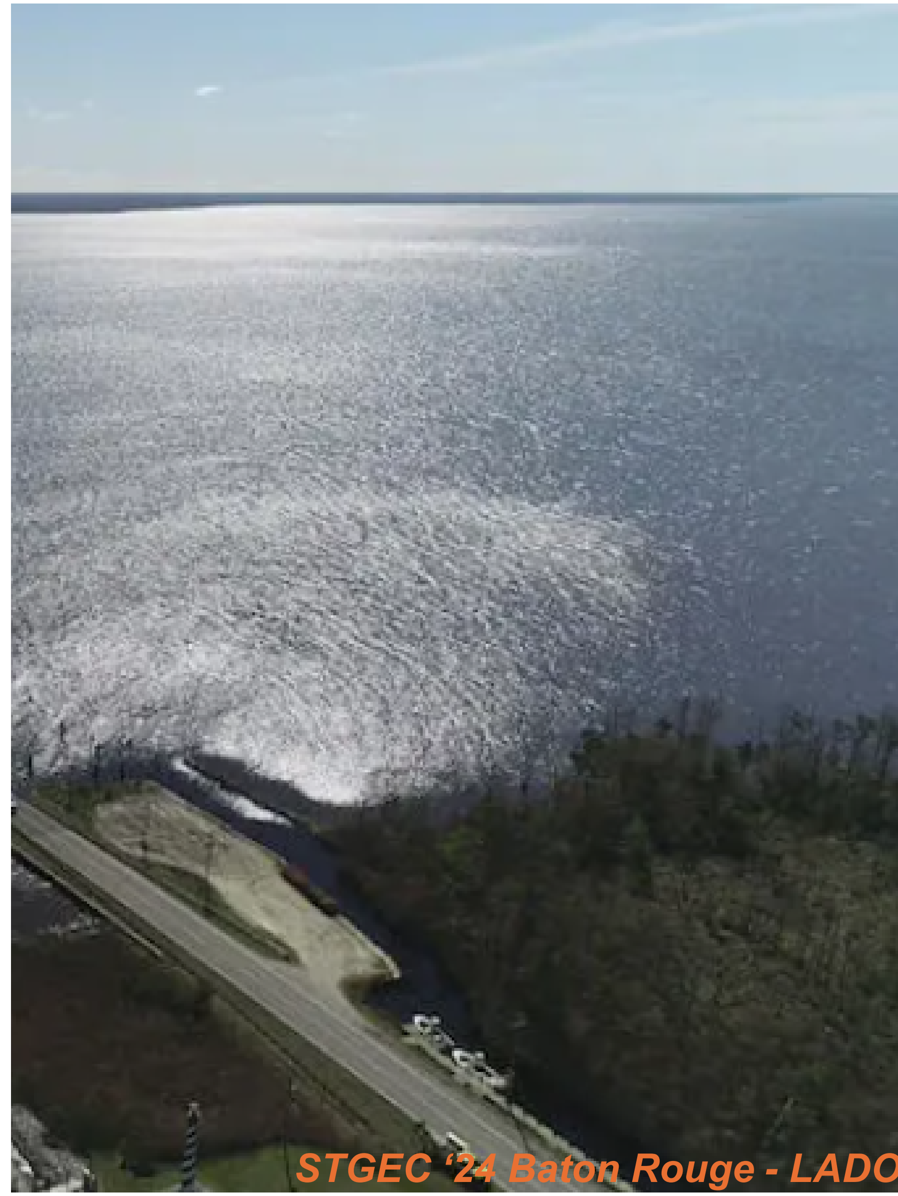
Alligator River Bridge Replacement

NCDOT Eastern Region
Geotechnical Group



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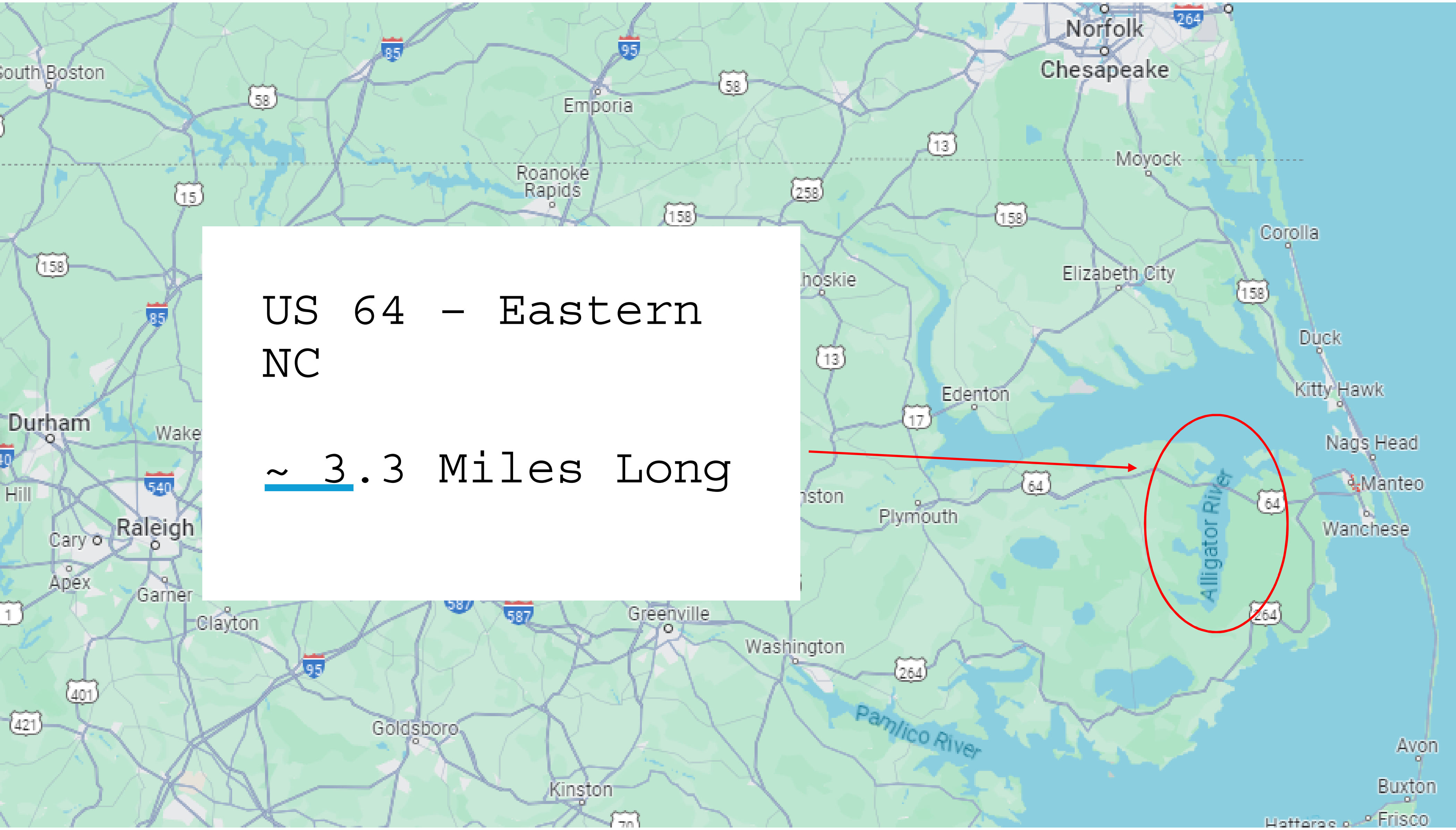
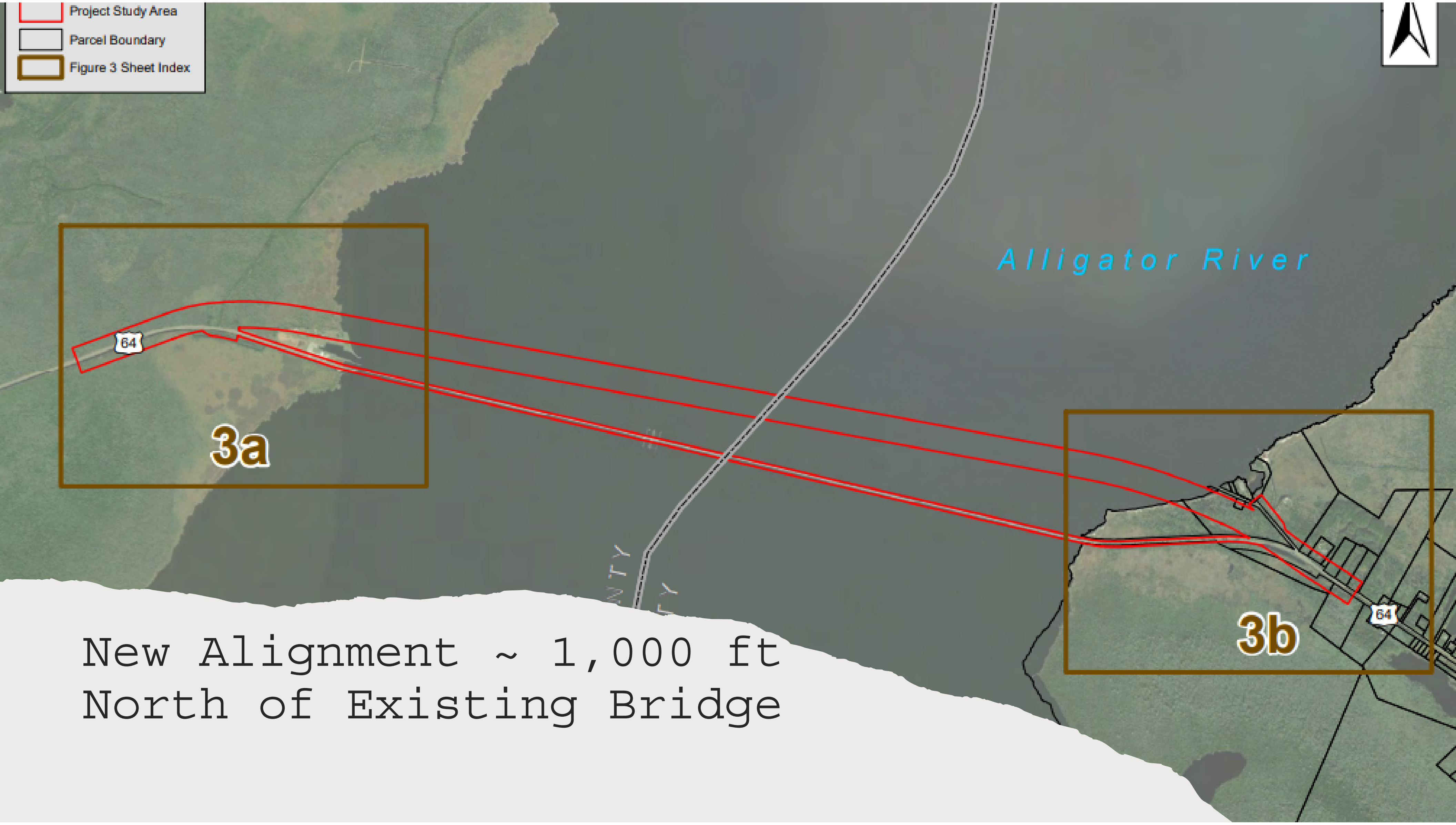
Overview

- Project overview
- Challenges associated with the design of the project
- Possible solutions to challenges
- Lab/field testing and results
- Pile driving program
- Conclusions

US 64 - Eastern NC

~ 3.3 Miles Long





New Alignment ~ 1,000 ft North of Existing Bridge

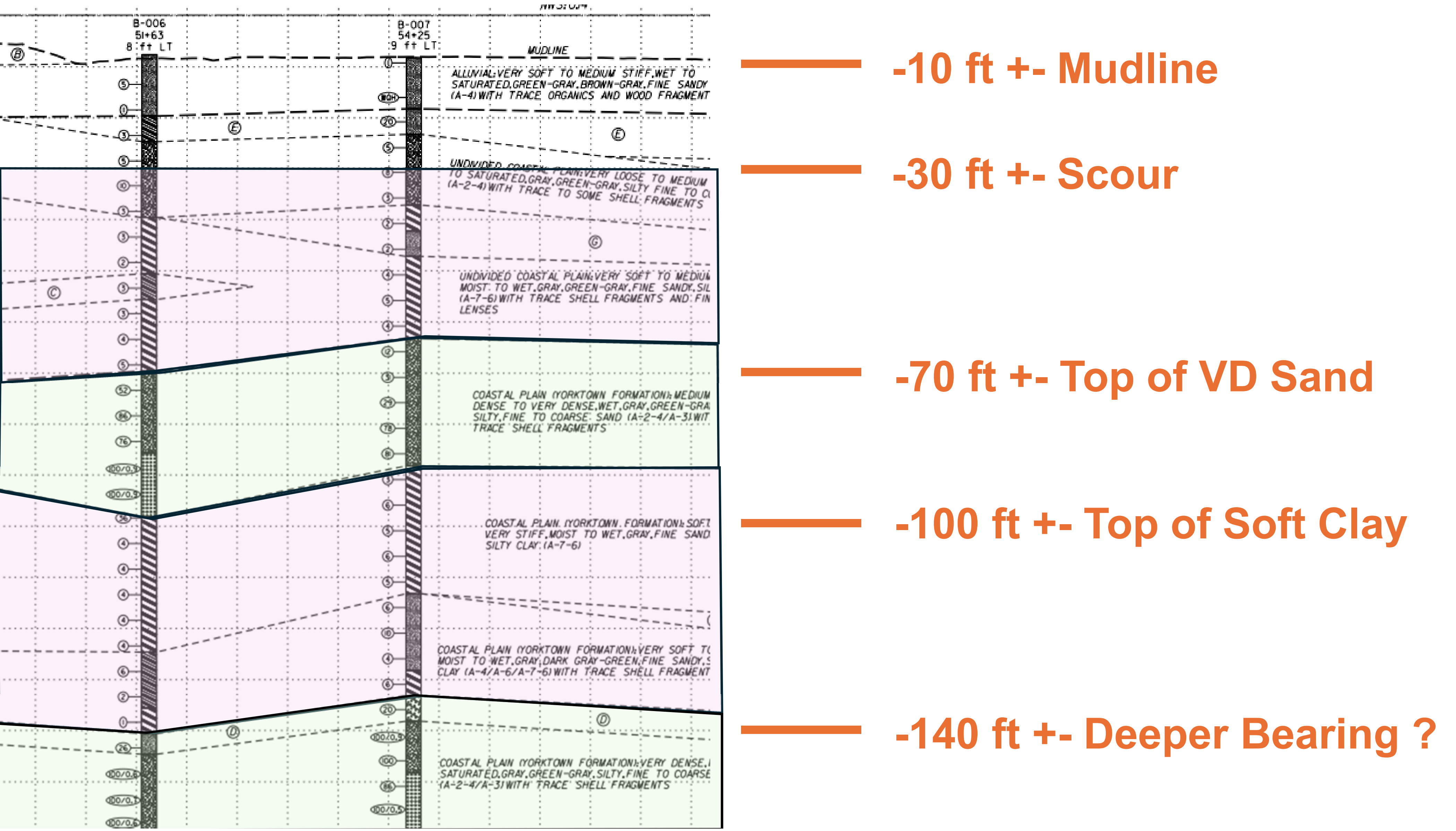
Challenges

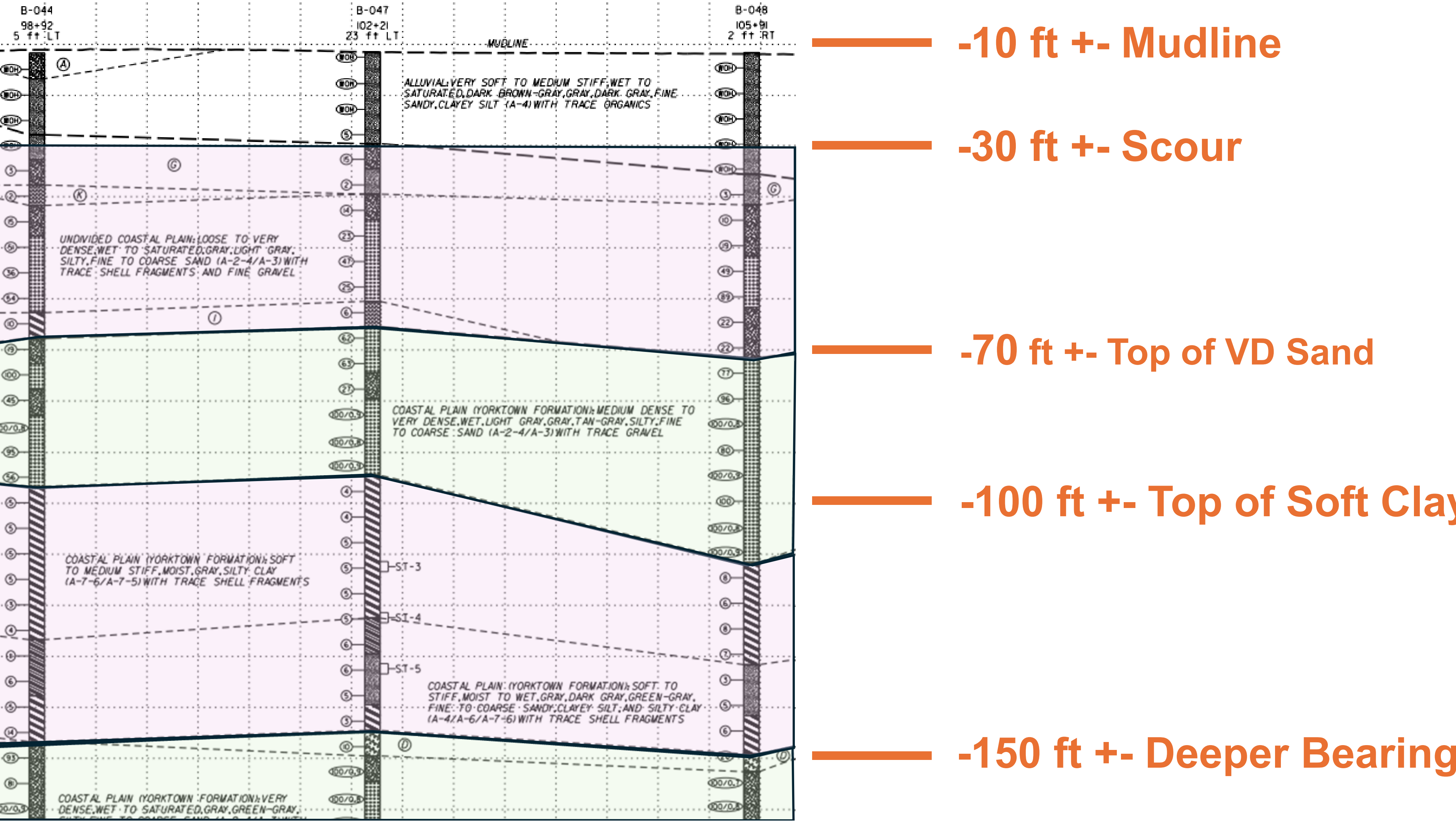
- River moratorium
  - Mid-February to October
  - Impacted field exploration
  - Will impact pile driving during construction
- Exploration on water
- Poor weather

Challenges

- Federal Grant Money –officially committed and now in a "big, big, big" hurry to let/build

- Difficult subsurface conditions for pile driving
  - Very dense sand underlain by "soft" silt/clay
  - What elevation to set minimum tip at?
  - Drive into or through the very dense sand layer?
  - Settlement concerns if we put the piles in very dense sand layer?


B-006
51+63
8 ft LT
B-007
54+25
9 ft LT
MUDLINE
ALLUVIAL: VERY SOFT TO MEDIUM STIFF, WET TO SATURATED, GREEN-GRAY, BROWN-GRAY, FINE SANDY (A-4) WITH TRACE ORGANICS AND WOOD FRAGMENT
COASTAL PLAIN (YORKTOWN FORMATION): MEDIUM DENSE TO VERY DENSE, WET, GRAY, GREEN-GRAY SILTY, FINE TO COARSE SAND (A-2-4/A-3) WITH TRACE SHELL FRAGMENTS
-10 ft +- Mudline
-30 ft +- Scour
-70 ft +- Top of VD Sand
-100 ft +- Top of Soft Clay
-140 ft +- Deeper Bearing ?



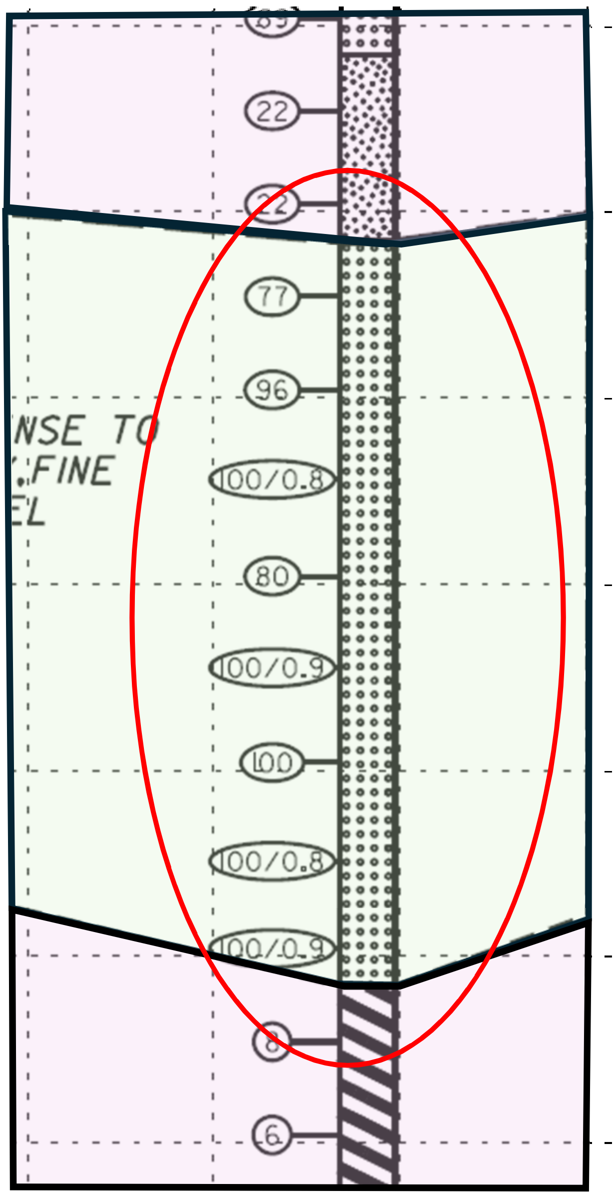
B-044
98+92
5 ft LT
B-047
102+21
23 ft LT
B-048
105+91
2 ft RT
MUDLINE
ALLUVIAL: VERY SOFT TO MEDIUM STIFF, WET TO SATURATED, DARK BROWN-GRAY, GRAY, DARK GRAY, FINE SANDY, CLAYEY SILT (A-4) WITH TRACE ORGANICS
UNDIVIDED COASTAL PLAIN: LOOSE TO VERY DENSE, WET TO SATURATED, GRAY, LIGHT GRAY, SILTY, FINE TO COARSE SAND (A-2-4/A-3) WITH TRACE SHELL FRAGMENTS AND FINE GRAVEL
COASTAL PLAIN (YORKTOWN FORMATION): MEDIUM DENSE TO VERY DENSE, WET, LIGHT GRAY, GRAY, TAN-GRAY, SILTY, FINE TO COARSE SAND (A-2-4/A-3) WITH TRACE GRAVEL
COASTAL PLAIN (YORKTOWN FORMATION): SOFT TO MEDIUM STIFF, MOIST, GRAY, SILTY CLAY (A-7-6/A-7-5) WITH TRACE SHELL FRAGMENTS
ST-3
ST-4
ST-5
COASTAL PLAIN (YORKTOWN FORMATION): SOFT TO STIFF, MOIST TO WET, GRAY, DARK GRAY, GREEN-GRAY, FINE TO COARSE SANDY, CLAYEY SILT, AND SILTY CLAY (A-4/A-6/A-7-6) WITH TRACE SHELL FRAGMENTS
COASTAL PLAIN (YORKTOWN FORMATION): VERY DENSE, WET TO SATURATED, GRAY, GREEN-GRAY,
-10 ft +- Mudline
-30 ft +- Scour
-70 ft +- Top of VD Sand
-100 ft +- Top of Soft Clay
-150 ft +- Deeper Bearing

Constructability of 36-inch Square PCP Driven Piles

- Can we drive through the very dense sand?
- Can we drive into the very dense sand far enough to satisfy lateral stability?
- Pile excavation needed?
- Drive study

Go CMGC

- Contractor expertise needed
- Contractor support needed to get answers (little time to work out foundation difficulties)
- Contractor can help find cost savings in design



to drive through this layer?

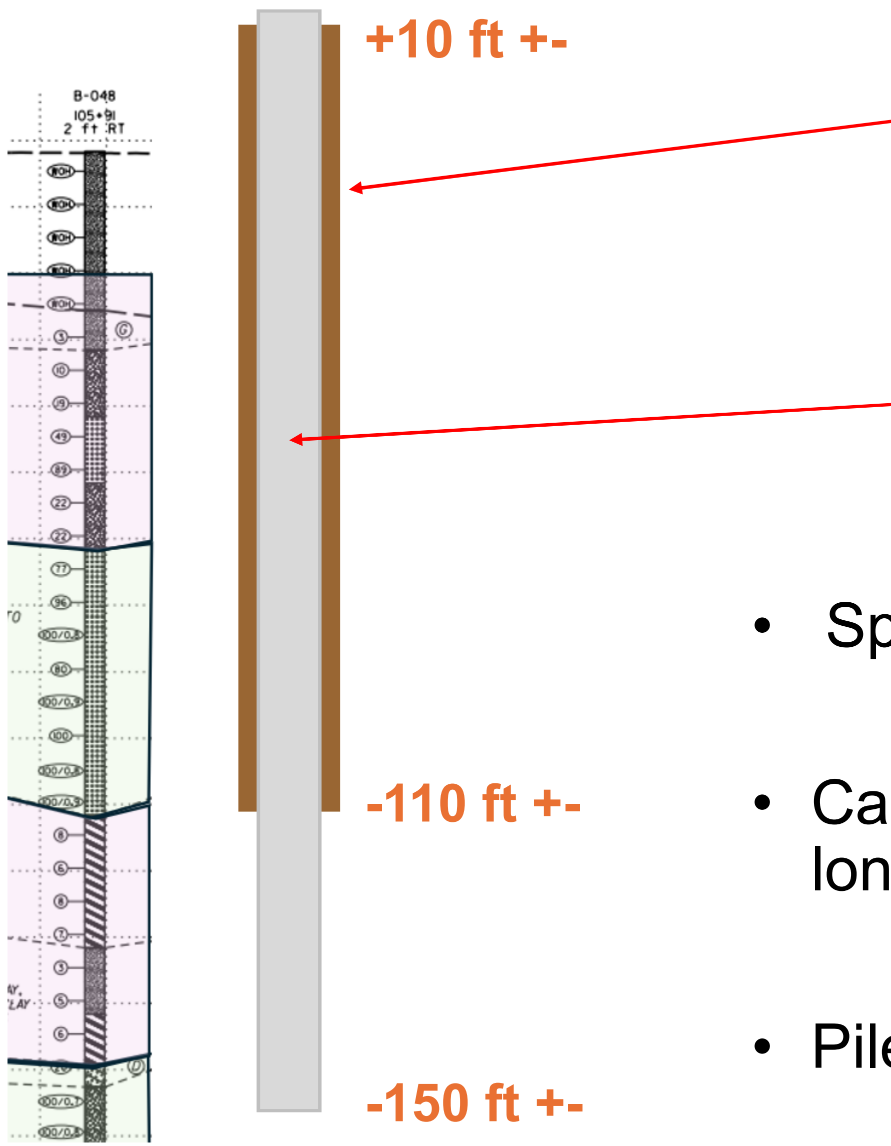
Conclusion during early design … No

Solution with long piles … Pile Excavation

We needed to investigate need and feasibility of pile excavation

Pile Excavation

- Perform excavation to bottom of the very dense sand
- If unstable/collapsing soils encountered, use temporary casings or slurry to maintain an open hole
- Stand, set, and then drive pile to lower bearing stratum



62-inch diameter steel casing

36-inch square PCP

- Spatial Variation
- Casings need to be 100 to 120 feet long
- Piles need to be 165 to 185 feet long

Excavation

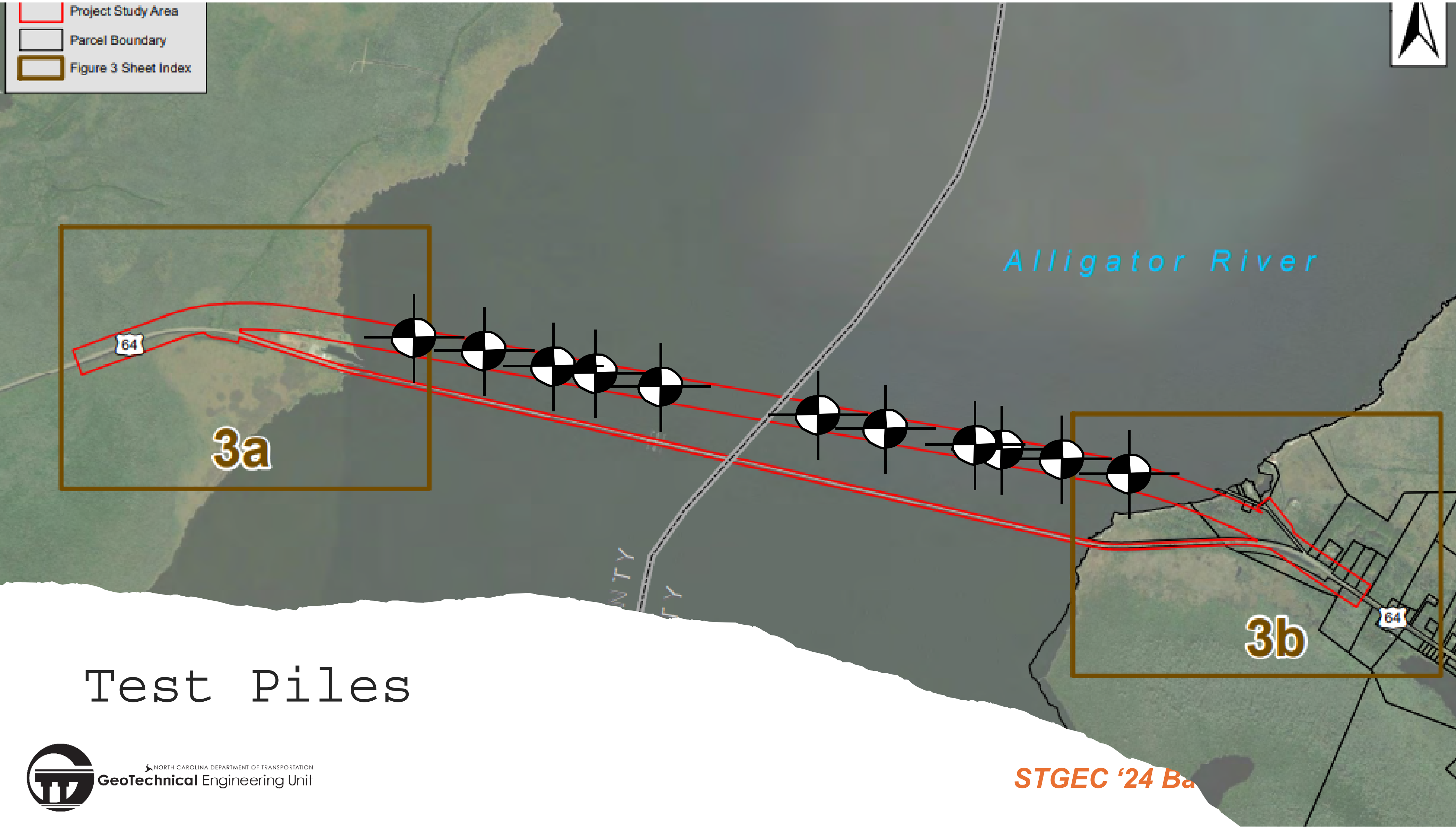
- 1000+ piles affected
- Moratorium for construction
  - Channel - Feb 15 to June 30
  - River – July 15 to Sept 30
- Approximately 30% of piles are in the Channel (high-rise portion of bridge) – only drive 5 months each year
- Remaining piles in low level, trestle portion of bridge – 8.5 months each year to drive piles

Initial Goals

- Start in January 2024
- Delays, delays, delays – Finally started in May 2024
- Prove we can drive through or at least some distance into the very dense sand (latter assumes settlement problem goes away)
- Prove we can excavate

36-Inch Square PCP's

- Cast ~15 piles with lengths of 165 to 185 feet
- Spread them out along bridge



Test Piles

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Meanwhile…

- Can we eliminate the settlement issue?
  - Short piles could be used

- Ideally prove this before test piles are driven…. but the test pile program was moving ahead

Limited Subsurface Sampling

- Emphasis on getting alignment drilled in small time window
- The few consolidation samples obtained were disturbed – not helpful resolving settlement concerns

Settlement of Bridge (Short Piles)

- Conservatively assumed OCR = 1
- The total expected settlement was 5-8 inches, with a differential settlement of 3-5 inches
- Computed using equivalent footing (FHWA)
- The deeper into the very dense sand the pile goes, the amount of settlement increases

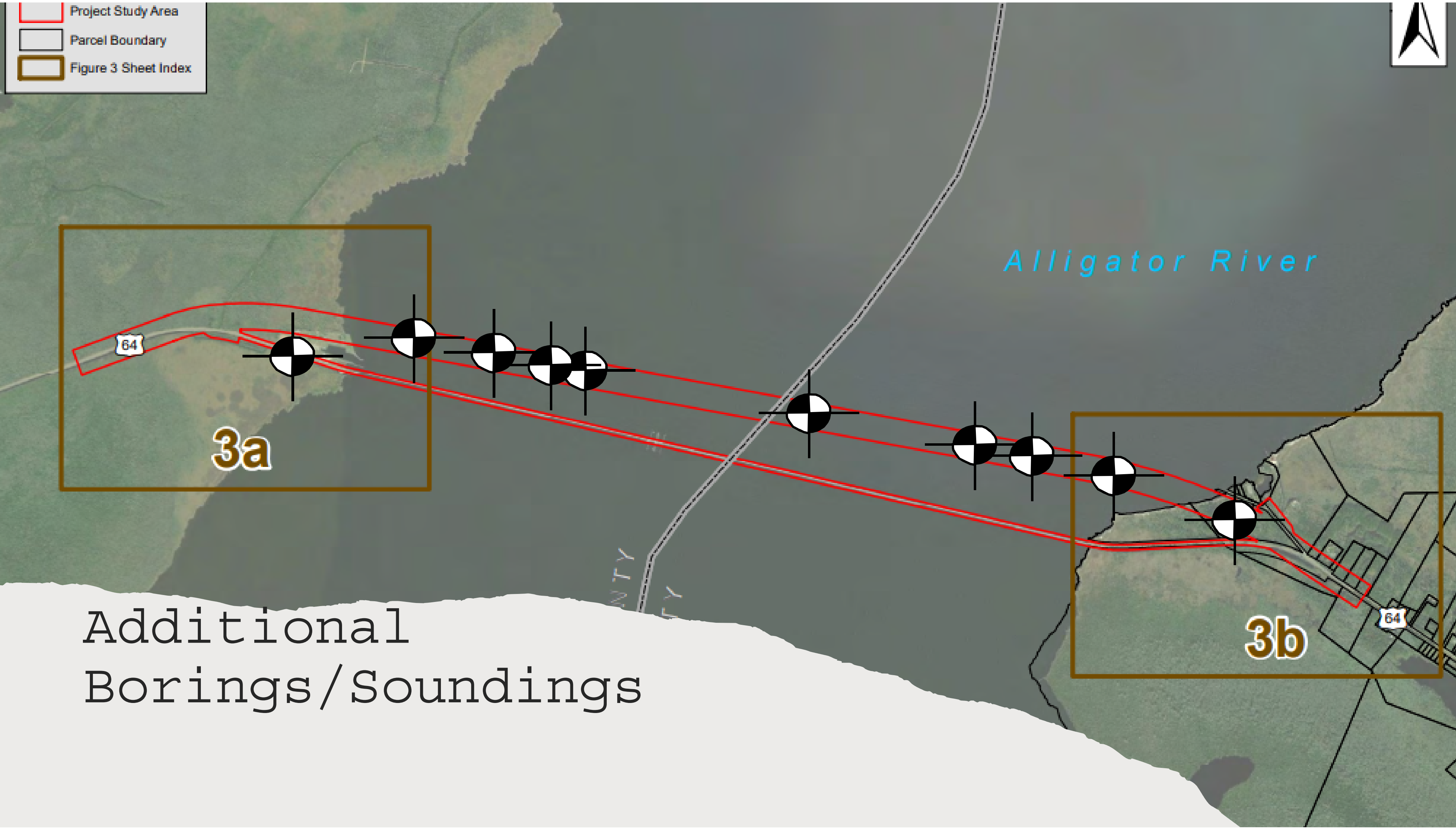
Key to Solving Settlement Problem - OCR = ?

- Geologically – Yorktown Formation, OCR 2+
- Disturbed Shelby Tubes from initial design provided no help in determining an accurate OCR
- OCR of ~1.5 or higher was needed to eliminate settlement concern

Get Samples and Test

- Assembled small group of geotechnical engineers
- Developed additional boring program utilizing the Contractor’s geotechnical consultant
- Two borings/soundings on land – easy drilling
- Eight borings/soundings spread across the bridge length in the river

Additional Borings/Soundings



SPT Borings &
Shelby Tubes

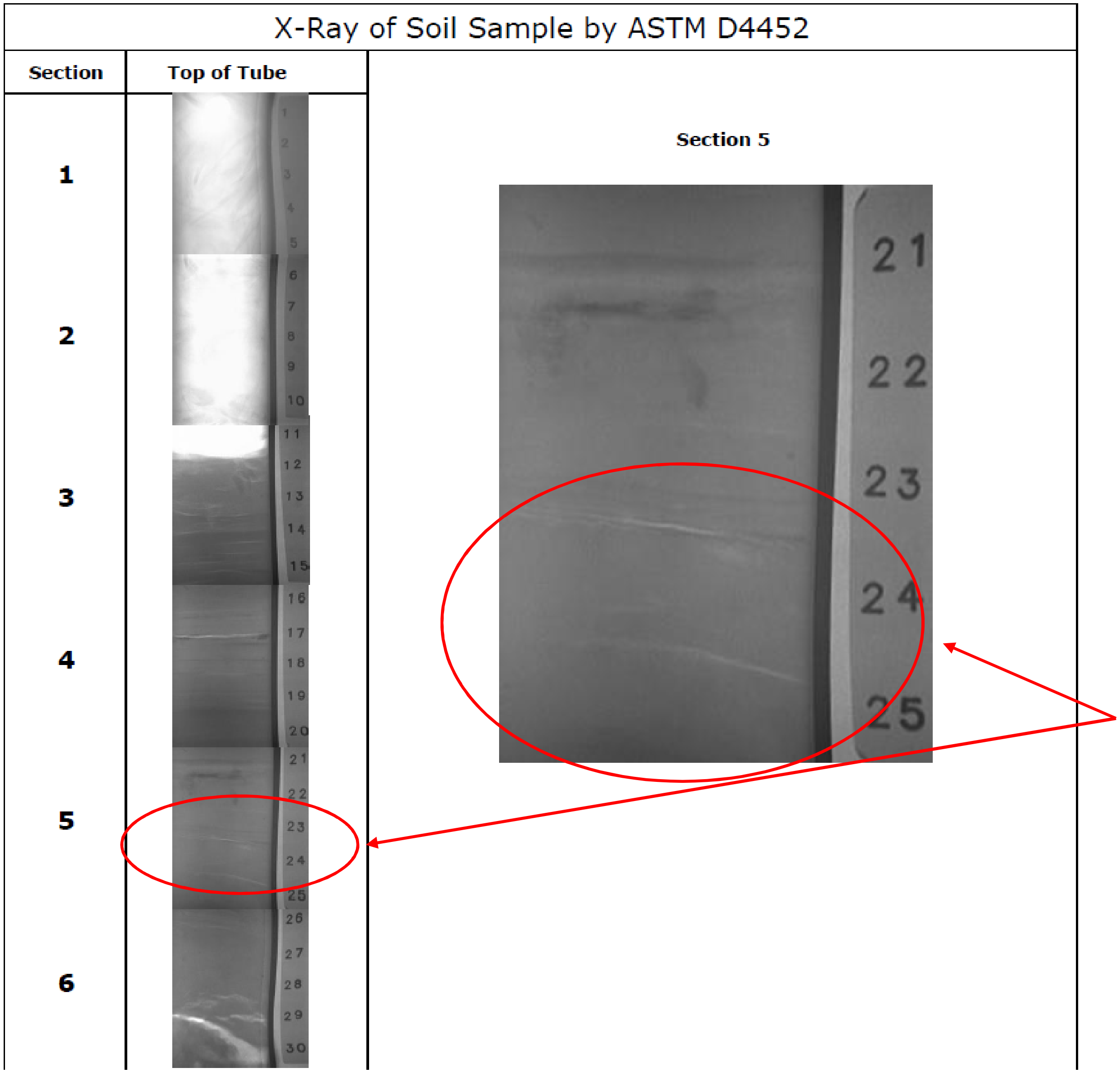
- Depths up to ~180+-
- SPT at five-foot centers to top of “soft” silt/clay
- Shelby Tubes in silt/clay – Eight to ten per location
- Continue boring to “deep” bearing layer and to confirm presence

CPT Soundings

- Pushed to refusal from mudline/ground surface
- Drilled and cased through the very dense sand
- Pushed through “soft” silt/clay
- Ran dissipation tests - ~ four per location, use for pile freeze

Lab Testing

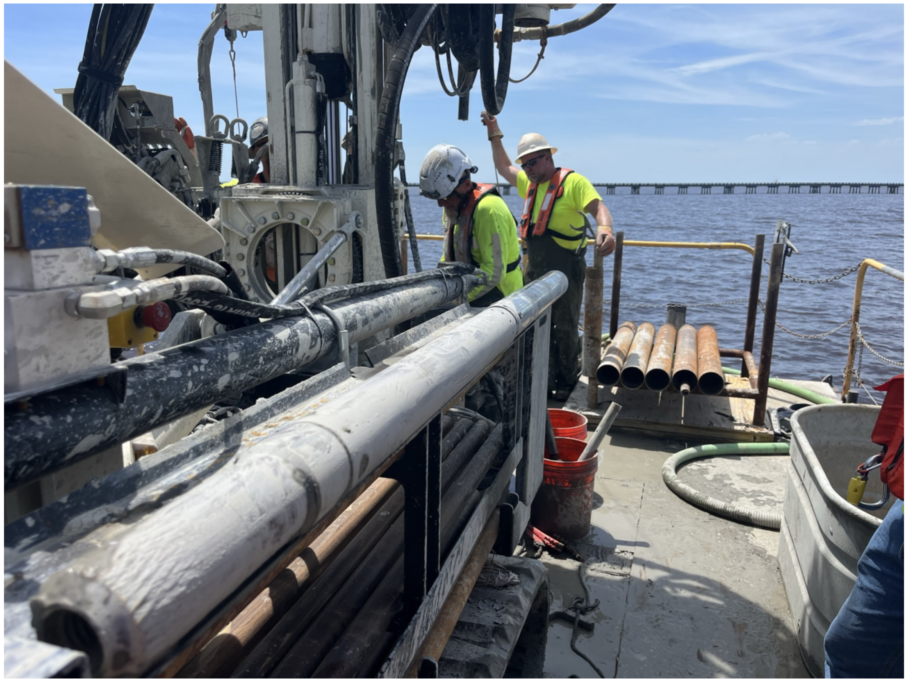
- Incremental consolidation
- Constant rate of strain consolidation
- CU Triaxial – Estimate OCR (SHANSEP and research by brilliant minds before us)
- X-ray all tubes



Typical X-Ray

Disturbance? – Yes

We had many with better results – X-Rays proved helpful



Sample Collection

On the barge

Shelby Tube Storage

Overwater and overland transport

Off to Boston…750 miles one way

Why Boston?

- The lab in Boston could handle the high pressures

- The lab in Boston had lots of machines/staff to handle our workload quickly

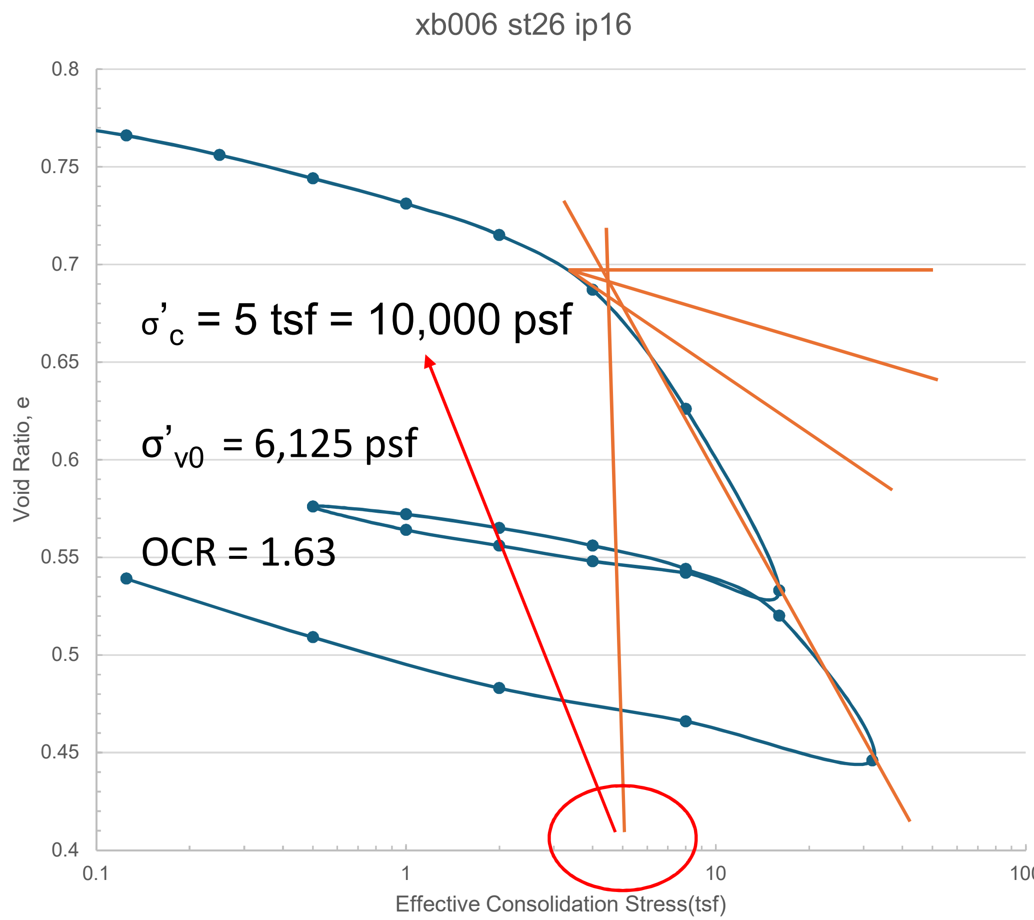
Determining OCR

- Oedometer testing
- CPT predictions
- CU Triaxial Testing (SHANSEP, Mayne 88)

Oedometer Testing

- Familiar, typical approach
- Interpretation needed
- Sensitive to disturbance

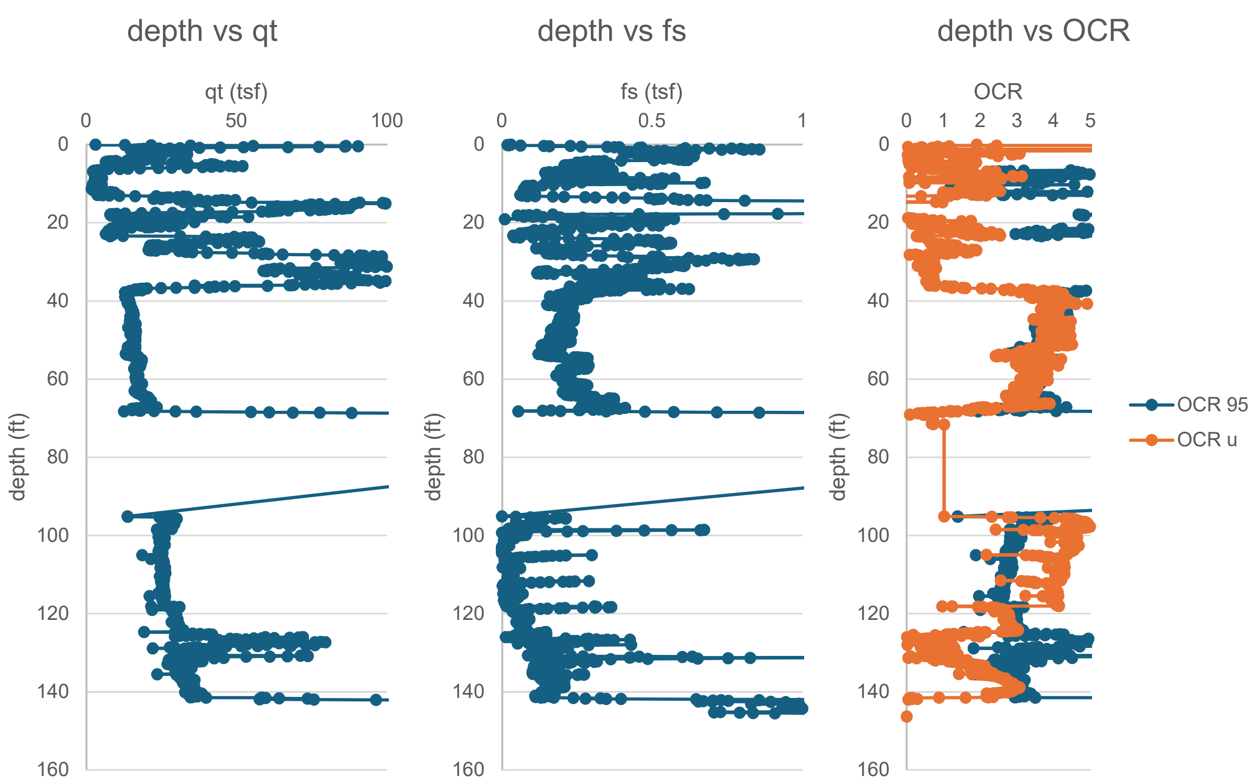
$OCR = \sigma'_c / \sigma'_{v0}$



CPT Sounding

- Familiar, quick approach
- Calibration to site needed (formulae empirical)
- Lots of data points, identifies a trend for the site

West Approach Land Boring



CU Triaxial Tests

Determining OCR in Clays From Laboratory Strength

Paul W. Mayne
Graduate Research Assistant
Cornell University
circa 1988

From the Abstract

"The results of triaxial and direct shear tests may be used to estimate the in situ over consolidation ratio of clays using a SHANSEP database"

$$OCR = \left[\frac{c_u / \sigma'_{v0}}{c_u / \sigma'_{vnc}} \right]^{1/\Delta}$$

Ladd et al. 1977

$$c_u / \sigma'_{vnc} = ?$$

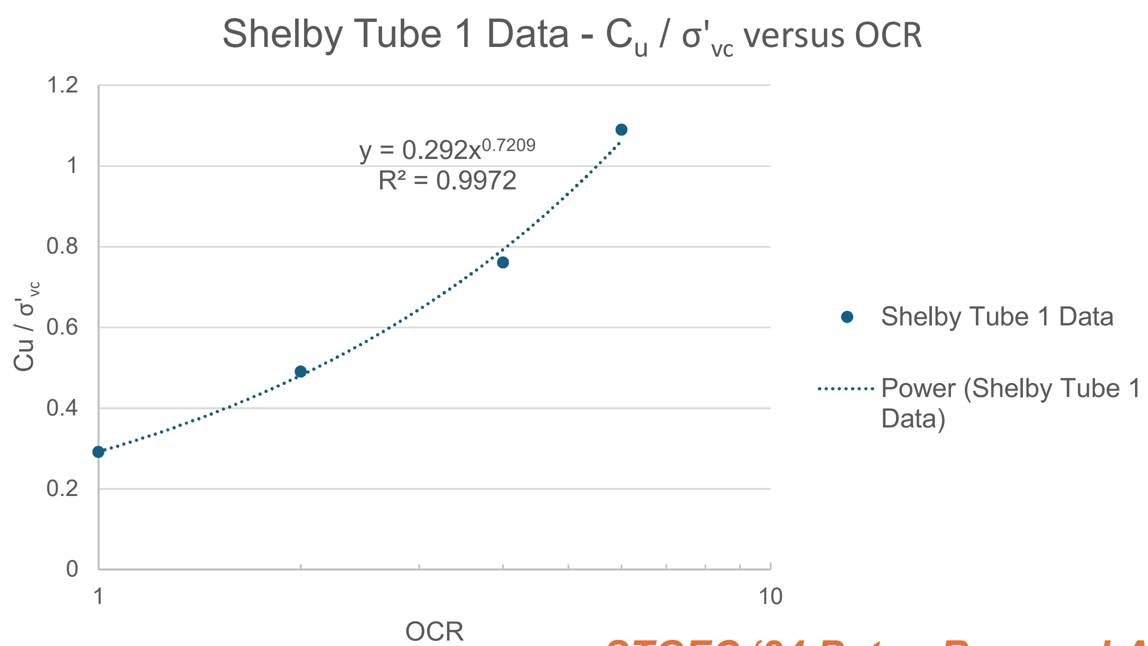
$$\Delta = ?$$

SHANSEP Database

- Purposely consolidate specimens to a very high pressure – we went to 6 times σ'_{v0} to guarantee at OCR = 1
- Maintained chamber pressures at time of undrained shear to pressures equal to OCR's between 1 to 6

For Example…								
GSE (ft) =	-10							
Ave γ (pcf) =	115							
H2O El (ft) =	0							
				Force Specimens to OCR = 1	After Consolidation Perform Undrained Shear on Specimens at Cell Pressures Equal to Various OCR's			
Shelby Tube	Depth (ft)	σ'_{v0} (psf)	OCR	Consolidate to 6 * σ'v0 (psi)	OCR = 1, Cell Pressure (psi)	OCR = 2, Cell Pressure (psi)	OCR = 4, Cell Pressure (psi)	OCR = 6, Cell Pressure (psi)
1	108	5680.80	?	236.70	236.70	118.35	59.18	39.45

Shelby Tube 1 Data				
Specimen	σ'_{vc} (psi)	Cu (psi)	Cu / σ'vc	OCR
1	236.70	69	0.29	1
2	118.35	58	0.49	2
3	59.18	45	0.76	4
4	39.45	43	1.09	6



Shelby Tube 2 Data				
Specimen	σ'_{v0} (psi)	Cu (psi)	Cu / σ'v0	OCR
5	34.70	20	0.58	2.57
6	42.01	23	0.55	2.39
7	43.83	25	0.57	2.53

- Test using confining pressure equal to σ'_{v0} – do not consolidate to higher pressure

- Compute OCR using … $OCR = \left(\left({}^{1}/_{0.292}\right)\left({}^{C_u}/_{\sigma'_{v0}}\right)\right)^{1/\Delta}$
  - Λ = 0.7209
  - $C_u / \sigma'_{vnc} = 0.292$

Back to Test Piles

- The plan to determine OCR is set
  - Borings have started
  - Lab testing is on going

- Meanwhile we have discovered pile excavation would be very costly…

Pile Excavation

- Minimum 2 days to set casing and excavate
- 1 day to drive
- Minimum 1 day to pull casing
- Schedule would be negatively affected

Pile Excavation Cost

- Need a good number of large diameter, long temporary casings
- Need excavation equipment (e.g., augers, clam shells)
- Need to store, transport, and waste spoils
- Unknown difficulties – increased risk of SA's

Bridge Cost

- Long piles and pile excavation very expensive
- What was ~300 million could now be ~500 million or more

Can we stand and drive piles into the very dense sand?

- 11 Piles driven before being stopped by the moratorium

Hammers

- APE D180 – Ram Weight 39.7 kips, OED
- APE D220 – Ram Weight 48.5 kips, OED
- APE 40-5 – Ram Weight 80 kips, Hydraulic


APE

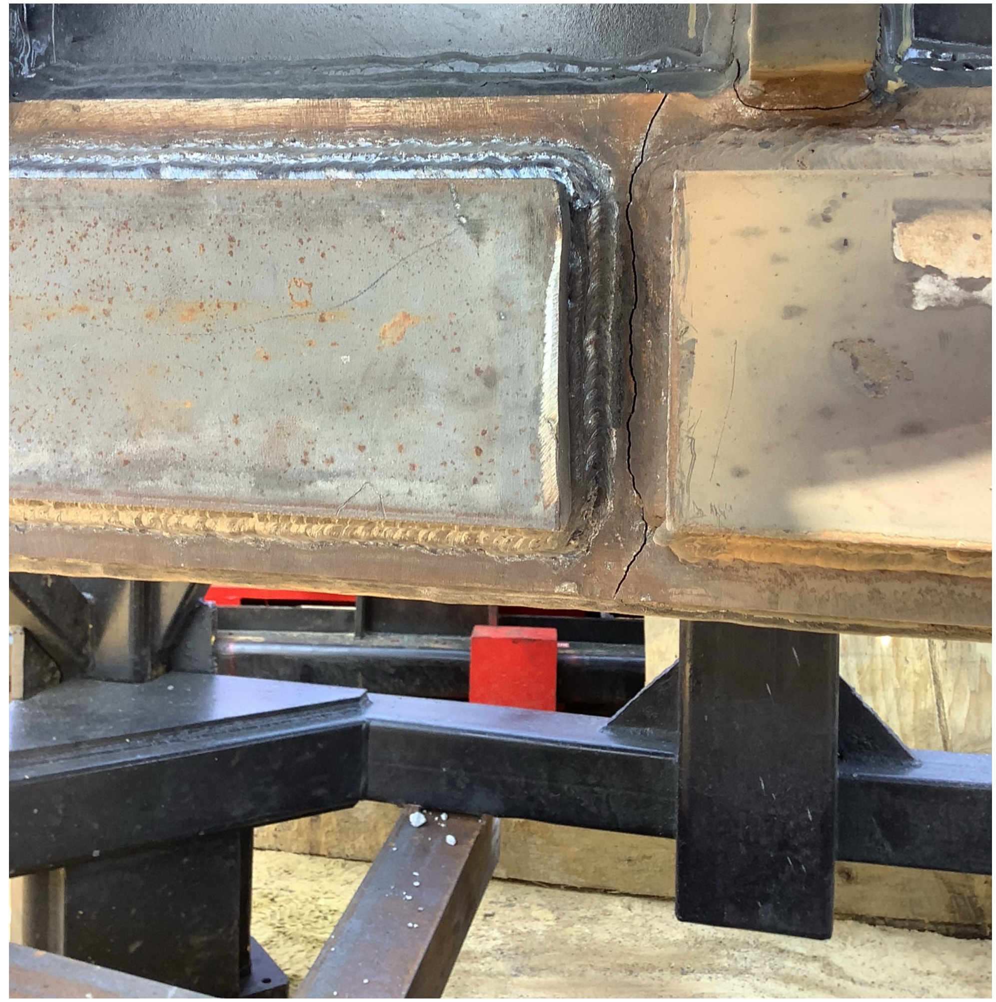
Takeaways regarding Hammers

- APE D180
  - Most reliable
  - Tension stress problems, couldn’t start due to soft soils

- APE D220
  - They got a “lemon”
  - Lots of problems starting and keeping it running
  - Tension stress problems

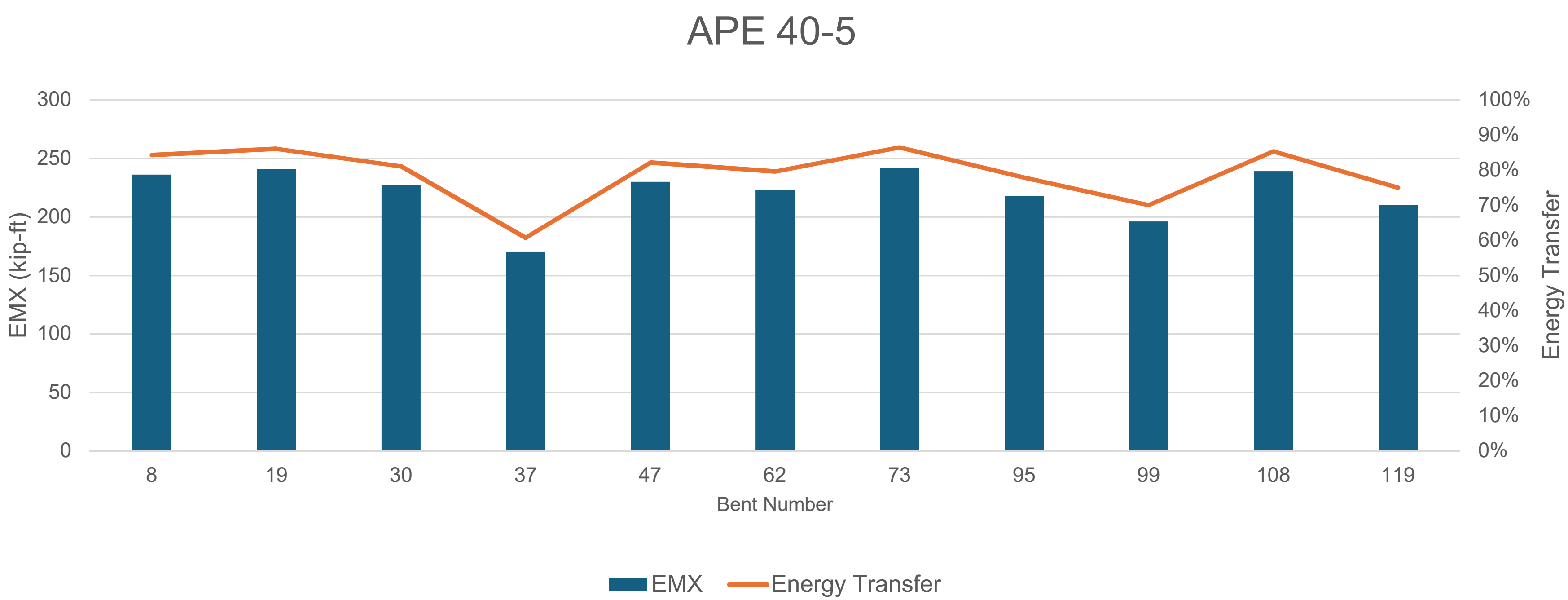
Takeaways regarding Hammers

- APE 40-5
  - Used some during installation once the pile had adequate penetration – too big, too heavy to use at start
  - All final re-strikes used this hammer with a 3.5-foot stroke
  - We achieved greater than 240 Equiv. BPF on 6 out of 11 piles
  - Helmet cracked multiple times (welded it back together)

APE 40-5 is a "Beast"

75 to 80% of Theoretical … OED generally about 55%



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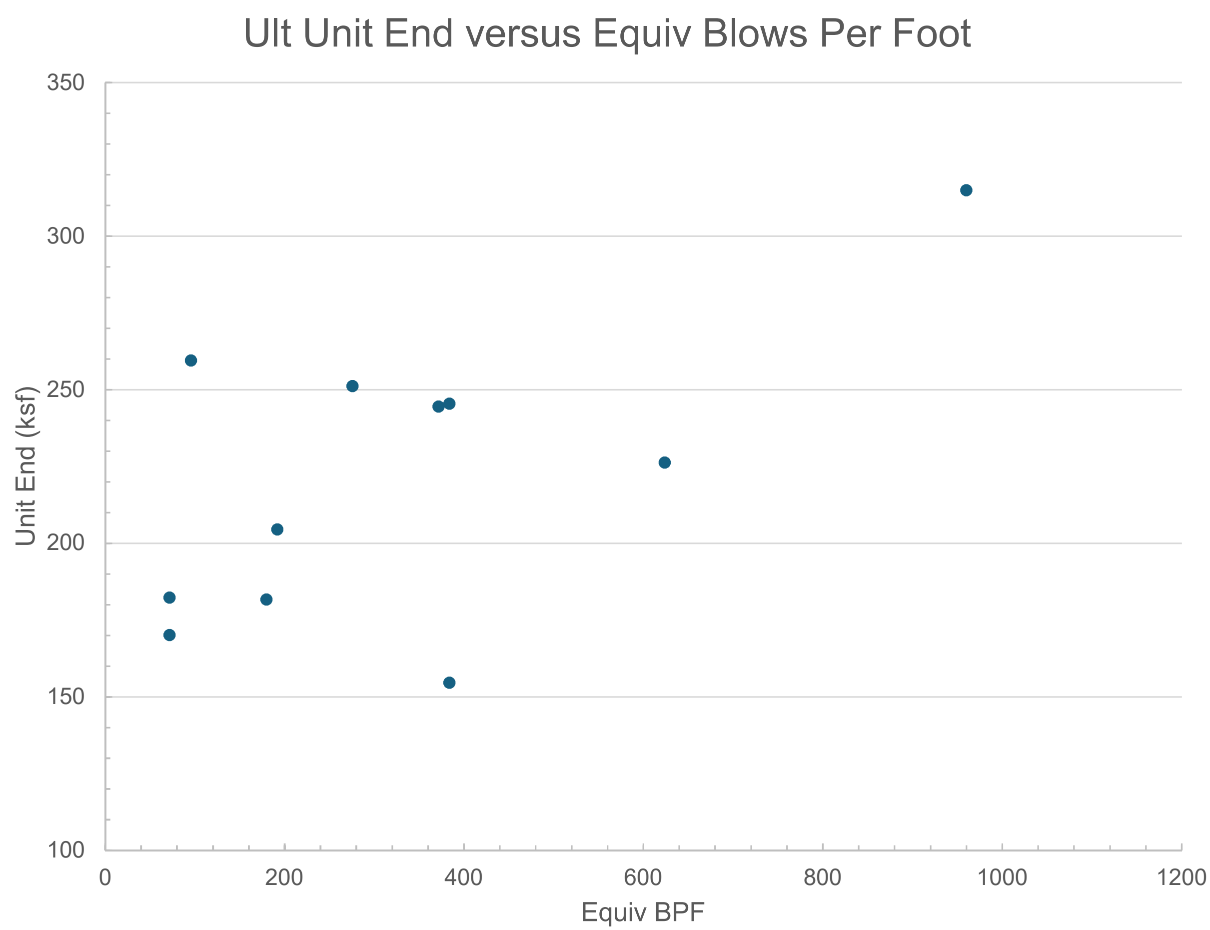
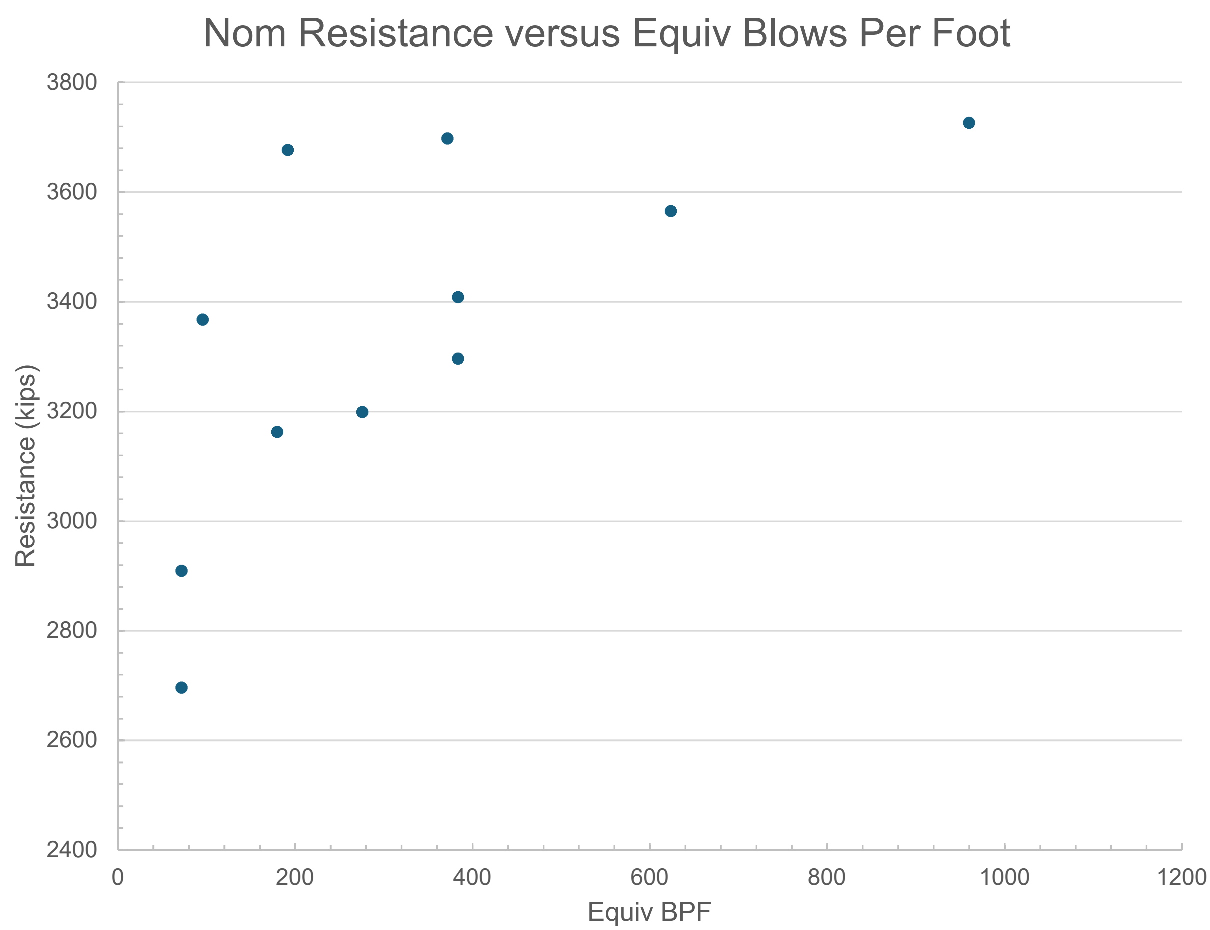
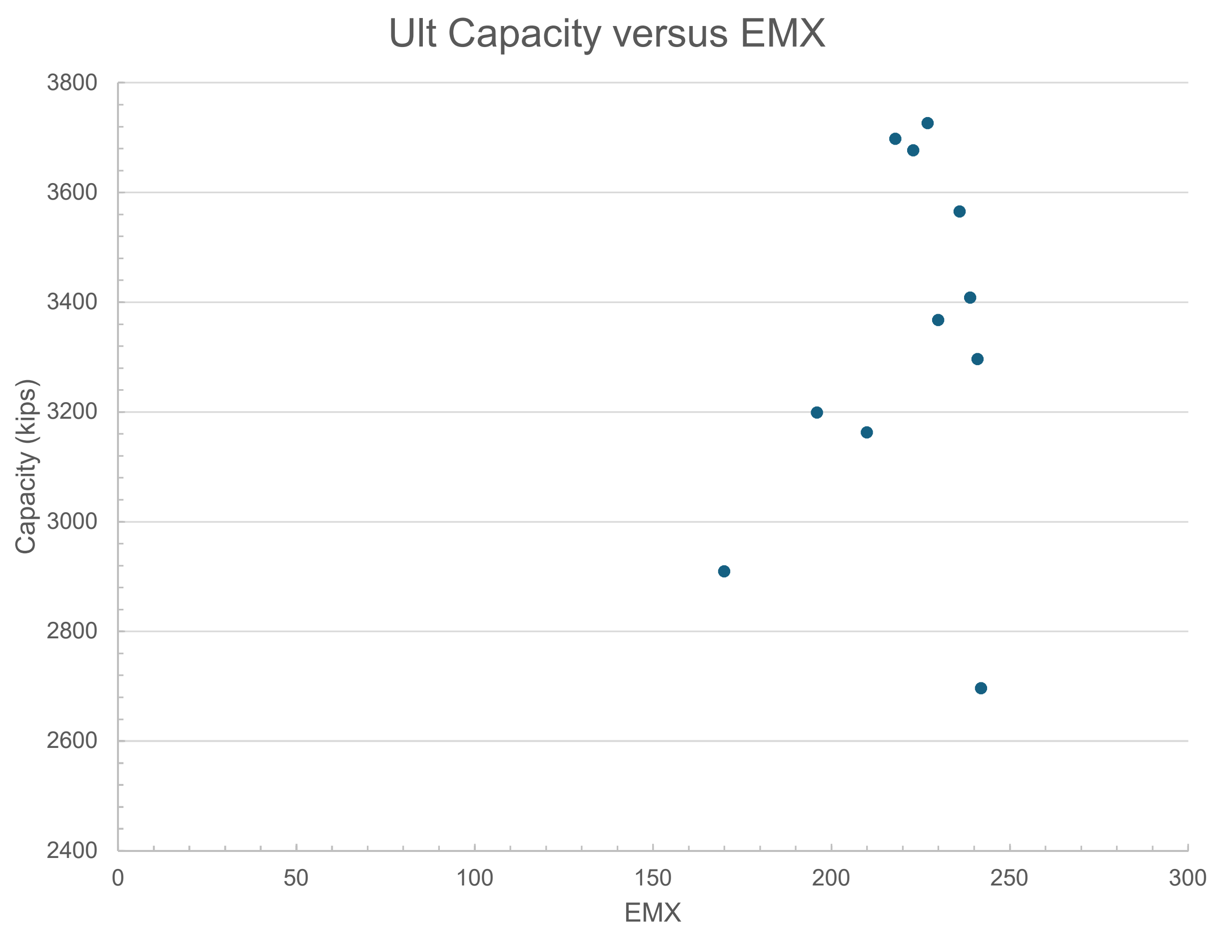
Moderate relationship between unit end bearing and BPF



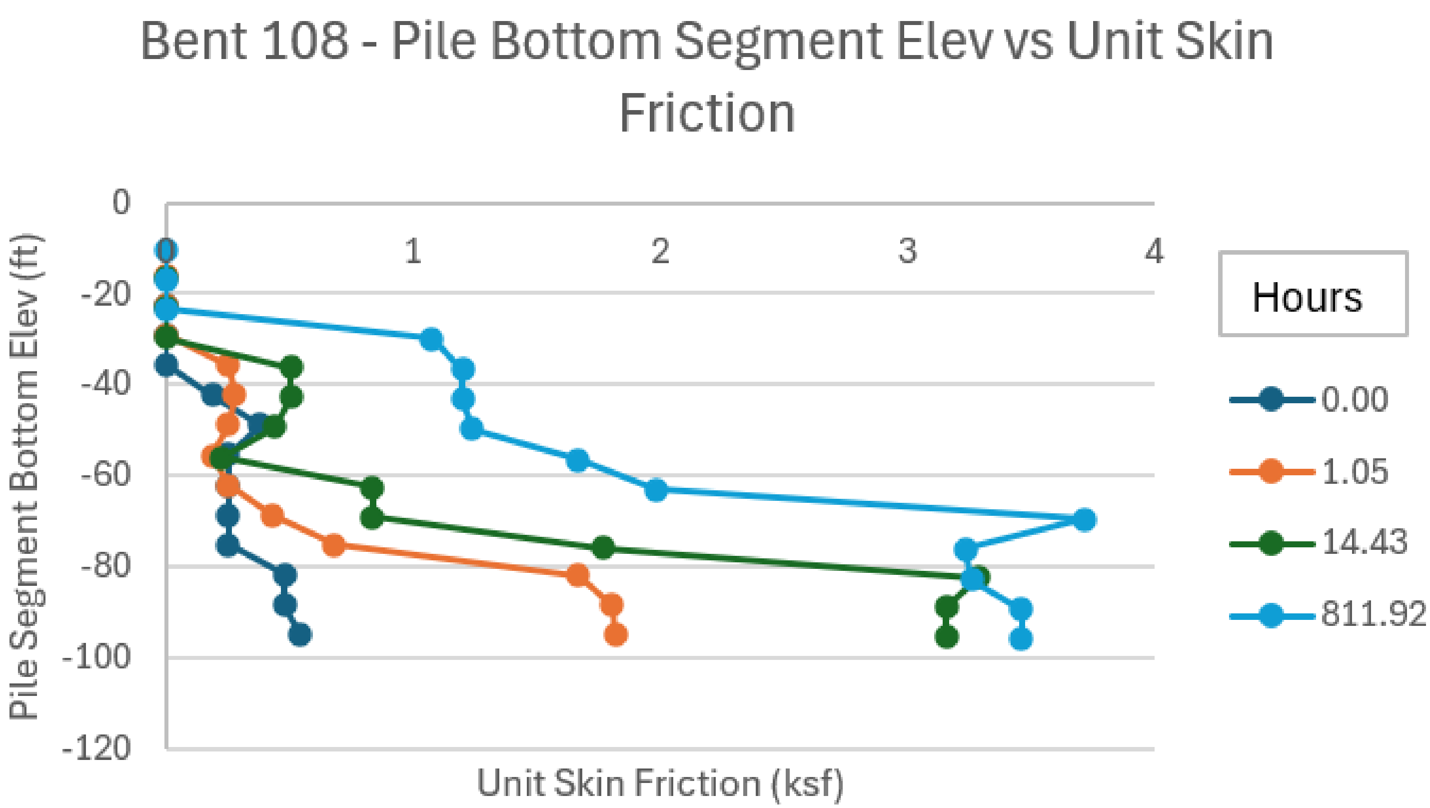
Similar for nominal resistance



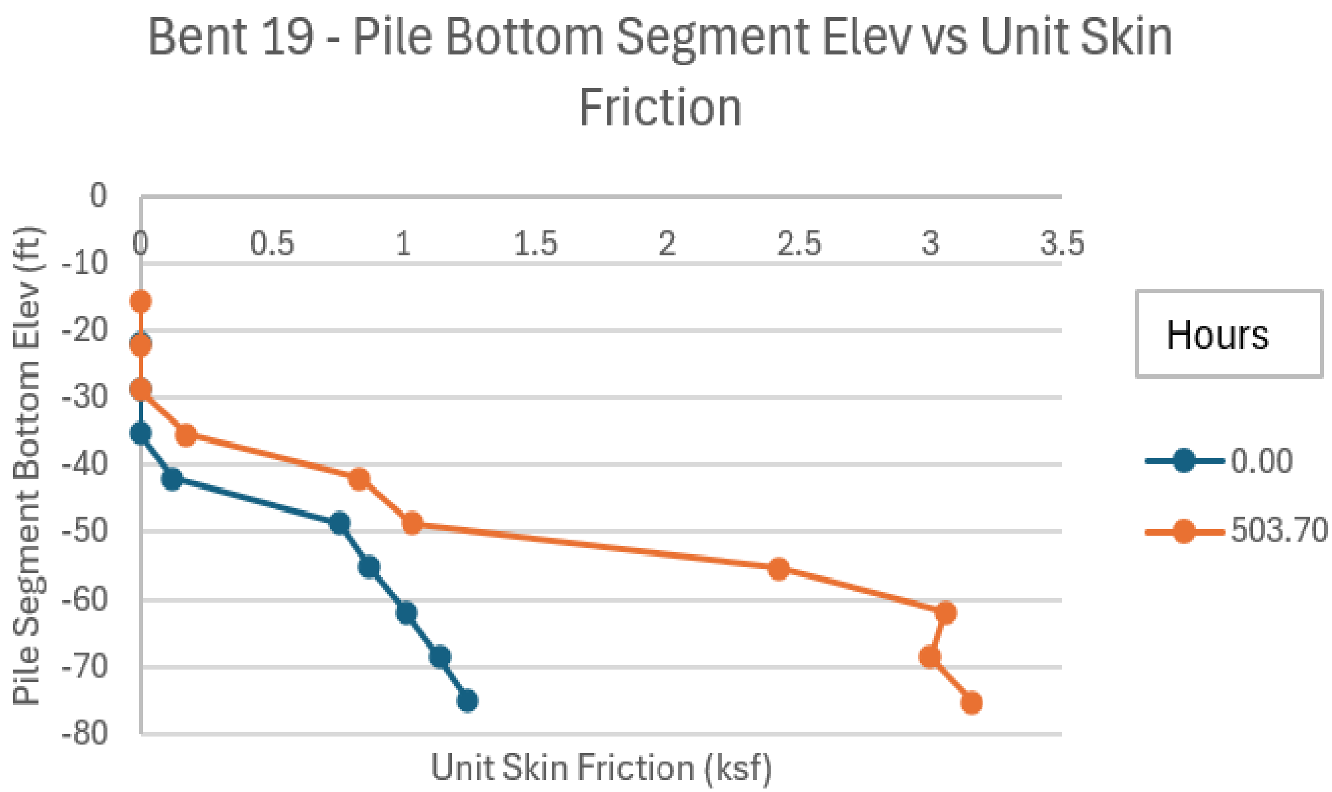
maxed out about 250 kip-ft



Takeaways Regarding Unit Skin



Takeaways Regarding Unit Skin



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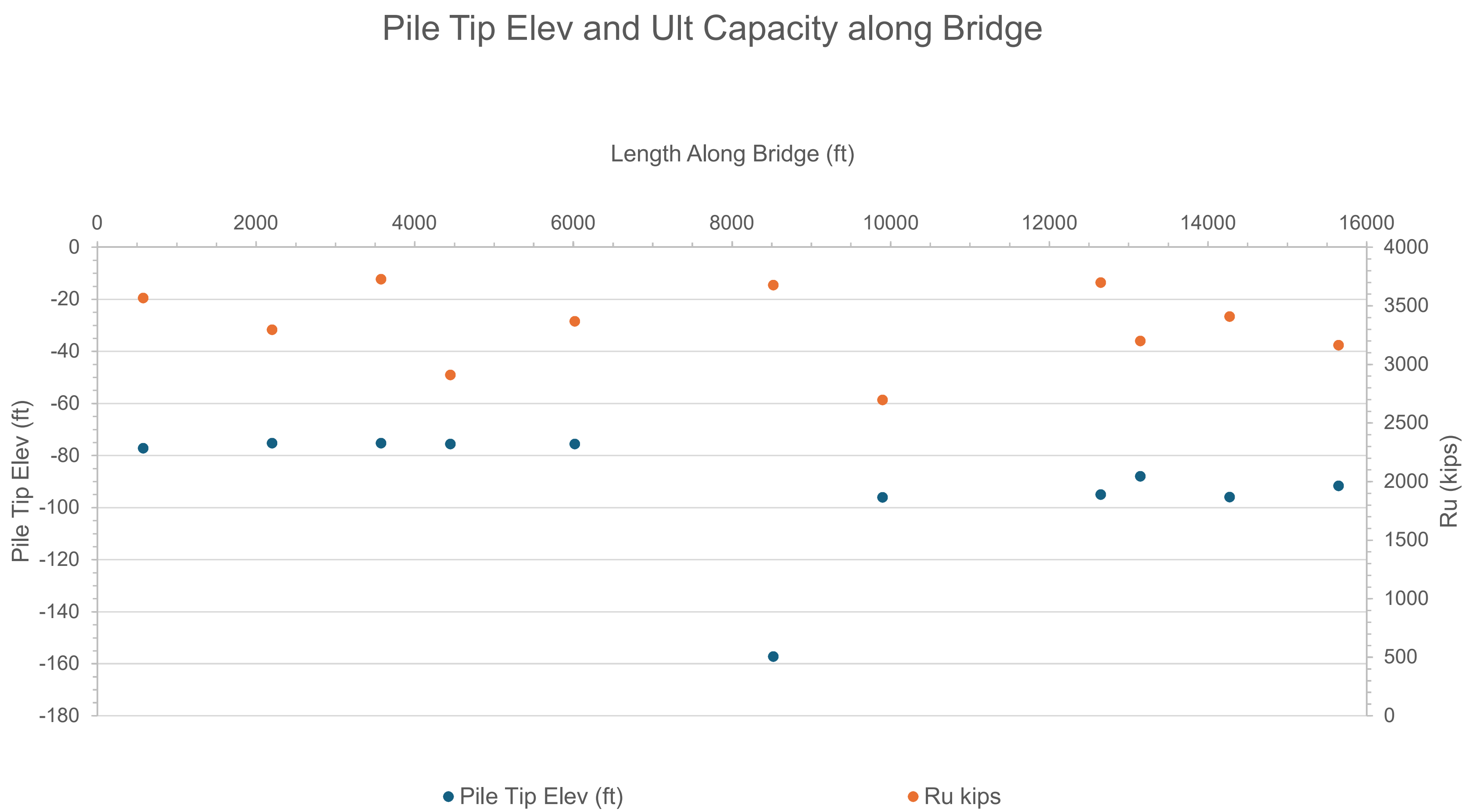

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Takeaways Regarding Capacity

- Original Design RDR ~ 900 kips
  - It is viable to tip the piles in this layer
  - We achieved 2000 kips or greater in upper very dense sand

- Redesign of Bents based on Contractor preferences
  - Higher RDR's (~ 1,400 kips)
  - Should be ok in upper very dense sands

Driving Through Very Dense Sand

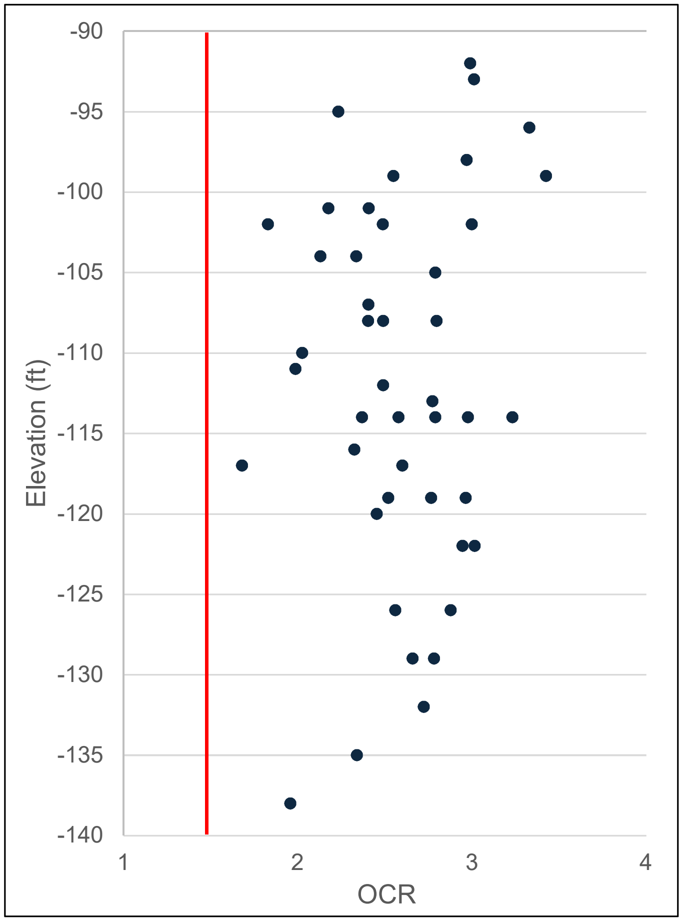
- Not a viable option
  - Reached blow counts (> 180 BPF) in the layer at 5 out of 11 locations
  - EOD capacities = > 2,000 kips (many ~3,000 kips)
  - 1 EOD capacity ~4,100 kips (EOD Equiv. BPF = 400)
  - Compression stresses would likely be a problem with more energy
  - Fatigue of piles would likely be a problem

- Pile Excavation
  - A slow process during our try
  - Deemed impractical due to extra time and costs

Summary of Lab Results

Oedometer Results

					OCR				
test	gse	depth	sample el.	p'0	Casagrande	DSEM	ITSE	Average	Schmert Cor
e1a st16 ip7	4	126	-122	6787.2	2.36	2.65	2.06	2.36	2.95
e1a st18 ip9	4	133	-129	7185.4	2.23	2.57	1.95	2.25	2.78
e1a st19 ip10	4	136	-132	7343.2	2.26	2.72	2.45	2.48	2.72
w1a st10 ip2	4	124	-120	6110	1.60	1.88	1.31	1.60	2.45
w1a st3 ip6	4	103	-99	5490.4	1.82	1.73	1.46	1.67	2.55
w1a st4 ip1	4	106	-102	5573.2	1.44	1.08	1.17	1.23	1.83
w1a st6 ip5	4	112	-108	5738.8	1.50	1.74	1.48	1.57	2.40
w1a st9 ip3	4	121	-117	5997.2	1.43	1.50	1.33	1.42	2.60



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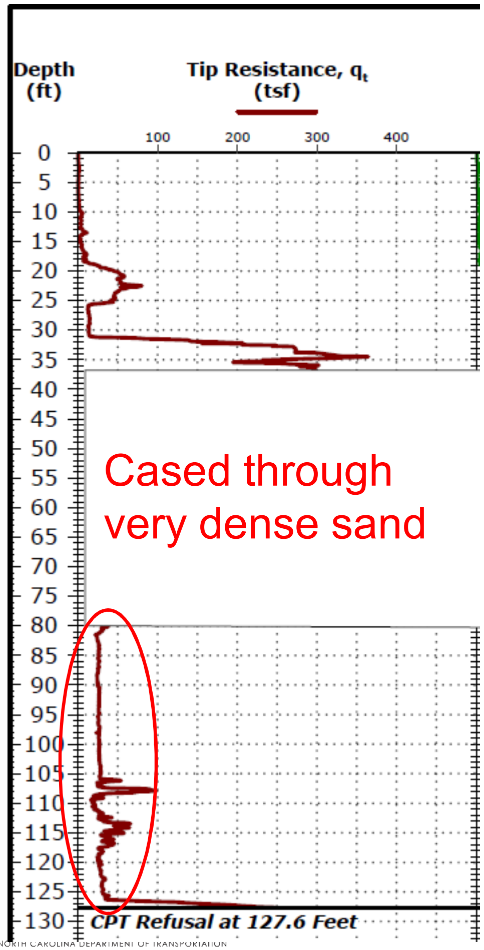
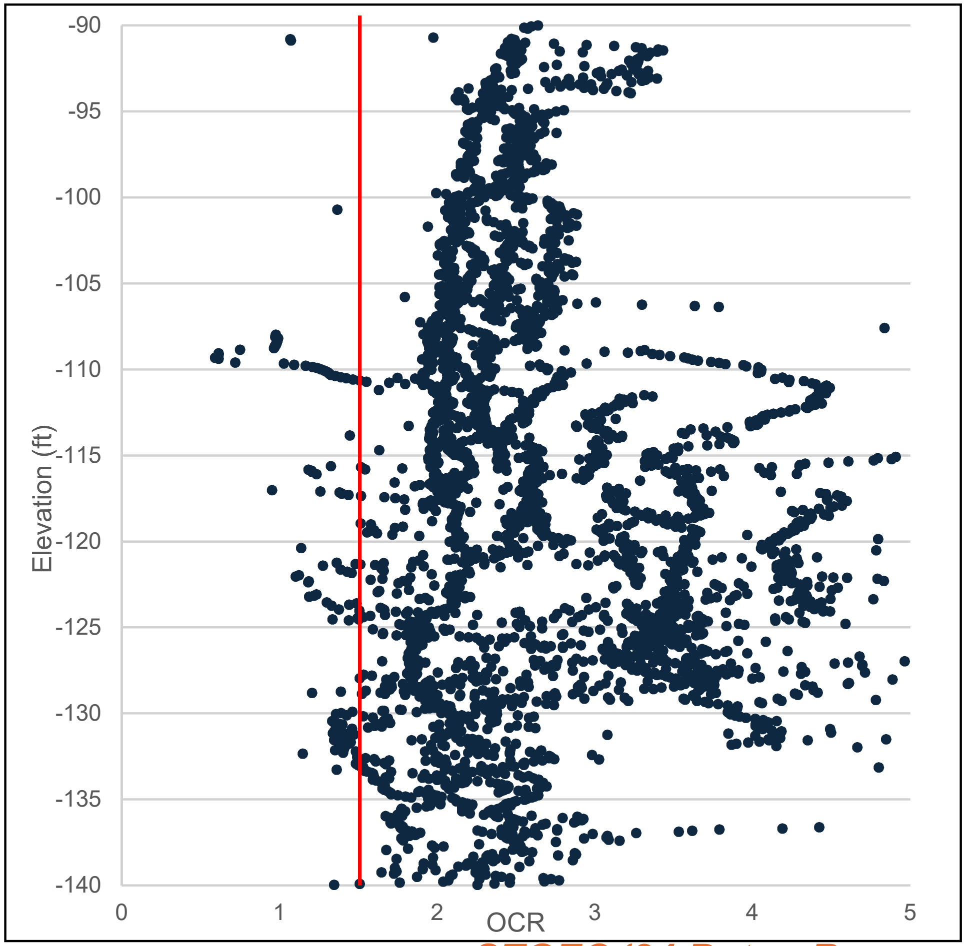
CPT Soundings





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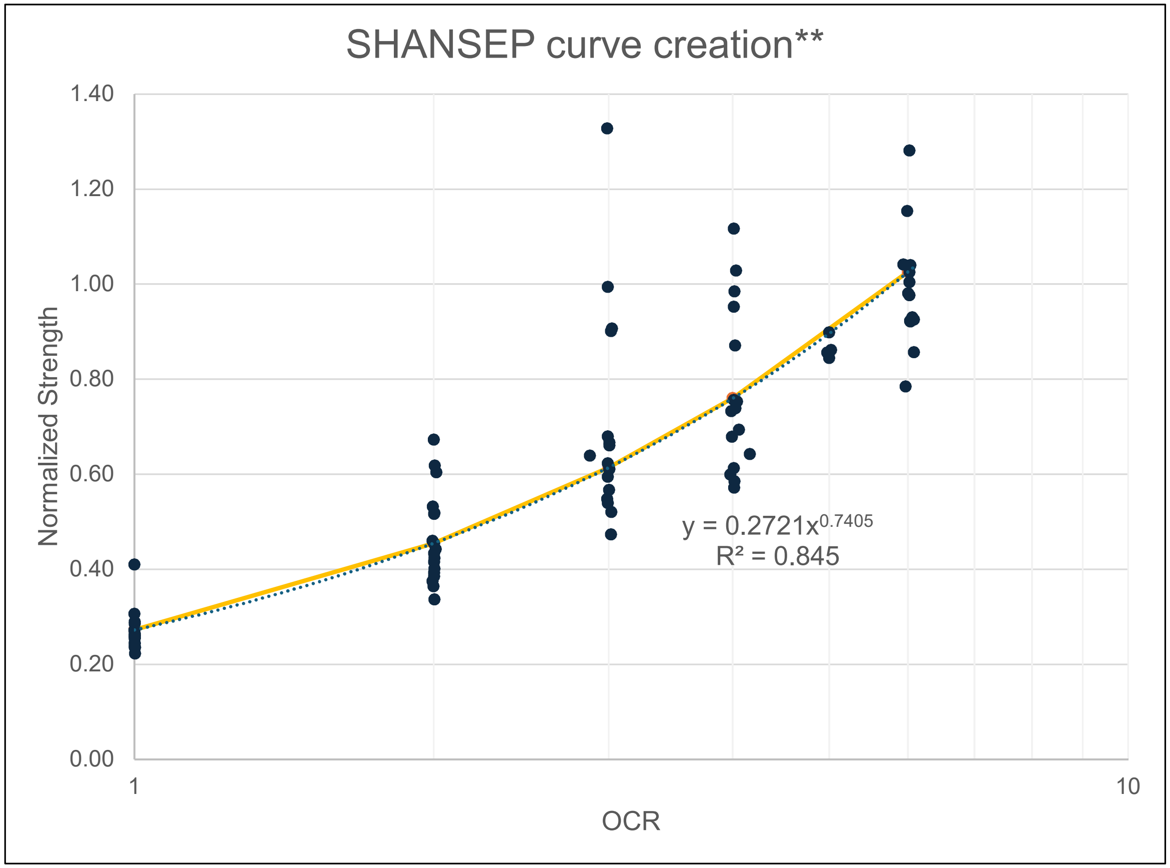
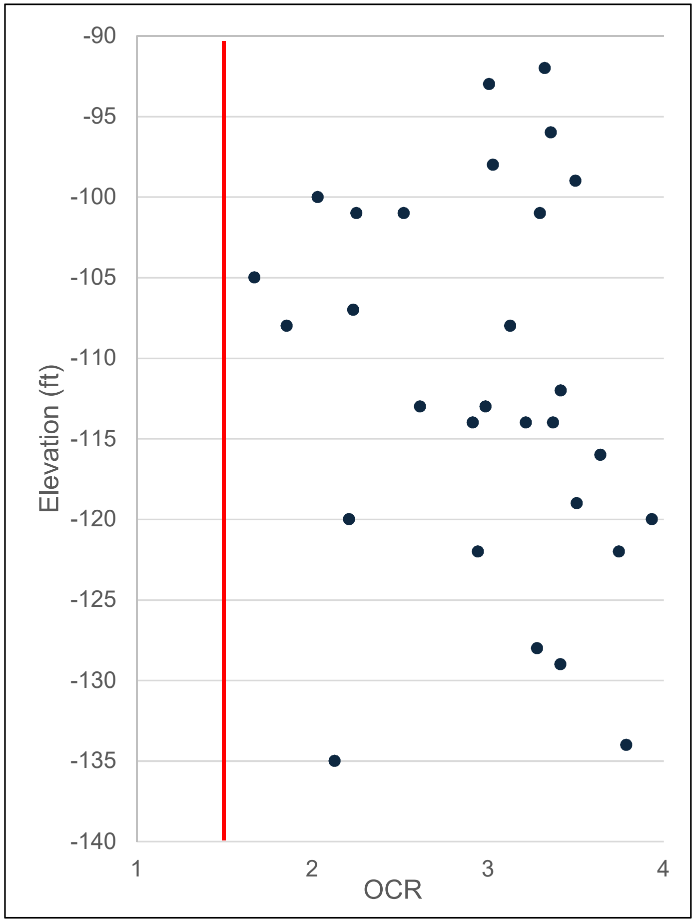
Approach



SHANSEP curve creation**
Normalized Strength
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
OCR
y = 0.2721x^0.7405
R² = 0.845



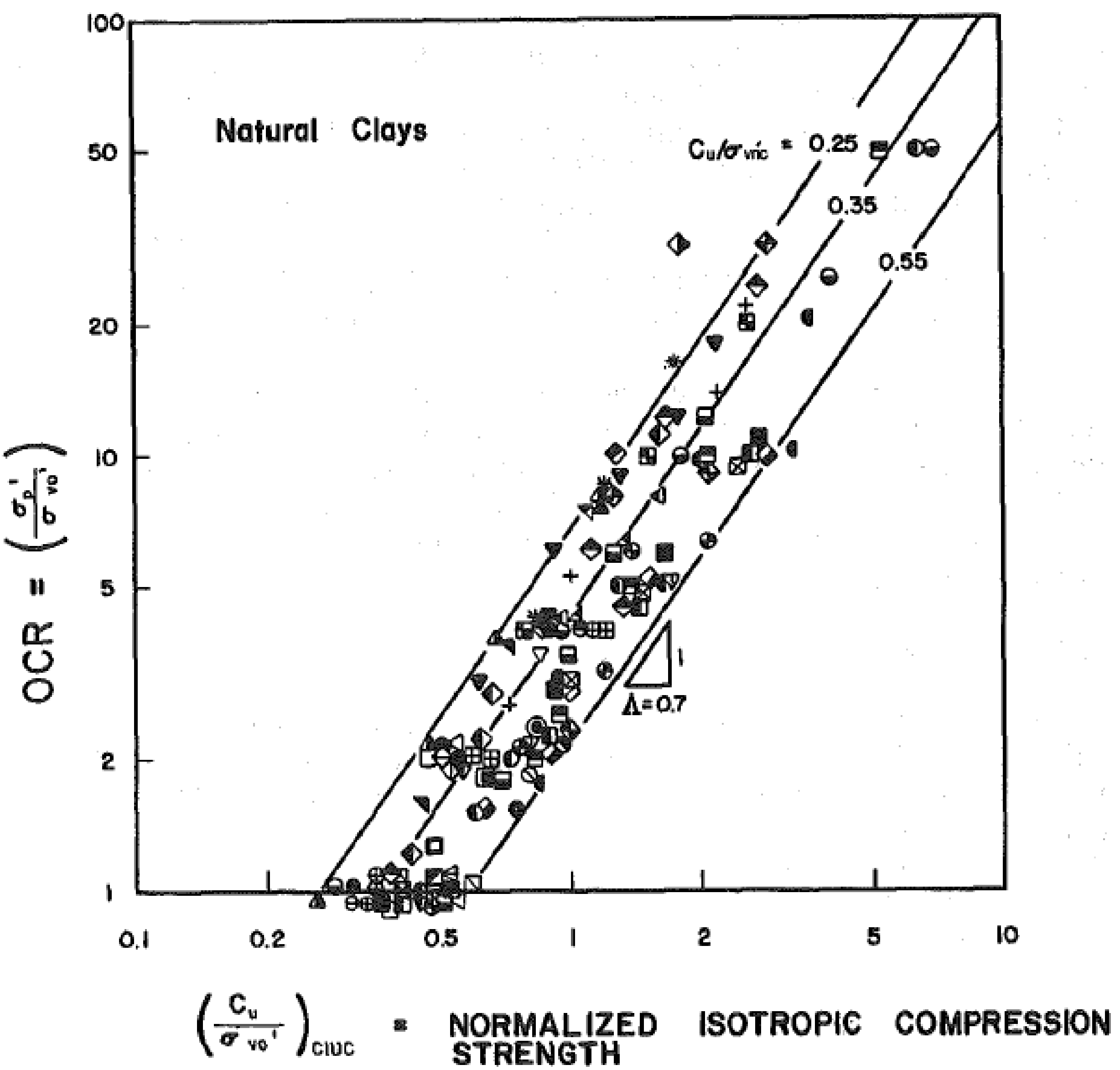
Elevation (ft)
-90
-95
-100
-105
-110
-115
-120
-125
-130
-135
-140
1
2
3
4
OCR

Figure 2 – Mayne 88

We defined…

$C_u / \sigma'_{vnc} = 0.2721$

$\Lambda = 0.7405$



Conclusions

- Oedometer, CPT, and CU Triaxial agree OCR > 1.5
- Settlement of underlying clay layer not an issue
- Short Piles OK Provided Lateral Stability OK

Hang Piles High

- Settlement concern eliminated with additional field testing and laboratory testing
- Lateral stability possible with short piles - FB Multipier analysis
- Ample capacity in upper very dense sand
- No pile relaxation at site

Increased Efficiency

- Stand and drive
- Shorter piles
- No pile excavation needed

STGEC ‘24 Baton Rouge - LADOTD

Cutting Costs

- Shortens piles by 85’ (100’ Vs 185’)
- Fewer crews/steps to install piles
- Less risk of supplemental agreements

Good Rate of Return?

- Additional borings and laboratory testing – $1.1 million

- Test piles - $13.6 million

- Estimated savings – $80 million + shortened schedule

Thank you

- ***Special Thanks to…***

- ***Mike Batten, Keller***
- ***Jerry DiMaggio, ARA***
- ***Bon Lien, WSP***
- ***Chien-Ting Tang, WSP***
- ***Michael Valiquette, ICE***