Geotechnical Applications using **OpenSees**

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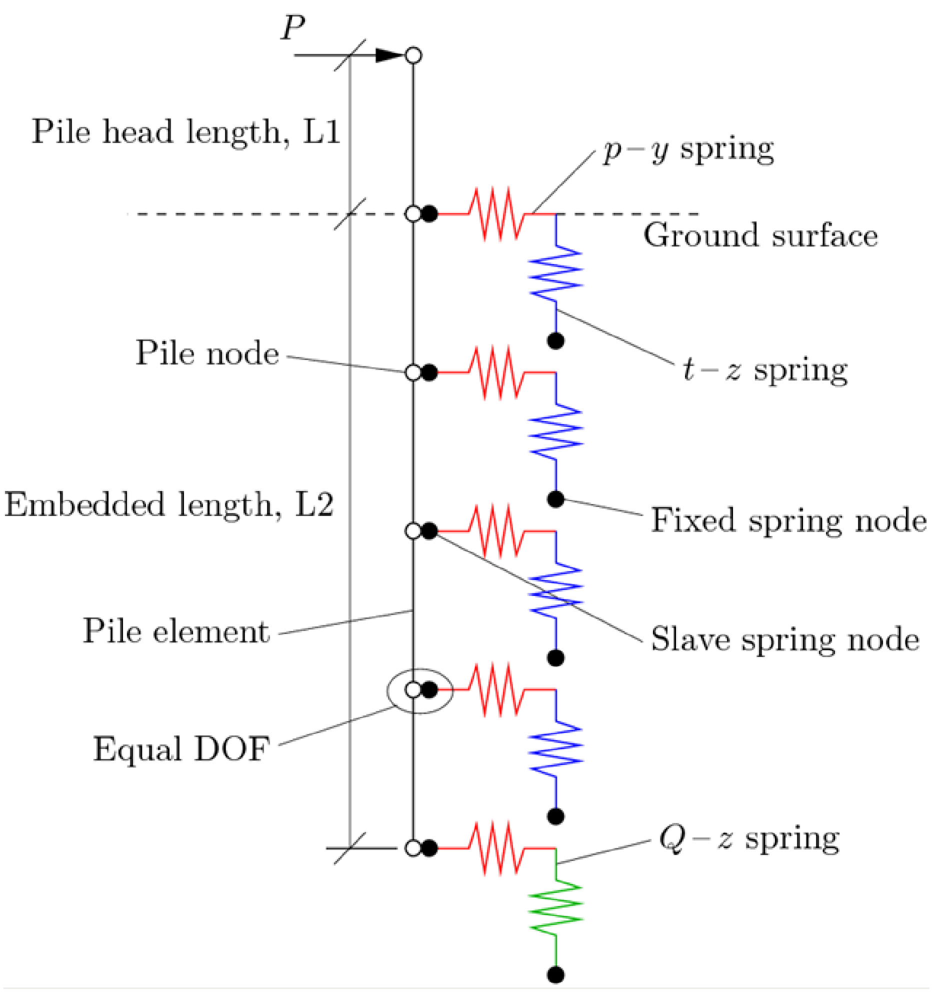
University of Washington, Seattle

2011 PEER Annual Meeting,

Geo Applications using OpenSees

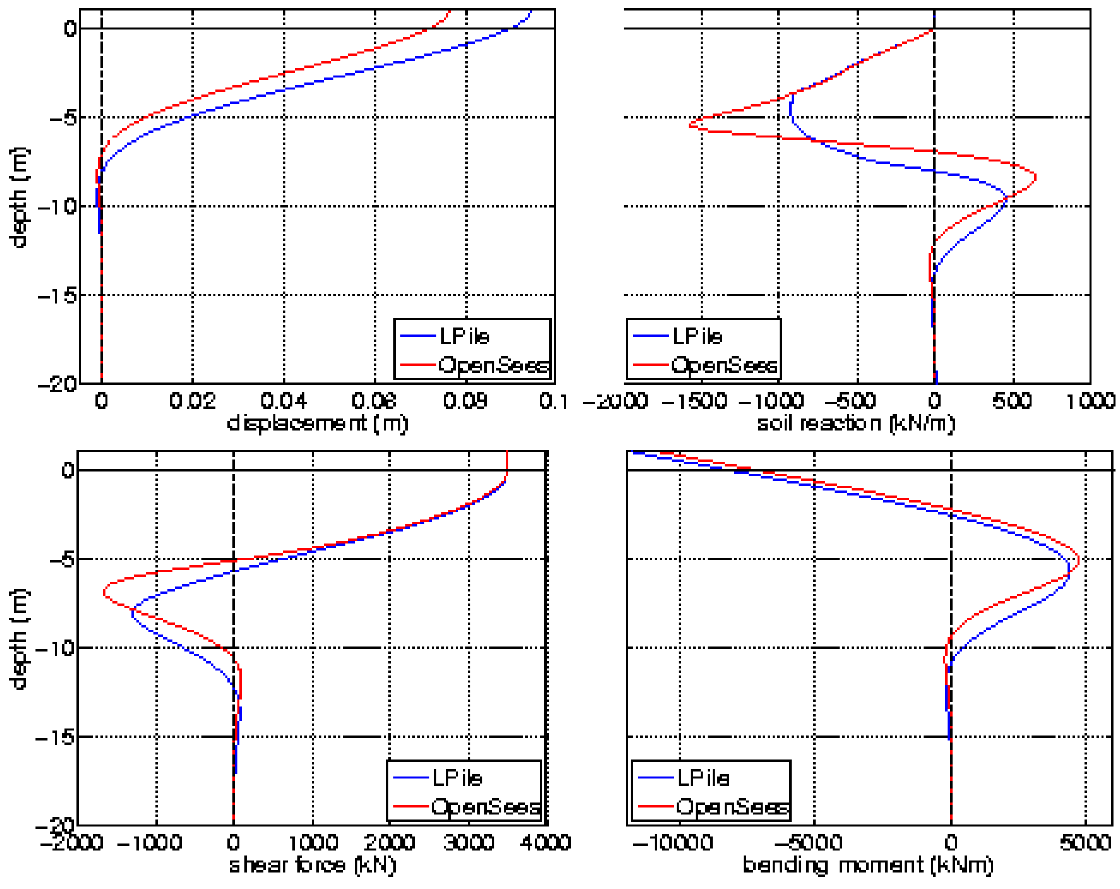
- What type of geotechnical problems can we currently analyzed using OpenSees?

Static and Dynamic Pile Analysis

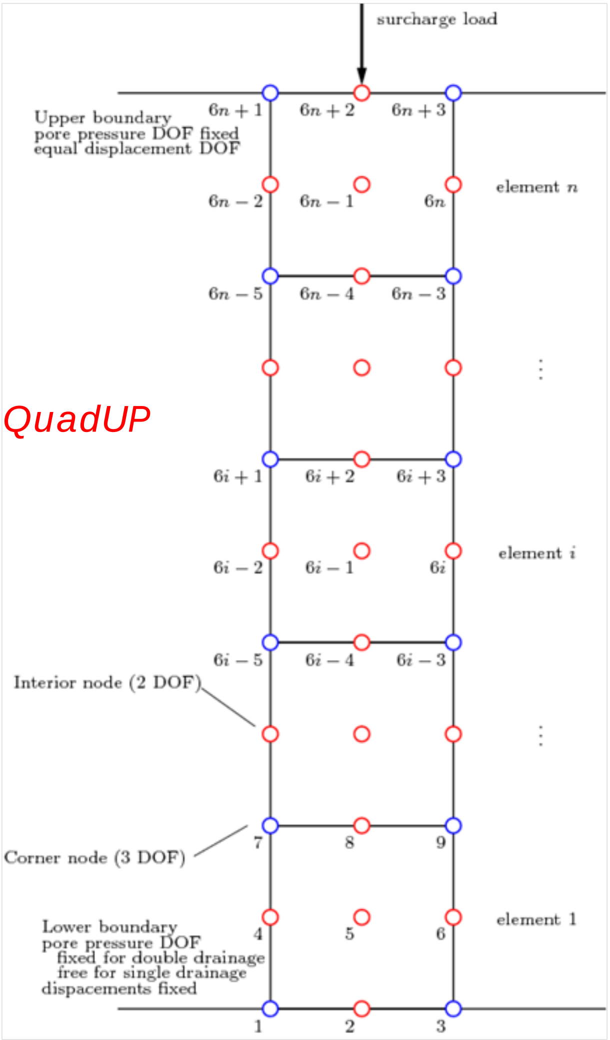


Pseudo-Static Pile Pushover Analysis

results of pushover analysis for a fixed-head pile



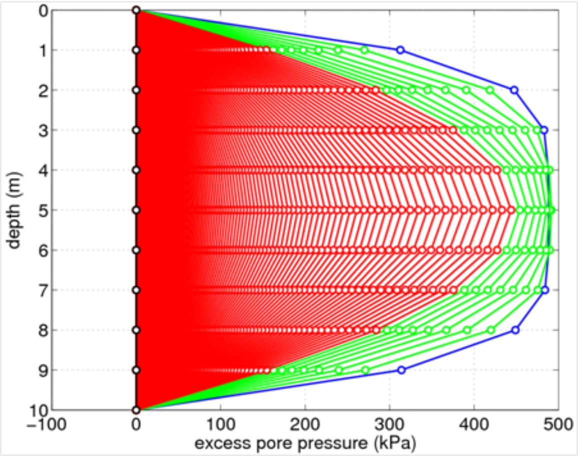
1D Consolidation



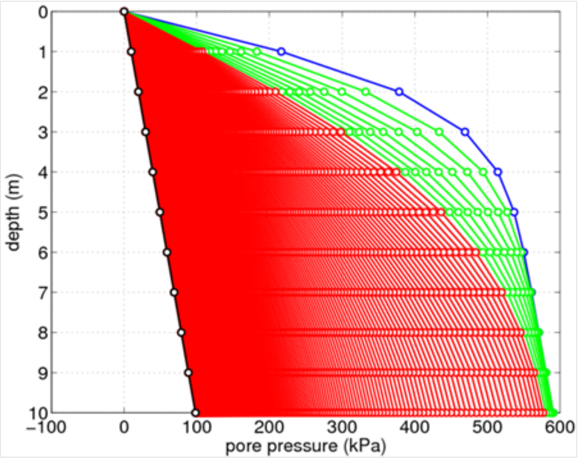
9_4_QuadUP

1D Consolidation

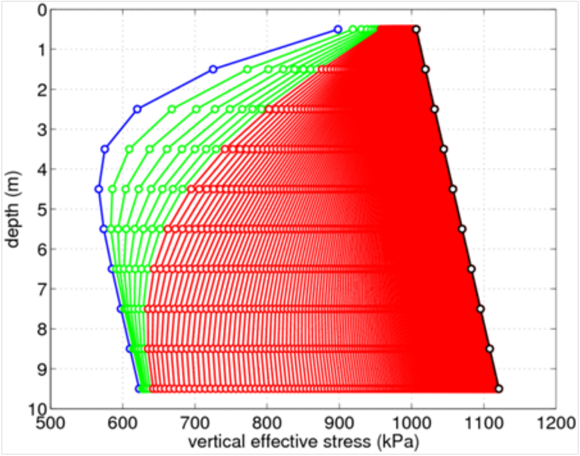
excess pore pressure: double drainage



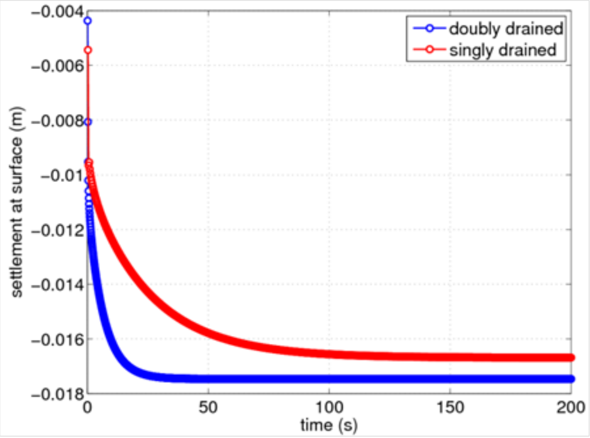
single drainage



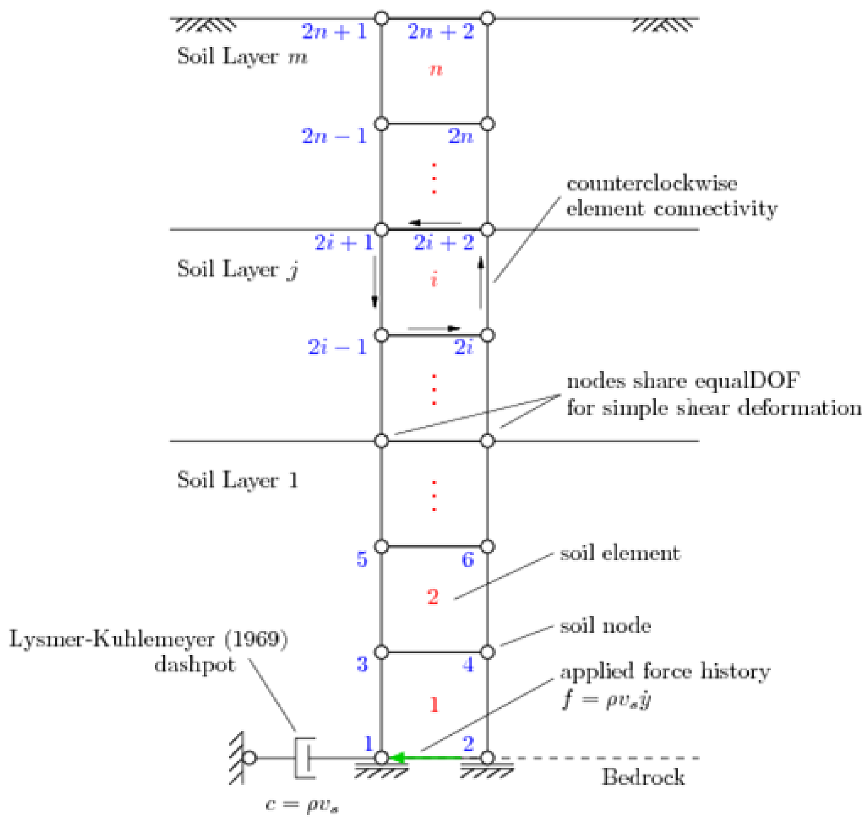
other results: vertical effective stress



vertical settlement



Total & Effective Stress Site Response Analysis



Soil constitutive models include:

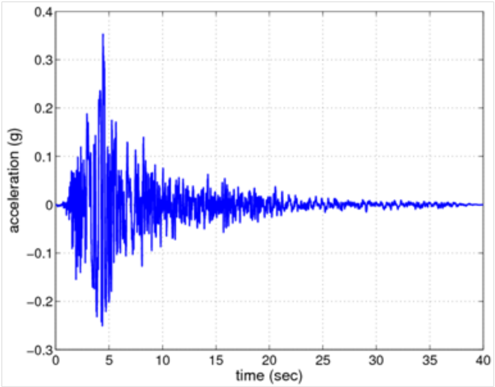
PressureDependMultiYield
PressureIndependMultiYield

A compliant base is considered using a viscous dashpot modeled using a *zeroLength* element and the *viscous* uniaxial material.

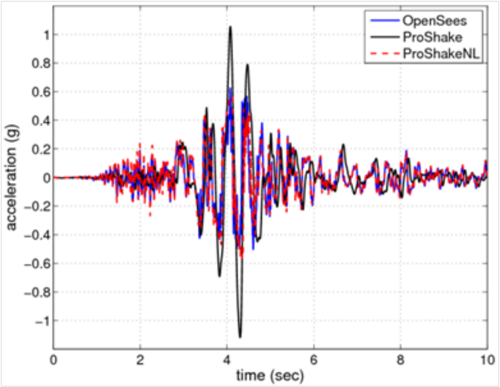
Total & EffectiveStress Site Response Analysis

comparison with other analytical methods

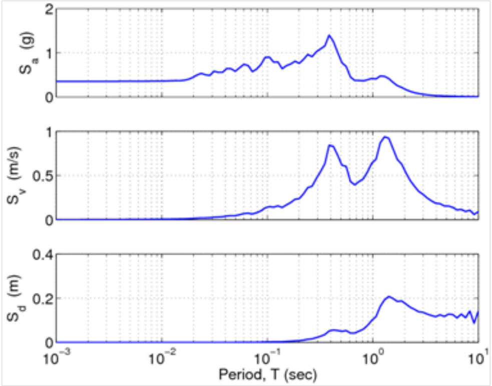
surface acceleration



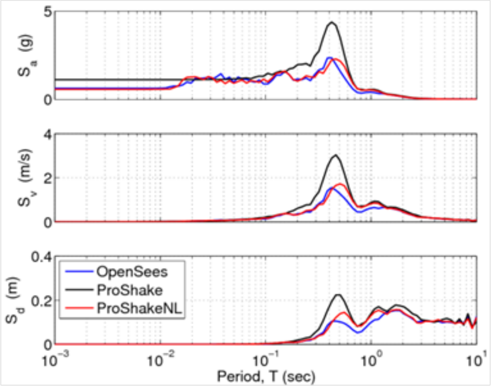
surface acceleration



surface response spectra

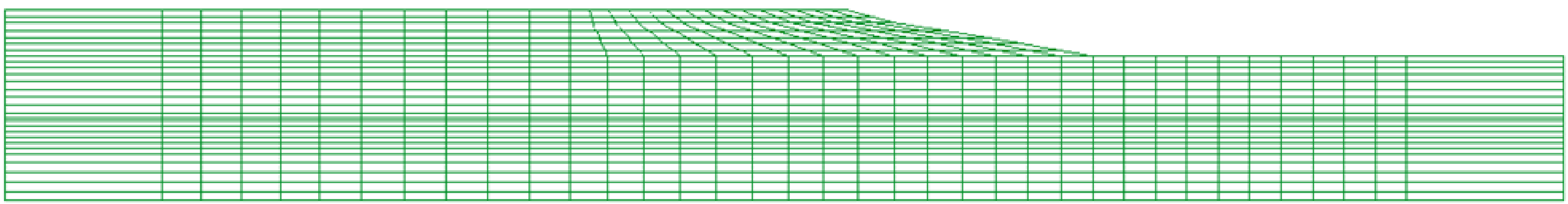


surface response spectra



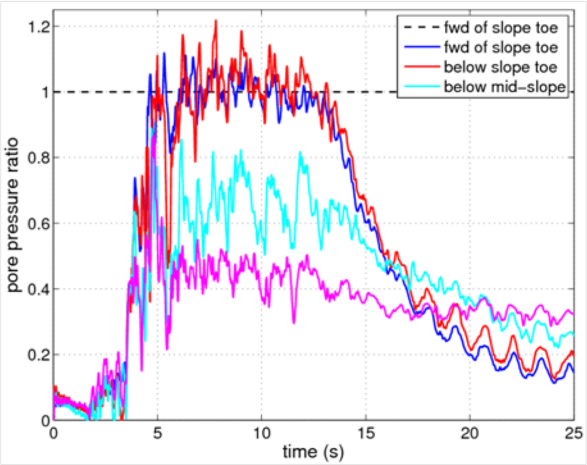
Dynamic Analysis of 2D Problems

Finite element mesh:

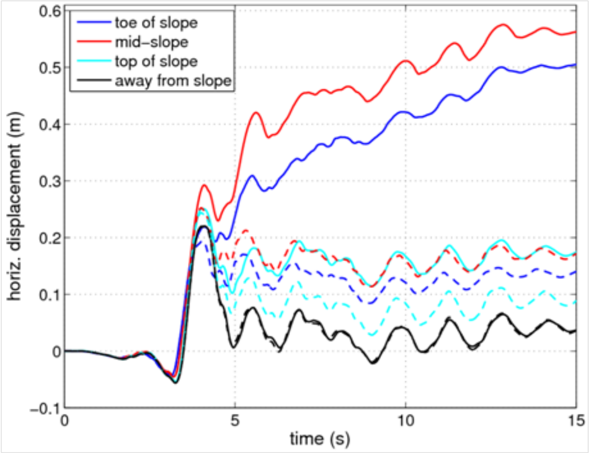


Dynamic Analysis of 2D Problems

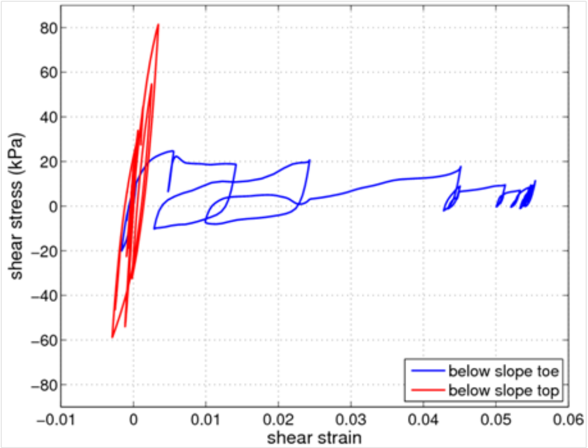
excess pore pressure ratio



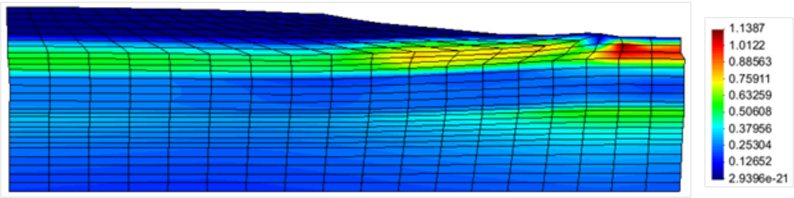
lateral displacement



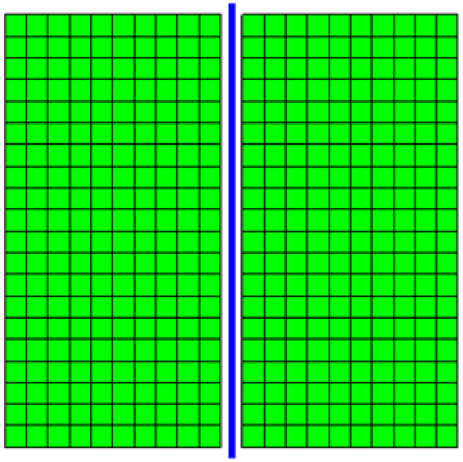
shear stress-strain



excess pore pressure ratio
contours near slope

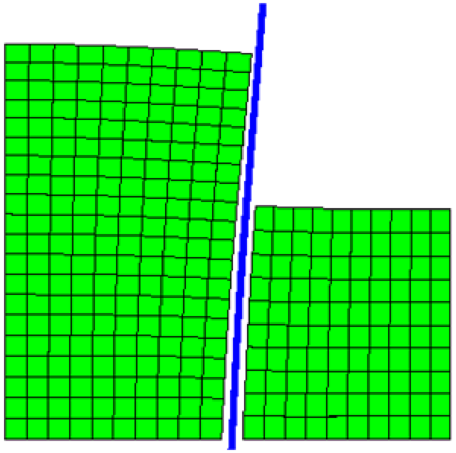


Excavation Analysis



The soil-wall interface is modeled using the *BeamContact2D* element.

The *InitialStateAnalysis* feature is used to create the gravitational state of stress in the model without accompanying displacements.

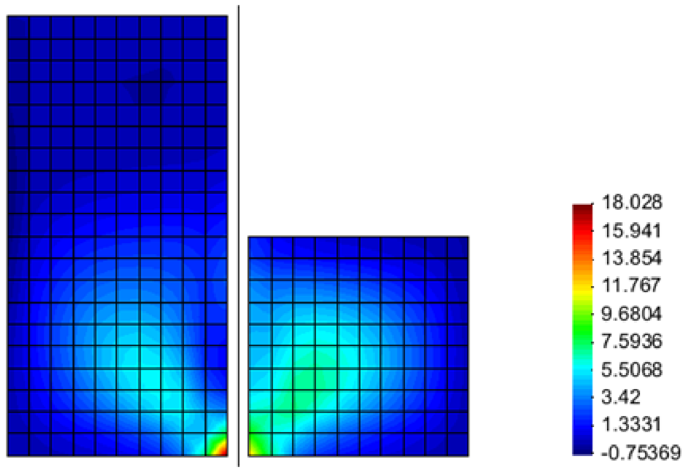


The plane strain formulation of the *quad* element is used for the soil with the *PressureDependMultiYield* nDMaterial for constitutive behavior.

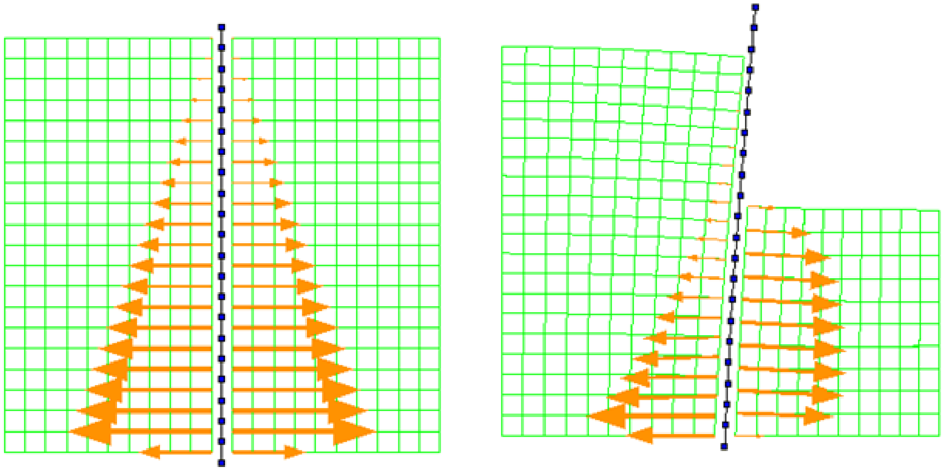
Soil elements to the right of the wall are progressively removed to simulate an excavation.

Excavation Analysis

shear stress contours

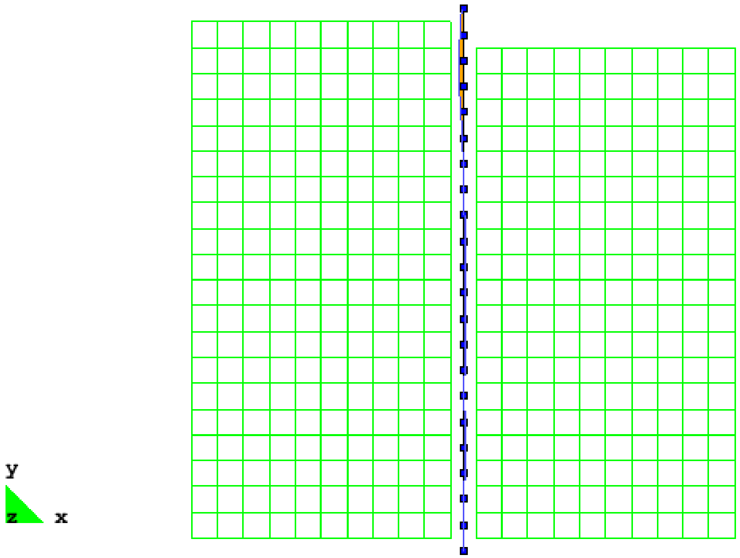


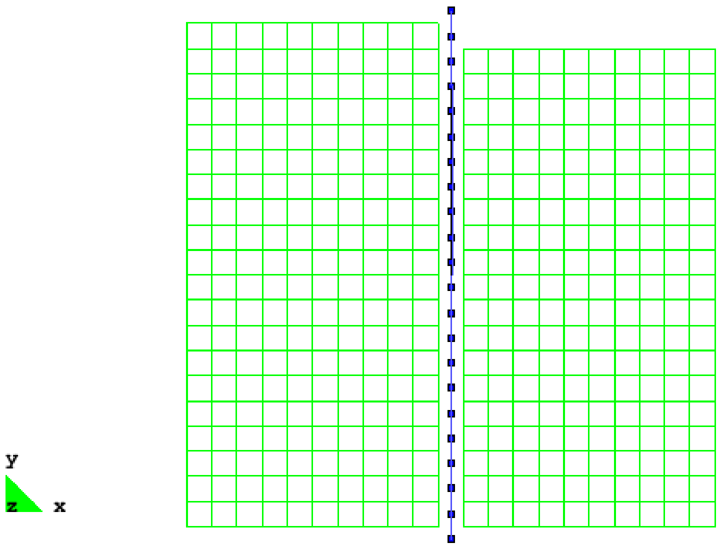
wall-soil contact forces



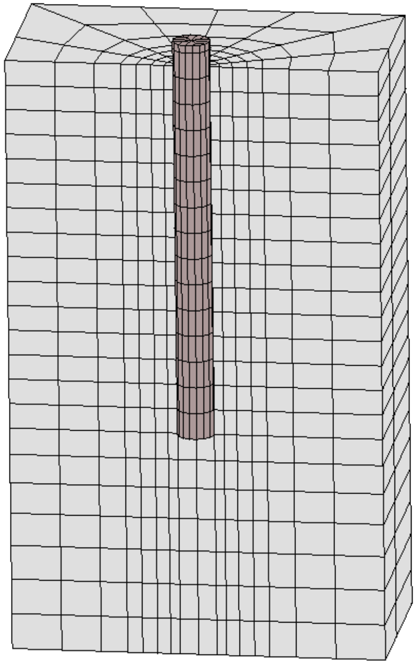
Excavation Analysis

shear and moment in the wall during the excavation analysis

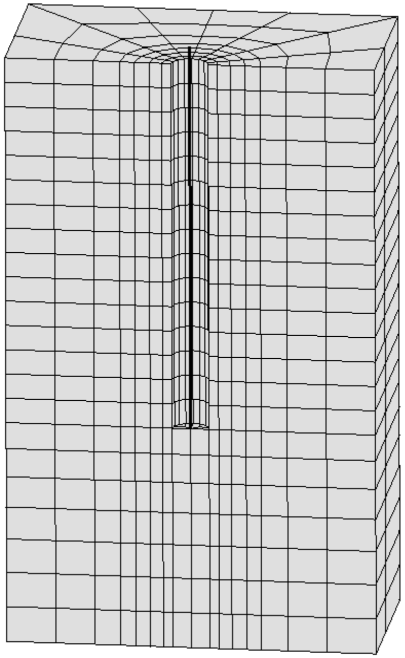




3D Foundation Analysis



Solid-Solid Model



Beam-Solid Model

3D Pile Analysis
Lateral Spreading Effects

... profile to the boundary of the model

... to capture pressure-dependent strength

Liquef...

redu...

Unliqu...

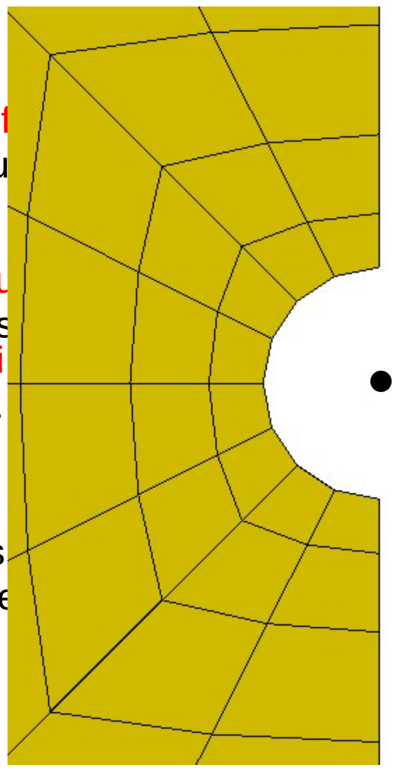
dens...

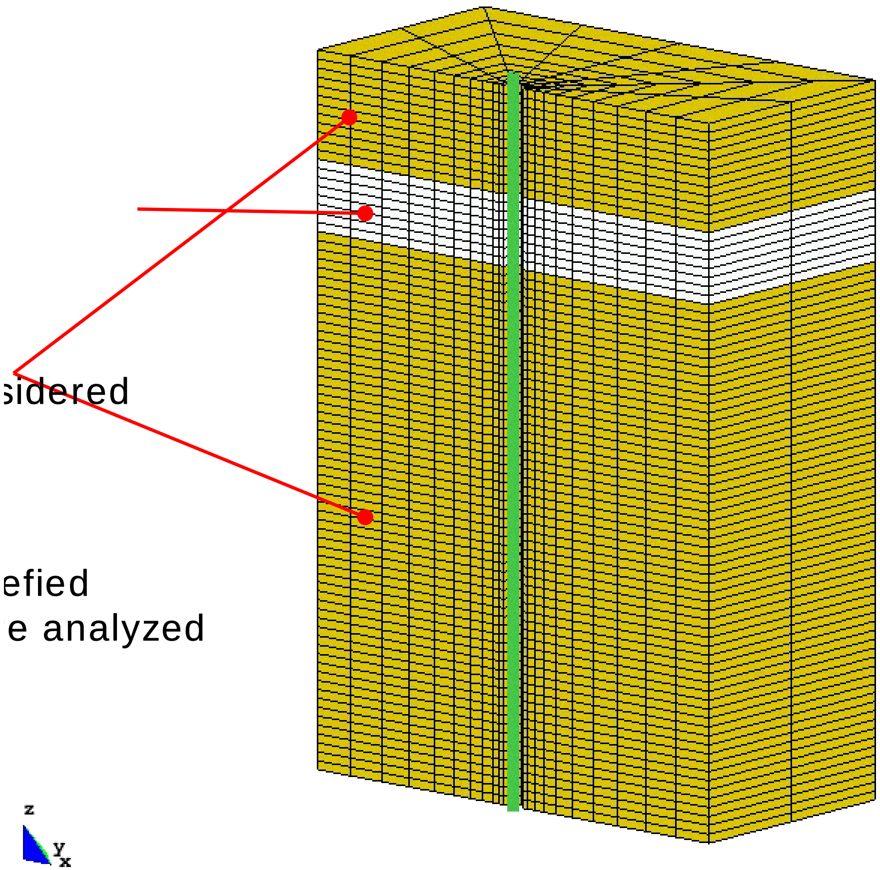
Three pi... ...sidered

(0.61, 1...

Various ... ...efied

layer de... ...e analyzed



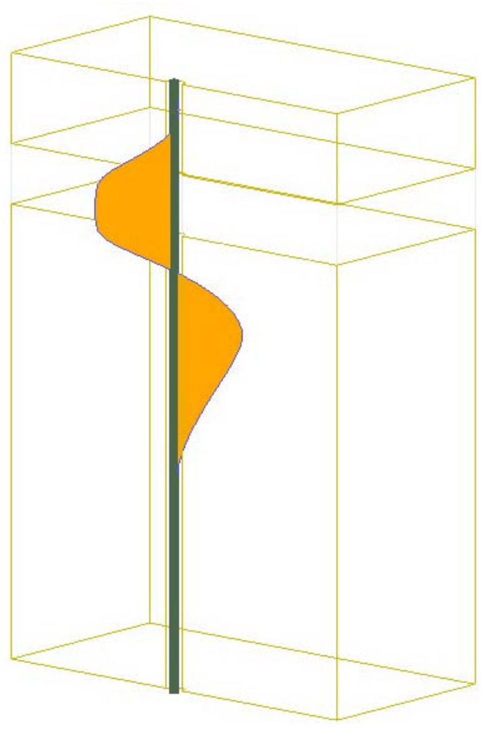


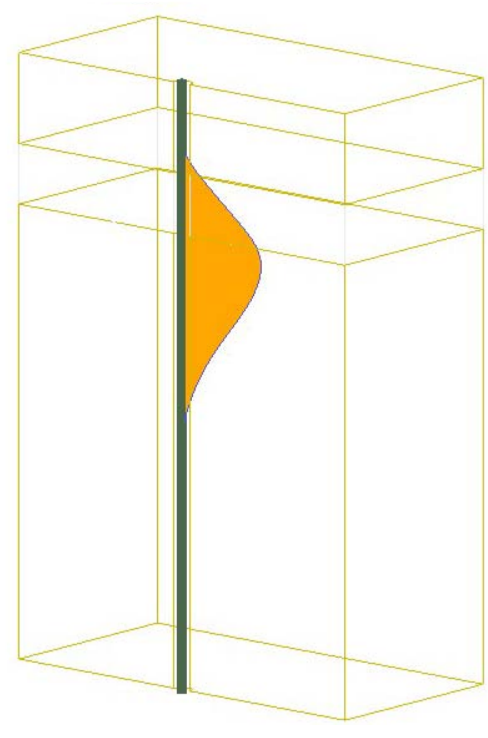
3D Pile Analysis
Lateral Spreading Effects

The beam-solid contact elements enable the use of standard beam-column elements for the pile

This allows for simple recovery of the shear force and bending moment demands placed upon the pile

Additionally, the surface traction acting on the pile-soil interface can be recovered and resolved into the forces applied by the soil to the pile



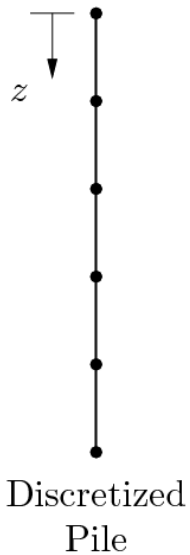


3D Pile Analysis
Lateral Spreading Effects

Work with 3D FE models has shown that use of a general pile deformation creates *p-y* curves which are influenced by the selected pile kinematics

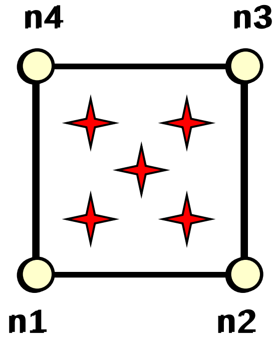
A rigid pile kinematic is used to evenly activate the soil response with depth and to obtain *p-y* curves which are free from the influence of pile kinematics, reflecting only the response of the soil.

Computational process



Current Efforts

Efficient solid element formulations would greatly benefit the performance of any simulation



How can we obtain more efficient finite element formulations?

- Reduced integration

  The integration of a typical 4-node quadrilateral element involves 4 integrations points. If this could be reduced to only a single integration point, that's 4 times less work. In 3D, it would be 8 times less work.

Can this be done?

- There are issues which must be overcome in order to use single point integration. The stiffness matrix becomes rank deficient, leading to spurious modes

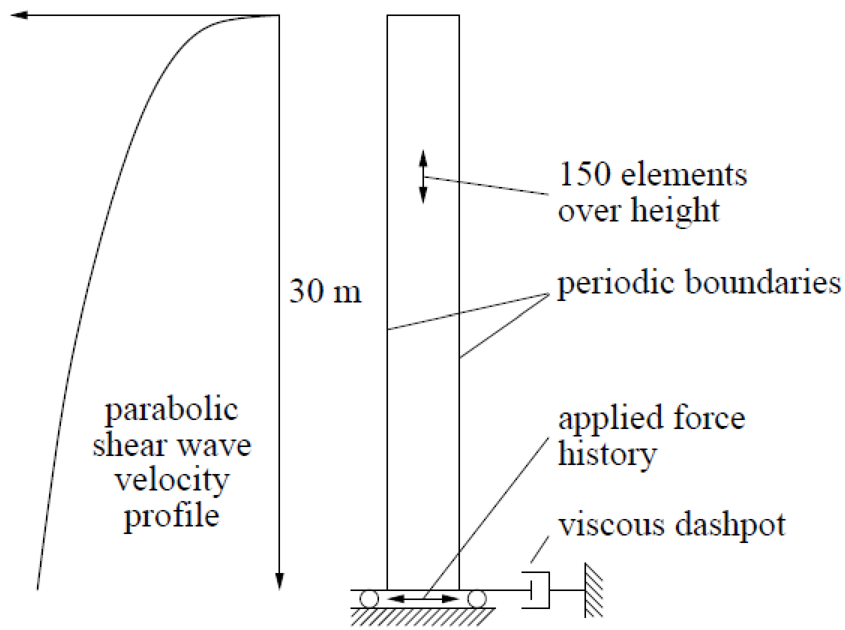
- Stabilization techniques can be used to overcome the rank deficiency

- A single-point integration element with assumed strain hourglass stabilization has been implemented in OpenSees → ***SSPquad***

Stabilized Single-Point Quad Element

The single-point element is less computationally demanding than the corresponding full integration element.

Site response analysis test problem



Execution time: Quad element = **330 sec** SSPquad element = **146 sec**

Modeling Tools and Improvements

Liquefaction and lateral spreading involve saturated soil. When saturated, soil behavior can be described as a two-phase medium.

Finite element formulations have been developed to consider this aspect of soil behavior (Zienkiewicz and Shiomi 1984, Prevost)

The **SSPquad** element has been extended for use in the analysis of fluid saturated porous media. This new element has also been implemented in OpenSees → ***SSPquadUP***

The ***SSPquadUP*** element uses a mixed pressure-displacement formulation commonly known as the u-p approach.

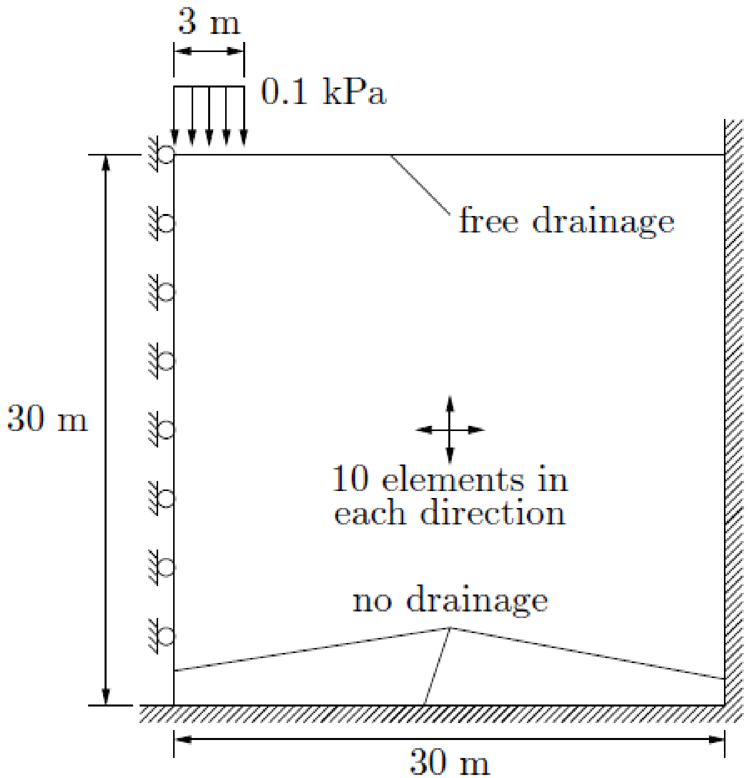
A staggered time integration scheme is used to introduce unconditional stability in the temporal solution and to symmetrize the coupled system.

Near the incompressible-impermeable limit, this element does not satisfy the inf-sup condition, and stability of the pressure field solution cannot be guaranteed. A consistent stabilizing term is added to the system.

Stabilized u-p Quad Element

The SSPquadUP element is evaluated using several test problems. The results are compared to a nine-node quad element with a u-p formulation.

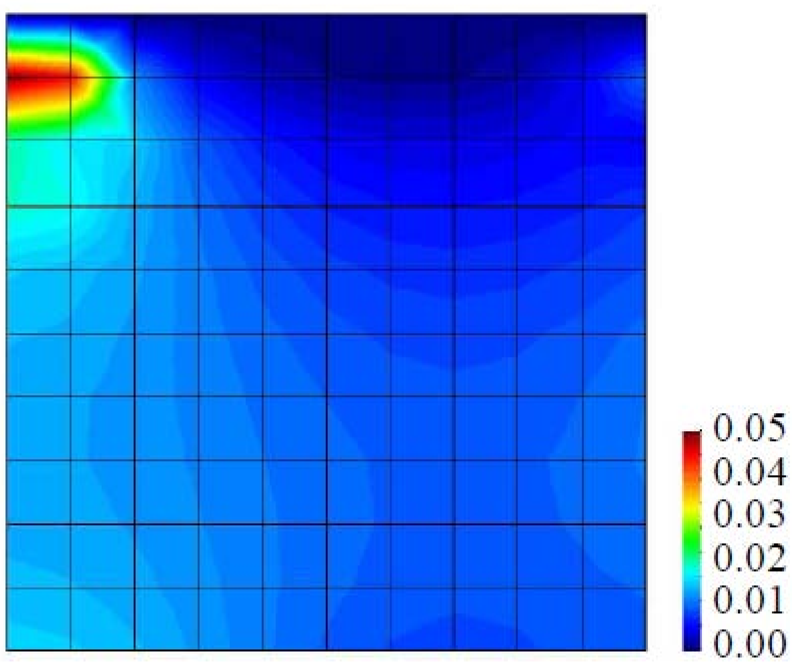
Flexible footing load test problem



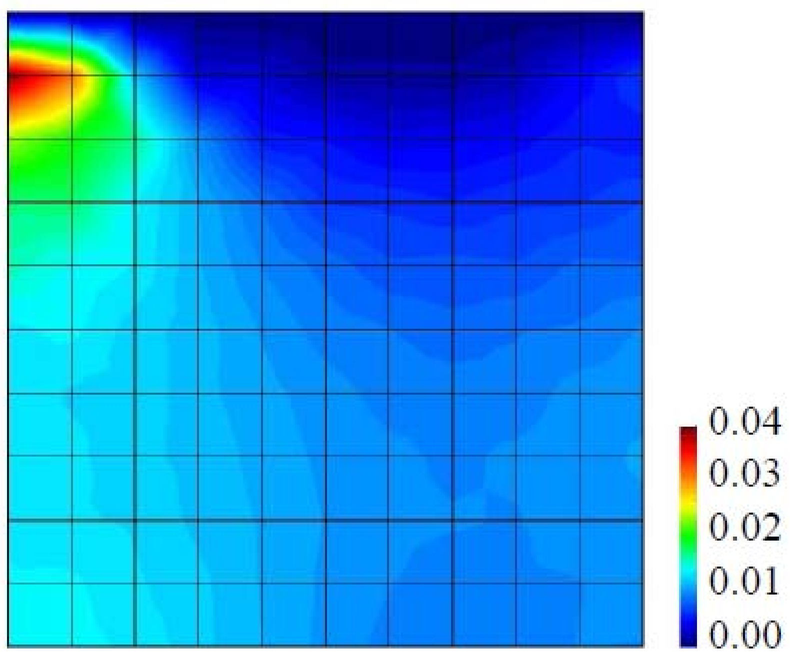
Stabilized u-p Quad Element

The effectiveness of the pressure field stabilization near the incompressible limit can be demonstrated by comparing the pore pressure distribution for stabilized and unstabilized cases.

9 node quad element



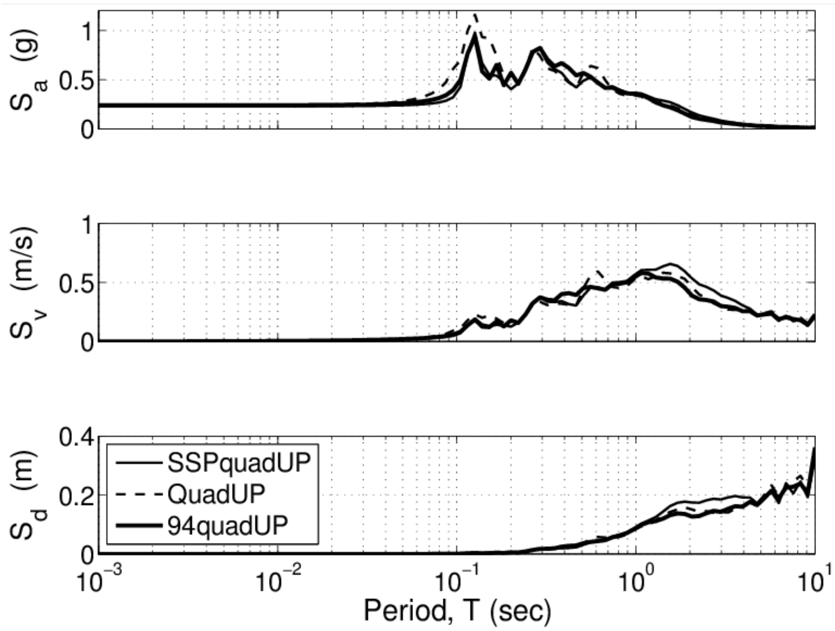
stabilized SSPquadUP



Stabilized u-p Quad Element

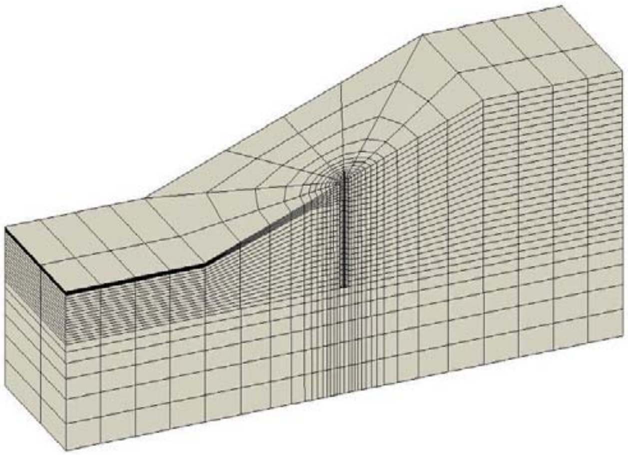
A site response analysis is conducted to gauge the robustness and efficiency of the SSPquadUP element.

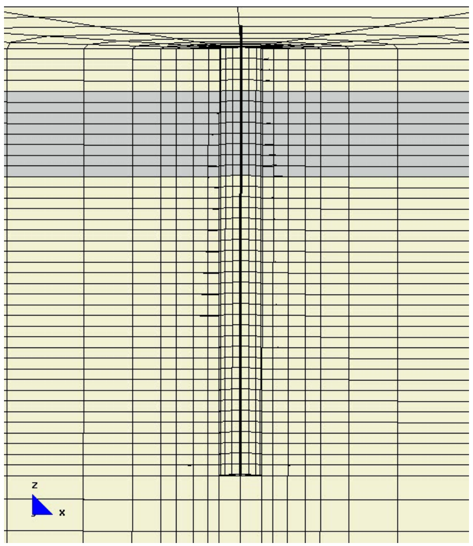
Surface response spectra

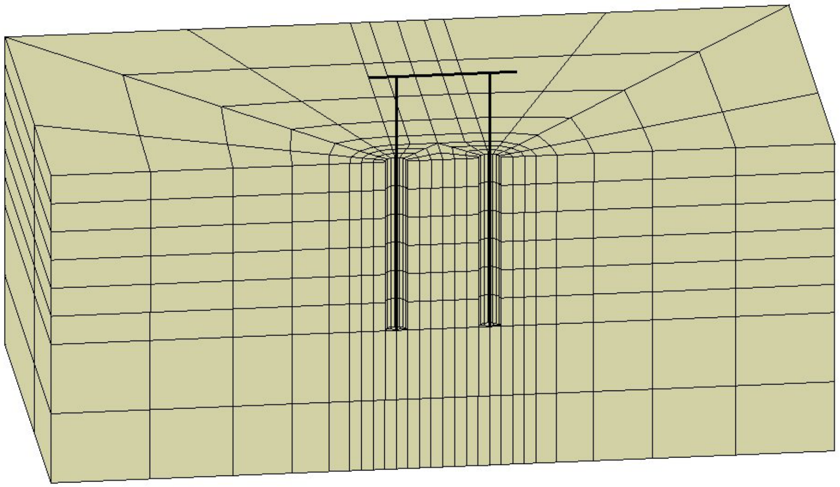


Element	SSPquadUP	QuadUP	94quadUP
Execution time	4 min 12 sec	17 min 41 sec	15 min 20 sec

Other Applications: Piles in Sloping Ground, Bridge bent analysis







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