Large Mobile Shakers for Natural Hazard Field Studies to Develop Resilient and Sustainable Infrastructure (Award CMMI-1520808)

Lead Institution:
The University of Texas at Austin (UT Austin)

Principal Investigator:
Dr. Kenneth H. Stokoe, P.E., NAE
UT Austin, Dept. of Civil, Architectural, and Environmental Engineering (CAEE)

Co-Principal Investigators:
Dr. Brady R. Cox, P.E.
UT Austin, CAEE

Dr. Patricia Clayton
UT Austin, CAEE

15 December 2015

NSF Engineering for Natural Hazards (ENH) Program

National Science Foundation
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Division of Civil, Mechanical and Manufacturing Innovation

Engineering for Natural Hazards (ENH)

CONTACTS

Name	Email	Phone	Room
Joy M. Pauschke	jpauschk@nsf.gov	(703) 292-7024	
Richard J. Fragaszy	rfragasz@nsf.gov	(703) 292-7011	

PROGRAM GUIDELINES

DUE DATES http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505177

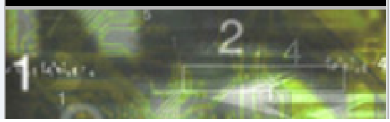
Full Proposal Window: February 1, 2016 - February 16, 2016
Proposals must be submitted by 5 p.m. proposer's local time on February 16, 2016;
February 1 - February 15, Annually Therafter

Natural Hazards Engineering Research Infrastructure (NHERI)

7 Experimental Facilities (EF's) with Large-Scale Equipment

1 Cyberinfrastructure Facility for Archiving and Sharing Data

Funding



Division of Civil, Mechanical and Manufacturing Innovation

Engineering for Natural Hazards (ENH)

While the ENH program supports research that utilizes the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) cyberinfrastructure and earthquake and wind engineering experimental facilities, it also supports research that does not require the use of NHERI. NHERI resources are the following:

- Cyberinfrastructure at the University of Texas at Austin;
- Twelve-Fan Wall of Wind at Florida International University;
- Large-Scale, Multi-Directional, Hybrid Simulation Testing Capabilities at Lehigh University;
- Large Wave Flume and Directional Wave Basin at Oregon State University;
- Geotechnical Centrifuges at the University of California, Davis;
- Large, High-Performance Outdoor Shake Table at the University of California, San Diego;
- Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators at the University of Florida; and
- Large, Mobile Dynamic Shakers for Field Testing at the University of Texas at Austin.

NHERI@Utexas Project Team

Director/PI
Kenneth Stokoe
Professor, UT Austin

Co-PI
Brady Cox
Assoc. Professor, UT Austin

Co-PI
Patricia Clayton
Asst. Professor, UT Austin

Senior Personnel
Sharon Wood
Dean & Prof., UT Austin

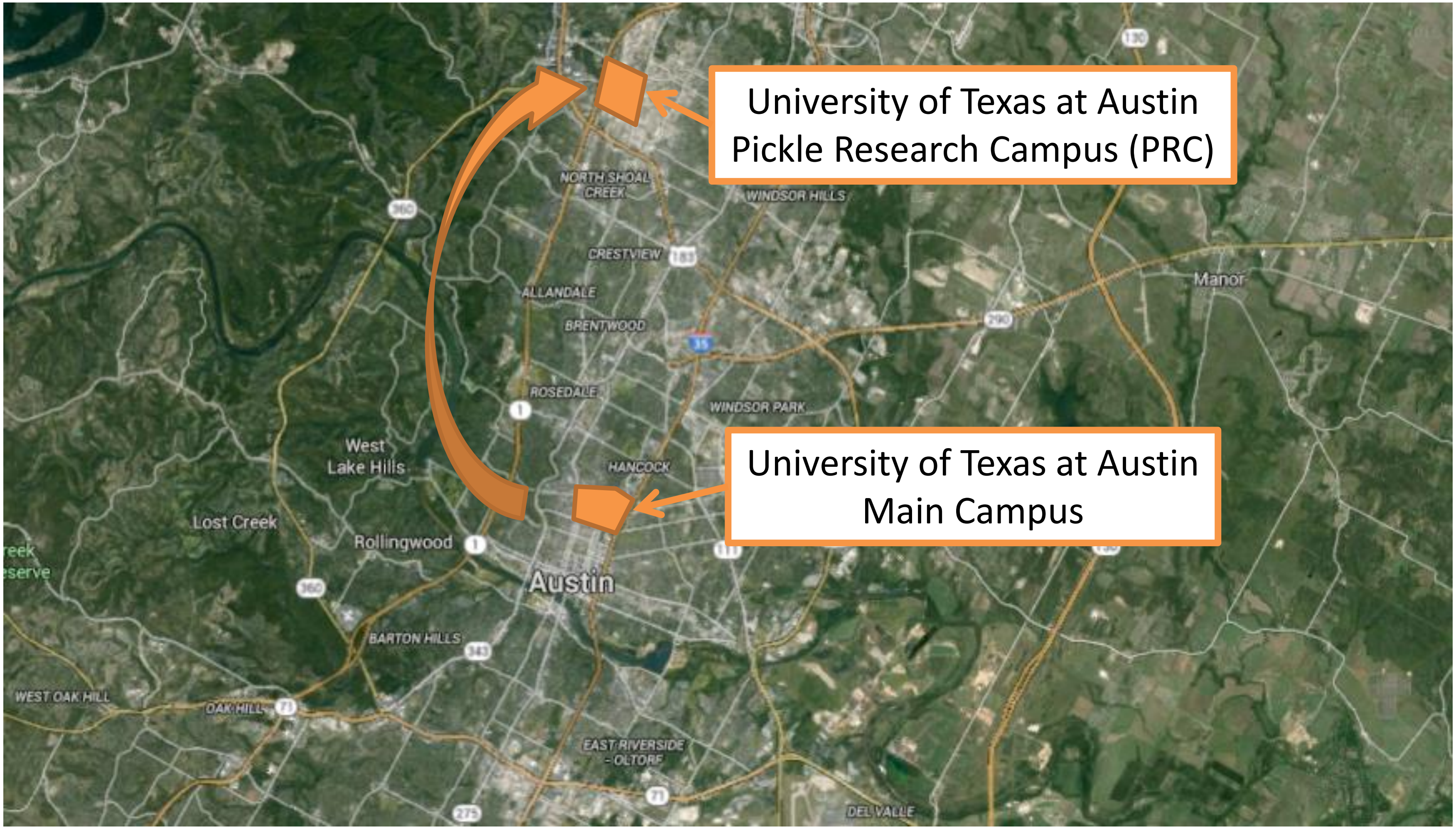
IT/Cybersecurity
Robert Kent
UT Austin

Operations Manager
Farnyuh Menq
UT Austin

Mobile Shaker Specialist
Cecil Hoffpauir
UT Austin

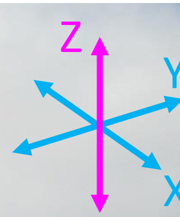
Hydraulics Technician
Andrew Valentine
UT Austin

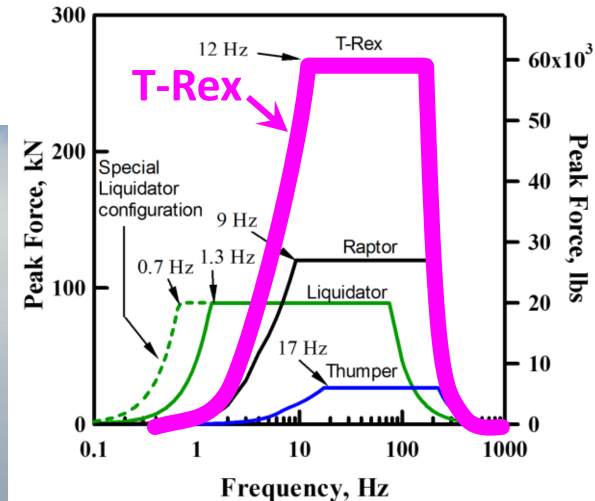
NHERI@UTexas Facility



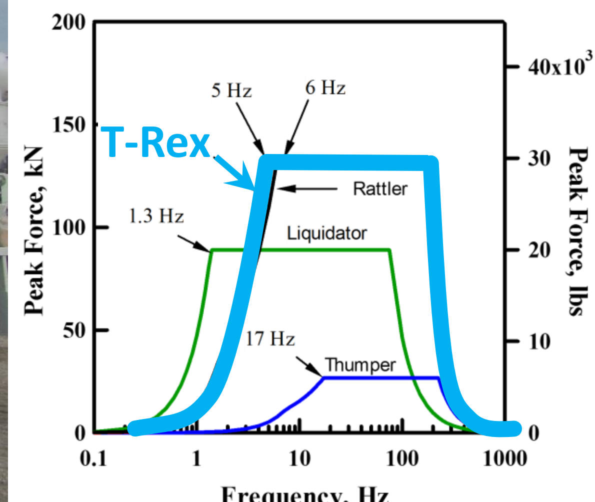
T-Rex

- Tri-axial shaker
- Push-button transformation of shaking orientation
- 32 ft long, 8 ft wide, Wt. = 64,000 lbs
- Only operating tri-axial vibroseis we are aware of in the world





Vertical force output

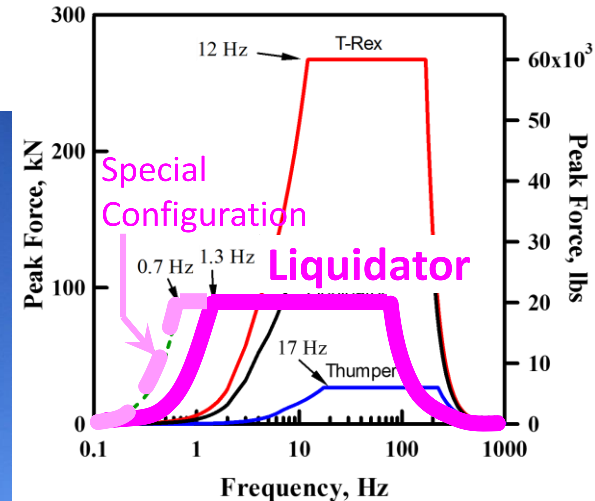


Horizontal force output

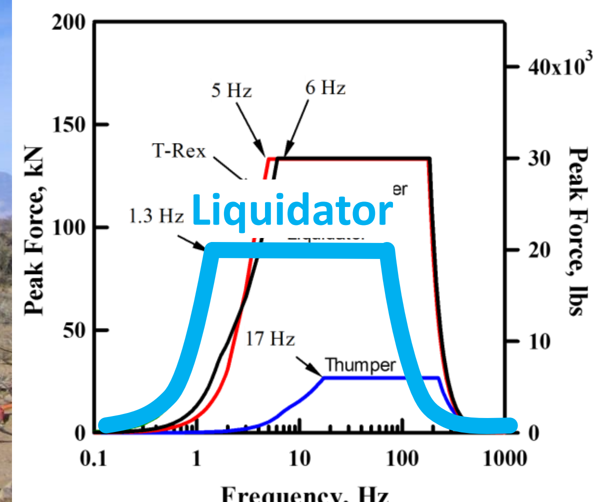
T-Rex – Vertical Shaking

Liquidator

- Custom-built, one-of-a-kind, low frequency shaker
- Two-shaking orientations
- One-day shop transformation of shaking orientation
- 32 ft long, 8 ft wide, Wt. = 72,000 lbs



Vertical force output



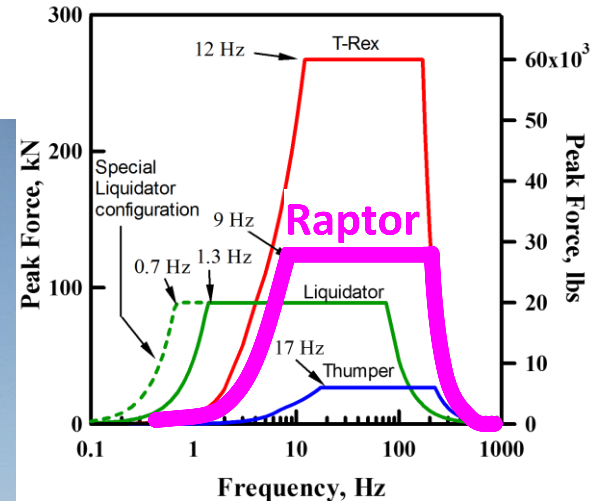
Horizontal force output

Liquidator – Standard Configuration

Liquidator – Special Configuration

Raptor

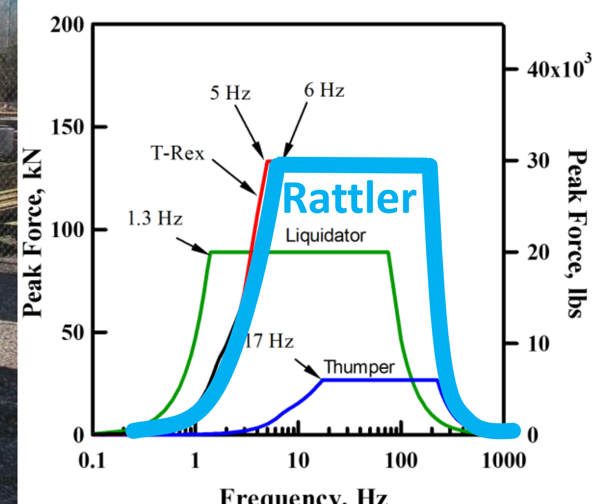
- Standard vibroseis, vertical shaker (P-wave)
- 32 ft long, 8 ft wide, Wt. = 41,200 lbs



Vertical force output

Rattler

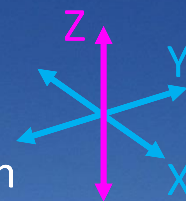
- Standard vibroseis, horizontal shaker (S-wave)
- 29 ft long, 8.5 ft wide, Wt. = 30,000 lbs

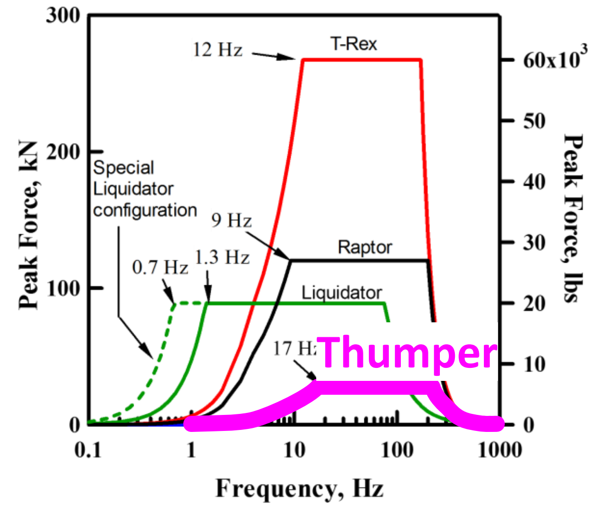


Horizontal force output

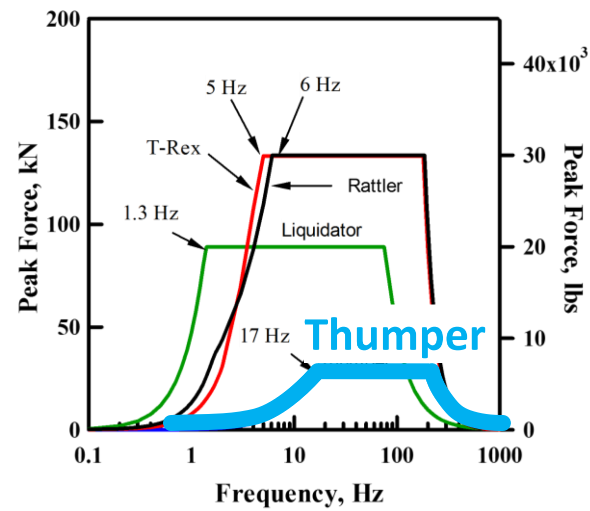
Thumper

- Mini-vibroseis/urban shaker
- Three vibrational orientations
- Two-hour field transformation of shaking orientation
- 27 ft long, 8.5 ft wide, Wt. = 28,400 lbs.





Vertical force output



Horizontal force output

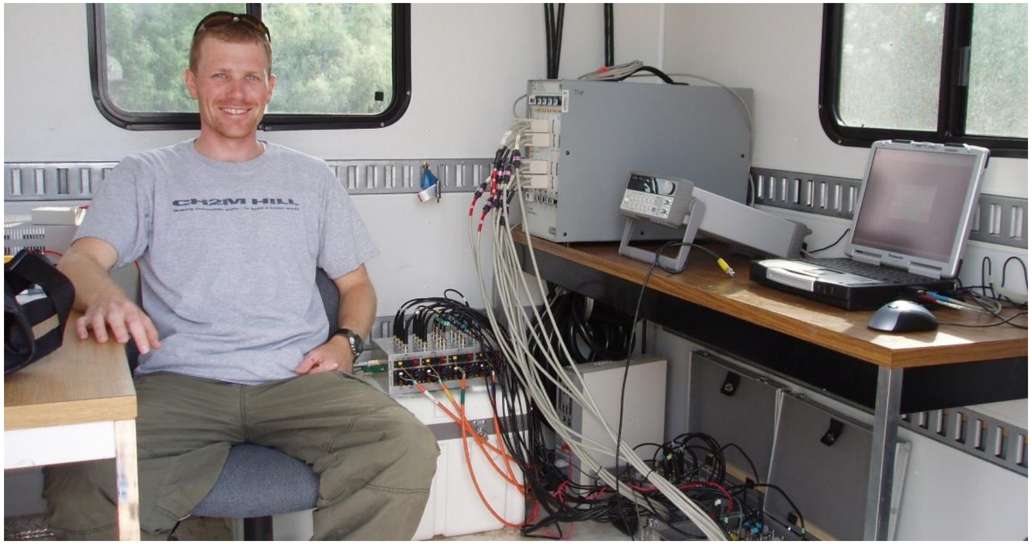
Big Rig

- 26-wheel tractor trailer for shipping T-Rex, Liquidator, and Rattler

Support Vehicles

Provide fuel, storage, and workspace in the field

Instrumentation – Data Acquisition (DAQ)



72-channel VXI DAQ

- 24 bit digitizer
- Up to 50 kHz sampling rate
- Real-time frequency domain capabilities

↓

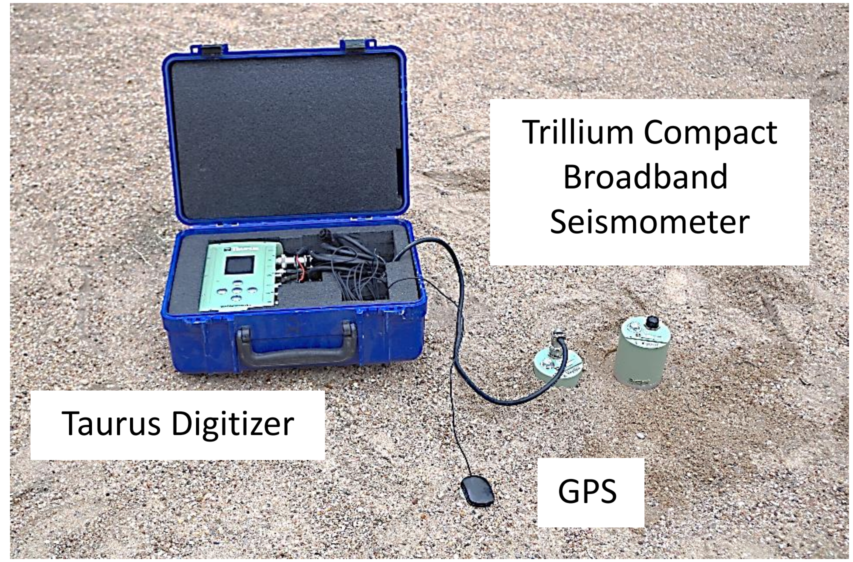
136 channels of DAQ

↑

64-channel Data Physics DAQ

- 24 bit digitizer
- Up to 200 kHz sampling rate
- Real-time frequency domain capabilities

Instrumentation – Sensors



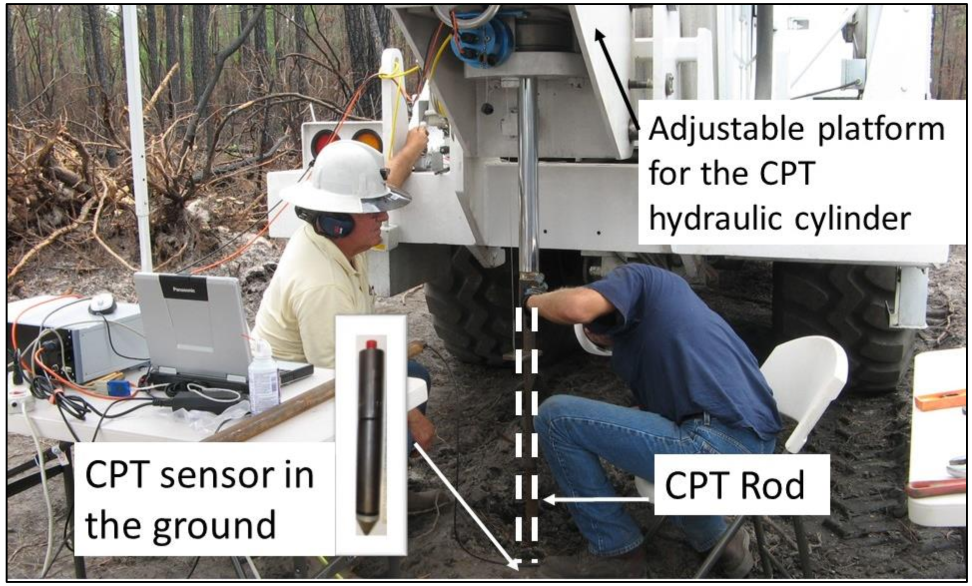
<u>109, 1-Hz Geophones</u>

- 85 vertical & 24 horizontal
- 15,000 ft of cable

<u>10, Nanometrics Broadband Seismometer Stations</u>

- 3-component, GPS synchronized
- 120-sec period Trillium Compact seismometers
- Flat response 0.01 to 100 Hz
- Taurus digitizers (24 bits)
- Structural and Geotechnical applications

Instrumentation – CPT and Liquefaction Sensors



Direct-Push Sensors

Cone Penetrometers

- Standard CPT
- Seismic CPT
- 4 different cones

Liquefaction Sensors

- Custom built
- Tri-axial MEMS accelerometers
- 2D or 3D geophones
- Pore water pressure transducers

Additional Instrumentation Resources

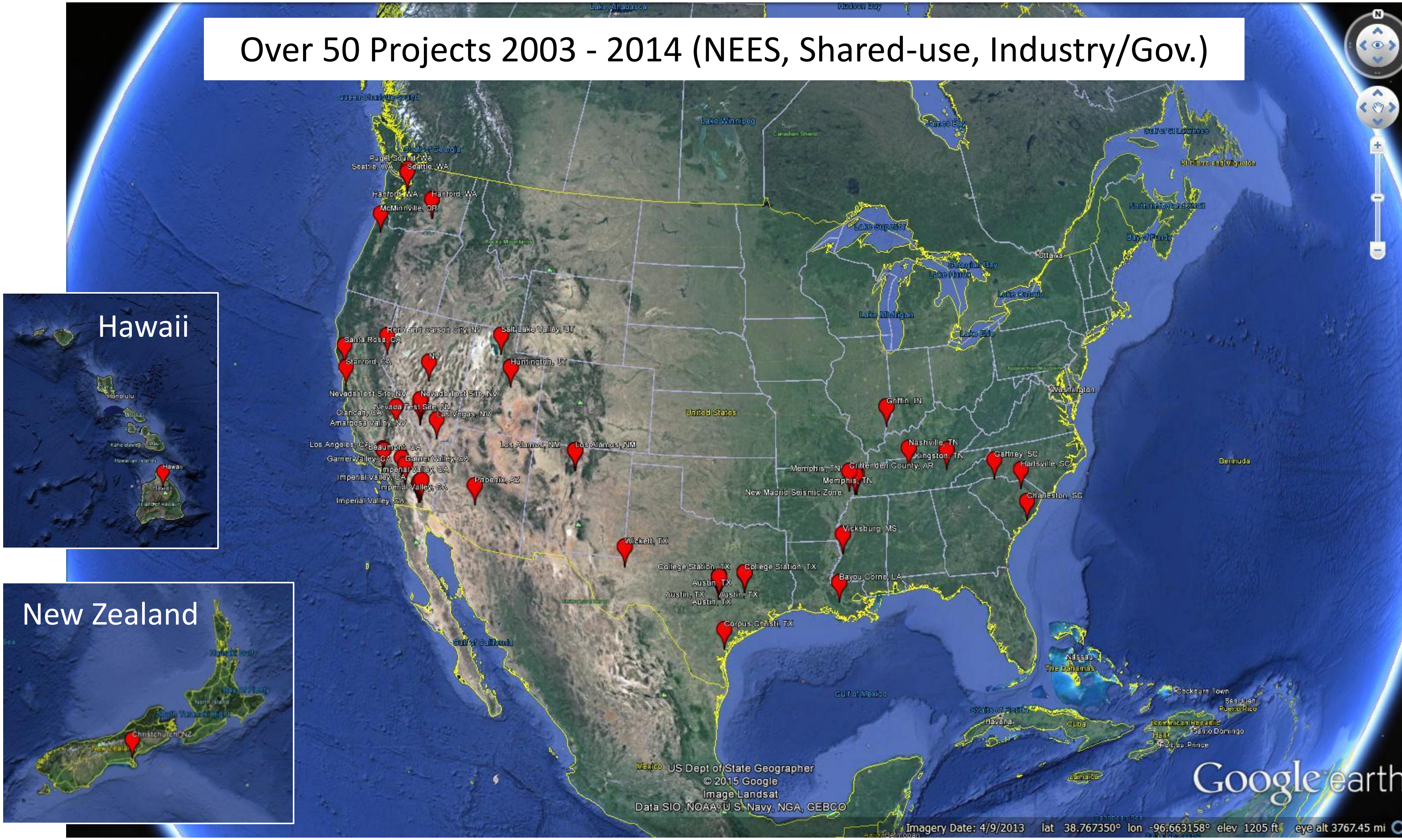
- IRIS/PASSCAL

Free to NSF-funded projects
*PI pays for shipping & travel expenses

- (35) 3D accelerometers
- Digitizers
- Field support
- and more…

"Have shaker trucks, will travel…"

Over 50 Projects 2003 - 2014 (NEES, Shared-use, Industry/Gov.)



T-Rex:

1.
Liq. Demo
SAGEEP
S. Carolina

2.
Explore UT
Austin
Texas

3.
Deep
Downhole
PNNL, WA

4.
Hoodoos
LANL
N. Mexico

5.
MSW
Landfill
Los Angeles

Thumper:

1.
Vs Profile
Mauna Kea
Hawaii

2.
Topo. Amp.
Deer Creek
Utah

3.
Hispanic
Eng. Week
South TX

4.
Geophysics
Sum. Camp
Colorado

5.
Vs Profile
Stanford U.
California

Liquidator:

1.
Deep Vs
Yucca Mtn.
Nevada

2.
Deep Vs
Mississippi
Embayment

3.
Deep Vs
Salt Lake
Valley
Utah

4.
Deep Vs
Hanford
PNNL, WA

5.
Deep Vs
Palo Verde
NPP
Arizona

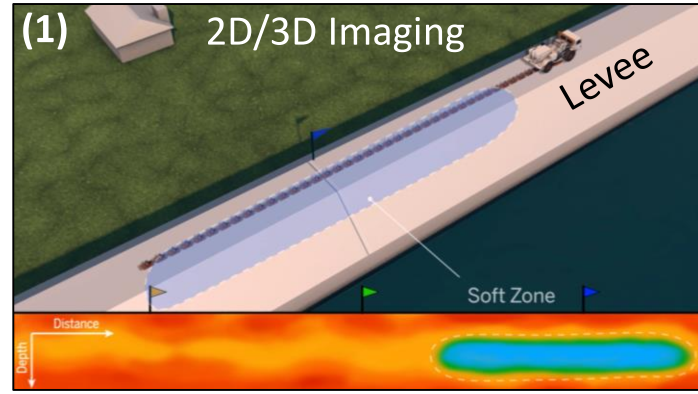
NHERI@UTexas
Marketing and Science Plan

Intellectual Merits

NHERI@UTexas will contribute ***unique, literally one-of-a-kind,*** large, mobile dynamic shakers and associated instrumentation to study and develop novel, ***in-situ testing*** methods that can be used to both evaluate the needs of ***existing infrastructure*** and optimize the design of ***future infrastructure*** under ***actual field conditions***, such that our communities become more resilient to earthquakes and other natural hazards. While there is a great deal to be learned from small- to large-scale laboratory testing, we feel strongly that in-situ experimental testing capabilities are needed in NHERI in order to develop the ***transformative tools needed for the next frontier of resilient and sustainable natural hazards research***.

Proof-of-Capability Workshops

- 3 field tests planned in Year 1
  - Each test aligned with one of three main areas in our Science Plan:
    - (1) Subsurface Imaging (2D/3D)
    - (2) In-situ Liquefaction/Nonlinear Testing
    - (3) Structural Health Monitoring/SFSI
  - Strategic locations across the country (e.g., levee imaging in New Orleans or Sacramento)



Proof-of-Capability Workshops cont…

- Marketing to broaden the user base
  - Familiarize potential users with NHERI@UTexas capabilities
  - Invite all interested parties (Gov/Academia/Industry)
  - Publicize through professional societies and popular media
  - Data and metadata posted to NHERI-CI (open access)
  - Generate preliminary proposal data

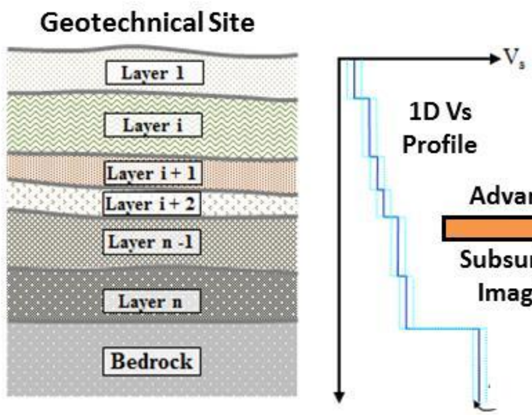
Science Plan #1:

Performing deeper, more accurate, higher resolution, 2D/3D subsurface geotechnical imaging

a. Ultrasound of the Past

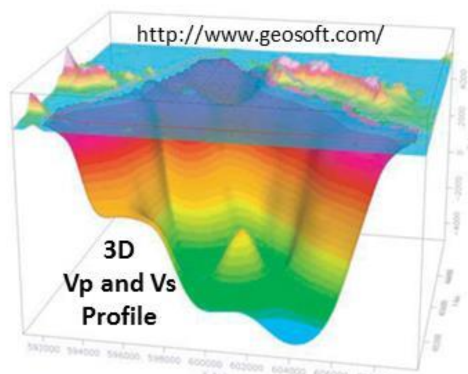
Advanced Medical Imaging

b. Ultrasound of the Present



c. 1D Geotechnical Imaging of the Present

Advanced Subsurface Imaging



d. 3D Geotechnical Imaging of the Future

Retrieve:

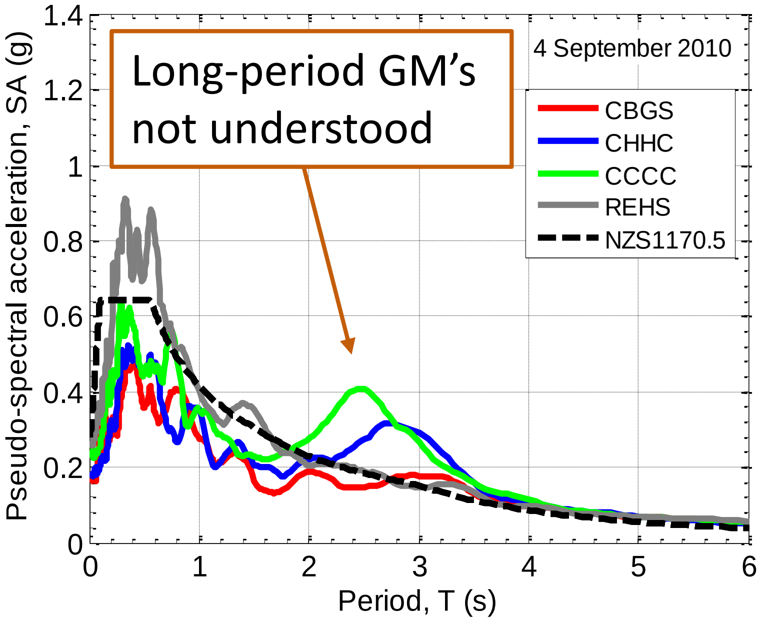
- Shear Wave Velocity (Vs)
- P-wave Velocity (Vp)

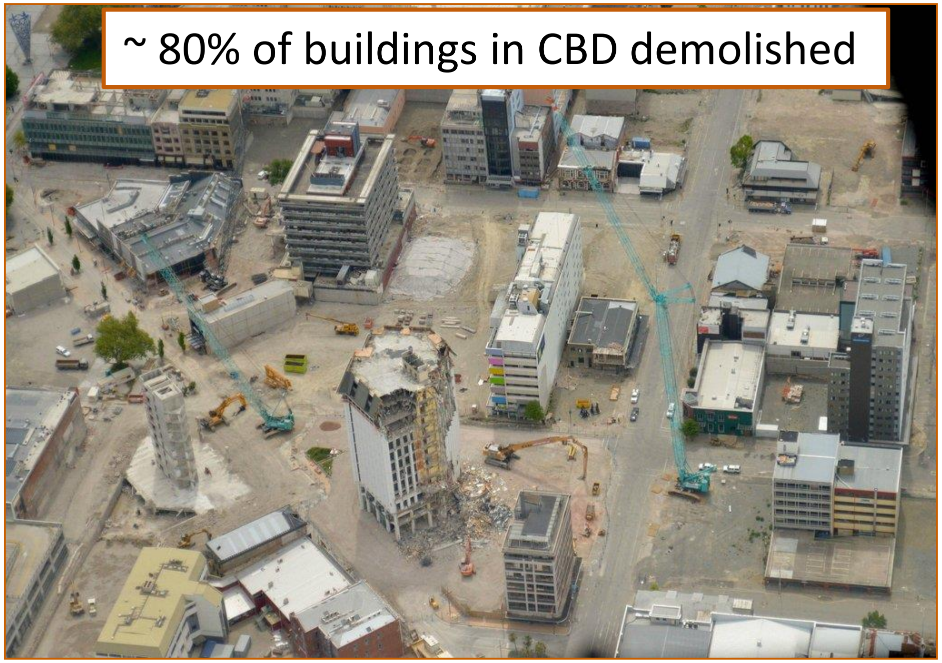
for direct determination of elastic moduli needed in engineering analyses

NEES@UTexas Project Highlight

"RAPID: Deep Shear Wave Velocity Profiling for Seismic Characterization of Christchurch, NZ - Reliably Merging Large Active-Source and Passive-Wavefield Surface Wave Methods"

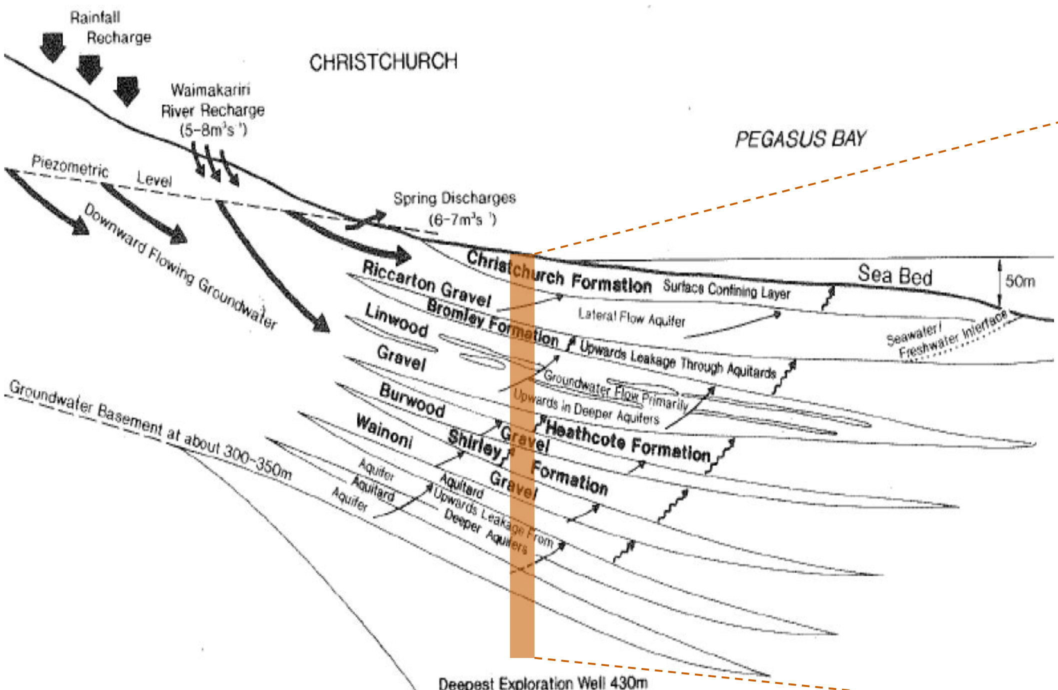
(CMMI-1303595)



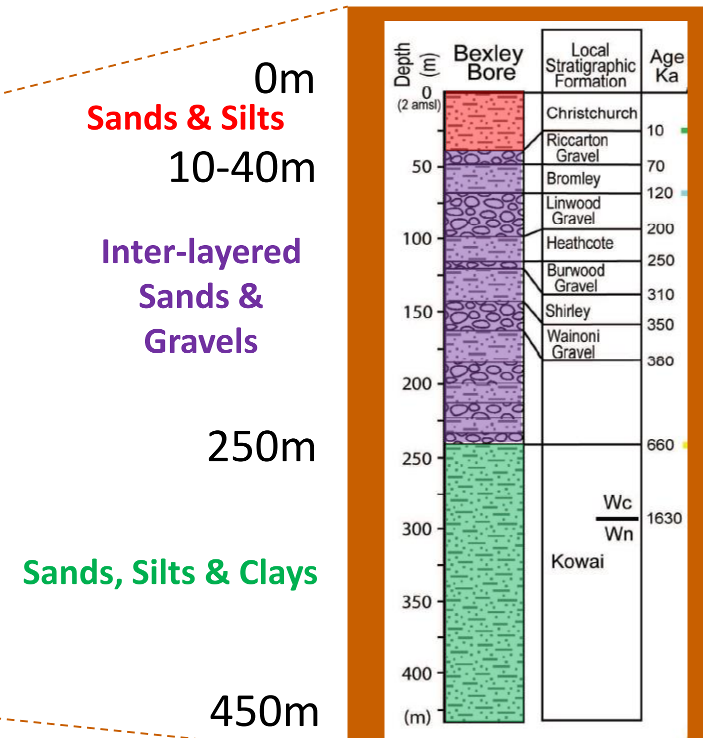


Complex Subsurface Conditions & Deep Bedrock

- Geotechnical investigations do not extend past Riccarton Gravel layer (artesian aquifer) at 10 – 40 m
- Result: no detailed Vs profiles deeper than 40 m in Christchurch
- Deepest well in city ~ 450 m … still no bedrock



(after Brown and Weeber 1992)



(after Brown 1998 and Barnes 2012)

T-Rex in Christchurch

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

NSF

EQC

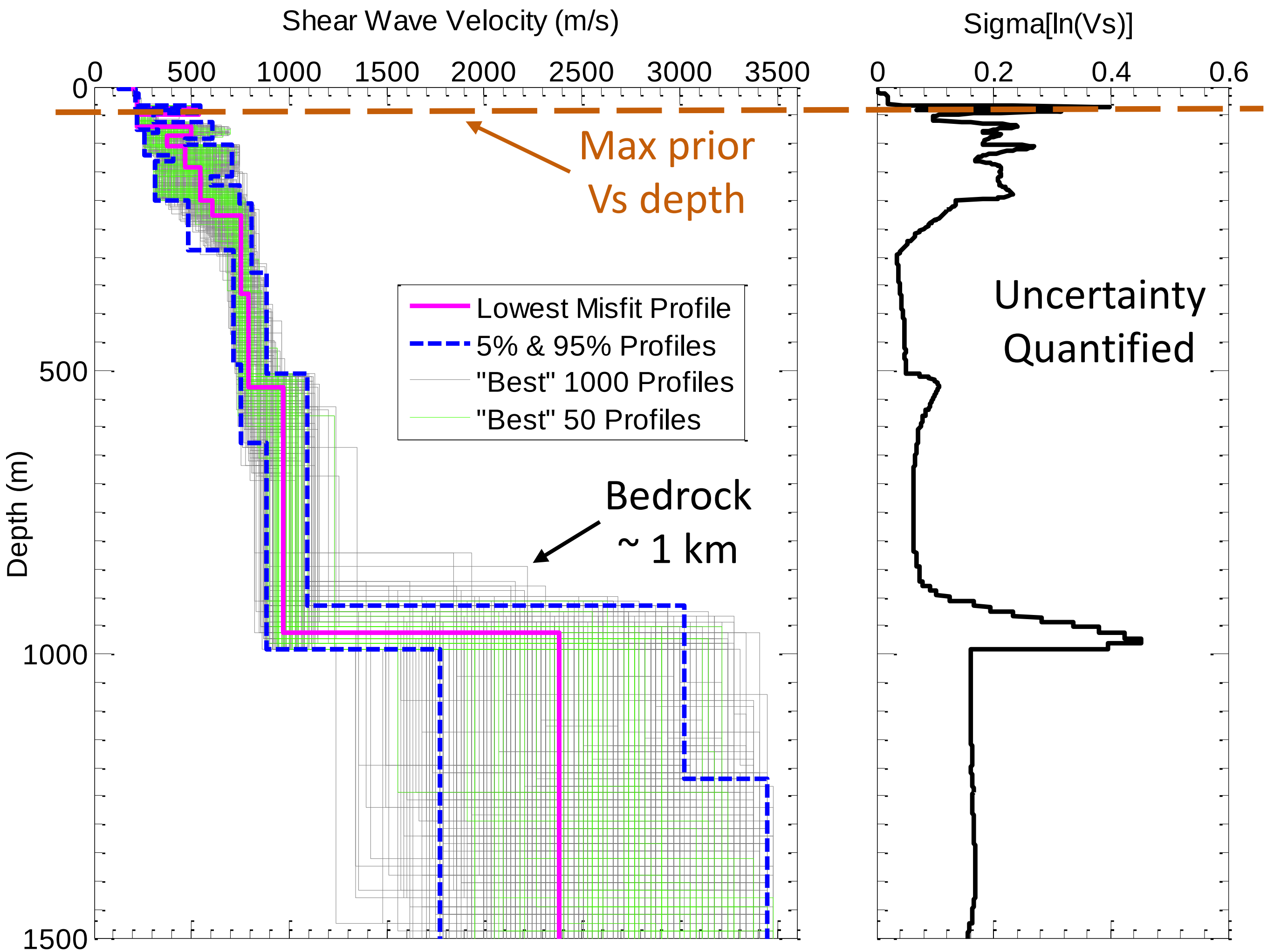
- Shipped from Texas to Christchurch in Feb. 2013

Combined Active-Source & Ambient-Wavefield Surface Wave Testing

Reliable 1D Vs Profiles to Record Depths

<u>Inversion Process</u>

- Analysis took weeks for each site
- Millions of models searched via Monte-Carlo/ Neighborhood algorithms
- Hours of computer time followed by user scrutiny, model adjustment, repeat inversion

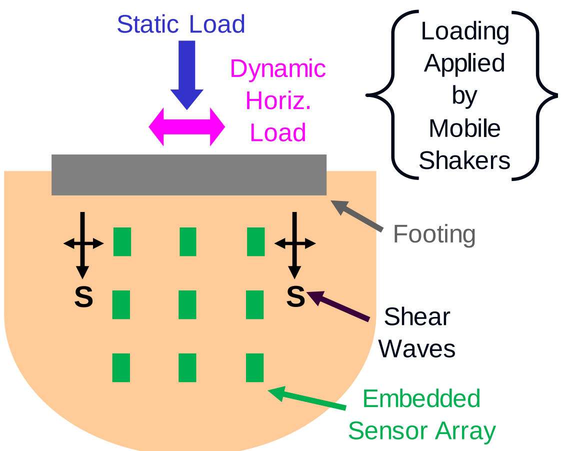


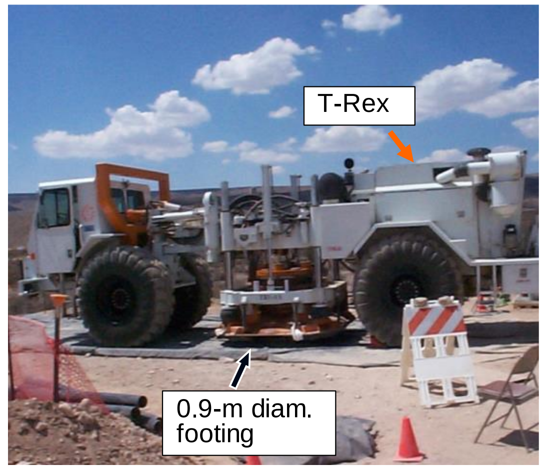
Vision for High-Resolution 2D/3D Imaging

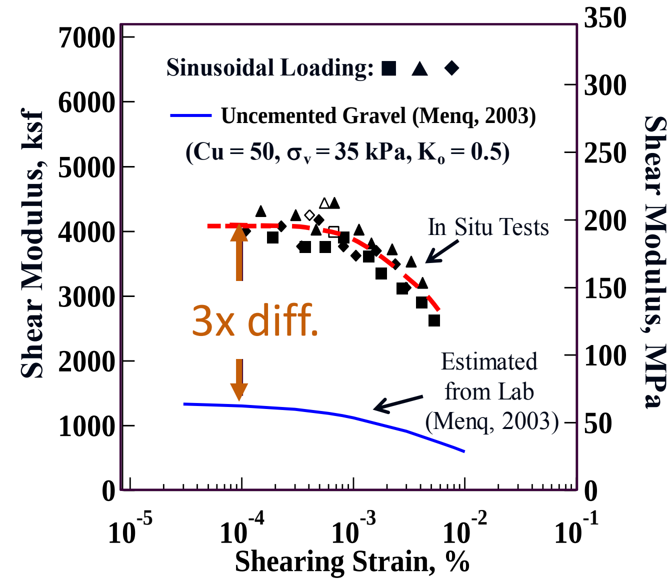
Pseudo 2D Subsurface
Seismic Imaging

Science Plan #2:

Characterizing the nonlinear dynamic response and liquefaction resistance of complex geomaterials **in situ**







Determine nonlinear relationship between:

- Shear modulus and shear strain
- Constrained modulus and axial strain
- Pore water pressure generation and shear strain

for use in static (settlement) and dynamic (site response) engineering analyses

In-Situ Nonlinear Geotechnical Testing

Shallow In Situ Non-linear Testing
of Liquefiable Soils

NEES@UTexas Project Highlight

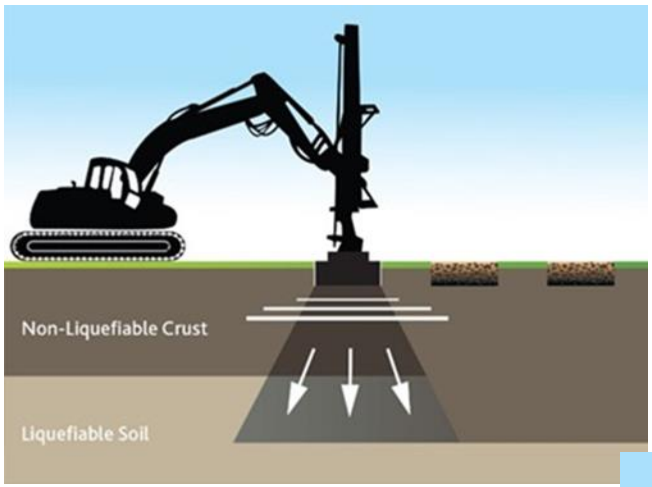
"Field Investigation of Shallow Ground Improvement Methods for Inhibiting Liquefaction Triggering; Christchurch, New Zealand" (CMMI-1343524)

10,000 RESIDENTIAL PROPERTIES MORE VULNERABLE TO LIQUEFACTION DAMAGE IN FUTURE EARTHQUAKE EVENTS

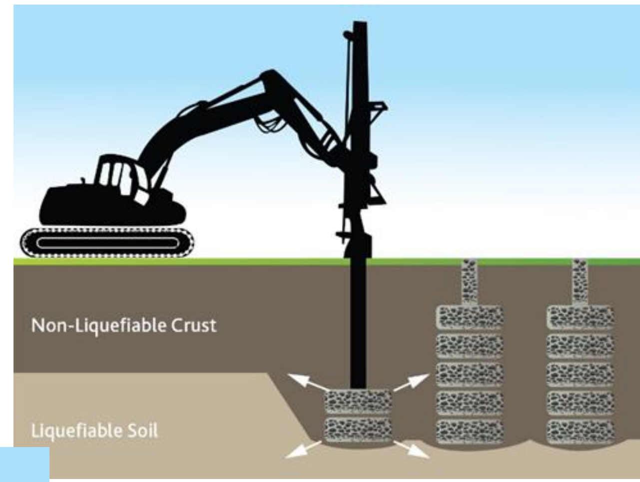
NZ EQC Ground Improvement Trials

Objective: Rebuild Christchurch with Affordable Resilience

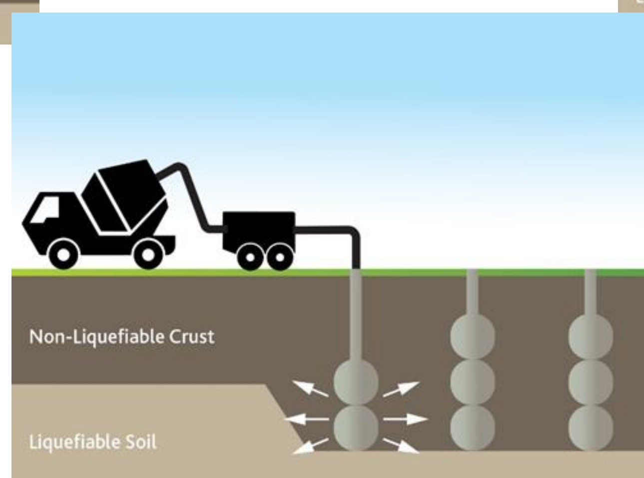
Techniques for "green" sites or demolished home sites



▲ **Rapid Impact Compaction (RIC)**

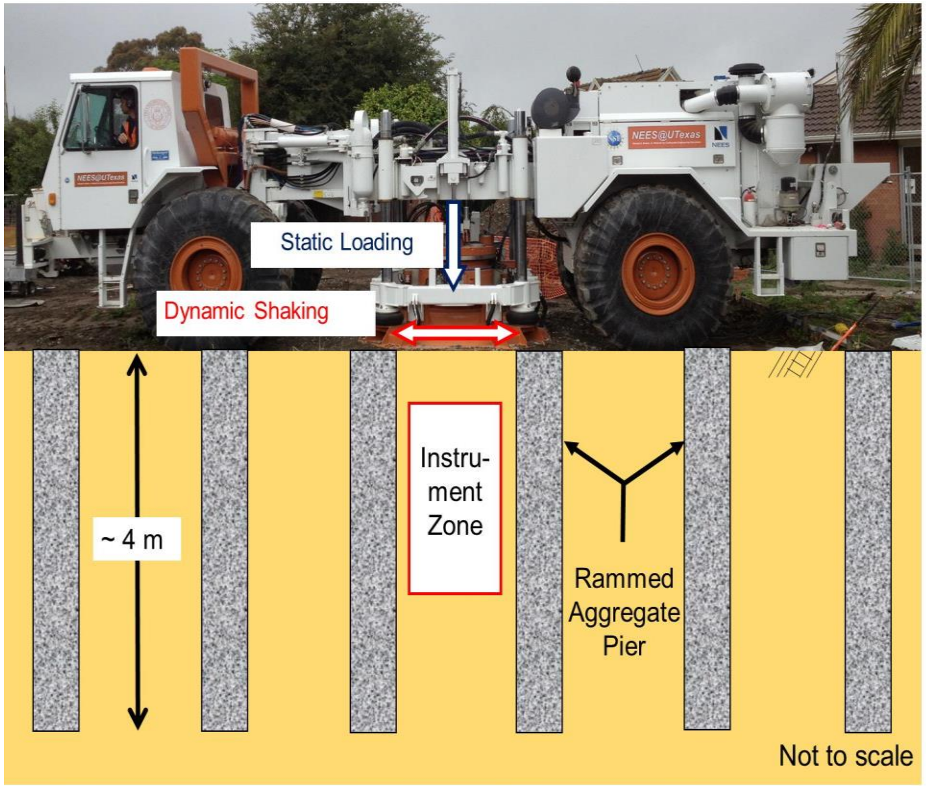


▲ **Rammed Aggregate Piers (RAP)**

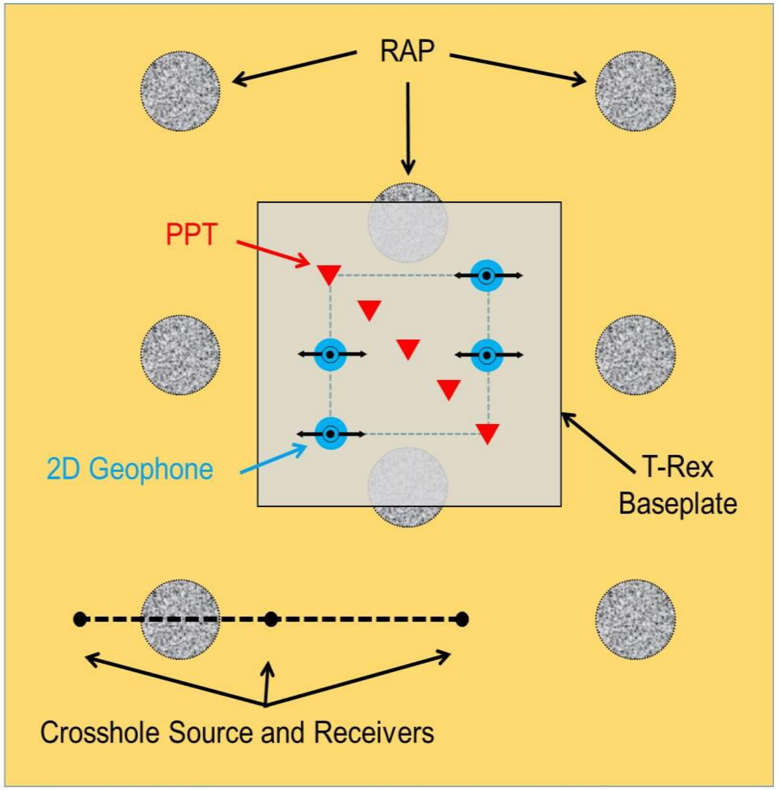


◀ **Low Mobility Grout (LMG)**

In-Situ Liquefaction Testing with T-Rex

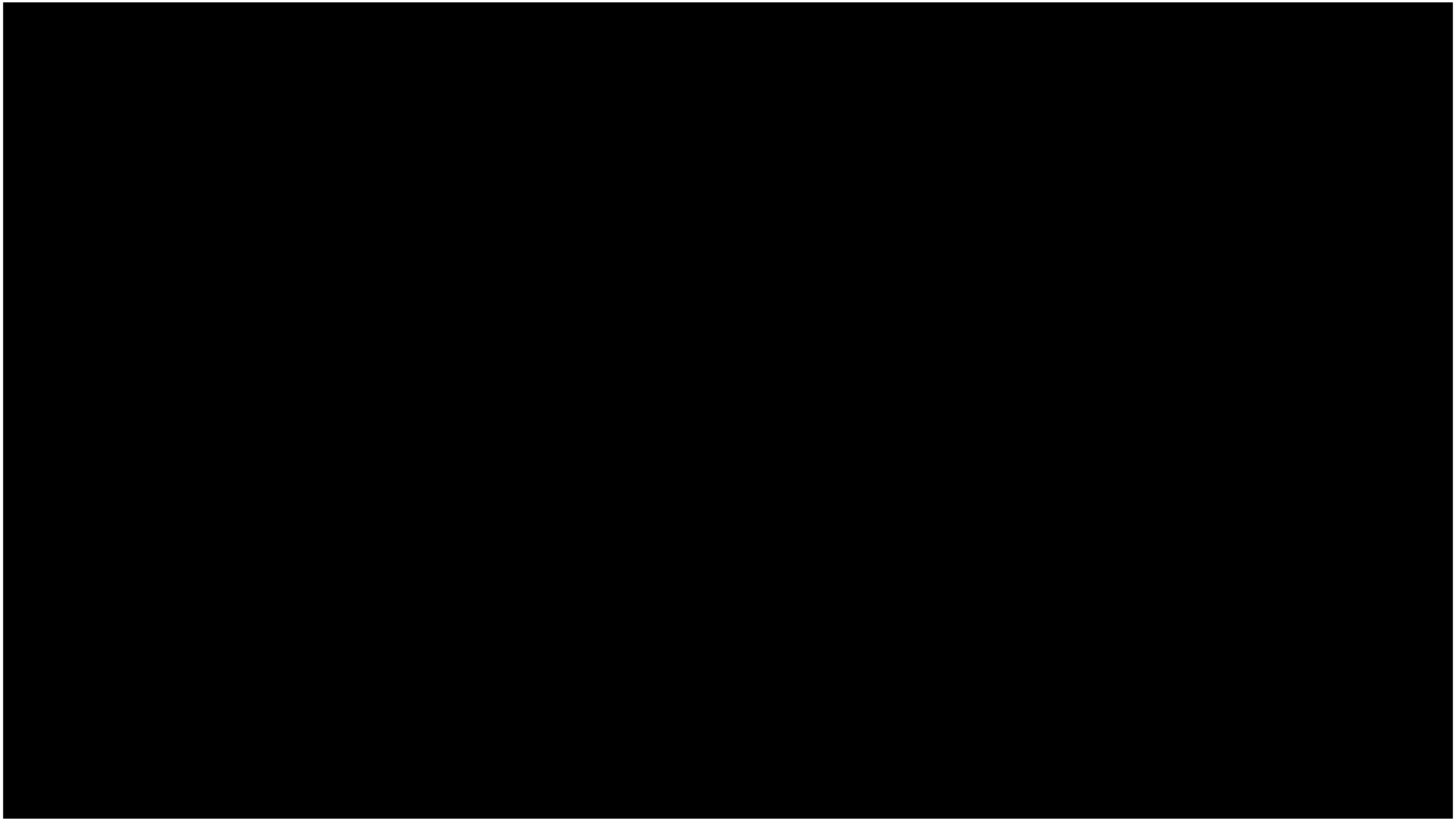


a. Cross-sectional perspective of T-Rex in place to shake the RAP.



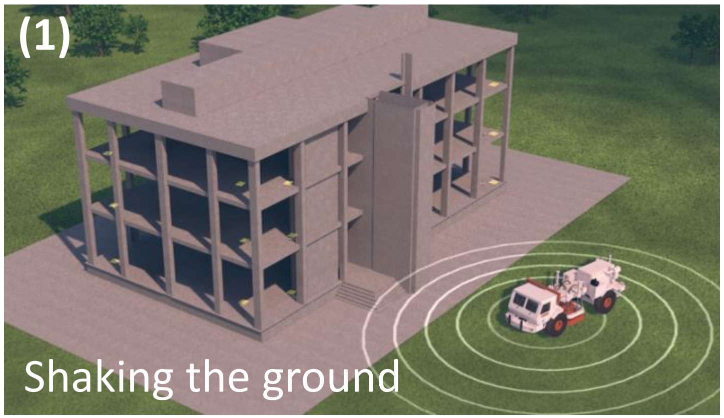
b. Plan view of central portion of RAP test panel

Ground Improvement Trials Video



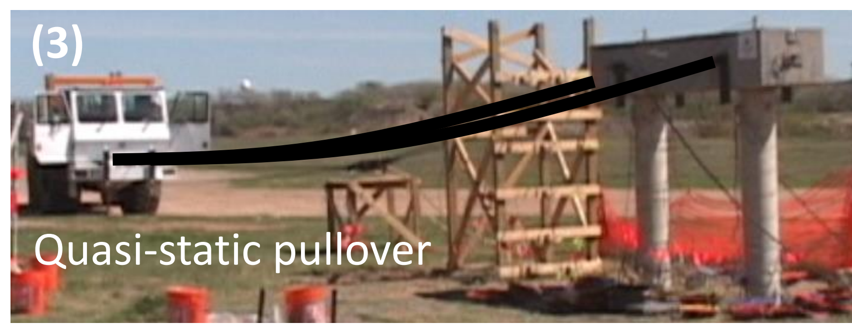
Science Plan #3:

Developing rapid, in-situ methods for non-destructive structural evaluation and soil-foundation-structure interaction (SFSI) studies



3 methods of structural testing with NHERI@UTexas equipment:

(1) Shaking ground around a structure
(2) Shake the structure directly
(3) Quasi-static pullover



Structural Testing

In the lab…

Hybrid testing at Lehigh

Shake table testing at UC San Diego

In the field…

Complex soil conditions

Corrosion

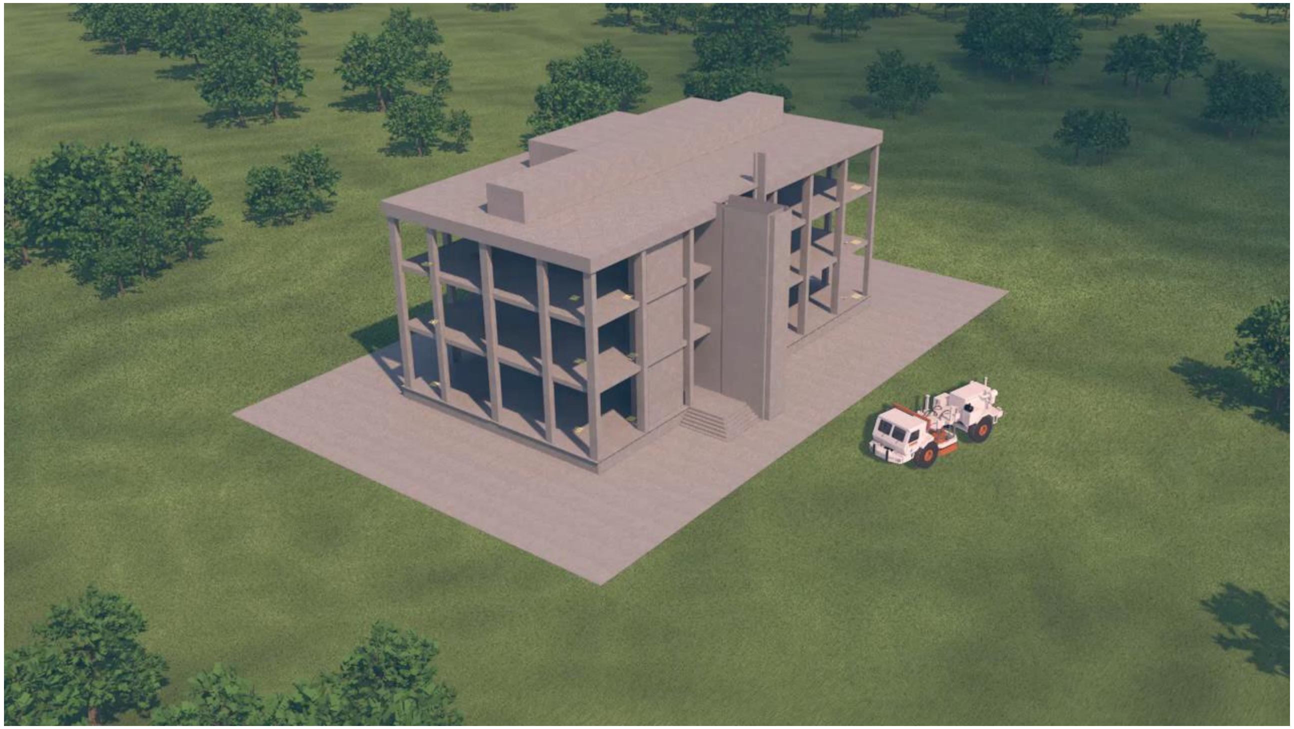
Scour

Degradation (below ground/water)

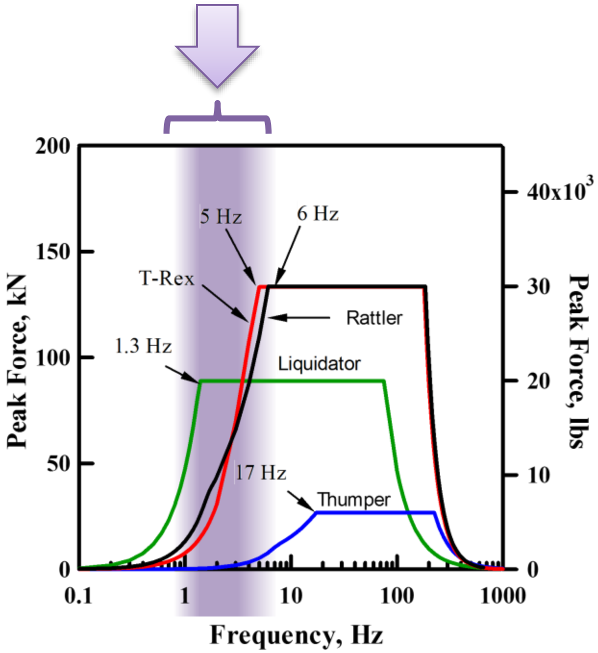
NEES@UTexas Project Highlight

"Collaborative Research: Demonstration of NEES for Studying Soil-Foundation-Structure Interaction" (CMMI-0324326)

Typical Structures



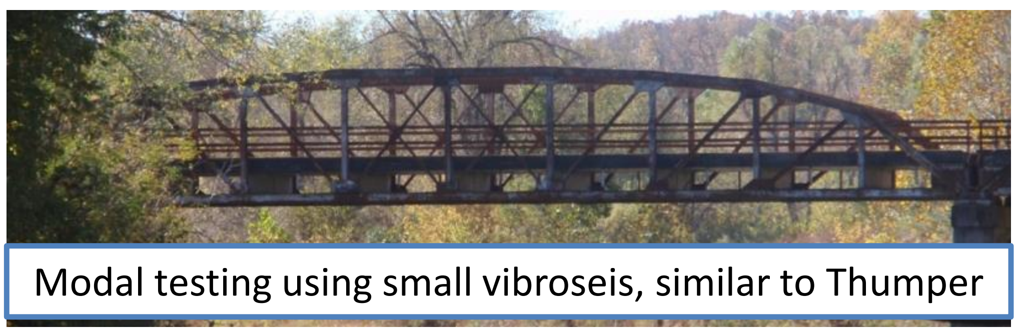
Fundamental frequency range for:
- Typical bridges
- Low-rise reinforced concrete and steel buildings
- Wood residential buildings
- Large-scale specimens

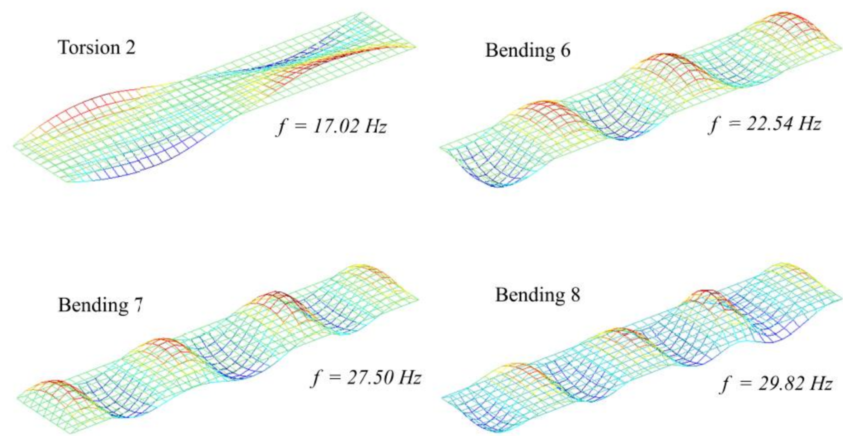


Horizontal force output

Other Examples

Zhang, R.R. & Olson, L.D. (2004) "Dynamic Bridge Substructure Condition Assessment with HHT: Simulated Flood and Earthquake Damage to Monitor Structural Health and Security," *Transportation Research Record*, pp. 153-159.





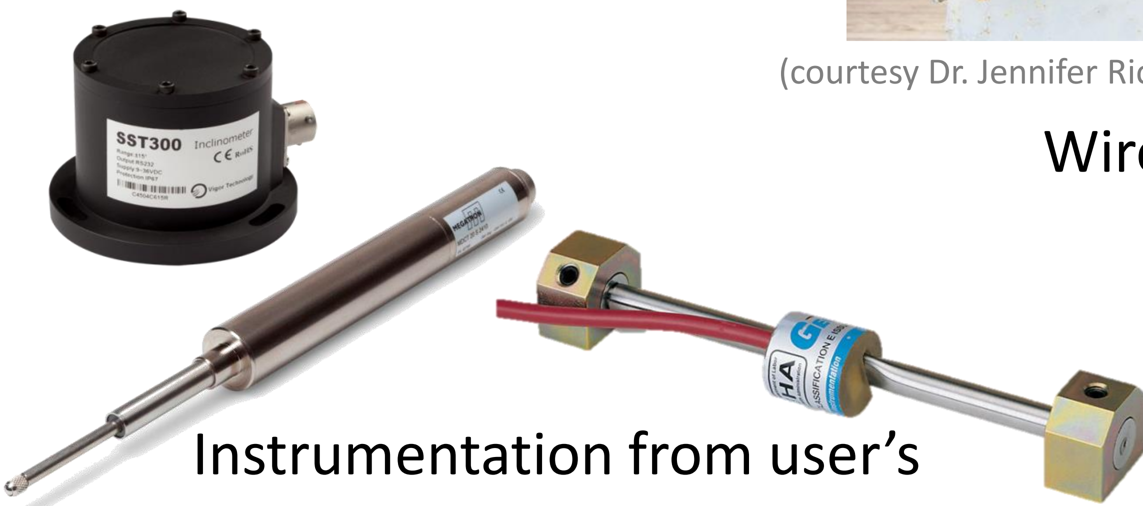
Fernstrom, E. V., Wank, T. R., & Grimmelsman, K. A. (2012) "Evaluation of a Vibroseis Truck for Dynamic Testing of Bridges," *TRB Annual Meeting 2012*, 15p.

Additional Instrumentation Resources

- IRIS/PASSCAL
- User-provided

(courtesy Dr. Jennifer Rice, Univ. of Florida)

Wireless Sensors for Structural Health Monitoring



Instrumentation from user's home institution
(e.g., LVDTs, inclinometers, strain gages, etc.)

Example of Estimated Costs* Associated with Using the NHERI@Utexas Equipment Facility on NSF-Funded Research Projects

Rate Name	Internal Rate	External Rate	Fuel Pass-through (NEES Projects only)	Distribution Base
T-Rex	$165.00	$208.00	$27.00	per hour
Liquidator	$146.00	$184.00	$27.00	per hour
Thumper - Vibration	$54.00	$68.00	$9.00	per hour
Thumper - Highway	$1.24	$2.00	$0.70	per mile
Big Rig	$4.00	$4.00	$1.13	per mile
Instrumentation Van - Highway	$0.86	$1.00	$0.45	per mile
Instrumentation Trailer	$250.00	$315.00	N/A	per project
Fuel Supply Truck - Highway	$0.86	$1.00	$0.45	per mile
Fuel Supply Small - Trailer	$125.00	$157.00	N/A	per mile
Raptor	$145.00	$183.00	$27.00	per hour
Rattler	$135.00	$170.00	$27.00	per hour
Data Physics 16-channel Analyzer	$322.00	$407.00		Per 4-channel per week
Data Physics Quattro Aanalyzer	$314.00	$397.00		Per unit per week
VXI technology 72-channel	$706.00	$892.00	N/A	Per 16-channel per week
Trillium Compact Seismometer with Taurus DAS system	$457.00	$577.00		Per station per week
Cone Penetration Test Equipment	$646.00	$817.00		Per week

*Estimated cost based on the NEES@Utexas Equipment Site and rates for 9/1/2012- 9/31/2013

Example NHERI@Utexas Budget*

Moderate-to-Deep Shear Wave Velocity Profiling by Combined Active-Source and Ambient-Wavefield Surface Wave Testing; Total Number of Vs Profiles Equals 10 to 12; Total Field Testing Time of 5, 8-hour days **

Personnel	Rate/Mo.	Months	Budgeted
Tech - C. Hoffpauir	XXXX	0.60	$0
Tech - A. Valentine	XXXX	0.60	$0
Total Personnel			**$0**
Fringe Benefits (30% based on S&W History)			**$0.00**
Expendable Goods and Supplies			
Shipping Liquidator to/from site			$21,000
Liquidator, operating time, 40 hours @$27.00/hr			$1,080
Field Supply Truck and Trailer, 4,000 miles @ $1.25/mi			$5,000
Active Seismic Equipment ((3222/wk for 4 channels) x 2)			$644
Passive Seismic Equipment (10 Trillium Compacts x 457)			$4,570
			$32,294
Travel Expenses: Field Testing (2 persons for 12 days)			
Per diem: $65/day * 12 days (avg) * 2			$1,560
Lodging: $125/night * 10 nights (avg) * 2			$2,500
			$4,060
Other Expenses			
None			$0
			$0
Total Direct Costs			**$36,354**
26% Overhead			**$9,452**
Total Direct and Indirect Costs			**$45,806**

*The NHERI@UTexas budget is estimated with "old" NEES@Utexas rates.
** Researcher has to pay for any overtime.

Additional Information & Proposal Help

- Dr. Kenneth Stokoe (PI) k.stokoe@mail.utexas.edu
- Dr. Brady Cox (co-PI) brcox@utexas.edu
- Dr. Patricia Clayton (co-PI) clayton@utexas.edu
- Dr. Farnyuh Menq (Operations Manager) fymenq@utexas.edu

- NHERI@UTexas website at www.designsafe-ci.org
  - Currently under construction (mid-January launch)
  - Webinar slides & updated budgetary info will be posted

Questions?