Testing and design of bridge deck-column-rocking foundation systems

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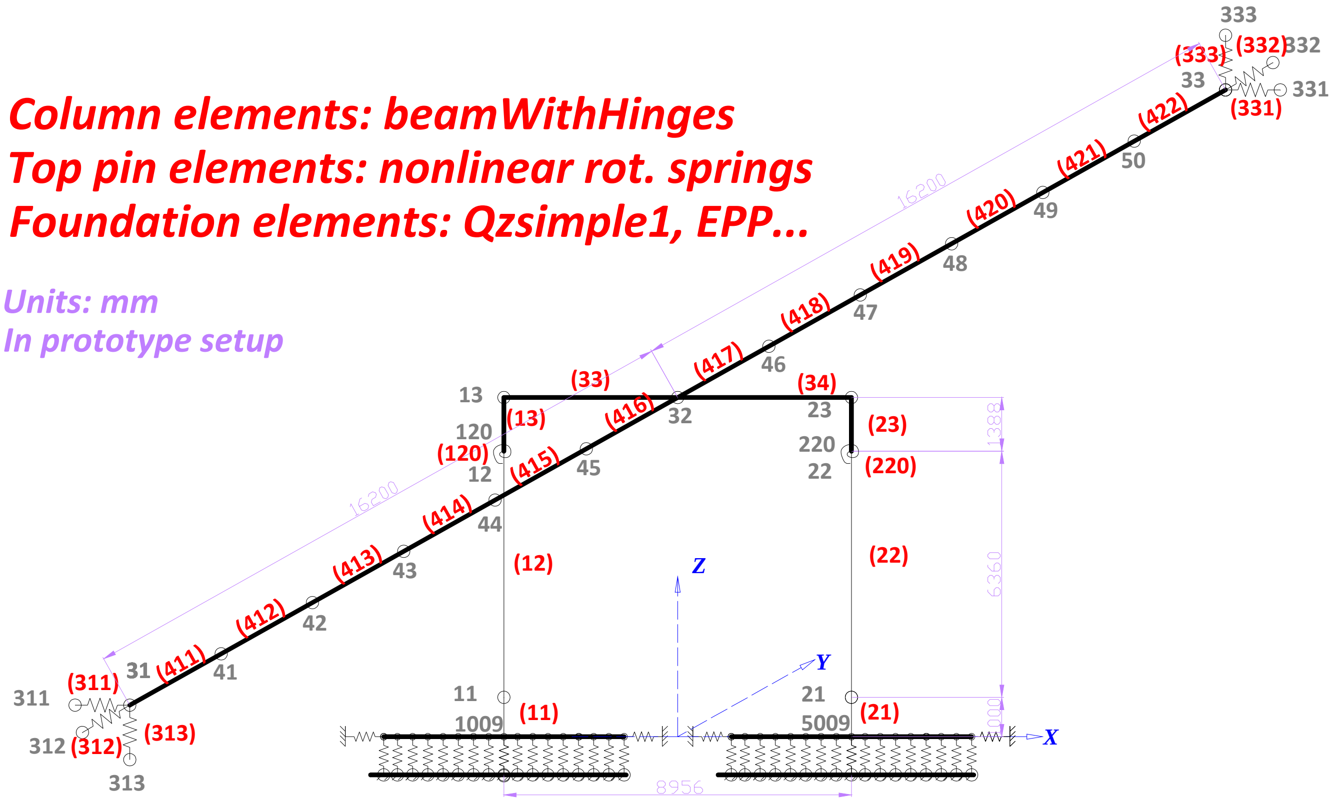
Outline

- System concepts
- Centrifuge tests and results
- Good observed performance of rocking foundations
- Draft design procedure
- Conclusions, questions, and future work

System Concepts

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

Units: mm
In prototype setup



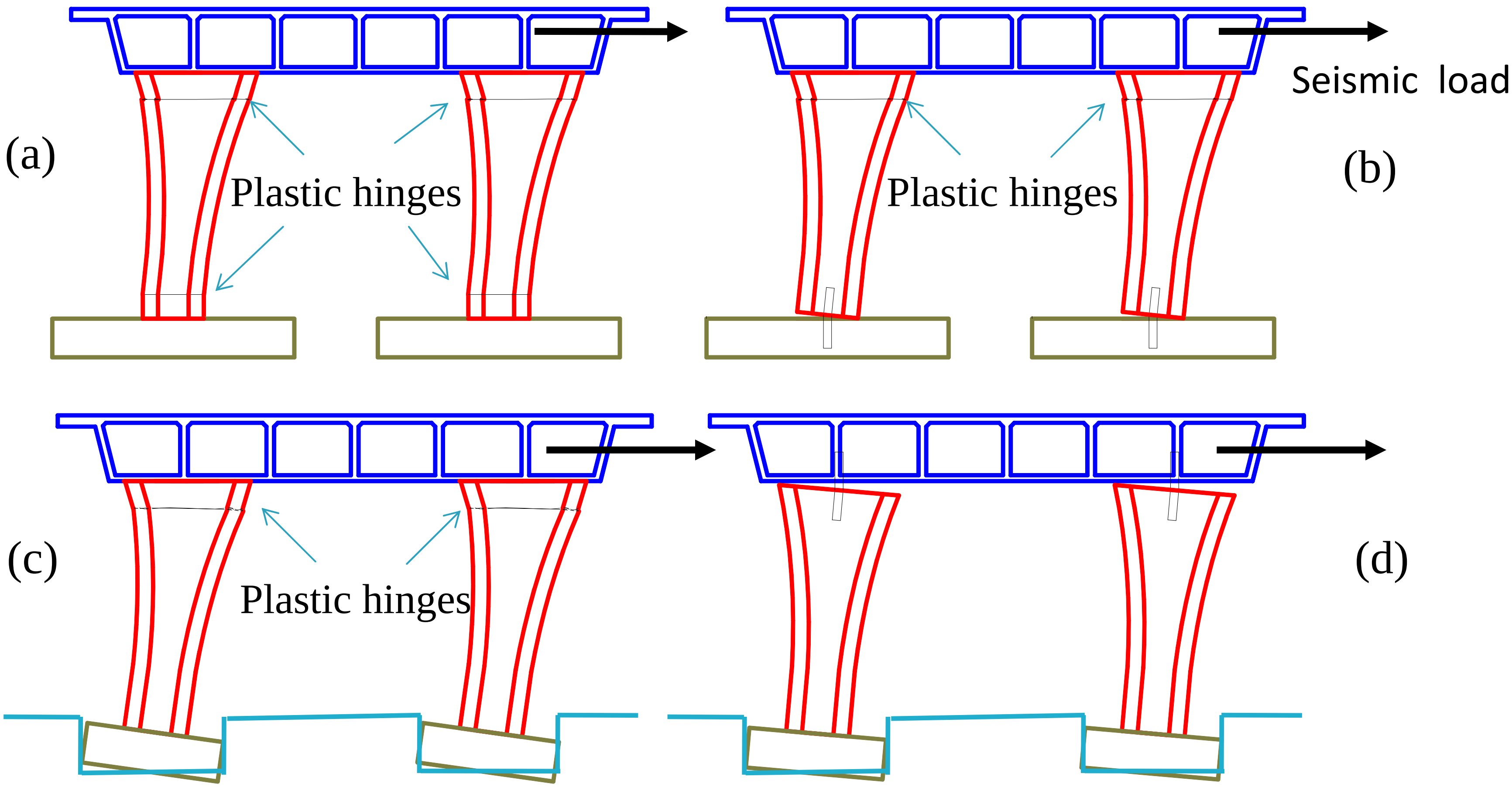
Caltrans SDC: *"foundation components shall be designed to remain essentially elastic when resisting the plastic hinging moments"*.

Destroyed columns from 1995 Kobe earthquake

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

Idealized failure mechanisms

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



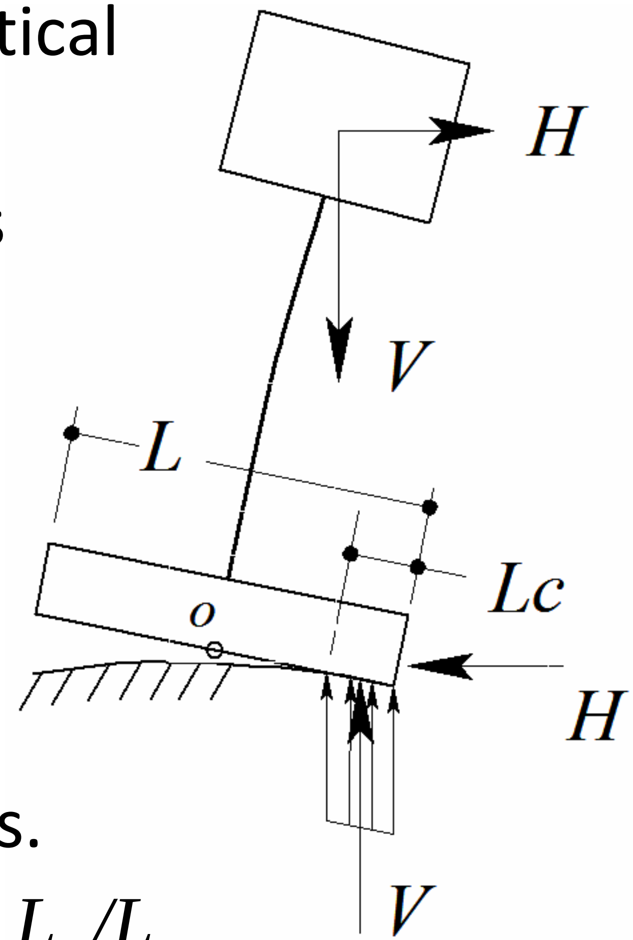
Column is protected by rocking isolation in case (d)

Definitions and basic concepts

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

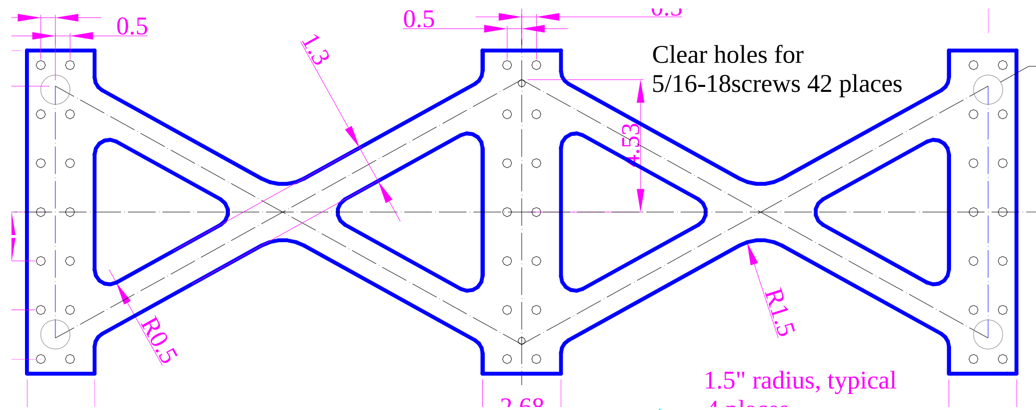
$$M_{o,ult} = V\frac{L}{2}\left[1 - \frac{L_c}{L}\right]$$

- Define $A_c = L_c B$
  where B = footing width
- note $A_c/A = L_c/L$ for 1-D loading
- L_c/L << 1 for typical bridge foundations.
- $\therefore M_{o,ult}$ is insensitive to L_c/L

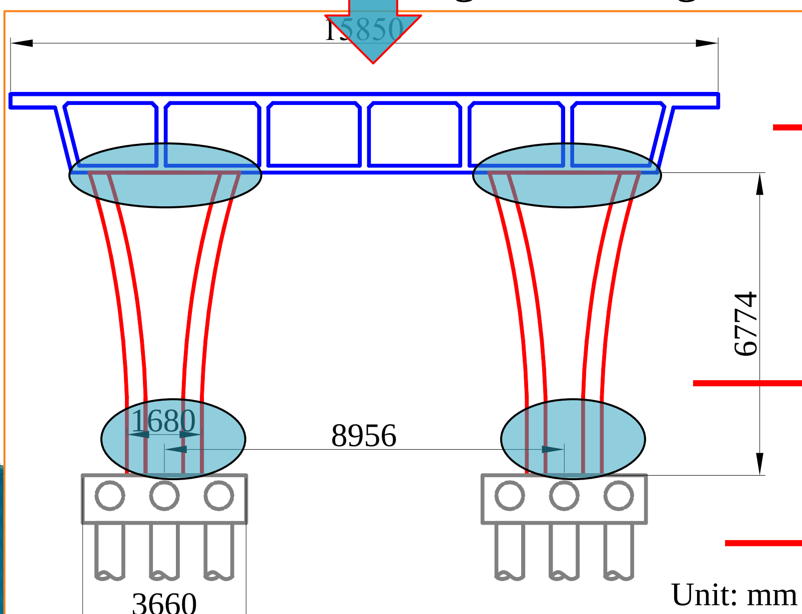


LJD02→ Centrifuge model design

Camino del Norte bridge, San Diego, CA



Plan view of model bridge deck

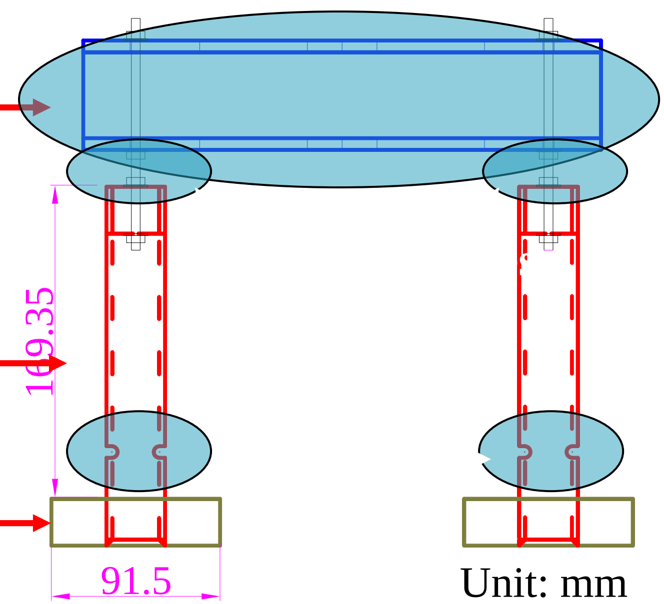


Prototype

m_{deck}, K_z, K_θ

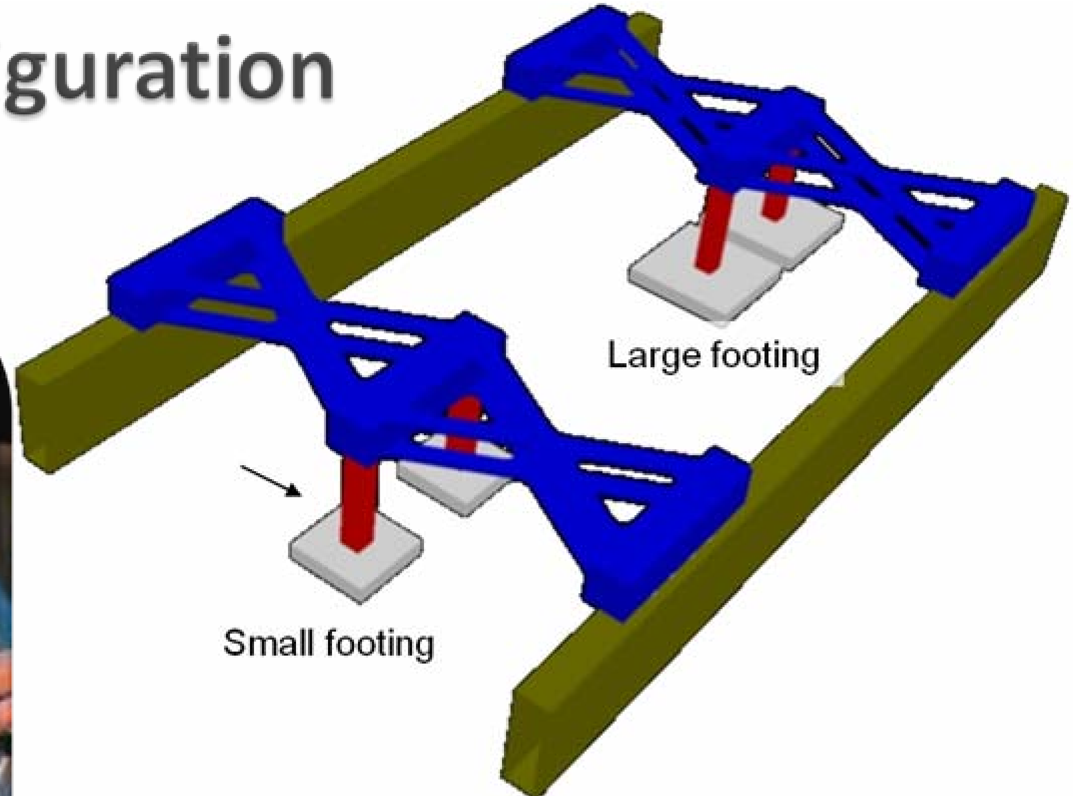
H_{col}, K_{col}

L/D=3, and 4.5



Model

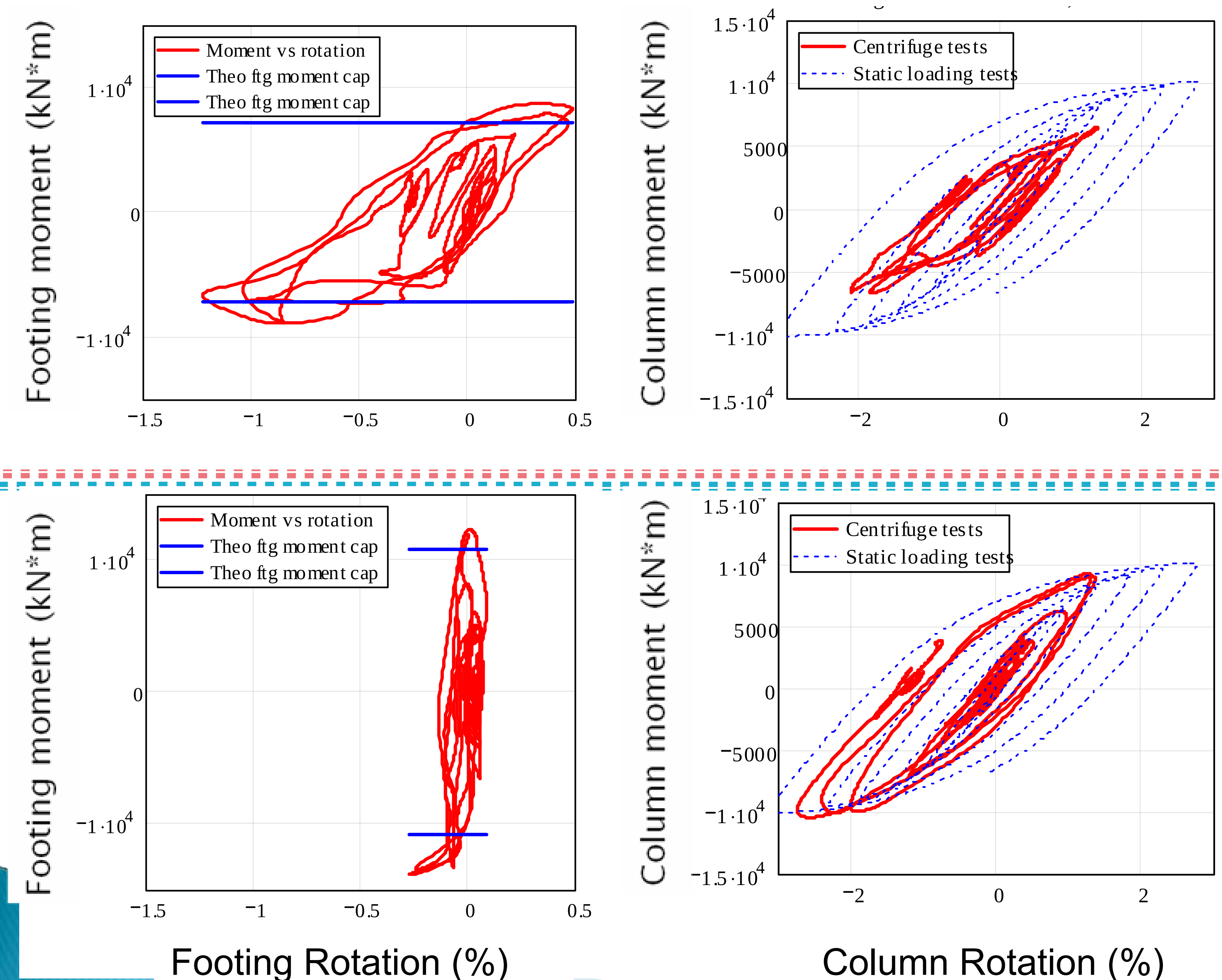
Centrifuge test configuration



Videos from LJD02_15 event (Large-footing bridge)

Videos from LJD02_15 event (Small-footing bridge)

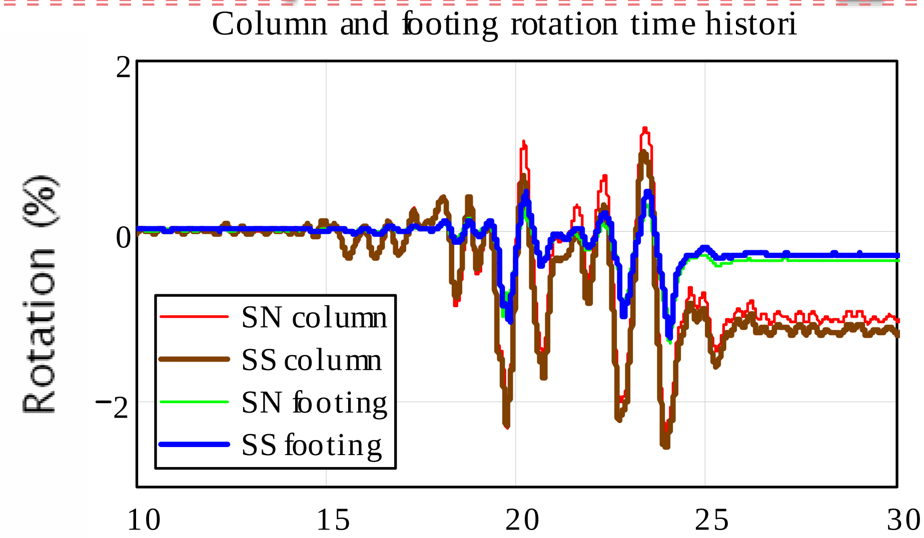
LJD02_15 event: Gazli 2.0

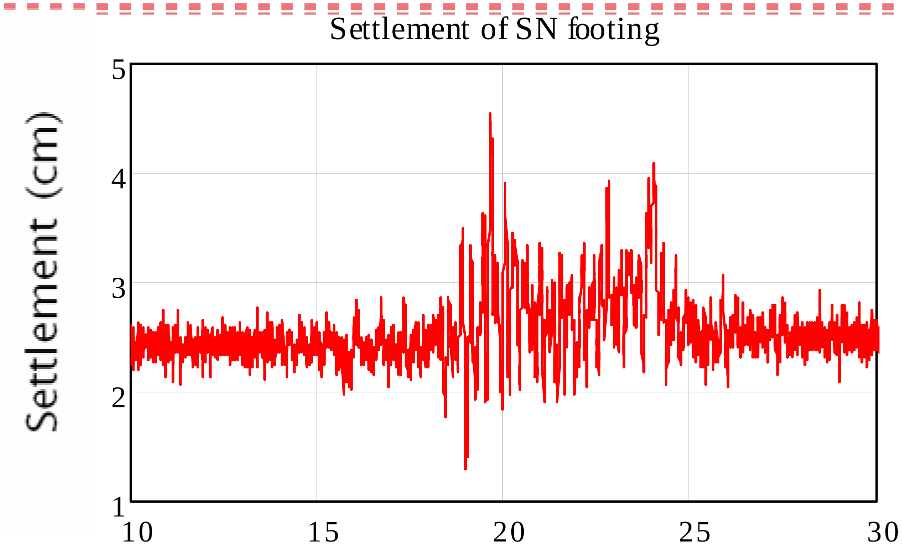


Small-footing bridge

Large-footing bridge

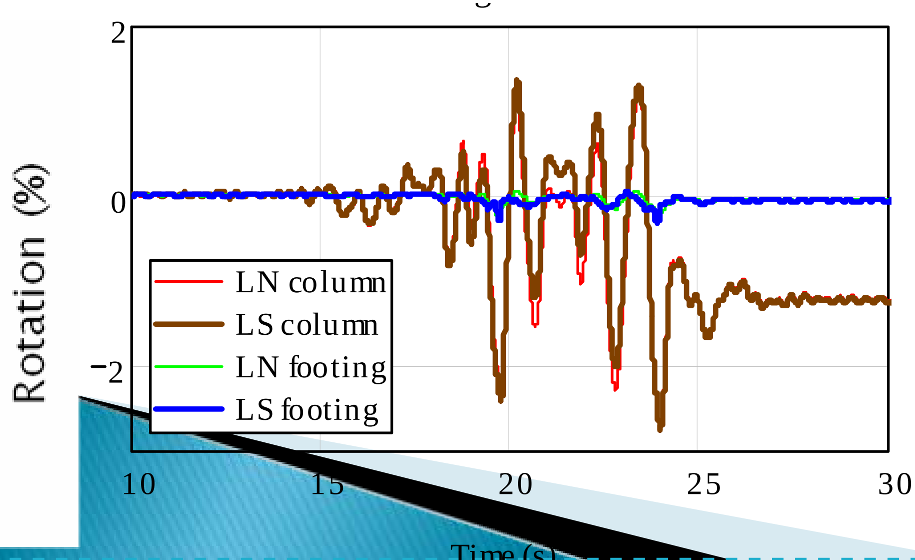
Critical plots of LJD02_15 event: Gazli 2.0

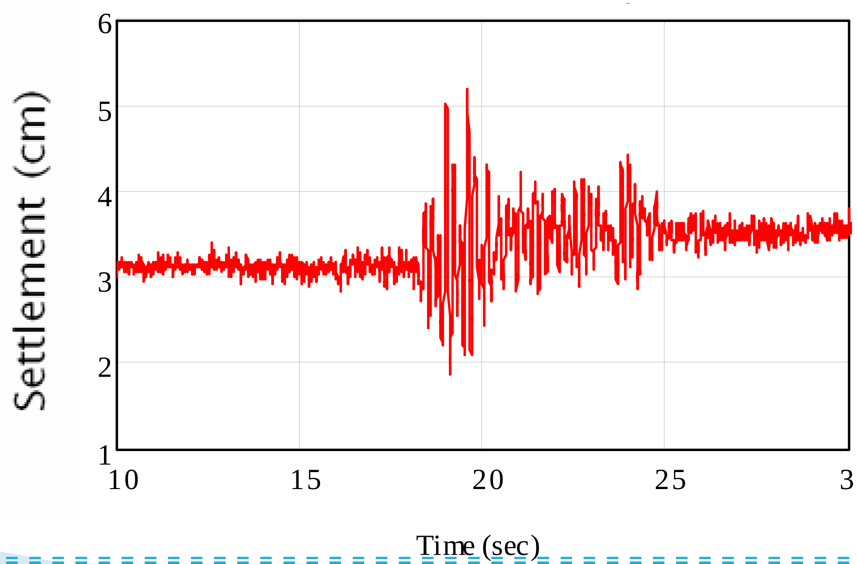




Small-footing bridge

Large-footing bridge



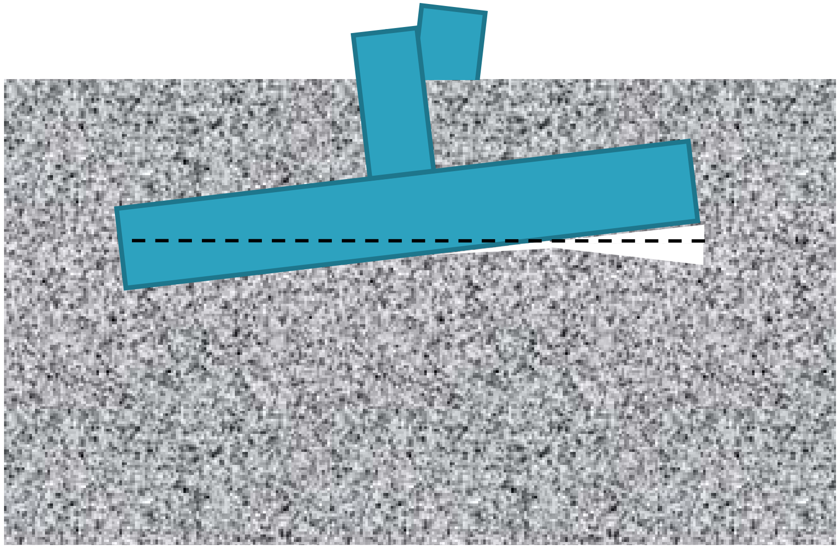


Learned from experiments

- 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 moment capacity
  - Isolation mechanism
  - Energy dissipation
- Difficult aspect of the problem: How to evaluate settlement (or uplift) associated with rocking.

Mechanism of Settlement

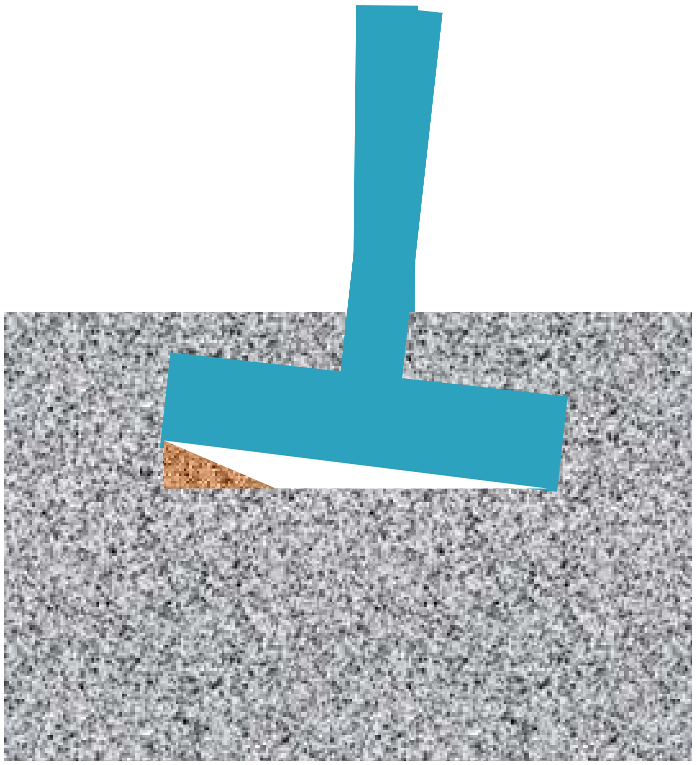
- Bearing Failure over length L_c under toe during rocking
- Rounding of surface and local bearing failure during reversal of rotation
- Main factors controlling are:



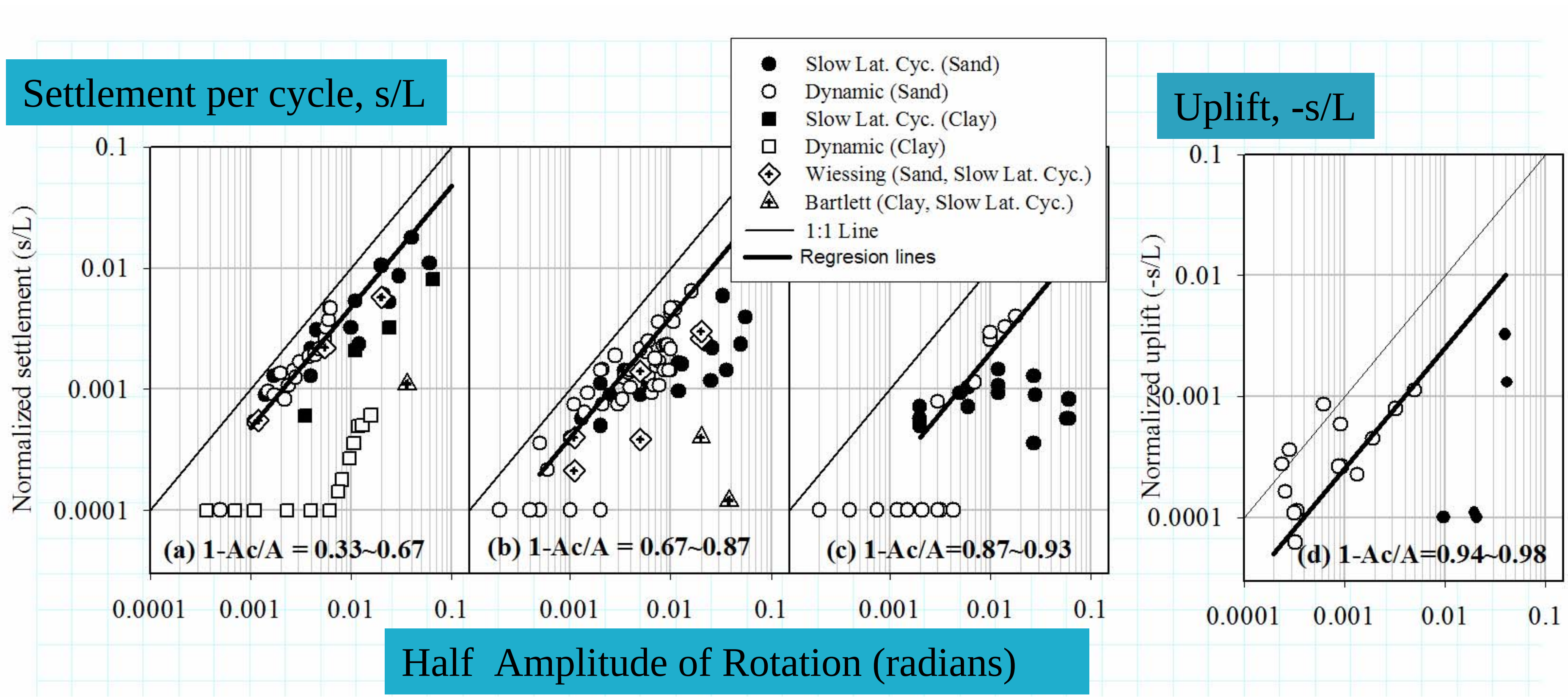
- $s/L \sim (L_c/L)(\theta)$

Mechanisms of uplift

- Soil falls under the footing under large rotation
  - Cohesion of backfill limits fall back
  - Suction could enhance fallback
- Dilatancy during sliding (but sliding is small for typical bridge foundations)



Empirical observations from experiments -settlement per cycle as a function of the size of the rotation cycle.



Small FS_v

Large FS_v

Draft design procedure (DDP) (1/5)

Assume: ordinary bridge, multi column bents, hinge at top of column, no sliding of shallow foundation, seat-type abutments.

1. Footings initially sized based on serviceability criteria and static loads. If weight of deck is m_{deck}, then the fraction of the vertical load taken by the columns is:

$$x \; m_{deck} \; g$$

The factor x may be affected by footing or abutment settlement

   a) AASHTO: settlement = 0.004*span
   b) Caltrans often uses: 1” (maybe too strict?)

DDP (2/5): Ground Motion and Rocking Accn

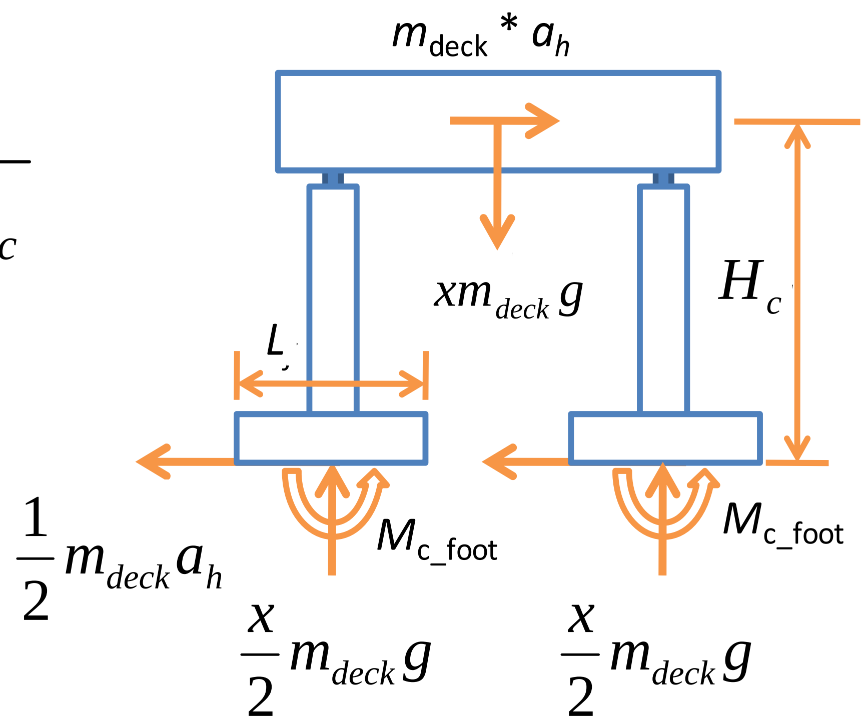
2. Ground motion selection
   a) ARS may be sufficient for MCE, safety evaluation
   b) Time histories for Functional-Evaluation Earthquake (FEE)
   (MTD 20-1 1999)

3. Compute rocking acceleration

$$\frac{a_h}{g} = \frac{x}{2}\frac{L}{H_c}(1 - L_c / L) \approx \frac{x}{2}\frac{L}{H_c}$$

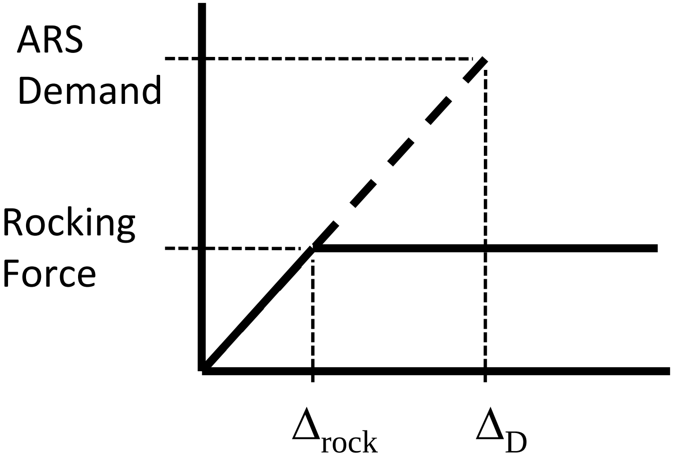
And "Rocking Force":

$$F_r = m_{deck} a_h$$



DDP (3/5): MCE Drift demand controls seat width

4. Drift demand in MCE



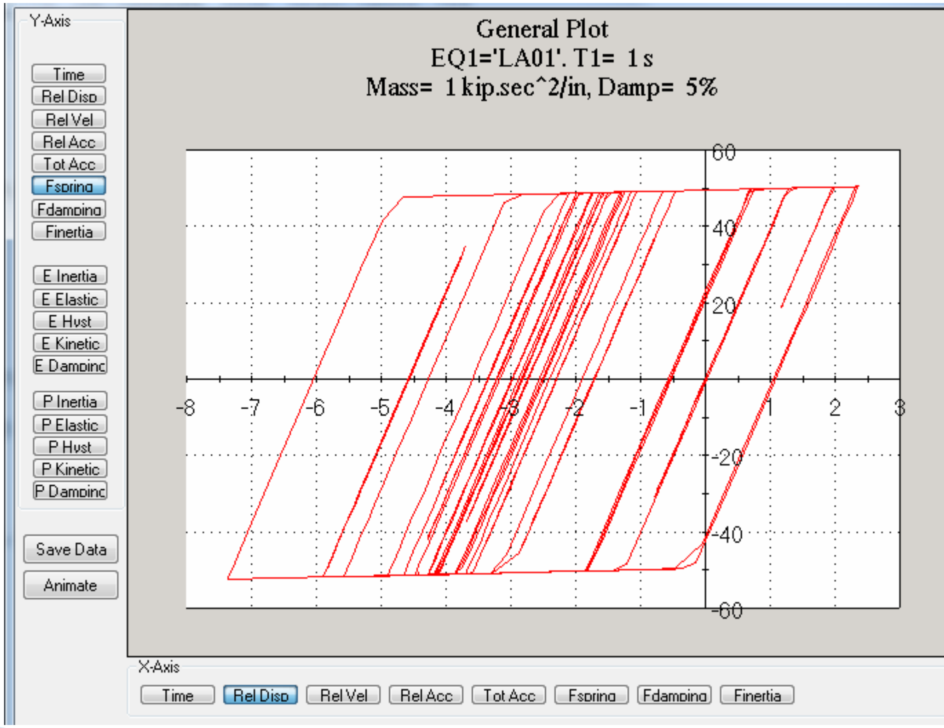
a) Estimate using ARS

b) Nonlinear dynamic analysis of SDOF;

BISPEC example:

PGA = 0.45g

Rocking acceleration = 0.13g

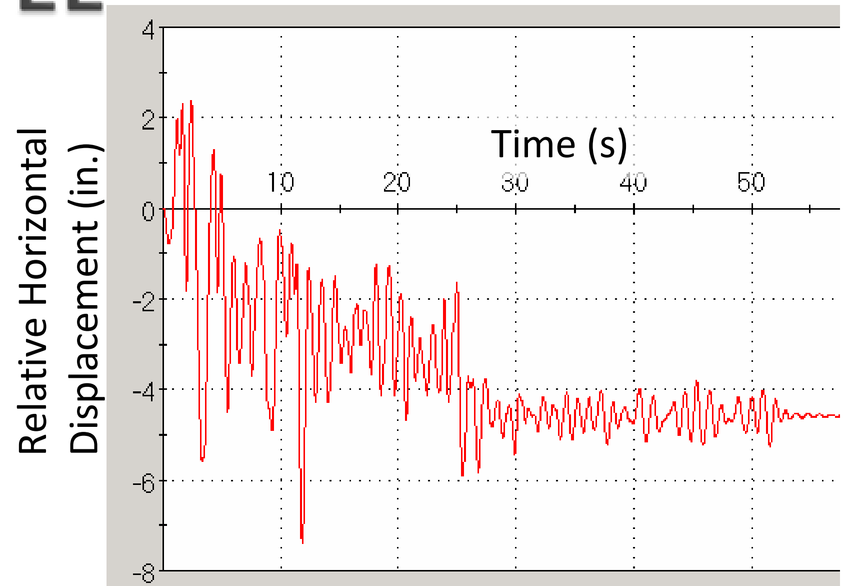


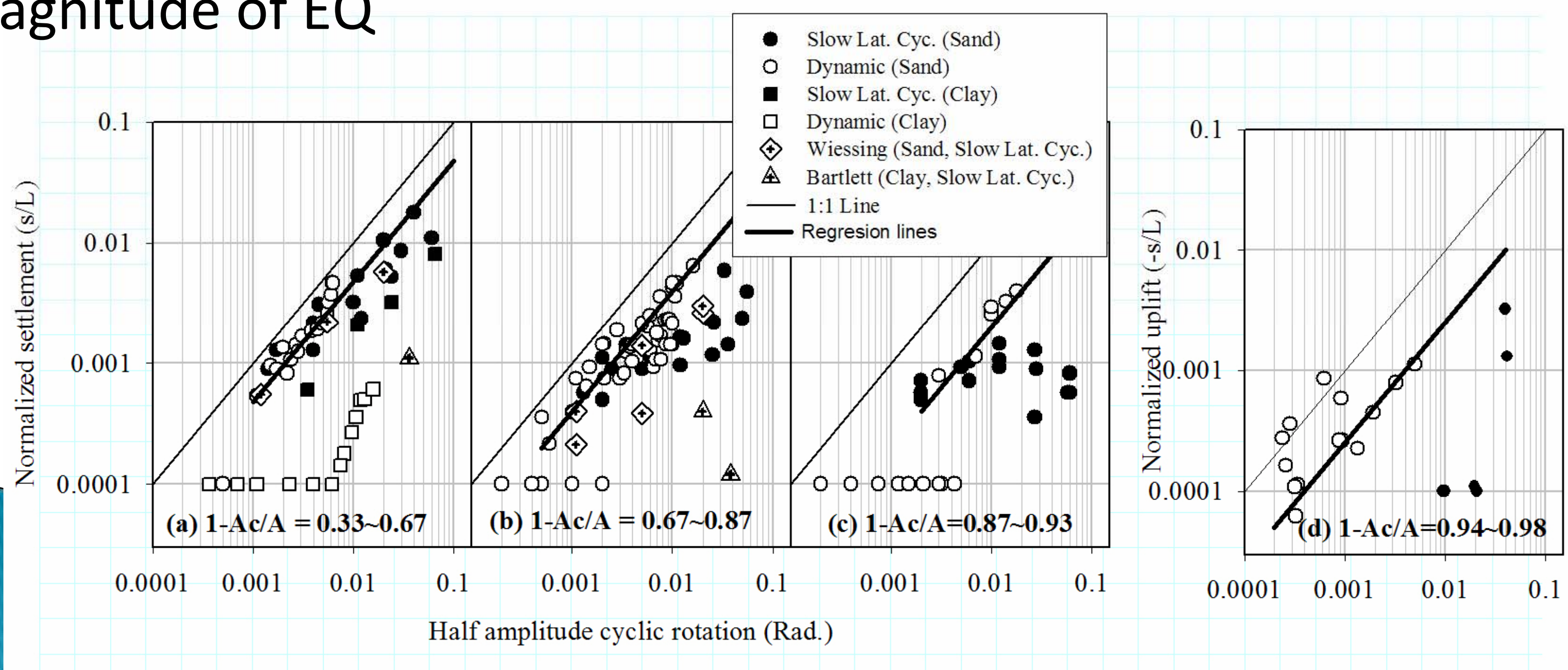
DDP (4/5): Settlement in FEE

5. Estimate the Settlement in the Functional Evaluation Earthquake; (work in progress) some current ideas:

a)Count number and size of cycles from BISPEC analysis

b)Correlate number of cycles to Magnitude of EQ





DDP (5/5): Check x-factor, overturning, column design

6. Check potential range in vertical loads on footing (the x-factor defined earlier); this will be affected by settlement/uplift of the footings or abutments. The x-factor will affect the yield acceleration and moment capacity of footings. Effect can be limited by increasing deck flexibility. May need to repeat above steps.
7. Check for overturning instability in transverse direction (unlikely to be a problem unless drift ~ L/2).
8. Design columns to have over-strength over the upper bound of moment capacity of footing. Detailing can be for limited ductility demand.

Conclusions, Questions, Future Work

- Performance of bridges on small rocking foundations can be superior to that on larger foundations.
- What is the allowable settlement?
  - Statically: 1” seems small
  - Functional Evaluation Earthquake: 0.004 x span (AASHTO)
  - MCE: avoid collapse due to excessive bending of deck
- Working on simplified procedures to estimate drift/rotation demand and associated settlement
- Working on an example design procedure, with real numbers
- One more centrifuge test
- Nonlinear finite element simulations (parametric studies on soil-fdn-col-deck-abutment systems.)

Acknowledgments

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