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

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AASHTO Soil Structures Committee

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Elevator Pitch

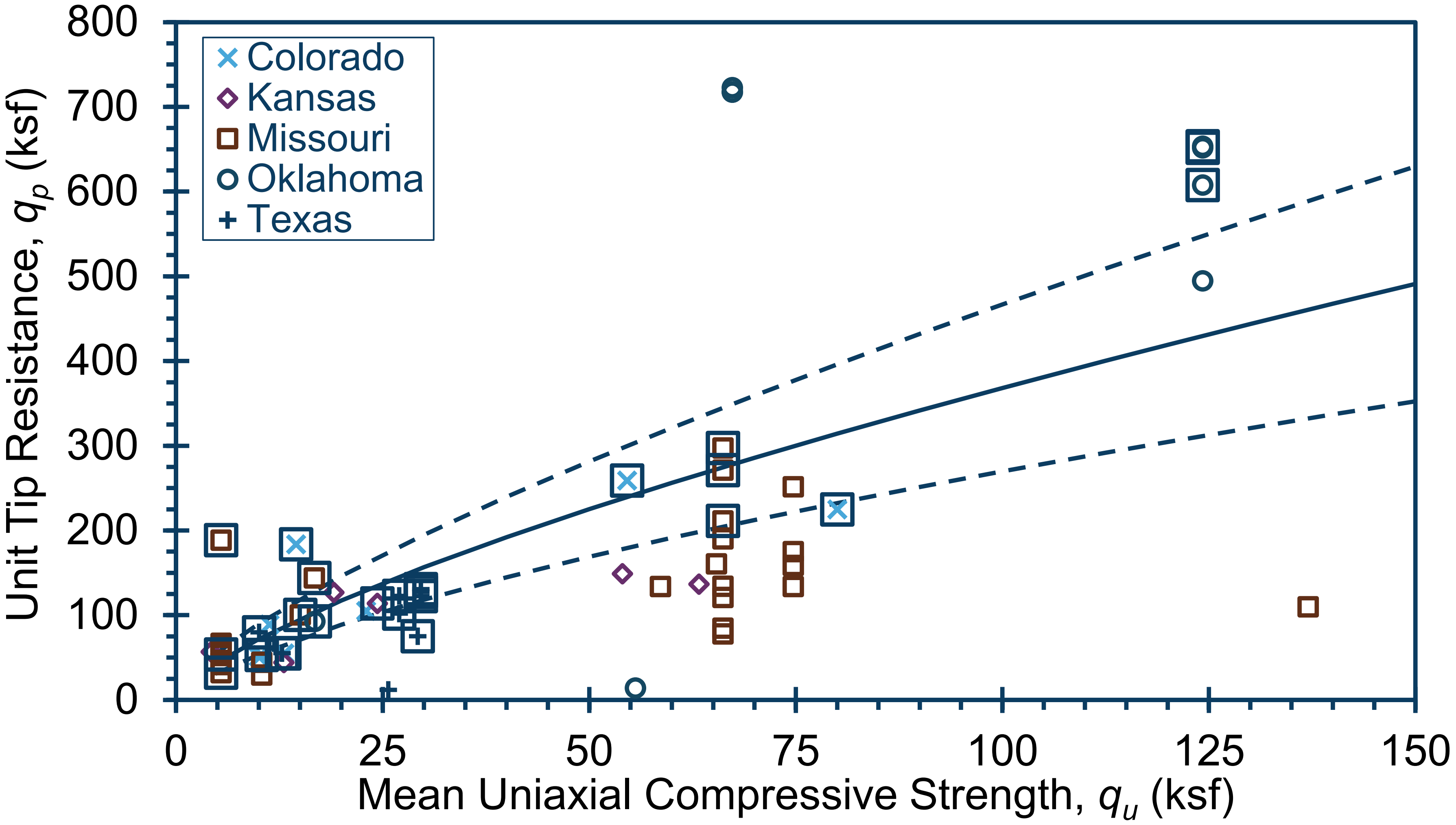
1. Revising Section 10 of the AASHTO LRFD BDS to reflect the uncertainty in *site characterization* by accounting for the reliability of different *subsurface investigation and design methods*.

2. Benefits include:
   1. improved design efficiency
   2. reduced subjectivity
   3. more consistent reliability
   4. adaptable & objective framework for new or different practices (e.g., MWD, AI)
   5. flexibility to appropriately address diverse design situations

3. Code is more complete as most resistance factors will vary based on coefficient of variation for design parameters.

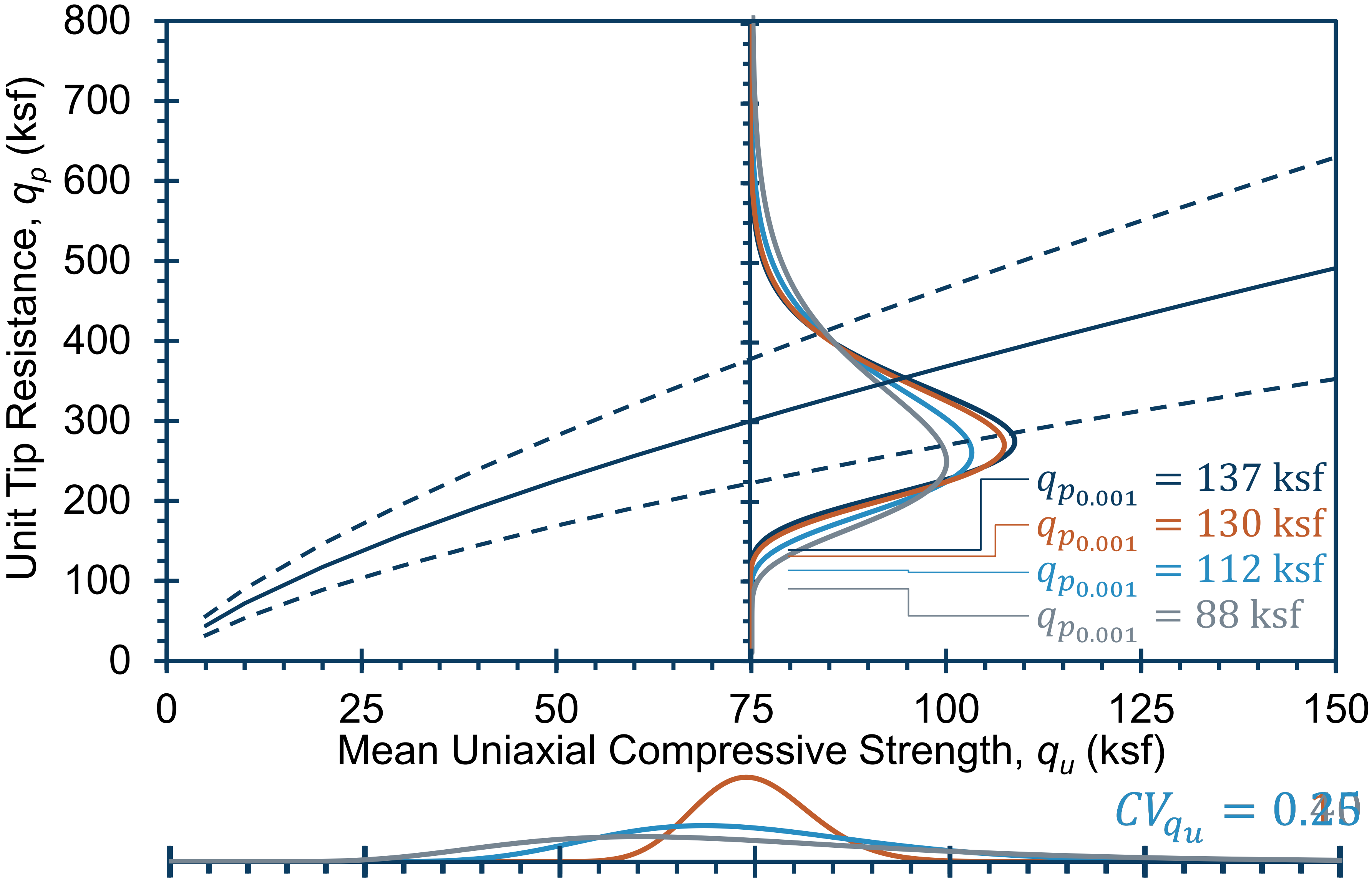
4. It will take a conscientious effort to effectively implement but, in the end, designers will be able to achieve more consistent and reliable results.

Motivation



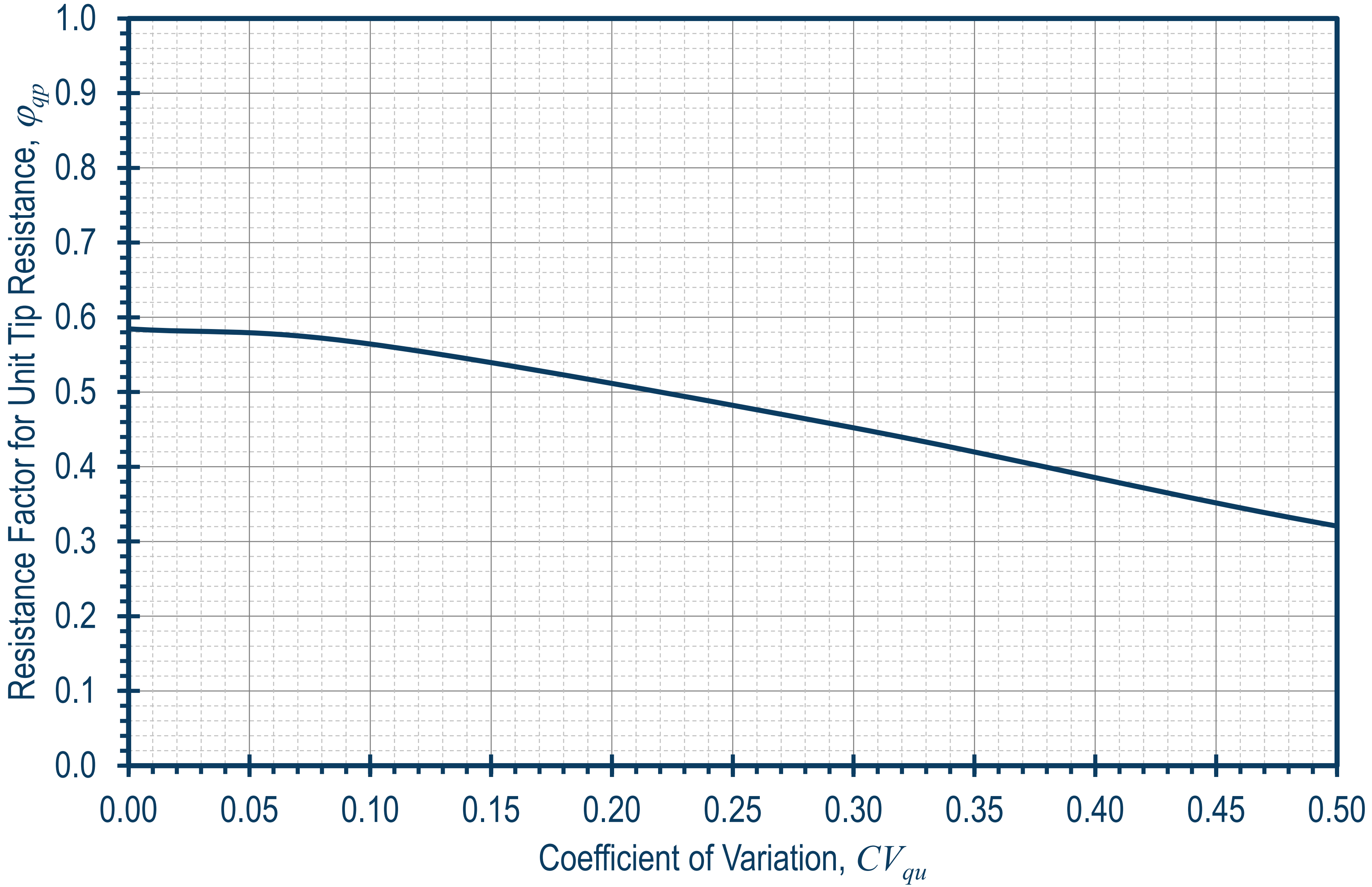
Loehr, et al. (2024)

Motivation

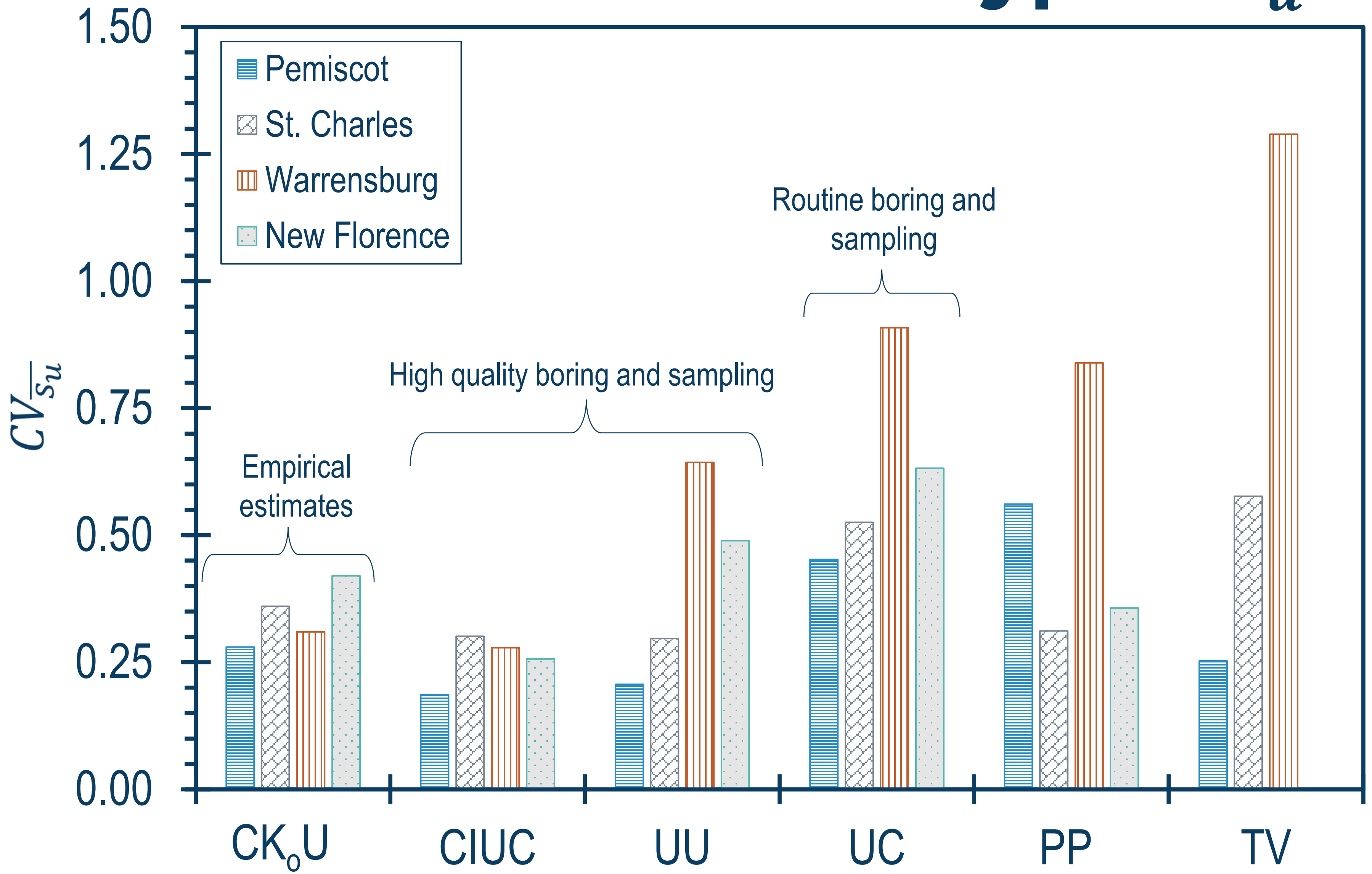


800
700
600
500
400
300
200
100
0
Unit Tip Resistance, q_p (ksf)
0
25
50
75
100
125
150
Mean Uniaxial Compressive Strength, q_u (ksf)
$q_{p_{0.001}} = 137$ ksf
$q_{p_{0.001}} = 130$ ksf
$q_{p_{0.001}} = 112$ ksf
$q_{p_{0.001}} = 88$ ksf
$CV_{q_u} = 0.25$

FHWA GEC 5 Approach

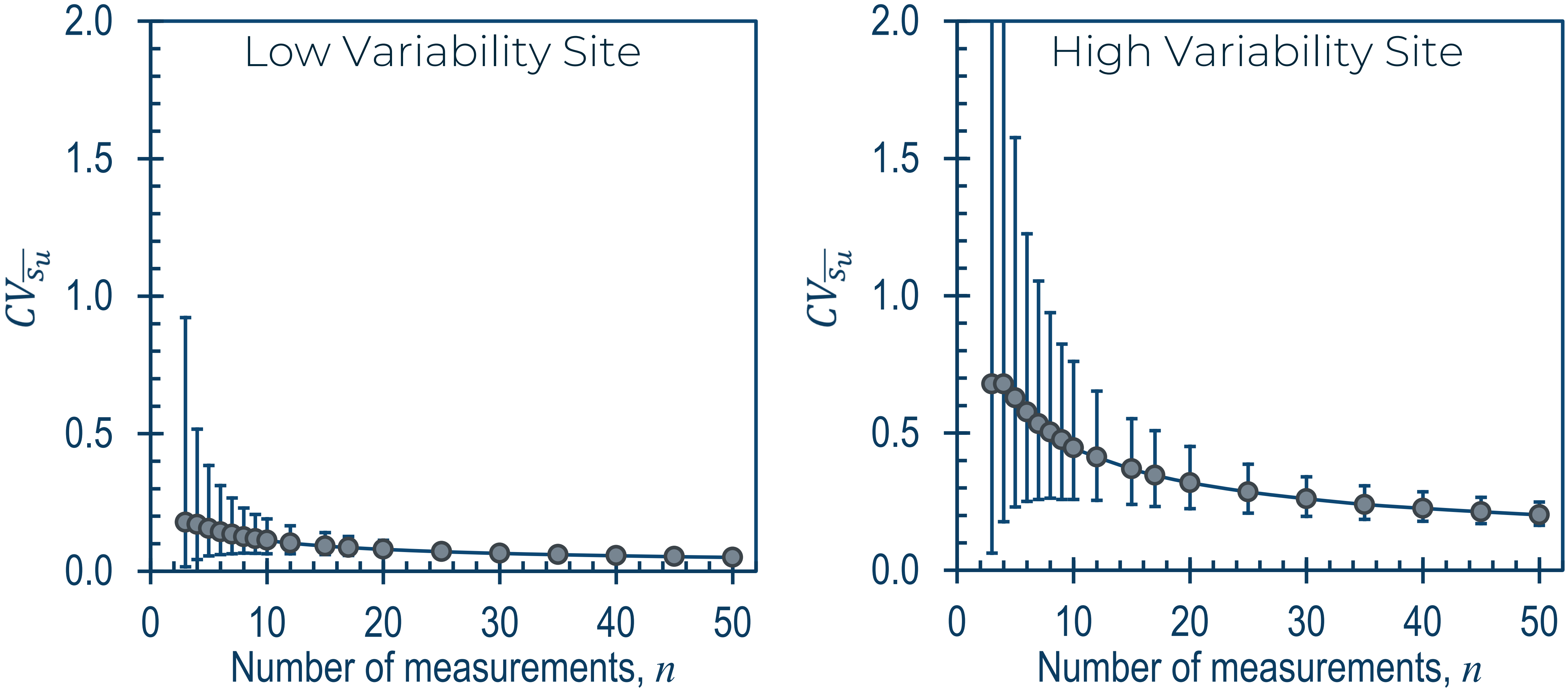


Influence of measurement type – s_u



Ding and Loehr (2019)

Influence of number of measurements



Loehr, Ding, and Likos (2015)

Summary of Changes to Section 10

- ~~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
- 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)
- Resistance factor tables are moved from 10.5 to article for associated foundation type
- Most resistance factors are specified with curves based on CV

Specification of resistance factors

Table 10.6

D Req	Factor
Bearin Resist	.3.2-1
	.3.3-1
	.3.4-1
Uplift Resist	
Slidin Resist	.5.1-1

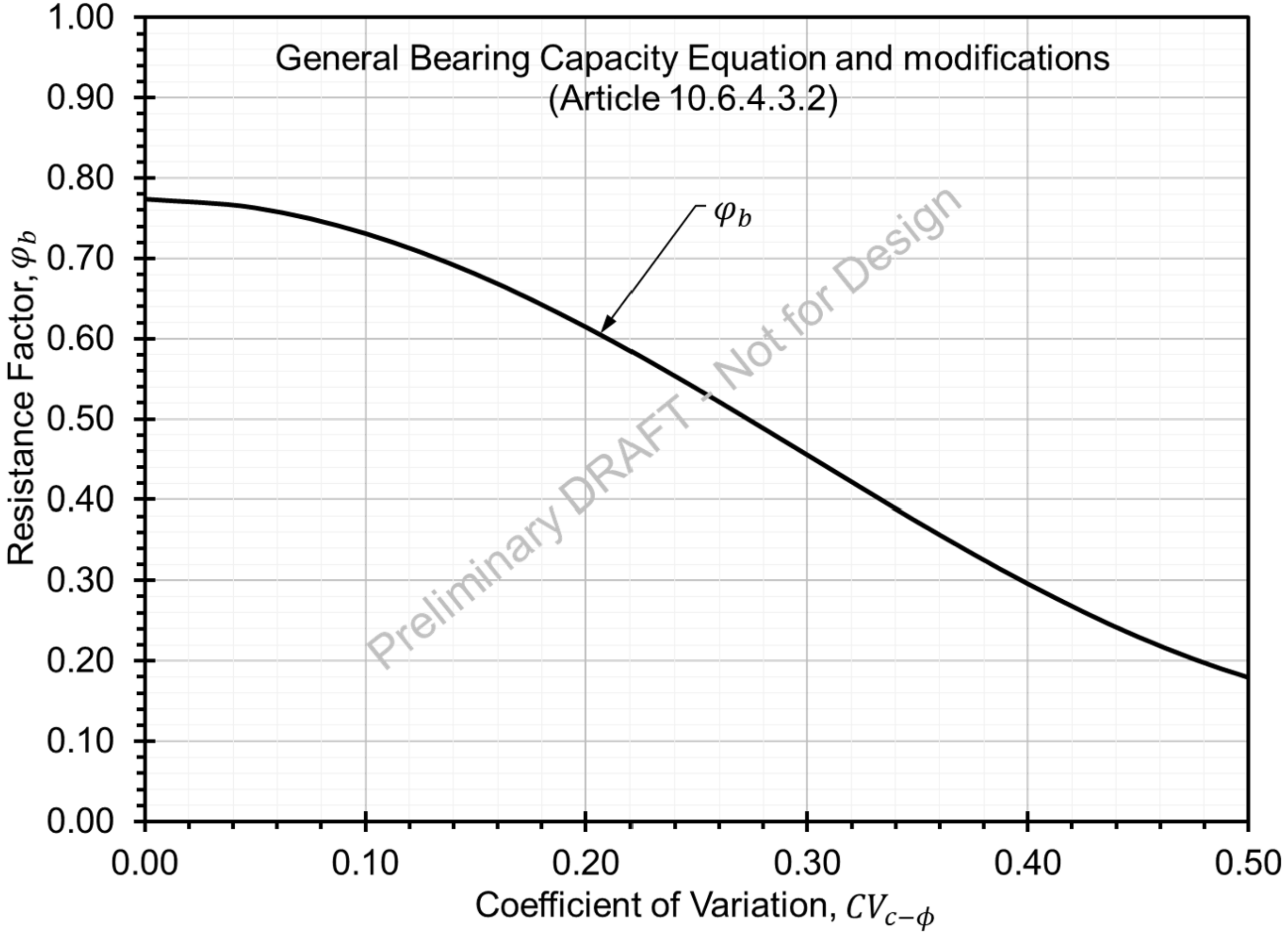


Figure 10.6.4.3.2-1—Resistance factor for bearing resistance determined using classical bearing capacity theory, including modifications to address punching shear, slopes, and layering (Article 10.6.4.3.2).

Summary of Changes (cont.)

- Methods for quantifying uncertainty in design parameters are explicitly defined
- New Terminology
  - Design Parameter vs. Critical Design Parameter (y_d or y_i)
  - Direct Measurement (x_d) vs. Indirect Measurement (x_i)
  - Design Area vs. Construction Control Area
  - Coefficient of Variation (CV_y)
  - Uncertainty (σ_y)

Design parameters

- Design parameter:

  a variable quantity that is a required input for a design or analysis method

- Critical design parameter:

  design parameter that has consequential influence on <u>both</u> design analyses <u>and</u> satisfaction of relevant limit state

Critical design parameters

- Designation requires consideration of:
  - specific design method used,
  - requirements for the specific limit state being evaluated, and
  - influence of parameter values when varied over plausible range

- Specification identifies design parameters that should often be considered critical design parameters for specific methods

10.7.4.3.2a—Nominal Unit Side Resistance Using α-Method

Where side resistance is determined using the α-method, the nominal unit side resistance, in ksf, shall be taken as:

$$q_s = \alpha \bar{s}_u \quad (10.7.4.3.2a\text{-}1)$$

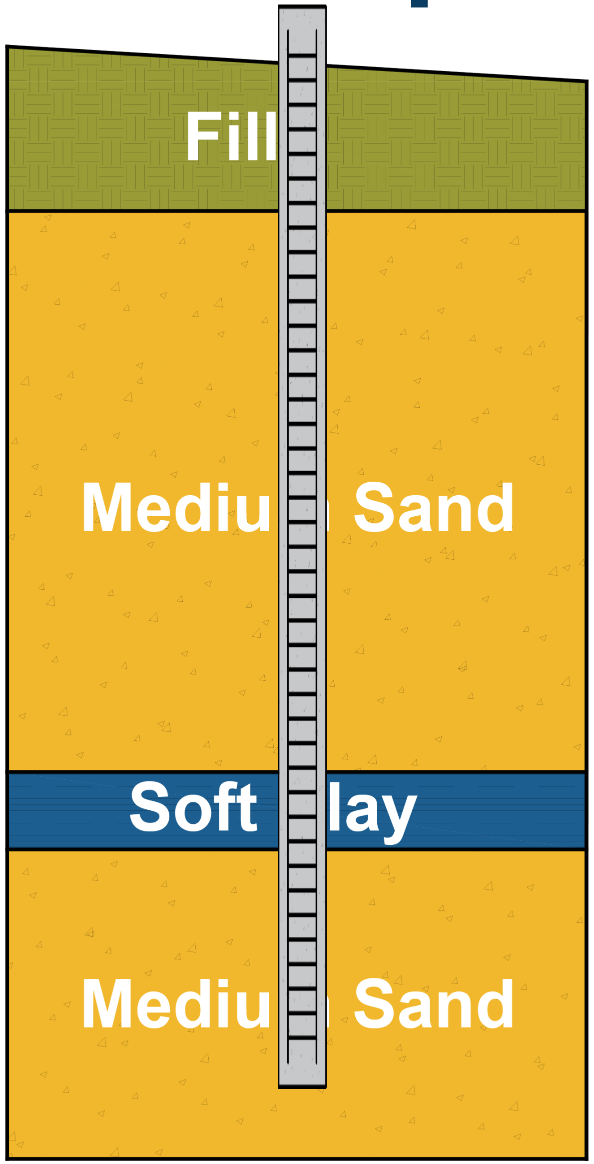
where:

$\bar{s}_u$ = nominal value of undrained shear strength established according to the provisions of Article 10.4.6 (ksf)

α = adhesion factor (dim)

Values for α shall be taken to vary with the nominal value of s_u as shown in Figure 10.7.4.3.2a-1. The value of s_u should generally be considered to be a critical design parameter according to the provisions of Articles 10.4.3 and 10.4.6 when applying the method described in this Article.

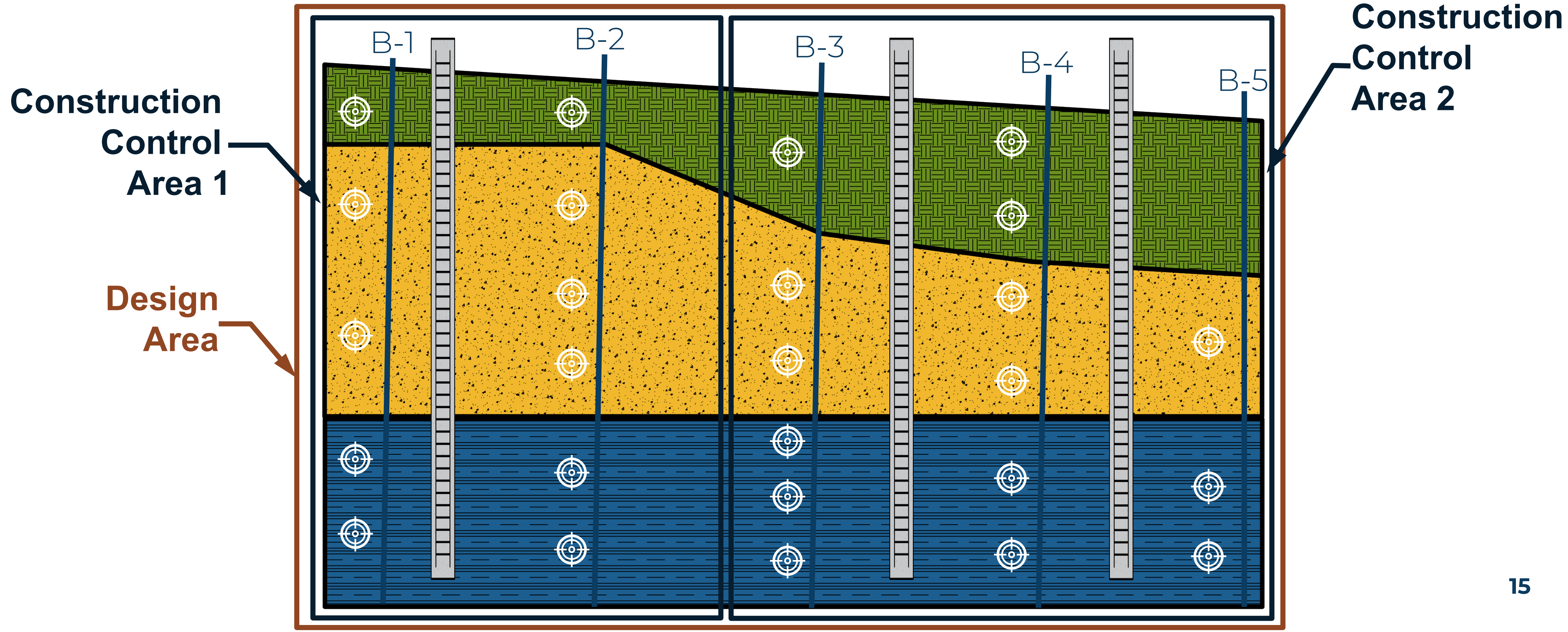
Conceptual example



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

Design Areas

- Site area over which critical design parameters are relatively consistent



Direct and indirect measurements

- Direct measurements:

  evaluate the engineering property or behavior associated with a design parameter without requiring an explicit or implicit transformation

- Indirect measurements:

  require explicit or implicit transformation to produce an estimate for a design parameter

- New provisions in Section 10 identify measurements that should be considered as direct and indirect measurements

Nominal values for design parameters

- Critical design parameters
  - Direct measurements

$$y = y_d = \overline{x_d} = \frac{\sum x_d}{n_d}$$

  - Indirect measurements

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

  - requires three or more independent measurements
  - must be “representative”

- Other design parameters
  - conservatively estimate or establish as for critical design parameters

Coefficient of variation, CV_y

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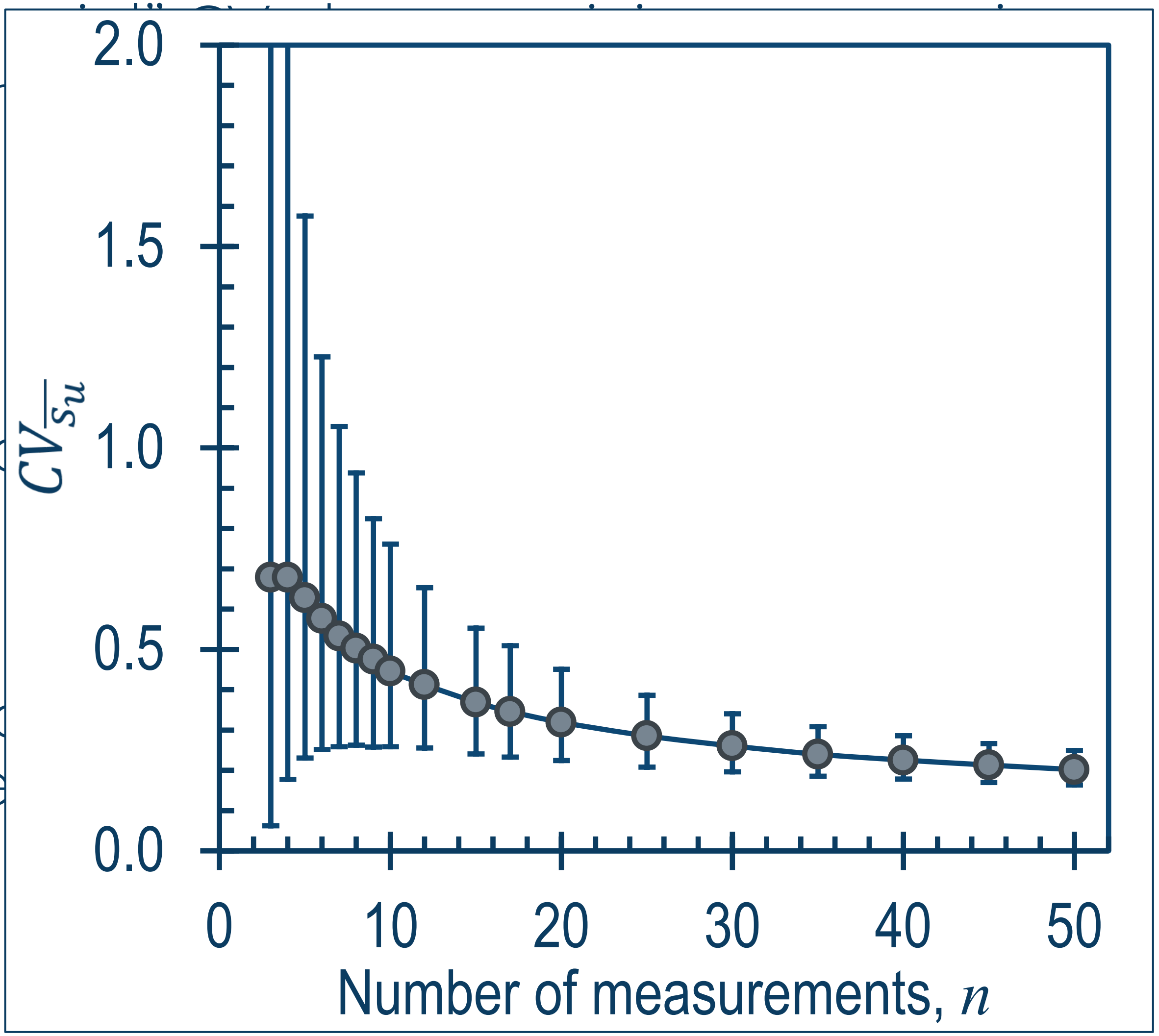


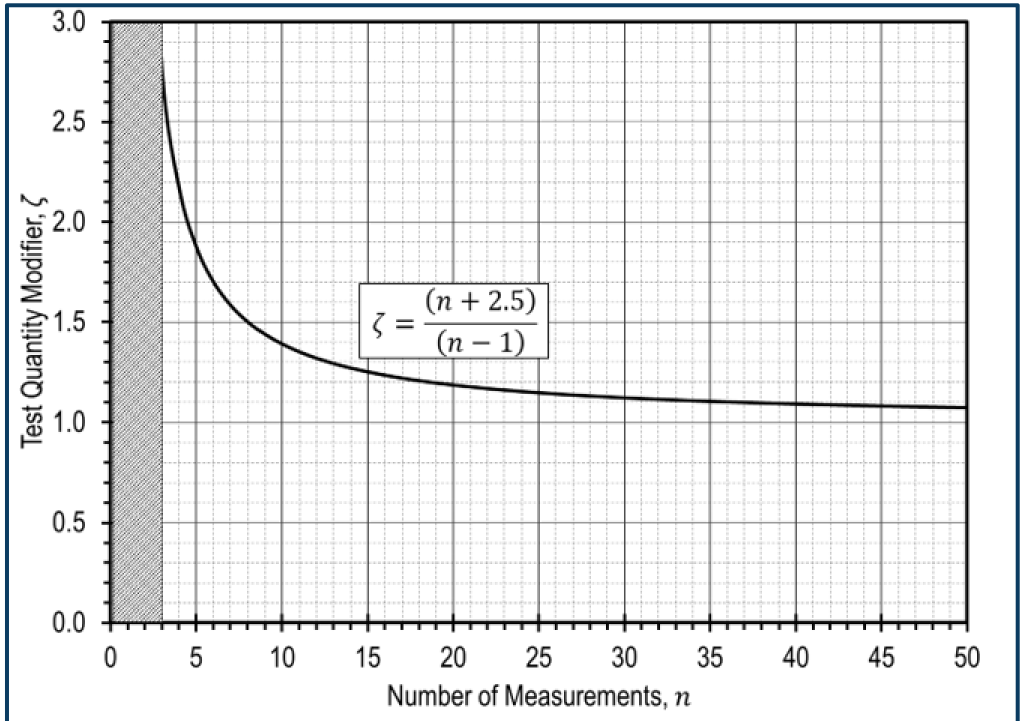


Figure 10.4.6.1.3-1—Test quantity modifier for establishing parameter uncertainty.

Uncertainty, $\boldsymbol{\sigma_y}$

- Direct measurements

$$\sigma_y = \sigma_{y_d} = \sigma_{\overline{x_d}} = \frac{SD_{x_d}}{\sqrt{n_d}}$$

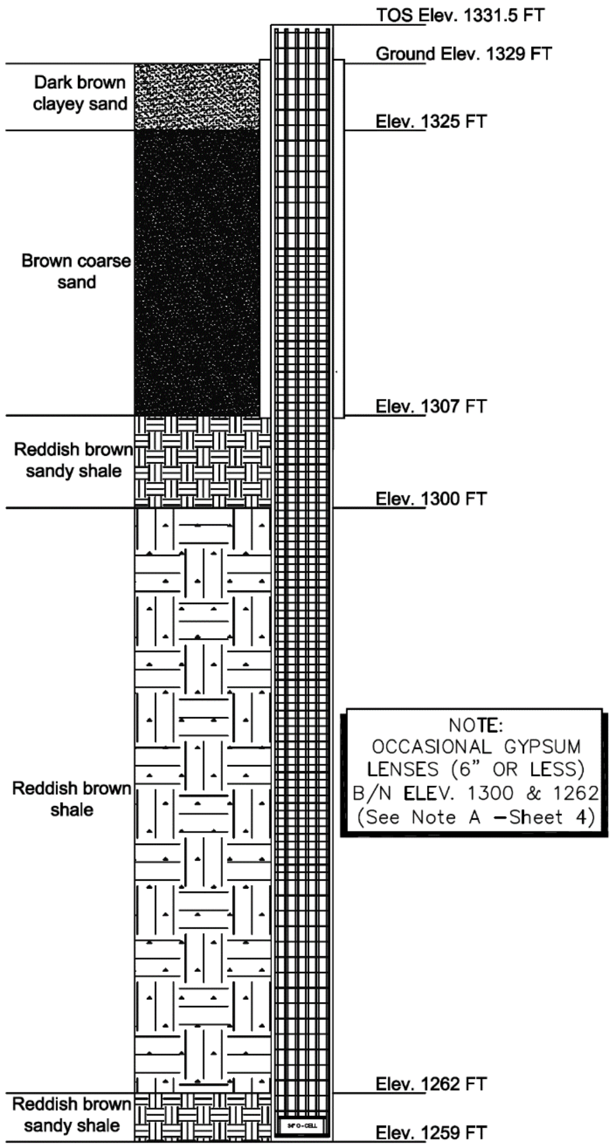
- Indirect measurements

$$\sigma_y = \sigma_{y_i} = \sqrt{{C_1}^2 + {C_2}^2\sigma_{\overline{x_i}}^2 + {C_3}^2(\overline{x_i} - C_4)^2}$$

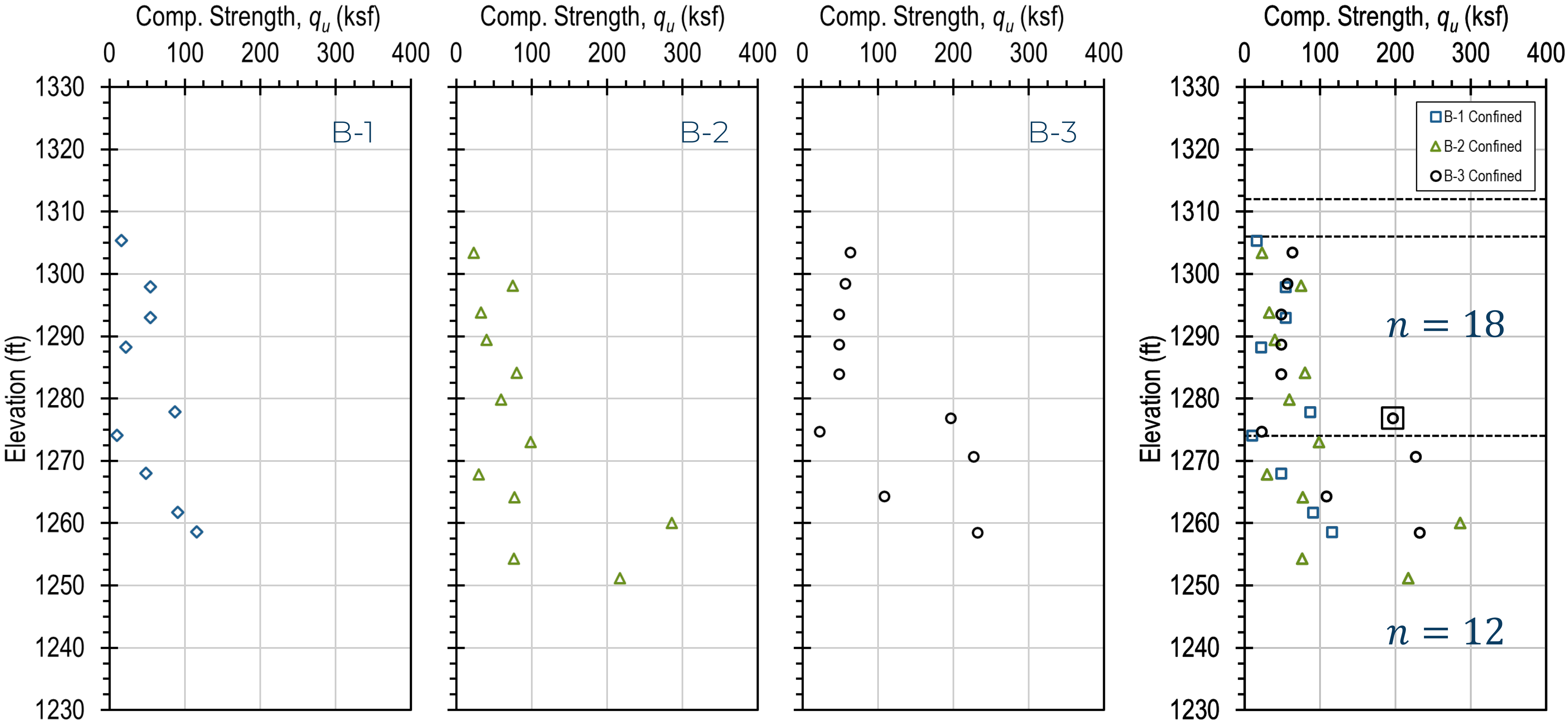
$$\sigma_{\overline{x_i}} = \frac{SD_{x_i}}{\sqrt{n_i}}$$

$$\overline{x_i} = \frac{\sum x_i}{n_i}$$

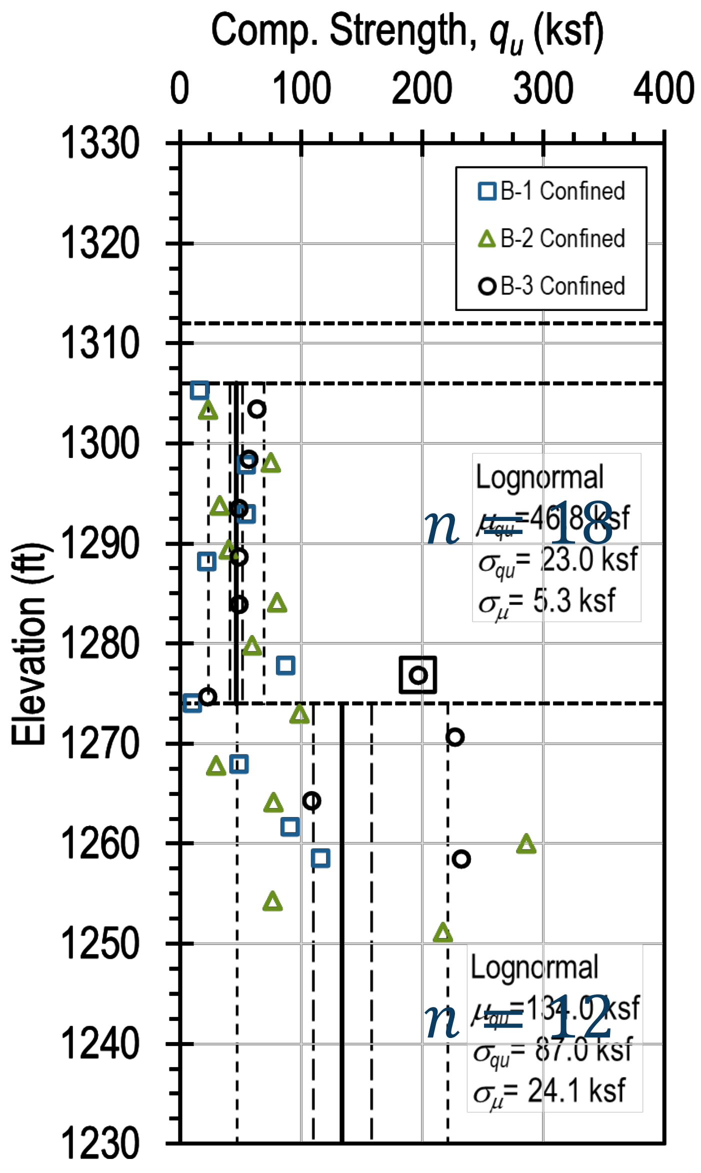
Example 1 – Direct Measurements



Example 1 – Comp. Strength



Example 1 – Nominal values, uncertainty & CV



- Nominal value:

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

- Uncertainty:

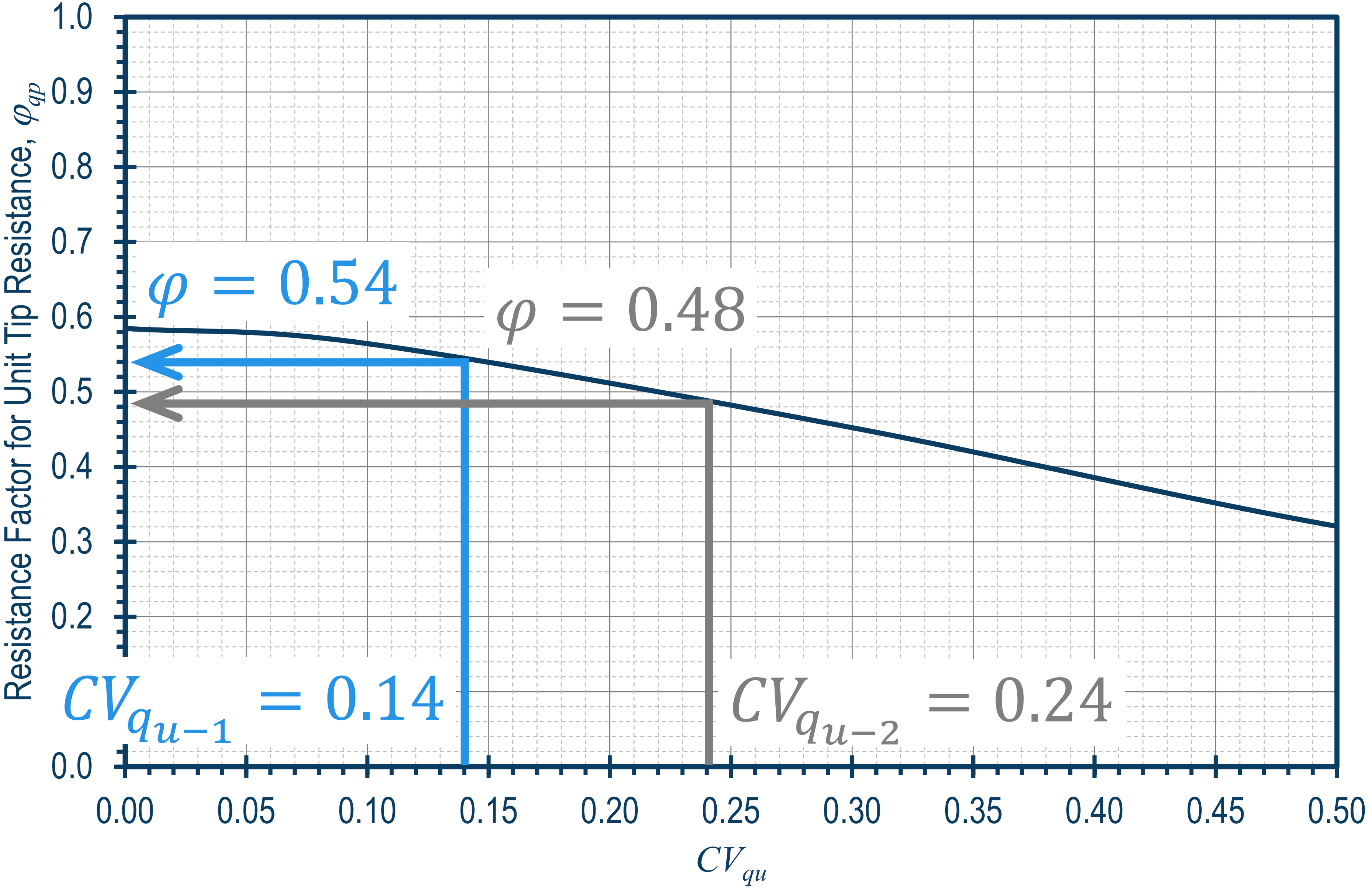
$$\sigma_{q_{u-1}} = \frac{SD_{q_u}}{\sqrt{n}} = \frac{22.4}{\sqrt{18}} = 5.3 \text{ ksf} \qquad \sigma_{q_{u-2}} = \frac{SD_{q_u}}{\sqrt{n}} = \frac{83.6}{\sqrt{12}} = 24.1 \text{ ksf}$$

- Coefficient of Variation:

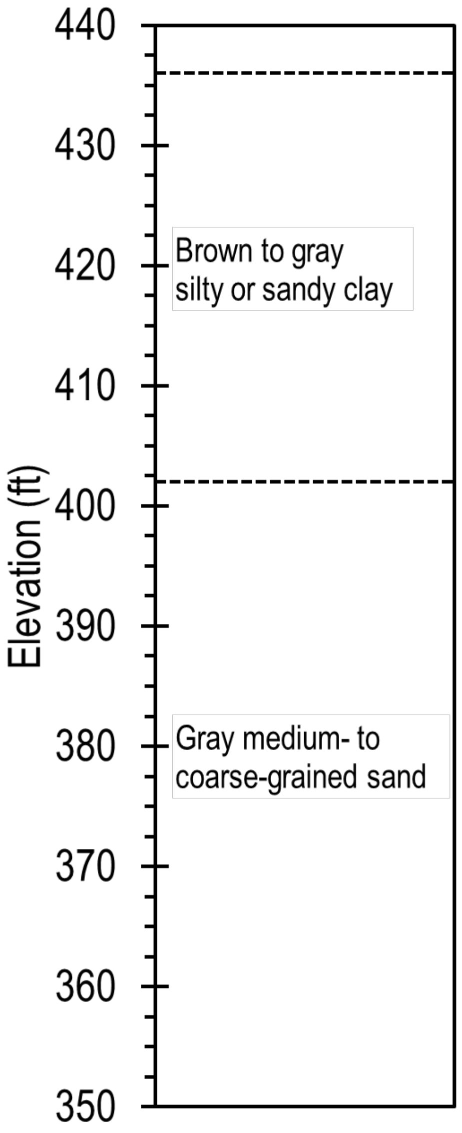
$$CV_{q_{u-1}} = \frac{\zeta \times \sigma_{q_{u-1}}}{q_{u-1}} = \frac{1.21 \cdot 5.3}{47} = 0.14$$

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

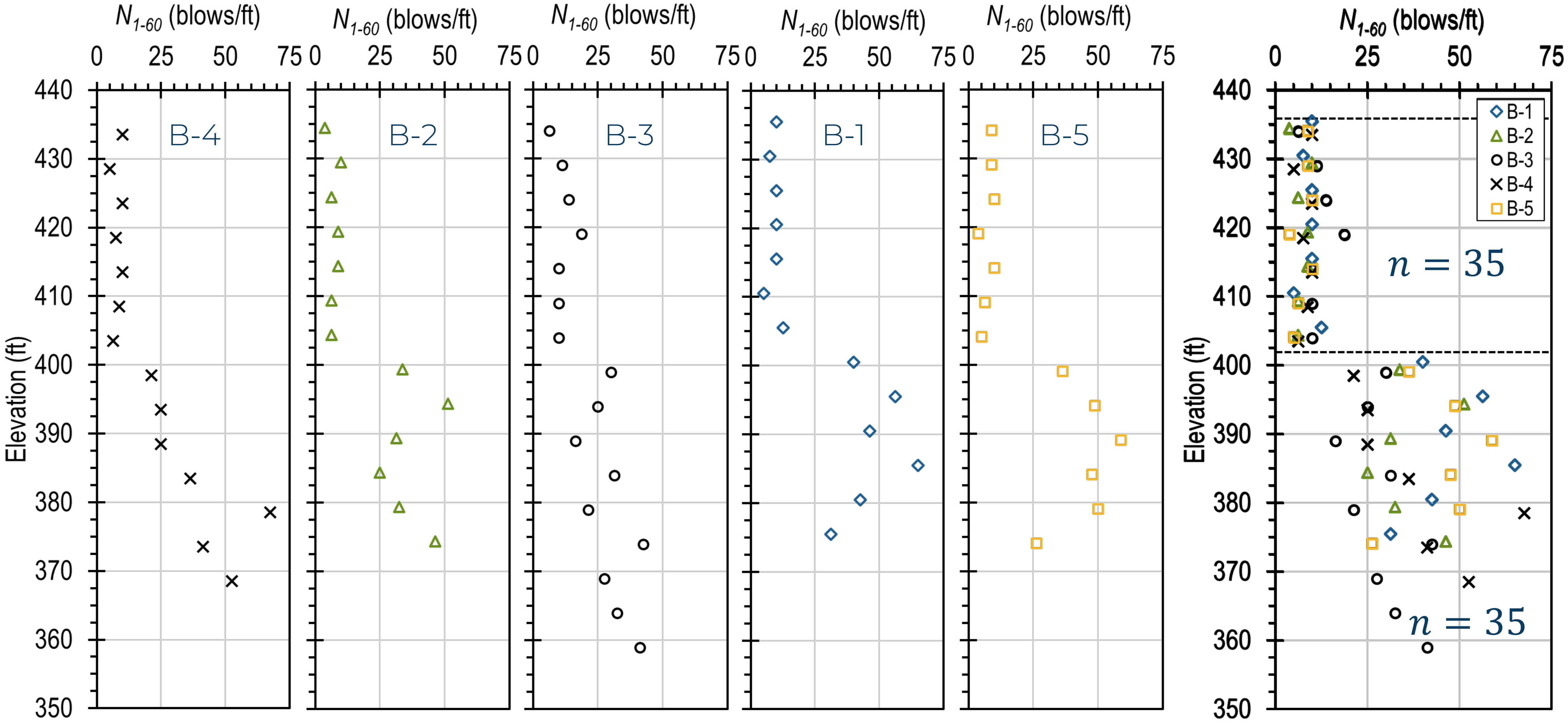
Resistance factors



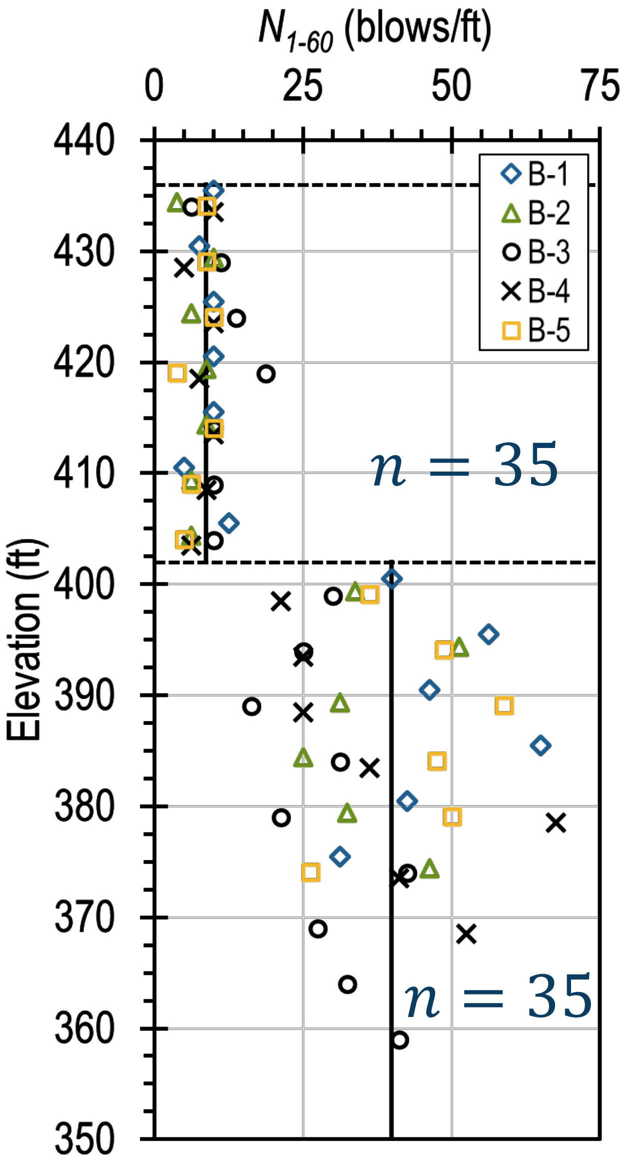
Example 2 – Indirect Measurements



Example 2 – SPT N-value



Example 2 – Nominal value of ϕ'



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

- Mean value of indirect measurements:

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

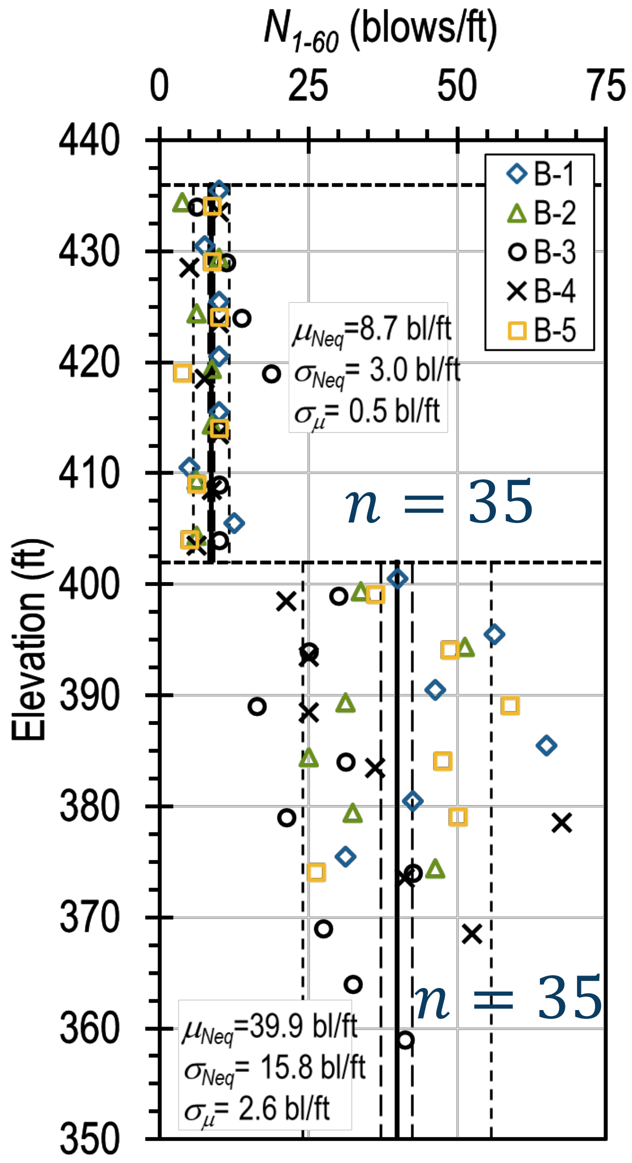
- Apply transformation:

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

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

Example 2 – Uncertainty



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

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

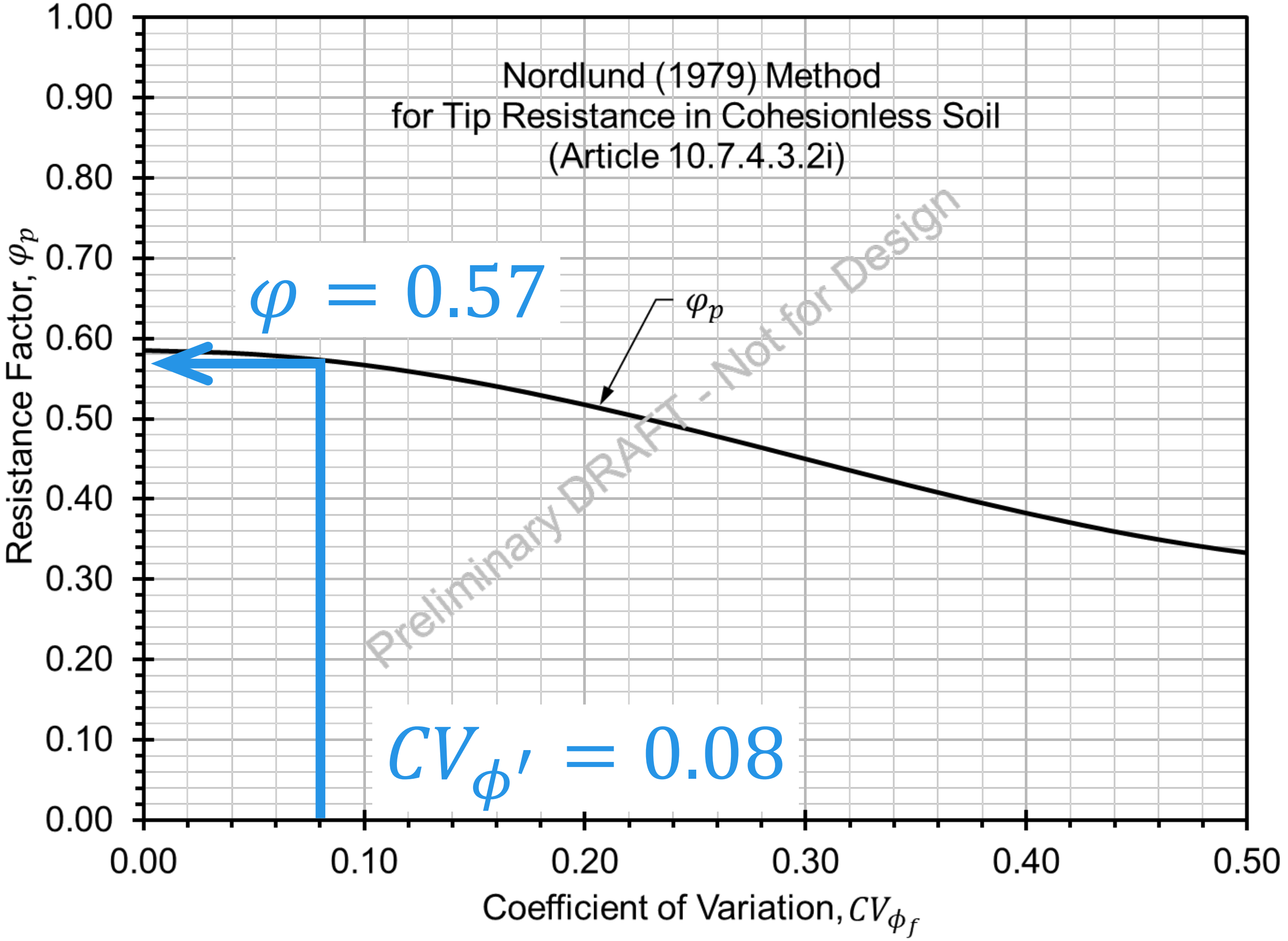
$$\sigma_{\overline{N1_{60}}} = \frac{SD_{N1_{60}}}{\sqrt{n}} = \frac{15.8}{\sqrt{35}} = 2.6\ \text{blows/ft}$$

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

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

Example 2 – Coefficient of variation

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



Anticipated Timeline

- 10.4 and 10.5 draft by the end of 2023
- Section 10 complete draft by COBS Annual Meeting in June 2024
- Examples by Soil Structures Mid-Year Meeting in October 2024
- Section 10 ballot by COBS Annual Meeting in summer of 2025

Thanks for your attention!