Numerical Tools for Modeling Rocking Foundations

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Seismic Research Seminar

PEER & Caltrans

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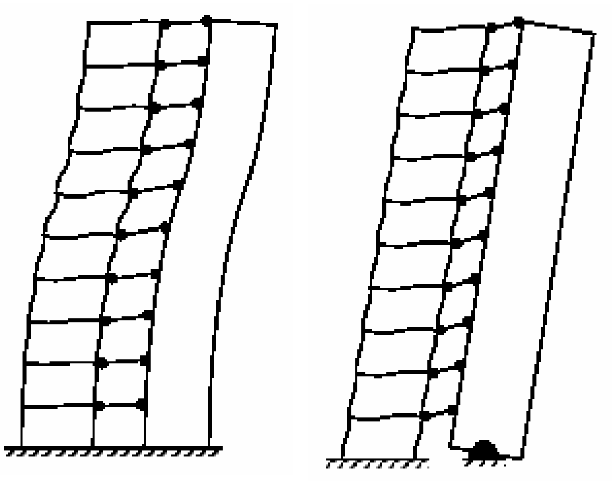


Collaborative Project

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

Two Models

- Contact Interface Model (CIM) [UC Davis]
- Beam-on-Nonlinear-Winkler (BNWF) model [UCSD]
- Implemented in OpenSees
- Calibrated with centrifuge (and other) experimental datasets
- Cross-comparised
- User input selection protocols, model documentation, and example files

Features of the Models

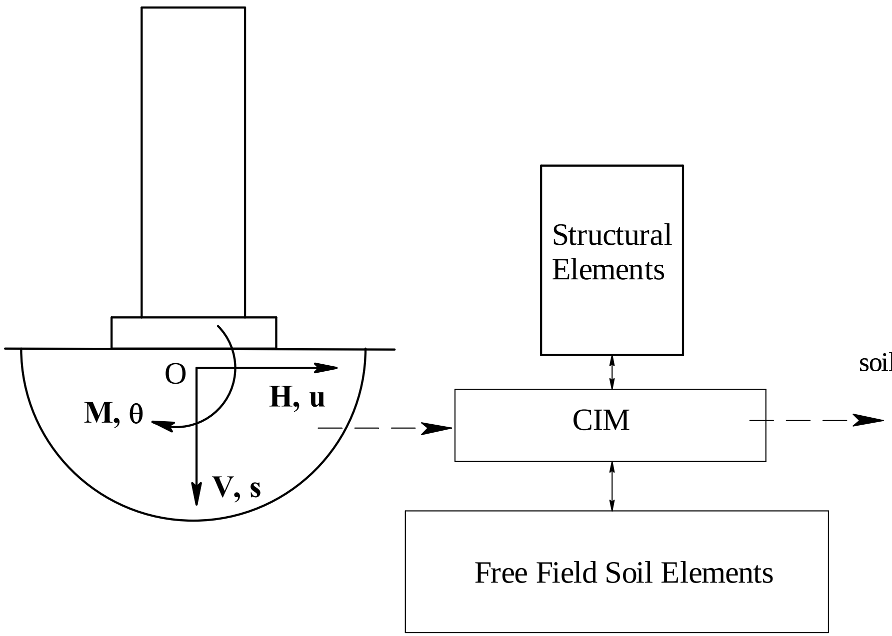
- Capture forces (Q, V, M) and deformations (s, v, θ) of (rocking-dominated) footings
  - i.e. quantify benefits and consequences during rocking
- Minimal number of input parameters for the user
- Packaged with well-developed parameter selection protocols for ease of use
- General use (buildings, bridges,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

Contact Interface Model (CIM)

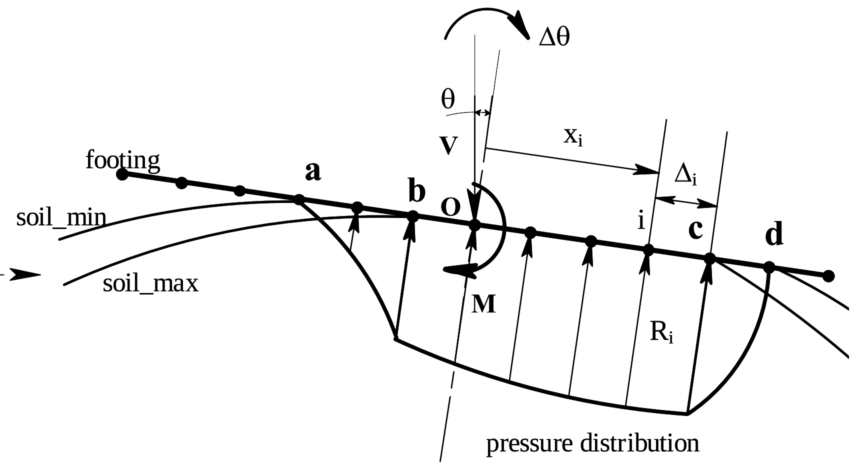
- **Lumps foundation and surrounding soil into one 'macro-model'**
- **Structural footing assumed rigid**
- **Couples foundation Q, V, *M* & deformations**
  - **V & *M*: Yield surface (interaction diagram) & associative flow rule**
  - **Q & *M*: tracking contact geometry**

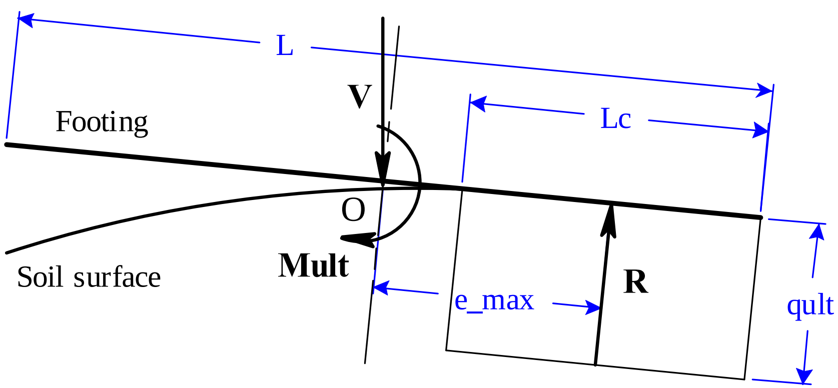
Gajan and Kutter (2008); Gajan (2007)

CIM

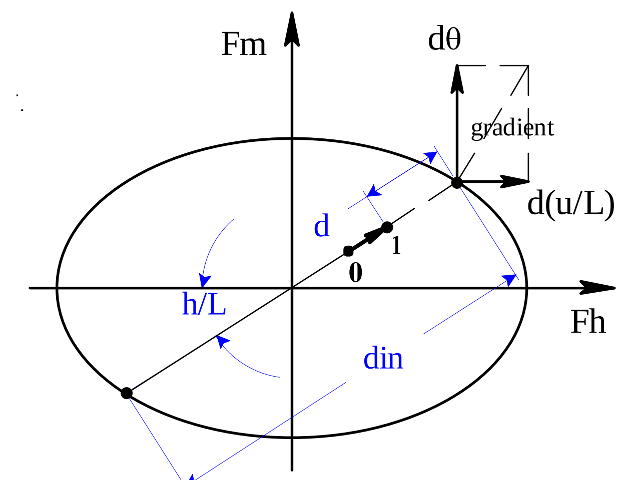


Framework





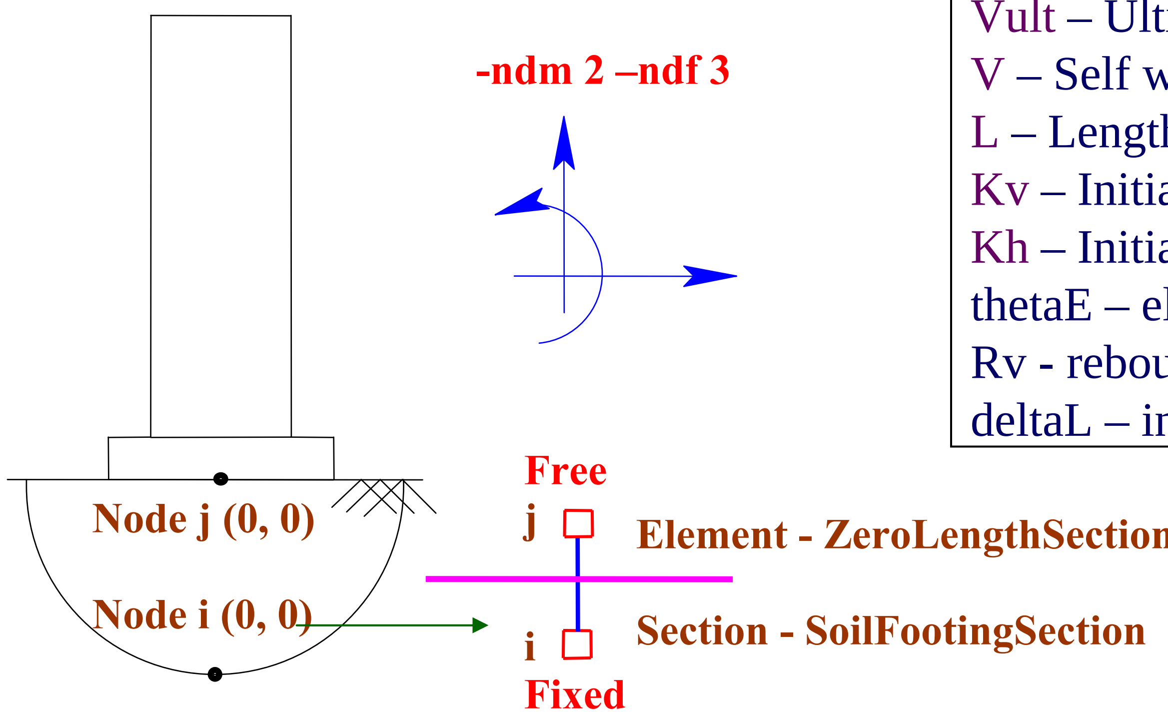
Critical Contact Length



M-H Bounding surface

CIM in OpenSees

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



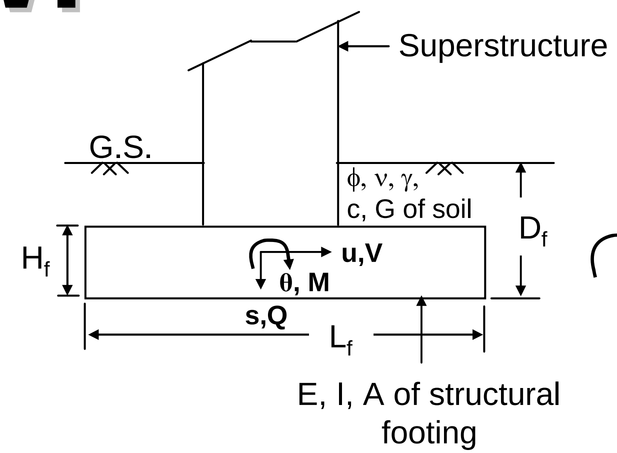
Vult – Ultimate vertical load
V – Self weight of the structure
L – Length of the footing
Kv – Initial vertical stiffness
Kh – Initial horizontal stiffness
thetaE – elastic rotation limit
Rv - rebound ratio
deltaL – internal footing node spacing

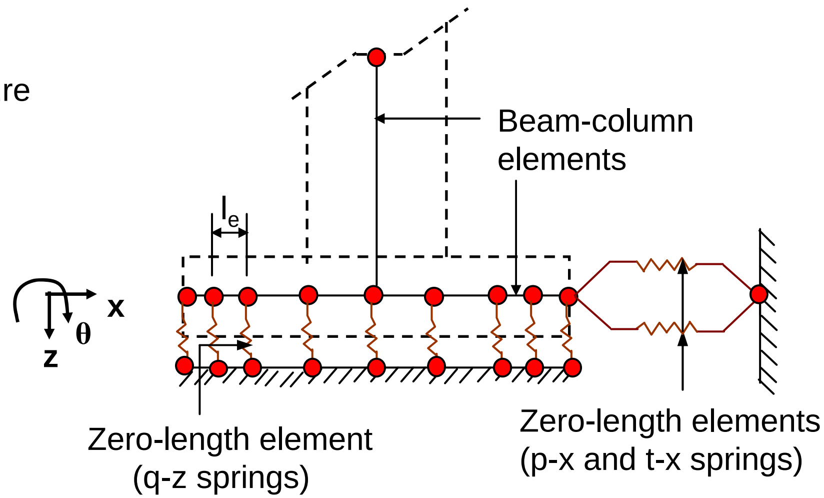
Beam-on-Nonlinear-Winkler (BNWF) Model

- Closely spaced, inelastic spring elements
- Vertical springs (θ, s); Lateral springs (v)
- Dashpots – radiation damping
- Gap elements – permanent deformations
- Large body of literature (extension of earlier pile-based formulations; Boulanger et al., 1999)
- Comfort level in practice

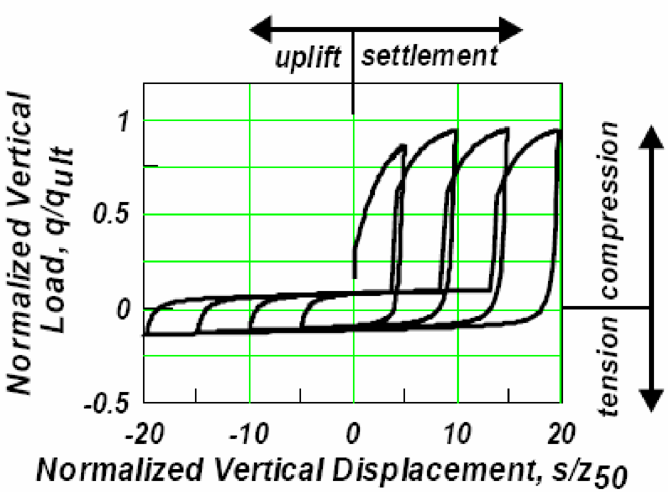
Raychowdhury (2008); Raychowdhury and Hutchinson (2009)

BNWF

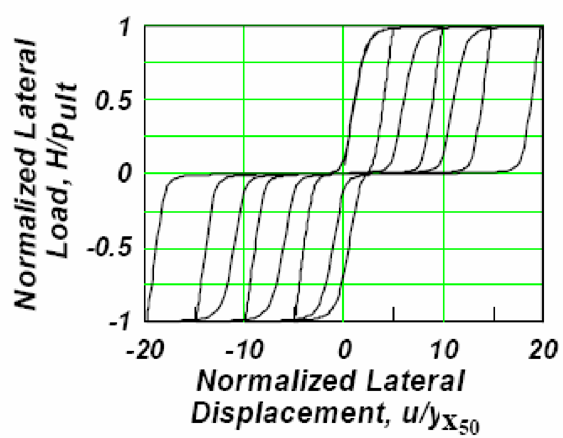




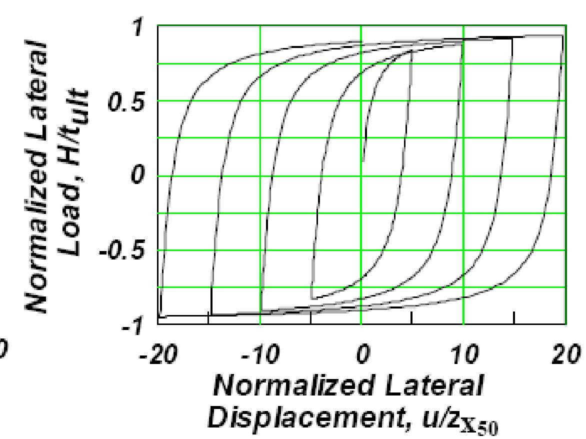
q-z springs



p-x springs



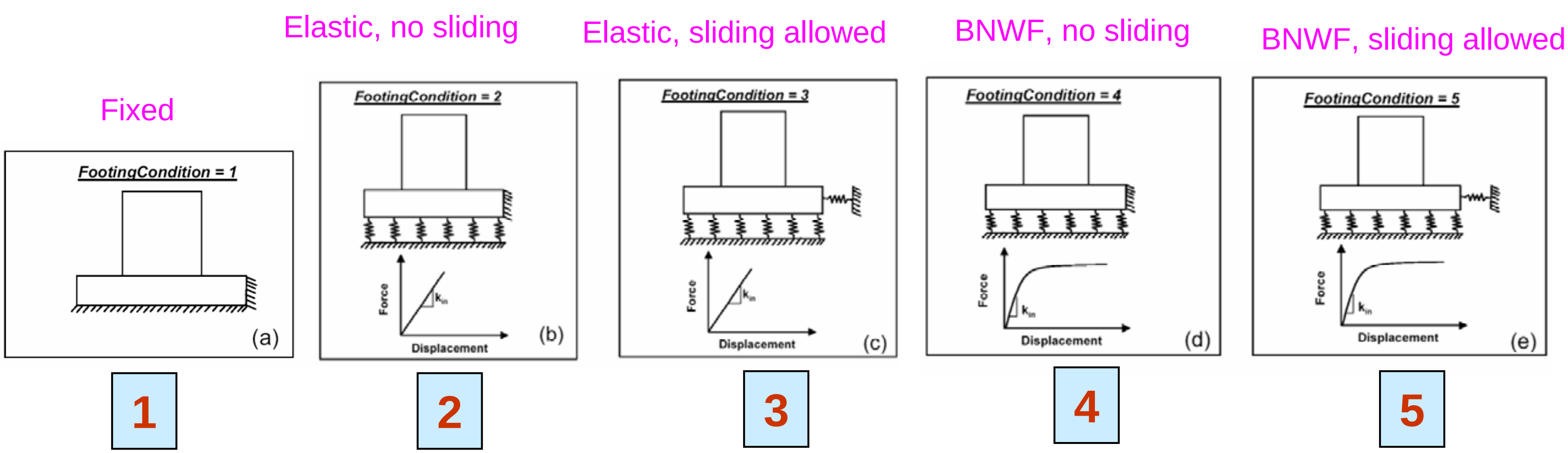
t-x springs



BNWF in OpenSees

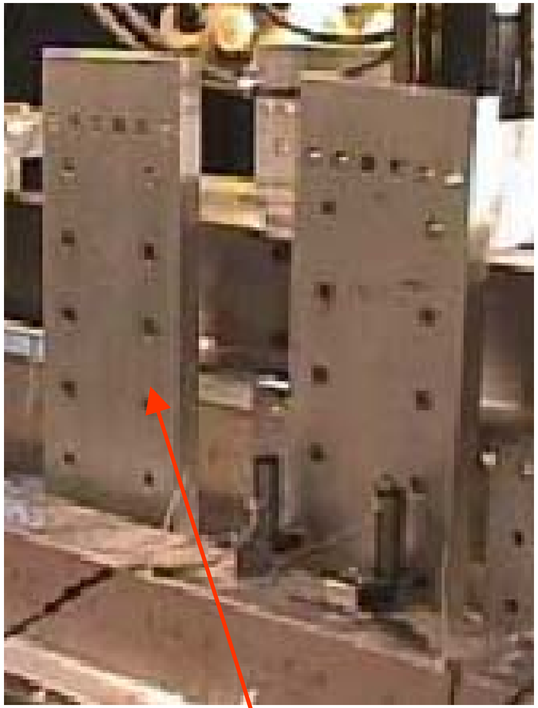
ShallowFoundationGen $FoundationTag $ConnectNode $InputFile $FootingCondition

- 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



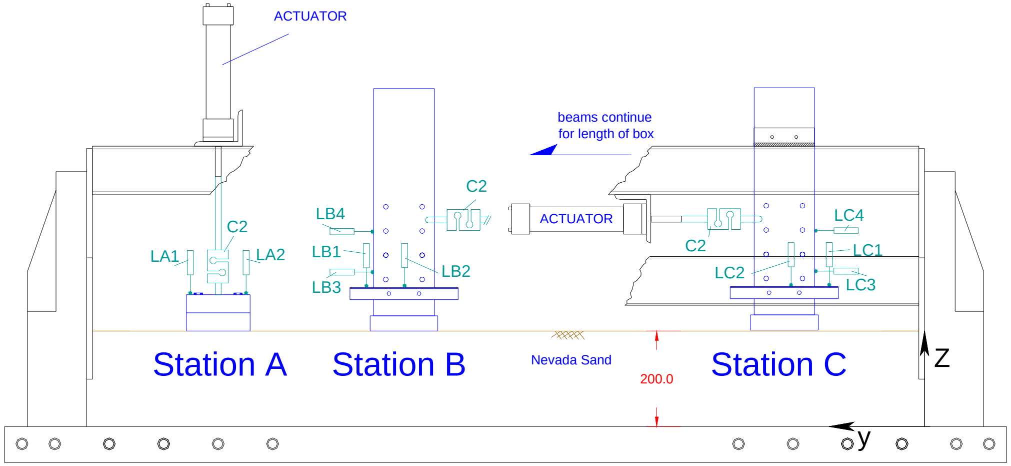
4 input parameters/spring type + 3 global mesh parameters = 15

Wall-Footing Experiments

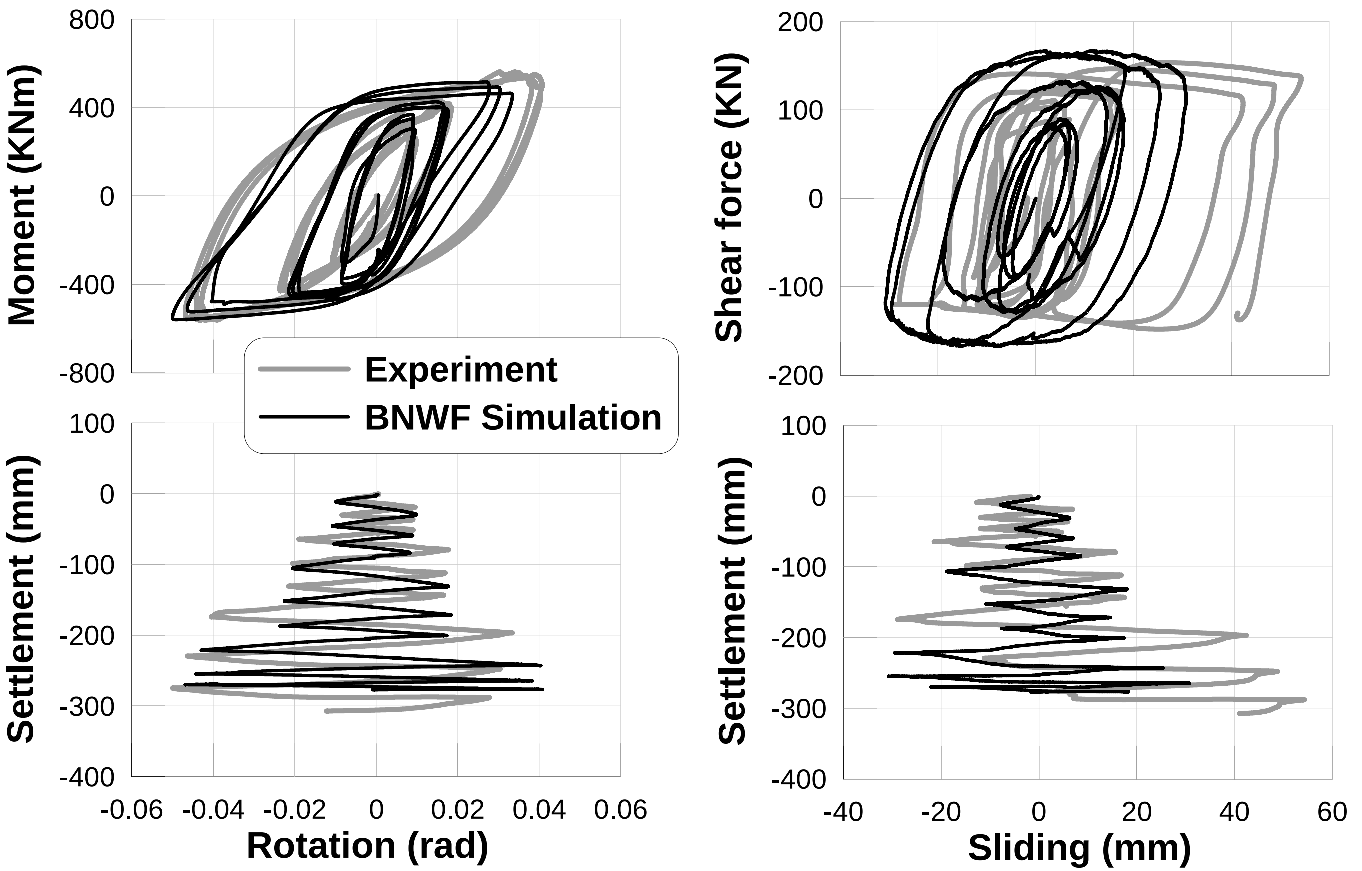


Planar wall-footing model

- Tests on clay and sand
- Varying embedment (0, B, 3B)
- Model wall-footing systems with range of FSv = 2-15
- Slow cyclic and dynamic loading



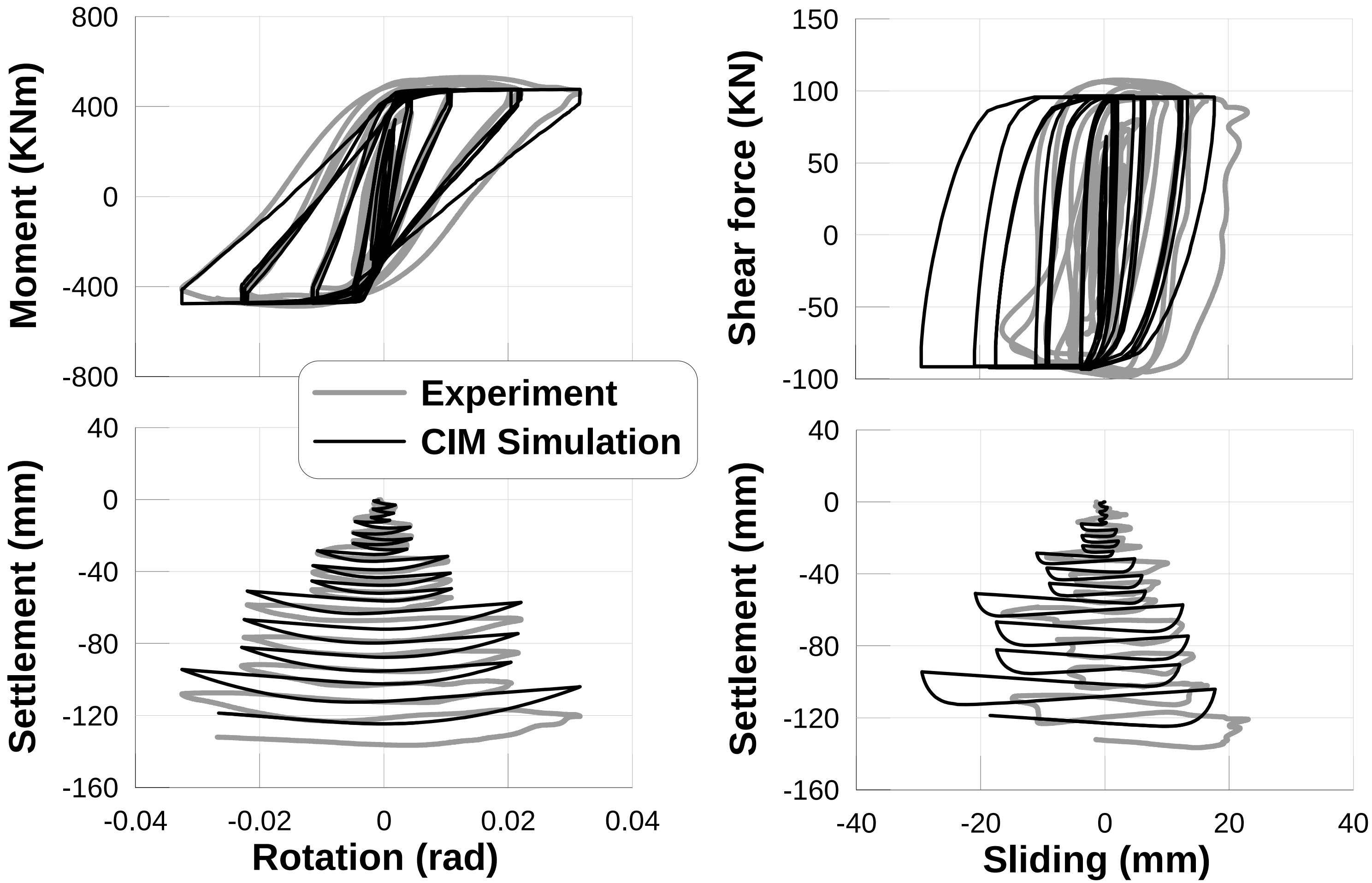
BNWF Experiment-Numerical Model Comparison



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

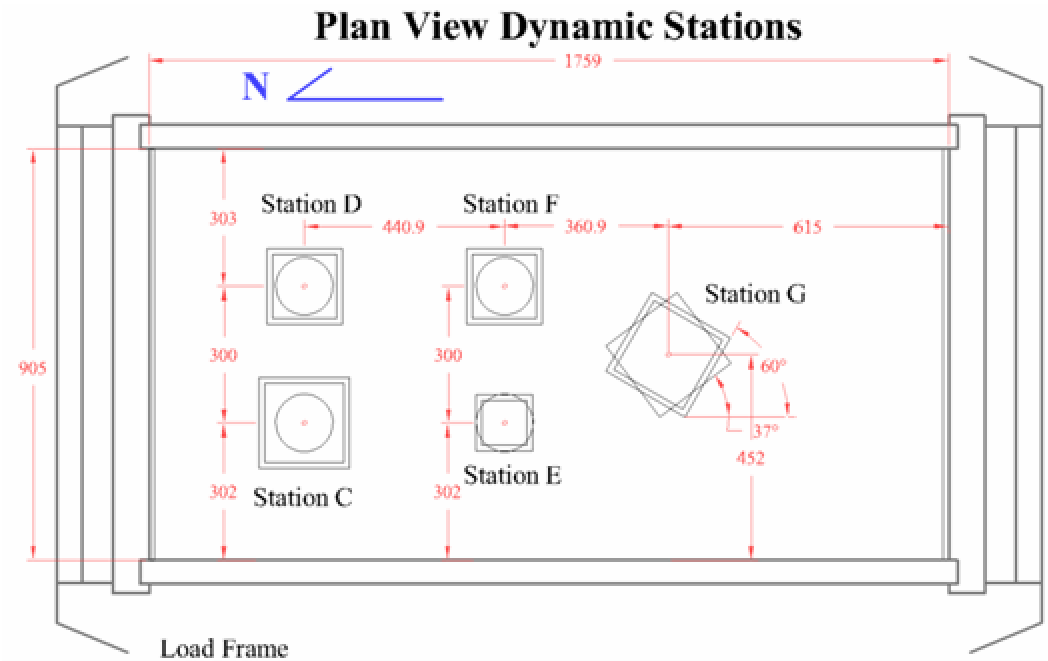
SSG04-06 test series by Gajan et al. (2006)

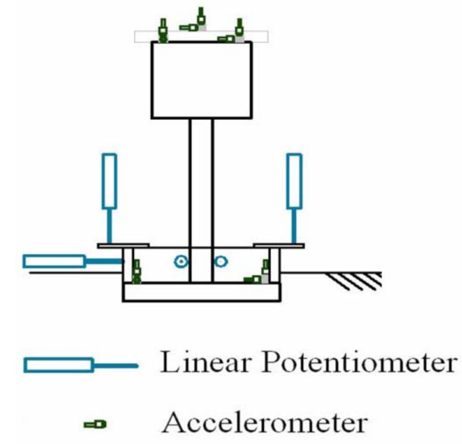
CIM Experiment-Numerical Model Comparison



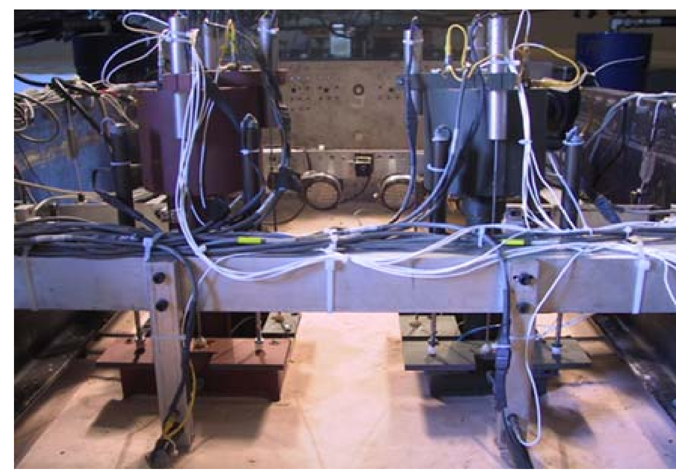
SSG02_05 centrifuge test (Dr = 80%, FS_v = 2.6, M/(H×L) = 1.72)

Comparison with Bridge Footing-Column Tests



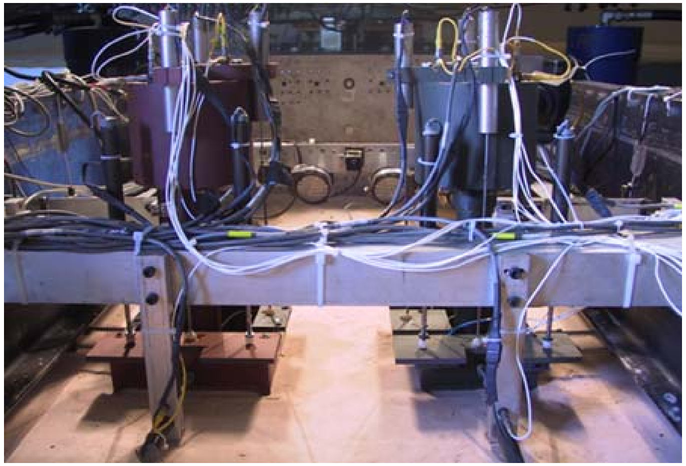


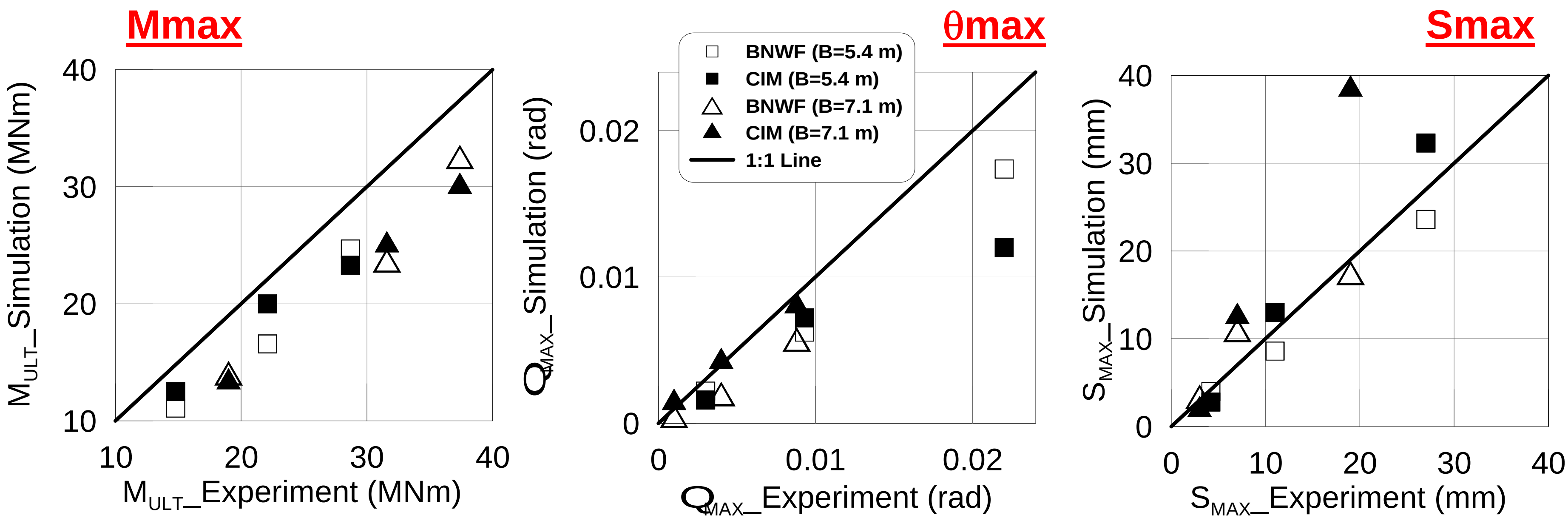
- Tests on sand; square footings
- Varying embedment (0.2-0.3B)
- FSv = 17 & 31; S controlled-design
- Earthquake base shaking



Ulgade et al., 2008

Comparison with Bridge Footing-Column Tests - Synthesis





Which model should I 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

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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