Innovative Experimental Technologies in Earthquake Engineering – An Overview

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Observations: experimental technologies (1)

- The digitally-controlled servo-valve revolutionized experimental structural dynamics
- Servo-controlled hydraulic actuators enabled researchers to apply dynamic loads in the laboratory that followed predetermined load and displacement histories, in real time
- Load frames and small shake tables became common place
- But in early 90s (during the Loma Prieta, Northridge, Kobe earthquakes…) the limitations of these facilities became apparent, and the push began to build bigger shake tables to capture real world behavior at as-large-a-scale-as-possible (NEES, NIED, NCREE, NHERI…)

Observation: experimental technologies (2)

- Not only shake tables, but also geotechnical centrifuges, laminar soil boxes, wave flumes and wave basins have all grown in size in an effort to reproduce nonlinear response to extreme events in the laboratory at a credible scale to:
  - gain insight into relevant physical phenomena
  - develop new codes and validate existing codes for numerical simulation of these phenomena, and
  - push the boundaries of earthquake engineering.

- But with increasing scale comes a family of challenges…

Experimental technologies

1. Shake tables and hybrid simulation (Performance-Based Design)
2. Geotechnical centrifuges and laminar soil boxes (Soil-Structure-Interaction)
3. Wave flumes and basins (Fluid-Structure Interaction: tsunami inundation)
4. Measurement technologies (wireless/contactless instrumentation)

1. Shake tables and hybrid simulation (1)

NIED Edefense Shake Table, Miki, Japan
20 m x 15 m platen, 1200 tonne payload
Estimated cost: US $400 m (2004)

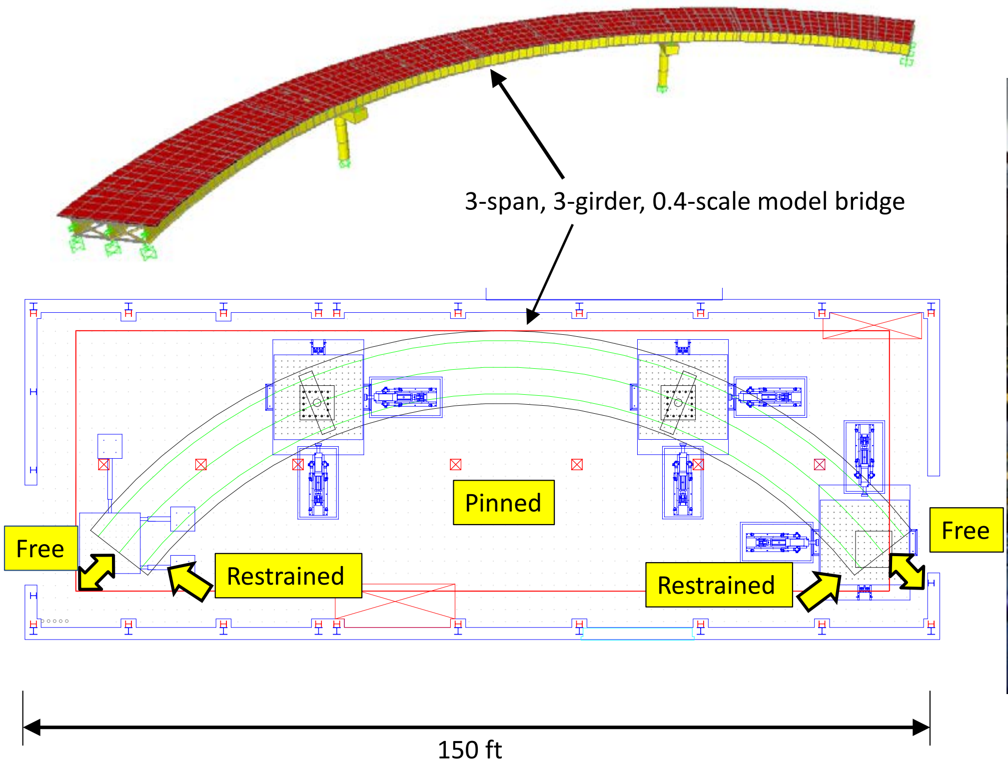
Challenges/innovations

1. Expensive to construct, operate, and maintain
2. Specimen costs also high
3. Productivity 'low' in terms of number of experiments/year
4. Costs may be reduced and productivity improved using:
    a. an array of shake tables
    b. hybrid simulation

Shake tables and hybrid simulation (2)

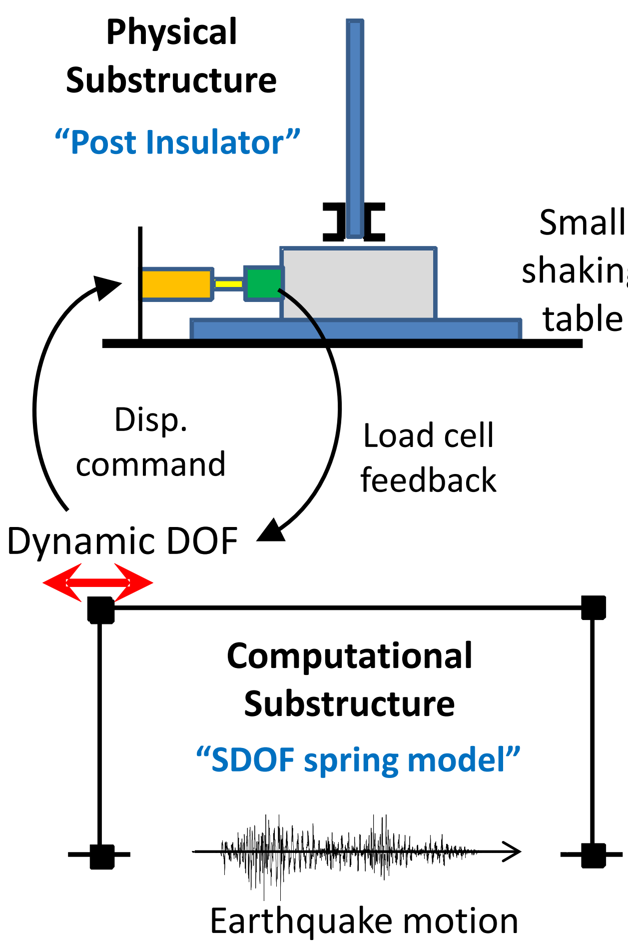
UNR Shake Table Array, Reno, US
3 x 50 ton, biaxial tables and 1 x 50 ton, 6-dof table
Tables may be spatially relocated such that ‘platen’ size can be up to 35 m x 25 m

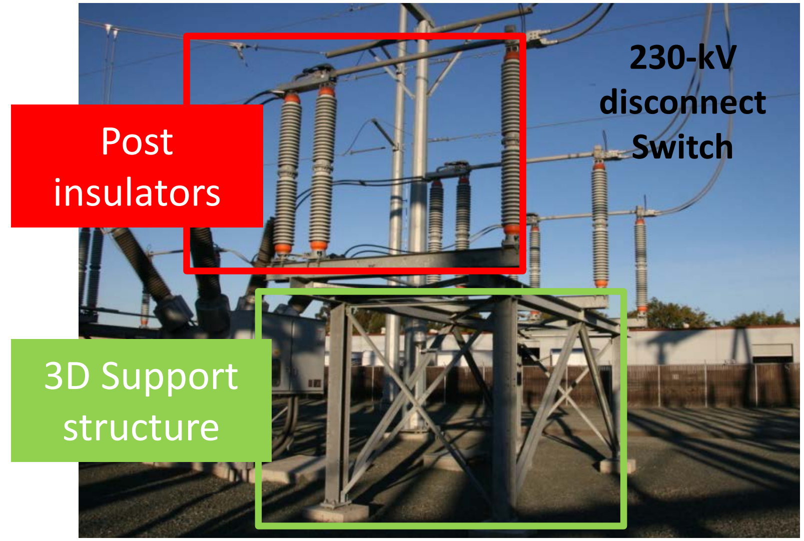
Shake tables and hybrid simulation (3)



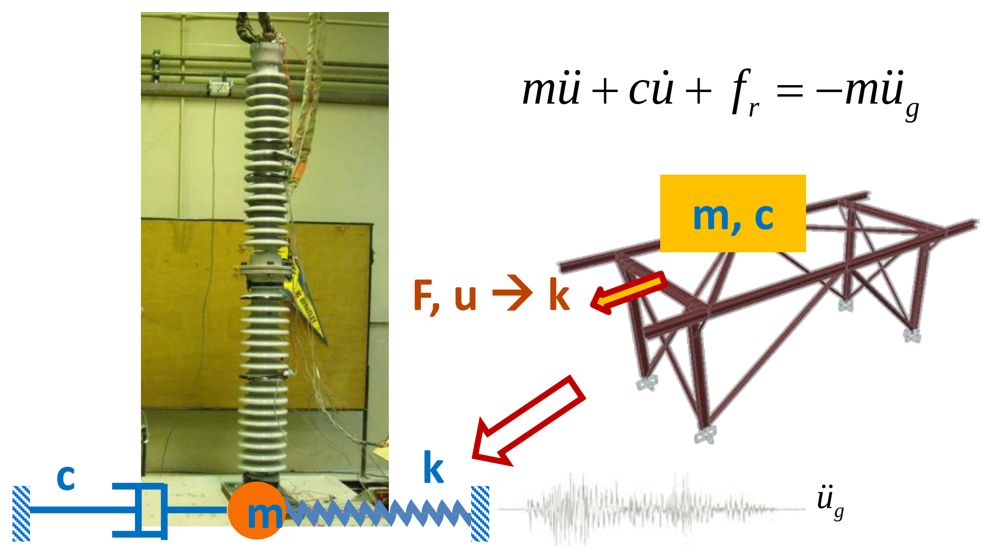
Curved bridge spanning 4 tables, UNR Shake Table Array, Reno, NV, USA

Shake tables and hybrid simulation (4)





$$m\ddot{u} + c\dot{u} + f_r = -m\ddot{u}_g$$

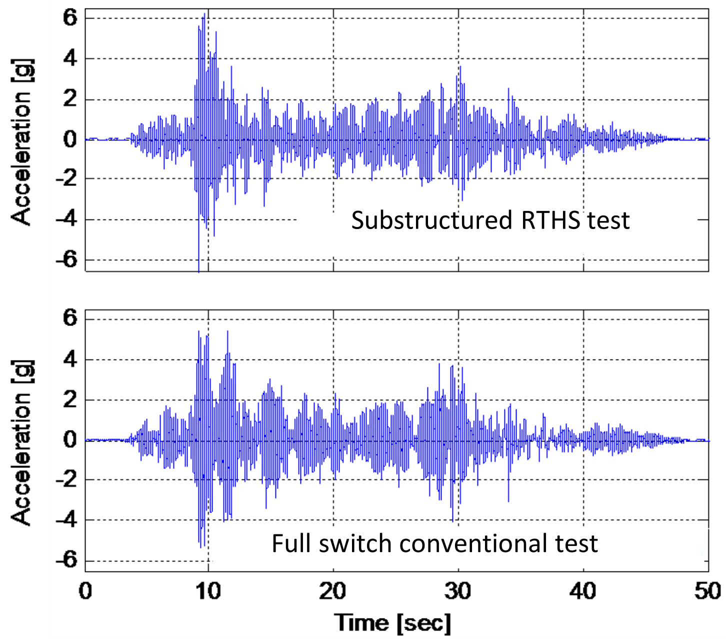


Shake tables and hybrid simulation (5)

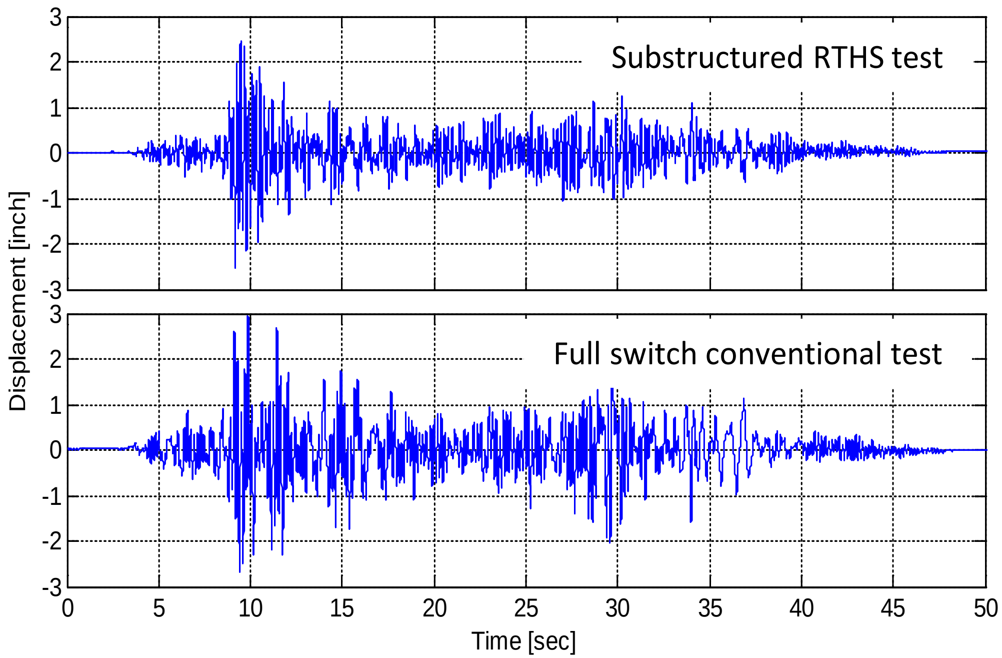
- Advances in real time hybrid simulation
  - New faster integration methods (e.g. explicit Newmark Integration Scheme implemented on Digital Signal Processor Card for solving equation of motion)
  - Enhanced communication schemes between server and controller (e.g. computed displacement sent as analog signal to controller)
  - Improved error compensation algorithms (e.g. feed forward algorithm)

Real-Time Hybrid Simulation Application

Real-time hybrid vs shake table test of switchyard insulator



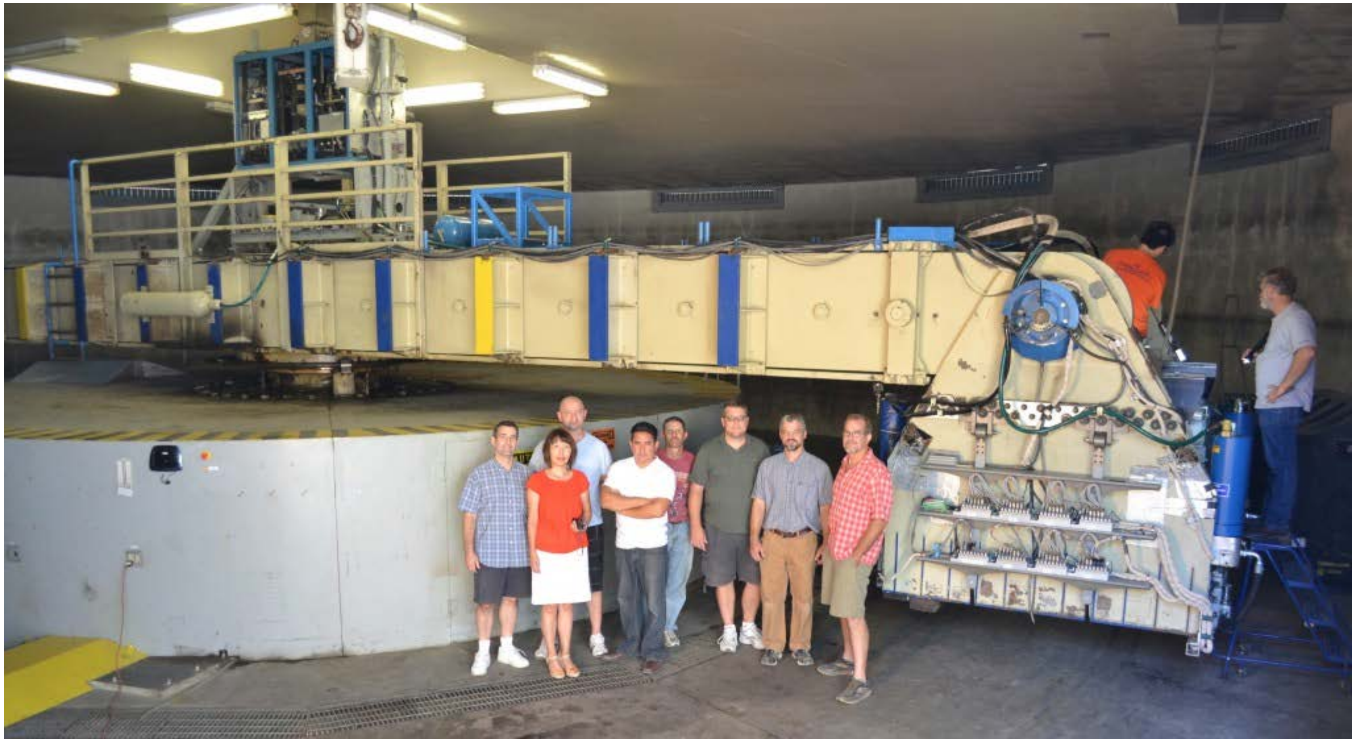
Accelerations



Relative displacements

Substructured RTHS test reproduced response from full switch shaking table test at significantly less cost. University of California Berkeley, CA, USA

2. Geotechnical centrifuges and soil boxes

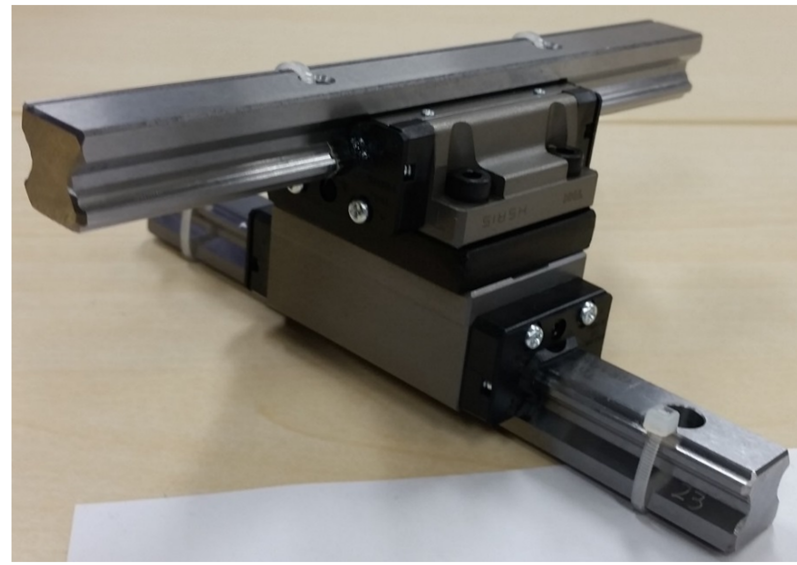


NHERI Geotechnical Centrifuge,
University of California Davis, US
9m arm, inflight shaker

Challenges/innovations

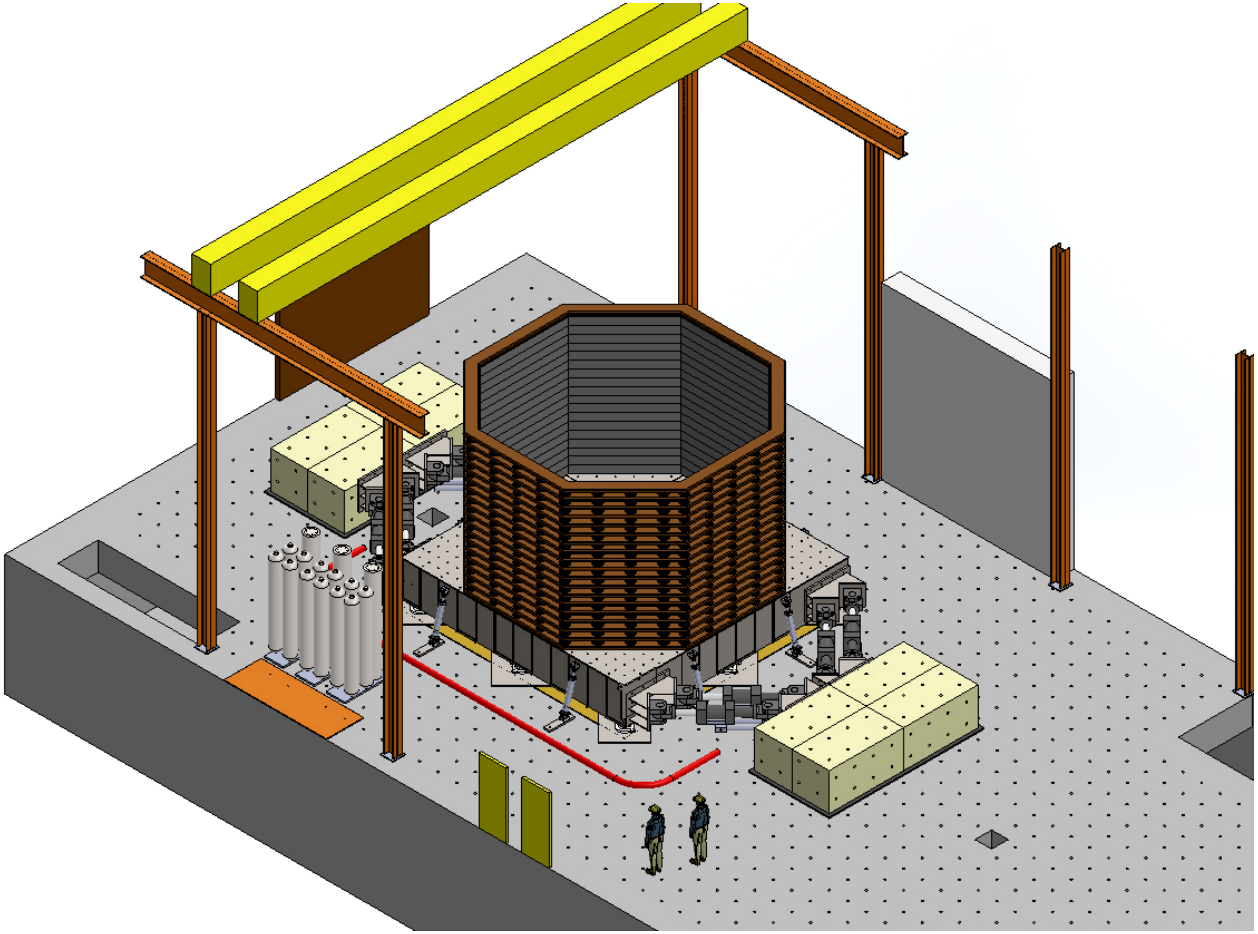
1. Despite accurate modelling of soil, small scale specimens mean structure models are not realistic.
2. Soil-structure-interaction experiments for nonlinear response not credible
3. Larger scale possible if a laminar soil box is used (mounted on a shake table)
4. But in-situ strength and stiffness of soil is not modelled correctly
5. Errors can be reduced by using as big-a-box-as-possible

Large laminar soil box (1)



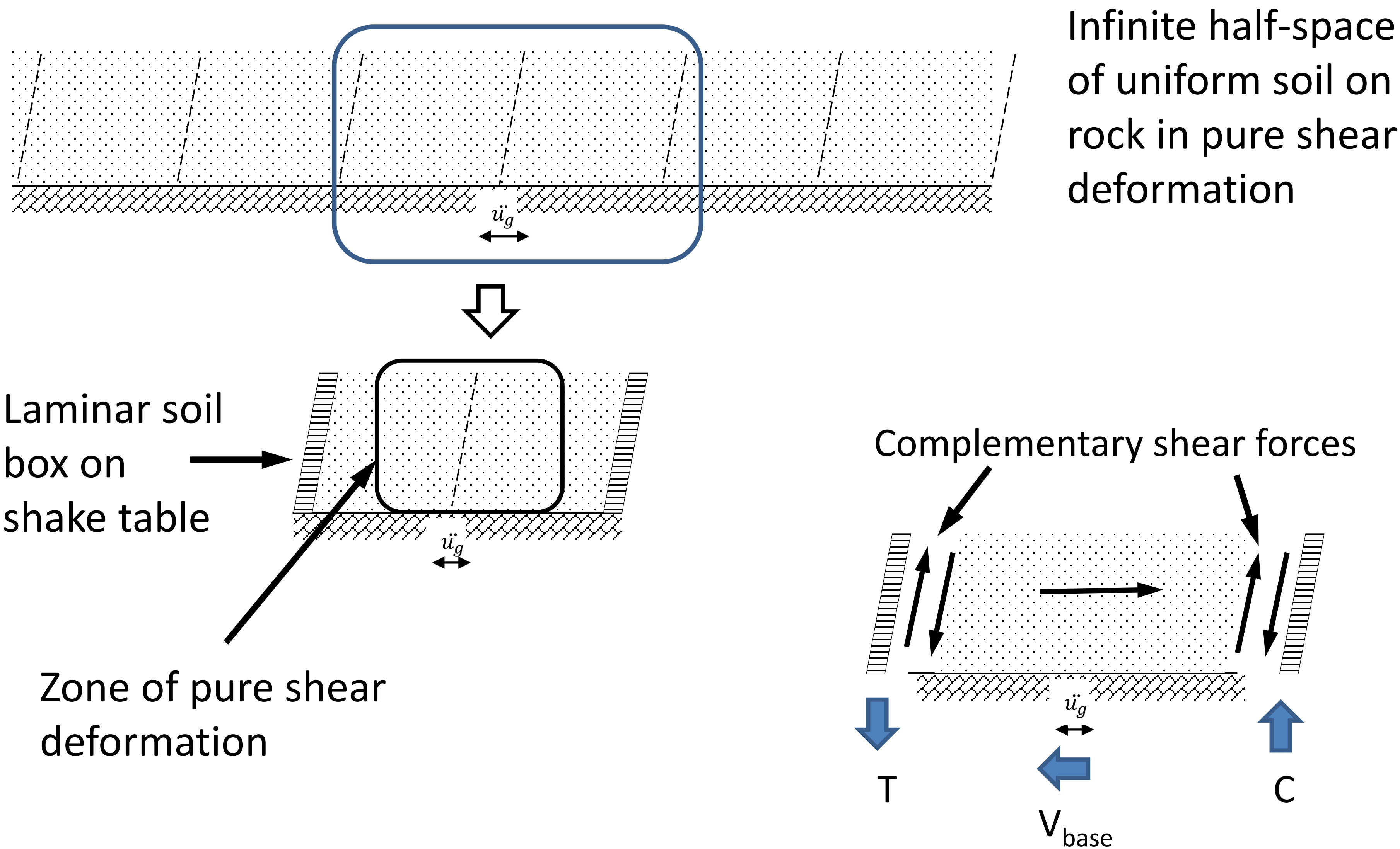
NIED Edefense Biaxial Soil Box, Miki, Japan, Completed 2004
6 m (H) x 8m diameter
600 ton capacity

Large laminar soil box (2)

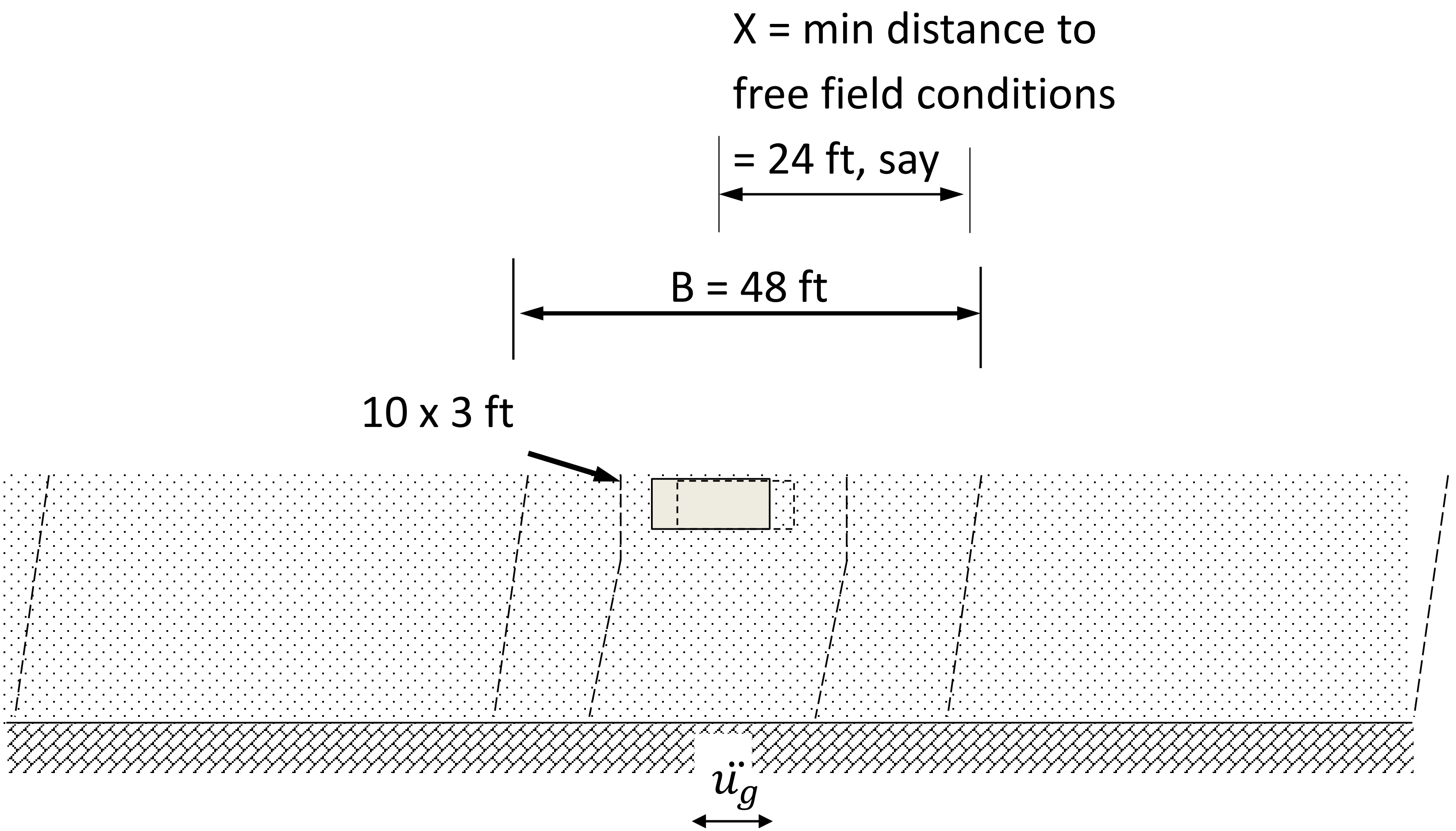


Biaxial Soil Box University of Nevada Reno, NV, USA
Under design: 4.6m (H) x 7m x 7m, 400 ton capacity

Soil box mechanics



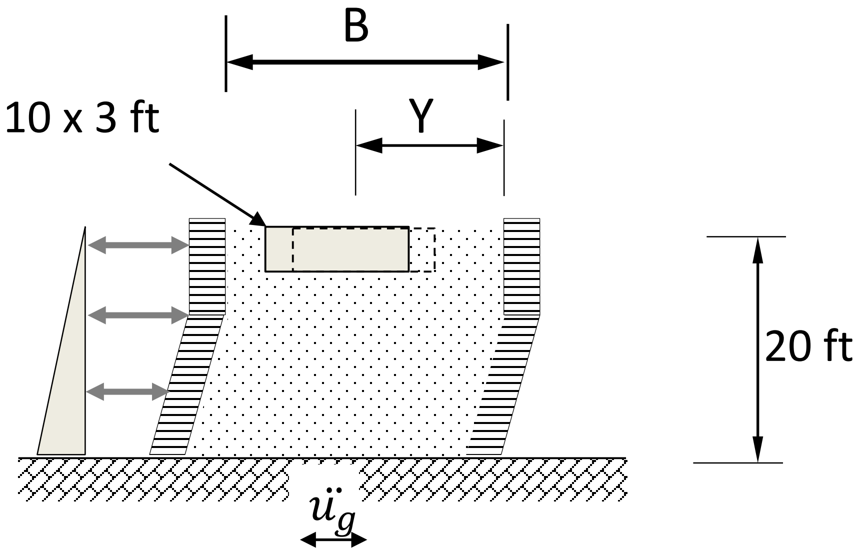
Soil box with embedded foundation

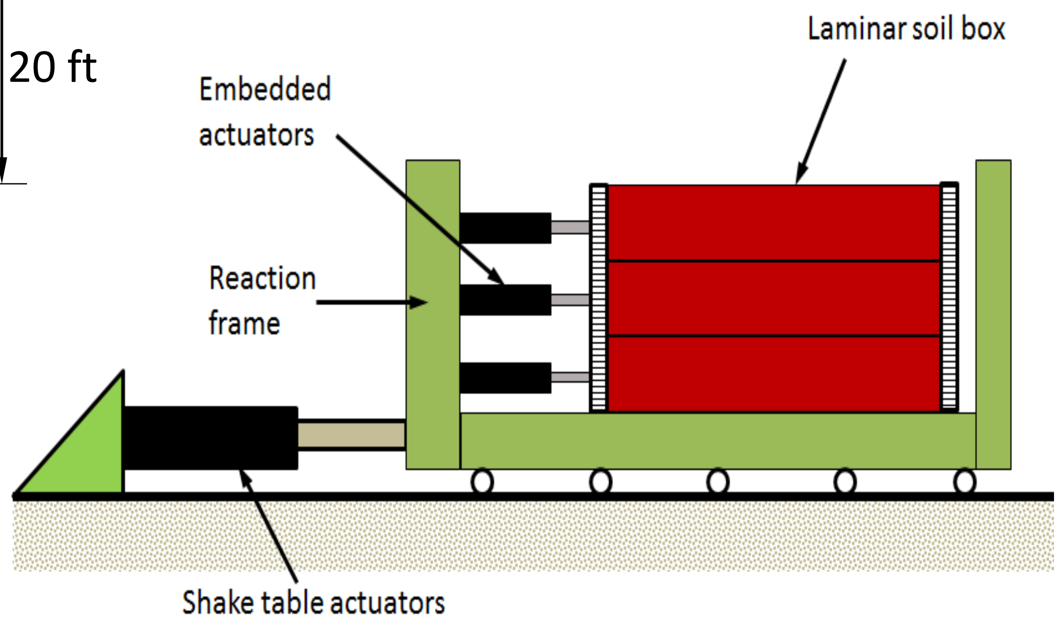


Soil box with active walls

If Y taken at 10 ft

then B = 2Y = 20ft,





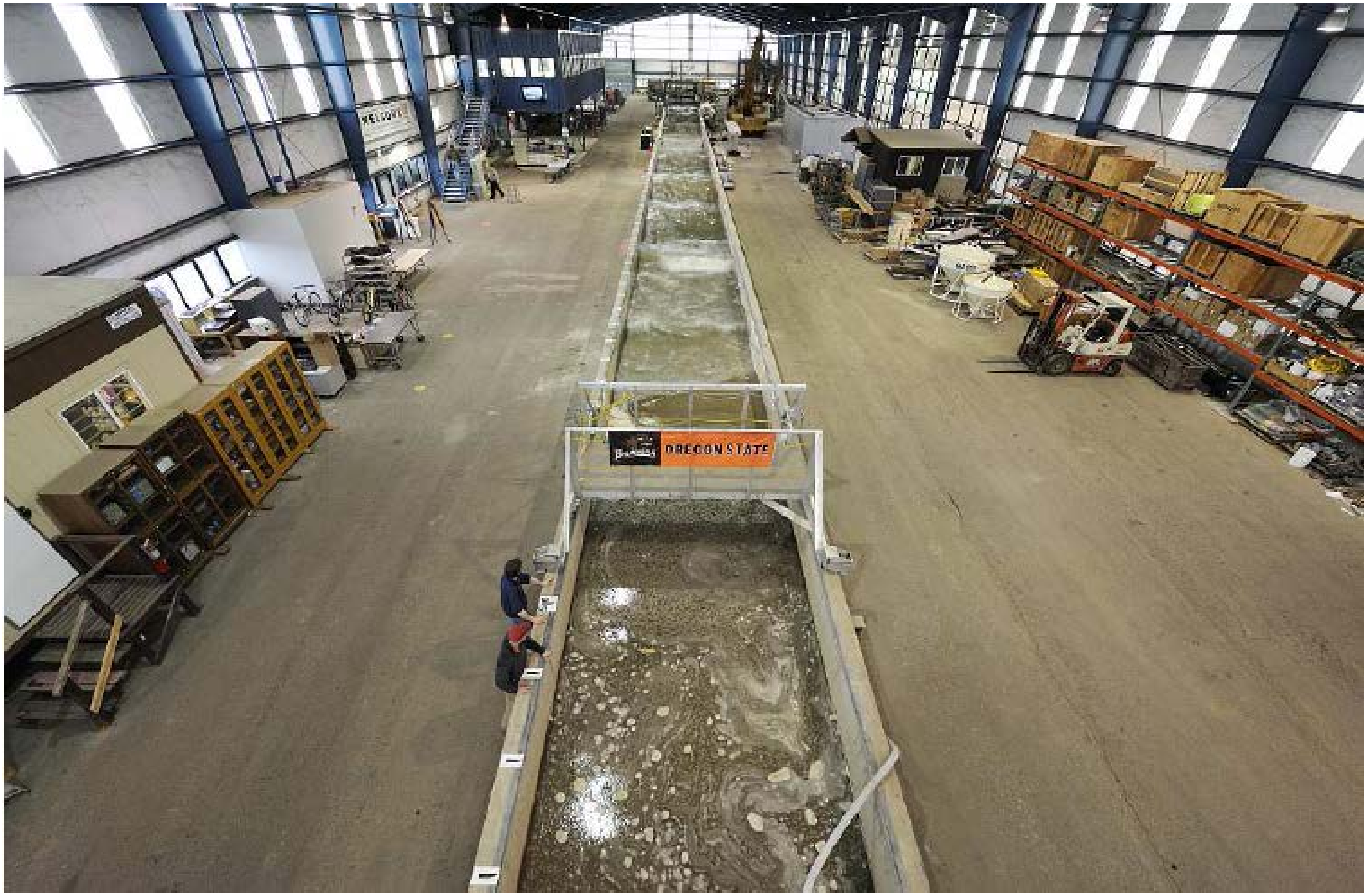
3. Wave basins and flumes (1)

NEHRI Wave Basin, Oregon State University, Corvallis
48.8m (L) x 26.5m (B) x 2.1m (D)

Challenges/innovations

1. Despite realistic modelling of wave, structural models are not realistic in most basins/flumes (rigid blocks often used)
2. Fluid-structure-interaction experiments are not credible.
3. Larger scale is possible using as big-a-basin or flume-as possible
4. But note, wave-makers in most flumes/basins not able to generate tsunami bores, only tsunami-like solitary waves (broken and unbroken)

Wave flumes and basins (2)

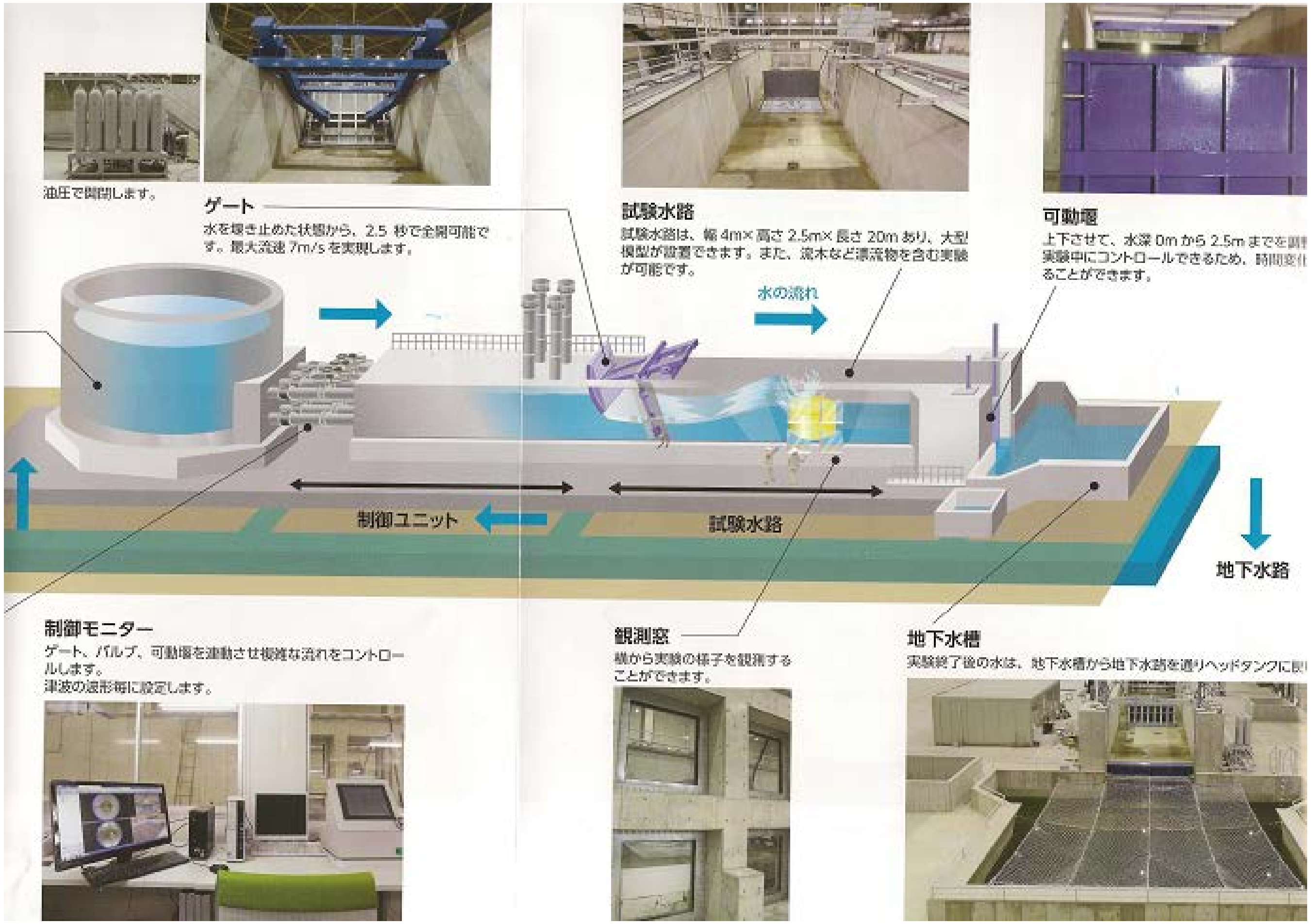


NEHRI Wave Flume, Oregon State University, Corvallis
104m (L) x 3.7m (B) x 4.6m (D)

Wave flumes and basins (3)

1:5 bridge model and solitary wave, NEHRI Wave Flume, OSU

Large-scale tsunami simulator (1)



CRIEPI Tsunami Facility, Abiko Campus, Chiba, Japan
20 m (L) x 4m (B) x 2.5m (D); 650 tons water

Large-scale tsunami simulator (2)

CRIEPI, Chiba, Japan

4. Measurement technologies

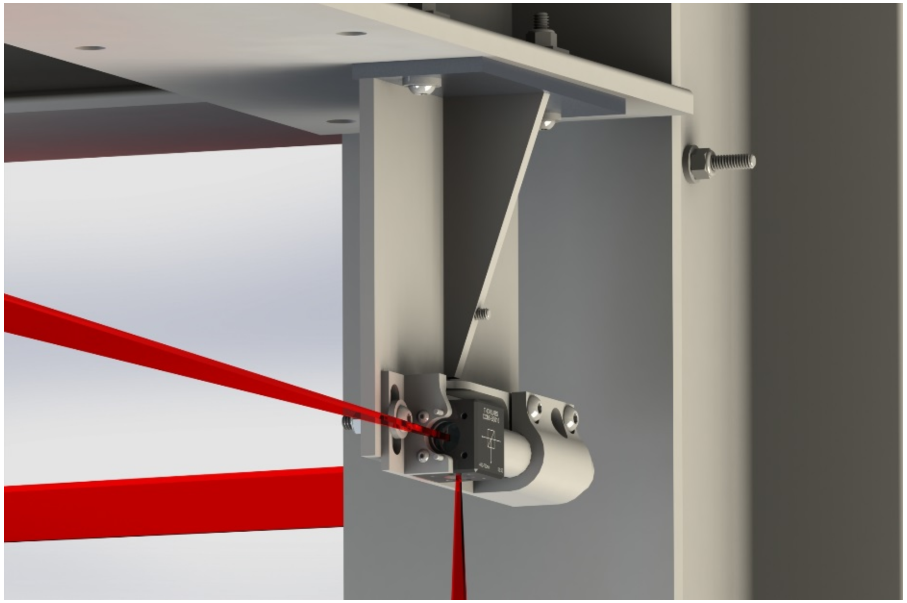
Cabling to accelerometers in trucks on 0.4-scale curved bridge model, University of Nevada Reno, NV, USA

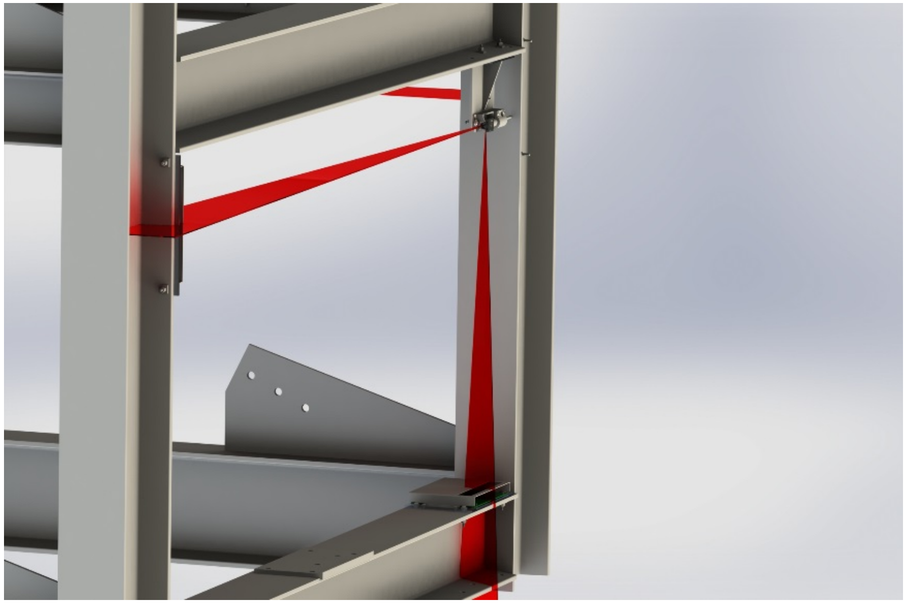
Challenge/innovations

Eliminate cabling by using:

a. Wireless transducers, or
b. Contactless instrumentation

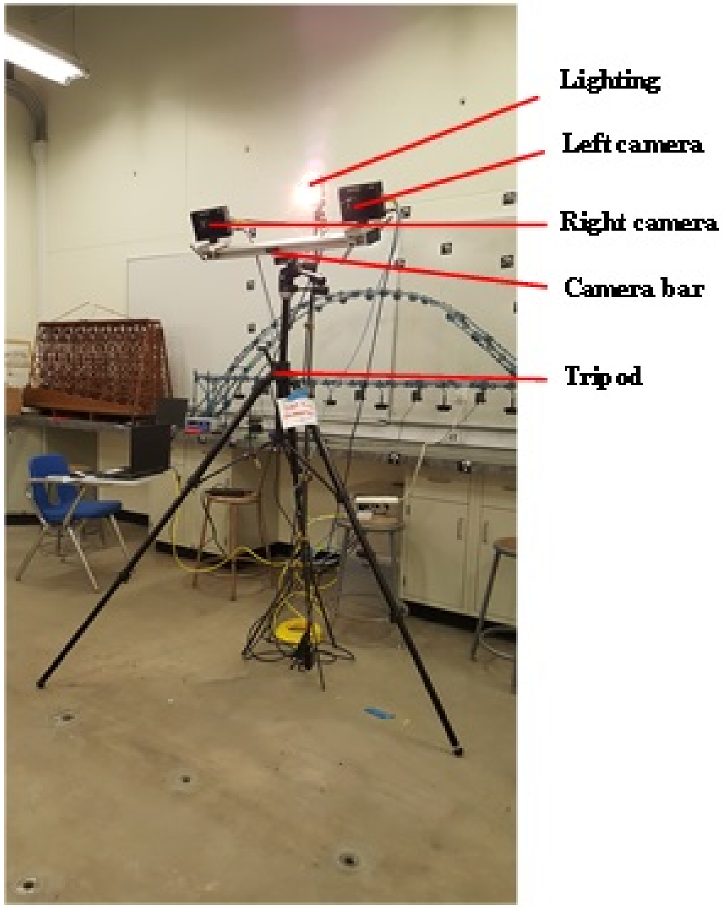
Wireless transducers

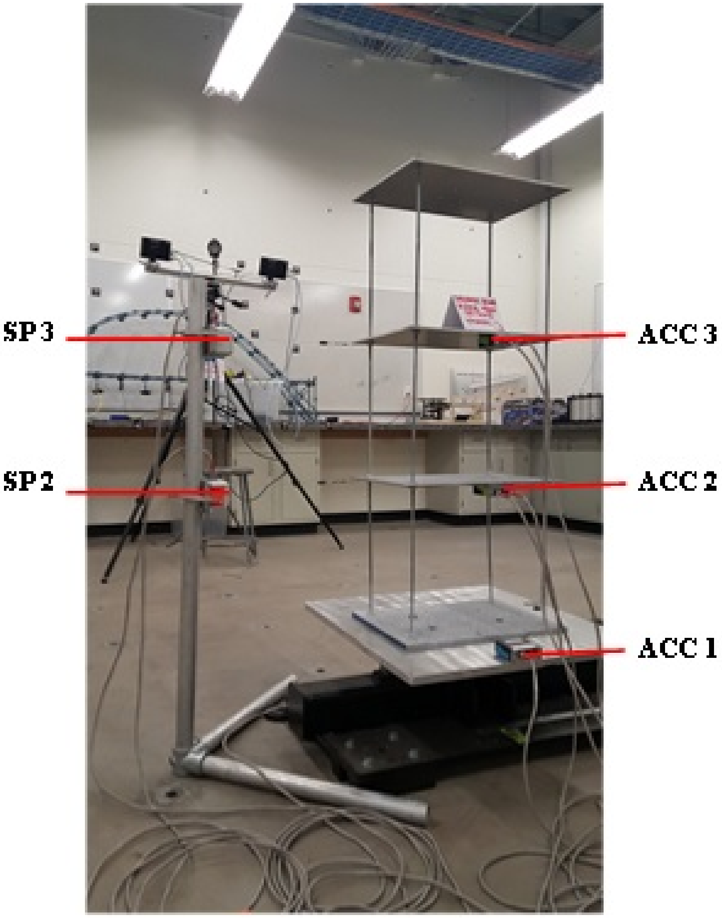




Optical sensors being used to measure interstory drift are monitored wirelessly using laboratory SCRAMNet, University of Nevada Reno, NV, USA

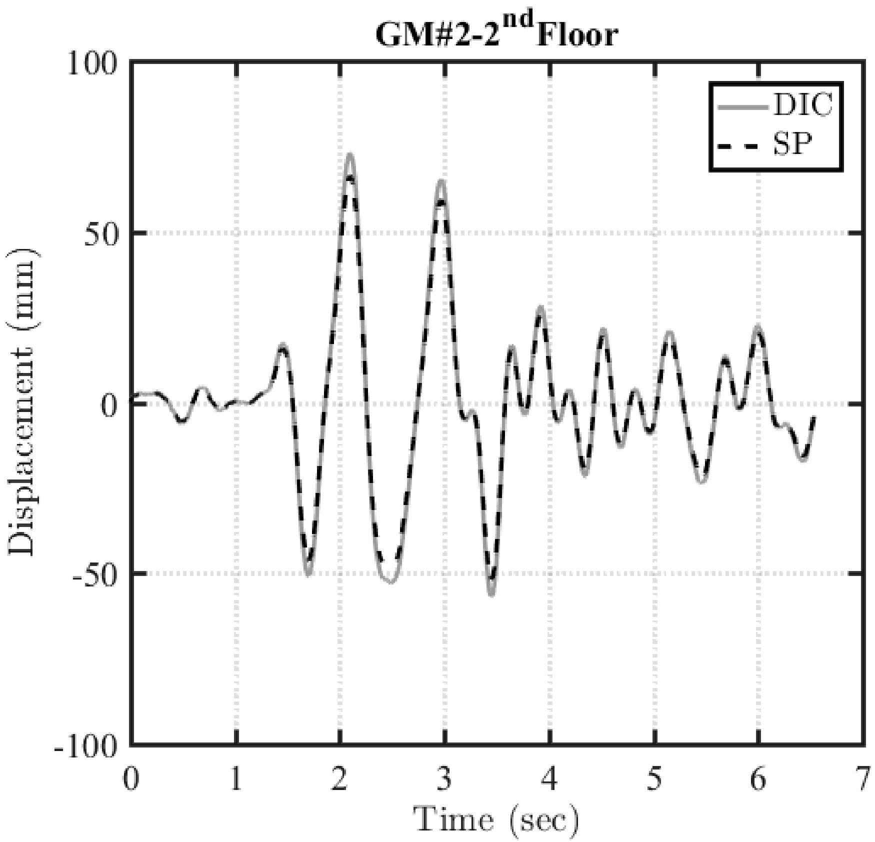
Contactless instrumentation (1)

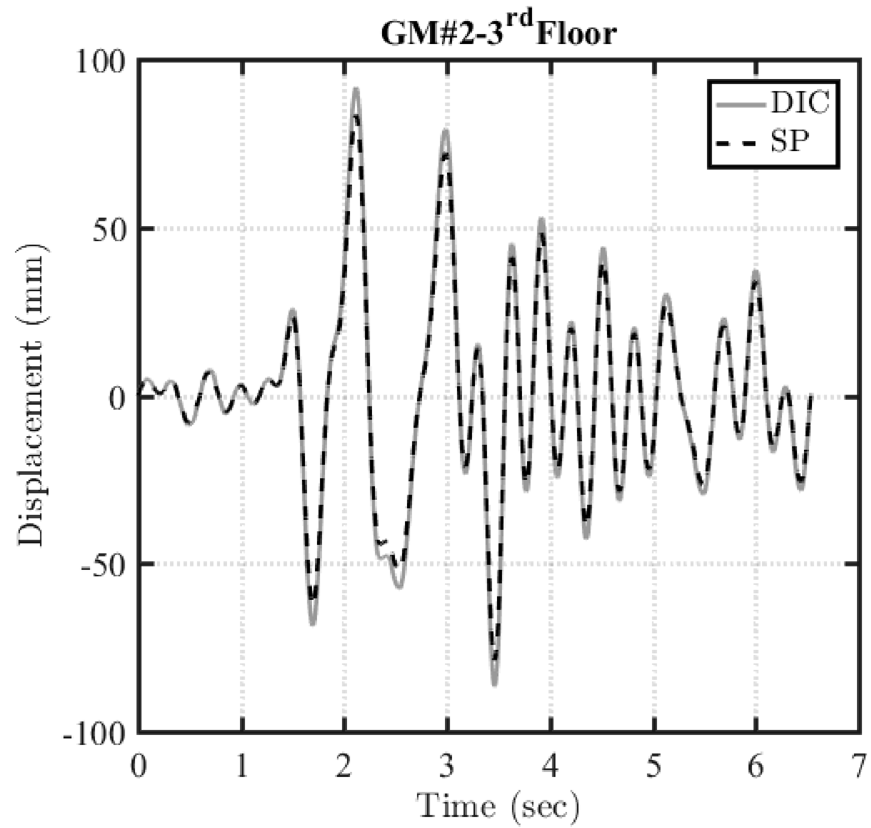




Digital Image Correlation technique being used to monitor response of small-scale, 3-story frame remotely, University of Nevada, Reno

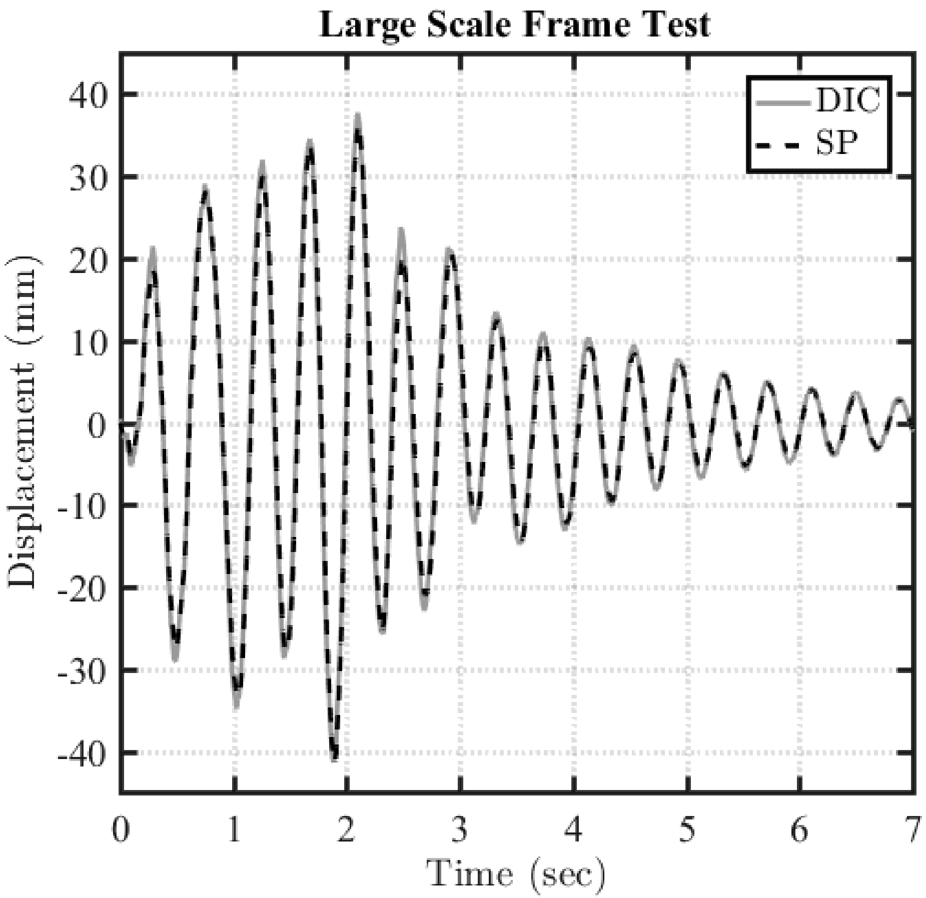
Contactless instrumentation (2)





Comparison of results from DIC and conventional measurements (string pots and accelerometers)

Contactless instrumentation (3)



Digital Image Correlation for monitoring large shake table tests at University of Nevada, Reno

Conclusions – experimental technologies

- To advance performance-based design, and both soil- and fluid-structure-interaction, experiments need to be at as large-a-scale-as possible
- But large-scale experiments are challenging and alternatives need to be explored
  - shake table arrays
  - advanced hybrid simulation, both conventional and real-time
  - smarter laminar soil boxes
  - modified wave-makers that can simulate 'dam break' at a lower cost
  - smarter instrumentation and DAQ systems for contactless imaging and visualization

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