An efficient approach for two-scale modeling of seismic Soil Structure Interaction (SSI)
Why bother?
Any examples of it’s effects?

Mexico city 1985

Source: Mexiconewsdaily.com
So what exactly is the SSI problem?

**Global Level:**
Large basin, 3D, irregularly layered soil profile.

**Local level:**
Small site with specific features.

**Overall Goal:** Solving for responses of arbitrary, irregular global and local domain

**Challenges:**
1) Complexity in modeling the far field geological basin
2) Complexity in modeling the site- Soil-structure system

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Model Problem

Structure with base mat resting on multi-layered soil

Two questions:

1) Check extent of effect of soil layers on displacement response.

2) If significant, provide an efficient way to solve the problem.

Units are in SI, unless specified
Parametric study

1. Homogenous soil profiles $\rho = 1800$
   - $C_s = 300$ (m/s)

2. $C_s = 500$

3. $C_s = 1000$

4. $C_s = 4000$, $\rho = 2700$
   - Rock

5. Soil

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Evolution of solution techniques

Dynamic analysis – Rigid base

Springs and dashpot models for soil

Analytical techniques

Substructure based methods

Direct methods

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Finite-element based approaches

• Generic and powerful: Applicable for a wide variety of problems

Some issues:

1) Needs efficient absorbing conditions incorporated in easy formulation

2) Computational cost of modeling global domain (exterior)

3) Computational cost for large multi-layered local domain (interior)
Site-Soil-Structure Interaction

Current focus: 1) Horizontally layered soil 2) Site located at far field

Damaging effects from vertically propagating shear waves

![Image Source: Wolf](image-source: Wolf)

![Image Source: Guddati & Siddharth](image-source: Guddati & Siddharth)

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Problem Setup

Current Focus: 2D domain

- Anti-plane shear
- Plane strain

Assumptions:

1) Horizontally layered soil

2) Site located at far field

Damaging effects from vertically propagating shear waves
3 Questions

1) How do you obtain the input forces for the analysis of local domain?

2) How can we model infinite exterior?

3) How can we reduce large number of elements in the interior?
Overview of the method

**Input**

\[ u_0, \sigma_0 \]

\[ \Delta z \]

\[ u_n, \sigma_n \]

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**CFEM**

Complex Finite Elements

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**Scattering Analysis**

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**Output**

\[ PMDL \]

2D/3D SSI Model

Perfectly matched discrete layers

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Performance of the approach

Comparison in the vertical direction:

No of elements in FE model: 120

No of elements in CFE model: 18

6 fold reduction!!

Extrapolating to 3D problem

(Assuming 100 FE elements in each horizontal direction)

Regular FE: \((120) \cdot (100)^2 = 1.2\) million elements!

With CFE: \((18) \cdot (100)^2 = 180,000\) elements.

Computational savings are huge!

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Convergence comparison

Fast convergence of CFE in contrast with slow convergence of FE

The number of elements of CFE required for a target relative error is order’s of magnitude smaller

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Summary and future work

- Order of magnitude reduction in number of elements used
- Requires minimal modification to existing FE code
- Extension to a 3D model is straightforward with expected reduction in computational cost to be significant
- Can be used immediately in current frequency domain analysis procedures that use a horizontally layered soil profile

Future work:

- Extending the method to time-domain analysis
- Developing the method for irregularly layered strata