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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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

“Improved” SASSI Modeling

Nonlinear soil solid elements

Iterative EQL

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.

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

FVM

Free Field Problem

Structure

Excavated Soil

SSI Problem (Flexible Volume)

MSM

Free Field Problem

Structure

Excavated Soil

SSI Problem (Modified Subtraction)

or ESM or FFV
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

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

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

Soil Site

Rock Site

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High-Elevation IS ISRS With and Without Piles

Soil Site

Horizontal

Vertical

Rock Site
Basemat Corner Relative Displacements wrt Ground Surface With and Without Piles

Soil Site

Rock Site

Horizontal

Vertical

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Axial Forces and Bending Moments in Corner Pile

Soil Site

Axial Force

Bending Moment

Rock Site

Forces for RBC Pile Model (Group 57, Pile4) - FX

Moments for RBC Pile Model (Group 57, Pile4) - MZZ

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Nonlinear Soil Behavior in Vicinity of Piles

Effective (Iterated SSI) Soil Octahedral Shear Strain Under Combined X-Y-Z Seismic Inputs
Nonlinear Soil Behavior in Vicinity of Piles

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

Zoomed area
Nonlinear Soil Behavior in Vicinity of Piles

Effective (Iterated SSI) Soil Shear Modulus

Free-Field Value

Zoomed area
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

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Nonlinear Soil Behavior in Vicinity of Piles.

ISRS at Top of IS

Horizontal

Vertical

RBC Model (Coherent) = ARS (Node 12710)
Direction Y at High Elev. in IS (-23.8672, 60.1442, 111.65)

RBC Model (Coherent) = ARS (Node 12710)
Direction Z at High Elev. in IS (-23.8672, 60.1442, 111.65)

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Displacements wrt Ground Surface at Basemat and High Elevation

**Basemat**

**High Elevation**

**Horizontal**

**Vertical**

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Axial and Bending Moments in Piles

Center Pile

Axial Force

Lateral Pile

Bending Moment

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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

Soil Site

Rock Site

Horizontal

Vertical
Relative Displacements at Basemat Corner

Soil Site

Rock Site

Horizontal

Vertical

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