Example of Total Project Planning – Case Study 2: “Geo-Structures”

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Example of Total Project Planning – Case Study 2: “Geo-Structures”

➢ Objectives

• This is not a technical research presentation!

• Share my experience with large-scale testing at UC San Diego using the Large Soil Confinement Box (LSCB) to study a dynamic soil-structure interaction problem

➢ Potential Outcomes

• If you already have a specific test in mind, you might now know something more about the specific steps involved in designing, constructing and testing your idea, and the various decisions you have to make

• If you don’t have a specific test in mind, perhaps you will become more aware about the facility’s capabilities to envision new tests
Outline

- Project Description
- Test Design
- Experiment Assembly and Construction
- Material Testing
- Instrumentation
- Seismic Testing Protocol
- Test Response
- Concluding Remarks
Project Description
Project Description

- **Rocking Foundations as an Earthquake Damage Resistant Mechanism**

![Diagram of rocking foundation with plastic hinge and conventional fixed-base]

- **Research Question:** Can we economically design highway bridge columns using rocking shallow foundations to remain undamaged and with small residual drifts at near fault regions?
Project Description

Why Large-scale 1g Testing of Rocking Foundations at UCSD?

- Both large-scale 1g and centrifuge testing do not come without shortcomings
- Confirm findings from previous centrifuge tests. Will they be different at large-scale?
- Examine response at large rotations / drift ratios

We also wanted to study

- Effect of ground water table proximity to the rocking footing
- Non-planar rocking response
- (Rocking piled foundations)

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Full-scale</th>
<th>1g Scale</th>
<th>Small-scale</th>
<th>Centrifuge Reduced-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing frequency of geo-structural systems</td>
<td></td>
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<tr>
<td>General scaling laws</td>
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<tr>
<td>Relative scaling of soil particles</td>
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<tr>
<td>Realistic soil construction</td>
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<tr>
<td>Realistic superstructural material</td>
<td></td>
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</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Previous tests on rocking foundations</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
“Analytical and Experimental Development of Bridges with Foundations Allowed to Uplift During Earthquakes”

- Award Amount: $741,479 (50% spent for the experiment)
- Funding: California Department of Transportation (Caltrans)

Project Components

- Experimental response of single bridge columns
- Numerical modeling validation for single bridge columns
- Parametric study of single bridge columns
- System-level analysis of two realistic, archetype bridges
- Displacement-based design method and guidelines for single bridge columns and bridge systems
Project Team

- Principal Investigators
  - Marios A. Panagiotou (formerly UC Berkeley)
  - Bruce L. Kutter (UC Davis)
  - Jose I. Restrepo (UC San Diego)
  - Patrick J. Fox (formerly UC San Diego)
  - Stephen Mahin (UC Berkeley)

- Graduate Student Researchers
  - Grigorios Antonellis (formerly UC Berkeley)
  - Andreas-Gerasimos Gavras (UC Davis)
  - Gabriele Guerrini (formerly UC San Diego)
  - Andrew C. Sander (UC San Diego)
Test Design
Test Design

» Rocking Foundations’ Response Controlling Parameters

- **Controlling Parameters**
  - **Normalized-moment-to-shear ratio, \( H / L \)**
    - Rocking vs. sliding and moment-to-shear coupling
    - \( H / L > 1.5 \) indicates rocking-dominated response
  - **Critical contact area ratio, \( A / A_c \)**
    - Recentering vs. energy dissipation, residual rotations and settlements
    - \( A / A_c > 8 \) to minimize settlement
  - **Rocking base strength ratio, \( C_r \)**
    - Peak rotations and overturning stability
  - **Absolute size, \( H \)**
    - Peak rotations and overturning stability for given \( H / L \)

\[
\frac{A}{A_c} = \frac{q_c}{q}
\]

\[
M_{foot} = \frac{W \cdot L}{2} \left( 1 - \frac{A_c}{A} \right) + \frac{P_p \cdot D}{3} + k \cdot P_p \cdot \frac{L}{2}
\]

\[
C_r = \frac{M_{foot}}{H \cdot W}
\]
Test Design

Rocking Foundations’ Response Controlling Parameters

Prototype vs. Model

For $S_a = 1$, $L_p = S_L \times L_m$ and $W_p = (S_L)^2 \times W_m$

- $L_p >> L_m$
- $(H / L)_p = (H / L)_m$ (correct scaling)
- $q_p = q_m$
- $(q_c)_p >> (q_c)_m$ (due to strong dependency of sand bearing capacity to actual footing size)
- $(A/A_c)_p >> (A/A_c)_m$ (prototype has significantly better re-centering)
- $(C_r)_p \sim (C_r)_m$ (prototype is slightly stronger statically)

\[
\frac{A}{A_c} = \frac{q_c}{q} \quad M_{foot} \leq \frac{W \cdot L}{2} \cdot \left(1 - \frac{A_c}{A}\right) + P_p \cdot \frac{D}{3} + k \cdot P_p \cdot \frac{L}{2} \quad C_r = \frac{M_{foot}}{H \cdot W}
\]
Test Design

**Design Approach**

- **Superstructure**
  - Structural 1g scaling laws used as a guidance to design superstructure based on the Restrepo et al. (2010) full-scale bridge column test and the available PEER mass blocks.
  - Length scale factor, $S_L = \sqrt{W_{ss_m}/W_{ss_p}} = 1/3$
  - Time scale factor, $S_t = \sqrt{S_L/S_a} = \sqrt{1/3 / 1} = 0.577$

- **Rocking foundation**
  - Designed directly in model-scale to $C_r = 0.26$, $A / A_c = 8-15$ and $H / L > 1.5$
  - Obtained response is representative of the tested model and not of a prototype

- **Soil deposit**
  - Sand with target relative density of 80%+ to represent competent soil conditions
  - Sufficiently deep soil profile to minimize boundary effects from the shake table platen
Test Design

Structure and Test Geometry

Key parameters
- $W = 290 \text{ kN}$
- $H / L = 2.0$
- $A / A_c = 13$
- $FS_v = 24$
- $C_r = 0.26$
- $C_y = 0.47$
Test Design

Structure and Test Geometry

- 2 structures tested concurrently with different footing orientation

![Diagram showing structure and test geometry with dimensions and orientations labeled.]
Test Design

- **Restraining System**
  - To prevent overturning and collision of the mass blocks with the box
Experiment Assembly and Construction
Experiment Assembly and Construction

- Simplified Construction Flowchart

- Casting of Footing, Column and Load Stub
  - Restraining System Installation
  - Assembly of Mass Blocks
    - Placement of Specimens
      - Footings Backfilling
        - Seismic Testing
      - Repair of the Soil Surface
    - Soil Fill and Compaction to EL+3.35m
      - Placement of Temporary Wooden Frames
    - Soil Fill and Compaction to EL+2.69m
      - Installation of Saturation/Dewatering System, and Observation Wells
    - Soil Fill and Compaction to EL+0.73m
      - Liner Installation
      - MSE Wall Testing
    - Removal of Soil and Retaining Wall to EL+0.60m
      - Construction of Soil and Retaining Wall
      - Box Assembly
    - Removal of Soil, Saturation/Dewatering System, and Observation Wells
    - Box Dismantling and Specimens Disposal
    - Removal of Specimens
Experiment Assembly and Construction

- Casting of footings, columns and load stubs
  - Detailed Construction Drawings
Experiment Assembly and Construction

- Casting of footings, columns and load stubs

Placement of rebars and formwork

Casting of columns and load stubs

Concrete footings, columns and load stubs
Experiment Assembly and Construction

- Restraining System Assembly

- Steel rods and grouting of HSS pipes
- Placement of outriggers
- Placement of tapered wood beams
- Completed restraining system
Experiment Assembly and Construction

- **Specimens and Restraining System Construction**

- Placement of mass support steel beams
- Placement of mass blocks
- Completed specimen

NHERI @ UCSD Workshop, 14-15 December, 2015
Experiment Assembly and Construction

- **Large Soil Confinement Box**

![Diagram showing large soil confinement box with labeled components: W24x84 Steel Confining Beams, W24x104 Steel Spacer Beams, Precast Concrete Panels, W24x84 Steel Corner Spacer Inserts, North orientation.]

(Source: Fox et al. (2015), Geotechnical Testing Journal)
Experiment Assembly and Construction

- **Large Soil Confinement Box**
  - Erection of Vertical Elements and Post-Tensioning to the Shake Table Platen
Experiment Assembly and Construction

- **Large Soil Confinement Box**
  - Placement of Concrete Panels
Experiment Assembly and Construction

- Time Lapse Video of Assembly
Experiment Assembly and Construction

- **Large Soil Confinement Box**
  - Exterior Views of Assembled Box
Experiment Assembly and Construction

- **Large Soil Confinement Box**
  - *Interior Views of Assembled Box*

  - 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
Experiment Assembly and Construction

- **Soil Filling and Removal**
  - Series of Conveyor Belts
    - Economic, but slow process
Experiment Assembly and Construction

- **Soil Filling and Removal**
  - Use of concrete hoppers/buckets and facility’s crane
    - Faster process, but less economic due to crane usage
Experiment Assembly and Construction

- **Liner**
  - *Preparation Before Placement*
Experiment Assembly and Construction

- **Liner**
  - Placement and Patching

![Liner Assembly and Construction Images]
Experiment Assembly and Construction

- Saturation and Dewatering System
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
Experiment Assembly and Construction

- **Testing Cycle**
  - Specimen placement
  - Backfill compaction
  - Leveling/compaction of soil surface
  - Water addition
  - Testing
  - Specimen removal
Material Testing
Concrete

- Slump tests taken prior to casting
- Cylindrical samples taken for UC tests from the footing and column batches to be tested 1, 2, and 4 weeks after casting and at Test Days 1 and 2

![Graph showing unconfined strength against elapsed days for footing and column units with specified strength of 6 ksi at Test Days 1 and 2.](image-url)
Reinforcing Steel

- 3 samples taken for tension tests from each of
  - Footing main rebars
  - Column longitudinal rebars
  - Column spiral
  - Load stub J-bar stirrups
  - Load stub staples

![Graph showing tensile stress and strain for column longitudinal rebars.](Image)
Material Testing

- **Soil Properties Overview**
  - *Clean, angular, poorly-graded medium sand (ASTM C33 washed concrete sand)*

<table>
<thead>
<tr>
<th>Classification</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel content [%]</td>
<td>0</td>
</tr>
<tr>
<td>Fines content [%]</td>
<td>2.8</td>
</tr>
<tr>
<td>Specific gravity, (G_S)</td>
<td>2.63</td>
</tr>
<tr>
<td>Grain size, (D_{50} (D_{10})) [(\mu m)]</td>
<td>737 (186)</td>
</tr>
<tr>
<td>Coefficient of uniformity, (C_u)</td>
<td>5.3</td>
</tr>
<tr>
<td>Coefficient of curvature, (C_c)</td>
<td>0.9</td>
</tr>
<tr>
<td>Dry unit weight, (\gamma_{d,min} (\gamma_{d,max})) [kN/m(^3)]</td>
<td>14.41 (17.72)</td>
</tr>
<tr>
<td>Void ratio, (e_{max} (e_{min}))</td>
<td>0.790 (0.456)</td>
</tr>
<tr>
<td>Constant-volume friction angle, (\phi_{cv}) [deg.]</td>
<td>(\approx 33)</td>
</tr>
</tbody>
</table>
Material Testing

- **Considered Methods for Measuring In-situ Relative Density \( (D_R) \)**
  - **Sand Cone Test**
    - Easy and cheap; can be done by the students
    - Also measures water content
    - High user uncertainty for \( D_R \) measurements; can yield scattered results
    - Two measurements possible per day; results available after 24h
  - **Cone Penetration Test**
    - Back-calculates \( D_R \) and effective friction angle
    - Needs to be conducted by subcontractors; more expensive, logistic / time issues
  - **Nuclear Density Gage**
    - Accurate measurement of \( D_R \)
    - Needs to be conducted by subcontractors; more expensive, logistic / time issues
Material Testing

Selected Method for Measuring In-situ Relative Density ($D_R$)

- **Sand Cone Test**
  - Logistics and time constraint issues for planned CPT pushes
  - Consistent compaction protocol with previous project yielding $D_R = 88\%$ based on sand cone tests and nuclear density gage measurements
### Sand Cone Test Results

<table>
<thead>
<tr>
<th>Description</th>
<th>Location</th>
<th>Relative density, $D_R$ (%)</th>
<th>Water content, w (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x (m)</td>
<td>y (m)</td>
<td>z (m)</td>
</tr>
<tr>
<td>Under skew footing center</td>
<td>-2.29</td>
<td>0.30</td>
<td>0.97</td>
</tr>
<tr>
<td>Under aligned footing center</td>
<td>2.59</td>
<td>0.30</td>
<td>0.97</td>
</tr>
<tr>
<td>Under skew footing center</td>
<td>-2.29</td>
<td>0.30</td>
<td>1.83</td>
</tr>
<tr>
<td>Under aligned footing center</td>
<td>2.59</td>
<td>0.30</td>
<td>1.83</td>
</tr>
<tr>
<td>Under skew footing center</td>
<td>-2.29</td>
<td>0.30</td>
<td>2.49</td>
</tr>
<tr>
<td>Under aligned footing center</td>
<td>2.59</td>
<td>0.30</td>
<td>2.49</td>
</tr>
<tr>
<td>Under skew footing center</td>
<td>-2.29</td>
<td>0.00</td>
<td>2.69</td>
</tr>
<tr>
<td>Under aligned footing center</td>
<td>2.59</td>
<td>0.00</td>
<td>2.69</td>
</tr>
<tr>
<td>Skew footing backfill before test 1, SE side middle</td>
<td>-1.79</td>
<td>-0.86</td>
<td>3.35</td>
</tr>
<tr>
<td>Aligned footing backfill before test 1, SE corner</td>
<td>3.58</td>
<td>-0.99</td>
<td>3.35</td>
</tr>
<tr>
<td>Aligned footing backfill before test 1, S side middle</td>
<td>2.59</td>
<td>-0.99</td>
<td>3.35</td>
</tr>
<tr>
<td>Skew footing center before test 3</td>
<td>-2.29</td>
<td>0.00</td>
<td>2.69</td>
</tr>
<tr>
<td>Aligned footing center before test 3</td>
<td>2.59</td>
<td>0.00</td>
<td>2.69</td>
</tr>
</tbody>
</table>

*Interpreted achieved average relative density, $D_R \approx 90\%$*
Instrumentation
Instrumentation

General Considerations

• Must consider available facility instrumentation in advance, and the need to purchase/fabricate sensors specific to your test
  ✓ Pore Pressure Transducers (PPT) to monitor pore pressure build-up in saturated soil
  ✓ Custom-made gap sensors to monitor dynamic evolution of the soil surface under the footings

• Clear instrumentation drawings and list of sensors distributed to data acquisition and video personnel before start of construction

• Understand construction and instrumentation placement time constraints – coordinate with data acquisition personnel
  ✓ What instrumentation is essential to my test?
    – No strain gage installation for the columns
  ✓ What is reasonable instrumentation redundancy?
    – Installed sensors = 137; initially proposed = 221
## Sensors Summary

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Location</th>
<th>No.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accelerometers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Box</td>
<td>4 (8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil, free-field</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil, under footings</td>
<td>8 + 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Footings</td>
<td>7 + 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protection system</td>
<td>(1+2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mass blocks</td>
<td>8 + 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td><strong>String Potentiometers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mass blocks</td>
<td>6 + 6</td>
<td>(4) 10in, (6) 25in, (2) 50in</td>
</tr>
<tr>
<td></td>
<td>Footings</td>
<td>6 + 6</td>
<td>(5) 5in, (7) 20in</td>
</tr>
<tr>
<td></td>
<td>Soil settlement</td>
<td>4 + 5</td>
<td>(9) 5in</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>33</td>
<td>(14) 5in, (4) 10in, (7) 20in, (6) 25in, (2) 50in</td>
</tr>
<tr>
<td><strong>Linear Potentiometers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gap/no gap</td>
<td>10 + 10</td>
<td>(20) 50mm</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>20</td>
<td>(20) 50mm</td>
</tr>
<tr>
<td><strong>Pore Pressure Transducers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil, free-field</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil, under footings</td>
<td>2 + 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>Total No. of Sensors</strong></td>
<td></td>
<td></td>
<td>137</td>
</tr>
</tbody>
</table>
**Instrumentation**

- **Sensors Nomenclature**

### A: Accelerometers

- **S:** Soil
- **F:** Free-field
- **S:** South position in S-N plane
- **E:** East position in E-W plane
- **S:** South orientation
- **0:** Reference
  - **EL+0'-0"**

- **F:** Footing
- **Z:** Under/at straight footing/specimen
- **M:** Middle position in S-N plane
- **N:** North position in E-W plane
- **E:** East orientation
- **W:** West orientation
  - **EL+6'-0"**

- **M:** Mass block
- **T:** Under/at skewed footing specimens
- **N:** North position in S-N plane
- **W:** West position in E-W plane
- **U:** Upwards orientation
  - **EL+8'-7"**

- **T:** Table
- **B:** Box

---

**Notes:**

- **INSTRUMENTATION OF ROCKING FOOTINGS SHAKE TABLE TEST**

- Sensors Description
  - **S:** South
  - **E:** East
  - **W:** West
  - **N:** North
  - **D:** Diagonal
  - **V:** Vertical
- **D:** Downward
- **U:** Upward
- **R:** Reference
  - **EL+0'-0"**
Instrumentation

Soil Instrumentation Drawings
**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
Instrumentation

Soil Pore Pressure Response

Sensor de-saturation or incomplete soil saturation?
Instrumentation

- **Structures’ Instrumentation**
  - Mass Blocks’ Accelerometers
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
Instrumentation

 vidéos Caméras Layout
Instrumentation

Coaxial Cameras Views
Seismic Testing Protocol

- **Developing a Motion Protocol**
  - Selection of number of motions and target drift ratios (Θ) for each motion
    - Test days 1 and 2: 6 motions of increasing intensity (peak Θ < 13% to avoid mobilization of the restraining system and damage to the column)
    - Test day 3: additional 2-3 motions
  - Pre-test prediction required to guide selection of motions to match objectives
  - Comparison of predicted and achieved response after each motion

- **Additional Considerations**
  - Candidate motions need to be selected and distributed to Operations Manager before filling the box with soil to run OLI tests
    - Candidate motions: 9 unique records; 15 in total
    - Used motions: 6 unique records; 9 in total
  - Peak input acceleration < 0.80 g to ensure LSCB integrity due to removal of the roof framing elements
Seismic Testing Protocol

- 3D Model in OpenSees for Motion Selection

![Diagram showing 3D model in OpenSees for motion selection. The diagram includes labels for nonlinear beam column element, stiff element, PySimple, QzSimple2, TzSimple, and the dimensions of the model. The model is shown in both Side View and Plan View.]
## Seismic Testing Protocol

### Motion Protocol

<table>
<thead>
<tr>
<th>No.</th>
<th>Earthquake</th>
<th>Ground motion</th>
<th>Scale Factor</th>
<th>Target Drift Ratio, $\Theta$ (%)</th>
<th>PGA, (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1989 Loma Prieta, CA</td>
<td>Gilroy #1</td>
<td>1.0</td>
<td>&lt;0.5</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>1989 Loma Prieta, CA</td>
<td>Corralitos</td>
<td>0.8</td>
<td>1</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>Imperial Valley, CA, 1979</td>
<td>El Centro #6</td>
<td>1.1</td>
<td>2</td>
<td>0.49</td>
</tr>
<tr>
<td>4</td>
<td>1971 San Fernando, CA</td>
<td>Pacoima Dam</td>
<td>0.8</td>
<td>4</td>
<td>0.52</td>
</tr>
<tr>
<td>5</td>
<td>1995 Kobe, Japan</td>
<td>Takatori</td>
<td>0.5</td>
<td>6</td>
<td>0.34</td>
</tr>
<tr>
<td>6</td>
<td>1995 Kobe, Japan</td>
<td>Takatori</td>
<td>1.0</td>
<td>&gt;8</td>
<td>0.68</td>
</tr>
<tr>
<td>7</td>
<td>1987 Superstition Hills (B)</td>
<td>Parachute Test Site</td>
<td>1.0</td>
<td>&gt;8</td>
<td>0.42</td>
</tr>
<tr>
<td>8</td>
<td>1987 Superstition Hills (B)</td>
<td>Parachute Test Site</td>
<td>-1.0</td>
<td>&gt;8</td>
<td>0.42</td>
</tr>
<tr>
<td>9</td>
<td>1987 Superstition Hills (B)</td>
<td>Parachute Test Site</td>
<td>1.1</td>
<td>&gt;8</td>
<td>0.46</td>
</tr>
</tbody>
</table>

**Notes**

1. Motions 7 – 9 only for Test 3.
2. White noise with 0.05g RMS amplitude and 5 mins duration applied before motion 1 and after each motion.
3. Motions compressed in time by $\sqrt{1/3} = 0.577$. 
Seismic Testing Protocol

- Comparison of Pre-test Prediction with Test Day 1 Results

**Aligned Specimen**

- Pre-test Prediction (G = 70 MPa)
- Pre-test Prediction (G = 140 MPa)
- Experiment

**Skewed Specimen**

- Pre-test Prediction (G = 70 MPa)
- Pre-test Prediction (G = 140 MPa)
- Experiment
Test Response
Test Response

Column Drift Ratio Time Histories for Test Days 1 and 2

Drift ratio, $\theta$ (%) Time Histories for Test Days 1 and 2

Test Day 1

Test Day 2

El Centro #6, 110%
Pacoima dam, 80%
Takatori, 50%
Takatori, 100%

Drift ratio, $\theta$ (%)

Time, $t$ (s)
Test Response

- **Mechanism for Flow of Sand under the Footing**

  - Gap formation
  - Sand flowing into the gap
  - Residual rotation
Test Response

- Post-test Soil Surface under Footings

Test Day 1

Test Day 2
Test Response

Remediation Method for Test Day 3

- Weak Concrete Cast around the Footings

Plastic sheet

Joint

Concrete, $f'_c \approx 3.5$ MPa [0.5 ksi]
(cast one day before the test)
Test Response

- Column Drift Ratio Time Histories (revisited)

<table>
<thead>
<tr>
<th></th>
<th>Time, t (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Centro #6, 110%</td>
<td>1.5% 0.1% 3.7% 0.4% 6.9% 0.8% 11.6% 3.4%</td>
</tr>
<tr>
<td>Pacoima dam, 80%</td>
<td>2.2% 0.1% 3.9% 0.5% 6.9% 1.4% 13.7% 7.8%</td>
</tr>
<tr>
<td>Takatori, 50%</td>
<td>1.3% 0% 3.3% 0.1% 5.9% 0.5% 10.1% 1.9%</td>
</tr>
<tr>
<td>Takatori, 100%</td>
<td>1.5% 0.1% 3.7% 0.4% 6.9% 0.8% 3.4%</td>
</tr>
</tbody>
</table>
Test Response

- **Foundation Hysteretic Response – Takatori, 50%**

![Test Response Diagram](image-url)
Test Response

- **System Softening and Period Elongation**
  - Determined from white-noise vibrations based on the ARS amplification ratio

![Graph showing fundamental period vs. motion number with legend for Test Day 1, Test Day 2, and Test Day 3.](image-url)
Test Response
### Cost Disaggregation

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner, Saturation and Dewatering System</td>
<td>$2,619</td>
<td>0.7</td>
</tr>
<tr>
<td>Pore Pressure Transducers</td>
<td>$1,719</td>
<td>0.5</td>
</tr>
<tr>
<td>Analysis of Soil Box</td>
<td>$5,737</td>
<td>1.6</td>
</tr>
<tr>
<td>Specimens Construction</td>
<td>$10,502</td>
<td>2.9</td>
</tr>
<tr>
<td>Restraining System</td>
<td>$18,000</td>
<td>4.9</td>
</tr>
<tr>
<td>Mass Blocks Shipment</td>
<td>$7,800</td>
<td>2.1</td>
</tr>
<tr>
<td>Box Demolition</td>
<td>$51,000</td>
<td>13.9</td>
</tr>
<tr>
<td>Facility Use</td>
<td>$101,000</td>
<td>27.5</td>
</tr>
<tr>
<td>Facility Labor</td>
<td>$98,858</td>
<td>26.9</td>
</tr>
<tr>
<td>Equipment Renting</td>
<td>$41,539</td>
<td>11.3</td>
</tr>
<tr>
<td>Other Materials</td>
<td>$28,285</td>
<td>7.7</td>
</tr>
<tr>
<td><strong>Total Experimental Cost</strong></td>
<td>$367,059</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Concluding Remarks

- This presentation focused on some of the design, construction and testing aspects of a large-scale 1g testing of a geo-structural system at UCSD.

- Detailed documentation of protocols and detailed preparation of designs increases quality of communication and coordination amongst the various processes.

- Testing decisions should reflect the target of measuring and gaining insights into specified targeted responses and mechanisms.

- The efficacy of a physical modeling test of this scale reflects the details of the preparation and execution phases.
Concluding Remarks

- The test progress is not a straight line. Adjustments should be expected subject to:
  - Preliminary results during the design phase
  - Gained insights during testing
  - Time- and cost-limitations
Thank you!
Questions?
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