OVERVIEW OF NEES@UTEXAS

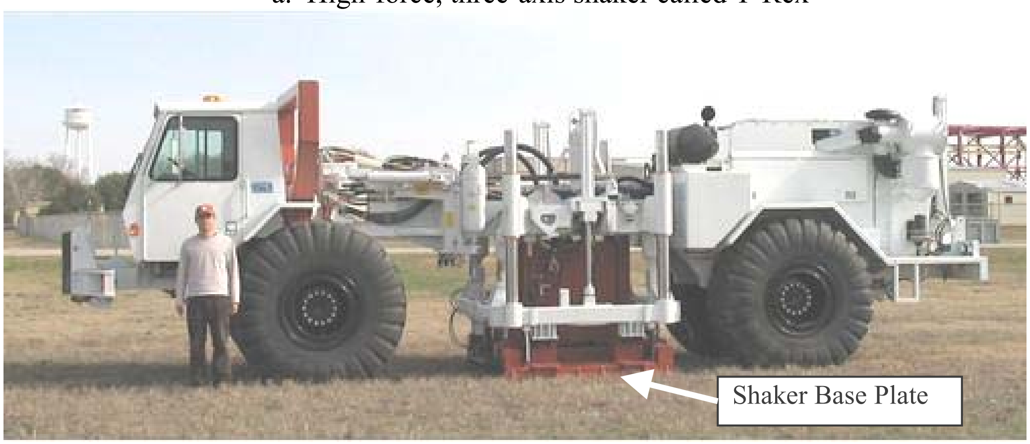
The nees@UTexas equipment includes: (1) three mobile shakers that have diverse force and frequency capabilities and a tractor-trailer rig to move the two largest shakers to and from the field sites, (2) an instrumentation van that houses state-of-the-art data acquisition systems and a satellite link-up, (3) a large collection of field instrumentation that includes wired and wireless sensors that measure vibrational motion and pore water pressure, and (4) telepresence capabilities that allow for remote participation in field experiments.

Field Mobile Shakers and Tractor-Trailer Rig

The three mobile shakers of nees@UTexas are called: (1) T-Rex, (2) Liquidator, and (3) Thumper. Each mobile shaker was designed and built by Industrial Vehicles International, Inc. (IVI), in Tulsa, Oklahoma. T-Rex was introduced by IVI in 1999 and is capable of generating large dynamic forces in any of three directions (X, Y, or Z directions). A photograph of T-Rex is shown in Figure 2a. The shaking system is housed on an off-road vehicle so that it can be operated in difficult geologic environments. Some important characteristics of T-Rex are: buggy-mounted off-road vibrator; total weight of 29,030 kg; three vibrational orientations (vertical, horizontal in-line, and horizontal cross-line); and push-button transformation of shaking orientation. Additional characteristics of T-Rex are given in Table 1. These characteristics make T-Rex an excellent vibrational source for subsurface seismic exploration and earthquake motion simulation. The theoretical performance of T-Rex (the actual force output of the shaker is site dependent) in both the vertical and horizontal modes is shown in Figure 3a. As shown in the figure, the force output in the vertical mode is about 267 kN and decreases with frequency below 12 Hz. In the horizontal mode, the maximum force output is about 133 kN, one-half of the maximum force output in the vertical mode. This force output does not begin to decrease with frequency until about 5 Hz. Several modifications to T-Rex have been made as part of the NEES project to improve its performance and capabilities for earthquake studies. The two most important modifications are: (1) addition of an electronic controller so that external drive functions can be used to drive the shaker with sinusoidal, random, or earthquake motions, and (2) control of the static hold-down system of the shaker so that variable vertical stresses can be applied to the ground surface during staged testing.

Liquidator is the other large mobile shaker. Liquidator is designed to be a lower frequency vibrator than T-Rex and is a one-of-a-kind shaker. A photograph of Liquidator during field trials in January, 2004 is shown in Figure 2b. As seen in the photograph, Liquidator has the same off-road buggy design as T-Rex, but the shaking system is specially designed to give a higher force output in the low-frequency range of 0.5 to 4.0 Hz. Some important characteristics of Liquidator are: buggy-mounted off-road shaker; total weight of 27,200 kg; two vibration orientations (vertical or horizontal transverse); shop transformable shaking orientation in about one day; movable weight of about 6100 kg; and peak-to-peak movement of 40 cm. Additional characteristics of Liquidator are given in Table 1. These characteristics make Liquidator an excellent low-frequency vibrational source for deep surface wave testing and earthquake motion simulation. The large peak-to-peak movement of the mass is required to create high force levels at low frequencies and requires a one-of-a-kind isolation system that makes Liquidator unique. The theoretical performance of Liquidator (actual force output is site dependent) in both the vertical and horizontal modes is shown in Figure 3b. As shown in the figure, the force output in both modes is about 89 kN and decreases with frequency below 1.3 Hz. Because the force from Liquidator does not start to fall off until 1.3 Hz, it can generate significantly larger forces than T-Rex in the frequency range of 0.5 to 4 Hz.

a. High-force, three-axis shaker called T-Rex



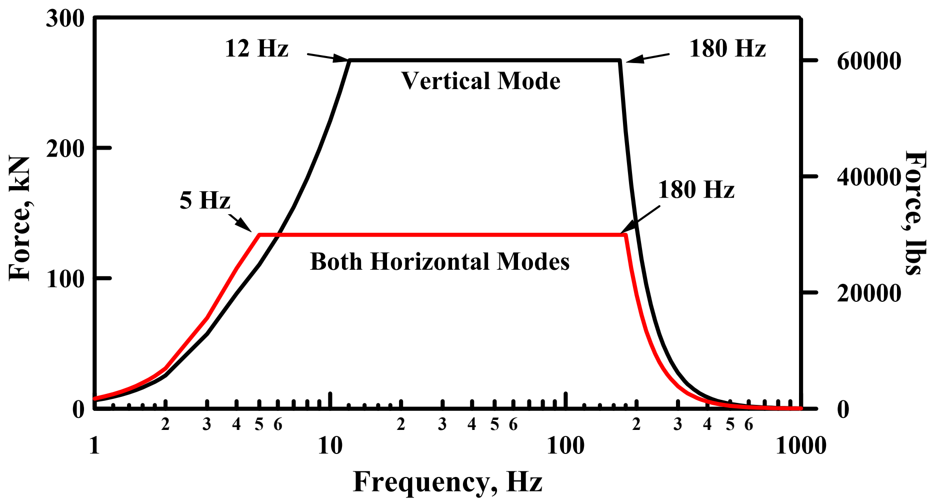
b. Low-frequency, two-axis shaker called Liquidator

c. High-frequency, three-axis shaker called Thumper

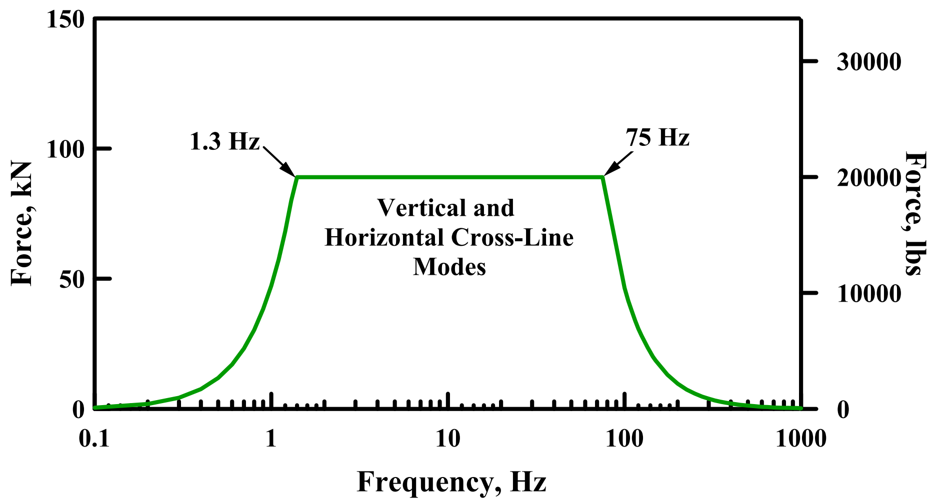
Figure 2 Photographs of the three mobiles shakers at nees@UTexas

Table 1 Characteristics of the three mobile shakers at nees@UTexas

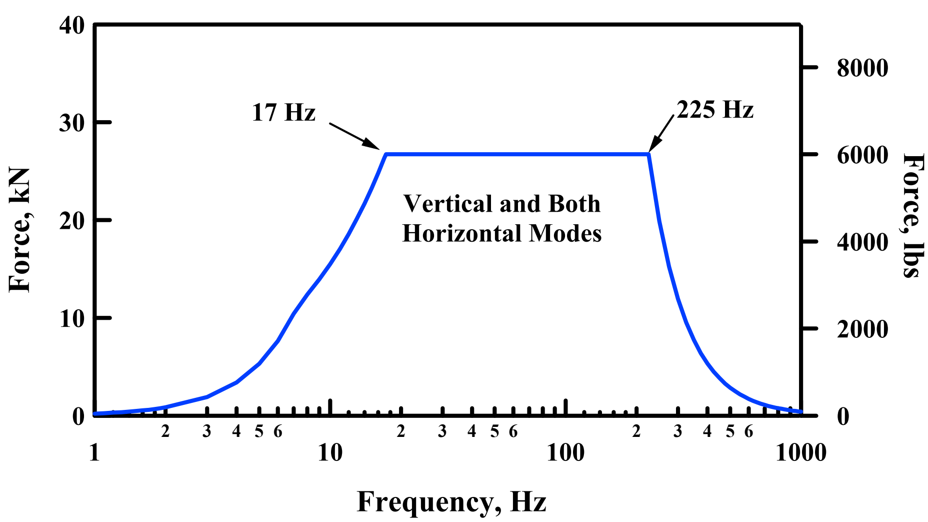
Shaker	T-Rex	Liquidator`	Thumper
Vehicle Type	Buggy-mounted shaker, articulated body	Buggy-mounted shaker, articulated body	Built on Ford F650 Truck
Driving Speed	Hydraulic drive system (<15 mph)	Hydraulic drive system (<15 mph)	Highway Speeds
Total Weight	29,030 kg (64,000 lb)	27,200 kg (59,900 lb)	9980 kg (22,600 lb)
Length	9.8 m (32 ft)	9.8 m (32 ft)	7.1 m (23 ft)
Width	2.4 m (8 ft)	2.4 m (8 ft)	2.4 m (8 ft)
Height	3.2m (10.5 ft)	3.2m (10.5 ft)	2.4 m (8 ft)
Hydraulic System Pressure	207 bar (3,000 psi)	207 bar (3,000 psi)	476 bar (4000 psi)
Vibrator Pump Flow	757 l/m (200 gpm)	530 l/m (140 gpm)	151 l/m (40 gpm)
Vibration Orientations	(1) Vertical, (2) Horizontal in-line, and (3) Horizontal cross-line	(1) Vertical, and (2) Horizontal cross-line	(1) Vertical, (2) Horizontal in-line, and (3) Horizontal cross-line
Shaking Orientation Transformation	Push-button transformation of shaking orientation	Shop transformable in about one day	Field transformable in about four hours
Maximum Output Force: (1) Vertical, and (2) Shear	(1) 267 kN (60,000 lb) (2) 134 kN (30,000 lb)	(1) 89 kN (20,000 lb) (2) 89 kN (20,000 lb)	(1) 26.7 kN (6000 lb) (2) 26.7 kN (6000 lb)
Base Plate Area	4.11 m^2 (44.2 ft^2)	4.34 m^2 (46.7 ft^2)	0.698 m^2 (7.50 ft^2)
Moving Mass: (1) Vertical, and (2) Shear	(1) 3,670 kg (8,100 lb) (2) 2,200 kg (4,850 lb)	(1) 13,475 lb (6,110 kg) (2) 13,475 lb (6,110 kg)	(1) 311 lb (140 kg) (2) 311 lb (140 kg)
Stroke (Peak to Peak): (1) Vertical, and (2) Shear	(1) 8.9 cm (3.5 in.) (2) 17.8 cm (7.0 in.)	(1) 40.6 cm (16.0 in.) (2) 40.6 cm (16.0 in.)	(1) 7.6 cm (3.0 in.) (2) 7.6 cm (3.0 in.)
Hydraulic Oil	Vegetable-based hydraulic oil	Vegetable-based hydraulic oil	Vegetable-based hydraulic oil
Special Features	(1) Cone pushing capacity (2) Hydraulic pressure take-off (3) Variable vertical hold-down force (4) Must be transported by tractor-trailer rig (5) Remote triggering (6) Measuring ground force	(1) Optimized for low freq. (down to 0.5 Hz) (2) Cone pushing capacity (3) Hydraulic pressure take-off (4) Must be transported by tractor-trailer rig (5) Remote triggering (6) Measuring ground force	(1) Built for high-frequency output (above 200 Hz) (2) Built for use in urban environments (3) Can be driven on highways (4) Remote triggering (5) Measuring ground force



a. Theoretical force output of T-Rex



a. Theoretical force output of Liquidator



c. Theoretical force output of Thumper

Figure 3 Theoretical force outputs of the three mobile shakers at nees@UTexas

Thumper is designed to be a moderate- to high-frequency vibrator used in seismic reflection and surface wave projects. A photograph of Thumper is shown in Figure 2c. As can be seen in the photograph, Thumper is housed on a much smaller vehicle, which aids in its transportation to and from sites and also allows it to be used in urban environments. Some important characteristics of Thumper are: mounted on a Ford F650 truck; total weight of about 9,900 kg; three vibration orientations (vertical, horizontal in- line, and horizontal cross-line); and field transformable shaking orientation in about four hours. These characteristics make Thumper an excellent vibrational source for shallow (depths less than 100 m) seismic reflection profiling and surface wave testing. The theoretical performance of Thumper (actual force output is site dependent) is shown in Figure 3c. As shown in the figure, the maximum force output is about 27 kN over the frequency range of 17 to 225 Hz. The force output decreases outside of this frequency band. The relatively low-force output (27 kN) makes Thumper an excellent shaker for testing in urban environments where disturbance or possible damage are concerns.

T-Rex and Liquidator must be transported to and from field sites on a tractor-trailer rig. The tractor-trailer rig that is part of the nees@UTexas vehicle fleet is shown in Figure 4. However, it is important to note that the combined weights of one of the large shakers and the tractor-trailer rig are between 45,000 and 48,000 kg. Therefore, the complete system is overweight when moving on the highways and thus requires overweight permits to transport. Also, two special features have been added to T-Rex and Liquidator to increase their usefulness. The first feature is a cone or sensor pushing capability that has been added on the back bumper. Pushing (or pulling) is done with the hydraulic cylinder controlled by a variable-flow value. This arrangement on the back of T-Rex is shown in Figure 5a. The second special feature is a hydraulic take-off so that either large shaker can be used to power other hydraulic equipment in the field. The hydraulic take-off on T-Rex is shown in Figure 5b.

Instrumentation Van and Data Acquisition Systems

The field instrumentation van is a customized Chevrolet cargo van that includes a diesel generator, an air-conditioned workspace, and a fully-integrated computational network. The instrumentation van is shown in Figure 6. The computational network includes two Sun workstations, a PC server and laptop computer, a local wireless network, and a satellite modem with up to 512 kbps transmission rate. This computational infrastructure allows for significant analytical capabilities while in the field. Additional equipment housed in the instrumentation van includes: digital video cameras, teleconferencing equipment, disk storage, and a power backup system.

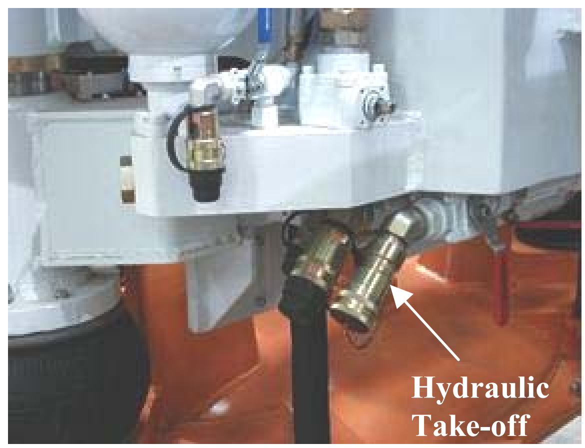
The instrumentation van also houses the two main data acquisition systems: (1) a VXI system and (2) a Sercel 408XL system. The VXI system includes 48 channels of acquisition at a sampling rate of 50 kS/s. The VXI hardware is controlled by software supplied by Data Physics. This software permits traditional data acquisition, and also has significant signal analyzer functions (e.g., swept-sine, playback, and zoom measurements). The Sercel 408XL is a state-of-the-art data acquisition system for the seismic testing and oil exploration industries. It can process up to 2,000 channels of data and is capable of connection to receivers via digital telemetry cables or via wireless radio links. Cabled receivers communicate their data over a digital network, so cables consist of only a twisted pair, making them light-weight. Wireless receivers can transmit their data from locations up to about 30 km away, depending on antenna and topographic conditions. Recording is available at 1, 2, and 4 millisecond time intervals when the wireless units are mixed with the cabled system. If only cabled receivers are in use, sample intervals as small as one-quarter millisecond are available.

Field Instrumentation

The field instrumentation available at nees@UTexas includes 1-Hz and 10-Hz geophones and a suite of in situ liquefaction sensors. Twelve sets of 3-component (3-D), 1-Hz geophones and twelve sets of 3-D

Figure 4 Photograph of the tractor-trailer rig used to transport T-Rex and Liquidator

a. Hydraulic cylinder used to push (or retrieve) sensors into ground



b. Hydraulic take-off so the pump can power other systems

Figure 5 Special features added to T-Rex and Liquidator

Figure 6 Photograph of the instrumentation van used in the field for data recording, processing, and teleparticipation

10-Hz geophones are available and are compatible with both the Sercel and VXI data acquisition systems. Sixteen additional 1-D (vertical), 1-Hz geophones are also available and compatible with both systems. The 1-Hz and 10-Hz geophones are used only for particle motion measurements (in terms of particle velocities) at the ground surface.

The in situ liquefaction sensors are being designed and constructed at the University of Texas, and will consist of three, orthogonally-oriented, 28-Hz geophones and a miniature pore pressure transducer housed in a single acrylic case. A prototype, 2-D version of this sensor, which has performed well in other studies [1, 2, 3], is shown in Figure 7. The 3-D liquefaction sensors will be relatively small, measuring about 18 cm in length and 3.6 cm in diameter, and have a total unit weight approximately equal to saturated, loose sand. The 28-Hz geophones were chosen to minimize the size of the sensors, but these geophones are not ideal for measuring vibrations at frequencies less than about 20 Hz. Therefore, additional liquefaction sensors utilizing micro-electro-mechanical-system (MEMS) accelerometers are also under consideration. The liquefaction sensors will be installed at multiple points in the ground to monitor ground motion and pore pressure generation at each point.

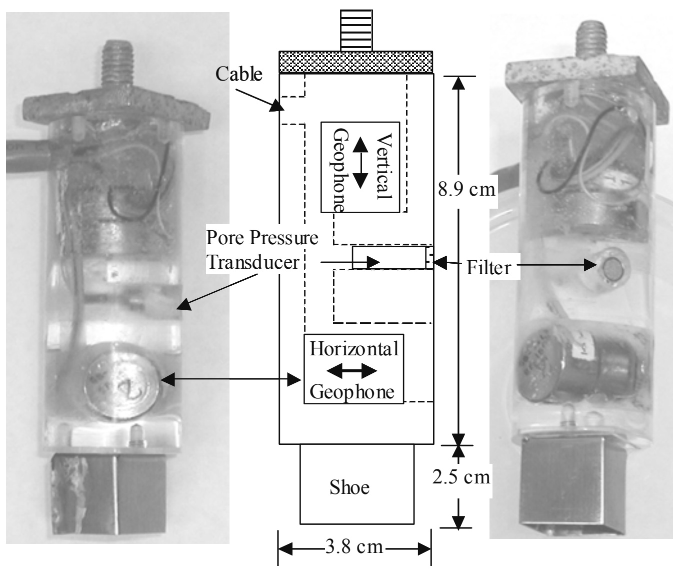


Figure 7 Schematic of in situ liquefaction test sensor used in earlier studies [1]

Remote Participation

The computational network and infrastructure housed within the instrumentation van allows for high-speed data acquisition, data viewing, and data analysis while in the field. However, a significant objective of NEES is the participation of remote researchers, as well as the general public, in experimental activities. The NEESgrid IT infrastructure (www.neesgrid.org), developed by the National Center for Supercomputing Applications at the University of Illinois, facilitates this remote usage, called teleparticipation. Specifically, NEESgrid services allow remote users to view data in real time, observe experiments, control some components of the experiment, communicate with researchers at the laboratory or field site, and link experimental data with computer simulation. To access these services, a remote user requires only internet access and a web browser.

To link the nees@UTexas field network and computational infrastructure to remote users, a satellite modem is utilized along with a NEES Point of Presence (NEESpop) server housed on the University of Texas (UT) campus. Inquiries from remote users (e.g., requests for data channels, video) are routed first to the NEESpop at the UT campus, rather than directly to the NEESpop in the field instrumentation van because of the limited bandwidth (512 kbps) across the satellite modem. The campus NEESpop then requests the data from the field NEESpop, the field NEESpop transmits the requested data, and the campus NEESpop multiplexes that data over the high-speed internet to the remote users who requested it. This command structure minimizes the amount of data transmitted over the limited bandwidth of the satellite modem.

There are several NEESgrid telepresence activities supported by nees@UTexas. Two digital cameras send visual data of field experiments to remote viewers. One camera also allows remote users to control its pan, tilt position and zoom level. Video teleconferencing between field personnel and remote users is available through Polycom hardware and software. Remote users can view multiple channels of data in near real-time, and can download data from the campus NEESpop via gridFTP shortly after experiments are over. These telepresence capabilities allow real-time interactions between field and remote researchers, improving the field experiment process.