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

NHERI Experimental Facility, NHERI@UTexas

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Stiffness-based Ground Deformation Predictions Workshop

Co-hosted by Prof. Richard Finno, Prof. Khiem Tran,
Ms. Lindsay Flangas, and Mr. King Chin
Seattle, WA, November 5, 2018

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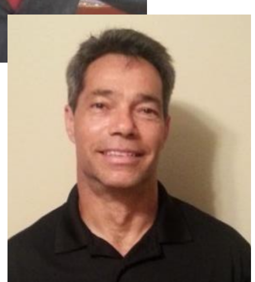

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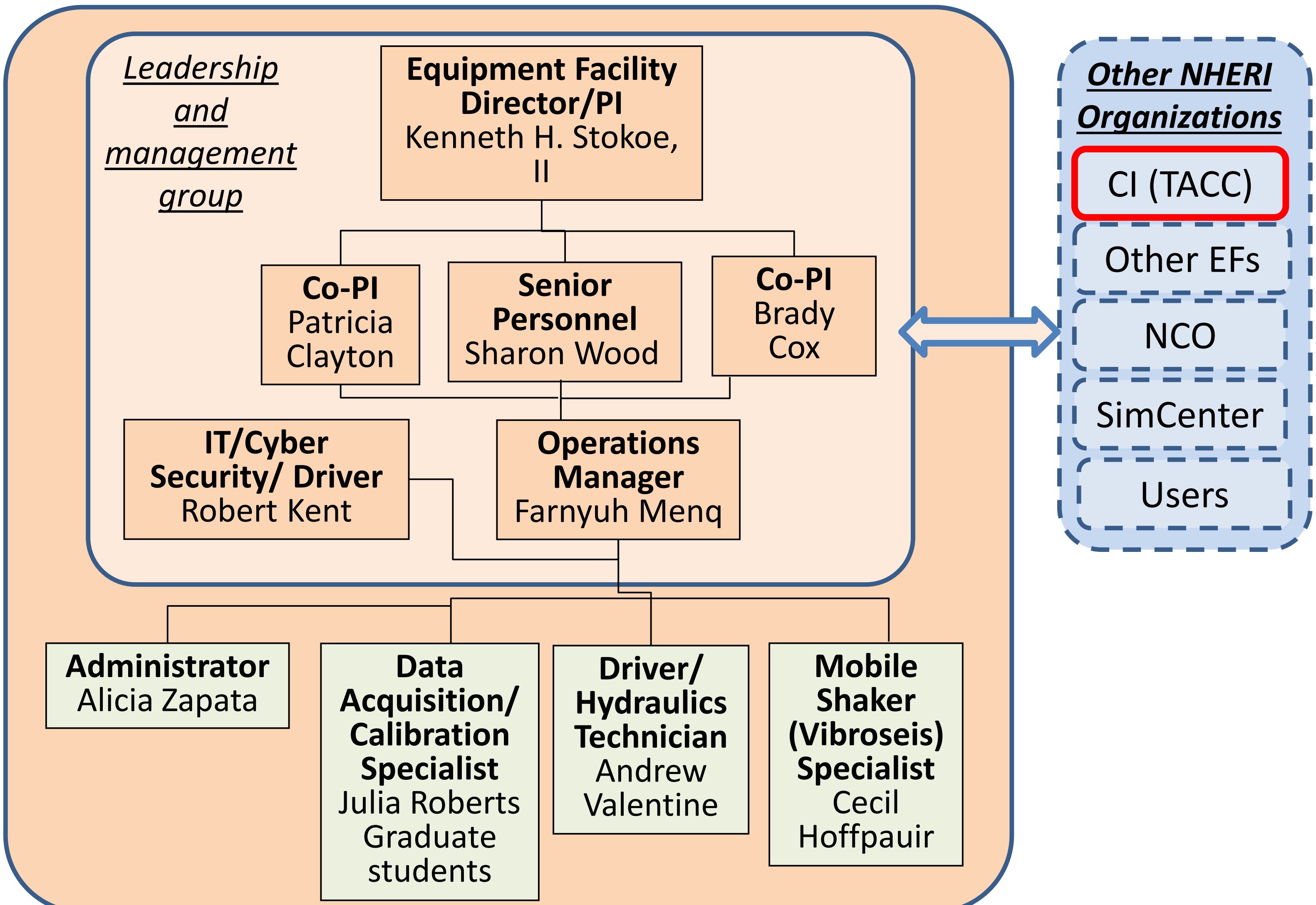
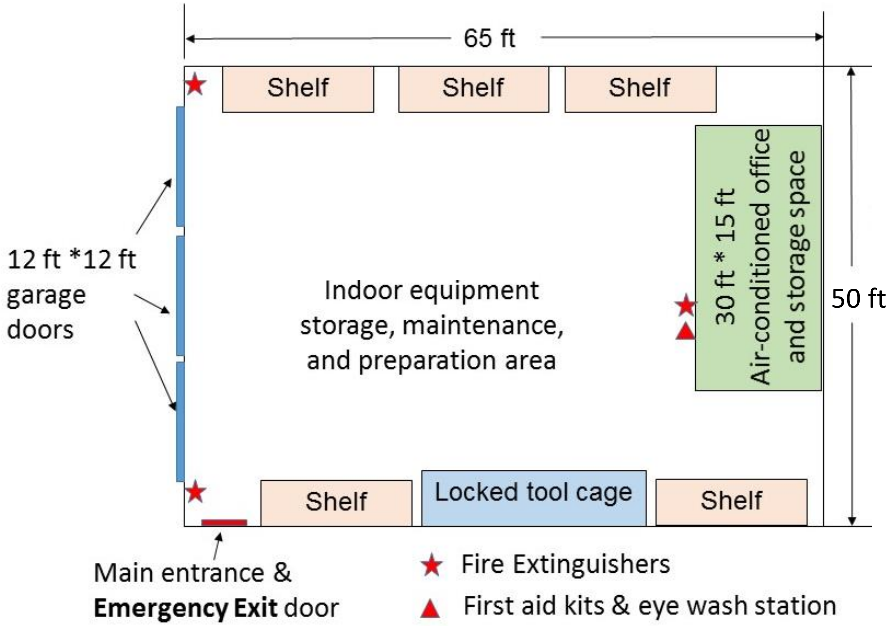
NHERI@UTexas Organization Chart



NHERI@UTexas - Building 46

Building 46 Facility



T-Rex (Tri-axial Shaker)
- Off-road buggy; weight = 64,000 lbs
- Three vibrational orientations
- Shear mode Peak Force = 30,000 lbs
- Vertical mode Peak Force = 60,000 lbs

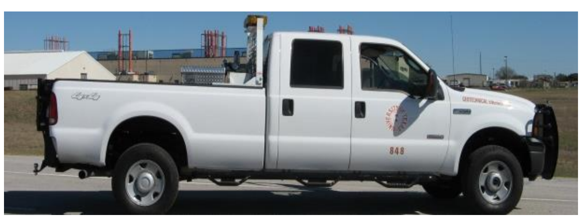
Liquidator (Low Frequency Shaker)
- Off-road buggy; weight = 72,000 lbs
- Two vibrational orientations
- Shear mode Peak Force = 20,000 lbs
- Vertical mode Peak Force = 20,000 lbs

Thumper (Urban Shaker)
- International 4300 truck; weight = 24,800 lbs
- Three vibrational orientations
- Shear mode Peak Force = 6,000 lbs
- Vertical mode Peak Force = 6,000 lbs

Raptor (Mid-Size Shaker)
- Highway legal truck; weight = 41,200 lbs
- Vertical mode Peak Force = 27,000 lbs

Rattler (Horizontal Shaker)
- Off-road truck; weight = 54,500 lbs
- Shear mode Peak Force = 30,000 lbs

Big-Rig
- 26 wheeler tractor-trailer rig for shipping T-Rex, Liquidator, and Rattler



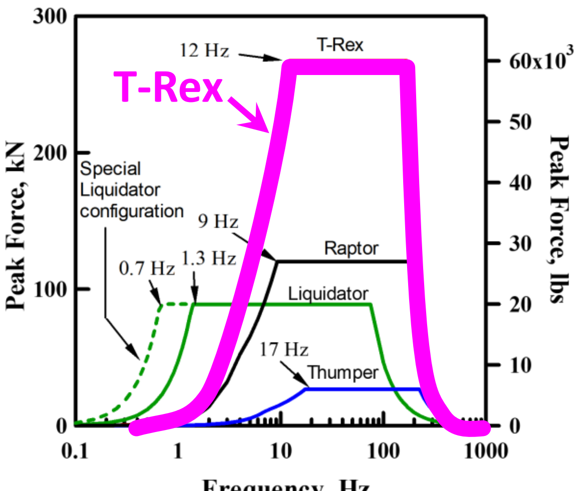
Field-Support Truck
- Carries diesel fuel for T-Rex and Liquidator
- Acts as a working platform for maintenance

Instrumentation Van & Trailer
- Cargo van with air-conditioned workspace
- Trailer with added work and storage spaces

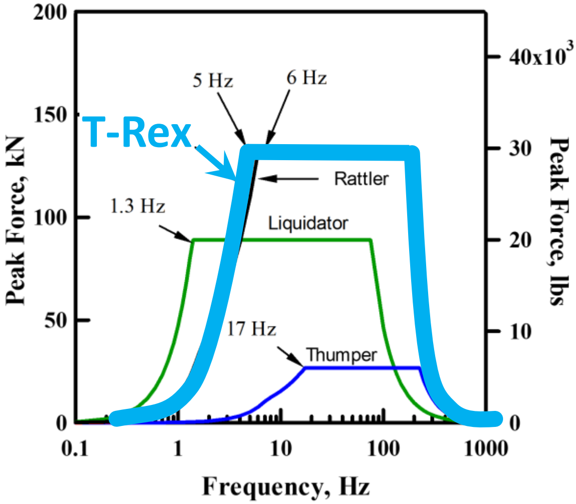
Hydraulic Cylinder with Adjustable Platform
- Platform mounted at the rear of T-Rex
- Pushing and retrieving subsurface sensors

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



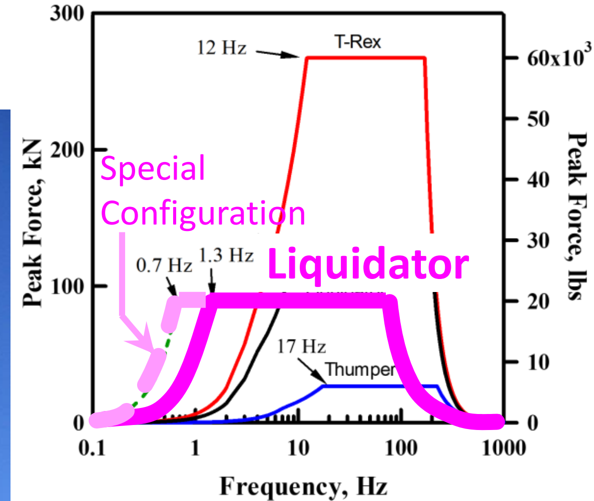
Horizontal force output

T-Rex – Vertical Shaking

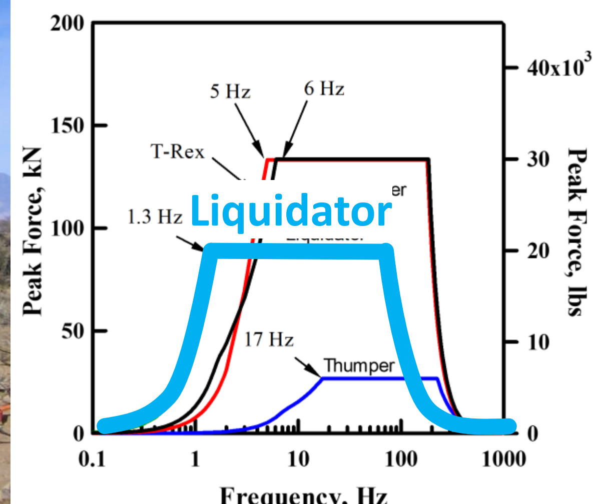
Liquidator

- 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

Z
Y



Vertical force output



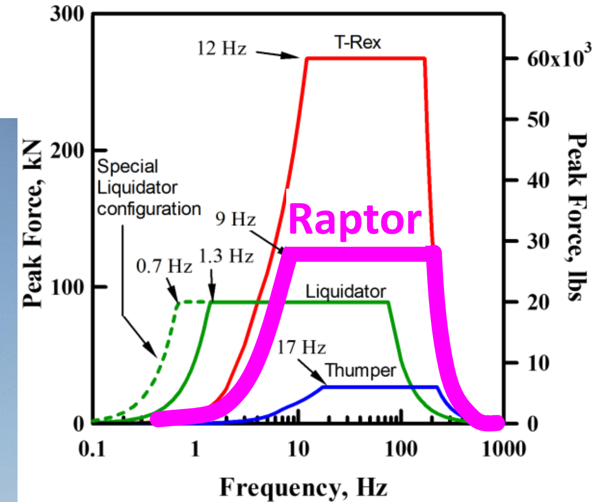
Horizontal force output

Liquidator – Standard Configuration

Liquidator – Special Configuration

Raptor

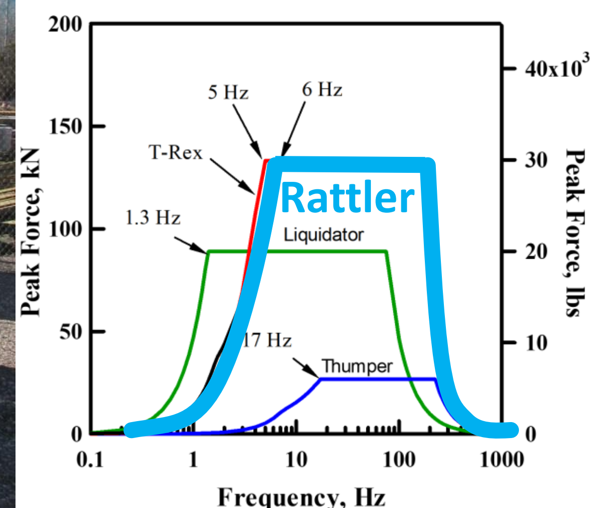
- Standard vibroseis, vertical shaker (P-wave)
- 32 ft long, 8 ft wide, Wt. = 41,200 lbs



Vertical force output

Rattler

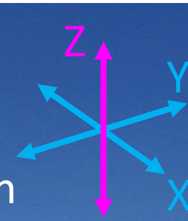
- Standard vibroseis, horizontal shaker (S-wave)
- 29 ft long, 8.5 ft wide, Wt. = 30,000 lbs

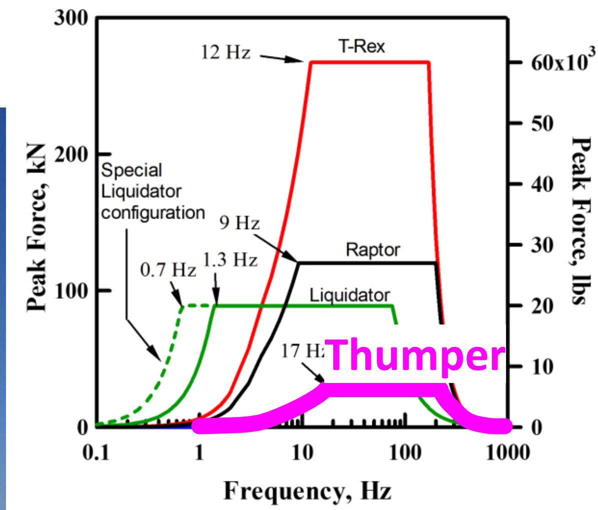


Horizontal force output

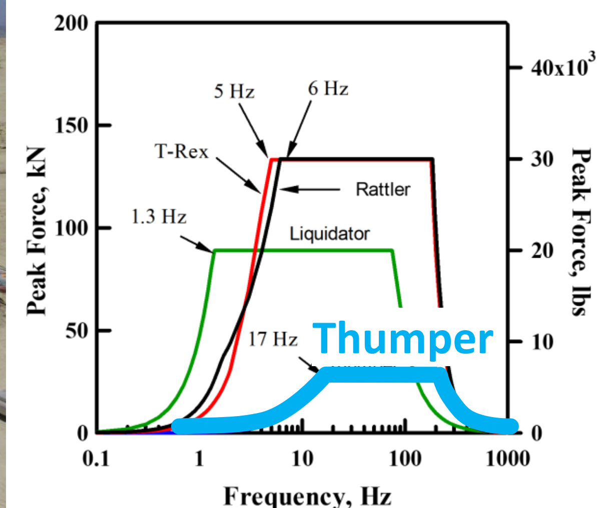
Thumper

- 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

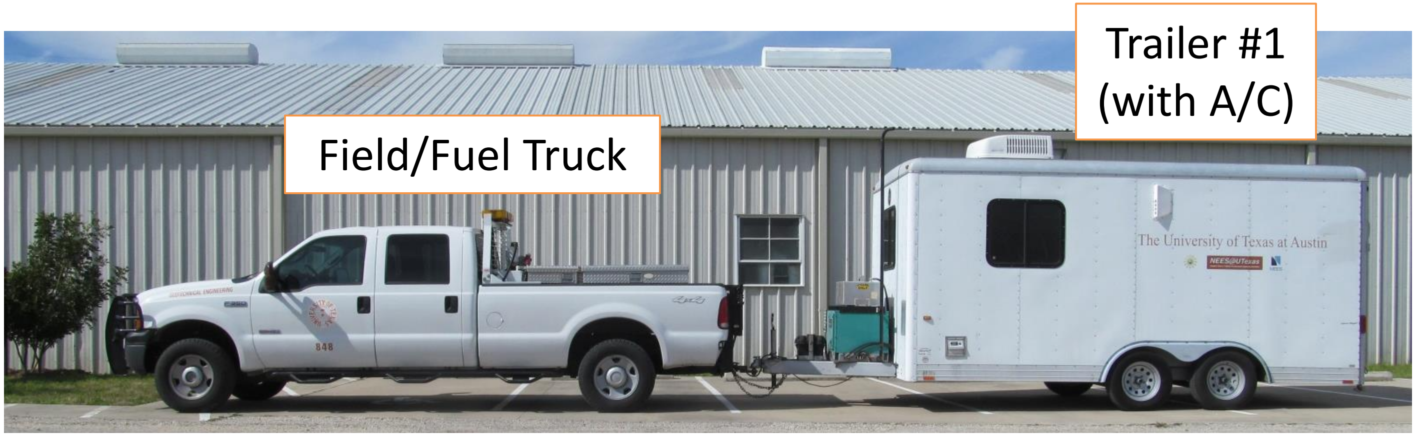


Horizontal force output

Big Rig

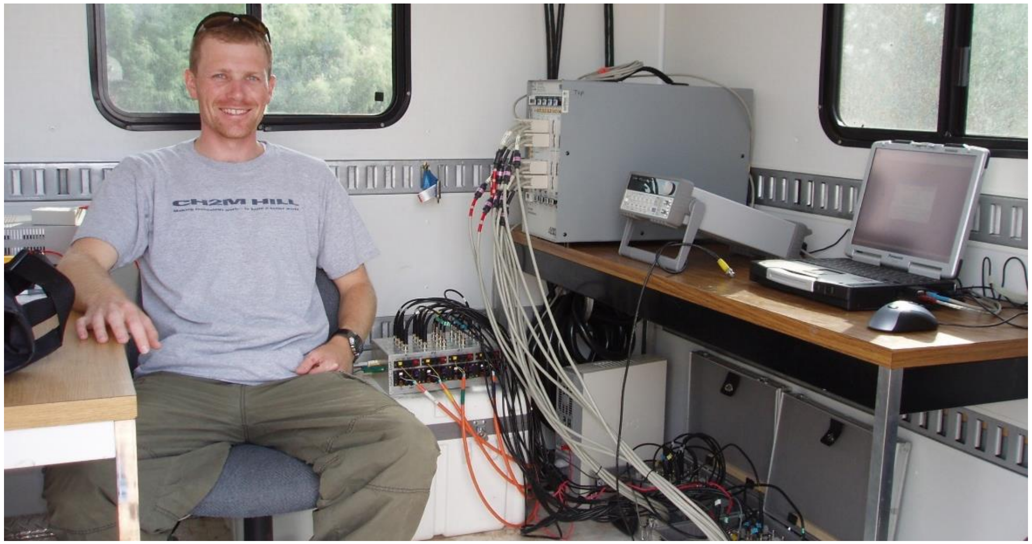
- 26-wheel tractor trailer for shipping T-Rex, Liquidator, and Rattler

Support Vehicles



Provide fuel, storage, and workspace in the field

Instrumentation – Data Acquisition (DAQ)



72-channel VXI DAQ

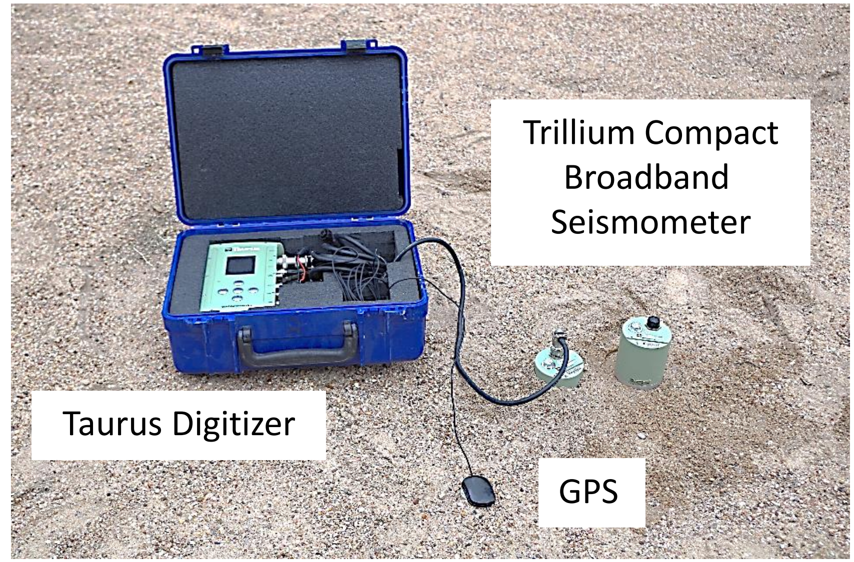
- 24 bit digitizer
- Up to 50 kHz sampling rate
- Real-time frequency domain capabilities

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



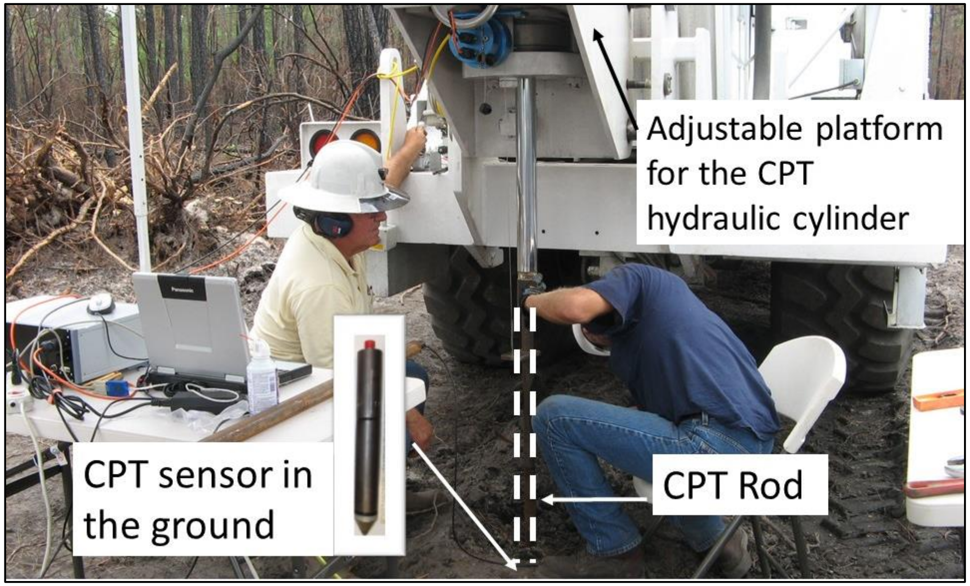
<u>109, 1-Hz Geophones</u>

- 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

<u>Cone Penetrometers</u>

- Standard CPT
- Seismic CPT
- 4 different cones

<u>Motion Sensors</u>

- Tri-axial MEMS accelerometers
- 2D or 3D geophones

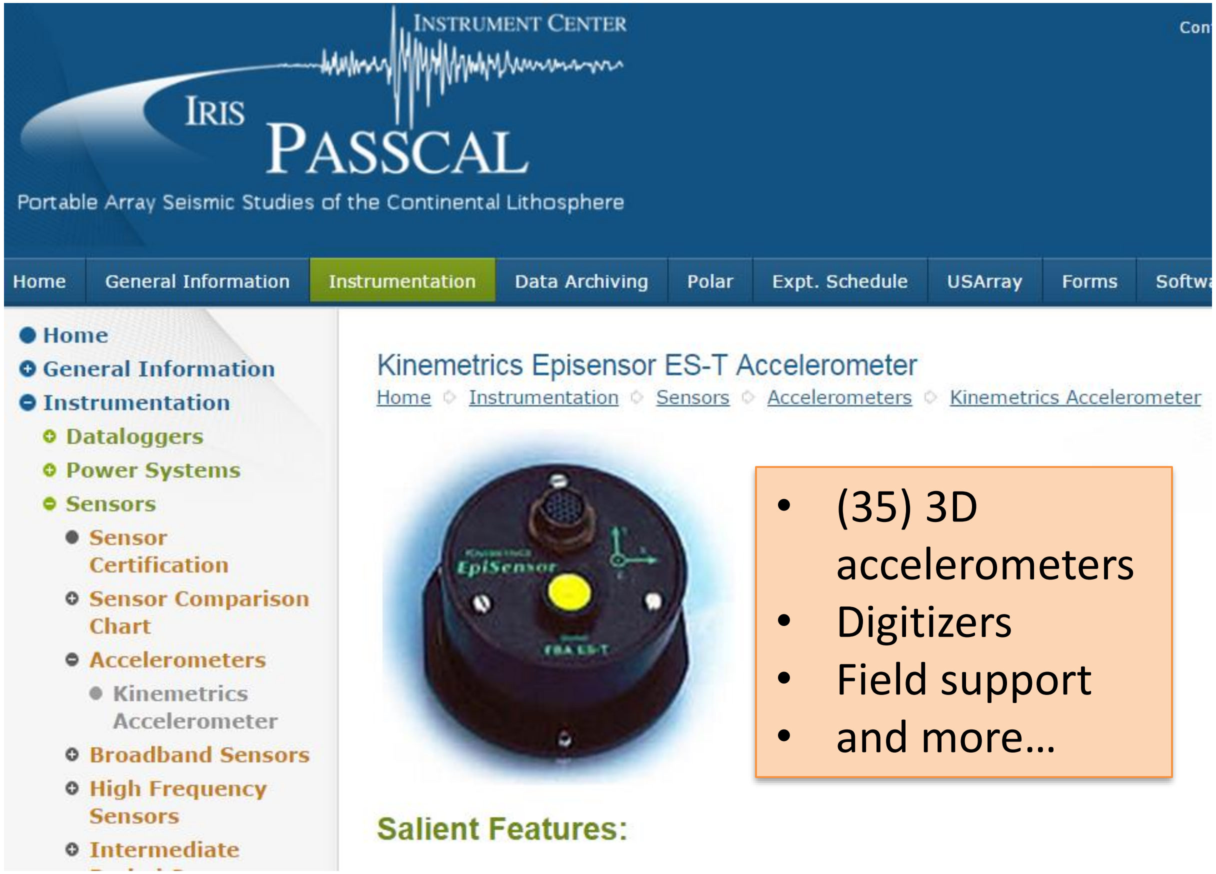
<u>Liquefaction Sensors</u>

- Custom built
- Pore water pressure transducers

Additional Instrumentation Resources

- IRIS/PASSCAL

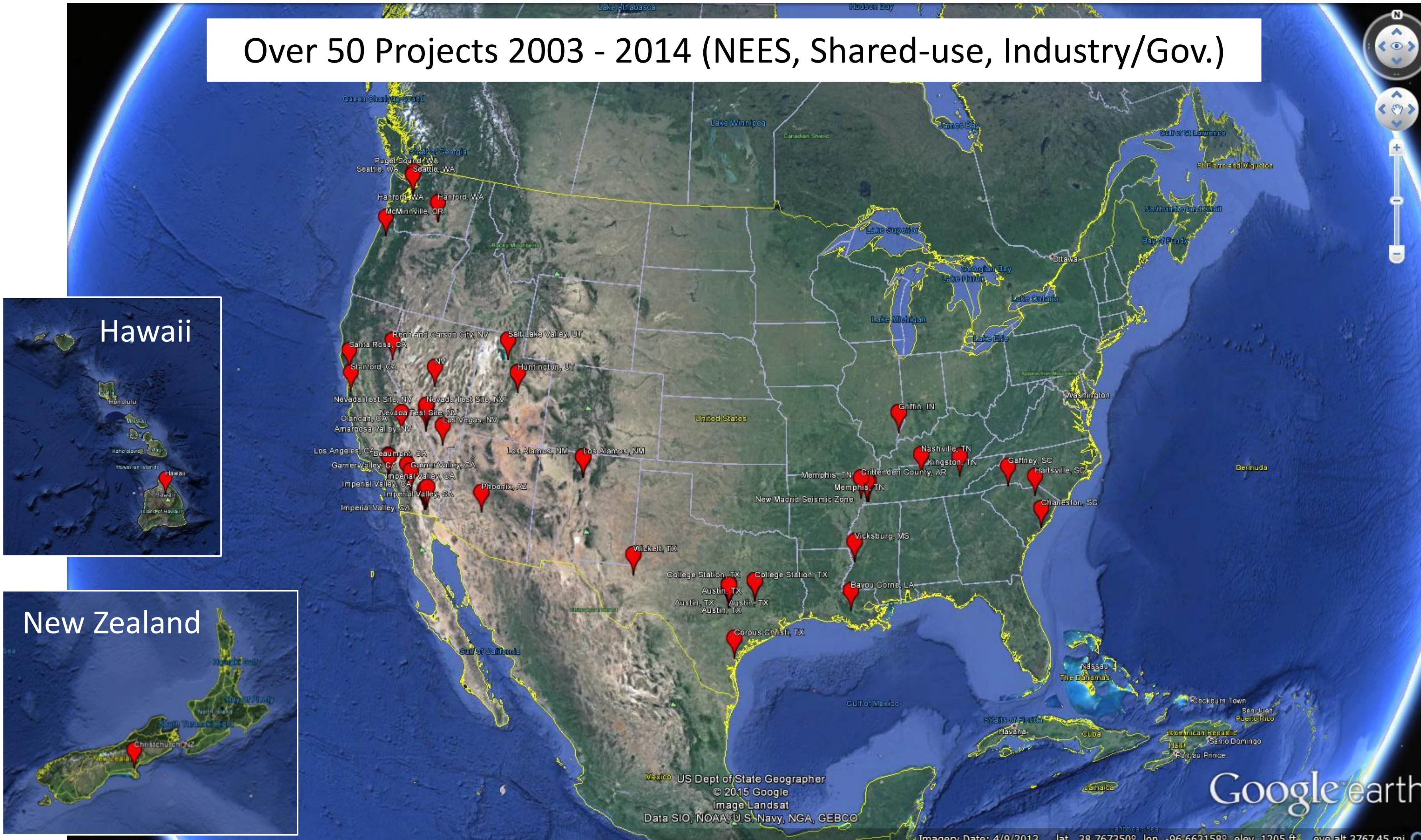
Free to NSF-funded projects
*PI pays for shipping & travel expenses



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

"Have mobile shakers, 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

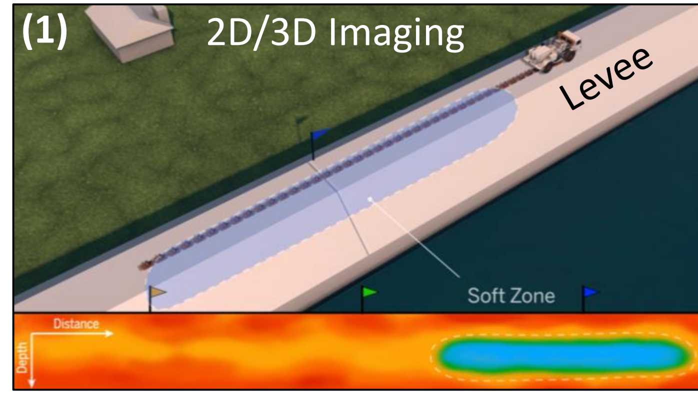
4.
Deep Vs
Hanford
PNNL, WA

5.
Deep Vs
Palo Verde
NPP
Arizona

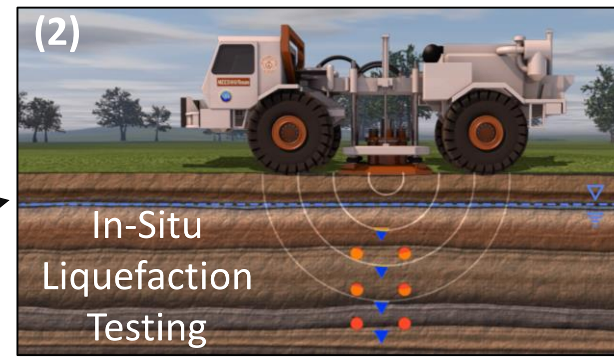
Proof-of-Capability Workshops

- Each test aligned with one of three main areas in our Science Plan:

  (1) Subsurface Imaging (2D/3D)
  (St. Louis, MO; November 11, 2016)



  (2) In-situ Liquefaction/Nonlinear Testing
  (Portland, OR; June 24, 2016)



  (3) Structural Health Monitoring/SFSI
  (Brunswick, NJ; August 3-4, 2017)

Proof-of-Capability Workshops cont…

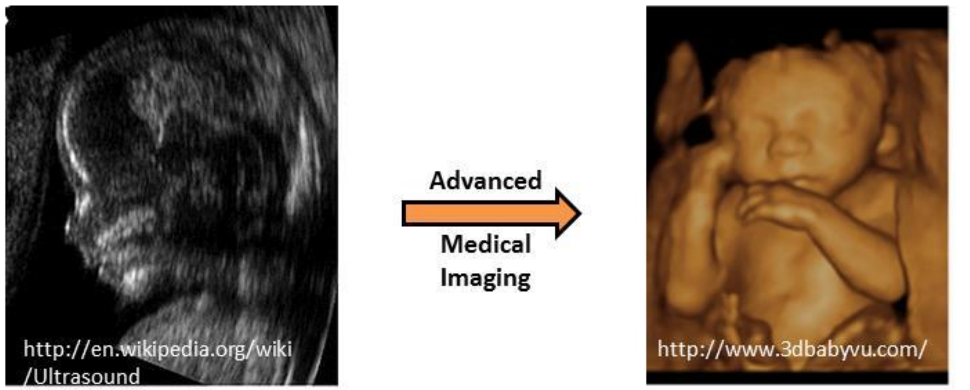
- Marketing to broaden the user base
  - Familiarize potential users with NHERI@UTexas capabilities
  - Invite all interested parties (Gov/Academia/Industry)
  - Data and metadata posted to NHERI DesignSafe-CI (open access)
  - Generate preliminary proposal data
  - Opportunities for piggy-back projects

Thumper at levee testing workshop

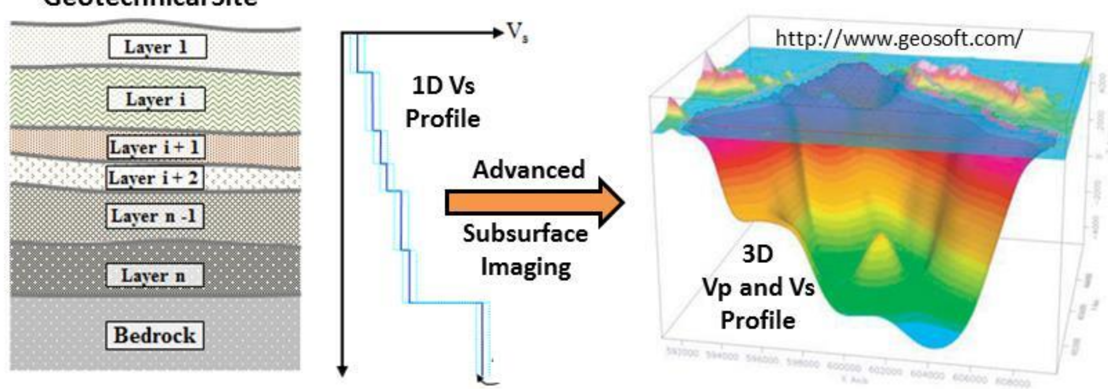
Liquefaction testing workshop

Science Plan #1:

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



a. Ultrasound of the Past   b. Ultrasound of the Present



c. 1D Geotechnical Imaging of the Present   d. 3D Geotechnical Imaging of the Future

Retrieve:

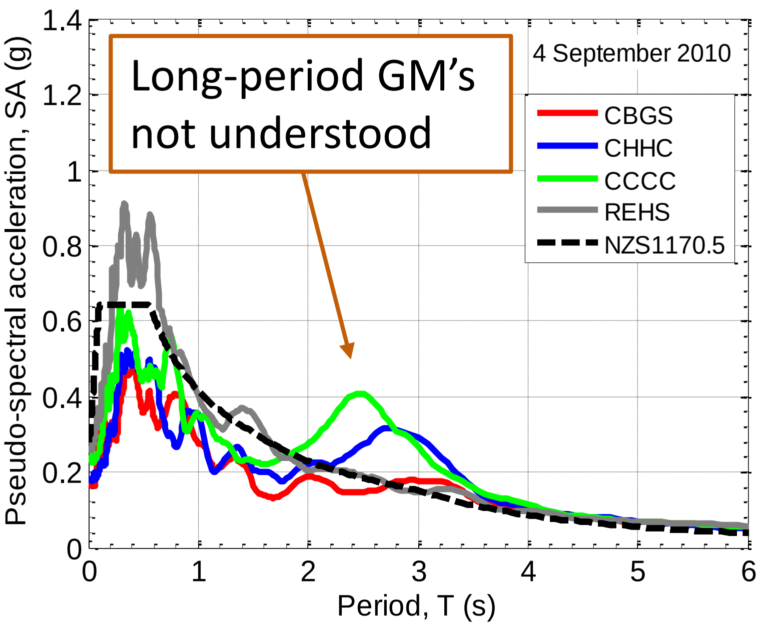
- Shear Wave Velocity (Vs)
- P-wave Velocity (Vp)

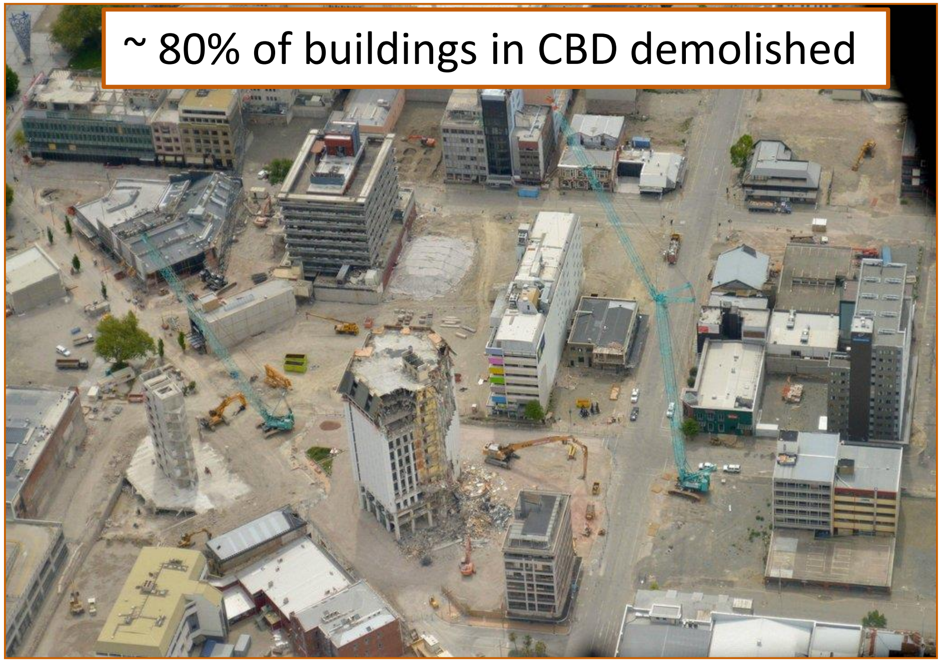
for direct determination of elastic moduli needed in engineering analyses

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"

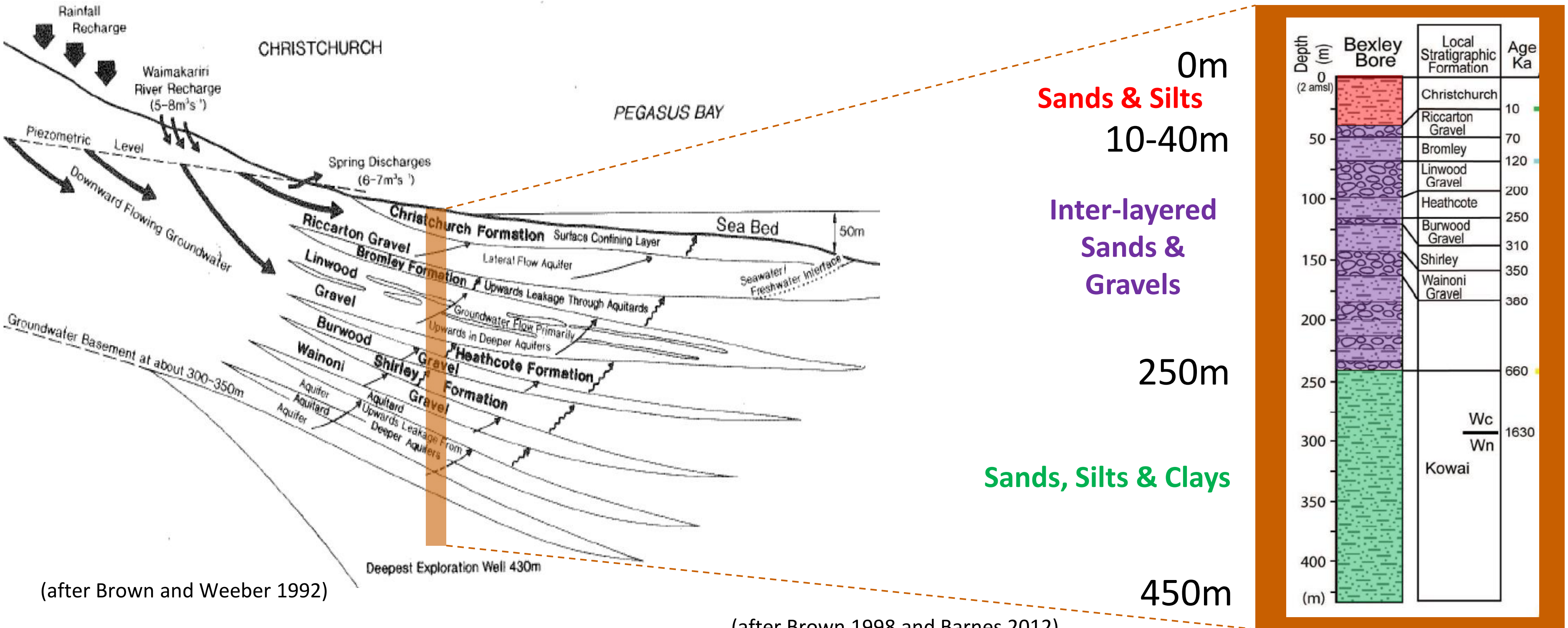
(CMMI-1303595)





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)

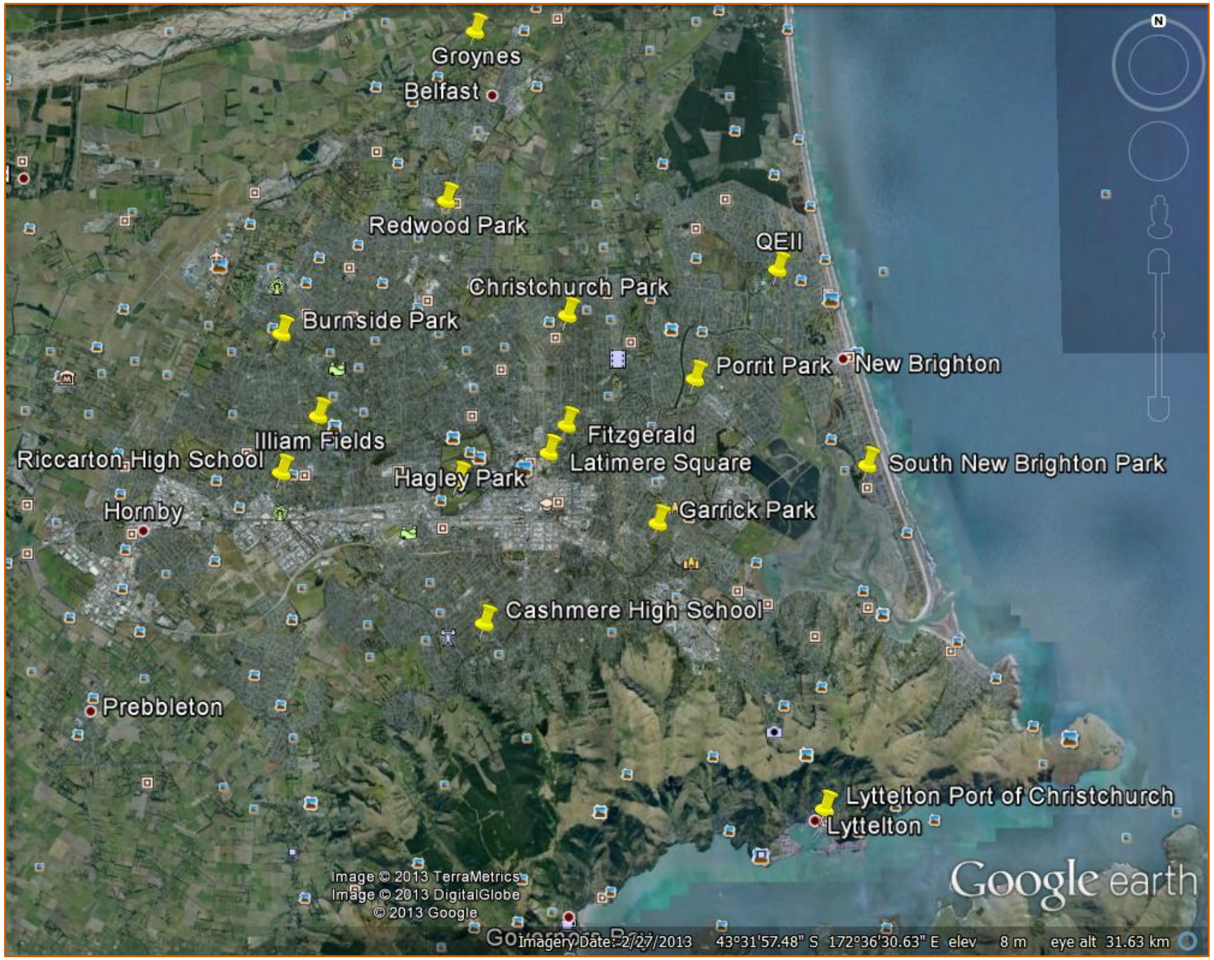
(after Brown 1998 and Barnes 2012)

T-Rex in Christchurch

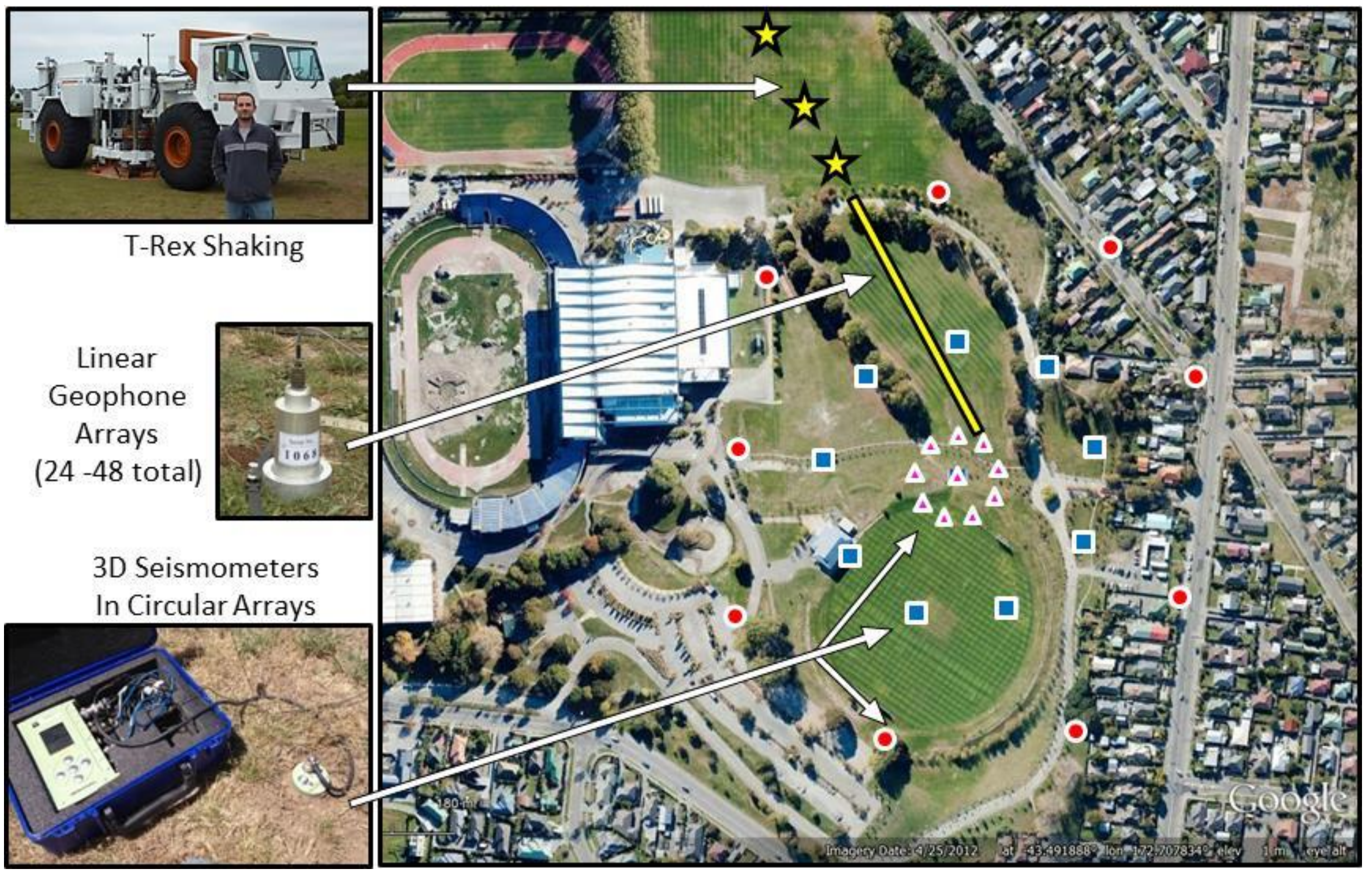
- Shipped from Texas to Christchurch in Feb. 2013

Christchurch Surface Wave Testing Sites

- 15 primary sites in greater Christchurch
- Target depth of Vs profiling: 400m – 1000m
- Approximately 2 days of testing per site



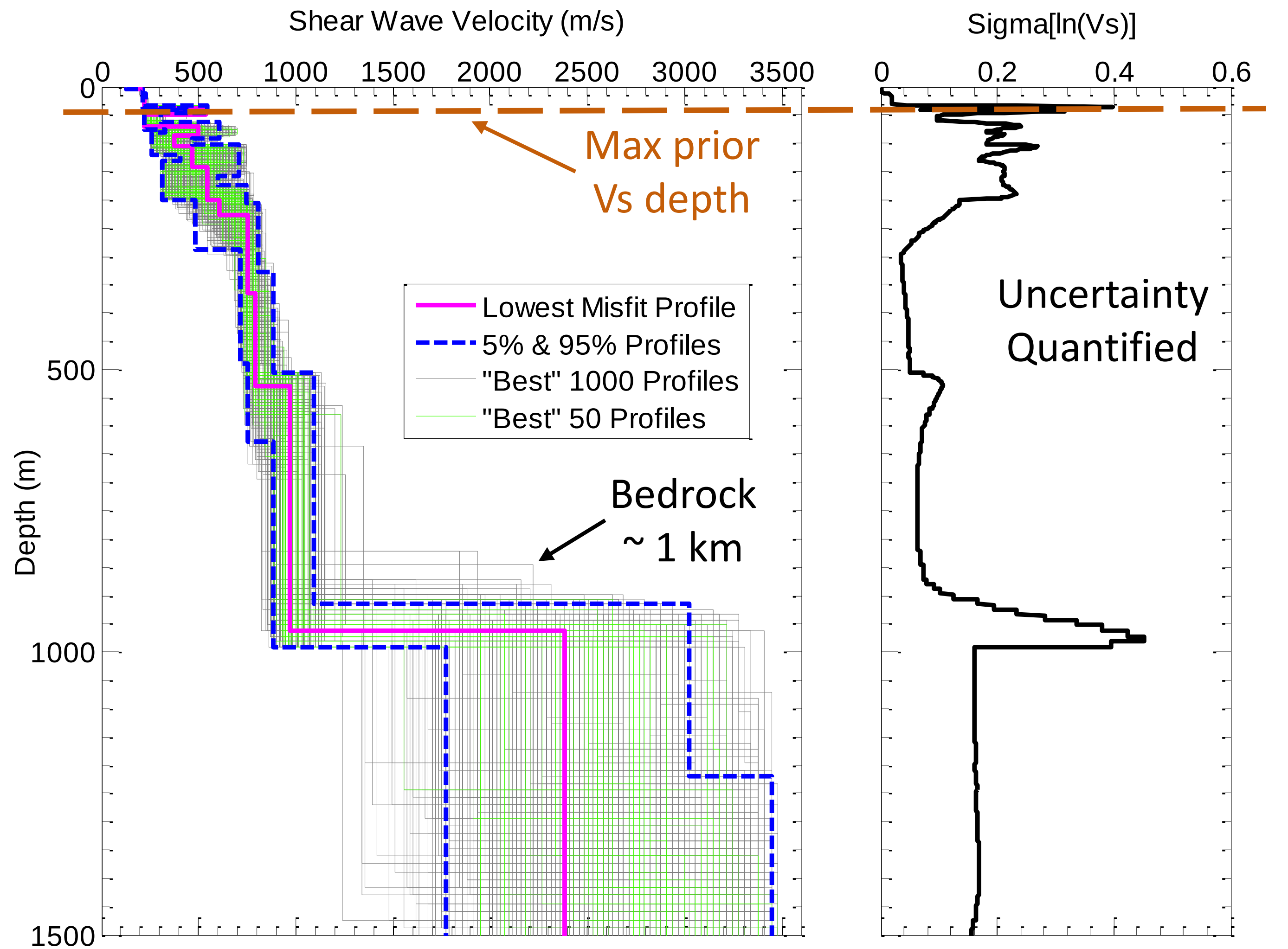
Combined Active-Source & Ambient-Wavefield Surface Wave Testing



Reliable 1D Vs Profiles to Record Depths

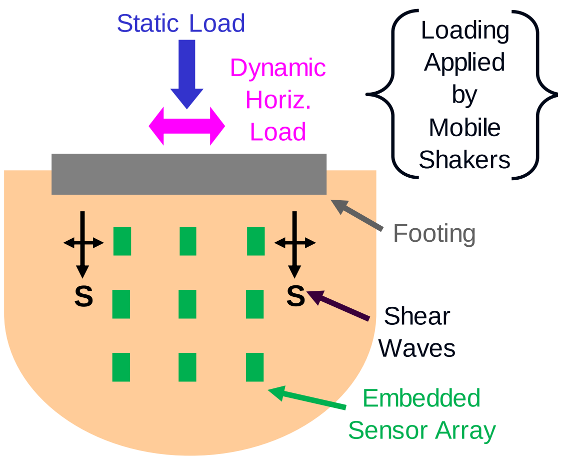
<u>Inversion Process</u>

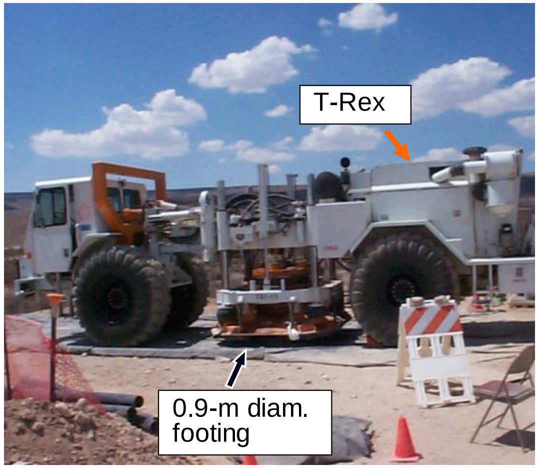
- Analysis took weeks for each site
- Millions of models searched via Monte-Carlo/ Neighborhood algorithms
- Hours of computer time followed by user scrutiny, model adjustment, repeat inversion

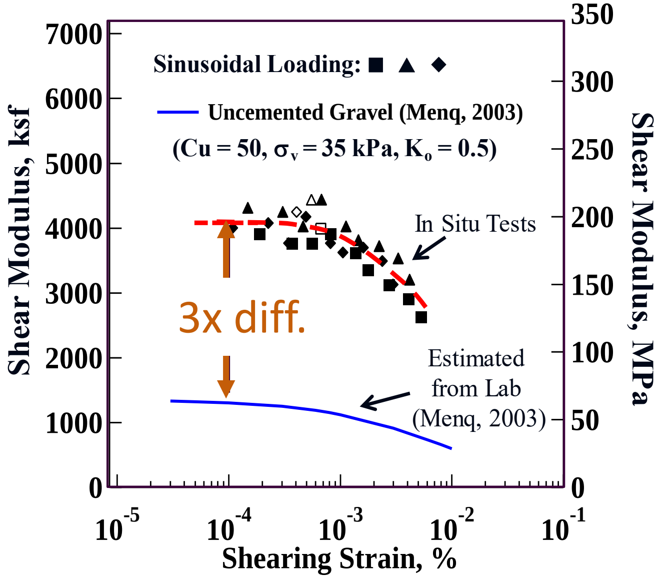


Science Plan #2:

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"

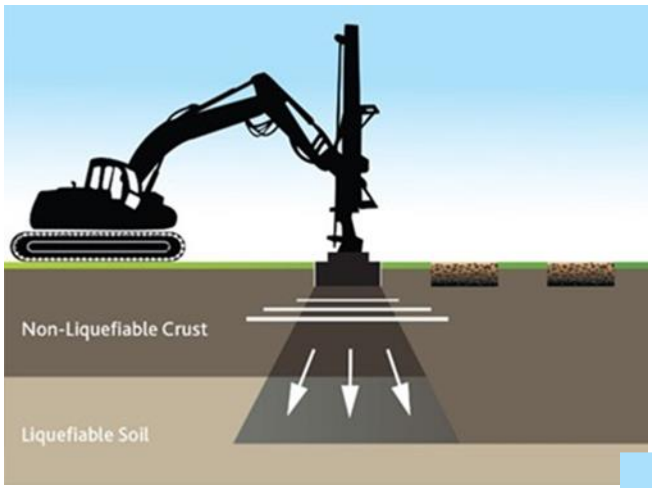
(CMMI-1343524)

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

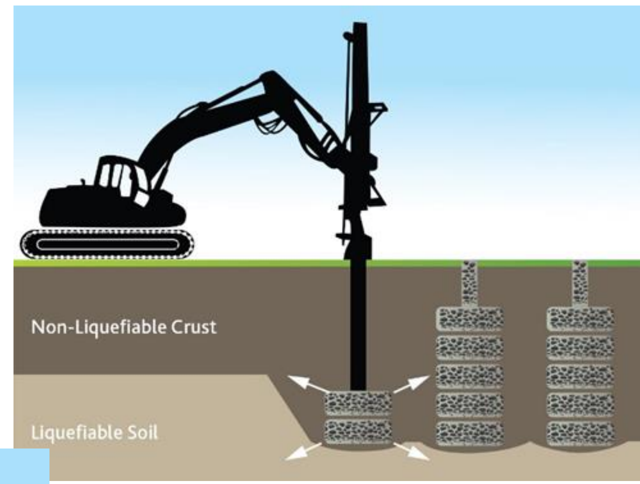
NZ EQC Ground Improvement Trials

Objective: Rebuild Christchurch with Affordable Resilience

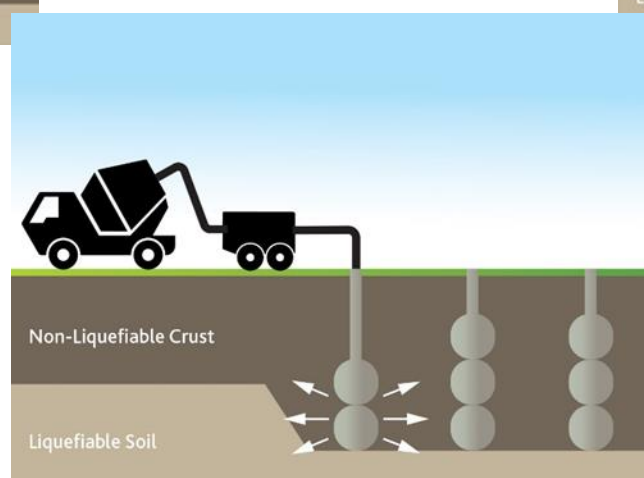
Techniques for “green” sites or demolished home sites



▲ **Rapid Impact Compaction (RIC)**

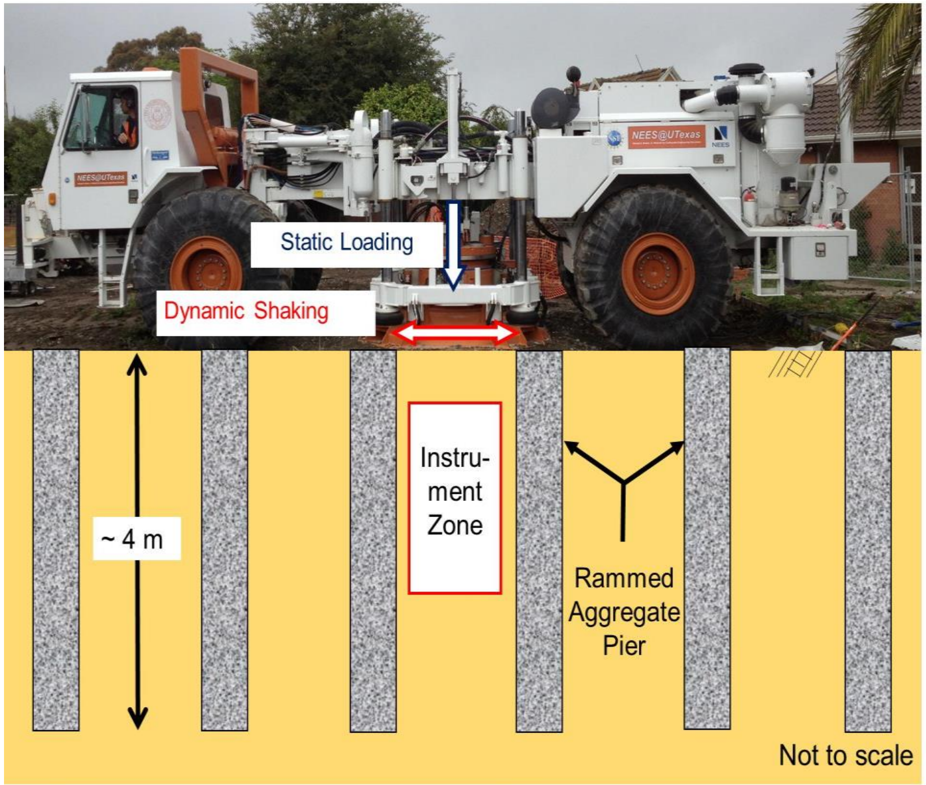


▲ **Rammed Aggregate Piers (RAP)**

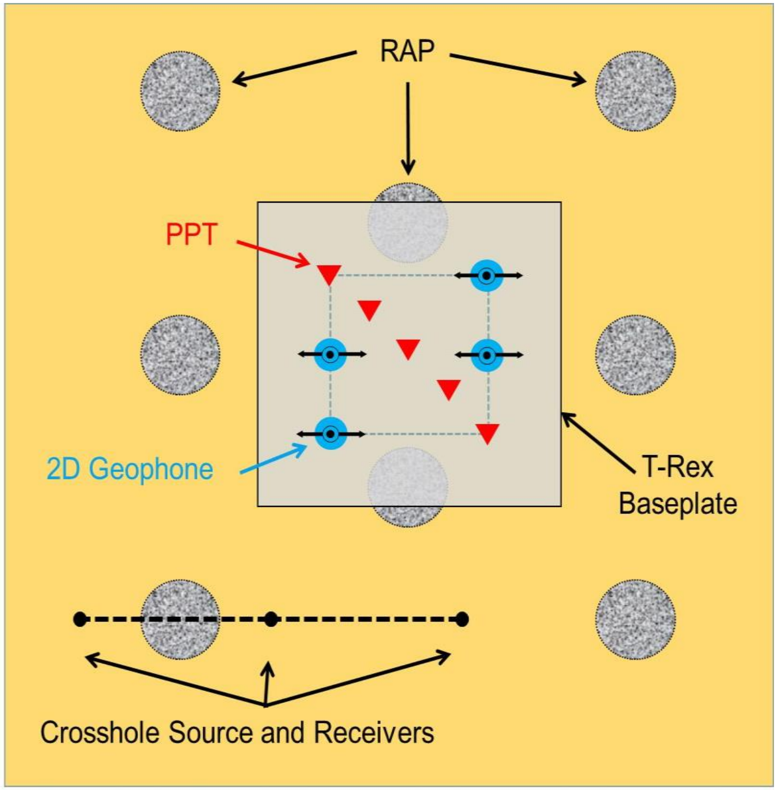


◀ **Low Mobility Grout (LMG)**

In-Situ Liquefaction Testing with T-Rex

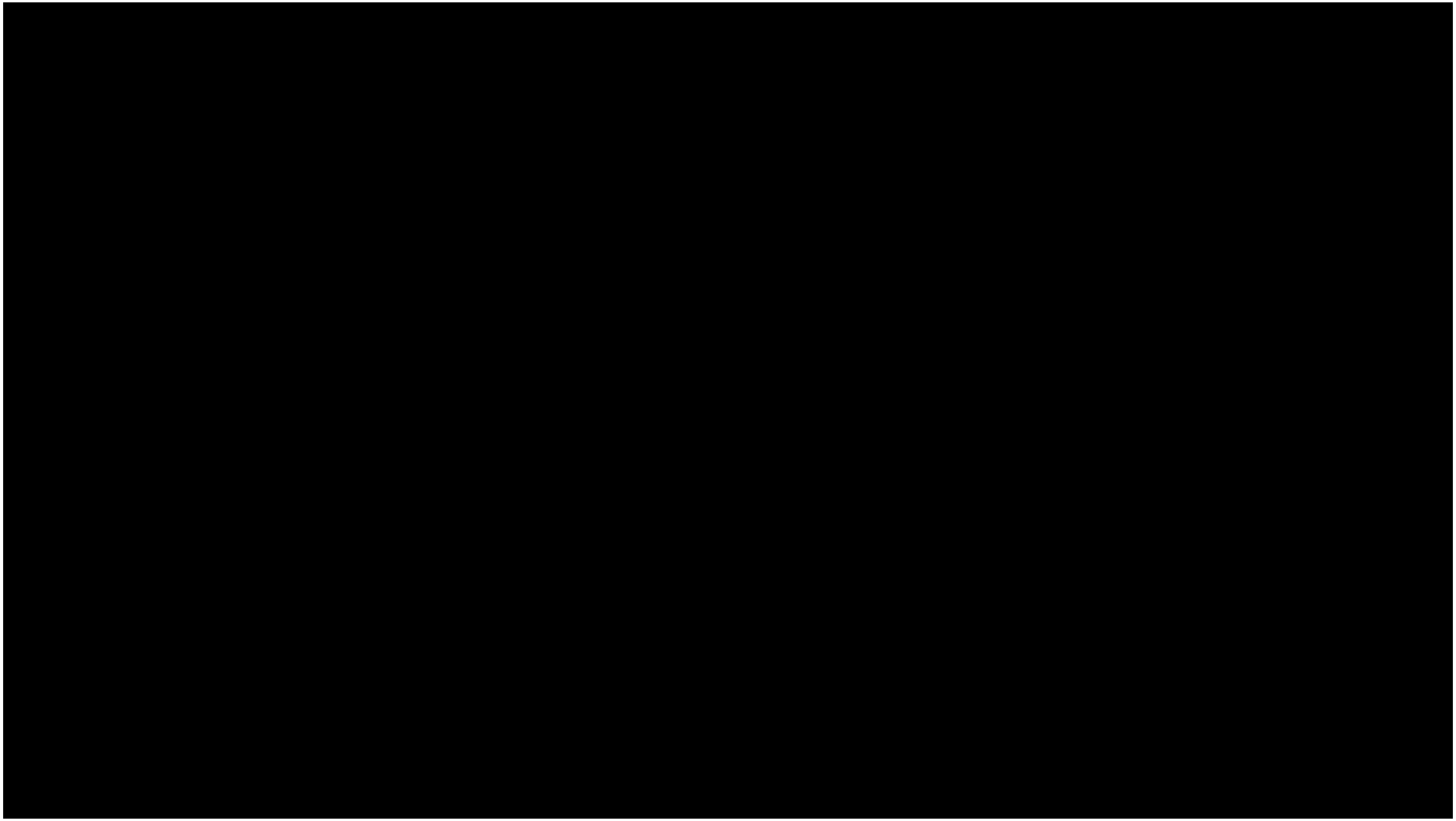


a. Cross-sectional perspective of T-Rex in place to shake the RAP.



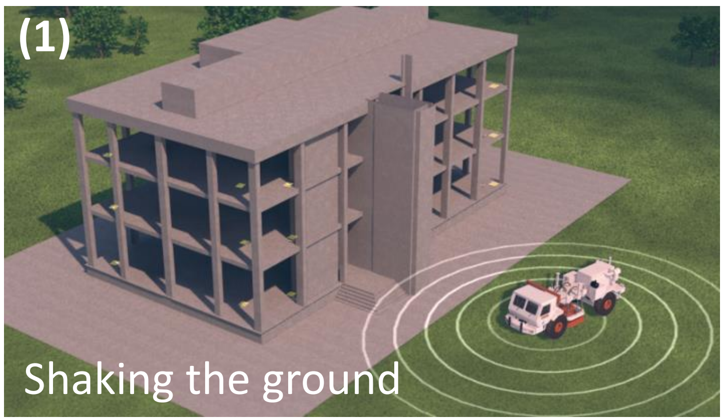
b. Plan view of central portion of RAP test panel

Ground Improvement Trials Video



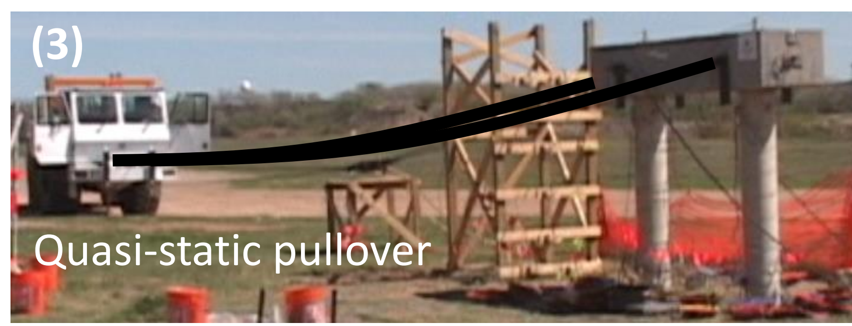
Science Plan #3:

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:

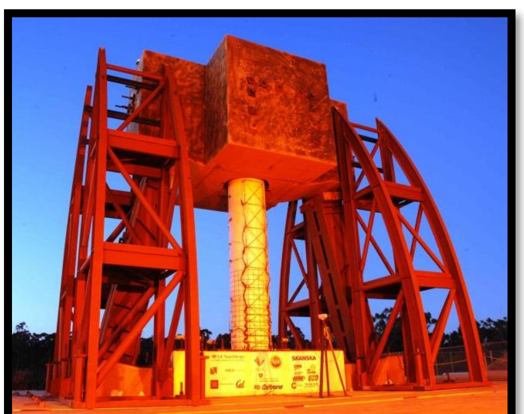
(1) Shaking ground around a structure
(2) Shake the structure directly
(3) Quasi-static pullover



Structural Testing

- In the lab…

Hybrid testing at Lehigh



Shake table testing at UC San Diego

- In the field…

Complex soil conditions

Corrosion

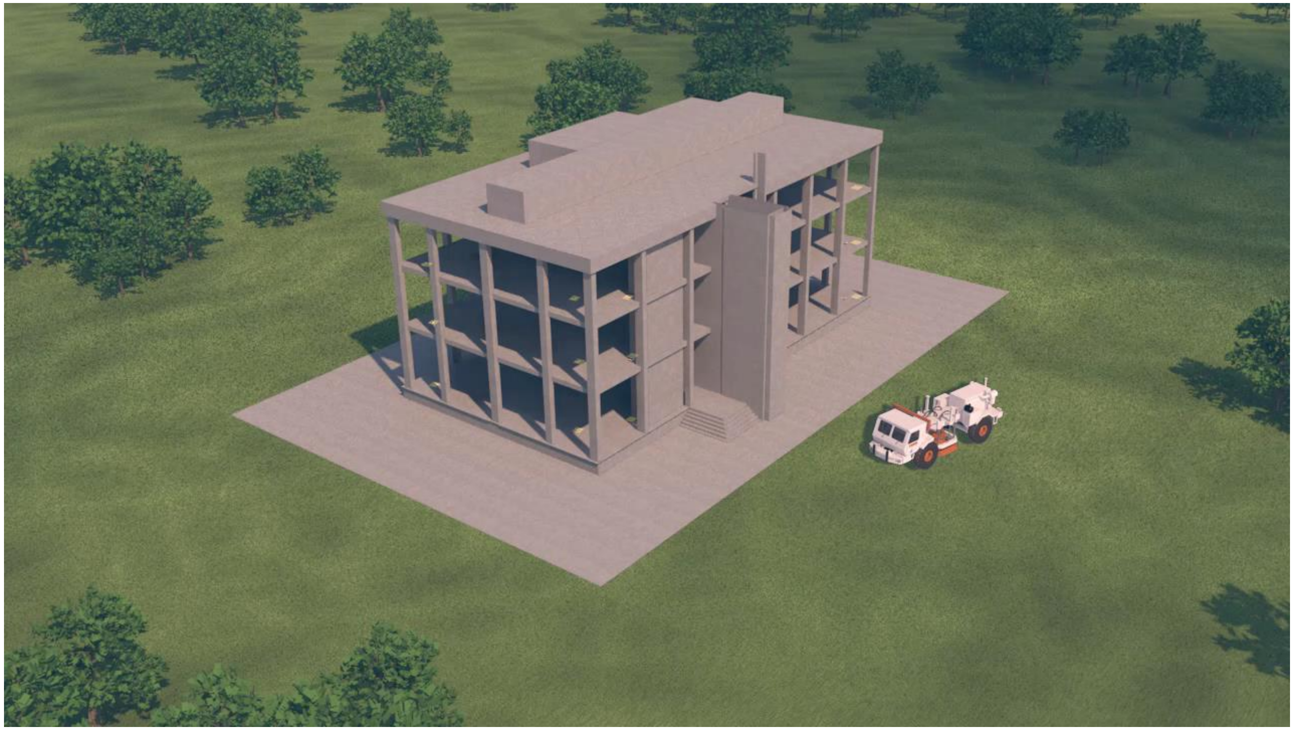
Scour

Degradation (below ground/water)

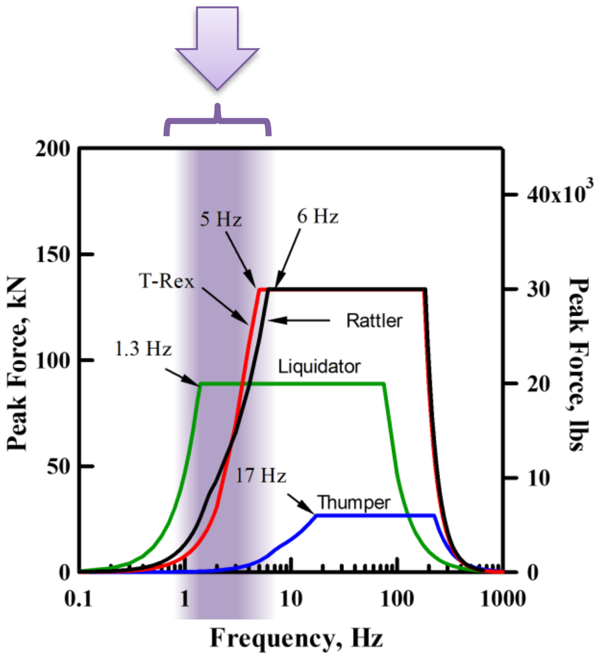
NEES@UTexas Project Highlight

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

Typical Structures

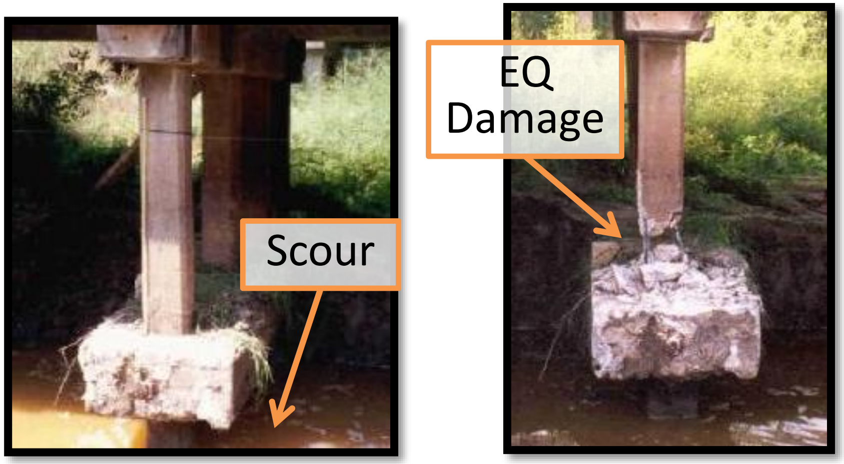


Fundamental frequency range for:
- Typical bridges
- Low-rise reinforced concrete and steel buildings
- Wood residential buildings
- Large-scale specimens

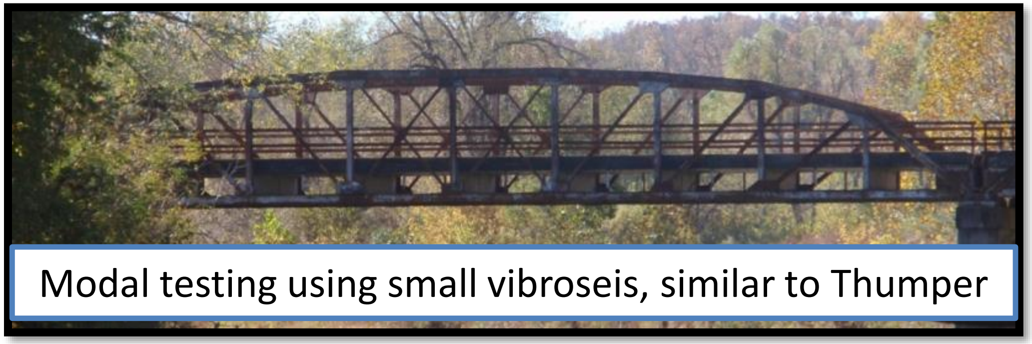


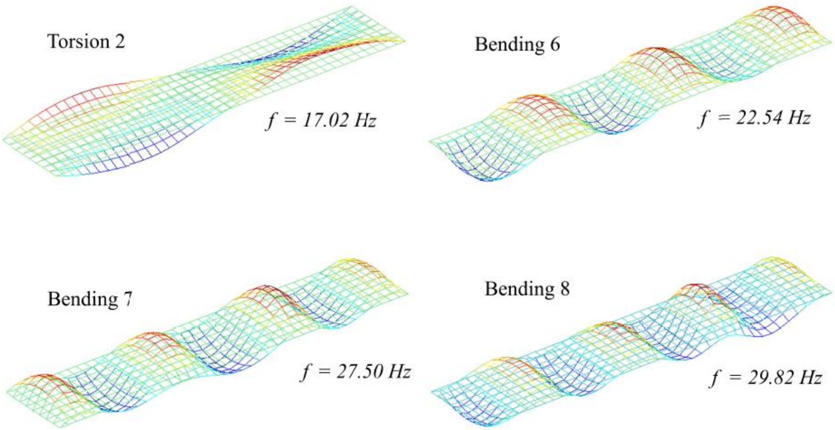
Horizontal force output

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

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

Budget worksheet posted on DesignSafe-CI

Step1 Estimated total time needed for the testing			
Estimated time required for testing	30	hours	include shaking + relocating shaker
Realistic estimatimation of required time	60	hours	* 2 for Try out + mistakes + DAQ malfunction + others
Total days of testing	10	days	6 hours of vibration each day
Travel	4	days	4 travel days to and from Austin + 4 * 0.5 days fr
weekends	2	days	UT personnel is required to take one day off
Days in the field	16	days	
Step 2: Estimated equipment costs			
T-Rex			
Vibraton	$1,620		▪ Vibrator oper
Tractor-Trailer			
Highway	$4,260		▪ weight permit + $1.13 fuel)
Fuel-Supply Pickup Truck			
Highway			(fuel cost only)
Recording equipment			porject
Instrumentation Trailer			pported porject
Total			Account category: Material and supply
Step 3: Estimated tra			
people	$6,000		▪ 3 people * days
rline tickets	$500		▪ 1 person 1 trip
Rental van	$500		
eakdown induced travel*			20% of estimated NHERI-EF@UTex of the NHERI-EF@
Total Travel	$7,000		Account category
Step 4: Estimated other cost			
Material and supply	$500		
Mobile phone service in the field			no charge for NSF supported project
Site liability insurance**			
Total Others	$500		Account category: Material and supply
Step 5: Estimated total cost			
Total direct cost	$14,280		
Indirect cost (55% overhead)	$7,854		Account category: Overhead
Total Cost	**$22,134**		

NSF user pays only for fuel for truck(s), truck shipment, and personnel travel

$22,134
(for this example)

THE UNIVERSITY OF TEXAS AT AUSTIN

NHERI@UTexas

"The nation is our laboratory"

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

Step1 Estimated total time needed for the testing

Estimated time required for testing	30	hours	include shaking + relocating shaker
Realistic estimatimation of required time	60	hours	* 2 for Try out + mistakes + DAQ malfunction + others
Total days of testing	**10**	**days**	6 hours of vibration each day
Travel	4	days	4 travel days to and from Austin + 4 * 0.5 days from site
weekends	2	days	UT personnel is required to take one day off for e
Days in the field	**16**	**days**	

Step 2: Estimated equipment costs

T-Rex			
	Vibraton	$10,200	▪ Vibrator operating ti
Tractor-Trailer (Big Rig)			
	Highway	$9,580	▪ 1000 mi ... mit + $3.79 per mile)
Fuel-Supply Pickup Truck			
	Highway	$1,260	... only)
	Recording equipment	$1,7	... per week * 4 (16 channels total)
Instrumentation Trailer			
	Total Equip		...egory: Material and supply

Step 3: Estimated travel co

	$6,000	▪ 3 people * days in the field * $125 /day / person
...ets	$500	▪ 1 person 1 trip
...ental van	$500	
...nduced travel*	$1,400	2
Total Travel	$8,400	A

...p 4: Estimated other cost

Material and supply	$500	
Mobile phone service in the field	$100	
Site liability insurance**	$3,000	
Total Others	$3,600	A

Non-NSF user pays for truck fuel and shipment, personnel travel & overtime + equipment usage fees

Step 5: Estimate of personnel cost

2 Technicians	$33,106	▪ 2 people *(days in the field + 6 days of preparations) * 11hr/day * $57/hr./person * 1.2 to account for overtime pay
1 Engineer	$25,265	▪ 1 person *(days in the field + 6 days of preparations) * 11hr/day * $57/hr./person * 1.2 to account for overtime pay
Total Personnel	$58,370	Account category: Salary

Step 6: Estimated total cost

Total direct cost	$93,441	
Indirect cost (55% overhead)	$51,393	Account category: Overhead
Total Cost	**$144,834**	

Budget worksheet posted on DesignSafe

$144,834 (6.5x more for this example)

Additional Information

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- NHERI@UTexas website at www.designsafe-ci.org for Webinar slides & budgetary information are posted

Thank you for your help in this workshop:

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