Construction Considerations in the Selection and Design of Drilled Shaft Foundations for Bridges

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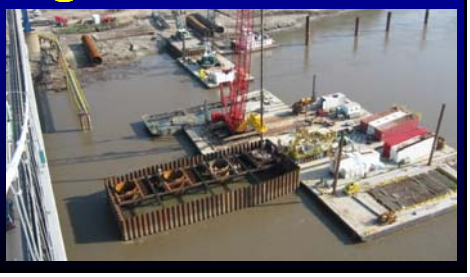


Overview

- Drilled Shaft Applications for Bridges
- New Machines and Capabilities
- Slurry Advancements
- Design of Rock Sockets
- Base Resistance
- Concrete & Reinforcing

Characteristics of Bridge Foundations

- Congested sites, existing structures & utilities
- Many equipment moves & difficult access
- Owner specifications & review, often in a design-build environment
- Extensive performance verification; structural integrity and axial resistance
- How do we build it?

Drilled Shaft Applications

- Bridges where small footprint is needed
- Usually minimal impact on nearby structures

Drilled Shaft Applications

Bridges constructed over water;
single shaft per column may avoid cofferdam

Drilled Shaft Applications

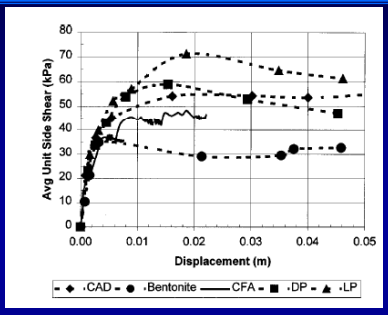
Very large foundation loads

Drilled Shaft Applications

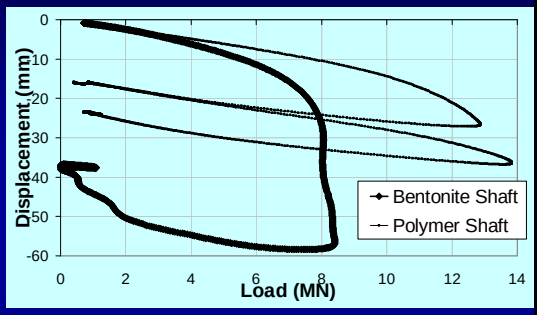
Foundations with deep scour or potential liquefaction, lateral spreading

Larger, More Powerful Machines

Influence of Slurry on Axial Resistance



Data from Auburn University



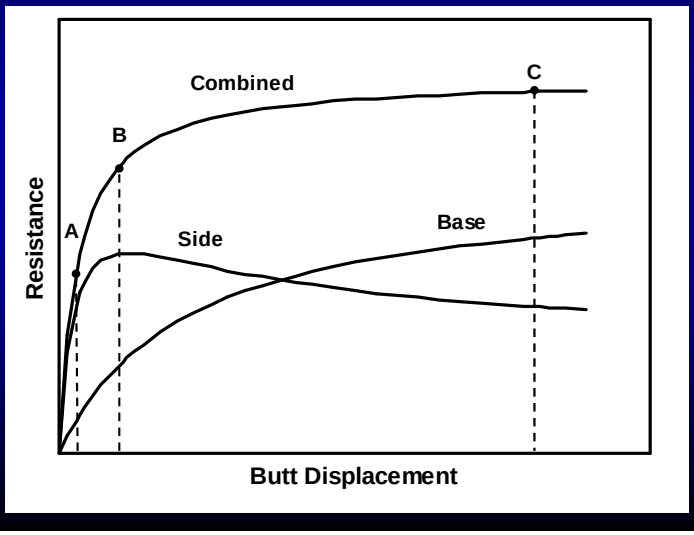
Data from Cape Fear Bridge, Wilmington, NC

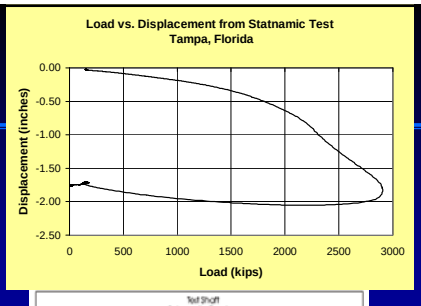
Rock Sockets

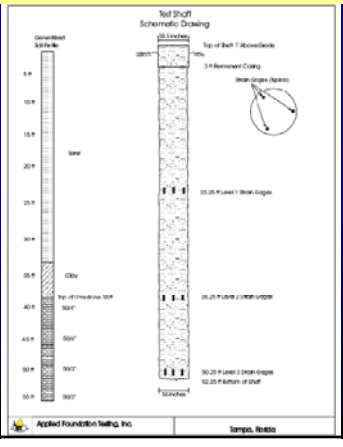
- Rock excavation can be ***expensive***
- Structural capacity of shaft may govern design
- Axial:
  - End bearing + side shear
- Lateral:
  - Perform sensitivity analysis

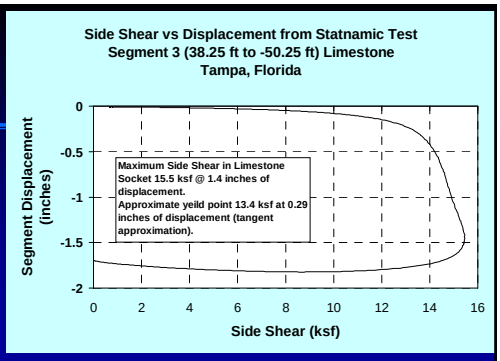
Rock Socket – Axial

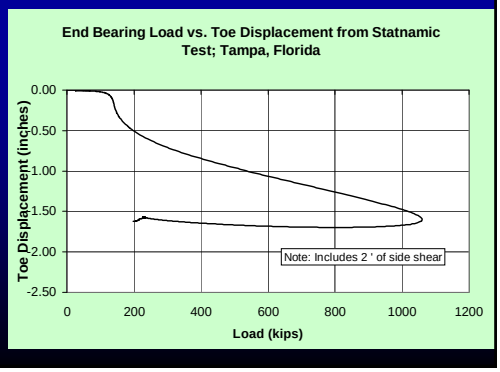
Ductility of Side Shear Resistance



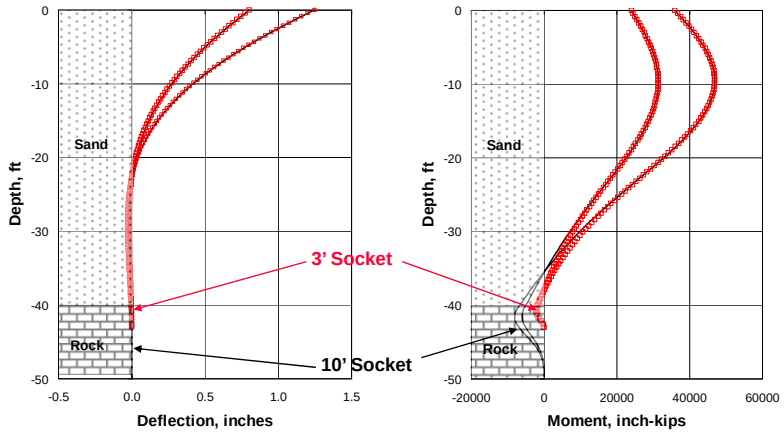








Rock Sockets - Lateral



6' Dia. Shaft
40' Lse to Med Dse Sand over
Sandstone (500psi = q_u)

Bottom Cleanout & Inspection

Techniques for slurry or underwater construction

Base Resistance & Cleanliness

- It is possible to get a reasonably clean base under water or slurry
- It is not possible to get a perfectly clean base in any circumstances
- Attempts to require a “dry hole” for end bearing may be counterproductive

Lumber River Test Shaft

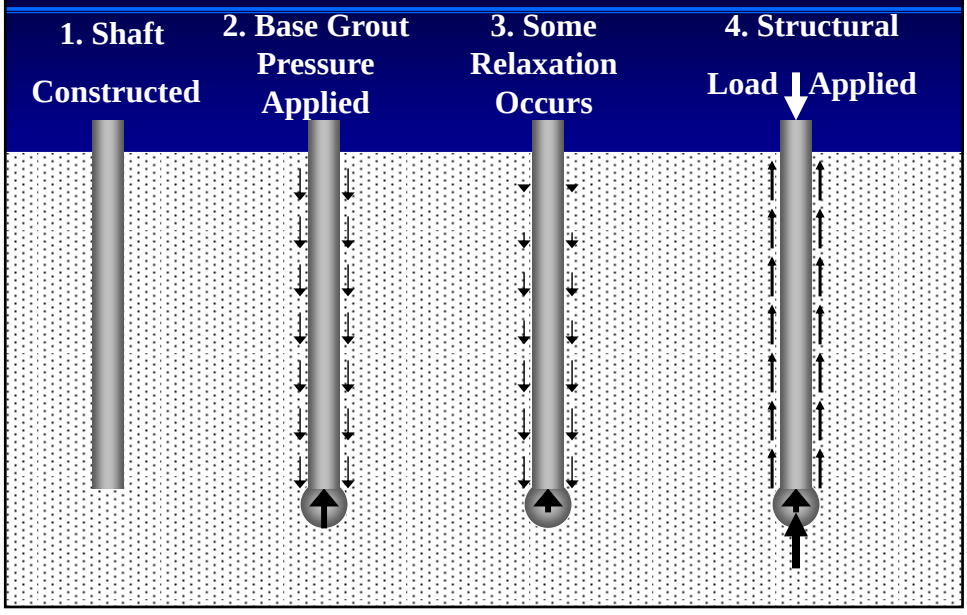
Base Resistance in Sands

- Cohesionless sands may never indicate sound base
- Base grouting can be very effective to enhance base resistance & QA

Base Grouting

- Enhance Axial Resistance
- Improve Reliability
- Mitigate Imperfections in Base Conditions

The Base Grouting Process



Base Grouting Apparatus

- Tube á Manchette (using CSL tubes)
- Cover Plate
- CSL Tube

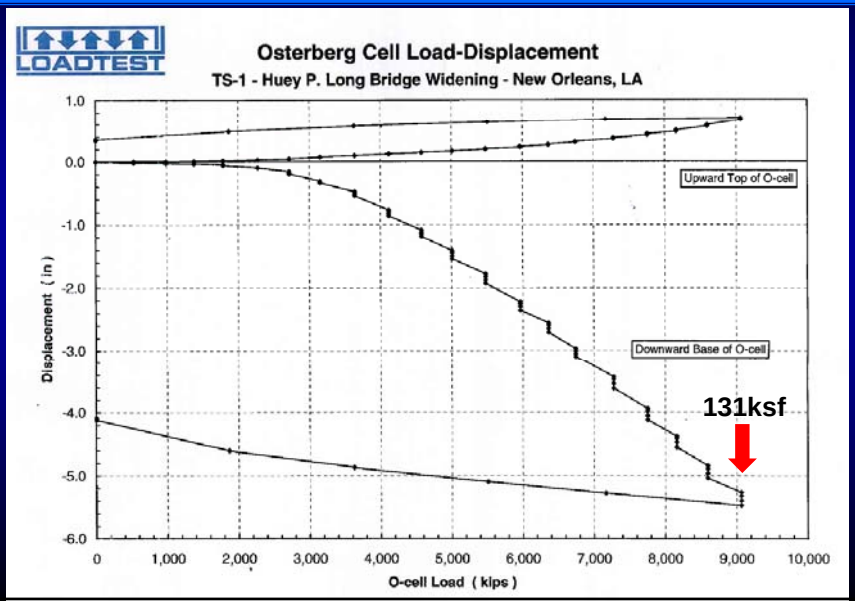
Criteria

- Target Pressure
- Minimum Net Volume
- Limit Upward Shaft Movement

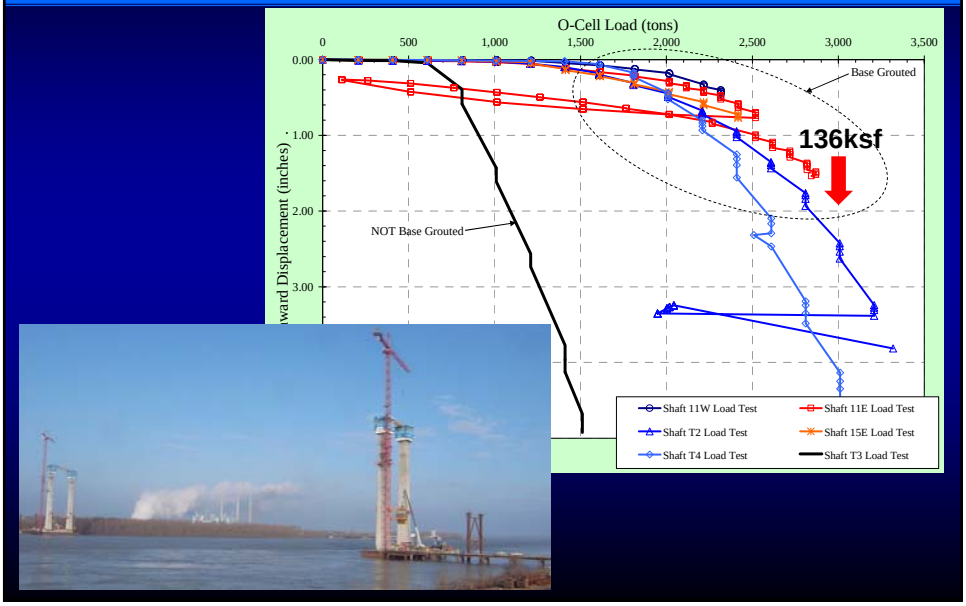
Exhumed Shaft

Huey Long Bridge, New Orleans

Huey Long Bridge, New Orleans



John James Audubon Bridge, La.



Concrete & Reinforcing

- Constructability Issues that can be significantly reduced during structural design
- Workability and passing ability of concrete
- Reinforcing cage congestion
- Time required to place cage and concrete (full slurry exchange)
  - Our slurry specs aren't tight enough for large shafts

Structural Design of Drilled Shafts

AASHTO (Article 10.8.3.9.1) :

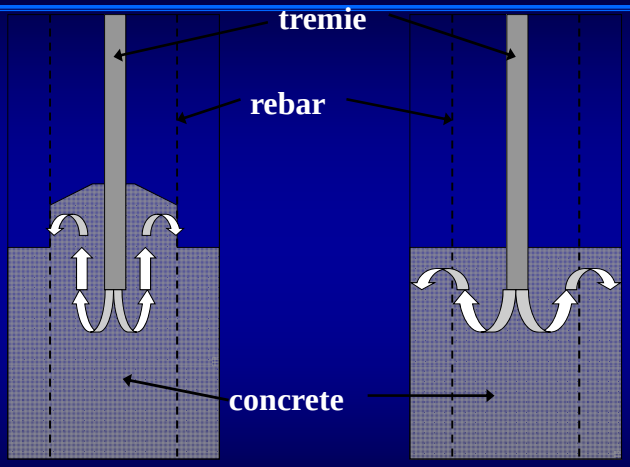
'*The structural design of drilled shafts shall be in accordance with the provisions of Section 5 for the design of reinforced concrete*'

But . . . with adequate consideration of drilled shaft constructability

Drilled Shaft Concrete

- **Unique Requirements**
  - Workability
  - Workability Retention
  - Passing ability
  - Segregation resistance
  - Bleeding characteristics
  - Heat of hydration (in large diameter shafts)

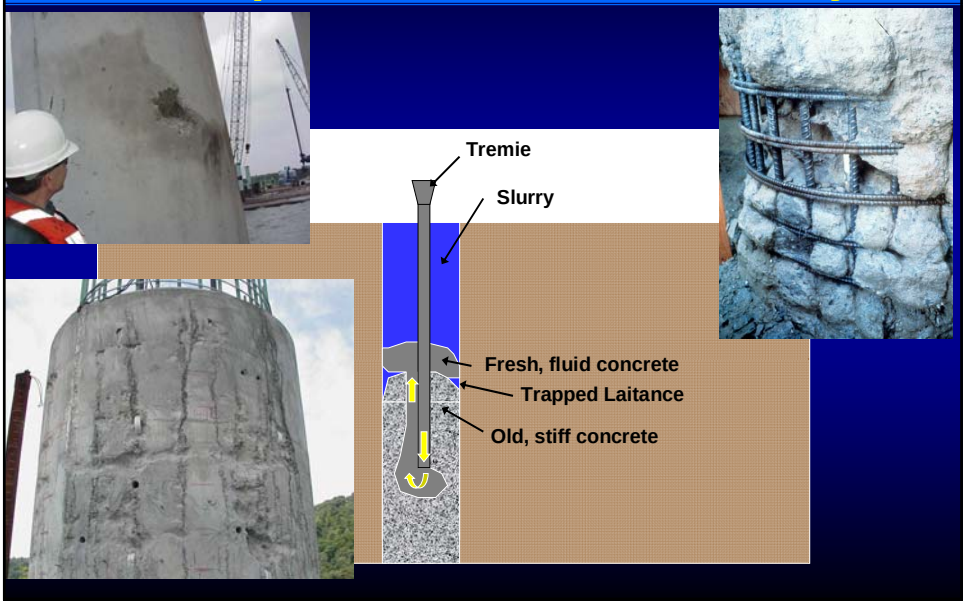
Need for Workability and Passing Ability



Congested Cage, Concrete with inadequate workability

Concrete with good workability and filling ability

Potential Problem w/ Inadequate Concrete Workability



Characteristics of HPDSC
(High Performance Drilled Shaft Concrete)

- 18”-24” Slump Flow
- Smaller, Rounded Coarse Aggregate
- Increased Sand/Coarse Agg. Ratio
- Supplementary cementing materials (SCM)
  - Fly ash
  - Slag cement
- Extensive use of chemical admixtures

Chemical Admixtures

- Air-Entraining Admixture
- Set-Controlling Admixture
  - Retarder
  - Hydration stabilizer (Type D)
- Water Reducing Admixture
- Viscosity Modifying Admixture (VMA)

Lumber River, Coastal South Carolina

Constituent	Value
Type I/II Cement	500 pcy
Class F Fly Ash	250 pcy
Sand	1366 pcy
#67 Gravel	1071 pcy
#789 Gravel	395 pcy
Water	306 pcy
w/cm	0.41
Air	2%
Delvo Stabilizer	8 oz/cwt
Glenium 3030 NS	8-12 oz/cwt
Rheomax VMA 358	2 oz/cwt
Slump Flow	18”-24”

Mullica River, Atlantic City, NJ

Constituent	Value
Type I Cement	526 pcy
Class F Fly Ash	132 pcy
Sand	1363 pcy
#8” CA	1500 pcy
Water	267 pcy
w/cm	0.405
Air	7.5%
HRWRA (Sika 2100 SP)	7 oz/cwt
Retarder/Water Reducer (Sika Plastiment)	4 oz/cwt
Spread	18”-24”

Strategies for Constructable Cages

- Use larger diameter shaft
- It's a compromise (big openings = big bars; small bars for durability).
- Reduce reinforcement below high moment
- Bundle bars (hoops, too) to increase openings
- Use permanent casing for confinement (instead of tight spirals)
- Use 6" cover for tolerance to match column
- Locate column splice above pour cutoff

Congested Rebar Cage

Constructability Problems with Congested Reinforcing Cages

Essentials of Cage Design for Constructability

- Clear Spacing Between All Bars ≥ 5 D of Largest Coarse Aggregate or 6 inches, (whichever is larger)
- Use Only Lap or Mechanical Splices
- Locate Splices As Deep As Possible

Limits on Longitudinal Steel

AASHTO 5.7.4.2:

$$1\% \leq \rho_s \leq 8\%$$

$$\frac{A_s f_y}{A_g f_c'} \geq 0.135$$

Seismic Zones 2, 3, and 4:

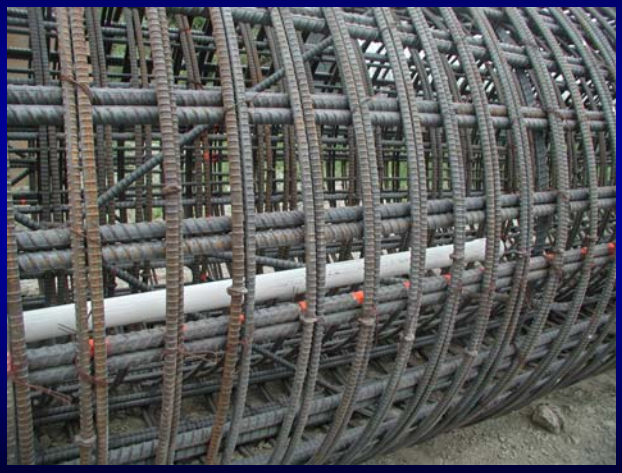
$$\rho_s \leq 6\%$$

Practical Limits for Drilled Shafts

- Typically: $1\% \leq \rho_s \leq 2\%$
- High seismic: $2\% \leq \rho_s \leq 3\%$
- As the value of ρ_s approaches 4% it becomes impossible to ensure flow of concrete and should be avoided (constructability)
- For axial loading only, when cross-section is larger than required:

  minimum $\rho_s \geq 0.5\%$

Bundle Bars

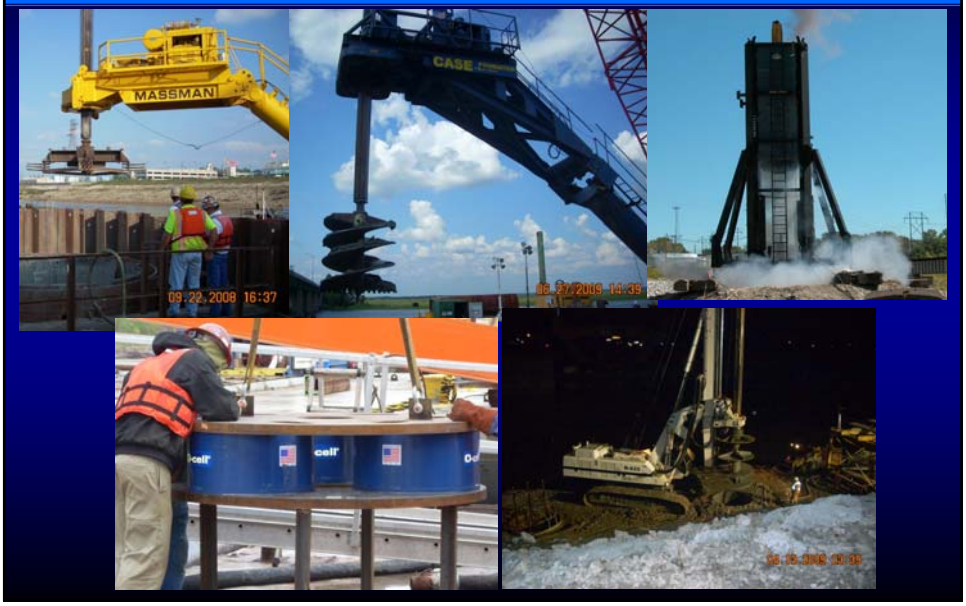


Partial Length Cage

Permanent Casing

- Often exists to help with constructability, particularly for water crossing bridges
- Provides confinement
- Increases flexural stiffness and capacity
- Consider corrosion losses
- Not fully utilized near ends of casing

Summary

- Bigger shafts are possible
  - may avoid need for coffer dam
  - may reduce impact on adjacent structures
- Count on base and side resistance
  - demonstrate with load test
  - reduces socket length
  - don't get carried away with lateral design
- Concrete & reinforcing designed considering constructability

Thanks for Listening!