Drilled Shaft Base Grouting – Zoo Interchange Project

Midwest Geotechnical Conference

East Lansing, Michigan

October 18, 2016

Bob Arndorfer

Project Background

- Located in Milwaukee
- SE Part of State
- Largest WisDOT Project to Date - >$1B
- Biggest Part is Zoo Core Interchange
- Flyovers With Three Levels
- 65 Bridges ≈ 1.2M sqft Bridge Deck
- 5 Year Construction Program
- Build Under Traffic

Project Background – Cont'd.

- Complex Urban Site
- Many Utilities In This Congested Area
- Consultant Design
- First WisDOT Use of Shaft Base Grouting (i.e. Tip Grouting or Post Grouting)
- First Use of Non-redundant Deep Foundations
- Completed Shaft Load Test Program – 6 Shafts, Presented at 2013 MWGC

General Map

- System-System Interchange
- Major Players Involved
- Adjacent to County Zoo

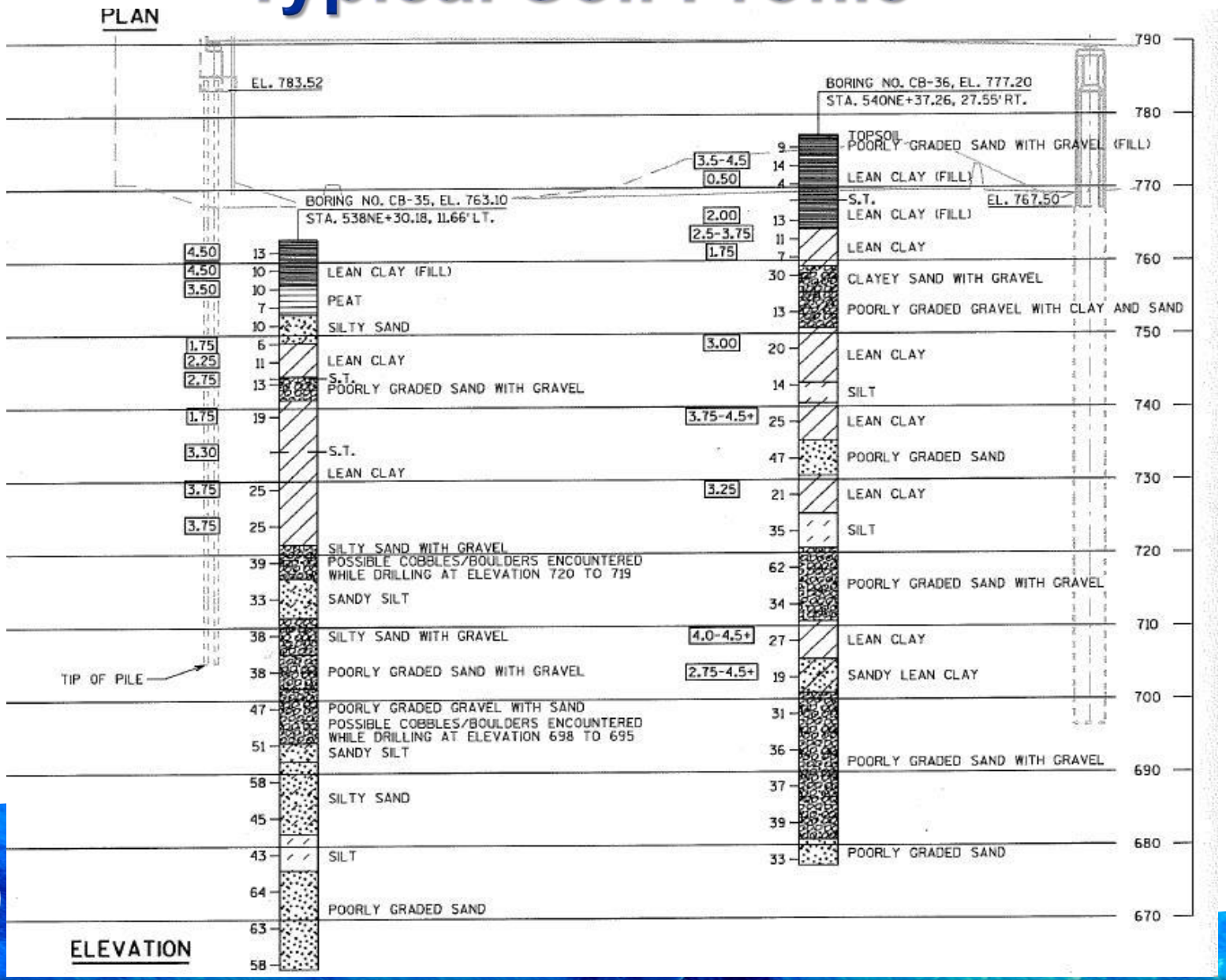
Rendition of Zoo Core Interchange

N

Geotechnical Site Characteristics

- Glacial Till/Outwash Soils
- Generally Consists of Clays and Silts That Can Be Mixed With Sands, and Sand Layers
- Can Find Layers of Sand/Gravel With Cobbles
- Profile is Not Very Consistent Between Borings
- Blow Counts 10-50
- Unconfined Compressive Strengths 1.5-4.5 tsf
- Dolomite Bedrock Generally 120’ Deep
- Watertable Generally 10-25’ Deep

Typical Soil Profile



Why Drilled Shafts?

- WisDOT Uses Shafts Sparingly
- Limited Number of Shaft Contractors in Wi
- Foundation Demands
  - Tall piers
  - Large overturning moments
  - Large axial loads
  - Large lateral loads
  - Would require large pile substructers
- Speed of Construction

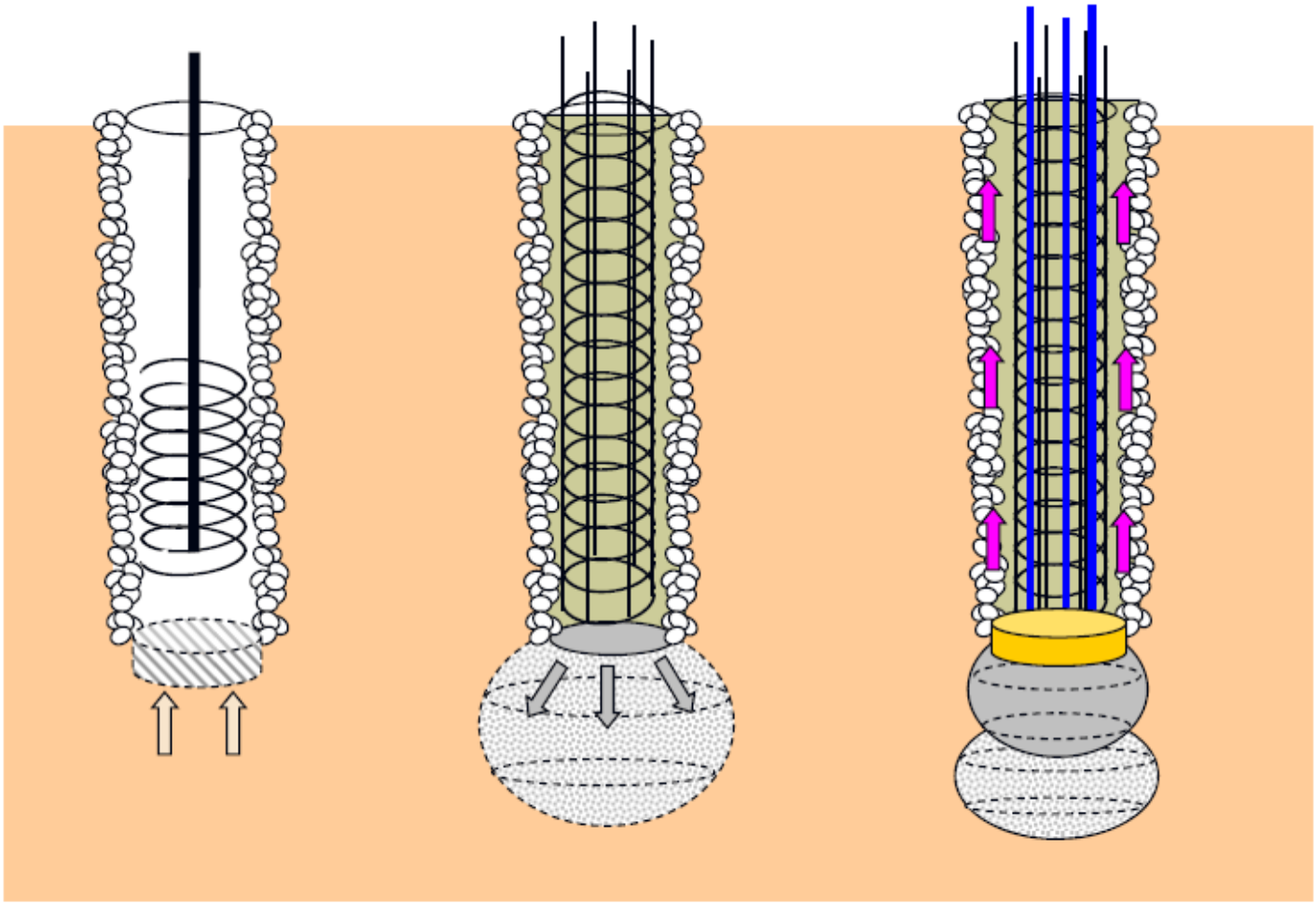
Why Drilled Shafts – Cont'd.?

- Footing Constraints – Smaller Footprint
  - Limited physical room for foundations
  - Underground utility conflicts
  - Overhead clearance problems
  - Staging/Traffic sequencing issues
- Cost Competitive

Base Grouting

- Been Done in US Over Last 15 Years – Generally Not Used On Many D-B Projects
- Most Done By Applied Foundation Testing (AFT) From Florida
- Benefits in Loadings/Resistance Factors
- Concern Over Non-redundant Foundations
- Limited Experience With Large-diameter Shafts
- **But**, Limited AASHTO Guidance on Design Methodology and How to Include Benefits in Design Process – FHWA Current Research

Base Grouting Basics



Disturbed bottom due to excavation and stress release

Water/ slurry percolation increases soil compressibility

Post grouting compensates soil compressibility and develops side friction, increasing stiffness and area

Benefits of Base Grouting

- Increase Usable Base Resistance (Higher ϕ)
  - Preloading base
  - Improving base soils – compaction/permeation
  - Increasing tip area – In some cases
  - Improve side resistance – upward grout movement
- Decrease Settlement
- Improve Reliability of Base Resistance
- Reduce Construction Risk – Increase Confidence Level
- Shorter or Smaller Shafts

Benefits Cont'd.

- Acts as a Partial 'Load Test' to Confirm Design Assumptions
- Improve Strain Compatabiliy Between Base and Shaft - Skin Friction and End Bearing Resistances Act Simultaneously
- Produces an Upward Reaction to 'Pre-load' Side Friction
- Compresses Base Soils to Reduce Soil Disturbance Due to Drilling Operations
- Generally Used For Granular Base Soils

What Base Grouting Is Not

- Is **Not** a True Load Test Unless Base Grout Pressures Are Equal to Applied Loads + Shaft Dead Load
- Is **Not** a Substitute For Proper Shaft Construction Operations/Inspection and Base Cleaning
- Does **Not** Remediate Shaft Defects/Issues
- Not All Base Grouters Are Equal

Base Grouting Design

- How To Account for Base Grouting In Design?

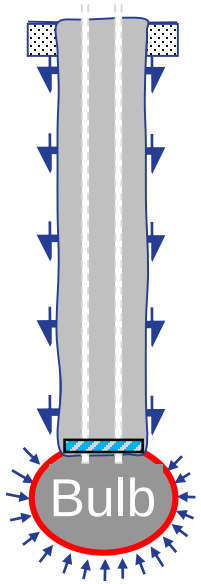
- Design Based on GEC 10 and AASHTO Code
- No AASHTO Guidance on Shaft Design Methodology When Base-Grouted
- Neither Design Guide Provides Resistance Factors When Base Grouting is Done
- Worked With Ben Rivers and Jerry DiMaggio on Design Methodologies/Resistance Factors

Base Grouting Design – Cont'd.

- 2012 FHWA/ADSC Synthesis Report On Post-Grouting of Drilled Shafts
- 2015 Workshop on Post-Grouted Shafts – FHWA, DFI, ADSC, CalTrans
- Use Tip Capacity Multiplier (TCM) Factor
  - TCM Used to Increase Base Resistance
  - Computed By Following GEC 10
  - Methodology Based on Tip Founded in Granular Soils
- No Guidance If a Reduction Factor Should be Applied to TCM Value (Used 1.0)

Base Grouting Design – Cont'd.

- Shaft Side and Base Resistances are Based on Vertical Displacement of 5% of Diameter
  - This value is excessive for serviceability
  - Used design value of 1"
- Checked Both Service and Strength Limits, Service Generally Controlled



Base Grouting Design – Cont'd.

- Used 0.7 Reduction Factor (AASHTO for Load Tests) for Both Side and Base Resistances
- Reduced by Another 20% for Non-redundant Application
- May Need to Consider Site Variability Factor
- WisDOT Final Shaft Reduction Factor of 0.56
- Neglect Side Resistance 0-5' Below Ground Surface (BGS)
- Limit Side Resistance 5-10' BGS to 1000 psf

Drilled Shaft Background

- Large (8 & 10'ϕ) Single Shafts (Non-redundant) Under Many Piers – 1st for WisDOT
- 30-40% of Shaft Resistance in Side Friction
- Base Grouting Allowed Shorter Shaft Lengths
- Alternative Foundation Designs in Plans – On 18 of 51 Flyover Ramp Foundations
- Pre-qualified Drilled Shaft Contractors
  - Large-diameter (>6 feet diameter) + Base-grouted
  - 6 approved (Case, Kiewit, Malcolm, Michels, Walsh)

Base Grouting – Spec. Highlights

- Required Prequalified Shaft and Base-Grouting Contractor Teams
- Grout: 2500 psi @ 28 Days
- Grout Pump of 800 psi Required
- Redundant Grout/Flush Pump Required on Site
- Base Gravel Pack Allowed
- End Grouting Criteria Set

Base Grouting Criteria

- Need to Meet One of the Following 3 Criteria
  1. All of the Following Are Met:
     - Minimum Grout Volume
     - Minimum Grout Pressure
     - Minimum Upward Movement – 0.125”
  2. Maximum shaft upward movement – 0.4”
  3. Grouting pressure reaches maximum rating of the pressure grouting equipment and lines (800 psi min.) This usually governed.
- All Shafts Took Min. Grout Volume, and Most Had Just Under 0.125” Movement

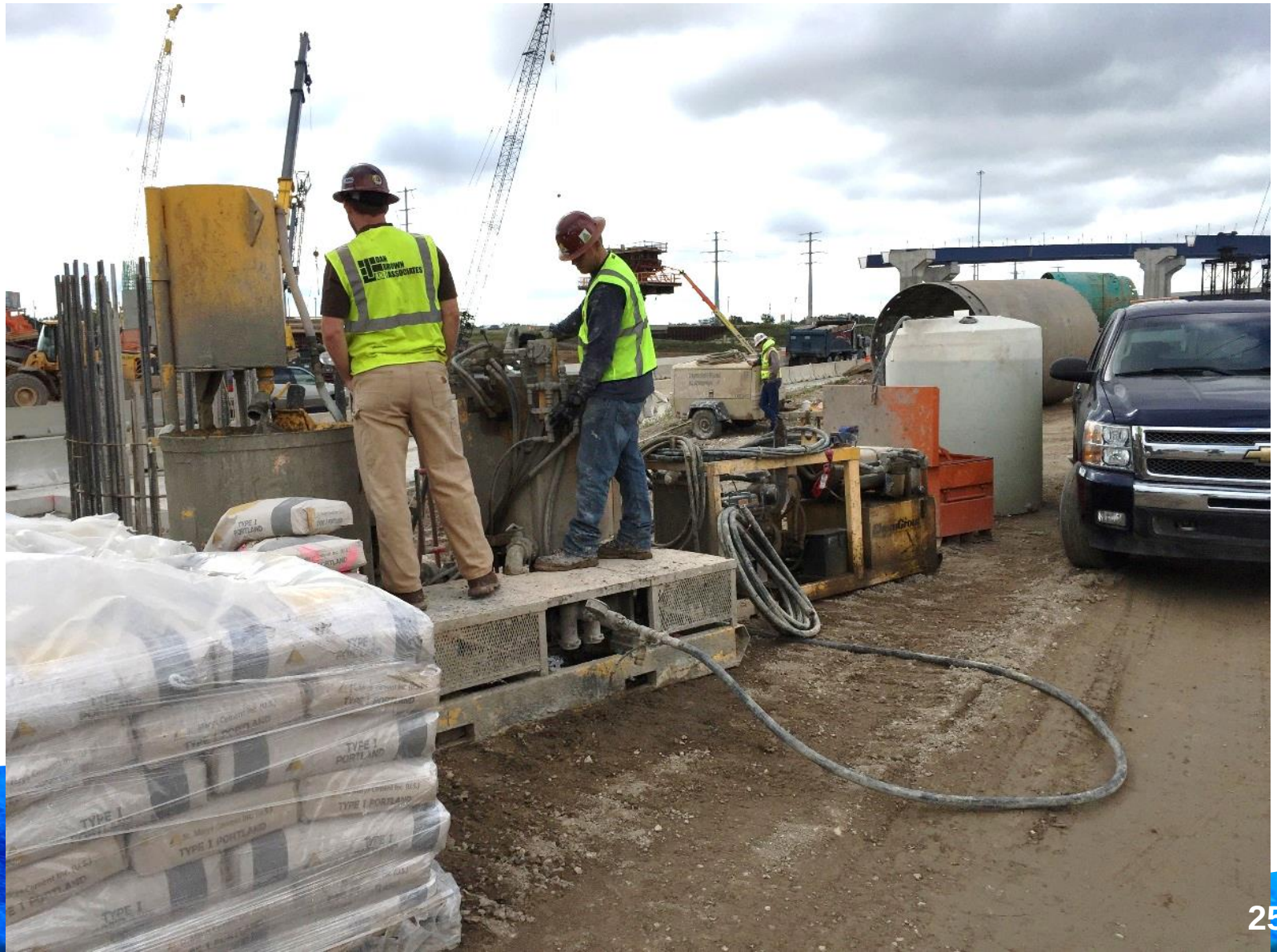
Base Grouting Aspects

- CSL Tubes Used to Deliver Grout
- Sleeve-port (Tube-a-Manchette [TAM]) Grout Tube Delivery System Used
- W/C Ratio: Generally 0.4 - 0.6
- Design Pressures Range from 450-600 psi
- Grout Volumes Exceeded Min. Required
- Some Shafts Needed Second Stage of Grouting, and One Took Three Stages
- Digital Level Used to Measure Movement

Grouting Equipment

Grouting Equipment

Grouting Equipment



Bottom Grout Tubes

Bottom Grout Tubes – Cont'd.

Packer Tubes

Packer Manifold Controls

Starting to Pump Grout

Grouting – Before Lock-off

Measuring Movement

Field Grout Report

Report on Drilled Shaft Base Grouting

General Information

Report Date:	September 19, 2016
AFT Project No.:	815121
Project Description:	Zoo Interchange – Phase 2
Client Name:	WALSH Construction
Client Address:	615 S. 89th St. Suite A Milwaukee, WI 53214
Client Contact:	Nicholas Reichl
Post Grout Date:	September 16, 2016
AFT Post Grout Specialist on Site:	Jordan Neslon, John Perrie
AFT Responsible Engineer:	Michael K. Muchard, P.E.

Drilled Shaft Information

Shaft Number	Diameter (feet)	Length (feet)	Installation Date	Gravel Bedding Depth (feet)
WN11	9.84	37.5	7/30/2016	1

Shaft Tip Elevation (feet)	Top of Concrete Elevation (feet)
+708	+745.5

Note: Drilled shaft information shown above provided to AFT at the time of this report and is provided **for information only**. AFT was not under contract to document the shaft construction. The information above may vary from the final contract record documents. Therefore, the reviewer should reference the contract construction documents.

Post Grout Information

Grout Distribution Apparatus Type:	Tube-a-Manchette w/48" Plate – 4 U-Tubes
Grout Tube Type:	2.0-Inch I.D. (standard) steel pipe
Number of Grout Tubes:	8
Average Tube Length (feet):	50.25 feet
Volume of Grout Tubes (cubic feet)	2.21 ft^3 per u-tube circuit
Grout Delivery Line Volume (cubic feet):	1.0 inch I.D., 50 ft hose =0.25 ft^3
Grout Plant Type:	ChemGrout CG600, 800 psi max, Double Acting Pump with Colloidal Mixer and Agitated Holding Tank.
Grout Type:	Type I/II Portland Cement and Water – W/C Ratio range 0.45 to 0.5 (adjusted as needed in field as shown on the Drilled Shaft Base Grouting Log)

Post Grouting Criteria

Design Grout Pressure:	300 psi for 2 minutes
Maximum Upward Shaft Displacement:	0.4 inch (measured at shaft top)
Minimum Grout Volume: (NET pumped to the toe of shaft)	18.26 cubic feet

Post Grouting Measurements and Instrumentation

Grout Pressure:	1) Manual Oil Filled Bourdon Gage
Upward Shaft Displacement:	1) Manual Survey
Grout Volume:	Stick Ruler in Holding Tank (Calibration 1-inch=0.483 cubic feet)
Other Instrumentation:	N/A

Summary of Post Grouting Results

Maximum Grout Pressure (psi)	Measured Upward Shaft Top Displacement During Grouting (inches)	Calculated Upward Bottom of Shaft Displacement (inches)	Gross Grout Volume (cubic feet)	Estimated Net Grout Volume Placed(1) (cubic feet)
900	0.112 Maximum 0.106 Final	0.2557 Maximum	59.65	41.39

1. Estimated Net Volume = Gross Grout Volume – Grout Volume of Tubes and Lines – Grout Volume of Voids in Gravel Bedding
   Also note that the net volume reported in the table above is a corrected calculation and the presiding value should it be different than in the field logs.

Figures and Attachments

Figure 1 - Grout Pressure vs. Time (Bourdon gage)
Figure 2 - Grout Pressure and Gross Grout Volume vs. Time
Figure 3 - Grout Pressure and Displacement vs. Time

Attachment - Drilled Shaft Base Grout Field Records

Post Grouting Comments

The shaft was post grouted to maximum pressures of 900 psi, which is above the target design pressure. The maximum top of shaft displacement was 0.1120 in. The maximum calculated upward bottom of shaft displacement was 0.2696 in. The net volume of grout pumped was 41.39 ft^3.

Field Grout Pressure vs Volume

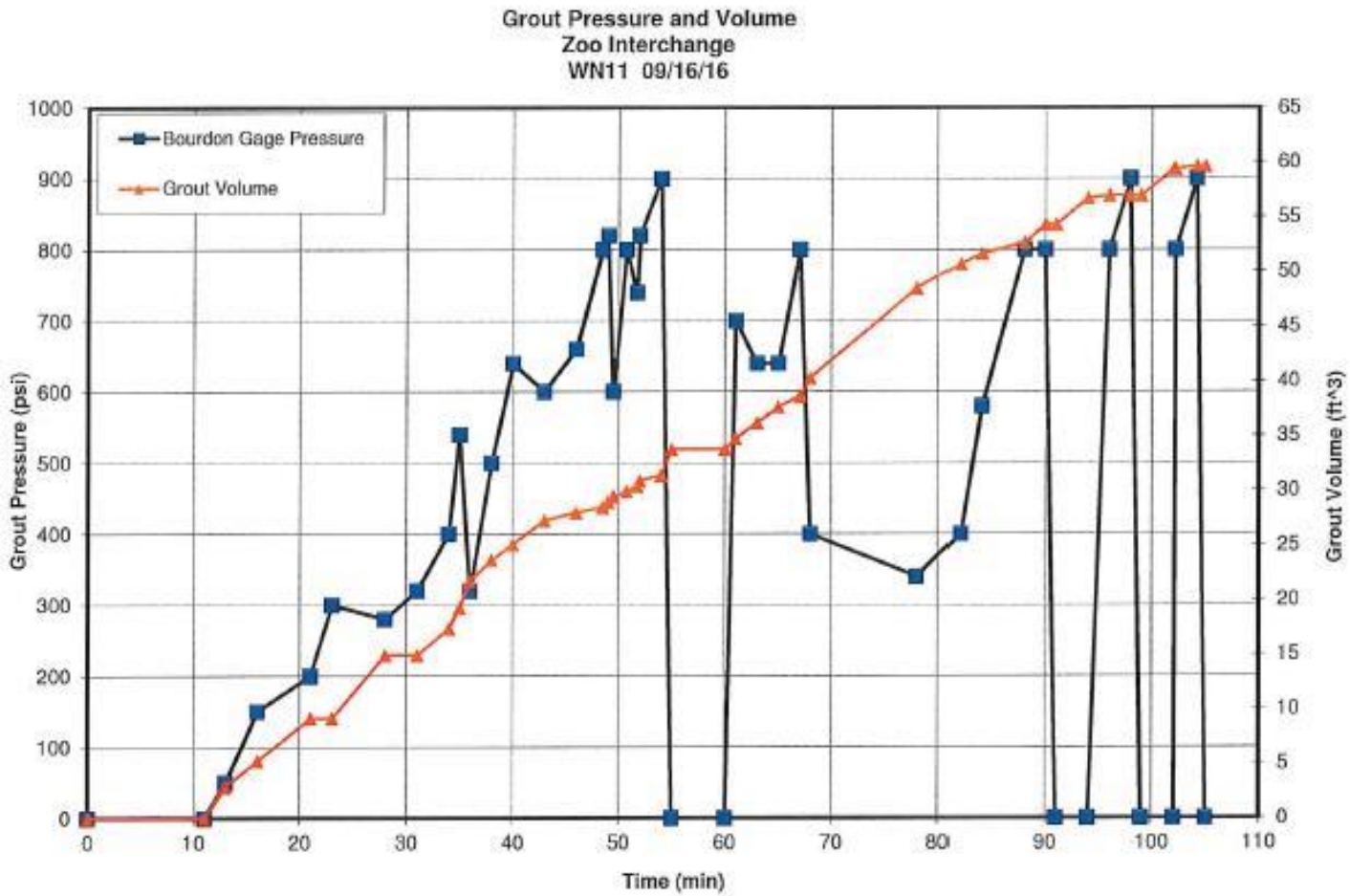


Figure 2

Applied Foundation Testing

Field Grout Pressure vs Movement

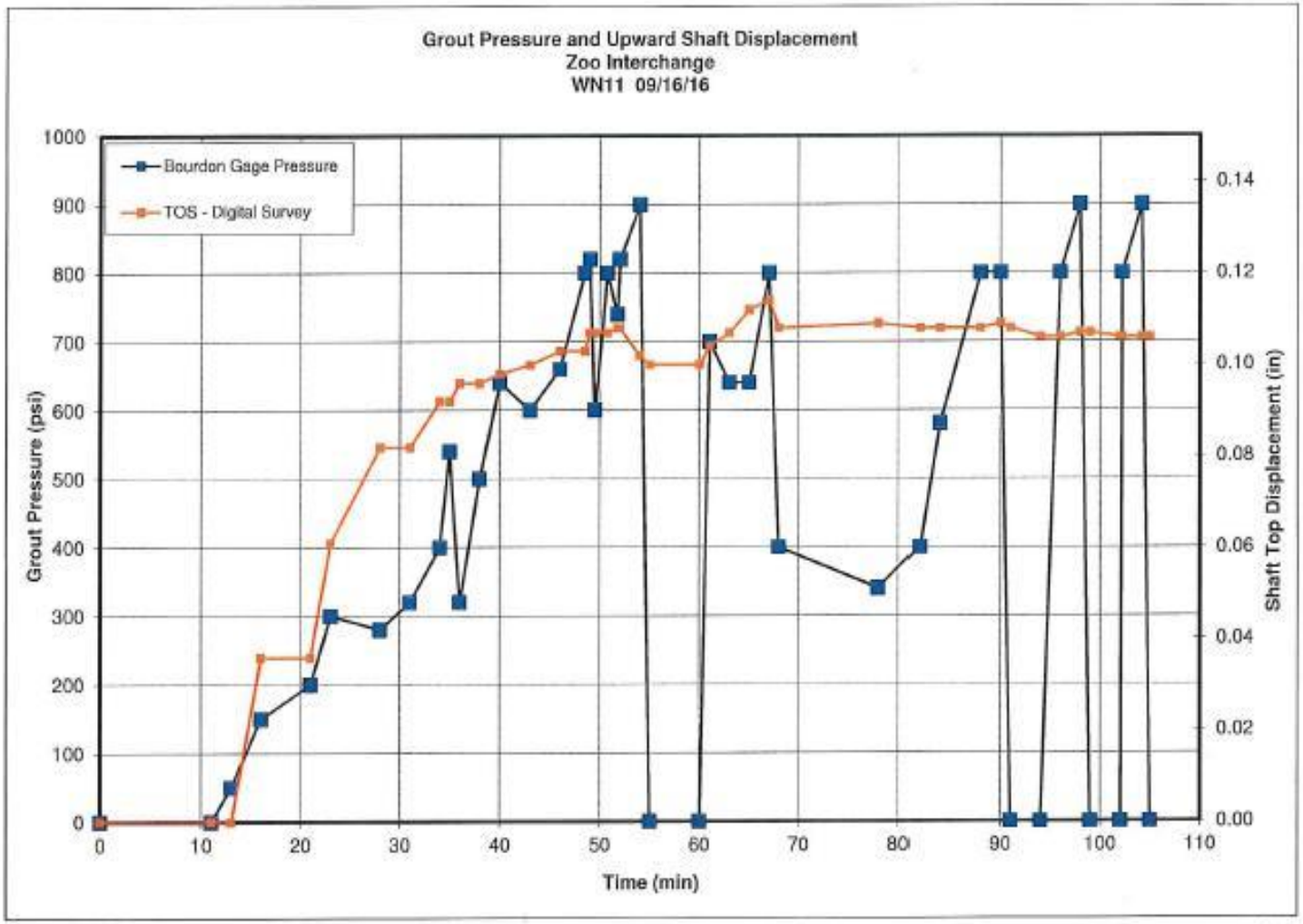


Figure 3

Applied Foundation Testing

Things We Learned

- Need Proper Grouting/Pumping Equipment in Good Operating Condition
- Redundant Grout Delivery System is Good
- Recommend Using Experienced Contractor
- Need to Make Real-time Decisions During Grouting Operations
- Used Clean Granular Gravel Pack
- Does Take Some Time to Complete

Conclusion

Things We Learned – Cont'd.

- Can Still Have Shaft Issues, Even With Base Grouting
- Base Grouting Does Not Remediate Shaft Defects/Issues
- Base Grouting Is Not a Substitute For Proper Shaft Construction Operations/Inspection and Base Cleaning

Base Grouting Costs

- 3 Bidders
- Alternate Foundations: 1-Shafts, 2-Piles

Item	Unit	Bidder 1*	Bidder 2	Bidder 3
Base Grouting	Each	$10,700	$22,000	$2,000
59”ϕ Shaft	Lin Ft	$805	$1350	$1370
98”ϕ Shaft	Lin Ft	$1120 - $1400	$2000	$2370
118”ϕ Shaft	Lin Ft	$1600 - $1650	$2200	$3017

Moving Forward

- Don’t Have Many Future Projects With Extensive Shaft Needs
- When WisDOT Does Use Shafts, Generally Involves Multiple 3-4’ϕ Shafts
- Will Incorporate Lessons Learned From Zoo Projects
- Will Probably Use Base Grouting Again if Have Similar Demands/Applications

Questions

- **Questions?**