LADOTD Drilled Shaft Design and Construction Practice

THIS IS HOW WE DO IT!

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Overview

- Drilled Shaft Selection
- Geotechnical Engineer’s Role during Design Phase
  - Design Criteria and Manuals
  - Axial and Lateral Geotechnical Resistances
  - Selection of Load Test and Resistance Factors
  - Drilled Shaft Data Table
- Geotechnical Engineers Role during Construction Phase
  - Review Drilled Shaft Installation Plan (DSIP)
  - Evaluate load test results to determine production shaft lengths
  - Review integrity testing results
- 2016 Standard Specifications overview
Drilled Shaft vs Driven Pile

- When should Drilled Shafts be considered instead of Driven Piles
  - Subsurface conditions that will make it difficult to drive piles
    - Hard Clay Soils
    - Very Dense Sands
  - Project Site Constraints
    - Reduce foundation size/footprint
    - Low overhead
    - Mitigate vibration concerns
  - Structural Loads
    - High axial loads
    - Lateral loads
Design Criteria

- AASHTO LRFD Bridge Design Specifications
  - Section 3
  - Section 5
    - 5.13.4.5 Cast In Place Piles
  - Section 10 Foundations
    - 10.5.5.2.4 Resistance Factors
    - 10.8 Drilled Shafts
- Bridge Design Technical Memorandum 32.2 (BDTM.32.2)
- Bridge Design Manual
- Geotechnical Design Manual
Design Manuals

FHWA-IF-99-025

FHWA-NHI-10-016
Limit States

- **Strength Limit State**
  - Axial factored resistance at 4-5% of diameter
  - Deflection using factored lateral resistance limited to 10% of diameter
  - Shaft group efficiency evaluated using factored resistance

- **Service Limit State**
  - Load-Transfer Settlement limited to 0.5 inches
  - Lateral deflection limited to 0.5 inches
  - Settlement of shaft groups estimated using group load

- **Extreme Limit State**
  - Nominal resistances used for all loading types
Axial Resistance Calculations

- Cohesionless Soils
  - Side Resistance: β-Method
  - Tip Resistance: Reese & O’Neill Method
- Cohesive Soils
  - Side Resistance: α-method
  - Tip Resistance: Total Stress Method
- Affect of construction methods
- Resistance Factors
  - AASHTO Table 10.5.5.2.4-1
  - Factors applied to each layer
- Computer Programs
  - Ensoft Shaft2012
Drilled shafts will have a certain amount of load-transfer settlement in order to mobilize axial resistance.

Strain compatibility of side and base resistances must be considered:
- Full side resistance mobilizes at 0.1 to 1.0 percent of shaft diameter.
- Full base resistance mobilizes at 4.0 to 5.0 percent of shaft diameter.

Load-transfer settlement should be estimated using the Normalized Load Displacement Curve (FHWA 2010).

Does not include consolidation settlement.

Figure 13-10: Normalized Load-Displacement Curve, Drilled Shaft in Axial Compression (Adapted from Chen and Kulhawy, 2002)

FHWA-NHI-10-016
Lateral Resistance

- Analysis performed using p-y curve analysis
- AASHTO recommends a resistance factor of 1.0 for geotechnical lateral resistance
- FHWA Drilled Shaft Manual recommends resistance factor of 0.67 for geotechnical resistance.
- For strength limit state apply resistance factors of
  - $\Phi = 0.67$ used to perform “push over” analysis
  - $\Phi = 1.0$ used to determine maximum shear and bending moment
- Estimate lateral deflection at service limit state using nominal resistance
- Computer Software
  - Ensoft LPile2013
Scour Zone Resistance
(AASHTO Section 10.X)

- Any side resistance derived in the scour zone should not be included in the ultimate nominal resistance
- Overburden effect in cohesionless soils must be considered
- Method of isolating side resistance in scour zone on test shafts must be considered
Downdrag (Negative Side Resistance)  
(AASHTO Sections 3.4, 3.11.8, 10.8)

- Downdrag should be investigated for any shafts constructed through a new or existing embankment that may settle after shaft construction is complete.
- Downdrag shall be considered a load in both the Strength and Service States as specified in Section 3.4 of AASHTO.
- Structural resistance of shaft should be evaluated.
- When possible surcharging or other methods to accelerate or reduce embankment settlement should be used prior to drilled shaft construction to mitigate downdrag.

Figure 13-19 Downdrag on a Drilled Shaft Caused by Soil Settlement

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Test Shaft and Load Testing

- Test shafts allow for higher resistance factors than static calculations
- Resistance factor is dependent on type of test
- Although load testing is typically performed during the construction phase of a project, the designer should be involved with reviewing the test set-up and results to determine production shaft lengths
- Three Types of load test have been commonly used
  - Static
  - Bi-Directional (O-Cell®)
  - High-Strain Dynamic
Static Load Test

- Corresponding resistance factor $\varphi=0.70$
- Advantages
  - Direct measurement of axial resistance
  - Relatively simple testing procedure
  - Shaft can be instrumented to determine resistance distribution
- Disadvantages
  - Reaction system can become prohibitively expensive for large test shafts
  - May require large foot print for set up
- When to use
  - Smaller diameter shafts (D<36 inches)
  - Easy access sites
Bi-Directional (O-Cell®) Load Test

- Corresponding resistance factor $\phi = 0.70$
- Advantages
  - No reaction system required
  - Can be instrumented to determine resistance distribution
- Disadvantages
  - Only possible on pre-planned shaft
  - Resistance mobilization limited by failure in either direction
  - Specialty sacrificial equipment
- When to use
  - Large diameter shafts
  - Congested sites
- Designer should develop instrumentation plan and estimate resistance balance point
High-Strain Dynamic Load Test

- Corresponding resistance factor $\phi=0.60$

Advantages
- Less Setup than Static test
- Lower cost than Bi-Directional
- Can be performed on any shaft

Disadvantages
- Lower resistance factor than Static or Bi-Directional
- Not instrumented to provide resistance distribution
- May not mobilize full resistance

When to Use
- Proof/verification testing
# Drilled Shaft Data Table

### Production Drilled Shaft Data Table - I-49 over MLK NB

| Station | Permanent Load | Dead Load | Live Load | Dynamic Load | Load Test
|---------|----------------|-----------|-----------|--------------|-----------
| MLK 1   |                |           |           |              |           |
| MLK 2   |                |           |           |              |           |
| MLK 3   |                |           |           |              |           |
| MLK 4   |                |           |           |              |           |
| MLK 5   |                |           |           |              |           |

### Production Drilled Shaft Data Table - I-49 over MLK SB

| Station | Permanent Load | Dead Load | Live Load | Dynamic Load | Load Test
|---------|----------------|-----------|-----------|--------------|-----------
| MLK 1   |                |           |           |              |           |
| MLK 2   |                |           |           |              |           |
| MLK 3   |                |           |           |              |           |
| MLK 4   |                |           |           |              |           |
| MLK 5   |                |           |           |              |           |

### Notes:
1. Position of 1-ton loading on each shaft in accordance with the specifications.
2. Remove from site and dispose of excavated material, ballast, etc. in accordance with the specifications.
3. The drilled shaft construction shall comply with the requirements of the specifications.
# Drilled Shaft Data Table

## Resistance Factor
- Use either average resistance factor from calculation or factor based on type of load test specified.

## Required Nominal Resistance
- Strength State load with geotechnical resistance factor applied (Strength load/\(\phi\))
- Scour zone resistance may need to be added

## Plan Length
- Based on experience and/or axial resistance calculation

## Bot. Of Permanent Casing El.
- If permanent casing is required the bottom elevation should be established during design

<table>
<thead>
<tr>
<th>BENT NO.</th>
<th>STATION</th>
<th>NO. OF DRILLED SHAFTS PER BENT</th>
<th>DIA. (IN)</th>
<th>LOAD (TONES)</th>
<th>SOIL RESISTANCE FACTOR ((\phi))</th>
<th>REQUIRED NOMINAL RESISTANCE (TONS)</th>
<th>MAX. TOP EL. (FT.)</th>
<th>PLAN LENGTH (FT.)</th>
<th>BOT. OF PERMANENT CASING EL. (FT.)</th>
<th>AS-BUILT TIP EL. (FT.)</th>
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<td>17</td>
<td>0.45</td>
<td>0.4</td>
<td>1.00</td>
<td>35</td>
</tr>
</tbody>
</table>

**Notes:**
- Resistance Factor
  - Use either average resistance factor from calculation or factor based on type of load test specified.
- Required Nominal Resistance
  - Strength State load with geotechnical resistance factor applied (Strength load/\(\phi\))
  - Scour zone resistance may need to be added
- Plan Length
  - Based on experience and/or axial resistance calculation
- Bot. Of Permanent Casing El.
  - If permanent casing is required the bottom elevation should be established during design
Other Design Considerations

- **Rebar Details (AASHTO 5.13.4.5)**
  - All rebar in drilled shaft must have a clear spacing of 5 inches
  - Rebar conflicts typically occur at the top of the shaft when columns use a Type II connection.
  - If dowel cage cannot meet spacing requirements the following options should be considered
    - Require construction joint at bottom of splice zone to allow for dry construction after completing shaft
    - Use of self-consolidating concrete (SCC) mix instead of class S

- **Trial/Technique Shaft**
  - Used to verify Contractor’s construction method
  - Can be combined with test shaft

- **Permanent Casing**
  - Primarily required for shafts constructed over water or near existing foundations and rail crossings
Construction Phase of Project
- Must be submitted 4 weeks prior to drilled shaft construction
- Geotechnical Engineer should review DSIP
  - Determine if installation methods are the same as assumed during design
  - Construction methods conform with Standard Specifications
  - Load testing will be performed in accordance with plans and specifications
- DOTD has 10 working days to accept or reject DSIP
Drilled Shaft Preconstruction Conference
LADOTD 2016 Section 803.04

- Required a minimum of 7 days prior to shaft construction
- Attendees should include representative from
  - DOTD Construction
  - Geotechnical Designer
  - Drilled Shaft Subcontractor
  - General Contractor
- The DSIP should be approved prior to meeting
Drilled Shaft Construction
LADOTD 2016 Section 803.03.4

- Geotechnical Engineer on site for first Shaft
  - Technique or Test Shaft
    - Verify constructed in accordance with DSIP
  - Assistance with Inspection
- Shaft Construction Logs (DOTD web site)
  - Casing
  - Excavation
  - Slurry
  - Concrete Placement
Test Shaft and Production Lengths
LADOTD 2016 Section 803.05.15

- Review test shaft installation records to see if construction method may have affected load test results
- Test Report provided to Engineer within 21 days
- Use Load test to verify shaft model and design assumptions
- Production Shaft lengths are based on load test results
- Provide lengths to Project Engineer within 10 working days
- Revise DSIP if construction methods change
Integrity Testing
LADOTD 2016 Section 803.05.11

- Cross-hole Sonic Logging (CSL)
  - Required for wet construction method
  - Performed by Testing Consultant as part of construction contract
  - Integrity Testing Report (All Construction Logs, Soil Borings, CPT data included)
  - Geotechnical Engineer has 5 working days to review.

- TIP (Thermal Integrity Profiler) or other
  - Performed in accordance with plans
Defective Shafts
LADOTD 2016 Section 803.05.16

- Recommend additional test methods to further evaluate defect
- Review testing or remediation plans prior to implementation
- Determine if remediation plan effectively addressed defect
- Assist contactor with identifying causes of anomalies and modifying the DSIP to prevent additional defective
2016 Standard Specification

- 814 Drilled Shaft Foundations => 803 Drilled Shafts
  - Foundation Element Specifications Near Front of Part 8
- Aligned with AASHTO Bridge Design and Construction Specifications
- Drilled Shaft Preconstruction Conference
2016 Specification

- Construction Log forms to be provided
- Trial Shaft is now Technique Shaft
- Separated Payment of CSL From Load Test
- Load Test Items are standard items
  - Static Load Test (Conform to ASTM D1143, Procedure A: Quick Test)
  - High-Strain Dynamic (ASTM D4945)
  - Force Pulse (Rapid) Load Test (ASTM D7383)
  - Bi-Directional Load Cell Test (O-Cell)
Questions?