Relaxation of Driven Piles in Florida Soils

BED25-977-05

GRIP 2024

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Background/Introduction

- Driven piles can exhibit an increase or decrease in capacity relative to end of drive conditions defined as *set-up* or *relaxation*, respectively.
- Set-up is beneficial to pile performance; relaxation is not.
- The mechanism of pile relaxation has been attributed to dilative soil conditions that cause negative pore pressure making the soils respond stronger during driving (until the pore pressure dissipates).

Pile Relaxation

- Case studies have shown restrikes have regained capacity in as little as 0.5in or as much as 7 ft.
- Large displacement required to regain capacity is likely to be caused by negative pore pressure
- Small displacements required to regain capacity could be due to concrete creep/shortening

- Creation of a database to include all information from PDA EOID and Restrikes is the primary effort (Task 2)

Problem Statement

Relaxation is the reduction in pile capacity with time. It is a phenomenon that has been observed in several projects, especially Design Build projects as a result of verification testing. There have been reported cases in which over ***25% of the original measured capacity has been lost*** *after initial pile driving. Currently the Department* ***does not have a methodology*** *to assist designers estimate relaxation (protocols for In-Situ testing or laboratory testing), nor a process to establish a pile driving criteria to accept piles during construction when relaxation occurs.* ***This creates delays, extra testing and extra costs*** *during construction, especially because the problem is typically found after pile driving begins. In most cases the issue has been resolved by additional driving until the piles reach a stable bearing layer.*

Objectives

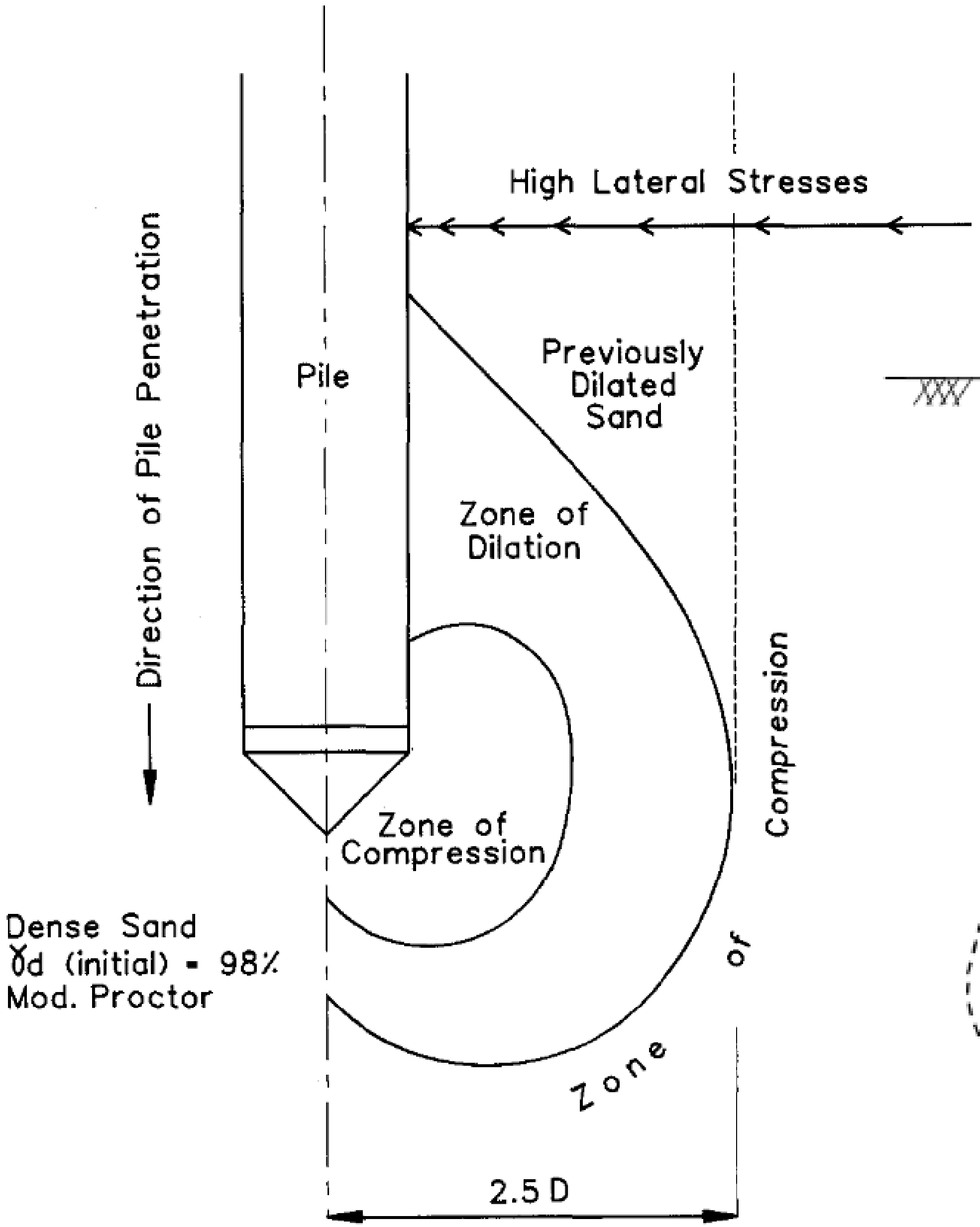
- The primary focus of this study is to document as many cases as possible from within the state of Florida where pile relaxation has been experienced.
- Determine what soil types and conditions are likely to create relaxation conditions
- Part 2?: to determining appropriate field and lab testing and/or protocols suitable for construction and design.

Revised Approach

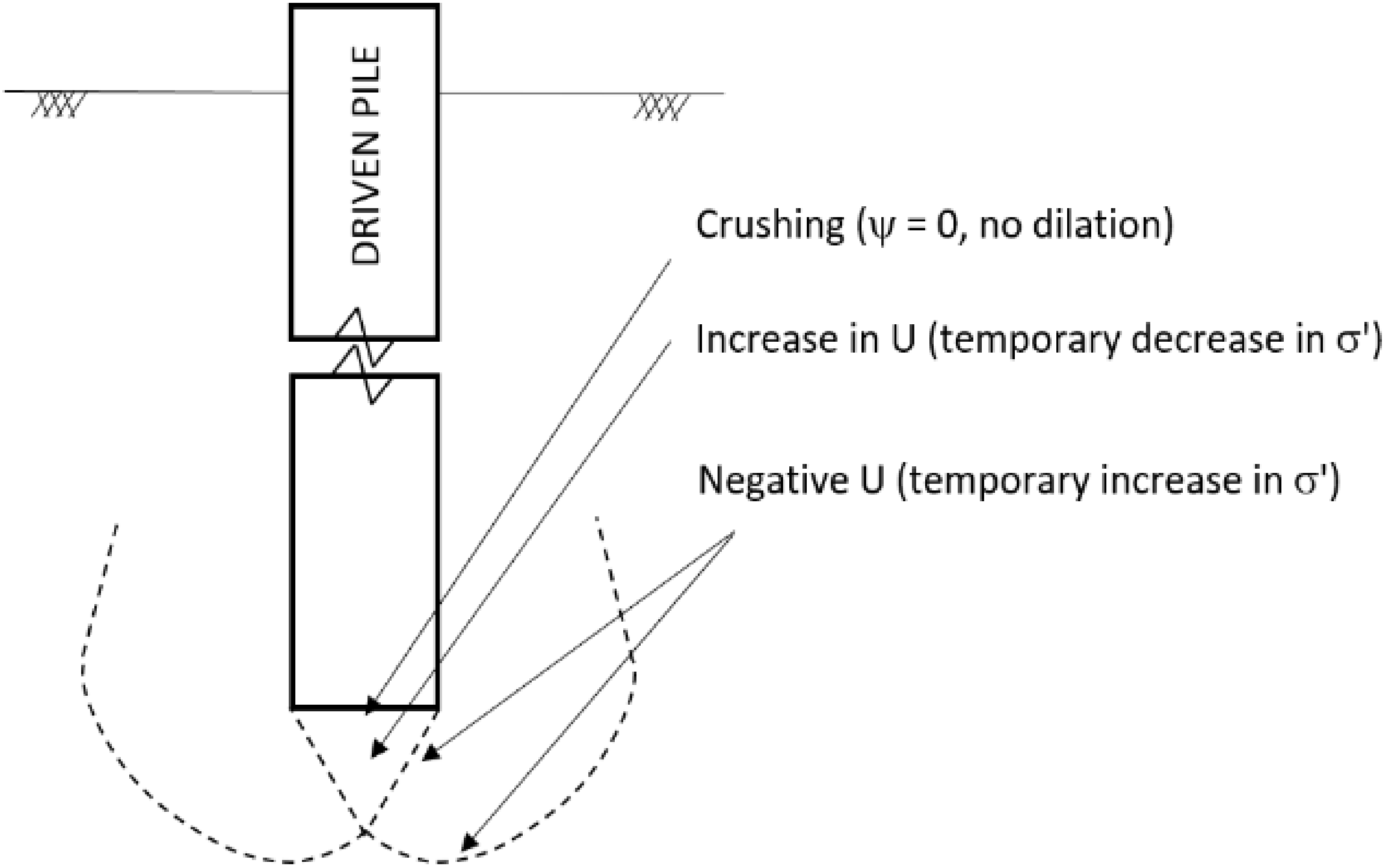
- Collect any restrike data sets to show where both set-up and relaxation might occur

Work Tasks

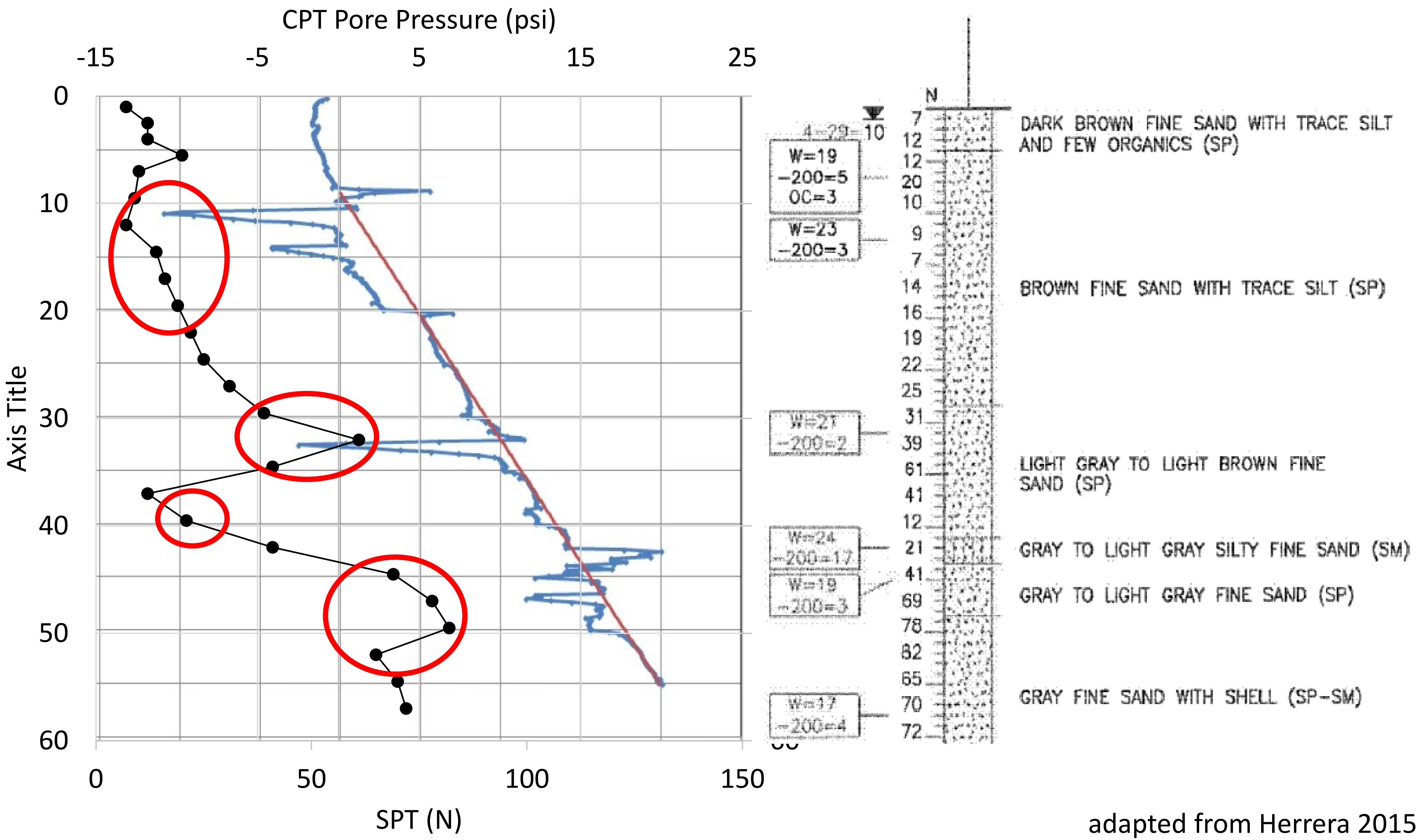
- Task 1: Literature Search
- Task 2: Data Collection
- Task 3: Data Analysis
- Task 4a: Draft Final Report
- Task 4b: Closeout Meeting / Presentation
- Task 5: Final Report



York et al. 1994



Herrera et al. 2018



adapted from Herrera 2015

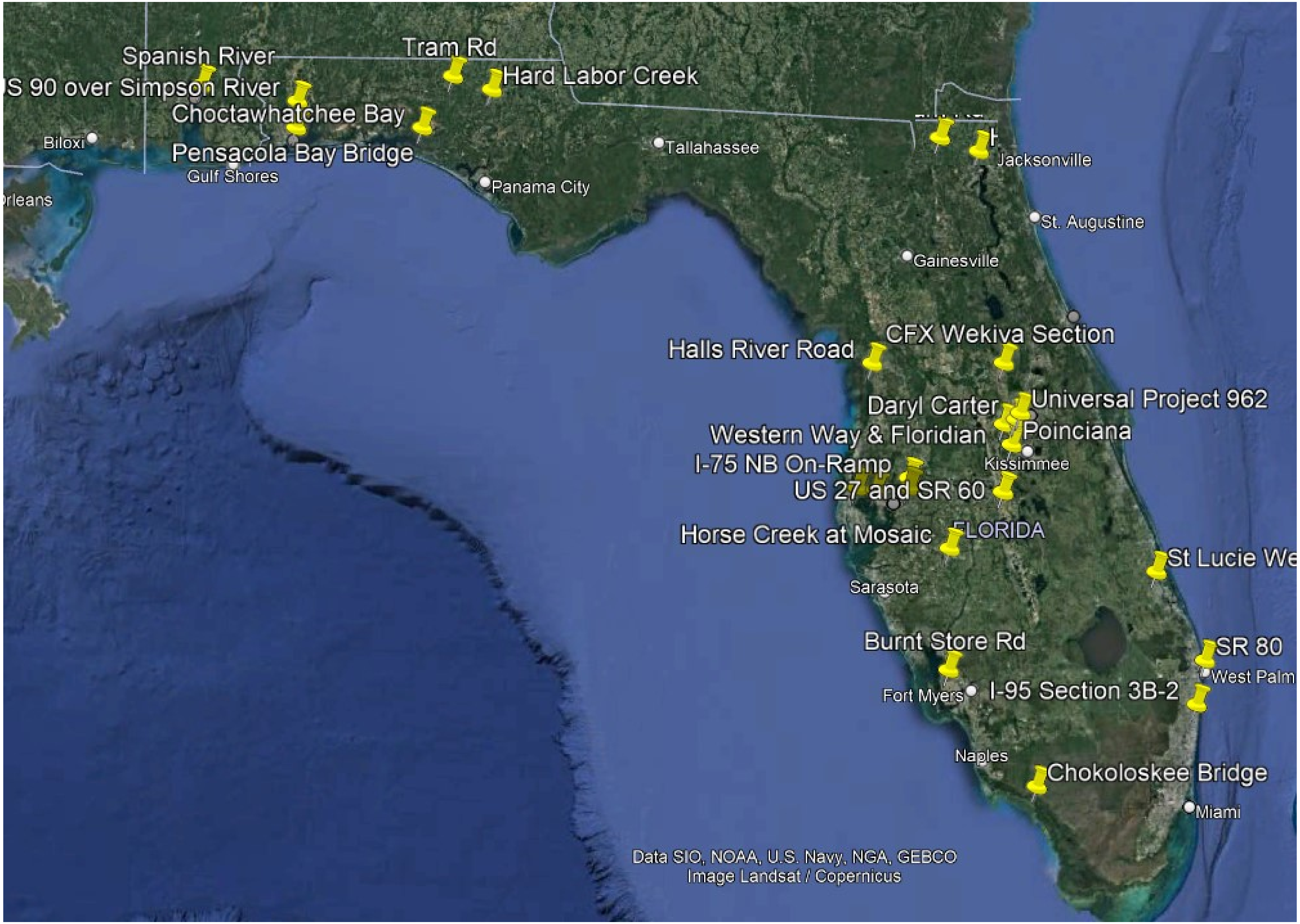
Granular Materials		
Relative Density	**Safety Hammer SPT N-Value (Blow/Foot)**	**Automatic Hammer SPT N-Value (Blow/Foot)**
Very Loose	Less than 4	Less than 3
Loose	4 – 10	3 – 8
Medium Dense	10 – 30	8 – 24
Dense	30 – 50	24 – 40
Very Dense	Greater than 50	Greater than 40

May dilate during pile driving

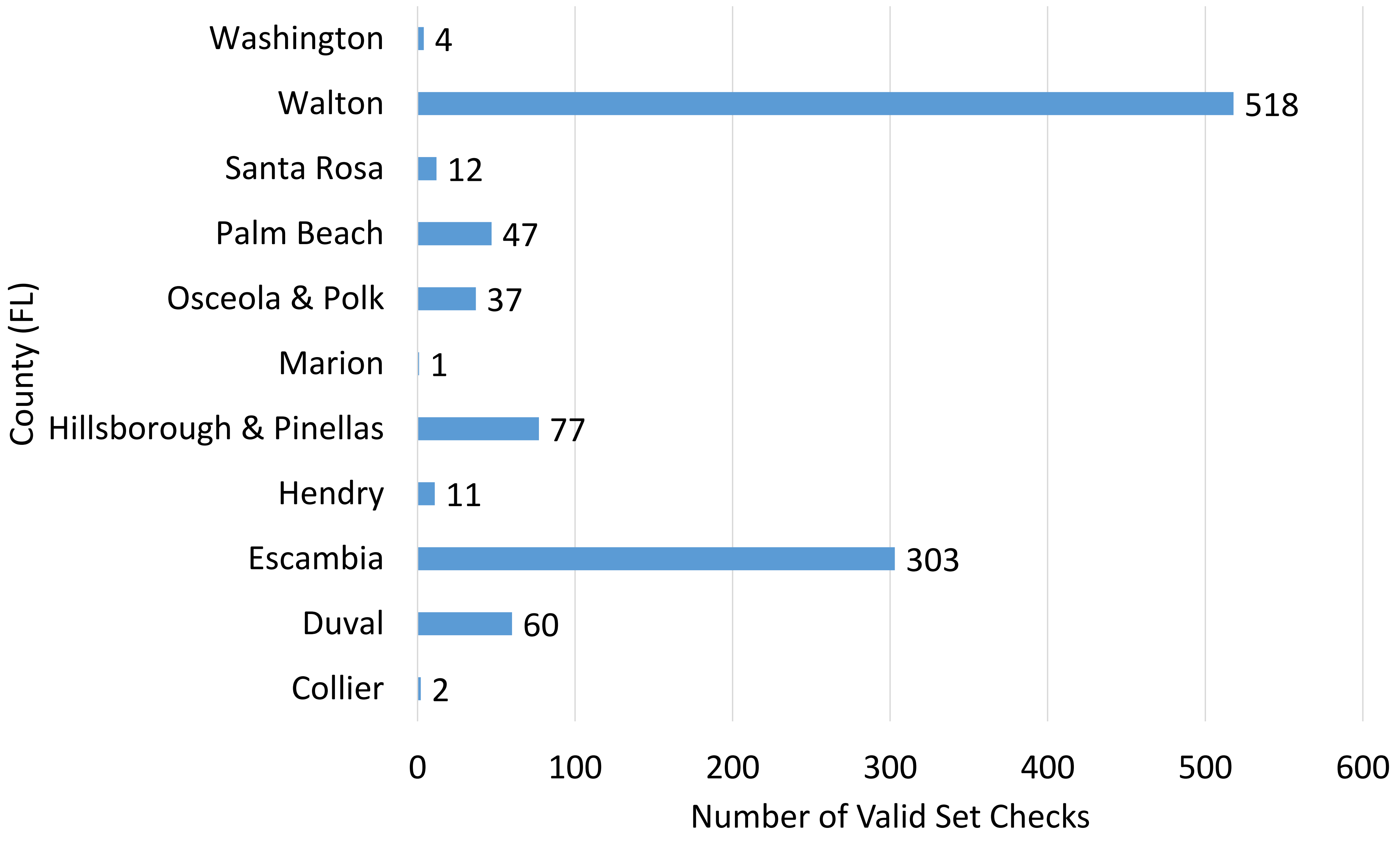
Herrera 2015

Task 2 Data Collection

- ~10,000 files review from ~6,000 piles
  - Plan sets
  - Boring logs
  - Driving logs
  - PDA reports
- Found 1111 set checks on 948 piles (EOID and Restrikes)
- 185 boring logs (some piles have same boring)
- 23 bridge sites throughout the state
- 13 counties
- 6 districts



Spanish River
Tram Rd
Hard Labor Creek
JS 90 over Simpson River
Choctawhatchee Bay
Biloxi
Pensacola Bay Bridge
Gulf Shores
Tallahassee
Jacksonville
Panama City
rleans
St. Augustine
Gainesville
CFX Wekiva Section
Halls River Road
Daryl Carter
Universal Project 962
Western Way & Floridian
Poinciana
Kissimmee
I-75 NB On-Ramp
US 27 and SR 60
Horse Creek at Mosaic
FLORIDA
St Lucie We
Sarasota
Burnt Store Rd
SR 80
West Palm
Fort Myers
I-95 Section 3B-2
Naples
Chokoloskee Bridge
Miami
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus

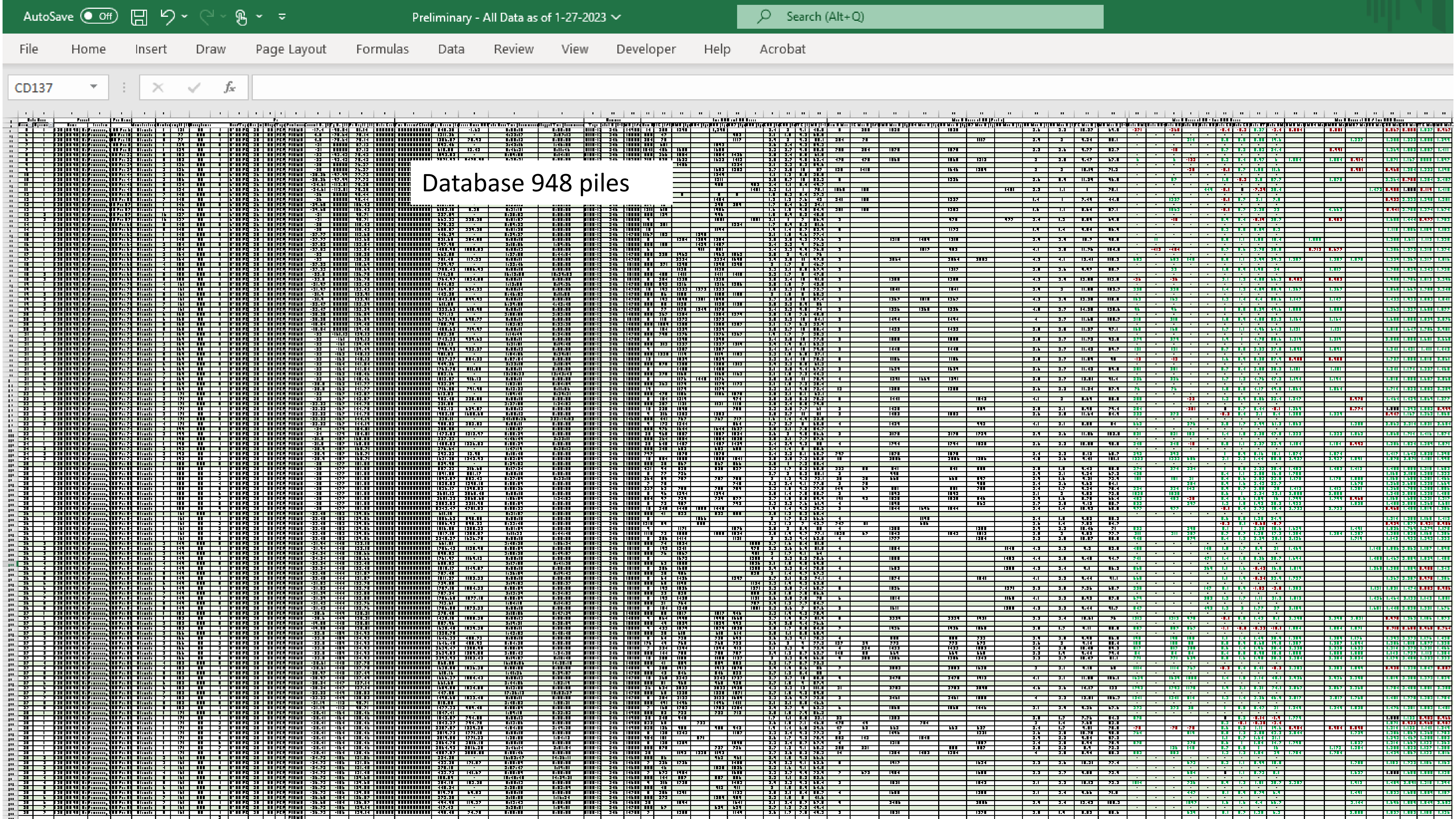

County (FL)
Washington
Walton
Santa Rosa
Palm Beach
Osceola & Polk
Marion
Hillsborough & Pinellas
Hendry
Escambia
Duval
Collier
4
518
12
47
37
1
77
11
303
60
2
0
100
200
300
400
500
600
Number of Valid Set Checks

Collected Data Types

- Pile
  - Manufacturer
  - Number
  - Length
  - Size
  - Type
  - Acceptance
  - Date Cast
  - Plumbness
- Hammer
  - Type
  - Rated E (k-ft)
- Boring Logs
  - SPT Counts
  - Soil Type
  - Soil Depth
- Ground Elevation
- Tip Elevation
- Time Driven
- Time Checked
- Total Drive Time
- Total Stopped Time
- Wave Speed

Collected Data Types

- Driving Records EOD
    - Blow Count
    - BLC (bl/ft)
    - RMX Values (RX4-RX8 depending on what is available) (kips)
    - CSX (ksi)
    - CSB (ksi)
    - STK (ft)
    - EMX (k-ft)
- Driving Records Restrike
    - Final and Max EMX of RS
    - Blow Count
    - BLC (bl/ft)
    - RMX Values (RX4-RX8 depending on what is available) (kips)
    - CSX (ksi)
    - CSB (ksi)
    - STK (ft)
    - EMX (k-ft)



AutoSave Off
Preliminary - All Data as of 1-27-2023
Search (Alt+Q)
File
Home
Insert
Draw
Page Layout
Formulas
Data
Review
View
Developer
Help
Acrobat
CD137
Database 948 piles

Sample Pile Installation Information

Howard Frankland Bridge - End Bent 1-1 Pile 3 15DSC Double Splice — 30" PSC Pile Total Length 220ft.
OP: DFC/BF — Date: 13-July-2022

AR: 900.00 in^2 — SP: 0.150 k/ft^3
LE: 215.00 ft — EM: 5,813 ksi
WS: 13,400.0 f/s — JC: 0.60

RMX: Maximum Case Method Capacity (JC)
CSX: Compression Stress Maximum
TSX: Tension Stress Maximum - Full Record Search
EMX: Maximum Energy
STK: Hammer Stroke
DMX: Maximum Displacement
ETR: Energy Transfer Ratio - Rated
BTA: Integrity Factor (1)
TLS: Tension Stress at Splice

BL#	Depth ft	BLC bl/ft	TYPE	RMX kips	CSX ksi	TSX ksi	EMX k-ft	STK ft	DMX in	ETR (%)	BTA (%)	TLS ksi
1	139.01	72	AV1	1,457	2.8	0.4	64.6	9.58	0.44	26.1	83.0	0.00
2	139.03	72	AV1	1,444	3.0	0.4	75.6	10.24	0.49	30.5	82.0	0.00
3	139.04	72	AV1	1,388	2.9	0.4	69.5	10.13	0.44	28.0	80.0	0.00
4	139.06	72	AV1	1,389	3.1	0.4	79.7	10.52	0.51	32.1	81.0	0.00
5	139.07	72	AV1	1,350	3.2	0.4	84.7	10.92	0.52	34.2	80.0	0.00
6	139.08	72	AV1	1,290	3.1	0.3	80.6	10.60	0.55	32.5	80.0	0.00
7	139.10	72	AV1	1,295	3.1	0.4	79.0	10.30	0.54	31.8	79.0	0.00
8	139.11	72	AV1	1,314	3.1	0.4	79.9	10.48	0.51	32.2	79.0	0.00
9	139.13	72	AV1	1,290	3.1	0.4	77.4	10.52	0.50	31.2	79.0	0.00
			Average	1,357	3.0	0.4	76.8	10.37	0.50	31.0	80.3	0.00

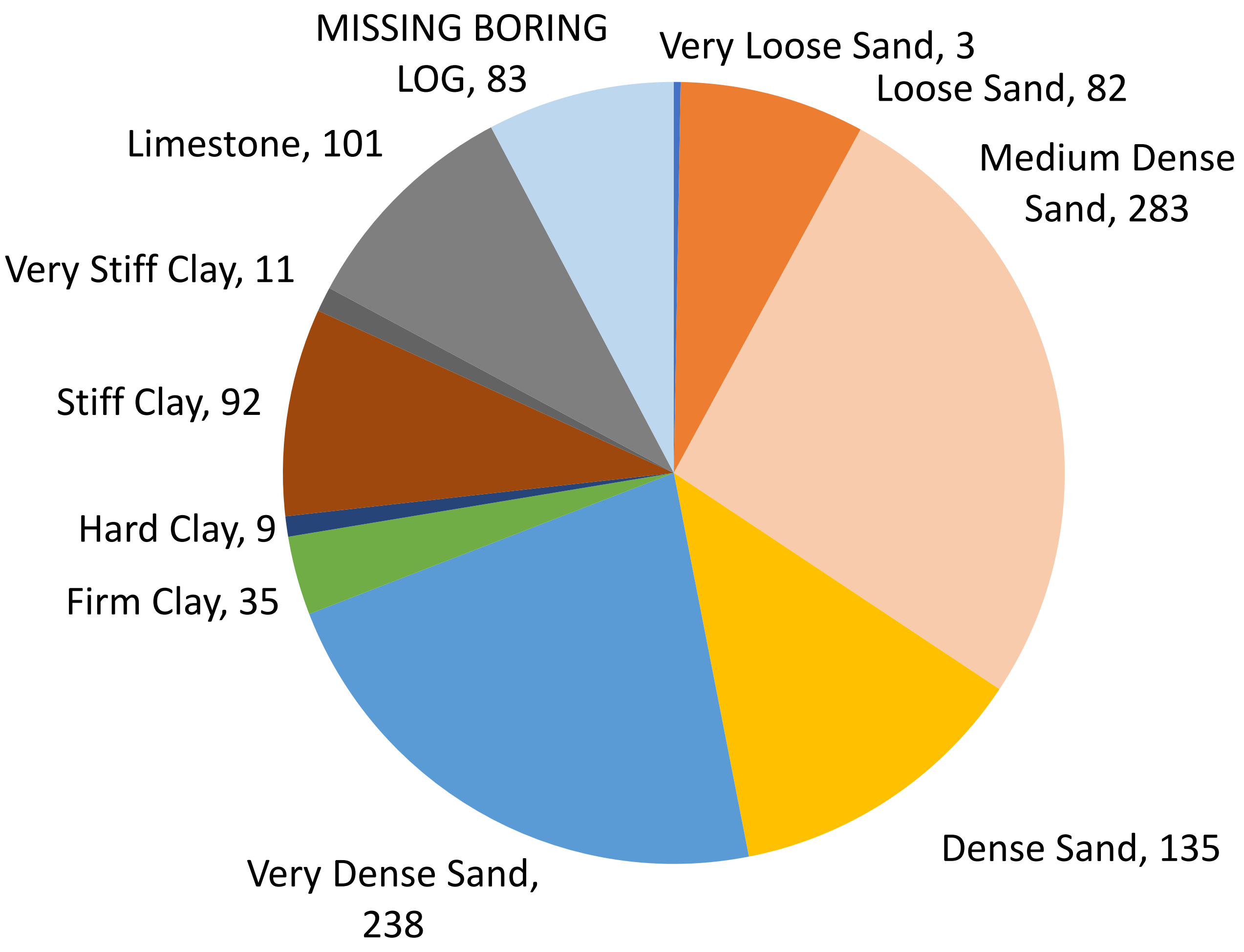
Total number of blows analyzed: 9

Exceed NBR

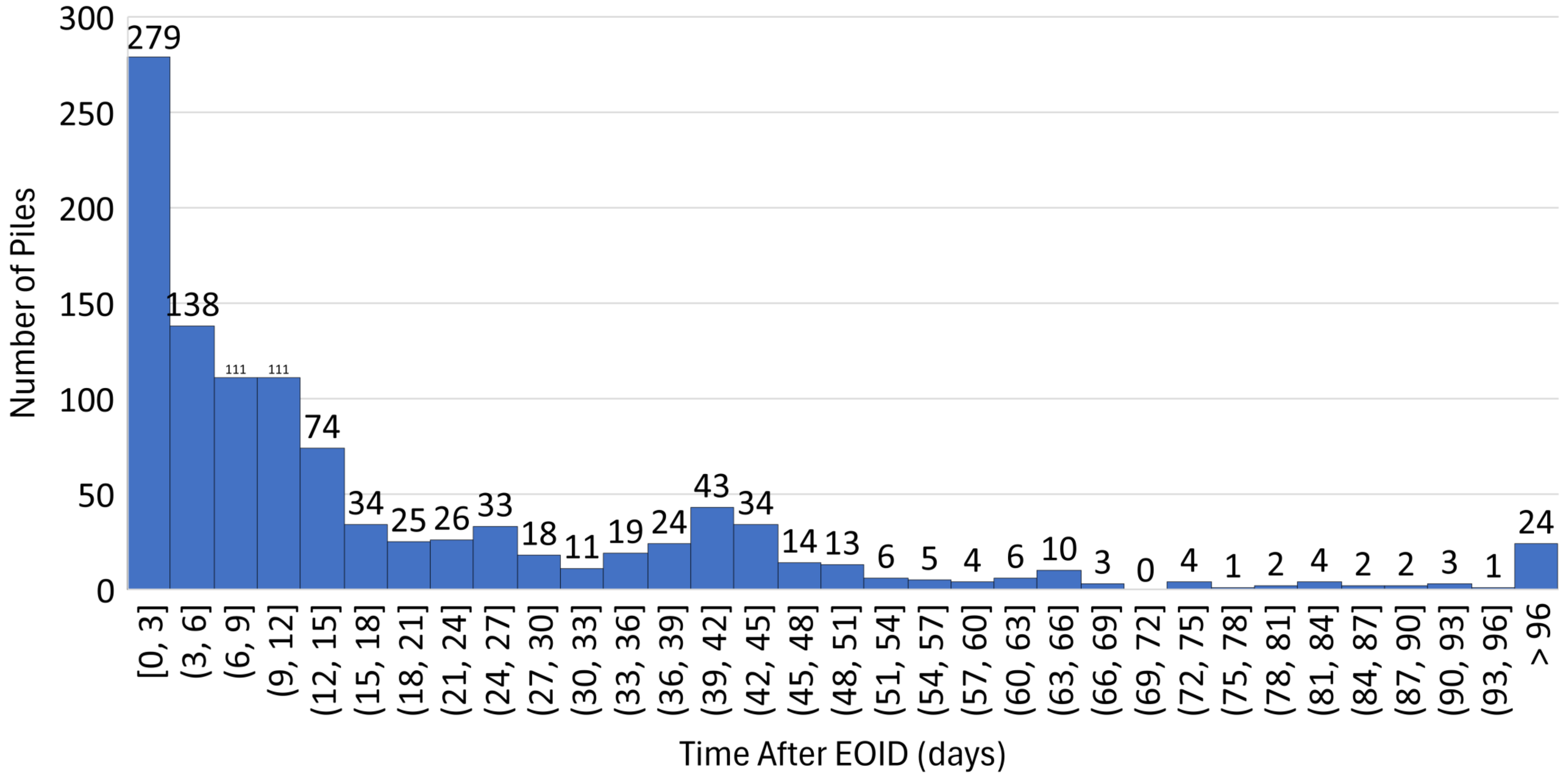
Average = 1,372 kips

All exceed 90% NBR

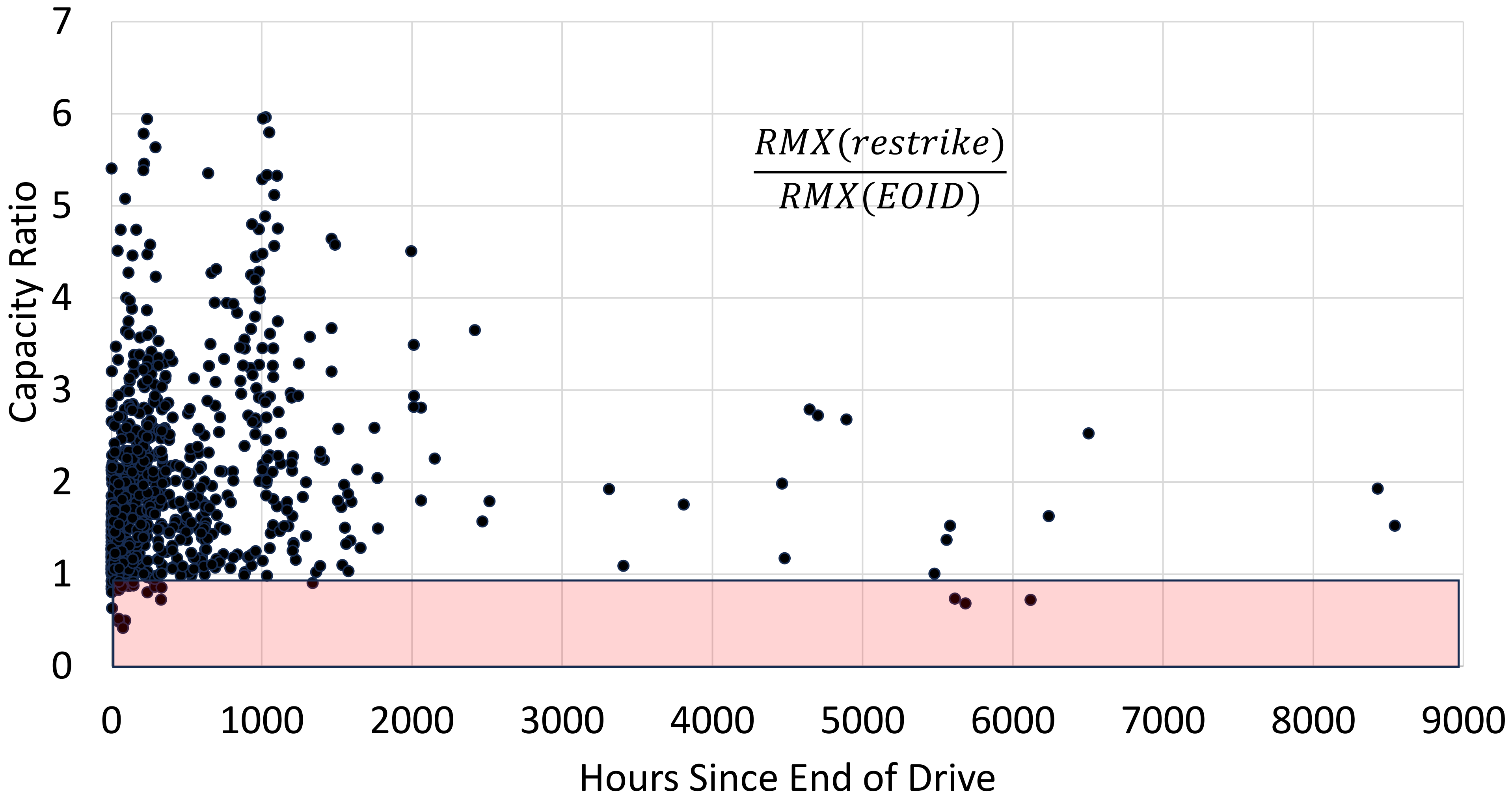
Bearing Layer Soil Types

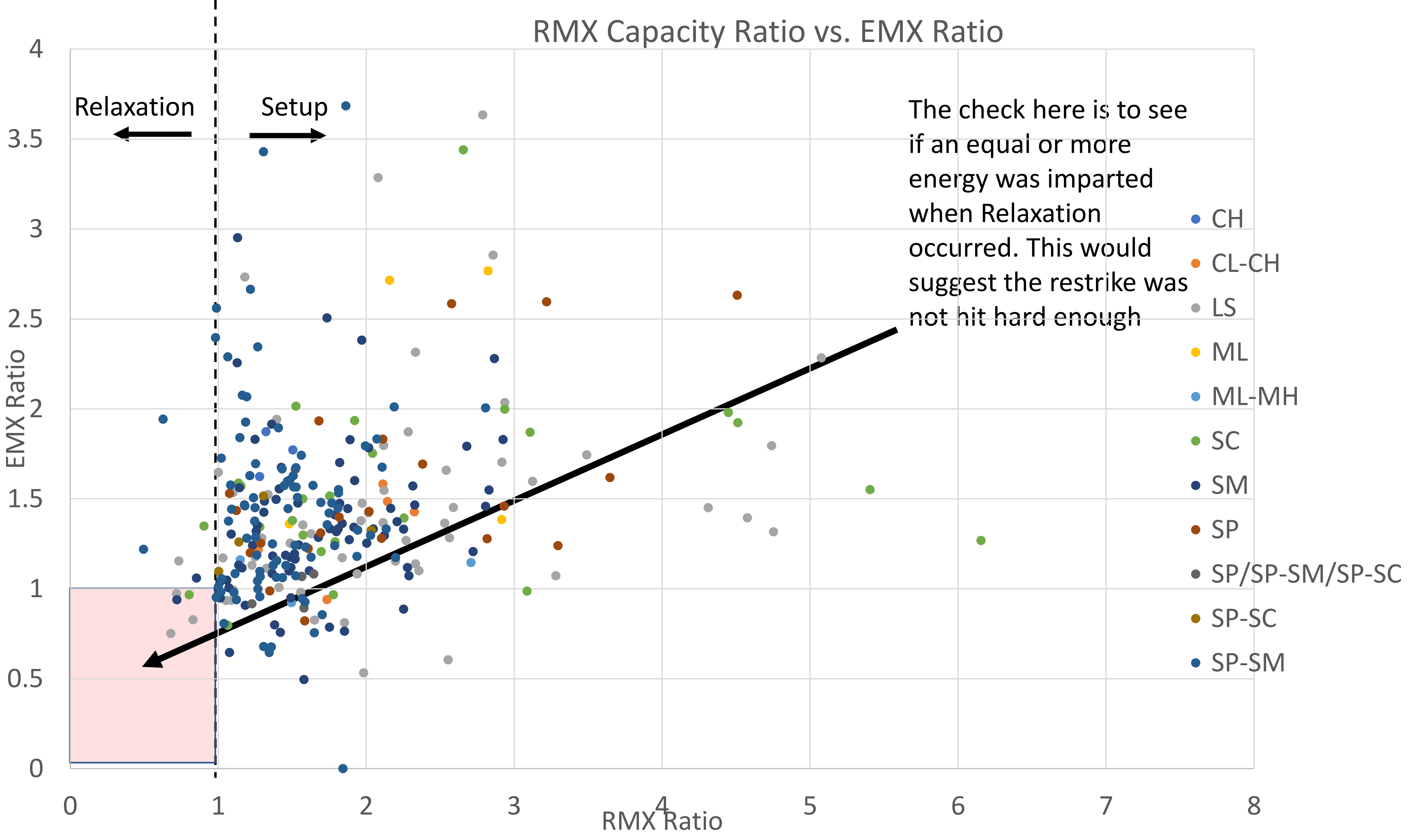


Time between Initial Drive and Restrike

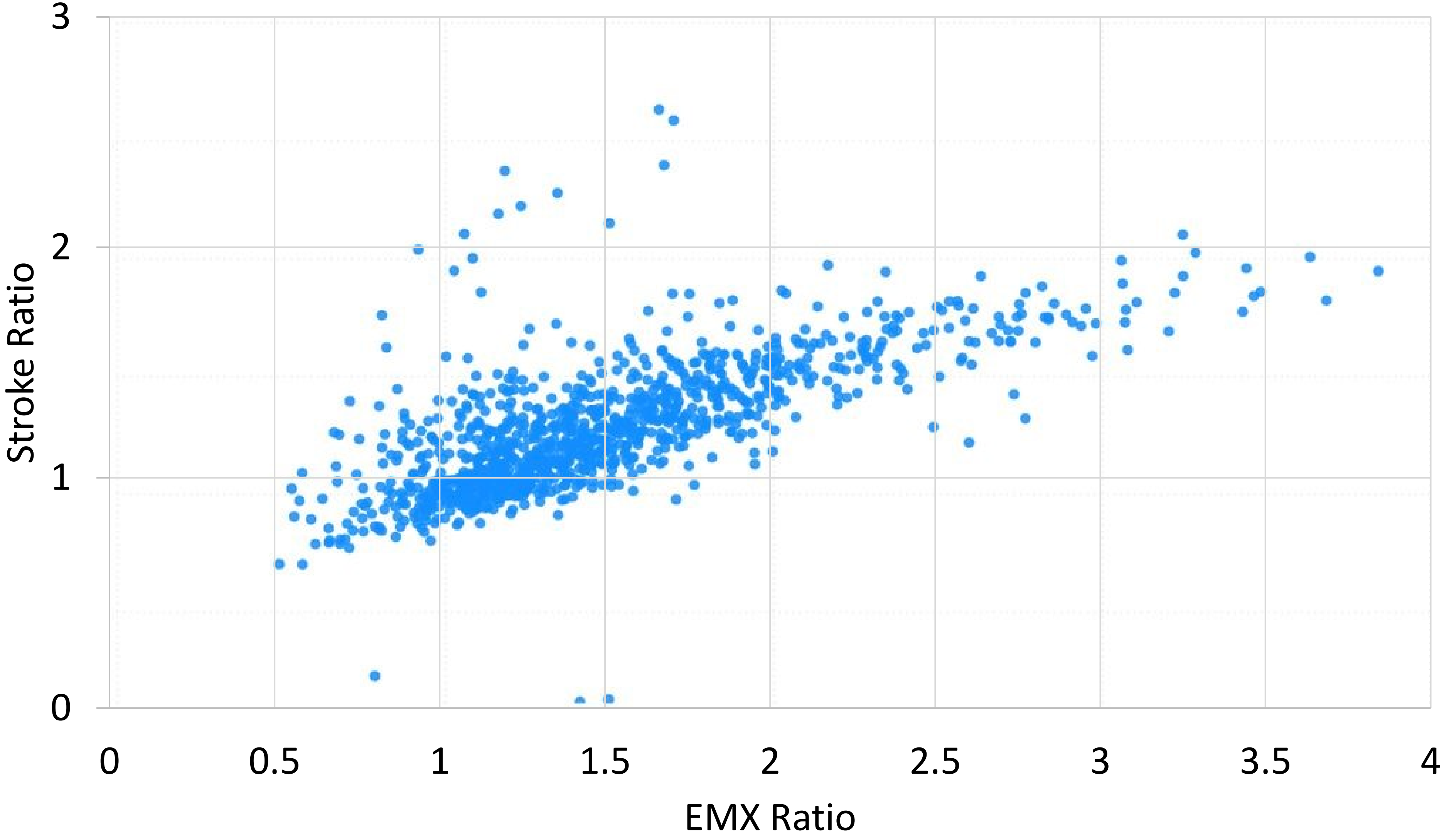


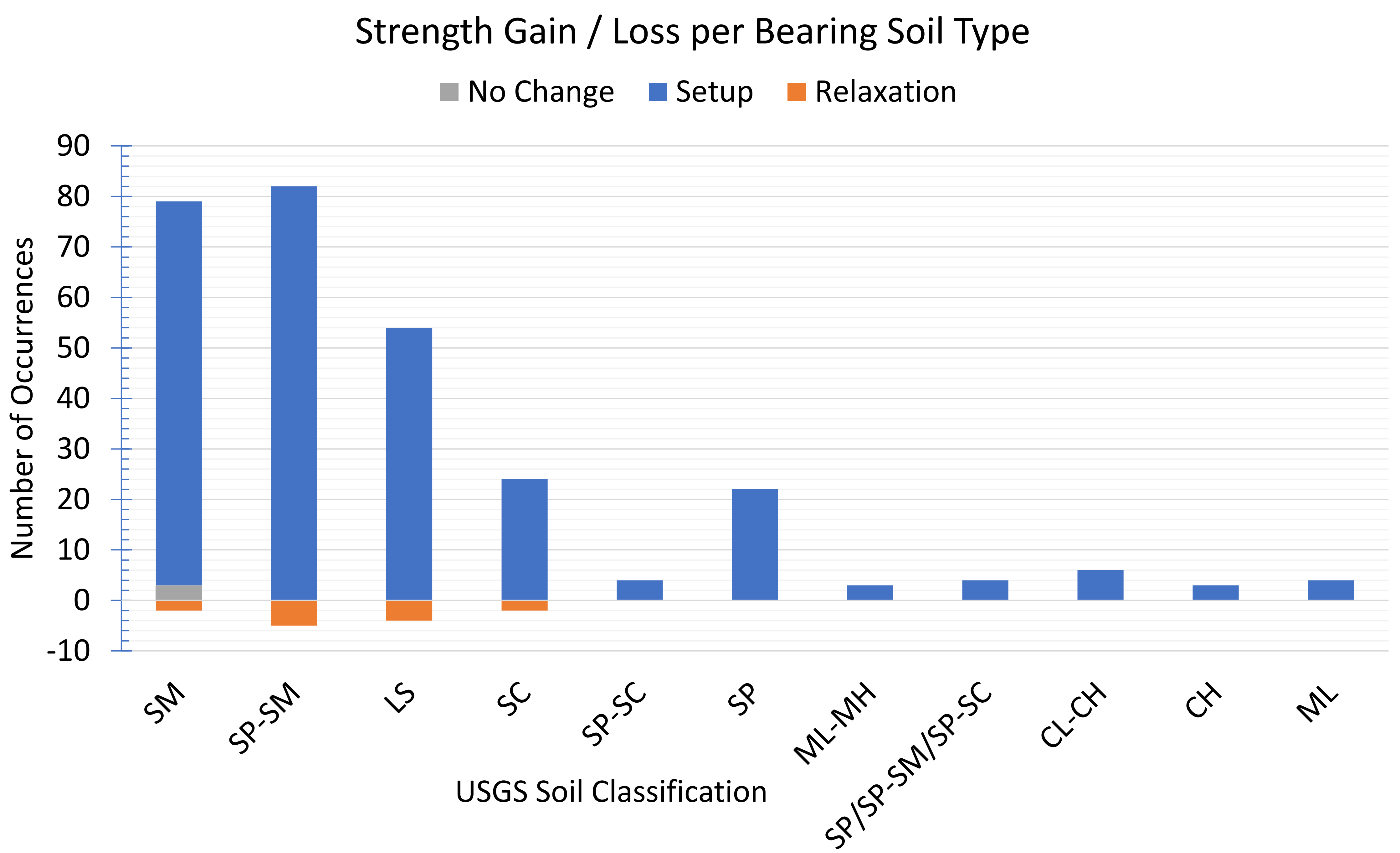
Capacity Ratio vs Wait Time




RMX Capacity Ratio vs. EMX Ratio
Relaxation
Setup
The check here is to see if an equal or more energy was imparted when Relaxation occurred. This would suggest the restrike was not hit hard enough
EMX Ratio
RMX Ratio
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
CH
CL-CH
LS
ML
ML-MH
SC
SM
SP
SP/SP-SM/SP-SC
SP-SC
SP-SM

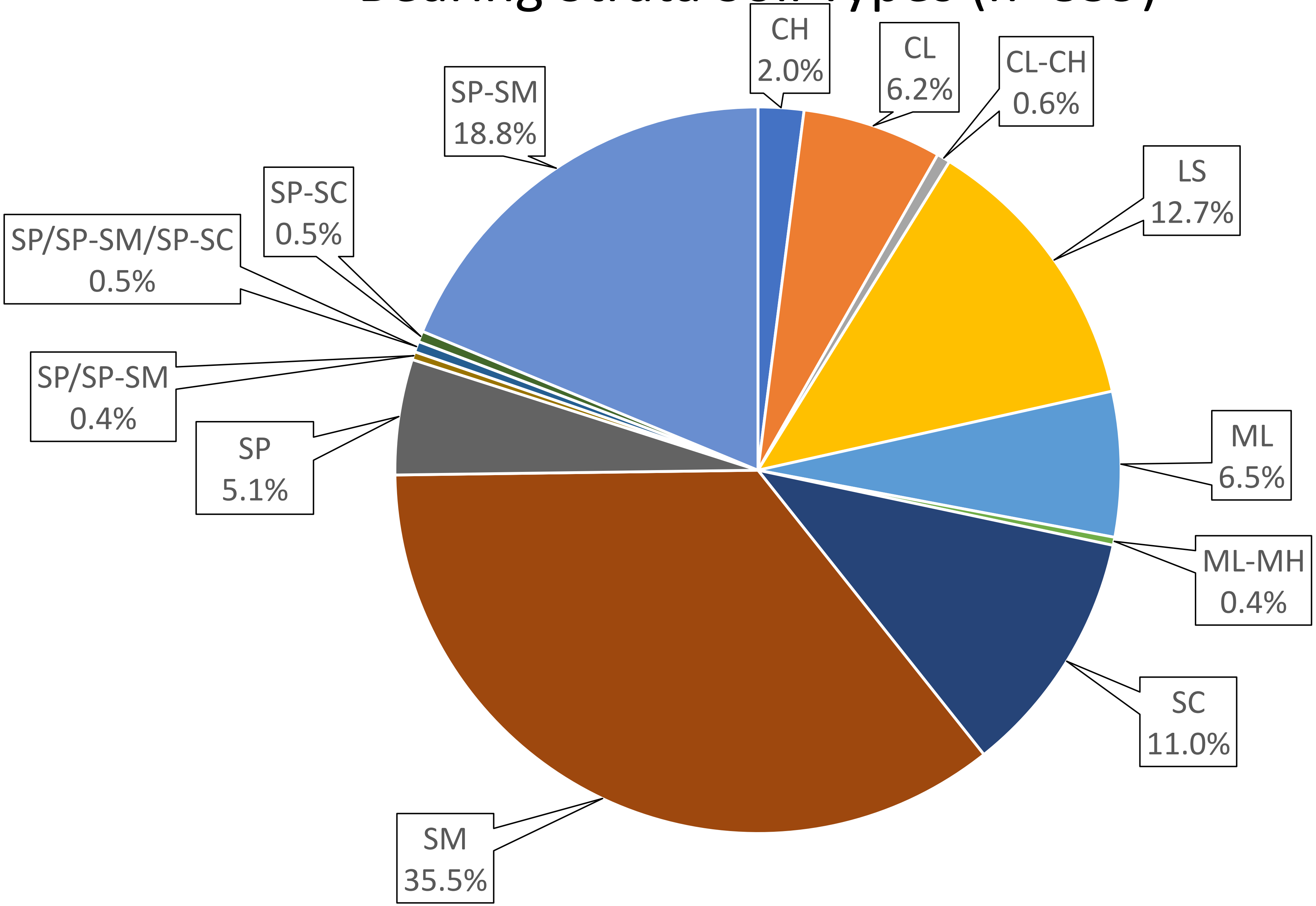
Stroke vs EMX
(not helpful but interesting)



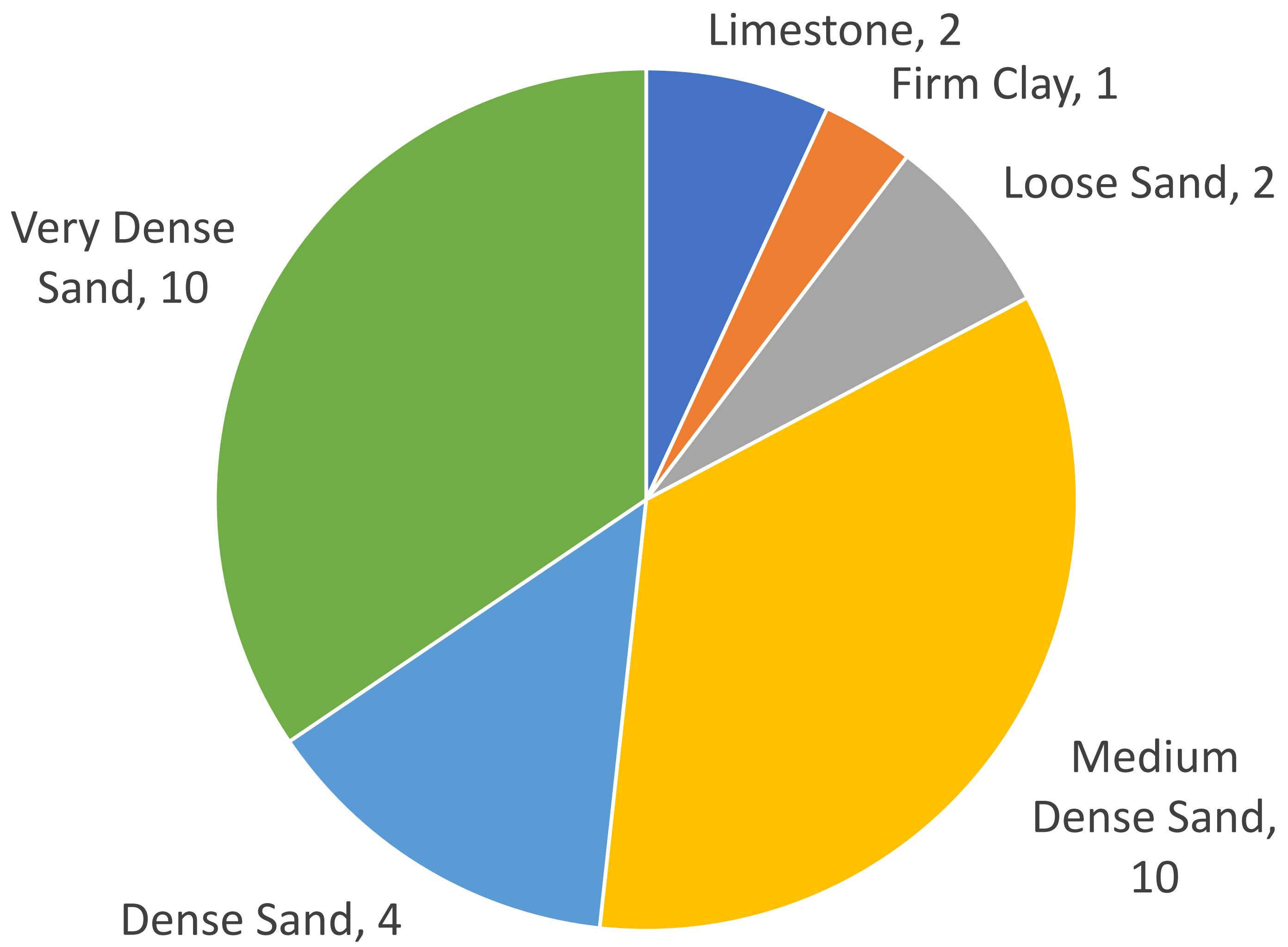


Strength Gain / Loss per Bearing Soil Type
No Change
Setup
Relaxation
Number of Occurrences
90
80
70
60
50
40
30
20
10
0
-10
SM
SP-SM
LS
SC
SP-SC
SP
ML-MH
SP/SP-SM/SP-SC
CL-CH
CH
ML
USGS Soil Classification

Bearing Strata Soil Types (n=839)

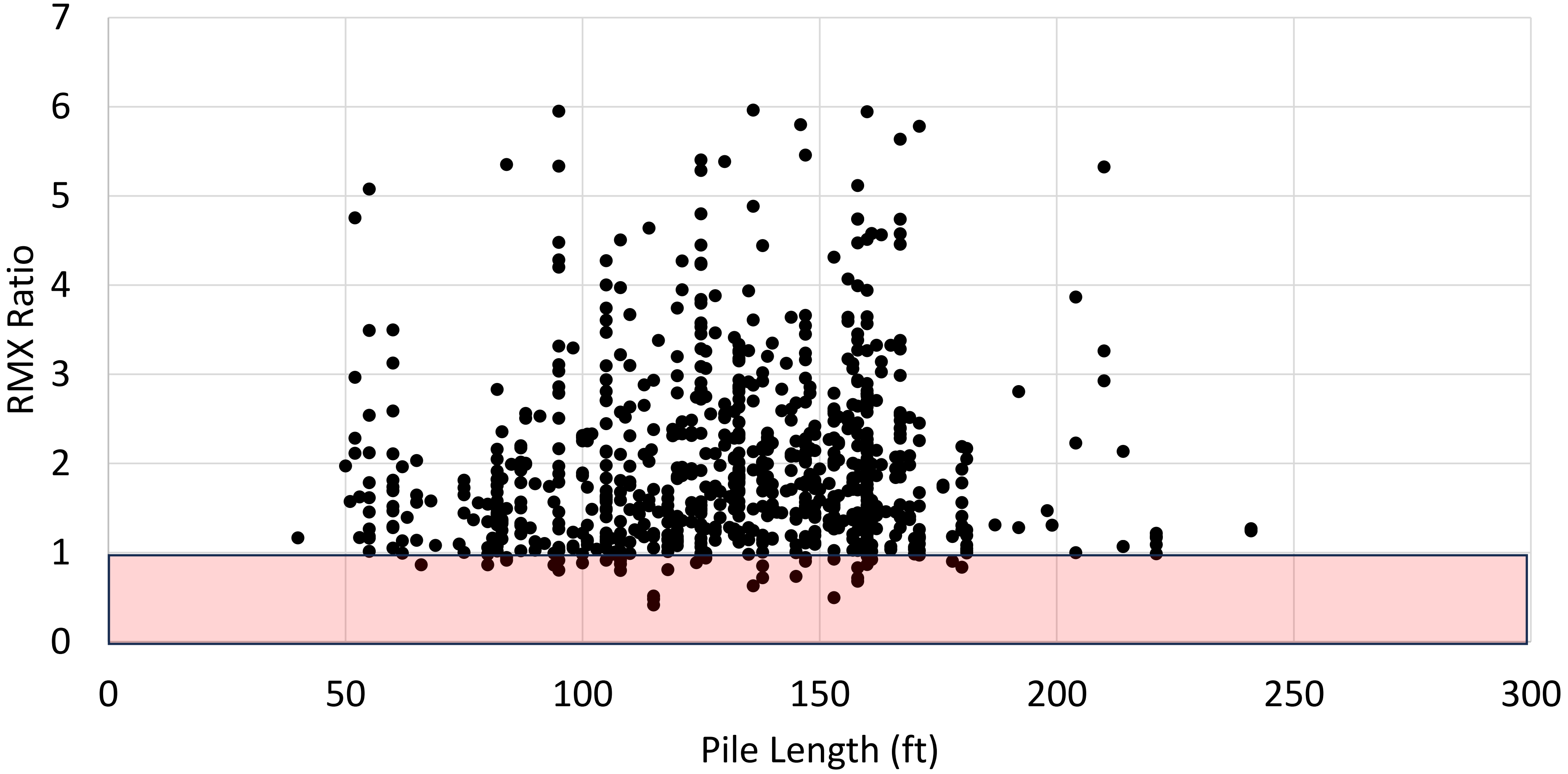


Bearing Layer (relaxation cases)

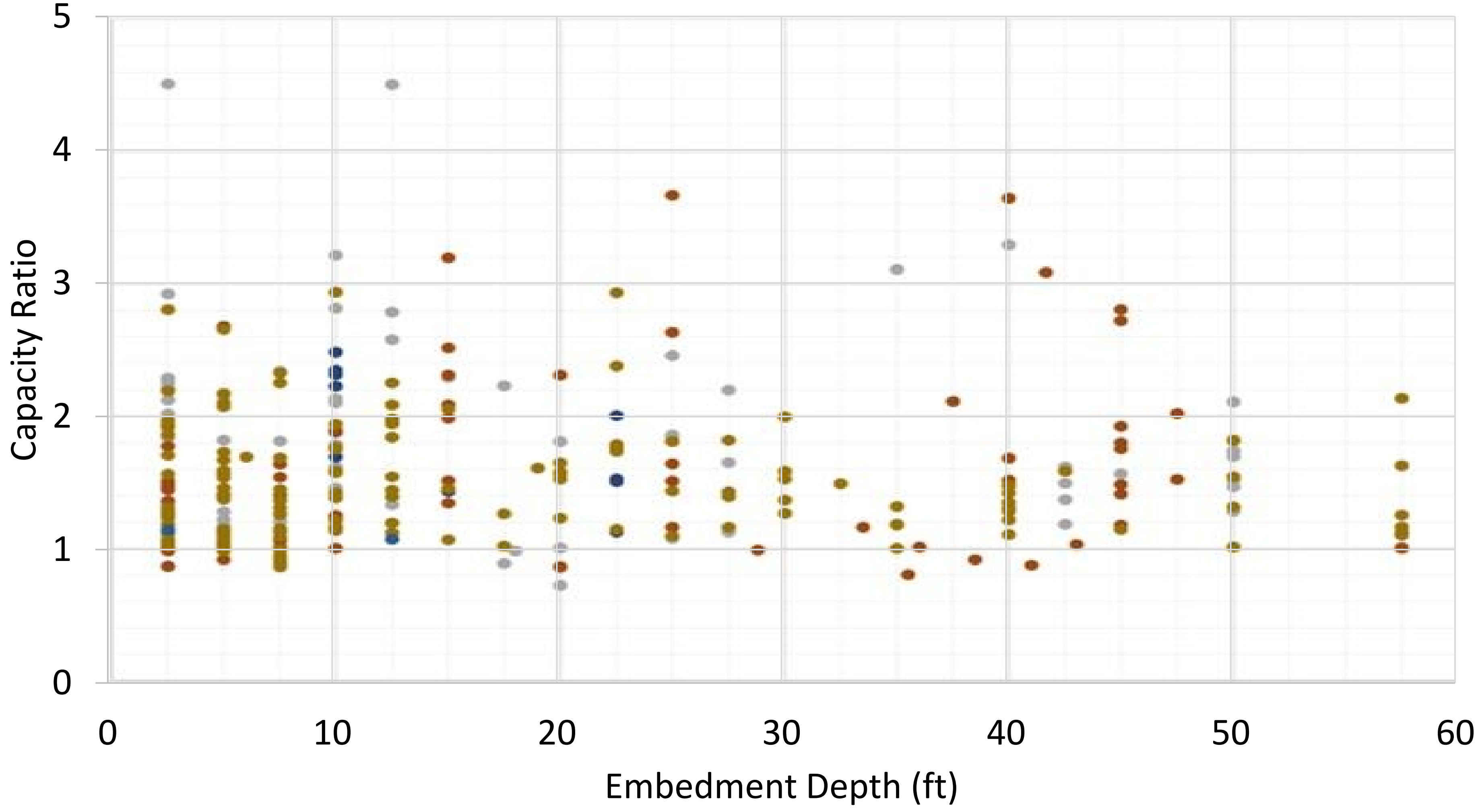


Capacity Ratio vs Pile Length

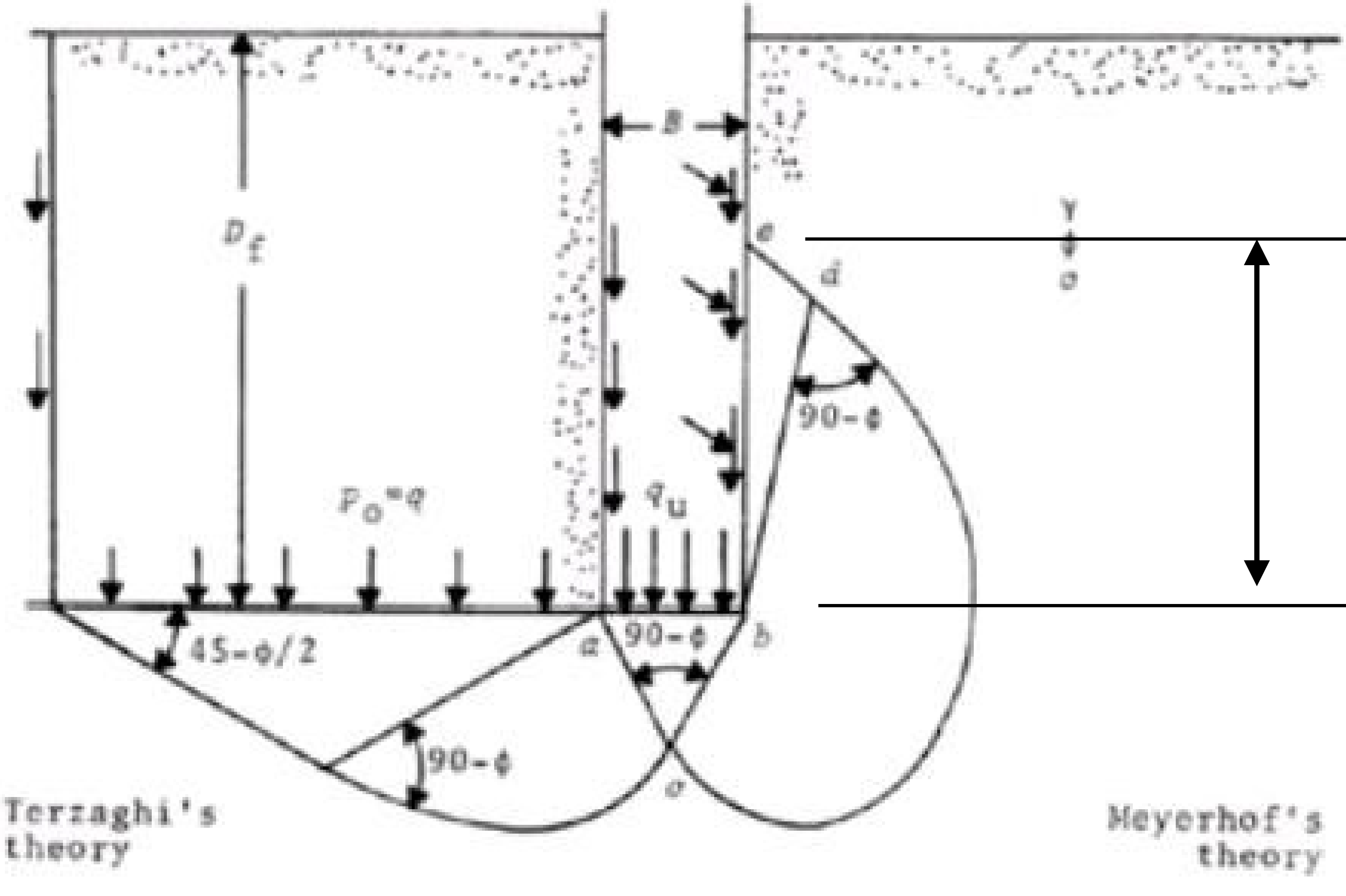
(short piles ≠ relaxation)



Capacity Ratio vs Embedment Depth
(based on same soil type)



Embedment Depth
(based on soil strength?)



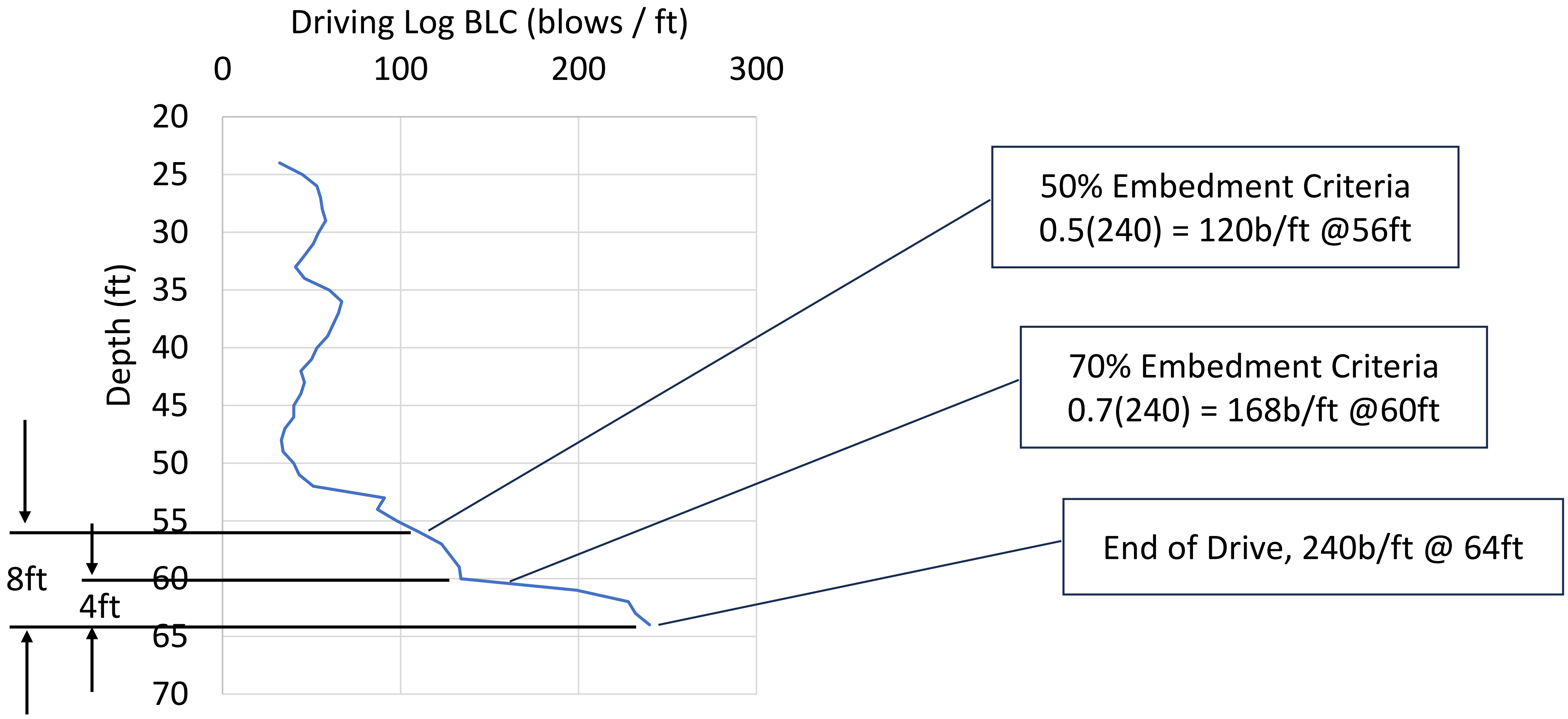
(b) Deep foundation

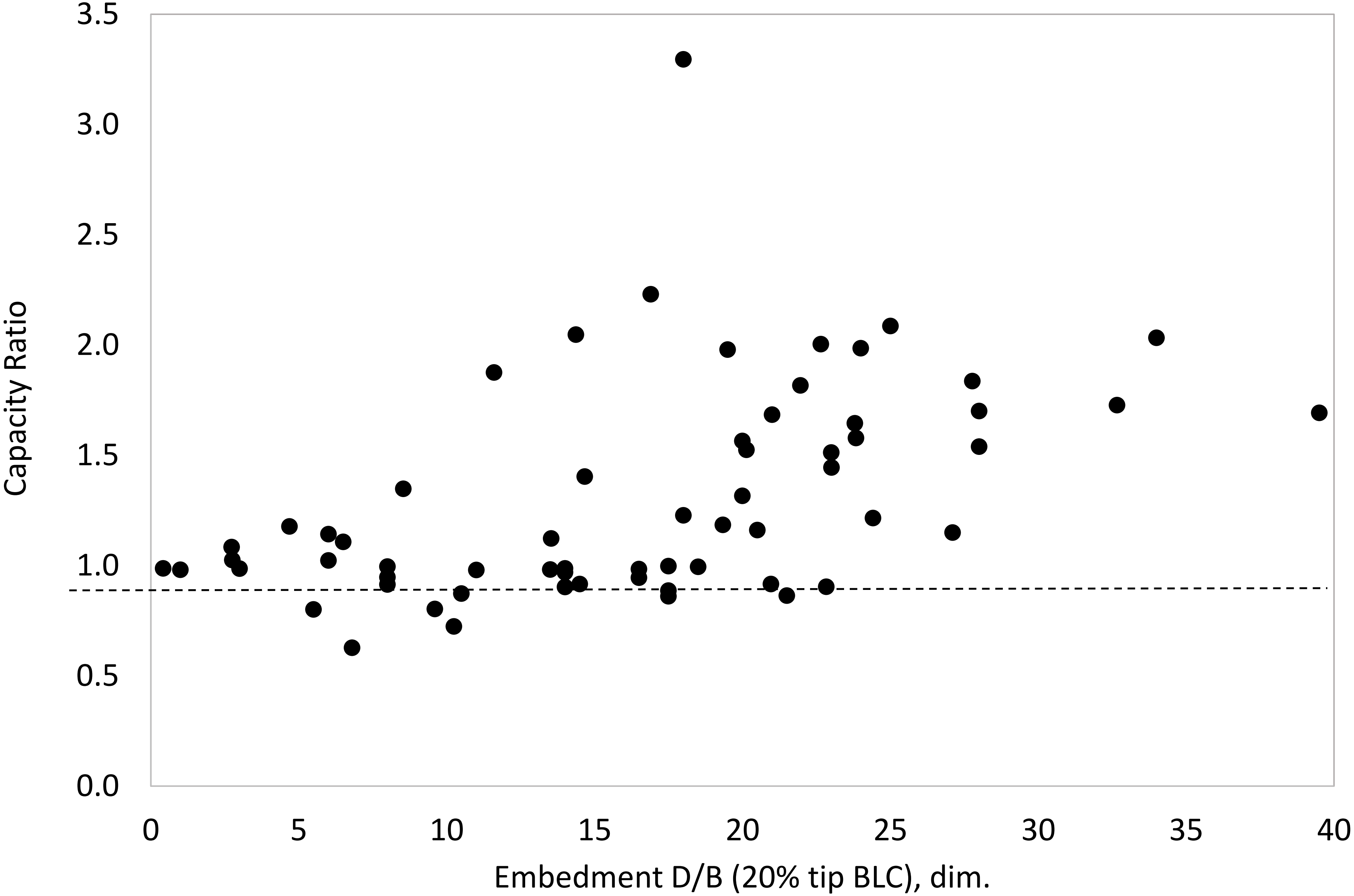
End bearing based on soil strength 8D above and 3.5B below tip (B is pile size)

RB-121, SPT89, 94, 97, FBDEEP

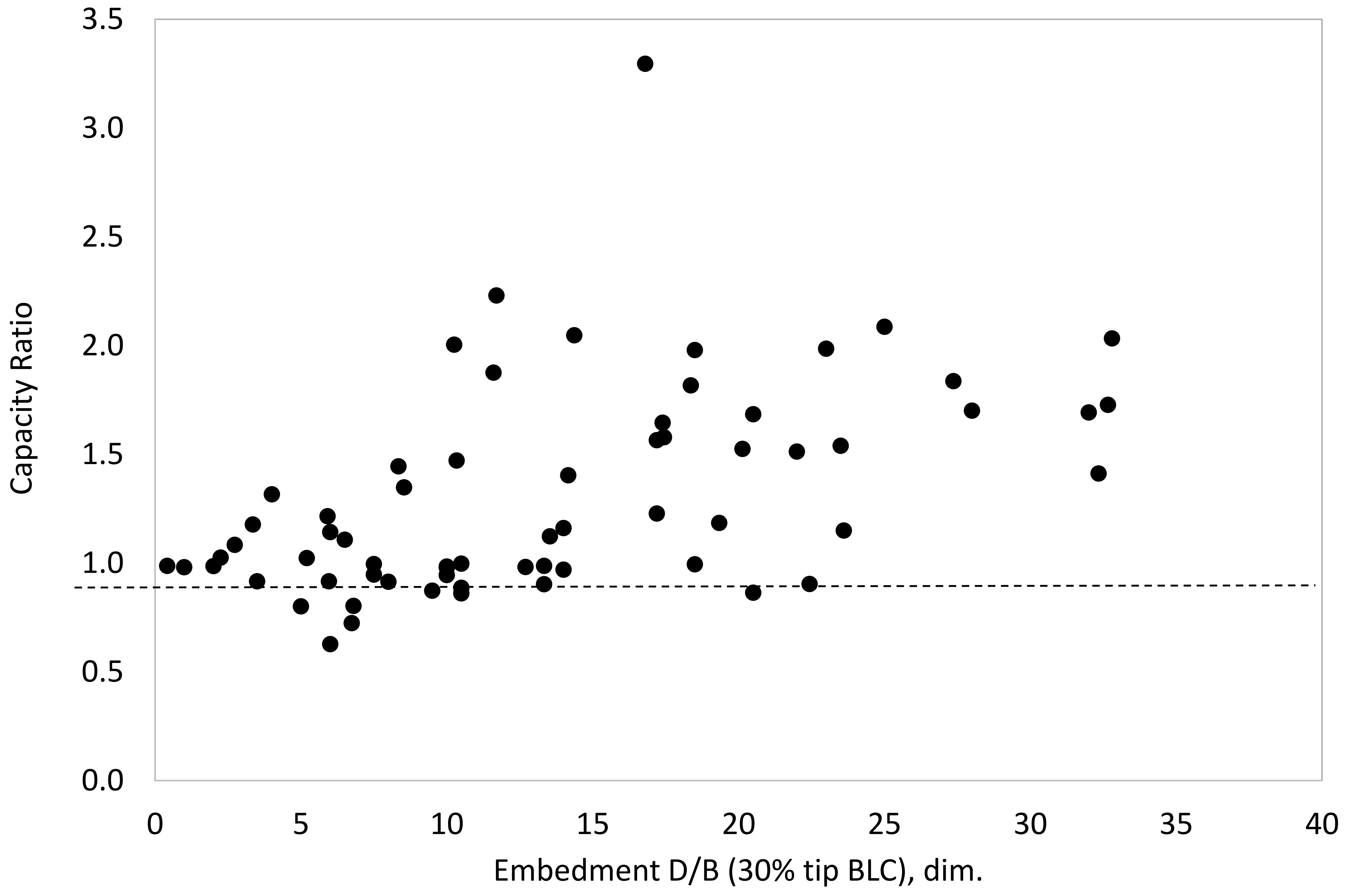
End bearing is subjected to critical depth correction (D/B ratio) dependent on soil type not strength

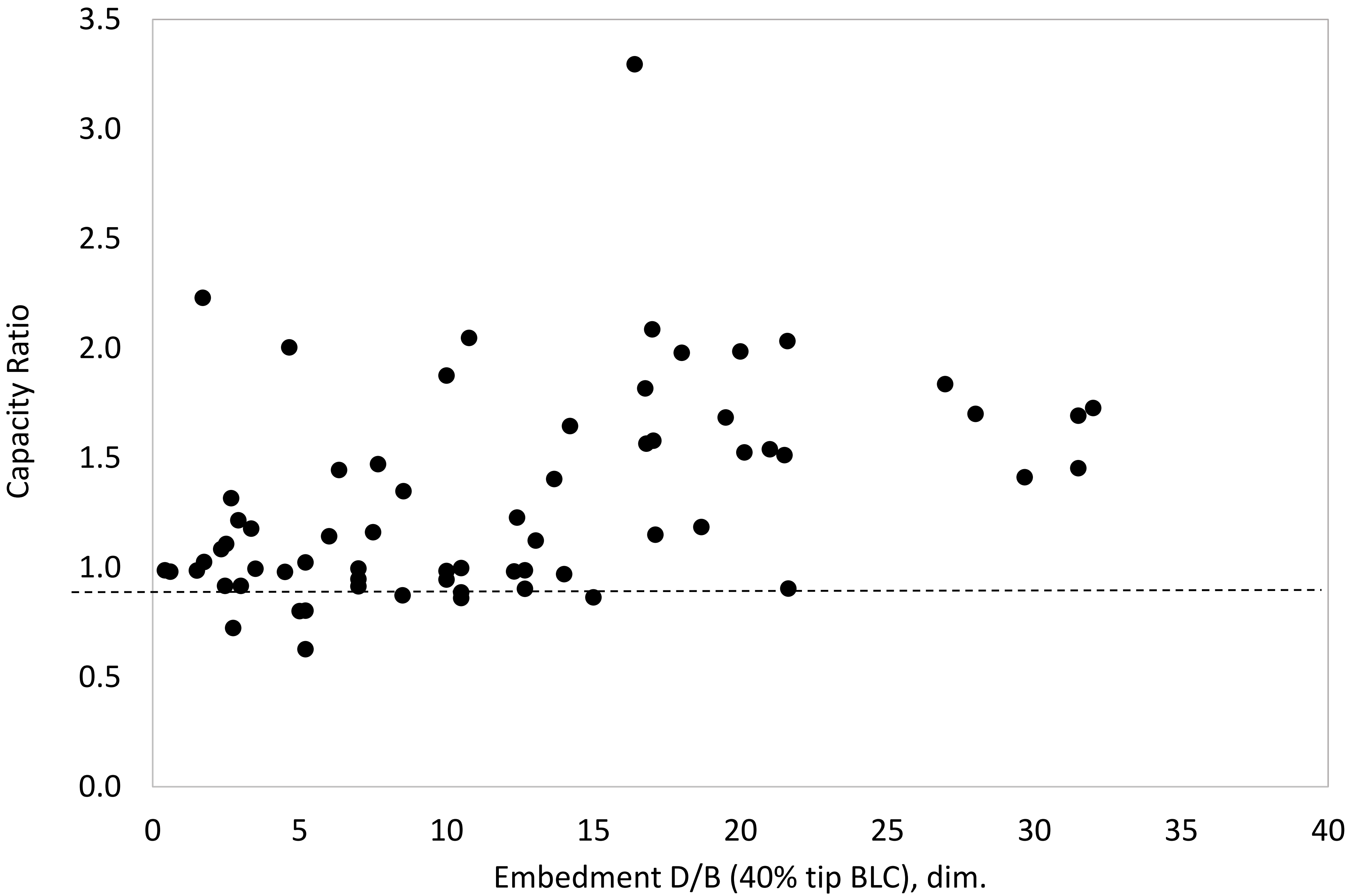
Example Strength-based Embedment Criteria

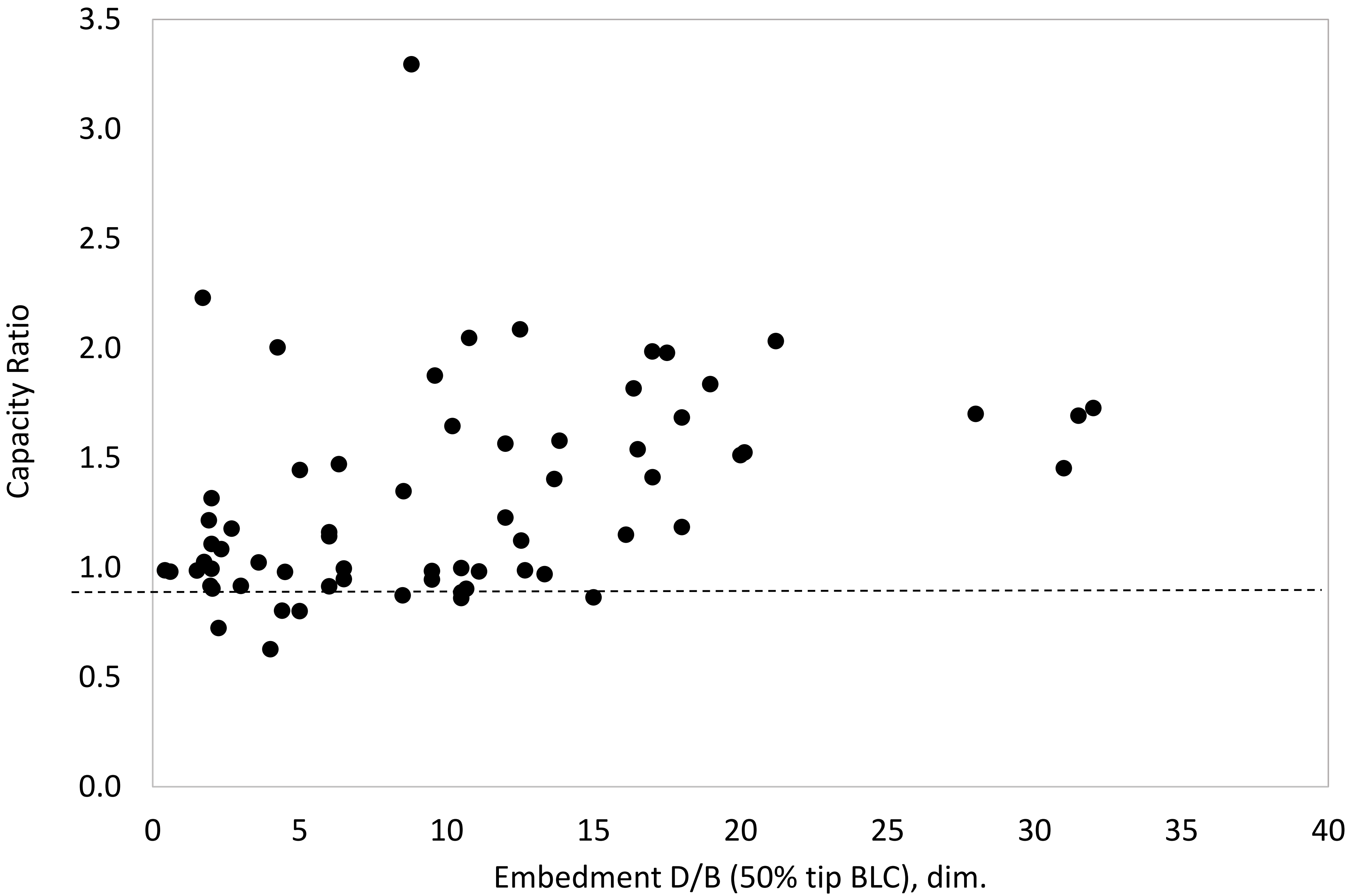


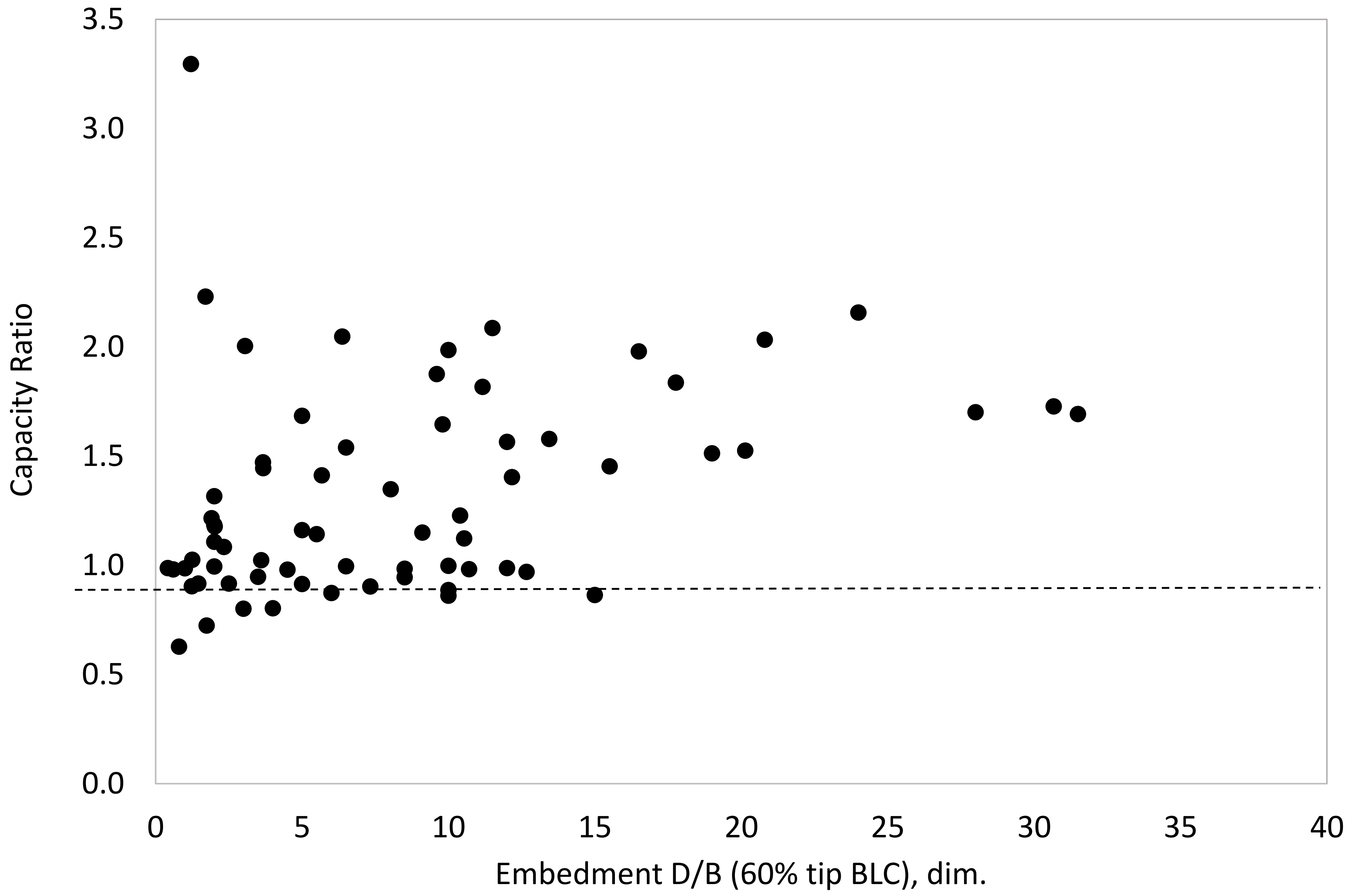


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (20% tip BLC), dim.

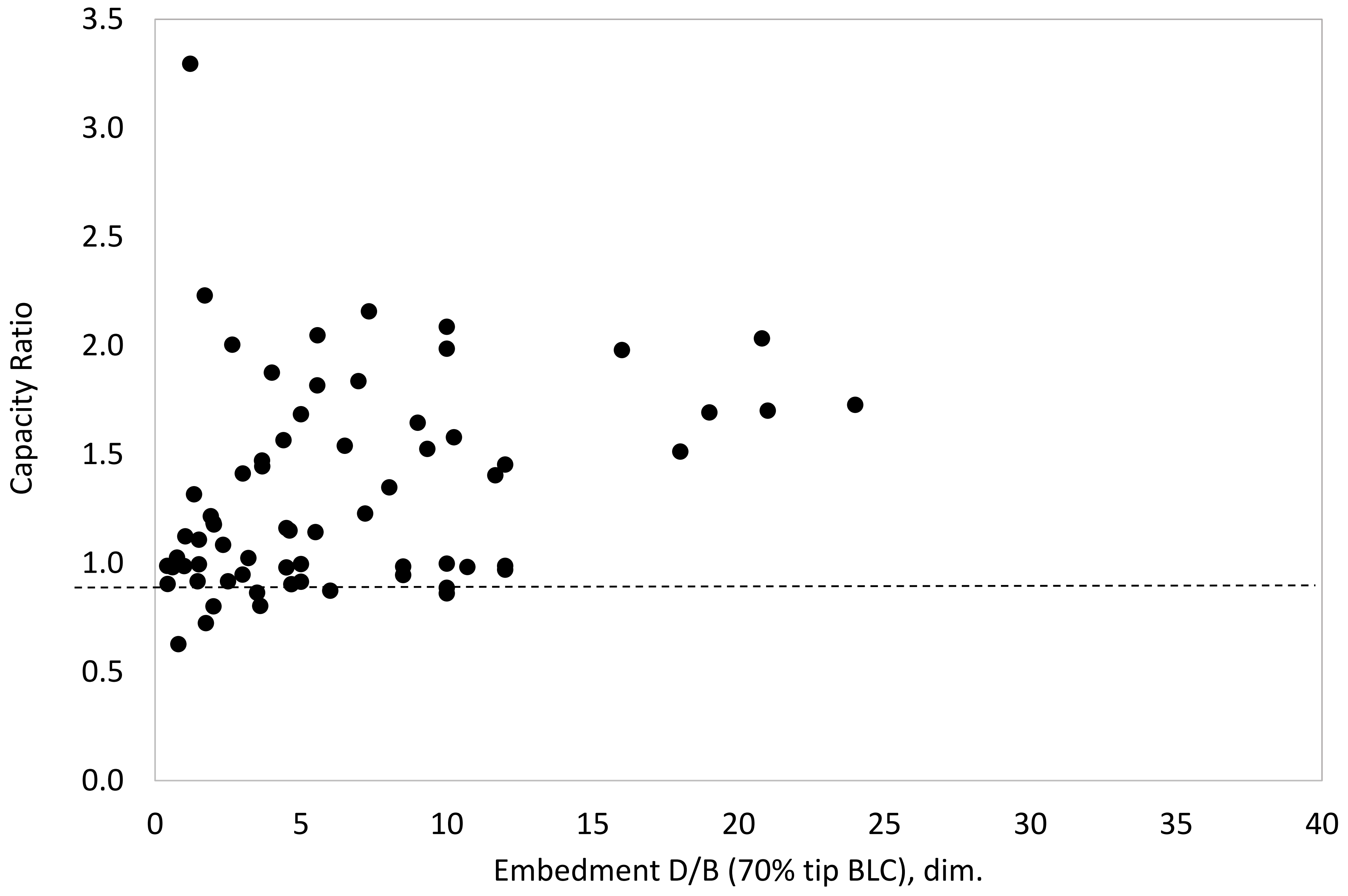

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (30% tip BLC), dim.

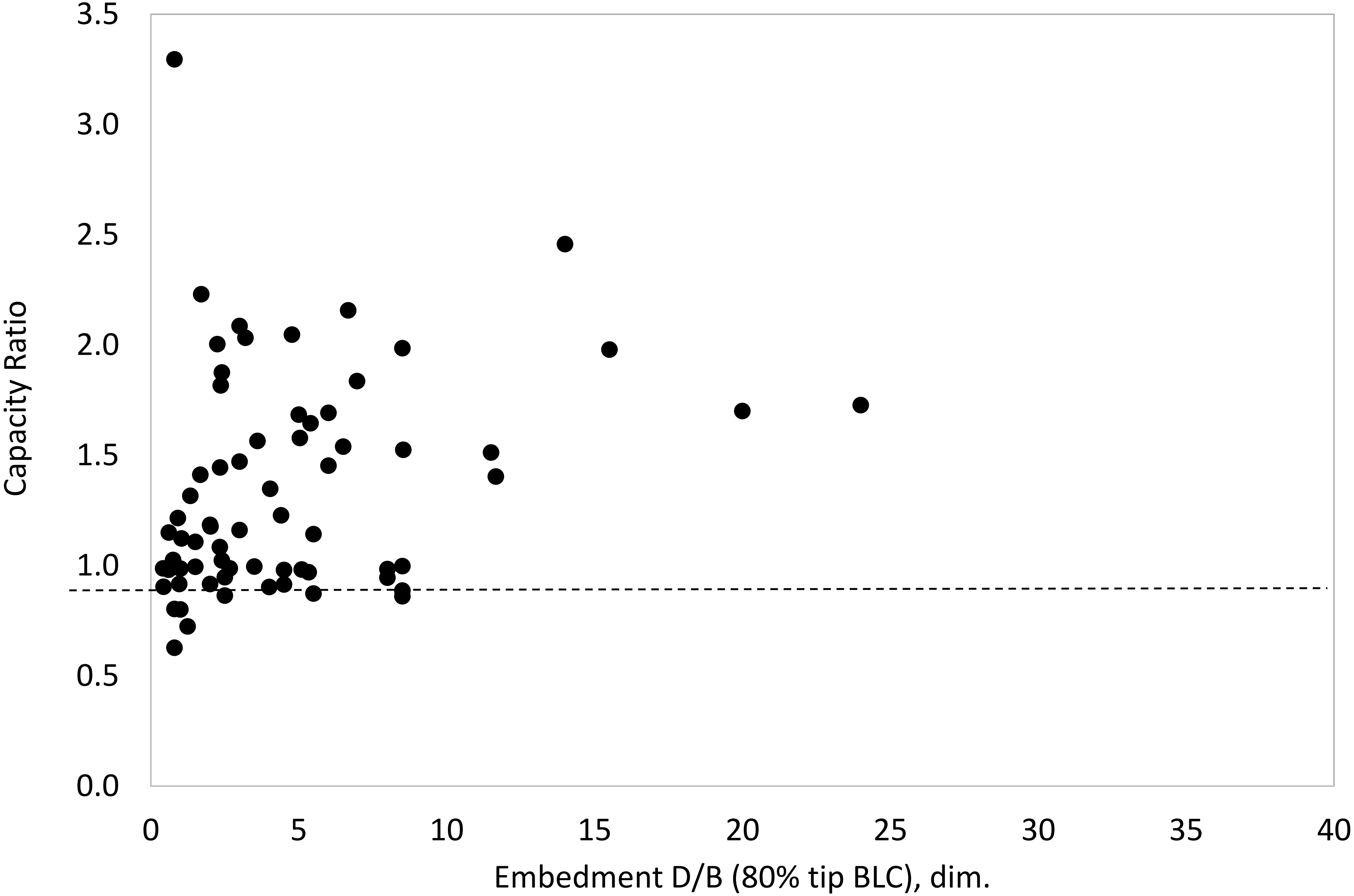

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (40% tip BLC), dim.

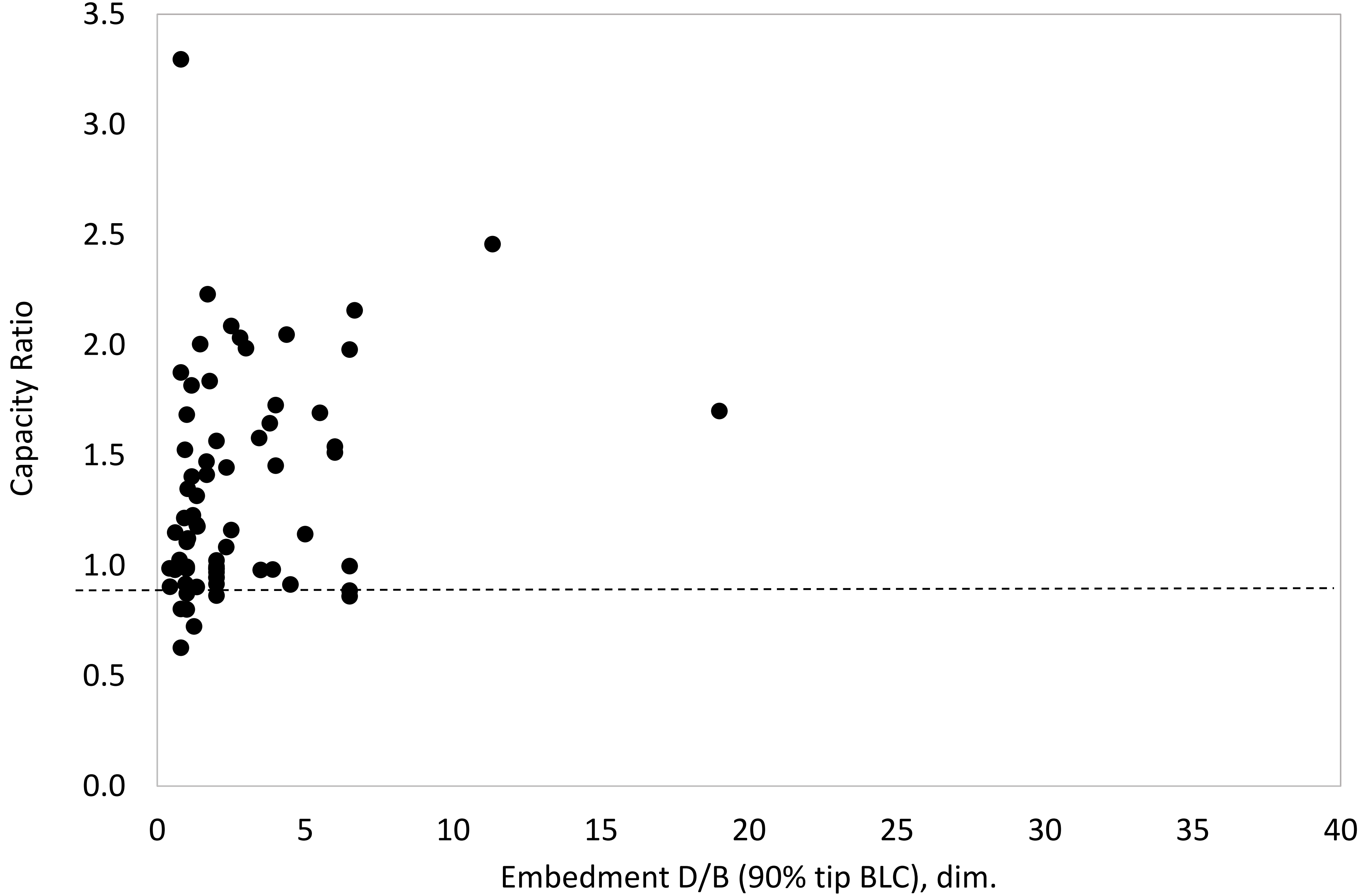

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (50% tip BLC), dim.



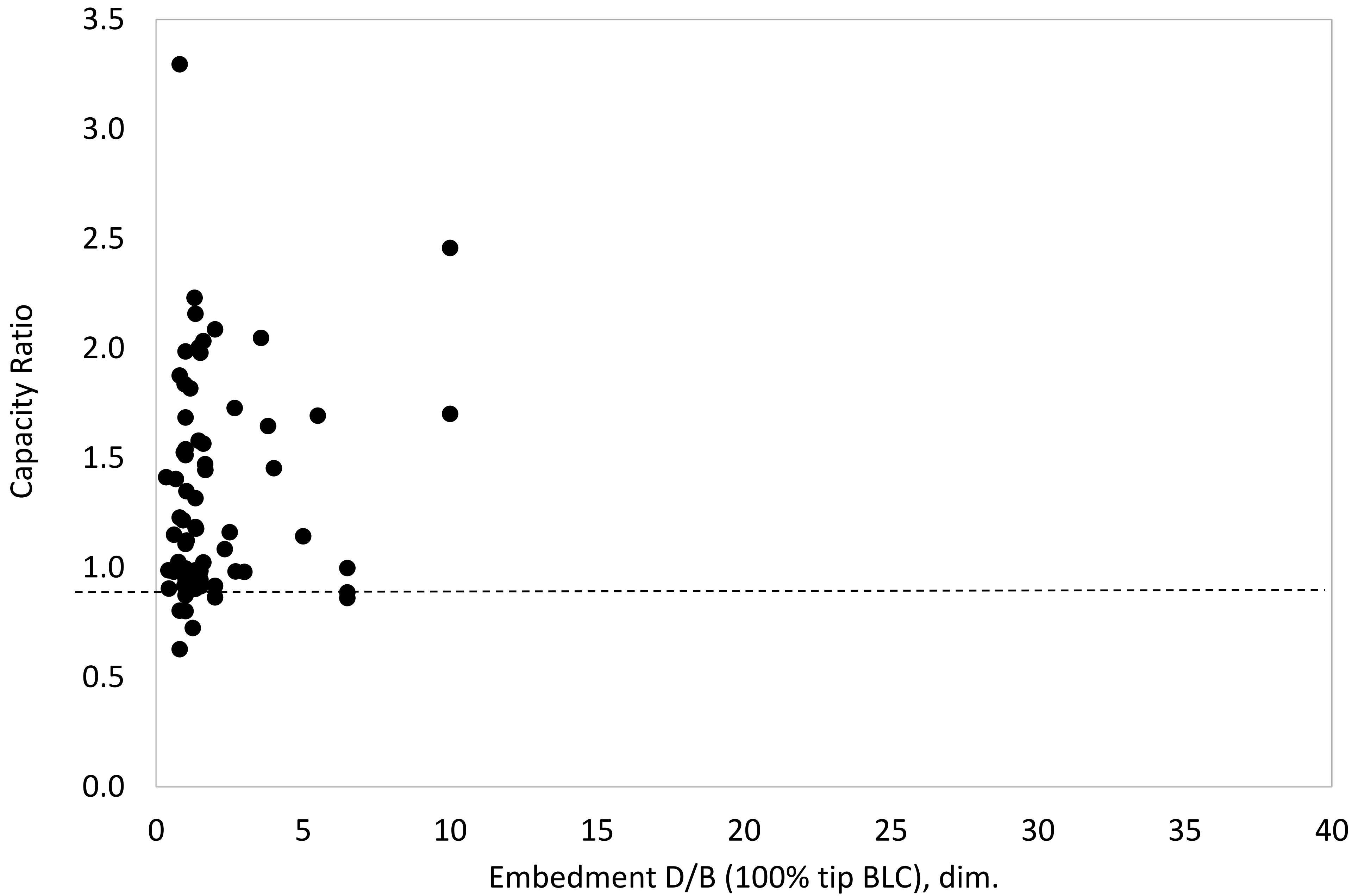
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (60% tip BLC), dim.

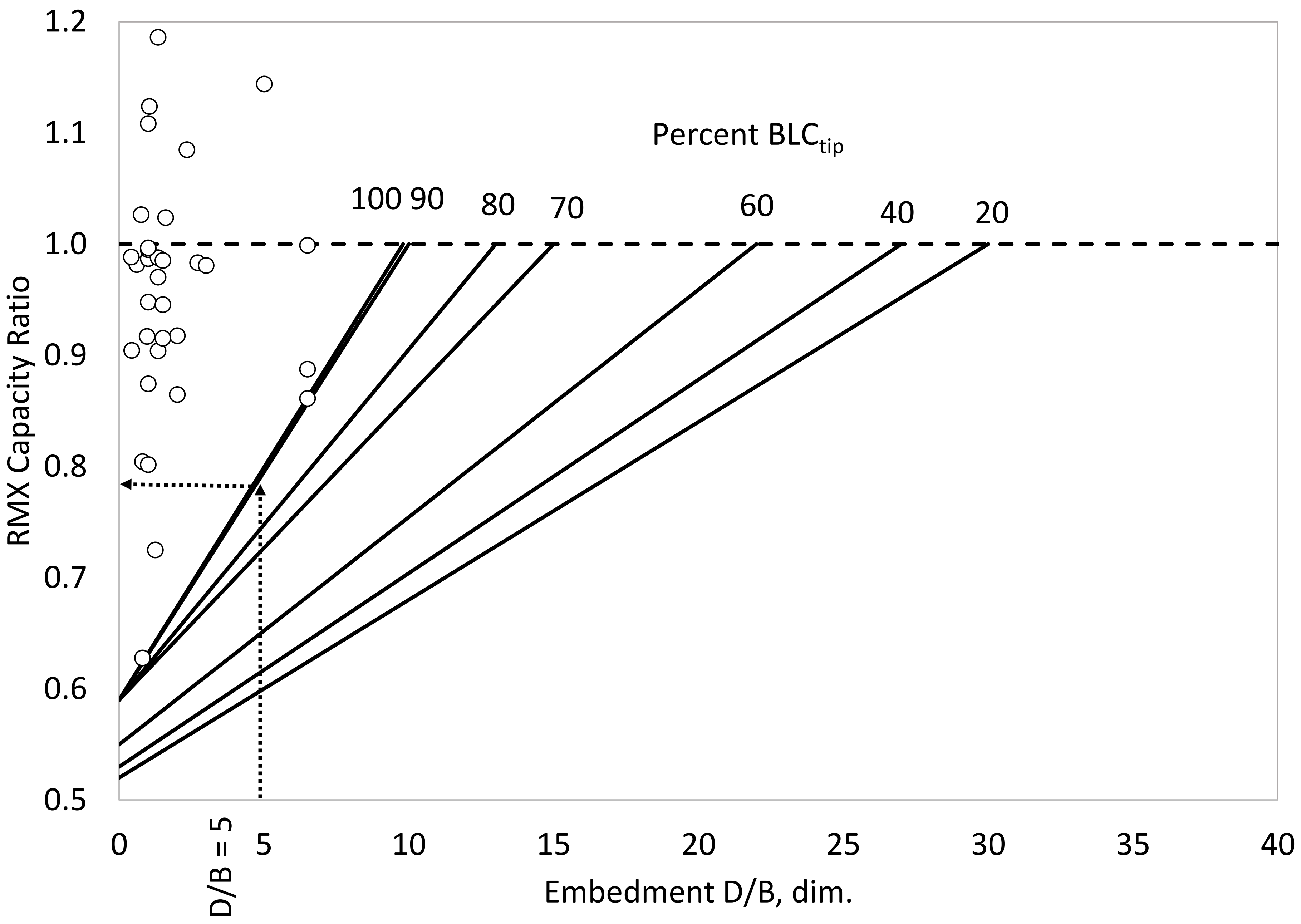

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (70% tip BLC), dim.


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (80% tip BLC), dim.

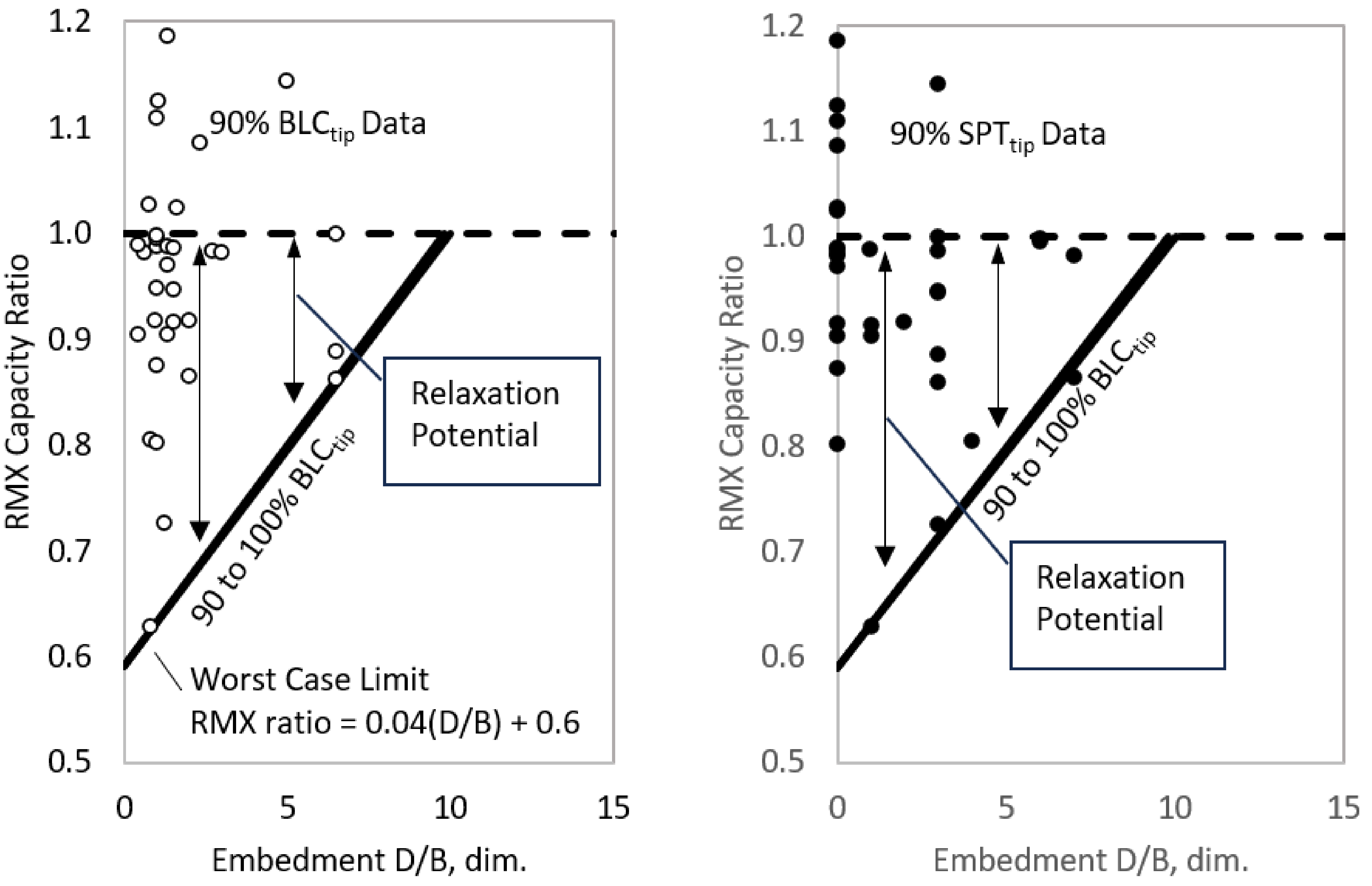


Capacity Ratio
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
20
25
30
35
40
Embedment D/B (90% tip BLC), dim.

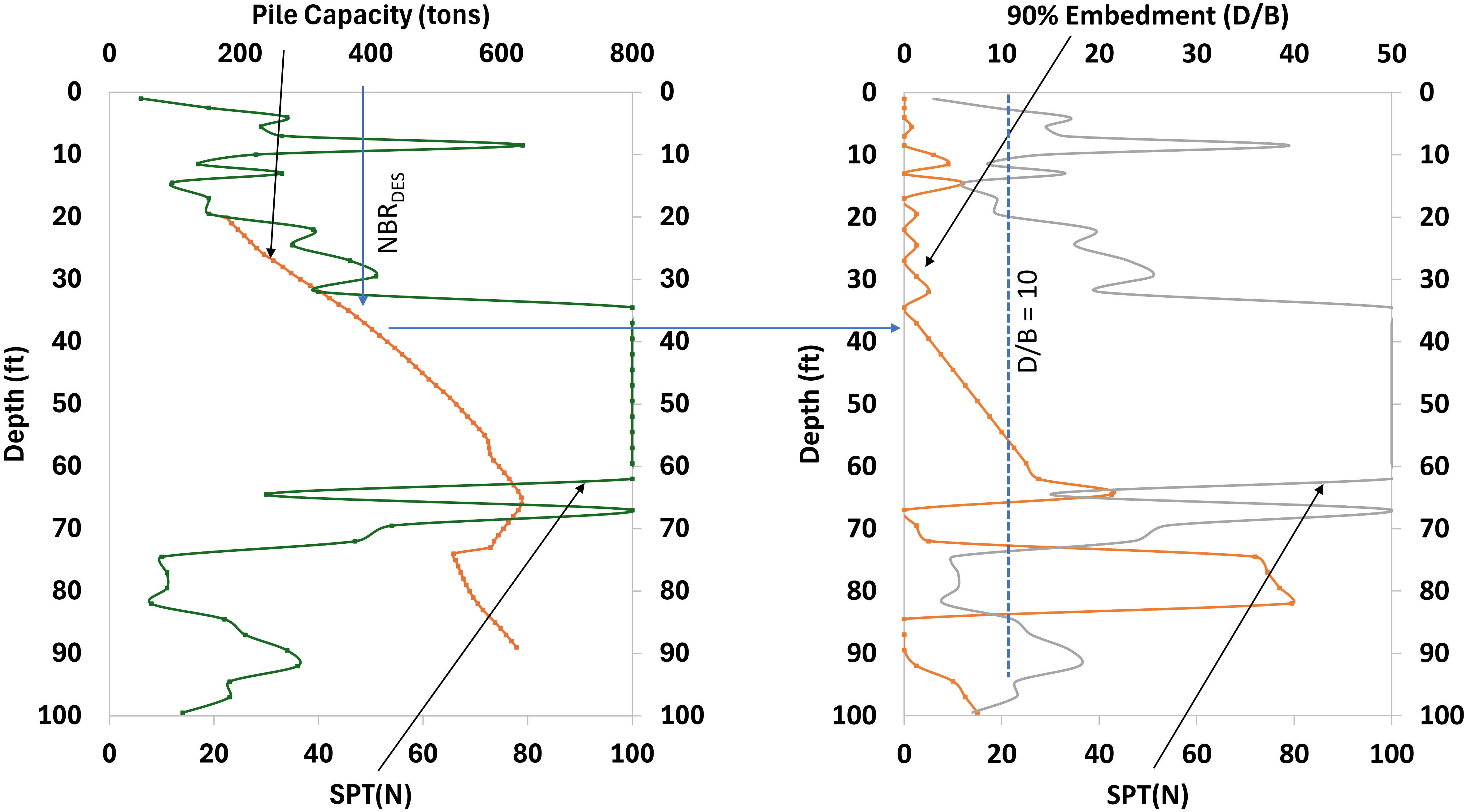

3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Capacity Ratio
0
5
10
15
20
25
30
35
40
Embedment D/B (100% tip BLC), dim.



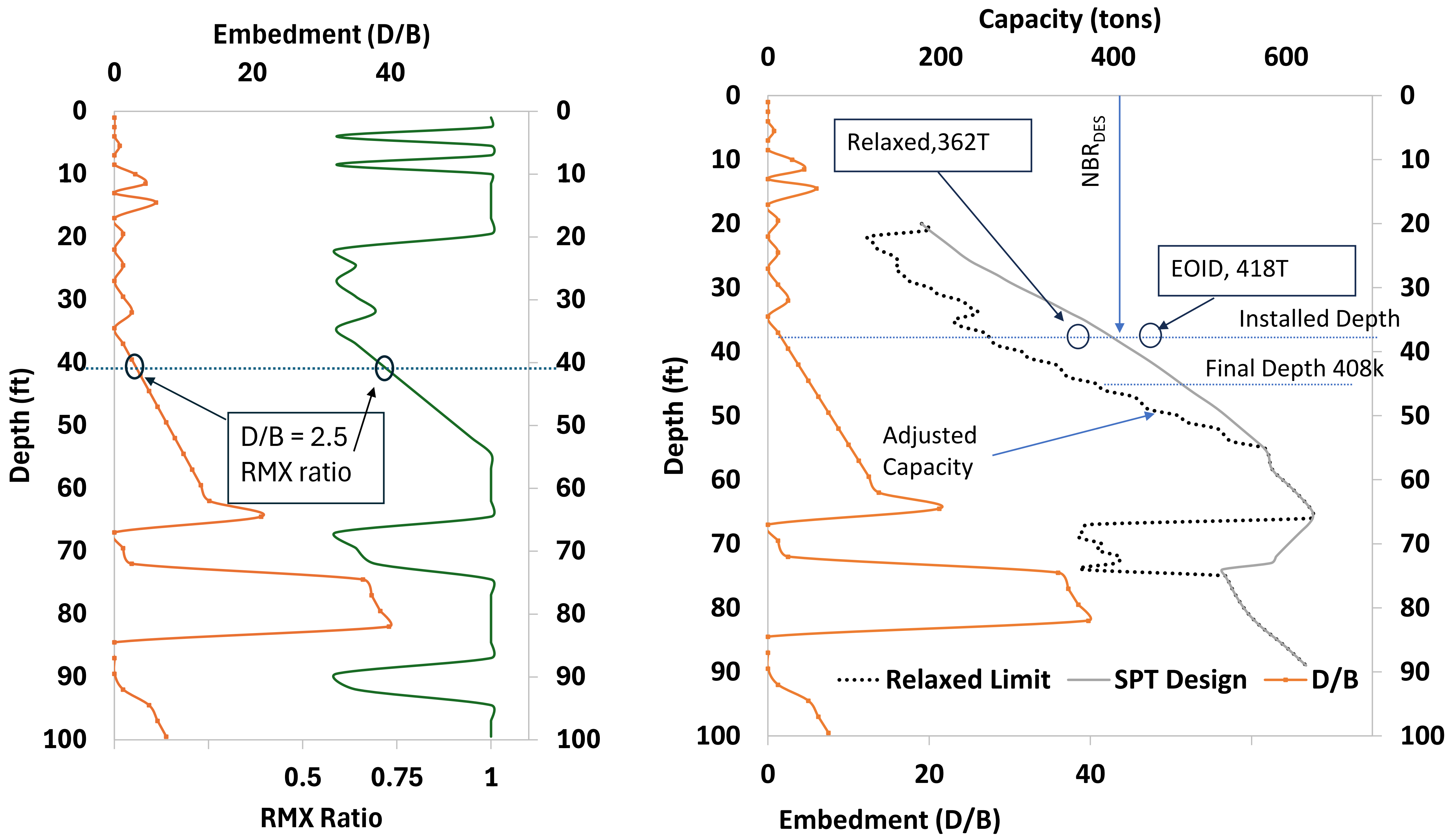
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
RMX Capacity Ratio
Percent BLC$_{tip}$
100 90
80
70
60
40
20
0
5
10
15
20
25
30
35
40
D/B = 5
Embedment D/B, dim.



1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
RMX Capacity Ratio
90% BLC$_{tip}$ Data
90 to 100% BLC$_{tip}$
Relaxation Potential
Worst Case Limit
RMX ratio = 0.04(D/B) + 0.6
0
5
10
15
Embedment D/B, dim.
90% SPT$_{tip}$ Data
90 to 100% BLC$_{tip}$
Relaxation Potential
Embedment D/B, dim.



Pile Capacity (tons)
0
200
400
600
800
NBR_DES
Depth (ft)
SPT(N)
90% Embedment (D/B)
0
10
20
30
40
50
D/B = 10
Depth (ft)
SPT(N)



Embedment (D/B)
0
20
40
Depth (ft)
0
10
20
30
40
50
60
70
80
90
100
D/B = 2.5
RMX ratio
0.5
0.75
1
RMX Ratio
Capacity (tons)
0
200
400
600
Relaxed,362T
NBR_DES
EOID, 418T
Installed Depth
Final Depth 408k
Adjusted
Capacity
Relaxed Limit
SPT Design
D/B
Embedment (D/B)

Summary

- Most relaxation cases occurred in medium dense, dense and very dense sand.
- Dilation theory is likely the best explanation
- Creep effects not found
- Pile length not specifically the cause of relaxation
- Sufficient embedment depth into competent bearing layer appears to be the strongest deterrent to relaxation
- D/B embedment > 10 showed no relaxation

Limitations

- Bearing layer correction does not address medium dense layers at higher elevations away from the pile tip which may also experience relaxation; some references suggest not as problematic
- The study examined only used end of restrike vs end of initial drive values. Relaxation that was observed during cushion changes or other intermediate installation pauses were not and could not be addressed.

Future Work

- Study was intended to identify cases of setup and relaxation and what conditions controlled each situation; a focus on laboratory tests that might predict relaxation were not within the scope.
- Other methods of designing for relaxation by correcting for SPT "N" like Terzaghi (Nd= 15 + 0.5(N-15) or Bazarra (Nd= 0.6(N)) for sandy soils with N>15 were not considered. Comparison of those methods with the proposed adjusted capacity should be performed.
- A strength-based critical depth correction should be explored in lieu of the soil type method currently used; this has the potential of addressing both relaxation and critical embedment depth criteria.