National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Physical modeling research strategy with examples related to liquefaction and soil-structure interaction

Bruce Kutter, Professor Emeritus
University of California, Davis

Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter

December 16-17, 2019
University of California, San Diego

LEHIGH NHERI
Real-Time Multi-Directional Testing Facility

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

SIMCENTER
COMPUTATIONAL MODELING AND SIMULATION CENTER

Advice for early and mid career physical modelers

- Pick a problem/topic
  - Important topic with funding prospects
- Bite off a piece of the big problem and test a hypothesis
- Update the problem statement and take another bite
- Be persistent
  - Maintain attention to fundamentals and rigor
  - Publish / disseminate
  - Share your data and information
  - Eventually, become an acknowledged expert

More advice for physical modelers

- Common motivations for physical model tests
  - Mechanisms can be explored with model tests
  - New or untested technologies (gaps) can be studied
  - Validation/calibration of analysis procedures and numerical methods
- Do hypothesis driven research
  - State your hypotheses
  - Don’t add complexity to an experiment that detracts from focus on testing the hypotheses.
- Multiprong approach/multiprong expertise
  - Theory & Fundamental mechanics
  - Small scale experiments (materials and components)
  - Simulation ←→ Experiment (validation/calibration)
  - Large scale testing (systems, proof of concept)
  - Implementation

Outline of this talk

- Picking a problem of importance
- Example 1: LEAP
- Example 2: Rocking Foundations Database
- Brainstorming new research areas
- Summary

Pick a problem with societal relevance

- Imagine new and future problems
  - Dealing with sea level rise
    - Low-lying/coastal population and infrastructure
    - Levees, waterfront structures
  - Green energy
    - Wind Farm foundations
  - Transportation
    - Mass transit, high speed rail, autonomous vehicles
  - Coupling with other hazards – earthquake and tsunami

- Ongoing Problems: Infrastructure assessment – e.g., ASCE report card
  - Existing buildings, dams, levees, ports, bridges, rail
  - Earthquake and Wind
- Overlooked problems, overdue fundamental academic problems
  - Validation of numerical methods
  - Implementation in practice
  - Accounting for uncertainty

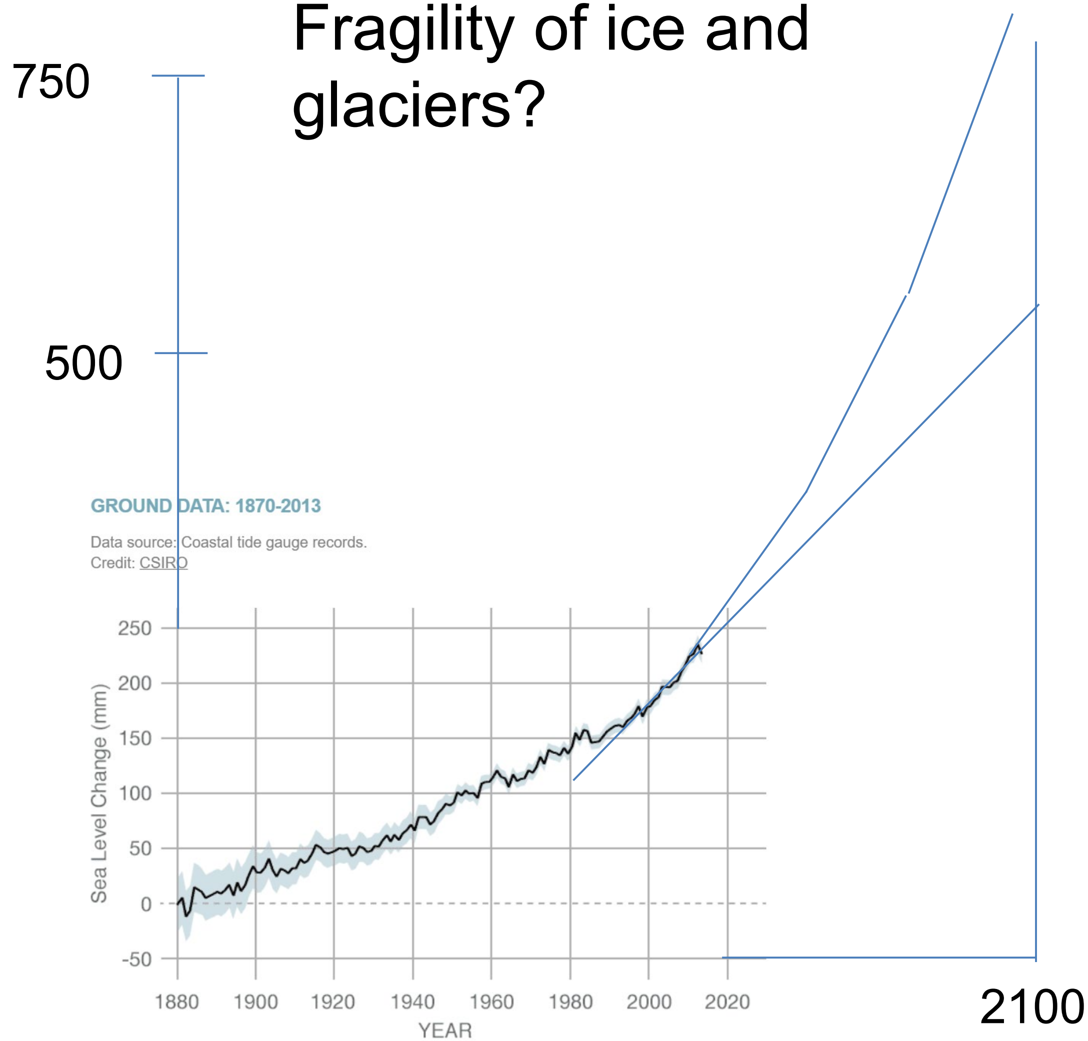
The Effects of Climate Change

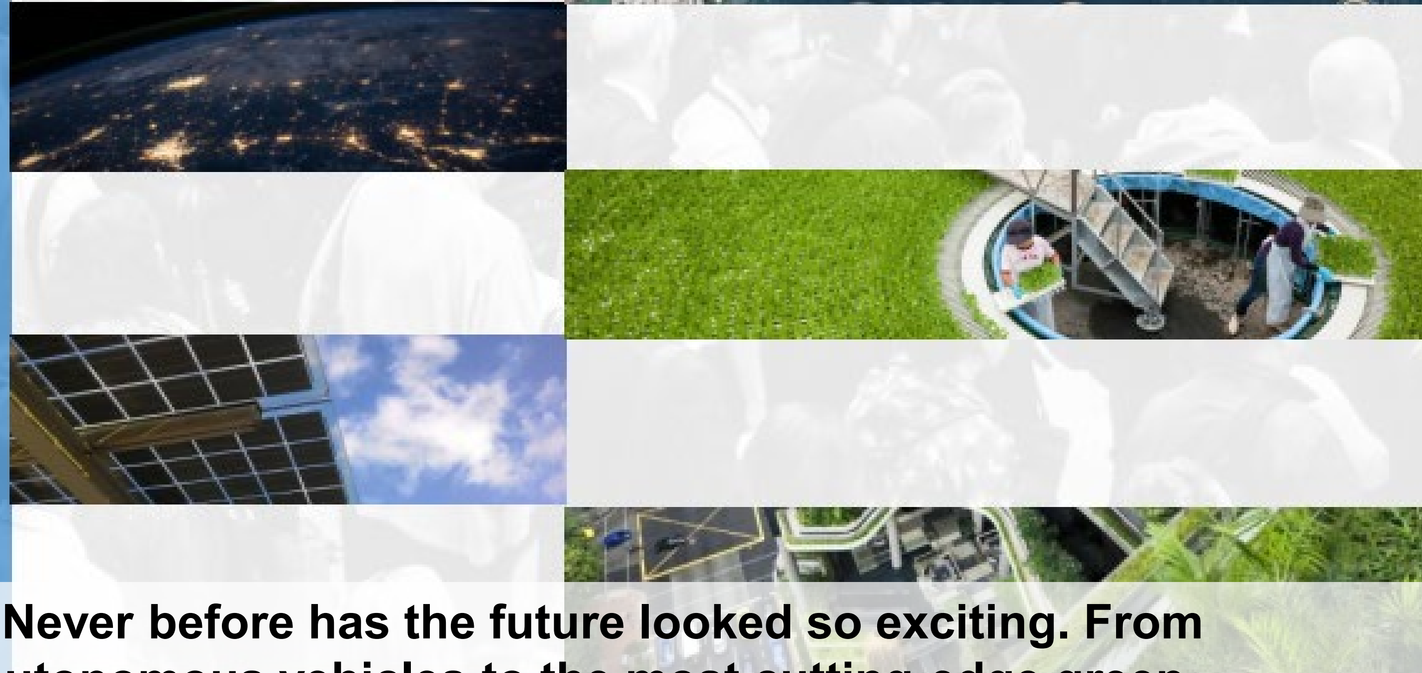
The potential future effects of global climate change include more frequent wildfires, longer periods of drought in some regions and an increase in the number, duration and intensity of tropical storms. Credit: Left - Mellimage/Shutterstock.com, center - Montree Hanlue/Shutterstock.com.

Sea level will rise from 1 to 3’ by 2100

https://climate.nasa.gov/vital-signs/sea-level/

ΔT?
Fragility of ice and glaciers?





ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

"Never before has the future looked so exciting. From autonomous vehicles to the most cutting-edge green technologies, the built environment is reshaping before our eyes. Exciting as it is, these changes breed challenges. The future will require a new way of doing things. …. ASCE has launched a bold, comprehensive project to anticipate, reimagine, and prepare for future changes."

Future World Vision:
Infrastructure Reimagined

May 2019

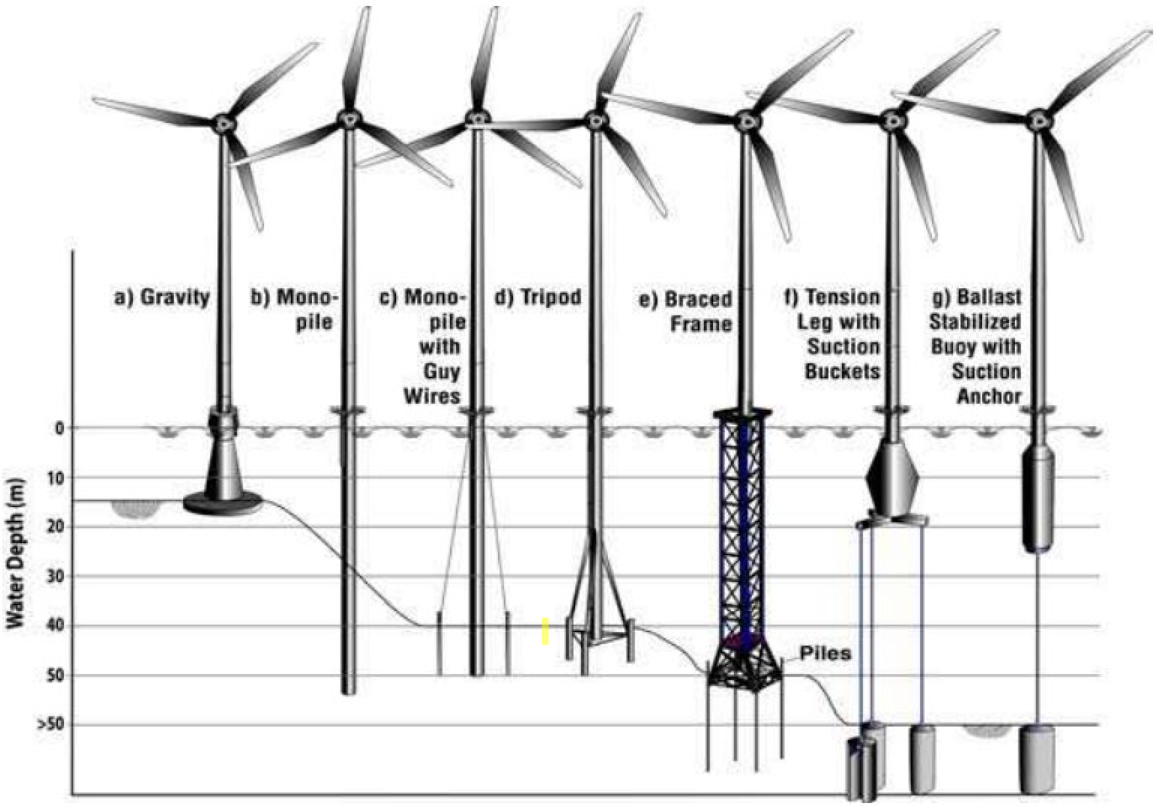
Future World Vision Example scenario

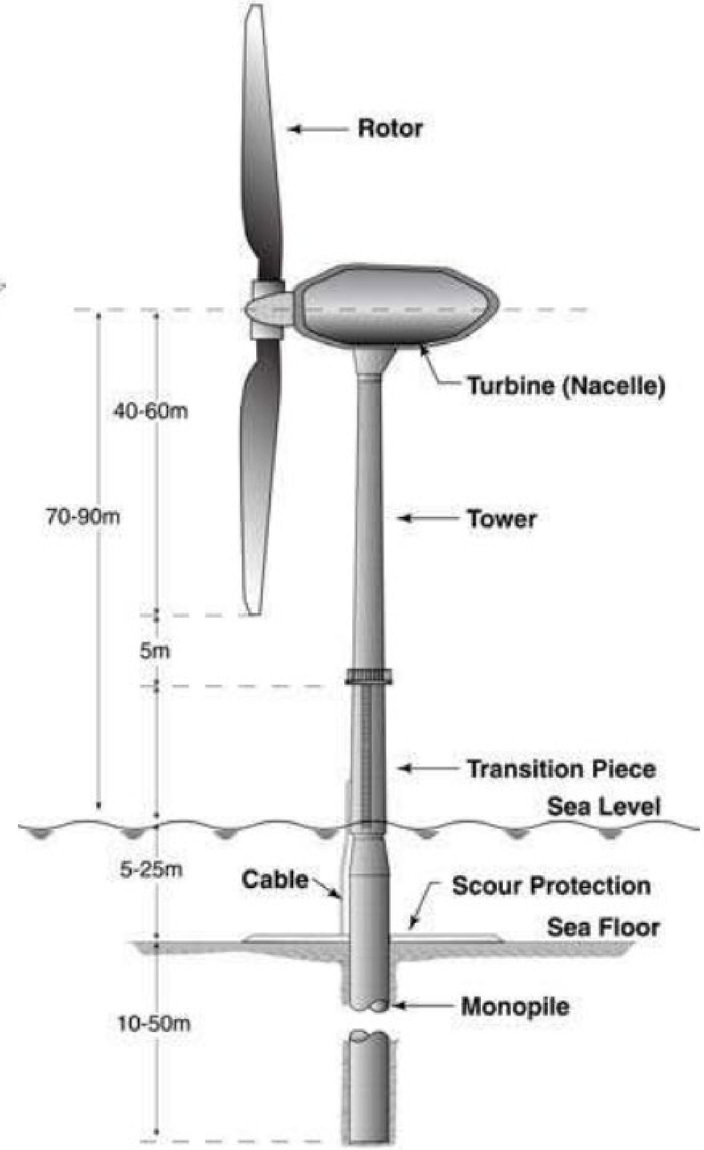
Resilient Cities

In this scenario, climate change wreaks havoc on urban and coastal cities. The increasing severity of the effects will increase the demand for substantial investments in long-term protective measures.

RESILIENT CITIES DETAILS

Another Example: Wind Turbine Systems



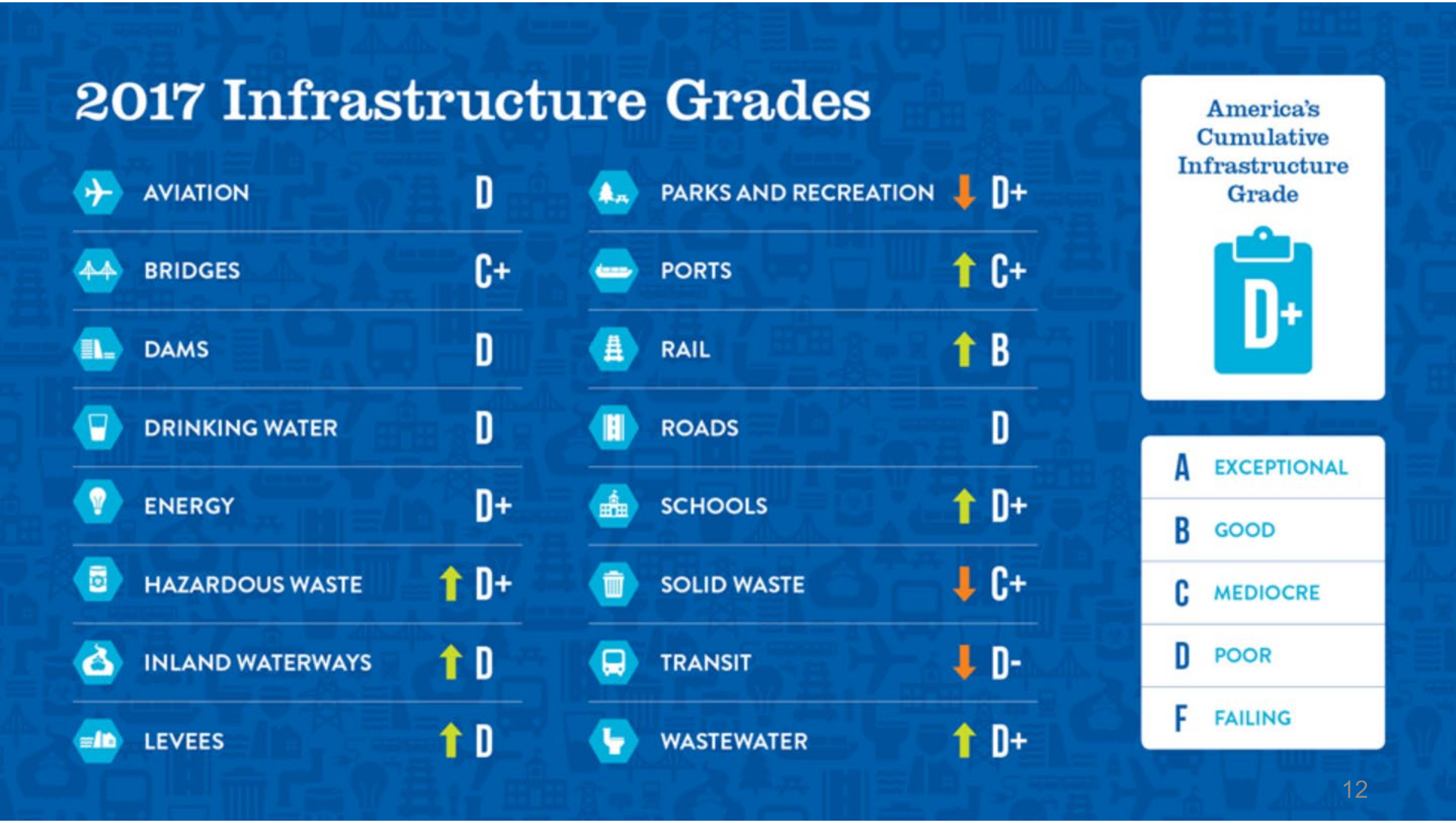


Malhotra, S. (2011), Selection, Design and Construction of Offshore Wind Turbine Foundations, Wind Turbines, Ibrahim Al-Bahadly (Ed.), ISBN: 978-953-307-221-0, InTech, Available from: http://www.intechopen.com/articles/show/title/selection-design-and-construction-of-offshore-windturbine-foundations

Pick a problem of societal importance

- New and future problems
  - Dealing with sea level rise
    - Low-lying/coastal population and infrastructure
    - Levees, waterfront structures, flooding frequency
  - Green energy
    - Wind Farm foundations
  - Transportation
    - Mass transit and High speed rail
  - Coupling with other hazards – earthquake and tsunami
- Ongoing Problems: Infrastructure assessment – e.g., ASCE report card
  - Existing and new buildings, dams and levees, ports, bridges, rail
  - Earthquake and wind
  - Fundamental mechanics
- Overlooked problems, overdue fundamental academic problems
  - Validation of numerical methods and analysis procedures
  - Implementation in practice
  - Accounting for uncertainty

ASCE infrastructure report card



Pick a problem of societal importance

- New and future problems
  - Dealing with sea level rise
    - Low-lying/coastal population and infrastructure
    - Levees, waterfront structures, flooding frequency
  - Green energy
    - Wind Farm foundations
  - Transportation
    - Mass transit and High speed rail
  - Coupling with other hazards – earthquake and tsunami
- Ongoing Problems: Infrastructure assessment – e.g., ASCE report card
  - Existing and new buildings, dams and levees, ports, bridges, rail
  - Earthquake and wind
  - Fundamental mechanics
- Overlooked problems, overdue fundamental academic problems
  - Validation of numerical methods and analysis procedures
  - Implementation in practice
  - Accounting for uncertainty

Examples

1. LEAP-UCD-2017 and LEAP-Asia-2019
2. Rocking foundations data bases: FoRCy and FoRDy

Example Topic 1: LEAP

48 Round-robin centrifuge model tests of liquefaction and lateral spreading: consistency of experiments and comparisons to simulations for LEAP

LEAP (Liquefaction Experiments and Analysis Projects) is an international effort to perform model tests to assess the accuracy of numerical procedures for predicting the effects of liquefaction

Acknowledgements

Trevor J Carey , Nicholas Stone, Bao Li Zheng, Andreas Gavras, Mourad Zeghal (RPI), Majid Manzari (GWU)

NSF awards:
CMMI 1635307
CMMI 1635524
CMMI 1635040

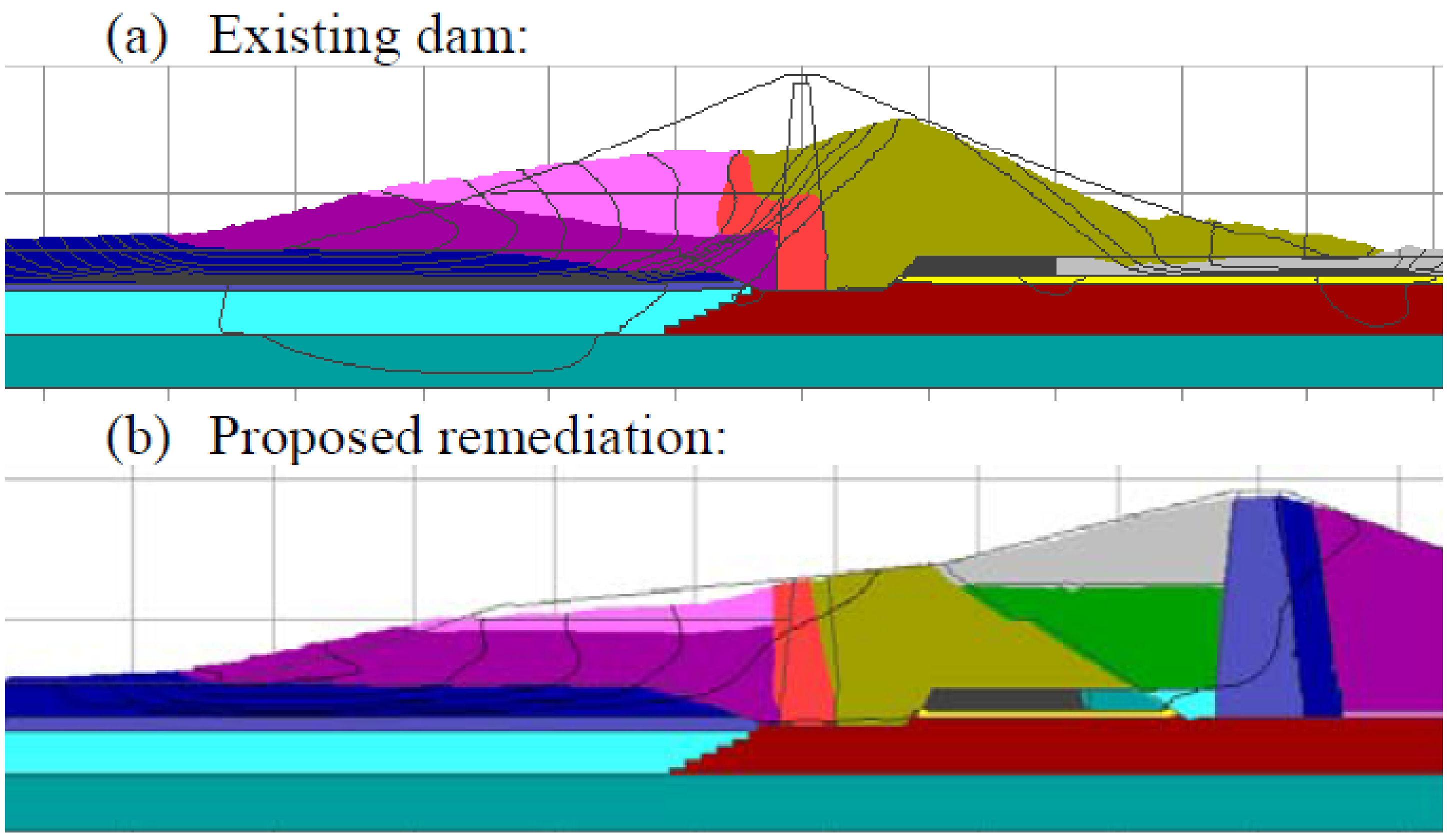
Experiment Teams

University of California, Davis USA
Rensselaer Polytechnic Institute, USA
George Washington University, USA
Cambridge University, UK
Ehime University, Japan
IFSTTAR, France
KAIST, Republic of Korea
Kansai University, Japan
Kyoto University, Japan
National Central University, Taiwan
Tokyo Institute of Technology, Japan
Zhejiang University, P.R. China

Numerical simulation teams:

US: U. Washington, UCSD, UCD, Auburn U., Fugro Corp.
Japan: Meisosha, Shimizu, Kyoto U., Kansai U., TEPCO, FLIP consortium
China: Tsinghua U., Zhejiang University
Italy: U. Napoli
Canada: U. British Columbia

Motivation for LEAP: We do not formally know how accurate these simulations are.
Yet, we depend more and more on their accuracy!



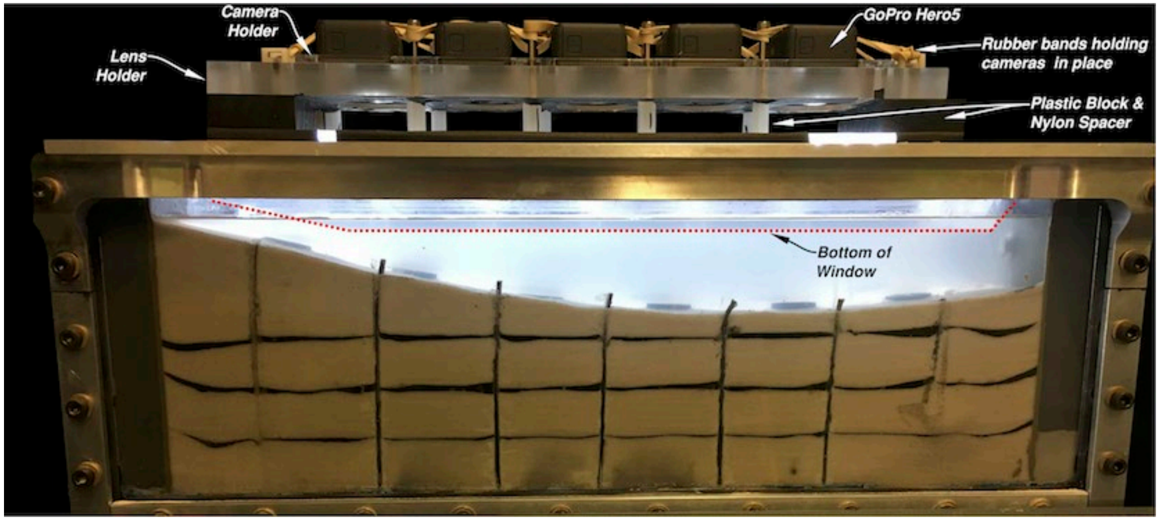
Perlea and Beaty (2010) - Success Dam deformation contours for MCE

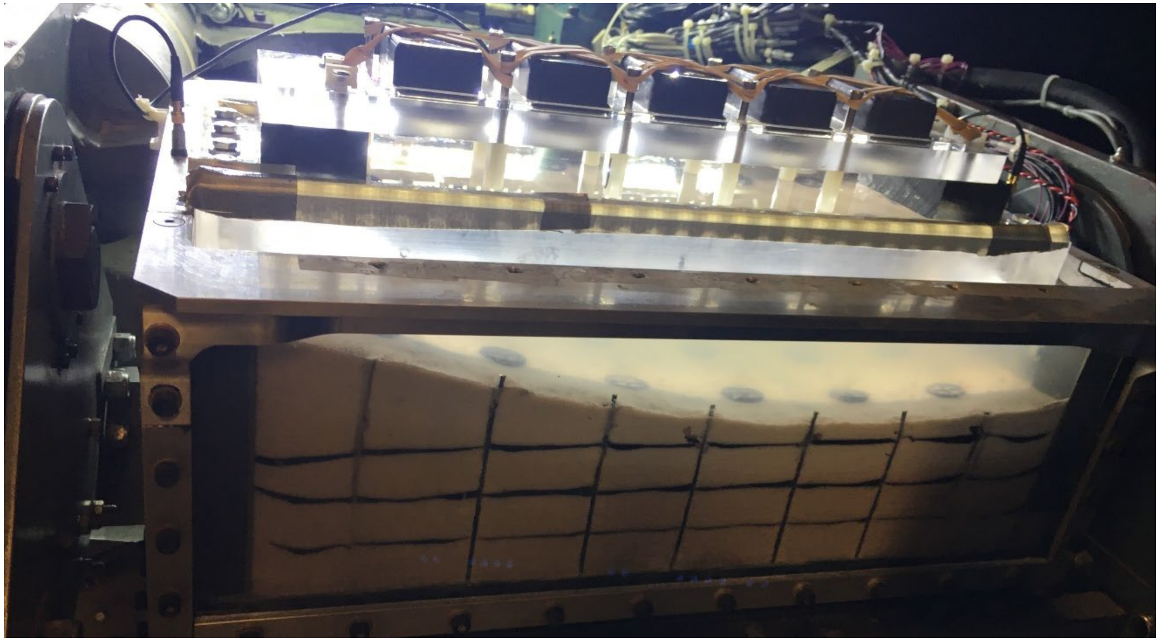
LEAP

- **Hypothesis: If we do a lot of similar liquefaction experiments in several laboratories, we will be able to assess the accuracy/uncertainty of the physical model test data.**
  - Quantitative assessments of the accuracy of a numerical procedure depend on knowing the accuracy and uncertainty of the reference experimental data.
  - To know the accuracy and uncertainty of the data, inter-laboratory reproducibility must be established.
  - Since reproducibility is not perfect, we need to account for:
    - the variability of initial conditions and boundary conditions, and,
    - the sensitivity of the results to the variations of these conditions.

LEAP-GWU-2015, LEAP-UCD-2017 LEAP-Asia-2019

used the same "simple" experiment configuration: submerged sloping ground in a rigid box subject to ramped sine wave base motion



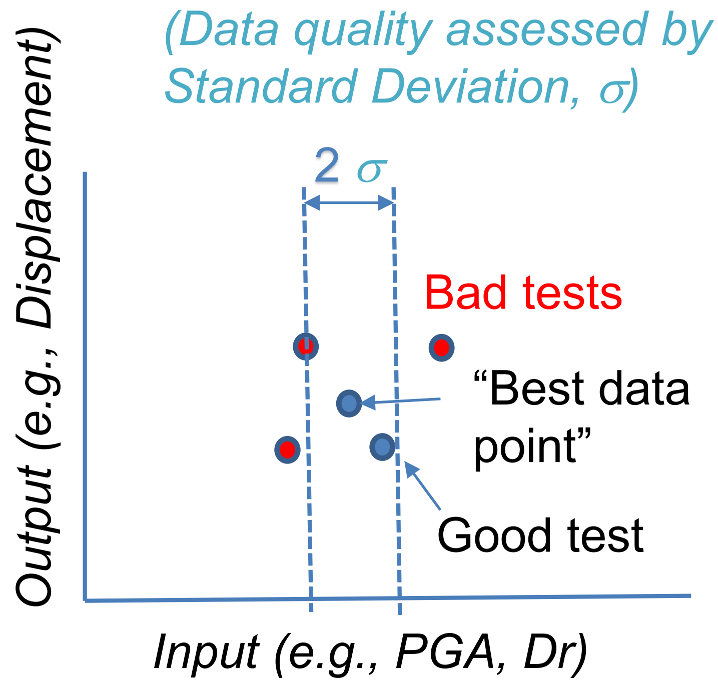


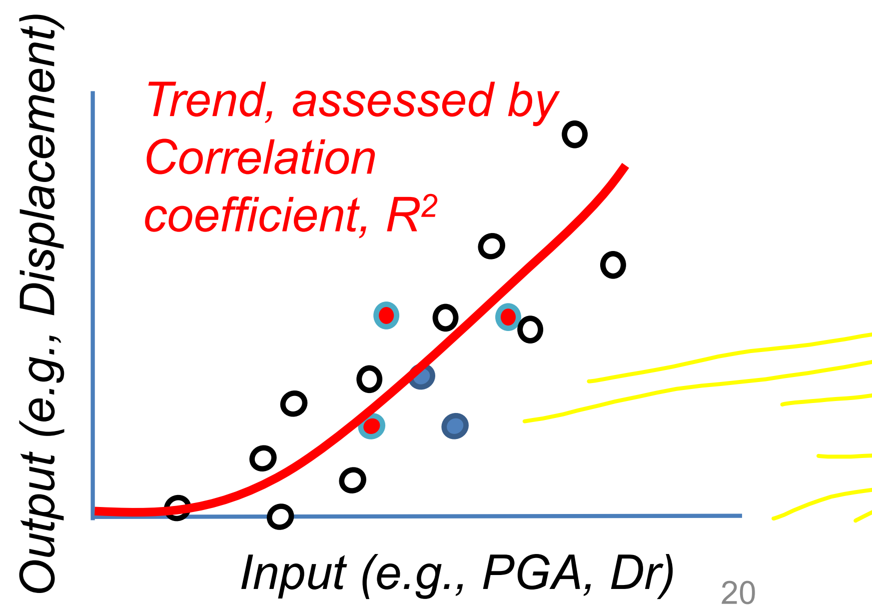
For LEAP-GWU-2015

- *Attempt to duplicate the same data point on different equipment.*
  - *Only some results were "close enough"*
  - *Differences suspected to be explained by errors and equipment limitations*
  - *"goodness of fit": Standard Deviation*

For LEAP-UCD-2017

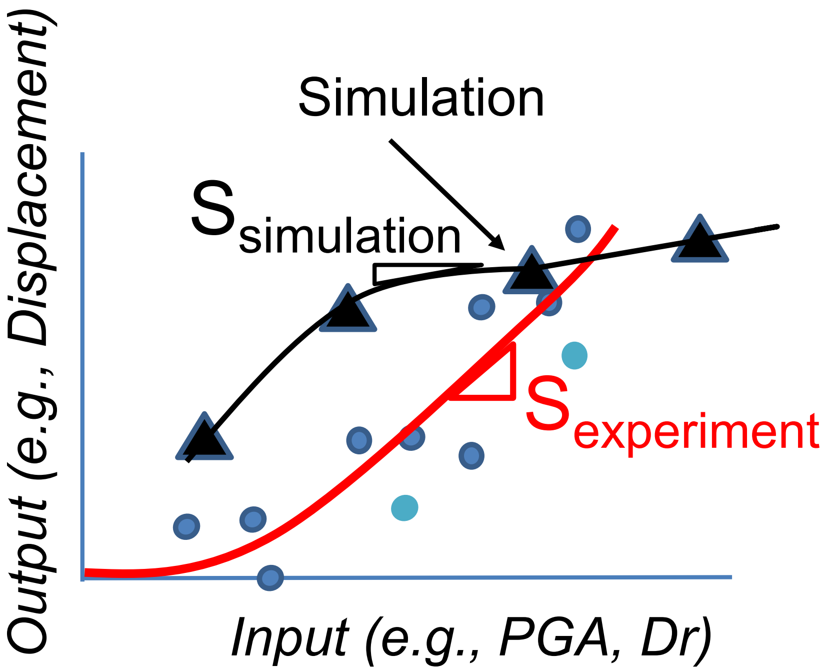
- *Embrace the variability, try to quantify variation, but also minimize and quantify uncertainty.*
- *Try to demonstrate a trend, not just a repeatable point*
  - *Sensitivity – slope of the trend*
- *"goodness of fit": R^2*
- *Multiple inputs require more dimensions*
- *Even the "bad tests" help define the trend*





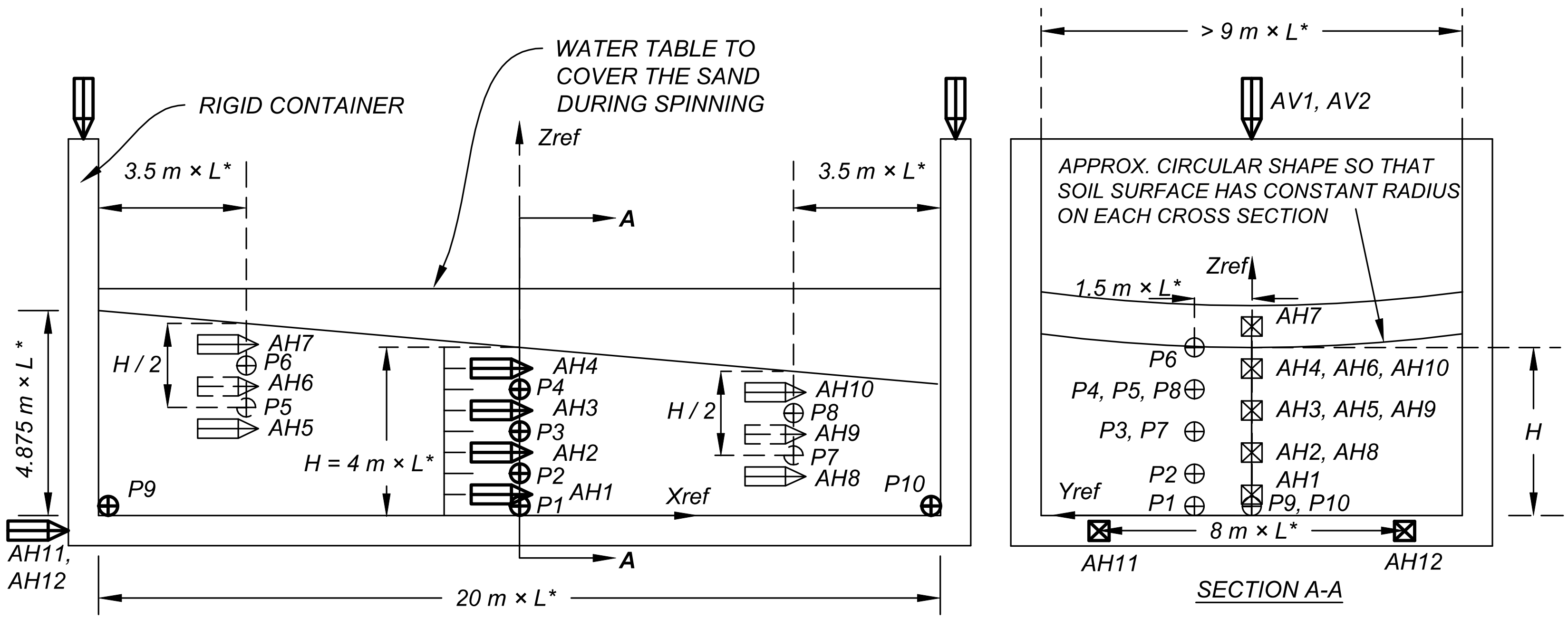
Evaluation of numerical simulations

Past validation efforts have often focused on comparisons between predictions and experiments for a single data point. Duplication of a single data point can be deceptive.

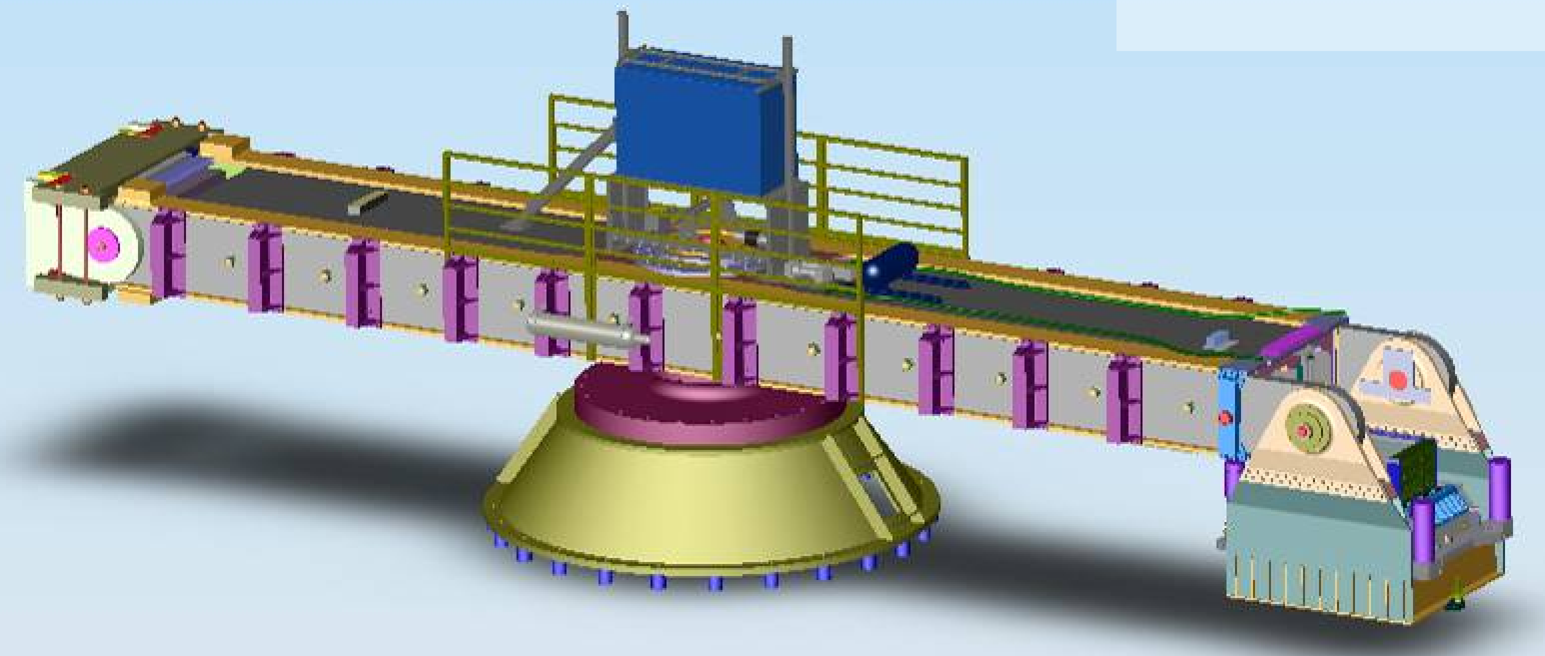


Hypothesis: It will be easier to validate simulations if we compare the experimental and simulation response functions.

Example data: pore pressures in the central array

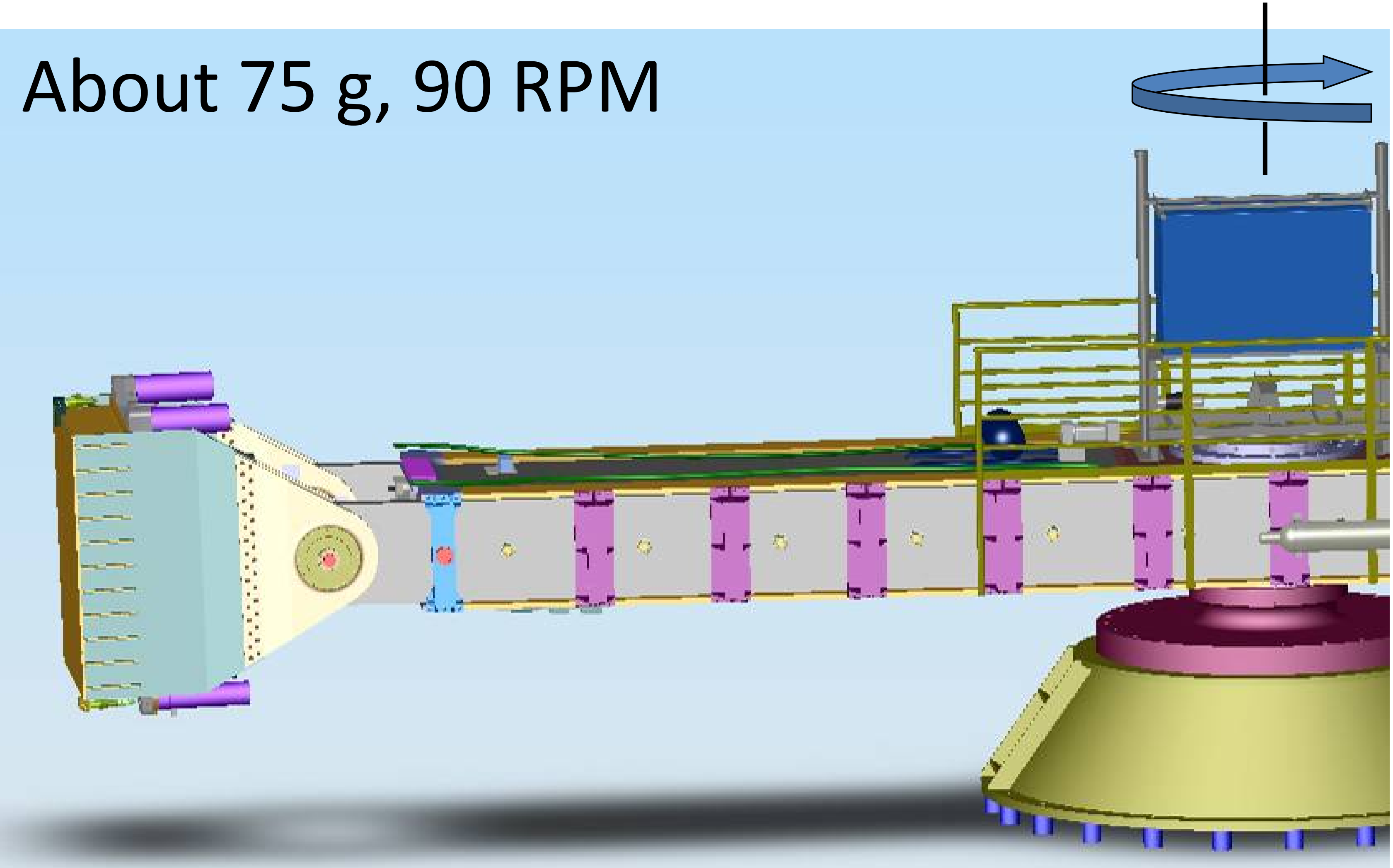


How does the centrifuge work?

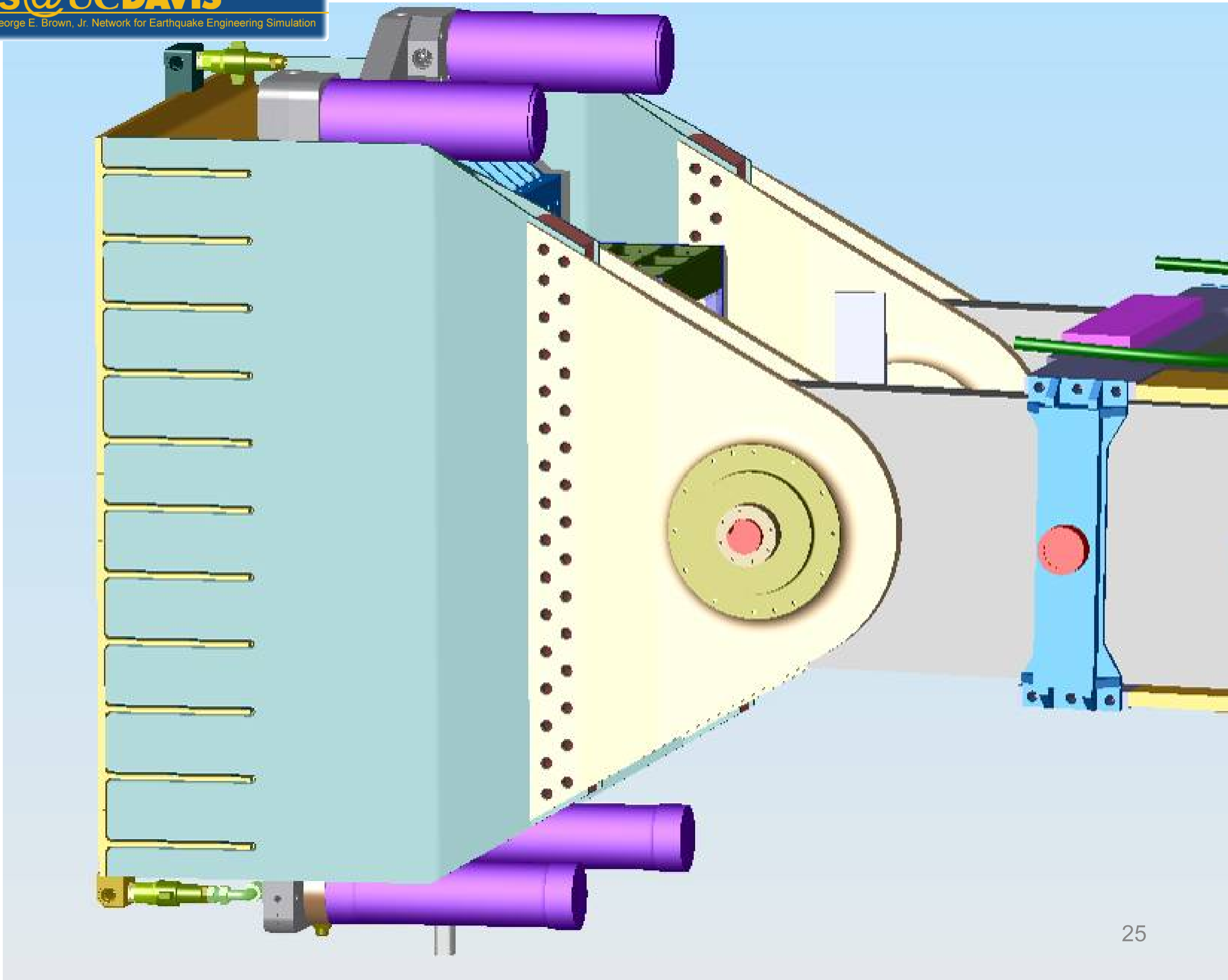


Credits: Cheney, Wilson, Boulanger, Pedersen

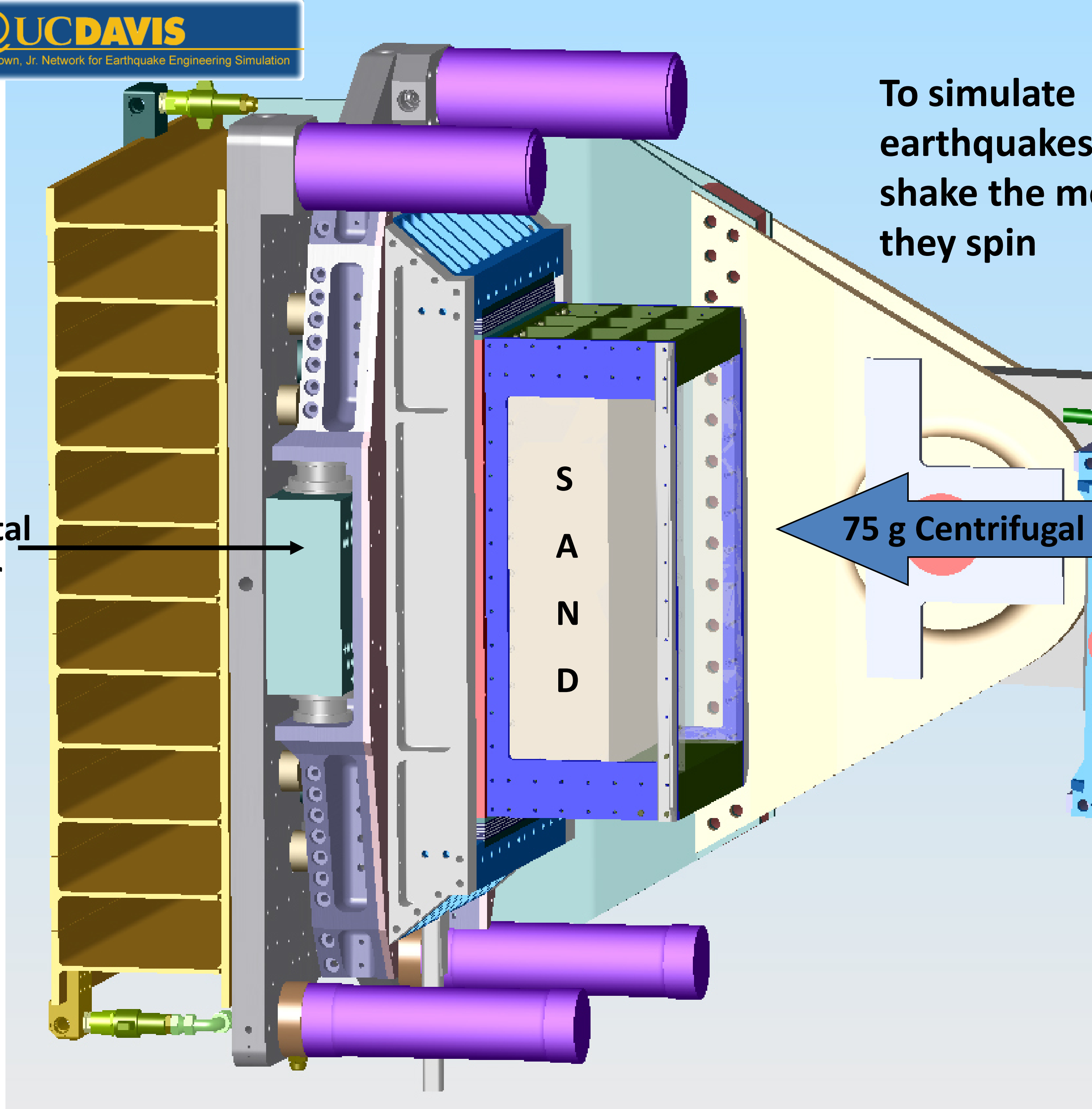
About 75 g, 90 RPM

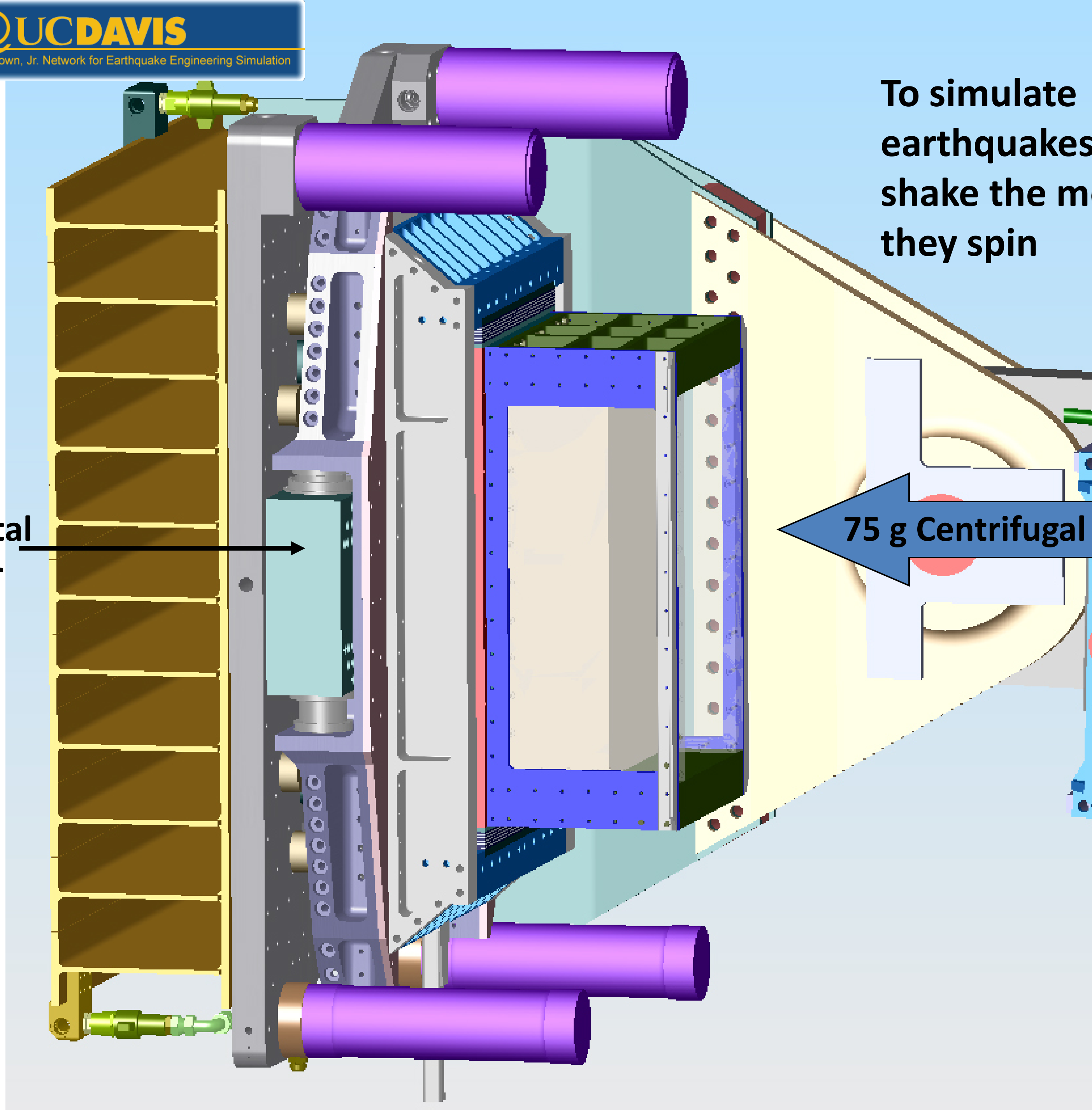


The centrifugal force increases the "weight" of the model to simulate weight of full scale Civil Structures



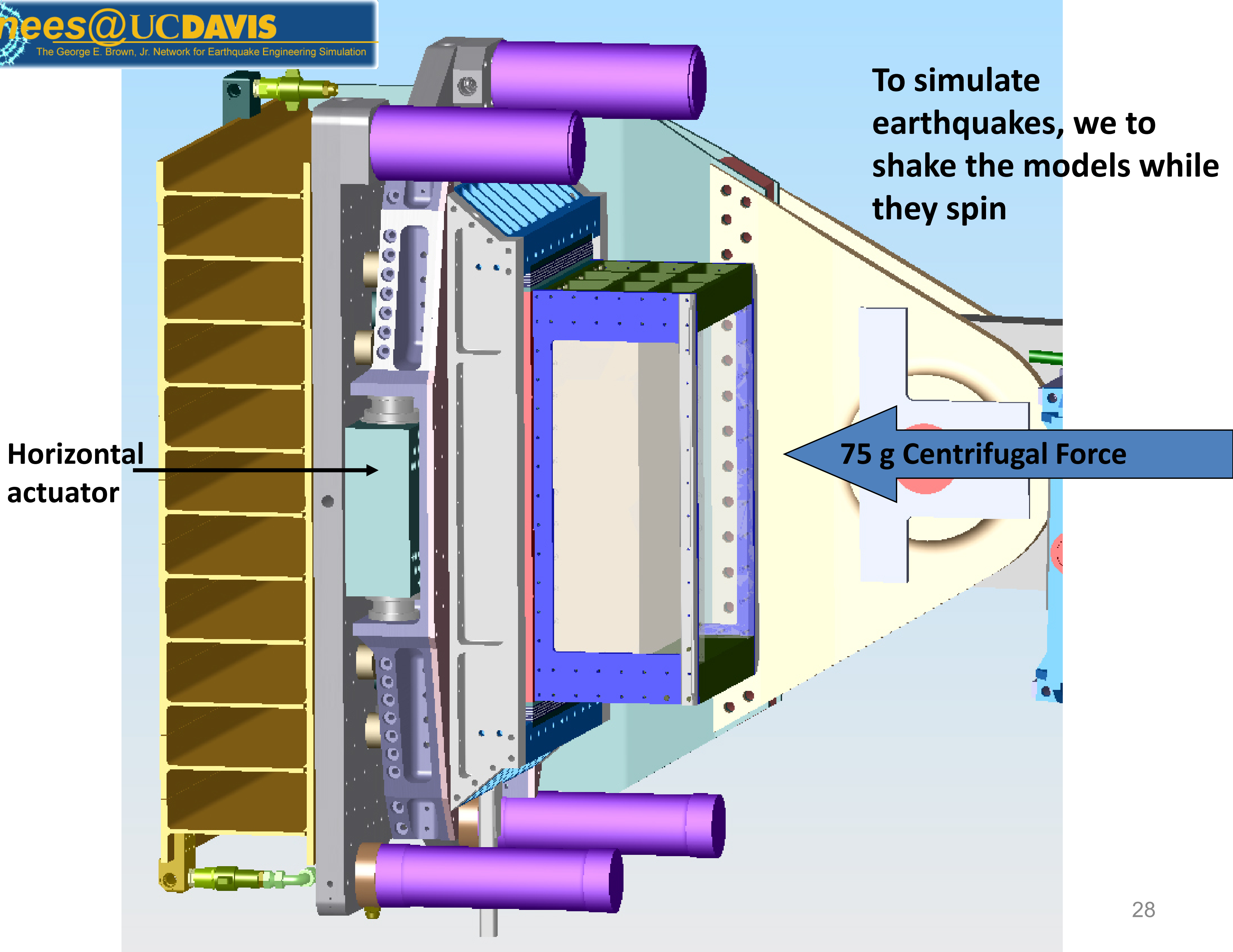
To simulate earthquakes, we to shake the models while they spin

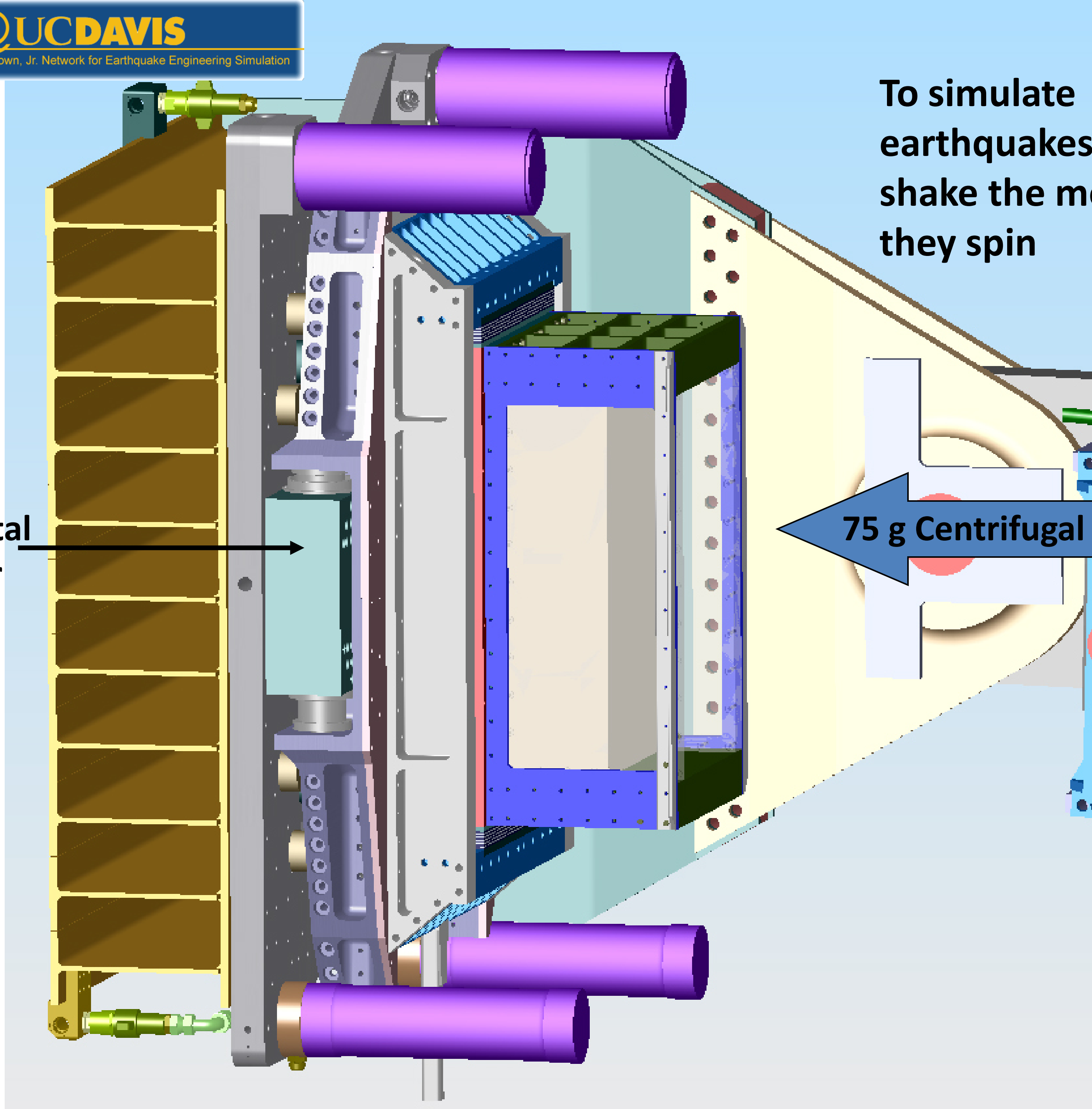




To simulate earthquakes, we to shake the models while they spin

To simulate earthquakes, we to shake the models while they spin

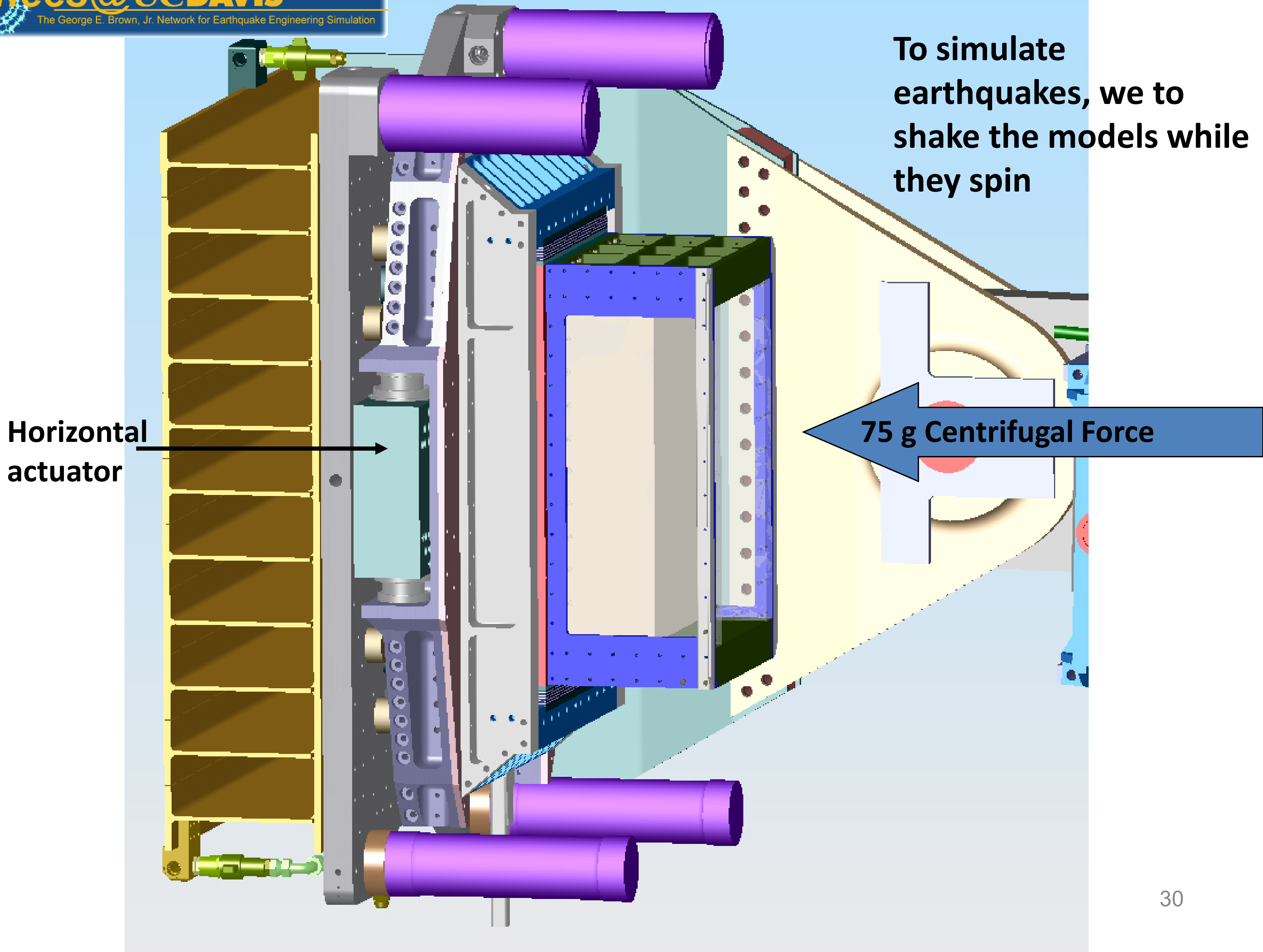


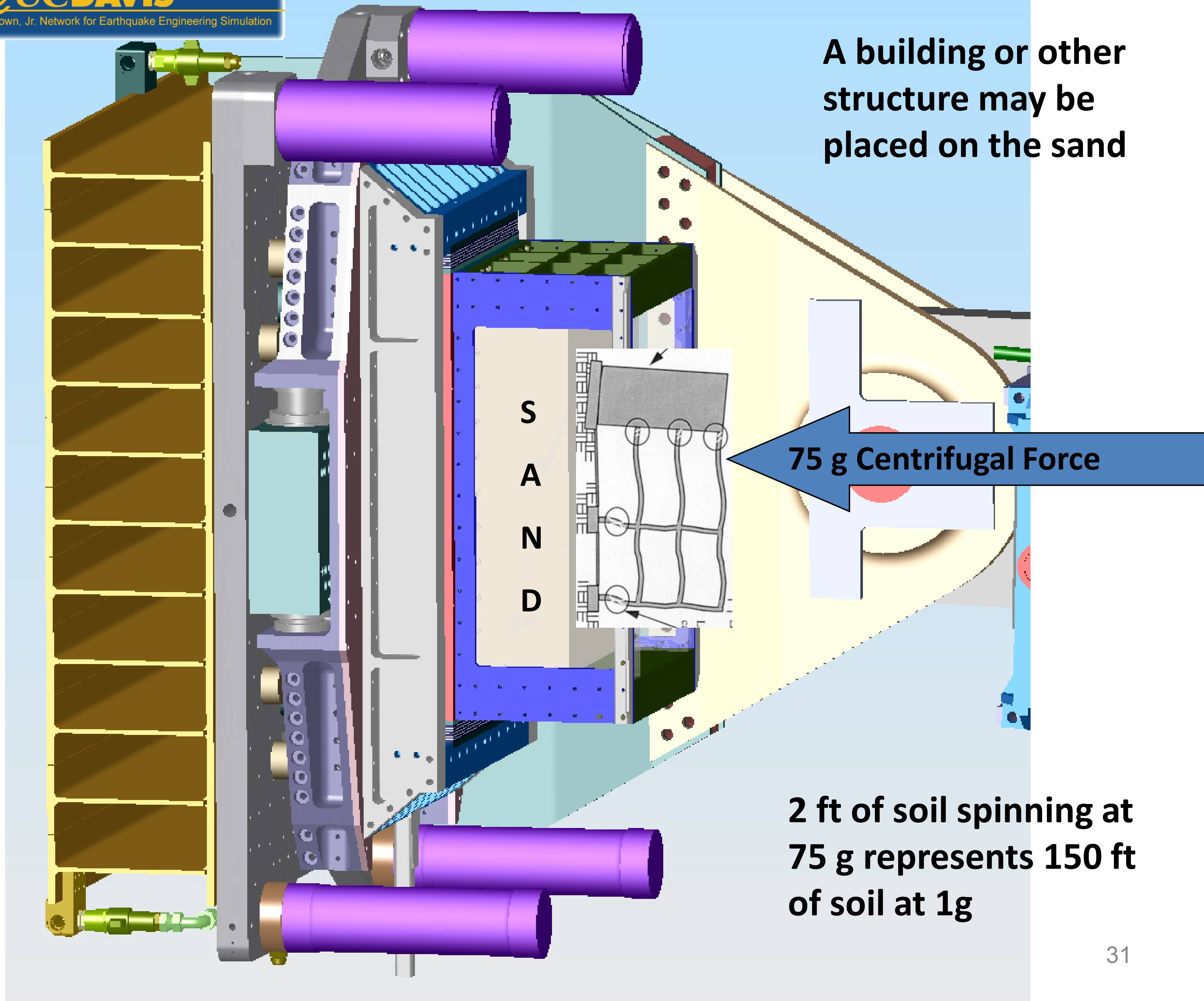


To simulate earthquakes, we to shake the models while they spin

nees@UCDAVIS
The George E. Brown, Jr. Network for Earthquake Engineering Simulation

To simulate earthquakes, we to shake the models while they spin

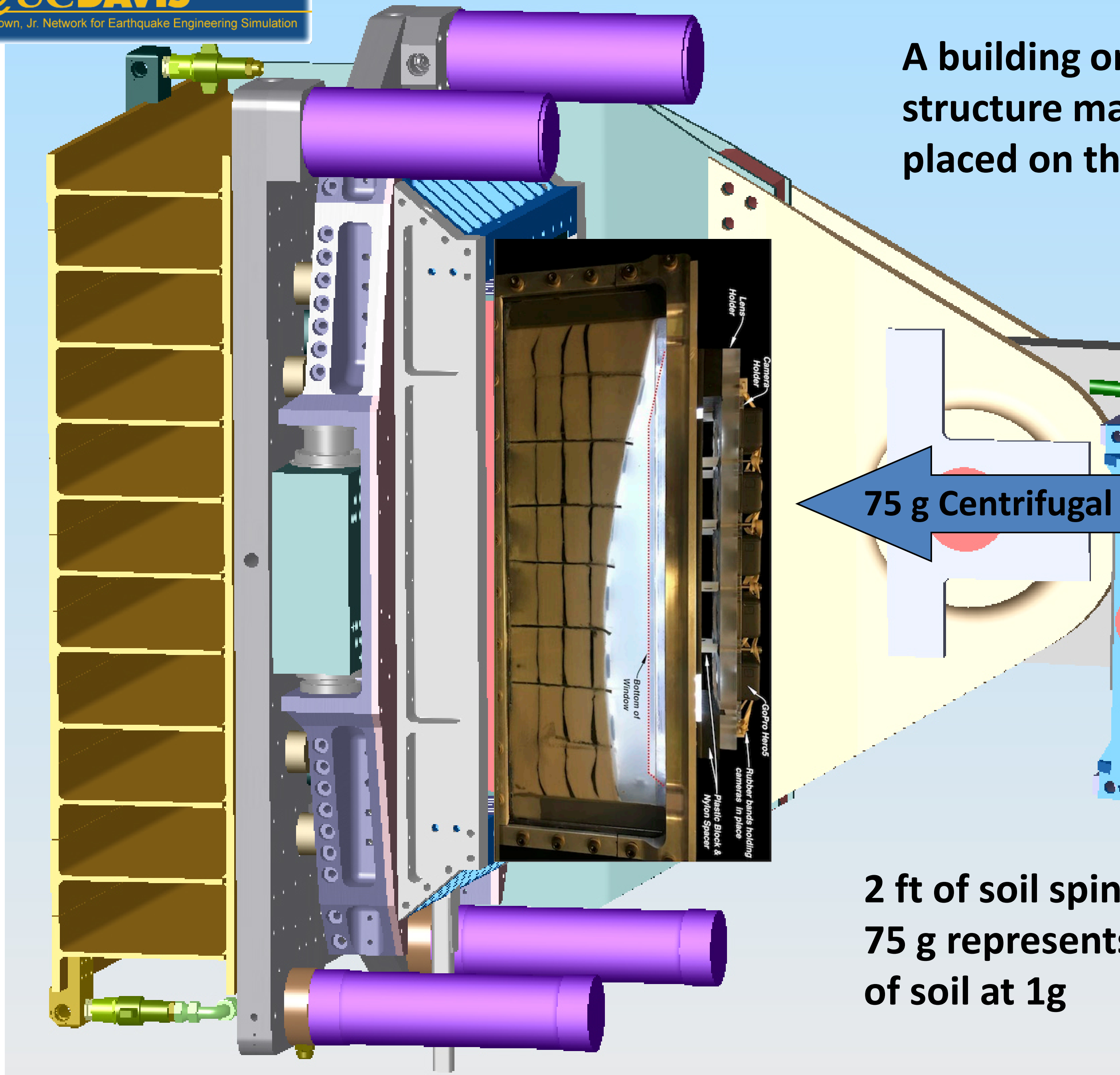




A building or other structure may be placed on the sand

2 ft of soil spinning at 75 g represents 150 ft of soil at 1g

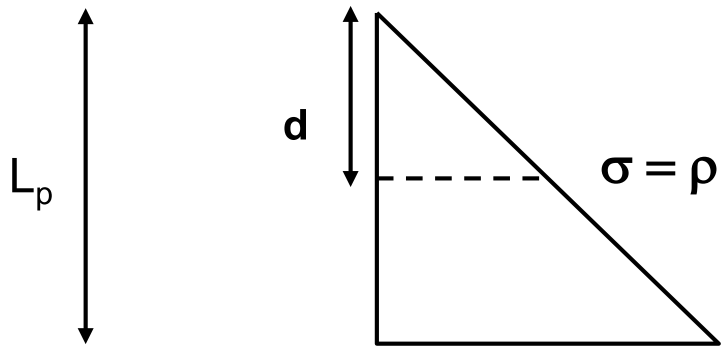
A building or other structure may be placed on the sand



2 ft of soil spinning at 75 g represents 150 ft of soil at 1g

PRINCIPLE OF CENTRIFUGE MODELLING

Prototype Stress Distribution



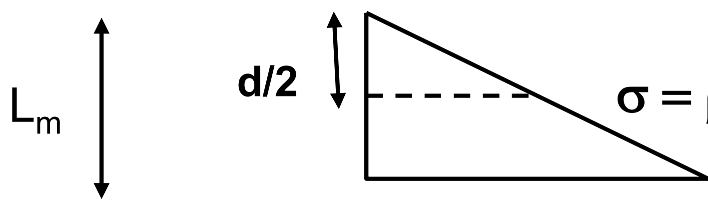
$$\sigma = \rho \, \mathbf{g} \, \mathbf{d}$$

$$\mathbf{L^* = L_m/L_p = 0.5}$$

$$\mathbf{g^* = g_m/g_p = 2}$$

$$\rho^* = \rho_m / \rho_p = 1$$

Stress Distribution in 1/2 Scale Model Under 2g

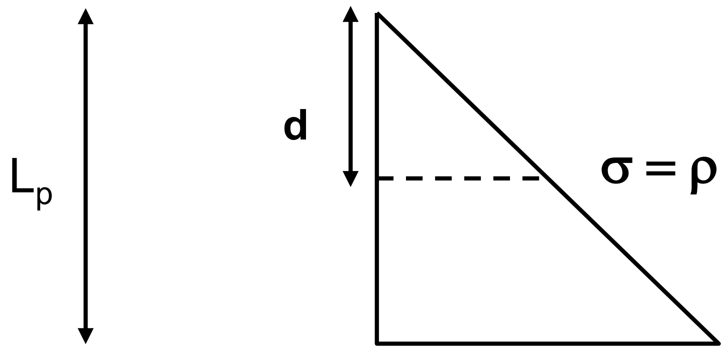


$$\sigma = \rho(2\mathbf{g})(\mathbf{d}/2) = \rho \mathbf{gd}$$

Idea is to produce a realistic stress *and* realistic stress distribution in controlled experiments with well defined boundary conditions and well defined material properties

PRINCIPLE OF CENTRIFUGE MODELLING

Prototype Stress Distribution



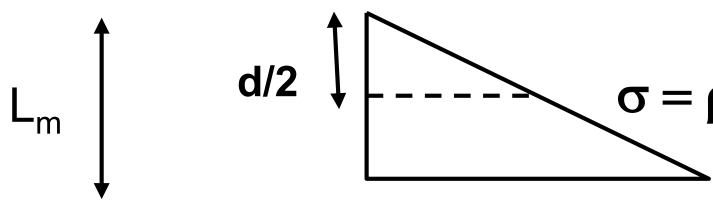
$\sigma = \rho \, \mathbf{g} \, \mathbf{d}$

$L^* = L_m/L_p = 0.5$

$g^* = g_m/g_p = 2$

$\rho^* = \rho_m/ \rho_p = 1$

Stress Distribution in 1/2 Scale Model Under 2g

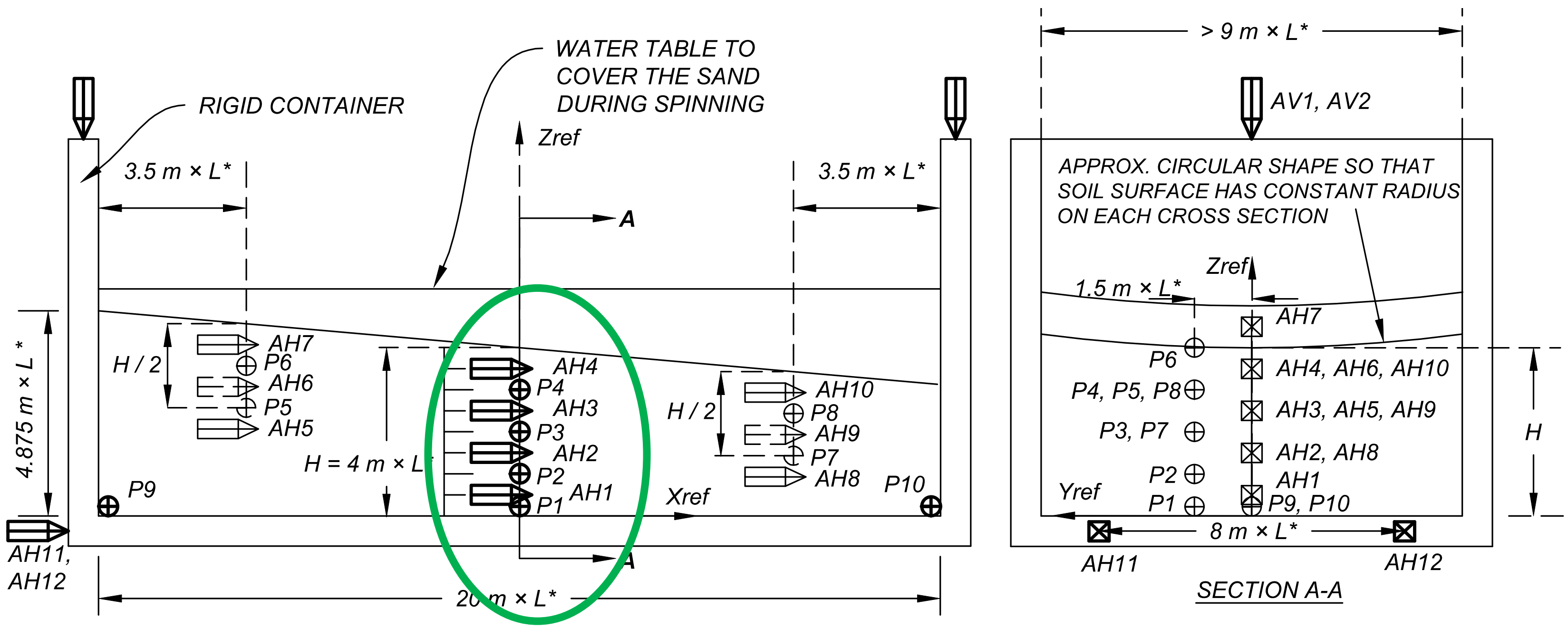


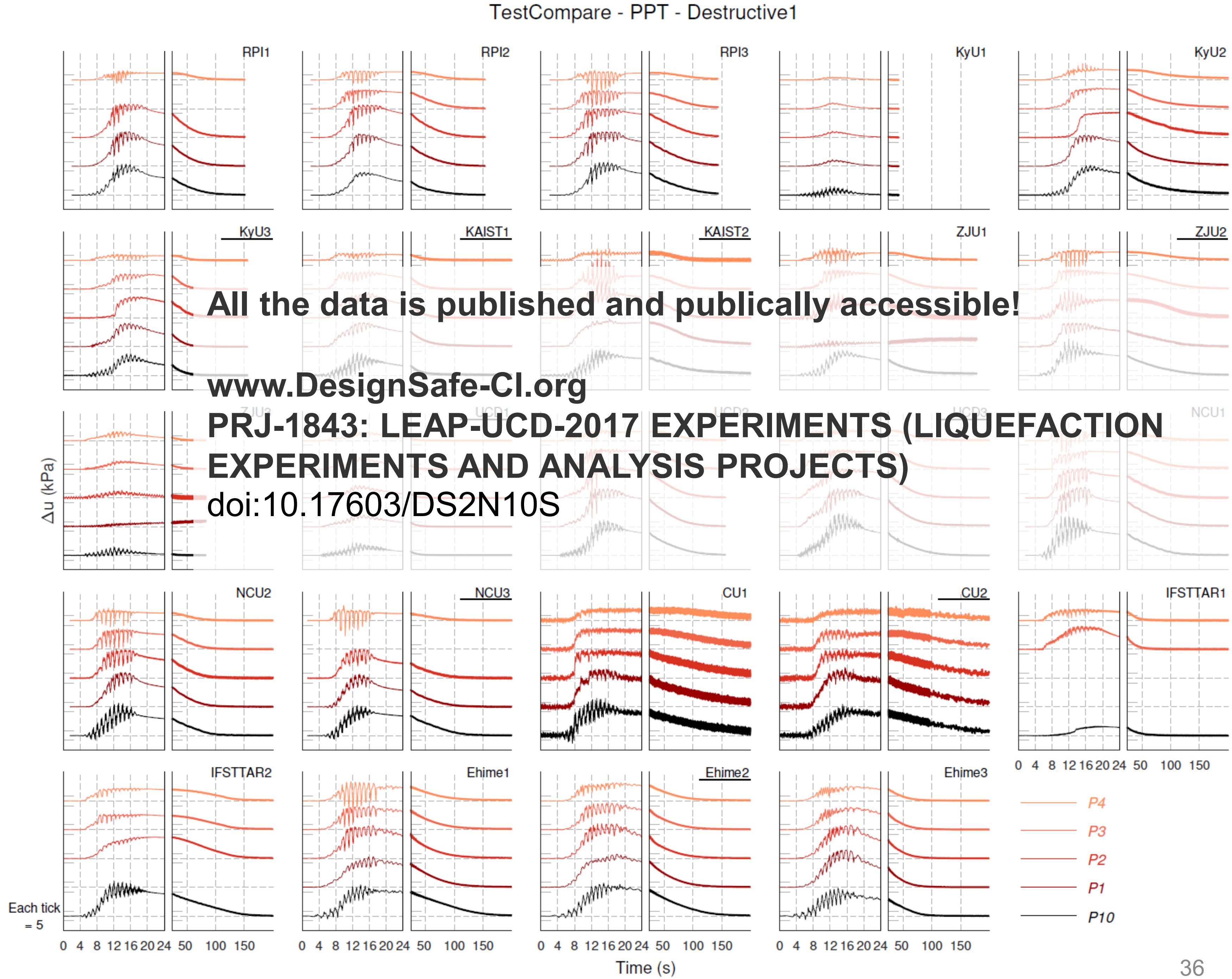
$\sigma = \rho(2\mathbf{g})(\mathbf{d}/2) = \rho\mathbf{gd}$

Idea is to produce a realistic stress *and* realistic stress distribution in controlled experiments with well defined boundary conditions and well defined material properties

$$\boldsymbol{\sigma^* = \sigma_m/ \sigma_p = 1}$$

Example data: pore pressures in the central array





All the data is published and publically accessible!

www.DesignSafe-CI.org

PRJ-1843: LEAP-UCD-2017 EXPERIMENTS (LIQUEFACTION EXPERIMENTS AND ANALYSIS PROJECTS)

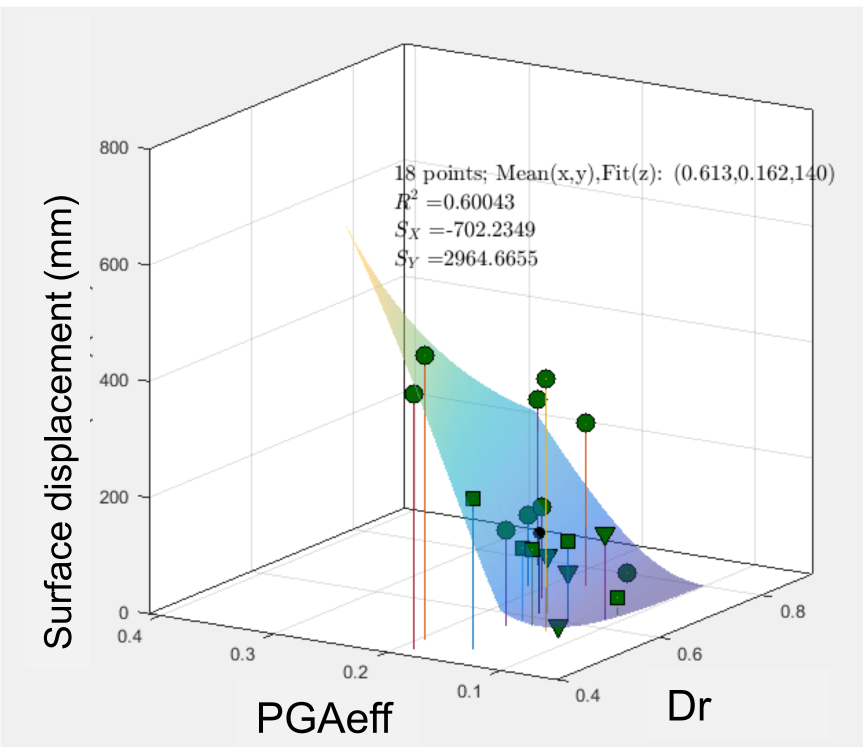
doi:10.17603/DS2N10S

Underlined test names = experiments selected for Type B predictions.

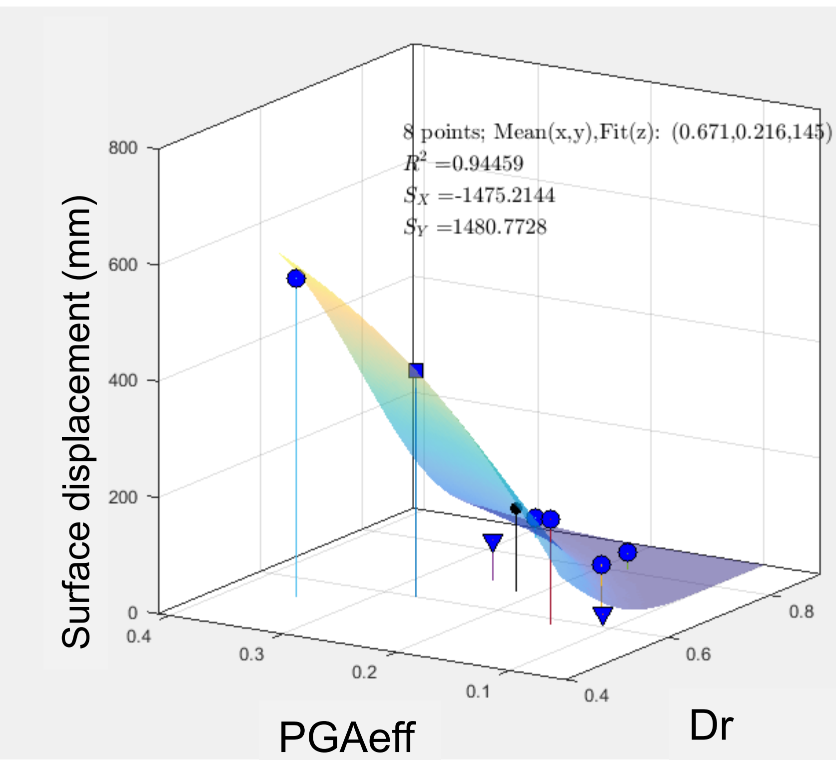
Comparison of 2017 and 2019 data

Only include data from tests using conventional centrifuge scaling laws, and only tests that included cone penetration tests

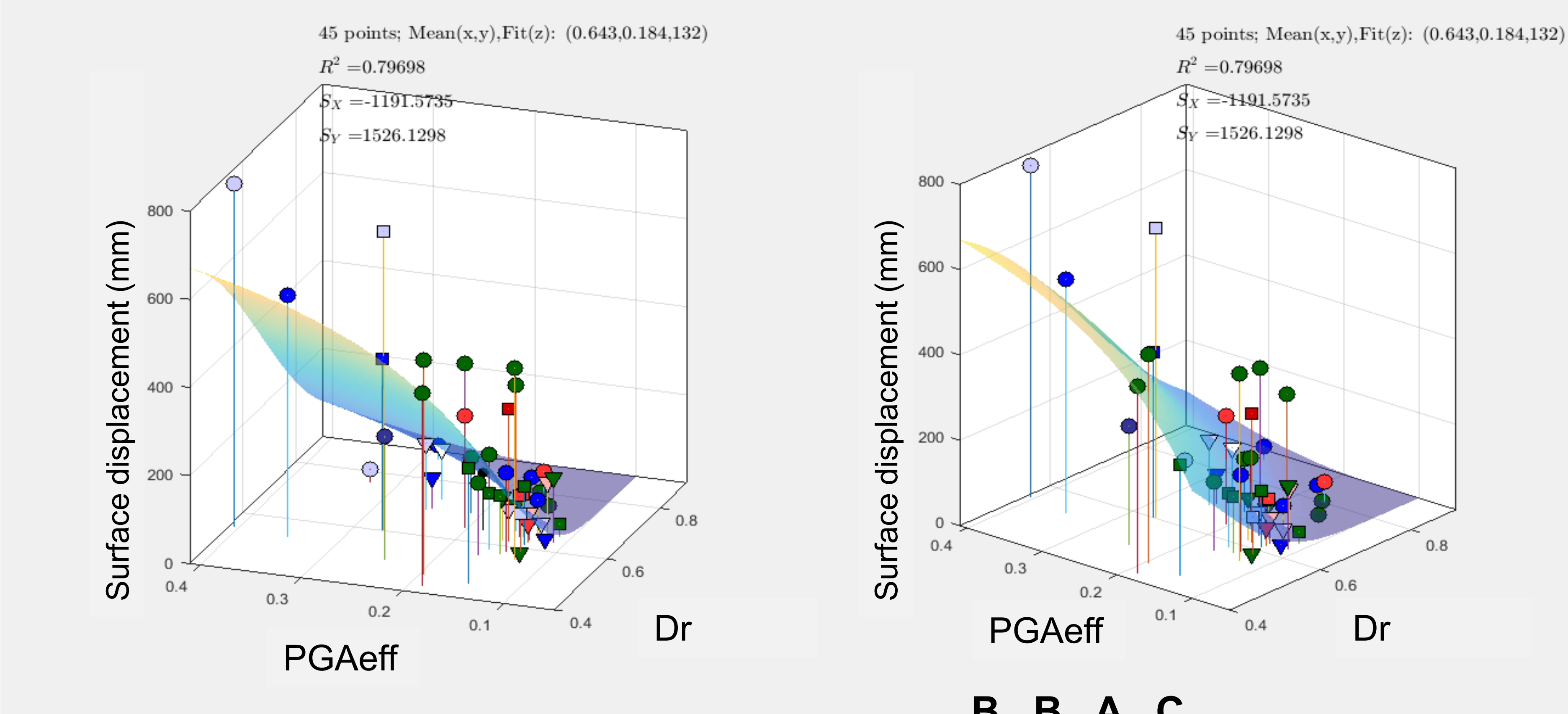
LEAP-UCD-2017
$R^2 = 0.60$



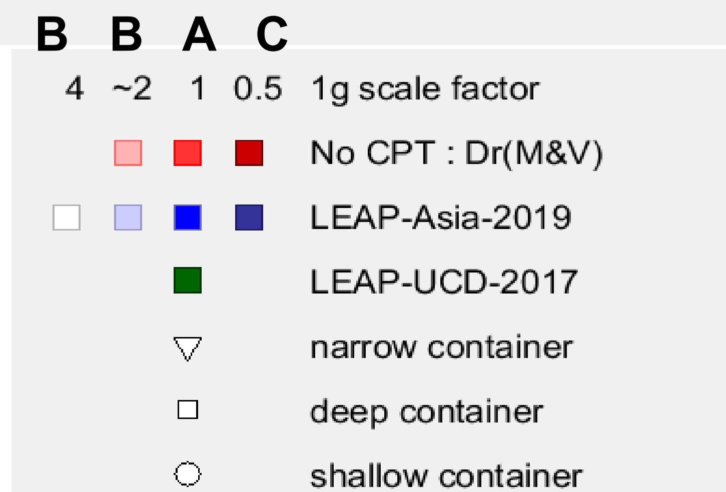
LEAP-Asia-2019
$R^2 = 0.94$



Similar surfaces, but apparent improvement in testing quality



- 2017 and 2018 data
- Conventional and non conventional scaling laws.
- CPT or no CPT
- <u>45 centrifuge tests on one graph!</u>
- <u>R^2 = 0.80</u>



Conclusions – LEAP experiments

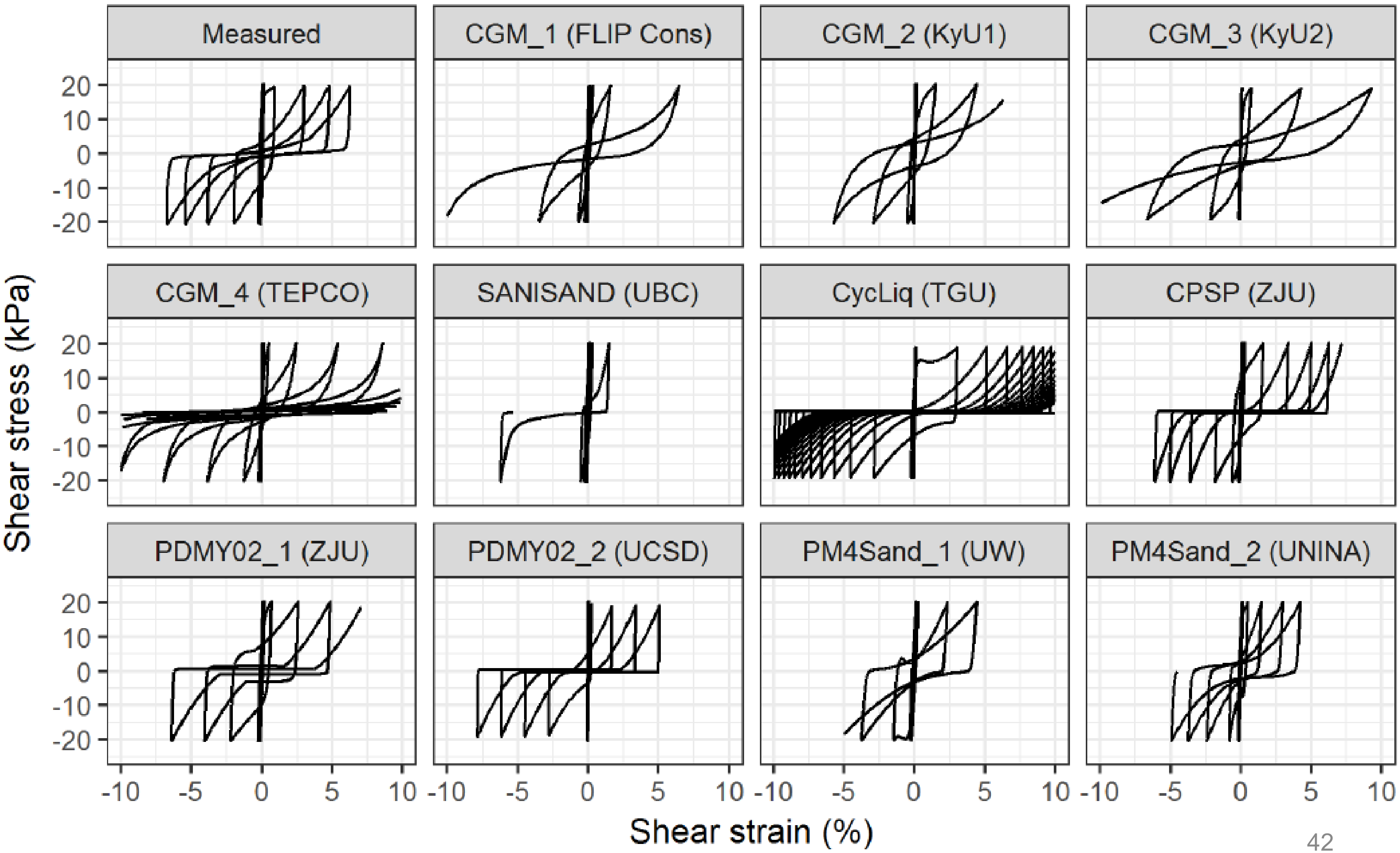
- The LEAP experiments are consistent with each other. The displacement response surface is correlated to the PGA and relative density with coefficient of correlation $R^2 \sim 0.8$ or greater.
- We are now able to estimate the variability of the experimental data by comparing the difference between the data and the regressed response surface
- Experimental data is published.
  - www.DesignSafe-ci.org
  - search for LEAP in Data Depot

Validation of numerical simulations of LEAP experiments

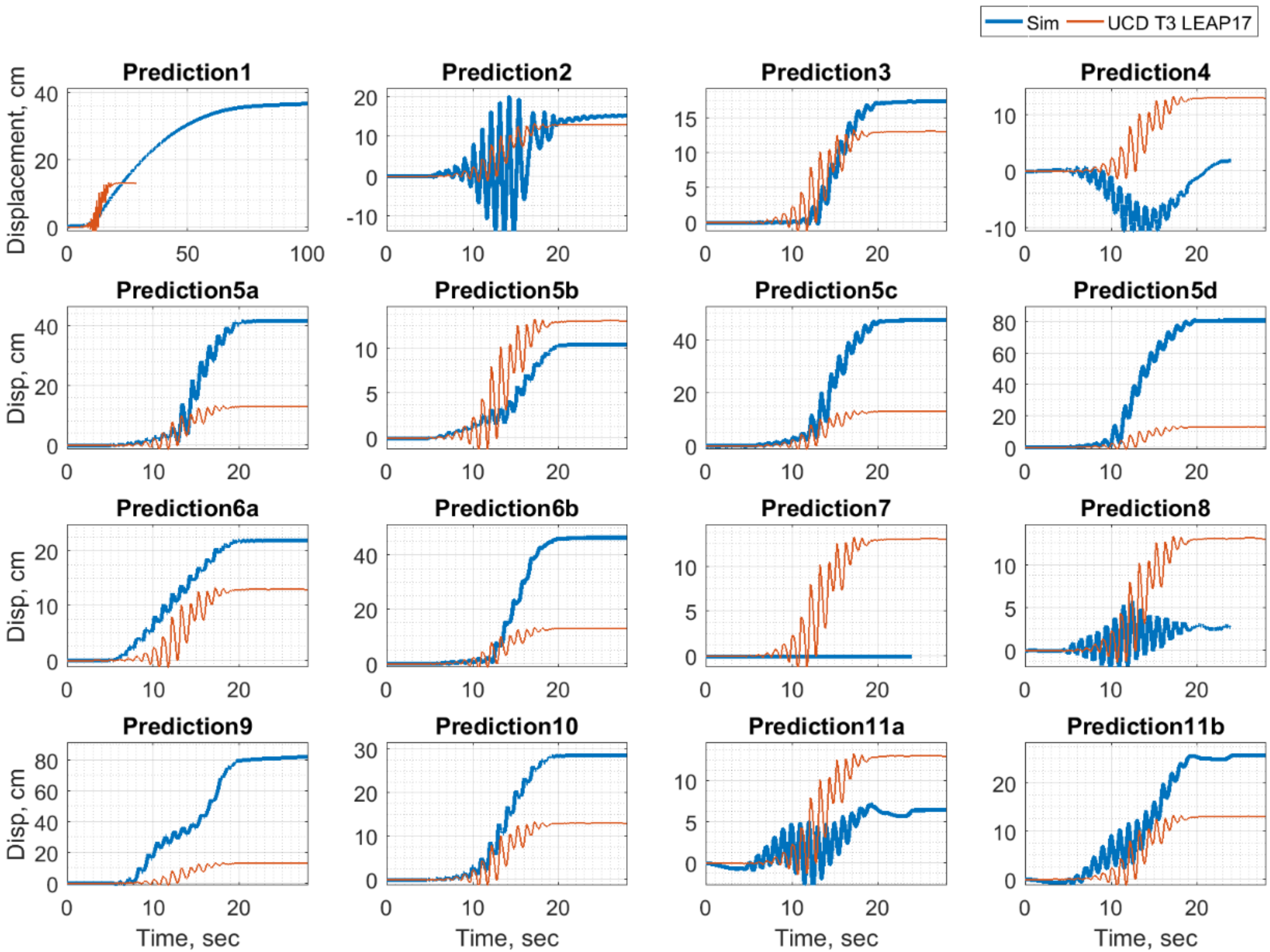
Numerical Simulation Team	Constitutive Model	Analysis Platform
1) Tsinghua University	Tsinghua Constitutive Model	OpenSEES
2) Meisosha Corporation	Cocktail Glass Model	FLIP Rose
3) Shimizu Corporation	Bowl Model	HiPER
4) University of Napoli	Hypoplastic Model	Plaxis
5) UC Davis - Auburn University	a) PM4Sand –Cal 1 b) PM4Sand –Cal 2 G_o larger c) PM4Sand –all Dr = 62% d) PM4Sand –even Lower Dr s) PM4Sand –corrected Dr	FLAC-2D
6) University of Washington	a) DM04 Model b) DM04 Model c) PM4Sand	OpenSEES OpenSEES (1D) OpenSEES (1D)
7) Kyoto University	Cocktail Glass Model	FLIP
8) Universidad del Norte	ISA-Hypoplasticity Model	ABAQUS
9) Univ. British Columbia	SANISand	FLAC-3D
10) UCSD	PDMY	OpenSEES
11) Fugro West	a) UBCSAND b) PM4Sand	FLAC-2D

Simulation of Element test data *Dr = 50% (r = 0.19)*

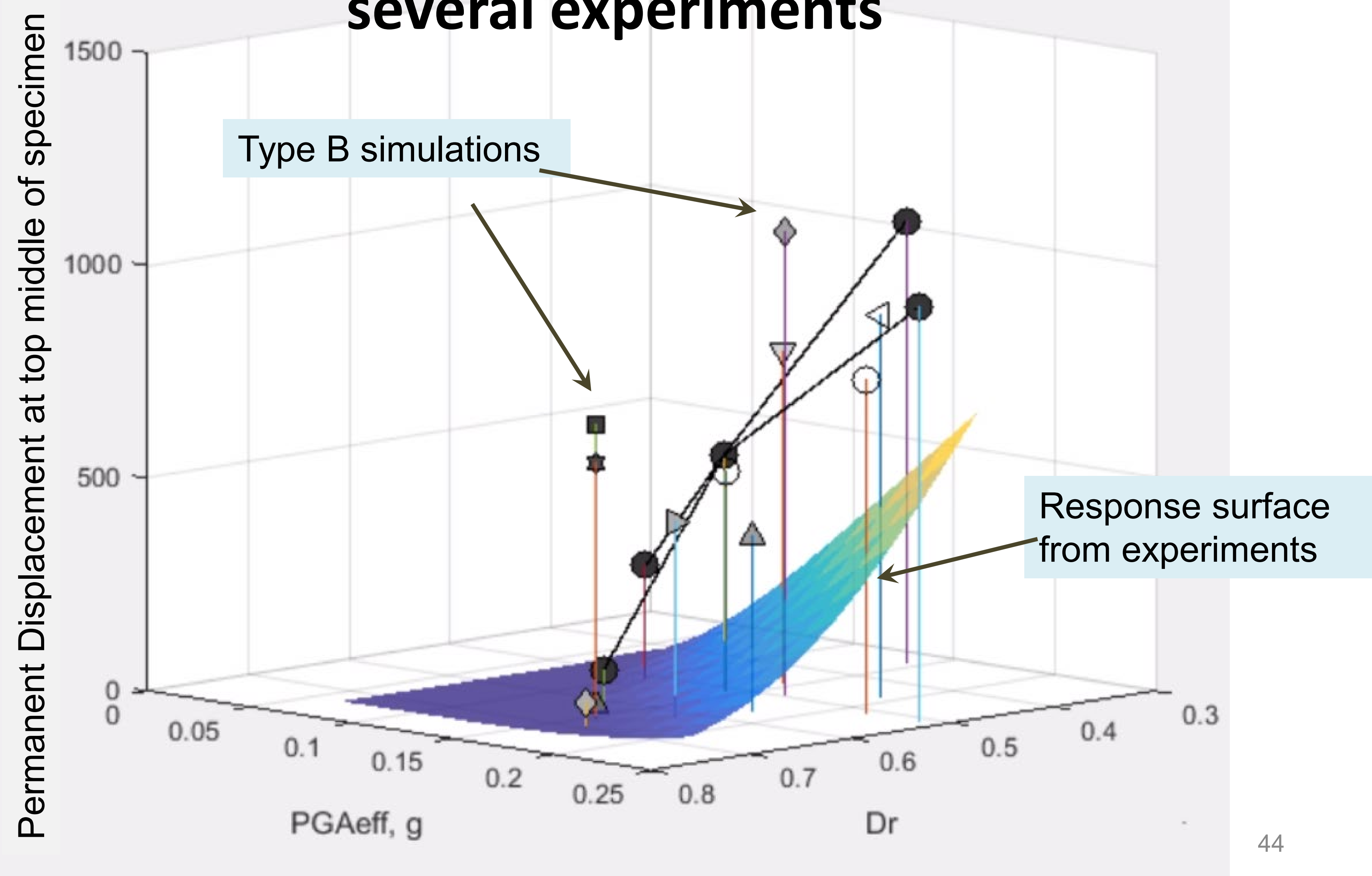
Ueda et al. (2019)

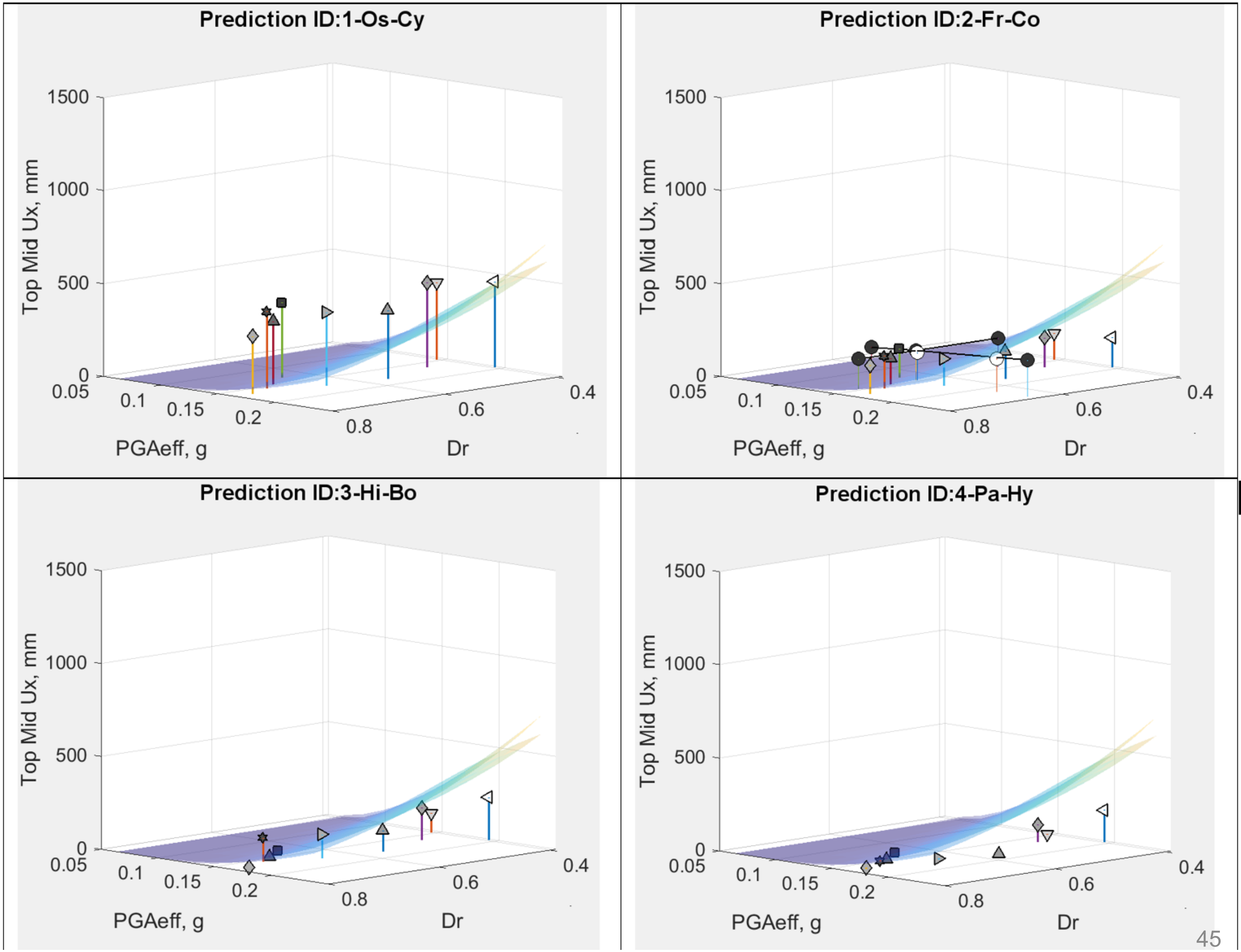


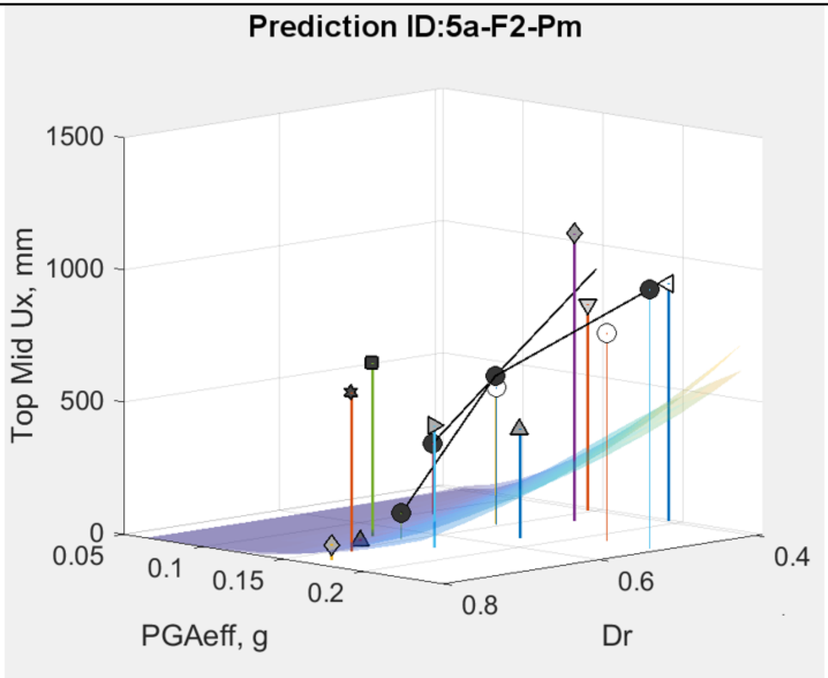
Here are 16 Type B predictions of one test.

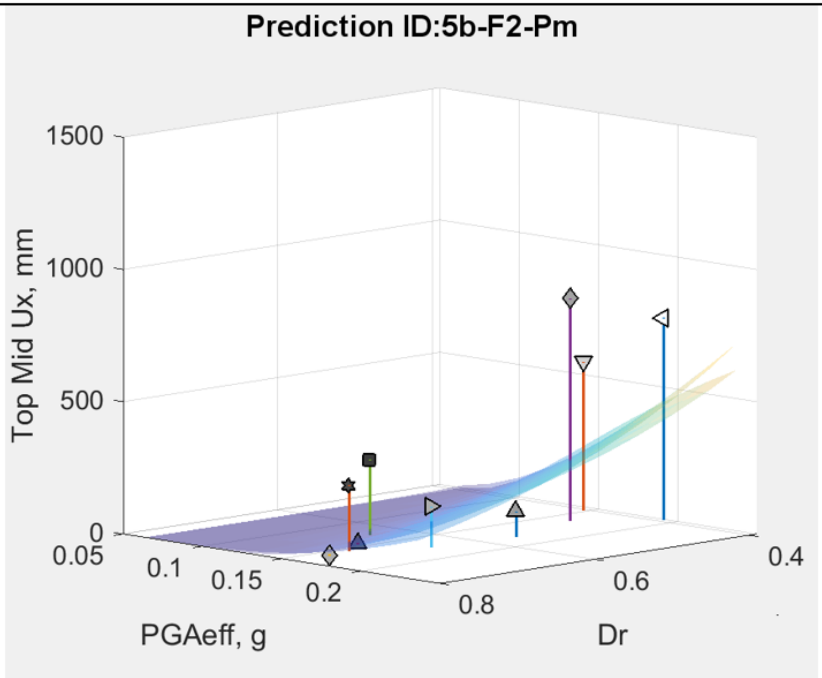


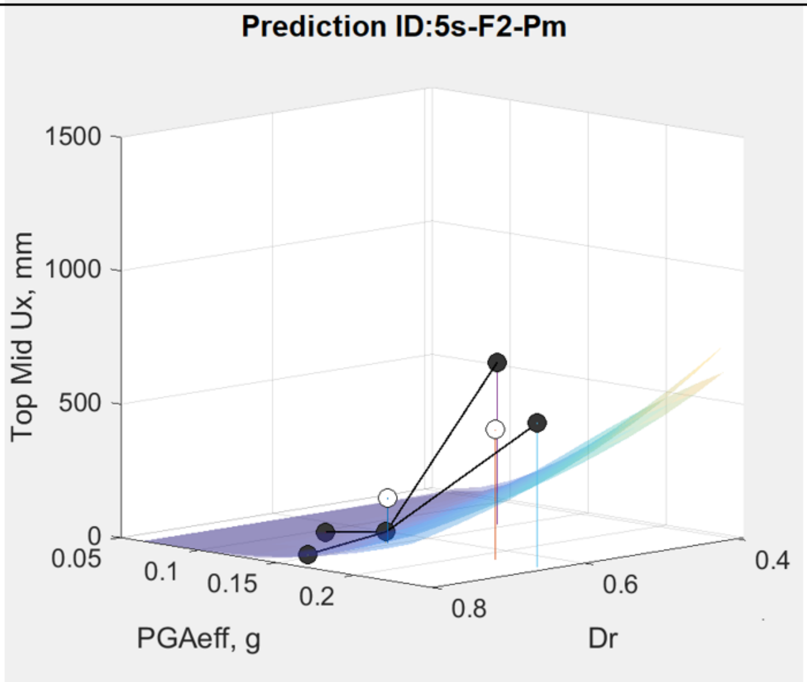
One simulation tool, several predictions compared to response surface from several experiments

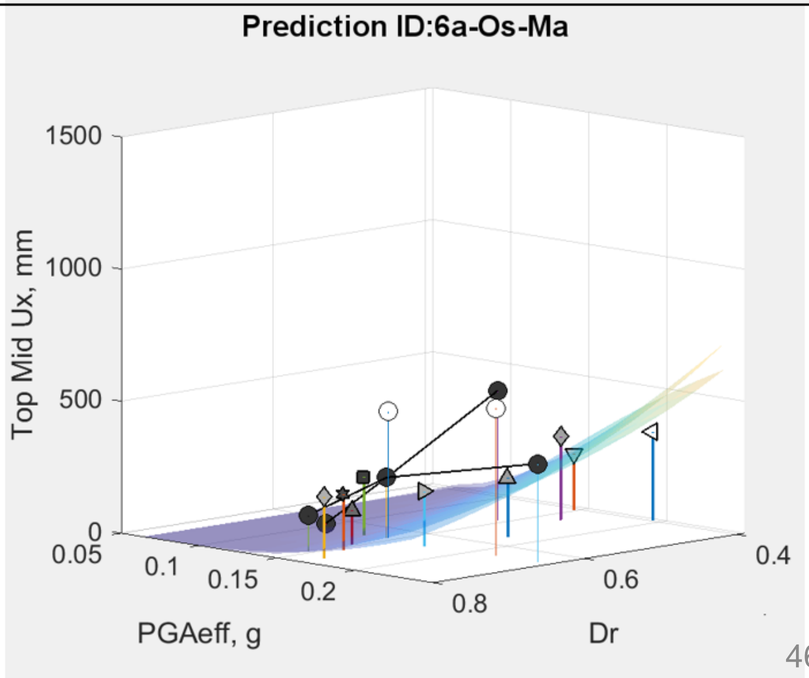


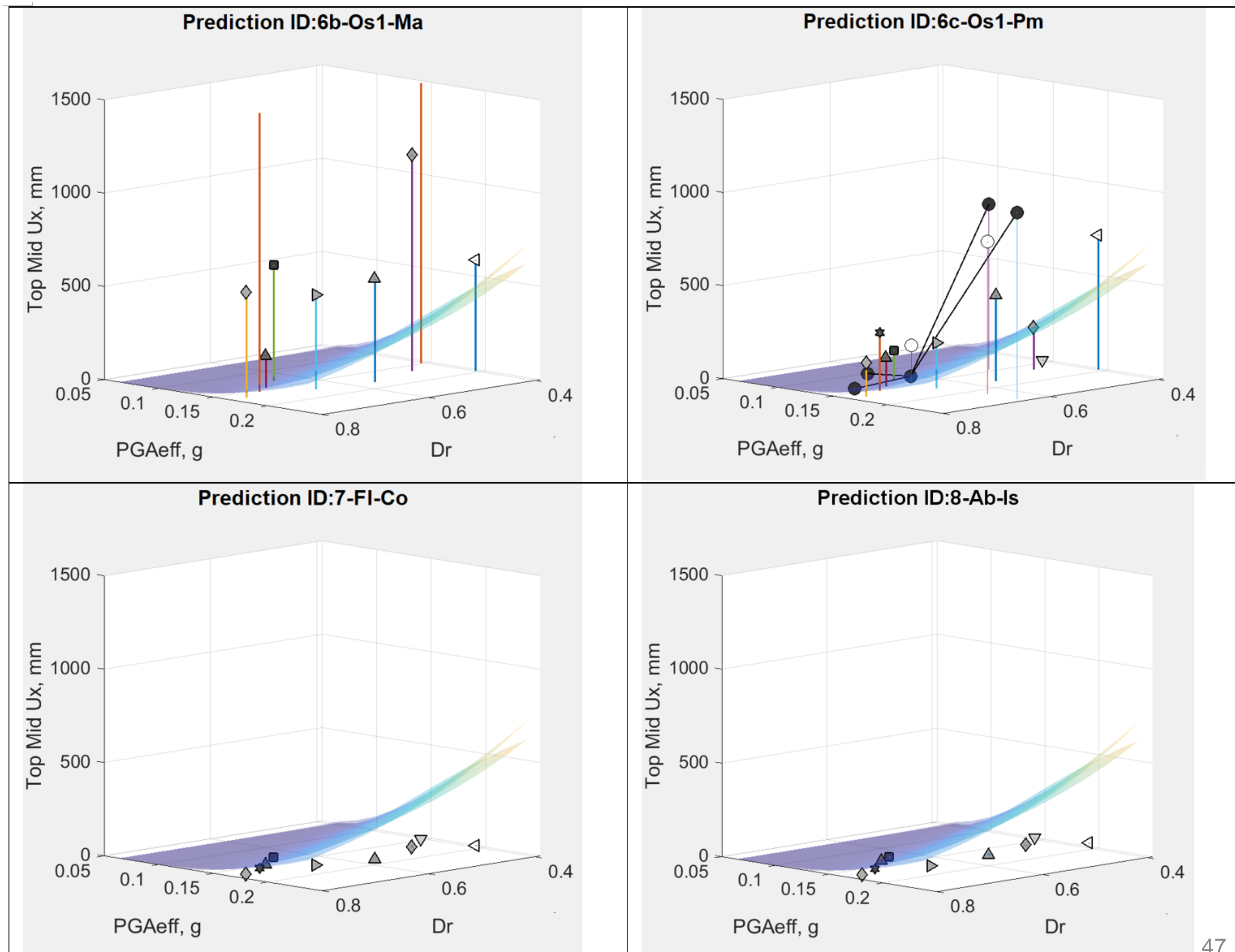

Prediction ID:1-Os-Cy
Prediction ID:2-Fr-Co
Prediction ID:3-Hi-Bo
Prediction ID:4-Pa-Hy
Top Mid Ux, mm
0
500
1000
1500
PGAeff, g
0.05
0.1
0.15
0.2
Dr
0.4
0.6
0.8

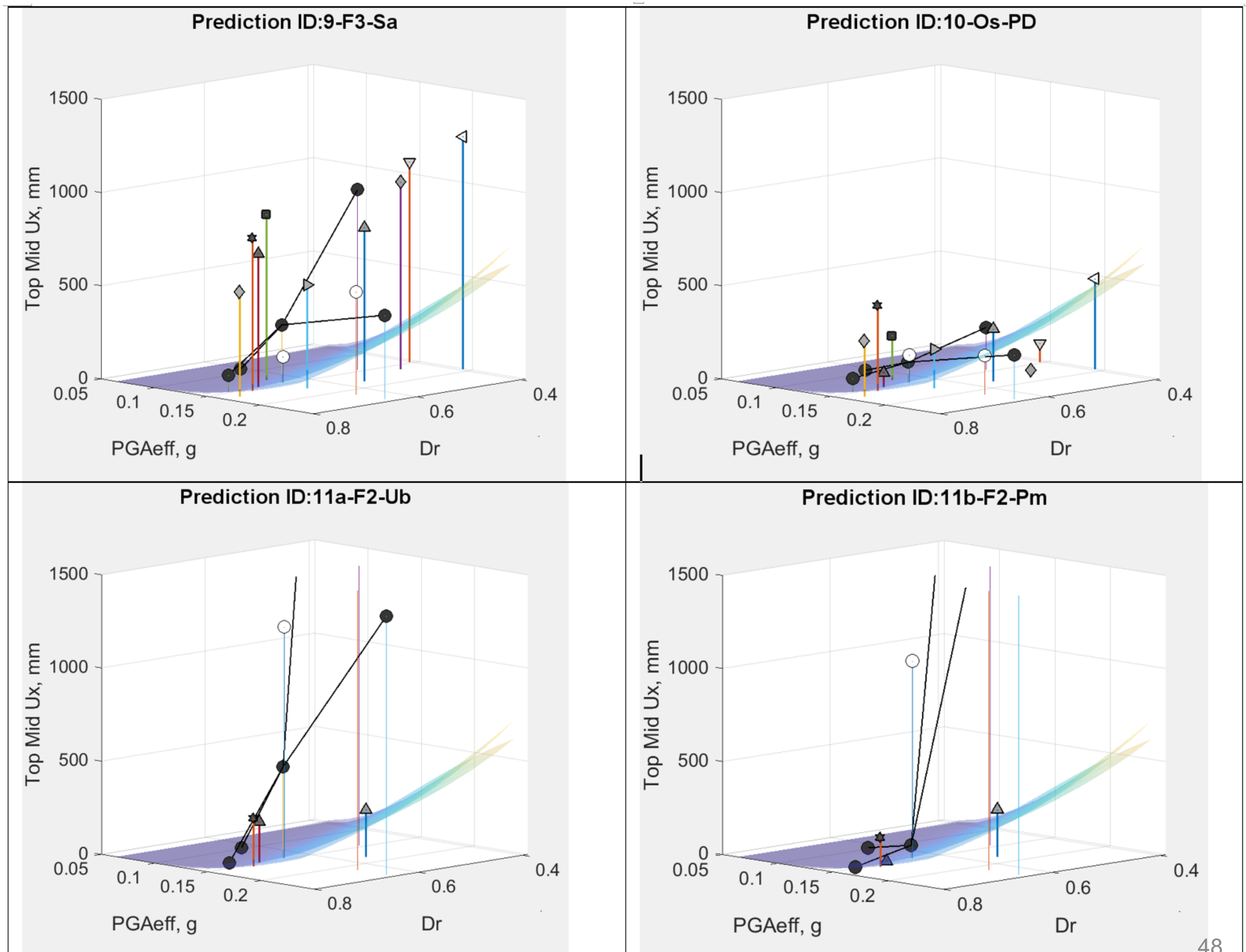

Prediction ID:5a-F2-Pm
Top Mid Ux, mm
1500
1000
500
0
0.05
0.1
0.15
0.2
PGAeff, g
0.8
0.6
0.4
Dr


Prediction ID:5b-F2-Pm
Top Mid Ux, mm
1500
1000
500
0
0.05
0.1
0.15
0.2
PGAeff, g
0.8
0.6
0.4
Dr


Prediction ID:5s-F2-Pm
Top Mid Ux, mm
1500
1000
500
0
0.05
0.1
0.15
0.2
PGAeff, g
0.8
0.6
0.4
Dr


Prediction ID:6a-Os-Ma
Top Mid Ux, mm
1500
1000
500
0
0.05
0.1
0.15
0.2
PGAeff, g
0.8
0.6
0.4
Dr


Prediction ID:6b-Os1-Ma
Prediction ID:6c-Os1-Pm
Prediction ID:7-FI-Co
Prediction ID:8-Ab-Is
Top Mid Ux, mm
0
500
1000
1500
PGAeff, g
0.05
0.1
0.15
0.2
Dr
0.4
0.6
0.8


Prediction ID:9-F3-Sa
Prediction ID:10-Os-PD
Prediction ID:11a-F2-Ub
Prediction ID:11b-F2-Pm
Top Mid Ux, mm
PGAeff, g
Dr

Conclusions and open issues: Validation

- Matching experimental/numerical response function over a range of key input parameters is useful for assessing the quality of a simulation procedure.
  - We focused on residual displacement response surface for a lateral spreading soil in a rigid box
    - Different response quantities
    - Different BC's for lateral spreading?
    - Layering, rigid walls,
  - The LEAP database provides a solid basis for one aspect of assessment

Conclusions and open issues

- It is easier to “assess” than to “validate”
  - Validation of “model” or validation of “modeler”?
    - Same code different people give different results
    - Mistakes, lack of careful review, time limitations
    - Subjective criticism of friends and competitors
    - Objective but general metrics depend on the problem at hand.
- Validation for other liquefaction problems
    - Void redistribution, flow failures, embankments
    - SSI problems: e.g. downdrag on piles, tilting of buildings
    - Remediation methods
    - Sheet pile walls is the subject of LEAP-RPI-2020

LEAP references

https://link.springer.com/book/10.1007/978-3-030-22818-7#about

Kutter, Bruce; Zeghal, Mourad; Manzari, Majid, (2018-10-08), "LEAP-UCD-2017 Experiments (Liquefaction Experiments and Analysis Projects)" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2N10S
https://doi.org/10.17603/DS2N10S

Ueda, Kyohei, (2018-12-04), "LEAP-Asia-2018: Stress-strain response of Ottawa sand in Cyclic Torsional Shear Tests" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2D40H
https://doi.org/10.17603/DS2D40H

Manzari, Majid, (2018-12-04), "LEAP-2018 - Stress-strain response of Ottawa F65 sand in Cyclic Simple Shear" , DesignSafe-CI [publisher], Dataset,
https://doi.org/10.17603/DS2HX3H

ElGhoraiby, Mohamed; Park, Hanna; Manzari, Majid, (2018-10-15), "LEAP-2017 GWU Laboratory Tests" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2210X
https://doi.org/10.17603/DS2210X

Vasko, Andrew; ElGhoraiby, Mohamed; Manzari, Majid, (2018-10-12), "LEAP-GWU-2015 Laboratory Tests" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2TH7Q
DOI: https://doi.org/10.17603/DS2TH7Q

Trevor Carey; Bruce L Kutter; Majid T Manzari; M. Zeghal (2017), "Leap Soil Properties and Element Test Data,"
https://datacenterhub.org/resources/leap_soil

Ana Maria Parra Bastidas; R. W. Boulanger; Trevor Carey; J. DeJong (2017), "Ottawa F-65 Sand Data from Ana Maria Parra Bastidas," https://datacenterhub.org/resources/ottawa_f_65.

Example topic 2

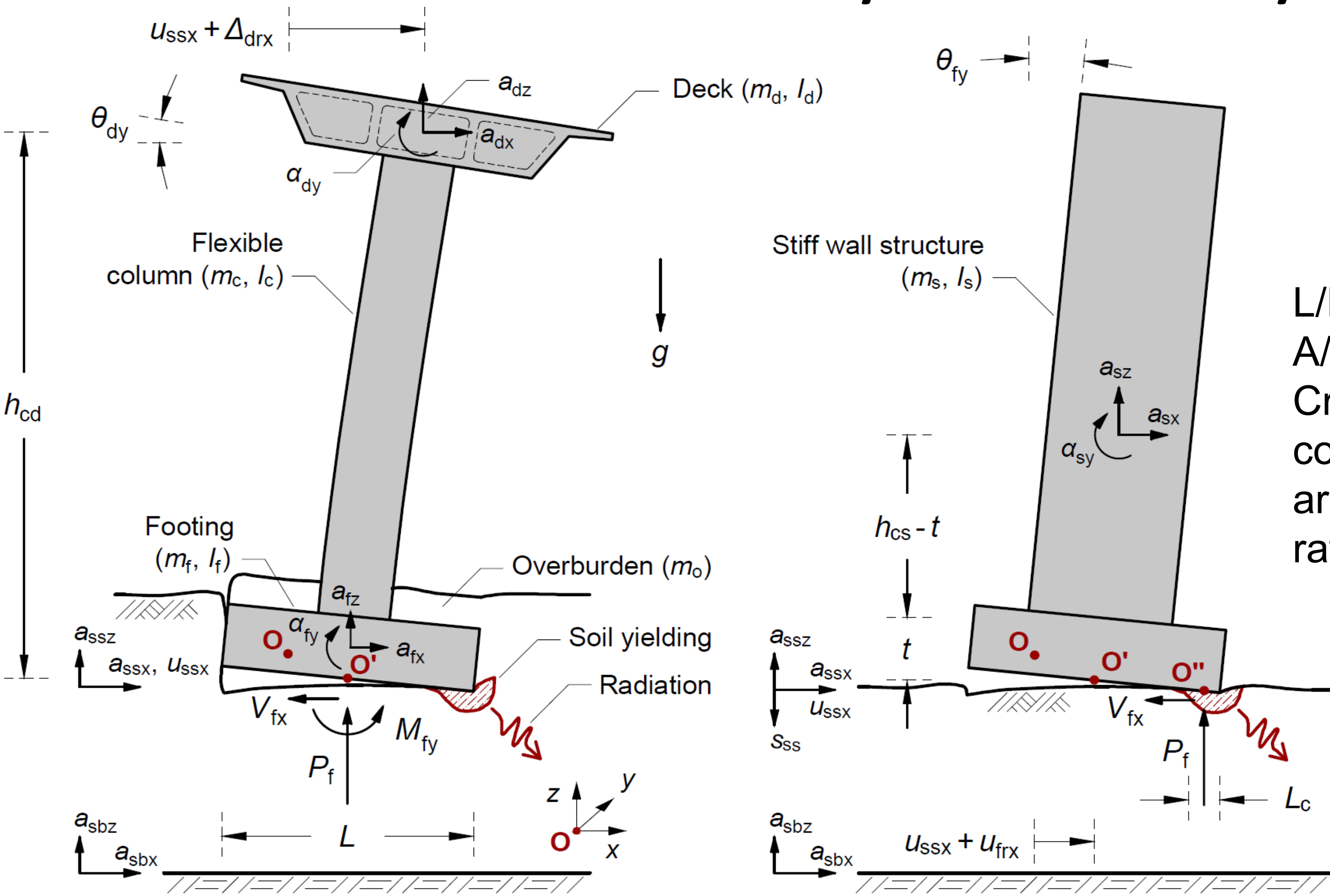
FoRDy: Database of Rocking Shallow Foundation Performance – Dynamic Shaking

FoRCy: Database of Rocking Shallow Foundation Performance – Slow Cyclic and Monotonic Loading

Andreas G. Gavras, Bruce L. Kutter, Manouchehr Hakhamaneshi, Sivapalan Gajan, Weian Liu, Angelos Tsatsis, Keshab Sharma, Giovanna Pianese, Tetsuya Kohno, Lijun Deng, Roberto Paolucci, Ioannis Anastasopoulos, and George Gazetas

Two in-press Data Papers to appear **in EERI Spectra** within a couple months
Data is already published at DataCenterHub
https://doi.org/10.13019/t0cq-qf64.
https://doi.org/10.13019/3rqyd929

Definition of some parameters documented in FoRCy and FoRDy

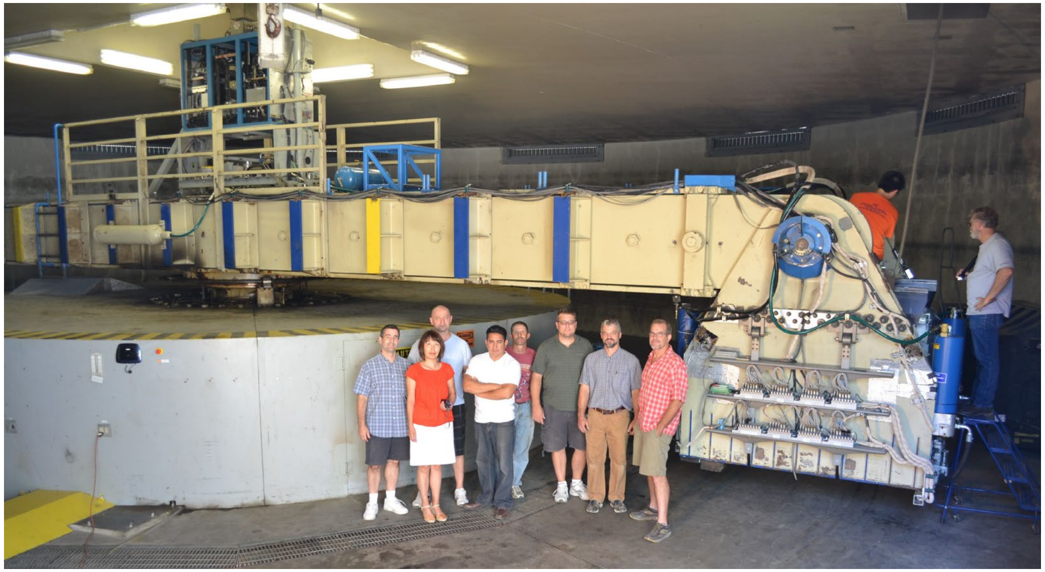


Note: O — Footing base centroid at t = 0; O' — Footing base centroid at t; O'' — Footing pole of rotation at t

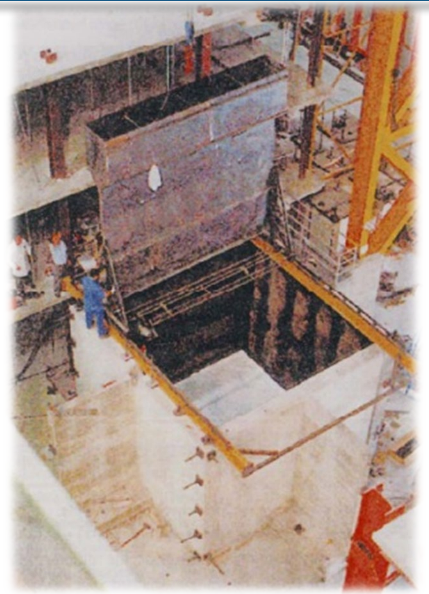
(a) (b)

L/Lc ~ A/Ac Critical contact area ratio

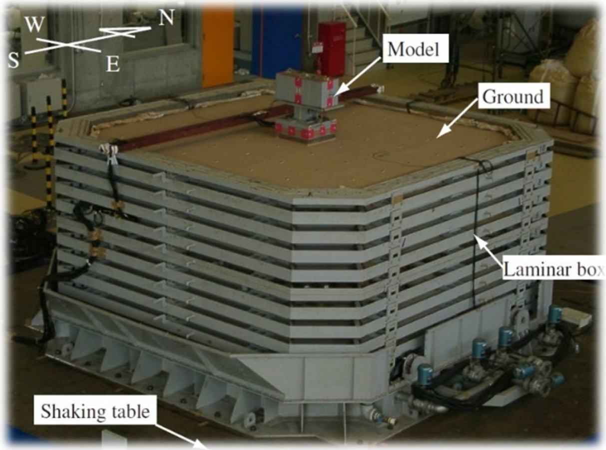
Validation database of experiments from many laboratories



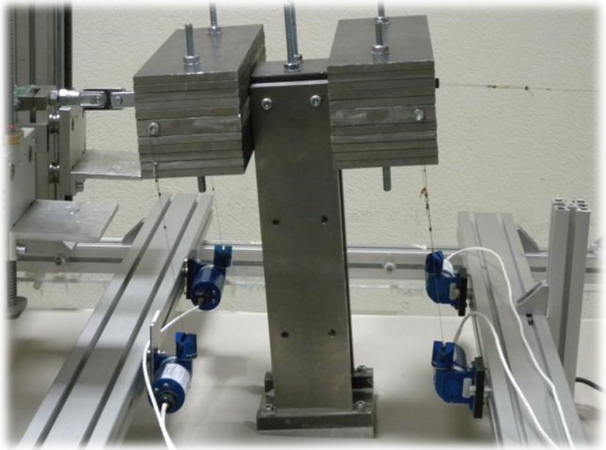
*Center for Geotechnical Modeling, **University of California—Davis***



*European Laboratory for Structural Assessment, **Joint Research Centre**, Italy*



*Foundation Engineering Laboratory, **Public Works Research Institute**, Japan*



*Laboratory of Soil Mechanics, **National Technical University of Athens**, Greece*

*Large High Performance Outdoor Shake Table, **University of California—San Diego***

The FoRCy Mastersheet

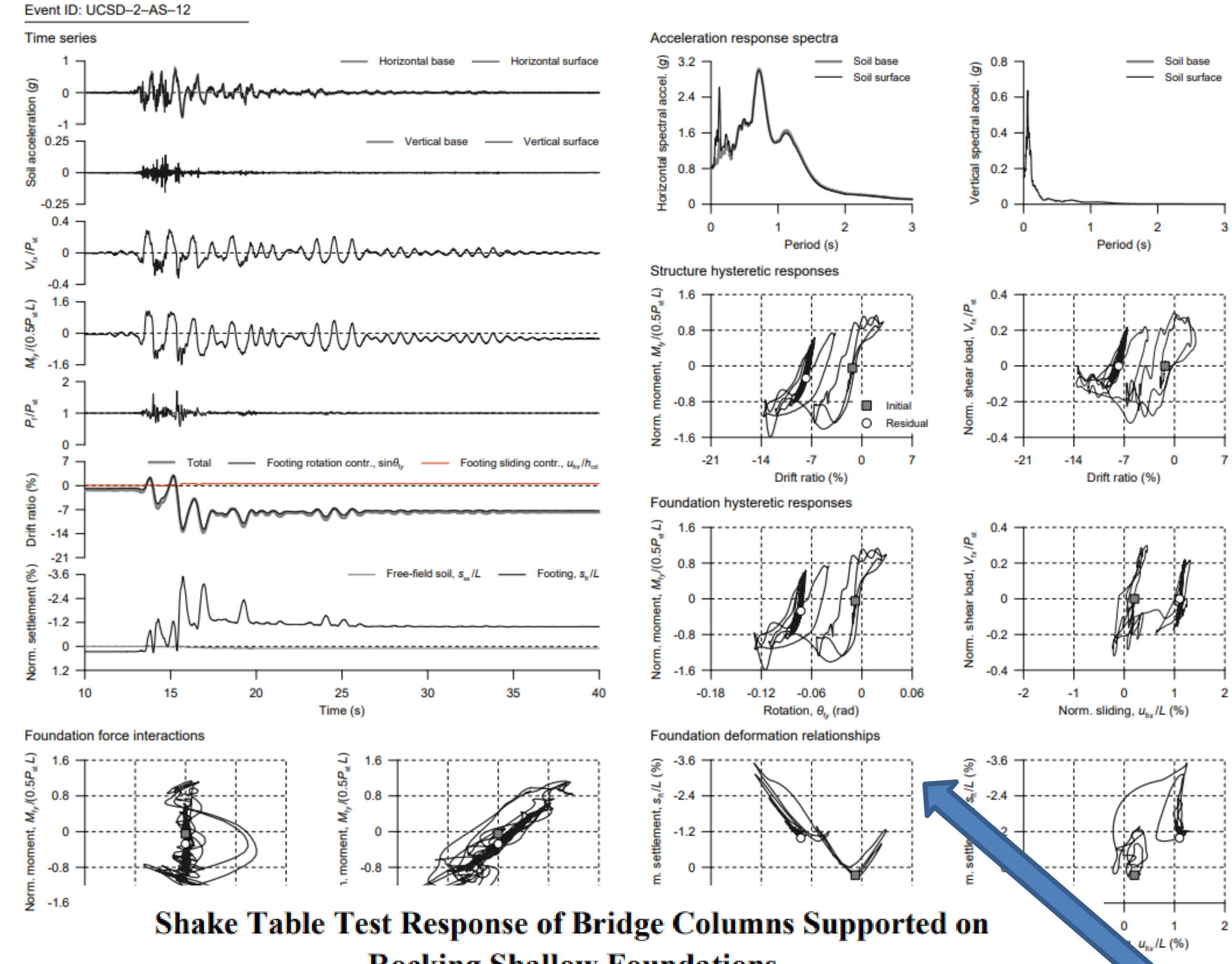
Download | Fullscreen | Clear Filters | No-Wrap

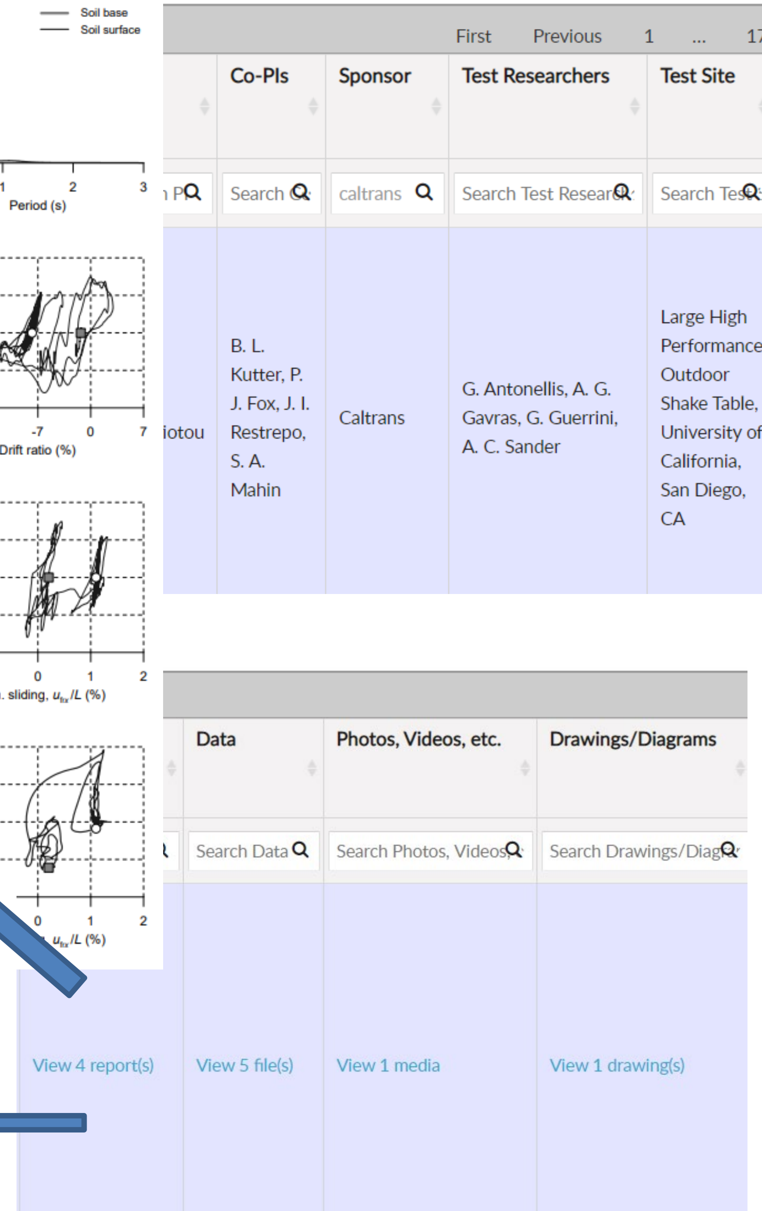
Show 100 entries

First Previous 1 2 3 4 5 Next Last

Row Num	Citation for data source	PI	Co-PI's	Researchers	Sponsor	Test Series	Test Site	Test Type	Cont. N.	Cont. L [m]	Cont. W [m]	Cont. H [m]	Actuator Type	N Actuators	Loading Protocol Description	Connection	Conn. Images	Event ID	Test Date	TN event packets	Packet N	RPM	Gravity*	Length*	Mass*	Time*	Model or Prot. Data?	Soil Depth [m]	Water Depth [m]	N Soil Layers	Modification	Mat_L1	H_L1 [m]	Dr_L1 [%]	phi_cv_L1 [degrees]	STDev_Dr_L1 [%]
Row	Citation for data source	PI	Co-PI's	Researchers	Sponsor	Test S.	Test Site	Test Type	Cont. N.	Cont. L	Cont. W	Cont. H	Actuator Type	N Actuators	Loading Protocol Description	Connection	Conn. Images	Event ID	Test Date	TN eve.	Packet N	RPM	Gravity*	Length*	Mass*	Time*	Model or P.	Soil D.	Water	N Soil .	Modification	Mat_L1	H_L1	Dr_L1	phi_cv_L1	STDev_Dr_L1
1	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	1	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
2	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	2	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
3	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	3	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
4	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	4	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
5	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	5	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
6	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_e_R_0.6	1-Aug-12	6	6	183.8	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
7	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	1	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
8	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	2	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
9	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	3	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
10	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	4	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
11	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	5	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
12	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.45_e_R_1.55	20-Jun-12	6	6	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
13	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	1	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
14	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	2	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
15	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	3	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
16	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	4	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
17	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	5	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
18	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.57_e_R_0.14	3-Aug-12	6	6	184.5	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
19	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	1	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
20	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	2	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
21	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	3	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
22	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	4	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
23	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	5	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
24	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.11	29-Aug-12	6	6	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
25	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	1	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
26	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	2	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
27	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	3	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
28	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	4	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
29	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	5	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
30	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H50_0.17	8-Nov-12	6	6	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	4
31	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	1	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
32	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	2	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
33	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	3	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
34	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	4	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
35	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	5	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
36	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.13	2-Nov-12	6	6	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	4
37	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	1	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
38	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	2	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
39	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	3	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
40	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	4	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
41	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	5	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
42	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H35_0.26	6-Nov-12	6	6	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	3
43	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	1	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
44	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	2	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
45	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	3	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
46	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	4	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
47	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	5	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
48	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_e_H65_0.09	28-Nov-12	6	6	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
49	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	1	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
50	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	2	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
51	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	3	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
52	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	4	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
53	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	5	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
54	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		2_s_R_1.55	6-Dec-12	6	6	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
55	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.6_s_R_0.14	6-Dec-12	5	1	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
56	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.6_s_R_0.14	6-Dec-12	5	2	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
57	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.6_s_R_0.14	6-Dec-12	5	3	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
58	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.6_s_R_0.14	6-Dec-12	5	4	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
59	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.6_s_R_0.14	6-Dec-12	5	5	184.4	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
60	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_s_R_0.6	6-Dec-12	5	1	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
61	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_s_R_0.6	6-Dec-12	5	2	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
62	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_s_R_0.6	6-Dec-12	5	3	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
63	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_s_R_0.6	6-Dec-12	5	4	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
64	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.4_s_R_0.6	6-Dec-12	5	5	184.3	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	82	9999	3
65	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.26	13-Dec-12	5	1	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
66	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.26	13-Dec-12	5	2	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
67	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.26	13-Dec-12	5	3	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
68	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.26	13-Dec-12	5	4	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
69	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.26	13-Dec-12	5	5	183.9	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
70	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.13	23-Jan-13	4	1	184	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
71	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.13	23-Jan-13	4	2	184	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
72	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.13	23-Jan-13	4	3	184	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
73	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H35_0.13	23-Jan-13	4	4	184	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	81	9999	3
74	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H50_0.17	28-Jan-13	5	1	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
75	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H50_0.17	28-Jan-13	5	2	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4
76	Hakhamaneshi, ...	Bruce L. Kutter	Sashi K...	M.Hakhamaneshi	NSF-NEESR	MAHS-1	UC Dav...	Centrifuge	Rigid Container	0.381	0.381	25.4	servo-hydraulic	1	Slow Cyclic disp controlled Lateral Loading	pin and...		1.5_s_H50_0.17	28-Jan-13	5	3	184.1	35	0.0286	0.0000233	0.0286	Model	0.15	7777	1	None	Nevada Sand	0.15	80	9999	4

FoRDy: Rocking Shallow Foundation Performance in Dynamic Experiments





Lumped-
bridge pi
model (fo
column-
with flex
elastic co

Shake Table Test Response of Bridge Columns Supported on Rocking Shallow Foundations

G. Antonellis*, A.G. Gavras†, M. Panagiotou*, B. L. Kutter†, G. Guerrini‡, A. Sander‡, P. J. Fox‡, J. I. Restrepo‡ and S. A. Mahin*

Structural Engineering Mechanics and Materials Report UCB/SEMM – 2014/07

Large High Performance Outdoor Shake Table, ***University of California—San Diego***

Credits: Andreas Gavras, Marios Panagiotou, Antonellis, Restrepo, Fox et al.

Large-scale models tested at 1 g.

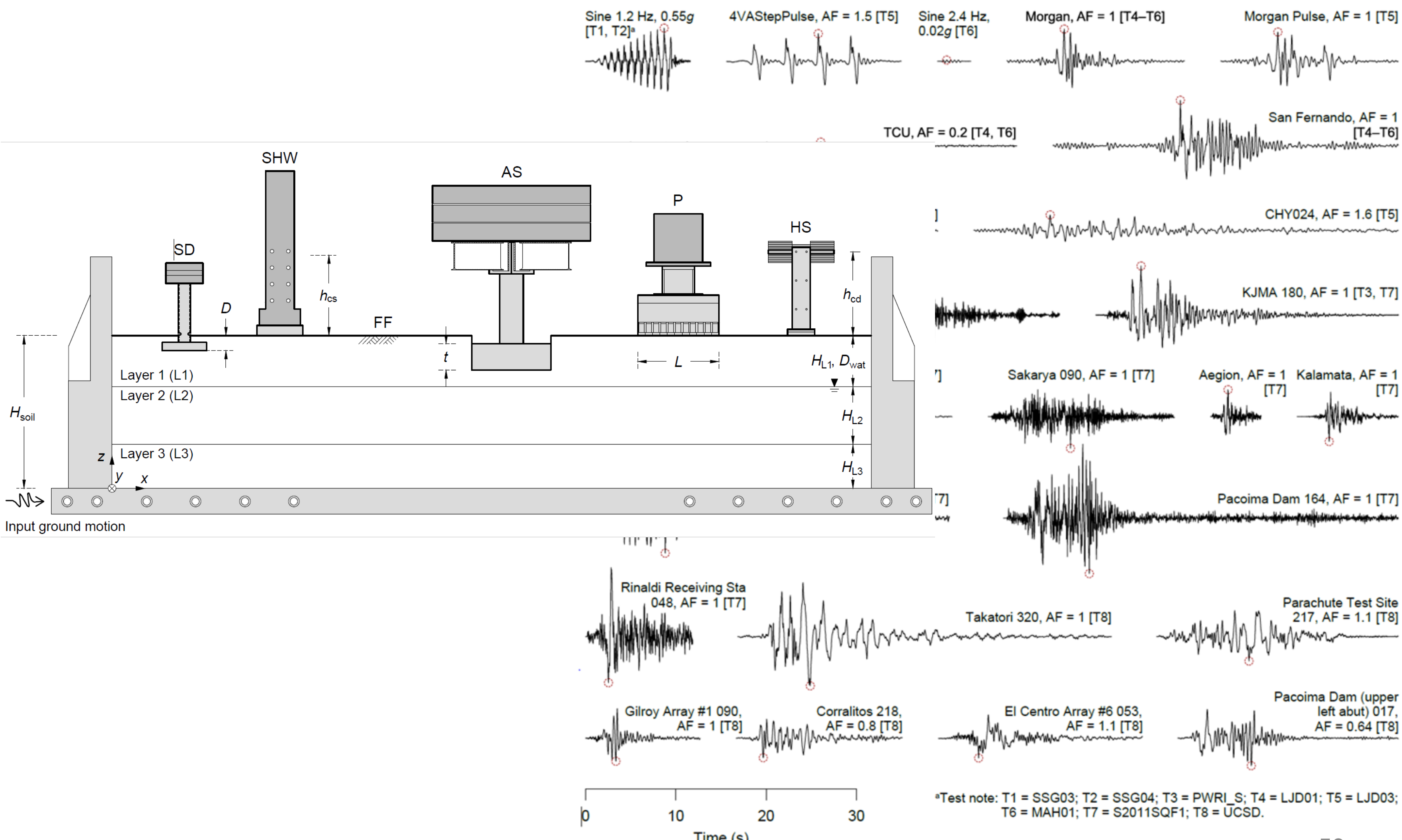
Key parameters

- *Soil*
  - *Sand, D_R = 90%*
- *Structure*
  - *P_{st} = 292 kN*
  - *H_{cm} = 2.64 m*
  - *L = 1.52 m and D = 0.66 m*
- *System*
  - *H_{cm} / L = 1.7*
  - *FS = 24.5 and A / A_c = 13.5*
  - *C_r = 0.30*
- *Base ground motion*
  - *Takatori—Fault-normal*
  - *1995 Kobe earthquake, Japan*
  - *PGA = 0.79 g*
- *Response*
  - *θ_{peak} = 0.108 rad*
  - *θ_{res} = 0.027 rad*
  - *s_{res} / L= -0.1%*

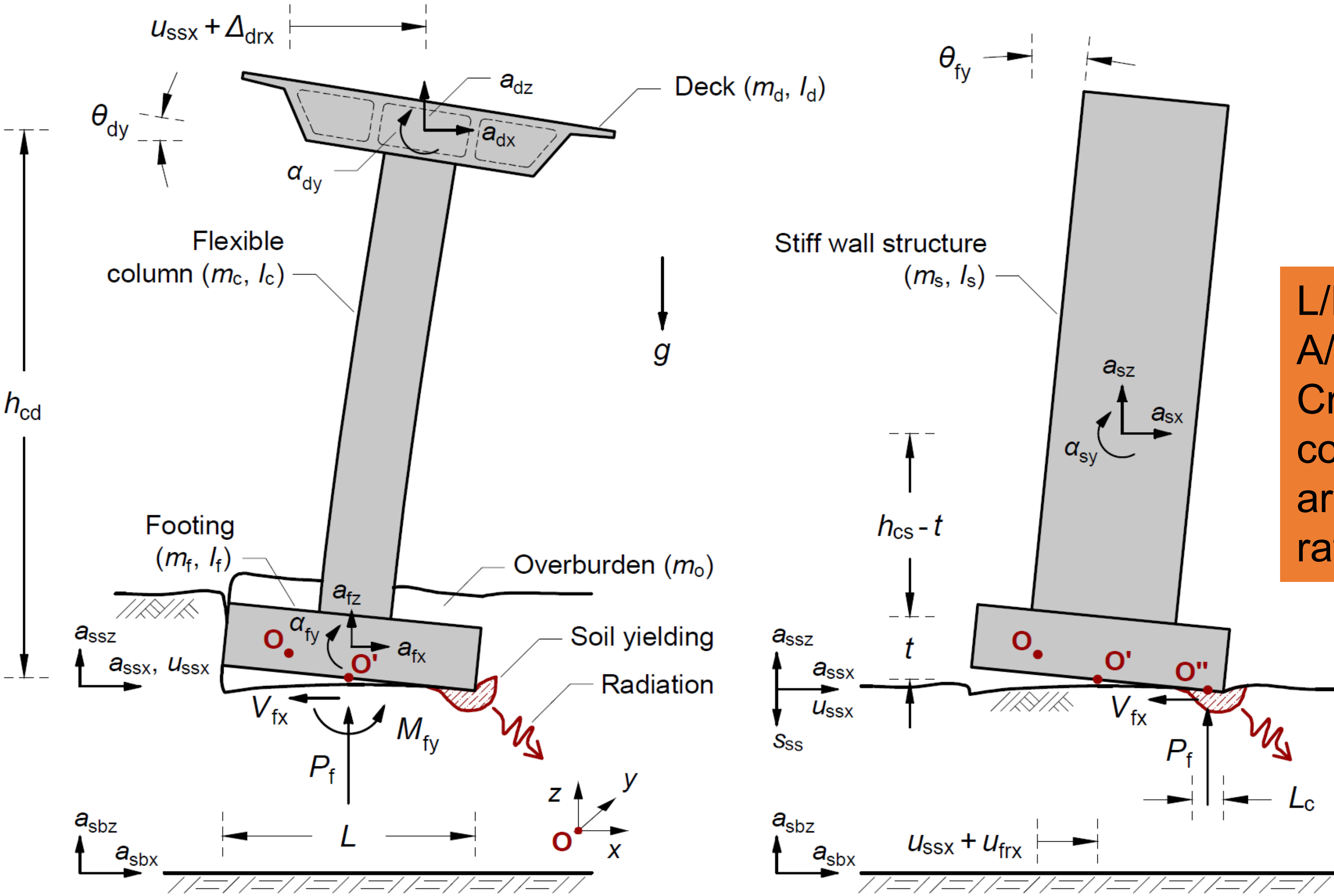
Antonellis et al. (2015)

Credits: Andreas Gavras, Marios Panagiotou, Antonellis, Restrepo, Fox, et al.

FoRDy configurations and motions



Definition of some parameters documented in FoRCy and FoRDy

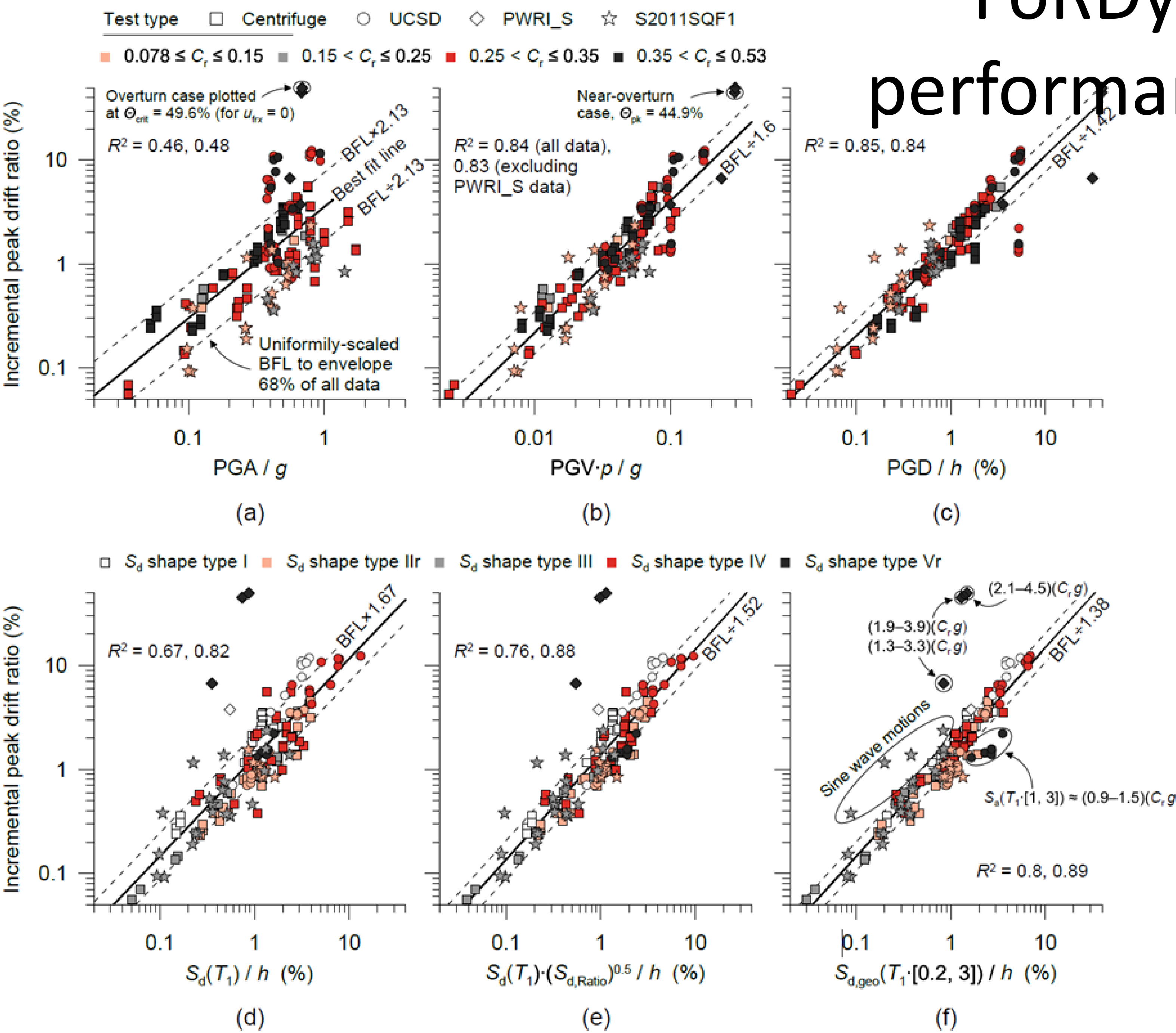


Note: O — Footing base centroid at $t = 0$; O' — Footing base centroid at t; O'' — Footing pole of rotation at t

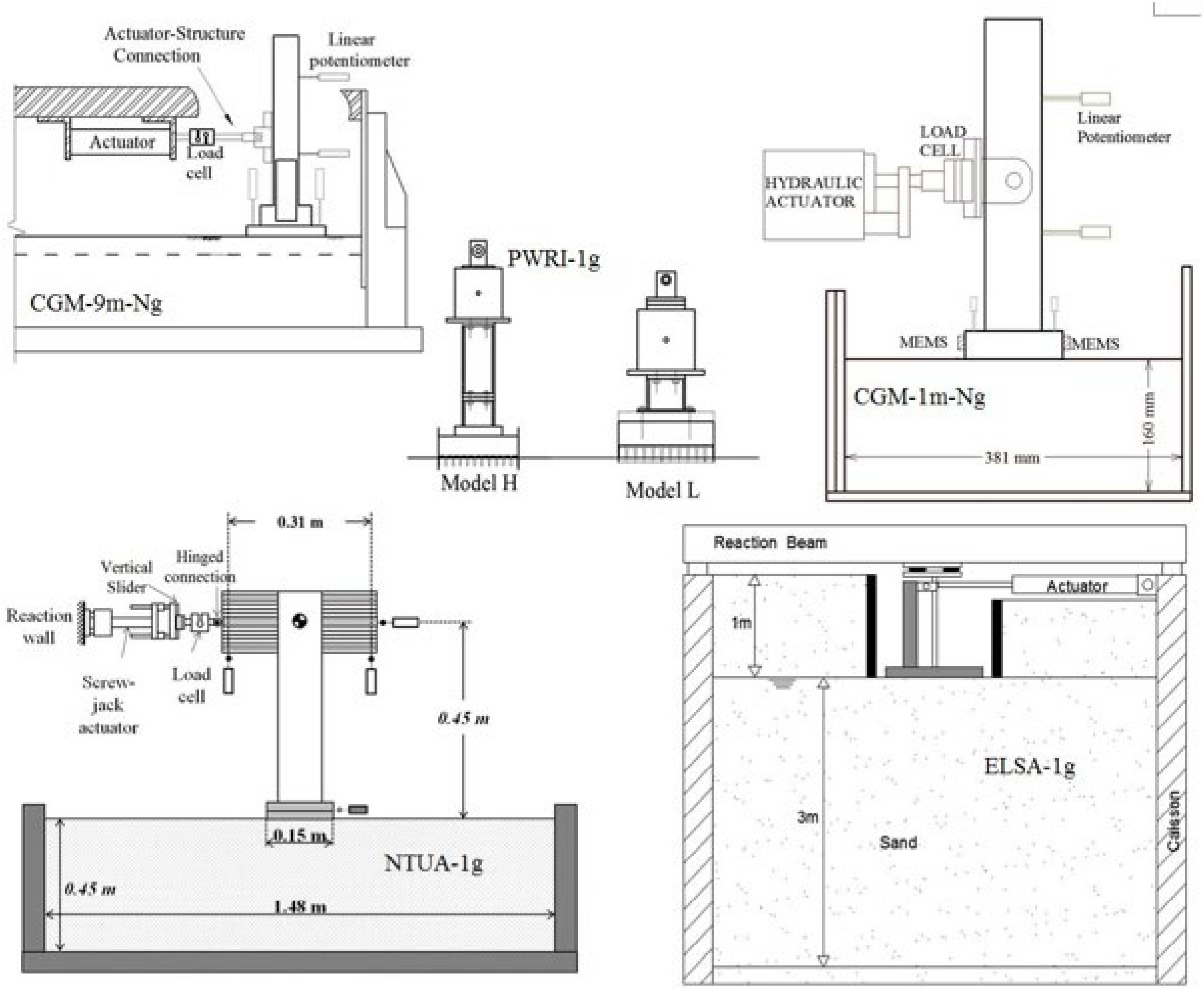
(a) (b)

L/Lc ~ A/Ac Critical contact area ratio

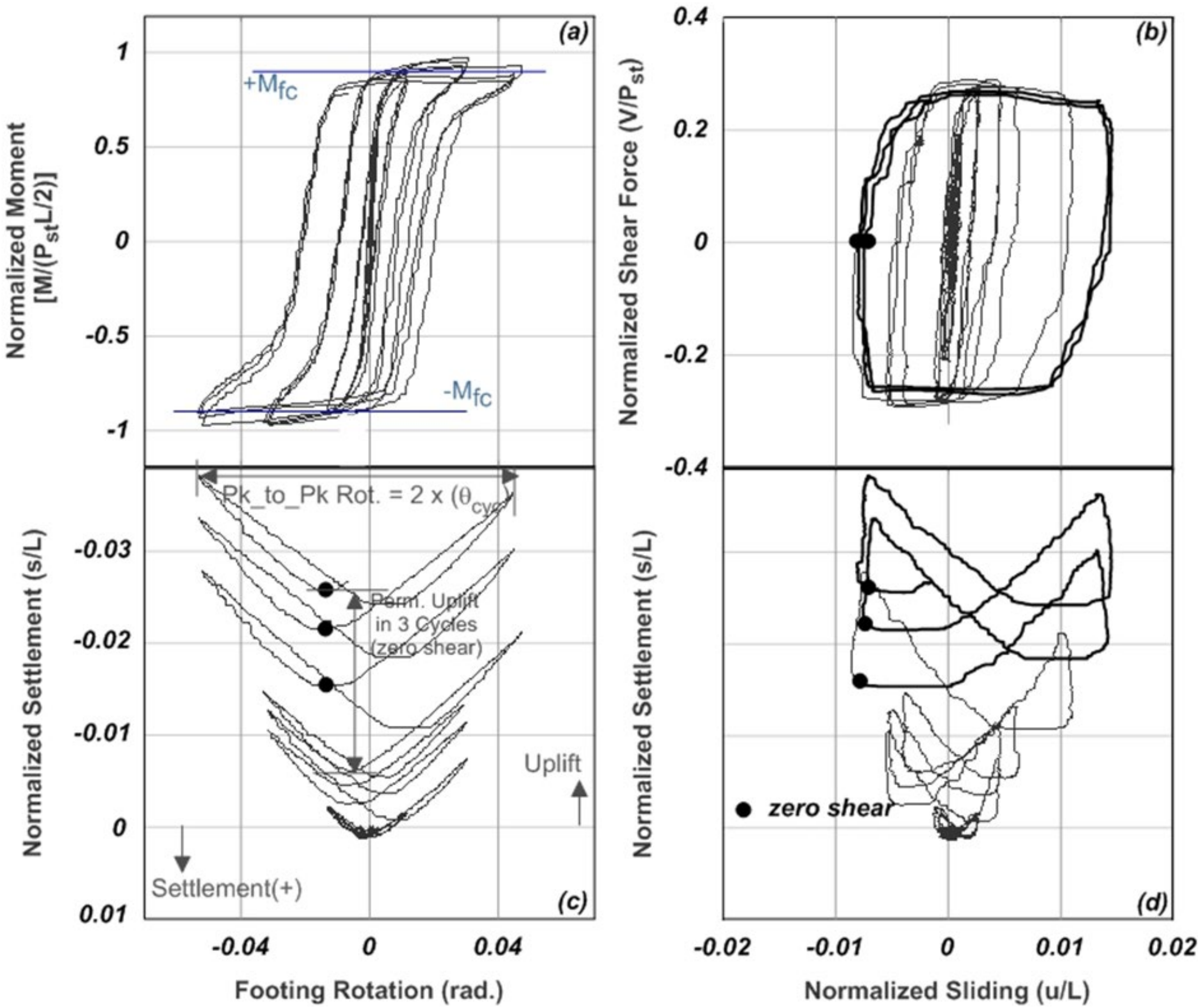
FoRDy performance



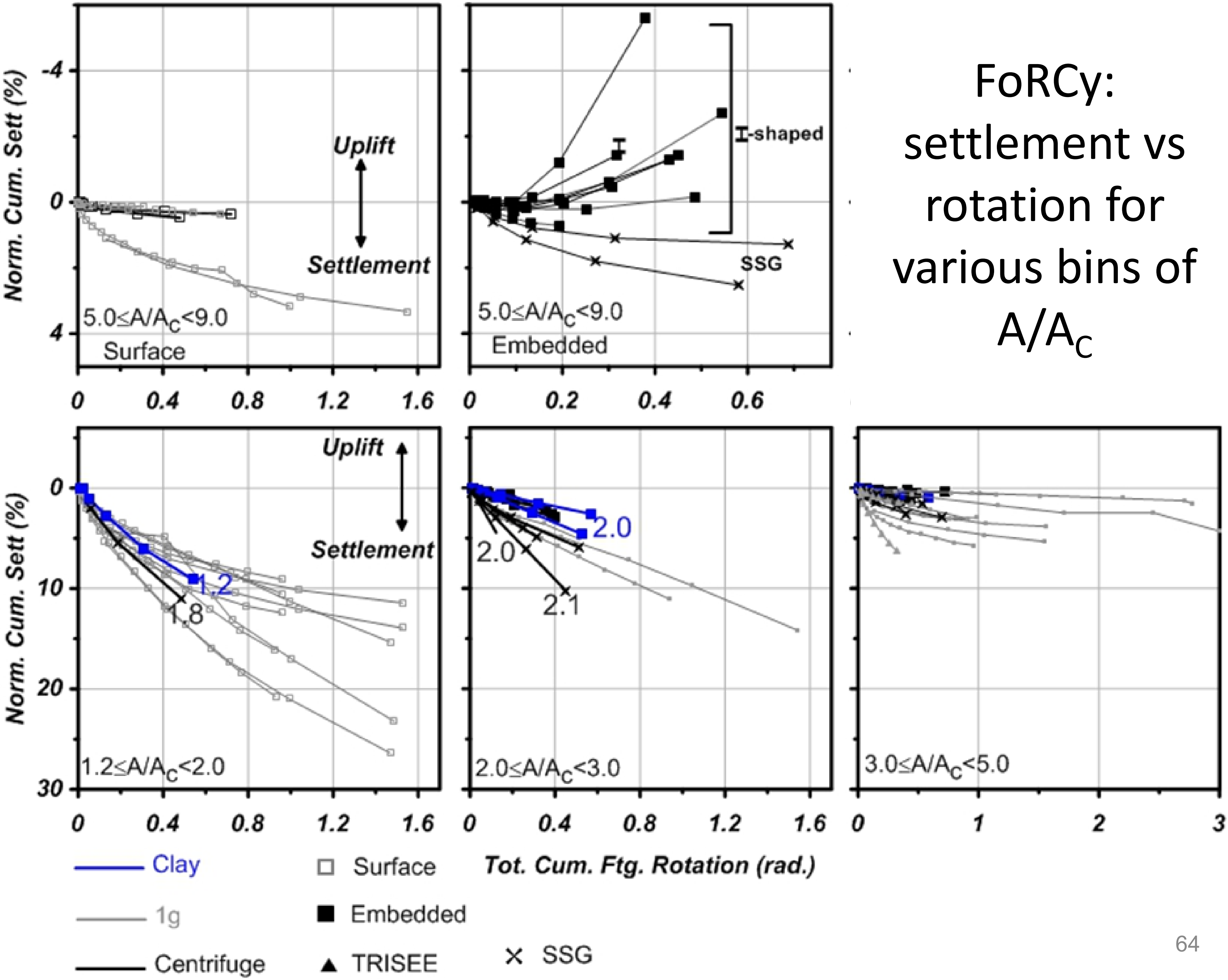
FoRCy configurations



Key plots in FoRCy (available for every entry in the database).



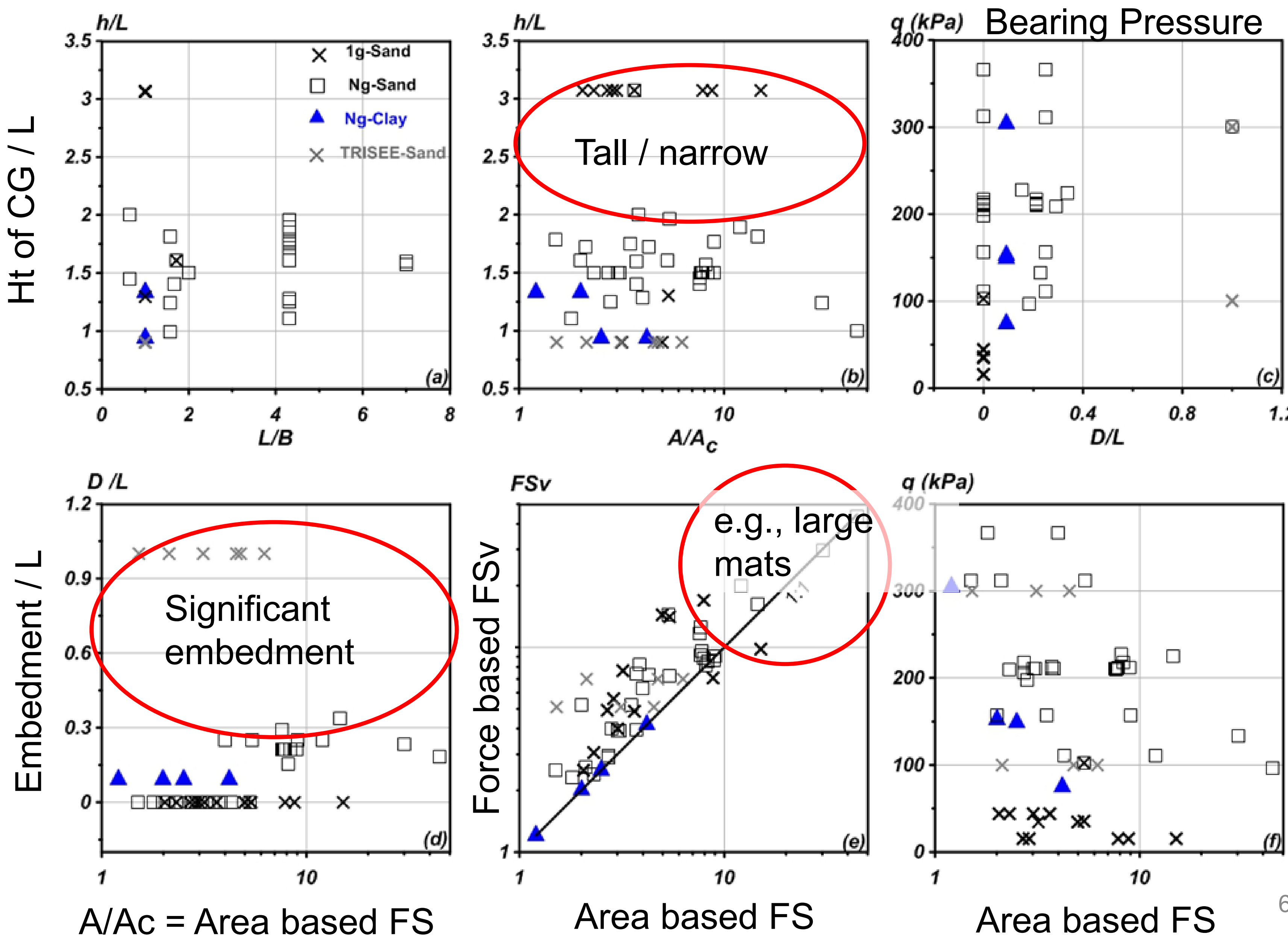
FoRCy: settlement vs rotation for various bins of A/A_C



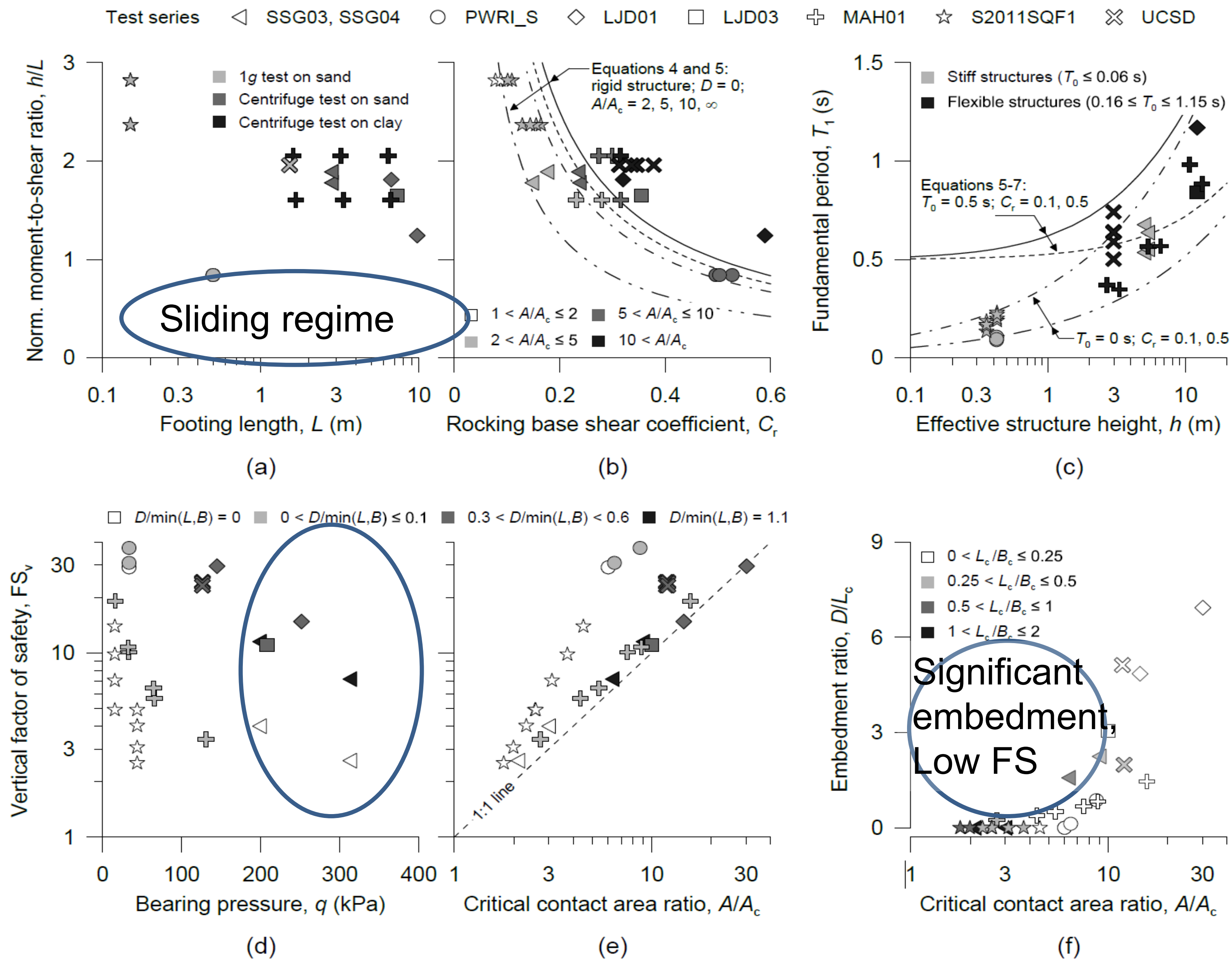
Conclusions from FoRCy and FoRDy

- Rocking foundations, like beams and columns, can be reliable energy dissipating components of seismic force resisting systems. They can reduce demands on the superstructure.
- Data sharing and reuse
  - A way to deal with human tendency to overlook limitations of their own experiments
- If you are interested in doing rocking experiments, please look at these databases
  - Fill gaps in the database

FoRCy Input Data Matrix - gaps



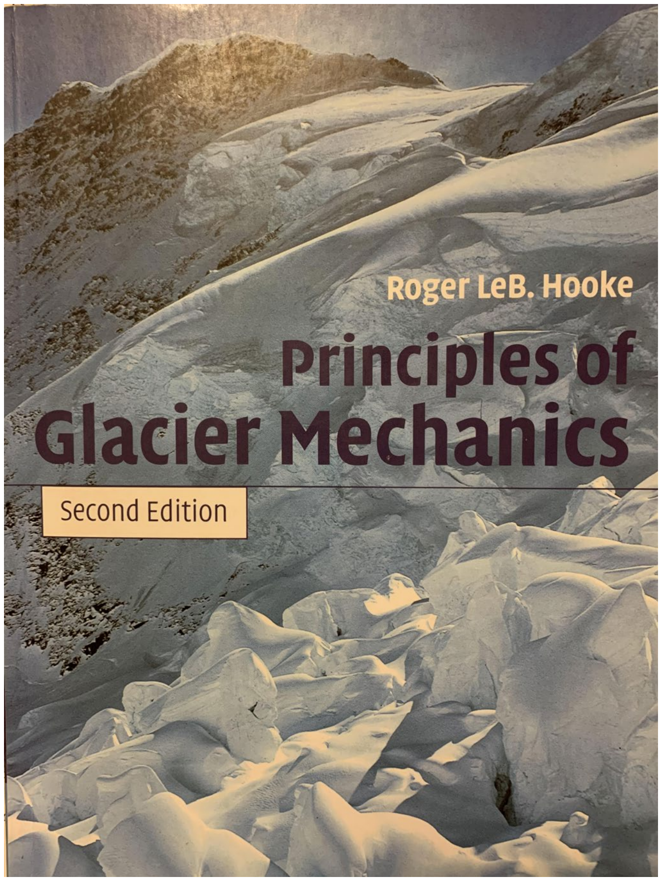
FoRDy Input Data Matrix - gaps



Brainstorming some research topics of the future

- Glacier movement: ice-water-soil-rock interaction problem
- Floating Cities?
- Mass transit and high speed rail
- Wind farm foundations
- Old problems and Overdue technology
  - Validation of numerical methods
  - Improved site investigation and models of the geotechnical environments
  - Accounting for uncertainty in experiments
  - Particle mechanics – what is the fundamental difference between silt and sand? Dealing with intermediate soils.
  - Liquefaction flow mechanisms

Ice-water-soil-rock interaction



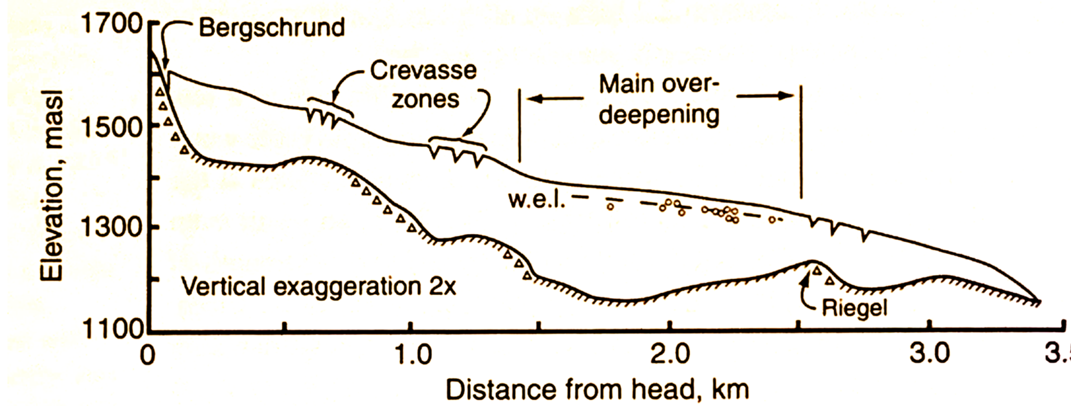


Figure 8.33. Longitudinal section of Storglaciären, Sweden, approximately along a flowline showing cirque, overdeepened basins, water-input points (crevasse zones and bergschrund), and inferred locations of quarrying (indicated by ΔΔΔ). Here w.e.l. = water equivalent line; circles (o) show heights of water in boreholes. (Modified from Hooke, 1991, Figure 2.)

Water pressure ~ total stress
Effective stress in till at the base of the glacier?
Effect of earthquake on glacier stability?
Effect on sea level?
Ice quakes (M ~ 5 ??)

Closing thoughts

- Research Topic
  - Imaginative, New, Grand Challenge
  - Old unsolved overlooked problems
- Validation of ability to simulate a function (not a data point)
- Become and expert – persistence
- Approach
  - Theory / fundamental mechanics / rigor
  - Small scale experiments (materials, components)
  - Large scale (systems/proof of concept)
  - Simulation (calibration and validation
  - Implementation
- Use existing data, share your data

Thank you for your attention