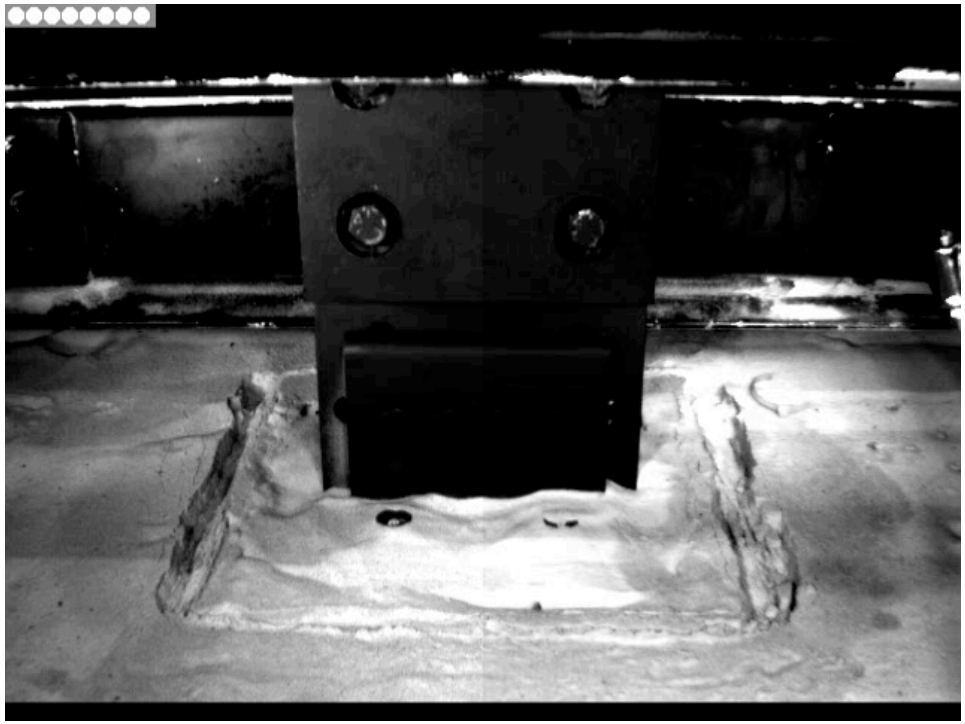
Numerical Tools for Modeling Rocking Shearwalls (Foundations)



Tara C. Hutchinson

PEER Annual Meeting

October 15-16, 2009

San Francisco, CA

Video courtesy of Kutter & Ulgade

UCSD

Contributions

- UCD (Kutter), UCLA (Stewart), UCSD (Hutchinson), USC (Martin)
- (former) Graduate Students: Rosebrook, Phalen, Gajan, Raychowdhury, Harden, Chang, ZhiQiang Chen
- Support provided by PEER

Scope

- Contact Interface Model (CIM) [UC Davis; Gajan & Kutter]
- Beam-on-Nonlinear-Winkler (BNWF) model [UCSD; Raychowdhury, Harden & Hutchinson]
- Calibrated with centrifuge (and other) experimental datasets
- Implemented in OpenSees
- Model documentation including user input parameter selection protocols, and example files
- Cross-compared

Features of the Models

- 2D elements, designed to capture the forces (Q, V, M) and deformations (s, v, θ) of (rocking-dominated) footings
  - i.e. quantify benefits and consequences during rocking
- Minimal number of input parameters for the user
- Packaged with well-developed parameter selection protocols for ease of use
- General use (buildings, bridges, etc.)

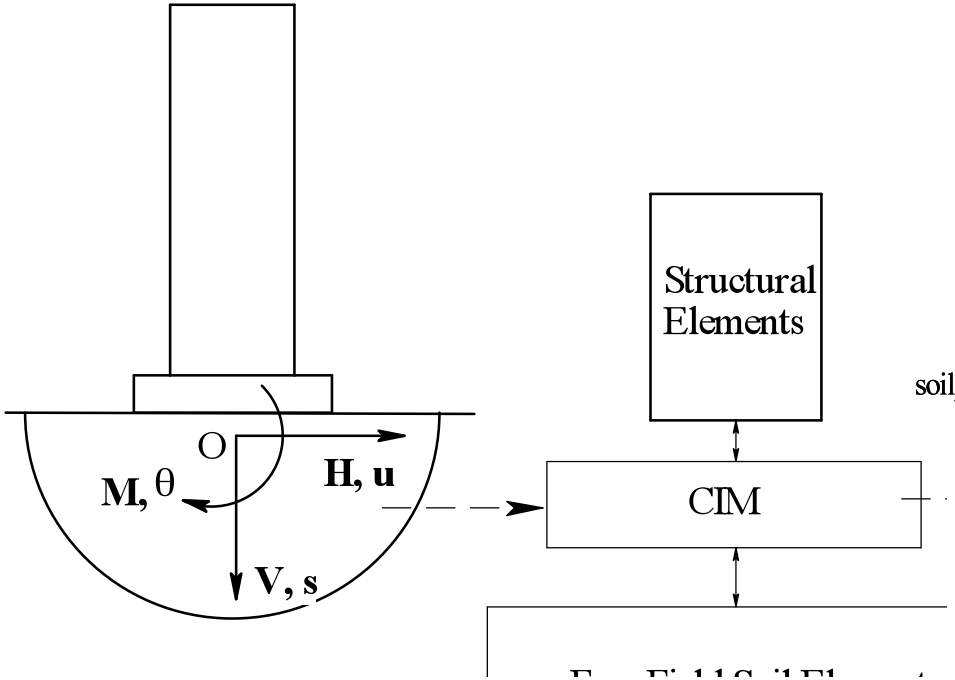
Contact Interface Model (CIM)

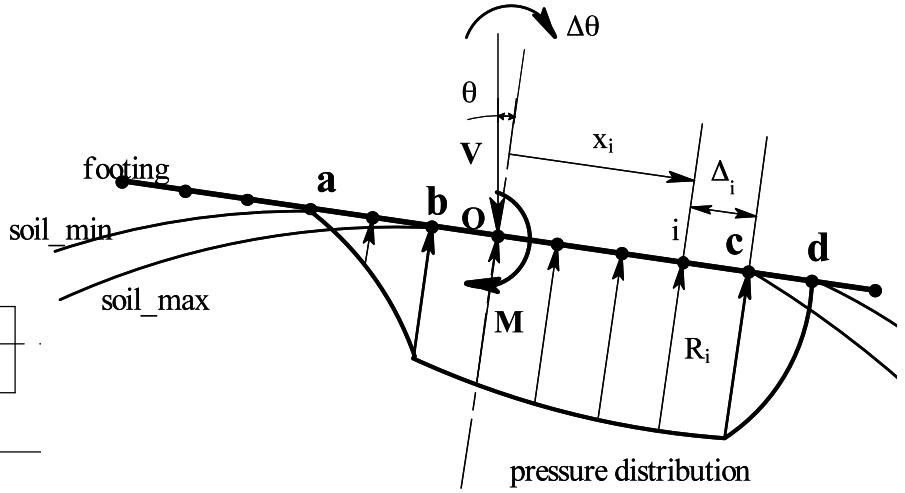
- Lumps foundation and surrounding soil into one 'macro-model'
- Structural footing assumed rigid
- Couples foundation Q, V, M & deformations
  - Q & M: tracking contact geometry
  - V & M: Yield surface (interaction diagram) & associative flow rule

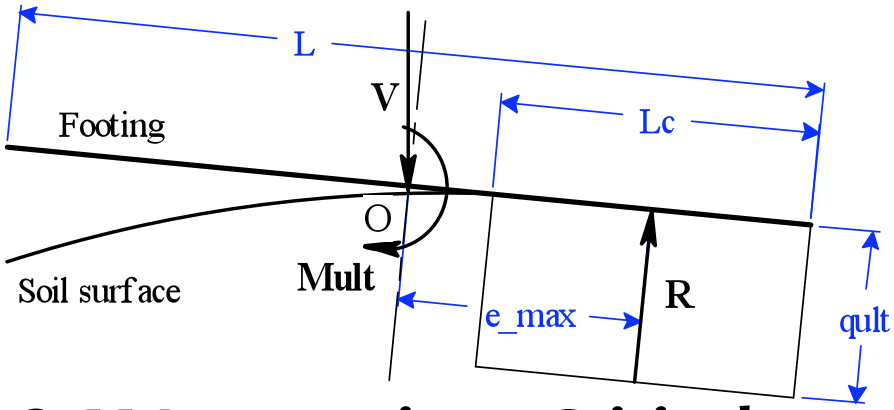
Gajan (2007) – PhD Dissertation ; Gajan and Kutter (2008) ASCE JGGE;

CIM – General Concepts

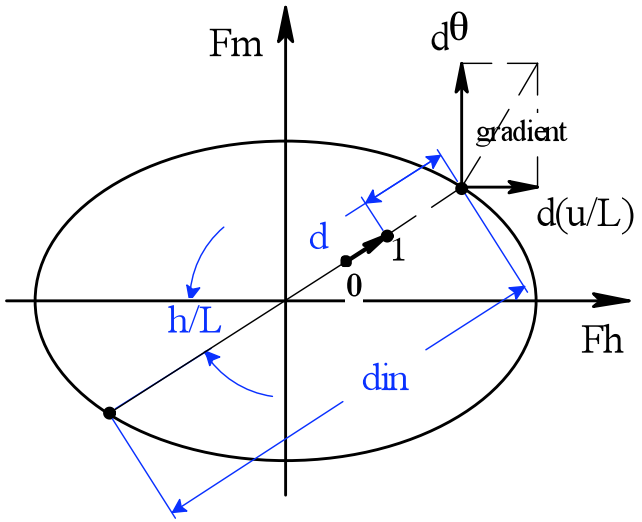
Framework







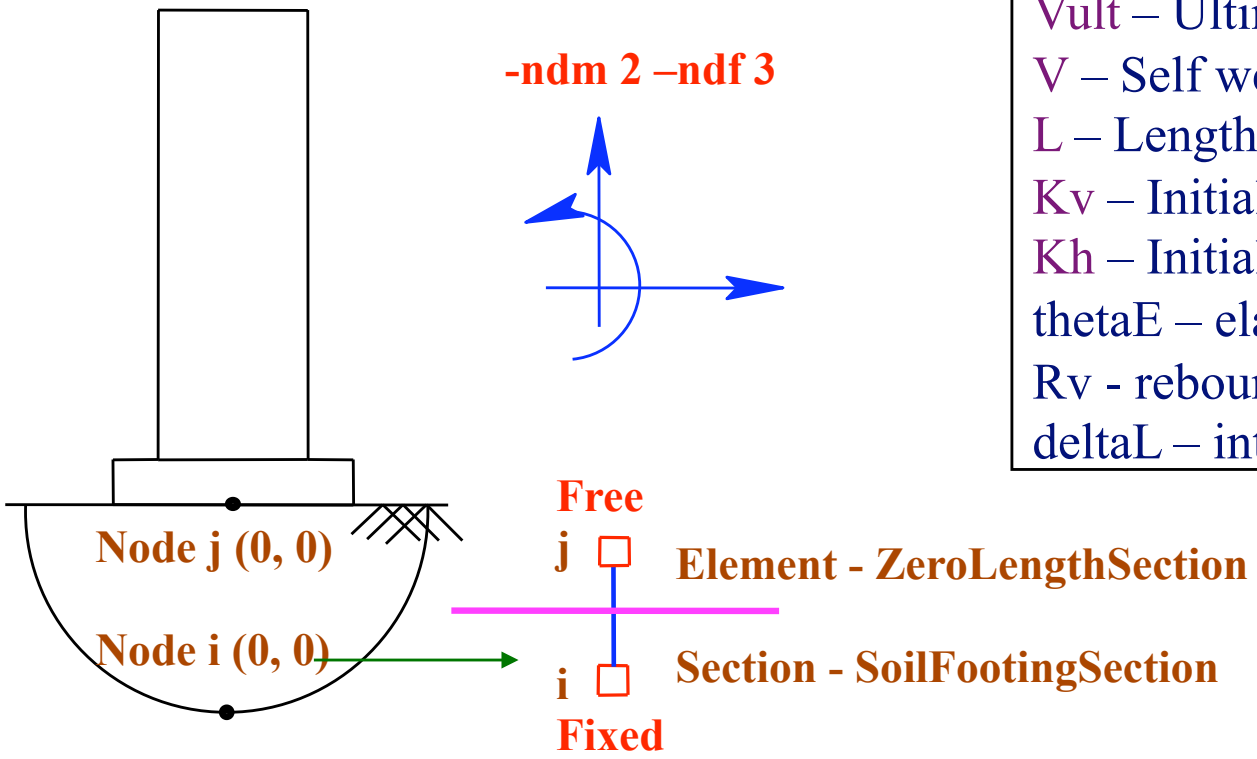
Q-M Interaction - Critical Contact Length



M-V Bounding surface

CIM in OpenSees

section SoilFootingSection -secID -FS -Vult -L -Kv -Kh –thetaE –Rv -deltaL
element ZeroLengthSection -eleID -iNode -jNode -secID <-orientation>



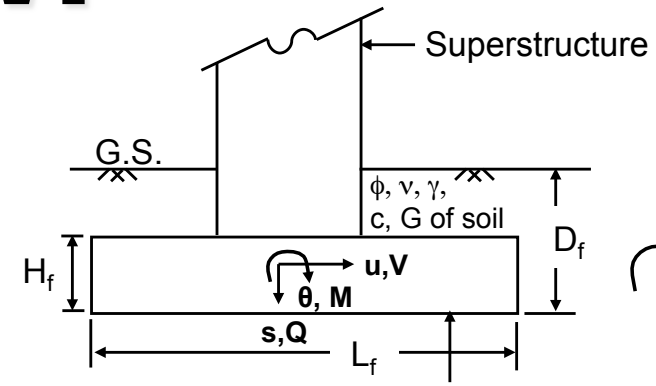
Vult – Ultimate vertical load
V – Self weight of the structure
L – Length of the footing
Kv – Initial vertical stiffness
Kh – Initial horizontal stiffness
thetaE – elastic rotation limit
Rv - rebound ratio
deltaL – internal footing node spacing

Beam-on-Nonlinear-Winkler (BNWF) Model

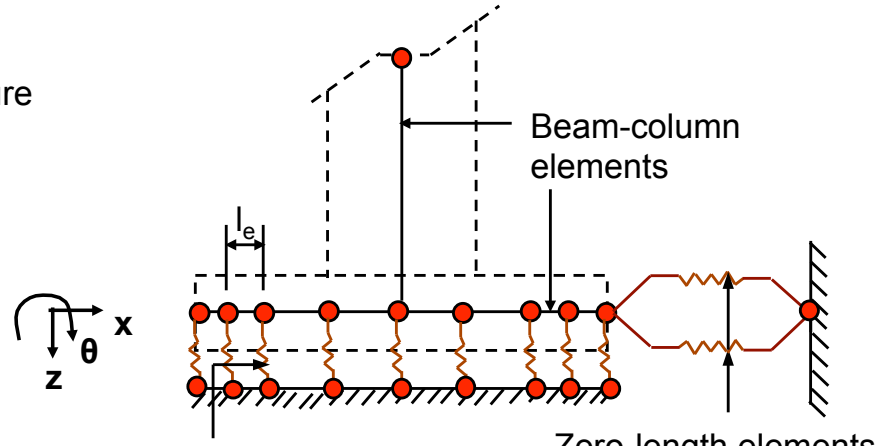
- Closely spaced, nonlinear vertical (θ, s) & lateral springs (v)
- Gap elements – permanent deformations
- Dashpots – radiation damping
- Large body of literature (extension of earlier pile-based formulations; Boulanger et al., 1999)
- Familiarity and comfort in practice

Raychowdhury (2008) – PhD Dissertation; Harden & Hutchinson – Spectra (2009); Raychowdhury and Hutchinson - EESD (2009)

BNWF



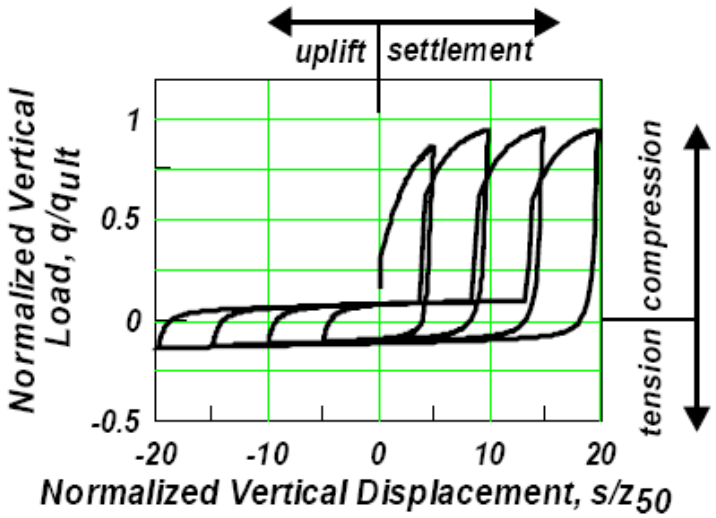
E, I, A of structural footing



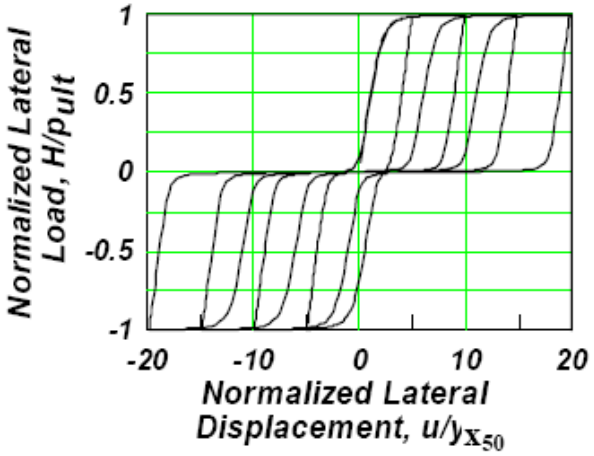
Zero-length element (q-z springs)

Zero-length elements (p-x and t-x springs)

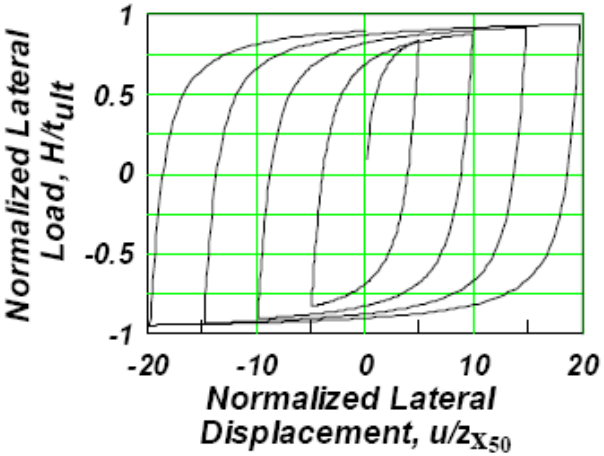
q-z springs



p-x springs (passive)



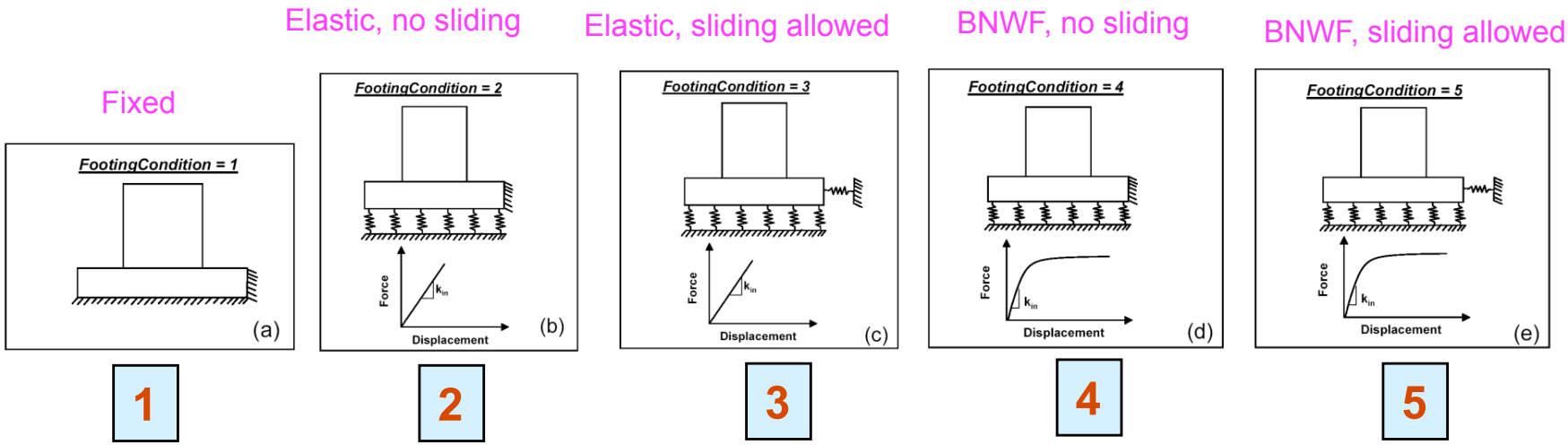
t-x springs (interface friction)



BNWF in OpenSees

ShallowFoundationGen $FoundationTag $ConnectNode $InputFile $FootingCondition

- Argument 1: $FoundationTag: An integer number denoting the foundation number
- Argument 2: $ConnectNode: Node of the structure that is to be connected with middle node of the foundation
- Argument 3: $InputFile: Name of input file containing soil and footing properties
- Argument 4: $FootingCondition: An integer value from 1 to 5 for different base conditions

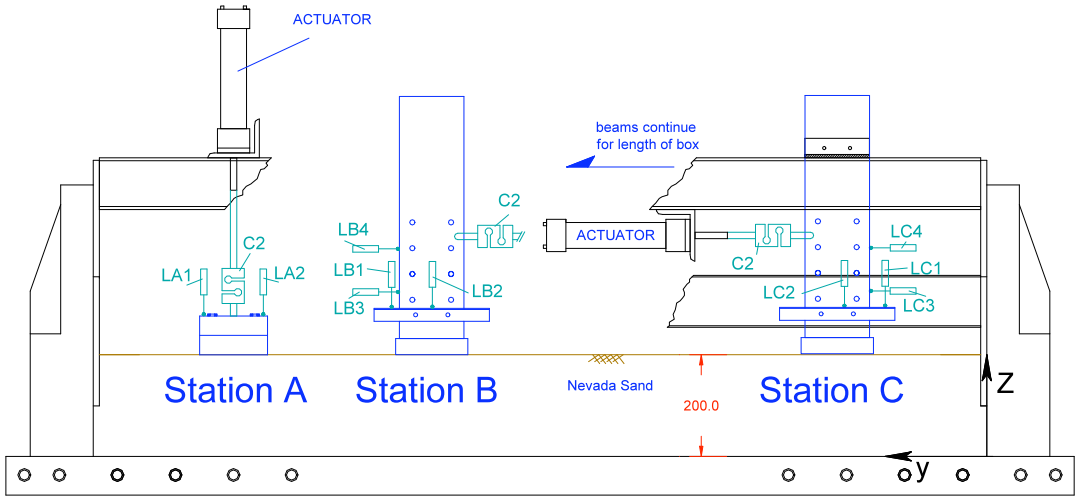


4 input parameters/spring type + 3 global mesh parameters = 15

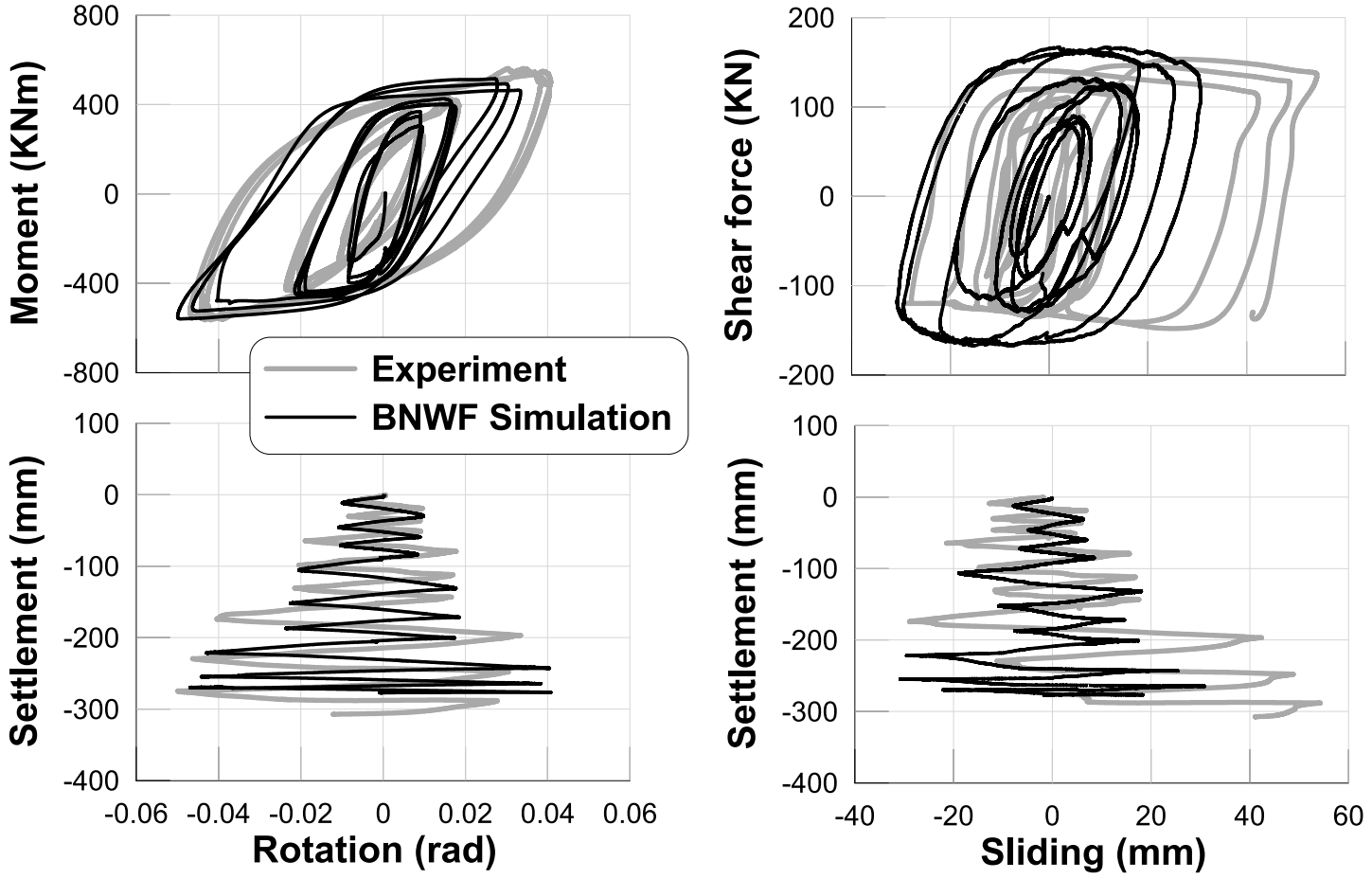
Wall-Footing Experiments

Planar wall -footing model

- Tests on clay and sand
- Varying embedment (0, B, 3B)
- Qu/Qa = 2-15
- Slow cyclic and dynamic loading



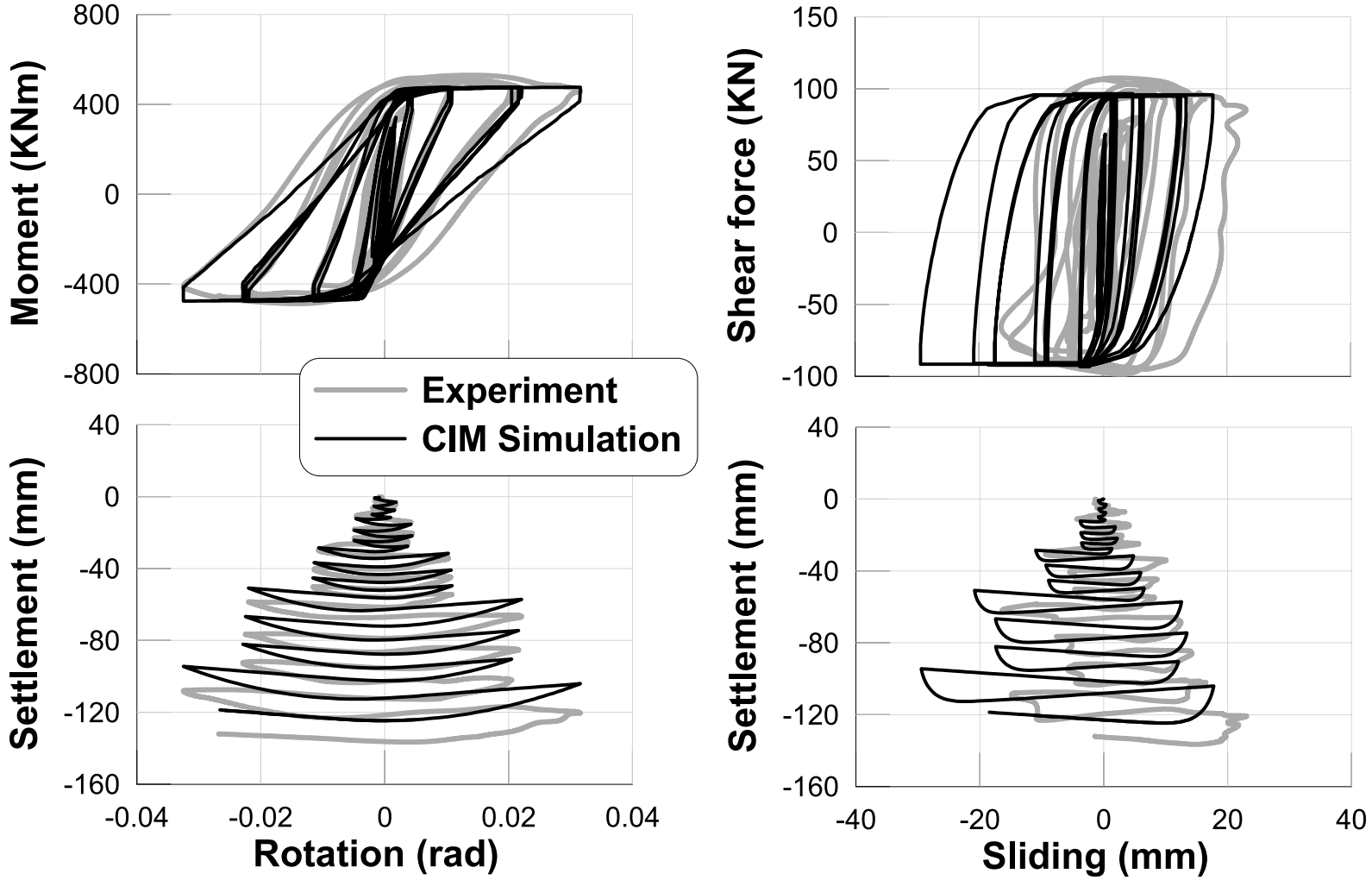
BNWF Experiment-Numerical Model Comparison



- 80% dry sand
- Strip footing (2.85m x 0.65m prototype size)
- Static cyclic loading
- Shearwall-footing test series
- Qu/Qa = 2.3
- M/(HL) = 1.2

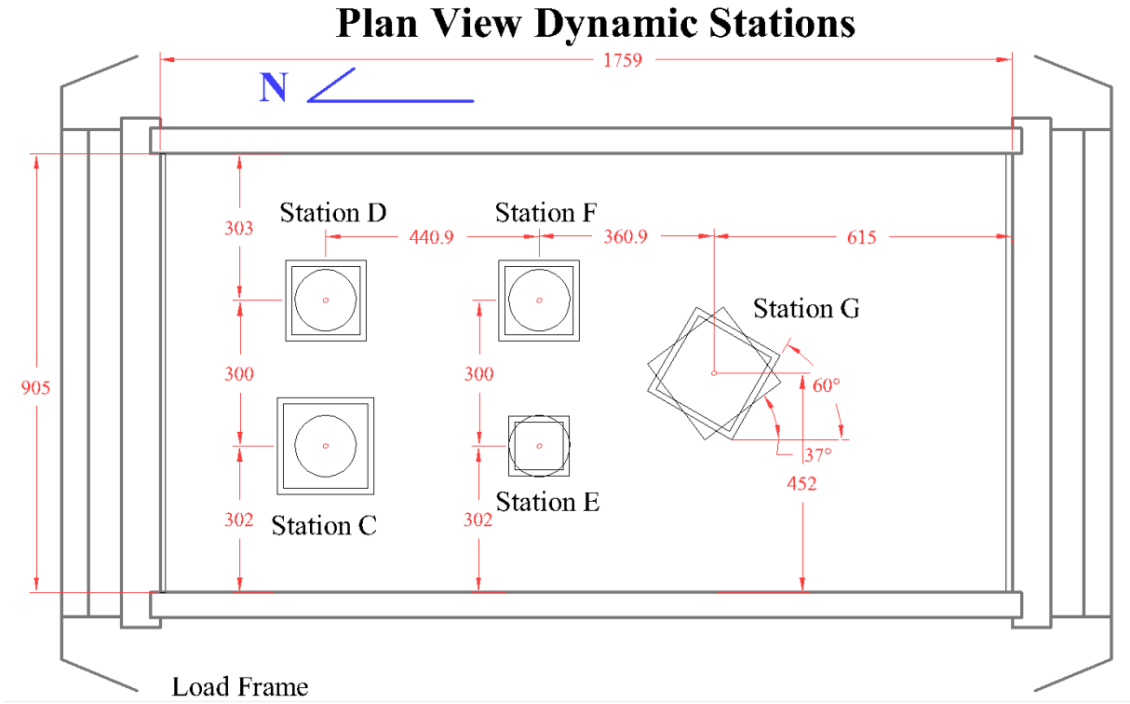
SSG04-06 test series by Gajan et al. (2006)

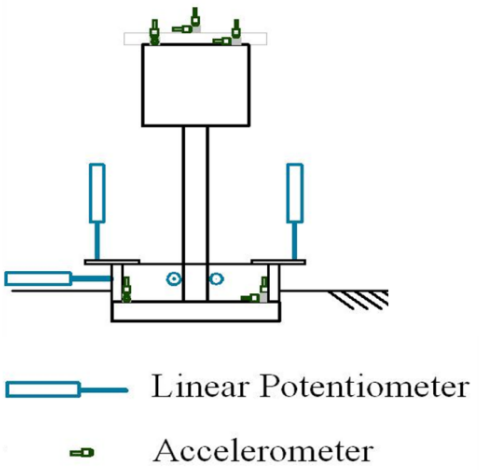
CIM Experiment-Numerical Model Comparison



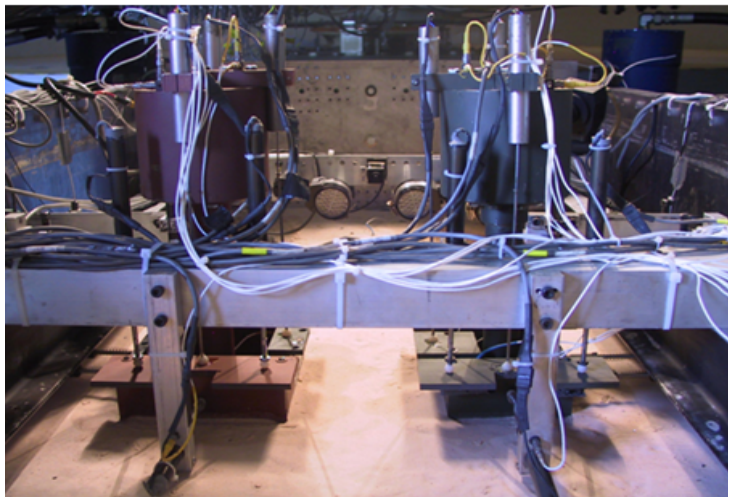
SSG02_05 centrifuge test (Dr = 80%, Qu/Qa = 2.6, M/(H×L) = 1.72)

Comparison with Bridge Footing-Column Tests



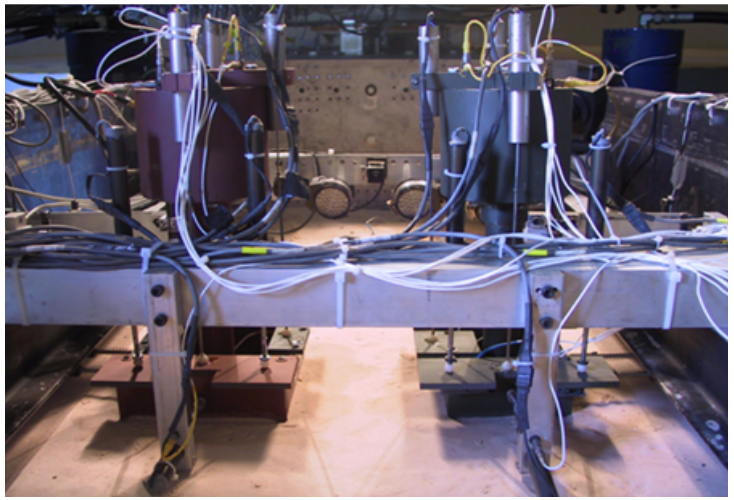


- Tests on sand; square footings
- Varying embedment (0.2-0.3B)
- Qu/Qa = 17 & 31; S controlled
- Earthquake base shaking

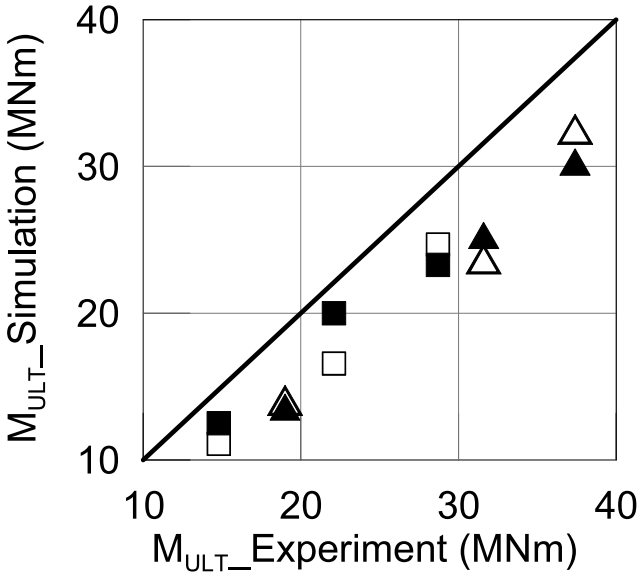


Ulgade et al., 2008

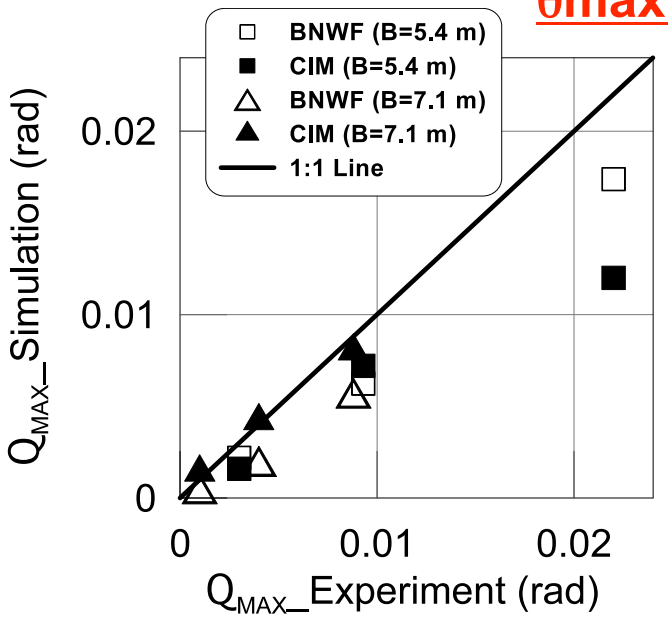
Comparison with Bridge Footing-Column Tests - Synthesis



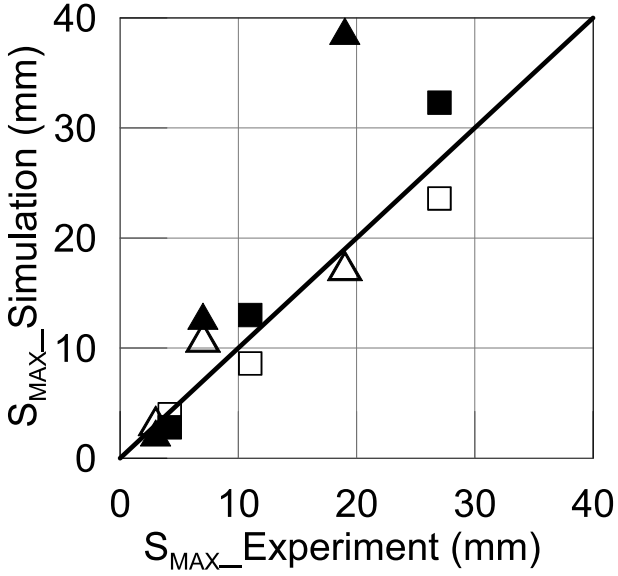
Mmax



θmax

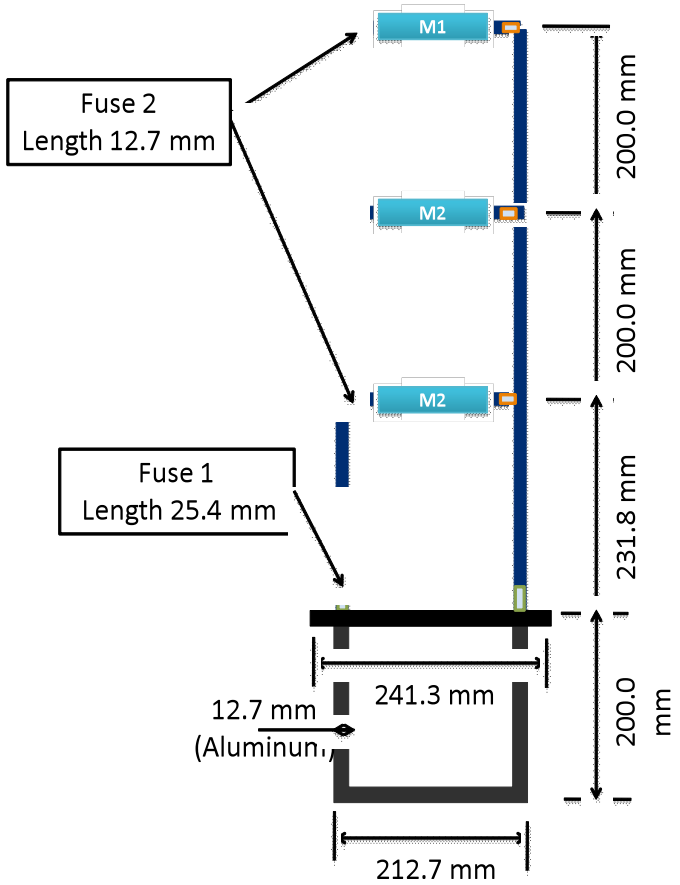


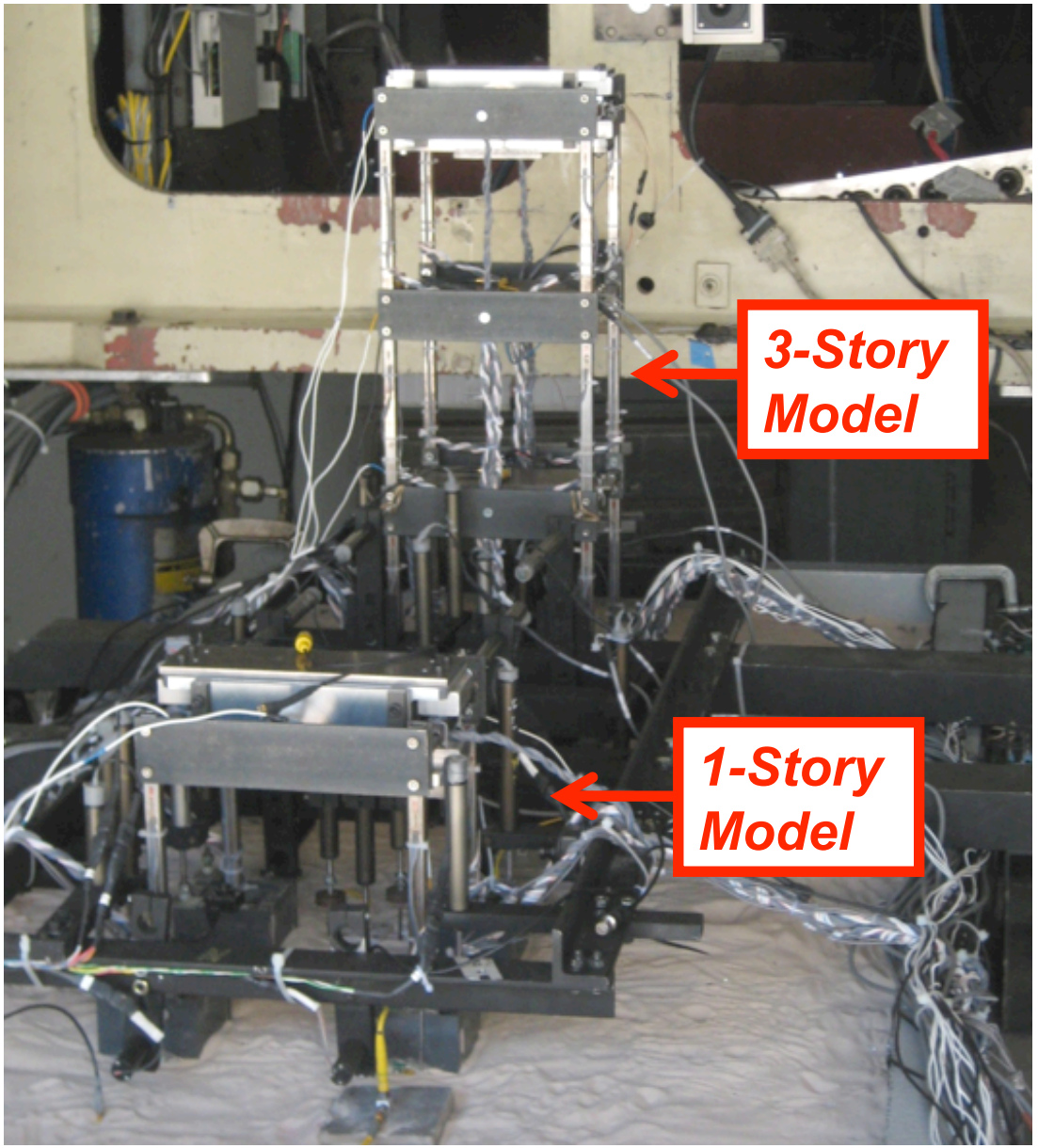
Smax



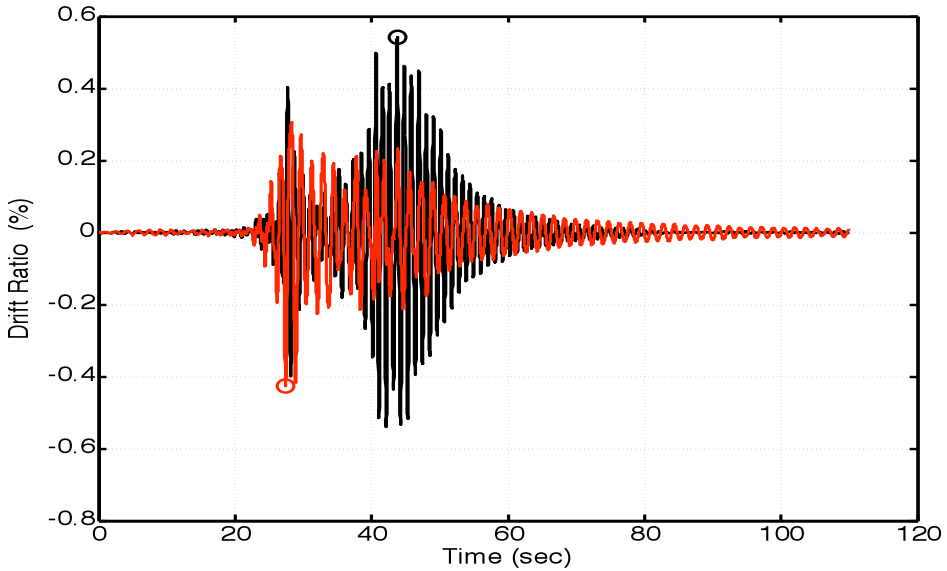
Application of Tools

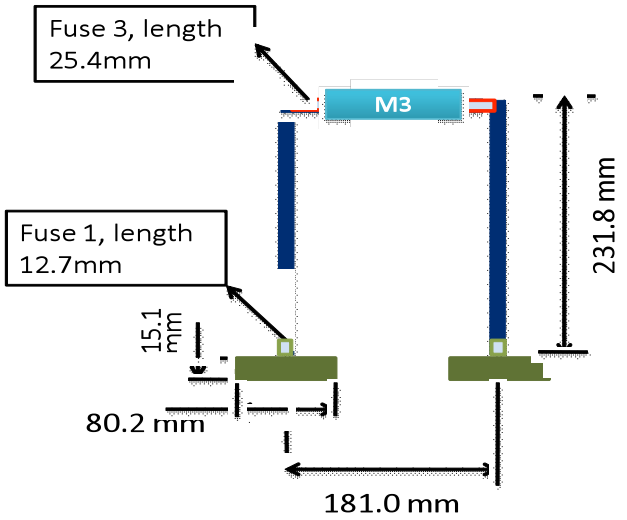
- NEESR "City Blocks" Pre-Test analysis





Pre-Test Predictions





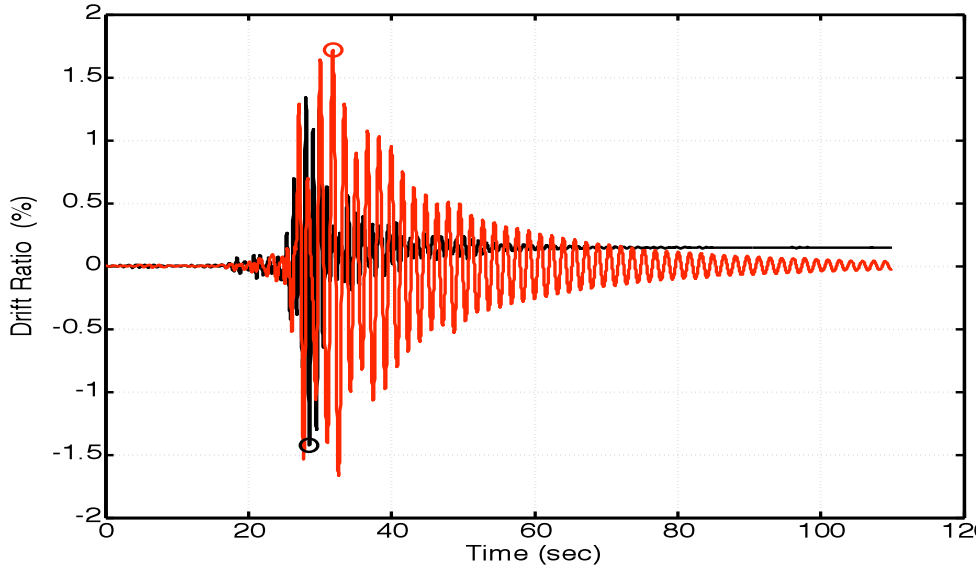
Fixed-base

BNWF model

1992 Landers, Joshua Tree Motion (Ord, LI)

- **Provide insight into motion protocol**
- **More reasonable evaluation of demands for final footing design as well as experimental (instrumentation) design**

1989 Loma Prieta, Saratoga Motion, (NF, HI)



Which model to use?

- **CIM:**
  - Straightforward implementation (7 input parameters)
  - Moment-shear-axial forces coupled
  - Structural footing not modeled
  - At present only available in OpenSees
- **BNWF:**
  - Straightforward implementation (15 input parameters)
  - Moment-shear-axial forces uncoupled
  - Structural footing modeled
  - At present available in OpenSees, however, concepts could be implemented by an analyst in other platforms

opensees.berkeley.edu

Outcomes

- **We hope to encourage use of these new tools by practice:**
  - **All data reports available on-line: cgm.engr.ucdavis.edu**
  - **OpenSees implementation and examples of various foundation-structural system models available at: opensees.berkeley.edu**
- **Findings from this work will help us:**
  - **Improve nonlinear static procedures**
  - **Improve accuracy of our nonlinear dynamic analyses capabilities**
  - **Provide improved confidence in the use of the foundation as an energy dissipative system**

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