Full Seismic Wave Inversion in 3D for ESSI Analysis

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Outline

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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

Dedication

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 σ_{ij}, ϵ_{ij}, u_i, $\dot{u}_i$, $\ddot{u}_i$

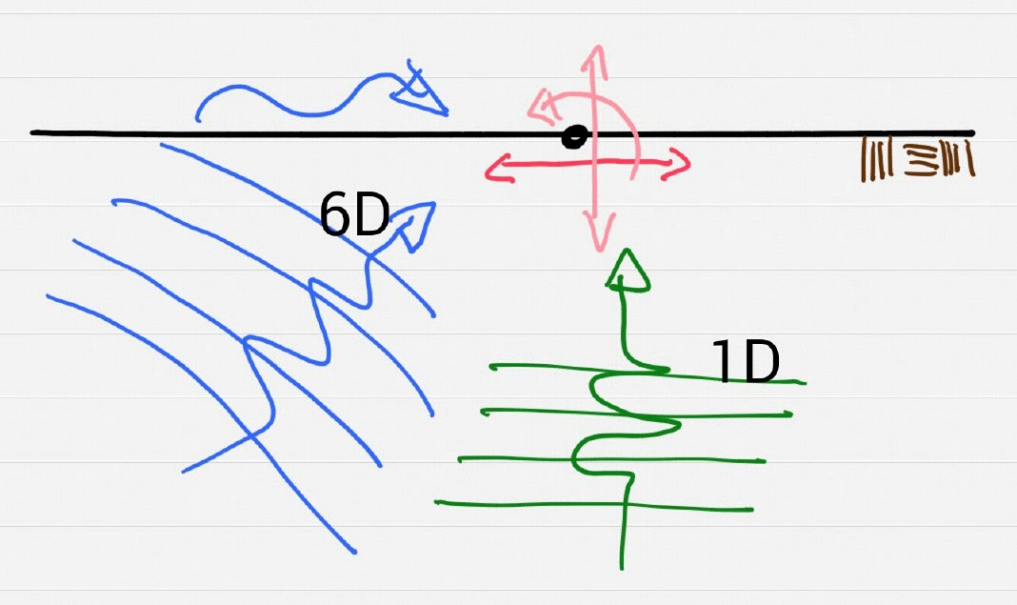
Goal: Reduction of Modeling Uncertainty

- 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

Outline

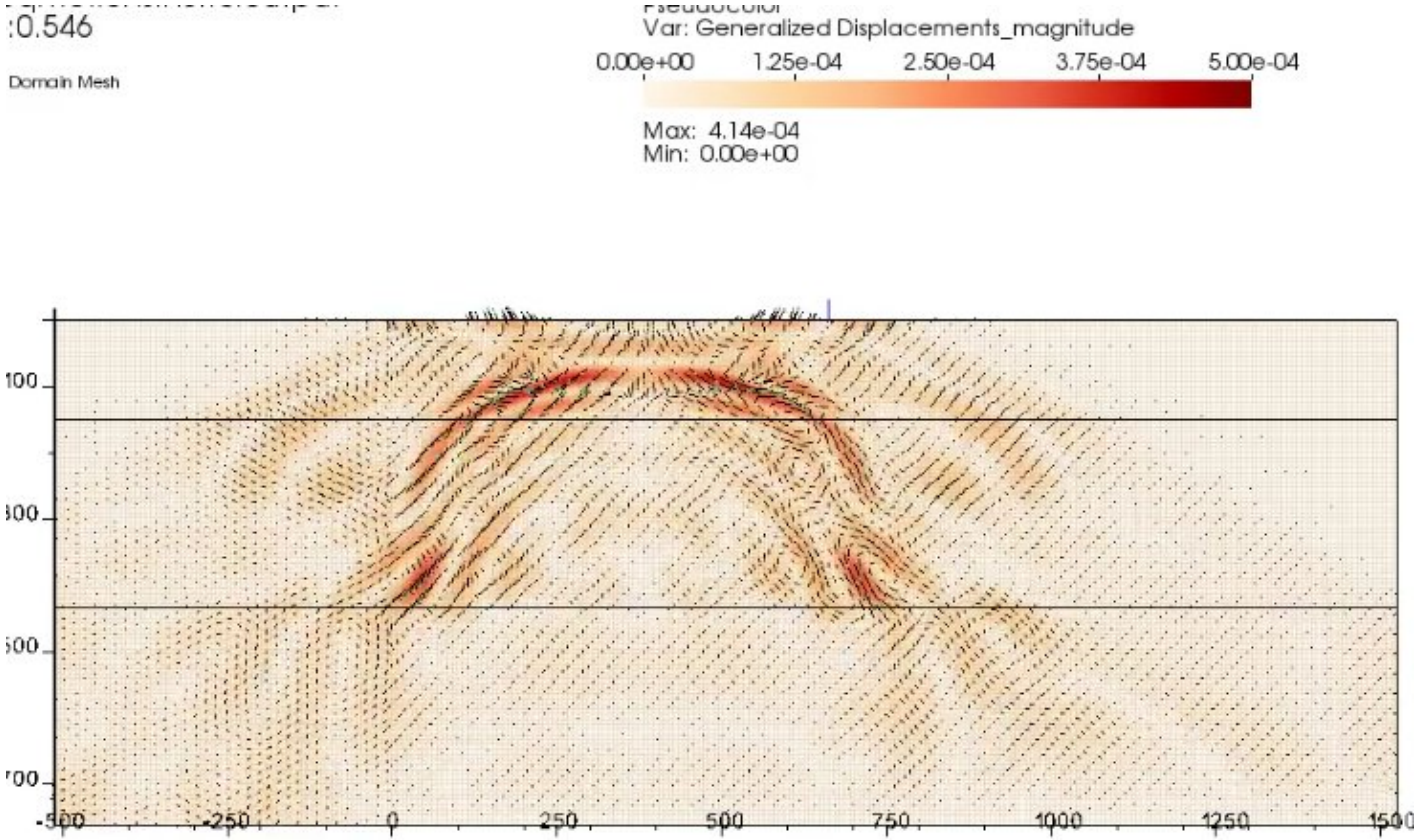
ESSI: 6C or 1C Seismic Motions

- 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 svstem



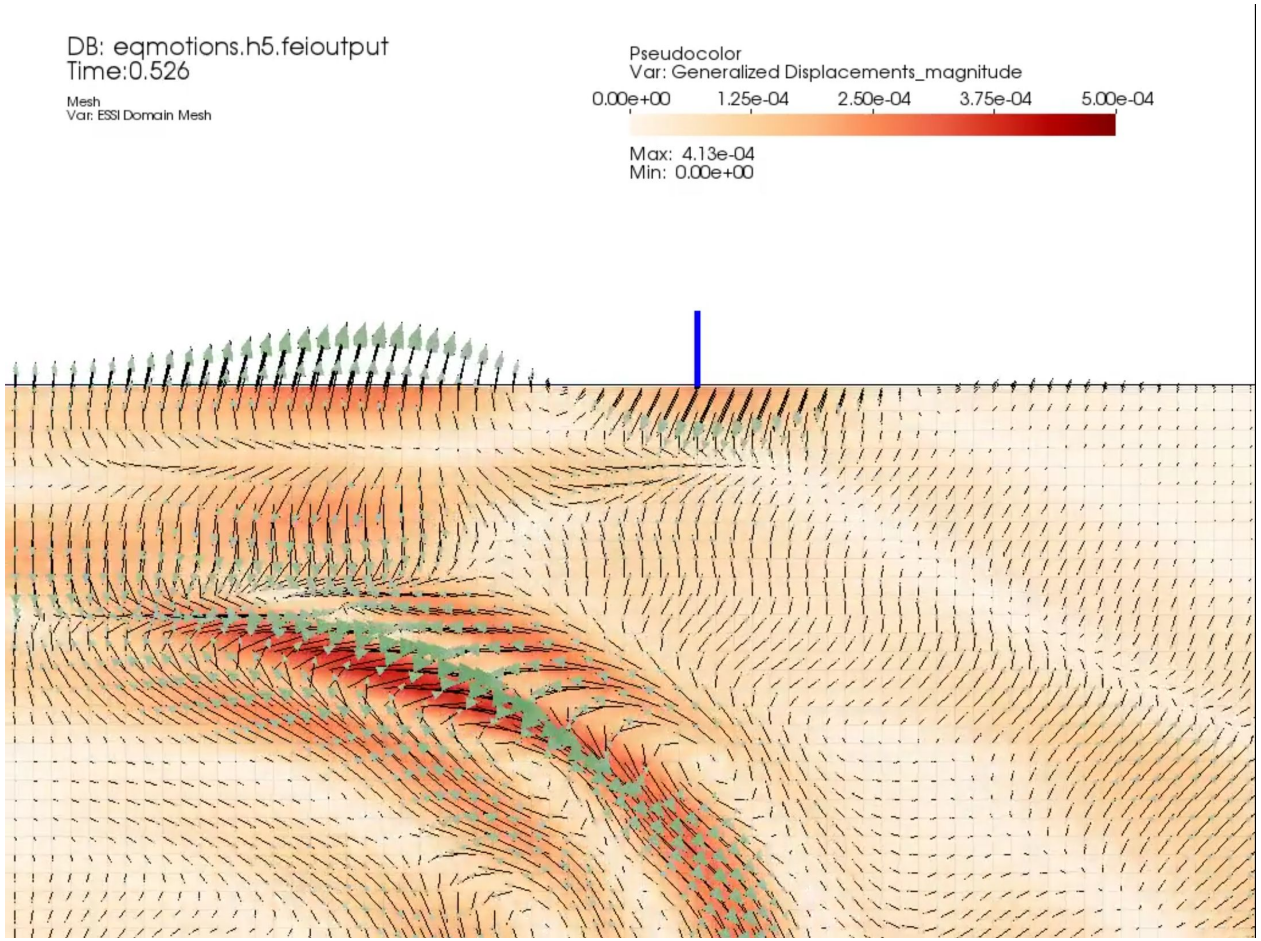
Realistic Ground Motions

- Free field seismic motion models



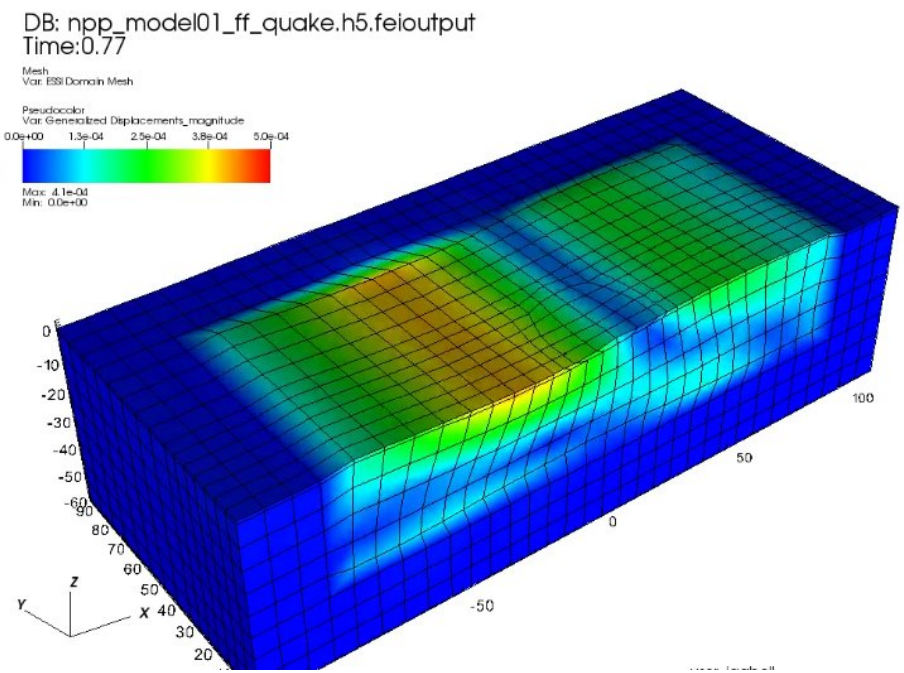
Development of Realistic Motions

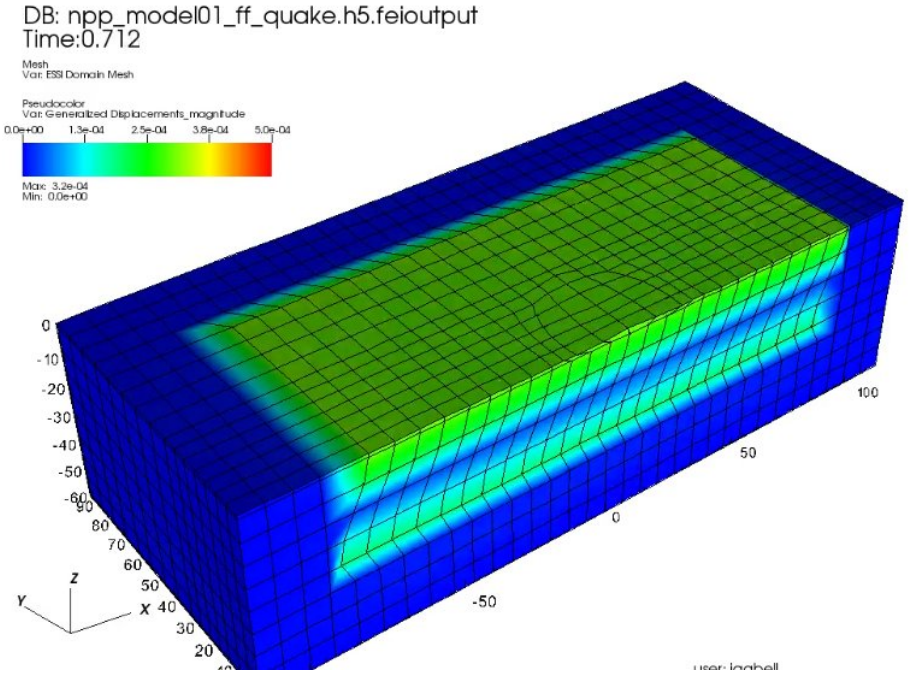
- Sources will send both P and S waves



1C vs 6C Free Field Motions

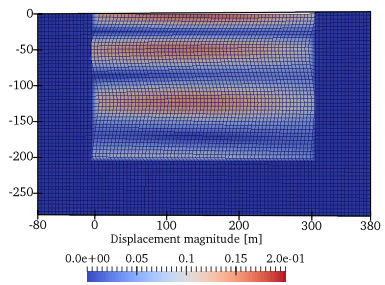
- One component of motions, 1C from 6C
- Excellent fit



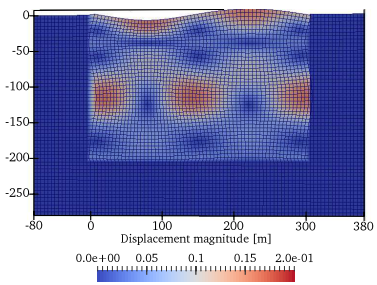


(MP4) (MP4)

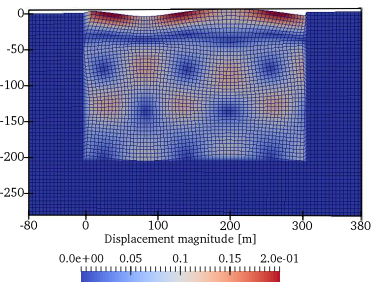
1C vs 6C Free Field Motions



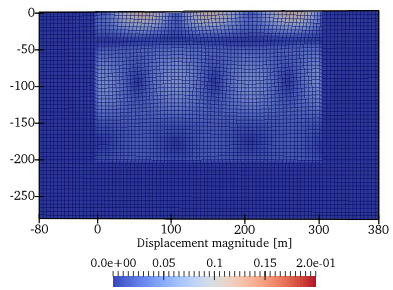
(a)
$f = 5Hz\ \theta = 10^o$



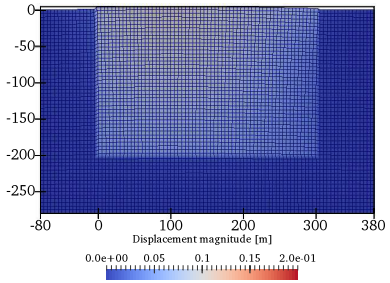
(b)
$f = 5Hz\ \theta = 45^o$



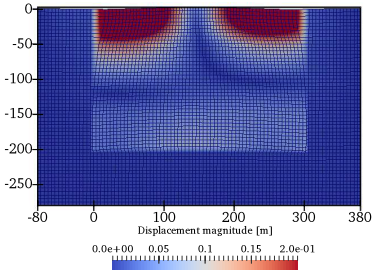
(c)
$f = 5Hz\ \theta = 60^o$



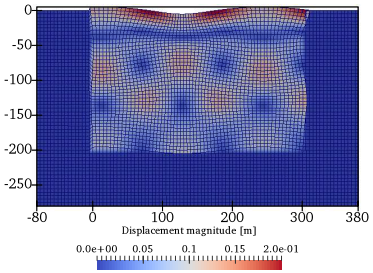
(d)
$f = 5Hz\ \theta = 80^o$



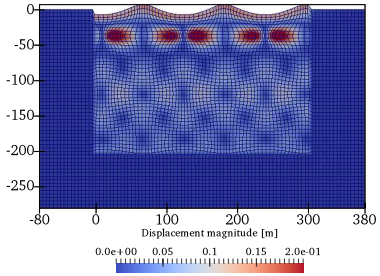
(e)
$f = 1Hz\ \theta = 60^o$



(f)
$f = 2.5Hz\ \theta = 60^o$



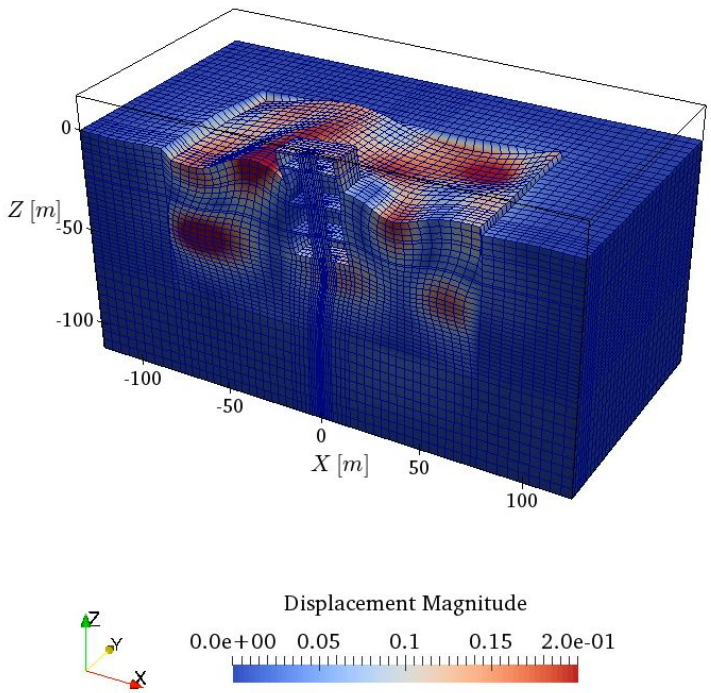
(g)
$f = 5Hz\ \theta = 60^o$



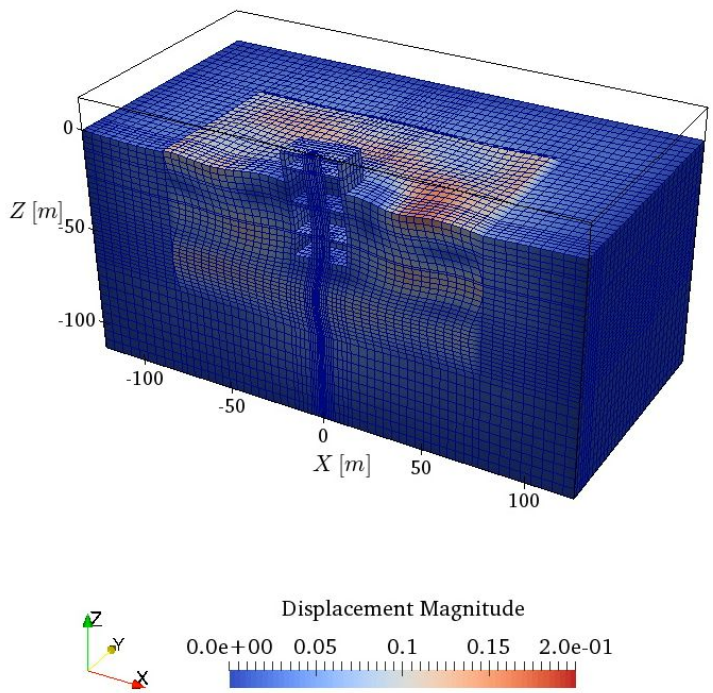
(h)
$f = 10Hz\ \theta = 60^o$

SMR ESSI, 3C vs 3×1C

$3C$



$3 \times 1C$

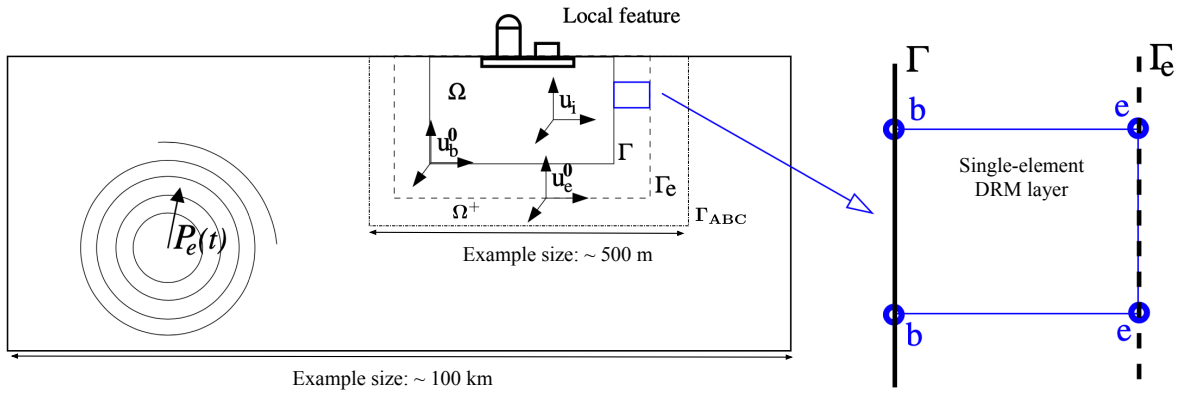


(OGV)

Development of 3D/3C Wave Fields

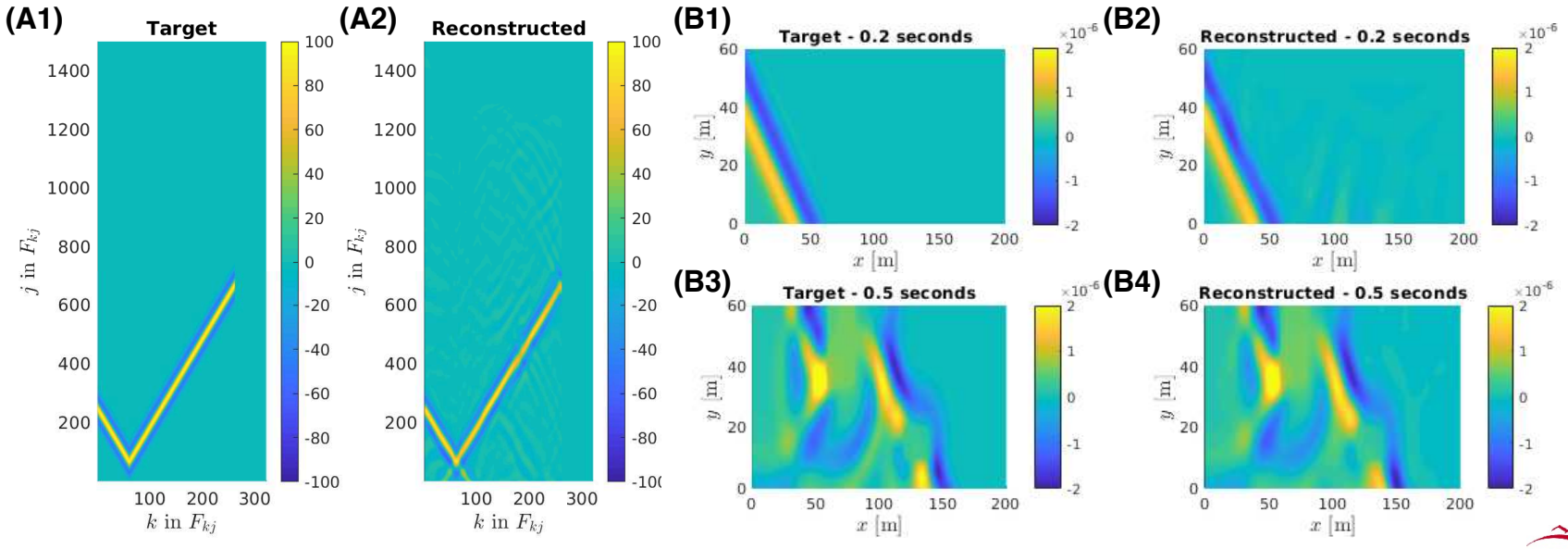
- PDE-constrained optimization
- Evaluate gradient of a misfit between measured and computed wave fields
- Optimize DRM effective forces

$$\mathbf{P}_{eff} = \begin{bmatrix} 0 \\ -\mathbf{M}_{be}^{\Omega^+}\ddot{\mathbf{u}}_e^0 - \mathbf{K}_{be}^{\Omega^+}\mathbf{u}_e^0 \\ +\mathbf{M}_{eb}^{\Omega^+}\ddot{\mathbf{u}}_b^0 + \mathbf{K}_{eb}^{\Omega^+}\mathbf{u}_b^0 \end{bmatrix}$$



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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Summary

- 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`