Soil-Structure Interaction Modeling Strategies for Response History Analyses of Buildings

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2012 PEER ANNUAL MEETING
October 26 - 27, 2012
Berkeley, California

This presentation:

SFSI Modeling Strategies

- Review of some procedures used in practice
- Substructure vs direct analysis
- Elements of complete substructure analysis
- Current capabilities for direct analysis
- Assessment of alternative approaches

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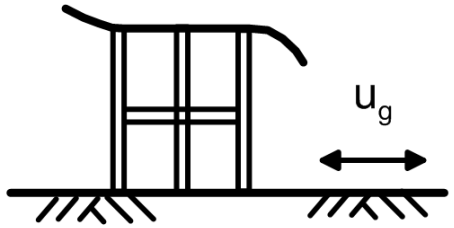
Practitioner Interviews

- Conducted by B. Lizundia and F. Naeim as part of ATC-83 project
- Geotechnical and structural engineers in CA
- Assessed understanding of basic SSI principles
- Identified strategies for SSI modeling used by design professionals (response history and pushover)
- Developed recommendations for improving GE-SE interactions in practice

SSI Modeling Strategies

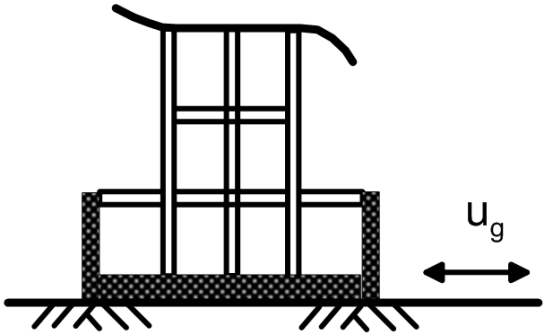
- **Model 1**
- Fixed at ground surface (no SSI)
- Base reactions applied to separate foundation model



(1)

SSI Modeling Strategies

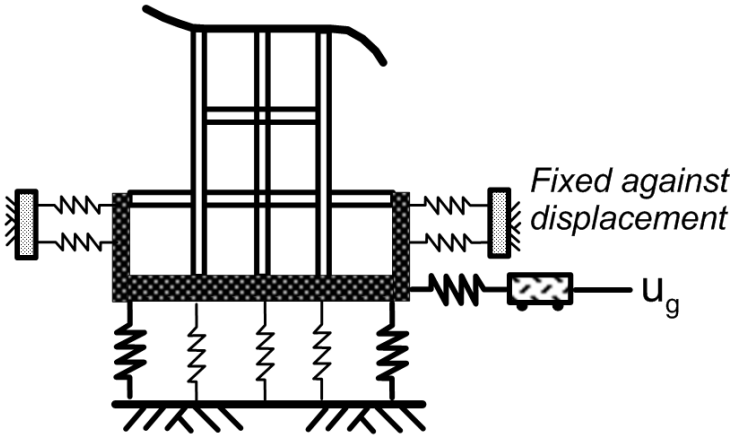
- **Model 2**
- Fixed at foundation level (no SSI, 2A)
- Sometimes vertical springs applied (2B)



(2)
A. No springs
B. V. springs

SSI Modeling Strategies

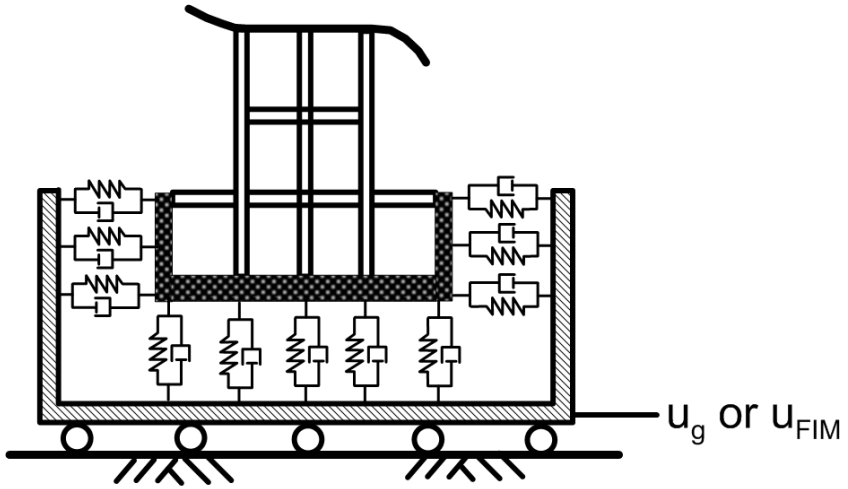
- **Model 3**
- Motion applied at base
- Springs on foundation walls fixed at ends
- Typically used for pushover analysis



(3)
A. H springs only
B. H & V springs

SSI Modeling Strategies

- **Model 4**
- Bathtub model
- Includes foundation springs
- No spatial variability of input motions
- Seldom used

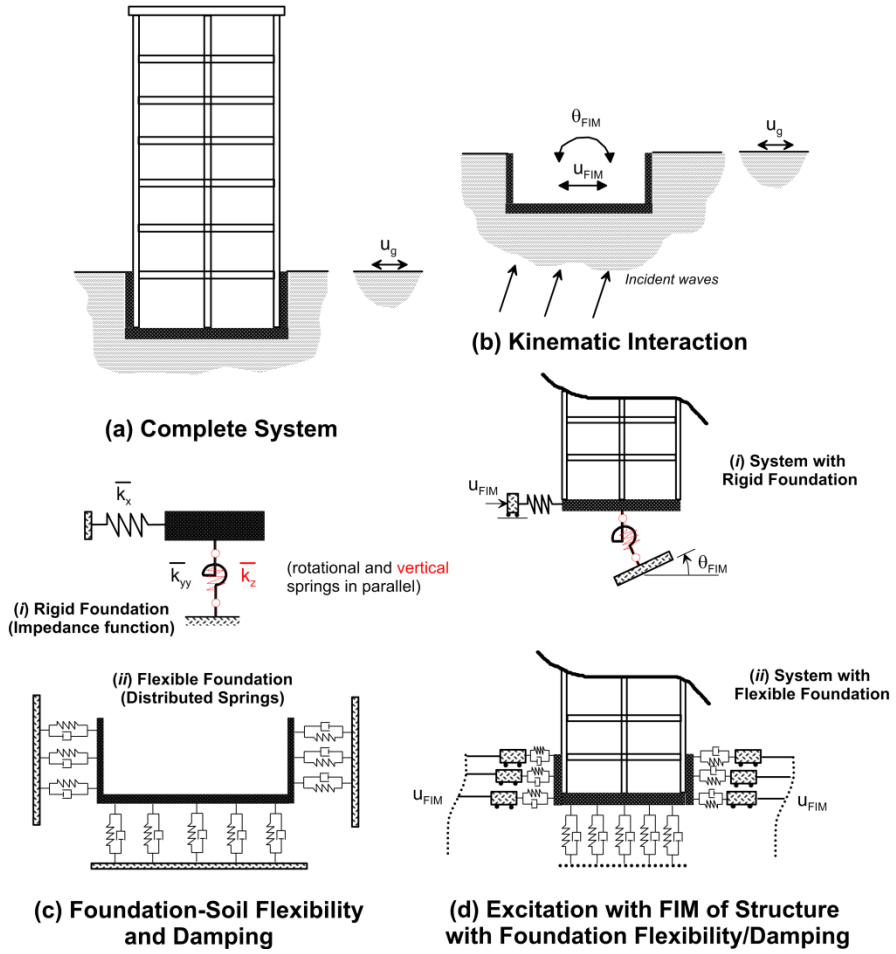


We'll look at the relative performance of these models momentarily

Substructure vs. Direct Analysis

Sub-Structure Analysis:

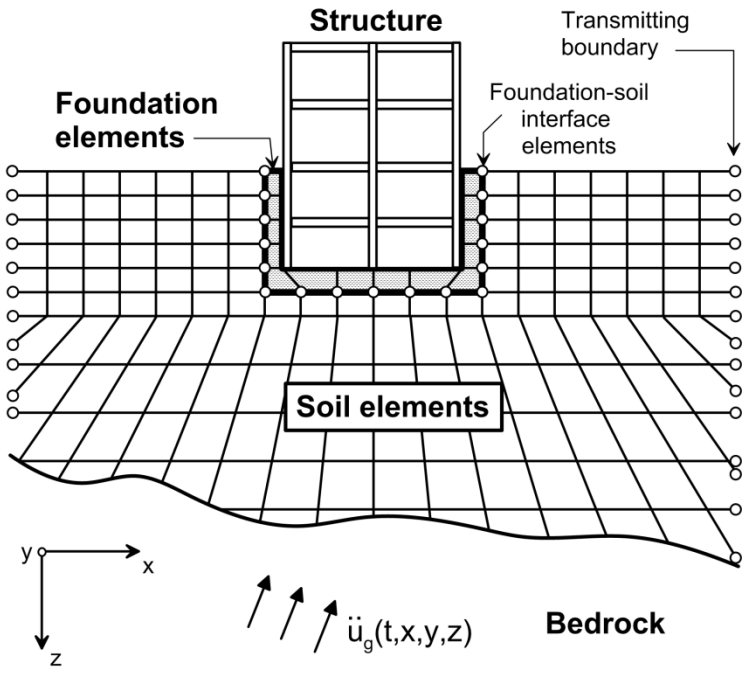
- FIM
- Foundation flexibility & damping
- Response analysis



Substructure vs. Direct Analysis

Direct Analysis:

- Soil, structural, and interface elements
- Amenable to fully nonlinear analysis (not EL)
- SVGMs problematic



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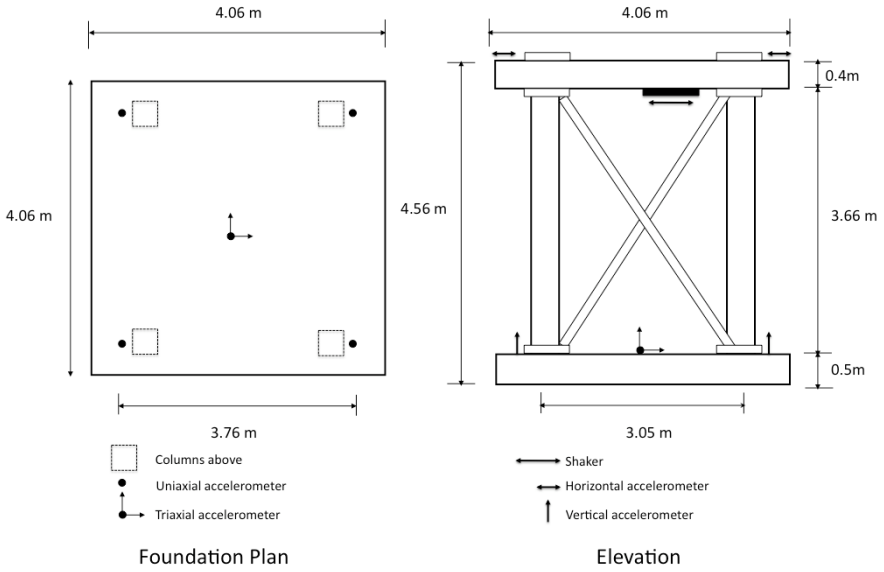
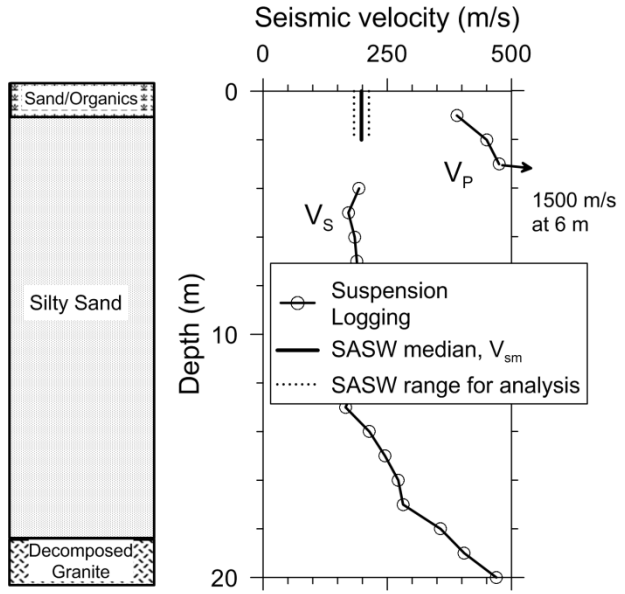
Elements of Substructure Analysis

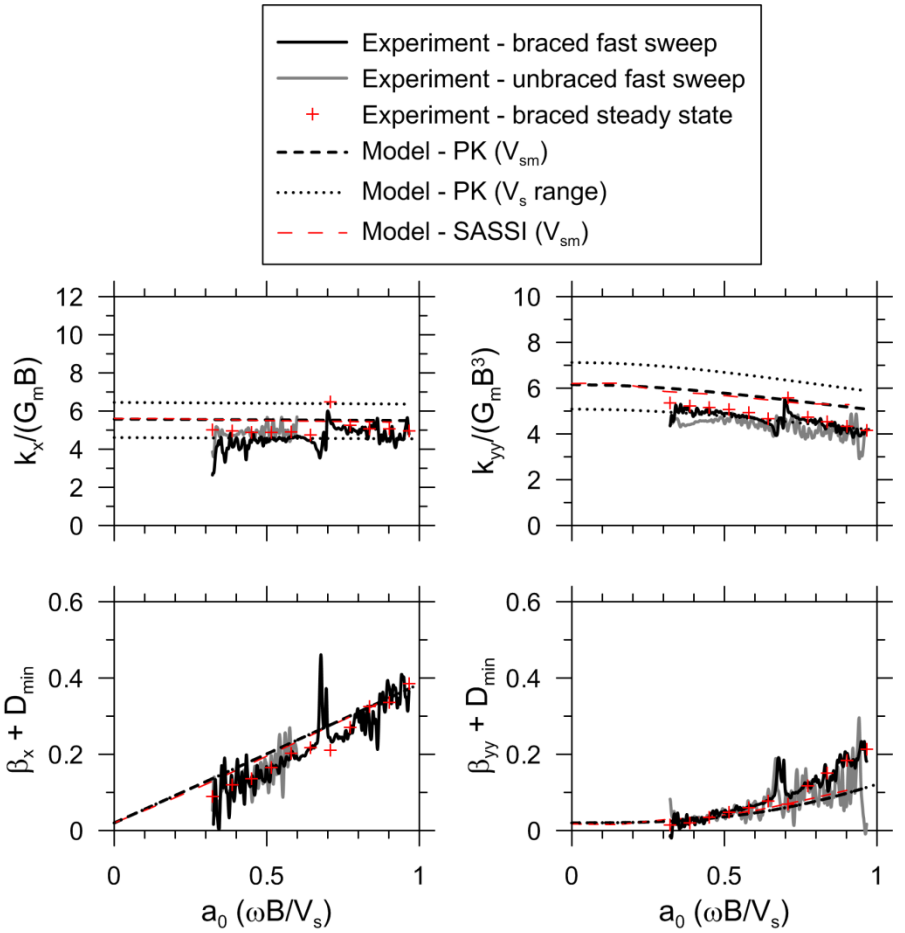
- Inertial interaction: springs, dashpots
  - Expressions for static foundation stiffness
  - Dynamic stiffness modifiers
  - Soil damping, D_{min}
  - Radiation damping

- Kinematic interaction

Garner Valley Test Structure







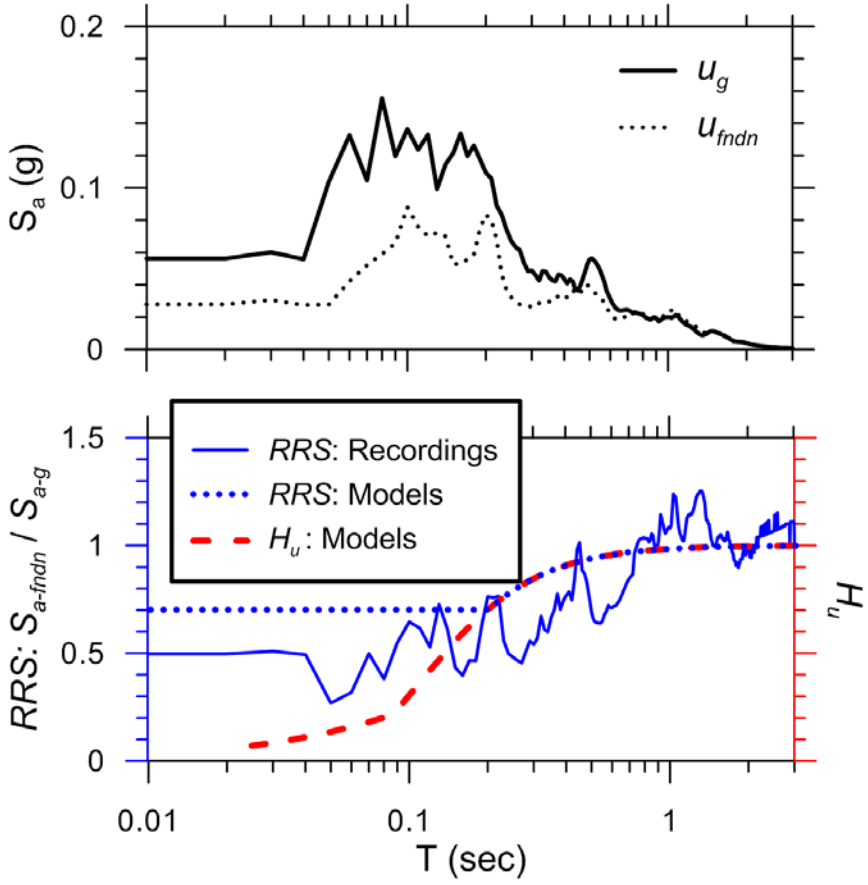
Figures from Tileylioglu et al. (2011)

Key features:

- Frequency-dependent stiffness for rotation (not translation)
- More damping in translation than rocking

Kinematic Interaction

Rancho Cucamonga Law & Justice Center
1987 Whittier Earthquake



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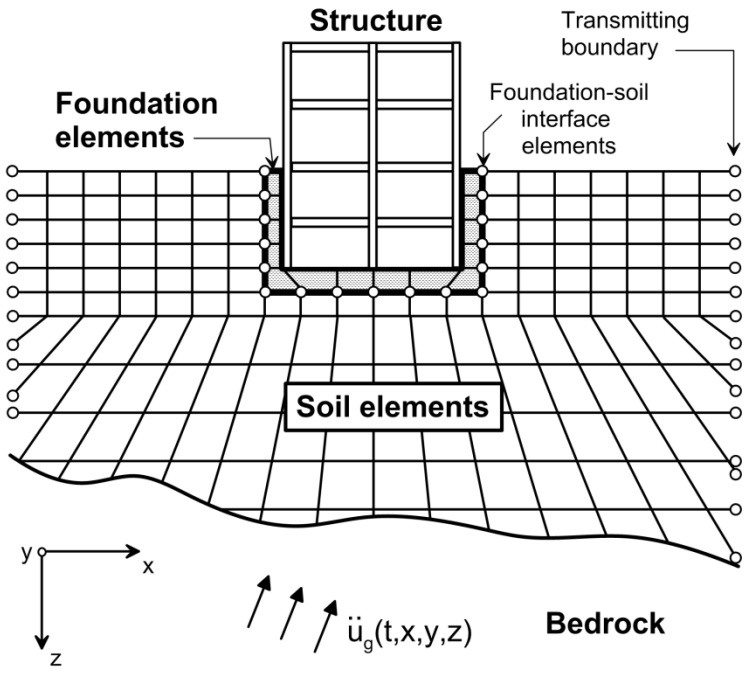
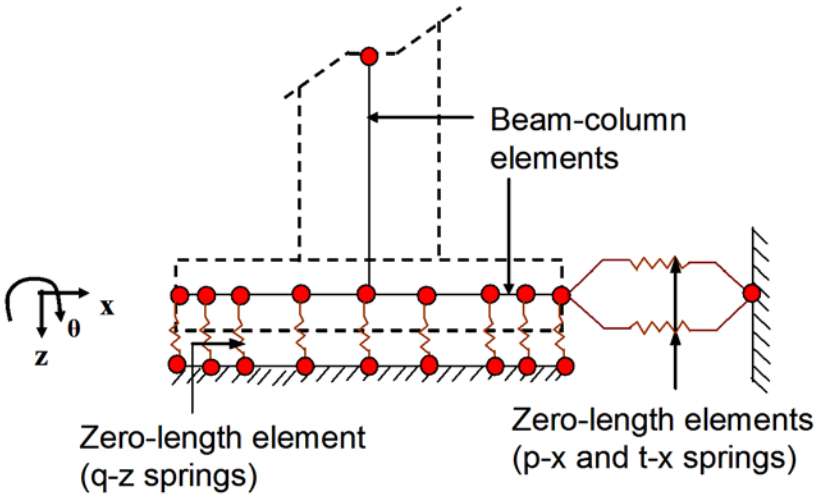
Direct Analysis Approaches

- Continuum modeling (e.g. Jeremic et al. 2009)



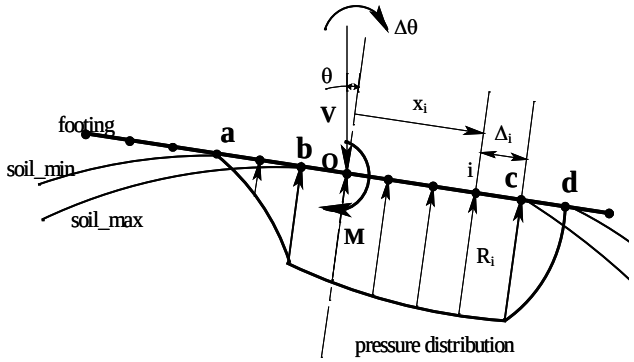
Direct Analysis Approaches

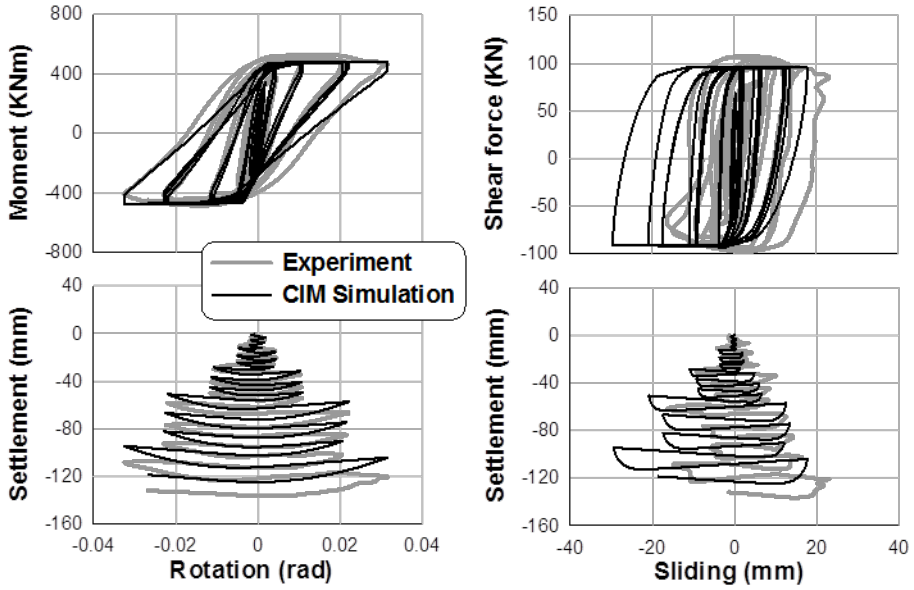
- Continuum modeling
- Beam on nonlinear Winkler foundation (e.g., Raychowdhury and Hutchinson, 2009)



Direct Analysis Approaches

- Continuum modeling
- Beam on nonlinear Winkler foundation
- Plasticity-based macroelements (e.g. Gajan and Kutter, 2009)





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Amenable to individual footings

Benefits when applied to full foundation system unclear

Problems with spatially variable input

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Assessment of Alternative Models

- Used instrumented buildings having recordings
- Develop 3D models in OpenSees including SSI components
- Tune structural parameters to match recordings (baseline model – “MB”)
- Strip out SSI elements to evaluate effects. Models 1-4.

Structure #1: Sherman Oaks

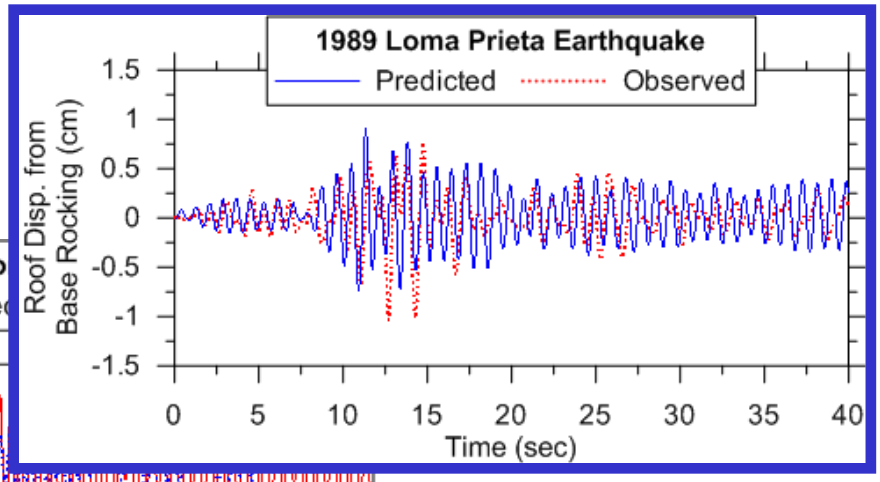
- Attributes:
  - RC frame
  - 2 levels of embedment
  - Alluvial soils, pile foundations
- Good:
  - Embedded foundation
  - Strong shaking, multiple events
  - Regular structure
- Bad:
  - No FF or rocking

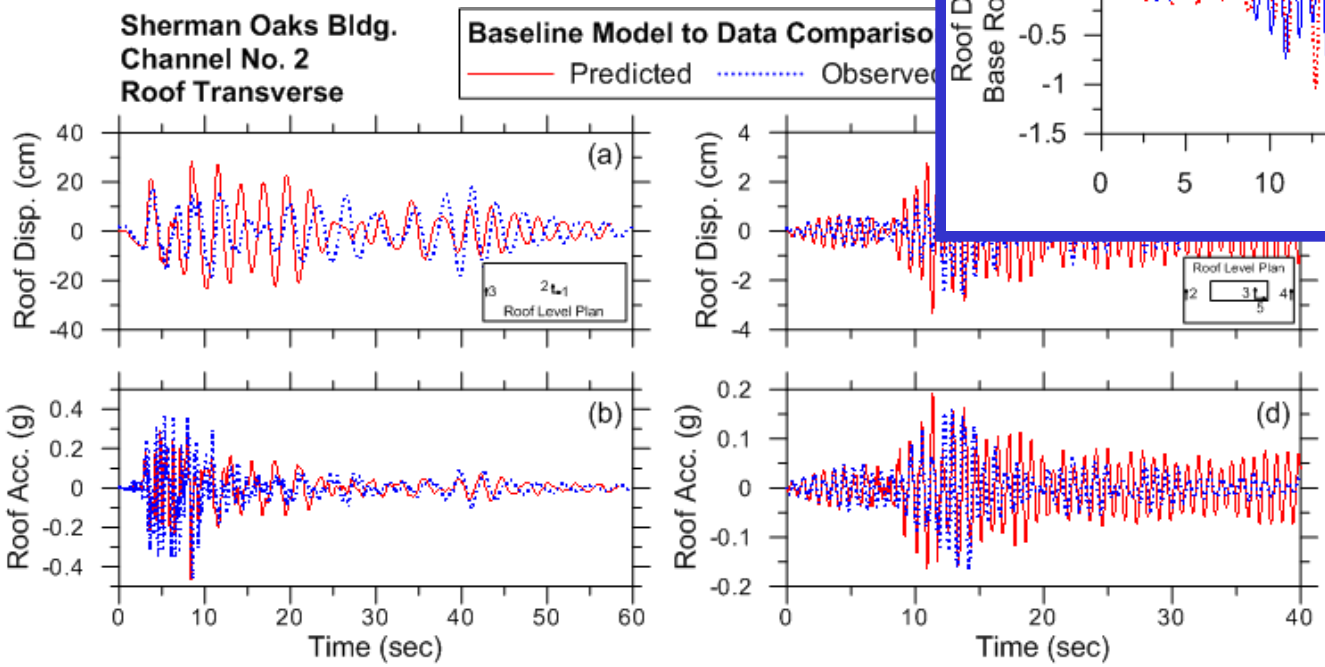
Structure #2: Walnut Creek

- Attributes:
  - Shear wall core & RC frame
  - No embedment
  - Shallow soils, mat foundation
- Good:
  - Base rocking
  - Stiff structure
- Bad:
  - Lack of embedment
  - No FF motion or strong motion

General Findings

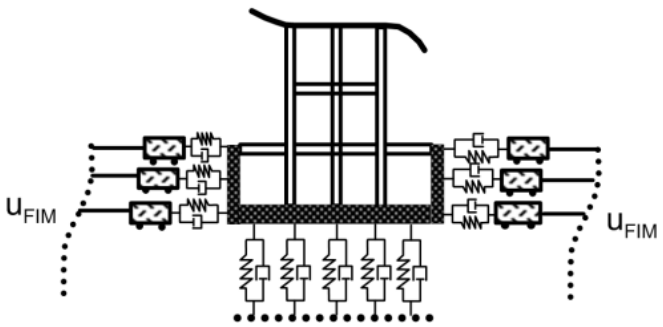
- Recorded responses well matched by MB



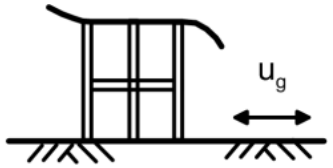


General Findings

- Recorded responses well matched by MB
- Models 1 and 3 perform poorly



Baseline Model (MB)



(1) Fixed at ground surface

General Findings

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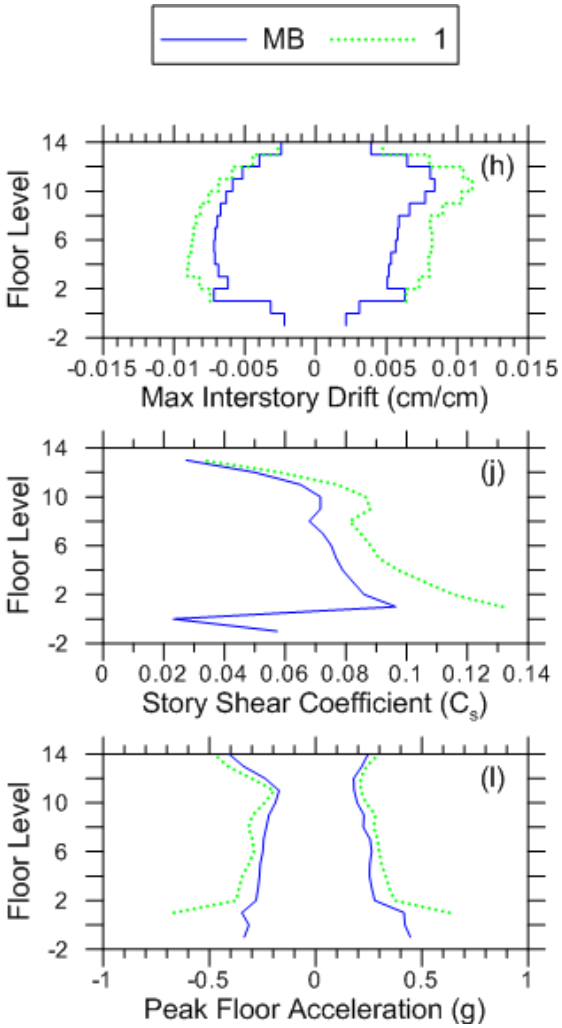
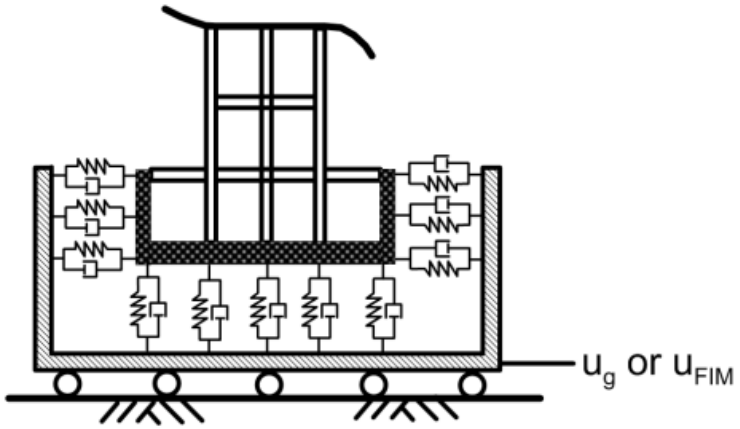


General Findings

- Recorded responses well matched by MB
- Models 1 and 3 perform poorly
- Model 4 (bathtub) performs well



(4) Rigid bathtub model

General Findings

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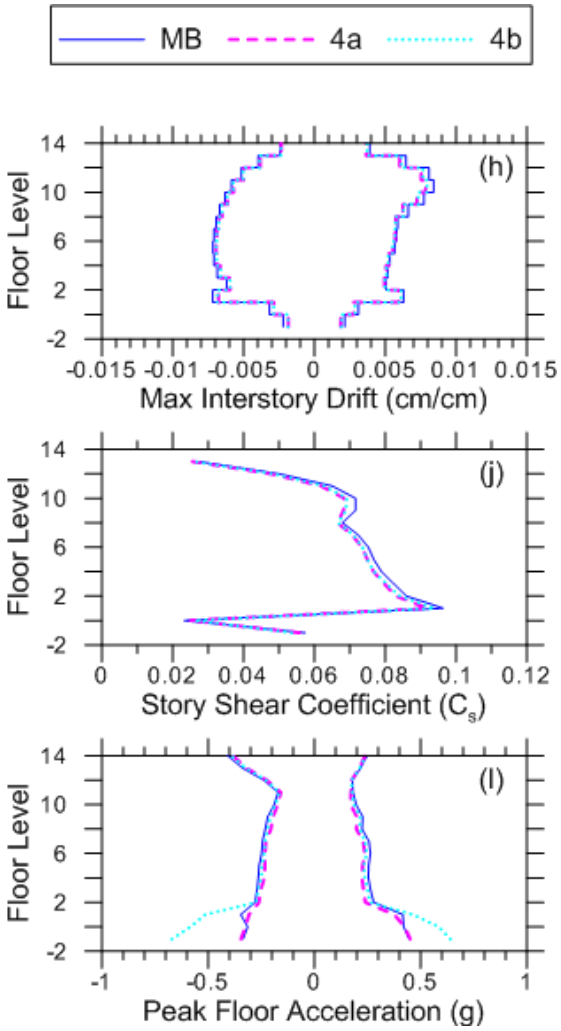
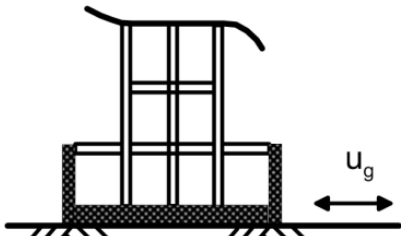


RHA Recommendations

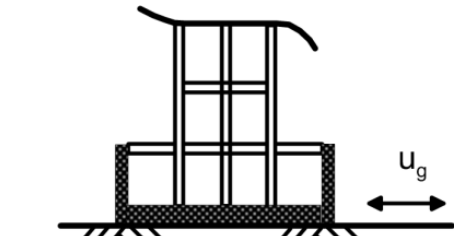
- Model subterranean levels, fix at base (Model 2)



(2) Subterranean model included, fixed at base

RHA Recommendations

- Model subterranean levels, fix at base (Model 2)
- Model subterranean, include foundation springs, bathtub supports for springs (Model 4)



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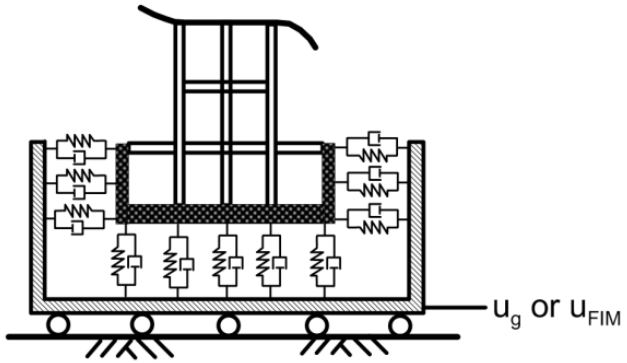

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RHA Recommendations

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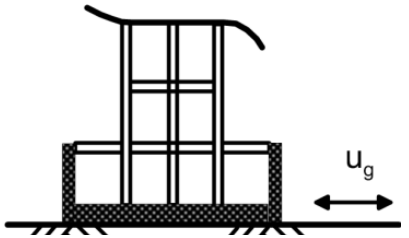
- Model subterranean, include foundation springs, bathtub supports for springs (Model 4)
- Consider kinematic effects for below-ground EDPs



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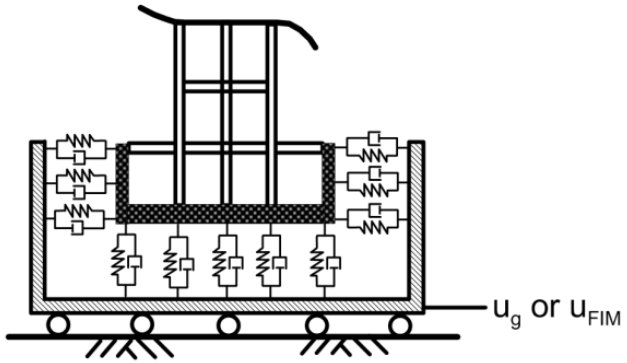

(4) Rigid bathtub model

Do not:

- Use conventional coefficients of subgrade reaction for dynamic spring stiffnesses
- Use limiting foundation pressures derived from settlement considerations or factored bearing capacity to develop limiting spring forces
- Reserve consideration of SSI only for “important” (often tall) buildings
- Assume that ignoring SSI is always conservative