PROBABILISTIC SEISMIC HAZARD ANALYSIS CASE HISTORIES

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Nuclear Waste Technical Review Board
Structural Geology and Geoengineering Panel

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PROBABILISTIC SEISMIC HAZARD CASE HISTORIES

Purpose of Talk

To present a few case histories illustrating the application of probabilistic seismic hazard analysis.

- **Regulatory context of studies**
- **Use of studies for decision-making**
- **Methods for incorporating earth sciences data and uncertainties**
- **How expert judgments are included**
- **Comparisons of probabilistic and deterministic analysis**

SOME COMMON APPLICATIONS OF PSHA

Nuclear Power Plants

- Regional studies in EUS (e.g., EPRI, LLNL)
- Site-specific studies in WUS (e.g., Diablo Canyon, Satsop)
- IPEEE evaluations of seismic margins (e.g., Palo Verde, SONGS, WNP-2)

DOE Nuclear and Non-nuclear Facilities

- New facility design (e.g., NPR at INEL, SRS)
- Design review (e.g., Hanford, Rocky Flats, INEL)

Major Bridges and Highway Structures

- Regional studies for design and review (e.g., IDOT, ODOT, ADOT)
- Site-specific design review (e.g., SF Bay, L.A.)

Dams

- Design review (e.g., FERC, commercial owners)
- Check on deterministic (e.g., Bureau of Rec., COE)

Building Codes

- Federal maps (e.g., USGS maps, BSSC)

Commercial Facilities

- Large building design (e.g., SF, L.A.)
- Large facility review
- Integrated risk assessment (e.g., spatially distributed facilities, other NPH)

DIABLO CANYON NUCLEAR POWER PLANT
LONG TERM SEISMIC PROGRAM

- Purpose: satisfaction of condition on operating license; input to analysis of risk

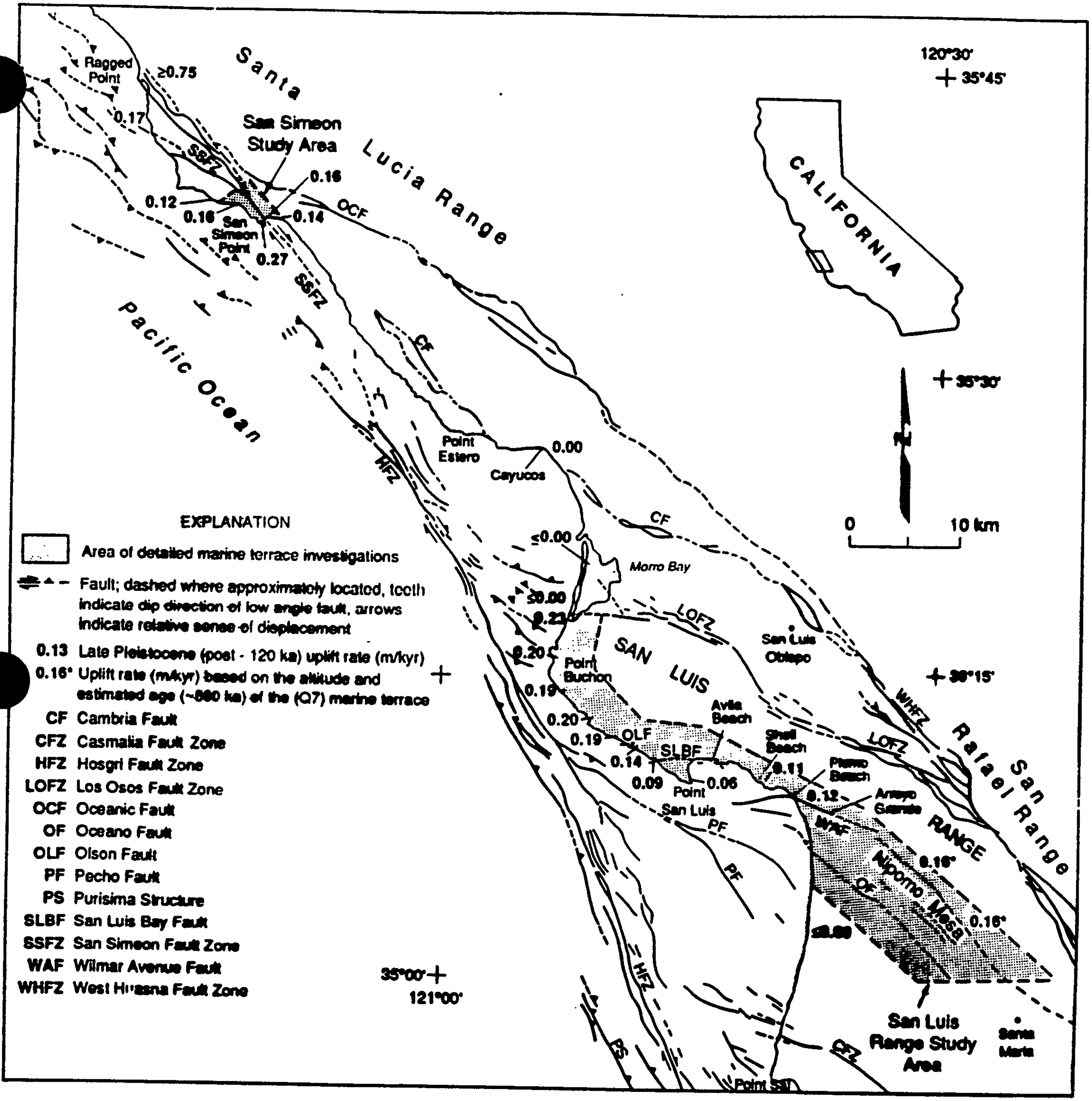
- Scoping study PSHA to identify significant issues, GSG studies

- Extensive program of data collection; interaction with NRC staff and consultants

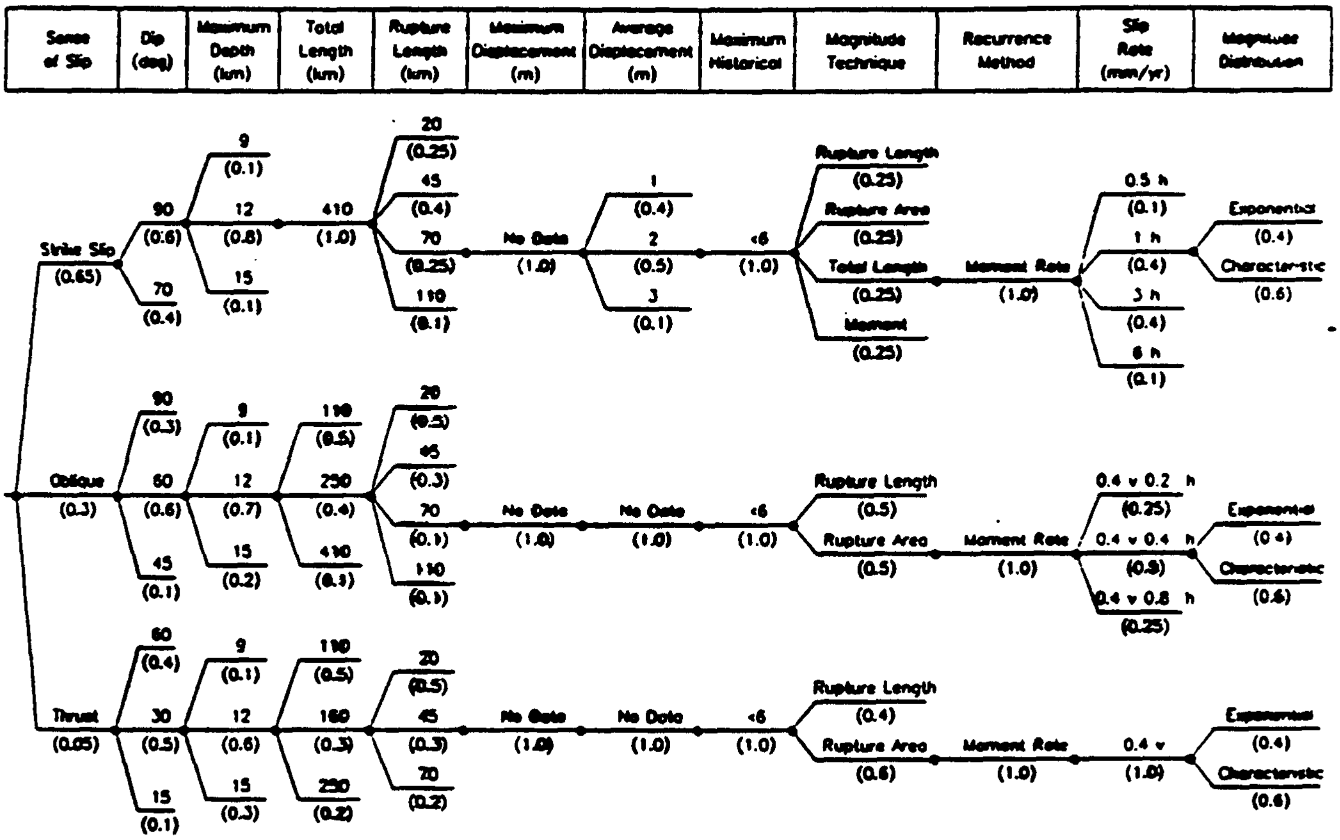
- Consensus assessments of uncertainty by large project team; participatory consulting board

- Extensive NRC staff review with consultants

- Both probabilistic and deterministic seismic margin review



Ragged Point
≥0.75
Santa Lucia Range
San Simeon Study Area
0.17
SSFZ
0.16
0.12
0.16
OCF
0.14
San Simeon Point
0.27
SSFZ
Pacific Ocean
CF
HFZ
Point Estero
Cayucos
0.00
CF
≤0.00
Morro Bay
≤0.00
0.23
LOFZ
0.20
SAN LUIS
San Luis Obispo
Point Buchon
0.19
Avila Beach
0.20
Shell Beach
0.19
OLF
SLBF
0.14
0.11
Pismo Beach
0.09
Point San Luis
0.06
0.12
Arroyo Grande
WAF
PF
PF
RANGE
0.16*
Nipomo Mesa
OF
0.16*
≤0.00
HFZ
CFZ
PS
Point Sal
San Luis Range Study Area
Santa Maria
WHFZ
LOFZ
San Rafael Range
CALIFORNIA
120°30'
35°45'
35°30'
35°15'
35°00'
121°00'
0
10 km
EXPLANATION
Area of detailed marine terrace investigations
Fault; dashed where approximately located, teeth indicate dip direction of low angle fault, arrows indicate relative sense of displacement
0.13 Late Pleistocene (post - 120 ka) uplift rate (m/kyr)
0.16* Uplift rate (m/kyr) based on the altitude and estimated age (~600 ka) of the (Q7) marine terrace
CF Cambria Fault
CFZ Casmalia Fault Zone
HFZ Hosgri Fault Zone
LOFZ Los Osos Fault Zone
OCF Oceanic Fault
OF Oceano Fault
OLF Olson Fault
PF Pecho Fault
PS Purisima Structure
SLBF San Luis Bay Fault
SSFZ San Simeon Fault Zone
WAF Wilmar Avenue Fault
WHFZ West Huasna Fault Zone



Notes:
Values in parentheses are probabilities
h = horizontal component of slip rate,
v = vertical component of slip rate

Figure 3-5
Logic tree for Hosgri fault zone.

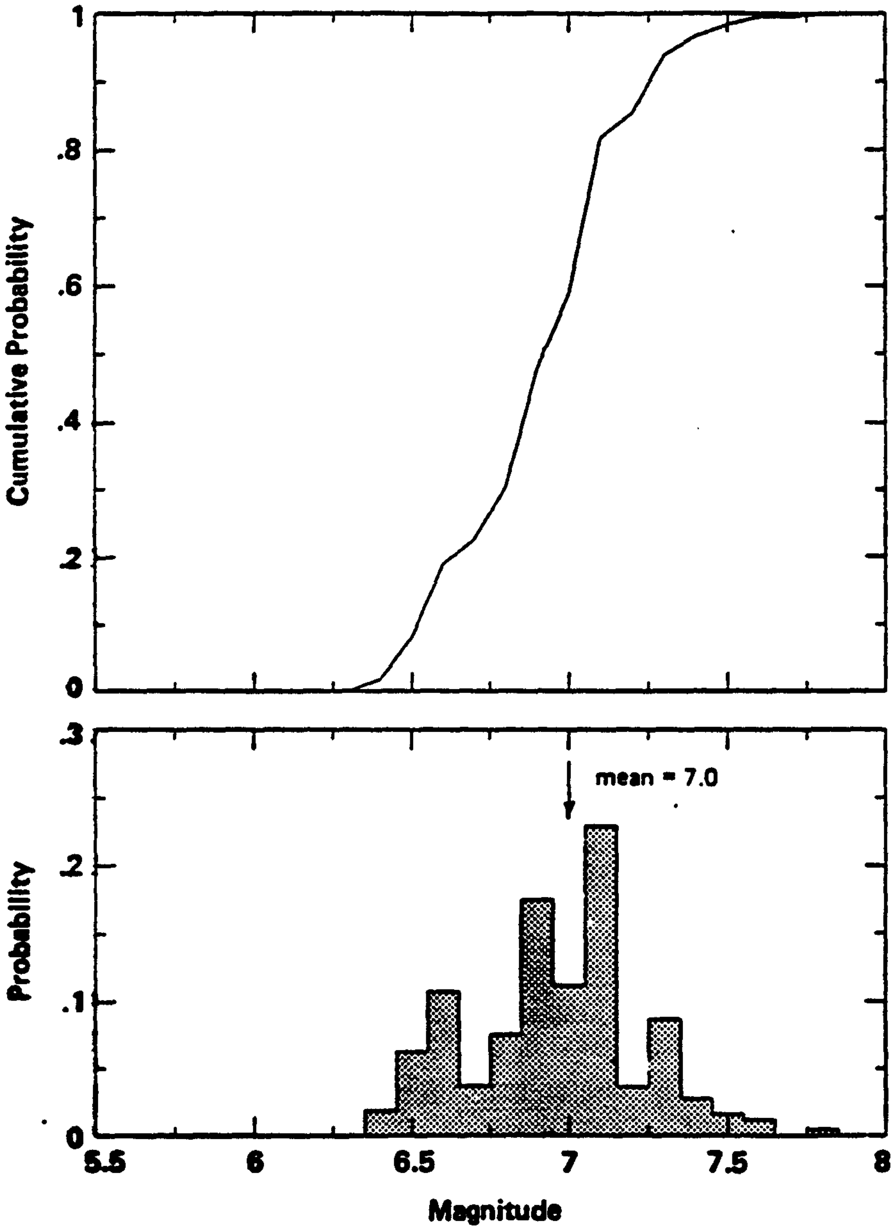
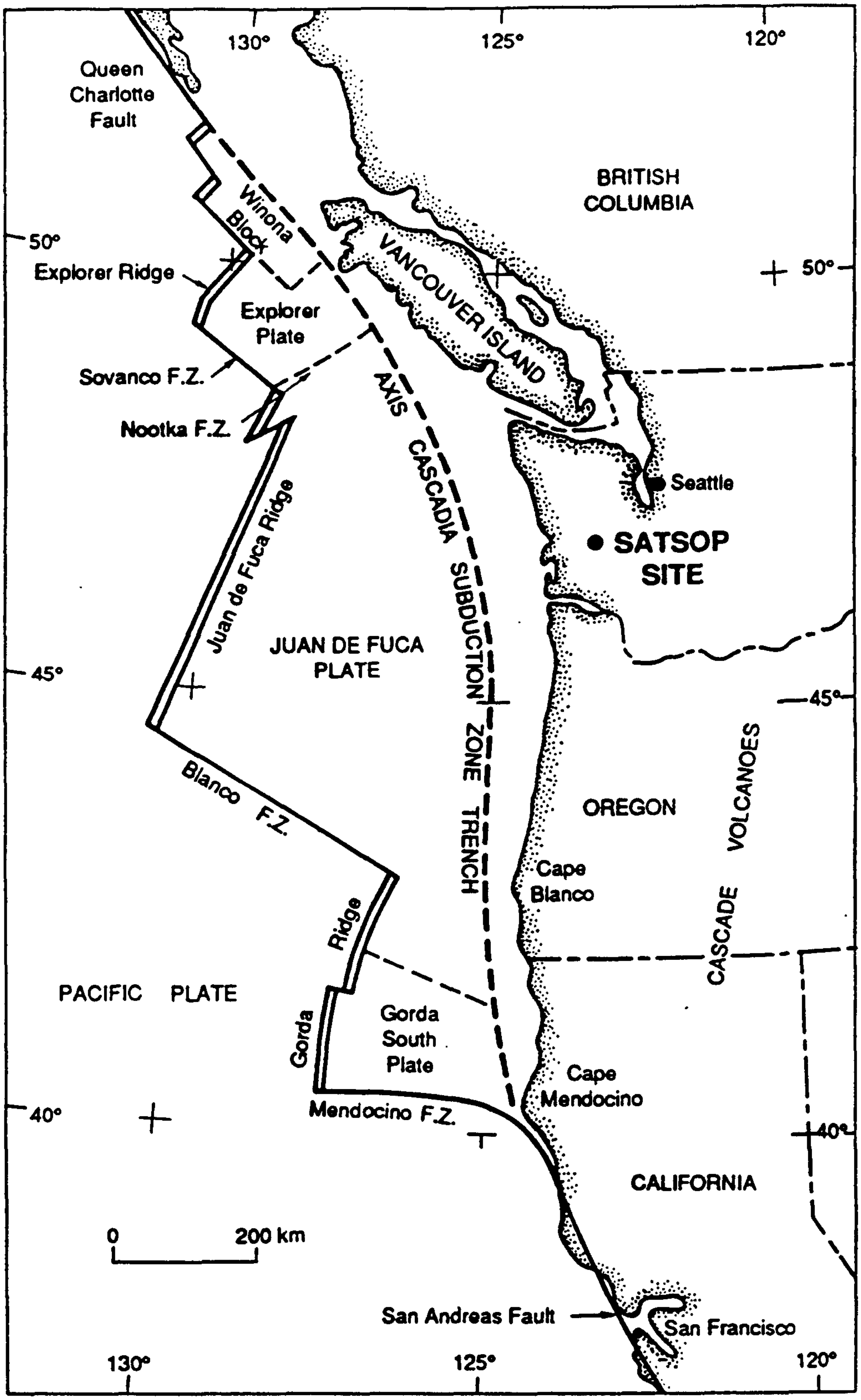


Figure 3-9
Maximum magnitude distribution for Hosgri fault zone.

WNP-3 SATSOP NUCLEAR POWER PLANT

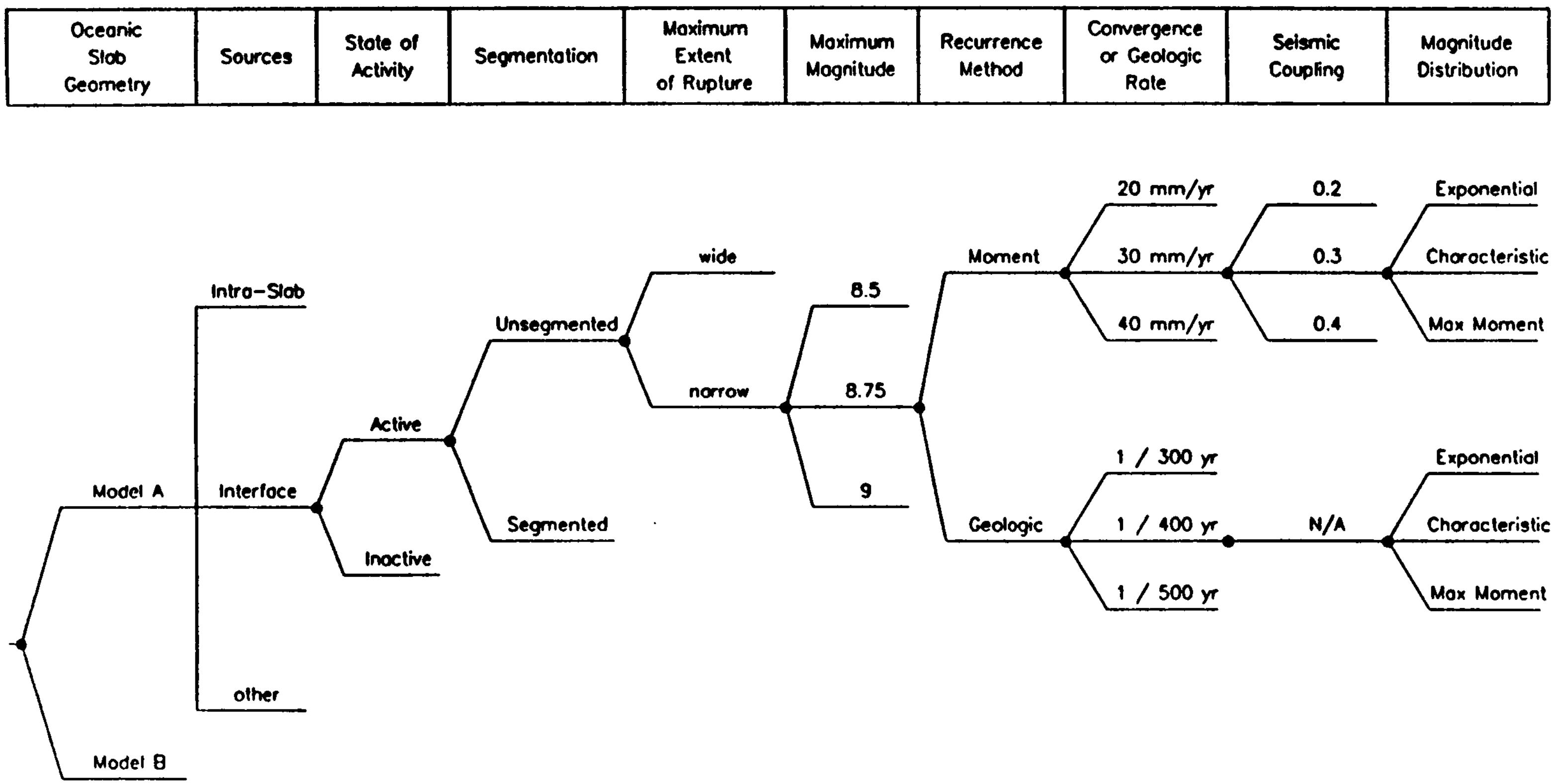
- Purpose: to answer NRC question to FSAR for licensing; probability of exceeding SSE
- Significant change in perceived hazard due to Cascadia subduction zone; strong diversity in scientific interpretations
- 14 experts elicited in individual interviews; extensive documentation
- Component-level aggregation to examine technical issues
- Used by NRC staff to evaluate 'conservatism' of SSE; little basis for comparing p(exceedance) of WUS sites
- Diversity among experts a significant contributor to total uncertainty



130°
125°
120°
Queen Charlotte Fault
BRITISH COLUMBIA
Winona Block
50°
Explorer Ridge
VANCOUVER ISLAND
50°
Explorer Plate
Sovanco F.Z.
Nootka F.Z.
AXIS
Seattle
CASCADIA
Juan de Fuca Ridge
SATSOP SITE
SUBDUCTION
JUAN DE FUCA PLATE
45°
ZONE
45°
VOLCANOES
Blanco F.Z.
OREGON
TRENCH
Cape Blanco
Ridge
CASCADE
PACIFIC PLATE
Gorda
Gorda South Plate
Cape Mendocino
40°
Mendocino F.Z.
40°
CALIFORNIA
0
200 km
San Andreas Fault
San Francisco
130°
125°
120°

Fig 1

Fig 3



Oceanic Slab Geometry
Sources
State of Activity
Segmentation
Maximum Extent of Rupture
Maximum Magnitude
Recurrence Method
Convergence or Geologic Rate
Seismic Coupling
Magnitude Distribution
Model A
Model B
Intra-Slab
Interface
other
Active
Inactive
Unsegmented
Segmented
wide
narrow
8.5
8.75
9
Moment
Geologic
20 mm/yr
30 mm/yr
40 mm/yr
1 / 300 yr
1 / 400 yr
1 / 500 yr
0.2
0.3
0.4
N/A
Exponential
Characteristic
Max Moment
Exponential
Characteristic
Max Moment

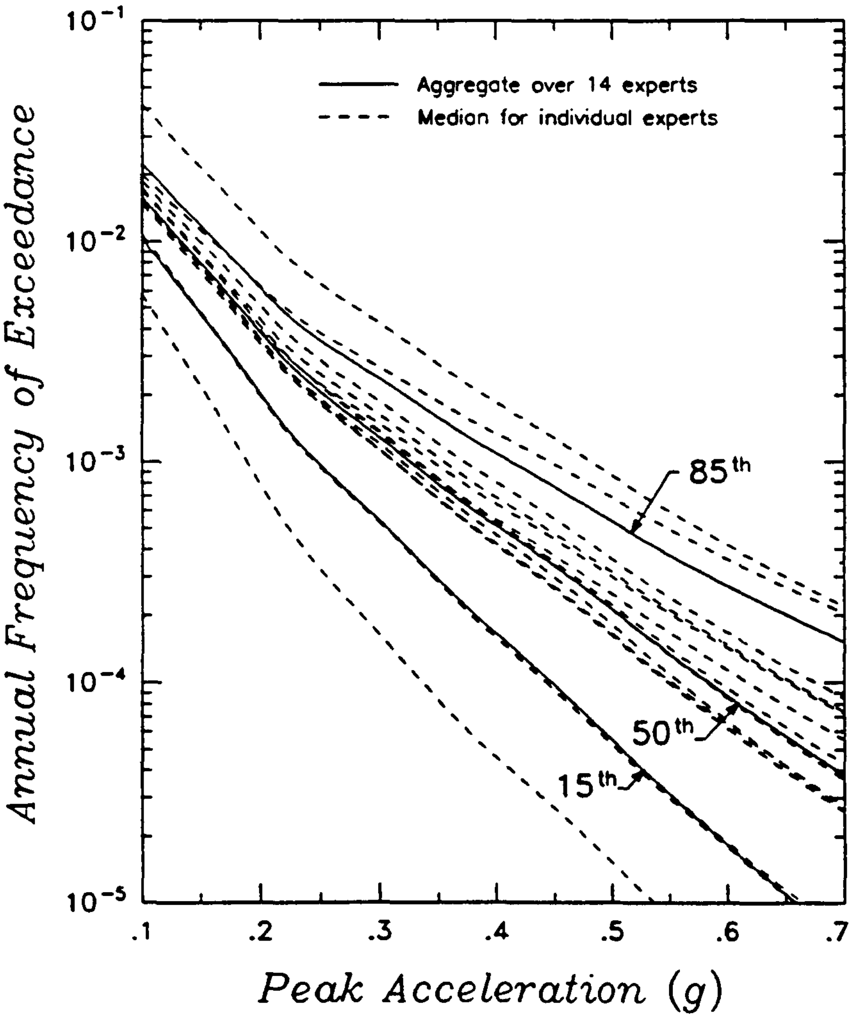

Aggregate over 14 experts
Median for individual experts
Annual Frequency of Exceedance
Peak Acceleration (g)
85th
50th
15th
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
.1
.2
.3
.4
.5
.6
.7

Fig 14

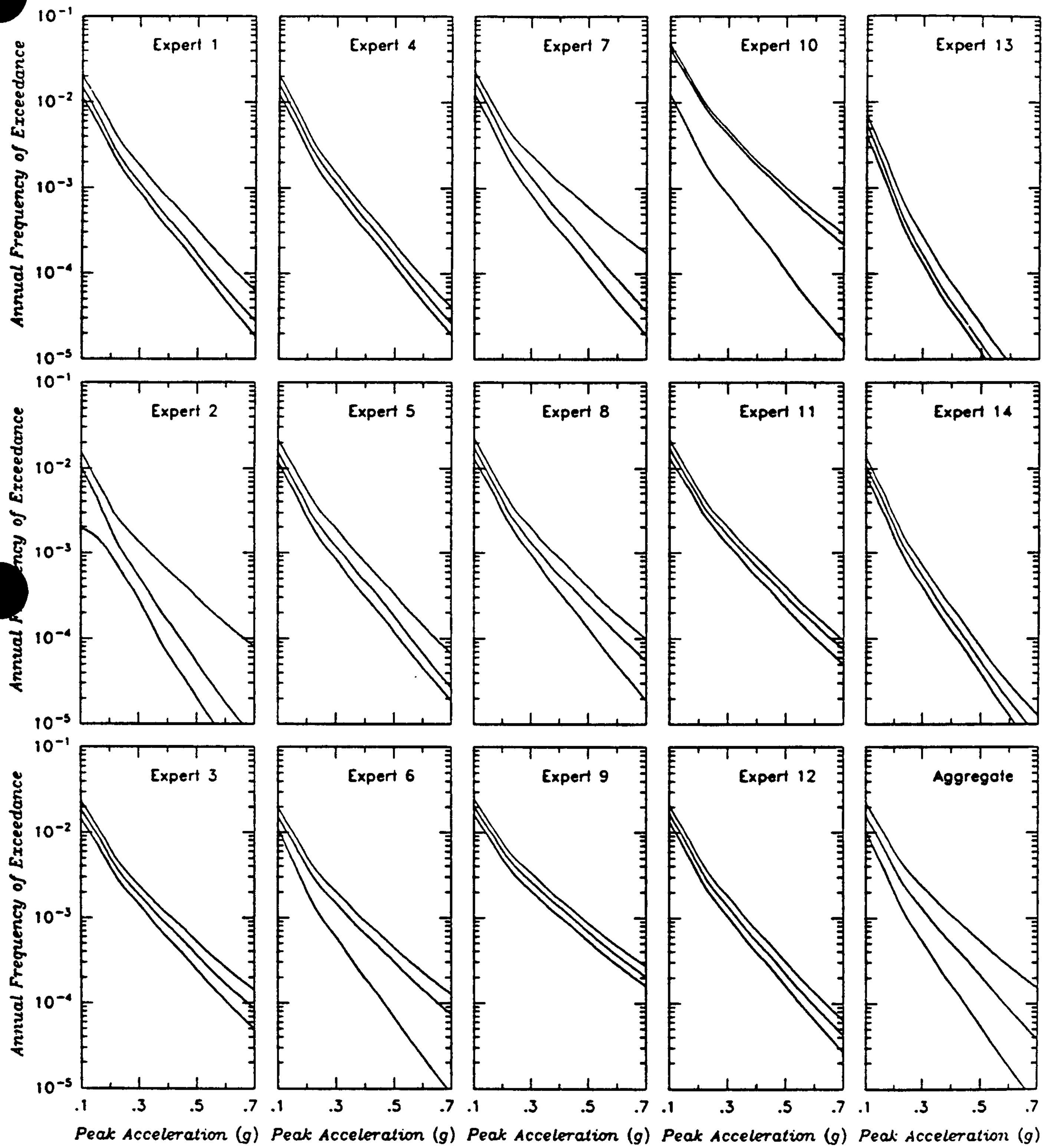
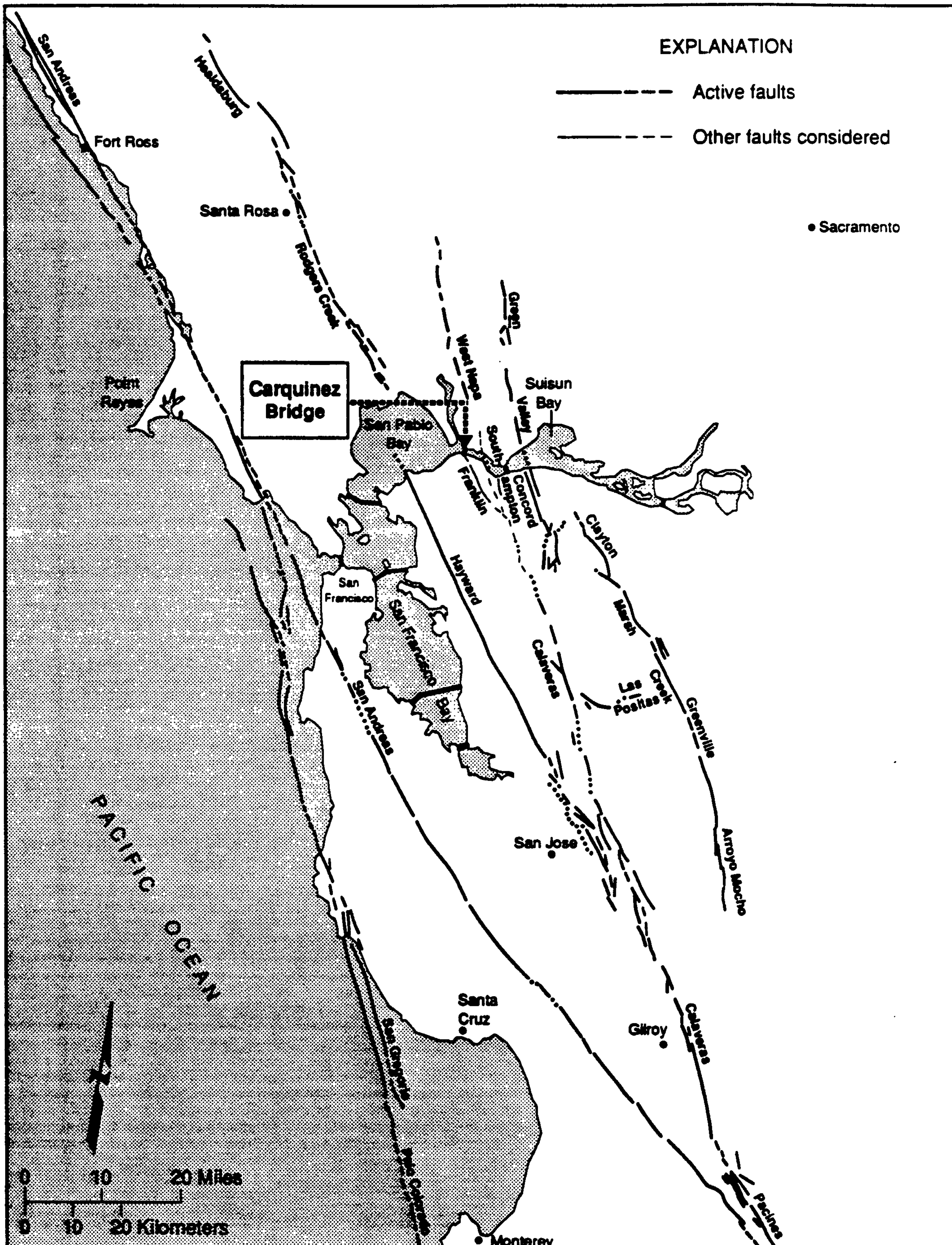

Expert 1
Expert 4
Expert 7
Expert 10
Expert 13
Expert 2
Expert 5
Expert 8
Expert 11
Expert 14
Expert 3
Expert 6
Expert 9
Expert 12
Aggregate
Annual Frequency of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
.1
.3
.5
.7
Peak Acceleration (g)

Fig 13

SAN FRANCISCO BAY AREA BRIDGES

- Purpose: define ground motion levels for design review of Caltrans bridges
- Site-specific assessments to be used for decisions regarding seismic retrofit
- Incorporation of fault-specific paleoseismic studies, tectonic models, recurrence models, seismicity
- Carried out by project team with consulting board review
- Selection of design through comparison of probabilistic and deterministic results



GEOMATRIX

REGIONAL SOURCE FAULT MAP
Seismic Ground Motion Studies for the Carquinez Bridge
Contra Costa and Solano Counties, California

Figure 2-1

Project No. 1606E

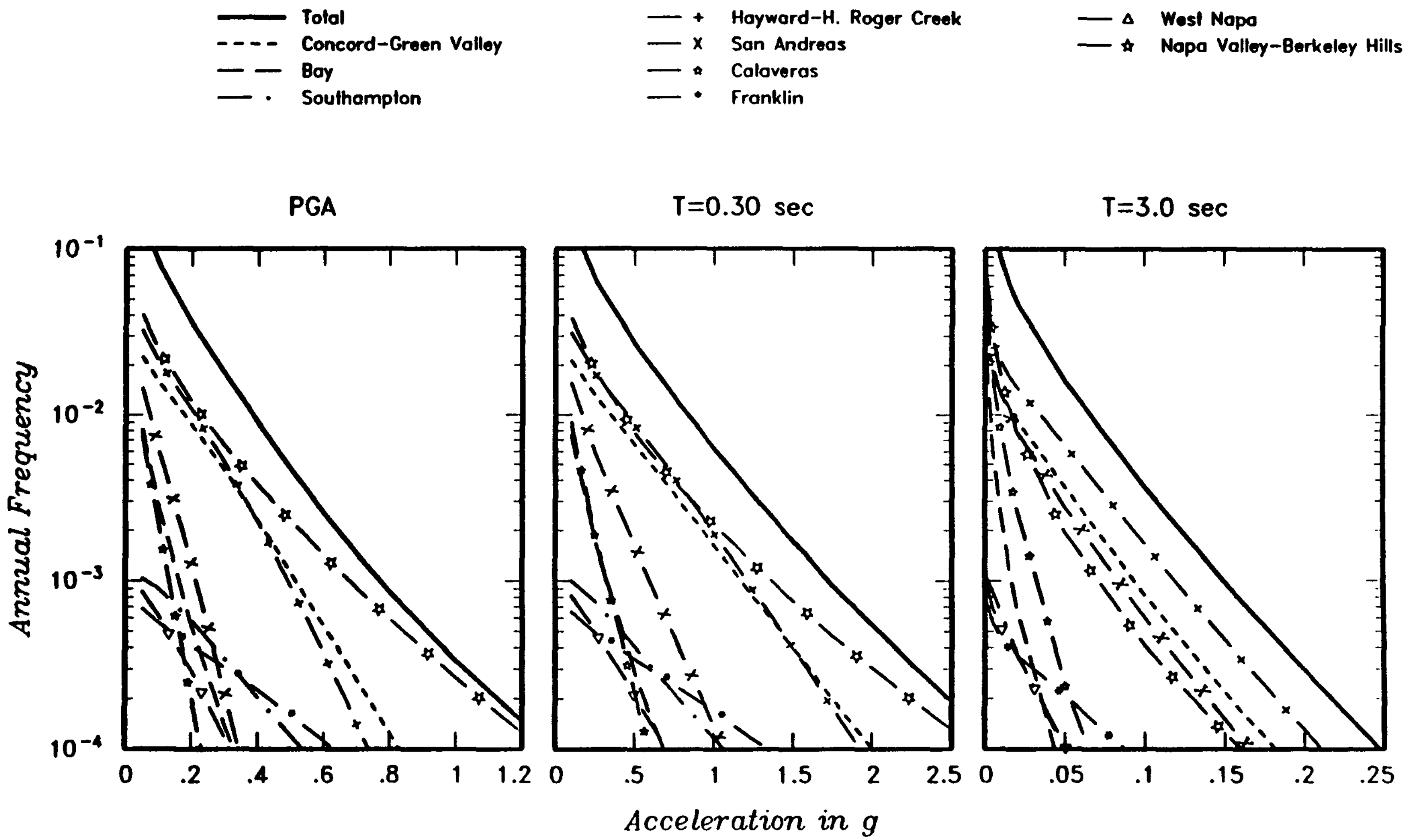


Figure 4-2 Contributions of various fault-specific sources to mean hazard at the Carquinez site. Shown are results for peak acceleration and 5 percent-damped spectral accelerations at periods of 0.3 and 3.0 seconds.

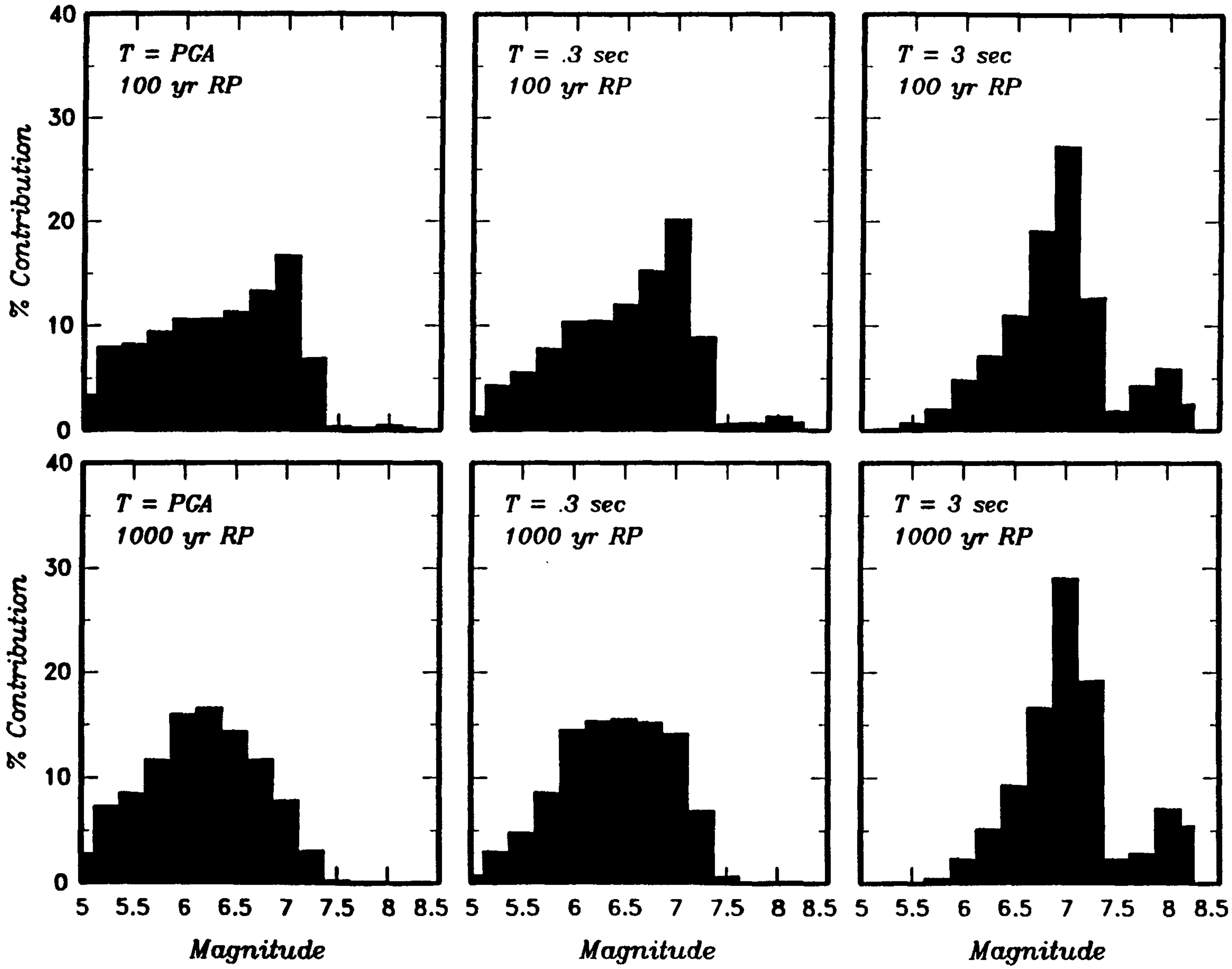


Figure 4-3 Contributions of events in various magnitude intervals to the mean hazard at the Carquinez site. Shown are results for peak acceleration and 5 percent-damped spectral accelerations at periods of 0.3 and 3.0 seconds.

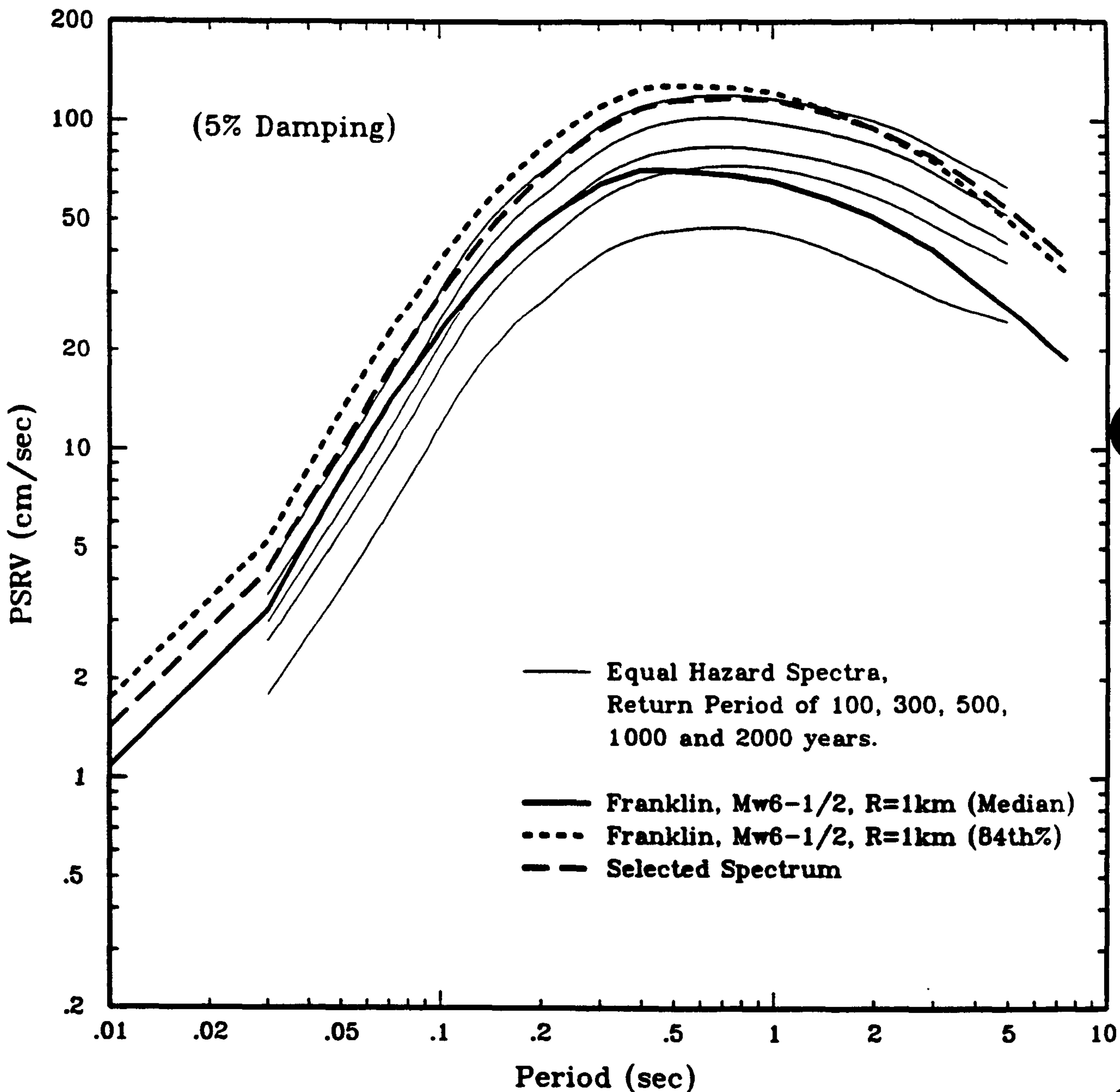


Figure 5-14 Carquinez Bridge, comparison of the deterministic median, 84th percentile, and selected spectra for the Franklin Event with equal-hazard spectra

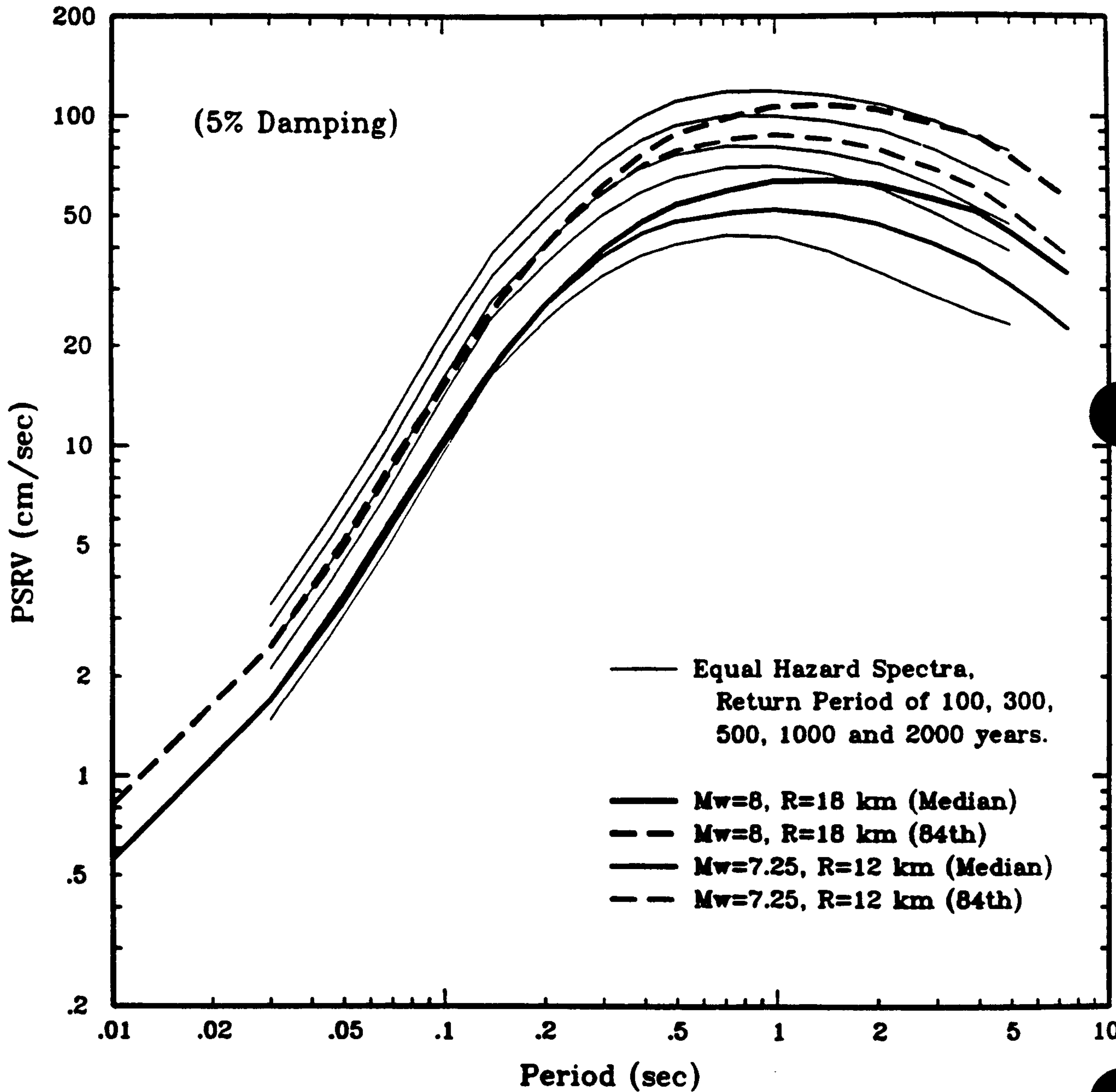


Figure 5-14 Comparison of the deterministic response spectra with equal-hazard spectra: West San Francisco Bay Bridge, east end.

DOE FACILITIES AT HANFORD, WASHINGTON

- Purpose: define ground motion levels for design review and for new design criteria
- Interpretations from project team including site technical personnel with extensive experience
- Alternative tectonic models considered in the PSHA
- Results to be used according to performance-based criteria of DOE Standard 1021-92

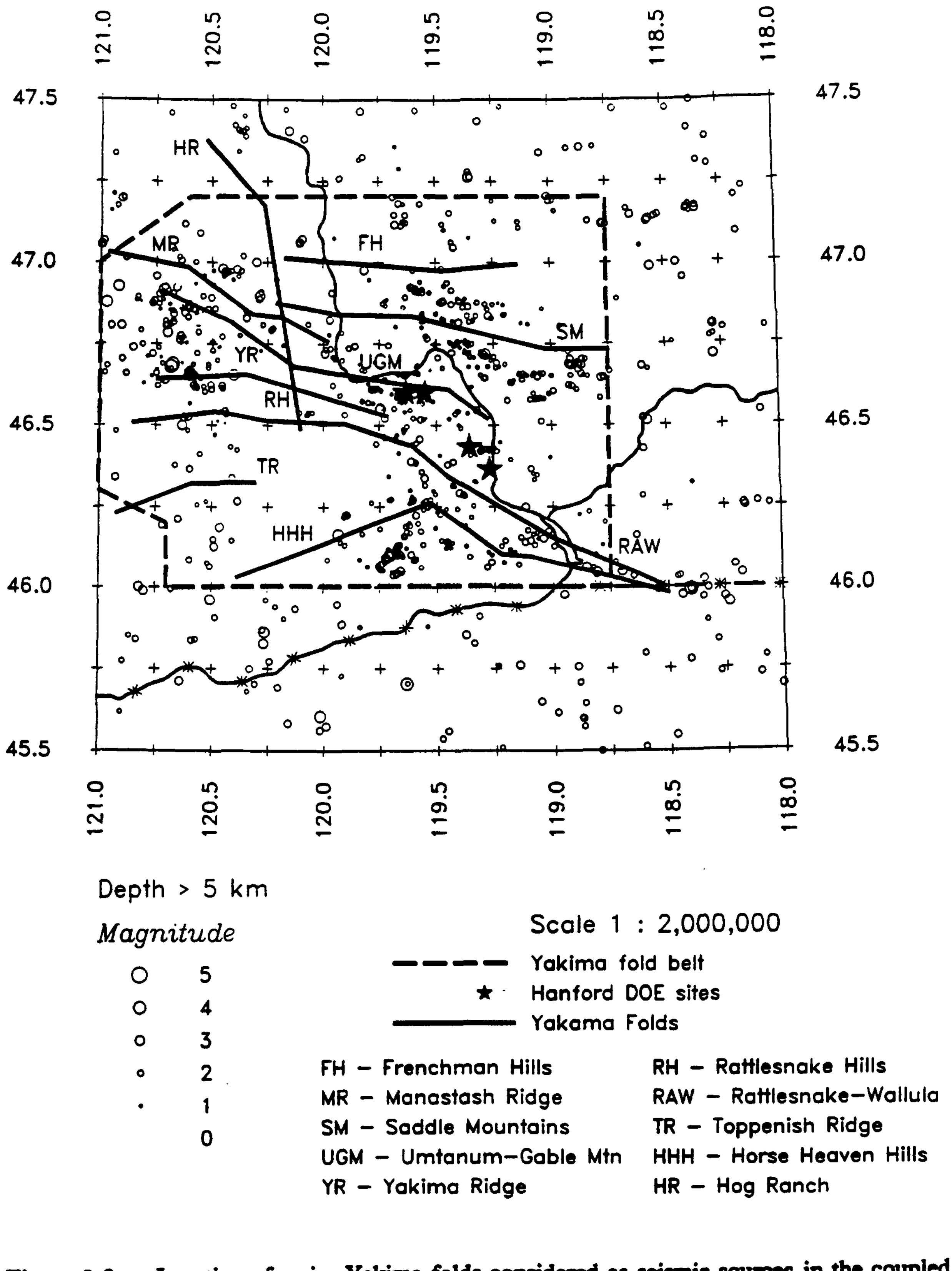


Figure 3-9 **Location of major Yakima folds considered as seismic sources in the coupled model. Superimposed is the spatial distribution of seismicity occurring primarily within the crystalline basement (focal depth > 5 km).**

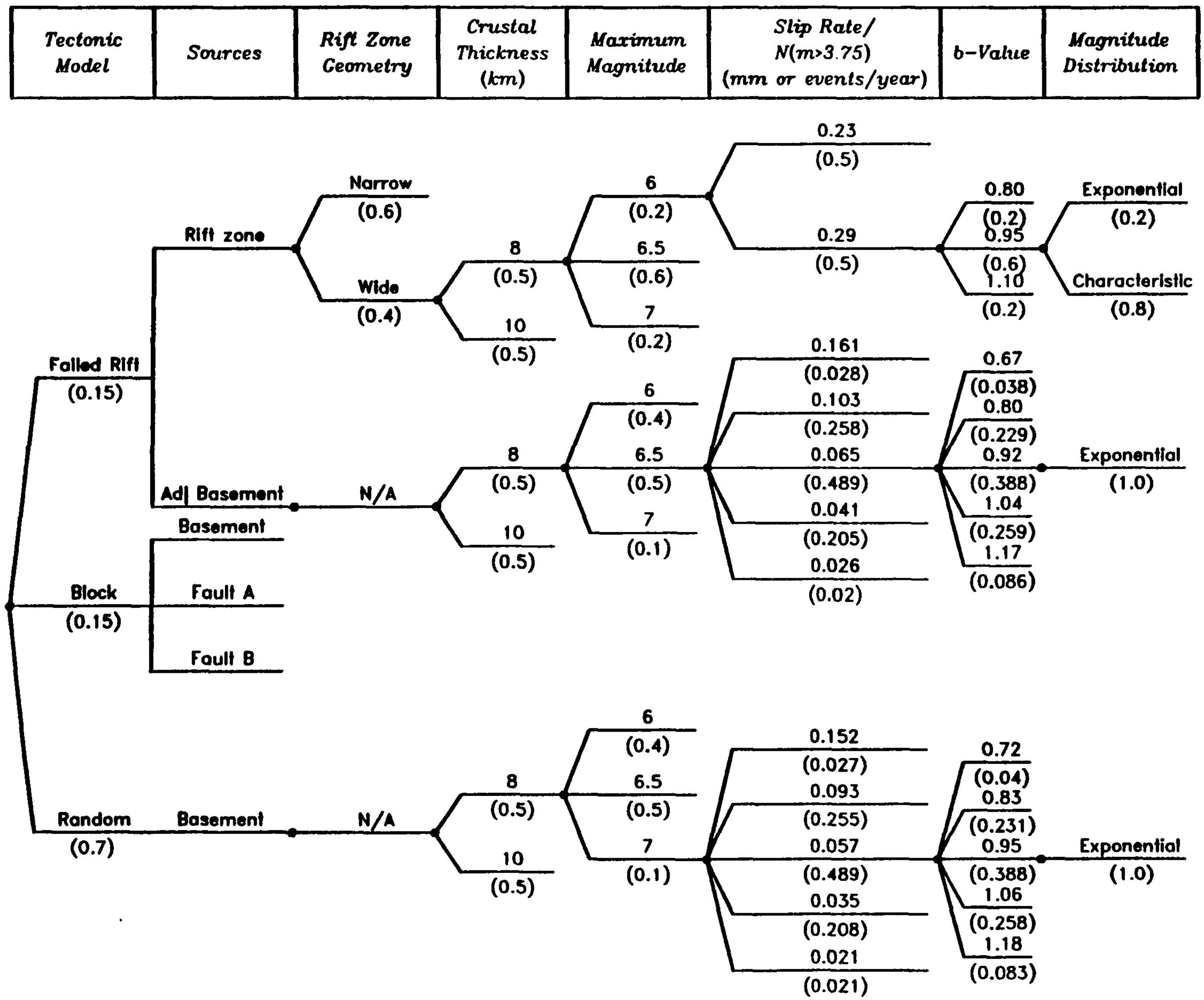
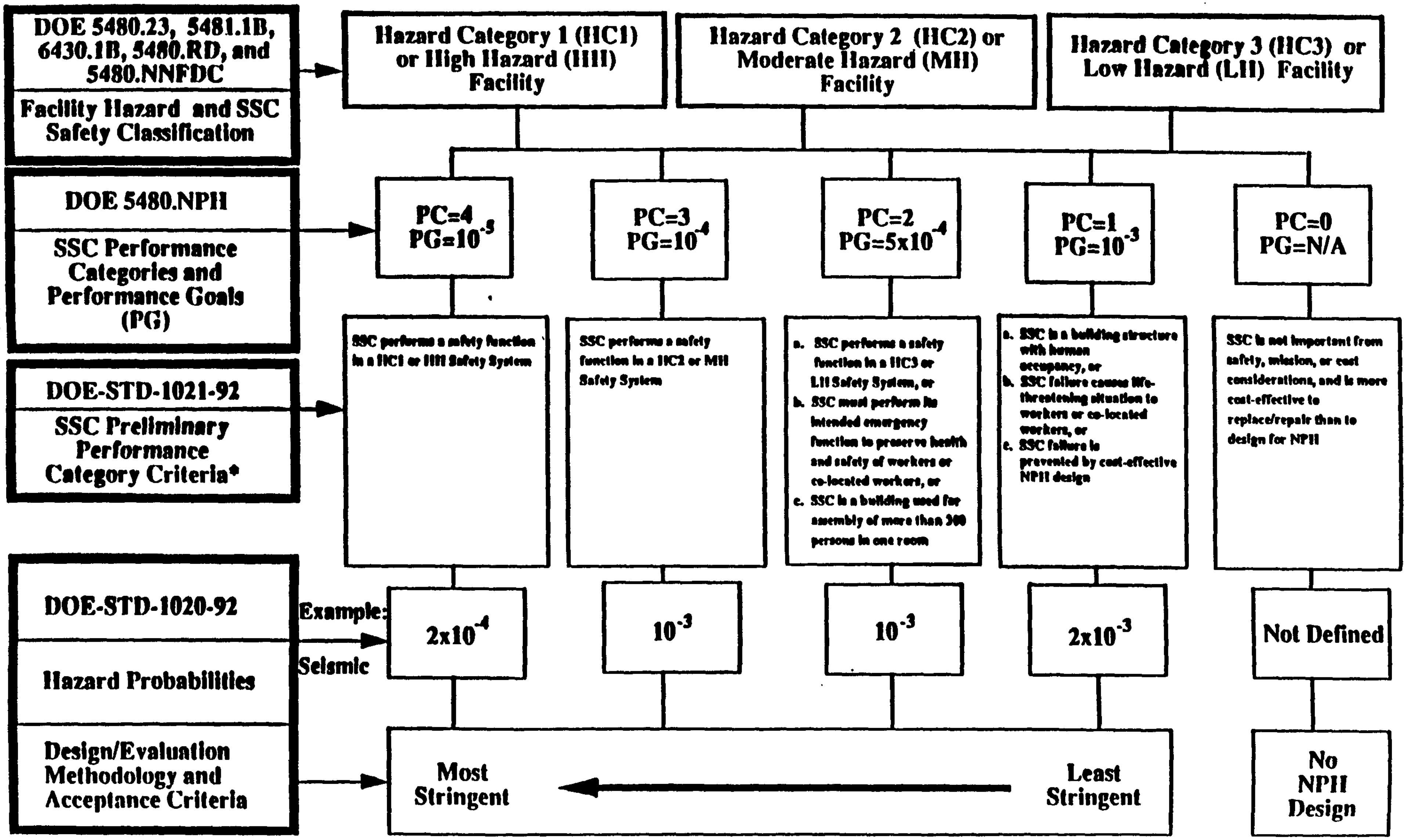


Figure 3-18 Logic tree for crystalline basement sources.

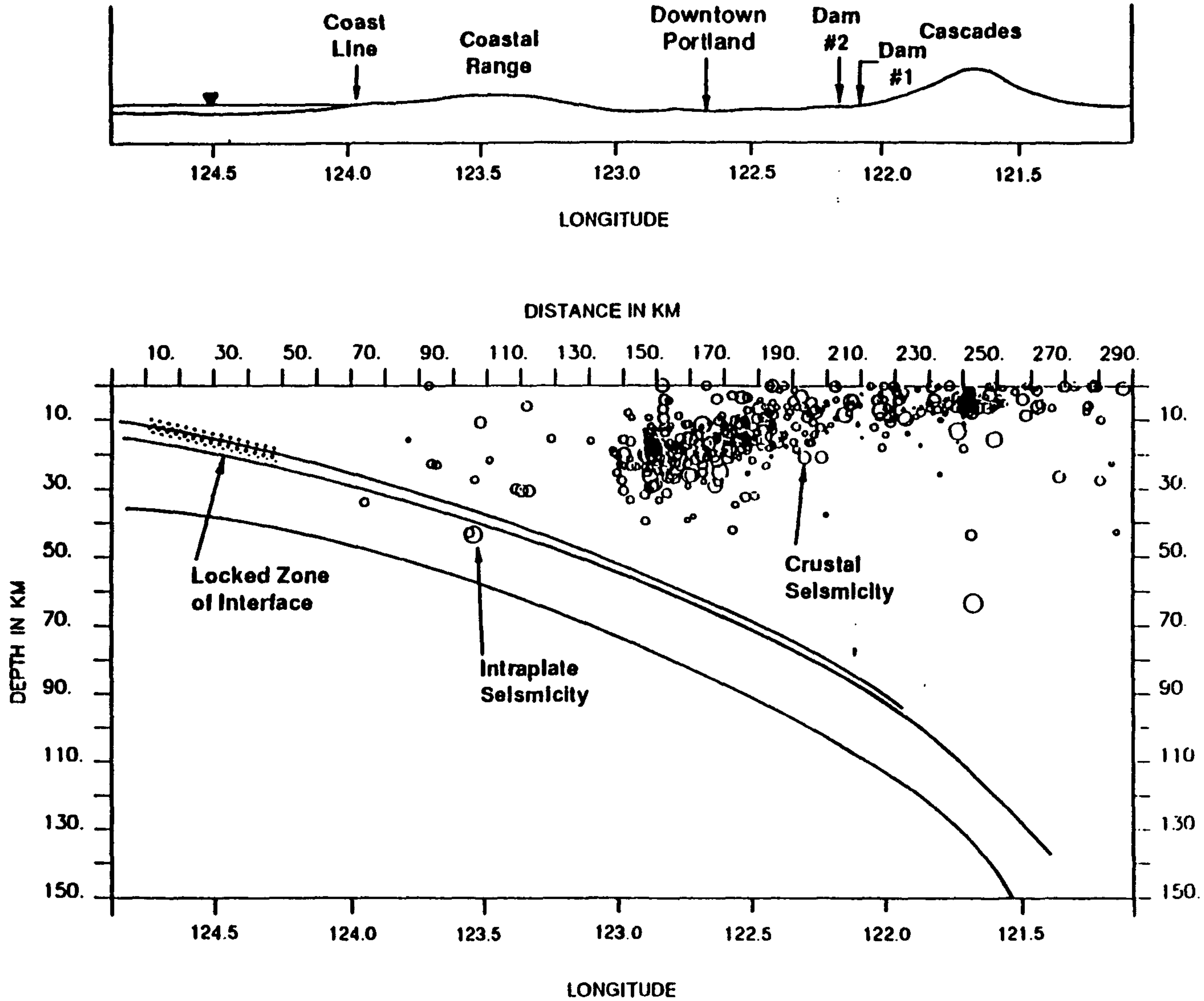
Figure 1-1: Relationship among Facility Hazard Class/Category, SSC Performance Category and Pertinent DOE Orders and Standards.



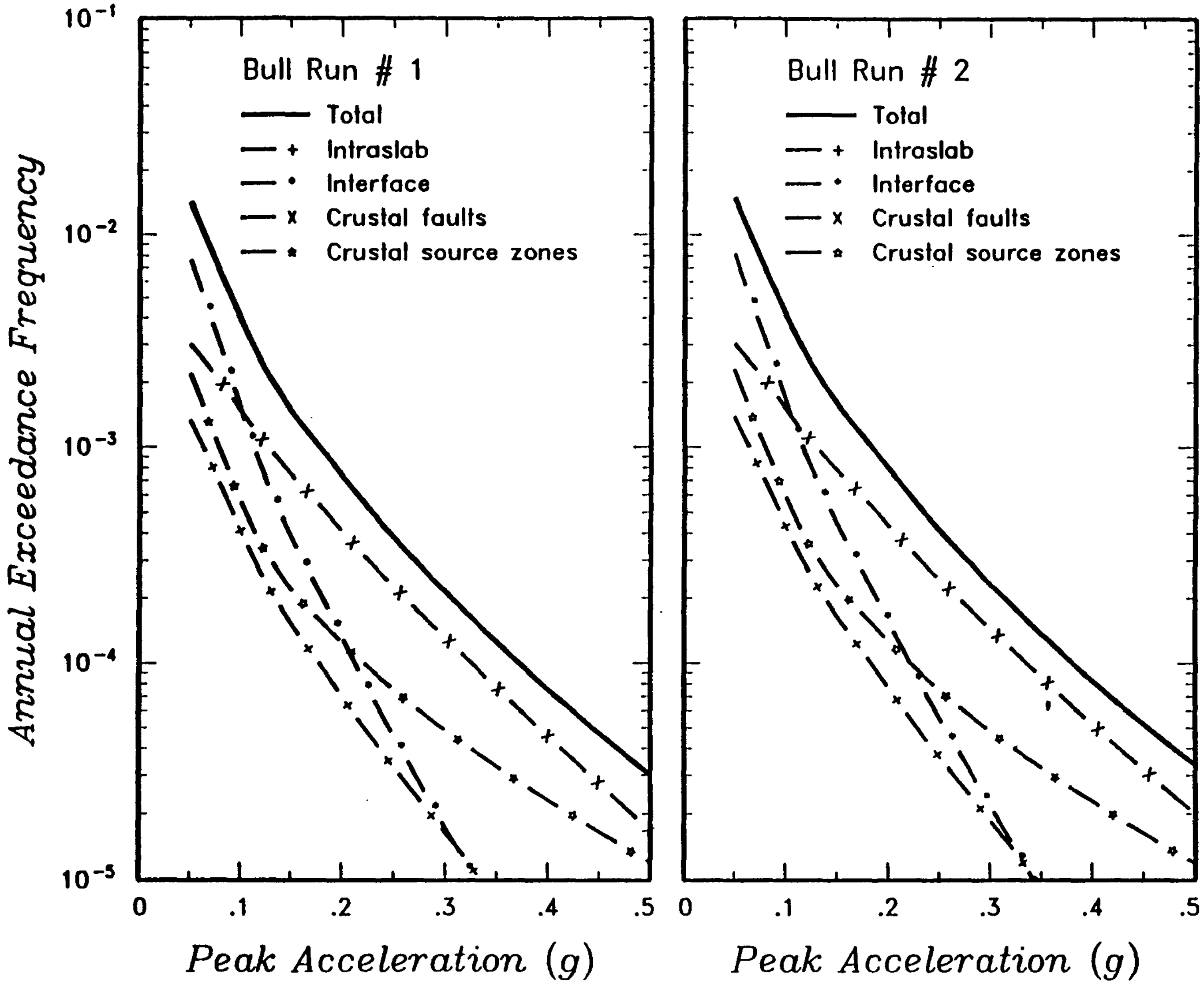
[illegible]e these criteria only in the context of Sections 2 and 3[illegible]is document; also, see Section 2.5 for System Interacti[illegible]ffects

BULL RUN DAM SITES, OREGON

- Purpose: define ground motions for FERC safety review using both probabilistic and deterministic approaches
- Particular interest in incorporating new knowledge of earthquake sources
- Source interpretations made by project team
- Probabilistic results used to establish 'conservatism' of mean and 84th percentile deterministic results



Cross-section of seismicity centered on latitude 45.5 with inferred location of subducted portion of Juan de Fuca Plate.



Contributions of various sources to the total hazard for the Bull Run Dams No. 1 and No. 2.

	Bull Run Dam No. 1			Bull Run Dam No. 2		
Ground Motion Level	Peak Accel. (g)	Probability of Exceedance	Return Period (years)	Peak Accel. (g)	Probability of Exceedance	Return Period (years)
Mean	0.21	$6x10^{-4}$	1,667	0.25	$4x10^{-4}$	2,500
84^{th}	0.30	$2x10^{-4}$	5,000	0.36	$1.5x10^{-4}$	6,667

LESSONS LEARNED FROM PSHA IN PRACTICE

- Deterministic approaches do not take into account likelihood of occurrence (rate) and uncertainties; design values were often contentious

- Probabilistic approaches have gained increasing use as methods have become better understood; rate-related parameters (slip rates, paleoseismic recurrence intervals, elapsed time, etc.) focus of research

- In some cases both deterministic and probabilistic results are desired to compare the two. The deterministic assessment is not a 'worst-case'; probabilistic analysis quantifies the likelihood of exceeding the deterministic case

- Probabilistic assessments incorporate uncertainties in models and parameter values; we have grown accustomed to acknowledging explicitly these uncertainties

- The burden and advantage of probabilistic approaches is the extensive documentation required to justify various models and parameters; such documentation is now commonplace in PSHA for critical facilities

- A variety of approaches have been used to capture differences in interpretations of data in PSHA; accepted approaches include elicitation of multiple experts individually; expert consensus assessments of uncertainties; and assessments by a single team with review by peer reviewers