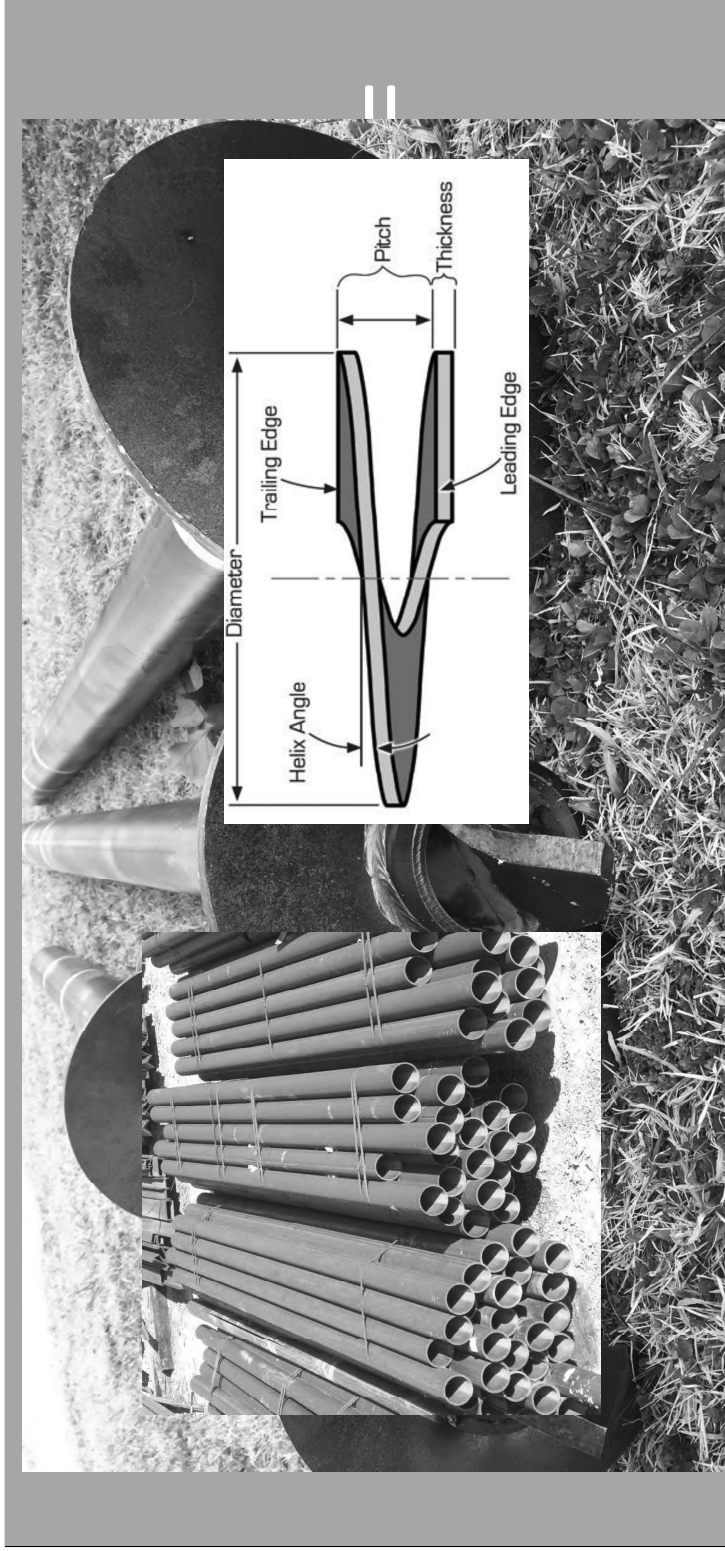




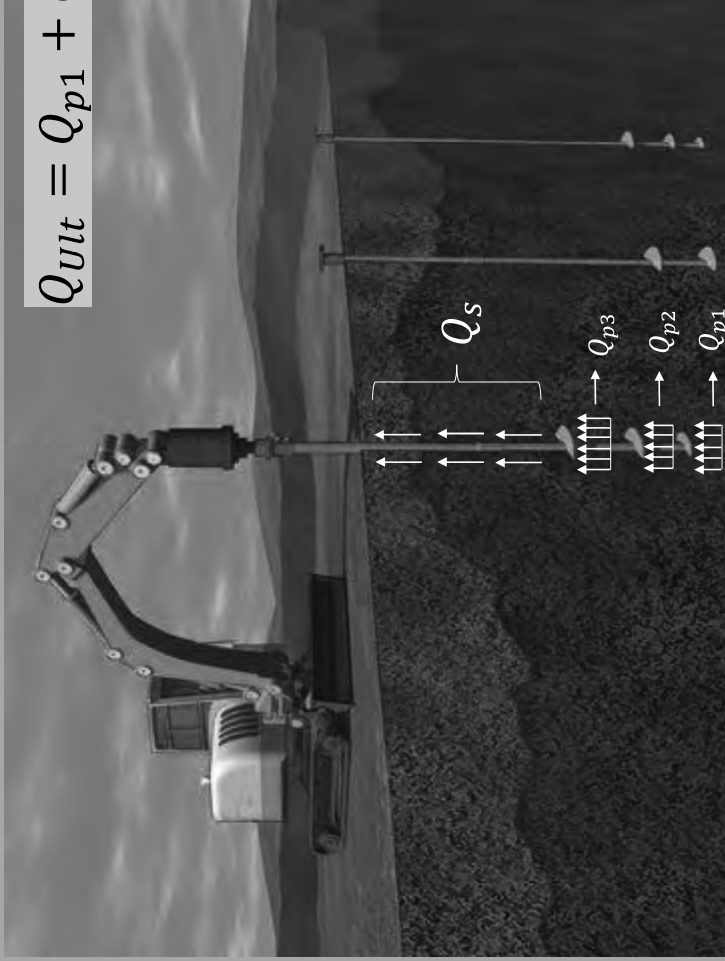
Amy Cerato, P.E., Ph.D.



Seismic Behavior of Helical Piles in Dense Sands



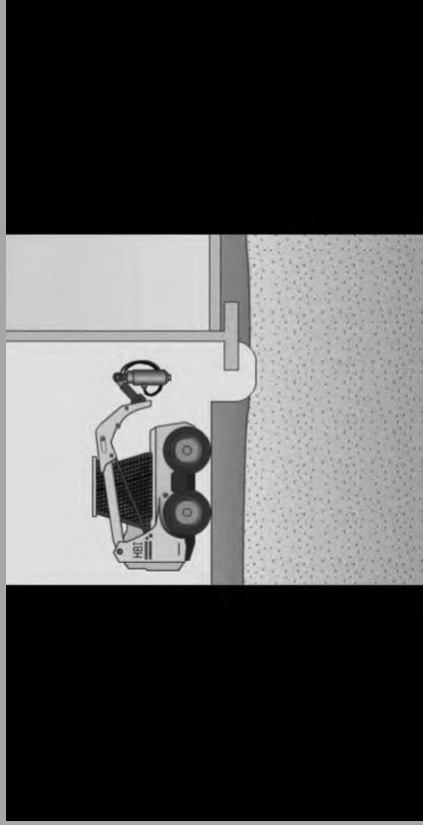
What are Helical Piles?



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

Individual Plate Bearing Method

$$Q_{ult} = KT$$

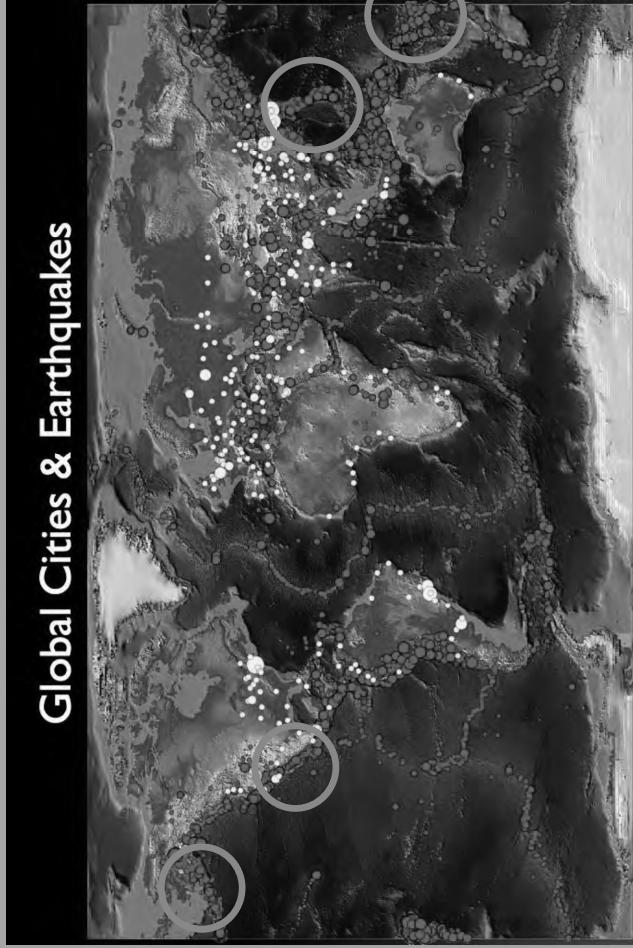


K = Correlation Factor

T = Avg. Torque of Last 3 Feet

Installation Torque Correlation

Global Cities & Earthquakes



Slenderness

High Damping Ratios

Resistance to Tip Uplift

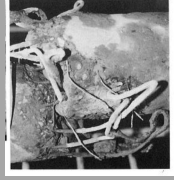
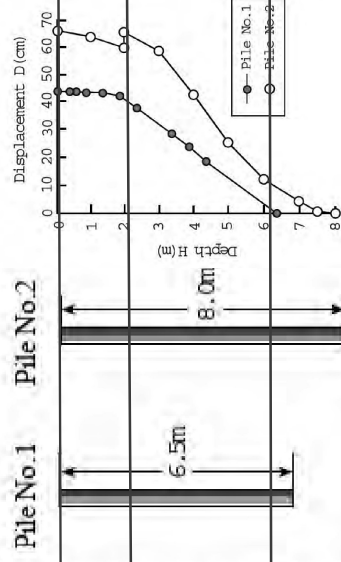
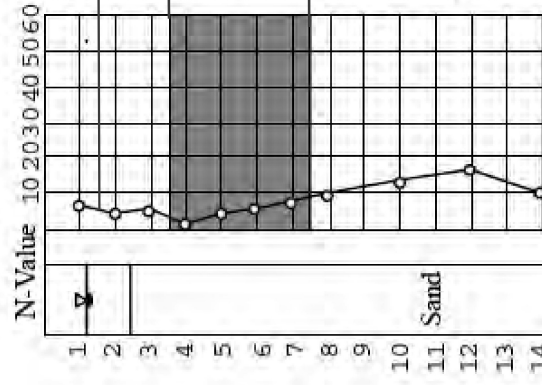
Ductility

all earthquakes (red) $M \geq 5.5$; cities (yellow) with population > 1000000

We know they shake well!

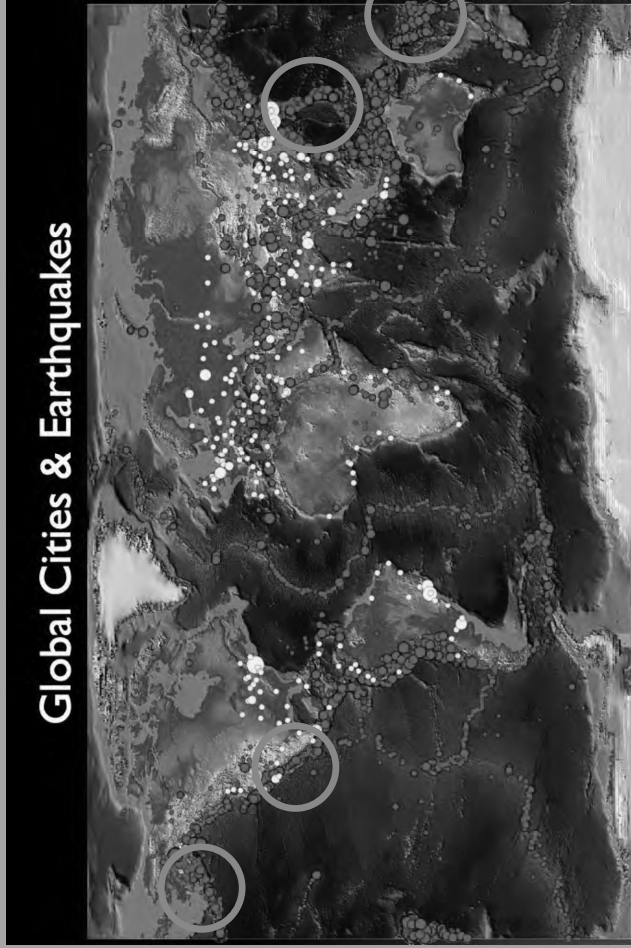
From Hamada and O'Rourke 1992

Bore Hole Data No. 1



1964 Niigata Earthquake

Global Cities & Earthquakes



Slenderness

Resistance to
Tip Uplift

High Damping
Ratios

Ductility

all earthquakes (red) $M \geq 5.5$; cities (yellow) with population > 1000000

We know they shake well!

ICC EVALUATION SERVICE, INC.
Evaluate • Inform • Protect



ACCEPTANCE CRITERIA FOR HELICAL FOUNDATION SYSTEMS AND DEVICES

AC308

Approved June 2007
Effective July 1, 2007

ICC EVALUATION
SERVICE

Most Widely Accepted and Trusted

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ACCEPTANCE CRITERIA FOR HELICAL PILE SYSTEMS AND DEVICES

AC308

Approved June 2013
(Editorially revised September 2014)

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

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

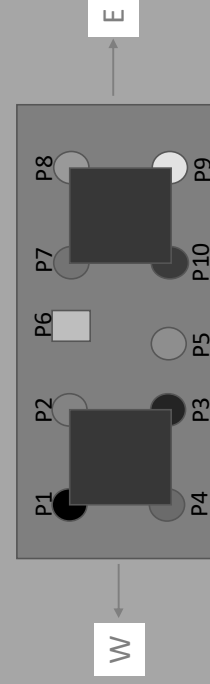
where P_u is the least value of:

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

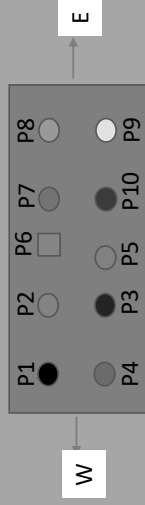
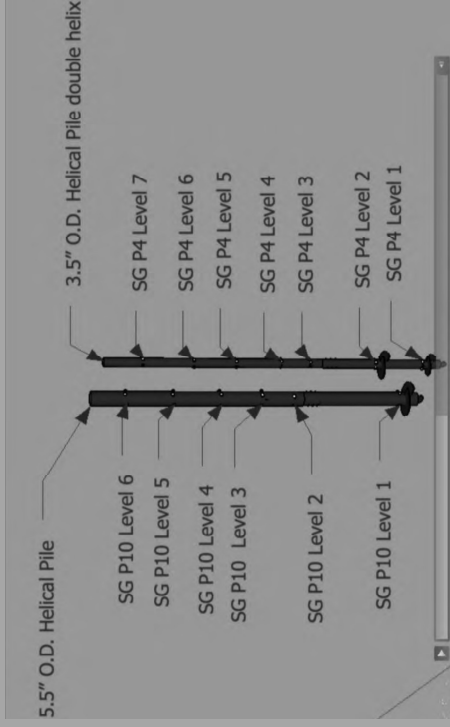


- **Single Pile Behavior**
 - Repeatability – multiple piles in the box that had same shaft shape, cross sectional area, helix configuration and coupling
 - Effect of helix – double helix compared with single helix
 - Effect of pile type – helical pile versus driven pile
 - Effect of shaft geometry –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

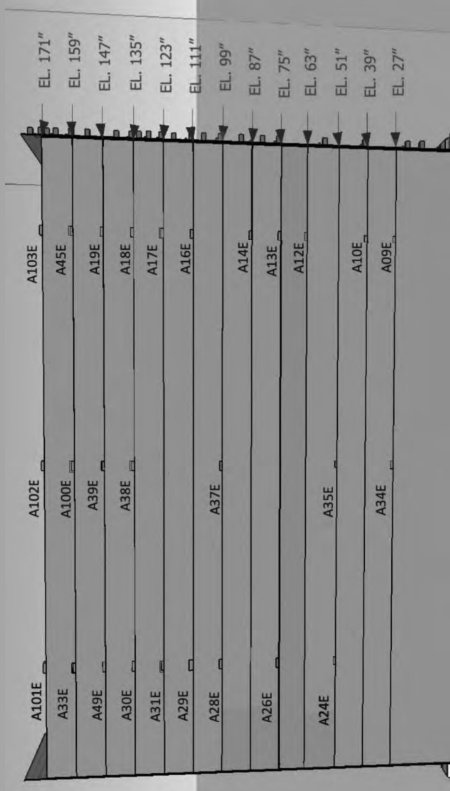
Parameters to Study



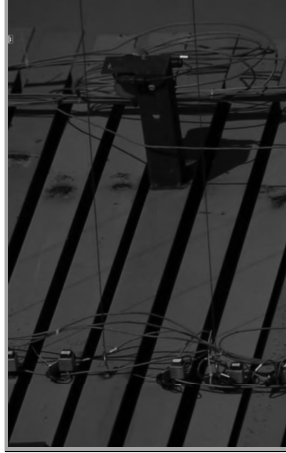
Pile Instrumentation
(152 strain gages)



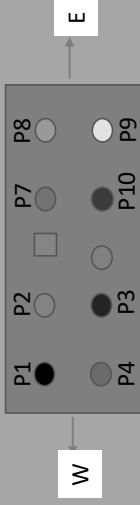
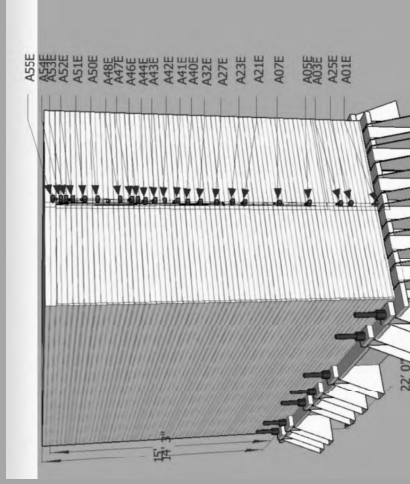
Sand Bed
(27 Accelerometers)



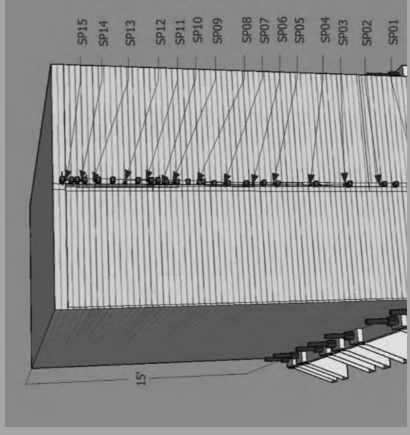
Instrumentation



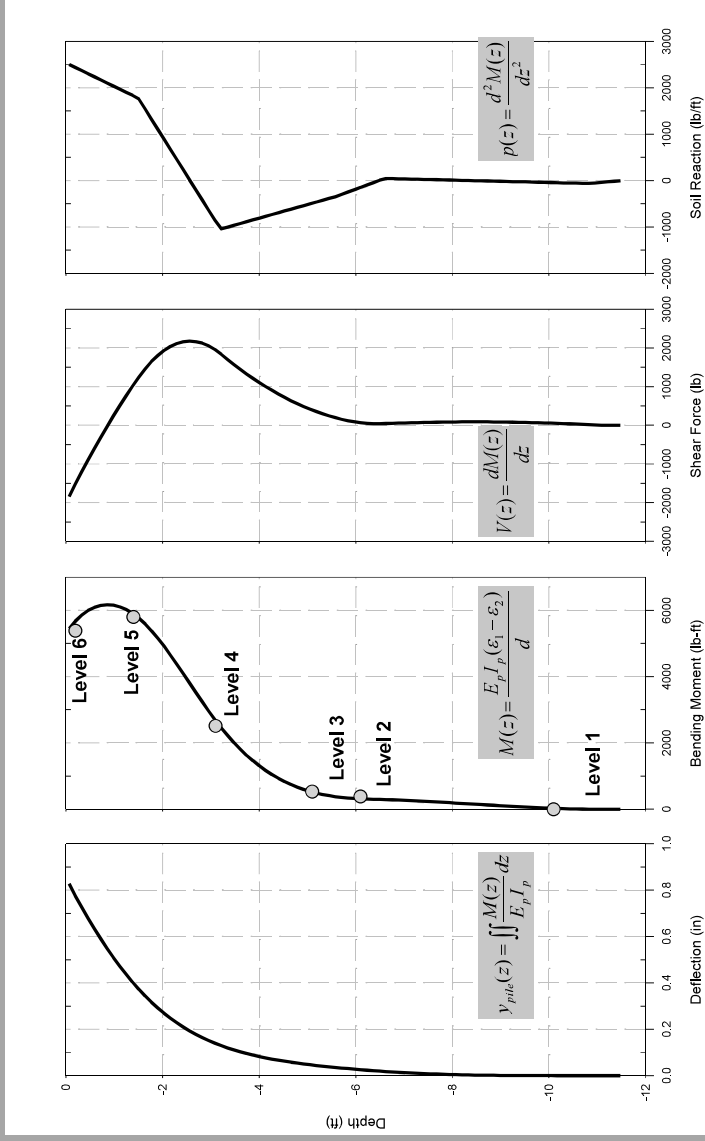
Laminar Soil Box
Accelerometers (23)



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



Instrumentation

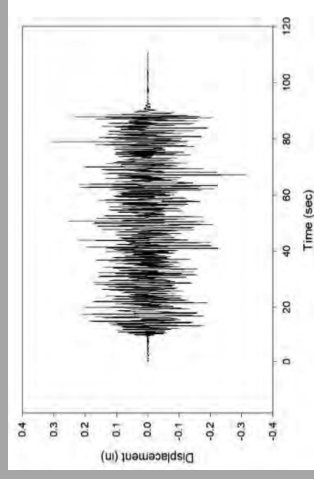
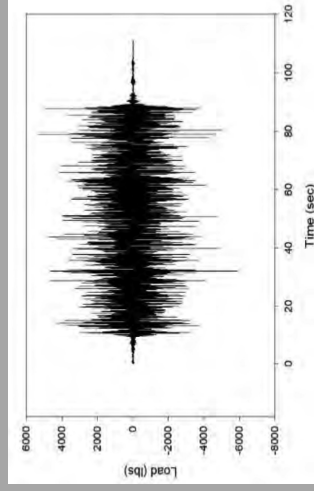
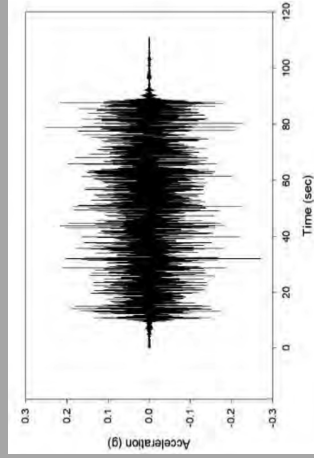


Measurements and Calculations

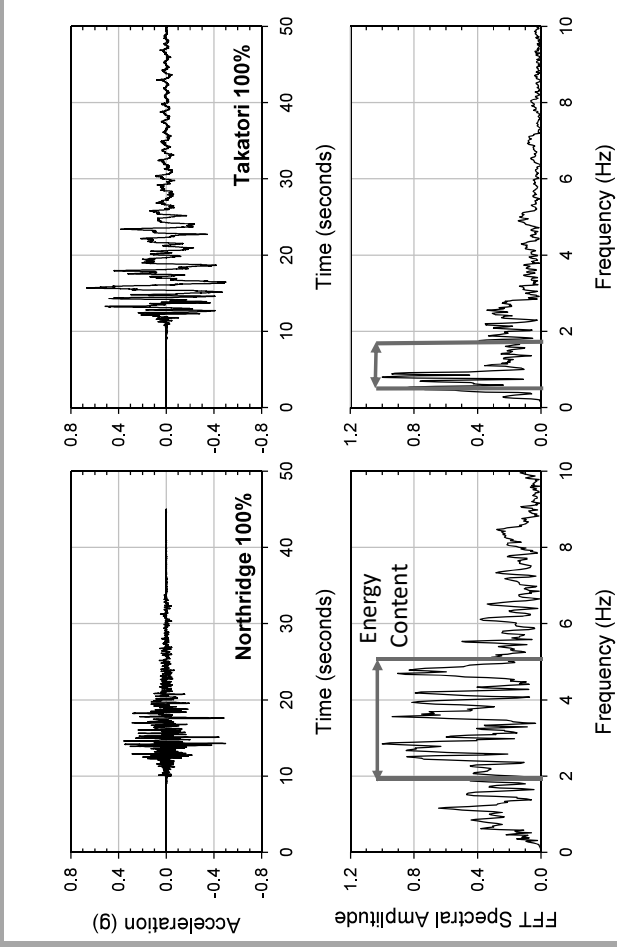
Load Time History =
Acceleration Time History *
Structure (or Supported) Mass

Displacement Time History =
Double Integration of Accelerometer

Accelerometer Time History

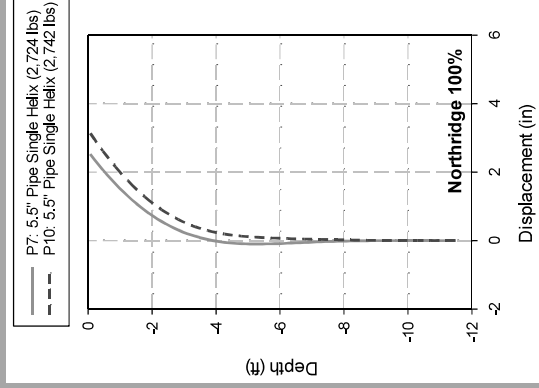
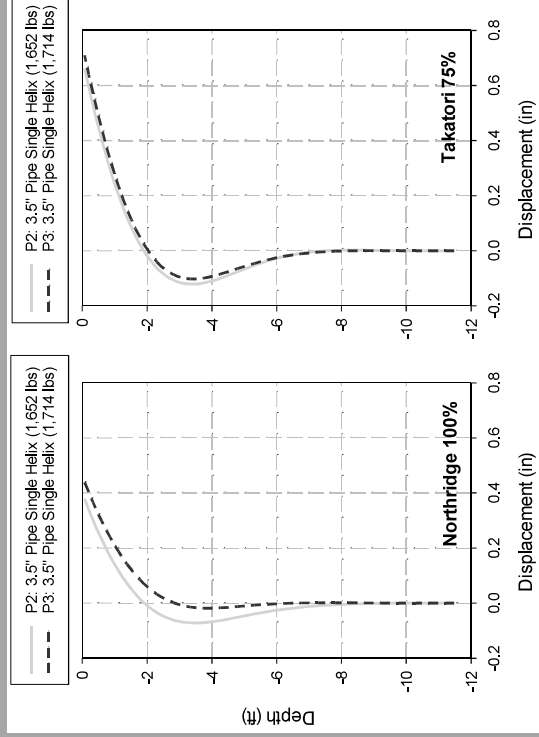
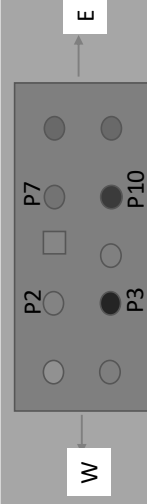


Measurements and Calculations



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

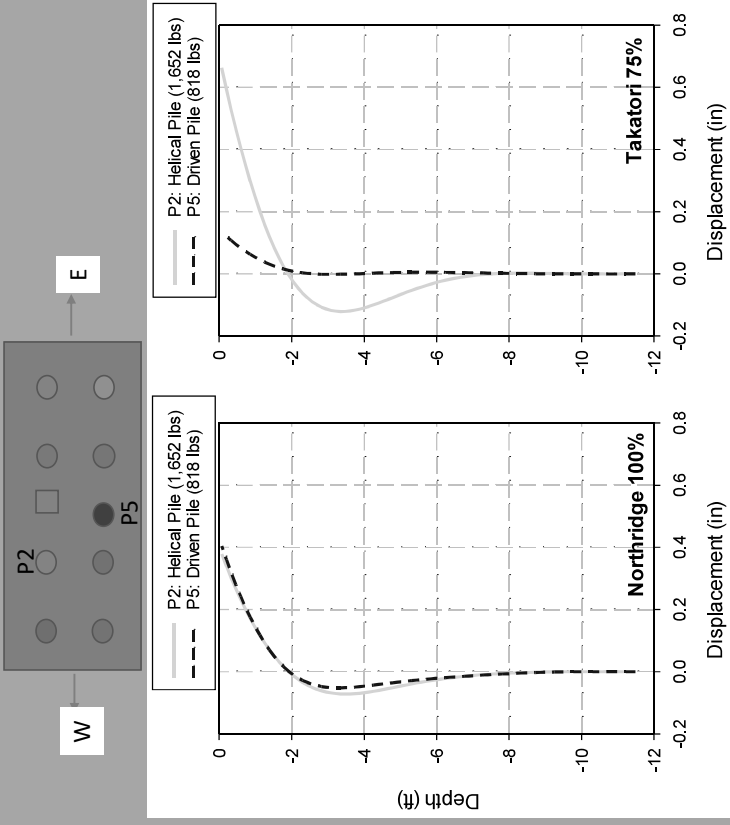
Pile Type



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

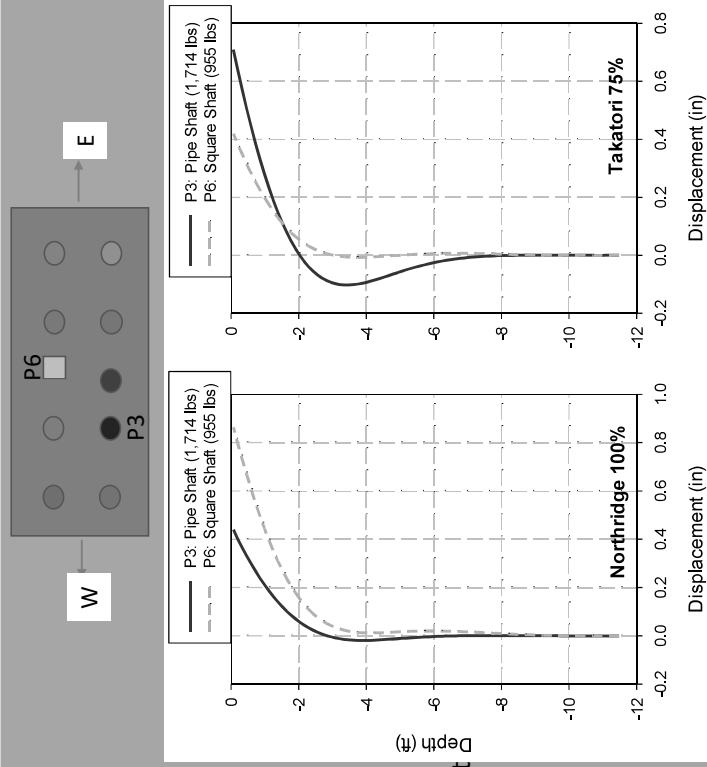
Shaft Geometry



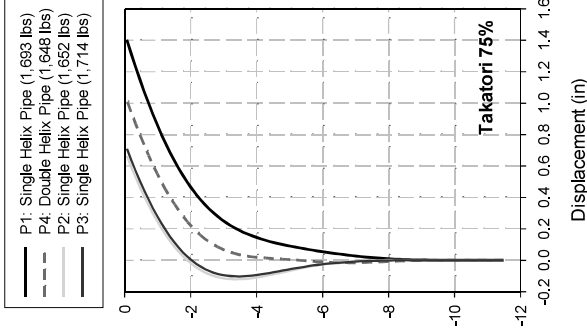
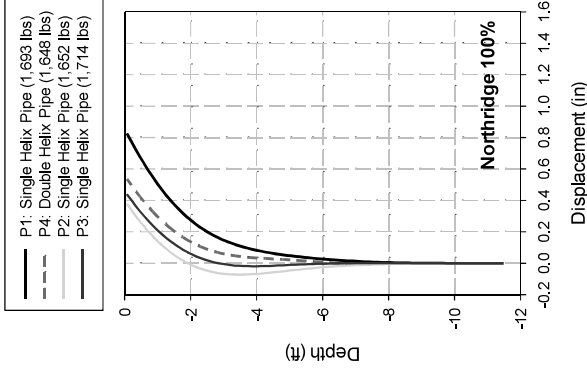
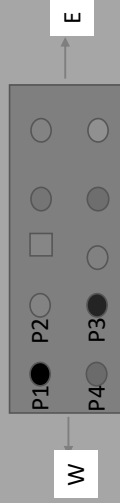
Natural Frequency of System VERY Important!

P3: $F_n = 1.88$ Hz

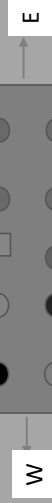
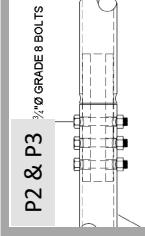
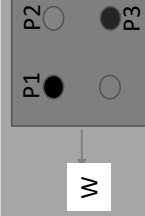
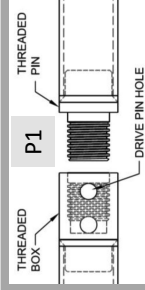
P6: $F_n = 3.78$ Hz as is, but reduces to 2.67 Hz considering same mass as P3



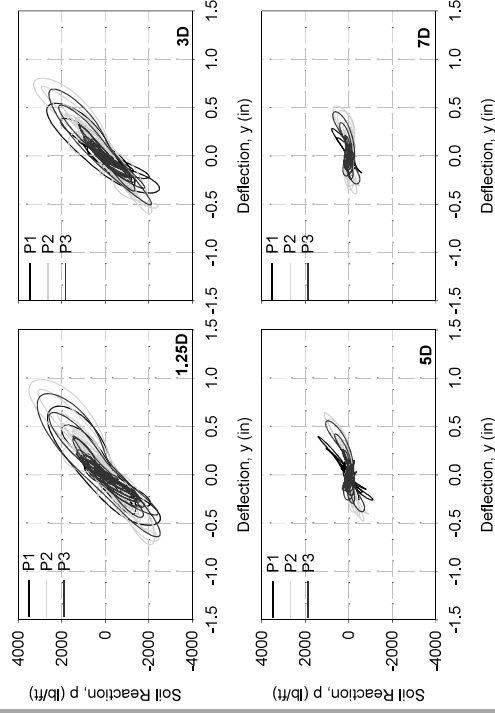
Effect of Natural Frequency



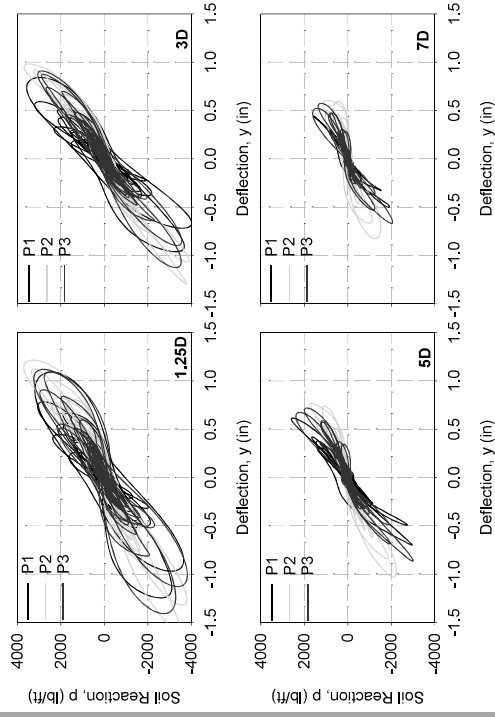
Effect of an Additional Helix



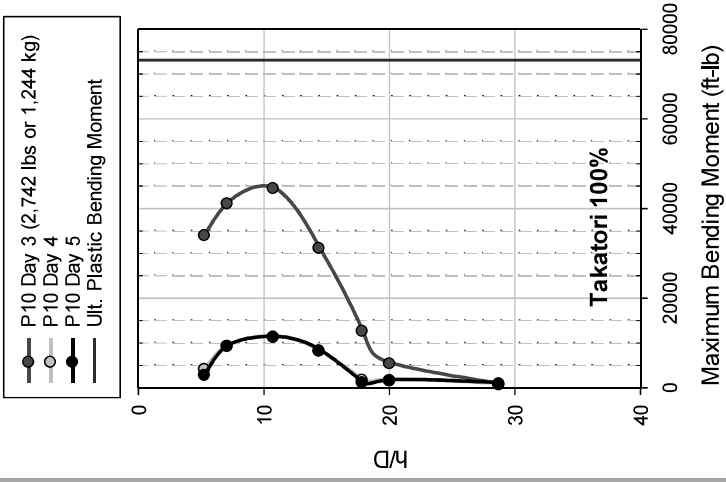
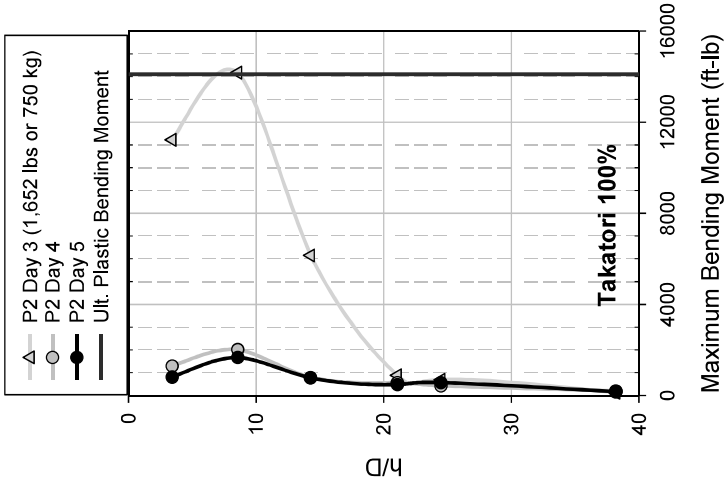
Northridge 100%



Takatori 75%



Effect of Coupling

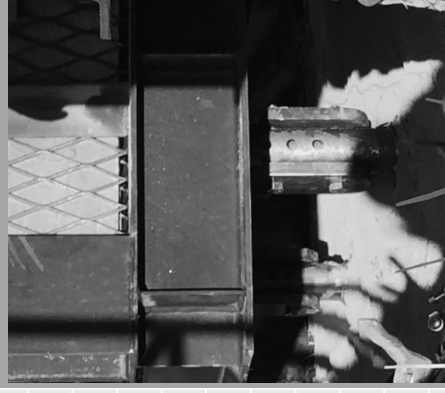


Effect of Grouping Helical Piles

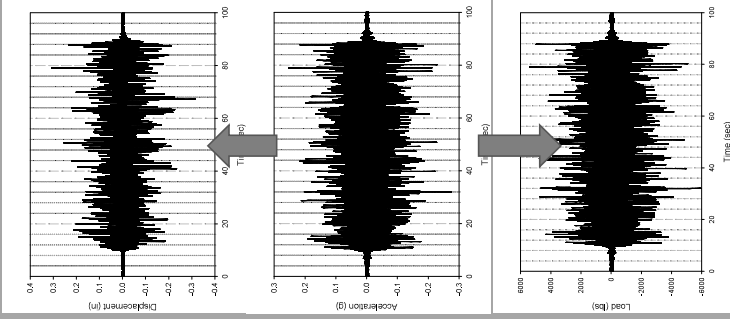


Takatori 100%

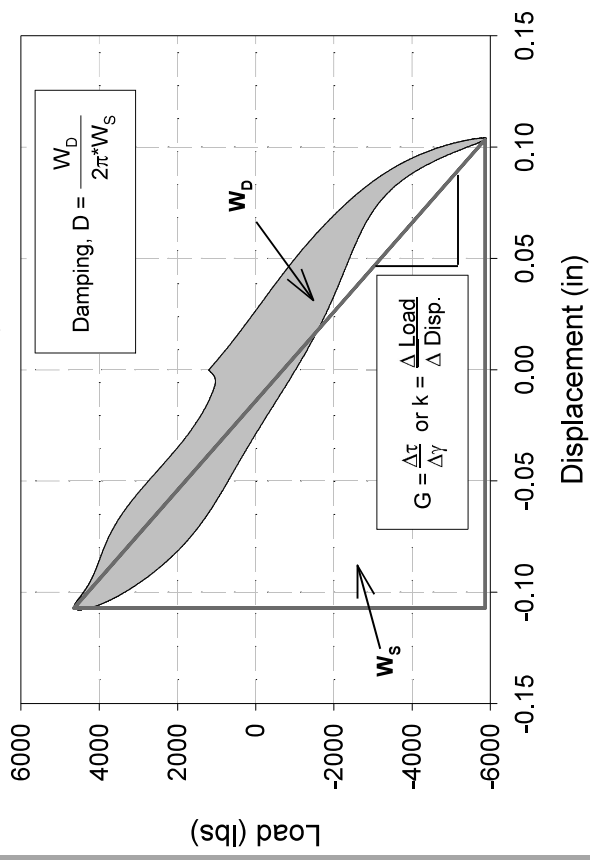
	Day 4 (Fixed)	Day 5 (Pinned)
	SKID 1	
Axial Load (lbs)	14,000	14,000
Acceleration (g)	1.34	1.18
Lateral Load (lbs)	19,000	16,000
Displacement (in)	6.8	6.6
	SKID 2	
Axial Load (lbs)	22,000	22,000
Acceleration (g)	2.11	1.94
Lateral Load (lbs)	47,000	43,300
Displacement (in)	7.5	7



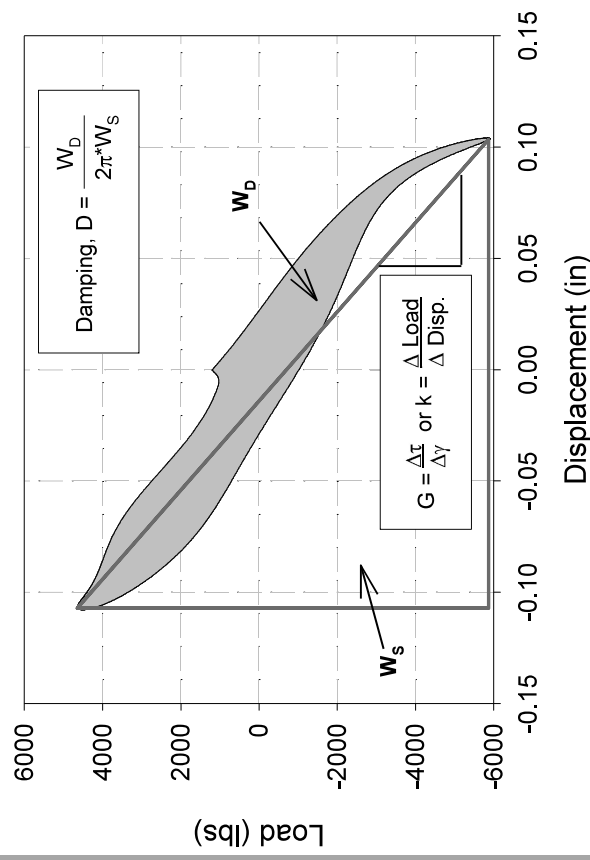
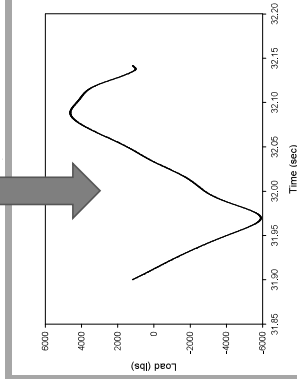
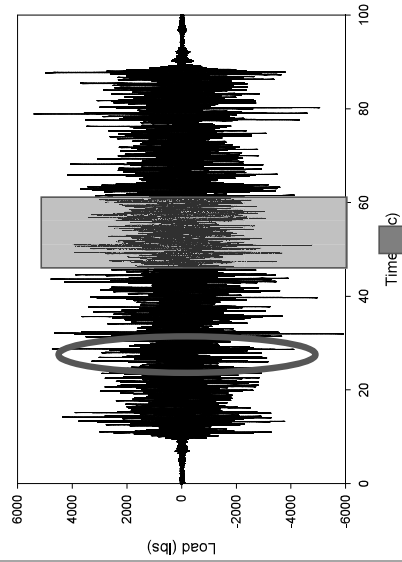
Effect of Pile-Structure Connection Type



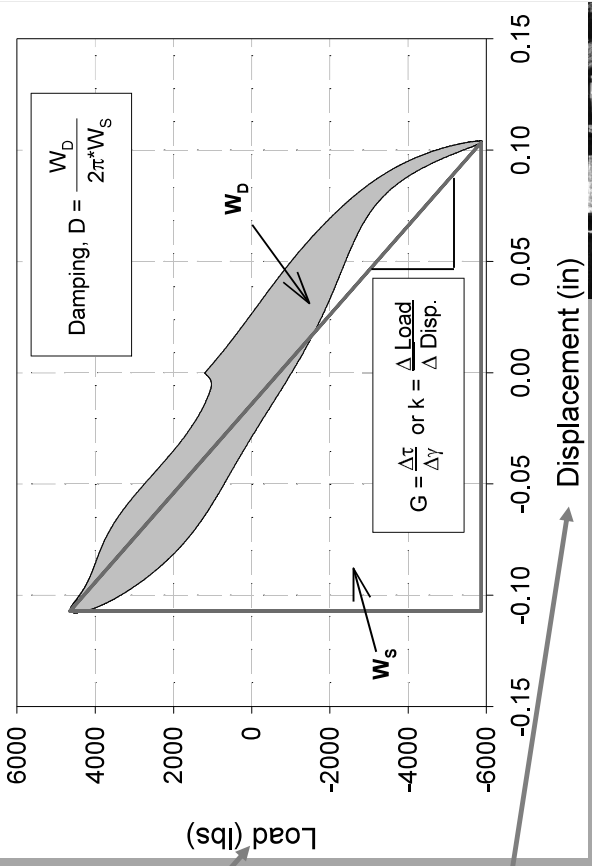
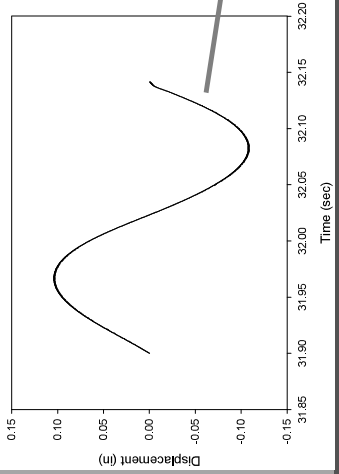
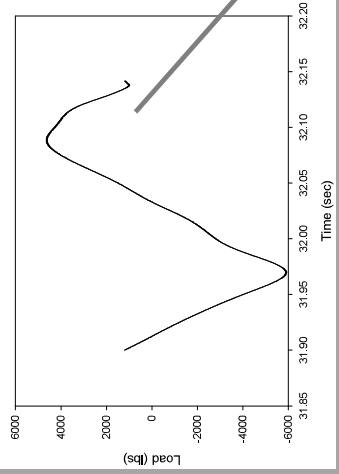
Generated Using White Noise Shake
Small-strains, stays elastic



Effect of Group – Damping



Effect of Group – Damping

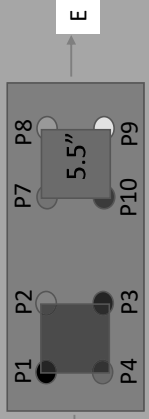


Effect of Group – Damping

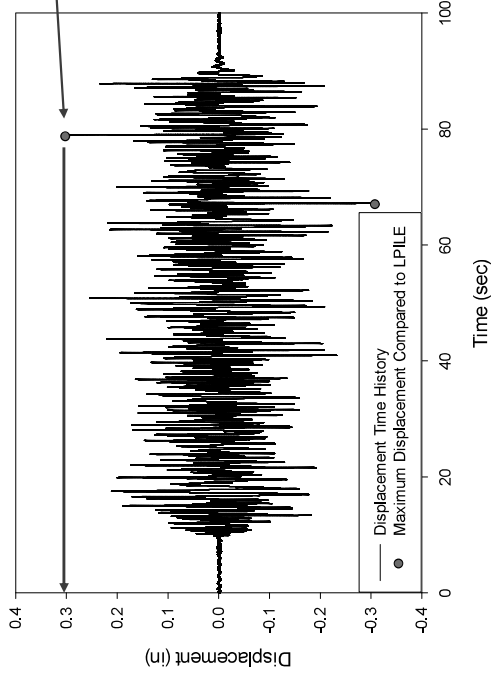
Day	System and Condition	Damping Ratio	System Stiffness
1	Soil Only	6.9%	
2	Soil With Single Piles No Weights	8.1%	
3	Soil With Single Piles Weighted	8.1%	
4	Soil With Group Piles Weighted : Fixed	3.5"	38.4 kip/in
		5.5"	49.6 kip/in
5	Soil With Group Piles Weighted : Pinned	3.5"	32.6 kip/in
		5.5"	49.1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



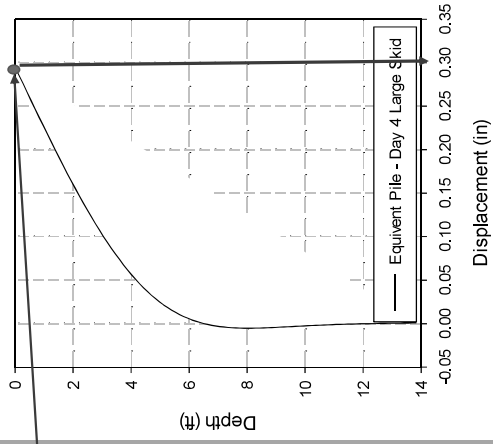
Effect of Group – Improve Damping



Day 4: Fixed 5.5" Skid Displacement Time History



LPILE: Equivalent Pile



White Noise

Equivalent Pile: 4I

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

Lateral Load: 5,662
lbs (Accelerometer)

$\phi = 48^\circ$ API Sand

Validation of Skid Performance

- **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

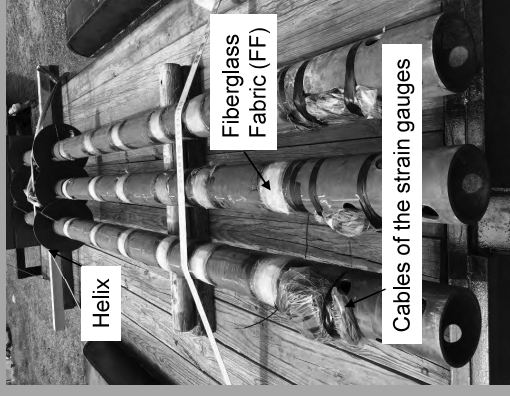
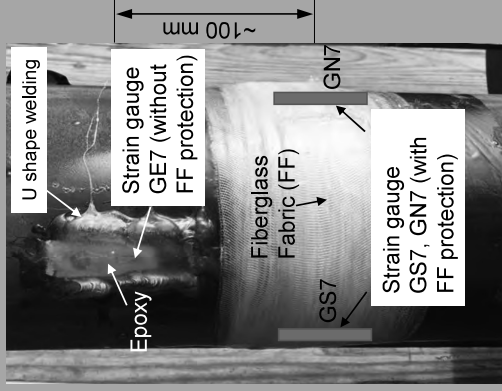
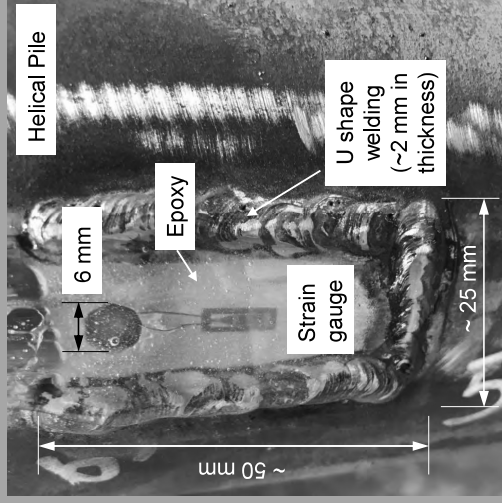
- **Effect of shaft geometry** – There was no clear advantage based on shaft geometry.
- **Effect of coupling** – The type of coupling (threaded versus bolted) does not seem to affect seismic behavior when the couple is at least 13.5d below the ground surface.

Conclusions – Single Pile Behavior

- 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 connections 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)



Recommendations for Future Research



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Project title: Large-Scale Strain Test to Quantify Seismic Response of Helical Piles in Dry Sand, Amy Gerada (c686314), 6/8/17 11:14 AM

Created: 6/8/17 11:14 AM

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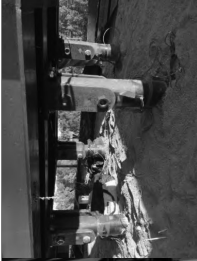
Data Repository



Enrichment Week at Terra Verde Discovery School
March 21 & 23, 2016
Mad Science I: Kindergarten - Second Grade



Educational Outreach



Dr. Amy Cerato, P.E., Ph.D
acerato@ou.edu
<http://cerato.ou.edu/>

Questions?