Large Mobile Shakers for Natural Hazard Field Studies to Develop Resilient and Sustainable Infrastructure (Award CMMI-1520808, 2016-2020)

NHERI Experimental Facility, NHERI@UTexas

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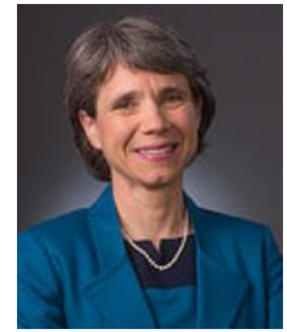
Stiffness-based Ground Improvement Monitoring Workshop

Co-hosted by Prof. Arash Khosravifar at Portland State University, and Prof. Ed Kavazanjian at the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) at Arizona State University
Portland, OR, September 11-12, 2019

NHERI@UTexas Technical Personnel



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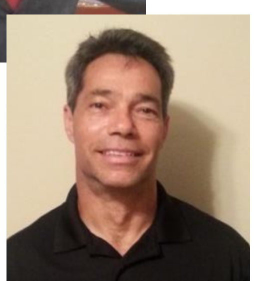


Hydraulics Technician
Andrew Valentine
UT Austin

Mobile Shaker Specialist
Cecil Hoffpauir
UT Austin

NHERI@UTexas - Building 46

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

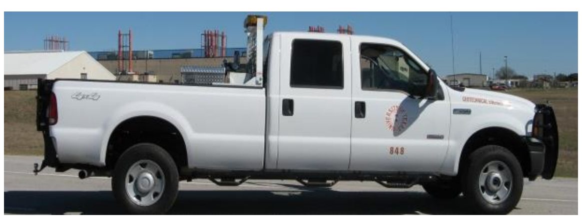
Liquidator (Low Frequency Shaker)
- Off-road buggy; weight = 72,000 lbs
- Two vibrational orientations
- Shear mode Peak Force = 20,000 lbs
- Vertical mode Peak Force = 20,000 lbs

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

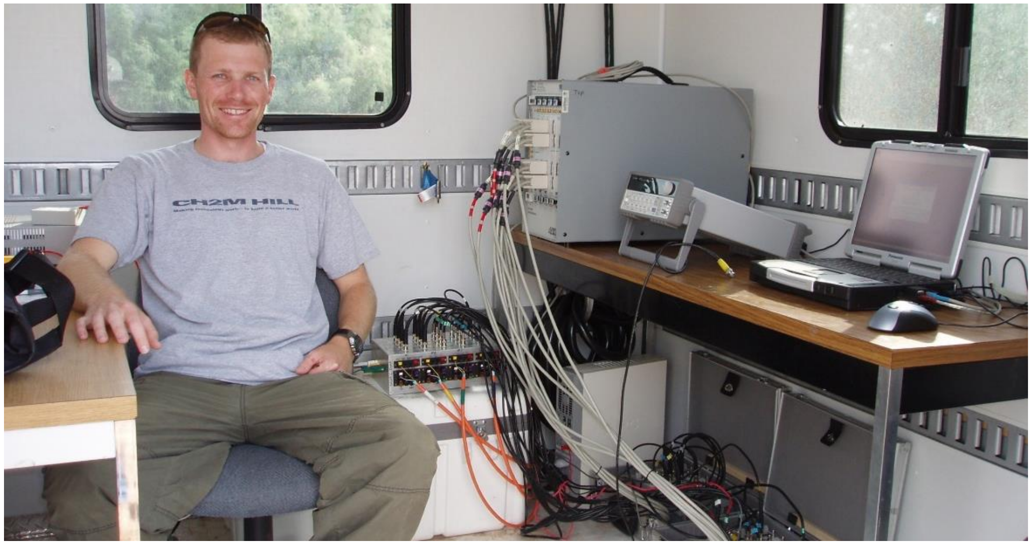


Field-Support Truck
- Carries diesel fuel for T-Rex and Liquidator
- Acts as a working platform for maintenance

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

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

↑

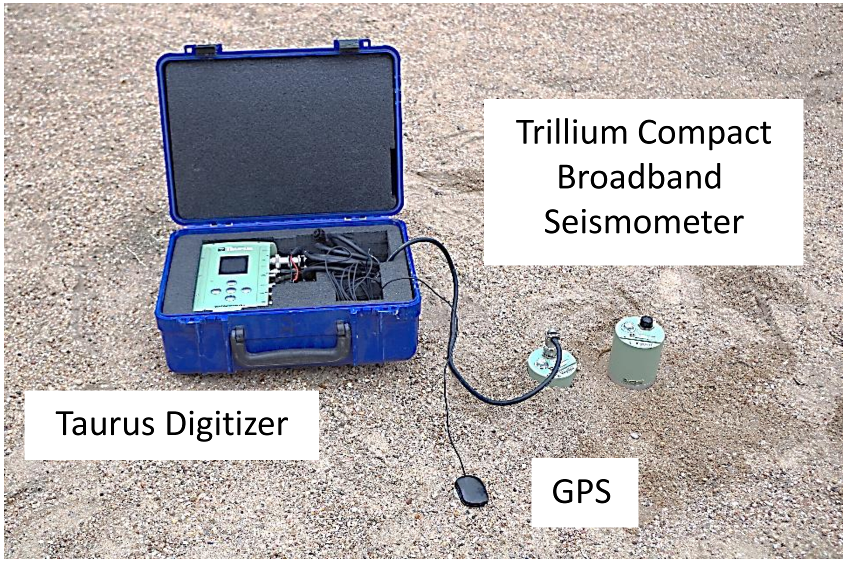
64-channel Data Physics DAQ

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

Instrumentation – Sensors

109, 1-Hz Geophones

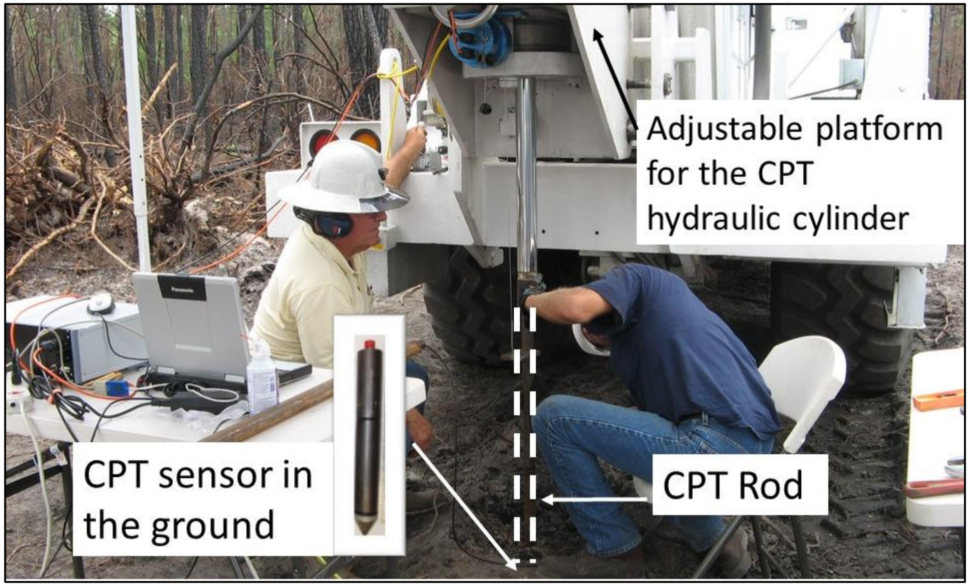
- 85 vertical & 24 horizontal
- 15,000 ft of cable



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

<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

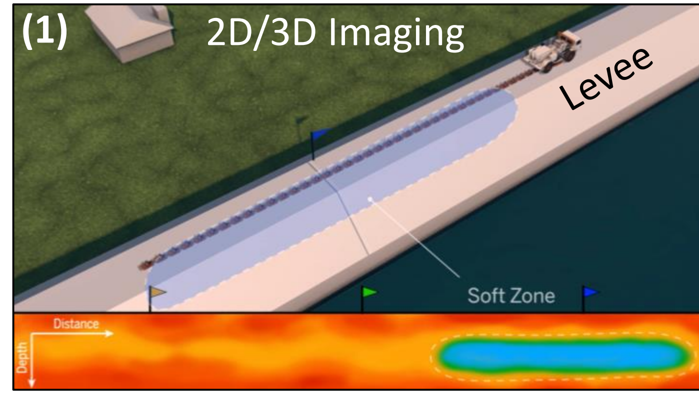
Free to NSF-funded projects
*PI pays for shipping & travel expenses

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

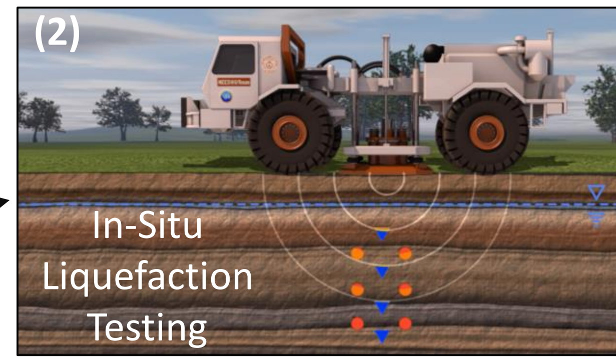
Proof-of-Capability Workshops

- 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

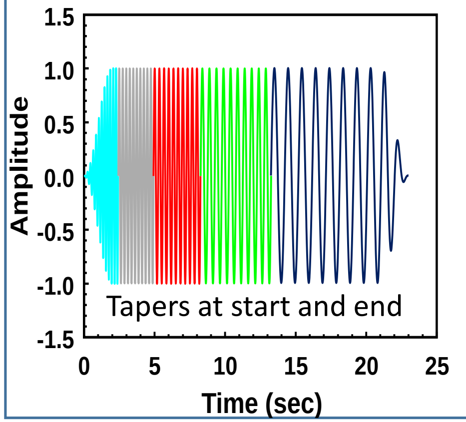

Liquefaction testing workshop

Example Field Studies of the Natural and Built Environments Using Large Mobile Shakers

Eight projects illustrating the use of the unique resources of NHERI@UTexas that include:

(a) shallow to very-deep noninvasive surface wave testing,
(b) deep downhole testing,
(c) parametric studies of linear and nonlinear shear stiffnesses,
(d) liquefaction testing, and
(e) dynamic and cyclic structural testing.

1. Shallow, Noninvasive, Active-Source, Surface-Wave (SASW) Testing of a Dam Spillway on Rock



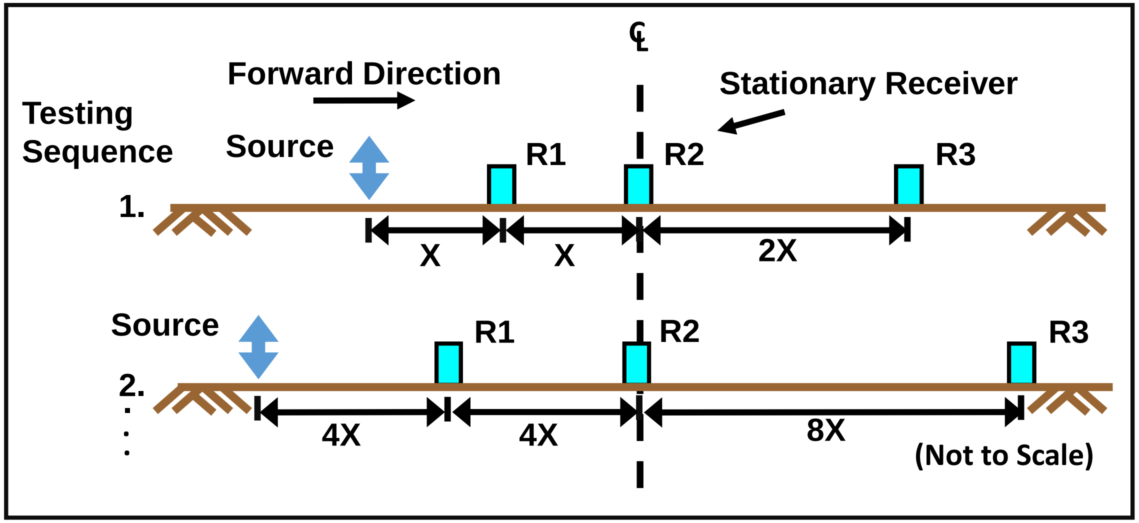
<u>Key Parameters</u>:

1. **Frequency range:**
   500 to 5 Hz

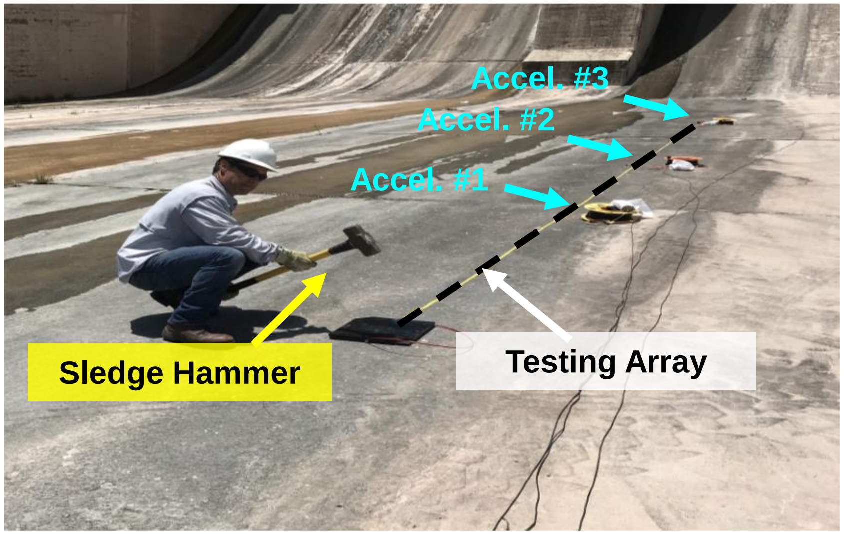
2. **Frequency range varies with receiver spacing:**
   shorter = 7.25 m: 500 to 5 Hz
   longer = 22.5 m: 350 to 5 Hz

3. **Approx. 100 frequency steps in each sweep.**

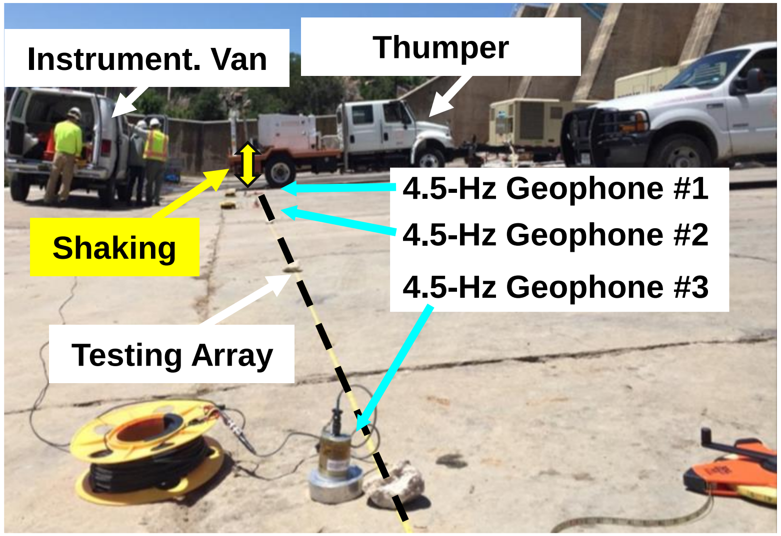
Examples of SASW Testing in the Dam Spillway Area



(a) Multiple source-receiver position; Common-middle-receiver-geometry

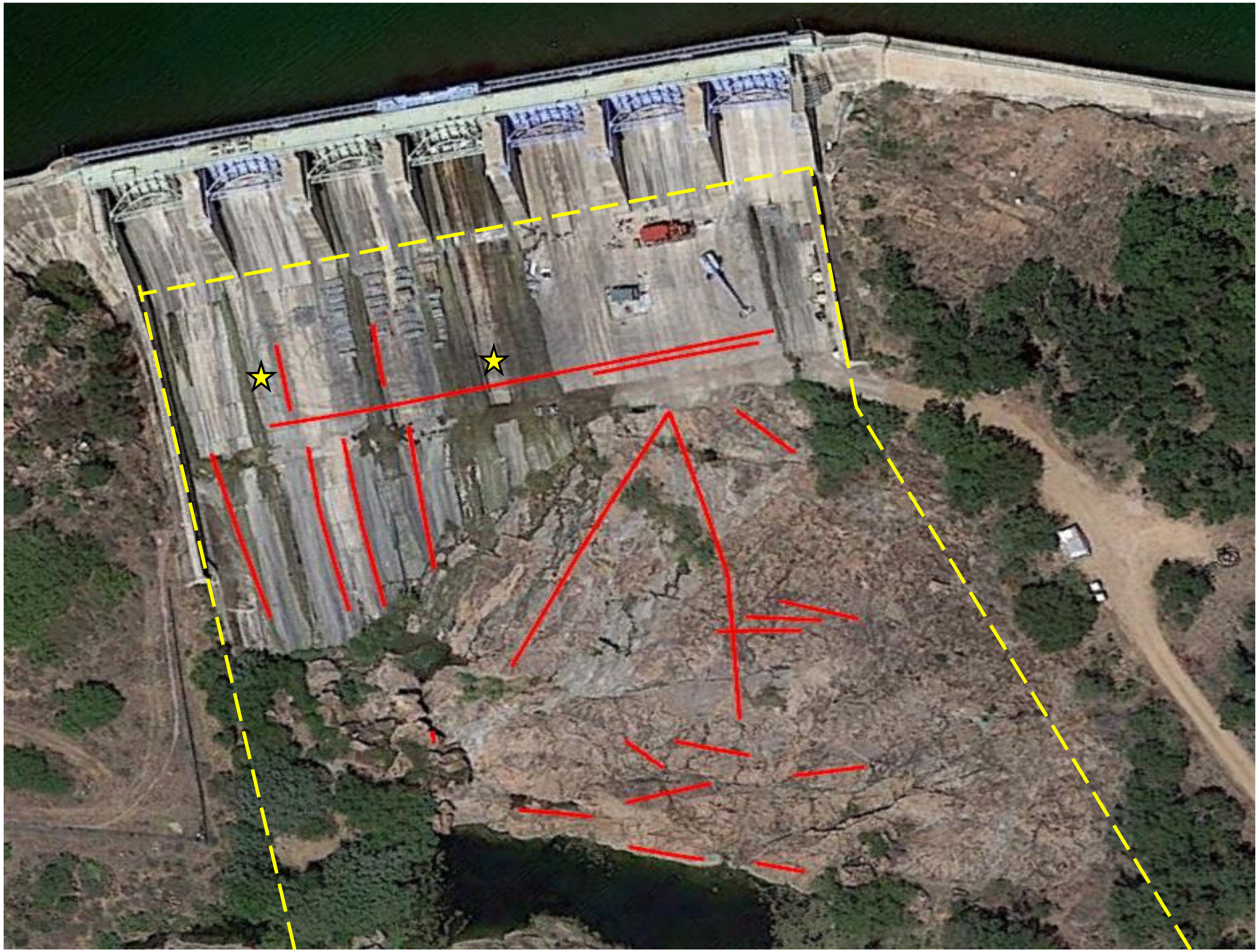


(b) Shorter source-receiver positions

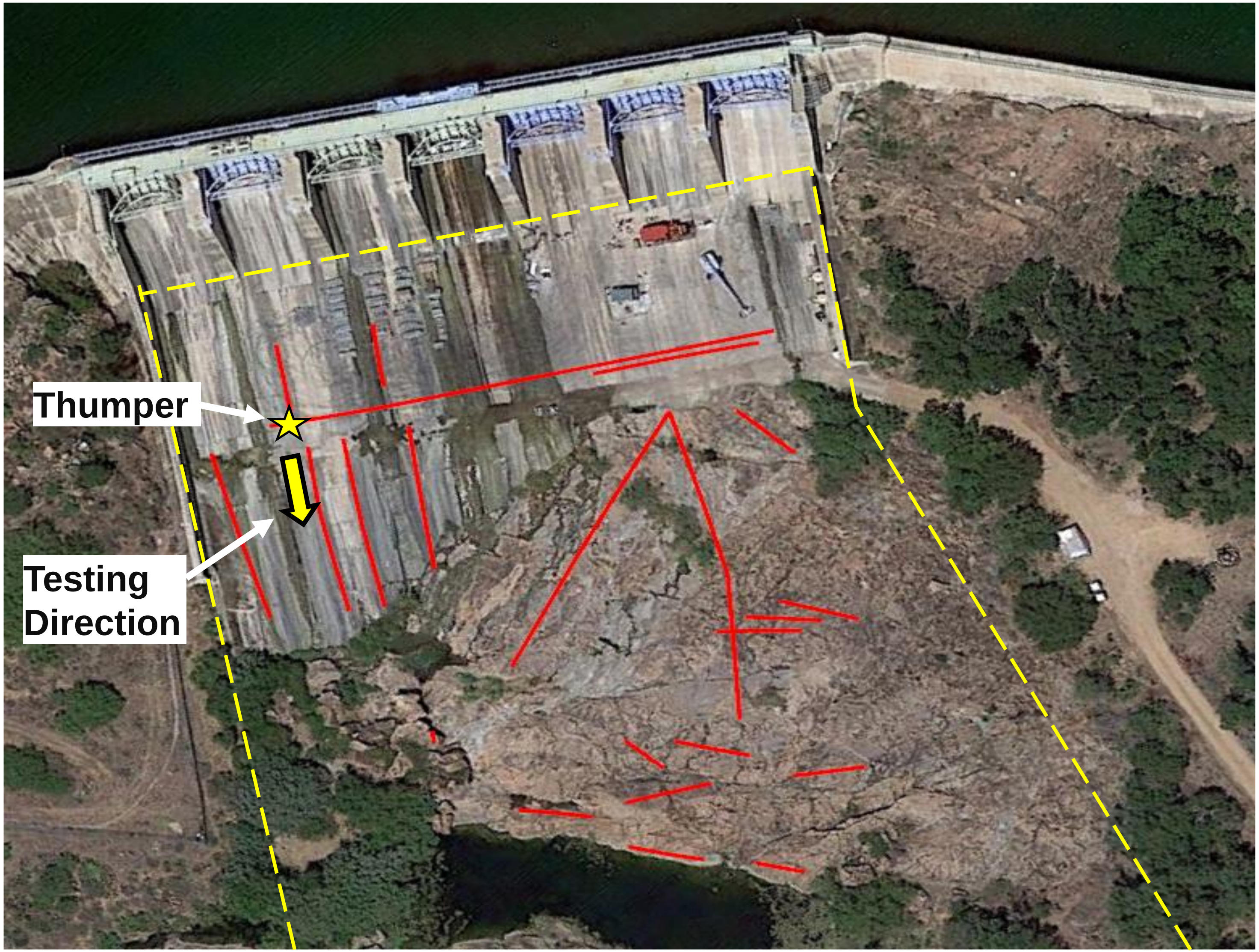


(c) Longer source-receiver positions

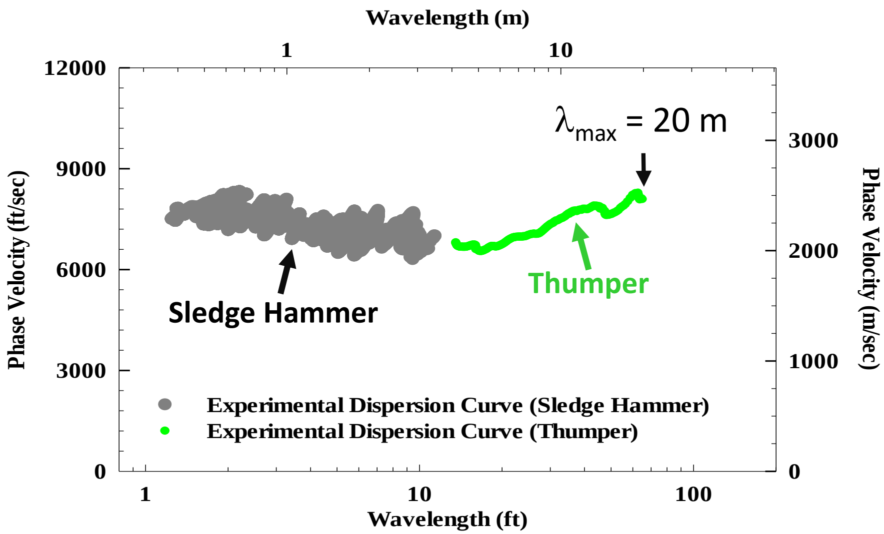
Locations of 22 SASW Testing Arrays; Profiling Depths from 2 to 25 m



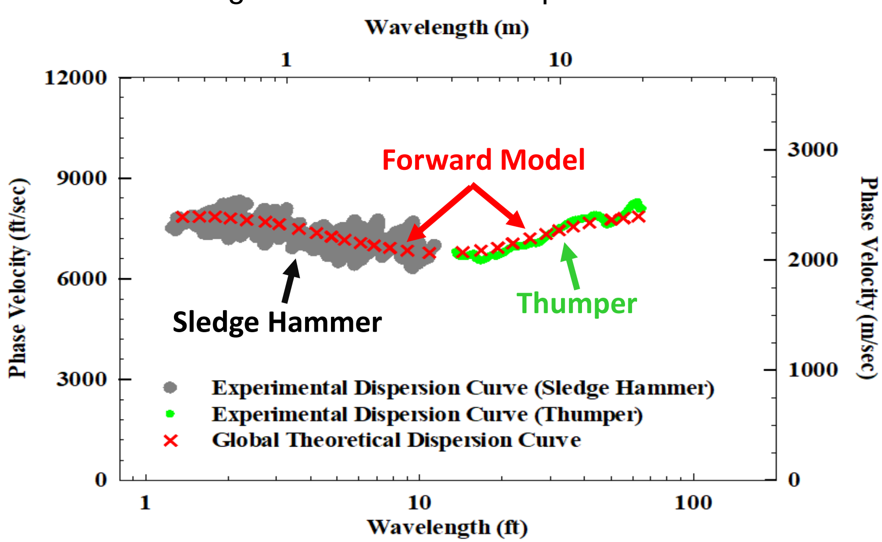
Example SASW Testing Results at One Location in the Dam Spillway Area



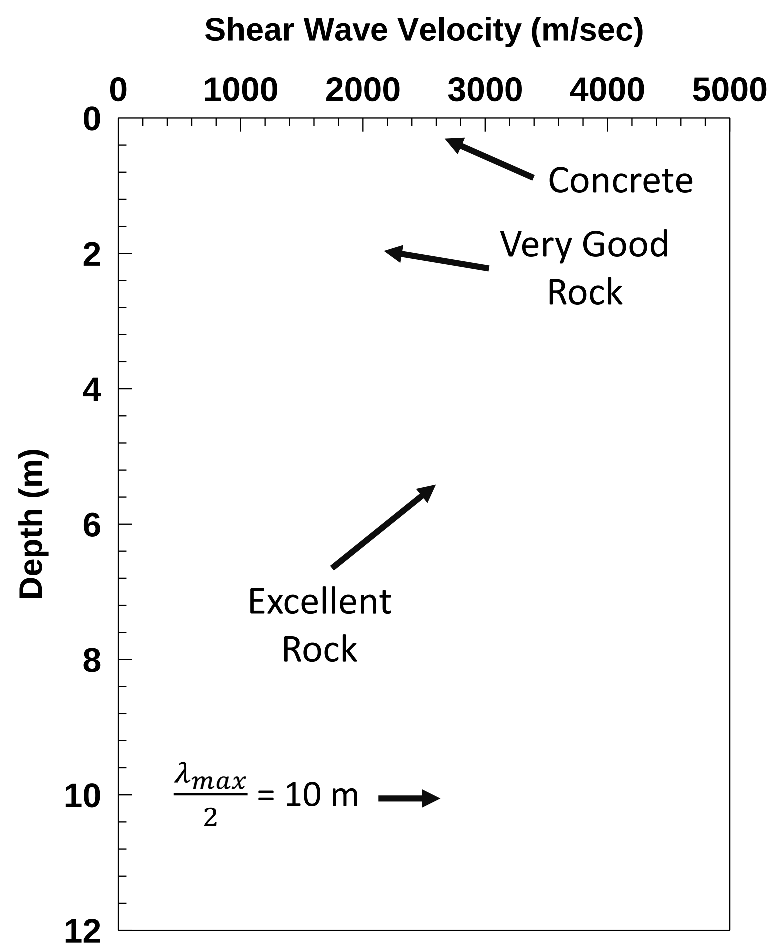
Example Measurements and Resulting V_S Profile



(b) Composite dispersion curve using sledge hammer and Thumper as sources

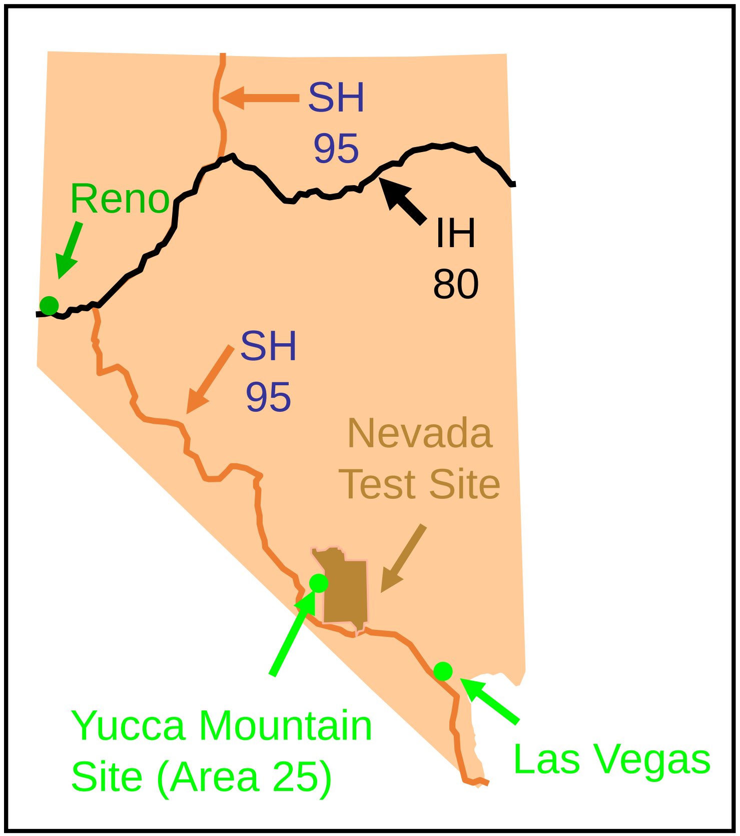


(b) Forward Modeling to fit the experimental dispersion curve with a global theoretical dispersion curve



(c) V_S profile determined from forward modeling

2. Deep (> 300 m) V_S Profiling on Top of Yucca Mountain, NV, using Liquidator as the Active, Low-Frequency Source

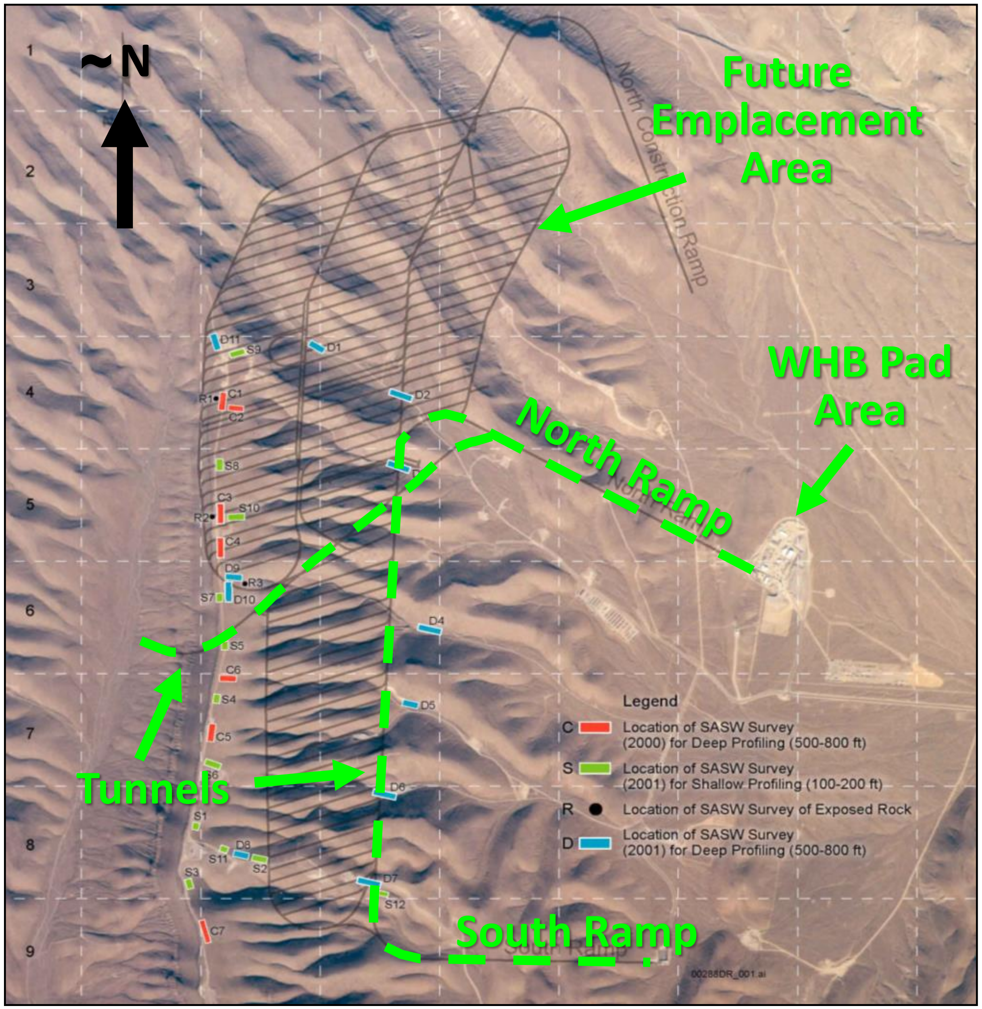


(a) Map of Nevada

(b) Liquidator shaking on Yucca Mountain

(c) Generating surface waves up to 900 m long

SASW Testing in the Exploration Site Facility (ESF) Tunnel in Yucca Mountain

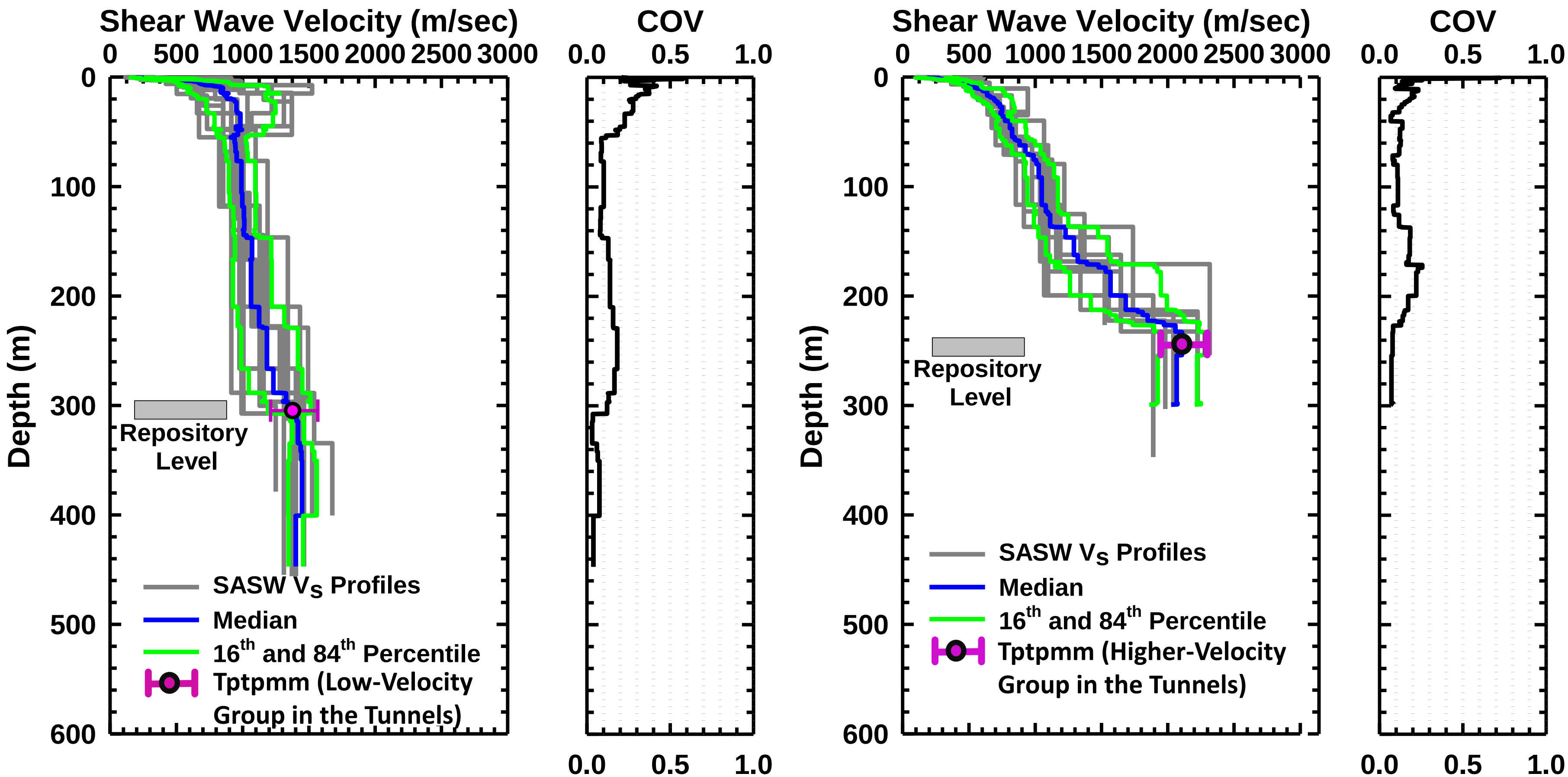


(a) SASW testing locations at Yucca Mountain

(b) SASW testing within the tunnel

(c) Complexity in the rock structure

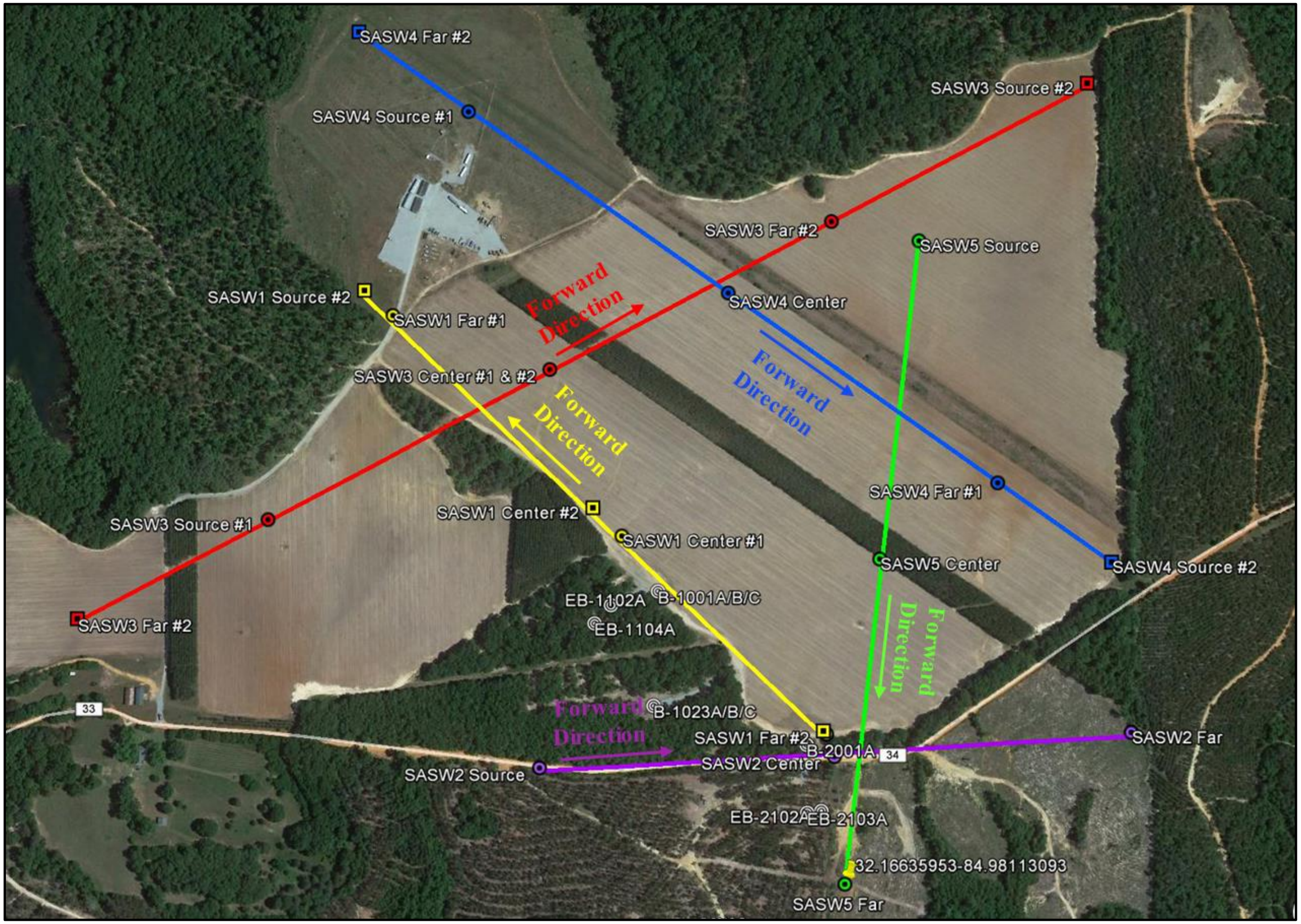
Comparison of Two Groups of V_S Profiles Determined in Two Different Areas at the Yucca Mountain Site (with comparisons of V_S measured in the tunnels)



(a) Nine “Softer Sites in Group 1

(b) Eight “Stiffer” Sites in Group 2

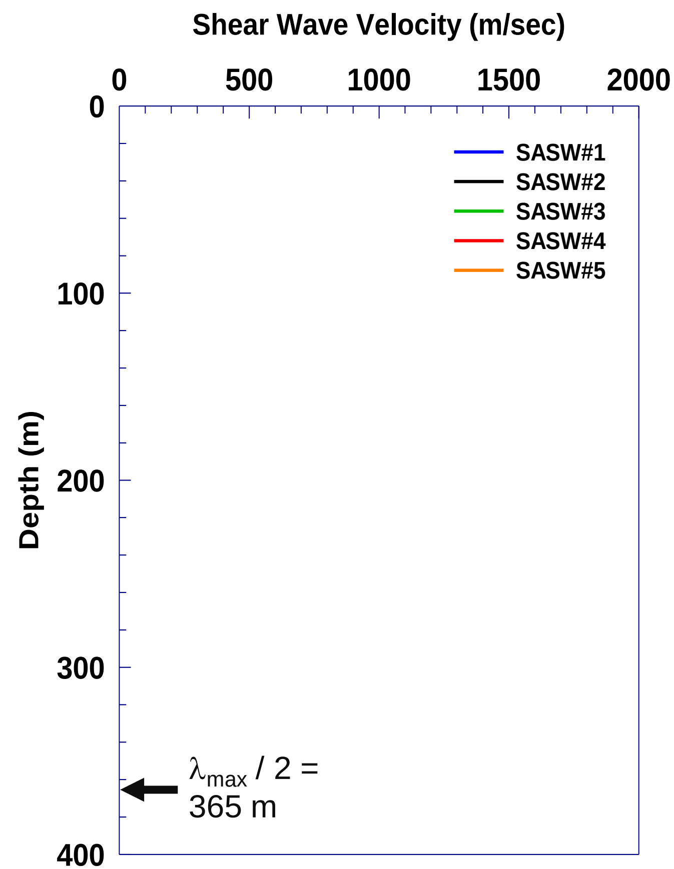
3. Very-Deep (> 500 m) V_S Profiling at a Greenfield Site in Georgia, USA, using Liquidator as the Low-Frequency Source



Site map showing the 5 SASW arrays

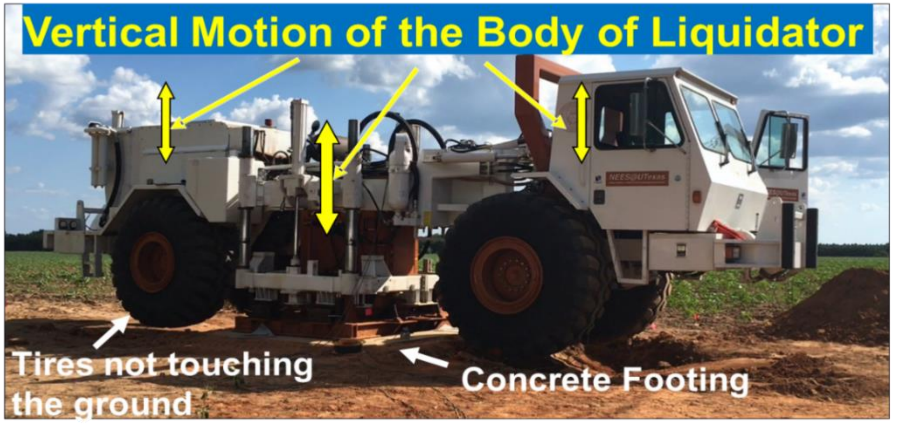
Initial SASW Profiling with Liquidator in the Normal Operating Mode at the Greenfield Site

(a) Normal operating mode

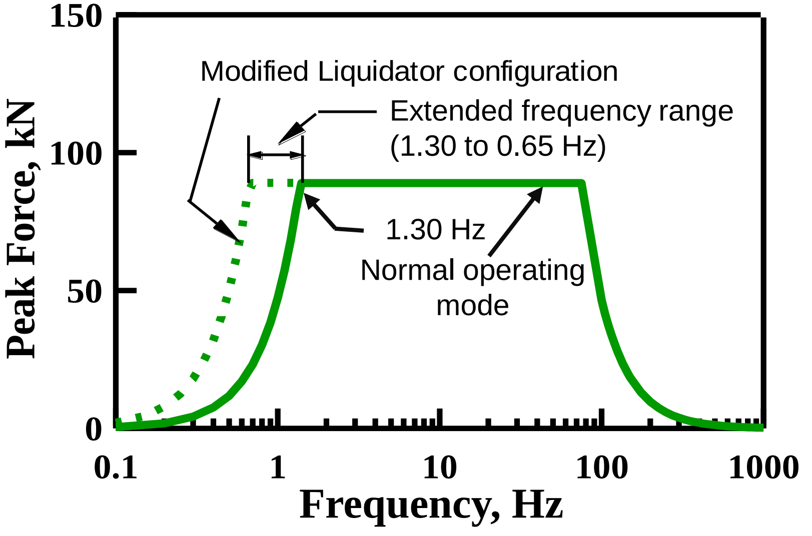


(b) Typical profiling depth

Special Low-Frequency Operating Mode with Liquidator at the Greenfield Site

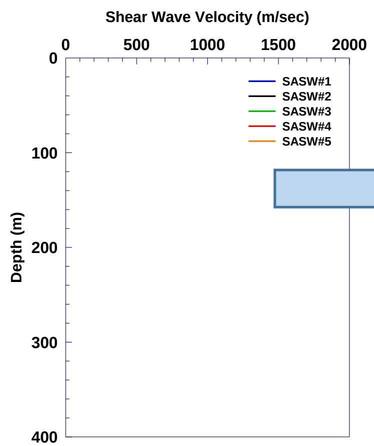


(a) Liquidator shaking in the modified mode where the 25-kg body of Liquidator moves up and down

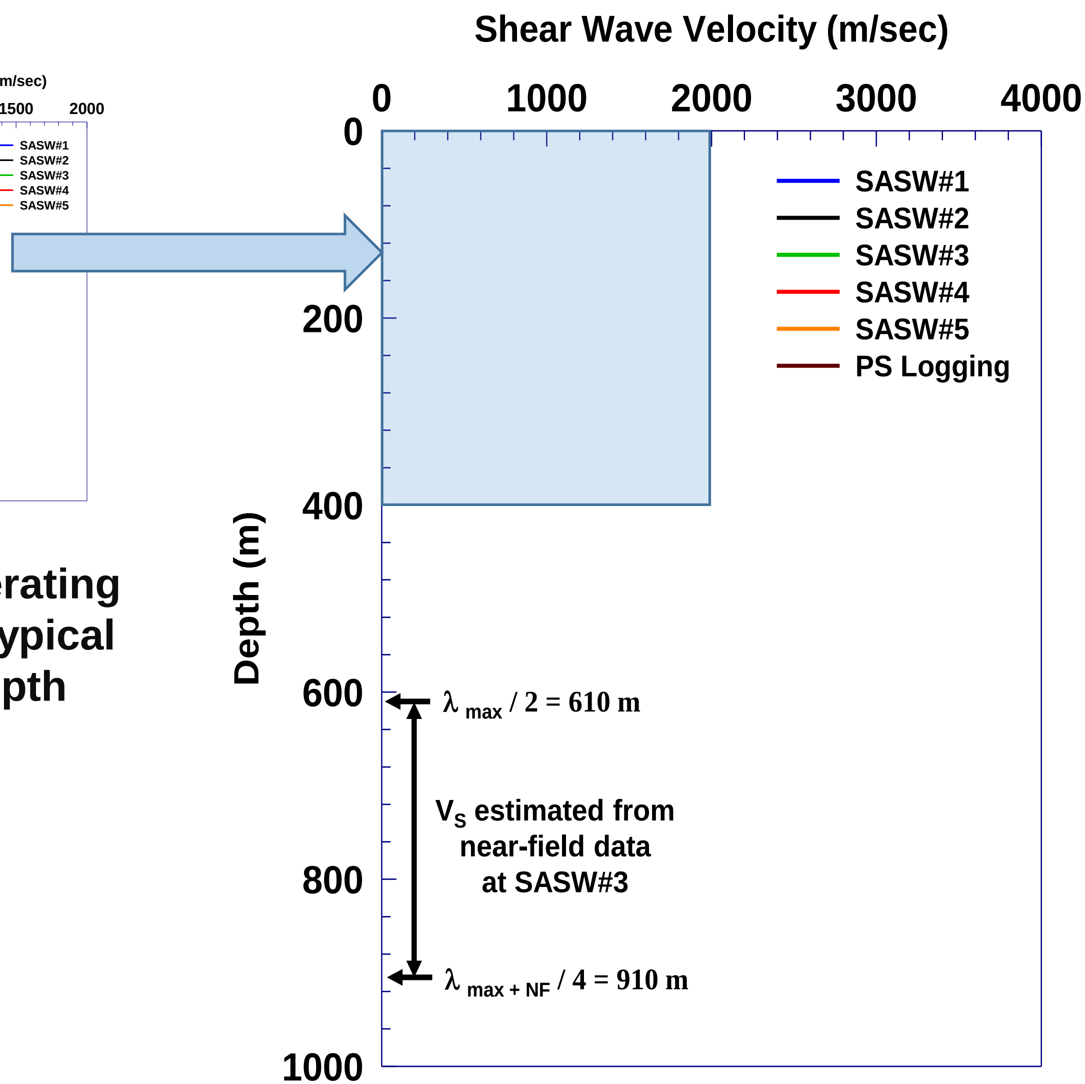


(b) Extended low-frequency shaking range

Active-Source, Very-Deep V_S Profiling

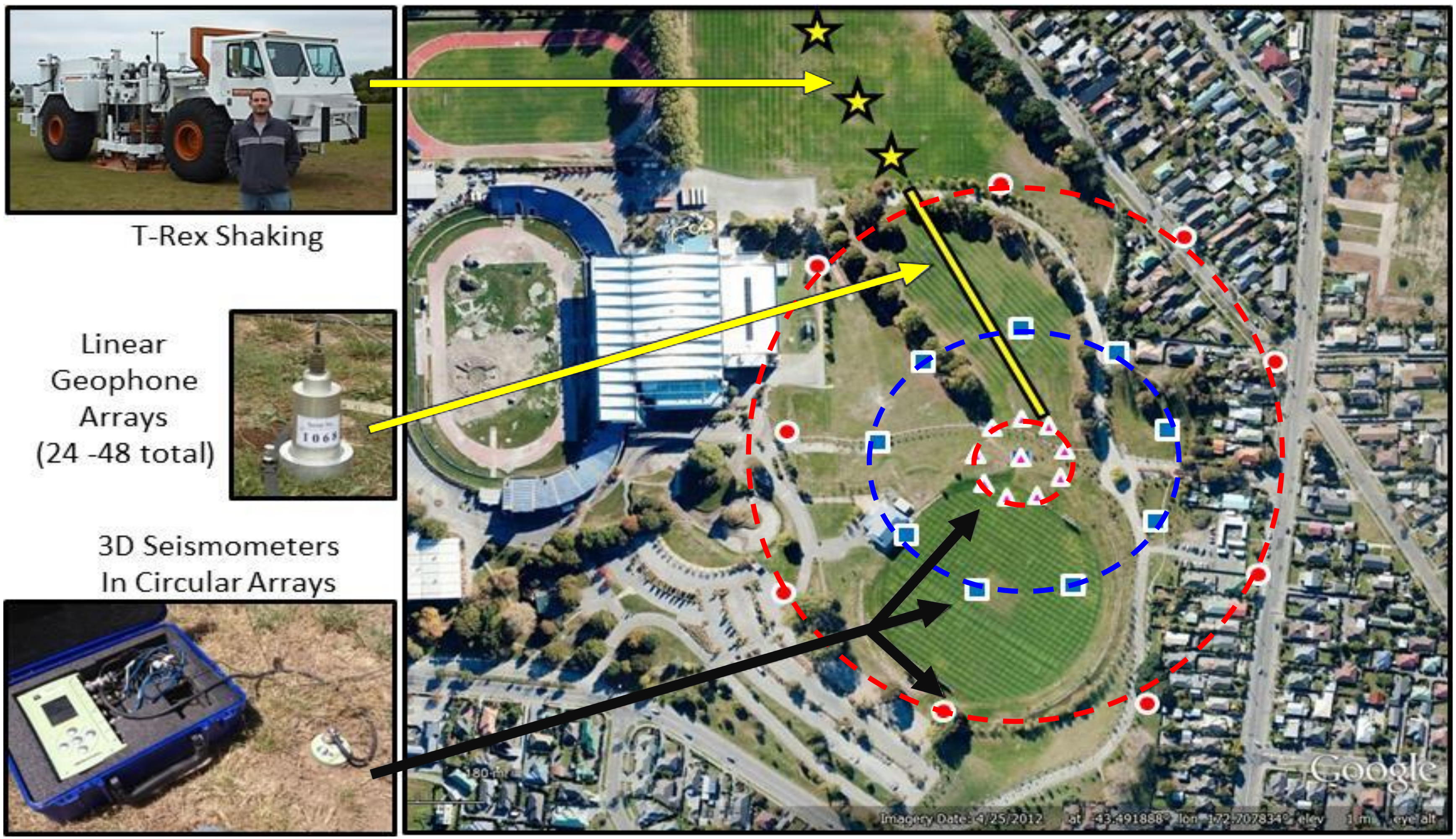


(a) Normal operating mode and typical profiling depth



(b) Improved profiling depth

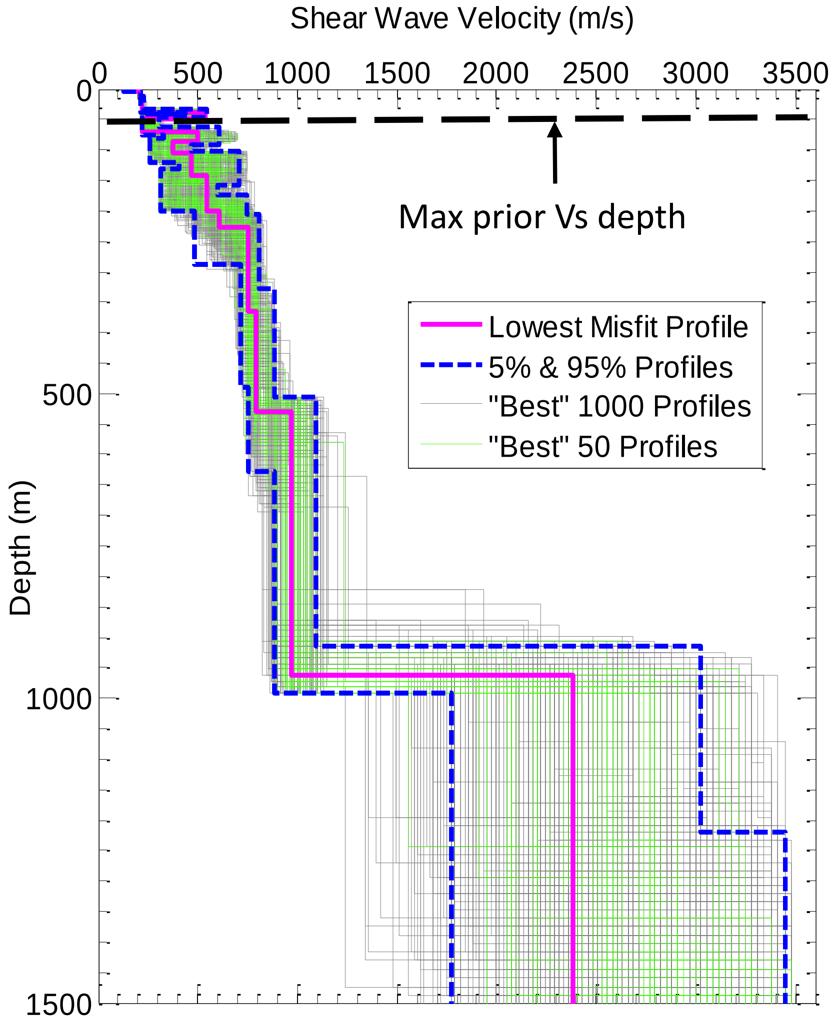
4. Very-Deep (> 500 m) Profiling using Combined Active-Source and Passive-Source, Surface-Wave Methods

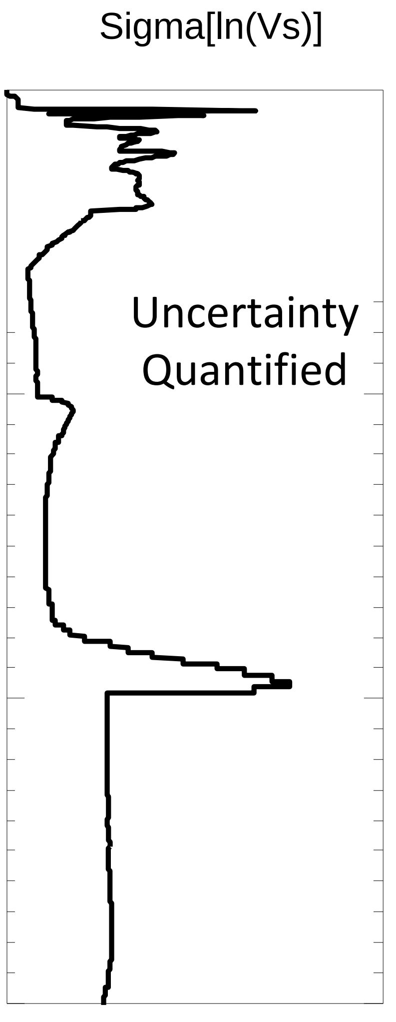


Reliable 1-D V_S Profiles to Record Depths

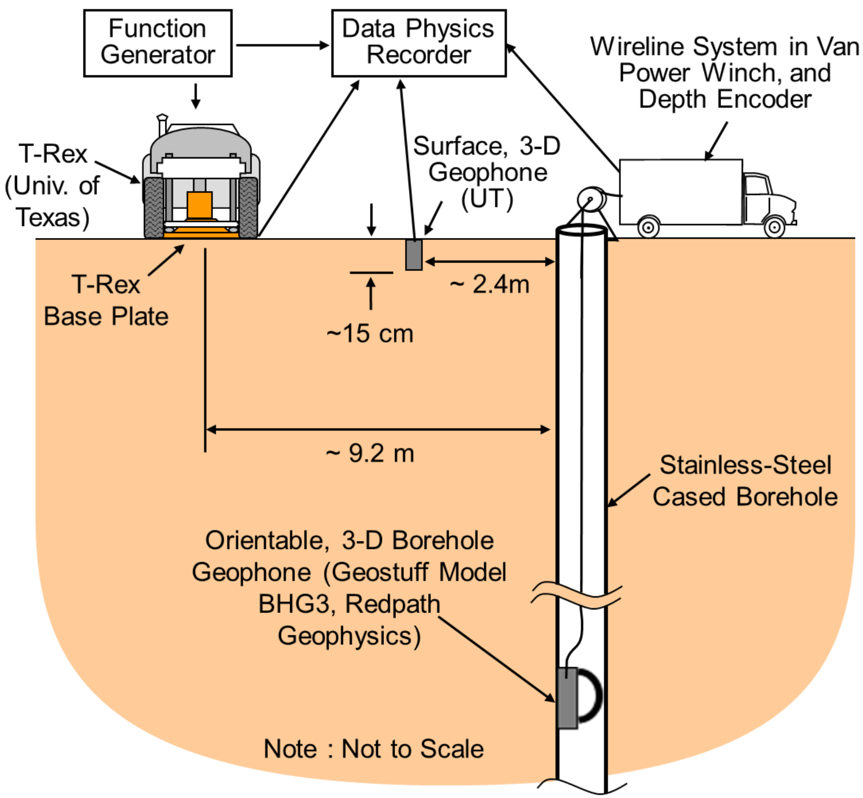
Inversion Process

- 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

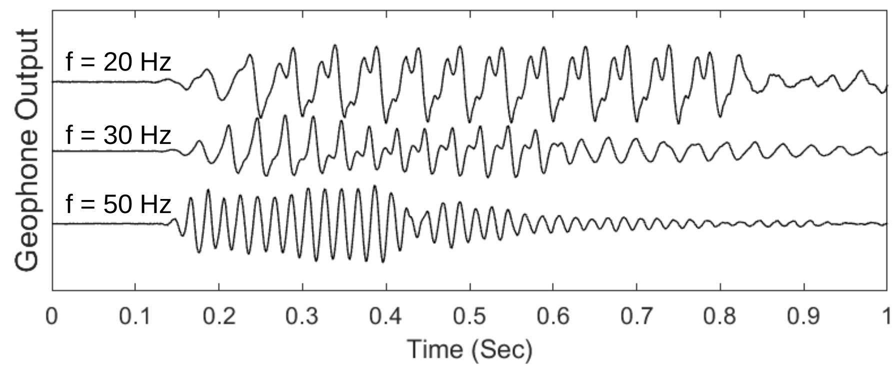




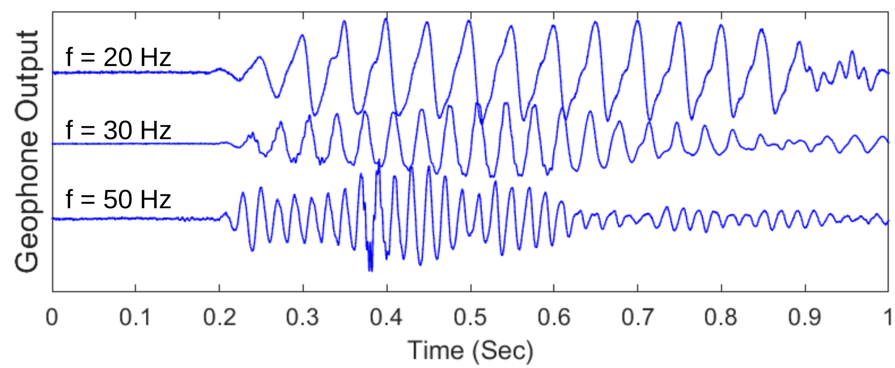
5. Deep Downhole Seismic Testing using T-Rex as an Active Source to Generate Controlled-Waveform P and S Waves



(a) Generalized field arrangement using T-Rex

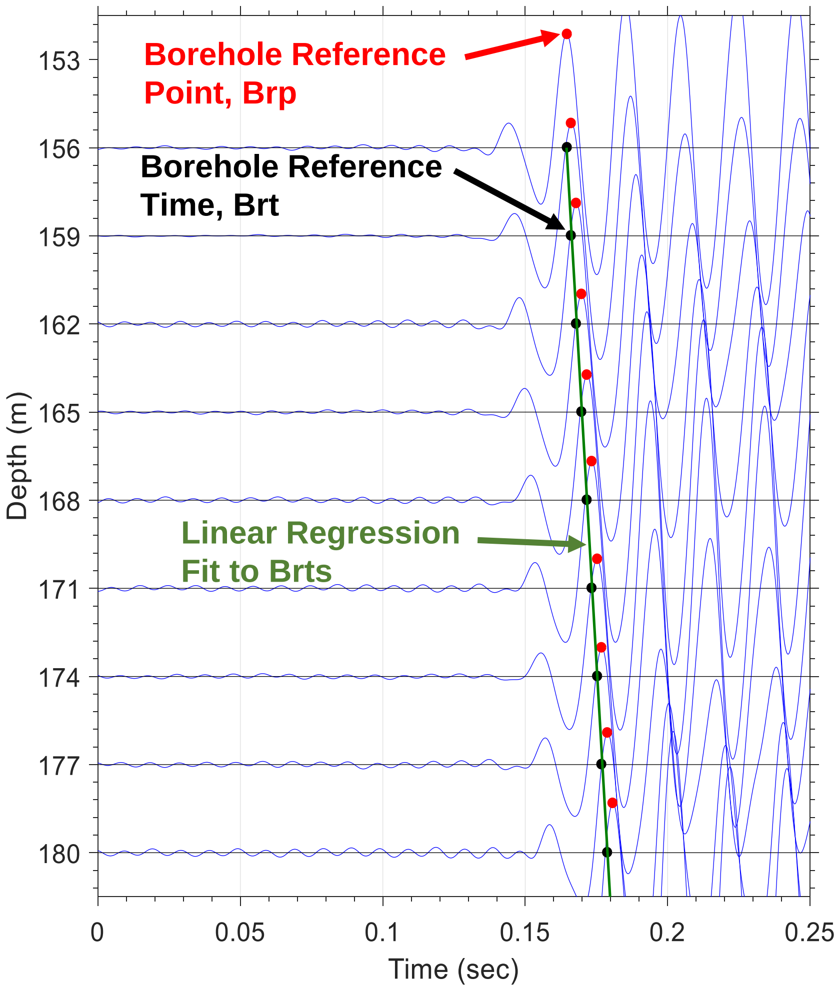


(b) Example sinusoidal P waveforms at 158 m

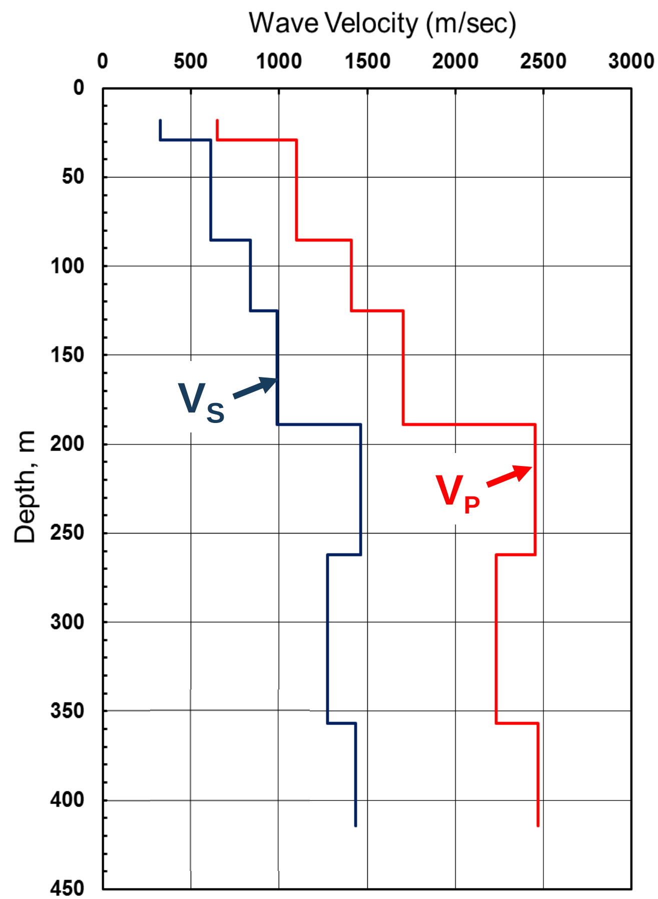


(c) Example sinusoidal P waveforms at 293 m

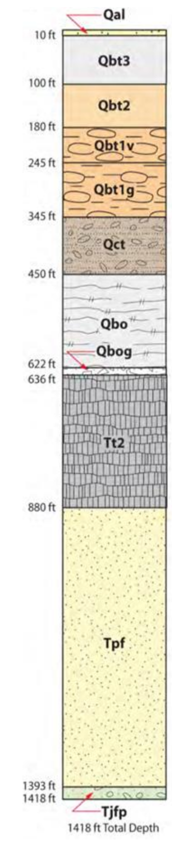
Example Analysis of P Waveforms, Resulting V_S and V_P Profiles and Geologic Profile



(a) Filtered P waveforms and reference travel-time “picks”, Brts, on each depth axis

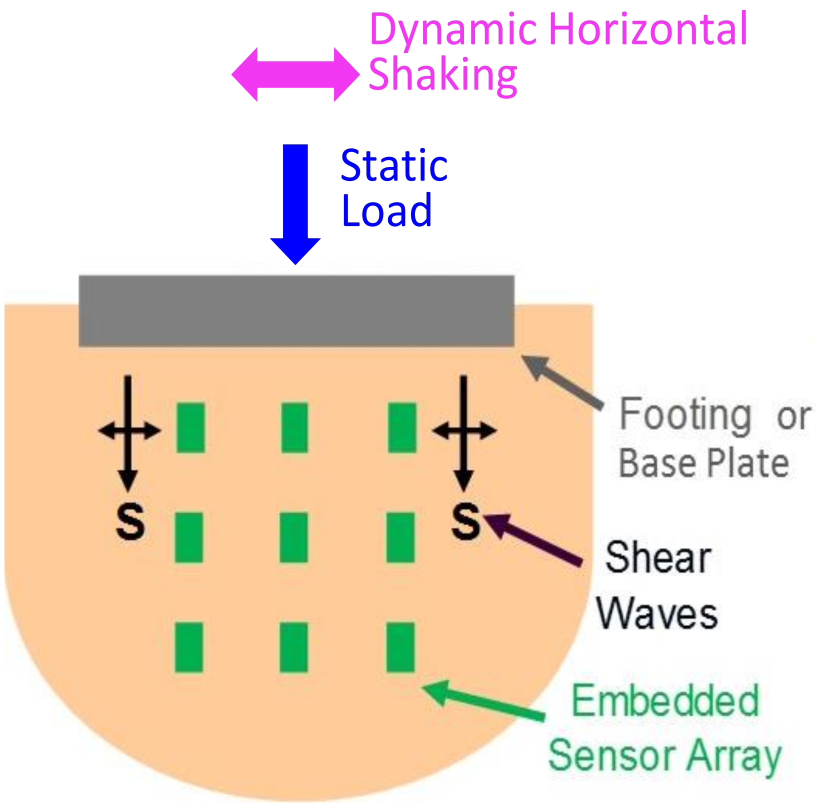


(b) Composite V_S and V_P Profiles

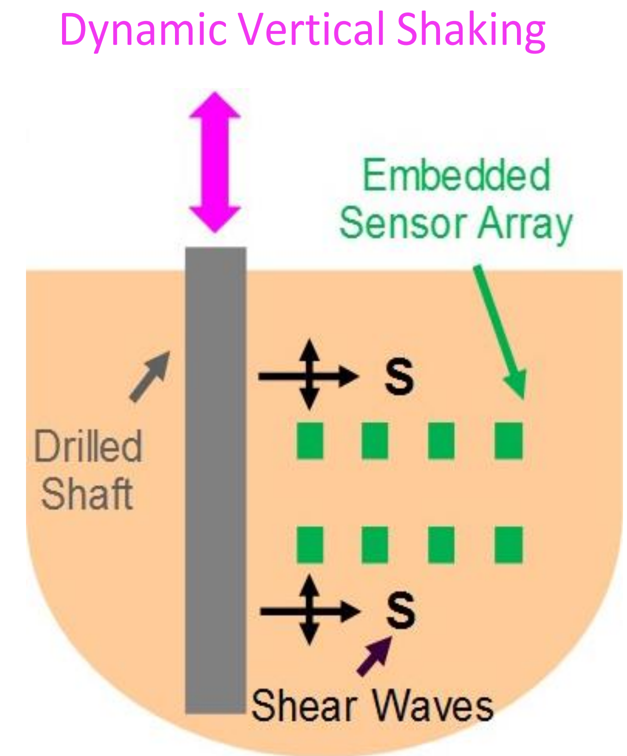


(c) Geologic Profile

6. Parametric Field Studies of Linear and Nonlinear Stiffnesses



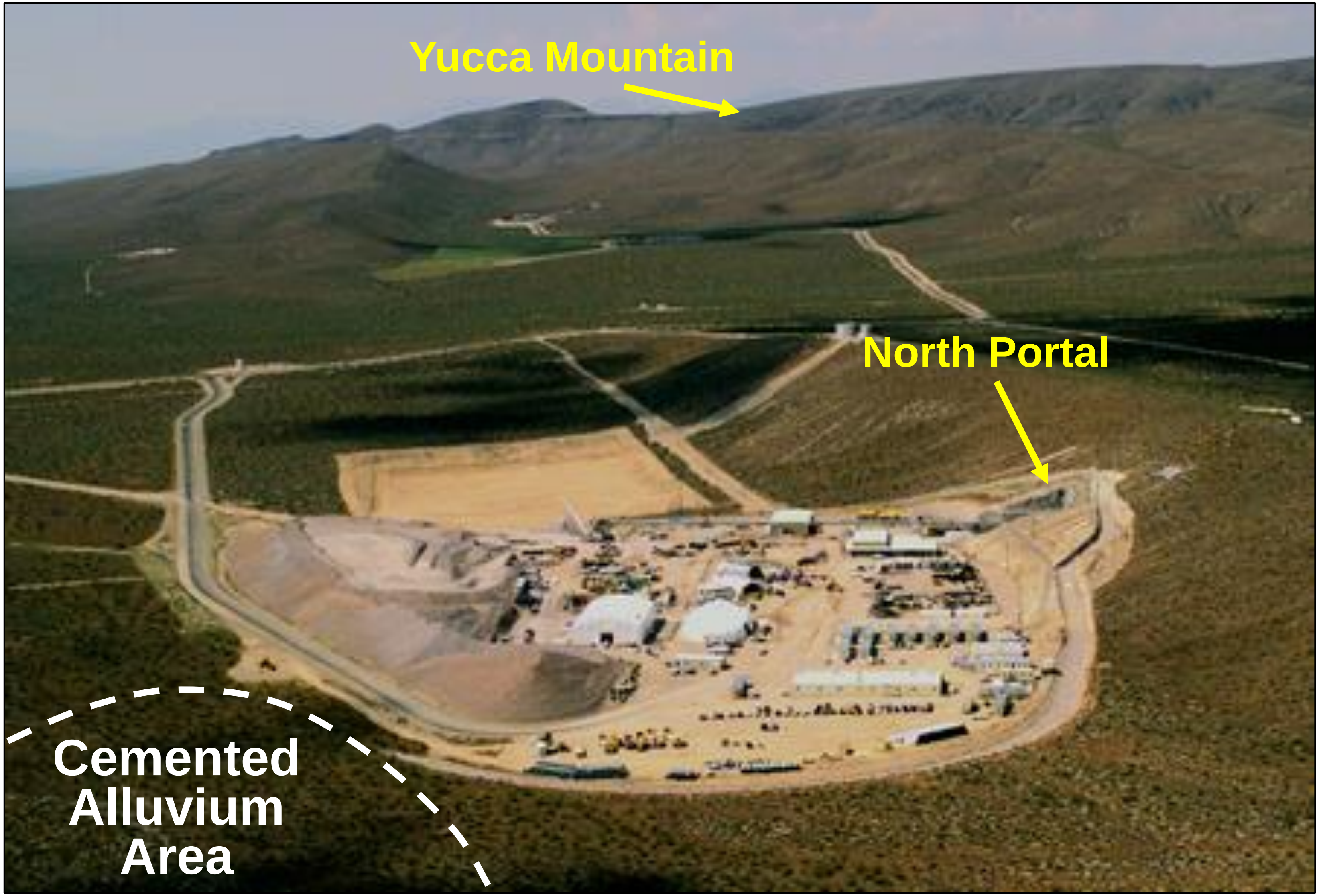
Loading Applied by Mobile Shakers



(a) Surface footing or shaker base plate as the loading platen (Park, 2010)

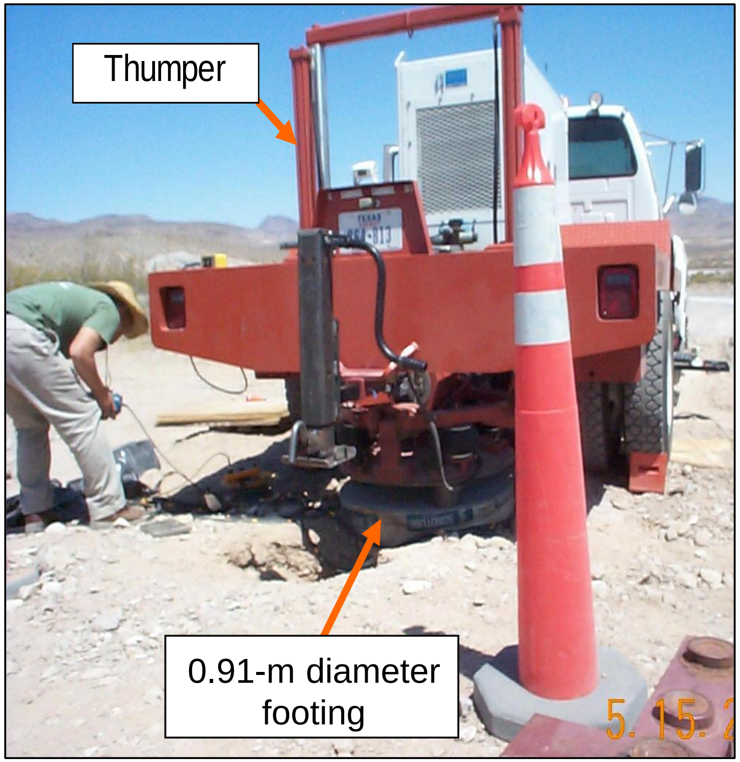
(b) Drilled shaft as the loading platen (Kurtulus and Stokoe, 2007)

Yucca Mountain Test Site, NV

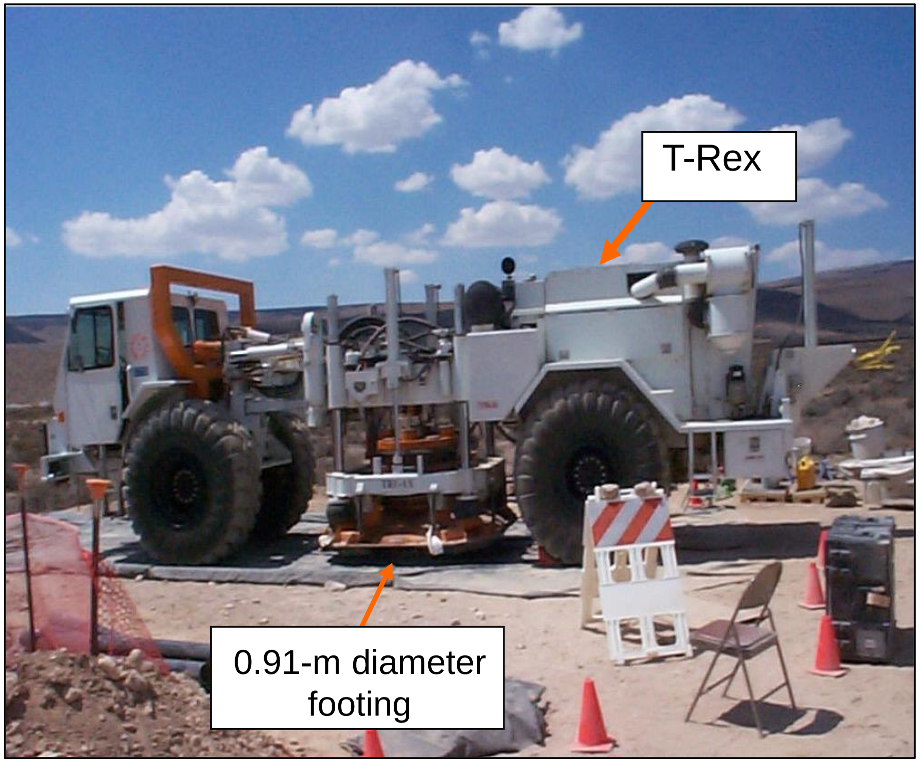


Test Pit in Cemented Alluvium

Linear and Nonlinear Steady-State Dynamic Tests: Yucca Mountain

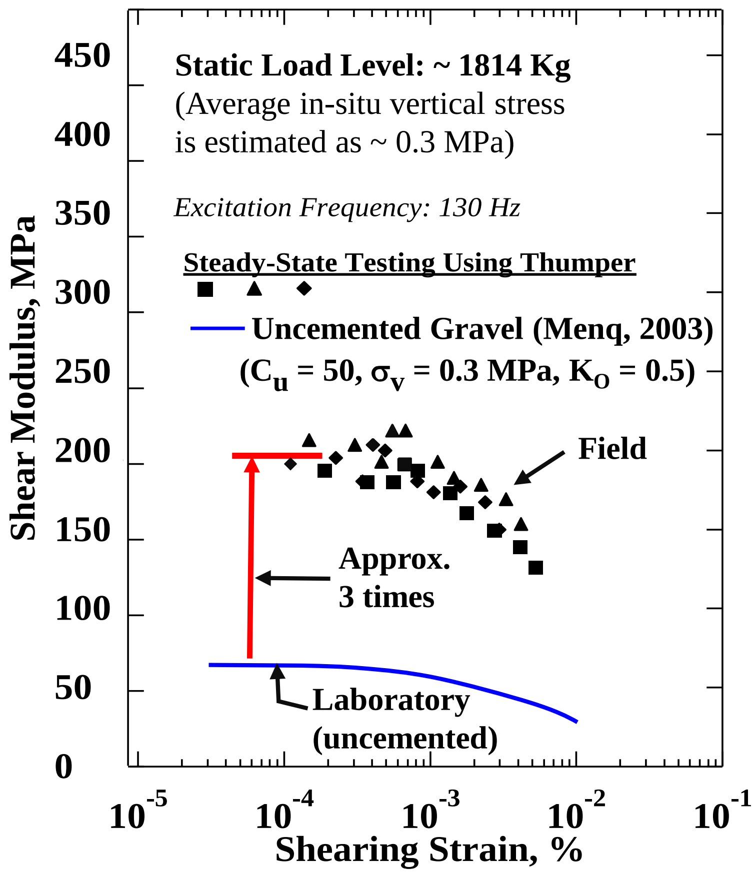


(a) Small-to-moderate shaking with Thumper

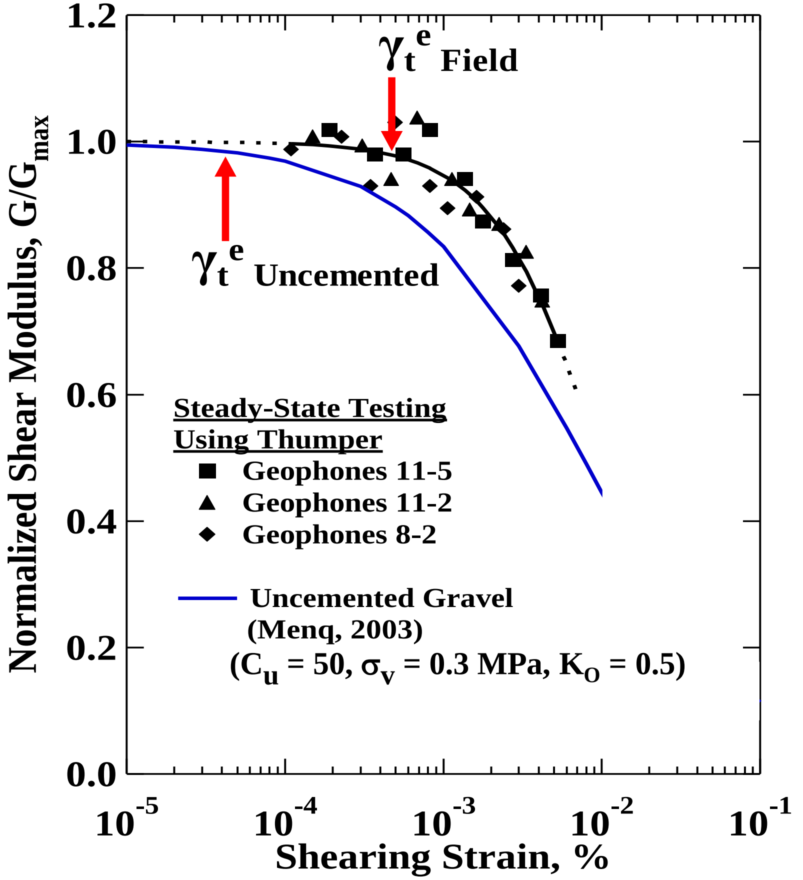


(b) Moderate-to-large shaking with T-Rex

Linear and Nonlinear Steady-State Tests

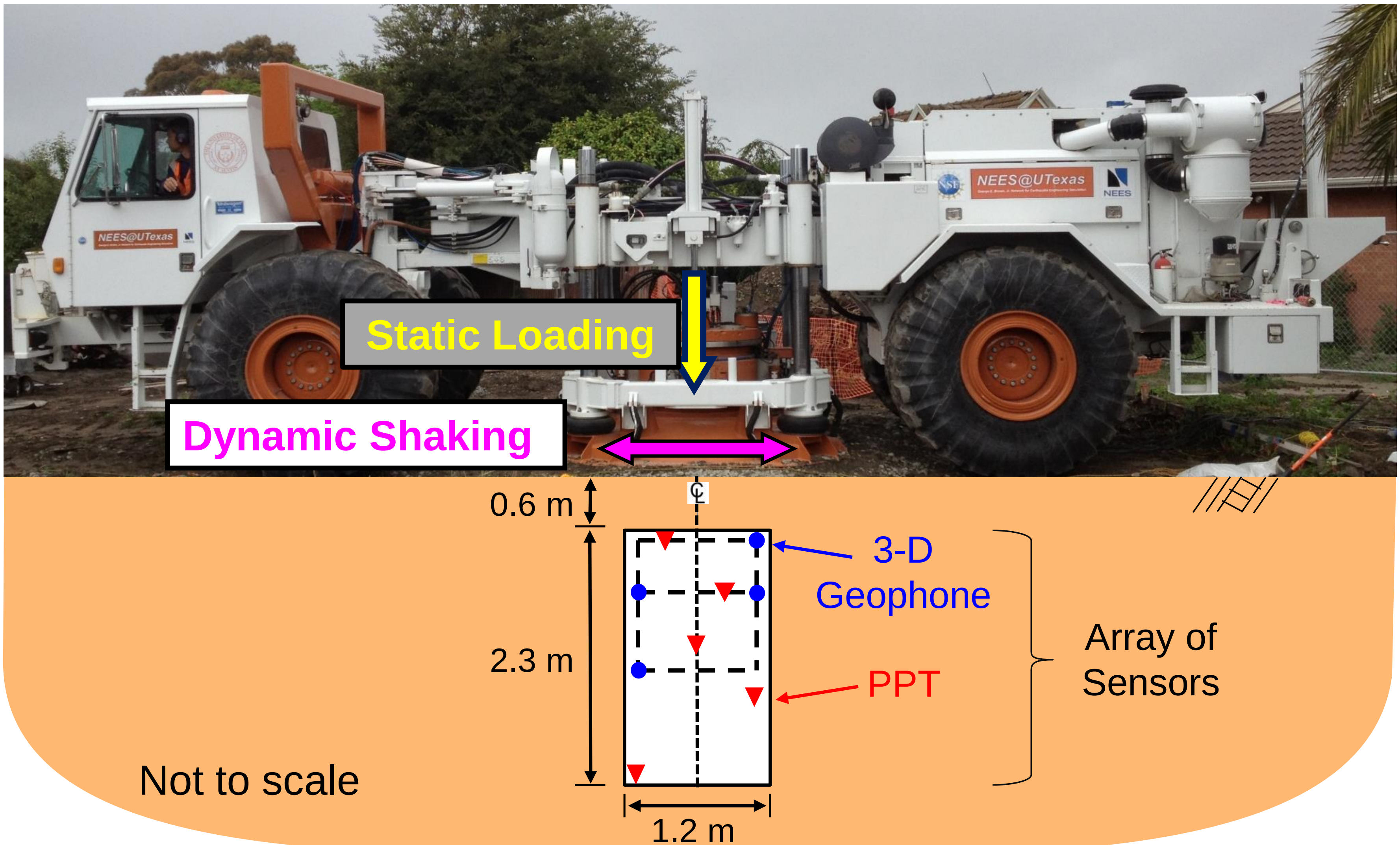


(a) G – log γ



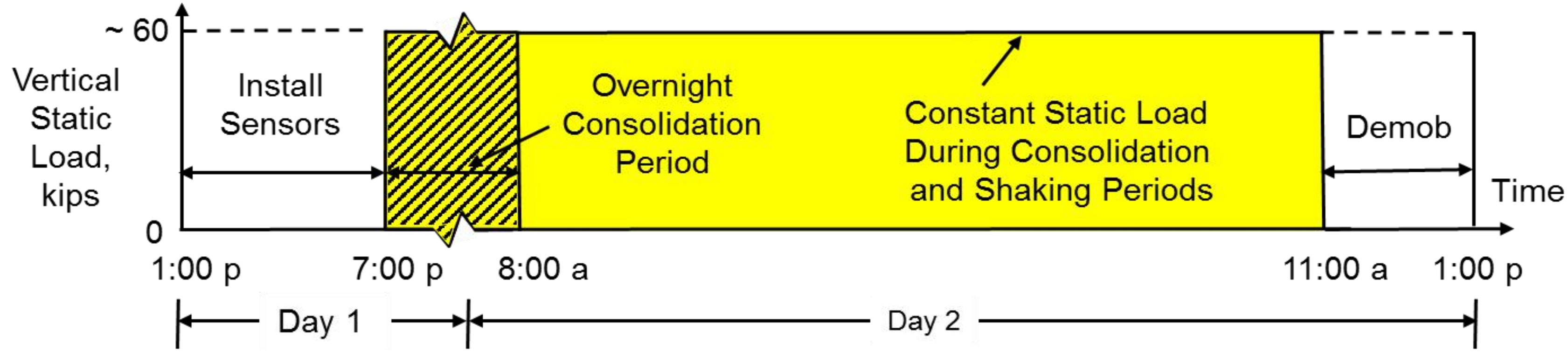
(b) G/G_{max} – log γ

7. In-Situ Liquefaction Testing Using T-Rex as the Controlled Source to Shake an Embedded Array of Sensors

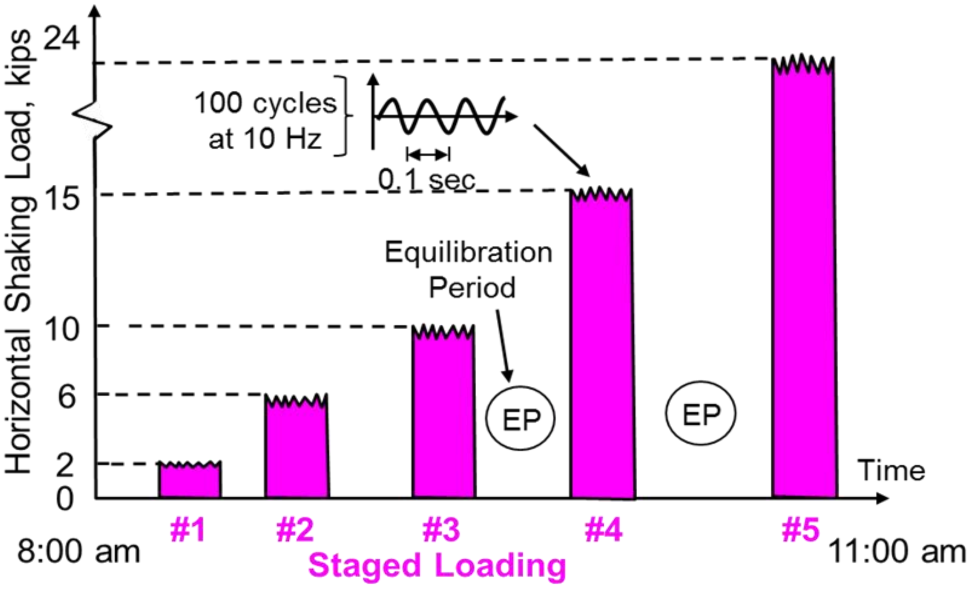


Staged Testing: 24-hr Process of Sensor Installation and Staged Loading with T-Rex at the Natural Soil Test Panel

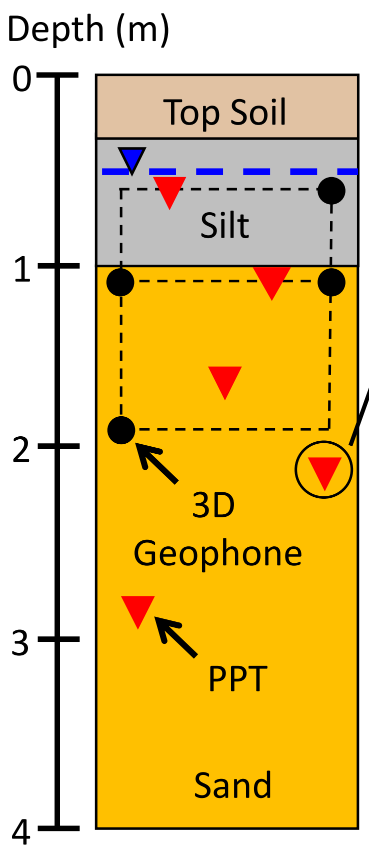
(a) Install Sensors, Vertical Static Loading, and Demobilization

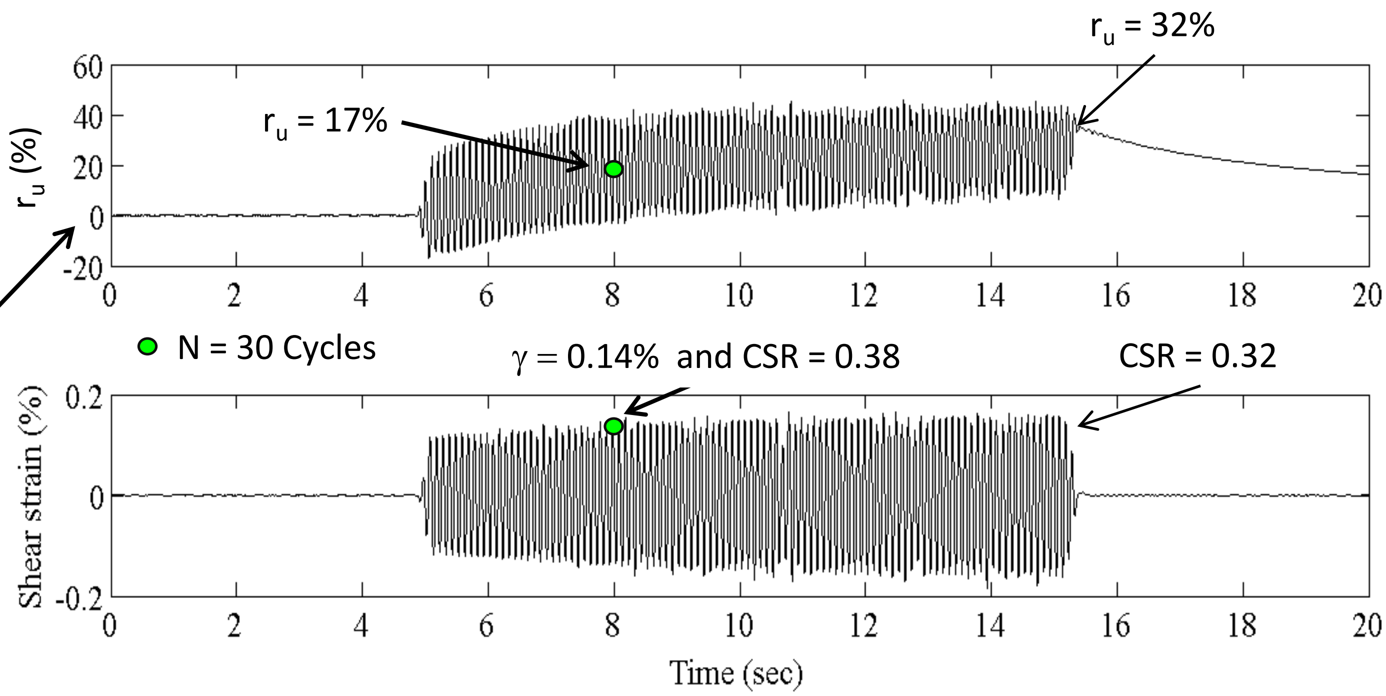


(b) Staged, Horizontal Shaking with T-Rex



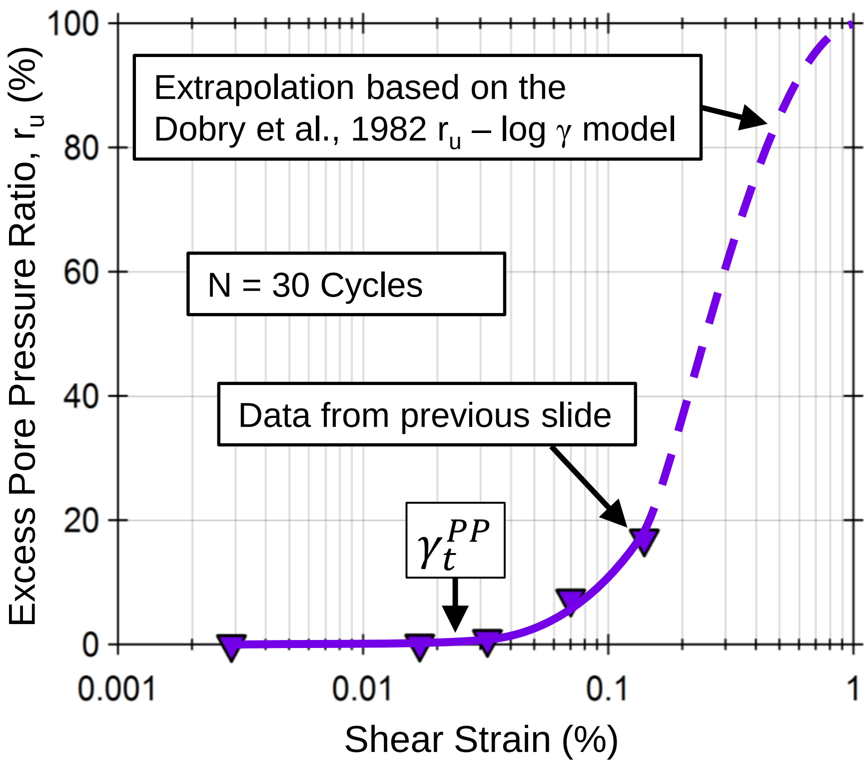
Liquefaction Testing of a Natural Soil Test Panel in Christchurch, NZ; pore pressure ratio, r_u , versus time and shear strain, γ, versus time for 100 cycles in Stage 5 loading



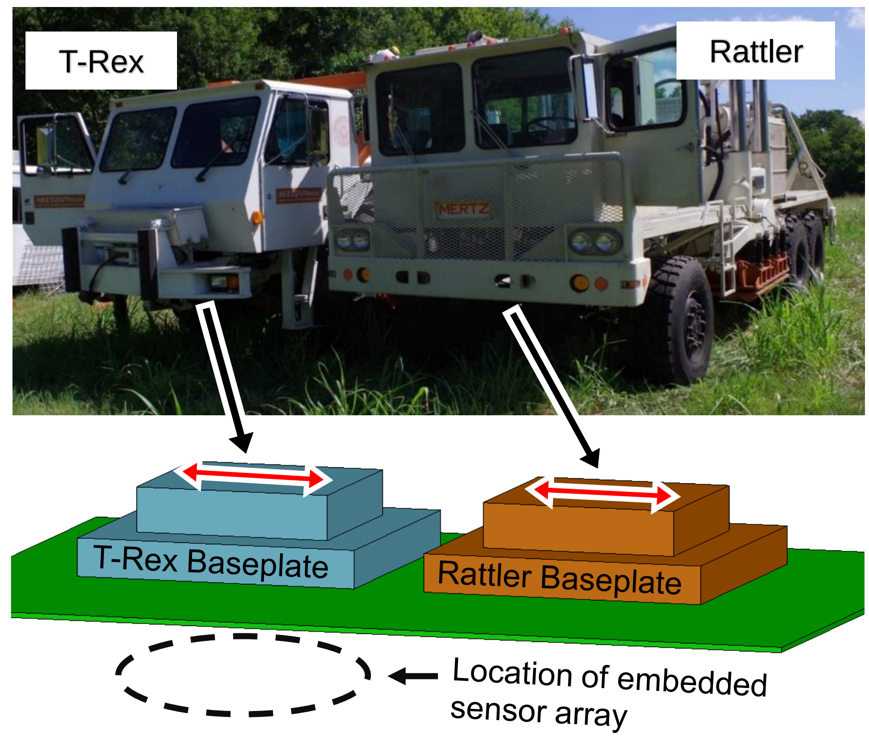


Notes: $r_u = u_{excess}/\sigma_v'$; $CSR = \tau/\sigma_v'$; $G = \tau/\gamma \longrightarrow \tau = G\,(\gamma)$

Example r_u - Log γ Relationship Estimated for Loose Sand and New Approach to Increasing Maximum Strain

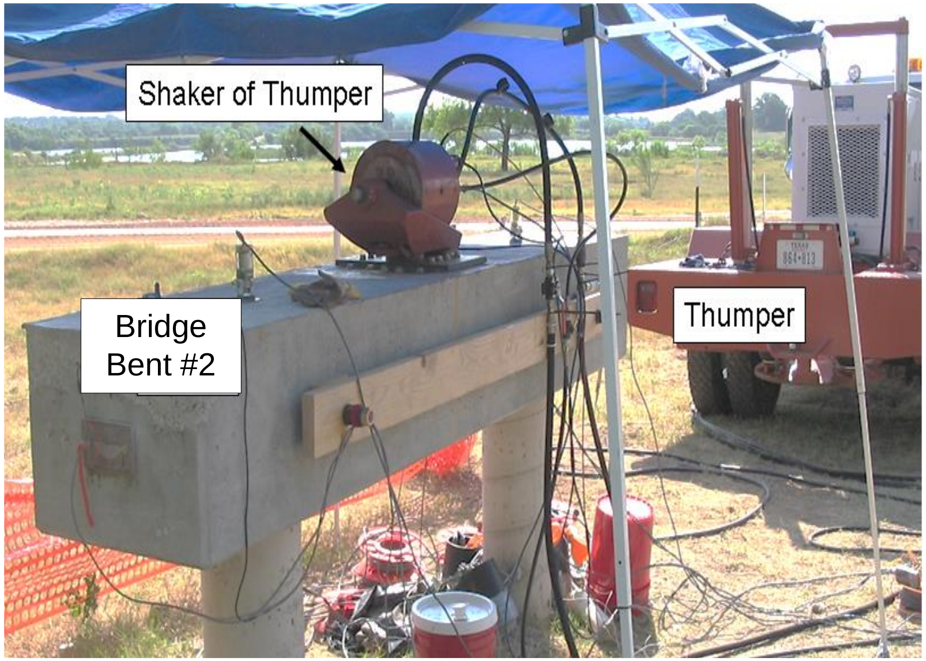


(a) Measured and extrapolated r_u -log γ relationship

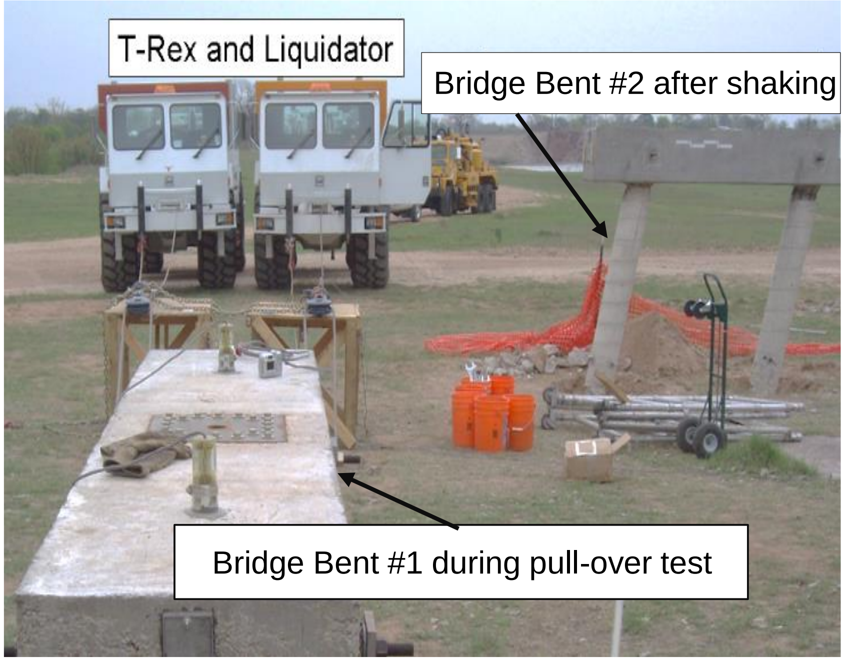


(b) New approach using two shakers to increase the largest strain levels

8. Investigating the Dynamic and Slow-Cyclic Responses of Scaled- Structural Systems in the Field



(a) Sinusoidal excitation of Bridge Bent #2 created by attaching the shaker from Thumper



(b) Slow pull-over testing of Bridge Bent #1 using T-Rex and Liquidator

Most Recent Dynamic Loading of a Full-Scale Bridge in the Field Using T-Rex

Preparing to dynamically load a two-span bridge over Interstate Highway I-195 in Trenton, NJ. Bridge deck was loaded longitudinally and laterally and the motions were large and easily seen. Shared-use project was performed for Professors Nenad Gucunski, Franke Moon, and John DeVitis from Rutgers University

Comments

- A new era in field testing, primarily in the geotechnical environment, is now possible with the large mobile shakers of NHERI@UTexas. This type of testing is also available to most researchers around the world because of the shared-use policy of the U.S. National Science Foundation.

- The large mobile shakers can be used to apply all types of controlled dynamic loads on the ground surface, to systems embedded in the ground, and to the above-ground portion of structures with ground-supported foundations.

- Hopefully the range in these examples will stimulate new ideas in you and other colleagues. We hope to have the opportunity to assist you in developing an improved understanding and new knowledge of the natural and built environments.

Additional Information

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- 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 for Webinar slides & budgetary information are posted

Special Thank you!

- National Science Foundation for the financial support to develop and operate the NHERI@UTexas Equipment under grants CMS-0086605, CMS-0402490, and CMMI-1520808.
- Yumei Wang, Oregon Department of Geology and Mineral Industries.

Example of Estimated Costs Associated with Using the NHERI@UTexas Equipment Facility on 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 fr
weekends	2	days	UT personnel is required to take one day of
Days in the field	**16**	**days**	

Step 2: Estimated equipment costs

T-Rex			
Vibraton	$1,620	▪ Vibrator opera	
Tractor-Trailer			
Highway	$4,260	▪ 1	weight permit + $1.13 fuel)
Fuel-Supply Pickup Truck			
Highway	$		(fuel cost only)
Recording equipment			porject
Instrumentation Trailer			pported porject
Total			ccount category: Material and supply

Step 3: Estimated tra

people	$6,000	▪ 3 people * days
irline 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

Budget worksheet posted on DesignSafe-CI

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

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**	

$22,134
(for this example)

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		...t 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

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

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

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