Нумеричко моделирање интеракције конструкције и тла у земљотресном инжињерству: КОНСТРУКЦИЈА

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17 Септембар 2020
Outline

Introduction

Structure
  Modeling
  Uncertain ESSI

Summary
Outline

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Structure
  - Modeling
  - Uncertain ESSI

Summary
Motivation

- Improve design and assessment of infrastructure objects
- Use of high fidelity numerical models to analyze behavior of earthquake, soil, structure interacting (ESSI) systems
- Control modeling uncertainty
- Propagate parametric uncertainty
Prediction under Uncertainty

► Modeling Uncertainty, Simplifying assumptions
Low, medium, high sophistication modeling and simulation
Choice of sophistication level for confidence in results

► Parametric Uncertainty, $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$,
Uncertain mass $M$, viscous damping $C$ and stiffness $K^{ep}$
Propagation of uncertainty in loads, $F(t)$
Results are PDFs and CDFs for $\sigma_{ij}, \epsilon_{ij}, u_i, \dot{u}_i, \ddot{u}_i$

Le doute n’est pas un état bien agréable, mais l’assurance est un état ridicule. (François-Marie Arouet, Voltaire)
## Outline

**Introduction**

**Structure**
- Modeling
- Uncertain ESSI

**Summary**
Verification and Validation

(Oden, Moser and Ghattas 2010)
Component Verification: ANDES Shell

<table>
<thead>
<tr>
<th>$N_{subd}$</th>
<th>$U_z$</th>
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<tbody>
<tr>
<td>2</td>
<td>96.2118</td>
</tr>
<tr>
<td>7</td>
<td>100.096</td>
</tr>
<tr>
<td>101</td>
<td>100.002</td>
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</tbody>
</table>

Mode 1, $T = 0.999959s$

Mode 1, $T = 0.998022s$
Component Validation, Concrete Wall

$u_y = 1.4 \text{ mm}$

$u_y = 1.8 \text{ mm}$

$u_y = 3.0 \text{ mm}$
Model Verification
Full ESSI Model
Structure Only Model
Time Domain Intrusive Seismic Risk Analysis

- Stochastic Elastic-Plastic Finite Element Method, SEPFEM, $M\ddot{u}_i + C\dot{u}_i + K^{ep}u_i = F(t)$,

- Uncertain seismic loads, from uncertain seismic motions, using Domain Reduction Method

- Uncertain elastic-plastic material, stress and stiffness solution using Forward Kolmogorov, Fokker-Planck equation

- Results, probability distribution functions for $\sigma_{ij}$, $\epsilon_{ij}$, $u_i$...
Stochastic Elastic-Plastic Finite Element Method

Stochastic system of equations

\[
\begin{bmatrix}
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_0 > K^{(k)} \\
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_1 > K^{(k)} \\
\vdots \\
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_P > K^{(k)} \\
\end{bmatrix}
\cdot
\begin{bmatrix}
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_0 > K^{(k)} \\
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_1 > K^{(k)} \\
\vdots \\
\sum_{k=0}^{P_d} \Phi_k \psi_0 \psi_P > K^{(k)} \\
\end{bmatrix}

= 
\begin{bmatrix}
\sum_{i=0}^{P_f} f_i < \psi_0 \zeta_i > \\
\sum_{i=0}^{P_f} f_i < \psi_1 \zeta_i > \\
\vdots \\
\sum_{i=0}^{P_f} f_i < \psi_P \zeta_i > \\
\end{bmatrix}
\]
Uncertainty Representation & Propagation

- Unified uncertainty representation for forces and material
  - Hermite polynomial chaos (PC) for marginal distribution
  - Karhunen-Loève (KL) expansion for correlation structure

- Hermite PCs: Non-Gaussian random field with underlying Gaussian random field
  \[
  D(x, \theta) = \sum_{i=0}^{P} D_i(x) \Omega_i(\gamma(x, \theta))
  \]
  with:
  \[
  \Omega_i = 1, \gamma, \gamma^2 - 1, \gamma^3 - 3\gamma, ...
  \]
  \[
  < \Omega_i > = 0; \quad < \Omega_i \Omega_j > = 0 \quad \text{for} \quad i \neq j
  \]
Stochastic Ground Motion Representation

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 Structural Response

![Graph showing the relationship between Interstory Drift \( \eta \) [m] and Restoring Force \( F^R \) [N]. The graph includes lines for Intrusive Median, Intrusive quantiles 30%, 70%, Intrusive quantiles 10%, 90%, MC Median, MC quantiles 30%, 70%, and MC quantiles 10%, 90%.]

- Intrusive Median
- Intrusive quantiles 30%, 70%
- Intrusive quantiles 10%, 90%
- MC Median
- MC quantiles 30%, 70%
- MC quantiles 10%, 90%
Probabilistic Dynamic Response

Probabilistic response of top floor from SFEM
Probabilistic Dynamic Response

Probabilistic density of displacements evolution of top floor
Maximum Inter-Story Drift Ratio (MIDR)

![Maximum Inter-Story Drift Ratio (MIDR) graph]

- **PDF**: Probability Density Function
- **1st Floor MIDR**: Distribution for the first floor
- **2nd Floor MIDR**: Distribution for the second floor
- **3rd Floor MIDR**: Distribution for the third floor
- **4th Floor MIDR**: Distribution for the fourth floor
- **Overall MIDR**: Combined distribution for all floors
Seismic Risk Analysis

\[ \lambda(MIDR > 1\%) = 9.7 \times 10^{-3} \]
\[ \lambda(MIDR > 2\%) = 1.7 \times 10^{-3} \]
\[ \lambda(MIDR > 4\%) = 5.9 \times 10^{-5} \]
Sensitivity Study

Source $\Delta \sigma$: 

![Graph showing annual exceedance rate for different values of $\Delta \sigma$.]

Site $\kappa_0$: 

![Graph showing annual exceedance rate for different values of $\kappa_0$.]
Sensitivity Study

If first mode structural frequency increases from 1.6Hz to 8Hz, significant effect of site $\kappa_0$:
Seismic Risk, Uncertain Material

![Graph showing annual exceedance rate vs. MIDR percentage.]

- Annual Exceedance Rate
  - $9 \times 10^{-4}$
  - $2.3 \times 10^{-4}$
  - $1 \times 10^{-4}$

- MIDR [%]
  - $10^{-6}$
  - $10^{-5}$
  - $10^{-4}$
  - $10^{-3}$
  - $10^{-2}$

- Curves for different values of $\sigma$:
  - $\sigma = 0.01$ (dotted blue)
  - $\sigma = 0.1$ (solid black)
  - $\sigma = 0.3$ (dashed red)
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- Importance of using realistic models
- Reduce modeling uncertainty
- Propagation of parametric, aleatory uncertainty
- Probabilistic response for decisions making