Challenges in the Design of Screw-Piles and Helical Anchors in Soils

Alan J. Lutenegger, P.E., PhD, F. ASCE
Professor
Department of Civil & Environmental Engineering
University of Massachusetts

GeoVirginia

April 28, 2015

Outline

What are Screw-Piles and Helical Anchors?

Challenge 1. Characterization of Soil Parameters

Challenge 2. Understanding Effects of Installation Disturbance

Challenge 3. Understanding Role of Shaft & Helix

A Comment on Torque-to-Capacity Ratios

International Building Code

Section 1802.1 defines a Helical Pile as:

"Manufactured steel deep foundation element consisting of a central shaft and one or more helical bearing plates. A helical pile is installed by rotating it into the ground. Each helical bearing plate is formed into a screw thread with a uniform defined pitch."

This Technology is Not New

It is Over 170 Years Old

1st Recorded use of Screw-Piles was by Alexander Mitchell (1780-1868) in 1836 for Ship Moorings and was then applied by Mitchell as Foundations for Maplin Sands Lighthouse in England in 1838

Mitchell's Screw-Pile Specifications for Maplin Sands

Material – Cast Iron

Shaft Diameter – 5 in.

Screw (Helix) Diameter – 4 ft.

Depth Below "Mudline" – 12 ft.

Orientation - Vertical

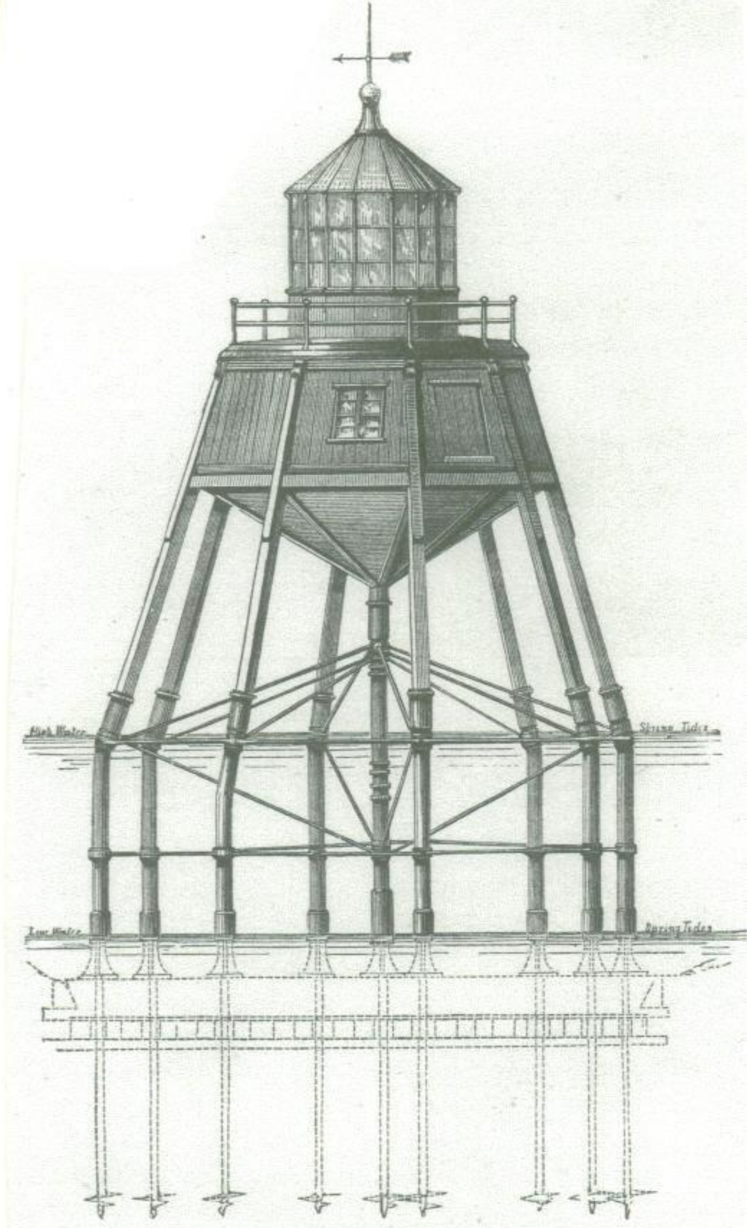
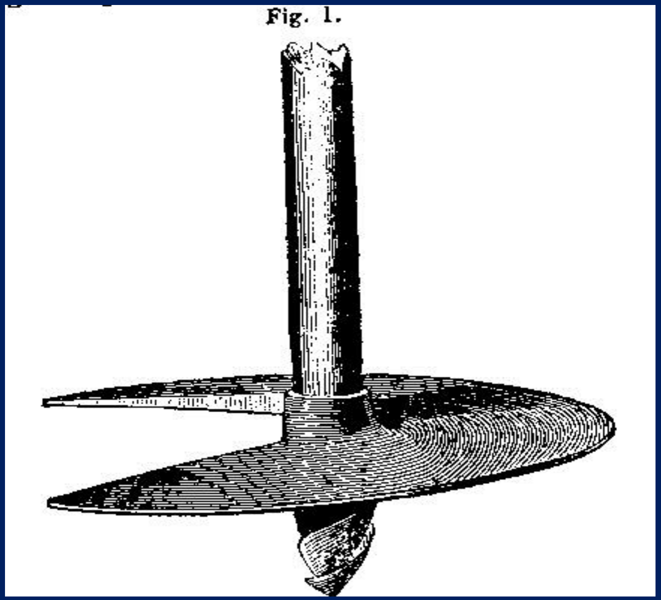
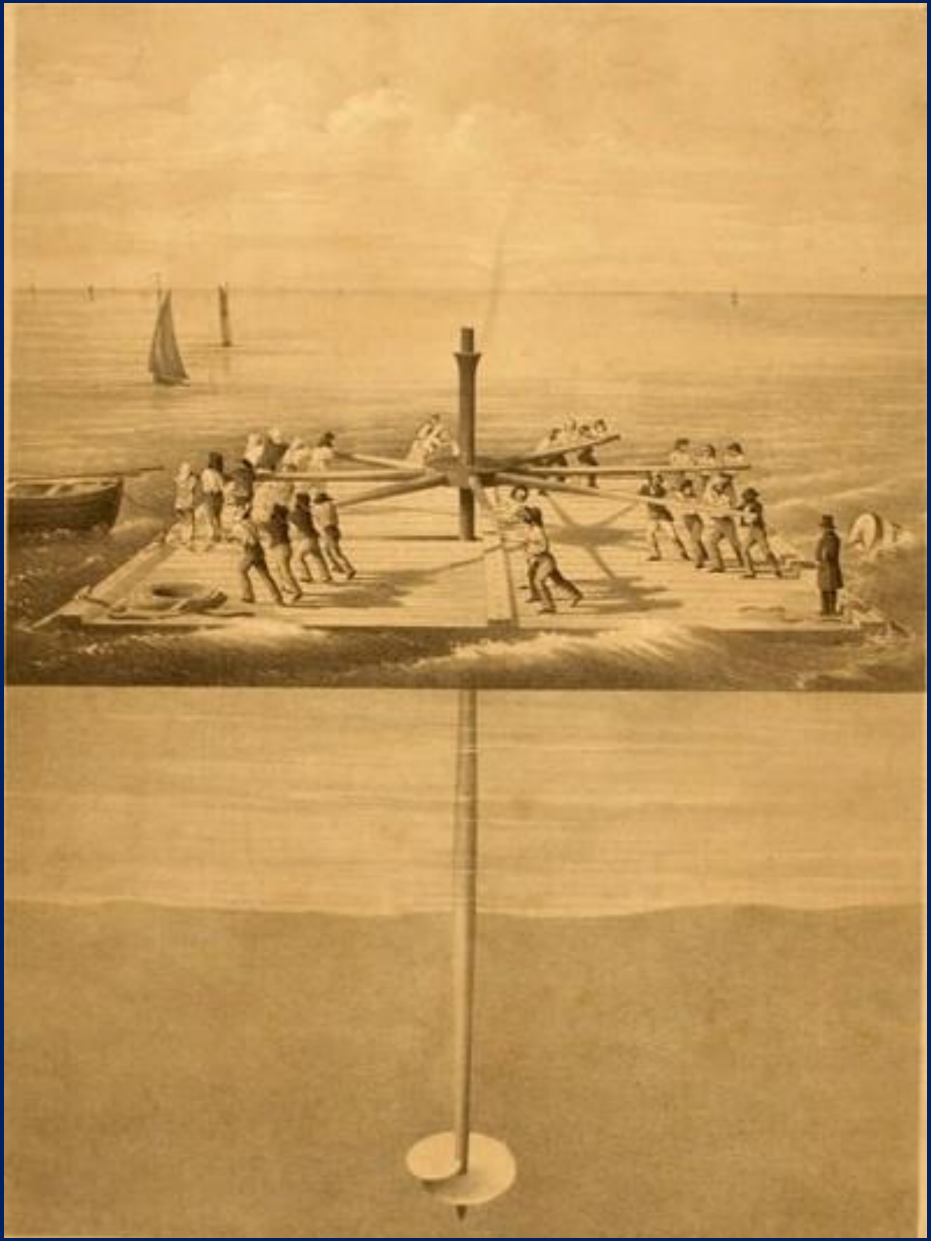


FIG. 3.—MAPLIN SANDS LIGHTHOUSE.

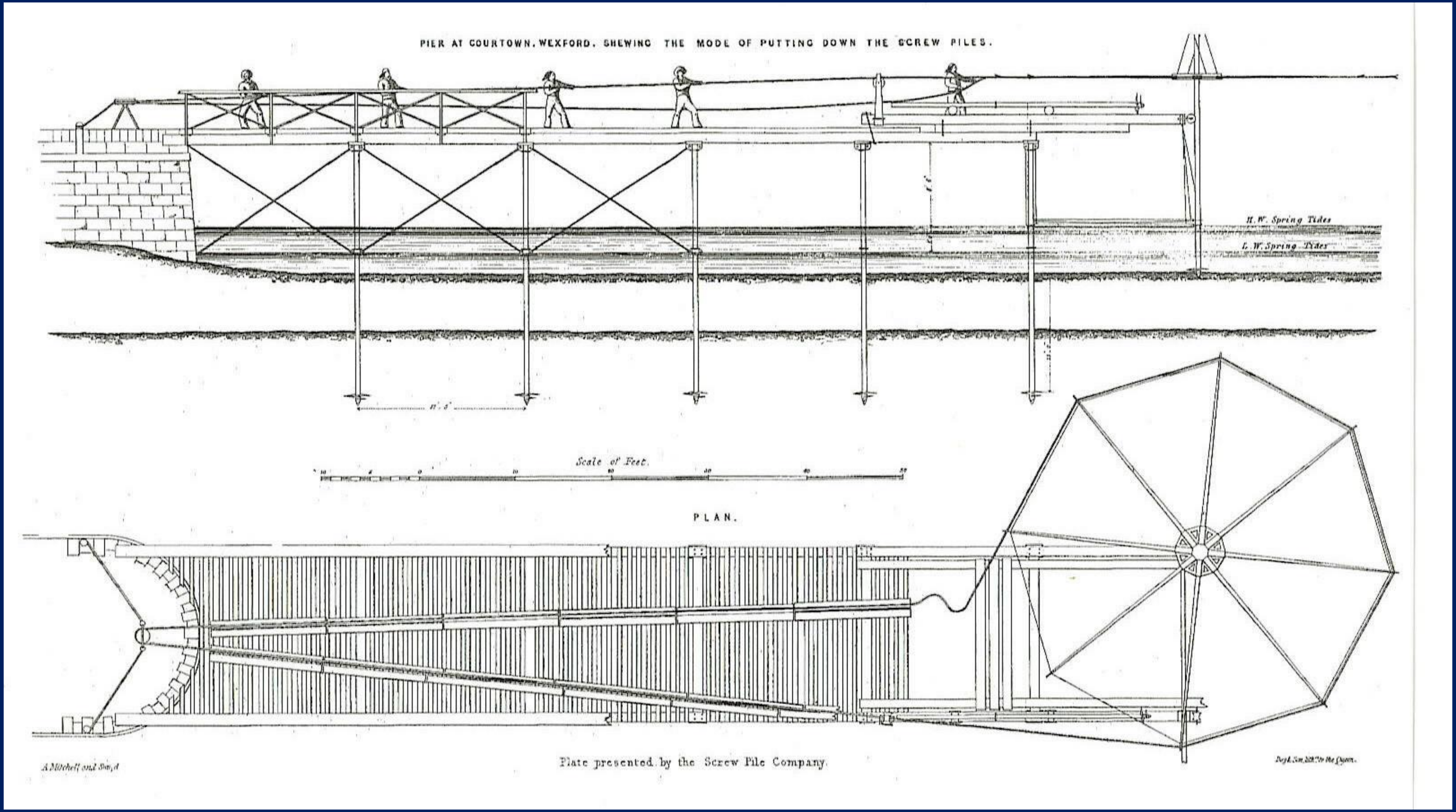
"On Submarine Foundations; particularly Screw-Pile and Moorings", by Alexander Mitchell, *Civil Engineer and Architects Journal*, Vol. 12, 1848.



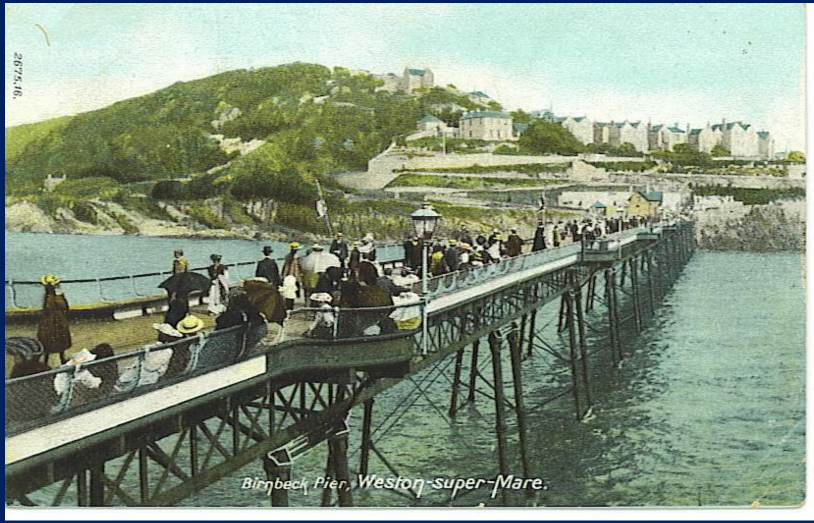
" Whether this broad spiral flange, or "Ground Screw," as it may be termed, be applied … to support a superincumbent weight, or be employed … to resist an upward strain, its holding power entirely depends upon the area of its disc, the nature of the ground into which it is inserted, and the depth to which it is forced beneath the surface."



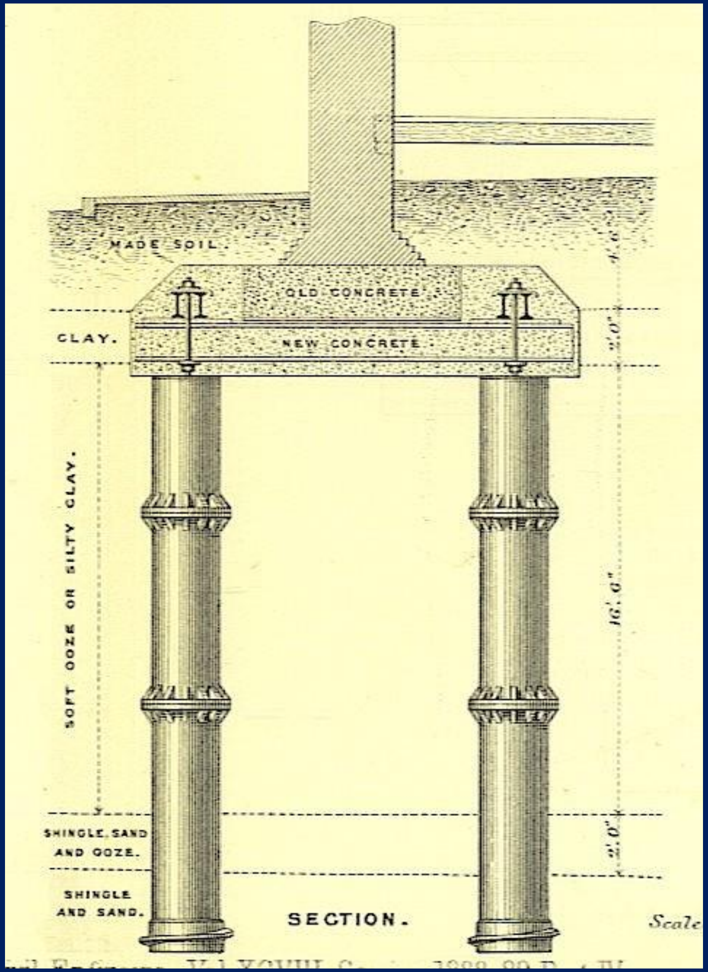
Pier Construction



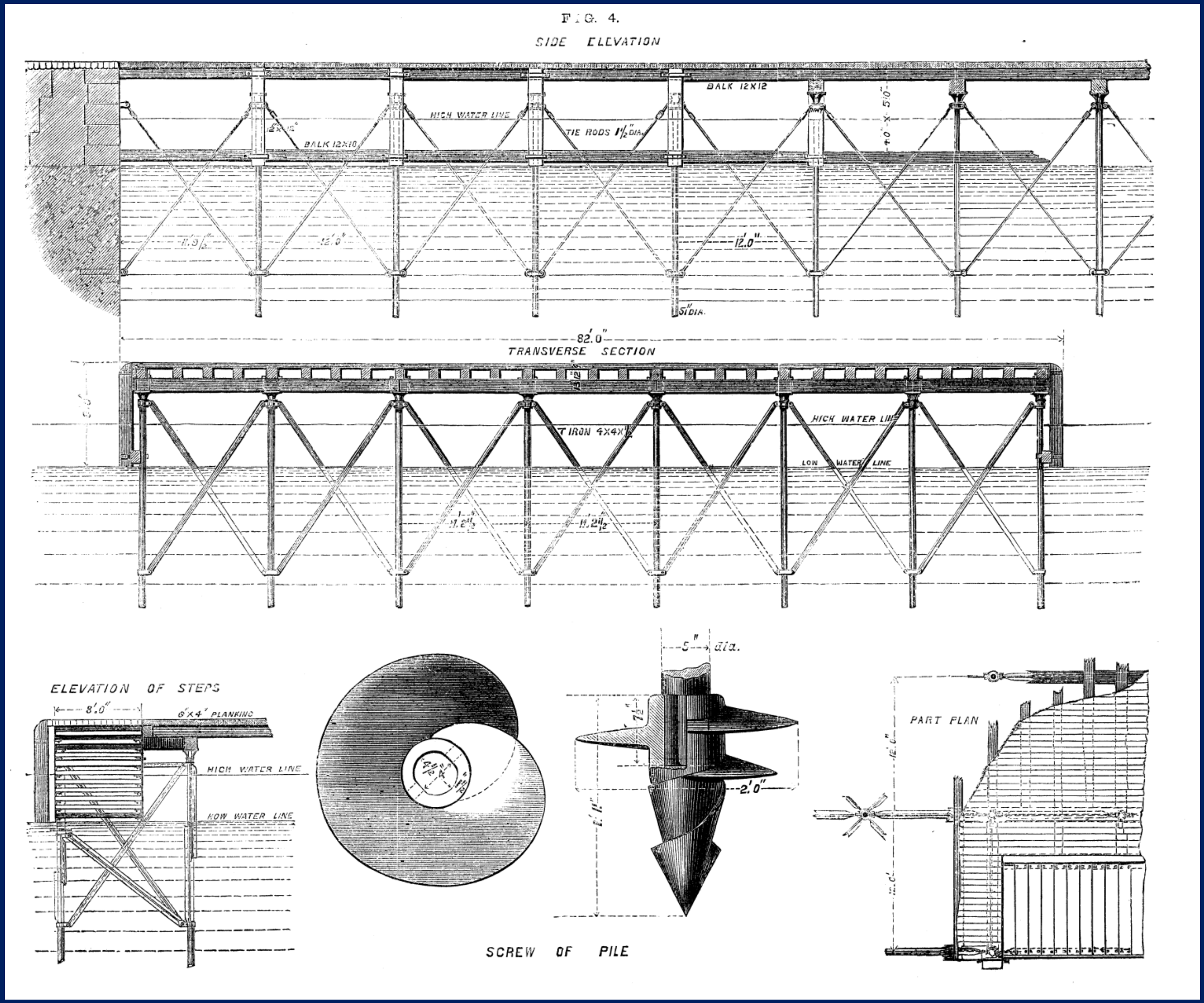
Pleasure Piers in England



Underpinning – Great Yarmouth Town Hall 1880



Bridge Foundations



How are Screw-Piles and Helical Anchors Currently Being Used in Civil Construction?

Electric Utilities

Underpinning/Retrofitting Existing Foundations

New Foundations and Anchor Systems


JCB
JCB


SMITHS

Factory Manufactured Foundation/Anchor System

The Industry is Largely Driven by Manufacturers and Contractors

The Complexity of Design

Single-Helix or Multi-Helix?
"Tapered" or Uniform Helices?
Close or Large Helix Spacing?
Square-Shaft or Round-Shaft?
Compression or Tension?
Sand or Clay?
Steel Shaft or Grouted Shaft?
Aging

What are the Challenges in Design?

Challenge 1. Characterization of Soil Parameters

Challenge 2. Understanding Effects of Installation Disturbance

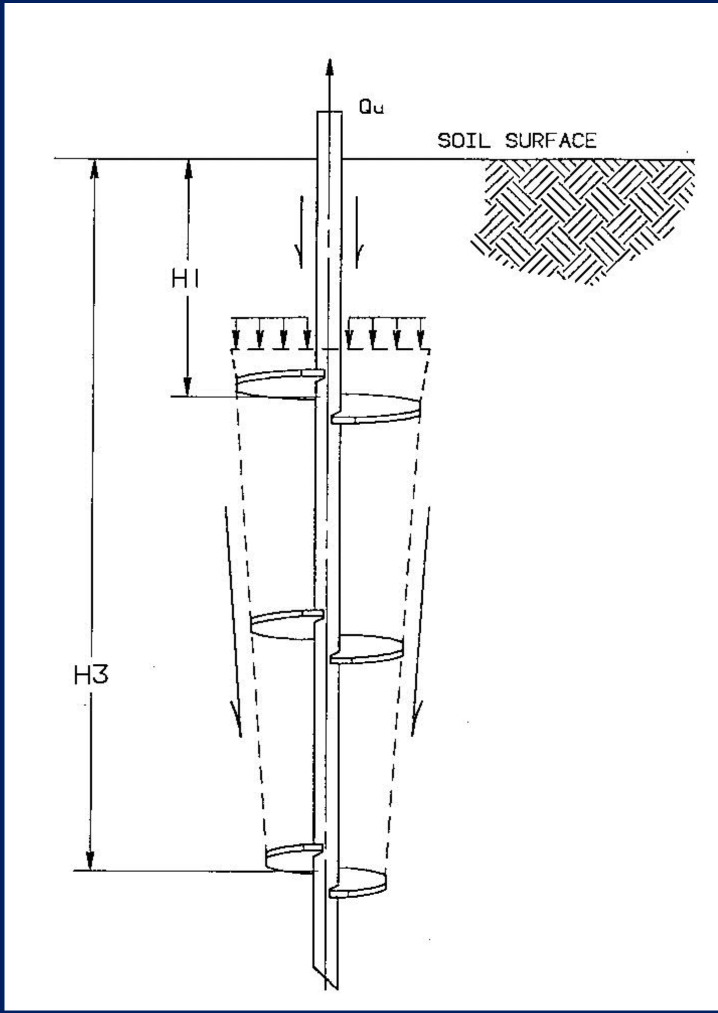
Challenge 3. Understanding Role of Shaft & Helix

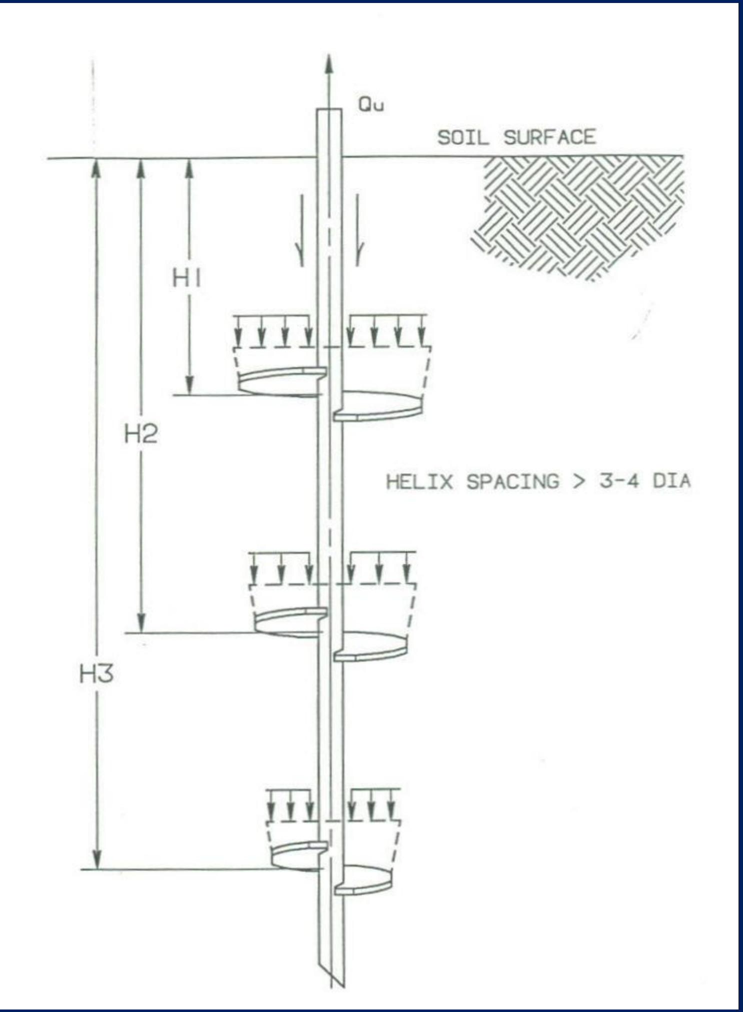
Challenge 1. Characterization of Soil Parameters

Not Unique to Screw-Piles and Helical Anchors but Needed for all Geotechnical Projects

We Need to Evaluate Models Used for Design and Determine Input Parameters

Traditional Design Models





Evaluation of Ultimate Capacity

(Traditional Soil Mechanics Approach)

Single-Helix

Clay – Undrained TSA

$$Q_H = s_u N_c A_H$$

Sand – Drained ESA

$$Q_H = N_q \sigma_v' A_H$$

Multi-Helix

$$Q_T = \sum Q_{HI}$$

In Uniform Soils with Same Size Helices

$$Q_T = N \times Q_{HI}$$

Now Include Shaft Resistance for Round Shafts

$$Q_T = \sum Q_{HI} + Q_S$$

$$Q_S = f_s A_S$$

$$f_s = s_u \alpha$$

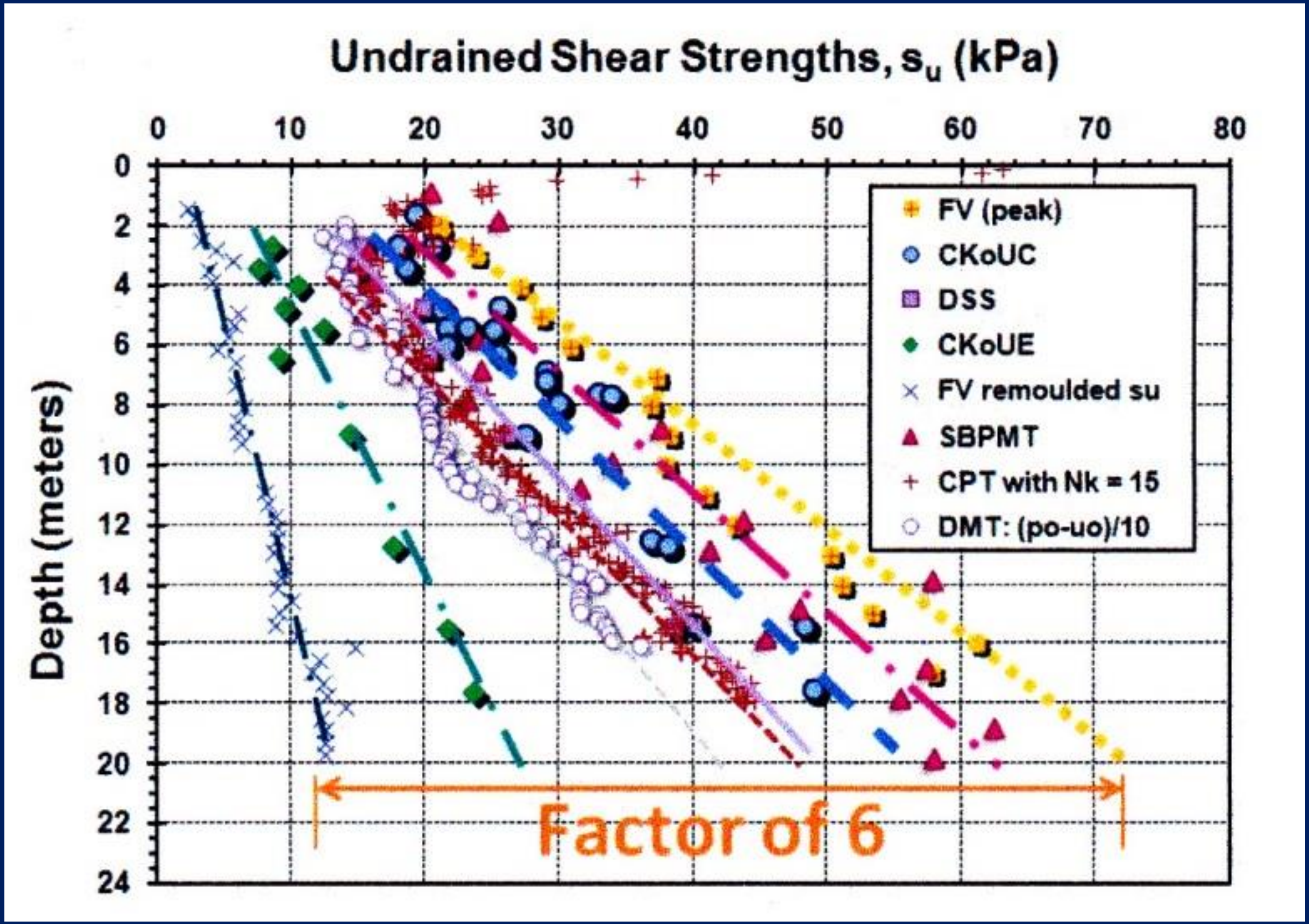
$$f_s = \beta \sigma'_v$$

Other than Compositional Characteristics, Most Soil Parameters are Not Unique

Clay – Undrained Shear Strength: but which s_u??

Sand - N_q from φ': but which φ' and which N_q?

Undrained Shear Strength of Clay from Different Tests (from Mayne)



N_q Chart from Popular Book

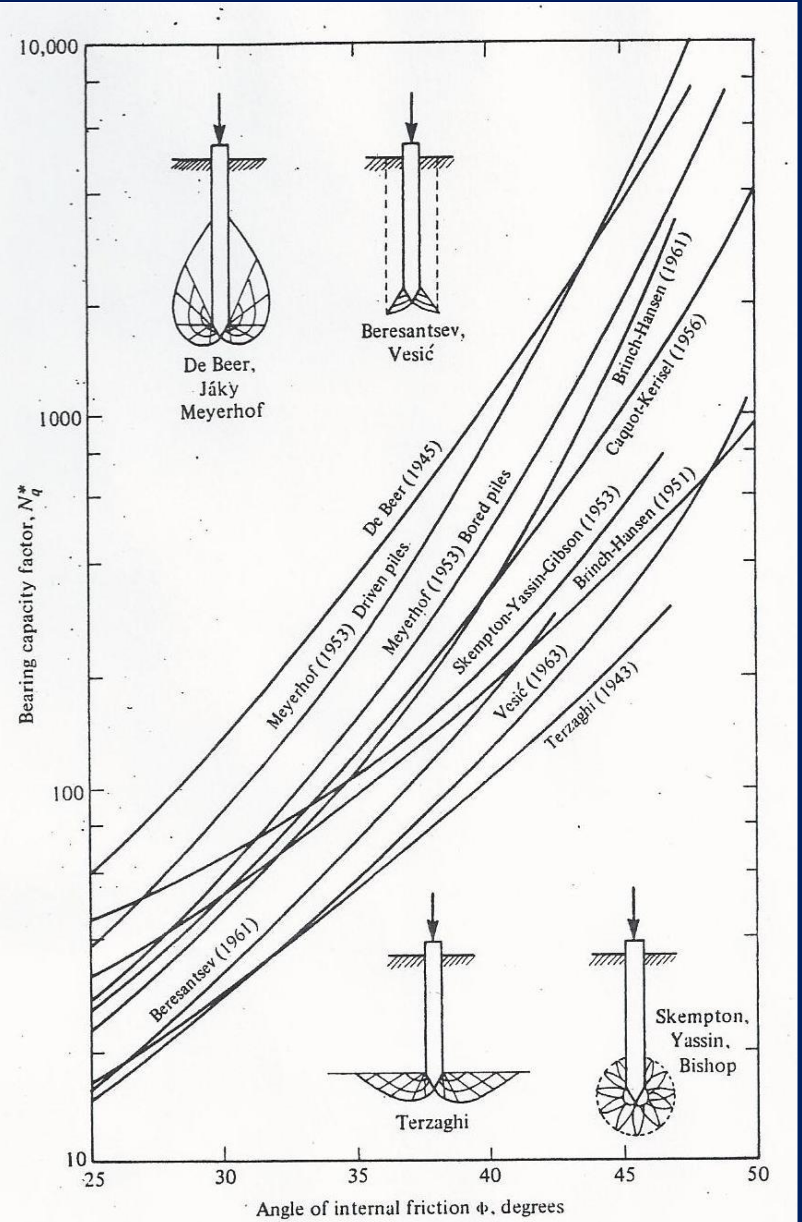


Fig. 19.49 Bearing capacity factors vs. angle of internal friction, according to various authors.

Challenge 2. Understanding Effects of Installation Disturbance

(Related to Challenge 1)

Somewhat Unique to Screw-Piles and Helical Anchors but Important for Many Deep Foundations

We Need to Evaluate How Contractor Installation May Affect Soil Parameters

Where Might We Expect Installation Disturbance and a Reduction in Helix Efficiency?

"Structured" Soils

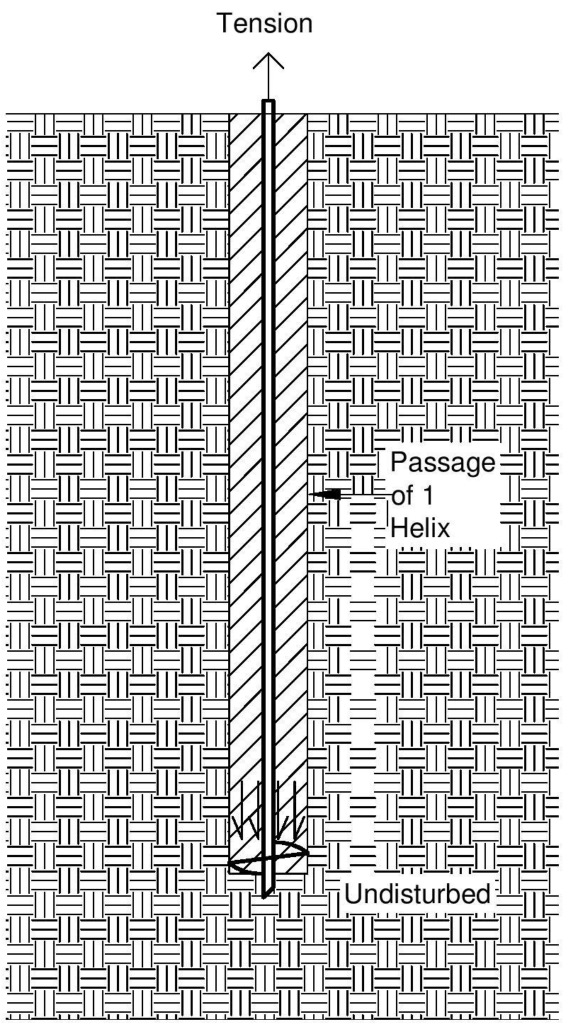
"Cemented" Soils

"Sensitive" Soils

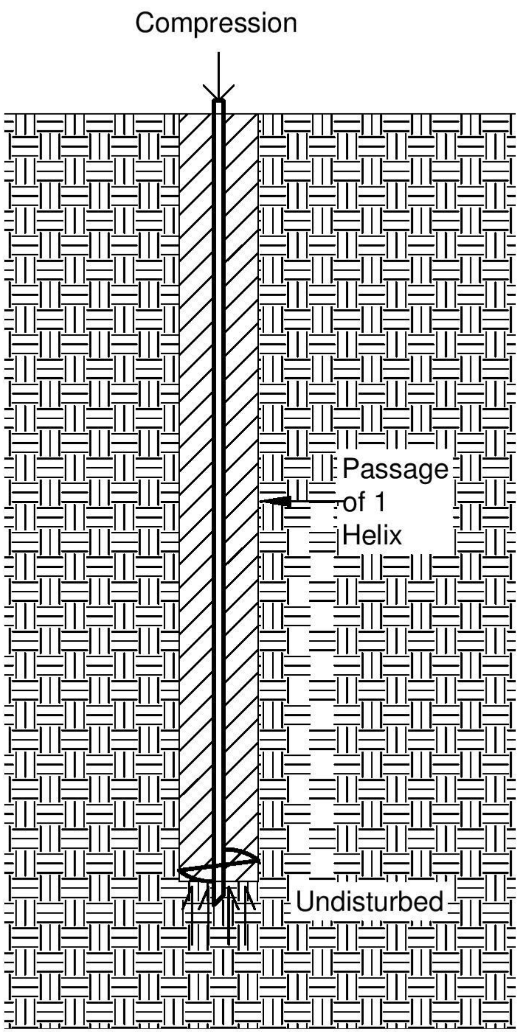
Dense Sands

All Soils?

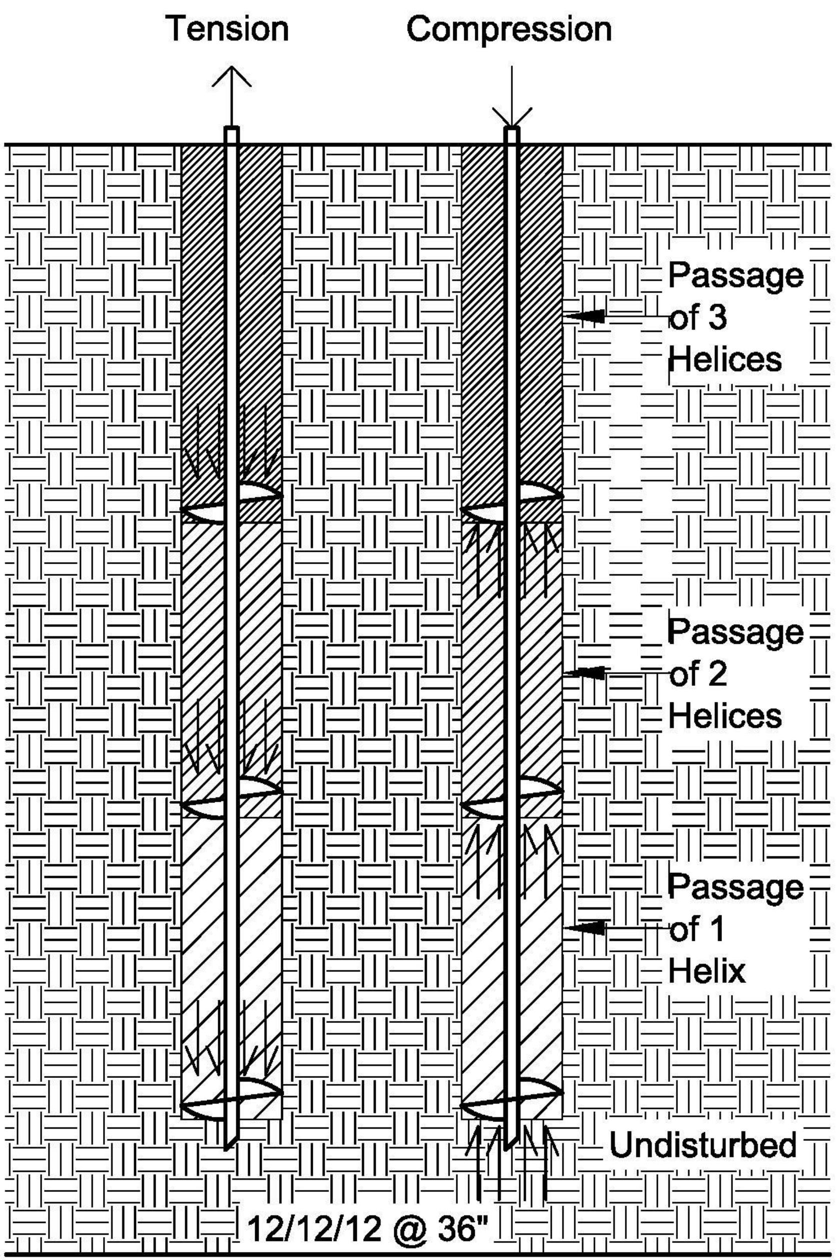
Tension Loading of Single-Helix in Clay



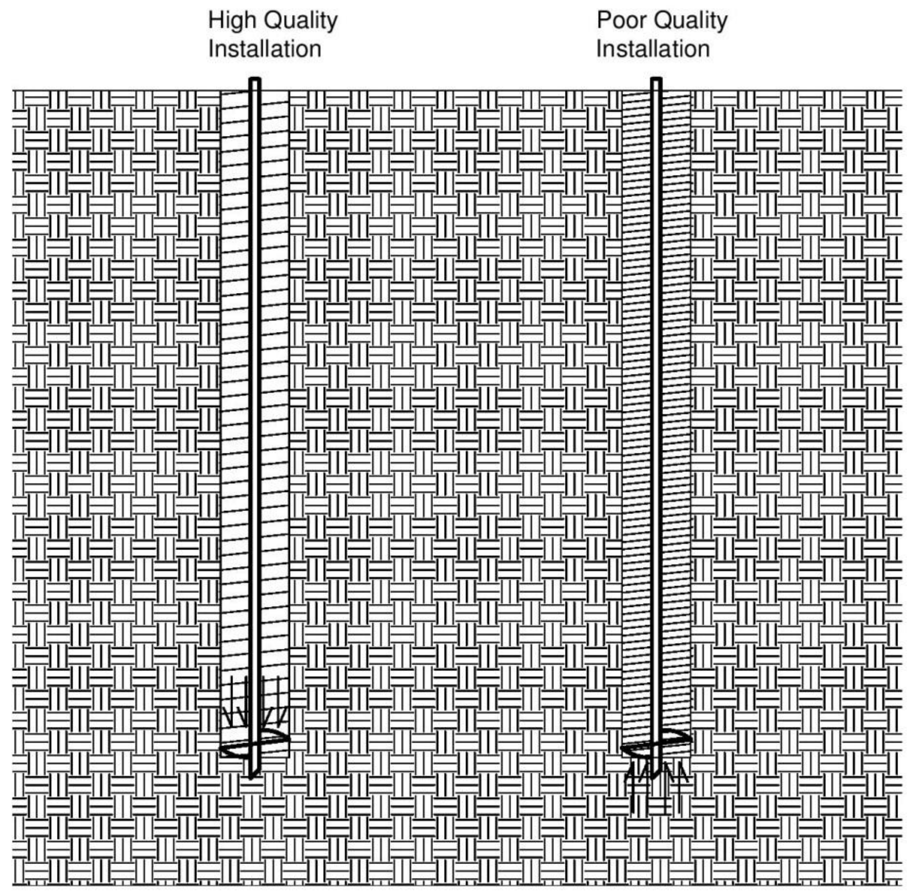
Compression Loading of Single-Helix in Clay



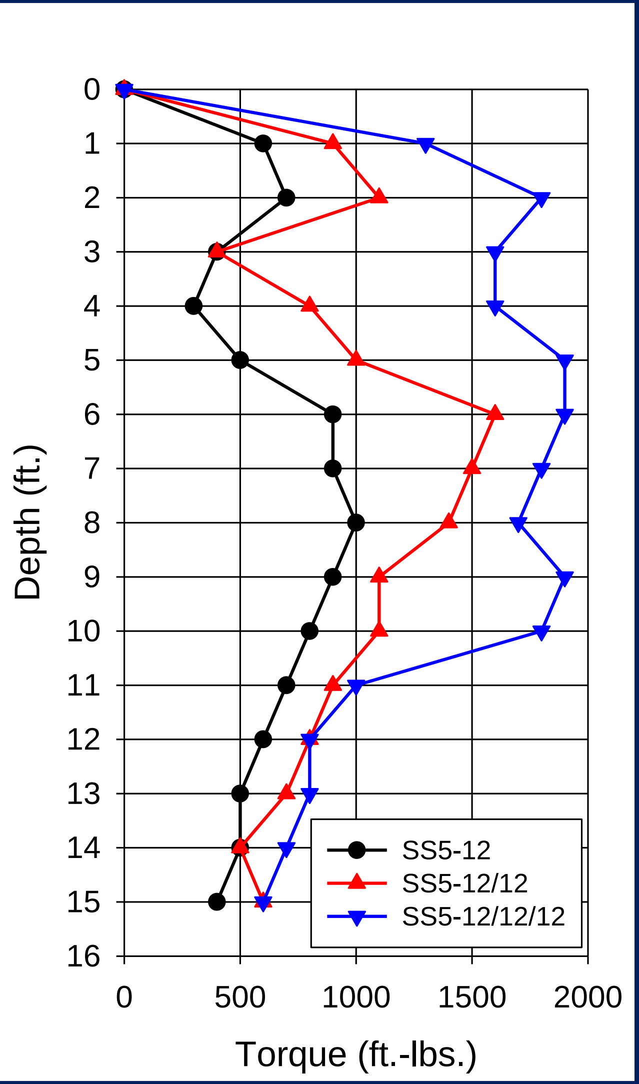
Tension and Compression Loading of Multi-Helix in Clay

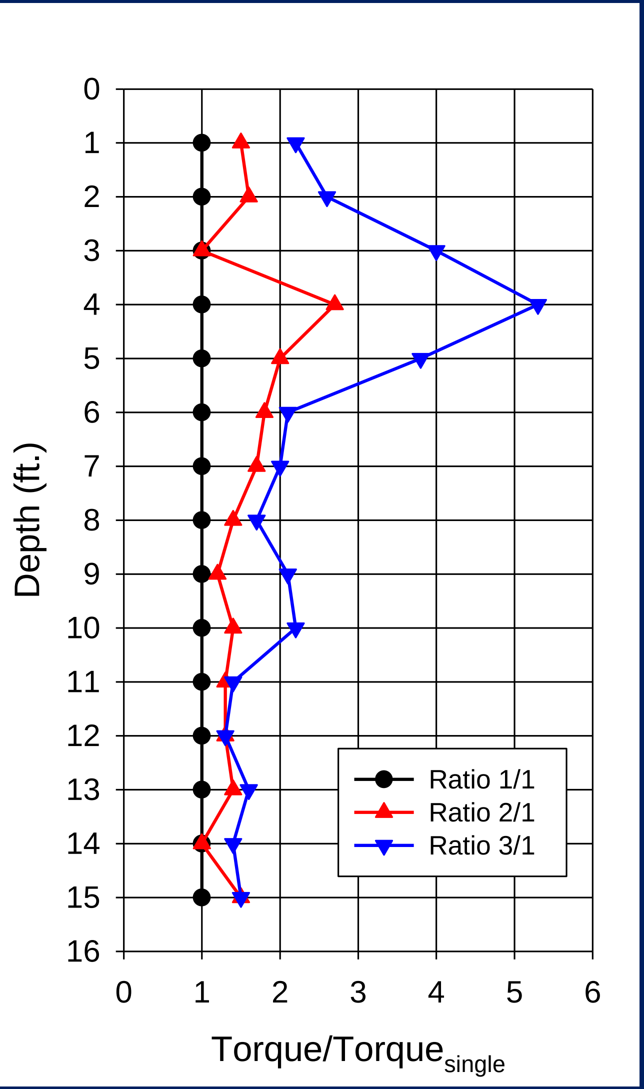


High Quality vs. Poor Quality Installation in Clay

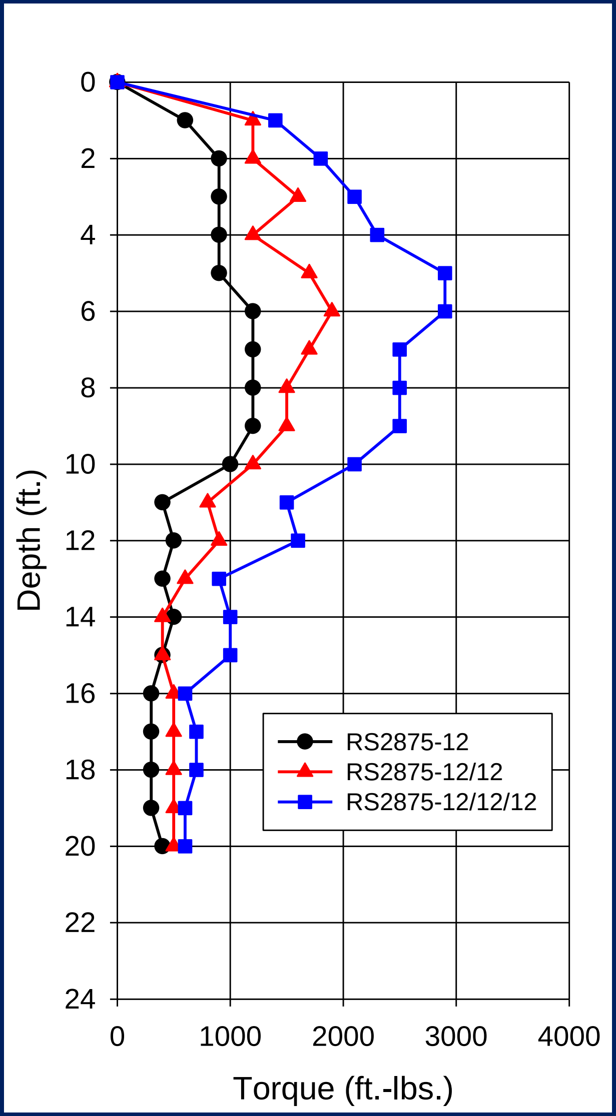


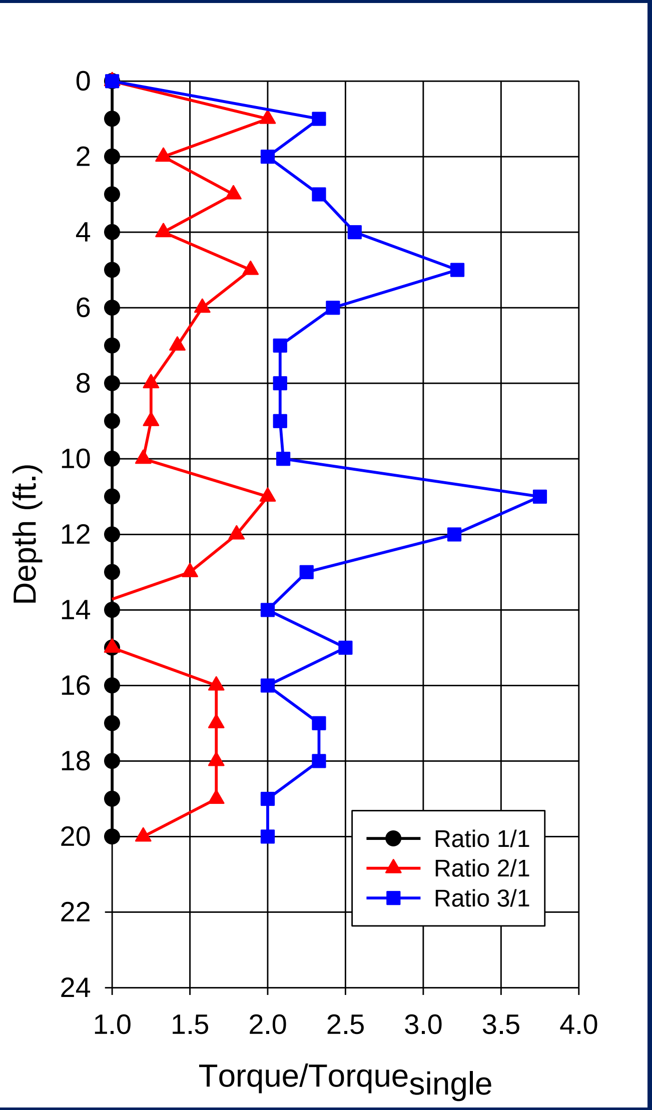
Square-Shaft Single- & Multi-Helix - Clay



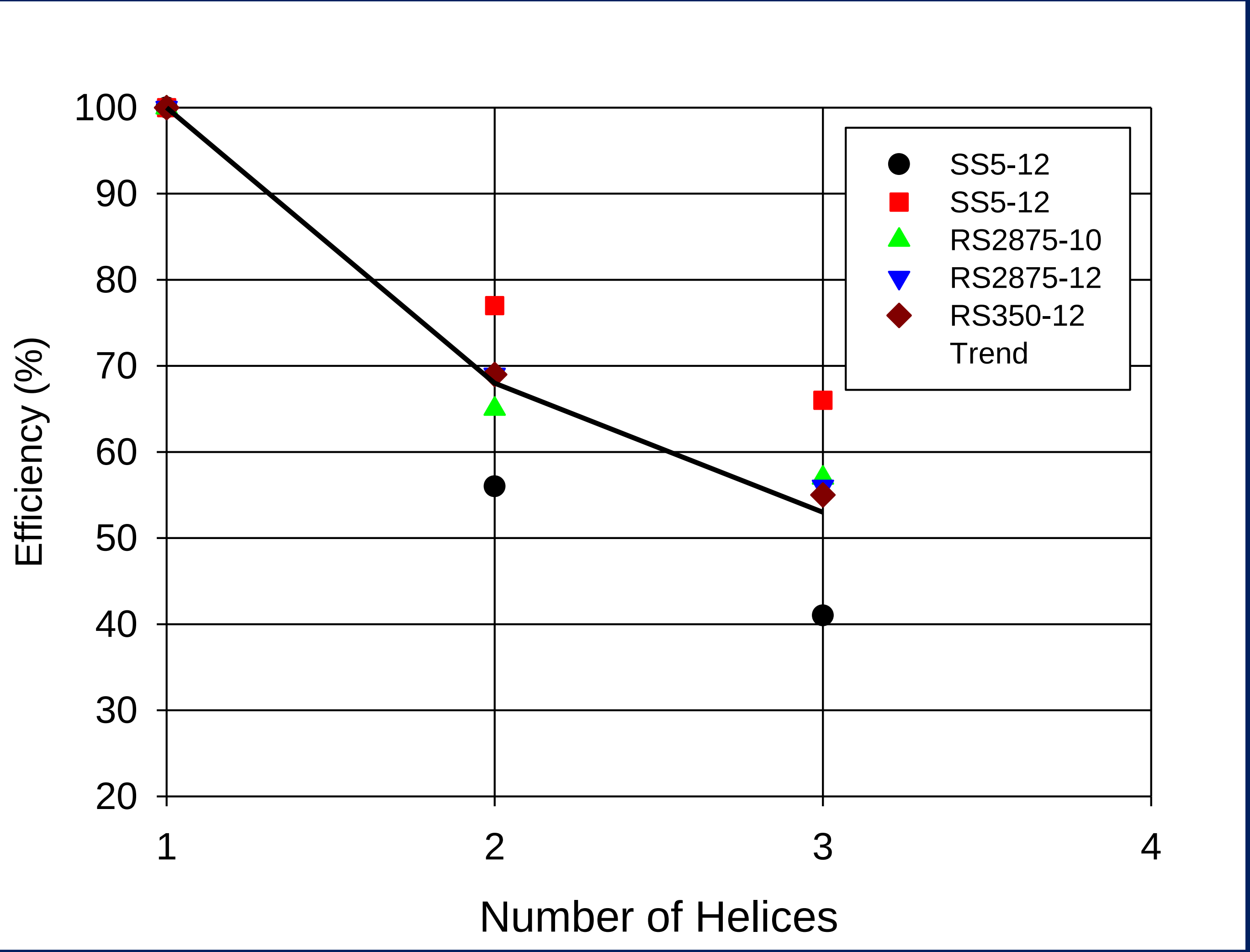


Round-Shaft Single- & Multi-Helix - Clay



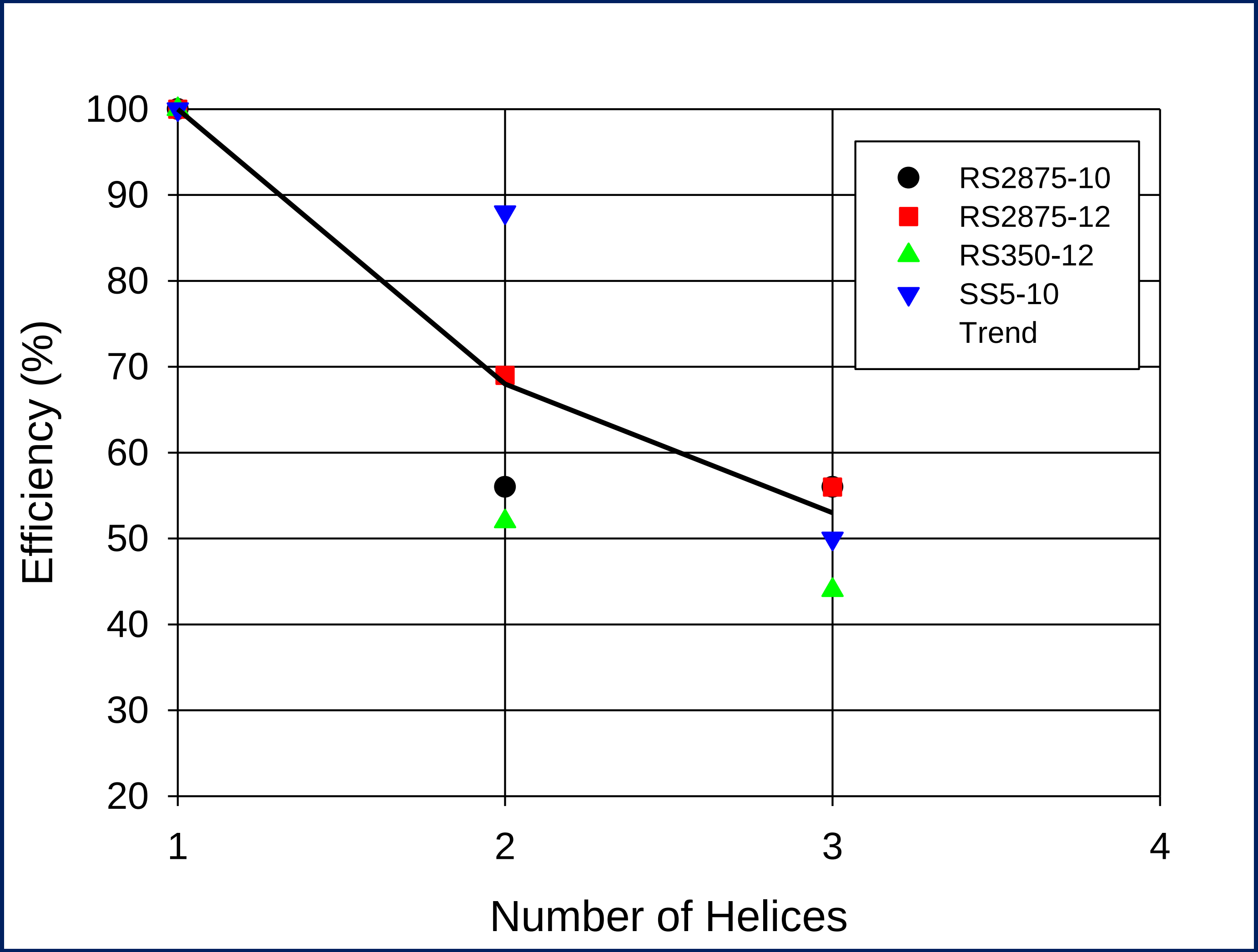


Soft Clay



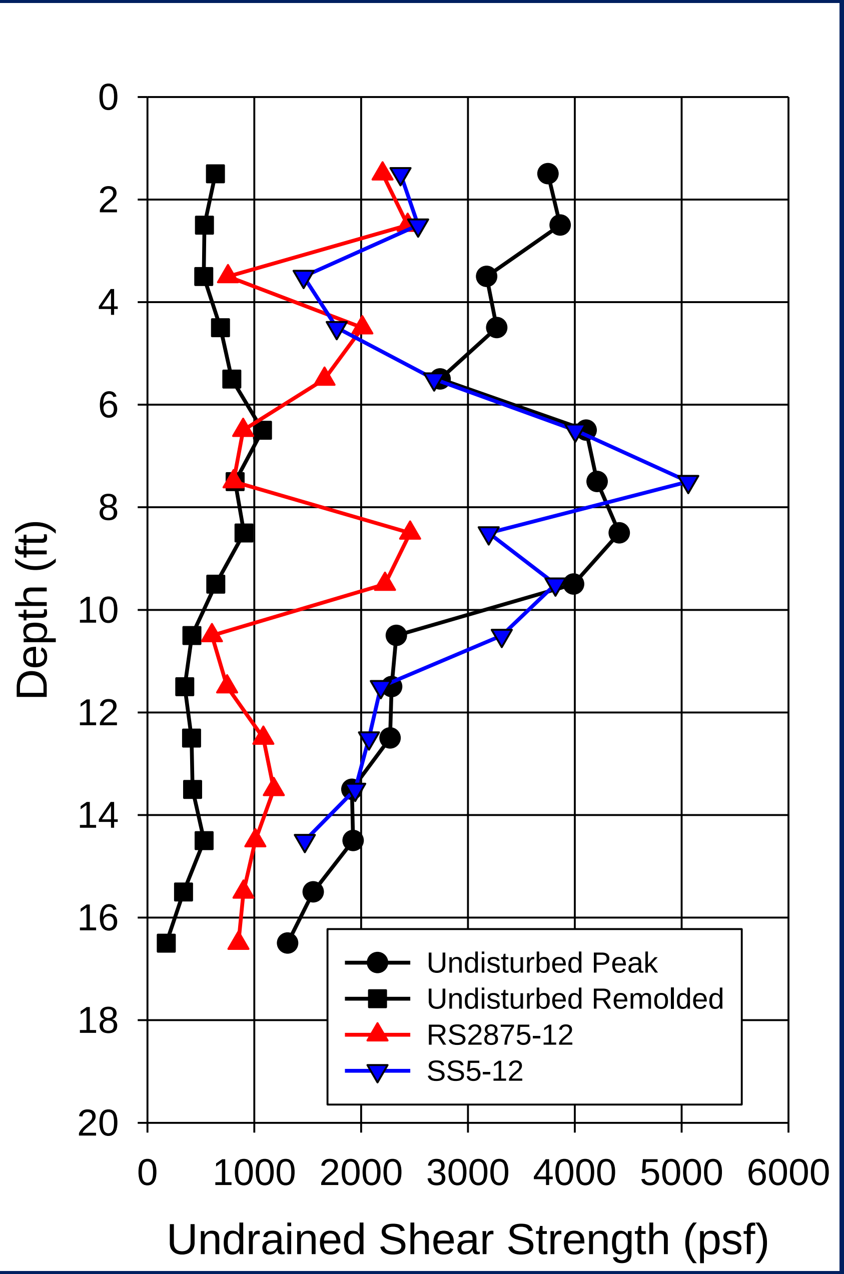
100
90
80
70
60
50
40
30
20
1
2
3
4
Efficiency (%)
Number of Helices
SS5-12
SS5-12
RS2875-10
RS2875-12
RS350-12
Trend

Stiff Clay

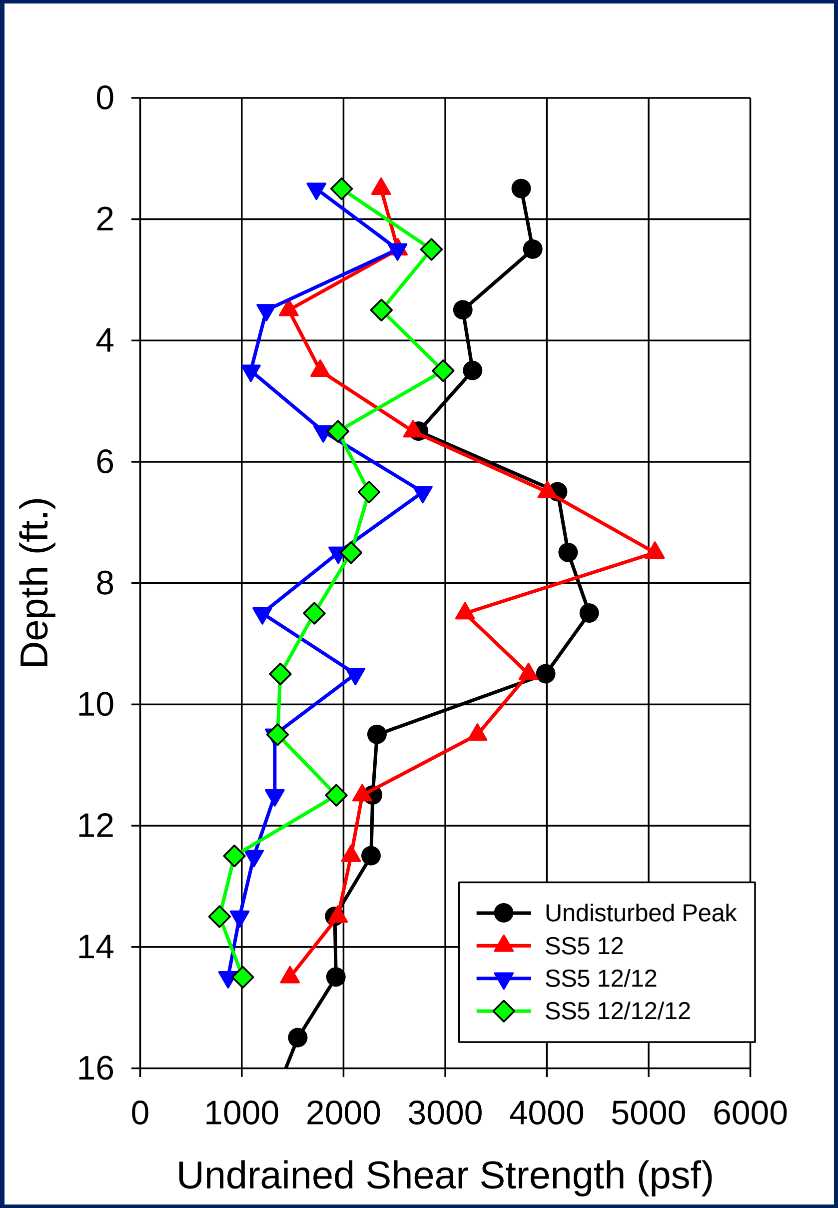


Efficiency (%)
100
90
80
70
60
50
40
30
20
1
2
3
4
Number of Helices
RS2875-10
RS2875-12
RS350-12
SS5-10
Trend

Vane Shear Tests Over Round-Shaft and Square-Shaft Single-Helix Anchors in Clay



Vane Shear Tests Over Square-Shaft <u>Single- Double- and Triple-Helix</u> Anchors in Clay



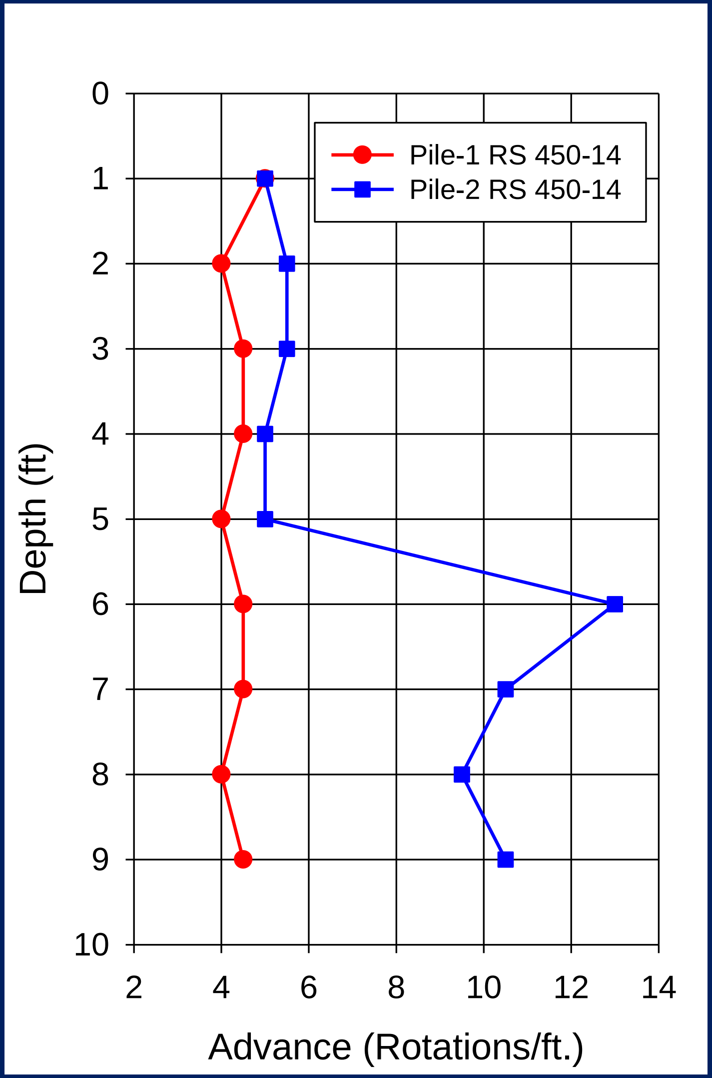
“Installation Disturbance Factor”

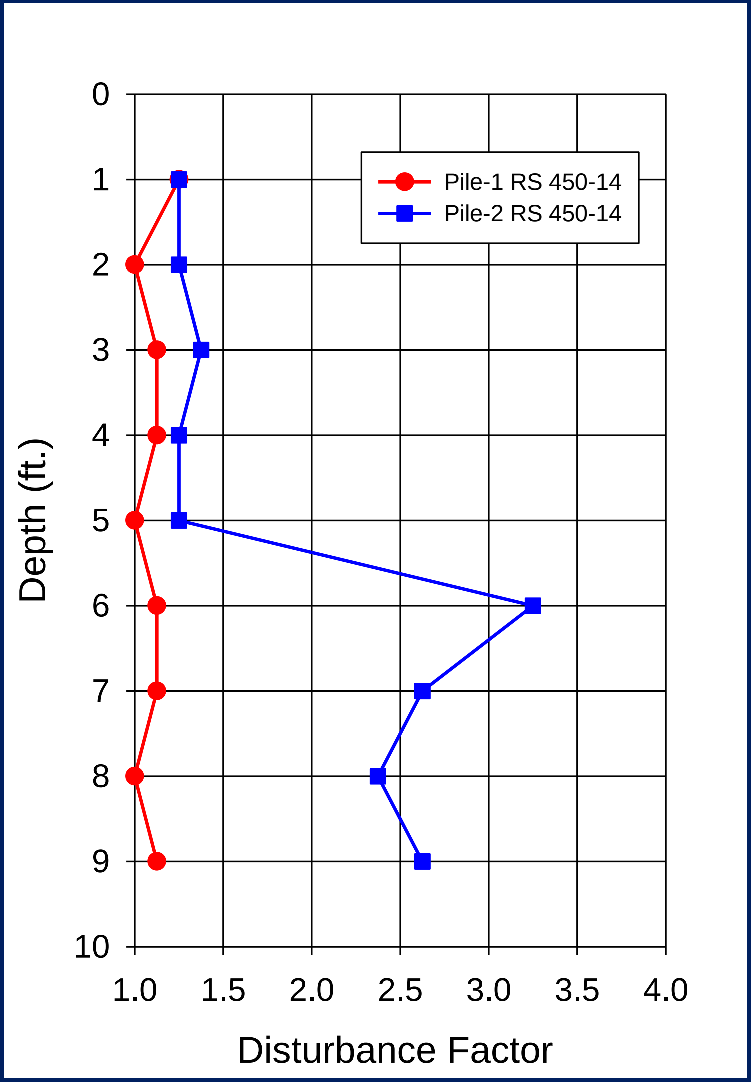
IDF = (Rotations per Advance)/(Ideal Advance/Pitch)

For Ideal or “Perfect” Installation of Screws with a 3 in. Pitch

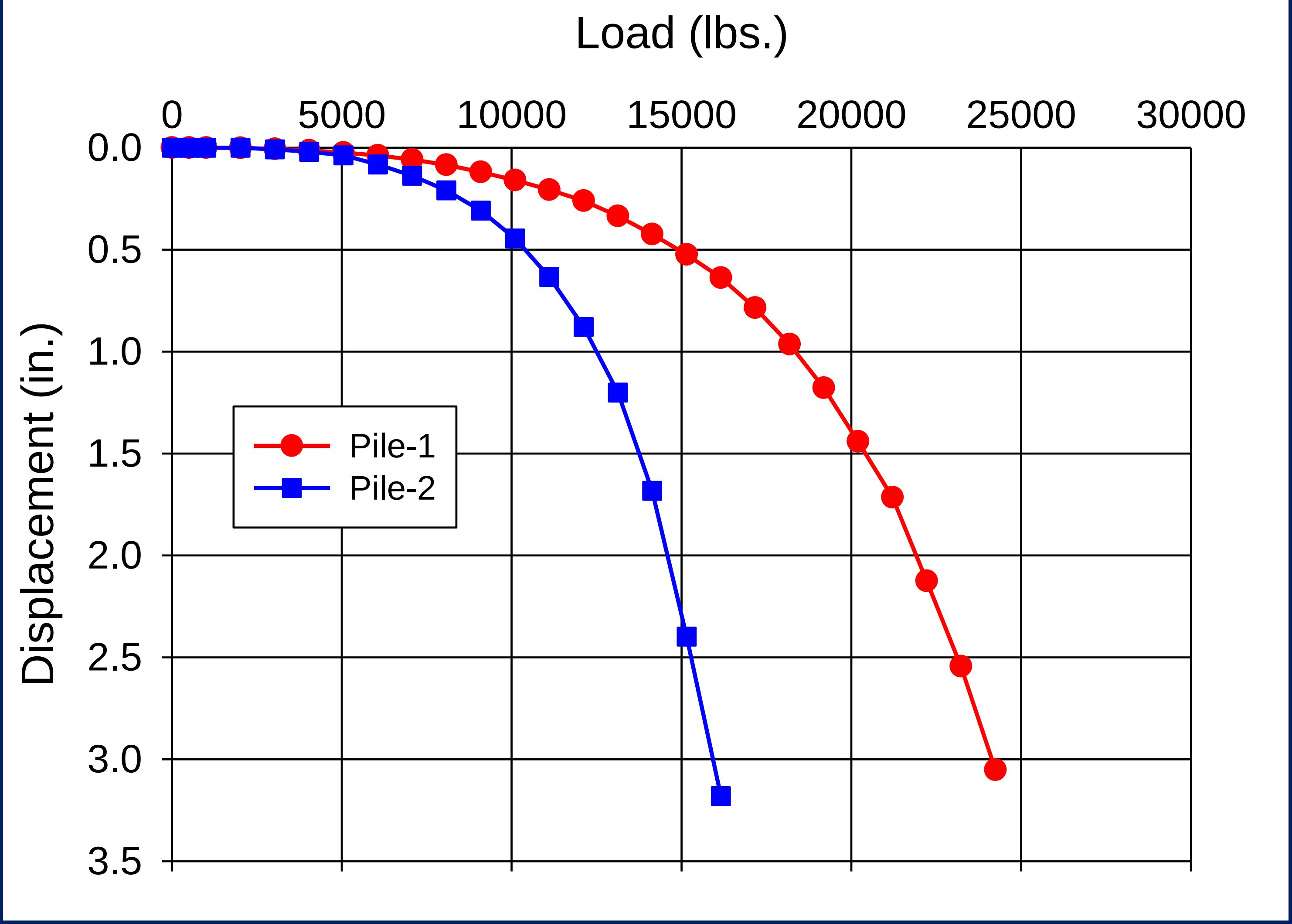
$$IDF = 4/4 = 1$$

Measured Disturbance Factor - Clay

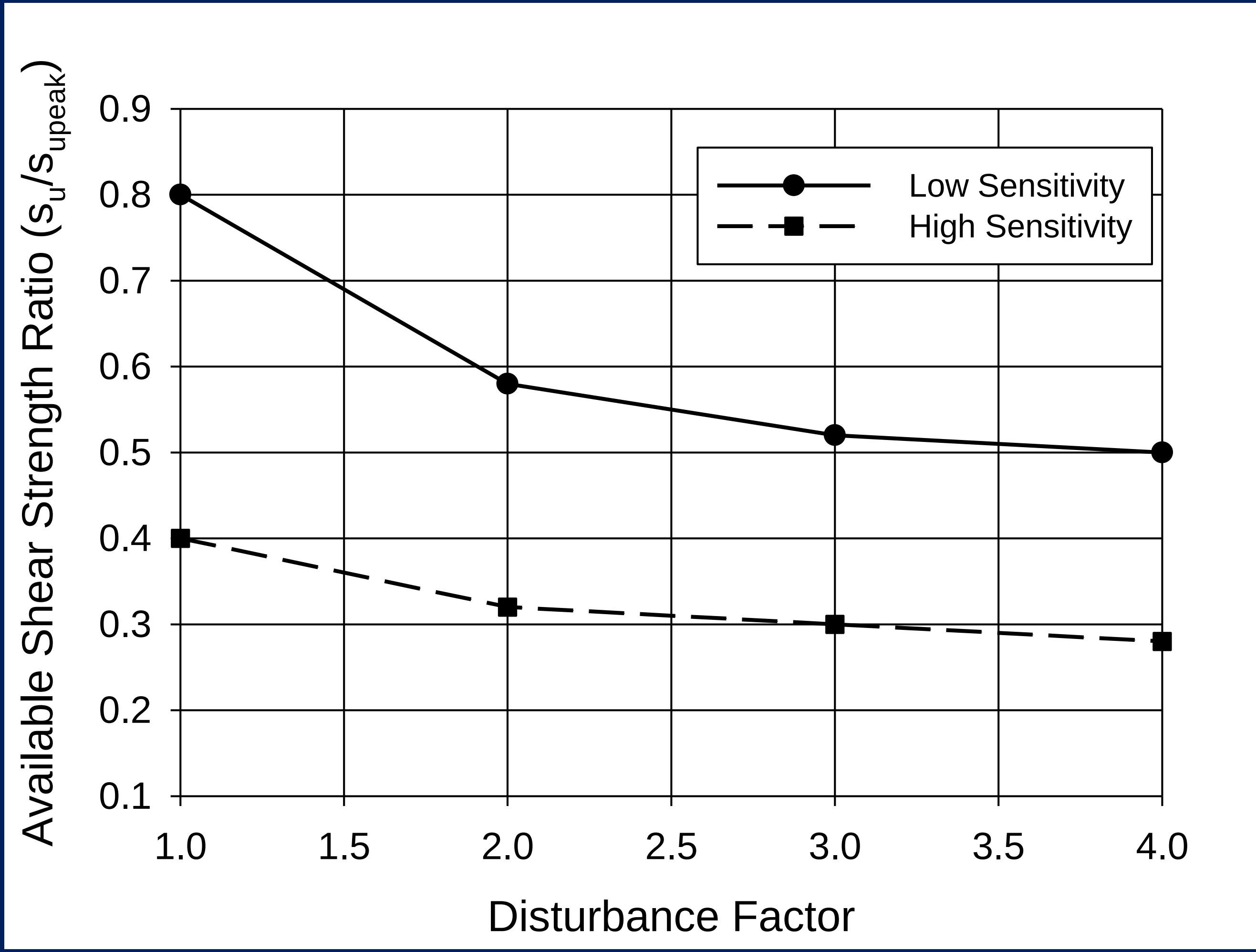




Influence on Load Test Results



For Clays We Might Want to Relate Available Strength to IDF



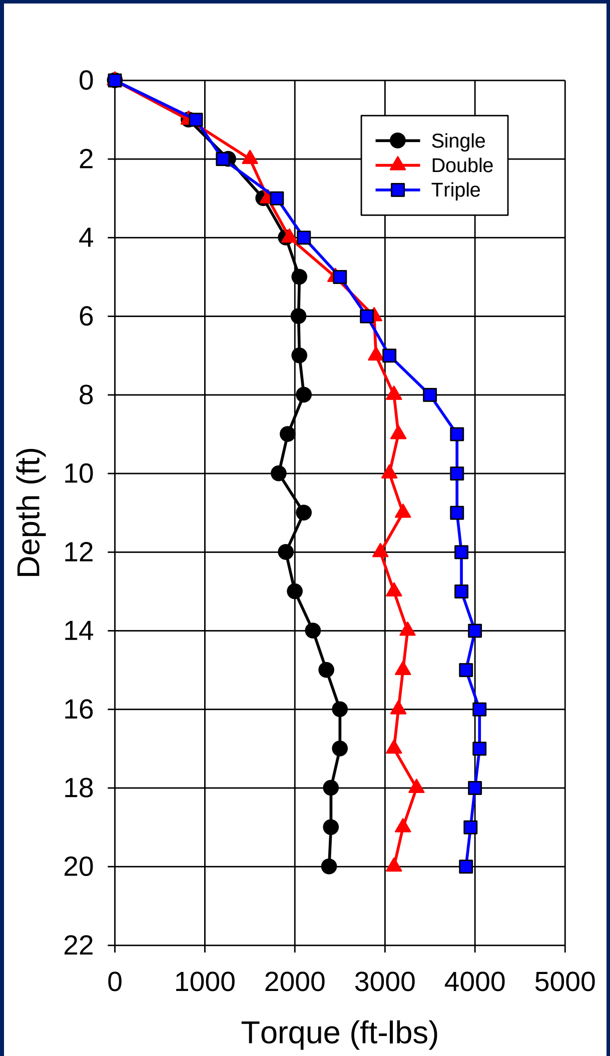
Skempton (1950)

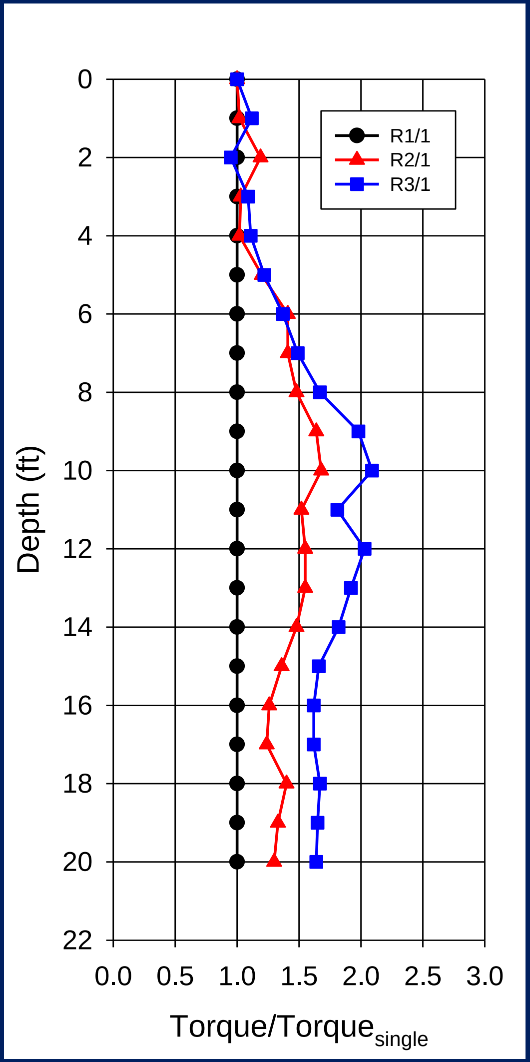
Referring to triple-helix screw-piles in compression;

"…For Mr. Morgan's double and triple screw-cylinders, it was necessary to recognize that the clay beneath the upper screws had been remoulded by the passage of the first screw. However, the whole of the volume of the clay contributing to the bearing capacity of the upper screws would not be fully remoulded and, as a rough approximation, it could be assumed that the average shear strength of the volume of clay was equal to:

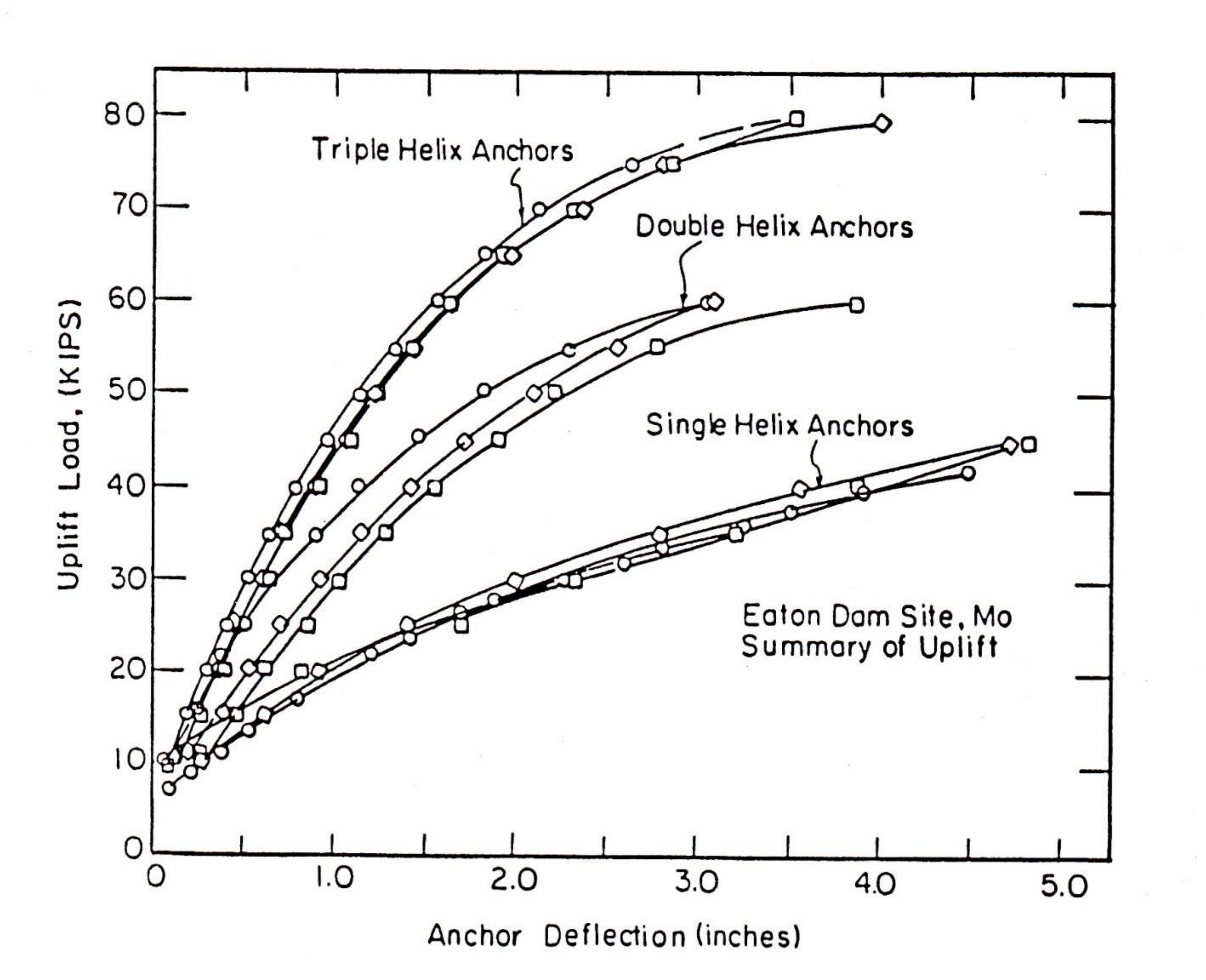
$$c_{p2} = c - \tfrac{1}{2}(c - c_r)$$

Torque Profiles in Sand (Clemence et al. 1994)





Single, Double and Triple Helix Anchors in Sand (Clemence et al. 1994)



Installation of Screw-Piles and Helical Anchors Causes Disturbance to the Soil

The Degree of Disturbance will Depend on a Number of Factors, Including: Soil Initial State, Sensitivity & Installation Quality

Using IDF Requires Monitoring Installation

Challenge 3. Understanding Role of Shaft for Large Round Shaft Screw-Piles and Helical Anchors

Somewhat Unique to Screw-Piles and Helical Anchors but Important for Many Deep Foundations

We Need to Evaluate How Design Load is Carried

What is the Role of the Shaft?

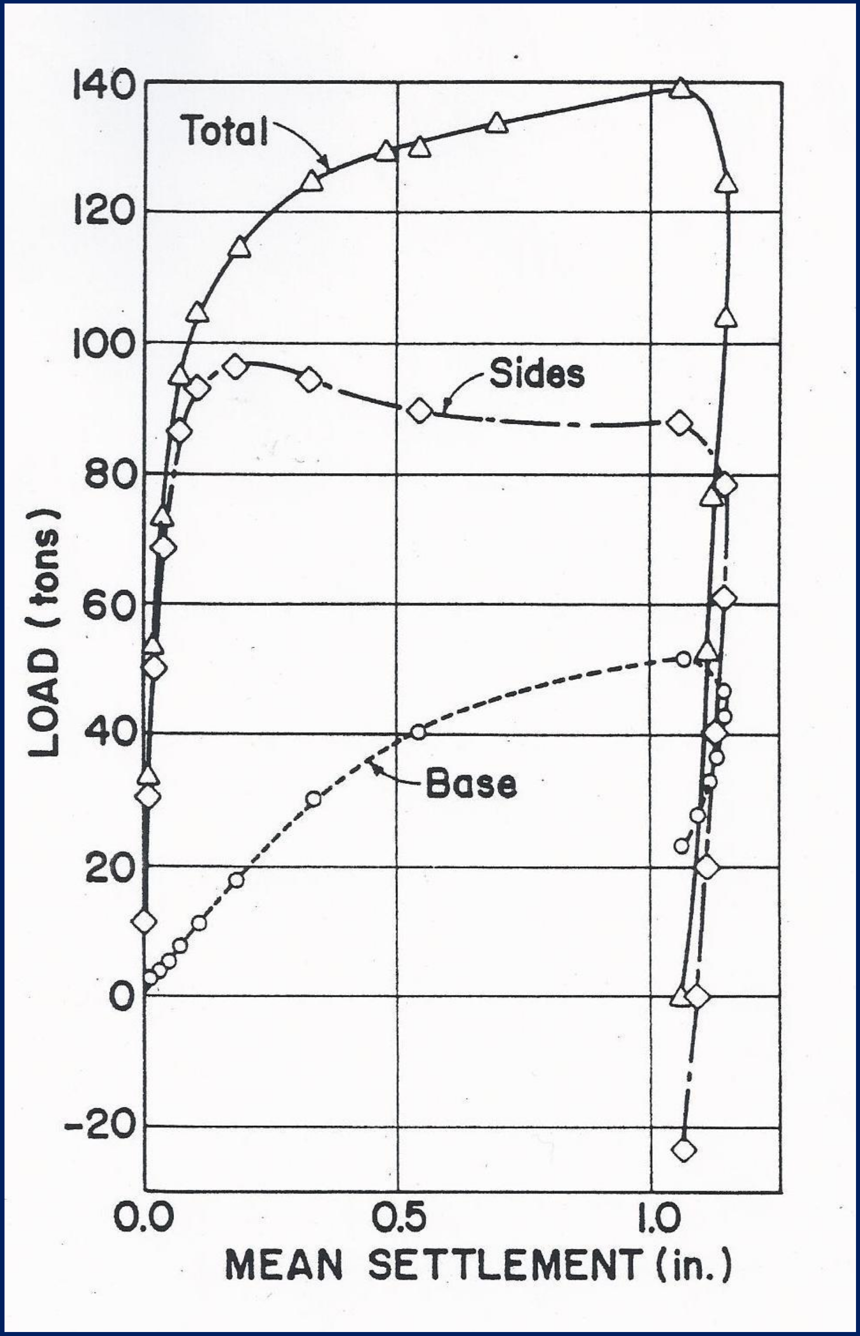
Transfer Load To Helix?

Provide a Component of Load Capacity?

Load Distribution in Deep Foundations (% End vs. % Side)

Depends on:
Pile Type & Use
Installation Method
Geometry (L/D)
Soil Type
Stratigraphy
Load Level (Relative to Ultimate)

End and Side Don’t Develop Capacity at the Same Rate

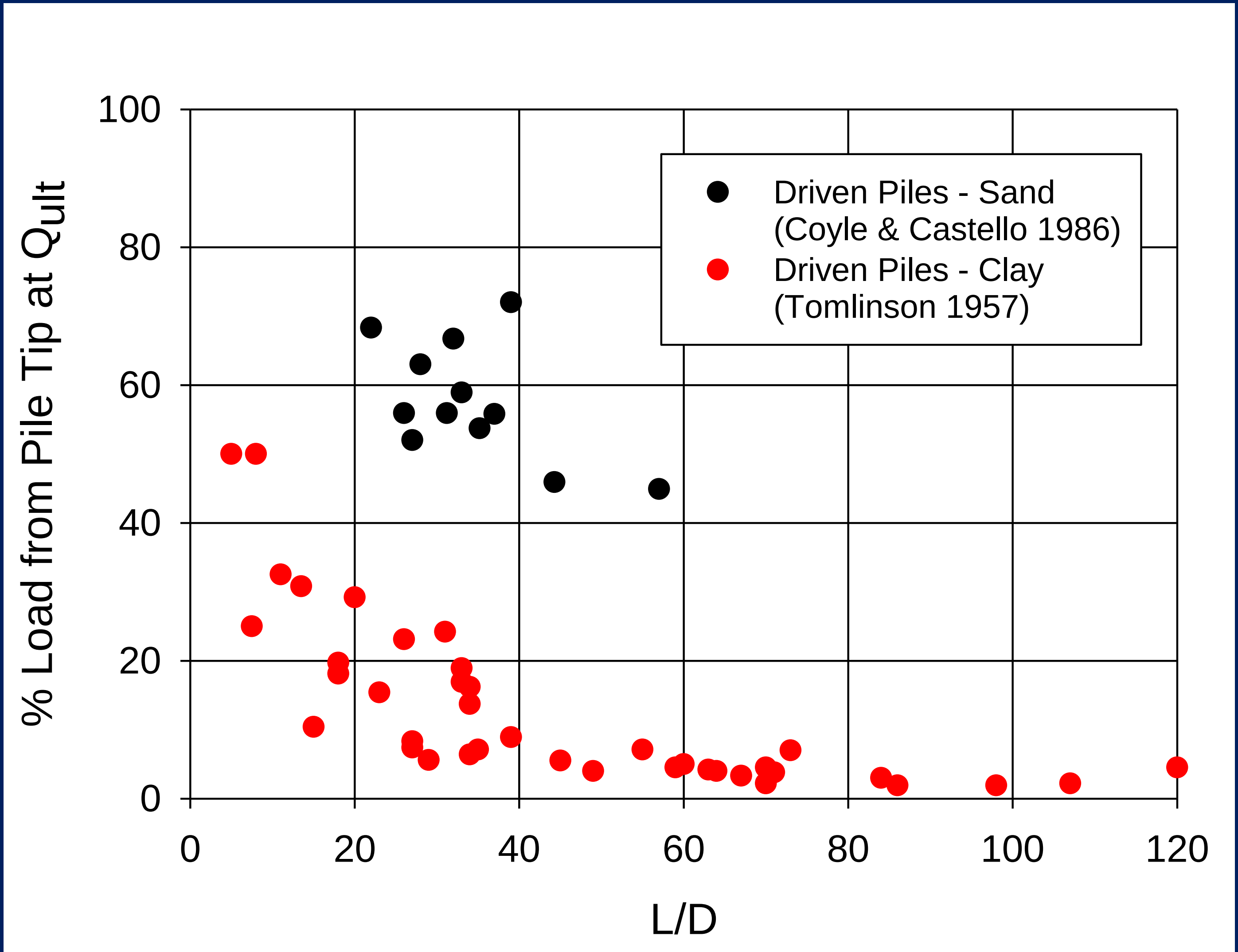


Reese et al. 1976

At Q_{ult}
36.8% End Bearing;
63.2% Side Resistance

At $Q_{ult}/2$
5.7% End Bearing;
94.3% Side Resistance

Observed Distribution @ Q_{ult}



Parametric Analysis of Contribution of Shaft in Clays – Round Shaft Single Helix in Tension

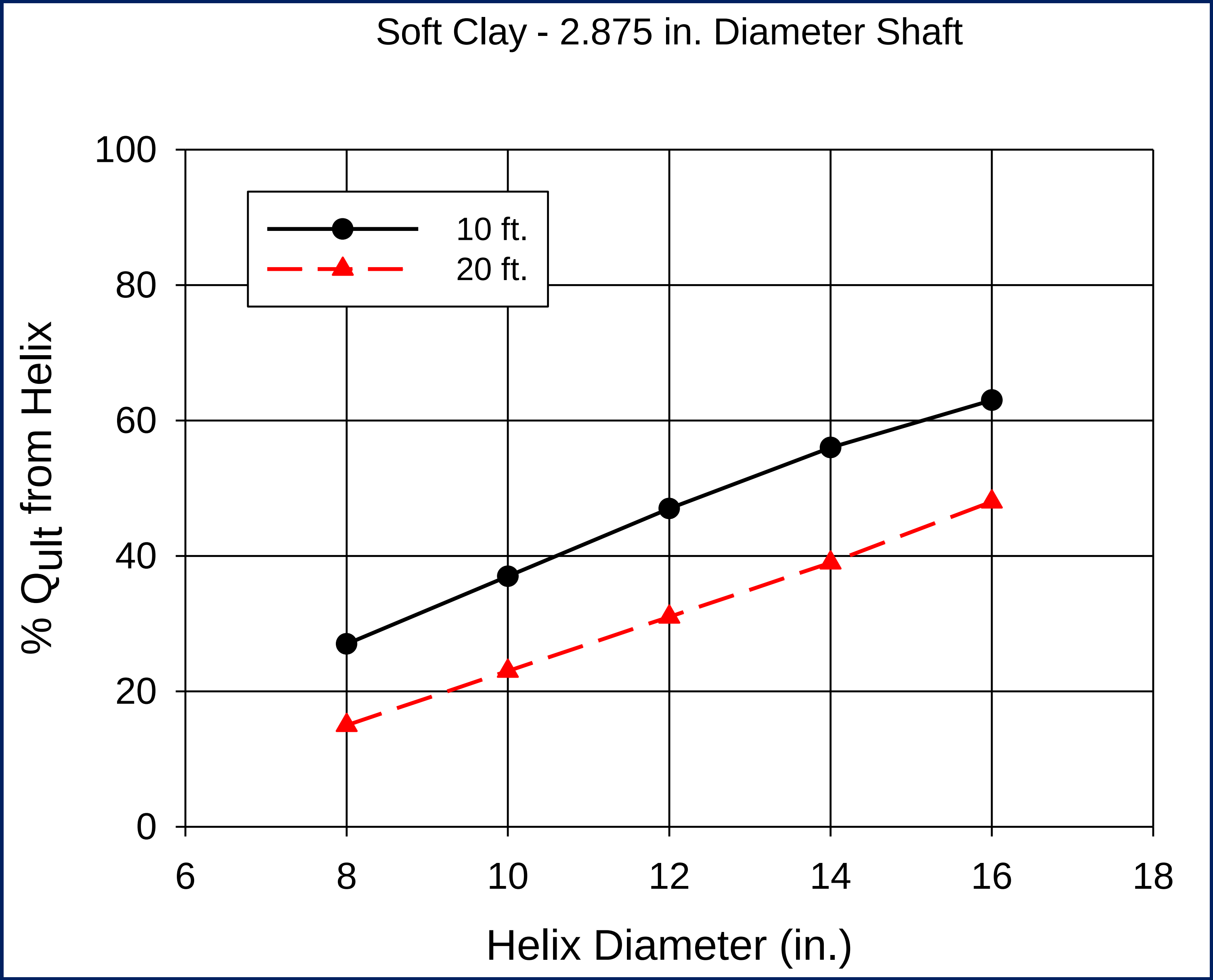
$$Q_T = Q_H + Q_S$$

$$Q_H = s_u 9 A_H \quad Q_S = f_s A_S$$

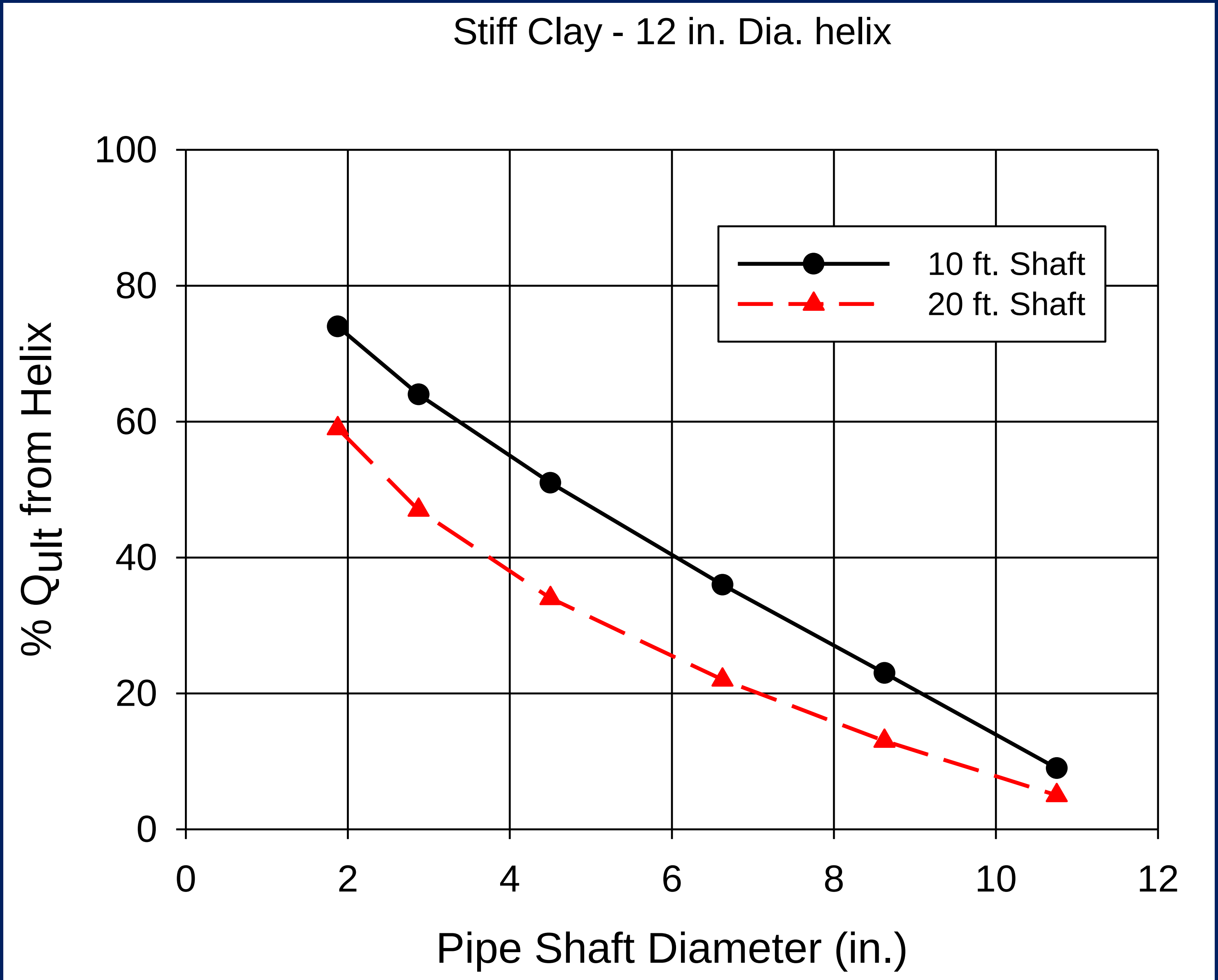
$$f_s = s_u \alpha$$

"soft" clay $s_u = 500$ psf $\alpha = 1$ $S_t = 2$

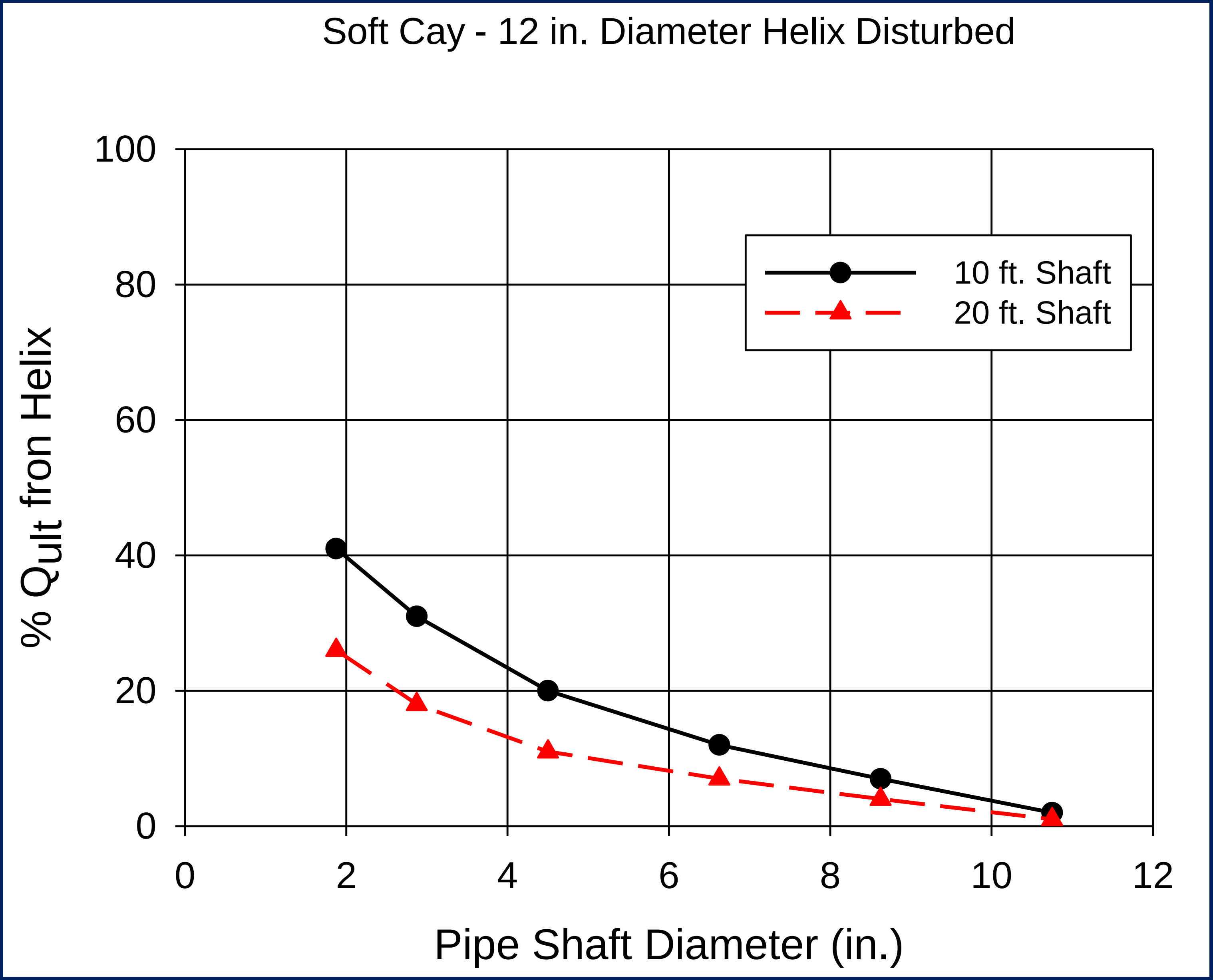
"stiff" clay $s_u = 2000$ psf $\alpha = 0.5$



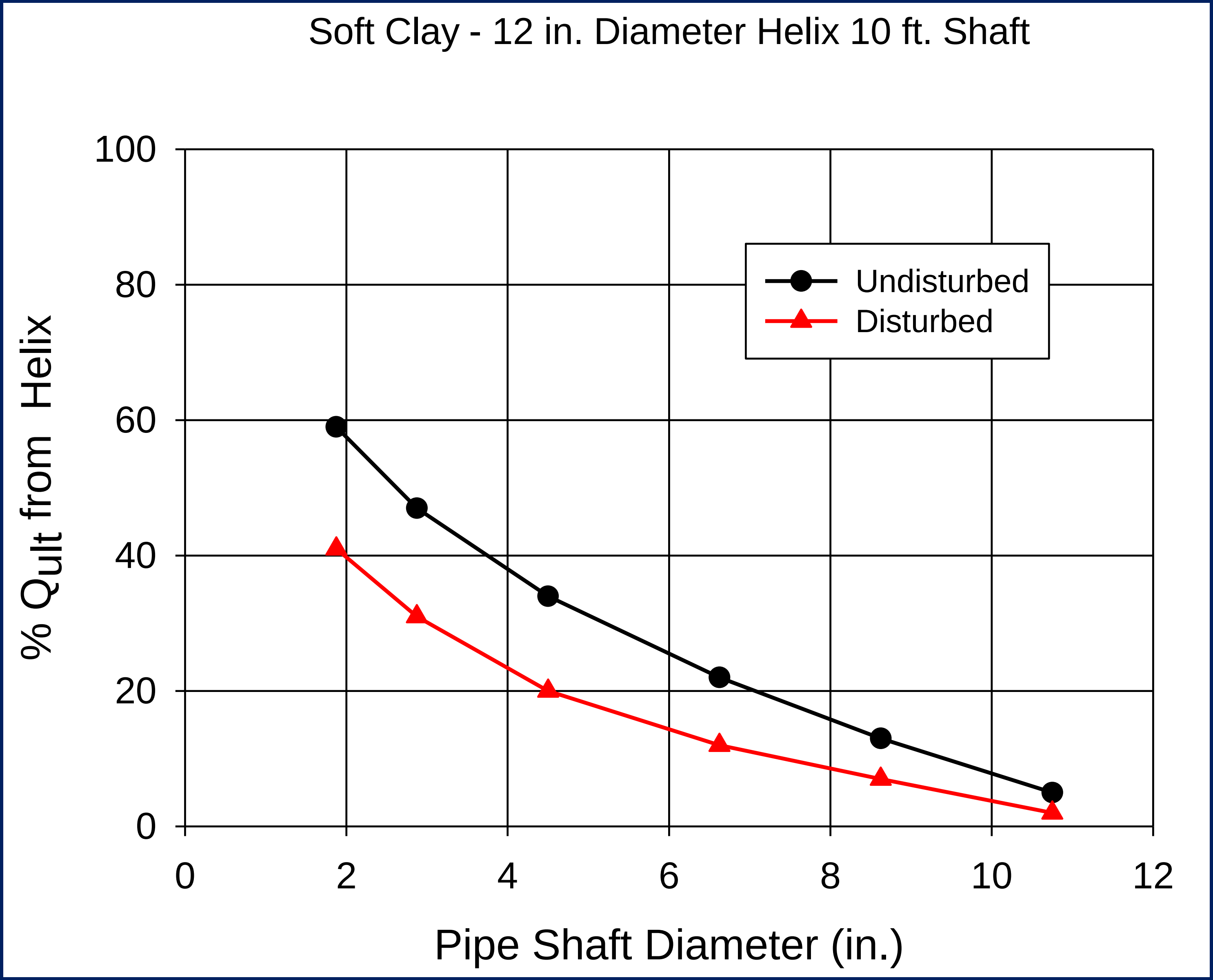
Soft Clay - 2.875 in. Diameter Shaft
10 ft.
20 ft.
100
80
60
40
20
0
6
8
10
12
14
16
18
% Qult from Helix
Helix Diameter (in.)



Stiff Clay - 12 in. Dia. helix
10 ft. Shaft
20 ft. Shaft
100
80
60
40
20
0
0
2
4
6
8
10
12
% Qult from Helix
Pipe Shaft Diameter (in.)



Soft Cay - 12 in. Diameter Helix Disturbed
100
80
60
40
20
0
% Qult fron Helix
0
2
4
6
8
10
12
Pipe Shaft Diameter (in.)
10 ft. Shaft
20 ft. Shaft

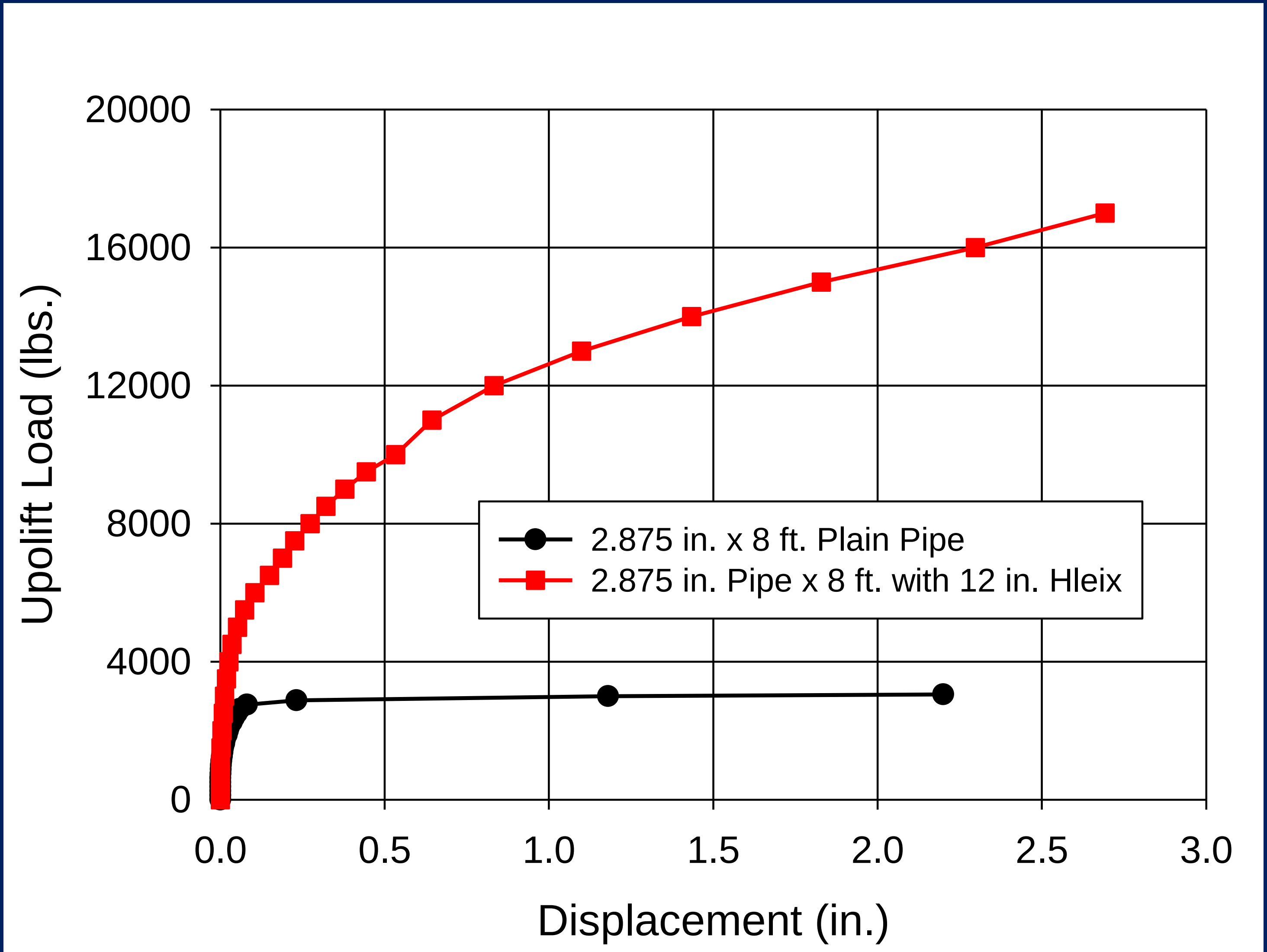


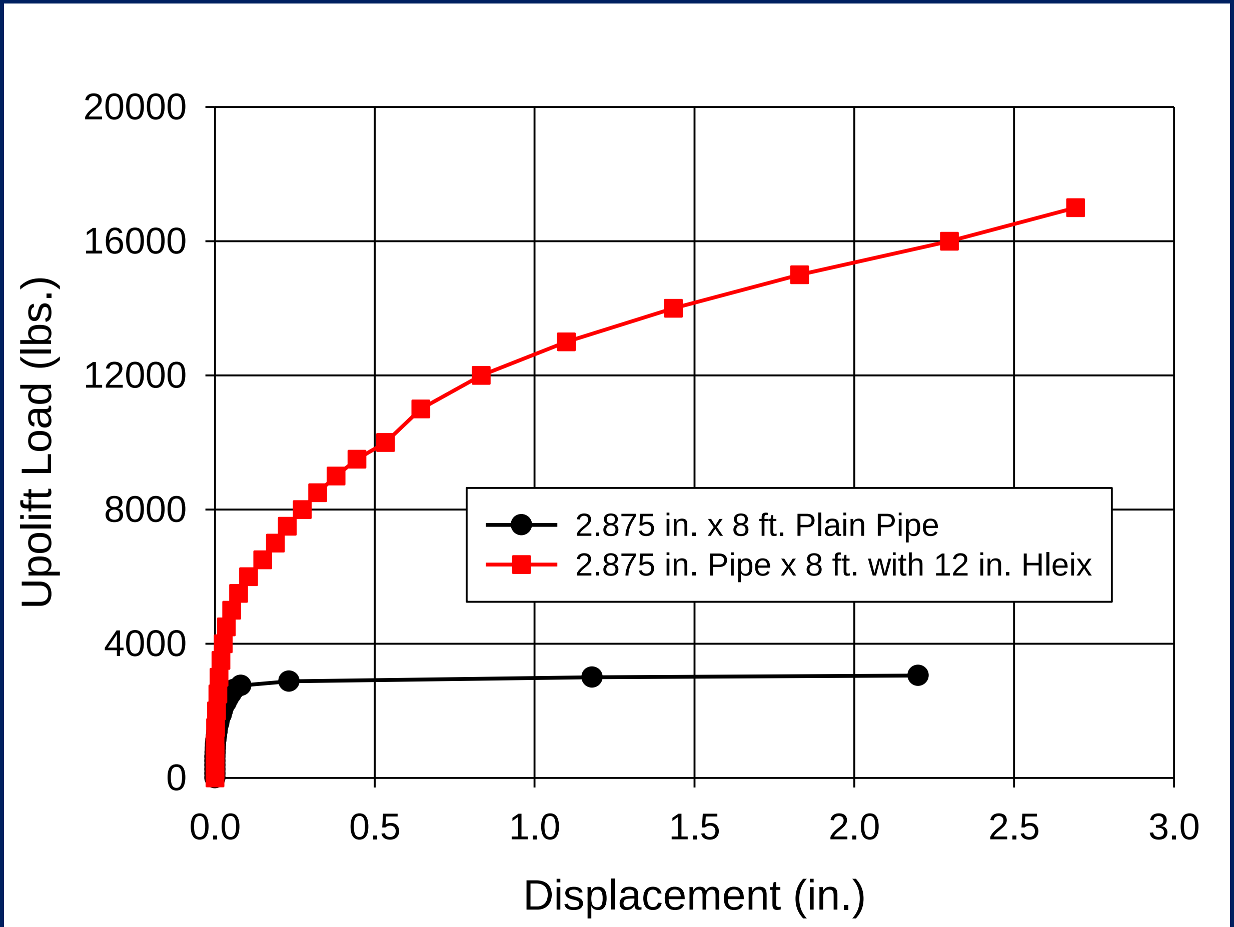
Soft Clay - 12 in. Diameter Helix 10 ft. Shaft
% Qult from Helix
Pipe Shaft Diameter (in.)
Undisturbed
Disturbed
0
20
40
60
80
100
0
2
4
6
8
10
12

Single-Helix Pipe Piles in Uplift

Load Tests to Failure on Helical Pile and Adjacent Plain Driven Pipe Pile

Stiff Clay - 2.875 in. Pipe



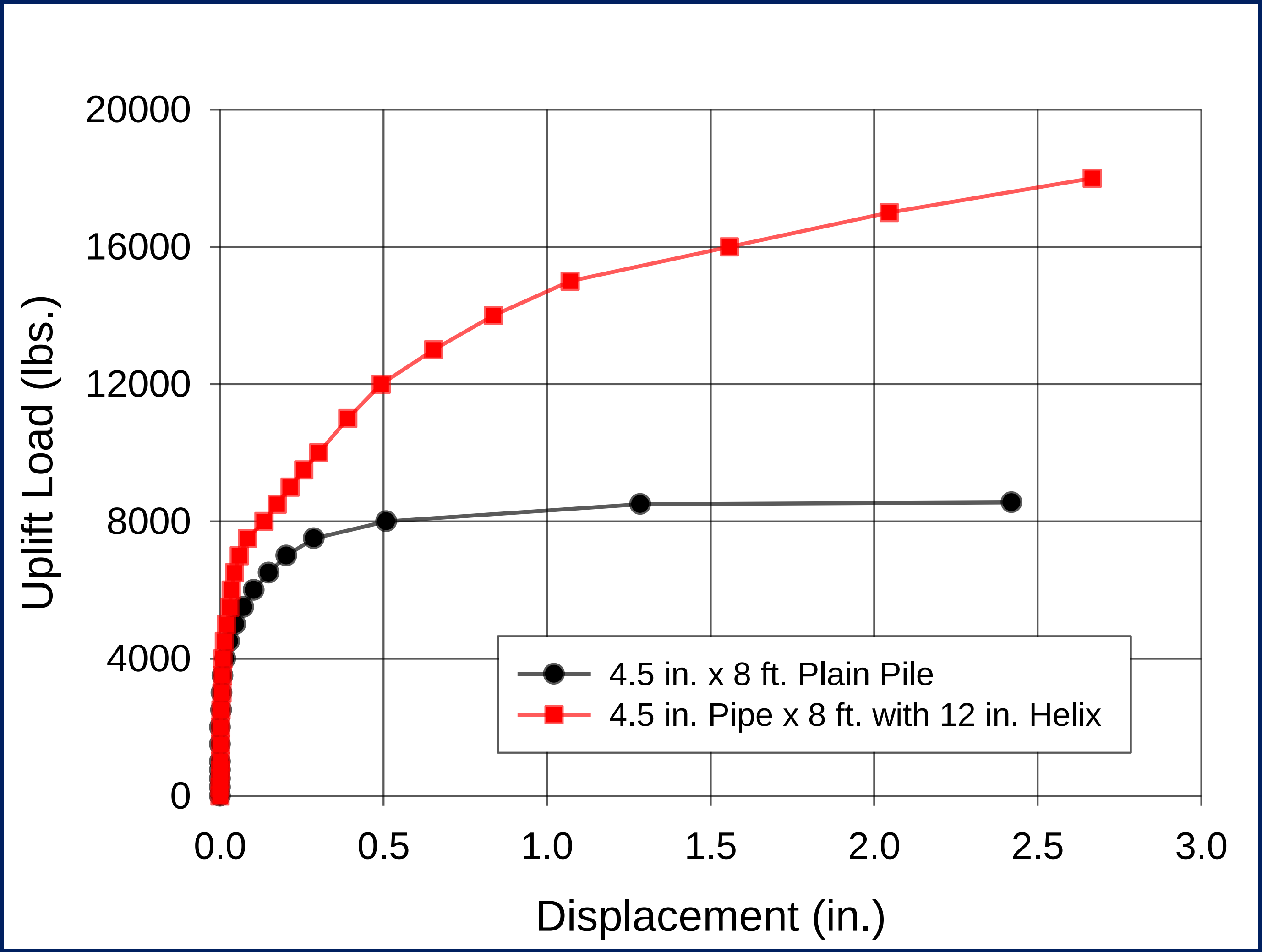


Q_{20} = 16,400 lbs.; Q_{10} = 13,200 lbs.

Q_{10}/Q_{20} = 0.80 Δ @ $Q_{10}/2$ = 0.18 in.

@ Q_{10} Q_{shaft} = 2600 lbs.; Q_{helix} =10,600 lbs.

Stiff Clay – 4.5 in. Pipe



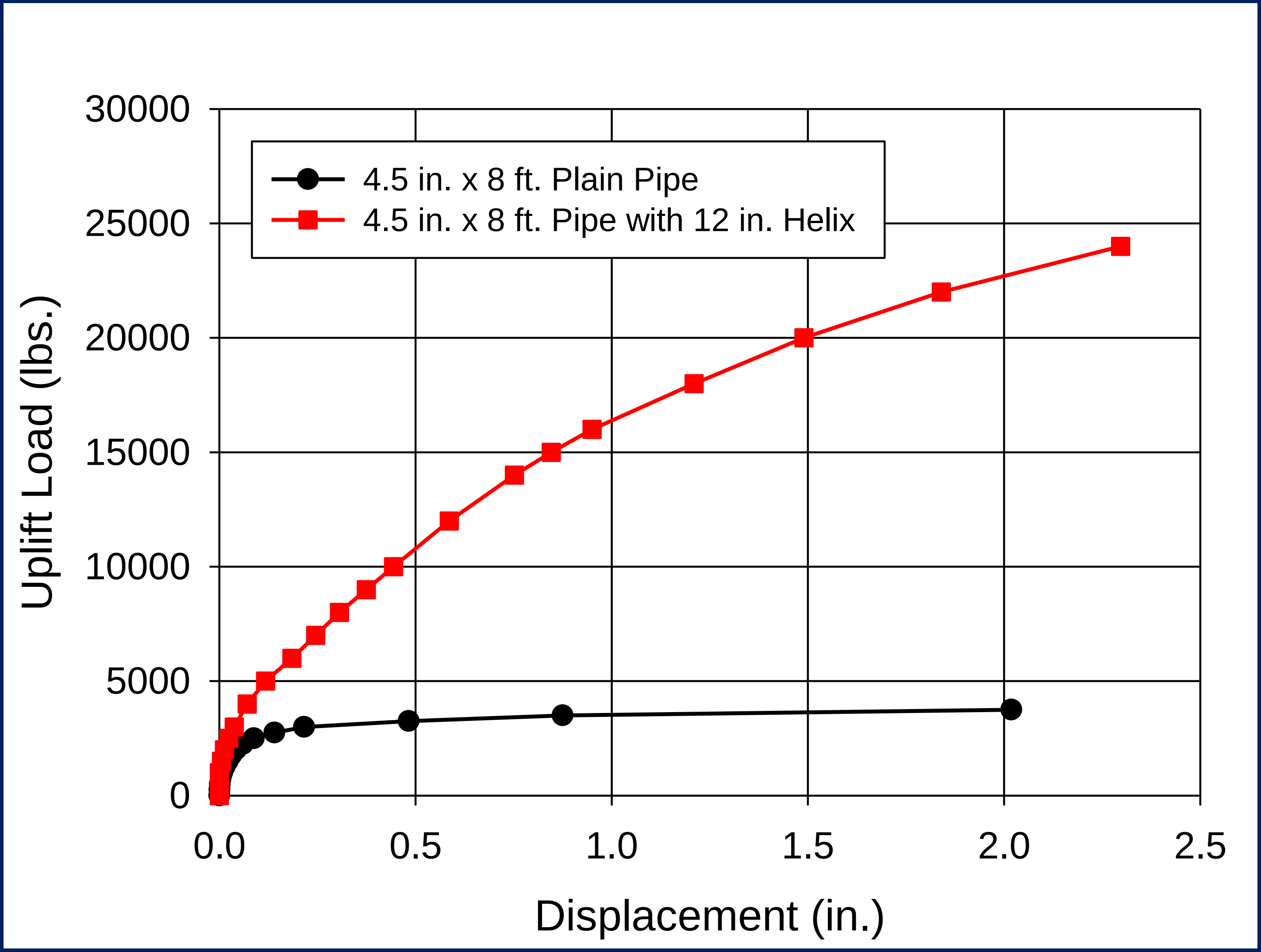
Distribution of Q_{shaft} & Q_{helix} at Q_{10}
(Q in lbs.)

Pipe Dia.	Q_T	Q_S	Q_H
2.875	13,200	2600(20%)	10,600 (80%)
4.5	15,250	8450 (55%)	6800 (45%)
6.625	20,000	10,600 (53%)	9400 (47%)

Distribution of Q_{shaft} & Q_{helix} at $Q_{10}/2$
(Q in lbs.)

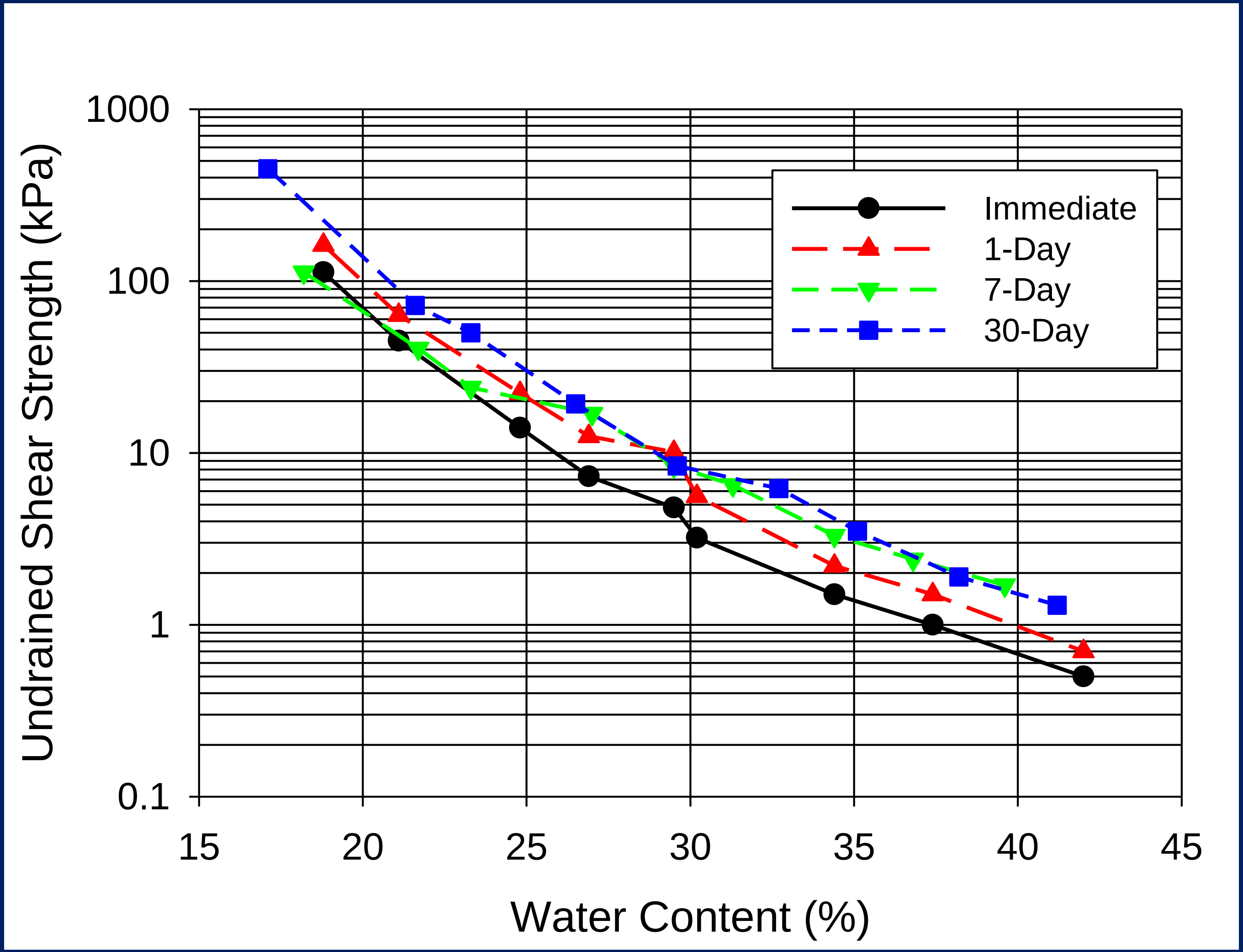
Pipe Dia.	Q_T	Q_S	Q_H
2.875	6600	3000 (45%)	3600 (55%)
4.5	7625	6100 (80%)	1525 (20%)
6.625	10,000	6500 (65%)	3500 (35%)

Silty Sand



30000
25000
20000
15000
10000
5000
0
Uplift Load (lbs.)
0.0
0.5
1.0
1.5
2.0
2.5
Displacement (in.)
4.5 in. x 8 ft. Plain Pipe
4.5 in. x 8 ft. Pipe with 12 in. Helix

Aging ?



1000
100
10
1
0.1
Undrained Shear Strength (kPa)
15
20
25
30
35
40
45
Water Content (%)
Immediate
1-Day
7-Day
30-Day

Summary

1. The Behavior of Screw-Piles and Helical Anchors is More Complex than has Previously Been Considered
2. Evaluation of Soil Parameters for Design Must Consider Installation Disturbance
3. Design Methodologies will Need to Change to Reflect These Considerations
4. Installation Monitoring of both Torque and Advance is Essential
5. As Industry moves to Large Diameter Pipe Shafts, the Role of the Helix Changes

Torque-to-Capacity Correlations? The Logic

Q_{ult} = f (Soil Properties & Pile/Anchor Geometry)

T = f (Soil Properties & Pile/Anchor Geometry)

$$Q_{ult} = TK_t$$

But… K_t Depends on a Number of Factors Because Torque Depends on a Number of Factors

Pile/Anchor Factors

1. Helix Diameter
2. Number of Helices
3. Helix Pitch
4. Surface Roughness
5. Helix Thickness
6. Shaft Shape (S/R)
7. Connection Style

Soil Factors

8. Soil Type
9. Soil Strength
10. Soil Stiffness
11. Soil Sensitivity
12. Water Table (sat. vs. unsat.)

Contractor (Installation) Factors

13. Rotation Rate
14. Advance Rate
15. Down Force (Crowd)
16. Inclination

Measuring Torque -*Direct* Methods

Monitoring Installation is Critical to Performance

Installation Torque

Installation Advance (rev/ft.)

International Society for Helical Foundations (ISHF)

www.helicalfoundations.org