FINITE ELEMENT ANALYSIS OF STANDARD CALTRANS 16" CIDH PILE USING OPENSEES FOR GENERAL COMPARISON WITH LPILE (WITH DEFAULT P-Y MULTIPLIER = 1.0)

Ahmed Elgamal and Jinchi Lu
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Introduction

In this study, we conduct a finite element simulation of the standard Caltran 16" CIDH pile using the 3D OpenSeesPL interface. The simulated pile responses are compared with LPILE results.

Laterally Loaded Pile

Pile Data

The geometric and elastic material properties of the pile are listed below:

Diameter D = 16"
Pile length l = 35 ft
Moment of Inertia of Pile I = 850 in^4
Young's Modulus of Pile E_c = 4030 ksi

In this initial study, the pile was modeled to remain linear (also in view of the applied load levels).

Soil Domain

Linear and nonlinear soil responses are investigated. The Medium relative-density granular soil type (Lu et al. 2006) is selected in the analyses. The material properties of the soil are listed below:

At the reference confinement of 80 kPa (or 11.6 psi), the Shear Modulus of Soil G_s = 10.88 ksi and the Bulk Modulus of Soil B = 29 ksi (i.e., Poisson's ratio ν_s = 0.33), see Lu et al. 2006.

Effective Unit Weight γ' = 110 pcf (given by CalTrans)

For nonlinear analysis, the Friction Angle $\varphi = 33°$ (given by CalTrans) and the peak shear stress occurs at a shear strain γ_{max} = 10% (at the 11.6 psi confinement). The parameter γ_{max} along with the shear modulus define the nonlinear soil stress-strain curve. Other values of γ_{max} should be explored in the future.

Lateral Load

Two load cases (Table 1) are studied. The loads are applied at the pile head.

Table 1: Load cases for the study.

	Shear (kips)	Moment (kip-ft)	Axial load (kips)
Load case 1*	16	0	52
Load case 2**	19.8	-100	52

* Fixed pile head connection
** Apply moment in opposite direction of shear.

Finite Element Simulation

In view of symmetry, a half-mesh (2,900 8-node brick elements, 19 beam-column elements and 180 rigid beam-column elements in total) is studied as shown in Figure 1. Length of the mesh in the longitudinal direction is 520 ft, with 260 ft transversally (in this half-mesh configuration, resulting in a 520 ft x 520 soil domain in plan view). Layer thickness is 60 ft (the bottom of the soil domain is 25 ft below the pile tip, so as to mimic the analytical half-space solution).

The floating pile is modeled by beam-column elements (Mazzoni et al. 2006), and rigid beam-column elements are used to model the pile size (diameter).

The following boundary conditions are enforced:

i) The bottom of the domain is fixed in the longitudinal (x), transverse (y), and vertical (z) directions.
ii) Left, right and back planes of the mesh are fixed in x and y directions (the lateral directions) and free in z direction.
iii) Plane of symmetry is fixed in y direction and free in z and x direction (to model the full-mesh 3D solution).

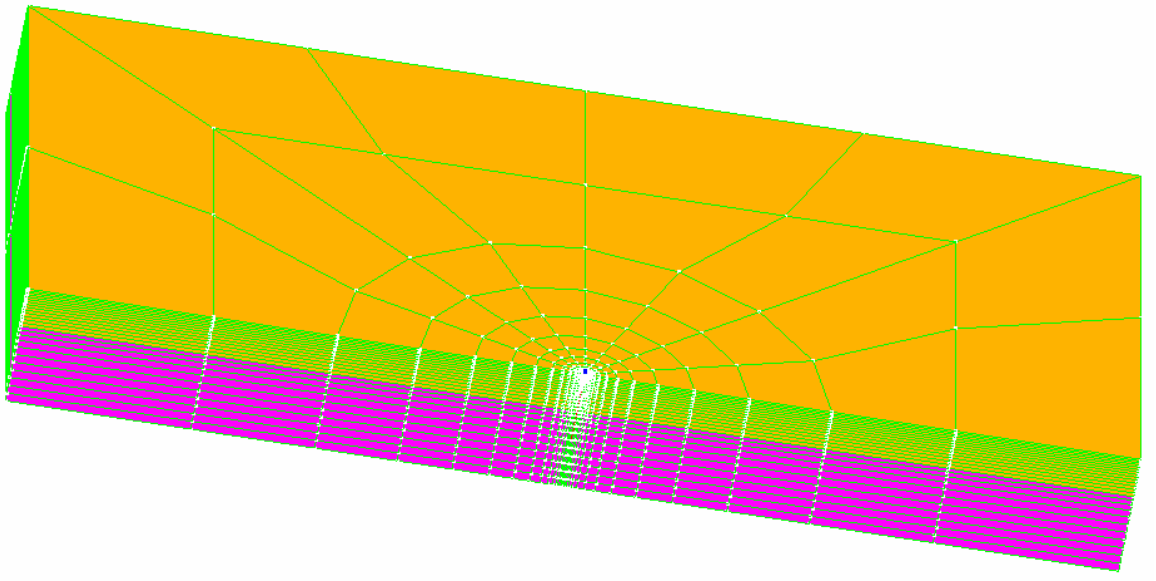
The lateral load is applied at the pile head (ground level) in x (longitudinal) direction.

The above simulations were performed using OpenSeesPL (Lu et al. 2006).

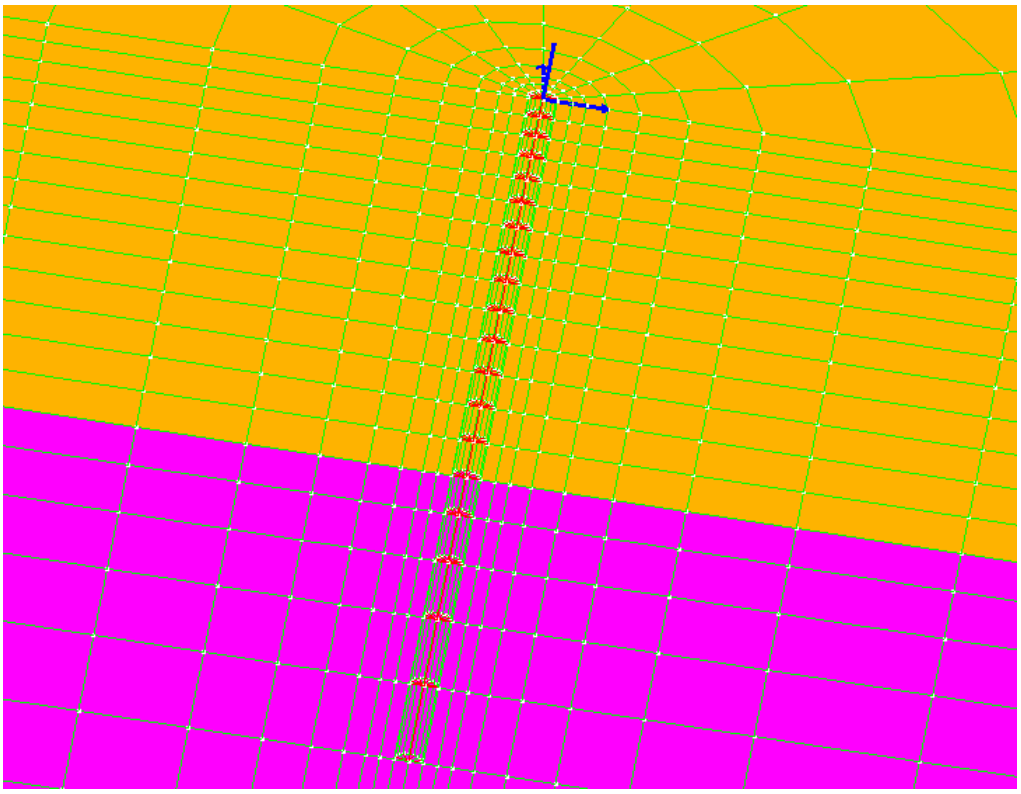
Simulation Results

The pile head deflections and the maximum bending moments for the linear and nonlinear analyses are listed in Table 2, along with LPILE results for comparison (see Appendix for partial output of LPILE results).

Figures 2-5 show comparisons of the pile deflection, rotation, bending moment and shear force profiles, respectively, for load case 1. Figures 6-9 show comparisons of the pile deflection, rotation, bending moment and shear force profiles, respectively, for load case 2. The stress ratio contour fill of the nonlinear runs for load cases 1 & 2 are displayed in Figures 10 & 11.



(a) Isometric view



(b) Pile head close-up

Figure 1: Finite element mesh employed in this study.

Table 2: CalTrans CIDH Pile OpenSees Simulation and LPILE Results.

	Analysis type	Soil stiffness variation with depth	Pile head deflection (in)	Max. bending moment M_{max} (kip-ft)	M_{max} depth (ft)	Profile displays
Load Case 1 Fixed Head H = 16 kips	LPILE		0.24	-48.2	0	Figures 2 & 4
	Linear soil	Parabolic	0.038	-20.8	0	
	Nonlinear soil	Parabolic	0.092	-32.3	0	
Load Case 2 Free Head M = -100 kip-ft applied opposite to shear	LPILE		-0.094	-100	0	Figures 6 & 8
	Linear soil	Parabolic	-0.06	-96.7	0	
	Nonlinear soil	Parabolic	-0.094	-96.9	0	

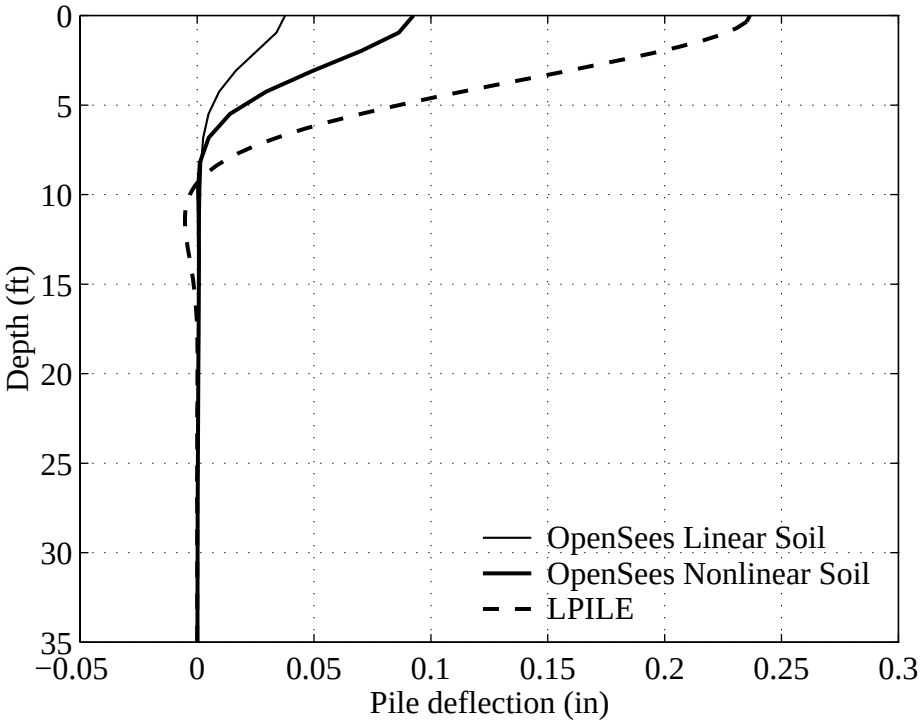


Figure 2: Comparison of pile deflection profiles for load case 1.

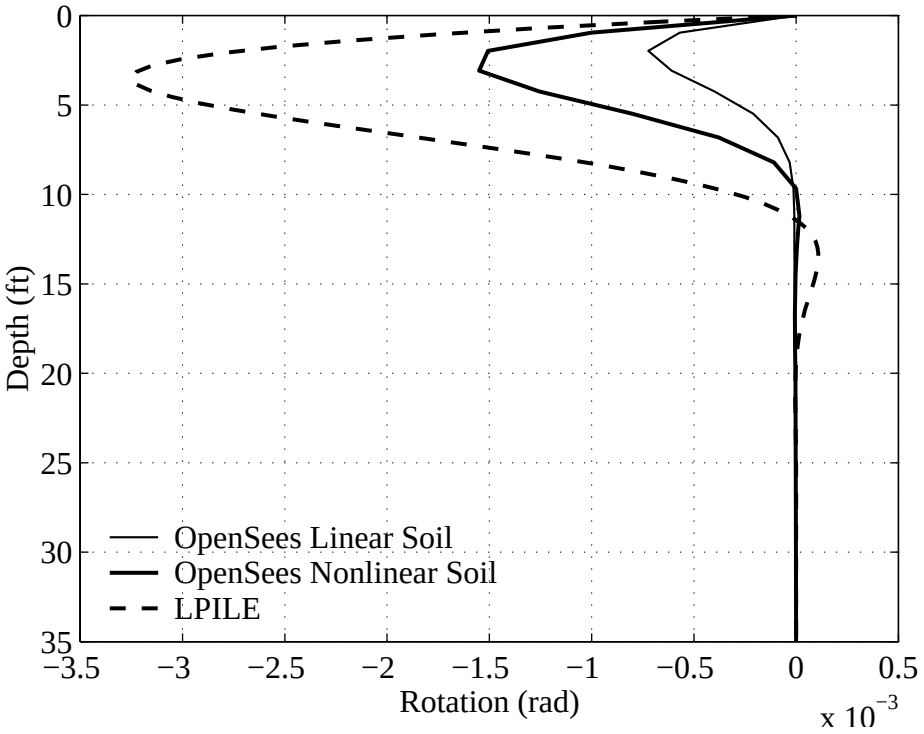


Figure 3: Comparison of pile rotation profiles for load case 1.

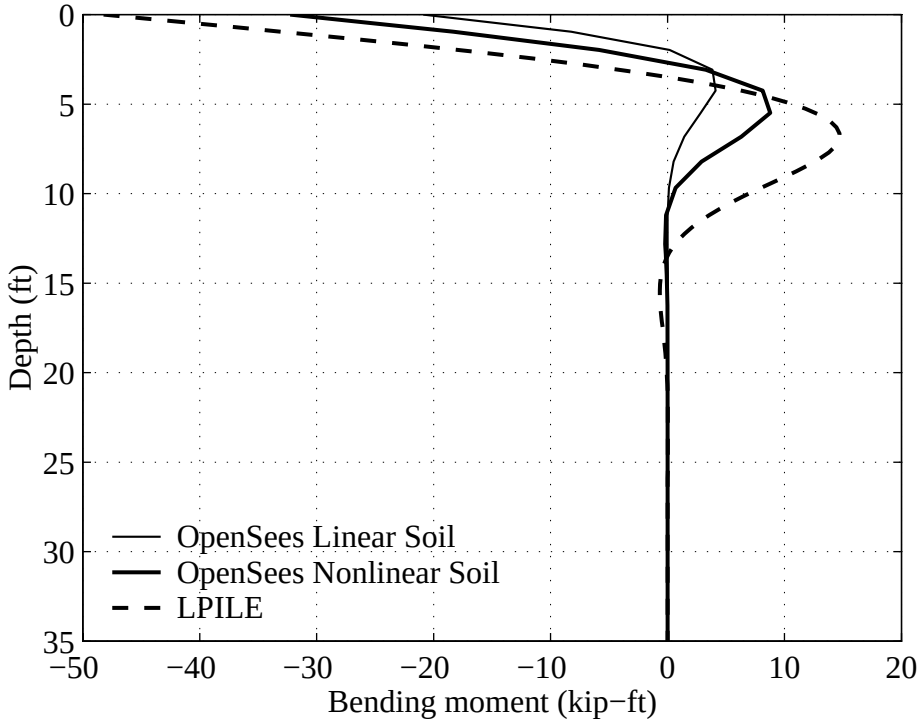


Figure 4: Comparison of bending moment profiles for load case 1.

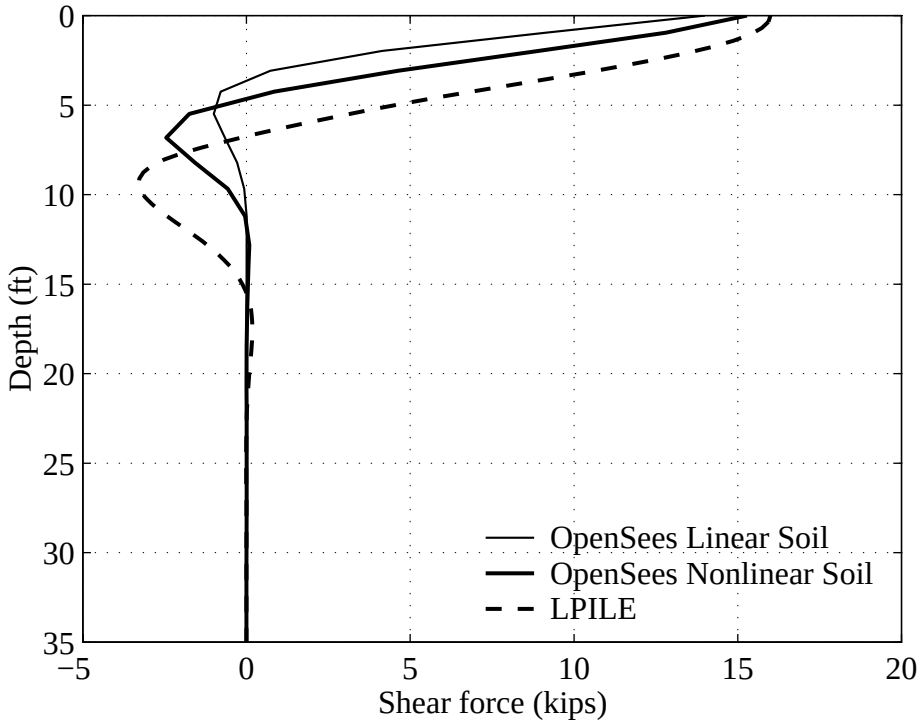


Figure 5: Comparison of shear force profiles for load case 1.

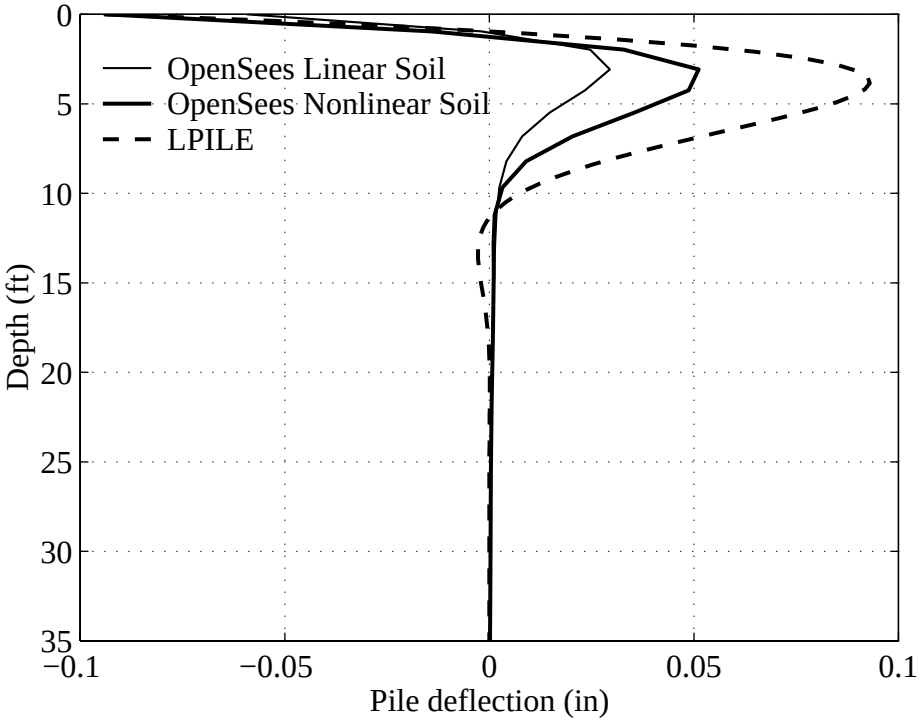


Figure 6: Comparison of pile deflection profiles for load case 2.

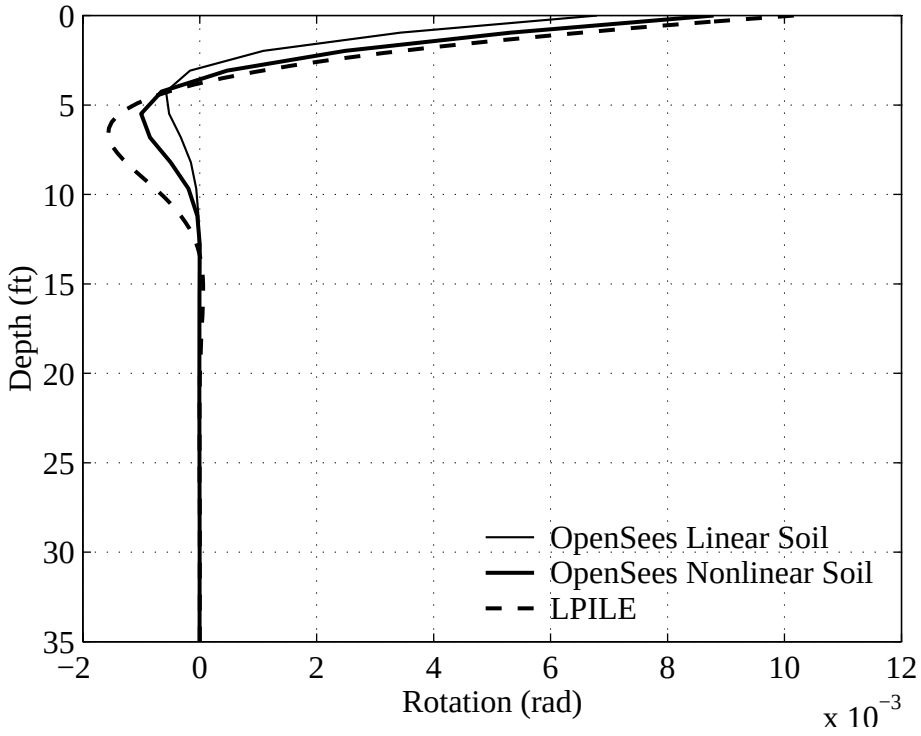


Figure 7: Comparison of pile rotation profiles for load case 2.

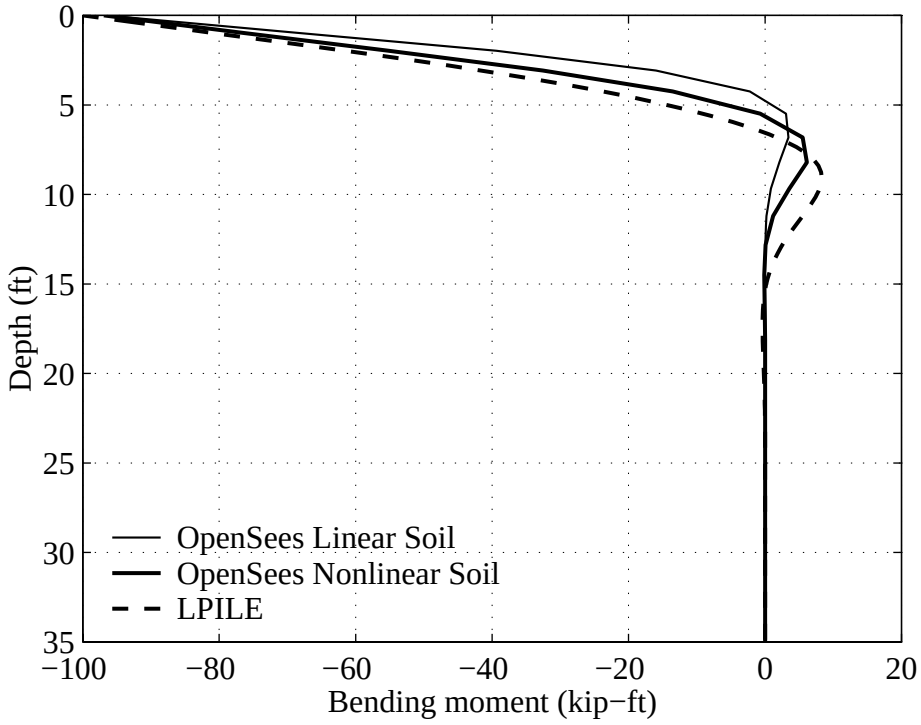


Figure 8: Comparison of bending moment profiles for load case 2.

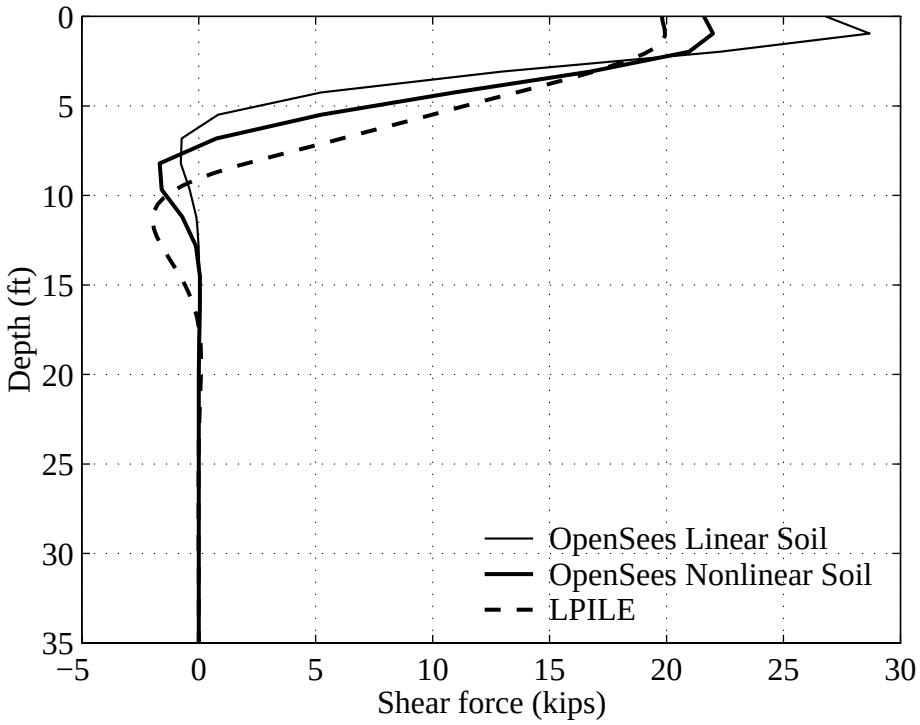
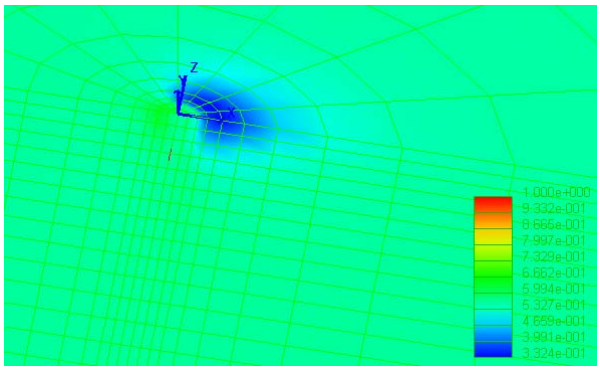
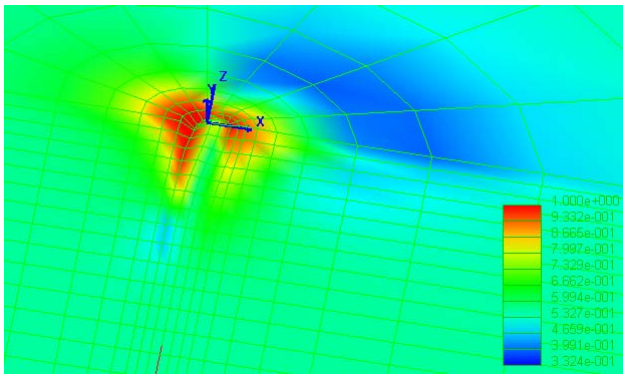


Figure 9: Comparison of shear force profiles for load case 2.

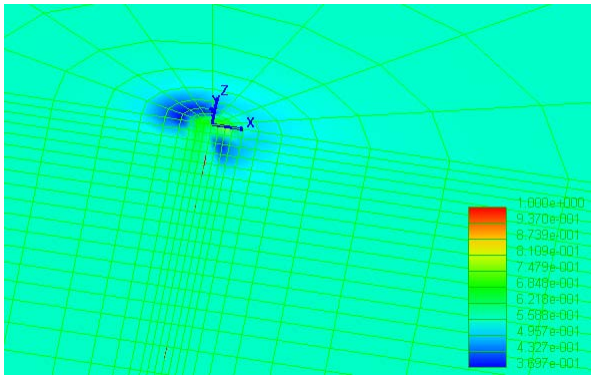


First step

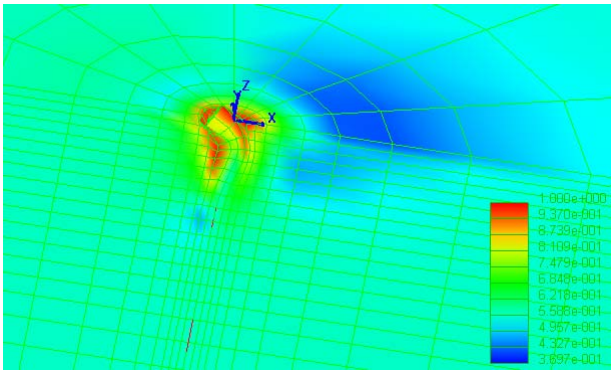


Final

Figure 10: Stress ratio contour fill for load case 1 (red color shows yielded soil elements).



First step



Final

Figure 11: Stress ratio contour fill for load case 2 (red color shows yielded soil elements).

Appendix: Partial Output of LPILE Results

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                LPILE Plus for Windows Student Edition

              Analysis of Individual Piles and Drilled Shafts
             Subjected to Lateral Loading Using the p-y Method

                   (c) 1985-2005 by Ensoft, Inc.
                       All Rights Reserved
================================================================================
--------------------------------------------------------------------------------
                      Time and Date of Analysis
--------------------------------------------------------------------------------

              Date:  September 28, 2007     Time:  17:14:43

--------------------------------------------------------------------------------
                  Pile Structural Properties and Geometry
--------------------------------------------------------------------------------

Pile Length                          =     420.00 in
Depth of ground surface below top of pile =        .00 in
Slope angle of ground surface        =        .00 deg.

Structural properties of pile defined using  2 points

Point    Depth        Pile      Moment of      Pile      Modulus of
          X         Diameter     Inertia       Area      Elasticity
          in           in         in**4        Sq.in     lbs/Sq.in
-----  ---------   -----------   ----------   ----------   -----------
  1      0.0000   16.00000000     850.0000     201.1000      4030000.
  2    420.0000   16.00000000     850.0000     201.1000      4030000.

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                    Soil and Rock Layering Information
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The soil profile is modelled using  1 layers

Layer  1 is sand, p-y criteria by Reese et al., 1974
Distance from top of pile to top of layer    =         .000 in
Distance from top of pile to bottom of layer =      600.000 in
p-y subgrade modulus k for top of soil layer =       90.000 lbs/in**3
p-y subgrade modulus k for bottom of layer   =       90.000 lbs/in**3

(Depth of lowest layer extends  180.00 in below pile tip)

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                  Effective Unit Weight of Soil vs. Depth
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Distribution of effective unit weight of soil with depth
is defined using 2 points

Point No.	Depth X in	Eff. Unit Weight lbs/in**3
1	.00	.06370
2	600.00	.06370

Shear Strength of Soils

Distribution of shear strength parameters with depth
defined using 2 points

Point No.	Depth X in	Cohesion c lbs/in**2	Angle of Friction Deg.	k_rm	E50 or %	RQD
1	.000	.00000	33.00	------	------	
2	600.000	.00000	33.00	------	------	

Notes:

(1) Cohesion = uniaxial compressive strength for rock materials.
(2) Values of E50 are reported for clay strata.
(3) Default values will be generated for E50 when input values are 0.
(4) RQD and k_rm are reported only for weak rock strata.

Loading Type

Static loading criteria was used for computation of p-y curves

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Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 2

Load Case Number 1

Pile-head boundary conditions are Shear and Slope (BC Type 2)
Shear force at pile head = 16000.000 lbs
Slope at pile head = .000 in/in
Axial load at pile head = 52000.000 lbs

(Zero slope for this load indicates fixed-head condition)

Load Case Number 2

Pile-head boundary conditions are Shear and Moment (BC Type 1)
Shear force at pile head = 19800.000 lbs
Bending moment at pile head = -1200000.000 in-lbs
Axial load at pile head = 52000.000 lbs

Non-zero moment at pile head for this load case indicates the pile-head may rotate under the applied pile-head loading, but is not a free-head (zero moment) condition.

Computed Values of Load Distribution and Deflection
for Lateral Loading for Load Case Number 1

Pile-head boundary conditions are Shear and Slope (BC Type 2)
Specified shear force at pile head = 16000.000 lbs
Specified slope at pile head = 0.000E+00 in/in
Specified axial load at pile head = 52000.000 lbs

(Zero slope for this load indicates fixed-head conditions)

Output Verification:

Computed forces and moments are within specified convergence limits.

Output Summary for Load Case No. 1:

Pile-head deflection = .23649635 in
Computed slope at pile head = 1.652118E-17
Maximum bending moment = -578641.19493 lbs-in
Maximum shear force = 16000.00000 lbs
Depth of maximum bending moment = 0.00000 in
Depth of maximum shear force = 0.00000 in
Number of iterations = 14
Number of zero deflection points = 4

Computed Values of Load Distribution and Deflection
for Lateral Loading for Load Case Number 2

Pile-head boundary conditions are Shear and Moment (BC Type 1)
Specified shear force at pile head = 19800.000 lbs
Specified moment at pile head = -1200000.000 in-lbs
Specified axial load at pile head = 52000.000 lbs

Non-zero moment for this load case indicates the pile-head may rotate under the applied pile-head loading, but is not a free-head (zero moment)condition.

Output Verification:

Computed forces and moments are within specified convergence limits.

Output Summary for Load Case No. 2:

Pile-head deflection = -.09425798 in
Computed slope at pile head = .01015620
Maximum bending moment = -1200000. lbs-in
Maximum shear force = 19935.10790 lbs
Depth of maximum bending moment = 0.00000 in
Depth of maximum shear force = 12.60000000 in
Number of iterations = 12
Number of zero deflection points = 5

Summary of Pile-Head Response(s)

Definition of Symbols for Pile-Head Loading Conditions:

Type 1 = Shear and Moment, y = pile-head displacment in
Type 2 = Shear and Slope, M = Pile-head Moment lbs-in
Type 3 = Shear and Rot. Stiffness, V = Pile-head Shear Force lbs
Type 4 = Deflection and Moment, S = Pile-head Slope, radians
Type 5 = Deflection and Slope, R = Rot. Stiffness of Pile-head in-lbs/rad

Load Type	Boundary Condition 1	Boundary Condition 2	Axial Load lbs	Pile-Head Deflection in	Maximum Moment in-lbs	Maximum Shear lbs
2	V= 16000.	S= 0.000	52000.0000	.2364964	-578641.	16000.0000
1	V= 19800.	M= -1.20E+06	52000.0000	-.0942580	-1200000.	19935.1079

The analysis ended normally.

References

Lu, J., Yang, Z., and Elgamal, A. (2006). "OpenSeesPL Three-Dimensional Lateral Pile-Ground Interaction, User's Manual, Version 1.00." *Report No. SSRP-06/03*, Department of Structural Engineering, University of California, San Diego.

Mazzoni, S., McKenna, F., and Fenves, G. L. (2006). *Open System for Earthquake Engineering Simulation User Manual*, Pacific Earthquake Engineering Research Center, University of California, Berkeley (http://opensees.berkeley.edu/).