Design-Oriented Characterization of Uncertainty in Computed Axial Capacities of Deep Foundation Members

STGEC | Tue. Oct. 18, 2022 | 1130 AM - 12 PM

Michael Davidson, PhD, PE
Bridge Software Institute
University of Florida

Bridge Software Institute

Outline

- Introduction
- Characterization of spatial variability
- Illustration case
- Summary

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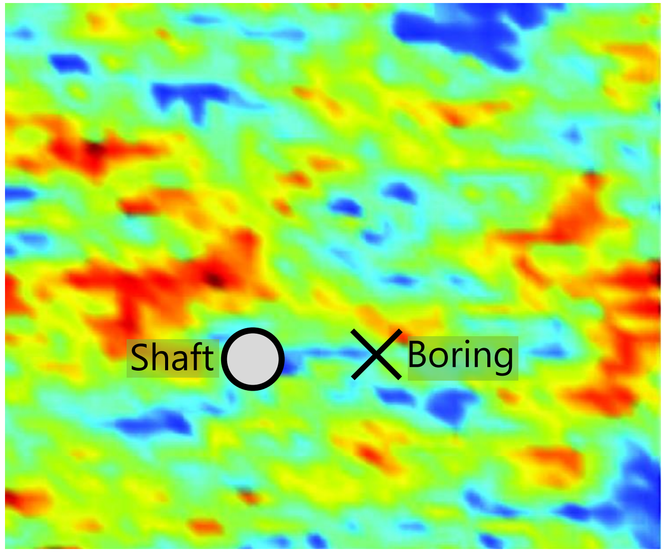
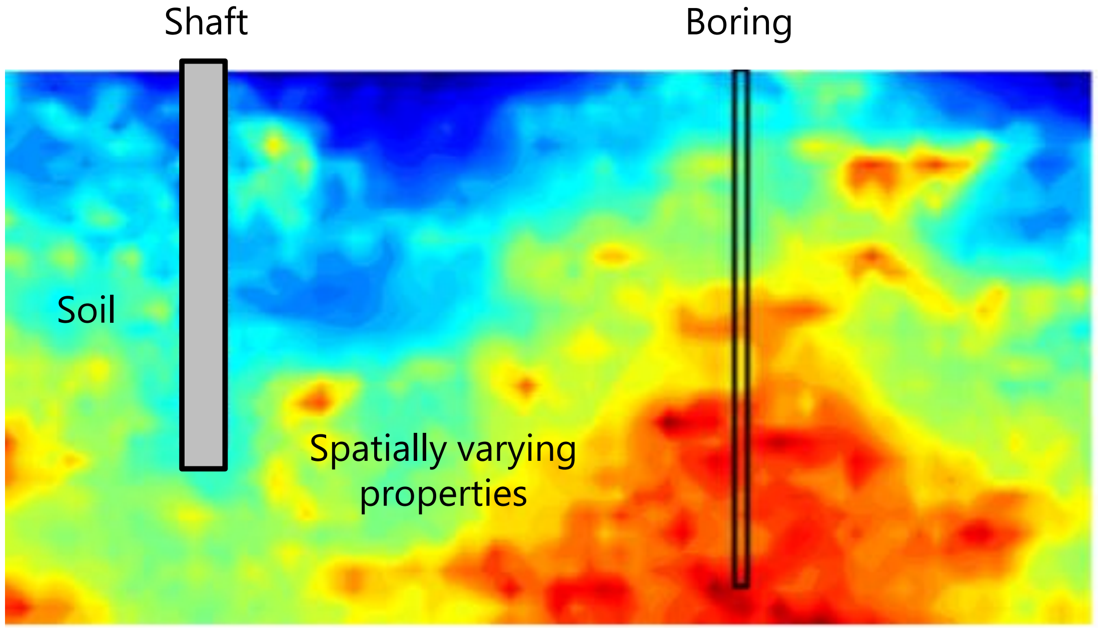
Introduction

- Spatial variability
  - Horizontal
  - Vertical



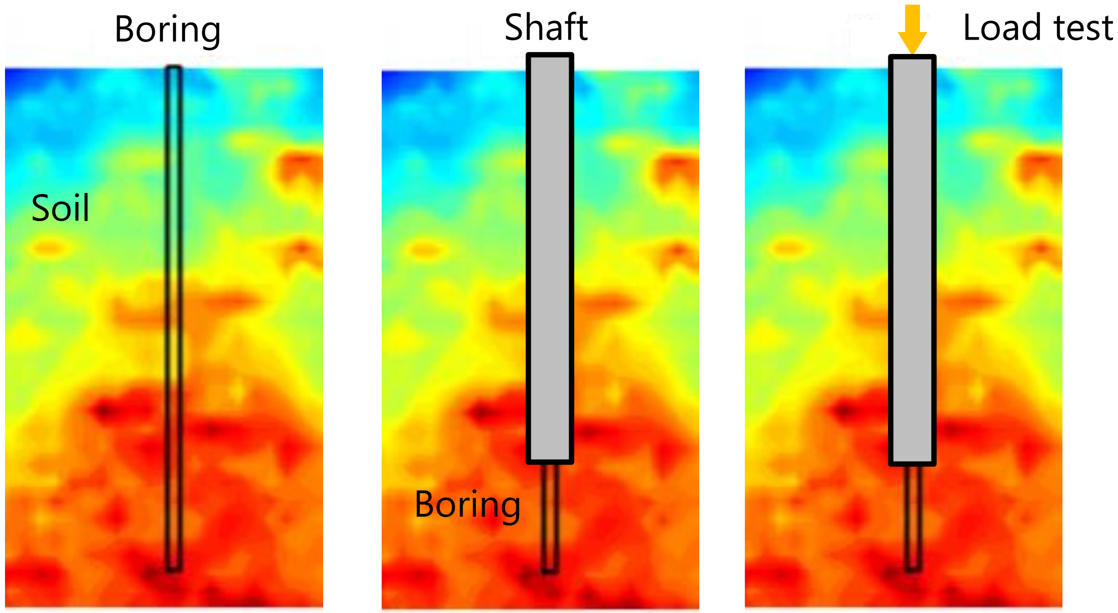
Plan view, illustrative
(contour image from Zhu and Zang 2013)



Elevation view, illustrative
(contour image from McVay et al. 2012)

Introduction

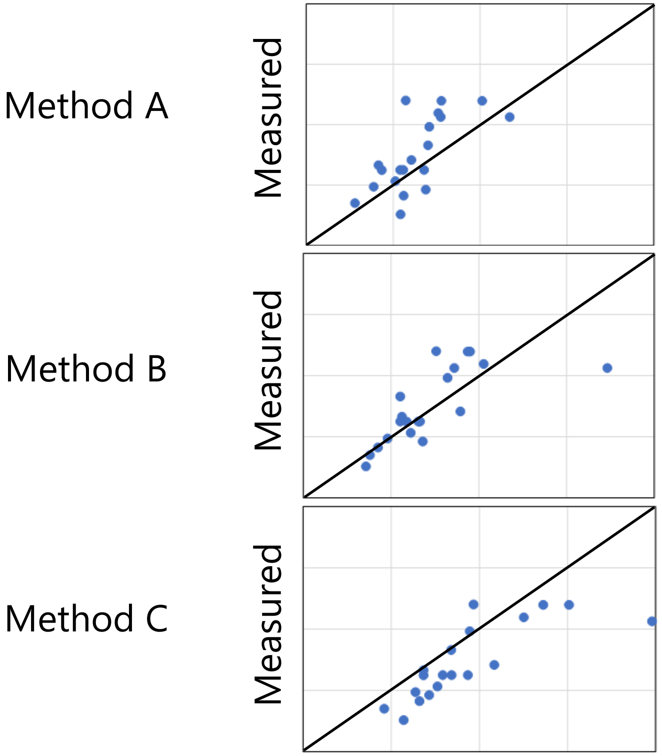
- Method error
  - Due to underlying assumptions in empirical methods
  - Correlation of measurement to unit resistance

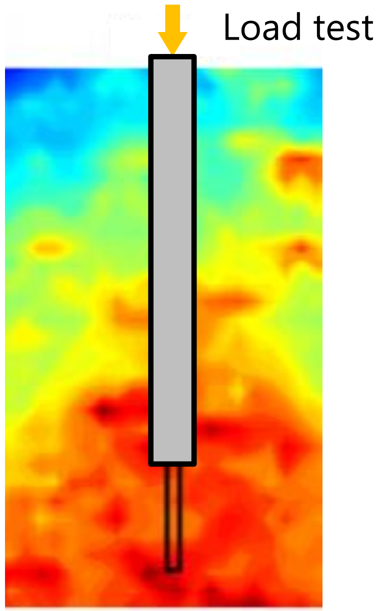


Example: boring in footprint of shaft

Introduction

- Method error
  - Increases uncertainty in computed capacities

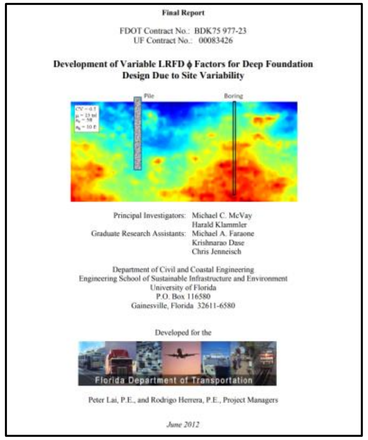




Example: boring in footprint of shaft

Previous research efforts

- FDOT BDK 977-23, BDV31 977-108, BDV31 977-143
  - Formulated geostatistical methodologies
  - Compiled method error data
  - Developed prototype and design tools



Final Report

FDOT Contract No.: BDK75 977-23
UF Contract No.: 00083426

Development of Variable LRFD ϕ Factors for Deep Foundation Design Due to Site Variability

Principal Investigators: Michael C. McVay, Harald Klammler
Graduate Research Assistants: Michael A. Faraone, Krishnarao Dase, Chris Jenneisch

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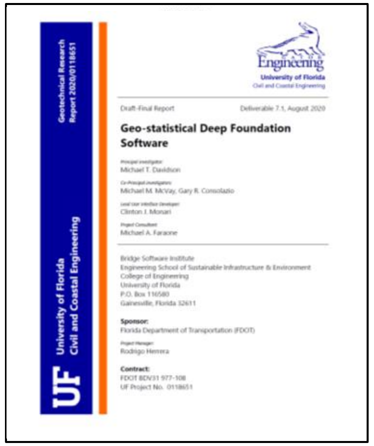
Developed for the
Florida Department of Transportation

Peter Lai, P.E., and Rodrigo Herrera, P.E., Project Managers

June 2012

FDOT BDK75 977-23 final report



Geotechnical Research Report 2020/0118651
University of Florida Civil and Coastal Engineering

Engineering
University of Florida
Civil and Coastal Engineering

Draft-Final Report — Deliverable 7.1, August 2020

Geo-statistical Deep Foundation Software

Principal Investigator: Michael T. Davidson
Co-Principal Investigators: Michael M. McVay, Gary R. Consolazio
Lead User Interface Developer: Clinton J. Monari
Project Consultant: Michael A. Faraone

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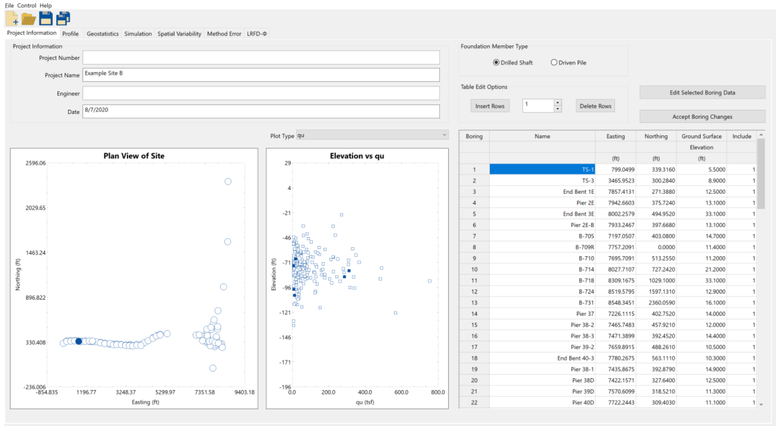
Gainesville, Florida 32611

Sponsor: Florida Department of Transportation (FDOT)
Project Manager: Rodrigo Herrera

Contract:
FDOT BDV31 977-108
UF Project No. 0118651

FDOT BDV31 977-108 final report



GeoStat design tool

Motivation

- How do variability and uncertainty affect design?

Motivation

- How do variability and uncertainty affect design?
  - Example: resistance factors

$$\phi = \frac{\lambda_R \left(\gamma_D \cdot \frac{Q_D}{Q_L} + \gamma_L\right) \cdot \sqrt{\frac{1 + COV_{QD}^2 + COV_{QL}^2}{1 + COV_R^2}}}{\left(\lambda_{QD} \cdot \frac{Q_D}{Q_L} + \lambda_{QL}\right) \cdot exp\left(\beta \cdot \sqrt{ln\left(\left(1 + COV_R^2\right) \cdot \left(1 + COV_{QD}^2 + COV_{QL}^2\right)\right)}\right)}$$

Resistance factor, ϕ, NCHRP 507

Term description	Symbol	Value
Dead load factor	γ_D	1.25
Live load factor	γ_L	1.75
Dead to live load ratio	Q_D/Q_L	2.00
Dead load bias factor	λ_{QD}	1.08
Live load bias factor	λ_{QL}	1.15
Mean resistance bias factor	λ_R	1.0
Dead load coefficient of variation	COV_{QD}	0.128
Live load coefficient of variation	COV_{QL}	0.18
Target reliability index	β	3.0

Illustrative values of component terms for evaluation of LRFD resistance factors, ϕ

Motivation

- How do variability and uncertainty affect design?
  - Example: resistance factors

$$\phi = \frac{\lambda_R\left(\gamma_D \cdot \frac{Q_D}{Q_L} + \gamma_L\right) \cdot \sqrt{\frac{1 + COV_{QD}^2 + COV_{QL}^2}{1 + COV_R^2}}}{\left(\lambda_{QD} \cdot \frac{Q_D}{Q_L} + \lambda_{QL}\right) \cdot exp\left(\beta \cdot \sqrt{ln\left(\left(1 + COV_R^2\right) \cdot \left(1 + COV_{QD}^2 + COV_{QL}^2\right)\right)}\right)}$$

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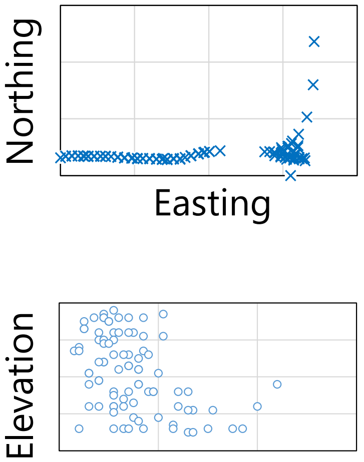
Illustrative values of component terms for evaluation of LRFD resistance factors, ϕ

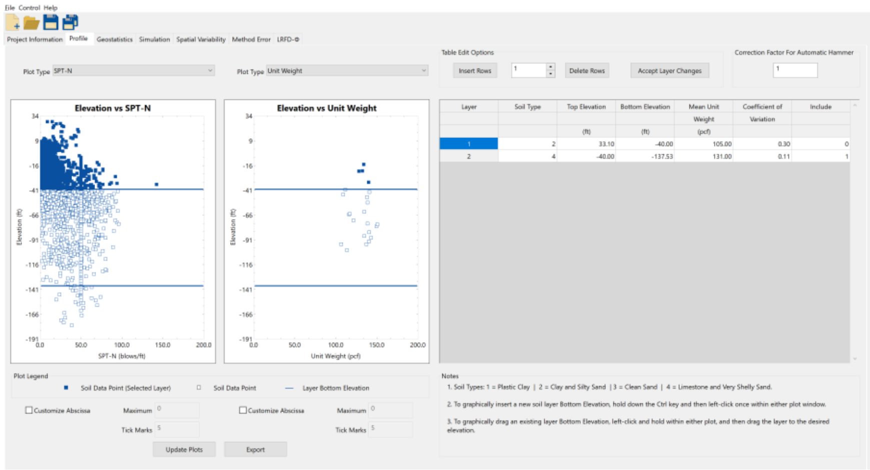
COV_R : Coefficient of variation in resistance

Motivation

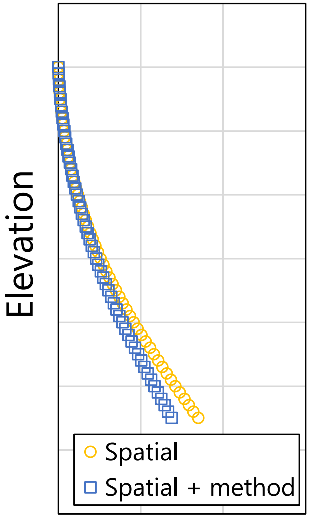
- Direct incorporation of variability and uncertainty can benefit foundation design
  - Assess sufficiency of available site data
  - More uniform levels of conservatism
  - Site-specific reflection of variability



Site measurements



Illustrative layer definitions in GeoStat



Computed resistance

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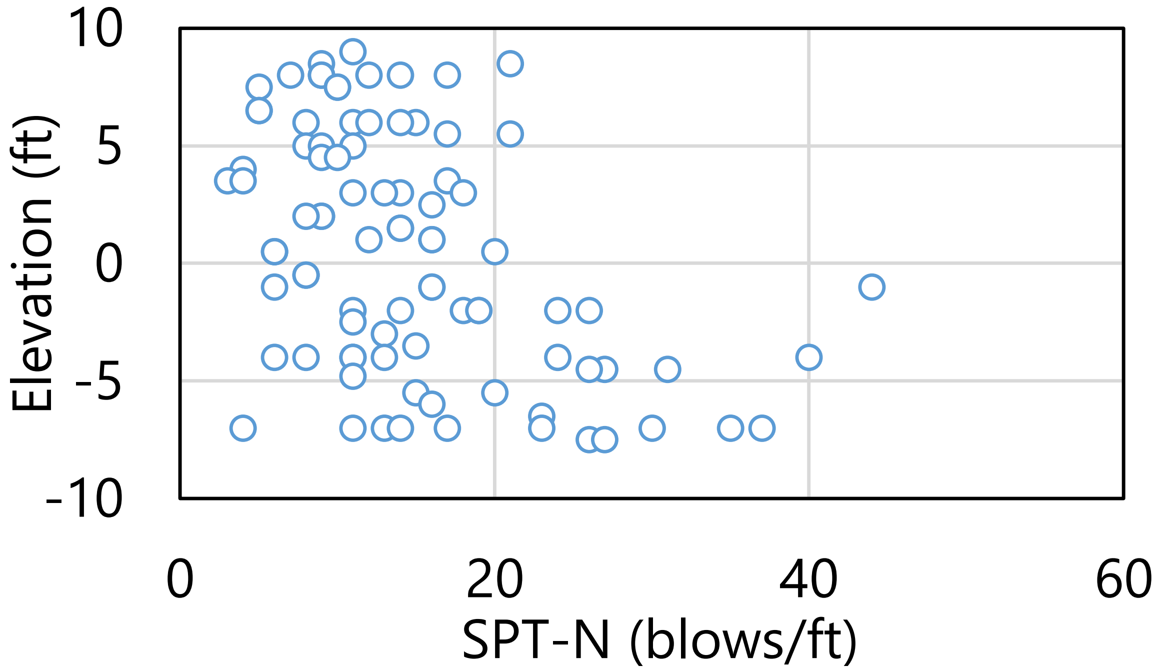
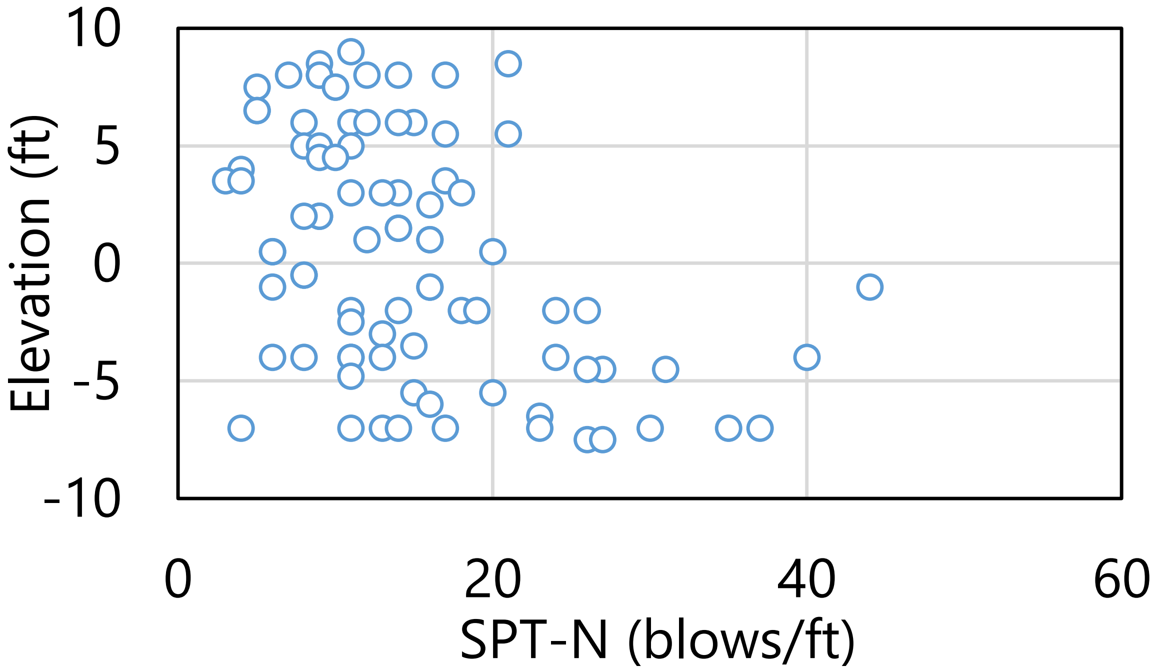
Consider a set of 88 SPT-N values

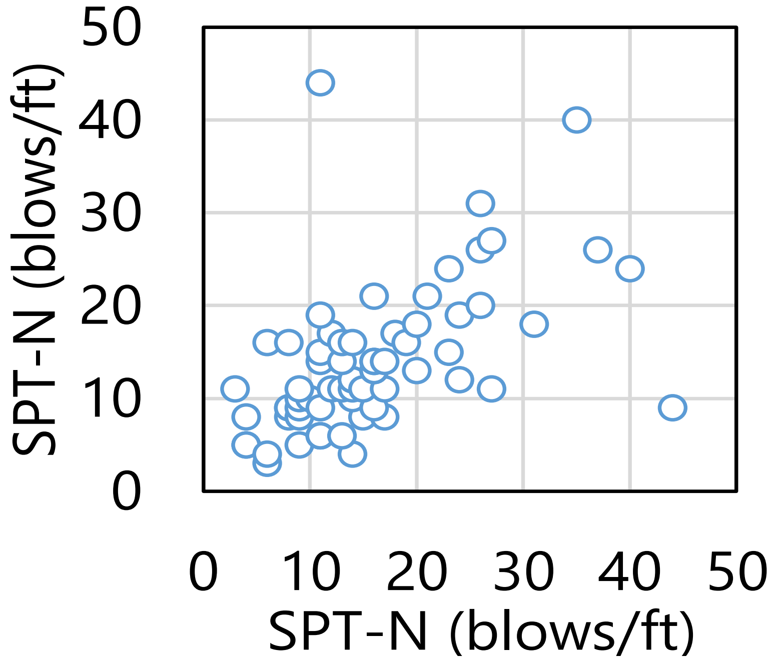


Illustrative collection of 88 SPT-N values

Examine pairs of values 2.5 ft apart

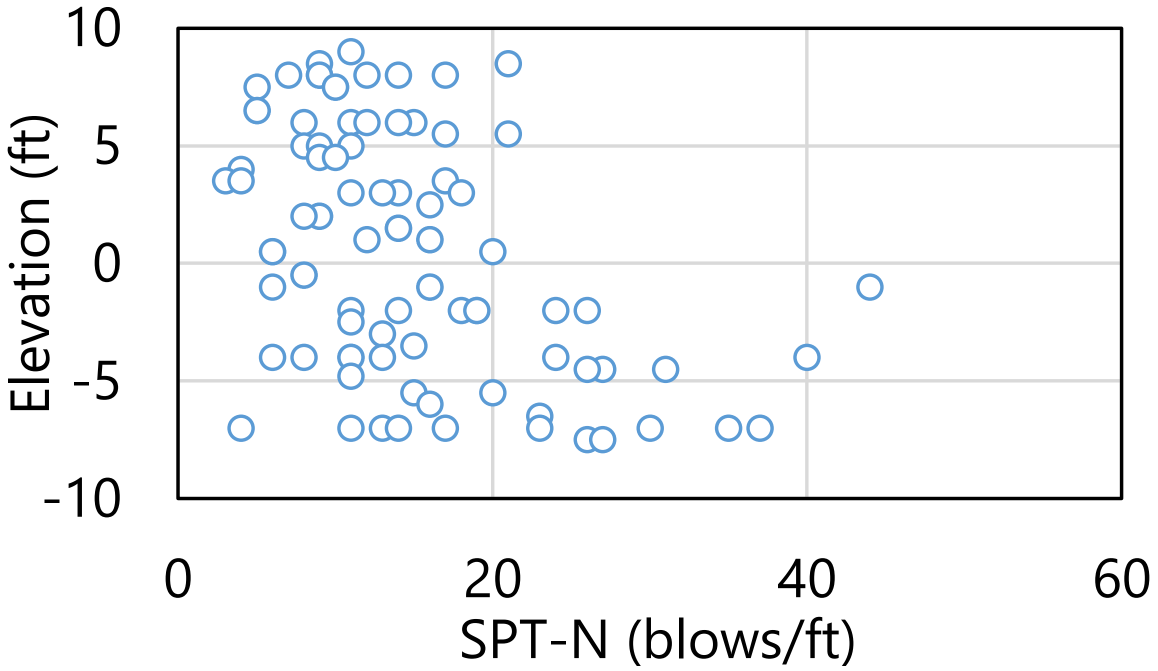


Illustrative collection of 88 SPT-N values

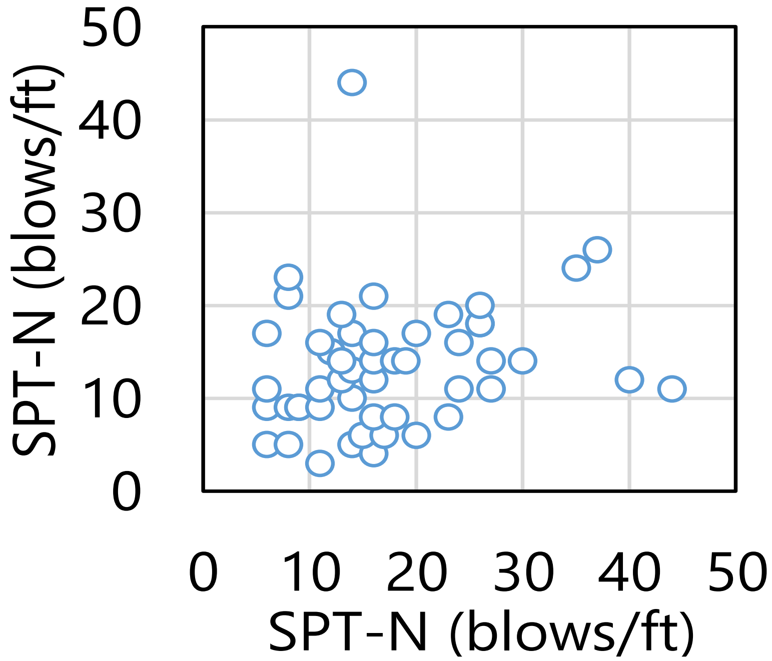


Pairs that lie 2.5 ft apart

Examine pairs of values 5.0 ft apart

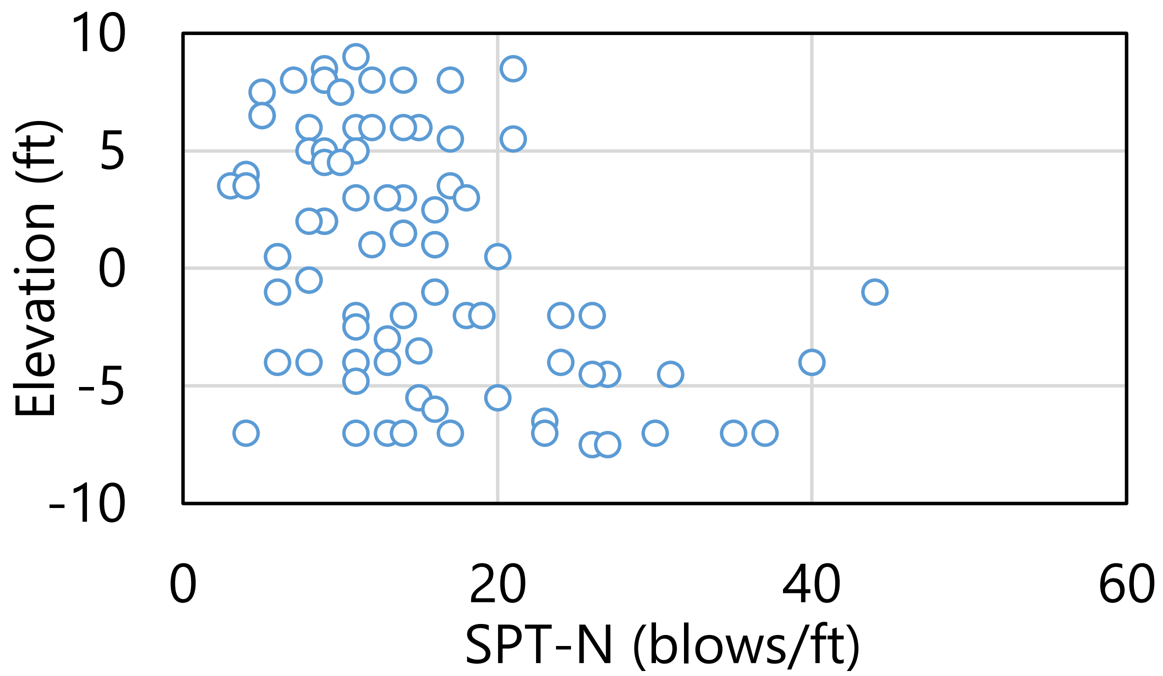


Illustrative collection of 88 SPT-N values

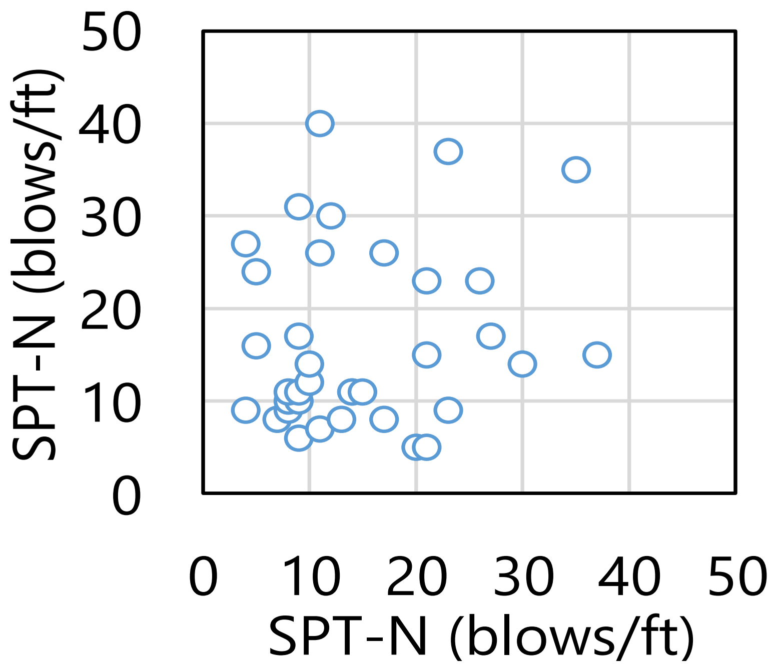


Pairs that lie 5.0 ft apart

Examine pairs of values 12.5 ft apart

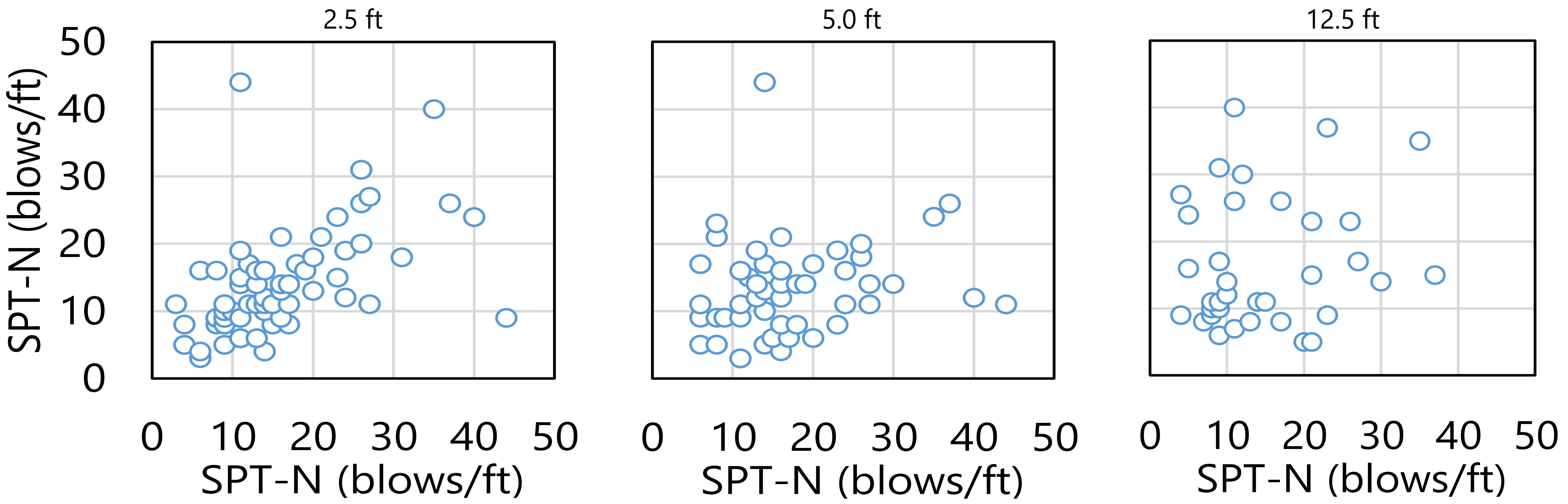


Illustrative collection of 88 SPT-N values



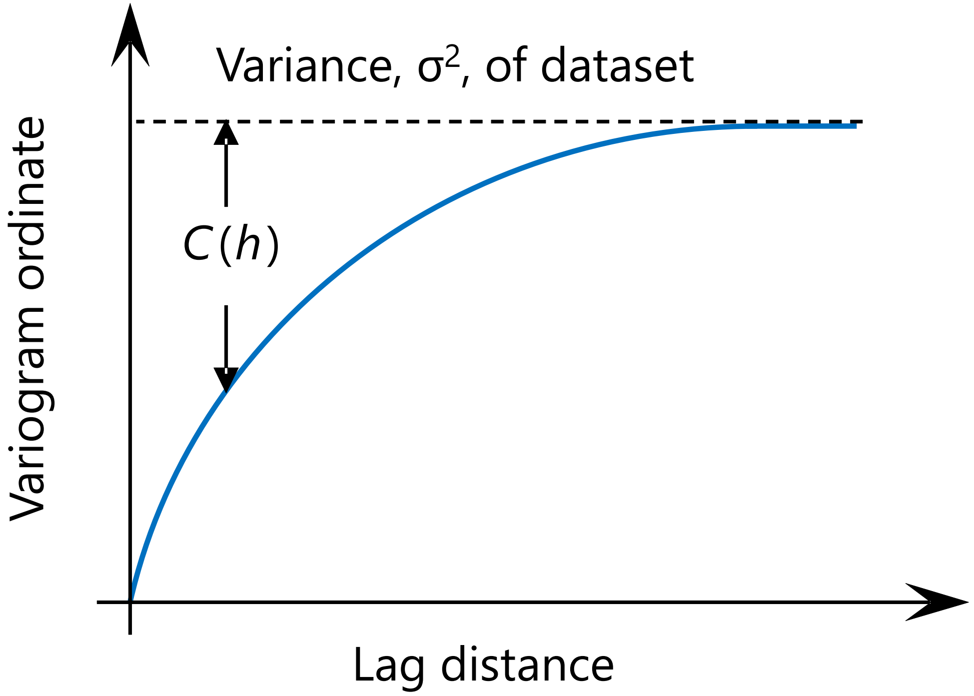
Pairs that lie 12.5 ft apart

Strength of correlation and covariance vary with respect to distance (*h*)



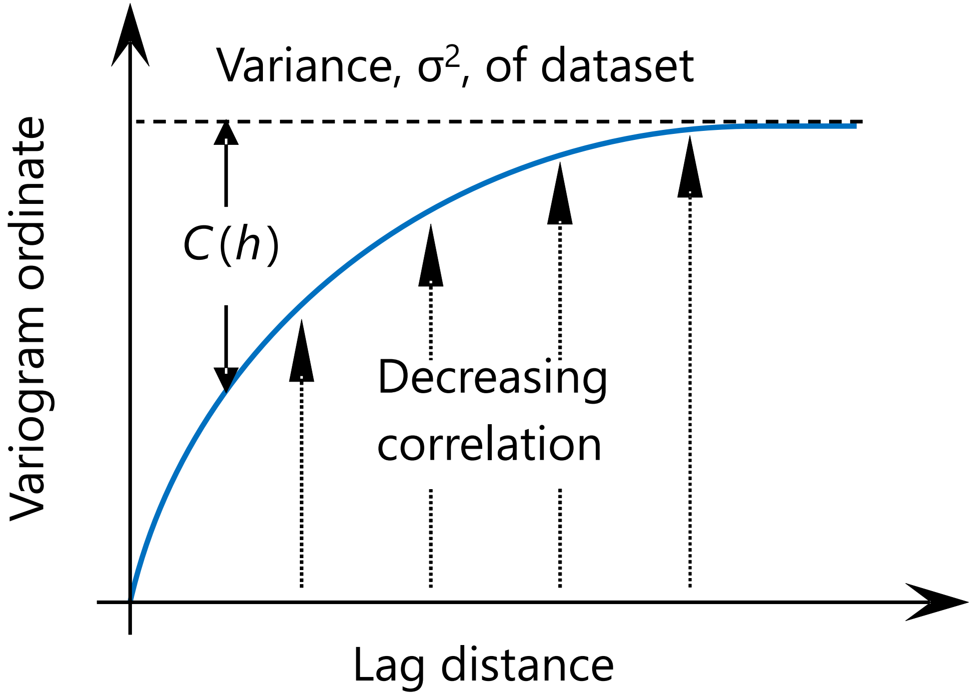
Covariance: $$C(h) = \frac{1}{n_{pairs}} \sum_{i,j=1}^{n_{pairs}} (SPT_i - Mean)^2 \cdot (SPT_j - Mean)^2$$

Variograms compactly express spatial variability phenomena



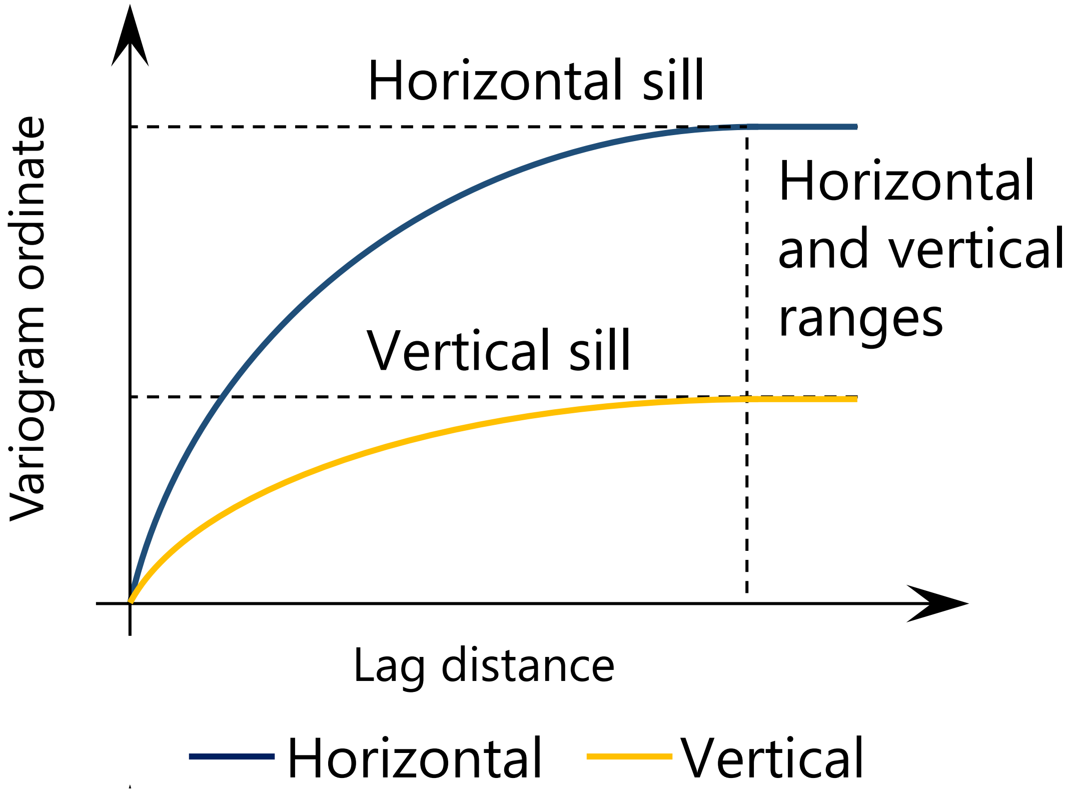
Variogram: $v(h) = \sigma^2 - C(h)$

Variograms compactly express spatial variability phenomena

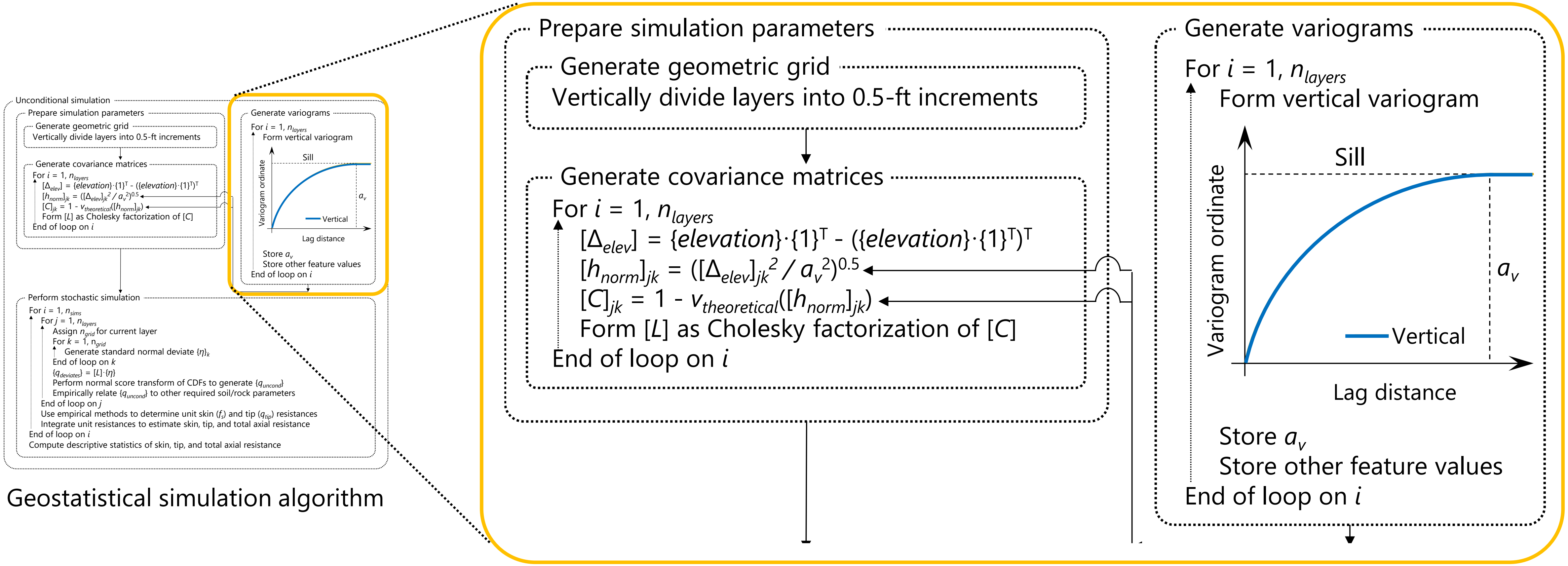


Distance between any two measurements (*h*)

Variograms can reveal geological zones



Variograms are necessary for geostatistical simulation



Geostatistical simulation algorithm

Outline

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- Characterization of spatial variability
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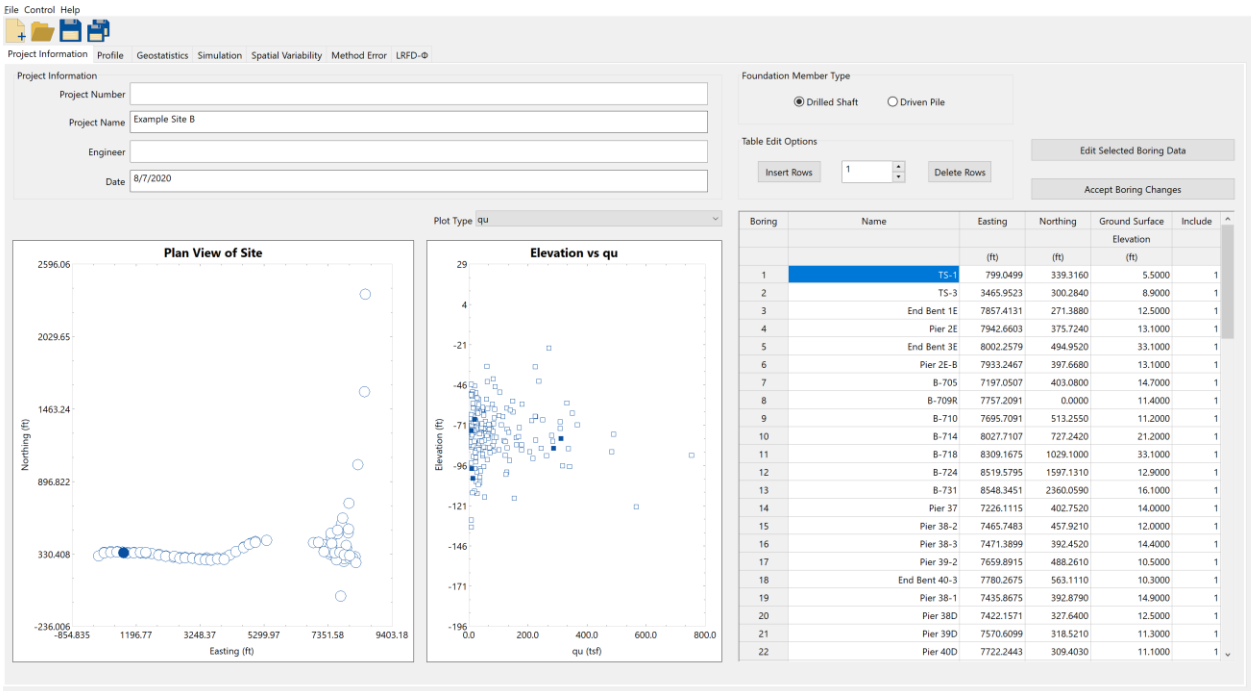
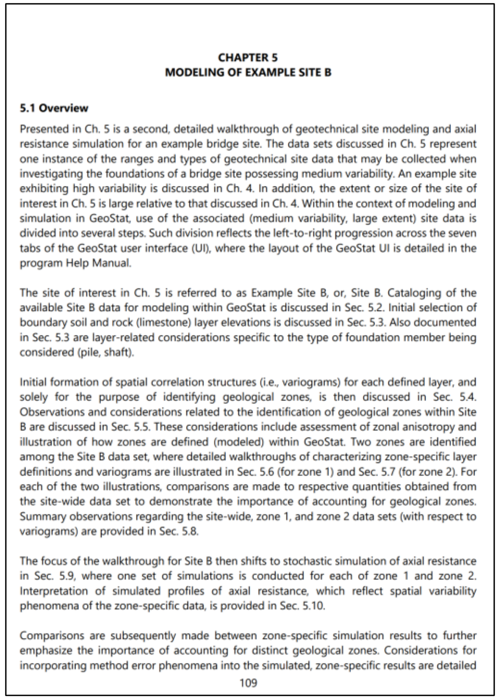
Use geostatistical tool to assess shaft axial capacities within an example site



GeoStat software



CHAPTER 5
MODELING OF EXAMPLE SITE B

5.1 Overview

Presented in Ch. 5 is a second, detailed walkthrough of geotechnical site modeling and axial resistance simulation for an example bridge site. The data sets discussed in Ch. 5 represent one instance of the ranges and types of geotechnical site data that may be collected when investigating the foundations of a bridge site possessing medium variability. An example site exhibiting high variability is discussed in Ch. 4. In addition, the extent or size of the site of interest in Ch. 5 is large relative to that discussed in Ch. 4. Within the context of modeling and simulation in GeoStat, use of the associated (medium variability, large extent) site data is divided into several steps. Such division reflects the left-to-right progression across the seven tabs of the GeoStat user interface (UI), where the layout of the GeoStat UI is detailed in the program Help Manual.

The site of interest in Ch. 5 is referred to as Example Site B, or, Site B. Cataloging of the available Site B data for modeling within GeoStat is discussed in Sec. 5.2. Initial selection of boundary soil and rock (limestone) layer elevations is discussed in Sec. 5.3. Also documented in Sec. 5.3 are layer-related considerations specific to the type of foundation member being considered (pile, shaft).

Initial formation of spatial correlation structures (i.e., variograms) for each defined layer, and solely for the purpose of identifying geological zones, is then discussed in Sec. 5.4. Observations and considerations related to the identification of geological zones within Site B are discussed in Sec. 5.5. These considerations include assessment of zonal anisotropy and illustration of how zones are defined (modeled) within GeoStat. Two zones are identified among the Site B data set, where detailed walkthroughs of characterizing zone-specific layer definitions and variograms are illustrated in Sec. 5.6 (for zone 1) and Sec. 5.7 (for zone 2). For each of the two illustrations, comparisons are made to respective quantities obtained from the site-wide data set to demonstrate the importance of accounting for geological zones. Summary observations regarding the site-wide, zone 1, and zone 2 data sets (with respect to variograms) are provided in Sec. 5.8.

The focus of the walkthrough for Site B then shifts to stochastic simulation of axial resistance in Sec. 5.9, where one set of simulations is conducted for each of zone 1 and zone 2. Interpretation of simulated profiles of axial resistance, which reflect spatial variability phenomena of the zone-specific data, is provided in Sec. 5.10.

Comparisons are subsequently made between zone-specific simulation results to further emphasize the importance of accounting for distinct geological zones. Considerations for incorporating method error phenomena into the simulated, zone-specific results are detailed

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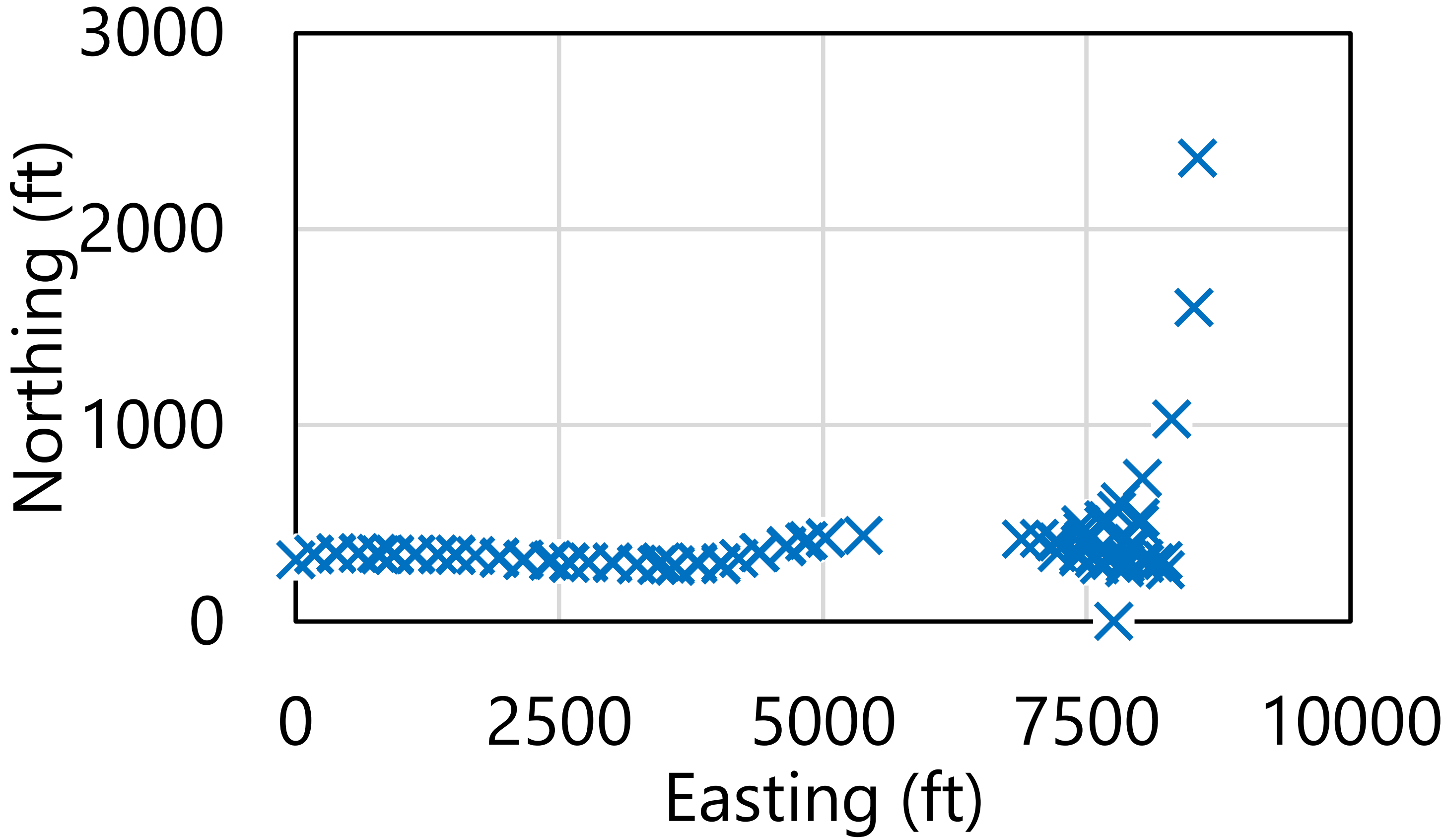
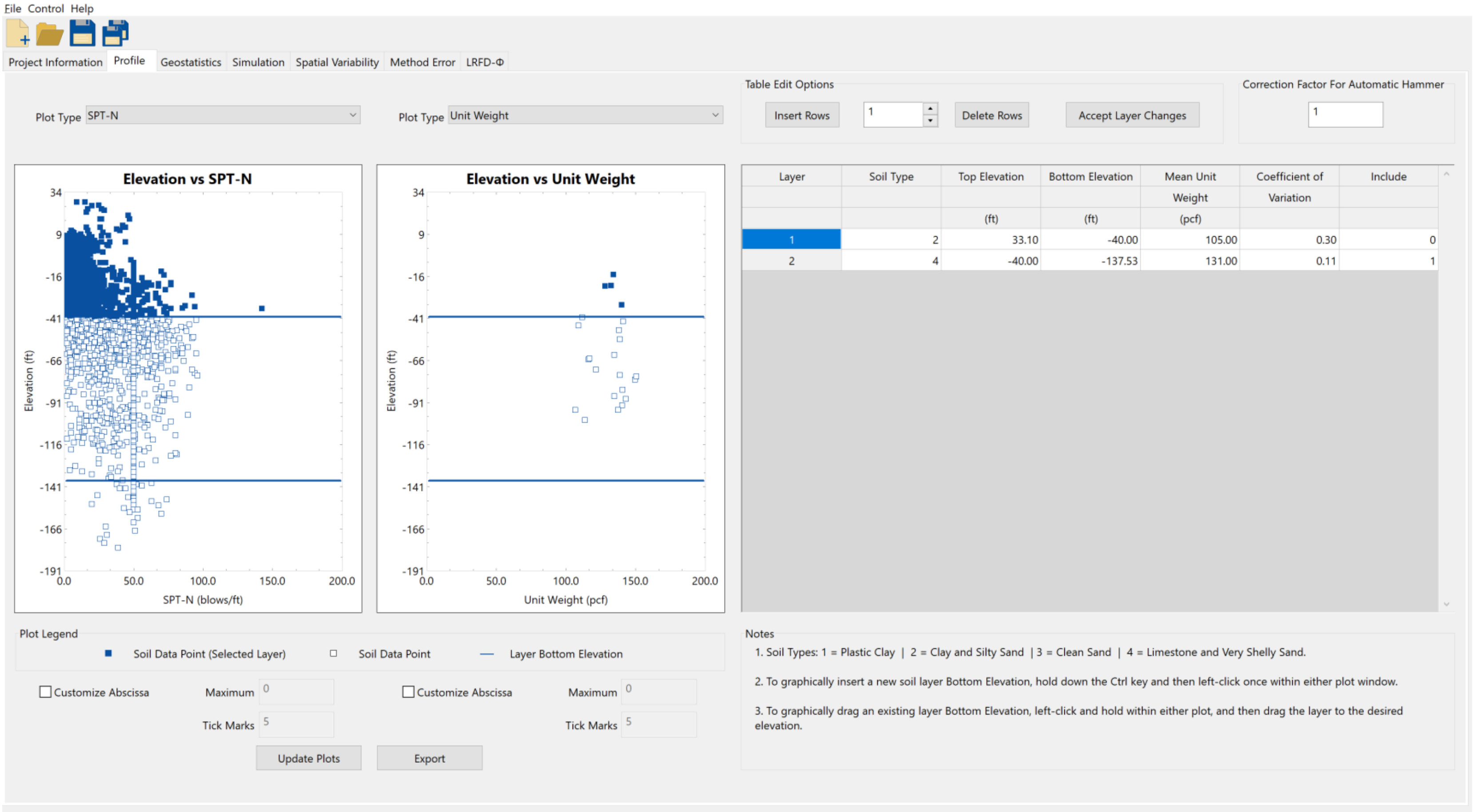
GeoStat technical manual (Ch. 5)

Consider a site with 90 boring locations

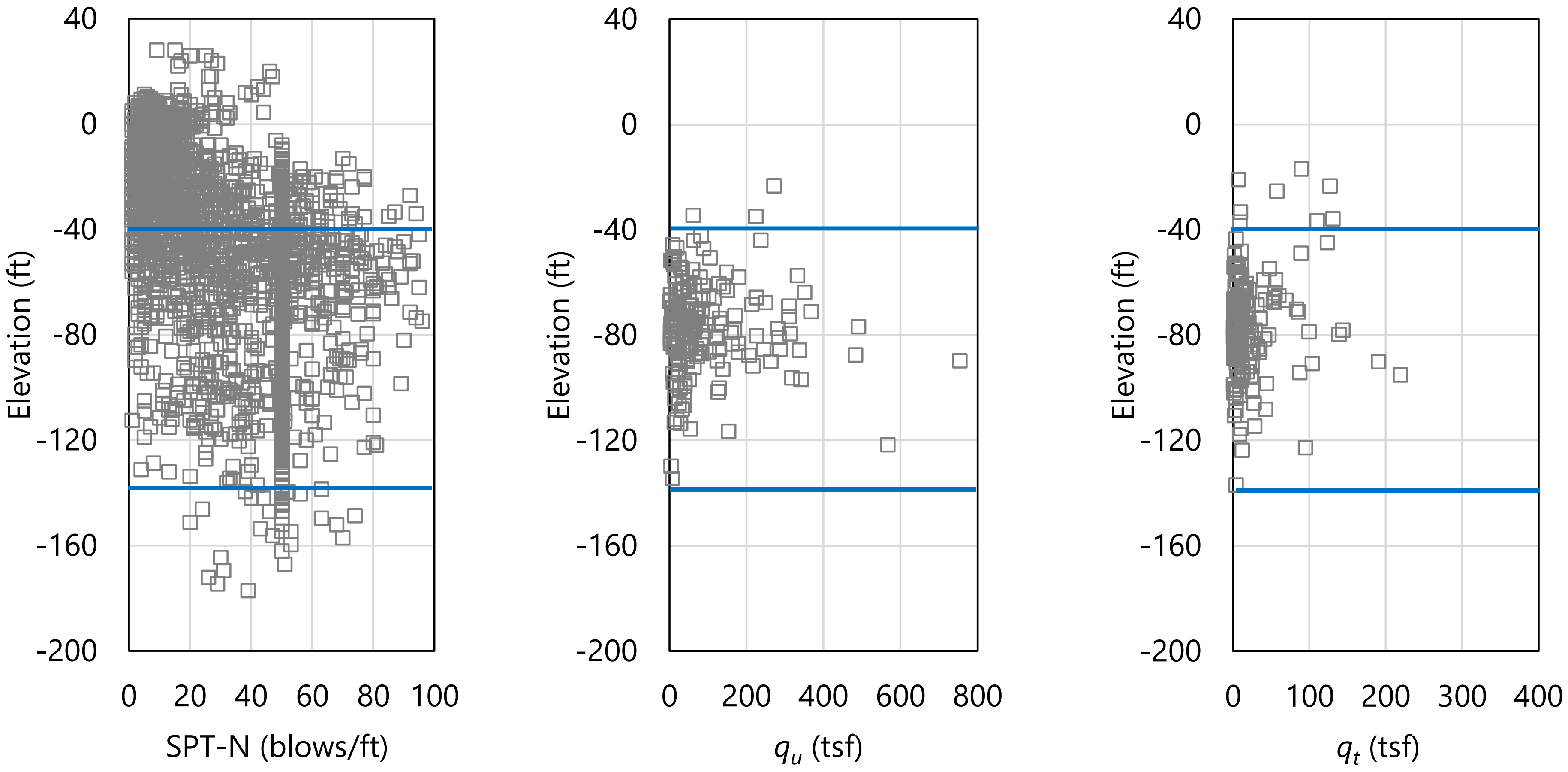


Determine layering

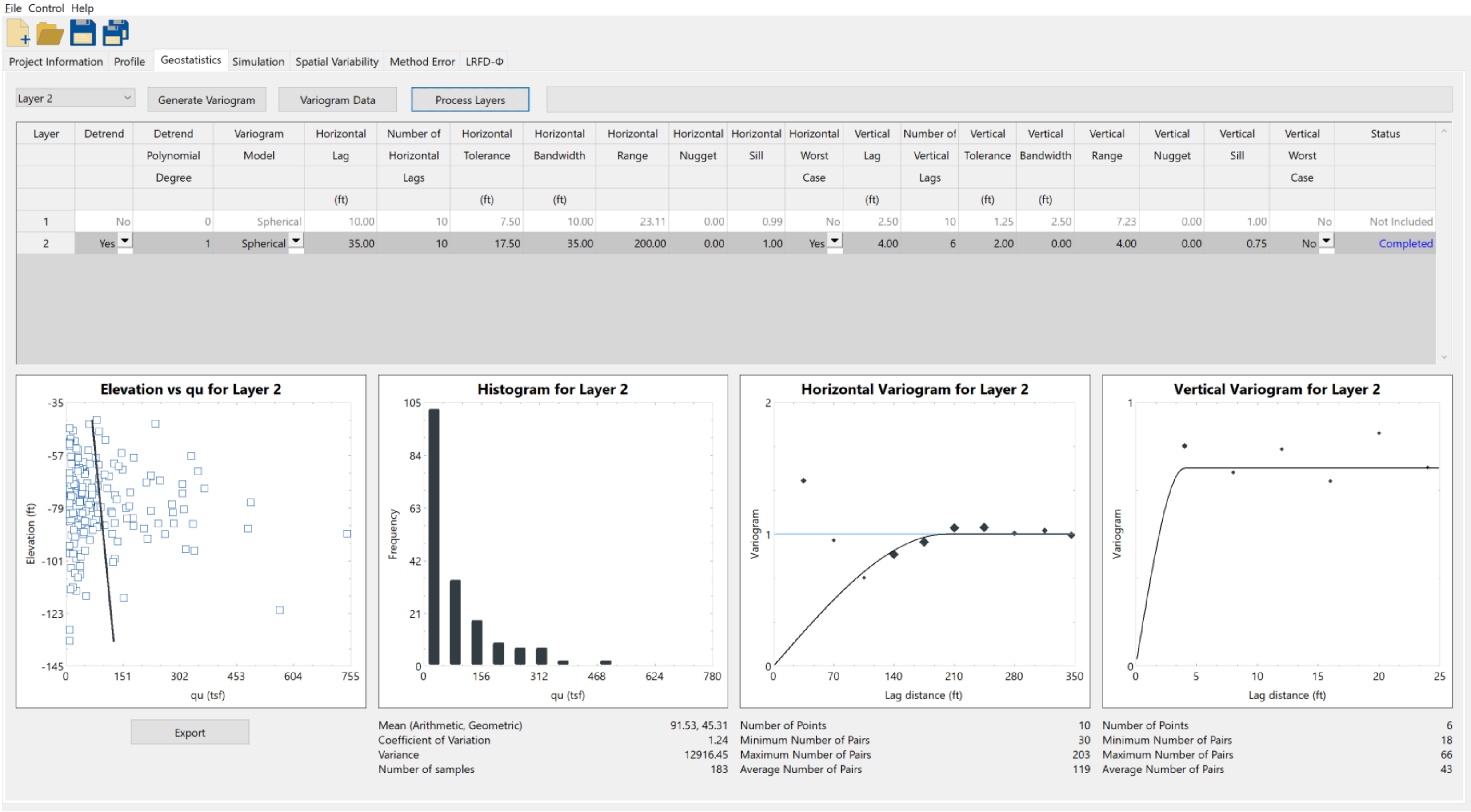


GeoStat – Profile tab

Determine layering



Form horizontal and vertical variograms for each layer



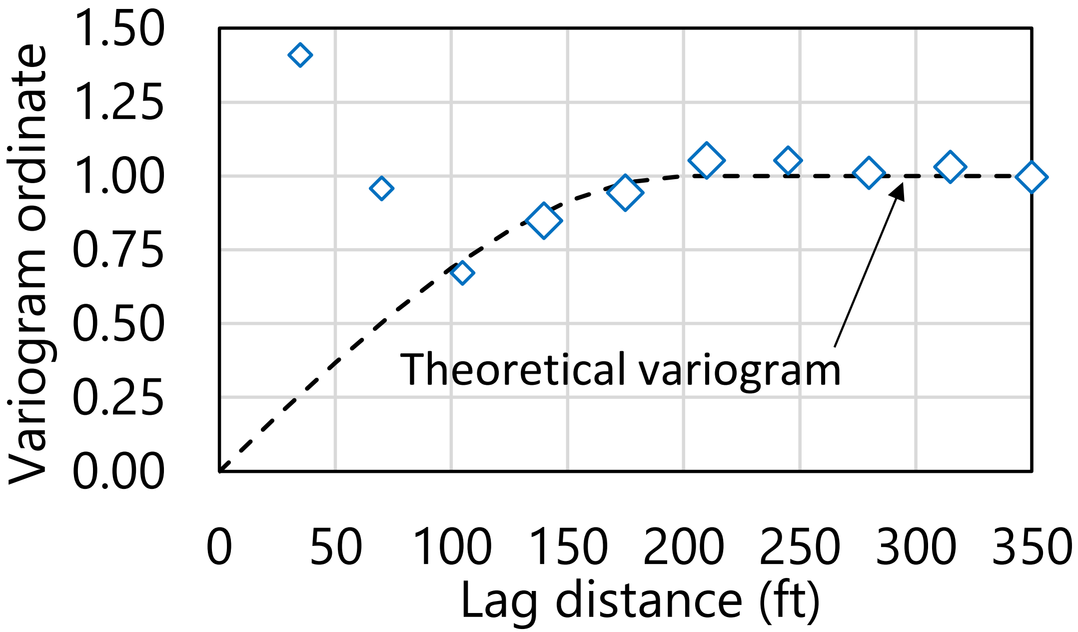
Layer	Detrend	Detrend Polynomial Degree	Variogram Model	Horizontal Lag (ft)	Number of Horizontal Lags	Horizontal Tolerance (ft)	Horizontal Bandwidth (ft)	Horizontal Range	Horizontal Nugget	Horizontal Sill	Horizontal Worst Case	Vertical Lag (ft)	Number of Vertical Lags	Vertical Tolerance (ft)	Vertical Bandwidth (ft)	Vertical Range	Vertical Nugget	Vertical Sill	Vertical Worst Case	Status
1	No	0	Spherical	10.00	10	7.50	10.00	23.11	0.00	0.99	No	2.50	10	1.25	2.50	7.23	0.00	1.00	No	Not Included
2	Yes	1	Spherical	35.00	10	17.50	35.00	200.00	0.00	1.00	Yes	4.00	6	2.00	0.00	4.00	0.00	0.75	No	Completed

GeoStat – Geostatistics tab

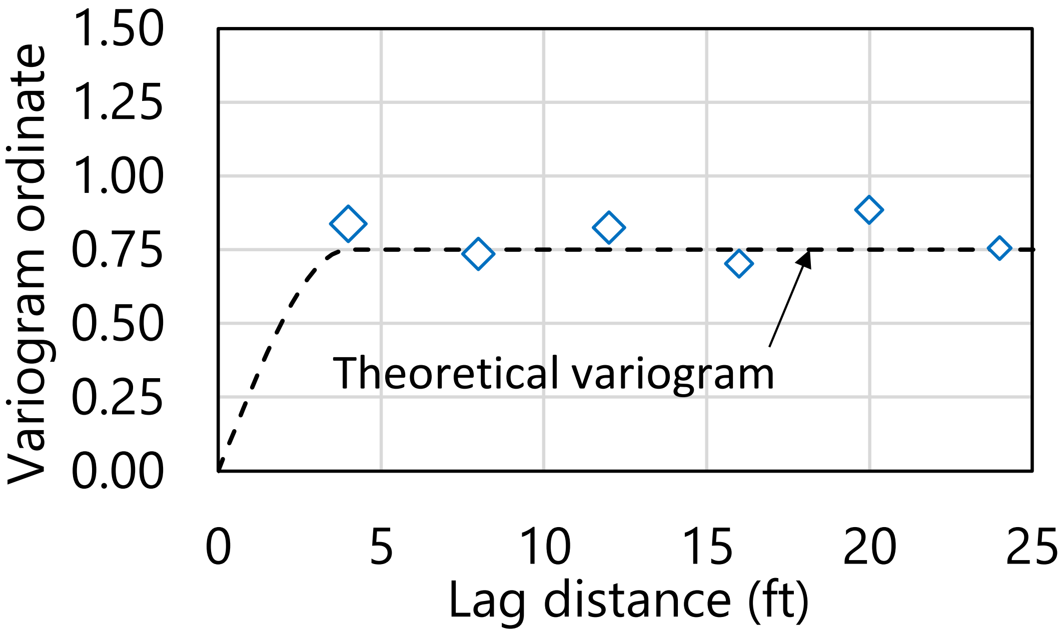
Technical Manual - Chs. 2, 5

Inspect variograms

- Example: layer 2



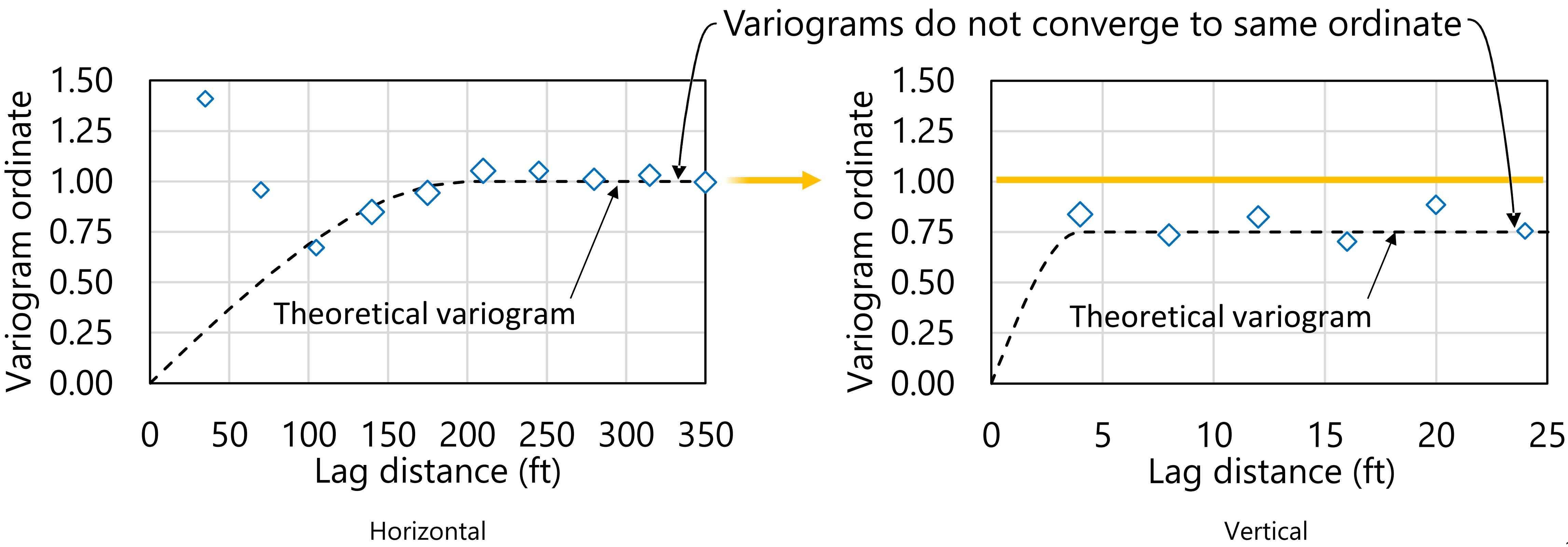
Horizontal



Vertical

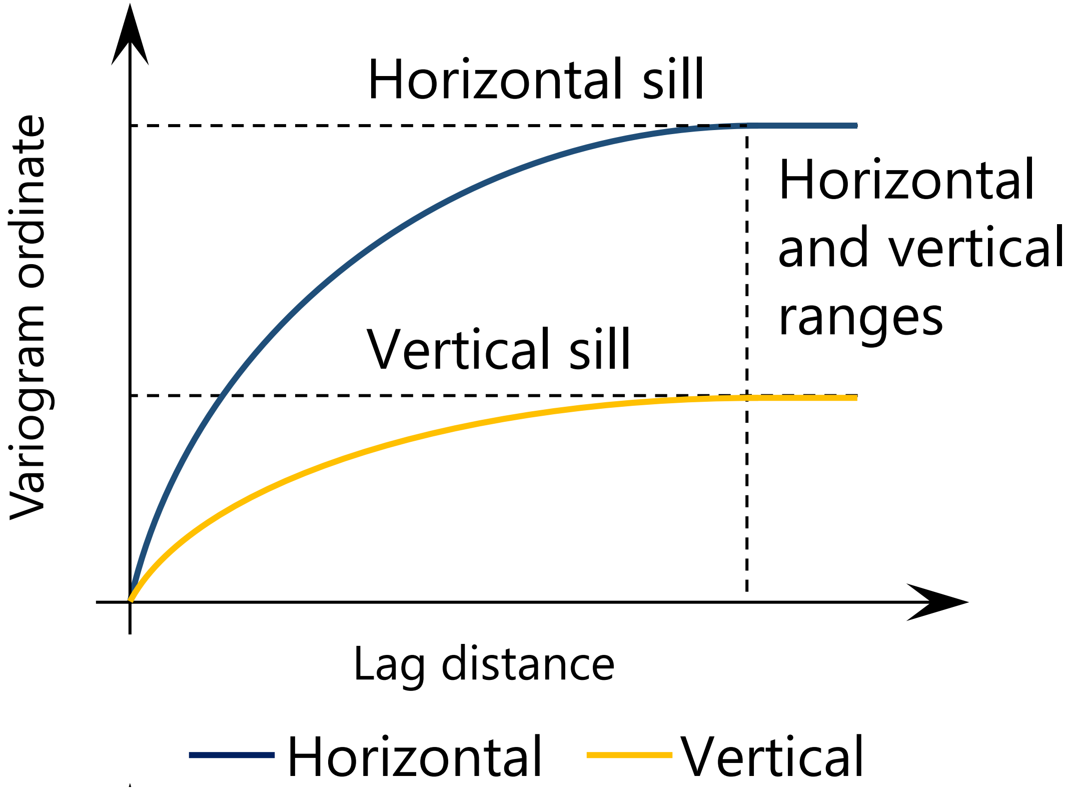
Inspect variograms

- Example: layer 2



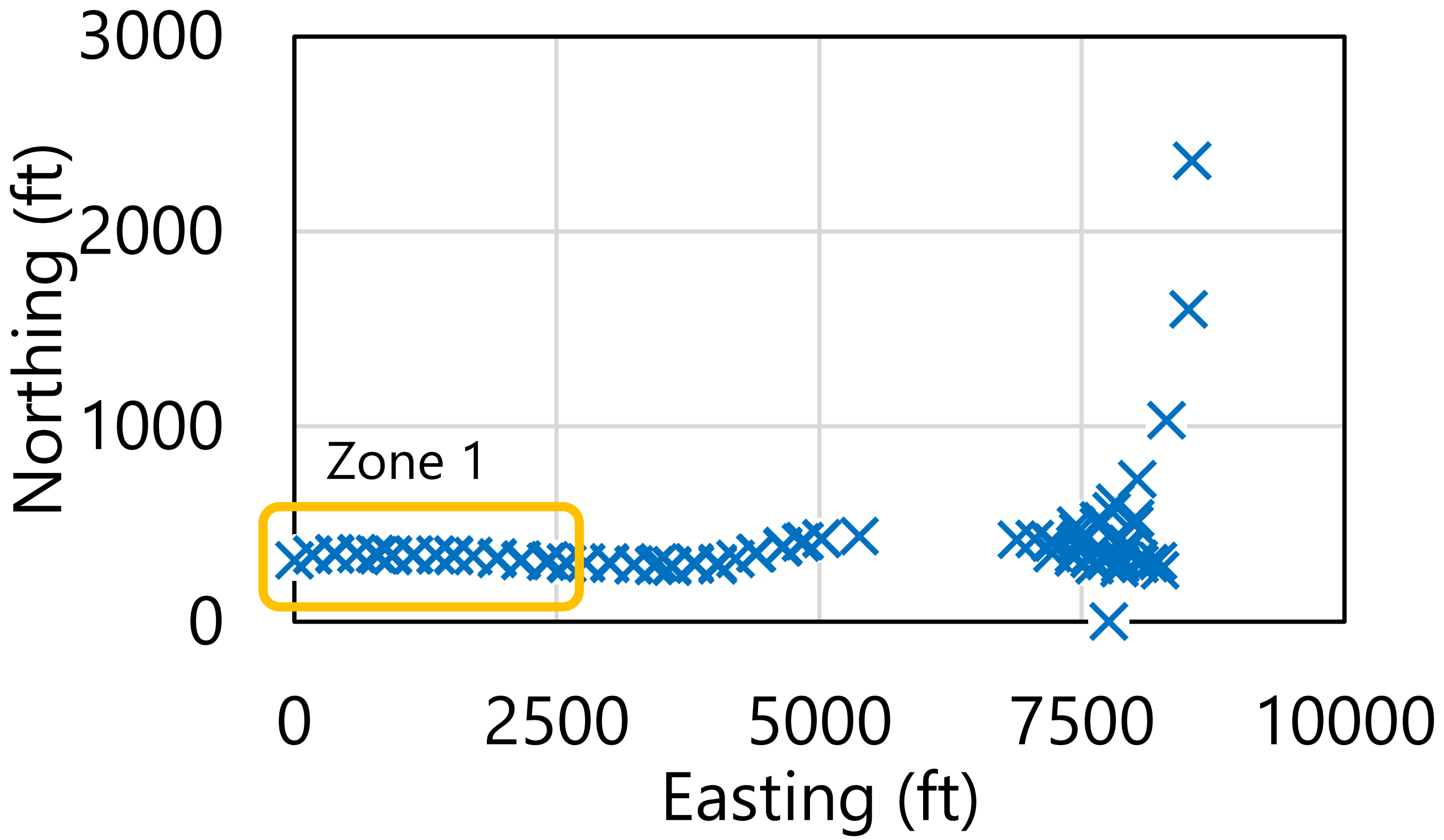
Inspect variograms

- Recall that variograms can reveal geological zones



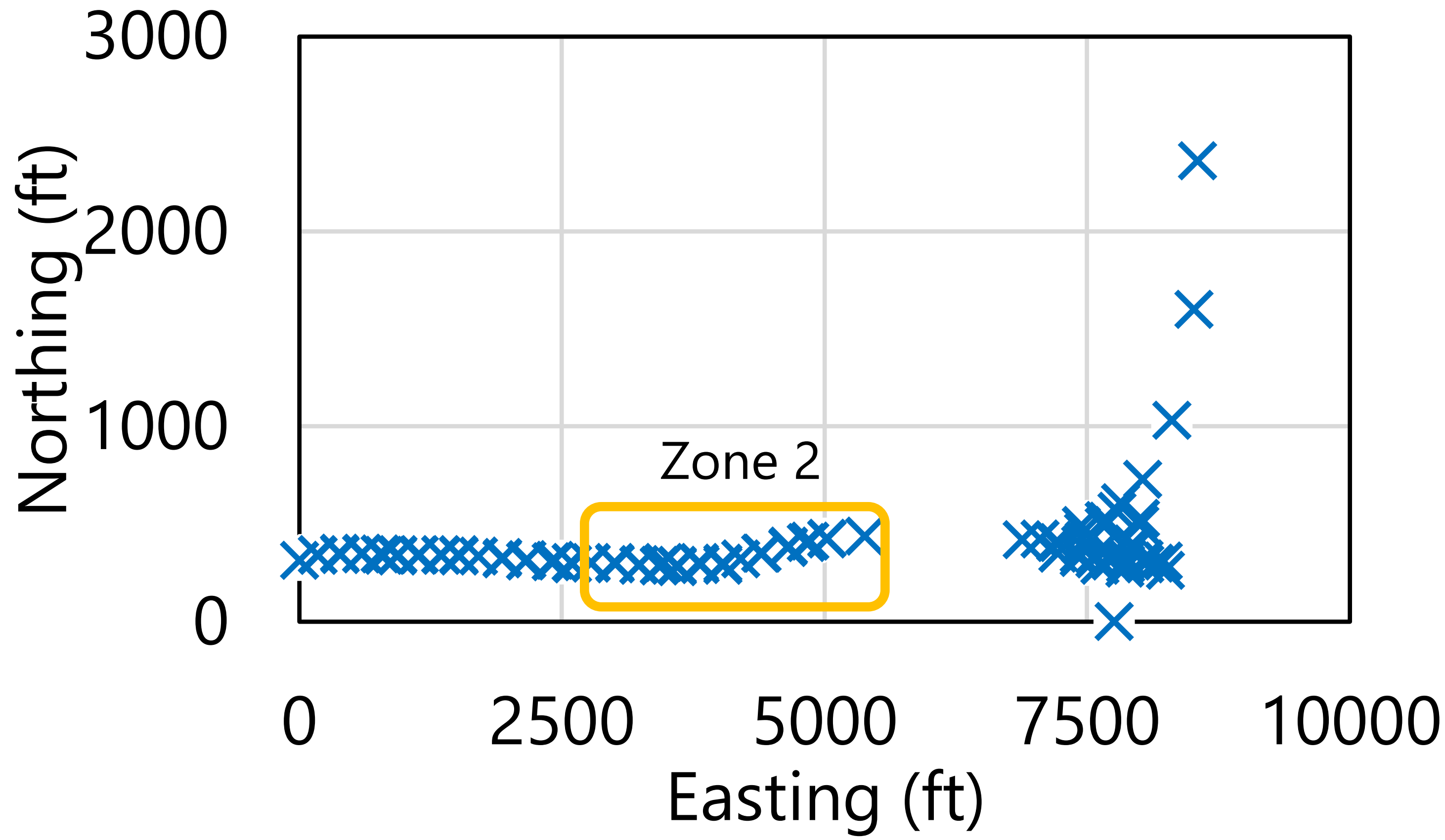
Return to plan view of site and select subsets of borings

- Example: Western "strip" of 25 borings



Return to plan view of site and select subsets of borings

- Example: Eastern "strip" of 23 borings

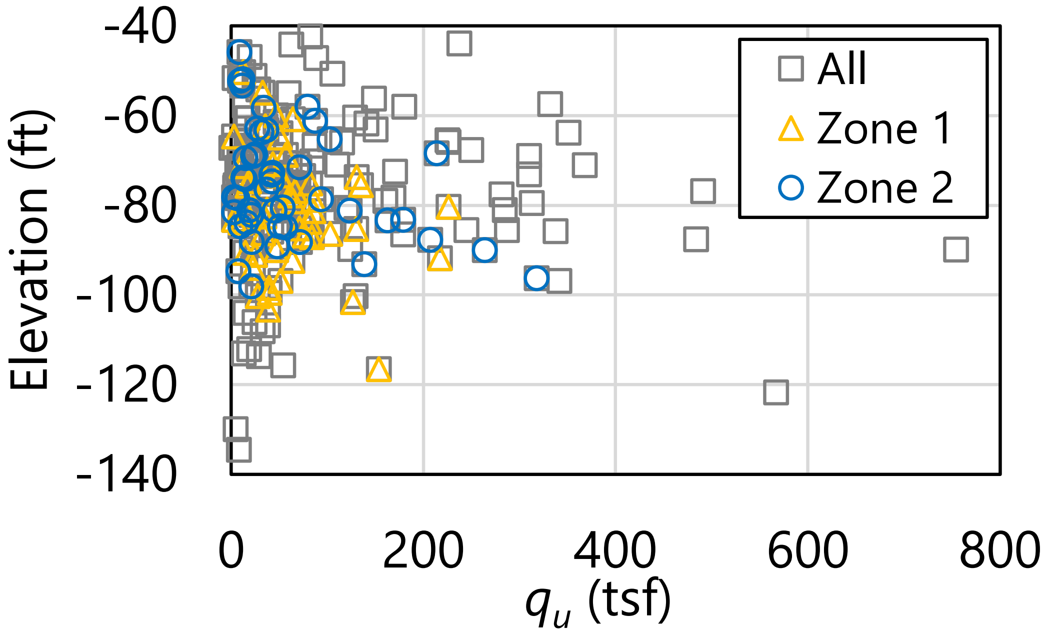


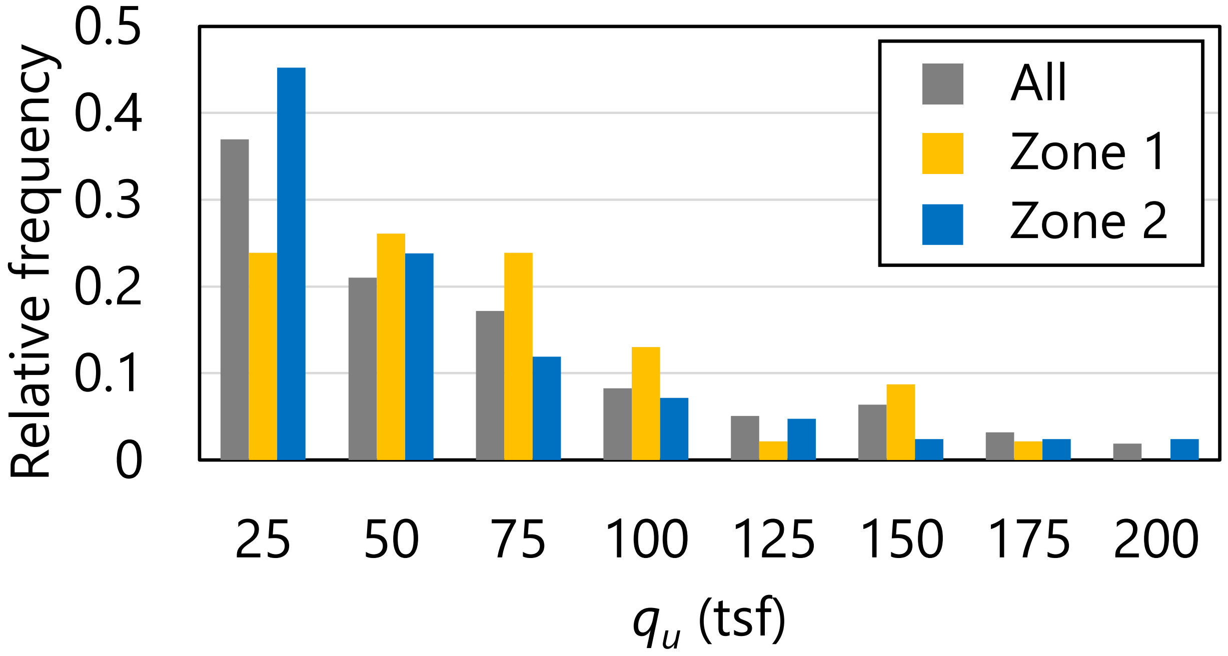
Use geostatistical tool to analyze each zone

- Form (or recheck) layer definitions
- Form variograms
  - Inspect variograms
- Conduct geostatistical simulation
- Incorporate method error
- View elevation profiles of computed axial resistance

Comparison of site-wide vs zonal data

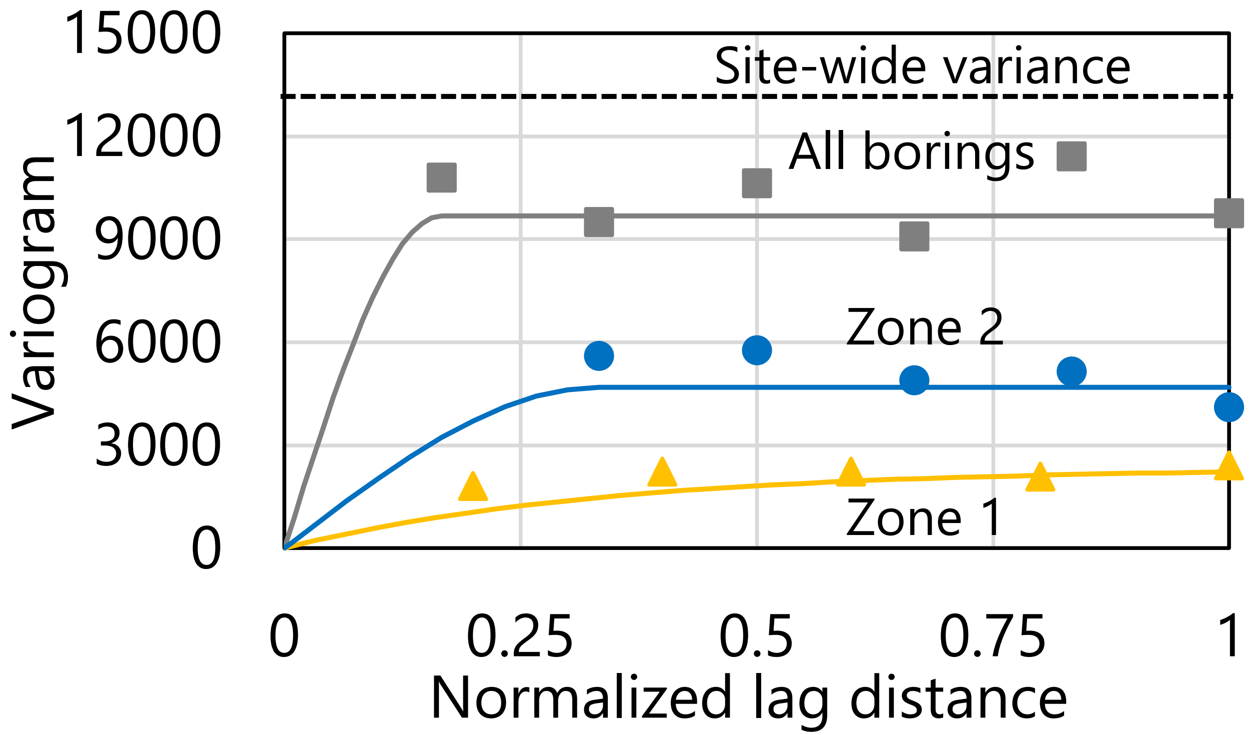
- Example: unconfined compressive strength (q_u) values within layer 2



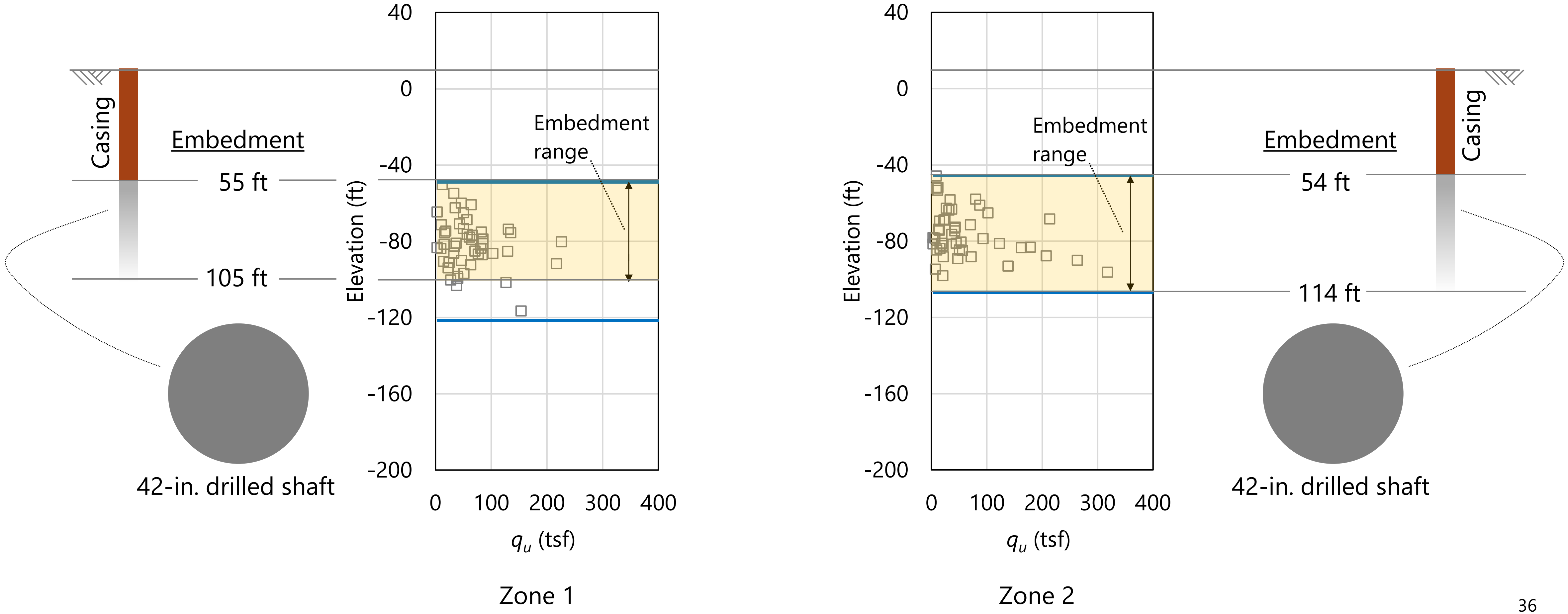


Comparison of site-wide vs zonal variograms

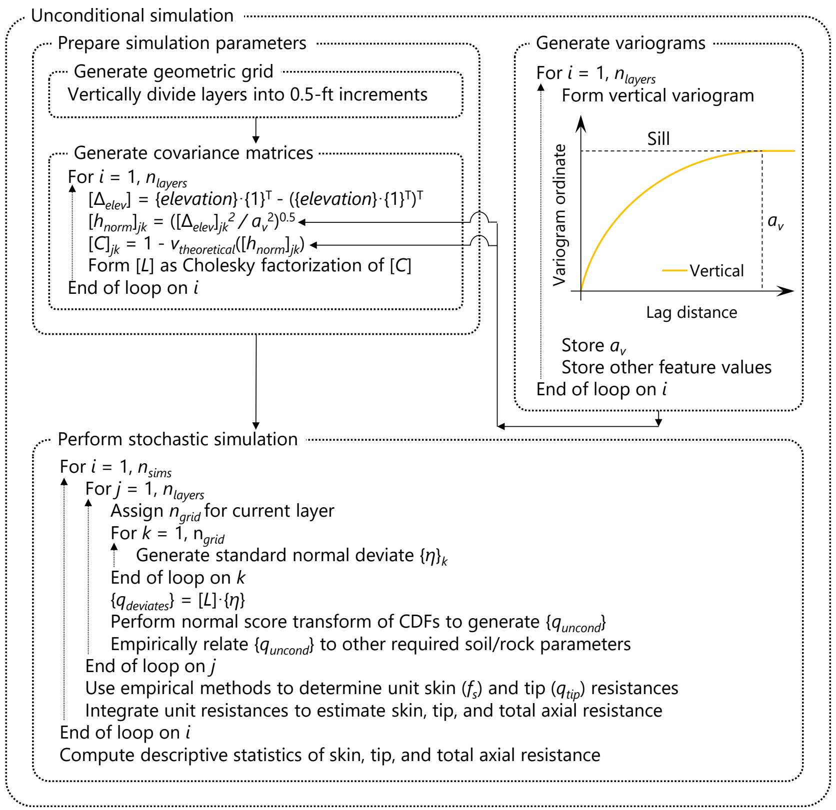
- Example: vertical variograms for layer 2



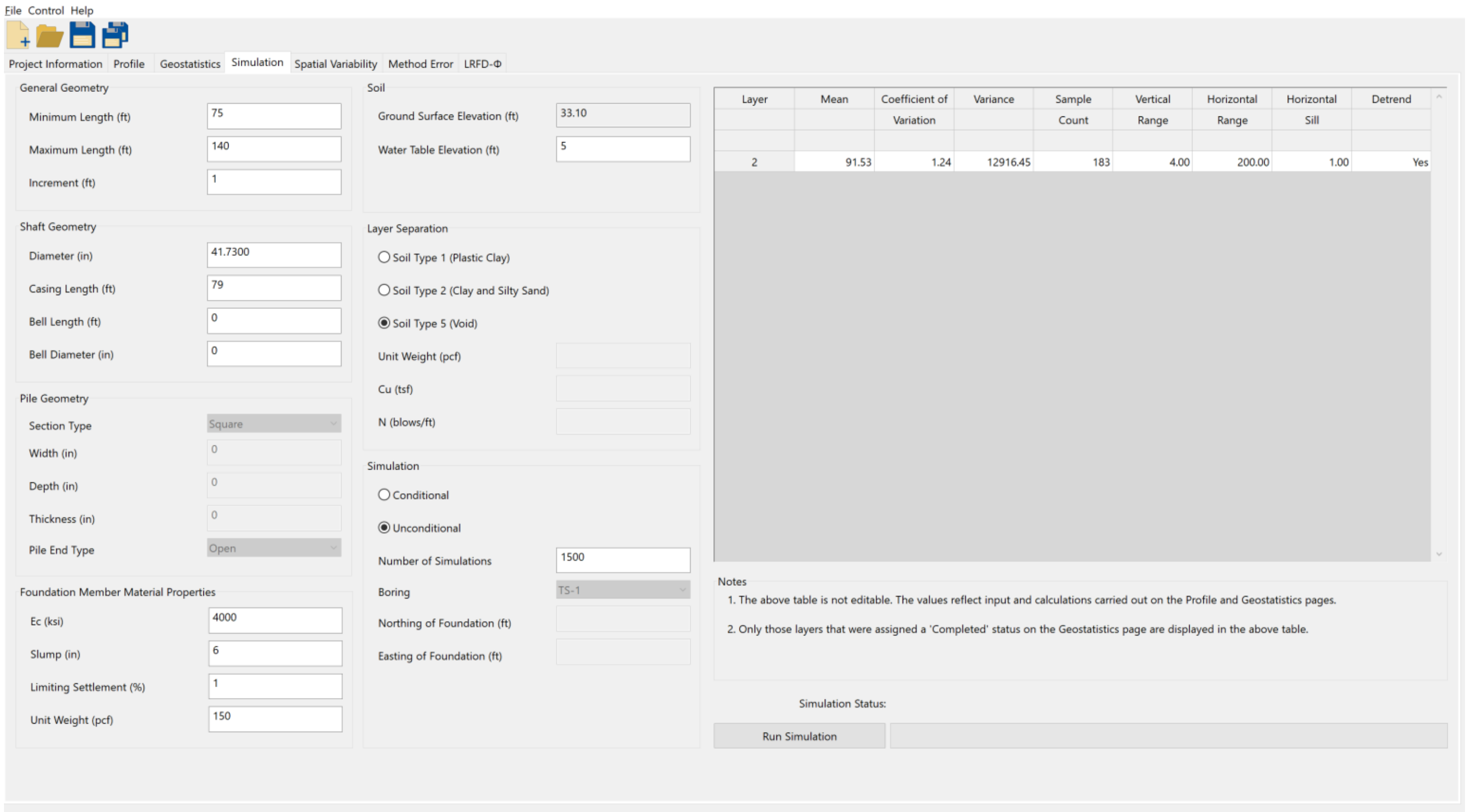
Define drilled shaft diameters and ranges of embedment lengths



Conduct geostatistical simulation for each zone



Simulation algorithm



GeoStat – Simulation tab

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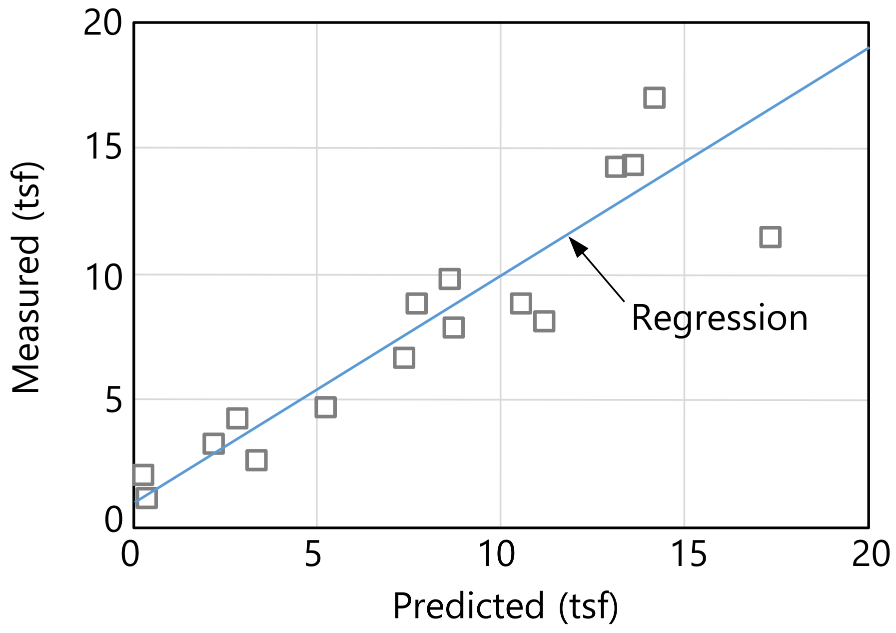
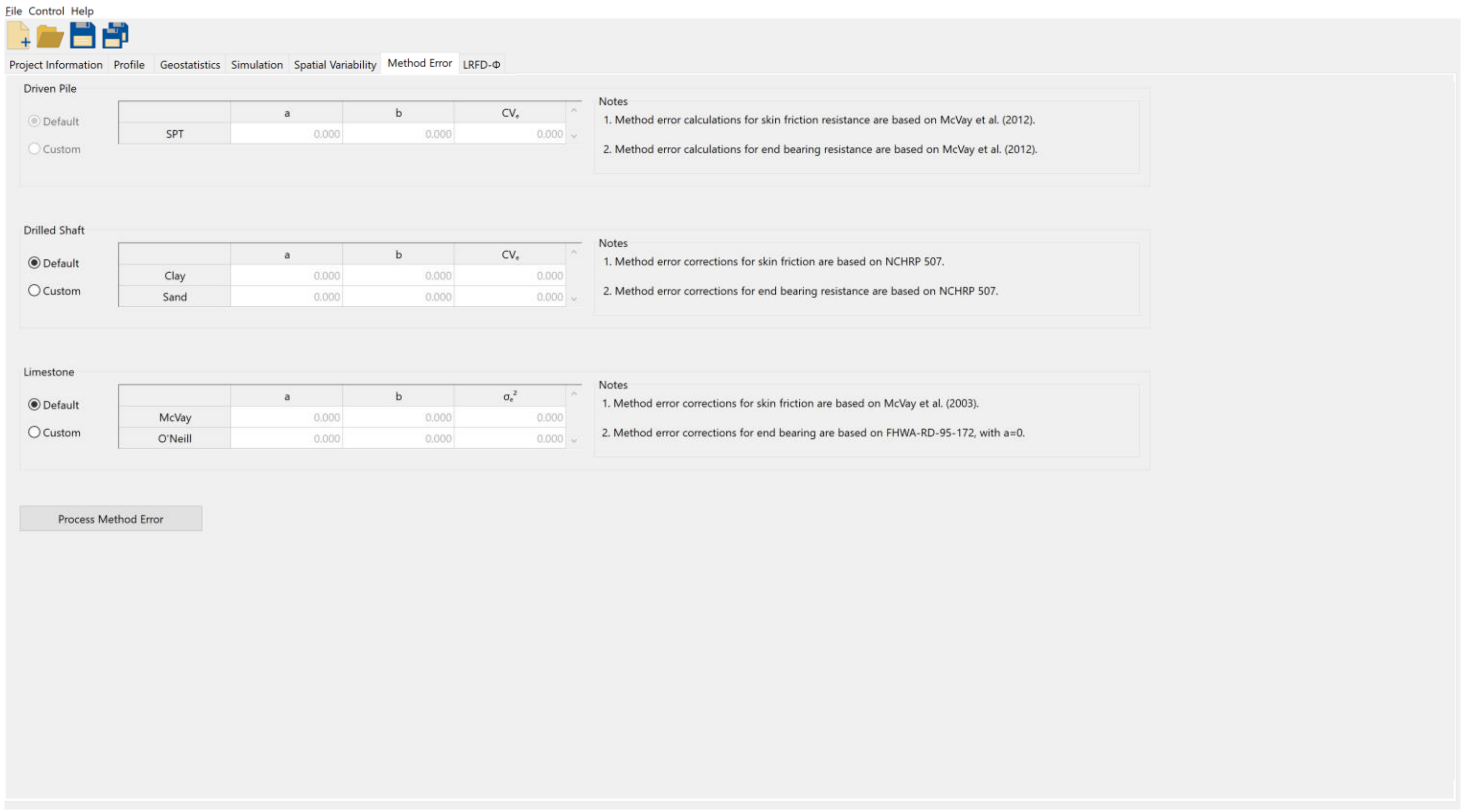
Incorporate method error

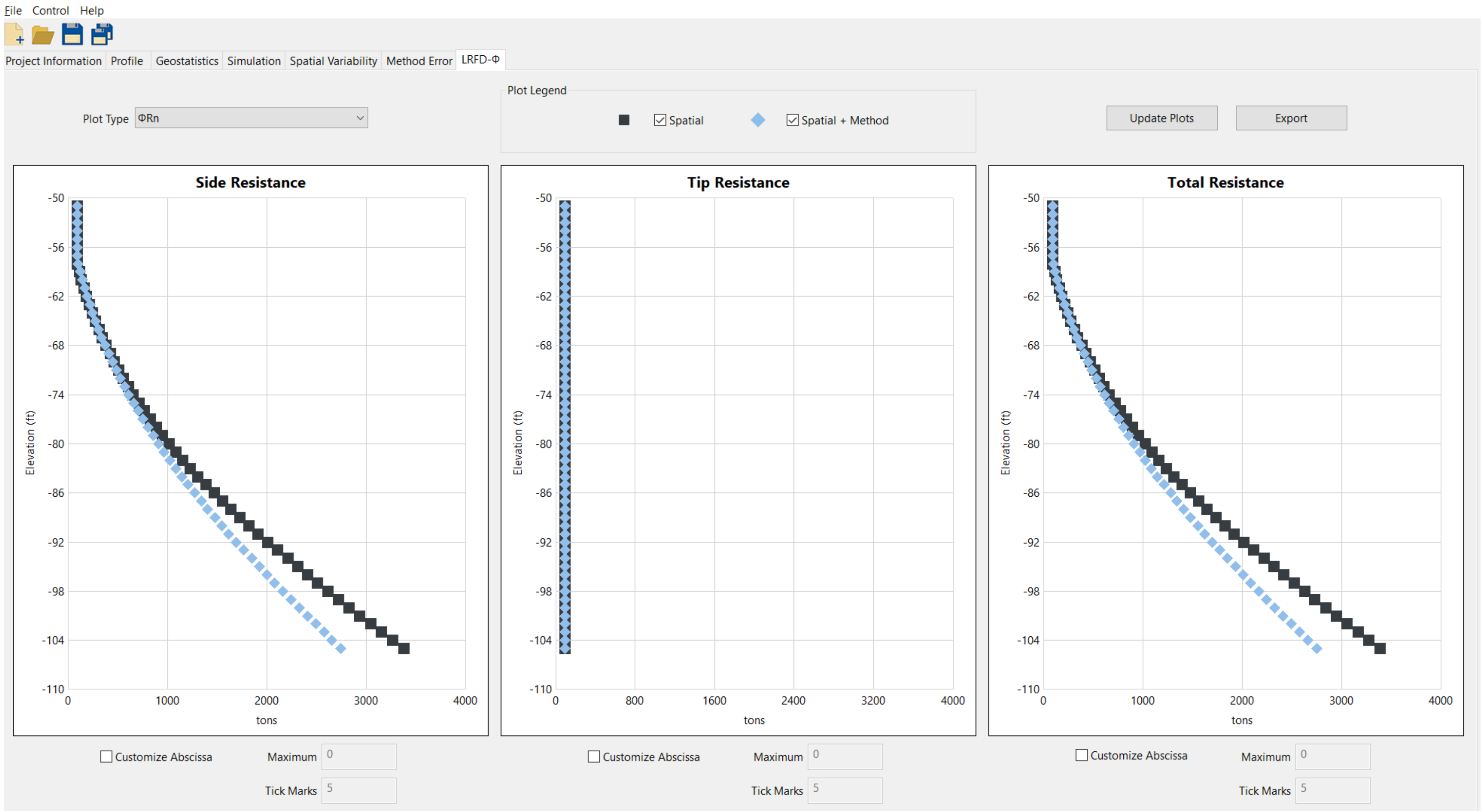


Measured versus predicted side shear resistance for drilled shafts in limestone (McVay et al. 2012)



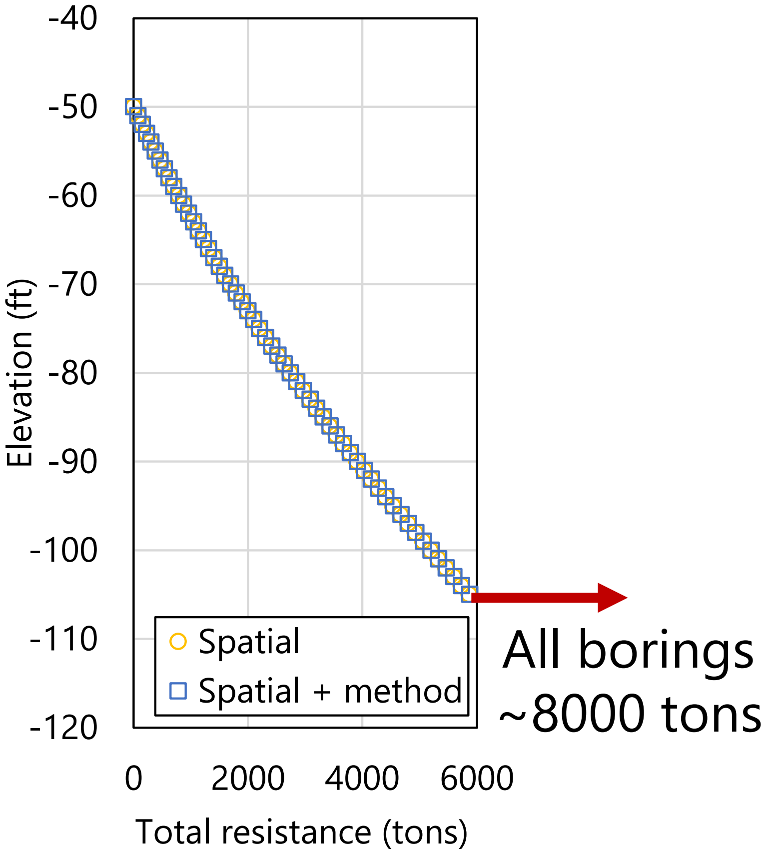
GeoStat – Method Error tab

View elevation profiles of computed results

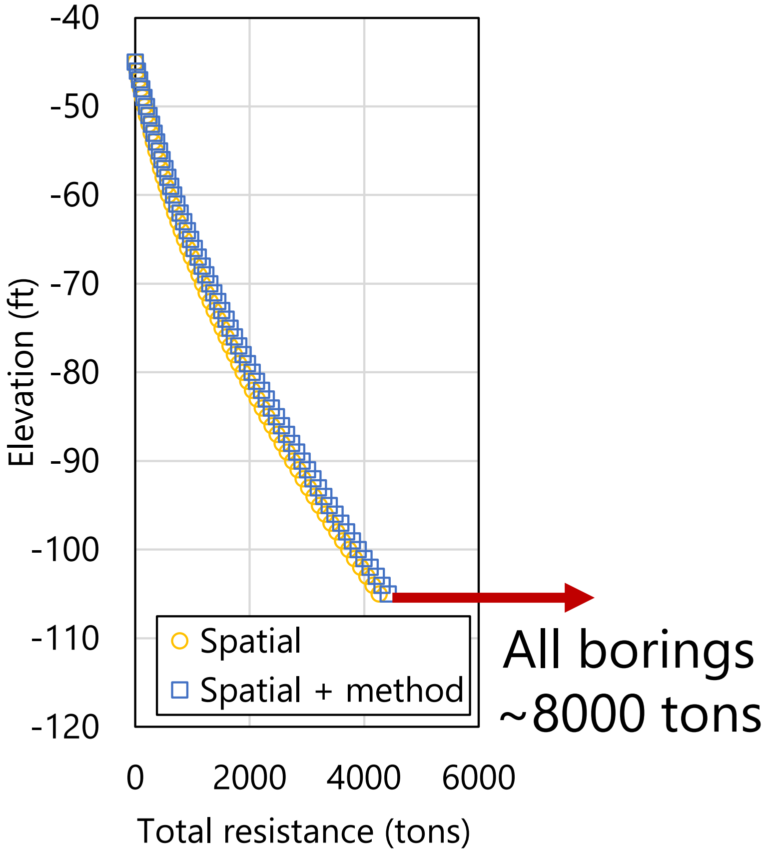


LRFD-ϕ tab for plotting profiles of resistance factors, ϕ, and factored resistances

Computed profiles of unfactored resistance

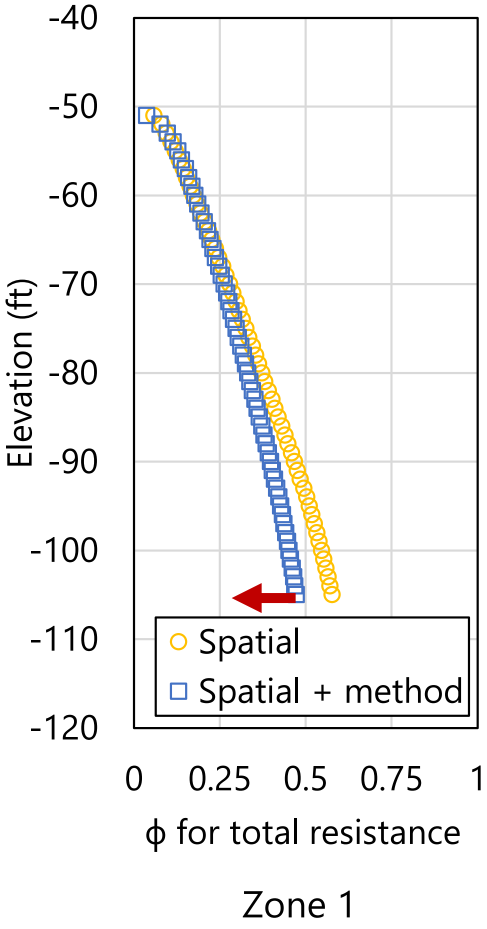


Zone 1

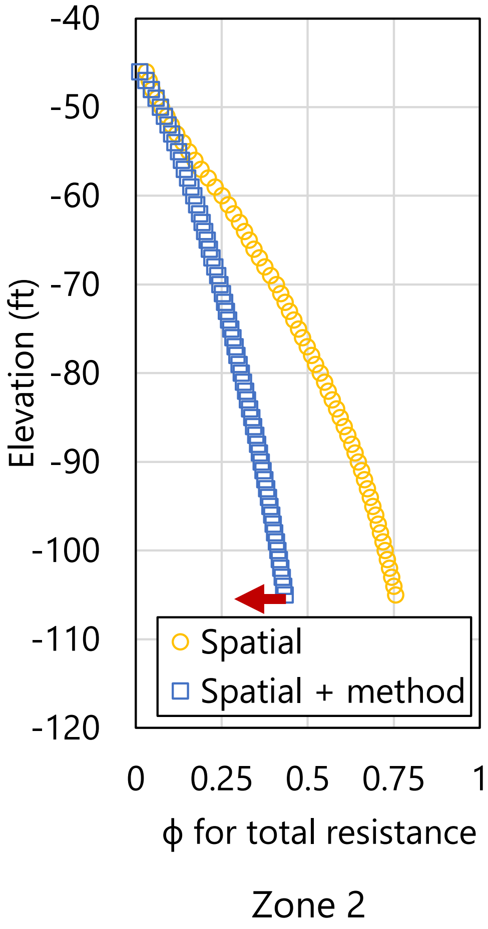


Zone 2

Computed profiles of resistance factor, ϕ

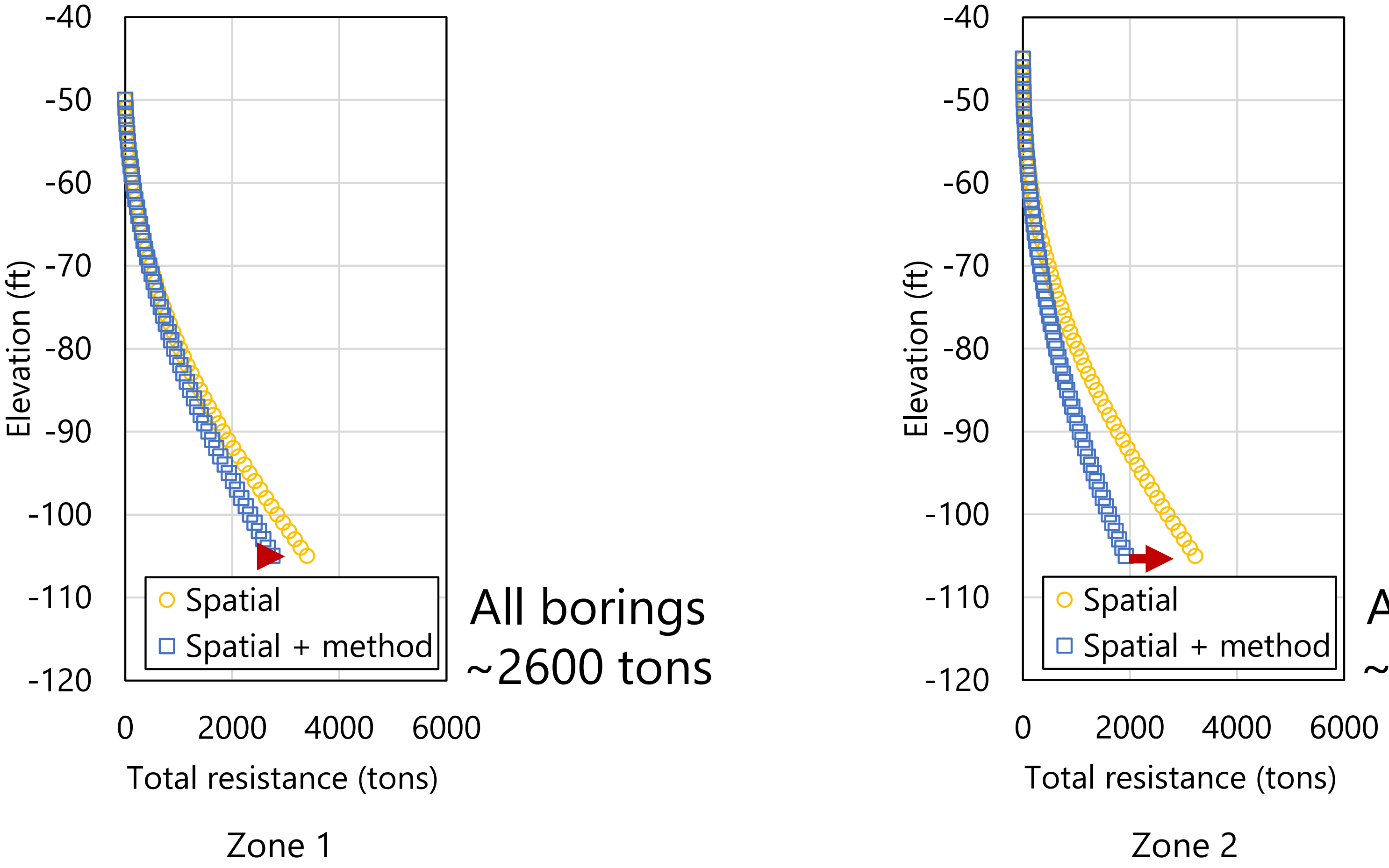


All borings
~0.3



All borings
~0.3

Computed profiles of factored resistance



All borings
~2600 tons

All borings
~2600 tons

Outline

- Introduction
- Characterization of spatial variability
- Illustration case
- Summary

Summary

- Spatial variability is intrinsic to site data
- Method error is present in empirical approaches
- Geostatistical design tool has been developed to directly address spatial variability and method error
  - Can be used to compute axial resistance
    - Driven piles
    - Drilled Shafts

Summary

- Benefits of using geostatistical design tool
  - Gauge sufficiency of available geotechnical site investigation data
  - More representative layer definitions
  - Prevent mixing data from different geological zones in axial resistance calculations
  - Compute axial resistance and associated variability/uncertainty
  - Calculate location-specific resistance factors (use must be approved by Owner)
- Additional types of site measurements in development
  - CPT
  - Measuring while drilling (MWD) for drilled shafts in limestone

Thank you

Bridge Software Institute

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