

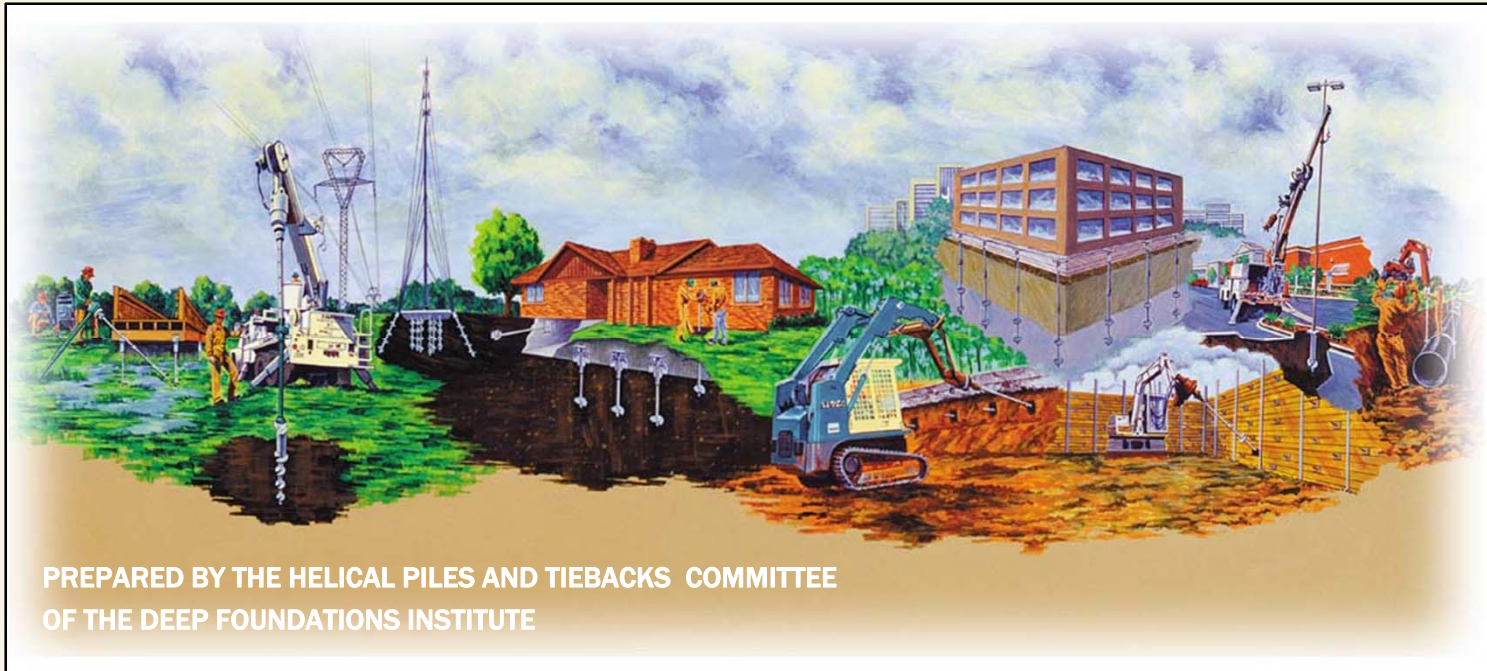


FINDING  
COMMON  
GROUND

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# Introduction to Helical Piles and Helical Anchors



PREPARED BY THE HELICAL PILES AND TIEBACKS COMMITTEE  
OF THE DEEP FOUNDATIONS INSTITUTE

Note to Instructor: The DFI does not advocate helical foundations over other types of foundation and anchoring systems. It is intended that this will be one of many instructional tools of the DFI.

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# Outline

- I. Helical Piles and Anchors Defined**
- II. Historical Development**
- III. Theory & Design**
  - A. Theoretical Capacity
  - B. Installation Torque Correlations
  - C. Buckling and Lateral Resistance
  - D. Minimum Depth
  - E. Group Effects
  - F. Corrosion and Life Expectancy
- IV. Practical Applications**
  - A. Shoring and Earth Retention
  - B. Underpinning
  - C. New Foundations
  - D. Pipelines and Utility Towers
- V. Case History**
- VI. Continued Study**
  - A. References
  - B. Organizations

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## Helical Piles and Anchors Defined

- **Helical Pile:** Factory-manufactured steel foundation pile consisting of a central shaft with one or more helical bearing plates  
Term generally used for compression applications
- **Helical Anchor:** Same as above except its primary purpose is for earth anchorage and other tension applications
- **Other Terms:** screw pile, helix pier, screw anchor, helical pier, torque pile, and torque anchor



## Helical Piles and Anchors Defined

- **Helical Foundation:** A foundation system for a building or other structure comprised of at least one helical pile or helical anchor element



# Common Components

## Terminology

Central Shaft

Pier Cap

Extensions

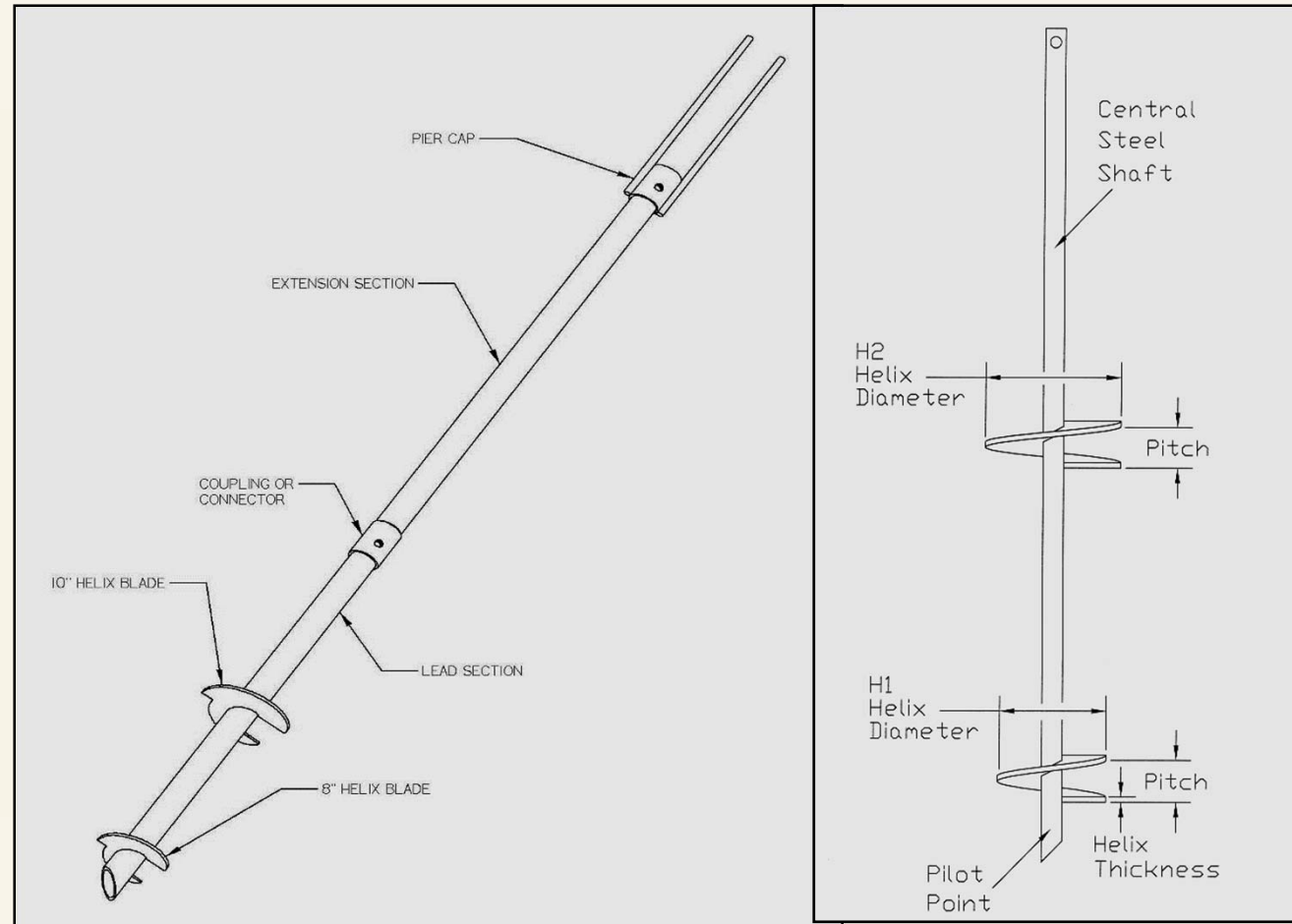
Coupling

Lead Section

Helical Blades

Pitch

Pilot Point





## Example Installation Process

### Installation

- 1) Rotate lead section into the ground using a hydraulic torque drive
- 2) Attach one or more extensions and continue rotation
- 3) Halt installation when specified torque is achieved



## Example Installation Process





## Vehicle - Mounted Torque Motors



**3,500 FT-LB**  
**12,000 FT-LB**  
**20,000 FT-LB**  
**100,000 FT-LB**  
*And Higher*



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## Hand Held Torque Motors



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## Types of Helical Piles/Anchors

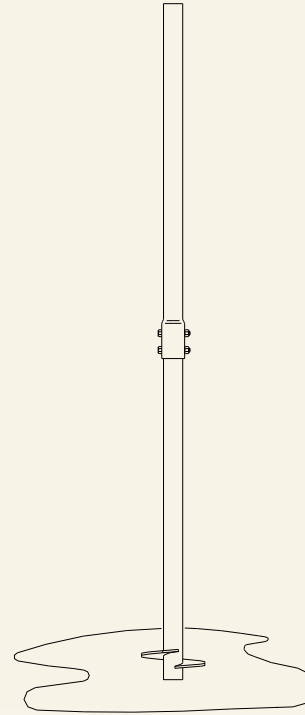
Note: Other types include combinations of these



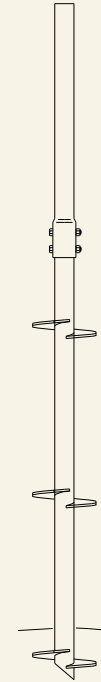
**Square Shaft**  
(Un-grouted)



**Square Shaft**  
(Grouted)



**Round Shaft**  
(Grouted)



**Round Shaft**  
(Un-grouted)



## Advantages of Helical Foundations

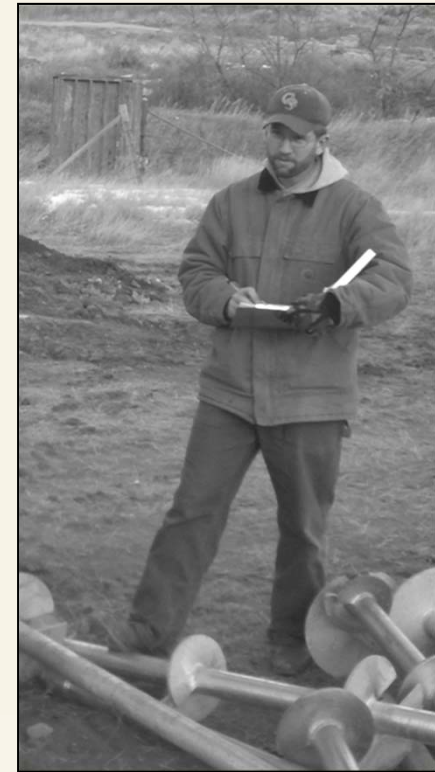
- Low mobilization costs due to small and inexpensive installation equipment
- Low noise and minimal vibrations
- Smaller shafts reduce effect of expansive soil heave
- Slender shafts dampen seismic forces
- Year-round installation in any weather
- Helical foundations can be removed and re-used for temporary structures
- Can be installed in confined spaces with minimal damage and disruption making them ideal for remedial work
- Provide both tensile and compressive support
- Does not produce drill spoils
- Installation torque can help to verify capacity





## Disadvantages of Helical Foundations

- Unable to penetrate competent bedrock without pre-drilling
- Potential refusal in heavy cobble and boulders
- Installation difficult in trash fill with concrete and other building material debris
- Low start-up cost can result in less qualified contractors
- Buckling limits capacity in very soft soils
- Lower lateral capacity may require augmentation in some cases
- Use of torque as a verification of capacity needs to be tempered with calculated theoretical capacity, engineering judgment and load tests when applicable
- Special inspection is recommended





# Historical Development

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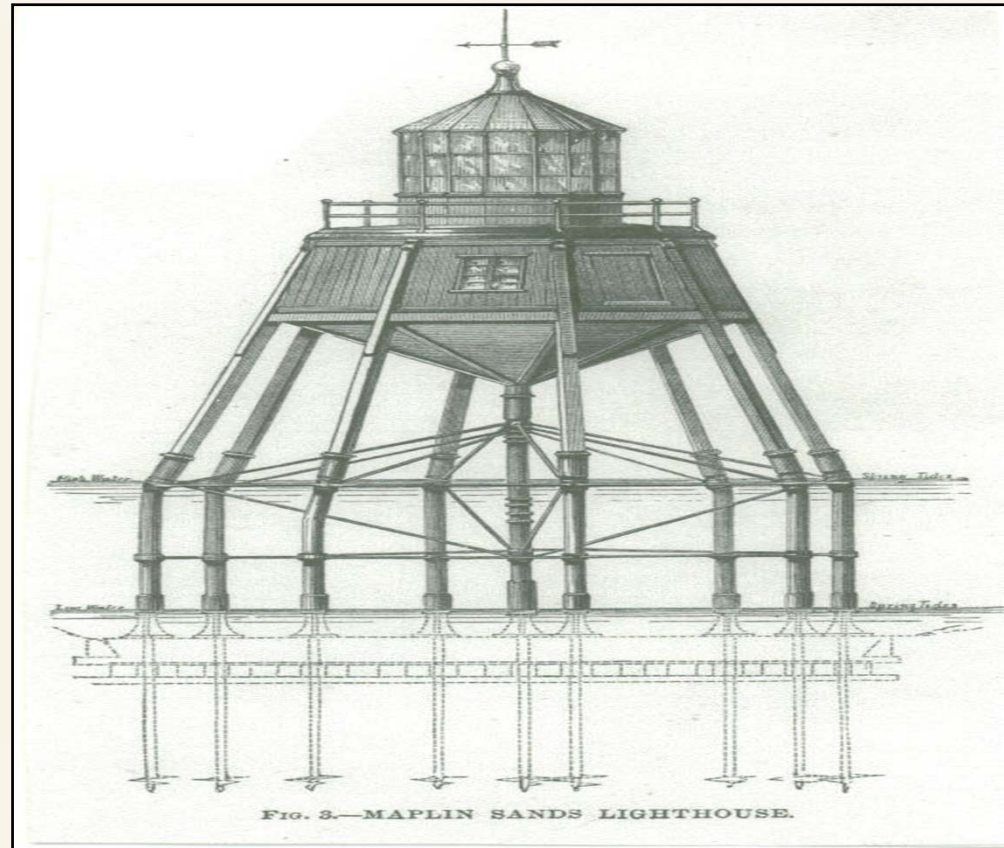


## Historical Perspective

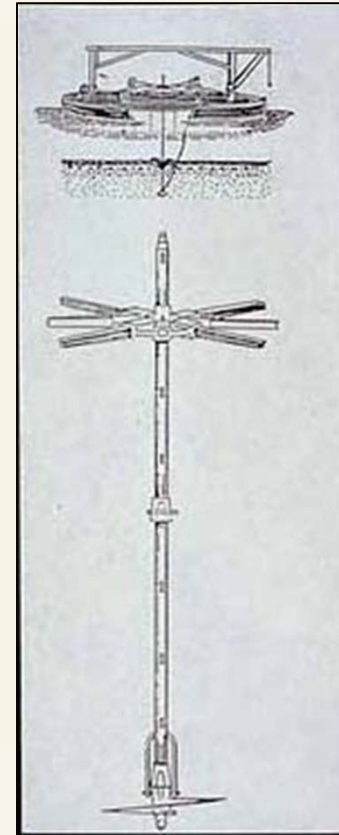
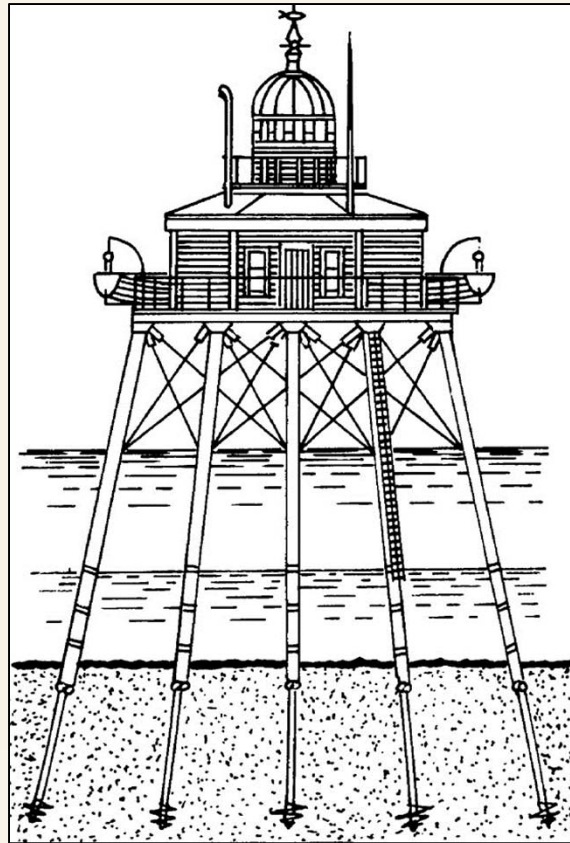
- 1<sup>st</sup> Recorded use of a Screw Pile was by Alexander Mitchell in 1836 for Moorings and was then applied by Mitchell to Maplin Sands Lighthouse in England in 1838
- In 1843, the 1<sup>st</sup> Screw Pile Light House in the U.S. was Constructed by Capt. William H. Swift at Black Rock Harbor in Connecticut. Swift used Mitchell Screw Pile Technology
- In the 1840's and '50's, More Than 100 Screw Pile Foundation Light Houses were Constructed Along the East Coast, the Florida Coast and the Gulf of Mexico
- Today, helical foundations are used regularly throughout the world

## Early (Pre-1900) Uses of Screw Piles

- Lighthouse foundations
- Moorings
- Ocean front piers
- Railway bridges
- Underpinning



## Mitchell's Screw Pile - 1836





## Mitchell's Screw Pile - 1836

*“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.”



## Middle Era (1900-1950)

- There was a “quiet” period that saw the rise of other foundation technologies and the decrease in use of Screw Piles
- During this time, other deep foundations such as Raymond, Drilled Foundations, Enlarged Base Foundations, Franki Piles, etc. developed along with major developments in mechanical equipment, e.g., hydraulics
- In 1950, Gulac Wilson published “The Bearing Capacity of Screw Piles and Screwcrete Cylinders”



## Modern Era (1950-Present)

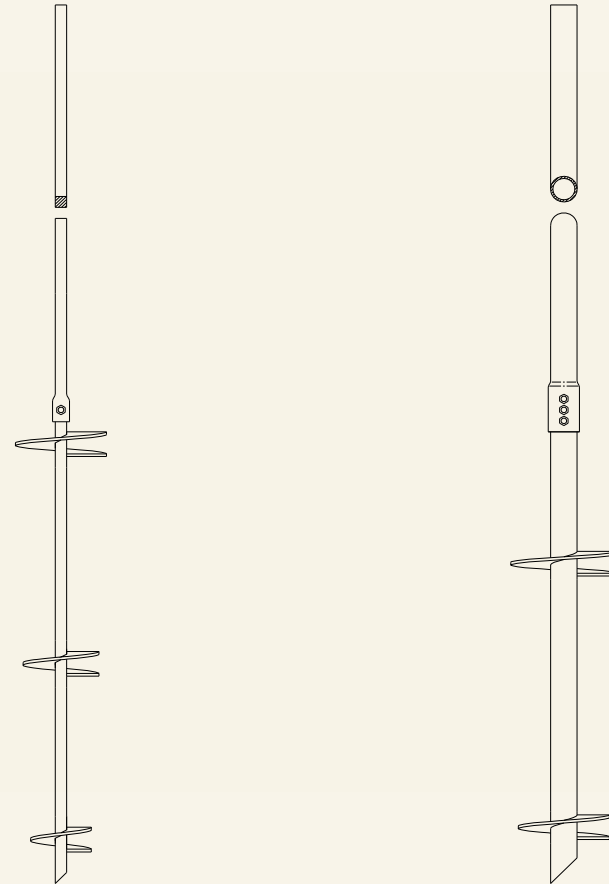
- Advances in installation equipment
- Advances in geometries
- Increased need for alternative foundation solutions
- Increased research into behavior
- Increased applications through aggressive marketing



## Typical Helical Foundations

Shaft dimensions range in size from 1.5 round corner square bar up to 12" and larger round pipe shafts with wall thicknesses of .25" to 1.00" or greater.

Helix bearing plate diameters range from 8" to 24" or greater with plate thicknesses of .3875" to 1.00" or greater.





# Theory and Design

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## Foundation & Anchor Capacity

### Design Considerations

- Theoretical Capacity
- Capacity to Torque Correlations
- Various Augmentation Methods
- Previous Experience at Site
- Contractor Experience
- Lateral Resistance
- Corrosion
- Group Efficiency
- Specifications
- Site Access
- Contaminated Soils
- Economics
- Location of Water Table
- Presence of Boulders
- Down Drag
- Buckling



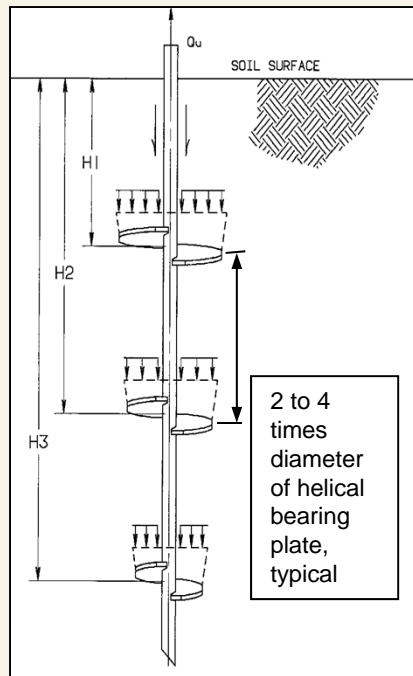
## Design Calculations

### Theoretical ultimate capacity no better than:

- Input Data
  - Soil properties
  - Water table location & fluctuation
  - Loads
  - Previous experience at the site
- Input Assumptions
  - Estimates
  - Correlations
  - Disturbance/Remolding

## Individual Bearing Plate Model

- Total capacity equal to sum of individual helix bearing capacities
- Capacity due to friction along shaft generally assumed negligible except if the shaft is grouted or shaft diameter greater than 3"



Example:

$$Q_H = \Sigma A(cN_C + qN_q + 1/2\gamma BN_\gamma)$$

← One or more of these terms can be omitted by the designer as required.

where

- $A$  = Area of helical bearing plate
- $c$  = Soil Cohesion
- $q$  = Overburden Stress
- $\gamma$  = Unit Weight of Soil
- $B$  = Helix Diameter
- $N_C$ ,  $N_q$ , &  $N_\gamma$  = Traditional Bearing Capacity Factors

Apply traditional bearing capacity theory to helix. The total bearing and pullout capacity of the helical pile is the sum of the individual capacity of each helix.

Note: Effective stress parameters should be used for long-term, slow loading applications in both sands & clays and total stress parameters should be used in rapid loading of saturated clays.



## Typical Bearing / Pullout Capacity

### Allowable Capacity

10 to 30 tons  
10 to 30 tons  
20 to 100 tons  
>100 tons

### Shaft Size

1.5"-2.0" SQR  
2.875"-3.5" O.D. RND  
4"-6" O.D. RND  
8"-12" O.D. RND



## Installation Torque Correlations

The Torque Required to Install a Helical Foundation or Anchor is Empirically and Theoretically Related to Ultimate Capacity

- $Q_{ult} = K_t T$ 
  - Where:
    - $Q_{ult}$  = Ultimate Capacity in Tension or Compression [lb (kN)]
    - $K_t$  = Capacity to Torque Ratio [ $\text{ft}^{-1}$  ( $\text{m}^{-1}$ )]
      - Typical Value = 10 (33) for 1.5" & 1.75" Square Shaft<sup>1</sup>
      - Typical Value = 9 (30) for 2.785" OD Round Shaft<sup>1</sup>
      - Typical Value = 8 (26) for 3" OD Round Shaft<sup>1</sup>
      - Typical Value = 7 (23) for 3.5" OD Round Shaft<sup>1</sup>
    - $T$  = Final Installation Torque [ft-lb (kN-m)]

<sup>1</sup> Per AC358 (2007) "Acceptance Criteria for Helical Foundations and Devices" ICC Evaluation Services, Inc.



## Installation Torque vs. Ultimate Capacity

- $K_t$  is not a constant - may range from 3 to 20 ft<sup>-1</sup> (10 to 66 m<sup>-1</sup>)<sup>2</sup>. Depends on various factors including:
  - **Soil Conditions and Prior Experience at Site**
    - Normally consolidated clay – Average  $K_t$  Values
    - Over consolidated clay – Sometimes Higher  $K_t$  Values
    - Sensitive clay – Sometimes Lower  $K_t$  Values
    - Sands – Sometimes Higher  $K_t$  Values
  - **Central Steel Shaft/Helix Size**
    - $K_t$  inversely proportional to shaft size
  - **Helix Thickness and Pitch**
    - $K_t$  inversely proportional to helix thickness and pitch
  - **Application (Tension or Compression)**
    - Compression capacity is generally higher than tension capacity although often assumed equal for purposes of simplicity

<sup>2</sup>Perko (2009) Helical Piles: A Practical Guide to Design and Installation, Wiley, NY



## Reliability of Torque / Capacity Model

- Uplift Capacity of Helical Anchors in Soil (Hoyt & Clemence 1989)<sup>3</sup>
  - Analyzed 91 load tests
  - 24 different test sites
  - Sand, silt, and clay soils represented
  - Calculated capacity ratio ( $Q_{act}/Q_{calc}$ )
  - Three different load capacity models
    - Cylindrical shear
    - Individual bearing
    - Torque correlation
- Torque correlation method used in combination with traditional soil mechanics and a factor of safety generally produces good results

<sup>3</sup>Hoyt, R.M. and Clemence, S.P. (1989) "Uplift Capacity of Helical Anchors in Soil" Proceedings of the 12<sup>th</sup> International Conference on Soil Mechanics and Foundations, Rio de Janeiro, Brazil



## Factor of Safety

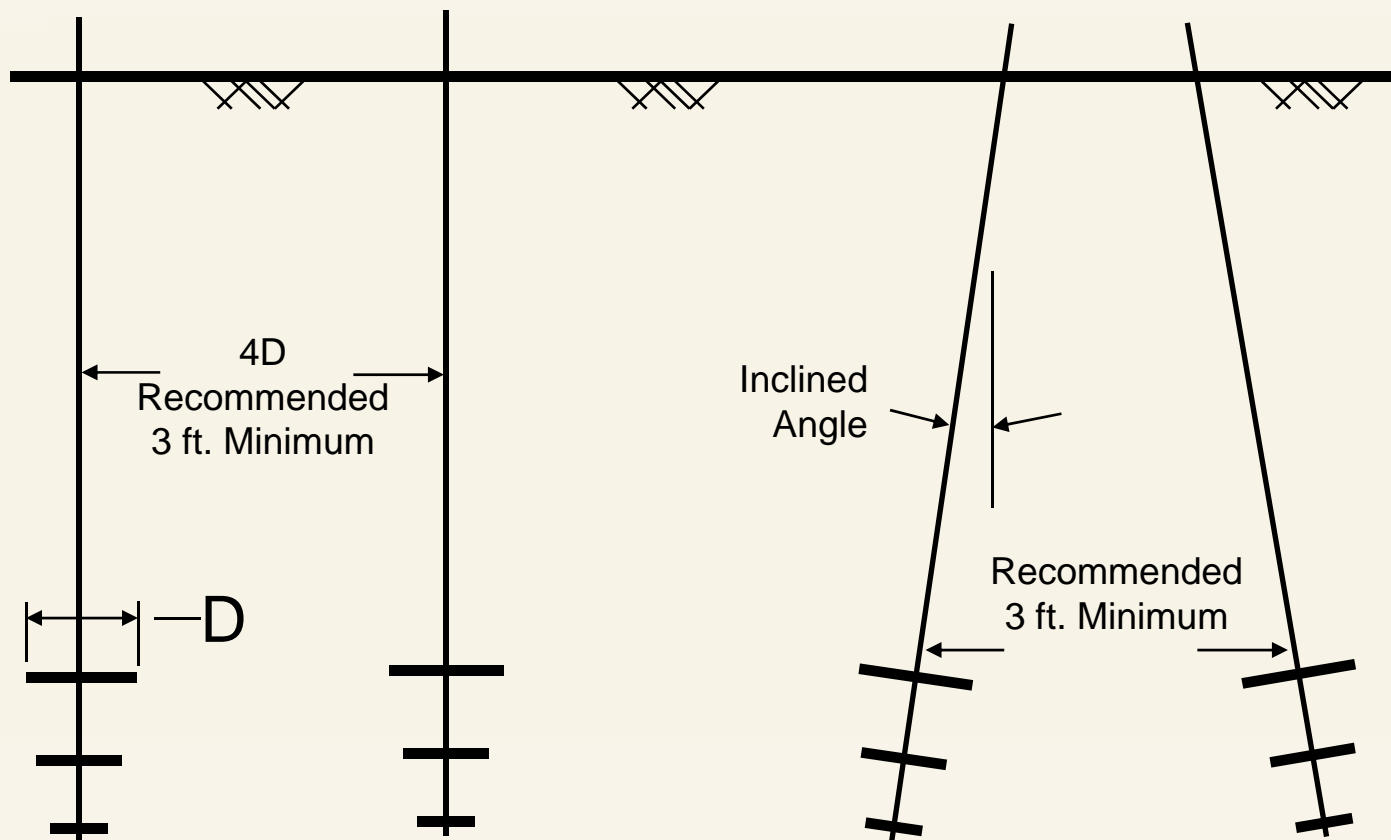
- Select an appropriate Factor of Safety (FS) to be applied to the Ultimate Capacity of the anchor/foundation to develop a design, or Working Capacity per anchor/foundation.
- In general, it is recommended to use a minimum  $FS = 2.0$ .
- For helical anchor projects where a significant fraction or all anchors are proof tested a  $FS = 1.5$  is common.



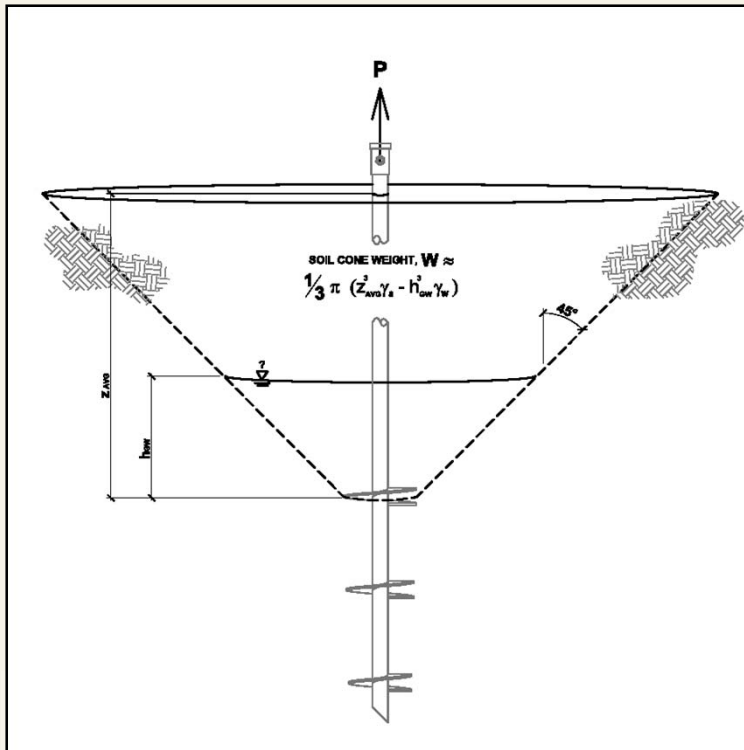
## Slenderness Ratio / Buckling

- Research shows elastic buckling is a practical concern only in the softest soils
  - Soil provides lateral support to shaft
  
- Practical Guideline: Soil with ASTM D-1586 blow count of 4 or less
  - Very soft & soft clays
  - Very loose sands
  
- Computer programs available for analysis
  - LPILE (ENSOFT, Austin, TX)
  - Finite Element Software - ANSYS®
  - UniPile5 (UniSoft Ltd, Ottawa, ON)
  - Other Software packages are available

## Helical Anchor / Foundation Spacing



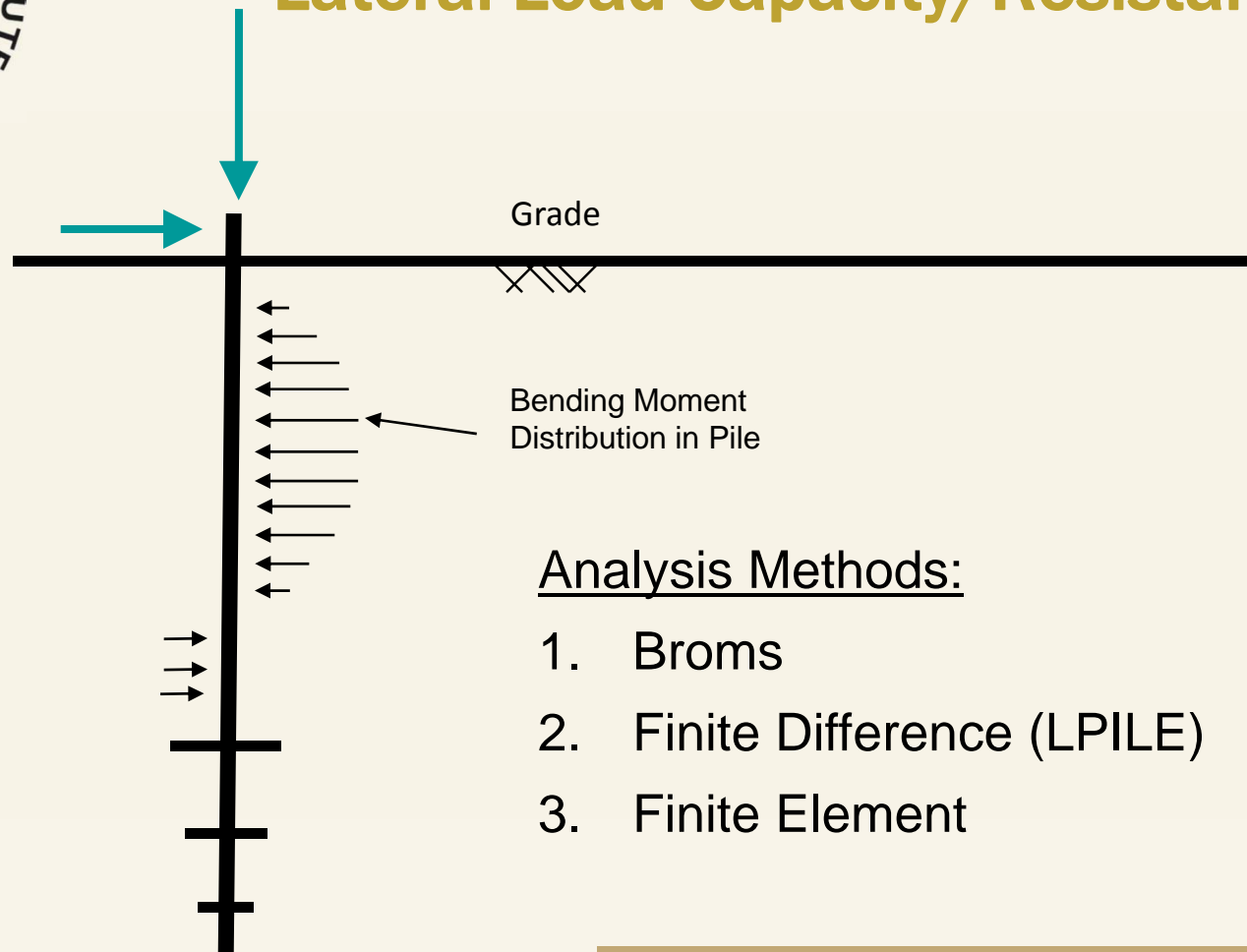
## Minimum Depth



- Specification of a minimum depth is required in expansive soils, for frost, and to ensure bearing in a certain stratum
- Specification of a minimum depth also is required in the case of pullout resistance to ensure a deep mode of behavior
  - Typically 7 to 10 helix diameters
  - Can be computed by comparing the weight of overburden soils with the required pullout resistance as in the figure to the left

"from Perko (2009) *Helical Piles*, Wiley, NY"

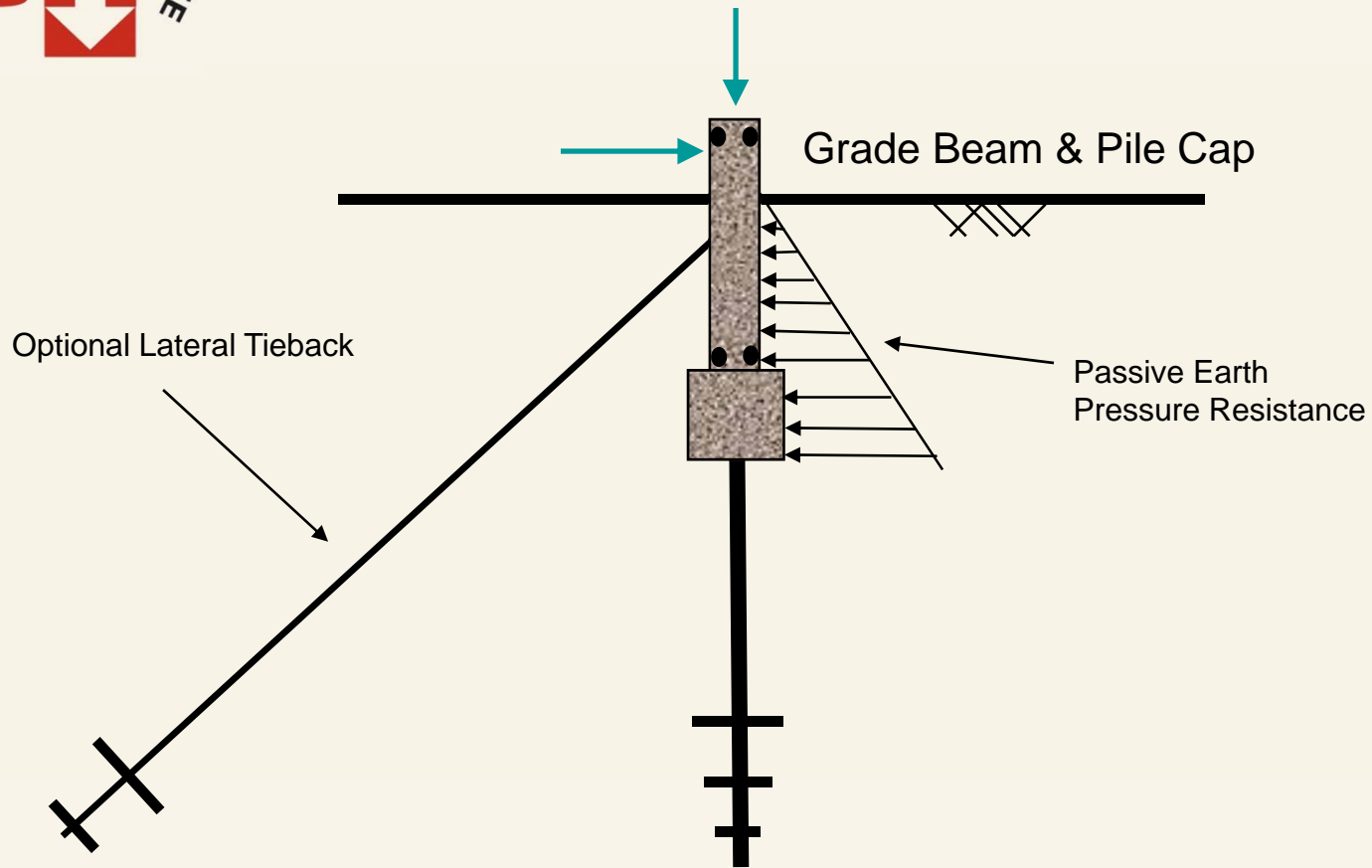
## Lateral Load Capacity/Resistance



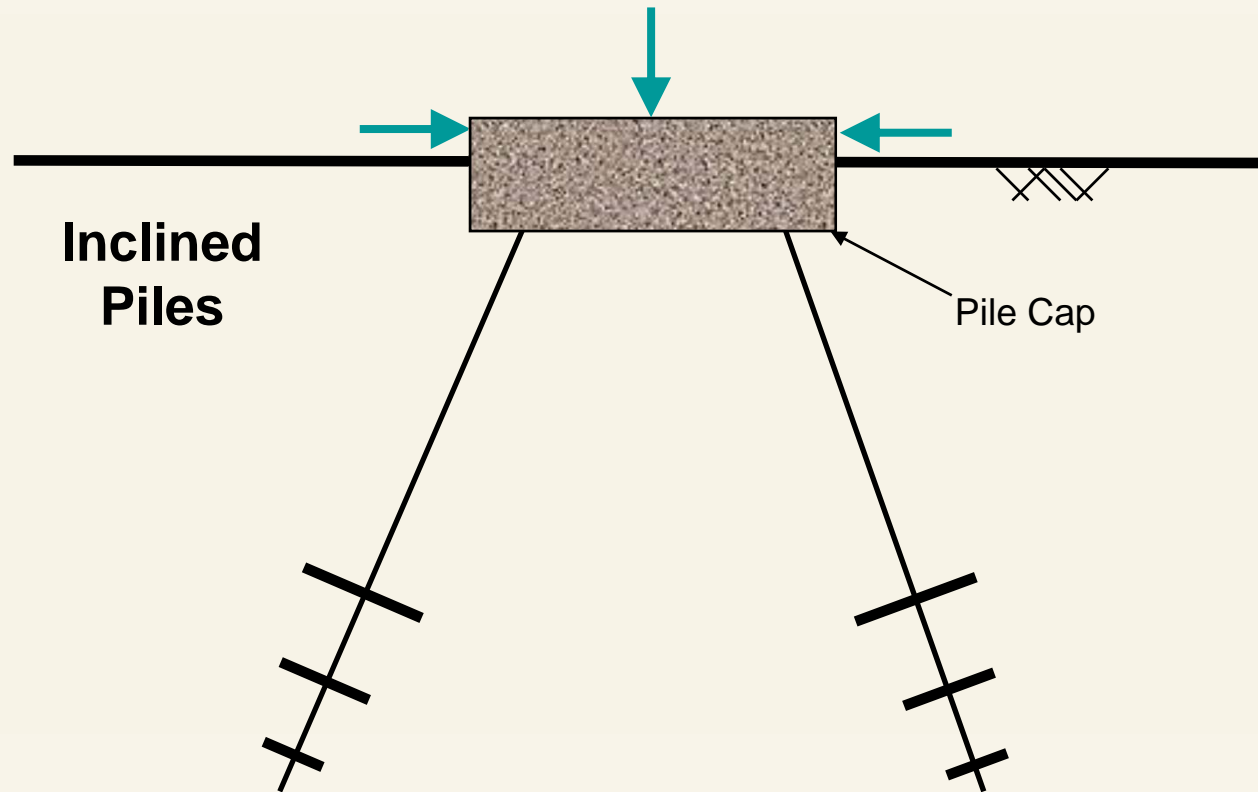
### Analysis Methods:

1. Broms
2. Finite Difference (LPILE)
3. Finite Element

# Lateral Load Capacity/Resistance



## Lateral Load Capacity/Resistance





## Corrosion

“... The data indicate that undisturbed soils are so deficient in oxygen at levels a few feet below ground line or below the water table zone, that steel pilings are not appreciably affected by corrosion, regardless of the soil types or the soil properties.”  
- from National Bureau of Standards Monograph 127 by Romanoff

Near surface, the top of helical foundations and anchors should be protected from corrosion by encasement in concrete, proper drainage, and other precautions.

Romanoff's monograph pertained primarily to driven steel piling that are traditionally designed using lower allowable stresses. For this reason, helical piles must be designed for corrosion by taking account sacrificial thickness lost to corrosion.

For permanent structures, corrosion may be accounted for adjusting shaft section properties by the sacrificial thickness per ICC-ES AC358.

AC358 Section 3.9 The thickness of each component shall be reduced by  $\frac{1}{2} T_s$  on each side for a net reduction in thickness of  $T_s$ .

$$T_d = T_n - T_s$$

where  $T_n$  is nominal thickness and  $T_s$  is sacrificial thickness (t=50 yrs).

Zinc-coated steel<sup>4</sup>:  $T_s = 25t^{0.65} = 0.013$  in

Bare steel:  $T_s = 40t^{0.80} = 0.036$  in

Powder coated steel:  $T_s = 40(t-16)^{0.80} = 0.026$  in

<sup>4</sup>Coating shall conform with ASTM A123/A153



## Model Specification Requirements

*Factors that affect the proper performance of helical piles and helical anchors*

- Proper sizing of helical bearing plates for the bearing and pullout capacity of the soil
- Minimum final installation torque
- Minimum overall depth required for frost, expansive soils, or to reach the proper bearing stratum
- Minimum shaft size and section modulus
- Mechanical capacity of pile and anchor components
- Proper connection to structure
- Training and experience level of contractor
- Inspection frequency and duration
- Load test requirements



## Types of Specifications

- **Open Specifications**
  - Contractor has sole responsibility for the scope, design, construction, capacity, and performance of the anchor/foundation
- **Performance Specifications**
  - Contractor has the responsibility for certain design and/or construction procedures
  - Testing or other mutually agreed upon acceptance criteria (i.e. installation torque) are required to demonstrate anchor/foundation load capacity to Owner.
  - Contractor and Owner share responsibility for the work
  - Most common specification used
- **Prescriptive (Means & Method) Specifications**
  - Owner has sole responsibility for scope, design, installation procedures and proper performance of the anchor/foundation
  - Contractor is responsible for fulfilling requirements as specified in the construction documents



# Applications

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## Excavation Shoring



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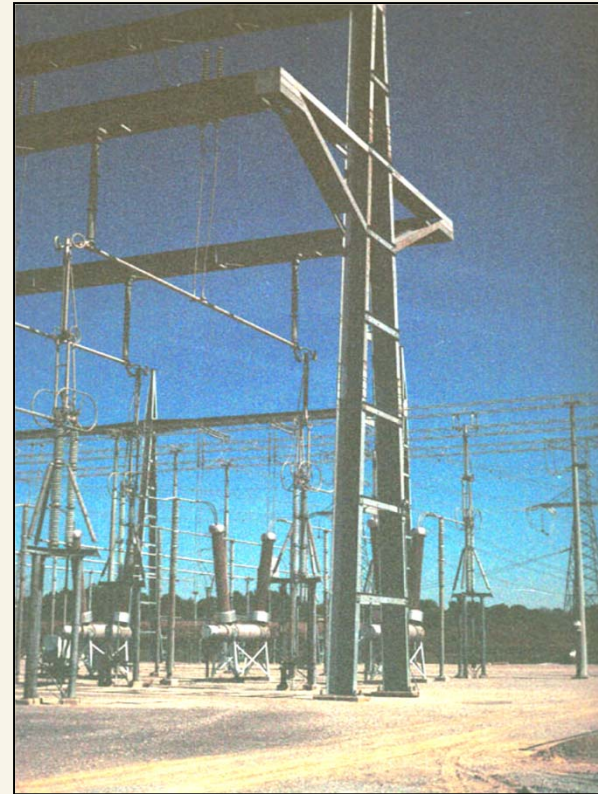
## Earth Retention



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## Electric Transmission Structures



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## Tower Guy Anchors



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## Buoyancy Control



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## Floor Slabs





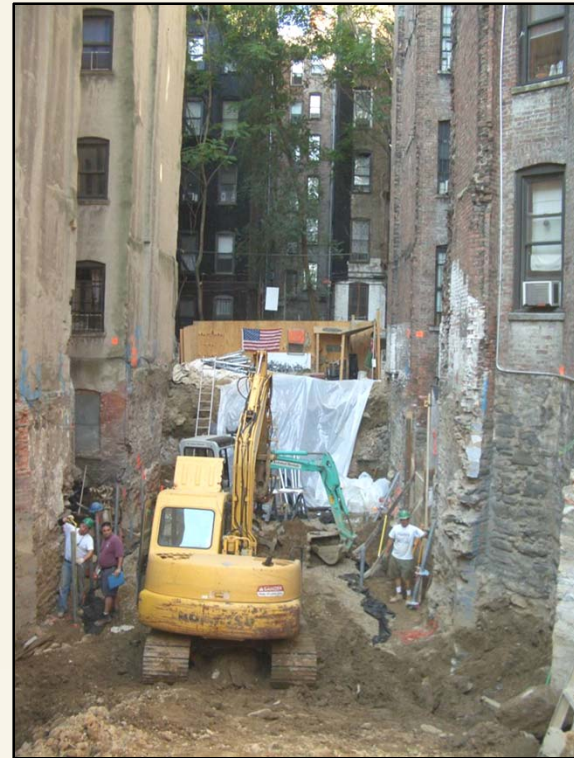
## Residential Foundations



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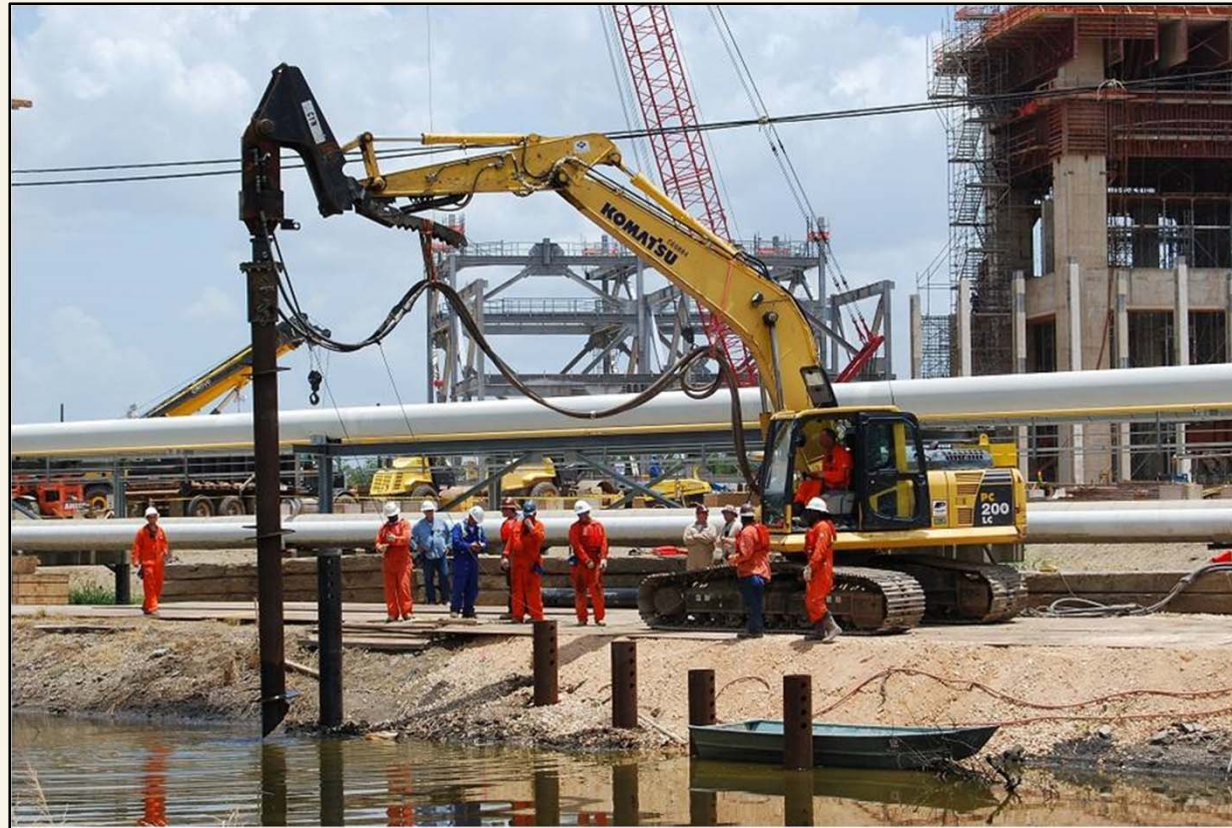


## Commercial Foundations



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## Oil Refineries



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## Oil Refineries



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## Pipelines



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## Grain Silos



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## Parking Garages



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## Recreation Facilities



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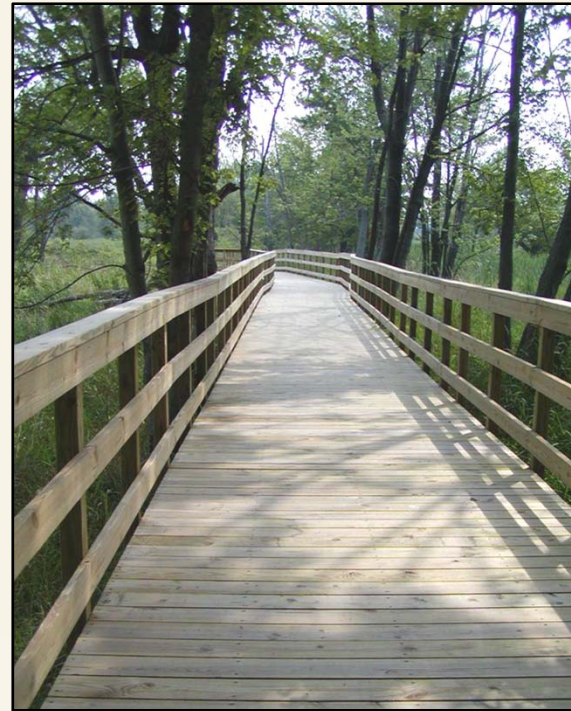
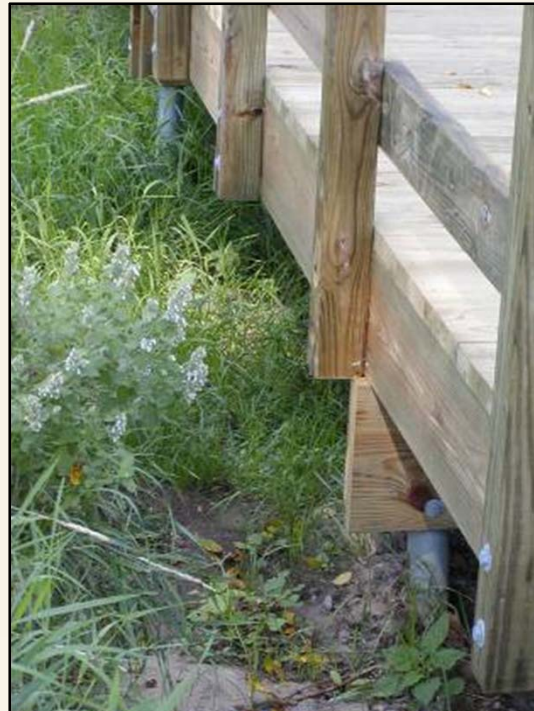
## Walkways for Wetlands



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## Nature Walks



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## Residential Additions



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## Decks & Gazebos



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## Underpinning



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## Underground Structures





## Other Applications

Signage	Elec Util	Government	Industrial	Soil Control
Awnings/Canopies	Elec Trans Guys	Airports	Equipment Fdn	Agriculture
Outdoor Advertising	Elec Trans Fdn	Bridges	Mines	Erosion Control
Sound Walls	Substation Fdn	HUD Housing	Nuclear/Chem Sites	Slope Retention
Roadway	Wind Generators	Flagpole		Aquaculture
		Military	Commercial	
Amusement	Marine	Parks	Commercial Structure	Miscellaneous
Parks	Bulkheads	Metro Rail	Constr Equip Fdns	Burial Vaults
Athletic Fields	Moorings	Native Amer Reserv	Elevator Pits	Load Test Anchors
Circus	Marine Constr	Railroad	Parking Lots	Logging
Golf		Rural Roadway/DOT	PreEngr Metal Buildings	Seismic Areas
Stadiums	TELCOM	Tunnel Approach	Tiebacks	Specialty Lighting
Zoos	Call Box	Urban Roadway		
	Cell Towers	Waste Water Facilities	Residential	
	Cell Twr Site Equip Fdn		Residential Fdn & Walls	
			Tiebacks	
	Oil			
	Oilfield			
	Pipeline			

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# Case History

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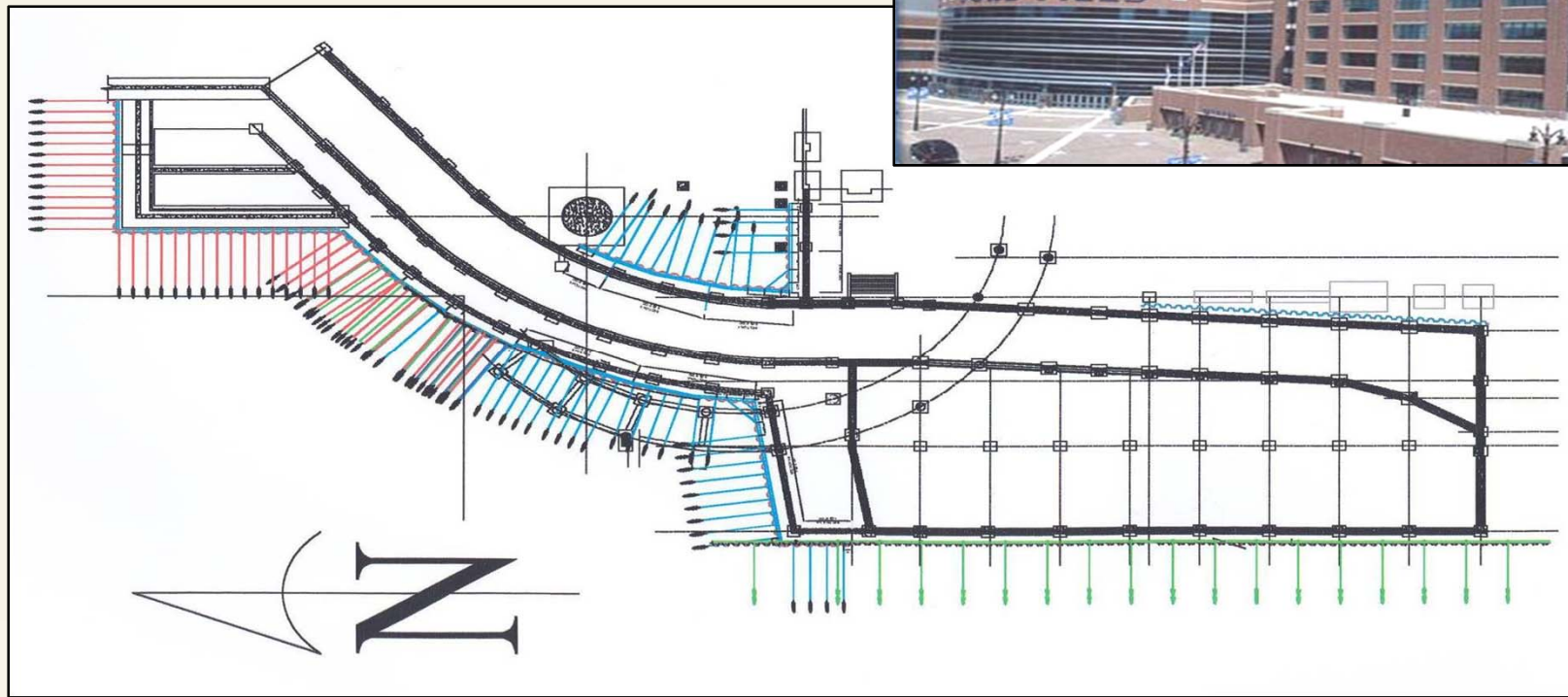
## Practical Design Application

Ford Field  
*Detroit Lions Stadium*



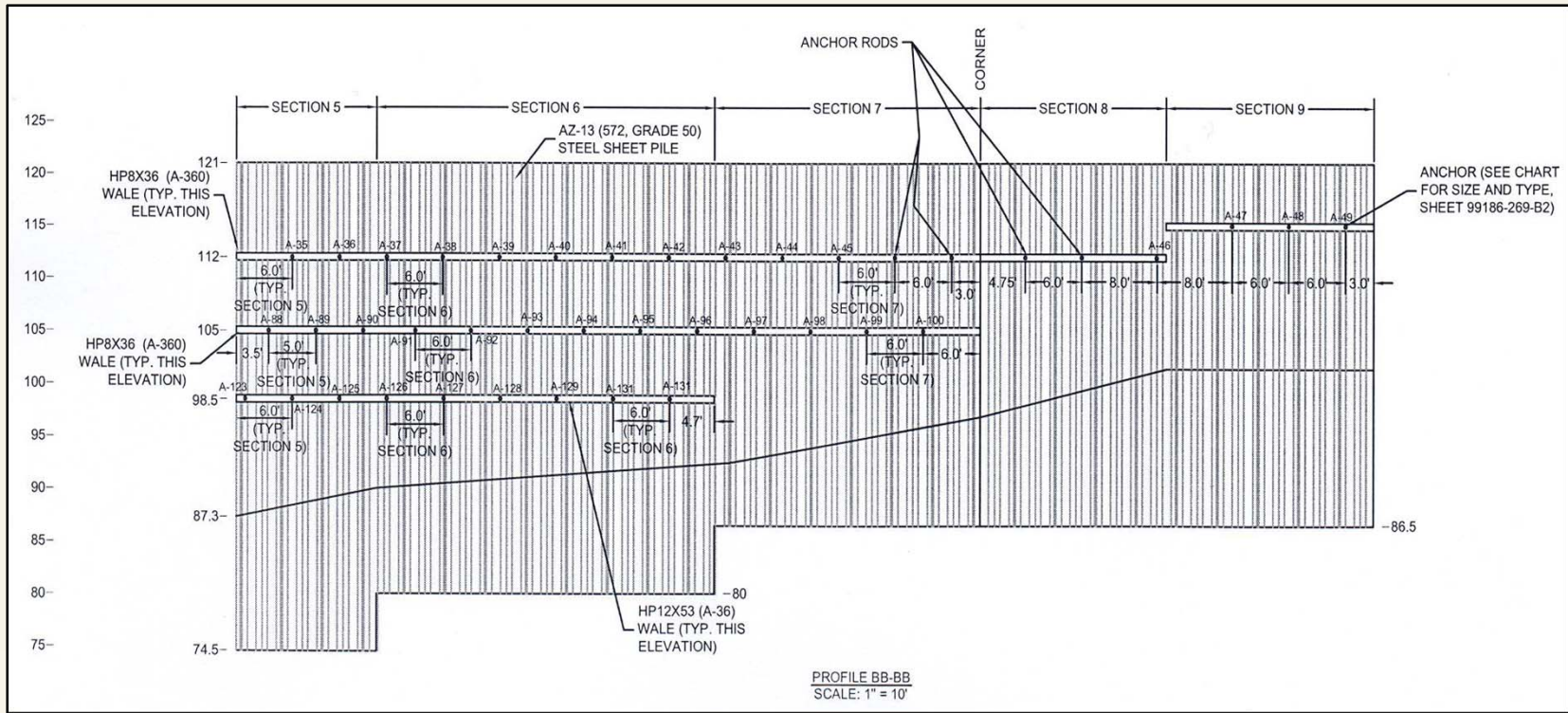
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## Plan View



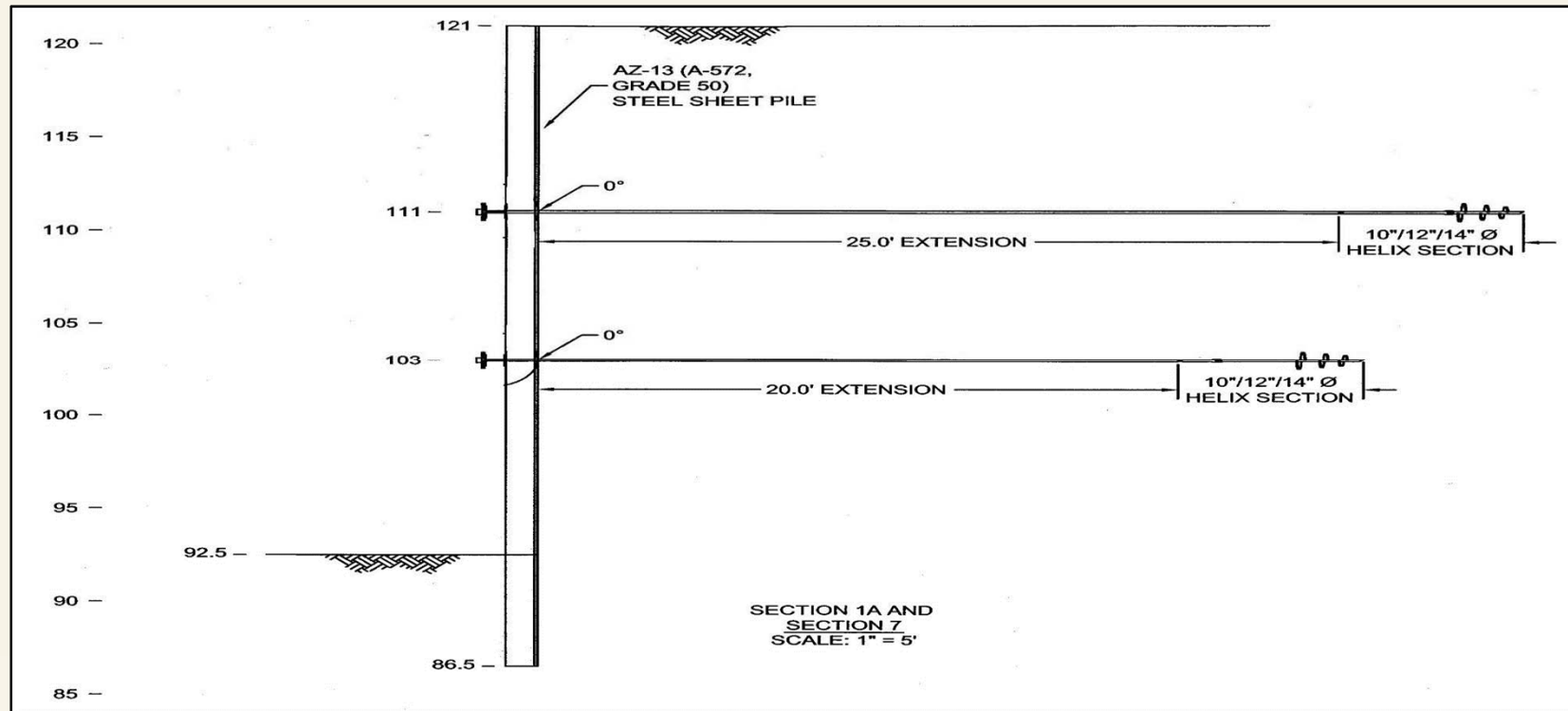


# Design Profile





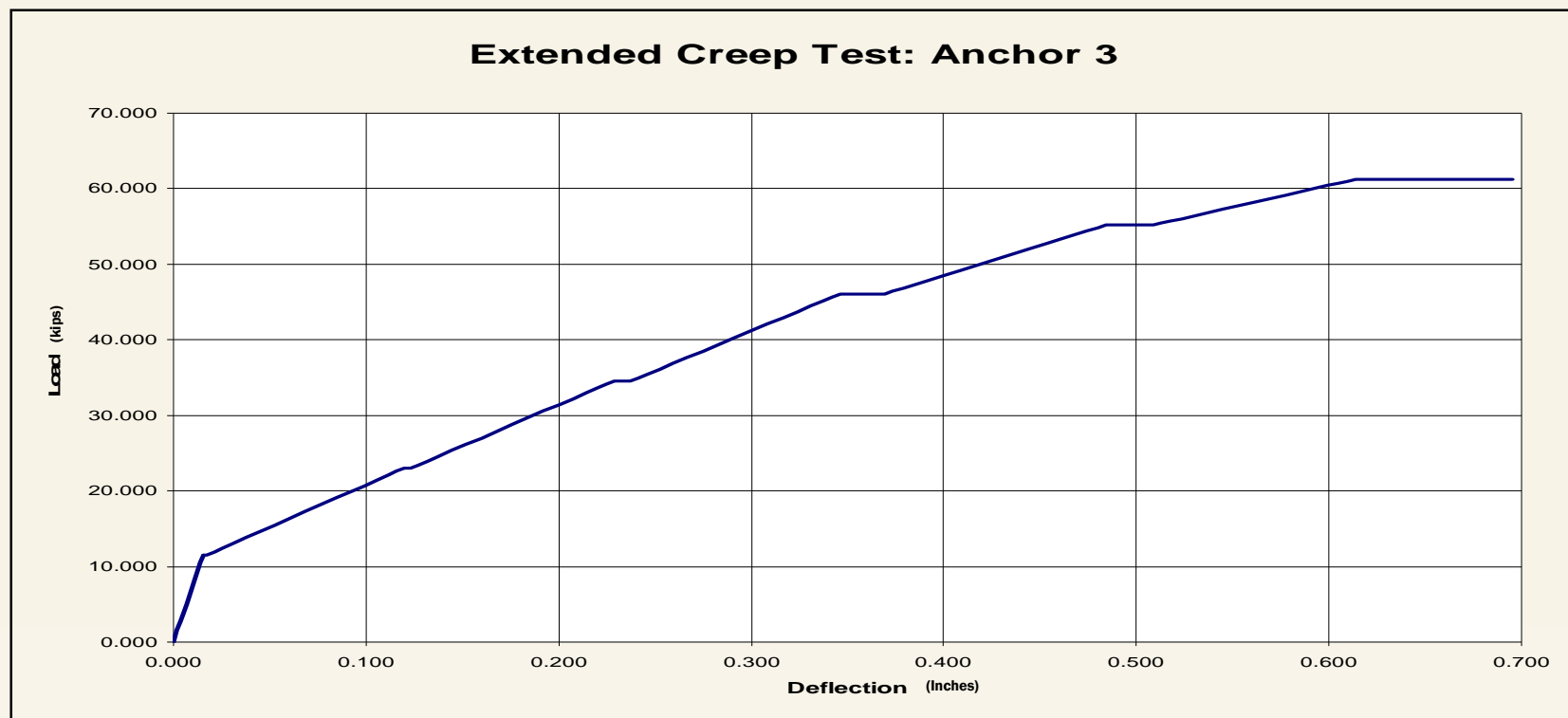
## Design Cross Section



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# Anchor Testing



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# Continued Study

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## Industry Organizations

- DFI (Deep Foundations Institute)
- ADSC (International Association of Foundation Drilling)
- ASCE (American Society of Civil Engineering)
- AGA (American Galvanizers Association)
- HelicalPileWorld.com



## Trade Shows / Seminars

- DFI Helical Pile & Tieback Conference
- Home Builders Expo
- DFI Annual Conference on Deep Foundations
- World of Concrete
- National Association of Tower Erectors
- Tower Show
- Con Expo
- Light Show
- Small Wind Installers Conference
- Solar Power International
- PV American (solar)
- Utility Solar Conference



## Books

- Howard A. Perko, *Helical Piles: A Practical Guide to Design and Installation*, Wiley, New York
- Donald P. Cuduto, *Foundation Design Principles and Practices*
- Gulac Wilson, *"The Bearing Capacity of Screw Piles and Screwcrete Cylinders"*
- Romanoff, *National Bureau of Standards Monograph 127*



## Conclusion

*Helical Piles & Anchors Offer a Wide Spectrum of Versatile Deep Foundation Solutions for Consideration by Engineers and Contractors*

### **DFI Disclaimer:**

This presentation is intended as an introduction to helical piles and helical anchors. It is neither intended to be comprehensive or exhaustive. The goal of the presentation is to complement undergraduate or graduate coursework in the study of deep foundation and anchor behavior. Helical piles and helical anchors are subject to many of the same limitations as other types of foundation and anchoring systems. There is no one solution for every ground condition. Prior to embarking on the design of helical foundation systems, the student is advised to seek further study in the proper design, installation, and application of helical piles and helical anchors.