Impedance Issues in SSI of Embedded and Deeply Embedded Structures

DOE Natural Phenomena Hazards Meeting
October 19, 2016

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Outline

- Impedance of deeply embedded structures
- Soil box impedance
- Effect of varying wave fields

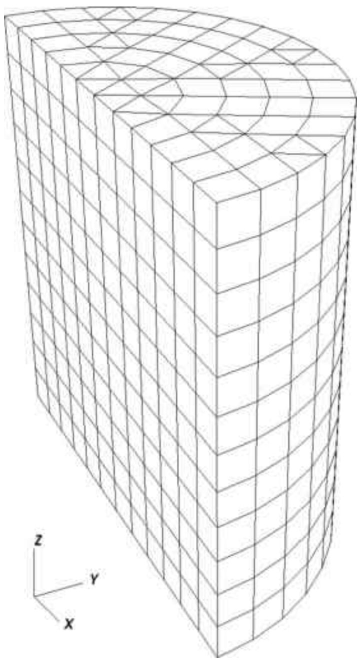
Note:

- This talk represents a snapshot of work in progress.
- Mixed results:
  - Some good
  - Some less than acceptable
- Sharing is encouraged

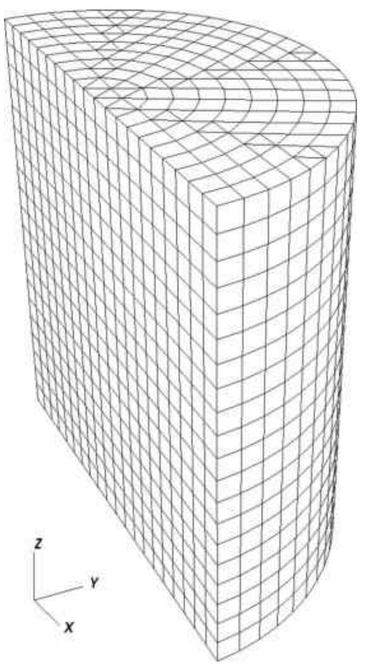
Embedded Cylinder Impedance

- Rigid massless cylinder
- Embedment=2•radius
- Symmetry
- Direct solution
- Different meshes

$$f \leq \frac{Vs}{6h}$$

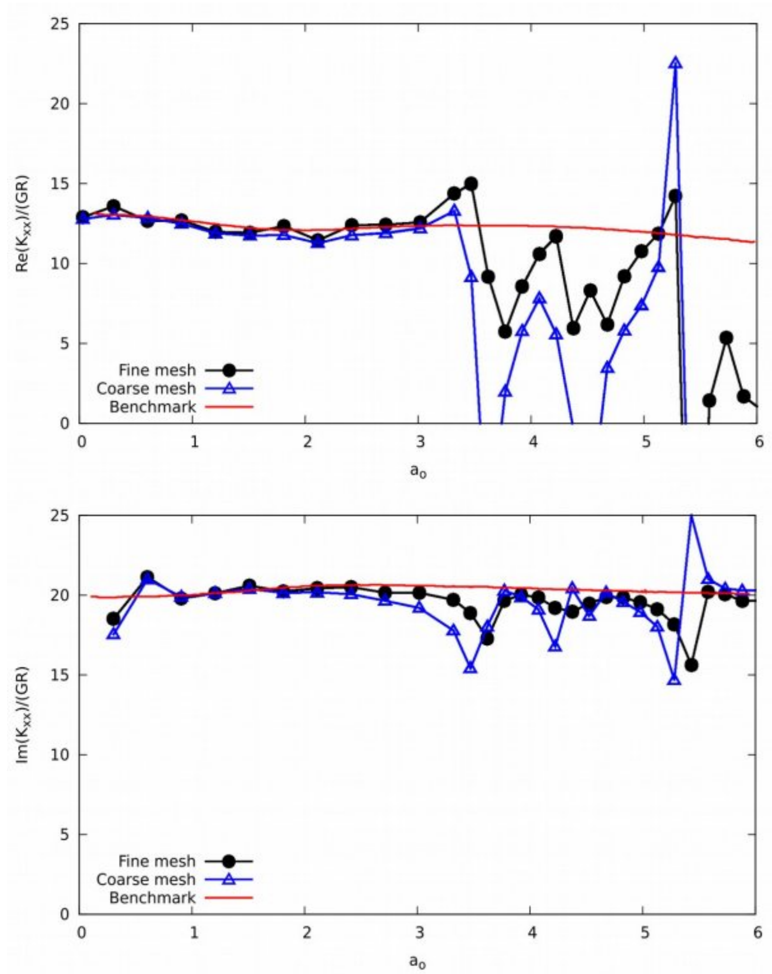


$$f \leq \frac{Vs}{10h}$$



Horizontal Impedance

- Poor comparison for $a_o>3$
- Minor improvement with mesh refinement
- At $a_o=3$, the fine mesh has Vs/21h
- Something besides mesh issues are perturbing the solution



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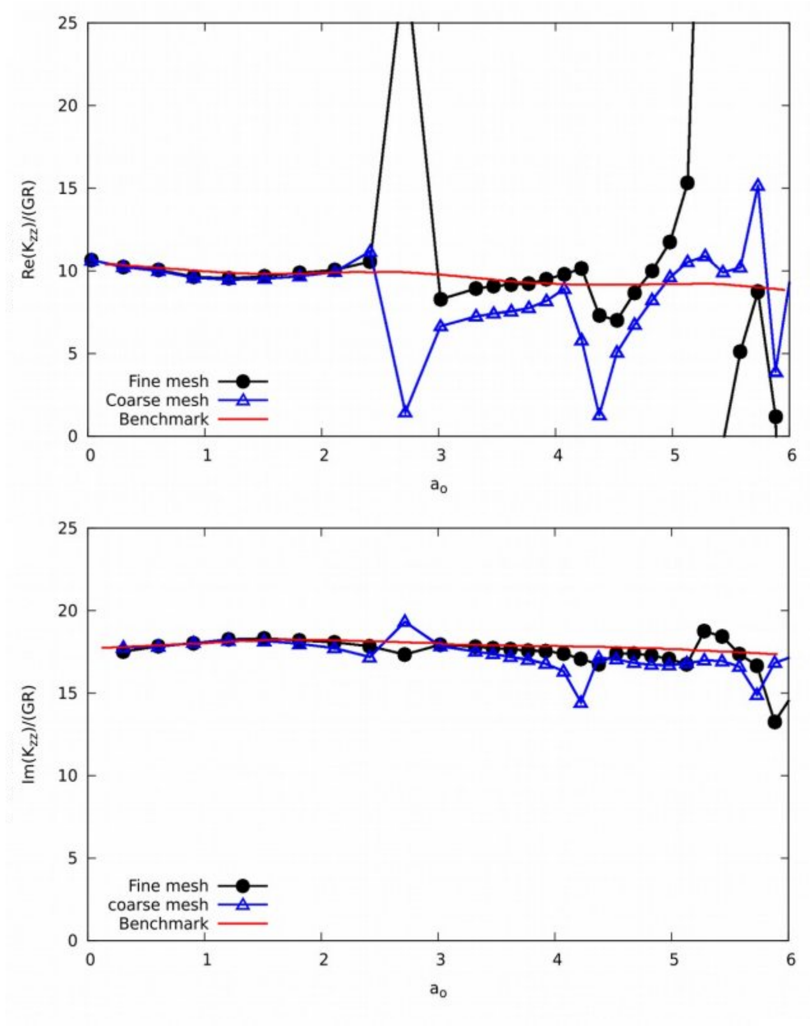
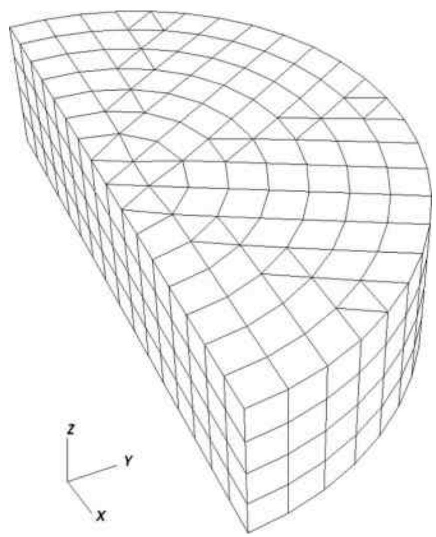
Vertical Impedance

- Poor comparison for a_o>2.5
- Minor improvement with mesh refinement
- Something besides mesh issues are perturbing the solution



Embedded Cylinder Impedance

- Same problem, with an embedment of 0.5•radius
- Vs/6h model



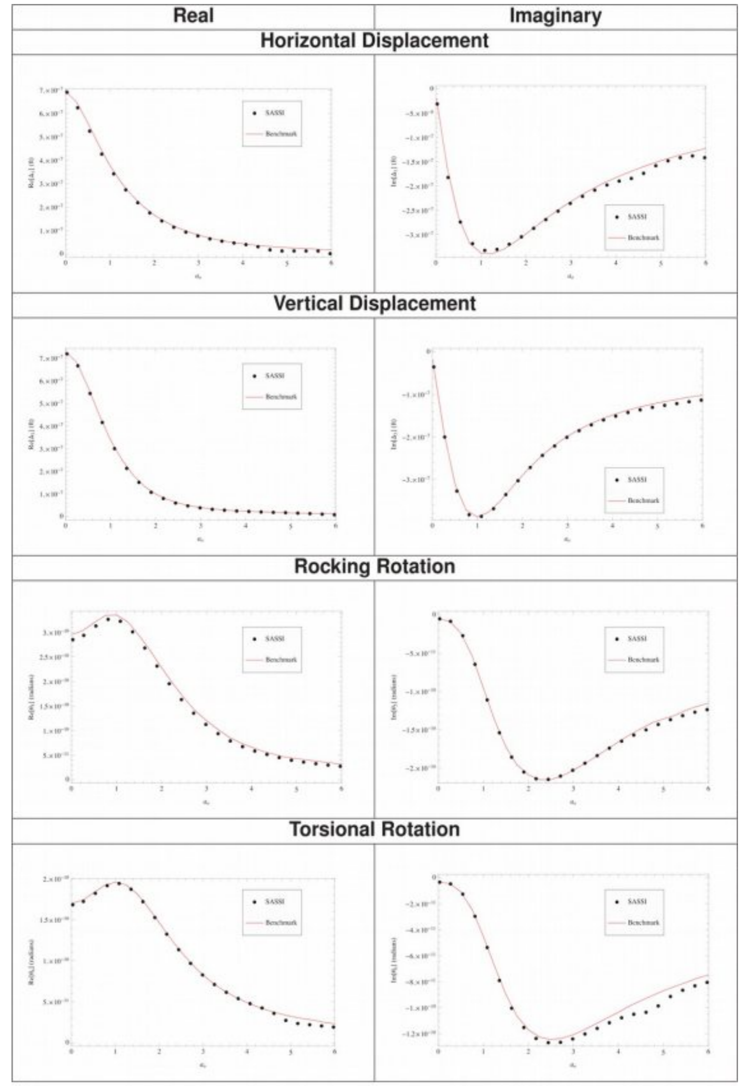


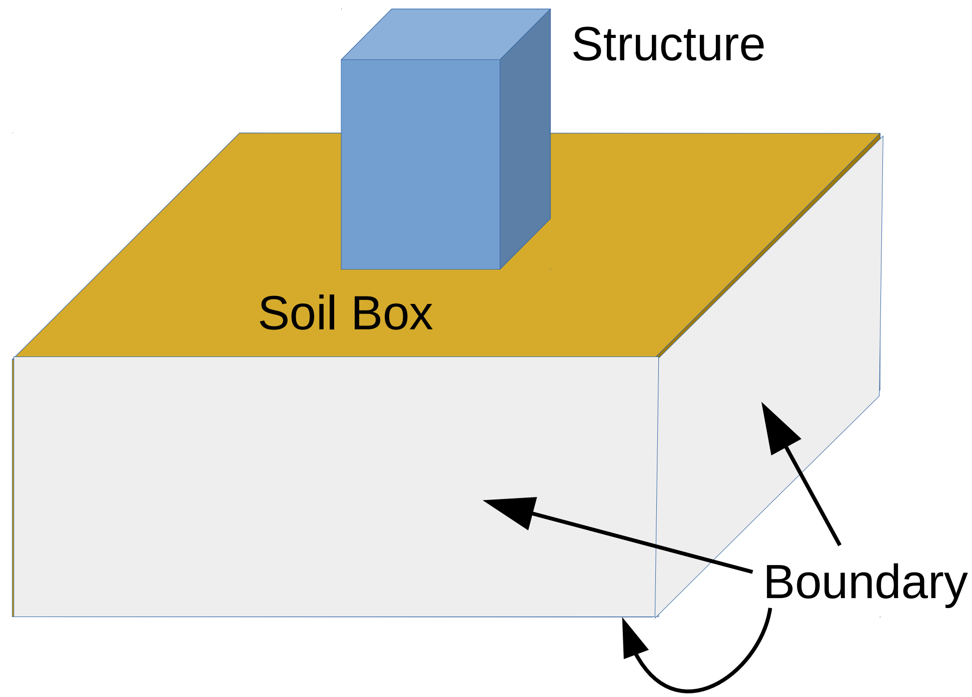
Figure 8.7: *Comparison of Displacements for Problem* $2a$

Summary of Deeply Embedded Structures

- SASSI V&V project considered embedment depths up to 50% of the effective radius
- Preliminary results for deeper embedment are unsatisfactory
  - Additional work is required to understand existing results and path forward
- Engineers are cautioned to ensure that their V&V fully encompasses the full range of parameters being evaluated

Soil Box Impedance

- Considering implementing time domain SSI
  - Can we implement, execute and defend analyses?
- Proposed models
  - Structure
  - Boundary
  - Soil box



Soil Box Impedance

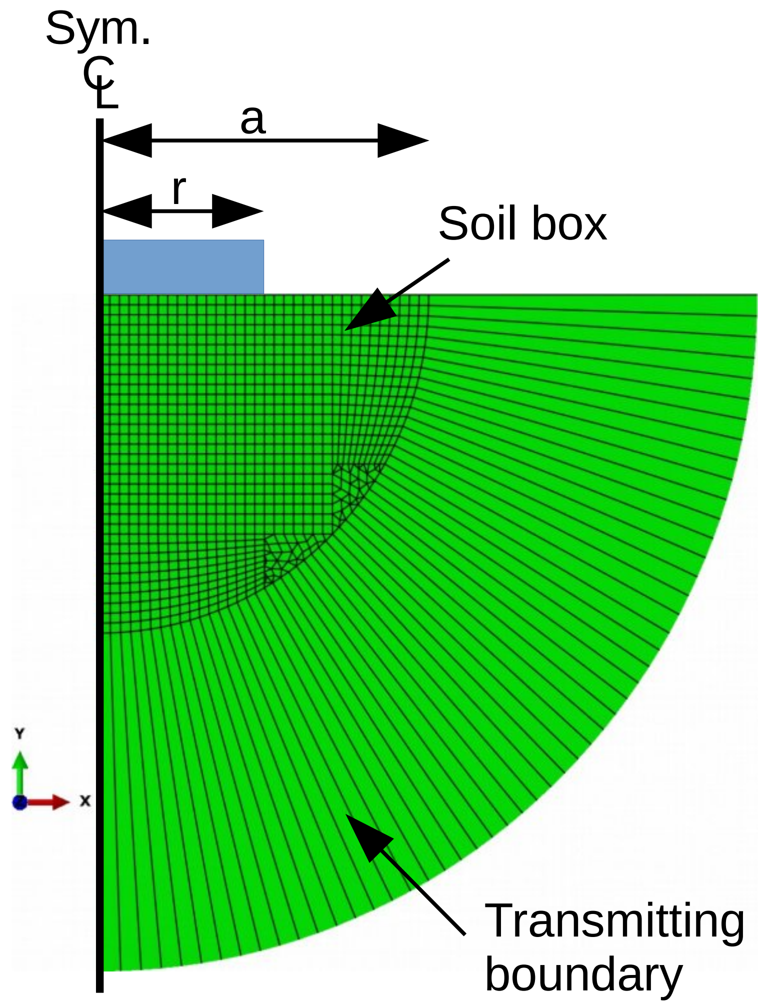
- Linear frequency domain SSI experience
  - Extensive V&V of soil impedance
    - What works
    - What doesn't work
- How does the time domain soil impedance compare with frequency domain benchmarks?

Impedance Comparison Methodology

- Focus on boundaries and soil box size
  - Omit nonlinear soil models
- Use common damping formulation
  - Abaqus viscoelastic soil model can be equal to SASSI complex soil damping
- Limited to lumped mass matrix
- Initial comparisons in frequency domain
  - Abaqus steady state dynamics with direct option yields complex stiffness and displacement
  - Use transmitting boundary (infinite elements) to calibrate soil box size
  - Rerun with alternate boundaries
- Time domain comparison
  - Abaqus explicit

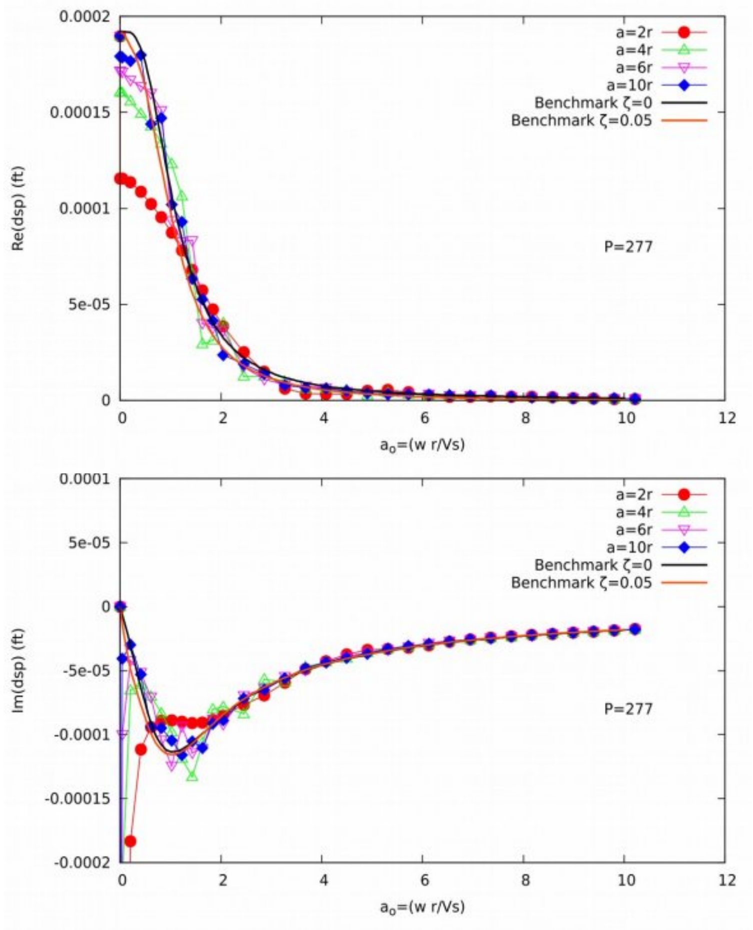
Axisymmetric Modeling

- Exploratory
  - Quick runs
- Frequency domain
- Calibrate damping
- Transmitting boundary
  - Limited to symmetric load
  - Asymmetric infinite boundary would be helpful
- SASSI V&V Task 6 Problem 5
  - Model parameters
    - r= foundation radius
    - a= soil box radius



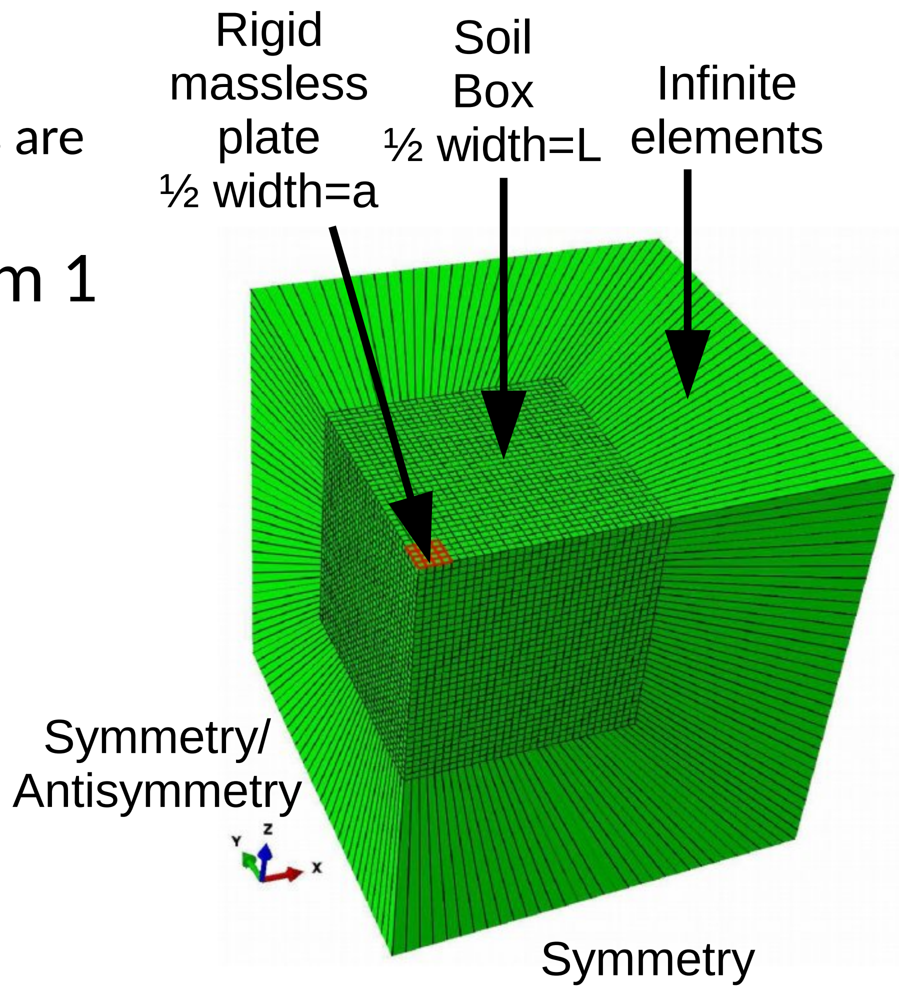
Axisymmetric Modeling

- High frequency behavior is good
  - Mesh ≈Vs/(10f_{max})
  - Initial mesh was problematic
- Low frequency behavior is problematic
  - Wavelength, λ ≈ 0.9Vs/f ≈ 5.6r/a_o
    - a=2r → λ=a at a_o=2.8
    - A=6r → λ=a at a_o=0.9
  - Response degrades when soil box radius, a ≤ λ
    - Mesh with infinite elements
    - Preliminary results



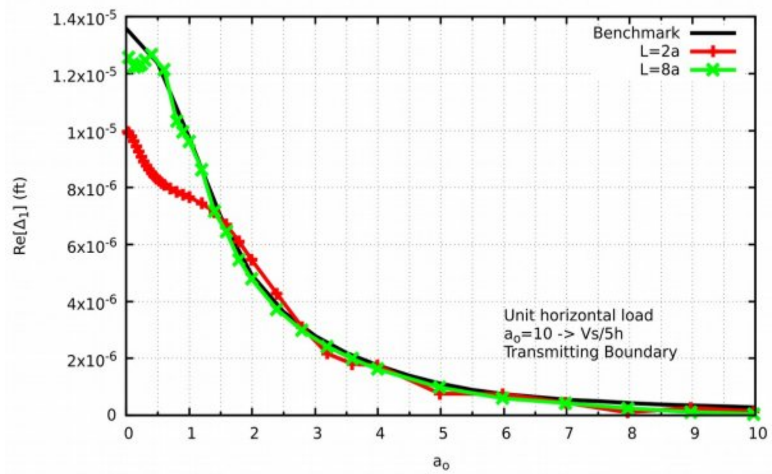
3D Modeling

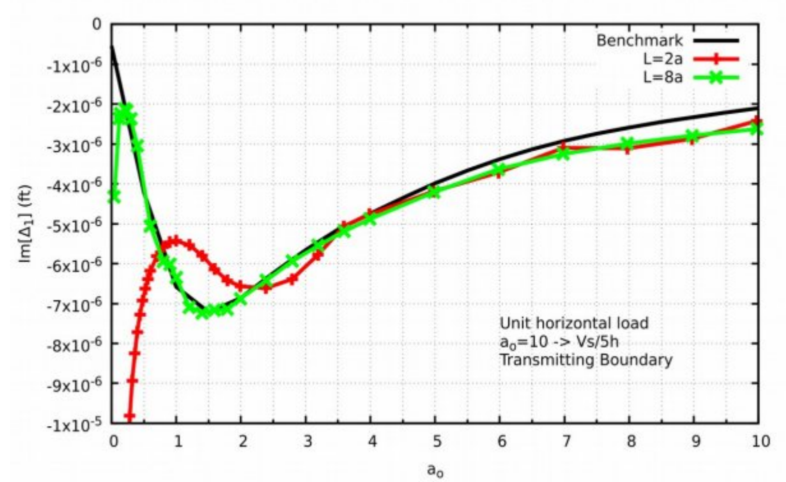
- Quarter symmetry
  - Some frequency domain runs are slow
- SASSI V&V Task 8 Problem 1
  - Square rigid massless surface plate, half-width=a
  - Uniform half-space
- Cases:
  - Infinite boundary
  - Side constraint plus infinite boundary on base only



3D Modeling – Frequency Domain

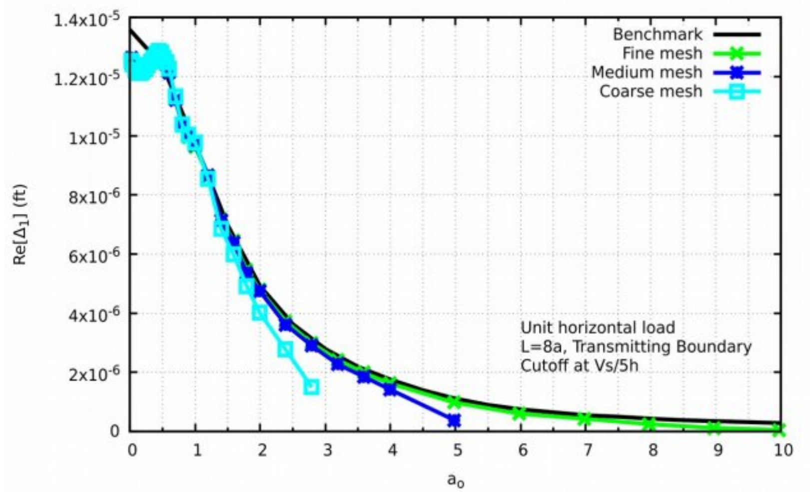
- Horizontal unit load
- Investigate soil box size
  - Low frequency problems similar to axisymmetric case
  - Response degrades when soil box width, L ≤ λ
    - L=2a → λ=L at a_o=2.8
    - L=8a → λ=L at a_o=0.7

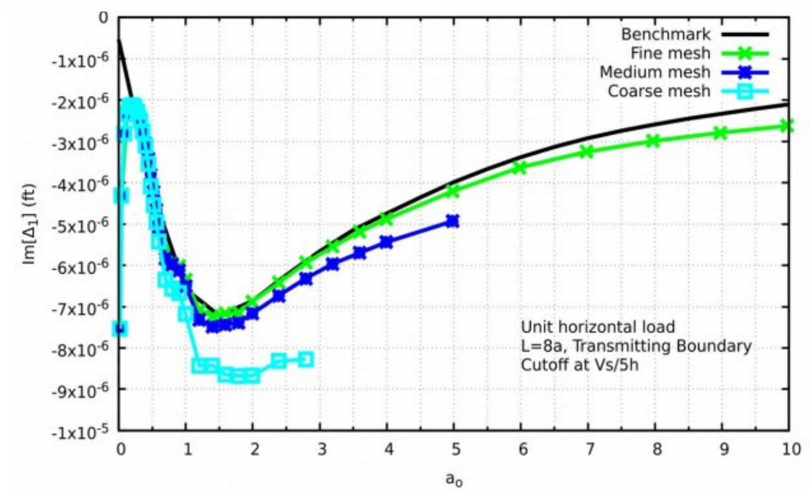




3D Modeling – Frequency Domain

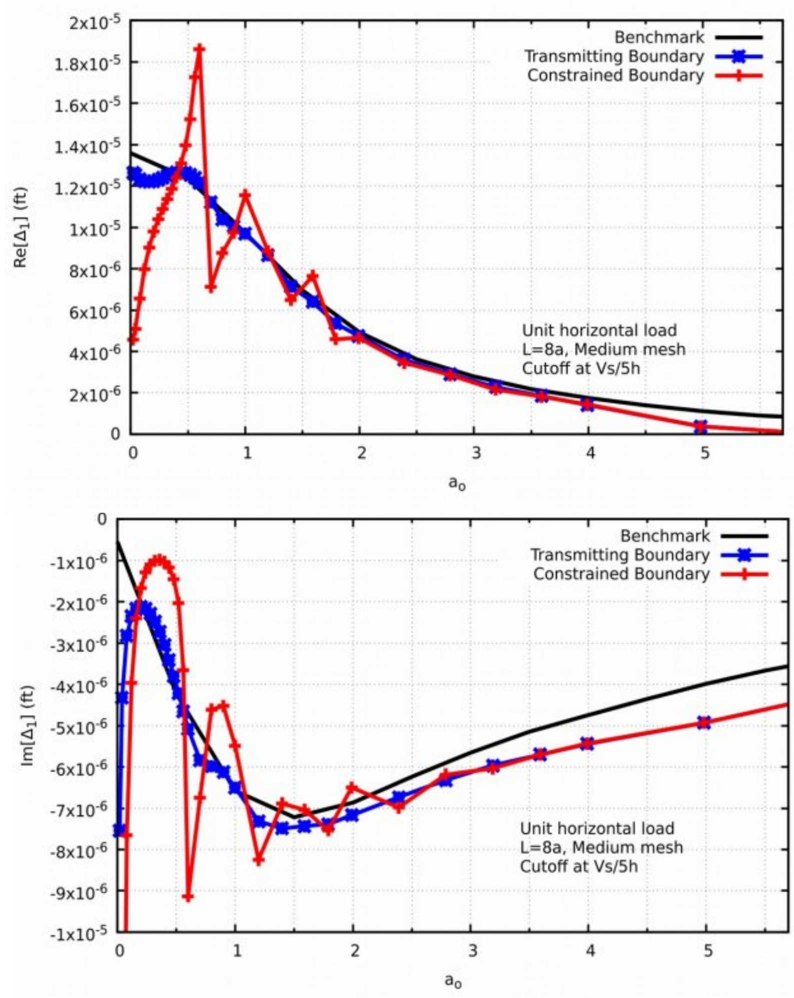
- Horizontal unit load
- Compare soil box mesh density
  - L=8a for all meshes
  - Each mesh meets λ/5
  - Response degrades at frequencies > λ/10
  - Note: Response is based on lumped mass matrix





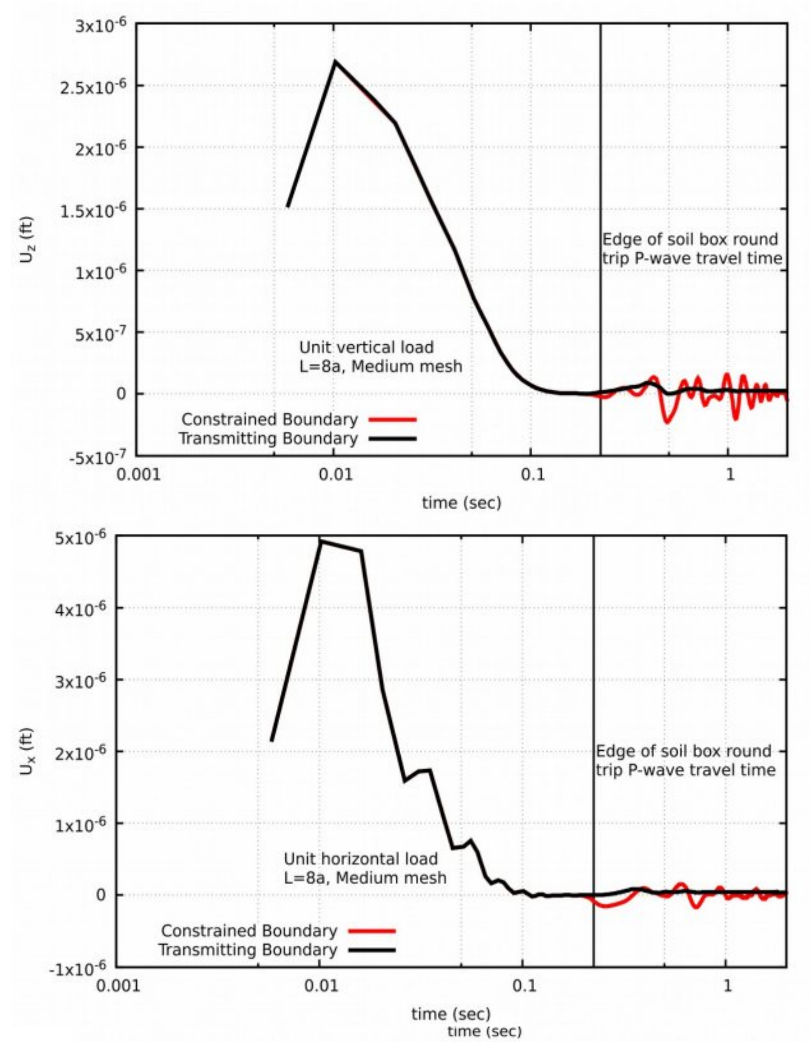
3D Modeling – Frequency Domain

- Horizontal unit load
- Compare transmitting and restrained boundaries
  - L=8a
  - Each mesh meets λ/5
  - Restrained boundary has spurious response due to reflected energy



Time Domain Response

- Abaqus explicit
- Response to unit impulse
- Significant reflections in constrained boundary solution
- To do…
  - Refine data extraction
  - Understand high frequency noise in horizontal response
  - Extract frequency domain displacement TF and compare to benchmark



Summary of Soil Box Impedance Study

- Preliminary results
  - Work in progress
- Abaqus transmitting boundary
  - Good comparisons with benchmark
  - 6-node wedge would be very use full
- Side constraint plus infinite boundary on base only
  - Reflections from side constraint corrupt solution at L=8a
- Mesh requirements
  - High frequency: element size < Vs/10h
  - Low frequency: soil box size > λ
- Overall, promising results
  - Additional work needed before implementation on a safety basis project

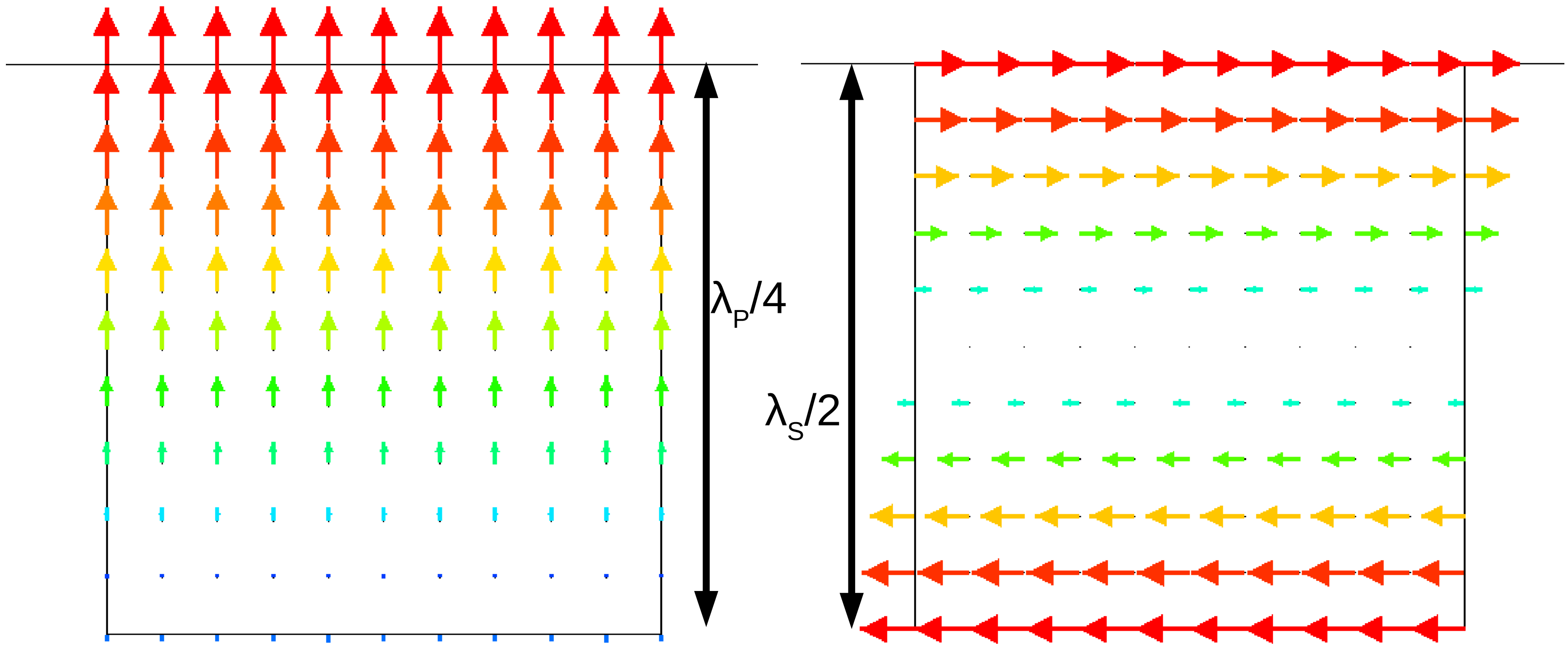
Effect of Varying Wave Fields on SSI Loads

- Current practice
  - Analyze vertically propagating P and S-waves
    - Maximize response in a surface or shallowly embedded structure
  - Magnitude anchored to input spectra at some elevation
- Actual wave field
  - Combined body and surface waves
    - P-wave, S-wave
    - Rayleigh wave, Love wave
- Potential issues
  - Are P and S wave fields realistic for both shallow and deeply embedded structures?
  - How do we evaluate alternate wave fields?
  - Does the actual wave field impact response?

P and S Wave Fields

Vp≈2000 fps
λ_P=400 ft @ 5hz

Vs=1000 fps
λ_S=200 ft @ 5hz

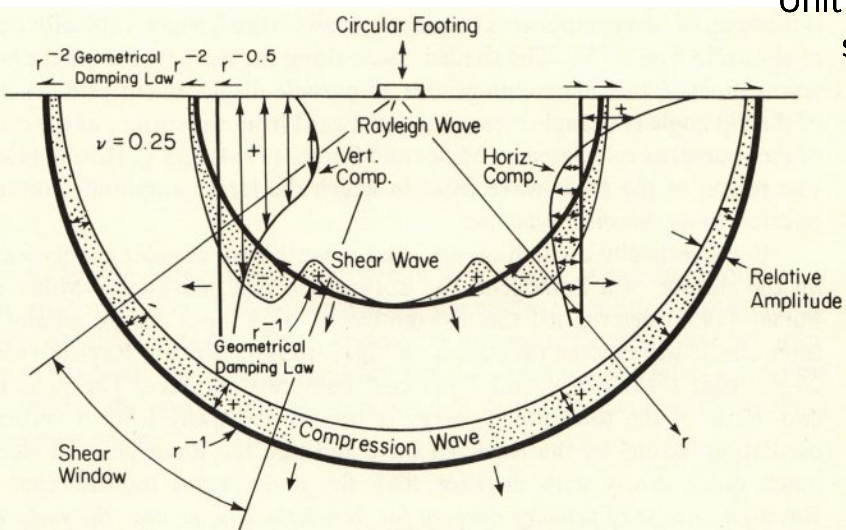


- Embedment, e=100', Radius, r=50', e/r=2
- Control point at surface
- Seismic input averaged over the depth of embedment is much less than a surface foundation.

Evaluation of Alternate Wave Field

- Wave field generation
  - Active R&D
  - Current study uses PUNCH to generate plane strain waves
- Analysis
  - Seismic load vector F=K Δ
  - Use PUNCH to develop free field displacement, Δ
  - Use SASSI for soil impedance, K
  - Import frequency dependent load vector into SASSI
  - Solve using traditional frequency domain approach

Wave field generation

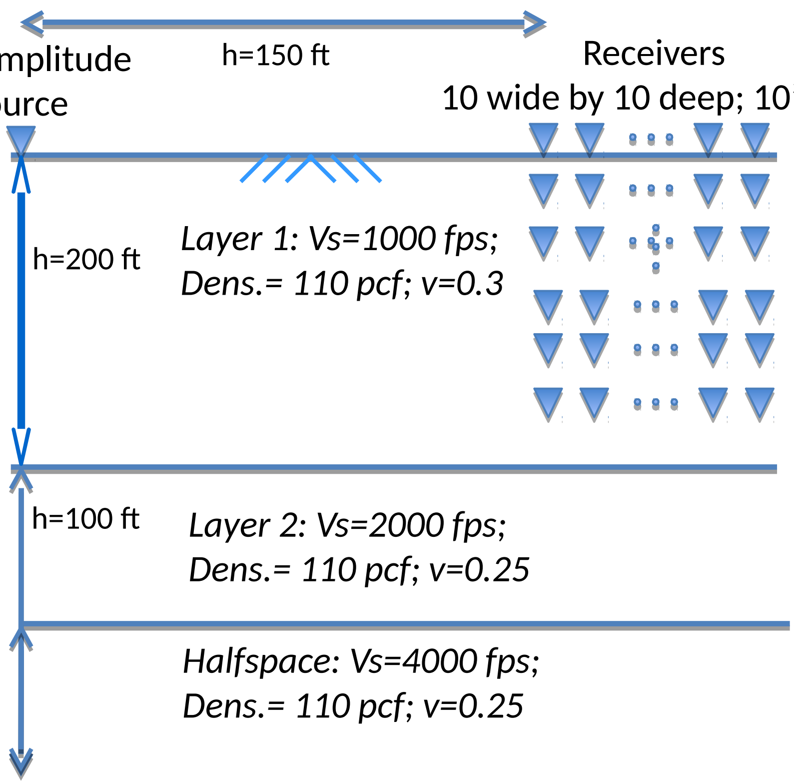


(a)

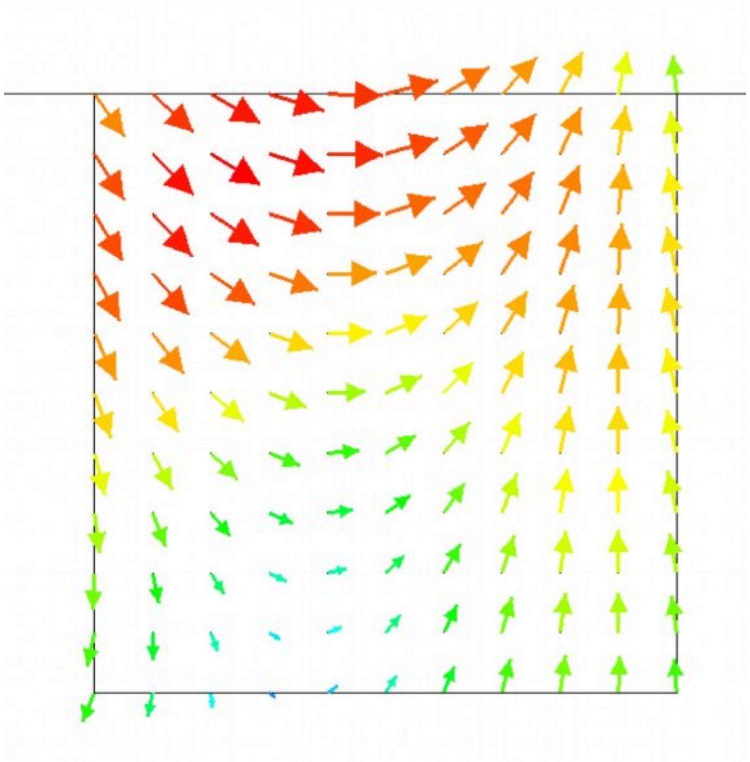
Wave Type	Per Cent of Total Energy
Rayleigh	67
Shear	26
Compression	7

(b)

Figure 3-16. Distribution of displacement waves from a circular footing on a homogeneous, isotropic, elastic half-space (*from Woods, 1968*).

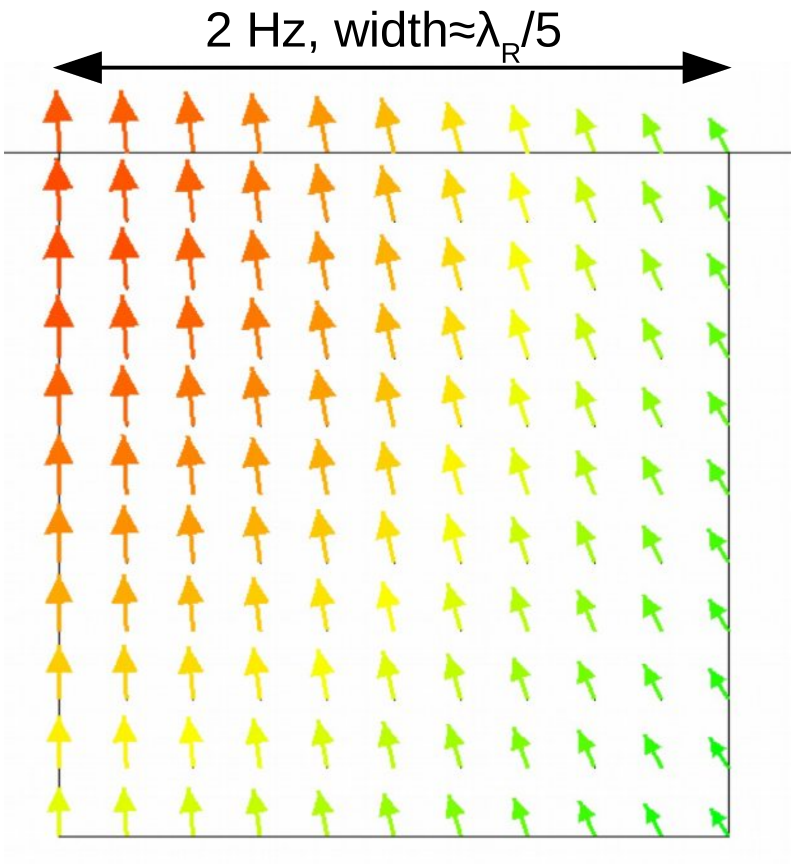


5 Hz Wave From Vertical Surface Input

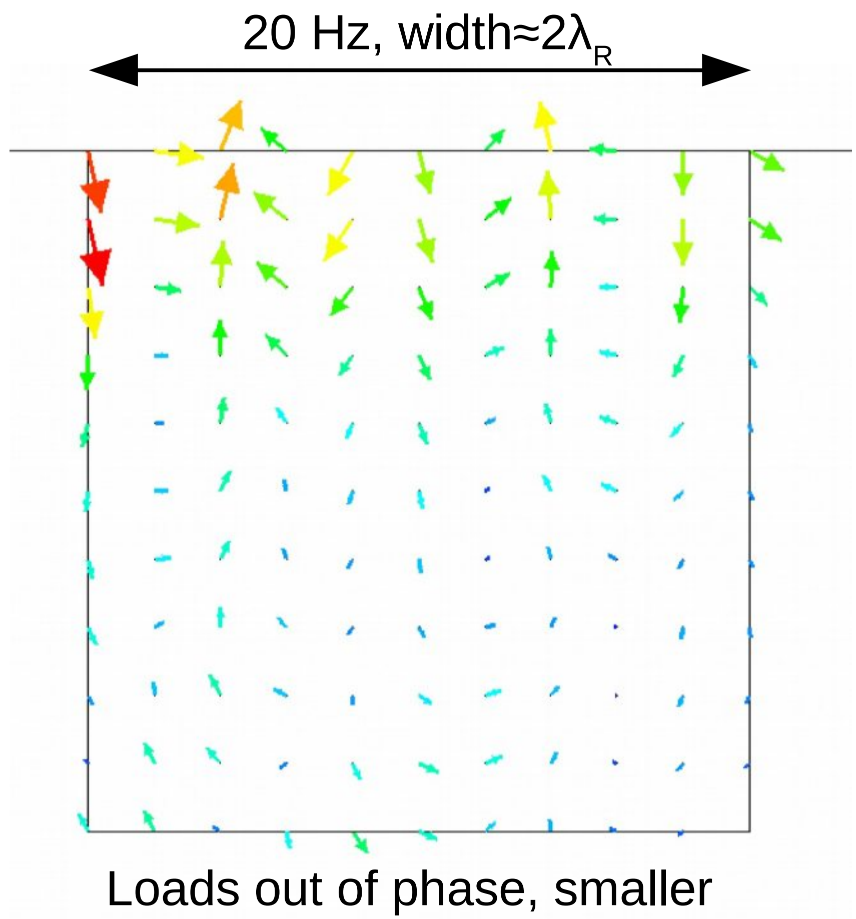


- Primarily Rayleigh wave
  - $\lambda_R \approx 180'$
  - $\lambda_R/2 \approx$ building width
  - Input is down on left size, up on right side with coupled translation
  - Direction and amplitude of input changes with phase angle

2 and 20 Hz Excitation



Loads in phase, greater total load than traditional analysis assumptions



Loads out of phase, smaller total load than traditional analysis assumptions

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Out of phase loading can have a significant impact on structural response.

Effect of Wave Fields

- Vertically propagating P-Wave
  - Analytical idealization
    - Yields spurious results in 1D convolution analyses
    - PSHA & Site studies use empirical V/H ratios
- Surface Waves
  - Combined vertical and horizontal input
  - Coherent building input when λ_R > building width
    - More total load for deeply embedded structures
  - Incoherent building input when λ_R < building width
    - Less total load for all structures at high frequencies
    - Excite building responses not observed in traditional analyses.

Summary for Varying Wave Fields on SSI Loads

- Surface waves are a viable alternative to traditional seismic input
  - Provide better insight into actual seismic response
    - Coherent low frequency input
    - Incoherent high frequency input
  - Superposition of multiple waves could be used to develop ground motions meeting target spectra
    - Additional work required to develop design motion
- Surface waves can be evaluated using existing analysis tools