April 4 & 5, 2013

Embassy Suites Hotel, Raleigh, North Carolina

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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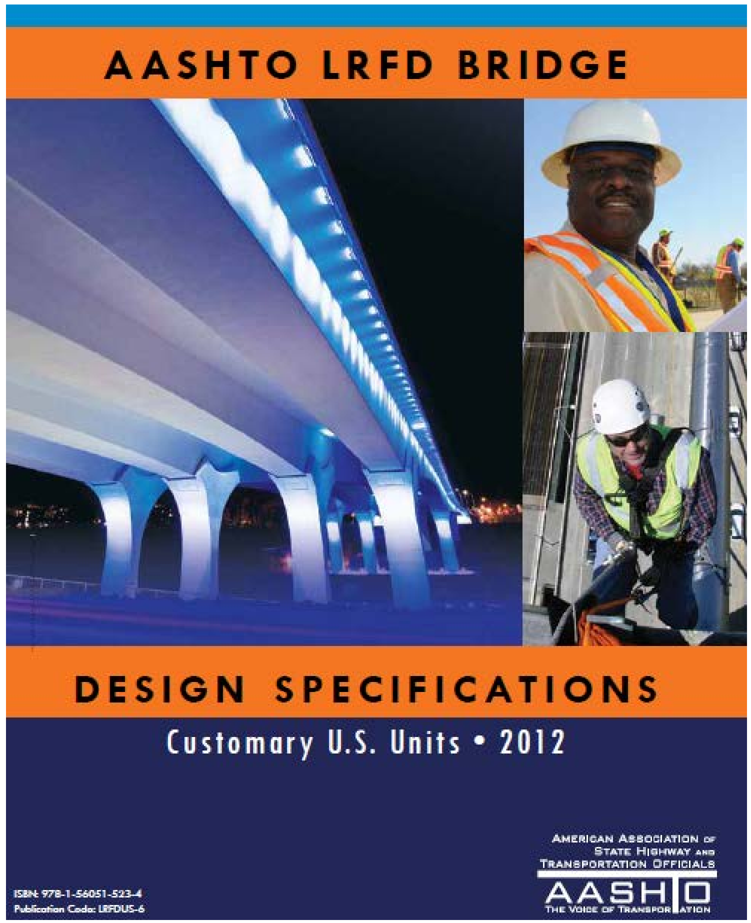
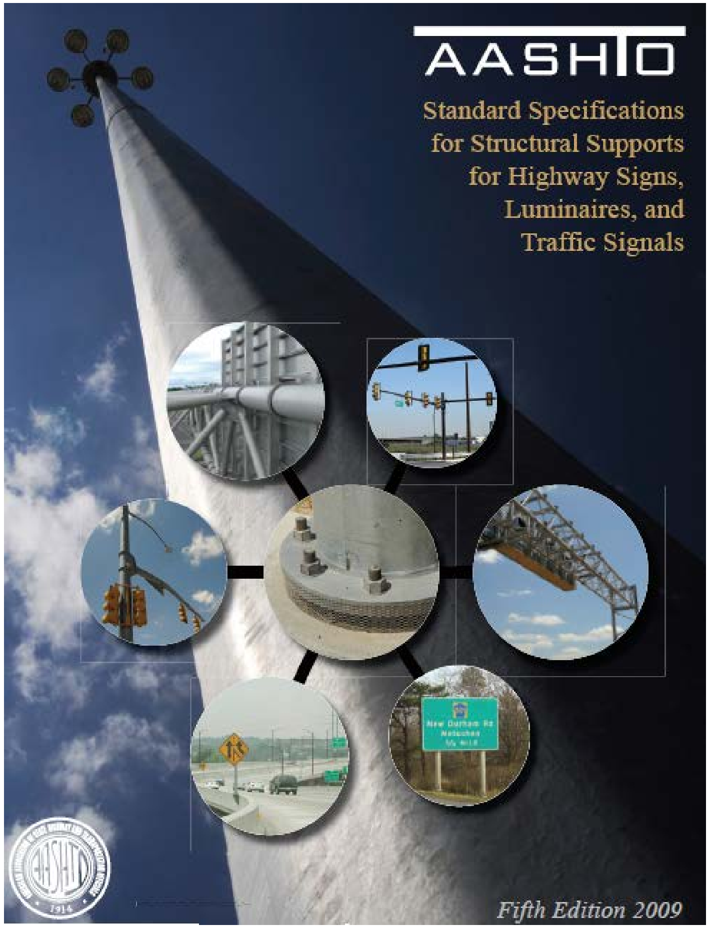
AASHTO Drilled Shaft Design Methodology

For Supporting ***<u>Bridge</u>*** 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

Drilled Shafts
Supporting ***Bridges*** & ***Signs***

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)

Drilled Shafts Supporting ***<u>Bridges</u>***

"Non-Redundant" Shafts

<u>NCHRP 507 (Paikowsky et al., 2004)</u>

- Four or fewer piles per pile cap

<u>AASHTO LRFD, Article 10.5.5.2.4</u>

- A single shaft supporting a bridge pier
- Reduce resistance factors by 20%

"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

Drilled Shafts
Supporting ***Bridges*** & ***Signs***

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**

(Geotechniacl & Structural Engineers need to communicate.)

Drilled Shafts
Supporting ***Bridges*** & ***Signs***

Different Design Requirements
for Shaft subject to Lateral Load

- **Tolerable Deflection**
- **Minimum Pile Penetration / Fixity**

(Geotechniacl & Structural Engineers
need to communicate.)

Fixity... sounds familiar?

The 6th GEOTECHNICAL, GEOPHYSICAL AND GEOENVIRONMENTAL TECHNOLOGY TRANSFER (Geo^{3}T^2) CONFERENCE AND EXPO

April 5 & 6, 2011
McKimmon Conference and Training Center
Raleigh, North Carolina

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

2012 ASCE-NC Annual Conference
August 23-24, 2012
Wilmington, North Carolina

Geotechnical Fixity & Structural Fixity of Laterally Loaded Piles

Fixity Requirements

Drilled Shafts
Supporting ***Bridges***

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.

Drilled Shafts
Supporting ***Bridges***

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.

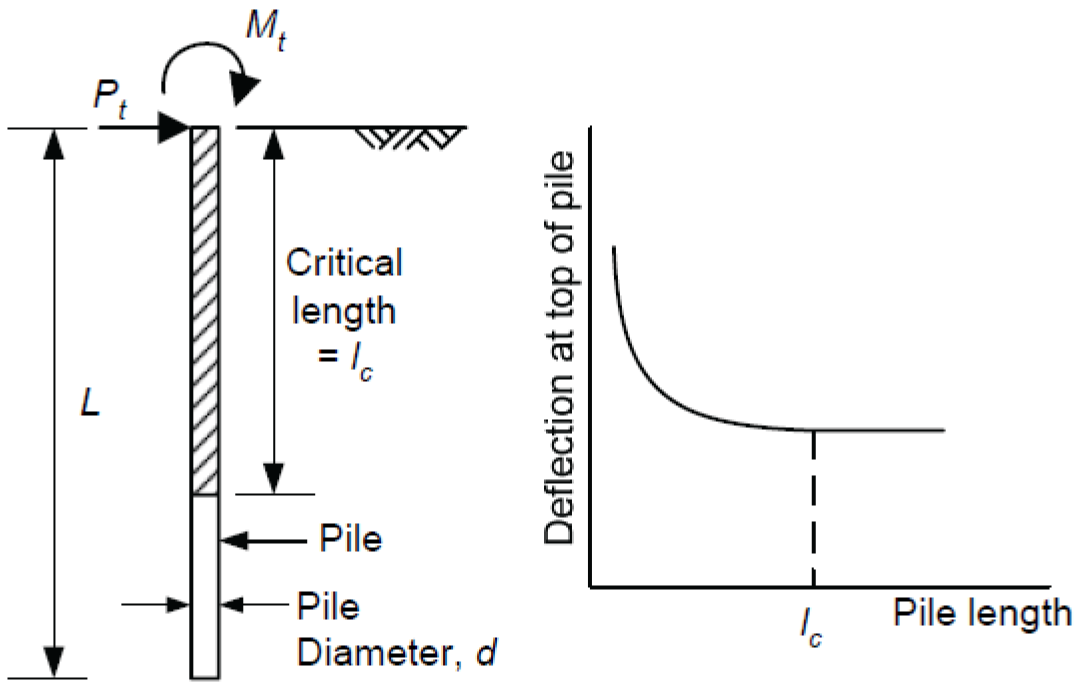
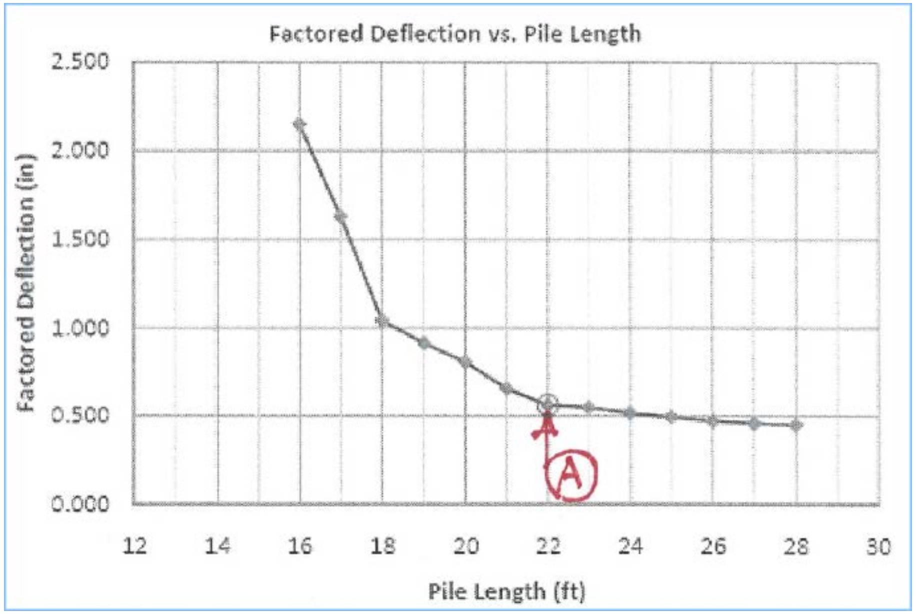


Figure 2-2: Critical length for a laterally loaded pile (after Reese and Van Impe, 2001)

Geotechnical Fixity (#8)

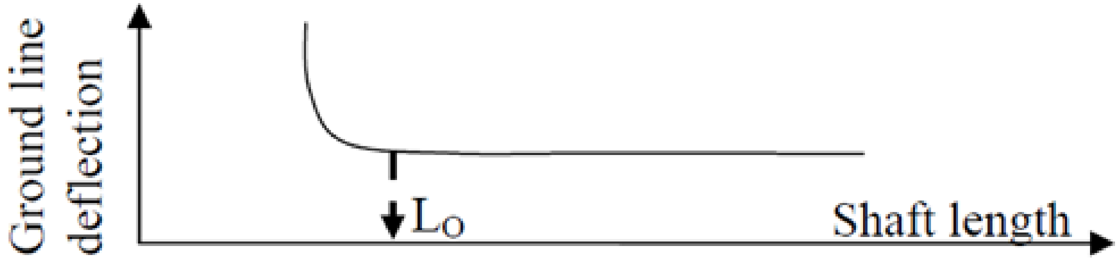
The turning point where the analyzed pile length results in UNSTABLE foundation when subject to Factored / Strength Limit State loads; then add 20% or 5 feet, whichever is less, to determine the Pile Minimum Tip Elevation (2010 FDOT, SDG 3.5.8)



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:



4. Identify shaft length, Lo, 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

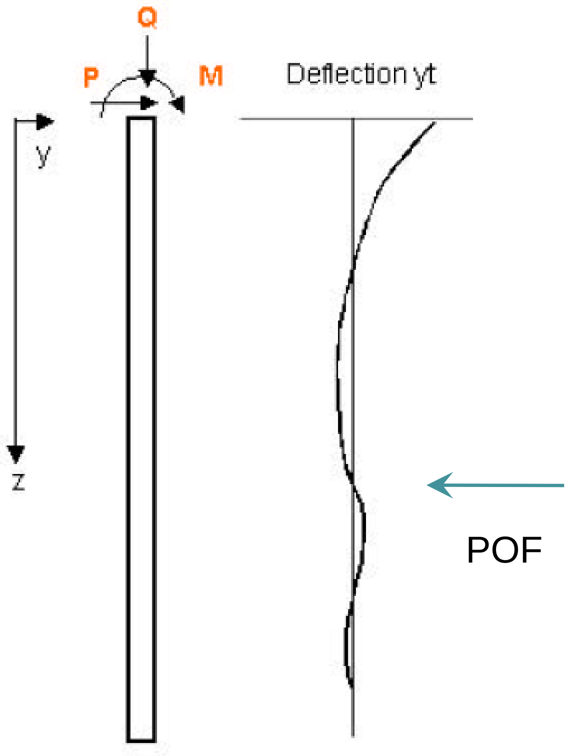
- Methodology better defined… *However, a significant undertaking!*

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.

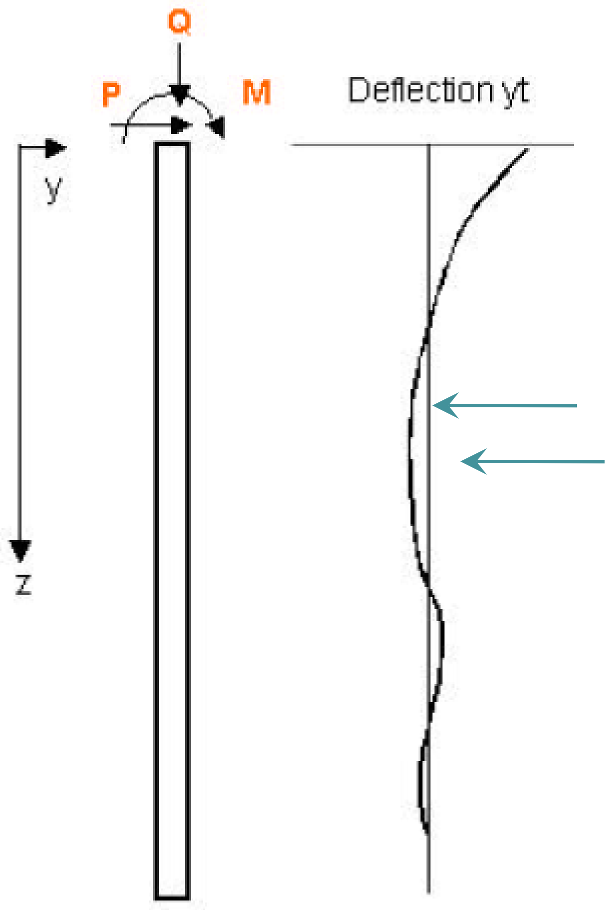
Drilled Shafts
Supporting ***Bridges***

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.

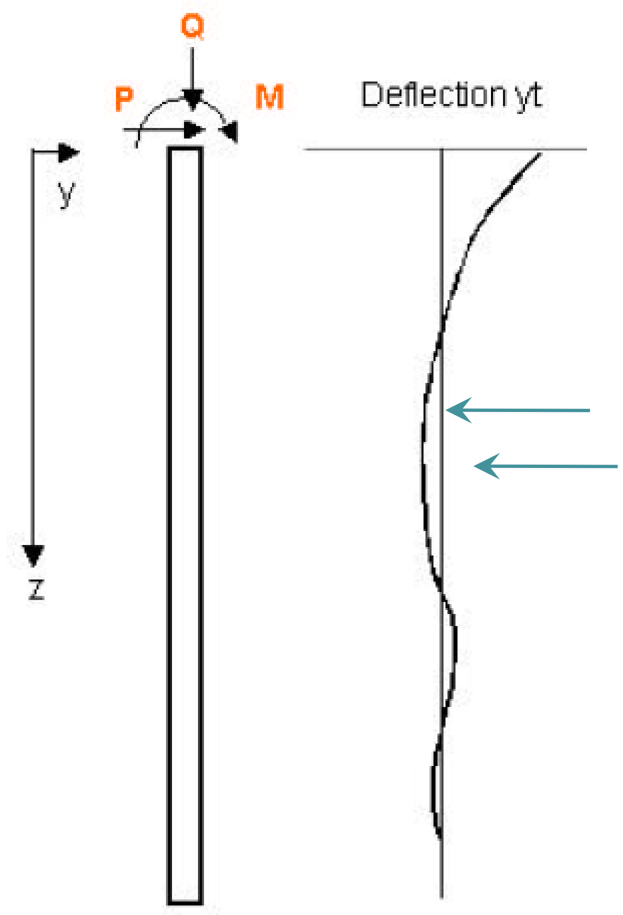
Drilled Shafts
Supporting ***Bridges***

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.

Question: Why Factored Load?

Determination of "Geotechnical Fixity" When Subject to Lateral Load

"Not-So-Good" News

A unified methodology is yet to come!

Determination of "<u>Geotechnical Fixity</u>" When Subject to Lateral Load

<u>"Good" News … What is it?</u>

Determination of "Geotechnical Fixity" When Subject to Lateral Load

"Good" News … What is it?

There is NO Fixity Requirement!!!

Drilled Shafts
Supporting ***Signs***

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"

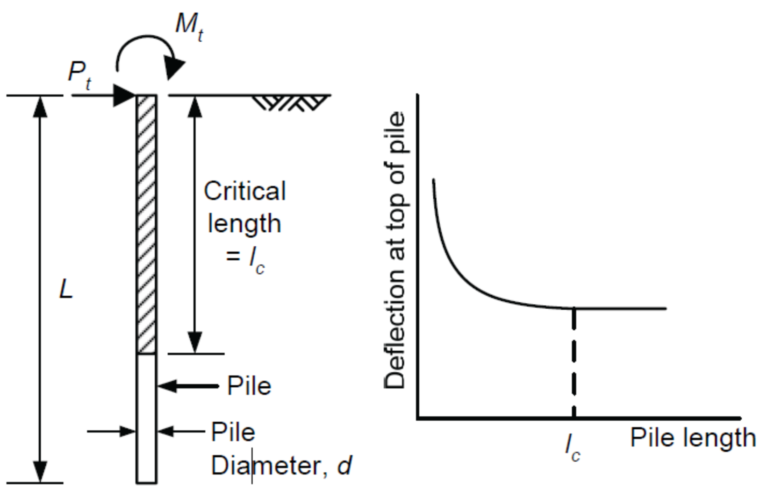


Figure 2-2: Critical length for a laterally loaded pile (after Reese and Van Impe, 2001)

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

Soil Condition	Rigid Pile Criteria		Flexible Pile Criteria	
	Free-Head	Fixed-Head	Free-Head	Fixed-Head
Cohesive	$\lambda L < 1.5$	$\lambda L < 0.5$	$\lambda L > 2.5$	$\lambda L > 1.5$
Cohesionless	$L/T < 2.0$		$L/T > 4.0$	

The Reason Why …

Drilled Shaft Subject to Lateral Load

Bridges

Requiring "Long / Flexible"

Because ……

Signs

Either "Long / Flexible" or "Short / Rigid"

As long as ……