Seismic Risk of Co-Located Critical Facilities – Effects of Correlation and Uncertainty

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Workshop on
Probabilistic Flood Hazard Assessment (PFHA)

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Overview

- Consider the following:
  - One or multiple dams are located upstream of a critical facility. What is the risk the critical facility may fail as a result of an earthquake or as a result of upstream dam failure*.
- Conducted a parametric study to evaluate the influence of a number of sources of dependence/correlation associated with the seismic hazard on seismic risk estimates.
- Parametric study for a small group of dams

*We have to assume of course that upstream dam results in inundation and failure of the downstream facility; otherwise the problem would not be a much Interest.

Taxonomy of Uncertainties

Element	Epistemic	Aleatory
Modeling	Uncertainty about a model and the degree to which it can predict events. Model, epistemic uncertainty addresses the possibility that a model may systematically (but not necessarily predictably), over- or under-predict events/results of interest (i.e., deformations).	Aleatory modeling variability is the variation not explained by a model. For instance, it is variability that is attributed to elements of the physical process that are not modeled and, therefore, represents variability (random differences) between model predictions and observations.
Parametric	Parametric epistemic uncertainty is associated with the estimate of model parameters given available data, indirect measurements, etc.	This uncertainty is similar to aleatory modeling uncertainty. However, this is variability that may be due to factors that are random, but have a systematic effect on model results.

Sources of Dependence & Correlation

- There are three sources of dependence & correlation that are considered.
- These are:
  - Epistemic uncertainty in seismic hazard estimates,
  - Aleatory uncertainty in the median ground motion,
  - Aleatory uncertainty and spatial correlation of ground motions for sites located in regional proximity one another.

Chance of Failure of the Downstream Facility

- The potential for failure of the downstream facility is a function of the ground motions that may occur at the facility itself and at the upstream dams, during the same seismic event.

For a facility on its own (no upstream dams) the frequency of failure can be estimate by:

$$\nu_{F,DS} = \int \nu(a)_{DS} P(f_{DS} | a) da$$

Seismic Hazard

Seismic Fragility for the Facility

Chance of Failure of the Downstream Facility

- When the upstream dams come into the picture a number of things change

Now the seismic fragility of the downstream facility can be expressed as follows:

$$P(f_{DS} \mid EQ) = [P(f_{DS} \mid EQ, (a(\underline{x}))$$ *(Original part – previous page)*

$$+ P(f_{DS} \mid DF) P(DF \mid EQ, a(\underline{x})) P(a(\underline{x}) \mid EQ)]$$

(New piece, that includes the potential for the dams failing and causing failure)

Chance of Failure of the Downstream Facility

EQ – Earthquake of a given magnitude, seismic source, and location on that source.

a($\underline{x}$) – spatial field of correlated ground motions, given an EQ

The frequency of failure is now:

$$\nu_{DS} = \int_{EQ} \int_{a(x)} [P(f_{DS} \mid EQ,(a(\underline{x})) +$$

$$P(f_{DS} \mid DF)P(DF \mid EQ, a(\underline{x}))P(a(\underline{x}) \mid EQ)\, da(\underline{x}) \quad dEQ$$

Probabilistic Seismic Hazard Analysis

- Modeling epistemic uncertainties is the primary focus of a PSHA.

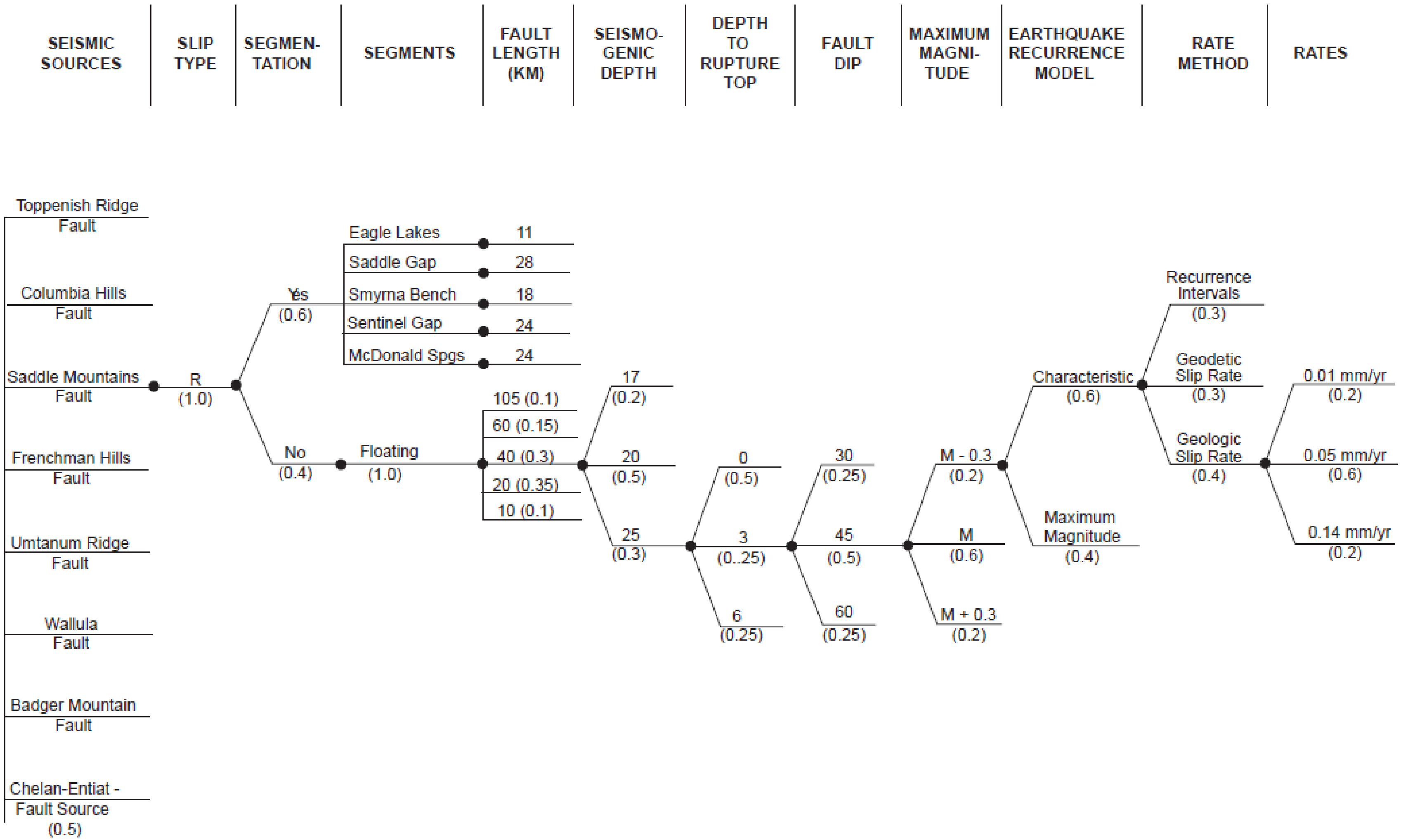
- The NRC currently requires that a SSHAC Level 3 or 4 be carried out for NPP sites.

- PSHAs are carried out to estimate the ground motion at a single site; a point in space.

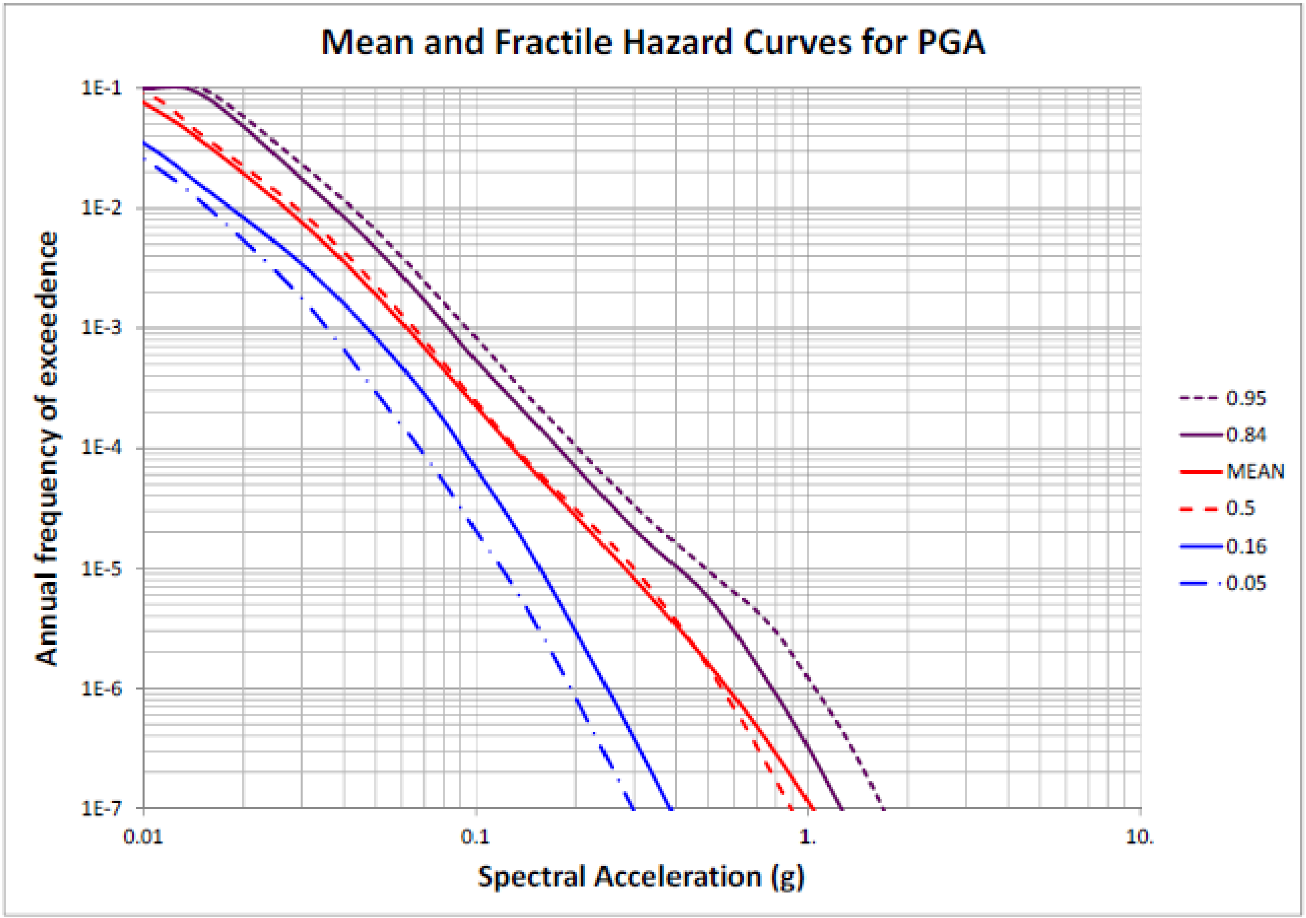
- Logic tree modeling
  - Model uncertainties / alternative interpretations of available scientific data (seismic source models, ground motion attenuation models, etc.)
  - Parametric uncertainties (M_{max}, earthquake rates, etc.)

- Expert elicitation; formal & structured process

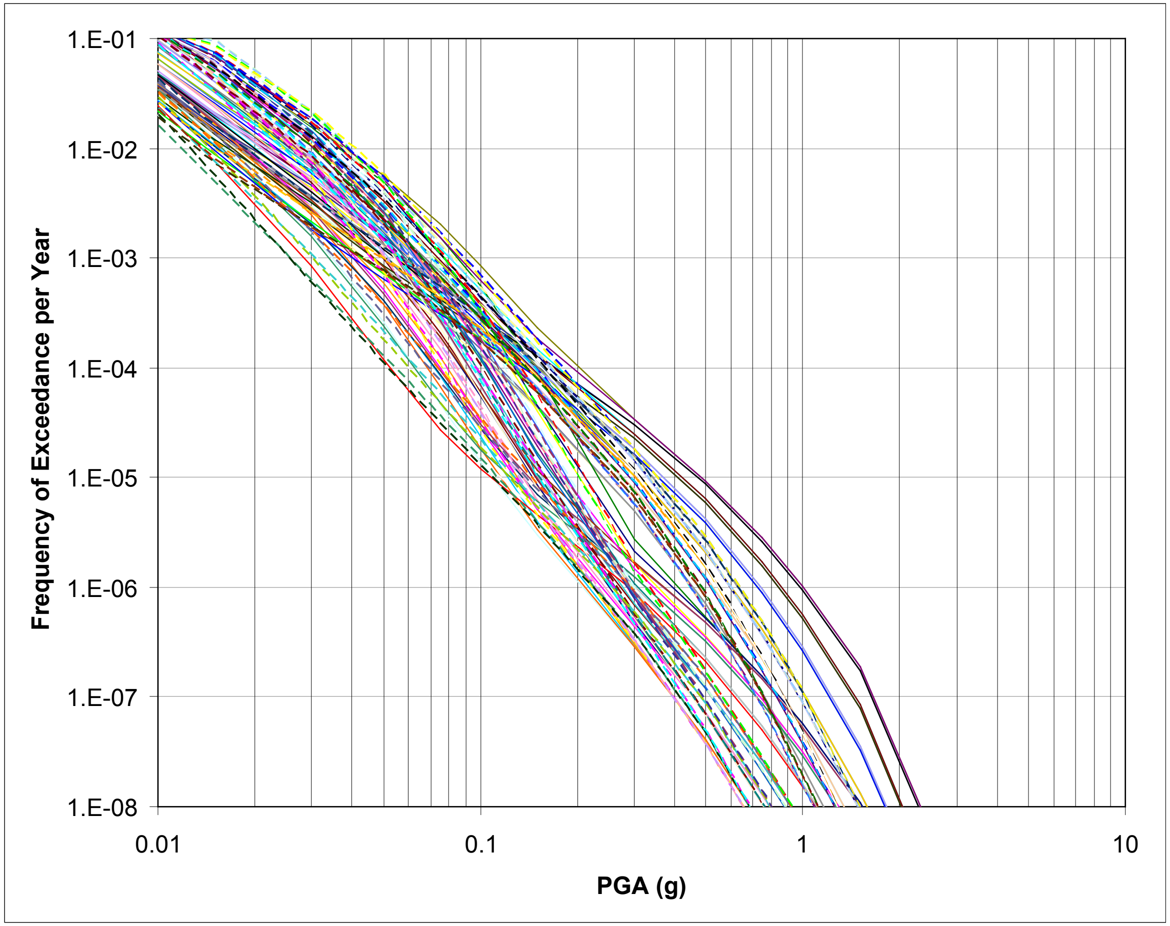
Illustration of Logic Tree For Fault Sources



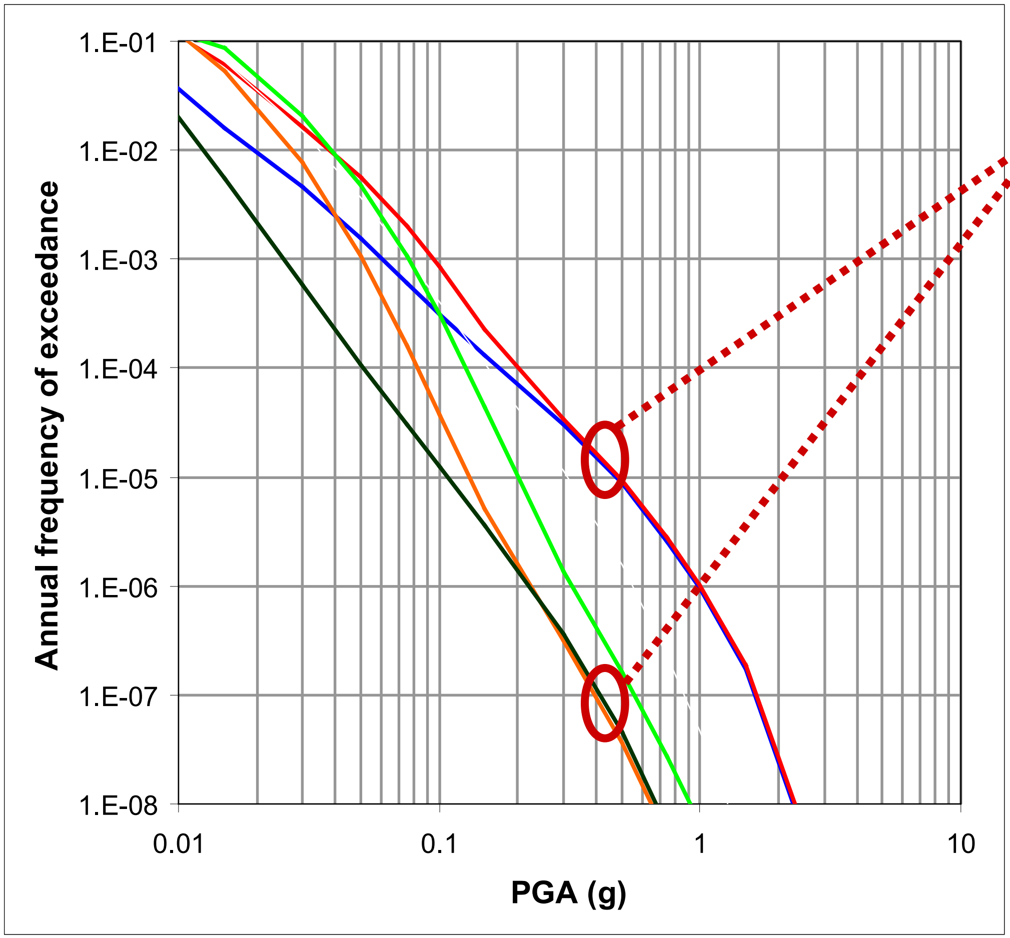
Typical PSHA Results



PSHA Results – Discrete Set of Curves



Epistemic Uncertainty in Seismic Hazard Estimates



Clearly the estimate of the frequency of failure will differ significantly for the hazard curves shown.

The difference in the level and shape of the hazard curves (slope) will lead to very different estimates of the frequency of failure.

Aleatory Uncertainty in Ground Motions

- There is considerable aleatory variability in earthquake ground motions.
- Logarithmic standard deviation ~ 0.6 (we have data to +/-2.5-3 standard deviations).
- Empirical studies have identified 2 basic parts to the aleatory uncertainty in ground motions:
  - Inter-event term (different between earthquakes of the same magnitude)
  - Intra-event terms

Ground Motion Variability

Ground motion aleatory variability

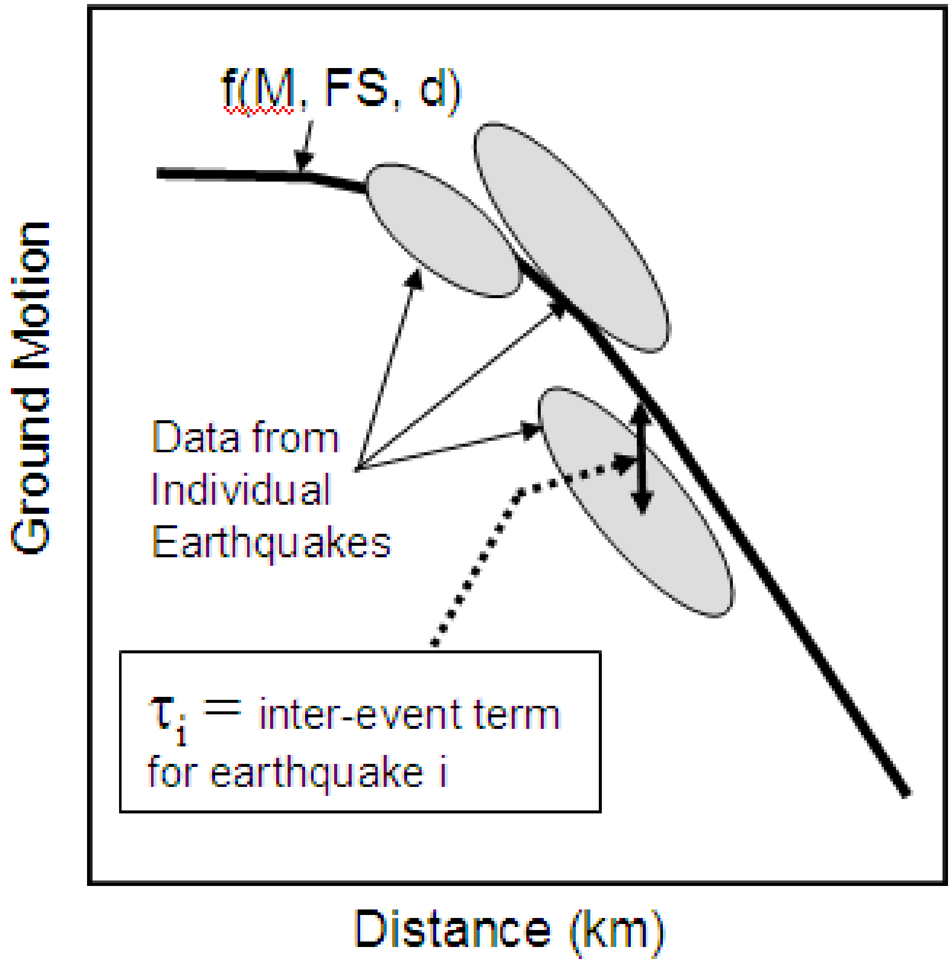
$$\sigma_T^2 = \tau^2 + \sigma_I^2$$

where,

$\tau =$ Inter-event terms, quantifies the random, but systematic difference between ground motions from earthquakes of the same magnitude.

$\sigma_I =$ Intra-event term, quantifies the random variability of ground motions within an event; these motions are spatially correlated (based on separation distance of sites).

Earthquake Ground Motion Variability Tau Effect

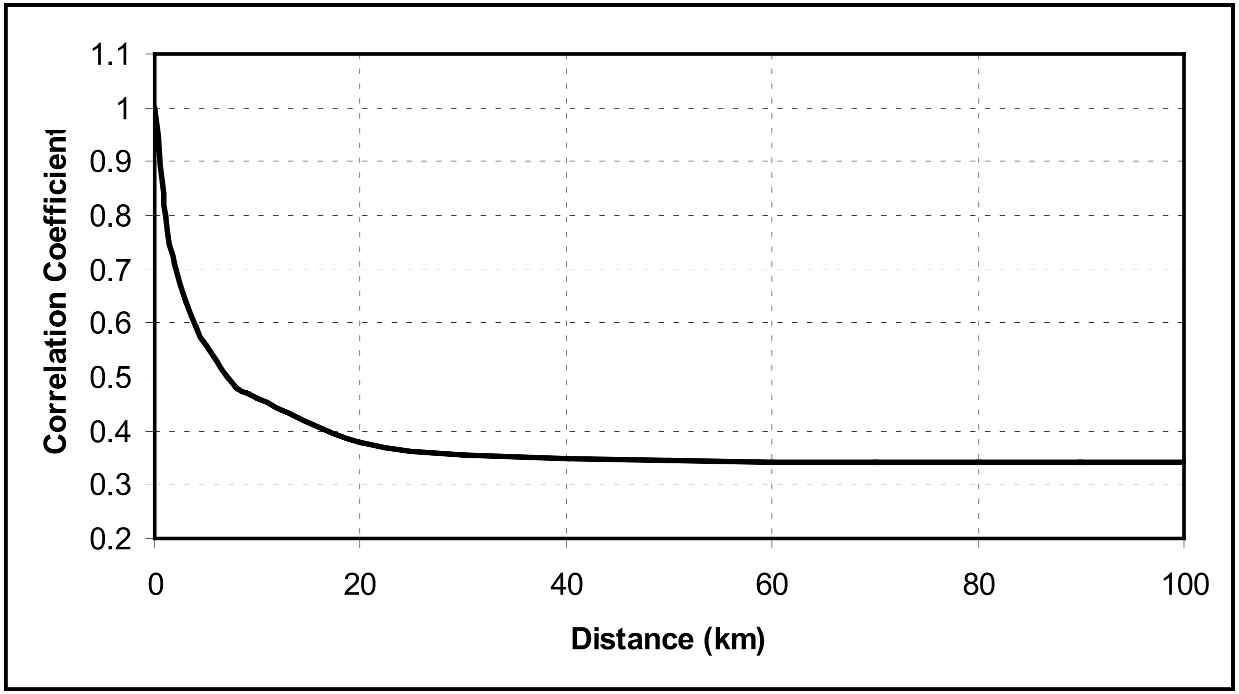


For earthquakes of the same magnitude **(**say **M6.5),** the median estimate of ground motions can systematically, but randomly vary from one earthquake to the next.

This (and the next source of correlation adds a complication to the hazard analysis for multiple sites and to a risk analysis.

Ground Motion – Spatial Correlations

- Seismologists have estimated the spatial correlation of ground motions based on the separation distance of sites



Applications

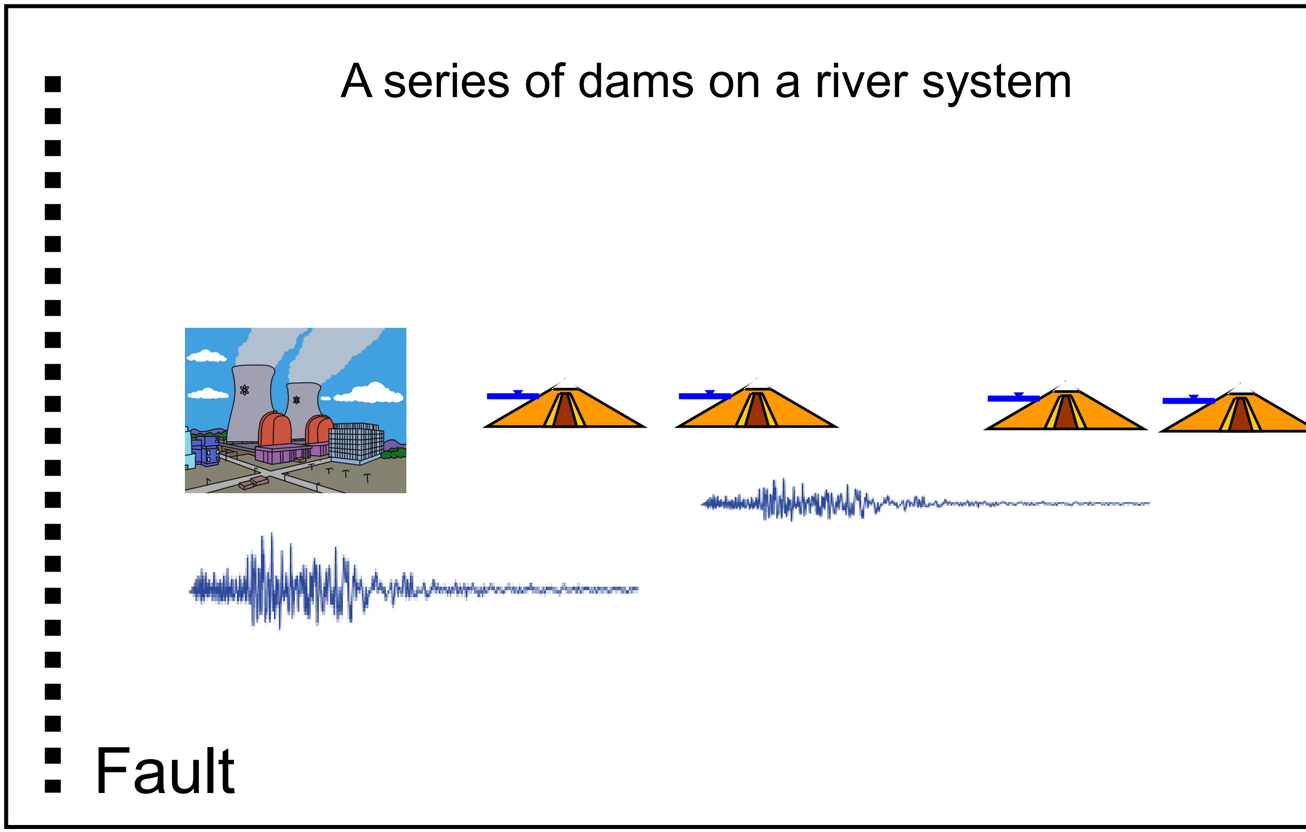
- Delta Risk Management Study in California – seismic risk for 1,200+ miles of levees (dams since water is up against the levees 24-7)

- Insurance portfolios

- Lifeline risk analysis

- Simulation methods are used to estimate the correlated ground motions (account for the Tau effect and $\boldsymbol{\sigma}_{I}$.

Fault Source, Critical Facility & a Series of Upstream Dam



Observations

- The evaluation of downstream risks is very site/situation specific:
  - Number of upstream facilities
  - The relative location of those facilities (separation distance)
  - Magnitude of earthquakes that can occur
  - Seismic fragility of the downstream facility and the upstream dams
  - Location of seismic sources relative to the various facilities

- Depending on the above factors, the impact can be relatively small (less than a factor of 2 in the frequency of failure), to considerably greater (>10).

- Risk studies and quantitative parametric studies make it clear that failure to account for the sources of correlation is unconservative (risk is under-estimated).