Rocking Foundations for Bridges

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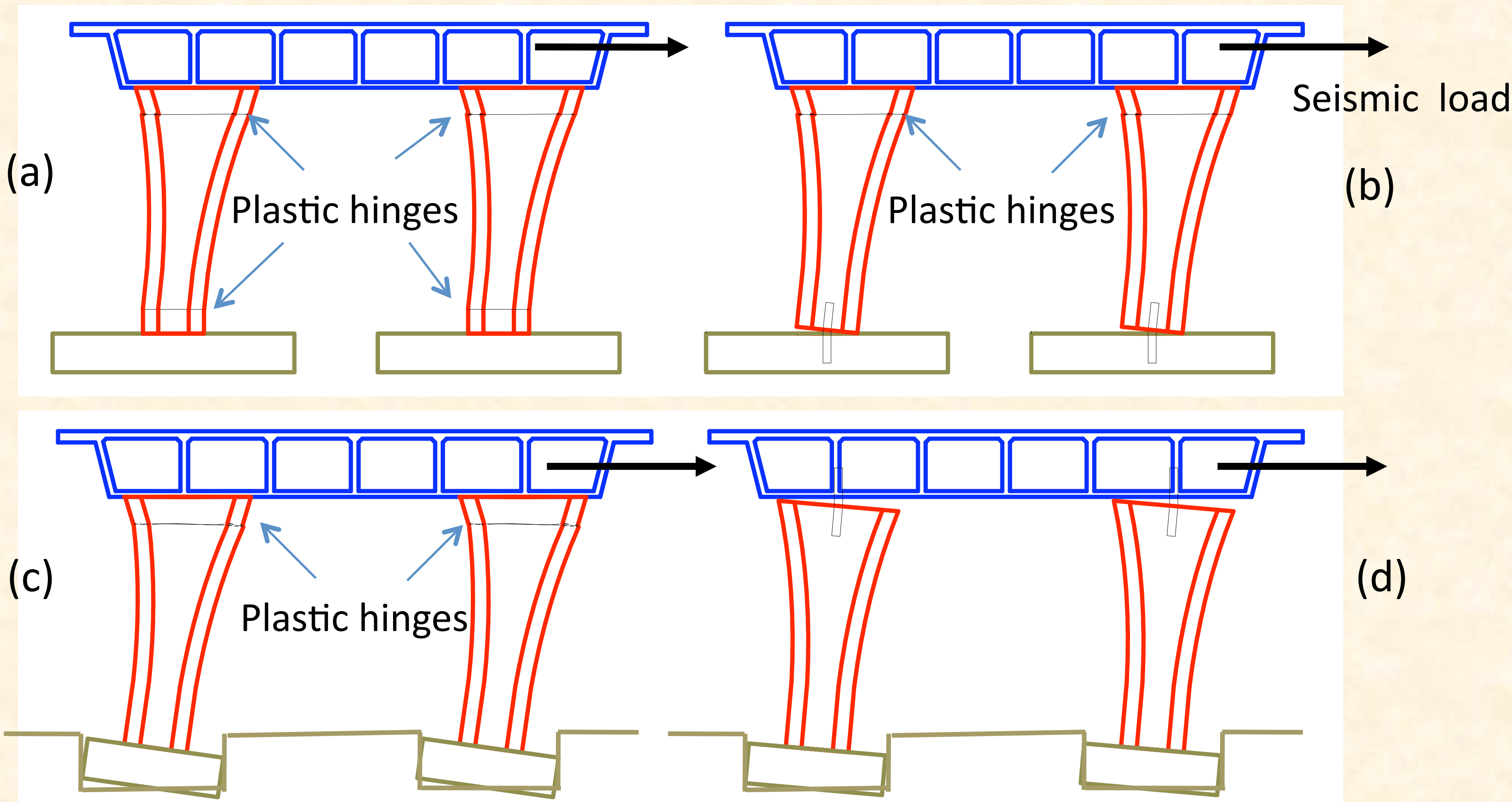
- Caltrans project (Mahin, Jeremic, Alameddine and Whitten)
- NEES@UCDavis, CGM staff, J. Ugalde, T. Algie of Univ. of Auckland, NZ.
- New project of rocking foundations for bridges) funded by PEER as of October 1.

Work for Caltrans: Idealized failure mechanisms

(a) fixed-fixed (b) fixed-hinged (c) fixed-rocking; (d) hinged-rocking



Column is protected by rocking isolation in case (d)

Caltrans SDC: *"foundation components shall be designed to remain essentially elastic when resisting the plastic hinging moments"*.

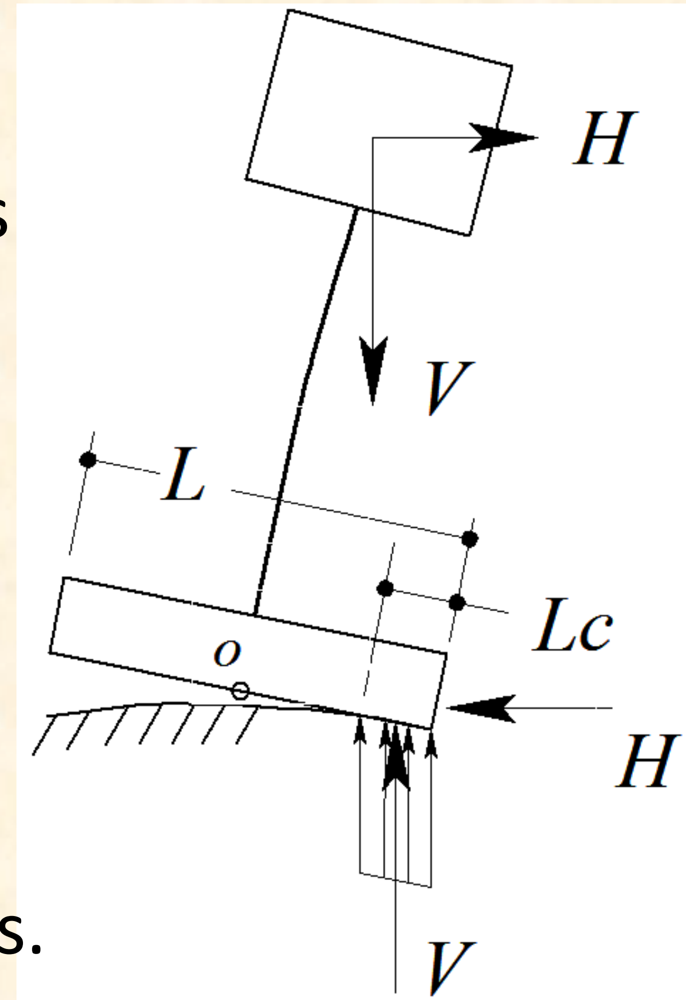
Destroyed columns from 1995 Kobe earthquake

Inspectable, controllable with proper reinforcing, but catastrophic results if ductility capacity is exceeded.

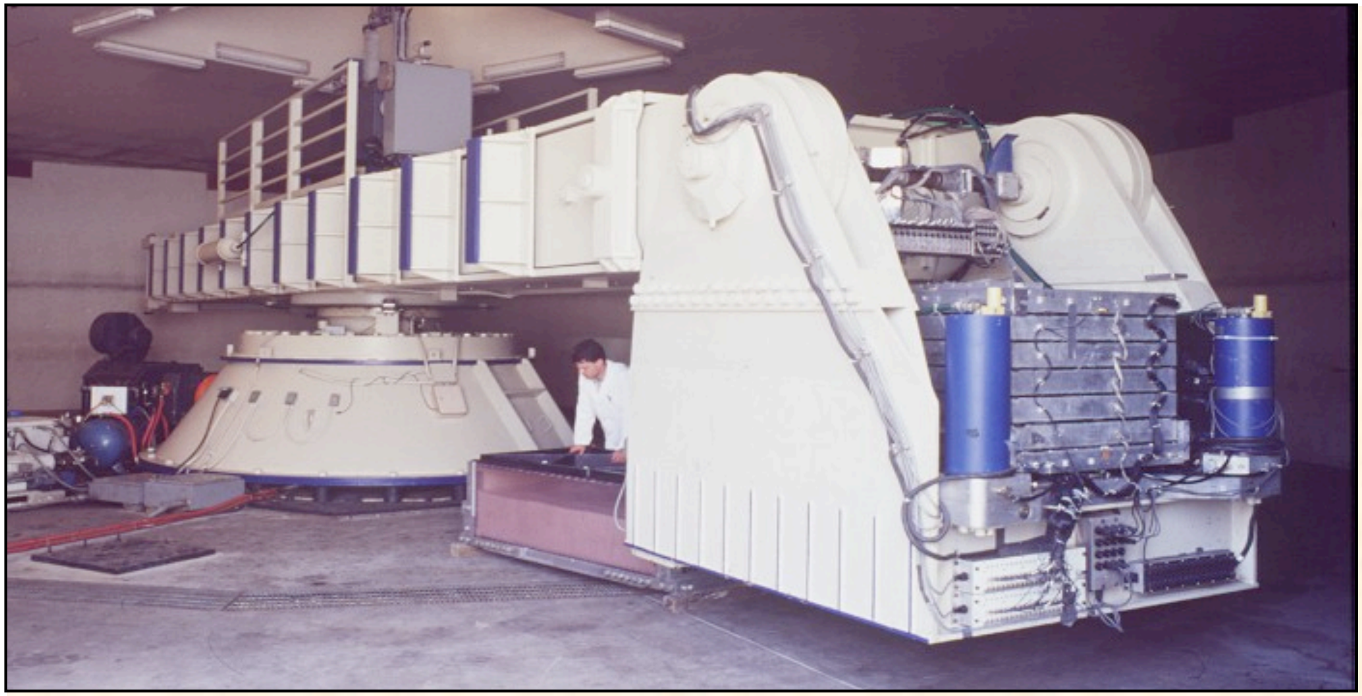
Definitions and basic concepts

- There is a critical (minimum) contact length, Lc, required to support the vertical load, V.
- Moment capacity (from equilibrium) is

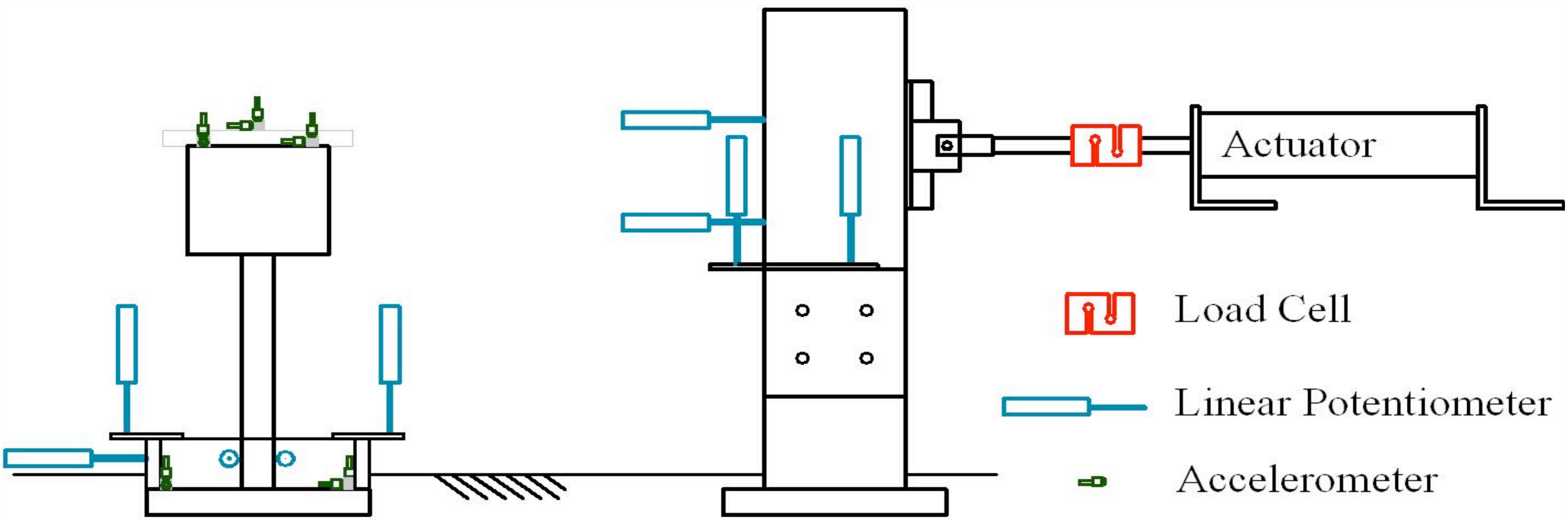
$$M_{o,ult} = V\frac{L}{2}\left[1-\frac{L_c}{L}\right]$$



- $L_c/L << 1$ for typical bridge foundations.
- $\therefore M_{o,ult}$ is insensitive to L_c/L



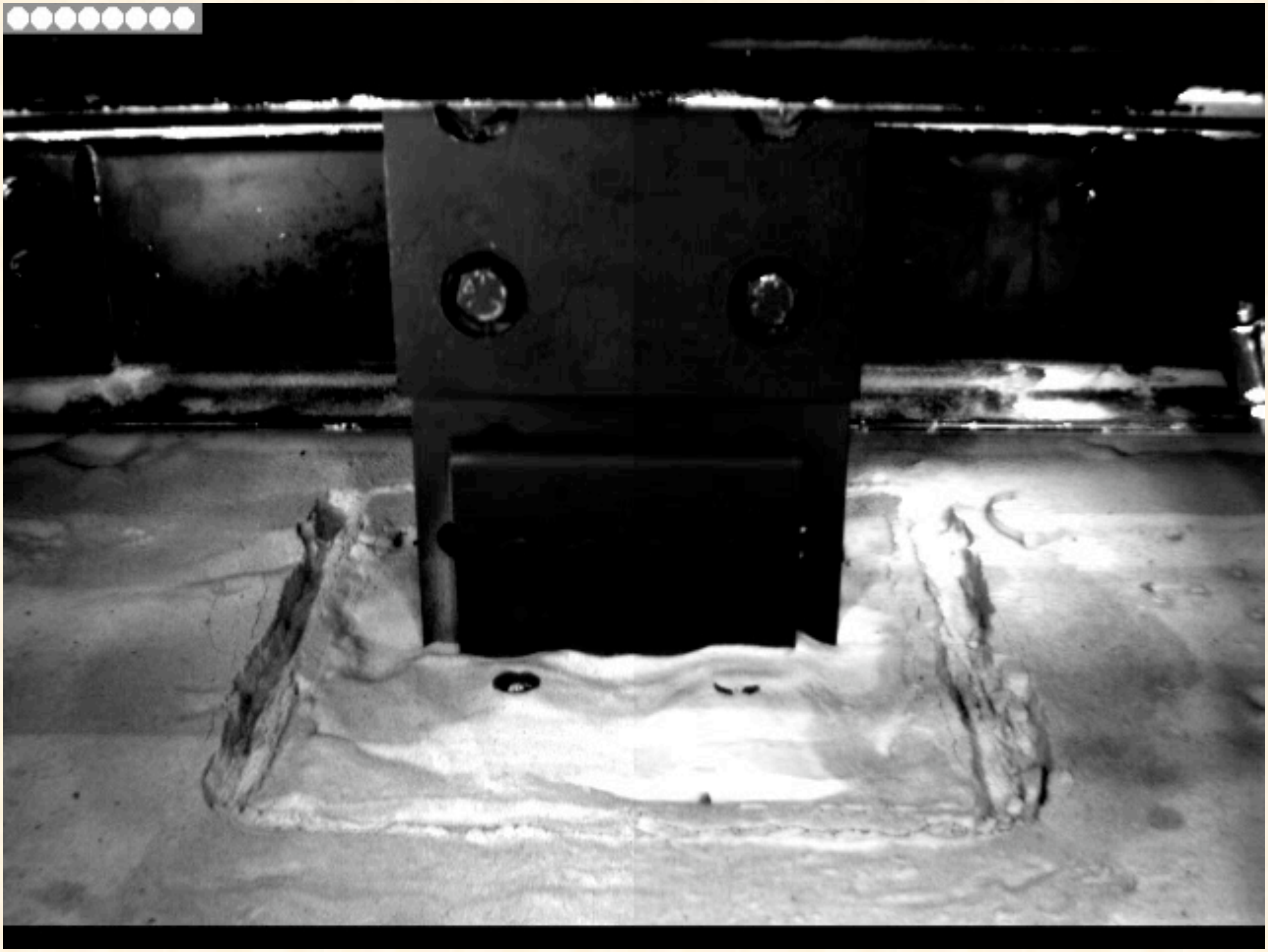
Dynamic base-shaking and slow cyclic loading tests on the 9 m radius NEES geotechnical centrifuge at UC Davis.



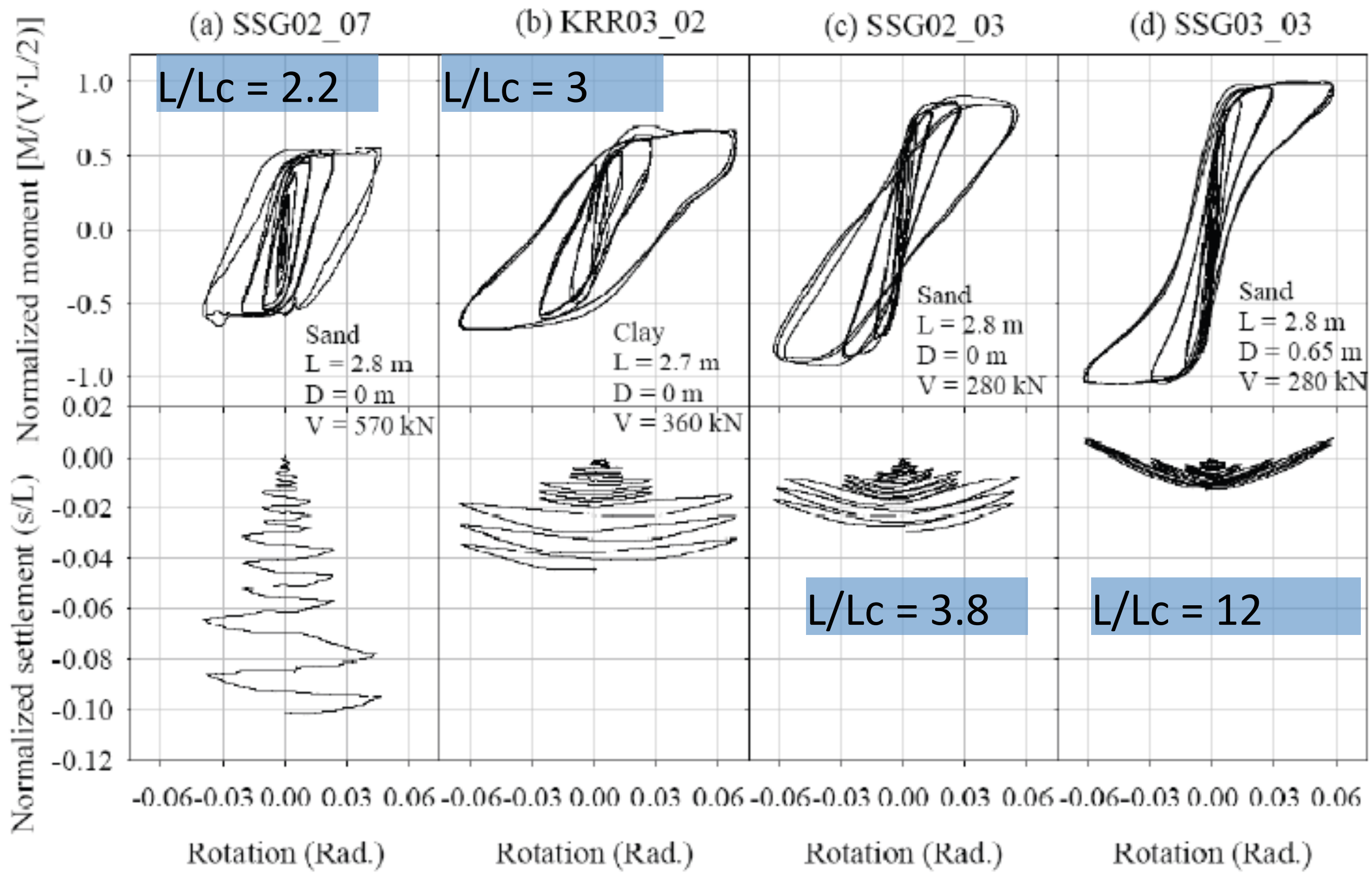
Base shaking tests

Slow cyclic loading tests

Ugalde movie – L/Lc ~ 30 to 50



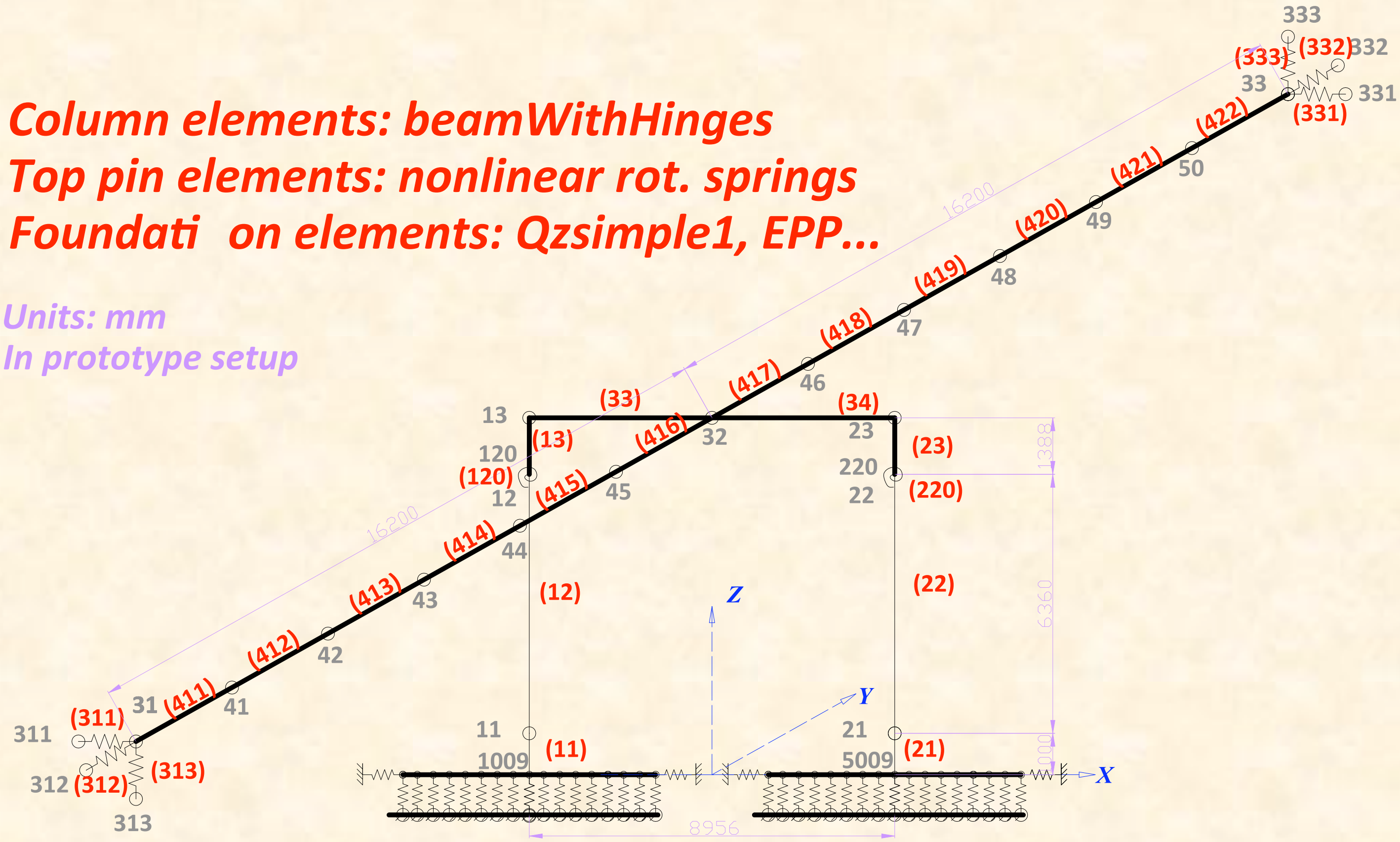
Moment-rotation-settlement behavior of rocking foundation from slow cyclic tests

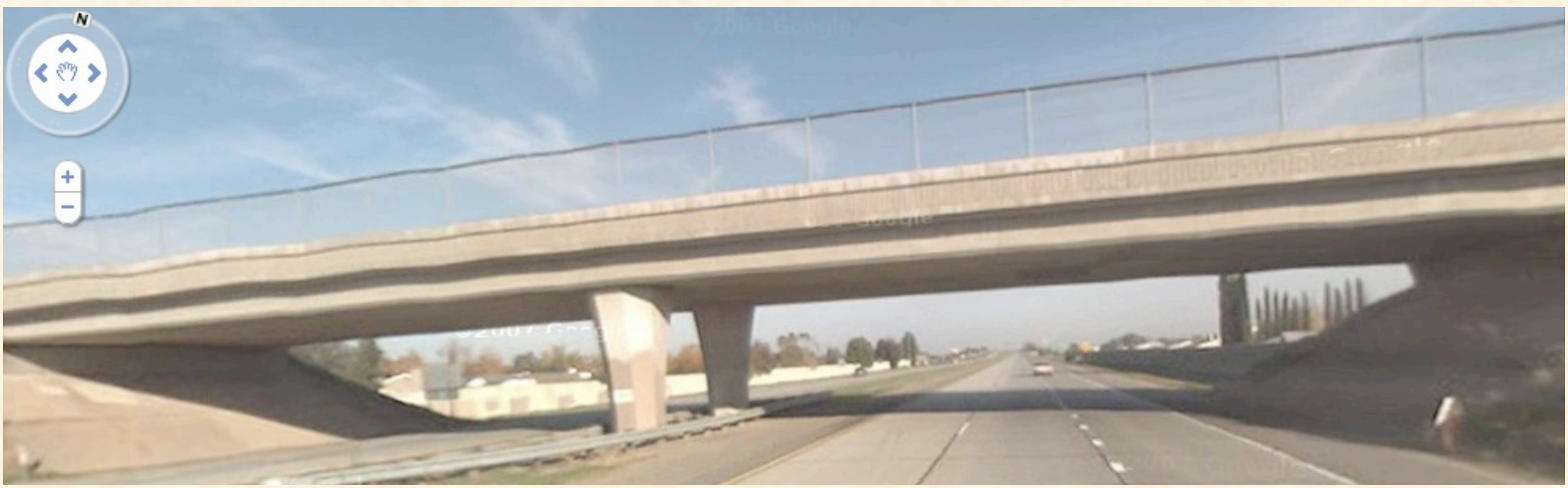


Bridge System Concepts

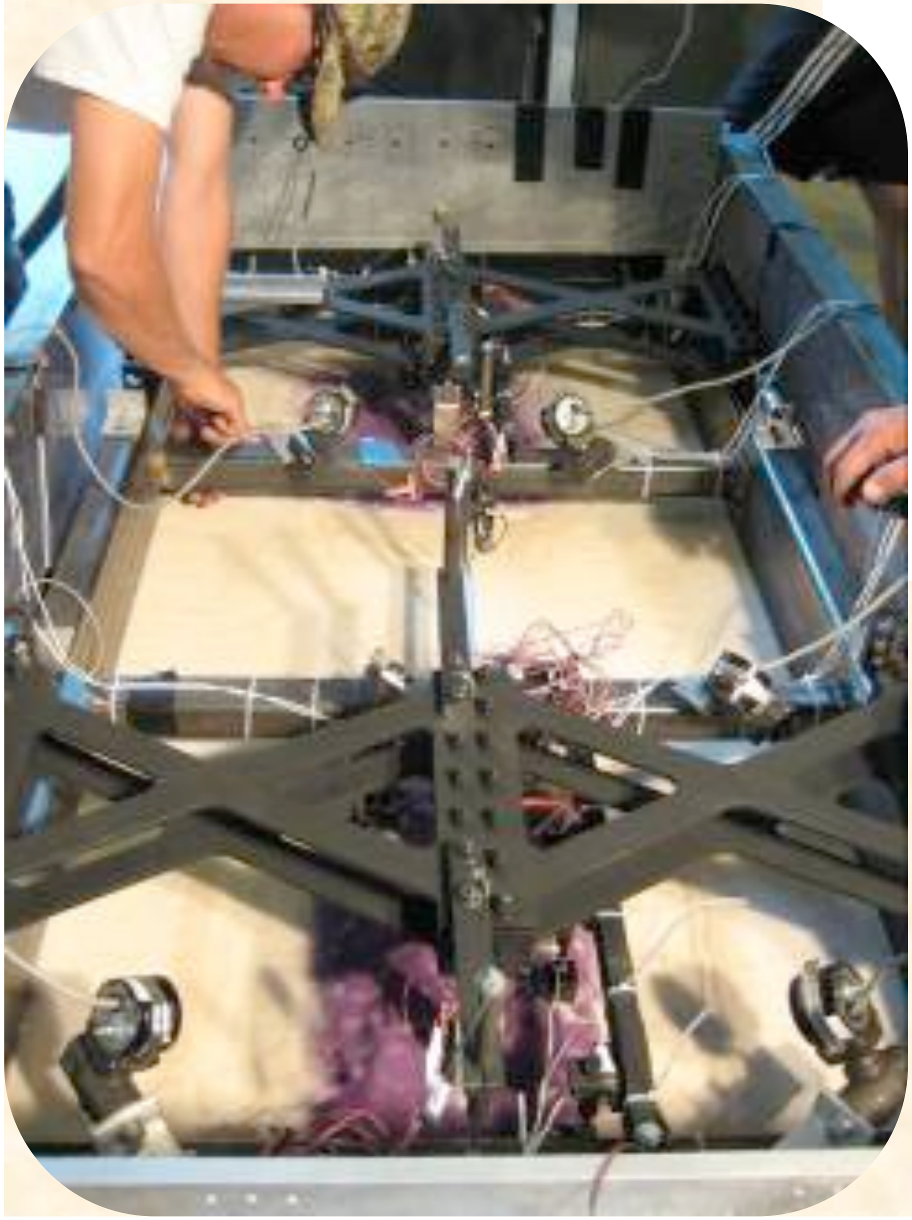
Column elements: beamWithHinges
Top pin elements: nonlinear rot. springs
Foundati on elements: Qzsimple1, EPP...

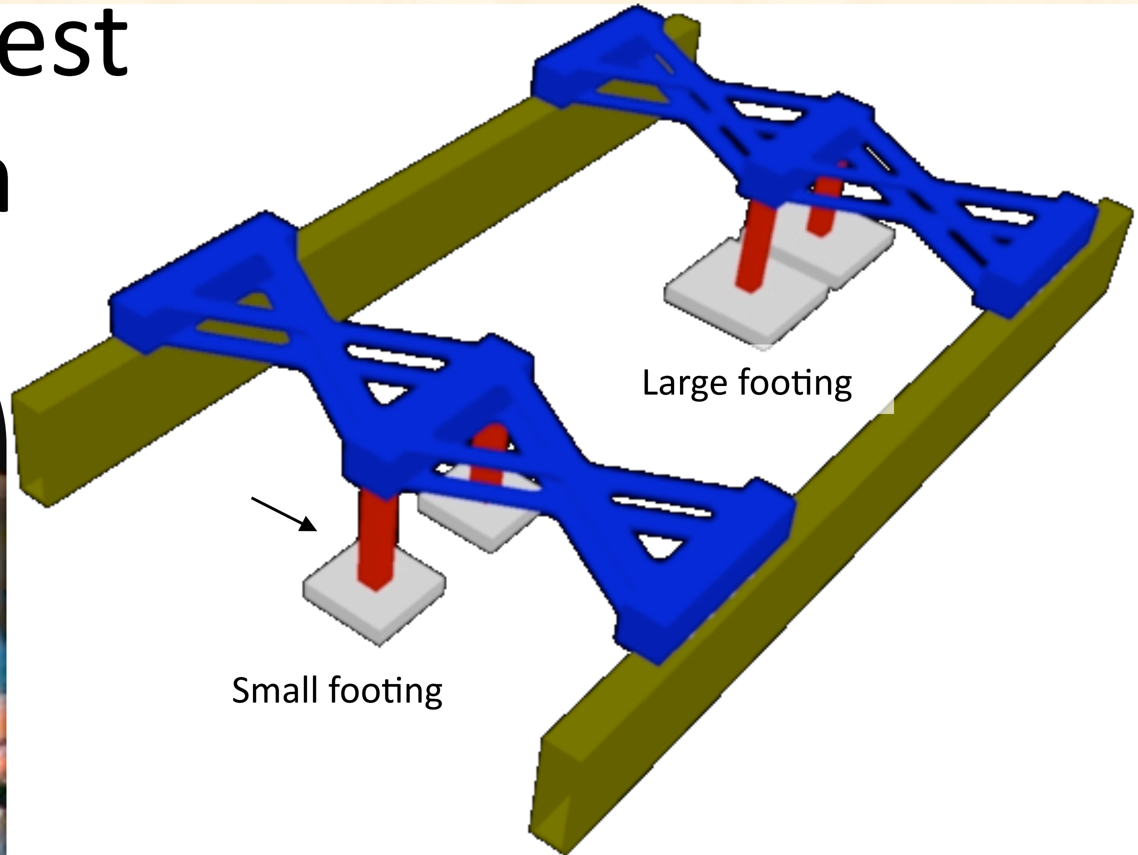
Units: mm
In prototype setup



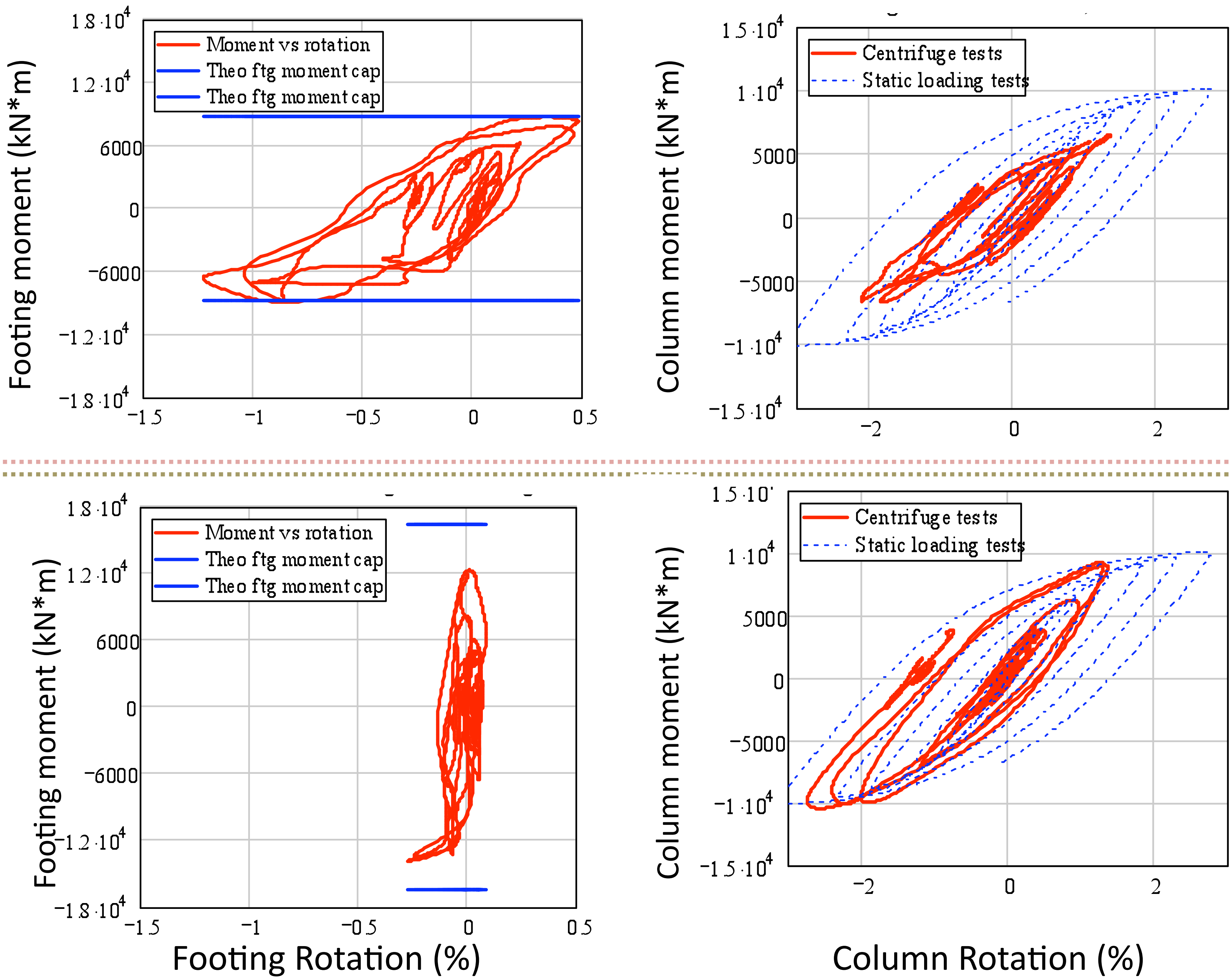


Bridge system test configuration





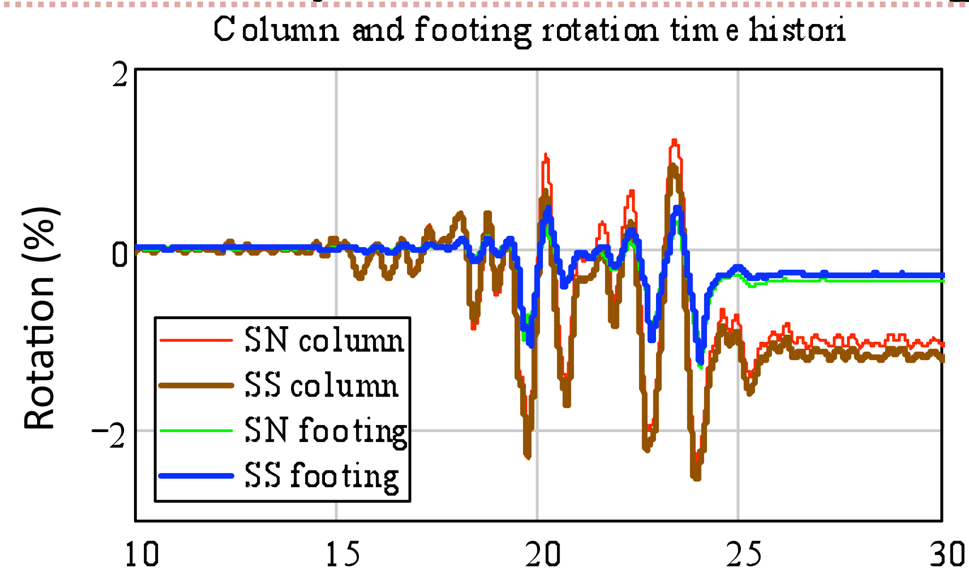
LJD02_15 event: Gazli 2.0

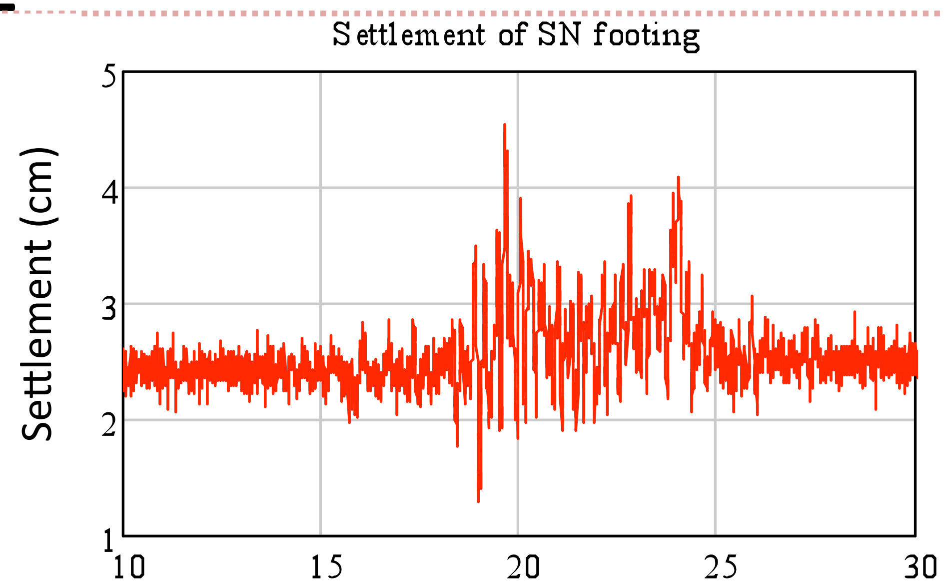


Small-footing bridge

Large-footing bridge

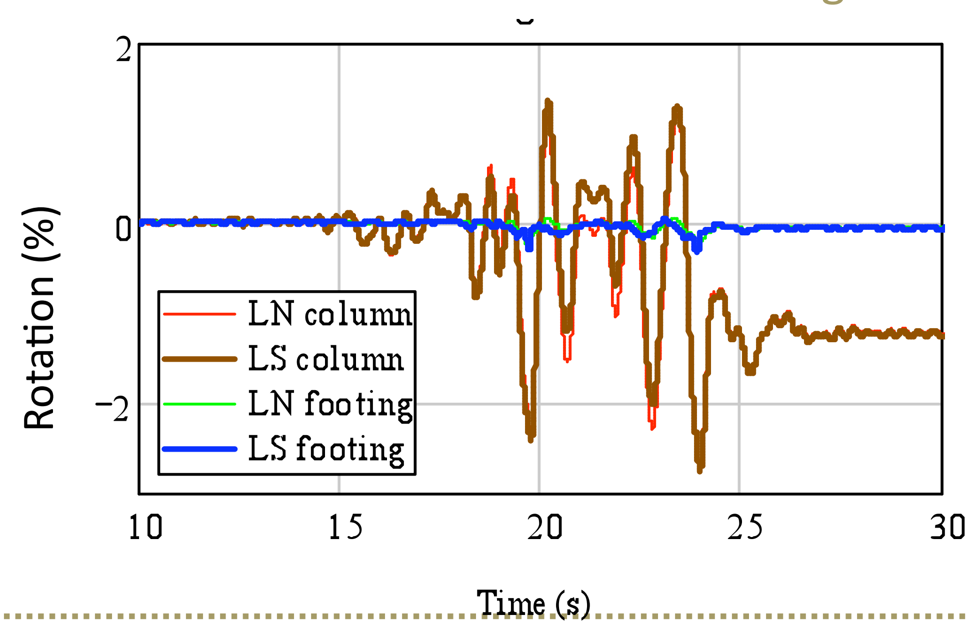
Critical plots of LJD02_15 event: Gazli 2.0

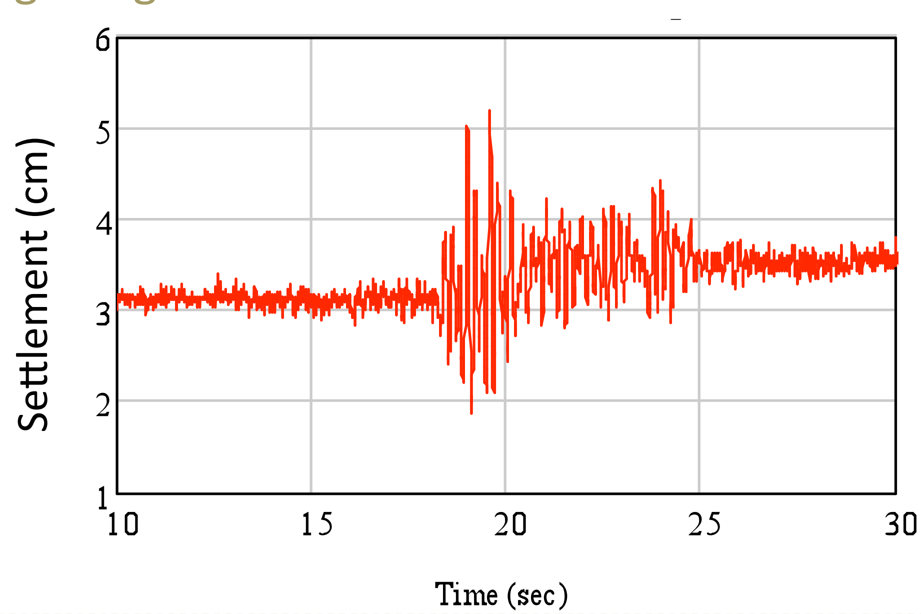




Small-footing bridge

Large-footing bridge





Learned from experiments

- Systems with small footings may perform better than systems with large footings
  - drift, ductility demand on columns
- Rocking foundations provide
  - Self-centering tendency
  - Non-degrading, well defined moment capacity
  - Isolation mechanism
  - Energy dissipation
- Difficult aspect of the problem: How to evaluate settlement (or uplift) associated with rocking.
  - But, magnitude of settlements is not unreasonable.

Draft Design Procedure for Bridges with Rocking Foundations

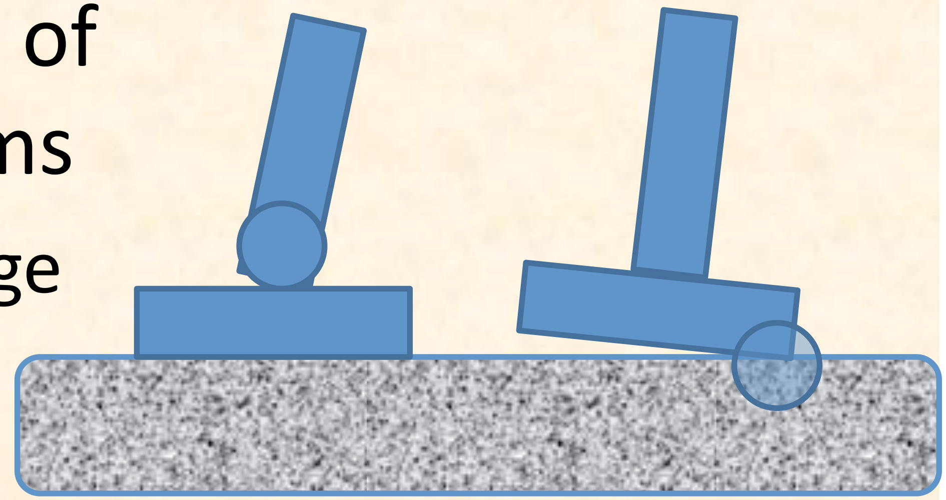
1. Determine design ground motions, site conditions, design spectra.
2. Determine superstructure information, geometry, dead loads and live loads, abutment constraints.
3. Estimate distribution of dead load on footings.
4. Size footings based on settlement considerations. L/Lc > ~10 and "yield acceleration" large enough to limit drift to acceptable levels.
5. Preliminary column design: sized to make their moment capacity greater than the footing moment capacity.

Draft Design Procedure for Bridges with Rocking Foundations

6. Confirm that drift and settlement do not violate serviceability limits in Functional Evaluation Earthquake. If drift is too large increase "yield acceleration"
7. No collapse in Maximum Considered Earthquake.
8. Check distribution of dead load on the footings (assumption in step 3).
9. Final design of columns

Hurdles to implementation of Rocking Foundations for Bridges

- Overcome excessive fear of tip over of rocking systems
  - A hinge is a hinge is a hinge *(Mark Moore)*

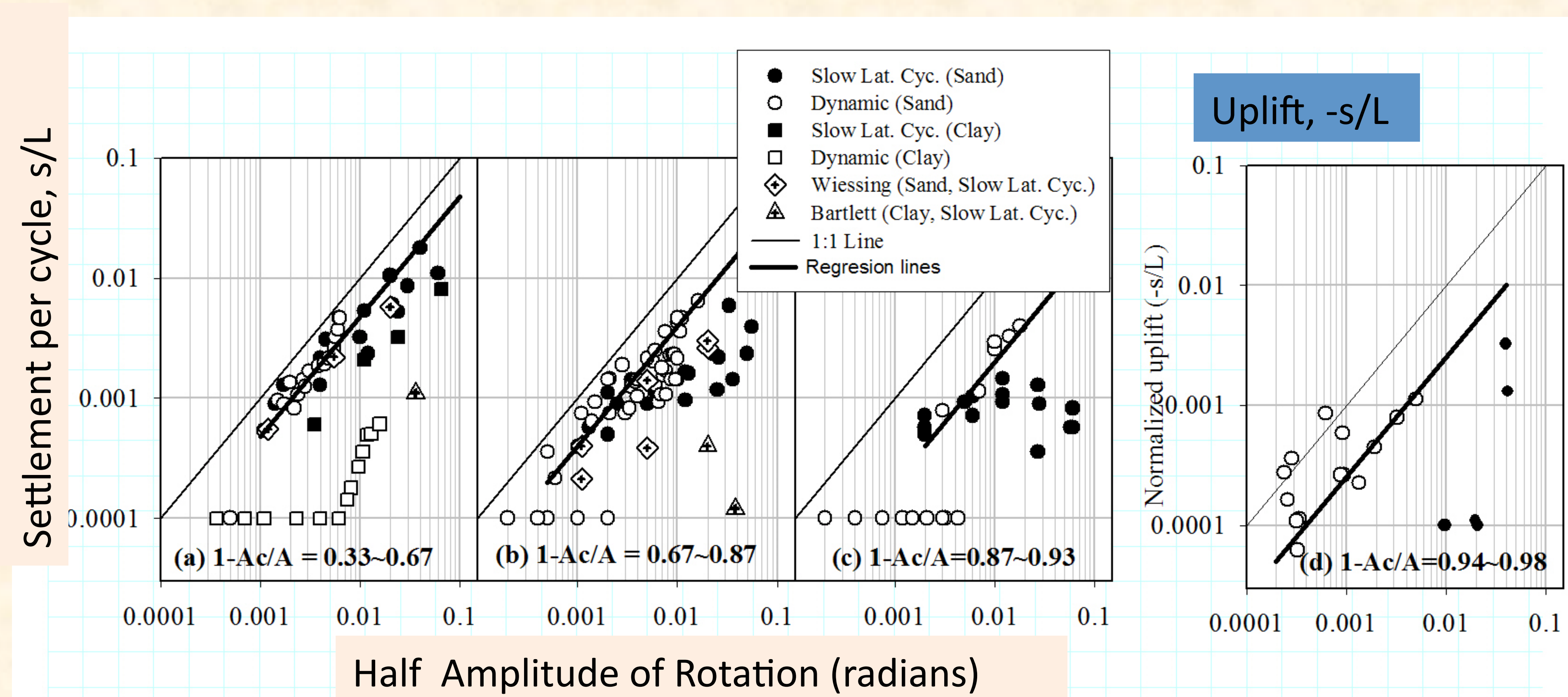


- Misconception that moment capacity of "soil" is highly uncertain

$$M_{o,ult} = V\frac{L}{2}\left[1 - \frac{L_c}{L}\right]$$

Hurdles to implementation of Rocking Foundations for Bridges

- Settlement assessment

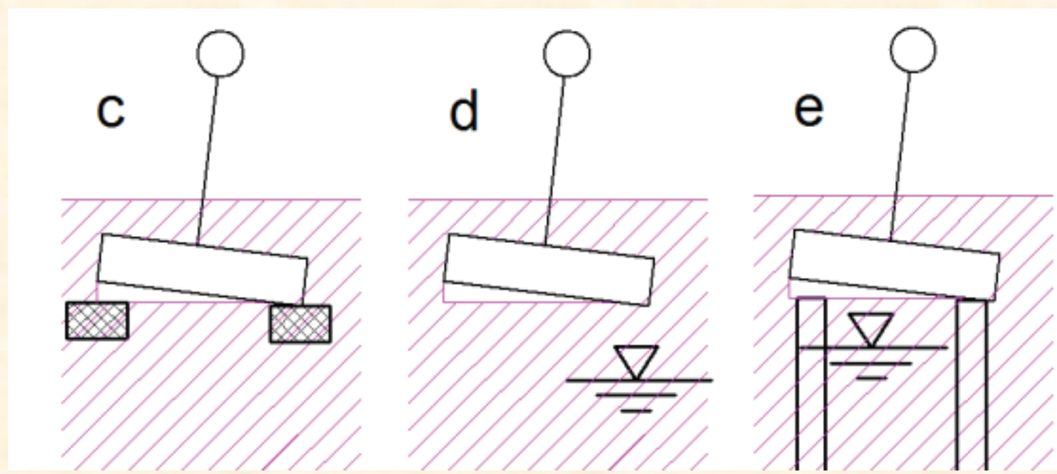


Small FS_v

Large FS_v

Hurdles to implementation of Rocking Foundations for Bridges

- Develop draft design procedure
  - Work with Caltrans engineers to address concerns and make it workable and understandable
- Revise seismic design guidelines
- Determine limits of applicability (liquefaction, water table, soft ground)
  - ground improvement
  - may extend limits



- Thanks again to PEER, Caltrans, and NSF