High-Fidelity Dynamic Analysis of Structures with Pile Foundations

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NHERI Natural Hazards Engineering Research Infrastructure

2024 NHERI Computational Symposium
February 1-2
Los Angeles, California

A new standard and workflow for dynamic analysis simulations of pile foundations is being developed. This approach involves creating a comprehensive workflow that spans from modeling the source to detailing soil-structure interactions, leveraging the capabilities of parallel computing. This workflow is designed to be adaptable for general users, allowing them to analyze their building models without needing in-depth knowledge of the intricate details involved.

Introduction

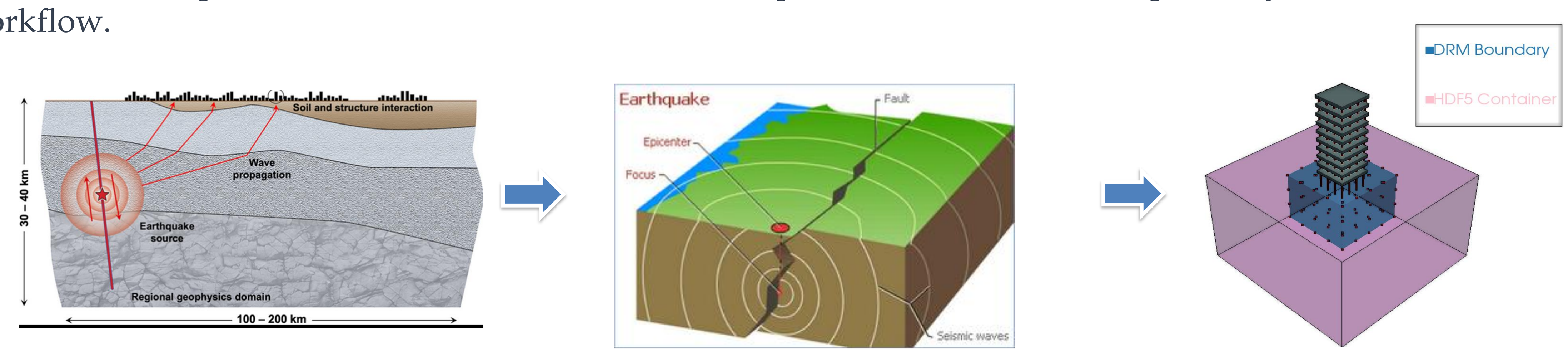
The surge in demand for precise and trustworthy simulations is undeniable. So, the role of precise modeling in predicting soil-structure interactions has never been more crucial. Finite element simulations stand at the forefront of this revolution, celebrated for their ability to model the complexities of geotechnical designs.

The goal of this research is to craft a workflow for pile foundation structures simulations that not only mirror real-world conditions but also deliver results of the highest accuracy and reliability. By integrating sophisticated techniques, we are setting a new standard for simulations for dynamic analysis of pile foundations structures using cutting-edge methods including:

- **Source modeling**
- **Domain Reduction Method**
- **Perfectly Matched Layer (PML) Elements**
- **Embedded Interface Elements**
- **Parallel Processing**

Source Modeling

- Begin the workflow by identifying hazards close to the targeted region or structure.
- Model the seismic source to realistically represent the hazard and its impact on a specific structure or area.
- Effectively interpolate results onto the grid relevant to the building or area in question, ensuring localized accuracy of data.
- Standardize output formats across different software platforms to ensure compatibility within a unified workflow.



a) Detecting faults

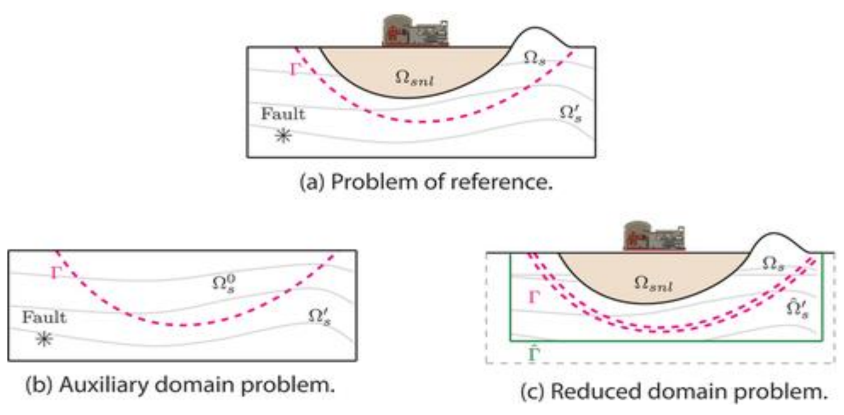
b) Running simulation for earthquake scenario

c) Report the results in a specified format around the desired structure

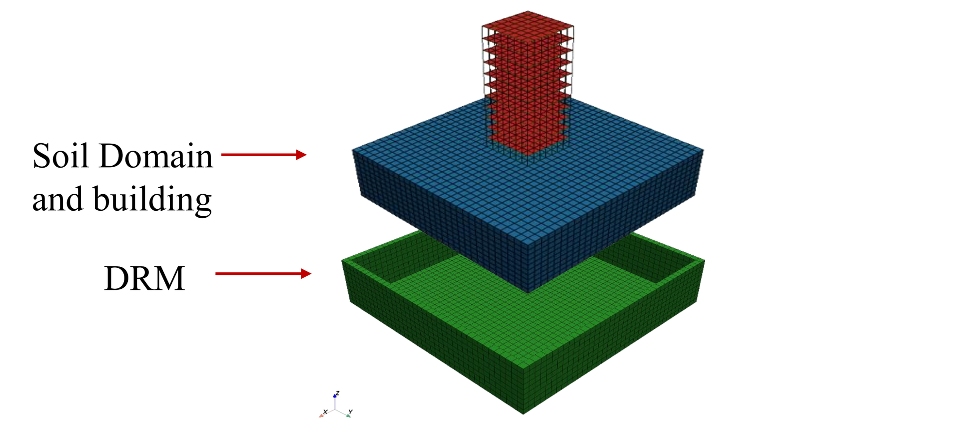
Domain Reduction Method

A computational approach that models a reduced section of a larger domain to efficiently capture the effects of source phenomena on a smaller scale with less computational cost.

- Yoshimura et al. (2003) introduced a two-step technique ideal for analyzing nonlinear earth geometries or liquefiable soils.
- It facilitates the repeated study of structures under near-fault earthquakes with directional velocity pulses and lasting displacement.



Schematic view of two step domain reduction method

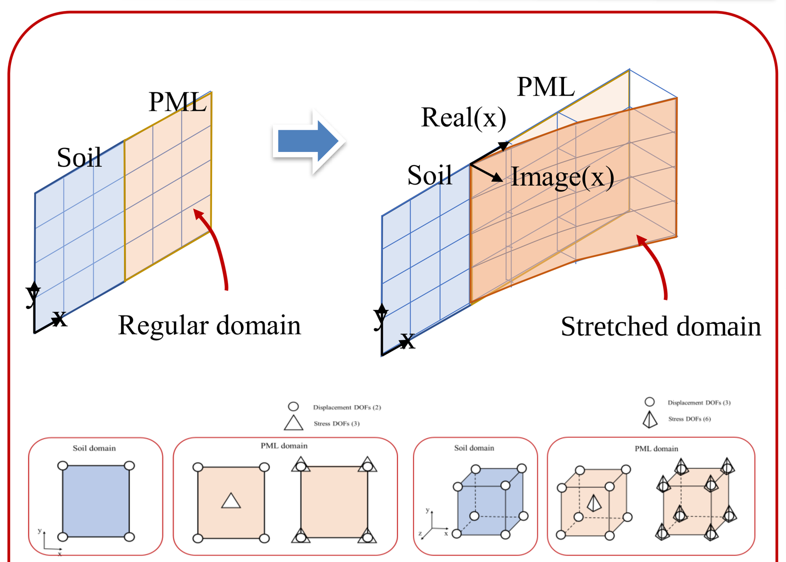


Sample of the finite element model with DRM layer around

Perfectly Matched Layer (PML) Elements

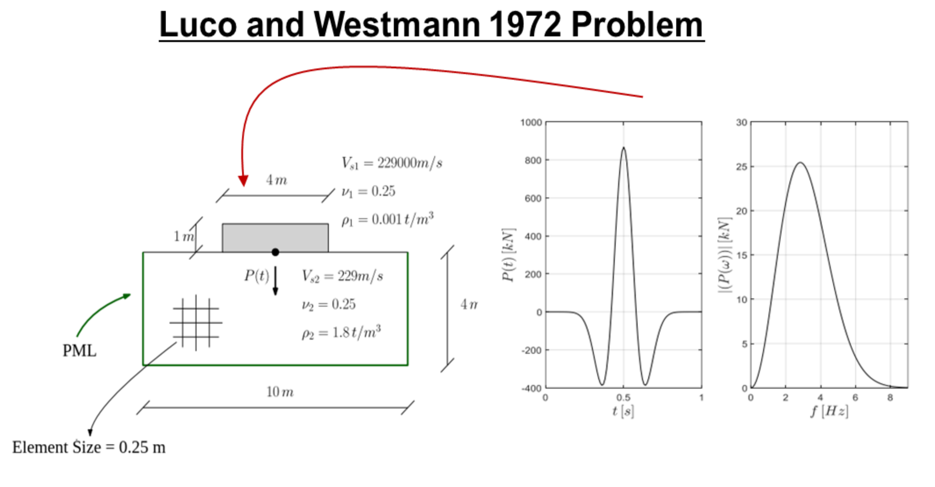
An artificial layer around the edges of the computational domain that effectively absorbs all outgoing waves.

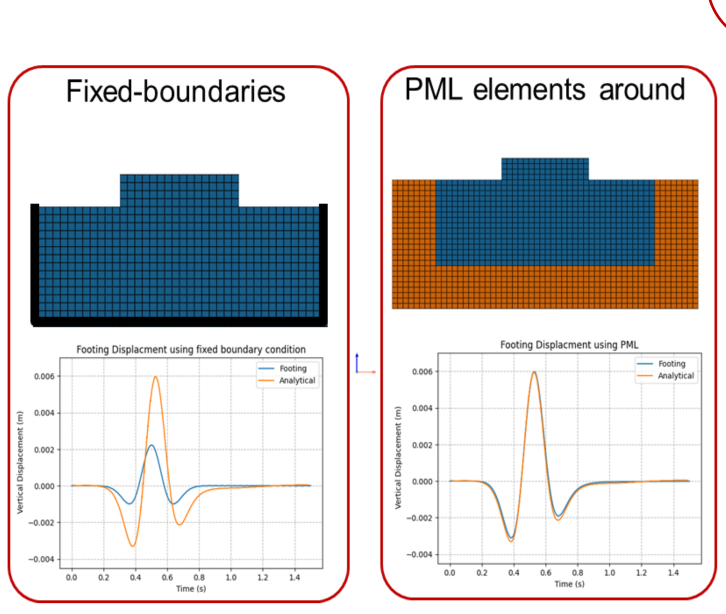
- PML formulation is based on replacing the physical coordinates of the domain with complex-valued coordinates
- Will be used in combination the DRM method to absorbs the outgoing waves caused by the DRM loading.
- Different versions of this element has been implemented and verified in OpenSees.

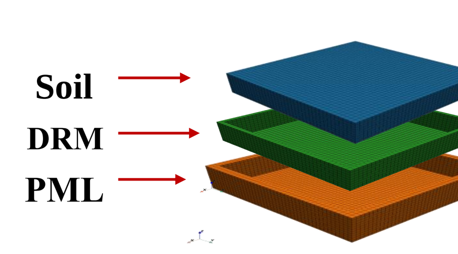


$$\lambda_i(x_i,\omega) = \alpha(x_i) + \frac{1}{j\omega}\beta(x_i)$$

Schematic view of the imaginary part of the PML elements and different versions of the PML implemented in OpenSees



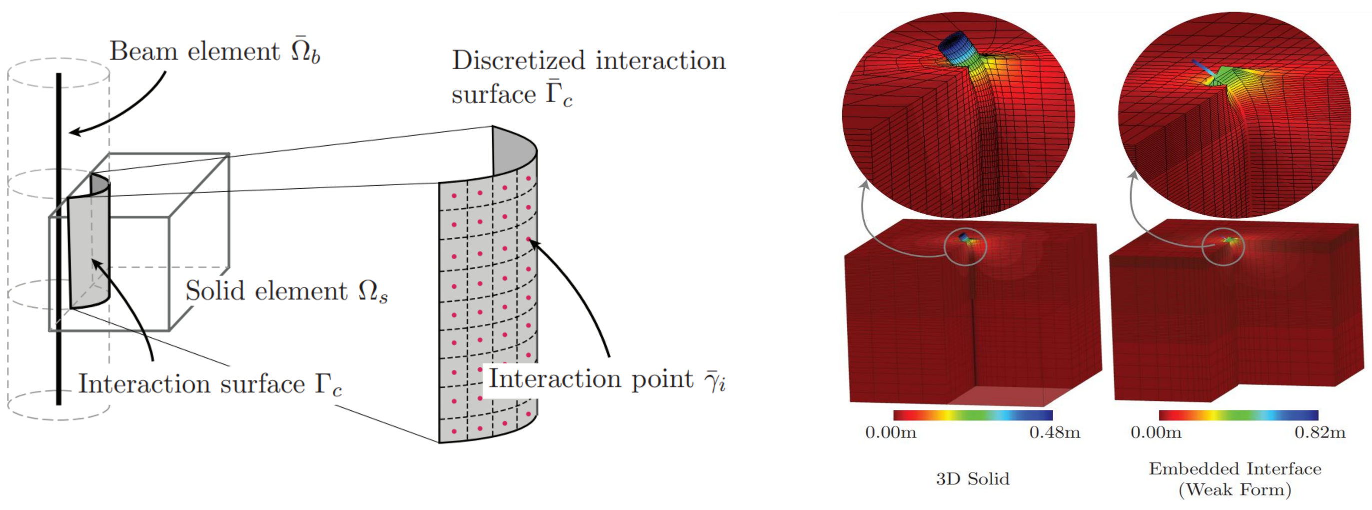




Sample of the finite element model with DRM and PML layers around

Embedded Interface Element

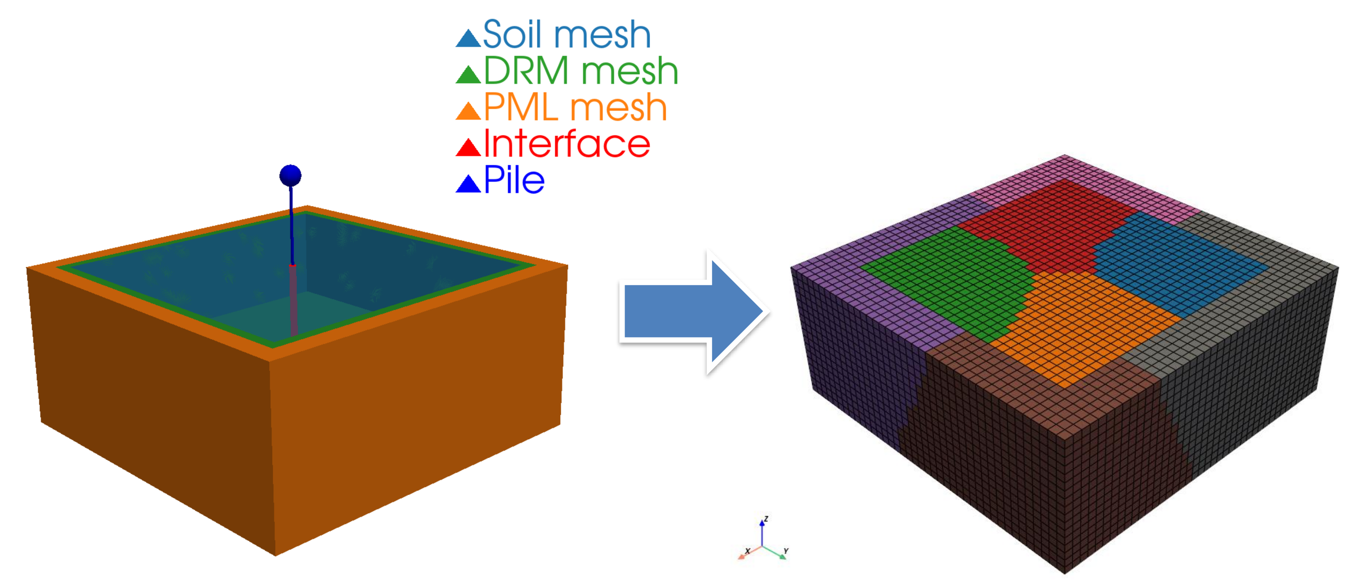
An important tool in this workflow seamlessly integrates soil and structural models, preserving crucial details. This element proposed by Turello et al. (2017) works by mapping beam degrees of freedom to solid nodal displacements by creating explicit interface, improving efficiency by eliminating the need for mesh refinement and enabling the creation of complex geometries.



Left: schematic view of the beam, solid and the explicit interaction surface among them. Right: Contour plots of horizontal displacement for 3D model and model using Embedded Interface

Parallel Processing

A key component in the workflow that expedites each step, from extracting DRM load data to decomposing the finite element model, ensuring a significantly quicker computational process. The objective is to create a simulation procedure that parses tasks across different processors, enabling users to integrate their complex structures with the pile foundations in the soil, without requiring detailed information about the underlying specifics.



Left: Finite element simulation of a wind turbine using beam elements and a lumped mass. Right: The same model partitioned across multiple processors, with each color representing a different core.

Summary

- Proposed step-by-step procedure for high-fidelity finite element simulations of structure on pile foundations
- Emphasis on realistic modeling details for accurate simulations.
- Methods designed to leverage high-performance computing and reduce run time

Acknowledgements

We would like to express our gratitude to DesignSafe, PEER, and SimCenter for providing the funding support for this research. Their contributions will play a crucial role in the successful execution of this research project.

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