



Numerical Predictions of Soil-Foundation-Structure Interaction

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with

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Outline

Motivation and Tools

Behavior of Piles and Pile Groups

Single Piles in Layered Soils

Pile Groups

Liquefying Soils

Single Element and Soil Column Liquefaction

Piles in Liquefying Soils

ESS Simulations

High Fidelity, 3D Models

Behavior for Short and Long Period Motions

Summary



Motivation

- ▶ Designers needs the best available tools for performance assessment
- ▶ Steady progress of numerical simulations over last 4 decades
- ▶ Steady progress of computer hardware
- ▶ Use of software and hardware tools for detailed (as needed) performance assessment
- ▶ In other words: simulation tools are available
- ▶ Need to convince practice (you) that these tools are useful, robust, verified, validated, and ready to be used



Program(s)

- ▶ UCD Computational Geomechanics libraries:
 - ▶ nDarray (tensor, matrix and vector manipulations)
 - ▶ FEMtools (dry and saturated elements)
 - ▶ Template3DEP (elastic–plastic computations)
 - ▶ Plastic–Domain–Decomposition (PDD, for parallel runs)
- ▶ Pre–processors (mesh generators) (ABAQUS, Matlab (UCD), ...)
- ▶ Post–processors (visualizers) (VEES (UCSC–UCD), Joey3D (UCD), Matlab, ...)
- ▶ Solvers (PETSc, UMFpack, ColSol (UCD)...))
- ▶ Graph partitioners (METIS, ParMETIS)
- ▶ OpenSees analysis model (revised at UCD)



Computer(s)

- ▶ Linux and Windows PCs
- ▶ Any other UNIX (Apple) based computer
- ▶ BeoWulf class parallel computers (clusters)
- ▶ Simulations possible on desktops and on large national parallel supercomputers!
- ▶ As hardware steadily progresses, frontiers are rapidly expanding



Verification, Validation and Prediction !

- ▶ Verification: the process of determining that a model implementation accurately represents the developer's conceptual description and specification. Mathematics issue. *Verification provides evidence that the model is solved correctly.*
- ▶ Validation: The process of determining the degree to which a model is accurate representation of the real world from the perspective of the intended uses of the model. Physics issue. *Validation provides evidence that the correct model is solved.*
- ▶ Prediction: use of computational model to foretell the state of a physical system under consideration under conditions for which the computational model has not been validated

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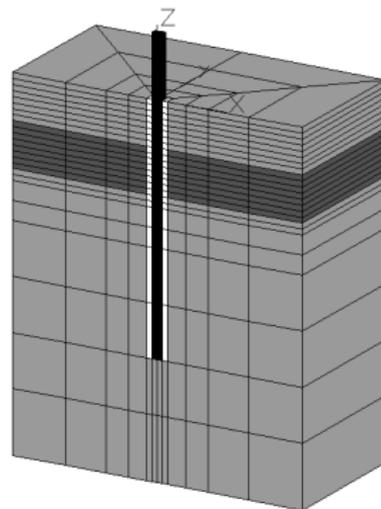
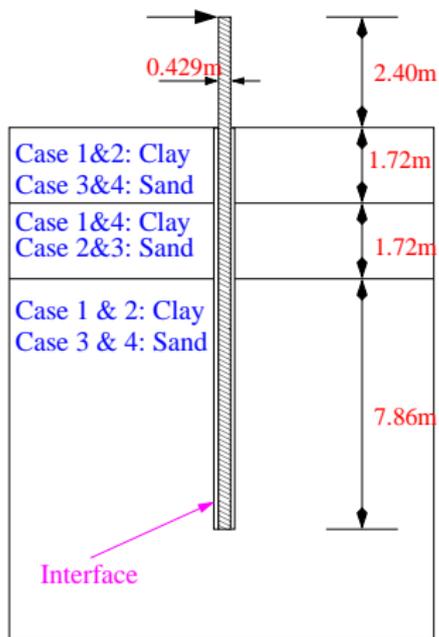
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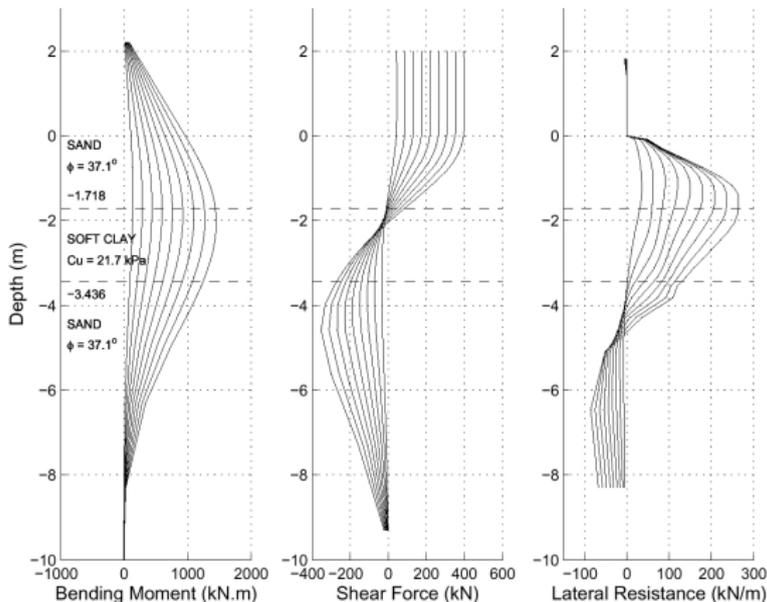


Single Pile in Layered Soils: Model



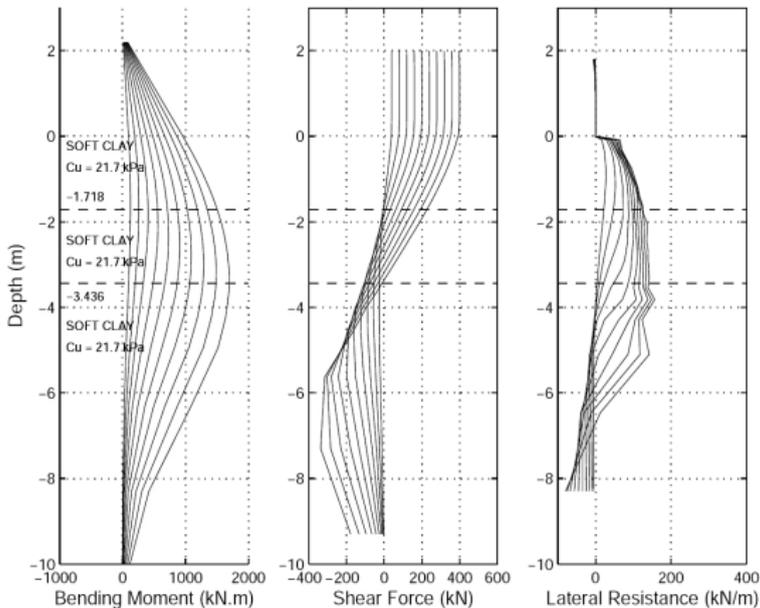


Single Pile in Sand: M, Q, p



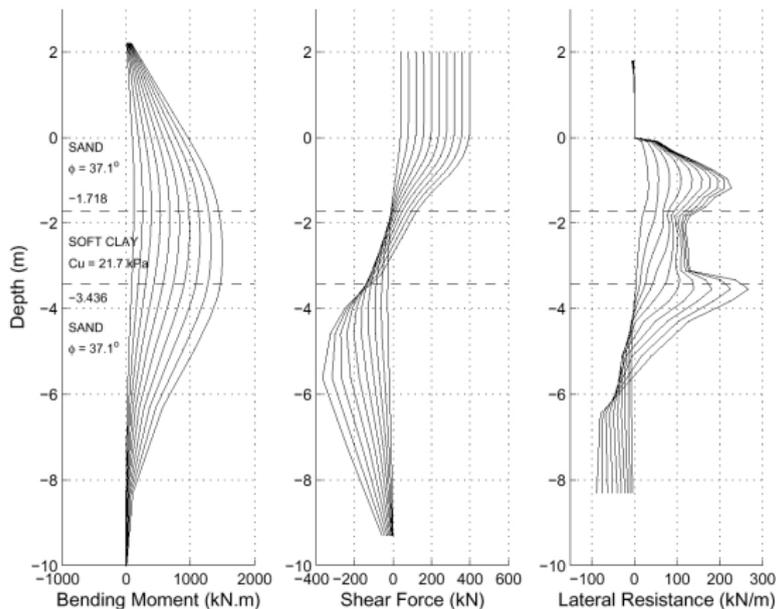


Single Pile in Clay: M, Q, p



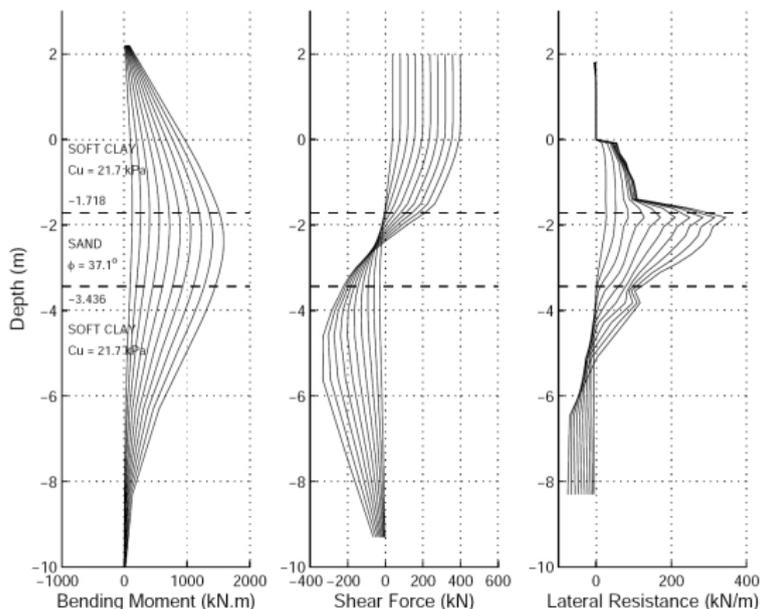


Single Pile in Sand with Clay Layer: M, Q, p



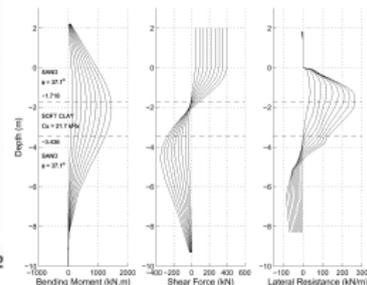
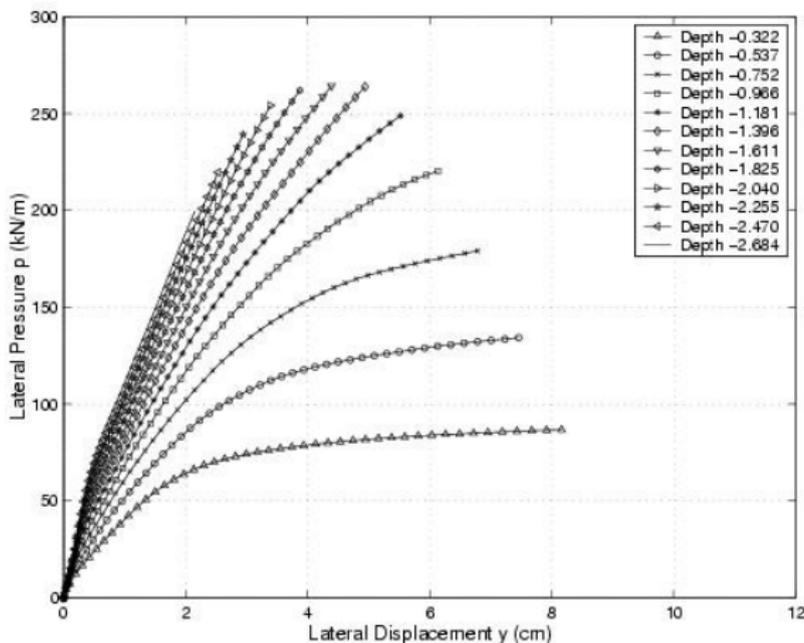


Single Pile in Clay with Sand Layer: M, Q, p



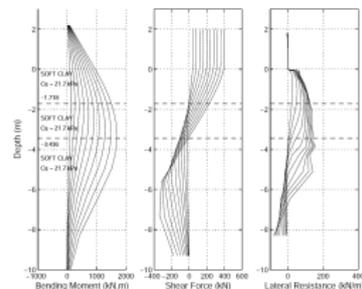
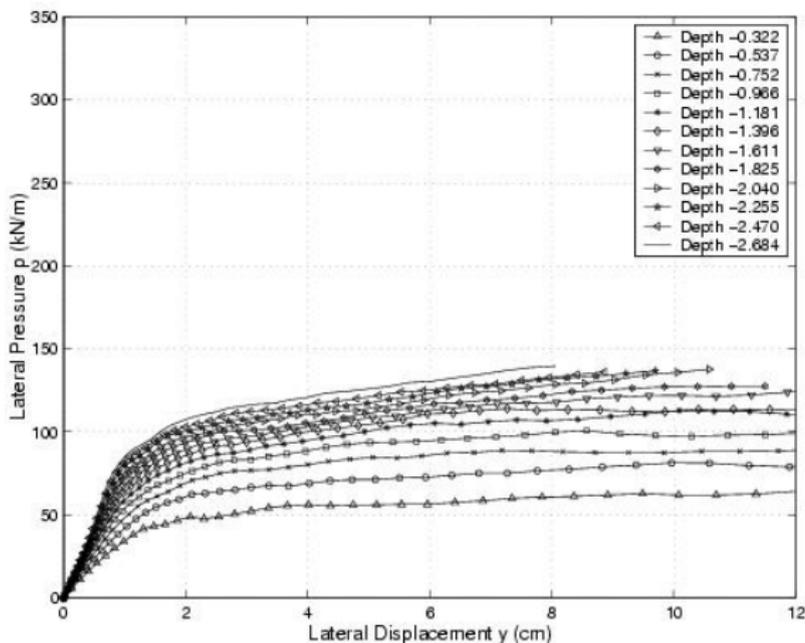


Single Pile in Sand: $p - y$ Response



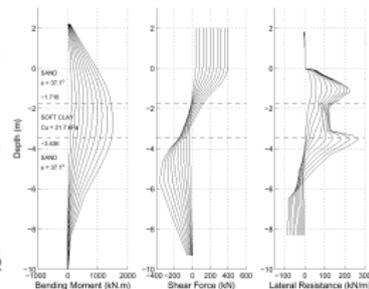
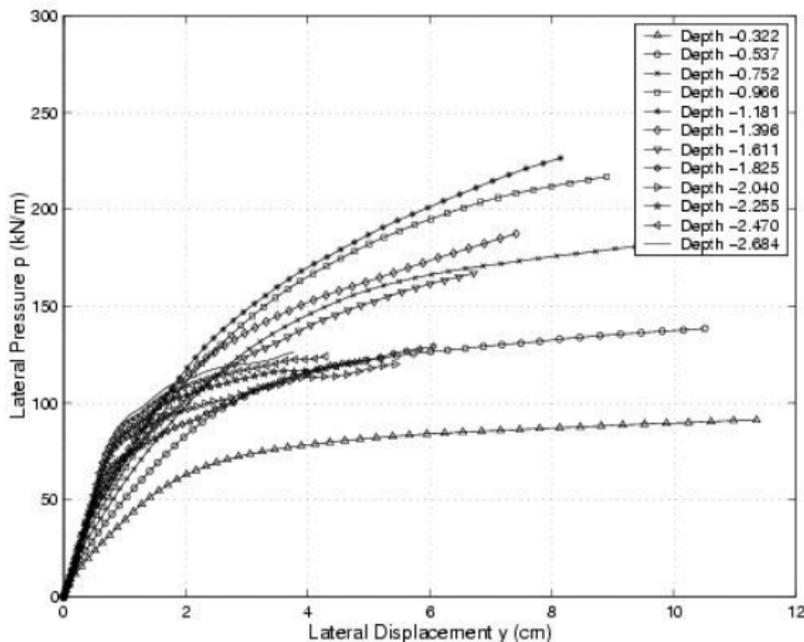


Single Pile in Clay: $p - y$ Response



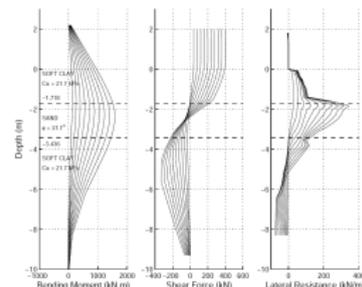
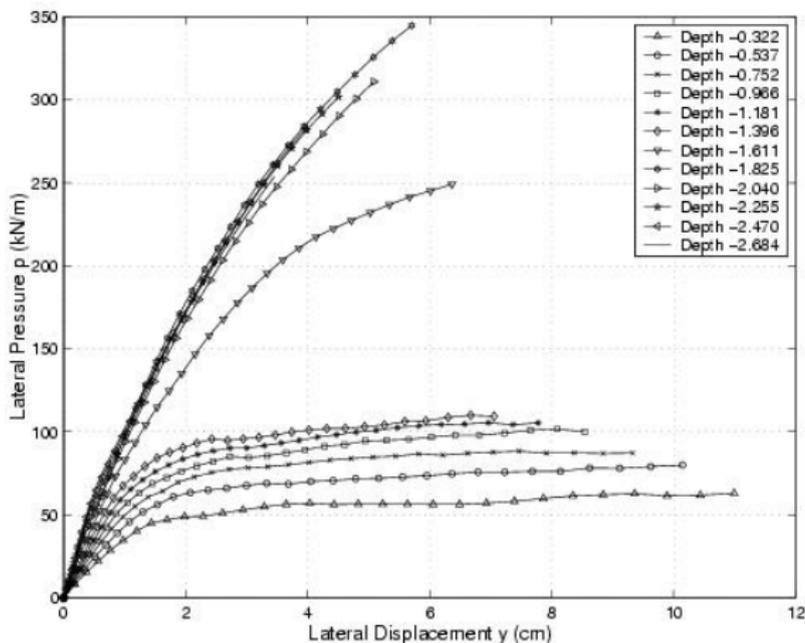


Single Pile in Sand with Clay Layer: $p - y$ Response



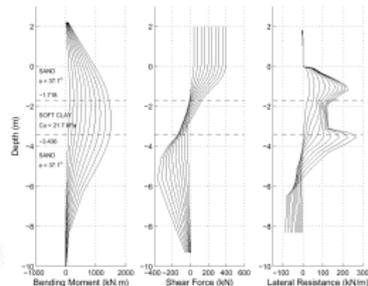
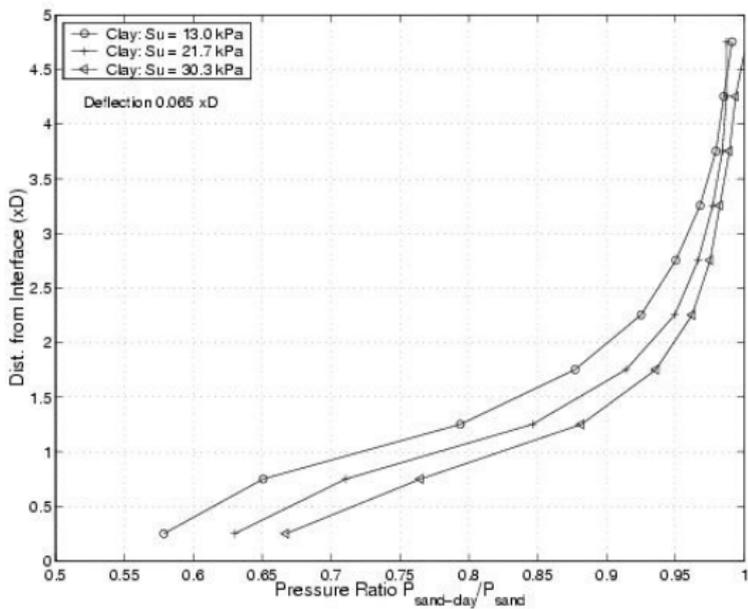


Single Pile in Clay with Sand Layer: $p - y$ Response





$p - y$ Pressure Ratio Reduction for Layered Soils





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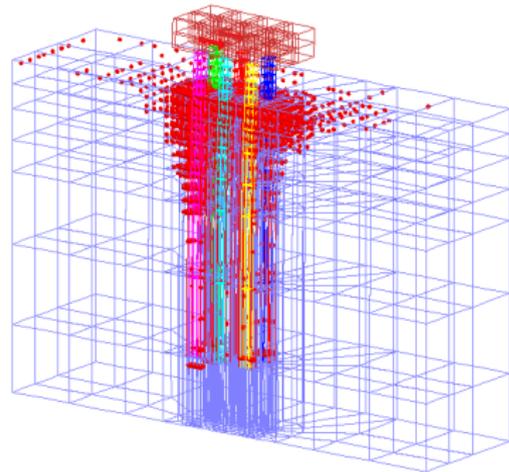
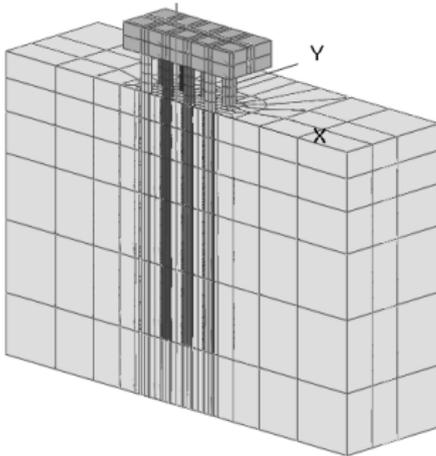
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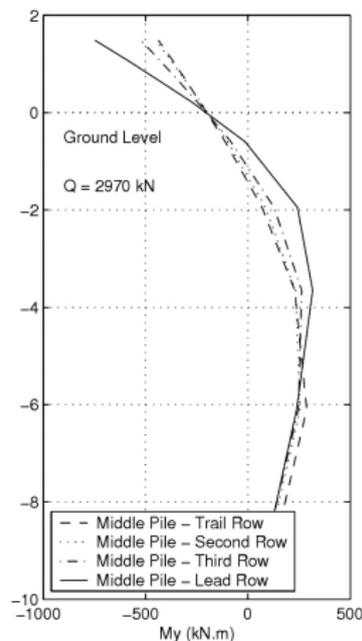
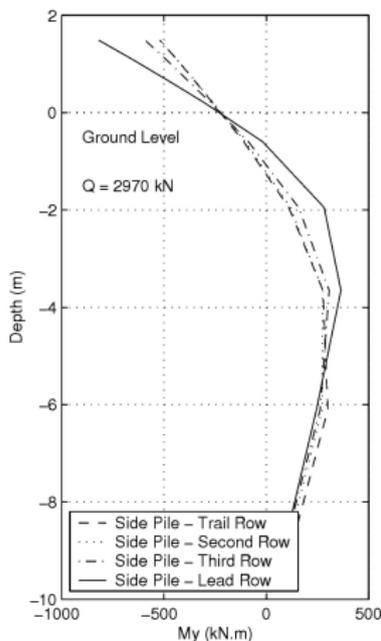


Pile Group Simulations



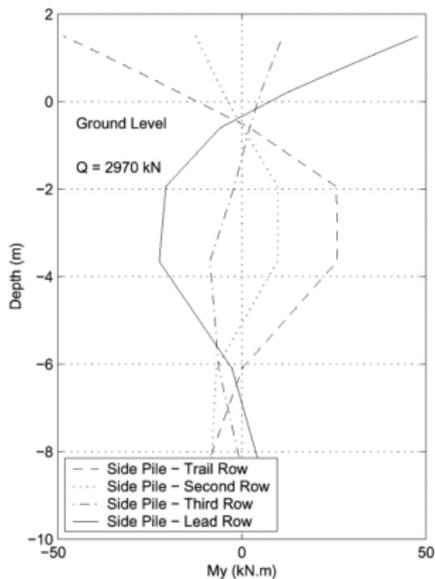


Bending Moments



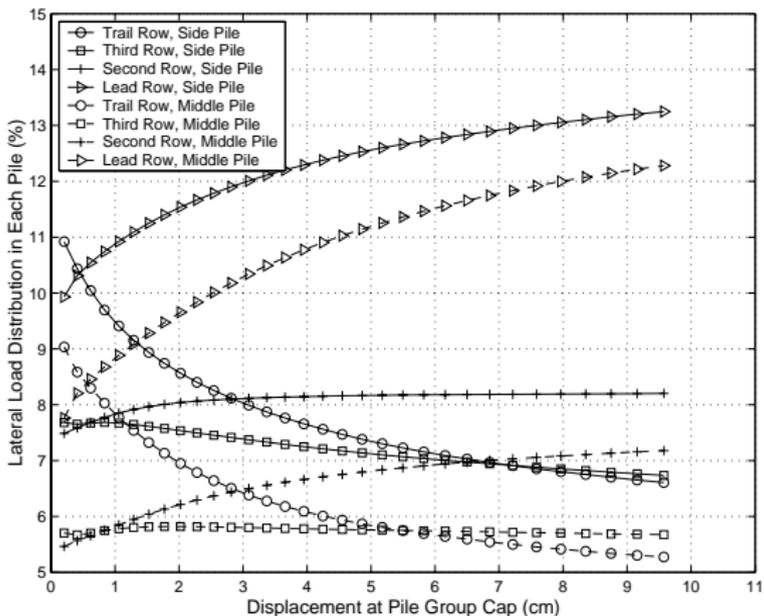


Out of Plane Effects



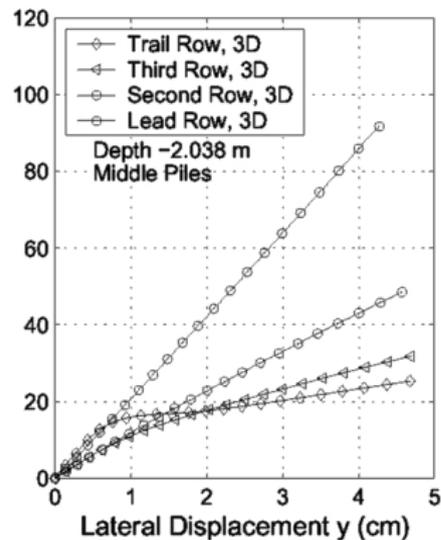
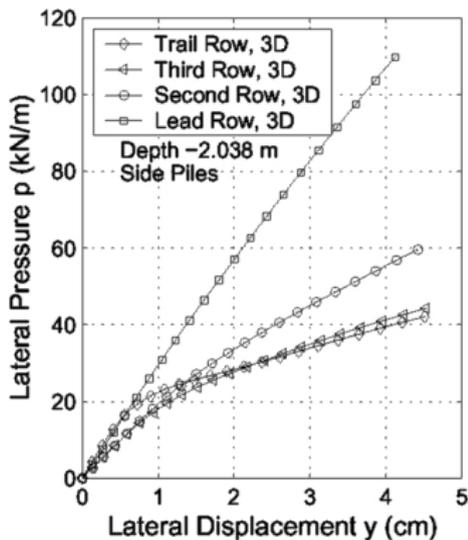


Load Distribution per Pile





Piles Interaction at -2.0m ($p - y$)



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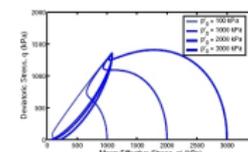
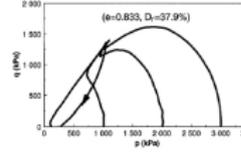
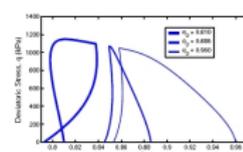
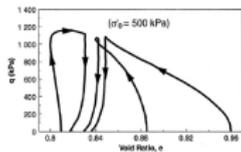
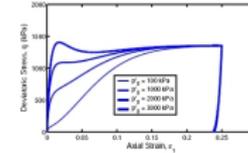
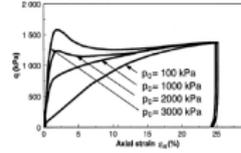
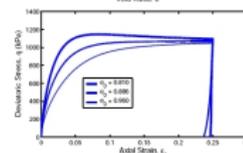
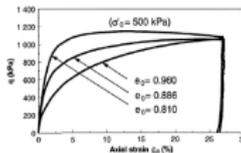
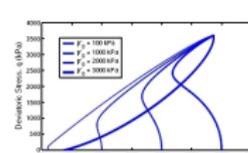
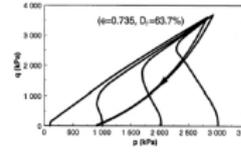
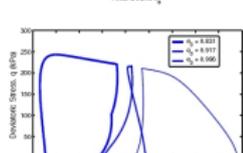
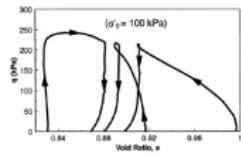
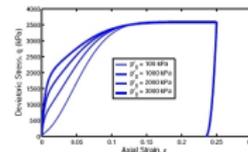
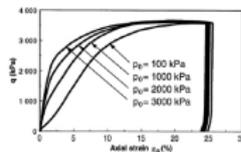
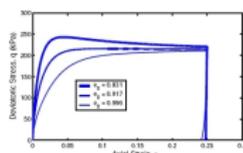
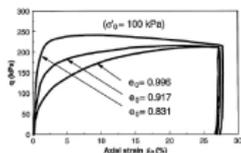
Behavior for Short and Long Period Motions

Summary



Single Element and Soil Column Liquefaction

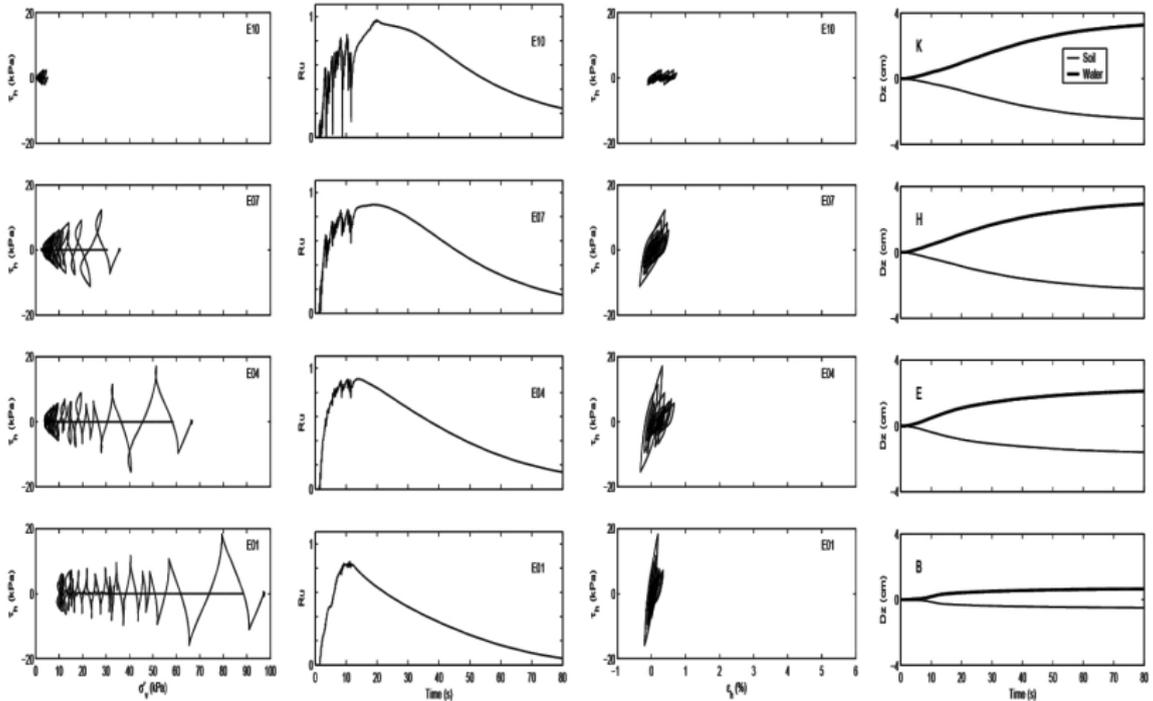
Material Model Validation





Single Element and Soil Column Liquefaction

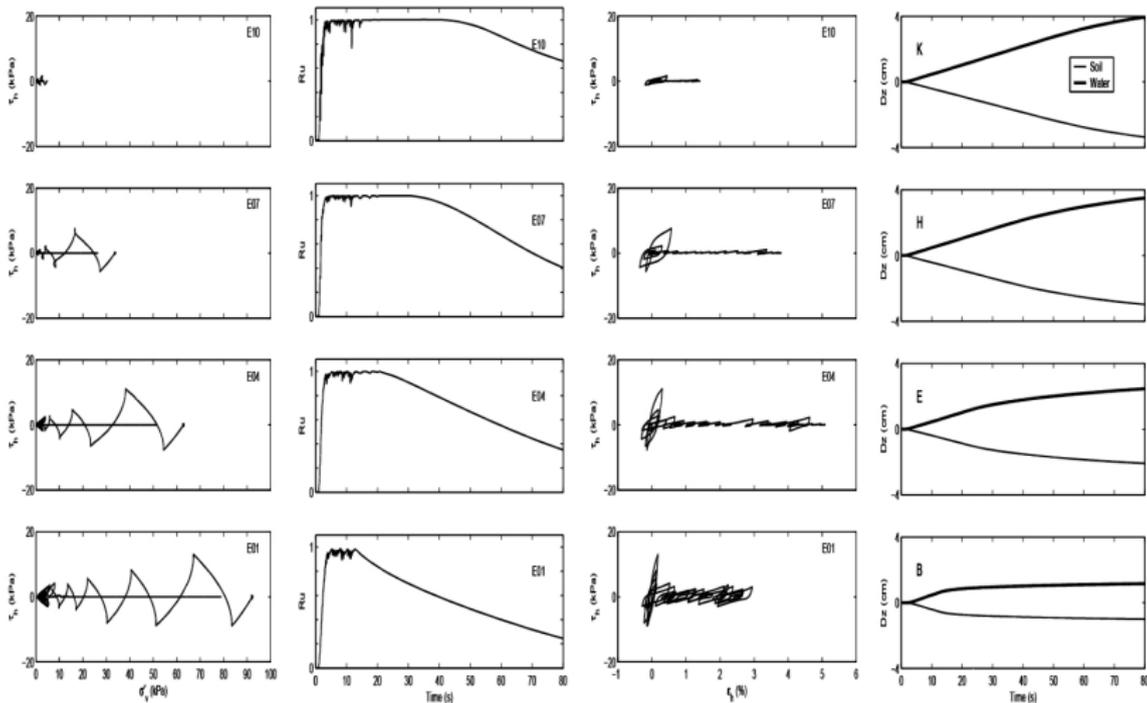
Level Ground, Dense Sand





Single Element and Soil Column Liquefaction

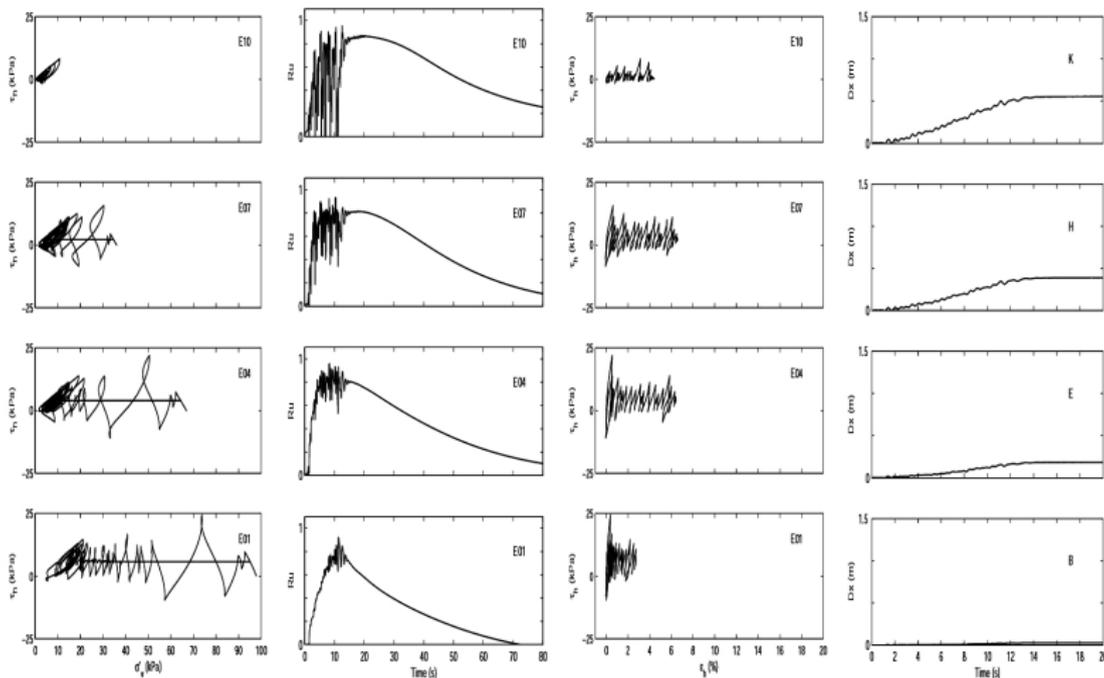
Level Ground, Loose Sand





Single Element and Soil Column Liquefaction

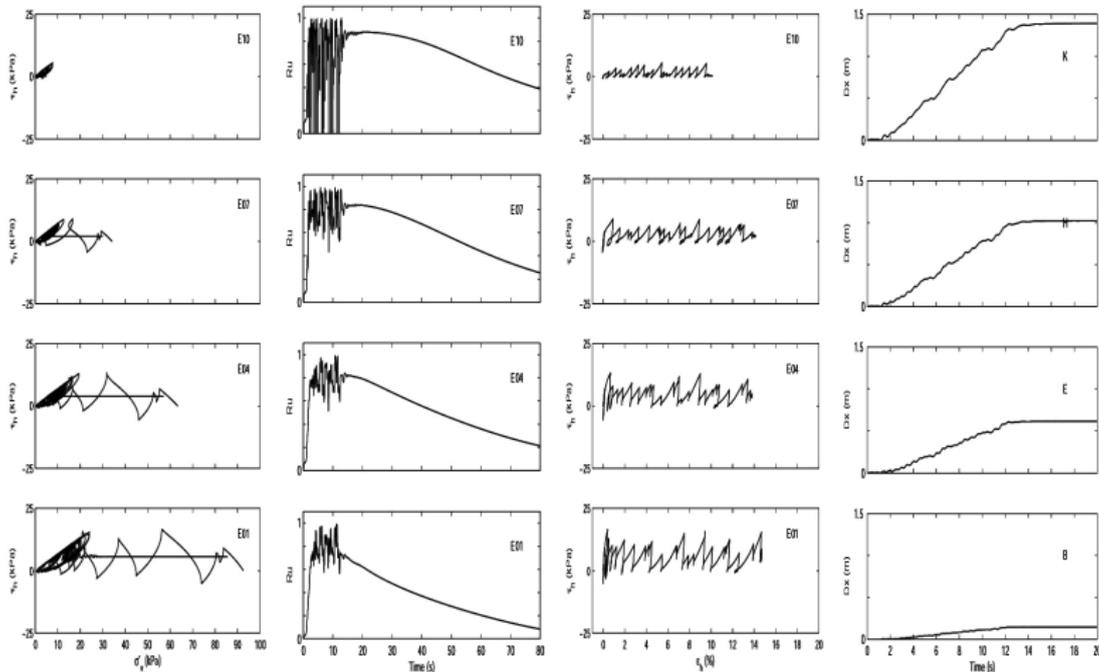
Sloping Ground, Dense Sand





Single Element and Soil Column Liquefaction

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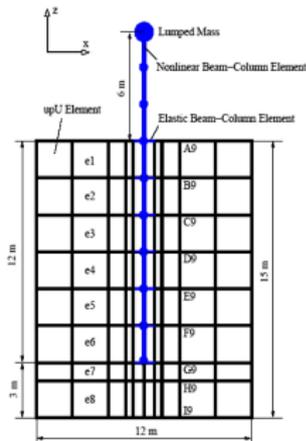
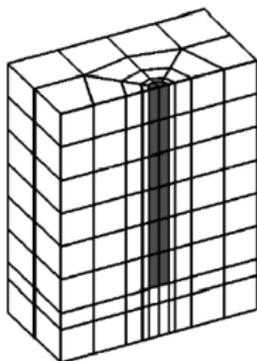
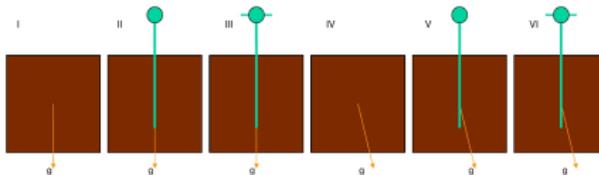
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Piles in Liquefying Soils

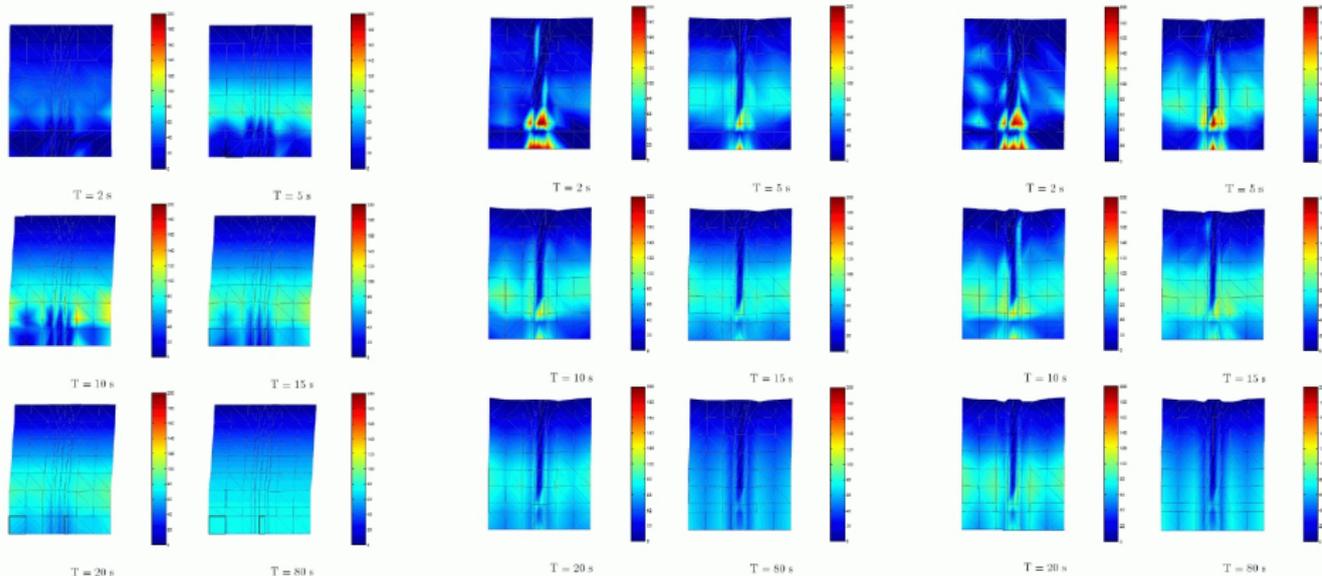
Bridge Pier–Pile Model





Piles in Liquefying Soils

Bridge Pier in Level Ground



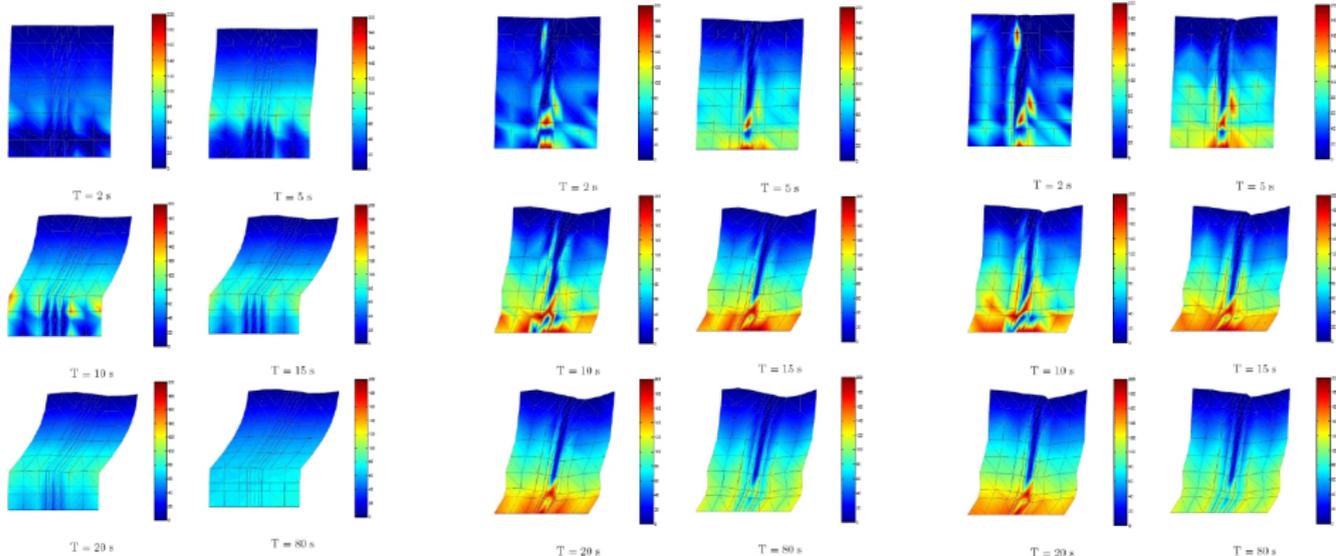
Case I

Case II

Case III



Bridge Pier in Sloping Ground



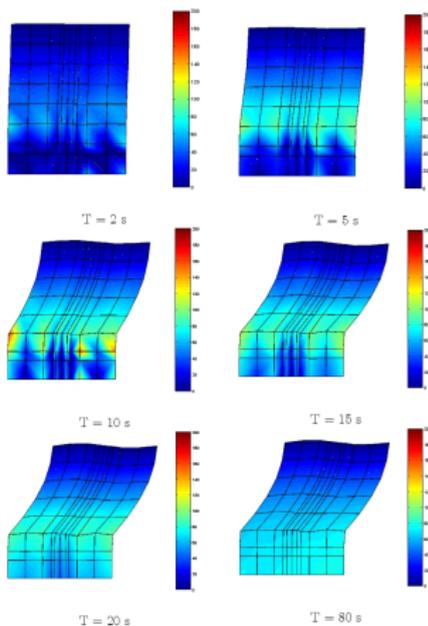
Case IV

Case V

Case VI

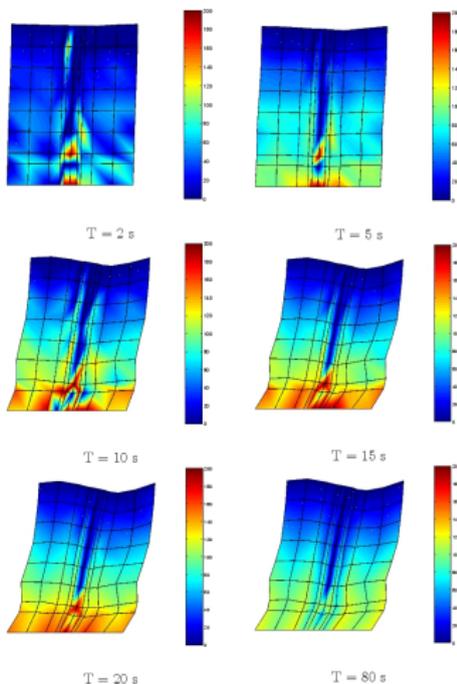


Case IV: Sloping Ground



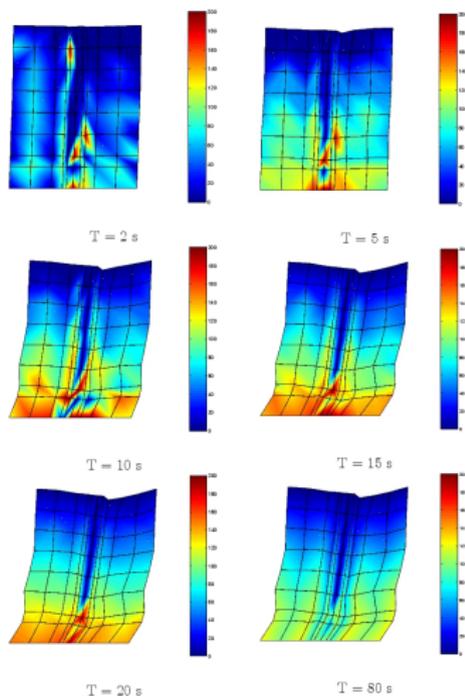


Case V: Pile in Sloping Ground, Free Top





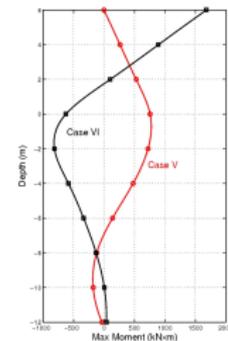
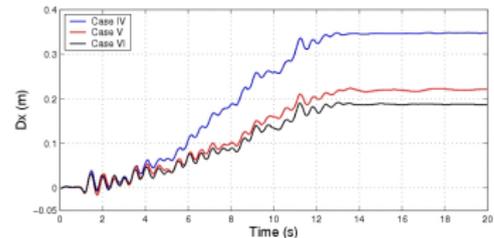
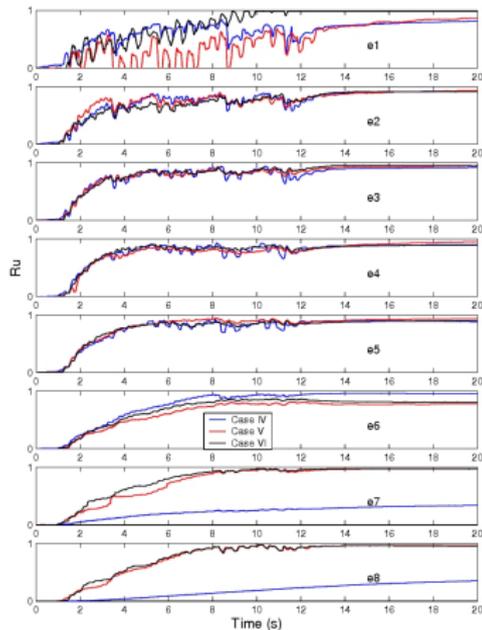
Case VI: Pile in Sloping Ground, Fixed Top Rotation





Piles in Liquefying Soils

Comparing Cases IV, V, and VI





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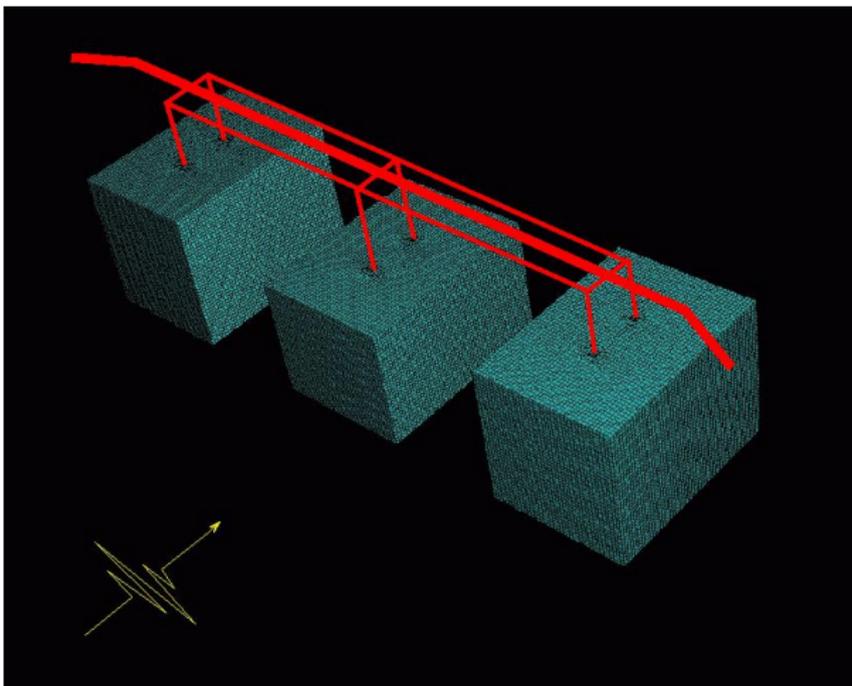
Detailed 3D, FEM model

- ▶ Construction process
- ▶ Two types of soil: stiff soil (UT, UCD), soft soil (Bay Mud)
- ▶ Deconvolution of given surface ground motions
- ▶ Use of the DRM (Prof. Bielak et al.) for seismic input
- ▶ Piles → beam-column elements in soil holes
- ▶ No artificial damping (only mat. dissipation, radiation)
- ▶ Structural model: collaboration UCD, UCB and UW
- ▶ Element size issues (filtering of frequencies)

model size (el)	el. size	f_{cutoff}	min. G/G_{max}	γ
12K	1.0 m	10 Hz	1.0	<0.5 %
15K	0.9 m	>3 Hz	0.08	1.0 %
150K	0.3 m	10 Hz	0.08	1.0 %
500K	0.15 m	10 Hz	0.02	5.0 %

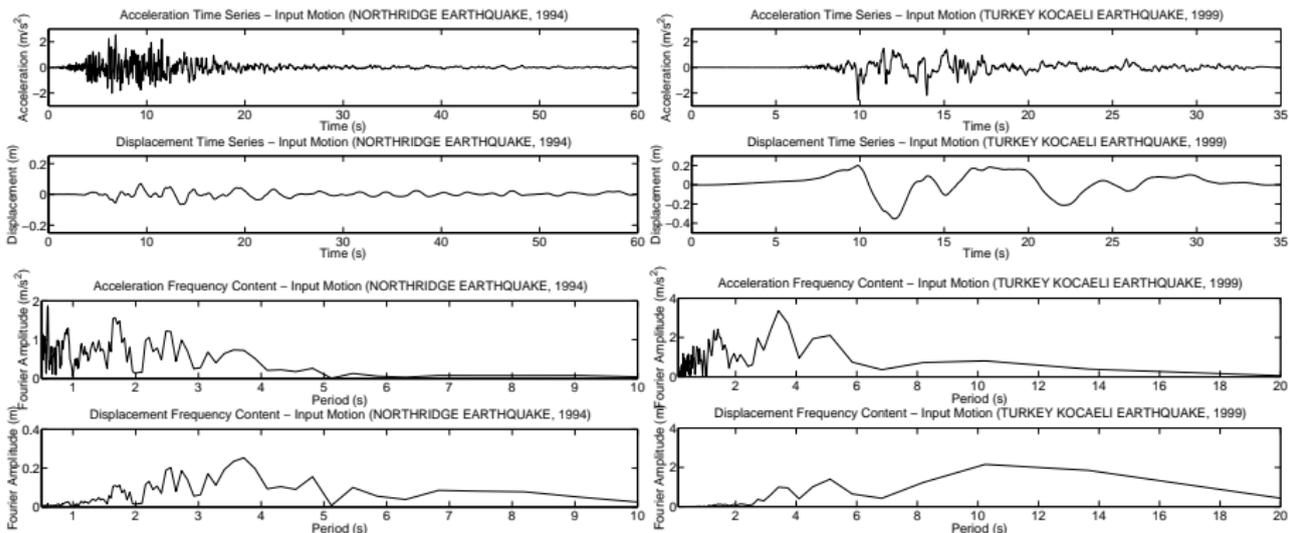


FEM Mesh (one of)



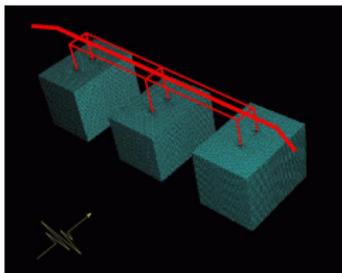
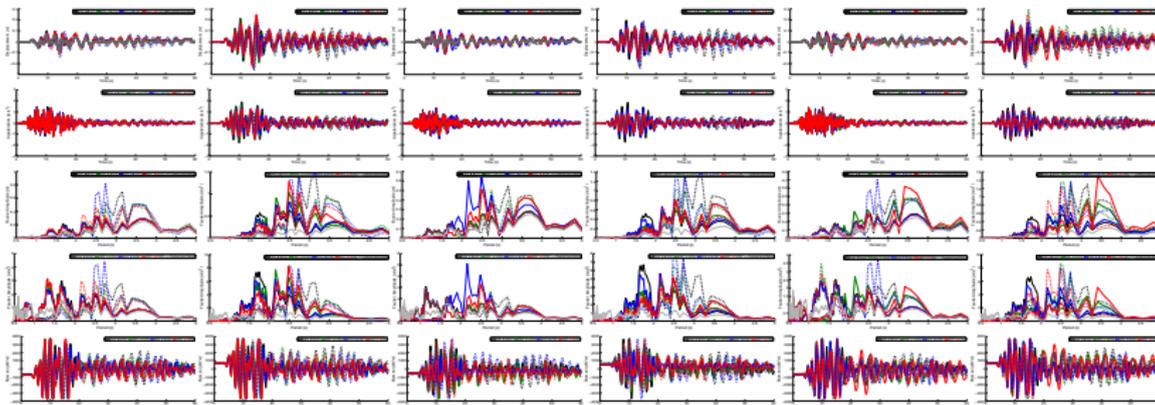


Northridge and Kocaeli Input Motions





Simulation Results





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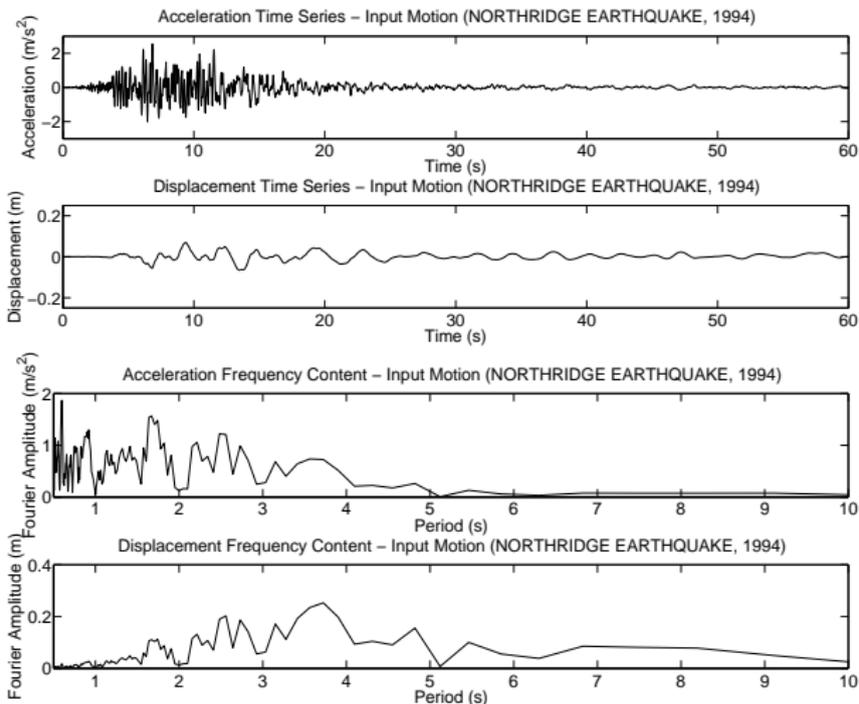
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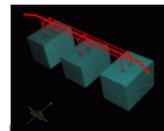
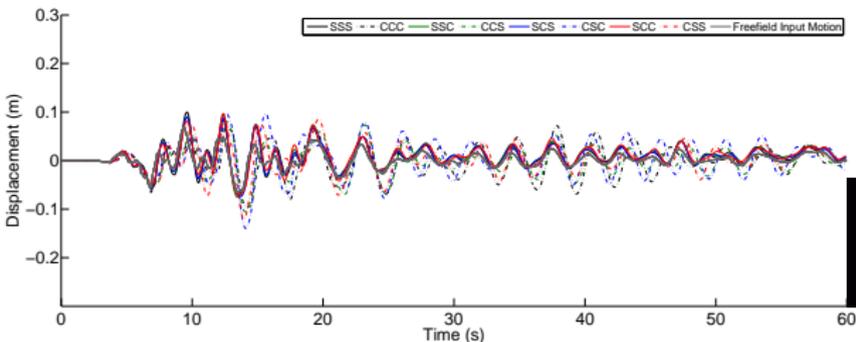
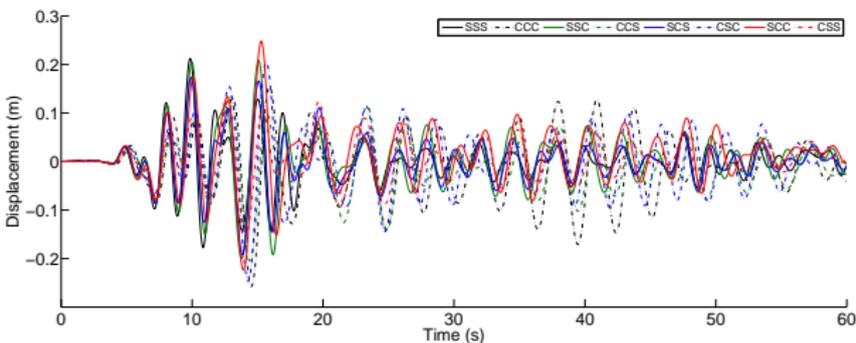


Northridge Input Motions



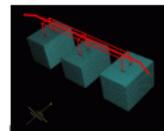
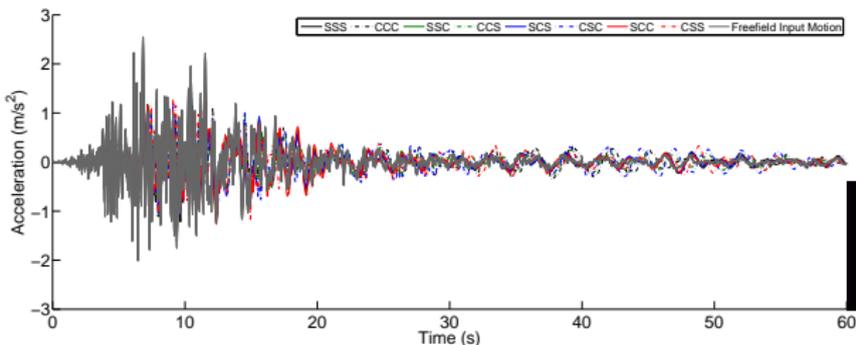
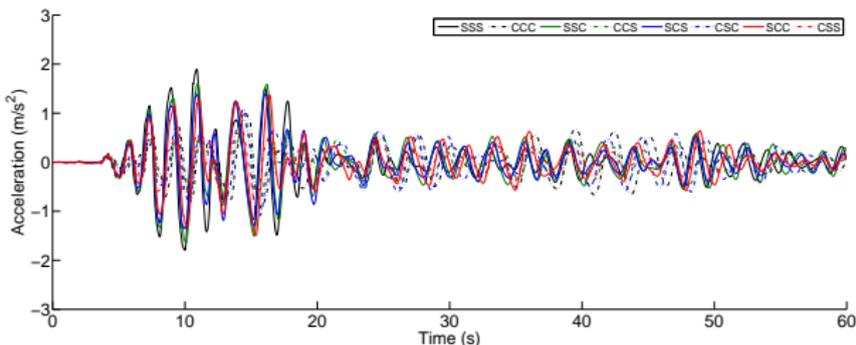


Short Period E.: Left Bent, Structure and Soil, Disp.



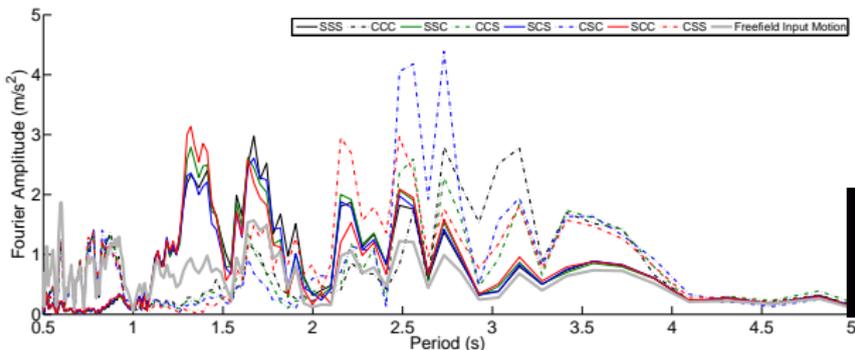
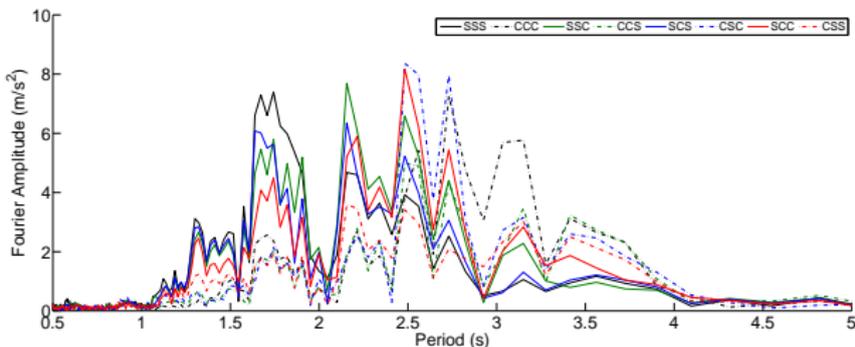


Short Period E.: Left Bent, Structure and Soil, Acc.





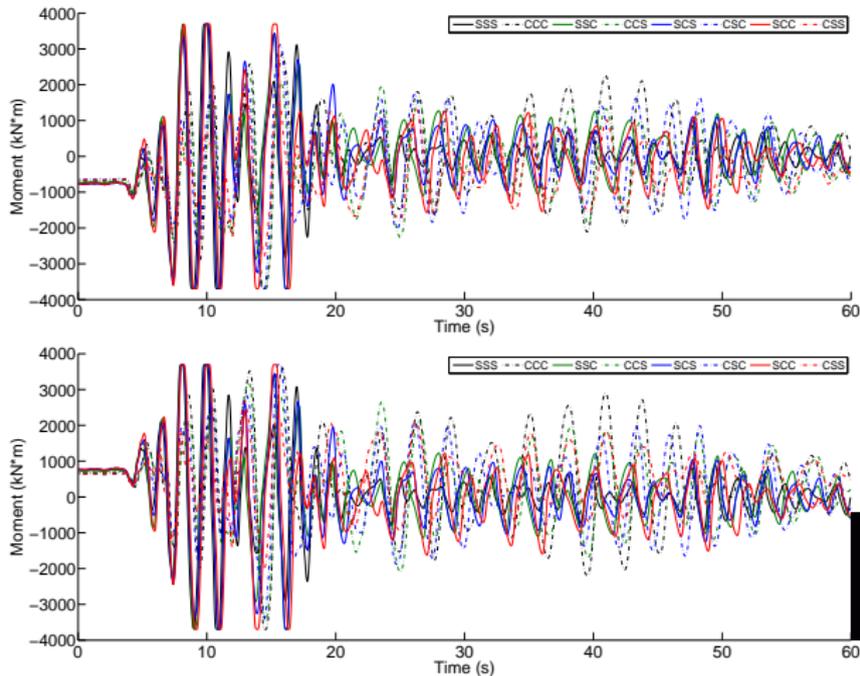
Short Period E.: Left Bent, Structure and Soil, Acc.Sp.





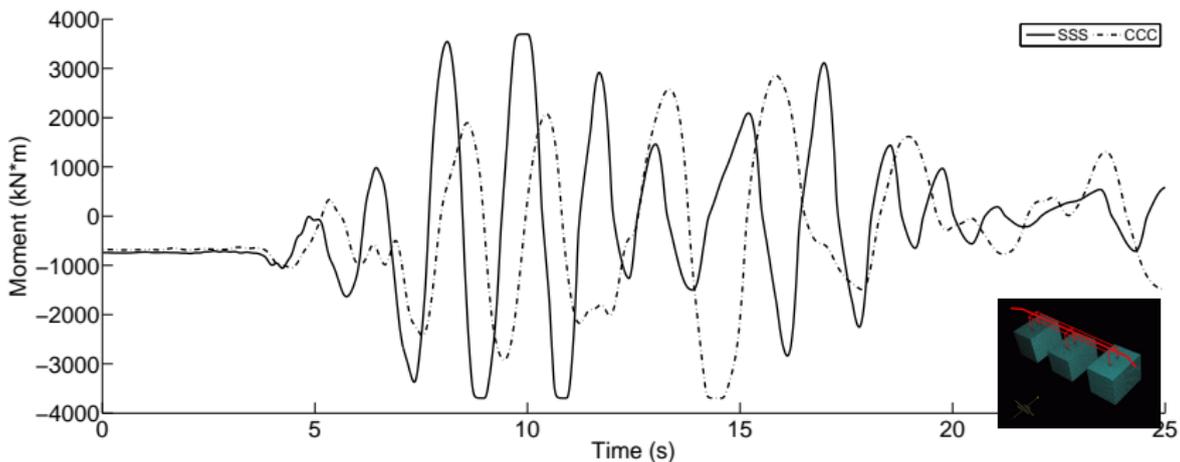
Behavior for Short and Long Period Motions

Short Period E.: Left Bent, Structure and Soil, M.





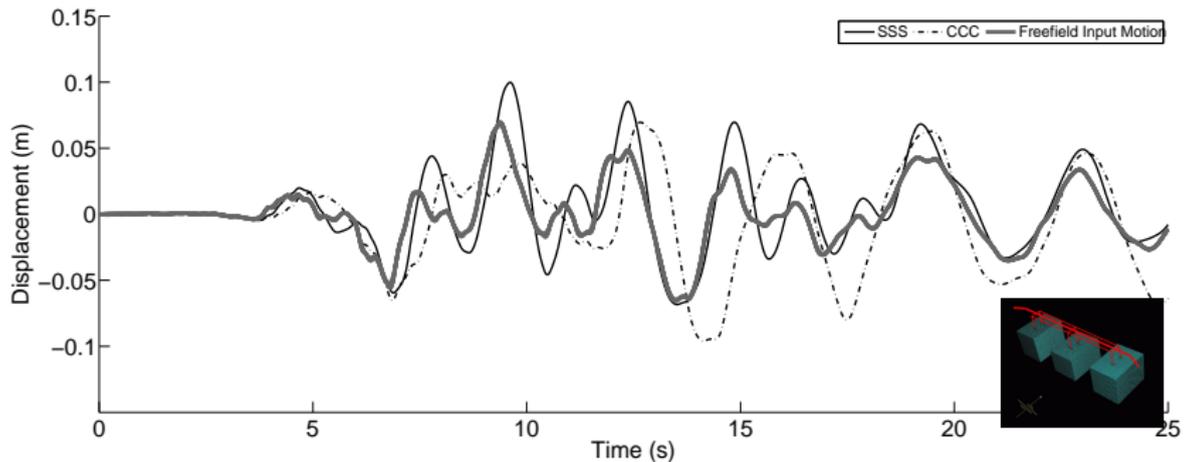
Short Period E.: Left Bent, Structure and Soil, M.





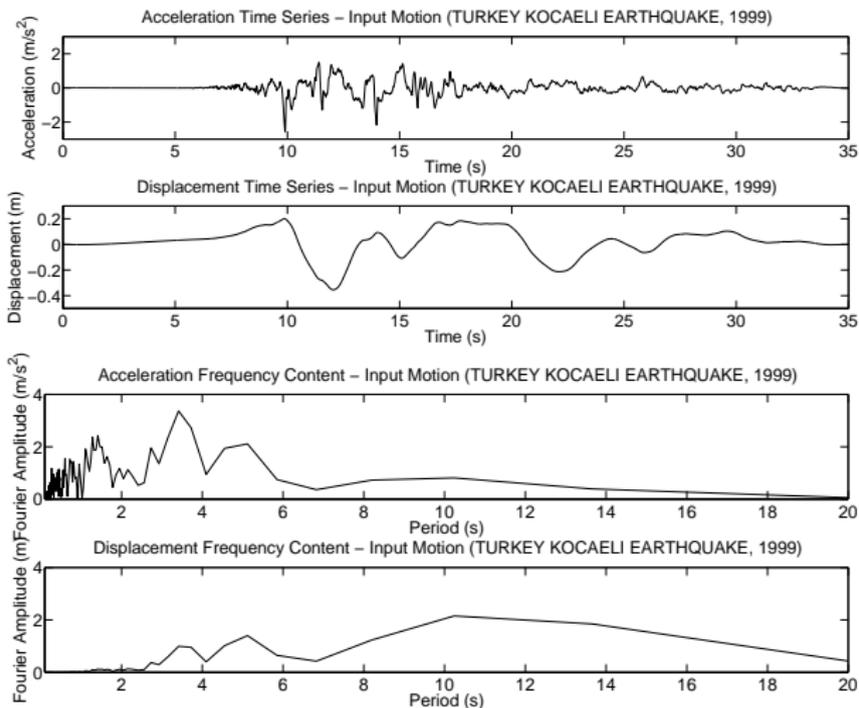
Behavior for Short and Long Period Motions

Short Period E.: Left Bent, Free Field vs Real Disp.



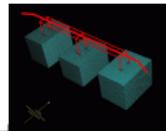
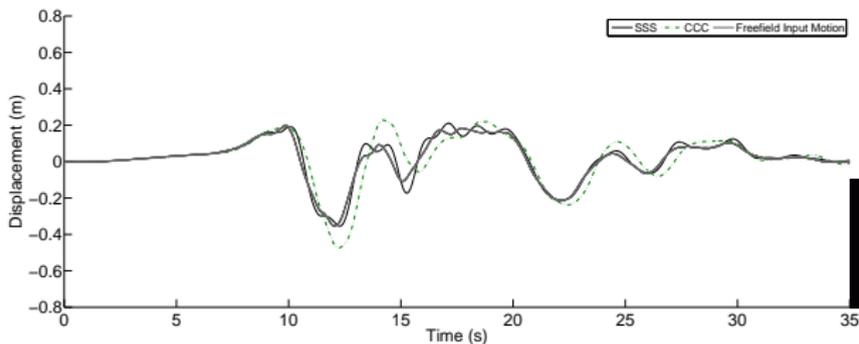
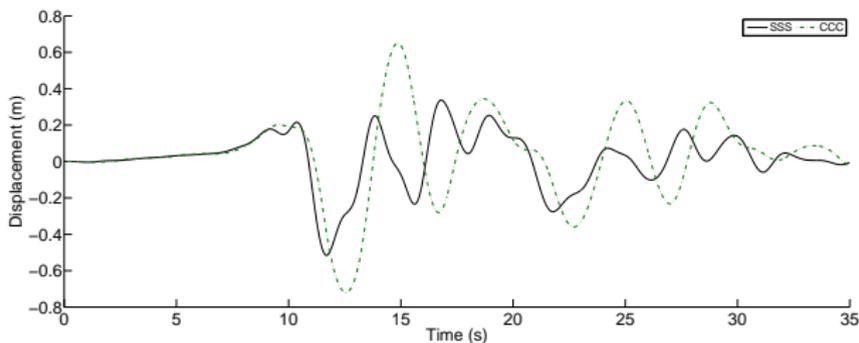


Kocaeli Input Motions



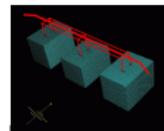
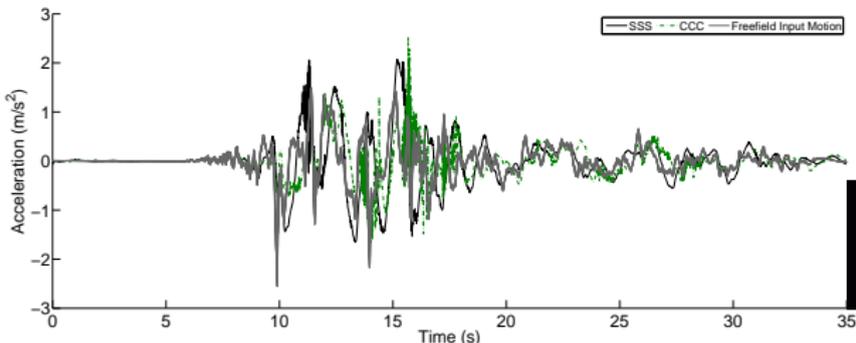
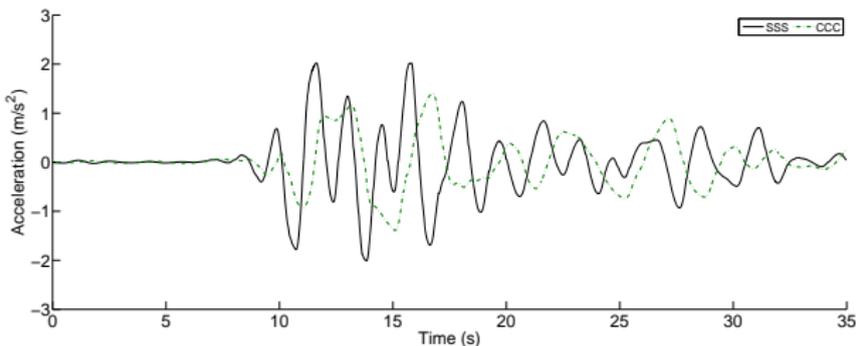


Long Period E.: Left Bent, Structure and Soil, Disp.



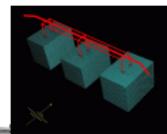
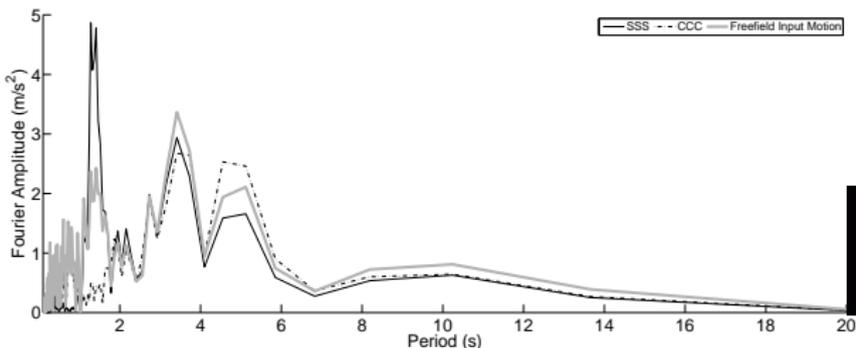
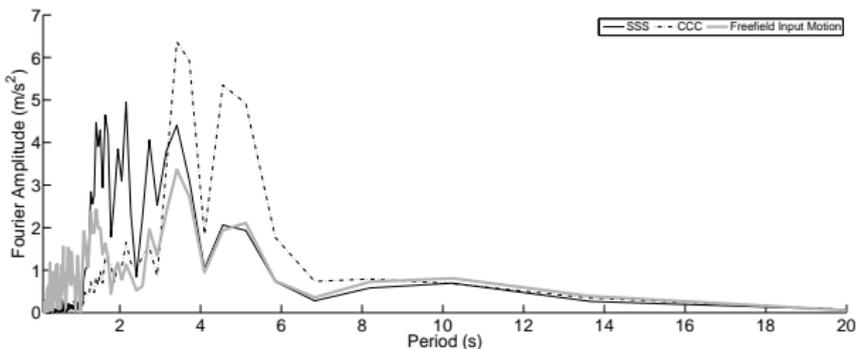


Long Period E.: Left Bent, Structure and Soil, Acc.



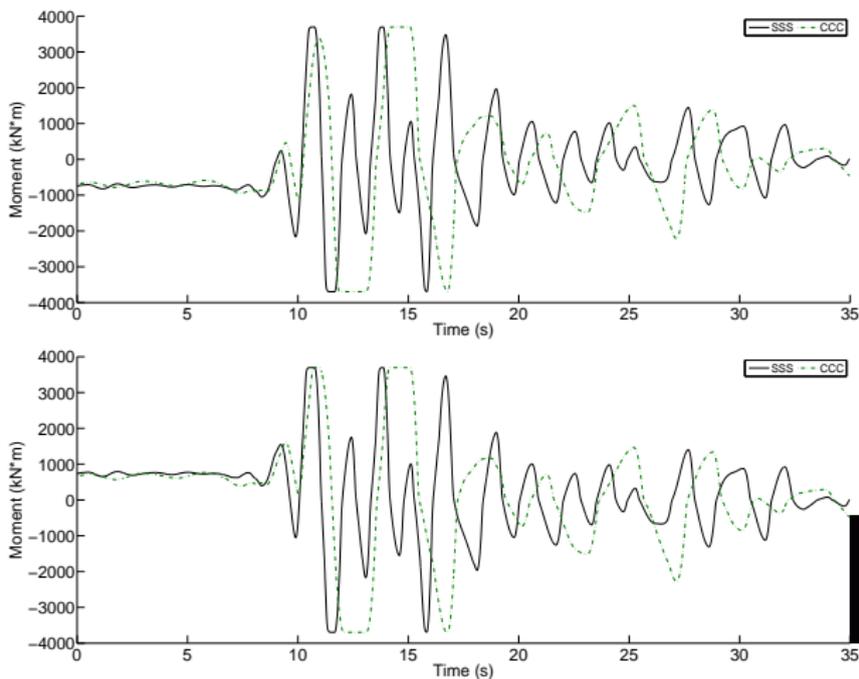


Long Period E.: Left Bent, Structure and Soil, Acc.Sp.





Long Period E.: Left Bent, Structure and Soil, M.





Summary

- ▶ Useful numerical tools are available
- ▶ Willing to help as much as I can to see these tools used in practice
- ▶ My web site contains many useful materials
- ▶ **<http://geomechanics.ucdavis.edu>**