Mobilization of Side and Base Resistance in Rock-Socketed Drilled Shafts

David Graham, P.E., BC.GE
Senior Engineer
DFI Drilled Shaft Committee Chair

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Forum Paper

Combined Side and Base Resistance in Rock-Socketed Drilled Shafts – A State of the Art Consensus

Paul Axtell[1]*, John Turner[2], Benjamin Turner[3], Scott Jacobs[4], Kirk McIntosh[5], Bernardo J. Vega[6], Bernhardt Hertlein[7] and Jesús Gómez[8]

- Not a design or load test interpretation guide
- Not a manual for proper site investigation or QC/QA procedures
- A synopsis encouraging inclusion of side + base for ***most*** cases

What do codes and design guides say?

Code	Include Side + Base in Rock Socket Design?
AASHTO (2020)	Allowed – with some contradictory and ambiguous language
FHWA GEC 10 (2018)	Allowed – recommended unless justified reason not to
IBC (2021)	Allowed – with adequate geotechnical investigation
ACI (318-19 & 336.1-01)	Silent – limited guidance can be inferred from construction spec
AREMA (2022)	Allowed – “the ultimate capacity of a drilled shaft which utilizes a rock socket shall be based on the sum of the ultimate tip and side resistance capacities”

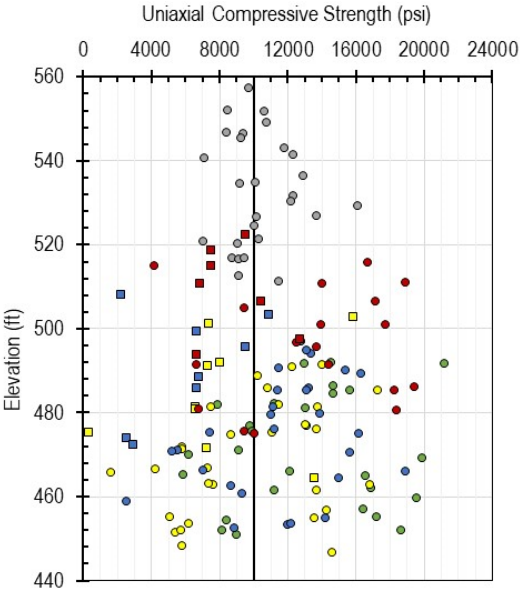
Despite the codes, many practitioners still disregard one or the other because:

1. Displacement compatibility, *i.e.*, idea that amount of displacement to mobilize base is significantly greater than that required to mobilize side (sometimes referred to “strain compatibility”)

2. Displacement-softening or brittle side resistance behavior

3. Lack of confidence in the design, construction, and inspection/verification
   - Base cleanliness
   - Sidewall condition and degradation

We have tools to sample and test the rock



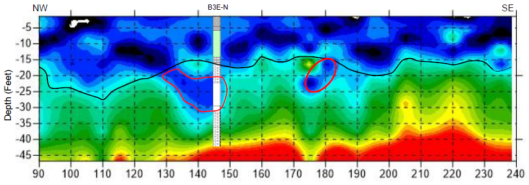
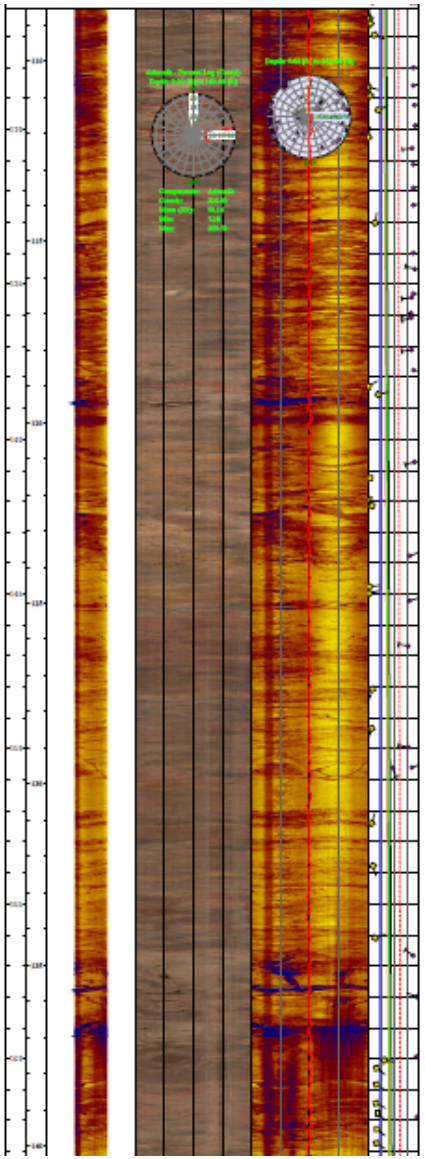


Table 1: Slake Durability Test Results.

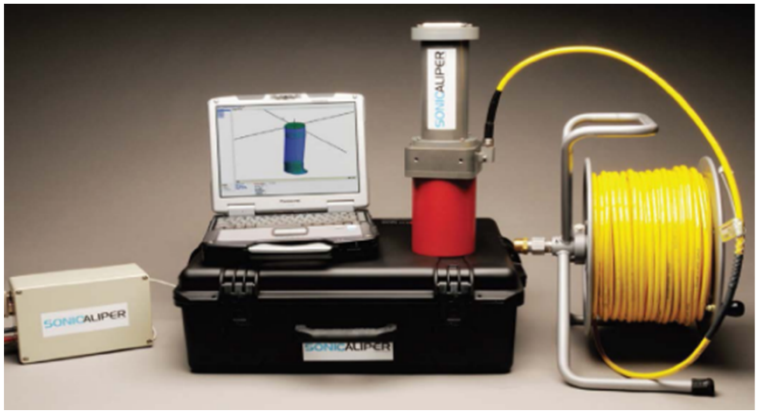
Sample	Natural Moisture Content (%)	Slake Durability Index Type	Slake Durability Index $I_d(2)$ (%)	Durability Rating Based on Shear Strength Loss Type	Durability Rating Based on Shear Strength Loss DR_s
River Water	8.3	II	72.2	Intermediate	61.9
Polymer Slurry	8.3	II	98.2	Hard, more durable	78.6



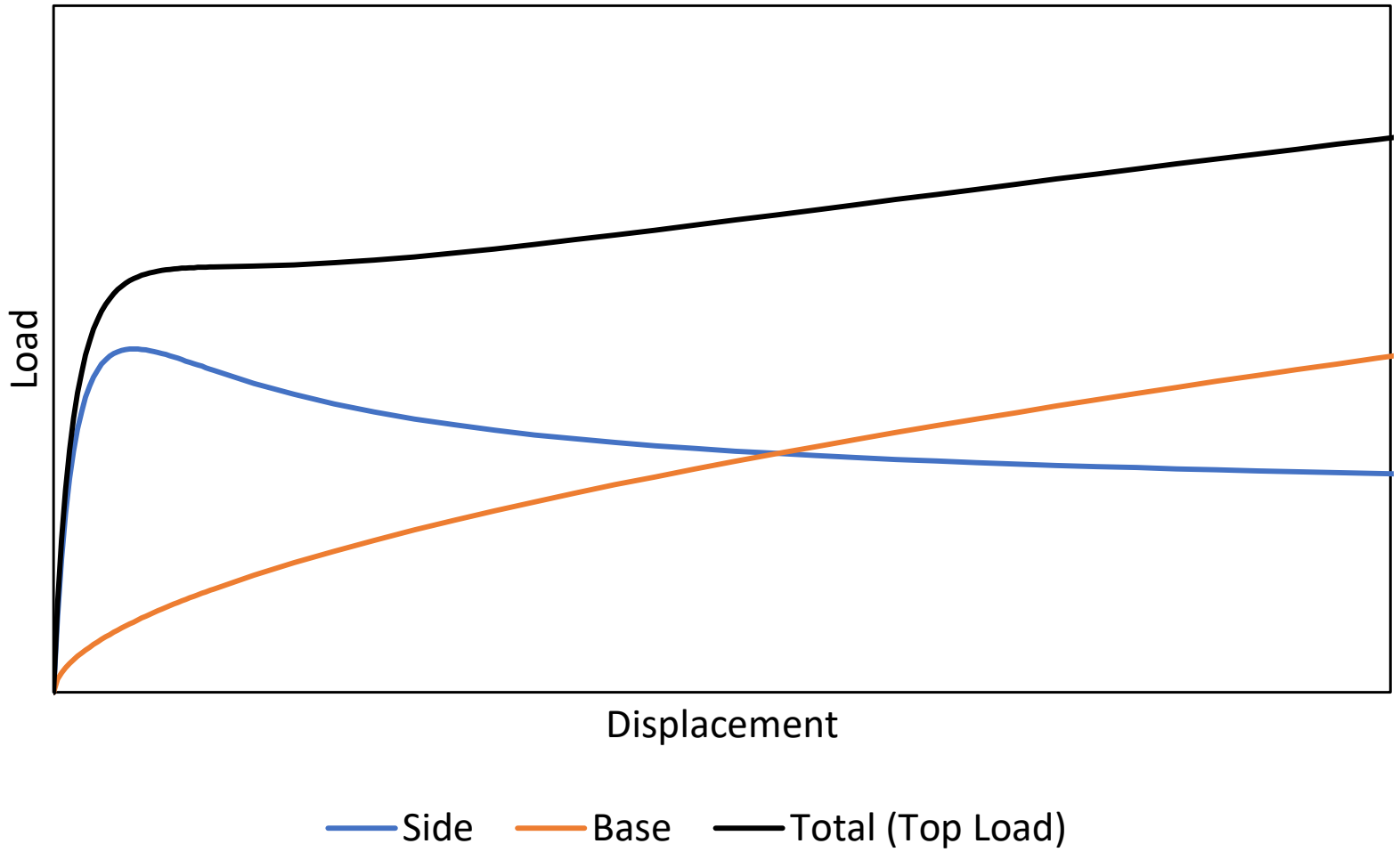
Don’t forget about load testing!

We have tools to address base and sidewall concerns

We have tools to inspect and verify



Displacement Incompatibility



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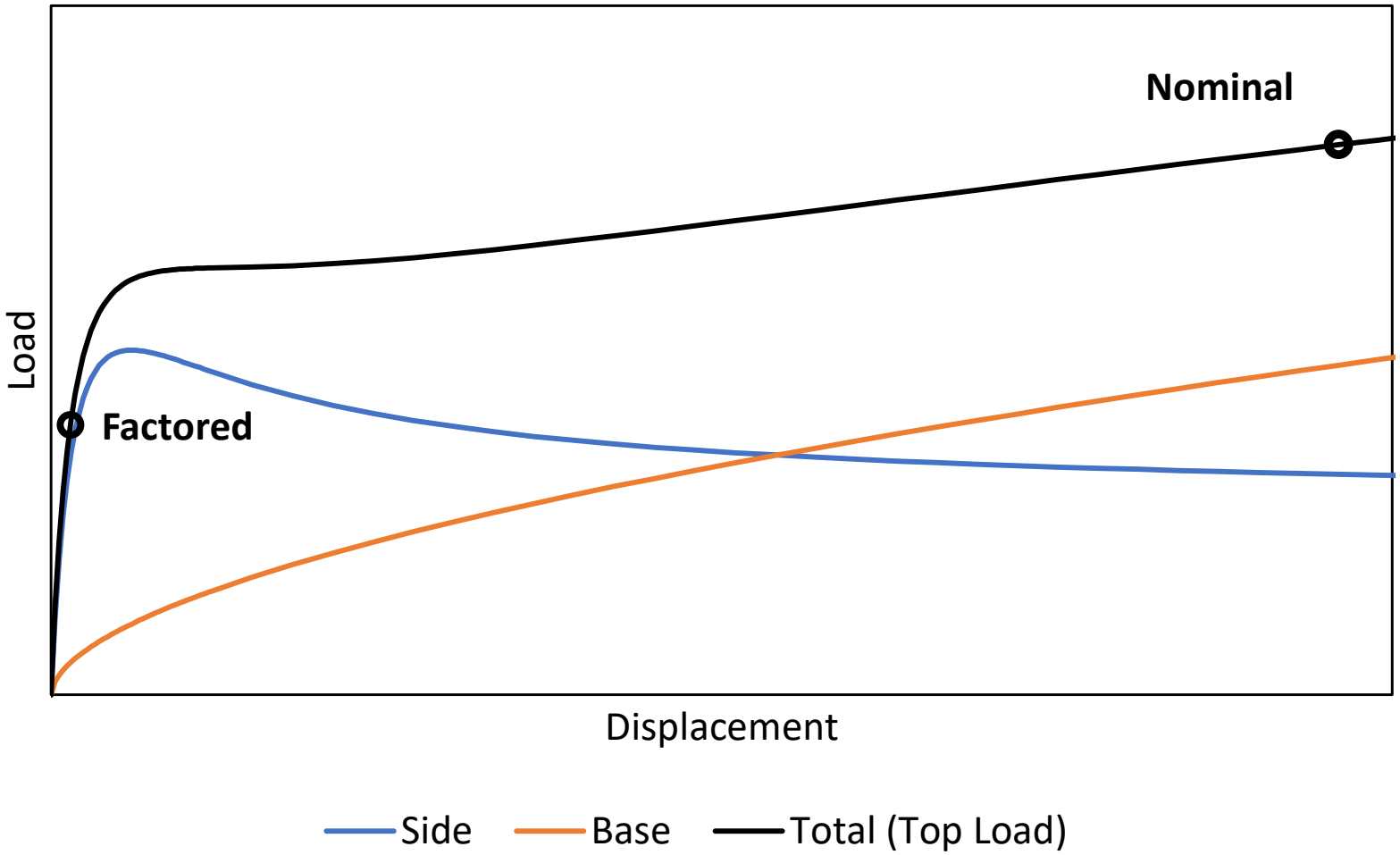
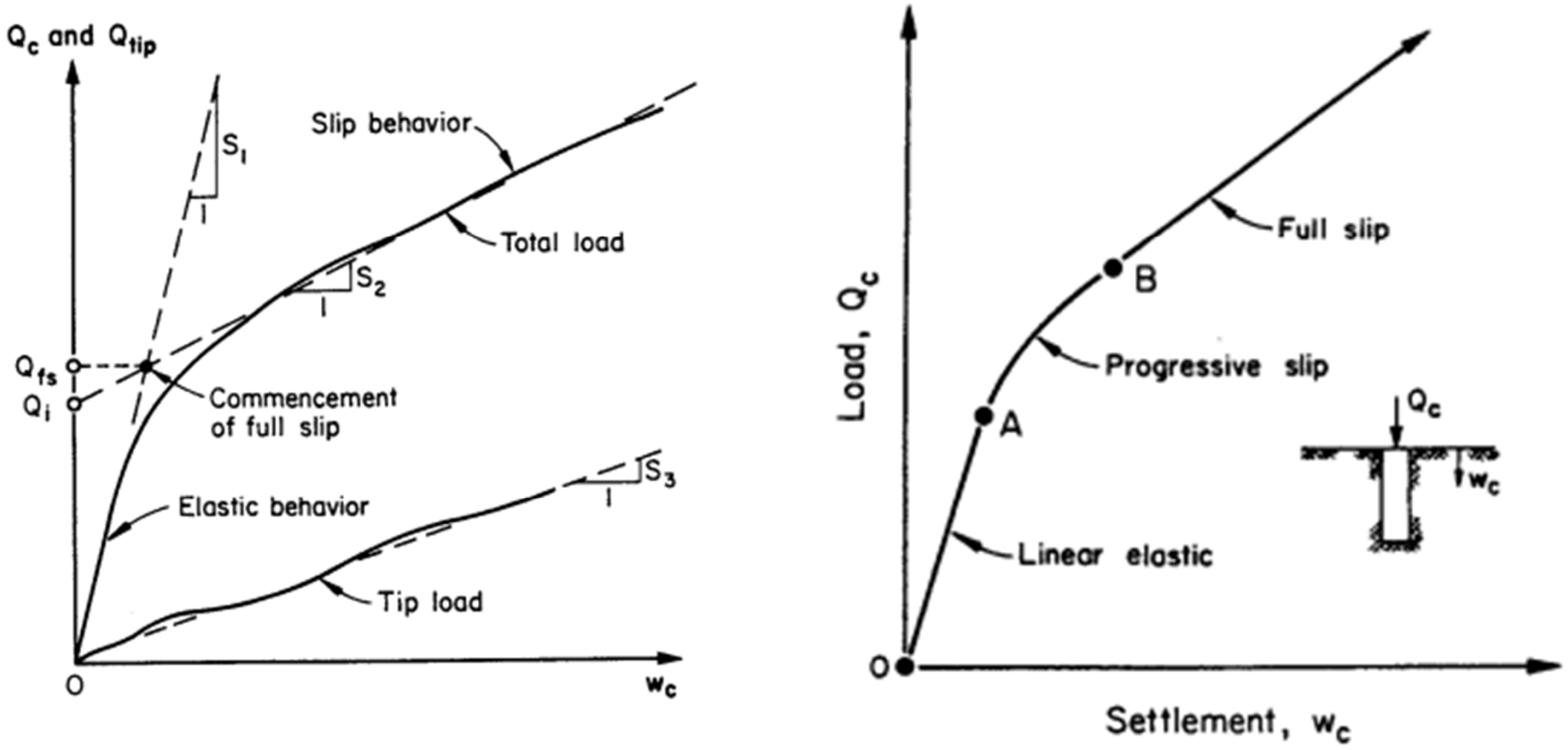


Rock Socket Load-Displacement Behavior



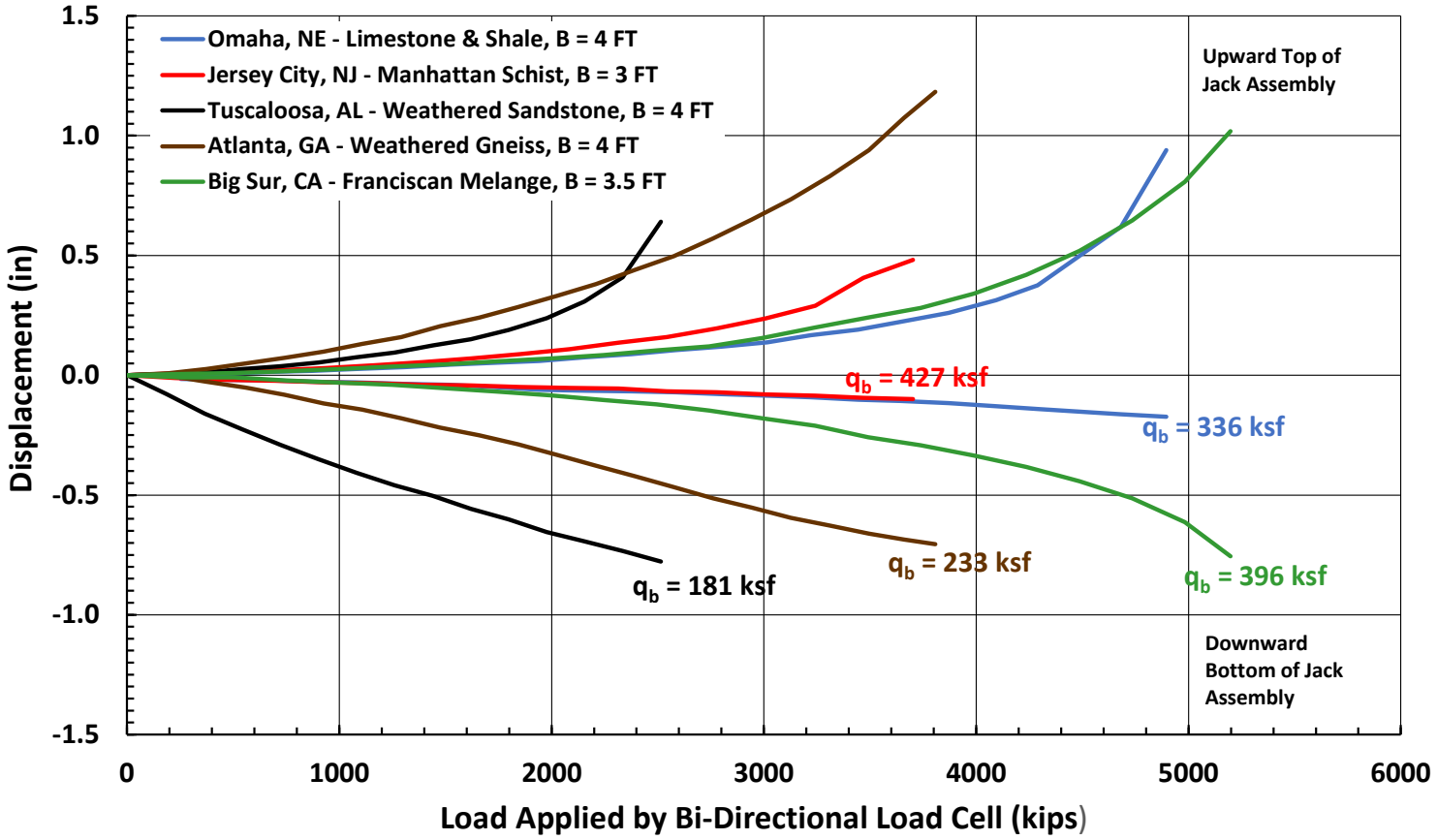
(after Carter and Kulhawy, 1988)

Key Points on load-displacement for Rock Sockets

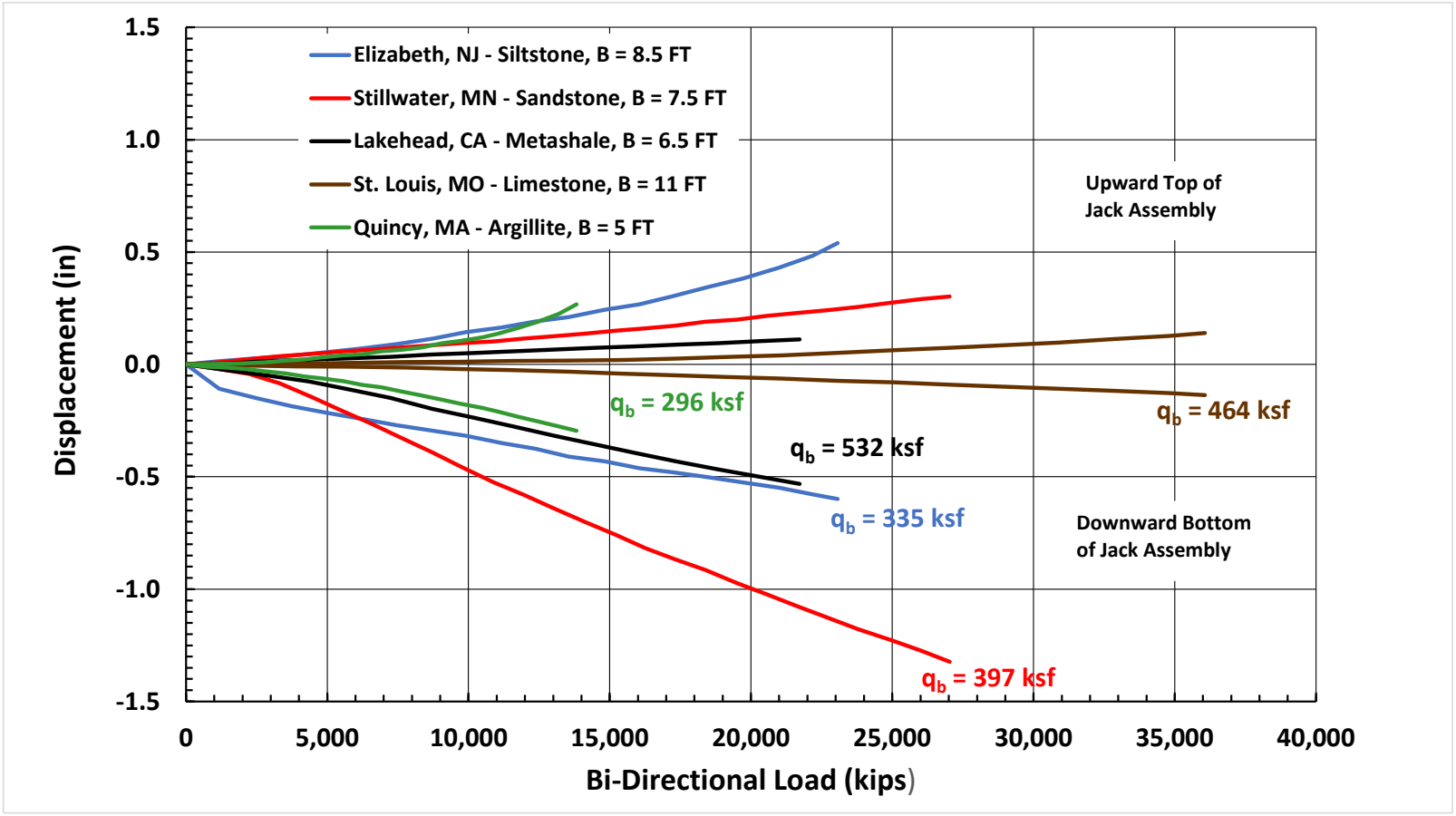
- Base resistance does not require large displacement to mobilize
- Even if large displacement is required to mobilize base resistance, that does not mean it cannot be relied upon for Strength Limit design
- Displacement should be evaluated based on service load
  (no factors, performance-based design)
- Displacement-softening is the exception not the rule, especially for rock sockets

What do bi-directional load test show?

Bi-directional load test results, small diameter



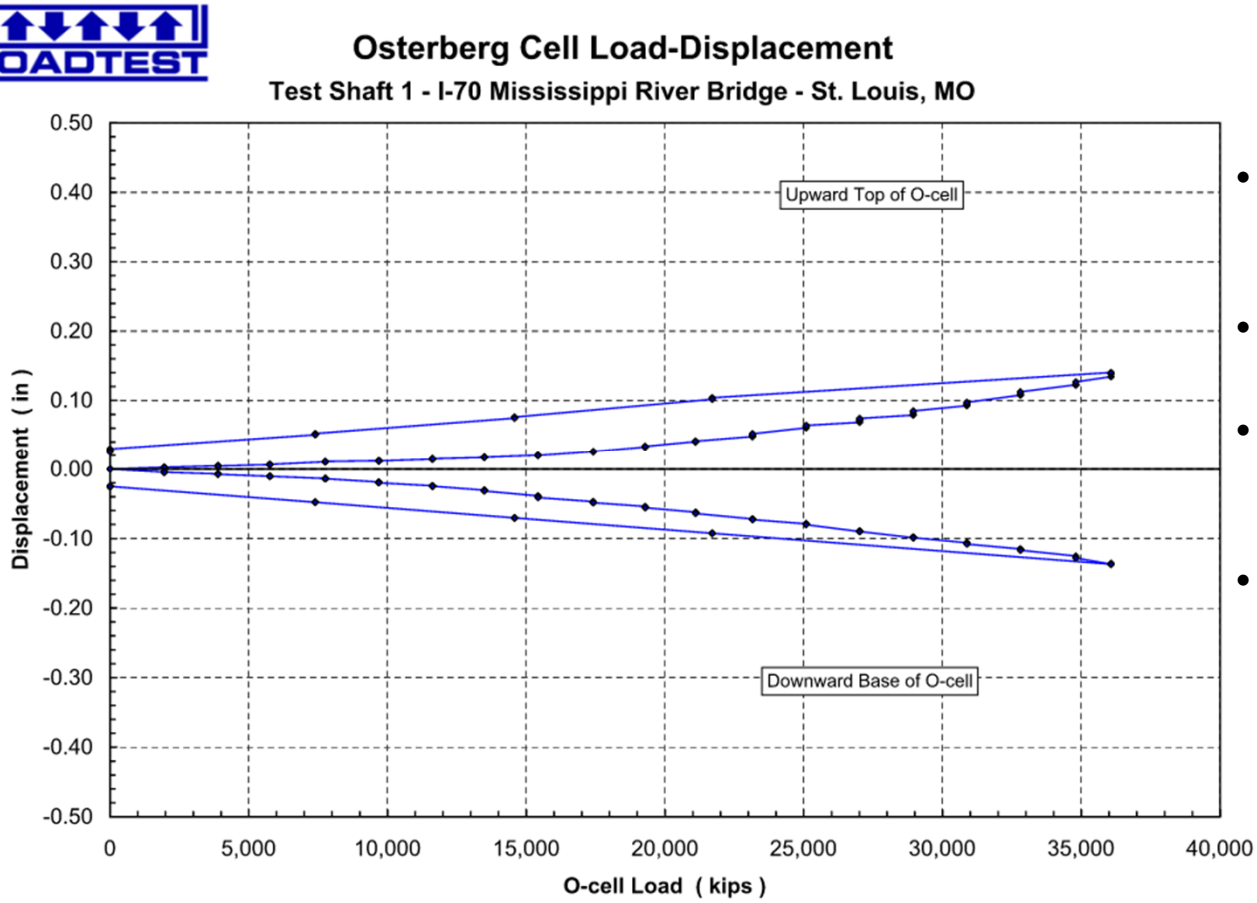
Bi-directional load test results, large diameter



Bi-directional load test results, key points

- Base resistance begins to mobilize immediately (i.e., very small displacement)
- Mobilization occurs at compatible displacements
- Nominal resistance not mobilized – typical in rock sockets, but usually side if at all…
- Displacements well within tolerance of most civil engineering structures.

Butterfly Graph from Bi-Directional Test in Limestone Bedrock



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Stan Musial Veteran's Memorial Bridge, I-70 over the Mississippi River, St. Louis, MO

Baseline Design	ATC Design
Side Resistance Only (no load test)	Side + Base Resistance (load test)
14 Drilled Shafts per tower	6 Drilled Shafts per tower
9.5-ft diameter x 44-ft long rock sockets	11-ft diameter x 19-ft long rock sockets
70 ft x 120' pile cap + seal & coffer cell	55 ft x 88 ft pile cap + seal & coffer cell
42% smaller pile cap + seal & coffer cell	
57% fewer, permanently cased drilled shafts	
16% larger diameter of drilled shafts	
81% less length of rock sockets (much less soil overburden length, too)	
75% less volume of rock sockets (much less soil overburden volume, too)	
Approximately $10 million in savings!	
Substantial reduction in risk (real risk)	

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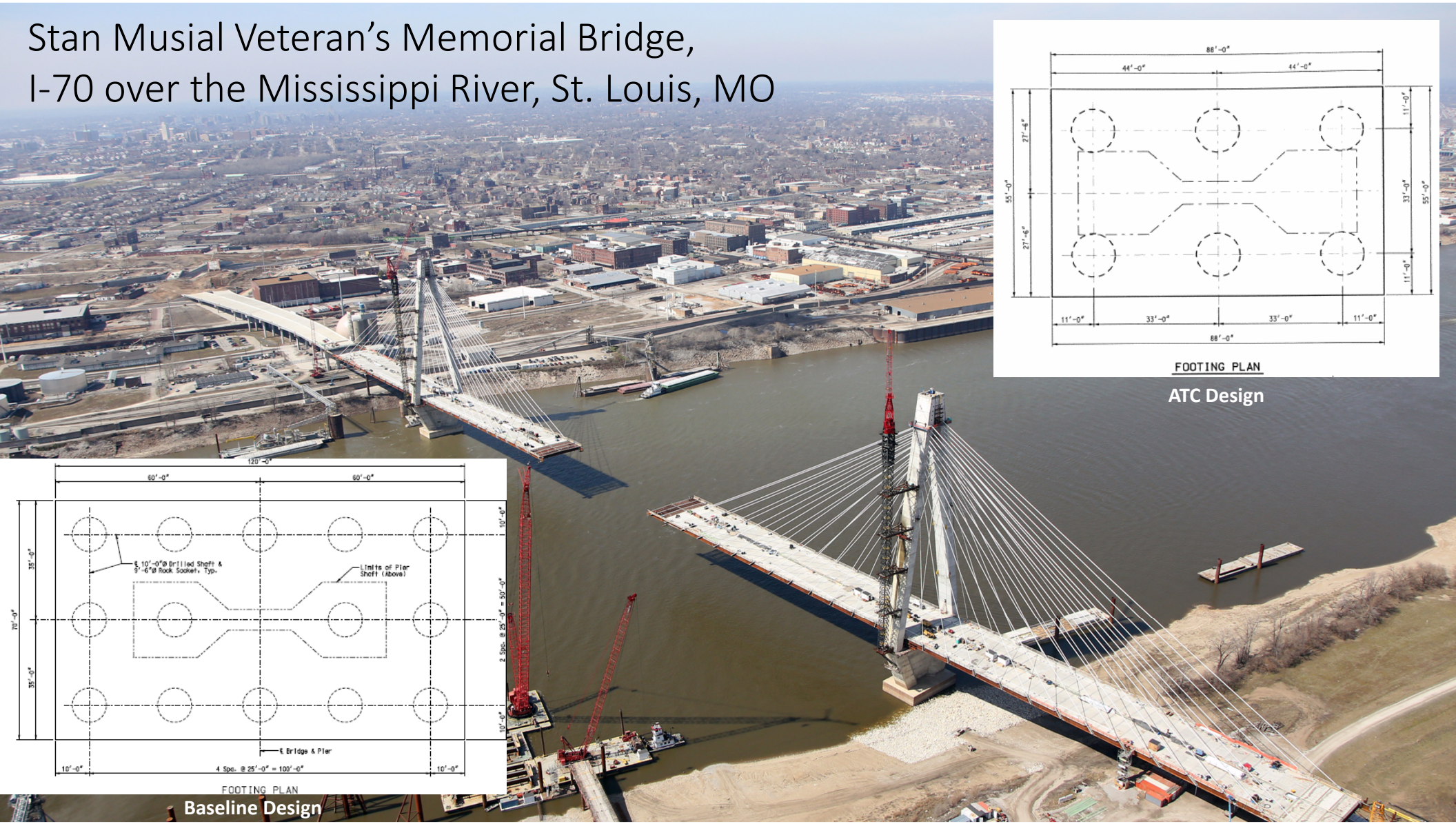


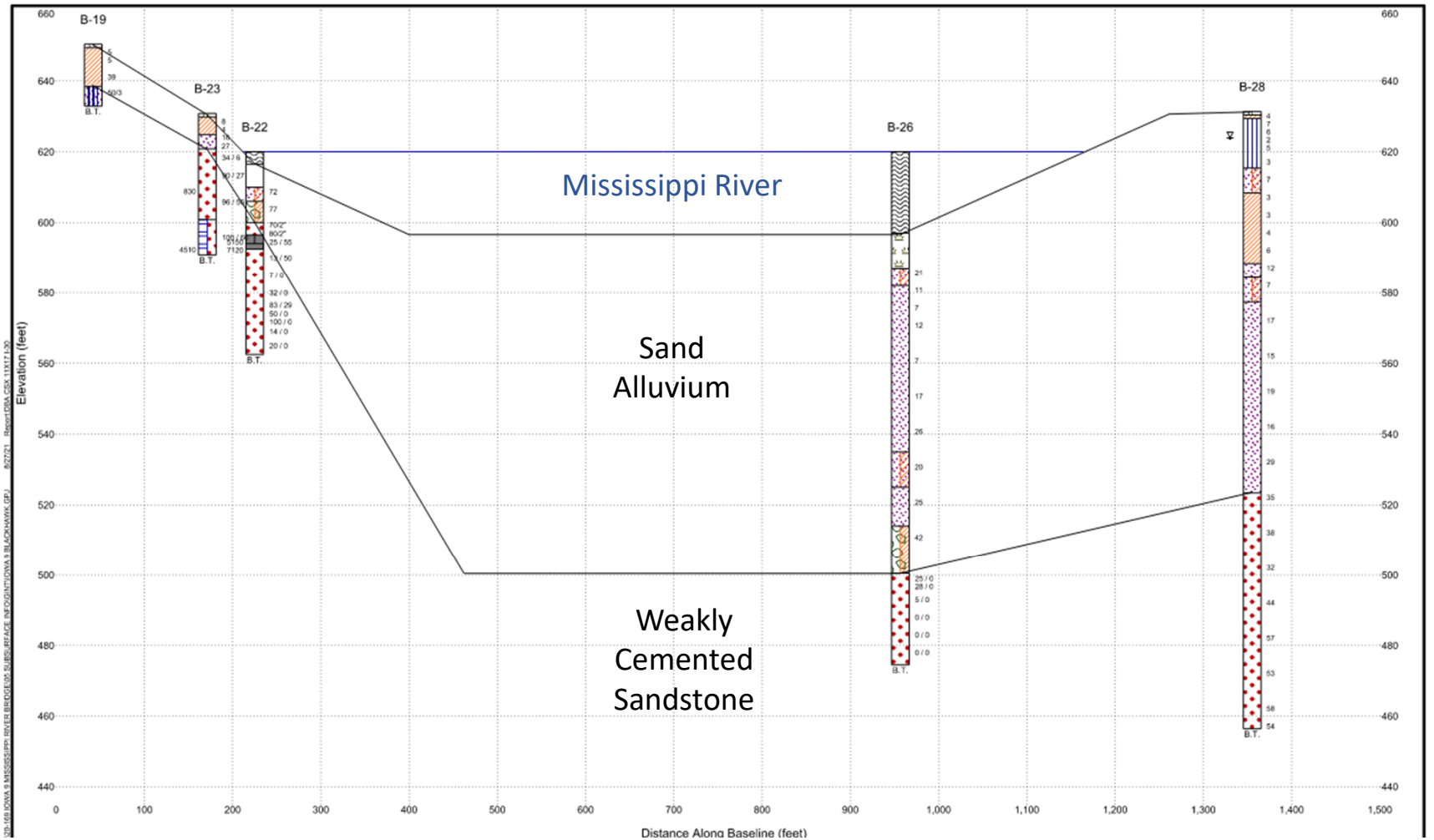
FOOTING PLAN

ATC Design

FOOTING PLAN

Baseline Design

What about bedrock that is not so great?



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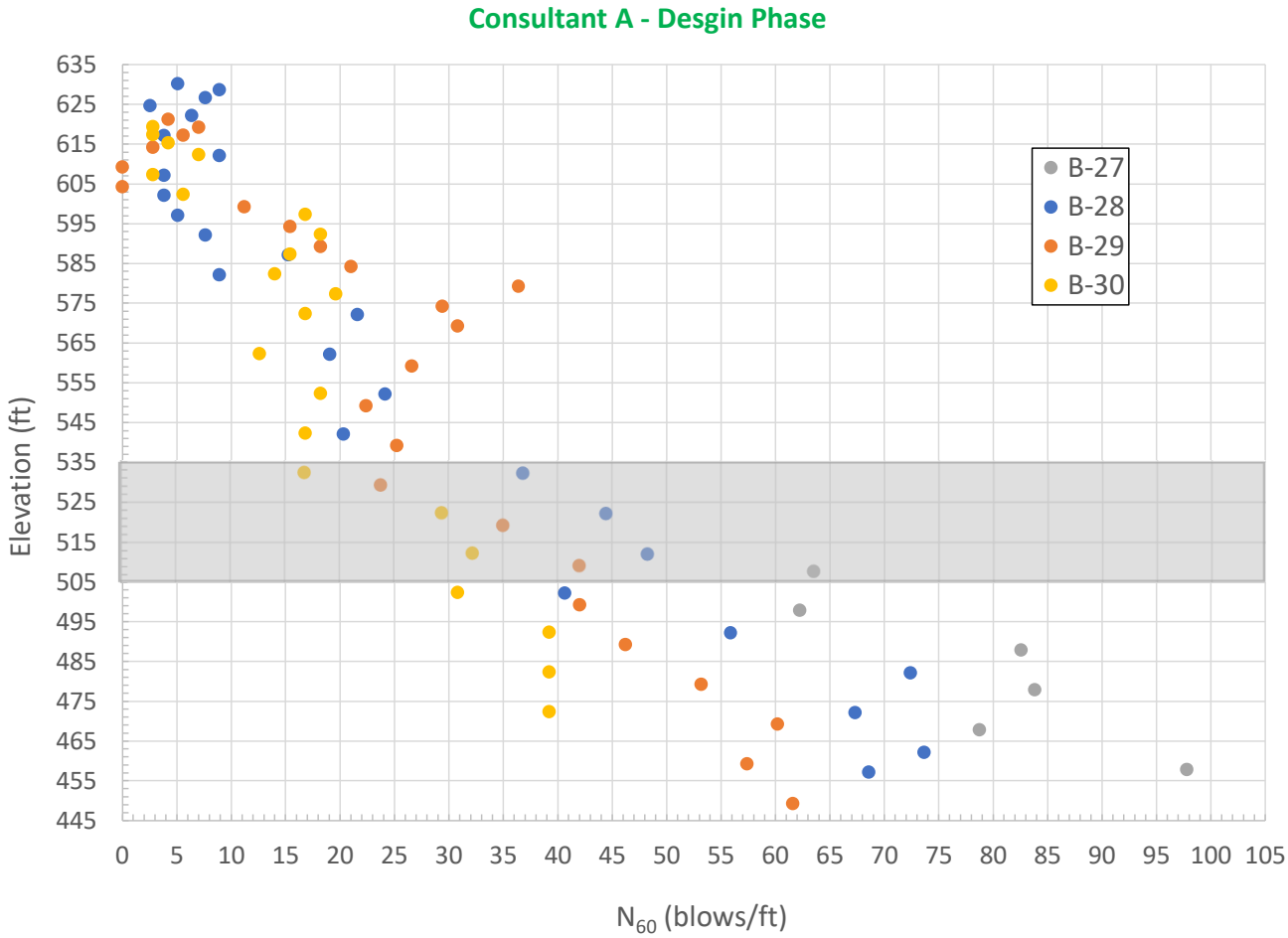

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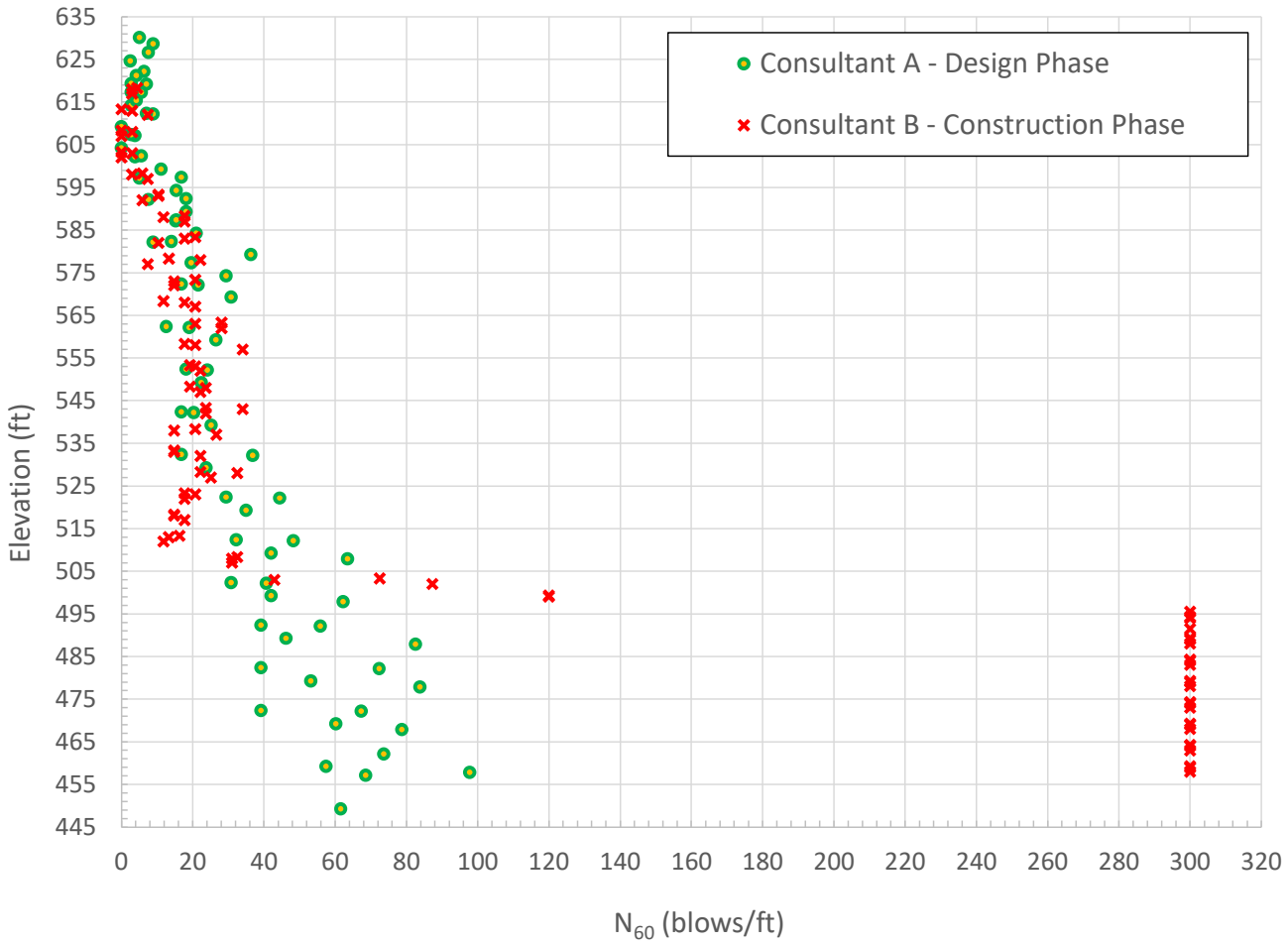
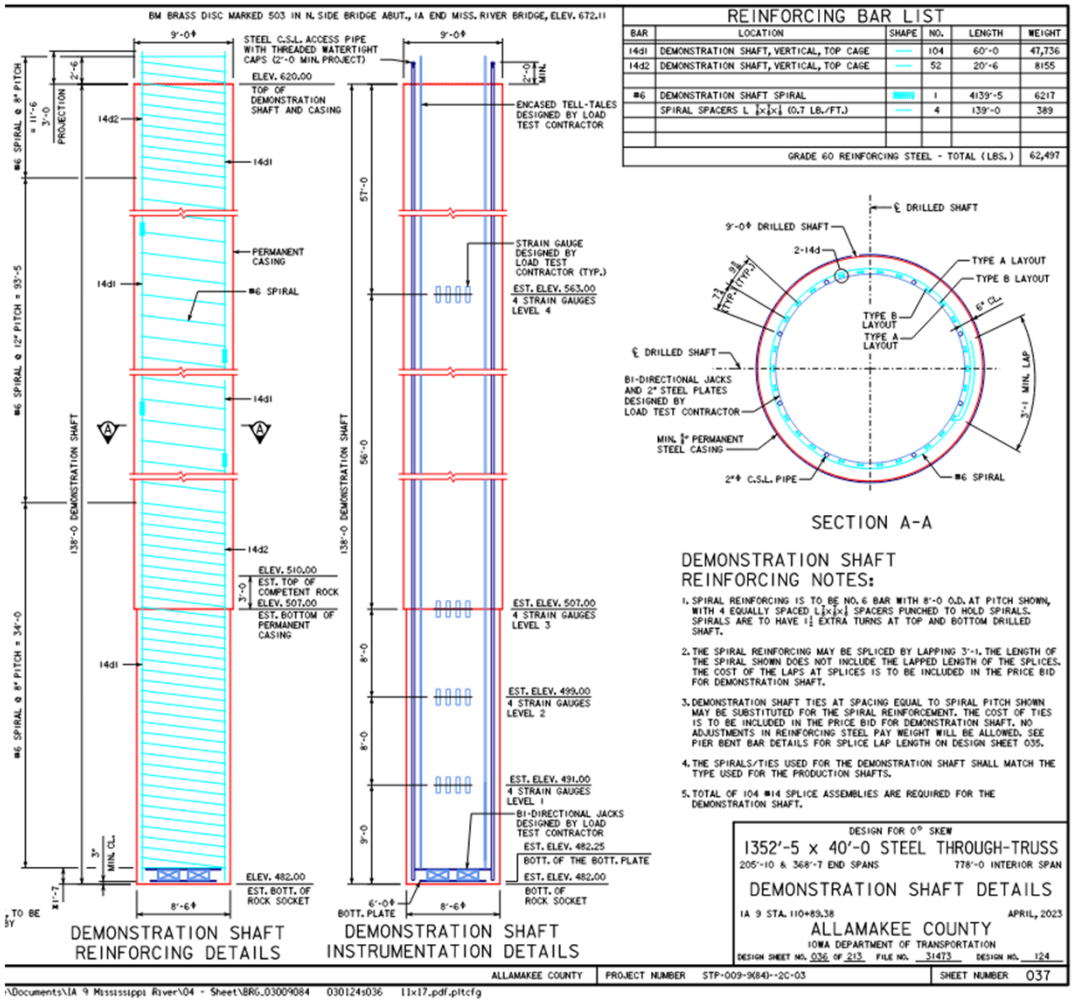


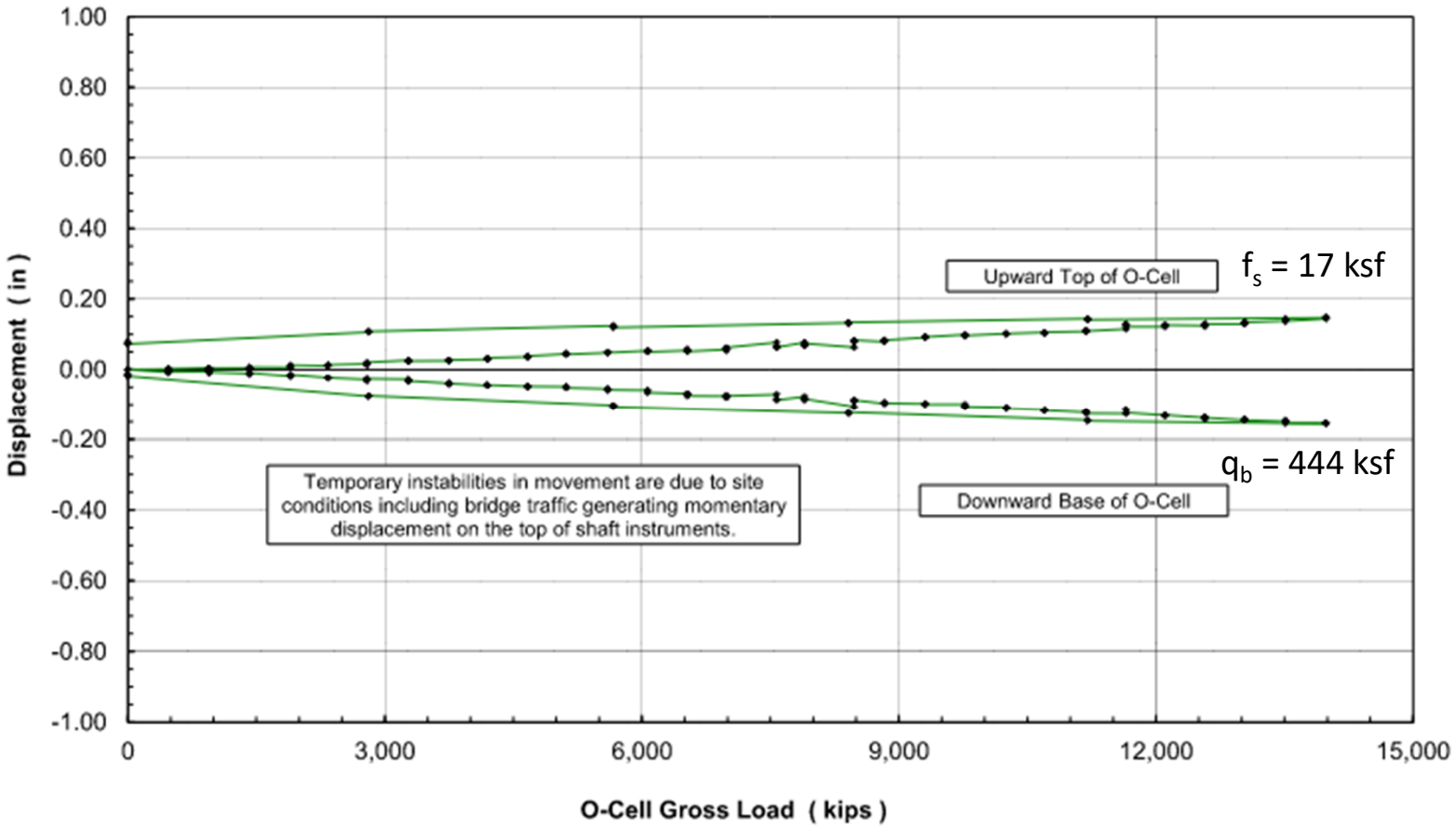
Demonstration and Test Shaft

- 8.5’ diameter rock socket
- 25’ long rock socket
- 9,000-kip min jack assembly rating
- Jacks on the bottom of the shaft
- 6’ diameter base load plate

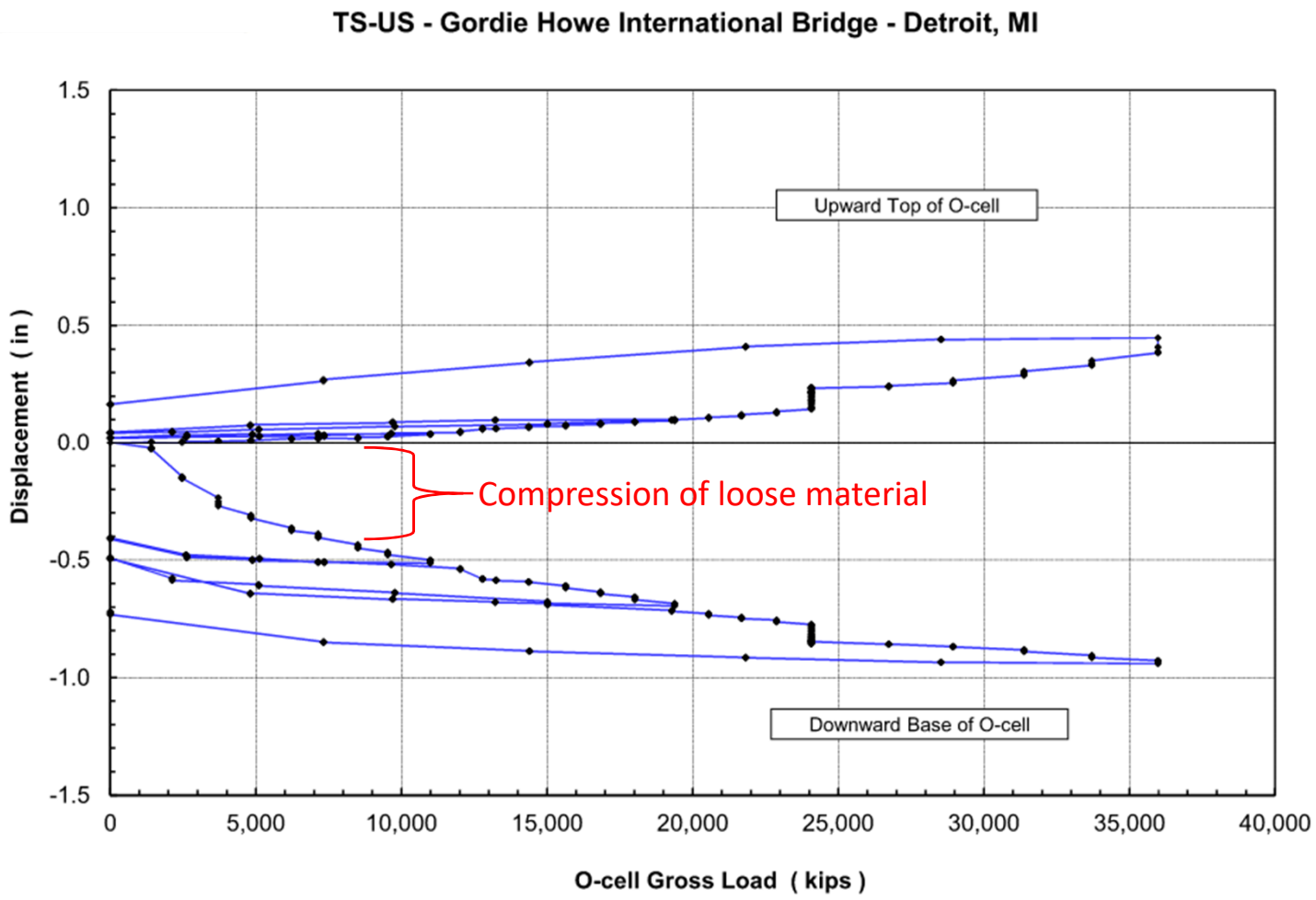


Sand or Sandstone?

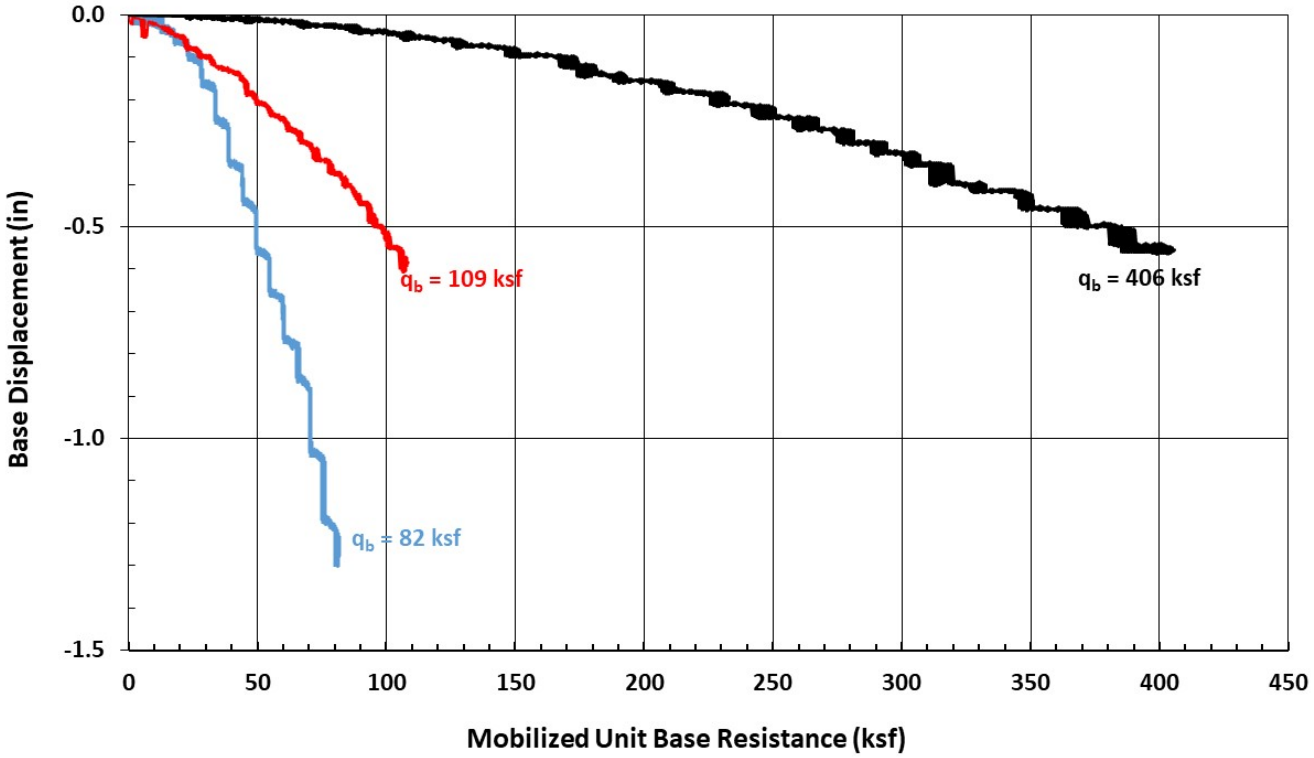
Butterfly Graph from Bi-Directional Test in Weak Sandstone



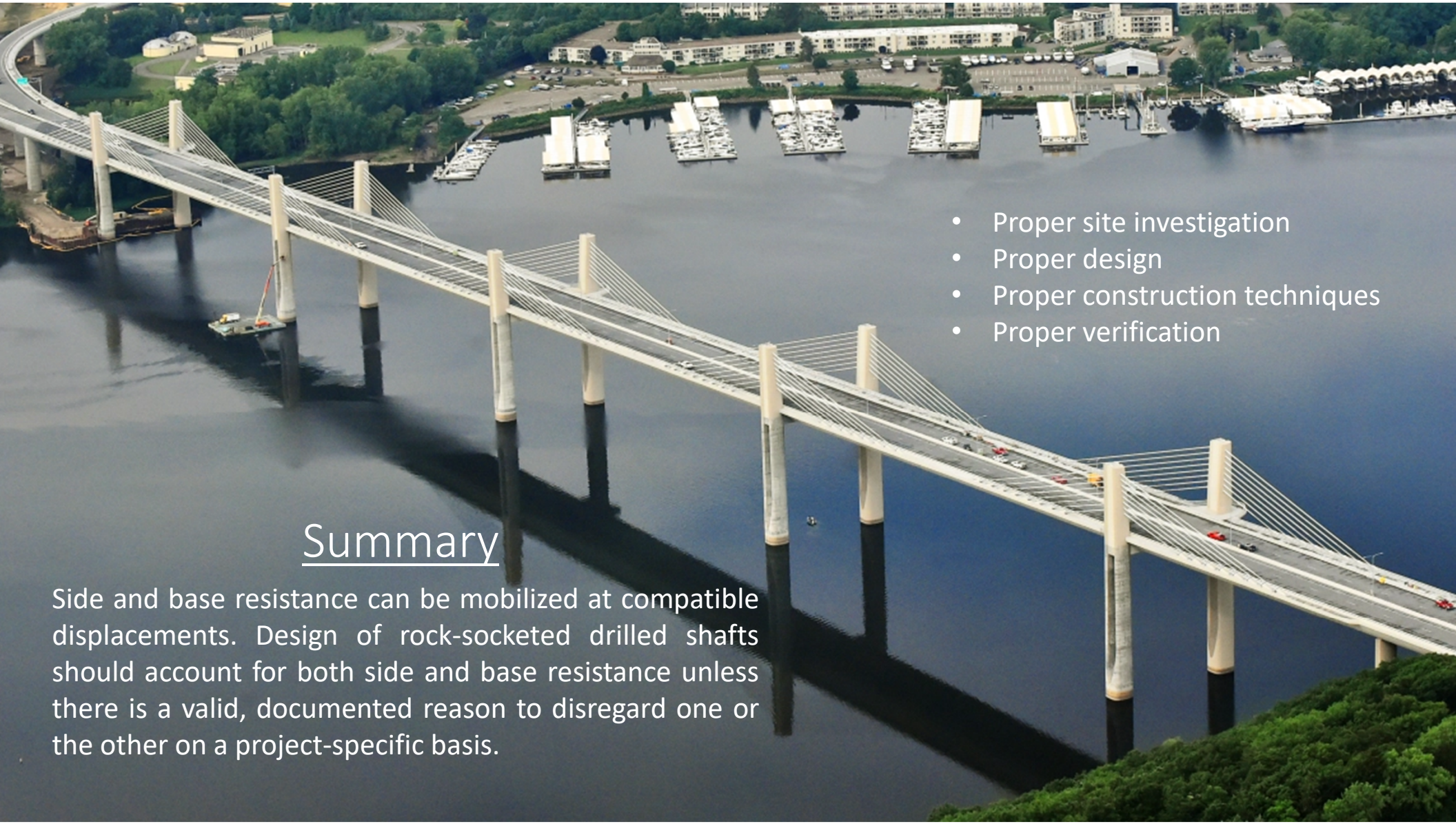
Bi-Directional Test with Sediment at the Base



Known conditions where caution is warranted



- Exception, not the rule
- Extreme spatial variability of rock type or quality
- Karst or soluble bedrock
- Some argillaceous (clay-rich) rocks
- Should be identified and evaluated during site investigation



- Proper site investigation
- Proper design
- Proper construction techniques
- Proper verification

Summary

Side and base resistance can be mobilized at compatible displacements. Design of rock-socketed drilled shafts should account for both side and base resistance unless there is a valid, documented reason to disregard one or the other on a project-specific basis.


Thank you for your time & attention.
Questions?
David Graham, P.E., BC.GE
Senior Engineer
DFI Drilled Shaft Committee Chair
(205) 427-0682
dgraham@dba.world
DAN BROWN AND ASSOCIATES
DEEP FOUNDATIONS INSTITUTE
DFI