Evaluation and Guidance Development for Post-Grouted Drilled Shafts for Highways: Project Update

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Overview

• Objectives of Project & Project History
• Summary or Phase I Work – Evaluations & Findings
• Summary of Future Research Needs & Anticipated Phase II Focus
Place reinforcement, NDT tubes, and post-grouting device
Place concrete for drilled shaft
Continue injection of grout until criteria is achieved.
Grouting Mechanisms

- **Sleeve-port (tube-á-manchette) Distribution System**
  - Steel plate – separation
  - Scuff ring – for strength and to “contain” grout
  - Gravel Pack - to level base

Source: Mullins et al (2001)
**Grouting Mechanisms**

- **Sleeve-port Distribution System**
  - Shafts with a flat bottom

Source: Sliwinski and Fleming (1984)

Source: FHWA (2010)
Grouting Mechanisms

- **Sleeve-port (tube-á-manchette) Distribution System**
  - Can be shaped for non-flat bottom
  - Down-hole grabs (clamshell) or reverse-circulation methods


Source: Castelli (2012)
Grouting Mechanisms

- **Flat-jack (“Pre-load cell”) Distribution System**
  - Grout is injected between steel plate and rubber membrane (expands)

Source: FHWA (2010)

Source: Mullins et al (2001)
Objectives of Study

- **Develop consensus opinion**
  - Improved understanding of how it works
  - Appropriate application of post-grouting
  - Guidance documents to facilitate rational and reliable design and construction of post-grouted drilled shafts

- **Primary objectives**
  - Bound use of post-grouting for current state of knowledge
  - Quantify improvement mechanism(s) for post-grouting
  - Develop design methodology(ies) for appropriate use
  - Provide method(s) for verification
Project Structure

Owner (FHWA)

Project Manager (ADSC)

Technical Working Group (TWG)
FLDOT, KSDOT, NYSDOT, SCDOT, WSDOT, FHWA

Peer Review Panel

Principal Investigators (PIs)

Advisory Panel
Project Team

**PROJECT MANAGER**
Dr. Antonio Marinucci

**PRINCIPAL INVESTIGATORS**
Dr. J. Erik Loehr, University of Missouri  
Dr. Dan A. Brown, Dan Brown and Associates  
Dr. Antonio Marinucci  
Dr. Jesús Gómez, Schnabel Engineering

**TECHNICAL ADVISORY PANEL**
Tom Armour, DBM Contractors  
Allen W. Cadden, Schnabel Engineering  
Michael Muchard, Applied Foundation Testing  
Dr. Donald A. Bruce, Geosystems, LLP  
Dr. Steve Dapp, Dan Brown and Associates
Project Milestones

• Synthesis – *Completed September 2012*
• Phase I - The State-of-Practice - Evaluation of Existing Data & Preliminary Recommendations – *To be Finalized December 2013*
Major Findings from Synthesis

• Five design approaches
• More comparable load-test data than expected
  ▪ 92 ungrouted/104 grouted for base resistance in published literature (worldwide)
  ▪ Within sand, gravel (limited), clay, silt and rock (limited)
• Four mechanisms contributing to improvements
• Improvements observed in vast majority of cases
• Use of strain-gages as an additional level of QA
From Synthesis

Preliminary Findings - Data in Sands

Graphs showing correlations between measured mobilized unit resistance and grout pressure for different scenarios in sands.
From Synthesis

**Preliminary Findings**

- Data in Clays
From Synthesis

Preliminary Findings - Data in Silts

Graphs showing comparisons between different types of resistance in silts:
- Base (Silts)
- Skin (Silts)
- Total (Silts)

Equations and correlation coefficients are provided for each graph.
Focus of Phase I Evaluation

• Comprehensive evaluation from results of existing load test programs
• Comparison of results to predictive methods
• Assessment of current practices
• Assessment of improvement mechanisms and quantification
• Identify additional knowledge gaps
• Findings and preliminary recommendations
• Recommendations of future work
Improvement Mechanisms

4 improvement mechanisms described in the literature

1. Due to “pre-loading” of drilled shaft
2. Due to improvement of the ground beneath the shaft tip
   - Densification of ground near tip of the shaft
   - Permeation of grout into ground at tip of the shaft
3. Due to enlarged tip area
4. Due to upward flow of grout around the perimeter of the shaft
Pre-mobilization

- **Fleming (1993) – Improvement due to pre-loading**
  - Pre-loading effect produces no increase in ultimate capacity
  - Increases resistance mobilized at a displacement

Following post-grouting, shaft is “pre-loaded” “negative” side resistance “positive” tip resistance

Side resistance mobilized from “X”

Tip resistance mobilized from “Y”

Post-grouted shaft

Ungrounded shaft
Pre-mobilization model example case: Ungrouted and grouted matches plotted over measured load test data from Texas A&M clay site
Ground Improvement Ratio

![Graph showing Ground Improvement Ratio (GIR) for different cases. The graph includes data points for Clay Cases and Sand Cases for various locations such as TAMU Sand, UH Sand, Broad. Viad., PGA Blvd., TAMU Clay, and UH Clay. Each location shows a range of GIR values, indicating the variability in improvement ratios across different sites. The graph highlights the distinct performance of clay and sand cases, with each data point marked with a symbol representing its location and type. The y-axis represents the Ground Improvement Ratio, while the x-axis lists the different cases.]
Summary statistics for GIR and TIR from comprehensive analysis of selected cases

<table>
<thead>
<tr>
<th></th>
<th>Sand</th>
<th>Clay</th>
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<tbody>
<tr>
<td></td>
<td>GIR</td>
<td>TIR w/o O-Cell</td>
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<td>7</td>
<td>4</td>
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<tr>
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<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Range</td>
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<tr>
<td>Std. Dev.</td>
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Summary of TIR analysis of drilled shafts tipped and post-grouted in sand

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<tr>
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<th>All Papers</th>
<th>Excluding Dapp et al. (2002)</th>
<th>Excluding Dapp et al. (2002) and Dai (2011)</th>
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<tr>
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<td>Range of TIR</td>
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<td>Coefficient of Variation of TIR</td>
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<td>0.43</td>
<td>0.36</td>
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</table>
TIR vs. diameter for sand, plotted by grouting apparatus

(a) Total Improvement Ratio (TIR) vs. Diameter, ft

- Flat-Jack
- Sleeve-Port
- Side-grout
- Unknown
- Numerical Model Flat-Jack
- Numerical Model Sleeve-Port
- Circled = Pt is Avg of Mult Shafts

Dapp and Mullins (2002)
Summary of TIR analysis of drilled shafts tipped and post-grouted in clay and sand

<table>
<thead>
<tr>
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<th>Clay</th>
<th>Sand</th>
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<tr>
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<td>All Data Points</td>
<td>Excluding Two Shafts with High GPI</td>
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TIR vs. diameter for clay, plotted by (a) grouting apparatus
Comparison of prediction methods in sand

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<tbody>
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<td>Range of TCM/TIR</td>
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<td>0.22 – 1.88</td>
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<td>Average Value of TCM/TIR</td>
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<td>Coefficient of Variation of TCM/TIR</td>
<td>0.50</td>
<td>0.58</td>
<td>0.44</td>
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</tbody>
</table>
Ratio of predicted TCM to observed TIR for TCM vs. diameter for sand
TIR in Relation to Ungrouted Resistance and Pressure (Sands)

- GPI from 0.36 to 0.64
- GPI from 0.96 to 1.26
- GPI from 1.33 to 1.50
- GPI from 1.73 to 2.03
- GPI from 2.20 to 2.50
- GPI from 2.58 to 2.93
Summary

- Large Variability in observed improvement
- No apparent dependency of TIR with diameter, grouting apparatus, grout pressure (alone)
- $\text{GIR}_{\text{mean}}=1.2$  $\text{TIR}_{\text{mean}}=1.8$
- Prediction mean values are comparable to $\text{TIR}_{\text{observed}}$, but with high variability (without site specifics)
Looking toward Phase II

- Evaluation of Pre-mobilization and Load Transfer
- Evaluation of Post-Grouting for Remedying “Soft Bottom” Conditions
- Evaluation of Post-Grouting as a QC/QA Tool
- Evaluation of Ground Improvement
- Evaluation of Reliability
- Evaluation of Potential for Degradation in Side Resistance
- Evaluation and Development of Improved Design Methods
- Evaluation of Alternative Grout Characteristics and Grouting Processes
- Shaft Performance – Stiffness vs. Resistance vs. Capacity
- Recommendations for Load Testing of Post-Grouted Shafts
Questions?