Probabilistic Seismic Risk Analysis for Inelastic Soil-Structure Systems

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Outline

Introduction

Probabilistic Seismic Risk
   Uncertainty Propagation
   Risk Analysis Example

Summary
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Motivation

Improve modeling and simulation of infrastructure objects

Modeling, epistemic uncertainty

Parametric, aleatory uncertainty

Goal is to Predict and Inform
Aleatory Uncertainties, Material, Motions

\[ E = (101.125 \times 19.3) N^{0.63} \]

(cf. Phoon and Kulhawy (1999B))

(cf. Wang et al. (2019))
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Forward Uncertainty Propagation

- Given uncertain material
- Given uncertain loads
- Determine uncertain response, $u_i, \dot{u}_i, \ddot{u}_i, \epsilon_{ij}, \sigma_{ij}$, PDFs/CDFs
- Direct, intrusive, analytic development
- Circumvent Monte Carlo inefficiencies, inaccuracies
Cam Clay with Random $G$, $M$ and $p_0$
Stochastic Elastic-Plastic FEM

Dynamic Finite Elements $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$

- Input random field/process (non-Gaussian, heterogeneous/non-stationary): Multi-dimensional Hermite Polynomial Chaos (PC) with known coefficients
- Output response process: Multi-dimensional Hermite PC with unknown coefficients
- Galerkin projection: minimize the error to compute unknown coefficients of response process
Probabilistic Seismic Risk Analysis

- Objective, quantitative decision making based on exceedance rate $\lambda(EDP > z)$
- PSRA: convolution of PSHA and fragility

$$
\lambda(EDP > z) = \int \left| \frac{d\lambda(IM > x)}{dx} \right| G(EDP > z | IM = x) \, dx
$$

$\lambda(\cdot)$: rate of exceedance
$EDP$: engineering demand parameter
$PSHA$: probabilistic seismic hazard analysis
$IM$: intensity measure, choice to be made (!)
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Application: Seismic Hazard

Seismic source characterization

Stochastic ground motion

Uncertainty propagation

Uncertainty characterization

\[ \lambda(EDP > z) = \sum N_i(M_i, R_i) P(EDP > z | M_i, R_i) \]
Example Object

- Fault 1: San Gregorio fault
- Fault 2: Calaveras fault
- Uncertainty: Segmentation, slip rate, rupture geometry, etc.

- 371 total seismic scenarios
- $M \sim 5.5$ and $6.5 \sim 7.0$
- $R_{jb} 20km \sim 40km$
Stochastic Ground Motion Modeling

Realizations of simulated uncertain motions for scenario $M = 7$, $R = 15\text{km}$:

Verification with GMPE:

Jeremić et al.
Stochastic Ground Motion Characterization

Acc. marginal mean  
Acc. marginal S.D.  
Acc. realization Cov.  
Acc. synthesized Cov.

Dis. marginal mean  
Dis. marginal S.D.  
Dis. realization Cov.  
Dis. synthesized Cov.
**Stochastic Soil and Structure Modeling**

(a) Frame

(b) Interstory response

Jeremić et al.
Probabilistic Dynamic Structural Response

- Coefficient of variation 15% for $H_a$ and $C_r$
- Time domain stochastic
  El-PI FEM analysis (SEPFEM)
Seismic Risk, Forward Analysis

- Damage measure defined on single EDP:

<table>
<thead>
<tr>
<th>Damage Measure</th>
<th>MIDR &gt; 0.5%</th>
<th>MIDR &gt; 1%</th>
<th>MIDR &gt; 2%</th>
<th>PFA &gt; 0.5 m/s²</th>
<th>PFA &gt; 1 m/s²</th>
<th>PFA &gt; 1.5 m/s²</th>
</tr>
</thead>
</table>

- Damage measure (DM) defined on multiple EDPs:

  \[ DM : \{ \text{MIDR} > 1\% \cup \text{PFA} > 1 \text{m/s}^2 \} \], seismic risk is \( 4.2 \times 10^{-3} \text{/yr} \)

  \[ DM : \{ \text{MIDR} > 1\% \cap \text{PFA} > 1 \text{m/s}^2 \} \], seismic risk is \( 1.71 \times 10^{-3} \text{/yr} \)

- Seismic risk for DM defined on multiple EDPs can be quite different from that defined on single EDP
Sensitivity, Backward Analysis

Total variance in PGA, in this particular case (!), dominated by uncertain ground motions

- 49% from uncertain rock motions at depth
- 2% from uncertain soil
- 49% from interaction of uncertain rock motions and uncertain soil
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- Analysis of uncertainties and sensitivities
- Full, direct, intrusive probabilistic modeling
- No need to define IMs
- http://real-essi.us/