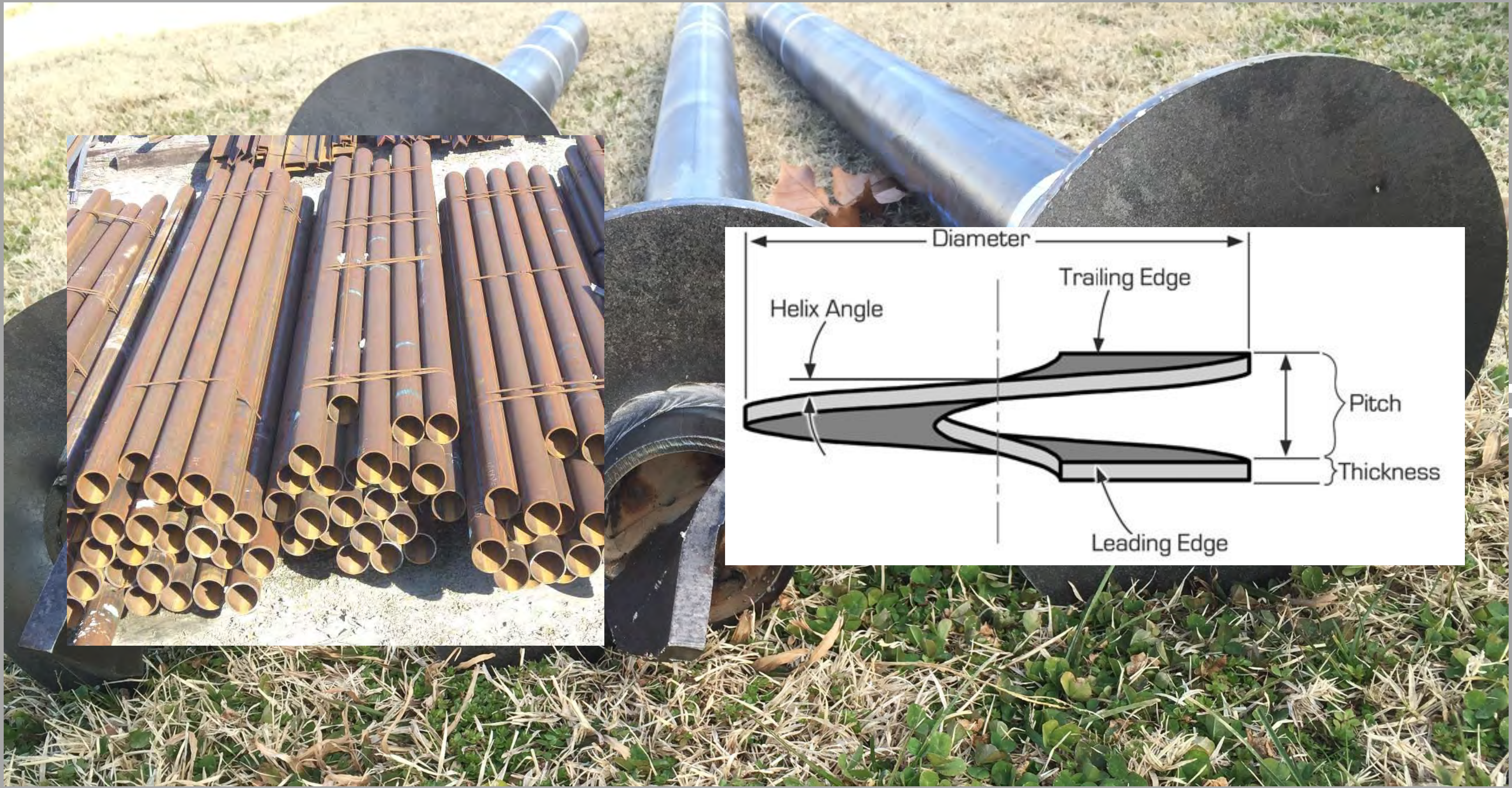
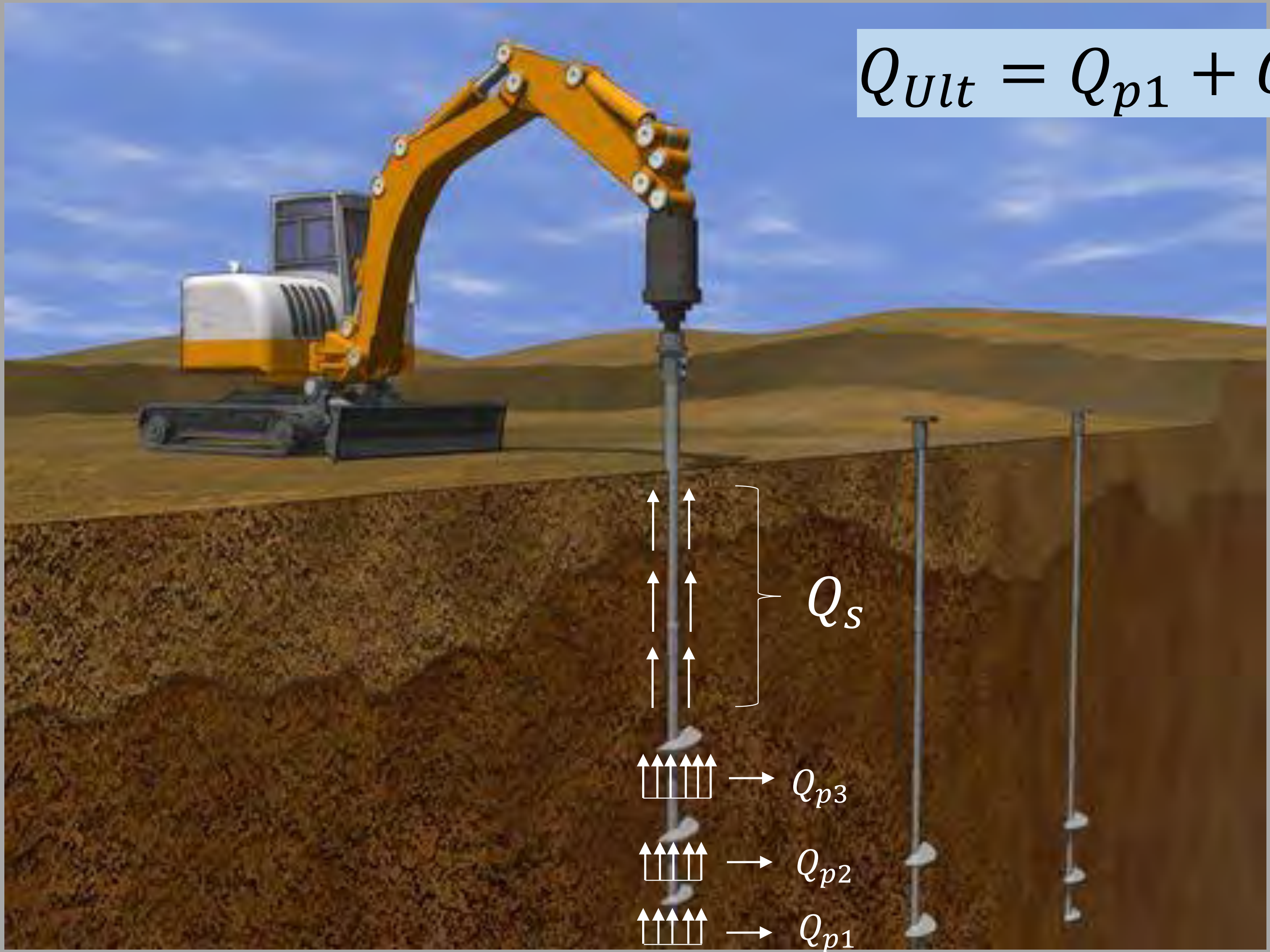
Amy Cerato, P.E., Ph.D.

Seismic Behavior of Helical Piles in Dense Sands



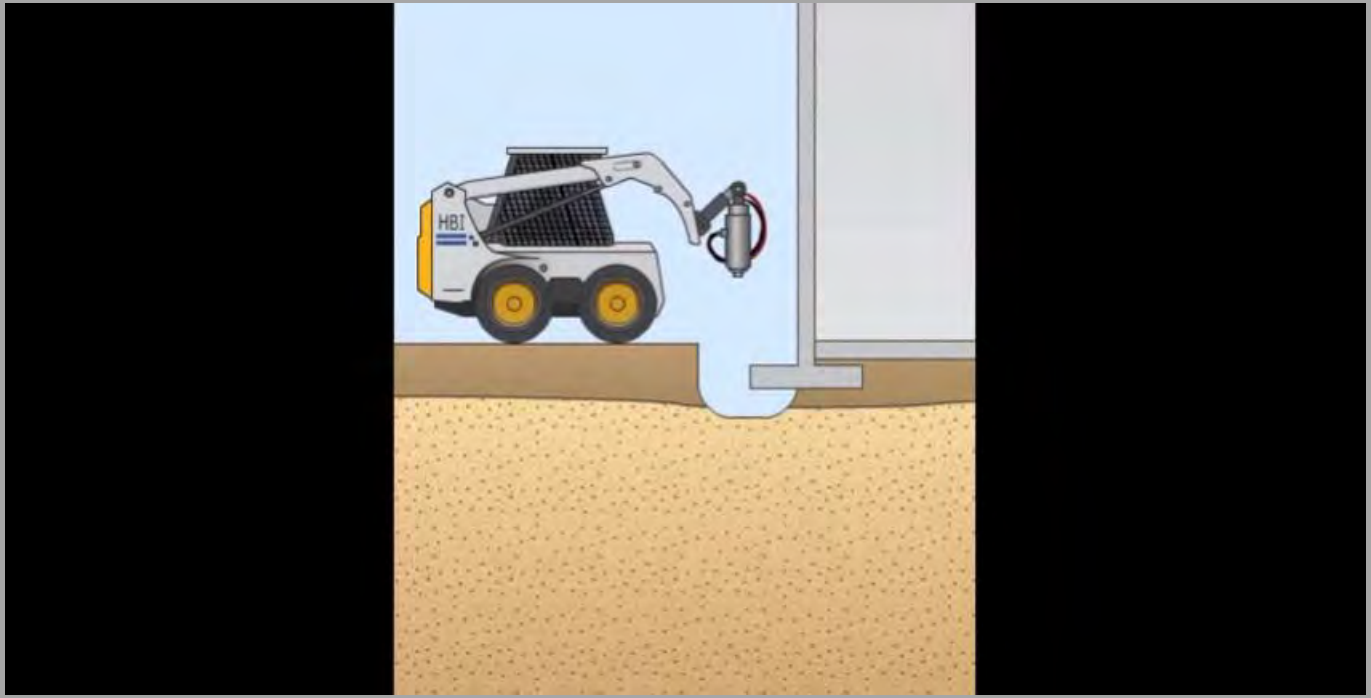
What are Helical Piles?

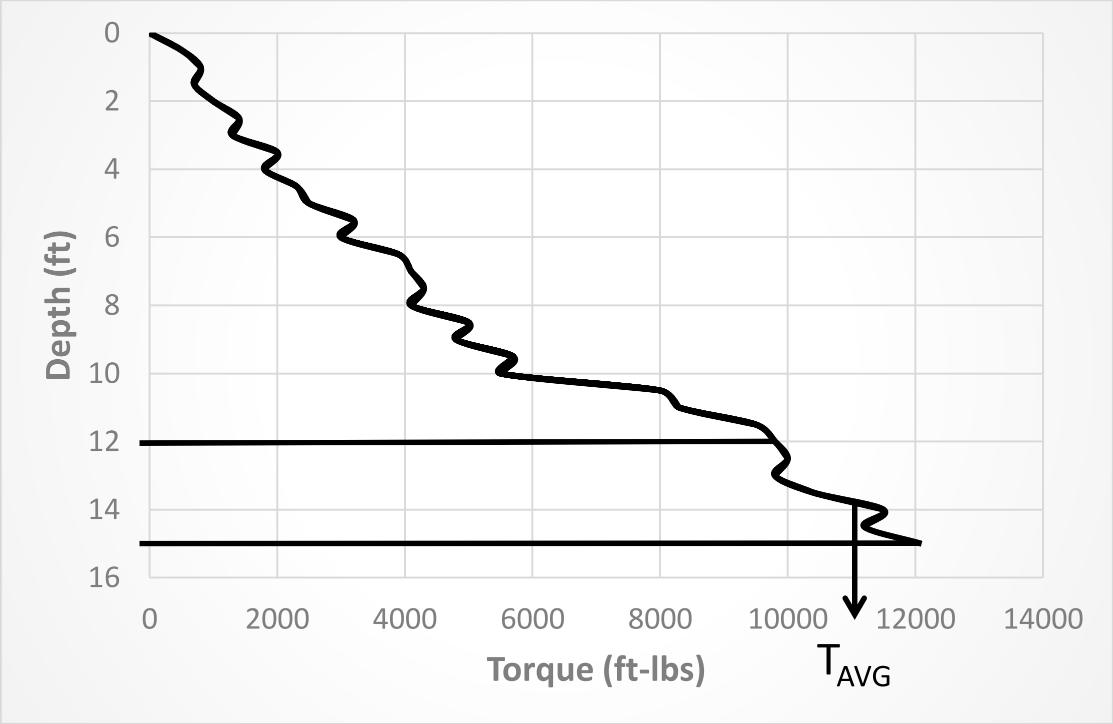
$$Q_{Ult} = Q_{p1} + Q_{p2} + Q_{p3} + Q_s$$



Individual Plate Bearing Method

$$Q_{ult} = KT$$





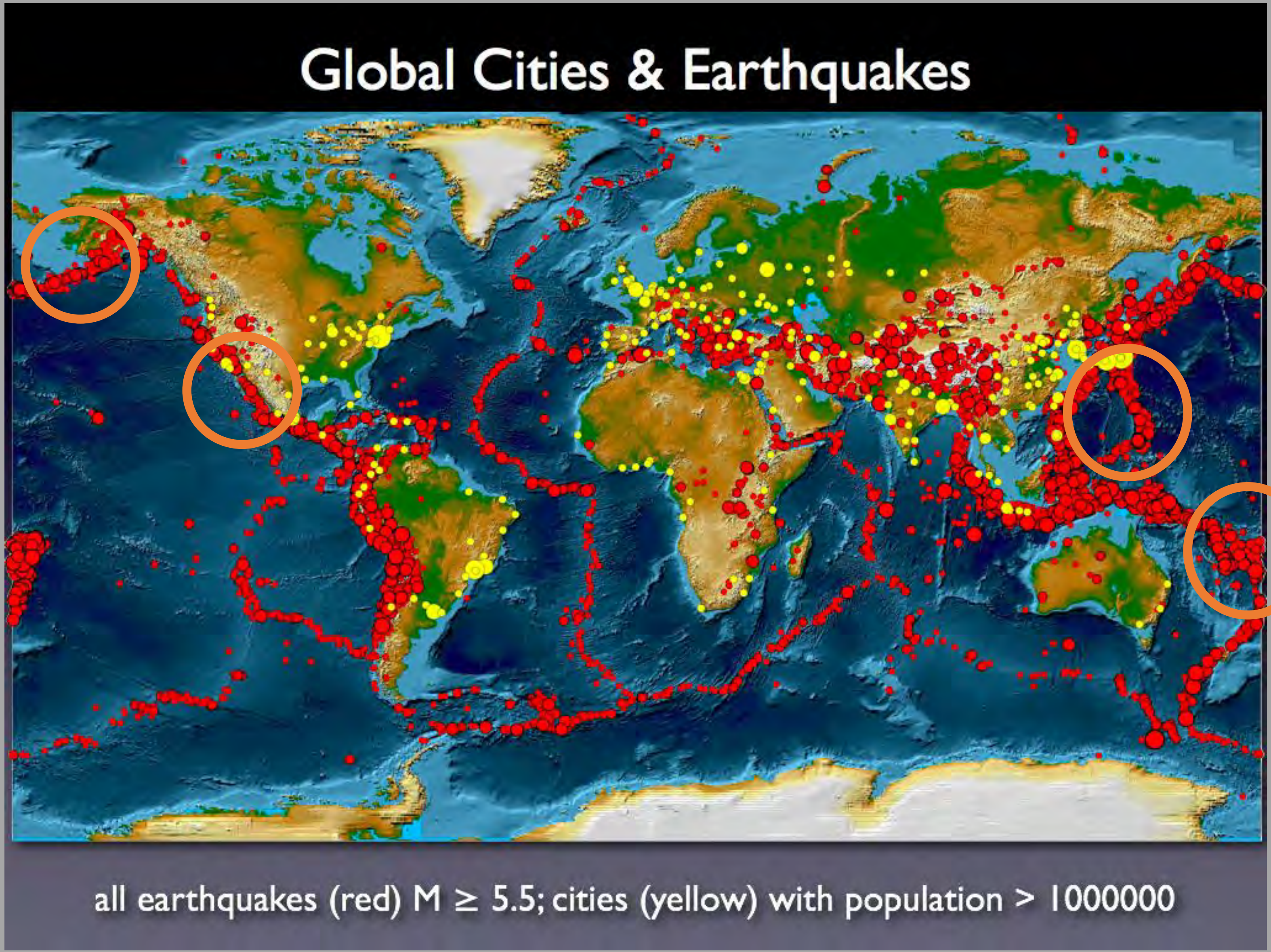
K = Correlation Factor

T = Avg. Torque of Last 3 Feet

Installation Torque Correlation

Slenderness

Resistance to
Tip Uplift

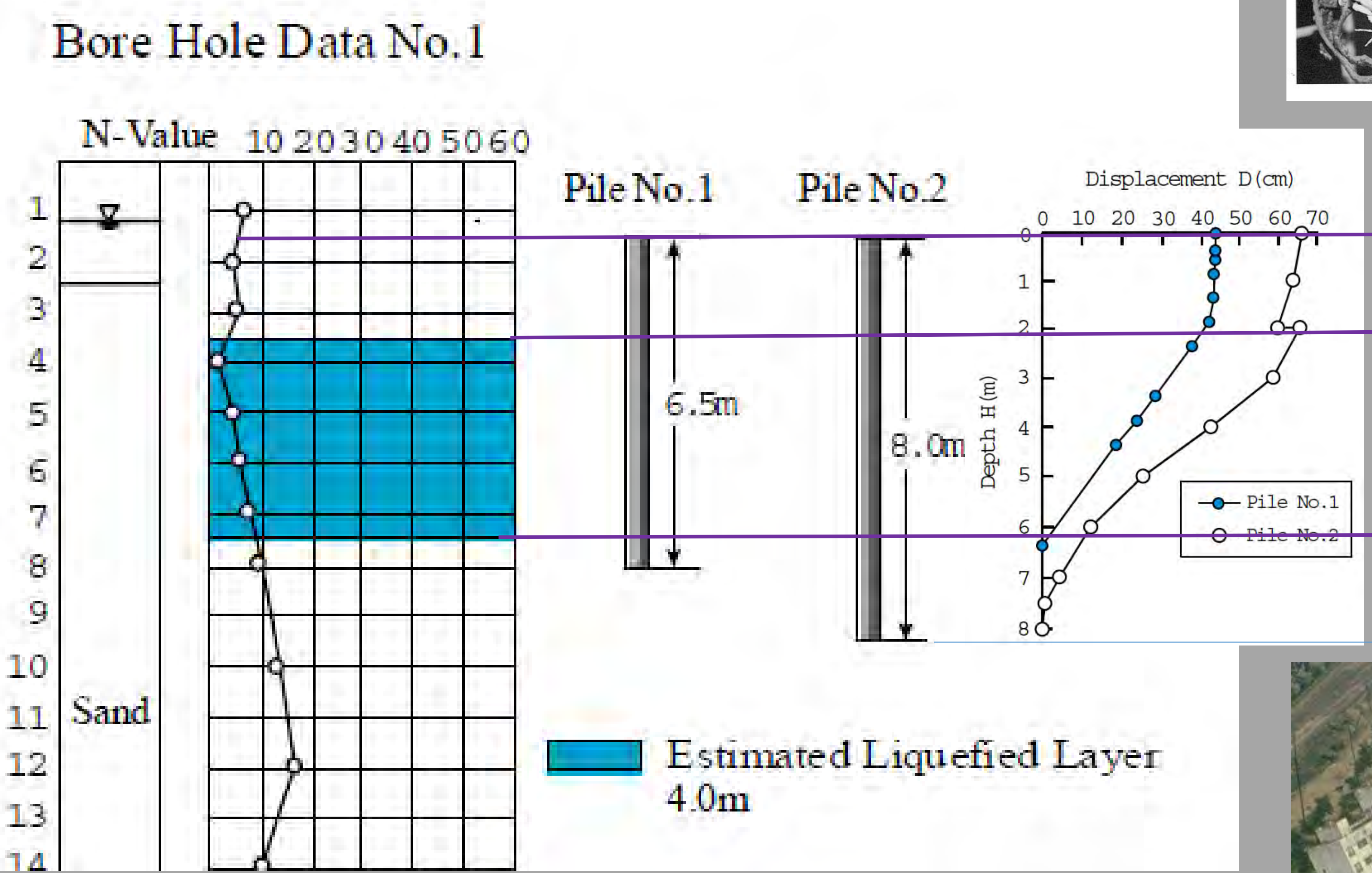


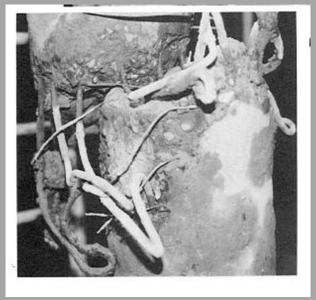
High Damping
Ratios

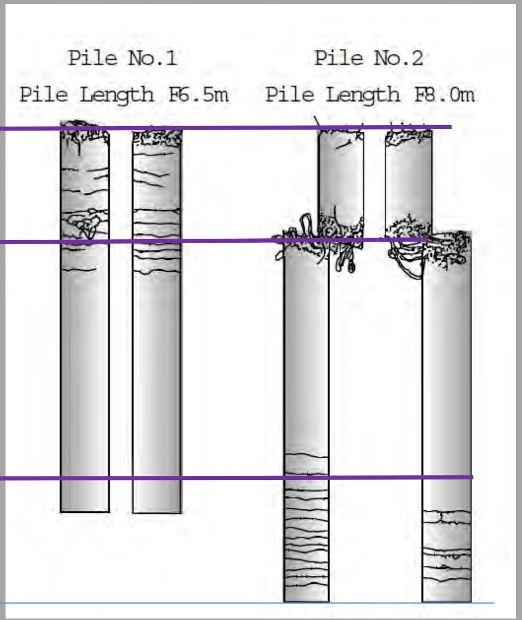
Ductility

We know they shake well!

From Hamada and O’Rourke 1992



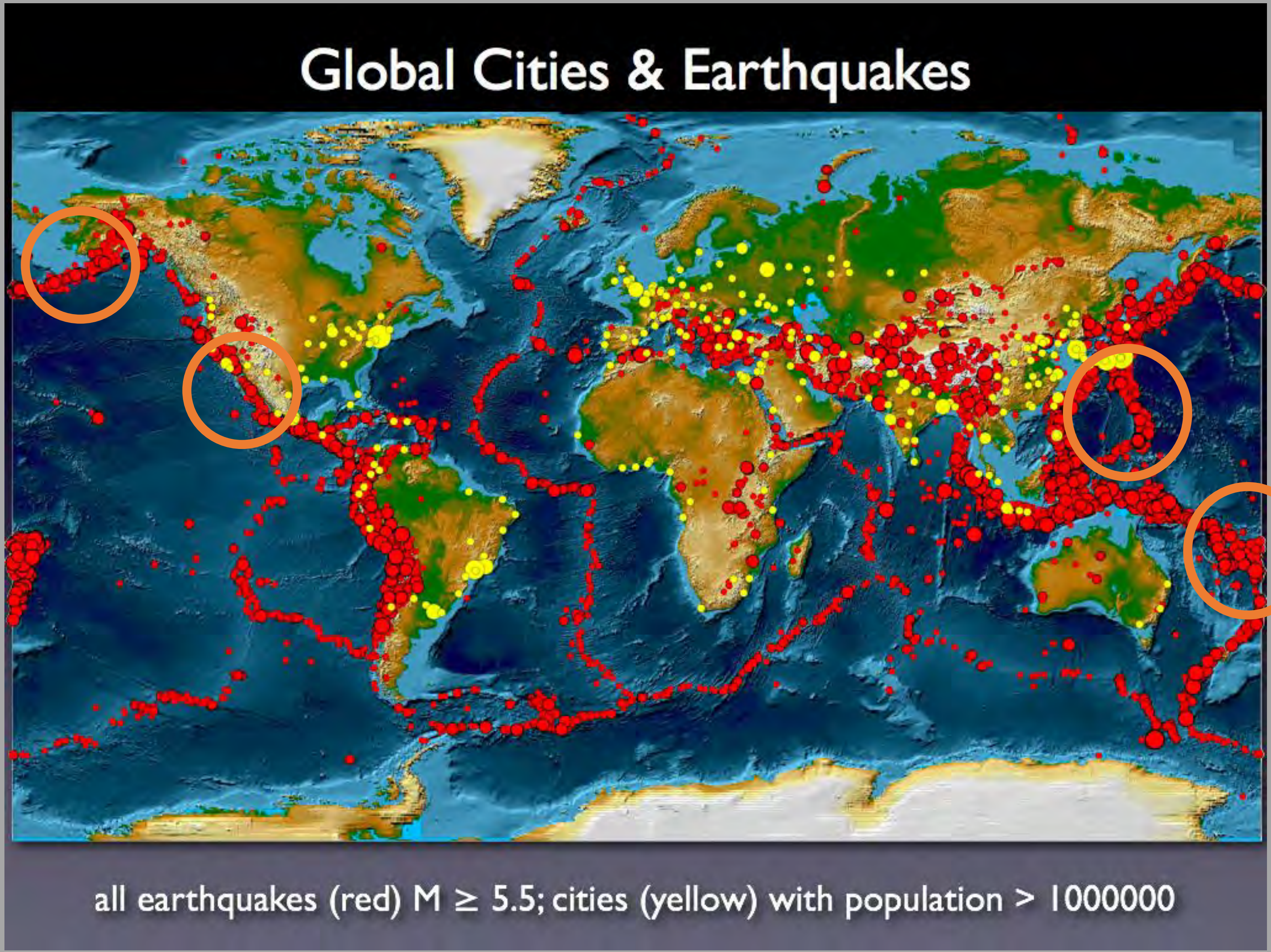




1964 Niigata Earthquake

Slenderness

Resistance to
Tip Uplift



High Damping
Ratios

Ductility

We know they shake well!

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ACCEPTANCE CRITERIA FOR
HELICAL FOUNDATION SYSTEMS AND DEVICES

AC358

Approved June 2007

Effective July 1, 2007

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ACCEPTANCE CRITERIA FOR
HELICAL PILE SYSTEMS AND DEVICES

AC358

Approved June 2013

(Editorially revised September 2014)

1810.3.3.1.9 Helical piles. The allowable axial design load, P_a, of helical piles shall be determined as follows:

$$P_a = 0.5\ P_u \quad \text{(Equation 18-4)}$$

where P_u is the least value of:

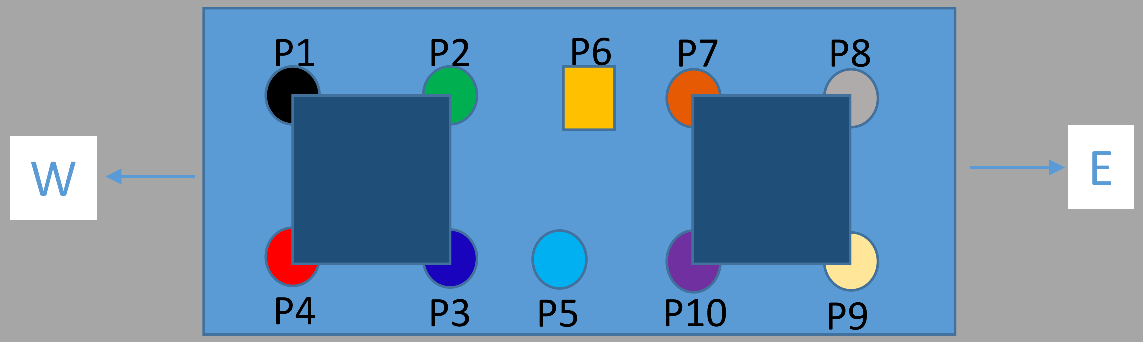
1. Sum of the areas of the helical bearing plates times the ultimate bearing capacity of the soil or rock comprising the bearing stratum.
2. Ultimate capacity determined from well-documented correlations with installation torque.
3. Ultimate capacity determined from load tests.
4. Ultimate axial capacity of pile shaft.
5. Ultimate axial capacity of pile shaft couplings.
6. Sum of the ultimate axial capacity of helical bearing plates affixed to pile.

This criteria are limited to helical pile systems and devices used under the following conditions:

1.2.1 Support of structures in **IBC Seismic Design Categories A, B, or C,** or UBC Seismic Zones 0, 1 or 2, only.

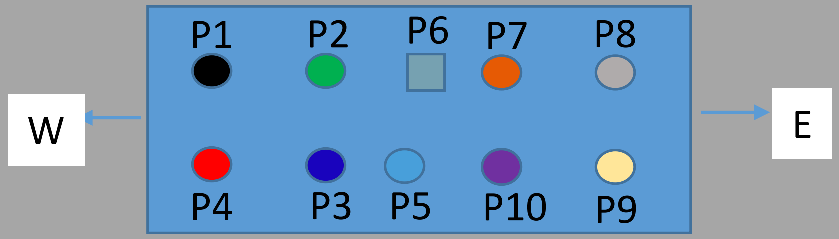
Helical Pile Design Evolution

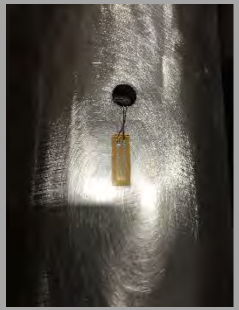

31
30
29
28
27
26
25



- Single Pile Behavior
  - Repeatability – multiple piles in the box that had same shaft shape, cross sectional area, helix configuration and coupling
  - Effect of helix – double helix compared with single helix
  - Effect of pile type – helical pile versus driven pile
  - Effect of shaft geometry – square versus pipe
  - Effect of coupling – threaded versus bolted
- Group Pile Behavior – FIRST time ever tested
  - Effect of pile head connection; fixed versus pinned

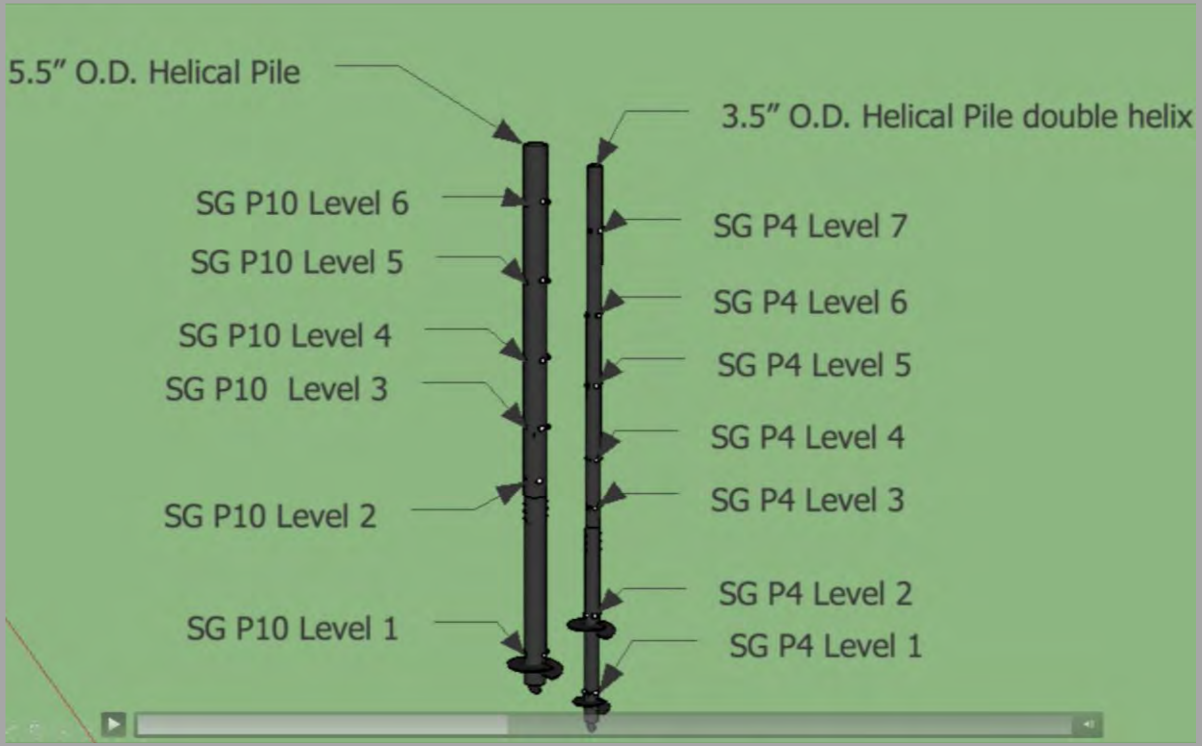
Parameters to Study

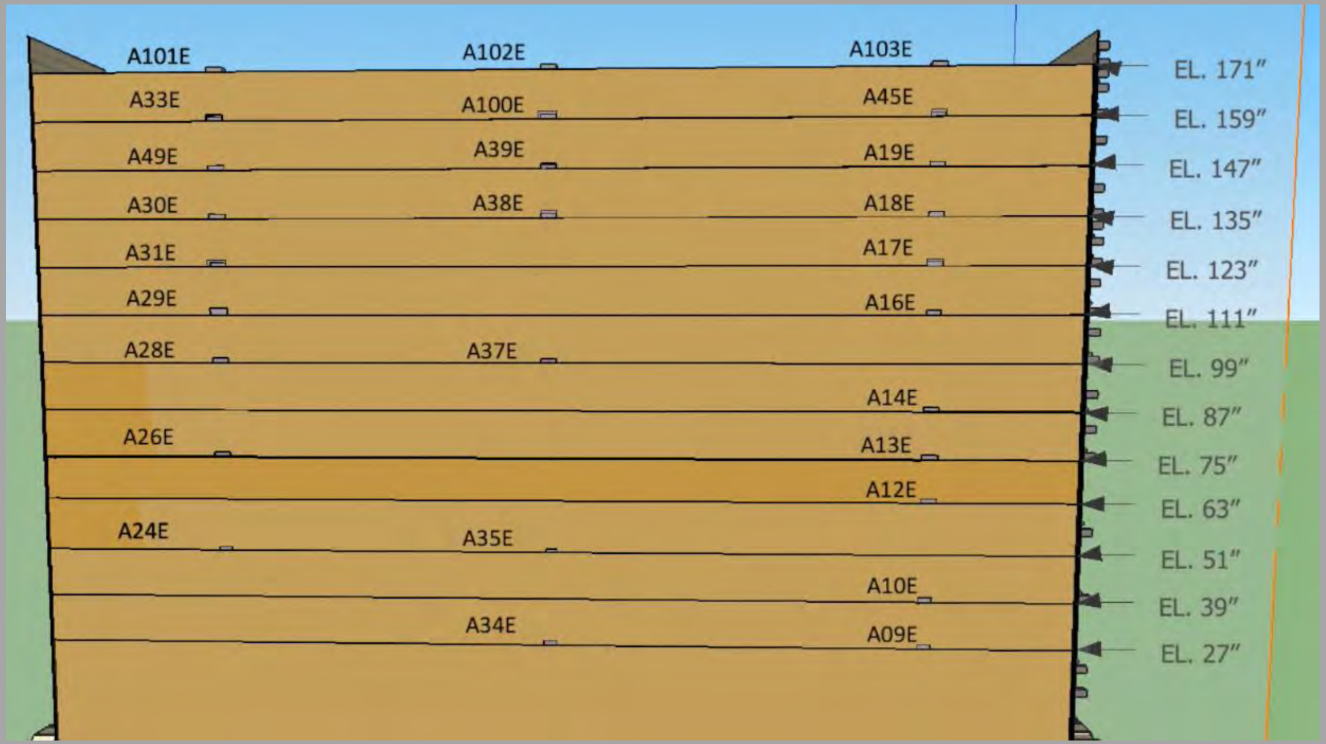




Pile Instrumentation
(152 strain gages)

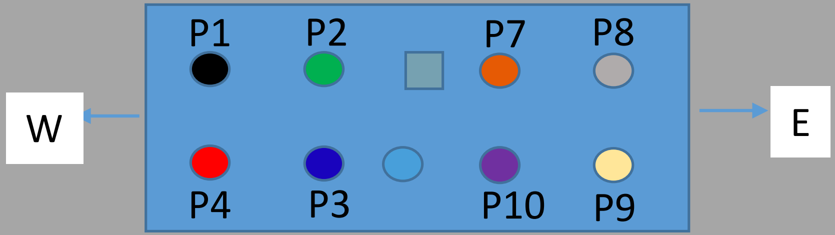
Sand Bed
(27 Accelerometers)



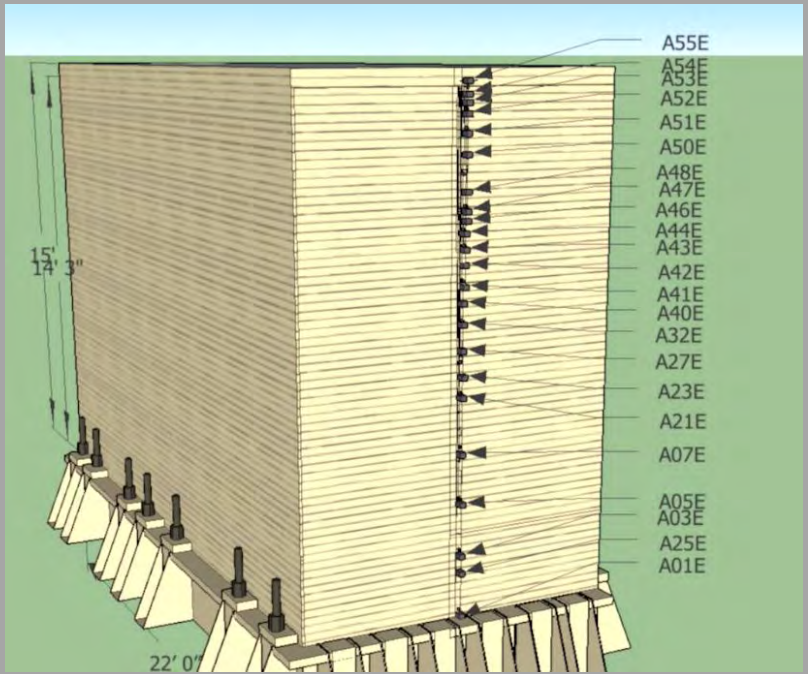


Instrumentation

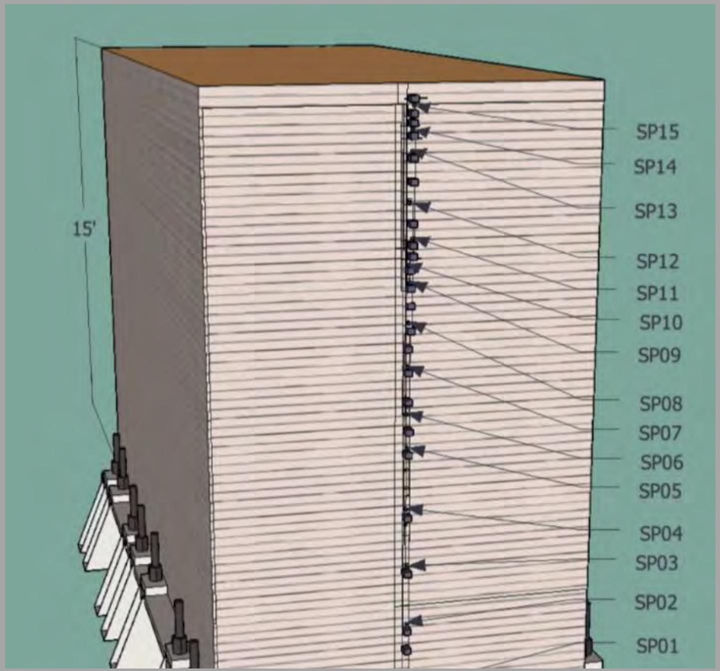
Instrumentation

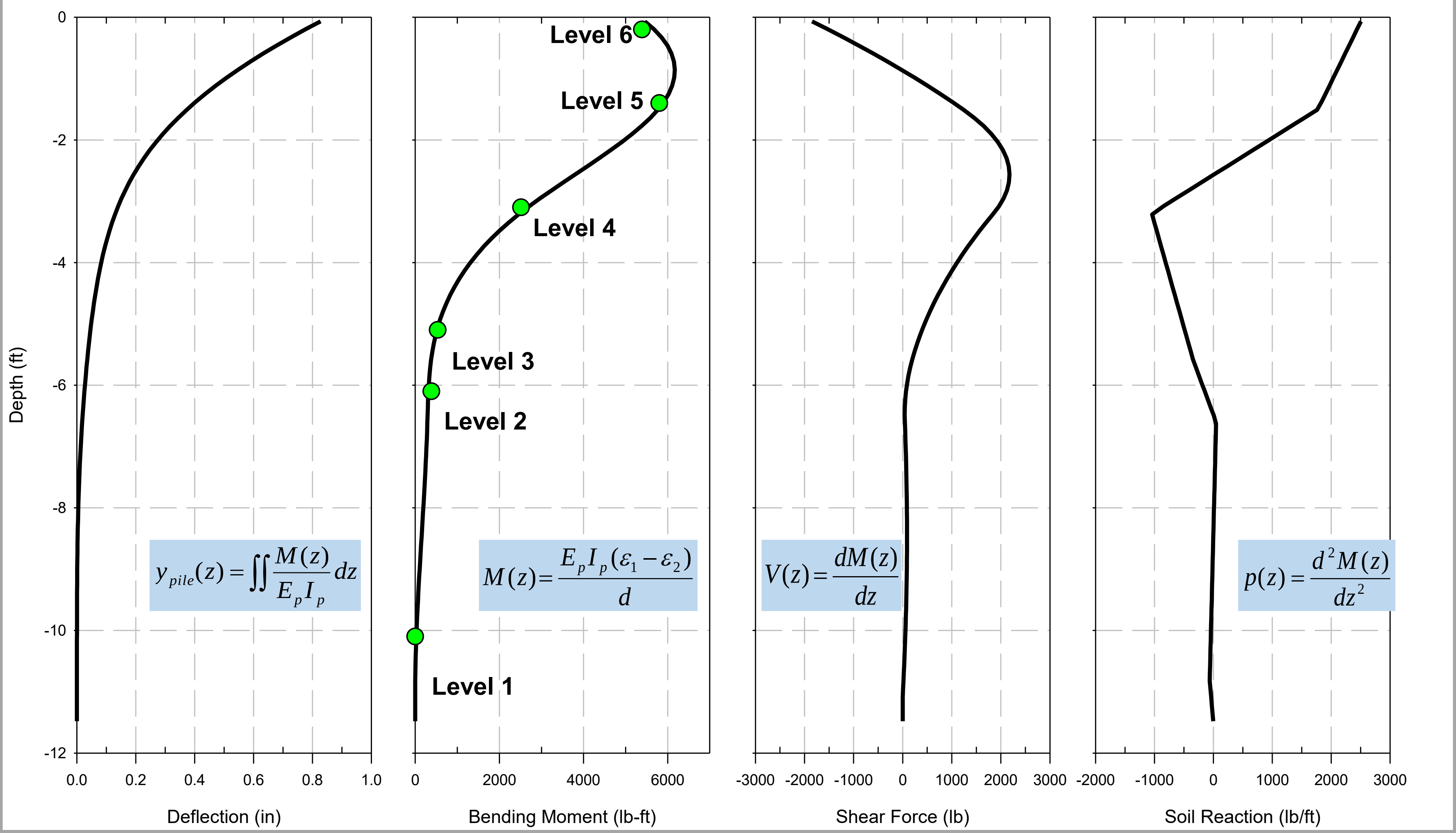


Laminar Soil Box Accelerometers (23)



Laminar Soil Box String Potentiometers (Direct Displacement Measurement) (15 + Skid)

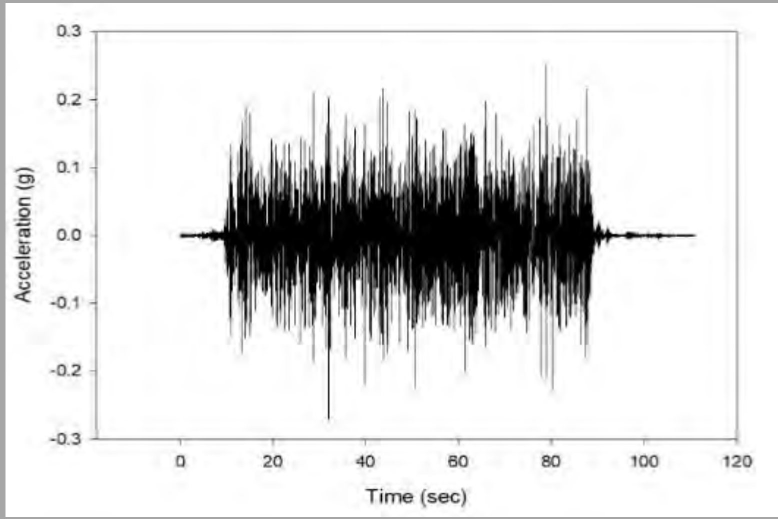




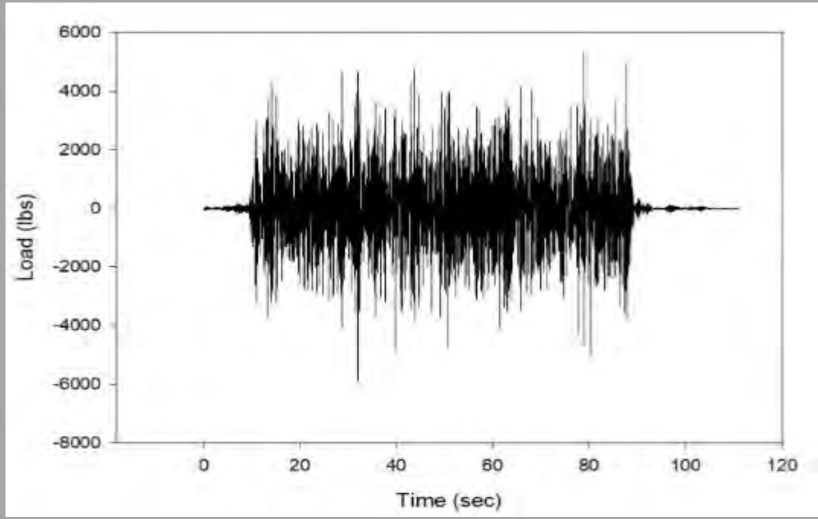
Measurements and Calculations

Measurements and Calculations

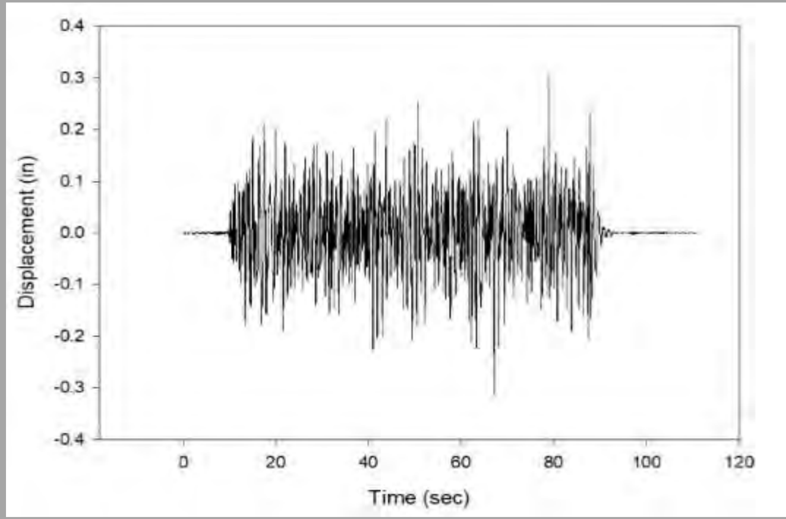
Accelerometer Time History

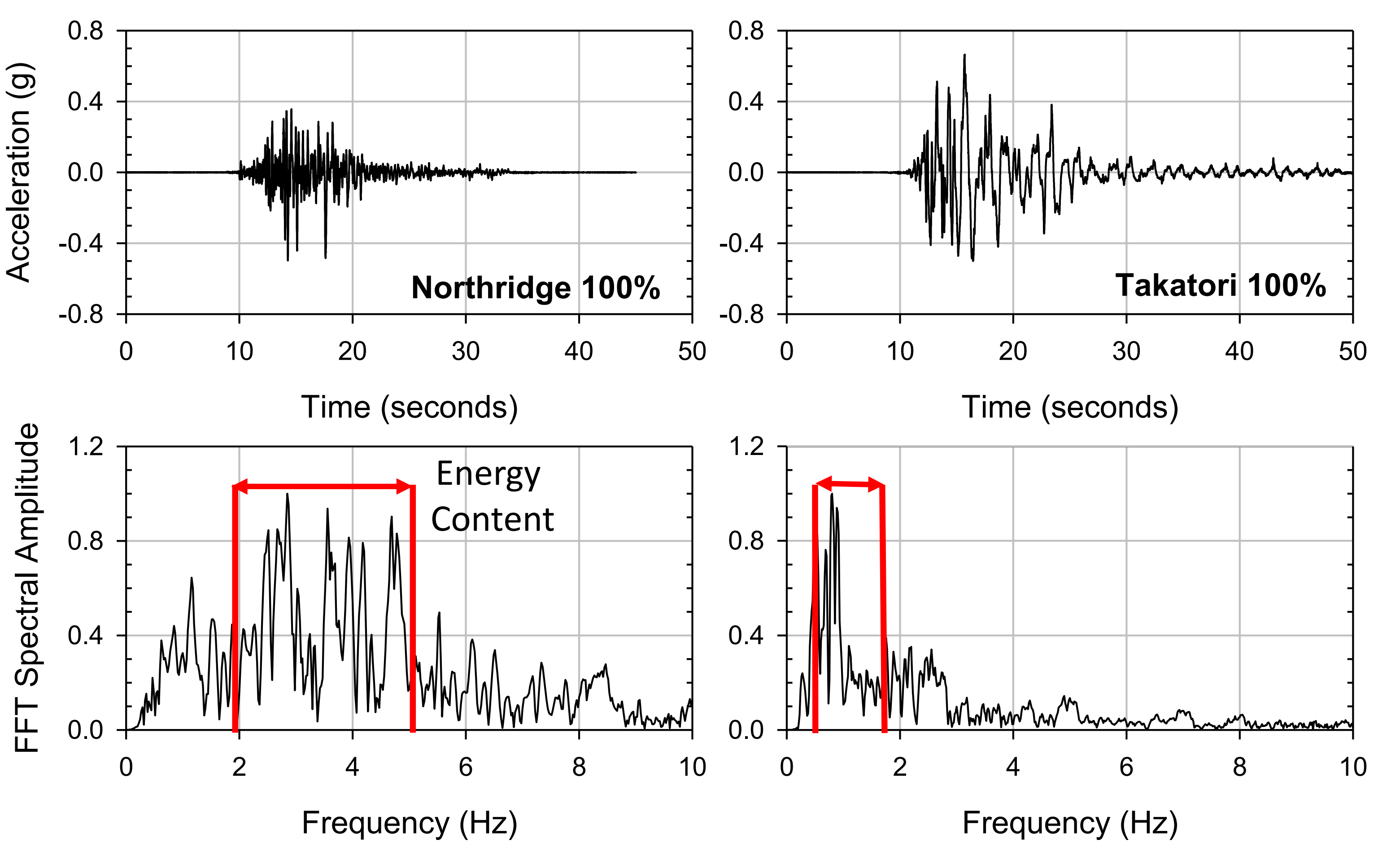


Load Time History =
Acceleration Time History *
Structure (or Supported) Mass



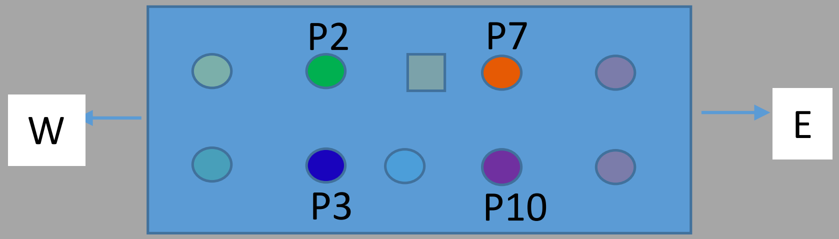
Displacement Time History =
Double Integration of Accelerometer

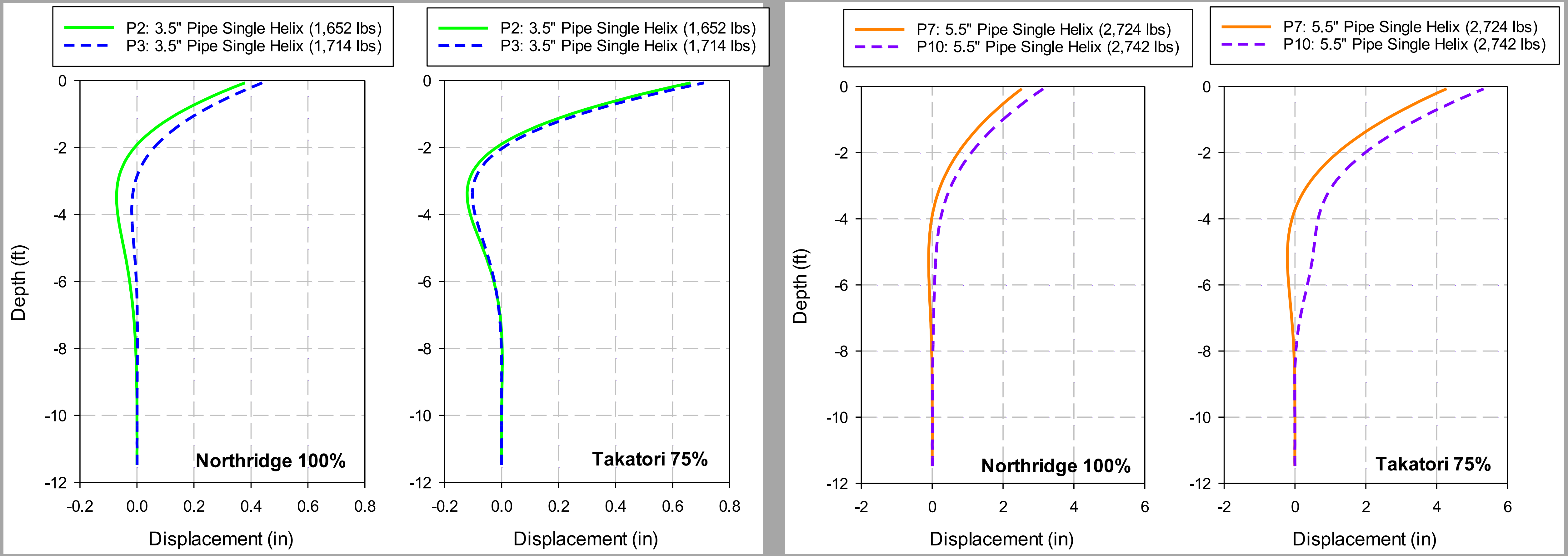




Quake	Intensity relative to unscaled (%)	Absolute peak acceleration (g)
NR	100	0.50
NF	75	0.37
NR	50	0.25
TAK	100	0.67
TAK	75	0.50
TAK	50	0.33

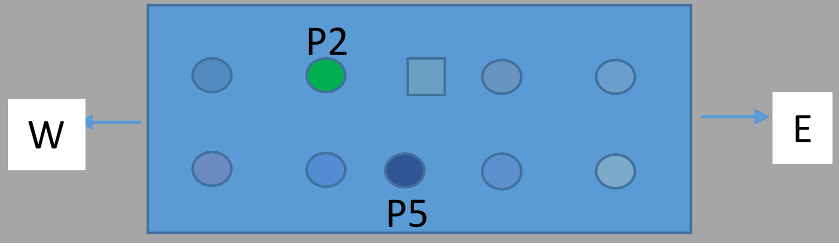
Earthquake Records and Frequency Content





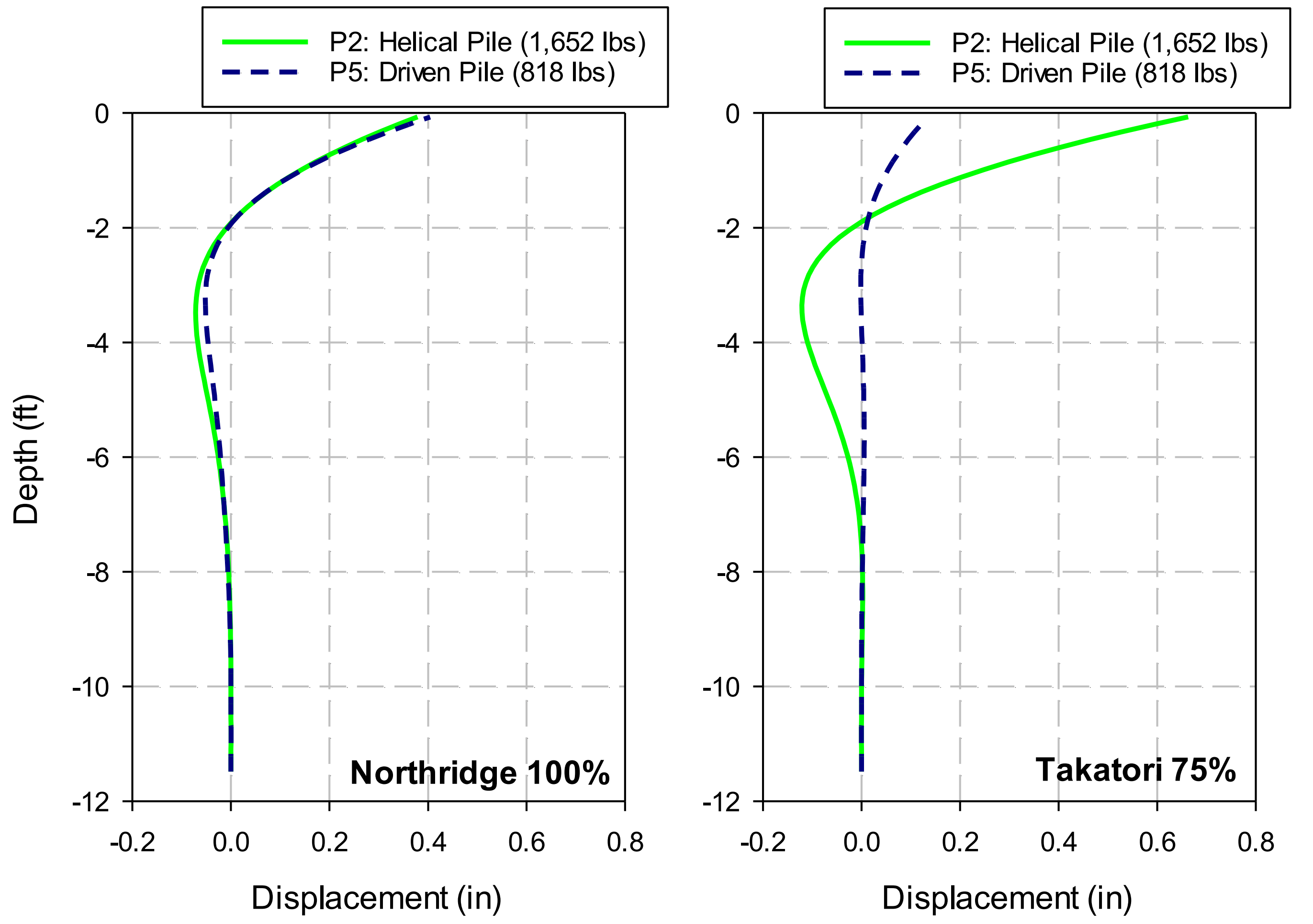
Repeatability

Pile Type



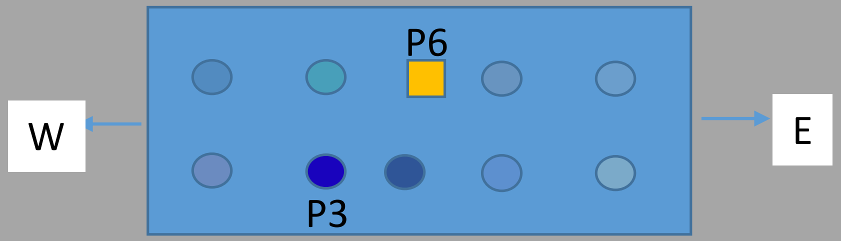
Natural Frequency of System VERY Important!

- P2: F_n = 2.33 Hz
- P5: F_n = 4.06 Hz as is, but reduces to 2.85 Hz considering same mass as P2



Effect of Natural Frequency

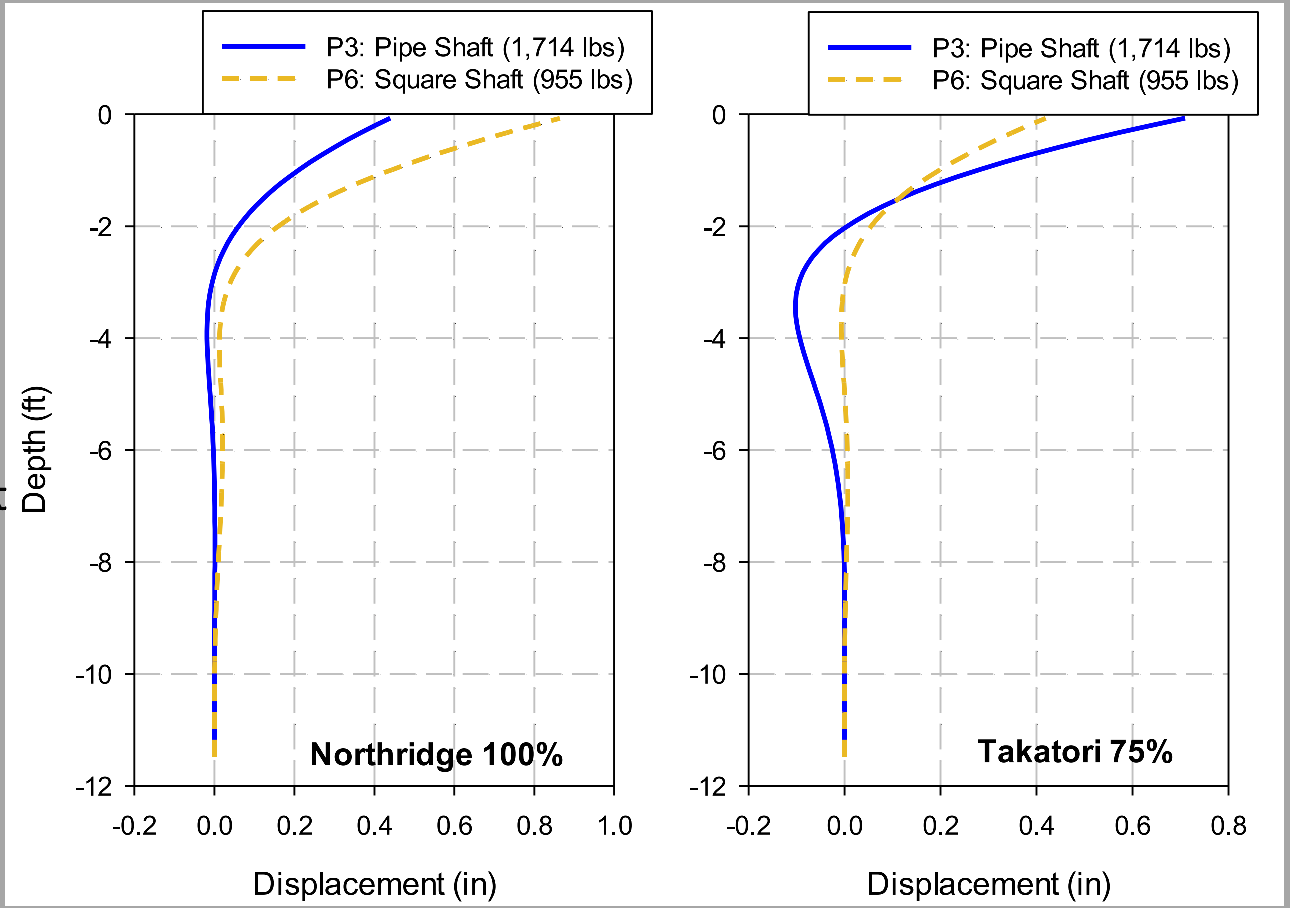
Shaft Geometry



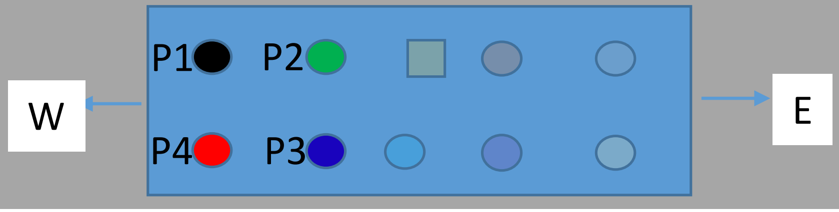
Natural Frequency of System VERY Important!

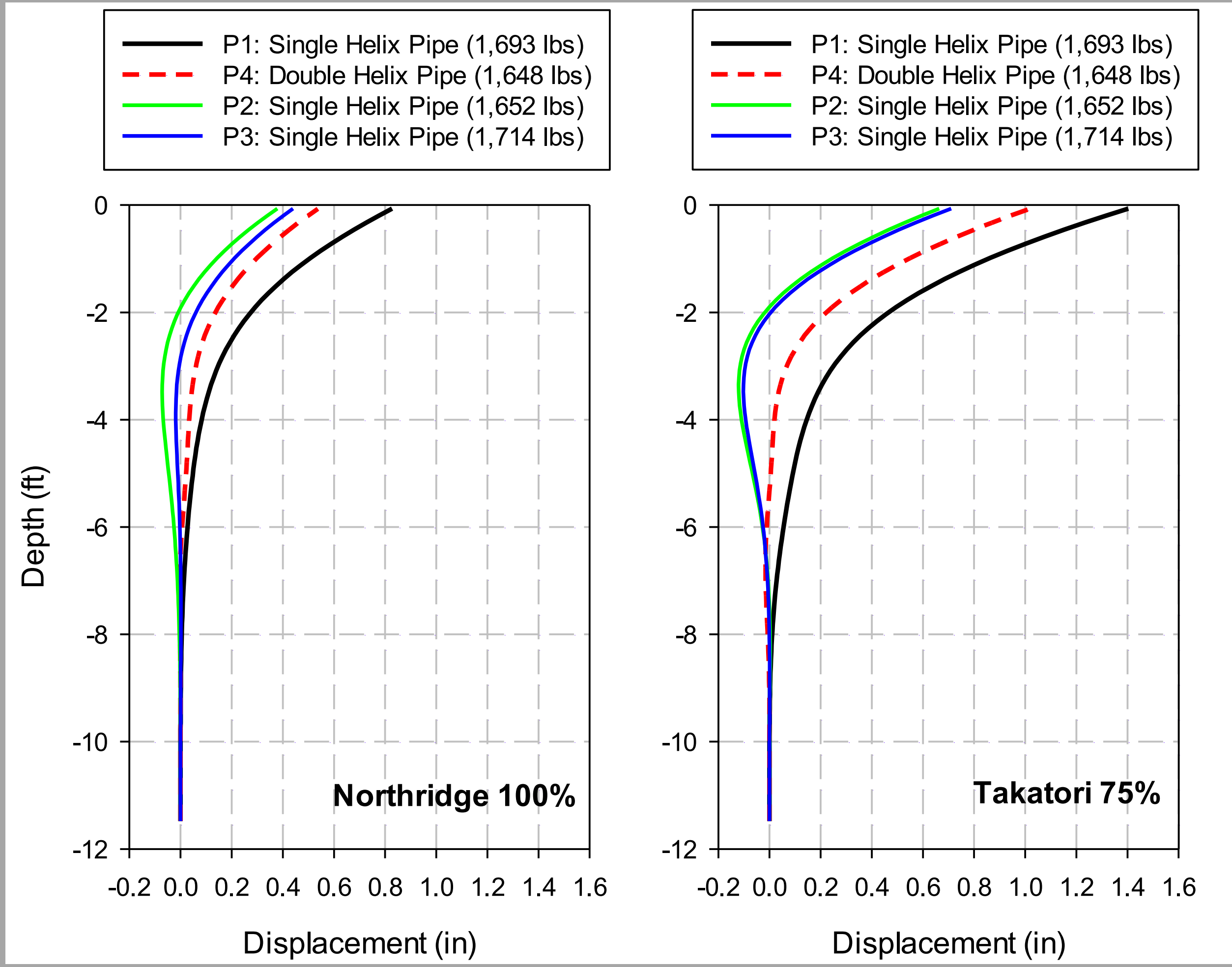
P3: Fn = 1.88 Hz

P6: Fn = 3.78 Hz as is, but reduces to 2.67 Hz considering same mass as P3

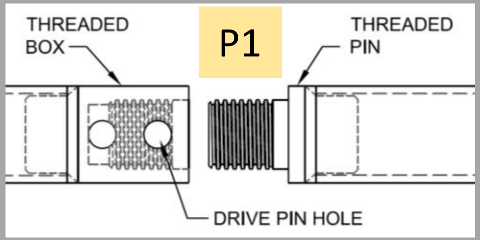


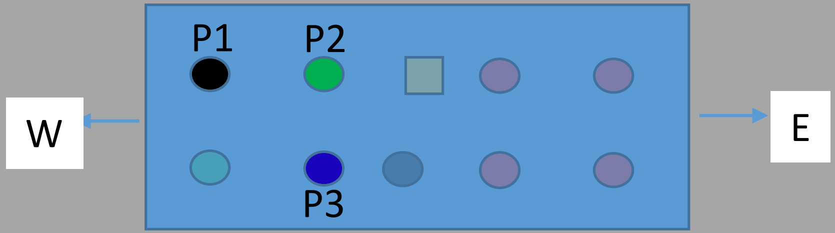
Effect of Natural Frequency

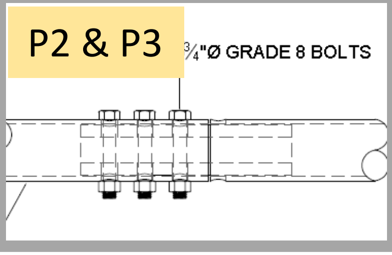


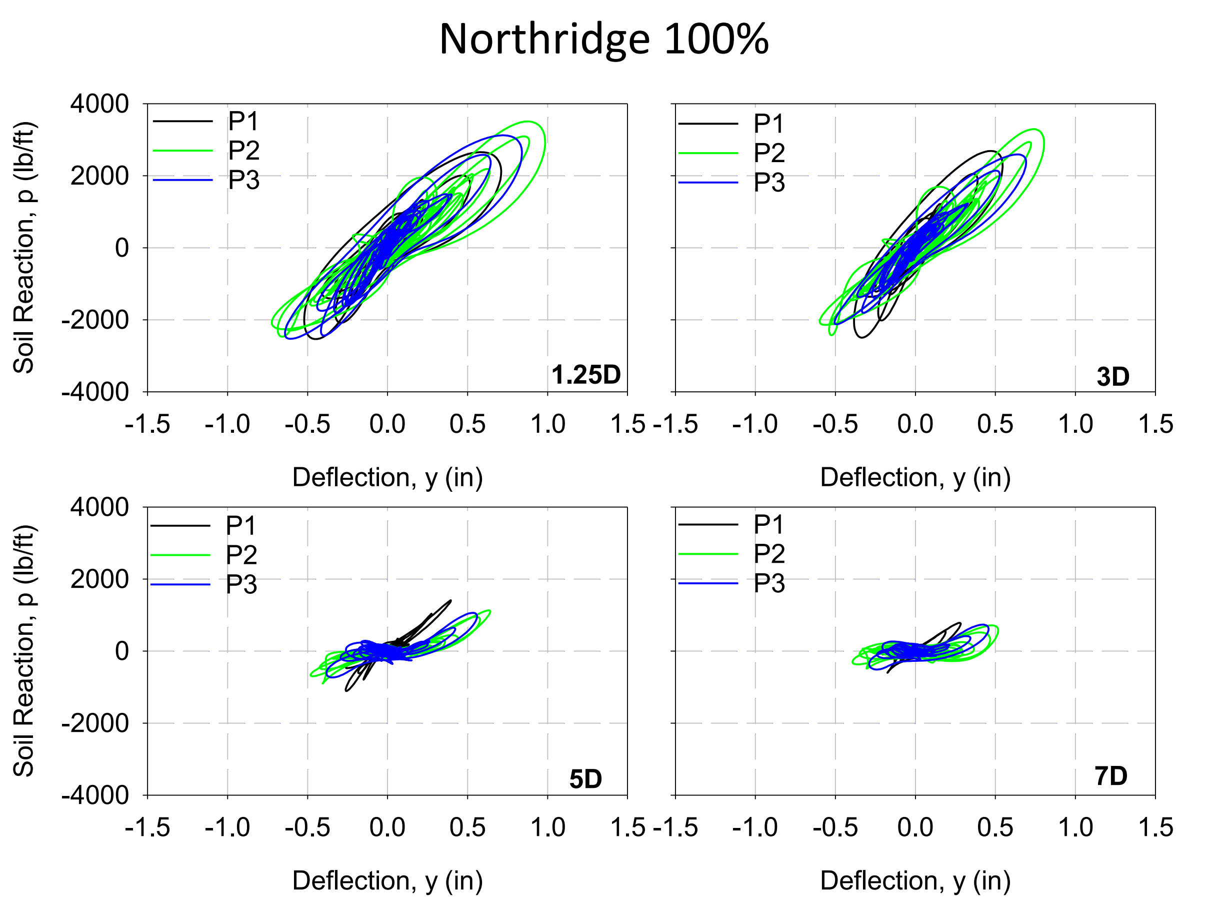


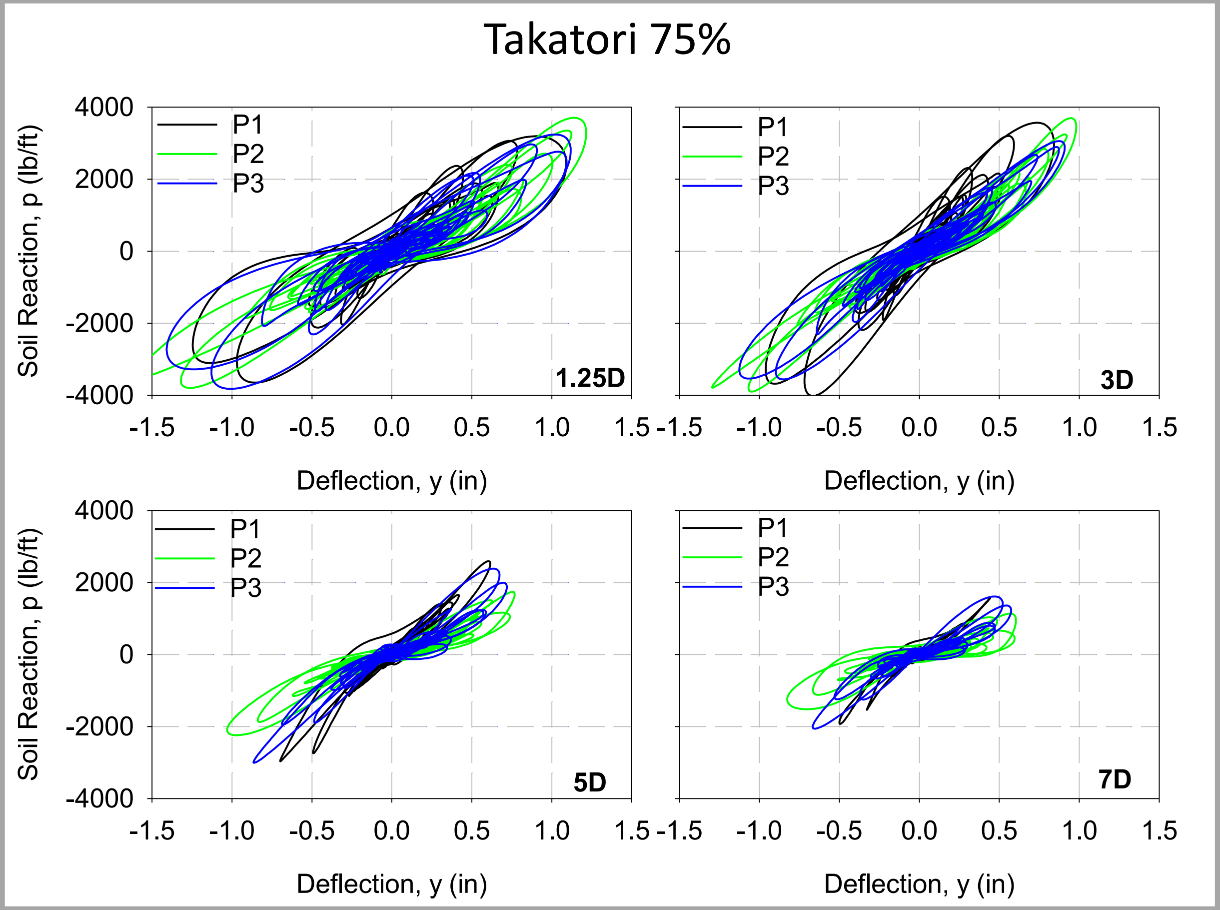
Effect of an Additional Helix



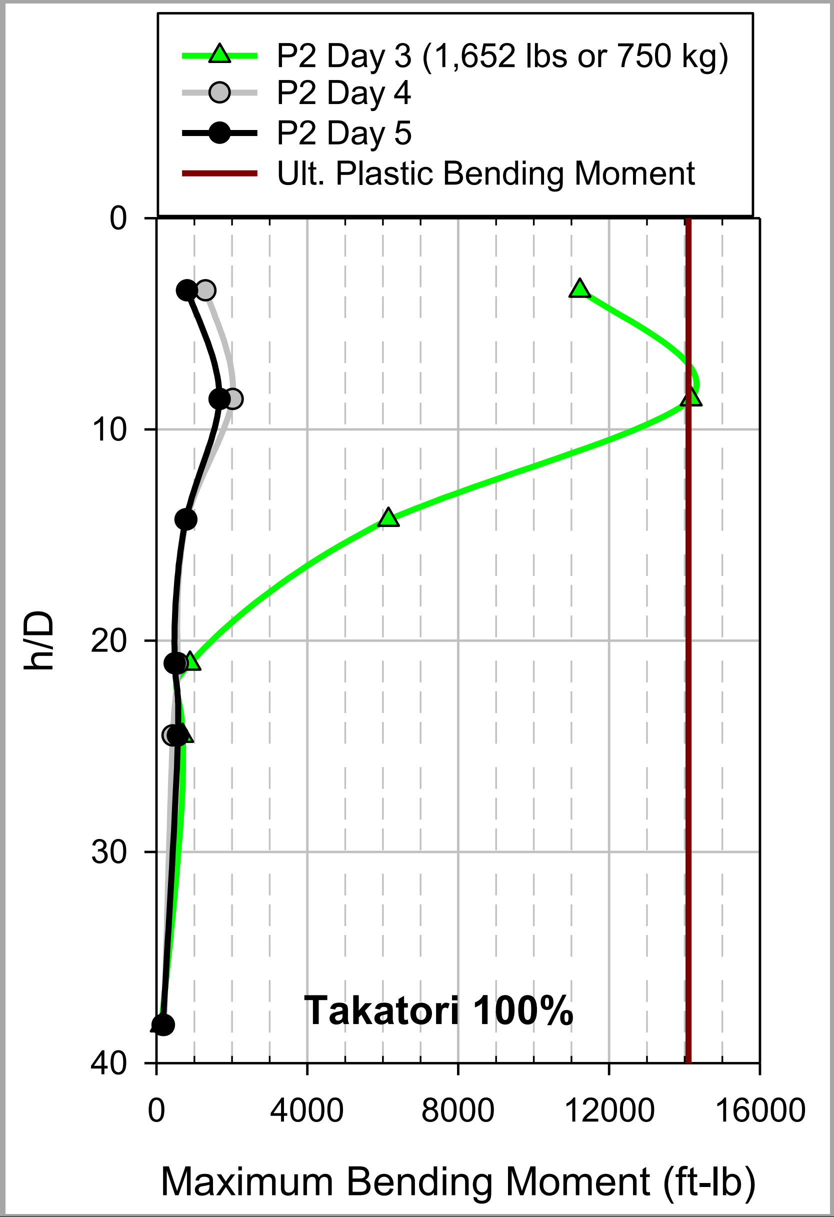


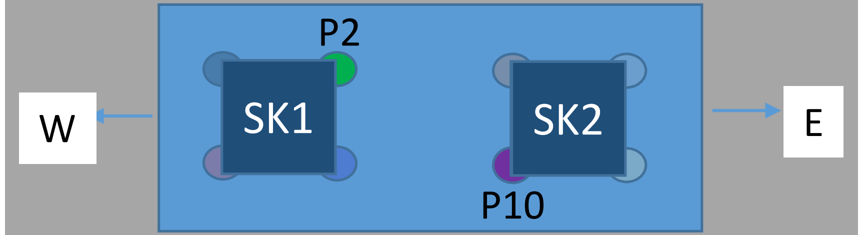




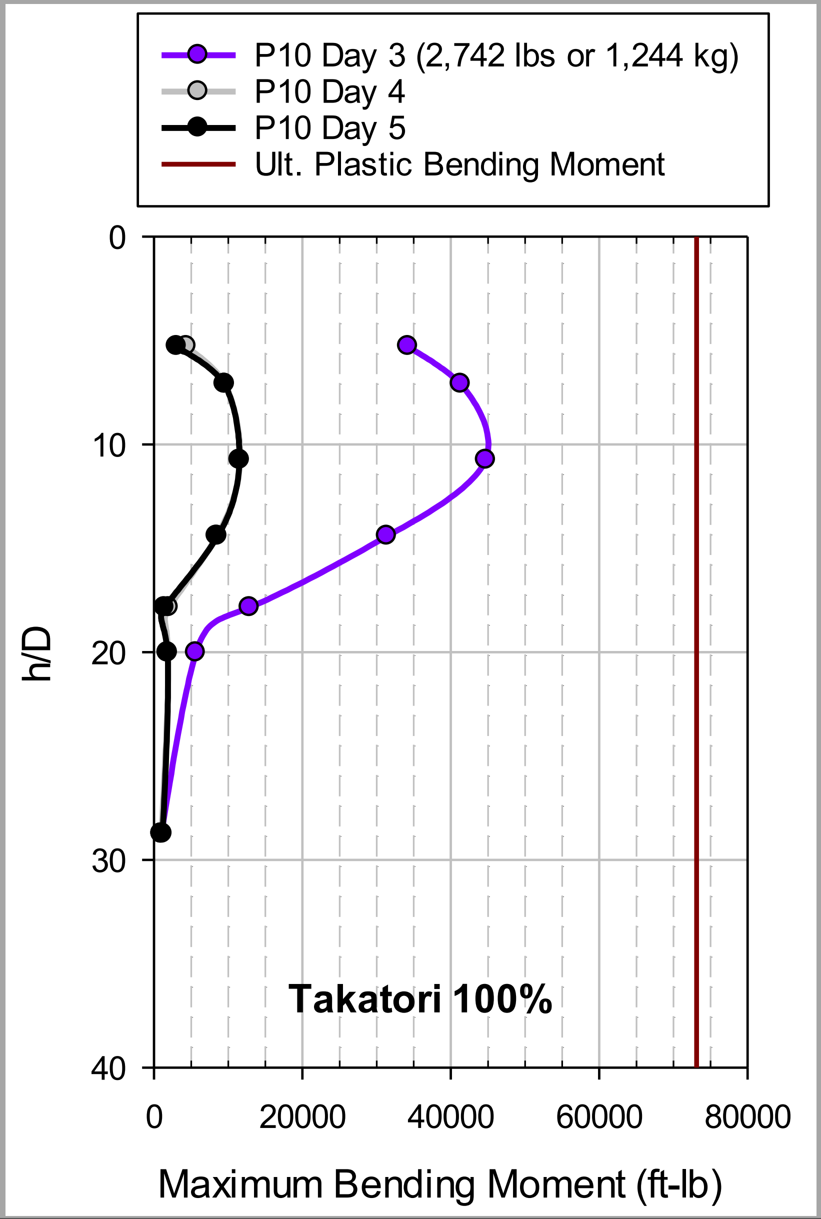


Effect of Coupling



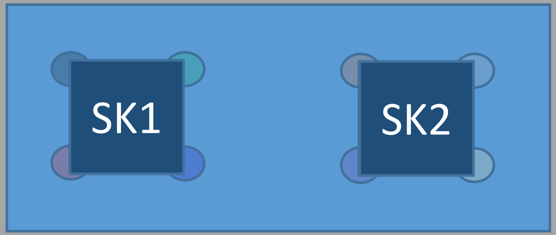


	Day 4 – FIXED	Day 5 - PINNED
	SKID 1 - **PER PILE**	
Axial Load (lbs)	3,500	3,500
Lateral Load (lbs)	4,750	4,000
	SKID 2 - **PER PILE**	
Axial Load (lbs)	5,500	5,500
Lateral Load (lbs)	11,750	10,825



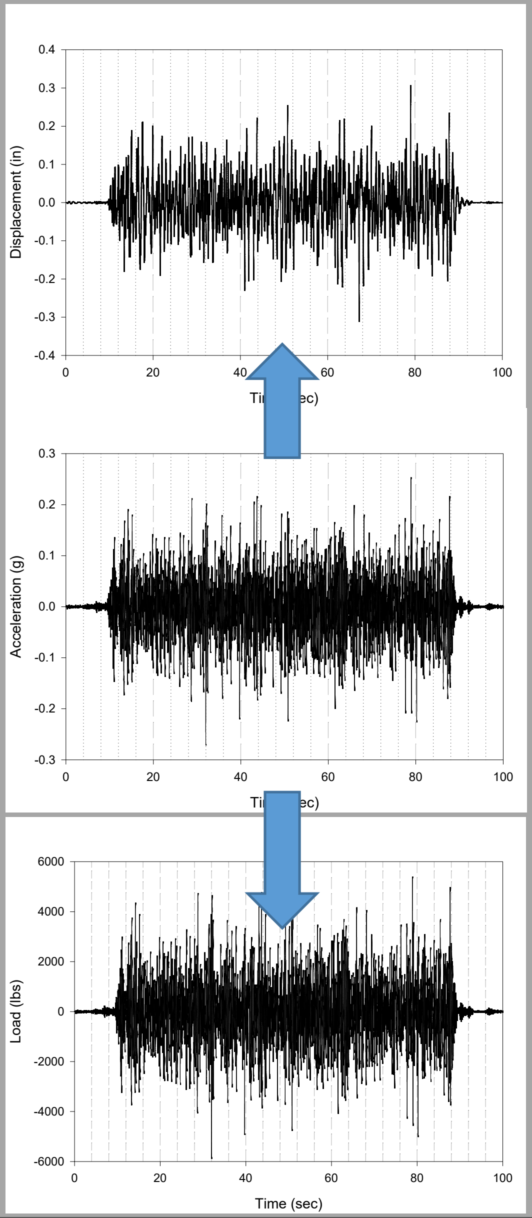
Effect of Grouping Helical Piles

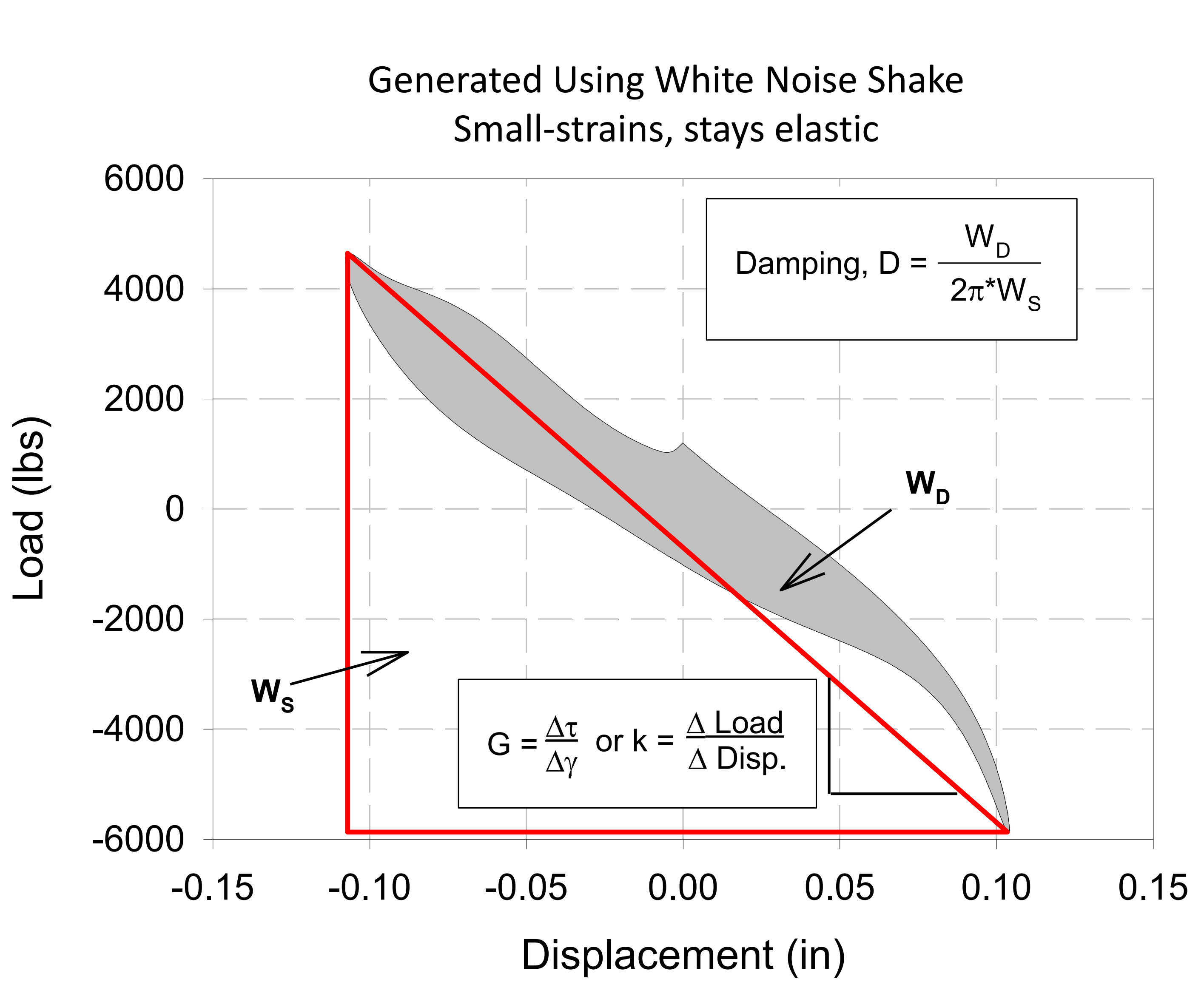
Effect of Pile-Structure Connection Type



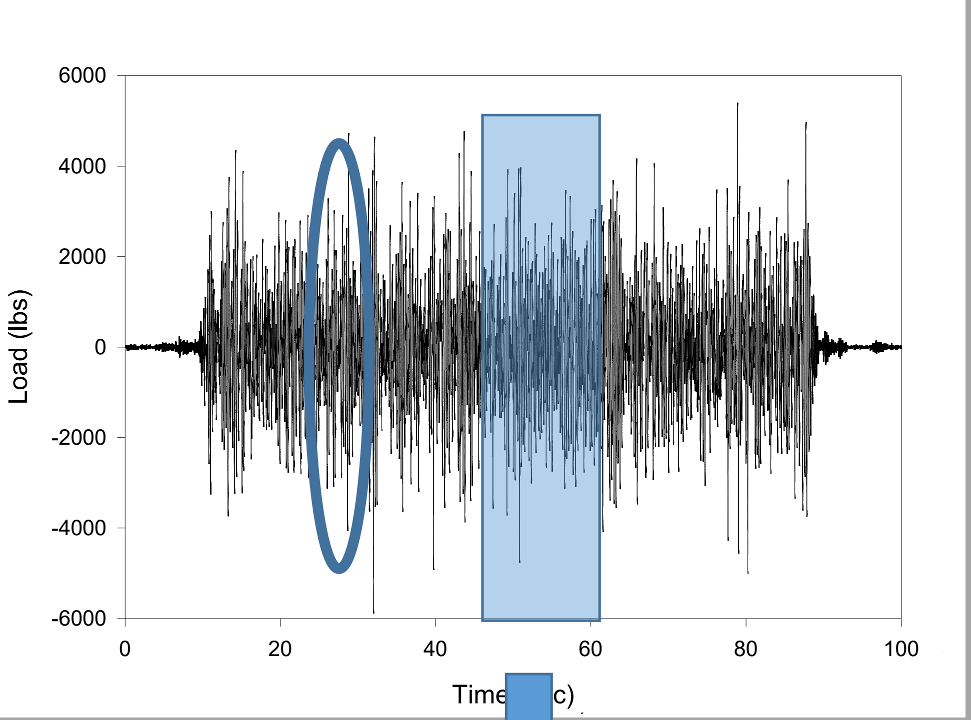
Takatori 100%

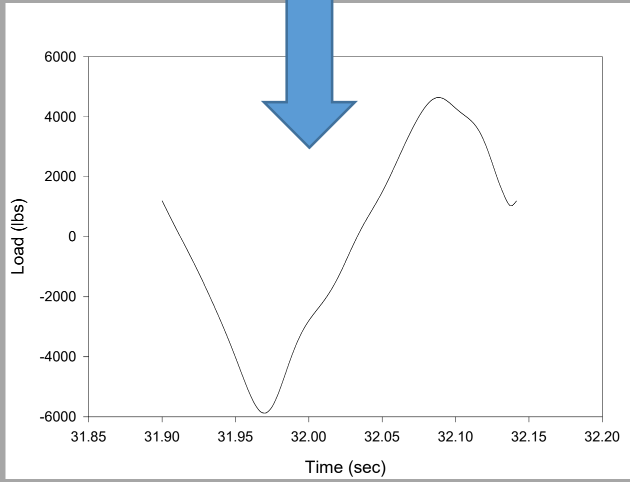
	Day 4 (Fixed)	Day 5 (Pinned)
	SKID 1	
Axial Load (lbs)	14,000	14,000
Acceleration (g)	1.34	1.18
Lateral Load (lbs)	19,000	16,000
Displacement (in)	6.8	6.6
	SKID 2	
Axial Load (lbs)	22,000	22,000
Acceleration (g)	2.11	1.94
Lateral Load (lbs)	47,000	43,300
Displacement (in)	7.5	7

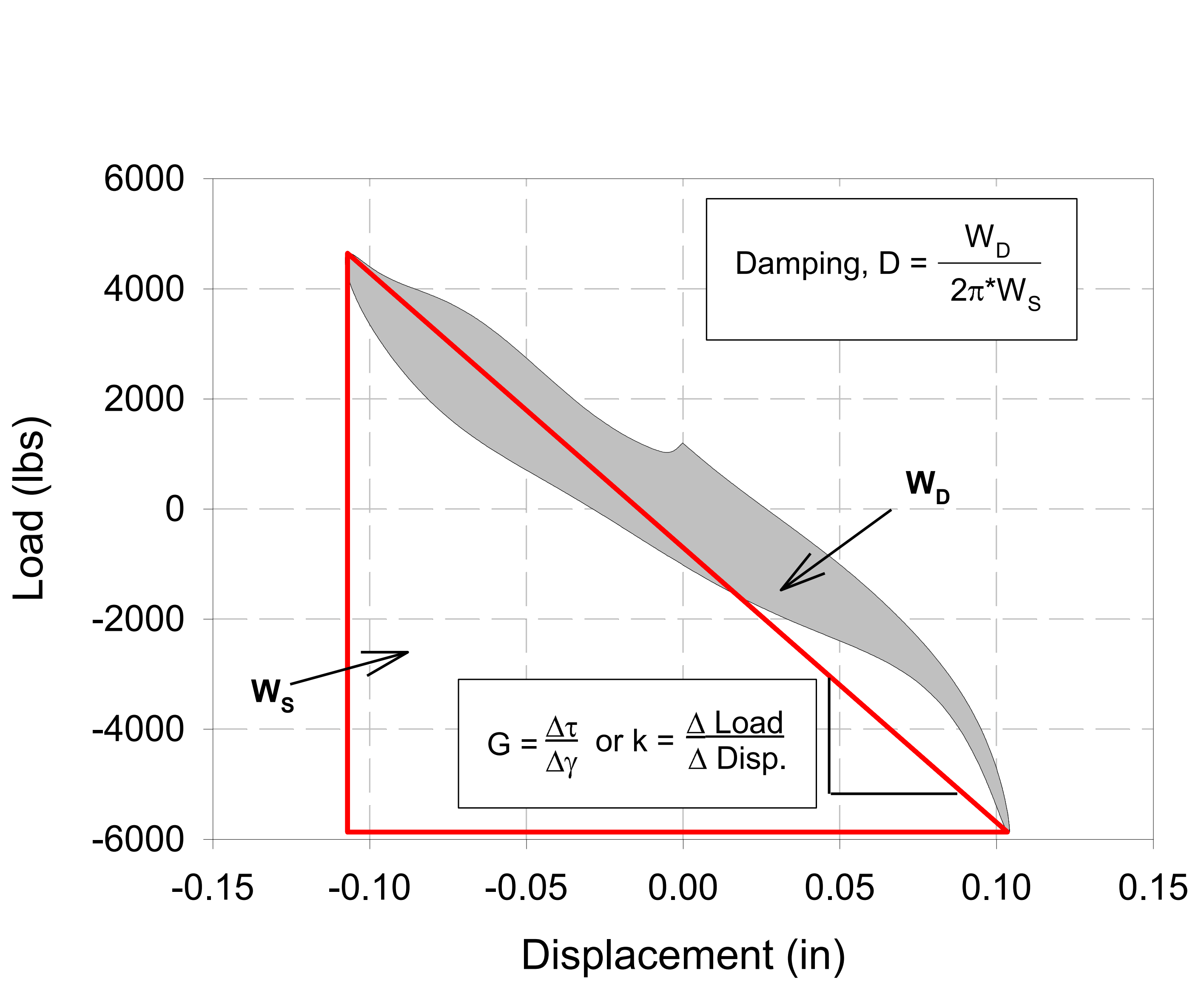




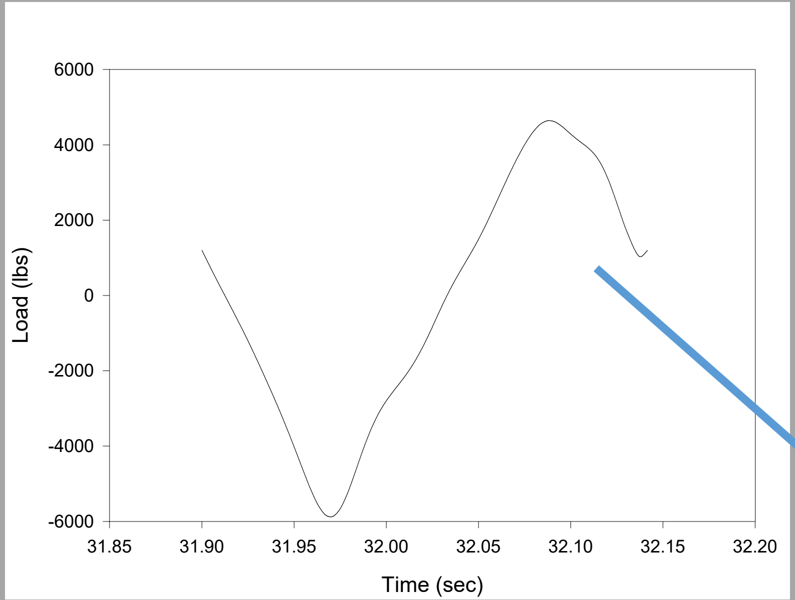
Effect of Group – Damping

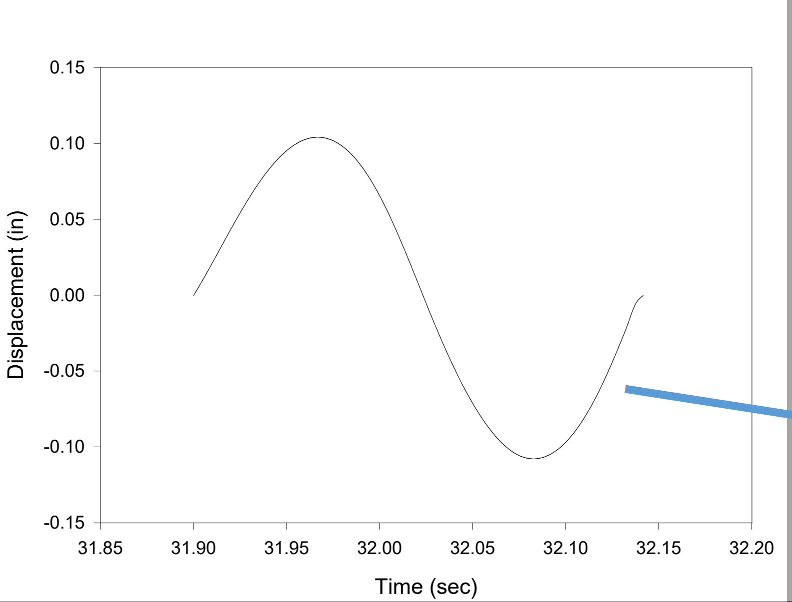


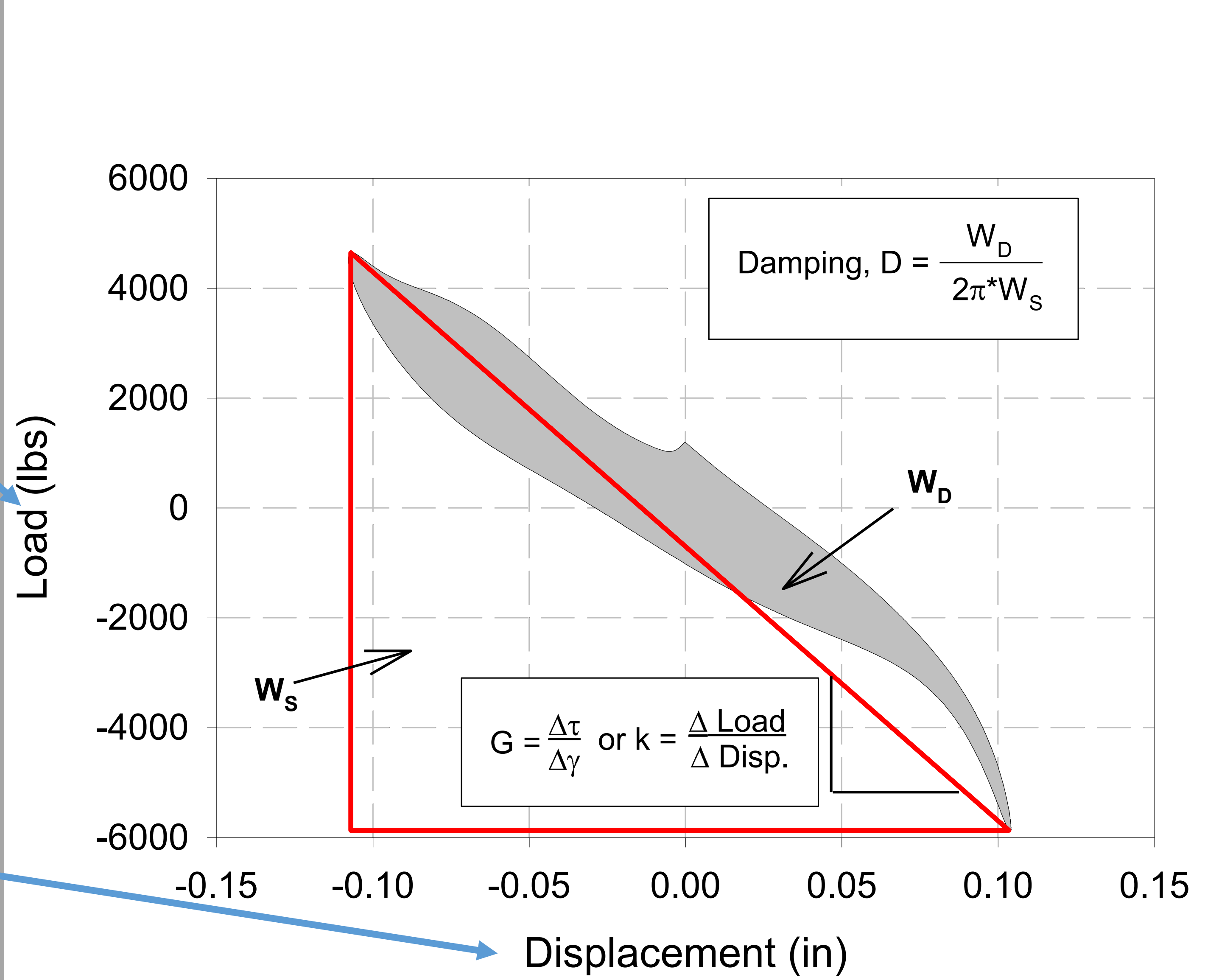




Effect of Group – Damping



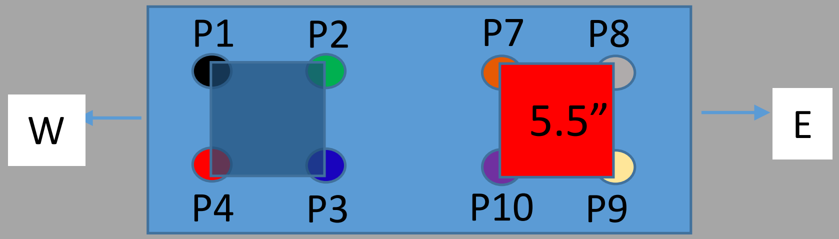


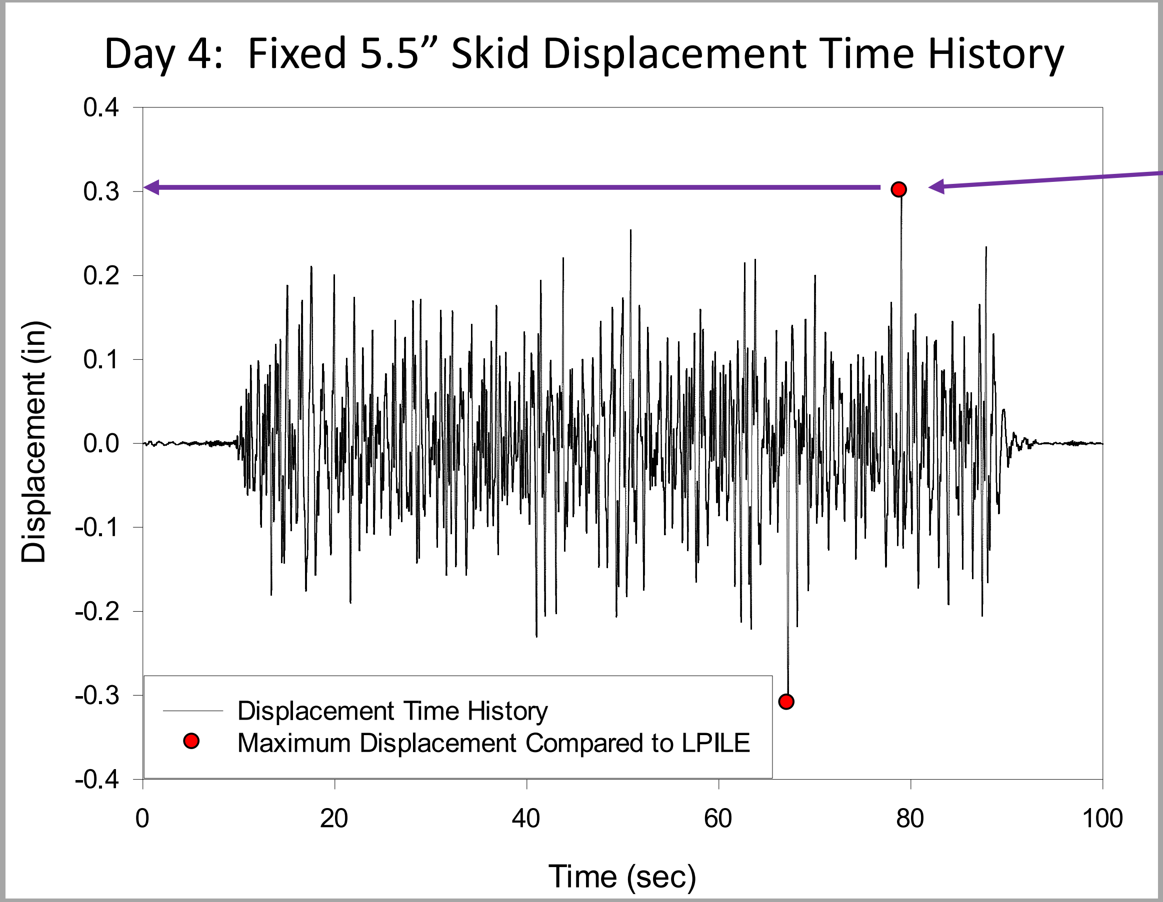


Effect of Group – Damping

Day	System and Condition	Damping Ratio		System Stiffness
1	Soil Only	6.9%		
2	Soil With Single Piles No Weights	8.1%		
3	Soil With Single Piles Weighted	8.1%		
4	Soil With Group Piles Weighted : Fixed	3.5"	9.3%	38.4 kip/in
		5.5"	9.4%	49.6 kip/in
5	Soil With Group Piles Weighted : Pinned	3.5"	10.6%	32.6 kip/in
		5.5"	10.9%	49.1 kip/in

Effect of Group – Improve Damping





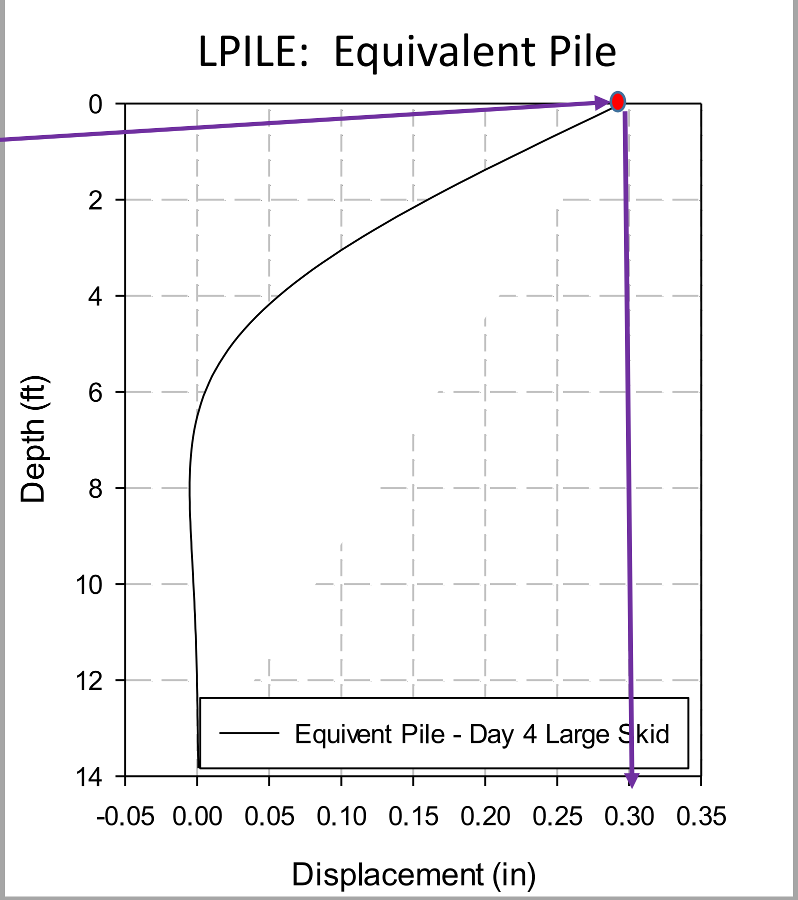
White Noise

Equivalent Pile: 4I

Axial Load: 22,000 lbs (Skid+ Sand)

Lateral Load: 5,662 lbs (Accelerometer)

ϕ = 48° API Sand



Validation of Skid Performance

Conclusions – Single Pile Behavior

- **Repeatability** – Piles showed good repeatability within the testing matrix further validating results.

- **Effect of helix** – The results from this testing program are inconclusive.

- **Effect of pile type** – A direct comparison could not be made due to the different masses used, and therefore, different calculated natural frequencies.

Conclusions – Single Pile Behavior

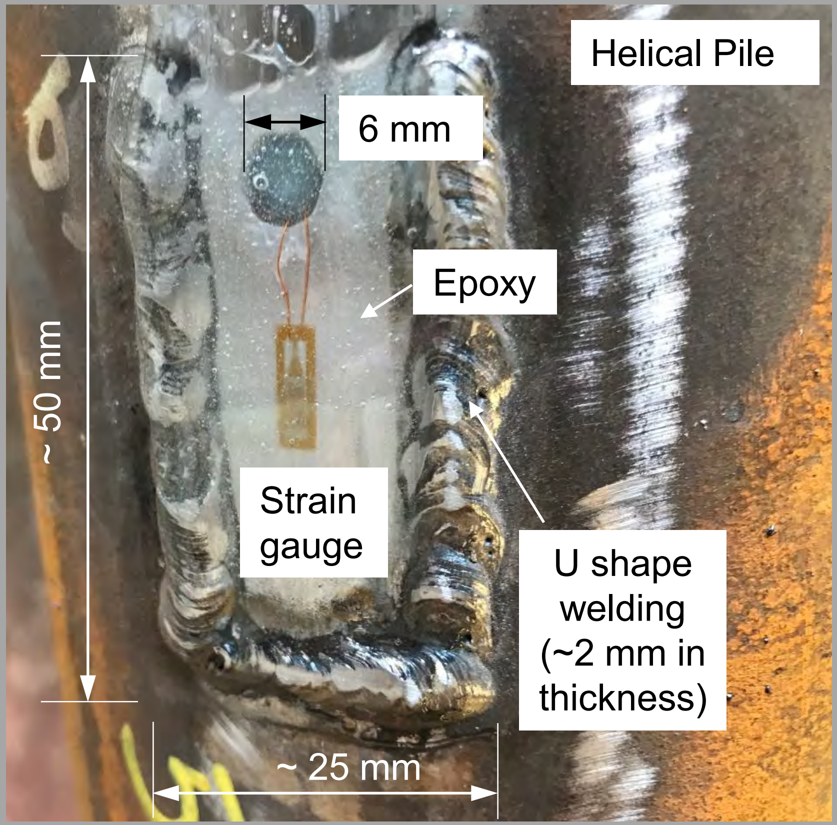
- **Effect of shaft geometry** – There was no clear advantage based on shaft geometry.

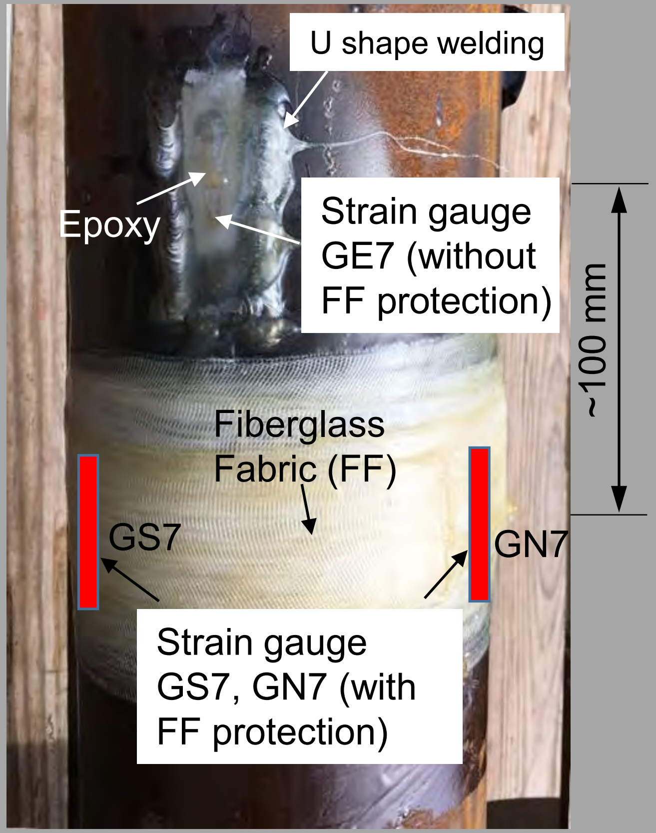
- **Effect of coupling** – The type of coupling (threaded versus bolted) does not seem to affect seismic behavior when the couple is at least 13.5d below the ground surface.

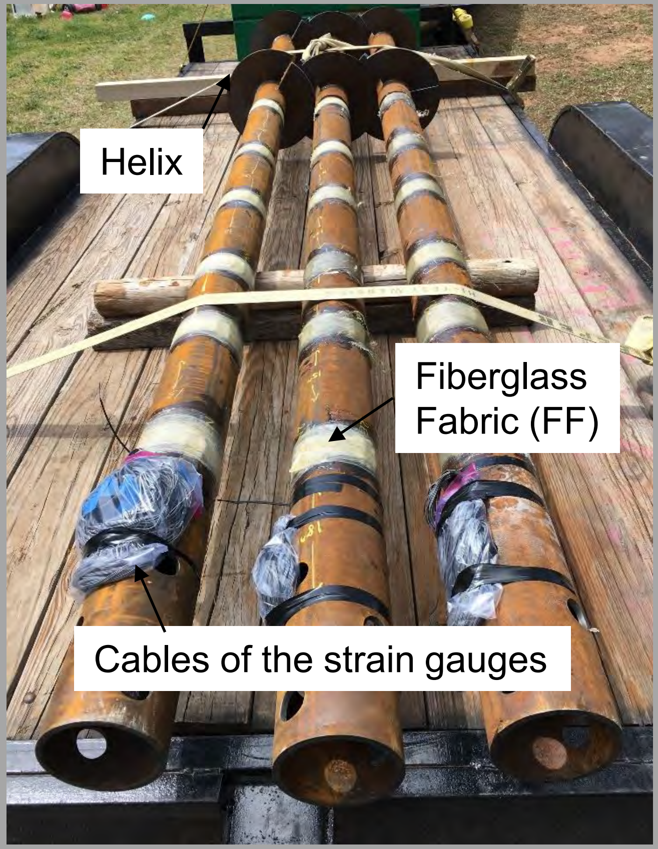
- Piles placed in a group take load much more effectively, and deflect much less, than simply the load/number of piles.
- Seismic group pile head displacement can be approximated by using a static equivalent pile size in LPILE.
- Pile head connection has a significant impact on system behavior.
- Pinned connections showed higher damping ratios, lower stiffness, lower generated accelerations, lower lateral loads and lower displacements than “fixed” connections.

Conclusions – Group Behavior

Instrumentation and monitoring of production piles in seismic zones







Recommendations for Future Research

- How does the helical pile-structure connection effect seismic behavior?
  - Typical concrete pile cap connection with piles versus “steel-to-steel” versus retrofits?
  - How do we effectively transfer the damping advantages of helical piles to the structure?
  - Rocking: How does the helix effect tip uplift resistance (single versus multi-helix)

Case History: Foundation Support Works

Recommendations for Future Research

The UNIVERSITY of OKLAHOMA
Gallogly College of Engineering
School of Civil Engineering and Environmental Science







https://www.designsafe-ci.org/

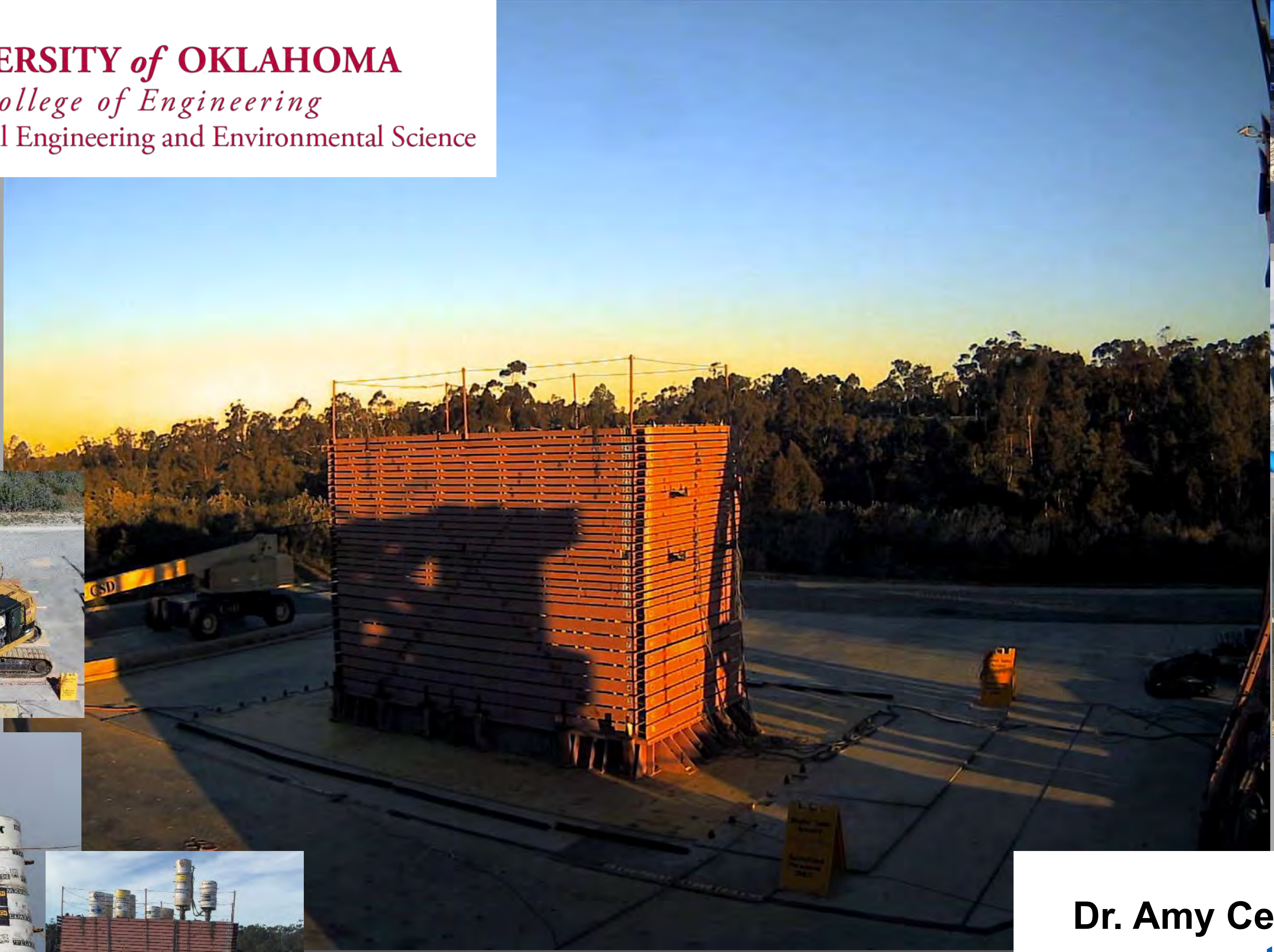
All data and metadata are curated at Design Safe-CI and available for public download.

Data Repository




Educational Outreach

The UNIVERSITY of OKLAHOMA
Gallogly College of Engineering
School of Civil Engineering and Environmental Science



Questions?

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acerato@ou.edu
http://cerato.ou.edu/