Rocking Foundations

Validation using large scale shake table testing

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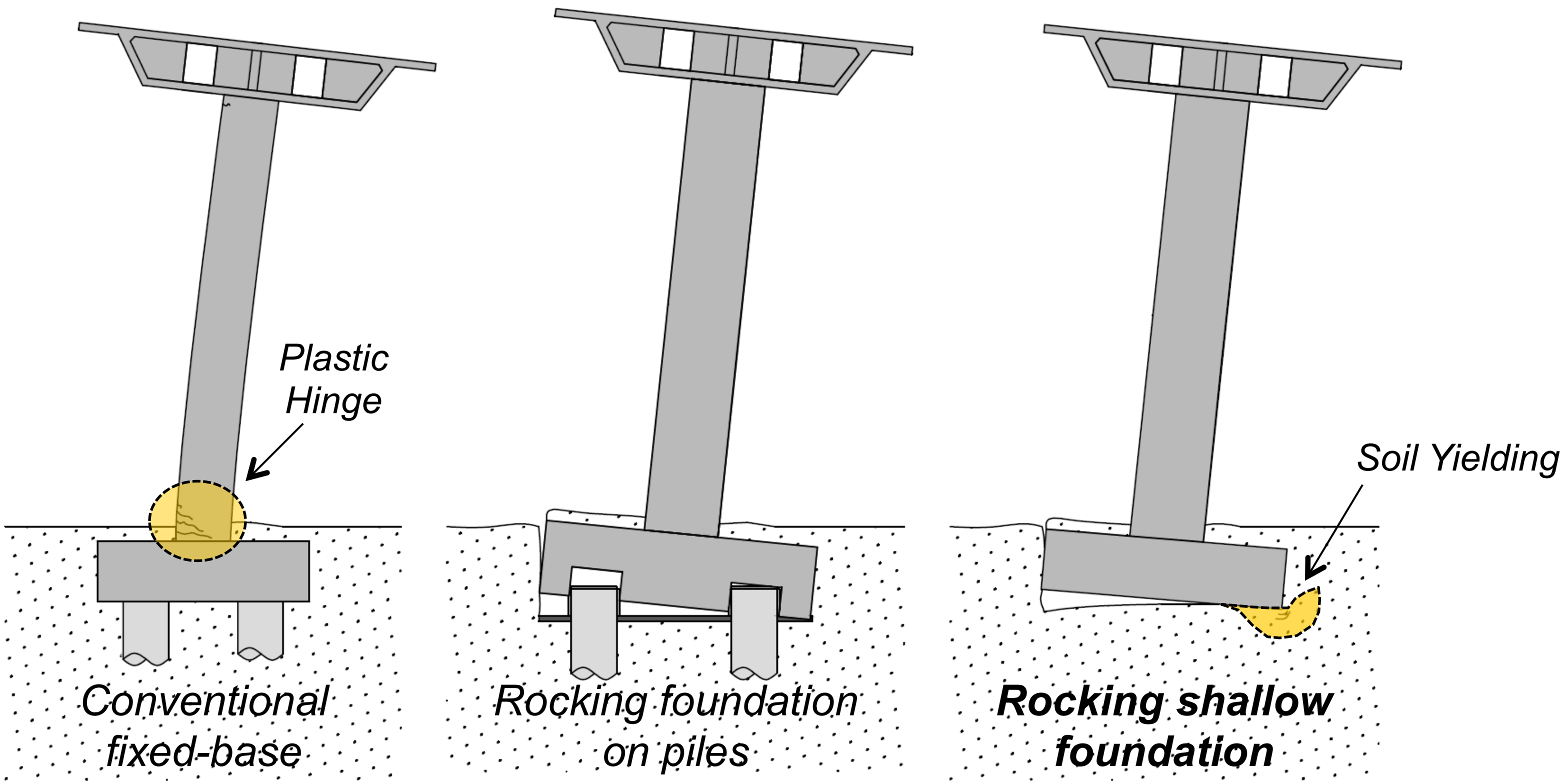
Project history

- Caltrans released a RFP for “innovative foundations”.
- Bruce Kutter (UCD) proposed use of “rocking foundations”.
- Several studies were performed at the UCD centrifuge.
- Numerical model and simplified design procedure developed
- Validation of numerical model and development of a full bridge design procedure

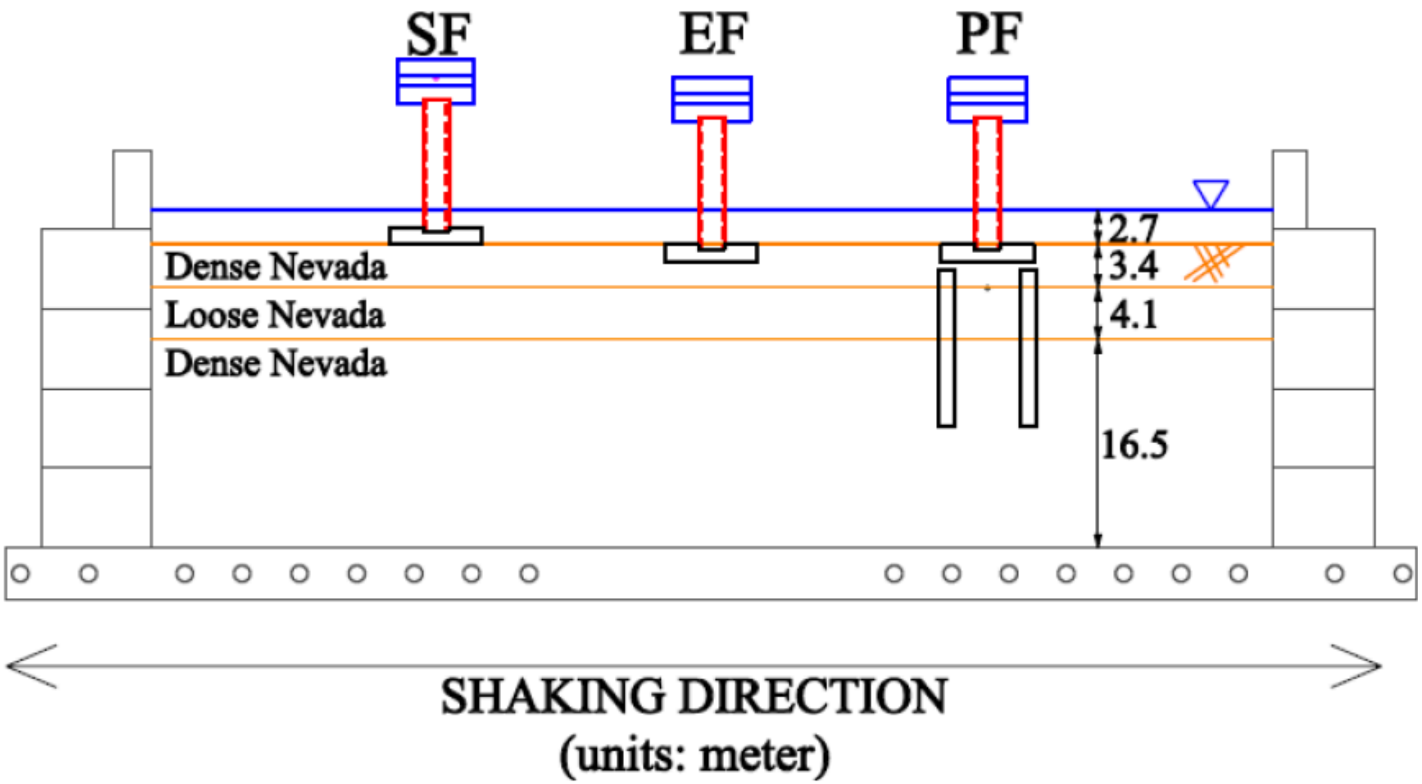
Basic concept

Single column bents:



Early testing

Centrifuge testing of different H/B ratios

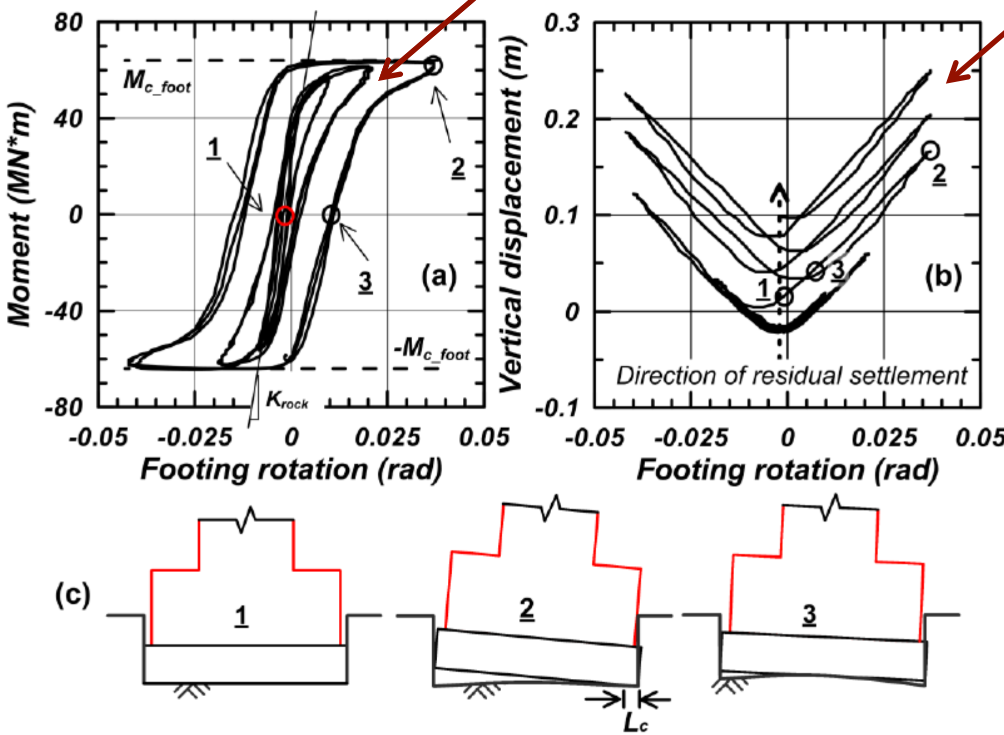


Rocking behavior

- *Typical results*

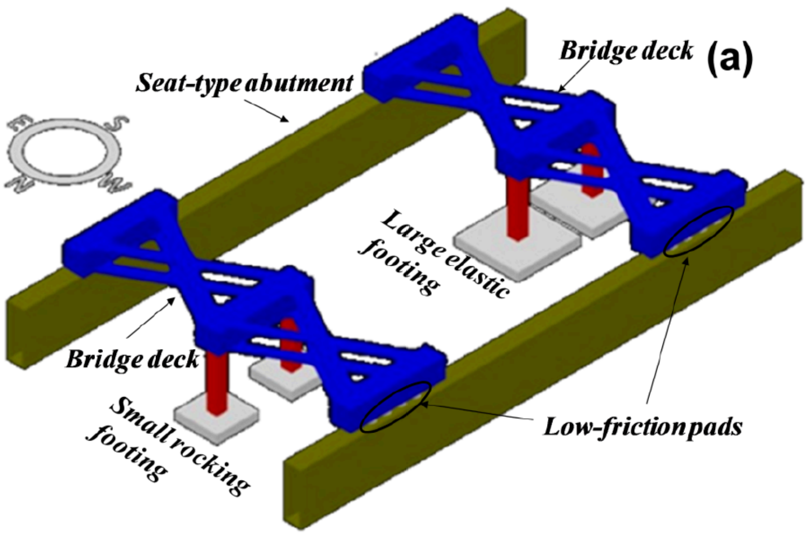
Good energy dissipation

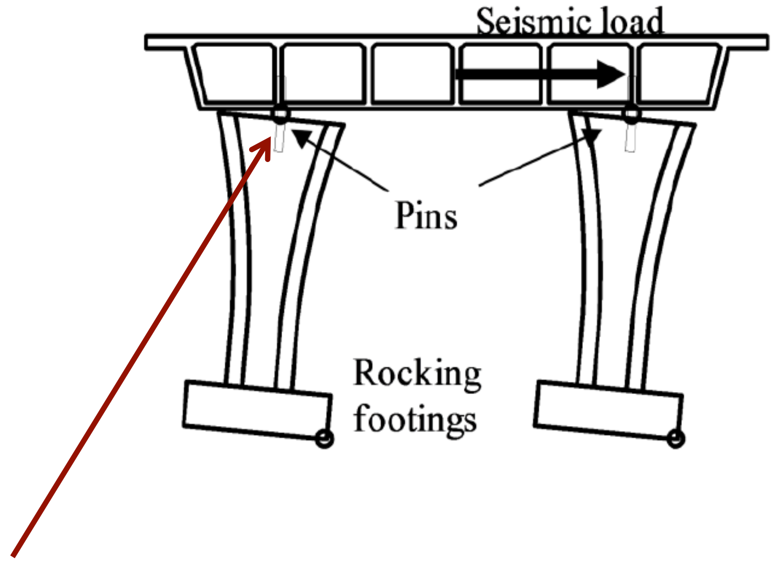
Too much uplift?



Trying to capture bridge behavior

- *Centrifuge testing of simple bridges*

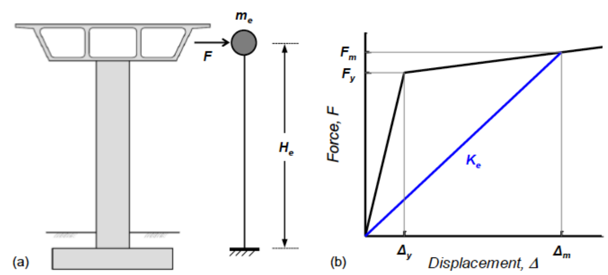




To enable rocking, the pin must be moved from the bottom of the column to the top.

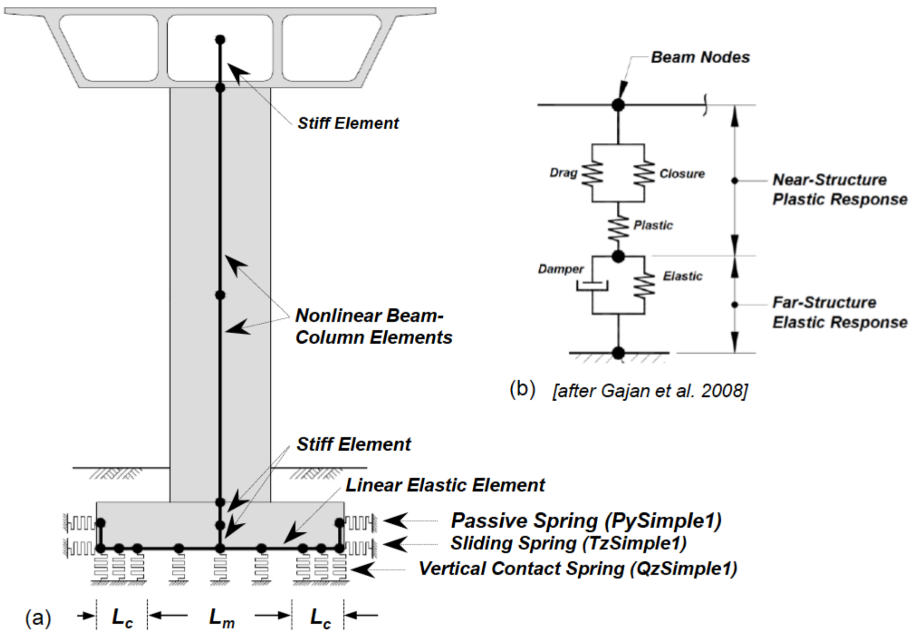
Analytical models

Simple hand calcs:

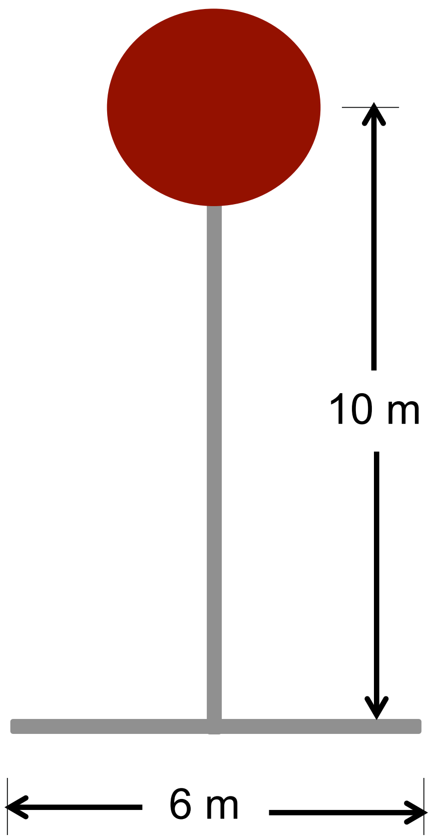


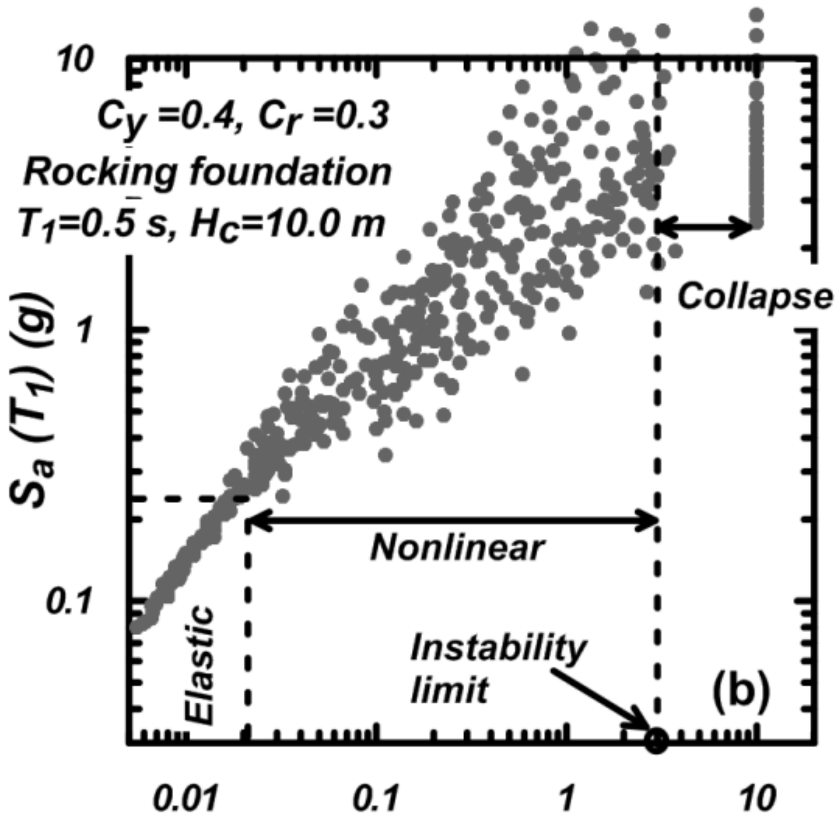
Transform into an equivalent SDF

Numerical models:



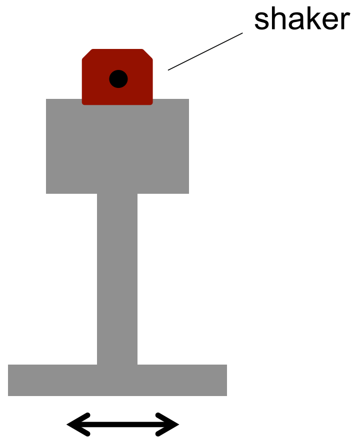
Stability evaluation

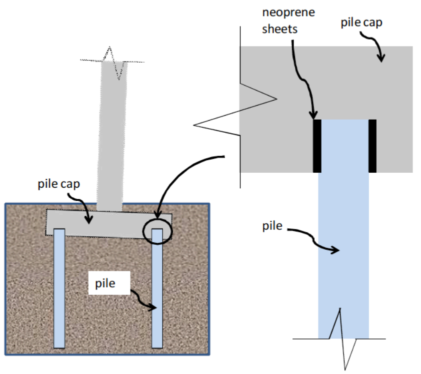




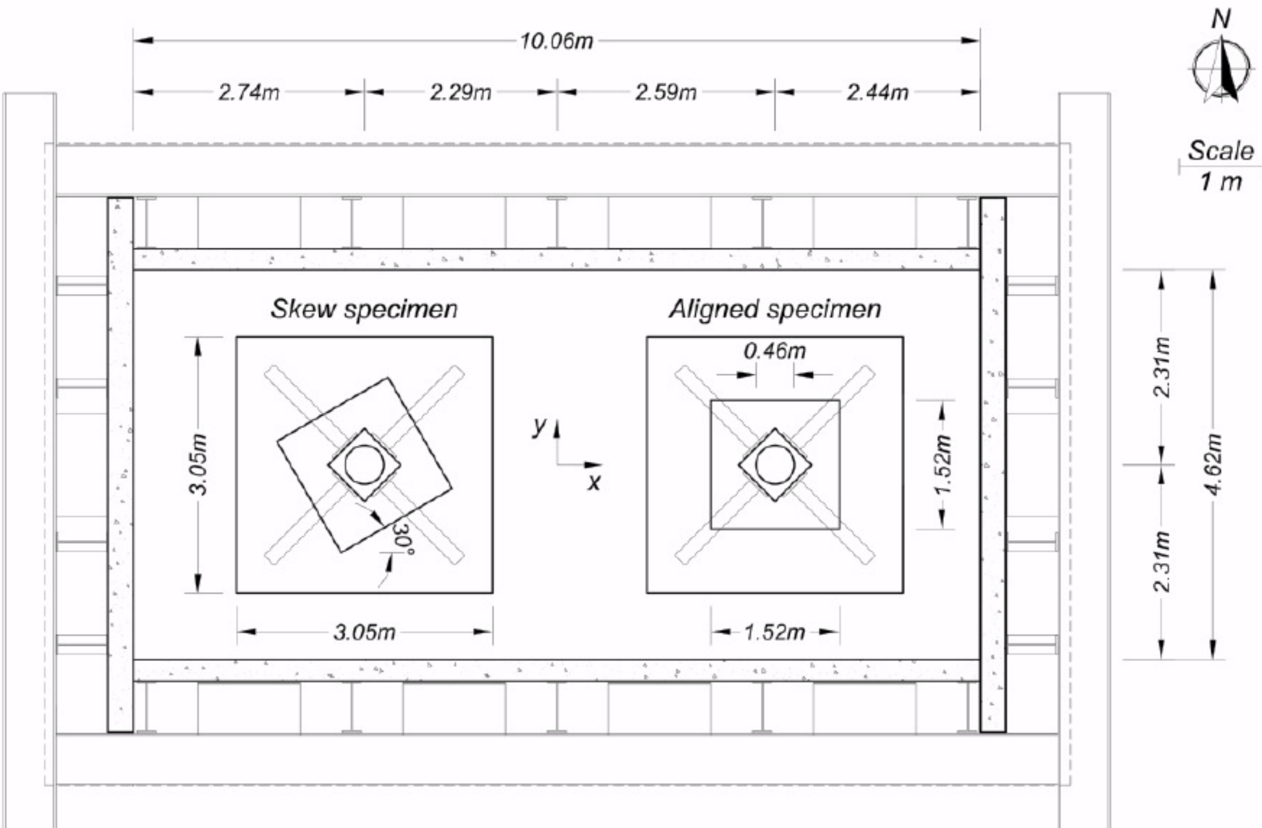
Motivation for shaketable testing

- Validate numerical model
- Investigate “off-axis” rocking
- Investigate pile-cap connection details
- Demonstrate that even under extreme shaking tip-over isn’t a issue





Test Layout

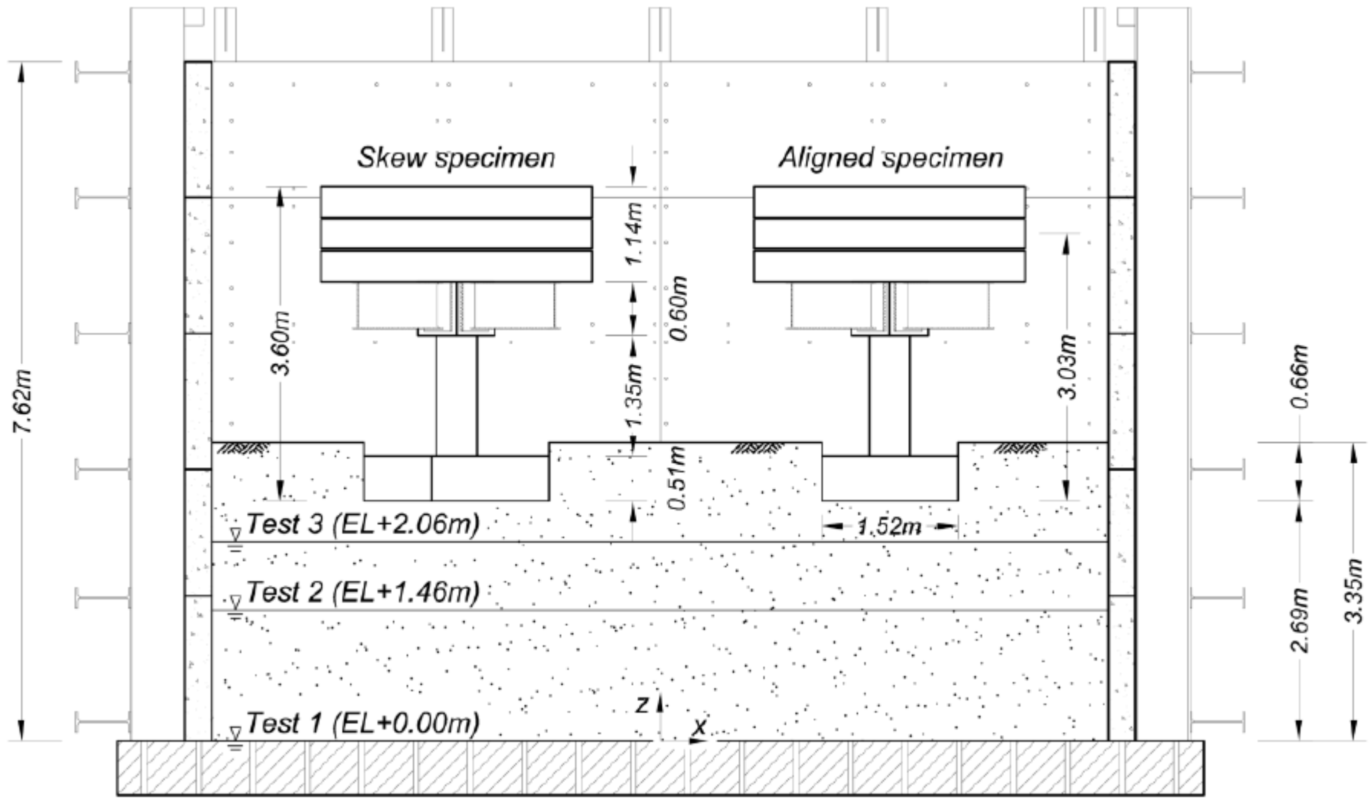


(a) Plan View

Key parameters

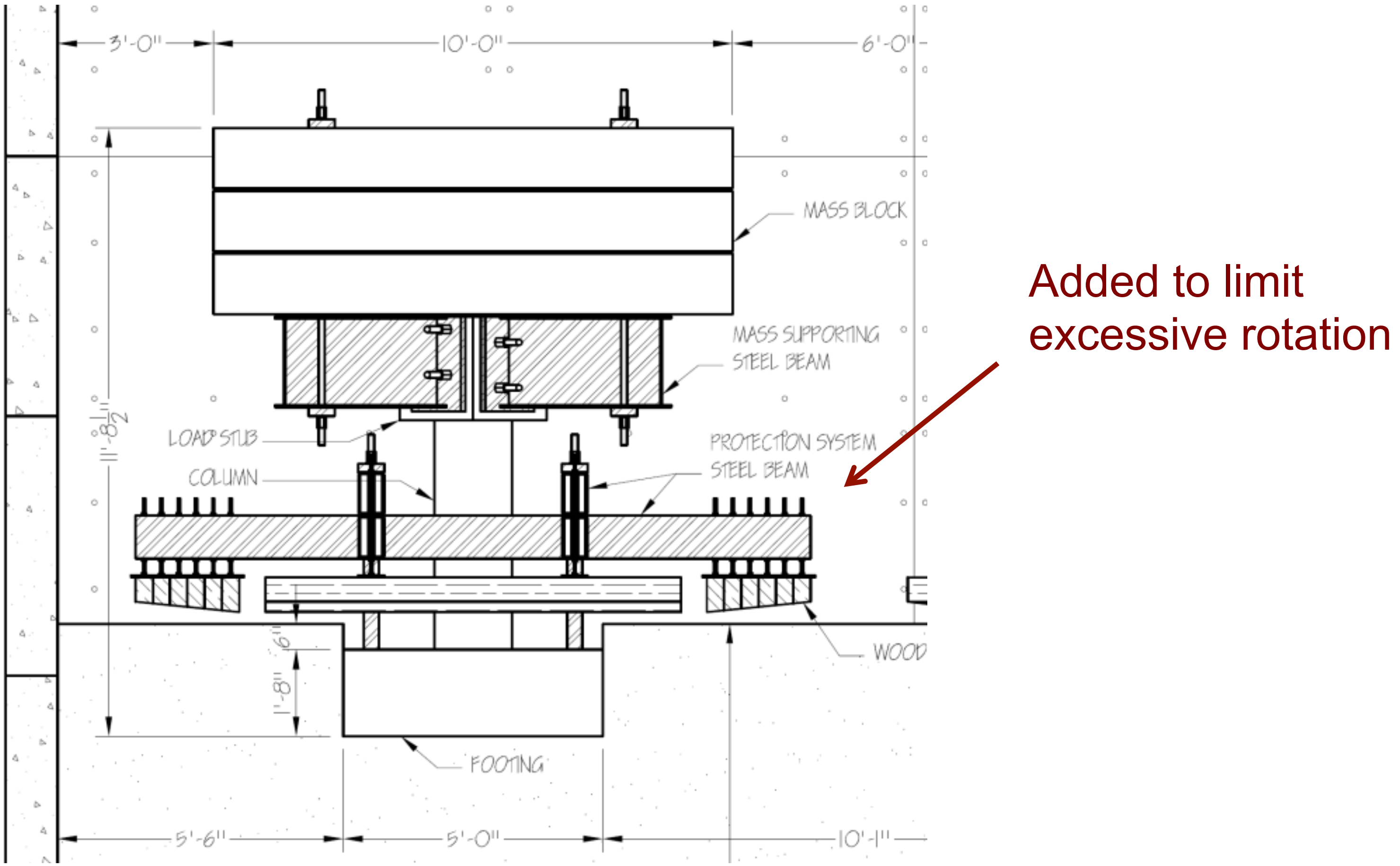
- W = 290 kN
- H / L = 2.0
- A / A_c = 13
- FS_v = 24
- C_r = 0.26
- C_y = 0.47

Test layout



(b) South Elevation View

Test layout

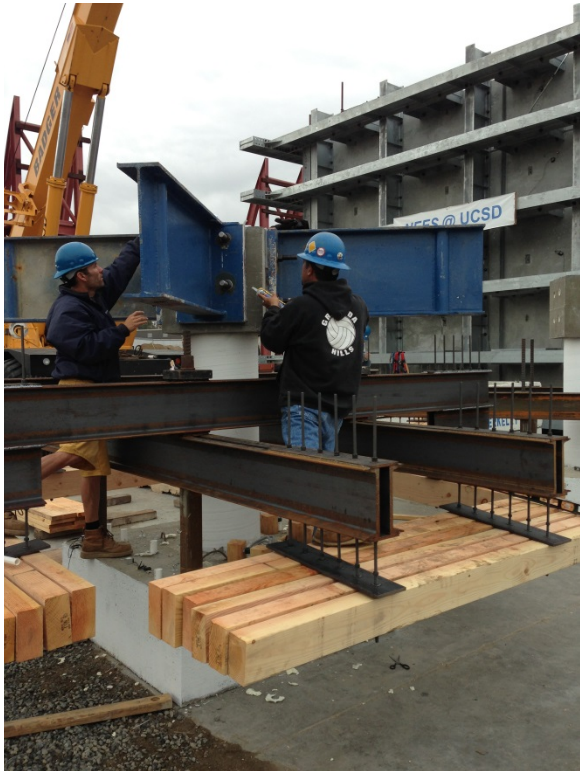

3'-0"
10'-0"
6'-0"
MASS BLOCK
MASS SUPPORTING STEEL BEAM
LOAD STUB
COLUMN
PROTECTION SYSTEM STEEL BEAM
11'-8 1/2"
6"
1'-8"
WOOD
FOOTING
5'-6"
5'-0"
10'-1"
Added to limit excessive rotation

Test specimen construction

Outrigger restrainer

Test specimen construction

- *Adding the block mass*



Soil box assembly

- *Erection of vertical elements and post-tensioning to the shake table platen*

Soil box assembly

- *Placement of Concrete Panels*

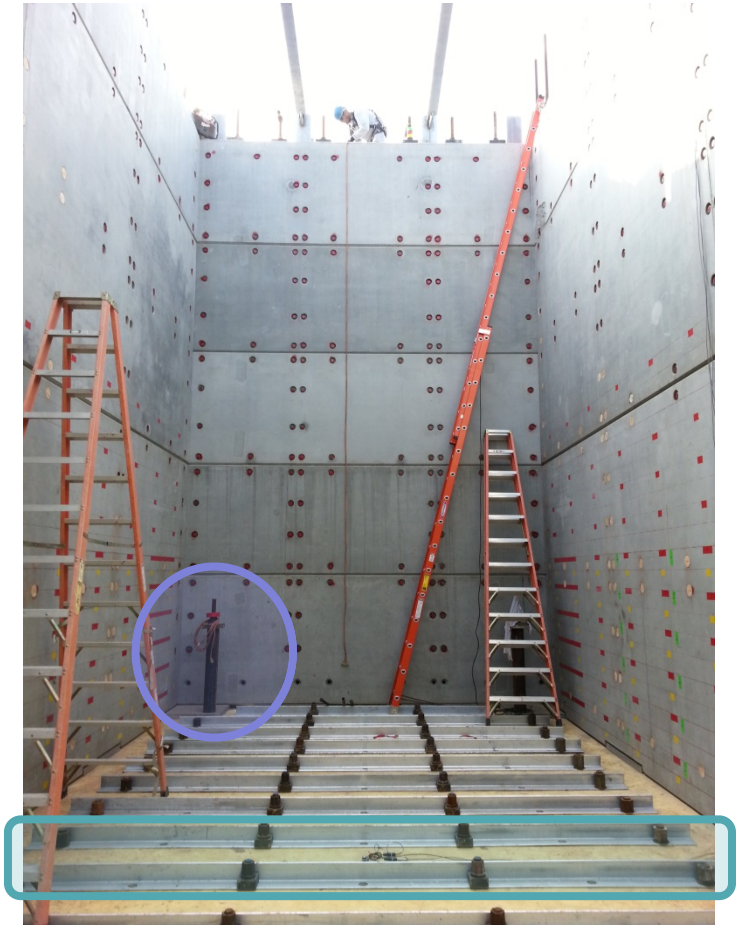
Soil box assembly

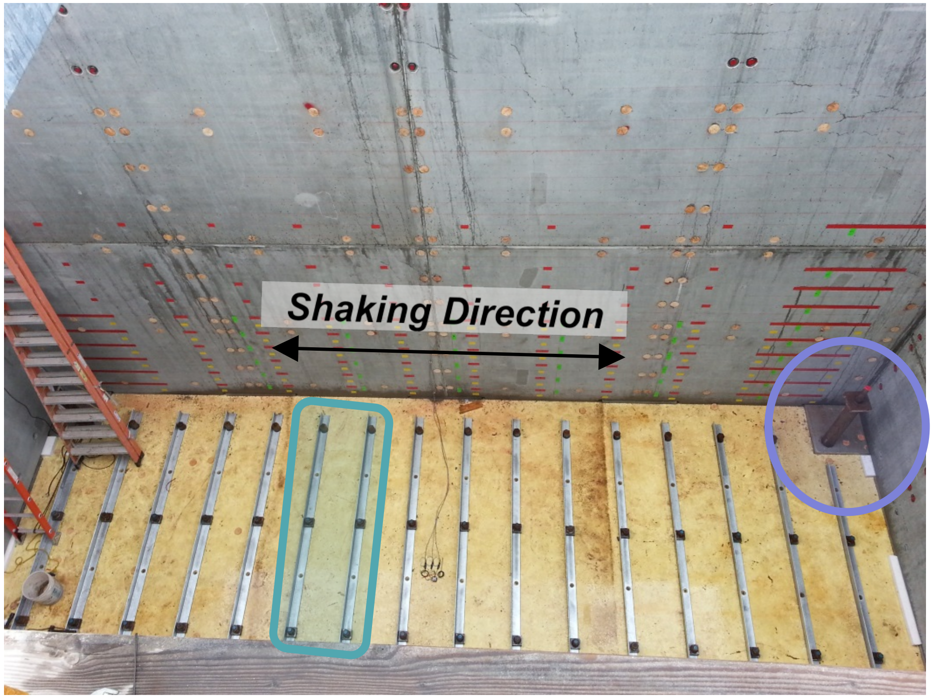
- *Completed soil box*

Interior box dimensions

Soil box assembly

- *Soil box interior*





16 steel angles bolt to the platen to provide no-slip condition at the bottom boundary

4 PT rods running through the parts of corner column base plates sticking into the box

Filling and removal

Conveyor belt method
(slow and cheap)

Hopper and crane method
(fast and expensive)

Membrane placement

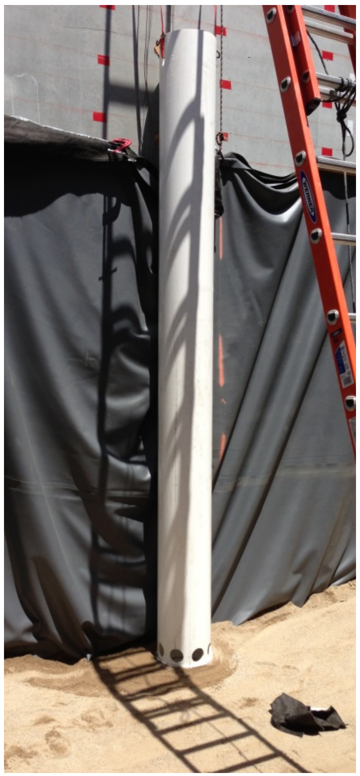
- *A geotextile was placed first to protect the liner*

Membrane placement

- *Placement and patching*

Soil placement

- *Saturation and dewatering system*



Soil placement

- ***Soil Compaction***
  - *Loose lifts of 200 mm thick compacted at a water content of 6% down to about 150 mm*
  - *Walk-behind vibratory plate with 8 passes per lift*
    - ✓ *First 4 lifts after placement of liner and saturation/dewatering system*
    - ✓ *Lifts above the footings' base elevation*
    - ✓ *Near box walls (in general)*
  - *Skid-steer loader with an attached vibratory roller (1.22 m wide, 7.95 kN heavy vibrating at 40 Hz) with 6 passes per lift*



Instrumentation

- *Soil accelerometers placement*

Marking of locations before placement

Placement of accelerometers

Covering with soil and cables running

Instrumentation

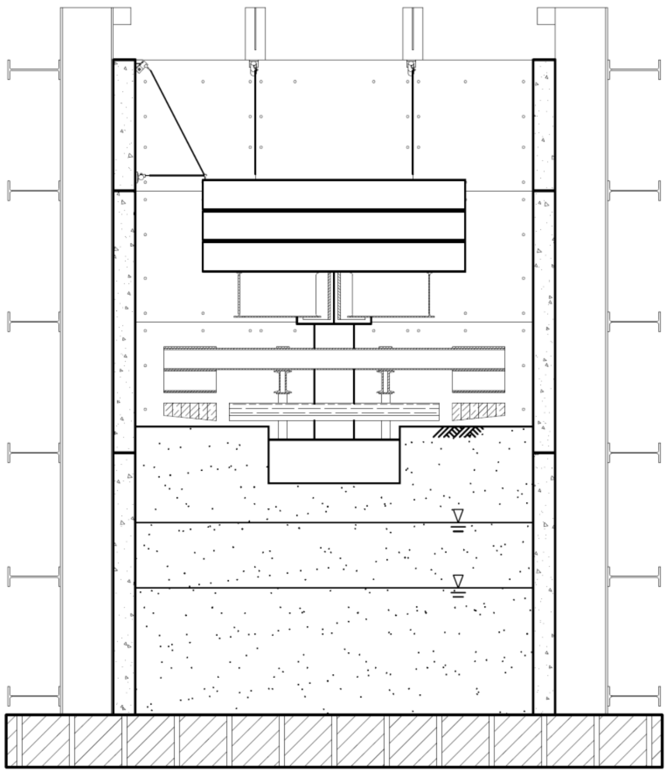
➢ ***Pore Pressure Transducers (PPT) Placement***

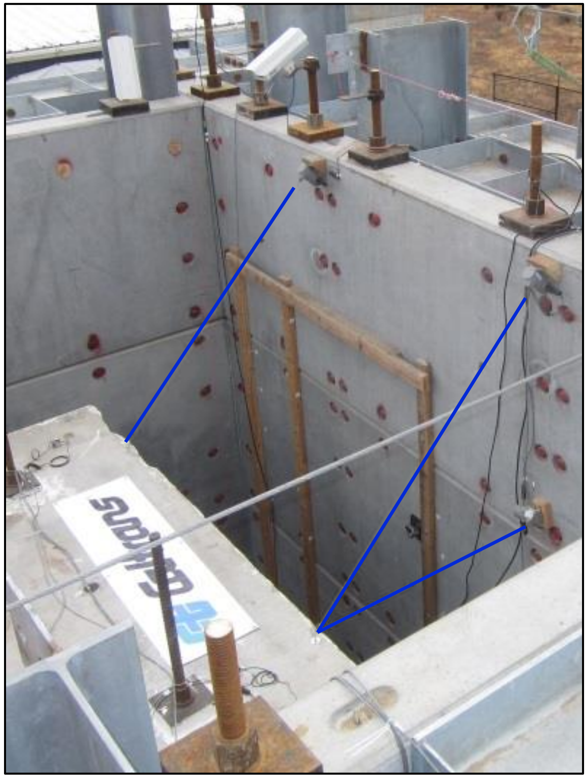
- *Challenging to prevent desaturation of sensors during the 2-3 weeks period for which they remained above water table*

Specimen placement

Instrumentation

- ***Structures' Instrumentation***
  - *Mass Blocks' String Potentiometers*
    - ✓ *6 linearly independent String Pots (3 horizontal + 3 vertical) to determine 6 DoFs*





Instrumentation

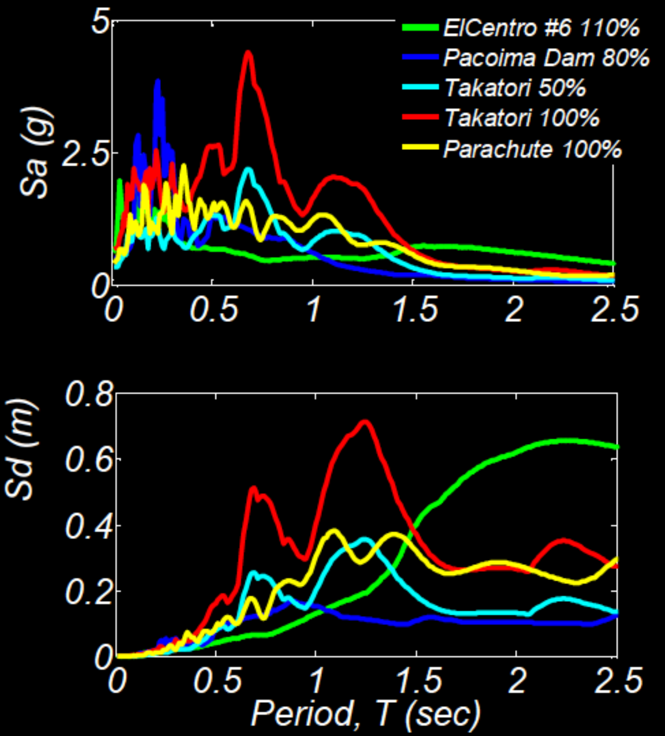
- **_Video Cameras Used_**
  - *Coaxial cameras [8]*
    - ✓ *Wired, power-supported, low resolution (768 × 494 pixels at 30 fps)*
    - ✓ *Live video streaming; can be played back during testing*
    - ✓ *168 out of 168 events successfully recorded*
  - *GoPro2 cameras [11]*
    - ✓ *Wireless, battery-supported, high resolution (1920 × 1080 pixels at 30 fps)*
    - ✓ *Can be accessed and played back after testing*
    - ✓ *126 out of 231 events successfully recorded*
  - *Sony cameras [2]*
    - ✓ *Man-operated, battery-supported, high resolution (1920 × 1080 pixels at 30 fps)*
    - ✓ *Can be accessed and played back after testing*
    - ✓ *29 out of 42 events successfully recorded*

Loading input

Test protocol and linear spectra (1% damping)

	Motion	Scale factor
1	Gilroy Array 1	1.0
2	Corralitos	0.8
3	El Centro Array 6	1.1
4	Pacoima Dam	0.8
5	Takatori	0.5
6	Takatori	1.0
7*	Parachute Site	1.0
8*	Parachute Site	-1.0
9*	Parachute Site	1.1

**Only for test day 3*



For all motions the time was compressed by 1.73

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Large-scale shake table test of columns supported on rocking shallow foundations

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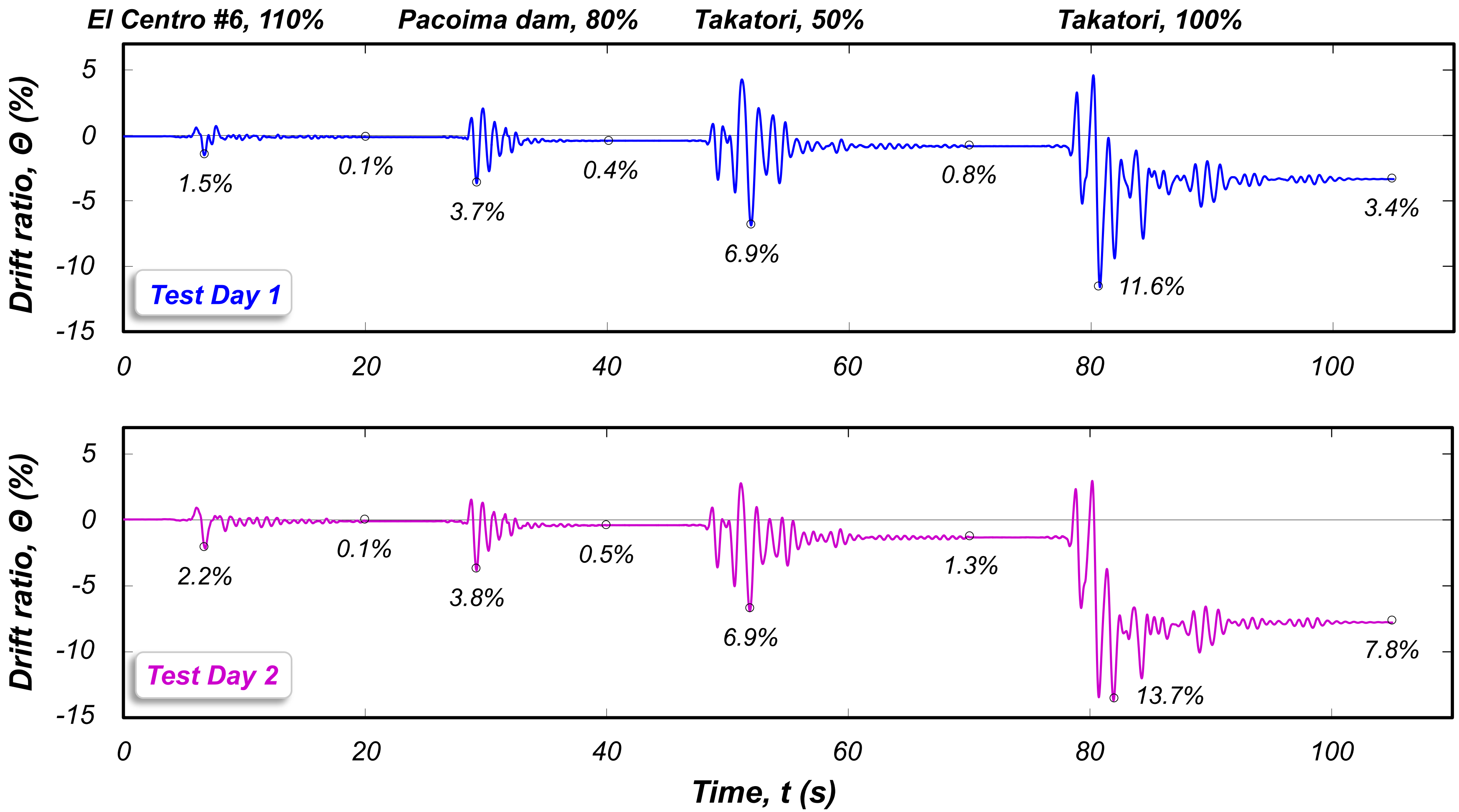
Test Response

➤ ***Column Drift Ratio Time Histories for Test Days 1 and 2***



Concluding Remarks

- *The road from initial concept to deployment is a long one…*
  - *Positives: Better performance for less $. The shaketable testing provided a clear illustration of excellent performance under extreme loading.*
  - *Negatives: Requires a substantial change in design philosophy*
- *Need to work on pile-footing connection details to expand application to pile supported foundations*
- *Soil box assembly and disassembly is expensive*

Acknowledgements

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  - *Marios Panagiotou (formerly UCB)*
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