Simulation of 3-D Global Bridge Response to Shaking and Lateral Spreading

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PEER Transportation Systems Research Program
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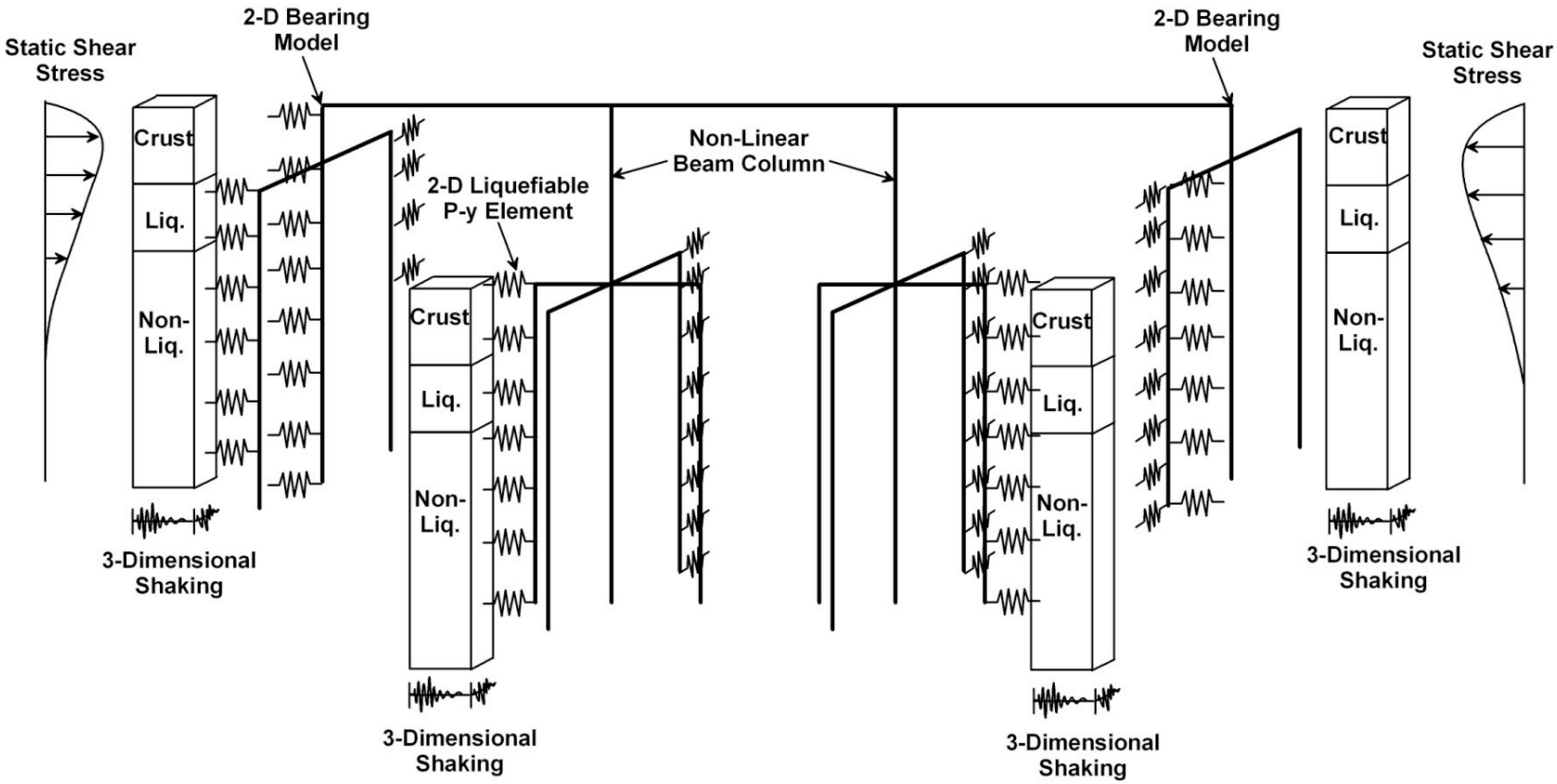
Project Description



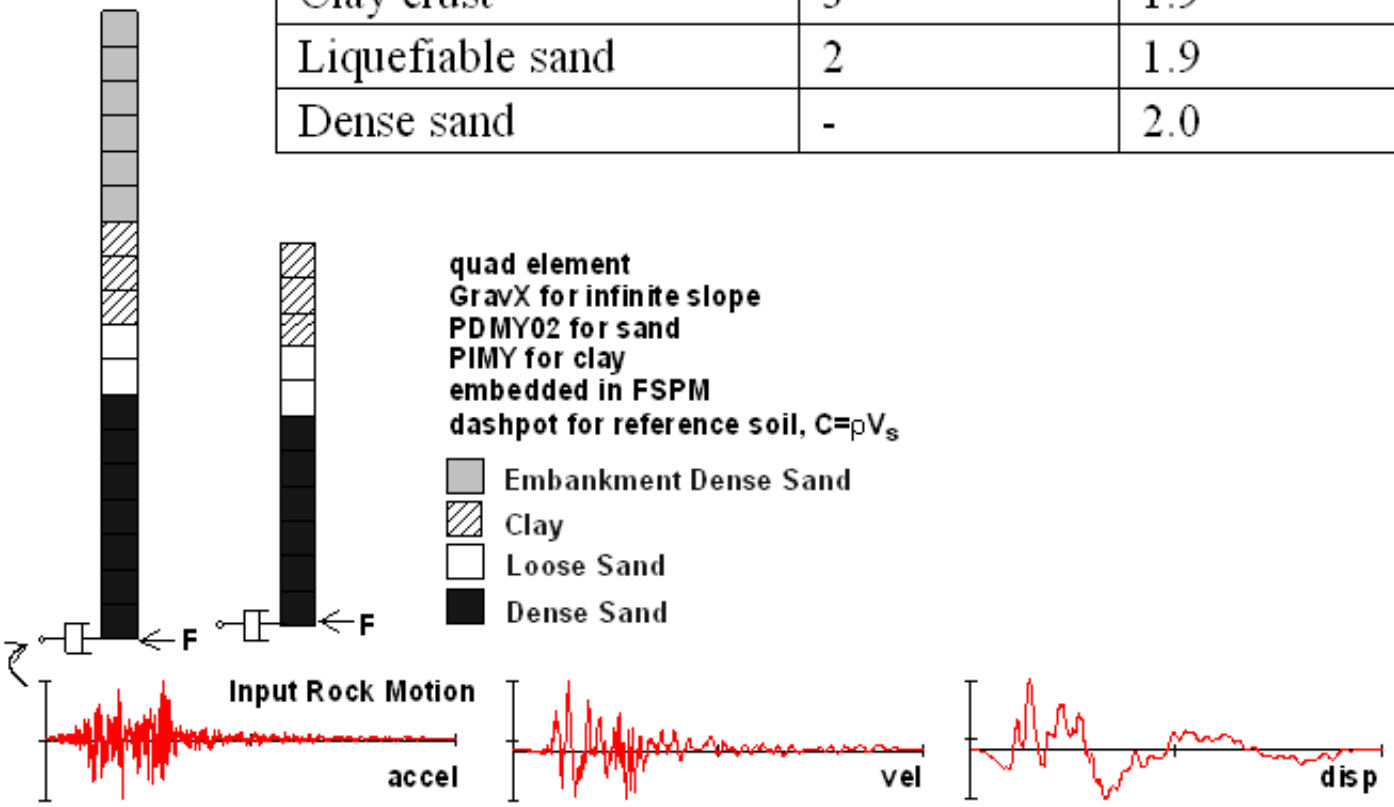
Deliverables

- ☑ Suite of liquefaction site response analyses (ground motion and effective stresses at each depth), surface ground motion reduction factors C_{liq}, and comparison of final lateral spreading displacements with common methods for estimating lateral spreading.
- ☑ A set of new OpenSees materials (PyLiq2 and TzLiq2) that permit direct input of displacements and effective stresses without being coupled to a soil continuum element.
- ☑ Validation exercise comparing nonlinear p-y method with equivalent linear macro spring method using Painter Street Bridge example, and for liquefaction case using centrifuge test data.
- ☑ Development of an analytical procedure for analyzing shaking and lateral spreading without explicitly modeling entire soil continuum.
- ☐ Combinations of inertia and kinematic demands for transverse and longitudinal response (useful for equivalent static analysis).
- ☐ Comparison with fragility functions for various bridge vintages and structural configurations (follow-up on previous PEER-LL study).

1-D site response analyses

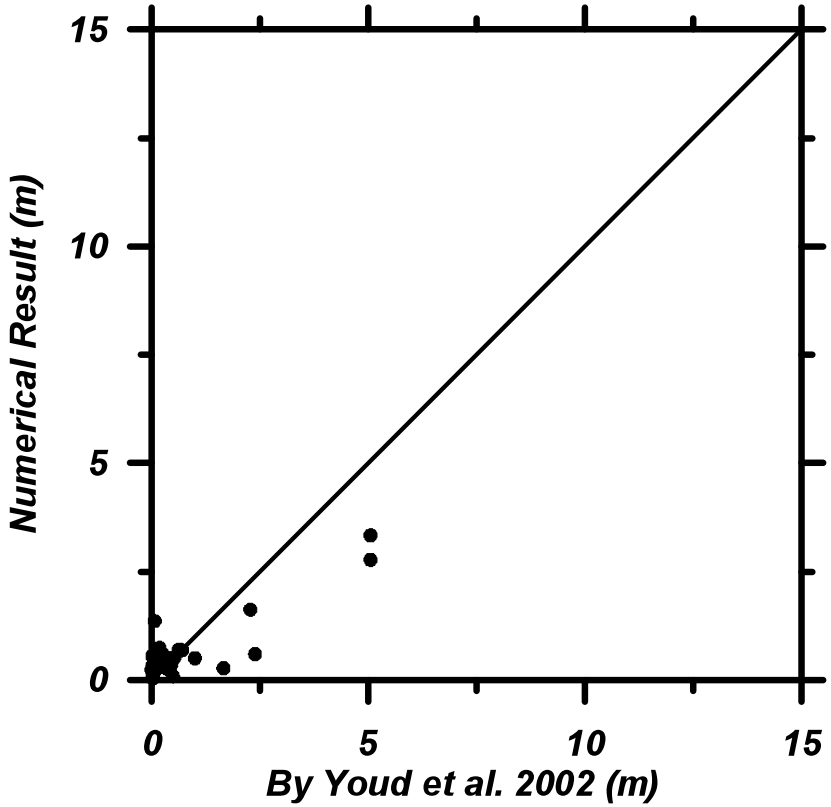
- Model

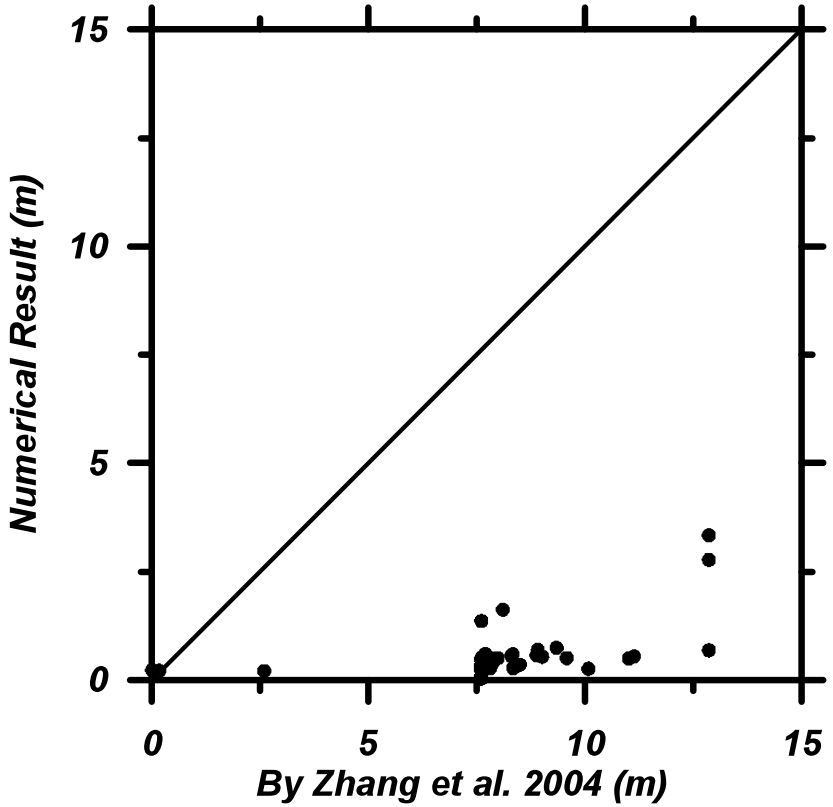
Soil layer	Thickness (m)	$\rho\,(Mg/m^3)$	$\phi\,(deg.)$	c (kPa)
Embankment dense sand	6	2.0	38	20
Clay crust	3	1.9	0	70
Liquefiable sand	2	1.9	32	-
Dense sand	-	2.0	38	-



1-D site response analyses

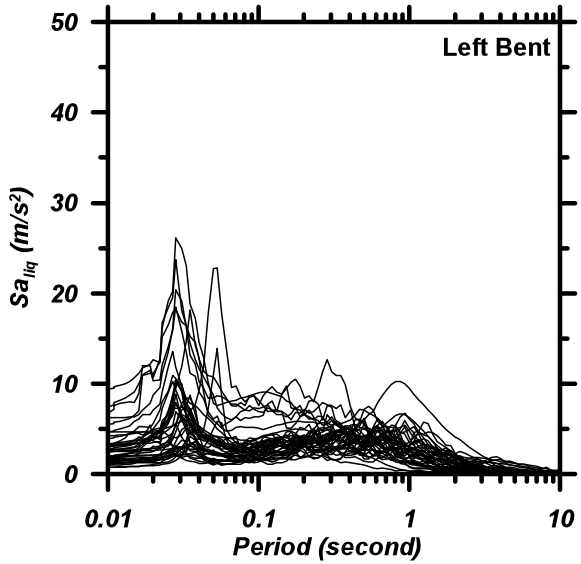
Comparison of Lateral Spread Displacements, Slope Degree is 4 degrees.

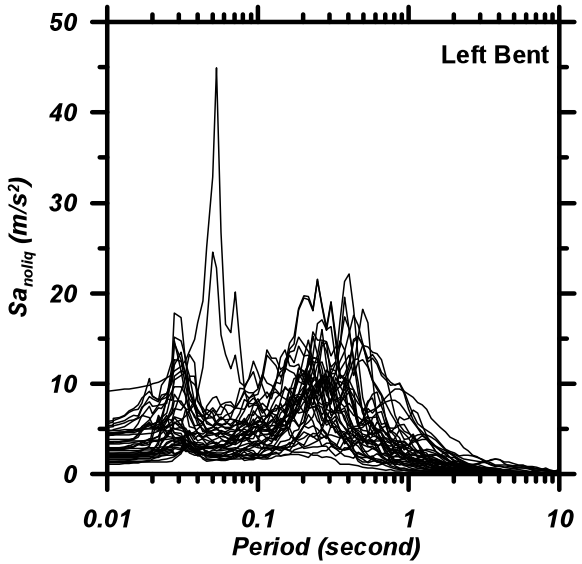


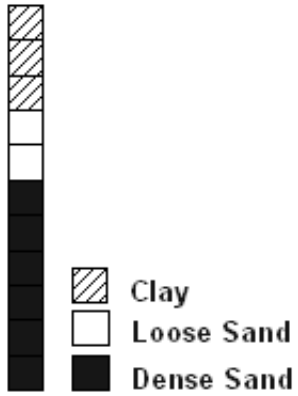


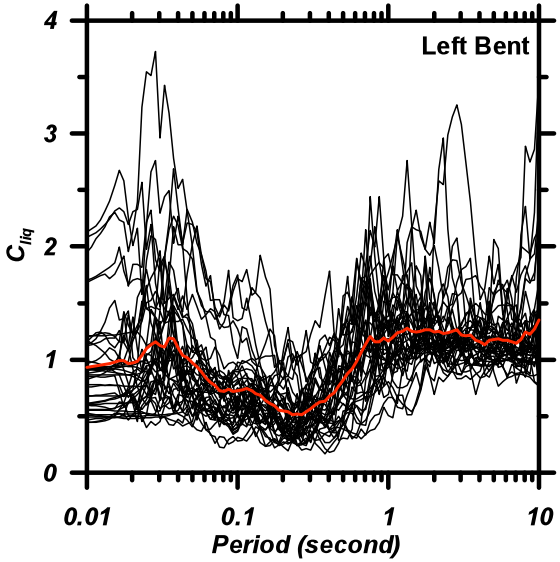
1-D site response analyses

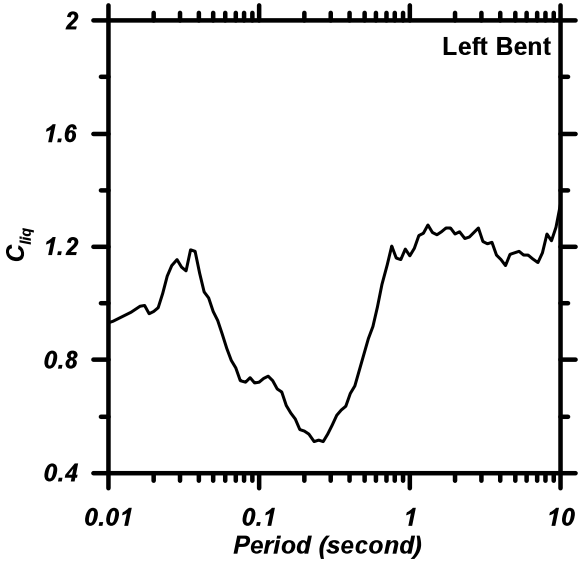
- Effect of liquefaction, $C_{liq}(T)$=mean(Sa_{liq}/Sa_{noliq})



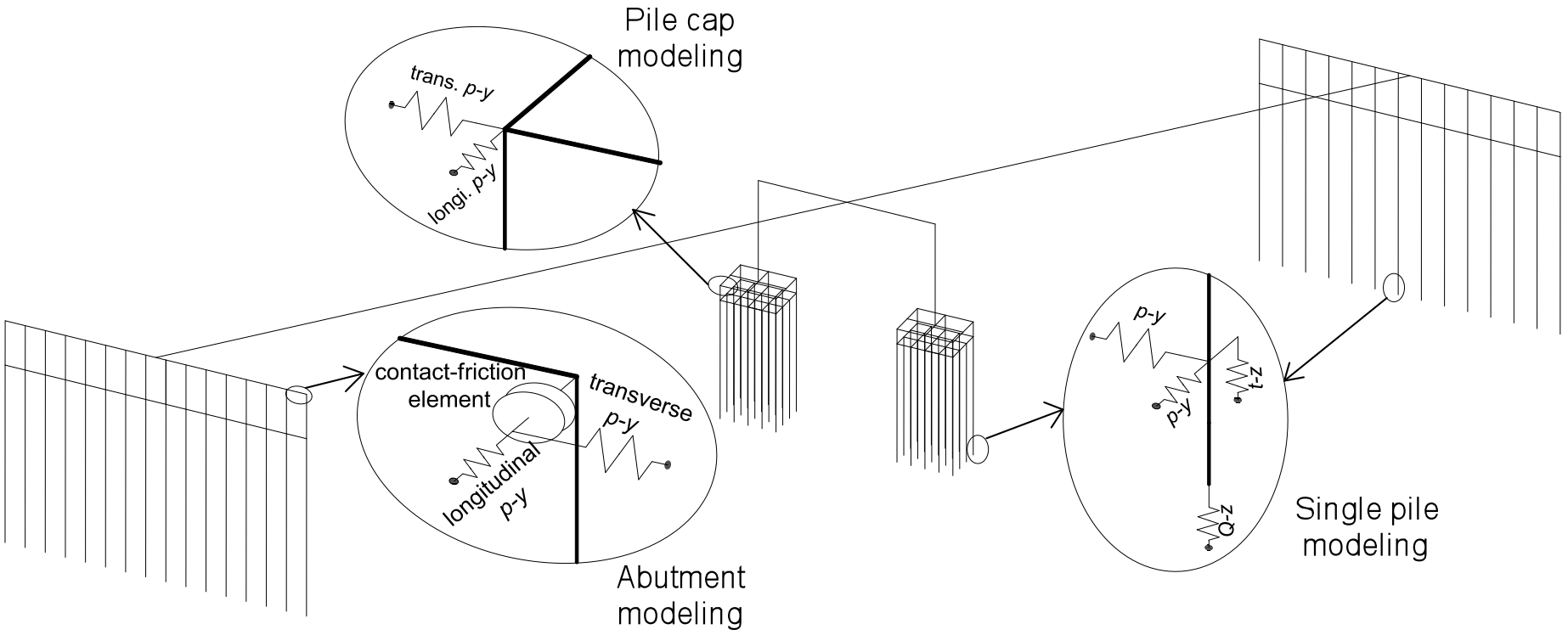




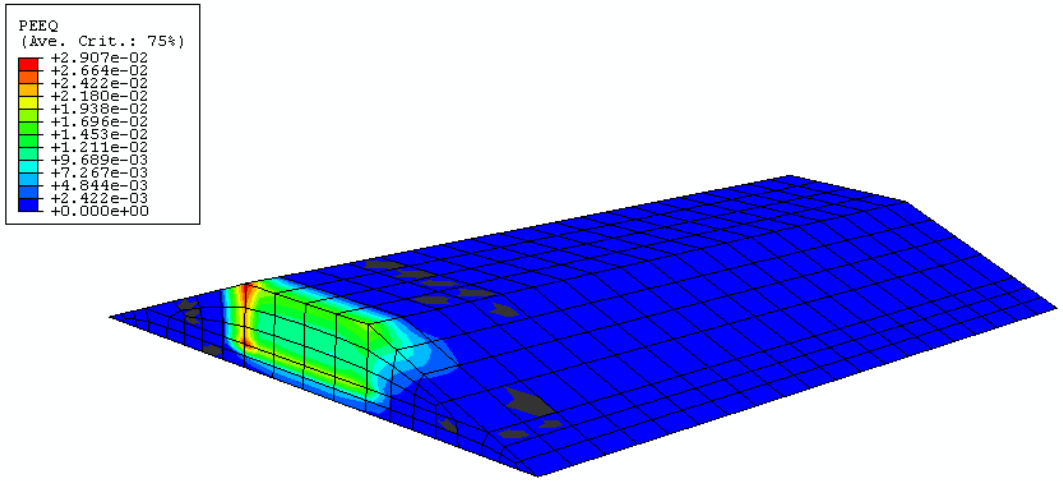


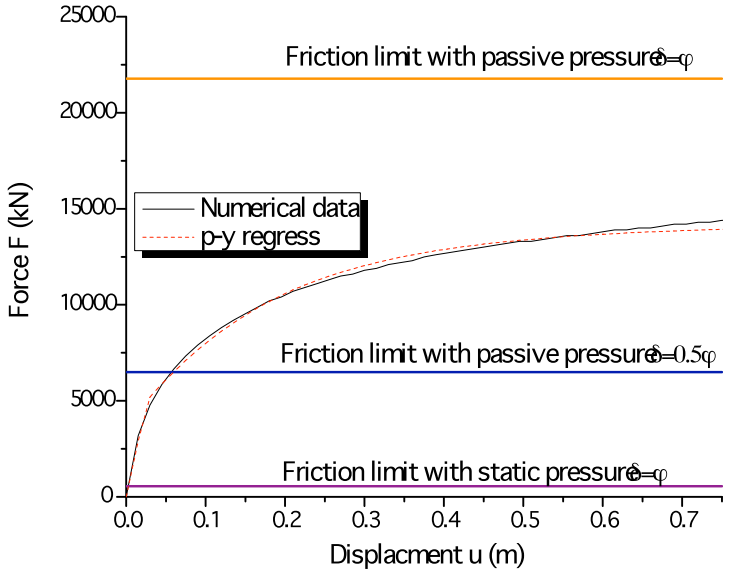


Modeling Validation without liquefaction – Painter Street Bridge



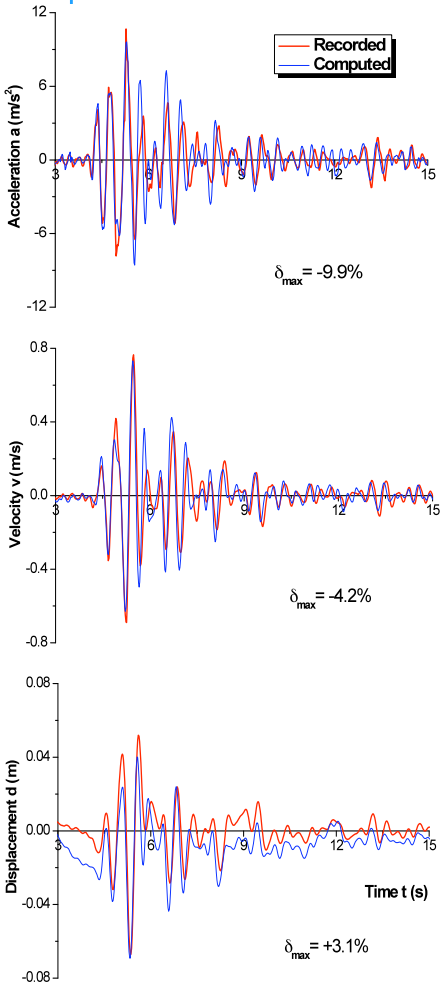
Painter Street Bridge



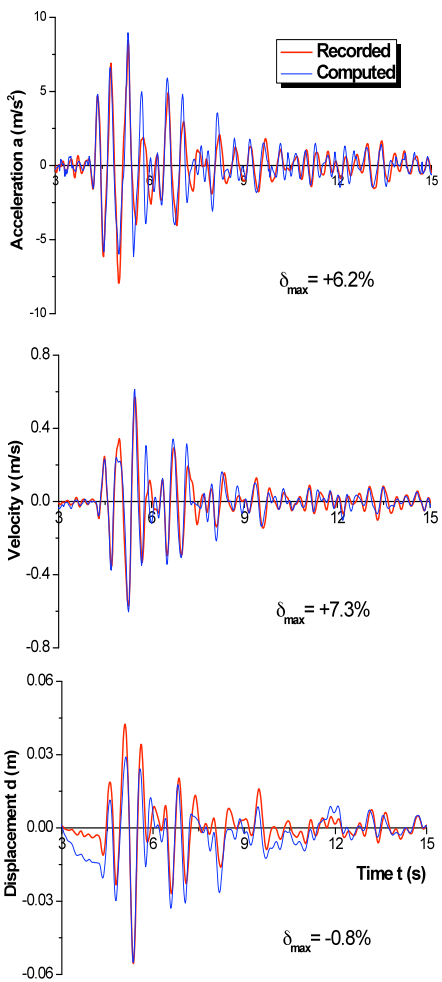


Painter Street Bridge

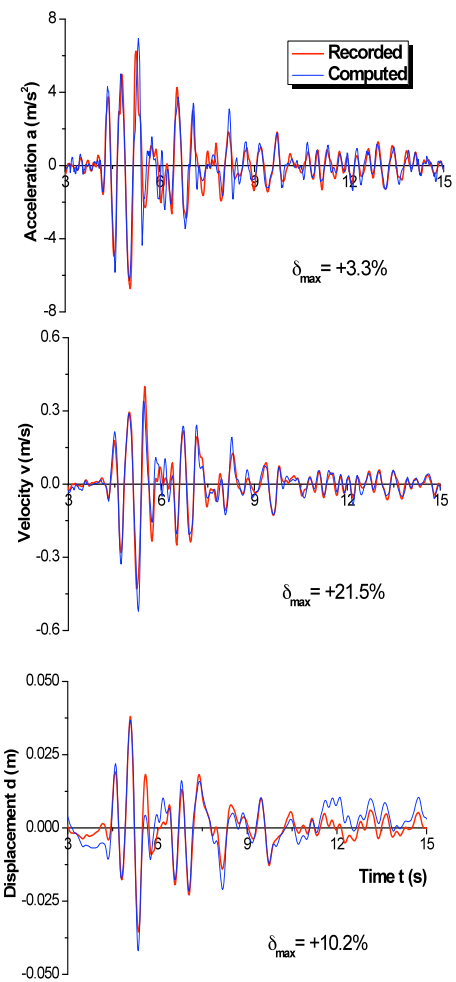
C4: Transverse @ close to left abutment



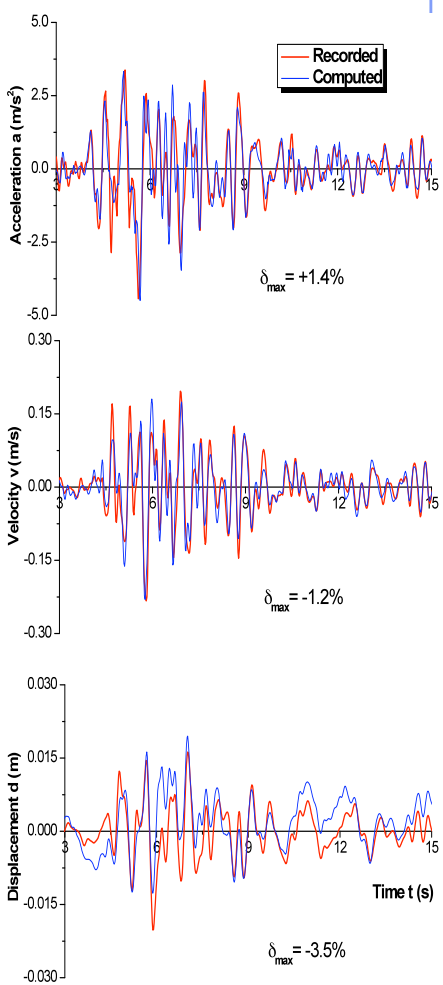
C7: Transverse @ middle bent top



C9: Transverse @ right abutment



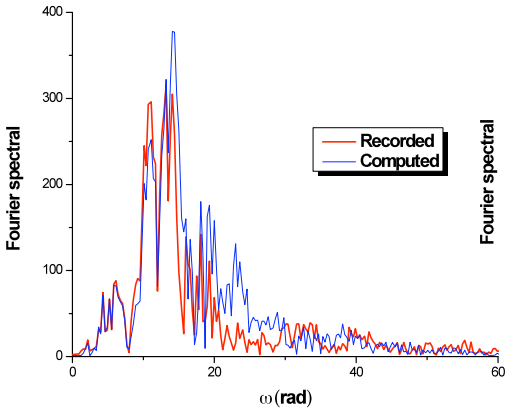
C11: Longitudinal @ right abutment



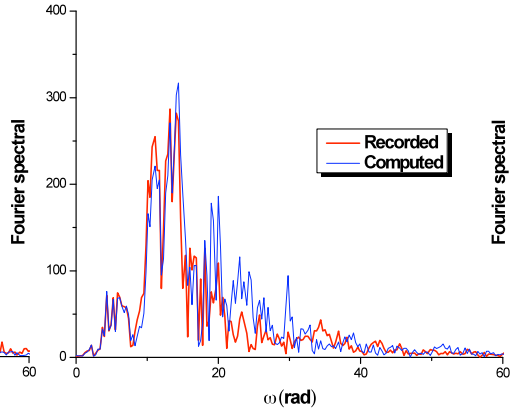
Painter Street Bridge

Errors of the maximum responses δ_{max} (Unit: %)

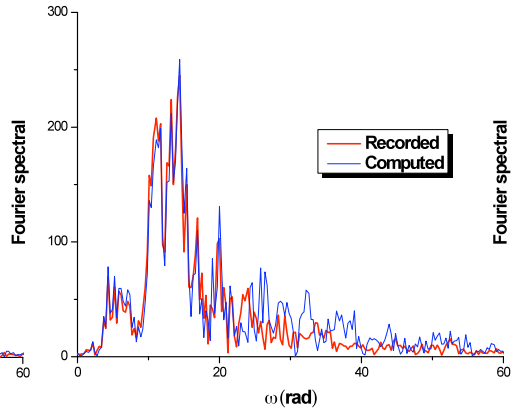
Recorder Channel	Absolute response			Relative response		
	Acceleration	Velocity	Displacement	Acceleration	Velocity	Displacement
C4	-9.9	+2.0	+7.9	+7.7	-4.2	+3.1
C7	+6.2	-14.7	+0.7	+3.4	+7.3	-0.8
C9	+3.3	-12.0	+11.2	+38.3	+21.5	+10.2
C11	+1.4	2.9	-1.7	+11.1	-1.2	-3.5



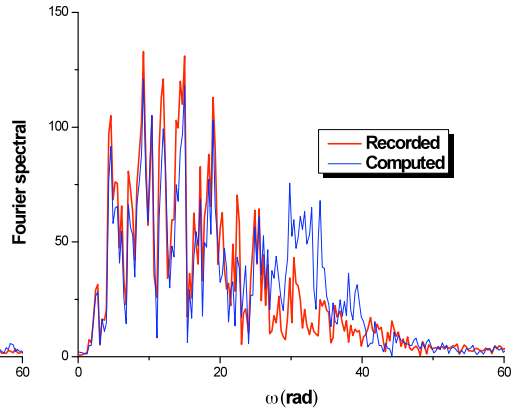
C4



C7

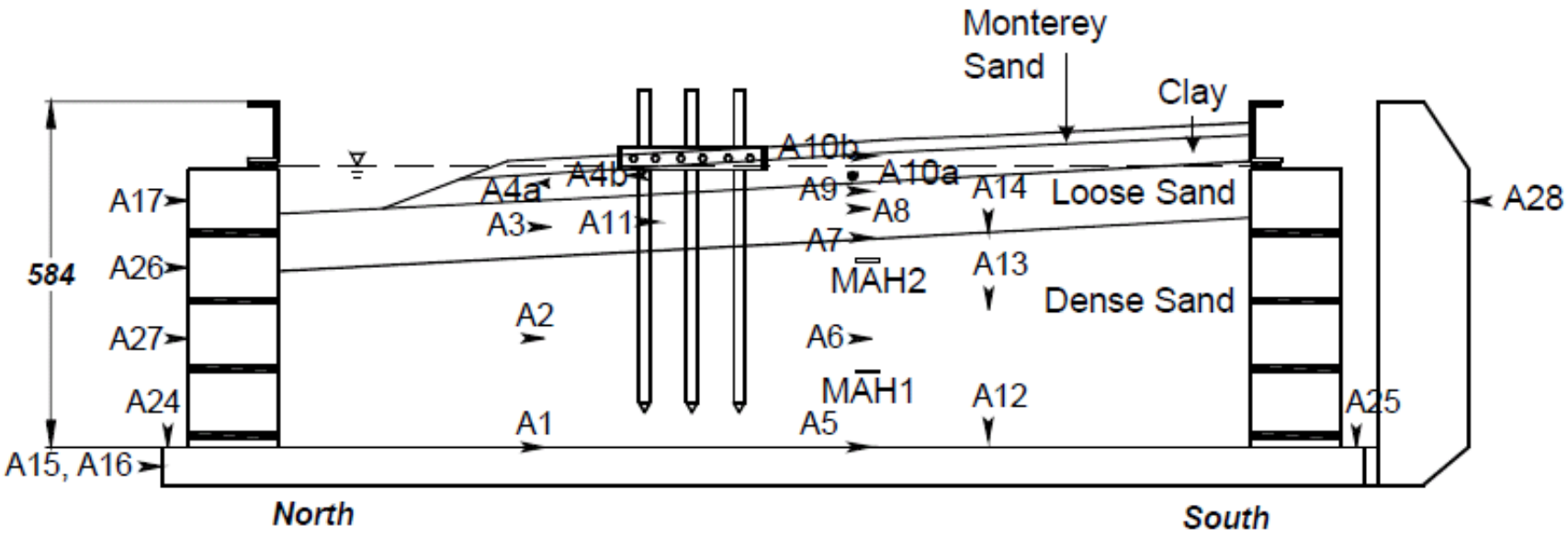


C9



C11

Modeling Validation with Liquefaction – Centrifuge Model

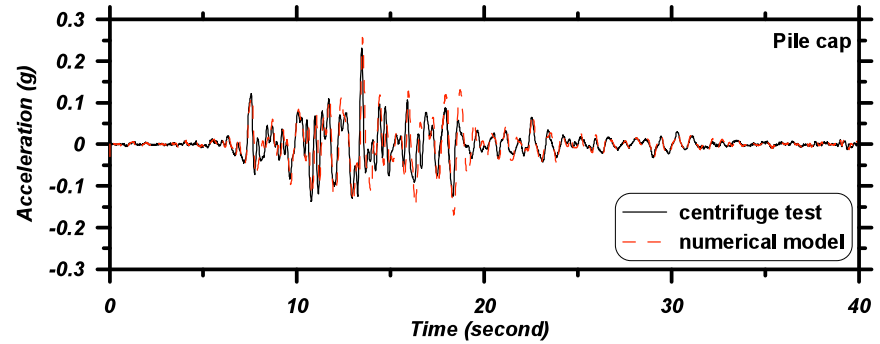


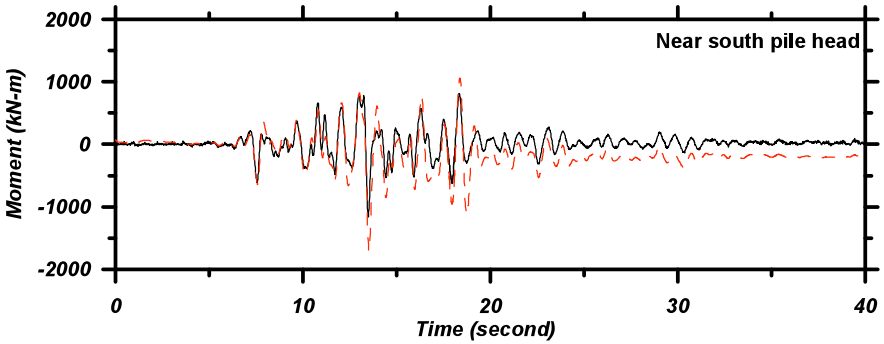
- **Impose known ground motion and effective stress time series into free ends of PyLiq2 materials.**

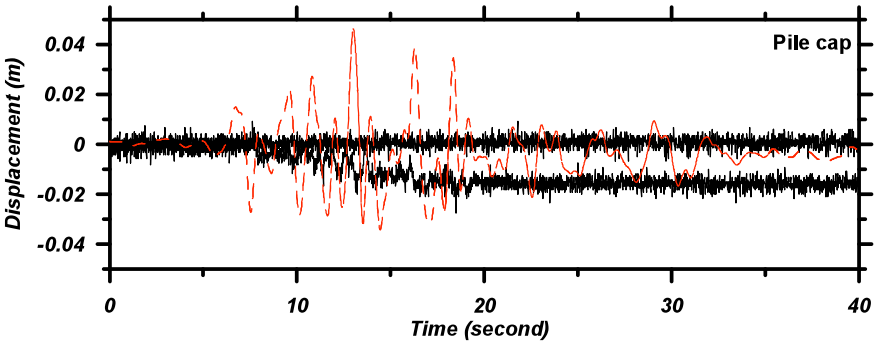
Centrifuge Model

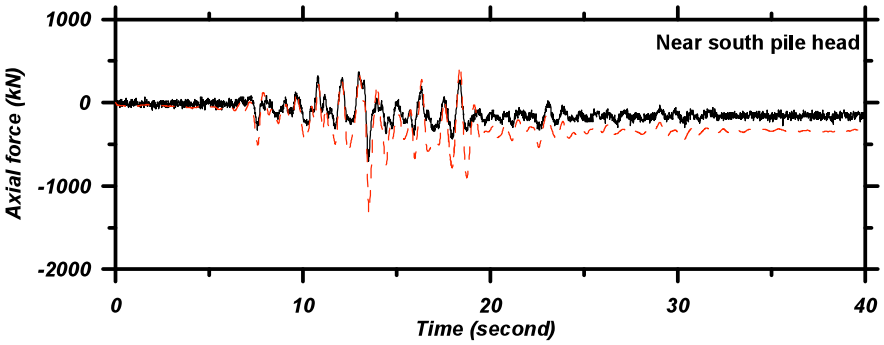
Result comparison

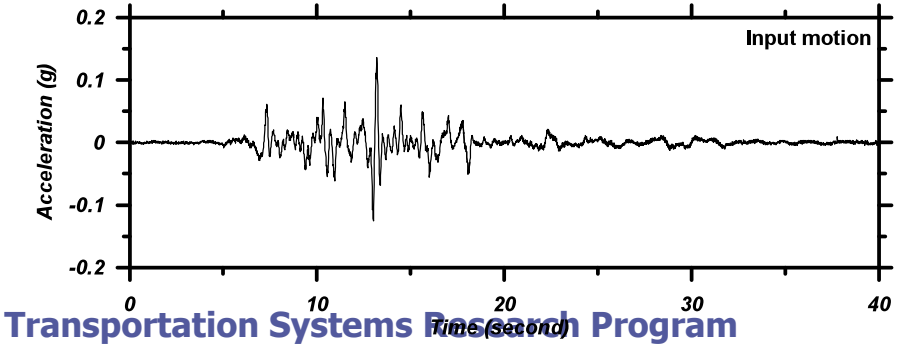
Small Santa Cruz motion, r_u = 0.3

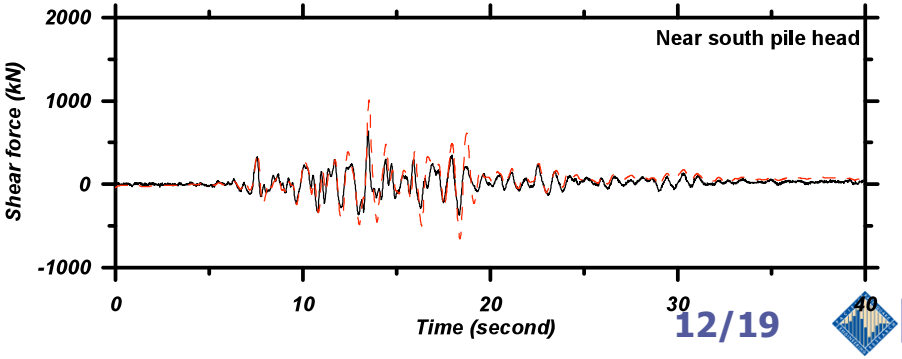






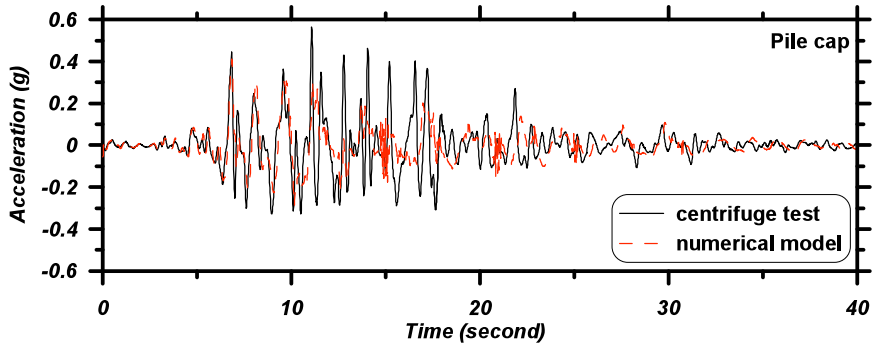


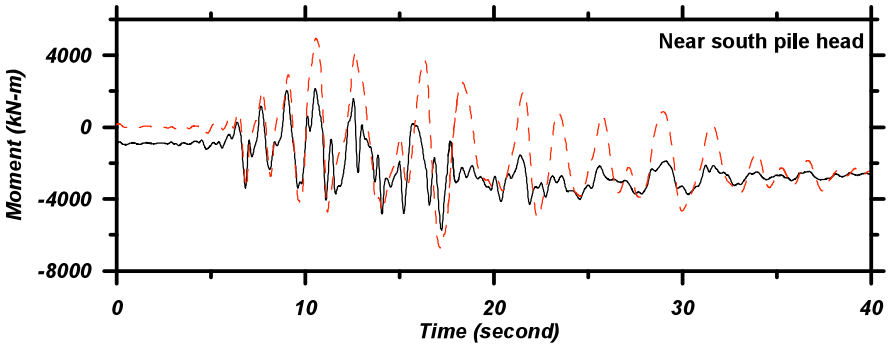


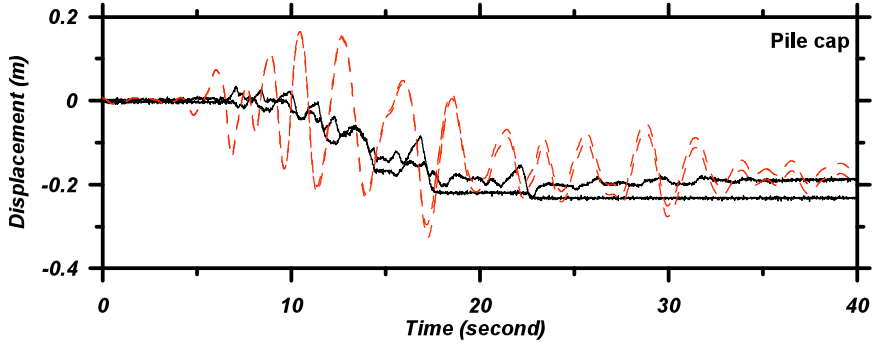


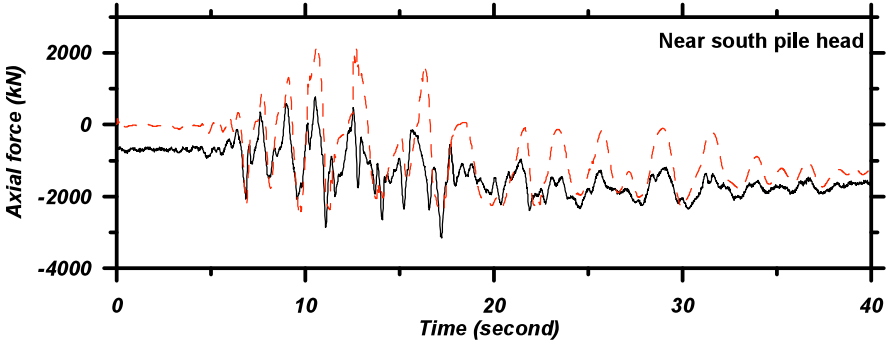
Validation against centrifuge tests

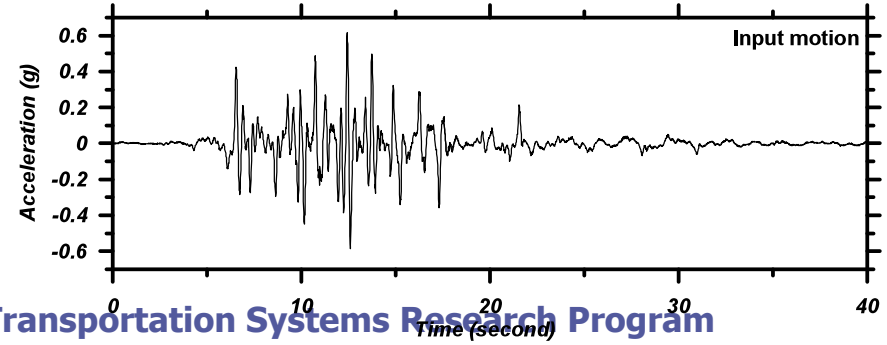
- Result comparison
  - Large Santa Cruz motion, $r_u > 1.0$

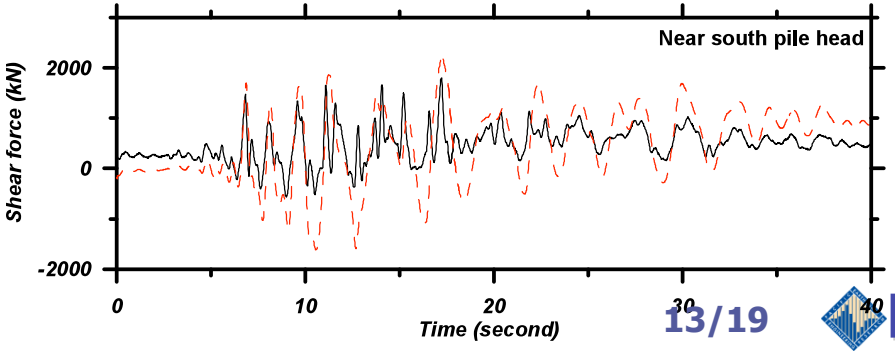






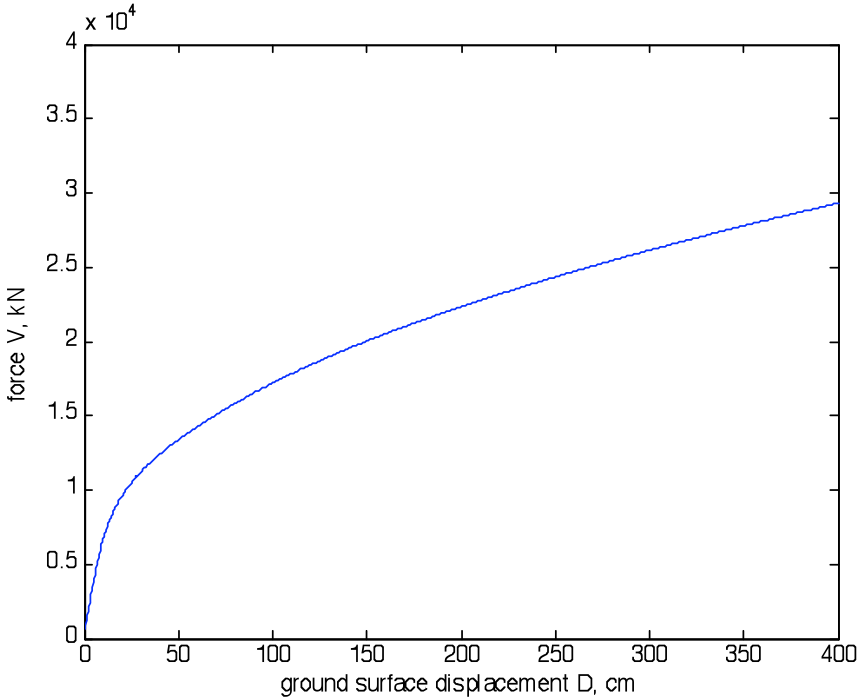


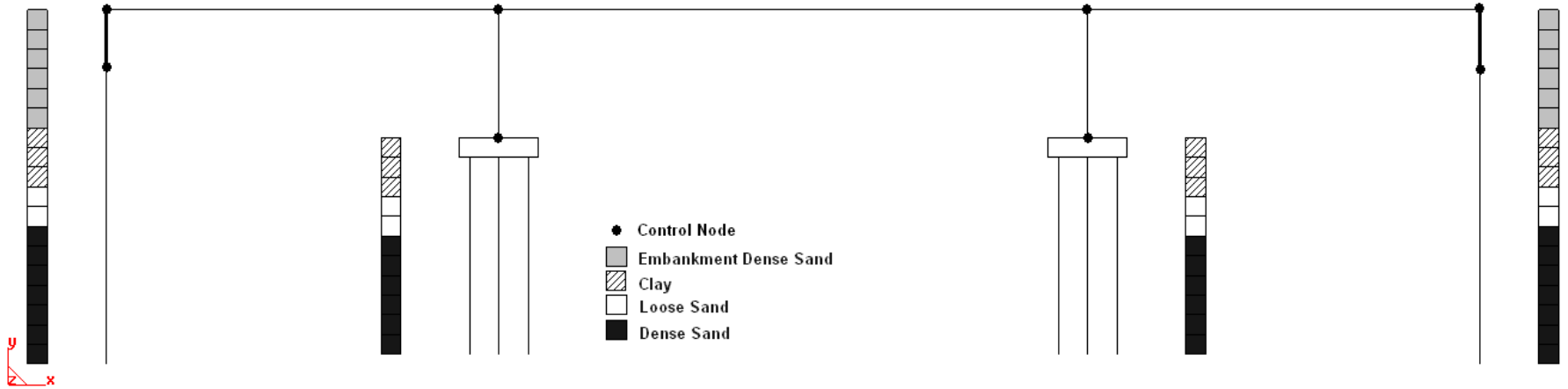




Pinning effect analyses

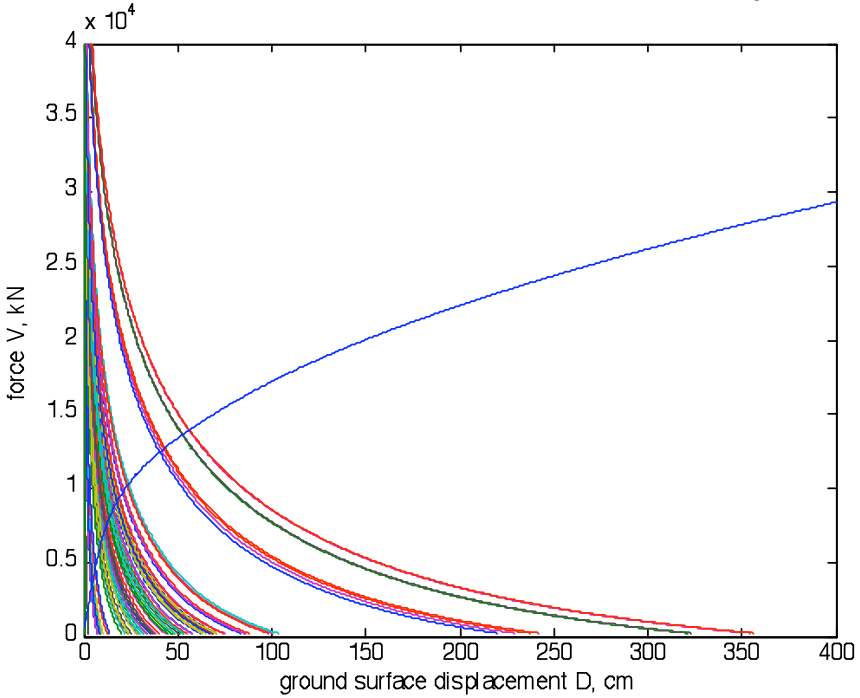
- Pushover analysis
  - Impose lateral displacement
  - Record reaction force by foundations in backfill and clay layers
  - Running average for non-constant force during earthquake shaking

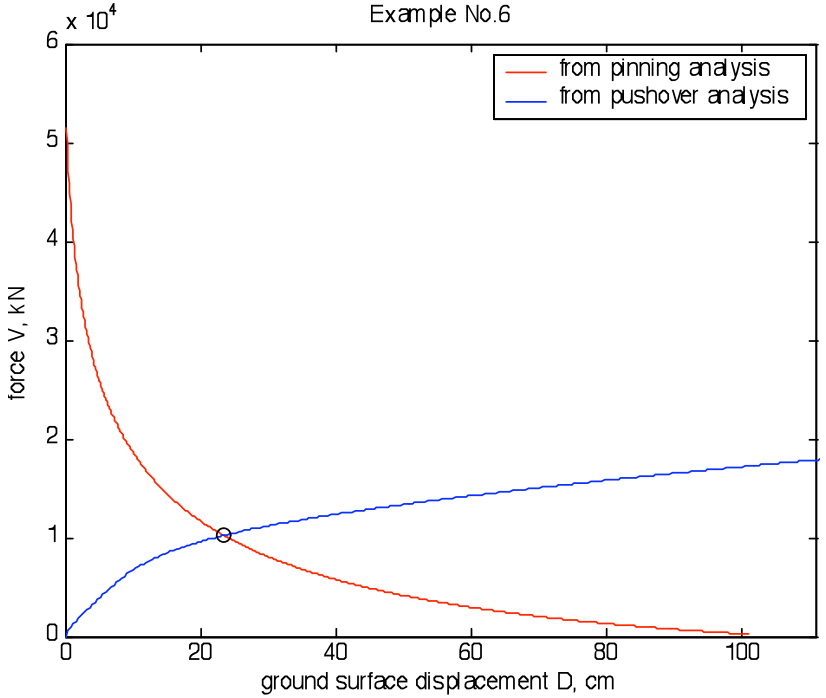




Pinning effect analyses

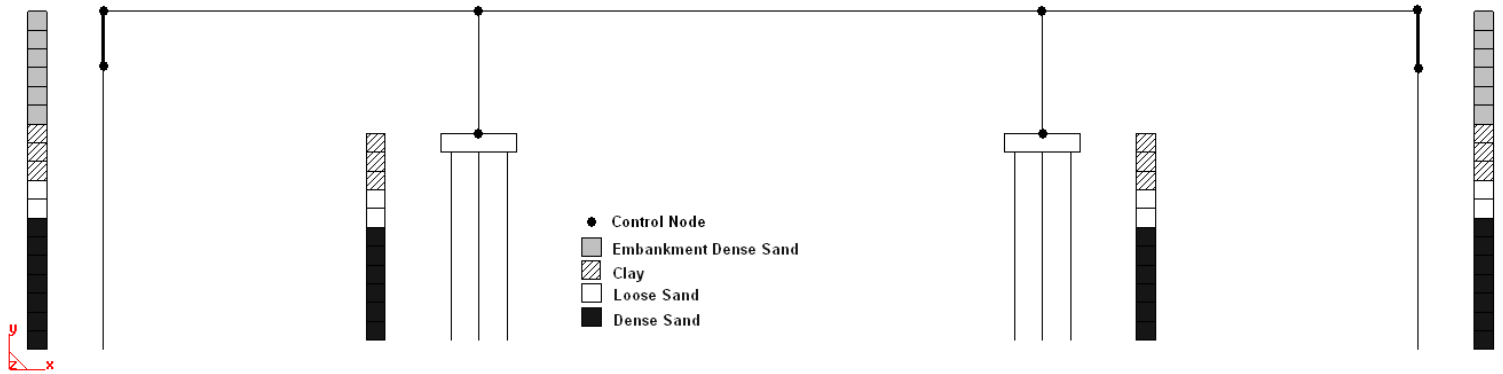
- D_{cmp} from D_{ff}
  - Plot pinning curves and pushover curve together
  - The intersection indicates D_{cmp}

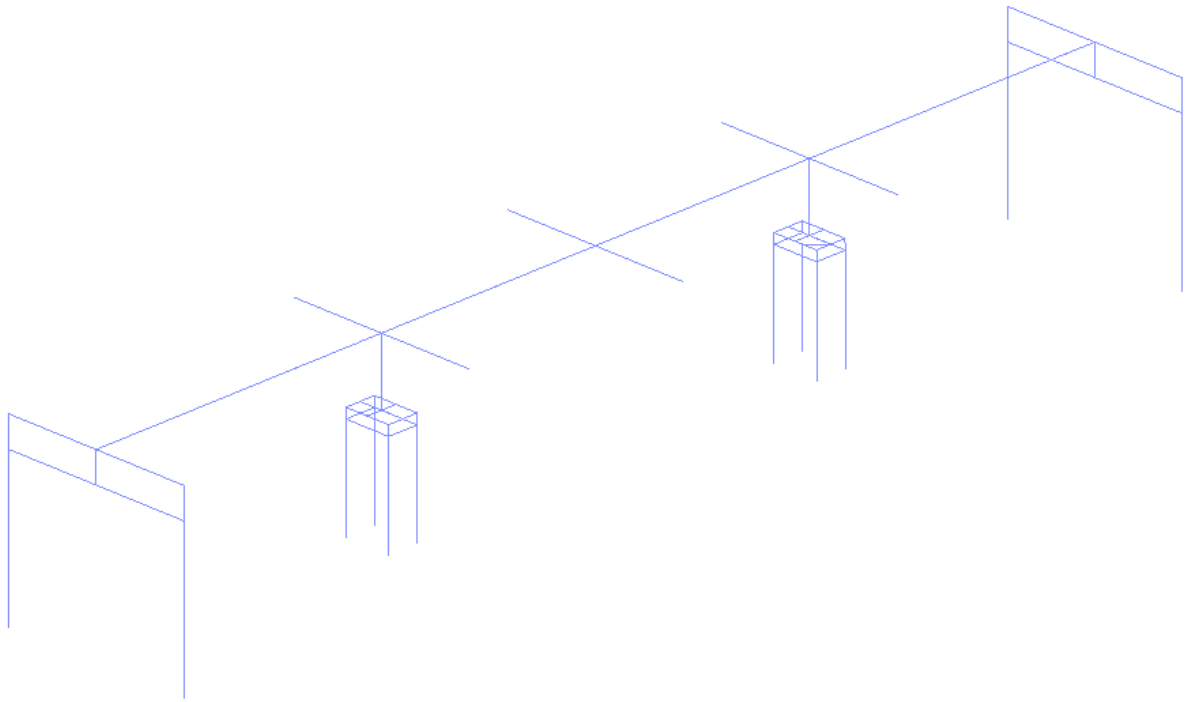




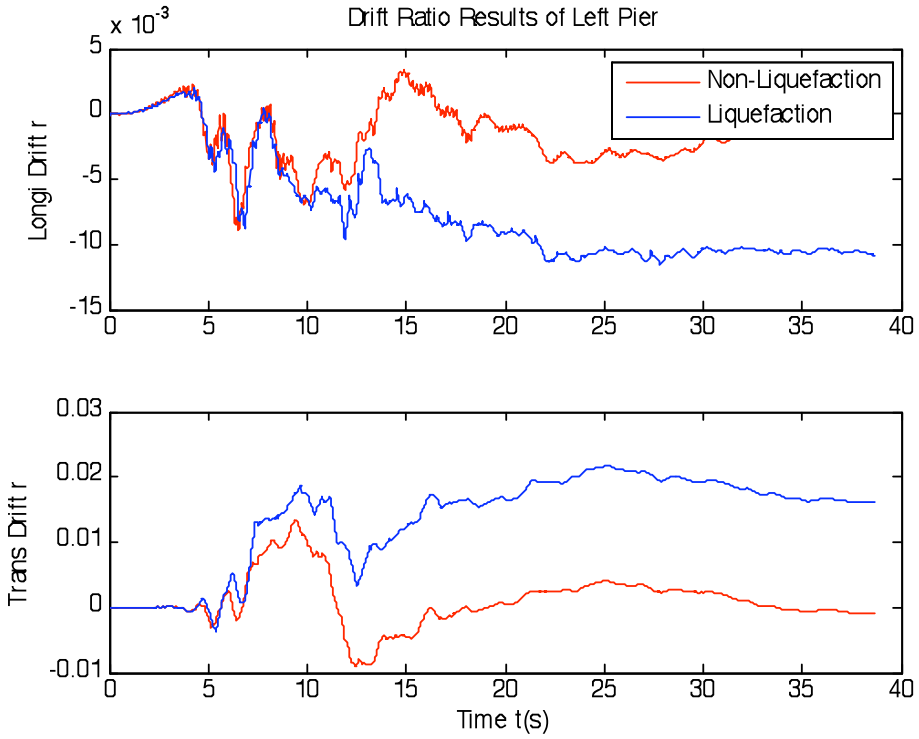
- **Scale the low frequency content of displacement time histories by D_{cmp}/D_{ff} to account for the pinning effect**

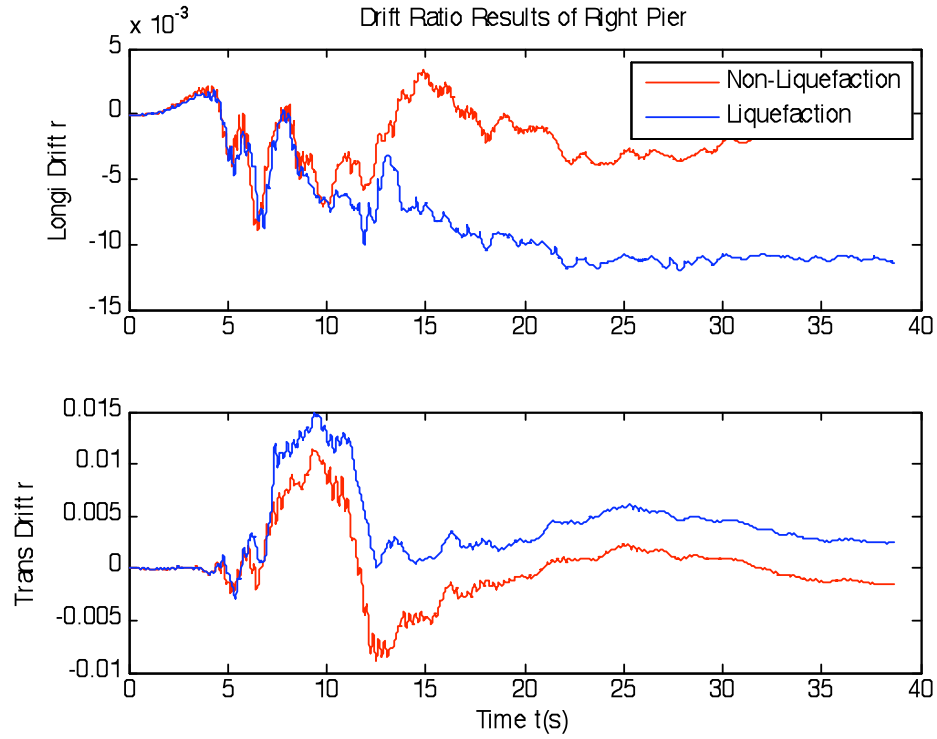
3-D Analysis


Control Node
Embankment Dense Sand
Clay
Loose Sand
Dense Sand
y
z
x



3-D Analysis


Drift Ratio Results of Left Pier
x 10^-3
Longi Drift r
Non-Liquefaction
Liquefaction
Trans Drift r
Time t(s)


Drift Ratio Results of Right Pier
x 10^-3
Longi Drift r
Non-Liquefaction
Liquefaction
Trans Drift r
Time t(s)

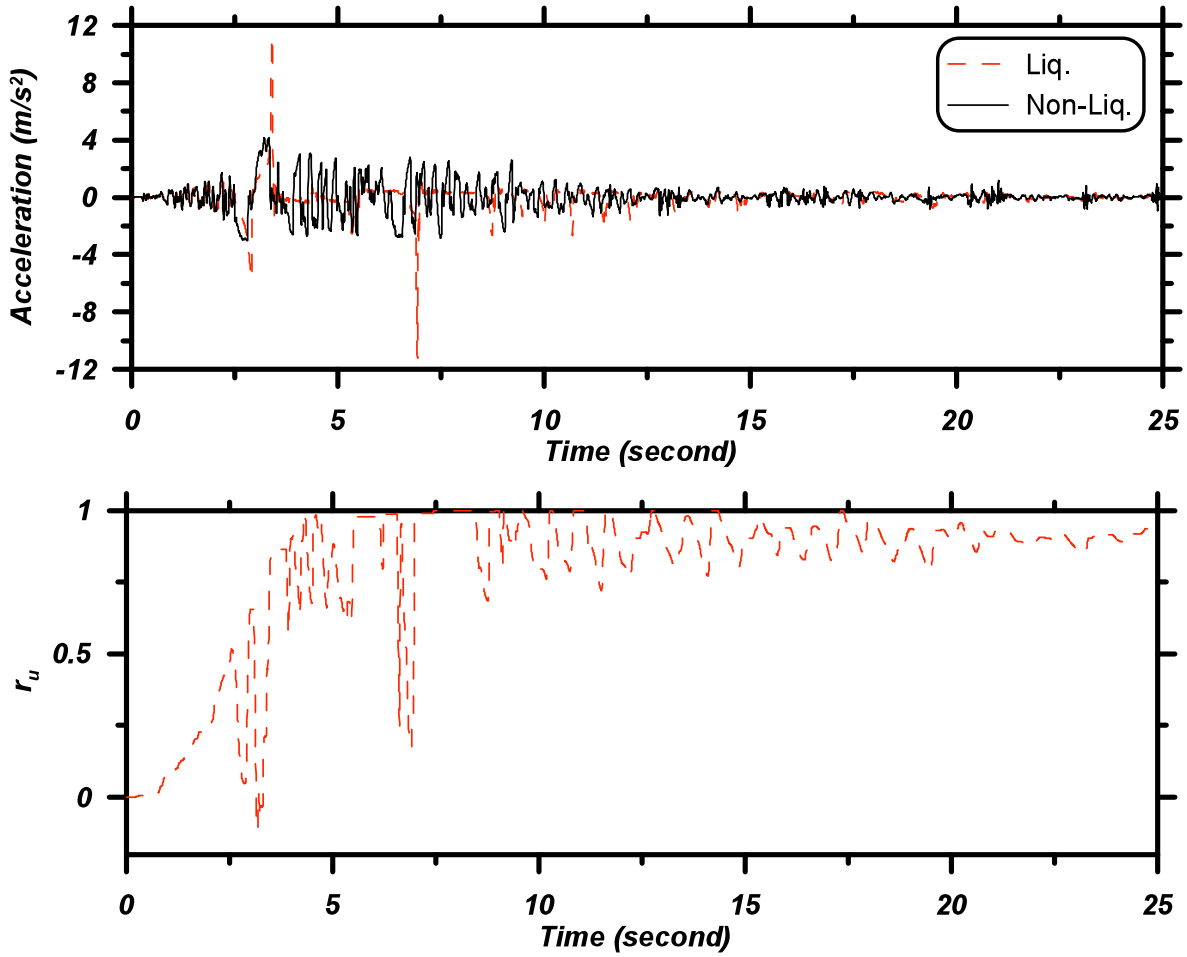
Remaining Work

- Solve convergence errors associated with such high nonlinearity in the material response of the PyLiq2 materials.
- Run suites of analyses on Hoffman2 computing cluster at UCLA using different structural configurations and input ground motions.
- Develop recommendations for phasing of kinematic and inertia loads as function of mobilized curvature ductility in pier columns.
- Compare with fragility functions for various bridge vintages and structural configurations (follow-up on previous PEER-LL study).
- Time Needed: 5 months. Hence, we are slightly behind schedule.

Questions?

1-D site response analyses

- Effect of liquefaction, $C_{liq}(T)$



- **$C_{liq}(0.01) > 1.0$, due to the transient drop of r_u and associated spike of acceleration for liquefiable case**

Ground Displacements