Full Seismic Wave Inversion in 3D for ESSI Analysis

Boris Jeremić

University of California, Davis, CA

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Outline

Introduction

Inverse Wave Field Analysis

Summary
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Summary

Jeremić et al.

Seismic Eave Field Inversion
Motivation

Improve modeling and simulation of nuclear installations

Reduction of modeling uncertainty

Development of full 3D/3C wave fields for ESSI analysis

Use surface, structure and limited downhole motion measurements for development of wave fields
Robert P. Kennedy, 1939-2018

"Response of a soil structure system is nonlinear, and I would really like to know what that response is!"

Nebojša Orbović, 1962-2021

"As an engineer, I have to know what are response sensitivities to modeling choices and model parameters."
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 \( \sigma_{ij}, \epsilon_{ij}, u_i, \dot{u}_i, \ddot{u}_i \)
Goal: Reduction of Modeling Uncertainty

- Modeling Uncertainty: introduced with unnecessary and unrealistic modeling simplification

- Simplified (or inadequate/wrong) modeling: important features are missed (3C (6C) seismic ground motions, inelasticity, etc.)

- Modeling simplifications are justifiable if one, two or higher level sophistication model demonstrates that features being simplified out are not important

- Use of HPC for low modeling uncertainty and direct probabilistic modeling and simulations
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ESSI: 6C or 1C Seismic Motions

- Assume that a full 6C (3C) motions at the surface are only recorded in one horizontal direction.
- From such recorded motions one can develop a vertically propagating shear wave (1C) in 1D.
- Apply such vertically propagating shear wave to same soil-structure system.
Realistic Ground Motions

- Free field seismic motion models
Development of Realistic Motions

- Sources will send both P and S waves
1C vs 6C Free Field Motions

- One component of motions, 1C from 6C
- Excellent fit

(MP4) (MP4)
1C vs 6C Free Field Motions

(a) \( f = 5\text{Hz} \), \( \theta = 10^\circ \)
(b) \( f = 5\text{Hz} \), \( \theta = 45^\circ \)
(c) \( f = 5\text{Hz} \), \( \theta = 60^\circ \)
(d) \( f = 5\text{Hz} \), \( \theta = 80^\circ \)
(e) \( f = 1\text{Hz} \), \( \theta = 60^\circ \)
(f) \( f = 2.5\text{Hz} \), \( \theta = 60^\circ \)
(g) \( f = 5\text{Hz} \), \( \theta = 60^\circ \)
(h) \( f = 10\text{Hz} \), \( \theta = 60^\circ \)
SMR ESSI, 3C vs 3×1C

(OGV)
Development of 3D/3C Wave Fields

- PDE-constrained optimization
- Evaluate gradient of a misfit between measured and computed wave fields
- Optimize DRM effective forces

\[ P_{\text{eff}} = \begin{bmatrix} 0 \\ -M_{\Omega}^{+} \ddot{u}_{e}^{0} - K_{\Omega}^{+} u_{e}^{0} \\ +M_{\Omega}^{-} \ddot{u}_{b}^{0} + K_{\Omega}^{-} u_{b}^{0} \end{bmatrix} \]

Example size: ~ 500 m
Example size: ~ 100 km

Jeremić et al.
Seismic Wave Field Inversion
Development of 3D/3C Wave Fields

- Preliminary results encouraging
- Minimizing number of measuring points
- Measurements of 1C, 2C or 3C motions
- Recreate full 3D/3C wave field
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- Importance of using realistic 3D/3C seismic wave fields
- PDE-constrained optimization
- Develop optimized DRM effective forces
- Use surface and at depth measurements (1C, 2C, 3C)
- Develop full, 3C wave field
- http://real-essi.us