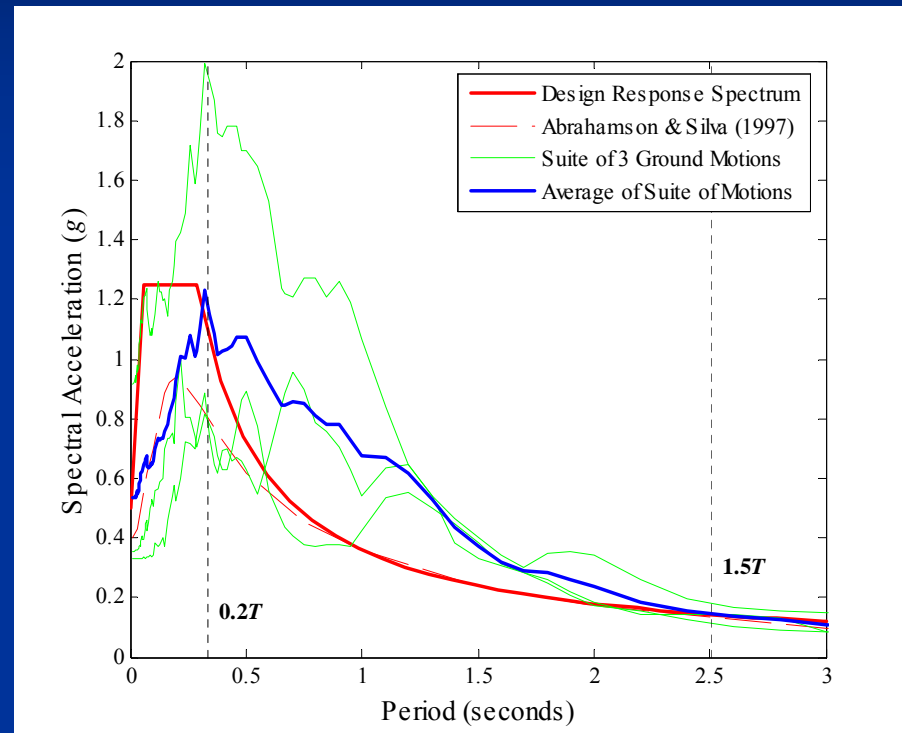
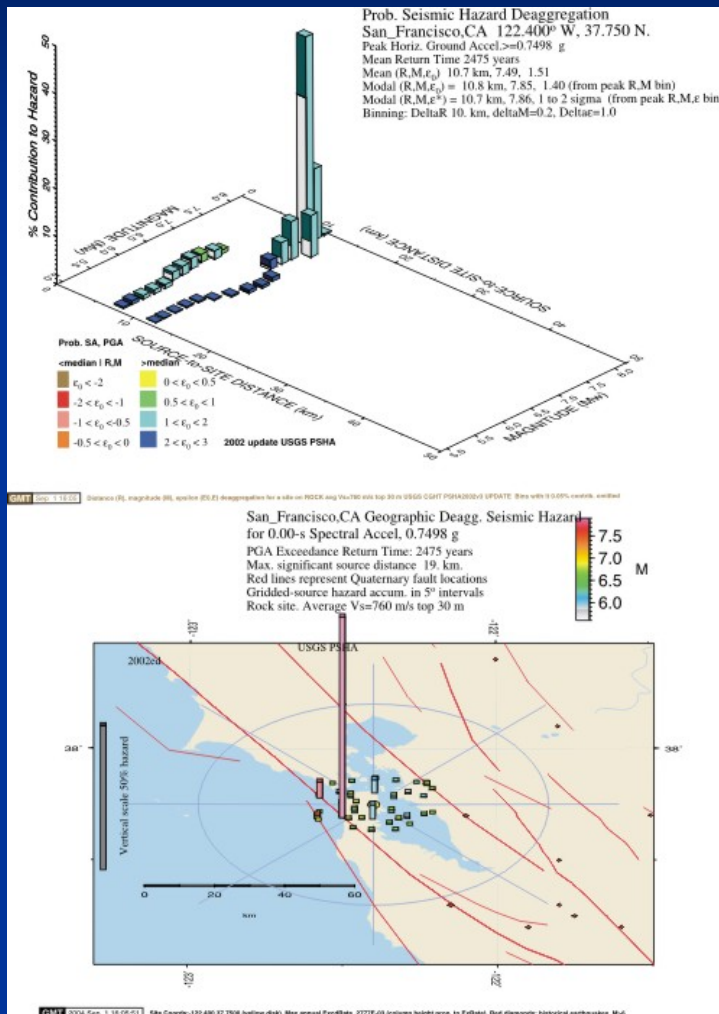


Period, sec	MCE Sa, g
0.00	0.600
0.08	1.500
0.20	1.500
0.41	1.500
0.50	1.221
0.60	1.018
0.70	0.872
0.80	0.763
0.90	0.678
1.00	0.611
1.10	0.555
1.20	0.509
1.30	0.470
1.40	0.436
1.50	0.407
1.60	0.382
1.70	0.359
1.80	0.339
1.90	0.321
2.00	0.305

Exit Viewer

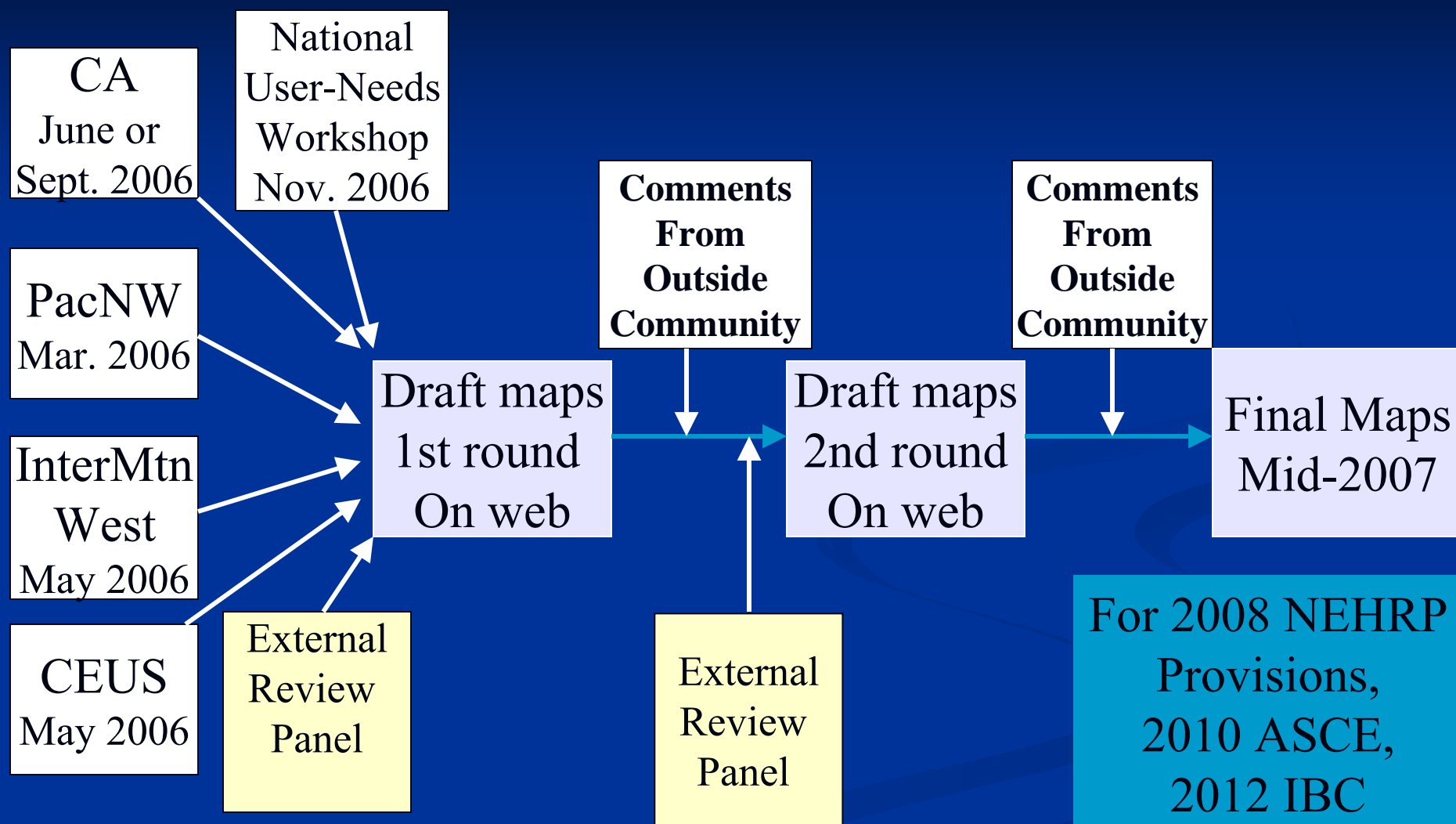
Print Spectrum

Time-history for dynamic analysis



DGML=Design Ground Motion Library

Process for 2007 Maps



Conclusions

- PSHA requires estimate of source magnitude, fault type, site conditions, distance
- International Building Codes based on 2% probability of exceedance in 50 years, firm rock, 0.2 and 1s Spectral Acceleration
- Web-tools available for use by engineers and other end-users