

A User-Friendly Interface for Pile Analysis Using OpenSees

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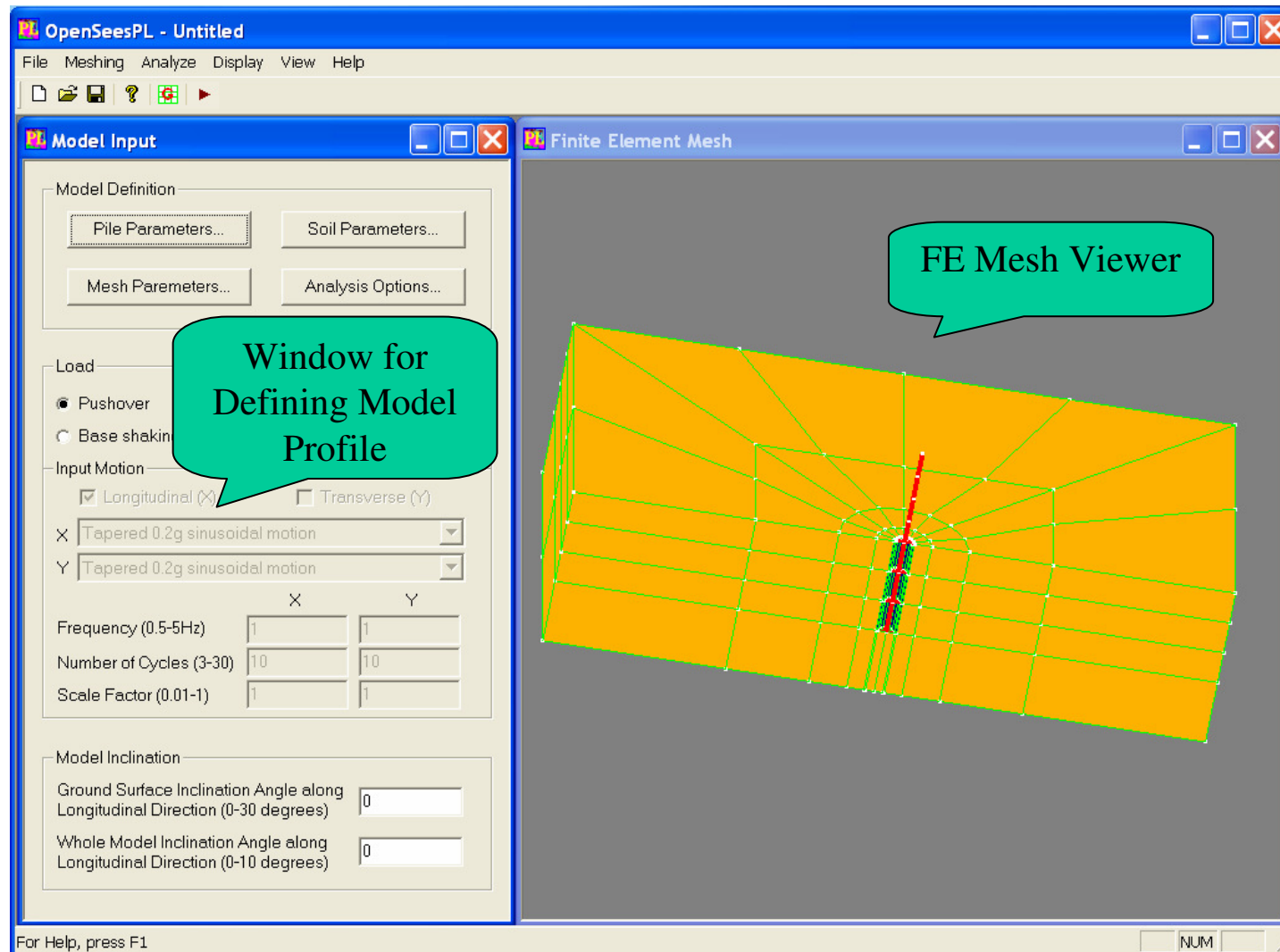
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University of California, San Diego



Single Pile in a Layered Half-Space

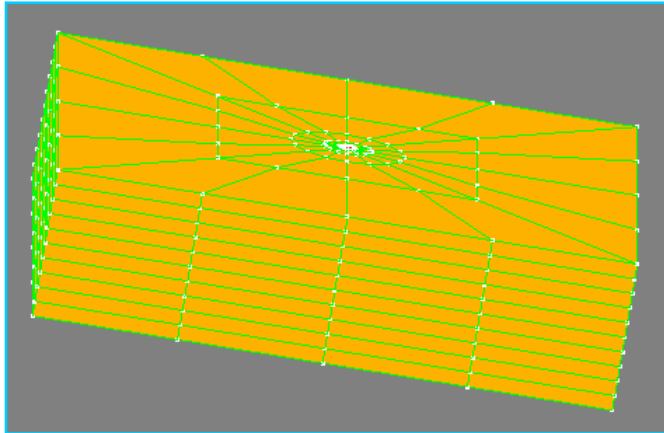


Circular pile in level ground: filled view of $\frac{1}{2}$ mesh due to symmetry

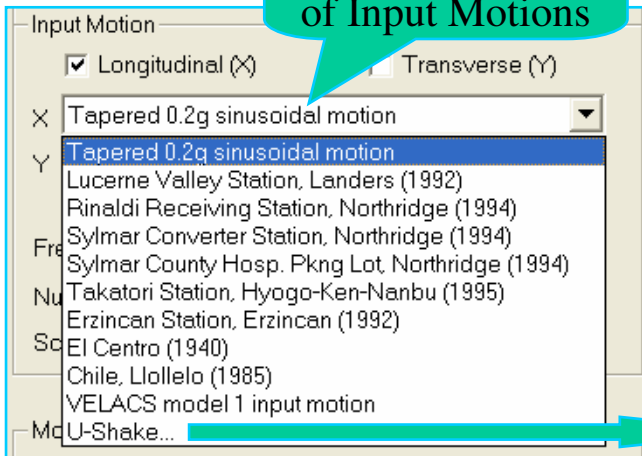
Problems could be Studied by the GUI

- **Seismic Excitation:** Linear and nonlinear (incremental plasticity based) 3D ground seismic response with capabilities for 3 dimensional excitation, and multi-layered soil strata.
- **Pushover Analysis:** Inclusion of a pile or shaft in the the 3D ground mesh (circular or square pile in a soil island).
- **Ground Modification:** Various ground modification scenarios may be studied by appropriate specification of the material within the pile zone.

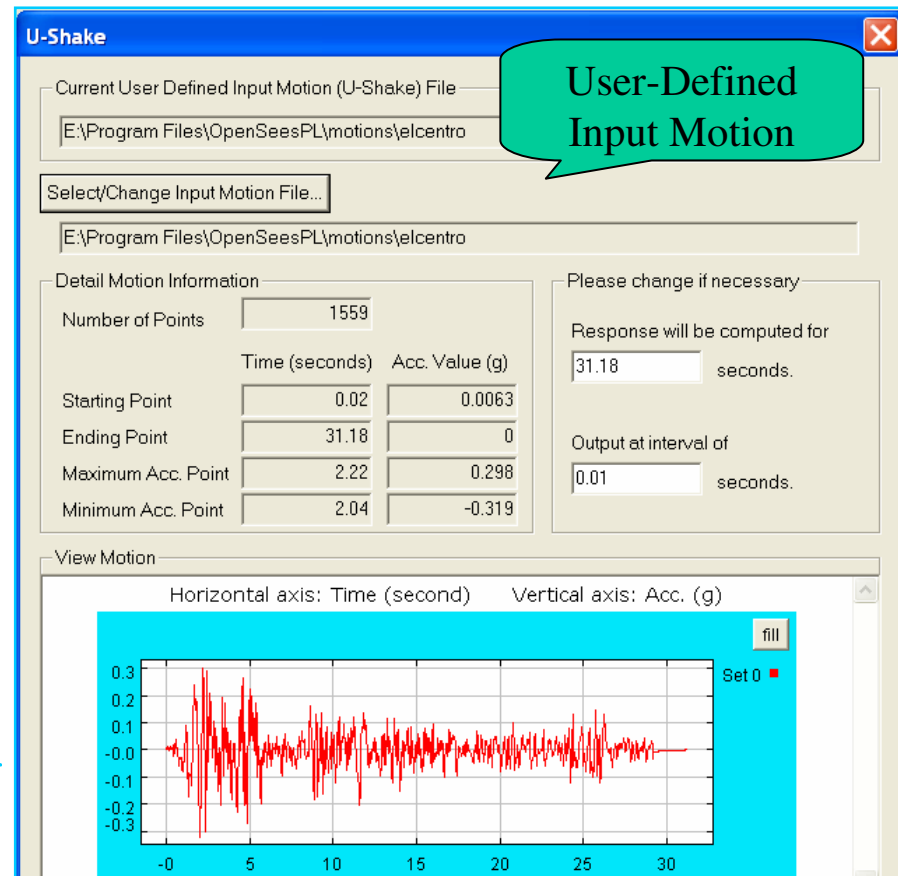
Seismic Excitation



Full Mesh for 3D
Seismic Response



Build-in Library
of Input Motions



User-Defined
Input Motion

Pushover Analysis

- Force Based or Displacement Based
- Monotonic or Cyclic

Pushover

Type

Monotonic Pushover

Cyclic Pushover (Sine Wave)

U-Push Define U-Push...

Method

Force-Based Method

Displacement-Based Method

Force Increment (Per Step)

Longitudinal (X) Force: 1 [kN]

Transverse (Y) Force: 0 [kN]

Vertical (Z) Force: 0 [kN]

Moment of X: 0 [kN-m]

Moment of Y: 0 [kN-m]

Moment of Z: 0 [kN-m]

Displacement Increment (Per Step)

Longitudinal Displacement: 0.01 [m]

Transverse Displacement: 0 [m]

Vertical Displacement: 0 [m]

Rotation around X: 0 [rad]

Rotation around Y: 0 [rad]

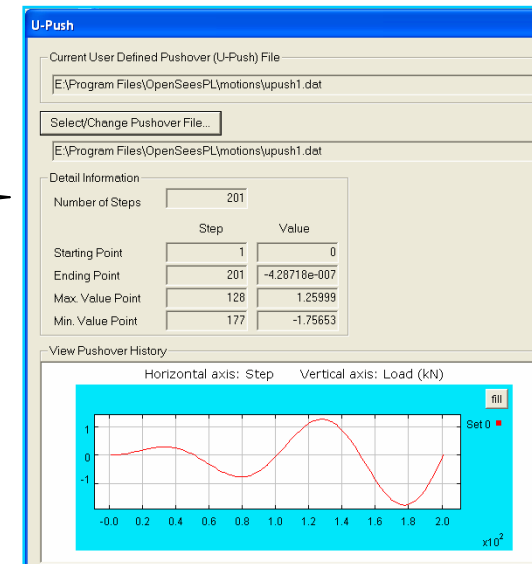
Rotation around Z: 0 [rad]

Sine Wave

Frequency (Hz): 1

Time

Total Number of Steps: 200



User-Defined Pushover

Pile Element Types

Linear Beam Element
 Nonlinear Beam Element

Linear Beam Properties
 Young's Modulus: 30000000 [kPa]
 Mass Density: 0 [ton/m3]
 Moment of Inertia: 0.0490873 [m4]

Nonlinear Beam Properties
 Aggregator Section

My & Mz: Flexural Rigidity EI: 158600 [kN-m2]
 Yield Moment: 1200 [kN-m]

Vy & Vz: Shear Rigidity GA: 3378000 [kN]
 T: Torsional Rigidity GJ: 42200 [kN-m2]

Isotropic Hardening Parameter: 0 [kN-m2]
 Kinematic Hardening Parameter: 0 [kN-m]

P: Axial Rigidity EA: 8785000 [kN]

Re-Calculate

Linear Pile Element

Aggregator Section

Fiber Section

- Linear pile element (elasticBeamColumn)
- Nonlinear pile elements (nonlinearBeamColumn)
 - Aggregator section
 - Fiber section

Fiber Section

Material

| | Core | Cover | |
|--|-----------|--------|-------|
| Concrete01: Concrete Compressive Strength | -29000 | -22332 | [kPa] |
| Concrete01: Concrete Strain at Maximum Strength | -0.014 | -0.006 | |
| Concrete01: Concrete Crushing Strength | -22332 | 0 | [kPa] |
| Concrete01: Concrete Strain at Crushing Strength | -0.004 | -0.002 | |
| Steel01: Yield Strength | 1860000 | | [kPa] |
| Steel01: Initial Elastic Tangent | 200000000 | | [kPa] |
| Steel01: Strain-hardening Ratio | 0.01 | | |

Circular Shape

| | Core | Cover | |
|--|---------|-------|------|
| Number of Subdivisions (fibers) in the Circumferential Direction | 16 | 16 | |
| Number of Subdivisions (fibers) in the Radial Direction | 4 | 4 | |
| Internal Radius | 0 | 0.457 | [m] |
| External Radius | 0.457 | 0.61 | [m] |
| Number of Reinforcing Bars along Layer | 16 | | |
| Area of Individual Reinforcing Bar | 0.00014 | | [m2] |
| Radius of Reinforcing Layer | 0.457 | | [m] |

OK Cancel

Soil Materials

- Elements: **brickUP, 20_8_BrickUP**
- Soil materials:
PressureDependMultiYield
PressureIndependMultiYield

- 8: Cohesionless medium, sand permeability
- 1: Cohesionless very loose, silt permeability
- 2: Cohesionless very loose, sand permeability
- 3: Cohesionless very loose, gravel permeability
- 4: Cohesionless loose, silt permeability
- 5: Cohesionless loose, sand permeability
- 6: Cohesionless loose, gravel permeability
- 7: Cohesionless medium, silt permeability
- 8: Cohesionless medium, sand permeability**
- 9: Cohesionless medium, gravel permeability
- 10: Cohesionless medium-dense, silt permeability
- 11: Cohesionless medium-dense, sand permeability
- 12: Cohesionless medium-dense, gravel permeability
- 13: Cohesionless dense, silt permeability
- 14: Cohesionless dense, sand permeability
- 15: Cohesionless dense, gravel permeability
- 16: Cohesive soft
- 17: Cohesive medium
- 18: Cohesive stiff
- 19: U-Sand1...
- 20: U-Sand2...
- 21: U-Clay1...
- 22: U-Clay2...

Build-in Library of Soil Materials

U-Sand2 for Soil Layer #1

| | | |
|--|-----|----------|
| Mass Density | 2.1 | [ton/m3] |
| Reference Shear Wave Velocity | 300 | [m/s] |
| Reference Mean Confinement | 100 | [kPa] |
| Confinement Dependence Coeff. (0.1-1.0) | 0.5 | |
| Initial Lateral/Vertical Confinement Ratio (0.1-0.9) | 0.5 | |
| Friction Angle (5-65 degrees) | 40 | |
| Peak Shear Strain (0.001-20%) | 3 | |
| Number of Yield Surfaces (0-30) | 20 | |

User-Defined Sand2

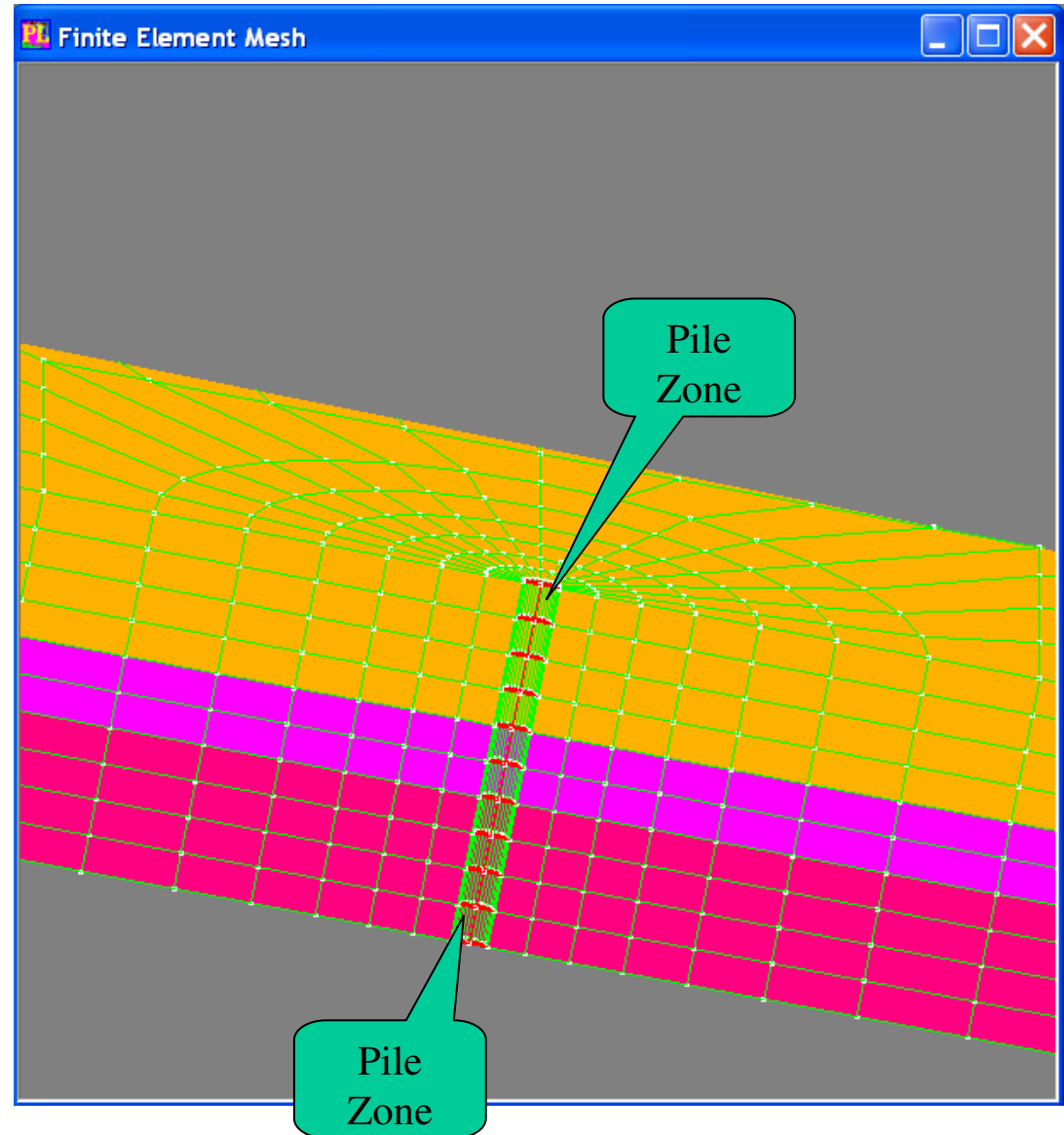
U-Clay1 for Soil Layer #-1

| | | | | |
|----------------------------------|---------|--------------------------------|---------------------------------|--------------|
| Soil Elastic Properties | | Modulus Reduction Curve | | |
| Saturated Mass Density | 1.8 | [ton/m3] | Number of Points Defining Curve | 0 |
| Reference Pressure | 100 | [kPa] | Shear Strain (%) | G/Gmax |
| Pressure Dependence Coefficient | 0 | | 1. | 0.0001 1 |
| Gmax | 160000 | [kPa] | 5. | 0.01 0.941 |
| Bmax | 500000 | [kPa] | 6. | 0.03 0.847 |
| Soil Nonlinear Properties | | 7. | 0.1 0.656 | |
| Peak Shear Strain (%) | 10 | | 8. | 0.3 0.438 |
| Friction Angle | 35 | [degree] | 9. | 1 0.238 |
| Cohesion | 75 | [kPa] | 10. | 3 0.144 |
| Fluid Properties | | 11. | 10 0.11 | |
| Fluid Mass Density | 1 | [ton/m3] | 12. | 30 0.11 |
| Combined Bulk Modulus | 2200000 | [kPa] | 13. | 100 0.11 |
| Horizontal Permeability | 1e-009 | [m/s] | | |
| Vertical Permeability | 1e-009 | [m/s] | | |

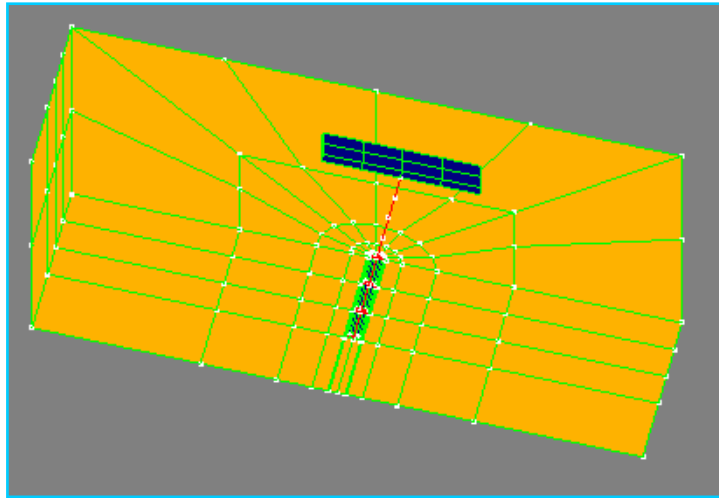
User-Defined Clay1

Ground Modification Scenarios

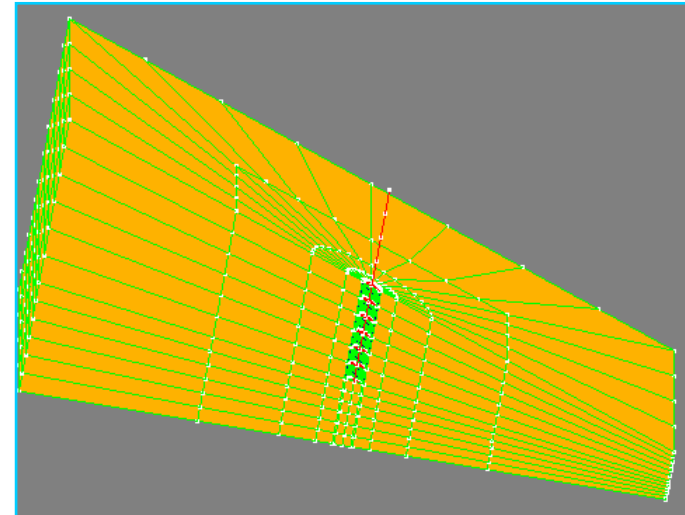
- Material within the pile zone (e.g., gravel permeability)
- Materials outside the pile zone (e.g., multi-layered soil strata with sand or silt permeability)



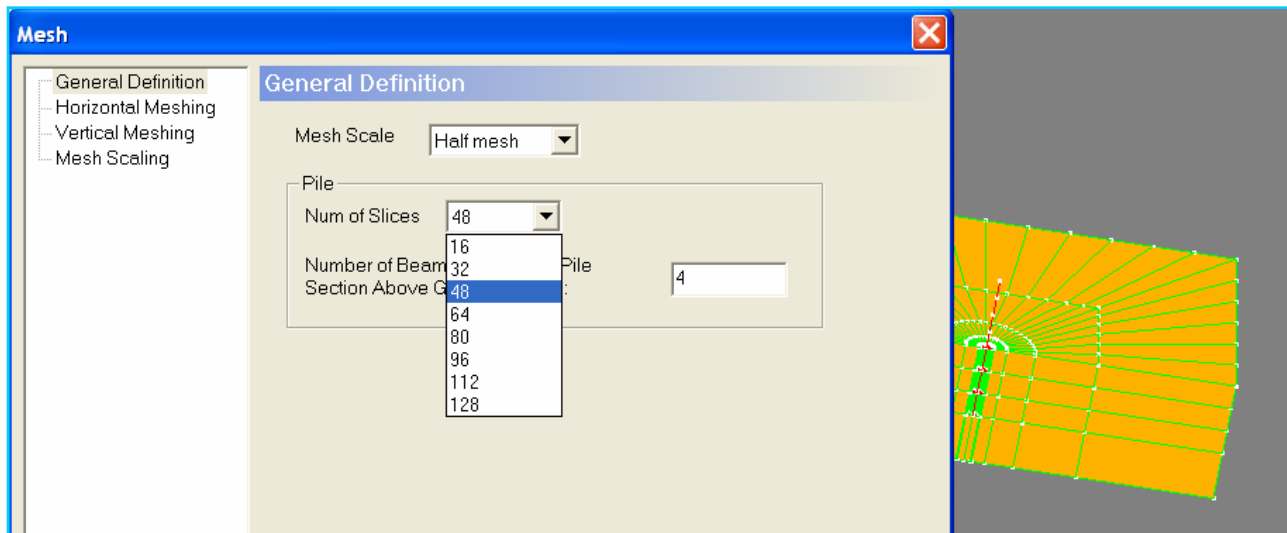
Other Features



Bridge Deck

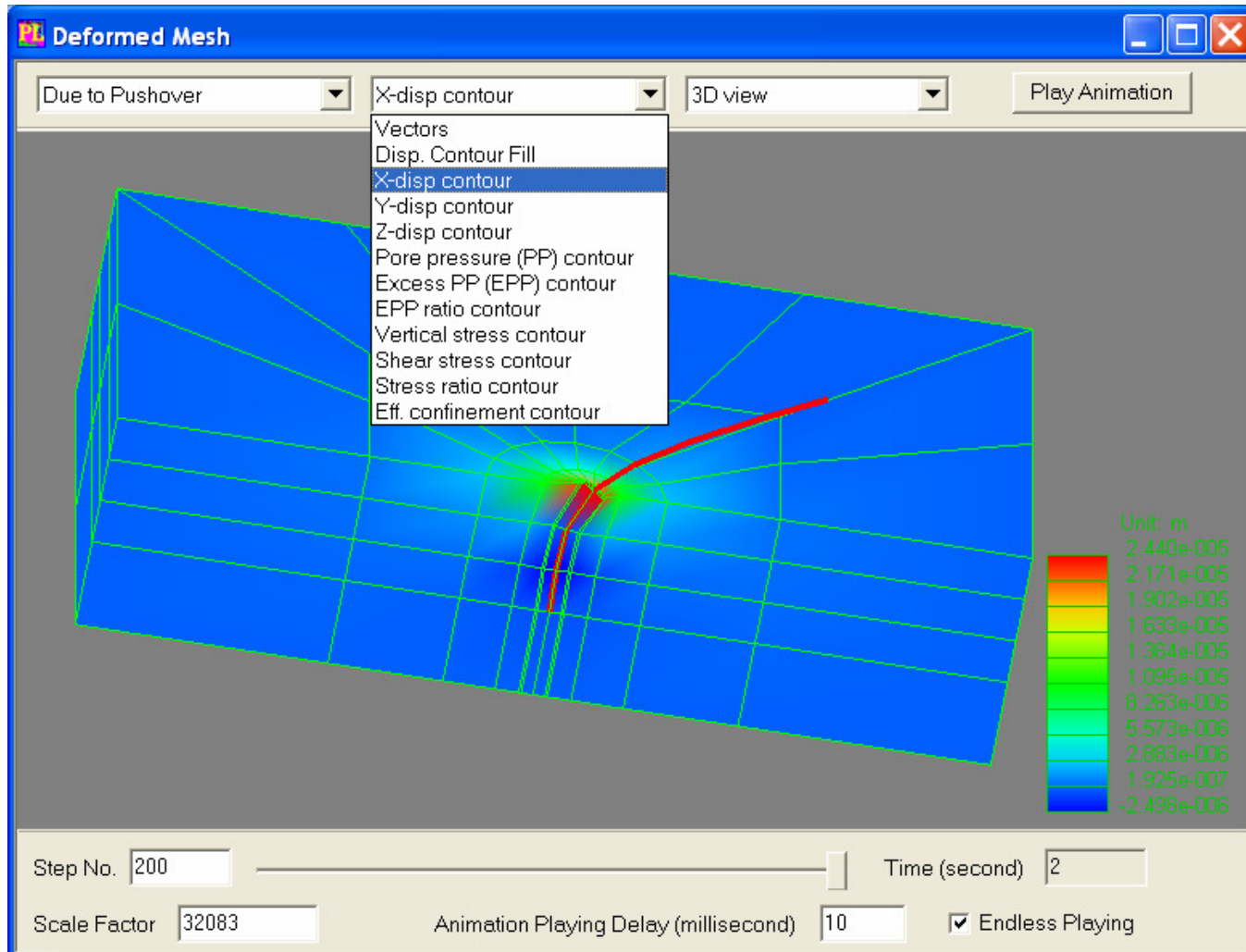


Pile in Sloping Ground

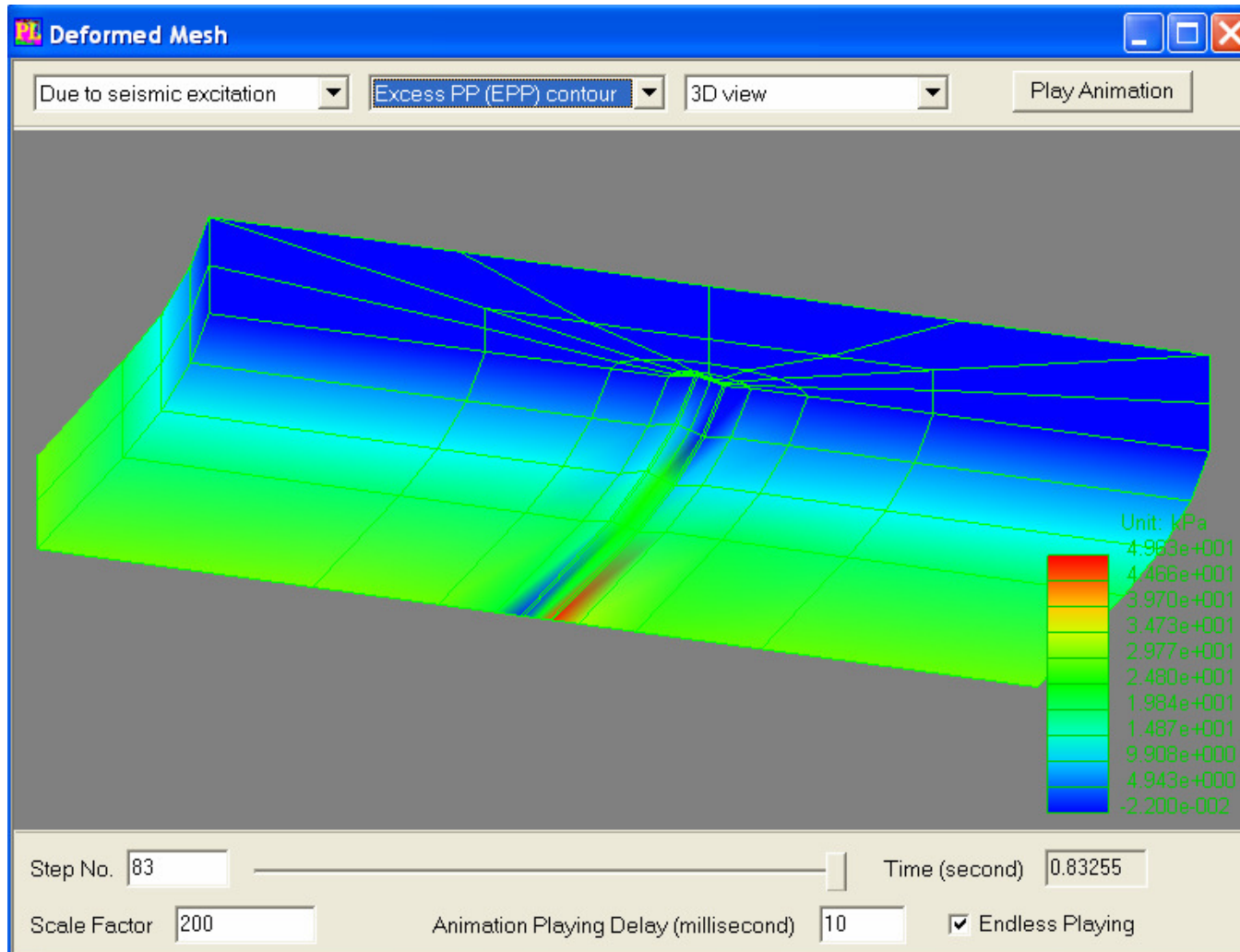


Straightforward
and fast mesh
definition/
refinement

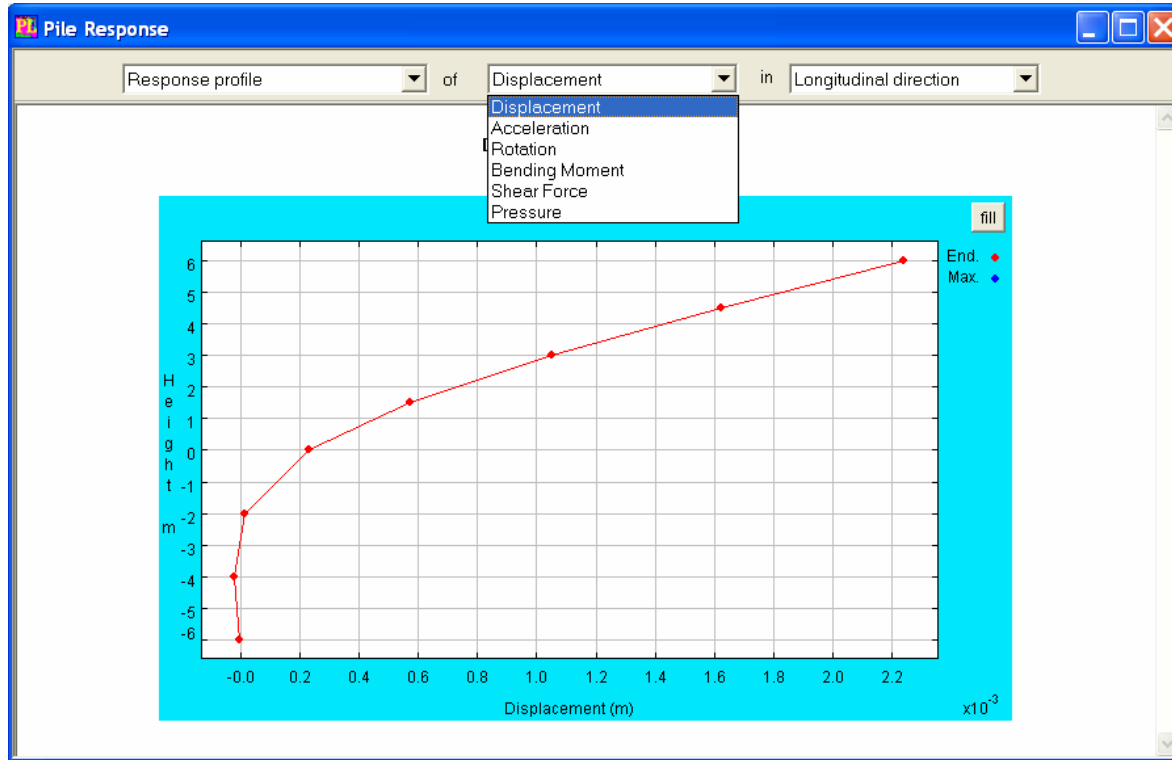
Output: Deformed Mesh



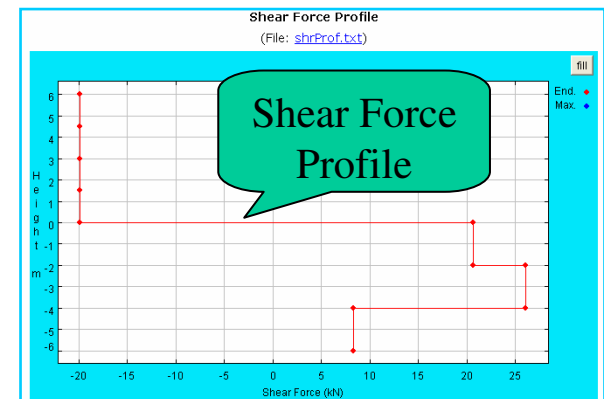
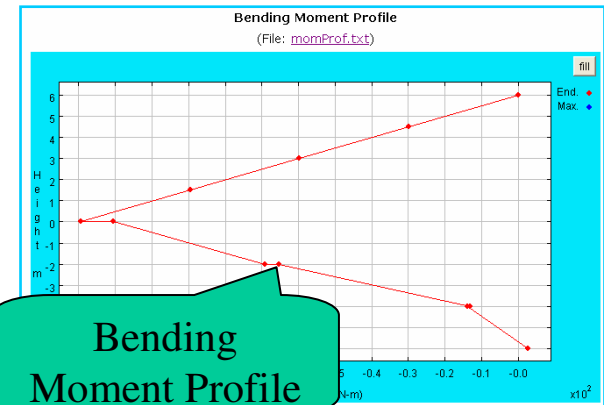
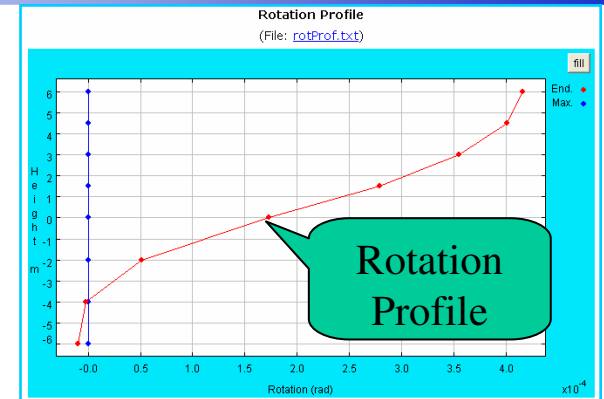
Output: Excess Pore Pressure Contour



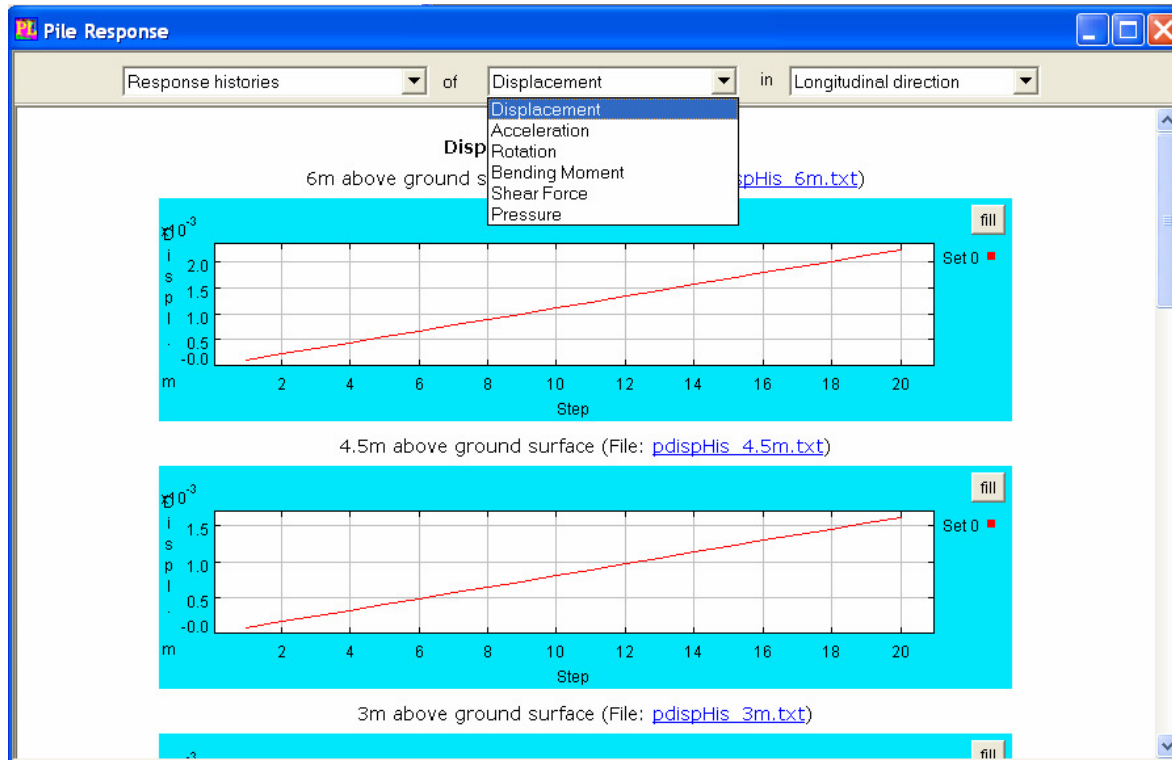
Output: Pile Response Profiles



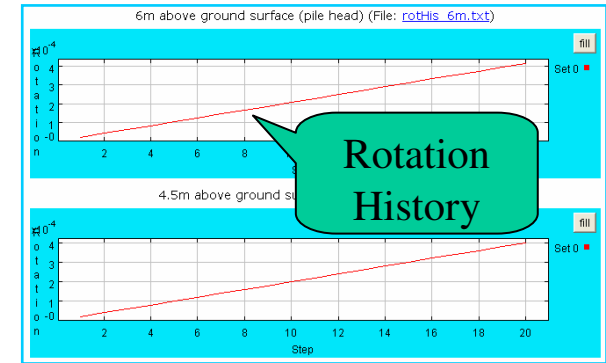
Displacement Profile



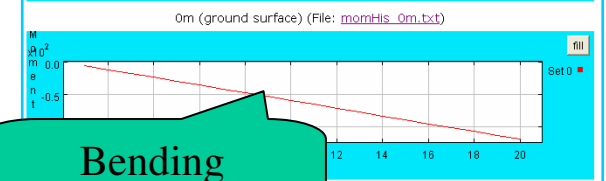
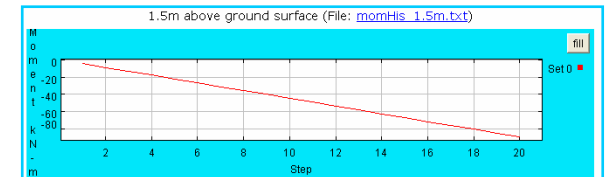
Output: Pile Response Histories



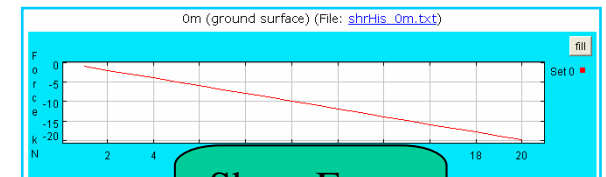
Displacement History



Rotation History

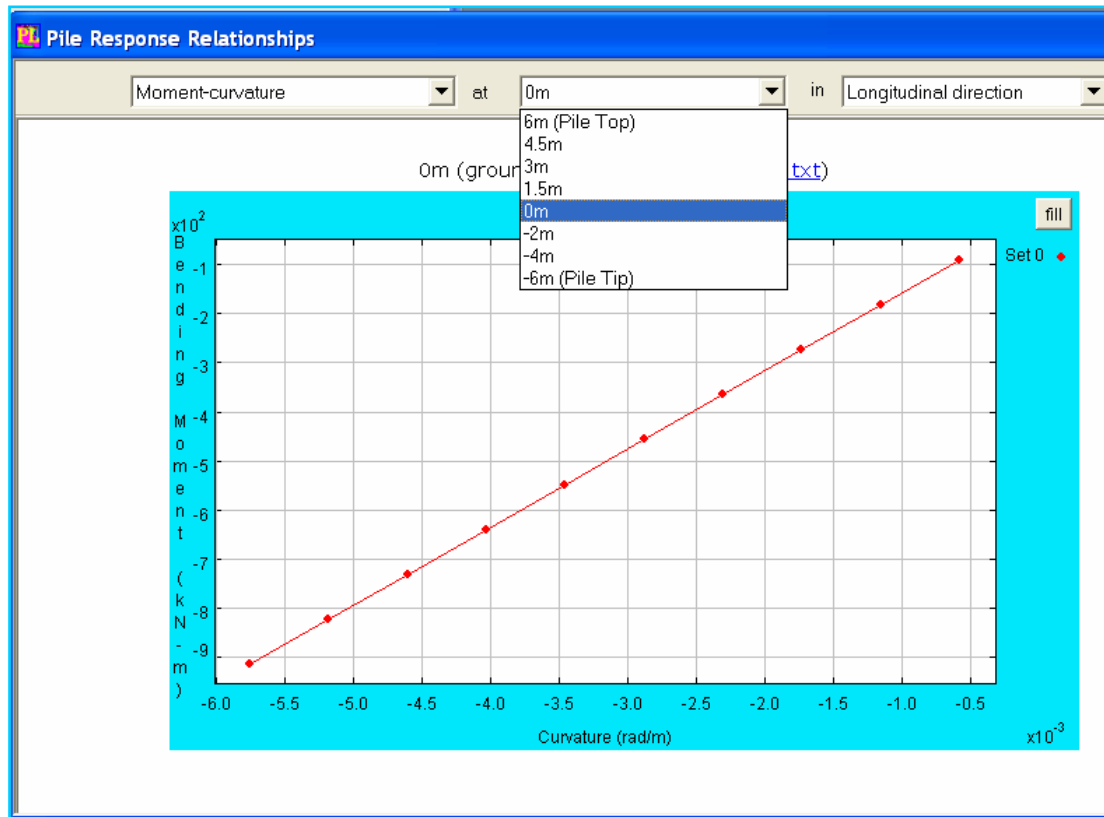


Bending Moment History

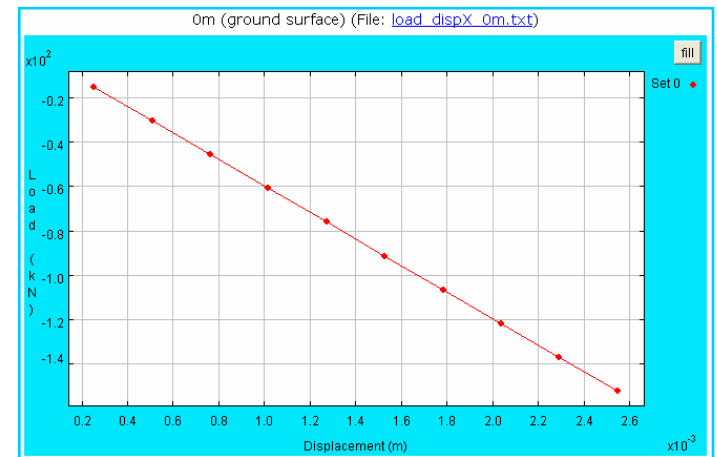


Shear Force History

Output: Pile Response Relationships

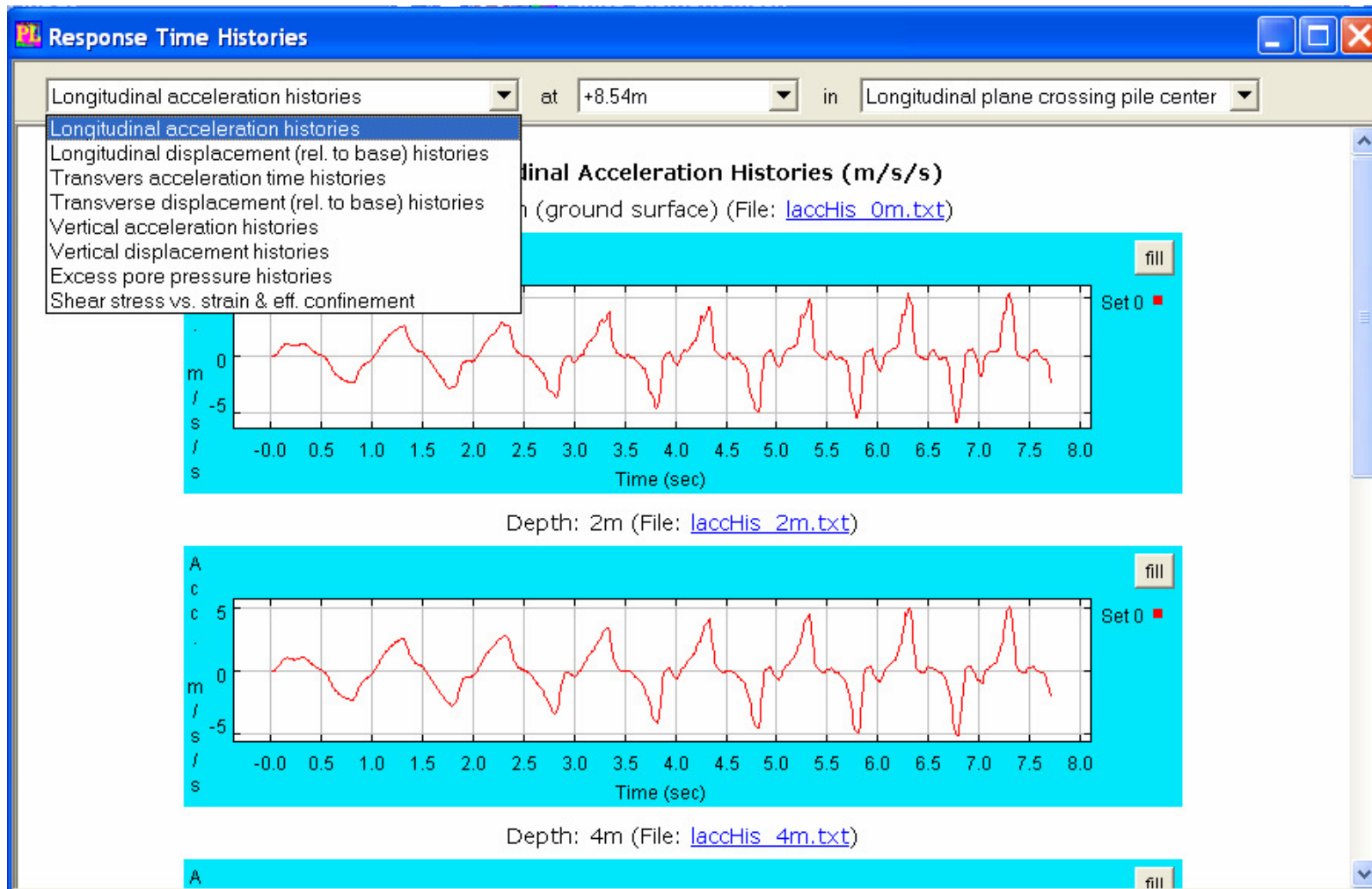


Moment-Curvature Relationship
(at Different Locations of Pile)

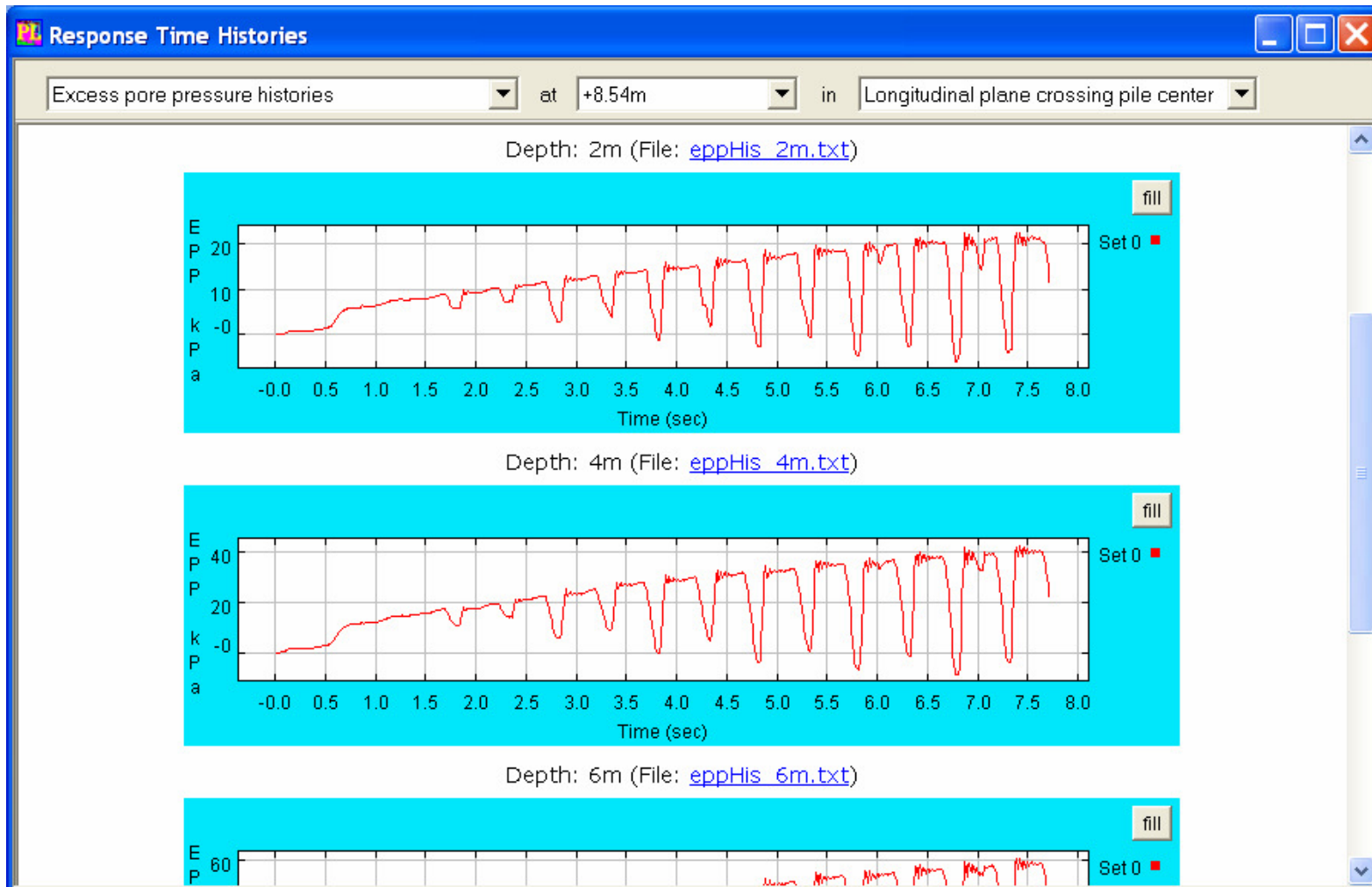


Load-Displacement
Relationship

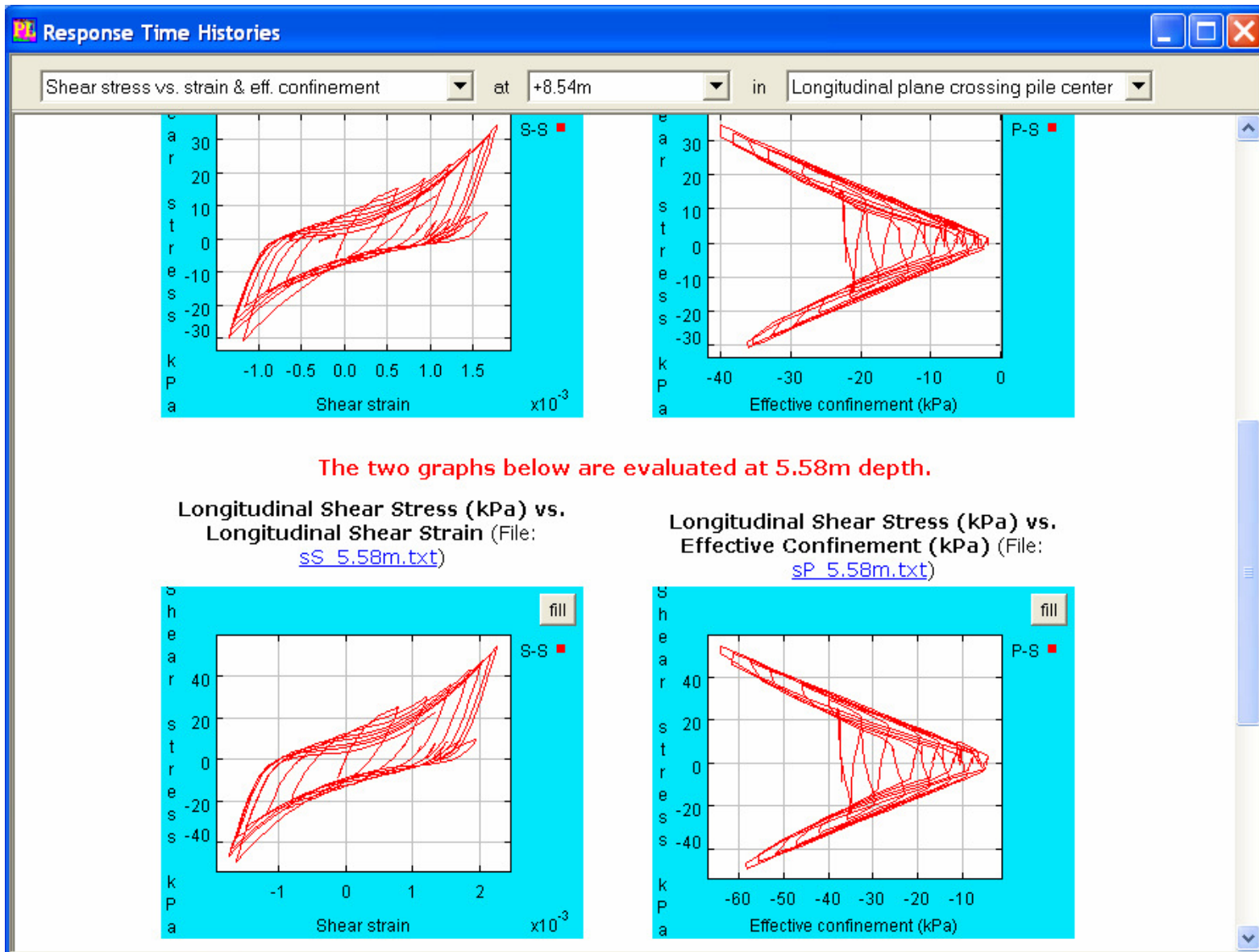
Output: Soil Acceleration Time Histories



Output: Excess Pore Pressure Time Histories



Output: Shear Stress vs. Strain & Effective Confinement

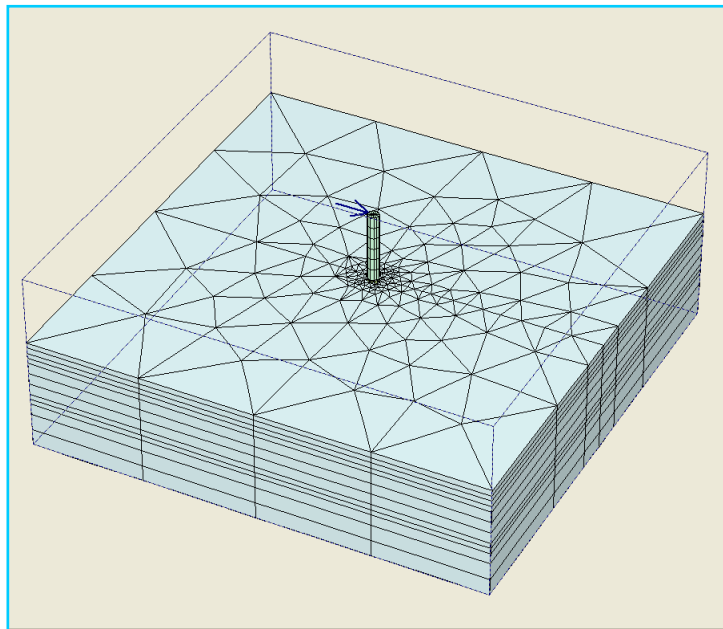


Comparison with PLAXIS

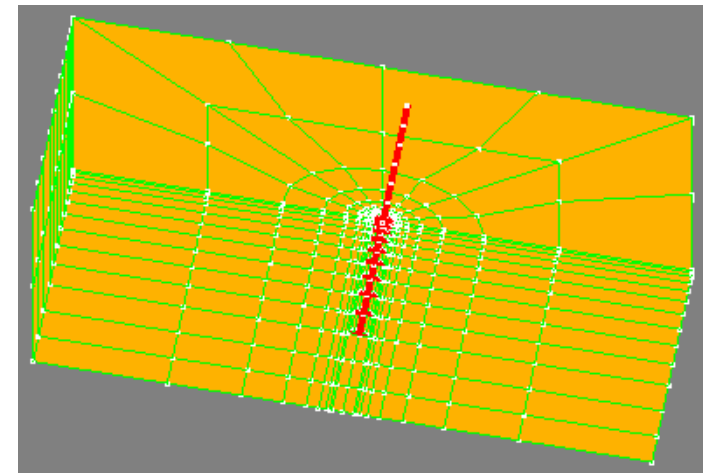
| Soil, linear elastic | E | ν |
|----------------------|---------|-----------------|
| | 100 MPa | 0.35 (K/G=3) |

| Compact elastic concrete pile | E | ν | Diameter | I |
|-------------------------------|--------|-------|----------|----------------------|
| | 20 GPa | 0.25 | 1 m | 0.049 m ⁴ |

The pile is 6m above terrain, 6m into soil. The soil layer is 10m thick. The load is 100kN at pile head.



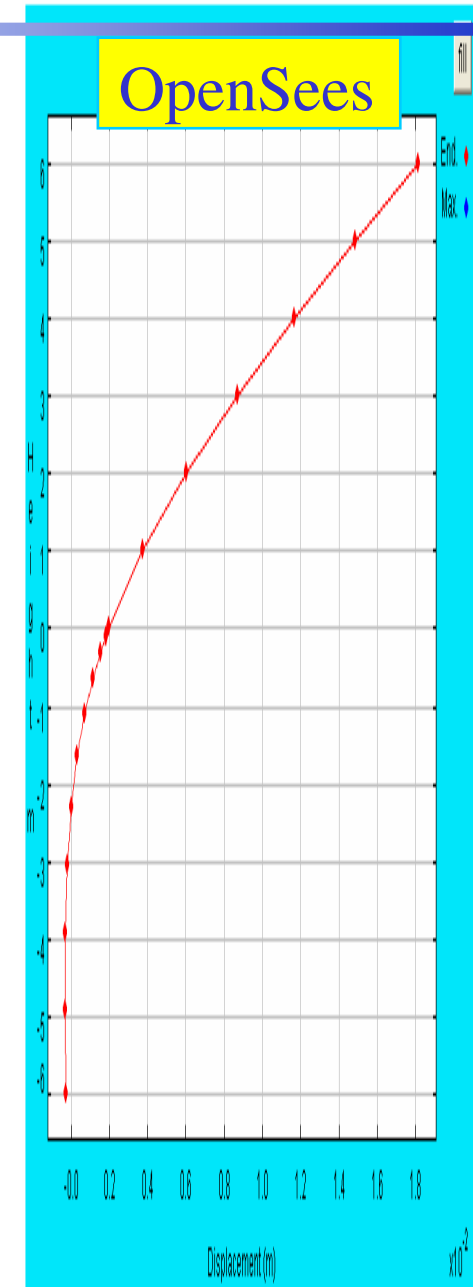
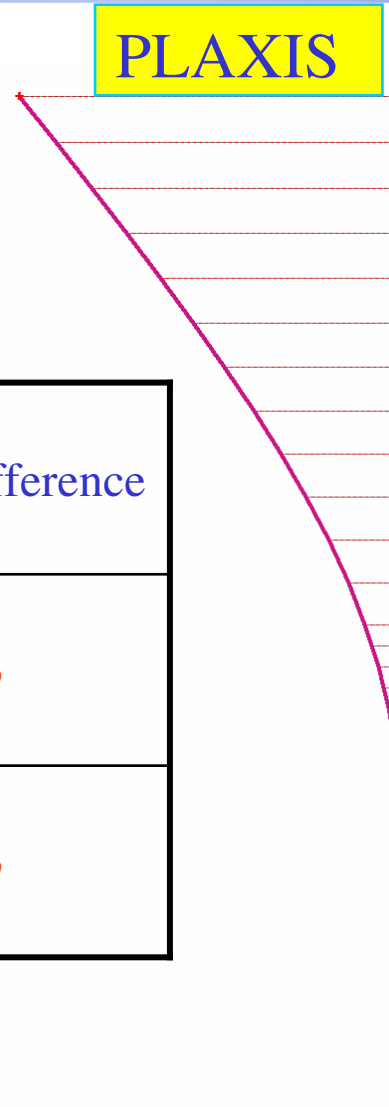
PLAXIS Mesh (S. Nordal, 2006)



OpenSees Mesh

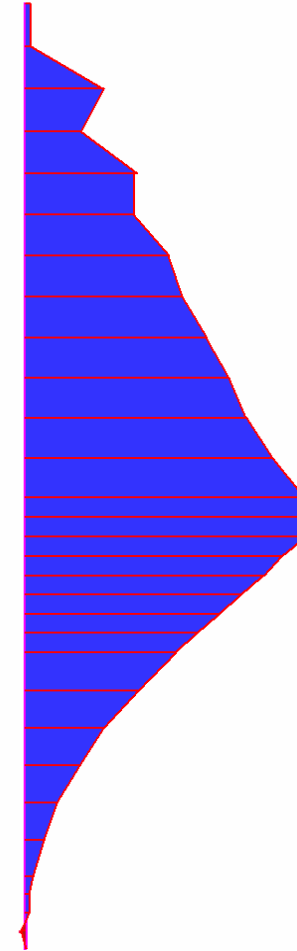
Deflection Comparison

| Deflection (mm) | PLAXIS | OpenSees | Difference |
|-----------------|--------|----------|------------|
| Pile head | 19.47 | 18.13 | 7% |
| Ground surface | 1.99 | 1.97 | 1% |

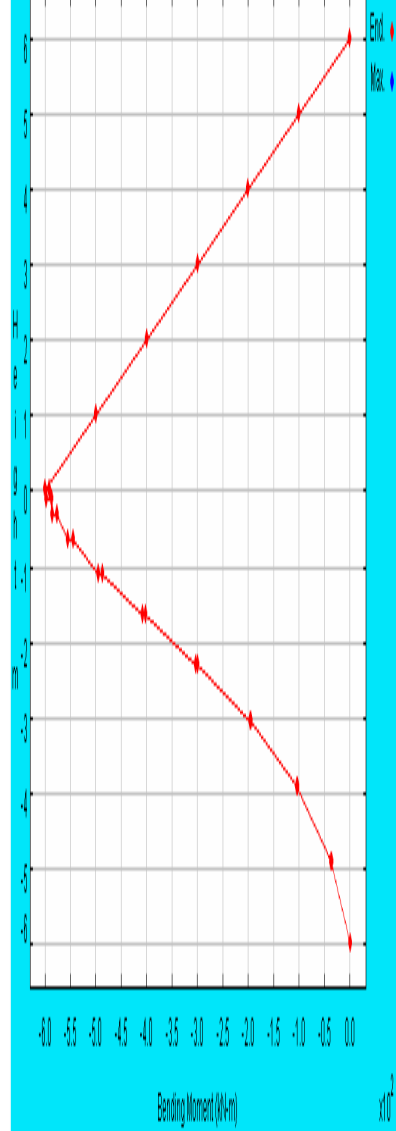


Bending Moment Comparison

PLAXIS



OpenSees



| | PLAXIS | OpenSees | Difference |
|--------------------|---------------------|--------------|------------|
| Max. Moment (kN-m) | 685 | 600 | 12% |
| Location for Max | 0.5 m below surface | Near surface | |

Summary

- A user interface for pile analysis using OpenSees was developed.
- Analysis options available include seismic excitation, pushover analysis and ground modification.
- Features include automatic meshing of soil and pile configurations, available libraries of already calibrated soil models, and structural models for seismic response.
- Future work includes option for pile group.
- OpenSeesPL can be downloaded from:
<http://cyclic.ucsd.edu/OpenSeesPL/>