Future of Geohazards

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There will be Greater Demand for Quantitative Risk Estimates

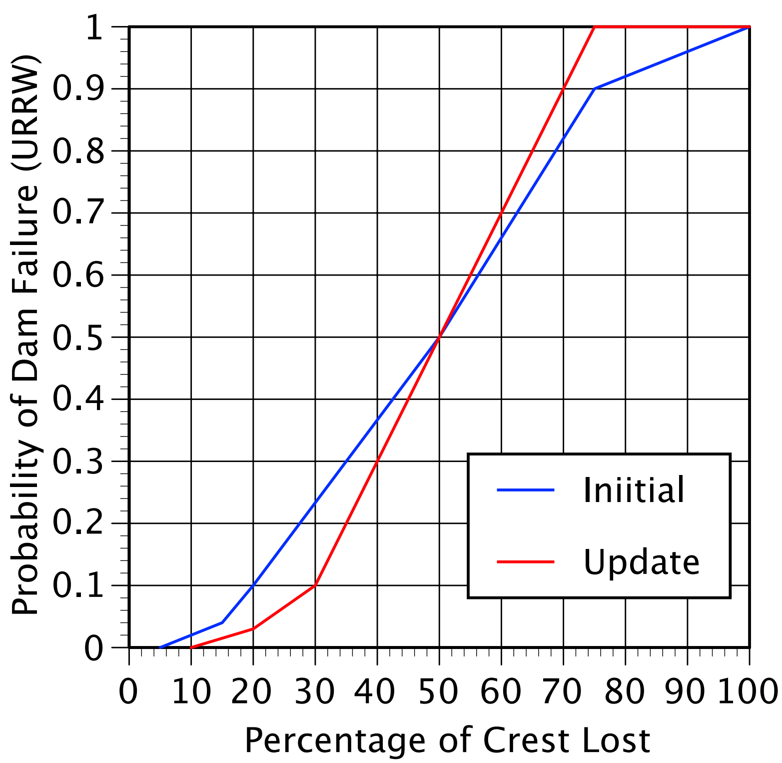
- Owners and regulators are asking for risk estimates
    - Go beyond compliance with minimum requirements in current practice
        - What is the risk that we are taking?
    - Risk scoring is most common for geohazards
    - Objective to move to quantitative risk estimates including epistemic uncertainties
- Currently, not very good at risk for geohazards
    - Conservatism commonly used in geotechnical engineering
    - Inconsistent treatment of variability between PSHA, site response on structural response
    - Inconsistent levels of complexities in the different steps
    - PSHA practice oriented to buildings, not geohazards
- Risk estimates have very large epistemic uncertainties
    - Decision making under large uncertainties needs to be addressed

Issues for Risk for Geohazards

- For risk estimates, the models and inputs should be mean centered with uncertainty
  - Conservatism is common in geotechnical engineering
  - Conservatism does not fit with probabilistic risk approach
  - Requires some change in geotechnical engineering practice

Example: Removing Conservatism from Risk Estimates

Judgment-Based Models from Panel of Experts



Risk of Dam Failure
(Uncontrolled Rapid Release of Water)

Water Level	Initial	Revised
Normal	1/300 yr	1/2000 yr
Lower 10 ft restriction	1/600 yr	1/12000 yr

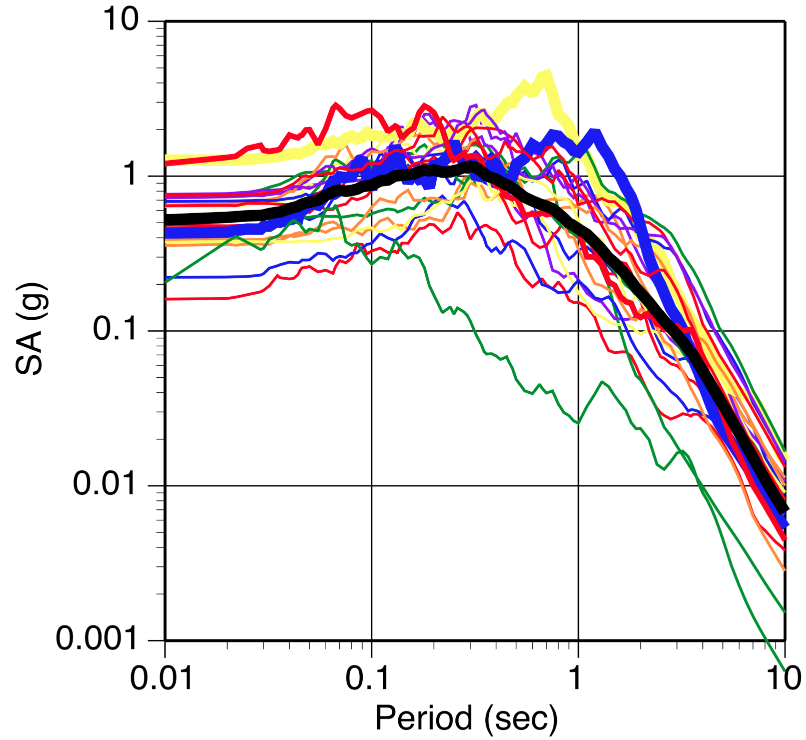
Issues for Risk for Geohazards

- Consistent treatment of variability between hazard, geotechnical, and structural evaluations
  - Risk is driven by the tails of the distributions
    - Variability is key to the results
  - Include all variability once, but only once
  - Each field wants to have the full variability in their part of the problem

Where Does the Variability in Spectral Shape Belong?

- Hazard analysis
  - PSHA includes variability as part of the standard deviation (sigma) of the GMM
- Site Response
  - Site-specific site effects (differences from the GMM) are modeled and combined with the PSHA results
- Time history selection
  - How much peak-to-trough variability should be included in the time histories?

M6.4 to 6.7,
R=5-15 km,
VS30=350-600 m/s



Issues for Risk for Geohazards

- Levels of complexity in each part of the problem
  - Each field tends to oversimplifies the other parts of the problem and makes detailed studies for their topic
    - Ground motion / hazard
    - Geotechnical
    - Structural
  - Goal to have a comparable level of complexity in each part of the problem

Levels of Complexity

- Example 1: Putting all the complexity into the model for the dam
  - Very complicated finite-element model of a dam
  - Long run times, so use only one time history
- Example 2: Putting all the complexity into the ground motions
  - 100s of sets of time histories to capture the full hazard
  - Many calculations, so use a very simple model for the dam
- Combined:
  - Use the simplified dam model with 100s of time histories to select a small set of time histories that represent the mean and variability of the response of the dam
  - Use this small set of time histories with the complex dam model

PSHA for Geohazards

- PSHA usually conducted for pseudo-spectral acceleration (PSA)
  - Design ground-motion levels and time histories chosen based on UHS or CMS for PSA
    - Easy to do
    - May work well for buildings
    - May be misleading for geohazards
- Secondary parameters considered for geohazards
  - Duration, I_a, CAV, PGV, …
  - Deformation for simplified (proxy) systems
- Should compute hazard and select time histories based directly on these other parameters that are more closely related damage to geotechnical systems
  - Stop treating geohazard as if they are buildings

PSHA

- Key concept of PSHA is that we are summing the rates of damaging motions from all earthquake scenarios
- Applicable if we are adding the rates of similar loading
    - Damaging and non-damaging rates should not be summed
    - If PSA(T) is not a good measure of damage for geohazard, then we should not be summing the hazard from different sources
    - In this case, the hazard should be computed for a different IM

IMs for Geohazards Applications

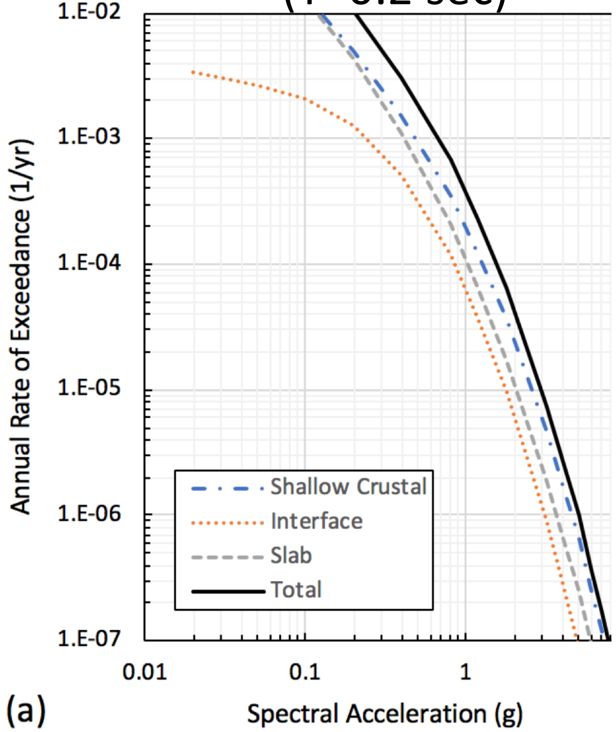
- Most of the GMM developed are for PSA(T)
  - PEER NGA projects are Large multi-year, multi-investigator efforts
  - Resulting in sets of alternative GMMs that have been well reviewed
    - Physical constraints on the extrapolation outside the data range
- For other IMs, fewer GMM available
  - May not be consistent with scaling in the PSA (T) models

Conditional GMM for Geohazards Applications

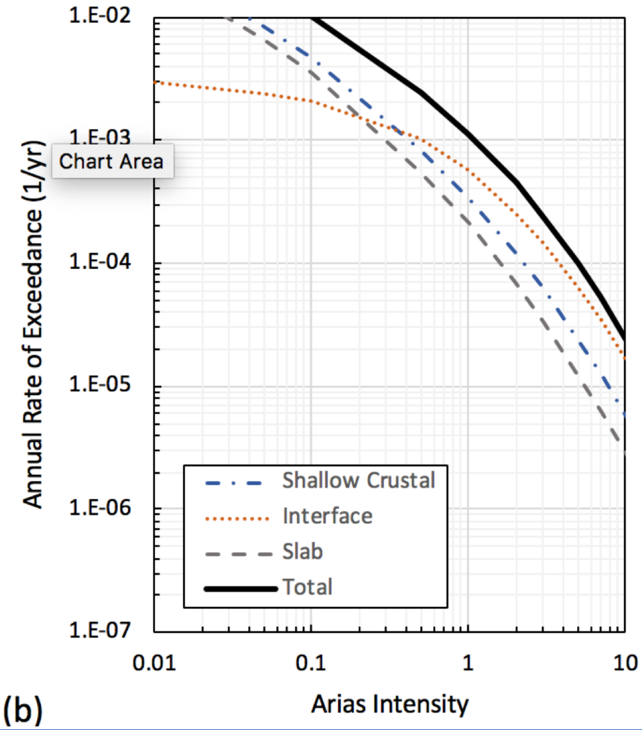
- Conditional GMMs use the observed PSA(T) as an input parameter
- Example: I_a model by Macedo et al (2018)
  - $Ln(I_a) = c_1 + c_2 ln(VS30) + c_3 M + c_4 ln(PGA) + c_5 ln(PSA(T=1))$
  - Similar approach used in simplified models for deformation
- Advantages of conditional GMM
  - Physical constraints for extrapolation and more complex scaling (HW, NL site, directivity) are represented in the PSA(T) values
  - Conditional GMM are simple to develop and robust
  - Can be combined with suite of PSA(T) models to get a suite of GMMs for the new IM
    - Can get a set of GMMs for the epistemic uncertainty without waiting for separate traditional models to be developed

Selecting Time Histories Using Contribution to Hazard

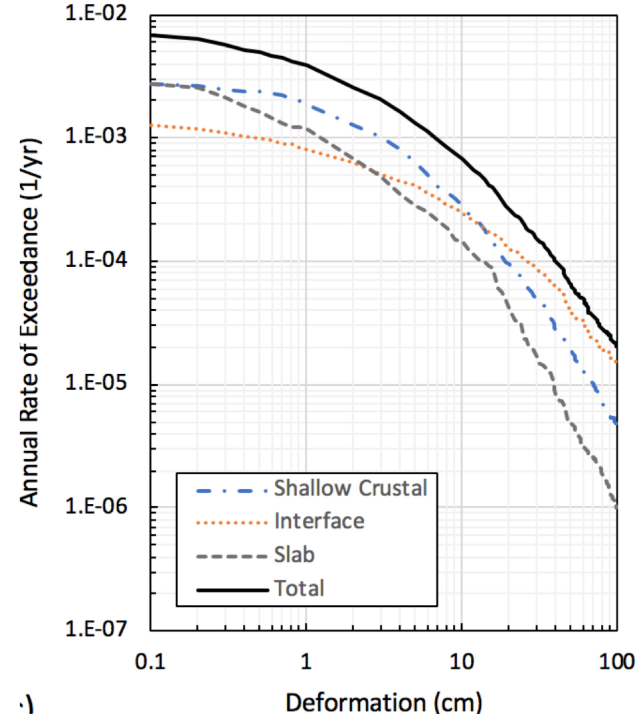
Spectral Acceleration (T=0.2 sec)



Arias Intensity



Simplified Deformation



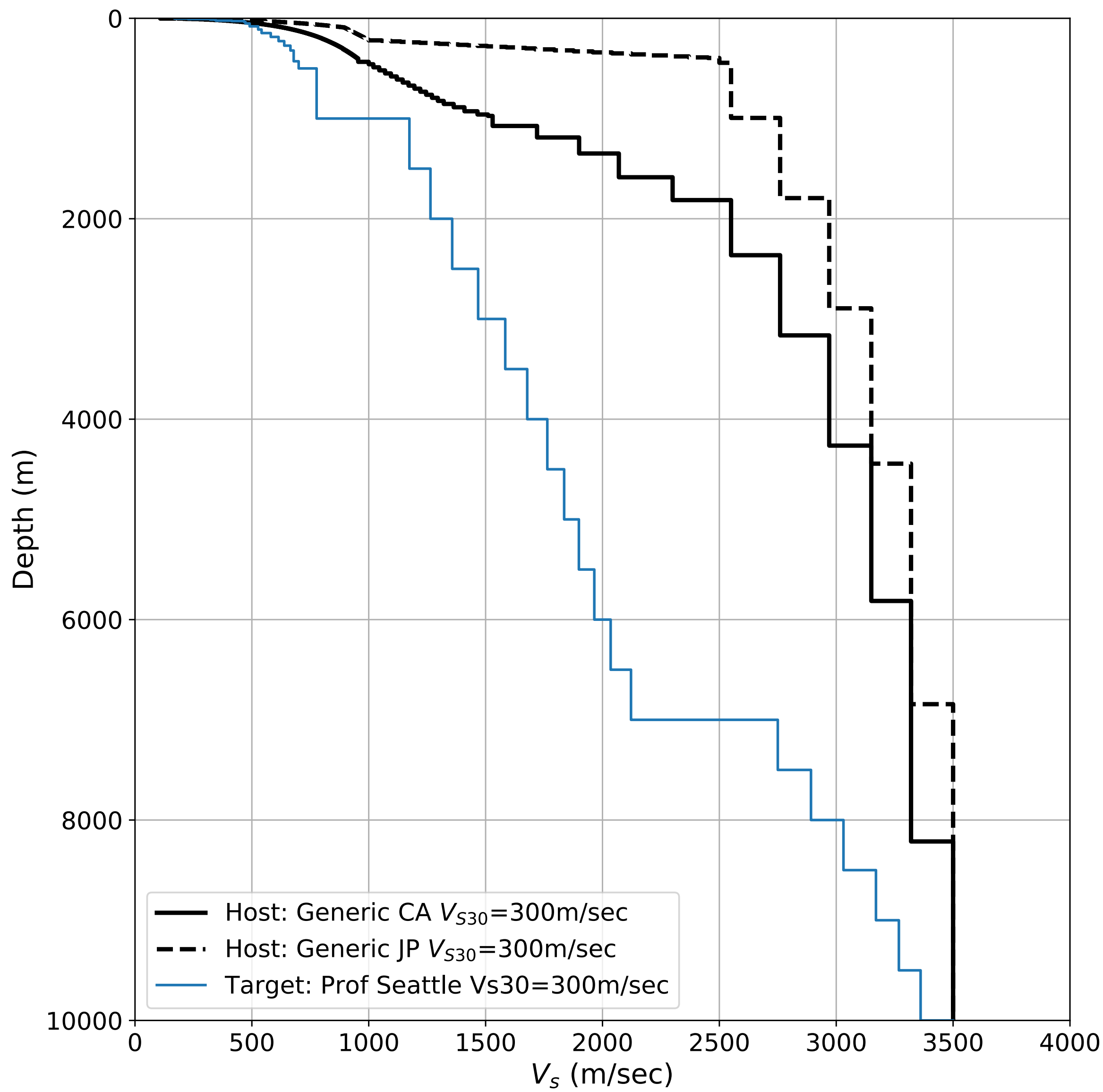
	Contribution to Hazard at 1E-4		
Source Type	SA (T=0.2)	AI	Deformation
Crustal	0.63	0.25	0.35
Slab	0.24	0.12	0.10
interface	0.13	0.63	0.55

From Tessa Williams

Handoff between PSHA and Geohazard

- PSHA uses VS30 as the site class
  - V_{S30} is not the fundamental physical parameter for site amplification.
    - Index of the velocity profile
    - Site class that is continuous
  - For typical strong motion sites in California, V_{S30} correlated with deeper Vs profile that controls the site amplification
    - Most soil sites are in alluvial basins (deep soils)
- Move to providing the VS profile that goes with the GMM and VS30 as the site class
  - Site response should model the differences in the site response for the GMM profile and the site-specific profile

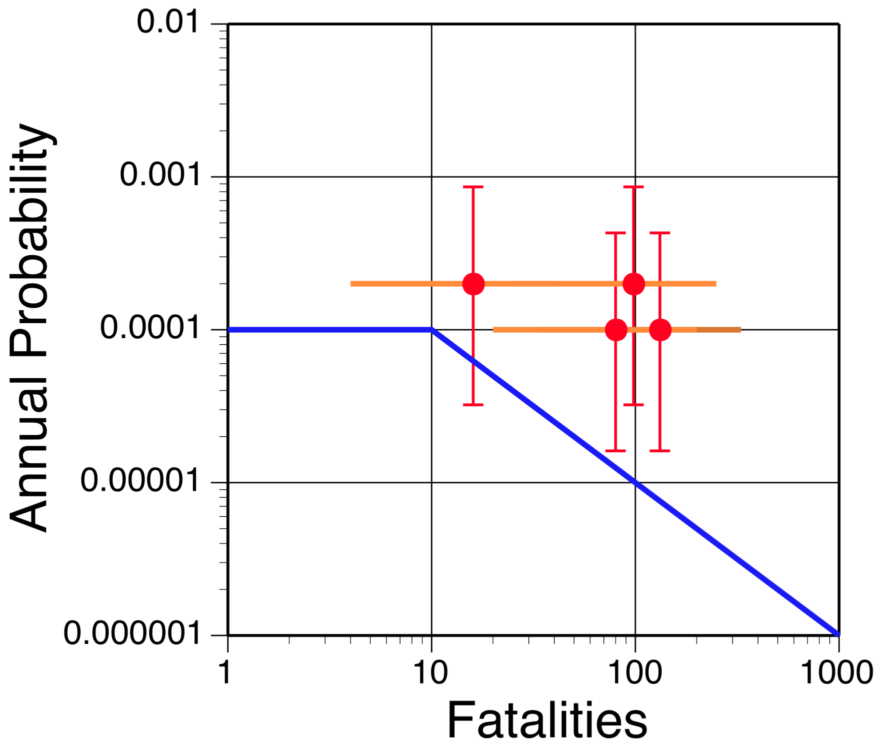
Example of Regional Differences in V_S Profiles for V_{S30}=300 m/s



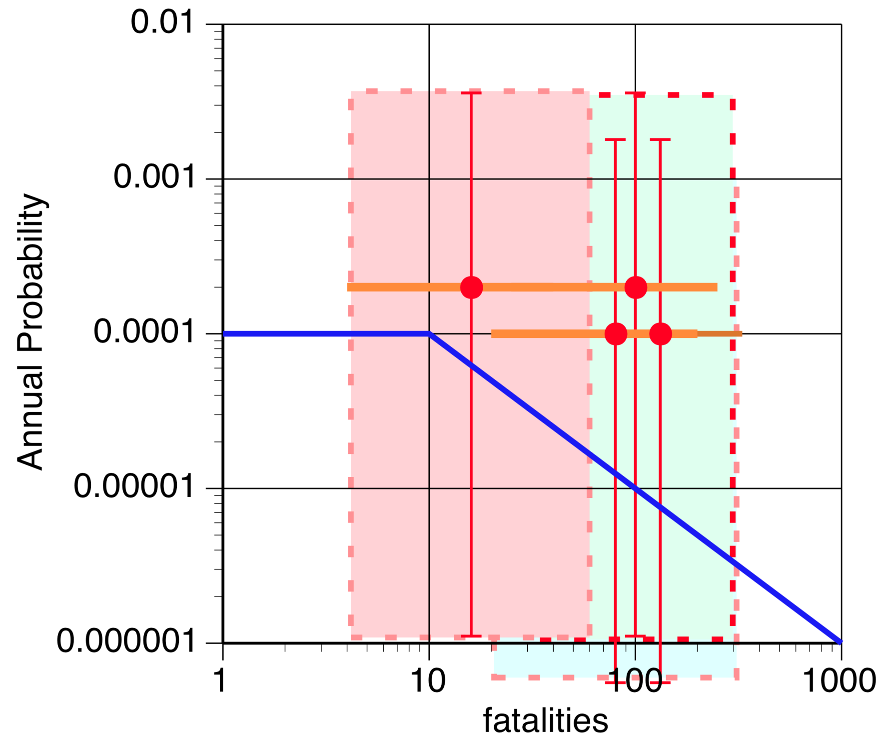
From Lavrentiadis and Abrahamson (2019)

Example of Uncertainty Risk for Dams in Norther California

Current Models
Factor of 50 uncertainty in risk



If full uncertainty is captured,
up to factor of 1000 in uncertainty



Decision Making with Large Uncertainties

- Uncertainties in risk
  - Hazard uncertainty usually dominates risk uncertainty
  - Uncertainties in fragilities are not well developed and may be underestimated currently.
- What is done?
  - Most common to use the mean risk
    - Single number that is easy to compare to a risk objective
    - Just using mean leads to misleading accuracy
  - Main use is for comparing risk between different structures
  - Some use of the value of mean risk to make retrofit decisions

Decision Making with Large Uncertainties

- What should we do?
  - Communicate the size of the uncertainty to decision makers
    - This uncertainty should be considered along with other engingeering judgments about the project
  - If the size of the uncertainty is understood, it makes the case for doing the research to significantly reduce uncertainties
  - Develop research to improve the models and collect site-specific data to reduce the uncertainties

Summary - Move to quantitative risk calculations for geohazards

- Requires consistent handoff of information between hazard analyst and geotechnical
  - Clear definition of site condition used for hazard (VS profile)
  - Partitioning of the variability between PSHA and site response
- Requires better understanding of how geotechnical systems actually perform
  - What is the expected behavior under a given loading condition?
    - Mean, aleatory variability
  - What is the epistemic uncertainty in the expected behavior?
- Large epistemic uncertainties in risk estimates should be considered in decision making
  - Just using the mean risk is not adequate