Treatment of Epistemic Uncertainty in Site Effects in Probabilistic Seismic Hazard Analyses

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18 October 2016
DOE Natural Phenomena Hazards (NPH) Meeting
Outline

- Probabilistic Seismic Hazard Analysis (PSHA)
  - Site effects accounted for by term in GMPE
  - Site effects accounted for by site response analyses
- Types of Uncertainties
- Treatment of Epistemic Uncertainty in Site Effects
  - Current approach
  - Shortcoming of current approach
  - Alternative approach
- Summary
Probabilistic Seismic Hazard Analysis (PSHA)

Seismic Source Characterization Model

Seismic Sources Magnitudes & Locations

Ground Motion Model

Earthquake Recurrence

Seismic Hazard Curves

Local Site Response

Design Ground Motions

(Reiter 1990; Kammerer 2015)
Probabilistic Seismic Hazard Analysis (PSHA)

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(Reiter 1990; Kammerer 2015)
PSHA for Site in Eastern Washington State
Types of Uncertainty

- There are two types of uncertainty
  - Aleatoric (or aleatory) variability
    - Inherent randomness in a physical phenomena
    - Quantification can be refined to limiting value dictated by nature of process
  - Epistemic uncertainty
    - Uncertainty that is related to “lack of knowledge”
    - Can be reduced to zero (in theory) with additional data
Types of Uncertainty

Aleatory
Integration over distribution of expected parameter values

Epistemic
Logic tree of technically defensible interpretations

(Kammerer 2015)
Aleatory Variability and Epistemic Uncertainty in Site Effects

- Aleatory variability: Spatial variability in soil properties and stratigraphy across site
- Epistemic uncertainty: Uncertainty in the geologic profile and dynamic properties of the strata
Treatment of Epistemic Uncertainty in Site Effects

PSHA Motions for Reference Horizon (bedrock)

Shear Wave Velocity Profile

$V_s\text{ Profile}_{UR}$ (0.3)

$V_s\text{ Profile}_{\text{mean}}$ (0.4)

$V_s\text{ Profile}_{LR}$ (0.3)

G/Gmax and Damping

EPRI (0.5)

Peninsular (0.5)

(EPRI 2013)
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Influence of Uncertainties on Hazard Curve
(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)
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(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)

Aleatory

Aleatory variability gives the curve its shape

Epistemic

Epistemic uncertainty leads to uncertainty bands

(Kammerer 2015)
The mean curve is used in risk assessment and design to better account for epistemic uncertainty.

The mean curve exceeds the median due to the log-normal distribution of most parameters.

Influence of Uncertainties on Hazard Curve
(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)

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(Kammerer 2015)
Greater epistemic uncertainty due to lack of data should lead to higher mean curve, which should lead to higher assessments of risk. This provides the impetus to collect data via field investigations, etc.

(Kammerer 2015)
Influence of Uncertainties on Hazard Curve

(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)

Greater epistemic uncertainty due to lack of data should lead to higher mean curve, which should lead to higher assessments of risk. This provides the impetus to collect data via field investigations, etc.

However, per current practice the opposite is true for site effects (i.e., a larger epistemic uncertainty can result in a lower mean curve)

(Kammerer 2015)
Influence of Uncertainties on Hazard Curve

(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)

Greater epistemic uncertainty provides the impetus to collecting data via field investigations, etc.

(Kammerer 2015)
“Base Case” Vs Profiles for Epistemic Uncertainty

\[ \sigma_\mu \ln = 0.35 \]
"Base Case" Vs Profiles for Epistemic Uncertainty

\[ \sigma_{\mu \ln} = 0.50 \]
Average Amplification Curve for “Base Case” Vs Profiles

[AF(T) vs. T for a given Probability of Exceedance]

\[ AF(T) = \frac{S_{a_{\text{soil}}}}{S_{a_{\text{rock}}}} \]

Oscillator Period (T)

amplification curves for each base case profile

weighted average amplification curve for site

Low Epistemic Uncertainty

High Epistemic Uncertainty
Average Amplification Curve for “Base Case” Vs Profiles

\[ AF(T) \text{ vs. } T \text{ for a given Probability of Exceedance} \]

\[ AF(T) = \frac{S_{a_{\text{soil}}}}{S_{a_{\text{rock}}}} \]

Weighted average amplification curve for lower epistemic uncertainty

Weighted average amplification curve for higher epistemic uncertainty
In this period range, spectral accelerations for soil motions will be higher for the case of lower epistemic uncertainty.
Influence of Uncertainties on Hazard Curve

(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)

Mean Curves

Hazard curves for **lower** epistemic uncertainty

Hazard curves for **higher** epistemic uncertainty
Alternative Approach
Conditioning of Amplification Curves
(on variables that have a significant influence in the site response)

\[ AF(T) = \frac{S_{a_{soil}}}{S_{a_{rock}}} \]

amplification curves for each base case profile
weighted average amplification curve for site

Oscillator Period (T)
Fundamental Period of Profile (T_p)
Treatment of Epistemic Uncertainty in Site Effects

PSHA Motions for Reference Horizon (bedrock)

**Shear Wave Velocity Profile**

1. **Vs Profile$_{UR}$ (0.3)**
   - **EPRI (0.5)**
   - \[ G_Z(z) = \int_0^\infty \int_0^\infty P \left( Y \geq \frac{z}{x} \mid x, T_p \right) f_{x,T_p}(x, T_p) dx \, dT_p \]

2. **Vs Profile$_{mean}$ (0.4)**
   - **EPRI (0.5)**
   - \[ G_Z(z) = \int_0^\infty \int_0^\infty P \left( Y \geq \frac{z}{x} \mid x, T_p \right) f_{x,T_p}(x, T_p) dx \, dT_p \]
   - **Peninsular (0.5)**
   - \[ G_Z(z) = \int_0^\infty \int_0^\infty P \left( Y \geq \frac{z}{x} \mid x, T_p \right) f_{x,T_p}(x, T_p) dx \, dT_p \]

3. **Vs Profile$_{LR}$ (0.3)**
   - **EPRI (0.5)**
   - \[ G_Z(z) = \int_0^\infty \int_0^\infty P \left( Y \geq \frac{z}{x} \mid x, T_p \right) f_{x,T_p}(x, T_p) dx \, dT_p \]
   - **Peninsular (0.5)**
   - \[ G_Z(z) = \int_0^\infty \int_0^\infty P \left( Y \geq \frac{z}{x} \mid x, T_p \right) f_{x,T_p}(x, T_p) dx \, dT_p \]
Annual Probability of Exceedance of Soil Ground Motion Level $z$

\[ G_Z(z) = \int_0^\infty P\left(Y \geq \frac{z}{x}\bigg| x\right) f_x(x) \, dx \]

\[ G_Z(z) = \int_0^\infty \int_0^\infty P\left(Y \geq \frac{z}{x}\bigg| x, T_p\right) f_{x,T_p}(x, T_p) \, dx \, dT_p \]

vs.

Probability conditioned on $x$ & $T_p$

Joint probability density function of $x$ & $T_p$
Influence of Uncertainties on Hazard Curve

(Hazard Curve: Prob. of Exceedance vs. SA for a Given Oscillator Period)
Uncertainty in PSHA is categorized as:
- Aleatory Variability (natural randomness)
- Epistemic Uncertainty (scientific uncertainty)

Epistemic uncertainty is accounted for by using logic tree
- LB, Mean, and UB Base case Vs profiles
- 2 sets of shear modulus and damping degradation curves

Current approach for treating epistemic uncertainty in site effects can result in an increase in computed seismic hazard as epistemic decreases (opposite of what you want)

Conditioning of amplification functions on variables that have a significant influence in the site response is one way of rectifying shortcoming in current approach of treating epistemic uncertainty
Questions?
References:

