NORTH CAROLINA
Department of Transportation

Upcoming Changes to Section 10 of the AASHTO LRFD Bridge Design Specifications

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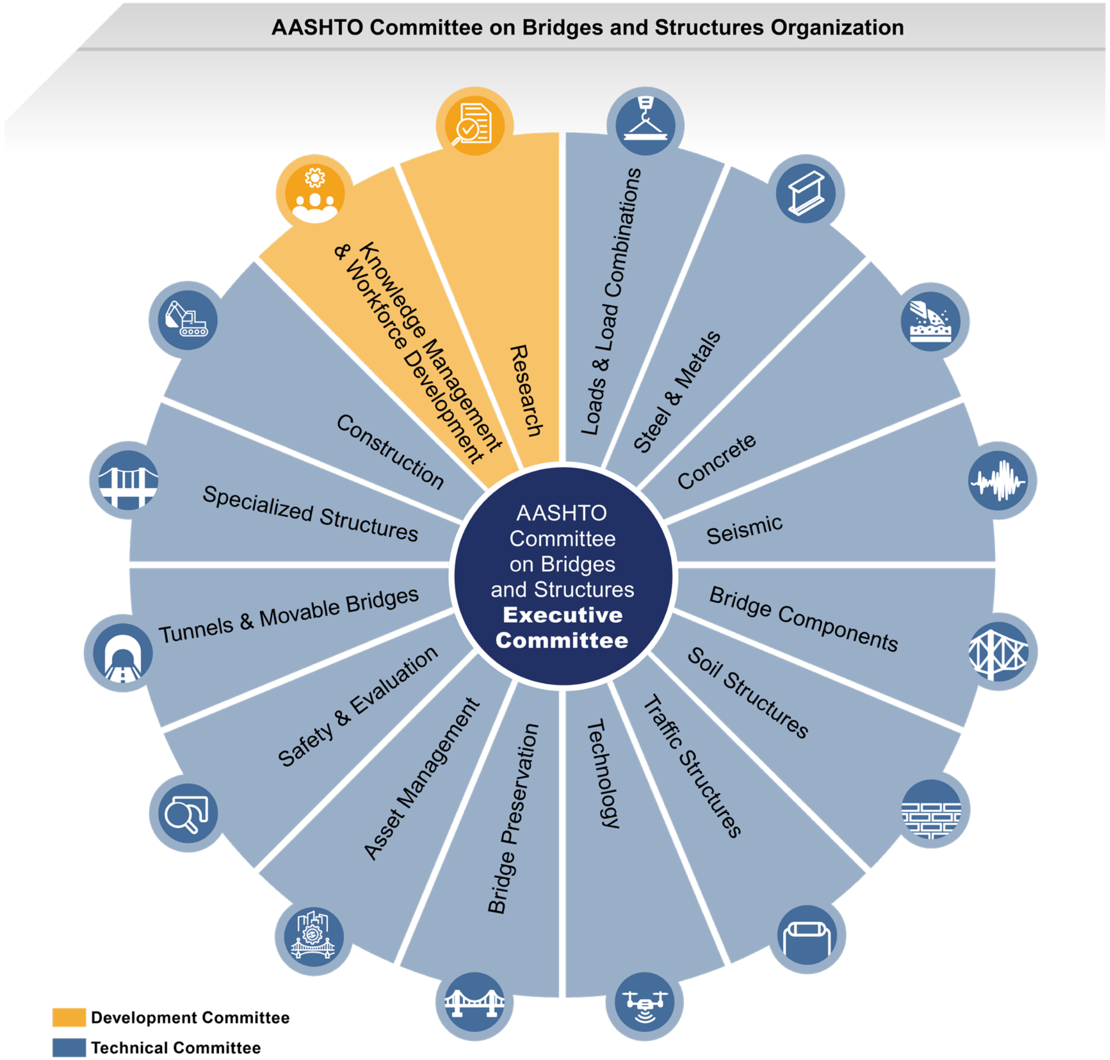
AASHTO COBS Soil Structures Technical Committee Chair

2023 Southeastern Transportation Geotechnical Engineering Conference (STGEC)

Connecting people, products and places safely and efficiently with customer focus, accountability and environmental sensitivity to enhance the economy and vitality of North Carolina

AASHTO Rebranding (new website too)

AASHTO COBS Reorganization



Soil Structures Technical Committee

Name	Agency	Designation	Concentration
Hidden, Scott	NCDOT	Chair	Geotech
Hastings, Jason	DelDOT	Vice Chair	Structures
Scott, Dave	NHDOT	Vice Chair	Structures
Nichols, Silas	FHWA	Liaison	Geotech
Booher, Jeff	WYDOT	Member	Structures
Dettloff, Alex	ODOT (Ohio)	Member	Geotech
Fiske, Andrew	WSDOT	Member	Geotech
Gaston, Steve	GDOT	Member	Structures
Guidry, Chris	LaDOTD	Member	Structures
Rauser, Jesse	LaDOTD	Proxy	Geotech
Hagemeyer, David	MoDOT	Member	Structures
Hart, Jennifer	INDOT	Member	Structures
Johnson, Steve	SDDOT	Member	Structures
Lacroix, Jim	VTrans	Member	Structures
Li, Hongfen	SCDOT	Member	Structures
Martinez, Jessica	CDOT	Member	Structures
Nako, Albert	ODOT (Oregon)	Member	Structures
Nop, Michael	IADOT	Member	Structures
Walker, Nick	ALDOT	Member	Structures
Chancellor Davis, Kaye	ALDOT	Proxy	Geotech
Zickler, Andy	VDOT	Member	Structures

Elevator Pitch

1. Revising Section 10 of the AASHTO LRFD bridge code to reflect the uncertainty in *site characterization* by accounting for the reliability of different *subsurface investigation and design methods*.

2. Benefits include improved design efficiency, reduced subjectivity in site characterization, more consistent reliability in design parameters and an adaptable and objective framework for incorporating new or different practices (e.g., MWD, AI, etc.).

3. Code is much more complete; includes new investigation methods (e.g., SHANSEP Method) and most resistance factors will vary based on coefficient of variation for design parameters.

4. It will take a conscientious effort to effectively implement but, in the end, designers will be able to achieve more consistent and reliable results.

Motivation

- Most engineers would agree that more subsurface data is better, and that higher quality data is better
- If two engineers investigate the same site and get significantly different design parameters, which engineer is "right"?
- In other words, which engineer is "more correct"?
- Whose site characterization has more uncertainty?
- It may be apparent who is "right" because.....
- But, in the current AASHTO LRFD bridge code, the uncertainty in the site characterization and design parameters is not quantified or explicitly accounted for in the design
- Which subsurface investigation and design methods have less risk, i.e., are more reliable?
- Shouldn't that reliability be incorporated into the design in a methodical way?

Quiz Question No. 1

Why are we doing this?

1. It will always save lots of $
2. FHWA (Silas) says we have to
3. AASHTO COBS Soil Structures Technical Committee needs something to do
4. To account for uncertainty in site characterizations so designs will have more consistent reliability

How did we get here?

- Considered codes from other countries (Canadian Highway Bridge Design [CHBD] Code, Eurocode and Australian Bridge Design Code)
- Used FHWA GEC 5 and MoDOT Engineering Policy Guidelines
- One key part is the approach to parameter uncertainty (prescriptive, quantitative, subjective)
- For example, the CHBD Code takes a subjective approach:

Application	Limit state	Test Method/Model	Degree of understanding		
			Low	Typical	High
Shallow foundations	Bearing, ϕ_{gu}	Analysis	0.45	0.50	0.60
		Scale model test	0.50	0.55	0.65
	Sliding, ϕ_{gu} Frictional	Analysis	0.70	0.80	0.90
		Scale model test	0.75	0.85	0.95
	Sliding, ϕ_{gu} Cohesive	Analysis	0.55	0.60	0.65
		Scale model test	0.60	0.65	0.70
	Passive resistance, ϕ_{gu}	Analysis	0.40	0.50	0.55
	Settlement or lateral movement, ϕ_{gs}	Analysis	0.7	0.8	0.9
		Scale model test	0.8	0.9	1.0

(Continued)

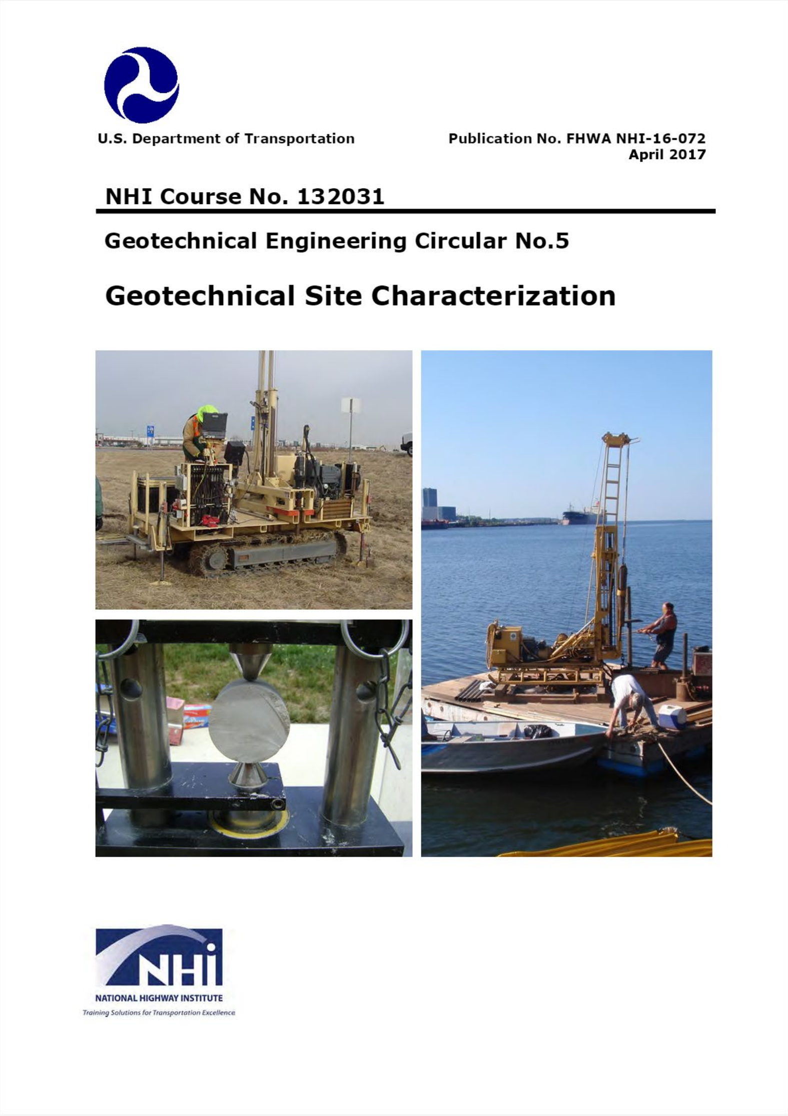
CHBD Code Degree of Understanding

- High understanding - extensive project-specific investigation procedures and/or knowledge are combined with prediction models of demonstrated quality to achieve a high level of confidence with performance predictions.

- Typical understanding - typical project-specific investigation procedures and/or knowledge are combined with conventional prediction models to achieve a typical level of confidence with performance predictions.

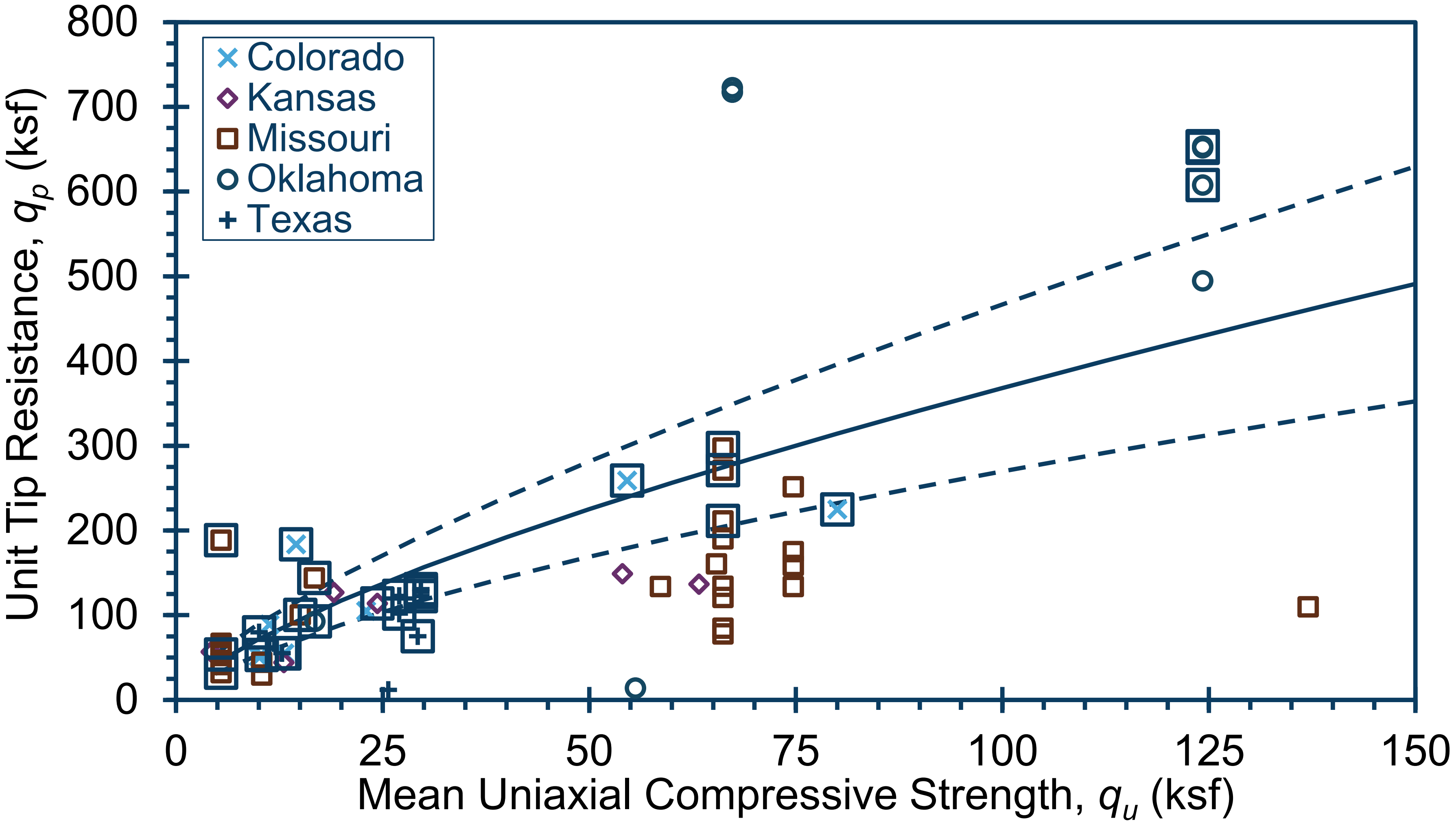
- Low understanding - limited representative information (e.g., previous experience, extrapolation from nearby and/or similar sites) combined with conventional prediction models to achieve a lower level of confidence with performance predictions.

FHWA GEC 5 Approach



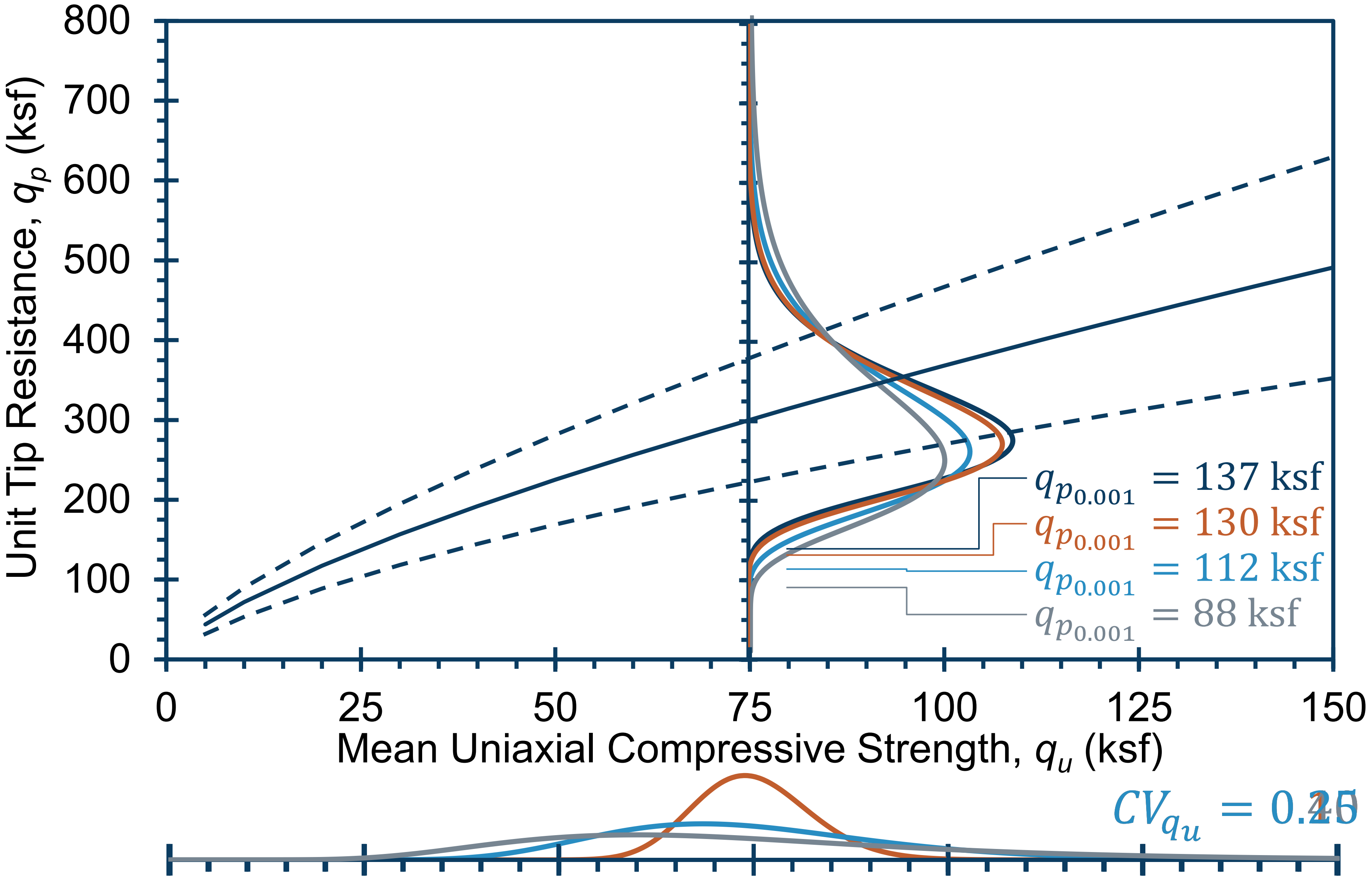
"Designs performed using parameters established from mean values with $COV_{Model} \leq 0.3$ are likely to have reliability that practically equals or exceeds the target reliability for design according to the AASHTO LRFD Bridge Design Specifications."

FHWA GEC 5 Approach

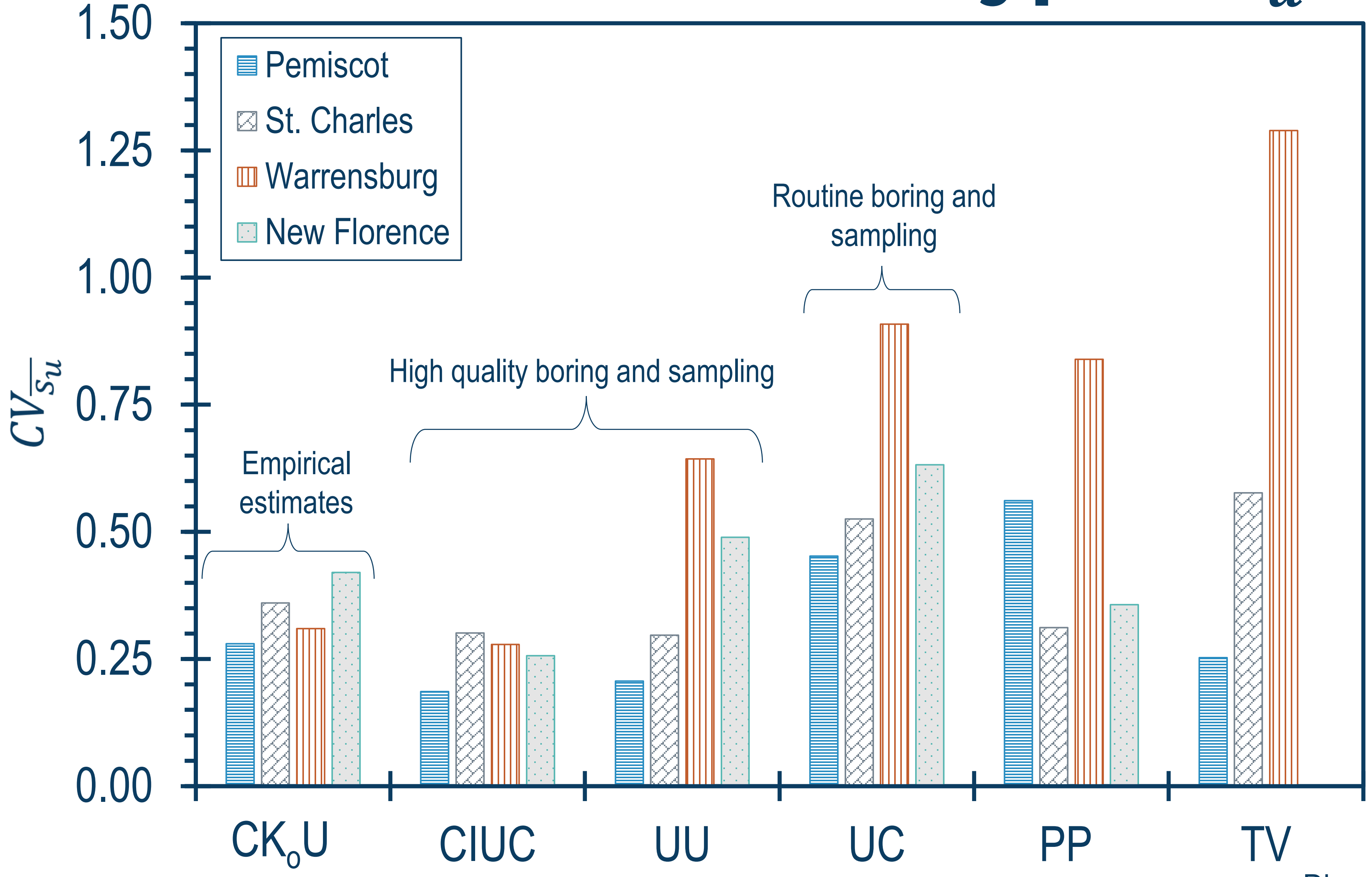


Loehr, et al. (2023)

FHWA GEC 5 Approach

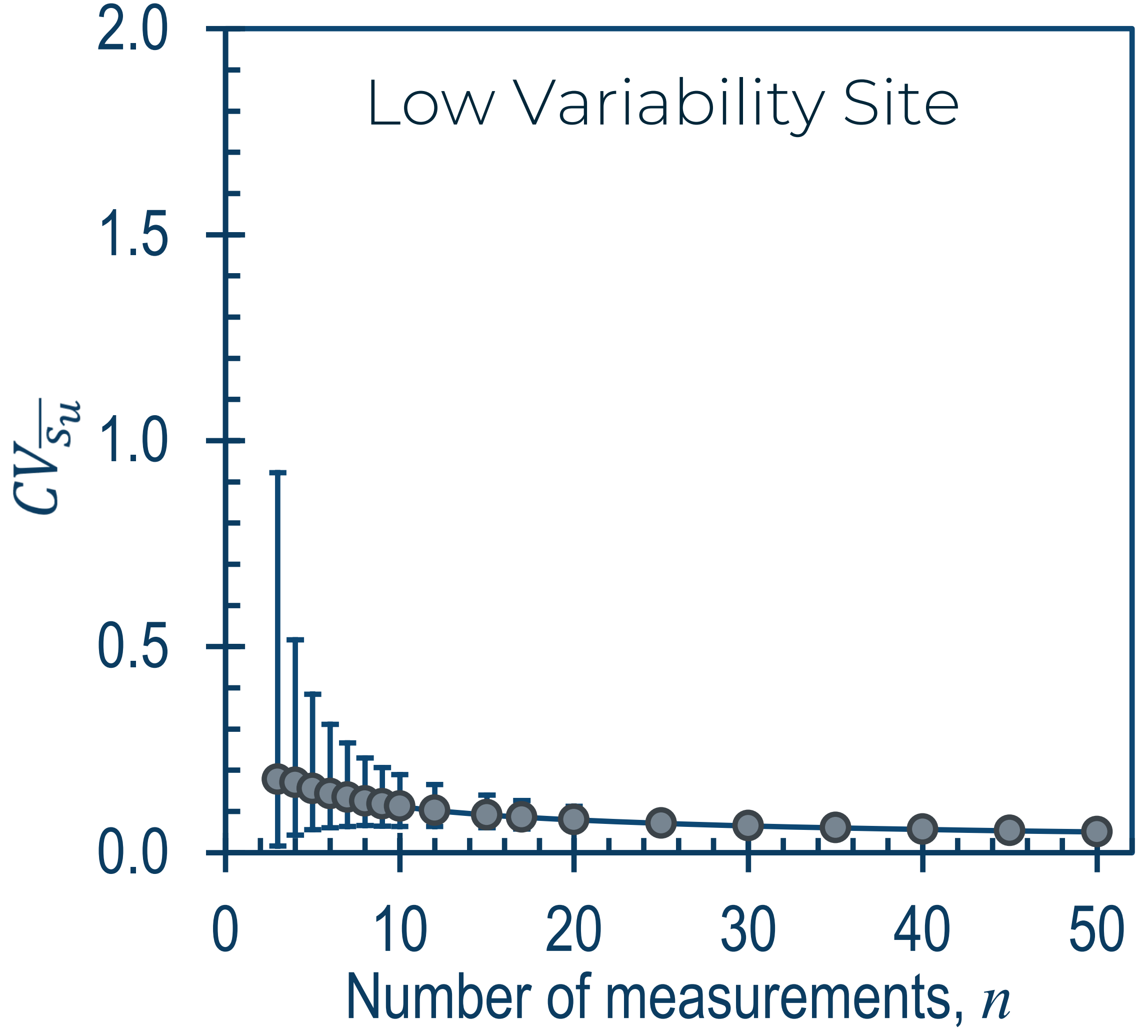


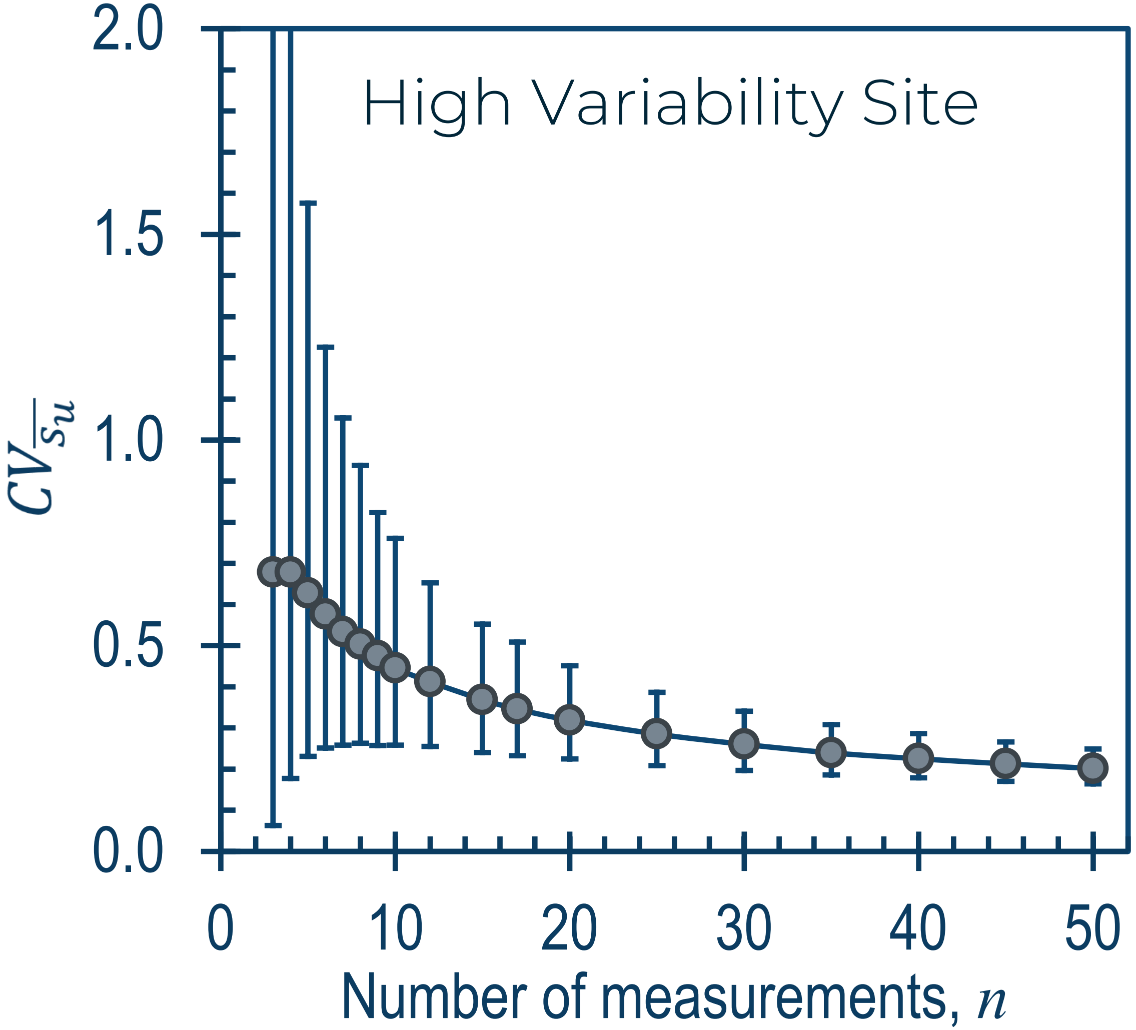
Influence of measurement type – s_u



Ding and Loehr (2019)

Influence of number of measurements





Loehr, Ding, and Likos (2015)

Quiz Question No. 2

What is the target CV for investigations in Section 10 of the code?

1. 0
2. π (3.1415926535….)
3. 0.30
4. Anything less than 1.0
5. It depends

Summary of Changes

- ~~Soil and Rock Properties~~ Site Characterization (10.4), ~~Limit States and Resistance Factors~~ Foundation Design Requirements (10.5) and Micropiles (10.9) are being completely rewritten
- Resistance factor tables for strength limit states moved from 10.5 to article for associated foundation type
- Rewritten 10.5 will incorporate NCHRP downdrag research and liquefaction updates for recently passed AASHTO ballot items
- Spread Footings (10.6), Driven Piles (10.7) and Drilled Shafts (10.8) have tracked changes; repetitive articles removed & consolidated in 10.5
- Changes to 10.7 incorporate FHWA research on large diameter open-end piles (LDOEPs)
- Most resistance factors are specified with curves based on CV

Resistance Factors

Table 10.

I Req	Factor
	3.2a-1
Beari Resist	.3.3-1
	.3.4-1
Slidin Resist	.5.1-1

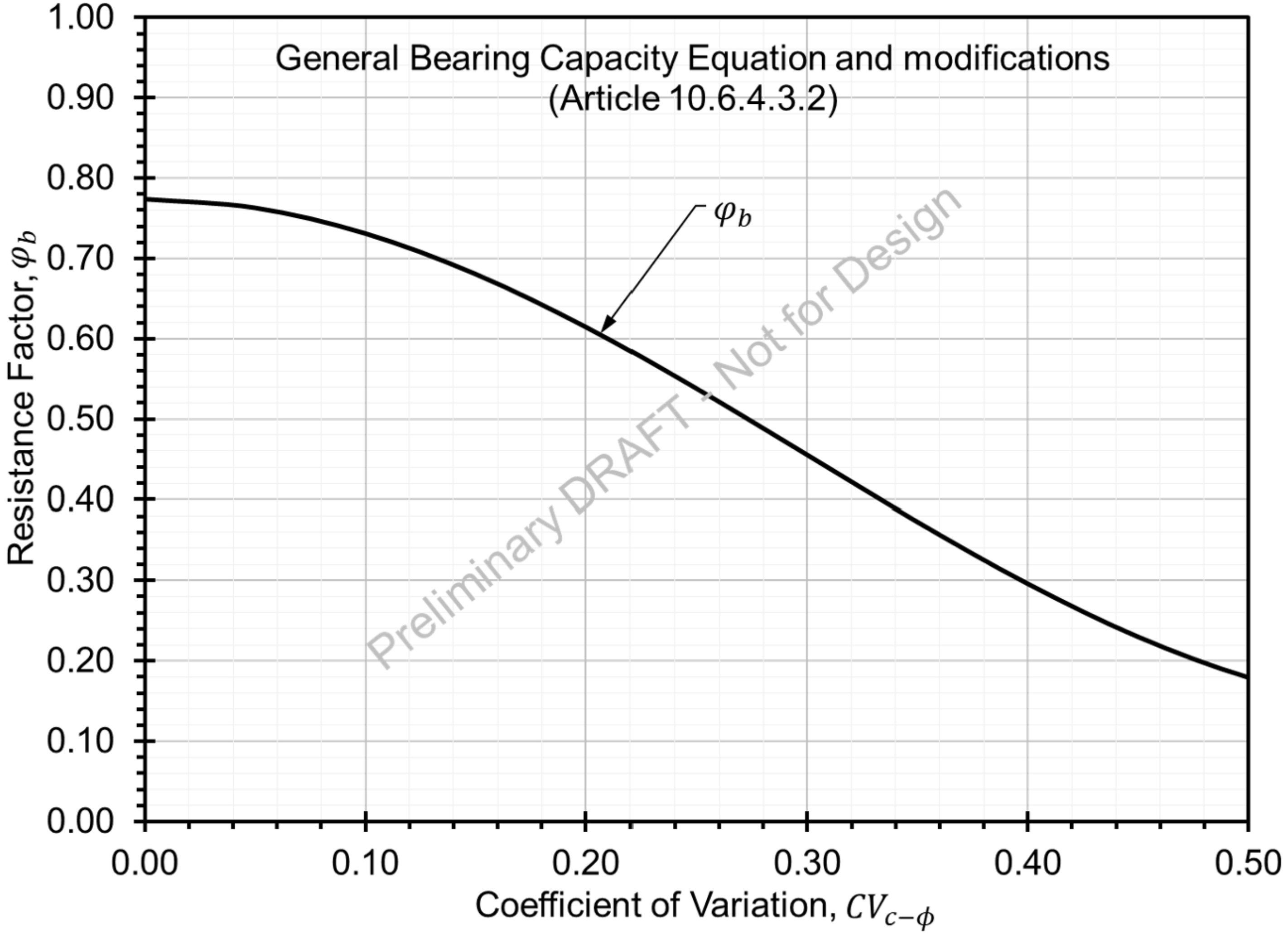


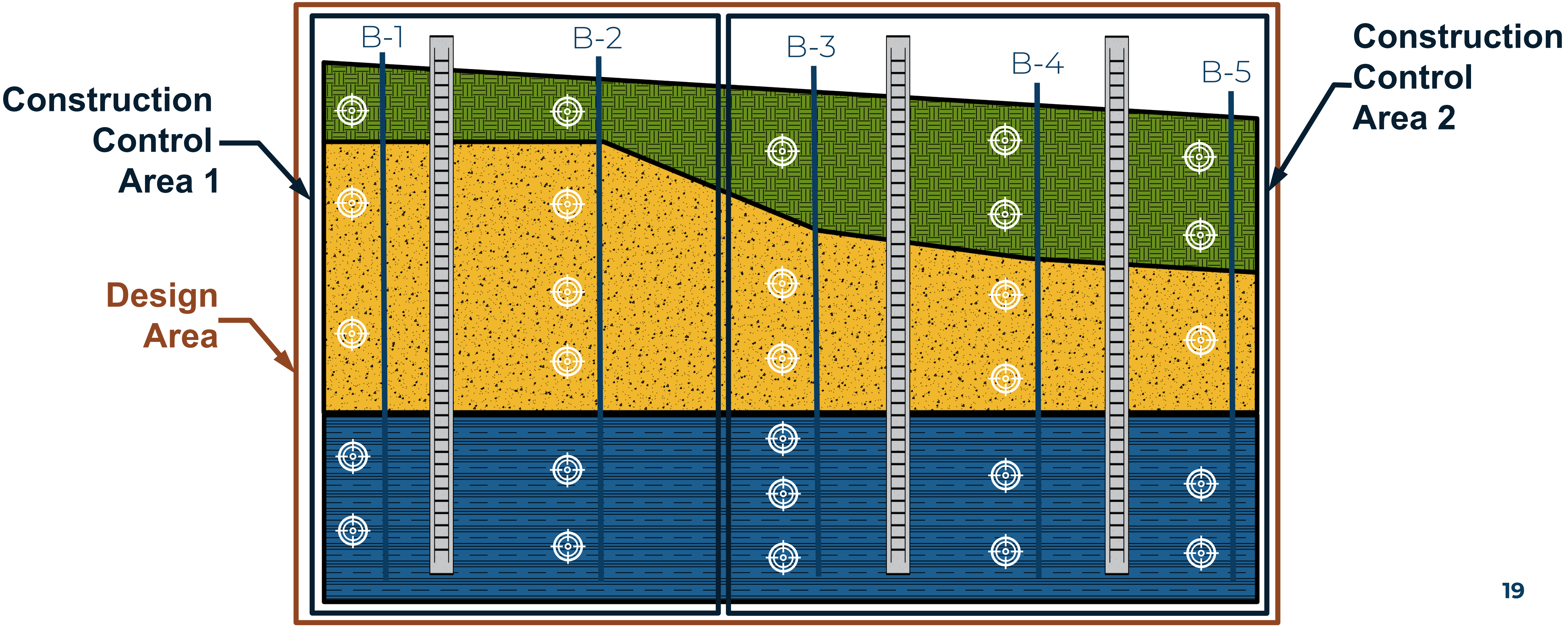
Figure 10.6.4.3.2-1—Resistance factor for bearing resistance determined using classical bearing capacity theory, including modifications to address punching shear, slopes, and layering (Article 10.6.4.3.2).

Summary of Changes (cont.)

- Methods for quantifying uncertainty in design parameters are explicitly defined
- New Terminology
  - Design Area vs. Construction Control Area
  - Direct Measurement (x_d) vs. Indirect Measurement (x_i)
  - Design Parameter vs. Critical Design Parameter (y_d or y_i)
  - Uncertainty (σ_x or σ_y)
  - Coefficient of Variation (CV_y)
- Anticipated Timeline
  - 10.4 and 10.5 drafts by the end of this year
  - Section 10 complete draft by COBS Annual Meeting in June 2024
  - Design examples by Soil Structures Mid-Year Meeting in October 2024
  - Section 10 ballot voted on at COBS Annual Meeting in summer of 2025

Design Area

✓ Area of a site over which critical design parameter values are relatively consistent



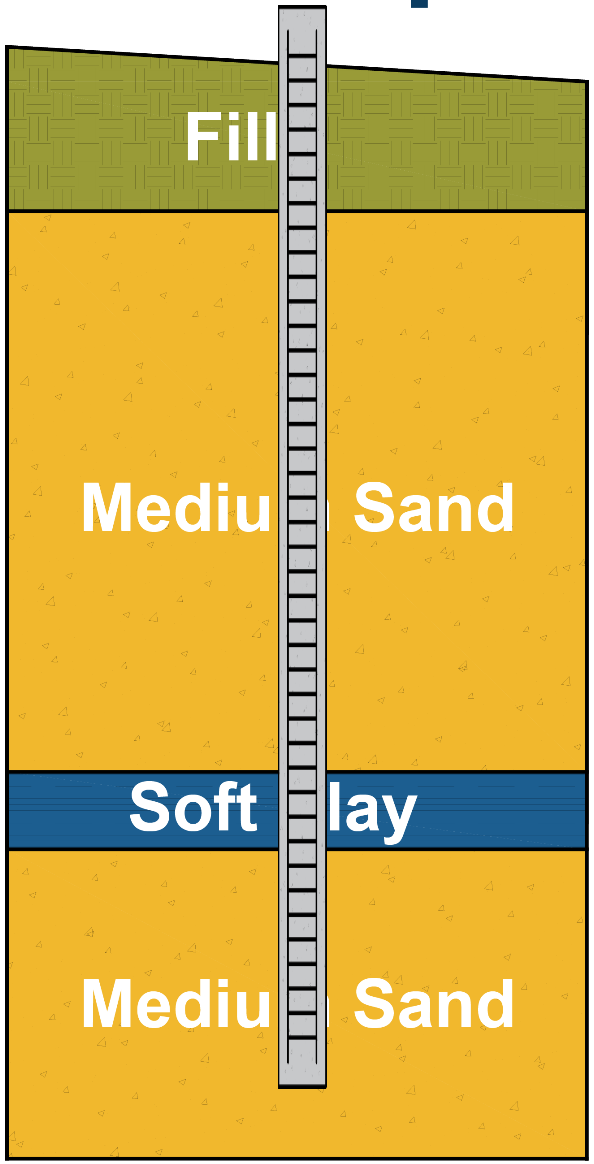
Definitions (subject to change)

- Direct Measurement:
  - ✓ Evaluate the engineering property or behavior associated with a design parameter without requiring an explicit or implicit transformation
- Indirect Measurement:
  - ✓ Require explicit or implicit transformation to produce an estimate of a design parameter
- Design Parameter:
  - ✓ Variable quantity that is a required input for a design or analysis method
- Critical Design Parameter:
  - ✓ Design parameter that has consequential influence on both design analyses and satisfaction of relevant limit state

Critical Design Parameters (It's in there!)

- Measurement type (direct or indirect) are identified for specific test methods (e.g., coefficient of consolidation, c_v, from the CPT vs. Atterberg limits)
- Formulas or transformations are specified for determining critical design parameters and uncertainty from direct and indirect measurements
- Design parameters not designated as critical can be determined from same formulas or estimated (e.g., total unit weight, γ)
- Critical design parameters are identified for specific design methods (e.g., undrained shear strength, S_u, for the α-method)
- Designating critical design parameters does not change settlement and resistance calculation methods in the code

Conceptual Example



- Is the strength of a thin seam of soft clay a critical design parameter?
- Deep foundation element extending through the soft clay seam?
- Retaining structure footing founded above the soft clay seam?

SCARY MATH!

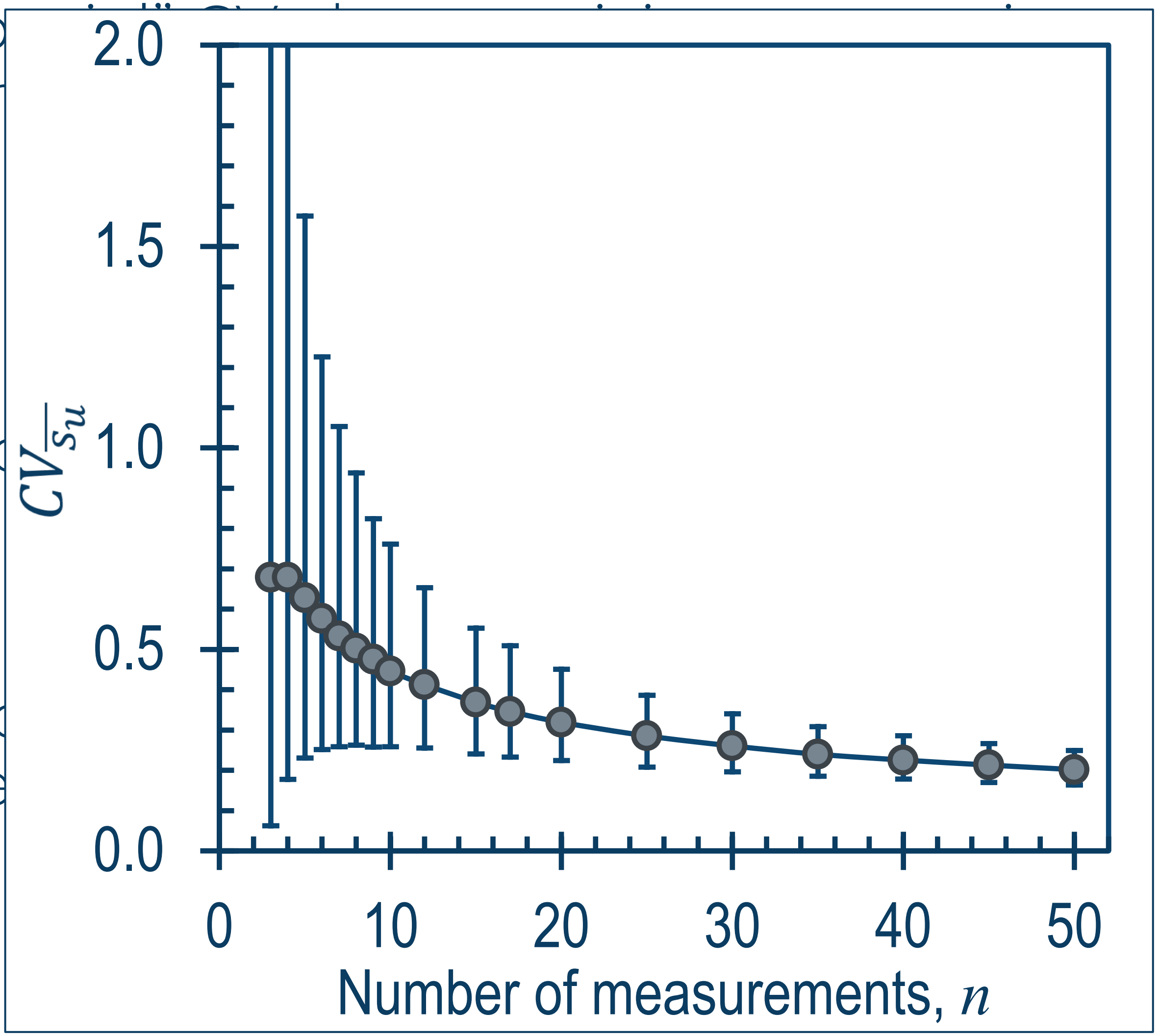
- Critical design parameters
  - Direct Measurements: $y = y_d = \overline{x_d} = \frac{\sum x_d}{n_d}$
  - Indirect Measurements: $y = y_i = f(\overline{x_i}) = f\left(\frac{\sum x_i}{n_i}\right)$

    "Transformation"
  - Requires three or more independent measurements
  - Must be "representative"
- Uncertainty
  - Direct Measurements: $\sigma_y = \sigma_{y_d} = \sigma_{\overline{x_d}} = \frac{SD_{x_d}}{\sqrt{n_d}}$
  - Indirect Measurements: $\sigma_y = \sigma_{y_i} = \sqrt{{C_1}^2 + {C_2}^2\sigma_{\overline{x_i}}^2 + {C_3}^2(\overline{x_i} - C_4)^2}$

$$\sigma_{\overline{x_i}} = \frac{SD_{x_i}}{\sqrt{n_i}} \qquad \overline{x_i} = \frac{\sum x_i}{n_i}$$

Coefficient of Variation, CV_y

- "Sp
  in r
- Rec
- Rec
  me



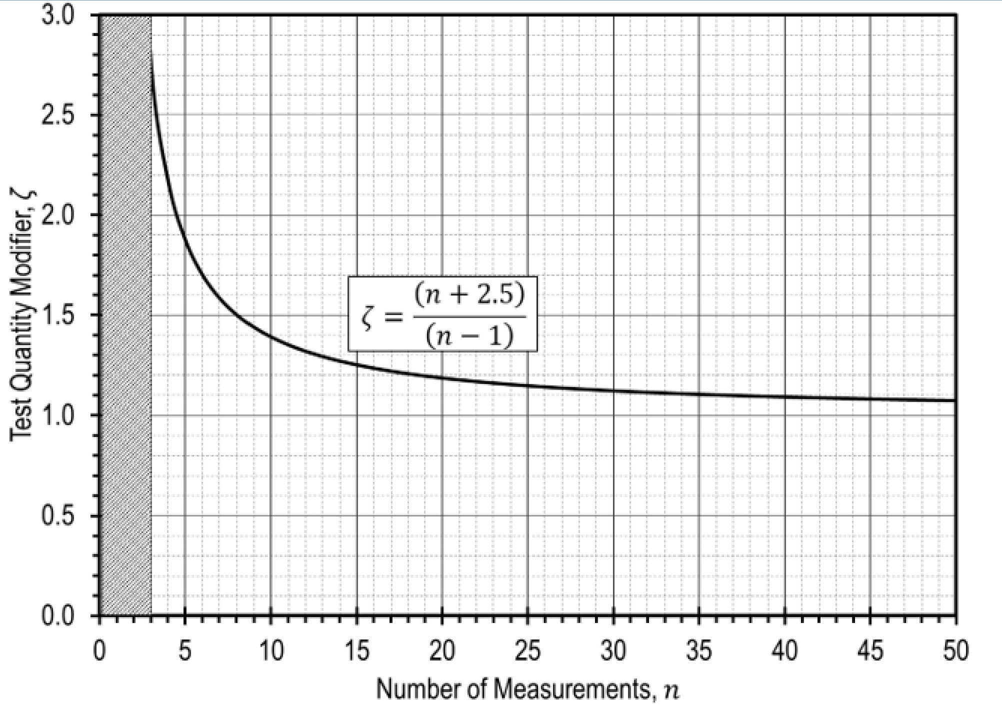
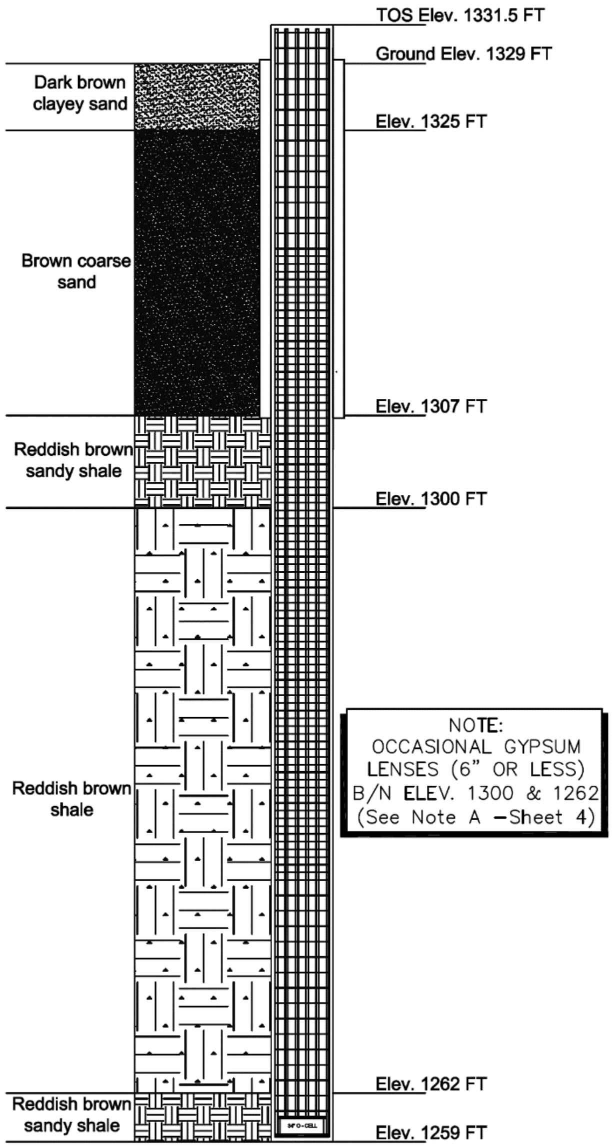
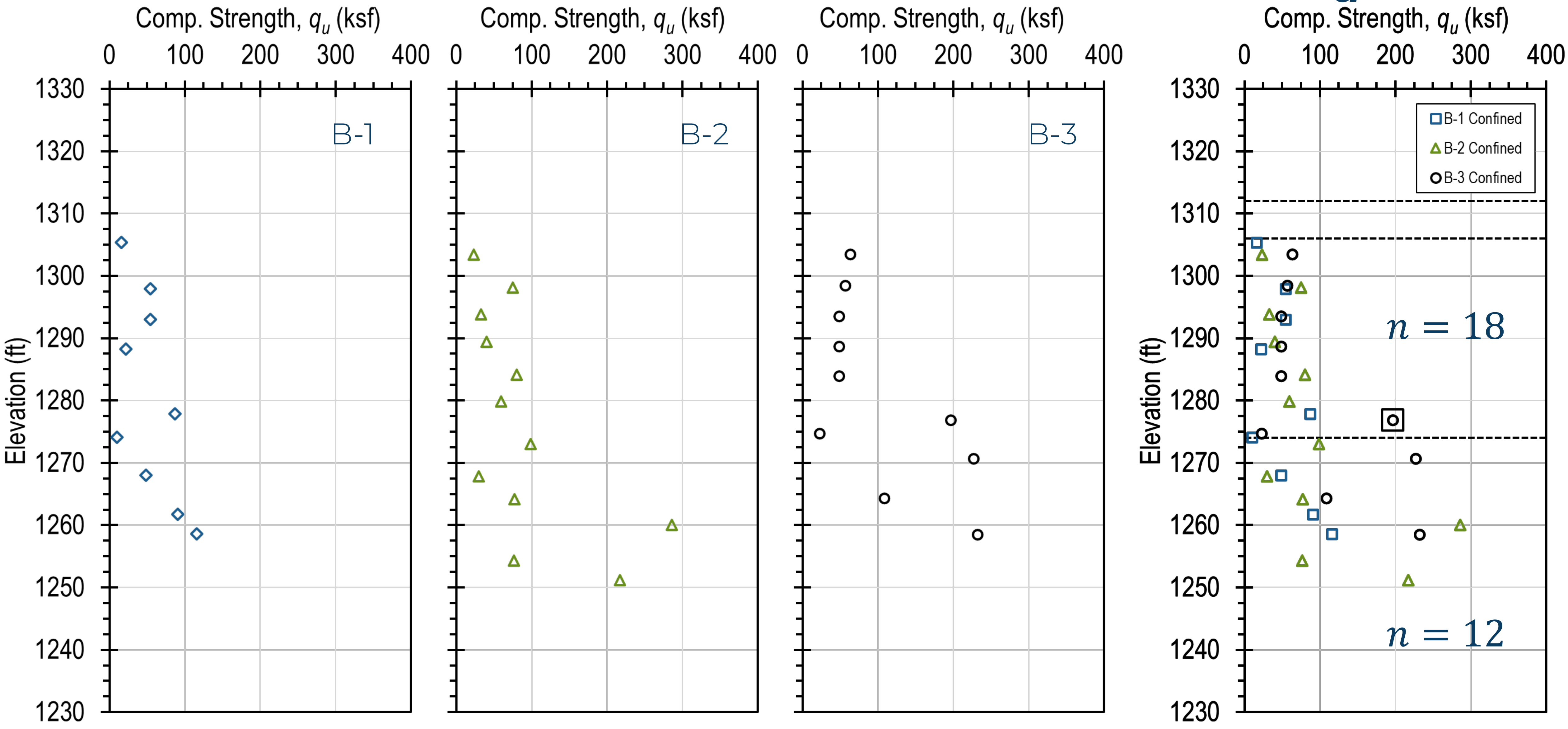


Figure 10.4.6.1.3-1—Test quantity modifier for establishing parameter uncertainty.

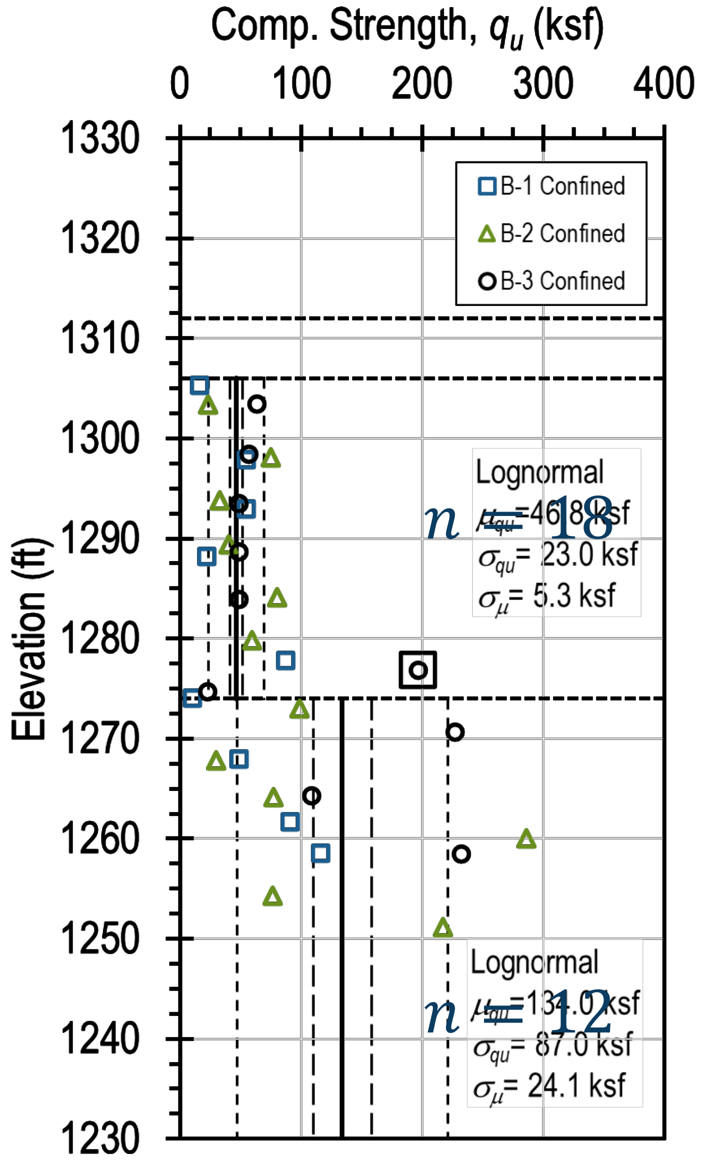
Example 1 – Direct Measurements



Example 1 – Compressive Strength, q_u



Example 1 – Calculations



- Nominal Value (mean):

$$q_{u-1} = \frac{\sum q_u}{n} = 47\text{ ksf} \qquad q_{u-2} = \frac{\sum q_u}{n} = 134\text{ ksf}$$

- Uncertainty:

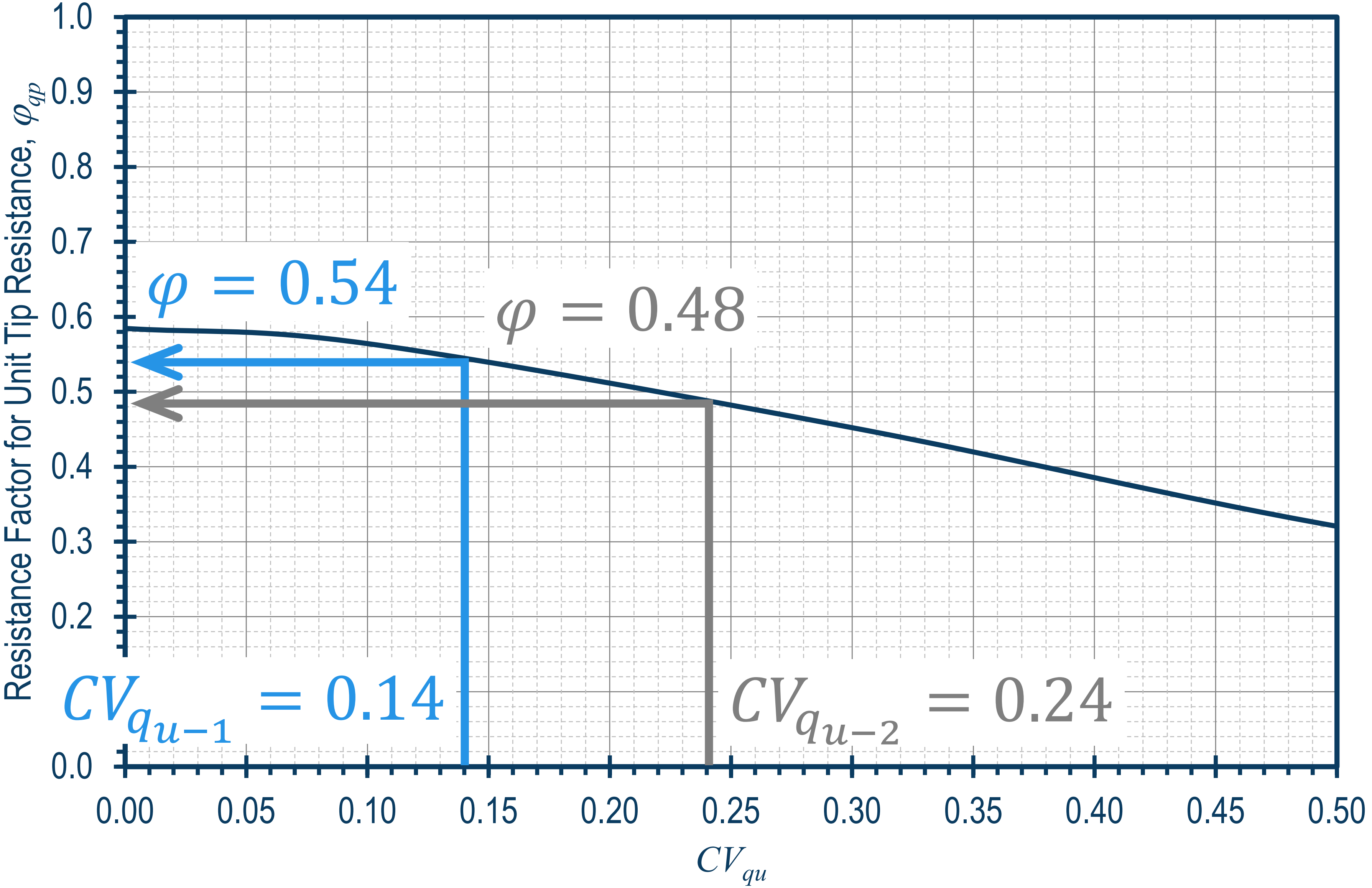
$$\sigma_{q_{u-1}} = \frac{SD_{q_u}}{\sqrt{n}} = \frac{22.4}{\sqrt{18}} = 5.3\text{ ksf} \qquad \sigma_{q_{u-2}} = \frac{SD_{q_u}}{\sqrt{n}} = \frac{83.6}{\sqrt{12}} = 24.1\text{ ksf}$$

- Coefficient of Variation:

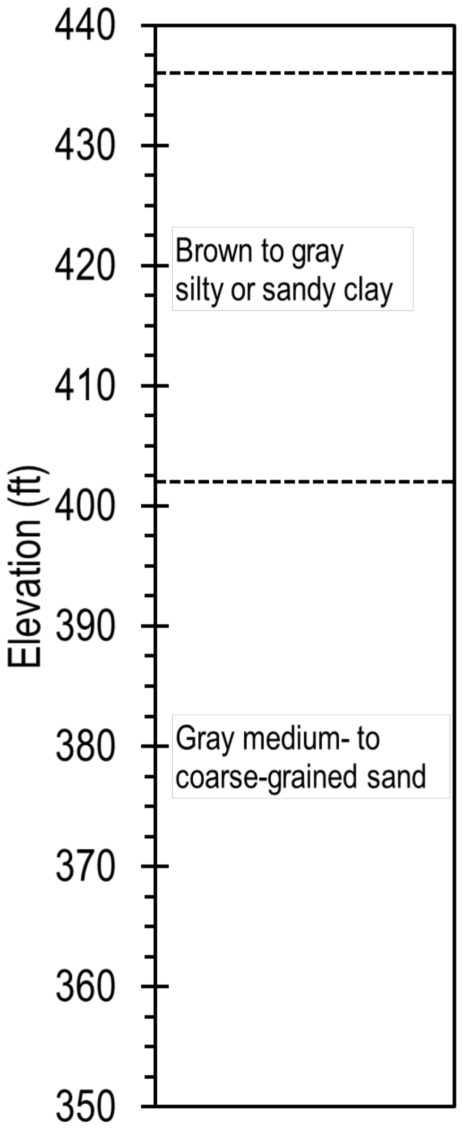
$$CV_{q_{u-1}} = \frac{\zeta \times \sigma_{q_{u-1}}}{q_{u-1}} = \frac{1.21 \cdot 5.3}{47} = 0.14$$

$$CV_{q_{u-2}} = \frac{\zeta \times \sigma_{q_{u-2}}}{q_{u-2}} = \frac{1.32 \cdot 24.1}{134} = 0.24$$

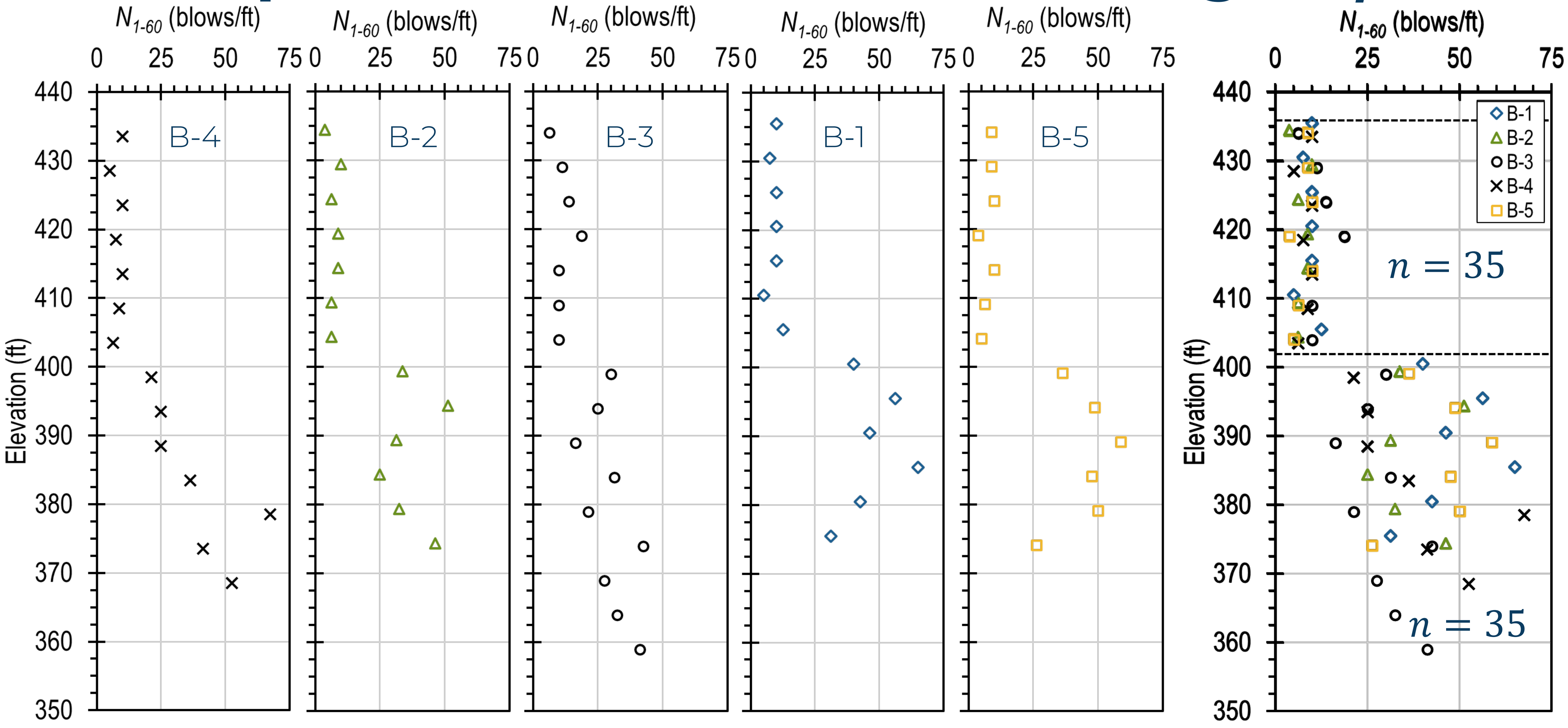
Example 1 – Resistance Factors



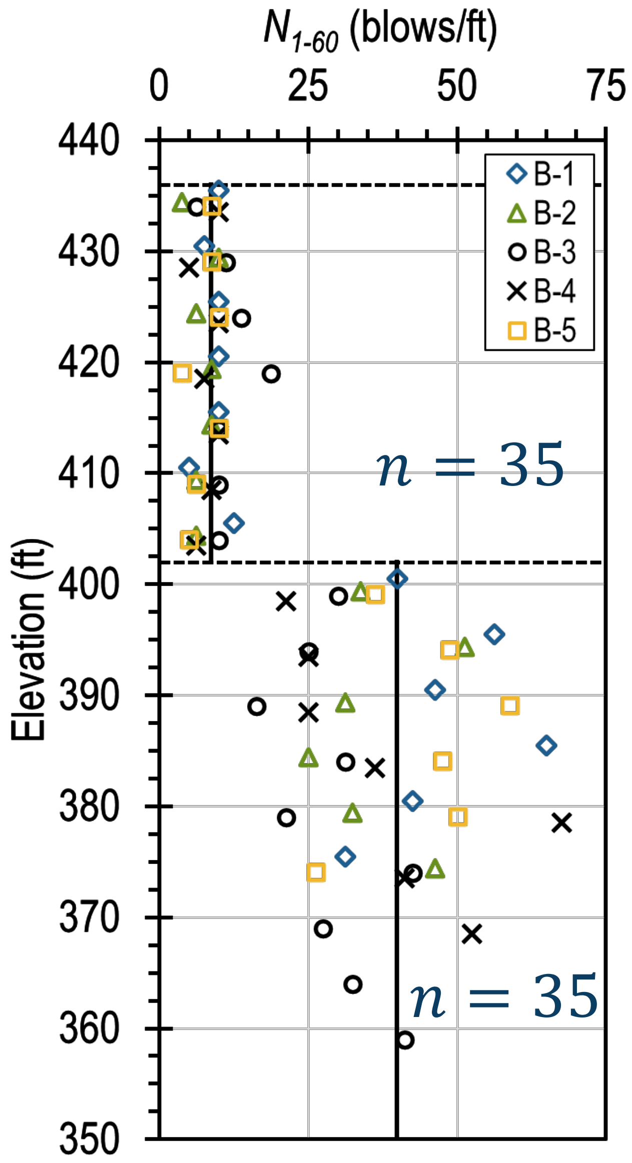
Example 2 – Indirect Measurements



Example 2 – Effective Friction Angle, ϕ'



Example 2 – Nominal Value of ϕ'



- Nominal Value (mean):

$$y = y_i = f(\overline{x_i}) = f\left(\frac{\sum x_i}{n_i}\right)$$

$$\overline{N1_{60-2}} = \frac{\sum N1_{60}}{n} = 39.9 \text{ blows/ft}$$

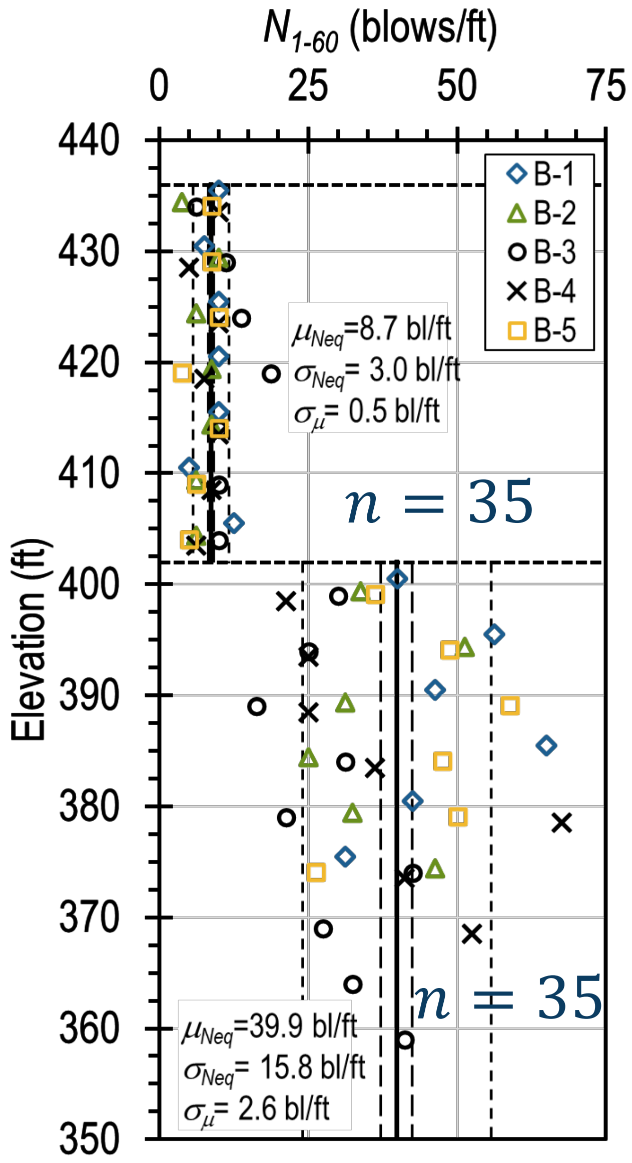
- Transformation:

Table 10.4.6.6.2-1—Effective stress friction angle, ϕ', in degrees, based on SPT *N*-value corrected for hammer efficiency and normalized to an overburden stress level of 1 atm, $N1_{60}$, in blows/ft (modified after Bowles, 1977).

$N1_{60}$	ϕ'
<4	25-30
4	27-32
10	30-35
30	35-40
50	38-43

$\rightarrow \phi' = 39$ deg.

Example 2 – Uncertainty in ϕ'



$$\sigma_{\phi'} = \sqrt{{C_1}^2 + {C_2}^2 \sigma^2_{\overline{N1_{60}}} + {C_3}^2\left(\overline{N1_{60}} - C_4\right)^2}$$

$$\overline{N1_{60-2}} = \frac{\sum N1_{60}}{n} = 39.9 \text{ blows/ft}$$

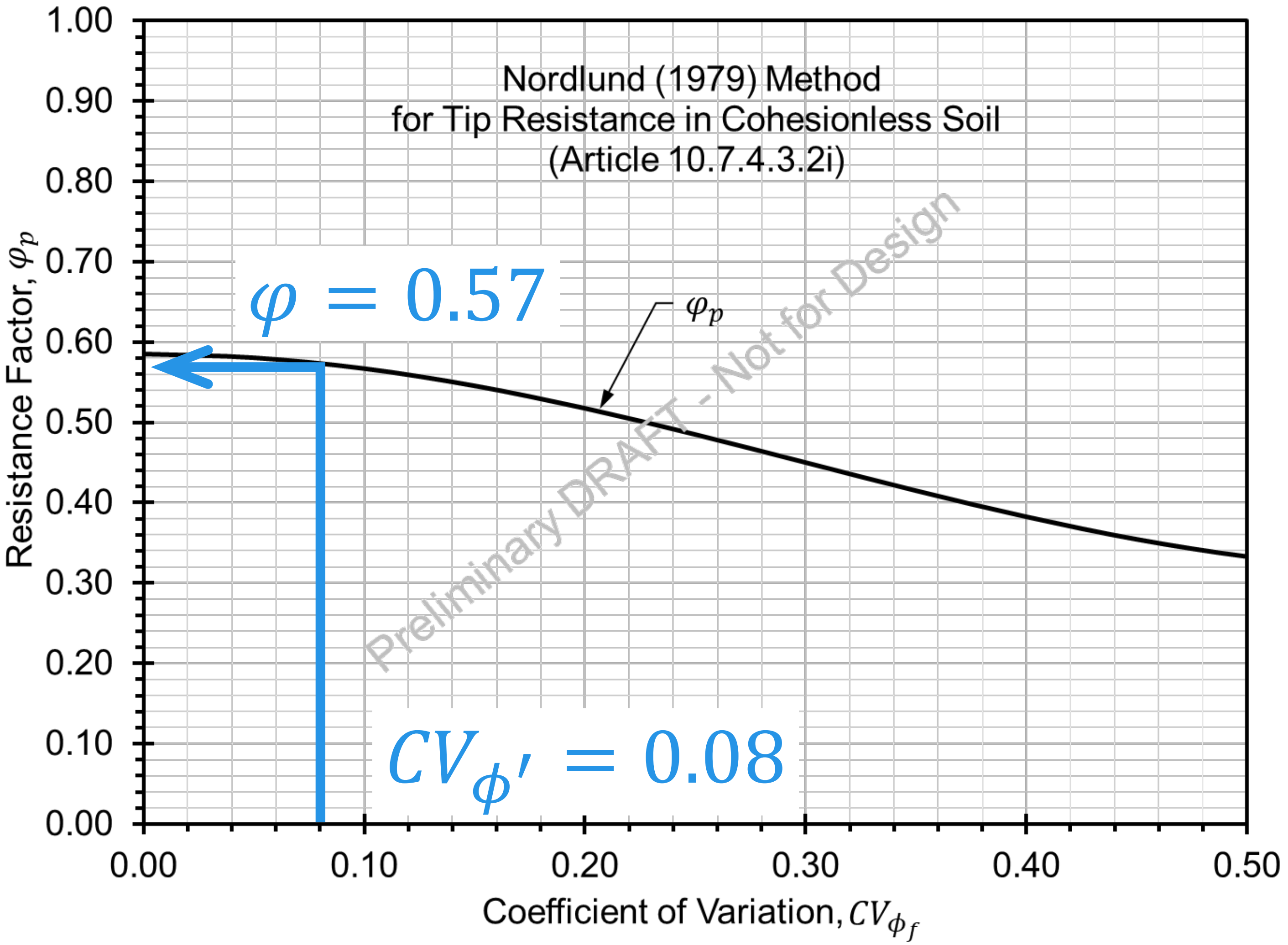
$$\sigma_{\overline{N1_{60}}} = \frac{SD_{N1_{60}}}{\sqrt{n}} = \frac{15.8}{\sqrt{35}} = 2.6 \text{ blows/ft}$$

Coefficient	Value
C_1	2.62 deg.
C_2	0.272 deg/blows/ft
C_3	0.011 deg/blows/ft
C_4	30

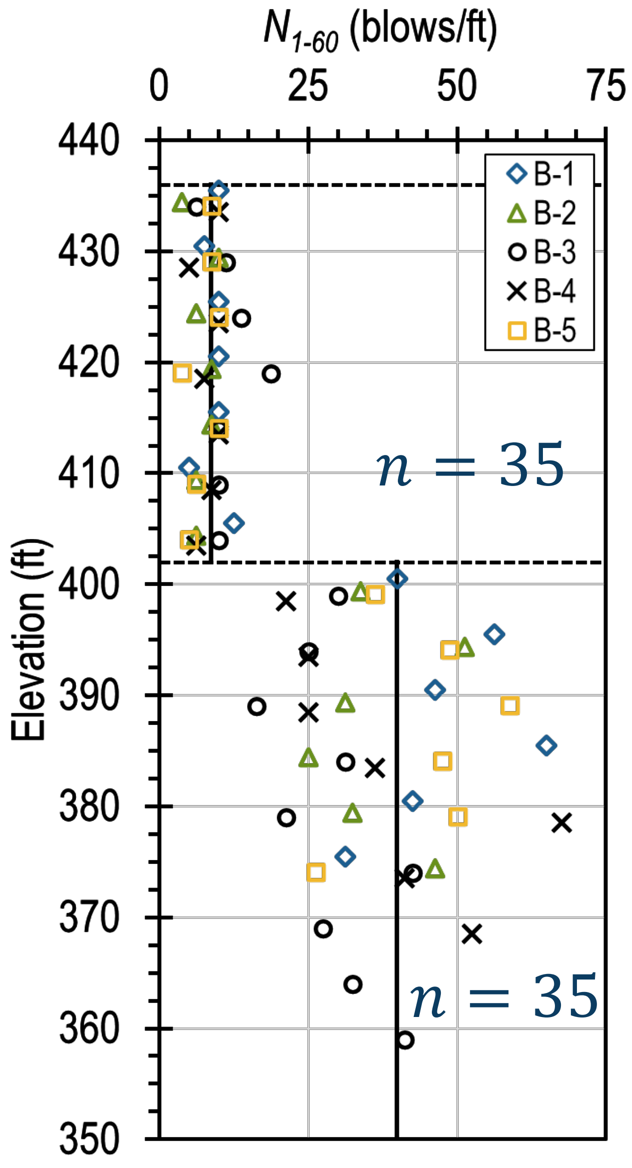
$\rightarrow \sigma_{\phi'} = 2.72$ deg.

Example 2 – Resistance Factor

$$CV_{\phi'} = \frac{\zeta \times \sigma_{\phi'}}{\phi'} = \frac{1.10 \cdot 2.72}{39} = 0.08$$



What is “wrong” with this transformation?



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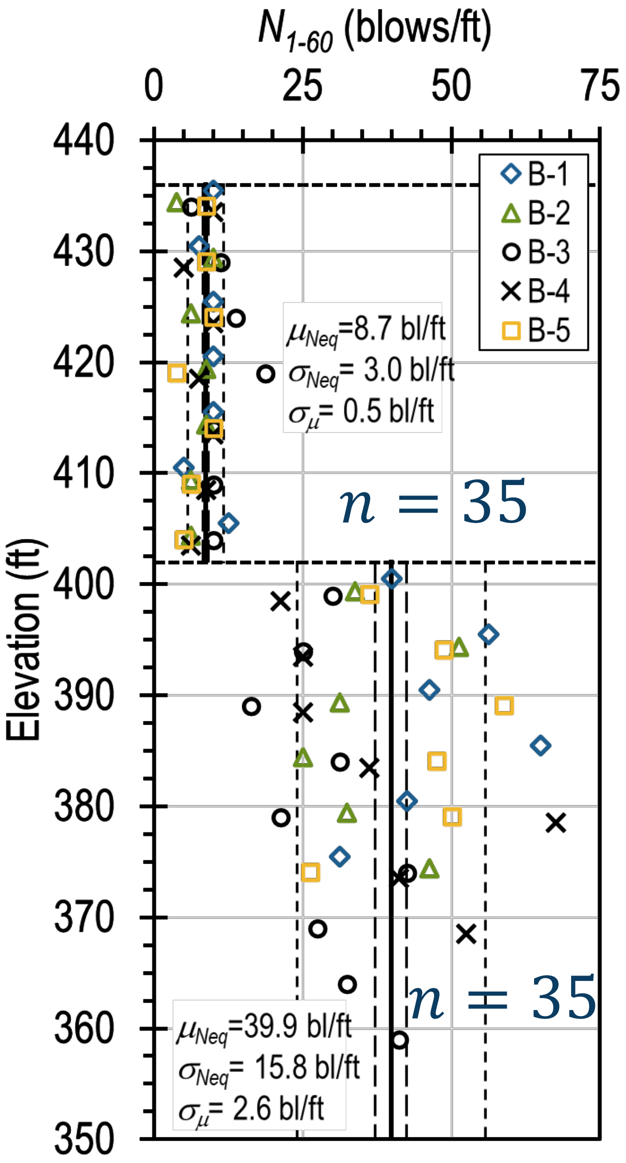
$N1_{60}$	ϕ'
<4	25-30
4	27-32
10	30-35
30	35-40
50	38-43

$\rightarrow \phi' = 39 \text{ deg.}$

Coefficients are questionable.....



$$\sigma_{\phi'} = \sqrt{{C_1}^2 + {C_2}^2 \sigma^2_{\overline{N1_{60}}} + {C_3}^2 \left(\overline{N1_{60}} - C_4\right)^2}$$

$$\overline{N1_{60-2}} = \frac{\sum N1_{60}}{n} = 39.9 \text{ blows/ft}$$

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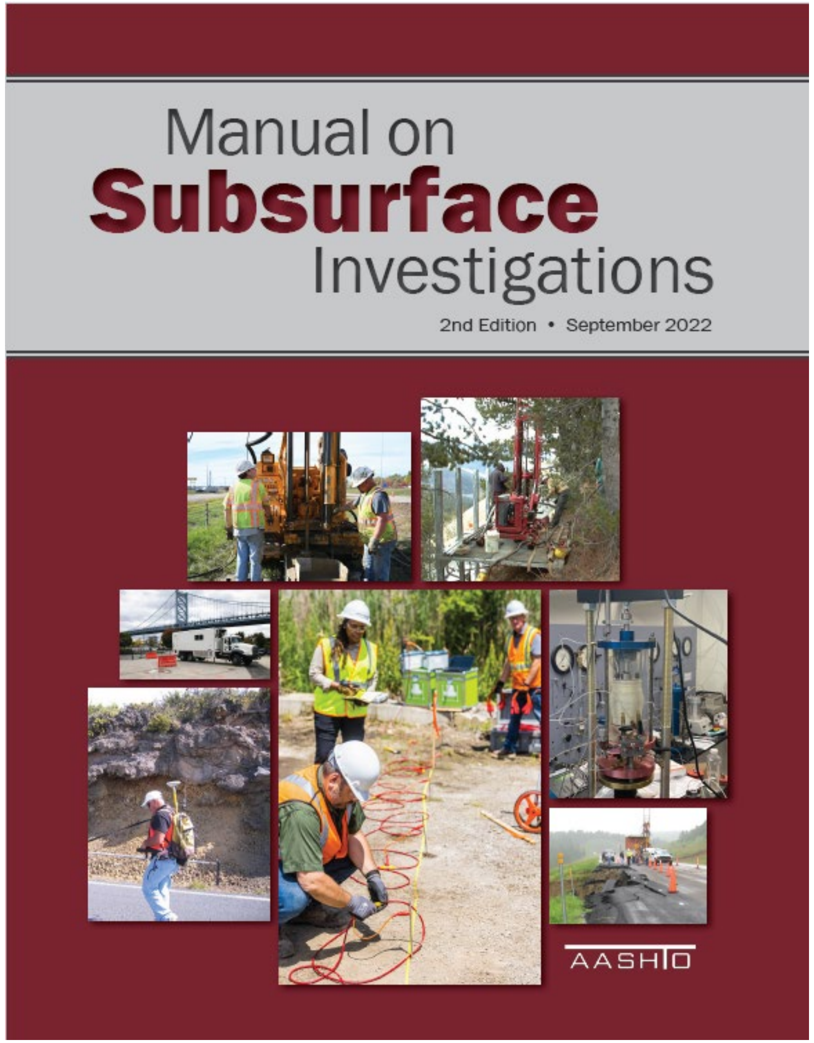
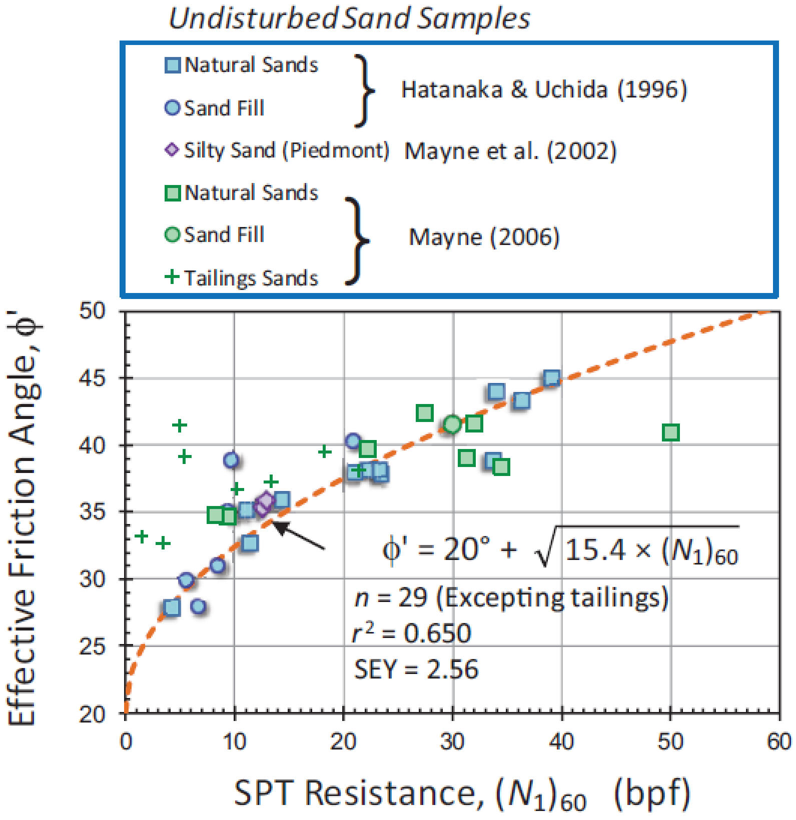
$\rightarrow \sigma_{\phi'} = 2.72$ deg.

New AASHTO Manual on Subsurface Inv (2nd Ed)



MANUAL ON SUBSURFACE INVESTIGATIONS, SECOND EDITION



Source: Paul Mayne

Figure I-19. Empirical Relationship for Effective Friction Angle of Sands from Stress-Normalized SPT N_{60} Value Using Data from Undisturbed Sampling Techniques

Quiz Question No. 3

What do you think of all this?

1. I love it, when can I get started?
2. I like it, I can see the benefits of implementing this
3. I don't like it, I am too old for this
4. I hate it, statistics gives me a headache
5. I don't care, I will retire before this gets into the code

American Association of State Highway and Transportation Officials
AASHTO

State of North Carolina Department of Transportation

Questions?