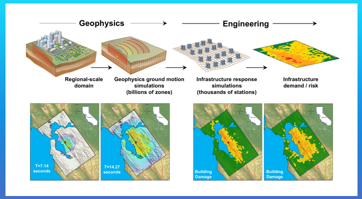

PEER International Pacific Rim Forum
June 16-17, 2021

Incorporation of Uncertainties in Seismic Hazard Characterization Using Numerical Simulations of Ground Motions

N. Abrahamson
M. Lacour
University of California, Berkeley

June 17, 2021

PEER

3-D Simulations of GM in Seismic Hazard

- 3-D Simulations
  - Include path-specific effects
  - Include fault geometry-specific effects
- From a seismic hazard point of view, 3-D simulations are non-ergodic GMMs
  - Not just magnitude, distance, site condition

Implementation of Non-Ergodic GMMs in Seismic Hazard

- For the specific source/site combination:
  - Median ground motion
  - Aleatory variability
  - Epistemic uncertainty in the estimate of the median

Uncertainty Matrix

	Aleatory Variability	Epistemic Uncertainty
Parametric	Multiple realizations of the source Sample pdf for source inputs - Rupture dimension - Slip distribution - Hypocenter location - Rupture-velocity distribution - Rake-angle distribution - ...	For a given simulation method: Alternative pdfs for the source inputs - mean and std dev Alternative 3-D velocity models
Modeling	Limitation of the simulation method to match data - variability that can’t be explained by the model is treated as aleatory variability Must be estimated empirically - Misfit between data and simulations for optimized source parameters.	Does the simulation method give the correct median GM? Alternative simulation methods Range of median values for different simulation methods for a specific site - using Single method - Evaluate the bias (simulations versus data) and standard error of the bias.

Uncertainty Matrix

	Aleatory Variability	Epistemic Uncertainty
Parametric	σ_{par}	σ_{μ_par}
Modeling	σ_{mod}	σ_{μ_mod}
Total	$\sigma = \sqrt{\sigma_{mod}^2 + \sigma_{par}^2}$	$\sigma_\mu = \sqrt{\sigma_{\mu\_mod}^2 + \sigma_{\mu\_par}^2}$

All Four Elements of uncertainty matrix Required for Hazard Implementation

- Single Realizations
  - Provide examples of the spatial variability, but are not useful for seismic hazard
- Current approach used in CyberShake and LBNL
  - single 3-D velocity model
  - multiple realizations of the source (σ_{par})
  - missing parts
    - modeling aleatory term (σ_{mod})
    - epistemic uncertainty of the 3-D velocity model (σ_{μ_par})
    - epistemic uncertainty of the distribution for source parameters (σ_{μ_par})
    - epistemic uncertainty from different methods (σ_{μ_mod})
- For hazard applications:
  - Missing values will be assumed
  - If you don't want the hazard analysts to pick values, 3-D simulations need to provide the estimates

Estimating Aleatory Elements of Uncertainty Matrix

- Parametric Aleatory term
  - Need to sample the full range of source properties
  - Straightforward, but requires a large number of 3-D simulations
    - Typically need about 50 realizations to get a good estimate of the standard deviation
- Modeling Aleatory term (Missing)
  - Need to compare with observations to quantify limitation of the method
  - Issues
    - May not have good 3-D velocity model for regions with data from large magnitude earthquakes
    - The geotechnical layer is often missing from the 3-D velocity. model
  - Does the misfit represent the limitation of the method or the limitation of the 3-D velocity model?
    - Validation (SCEC BBP) provide estimates of the model misfit from 1-D simulations
    - Can we use modeling aleatory from 1-D model misfits to approximate 3-D modeling aleatory?

Estimating Epistemic Elements of Uncertainty Matrix

- Parametric Epistemic term (missing)
  - Uncertainty in the 3-D velocity model
    - Need method to develop alternative 3-D velocity models
    - Large increase in the number of 3-D simulations needed
  - Uncertainty in the source model inputs
    - Different distributions of the source parameters (e.g. mean and std dev)
    - Can change weights to realizations used for the parametric aleatory term
    - May not need an increase in 3-D simulations
- Modeling Epistemic term (missing)
  - Multiple methods
    - Range of median from alternative simulation methods
      - Different rupture generation methods
      - Different methods for 3-D simulations
    - Increase number of simulations
  - Single method
    - Uncertainty in the bias from comparison with data
    - Part of the validation

Estimating Full Uncertainty Matrix

- Key issue:
  - Need a significant increase in the number of 3-D simulations
- Can we do this in a more efficient manner than Monte Carlo sampling?

Efficient Methods for Increasing Number of Realizations of 3-D simulations

- Objective:
  - Generate a large number of realizations from a small number of available 3-D calculations without using Monte Carlo
- Possible Method - Probabilistic Learning on Manifolds (PLoM) by Soize & Ghanem (2016 - 2020)
  - Non-intrusive (no change to the 3-D simulation program)
  - Designed for expensive, large-scale simulations
  - Assumes a limited number of simulations available (50-100)
  - Learns solutions’ statistics from small ’training’ dataset and physical constraints
  - Efficiently generates many additional ’learned’ realizations from learning phase
  - Reconstructs full statistics of the solution efficiently
    - Results are time series, not just response spectra

Planning a Trial Application

- Use 25 realizations for the Hayward events (training data)
- Test implementation of the PLoM method
  - Generate a suite of new realizations using PLoM
- Evaluate the predicted distribution of time series from PLoM with a second set of realizations from the 3-D simulations (Test data)

Summary

- Current sets of 3-D simulations can be used to quantify the parametric aleatory term from multiple realizations of the source
- Most are missing three other uncertainty terms for 3-D simulations
  - Aleatory - modeling
    - Ideally, conduct validations 3-D simulations
    - Initially, use 1-D validation results as an estimate
  - Epistemic – parametric
    - Requires simulations for alternative 3-D models
    - Can reweight the simulations for alternative pdfs of source parameters
  - Epistemic – modeling
    - Different simulation methods - set up a common problem for multiple methods to use
    - Single method – requires results from validation with data for the uncertainty in mean bias