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UPDATE ON THE SEISMIC SHAKE TABLE TEST

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NHERI@UC San Diego User Training Workshop

EXTENDED STORAGE COLLABORATION PROGRAM

SAND2021-13808 PE

DECEMBER 17, 2021

Seismic Shake Table Test Roadmap

New Methodology to Define Representative Free-Field GMs

GM – ground motion

Free-Field GM Spectra and Amplitudes

TH – time history

Free-Field THs

TH for Hard Rock Sites

TH Simulation on the Shake Table

Final Set of the Test THs

SSI and Pad Flexibility Analyses

TH for Soft Rock and Soil Sites

SSI – soil-structure interaction

Dummy Assemblies

Surrogate Assemblies

Canister

Dry Storage Overpack(s)

Test Unit

Final Test Plan

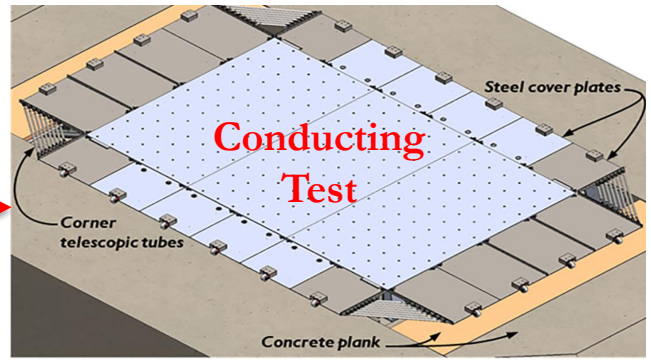
Pre-Test Modeling

ISFSI Pad Concrete Formulations

Concrete Layer on the Shake Table

Instrumentation

Final Instrumentation Procedure

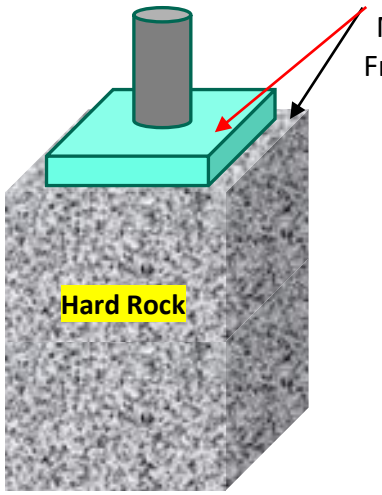


FY 21 Project Reports

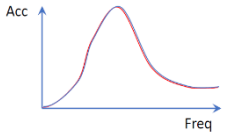
- Kalinina et al., "*Ground Motion Inputs for the Seismic Shake Table Test*", June 2021 SAND2021-7603 R.
- Kalinina et al., "*Seismic Shake Table Test Plan*", September 2021, SAND2021-11207 R

Developing Shake Table Inputs Representative of Seismic and Site Conditions in Central&Eastern U.S.(CEUS) and Western U.S. (WUS)

Hard Rock Sites



Shake Table Motion Same as Free-Field Ground Motion

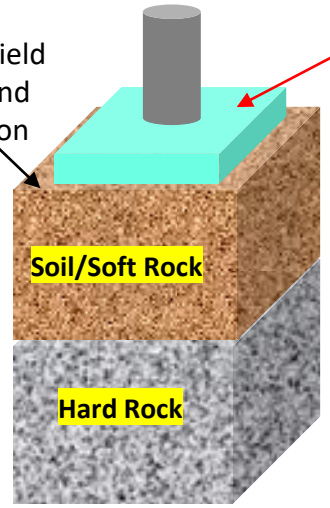


24 Sites in CEUS

Soil and Soft Rock Sites

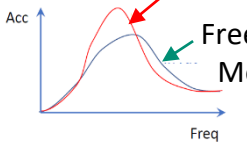
Free-Field Ground Motion

Shake Table Motion with Account for Soil-Structure Interaction



Shake Table Motion

Free-Field Motion



16 Soil Sites

11 Soft Rock Sites

PGA GMRS – peak ground acceleration (PGA) from the **re-evaluated in 2014-2018** Ground Motion Response (GMRS)

SSE – safe shutdown earthquake

Developing Free-Field Ground Motion Spectral Shapes (CEUS)

The free-field ground motions are the shake table inputs for the hard rock sites and boundary conditions for soil-structure interaction (SSI) analyses

A new methodology was developed by SC Solutions (Dr. Abrahamson) in collaboration with SNL and PNNL to define the representative free-field ground motions – **spectral shapes and amplitudes**.

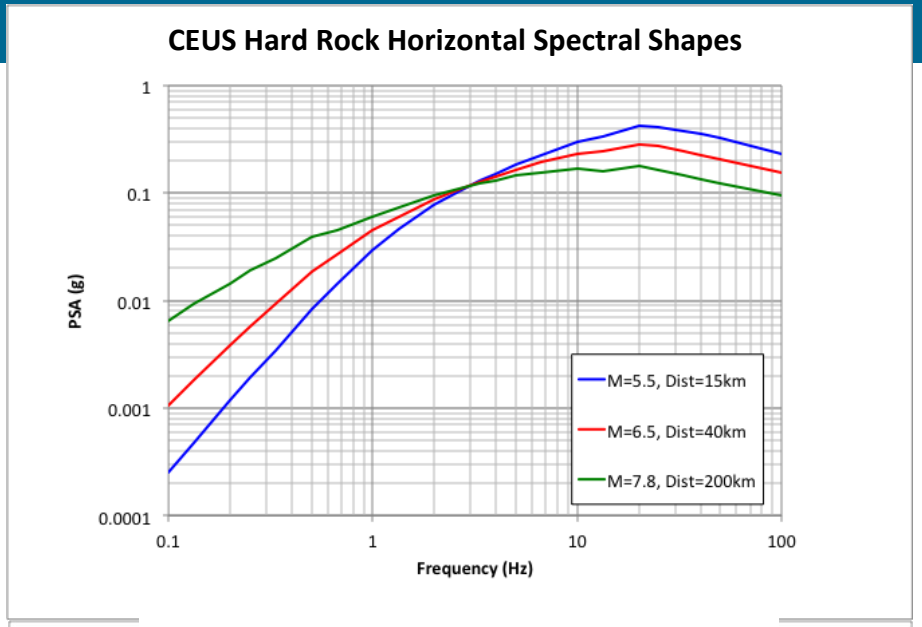
❑ Defining Spectral Shapes

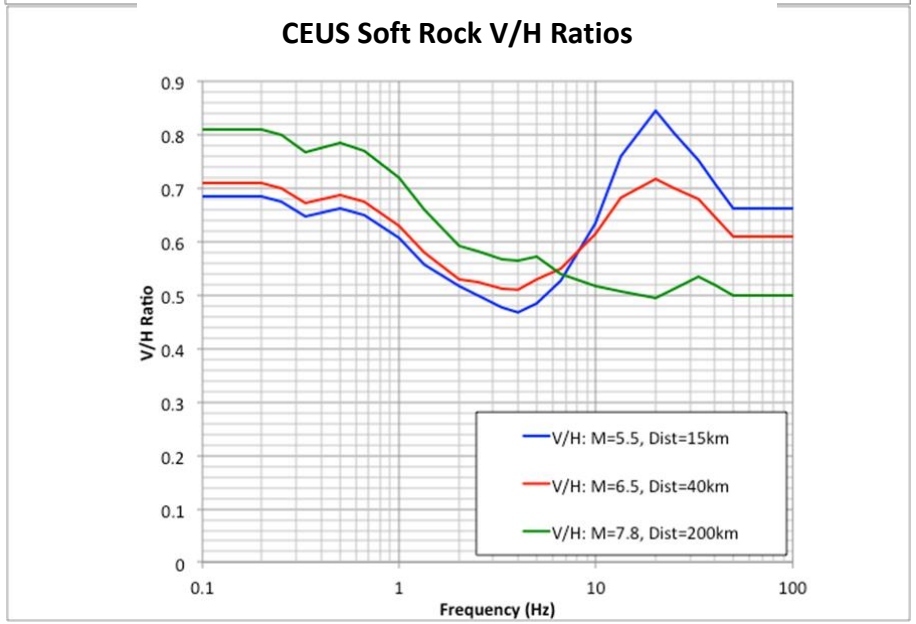
Three scenarios were selected as representative for sites in the **CEUS**:

- Local event with magnitude **5.5** at **15** km
- Moderate event with magnitude **6.5** at **40** km
- Large magnitude distant event with magnitude **7.8** at **200** km

The median horizontal ground motion spectra were calculated based on the NGA-East Ground Motion Model for 1E-04 hazard level.

The **vertical spectral** shapes were developed based on an empirical vertical to horizontal (V/H) spectral ratio model (Abrahamson).





Developing Free-Field Ground Motion Spectral Shapes (WUS)

❑ Defining Spectral Shapes

Three scenarios were selected as representative for sites in the W**US**:

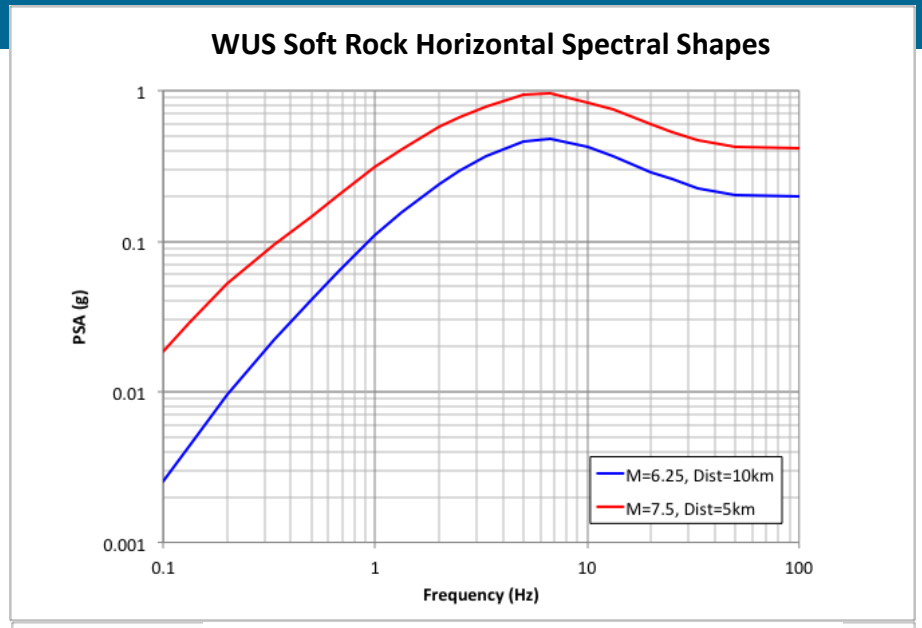
- Local event with magnitude **6.25** at **10** km (6.21 mi)
- Large magnitude local event with magnitude **7.5** at **5** km
- Large magnitude distant event with magnitude **7.5** at **200** km

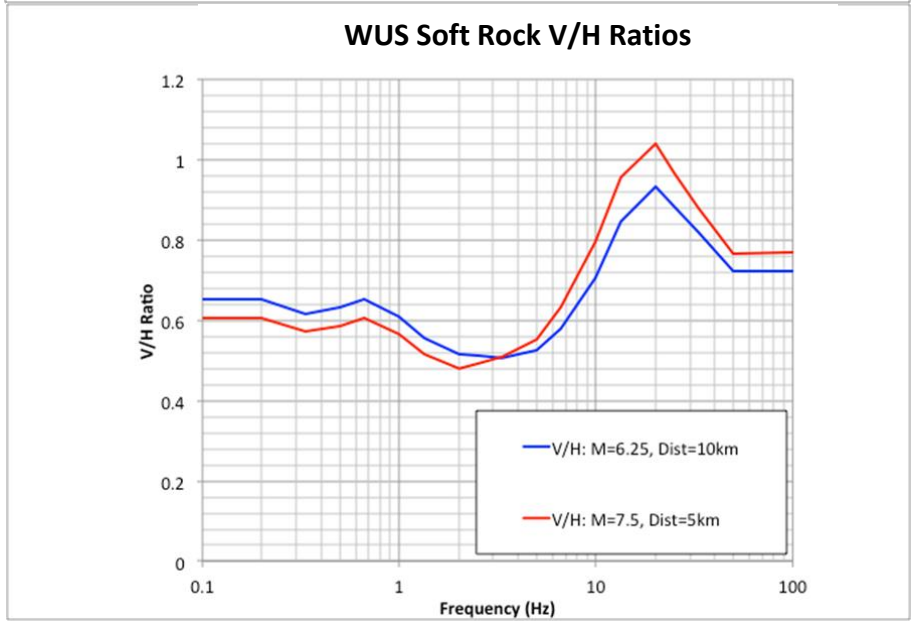
The median horizontal ground motion spectra were calculated based on weighted mean calculated from four NGA-West2 GMMs for 1E-04 hazard level.

Scenarios 1 and 2 are applicable to the soft rock sites (Diablo Canyon, Hanford, and other).

Scenarios 1 and 3 are applicable to soil sites (Palo Verde and other).

The **vertical spectral** shapes were developed based on an empirical vertical to horizontal (V/H) spectral ratio model (Abrahamson).



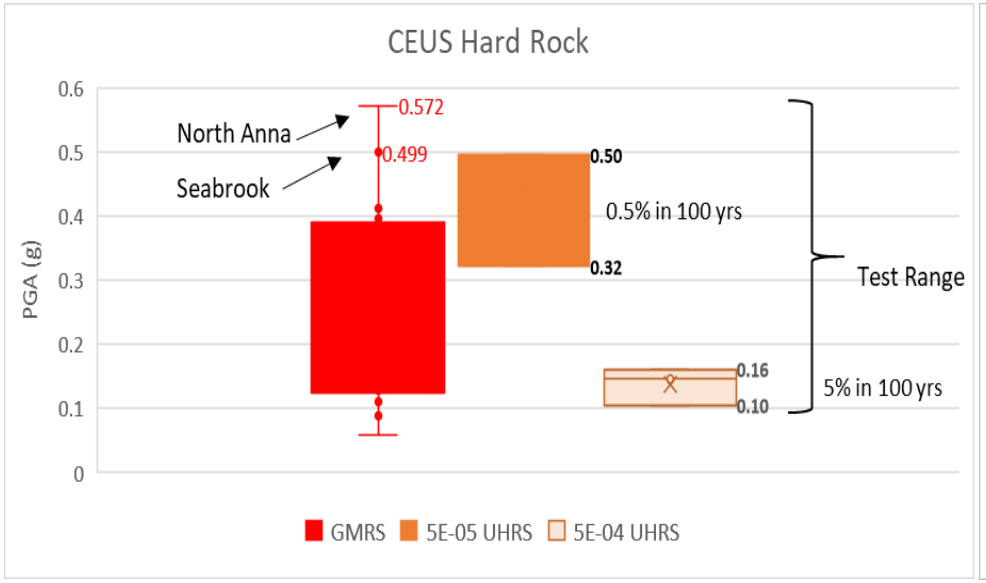


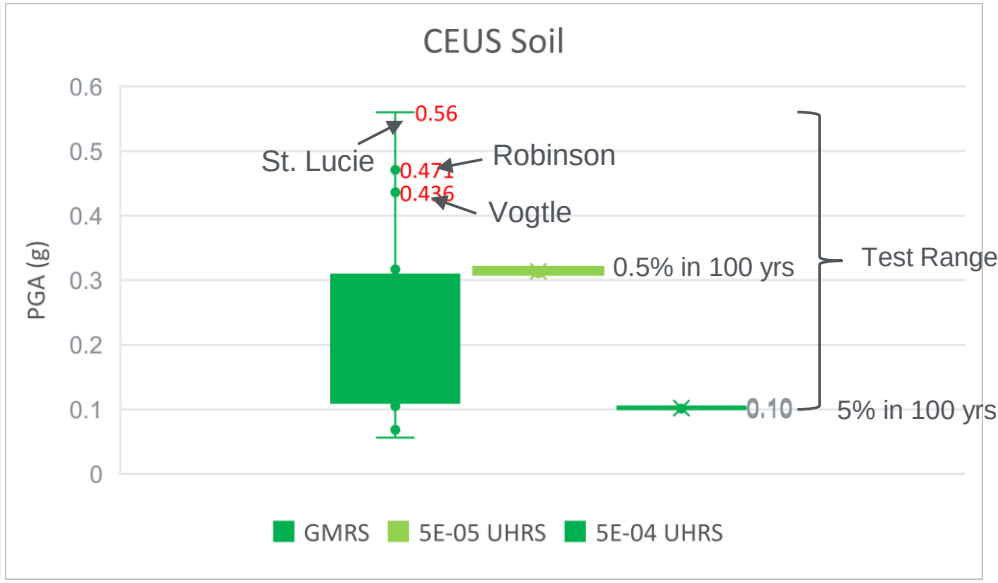
5E-05 and 5E-04 Hazard Level PGAs Compared to Re-Evaluated NPP PGAs

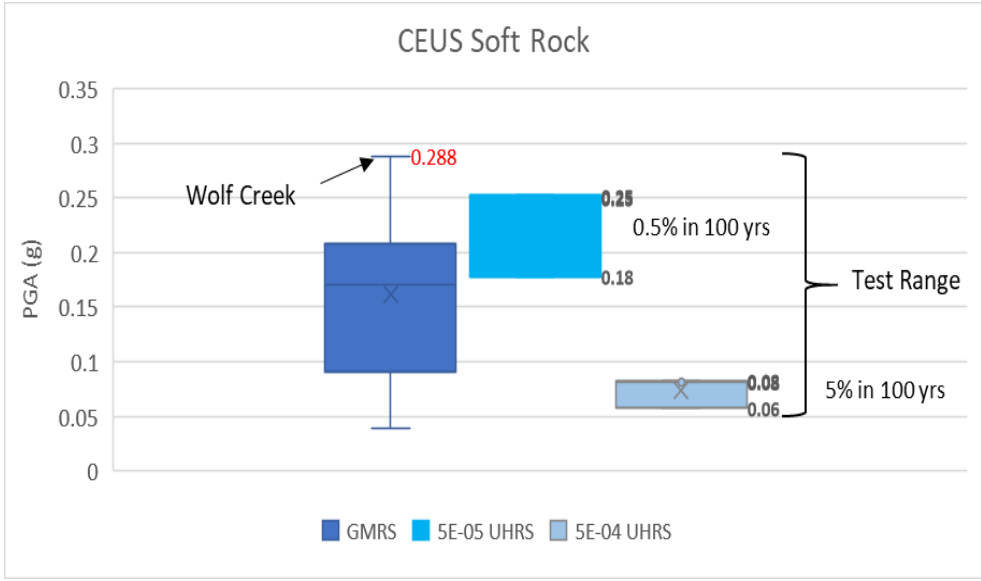
Defining Spectral Shape Amplitudes for 5e-05 and 5E-04 Hazard Levels

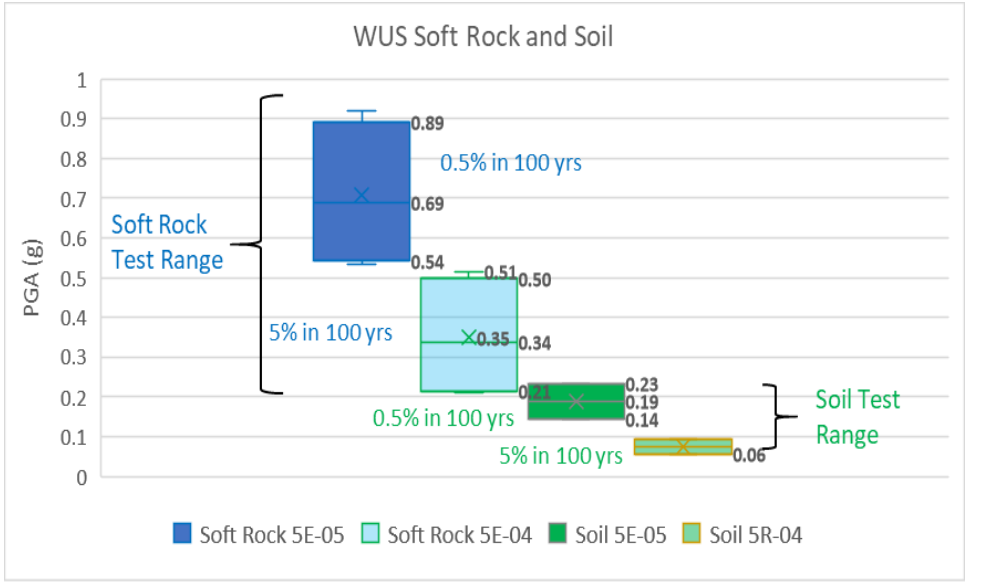
- 1E-04 hazard level PGAs corresponds to 84th percentile PGAs (CEUS) and to median PGAs (WUS).
- Scaling factors were developed to scale 1E-04 hazard level PGAs to 5E-05 (approximately corresponding to a level of SSE) and 5E-4 hazard levels.

Re-evaluated PGAs are from the NPP screening reports





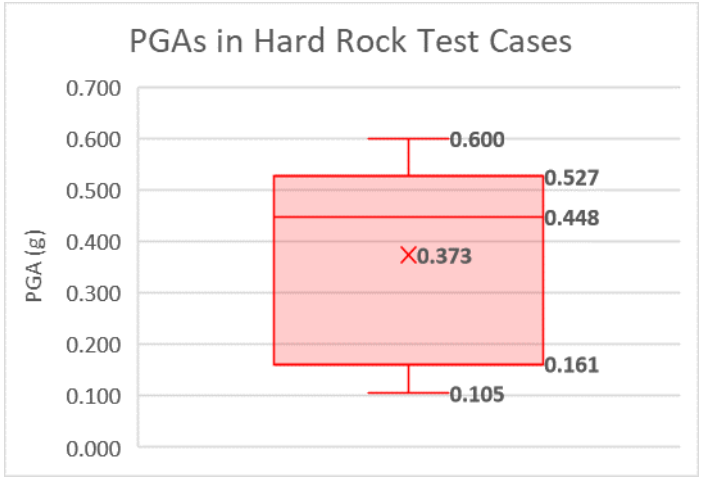


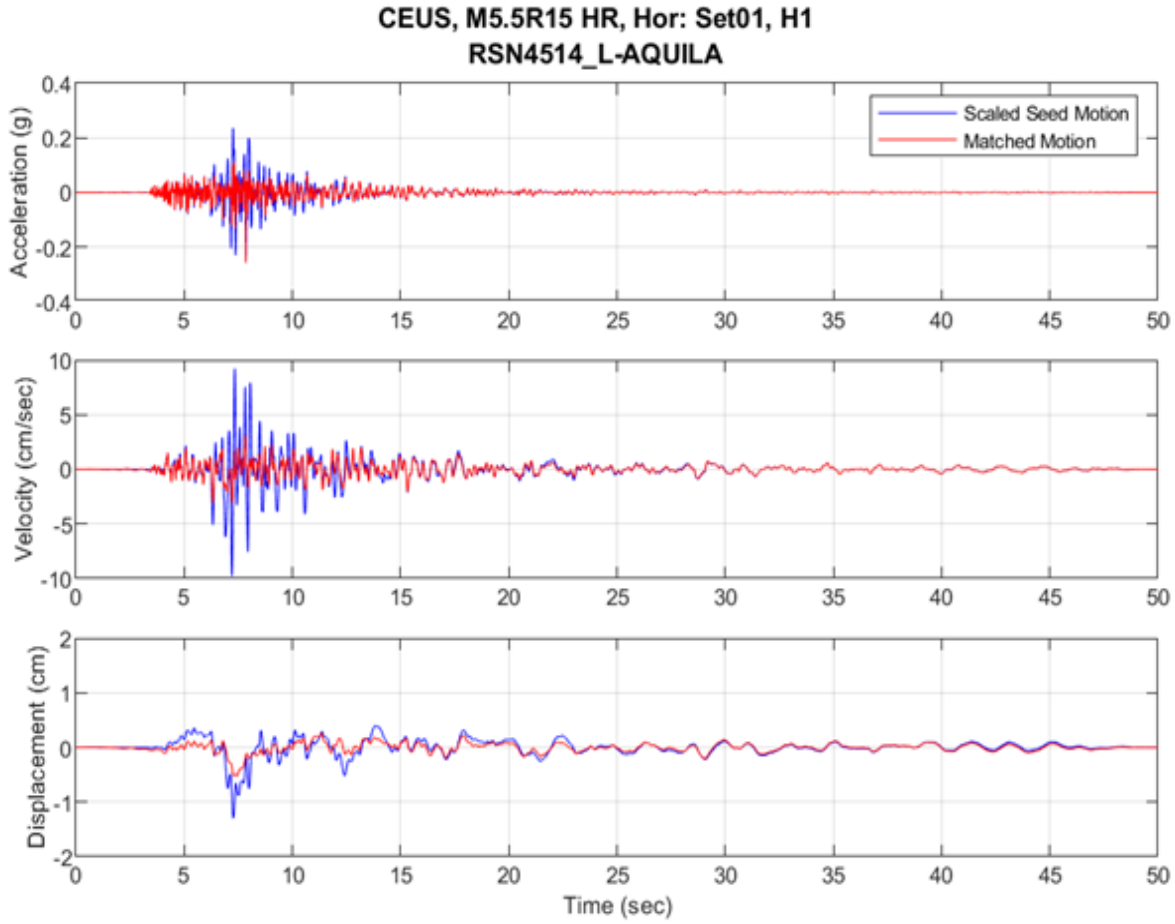


Defining Three-Component Time Histories

- The time histories were developed using the **candidate seed time histories** from the NGA-West2 program database.
- Seed time histories were matched to the component-specific spectral shapes:
  - 9 spectral shapes in CEUS
  - 4 spectral shapes in WUS
- Five time histories were developed for each spectral shape with a total of **65** time histories.
- Time histories will be anchored to 84th percentile PGA (CEUS) and to median PGAs (WUS) and then scaled to **5E-05** and **5E-04** hazard levels.

Hard rock time histories were used to define shake table inputs for the **hard rock** conditions in CEUS. A total of **55** test cases were defined.

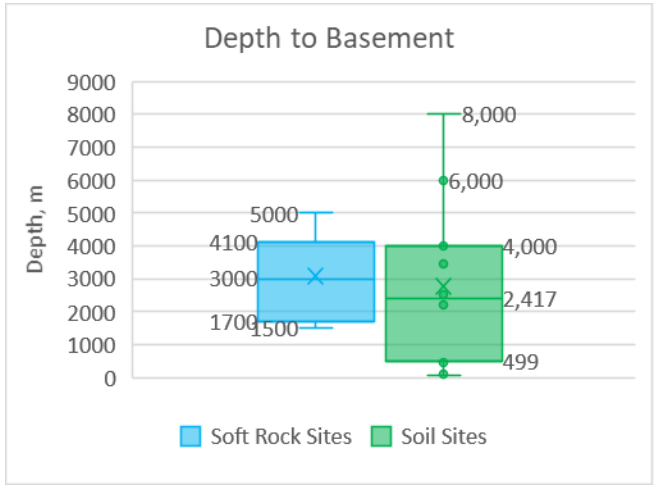




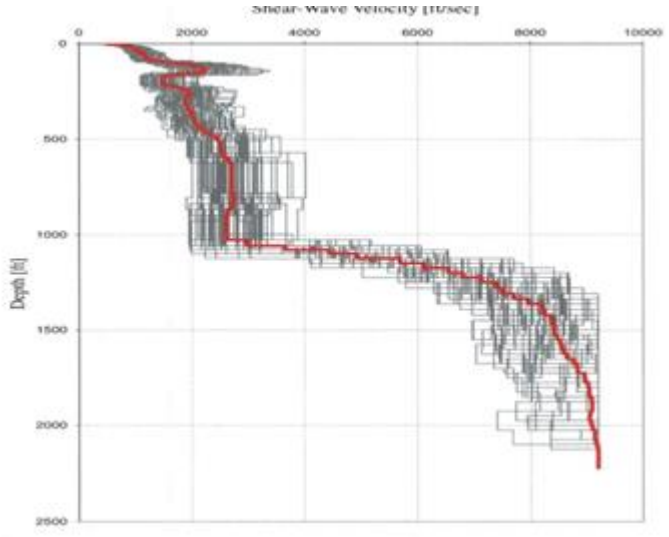
Horizontal Time Histories for CEUS Hard Rock Conditions 5.5 Magnitude Earthquake at 15 km

Seed: L'Aquila (aftershock 1) Italy, 2009

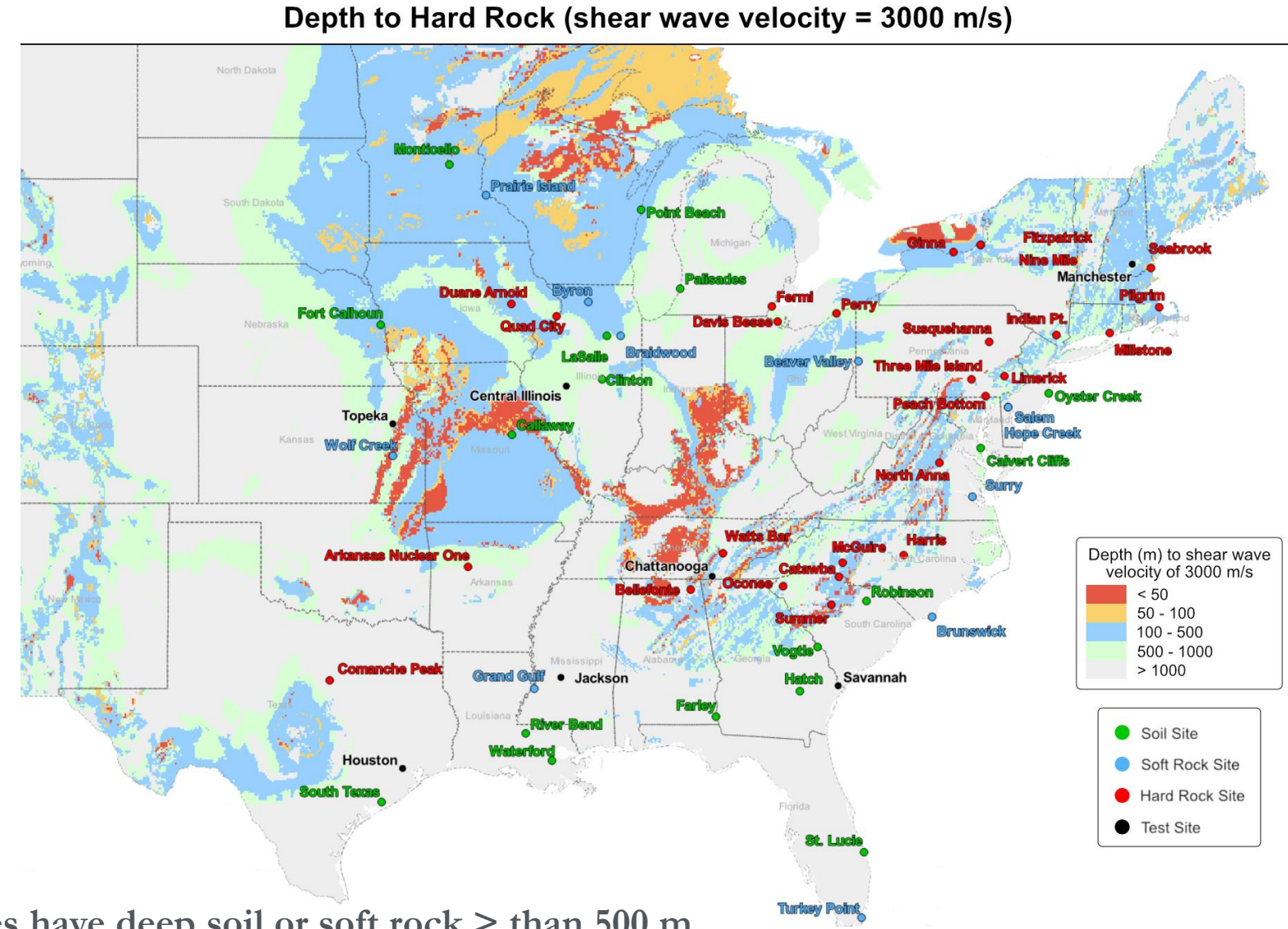
Conditions at the Soil and Soft Rock Sites



Depth to Hard Rock



Soil Site Sheer Velocity Profile



Most sites have deep soil or soft rock > than 500 m.

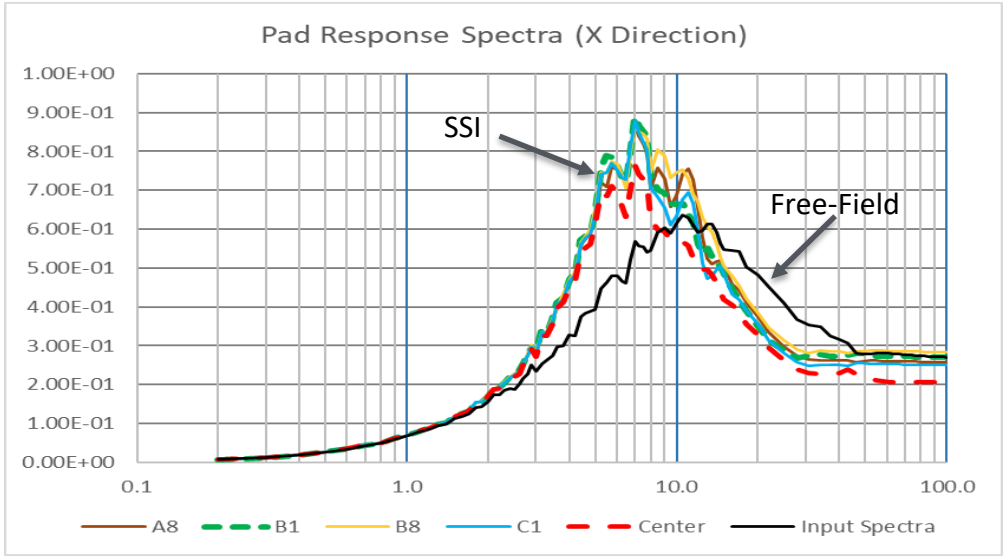
Soil-Structure Interaction (SSI) and Pad Flexibility

SSI analyses will consider:

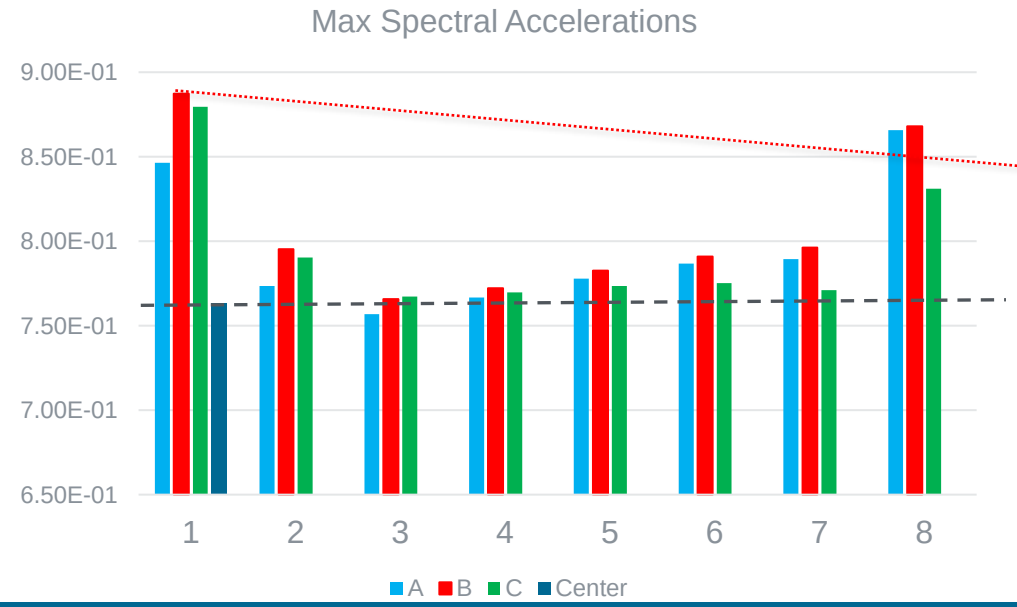
- All earthquake scenarios
- Representative deep soil and soft rock profiles in CEUS and WUS
- 3-4 representative PGAs for each case
- Representative fully and partially loaded pad configurations

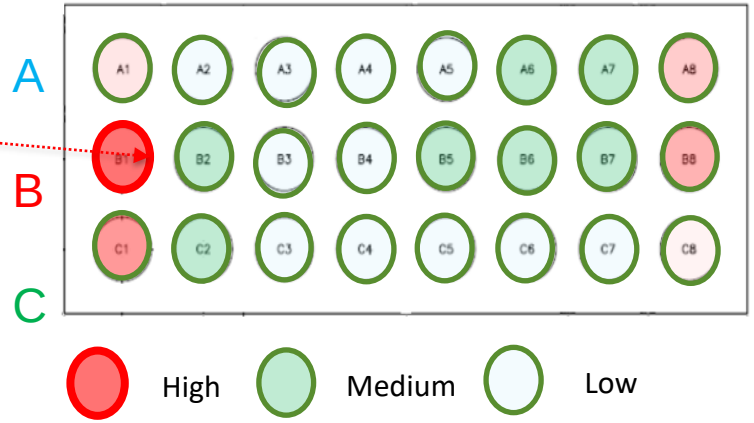
Analysis Results:

- Soil and soft rock site time histories with account for SSI at the pad location with max spectral accelerations



Google Image of an ISFSI Pad

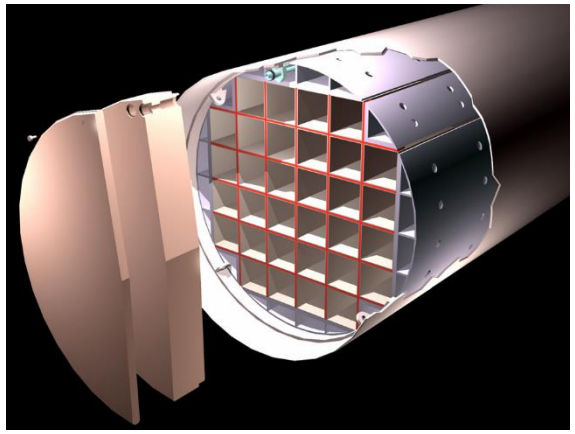




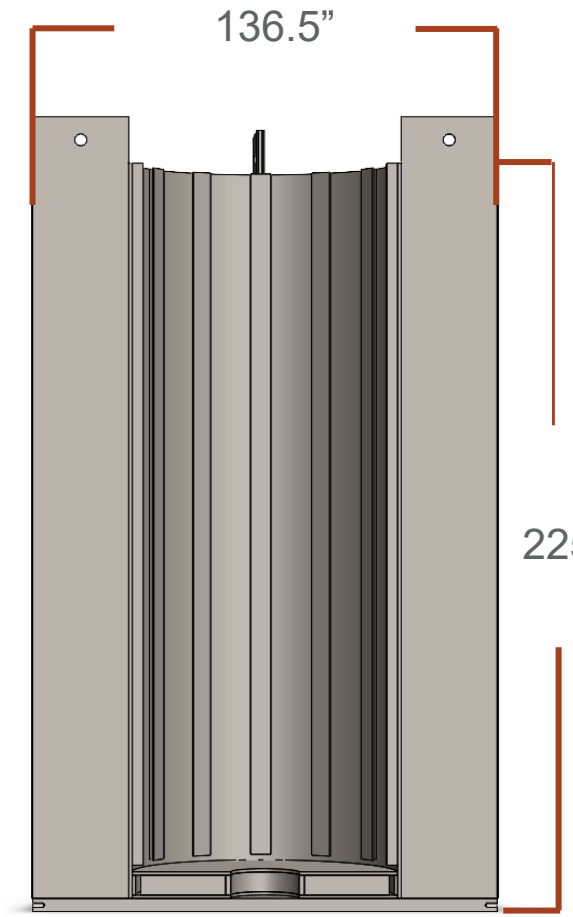
Max Horizontal Spectral Accelerations

Test Unit

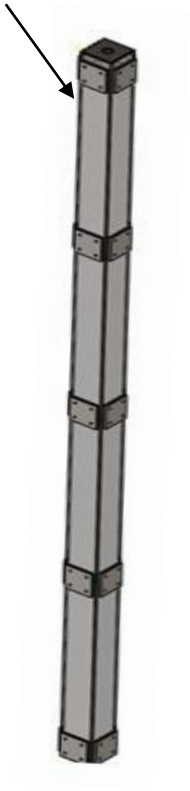
NUHOM 32 PTH2 Canister



Vertical Cask Model: Steel-Concrete-Steel



Empty Weight: 234,700 lbs
Loaded Weight: 335,952 lbs



Dummy Assembly

Dummy Assemblies

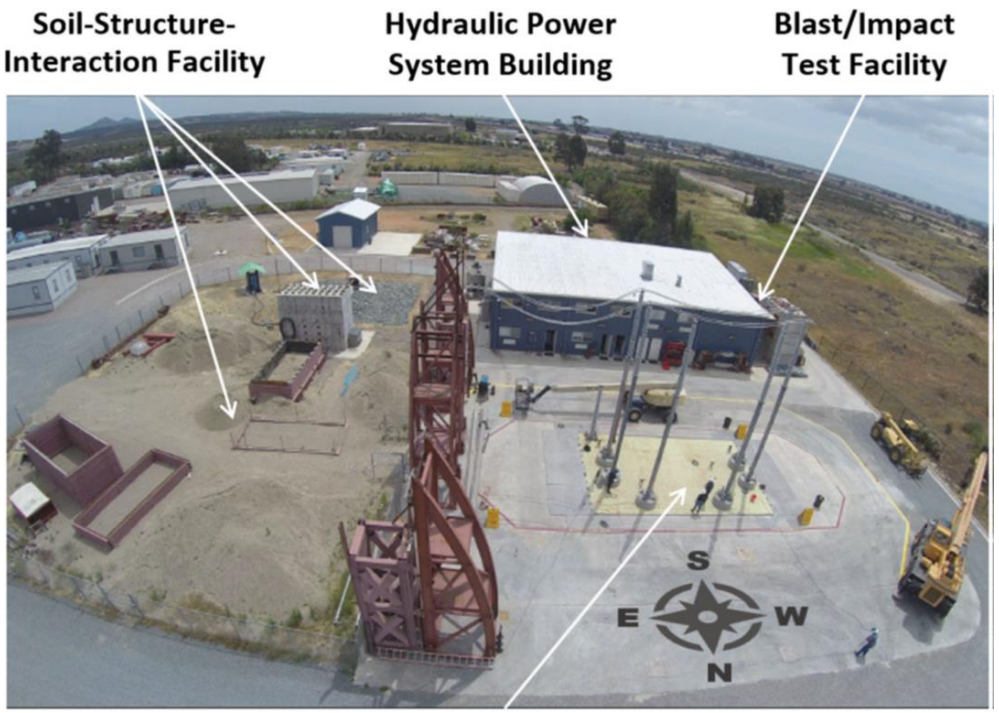
Width (mm)	Weight (lbs)	Number
207	1395.53	26
210	1406.55	1
214	1421.98	1

Surrogate Assemblies

- 16x16 CE PLUS7
- 17x17 Westinghouse Intact
- 17x17 Westinghouse slightly damaged
- 16x16 Framatome or Westinghouse

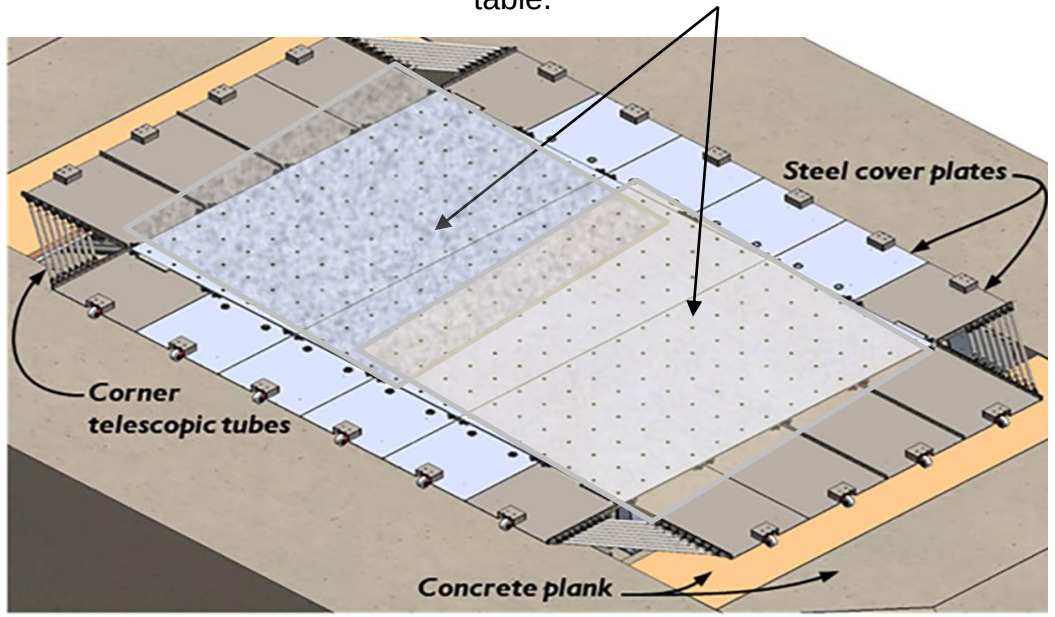
Slightly Damaged 17x17 Westinghouse

Simulating Representative ISFSI Pad Conditions



Large High-Performance Outdoor Shake Table (LHPOST)

Concrete layers possessing different finishes on the left and right side of the table.



- The concrete finish on the left and right side of the table will be different to represent different ISFSI pad conditions
- Experiments will be conducted with different concrete samples to find concrete finish formulations to achieve desired steel to concrete friction.

Proposed Instrumentation

Accelerometers

Instrumented Element	Location	NN of Triaxial	NN of Uniaxial
Dummy Assemblies (28)	top	28	(84)
Surrogate Assemblies (4)	tie plate	4	(12)
Surrogate Assemblies (4)	rods		32
Canister	top	2	(6)
Canister	bottom	2	(6)
Cask	top	2	(6)
Cask	bottom	2	(6)
Basket	top		2
Total		**40**	34 (120)

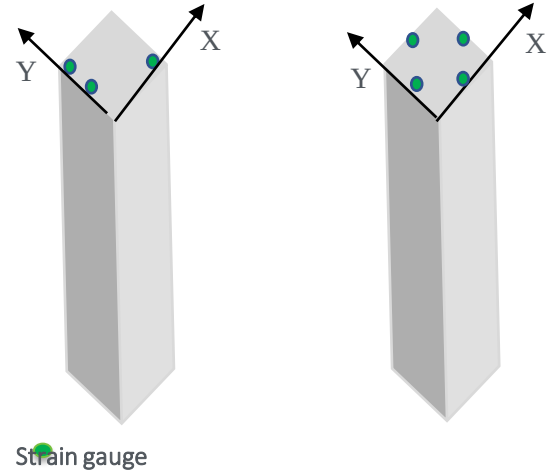
Strain Gauges

Instrumented Element	Location	NN, Alternative 1	NN, Alternative 2
Surrogate Assembly (4)	rods	96	`128

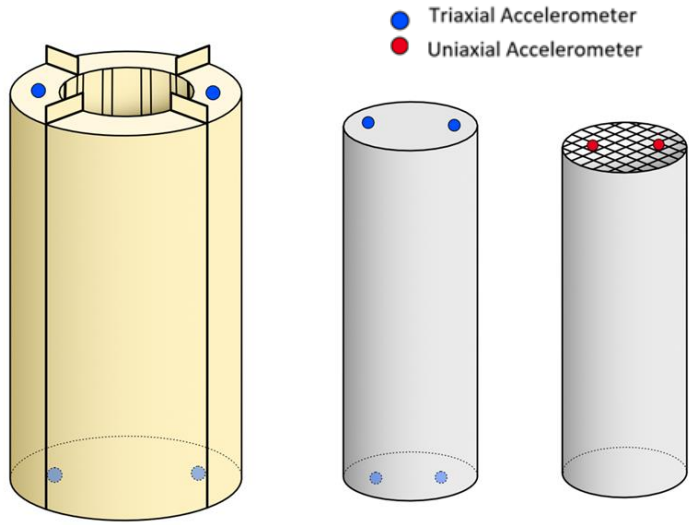
Dynamic Inclinometers

Instrumented Element	Location	NN
Canister	Top	2
Cask	Top	2
Shake table	top	2
Total		6

Locations of Instrumented Rods

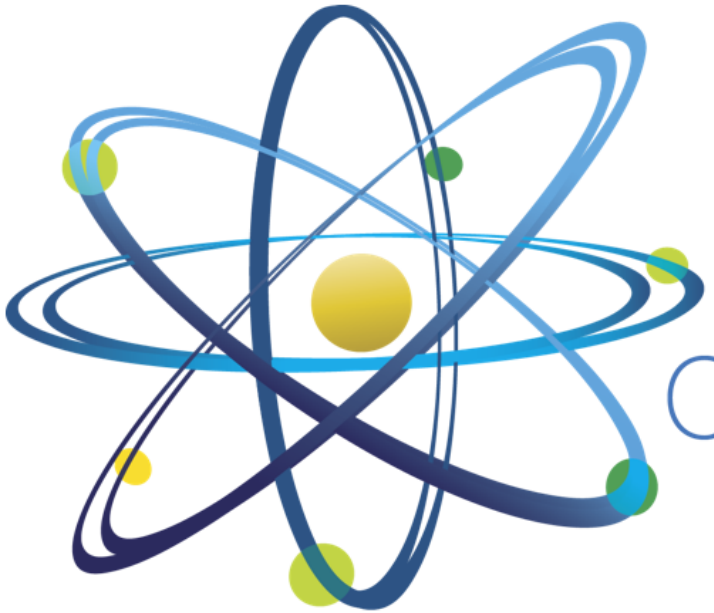


Cask, Canister, and Basket Instrumentation



- Details of the surrogate assembly instrumentation will be defined based on pre-test modeling results

Questions?



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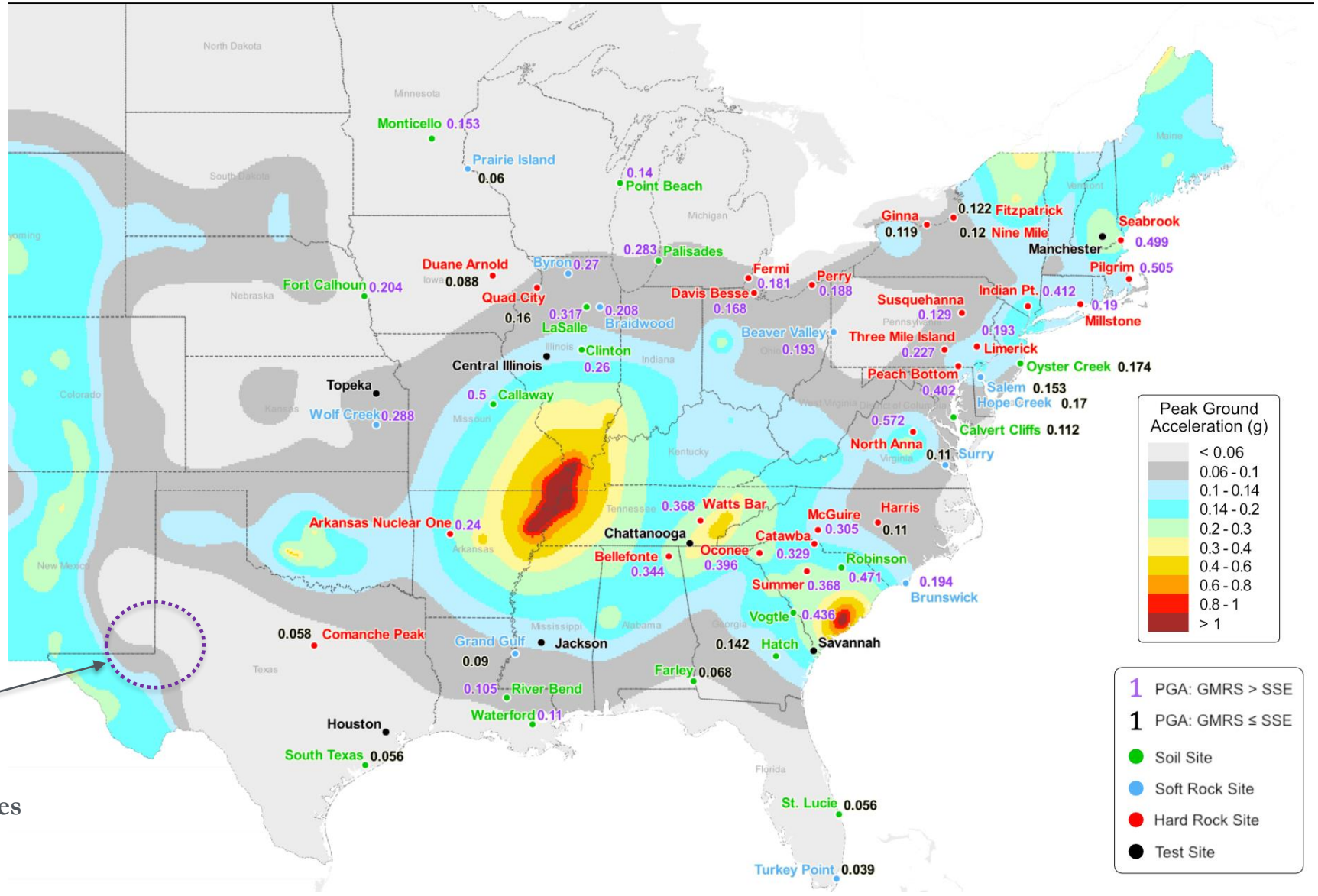
4E-04 Hazard Level PGAs in CEUS

In May of 2021 the USGS released the 4E-04 hazard level (2% exceedance in 50 years) map for the U.S. for the sheer wave velocity within the top 30 m of:

- 260 m/s (soil)
- 760 m/s (soft rock)
- 1,500 m/s (hard rock)

2% exceedance in 50 years PGA map for Vs30 = 260 m/s



Private Consolidated Storage Facilities