# I-86/I-15 System Interchange

## Lessons Learned: Drilled Shaft Construction

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In Memory of the project's
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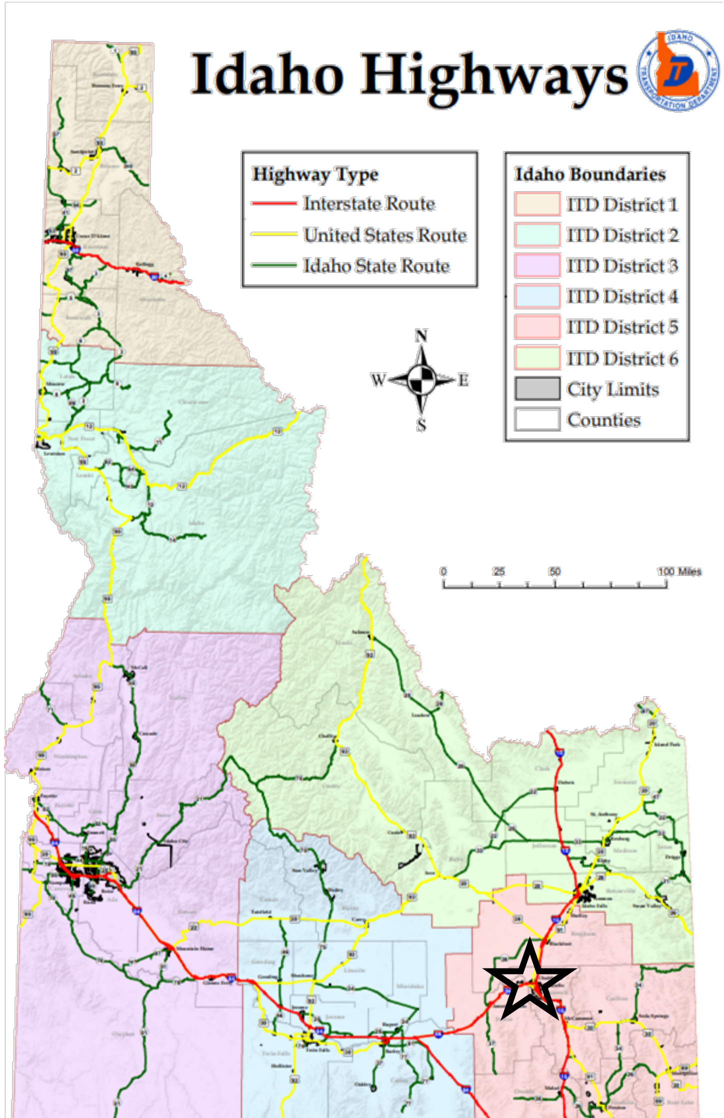


# Project Overview

- One of Idaho's largest and most expensive construction projects ($111.9M)
- Replaces the entire three leg interchange in Pocatello, Idaho
- 8 New Bridges and 10 MSE retaining walls (Existing bridges built in 1960s)
- Summer 2022: Construction Started
- Summer 2025: Anticipated Completion

# Previous Condition

# Proposed Reconstruction

MT

Boise

UT

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# The Details: Bridges and Drilled Shafts

- Two-Span Steel Girder Bridges
- 6’-6” (2.0m) Diameter, 50’ Drilled Shafts (as designed)
- 5’-0” “Diameter” Column
- Constructed using Oscillator Method
  - Caving risk and boulders anticipated at project site
- 10’ Permanent Casing at Top
- 16 Drilled Shafts – 800 feet total
- Static Bi-Directional Load Test to Optimize Shaft Design

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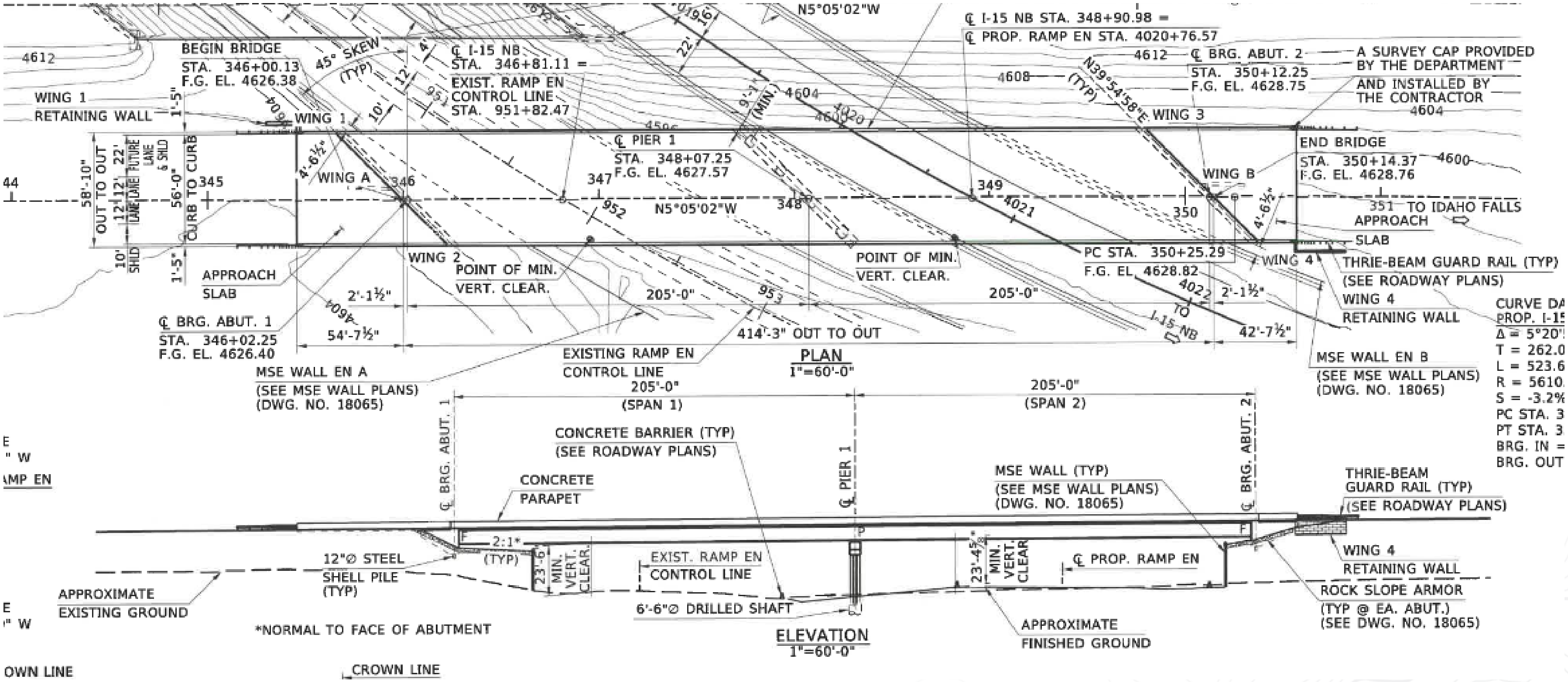
# Bridge Layout

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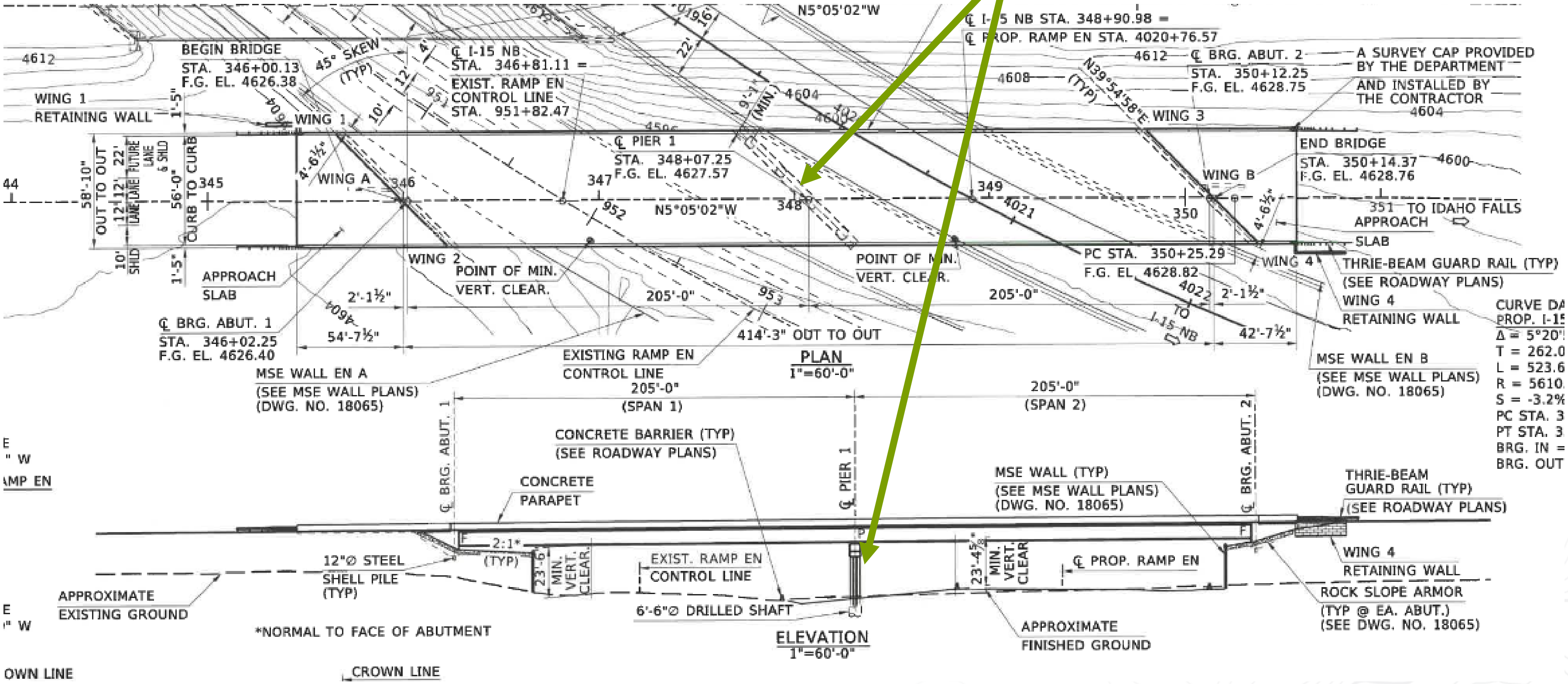
# Bridge Layout

Center Pier on Drilled Shafts

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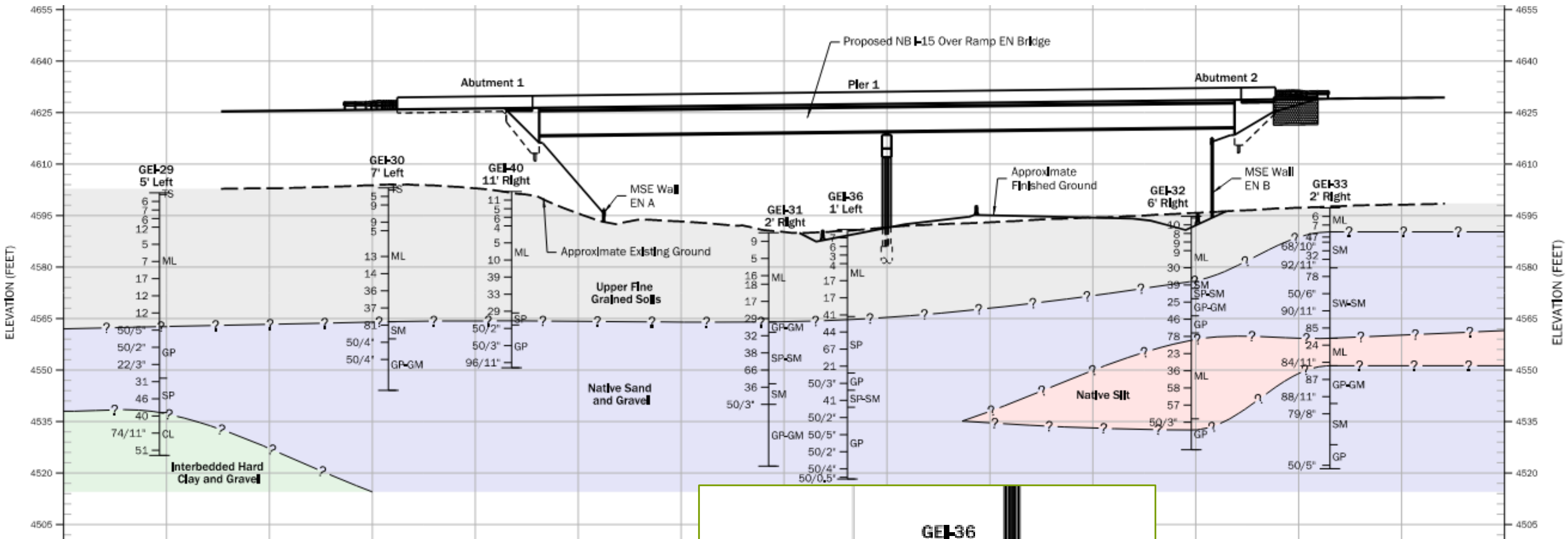
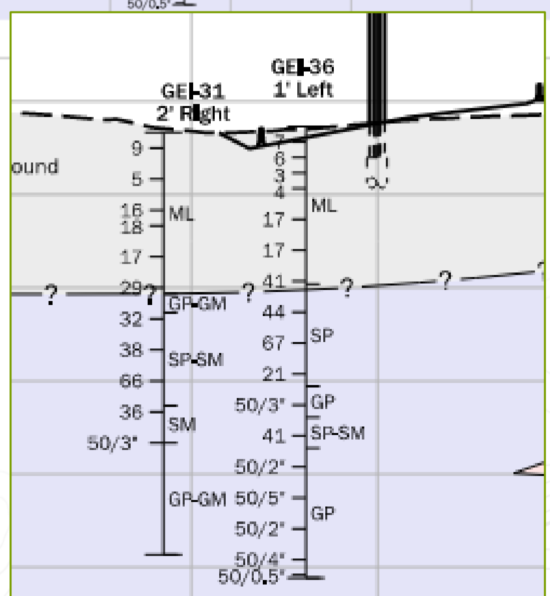
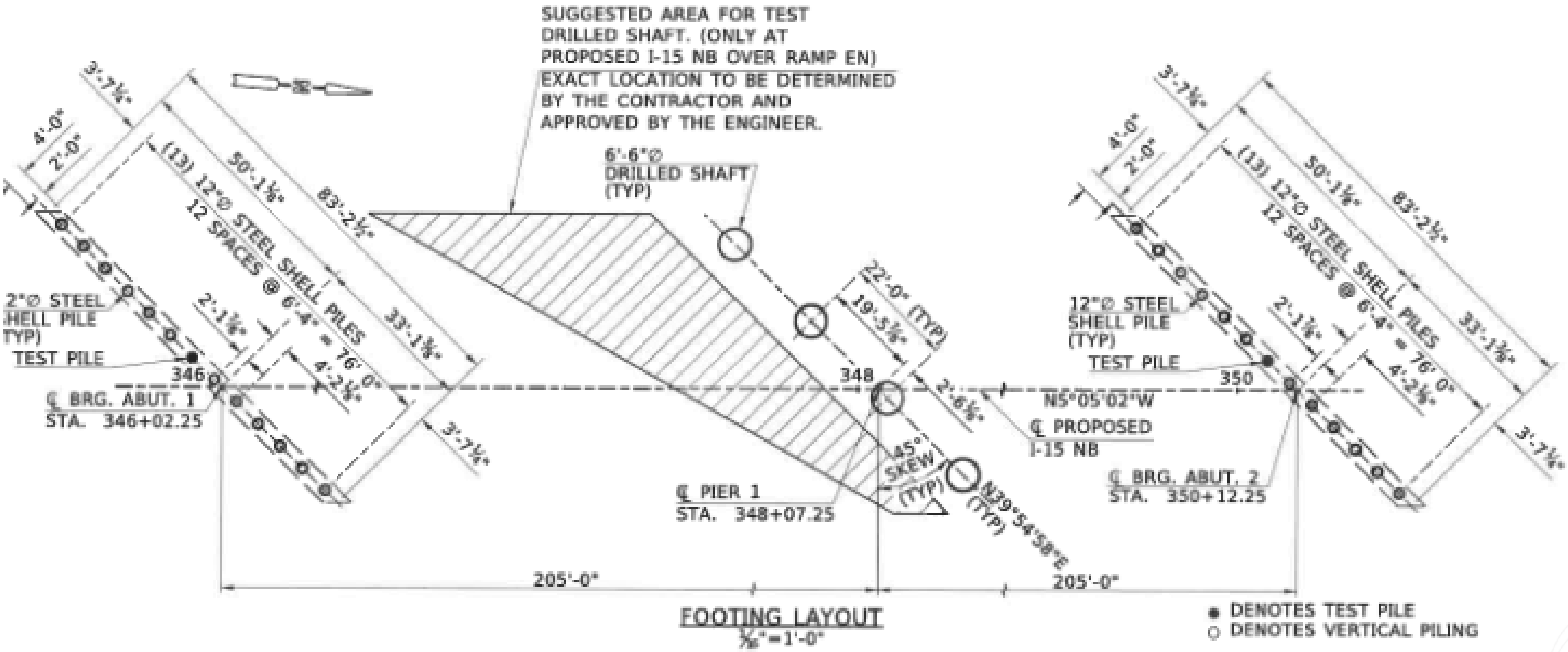
# Subsurface Conditions

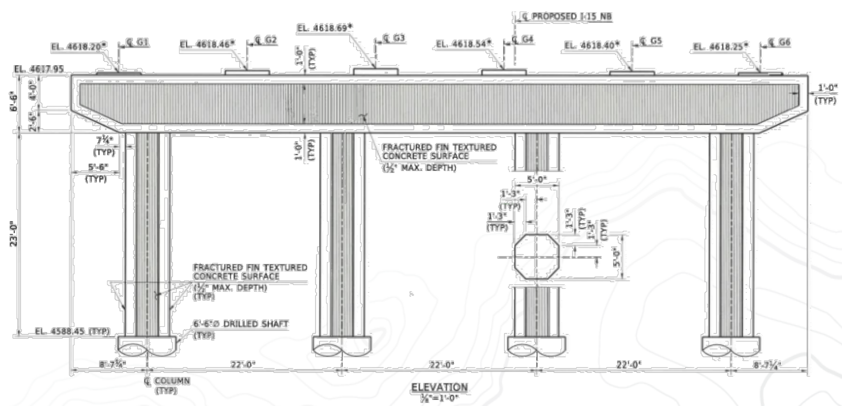



- Loess
- Alluvial Fan Deposits (w/ Boulders)

# Drilled Shafts

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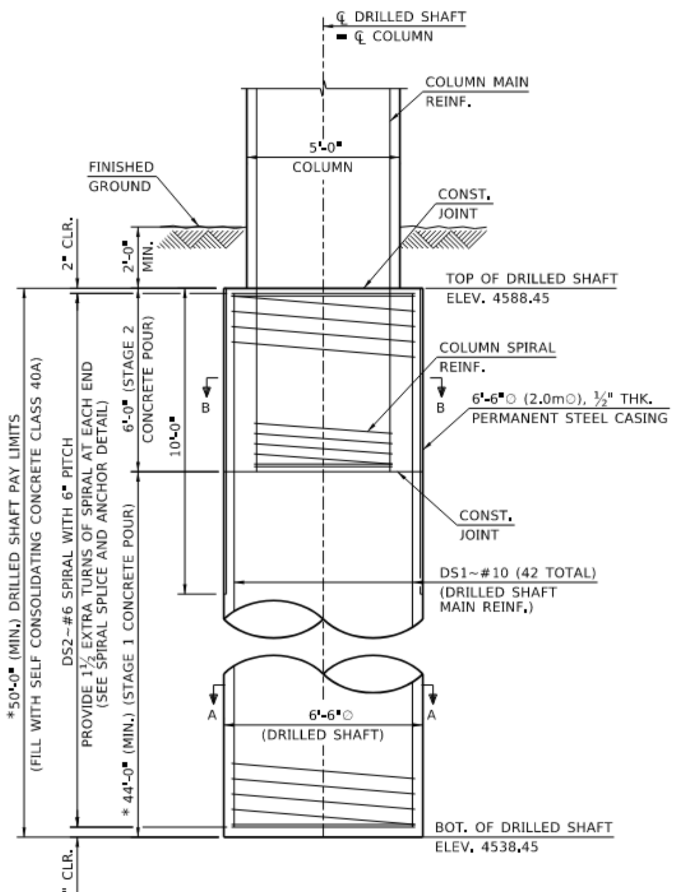
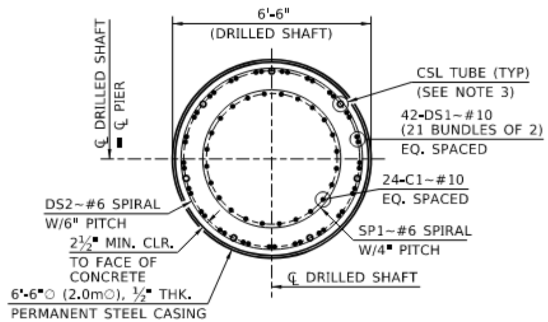
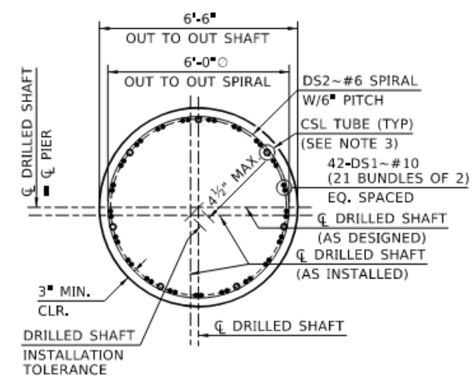
# Drilled Shafts

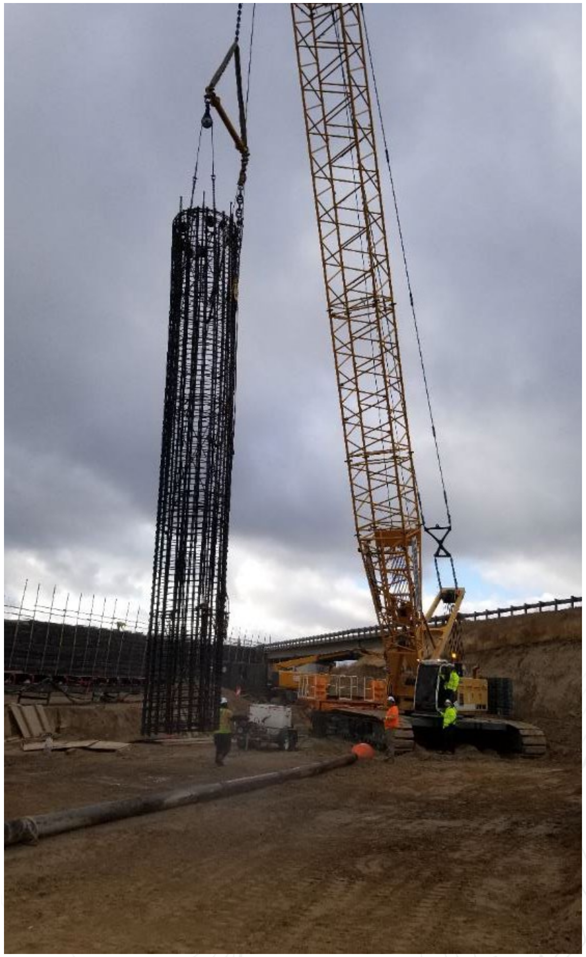



TYPICAL PIER DRILLED SHAFT
¼"=1'-0"




SECTION B-B
¼"=1'-0"



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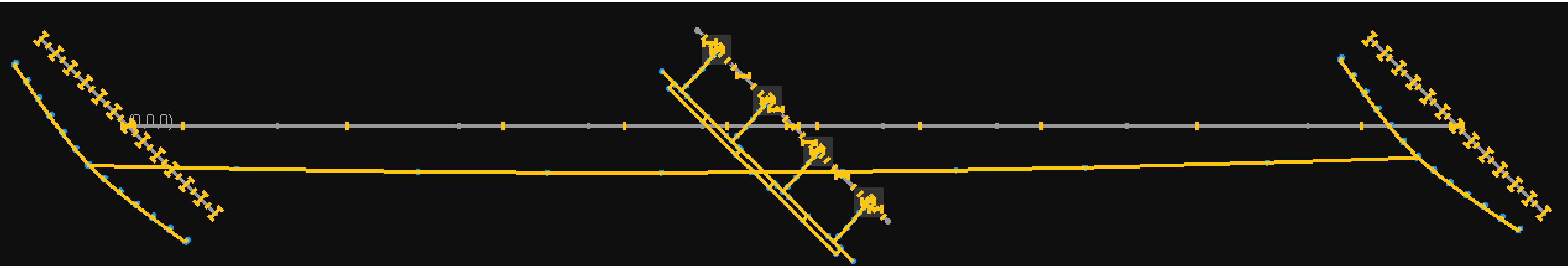

# Drilled Shaft Design - Structural

- Designed using AASHTO LRFD Bridge Design Specifications
- Seismic Zone 2 – Force Based Design ($S_{D1}$ = 0.26)
- RSA analysis in Larsa4D
- Drilled Shaft Diameter effects included in RSA
- Critical Bridge in accordance with ITD Policy
  - R Factor of 3.5 applied to column demands
  - R Factor of 1.0 applied to shaft demands
- Extreme Event II – CT controlled column design
- Extreme Event I – Seismic controlled shaft design

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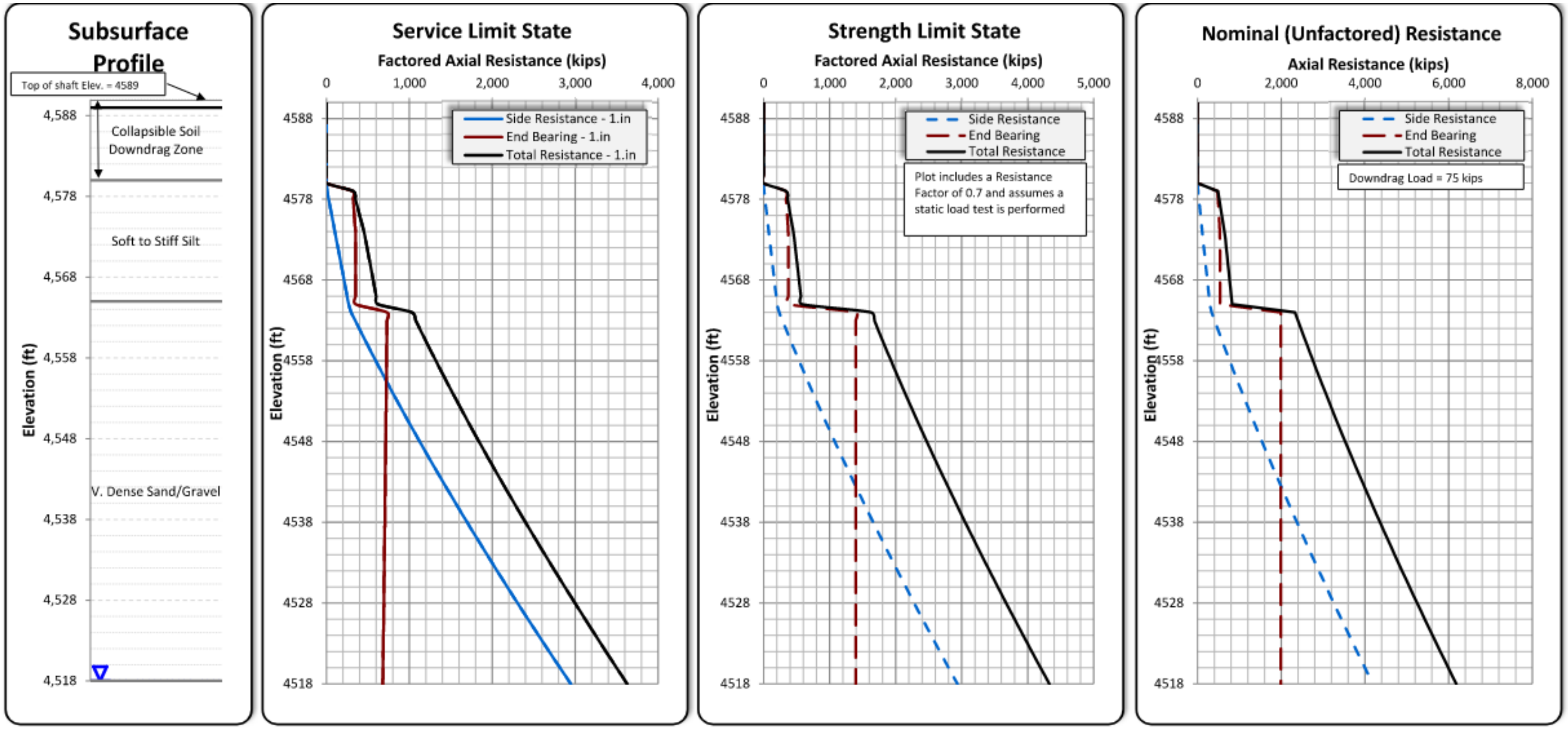
# Drilled Shaft Design - Geotechnical

- Designed using AASHTO LRFD Bridge Design Specifications
- Axial resistance reduced for collapsible loess soils



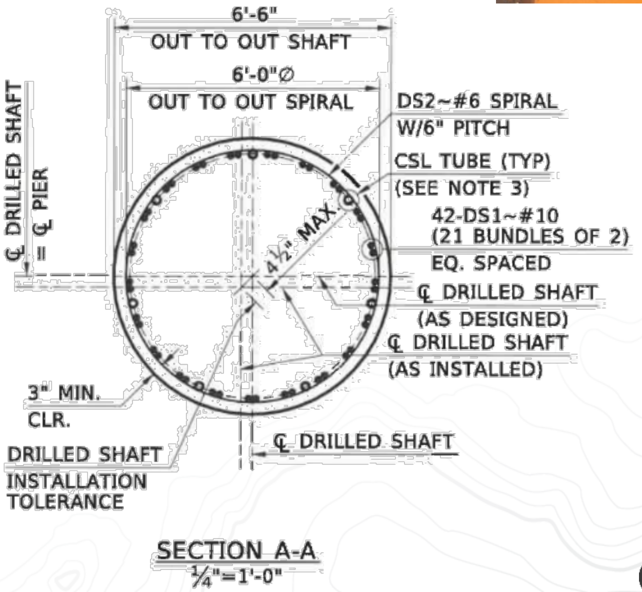
# Drilled Shaft Design - Geotechnical

- Lateral fixity often controls embedment for shafts in granular soils
- Axial resistance controlled the design embedment

| | | Lateral | Axial |
|---|---|---|---|
| | | Minimum Drilled Shaft Length (feet) [1] | Estimated Drilled Shaft Length (feet) [2] |
| **Bridge** | **Shaft Location** | **6.5' Diameter Shaft** | **6.5' Diameter Shaft** |
| I-15 SB over Ramp EN | Pier 1 | 40 | 57 |
| I-15 NB over Ramp EN | Pier 1 | 40 | 52 |
| I-15 SB over Ramp NW | Pier 1 | 38 | 53 |
| I-15 NB over Ramp NW | Pier 1 | 41 | 57 |

# Drilled Shaft Size Change

- During Bidding - driller concerned with concrete cover on shaft
- Oscillator casings are ~2" thick
- Recommended 2.2m (7.2') shaft diameter

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# Drilled Shaft Size Change - Considerations

- What sizes are available?
  - Confirmed with numerous drillers to that the 2.2m size is common.
- Does the design still work?
  - Bigger is not always better.
- How much time do we have?
  - Wanted to release addendum in time to prevent pushing bid opening.
- How do the quantities/pay items change?
  - Paid for the drilled shafts by the foot.
- How involved are the changes on the plans?
  - Able to cloud/redline changes in Bluebeam, plan changes took a few hours at most.

# Lessons Learned: Drilled Shaft Size Change

- Use more cover on drilled shafts (6" preferable)
  - Allows for more tolerance with cage placement
  - Cover requirements added to ITD Bridge Design Manual
- Change during bid advertisement was uncomfortable
  - Better to be uncomfortable than deal with a major change order or construction issue
- WSDOT has excellent guidance for drilled shaft cage diameters and cover for oscillating casing
  - Table 7.8.2-2 in the WSDOT Bridge Design Manual

**Table 7.8.2-2** Expected Reinforcing Cage Diameters and Clear Cover

| Nominal (Outside) Metric Casing Diameter | | Maximum (Outside) Reinf. Cage Diameter to Accommodate Metric Casing[1] | | Inside Diameter of Metric Casing[2] | Nominal (Outside) Metric Slip Casing Diameter[3] | | | Cage Clearance Below Slip Casing | Cage Clearance at Slip Casing[4] |
|---|---|---|---|---|---|---|---|---|---|
| Meters | Feet | Inches | Feet | Inches | Inches | Feet | Meters | Inches | Inches |
| 3.73 | 12.24 | 130.52 | 10.88 | 140.52 | 137.52 | 11.46 | 3.49 | 8.16 | 3.0 |
| 3.43 | 11.25 | 118.71 | 9.89 | 128.71 | 125.71 | 10.48 | 3.19 | 8.16 | 3.0 |
| 3.00 | 9.84 | 101.81 | 8.48 | 111.84 | 108.81 | 9.07 | 2.76 | 8.15 | 3.0 |
| 2.80 | 9.19 | 95.51 | 7.96 | 105.51 | 102.51 | 8.54 | 2.60 | 7.36 | 3.0 |
| 2.50 | 8.20 | 83.70 | 6.98 | 93.70 | 90.70 | 7.56 | 2.30 | 7.36 | 3.0 |
| 2.20 | 7.22 | 71.89 | 5.99 | 81.89 | 78.89 | 6.57 | 2.00 | 7.36 | 3.0 |
| 2.00 | 6.56 | 64.02 | 5.34 | 74.02 | 71.02 | 5.92 | 1.80 | 7.36 | 3.0 |

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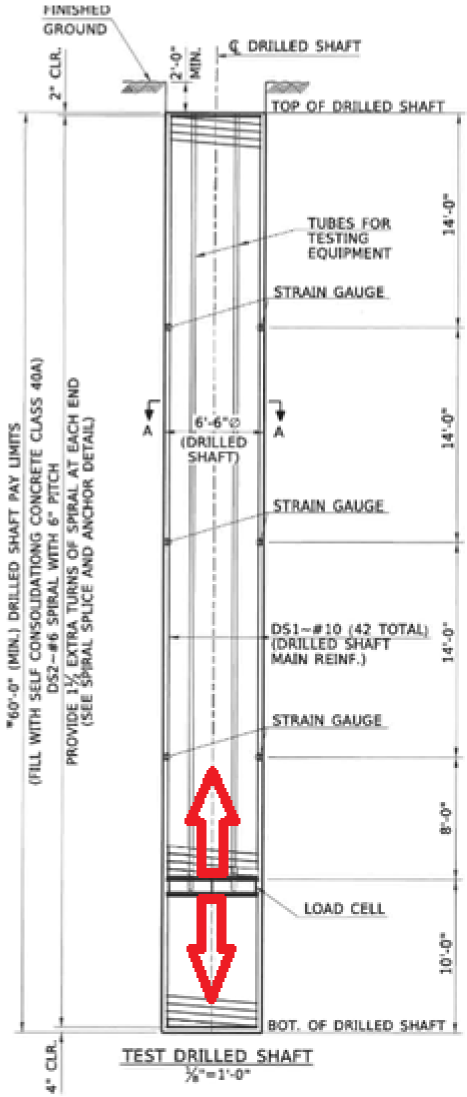
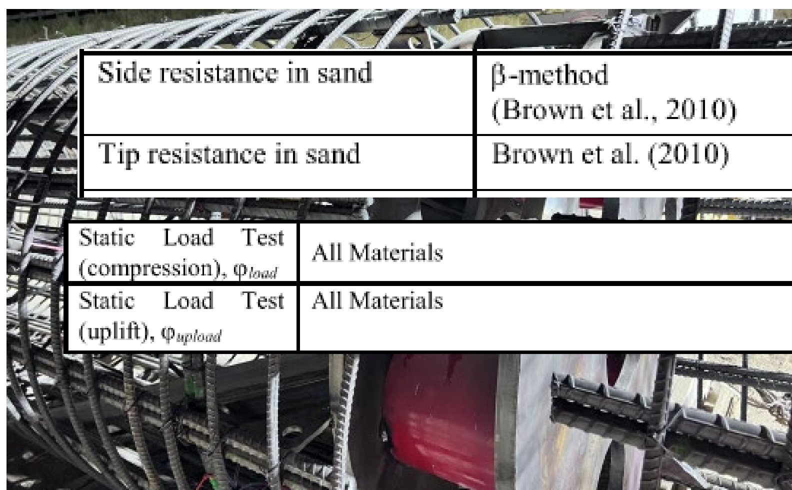



# Test Drilled Shaft

- One Sacrificial Test Shaft – 60 ft. long
  - Bi-Directional Load Cell Test (Osterberg Cell)
- Gave ITD a high level of confidence
- Increased geotechnical axial resistance factors
  - Table 10.5.5.2.4-1 in AASHTO BDS
- Reduced length of production shafts *both* during design and construction



| | | |
|---|---|---|
| Side resistance in sand | β-method (Brown et al., 2010) | 0.55 |
| Tip resistance in sand | Brown et al. (2010) | 0.50 |

| | | |
|---|---|---|
| Static Load Test (compression), $\varphi_{load}$ | All Materials | 0.70 |
| Static Load Test (uplift), $\varphi_{upload}$ | All Materials | 0.60 |

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# Results: Test Drilled Shaft

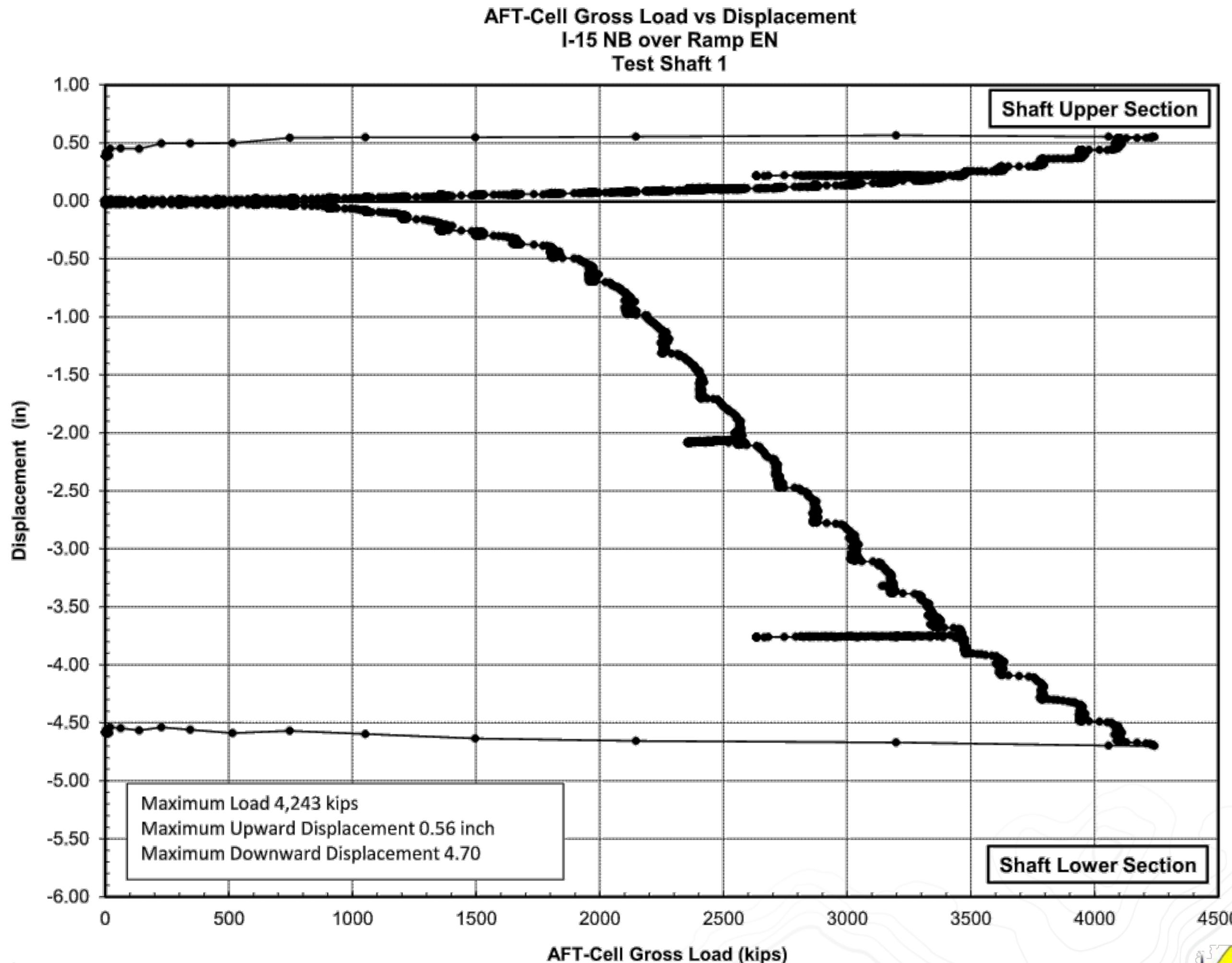


Figure 1

Applied Foundation Testing

# Results: Test Drilled Shaft

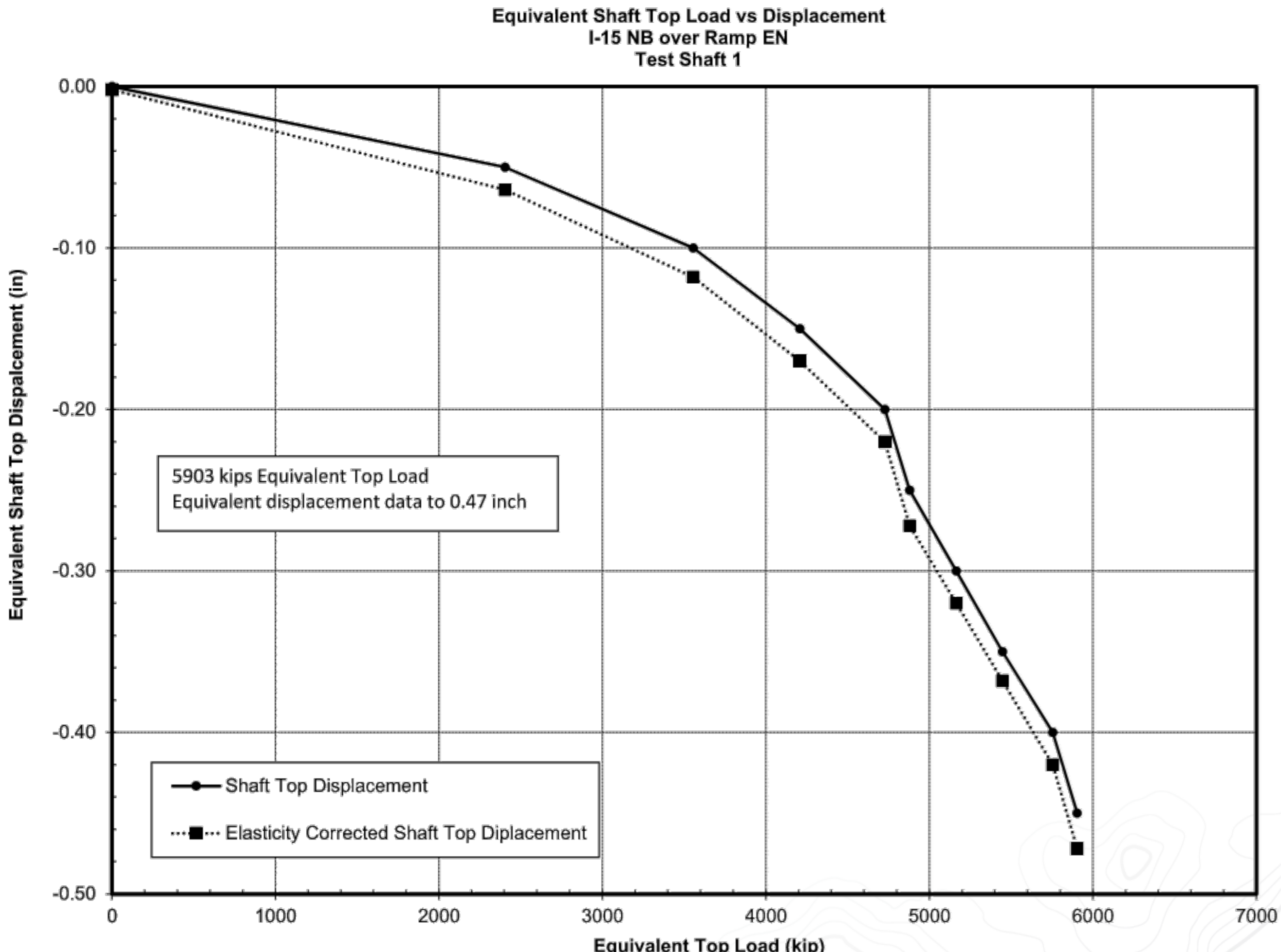


Figure 10

Applied Foundation Testing

# Results: Test Drilled Shaft

- Bi-directional load test resulted in a maximum equivalent top load of 5903 kips

**TABLE 1. SIDE AND END BEARING UNIT RESISTANCE VALUES FROM LOAD TEST**

| Load Test Segment (Soil Layer) | Correlated Soil Type | Service Limit State 1-inch of Settlement | | Nominal (Unfactored) | | Strength Limit State | |
|---|---|---|---|---|---|---|---|
| | | Unit Side Resistance (ksf) | Unit End Bearing Resistance (ksf) | Unit Side Resistance (ksf) | Unit End Bearing Resistance (ksf) | Unit Side Resistance (ksf) | Unit End Bearing Resistance (ksf) |
| **1** | Soft to Stiff Silt | 0.67 | Not Applicable | 0.71 | Not Applicable | 0.5 | Not Applicable |
| **2** | Stiff to Very Stiff Silt | 4.28 | Not Applicable | 4.35 | Not Applicable | 3.05 | Not Applicable |
| **3** | Very Dense Sand and Gravel | 3.74 | 33 | 3.90 | 78 | 2.73 | 54.6 |
| **4** | Very Dense Gravel | 4.28 | 33 | 3.56 | 78 | 2.49 | 54.6 |

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# Results: Test Drilled Shaft

- Bi-directional load test resulted in a maximum equivalent top load of 5903 kips for 60-foot shaft
  - Strength Limit state axial demand = 2560 kips
- Initial Analysis:

| Bridge | Shaft Location | Minimum Drilled Shaft Length (feet) [1] | Estimated Drilled Shaft Length (feet) [2] |
|---|---|---|---|
| | | 6.5' Diameter Shaft | 6.5' Diameter Shaft |
| I-15 SB over Ramp EN | Pier 1 | 40 | 57 |
| I-15 NB over Ramp EN | Pier 1 | 40 | 52 |
| I-15 SB over Ramp NW | Pier 1 | 38 | 53 |
| I-15 NB over Ramp NW | Pier 1 | 41 | 57 |

- Post-test:

| Bridge | Min. Length for Lateral Stability (feet) | Min. Length for Axial Capacity (feet) | Recommended Minimum Shaft Length [1] (feet) |
|---|---|---|---|
| I-15 NB Over Ramp EN | 45 | 23 | 45 |
| I-15 SB Over Ramp EN | 45 | 25 | 45 |
| I-15 SB over Ramp NW | 45 | 20 | 45 |
| I-15 NB over Ramp NW | 45 | 20 | 45 |

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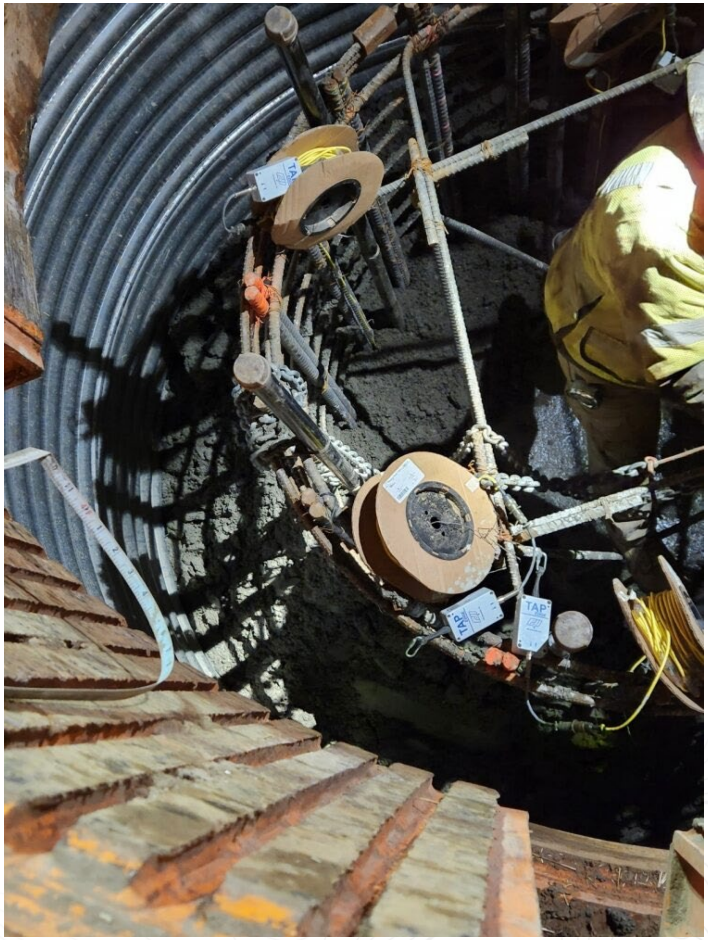
# Results: Test Drilled Shaft

- Test Shaft cost ~$200,000
- Reduced all production shafts by 5’
  - Saved ~$170,000 in production shaft costs
  - Does not include design savings with higher RF
- Value of increased confidence ($$$?)

# TIP & CSL Test Results

- TIP = Thermal Integrity Profiling
- CSL = Cross-Hole Sonic Logging
- Contract required both TIP and CSL testing
- Overall results were very good from both TIP and CSL testing
- Two shafts had questionable results – having both the TIP and CSL was beneficial to vetting issues



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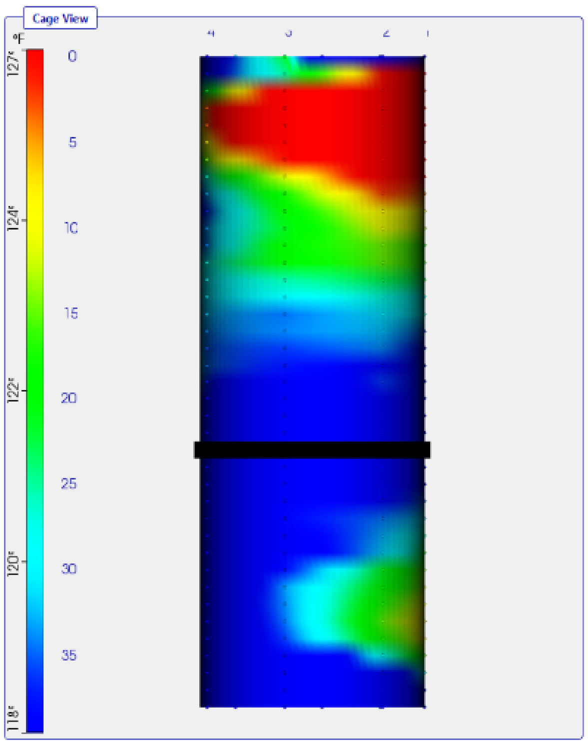
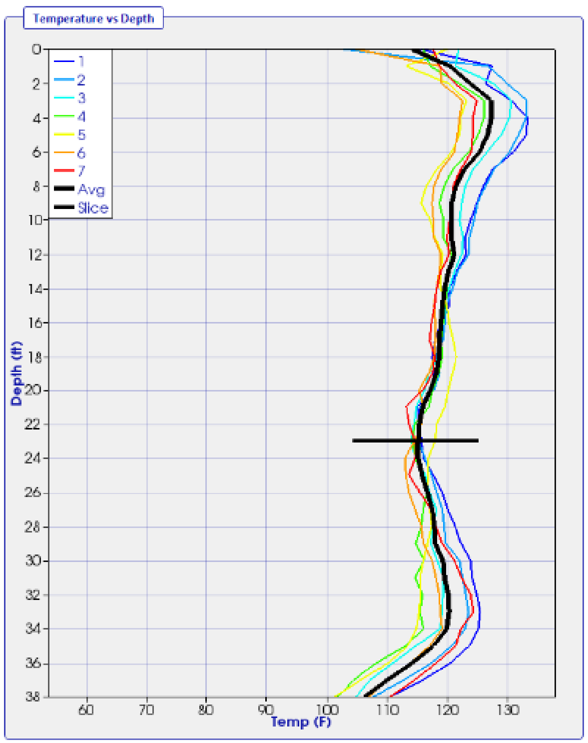
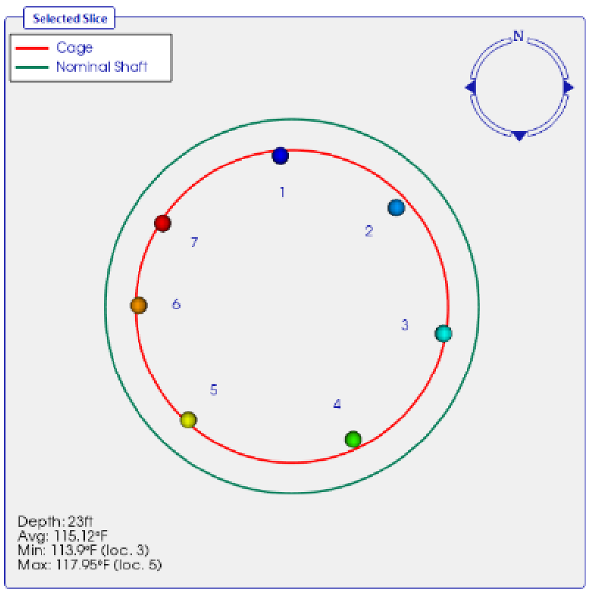
# TIP & CSL Test Results – Shaft P1-1

*TIP testing indicated potentially lower quality concrete at a depth of 20-26ft.*




**Shaft Information**

| | |
|---|---|
| Time Of Test Start: | 10/26/22 00:16 |
| Data Time: | 10/28/22 10:34 (58h:18m elapsed) |
| Cage Diameter: | 72 in |
| Shaft Length / Diameter: | 38 ft / 86 in |
| Avg Temp: | 118.45°F |
| Min Temp: | 112.89°F at 24ft / 6 where local avg is 115.11°F |
| Max Temp: | 127.74°F at 7ft / 2 where local avg is 122.85°F |

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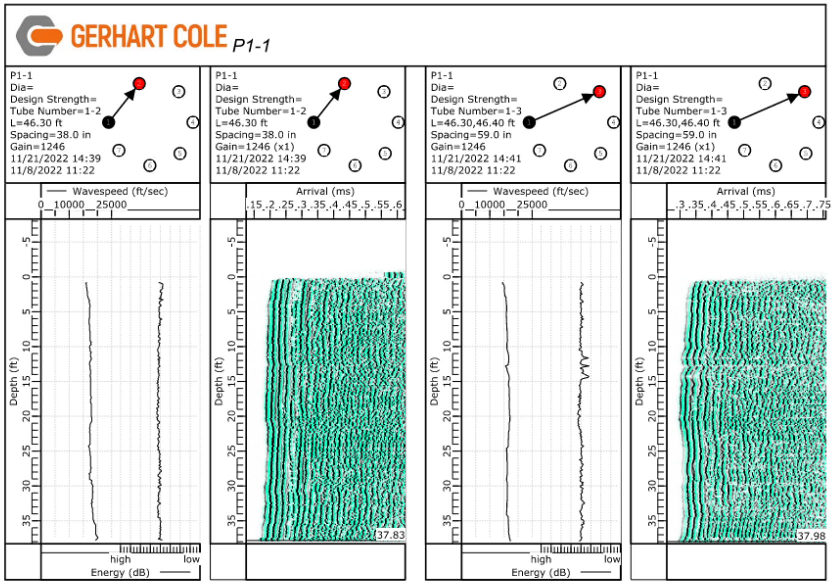
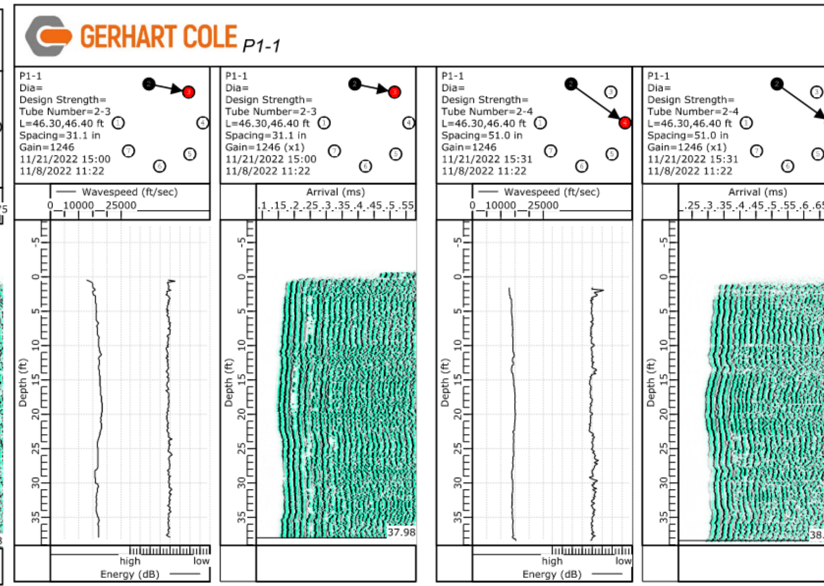
# TIP & CSL Test Results – Shaft P1-1

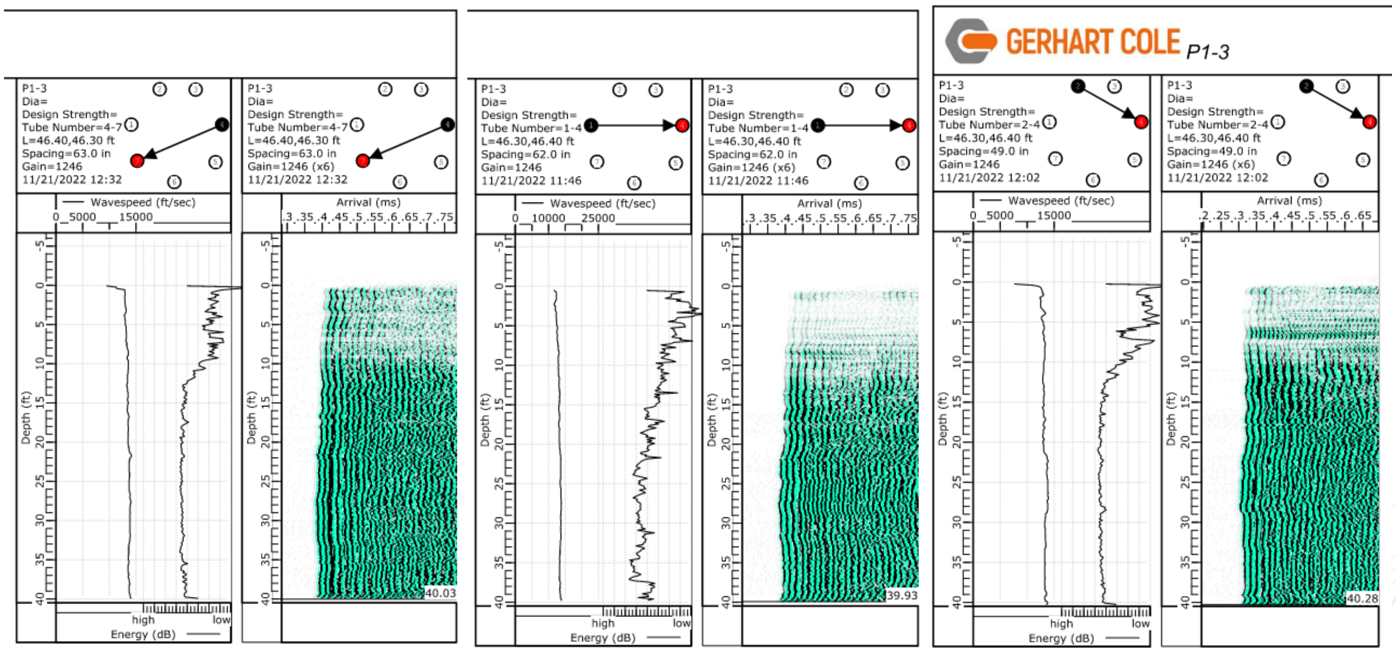
*CSL test results did not corroborate the potentially lower quality concrete between 20-26ft and gave good results.*



# TIP & CSL Test Results – Shaft P1-3

- CSL results indicated signal loss in several of the waterfall diagrams
  - All relating to tube 4 in the top 10 feet

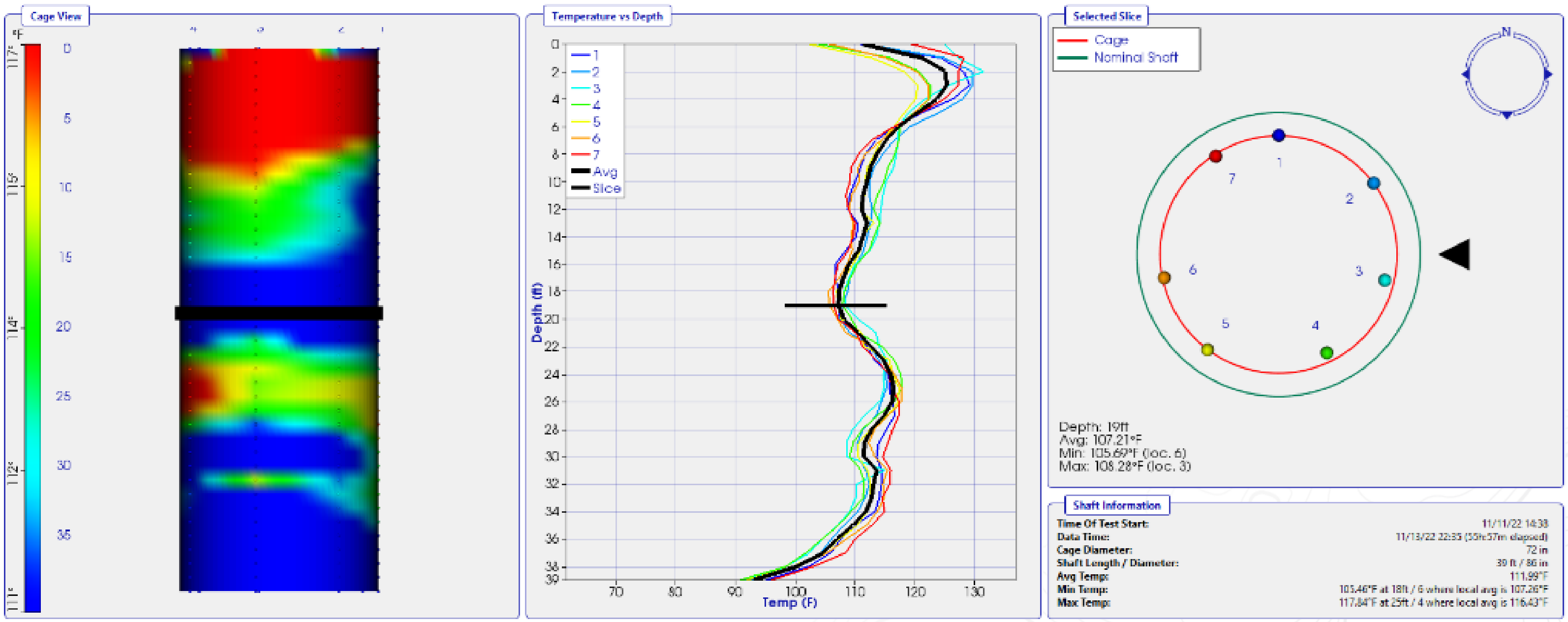


# TIP & CSL Test Results – Shaft P1-3

*TIP testing did not corroborate this signal loss*

**I-86/I-15 System Interchange- I-15 NB Over Ramp EN**

**Shaft P1-3**

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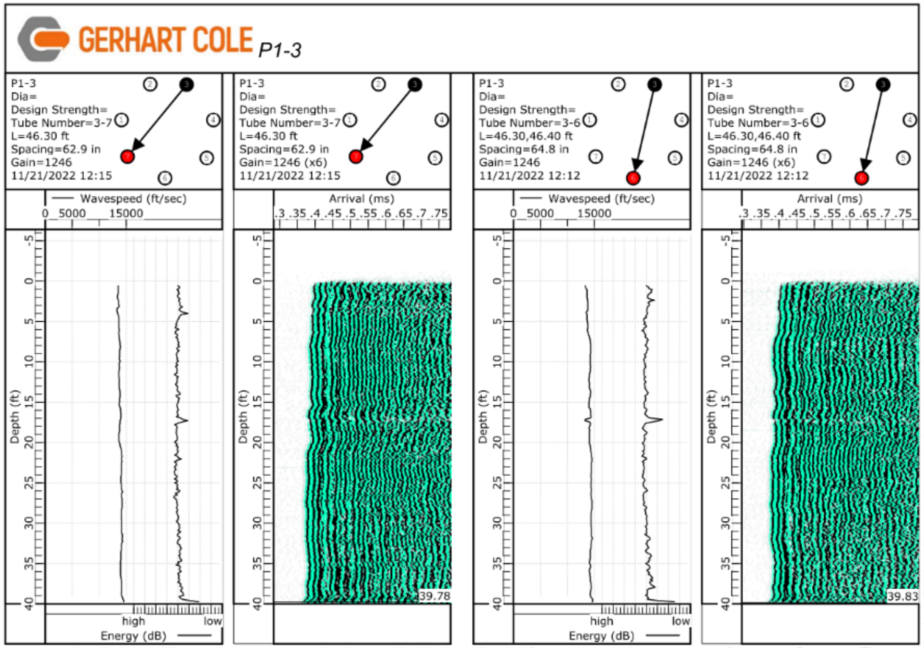
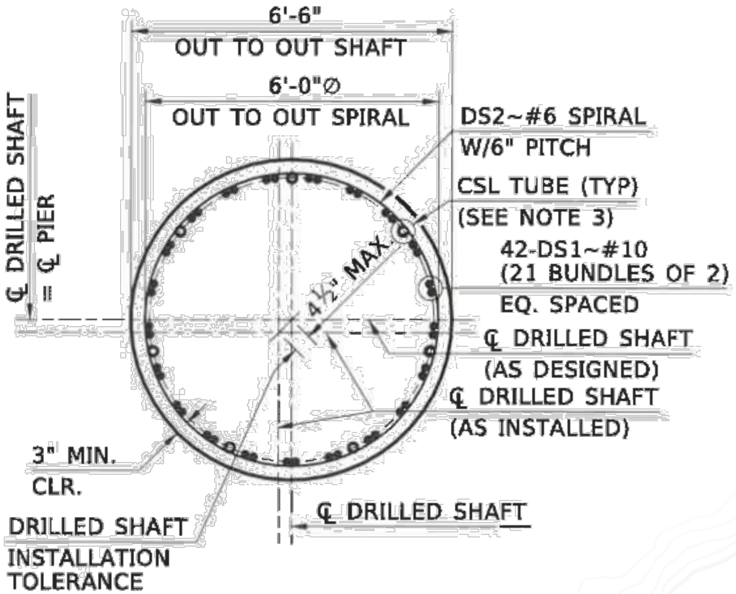
# TIP & CSL Test Results – Shaft P1-3

- Water was not placed in CSL tube prior to concrete pour
  - This can cause debonding of the CSL tube to the concrete, which can result in signal loss
- CSL testing between other tubes did not agree with tube 4 results
- Shaft was accepted as is.



# Drilled Shaft Location Issues

- Horizontal placement tolerance 4.5” on plans
- NB over EN Bridge –
  - Two Shafts out of location 7” & 11”




SECTION A-A
¼"=1'-0"

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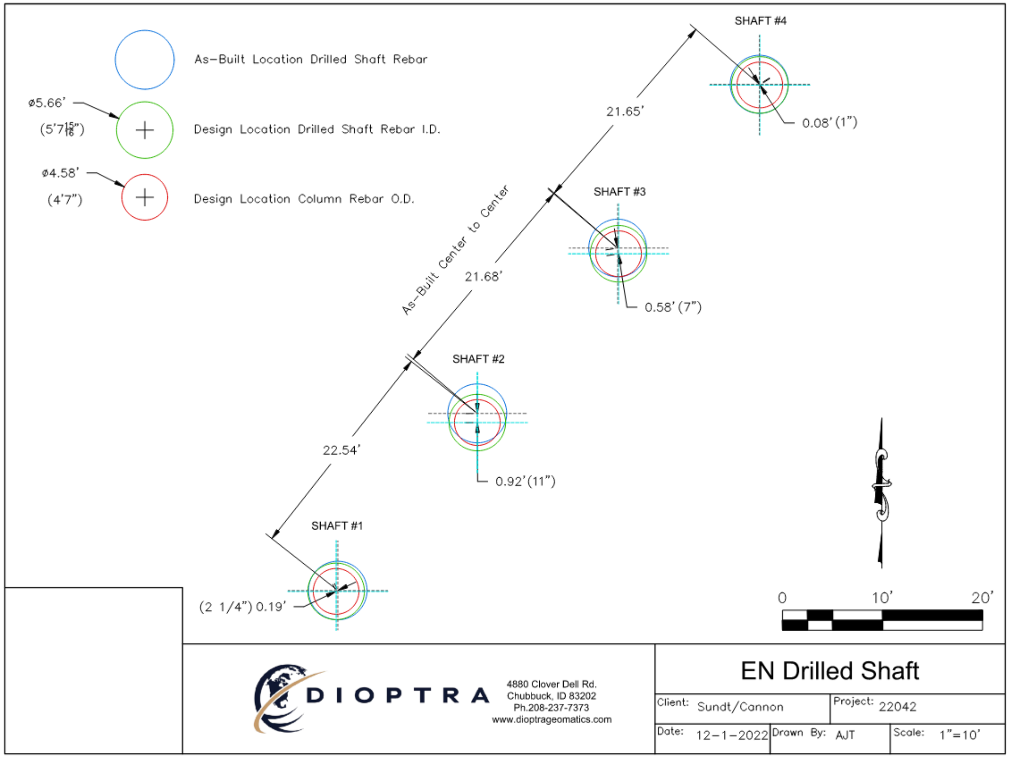
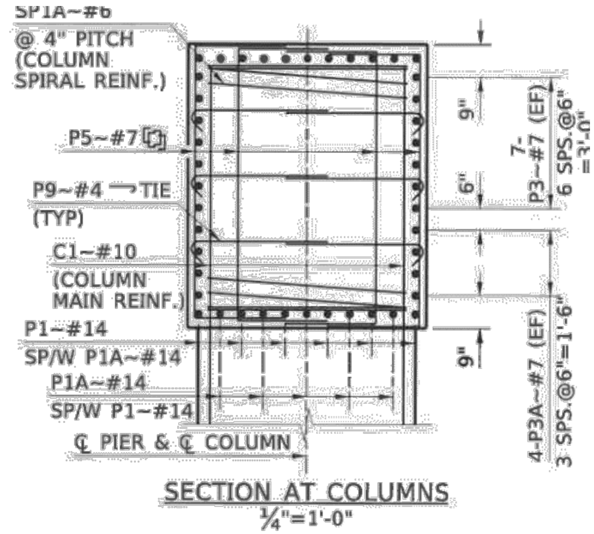
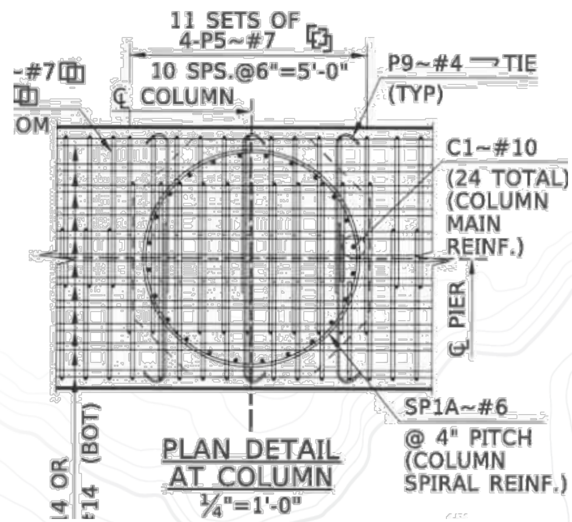
# Drilled Shaft Location Issues

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# Drilled Shaft Location Issues – Considerations

## Option 1 – Make the cap wider

| Positives | Negatives |
|---|---|
| Easier to fit longitudinal rebar | Cap Rebar Changes |
| Bearing locations stay the same relative to cap | More Concrete = More Mass |
| More flexibility for column locations | More Analysis |

## Option 2 – Shift the entire cap

| Positives | Negatives |
|---|---|
| Cap Rebar stays the same | Challenge to fit longitudinal rebar |
| Structure Mass and loads are similar | Bearing locations change relative to cap CL |
| Less Detailing Changes | Some Additional Analysis – Cap Torsion |

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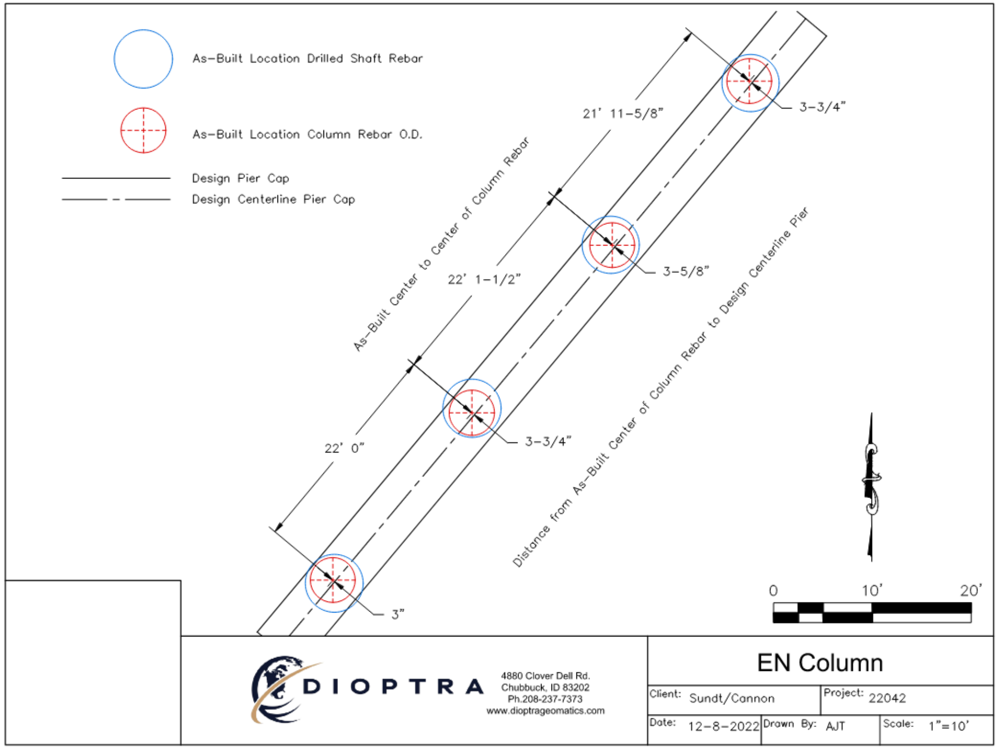
# Drilled Shaft Location Issues - Solution

- Contractor proposed option 2 (Cap Shift) with ITD's approval
- ITD Bridge ran reanalysis to confirm design still acceptable

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# Lessons Learned – Location Issues

- Design
  - Make future caps wider than 3” on each side of column
  - Increase allowable column placement tolerance within shaft, 4.5” was reasonable, but ITD specifications are normally 6”
- Construction
  - Double check survey – survey as close to drilling date as possible
  - Potentially survey shaft cage before placing concrete
  - Work together to come up with solutions – we are all on the same team

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# Summary of Lessons Learned

- **Everybody** makes mistakes
  - Don’t be afraid of change
  - Act quickly - problems don’t age well
  - We are all on the same team
- CSL and TIP for confirmation
  - Water in CSL tubes
- Static load tests can pay off
  - Resistance factors
  - Optimizing design after test
  - Increased confidence
- Survey control during construction is critical
  - Teamwork can usually resolve minor issues in tolerance

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# Questions?


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# Extra Slides

# Concrete Placement in Extreme Temperatures

## ITD Concrete Specification

- Max Concrete Temp. 80° at time of placement
- Min Concrete Temp. 50° at time of placement
- Max Internal Curing Temp.

| I-15/I-86 System IC Drilled Shaft Concrete Placement | | | | | | |
|---|---|---|---|---|---|---|
| | | Date | Air Temp | Concrete Temp | Max Internal Temps °F | Yards |
| | Test Shaft 1 | 9.1.2022 | 94° | 78° | | 90 |
| Bridge 1 | Drilled Shaft 1 | 10.25.2022 | 43° | 52° | 145° | 73 |
| Bridge 1 | Drilled Shaft 2 | 10.31.2022 | 44° | 55° | 143° | 60 |
| Bridge 1 | Drilled Shaft 3 | 11.3.2022 | 28° | 50° | 146° | 63 |
| Bridge 1 | Drilled Shaft 4 | 11.11.2022 | 26° | 52° | 146° | 63 |
| Bridge 2 | Drilled Shaft 5 | 1.20.2023 | 17° | 49° | 195° | 64 |
| Bridge 2 | Drilled Shaft 6 | 1.23.2023 | 18° | 53° | 150° | 65 |
| Bridge 2 | Drilled Shaft 7 | 1.26.2023 | 24° | 53° | 120° | 64 |
| Bridge 2 | Drilled Shaft 8 | 1.28.2023 | 27° | 53° | 144° | 64 |

# Hot Weather Concrete - Ice

- Test Shaft
  - Used Ice to cool down loads (400-1000lbs of ice used)
- Drilled Shafts 1-3
  - Used Ice to cool down loads (540-750lbs of ice used)
  - Placement in afternoon to night

| Load Size | Mix Code | Returned | Qty | Mix Age | Seq | Load ID |
|---|---|---|---|---|---|---|
| 9.00 CY | 40ASCC12 | | | | D | 82383 |

| Material | Design Qty | | Required | Batched | % Var | % Moisture | Actual | Wat |
|---|---|---|---|---|---|---|---|---|
| ROCK-3/8 | 1475 lb | | 13375 lb | 13340 lb | -0.26% | 0.75% M | | 12 gl |
| SAND-P | 1406 lb | | 13250 lb | 13140 lb | -0.83% | 4.71% A | | 71 gl |
| CEM-I/II | 599 lb | | 5391 lb | 5395 lb | 0.07% | | | |
| FLYASH-N | 200 lb | | 1800 lb | 1810 lb | 0.66% | | | |
| AIR | .33 oz | # | 2.97 oz | ~~.00~~ oz 2 oz | 100.00% | | | |
| LITHIUM | .00 | # | .00 oz | .00 oz | | | | |
| HIGH RANGE | 64.00 oz | | 576.00 oz | 580.00 oz | 0.69% | | | |
| WATER | 32.0 gl | | 123.7 gl | 124.0 gl | 0.26% | | | 124.0 gl |
| HOT | .0 % | # | .0 gl | .0 gl | | | | |

Actual Num Batches: 1 Manual 19:35:15

Load 34756 lb Design W/C: 0.334 Water/Cement: 0.239 A Design 288.0 gl Actual 206.7 gl To Add: 81.3 gl

Slump: 7.00 in # Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -9.0 gl / CY

Actual W/C Ratio: 0.239 Actual Water: 207 gl Batched Cement: 7205 lb Allowable Water: 682 lb

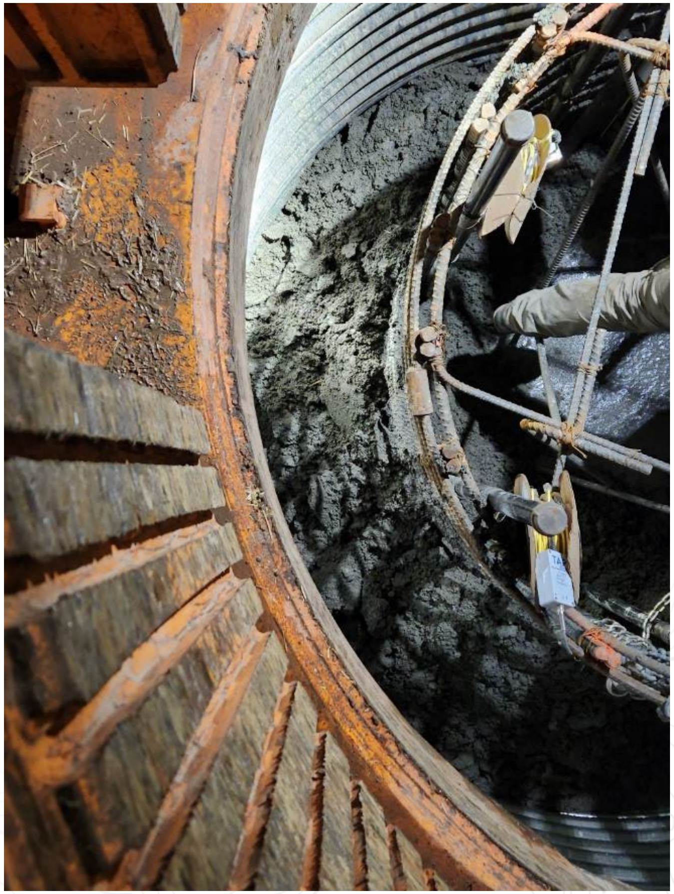
27 bags ~~Water~~ Ice

540 lbs Ice 65 galons

109 oz Lithium

# Cold Weather Concrete - Flash Freeze

- Drilled Shaft #3
  - Ambient temperature at pour: 28°
  - Concrete Temperature: 50°
  - In place Concrete Temperature: 27°



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# Cold Weather Concrete – Lessons Learned

- Cold Weather Plan
  - Heat enough to where steel is warm but not too hot
  - Between a set of trucks, put heat back on.
  - Cover after placement and heat.

# Concrete Cured -- How hot?

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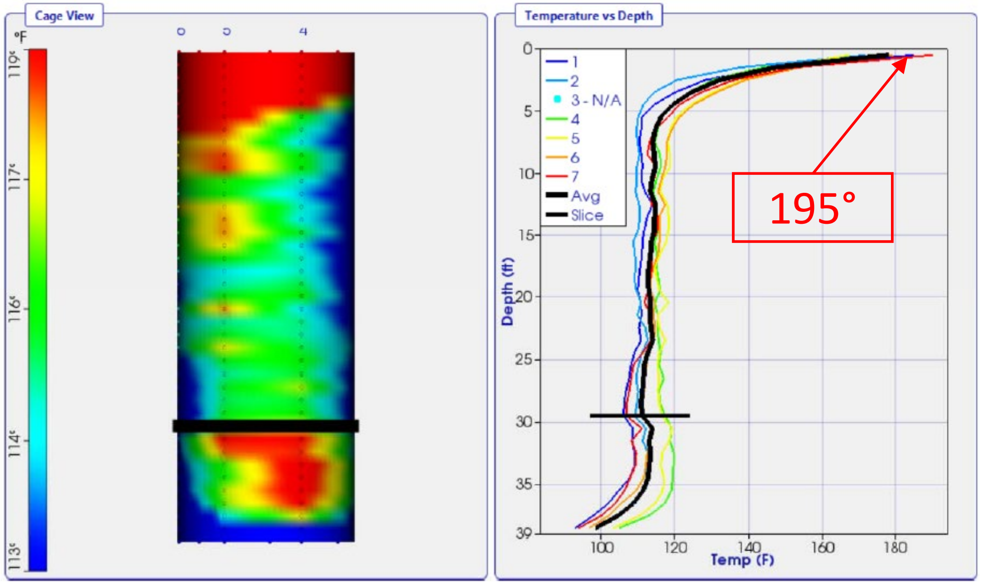
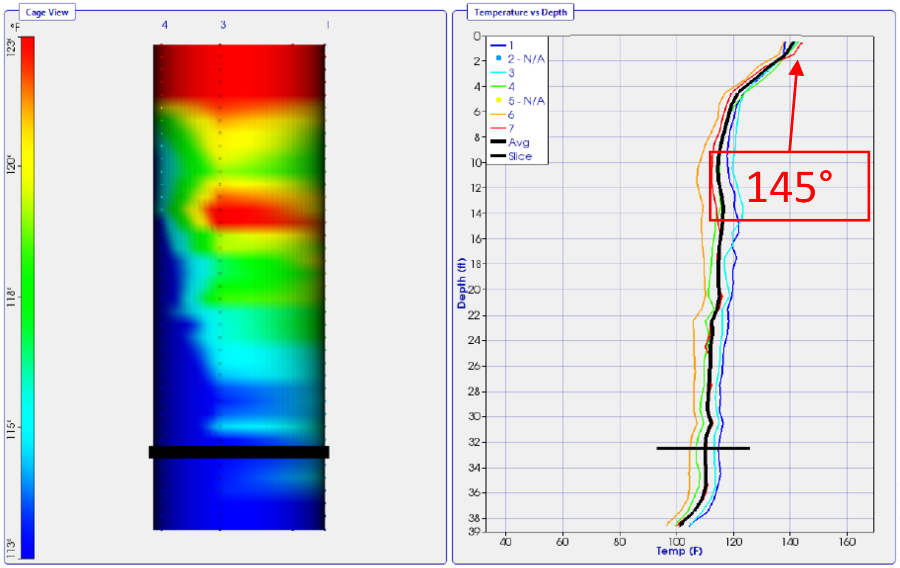
# Concrete Cured -- How hot?




**Shaft P1-1**

**Shaft P1-3**

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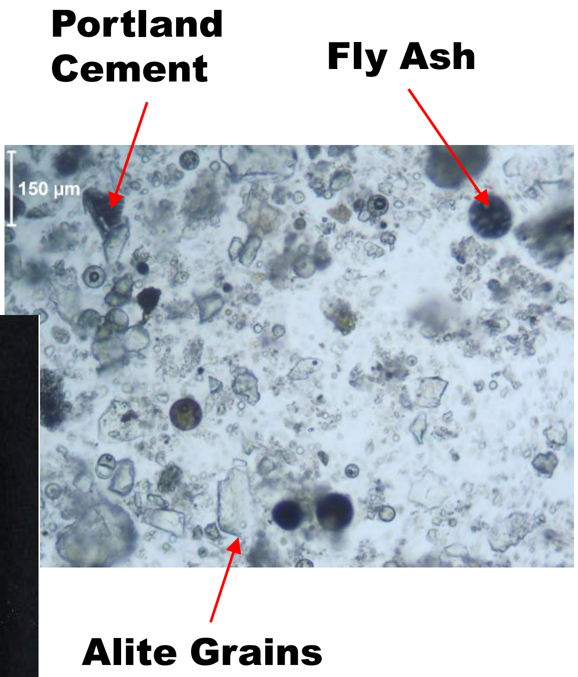
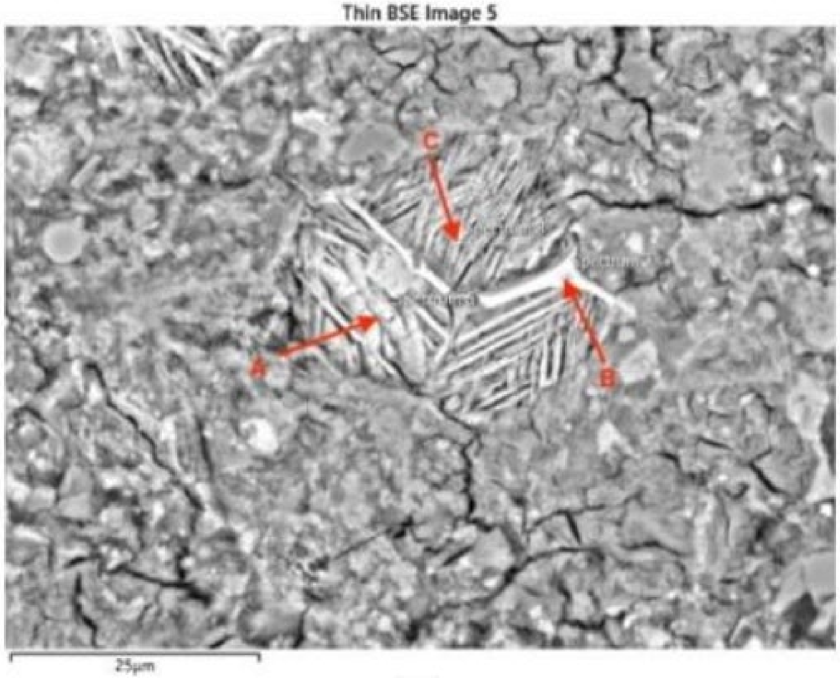
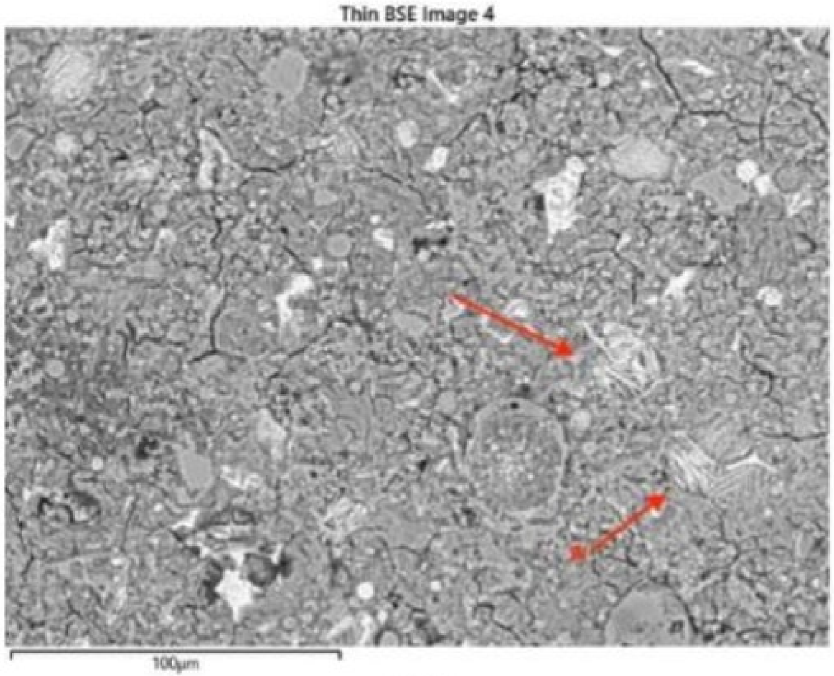
# Testing the Concrete


Figure A3. Photographs of the polished section of Shaft 1A.



# Petrographic Analysis
*Delayed Ettringite Formation (DEF)*



# Concrete Placement – Lessons Learned

- Internal Temperature Probes in the Center are Valuable
- Watch Steel Casing temperatures
- Temperature control is Key
- If something looks off, take the time to investigate

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