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(ε)
  - 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

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

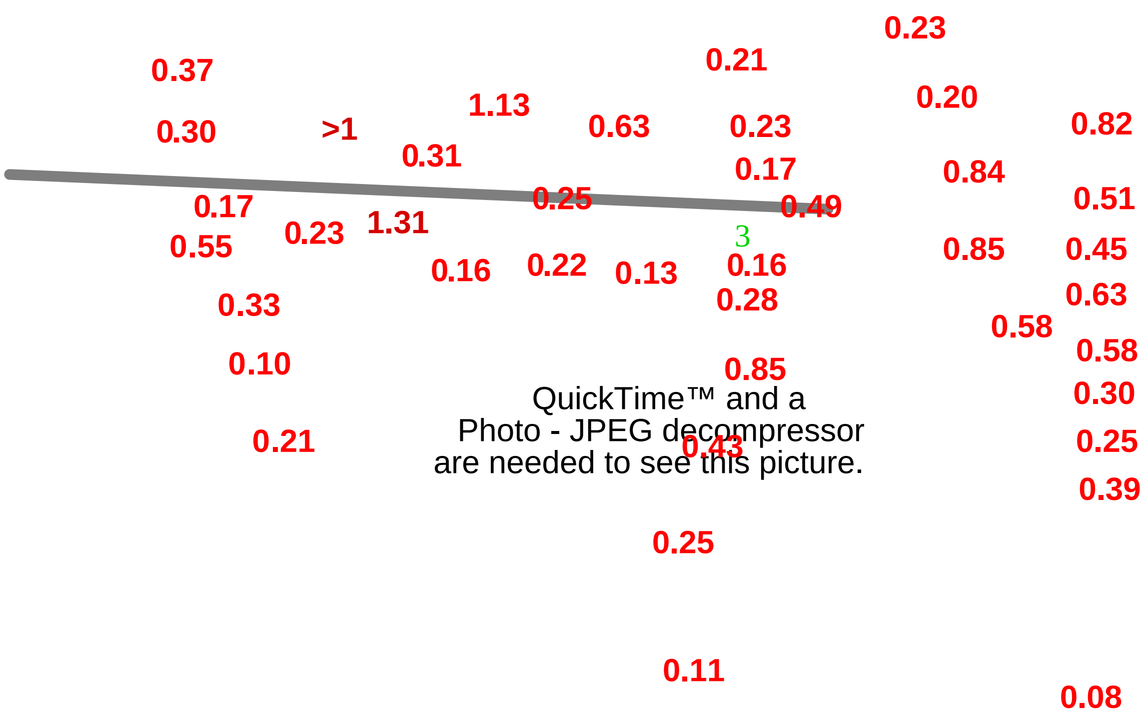
- Alternative form (explicit ground motion aleatory variability)

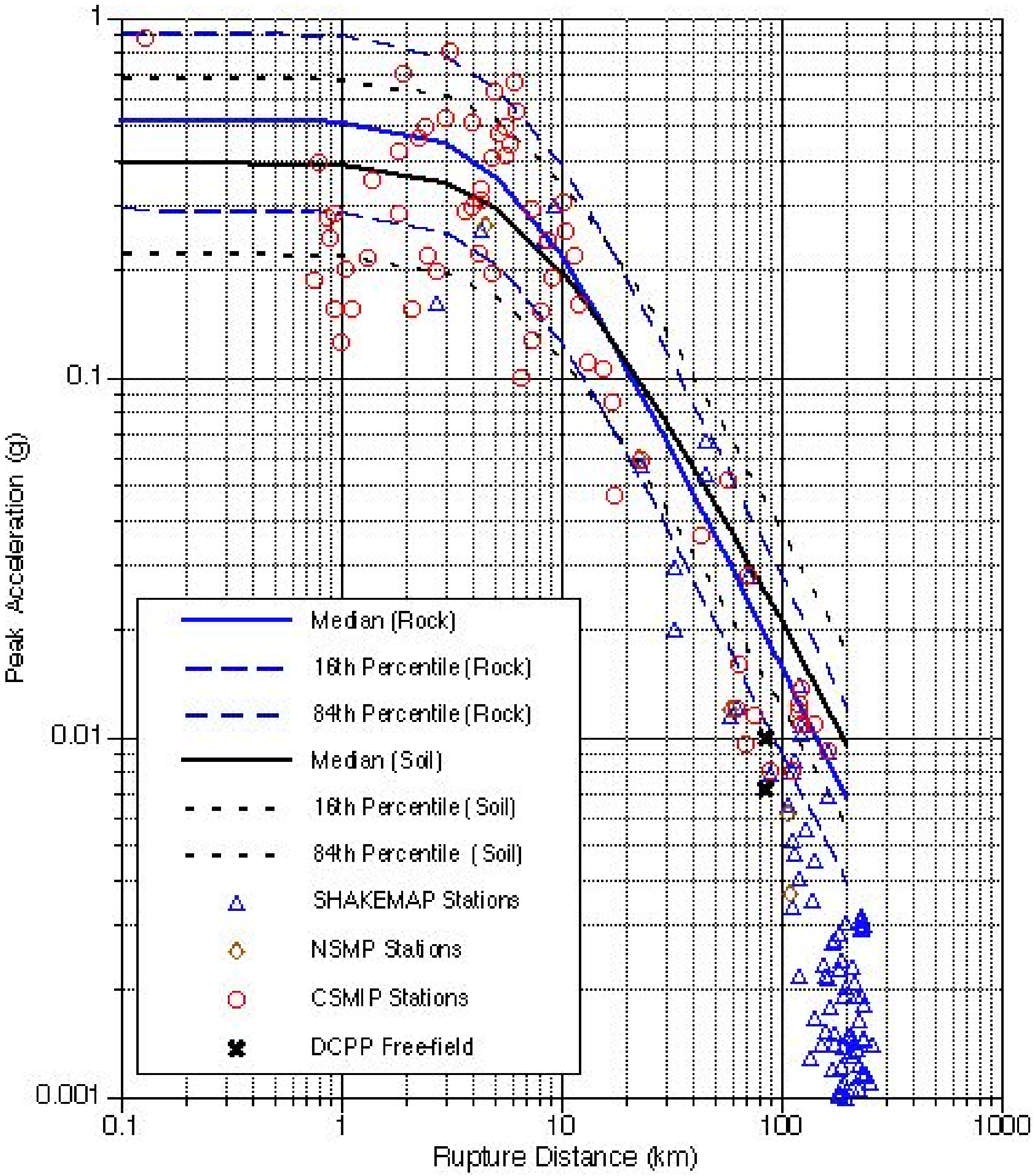
$$v(Sa > z) = \sum_{i=1}^{nSource} N_i(M_{\min}) \int_M \int_R \int_\varepsilon f_{mi}(M)\, f_{Ri}(r,M)\, f_\varepsilon(\varepsilon) P(Sa > z \mid m, R, \varepsilon)\, d\varepsilon\, dR\, dM$$

Deterministic Approach

- Select a specific magnitude and distance (location)
  - For dams, typically the “worst-case” earthquake
  - (Maximum Credible Earthquake)
- 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



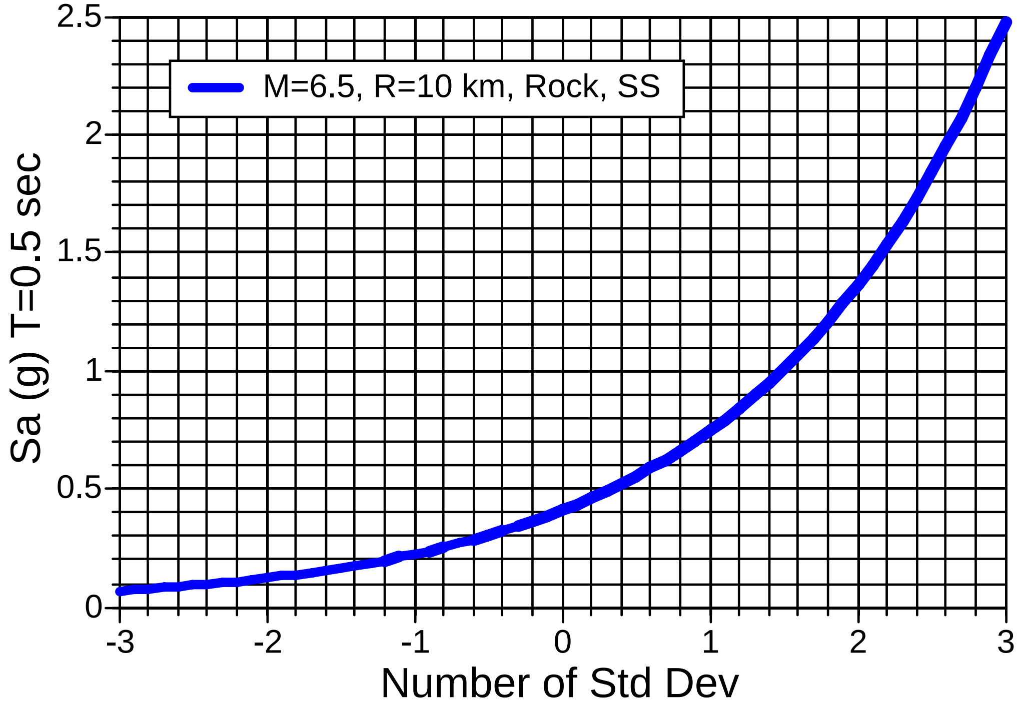


2004 Parkfield Attenuation

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
  - Select ground motion below the worst-case

Considering Multiple Scenarios

- Once we back off from worst-case ground motion, can no longer ignore the smaller or more distant earthquakes
  - Can get the same ground motion from smaller magnitudes with larger number of std dev of ground motion
  - Flt1: M=6.5, R=10km, ε=0: PGA = 0.35g
    - Rate eqk = 1/5000, P(ε> 0)=0.5, combined=1/10,000
  - Flt1: M 5.5, R=10 km, ε=1.5, PGA=0.35g
    - Rate eqk = 1/500, P(ε> 0)=0.07, combined=1/7,000
  - Flt2: M 7.0, R=20 km, ε=1.2, PGA=0.35g
    - Rate eqk = 1/600, P(ε> 0)=0.12, combined=1/5,000
- What is "reasonable" needs to account for the multiple earthquakes that could cause the design ground motion to be exceeded

Probabilistic Approach

- Consider all possible earthquakes and ground motion levels and compute rates of each scenario
- Hazard Calculation
  - Rank scenarios (M,R, ε) in order of decreasing severity of shaking (Typically 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)

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
  - 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
- Return period implies a time interval
  - A 10,000 year return period simply means an annual rate of 1/10,000. It has nothing to do with extrapolating models over the next 10.000 years

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

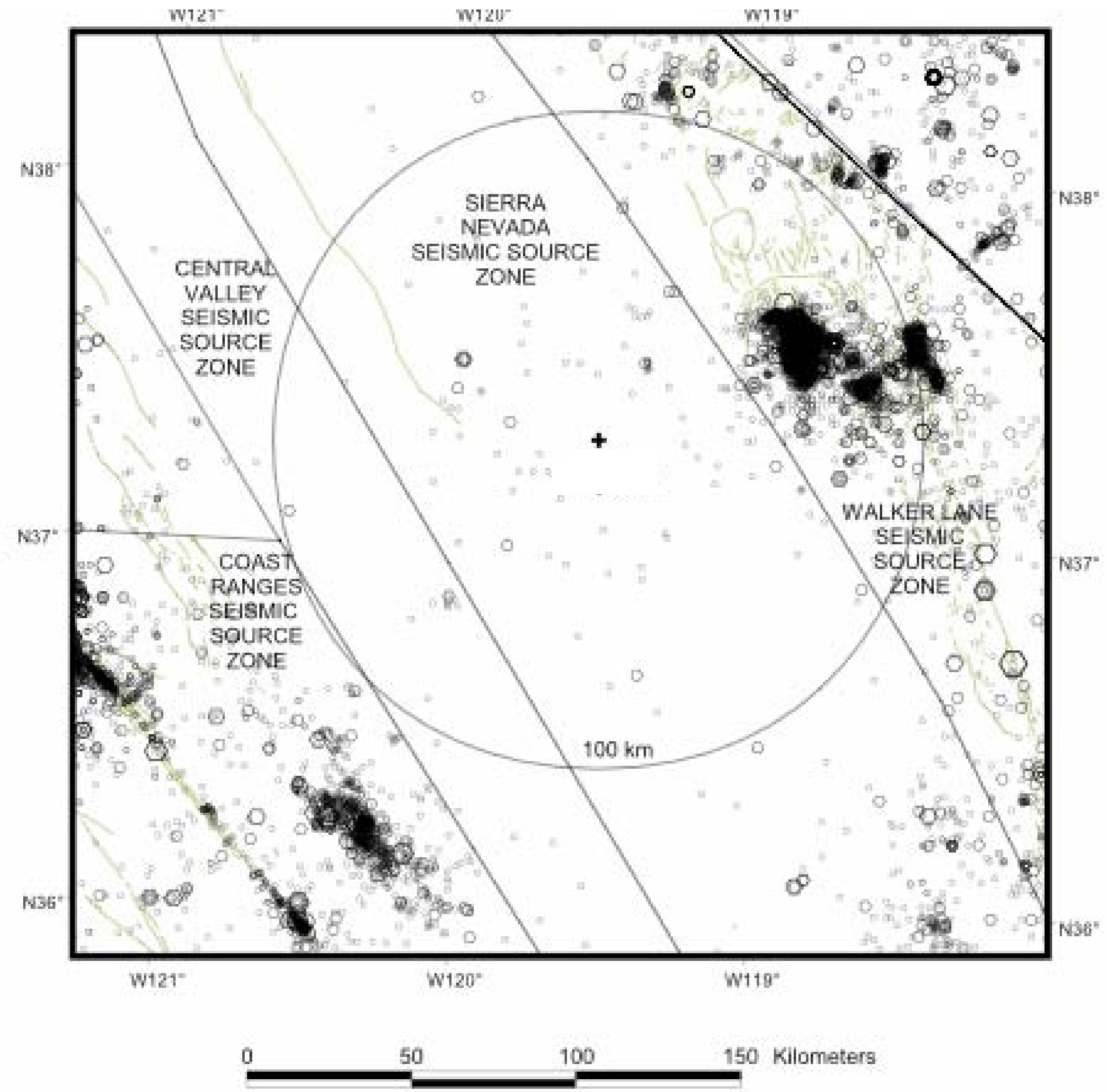
Epistemic Uncertainty

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

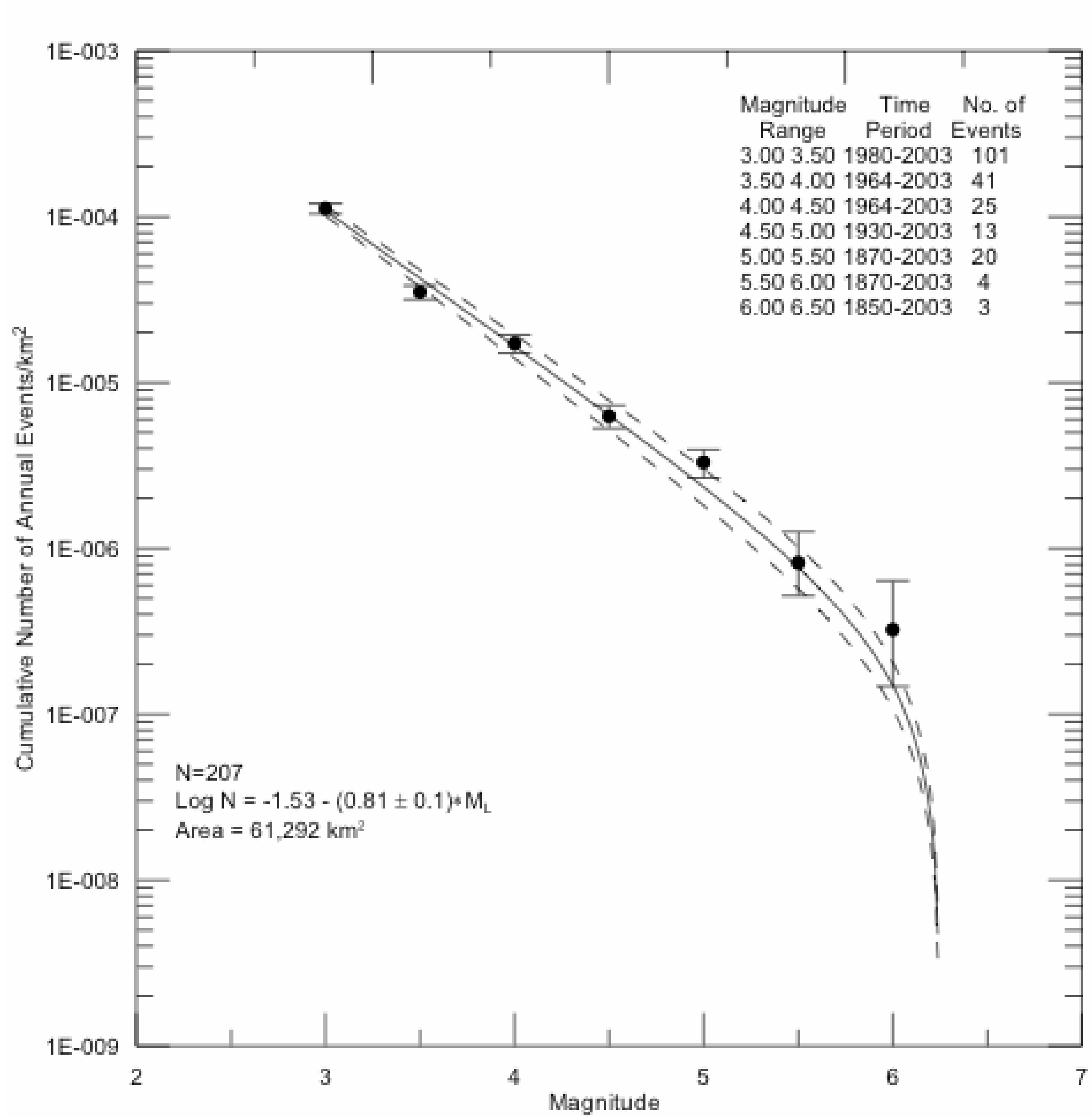
- In practice, not always the case

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

Example Hazard



Sierra Nevada Seismic Source Zone



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)

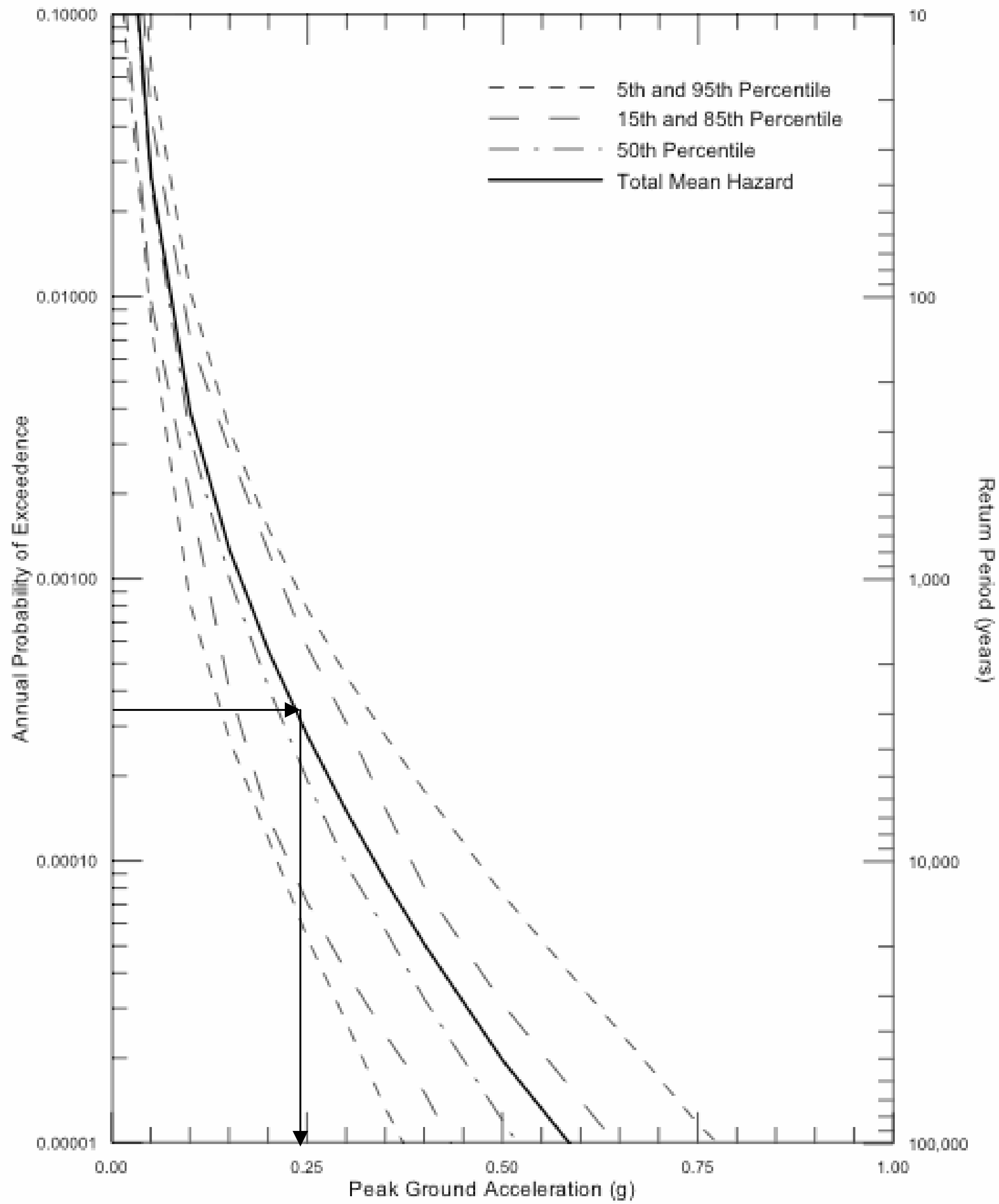
    A = fault area in cm^2

    S = slip-rate in cm/yr

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

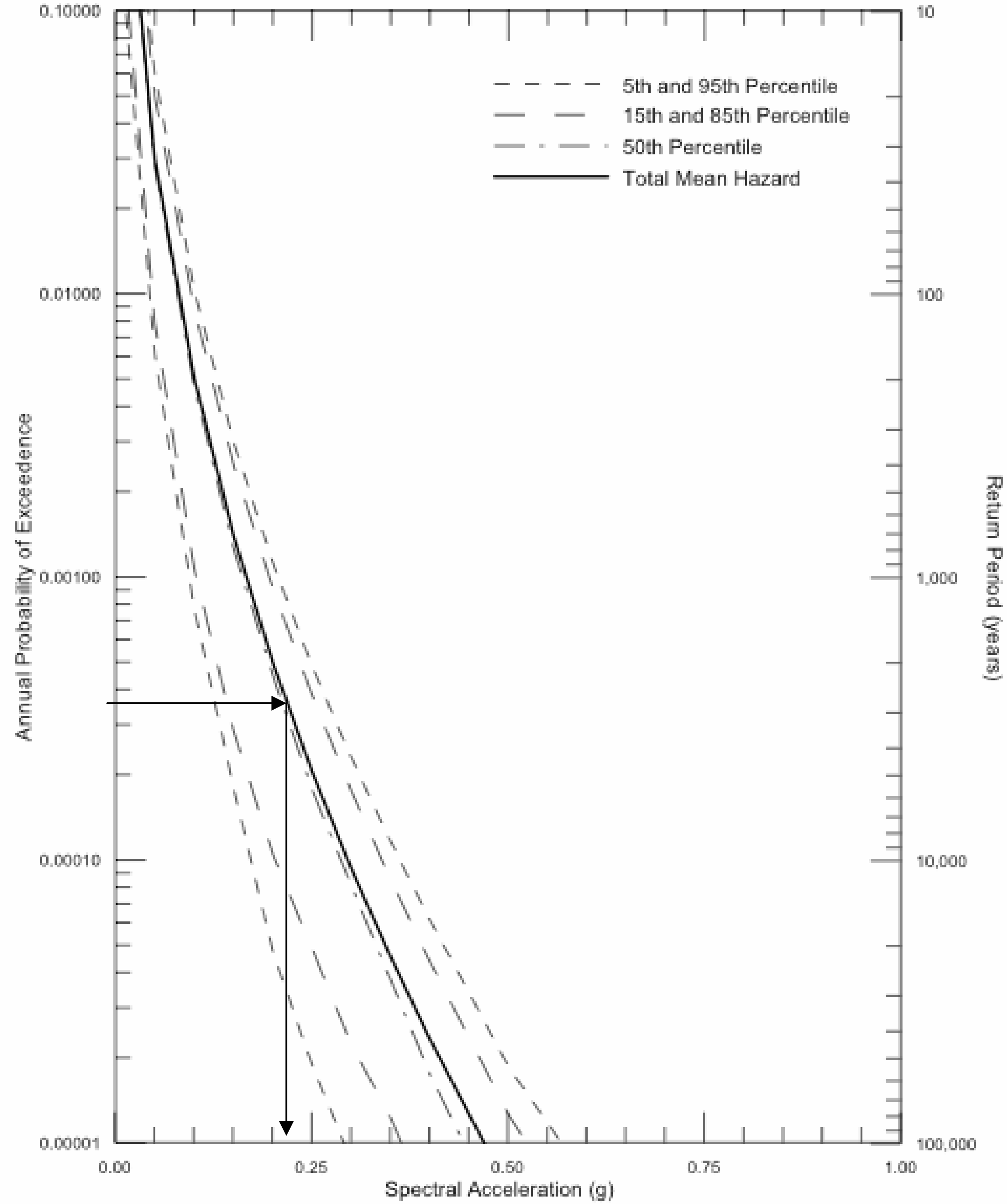
PGA Hazard

3000 yr return period
PGA = 0.24g

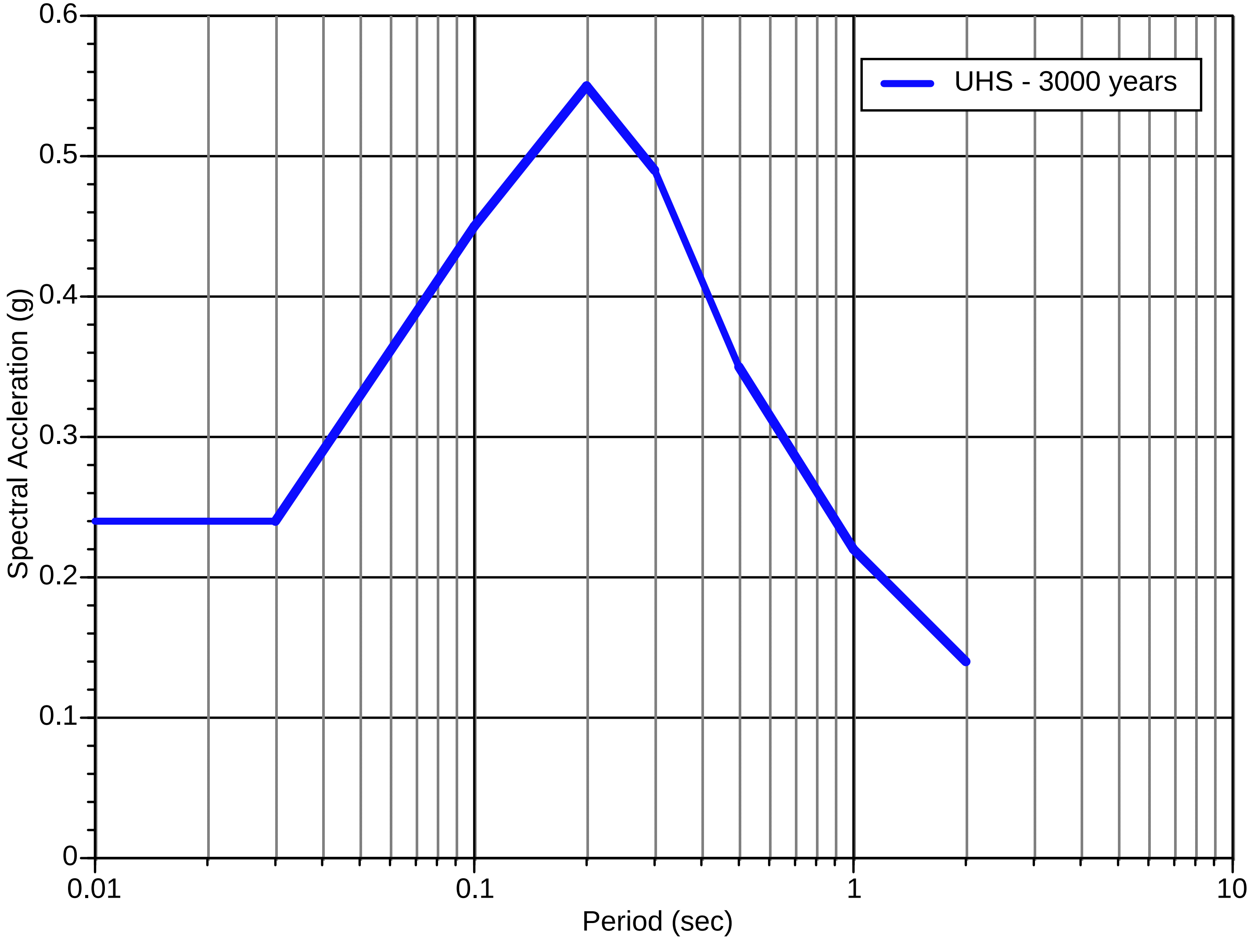


T=1 sec Hazard

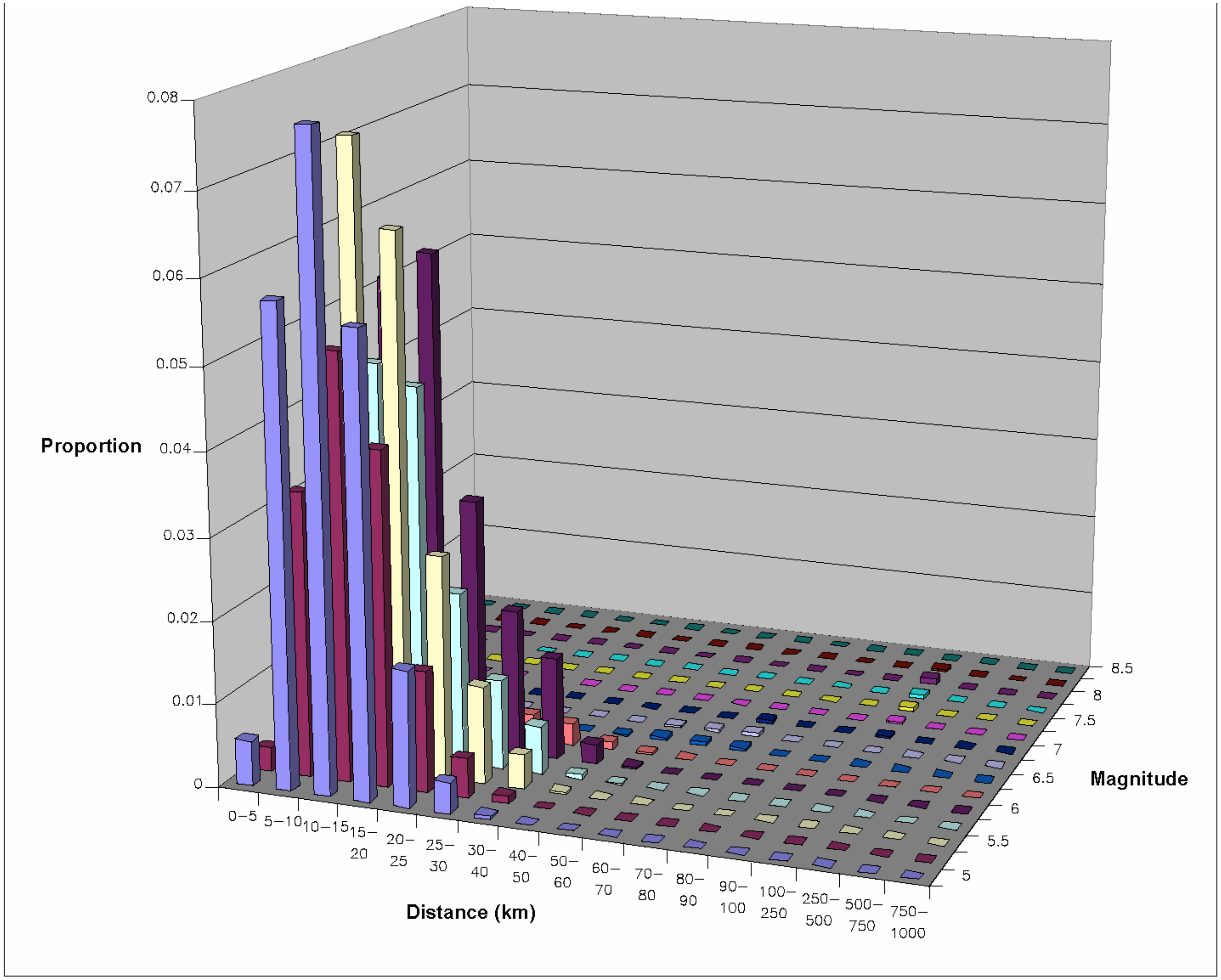
3000 yr return period
Sa(T=1) = 0.22g



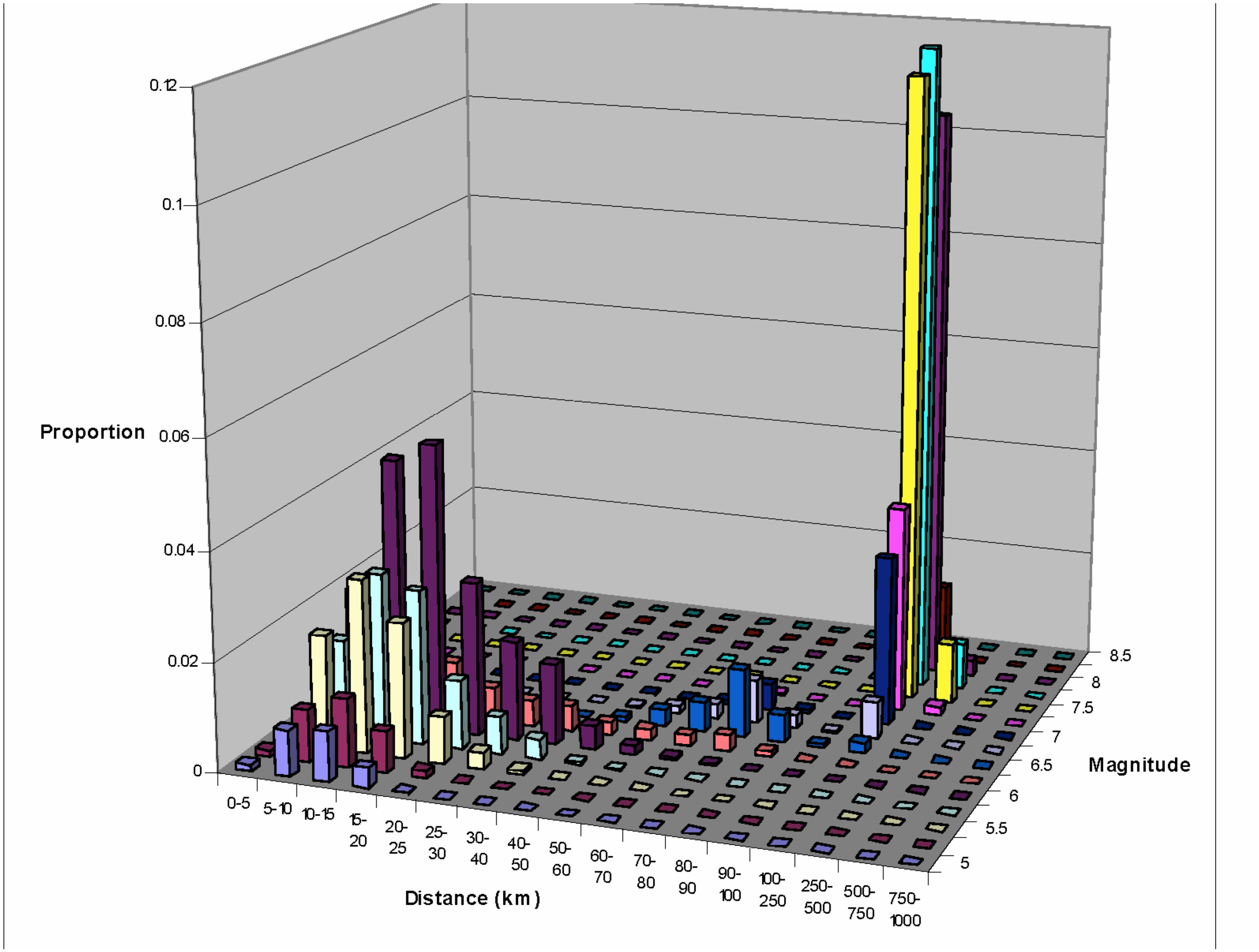
Uniform Hazard Spectrum



Deaggregation for PGA=0.24g



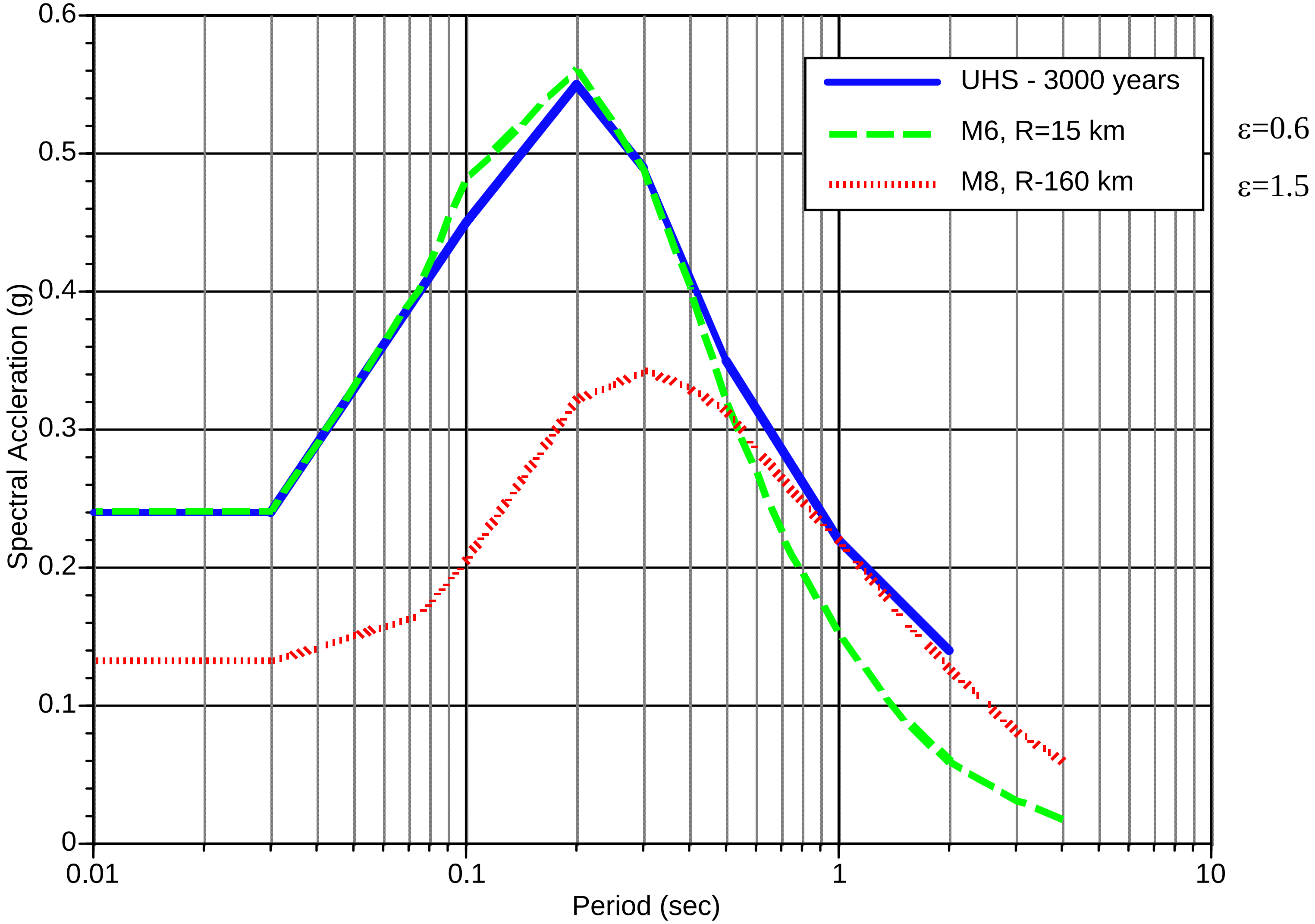
Deaggregation for Sa(T=1)=0.22g



Controlling Scenarios

- For return period = 3000 years:
  - PGA: M=6.0, R=15 km, ε=0.6
  - Sa(T=1): M=8.0, R=160 km, ε=1.5

UHS Scenarios



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
- Deterministic (median, or 84th percentile)
  - Advantages: simple to use for faults and understand
  - Disadvantages: unknown hazard, can be inconsistent between sites. For areal sources, selection of deterministic event is uncertain
- Probabilistic
  - Advantages: known hazard, handles areal sources in a consistent way.
  - Disadvantages: more complex, still wide-spread misunderstanding

Summary

- 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?
    - Use PSHA with a deterministic floor?
    - Use deterministic with a PSHA cap?
- What return period is reasonable?
  – Commonly quoted value of 10,000 yrs
    - Is this reasonable for active regions?
  – Compare to return periods accepted for other structures
  – Use risk calculations to help determine what is a reasonable hazard level
    - Downstream consequences
- Should a minimum earthquake be required?
  – Defined as a ground motion or an earthquake scenario?