Нумеричко моделирање интеракције конструкције и тла у земљотресном инжињерству: КОНСТРУКЦИЈА

Борис Јеремић

Professor, University of California, Davis, CA, USA
Faculty Scientist, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Српско удружење за земљотресно инжењерство
СУЗИ
17 Септембар 2020

Outline

Outline

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 σ_{ij}, ϵ_{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. (Francois-Marie Arouet, Voltaire)

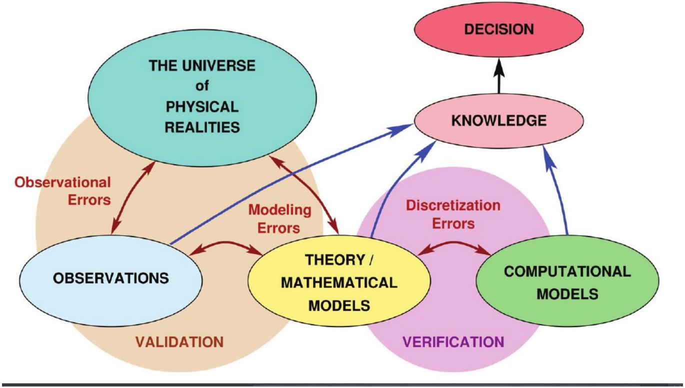
Outline

Introduction

Structure
- Modeling
- Uncertain ESSI

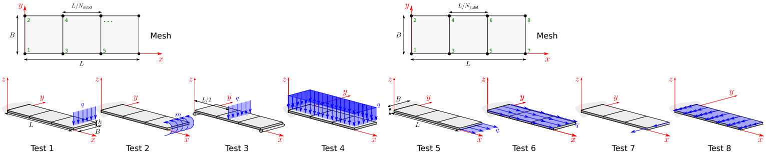
Summary

Verification and Validation

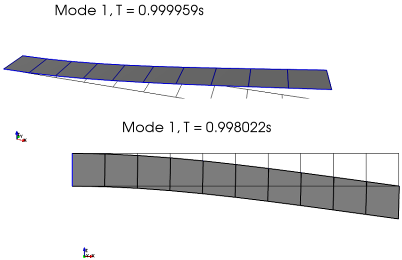


(Oden, Moser and Ghattas 2010)

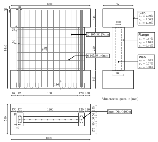
Component Verification: ANDES Shell

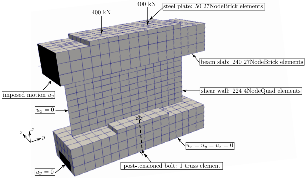


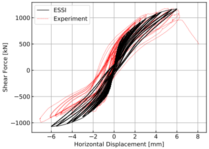
N_{subd}	u_z
2	96.2118
7	100.096
101	100.002

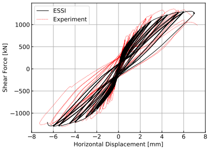


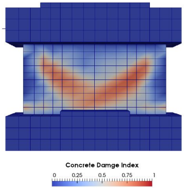
Component Validation, Concrete Wall



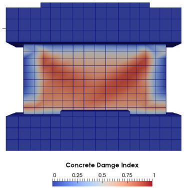




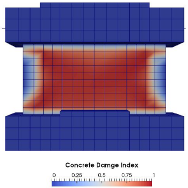




u_y = 1.4 mm

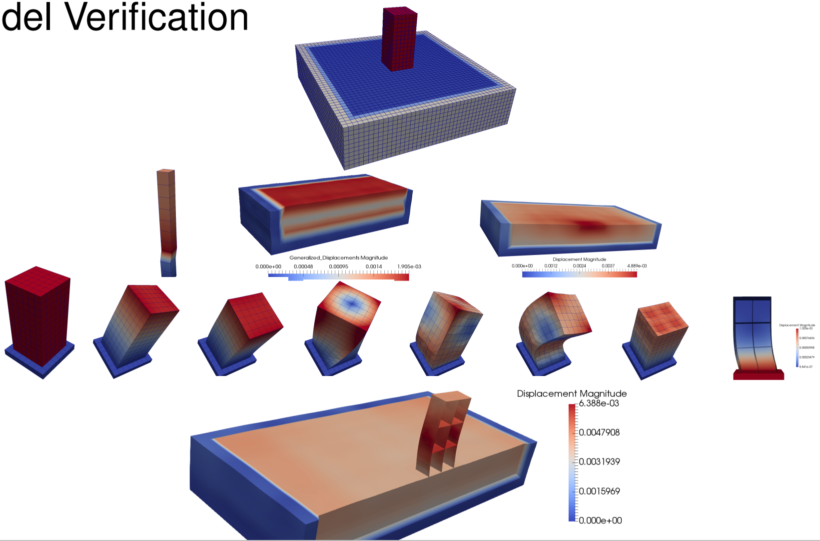


u_y = 1.8 mm

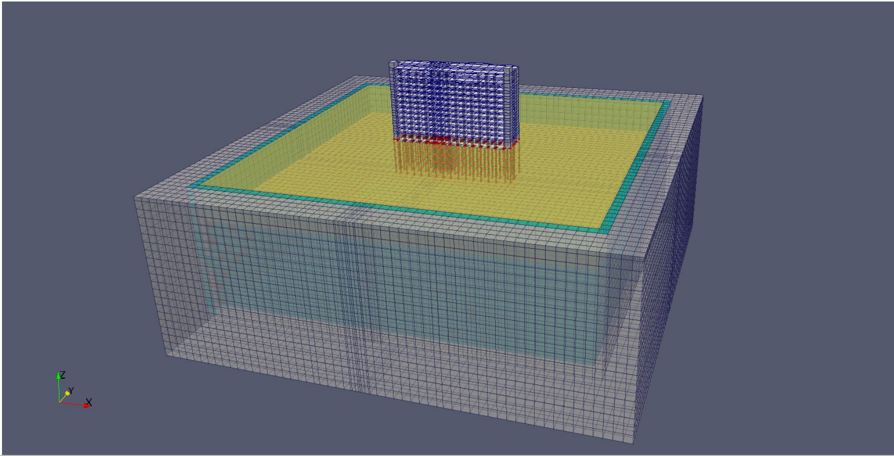


u_y = 3.0 mm

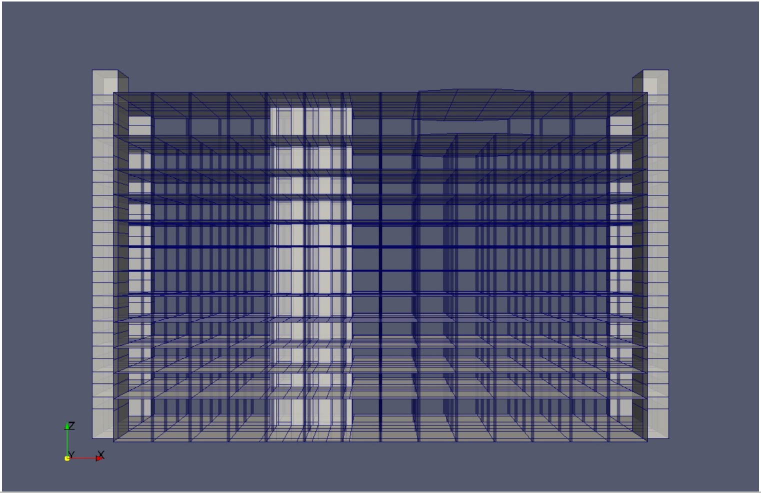
Model Verification



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 σ_{ij}, ϵ_{ij}, u_i...

Stochastic Elastic-Plastic Finite Element Method

Stochastic system of equations

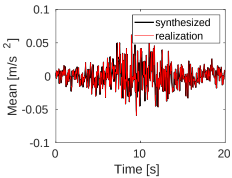
$$
\begin{bmatrix}
\sum_{k=0}^{P_d} < \Phi_k \Psi_0 \Psi_0 > K^{(k)} & \dots & \sum_{k=0}^{P_d} < \Phi_k \Psi_P \Psi_0 > K^{(k)} \\
\sum_{k=0}^{P_d} < \Phi_k \Psi_0 \Psi_1 > K^{(k)} & \dots & \sum_{k=0}^{P_d} < \Phi_k \Psi_P \Psi_1 > K^{(k)} \\
\vdots & \vdots & \vdots & \vdots \\
\sum_{k=0}^{P_d} < \Phi_k \Psi_0 \Psi_P > K^{(k)} & \dots & \sum_{k=0}^{M} < \Phi_k \Psi_P \Psi_P > K^{(k)}
\end{bmatrix}
\begin{bmatrix}
u_{10} \\ \vdots \\ u_{N0} \\ \vdots \\ u_{1P_u} \\ \vdots \\ u_{NP_u}
\end{bmatrix}
=
\begin{bmatrix}
\sum_{i=0}^{P_f} f_i < \Psi_0 \zeta_i > \\
\sum_{i=0}^{P_f} f_i < \Psi_1 \zeta_i > \\
\sum_{i=0}^{P_f} f_i < \Psi_2 \zeta_i > \\
\vdots \\
\sum_{i=0}^{P_f} f_i < \Psi_{P_u} \zeta_i >
\end{bmatrix}
$$

# KL terms material	# KL terms load	PC order displacement	Total # terms per DoF
4	4	10	43758
4	4	20	3 108 105
4	4	30	48 903 492
6	6	10	646 646
6	6	20	225 792 840
6	6	30	$1.1058\ 10^{10}$
...	...	...	...

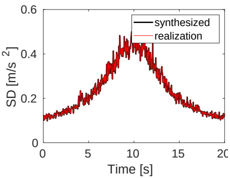
Uncertainty Representation & Propagation

- 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 $D(\boldsymbol{x},\theta) = \sum_{i=0}^{P} D_i(\boldsymbol{x})\Omega_i(\gamma(\boldsymbol{x},\theta))$ with:
  $\Omega_i = 1, \gamma, \gamma^2 - 1, \gamma^3 - 3\gamma, ...$
  $< \Omega_i >= 0; \;\; < \Omega_i \Omega_j >= 0 \;\; for \;\; i \neq j$

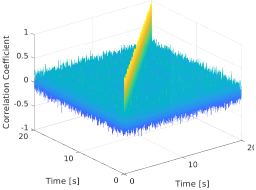
Stochastic Ground Motion Representation



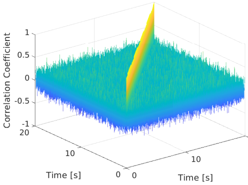
Acc. marginal mean



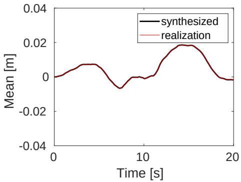
Acc. marginal S.D.



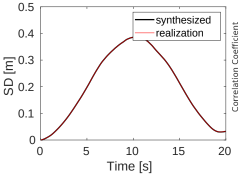
Acc. realization Cov.



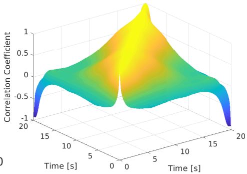
Acc. synthesized Cov.



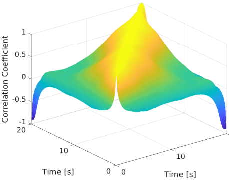
Dis. marginal mean



Dis. marginal S.D.

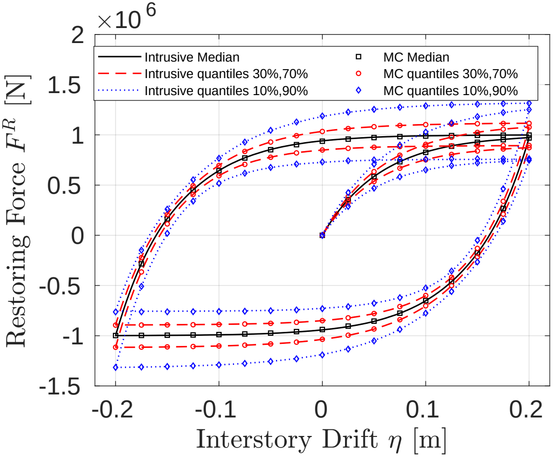


Dis. realization Cov.

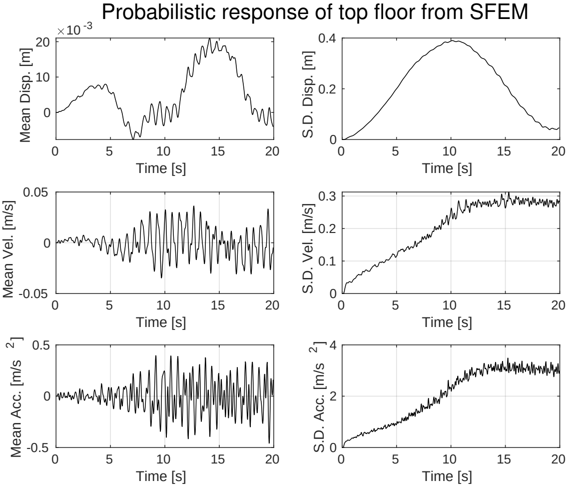


Dis. synthesized Cov.

Stochastic Structural Response

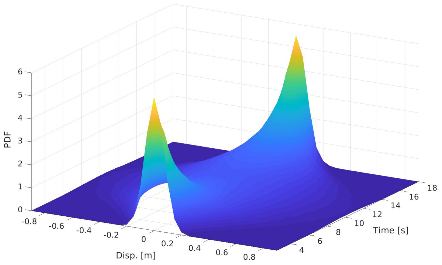


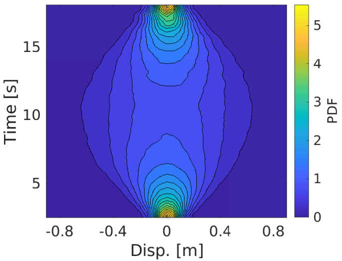
Probabilistic Dynamic Response



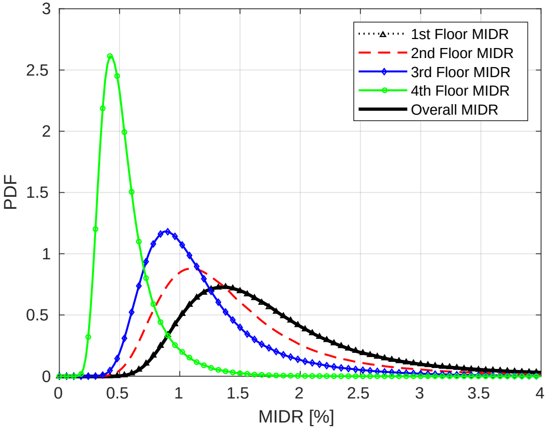
Probabilistic Dynamic Response

Probabilistic density of displacements evolution of top floor

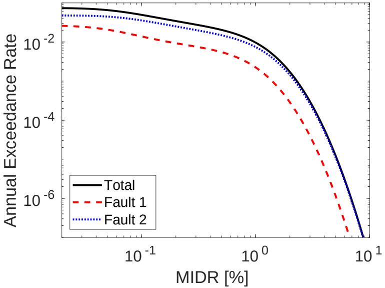


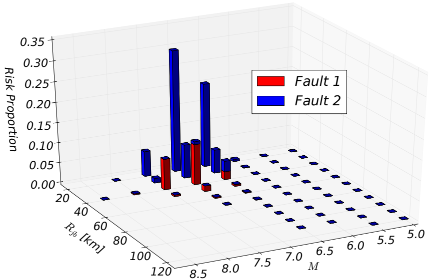


Maximum Inter-Story Drift Ratio (MIDR)



Seismic Risk Analysis



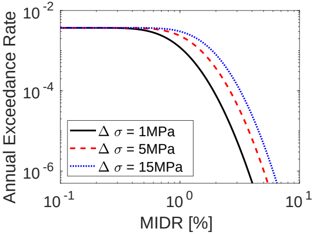


$$\lambda(MIDR > 1\%) = 9.7 \times 10^{-3}$$
$$\lambda(MIDR > 2\%) = 1.7 \times 10^{-3}$$
$$\lambda(MIDR > 4\%) = 5.9 \times 10^{-5}$$

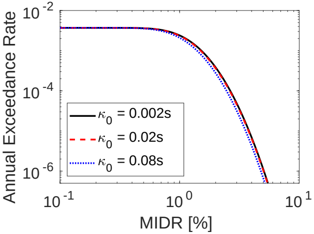
Risk de-aggregation for $\lambda(MIDR > 1\%)$

Sensitivity Study

Source $\Delta\sigma$:

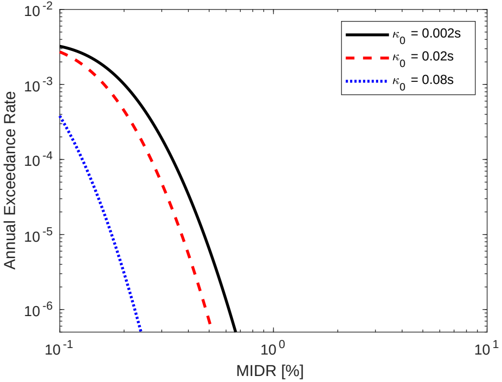


Site κ_0:

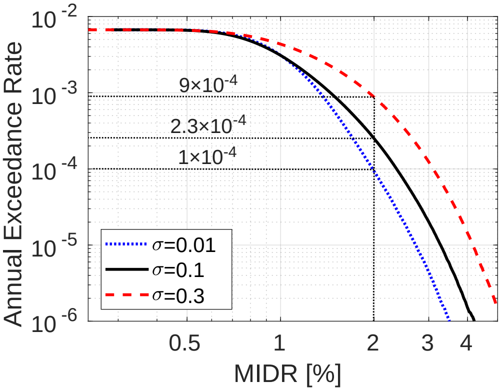


Sensitivity Study

If first mode structural frequency increases from 1.6Hz to 8Hz, significant effect of site κ_0:



Seismic Risk, Uncertain Material



Outline

Summary

- Importance of using realistic models
- Reduce modeling uncertainty
- Propagation of parametric, aleatory uncertainty
- Probabilistic response for decisions making