FINITE ELEMENT ANALYSIS OF ARKANSAS TEST SERIES PILE #2 USING OPENSEES (WITH LPILE COMPARISON)

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Introduction

In this study, we conduct a finite element simulation of Pile No. 2 of the Arkansas test series (Alizadeh and Davisson 1970) using the OpenSeesPL interface. This pipe pile is subjected to lateral loads. Comparison with LPILE is also included in Appendix I.

Laterally Loaded Pile

Pile Data

The pile employed in the OpenSees simulation is circular with a diameter of 16" (radius a = 8") while the one for the experimental test is a cylindrical pipe pile of the same radius and a wall thickness h = 0.312". The cross-sectional moment of inertia of the pipe pile I = 838.2 in^4 (Bowles 1988, pages 777-778), which will be used for the circular pile in the OpenSees simulation.

The geometric and elastic material properties of the pile are listed below (Bowles 1988):

Diameter = 16" or Radius a = 8"
Pile length l = 52.9 ft
Young's Modulus of Pile E_p = 29000 ksi
Moment of Inertia of Pile I = 838.2 in^4

Soil Domain

In this section, the pile is embedded in a uniform soil layer (pile top is 0.1' above the ground line). Linear and nonlinear soil responses are investigated. The Medium density (relative) granular soil type (Lu et al. 2006) is selected in this initial attempt. 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.
Submerged Unit Weight γ' = 62.8 pcf (Bowles 1988)
For nonlinear analysis, the Friction Angle φ = 32° (Bowles 1988) and the peak shear stress occurs at a shear strain γ_{max} = 10% (at the 11.6 psi confinement)

Lateral Load

The pile head (with a free head condition), which is 0.1' above the ground surface, is subjected to horizontal loads (*H*) of 21 kips, 31.5 kips and 43 kips (Bowles 1988).

Finite Element Simulation

In view of symmetry, a half-mesh (2,900 8-node brick elements, 23 beam-column elements and 207 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 80 ft (the bottom of the soil domain is 27.2 ft below the pile tip, so as to mimic the analytical half-space solution).

The floating pile is modeled by beam-column elements, 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.

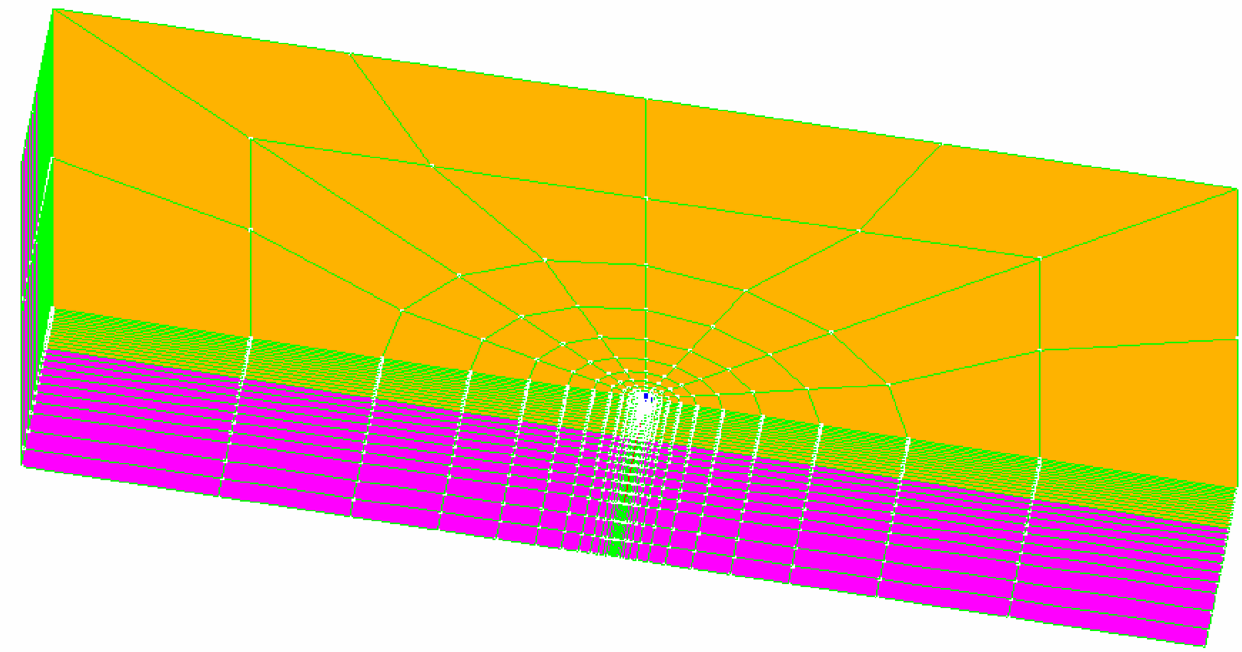
The above simulations were performed using OpenSeesPL (Lu et al. 2006).

Simulation Results

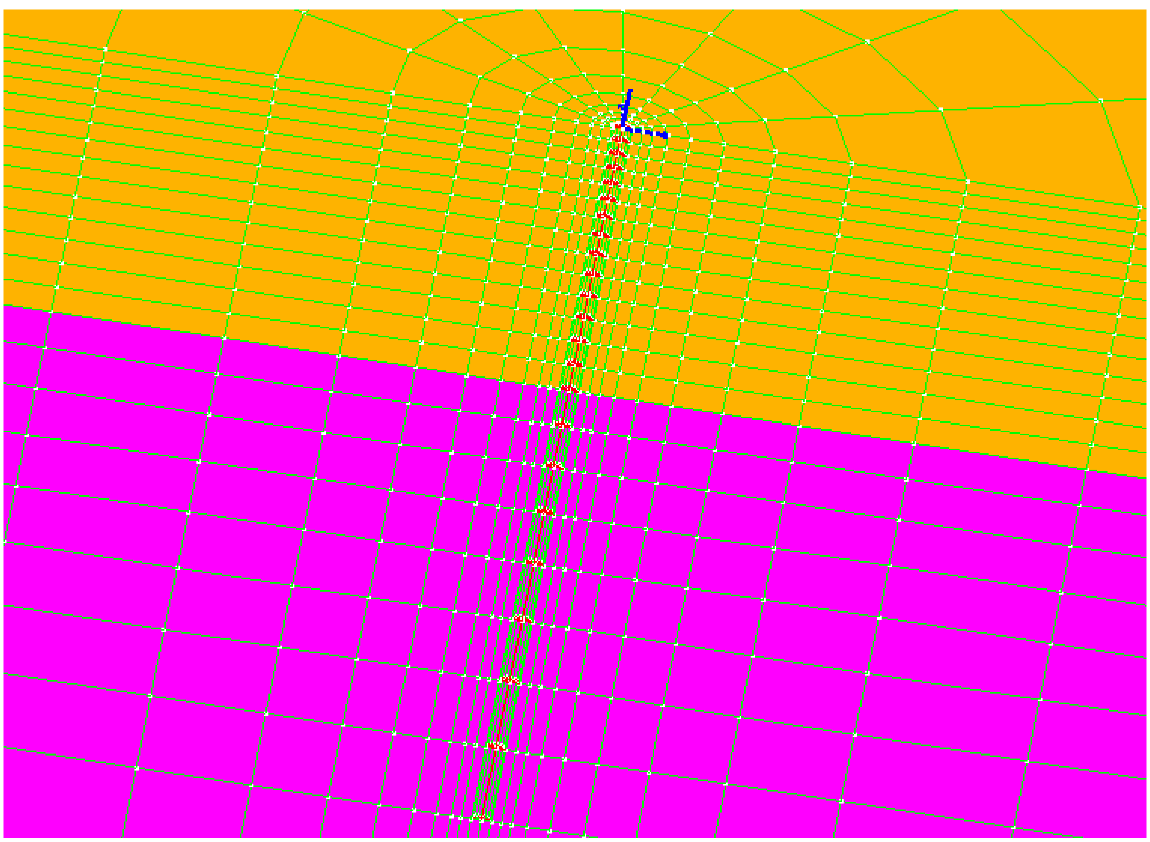
The pile deflections at the ground line and the maximum bending moments for the linear and nonlinear analyses are listed in Table 2, along with the experimental measurements for comparison (Alizadeh and Davisson 1970; Bowles 1988).

Figure 2 shows the load-deflection curve for the linear and nonlinear runs. Comparison of the pile deflection profiles for the linear and nonlinear analyses are displayed in Figure 3a-c. The bending moment profiles for the 3 load levels are shown in Figure 4a-c, along with the observed for comparison (Alizadeh and Davisson 1970). The stress ratio contour fill of the nonlinear run is displayed in Figure 5.

Comparison with LPILE is included in Appendix I.



(a) Isometric view



(b) Pile head close-up

Figure 1: Finite element mesh employed in this study.

Table 1: OpenSees Simulation Results and Experimental Measurements

	Analysis type	Soil stiffness variation with depth	Pile deflection at ground line (in)	Max. bending moment M_{max} (kip-ft)	M_{max} depth (ft)	Profile displays
H = 21 kips						
Experimental			0.17	62	4	
Case 1	Linear soil	Parabolic	0.085	35.1	3.1	Figures 3a & 4a
Case 2	Nonlinear soil	Parabolic	0.31	70.5	6.8	
H = 31.5 kips						
Experimental			0.26	85	5	
Case 3	Linear soil	Parabolic	0.13	52.6	3.1	Figures 3b & 4b
Case 4	Nonlinear soil	Parabolic	0.56	115.5	6.8	
H = 43 kips						
Experimental			0.4	120	5	
Case 5	Linear soil	Parabolic	0.17	70.1	3.1	Figures 3c & 4c
Case 6	Nonlinear soil	Parabolic	0.89	164.7	6.8	

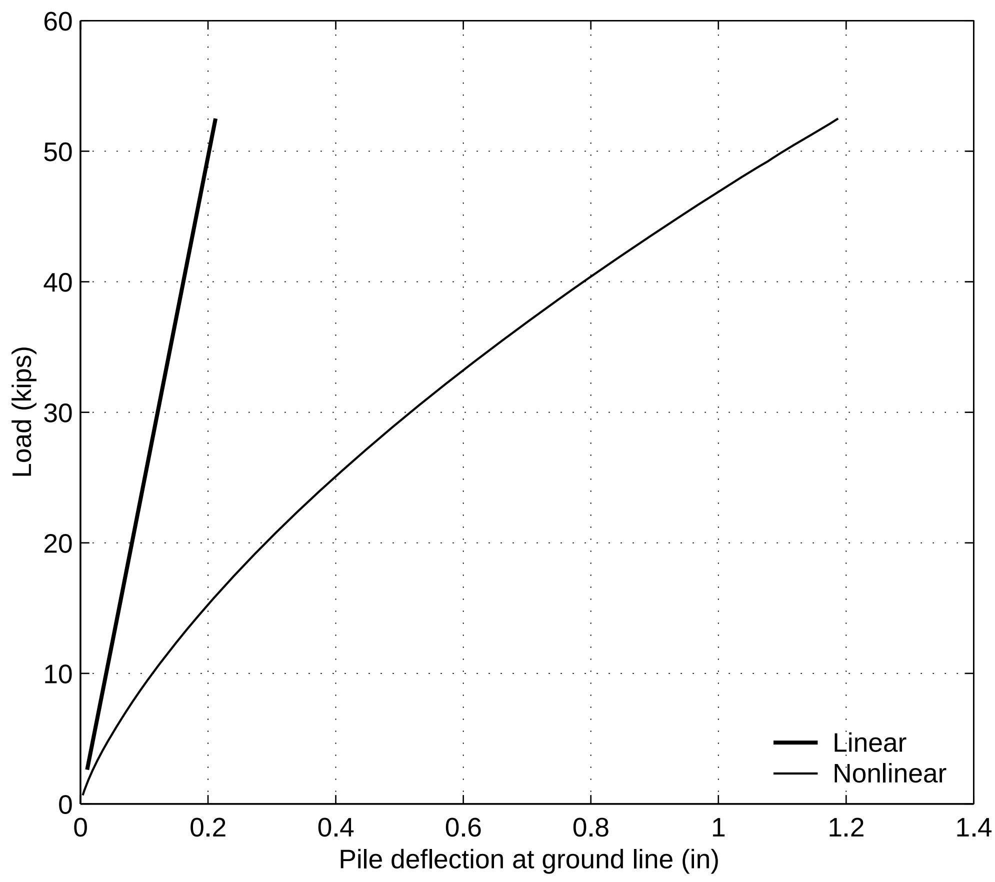
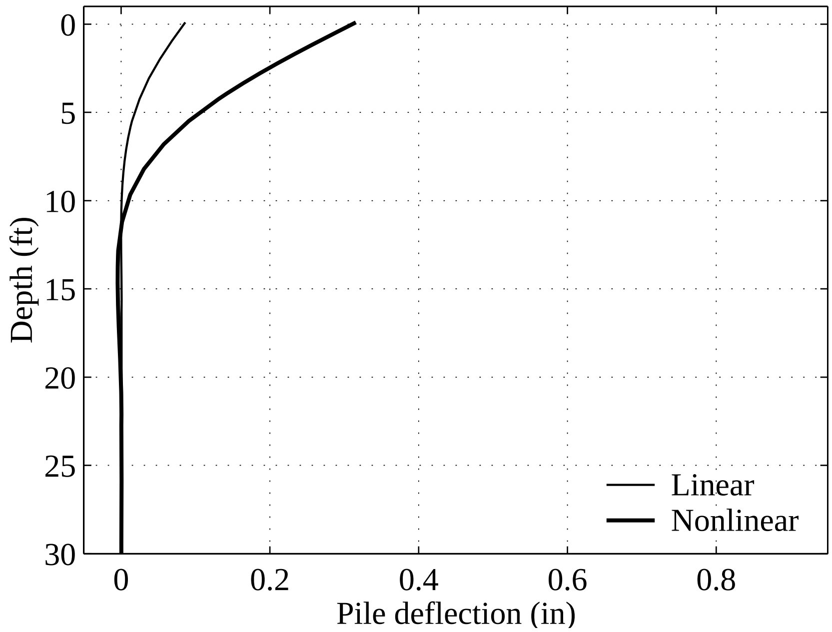
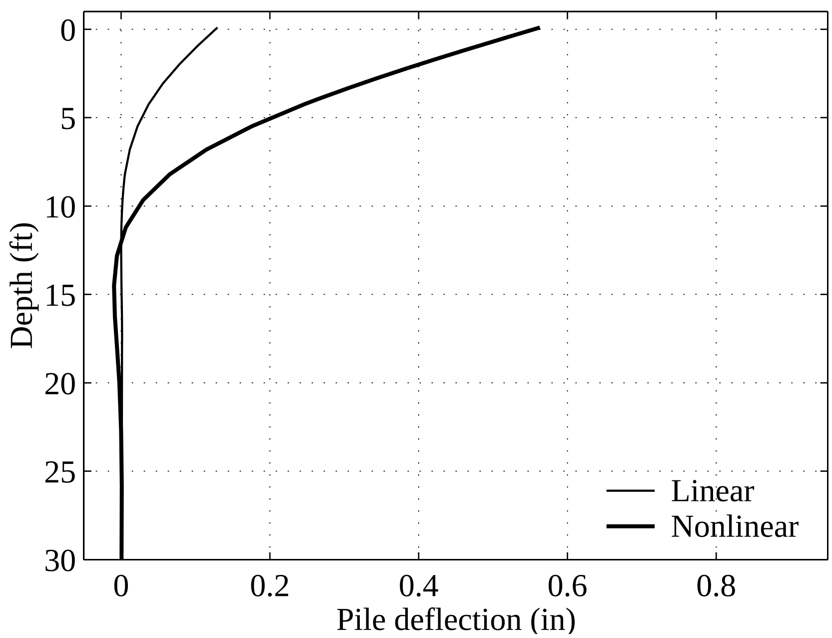


Figure 2: Comparison of the load-deflection curves for the linear and nonlinear runs.

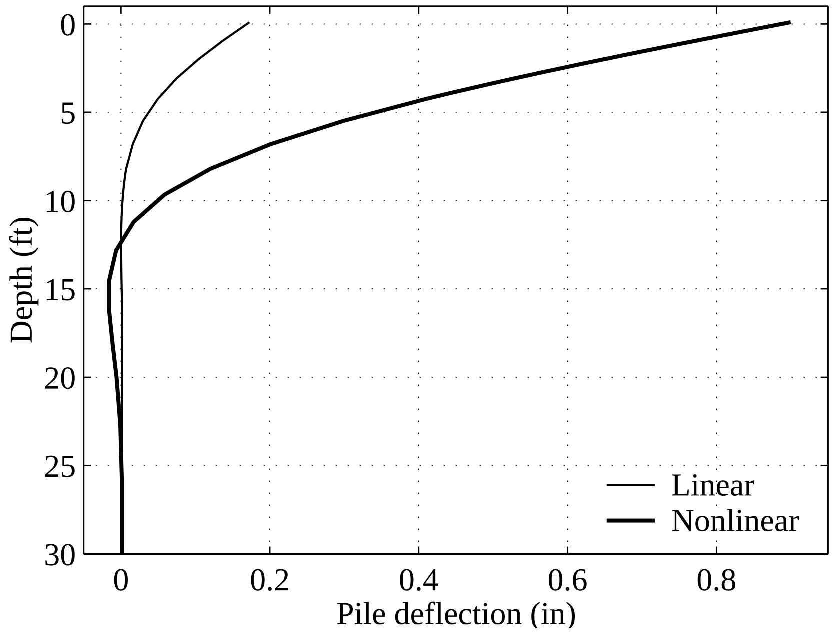


a) H = 21 kips



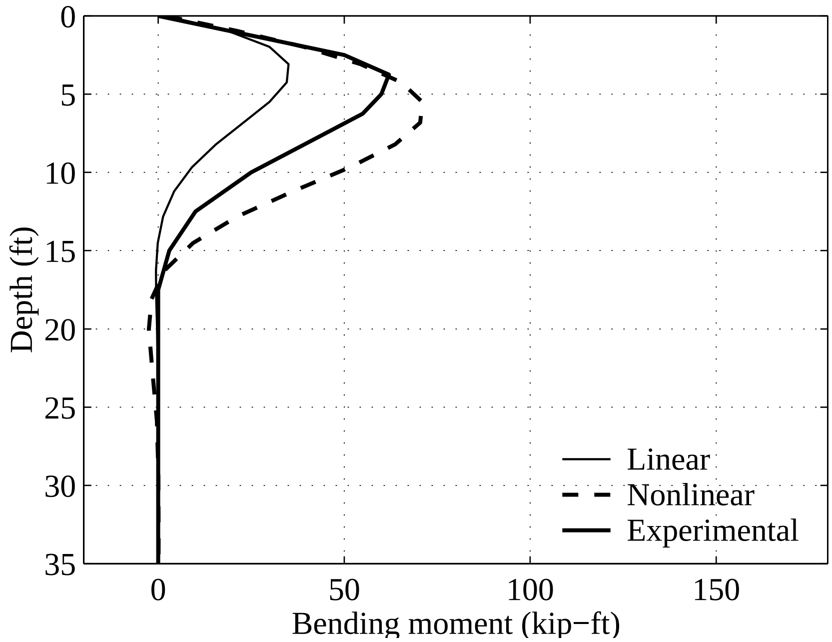
b) H = 31.5 kips

Figure 3: Comparison of the pile deflection profiles for the linear and nonlinear runs.

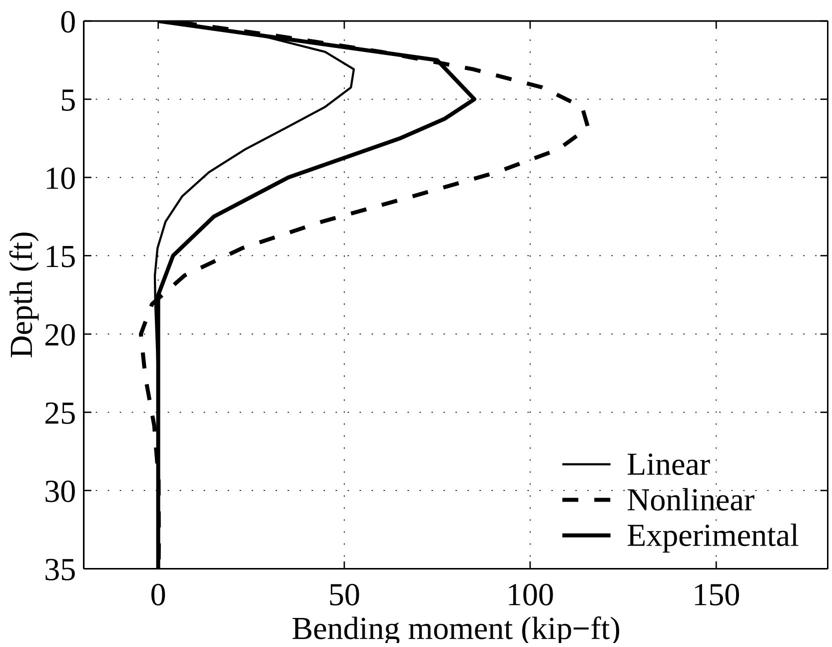


c) *H* = 43 kips

Figure 3: (continued).

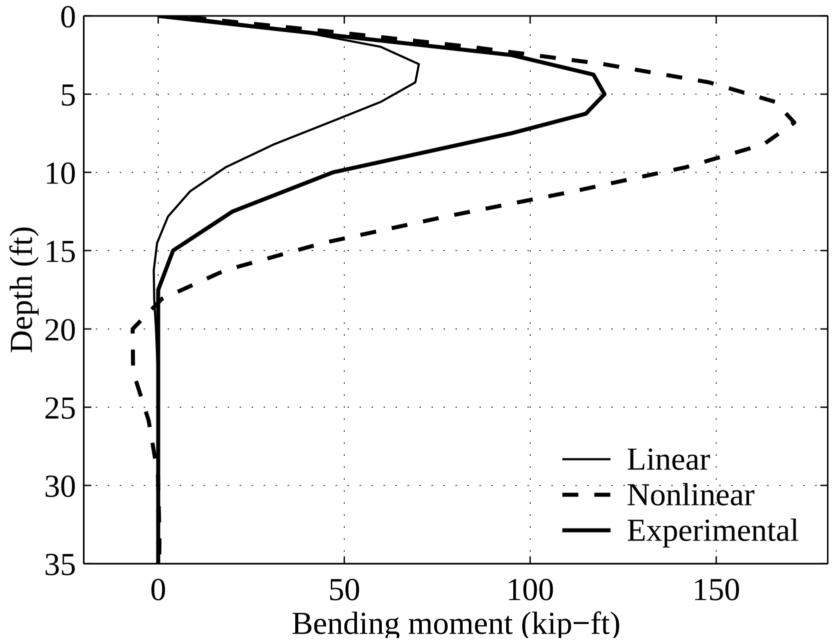


a) H = 21 kips



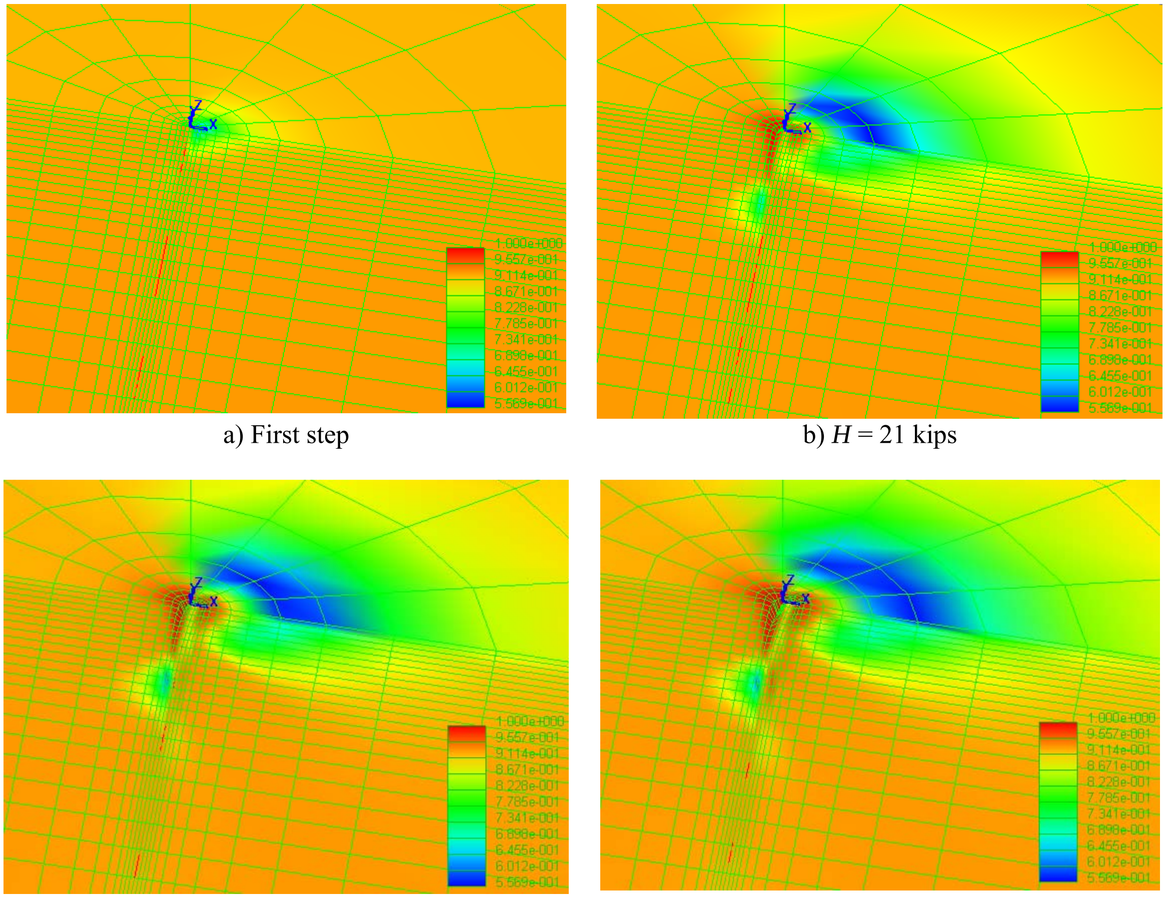
b) H = 31.5 kips

Figure 4: Comparison of the pile bending moment profiles for the linear and nonlinear runs.



c) *H* = 43 kips

Figure 4: (continued).



a) First step

b) H = 21 kips

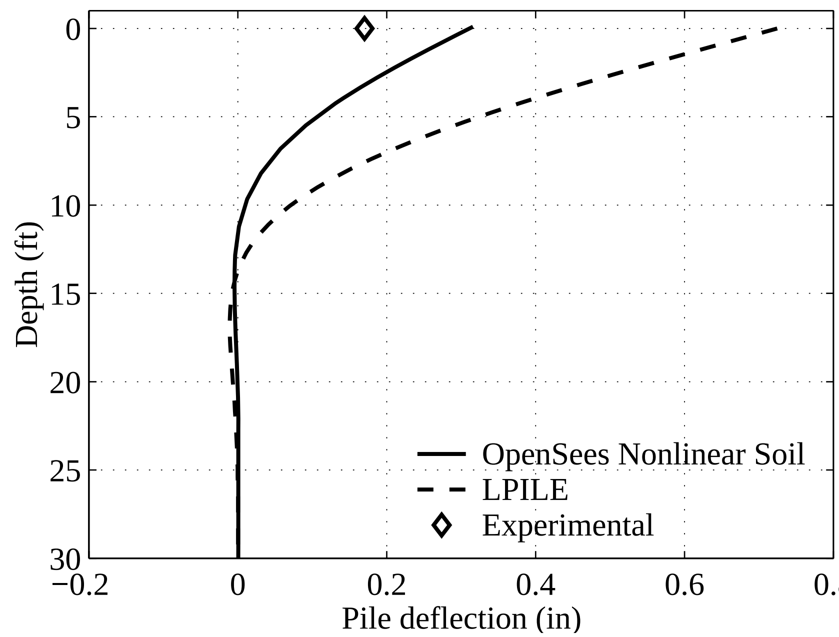
c) H = 31.5 kips

d) H = 43 kips

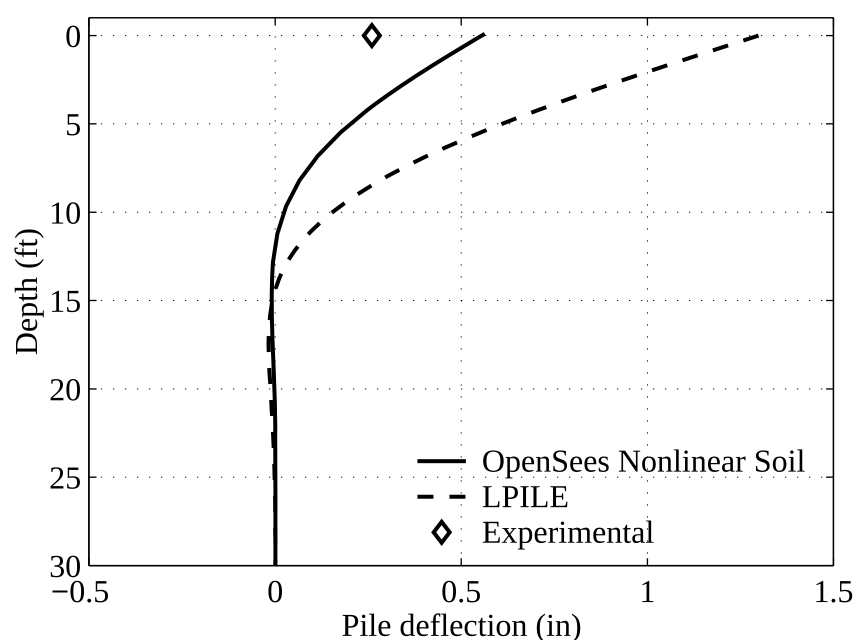
Figure 5: Stress ratio contour fill of the nonlinear run at different load levels (red color shows yielded soil elements).

Appendix I: Comparison with LPILE

In the LPILE run, a p-y modulus of 90 psi is employed (p-y multiplier = 1.0). All other properties are the same as described earlier.

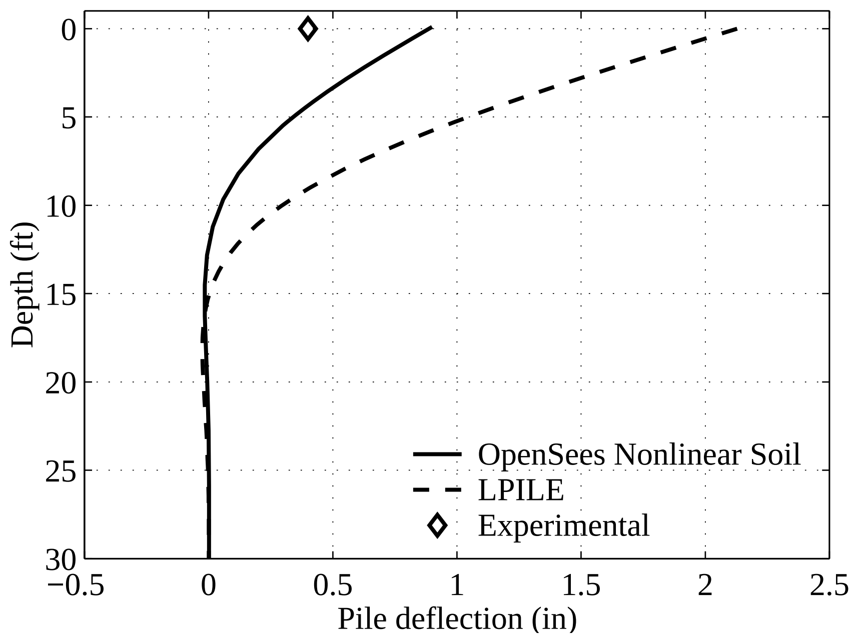


a) H = 21 kips



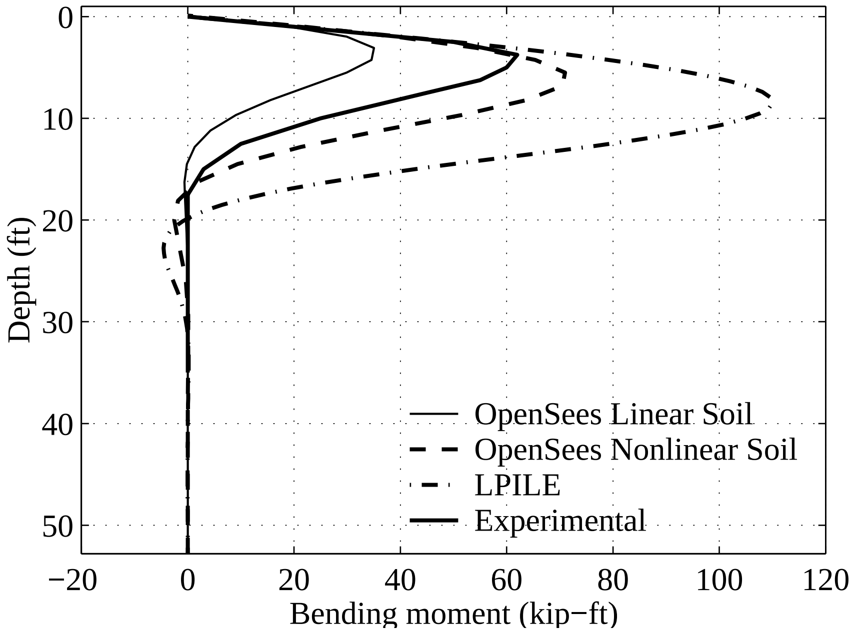
b) H = 31.5 kips

Figure 6: Comparison of the pile deflection profiles for the linear and nonlinear runs.

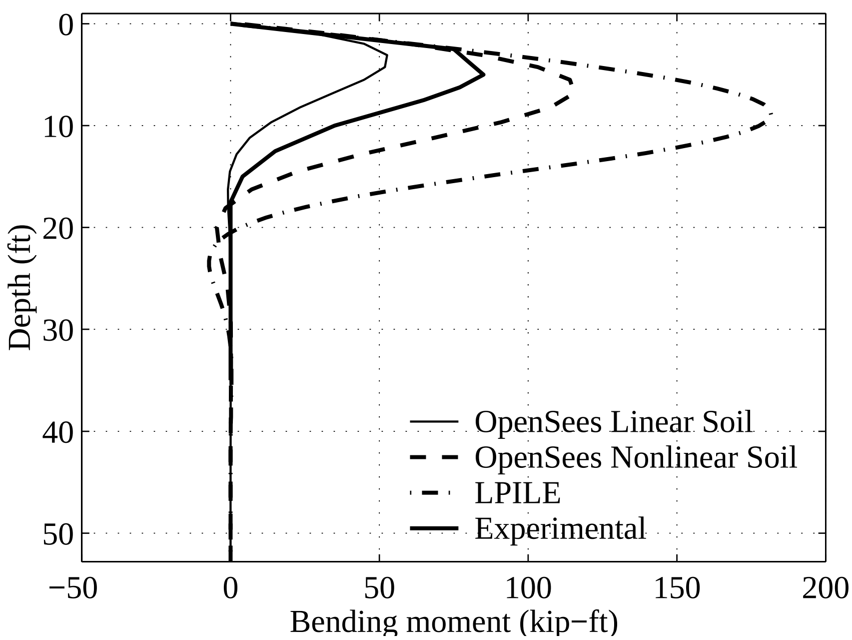


c) H = 43 kips

Figure 6: (continued).

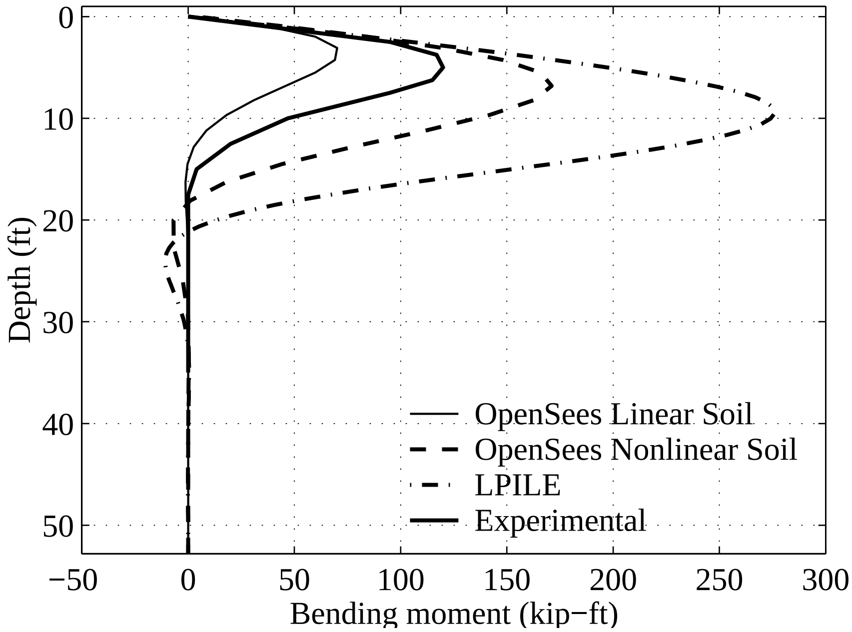


a) *H* = 21 kips



b) *H* = 31.5 kips

Figure 7: Comparison of the pile bending moment profiles for the linear and nonlinear runs.



c) H = 43 kips

Figure 7: (continued).

Reference

M. Alizadeh and M. T. Davisson (1970). "Lateral Load Tests on Piles – Arkansas River Project", JSMFD, ASCE, Vol. 96, SM5, September, pp. 31-40

J. E. Bowles (1988). *Foundation Analysis and Design, 4th Edition*, McGraw-Hill Book Co., New York, NY 10020.

Jinchi Lu, Zhaohui Yang, and Ahmed Elgamal (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.