AASHTO Methodologies for Drilled Shafts Supporting Bridges and Sign Structures:

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AASHTO Methodologies for Drilled Shafts Supporting Bridges and Sign Structures: They are Different!

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AASHTO Drilled Shaft Design Methodology

For Supporting *Bridge* Structures
AASHTO Drilled Shaft Design Methodology

For Supporting **Sign** Structures
Similar in Design Calculations:

• End-Bearing Resistance
• Shaft Resistance
Drilled Shafts
Supporting *Bridges* & *Signs*

Different Design Govern (most likely):

**Bridges**
Axial or Lateral Load

**Spanned Signs** *(conventional)*
Lateral Load

**Cantilevered Signs** *(conventional)*
Torsional Load

**Digital Spanned Signs**
Lateral or Axial Load
Different Design Considerations/Assumptions:

**Bridges**

may Ignore shaft resistance; particularly for shafts constructed with slurry.

...over-conservative; safer

... not realistic (load transfer mechanism)

**Signs**

Shaft resistance CANNOT be ignored;

particularly, for cantilevered signs.
Different Definitions & Requirements:

“Redundant” or “Non-Redundant”

“Non-redundant member is one for which failure will directly affect the element carried by it with limited or no ability of other foundations supporting the same element to mitigate the effect of the failure of the member.”

(NCHRP 507)
“Non-Redundant” Shafts

**NCHRP 507 (Paikowsky et al., 2004)**
- Four or fewer piles per pile cap

**AASHTO LRFD, Article 10.5.5.2.4**
- A single shaft supporting a bridge pier
- Reduce resistance factors by 20%
Drilled Shafts
Supporting Bridges

“Non-Redundant” Shafts
FDOT Structures Design Guidelines

3.6.9 Nonredundant Drilled Shaft Foundations (Rev. 01/12)

A. Refer to the Soils and Foundations Handbook for special design phase investigation and construction phase testing and inspection requirements for nonredundant drilled shafts.

B. Nonredundant drilled shaft bridge foundations consist of:
   1. Bents with three or fewer drilled shafts,
   2. Single column piers with three or fewer drilled shafts,
   3. Two column piers with one or both of the columns supported by one or two drilled shafts,
   4. Those shafts deemed nonredundant per LRFD [1.3.4].

C. Shafts for bridge widening when the substructure is attached to the original structure, and shafts up to 60 inches in diameter installed to support miscellaneous structures (i.e. sign structures, mast arms, high-mast light poles, noise walls) are exempt from these requirements.
Are there “Non-Redundant” Shafts?

FDOT Structures Design Guidelines

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Different Design Requirements for Torsion

• Less Stringent for Signs
• Seldom Govern for Bridge
• Become Lateral Load Demand when Coupled
Different Analysis for Shaft Subject to Lateral Load

**Bridges**
Require Soil-Pile Interaction Analysis
Utilizing LPILE, FB-Multipier, etc.

**Signs**
Conventional methodology is also acceptable, such as Broms’ Method, etc.
Different Design Requirements for Shaft subject to Lateral Load

• Tolerable Deflection

• Minimum Pile Penetration / Fixity

( Geotechnical & Structural Engineers need to communicate.)
Different Design Requirements for Shaft subject to Lateral Load

• Tolerable Deflection

• Minimum Pile Penetration / Fixity

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Fixity… sounds familiar?
Where is the Fixity below Top of an Embedded Laterally Loaded Pile or Drilled Shaft?

Geotechnical Fixity & Structural Fixity of Laterally Loaded Piles
Drilled Shafts
Supporting *Bridges*

**Fixity Requirements**
Referring to AASHTO LRFD, Article/Commentary 10.7.3.12

... requires reinforcing steel extending a minimum of 10.0 ft. below the plane where the soil provides “Fixity”.

“Fixity”

• Depth to Fixity (C10.7.3.13.4
• Equivalent Pile Length
• “Structural Fixity”

“Depth to Fixity” is ONLY for Structural (Buckling) Stability Evaluation.
Referring to AASHTO LRFD, Article/Commentary 10.7.3.12

... requires minimum pile penetration to reach “Fixity” for resisting the applied Strength Limit State lateral loads (10.7.3.12)

“Fixity”
- Pile Fixity
- Point of Fixity
- “Geotechnical Fixity”

• Determining the Minimum Pile Penetration by reaching the “Pile Fixity” should be based upon result of soil-structure interaction.
"Critical Length" of Laterally Loaded Pile
Beyond which any additional pile length has no further influence on the pile head response.

Figure 2-2: Critical length for a laterally loaded pile (after Reese and Van Impe, 2001)
Drilled Shafts Supporting Bridges

Geotechnical Fixity (#8)

The turning point where the analyzed pile length results in UNSTABLE foundation when subject to Factored / Strength Limit State loads; then add 20% or 5 feet, whichever is less, to determine the Pile Minimum Tip Elevation (2010 FDOT, SDG 3.5.8)
Drilled Shafts
Supporting Bridges

Geotechnical Fixity (#9)

Arizona DOT Geotechnical Design Policy DS-3 Procedures (12/2010)

1. Select shaft diameter; perform lateral load analysis using strength limit state and gross (uncracked) moment of inertia.
2. Select an initial, long shaft length of 10 to 15 times the shaft diameter.
3. Repeat computations with the shaft length reduced in 10 to 15% increments; graph the following:

   ![Graph showing ground line deflection vs. shaft length]

   Ground line deflection

   Shaft length

   \( L_0 \)

4. Identify shaft length, \( L_0 \), which is has a deflection change less than 5% between two consecutive increments of lengths.
Geotechnical Fixity (#9)

Arizona Geotechnical Design Policy DS-3 Procedures (Dec., 2010)

5. Use Lo, run lateral analysis using **Strength Limit State** for reinforcing steel design; using **Service Limit State** for deflections; Use **cracked moment of inertia** for both analyses.

6. Determine final shaft length as the longest from the overturning strength limit state (geotechnical stability), strength limit state (structural detailing), and service limit state (serviceability evaluation).

7. Repeat all the above w/ different shaft diameters to determine the most efficient and cost-effective one.

8. Perform parametric studies using a range of soil parameters.

**Comments**

- Methodology better defined... **However, a significant undertaking!**
Drilled Shafts
Supporting Bridges

QUESTION

Is it really necessary to reach the “Critical Length”? 
Geotechnical Fixity (#2)

Point where the Deflection Curve crosses the zero line the 2nd time when subjected to Unfactored / Service Limit State loads.

Comment
- Conservative, in general.
Geotechnical Fixity (#6)

Point of Maximum Negative Deflection when subject to Factored / Strength Limit State lateral loads (NCDOT 2007)

Geotechnical Fixity (#7)

“Point of Fixity” between Max. Negative Deflection and 1st time crossing Zero Deflection when subject to Factored / Strength Limit State loads (NCDOT 2011)

NOTE
Shaft Length Iteration Needed.
Geotechnical Fixity (#6)

Point of Maximum Negative Deflection when subject to Factored / Strength Limit State lateral loads (NCDOT 2007)

Geotechnical Fixity (#7)

“Point of Fixity” between Max. Negative Deflection and 1st time crossing Zero Deflection when subject to Factored / Strength Limit State loads (NCDOT 2011)

Question: Why Factored Load?

NOTE
Shaft Length Iteration Needed.
Determination of “Geotechnical Fixity”
When Subject to Lateral Load

“Not-So-Good” News
A unified methodology is yet to come!
Drilled Shafts
Supporting Signs

Determination of “Geotechnical Fixity”
When Subject to Lateral Load

“Good” News … What is it?
Determination of “Geotechnical Fixity”
When Subject to Lateral Load

“Good” News … What is it?

There is NO Fixity Requirement!!!
Determination of “Geotechnical Fixity”
When Subject to Lateral Load

“Good” News … What is it?

There is NO Fixity Requirement!!

WHY???
“Short / Rigid” vs. “Long / Flexible”

Figure 2-2: Critical length for a laterally loaded pile (after Reese and Van Impe, 2001)

Table 2-1: Rigid and flexible pile criteria from Broms (1964a, 1964b)

<table>
<thead>
<tr>
<th>Soil Condition</th>
<th>Rigid Pile Criteria</th>
<th>Flexible Pile Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Free-Head</td>
<td>Fixed-Head</td>
</tr>
<tr>
<td>Cohesive</td>
<td>$\lambda L &lt; 1.5$</td>
<td>$\lambda L &lt; 0.5$</td>
</tr>
<tr>
<td>Cohesionless</td>
<td>$L/T &lt; 2.0$</td>
<td></td>
</tr>
</tbody>
</table>
The Reason Why …

Drilled Shaft Subject to Lateral Load

Bridges
Requiring “Long / Flexible”
Because …..

Signs
Either “Long / Flexible” or “Short / Rigid”
As long as …..