OpenSees User Workshop
Geotechnical tools

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Enabling Technologies Overview

- Object Oriented Framework (OpenSees core, nDarray,)
- Template Elasto–Plasticity
- Full Coupling of Solid and Fluid
- Domain Reduction Method
- Distributed Memory Parallel Computing
- General Large Deformations
- Stochastic Elasto–Plasticity
- Visualization

Applications Overview

- Template Elasto–Plasticity and Damage (constitutive behavior, isotropic, kinematic, distortional hardening/softening)
  - Small deformations
  - Large deformations
- Static behavior of pile–soil systems
  - Single piles in layered soils
  - Interaction of piles in pile groups
- Wave (synthetic and seismic) propagation in soils (1D – 3D)
  - Single phase soils (dry)
  - Multiphase phase soils (saturated, coupled fluid–solid)
- Seismic Soil–Foundation–Structure (SFS) Interactions
  - Free field motions in 1D, 2D and 3D
  - SFS Interaction in 1D, 2D and 3D

Template Elasto–Plasticity

Yield function (or lack of YF), potential function (and/or flow directions), hardening/softening laws (scalar, rotational/translational kinematic, distortional...)

- Independent definitions of:
  1. Yield function (and it's derivatives)
  2. Plastic flow direction (first and second derivatives of potential function)
  3. Evolutions laws for the above two
- This is used to create Template Elastic–Plastic Models

Template Commands

```
## Yield surface
set ys "-DP"
## Potential surface
set ps "-DP 0.2"

## Isotropic evolution law:
set ES1  "-Leq  0.0"
## Kinematic evolution law:
set ET1  "-Linear 100.0"

## Elastic model
nDMaterial ElasticIsotropic3D 1 70000.0 0.2 1.8

## EPState_____________alpha___k
set EPS "-NOD 1 -NOS 2  0.2  2.0"

## Creating nDMaterial-----MatTag--ElMatTag--
nDMaterial Template3Dep      2       1     -YS $ys -PS $ps -EPS $EPS -ELS1 $ES1 -ELT1 $ET1

##_____________tag_____8 nodes________matID__bforce1_bforce2_bforce3_rho
element Brick8N  1    5 6 7 8 1 2 3 4    2      0.0     0.0     0.0    1.8
```

Template Elastic–Plastic Models

- Yield surfaces: von Mises `VM`, Drucker–Prager `DP`, Rounded Mohr–Coulomb `RMC`, Cam–Clay `CC`, Parabolic Leon `PL`, User added (really easy),

- Plastic flow directions (potential surfaces): von Mises `VM`, Drucker–Prager `DP`, Rounded Mohr–Coulomb `RMC`, Cam–Clay `CC`, Manzari–Dafalias `MD`, Parabolic Leon `PL`, User added (really easy),

Template Elastic–Plastic Models (contd)

- Isotropic and/or kinematic and/or distortional hardening/softening
  - linear and/or nonlinear isotropic hardening/softening
  - linear or nonlinear kinematic hardening/softening
    - Armstrong–Fredericks nonlinear kinematic hardening/softening
    - Bounding surface nonlinear (Dafalias–Popov) kinematic hardening/softening
  - User defined distortional hardening

- Hierarchical database of models (by materials)

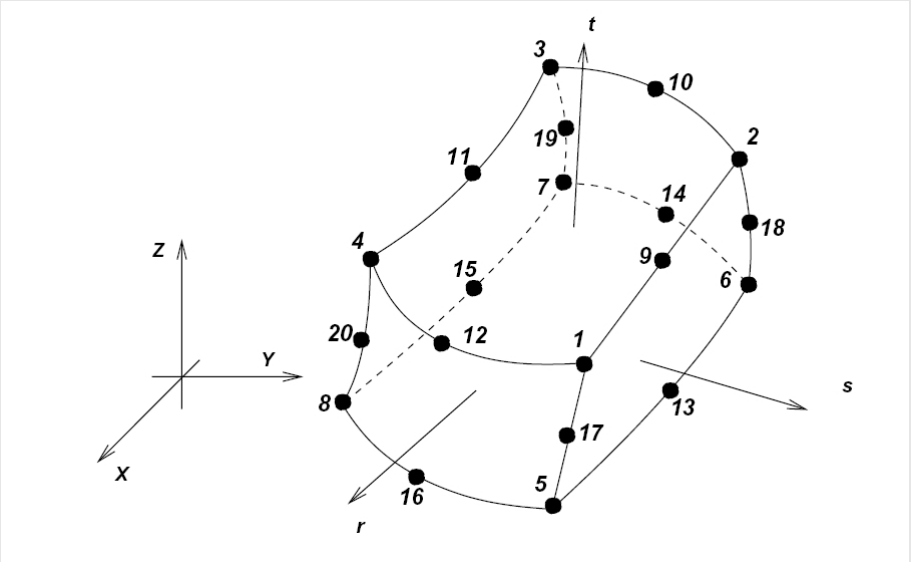
3D Solid Elements

Three types of brick elements:

- 8 node brick element `Brick8N`

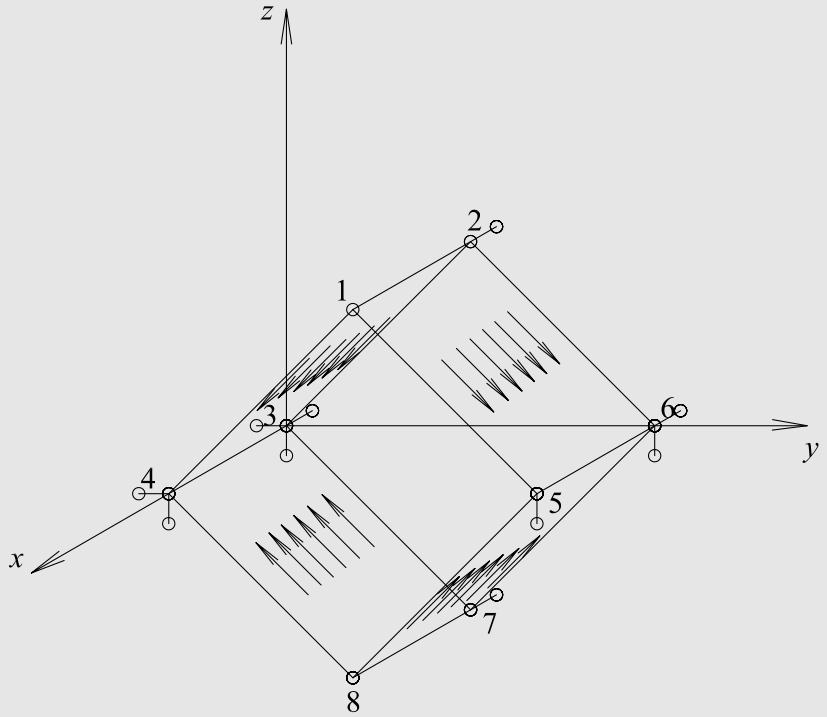
```
#_____________tag_____8 nodes_____matID__bforce1_bforce2_bforce3_rho
element Brick8N  1  1 2 3 4 5 6 7 8  1      0.0     0.0     $g     $rho
```

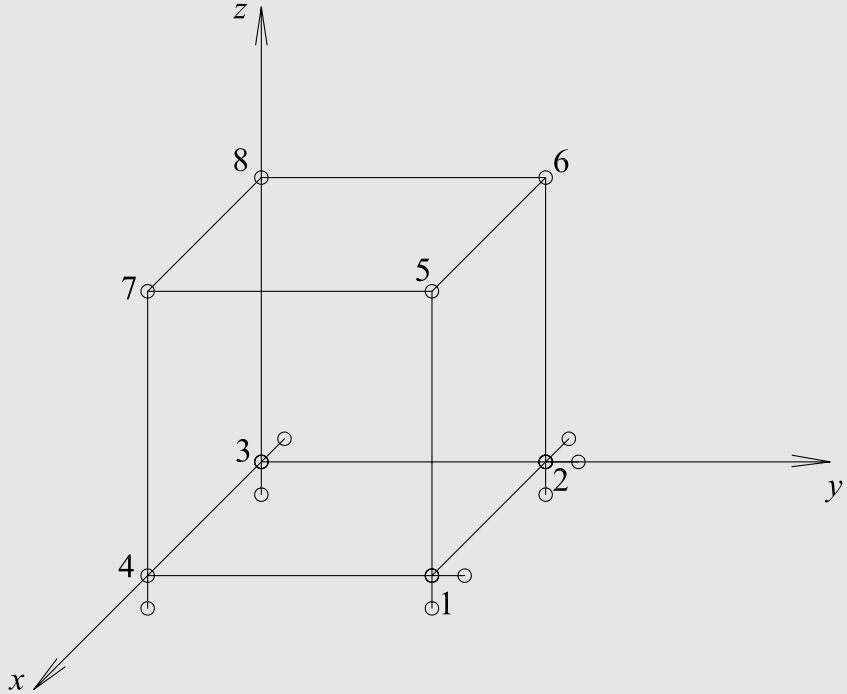
- 20 node brick element `Brick20N`
- 27 node brick element `Brick27N`



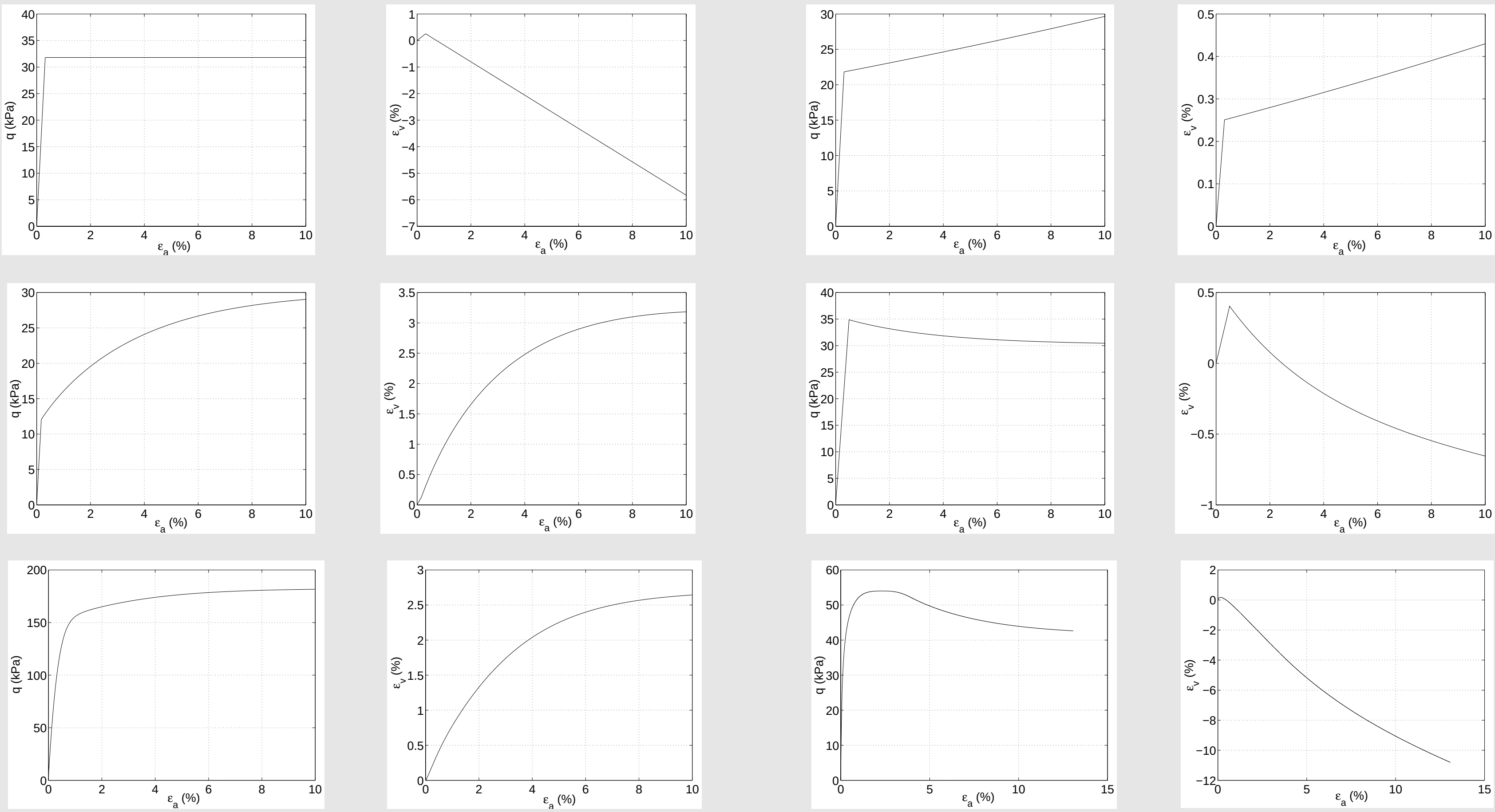
Template E-P Examples

- `SmallDeformationExamples.tcl`
- `Pure_Shear_Test.ops`
- `Triaxial_Test.ops`
- `Simple_Shear_Test.ops`

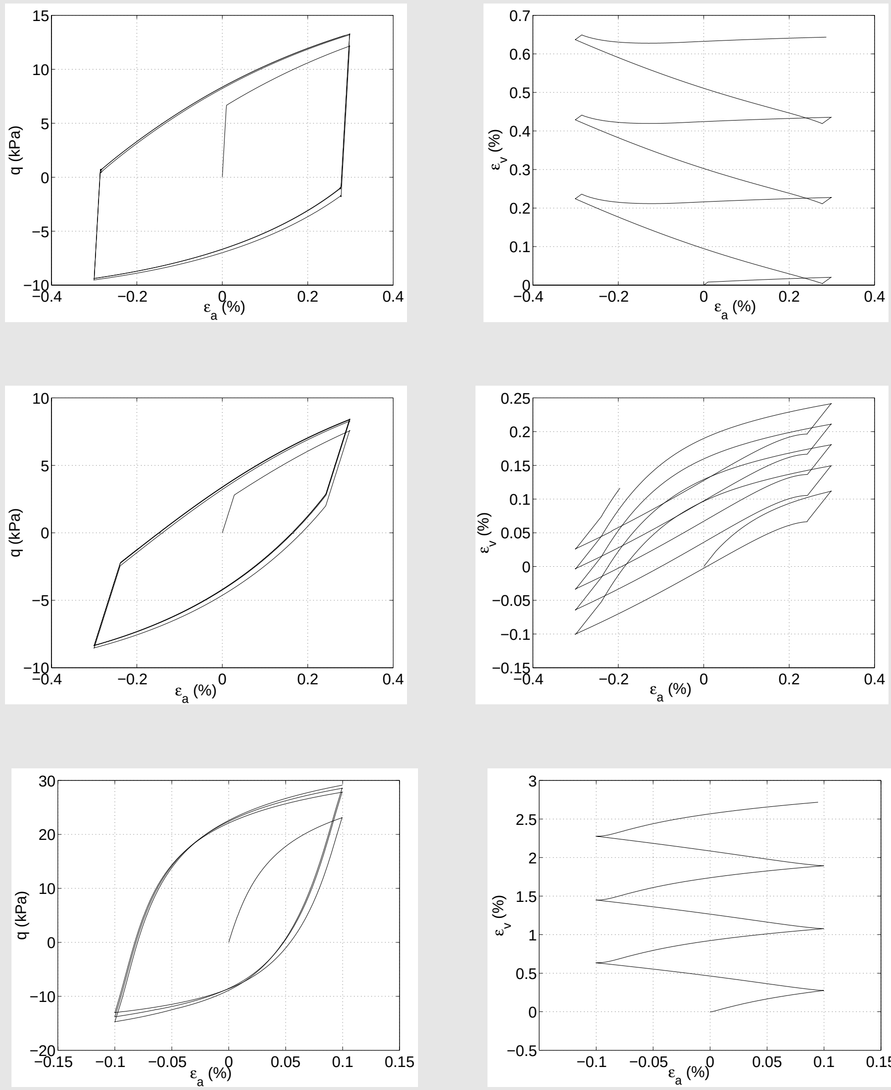




Template Examples



Template Cyclic Examples



Winkler Springs (aka PY springs)

```
uniaxialMaterial PySimple1 matTag? soilType? pult? y50? Cd? <c>

uniaxialMaterial TzSimple1 matTag? tzType? tult? z50? <c>

uniaxialMaterial QzSimple1 matTag? qzType? qult? z50? <suction?  c?>

uniaxialMaterial PySimple1 1 1 100 0.01 0.0
element zeroLength 2 2 3 -mat 1 -dir 1
```

- Type is usually set to 1 for clay and 2 for sand.
- Note that `p` and `pult p` are distributed loads [force per length of pile] in common design equations, but are both loads for this uniaxialMaterial [i.e., distributed load times the tributary length of the pile].

Full Coupling of Solid and Fluid

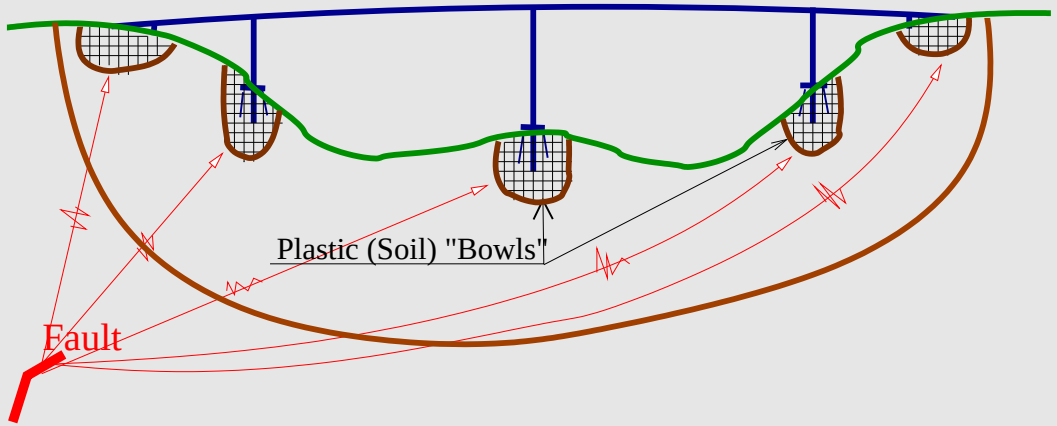
- General form, full coupling, (currently only small deformations)
- DOFs: $\bar{u}_{Lj} \rightarrow$ solid displacement $\bar{p}_L \rightarrow$ fluid pressure $\bar{U}_{Lj} \rightarrow$ fluid displacement
- 8 node brick element `Brick8N_u_p_U`

```
#(28 args)____________tag____8 nodes____matID_bforce1_bforce2_bforce3
                  porosity alpha solid_density fluid_density
                      perm_x perm_y perm_z s_bulk_modu f_bulk_modu pressure
element Brick8N_u_p_U 1   5 6 7 8 1 2 3 4    1      0.0     0.0     -9.81
                     0.8      1.0        1.8             1.0
                       10e-5  10e-5   10e-5    10e5          10e5      0
```

- 20 node brick element `Brick20N_u_p_U`

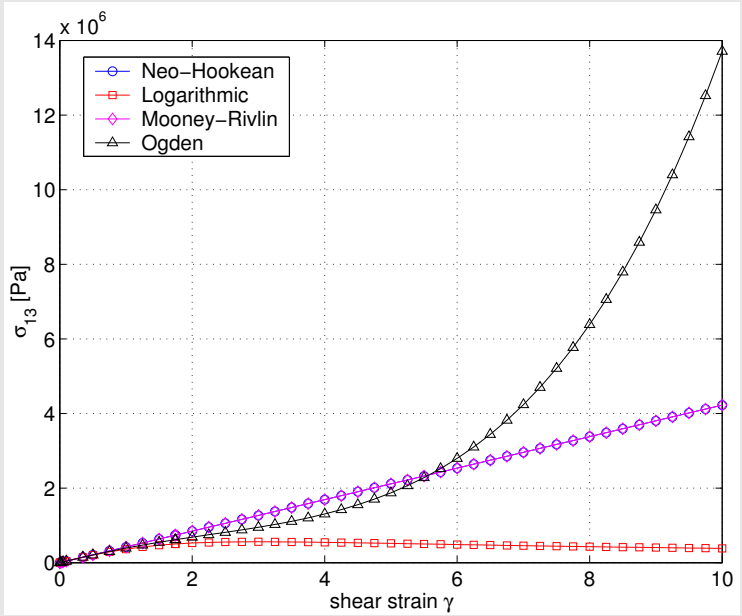
Plastic Bowl Loading (aka Domain Reduction Method)

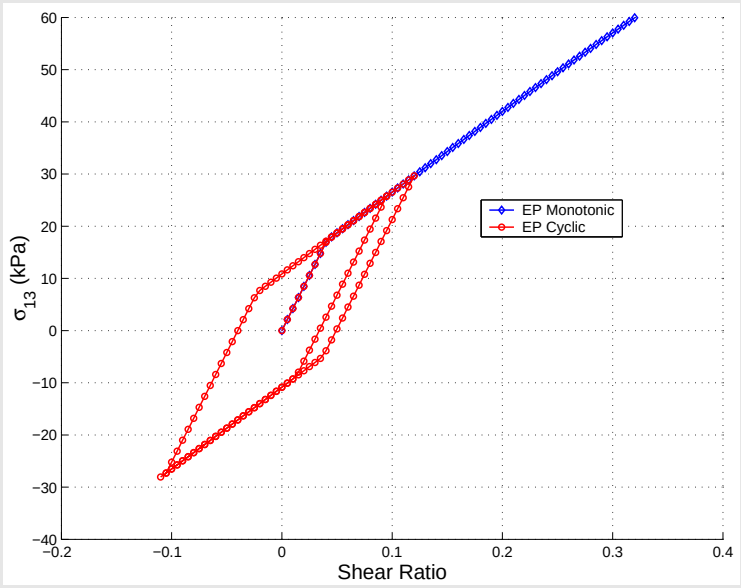
- Based on work by Bielak et al. at CMU.
- Seismic motions and accelerations input at the layer of elements that encompass an elastic–plastic zone (using SHAKE, Green's functions, Quake, SCEC...), non–reflective boundaries
- ```
  pattern PBowlLoading 1 -pbele "$Dir/PBElements.dat"
        -acce "$Dir/Inp_acce.dat" -disp "$Dir/Inp_disp.dat" -dt 0.02
             -factor 1 -xp 6.0 -xm -6.0 -yp 6.0 -ym -6.0 -zp 0.0 -zm -17.5
  ```


  ```

General Large Deformations Hyperelasto–Plasticity

- Based on the multiplicative decomposition of the deformation gradient.
- More general approach (applicable to anisotropic material, cyclic loading) than current state of the art (based on Simo's work)

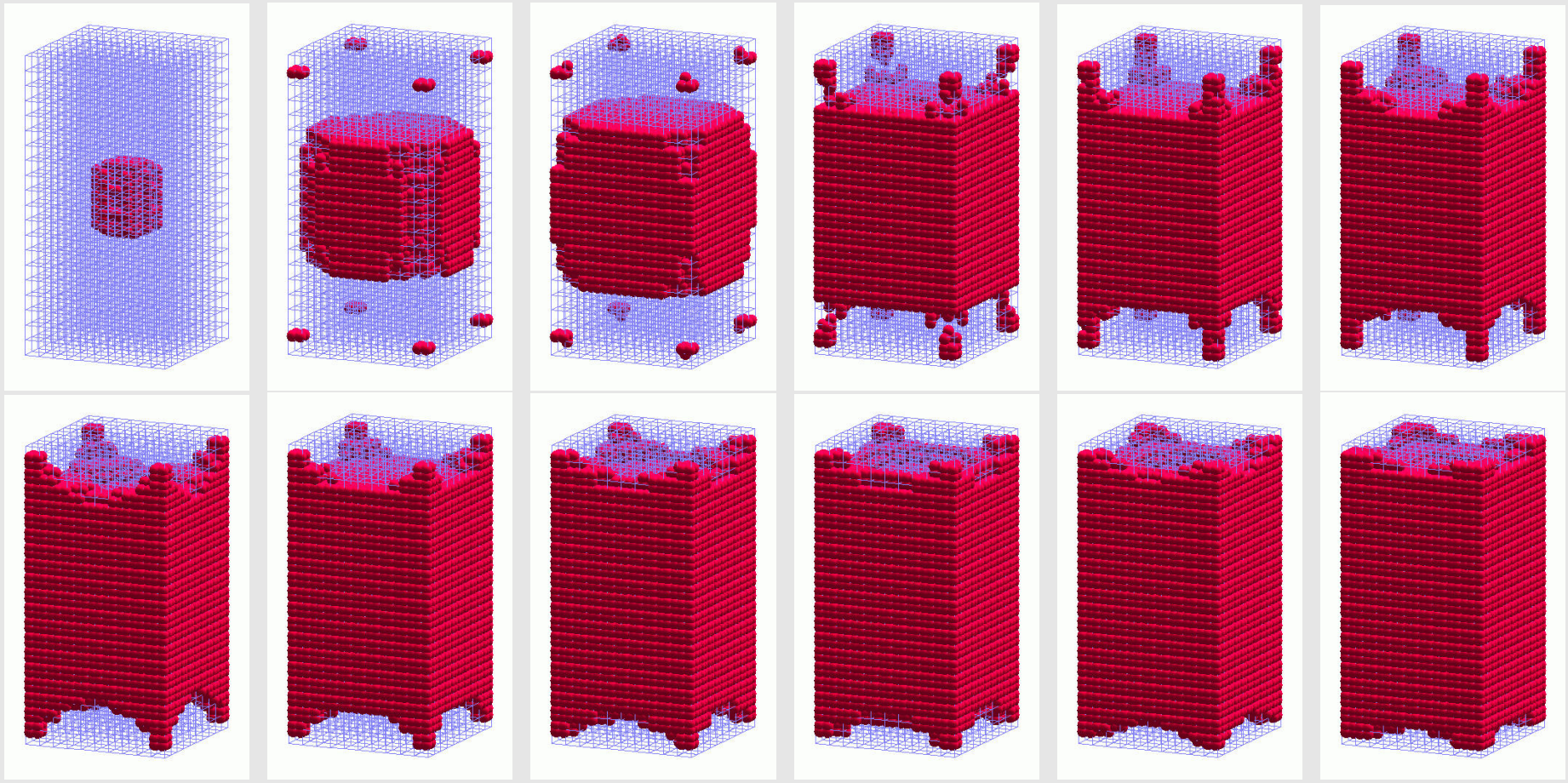




Geotechnical Applications

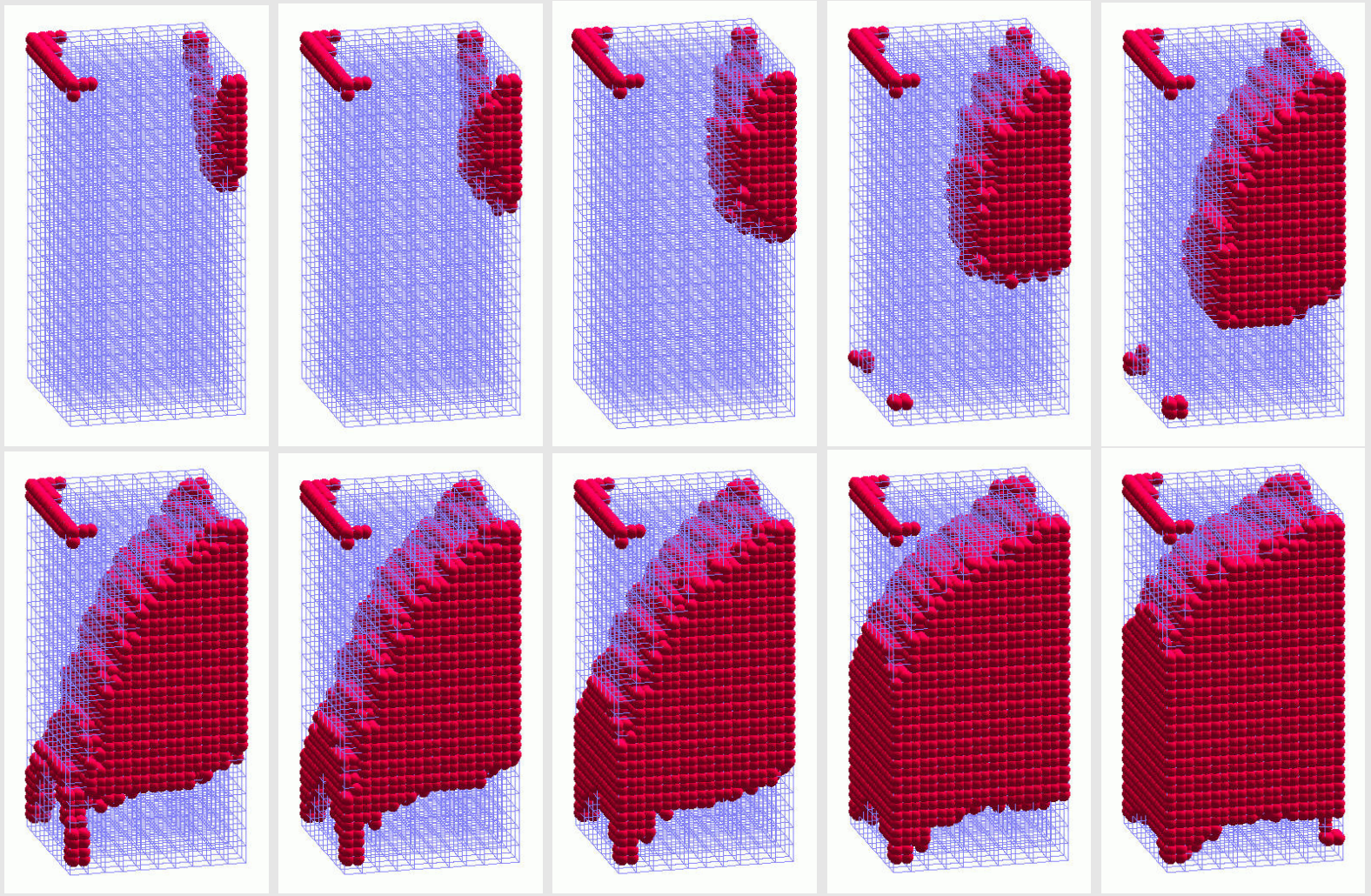
- Constitutive behavior of test specimens
- Behavior of piles in layered soils
- Interactions of piles in pile groups
- Wave propagation in saturated soils
- Seismic behavior of soils and soil-structure interactions (1D and 3D)

Long Specimen

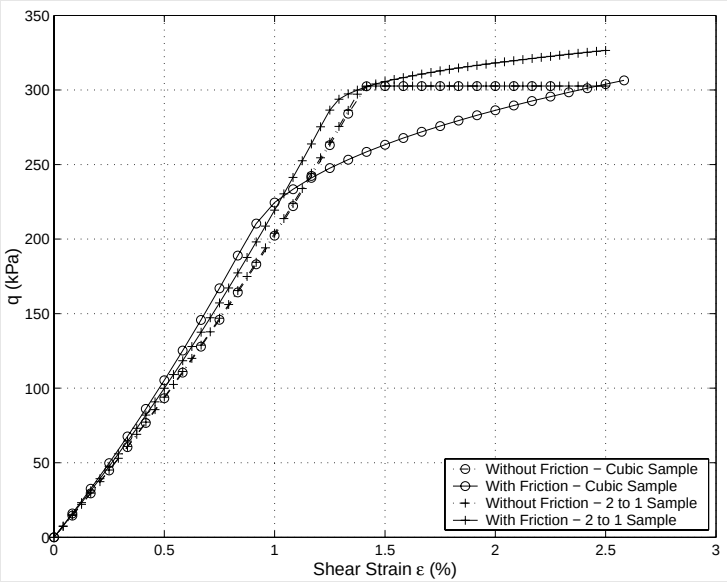


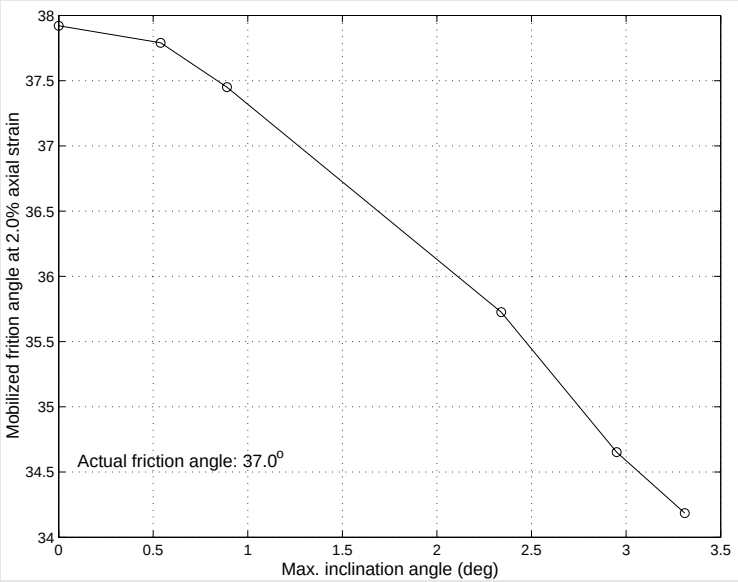
Progression of plastic zone for a long specimen with high friction end platens

Non–Level End Platens

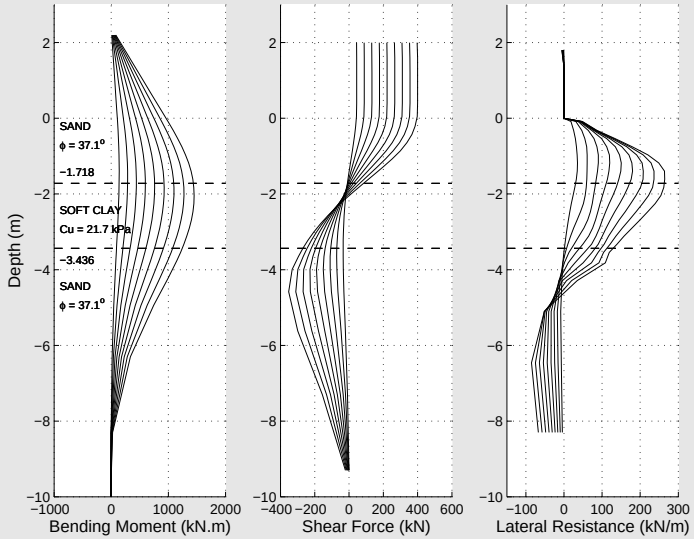


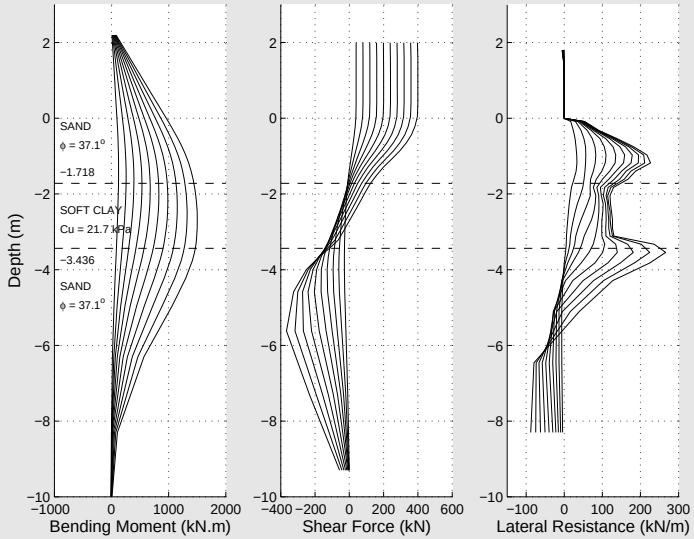
Constitutive Response?

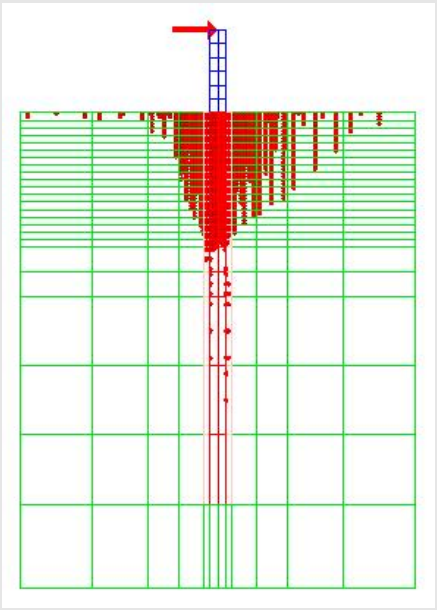


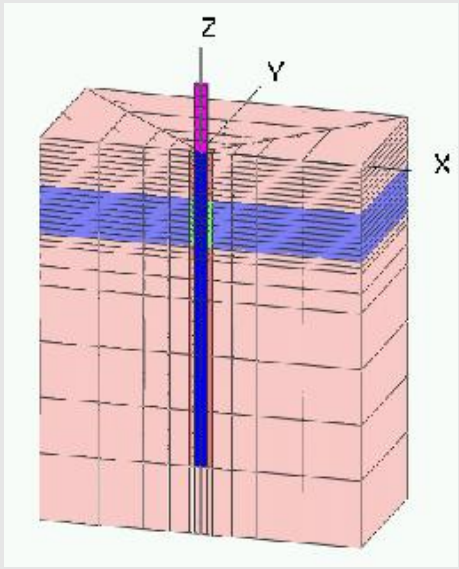


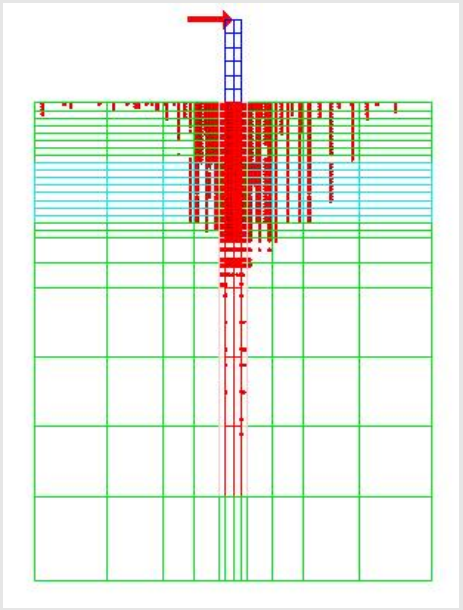
Single Pile in Layered Soils



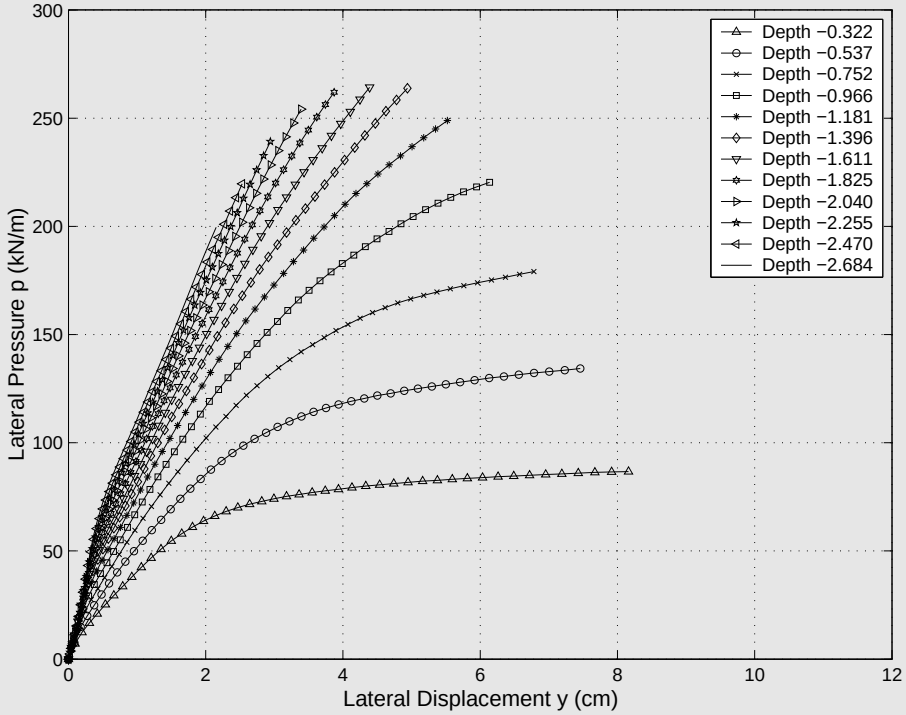


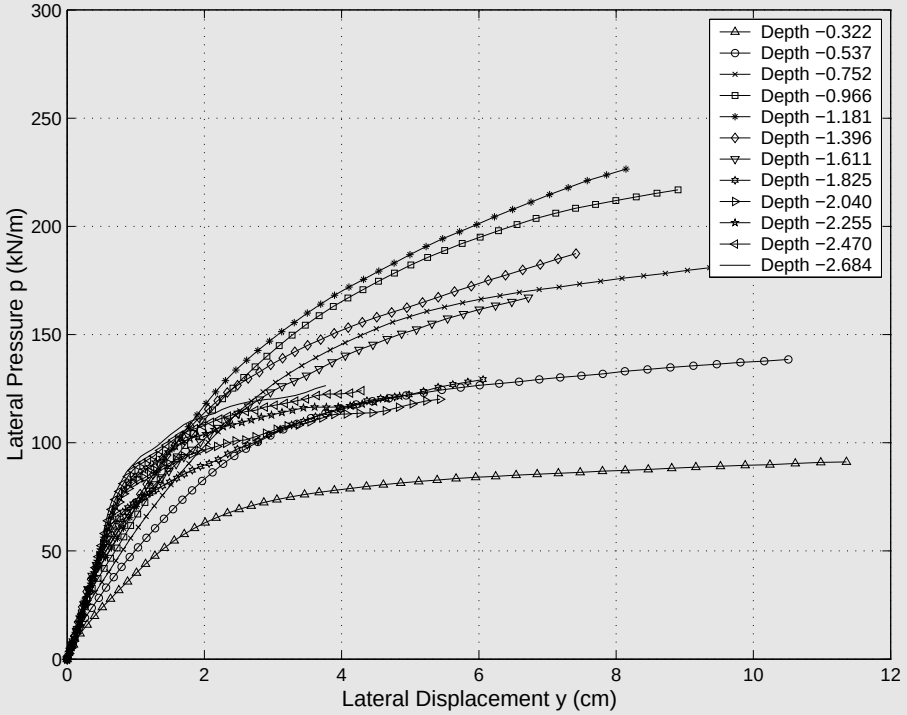






$p - y$ Response for Single Pile in Layered Soils



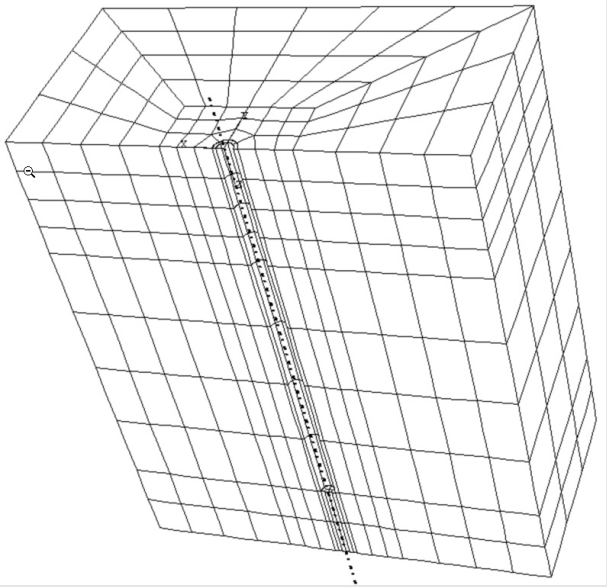


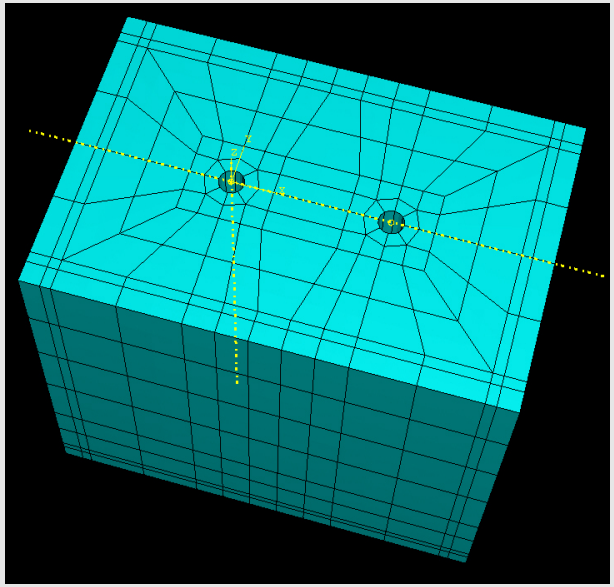
- Influence of soft layers propagates to stiff layers and vice versa
- Can have significant effects in soils with many layers

Examples

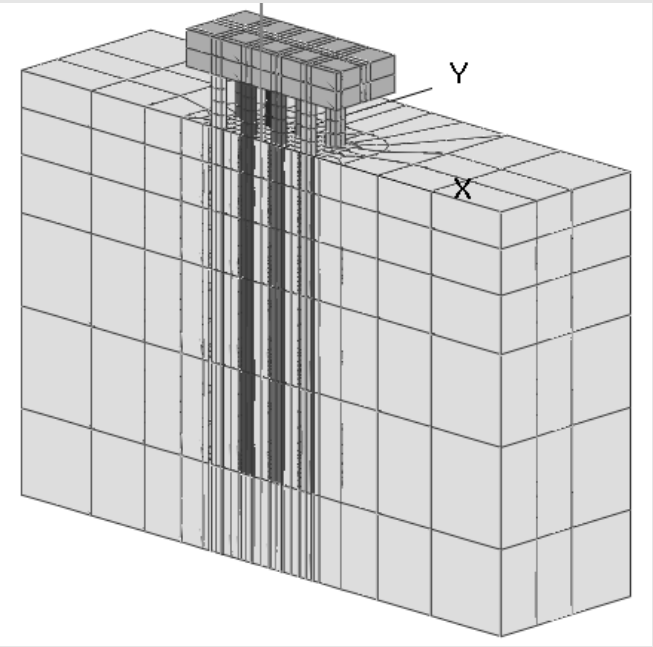
- Number of example models available at

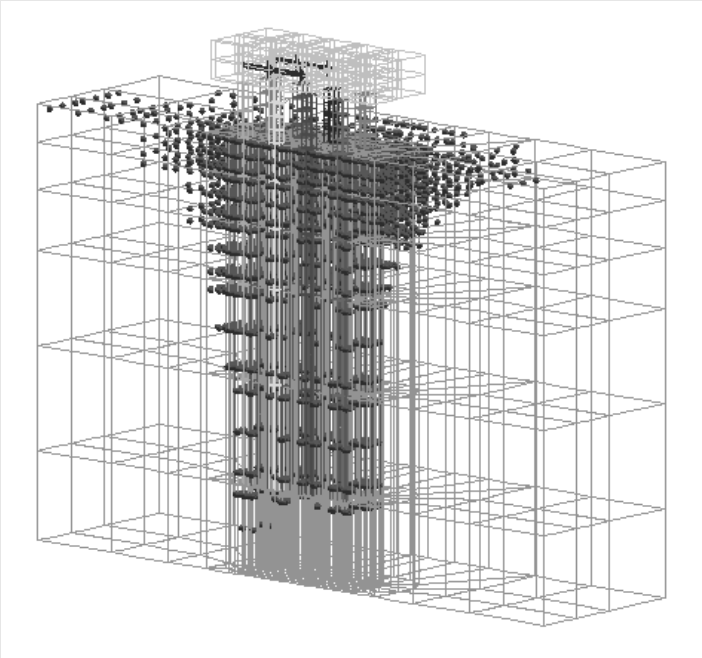
  http://cml00.engr.ucdavis.edu/~guanzhou/NEES_Project/
- Single pile (elastic solid beam or inelastic beam-column) in inelastic soil (solids)
- Stages of loading (self weight for soil only, static pushover, dynamic motions (seismic, surface shaker)





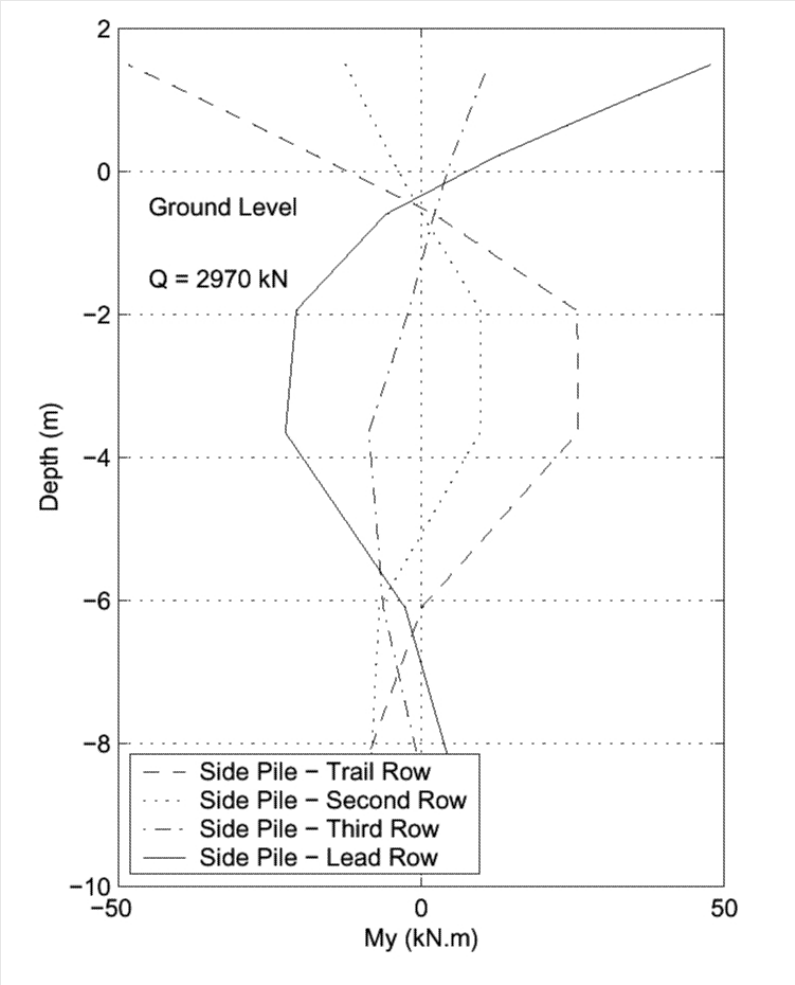
Pile Group Simulations

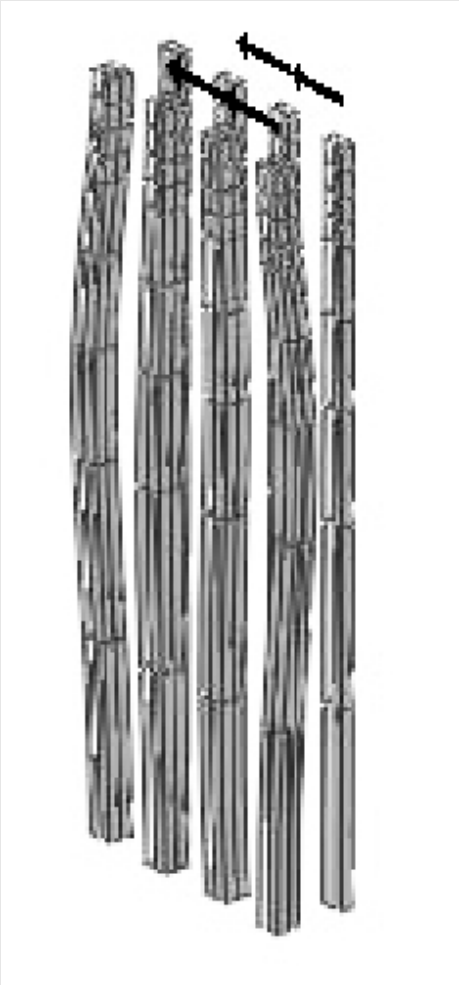




- 4x3 pile group model and plastic zones

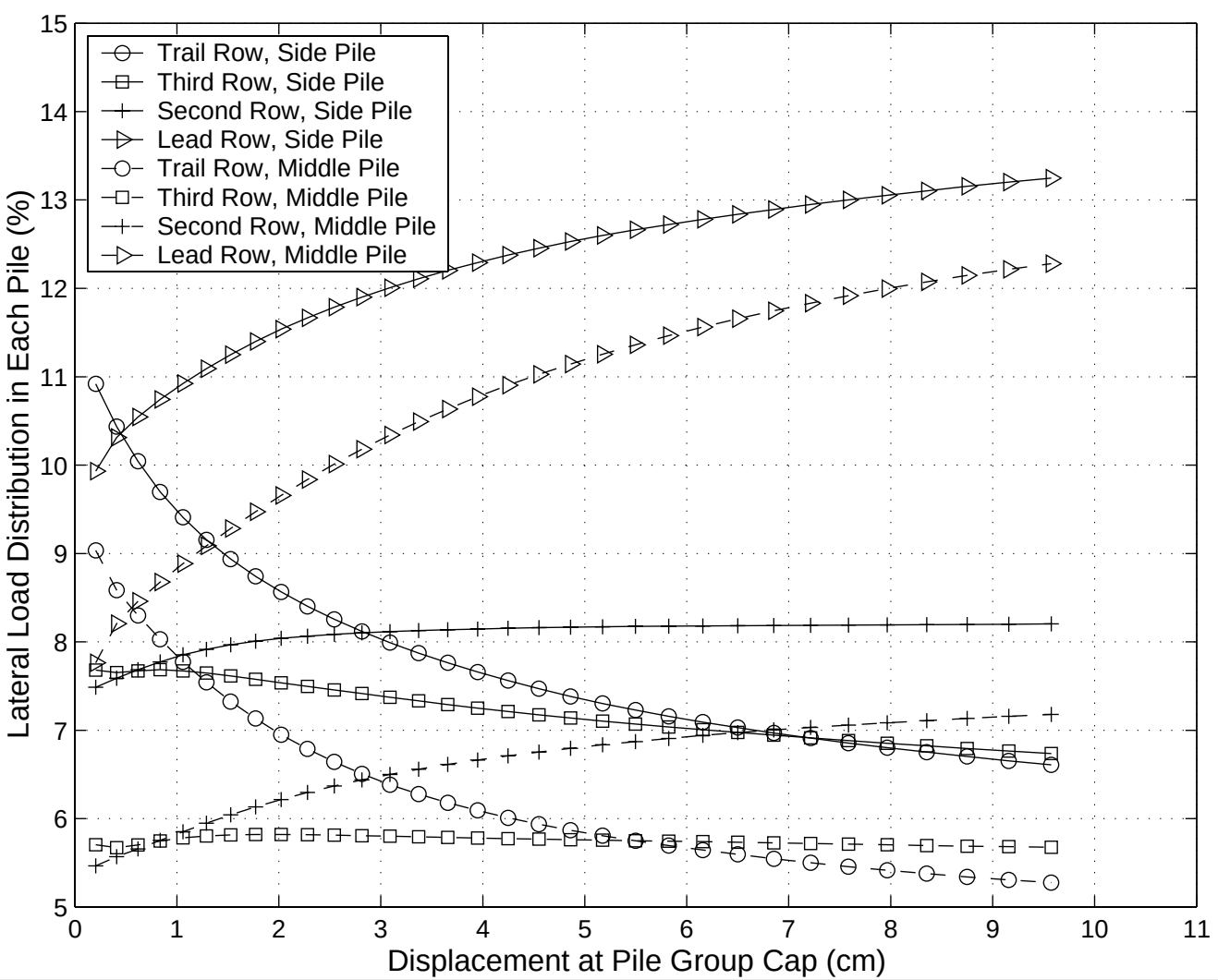
Out of Plane Effects



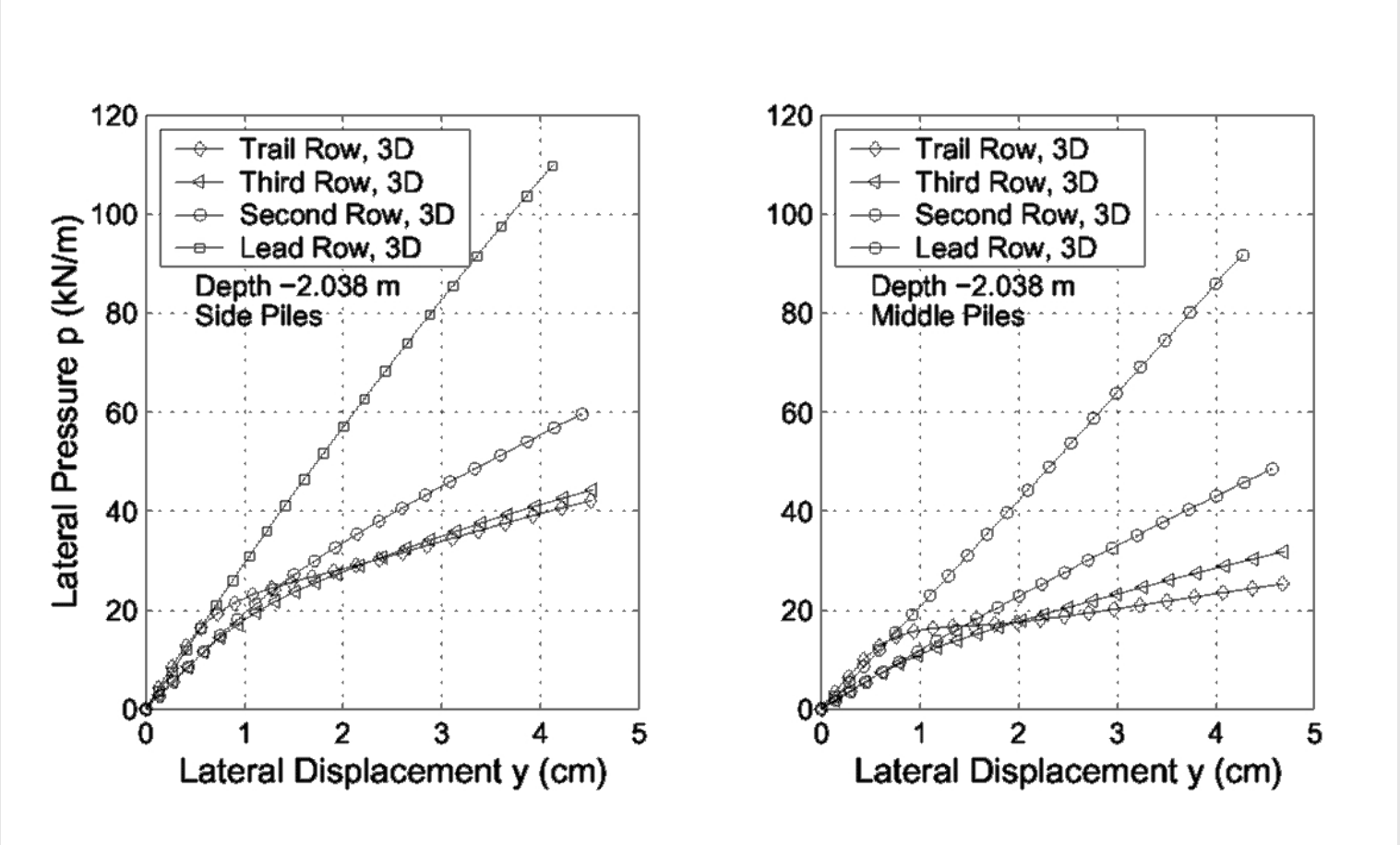


- Out-of-loading-plane bending moment diagram,
- Out-of-loading-plane deformation.

Load Distribution per Pile

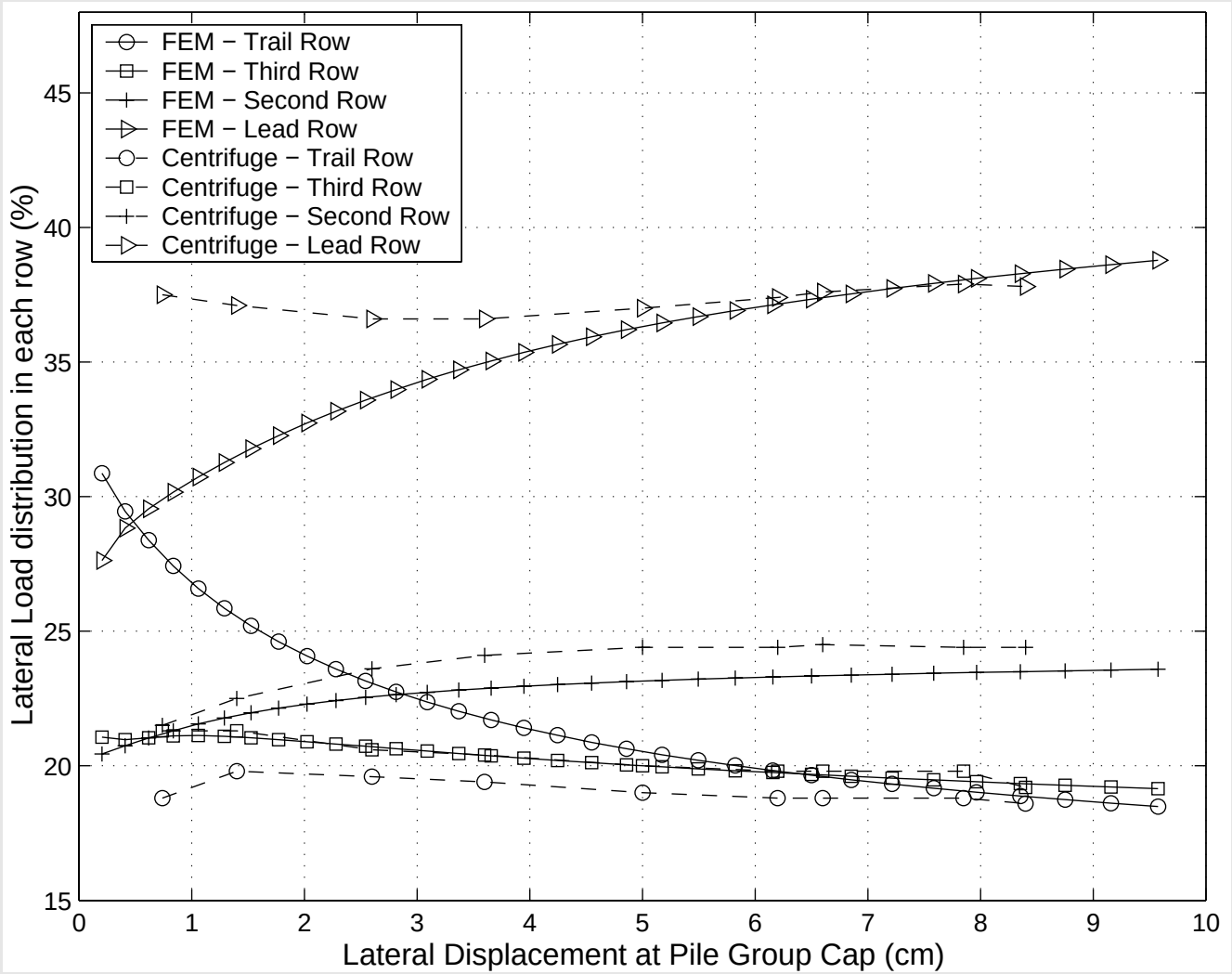


Piles Interaction at -2.0m

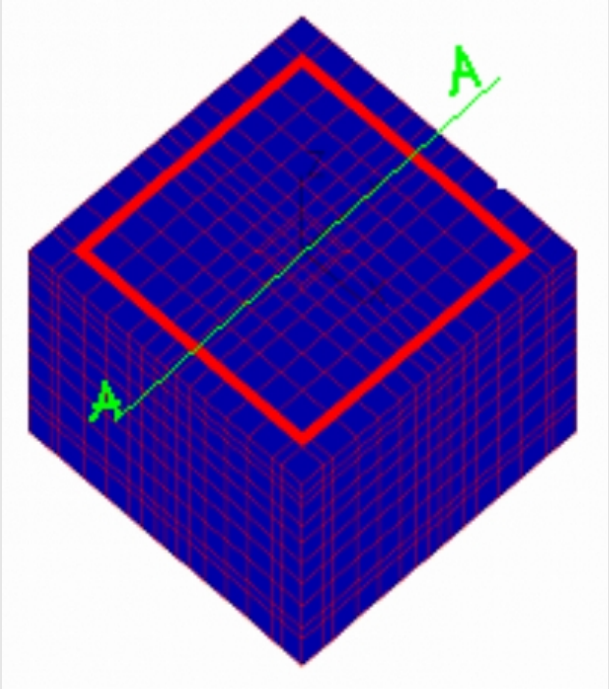


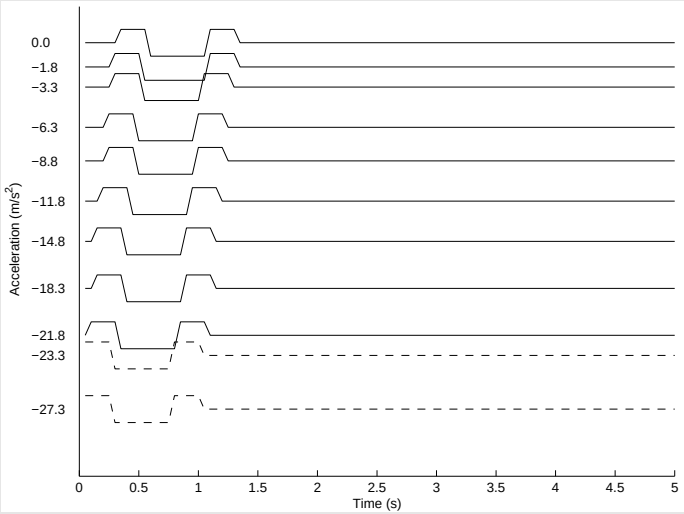
- Note the difference in response curves (cannot scale single pile response for multiple piles)

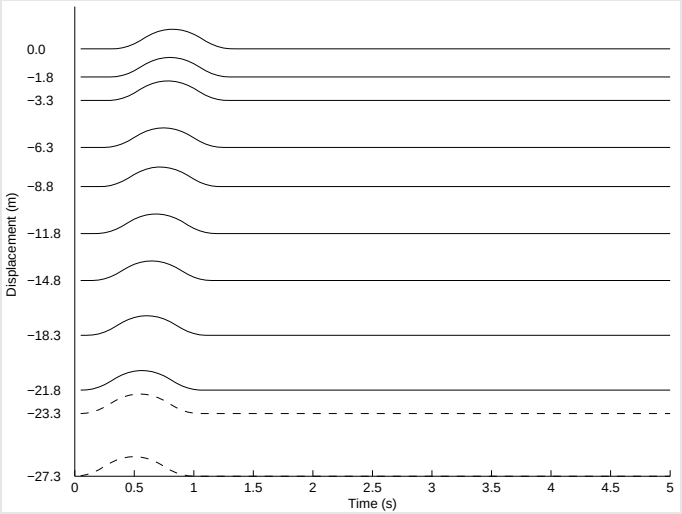
Validation with Centrifuge Tests



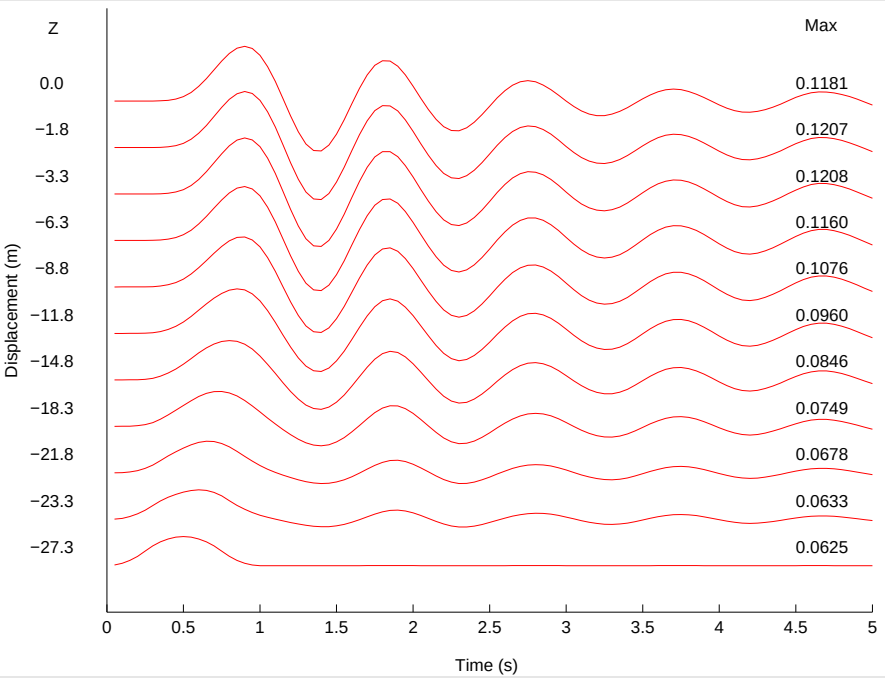
Seismic Wave Propagation Model

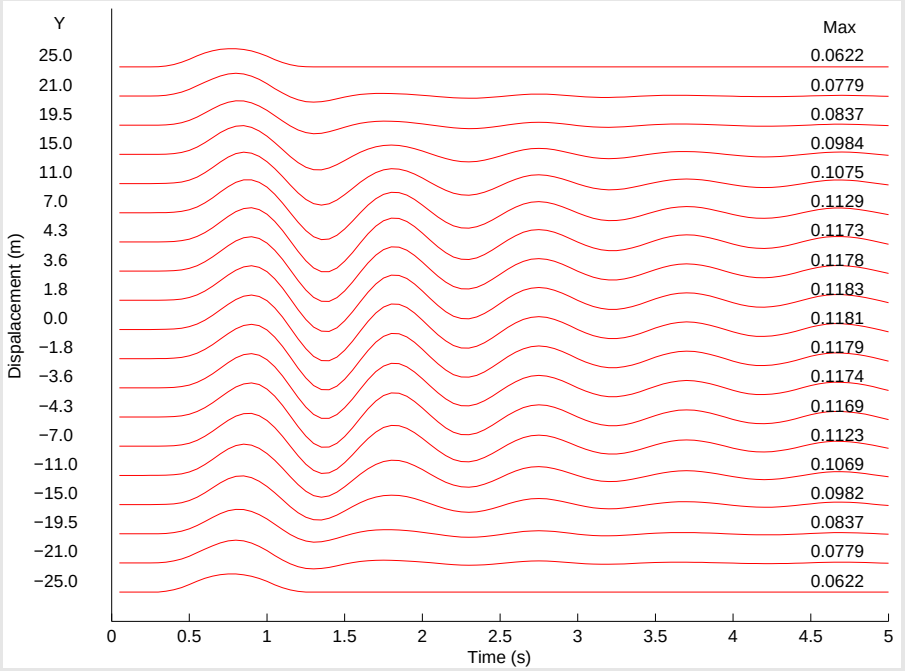




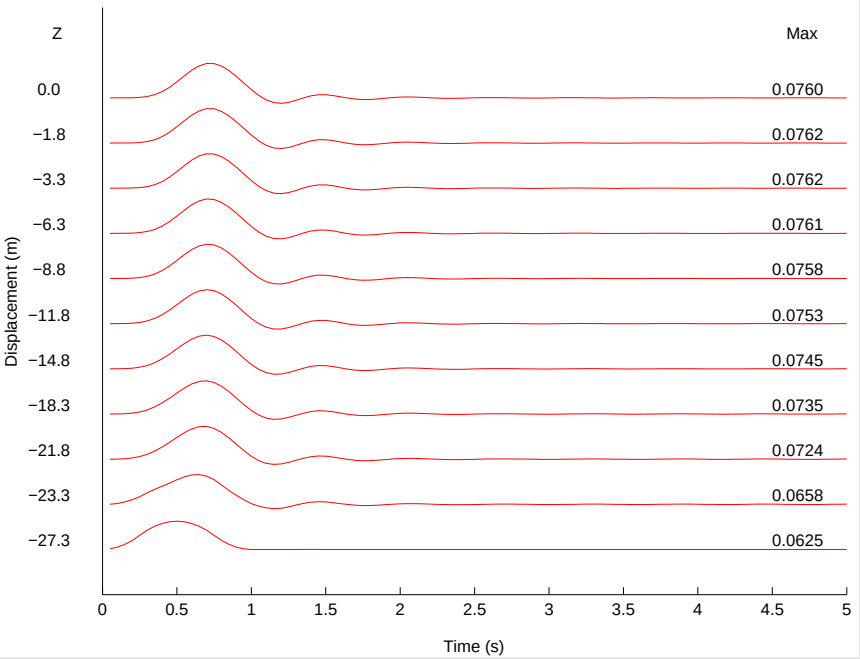


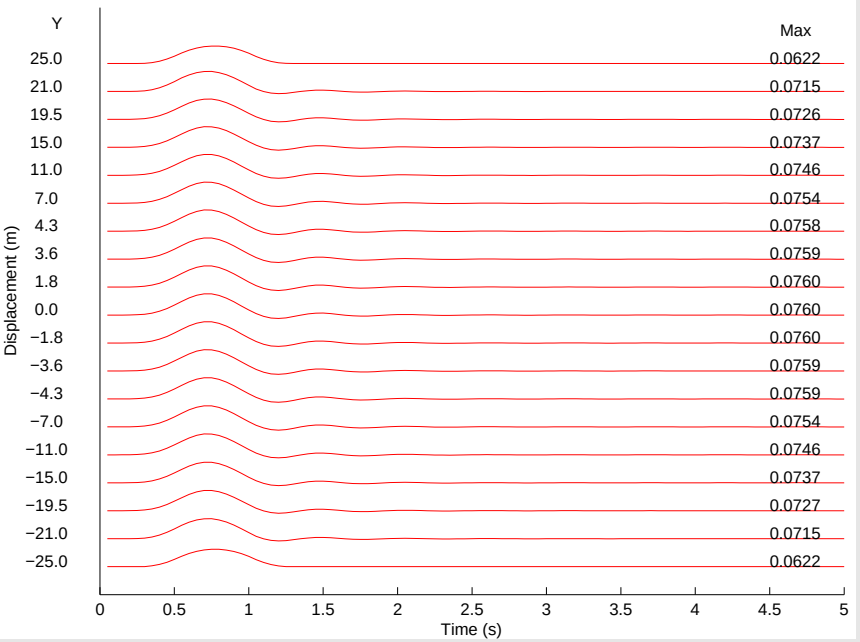
Seismic Wave Propagation
Soft Soil



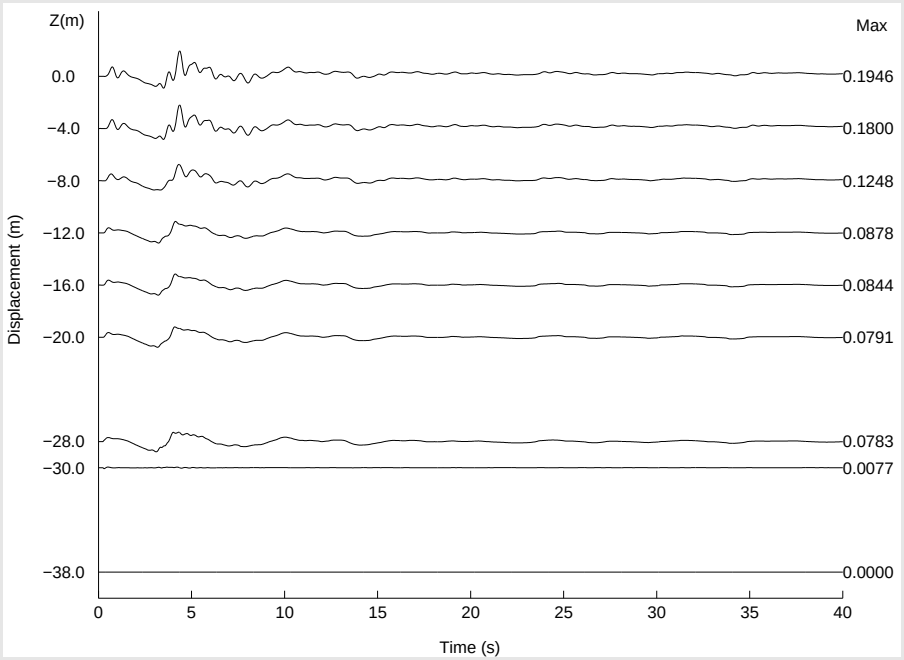


Seismic Wave Propagation
Stiff Soil

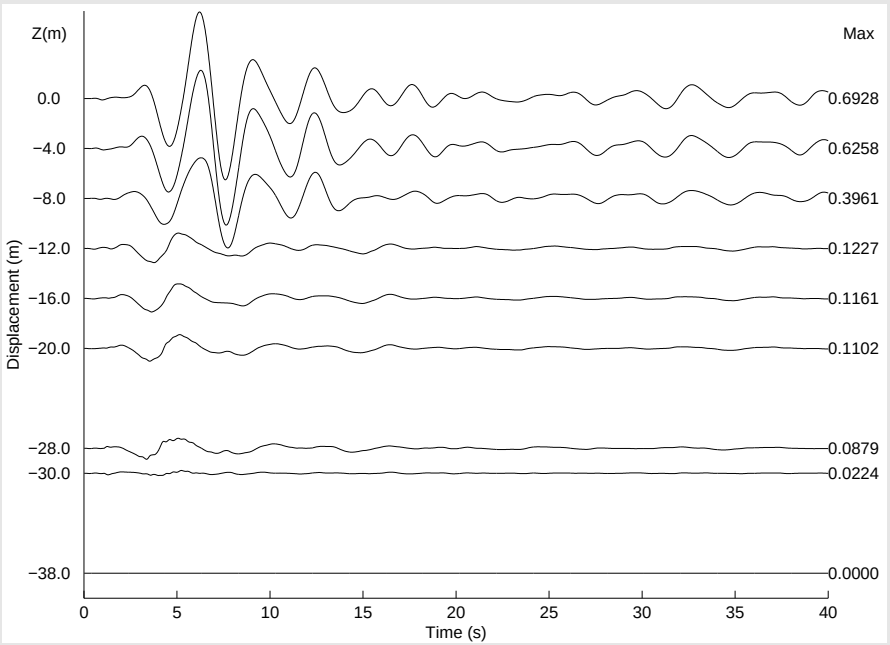




SSI Model: Seismic Results

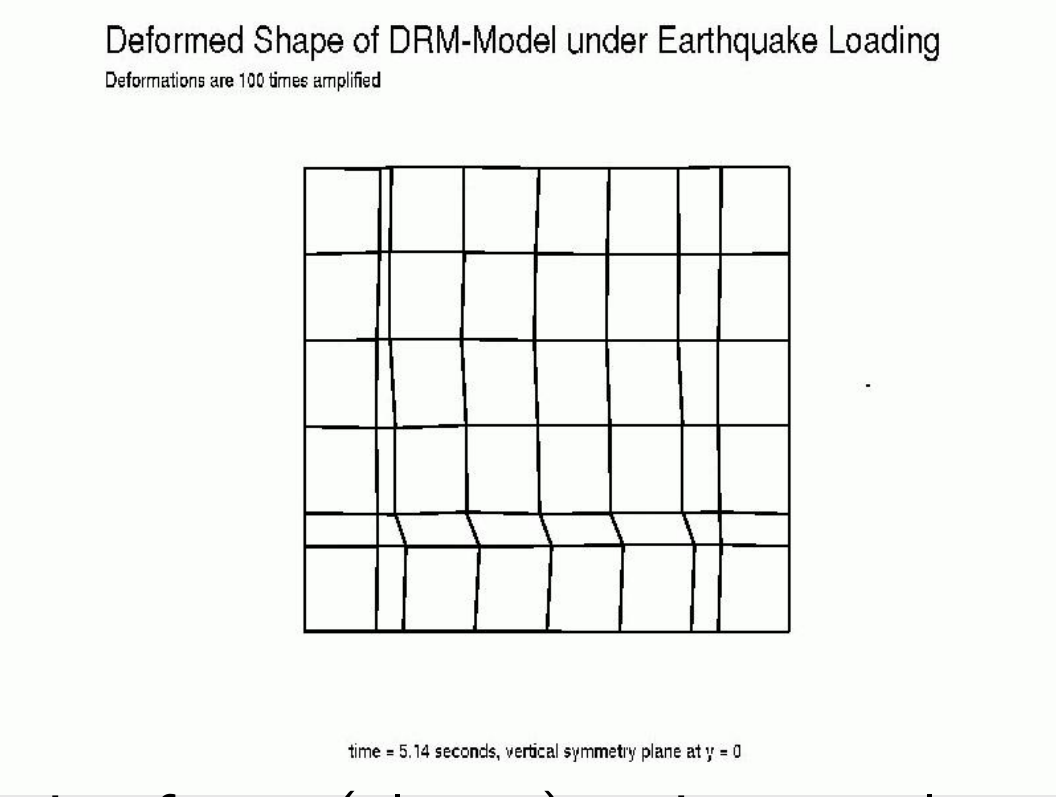


Stiff soil



Soft soil

DRM Model Analysis



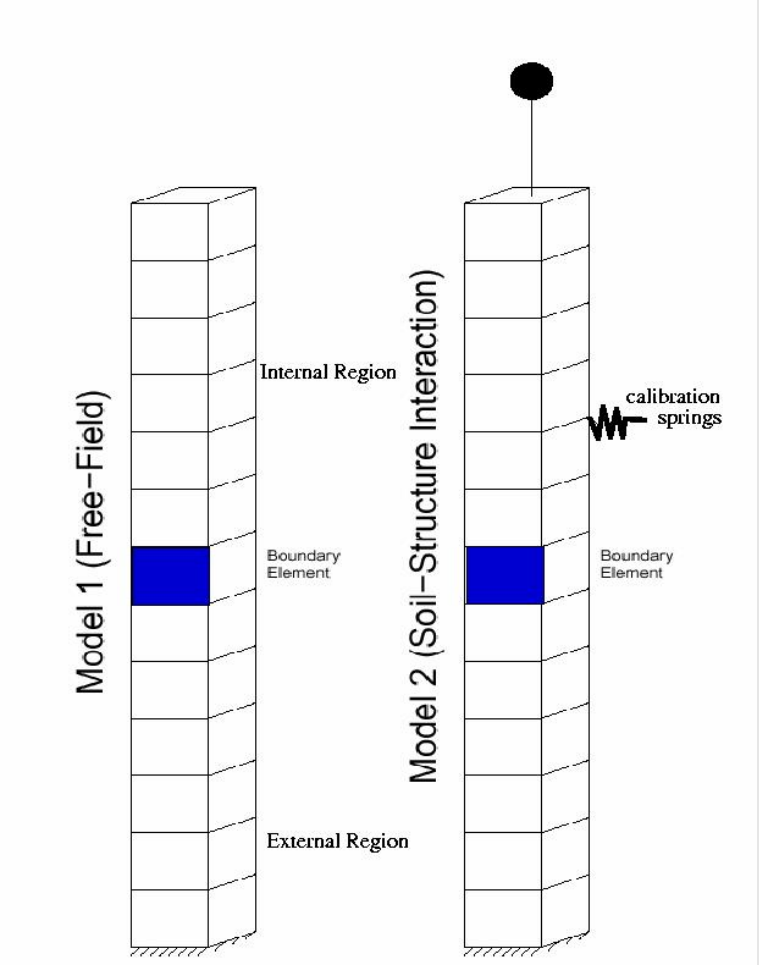
- Self–equilibrating forces (almost) acting on a layer of element
- Dynamically equivalent to the far field dynamic excitation
- Externally radiating motions come from the structure
- examples available at

  http://sokocalo.engr.ucdavis.edu/~jeremic/CG/Examples/SoilFoundationStructureInteraction/3D/

Seismic Motions Examples

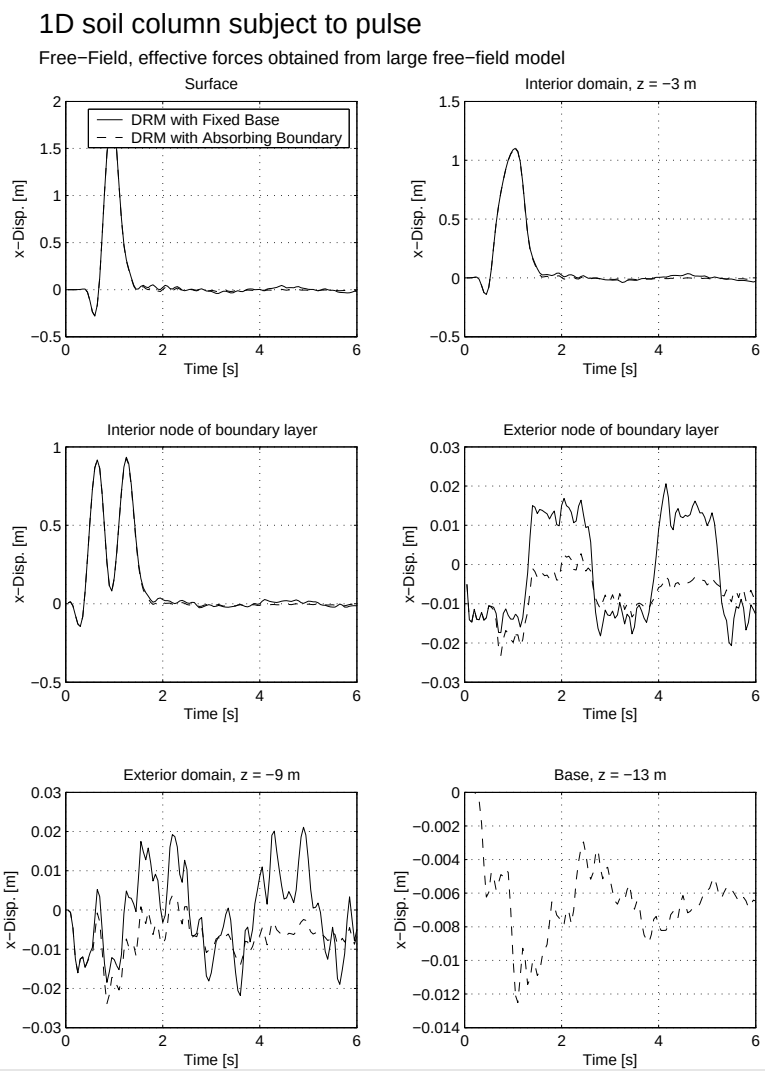
1D Model (Verification Study)

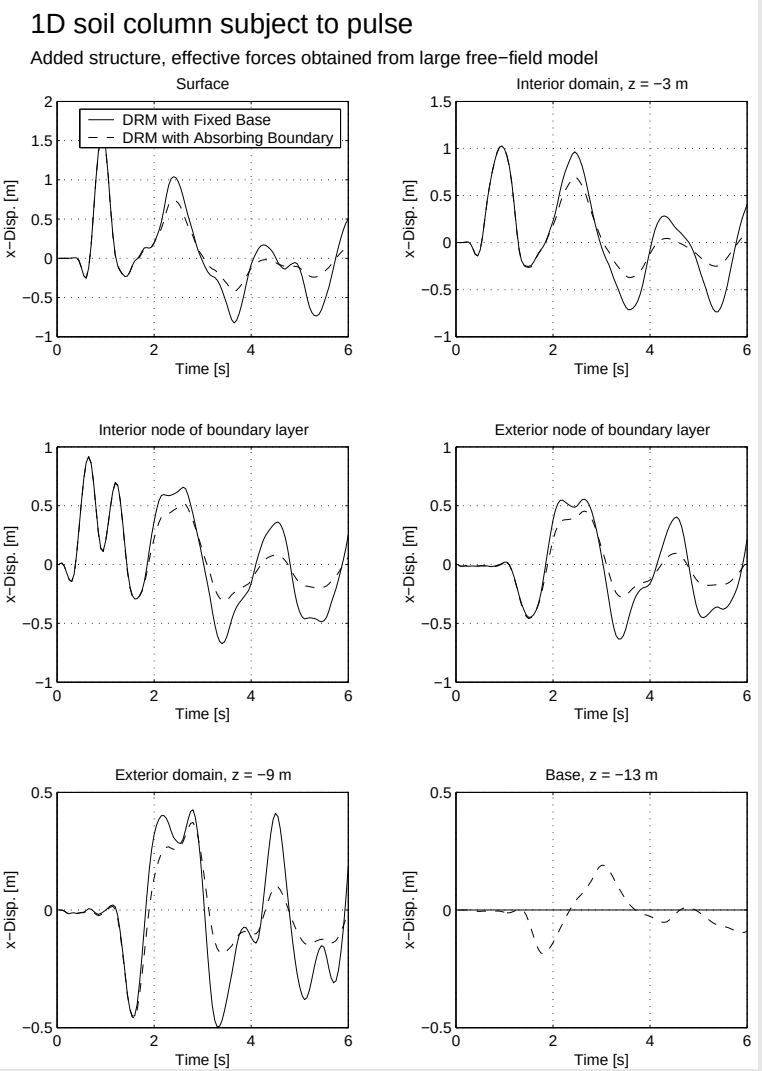
- 1D model used for validation
- Vertically propagating shear wave
- Used both closed form and numerical solutions for generating DRM forces
- Calibration springs used to model support of soils on the side
- Outgoing waves represent the dynamic characteristic of structure
- tested using harmonic and fling (pulse) motions
- examples available at



http://sokocalo.engr.ucdavis.edu/~jeremic/CG/Examples/SoilFoundationStructureInteraction/1D/

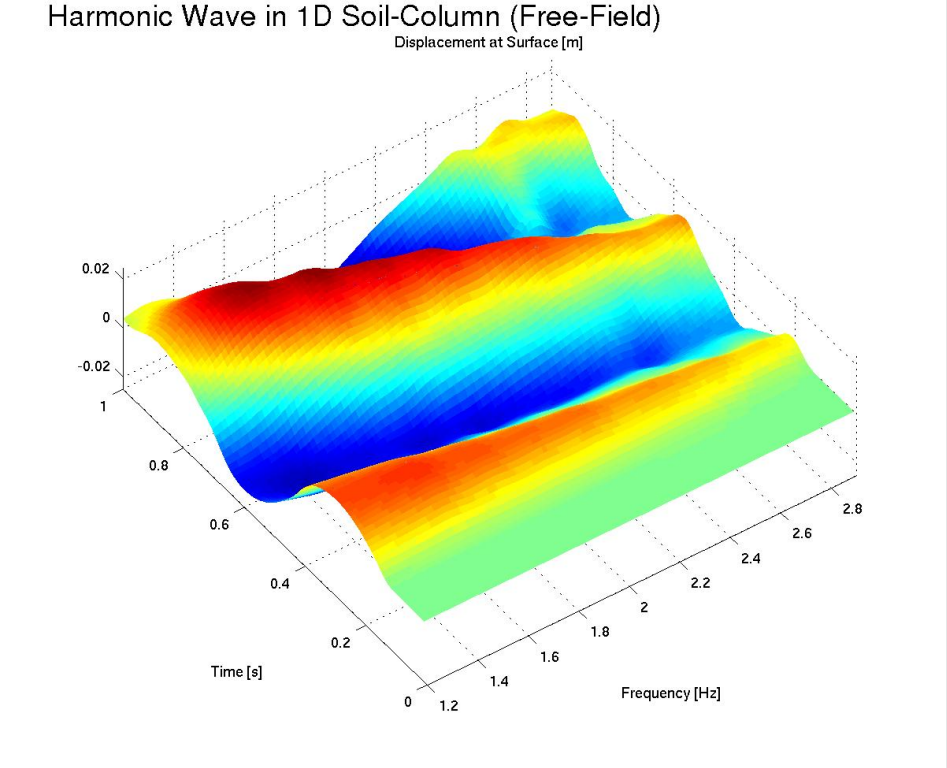
Comparing Free Field and SFSI

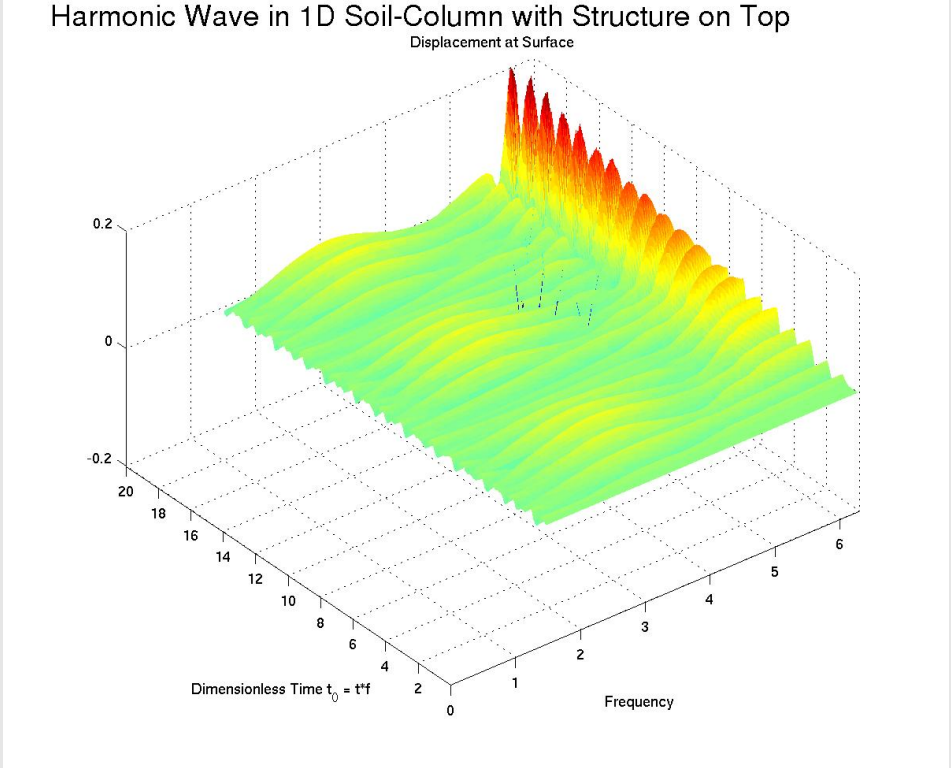




Parametric Study: FF and SFSI

- Site amplification for harmonic motions
- Significant change of FF motions in presence of structure
- Can (should) be used in estimating optimal design for given type of earthquake





Conclusions

- Lecture notes (work in progress)

  http://sokocalo.engr.ucdavis.edu/~jeremic/CG/CompGeomechanicsLectureNotes.pdf

- Examples

  http://sokocalo.engr.ucdavis.edu/~jeremic/CG/Examples

- Applications/Examples Web Portal

  http://sokocalo.engr.ucdavis.edu/~jeremic/CG/Portal

- Fresh executables (Linux, MS Windows)

  http://sokocalo.engr.ucdavis.edu/~jeremic/OpenSees/EXECUTABLES

- Questions, comments (once you digest all of this): jeremic@ucdavis.edu