Deterministic and Probabilistic Assessments

Norm Abrahamson

PG&E

Deterministic vs Probabilistic

- Deterministic
  - Consider of small number of scenarios (Mag, dist, number of standard deviation of ground motion)
  - Choose the largest ground motion from cases considered
- Probabilistic
  - Consider all possible scenarios (all mag, dist, and number of std dev)
  - Compute the rate of each scenario
  - Combine the rates of scenarios with ground motion above a threshold to determine probability of “exceedance”

PSHA Calculation

- Standard form of hazard

$$v(Sa > z) = \sum_{i=1}^{nSource} N_i(M_{\min}) \int_M \int_R f_{mi}(M)\, f_{Ri}(r,M) P(Sa > z \mid m,R)\, dR\, dM$$

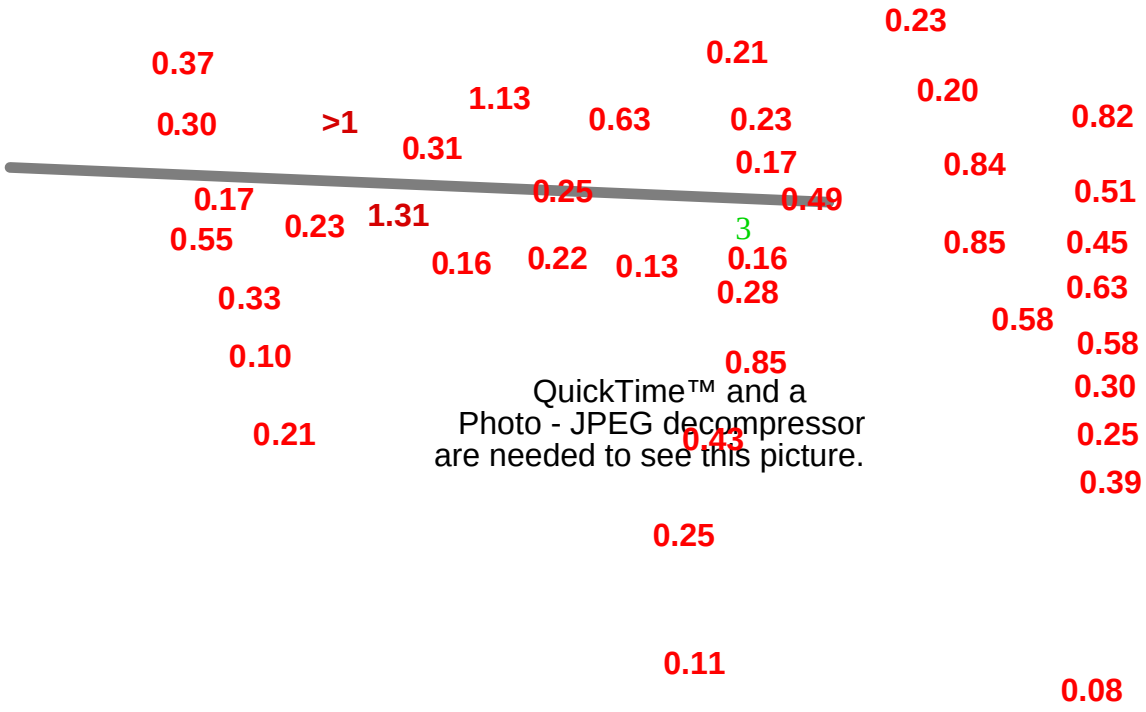
- Alternative form (explicit ground motion aleatory variability)

$$v(Sa > z) = \sum_{i=1}^{nSource} N_i(M_{\min}) \int_M \int_R \int_\varepsilon f_{mi}(M)\, f_{Ri}(r,M)\, f_\varepsilon(\varepsilon) P(Sa > z \mid m,R,\varepsilon)\, d\varepsilon\, dR\, dM$$

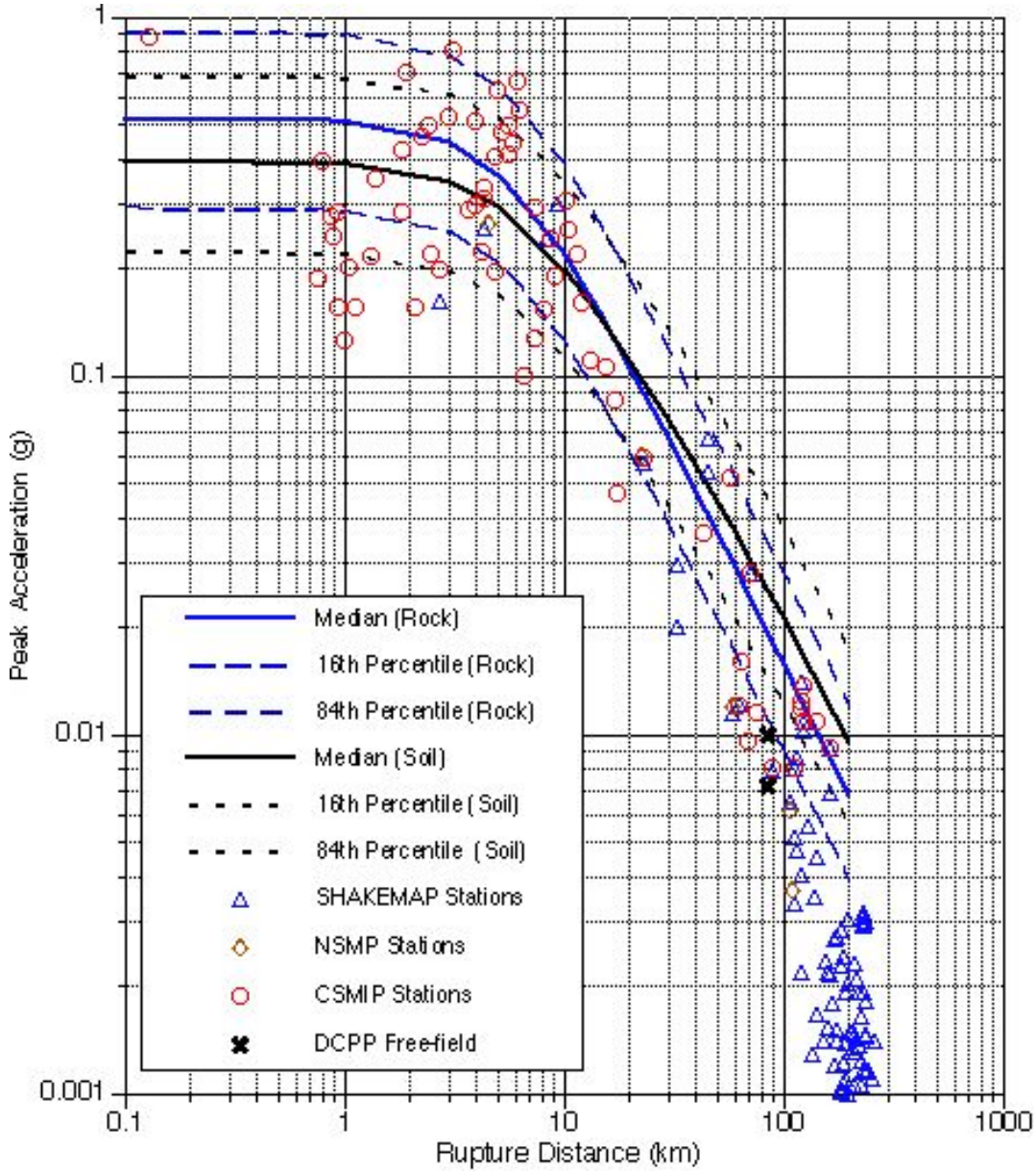
Deterministic Approach

- Select a specific magnitude and distance (location)
  - For dams, typically the “worst-case” earthquake
  - (MCE)
- Design for ground motion, not earthquakes
  - Ground motion has large variability for a given magnitude, distance, and site condition
  - Key issue: What ground motion level do we select?

2004 Parkfield
Near Fault PGA Values



QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

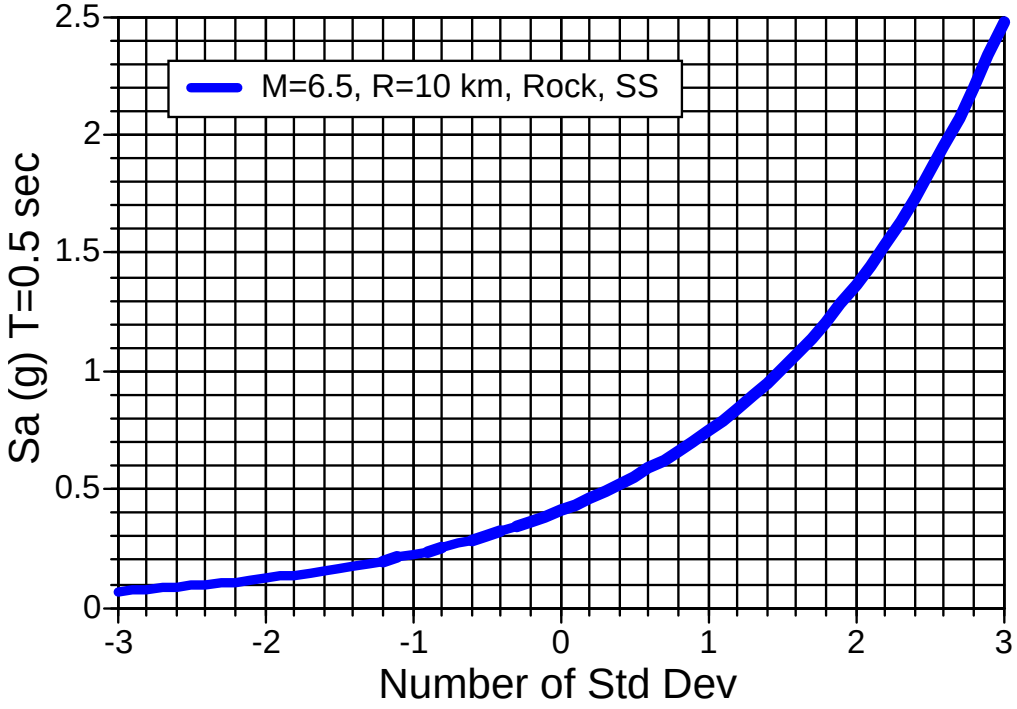


2004 Parkfield Attenuation

Comparison with A&S 97

Ground Motion Levels

- By tradition, select median or 84th percentile
- Worst-case ground motion is much higher



Worst-Case Ground Motion is Not Selected in Deterministic Approach

- Combing largest earthquake with the worst-case ground motion is too unlikely a case
  - The occurrence of the maximum earthquake is rare, so it is not "reasonable" to use a worst-case ground motion for this earthquake
  - Chose something smaller than the worst-case ground motion that is "reasonable".

What is “Reasonable”

- The same number of standard deviation of ground motion may not be “reasonable” for all sources
  - Median may be reasonable for low activity sources, but higher value may be needed for high activity sources
- Need to consider both the rate of the earthquake and the chance of the ground motion

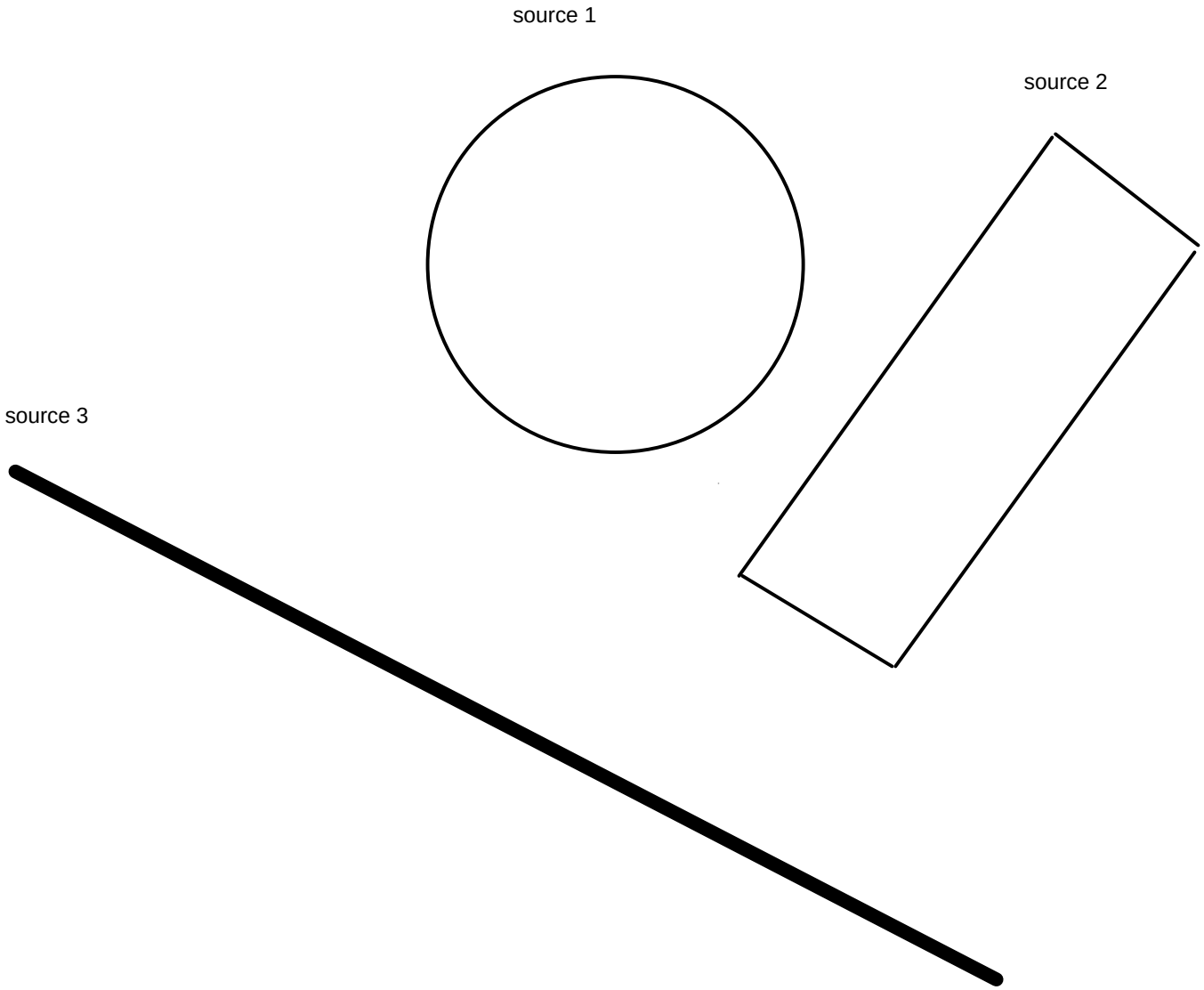
Probabilistic Approach

- Source Characterization
  - Develop a comprehensive set of possible scenario earthquakes: M, R(location)
  - Specify the rate at which each scenario earthquake (M,R) occurs
- Ground Motion Characterization
  - Develop a full range of possible ground motions for each earthquake scenario (ε=number of std dev above or below the median)
  - Compute the probability of each ground motion for each scenario

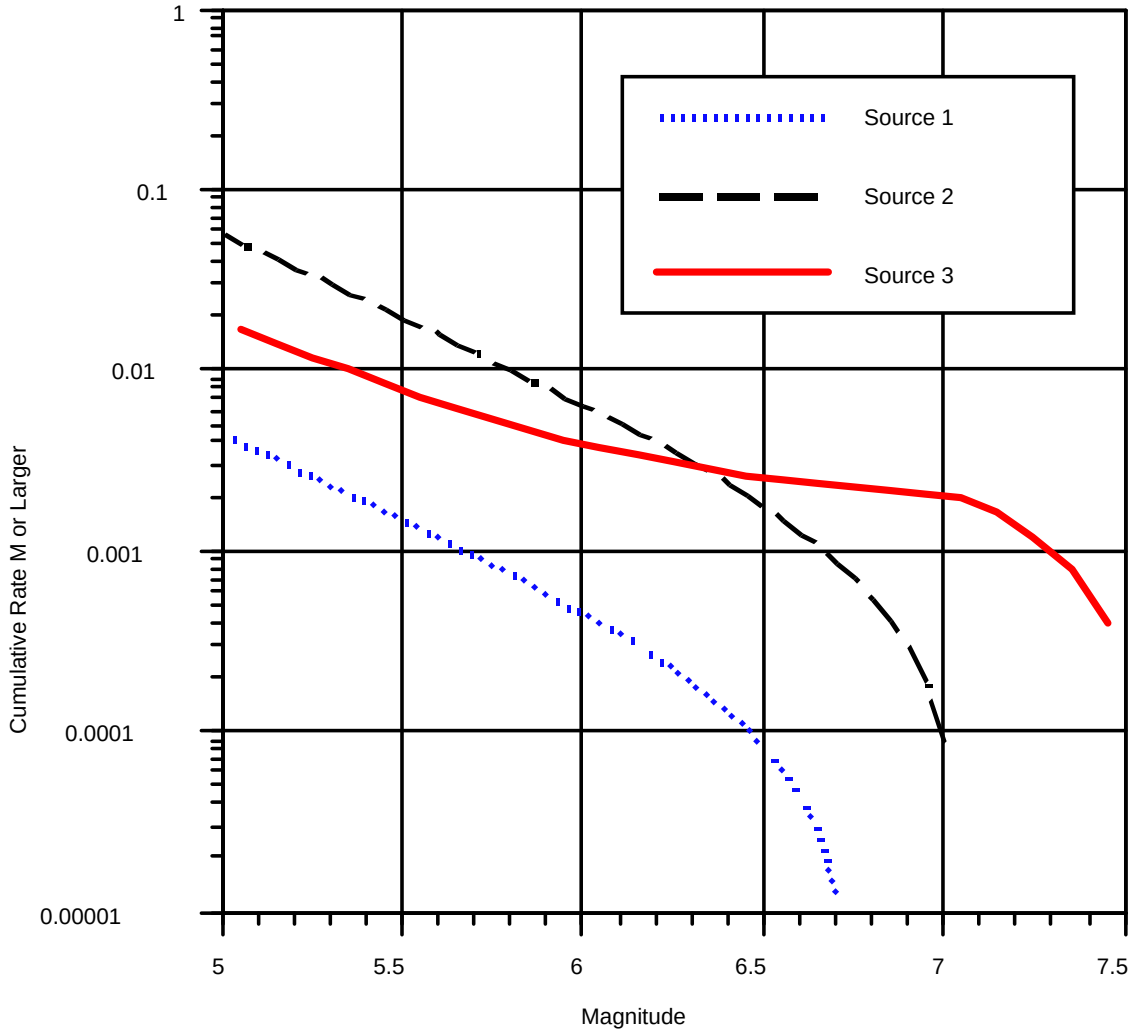
Probabilistic Approach (cont)

- Hazard Calculation
  - Rank scenarios (M,R, ε) in order of decreasing severity of shaking (Here, use Sa)
  - Result: Table of ranked scenarios with ground motions and rates
  - Sum up rates of scenarios with ground motion above a specified level (hazard curve)
- Select a ground motion for the design hazard level
  - Back off from worst case ground motion until either:
    - The ground motion is does not lead to excessive costs, <u>or</u>
    - The hazard level is not too small (e.g. not too rare) to ignore (e.g. the design hazard level)

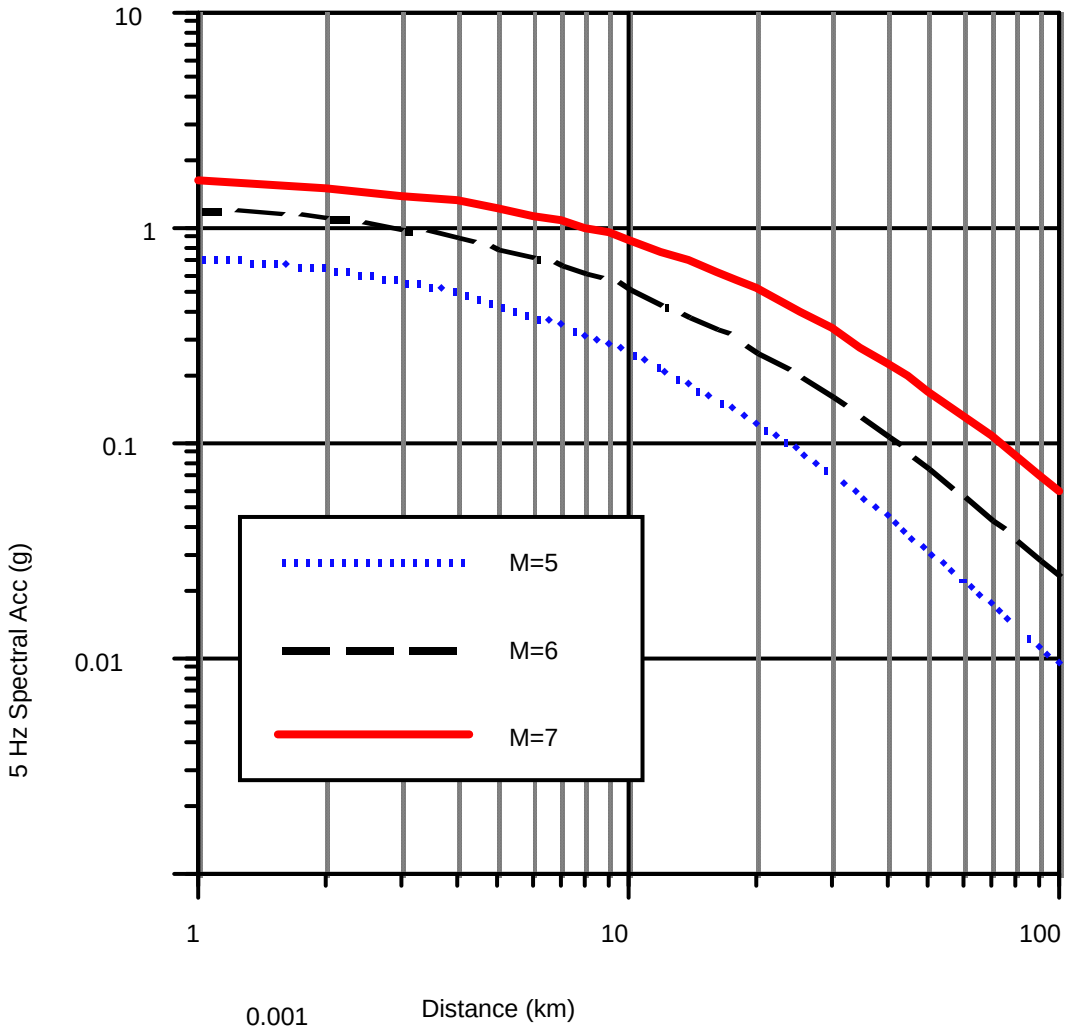
Example Sources



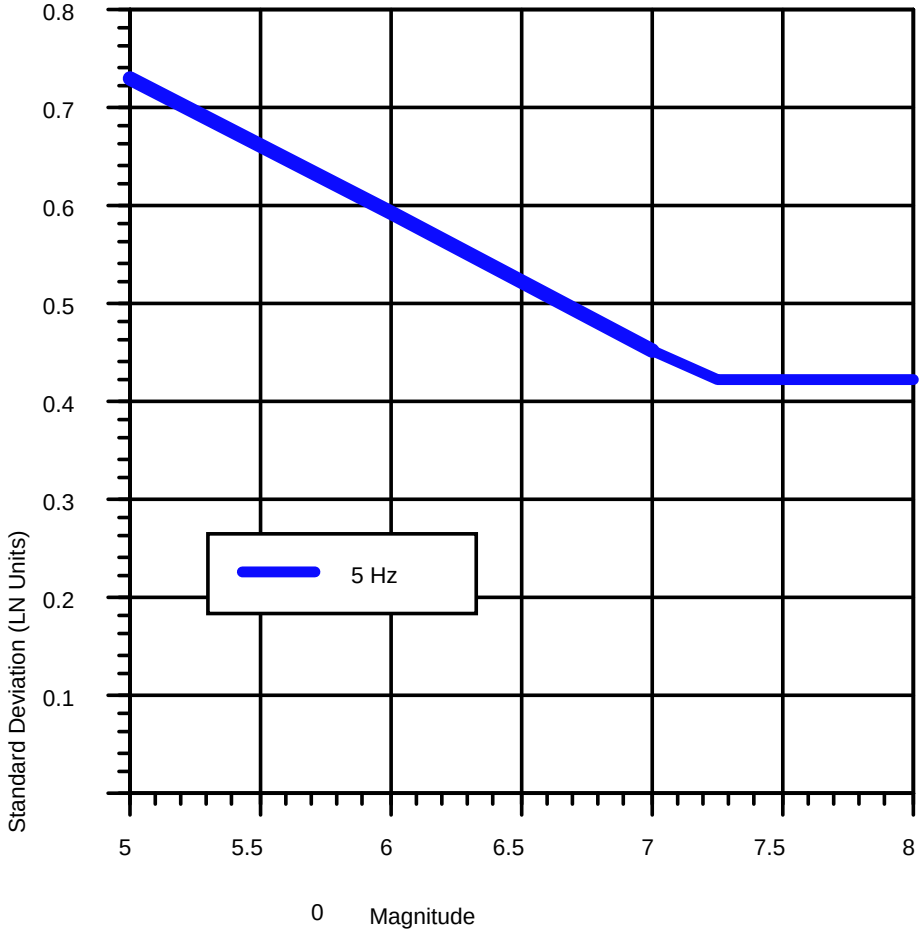
Example Source Characterization



Median Ground Motion



Standard Deviation of Ground Motion



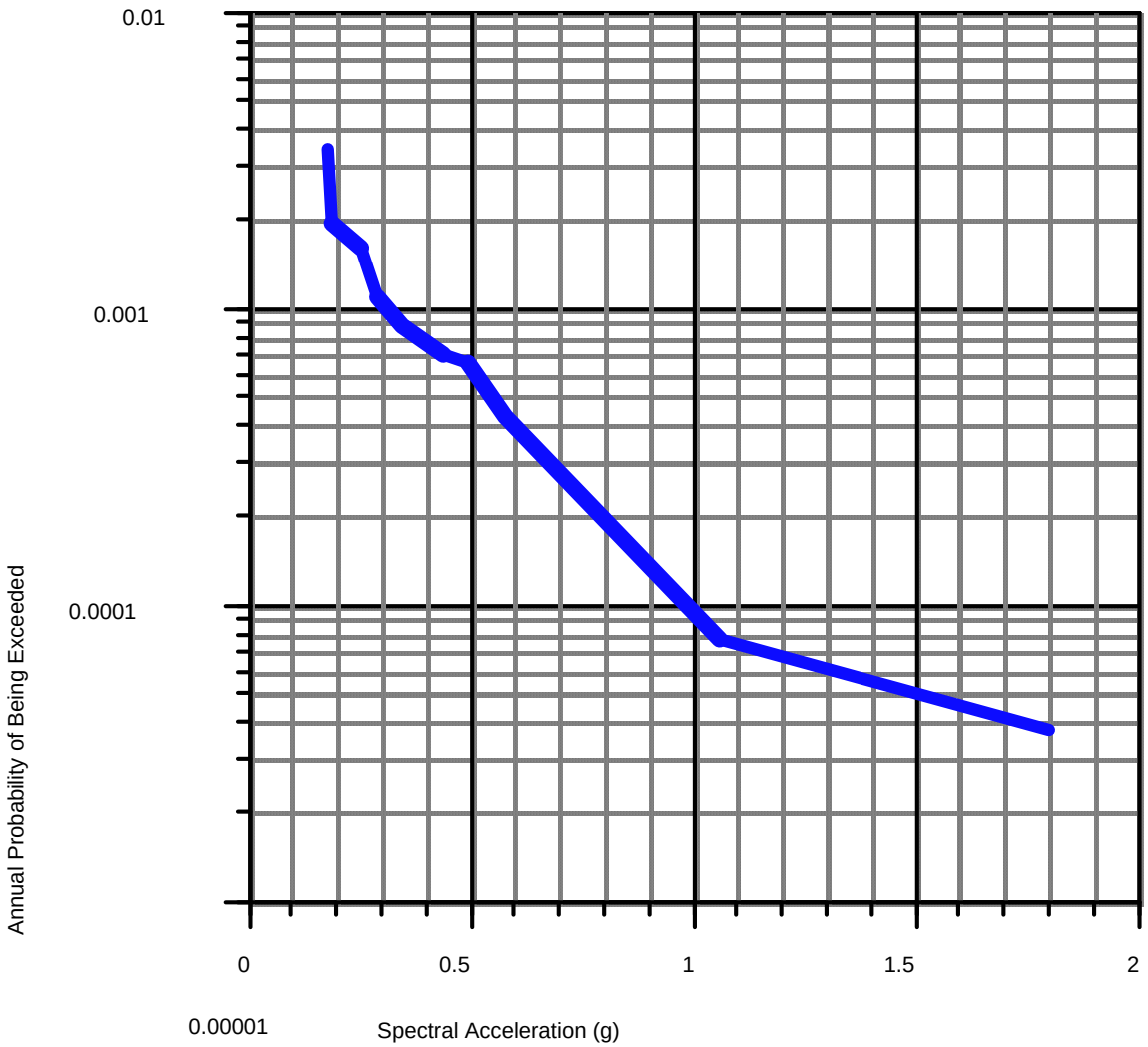
Partial List of Scenarios

Source	Mag	R (km)	Rate of Sa	Median Sa	Std Dev	ε	P(e)	Sa(g)	Rate
1	6.50	2	0.00022	1.38	0.53	0.5	0.175	1.80	0.000038
1	6.50	2	0.00022	1.38	0.53	-0.5	0.175	1.06	0.000038
1	5.00	2	0.00180	0.58	0.73	0.0	0.197	0.58	0.000355
1	5.00	10	0.00180	0.24	0.73	1.0	0.121	0.49	0.000218
2	5.50	40	0.02216	0.07	0.66	1.5	0.066	0.18	0.001453
2	6.00	40	0.00786	0.10	0.59	1.5	0.066	0.25	0.000516
2	6.50	40	0.00279	0.16	0.52	1.5	0.066	0.35	0.000183
3	7.25	60	0.00170	0.19	0.42	2.0	0.028	0.44	0.000047
3	7.25	60	0.00170	0.19	0.42	1.0	0.121	0.29	0.000206
3	7.25	60	0.00170	0.19	0.42	0.0	0.197	0.19	0.000336

Rank Scenarios by Ground Motion

Source	Mag	R (km)	ε	Sa(g)	Rate	Hazard
1	6.50	2	0.5	1.80	0.000038	0.000038
1	6.50	2	-0.5	1.06	0.000038	0.000076
1	5.00	10	0.0	0.58	0.000355	0.000432
3	7.25	60	1.0	0.49	0.000218	0.000649
2	6.50	40	1.5	0.44	0.000047	0.000697
3	7.25	60	1.5	0.35	0.000183	0.000880
1	5.00	2	1.5	0.29	0.000206	0.001085
2	6.00	40	2.0	0.25	0.000516	0.001601
3	7.25	60	1.0	0.19	0.000336	0.001937
2	5.50	40	0.0	0.18	0.001453	0.003390

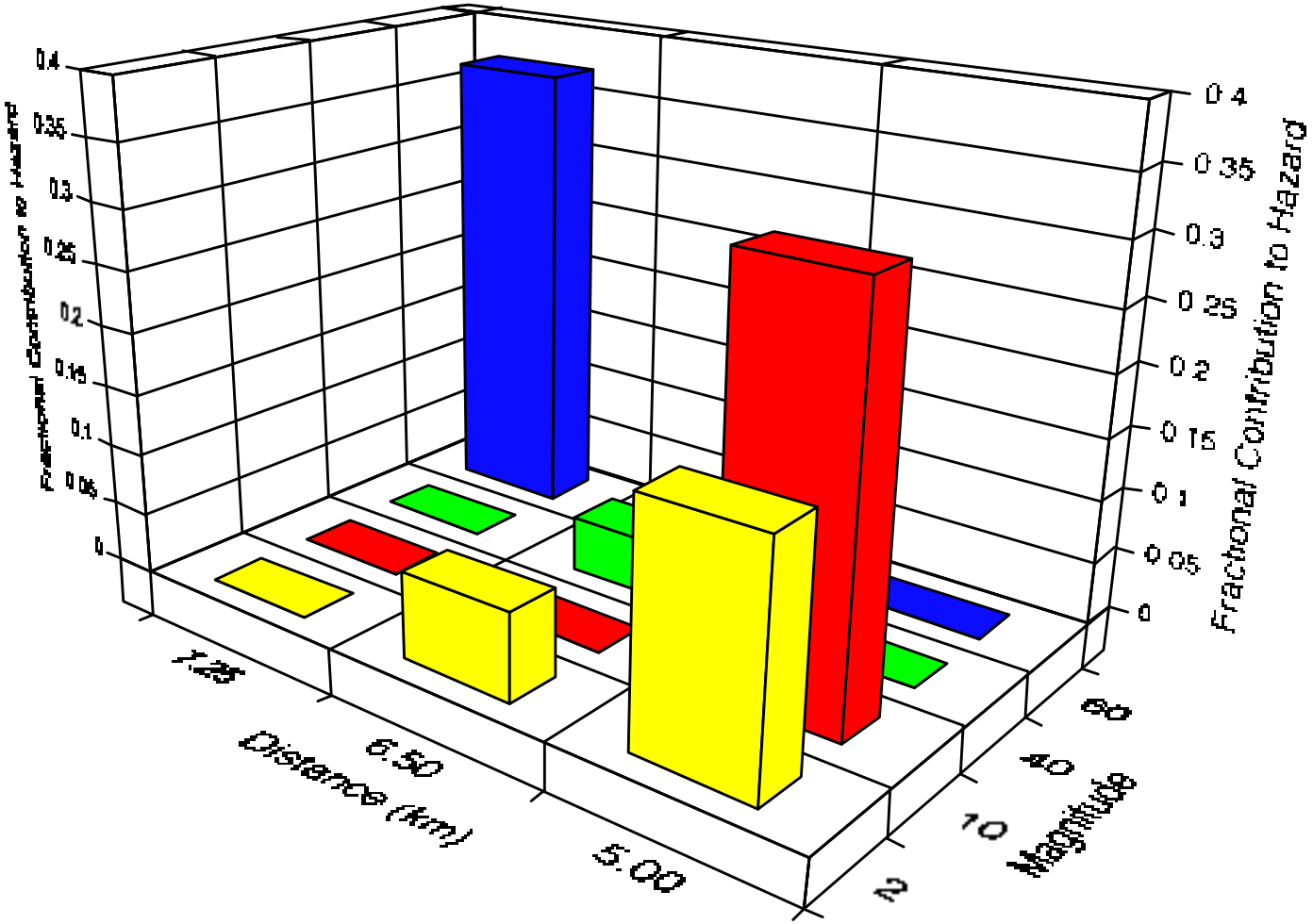
Hazard Curve



Deaggregation at 10^{-3} Hazard

Source	Mag	R (km)	ε	Sa(g)	Rate	Hazard	Deagg
1	6.50	2	0.5	1.80	0.000038	0.000038	0.035
1	6.50	2	-0.5	1.06	0.000038	0.000076	0.035
1	5.00	10	0.0	0.58	0.000355	0.000432	0.327
3	7.25	60	1.0	0.49	0.000218	0.000649	0.201
2	6.50	40	1.5	0.44	0.000047	0.000697	0.044
3	7.25	60	1.5	0.35	0.000183	0.000880	0.169
1	5.00	2	1.5	0.29	0.000206	0.001085	0.190
2	6.00	40	2.0	0.25	0.000516	0.001601	
3	7.25	60	1.0	0.19	0.000336	0.001937	
2	5.50	40	0.0	0.18	0.001453	0.003390	

Group Similar Scenarios for Deaggregation Plots



Common Misunderstandings in PSHA

- PSHA combines ground motions from different earthquakes
  - No, PSHA <u>ranks</u> ground motions from different earthquakes, it does not combine ground motions
    - UHS does combine ground motions, but not required in PHSA
  - PSHA combines the chance of getting a specified level of ground motion from different earthquakes
    - - There is more than one earthquake that can lead to a specified ground motion at the site
- PSHA does not give earthquake scenarios
  - Deaggregation provides descriptions of scenarios

Aleatory Variability and Epistemic Uncertainty

- Scientific Uncertainty (epistemic)
  - Due to lack of information
  - Incorporated in PSHA using logic trees (leads to alternative hazard curves)
  - Impacts the mean hazard
- Random Variability (aleatory)
  - Randomness in M, location, ground motion (ε)
  - Incorporated in hazard calculation directly

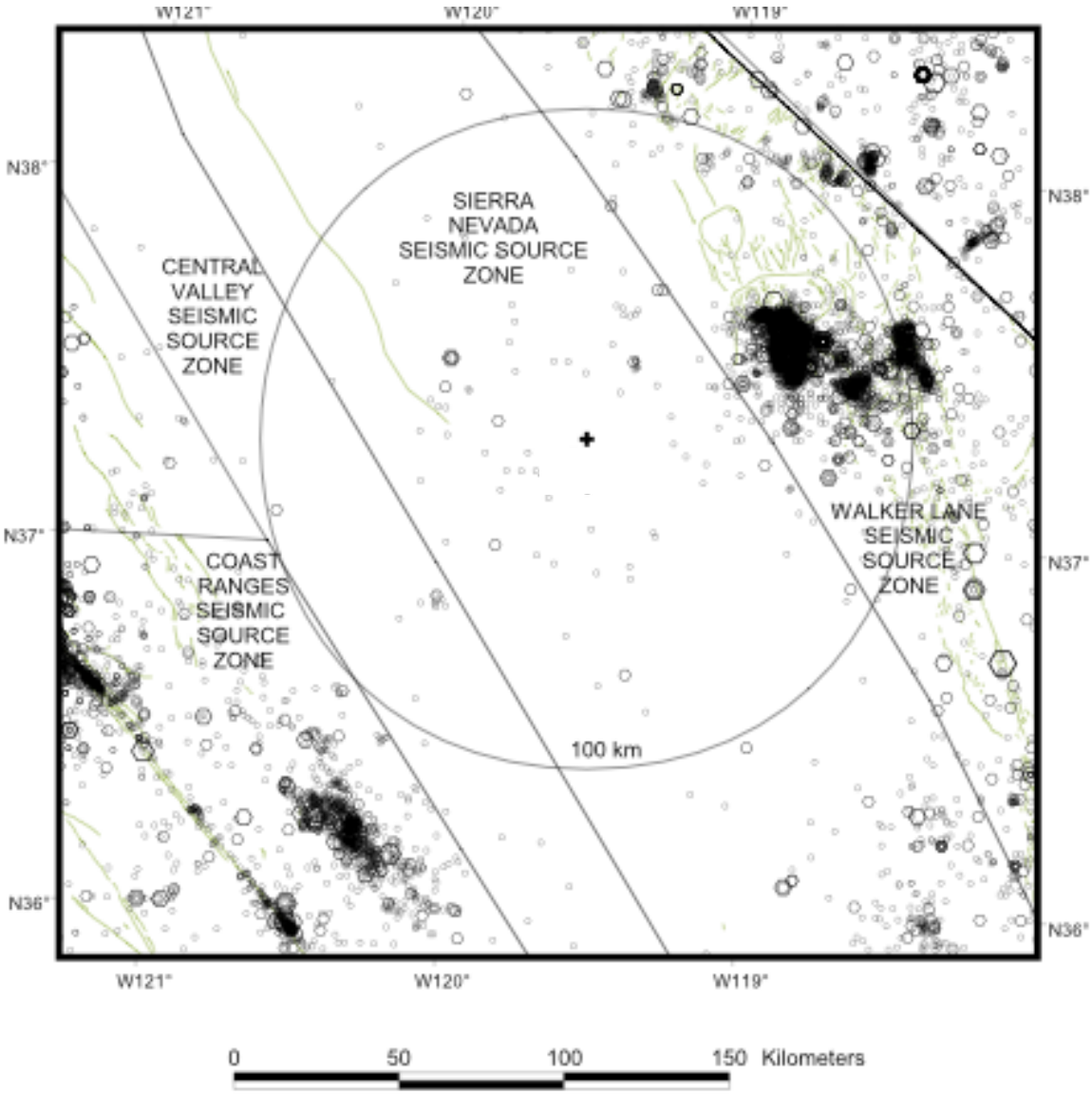
Epistemic Uncertainty

- Due to lack of data
  - Sparse data implies large uncertainty

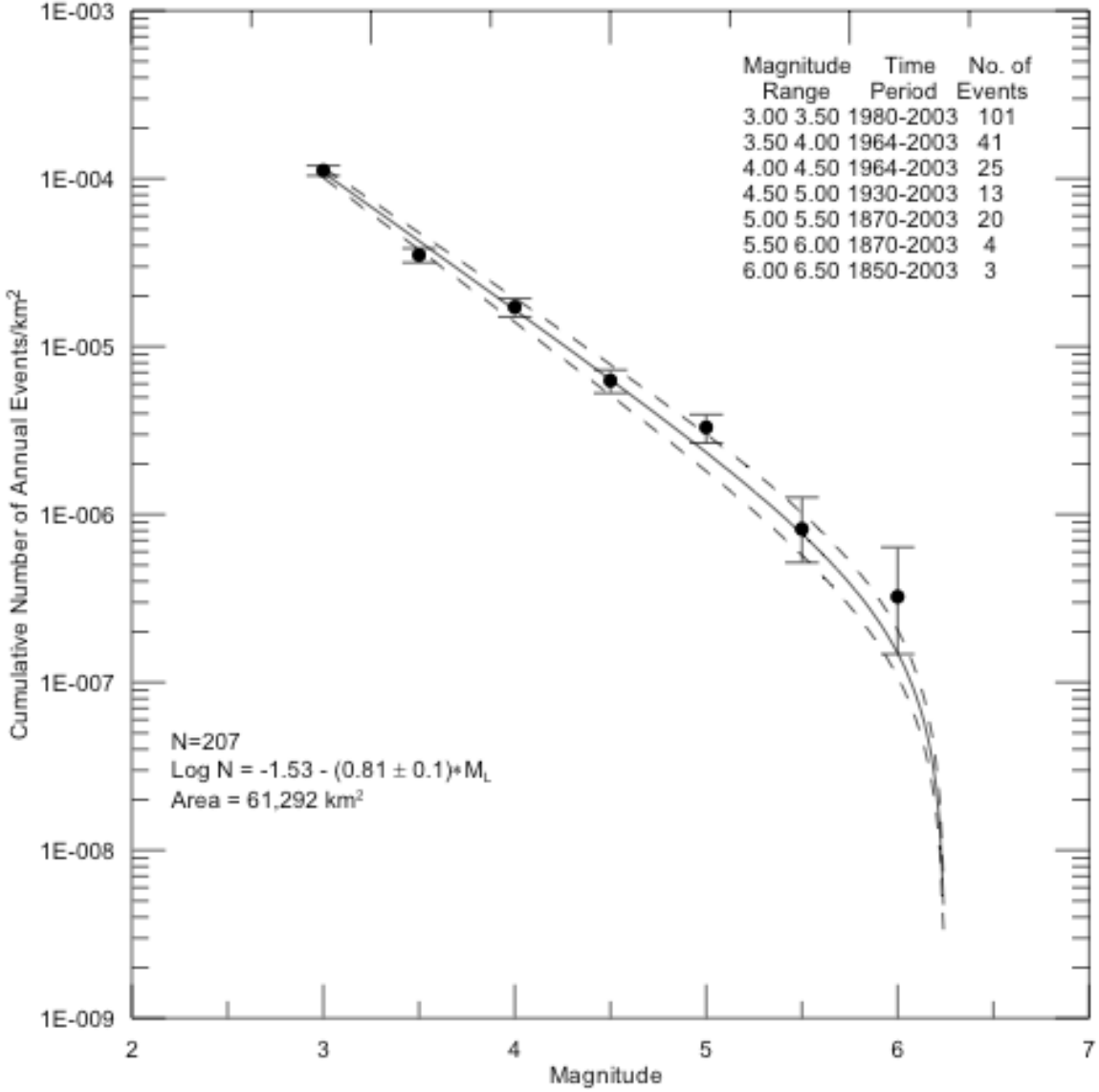
- In practice, not always the case

  Estimated using alternative available models/data
  - Few available studies leads to small uncertainty (few alternatives available)
  - Many available studies leads to larger uncertainty (more alternatives available)

Example Hazard



Background Rate



Fault Sources

- Mean Characteristic Magnitude
  - M = log(fault area) + 4
- Usually balance moment-rate on fault
  - $M_o(M) = 10^{1.5M+16.05}$
  - Moment-rate = μAS

    μ = shear modulus (3E11 dyne/cm^2)

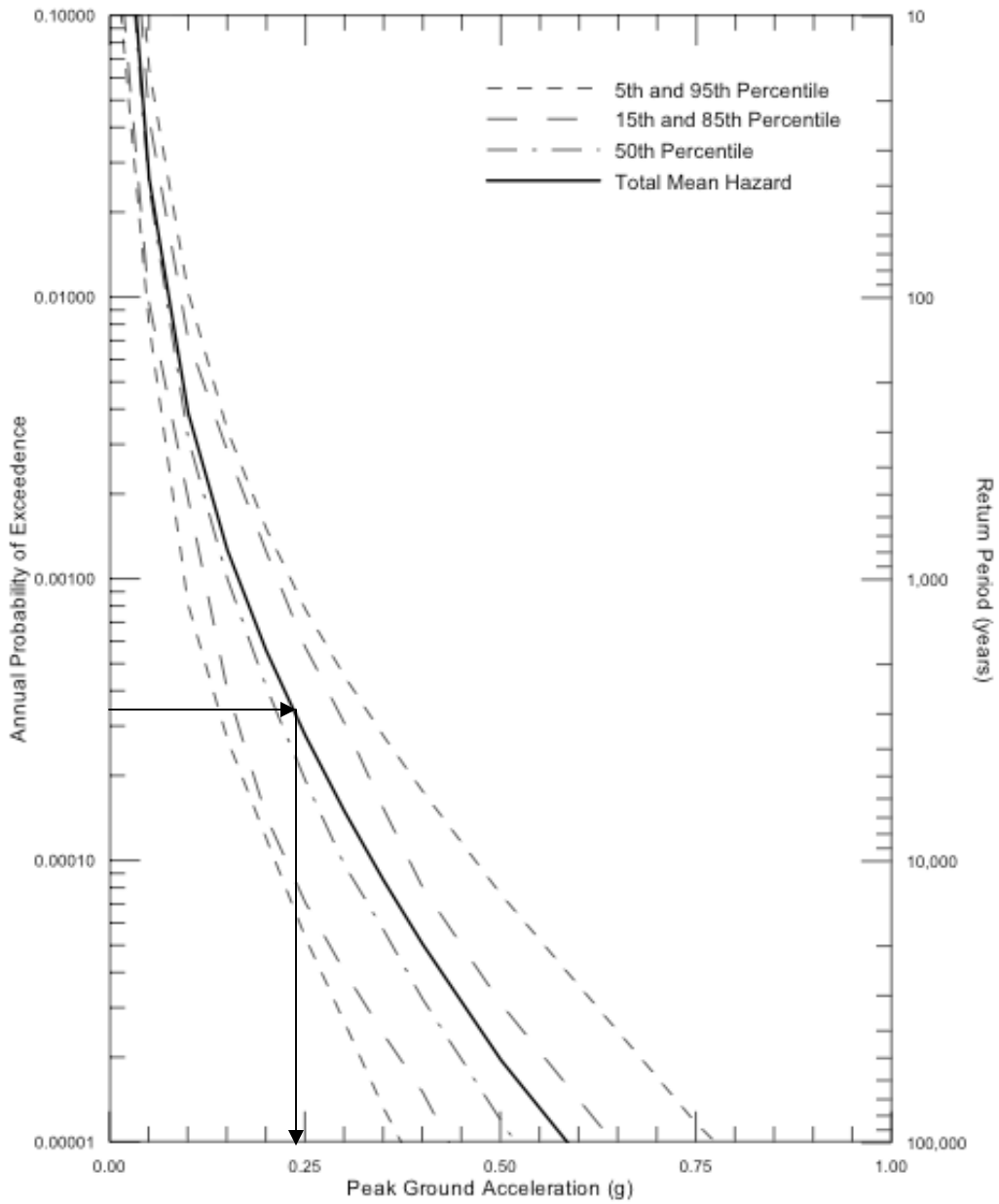
    A = fault area in cm^2

    S = slip-rate in cm/yr

$$Eqk\,rate = \frac{Moment\ Rate}{Moment\,/\,Eqk}$$

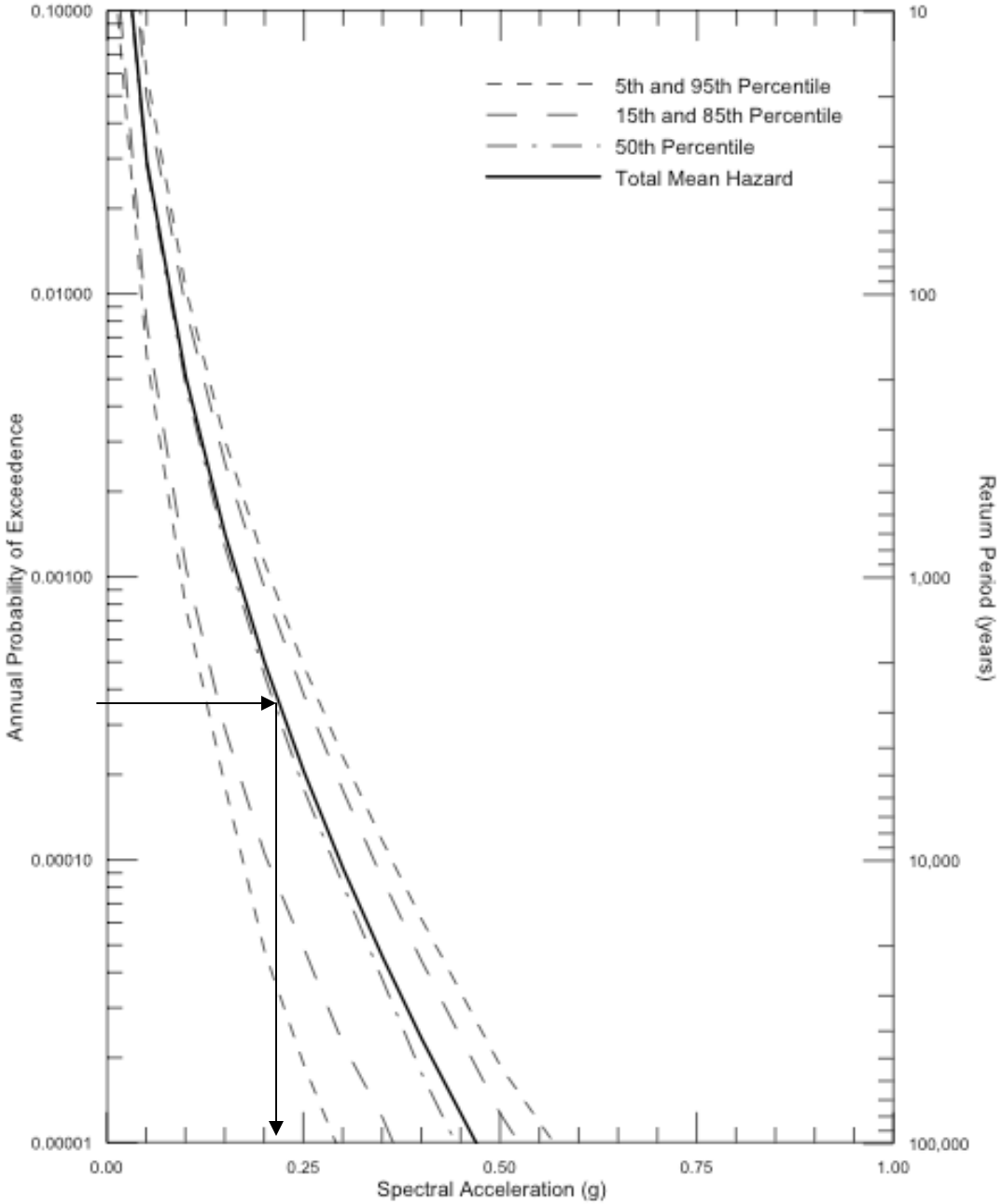
PGA Hazard

3000 yr return period
PGA = 0.24g

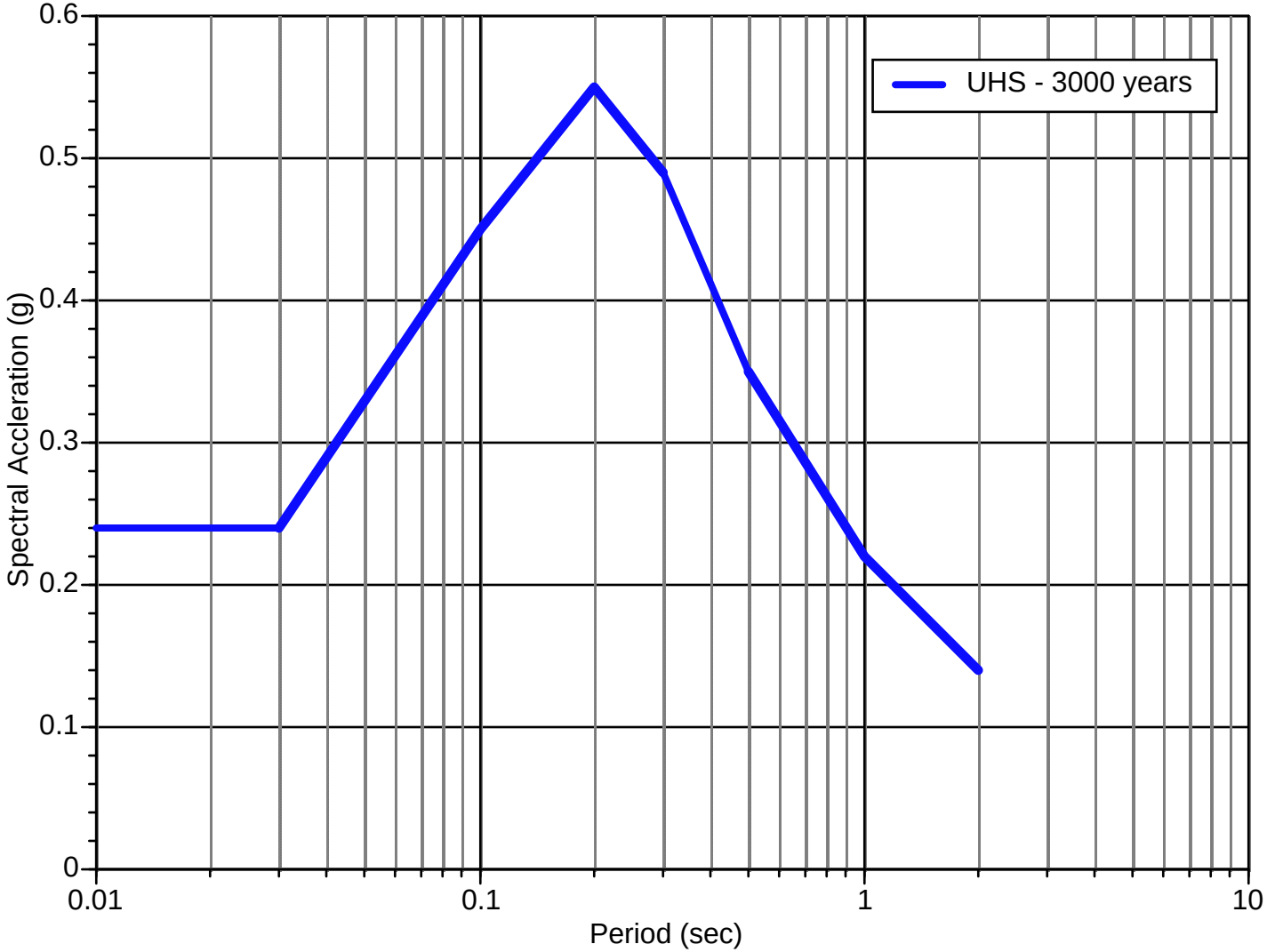


T=1 sec Hazard

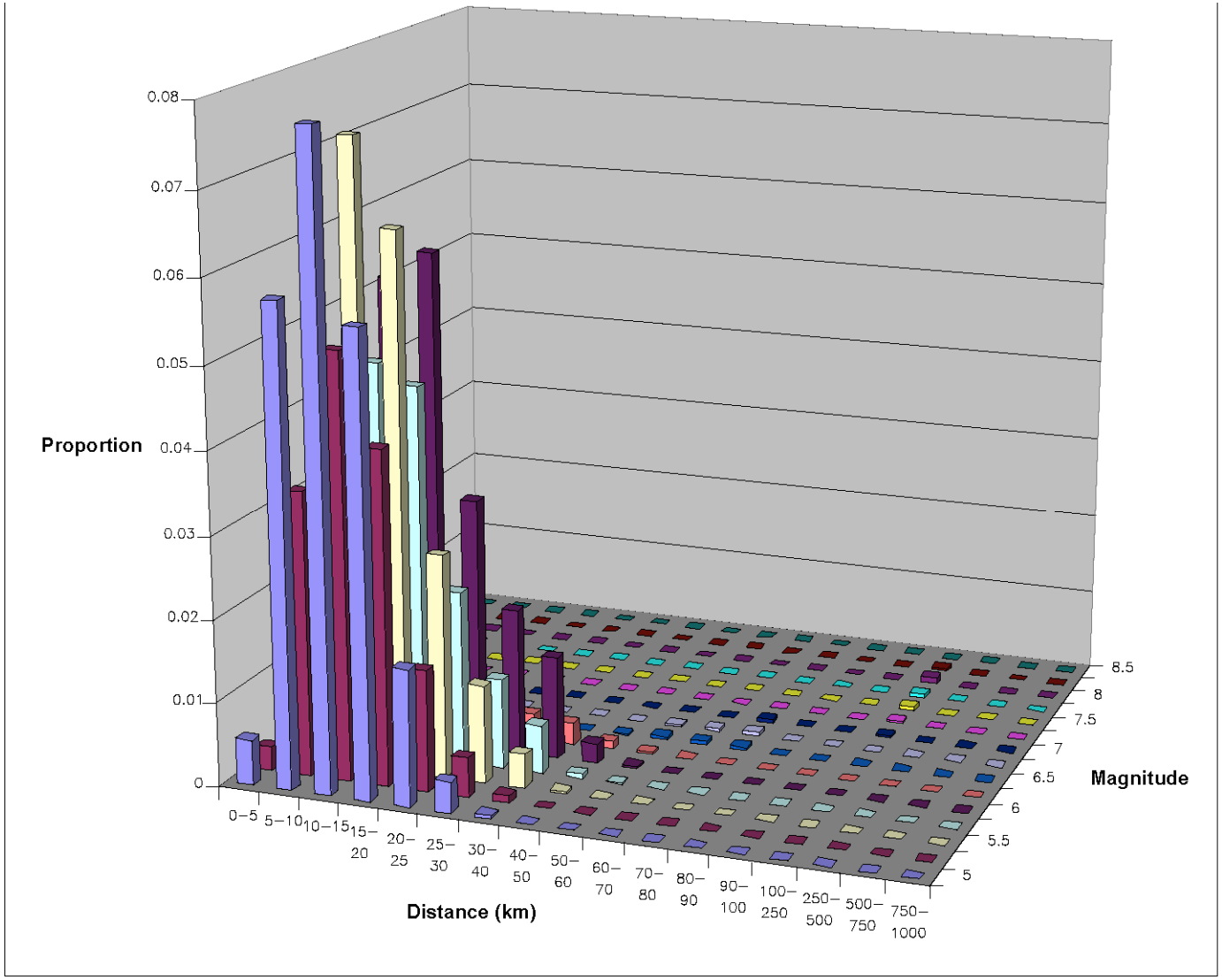
3000 yr return period
Sa(T=1) = 0.22g



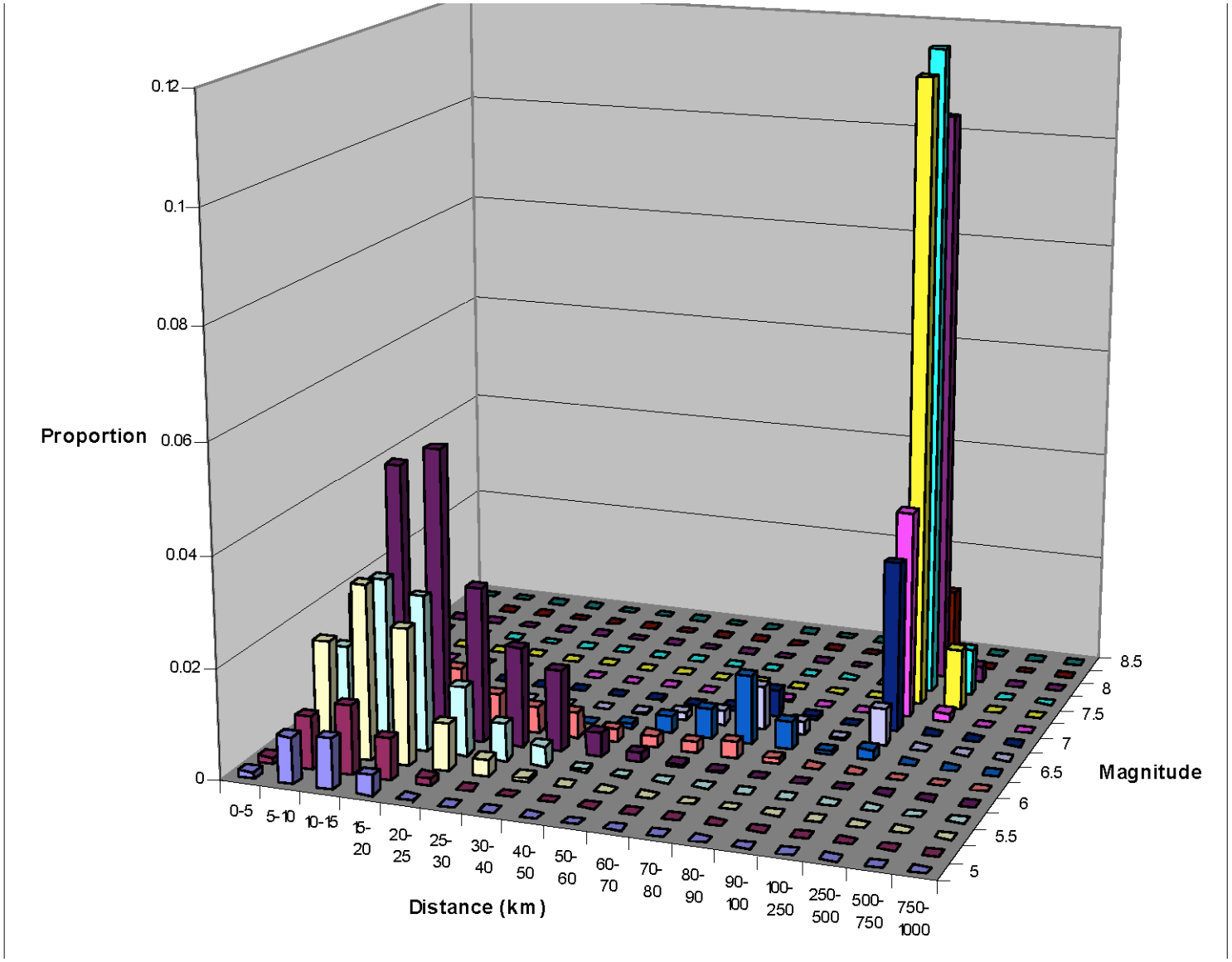
Uniform Hazard Spectrum



Deaggregation for PGA=0.24g



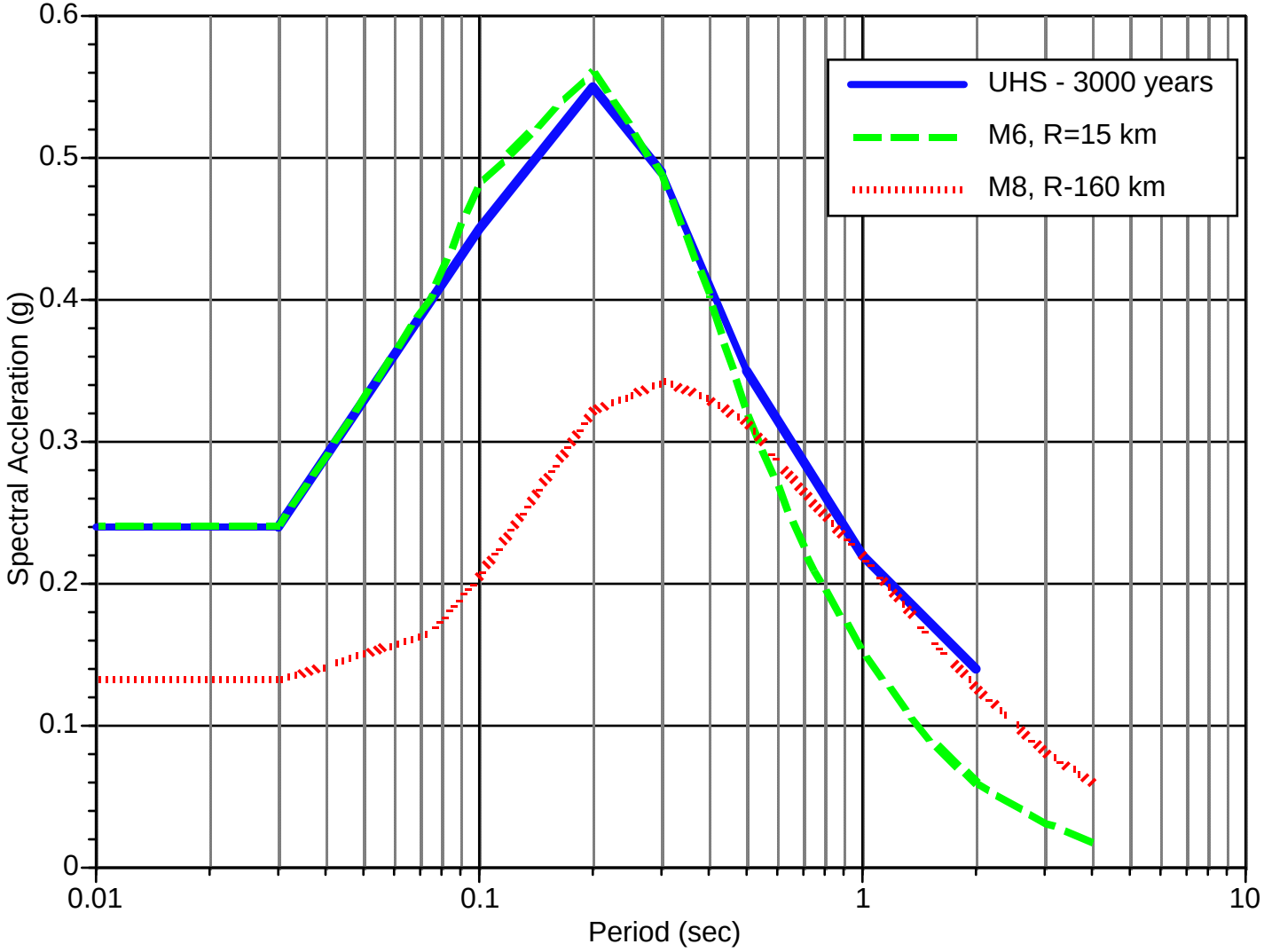
Deaggregation for Sa(T=1)=0.22g



Controlling Scenarios

- For 3000 years:
  - PGA: M=6.0, R=15 km
  - Sa(T=1): M=8.0, R=160 km

UHS Scenarios



UHS

- Hazard reports should provide spectra for scenarios that control the UHS
- UHS envelopes the alternative scenarios
  - used to reduce engineering analysis costs by reducing number of scenarios to consider, it is not required in PSHA
- Decision to use UHS or individual scenarios should be made by engineers involved in the analysis of structure, not by hazard analyst

Rate of Occurrence

- Hazard curve gives rate of exceeding a ground motion
- Is is simple to convert this to a rate of occurrence:

$$\nu(a_1 > Sa > a_2) = Haz(a_1) - Haz(a_2)$$

Rate of Occurrence - by Mag-Dist-GM

Rate of Occurrence for a specific magnitude, distance and ground motion range is easily computed from the hazard and the deaggregation

This provides information needed for risk calculations

Summary

- Both deterministic and probabilistic approaches involve probability
  - Goal of both approaches is to select a “reasonable” ground motion that is smaller than the worst-case ground motion
- For design ground motions (not risk assessment), purpose of PSHA is to select <u>reasonable</u> scenarios (Mag, Dist, Number of std dev) from the complete set of all scenarios
  - Select the most severe scenarios that is either not too rare <u>or</u> not too costly

Key Issues for Seismic Hazard Assessment for Dams

- Which approach, Deterministic or Probabilistic?
  - If both used, how are they combined?
- What return period is reasonable?
  - Should this be the same for active an inactive?
- Should a minimum earthquake be required?
  - Defined as a ground motion or an earthquake scenario?
  - Related to “not too costly”