Soil-Foundation-Structure Interaction: Implications for Performance Based Engineering

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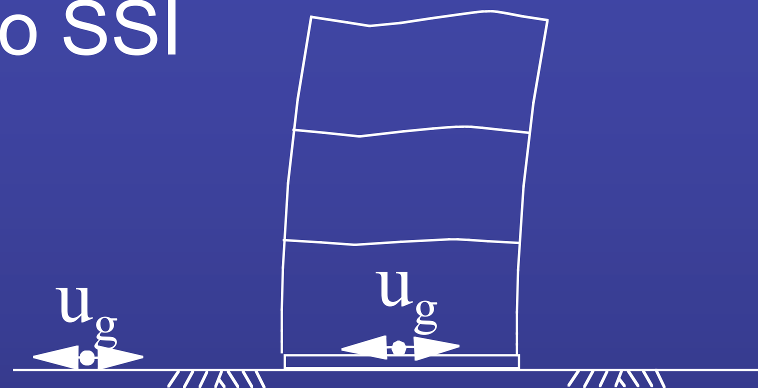
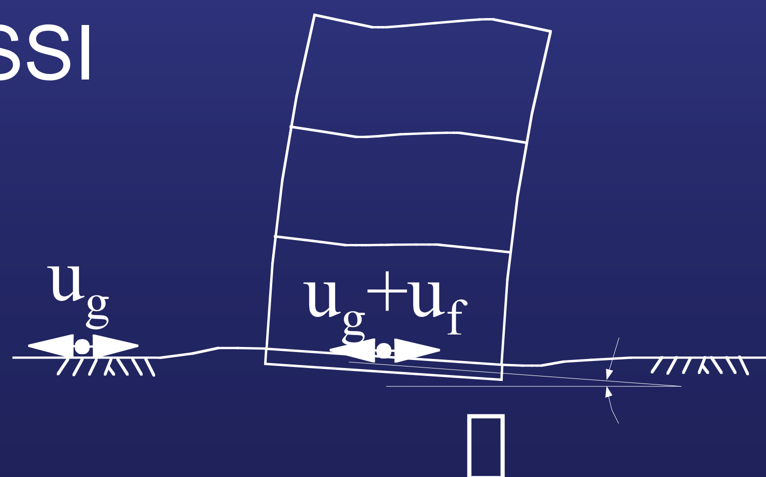
SFSI: Overview

No SSI



- No SFSI:
  - rigid soil
  - vertically propagating, coherent waves
  - surface foundation
- SFSI:
  - Soil compliance + damping
  - Realistic wave field

SSI

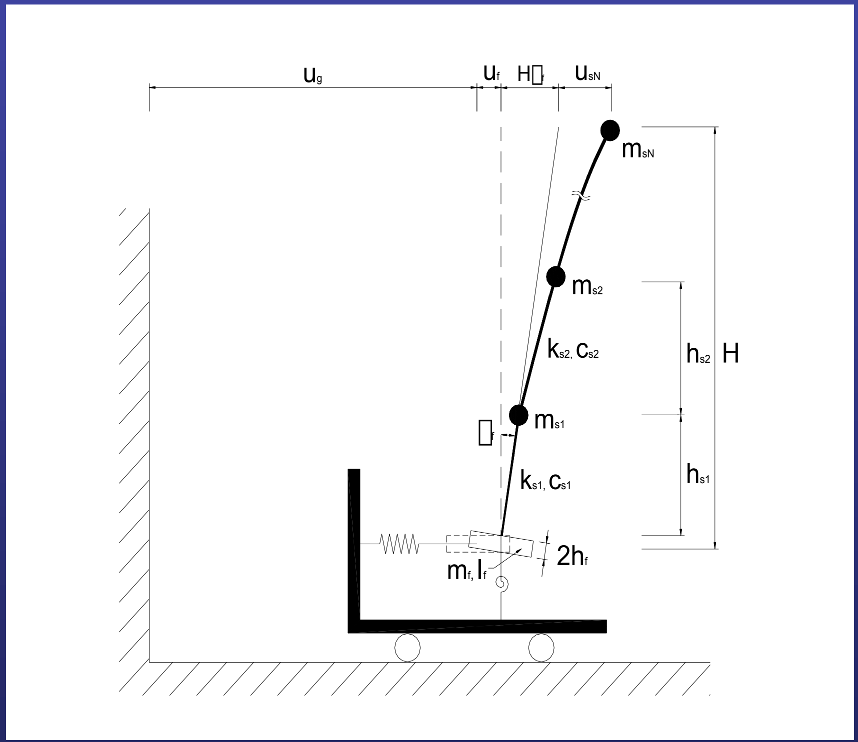


Context in PBSD: Nonlinear Static Procedures

- Capacity spectrum
  - Soil springs in pushover analysis
- Initial seismic demand
  - Should be drawn for foundation motion, not free-field
  - Spectral ordinates should reflect system damping ratio

Context in PBSD: Nonlinear Time History Analyses

- Foundation springs and dashpots, ideally:
  - Nonlinear
  - Frequency dependent
  - Capable of accumulating permanent displacement



- Seismic demand
  - Should reflect foundation motion, not free-field

Context for PEER

IM _ EDP _ DM _ DV

- Foundation / Free-field transfer function to modify IMs
- Kinematic interaction

- Account for foundation flexibility and damping
- Foundation impedance function
  - Soil springs
  - Dashpots

Does SFSI Matter?

- YES, especially for short-period structures
- Field data shows:
  - Foundation damping ratios up to ~ 10-20%
  - Period lengthening up to ~ 1.5
  - Foundation/ff Sa's at low period as low as ~ 0.5

Existing Models and Research Needs

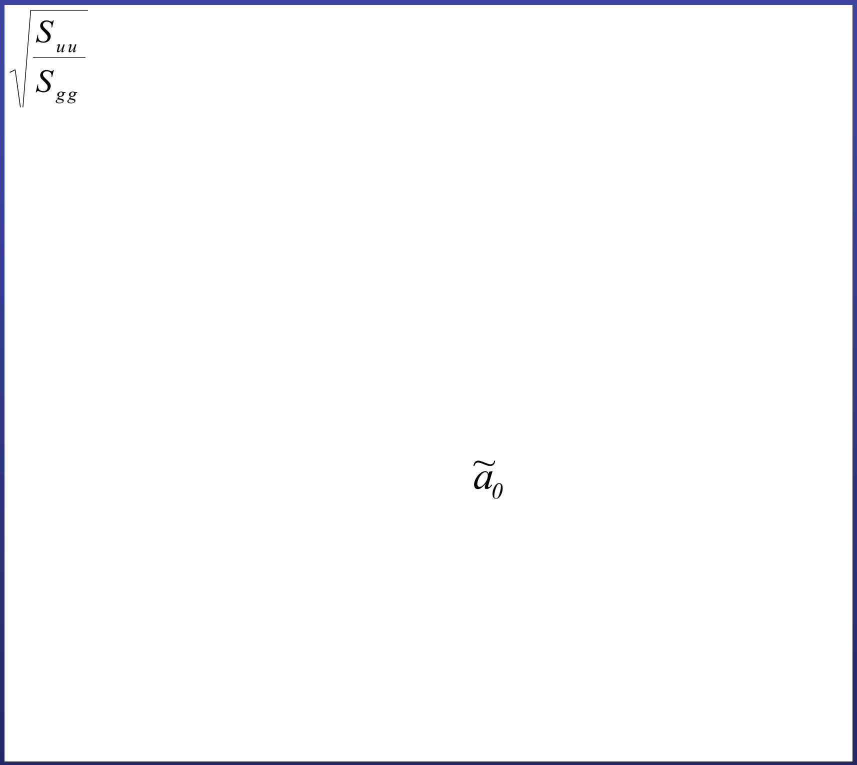
- Kinematic Interaction
  - Problem: incoherent or inclined incident wave field
  - Continuous foundation case
  - Discontinuous foundation case
- Foundation Stiffness and Damping

Kinematic Interaction: Continuous Foundations

- Contributions from:
  - Base-slab averaging
  - Foundation embedment
  - Wave scattering
- Negligible for:
  - Surface foundations *and*
  - Vertically propagating coherent shear waves

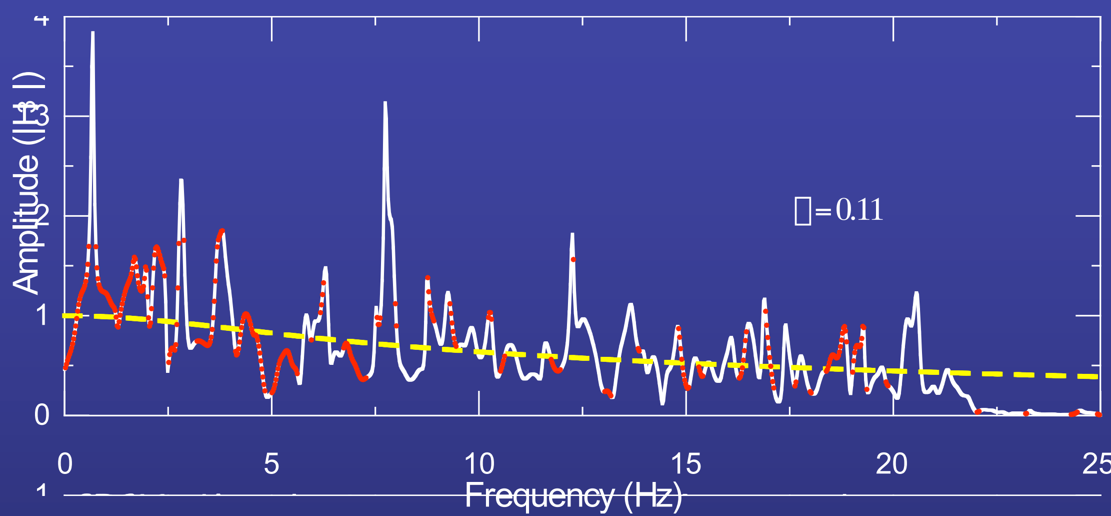
Base Slab Averaging

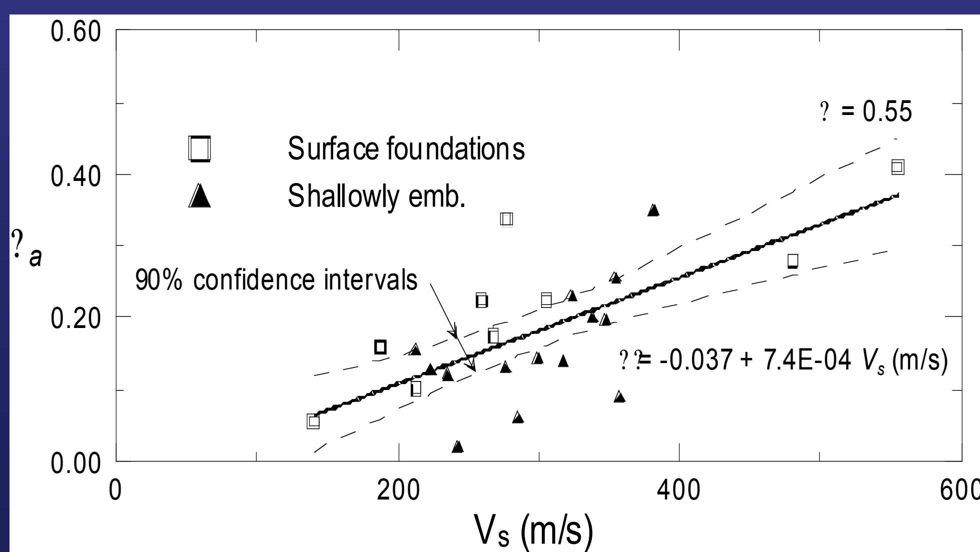
- Existing theoretical models
  - User-specified incoherence parameter, _
  - Rigid foundation, uniform soil
- Result is foundation / free-field transfer function, not RRS



$$\tilde{a}_0 = \frac{\square b_e}{V_{s,r}}\sqrt{\square^2 + \sin^2 \square_v \left(\frac{b}{b_e}\right)^2}$$

Calibration against field data



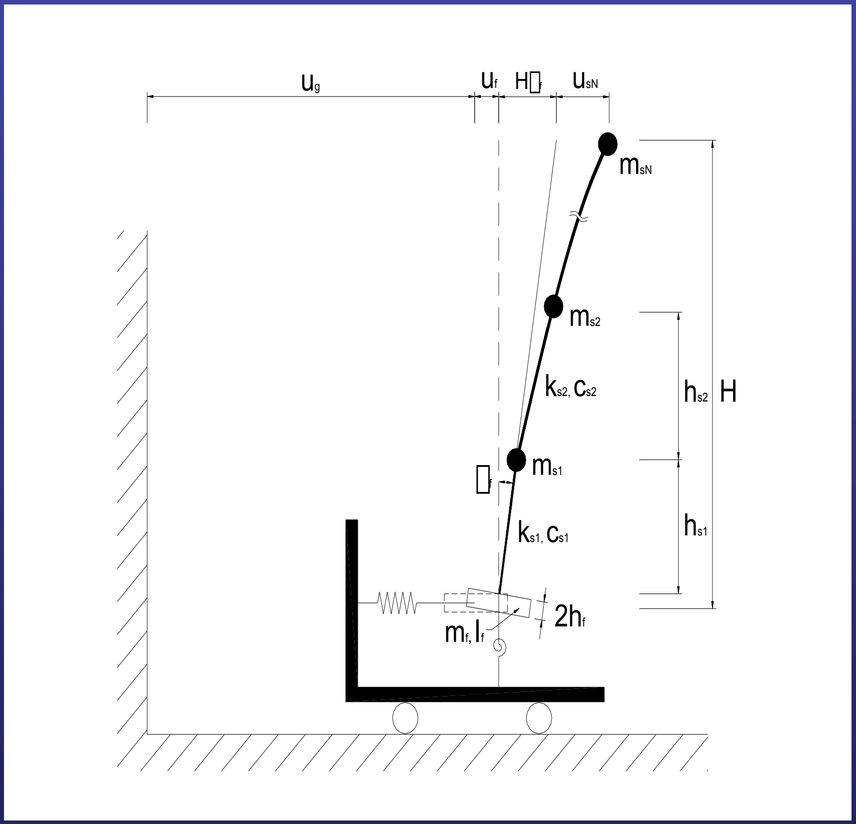


Application

- Available
  - Model for for continuous foundations
  - Guidelines for selection of V_s for non-homogeneous soil
  - Provides estimate of transfer function amplitude
- Needed
  - Transfer function phase models
  - RRS and other IMs from transfer functions
  - Guidelines for non-continuous foundations
  - Guidelines for pile foundation with cap-soil contact

Foundation Stiffness / Damping

- *Inertial* interaction effects
- Foundation Stiffness
  - Single spring set for rigid foundation
  - Distributed springs for non-rigid foundation
- Foundation damping
  - radiation damping
  - hysteretic soil damping
- Affected by:
  - Structure/soil stiffness
  - Soil layering
  - Foundation embedment, shape, flexibility



Impedance Function Models

- Soil:
  - Homogeneous or prescribed variations with depth
  - Linear
- Rigid foundation
- Accounts for frequency-dependence

Implementation Challenges

- Representation of non-uniform profiles
- Parameter selection for time history analysis
  - What frequency?
- Flexible and/or dis-continuous foundations
- Foundation inelasticity
  - Effect on radiation damping

Challenges (con't)

- Strain field beneath foundation
  - Key: difference from free-field
  - Affects soil stiffness and damping
  - Permanent deformations