Sensitivity Studies for Nuclear Island Founded on Piles Including the Effects of Seismic Motion Spatial Variation and Local Nonlinear Soil Behavior

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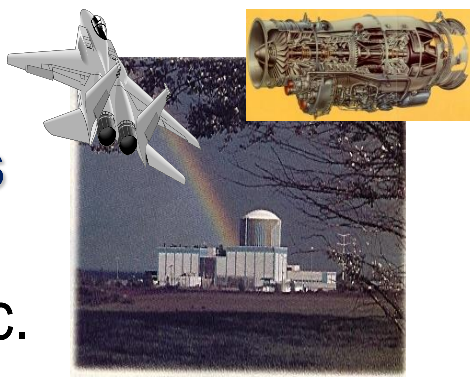

SMiRT25 Conference, Division III

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Purpose of Presentation:

To investigate SSI effects for a NI complex founded on piles.

Both floating piles (Case A) and peak-bearing piles (Case B) are considered.

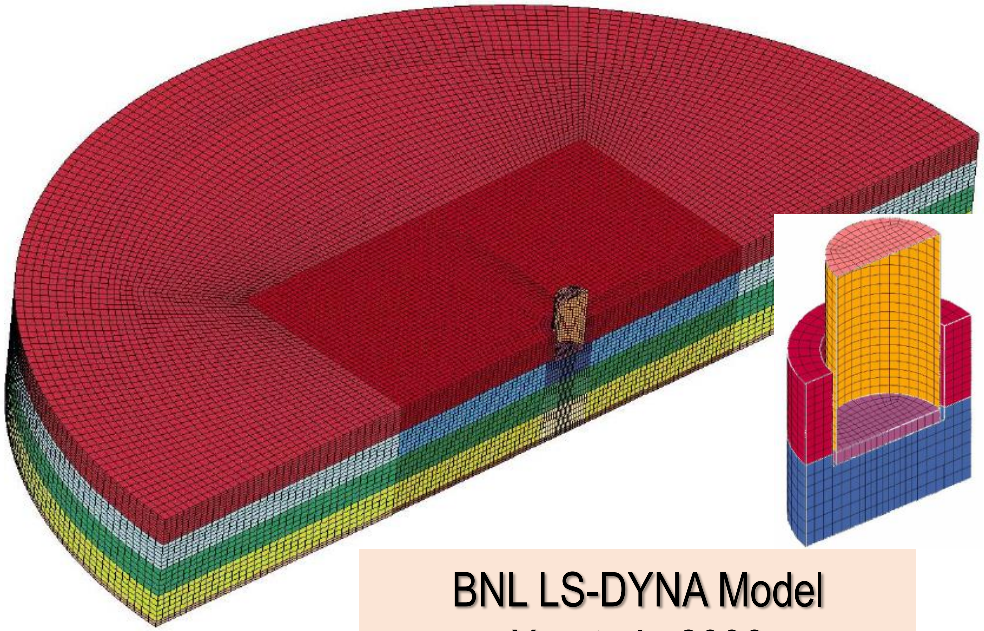
Investigate the effects of
- Floating piles (Case A) vs. peak-bearing piles (Case B)
- Motion spatial variation effects (incoherency and wave passage)
- Local nonlinear soil behaviour in the vicinity of piles.

Used the 2019 ACS SASSI V4 software

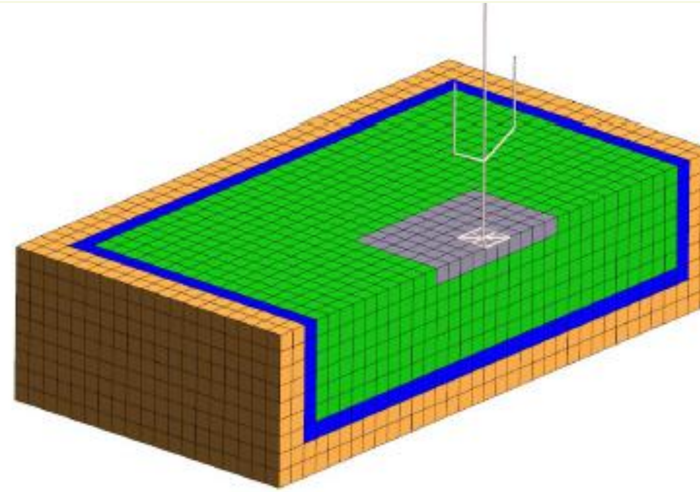
1. Application of SASSI Methodology

- Nonlinear Soil Behavior in Vicinity of Foundations
- Excavated Soil Modeling (Mesh and Interaction Nodes)

Direct SSI and SASSI Approach FE Models

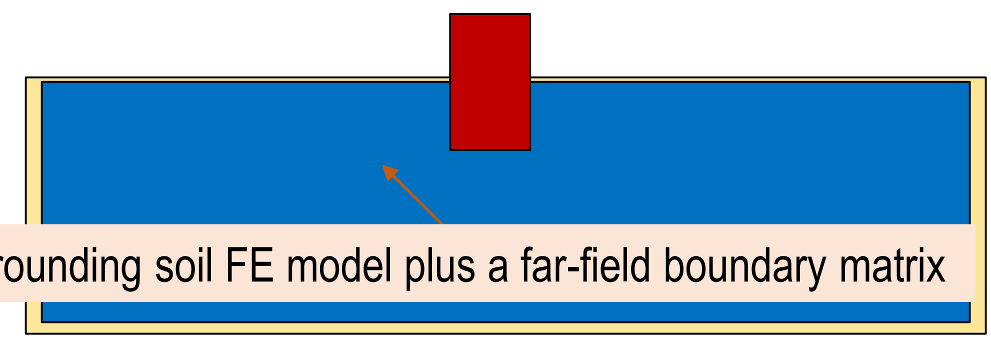


BNL LS-DYNA Model
Xu et al., 2006



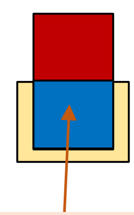
E-SSI Model
Neboja et al., 2015

Time-Domain SSI Approach



Surrounding soil FE model plus a far-field boundary matrix

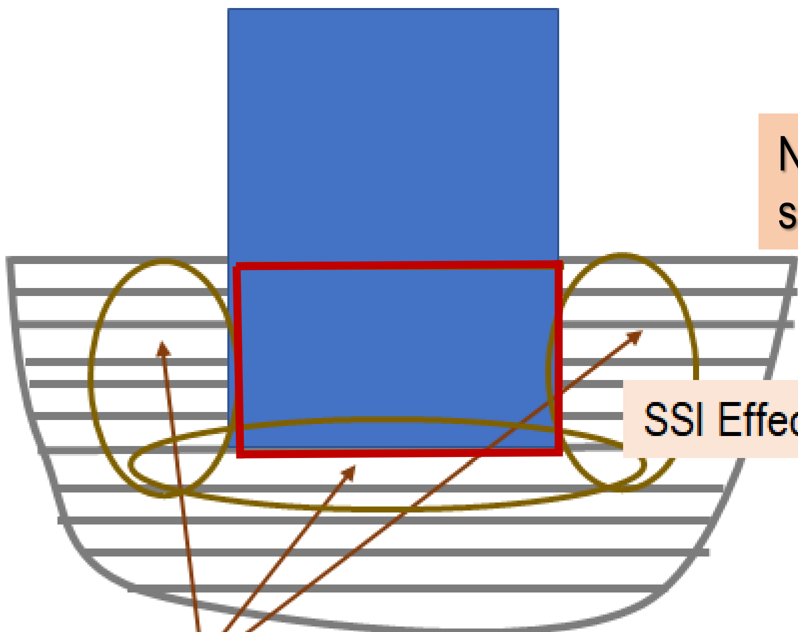
SASSI Approach



Excavated soil FE model plus the far-field soil impedance matrix

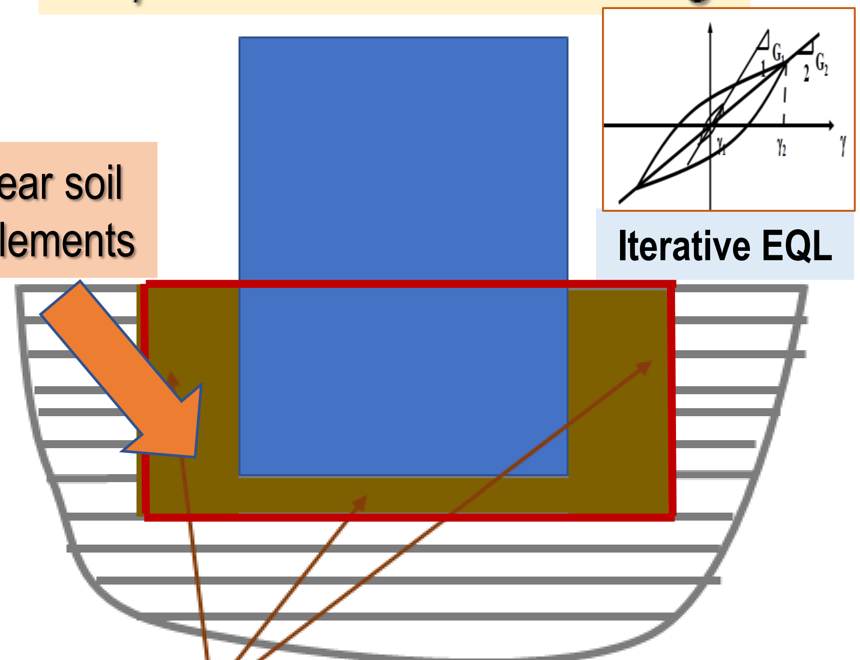
Improving SSI Modeling for Soft Soil Sites or Stiffer Soil Sites with Soft Backfills

"Standard" SASSI Modeling



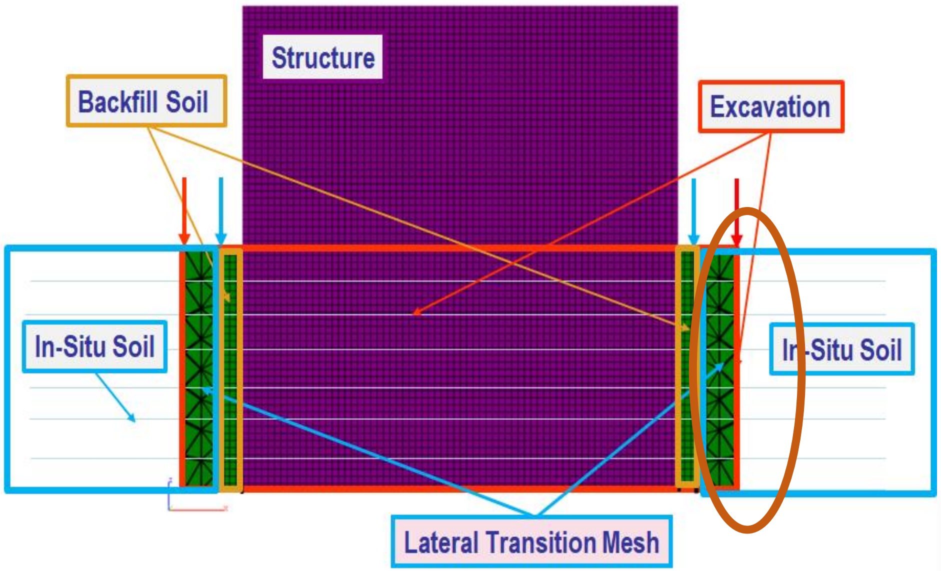
Typically, SSI model uses in the vicinity of foundation iterated strain-compatible soil layer properties computed using iterative 1D wave propagation equivalent-linear approach, *EQL via SHAKE methodology*. SSI effects on soil behavior are neglected.

"Improved" SASSI Modeling

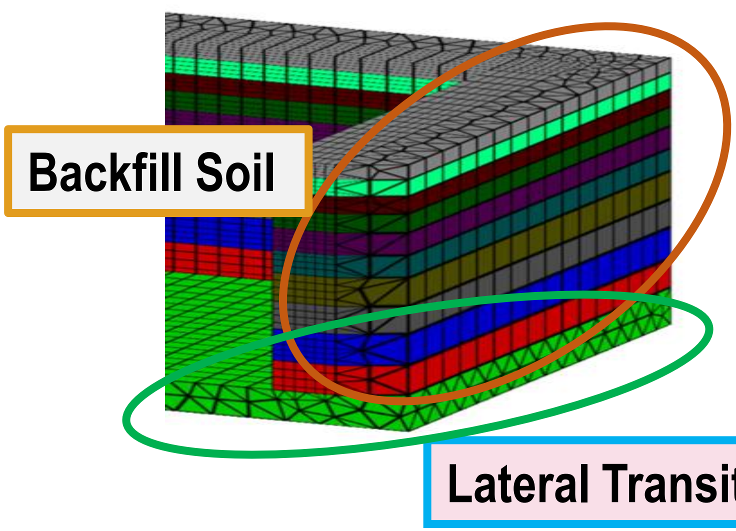


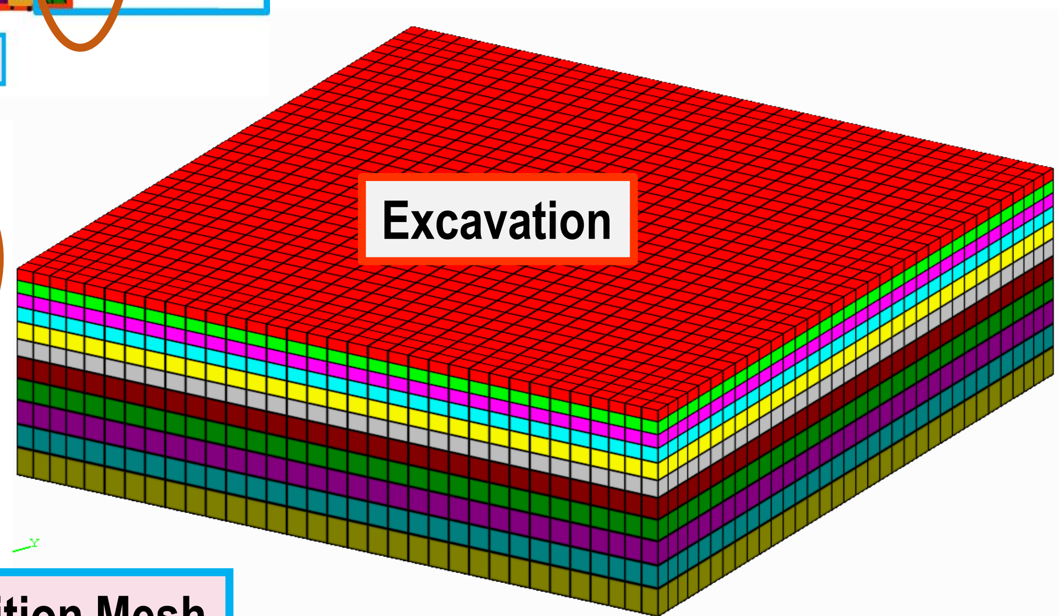
SSI model uses in the vicinity of foundation iterated strain-compatible soil layer properties computed using iterative 3D SASSI equivalent-linear approach to capture SSI effects, *EQL via fast SASSI iterations.*

Transition Mesh Zones Are Necessary to Get A Regular Mesh Excavation FE Model



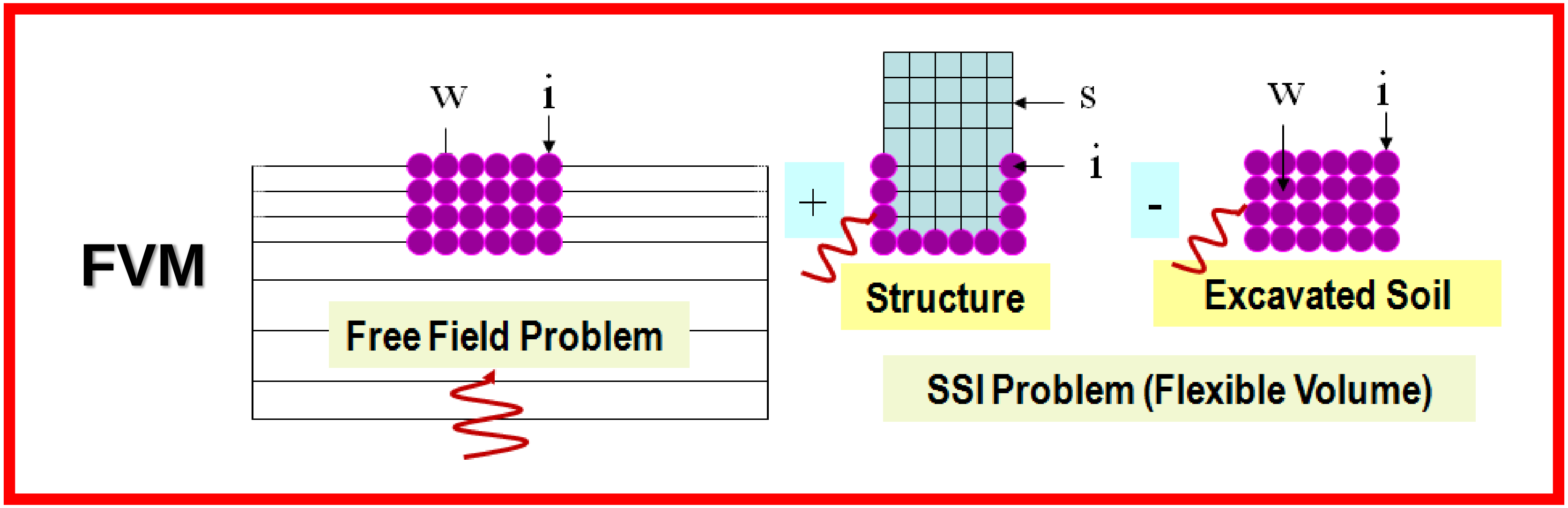
Regular mesh excavated soil FE models capture accurately the high-frequency wave scattering effects, and also ensures more efficient SSI runs (less int. nodes). *See conclusions of the Brookhaven National Lab Report BNL-102434 by USNRC BNL Consultants (Nie et al., 2013)*

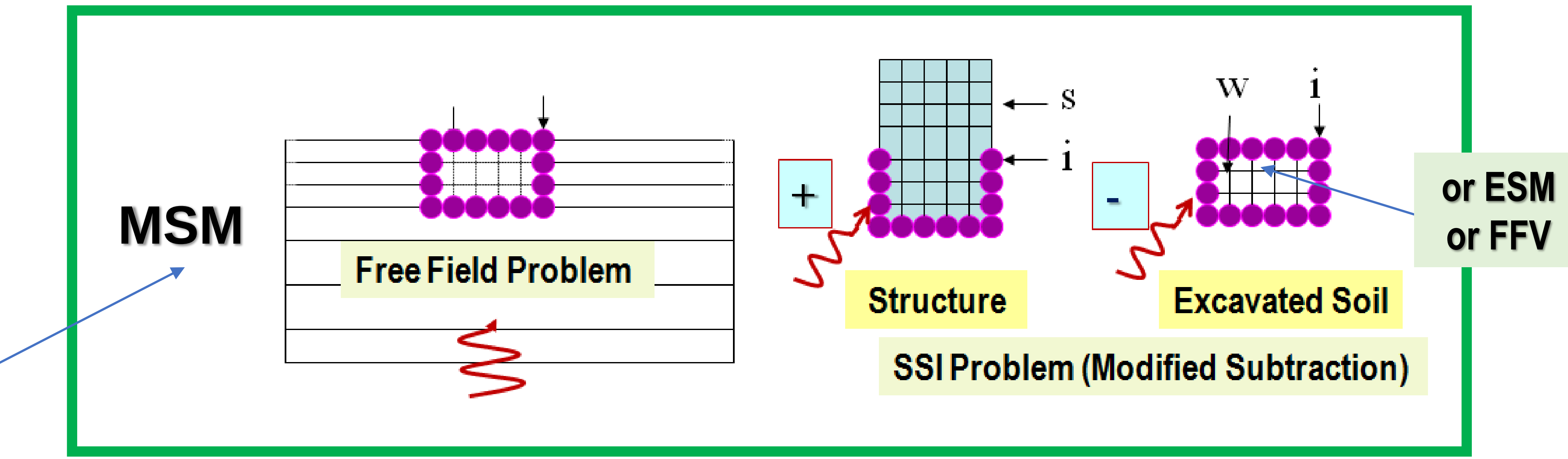




SASSI Flexible Volume Substructuring Methods

Reference FVM vs. *Faster* MSM, ESM or FFVM



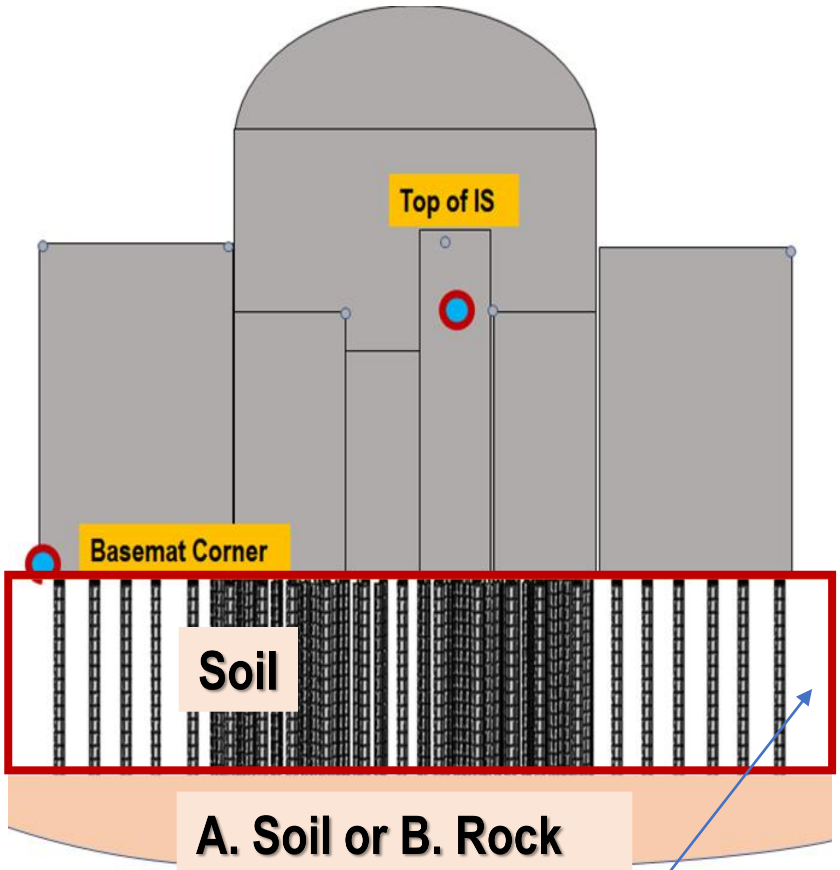


2. RB Complex on Pile Foundation Sensitivity Study

- Floating Pile (FP) vs. Peak Bearing Pile (PBP)
- Coherent vs. Incoherent Seismic Input Motions
- Nonlinear vs. Linear Soil Behavior in Vicinity of Piles

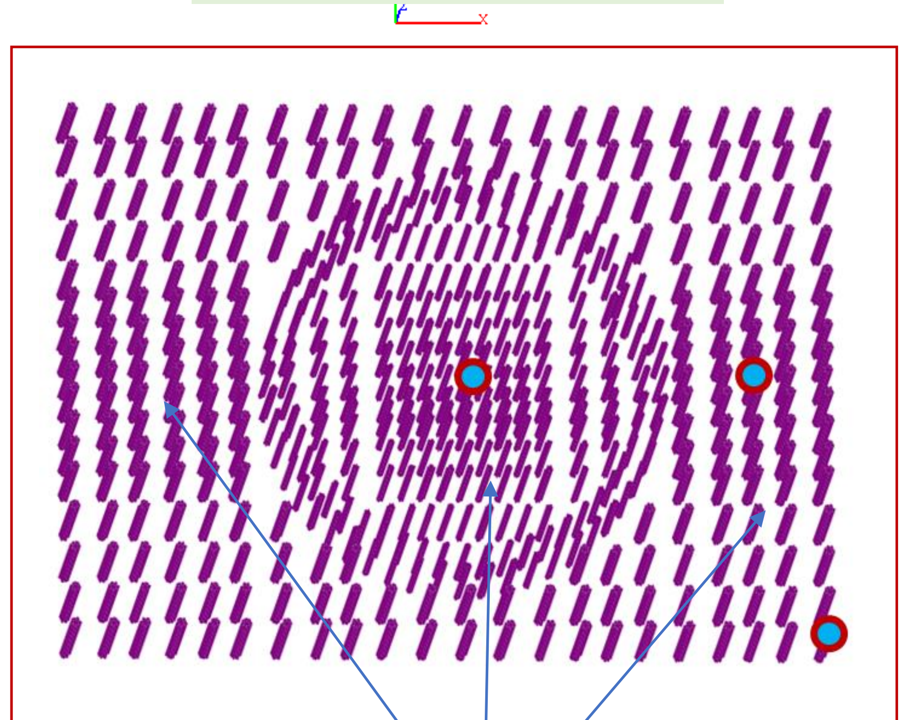
SSI Modeling of RB Complex on Pile Foundation

RB Complex on Piles



Excavated soil has a much larger horizontal size than vertical size. Efficient MSM is applicable.

Pile Foundation (about 500 piles)

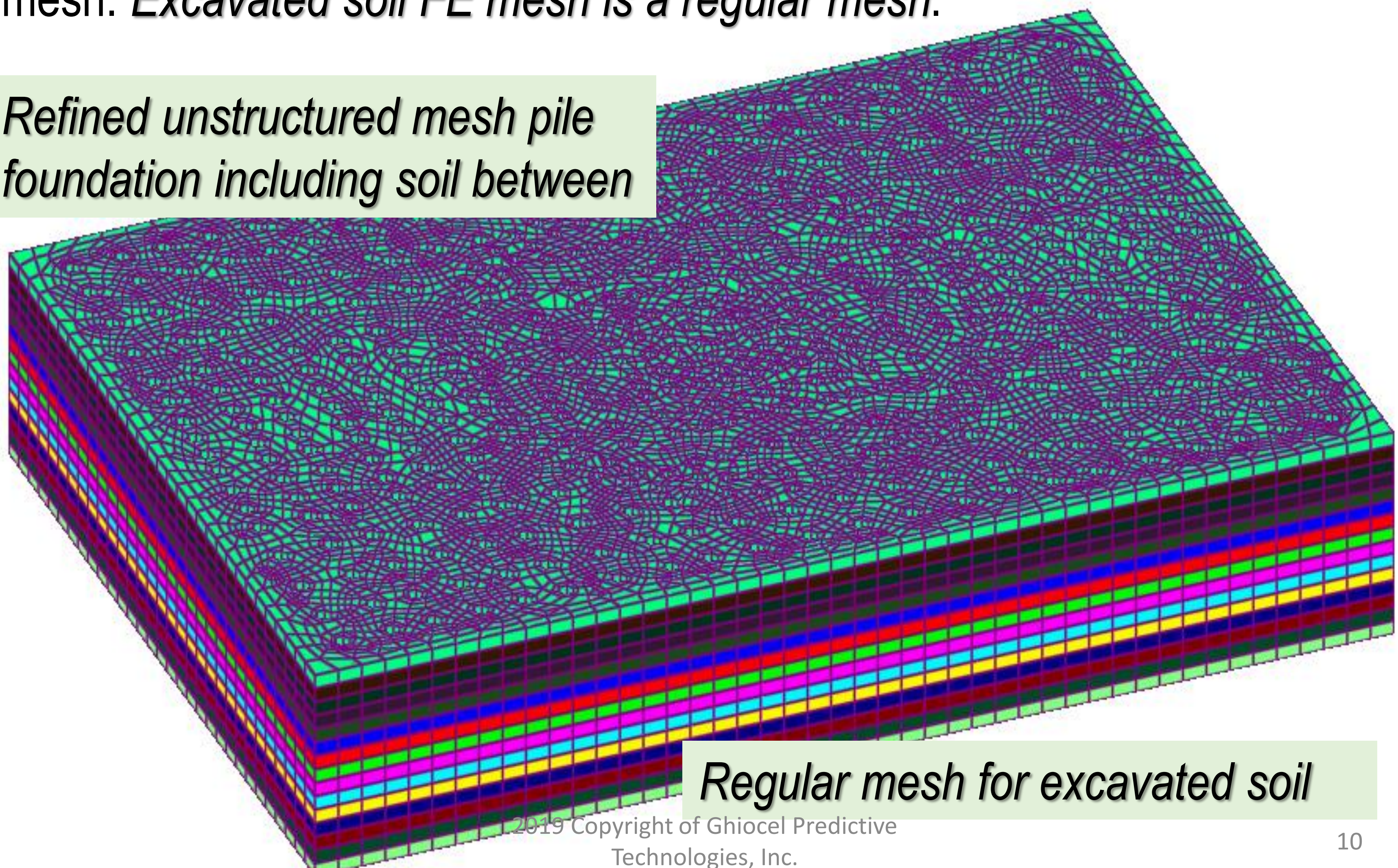


Pile diameter and density varies; D1=1m diameter, D2=1.5m diameter

RB Complex Pile Foundation Modeling

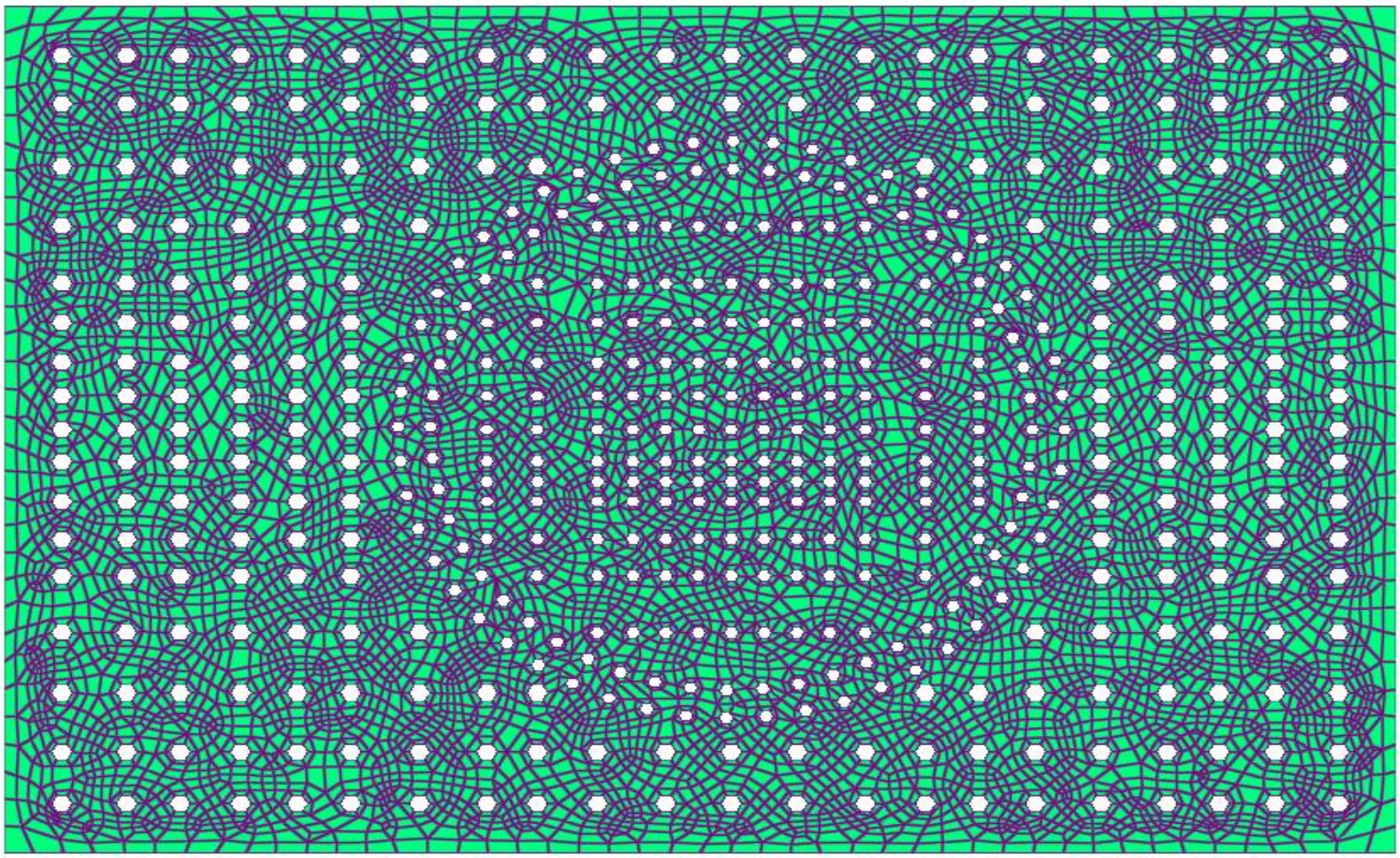
The *soil FE mesh is refined unstructured between piles*, but it is coarser and *regular* at the mesh boundaries were connected to the excavated soil mesh. *Excavated soil FE mesh is a regular mesh*.

Refined unstructured mesh pile foundation including soil between



Regular mesh for excavated soil

RB Complex Pile Foundation Modeling



This pile foundation SASSI modelling provides a high numerical efficiency. MSM is applicable. The SSI model of about 250,000 nodes was run on a 256GB RAM PC under MS Window 10 in about 20 hours for 100 SSI frequencies (w/ ACS SASSI V4 software).

Other SSI Modeling Aspects

Foundation Basemat Connection with Piles

The RB complex basemat is assumed with no embedment and sitting only on the concrete piles. It was assumed that the basemat was not directly transmitting any load pressures to the surrounding soil. The basemat forces are transmitted to the concrete piles only. This SSI modelling avoids on purpose including the potential basemat contribution to the overall pile foundation impedance.

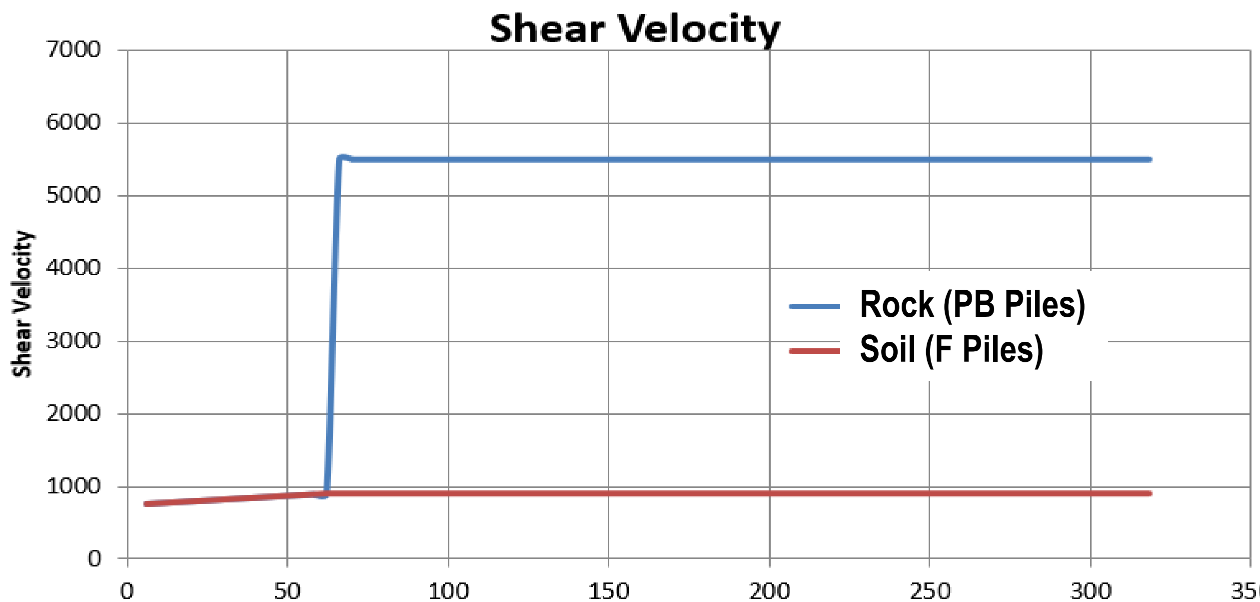
Nonlinear Soil Behaviour in Vicinity of Piles

A highly efficient global-local SSI analysis was used based on computing iteratively the SSI response for the equivalent-linearized system in complex frequency, and, then, for each soil element the local nonlinear soil behaviour in time domain for the simultaneous X, Y and Z inputs.

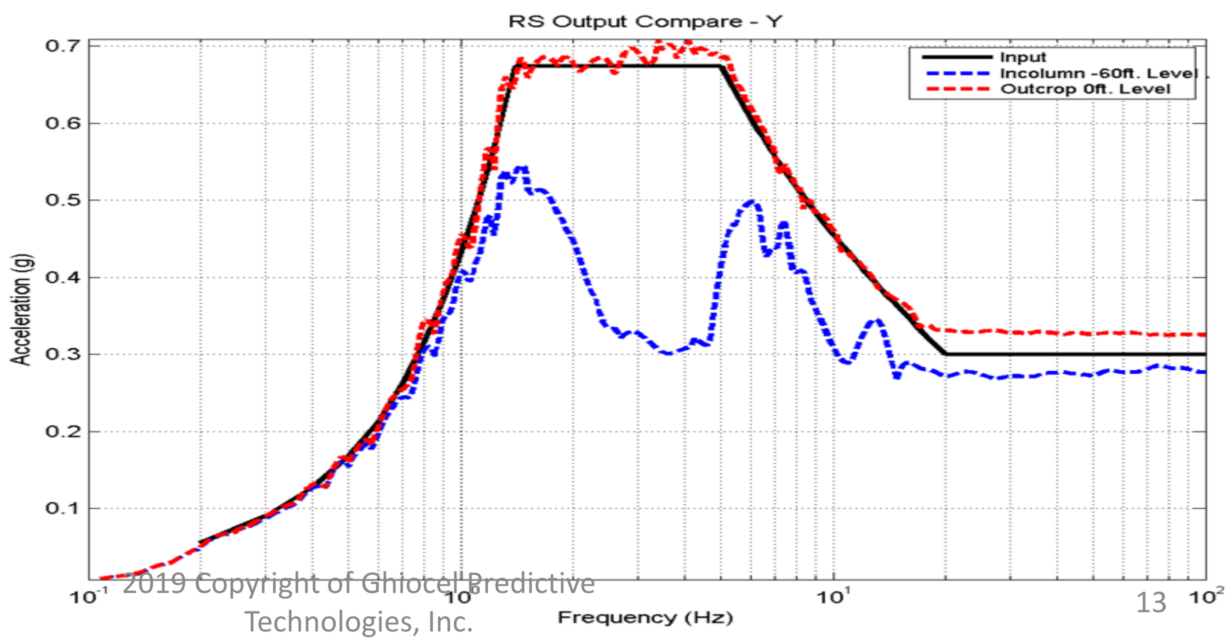
The octahedral shear strain from computed for each input direction X, Y and Z were combined before considering the nonlinear behaviour in time domain.

Seismic Input Motion and Soil Layering Cases

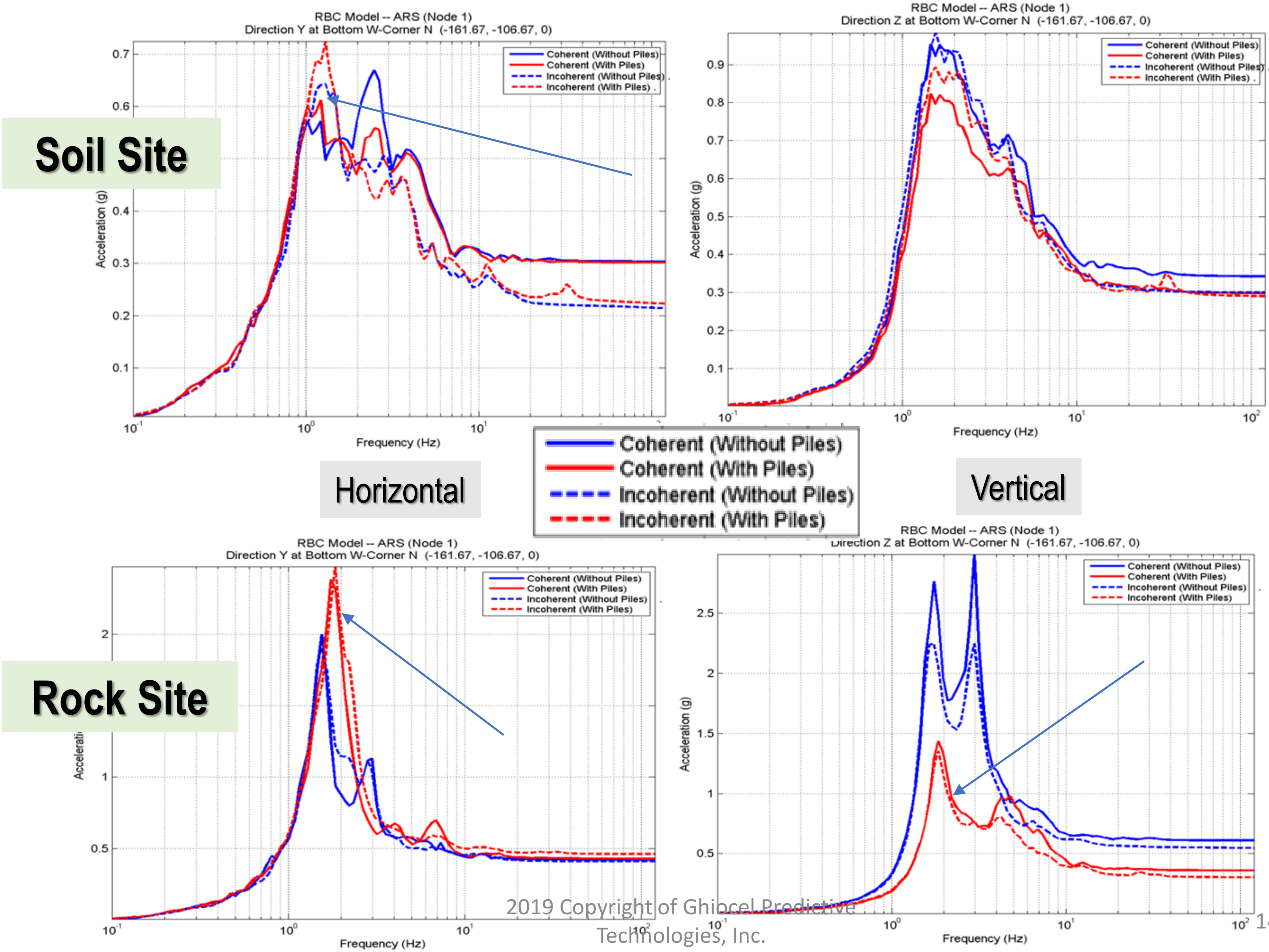
Soil Layering Cases



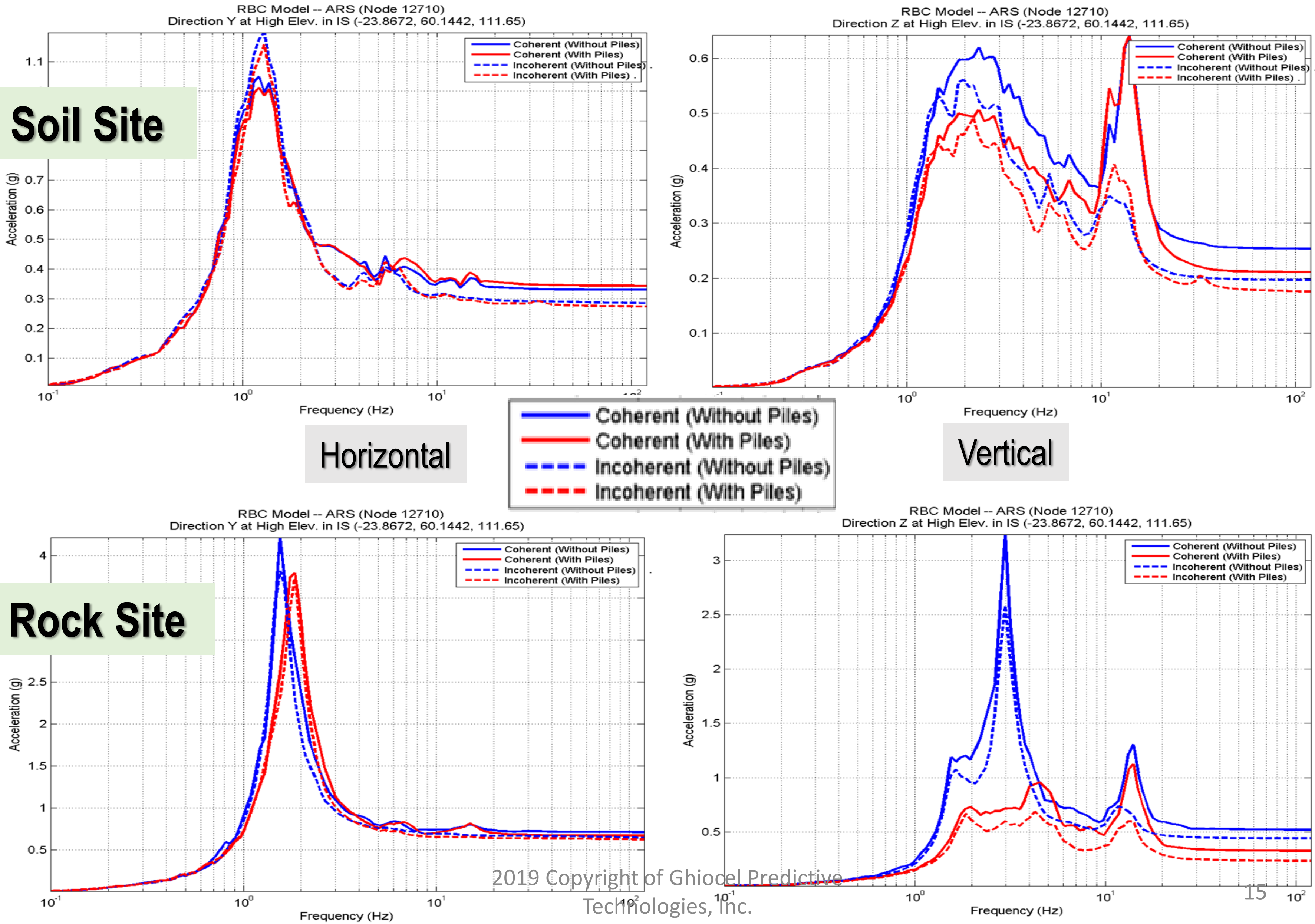
Seismic FIRS Input (Soil Site for IC)



Basemat Corner ISRS *With* and *Without Piles*

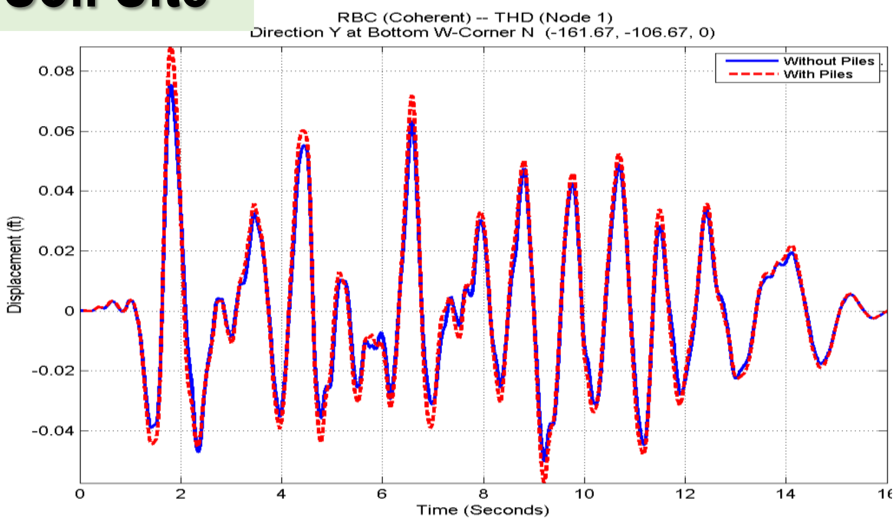


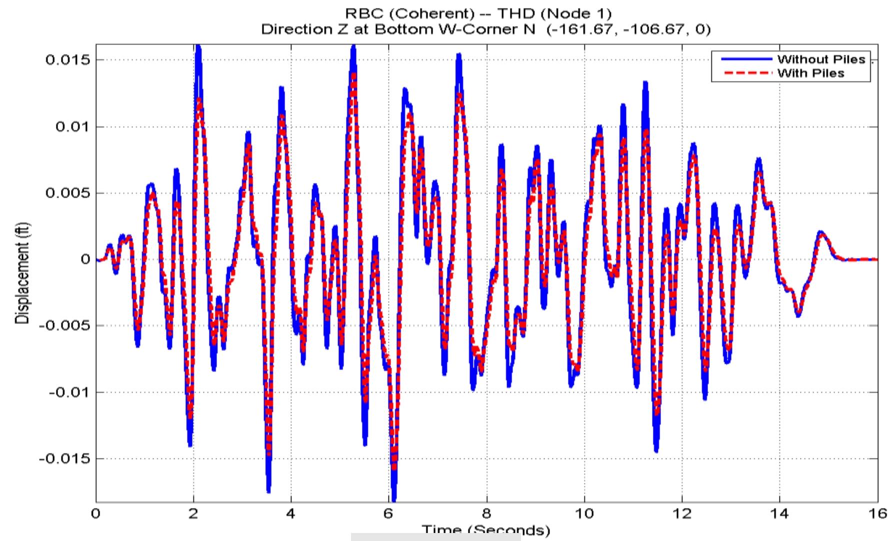
High-Elevation IS ISRS *With* and *Without Piles*



Basemat Corner Relative Displacements wrt Ground Surface *With* and *Without Piles*

Soil Site

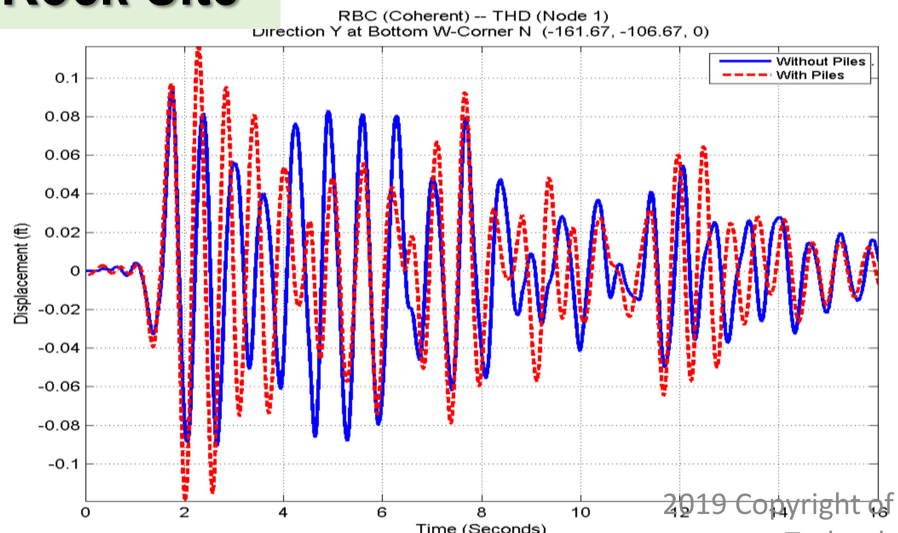


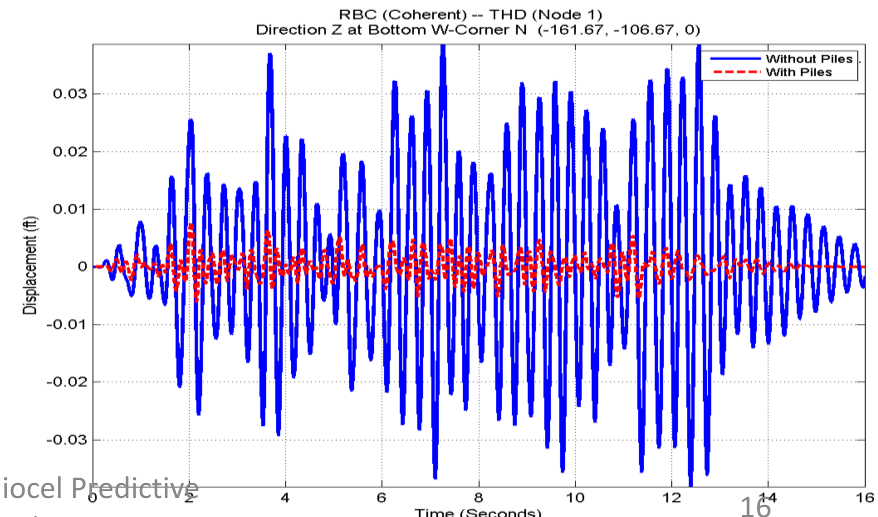


Rock Site

Horizontal

Vertical

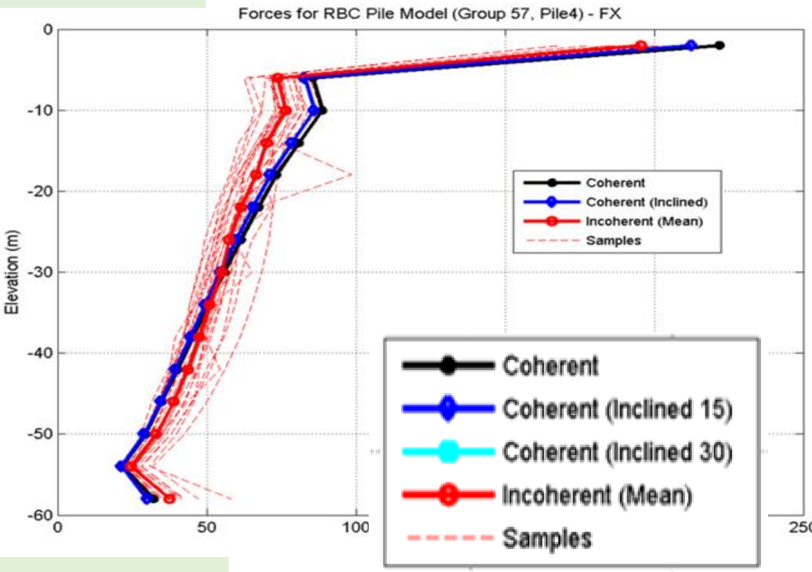




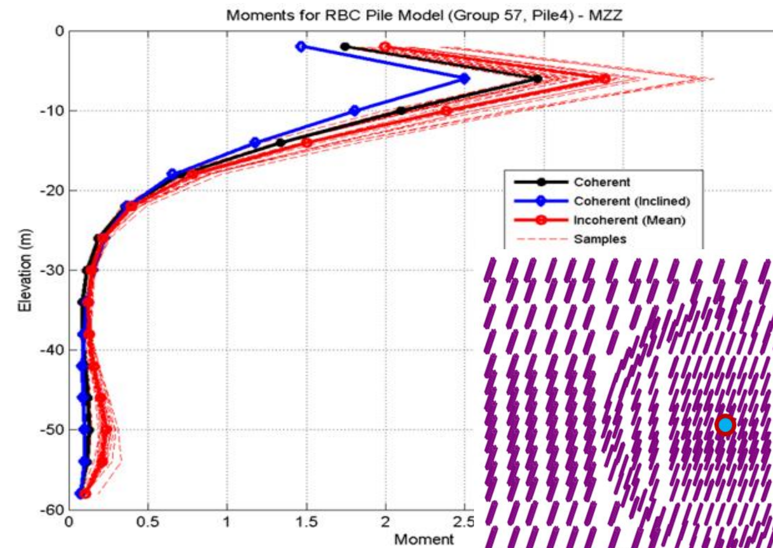
Axial Forces and Bending Moments in Corner Pile

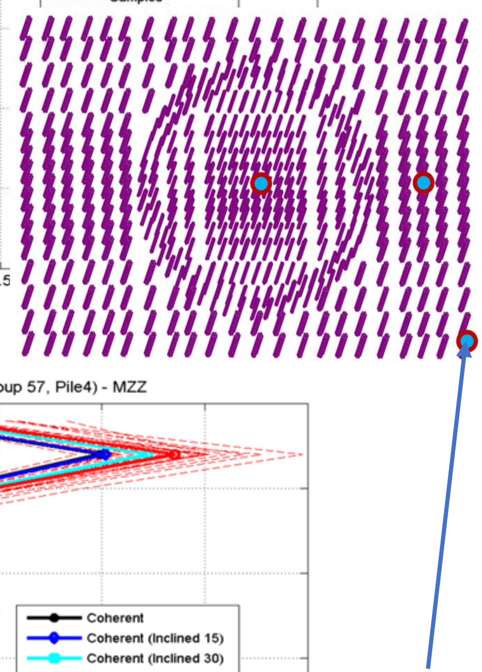
Soil Site

Axial Force

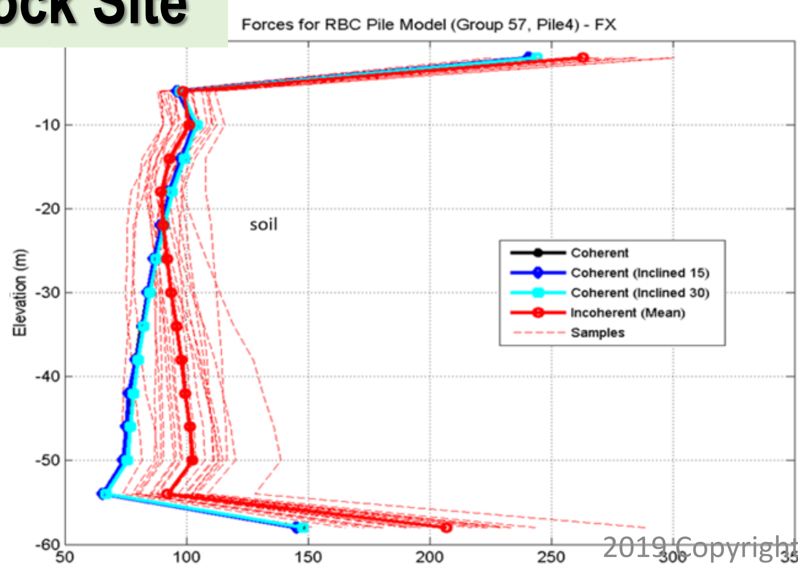


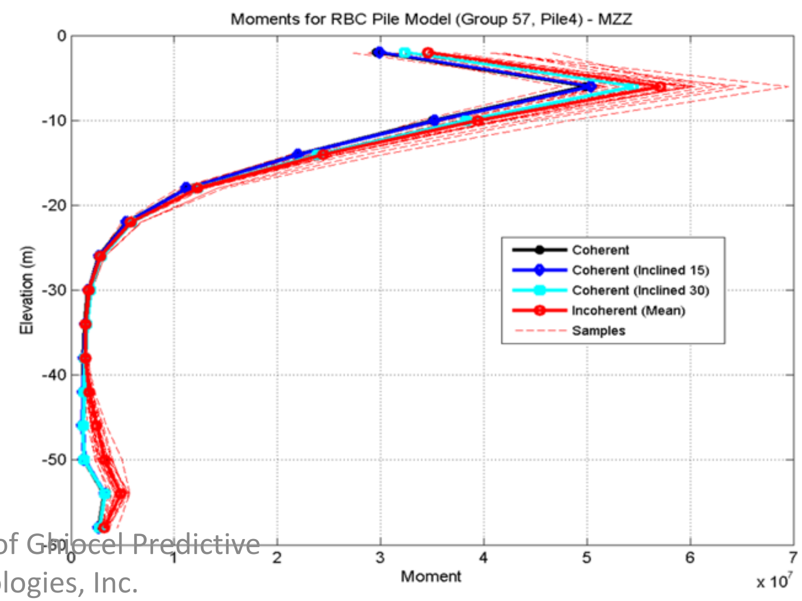
Bending Moment





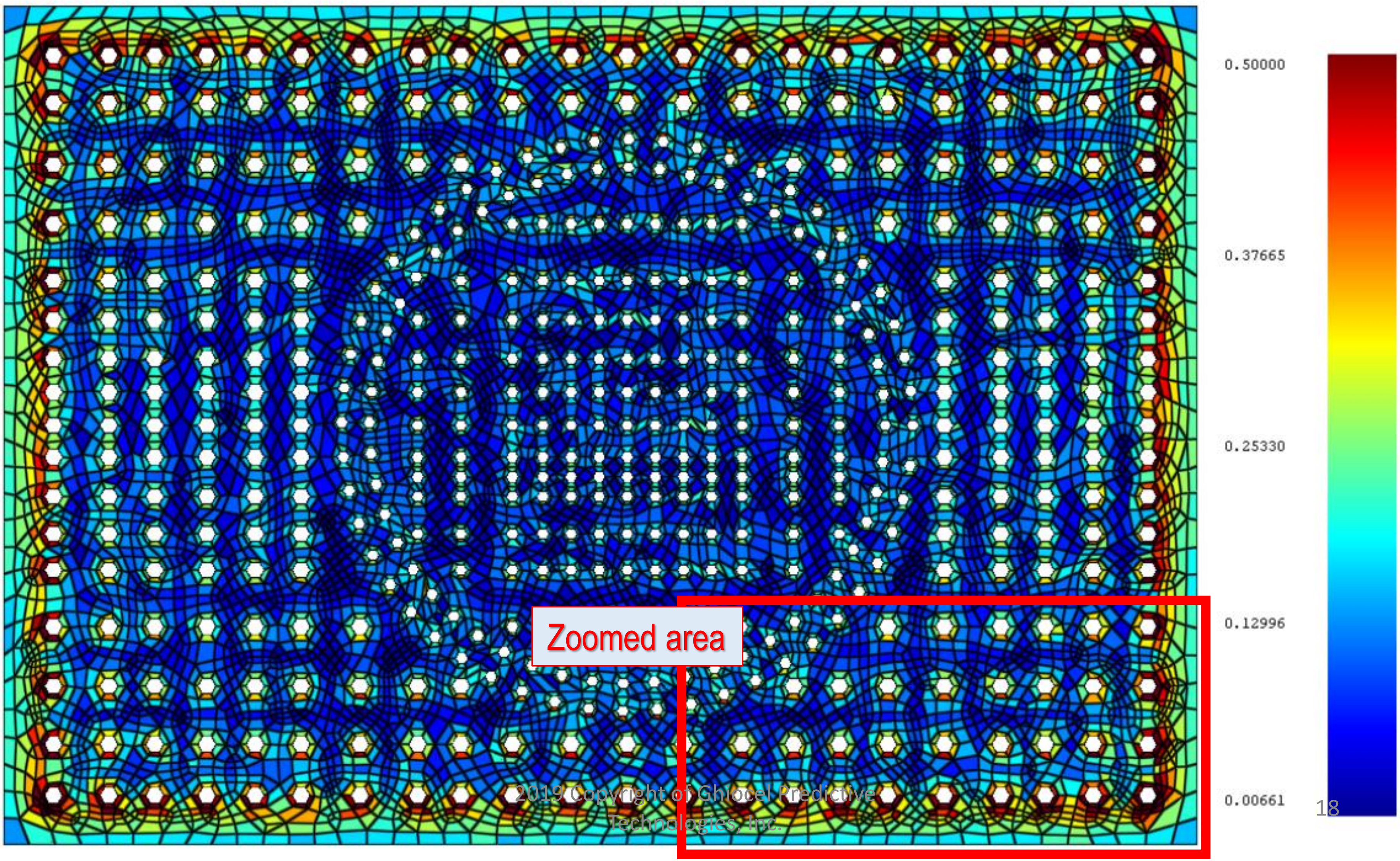
Rock Site





Nonlinear Soil Behavior in Vicinity of Piles

Effective (Iterated SSI) Soil Octahedral Shear Strain Under Combined X-Y-Z Seismic Inputs



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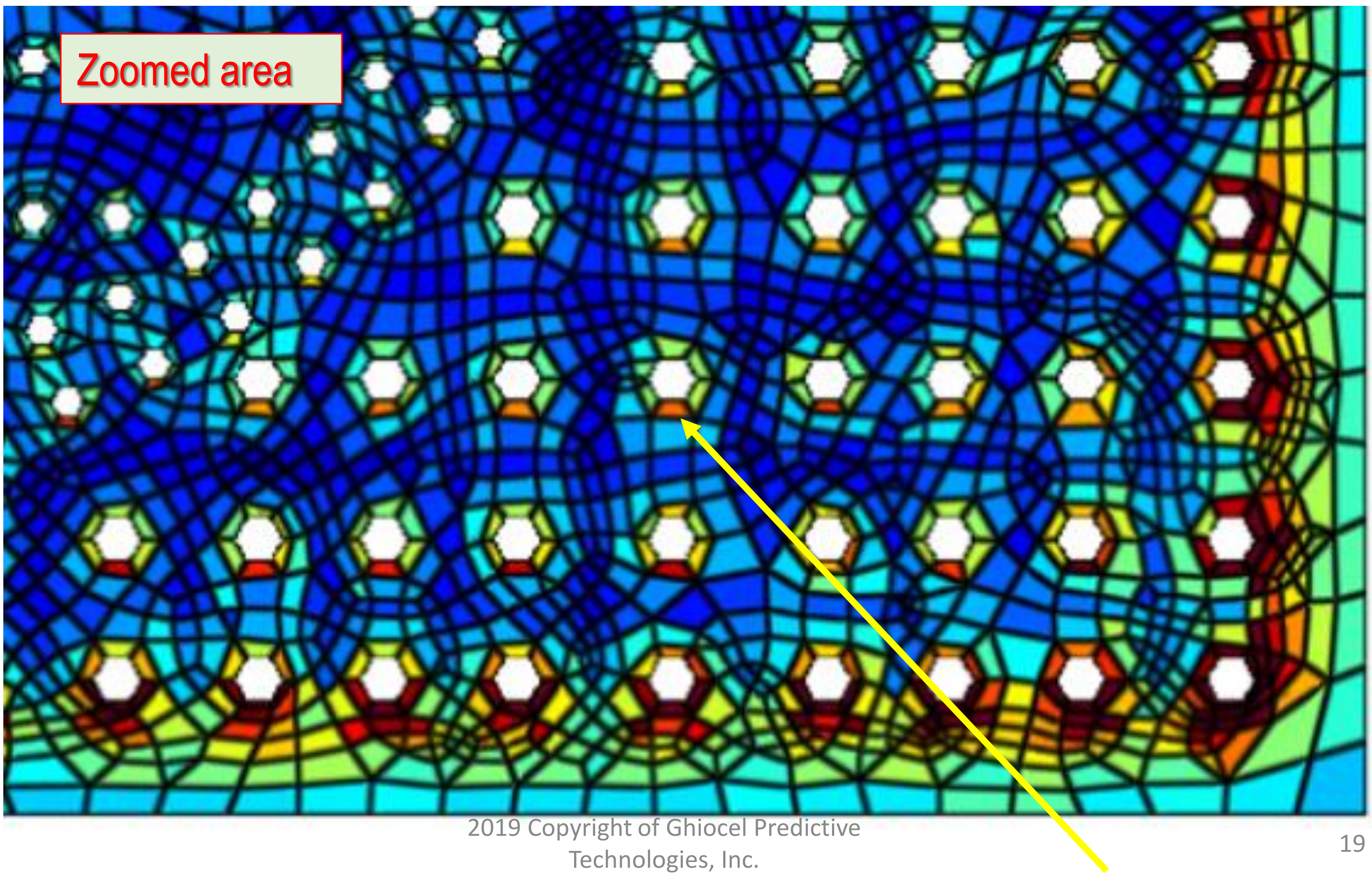
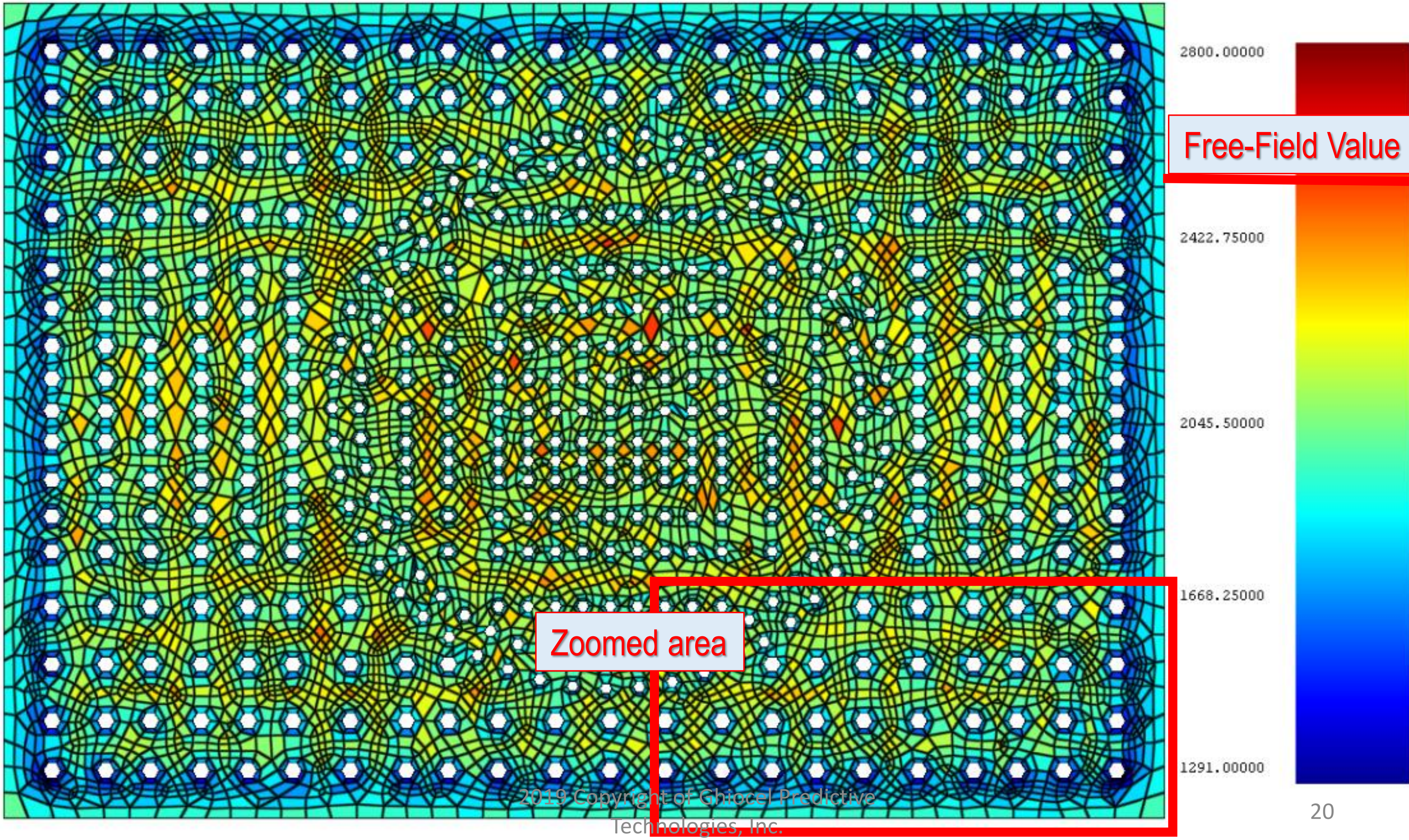


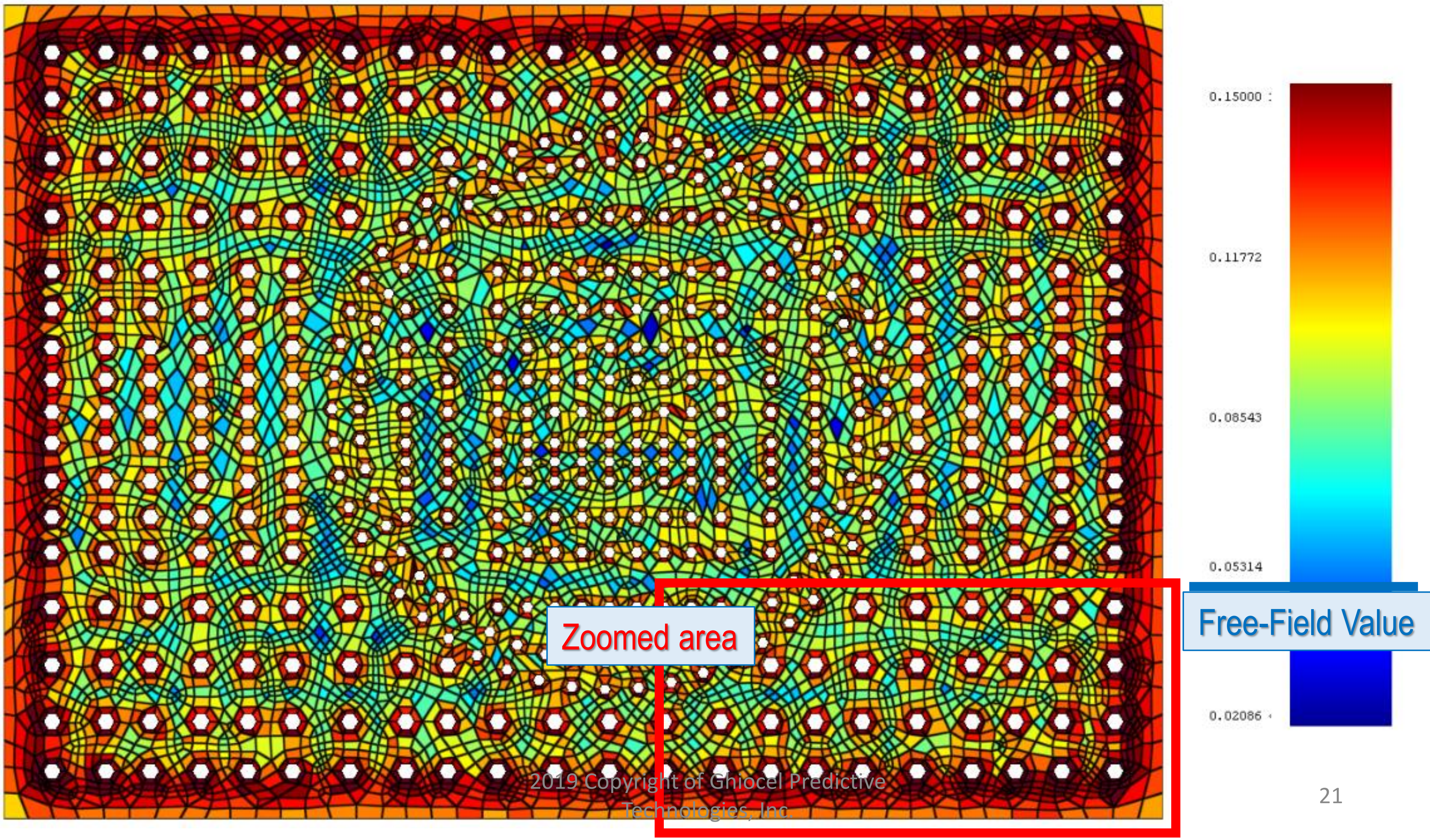
Nonlinear Soil Behavior in Vicinity of Piles

Effective (Iterated SSI) Soil Shear Modulus



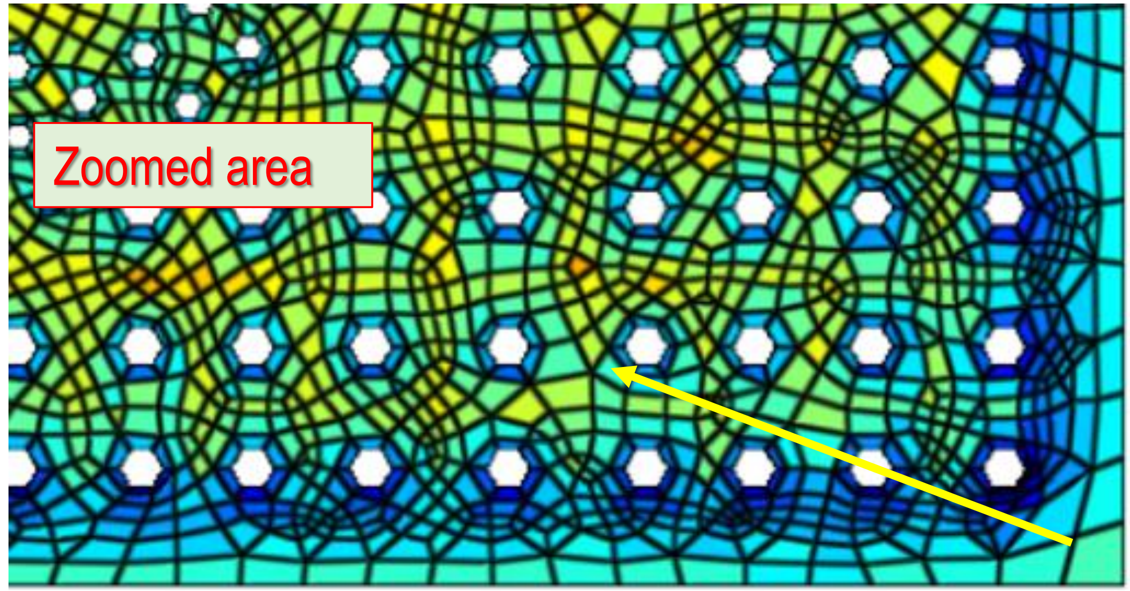
Nonlinear Soil Behavior in Vicinity of Piles

Effective (Iterated SSI) Soil Damping

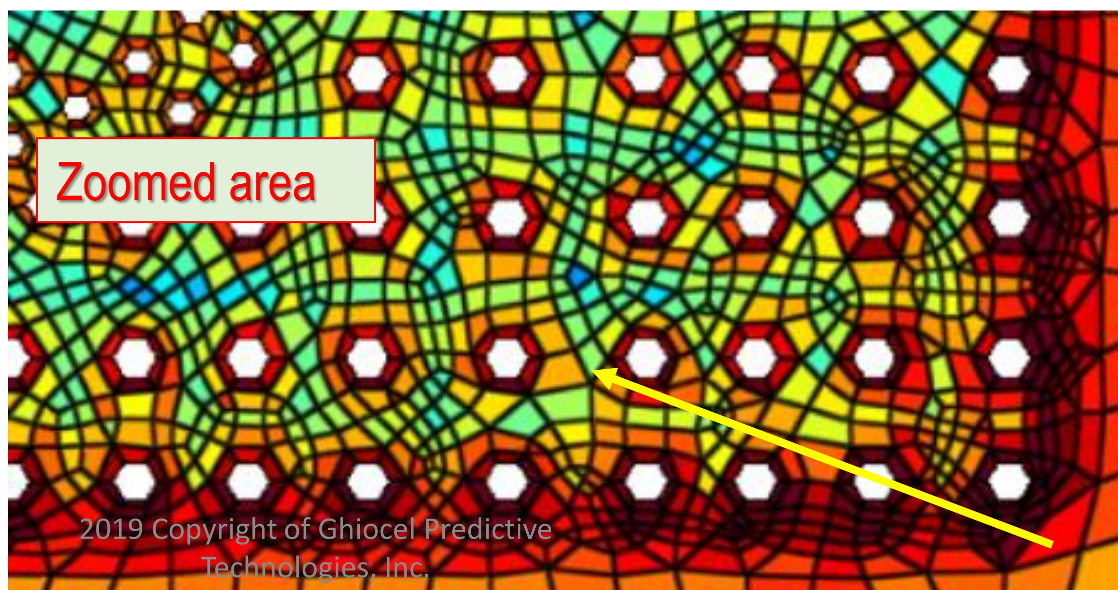


Nonlinear Soil Behavior in Vicinity of Piles

Effective Soil Shear Modulus

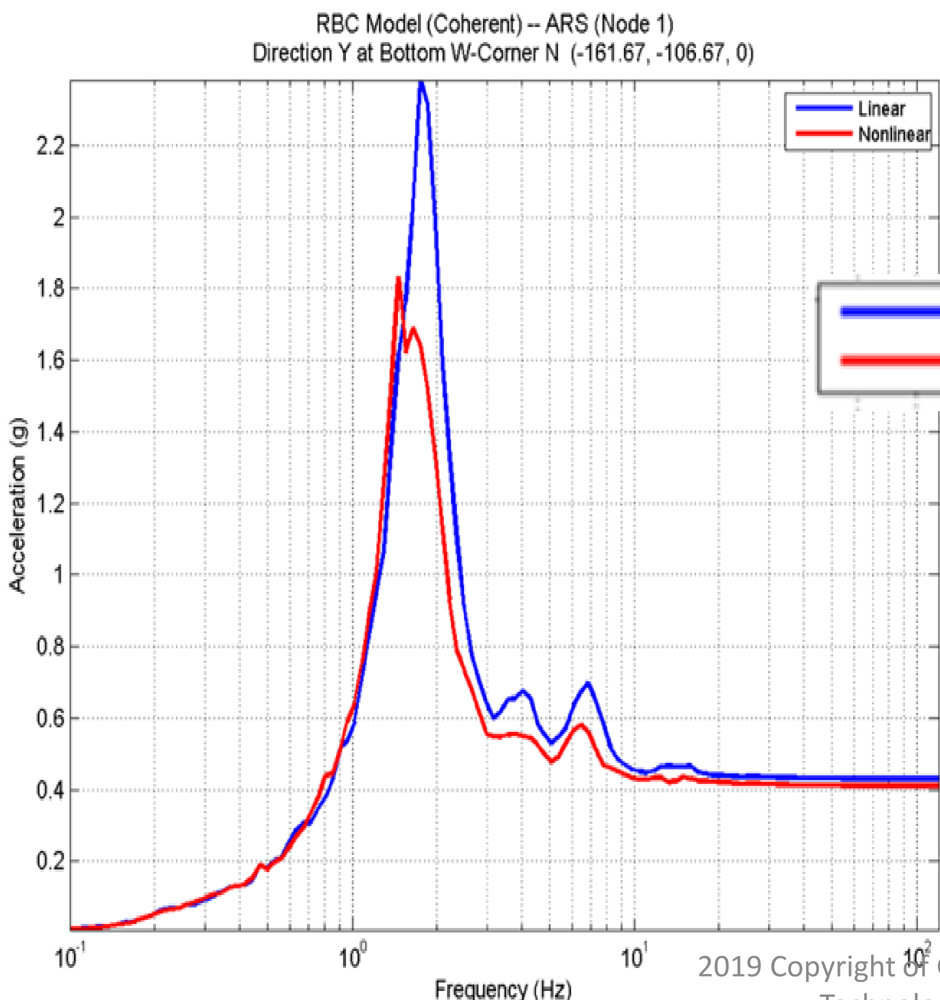


Effective Soil Damping

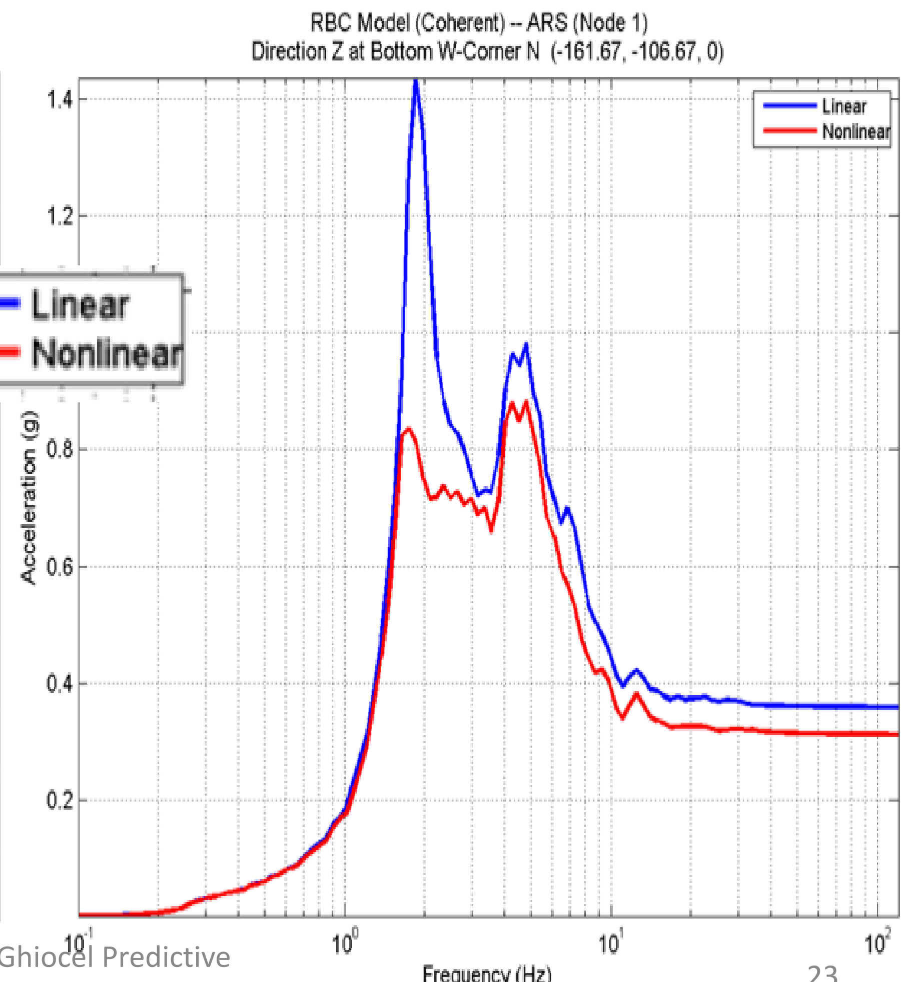


Nonlinear Soil Behavior in Vicinity of Piles. ISRS at Basemat Level

Horizontal

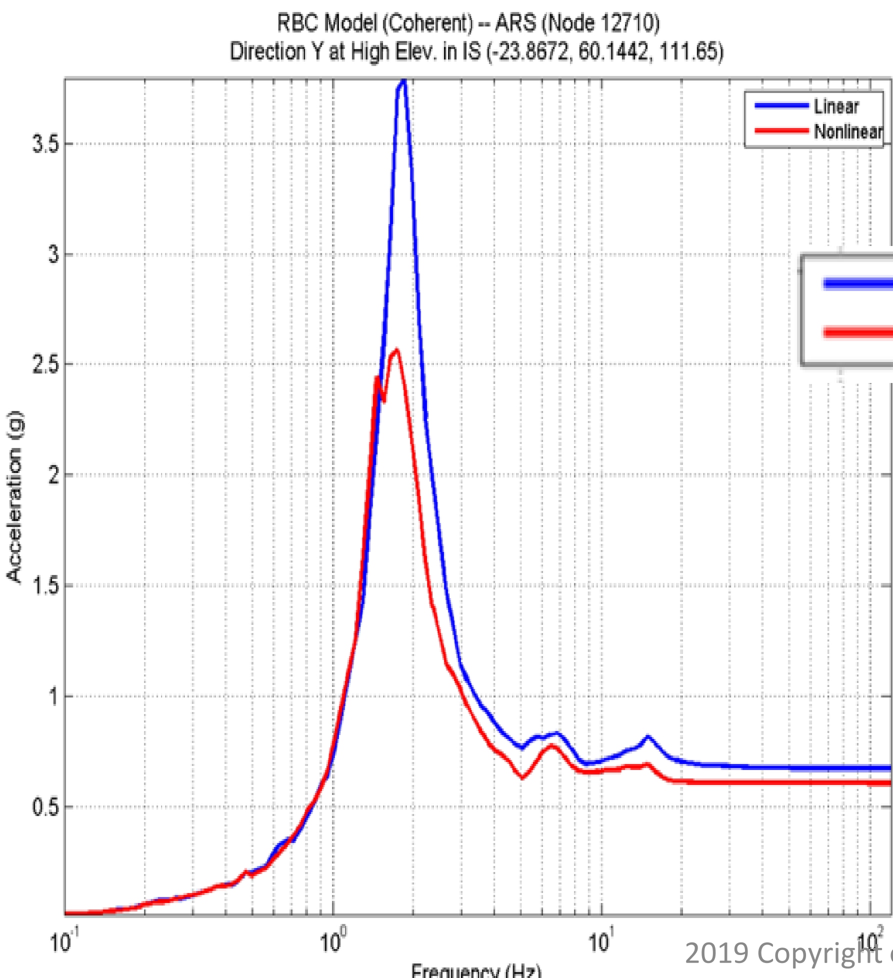


Vertical

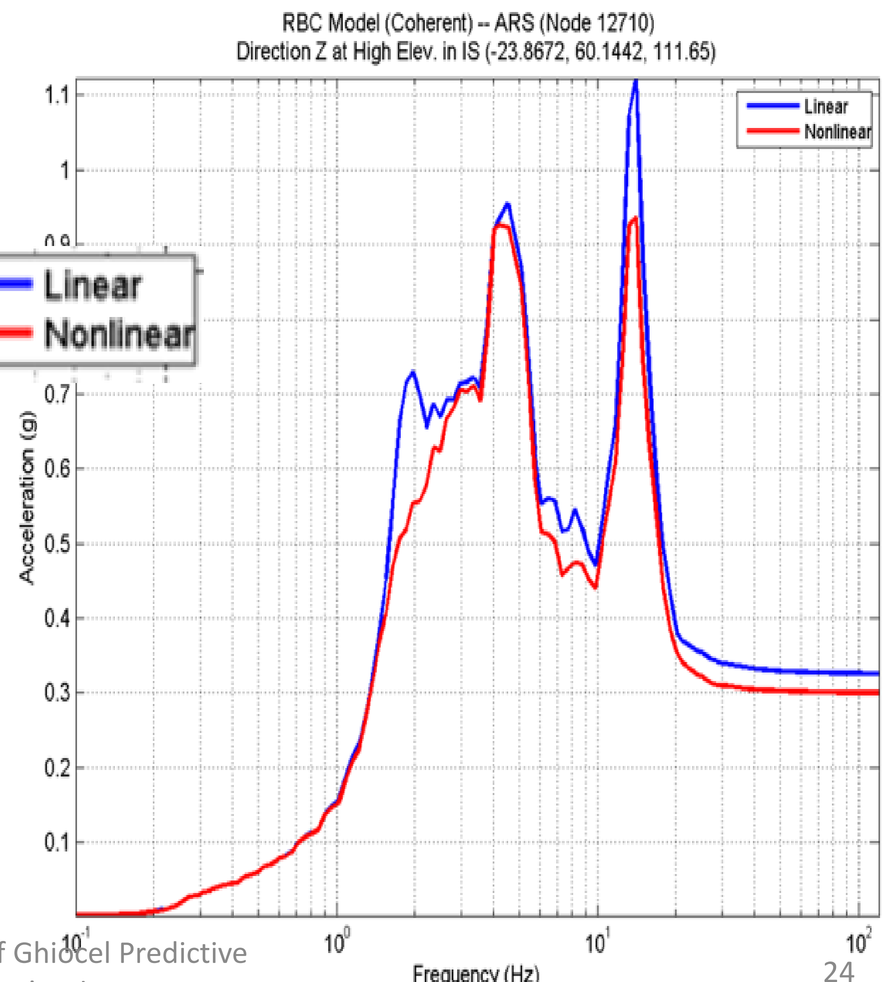


Nonlinear Soil Behavior in Vicinity of Piles. ISRS at Top of IS

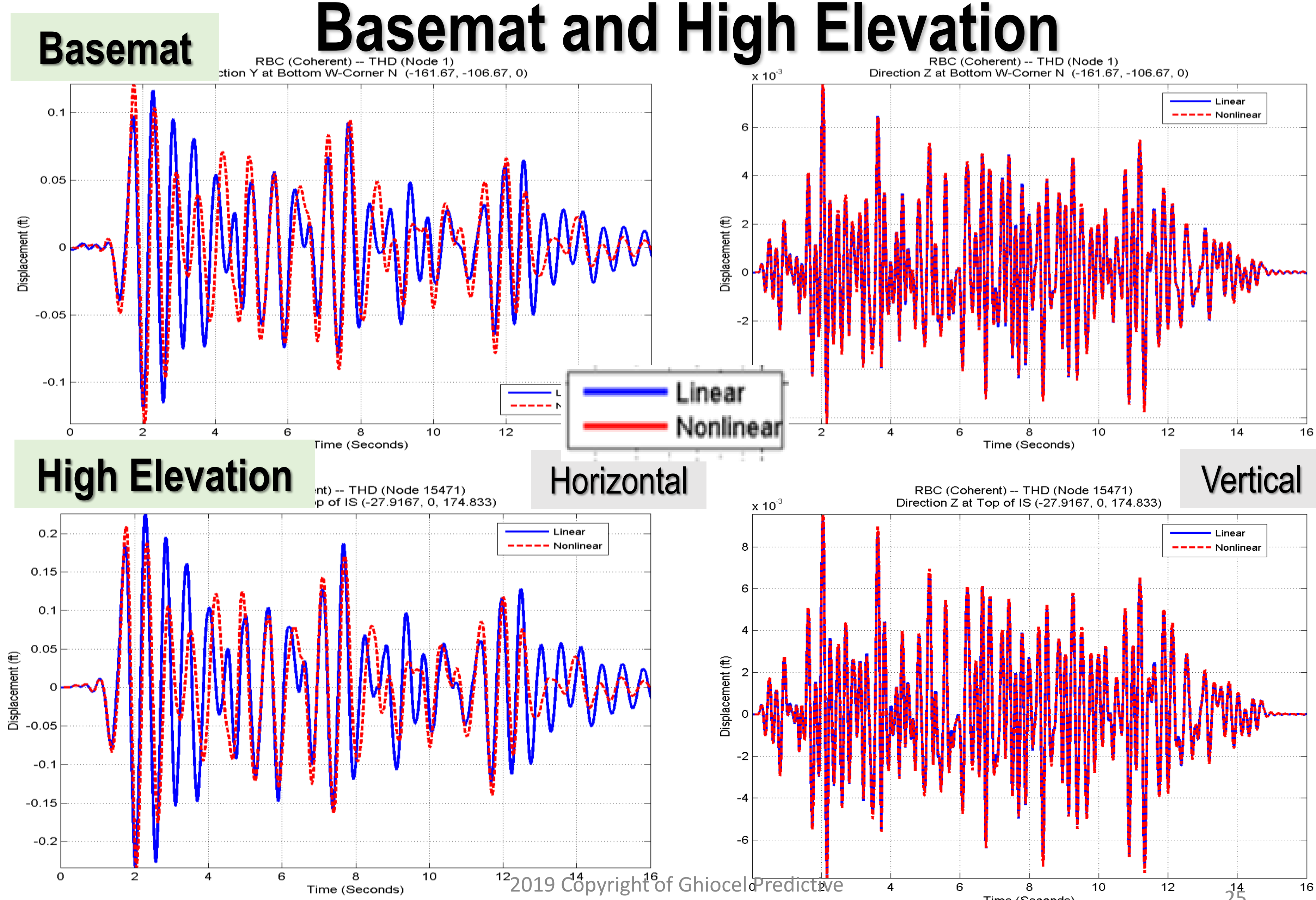
Horizontal



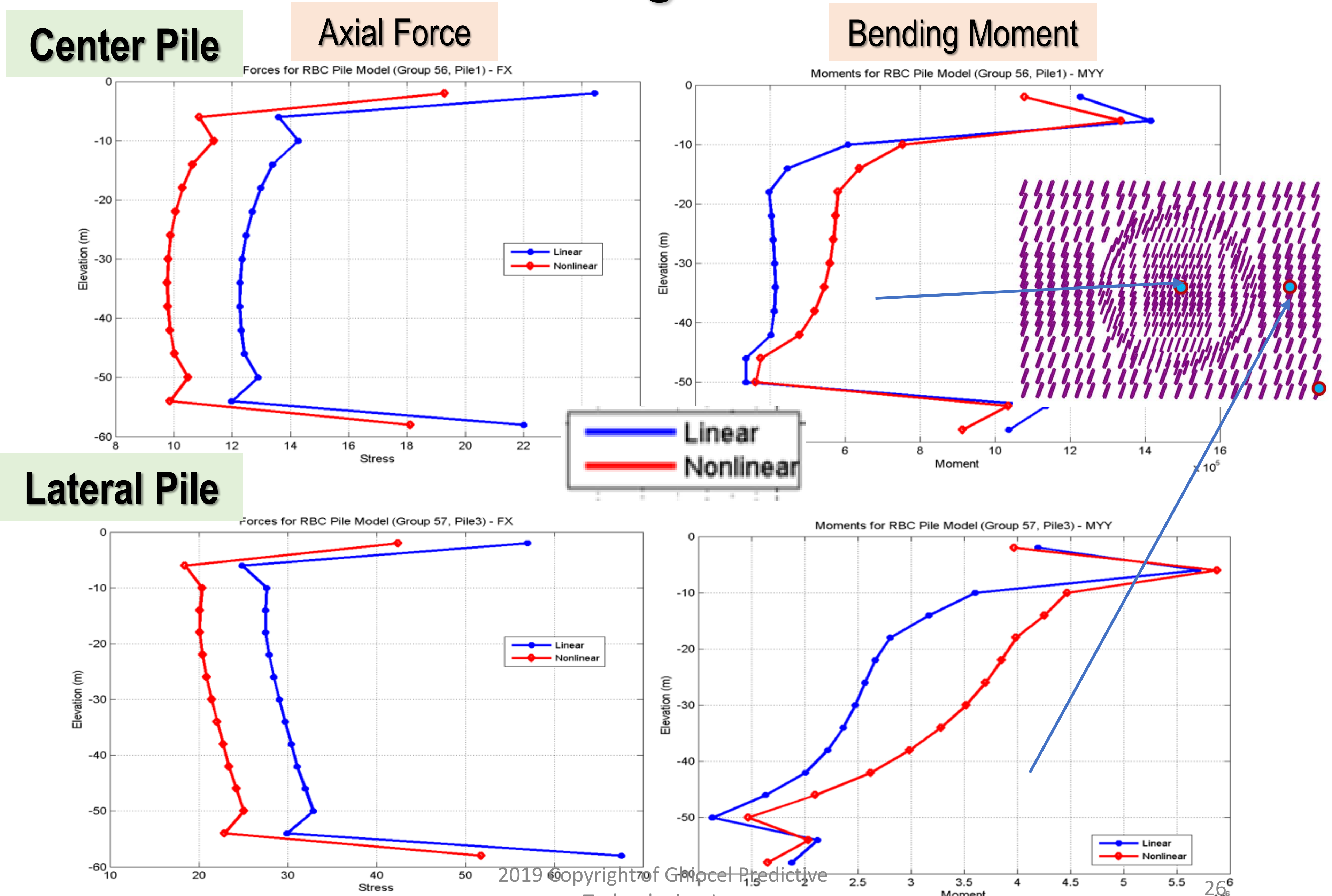
Vertical



Displacements wrt Ground Surface at Basemat and High Elevation



Axial and Bending Moments in Piles



3. Concluding Remarks

- The paper describes an accurate and efficient SSI modelling for the pile foundation.

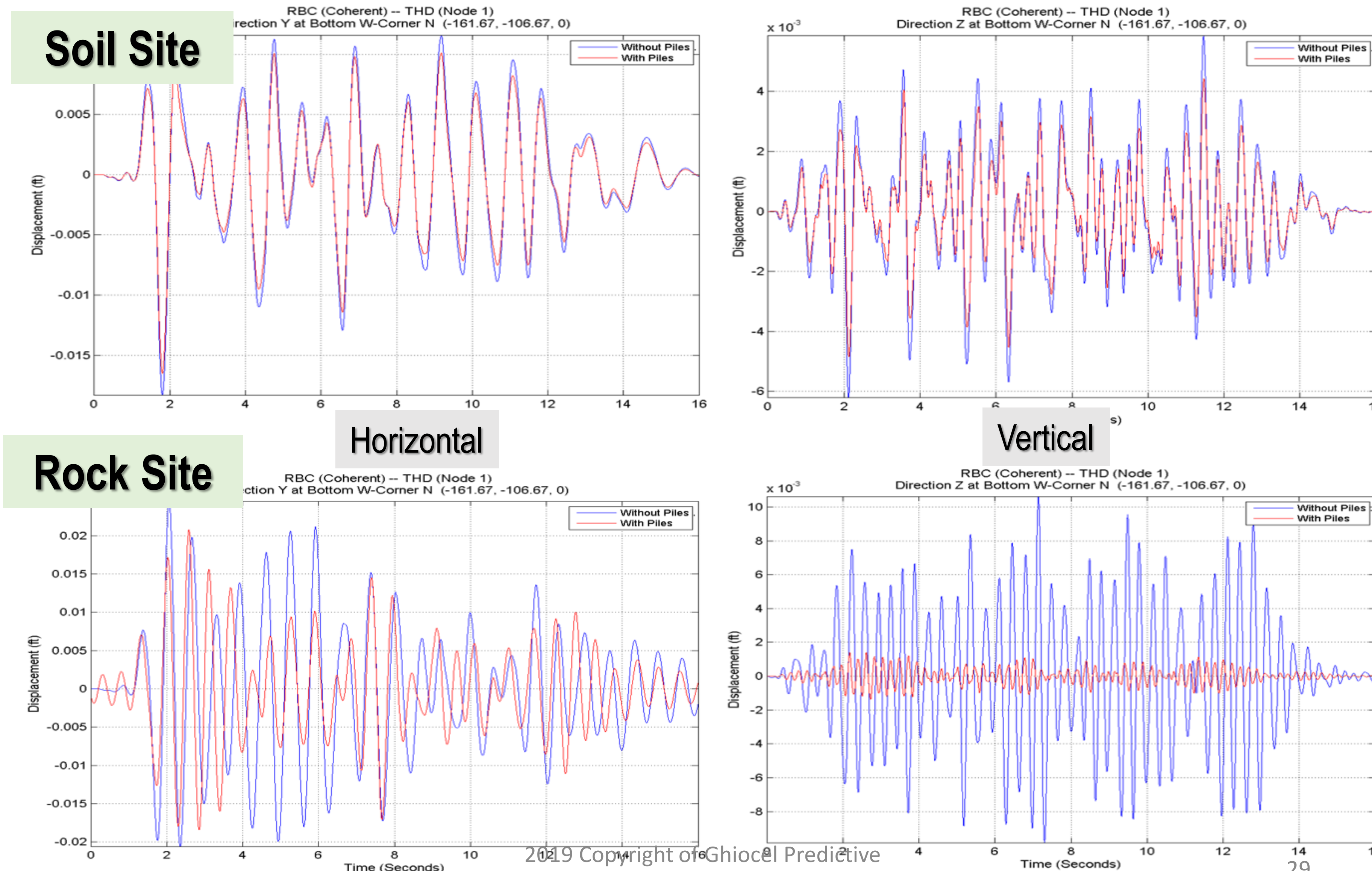
- Computed results show that the pile influence on various SSI responses is weak for the floating piles, and much more significant for the peak-bearing piles.

- Motion incoherency effects are reduced. Incoherency may increase pile axial forces and bending moments in corner piles.

- The nonlinear hysteretic soil behaviour in the vicinity of the piles reduces significantly the ISRS spectral peaks due to the large increase of soil material damping in the vicinity of piles.

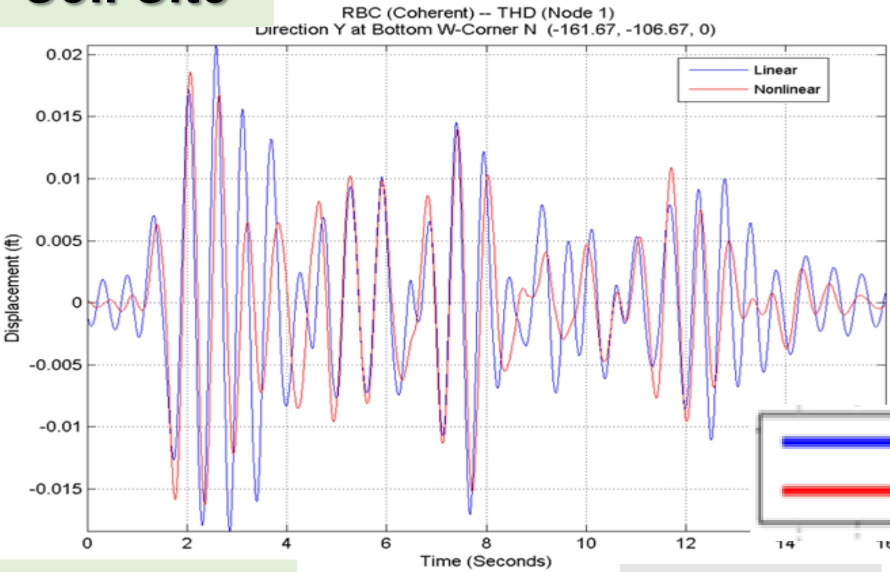
Thank you!

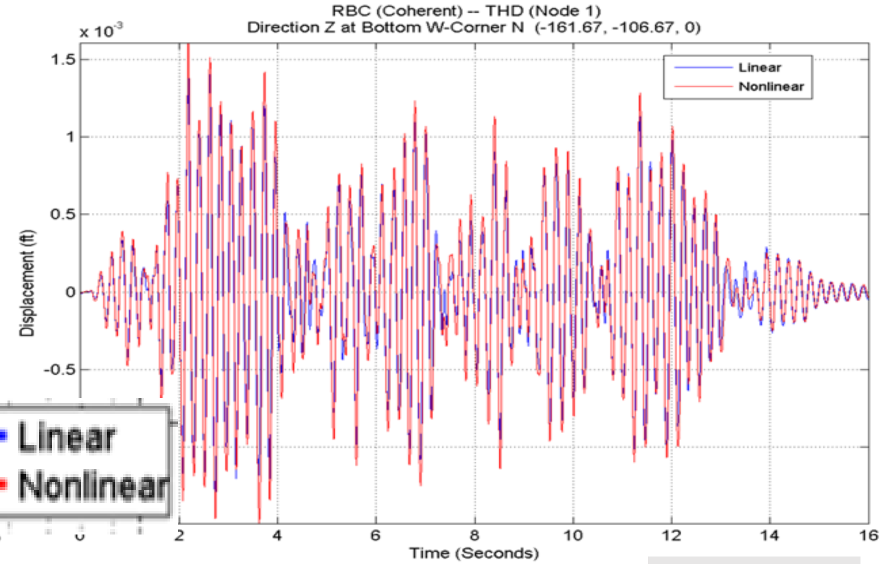
Basemat Corner Relative Displacements wrt Base Center With and Without Piles



Relative Displacements at Basemat Corner

Soil Site





Rock Site

Horizontal

Vertical