Large-Scale Shake Table Testing

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Pros and Cons of Shake Table Experiments

- Shake table experiments at the NHERI@UC San Diego facility are ideal for large to full-scale structural, geotechnical and geo-structural systems where:
  - There is significant in-built inertial mass
  - Rate of loading is identified as an important variable
  - Off-the-shelf products are a key part of the experiment:
    - ✓ BRBs, viscous dampers, seismic isolators, etc.
    - ✓ Doors, HVAC equipment, fire protection equipment, etc.
  - The response to near faults earthquake excitation is important in the study:
    - ✓ NHERI@UC San Diego peak velocity is 1.8 m/s (harmonic)

Pros and Cons of Shake Table Experiments

- The NHERI@UC San Diego shake table is also ideal for testing large or full-scale, providing that suitable measures are taken to build an inertial mass:
  - For multiple component tests consider using inertial masses that can be removed and replaced
  - Consider the cost of the crane if the weight of the removable/replaceable inertia mass exceeds 40 kips

Pros and Cons of Shake Table Experiments

- The NHERI@UC San Diego shake table is less suitable for small scale model testing or very rigid specimens when:
  - the natural frequency of the highest mode of interest of the model is greater than 33 Hz
  - One of the natural frequencies of interest falls within the frequency band of the notch filter placed to control the response of the shake table around the oil column frequency. Note that the oil column frequency depends on the mass and dynamic characteristics of the specimen placed atop the platen.

Experiment Design

- Understanding the NHERI@UC San Diego shake table limitations
  - Shake table is 1DOF in its current configuration
  - Frequency range of operation is 0.25-33 Hz. Some tests may be conducted with input motions rich in frequency below 0.25 Hz, but verification is required (i.e. for seismic isolation tests) and approval by the facility PI is needed
  - Test specimens taller than 100 ft (30 m) may require special temporary permits from FAA plus additional FAA obstruction lights
    - ✓ The shake table is in close proximity to the Miramar Marine Corps Air Station
  - For heavy specimens, the OLI calibration of the input ground motions takes place with the bare table or at reduced amplitude if the test specimen is on
  - Some motions may not be reproduced by the shake table as it did during the OLI calibration. Adjustments of the settings during the test phase is highly discouraged and only will take place under exceptional circumstances and with the direct approval by the facility PI

Experiment Design

- Assembling the right team
  - A good team, regular meetings and fluid communication is essential for the success of a project:
    - ✓ NHERI@UC San Diego PIs, Senior Personnel and Technical Personnel have a wealth of expertise and are willing to share it with you, contact them early and benefit from it!
    - ✓ NHERI@UC San Diego Personnel will help finding suitable contractors. A suitable contractor has personnel who understand the nature of a research project and are willing to work with not so experienced students and faculty.
    - ✓ Establish regular online and site meetings with NHERI@UC San Diego Personnel, share your thoughts, test plans, drawings and problems. Personnel are here to help and to offer constructive criticism that will enhance your research experience.

Experiment Design

- Your ideas vs time & budget
  - A poorly planned and ambitious project can turn up in significant cost overruns
  - The availability of a single boomlift can hamper the rate of sensor deployment in tall projects. Budgeting a second boomlift can be beneficial to these kind of projects.
  - Check the UC San Diego personnel recharge rates when preparing your budget. Not all personnel costs are covered by NHERI.
  - Talk to construction and demolition contractors early while preparing your budget. UC San Diego personnel will help finding suitable companies if asked.
  - Demolition costs can be a high cost item in your budget, particularly in taller test specimens.

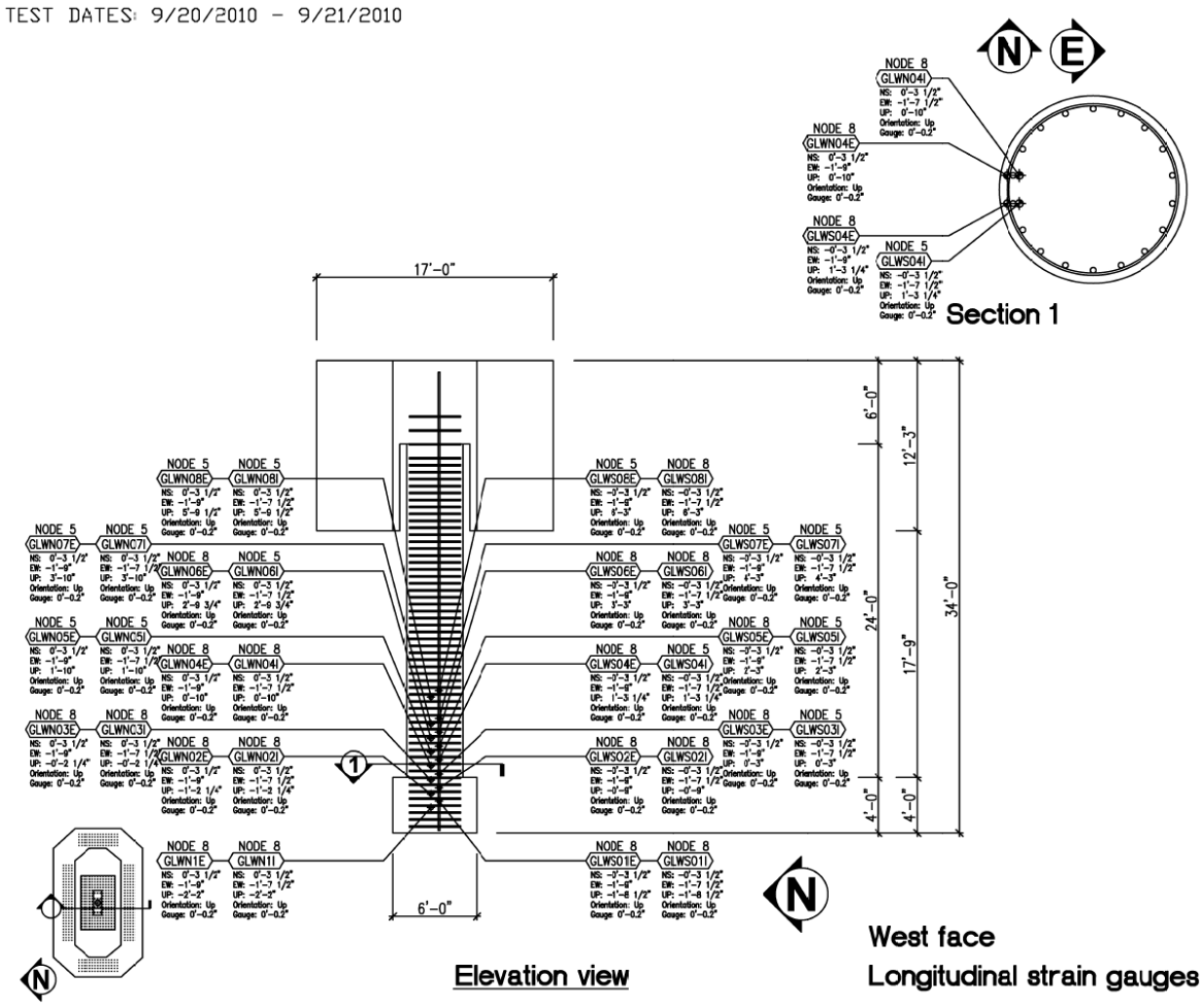
Experiment Design

➢ Instrumentation & Data Acquisition

- The facility offers a wide range of sensors:
  - ✓ Displacement sensors like DVDT's and string potentiometers
  - ✓ 50 Hz GPS location sensors
  - ✓ Accelerometers
  - ✓ Pressure cells
  - ✓ Strain gauges and similar are considered disposable and are not offered by the facility as part of the instrumentation. Training for placing strain gauges is provided to users.
  - ✓ Redundancy in instrumentation is desirable, but excessive instrumentation can cause delay. Budget a deployment of 15 sensors per day per instrumentation crew for 40-80 ft (12-24 m) tall tests and of 25 sensors per day per crew for tests below 20 ft (6 m) high. The rate of installation includes fabrication and fastening of brackets, actual deployment, connections, debugging and corrections.
  - ✓ Typically a project supports a single instrumentation crew
  - ✓ The existing DAQ is typically configured to sample at 240 Hz (a multiple of 30 Hz, which is the sampling rate of the video system). This allows for synchronization and has a Nyquist frequency of 120 Hz which is quite sufficiently high for most applications.
  - ✓ For special applications the DAQ can be configured to sample anywhere between 10 and 500 Hz, with a burst rate at 3000 Hz.
  - ✓ NHERI@UC San Diego provides NIST traceable sensors and sensors that are robust and have proven to give reliable results. The facility welcomes the deployment of experimental sensors (not supported by the facility like wireless sensors and noncontact sensors)

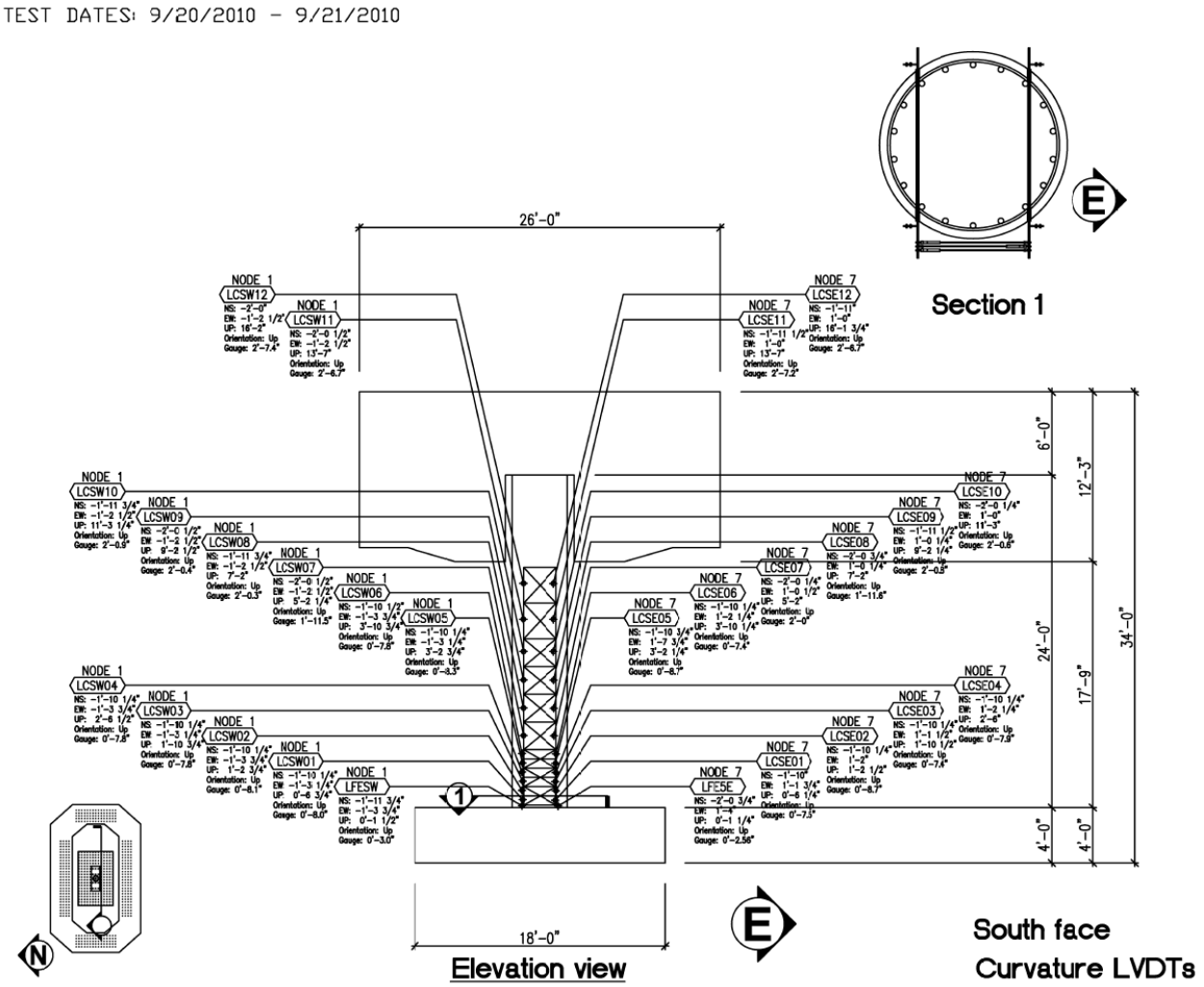
Experiment Design

- Example of an instrumentation plan



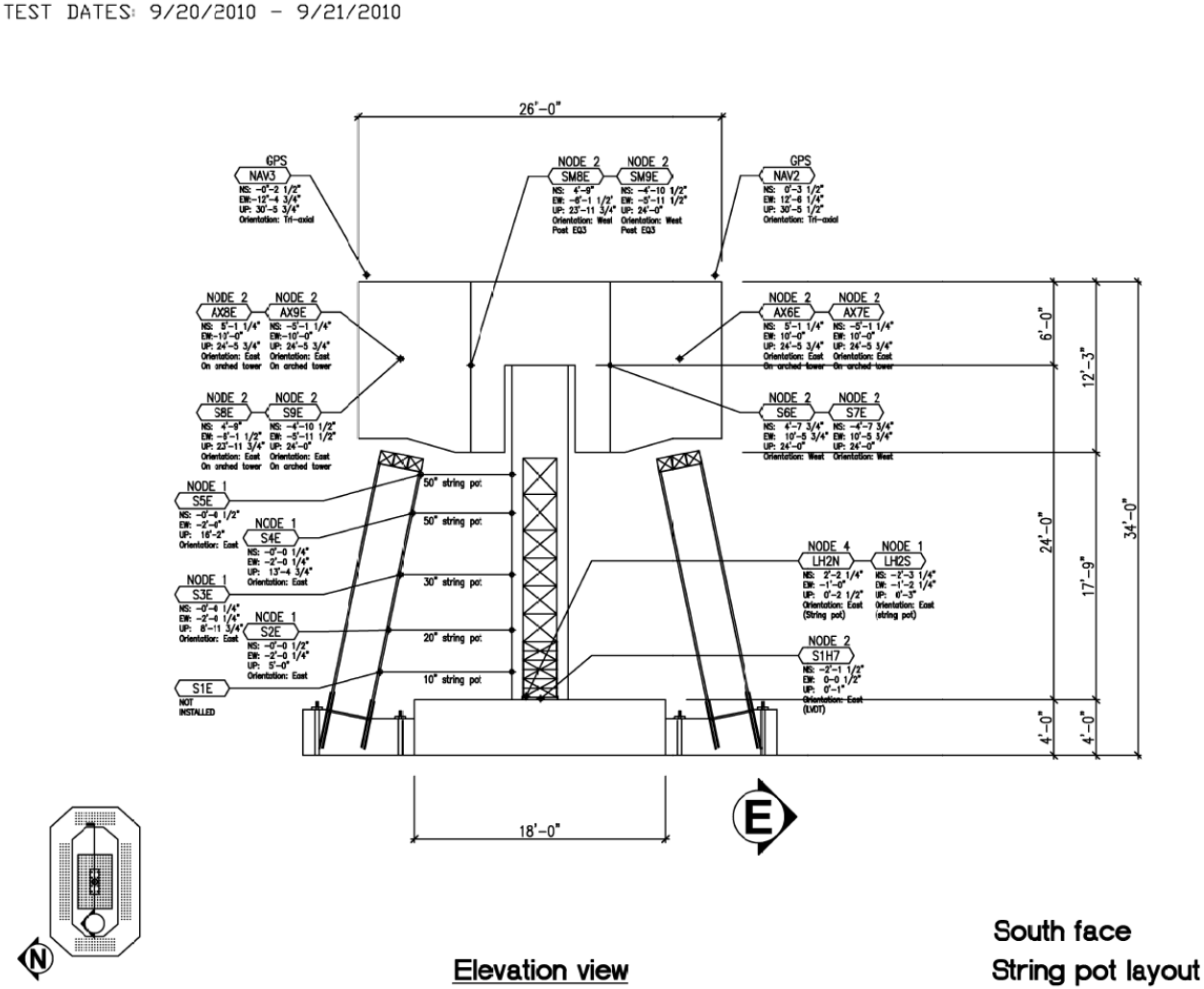
Experiment Design

- Instrumentation Plan



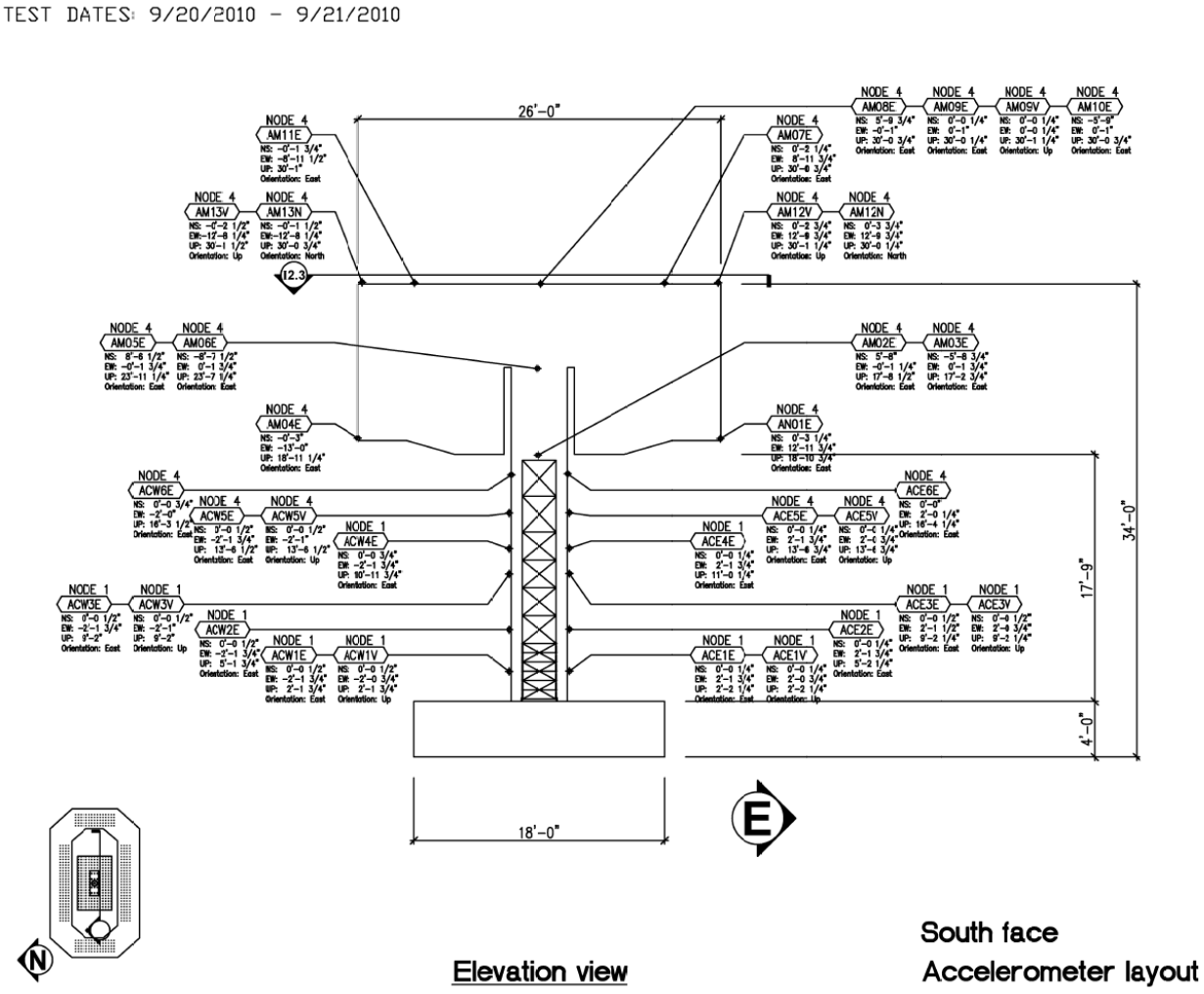
Experiment Design

- Instrumentation Plan



Experiment Design

- Instrumentation Plan



Test Execution

- Test protocol
  - The research team should select a number of historical, spectral matching, artificial or other input ground motions and pass this ensemble to NHERI@UC San Diego as early as practicable, so that the motions can be subjected to an OLI calibration as a window opens.
  - The research team should provide the motions scaled in time when applicable. Do not expect NHERI@UC San Diego personnel to take responsibility for scaling.
  - Communicate whether the input motions need to be calibrated at different amplitude scales and provide the corresponding names (i.e. 50% scale, 100% scale, 125% scale, 200% scale). NHERI@UC San Diego personnel will check whether the motions are within the physical limits of the facility:
    - ✓ Limits in terms of force, velocity, displacement and of swept displacement
    - ✓ When exceeding one of the limits, NHERI@UC San Diego will communicate so and offer suggestions (i.e. narrow the low pass filter frequency, etc.)

Test Execution

- Test execution
  - Although there is not a typical test, there are a number of steps that have been common to most projects. A typical day of test may include one or two earthquake input ground motions. The execution follows this order:
    - ✓ Perform ambient vibration tests (for AV tests, it is recommended deploying high-end 120db 24 bit accelerometers as the noise level in 90db 16 bit mems accelerometers may be within the AV signal).
    - ✓ Pressurize the hydraulics– All personnel off the table
    - ✓ Perform long duration band clipped (0.25-33 Hz) white noise tests
      - White noise tests can be performed at various intensity levels, ensuring the test specimen remains elastic throughout (i.e. 1.5%, 3 and 4.5% RMS).
      - WN test signals can be generated at the site. The project PI is responsible to check and approve that the desired amplitude is that replayed before the test.
      - The duration can be made a function of the fundamental period of the test specimen (i.e. 400 T) that will allow for the use of signal processing windowing techniques.
    - ✓ Test earthquake input motion
    - ✓ Depressurize the shake table – Personnel can step up on the table and conduct the damage survey

Test Execution

- Site Safety
  - Safety is paramount at the NHERI@UC San Diego facility. The facility has a ten years record of no accidents. Help it keeping it that way!
  - Alex Sherman is the Site Safety Officer
  - Take the time to read the facility Safety Manual, downloadable from the website
  - Every student and visitor needs to have safety boots, glasses and a hard hat. Safety gloves are needed for some particular jobs.
  - All researchers must abide the safety requirements. Student must attend bi-weekly meetings.
  - Site contractors must present prove of liability insurance of 1 to 5 million depending on the complexity of the job. Dan Radulescu will deal with Contracts and Grants to ensure the liability insurance is presented.

Project Management

- Gantt charts:
  - Gantt charts can be developed using proprietary software (i.e. MS Project) or OpenSource software (i.e. ProjectLibre)
  - It is advisable to develop and revise the project Gantt chart in collaboration with the facility personnel and with the construction and demolition contractors
  - Revision can be made after the research project progress is evaluated on a weekly basis

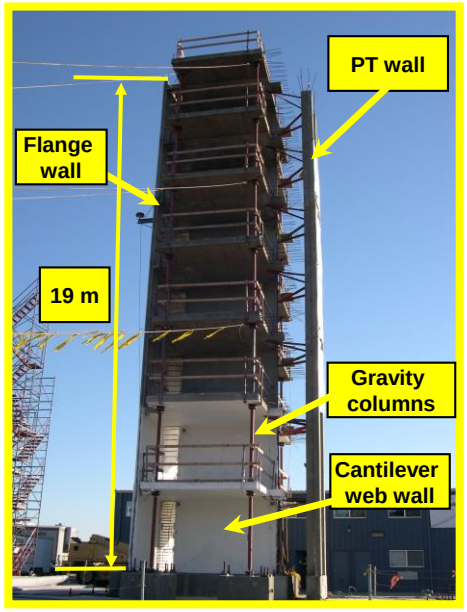
Project Management

- Recharge Personnel Expenses:
  - Recharge personnel hours and cost can be reviewed online on a daily basis. PIs are encouraged to review the personnel hours sheets.

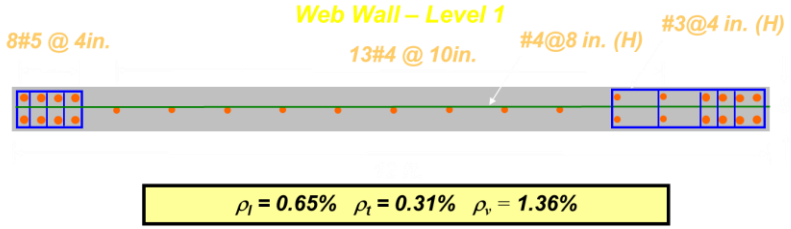
- Data reduction and interpretation
  - Data is immediately given to the project PI or his/her delegate after a test
  - The facility offers a simple dataviewer program that enables the research team to check for data quality
  - Data reduction and interpretation are the responsibility of the research team. The research team is encouraged to write a data reduction program with a variety of filters and algorithms built in. Many teams write the programs in Matlab.
  - The faculty encourages research students to have prior knowledge of digital signal processing techniques

Examples of Tests

- 7-story building (2007) funded by Industry through the Englekirk Board of Advisors
  - Slender RC bearing wall, slab and gravity column system tested to:
    - ✓ Verify the seismic response of well confined thin structural walls
    - ✓ To prove a displacement-based design method
    - ✓ To enable the calibration of nonlinear finite elements
    - ✓ To bring the community together and discuss various modeling techniques via a blind prediction contest



- ***Phase 1 Testing:***
  12ft long rectangular wall
- ***Phase 2 Testing:***
  16ft long T-wall



Examples of Tests

- 7-story building

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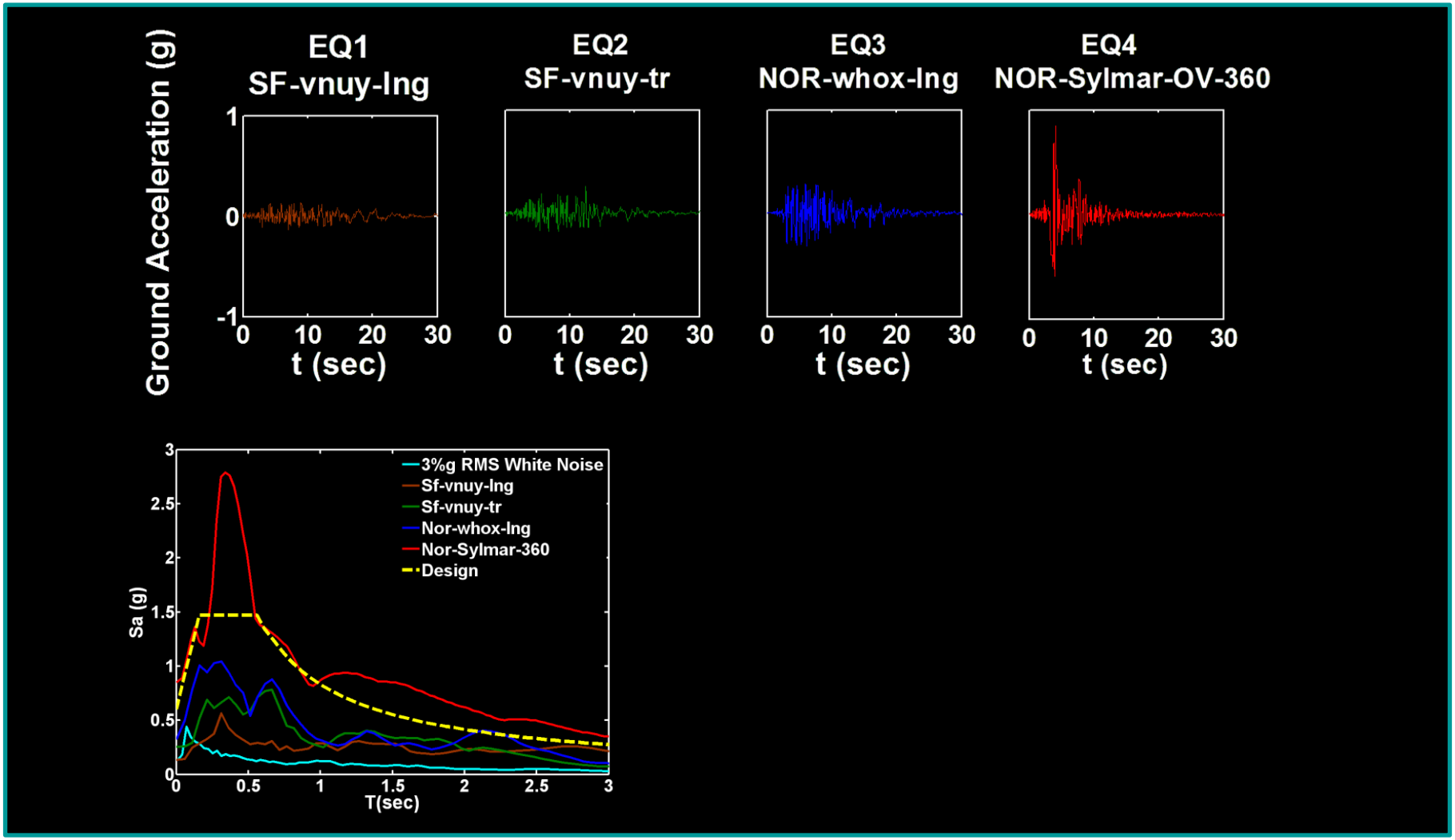
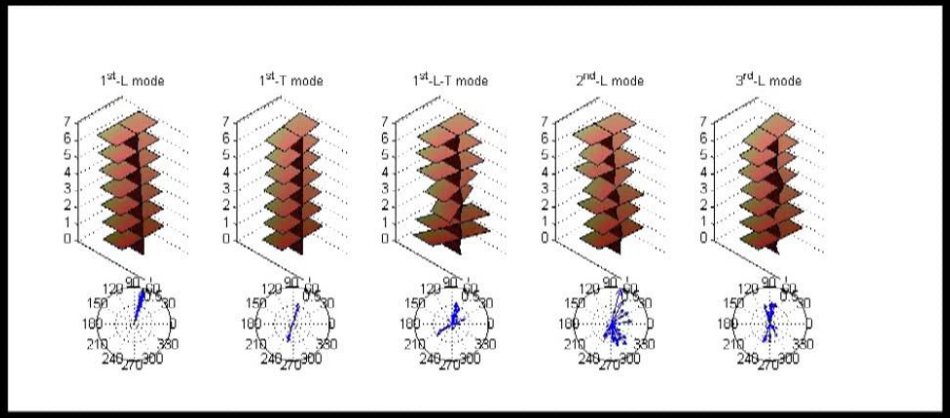


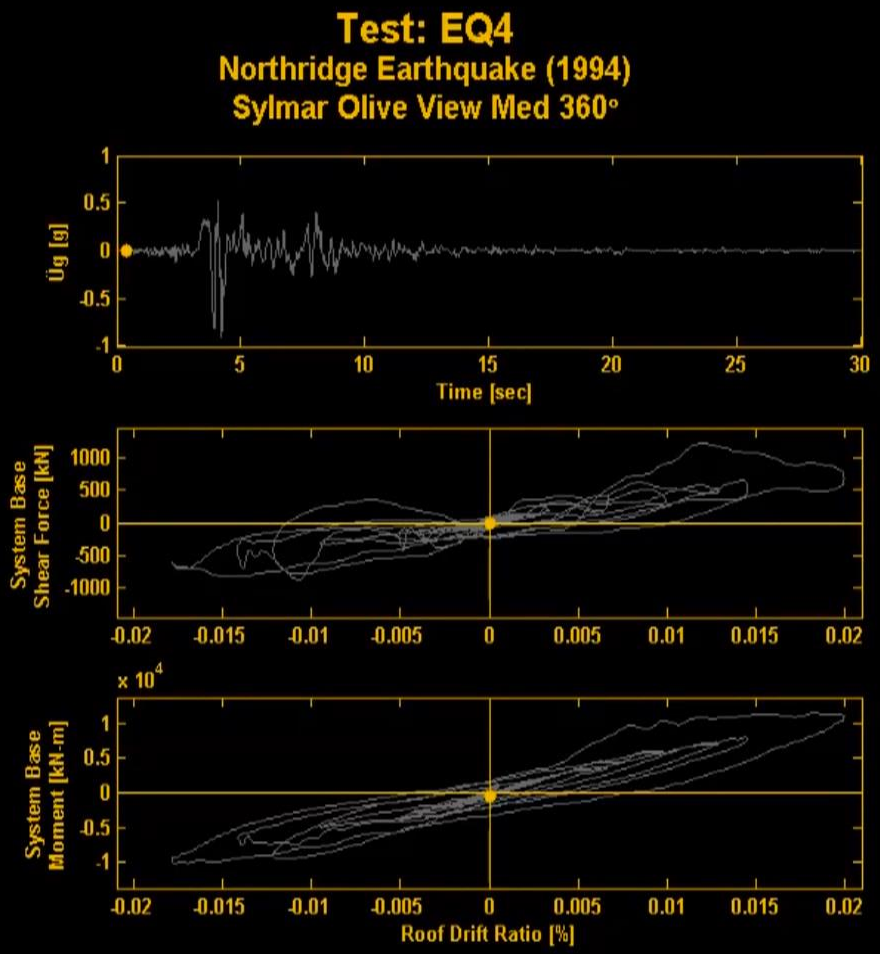
Examples of Tests

UC San Diego

System Identification

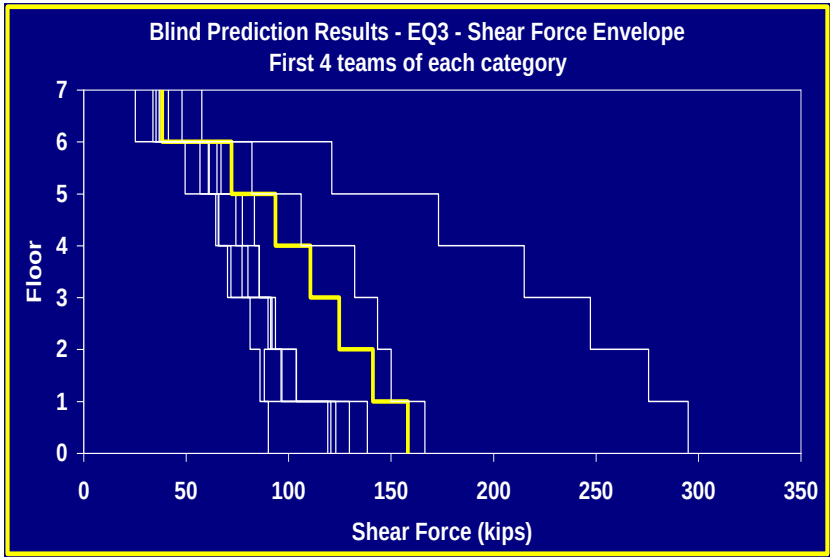


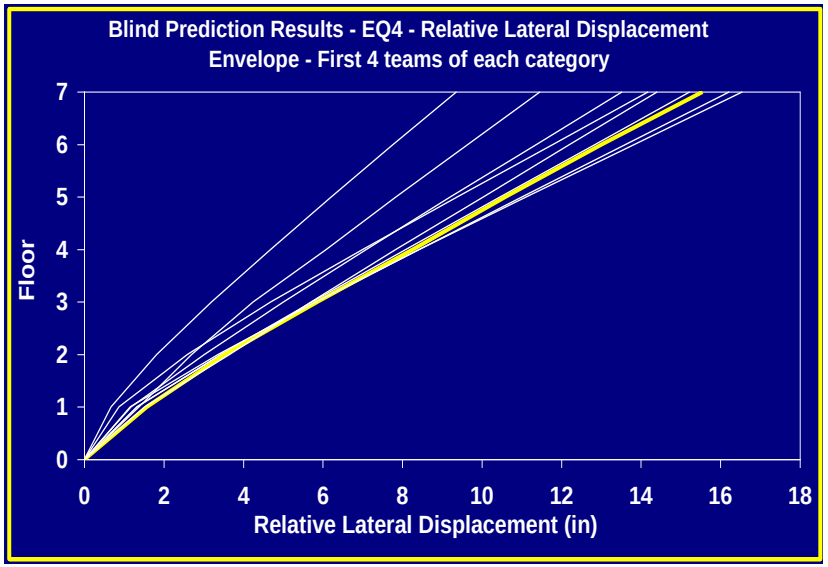
Examples of Tests



Examples of Tests

- 7-story NEES-PCA building blind prediction
  - 21 total entries/ 8 countries
  - Undergraduates – 2 teams / 2 countries
  - Researchers/Academics – 11 teams / 8 countries
  - Engineering Practitioners – 8 teams / 2 countries





Examples of Tests

- Large Bridge Column (2010) funded by PEER/Caltrans/FHWA
  - Observe and document the nonlinear dynamic response up to collapse of a full-scale bridge column designed as per Caltrans SDC
  - Observe scale effects with shake table testing of columns being carried out at UC Berkeley
  - Landmark test offering practitioners and researchers the chance to blindly predict the response of the test structure, to investigate epistemic uncertainty in nonlinear modeling and to enhance future modeling techniques
  - Eight weeks long project (Start to demolition)

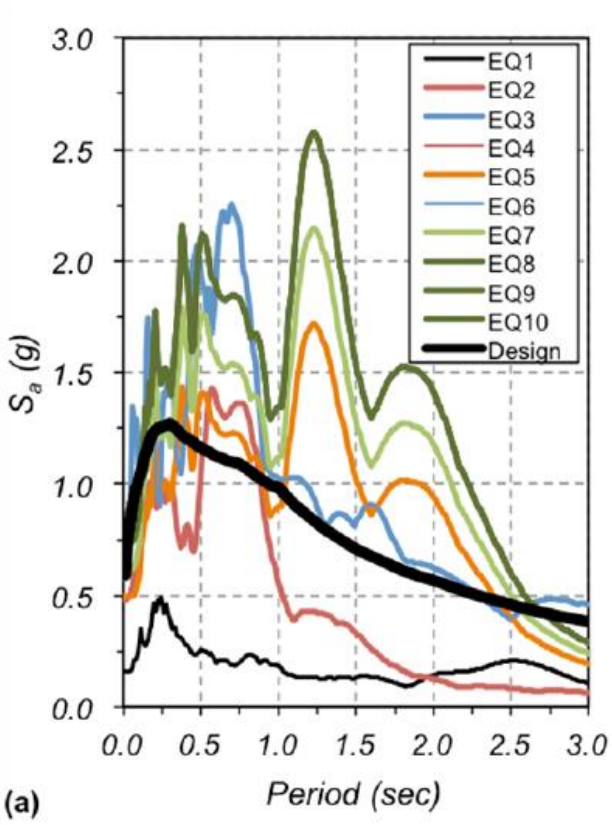
➢ Large Bridge Column

Phase I – As in Test Plan

Test	Earthquake	Date	Moment magnitude	Station	Component	Scale factor
EQ1	Loma Prieta	10/18/1989	6.9	Agnew State Hospital	090	1.0
EQ2	Loma Prieta	10/18/1989	6.9	Corralitos	090	1.0
EQ3	Loma Prieta	10/18/1989	6.9	LGPC	000	1.0
EQ4	Loma Prieta	10/18/1989	6.9	Corralitos	090	1.0
EQ5	Kobe	01/16/1995	6.9	Takatori	000	-0.8
EQ6	Loma Prieta	10/18/1989	6.9	LGPC	000	1.0

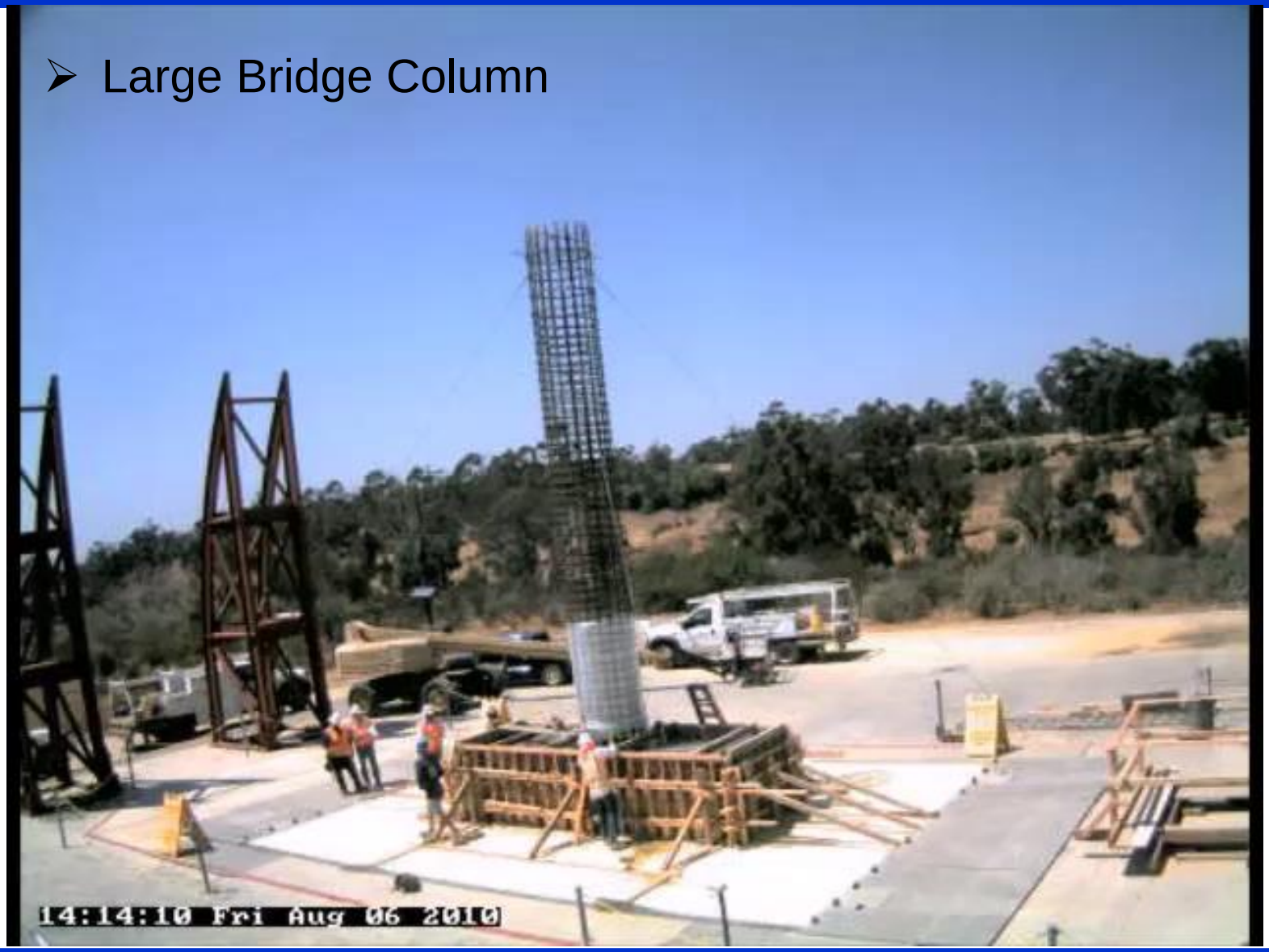
Phase II – Extended Testing

Test	Earthquake	Date	Moment magnitude	Station	Component	Scale factor
EQ7	Kobe	01/16/1995	6.9	Takatori	000	1.0
EQ8	Kobe	01/16/1995	6.9	Takatori	000	-1.2
EQ9	Kobe	01/16/1995	6.9	Takatori	000	1.2
EQ10	Kobe	01/16/1995	6.9	Takatori	000	1.2



Examples of Tests

- Large Bridge Column



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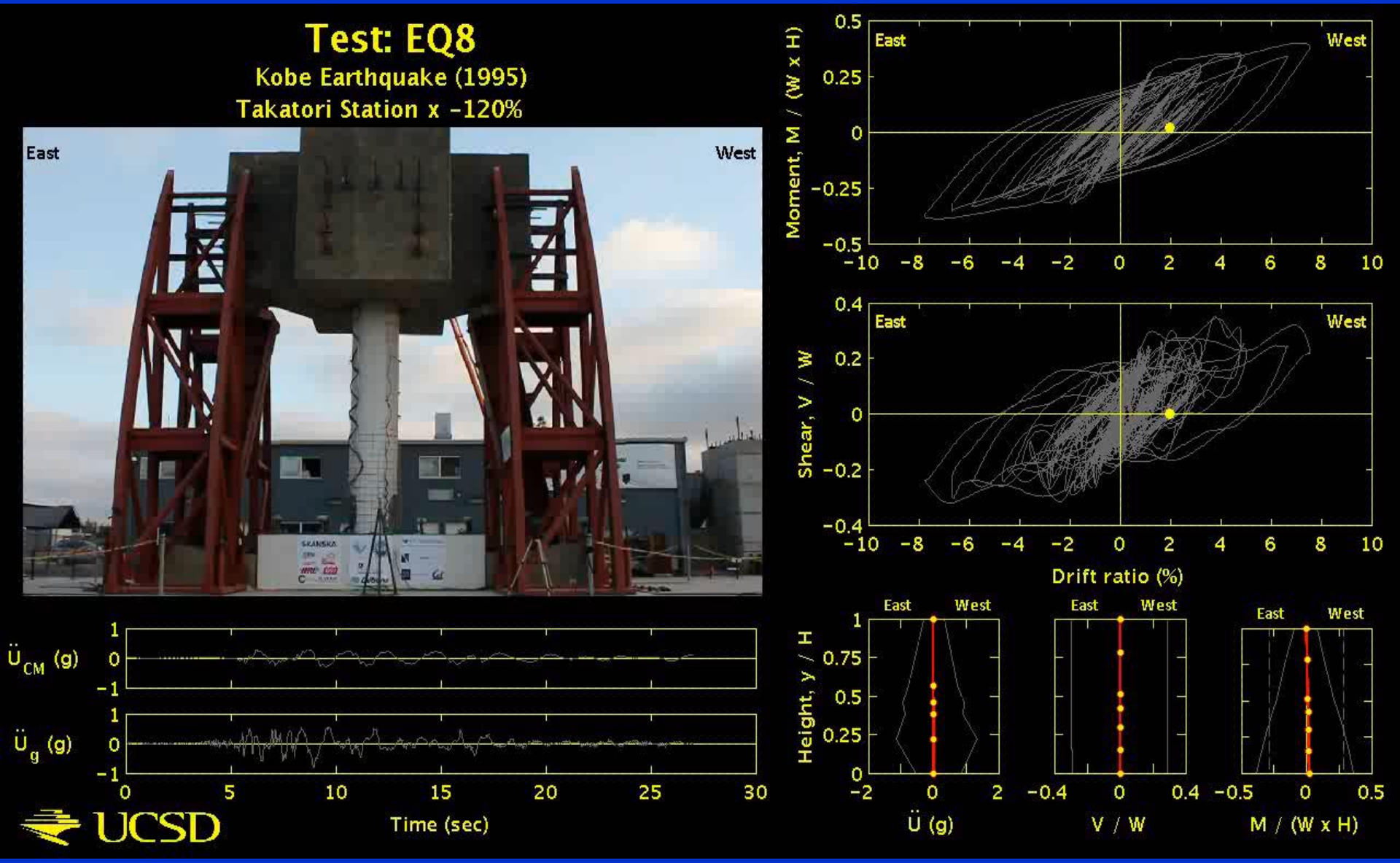
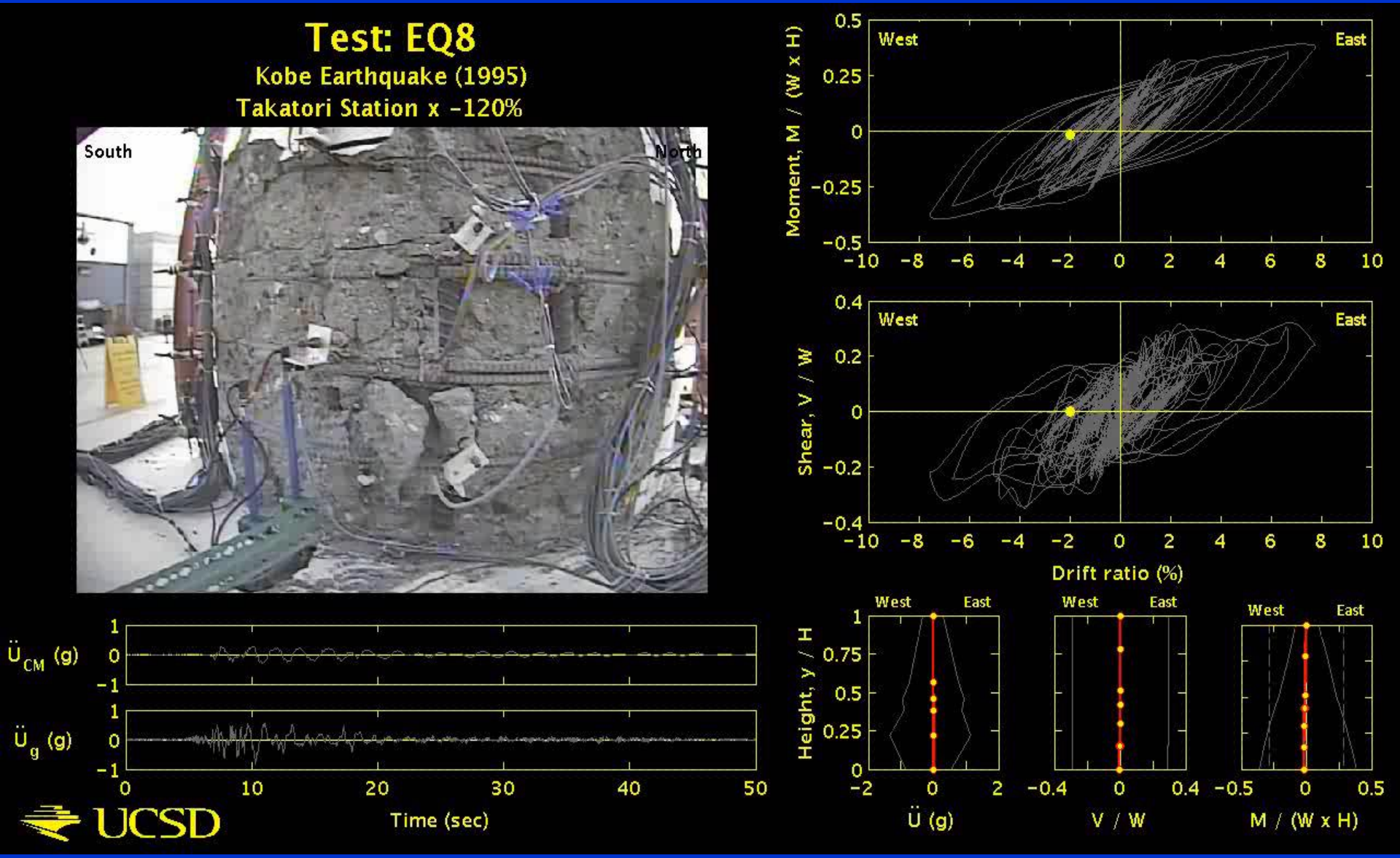
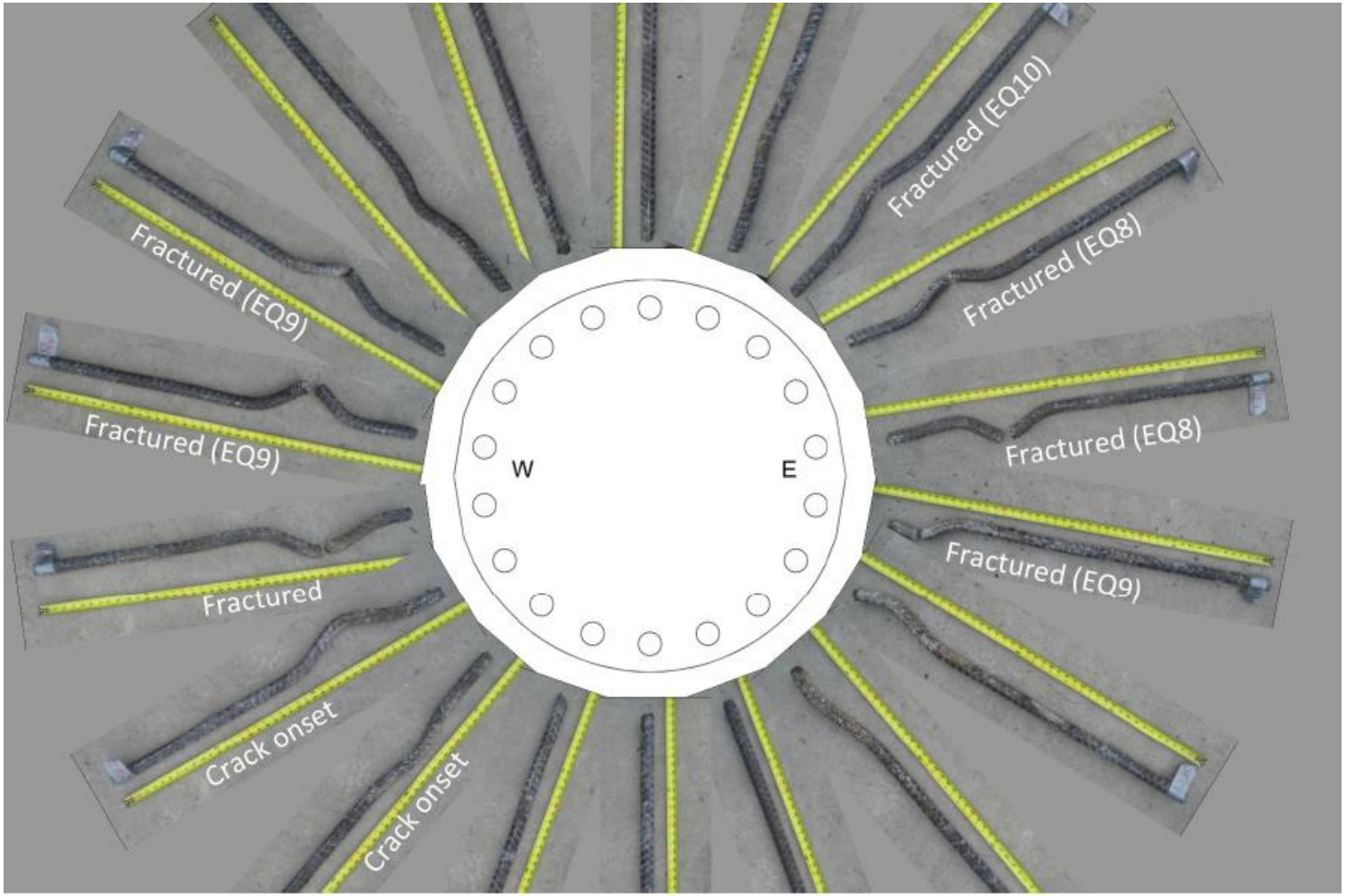


Examples of Tests



Examples of Tests

- Large Bridge Column



Examples of Tests

- Large Bridge Column PEER Blind Prediction

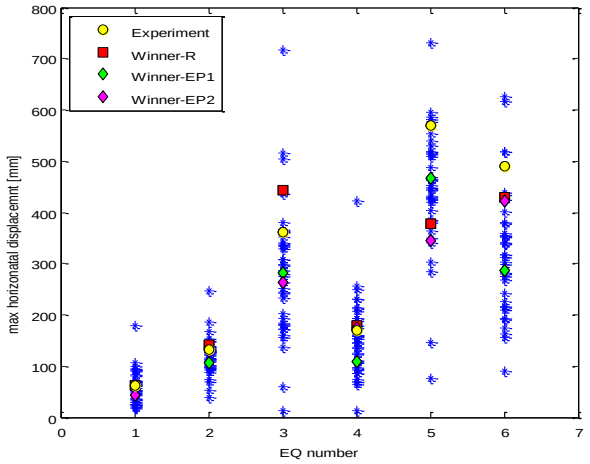
NOTE: Values should be reported in absolute terms
NOTE: y=0.0 is at the platen surface

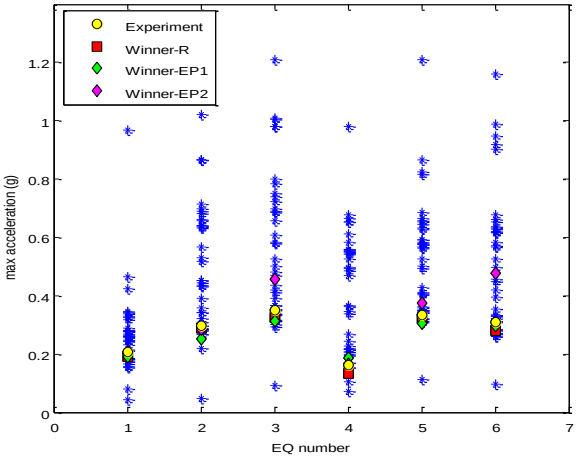
			Predicted Quantitiy					
			EQ1	EQ2	EQ3	EQ4	EQ5	EQ6
1	Relative horizontal displacement (mm) at level 6: y=8.534-m:	Maximum						
		maximum						
2	Total horizontal acceleration (g) at level 6: y=8.534-m:	Maximum						
		maximum						
3	Bending moment (kN-m) at level 0: y=1.219-m:	Maximum						
		maximum						
4	Shear force (kN) at level 0: y=1.219-m:	Maximum						
		maximum						
5	Average curvature (rad/km) between y = 1.270 and 1.473 m	Maximum						
		maximum						
6	Average axial strain (x10^6) between y = 1.270 and 1.473 m	Maximum						
		maximum						
7	Relative residual displacement (mm) at level 6: y=8.534-m:							
8	Largest column compressive axial force (kN)at level 0: y=1.219-m:							

9 Mode of failure (type corresponding number):

Specify if "Other":

1: None
2: Column shear failure
3: Column longitudinal bar anchorage failure
4: Column hoop fracture
5: Column longitudinal bar fracture
6: Other





- Two Categories: Researchers and Engineering Professionals
- 41 entries from 14 countries

Questions?