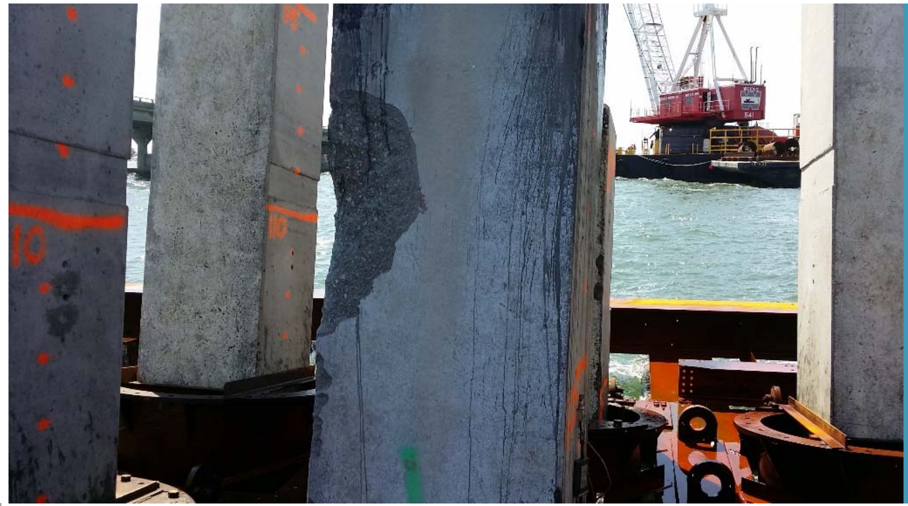


EVALUATION OF NON-CONFORMING PILES

TOPICS

- Minimum Tip Elevation
- Required Driving Resistance
- Geometrical Tolerance
- Pile Damage

MINIMUM TIP ELEVATION

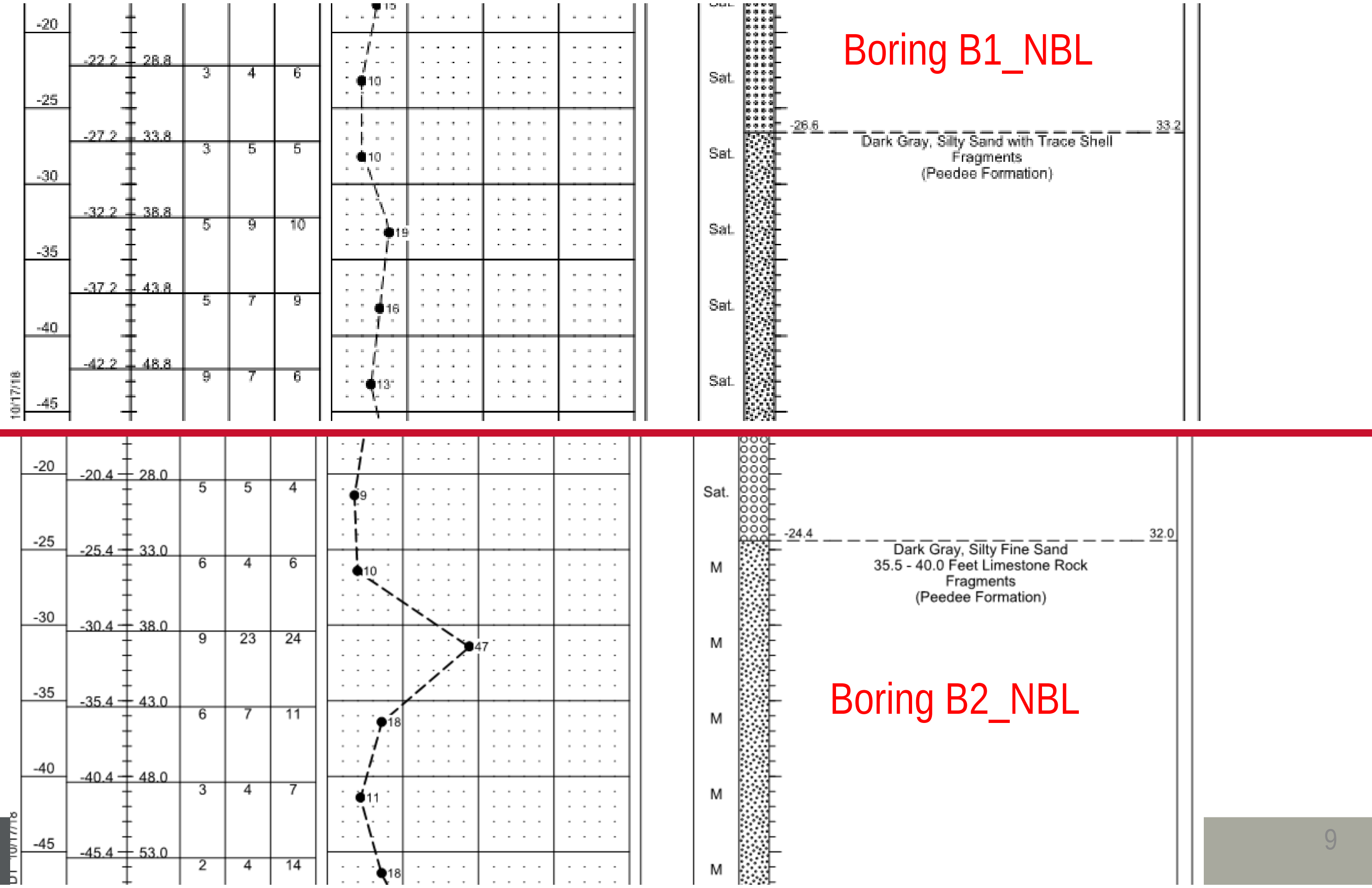
- Minimum tip elevation most often set to provide fixity at the pile toe
- Highly variable subsurface conditions can be impediments to reaching minimum tip
- NCDOT: US 421 Bridge over Fishing Creek – Emergency project after Hurricane washed out the roadway
- Scenario to consider: Many piles do not reach minimum tip elevation

US 421 AT FISHING CREEK AFTER HURRICANE FLORENCE

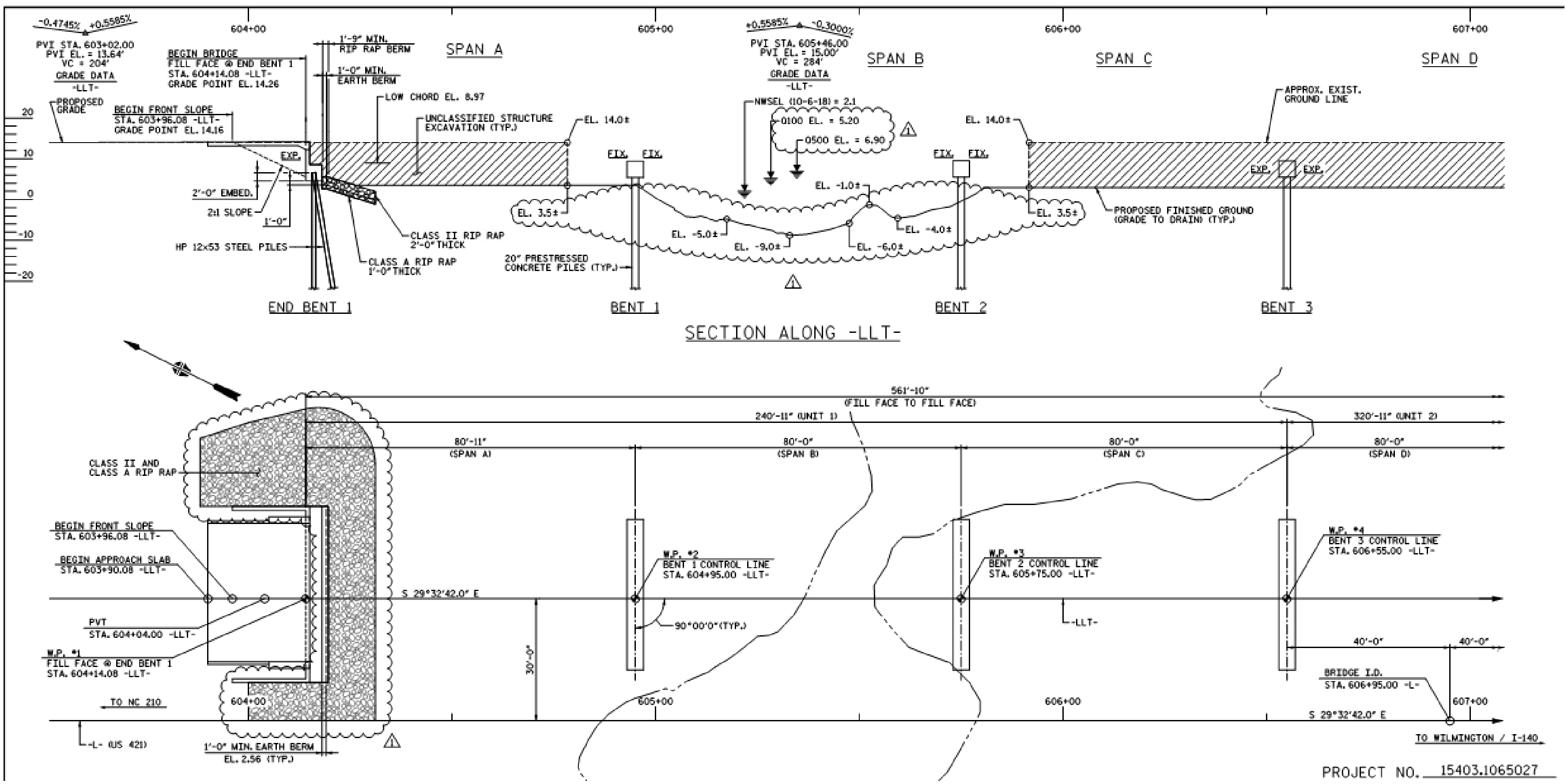
- Roadway badly damaged
- Emergency design requested by NCDOT
- Partially inaccessible for drill rig access

BORING LOCATION PLAN

SUBSURFACE VARIABILITY



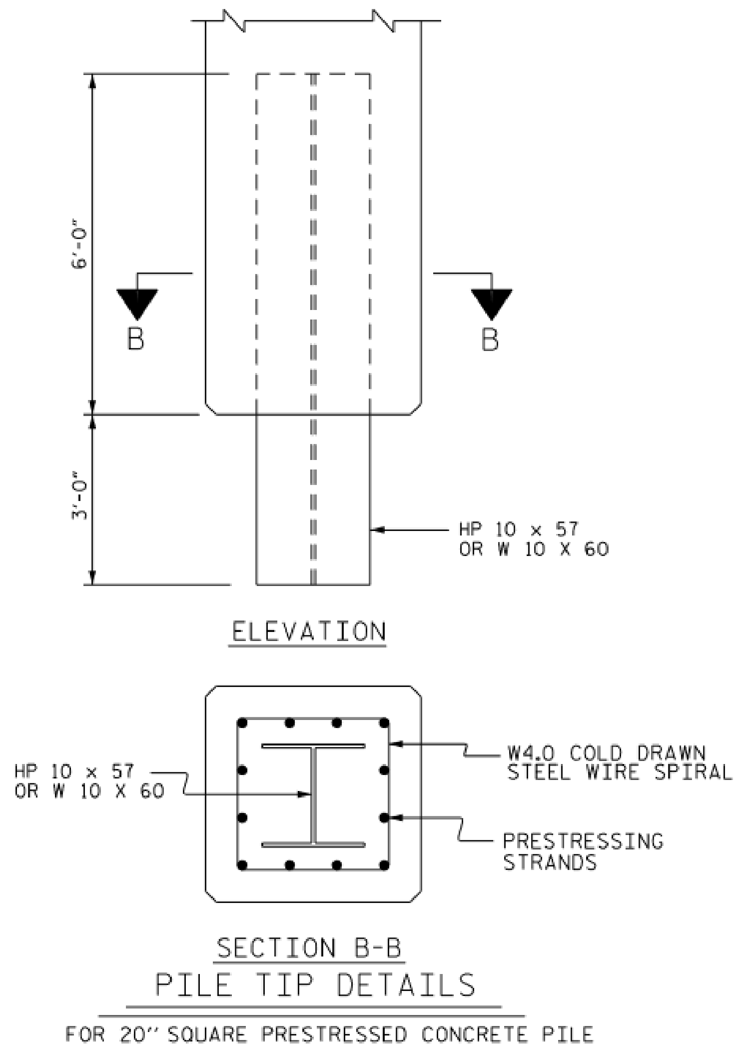
PARALLEL 7 SPAN BRIDGES OVER FISHING CREEK

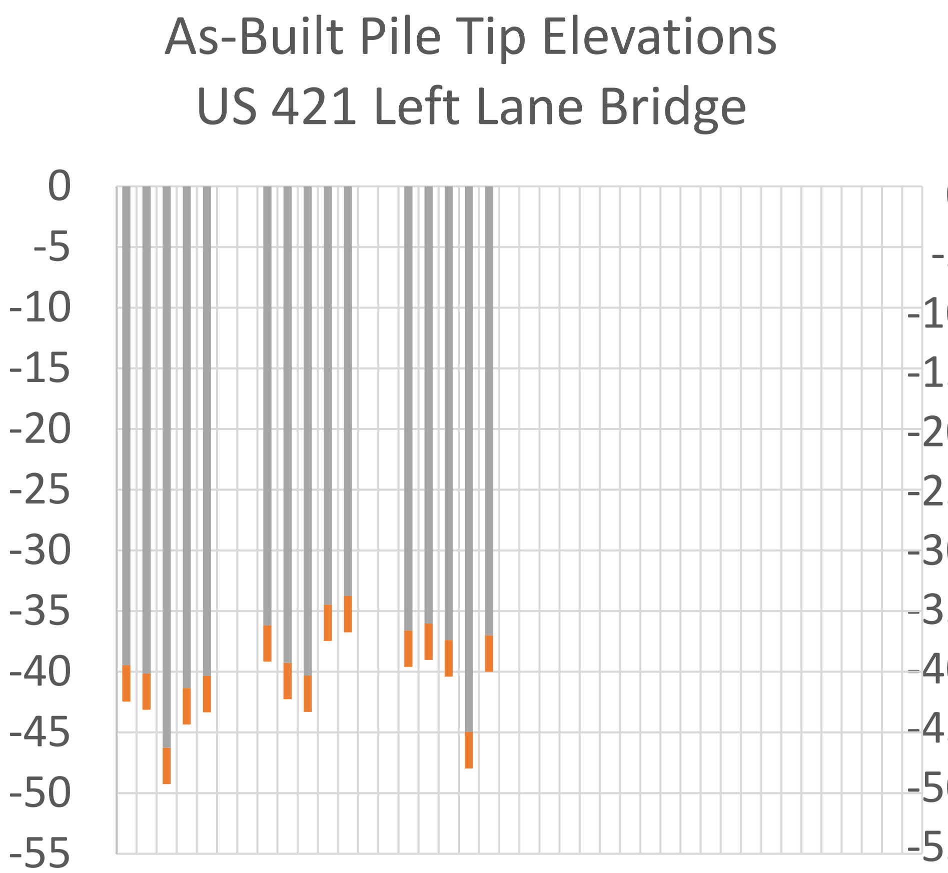


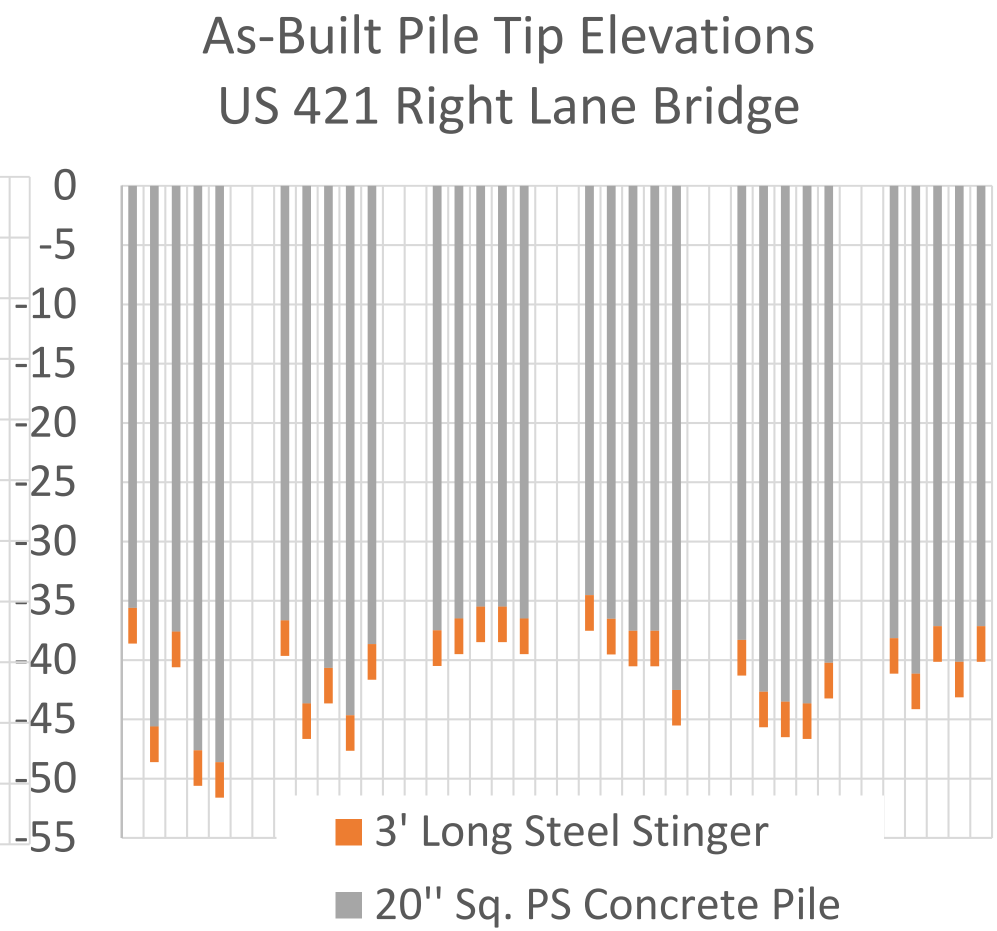
20” SQUARE PRESTRESSED CONCRETE PILES

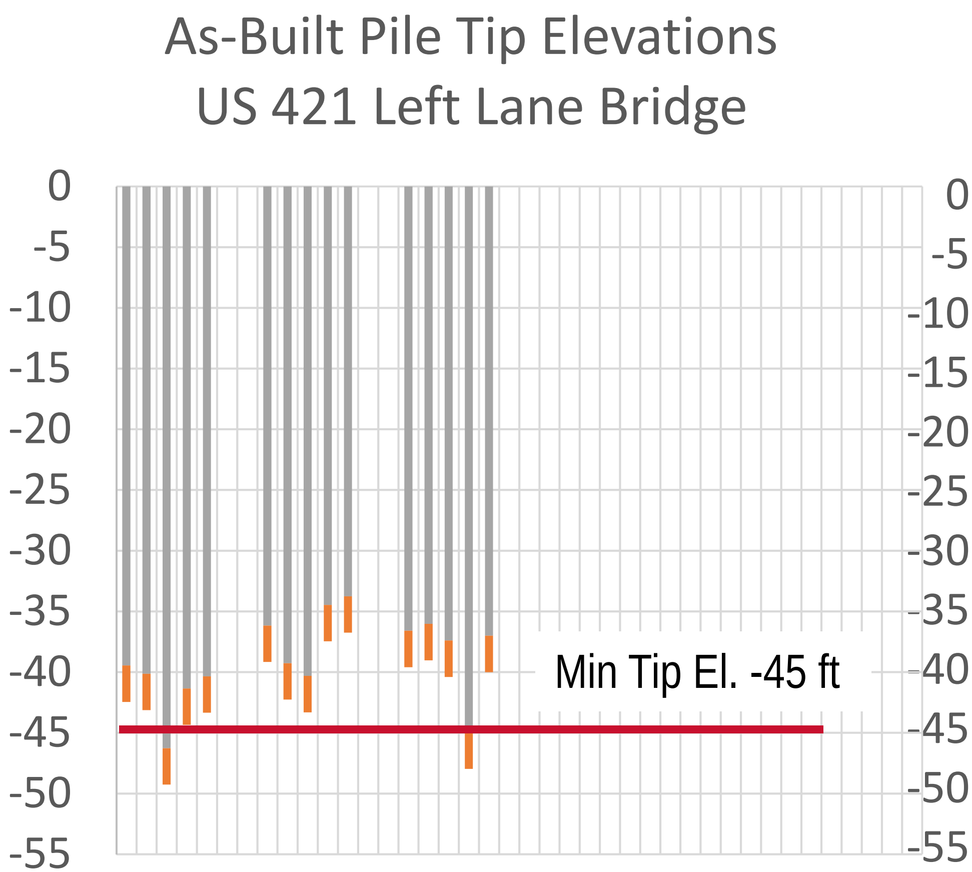
- NCDOT typically requires short (3 ft) HP stingers for concrete piles driven in hard driving conditions

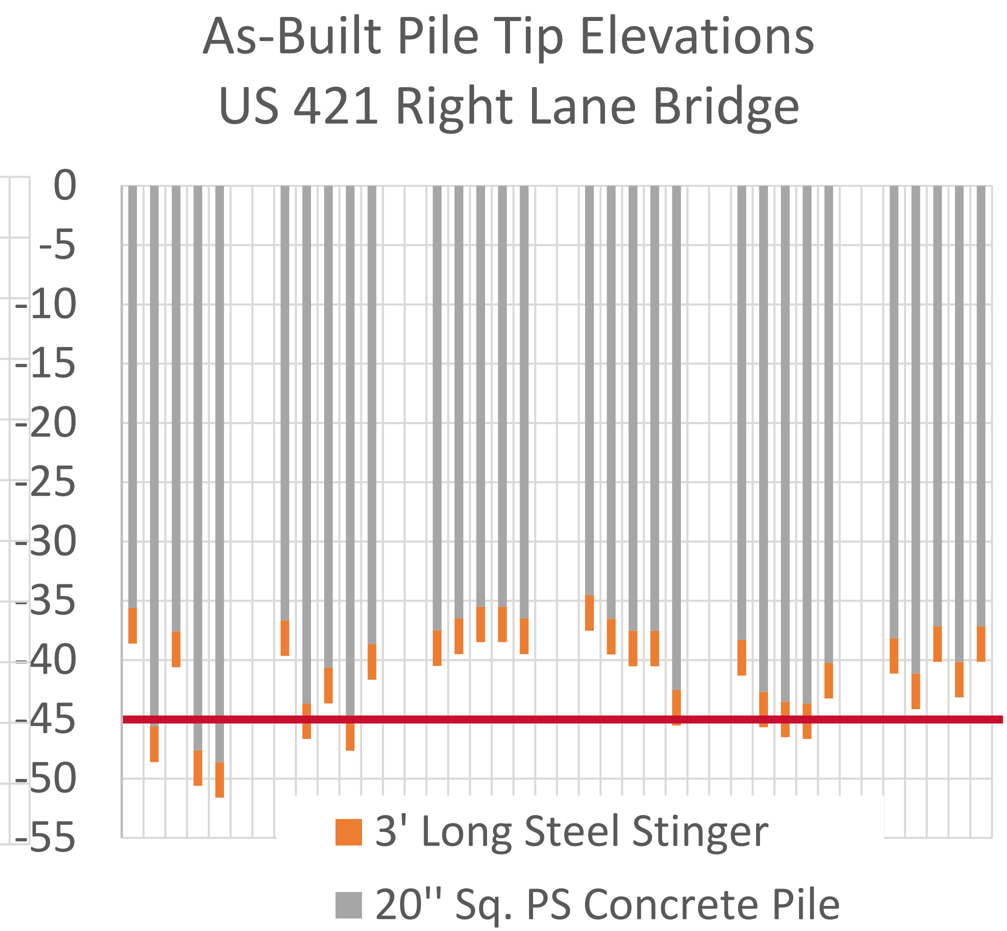
- HP stingers only considered as toe protection, not used in design




As-Built Pile Tip Elevations
US 421 Left Lane Bridge
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55


As-Built Pile Tip Elevations
US 421 Right Lane Bridge
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
3' Long Steel Stinger
20'' Sq. PS Concrete Pile


As-Built Pile Tip Elevations
US 421 Left Lane Bridge
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
Min Tip El. -45 ft


As-Built Pile Tip Elevations
US 421 Right Lane Bridge
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
3' Long Steel Stinger
20'' Sq. PS Concrete Pile

CAPWAP SUMMARY
BENT 2 PILE 5

- HP stinger showing ~123 kips of resistance at 10.7 ksf unit skin friction
- API RP2A guidelines for siliceous sand indicate maximum 2.4 ksf unit skin friction for very dense sand and gravel
- 8+ ksf likely limestone

Depth Below Grade ft	Unit Resist. (Depth) kips/ft	Unit Resist. (Area) ksf
3.8	2.68	0.40
6.8	3.74	0.56
9.8	3.14	0.47
12.8	2.84	0.43
15.8	3.74	0.56
18.8	4.07	0.61
21.8	3.54	0.53
24.8	3.47	0.52
27.8	3.10	0.47
30.8	3.10	0.47
33.8	1.70	0.26
36.8	1.70	0.26
39.9	3.31	0.50
42.9	3.78	0.57
		179.86
46.4	40.99	10.70

3 ft long HP stinger ->>

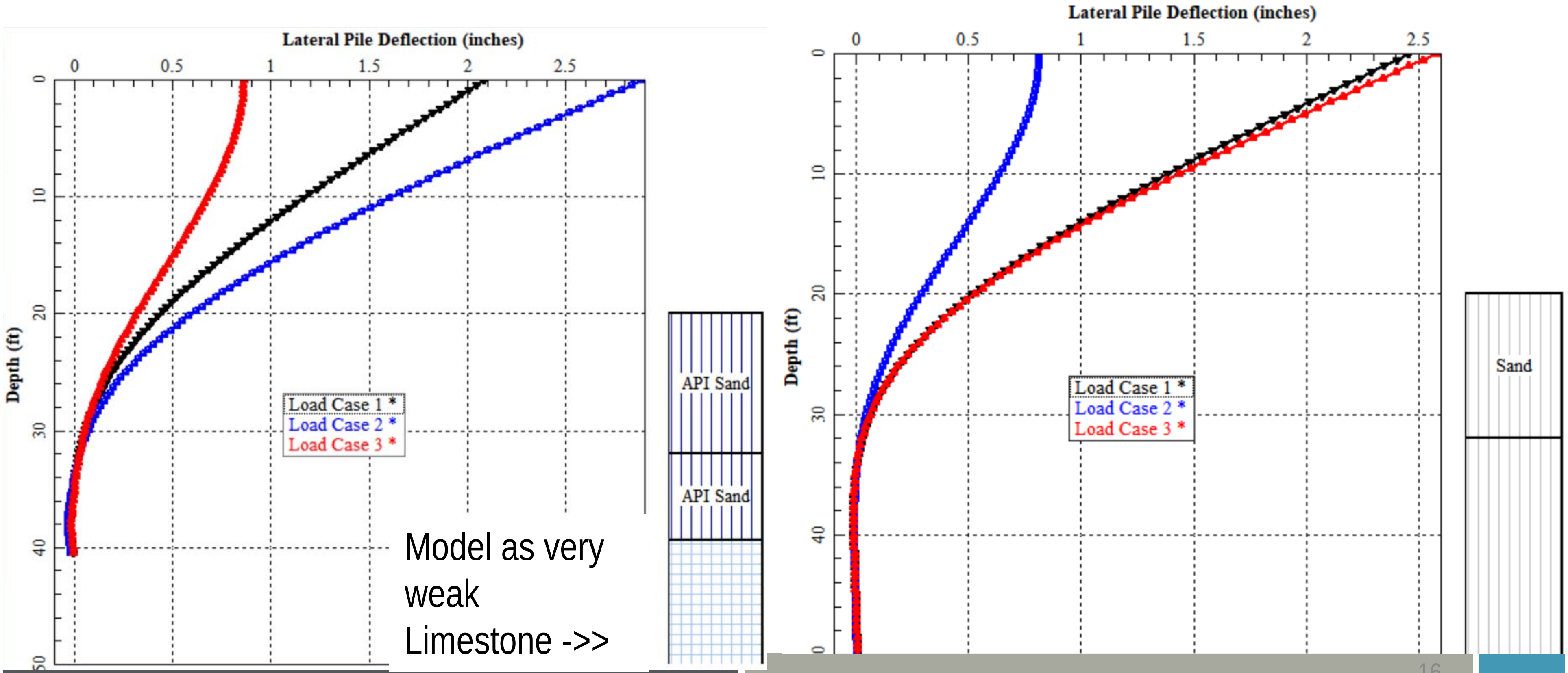
DRIVING LOG
BENT 2 PILE 5

- HP stinger appears to be embedded in very dense materials
- Reasonable assumption of at least 3 ft of limestone at the toe of the pile
- Inspector driving logs recording blows per ft critical to this evaluation

Depth (ft)	Blows Per Foot
26	73
27	62
28	72
29	68
30	
31	
32	
33	
34	139
35	180
36	182
37	120
38	119
39	129
40	
41	191
42	343
43	194
44	289

Very hard driving last ~ 4 ft ->>

AS-BUILT LPILE ANALYSIS BENT 2



Model as very weak Limestone ->>

TOPICS

- Minimum Tip Elevation
- Required Driving Resistance
- Geometrical Tolerance
- Pile Damage

REQUIRED DRIVING RESISTANCE

- Insufficient axial resistance at the final pile tip elevation

- Common problem with PS concrete piles in coastal geology, particularly when splicing is not allowed

- NCDOT: Bonner Bridge Replacement project

- Scenario to consider: A few piles have insufficient axial resistance but others have excess resistance

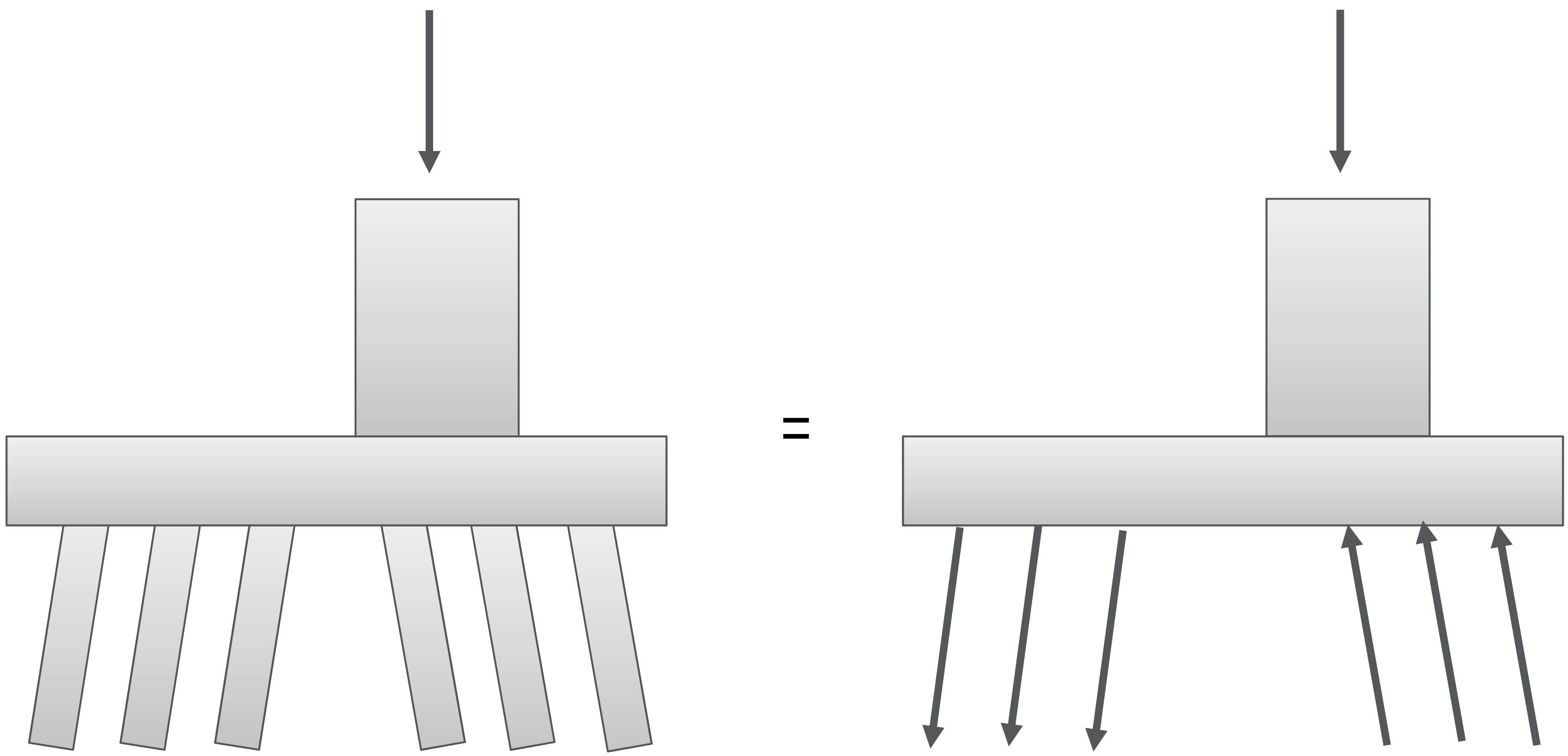
REQUIRED DRIVING RESISTANCE – POTENTIAL SOLUTIONS

- Evaluate actual pile loading against PDA test data and pile driving logs rather than applying maximum pile load to all piles
  - Driving resistance can be estimated from pile driving logs using a refined wave equation analysis in GRLWEAP

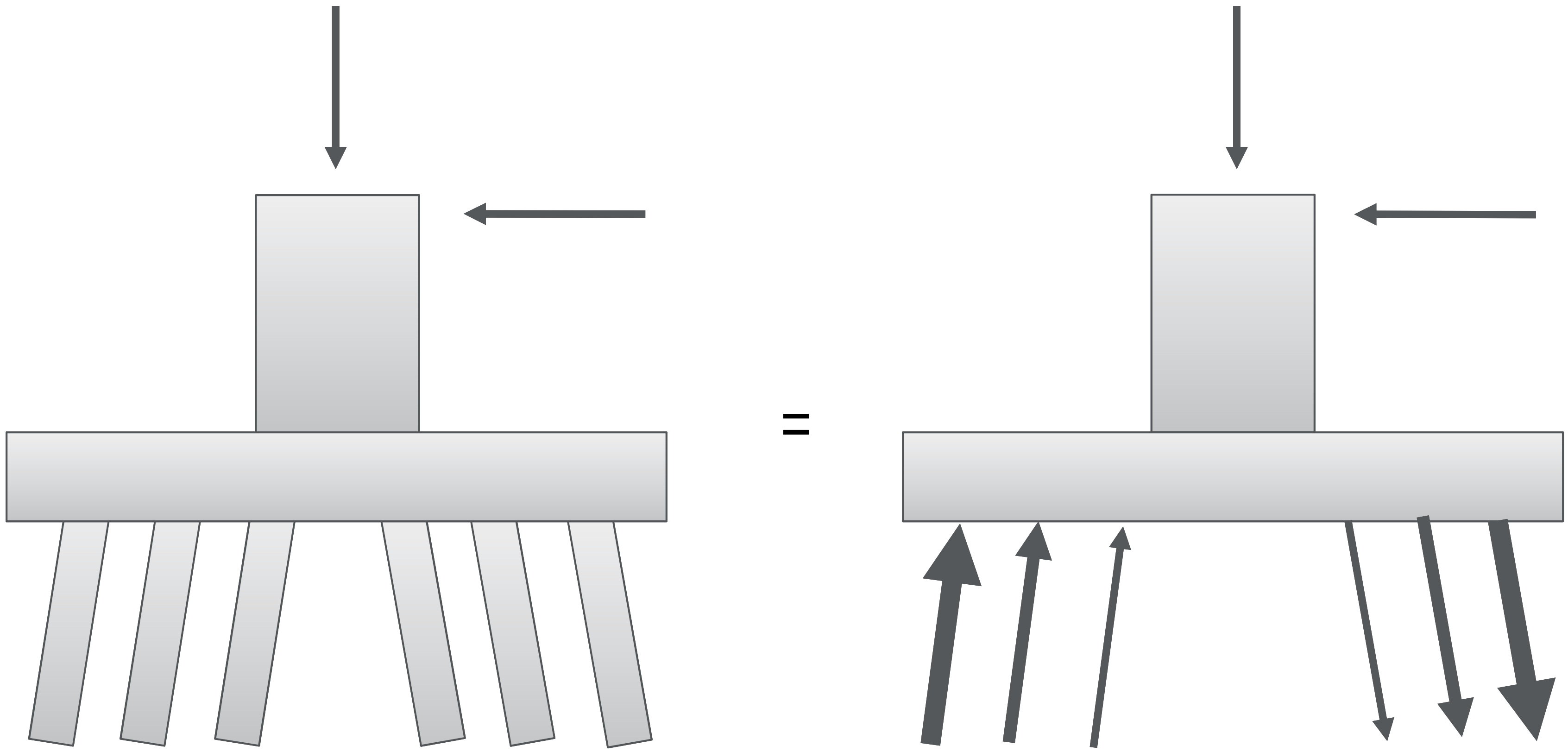
- Calibrate axial stiffness of soils (T-Z and Q-Z) curves such that the load on the pile is limited to the driving resistance from PDA or driving logs

- Superposition of skin friction and end bearing for displacement piles

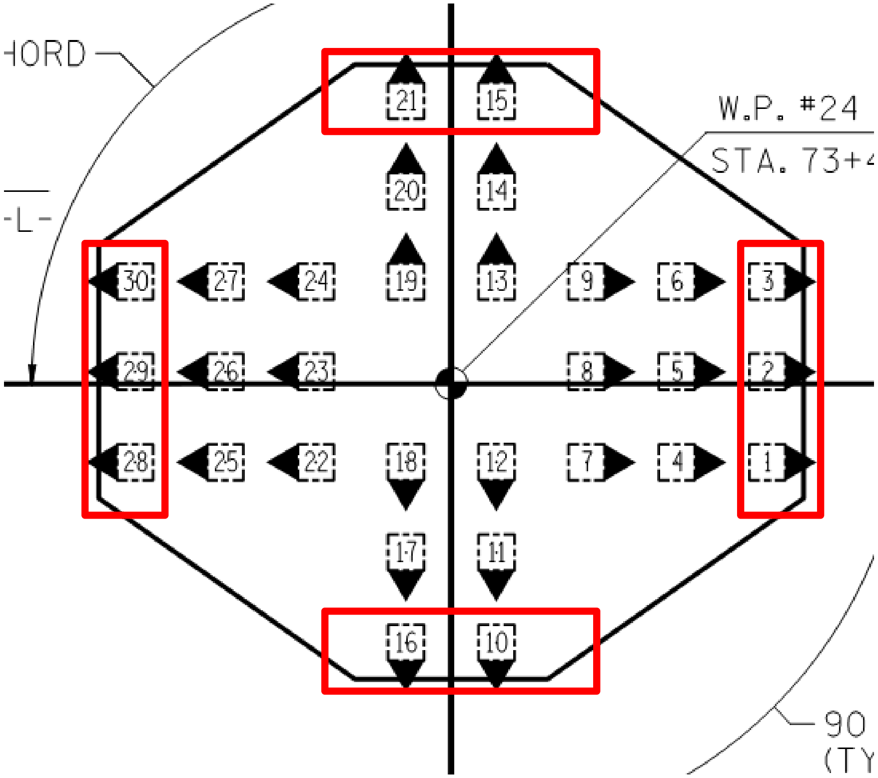
ACTUAL PILE LOAD DISTRIBUTION



ACTUAL PILE LOAD DISTRIBUTION

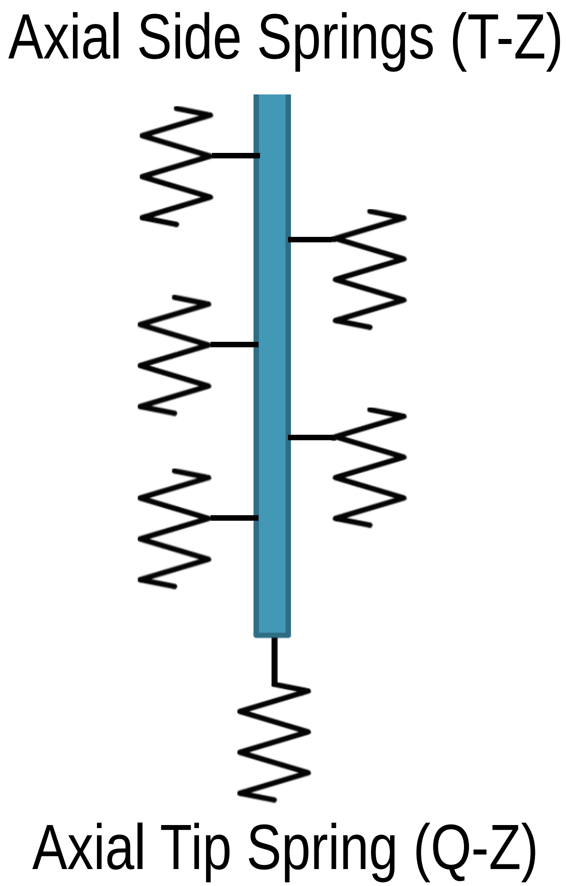


ACTUAL PILE LOAD DISTRIBUTION



AXIAL STIFFNESS CALIBRATION

- FB MultiPier was used to model soil structure interaction of pile groups
- Lateral, axial, and rotational spring stiffness of soils modeled in FB MultiPier
- PDA test results can be used to validate or modify the spring stiffness of as-built conditions



AXIAL SOIL SPRING PARAMETERS (T-Z AND Q-Z)

- Driven Pile (McVay) T-Z and Q-Z models utilized

- T-Z inputs: ultimate unit side friction, Poisson's ratio, shear modulus

- Q-Z inputs: ultimate tip resistance, Poisson's ratio, shear modulus

- High confidence in ultimate values, low confidence in shear modulus values based on routine test methods

TIP SOIL SPRING (Q-Z)

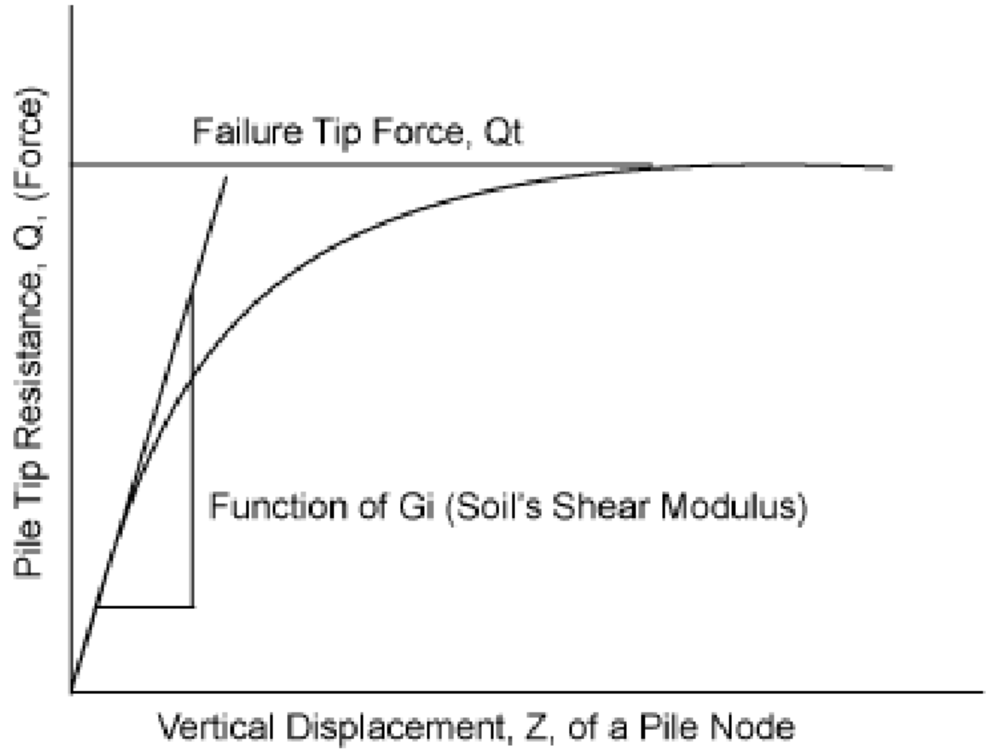
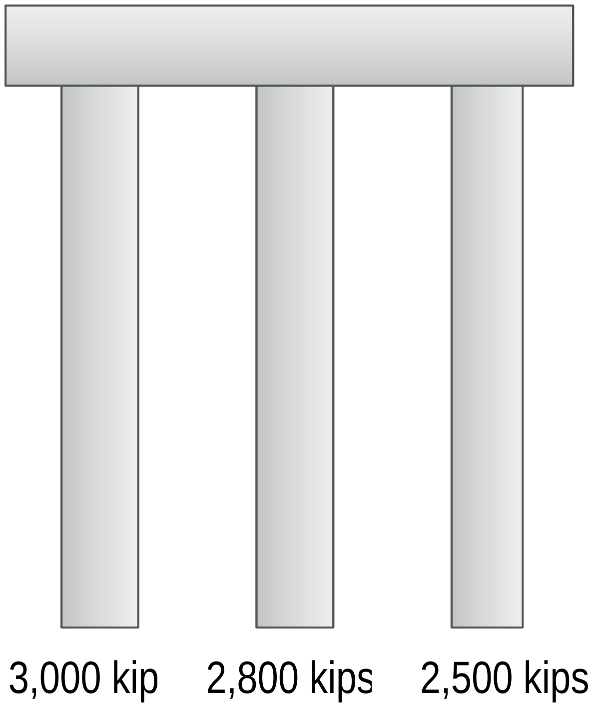


Figure: 12.5.a Q-Z Curve for Driven Pile

Reference FB MultiPier Help Manual

AXIAL STIFFNESS CALIBRATION



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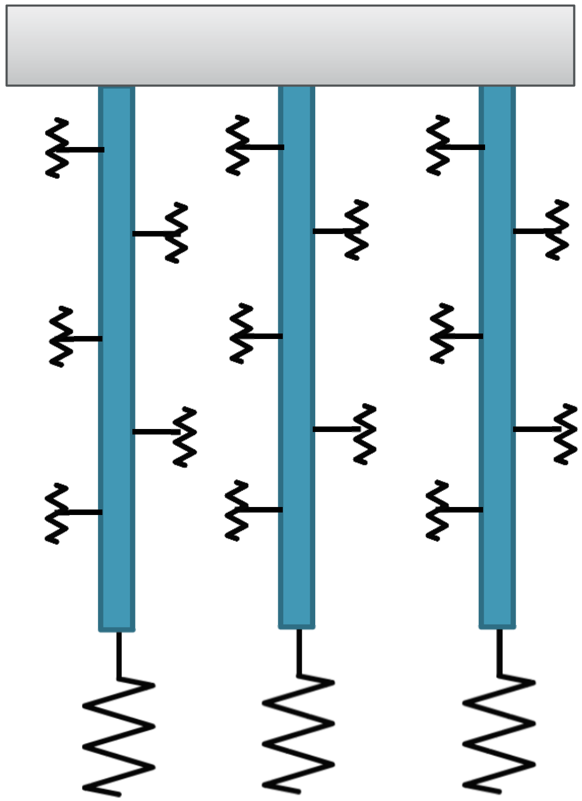
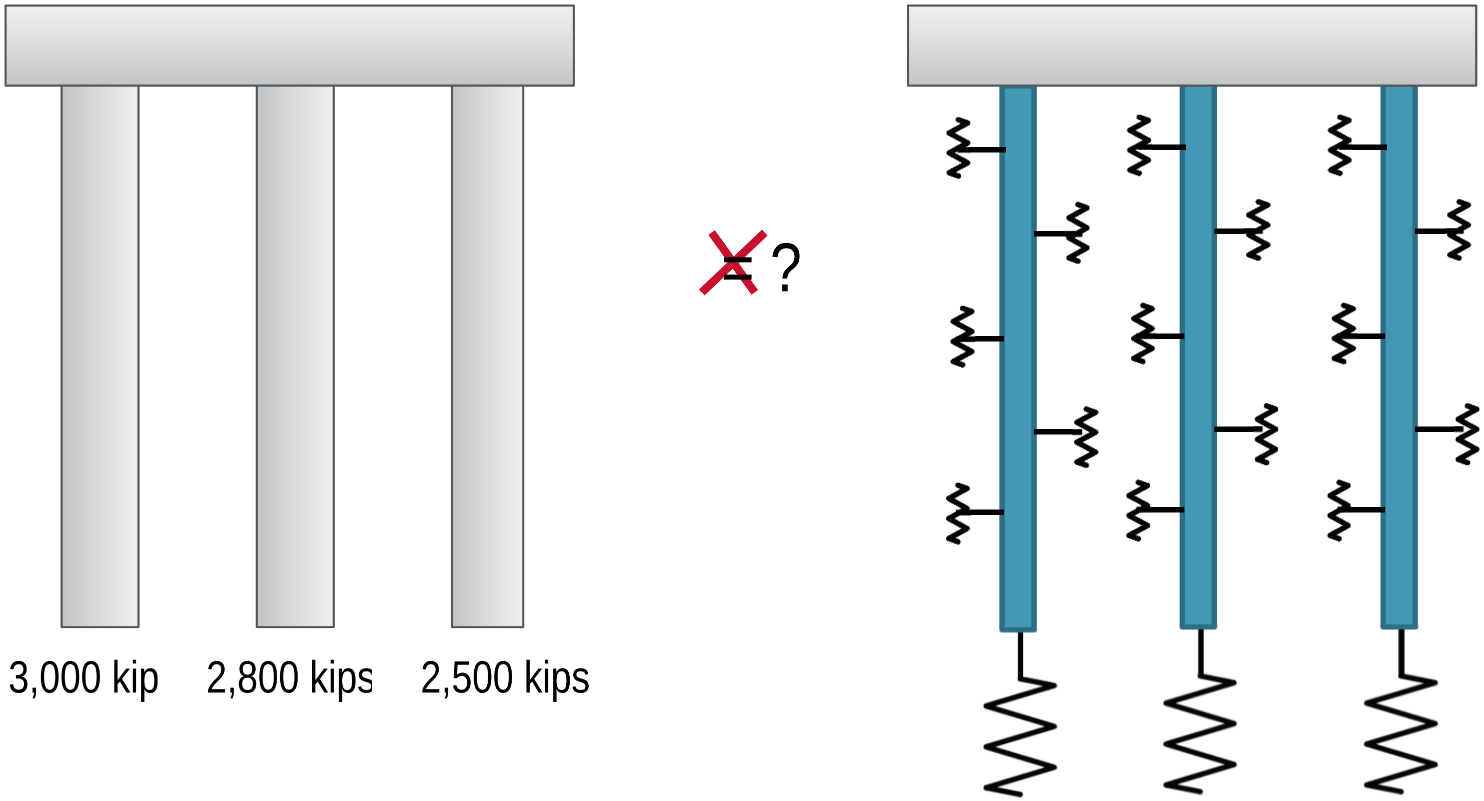
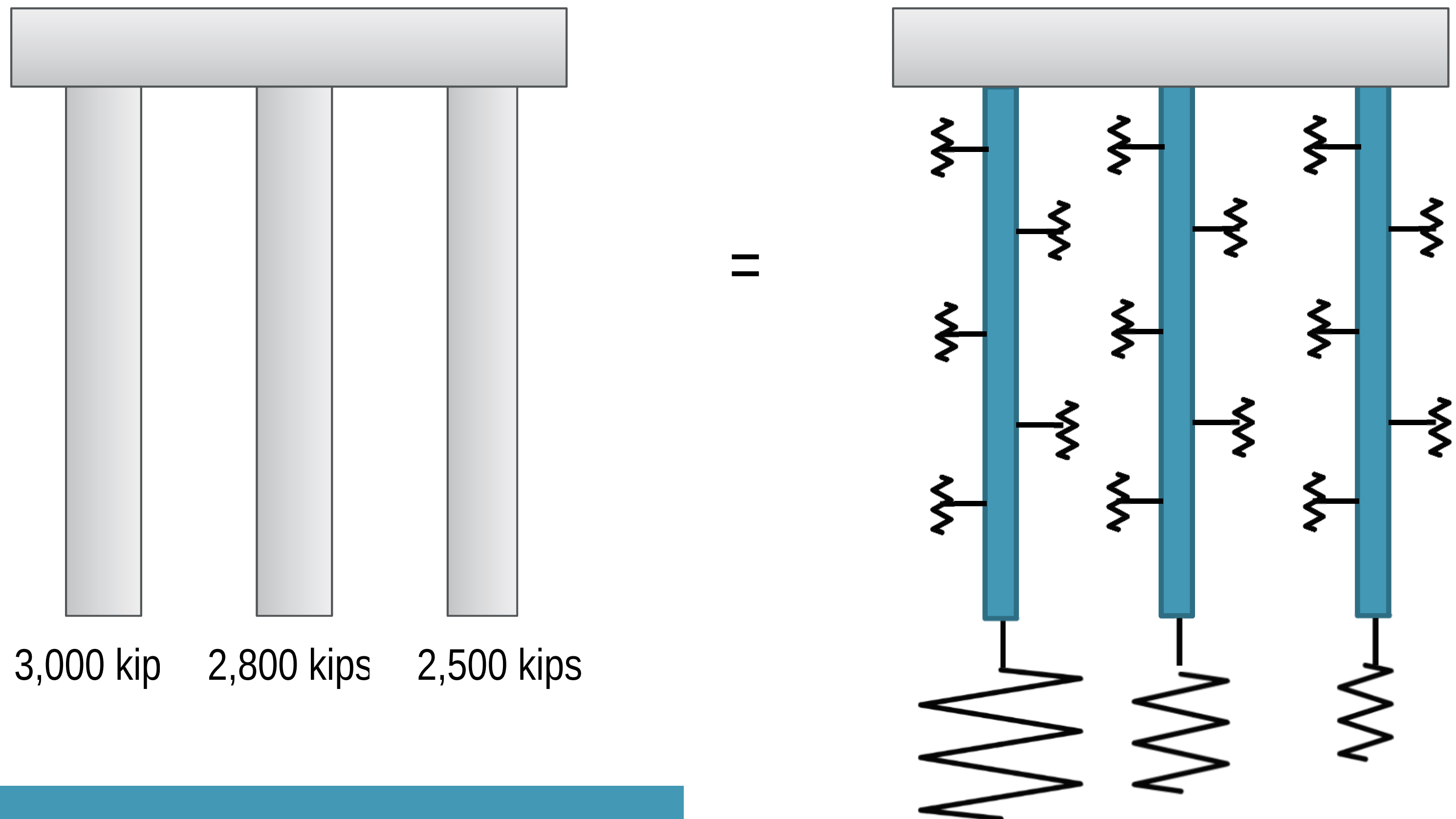


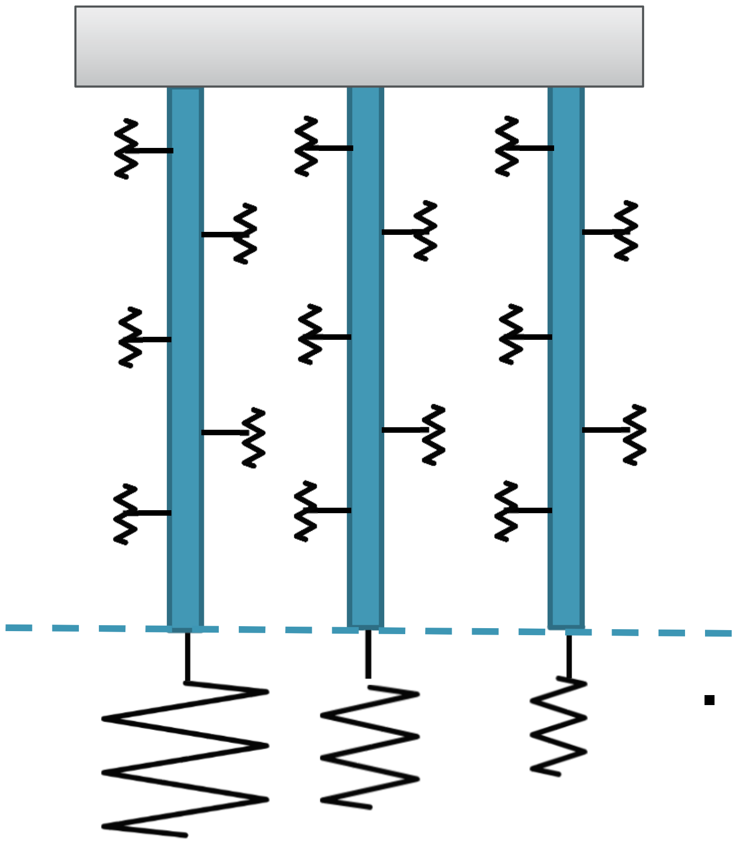
AXIAL STIFFNESS CALIBRATION



AXIAL STIFFNESS CALIBRATION



AXIAL STIFFNESS CALIBRATION



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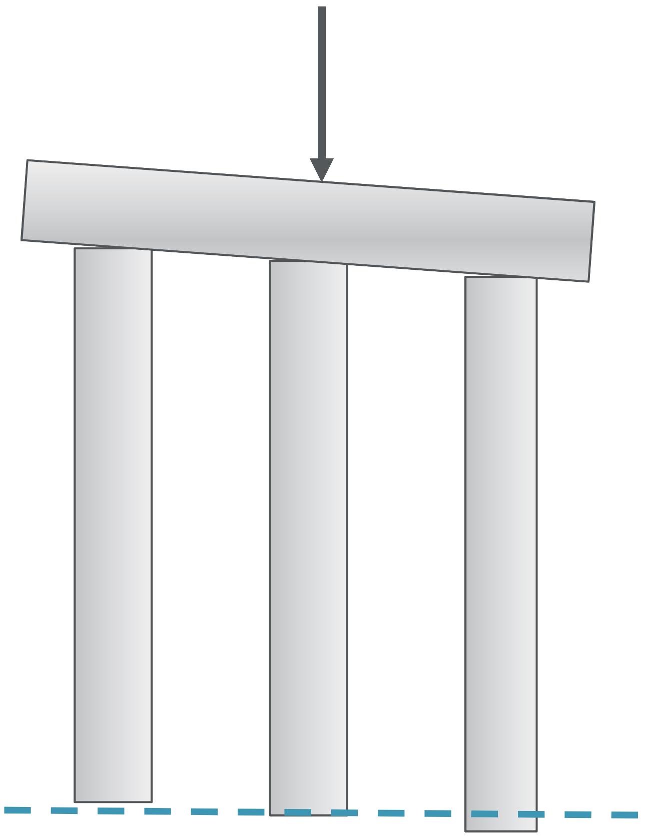


- Bridge designer to evaluate revised stresses and displacements of pier cap to determine if they are acceptable

CALIBRATION OF TIP SPRINGS

Reference FB MultiPier Help Manual

- Shear modulus values are difficult to reliably estimate
- Small strain stiffness measurements such as shear wave velocity testing needed
- How to evaluate shear modulus of a soil plug at the toe of a displacement pile? The in-situ measurements are NOT representative of final stress state of soil.
- Calibrate Q-Z springs such that individual max pile loads are limited to measured values

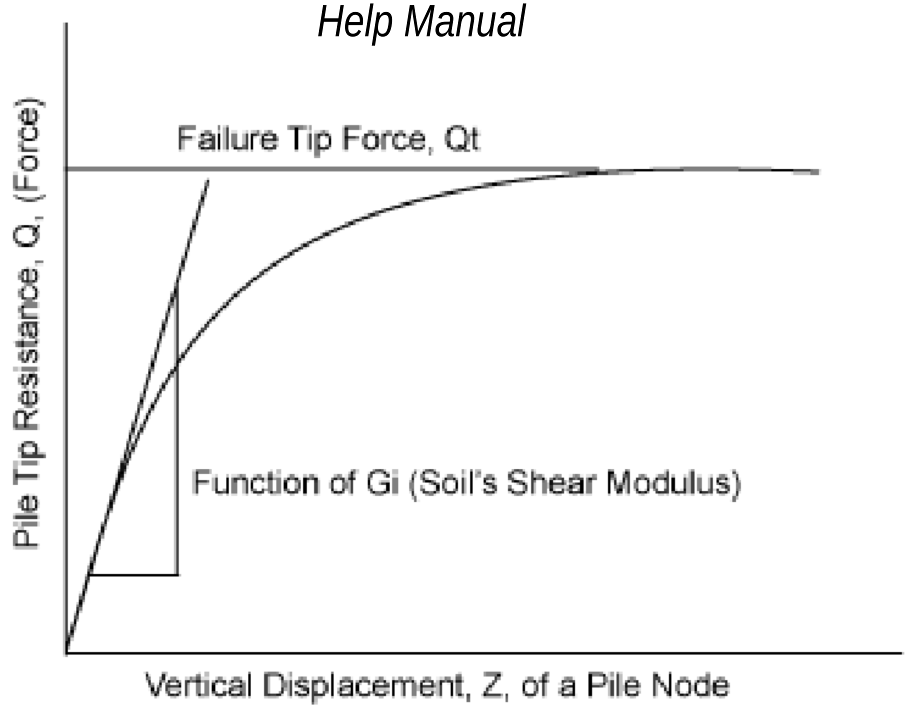
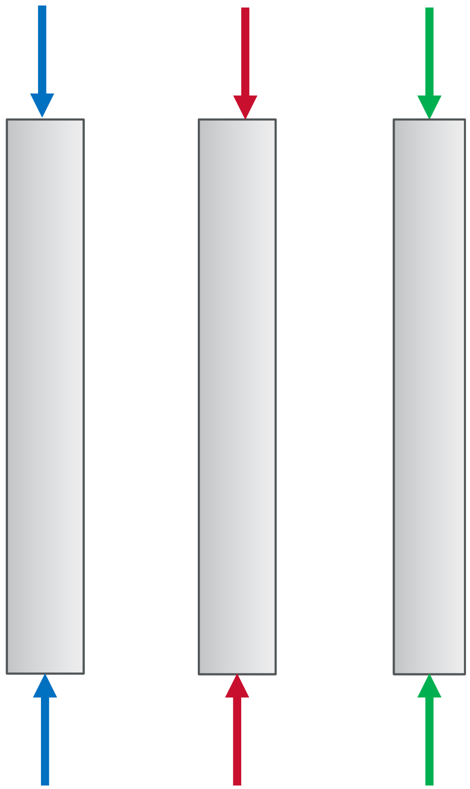


Figure: 12.5.a Q-Z Curve for Driven Pile

AXIAL STIFFNESS CALIBRATION



- Soften tip spring stiffness on piles with less axial resistance (red and green) until the modeled load on these piles is less than or equal to PDA measured resistance
  - Iteratively revise shear modulus and ultimate tip capacity if needed

- Pile with highest axial resistance (blue) will attract more load to compensate for softer springs at red and green
  - Determine if revised increased load on this pile is acceptable based on PDA measurements

- Consequence: The cap will rotate and deflect, generating differing stress distribution. Bridge designer must evaluate increased cap stress and deformation.

SUPERPOSITION OF SKIN FRICTION / END BEARING

- Potential for insufficient driving resistance due to high pore pressures at end of initial drive
- Restrikes often show higher skin friction, but can show less end bearing than end of initial drive
- Decrease in end bearing could be due to relaxation or likely due to **insufficient hammer energy to mobilize tip resistance** with increased skin friction due to setup
- Static load testing with indicator pile proved relaxation is not an issue

SUPERPOSITION OF SKIN FRICTION / END BEARING

- End bearing may be fully mobilized at end of initial drive with limited skin friction due to pore pressure buildup
- On restrike pore pressures dissipated so skin friction increases, but hammer energy may be too low to mobilize end bearing
- Superposition combines skin friction at **beginning of restrike** with end bearing at **end of restrike** or at **end of initial drive**

Bent 74

	CAPWAP Results		
Time of PDA	Skin Resistance, kips	Tip Resistance, kips	Total Resistance, kips
EOID	880	1120	2000
14 Day BOR	1850.1	550	2400.1
14 Day EOR	1303	1037	2340
			2887.1

TOPICS

- Minimum Tip Elevation
- Required Driving Resistance
- Geometrical Tolerance
- Pile Damage

PILES OUT OF HORIZONTAL POSITION OR BATTER ANGLE

- Large diameter battered piles in marine environments **very difficult** to position with tight geometrical tolerances
- +/- 3 inches horizontal tolerance is typical
- +/- 6 inches horizontal tolerance is more reasonable for large diameter piles
- Large number of piles out of +/- 3 inch horizontal tolerance

HORIZONTAL TOLERANCE - RESOLUTION

- Most piles ended up within +/- 6 inches of horizontal position
  - Typical solution was to adjust reinforcing steel in cap and add ‘filler’ reinforcement so there no large unreinforced gaps in the pile caps
- FB MultiPier models typically updated with as-built pile positions and batter angles
  - Small adjustment in horizontal position makes little difference in pile loading and structure behavior
  - Adjustment to batter angle tends to distribute pile load differently
- Precast pile caps require tight geometric tolerance to fit, field adjustment is not possible
  - Very stout frame used to position cylinder piles with precast caps


Vent
Vent
Vent


WD-40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NYKU
2796 08 8
MUSTER
POINT

TOPICS

- Minimum Tip Elevation
- Required Driving Resistance
- Geometrical Tolerance
- Pile Damage

PILE DAMAGE

- Surficial spalling is typical on concrete piles and often does not affect pile integrity and can be repaired in place

- Structural pile damage typically determined by change in cross sectional area of pile

- Beta (BTA) method refers to %change in pile impedance in PDA records to evaluate damage

$$Impedance = \frac{EA}{c}$$

- C (wavespeed) is known for the material type, E (modulus) is assumed constant, so a change in impedance suggests a change in A (cross sectional area)

PILE DAMAGE GUIDELINES

- FHWA *Design and Construction of Driven Pile Foundations* provides the following table to evaluate extent of pile damage based on BTA values from PDA testing

Table 10-2 Pile Damage Guidelines (after Rausche and Goble 1979)

BTA	Severity of Damage
1.0	Undamaged
0.8 – 1.0	Slightly Damaged
0.6 – 0.8	Damaged
Below 0.6	Broken

CYLINDER PILE SURFICIAL DAMAGE

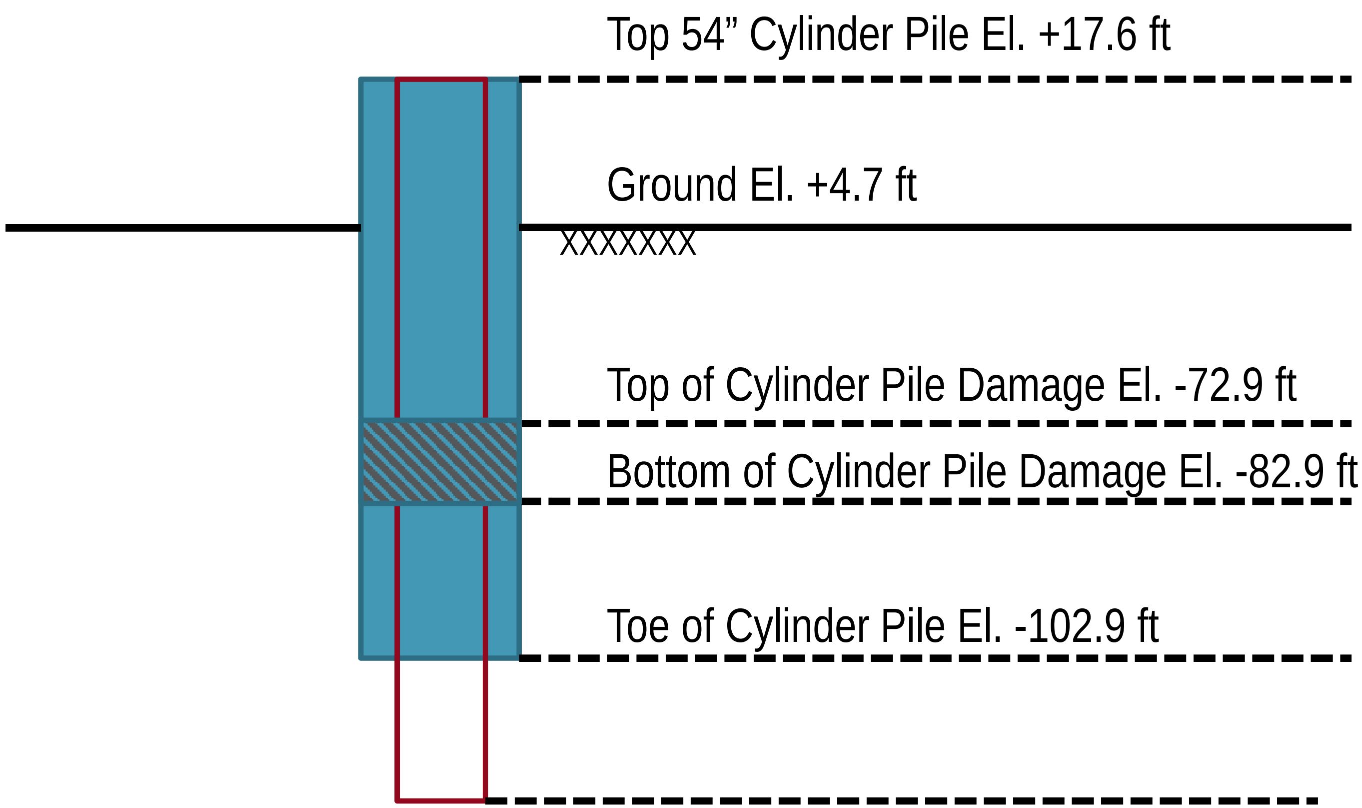
- Damage to pile top was surficial only
- Damaged portion cut off after driving

CYLINDER PILE STRUCTURAL DAMAGE

- Impedance change (damage) starting approximately 86.9 ft below grade and extending to approximately 113.7 ft below grade
- Assume complete section loss due to 93.9% impedance reduction
- No moment capacity below 86.9 ft
  - Pile fixity achieved above 86.9 ft so no moment capacity needed below this depth
- Insufficient driving resistance due to pile damage, retrofit needed

Segmnt Number	Dist. B.G. ft	Impedance kips/ft/s	Imped. Change %
1	3.3	410.10	0.00
26	86.9	410.00	-0.03
27	90.3	370.00	-9.78
28	93.6	275.00	-32.94
29	96.9	150.00	-63.42
30	100.3	25.00	-93.90
31	103.6	95.00	-76.84
32	107.0	175.00	-57.33
33	110.3	200.00	-51.23
34	113.7	350.00	-14.66
35	117.0	410.10	0.00

CYLINDER PILE STRUCTURAL DAMAGE RETROFIT



CYLINDER PILE STRUCTURAL DAMAGE RETROFIT

- Cylinder pile annulus cleaned out
- Rollers used to guide 36” OD x ½” wall thickness open ended steel pipe pile inside cylinder pile
- Steel pile vibrated to below the toe of cylinder pile then impact driven
- Skin friction of cylinder pile above damage point superimposed with end bearing of steel pipe pile to provide adequate driving resistance


QUESTIONS?