

The Updated Drilled Shaft Manual: Potential Impacts on AASHTO Specifications



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Drilled Shafts: Construction Procedures and LRFD Design Methods

Update and Revision of NHI Manual by O'Neill and Reese (1999)

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Objective

Identify issues addressed in the revised manual that the authors believe should be brought to the attention of Committee T-15, for making future updates to the AASHTO LRFD Bridge Design Specifications.

The list is not exhaustive; rather it highlights some of the most significant issues

1. Design for Lateral Loading

Article 10.8.3.1 identifies

‘lateral geotechnical resistance of soil and rock stratum’

as a strength limit state for design of drilled shafts

Article 10.8.3.8 Nominal Horizontal Resistance of Shaft and Shaft Groups: “The provisions of Article 10.7.3.12 apply” (driven piles)

C10.7.3.12: “The strength limit state for lateral resistance is only structural”

A Rational Approach:

For a given trial shaft diameter, establish the depth of embedment at which a strength limit state occurs by overturning of the shaft (a *pushover* analysis).

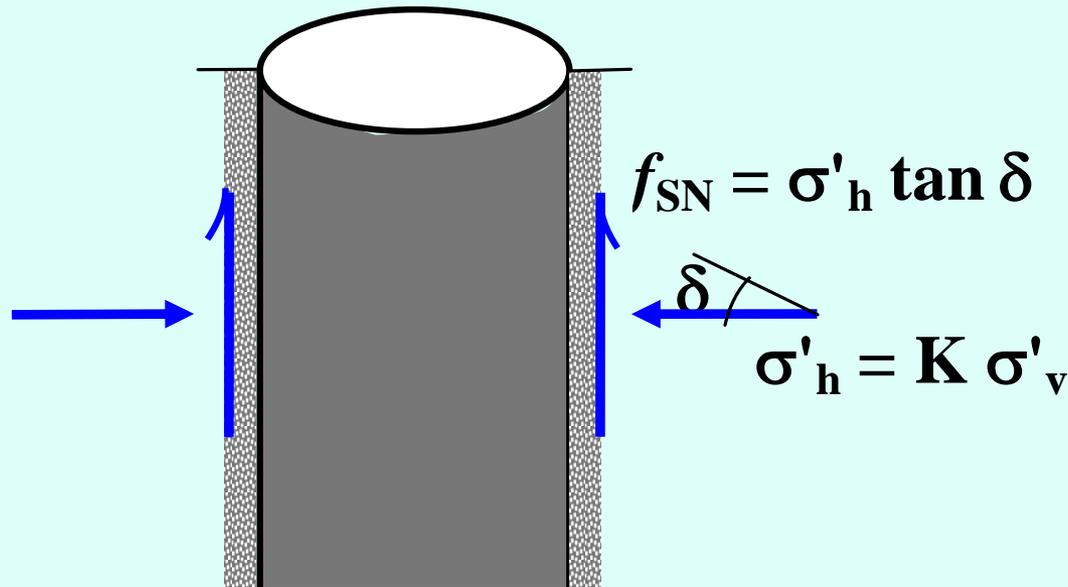
This is the limit state controlled by the strength of the supporting soil and rock strata.

Approach Presented in Ch. 12 of the Revised Manual:

- Model the shaft as linear elastic beam
- Perform p - y analyses to find minimum length for stable solution with $(1/\phi)$ x factored loads
- Use $\phi = 0.67$ for Strength I-V Load Cases
- Use $\phi = 0.8$ for Extreme Event Load Cases

2. Axial Side Resistance: Cohesionless Soil

side resistance: effective stress analysis



σ'_h = horizontal effective stress, which acts as a normal stress at the soil/foundation interface

δ = interface angle of friction (soil/concrete) = ϕ'

K = coefficient of lateral earth pressure

Nominal Unit Side Resistance Cohesionless Soils

$$f_{SN} = \sigma'_v K \tan \phi'$$

$$f_{SN} = \beta \sigma'_v$$

'Beta method'

Changes to the '*Beta method*'

$$f_{SN} = \beta \sigma'_v$$

Currently: Depth-dependent β method

(O'Neill & Reese, 1999)

For sandy soils:

$$\beta = 1.5 - 0.135 (z)^{0.5}$$

for $N_{60} \geq 15$

Rational Method for Nominal Unit Side Resistance in Cohesionless Soils

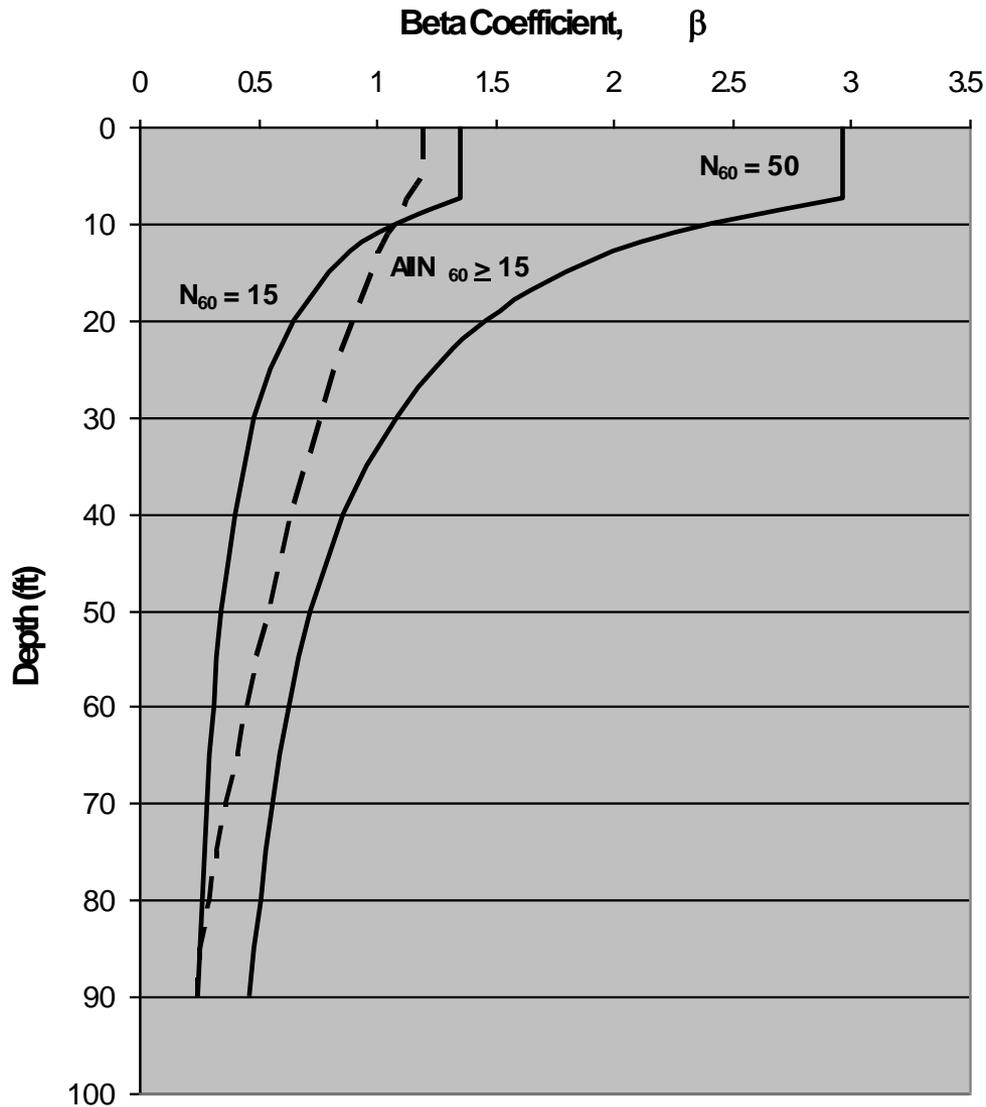
$$f_{SN} = \sigma'_v K \tan \phi'$$

value at middle of layer of interest

from correlation with N_{60} and σ'_v

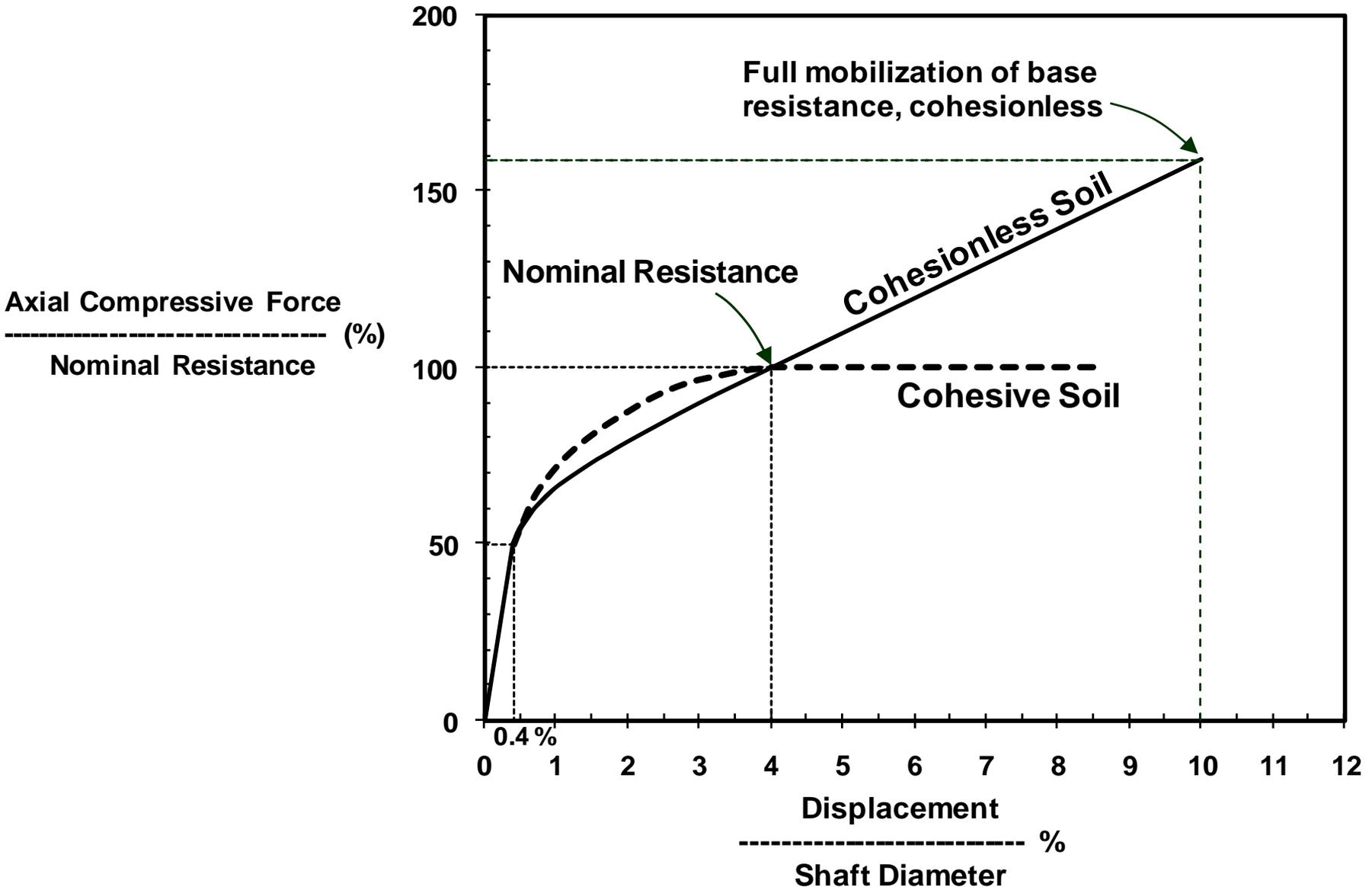
from correlation with N_{60} , σ'_v and ϕ'

Comparison: Depth-Dependent versus Rational Method for β

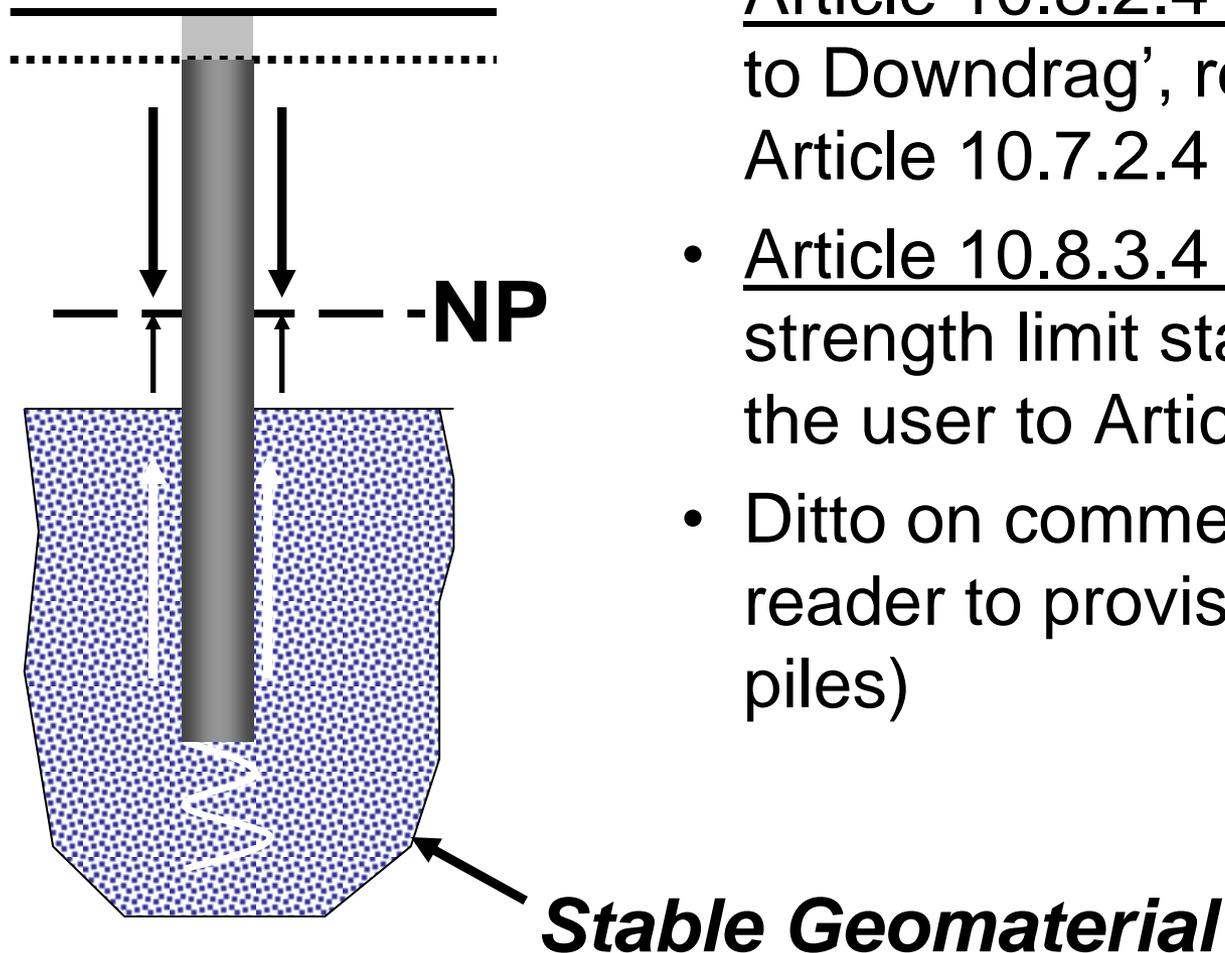


See Appendix C for full discussion

3. Updated Load-Settlement Model



4. Downdrag

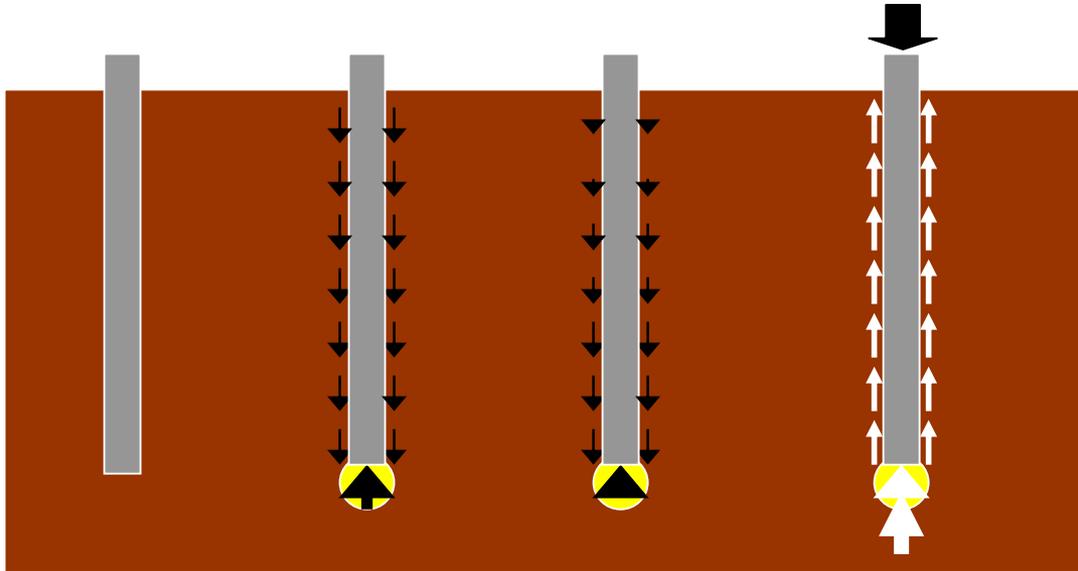


- Article 10.8.2.4 'Settlement Due to Downdrag', refers the user to Article 10.7.2.4 (Piles)
- Article 10.8.3.4 'Downdrag', for strength limit state design, refers the user to Article 10.7.3.6 (Piles)
- Ditto on commentary (refers the reader to provisions for driven piles)

Comments on Downdrag

- Section 13.6.5 of the revised manual addresses downdrag specifically for drilled shafts; stand-alone AASHTO provisions for drilled shafts should be considered
- Service limit state (settlement) will control in most cases
- May be appropriate to consider different load combinations for evaluation of geotechnical strength limit states than for structural strength limit states, when downdrag occurs (e.g., geotechnical strength limit states should be limited to permanent load only + downdrag)

5. Base Grouting



- Not currently addressed in AASHTO
- Research and experience are now sufficiently advanced for inclusion in transportation practice
- Design equations in Appendix C (Section C.3) of Manual
- Requires development of resistance factors

6. Structural Issue: Tightly Spaced Transverse Reinforcement



- Transverse reinforcement requirements (Section 5)
- Seismic Zones 2, 3, and 4:
 $s_{\max} = 4.0$ inches to depth of $3B$ below fixity
- Conflicts w/ constructability
 $s_{\min} =$ larger of 5.0 inches or $5X$ max aggregate size

7. Structural Issue: Resistance with Permanent Casing

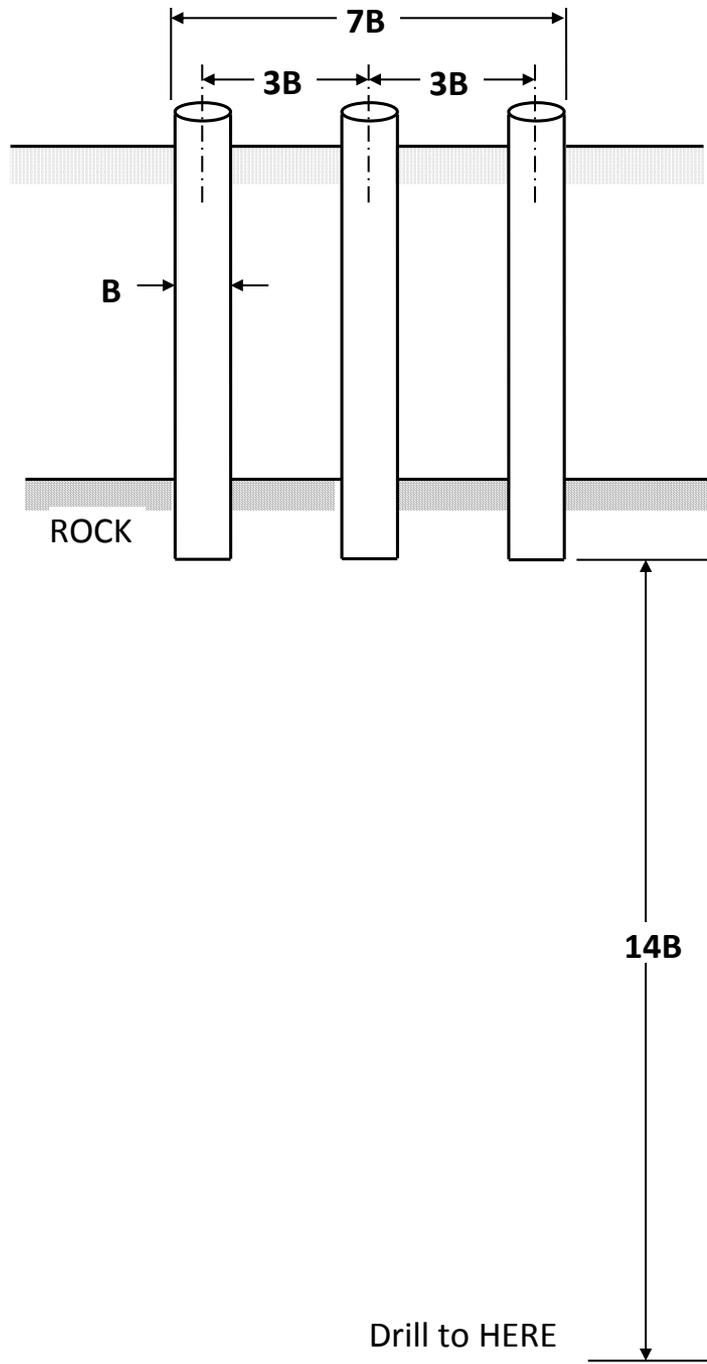
- Article 5.13.4.5 'Cast-In-Place Piles' includes both drilled shafts and piles cast in driven steel shells, but does not specifically cover design of drilled shafts with both reinforcing cage and permanent casing
- Casing provides confinement, increased flexural stiffness, increased axial and flexural strength
- Recommend adding information to cover this topic specifically for drilled shafts

8. Depth of Borings

Table 10.4.2-1:

“For shafts supported on or extending into rock, a minimum of 10 ft. of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or ***two times the maximum shaft group dimension***, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.”

The above may be unrealistic for groups of drilled shafts



9. Definition of a Site for Static Load Test

- Resistance factors and definition of a 'site' for static load testing of drilled shafts is tied to Table 10.5.5.2.3-2.
- Text in Article 10.5.5.2.3 says this table to be used together with signal matching analysis of dynamic test data (intended for driven piles)

10. Resistance Factors, Group Redundancy, and Load Testing

- 20 percent increase in resistance factors allowed for groups of five or more drilled shafts
 - Example: $\phi = 1.2 \times 0.55 = 0.66$
- For static load testing, max resistance factor of 0.70 allowed
- For groups of 5 or more shafts, incentive to conduct static load testing is thus greatly diminished
- Reconsider the 20 percent increase for groups of 5 or more shafts; consider allowing a single shaft within a group to carry a higher load by increasing resistance factor

Summary

- Proposed analysis for lateral geotechnical strength fulfills a need that is not being addressed currently with a rational approach that can be implemented using existing analytical tools
- Replacing the depth-dependent β method is a long-overdue improvement for design of shafts in cohesionless soils
- Additional refinements are identified to address downdrag, base grouting, structural design, depth of borings, and shaft redundancy
- Calibrations are needed to establish resistance factors for newly-proposed design equations and to update existing methods