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:
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UT Austin, Dept. of Civil, Architectural, and Environmental Engineering (CAEE)

Co-Principal Investigators:
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UT Austin, CAEE

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15 December 2015

NSF Engineering for Natural Hazards (ENH) Program

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 Thereafter
Natural Hazards Engineering Research Infrastructure (NHERI)

7 Experimental Facilities (EF’s) with Large-Scale Equipment
1 Cyberinfrastructure Facility for Archiving and Sharing Data

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

University of Texas at Austin
Pickle Research Campus (PRC)

University of Texas at Austin
Main Campus

Introduction to NHERI@UTexas

Marketing & Science Plan

People  Facility  Shakers  Instrumentation  Year 1 Plan  2D/3D Imaging  In-situ Liquefaction  Structures

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

Horizontal force output

Vertical 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
Liquidator – Standard Configuration

Liquidator – Special Configuration
Raptor

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

Rattler

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

Big Rig

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

Field/Fuel Truck

Trailer #1 (with A/C)

Provide fuel, storage, and workspace in the field

Instrumentation Van

Trailer #2

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

The nation is our laboratory
**Instrumentation – Sensors**

- 109, 1-Hz Geophones
  - 85 vertical & 24 horizontal
  - 15,000 ft of cable

10. Nanometrics Broadband Seismometer Stations
- 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.)
"The nation is our laboratory"

### 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
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

Retrieval:
- Shear Wave Velocity (Vs)
- P-wave Velocity (Vp)
for direct determination of elastic moduli needed in engineering analyses

NEES@UTexas Project Highlight
(CMMI-1303595)

~ 80% of buildings in CBD demolished
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

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

- T-Rex Shaking
- Linear Geophone Arrays (24-48 total)
- 3D Seismometers in Circular Arrays
**MASW Dispersion Processing/Transformation**

### 2D Transformation
- **Time (t)**
- **Frequency (F)**
- **Space (x)**
- **Wavenumber (K)**

\[ V_R = F \left( \frac{2\pi}{K} \right) \]

**Equation:**

\[ G_{ij}(f) = \frac{1}{N} \sum_{m=1}^{M} S_{im}(f) S_{jm}^{*}(f) \]

\[ F(f,k) = \sum_{i=1}^{N} \sum_{j=1}^{N} G_{ij}(f) \cdot e^{ik(x_i - x_j)} \]

---

**MAM: Ambient-Wavefield Processing**

\[ F(f,k) = \left[ \sum_{i=1}^{N} \sum_{j=1}^{N} q_{ij}(f) \cdot e^{ik(x_i - x_j)} \right]^{-1} \]

- 2D High-resolution FK (HFK) (Capon 1969)
- Vertical components = Rayleigh
- Horizontal components = Love and Rayleigh

\[ q_{ij}(f) = |G_{ij}(f)|^{-1} \]
Reliable 1D Vs Profiles to Record Depths

**Inversion Process**

- 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

**ANIMATION VIDEO**
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.
NEES@UTexas Project Highlight

“The nation is our laboratory”

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

- **Rapid Impact Compaction (RIC)**
- **Rammed Aggregate Piers (RAP)**
- **Low Mobility Grout (LMG)**

Techniques for “green” sites or demolished home sites
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

Kenneth Stokoe II, Dept of Civil Engineering, University of Texas
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)

VIDEOS

Typical Structures

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


Modal testing using small vibroseis, similar to Thumper

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

<table>
<thead>
<tr>
<th>Rate Name</th>
<th>Internal Rate</th>
<th>External Rate</th>
<th>Fuel Pass-through (NEES Projects only)</th>
<th>Distribution Base</th>
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</thead>
<tbody>
<tr>
<td>T-Rex</td>
<td>$165.00</td>
<td>$208.00</td>
<td>$27.00 per hour</td>
<td></td>
</tr>
<tr>
<td>Liquidator</td>
<td>$146.00</td>
<td>$184.00</td>
<td>$27.00 per hour</td>
<td></td>
</tr>
<tr>
<td>Thumper - Vibration</td>
<td>$54.00</td>
<td>$64.00</td>
<td>$9.00 per hour</td>
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<tr>
<td>Thumper - Highway</td>
<td>$1.24</td>
<td>$2.00</td>
<td>$0.70 per mile</td>
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</tr>
<tr>
<td>Big Rig</td>
<td>$4.00</td>
<td>$4.00</td>
<td>$1.13 per mile</td>
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<tr>
<td>Instrumentation Van - Highway</td>
<td>$0.86</td>
<td>$1.00</td>
<td>$0.45 per mile</td>
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<tr>
<td>Instrumentation Trailer</td>
<td>$250.00</td>
<td>$315.00</td>
<td>N/A per project</td>
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</tr>
<tr>
<td>Fuel Supply Truck - Highway</td>
<td>$0.86</td>
<td>$1.00</td>
<td>$0.45 per mile</td>
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<tr>
<td>Batter</td>
<td>$125.00</td>
<td>$157.00</td>
<td>N/A per mile</td>
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<tr>
<td>Batterer</td>
<td>$145.00</td>
<td>$183.00</td>
<td>$27.00 per hour</td>
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<tr>
<td>Data Physics 16-channel Analyzer</td>
<td>$322.00</td>
<td>$407.00</td>
<td>N/A per 4-channel per week</td>
<td></td>
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<tr>
<td>Data Physics Quattro Analyzer</td>
<td>$314.00</td>
<td>$397.00</td>
<td>Per unit per week</td>
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<tr>
<td>VXI technology 72-channel</td>
<td>$706.00</td>
<td>$892.00</td>
<td>N/A per 16-channel per week</td>
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</tr>
<tr>
<td>Trillium Compact Seismometer with Taurus DAS system</td>
<td>$457.00</td>
<td>$577.00</td>
<td>Per station per week</td>
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<tr>
<td>Core Penetration Test Equipment</td>
<td>$646.00</td>
<td>$817.00</td>
<td>Per week</td>
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</table>

Note: These are preliminary rates (Final rates to be posted in January 2016)

*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 **

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Rate/Mo.</th>
<th>Months</th>
<th>Budgeted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech - C. Hoffpauir</td>
<td>XXXX</td>
<td>0.60</td>
<td>$0</td>
</tr>
<tr>
<td>Tech - A. Valentine</td>
<td>XXXX</td>
<td>0.60</td>
<td>$0</td>
</tr>
<tr>
<td>Total Personnel</td>
<td></td>
<td>$0</td>
<td></td>
</tr>
</tbody>
</table>

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/mile $5,000
- Active Seismic Equipment (3222/wk for 4 channels x 2) $644
- Passive Seismic Equipment (10 Trillium Compacts x 457) $4,570

Travel Expenses: Field Testing (2 persons for 12 days) $32,294
- Per diem $65/day * 12 days (avg) * 2 $1,560
- Lodging: $125/night * 10 nights (avg) * 2 $2,500

Other Expenses $4,060
- None $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.

Note: Estimation Based on Preliminary Rates
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. Fanyuh Menq (Operations Manager) fymenq@utexas.edu

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

Questions?