# LEAP: Liquefaction Experiments and Analysis Projects

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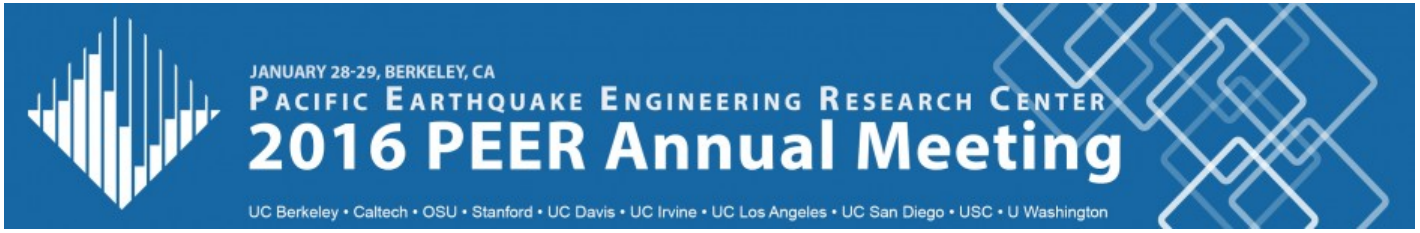
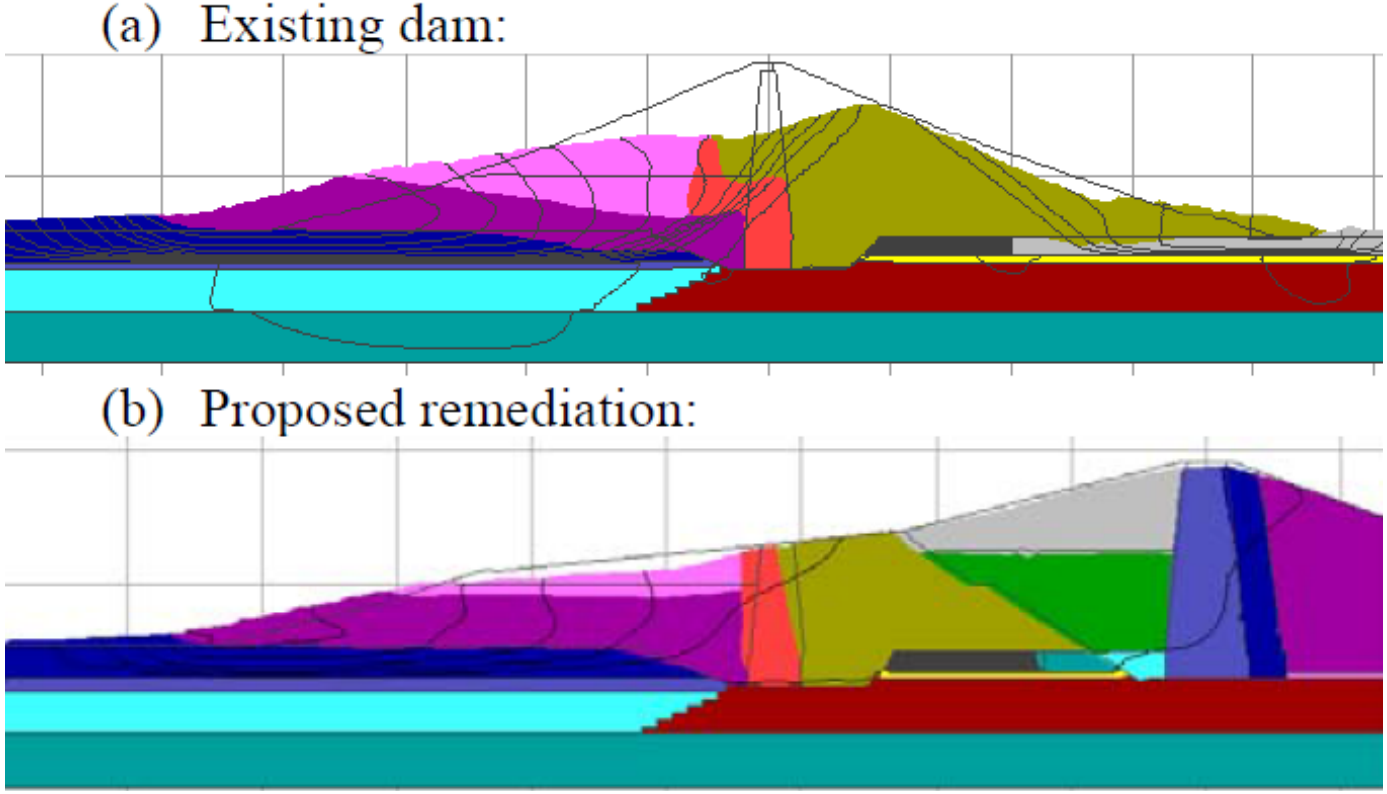


# How accurate are numerical methods that are use for design of critical infrastructure?




Perlea and Beaty (2010) - Success Dam Deformation contours for MCE

# Q. How accurate are numerical methods for liquefaction?

- Answer:  We don't know, but we should!

- This presentation summarizes some results from an NSF-NEES "Planning Project" designed to help answer the question.

# LEAP – Liquefaction Experiments and Analysis Projects

An international effort to produce a set of high quality test data for validation of numerical methods of liquefaction analysis. A wide range of problems requires a wide range of experiments – multiple leaps.

# LEAP – Liquefaction Experiments and Analysis Projects

- Validation is accomplished through a combination of
  A. before-the-event (true) “pre”- dictions
  B. after-the-event (blind) simulations,
  C. after-the-event simulations comparing divulged results for an array of sensors and/or a sequence of events. (Validates the numerical method, but does not validate a persons ability to “pre”-dict the parameters.)
- LEAP database is to archive data from experiments and simulations to enable calibration, verification, and validation

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RPI: Zeghal, Abdoun, Kokkali

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Zhejiang U (China): Zhou, Chen, Sun

Virginia Tech: *Ziotopoulou*

Beaty Engineering: Beaty

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# Databases for calibration, verification, and validation

## Verification Simulations

### Numerical model

- Integration scheme
- Damping
- Biot formulation

### Constitutive model

- Undrained test paths
- Critical state
- Consolidation and reconsolidation

## Soil Properties and Element Test Data

### Grain characterization

- Size distribution
- Max and min densities
- Specific gravity
- Source and batch

### Element test data

- Drained/ Undrained
- Triaxial/DSS
- Monotonic/cylic

## Specifications for Experiments and Numerical Simulations

### Experiment specifications

### True prediction instructions

### Recorded input data; instructions for after-the-event simulation

## LEAP GWU 2015 Validation Data

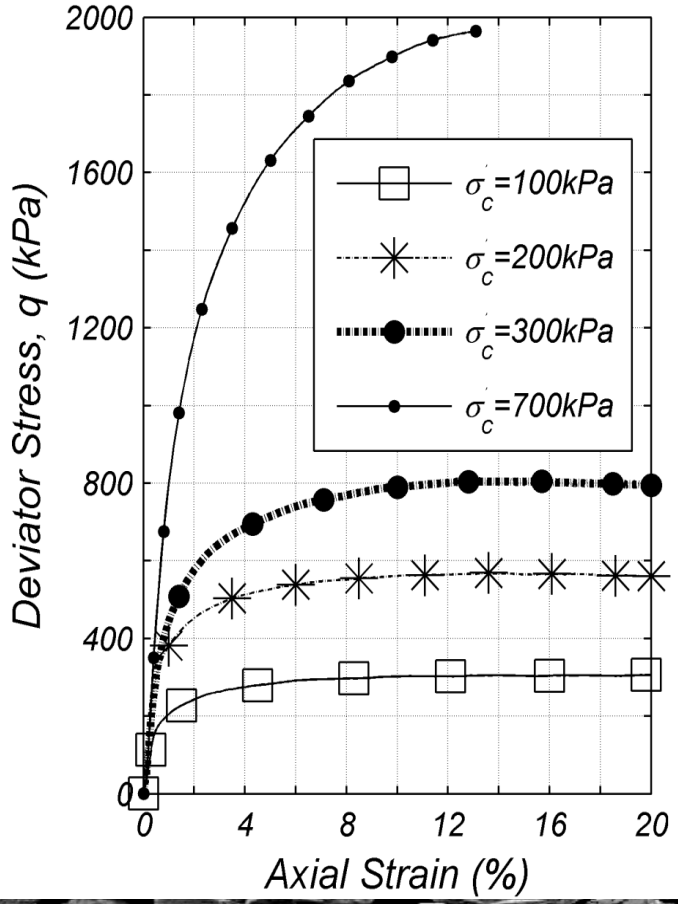
### Experiment Data

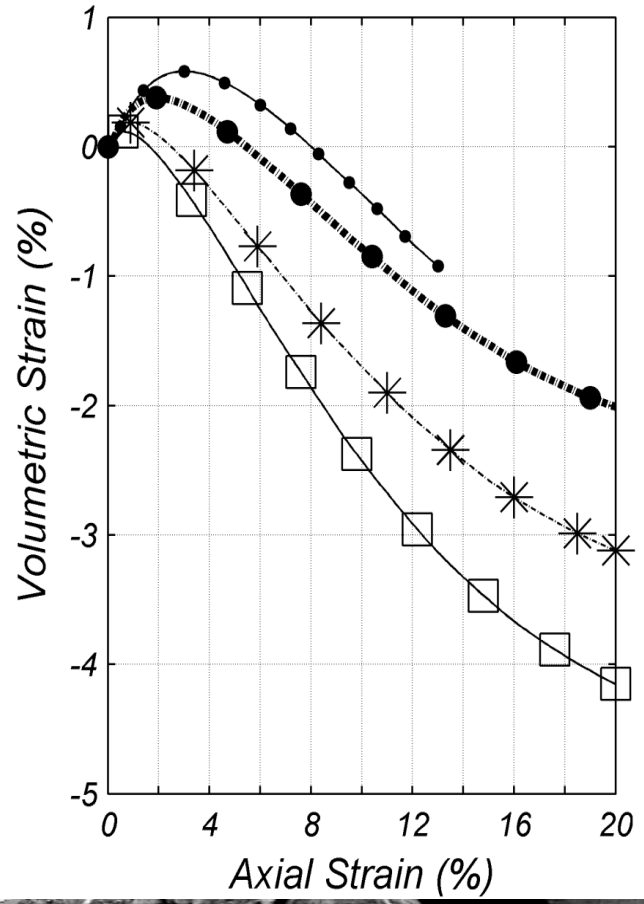
- Sensor data for each event
- Images
- Geometry

### Simulated Data

### Comparisons between simulations and experiments

# Soil properties and Element Tests




**Example triaxial test data in the LEAP database (Vasko, 2015)**

# Databases for verification and validation

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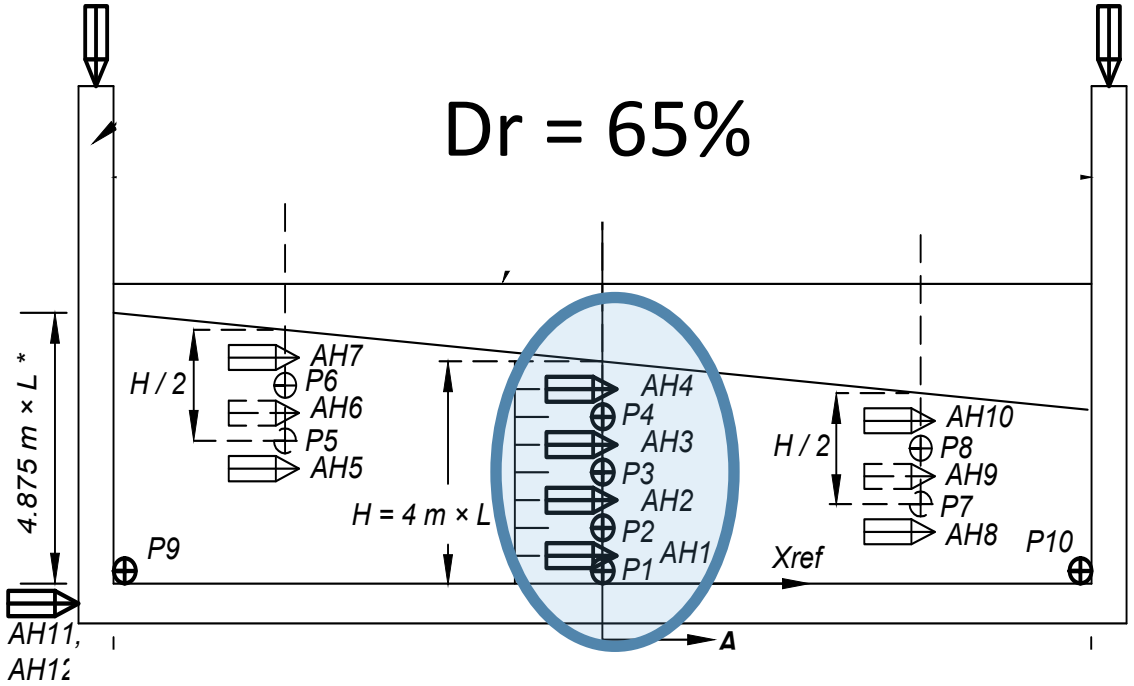
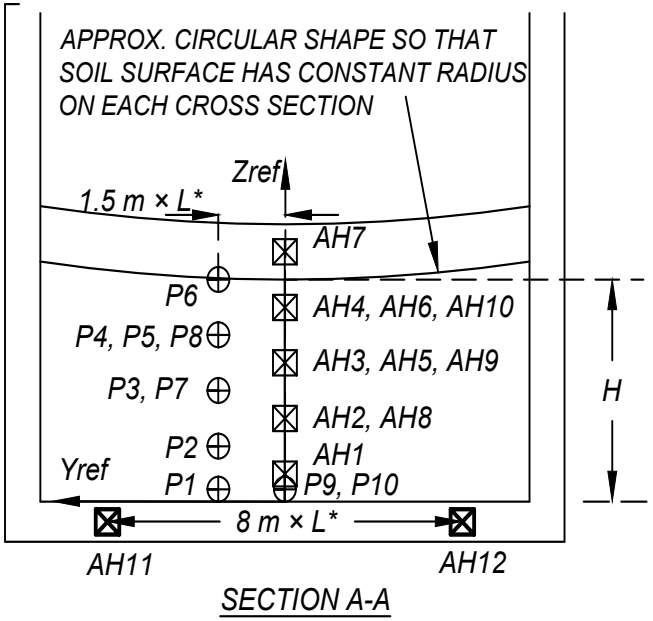
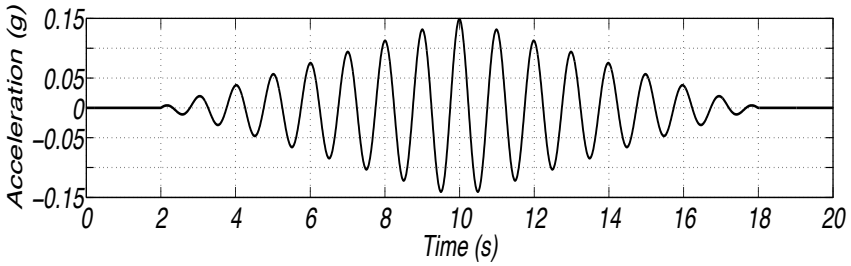
# Specifications for LEAP-GWU-2015 experiments



# Centrifuges use in LEAP-GWU-2015

| Facility | g* | Shaking direction | Centrifuge radius to 1/3 depth of the model soil (m) |
|---|---|---|---|
| Cambridge | 40.0 | Tangential | 3.61 |
| Kyoto | 44.4 | Tangential | 2.527 |
| Davis | 43.0 | Tangential | 1.035 |
| Nat. Central U | 26.0 | Axial | 2.085 |
| RPI | 23.0 | Axial | 2.7 |
| Zhejiang | 26.0 | Axial | 4.183 |

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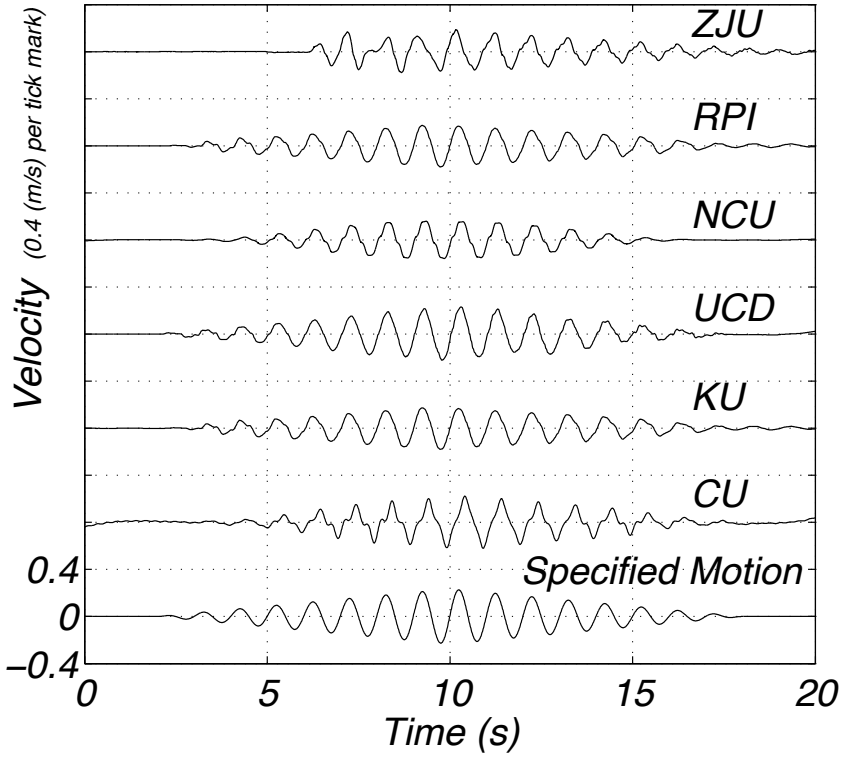
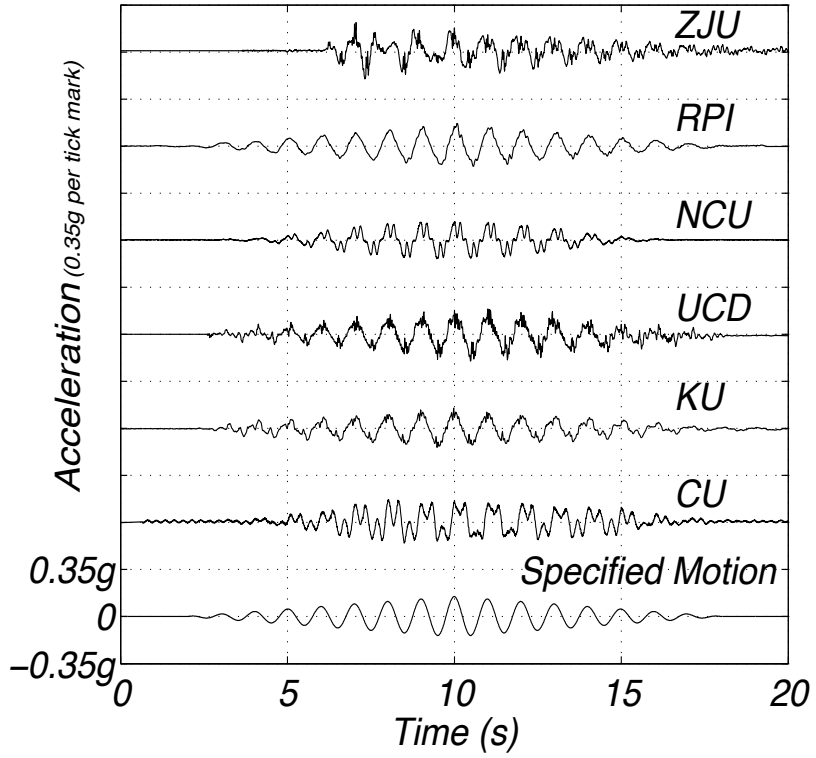
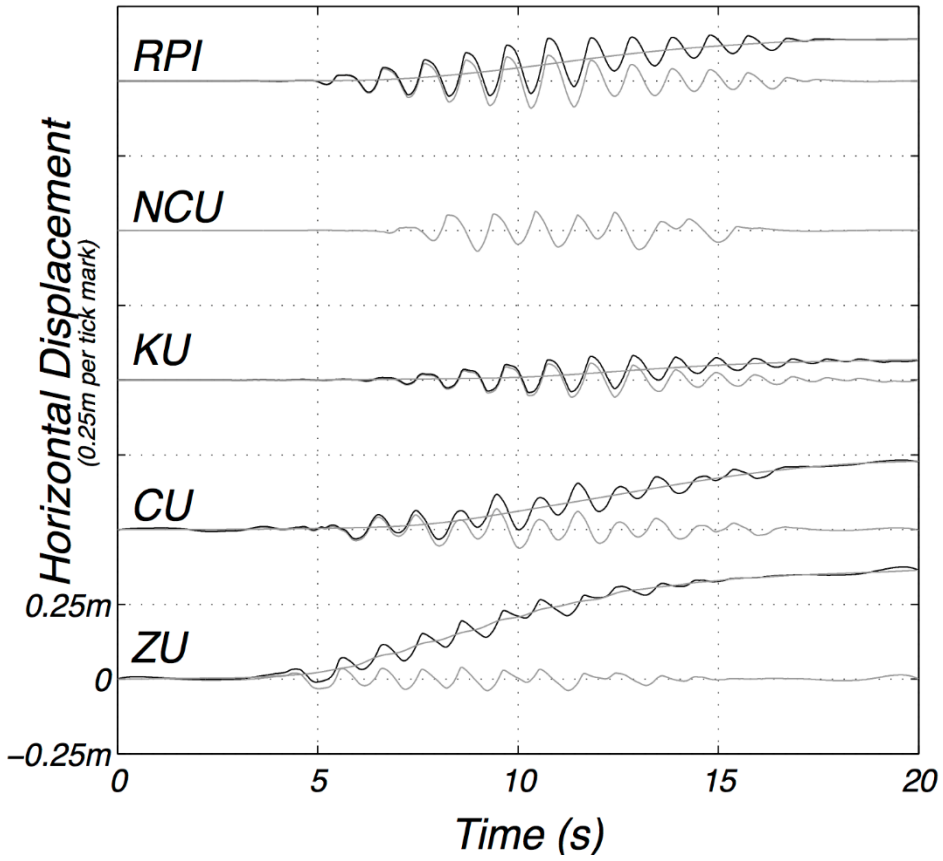
# Motion #2 – base acceleration and velocity



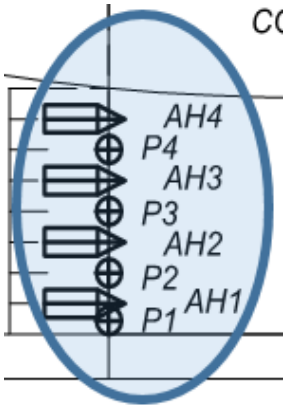



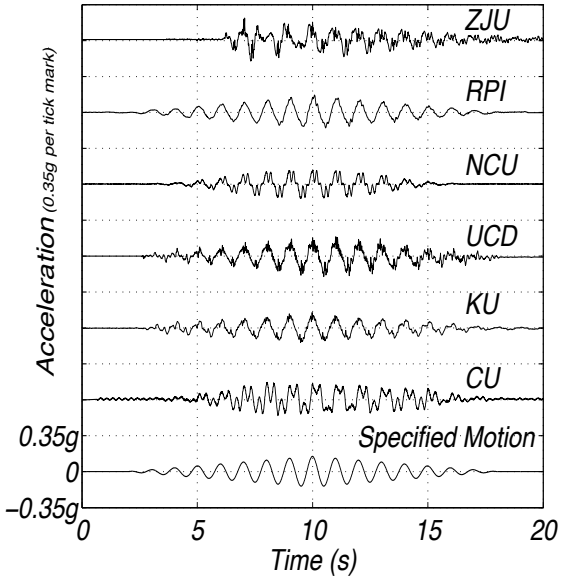
# Lateral displacements in repeated experiments

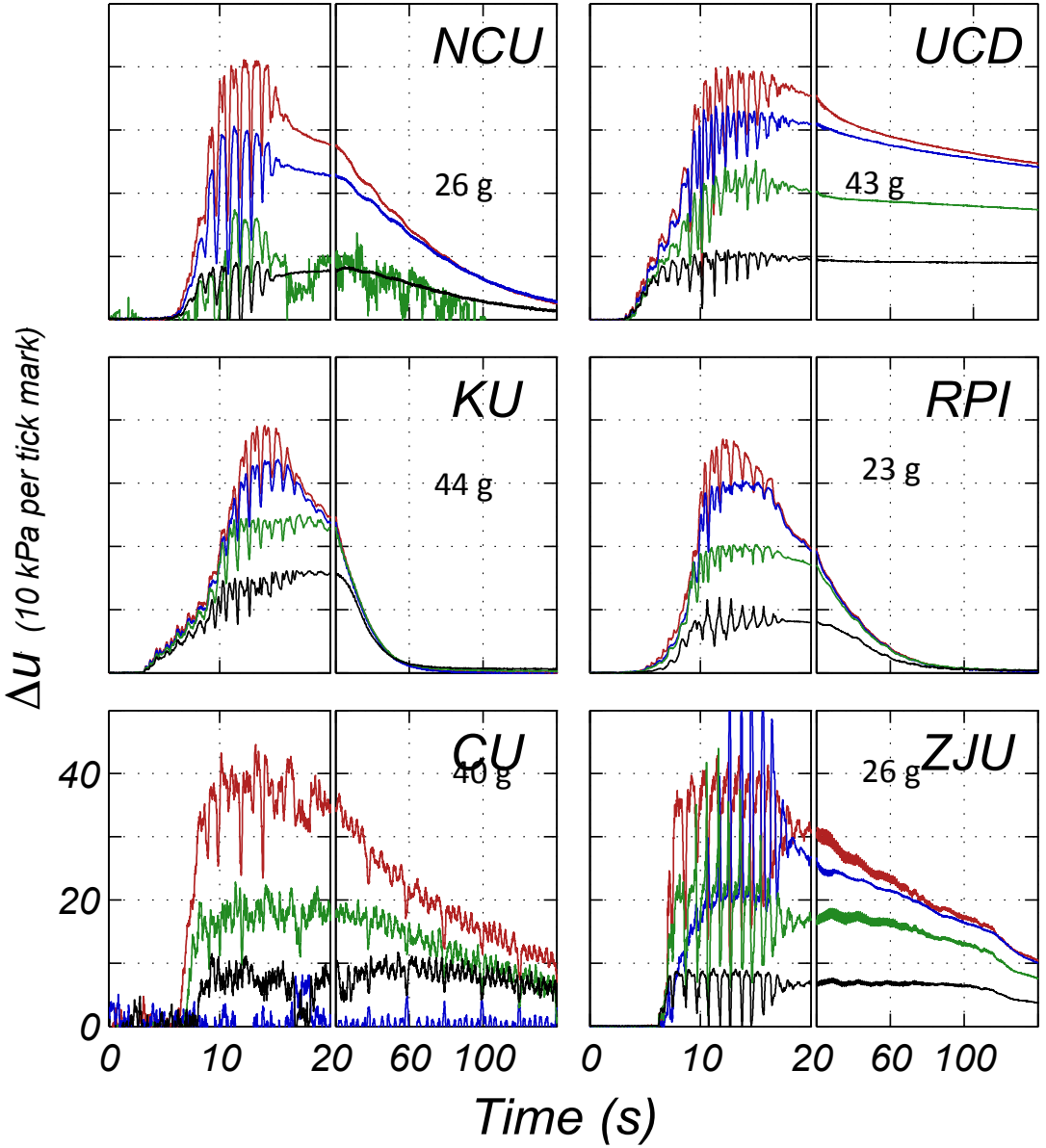
Cyclic displacements are well repeated but residual displacements are quite sensitive to differences in the experiments



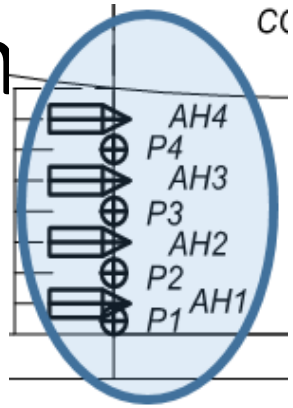
# Pore pressures Motion #2

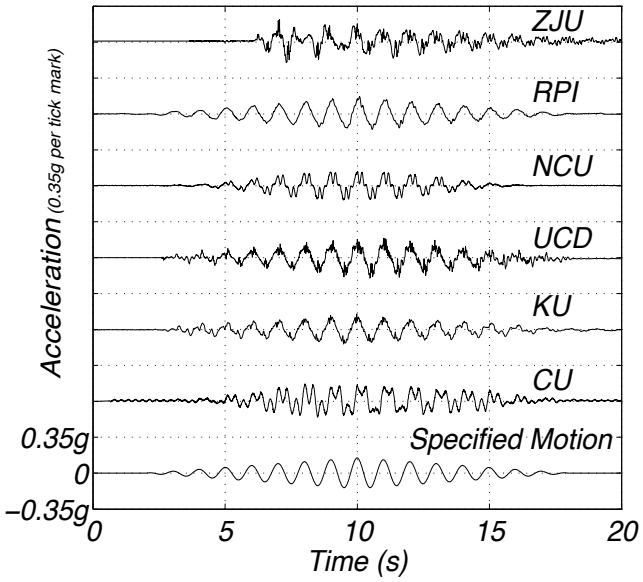


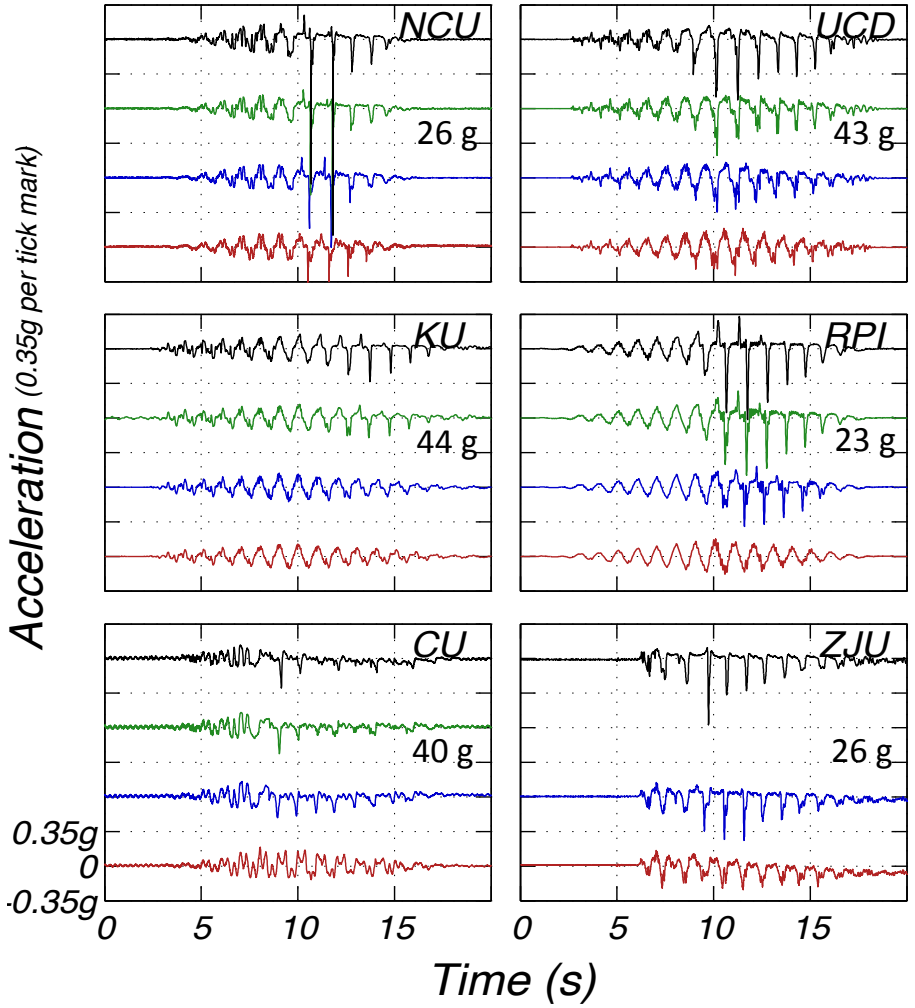



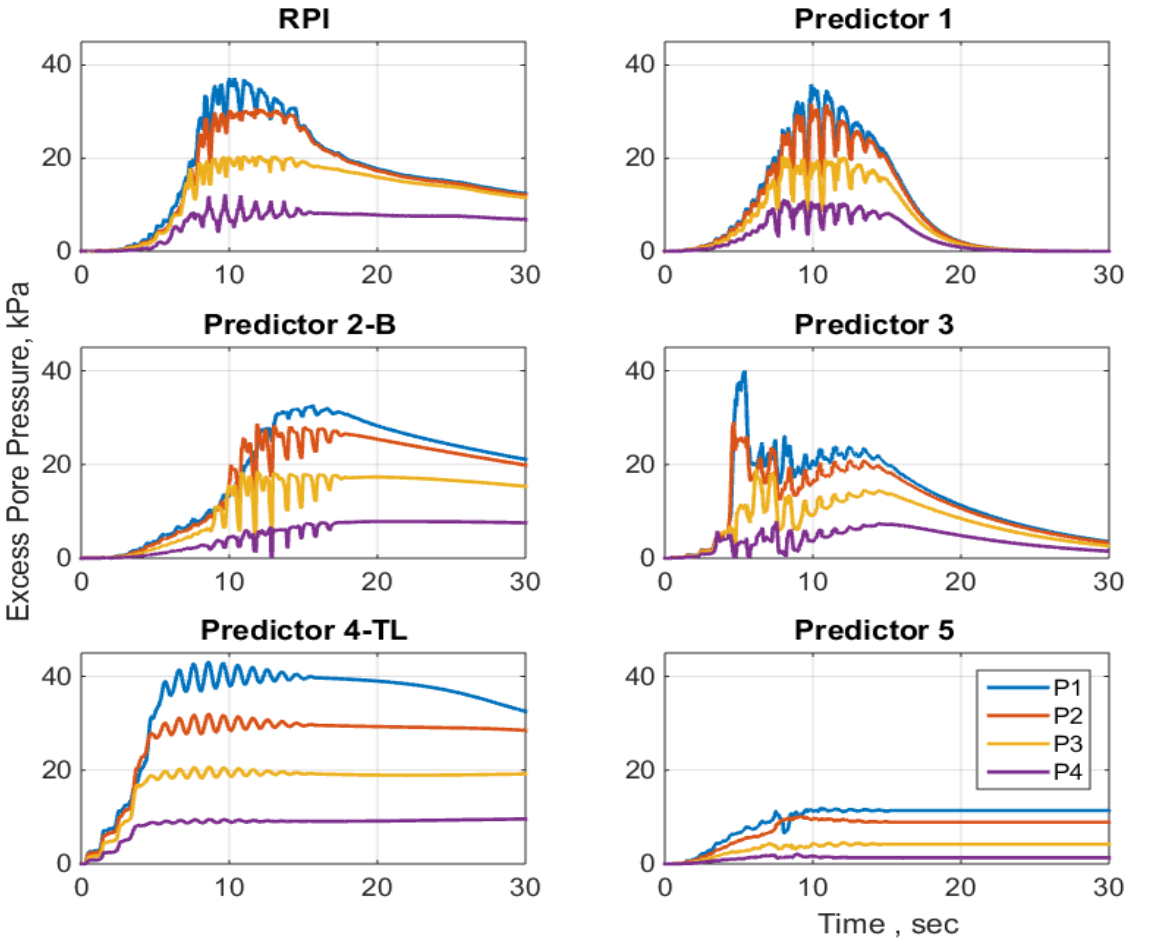
# Acceleration Motion #2



# Comparison between predictions and experiment




| | RMSE-t16-P1 | RMSE-t16-P2 | RMSE-t16-P3 | RMSE-t16-P4 |
|---|---|---|---|---|
| P 1 | 0.1179 | 0.1182 | 0.1124 | 0.2435 |
| P 2-A | 0.1175 | 0.1015 | 0.1392 | 0.1843 |
| P 2-B | 0.2522 | 0.2076 | 0.2019 | 0.1973 |
| P 3 | 0.2810 | 0.2893 | 0.2286 | 0.1872 |
| P 4-IS | 0.3893 | 0.4158 | 0.4066 | 0.4499 |
| P 4-TL | 0.3814 | 0.4058 | 0.3961 | 0.4326 |
| P 5 | 0.3620 | 0.3774 | 0.4439 | 0.3525 |

RMSE is computed based on the normalized excess pore pressure

# Conclusions

- 6 centrifuge facilities performed comparable experiments that were used for a prediction exercise.
  - It is important to repeat experiments!
  - Cyclic displacements are easy to duplicate
  - Residual displacements are sensitive to variations between experiments
  - Variability allows us to better understand the sensitivity of performance to differences in initial conditions
  - Provides important basis for judging the quality of the data and the quality of a validation

- LEAP databases of soil properties and specifications are now public
  - https://nees.org/resources/13507/; https://nees.org/resources/13689/

# Conclusions

- Results of the LEAP planning project were very successful.
- Have developed a protocol for sharing and archiving the data that may be followed and improved in future leaps.
- LEAP will contain a series of leaps
  - LEAP-Kyoto-2014 – lateral spreading in a laminar box
  - LEAP-GWU- 2015 – lateral spreading in a rigid box
  - LEAP ------ 2017 – improvement and quantification of sensitivity and reproducibility of simulations and experiments
  - LEAP - Earth Dams?
  - LEAP - Bridges or Soil-Structure Interaction?
  - Field case histories?
- Interaction with PEER - and especially NGL – Next Generation Liquefaction Models.

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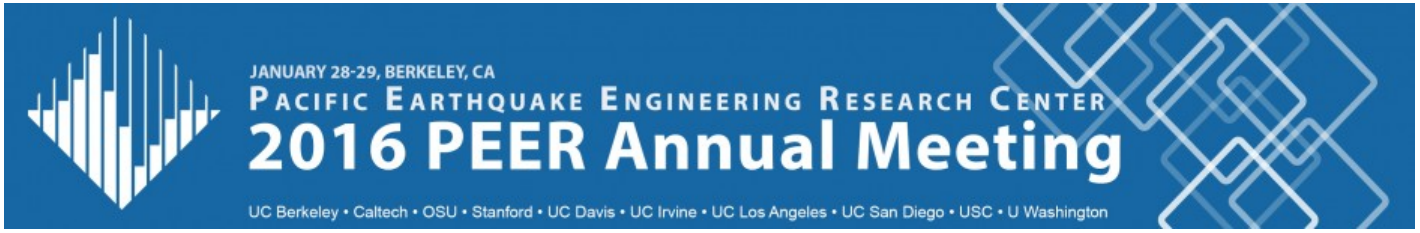
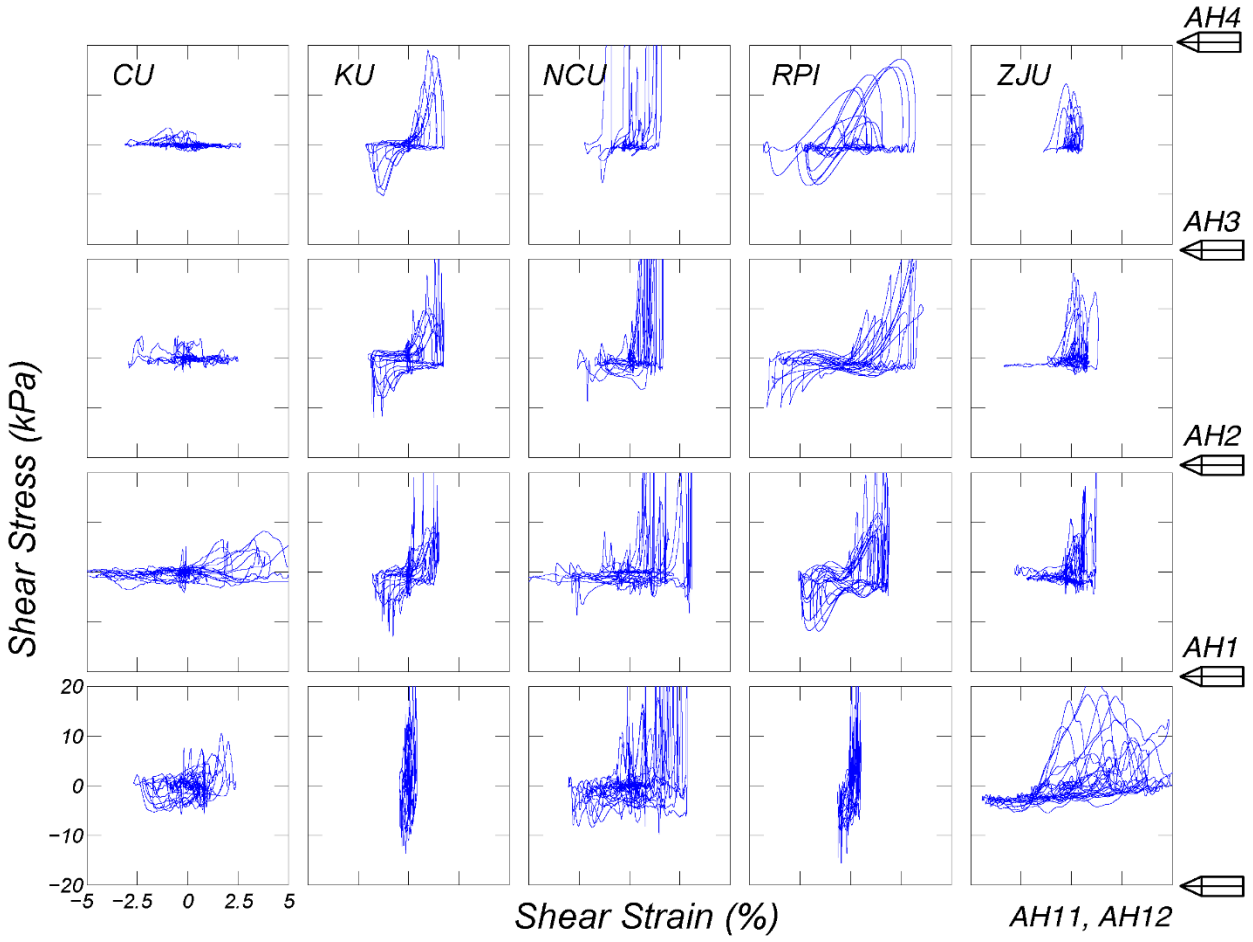


# Motion #4


CU
KU
NCU
RPI
ZJU
AH4
AH3
AH2
AH1
AH11, AH12
Shear Stress (kPa)
Shear Strain (%)
20
10
0
−10
−20
−5
−2.5
0
2.5
5

# Response spectra – Motion #2