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Repair of A Large Diameter Non-Redundant Drilled Shaft

2017 Western Bridge Engineers' Seminar
September 7, 2017
Alan Marchman, PE and Kuan Go, PE, SE



Project Description

- Honolulu High Capacity Transit Corridor Project (HHCTP)
  - Owner: Honolulu Authority For Rapid Transportation (HART)
  - Contractor: Kiewit Infrastructure West, Inc.
  - Lead Designer: HNTB
  - Design Team: FIGG, SWI
  - Shaft Testing: Applied Foundations Technology (AFT)
- HNTB Delivered Design For First 10 Miles Under 2 Contracts ($669M & $392M)

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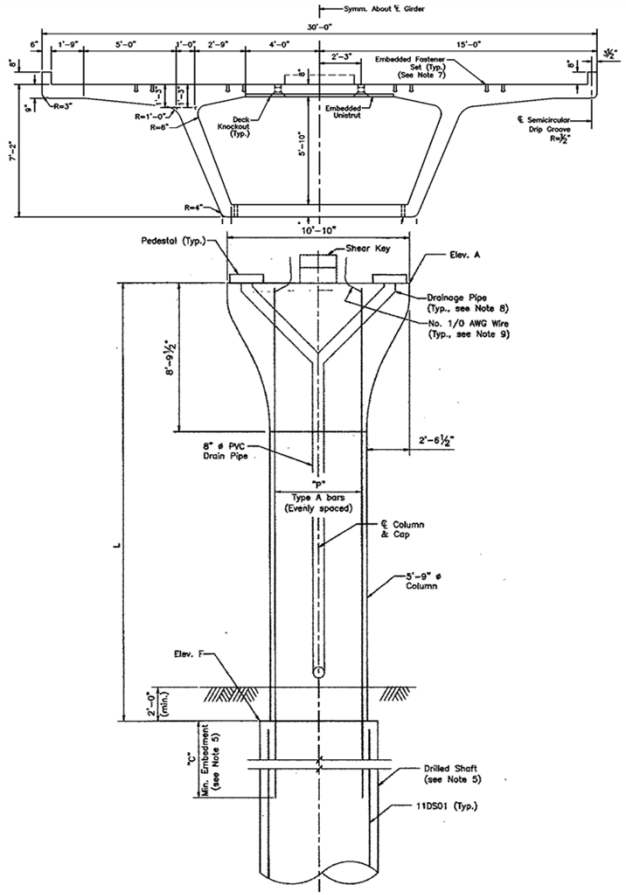
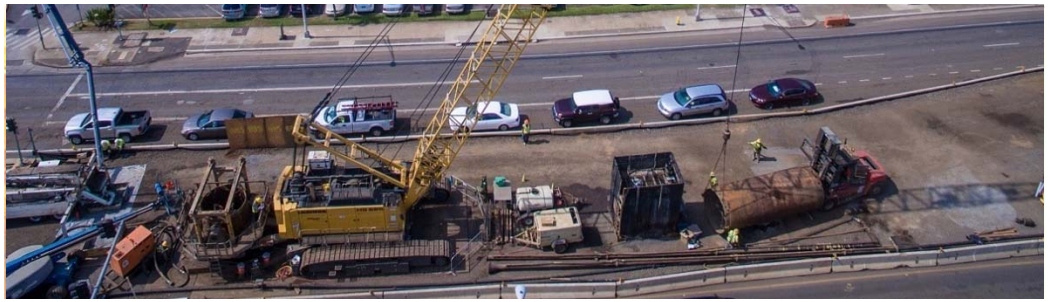
Design Features

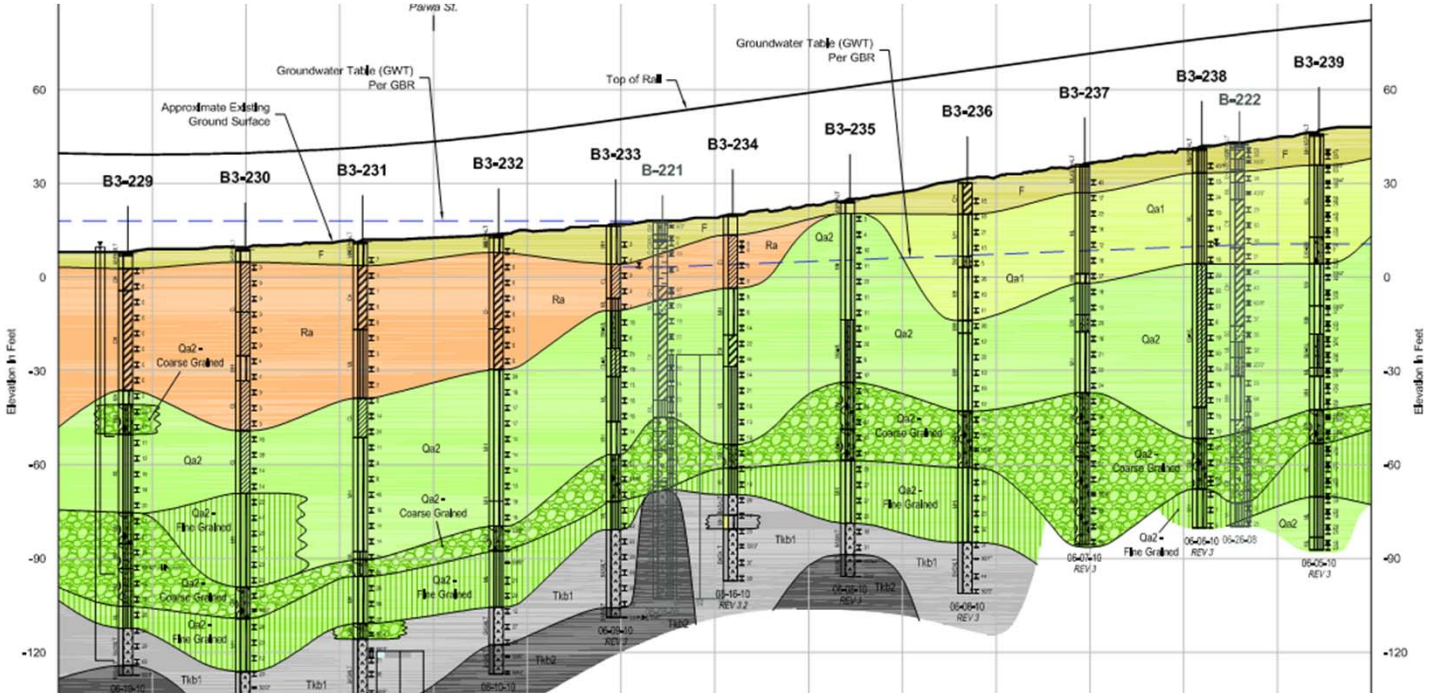
- 437 Spans
- 2 Balanced Cantilever Interstate Crossings
- 457 Piers
- Single Column On Single Shafts





Drilled Shaft Design

- Varying Geology Required Close Coordination With Geotechnical



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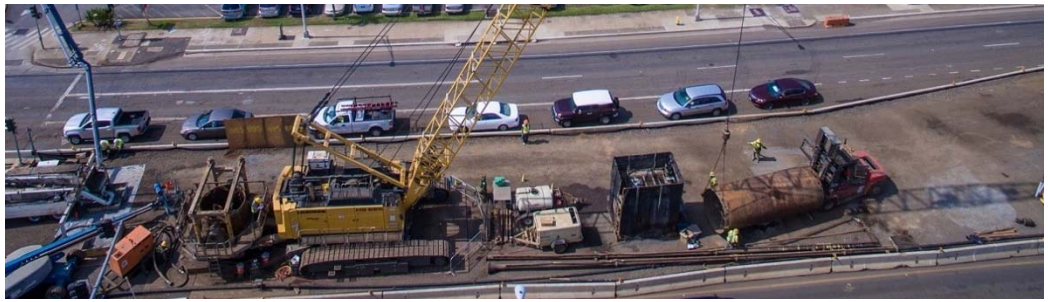
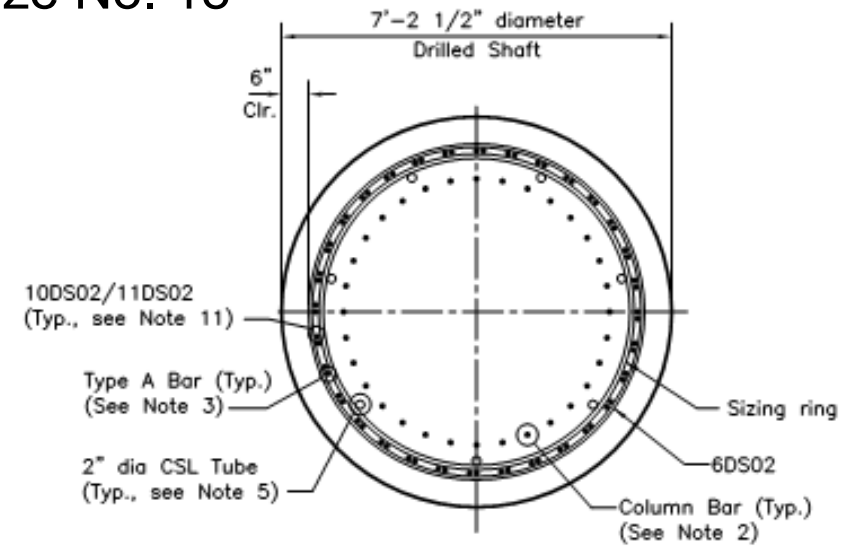


Drilled Shaft Design

- Seismic Region - Capacity Protected Members
- Rebar Grades 60, 75, And 80, Up To Size No. 18
- Transverse Spiral Reinforcing
- Concrete Strength = 4,000 Psi
- Diameters 7 Ft. To 8.2 Ft.
- Lengths 30’ To 120’
- Cased And Uncased Construction



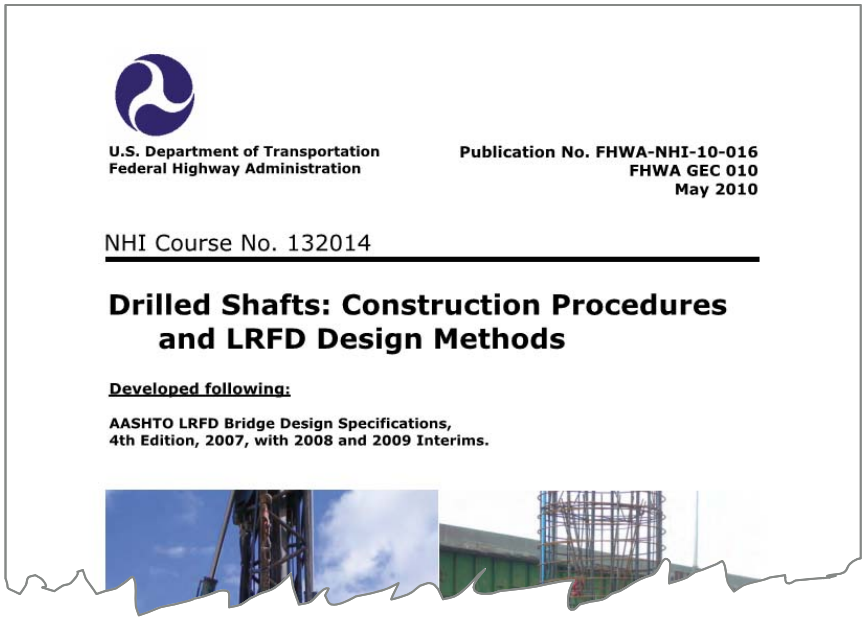
Design Role During Construction

- Shaft QA Utilized Cross-hole Sonic Logging (CSL) Testing (ASTM D6760)
- Acceptance Of Shaft Based On CSL Results And Construction Logs
- Review Criteria Per Project Specification 31 63 30 Section 3.13.G:

> Drilled shafts with velocity reductions exceeding 20% in an area between half a shaft diameter below the shaft construction joint, and one foot above the shaft tip shall be evaluated and tracked in an NCR per 3.13.H.

- Previous Shafts Repaired, Typically With High Pressure Grouting Through Core Holes.

Design Role During Construction

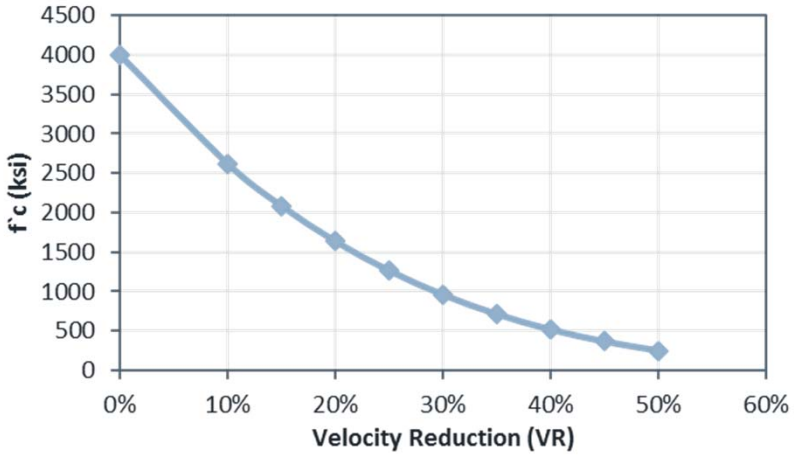


- Relationship Between Concrete Strength And Velocity Reductions:

$$f`_c \propto VR^2$$

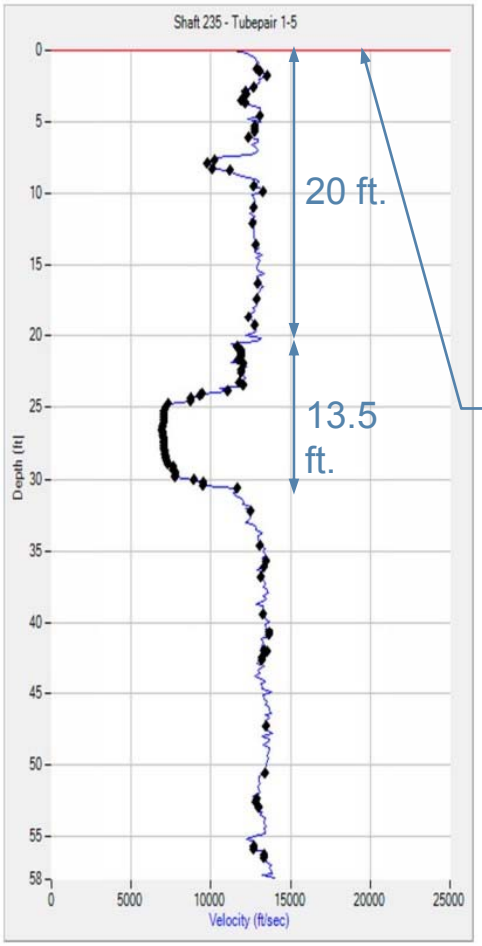
- Simplified Relationship
- Calibrated With Break Data
- Quickly Check Models

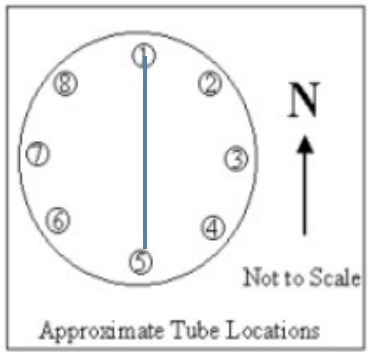
$$f`_{c_{Mod}} \cong f`_c(1 - VR^2)$$



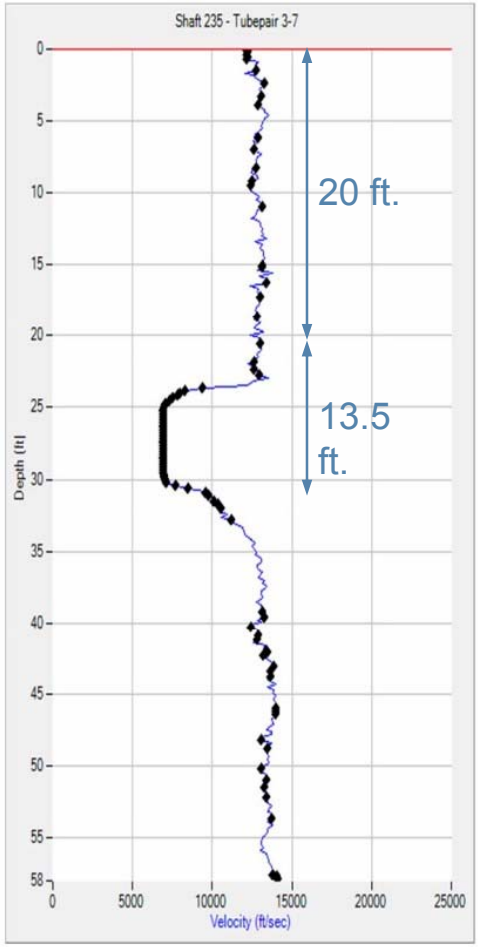
Shaft 235 Repair: Initial Report

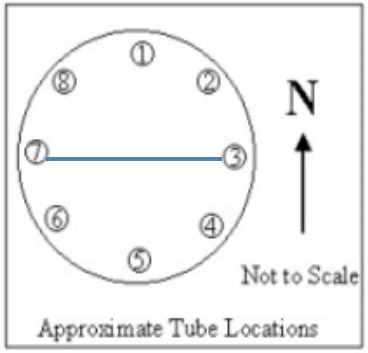
- CSL Reported Velocity Reductions >50% In Critical Regions About 13.5 Feet Deep





Top of Concrete (CJ)



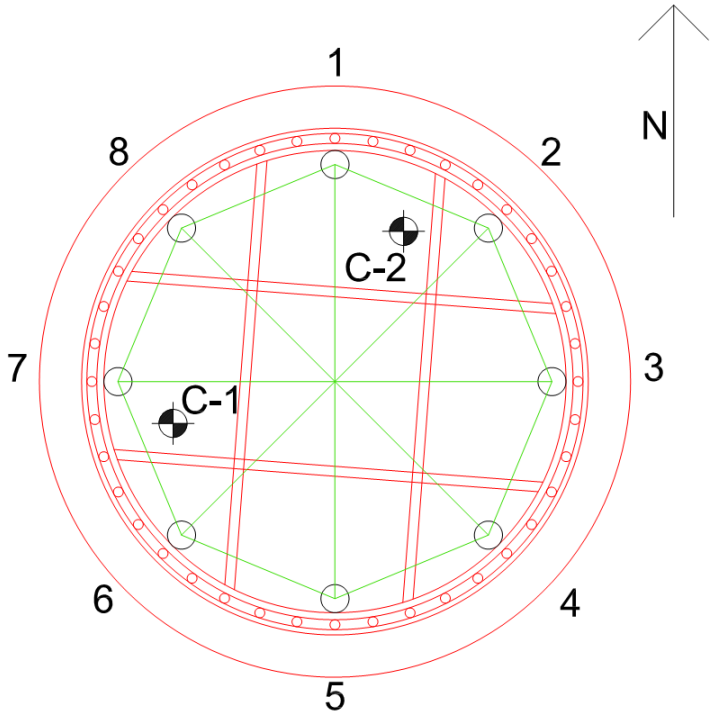


Shaft 235 Repair: Initial Report

- Cored Anomalous Areas Showed Non-homogenous Concrete

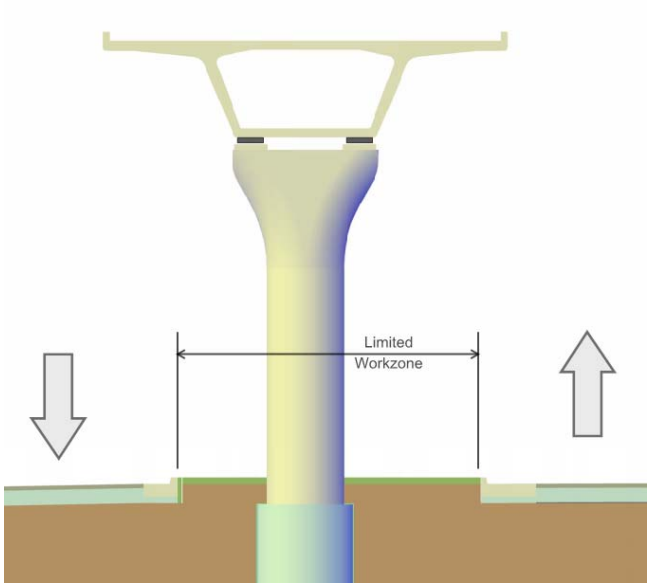
Core C-1 Run 7

Core C-2 Run 7

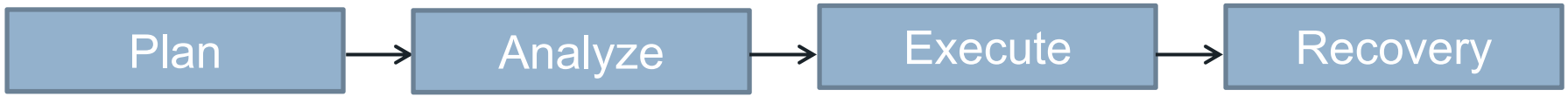


Shaft 235 Repair: Challenges

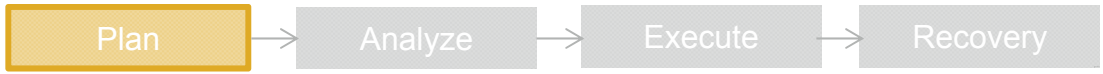
- Small Working Footprint
- Erection Truss Schedule Demands
- Long Lead Times & High Costs For Moving Materials And Equipment On Island
- High Water Table
- Non-redundant Shaft Means Repaired Shaft Must Meet Original Design Criteria



Shaft 235 Repair: The Process



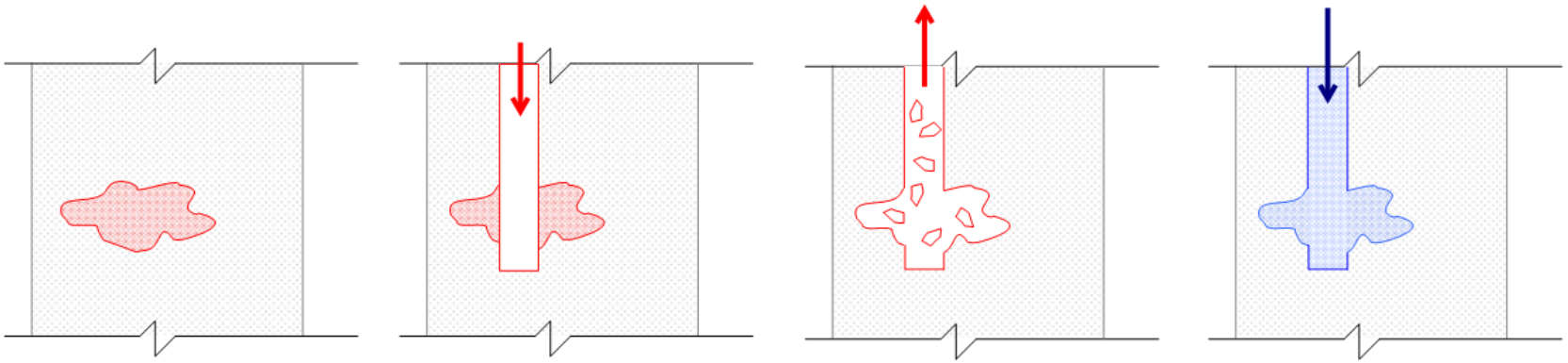
Shaft 235 Repair: Options



- Material Replacement
- Hydro-demolition And High Pressure Grouting
- Innovative Micropile Installation
- “Sister” Shafts With Cap

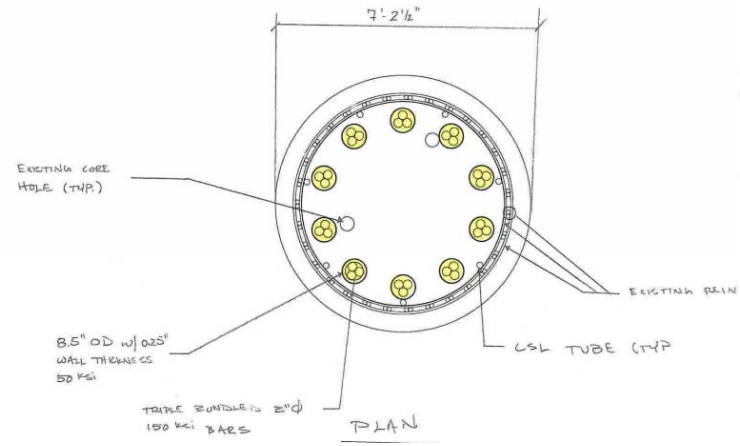
Shaft 235 Repair: Options

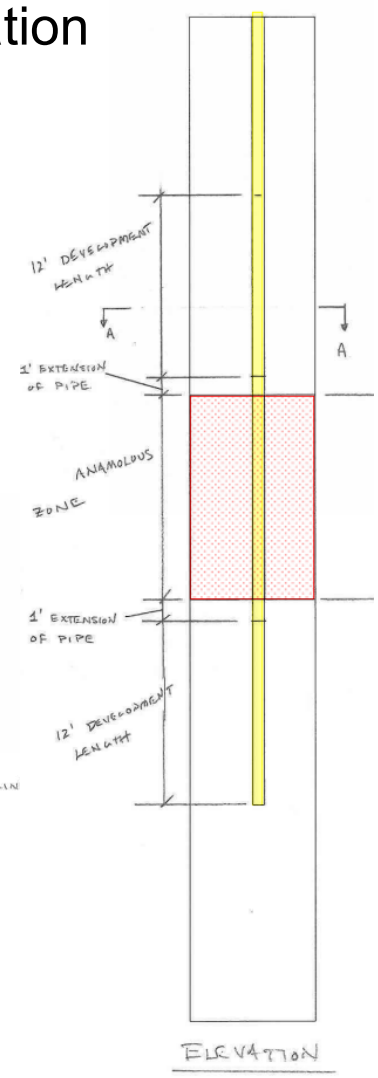
- Hydro-demolition And High Pressure Grouting
  - Successful At Other Shafts
  - Anomaly Too Large, Risk Pressure Loss
  - QA Difficulties

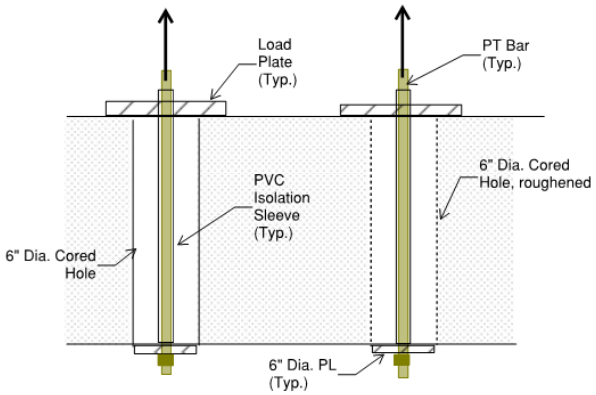


Shaft 235 Repair: Options

- Innovative Micropile Installation
  - Field Tested For Bond
  - Modeled In Fb-pier
  - Lacked Shear Capacity



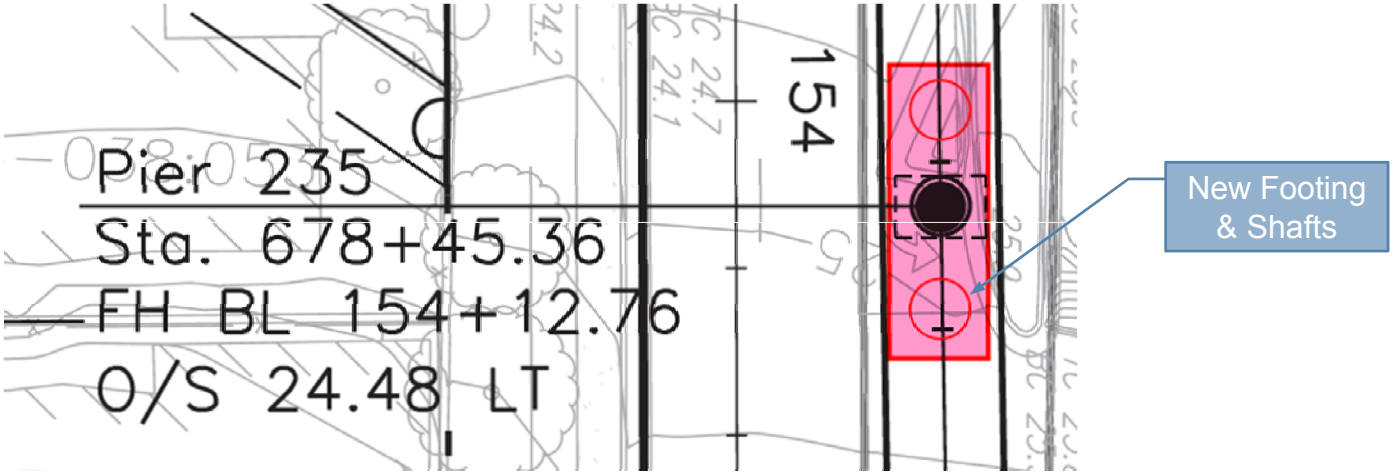




Before test...concrete surface has been ground smooth and new jack chair with plates distribute load to concrete.

Shaft 235 Repair: Options

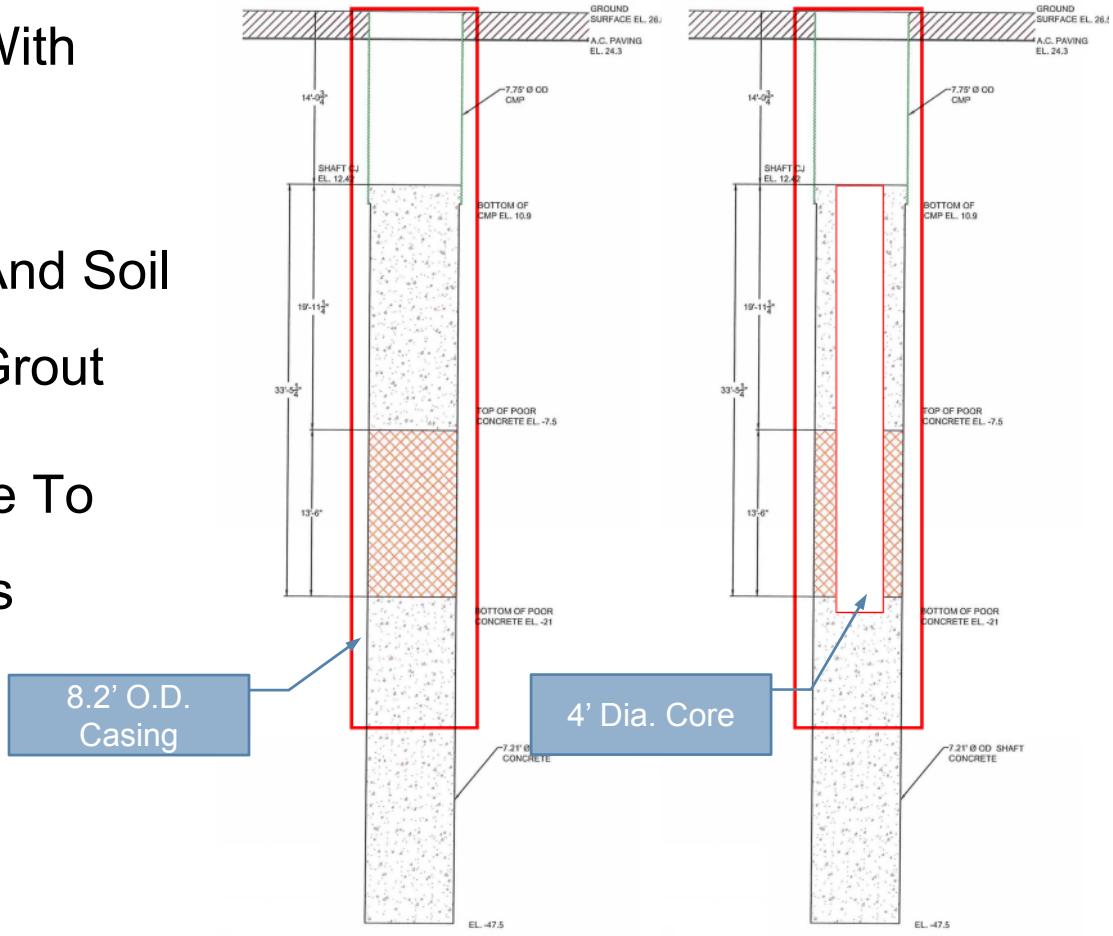
- "Sister" Shafts With Cap
  - Limited Footprint
  - Load Distribution Impacts
  - Long Material Lead Times
  - Cost & Schedule Prohibitive



Shaft 235 Repair: Plan

Plan → Analyze → Execute → Recovery

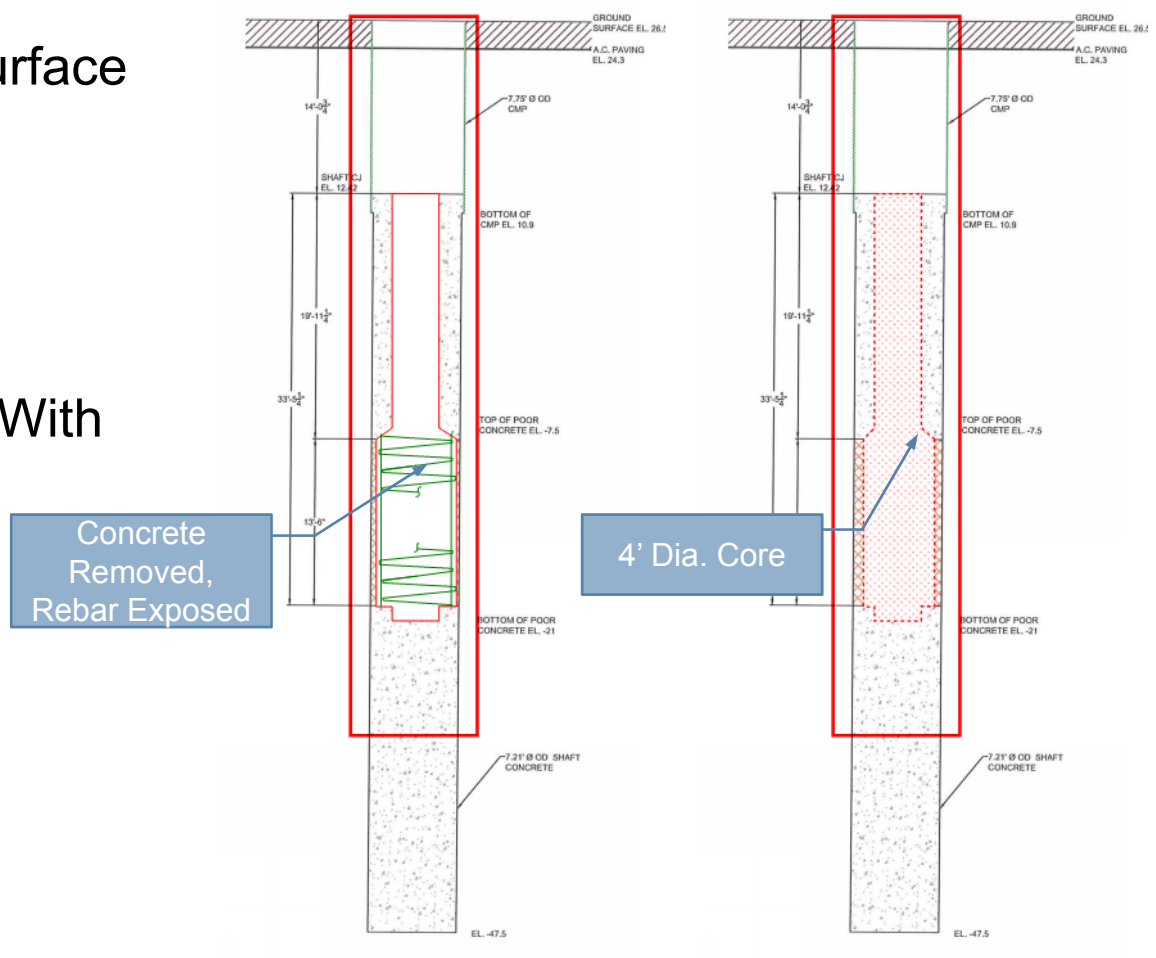
- Replace Poor Material With New Concrete
- Seal Out Groundwater And Soil With 8.2’ OD Casing + Grout
- 4’ Diameter Central Core To Gain Access To Regions



Shaft 235 Repair: Plan

Plan → Analyze → Execute → Recovery

- Final Demolition And Surface Preparation By Hand
- Inspection
- Concrete Replacement With Self-consolidating Mix
- Post-repair Evaluation



Shaft 235 Repair: Designer Responsibility

Plan → Analyze → Execute → Recovery

- Evaluate Stability At Each Stage
- Analysis Of Proposed Repair
- Verify Composite Behavior
- Impact Of Installing Casing (SWI)
  - To Existing Shaft
  - Performance Of Final Condition
- Inspections
- Final Analysis

Shaft 235 Repair: Execute

- Installing Casing and Coring

Plan → Analyze → Execute → Recovery

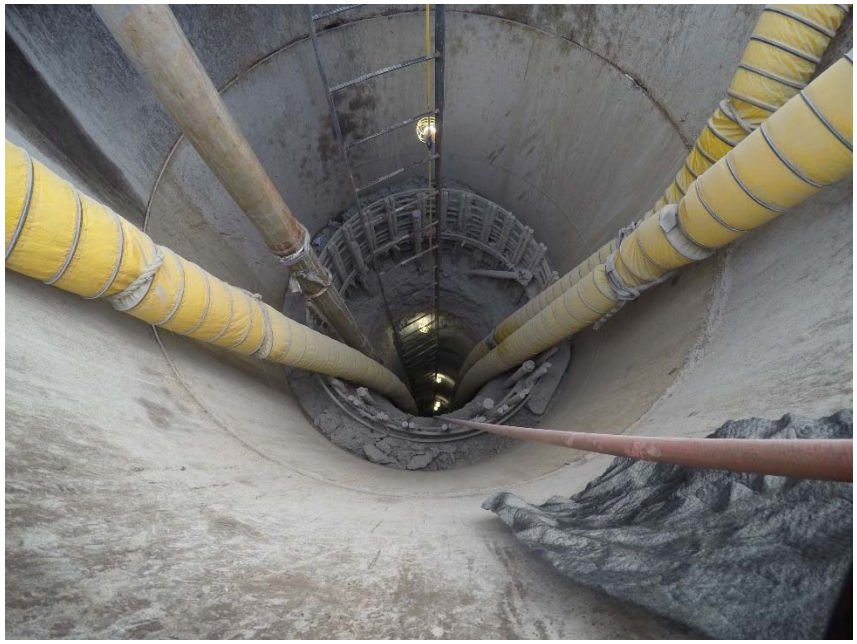
Shaft 235 Repair: Execute

- Installing Casing and Coring

Plan → Analyze → Execute → Recovery

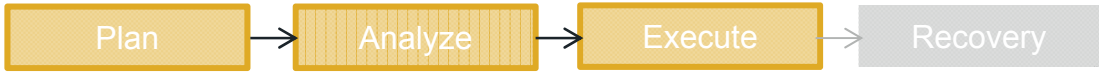
Shaft 235 Repair: Execute

- Inspection



Plan → Analyze → Execute → Recovery

Shaft 235 Repair: Execute

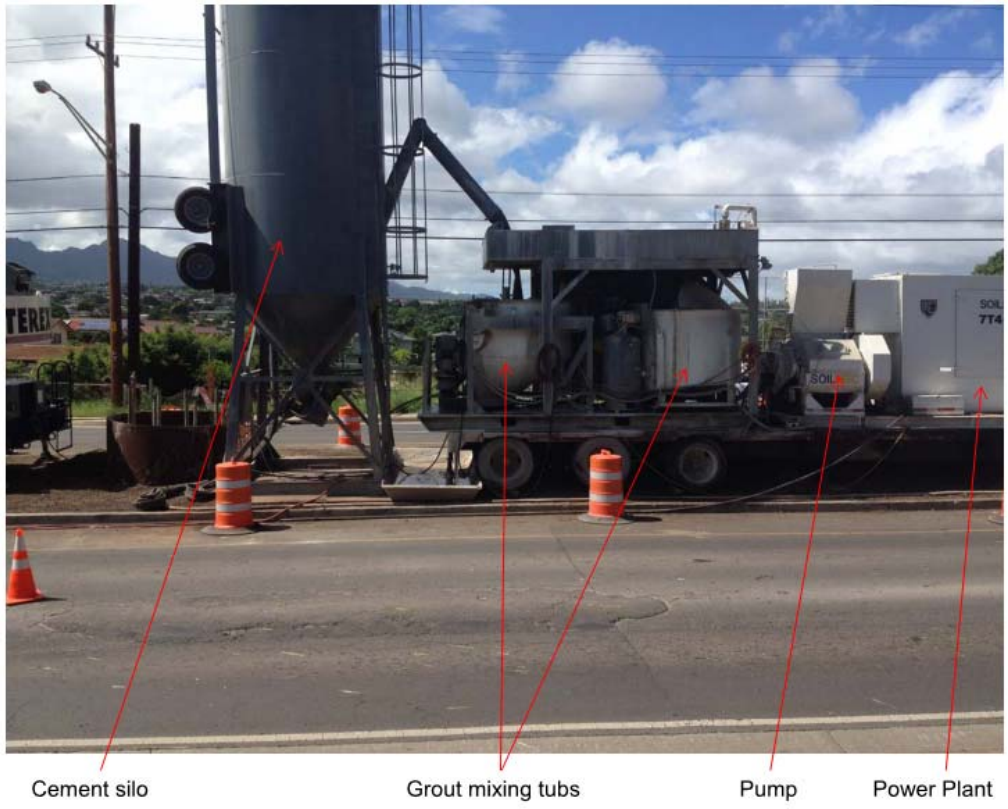


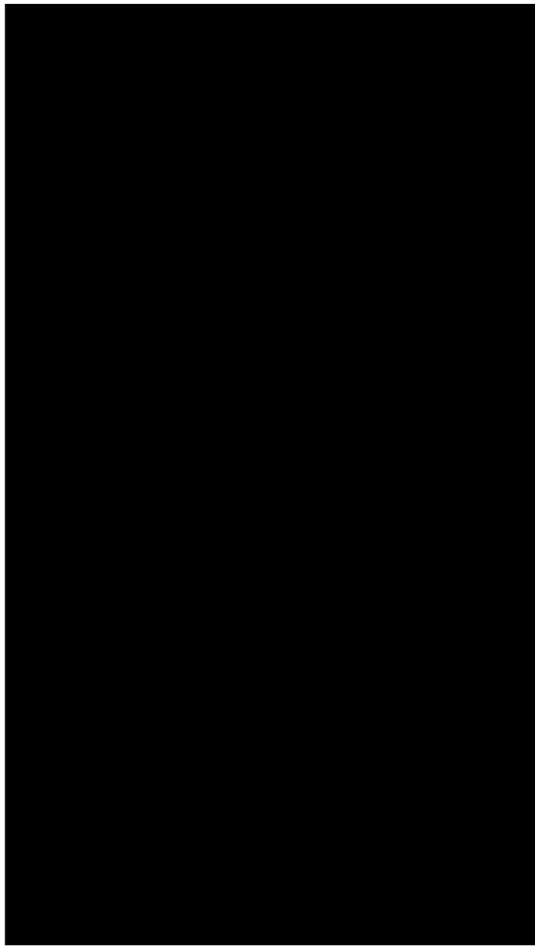
- Inspection

Shaft 235 Repair: Execute

- Repair & Pour Back

Plan → Analyze → Execute → Recovery

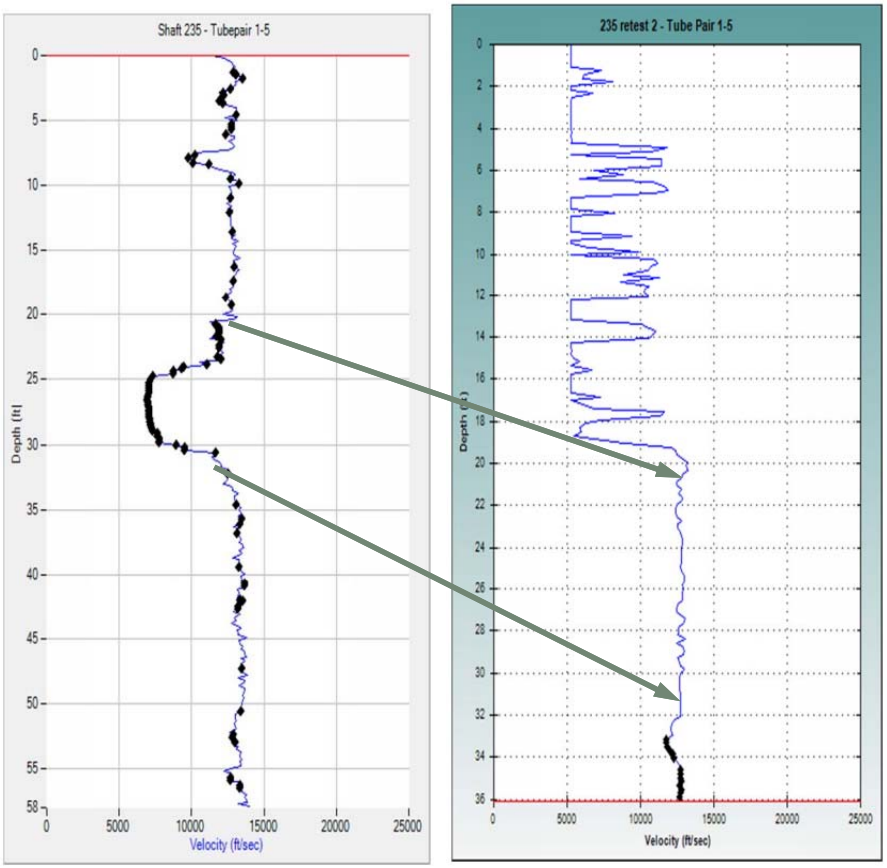




Shaft 235 Repair: Recovery

Plan → Analyze → Execute → Recovery

- CSL Re-testing & Verification Coring
  - Damaged CSL Tubes

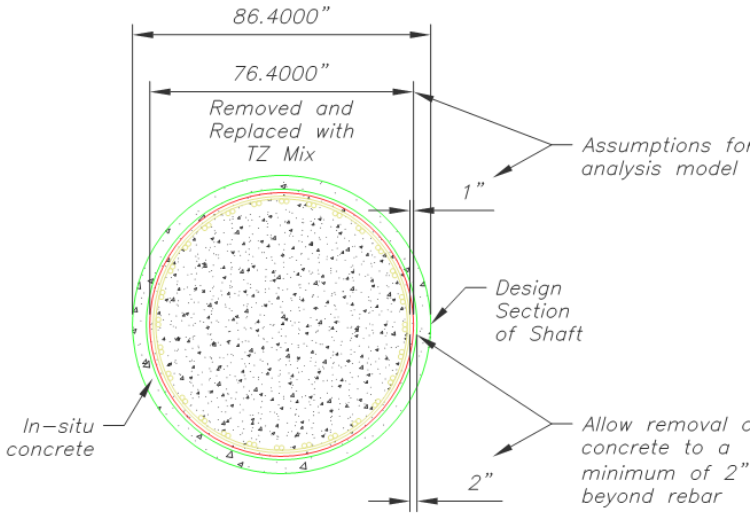


Cyl ID	Cast Date	Break Date	Age	Description	Frac Type	Test Load	Test PSI	Spec PSI
13494	10/27/15	11/24/15	28	Shaft 235 repair	3	102695	8170	6500
13495	10/27/15	11/24/15	28	Shaft 235 repair	3	103190	8210	6500
13496	10/27/15	11/24/15	28	Shaft 235 repair	3	96240	7660	6500

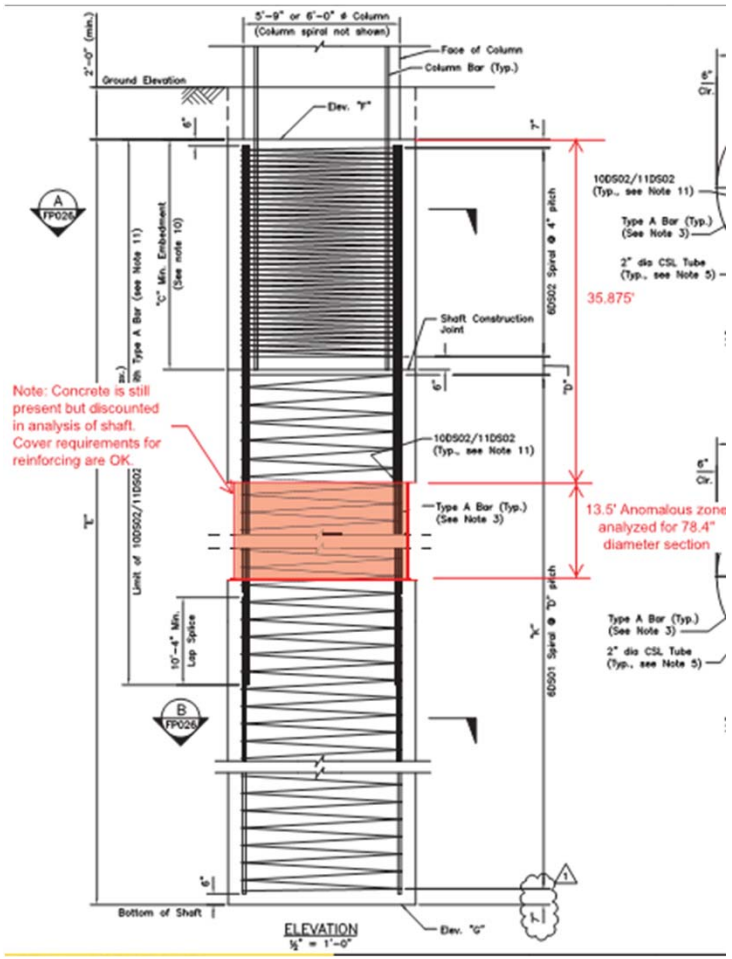
Shaft 235 Repair: Recovery

Plan → Analyze → Execute → Recovery

- As-built Analysis Via Fb-pier
  - Verify Force Distribution
  - Confirm Capacity



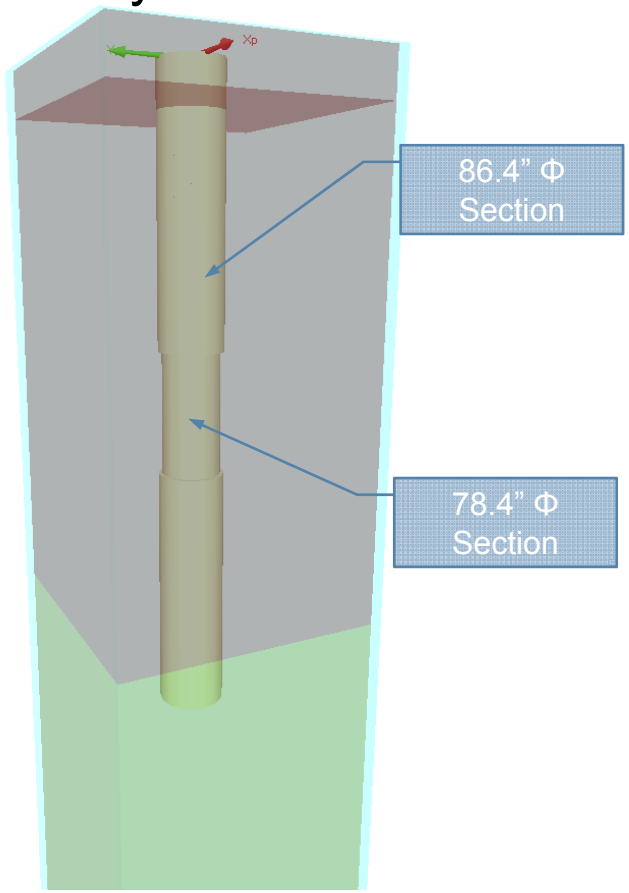
Typical Section Through 13.5'-Deep Anomalous Region

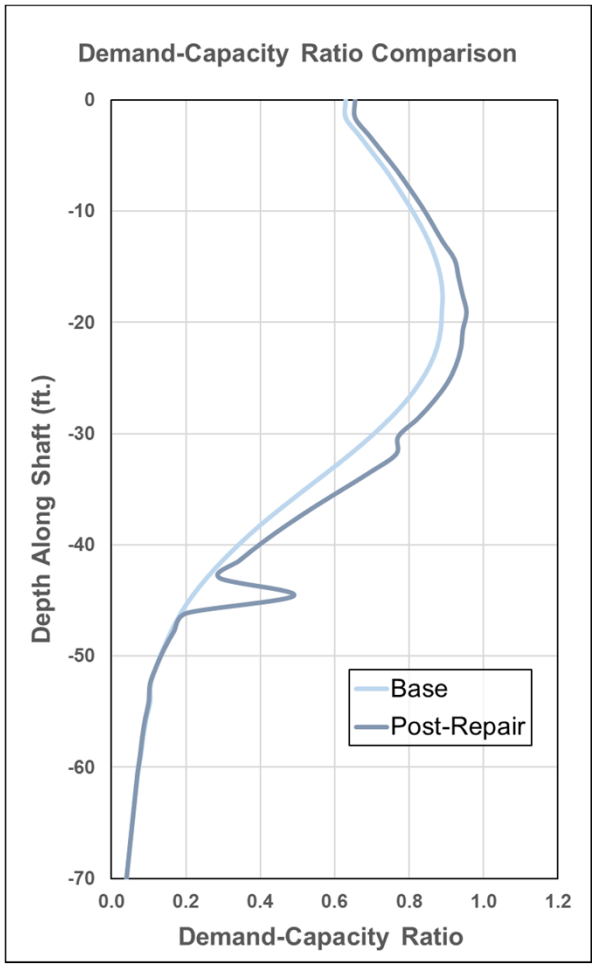


Shaft 235 Repair: Recovery

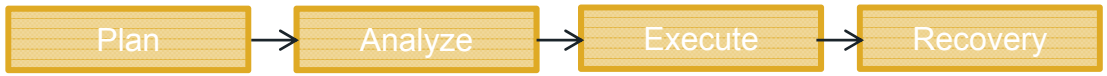
Plan → Analyze → Execute → Recovery

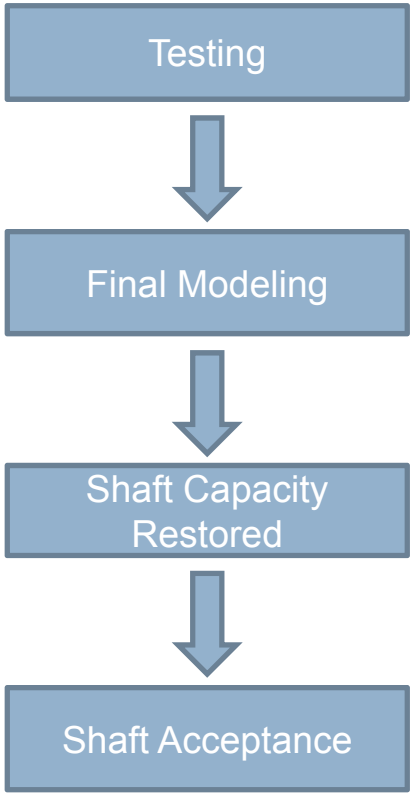
- As-Built Analysis via FB-Pier





Shaft 235 Repair: Recovery



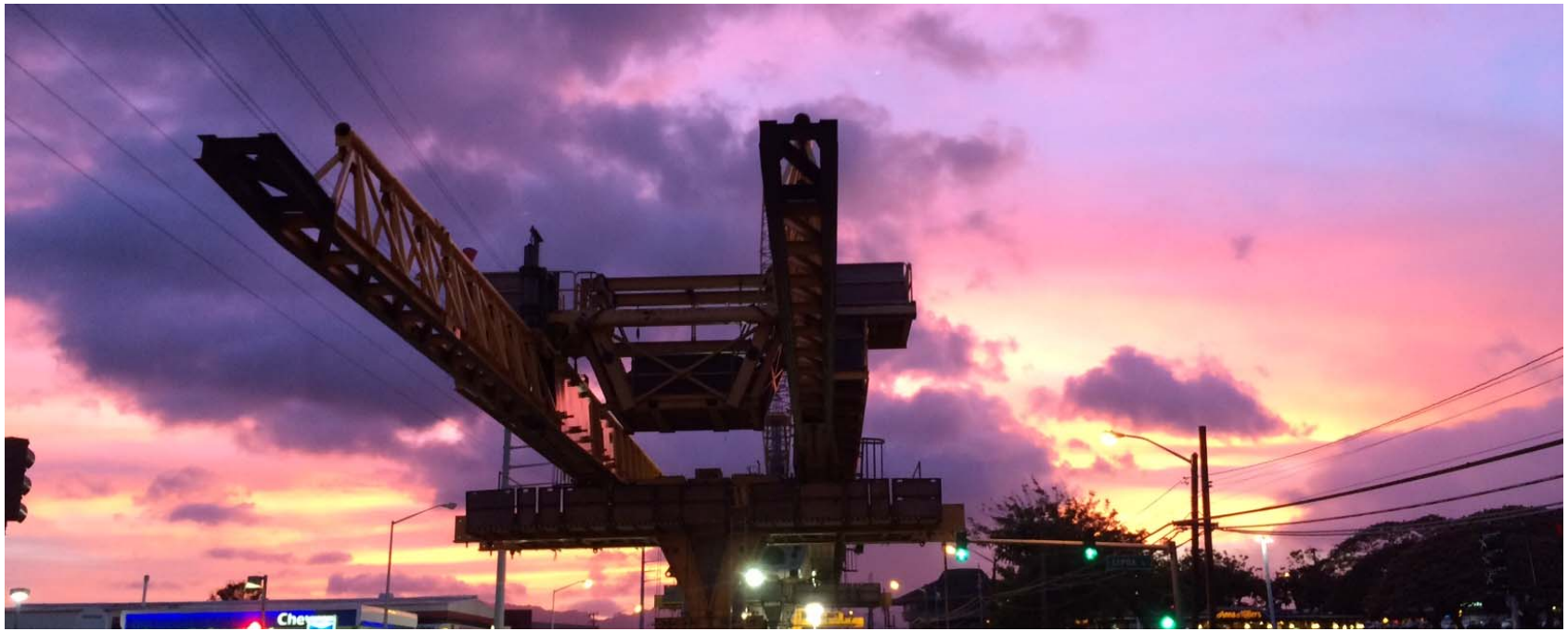


Conclusion

- Had Bad Concrete
- Developed And Vetted Solutions
- Implemented And Followed Quality Plans For The Repair
- Provided An End Product That Would Perform As Intended

Lessons Learned

- What Led To The Poor Concrete
- Teamwork Combined With Early And Often Engagement Is Mission Critical
- Don’t Overlook The Straightforward Approaches



Special Thanks to Those Making It Possible

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SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

AFT Applied Foundation Testing

- HNTB
  - San Jose, CA
  - Oakland, CA
  - Lake Mary, FL
  - Kansas City, MO

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Questions?

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