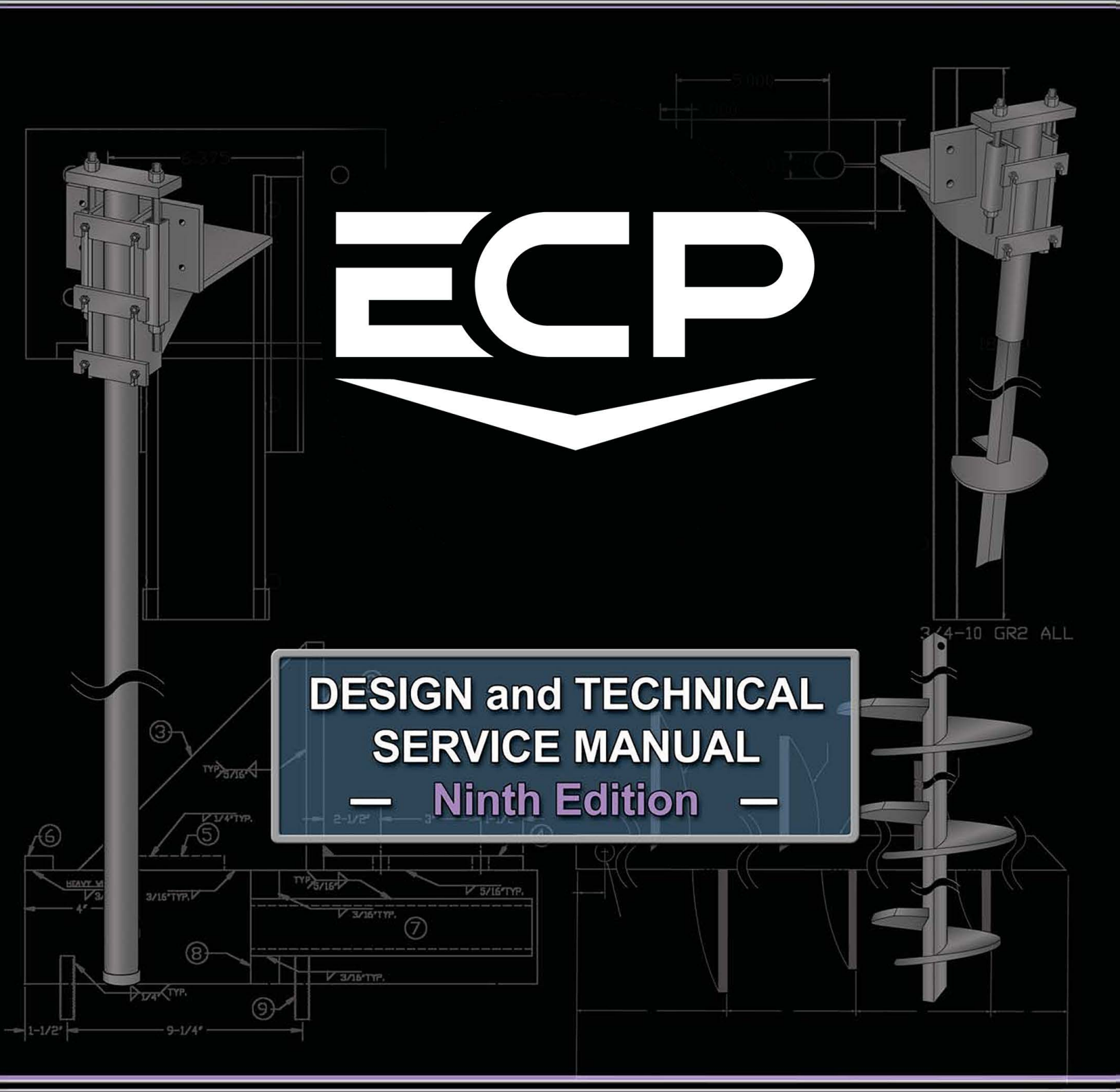
Foundation Repair Products

and

Helical Torque Anchors™



DESIGN and TECHNICAL SERVICE MANUAL

— Ninth Edition —

"Designed and Engineered to Perform"

www.earthcontactproducts.com

"DESIGNED AND ENGINEERED TO PERFORM"

Design and Technical Service Manual

-- Ninth Edition --

By: Donald J. Clayton, PE

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EARTH CONTACT PRODUCTS

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Earth Contact Products, LLC
Company Office and Manufacturing Facility
15612 South Keeler Terrace, Olathe, Kansas 66062
913 393-0007 - FAX 913 393-0008
Toll Free – 866 327-0007
www.earthcontactproducts.com

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From the author:

This manual was written and configured with reader in mind. The goal was to present the technical theories and equations in a simple, understandable way. This manual is not a rigorous text on soil mechanics and engineering theory. The intent was to produce a manual that distilled the theory down to make is easy to understand and to reach an answer or a solution in a timely manner. The technical information provided herein can help the engineer with a basic understanding of foundation support to delve deeper into the subject. Unlike some other technical manuals, there is nothing left out of this *ECP Design and Technical Service Manual* that would prevent the reader from performing an analysis and arriving at a solution without calling to the manufacturer or an engineer for assistance.

Engineers were in mind when the theoretical explanations, the assumptions, and equations to arrive at solution were written. It is the goal to provide sufficient technical data and guidance necessary to design typical foundation support or tieback systems. This book is not intended to be a thorough analysis of the subject area but rather a handbook for solutions to typically encountered situations in the field.

The book also has been written for non-engineers such as project managers, estimators, contractors; and foundation repair company owners, office supervisors and field superintendents in the business of installing foundation support systems. The dry, technical theory is there if the reader is interested in learning the subject matter more thoroughly, but the extensive use of tables and graphs in this edition reduces the need to master the theory and the need to go into difficult equations to get a solution.

New to this edition is our "Quick and Rough" estimating methods. These "Quick and Rough" methods are presented throughout the book. "Quick and Rough" estimating allows the non-engineer to arrive at a solution to a foundation support problem with a minimum of time and only a small amount of mathematics. Most of the design examples presented in this manual are solved using both methods. The results from both methods have shown reasonably comparable results from the same design example.

The manual is divided into three distinct sections; Helical Screw Products, Resistance Piers, and Corrosion Considerations. The divisions can clearly be determined from the tab markings on the right edge of the book. While some topics overlap, an attempt to make each section stand alone so that the reader can concentrate on only the subject of interest at the time.

This manual not intended to replace professional engineering input and judgment. It is highly recommend that you seek professional engineering input on any critical projects. It is also considered good practice to incorporate a minimum factor of safety of 2.0 into each and every preliminary design, to perform a field load test on any heavily loaded foundation element or on any critical projects; and to seek professional engineering input when in doubt or when available information is incomplete or confusing.

Finally, special thanks to a friend and colleague, Mr. Aaron Grayham, for his help, suggestions, constructive criticisms and vision for this manual. His suggestions have helped to transform the previous editions of the *ECP Design and Technical Service Manual* into the more detailed and user friendly book that you hold in your hand.

DJC/September 2013

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Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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Technical Design Assistance

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Chapter 1

ECP Helical Torque Anchors™ Technical Design Manual

- **Square Bar Helical Torque Anchors™**
- **Tubular Helical Torque Anchors™**
- **Torque Anchor™ Pile Caps, Utility Brackets and Shaft Terminations**

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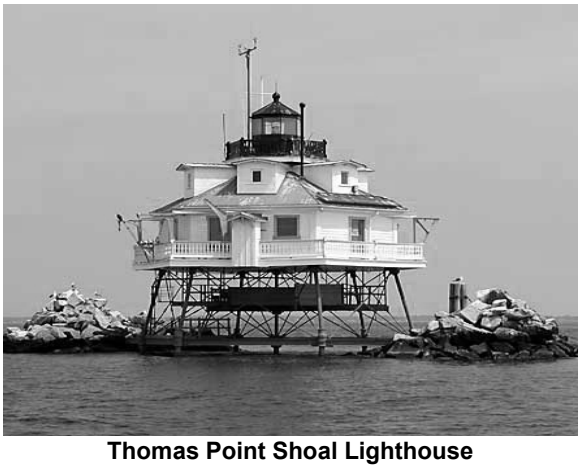
Screw piles have been in use for more than 160 years. In 1838 a lighthouse was built upon screw piles designed by an Irish engineer, Alexander Mitchell. In 1863, Eugenius Birch designed the Brighton West Pier in Brighton, England. These piers are still in use 150 years later. The original screw piles were installed at 10 feet per hour using eight 20 foot long torque bars and the force of 32 up to 40 men.

In the United States, the Thomas Point Shoal Lighthouse on Chesapeake Bay, Maryland, near Annapolis, Maryland; is the only remaining lighthouse built upon helical screw piles that is situated at its original location. This lighthouse has a hexagonal shape measuring 35 feet across, and it is still supported by seven original helical screw piles. The Thomas Point Shoal Lighthouse was constructed and first put into



Thomas Point Shoal Lighthouse

operation on November 20, 1875. The helical screw piles that support the structure consist of ten inch diameter wrought iron shafts with cast iron helical screw flanges at the end of the shafts. At Thomas Point, the screw piles were advanced into to sandy bottom of Chesapeake Bay to a depth of 11-1/2 feet. The signal light is mounted 43 feet above the surface of the water.

Cast iron coupling at Thomas Point Lighthouse

Sporadic use of screw piles has been documented throughout the 19th and early 20th centuries mainly for supporting structures and bridges over weak or wet soil.

Hydraulic torque motors became available in the 1960's, which allowed for easy and fast installation of screw piles. Screw piles then became the favored product for resisting tensile forces. Electric utility companies began to use screw piles for tie down anchors on transmission towers and for guy wires on utility poles.

Screw piles are ideal for applications where there is a need to resist both axial tension and compression forces. Some examples of structures requiring resistance to both compressive and tensile forces are metal buildings, canopies and monopole telecommunication tower foundations. Current uses for screw pile foundations include foundations for commercial and residential structures, light poles, retaining walls tieback anchors, restorations of failed foundations, pipeline and pumping equipment supports, elevated walkways, bridge abutments, and numerous uses in the electric utility industry.

ECP Torque Anchors™

ECP Torque Anchors™ are a part of the complete product line of screw piles, steel piers and foundation support products manufactured by Earth Contact Products, LLC, a family owned company based in Olathe, Kansas. The company was built upon the ECP Steel Pier™, a fourth generation end bearing steel mini-pile designed and patented for ECP.

Our 100,000 square foot state of the art manufacturing facility produces all components and steel assemblies. The only processes not done in our facility are galvanization and hot forge upsetting of shaft couplings. We are able to custom design and configure products to your engineered specific applications. Earth Contact Products uses only certified welders and robotics for quality fabrication.

Torque Anchor™ Components

The ECP Torque Anchor™ consists of a shaft fabricated from either solid square steel bar or tubular steel. Welded to the shaft are one or more helical plates. The plates can vary in diameter from 6 inches to 16 inches and have a thickness of 3/8 or 1/2 inch depending upon the

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application. Typically the plate diameters increase from the bottom of the shaft upward, and are spaced a distance of three times the diameter of the plate directly below unless specified otherwise by the engineer. The standard thickness for all helical plate diameters is 3/8 inch, except for the 16 inch diameter helical plate which is manufactured only in 1/2 inch thickness. In high capacity applications or in obstruction laden soils, a helical plate thickness of 1/2 inch may be special ordered for all sizes of plates. The standard pitch of all helical plates is three inches, which means that the anchor advances into the soil a distance of three inches during one revolution of the shaft.

The standard lead shaft lengths of most products are 10 inches, 5 feet, 7 feet and 10 feet, however, other lengths may be specially fabricated for large quantity specialized applications. Because Torque Anchors™ are considered deep foundation elements; they are usually installed into the soil to a depth greater than just the length of the typical lead section.

Extensions of various lengths are available and are supplied with couplings and hardware for attachment to the lead or other extensions allowing the Torque Anchor™ assembly to reach the desired depth. Helical plates may also be installed on the extensions where the length of the lead is not sufficiently long enough to allow for the proper interval between plates. The number of the plates per Torque Anchor™ is limited only by the shaft capacity to transmit the torque required to advance the Torque Anchor™ into the soil.

Torque Anchors™ may terminate with a pile cap that embeds into a new concrete foundation. In other applications such as tieback anchors, a transition is made from the anchor shaft to a continuously threaded rod for attachment to the wall. Various beams, wall plates, etc. can be attached to the threaded bar for wall support, for restorations, or to simply stabilize walls or other structure from overturning forces. When the application requires existing foundation restoration or stabilization, foundation brackets are available that attach between the Torque Anchor™ and the foundation beam, footing or slab. The purpose of the foundation bracket is to transfer the load from the foundation element to the Torque Anchor™.

Product Benefits

- **Quickly Installed**
- **Low Installed Cost**
- **Installs With Little Or No Vibration**
- **Installs In Areas With Limited Access**
- **Little Or No Disturbance To The Site**
- **Soil Removal From Site Unnecessary**
- **Installed Torque Correlates To Capacity**
- **Easily Load Tested To Verify Capacity**
- **Can Be Loaded Immediately After Installation**
- **Installs Below The Unstable And Sinking Soil To Firm Bearing**
- **Small Shaft Size Limits "Down Drag" From Shallow Consolidating Soils**
- **All Weather Installation**

Product Limitations

Torque Anchors™ are not suitable in locations where subsurface material may damage the shaft or the helices. Soils containing cobbles, large amounts of gravel, boulders, construction debris, and/or landfill materials are usually unsuitable for helical products.

Because the products have slender shafts, buckling may occur when passing through extremely weak soil because the soft soil may not exert sufficient lateral force on the narrow shaft to prevent buckling. When extremely soft soils are present, generally having a Standard Penetration Test – "N" < 5 blows per foot, one must take into consideration the axial stiffness of the anchor shaft in the design.

The slender shafts also render the typical Torque Anchor™ ineffective against large lateral loads or overturning moments.

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Table 1. ECP Torque Anchor™ Product Designations		
Product	**Prefix**	**Product Description**
Helical Lead Sections	TAH	Lead Section With One 3/8" Thick Helical Plate
	HTAH	Lead Section With One 1/2" Thick Helical Plate
	TAF	Lead Section with Multiple 3/8" Thick Helical Plates
	HTAF	Lead Section with Multiple 1/2" Thick Helical Plates
Shaft Extensions	TAE	Extension Section with Coupling & Hardware
Transitions	TAT	Transition Coupling – Helical Tieback Anchor Shaft to Threaded Bar
New Construction Pile Caps	TAB–NC	New Construction Compression Pile Cap
	TAB–T	New Construction Tension Pile Cap (Compression and uplift support)
Brackets for Foundation Repair	TAB-150-SUB + TAB-150 TT TAB-288L-MUB + TAB-288-TTM	Foundation Bracket – Fits 1-1/2" Sq. Shaft Helical Pile Shaft Foundation Bracket – Fits 2-7/8" x 0.203" Wall Tubular Helical Pile Shaft
	TAB - LUB TAB-175-TT TAB-288-TT TAB-350-TT	Large Foundation Bracket – Fits Under Footing and Connects to Pile Shaft: T-Tube for use with 1-3/4" Square Shaft T-Tube for use with 2-7/8" Diameter Tubular Shaft T-Tube for use with 3-1/2" Diameter Tubular Shaft
Brackets for Slab Repair	TAB-150-LP TAB-288-LP	Porch Bracket – Fits 1-1/2" Square or 2-7/8" Dia. Helical Pile Shaft
	TAB-150-SSB	Screw Lift Slab Bracket – Fits 1-1/2" Square Helical Pile Shaft
	TAB-150-HSB	Hydraulic Lift Slab Bracket – Fits 1-1/2" Square Helical Pile Shaft
	TAB-288-LHSB TAB-288-HSB	Hydraulic Lift Slab Bracket – Fits 2-7/8" Diameter Tubular Shaft Also Fits: 1-1/2" Square Shaft 1-3/4" Square Shaft
Timber Bracket	TAB-150-TB	Bracket to timber beams – Fits 1-1/2" Square Helical Pile Shaft
Wall Plate	PA	Stamped Wall Plate – Fastens Wall To Threaded Shaft From Tieback

Table 2. Capacities of ECP Helical Torque Anchors™					
Shaft Size	Installation Torque Factor (k)	Axial Compression Load Limit	Ultimate-Limit Tension Strength	Useable Torsional Strength	Practical Load Limit Based on Torsional Strength
1-1/2" Square Bar	9 - 11	70,000 lb.	70,000 lb.	7,000 ft-lb	Load limited to the rated capacity of the attachments and the lateral soil strength against the shaft
1-3/4" Square Bar	9 - 11	100,000 lb.	100,000 lb.	10,000 ft-lb	
2-1/4" Square Bar	10 - 12	200,000 lb.	200,000 lb.	23,000 ft-lb	
2-7/8" Tubular – 0.203" Wall	8 - 9	60,000 lb.	60,000 lb.	5,500 ft-lb	44,000 lb
2-7/8" Tubular – 0.262" Wall	8 - 9	100,000 lb.	100,000 lb.	9,500 ft-lb	80,000 lb
3-1/2" Tubular – 0.300" Wall	7 - 8	115,000 lb.	120,000 lb.	13,000 ft-lb	97,000 lb
4-1/2" Tubular – 0.337" Wall	6 - 7	160,000 lb.	160,000 lb.	22,000 ft-lb	143,000 lb

The designer should select a product that provides adequate additional torsional capacity for the specific project and soil conditions.

IMPORTANT NOTES:

The capacities listed for "Axial Compression Load Limit", "Ultimate Limit Tension Strength" and "Useable Torsion Strength" in Table 2 are mechanical ratings. One must understand that the actual installed load capacities for the product are dependent upon the actual soil conditions on a specific job site. The shaft "Useable Torsional Strengths" given here are the **maximum** values that should be applied to the product. Furthermore, these torsional ratings assume homogeneous soil conditions and proper alignment of the drive motor to the shaft. In homogeneous soils it might be possible to achieve up to 95% or more of the "Useable Torsional Strength" shown in Table 2. In obstruction-laden soils, torsion spikes experienced by the shaft may cause impact fractures of the couplings or other components. Where impact loading is expected, reduce shaft torsion by 30% or more from "Useable Torsional Strength" depending upon site soil conditions to reduce chance of fracture or damage.

Another advantage of selecting a torsional rating below the values shown in Table 2 is that one may be able to drive the pile slightly deeper after the torsional requirements have been met, thus eliminating the need to cut the pile shaft in the field.

The load transfer attachment capacity must be verified for the design. Standard attachments and ratings are shown on the following pages. Special configurations to fit your project can be fabricated to your specifications upon request.

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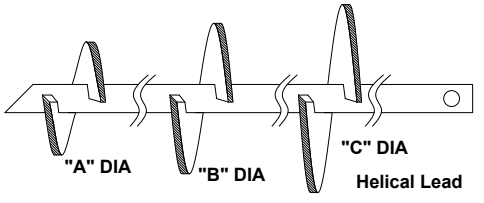
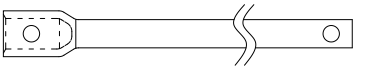
1-1/2" Round Corner Square Bar Torque Anchors™





Standard ECP Torque Anchor™ Lead Configurations – 7,000 ft-lb*

Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
TAH-150-10 08	8	--	--	0.33	10"
TAH-150-10 10	10	--	--	0.53	10"
TAH-150-10 12	12	--	--	0.77	10"
TAH-150-60 08	8	--	--	0.33	60"
TAH-150-60 10	10	--	--	0.53	60"
TAH-150-60 12	12	--	--	0.77	60"
TAF-150-60 06-08	6	8	--	0.51	60"
TAF-150-60 08-10	8	10	--	0.86	60"
TAF-150-60 10-12	10	12	--	1.30	60"
TAH-150-84 12	12	--	--	0.77	84"
TAF-150-84 08-10-12	8	10	12	1.63	84"
TAF-150-84 10-12	10	12	--	1.30	84"
TAF-150-84 10-12-14	10	12	14	2.35	84"
TAF-150-120 8-10-12	8	10	12	1.63	120"
TAF-150-120 10-12-14	10	12	14	2.35	120"

Standard ECP Torque Anchor™ Extensions

Part Number			
36"	60"	84"	120"
TAE-150-36	**TAE-150-60**	**TAE-150-84**	**TAE-150-120**

Note: Products Listed Above Are Standard Items And Are Usually Available From Stock.
Other Specialized Configurations Are Available As Special Order – Allow Extra Time For Processing.
All Helical Plates Are Spaced At Three Times The Diameter Of The Preceding Plate
Effective Length Of Extension Is 3" Less Than Overall Dimension Due to Coupling Overlap
All Product Hot Dip Galvanized Per ASTM A123 Grade 100
Shaft Weight per Foot – 7.7 lb.

* Please see "IMPORTANT NOTES" on Table 2

If a Torque Anchor™ configuration is not shown above as a standard product; please see "How to Specify Special Order Torque Anchors™" on page 10.

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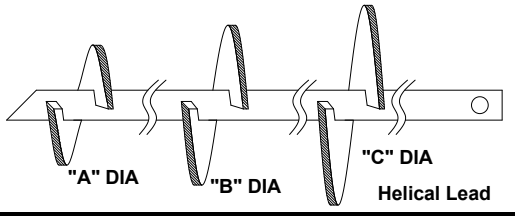
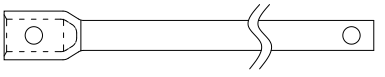
1-3/4" Round Corner Square Bar Torque Anchors™





Extension (Supplied with hardware)

Standard ECP Torque Anchor™ Lead Configurations – 10,000 ft-lb*

Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
HTAH-175-60 08	**8**	--	--	0.33	60"
TAF-175-60 10-12	10	12	--	1.29	60"
TAF-175-84 10-12-14	10	12	14	2.34	84"

Standard ECP Torque Anchor™ Extensions

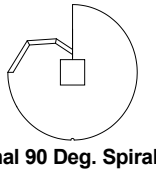
Part Number			
36"	60"	84"	120"
TAE-175-36	**TAE-175-60**	**TAE-175-84**	**TAE-175-120**

Note: Products Listed Above Are Standard Items And Are Usually Available From Stock
See page 11 – "How to Specify Special Order Torque Anchors™ for Specialized Configurations – Allow Extra Time For Processing.
All Helical Plates Are Spaced At Three Times The Diameter Of The Preceding Plate
Effective Length Of Extension Is 3" Less Than Overall Dimension Due to Coupling Overlap
All Product Hot Dip Galvanized Per ASTM A123 Grade 100
Shaft Weight per Foot – 10.4 lb/ft.

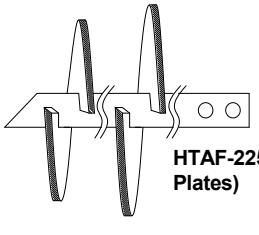
"H" before part designation indicates helical plate thickness of 1/2 inch instead of standard 3/8"

2-1/4" Round Corner Square Bar Torque Anchors™

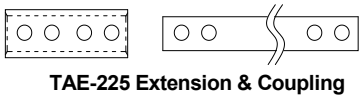
2-1/4" Square Bar Torque Anchor™ Leads – 23,000 ft-lb*



Optional 90 Deg. Spiral Cut Helical Plate - Specify Which Plate(s)



HTAF-225 (1/2" Thick Plates)



TAE-225 Extension & Coupling (Supplied Wih Hardware)

2-1/4" Square Bar Torque Anchor™ Extensions

Shaft Length	36"	60"	84"	120"
Part Number	**TAE-225-36**	**TAE-225-60**	**TAE-225-84**	**TAE-225-120**

Note: All 2-1/4" square bar products available as special order – Inquire for pricing and delivery
See page 11 – "How to Specify Special Order Torque Anchors™ for information
Helical plates are 1/2" thick and spaced at three times the diameter of the preceding plate.
Extensions supplied with coupling and SAE J429 grade 8 bolts and nuts.
Product hot dip galvanized per ASTM A123 grade 100.
Shaft weight per foot – 17.2 lb.

* Please see "IMPORTANT NOTES" on Table 2

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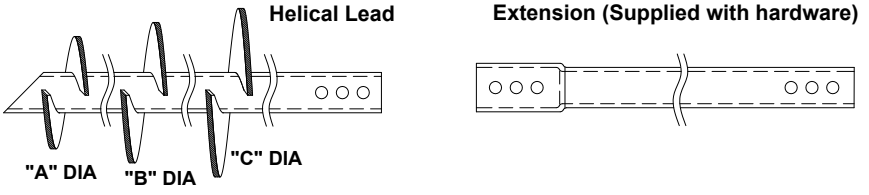
2-7/8" Dia. x 0.262 Wall Tubular Shaft Torque Anchors™



Standard ECP Torque Anchor™ Lead Configurations - 9,500 ft-lb*

Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
TAH-288-60 08	8	--	--	0.30	60"
TAH-288-60 10	10	--	--	0.50	60"
TAH-288-60 12	12	--	--	0.74	60"
TAF-288-60 8-10	8	10	--	0.80	60"
TAF-288-60 10-12	10	12	--	1.24	60"
TAF-288-84 08-10	8	10	--	0.80	84"
HTAF-288-84 08-10	**8**	**10**	--	0.80	84"
TAF-288-84 10-12	10	12	--	1.24	84"
HTAF-288-84 10-12	**10**	**12**	--	1.24	84"
TAF-288-84 8-10-12	8	10	12	1.54	84"
TAF-288-84 10-12-14	10	12	14	2.26	84"
TAF-288-120 8-10-12	8	10	12	1.54	120"
TAF-288-120 10-12-14	10	12	14	2.26	120"
TAF-288-120 14-14-14	14	14	14	3.07	120"

Standard ECP Torque Anchor™ Extensions

Part Number			
36"	60"	84"	120"
TAE-288-36	**TAE-288-60**	**TAE-288-84**	**TAE-288-120**

Note: Products Listed Above Are Standard Items And Are Usually Available From Stock.
Other Specialized Configurations Are Available As Special Order – Allow Extra Time For Processing.
All Helical Plates Are Spaced At Three Times The Diameter Of The Preceding Plate
Effective Length Of Extension Is 6" Less Than Overall Dimension Due to Coupling Overlap
All Product Hot Dip Galvanized Per ASTM A123 Grade 100
Shaft Weight per Foot – 7.7 lb.

"H" before part designation indicates helical plate thickness of 1/2 inch instead of standard 3/8"

* Please see "IMPORTANT NOTES" on Table 2

If a Torque Anchor™ configuration is not shown above as a standard product; please see "How to Specify Special Order Torque Anchors™" on page 10.

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3-1/2" Dia. x 0.300 Wall Tubular Shaft Torque Anchors™

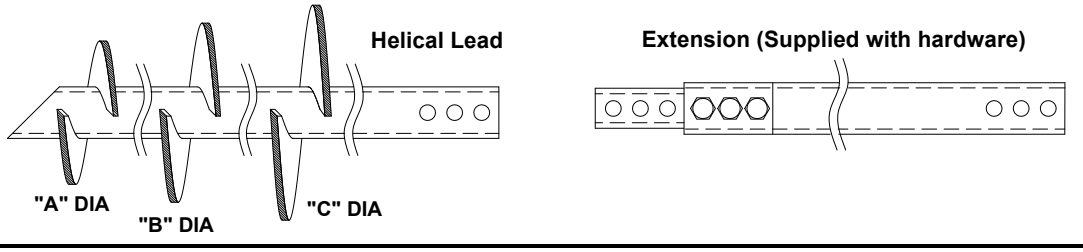
Standard ECP Torque Anchor™ Lead Configurations – 13,000 ft-lb*

Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
TAF-350-60 10-12	10	12	--	1.20	60"
TAF-350-84 8-10-12	8	10	12	1.48	84"
TAF-350-120 8-10-12	8	10	12	1.48	120"
TAF-350-120 10-12-14	10	12	14	2.20	120"

Standard ECP Torque Anchor™ Extensions

Part Number			
36"	60"	84"	120"
TAE-350-36	**TAE-350-60**	**TAE-350-84**	**TAE-350-120**

3-1/2" Dia. x 0.300 Wall Tubular Shaft Torque Anchors™ and 4-1/2" Dia. x 0.337 Wall Tubular Shaft Torque Anchors™



4-1/2" Dia. x 0.337 Wall Tubular Shaft Torque Anchors™

Standard ECP Torque Anchor™ Lead Configurations – 22,000 ft-lb*

Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
TAF-450-84 10-12-14	10	12	14	2.07	84"
HTAF-450-120 10-12-14	**10**	**12**	**14**	2.07	120"

Standard ECP Torque Anchor™ Extensions

Part Number				
Length	36"	60"	84"	120"
Part Number	**TAE-450-36**	**TAE-450-60**	**TAE-450-84**	**TAE-450-120**

Note: Products Listed Above Are Standard Items And Are Usually Available From Stock.
Other Specialized Configurations Are Available As Special Order – Allow Extra Time For Processing.
All Helical Plates Are Spaced At Three Times The Diameter Of The Preceding Plate
Extensions are Supplied with an Internal Coupling and Hardware.
All Product Hot Dip Galvanized Per ASTM A123 Grade 100.
Shaft Weight per Foot – TAF-350 - 10.2 lb; TAF-450 – 15.4 lb

"H" before part designation indicates helical plate thickness of 1/2 inch instead of standard 3/8"

* Please see "IMPORTANT NOTES" on Table 2

If a Torque Anchor™ configuration is not shown above as a standard product; please see "How to Specify Special Order Torque Anchors™" on page 10.

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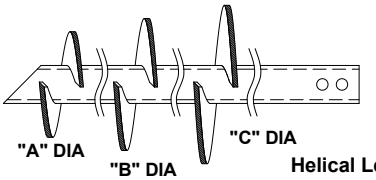
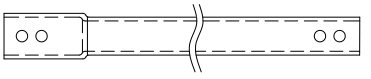
2-7/8" x 0.203" Wall Tubular Shaft – Light Duty Torque Anchors™





Standard ECP Torque Anchor™ Lead Configurations – 5,500 ft-lb*

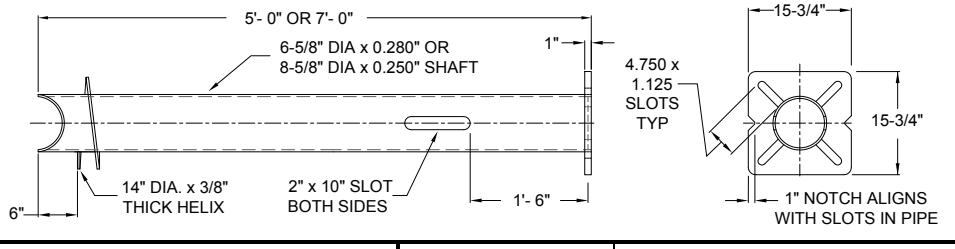
Product Designation	Plate Diameter - inches			Plate Area sq. ft.	Length
	"A"	"B"	"C"		
TAF-288L-60 08-10	8	10	--	0.80	60"
TAF-288L-60 10-12	10	12	--	1.24	60"
TAF-288L-84 08-10	8	10	--	0.80	84"
TAF-288L-84 10-12	10	12	--	1.24	84"
TAF-288L-60 12	12	--	--	0.74	60"
Available ECP Torque Anchor™ Lead Configurations – Not Stocked**					
TAF-288L-84 8-10-12	8	10	12	1.54	84"
TAF-288L-84 10-12-14	10	12	14	2.26	84"
TAF-288L-84 12-14	12	14	-	1.76	84"

Standard ECP Torque Anchor™ Extensions

Part Number		
60"	84"	120"
TAE-288L-60	**TAE-288L-84**	**TAE-288L-120**

Note: **NO SPECIAL ORDERS ACCEPTED -** Only the products shown above are stocked or available
Effective Length Of Extension Is 5" Less Than Listed Due to Coupling Overlap; supplied with ASTM A325 bolts & nuts.
All Product Hot Dip Galvanized Per ASTM A123 Grade 100. Shaft weight per foot – 5.8 lb.

Light Pole Support Torque Anchors™



Torque Anchor™ Configuration	Part Number	Ultimate-Limit Capacity at SPT ≥ 5 bpf	
		Overturning Moment	Lateral Load
6-5/8" Dia. x 0.280" Wall & 14" Helix – 7'- 0" Long**	HTAF-663-84 14	< 12,000 ft-lb	< 1,000 lb
8-5/8" Dia. x 0.250" Wall & 14" Helix – 7'- 0" Long**	HTAF-863-84 14	< 17,500 ft-lb	< 1,200 lb

Note: Integral Pile Cap is 1" Thick x 15-3/4" Square Pile Cap Welded to Shaft With Slots for 1" Diameter Mounting Bolts
2" x 10" Cable Access Slot Provided on Both Sides of Shaft
Double Cut Chamfer on Bottom of Shaft Aligns Pile and Eases Installation
We Will Fabricate Custom Light Pole Supports to Your Design Specifications – Allow Extra Time For Processing.
Other Shaft Lengths are Available to Meet Your Engineering Specifications
Product Supplied Hot Dip Galvanized Per ASTM A123 Grade 100.

* Please see "IMPORTANT NOTES" on Table 2
** The products shown shaded are available but are not stocked – allow extra time for fabrication

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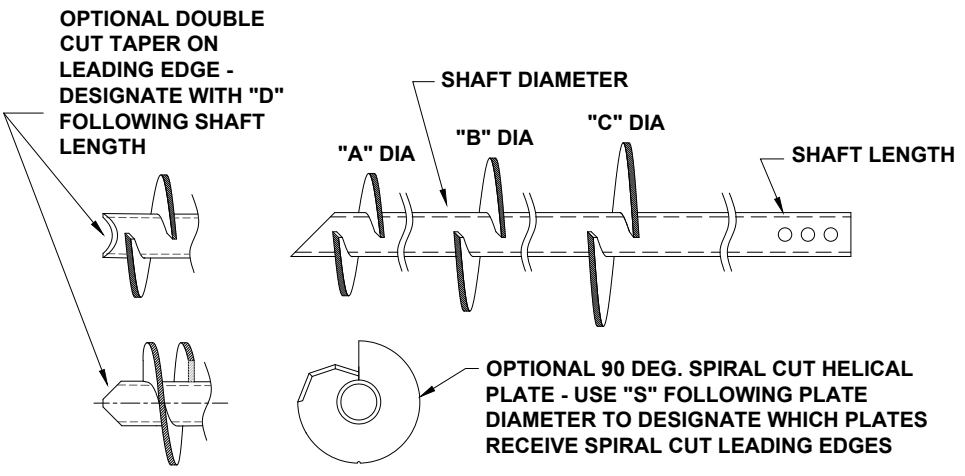
HOW TO SPECIFY SPECIAL ORDER TORQUE ANCHORS™

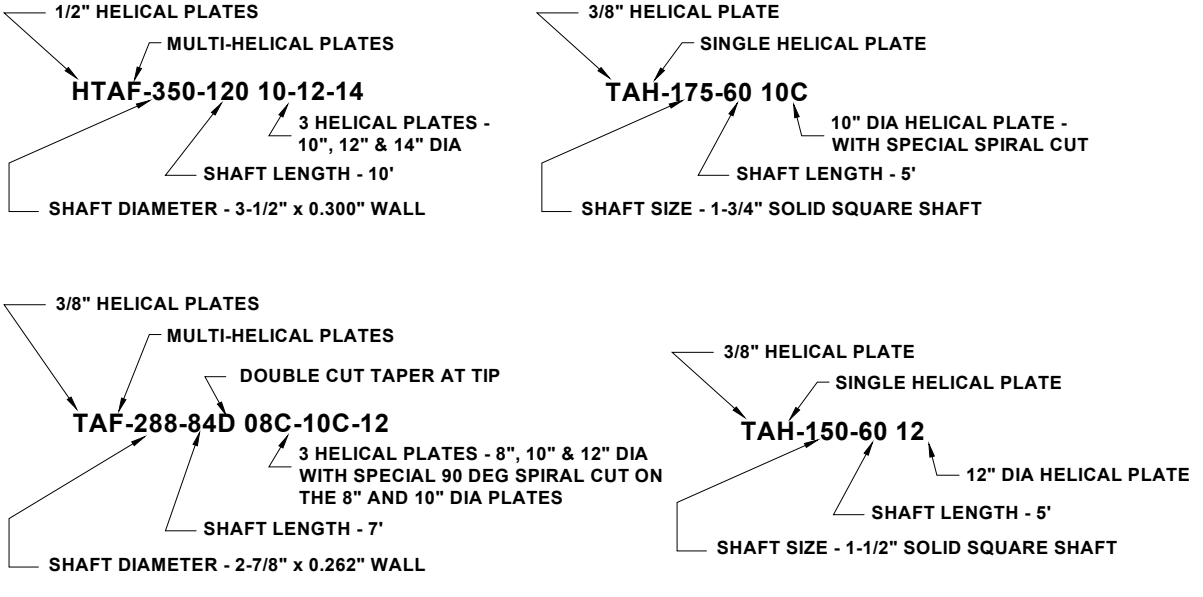


Typical Product Designation System:

(H)TAF-(Shaft Dia.)-(Shaft Length)(D*) (Plate Dia – "A(C)" -"B"-"C")

*** Notes:** "H" at the beginning of the designation indicates that all helical plates will be 1/2" thick
"F" following TA indicates a multi-helix configuration – "TAH" indicates a single flight pile
"D" following the shaft length indicates a double taper cut at the tip of the shaft
"C" following a plate diameter indicates that the plate will receive a special 90^0 spiral cut leading edge treatment.

Special Order Product Designation Examples:



Notes: Allow Extra Time and Cost For Processing – Inquire for Pricing and Delivery
All Helical Plates Are Spaced At Three Times The Diameter Of The Preceding Plate
All Product Hot Dip Galvanized Per ASTM A123 Grade 100.

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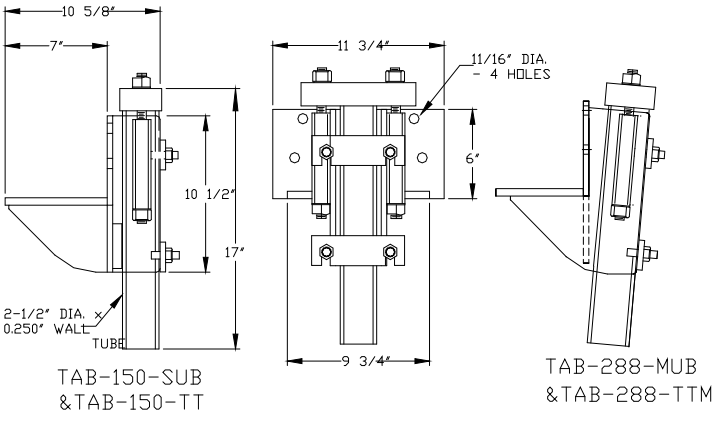
Torque Anchor™ Utility Brackets

TAB-150-SUB Standard Duty & TAB-288-MUB Light Weight Utility Bracket

Shaft Size:	1-1/2" Sq.	2-7/8" Dia.
Bracket Designation:	TAB-150-SUB	TAB-288-MUB
Pier Cap:	TAB-150-TT T-Tube	TAB-288-TTM T-Tube
Ultimate-Limit Capacity:	40,000 lb.[1]	
Bearing Area:	68-1/4 sq. inches	
Standard Lift Capacity:	4 inches[2]	



DETAILS FOR
TAB-150-SUB & TAB-150-TT BRACKET ASSY
TAB-288-MUB & TAB-288-TTM BRACKET ASSY

TAB-LUB Large Utility Bracket

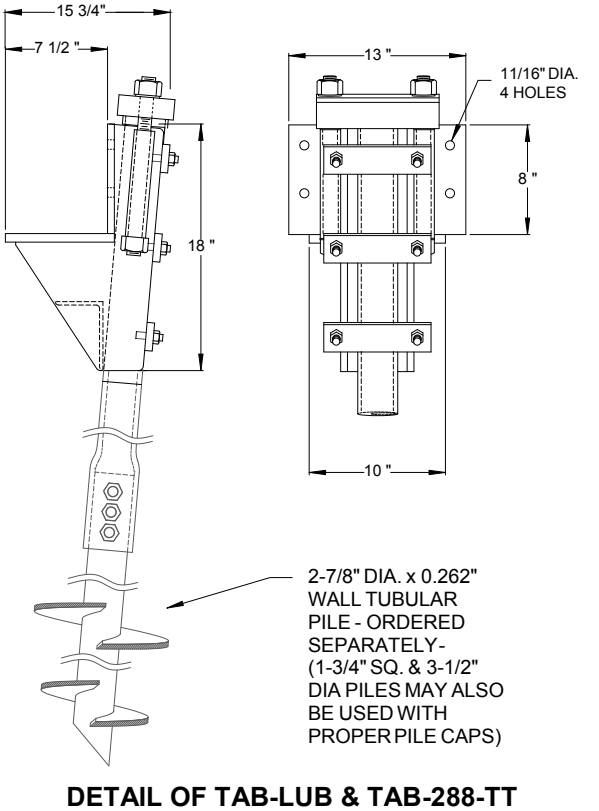
Shaft Size:	1-3/4" Sq.	2-7/8" Dia	3-1/2" Dia
Bracket Designation:	TAB-LUB	TAB-LUB	TAB-LUB
Pier Cap:[3]	TAB-175-TT T-Tube	TAB-288-TT T-Tube	TAB-350-TT T-Tube
Ultimate-Limit Capacity:	98,000 lb.[1]		
Bearing Area:	75 square inches		
Standard Lift Capacity:	5-1/2 inches[2]		

NOTES:

1. These are mechanical capacity ratings. Foundation strength and soil capacity will dictate actual capacity.

2. Bracket Lift Height Can Easily Be Increased By Ordering Longer Continuously Threaded Bracket Rods.

3. The TAB-LUB Bracket is the same component for three different shaft sizes; the Pile Cap configuration varies to accommodate the appropriate shaft for the application.



DETAIL OF TAB-LUB & TAB-288-TT
SUPPORT SYSTEM ASSEMBLY

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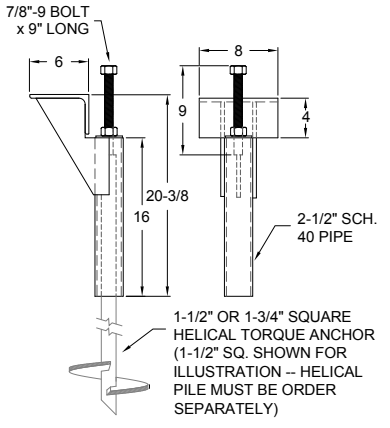
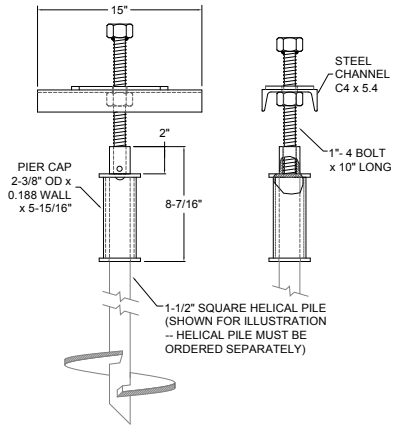
Torque Anchor™ Porch & Slab Brackets

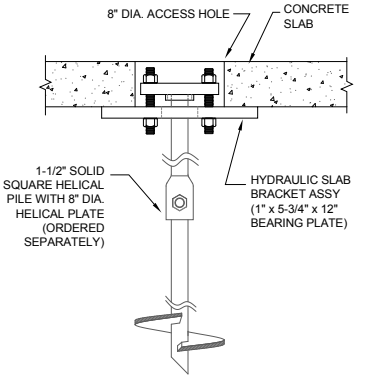
TAB–150-LP Porch Bracket
TAB–288-LP (not shown)



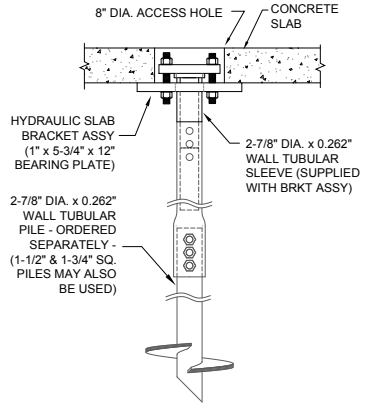
TAB-150 SSB Slab Bracket



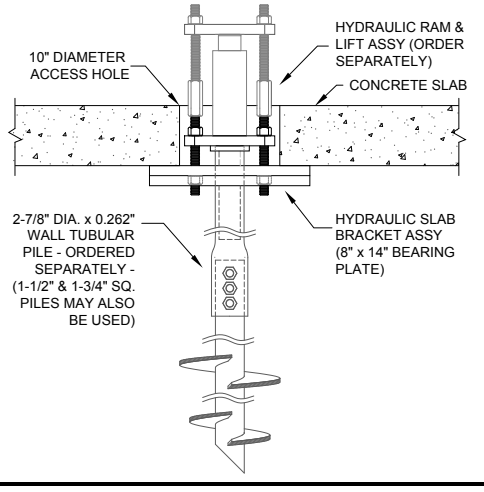
TAB–150-HSB Hydraulic Lift Slab Bracket*



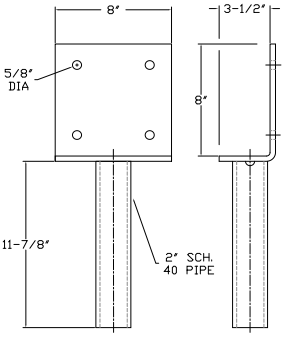
TAB–288-LHSB Hydraulic Lift Slab Bracket*



TAB-288-HSB Hydraulic Lift Slab Bracket*



TAB–150-TB 3-1/2" x 8" Timber Bracket[4]



PRODUCT DESIGNATION	FITS TORQUE ANCHOR	ULT.-LIMIT CAPACITY[1, 3]	LIFT CAPACITY[2]
TAB-150-LP	1-1/2" Sq	9,000 lb	4-1/2"
	1-3/4" Sq.	16,000 lb	
TAB-150 SSB (8" Dia. Hole)	1-1/2" Sq.	8,000 lb	4-1/2"
TAB-150 HSB (8" Dia. Hole)	1-1/2" Sq.	20,000 lb	4"

PRODUCT DESIGNATION	FITS TORQUE ANCHOR	ULT. LIMIT CAPACITY[1, 3]	LIFT CAPACITY[2]
TAB-288-LHSB (8" Dia. Hole)	1-1/2", 1-3/4" Sq. & 2-7/8" Dia.	20,000 lb	4"
TAB-288-HSB (10" Dia. Hole)	1-1/2", 1-3/4" Sq. & 2-7/8" Dia.	40,000 lb	4"
TAB-150 TB	1-1/2" Sq.	20,000 lb	N/A

* Load transfer and elevation recovery is accomplished using ECP Steel Pier™ Bracket Lift Assemblies (Purchased Separately) The TAB-150-HSB and TAB-288-LHSB Bracket requires an ECP Model 300 Lift Assembly and the TAB-288-HSB Bracket requires an ECP Model 350 Lift Assembly.

1. The capacities listed for foundation brackets are mechanical ratings, and the actual installed load capacities are dependent upon the strength and condition of the concrete, and the specific soil conditions on the job site. Concrete strength for the above ratings was assumed to be 3,000 psi.
2. Bracket lift height may be increased by ordering longer continuously threaded bracket rods.
3. Capacities based upon "soft" soil values "N" > 5 blows per foot
4. Special configurations to fit your project can be fabricated to your specifications upon request. Allow extra time for processing.

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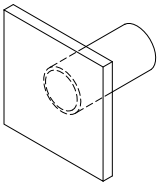
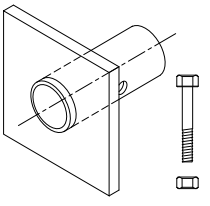
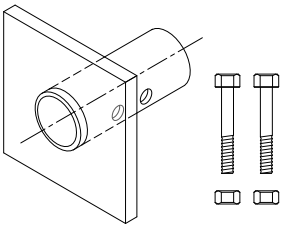
Torque Anchor™ Pile Caps



Compression (No Bolts)



Tension Illustration "A" (One Bolt)



Tension Illustration "B" (Two Bolts)

Square Bar Torque Anchor™ Pile Caps

Part Number (Compression)	TAB-150 NC	TAB-175 NC	TAB-288L NC
Part Number (Tension)	TAB-150-T (Illustration "A")	TAB-175-T (Illustration "A")	TAB-288L-T NOTE 2 (Illustration "A")
Pier Size	1-1/2" Sq. Bar	1-3/4" Sq. Bar	2-7/8" Dia. Tubular
Bearing Plate	1/2" x 6" x 6"	3/4" x 8" x 8"	1/2" x 6" x 6"
Pier Sleeve	2-3/8" Dia. x 5-3/4"	2-7/8" Dia. x 7-3/4"	3-1/2" Dia. x 5-3/4"
Ultimate-Limit Compressive Capacity	55,000 lb	70,000 lb	55,000 lb.
Ultimate-Limit Tension Capacity	40,000 lb	70,000 lb.	40,000 lb.

Tubular Torque Anchor™ Pile Caps

Part Number (Compression)	TAB-288 NC	TAB-350 NC	TAB-450 NC
Part Number (Tension)	TAB-288-T NOTE 2 (Illustration "B")	TAB-350-T (Illustration "B")	TAB-450-T (Illustration "B")
Pier Size	2-7/8" Dia. Tubular	3-1/2" Dia. Tubular	4-1/2" Dia. Tubular
Bearing Plate	3/4" x 8" x 8"	3/4" x 8" x 8"	1" x 10" x 10"
Pier Sleeve	3-1/2" Dia. x 7-3/4"	4" Dia. x 7-3/4"	5-9/16" Dia. x 9-3/4"
Ultimate-Limit Compressive Capacity	70,000 lb.	70,000 lb.	120,000 lb.
Ultimate-Limit Tension Capacity	70,000 lb.	70,000 lb.	120,000 lb.

Pile Cap Notes:

1. Capacities based upon 3,000 psi concrete. Reduce loading or increase plate area appropriately for lower strength concrete.
2. Pile caps shown are standard items and are usually available from stock. Note: TAB-288L-T and TAB-288-T are not interchangeable because bolt hole spacing varies.
3. Part numbers for tension include attachment holes and SAE J429 Grade 8 hardware as shown; compression pile caps do not include hardware or mounting holes.
4. Compressive capacity ratings of some pile caps are limited by compressive pile shaft capacity.
5. Pile caps are supplied plain steel -- hot dip galvanized per ASTM A123 Grade 100 is available.
6. Configuration for the TAB-225 NC Pile Cap is slightly different than illustrations

Custom fabricated pile caps are available for all shaft sizes by special order – allow extra time for processing.

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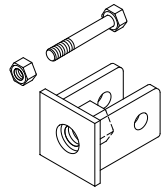
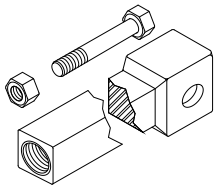
Torque Anchor™ Transitions & Wall Plates

Transition Assemblies

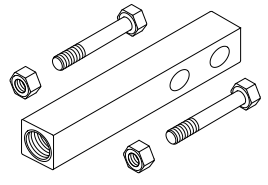


TAT-150



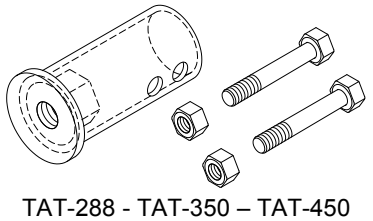
TAT-150-HD
TAT-175-HD

TAT-150	TAT-150-HD	TAT-175-HD	TAT-225
Output Thd. Major Dia. 1" (B-12 Coil Rod)	Output Thd. Major Dia. 1-1/8" (WF-8)	Output Thd. Major Dia. 1-3/8" (WF-10)	Output Thd. Major Dia. 1-7/8" (WF-14)
Plate Washer 3/8" x 5" x 5"	Plate Washer 3/8" x 5" x 5"	Plate Washer 3/8" x 6" x 6"	Plate Washer Not Supplied
Ultimate-Limit Capacity 38,000 lb.	Ultimate-Limit Capacity 70,000 lb.	Ultimate-Limit Capacity 99,000 lb.	Ultimate-Limit Capacity 225,000 lb.



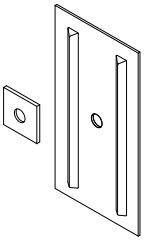
TAT-225

TAT-288	TAT-350	TAT-450
Output Thd. Major Dia. 1-3/8" (WF-10)	Output Thd. Major Dia. 1-3/8" (WF-10)	Output Thd. Major Dia. 1-1/2" (WF-11)
Plate Washer Not Supplied. Order Separately to the Engineering Requirements		
Ultimate-Limit Capacity 100,000 lb.	Ultimate-Limit Capacity 120,000 lb.	Ultimate-Limit Capacity 140,000 lb.



TAT-288 - TAT-350 – TAT-450

Stamped Wall Plates

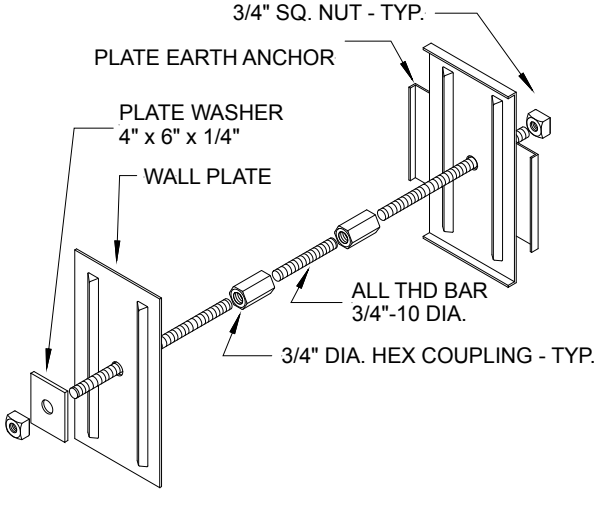
PA-SWP	PA-LWP
11" x 16" 1.2 ft^2 Bearing	12" x 26" 2.2 ft^2 Bearing
	Wall Plates include: Flat Washer 3/16" x 4" Sq. Hot Dip Galv.
	Clamping Capacity: 8,250 lb

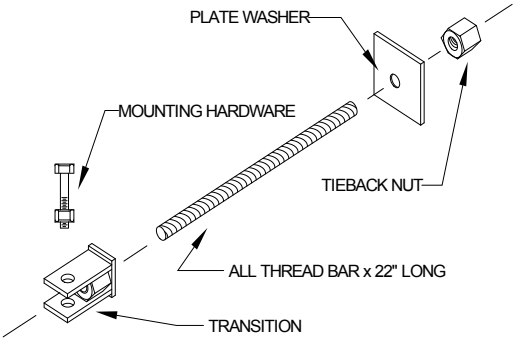
Transition Notes:

1. Transitions listed are standard items; usually available from stock.
2. Hot dip galvanized per ASTM A123 Grade 100
3. The capacities listed are mechanical ratings.
4. All Transitions are supplied with 22" All Thread Rod, Nut and Mounting Hardware. Square shaft transitions also have a flat washer included with the exception of the TAT-225 Transition. (See Sketch Below)

ECP Plate Anchor Kit

ECP Earth Plate Anchors are supplied as illustrated below. Available wall plate area is 1.3 or 2.3 ft^2 and available soil bearing area is 1.3, 1.6, 2.3 or 3.0 ft^2. The ultimate-limit tension capacity is 10,000 lb. The plate spacing is adjustable from 9 ft to 17-1/2 ft.
(Please request Typical Specifications for installation and load details.)





The sketch above shows the components that are shipped with solid bar transition assemblies. The transition and the hardware required to attach the transition to the tieback will vary depending upon the product ordered. Please refer to the table above for additional details. Tubular transitions and TAT-225 do not include a flat wall plate. As the angle of installation usually varies generally from 15^0 to 30^0, bevel washers should be ordered separately.

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Table 3. Symbols Used In This Chapter	
α	Tieback installation angle from horizontal
A	Projected area of helical plate – ft^2
c	Undrained shear strength of the soil – lb/ft^2
d_x	Helical plate diameter -- ft
$d_{largest}$	Diameter of Largest Helical Plate
D	Critical Depth – The distance from ground surface to the shallowest helical tieback plate. ($D = 6 \times d_{largest}$)
γ	Dry Density Of The Soil – lb/ft^3
FS	Factor Of Safety (Generally FS = 2)
H	Height of soil against wall or basement - ft
h	Vertical depth from surface to helical plate
h_{mid}	Vertical depth from the ground surface to a point midway between the lowest and highest helical plates – ft
k	Empirical factor relating ultimate capacity of a pile or tieback to the installation torque – ft^{-1} ($k = P_u$ or T_u / T)
K	Torque conversion factor that is used to determine torque motor output from pressure differential across motor
L	Total length of product required by the design
L_0	Minimum required horizontal embedment
L_{15}	Distance to achieve the minimum required embedment length, "L_0" at 15^0 Installation Angle
N	Standard Penetration Test (SPT) Results. N = Number of blows with a 140 lb hammer to penetrate the soil a distance of one foot. (Note: "N" may be given directly or in 3 segments. Always add the last two segment counts to get "N" – 4/5/7 is N = 12.)
N_c	Bearing capacity factor for clay soil
N_q	Bearing capacity factor for granular soil
pH	Measure of acidity or alkalinity
P	Foundation or Wall Load – lb/Lineal ft
P_u	Ultimate pile or anchor capacity* – lb.
P_w	Working or design load – lb.
Δp	Pressure differential measured across a torque motor $\Delta p = p_{in} - p_{out}$ - psi
q	Soil overburden pressure (lb/ft^2)
S	Helical Plate Embedment for Tension - ft
T	Installation or Output Torque – ft-lb
T_u	Ultimate Tension Capacity – lb
T_w	Working Tension Load – lb
w	Distributed load along foundation – lb/lin.ft.
X	Product Spacing - ft

* Unfactored Limit, use as nominal, "P_u" value per design codes

Design Criteria

The Bearing Capacity of a Torque Anchor™ (P_w) can be defined as the load which can be sustained by the Torque Anchor™ without producing objectionable settlement, either initially or progressively, which results in damage to the structure or interferes with the use of the structure.

Bearing Capacity is dependant upon many factors:

- Kind Of Soil,
- Soil Properties,
- Surface and/or Ground Water Conditions,
- Torque Anchor™ Configuration (Shaft Size & Type, Helix Diameter(s), and Number Of Helices),
- Depth to Bearing,
- Installation Angle,
- Torque Anchor™ Spacing,
- Installation Torque,
- Type of Loading - Tension, Compression, Alternating Loads, etc.

The design of Helical Torque Anchors™ uses classical geotechnical theory and analysis along with empirical relationships that have been developed from field load testing. In order to prepare an engineering design, geotechnical information is required from the site along with structural load requirements including a factor of safety - "FS".

The most accurate design requires knowledge from soil testing using the Standard Penetration Test (SPT) standardized to ASTM D1586 plus laboratory evaluations of the soil shear strength, which is usually given as soil cohesion – "c", soil density – "γ", and granular friction angle – "ϕ"

Soils will vary from site to site and may vary from point to point on some sites. Each analysis must use data relevant to the project at hand as each project has different parameters.

Each design requires specific information involving the structure and soil characteristics at the site. Each design should involve geotechnical and engineering input.

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The following preliminary design information is intended to assist with the selection of an appropriate ECP Torque Anchor™ system for a given project.

Deep Foundations

Torque Anchor™ systems must be considered as deep foundation elements.

As a rule of thumb, helical products must be installed to a Critical Depth of at least six times the diameter of the largest helix. The depth is measured from the intended final surface elevation to the uppermost helical plate of the Torque Anchor™.

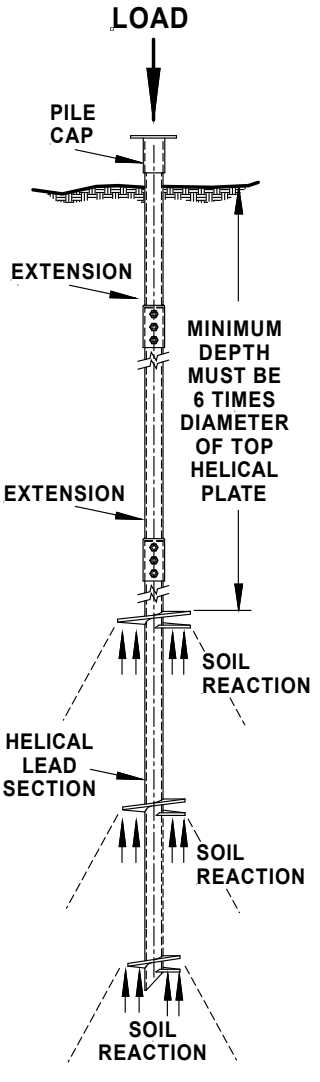

Figure 1. Helical Pile Load and Reaction Diagram

The capacity of a multi-helix deep foundation system assumes that the ultimate bearing capacity is the sum of the bearing support from each plate of the system. Testing has shown that when the helical plates are spaced at three times the diameter away from the adjacent lower helical plate, each plate will develop full efficiency in the soil. Spacing the helical plates at less than three diameters is possible, however, each plate will not be able to develop full capacity and the designer will have to include a plate efficiency factor in the analysis when conducting the design.

Pile or anchor spacing should be no closer than five times the diameter of the largest plate at the bearing depth. Pile spacing as close as three diameters has been successfully installed, but this work requires special installation equipment that can maintain accurate installation angles. The spacing requirement of five times the diameter of the largest plate is measured at the target depth. It is acceptable to install several shafts at the same surface location with suitable outward batter to accomplish the required shaft to shaft spacing at the final installed depth.

Using guidelines described above, the ultimate capacity of an ECP Torque Anchor™ system can be calculated from the following equation:

Equation 1: Ultimate Theoretical Capacity:

$$P_u \text{ or } T_u = \Sigma A_H (c\, N_c + q\, N_q)$$

Where:

P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
ΣA_H = Sum of Projected Helical Plate Areas (ft^2)
c = Cohesion of Soil - (lb/ft^2)
N_c = Bearing Capacity Factor for Cohesion
q = Soil Overburden Pressure to h_{mid} depth – (lb/ft^2)
N_q = Bearing Capacity Factor for Granular Soil.

The ultimate capacity is defined as the load that results in a deformation of one inch. In general ultimate capacity is the working or service load with a factor of safety of 2.0 applied.

If one has access to a soil report in which "c", "γ", and "ϕ" are given, then Equation 1 can be solved directly. Unfortunately, often many soil reports do not contain these values and the designer must decide which soil type is more likely to control the ultimate capacity.

When one is unsure of the soil type or the soil behavior cannot be determined, we recommend that one calculate loads using cohesive soil behavior because the result will be conservative.

In all cases, we highly recommend field testing to verify the accuracy of the preliminary design load capacities.

Soil Behavior

The following information is provided to introduce the reader to the field of soil mechanics. Explained are the terms and theories used to determine soil behavior and how this behavior relates to Torque Anchor™ performance. This is not meant to substitute for actual geotechnical soil evaluations. A thorough study of this subject is beyond the scope of this manual. The values presented here are typical of those found in geotechnical reports.

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Cohesive Soil (Clays & Silts)

Cohesive soil is soil that is generally classified as a fine grained clay soil and/or silt. By comparison, granular soils like sands and gravels are sometimes referred to as non-cohesive or cohesionless soil.

Clays or cohesive soils are defined as soils where the internal friction between particles is approximately zero. This internal friction angle is usually referred to as "ϕ" or "phi".

Cohesive soils have a rigid behavior when exposed to stress. Stiff clays act almost like rock. They remain solid and inelastic until they fail. Soft clays act more like putty. The soft clay bends and molds around the anchor when under stress.

Undrained Shear Strength – "c": The undrained shear strength of a soil is the maximum amount of shear stress that may be placed on the soil before the soil yields or fails. This value of "c" only occurs in cohesive soils where the internal friction "ϕ" of the fine grain particles is zero or nearly zero. The value of "c" generally increases with soil density; therefore, one can expect that stiff clays have greater undrained shear strength than soft clay soil. It is easy to understand that when dealing with cohesive soils; that the greater the shear strength "c" of the soil, the greater the bearing capacity. It also follows that the capacity of the soil tends to increase with depth.

Table 4. Cohesive Soil Classification

Soil Description	USCS Symbol	Density Description	Density "γ" lb/ft³
Inorganic silt, rock flour, silty or clayey fine sand or silt with low plasticity	ML	Soft	90
		Stiff	110
		Hard	130
Inorganic clay of low to medium plasticity, sandy clay, gravelly clay, lean clay	CL	Soft	90
		Stiff	110
		Hard	130
Organic silts and organic silty clays, low plasticity	OL	Soft	75
		Stiff	90
		Hard	105
Inorganic silt, fine sandy or silty soils, elastic silts - high plasticity	MH	Soft	80
		Stiff	93
		Hard	105
Inorganic clays of high plasticity, fat clay, silty clay	CH	Soft	90
		Stiff	103
		Hard	115
Organic silts and organic clays of medium to high plasticity	OH	Soft	75
		Stiff	95
		Hard	110
Peat and other highly organic soils	PT	--	--

Table 5. Properties of Cohesive Soil

Soil Density Description	SPT Blow Count - "N"	Undrained Shear Strength "c" -- lb/ft²	Unconfined Compressive Strength lb/ft²
Very Soft	0 – 2	< 250	< 500
Soft	2 – 4	250–500	500—1,000
Firm	4 – 8	500–1,000	1,000—2,000
Stiff	8 – 15	1,000–2,000	2,000—4,000
Very Stiff	15 – 32	2,000–4,000	4,000—8,000
Hard	32 – 48	4,000–6,000	8,000—12,000
Very Hard	> 48	> 6,000	> 12,000

Cohesive Bearing Capacity Factor - "N_c": The bearing capacity factor for cohesion is an empirical value proposed by Meyerhof in the Journal of the Geotechnical Engineering Division, Proceedings of ASCE, 1976. For small shaft helical piles or tieback anchors with plate diameters under 18 inches, the value of the Cohesive Bearing Capacity Factor, "N_c" was found to be approximately nine, therefore "N_c" = 9 is generally accepted as a reasonable value to use when determining capacities of these helical piles and anchors embedded in cohesive soils.

When determining the ultimate capacity for a Torque Anchor™ situated in cohesive soil, Equation 1 may be simplified because the internal friction, "ϕ", of the soil particles can be assumed to be zero and the cohesive bearing factor, "N_c", is assumed to be 9. Equation 1 can be modified when dealing with cohesive soil as shown below:

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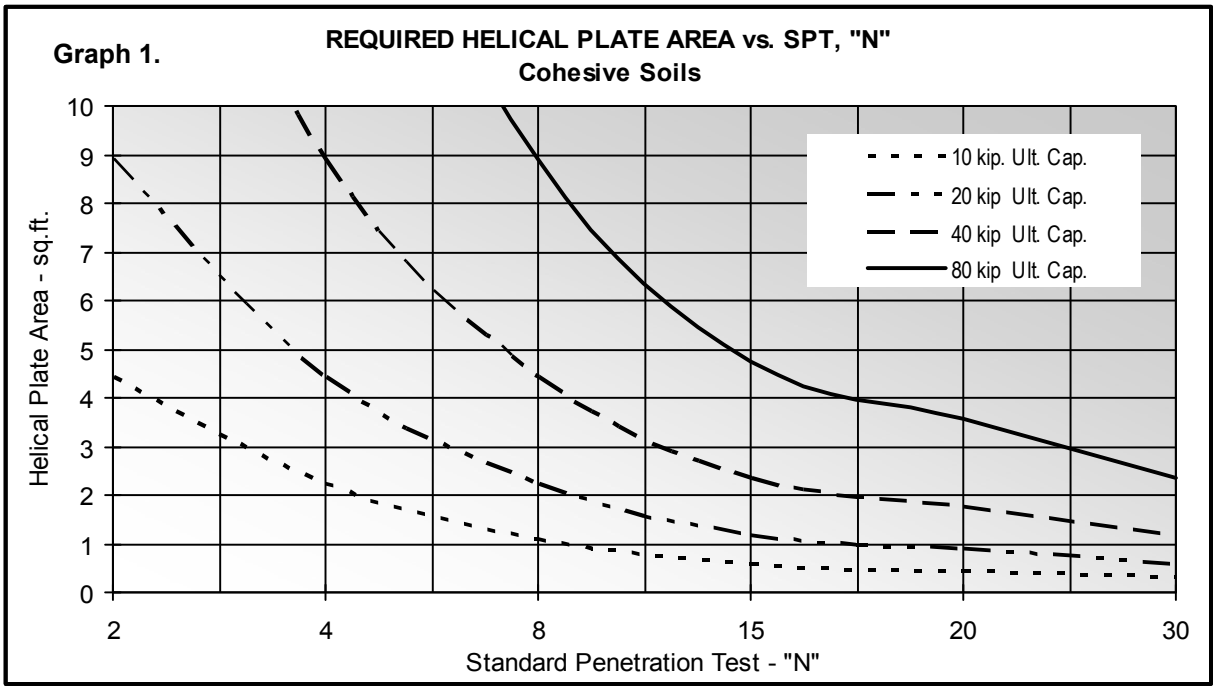
Equation 1a
Ultimate Capacity - Cohesive Soil
P_u **or** $T_u = \Sigma A_H$ **(9c)** or $\Sigma A_H = P_u$ **or** T_u **/ (9c)**

Where:
P_u or T_u = Ultimate Cap. of Torque Anchor™ - (lb)
ΣA_H = Sum of Projected Helical Plate Areas (ft^2)
c = Cohesion of Soil - (lb/ft^2)



Graph 1 above may be used to quickly get a rough estimate the plate area requirements in cohesive (clay & silty) soils based upon Standard Penetration Test, "N", values at the termination depth of the pile or anchor. One may also use Graph 1 to compare results obtained from Equation 1a.

Cohesionless Soil (Sands & Gravels)

In cohesionless soil, particles of sand act independently of each other. This type of soil has fluid-like characteristics. When cohesionless soils are placed under stress they tend to reorganize into a more compact configuration as the load increases.

Cohesionless soils achieve their strength and capacity in several ways.

- The soil density,
- The overburden pressure (The unit weight of the soil above the Torque Anchor™),
- The internal friction angle "ϕ",

Soil Overburden Pressure – "q": The soil overburden pressure at a given depth is the summation of density "γ" (lb/ft^3) of each soil layer multiplied by its thickness, "h". The moist density of the soil is used when calculating the value of "q" for soils above the water table. Below the water table the buoyancy effect of the water must be taken into consideration. The submerged density of the soil where all voids in the soil have been filled with water is

Table 6. Cohesionless Soil Classification

Soil Description	USCS Symbol
Well Graded Gravel Or Gravel-Sand	GW
Poorly Graded Gravel Or Gravel-Sand	GP
Silty Gravel Or Gravel-Sand-Silt Mixtures	GM
Clayey Gravel Or Gravel-Sand-Clay Mixtures	GC
Well Graded Sand Or Gravelly-Sands	SW
Poorly Graded Sand Or Gravelly-Sands	SP
Silty Sand Or Sand Silt Mixtures	SM
Clayey Sands Or Sand-Clay Mixtures	SC

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determined by subtracting the buoyant force of the water (62.4 lb/ft^3) from the moist density of the soil.

To arrive at value for soil overburden pressure on a single helical plate of a Torque Anchor™, the value of "q_{plate}" for each stratum of soil must be determined from the intended final surface elevation to the helical plate elevation, "h_{plate}". By using Equation 2b, the ultimate bearing capacity of the helical plate is determined. The ultimate capacity of a multi-plate helical pile may be determined by summing the capacities of all helical plates. A simpler method often used to estimate the ultimate capacity of a multi-plate pile configuration is to determine the soil overburden, "q", at a depth midway between the upper helical plate and the lowest helical plate, "h_{mid}". This value of "q" is used to estimate the ultimate capacity of the pile configuration.

Table 7. Properties of Cohesionless Soil

Soil Density Description	SPT Blow Count "N"	Friction Angle "ϕ"	Bearing Capacity Factor "N_q"	Density "γ" lb/ft^3	
				Moist Soil	Submerged
Very Loose	≤ 2	28^0	12	70 – 100	45 - 62
	3 – 4	28^0	13		
Loose	5 – 7	29^0	14 – 15	90 – 115	52 - 65
	8 – 10	30^0	15 – 16		
Medium Dense	11 – 15	30^0 - 32^0	17 - 19	110 –130	68 - 90
	16 – 19	32^0 - 33^0	20 – 22		
	20 – 23	33^0 - 34^0	23 – 25		
	24 – 27	34^0 - 35^0	26 – 29		
	28 – 30	35^0 - 36^0	30 – 32		
Dense	31 – 34	36^0 - 37^0	34 - 37	110 – 140	80 - 97
	35 – 38	37^0 - 38^0	39 – 43		
	39 – 41	38^0 - 39^0	45 – 48		
	42 – 45	39^0 - 40^0	50 – 56		
	46 – 50	40^0 - 41^0	59 – 68		
Very Dense	> 50	> 42^0	End Bearing	140+	> 85

Cohesionless Bearing Capacity Factor - "N_q": Zhang proposed the ultimate compression capacity of the helical screw pile in a thesis for the University of Alberta in 1999. From this work the dimensionless empirical value "N_q" was introduced. "N_q" is related to the friction angle of the soil - "ϕ", as estimated in Table 7.

When determining the ultimate capacity for a Torque Anchor™ in cohesionless soils, Equation 1 may be simplified because granular soils have no soil cohesion. Therefore "c" may be assumed to be zero. Equation 1 when used for cohesionless soils can be modified as follows:

Equation 1b:
Ultimate Capacity - Cohesionless Soil
$$P_u \text{ or } T_u = \Sigma A_H (q\ N_q) \text{ or}$$
$$\Sigma A_H = P_u \text{ or } T_u/(q\ N_q)$$

Where:
P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
ΣA_H = Projected Helical Plate Area(s) (ft^2)
q = Soil Overburden Pressure from the surface to plate depth "h" – (lb/ft^2)
N_q = Bearing Capacity Factor for Granular Soil.

Effect of Water Table on Pile Capacity:
It cannot be emphasized enough that the buoyant force of water on the soil overburden can dramatically change the load capacity of the helical pile or anchor. Calculating soil overburden for a specific site usually entails determining the density of each stratum of soil between the surface and the termination depth of the helical support product.

To illustrate the effect of the water table on the pile capacity the following example assumes that site contains 25 feet of cohesionless soil that is homogeneous, has a constant density of 100 lb/ft^3 and a constant SPT - "N" = 10 bpf that extends beyond 25 feet. Such uniform soil as this is seldom found. In the second example all assumptions remain except the water table is assumed to be located ten feet below grade.

Using Equation 1b and Table 7 the ultimate capacity of a TAF-288 (8-10-12) pile (1.54 ft^2) is calculated when no ground water is present:

$P_u = \Sigma A_H (q\ N_q)$ = 1.54 [(100 x 25 ft) x 16]
P_u = 61,600 lb (Damp soil - no water Present)

When the water table is present at 10 feet below grade, notice the reduction in pile capacity that is caused by the buoyant force of the water.

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$P_u = \Sigma A_H (q\ N_q)$
P_u = 1.54 [(100 x 10 ft) + (60 x 15)] x 16
P_u = 46,816 lb (Water Table at 10 feet)

The reduction in capacity of the same pile configuration in the same soil when water is present at 10 feet below grade is approximately 76%. This demonstrates that knowing the level of the water table is necessary for safe design.

Using Equation 1b must be used again to determine a new helical plate area requirement and a new pile configuration that will have sufficient plate area to support 61,600 pounds in the soil with the higher water table.

$\Sigma A_H = P_u/(q\ N_q)$
ΣA_H = 61,600/[(100 x 10 ft) + (60 x 15)] x 16
ΣA_H = 2.03 ft^2

The closest standard product that will provide this helical plate area is a TAF-288 (10-12-14), which offers 2.26 ft^2 of plate area.

This example clearly illustrates that if subsurface water is not considered during the designing process, it is highly likely that the pile or anchor will be under designed and could fail.

Mixed Soils – Cohesive and Cohesionless Soils

When reviewing soil boring logs one often sees descriptions that combine the two soil types. One often sees such terms as "clayey sand" or "sandy clay" in the soil descriptions on the soil boring log.

The soils engineers use terms to describe soils that contain both cohesive soil and granular soil in the samples. When one encounters such descriptions in the soil report, the design analysis requires that both soil types be considered. Equation 1 must be used to determine the ultimate capacity or projected helical area requirement. The designer must assign a percentage of each type of soil present when placing data into Equation 1.

Table 8 provides guidance for relative percentages of each type of soil. Experience has shown that there is no national standard for these soil descriptions. Because of this, Table 8 provides the most typical percentages. It is always a good idea to check with the soil engineer to verify his or her soil type percentages on a specific soil boring log when working on a critical project.

When preparing a load capacity design when mixed soils are present, adjust for the percentages of cohesive and cohesionless soils present in Equation 1. For example, assume that the soils engineer described the soil on the site as being "clayey sand". Referring to Table 8 there is a range from 20% to 49% for the cohesive clay component in the sample. For this illustration it is assumed that no additional data is available from the soil engineer regarding the percentages present. A value for the cohesive clay component of the soil is estimated at 30% and the remaining 70% of the soil is assumed to be sand:

Table 8 Mixed Soil Descriptions

Soil Description	Estimated Percentage Present
"trace"	1% to 5%
"slightly"	6% to 15%
"little"	10% to 20%
"with"	15% to 25%
"silty" or clayey"	20% to 49%
"some"	20% to 34%
"very"	35% to 49%

Note: There is no national standard for soil description percentages reported by soil engineers. Listed above are the descriptors and most commonly encountered percentages. For increased accuracy, or when working on a critical project, verify the descriptive percentages with the project soil engineer.

Equation 1 is modified as shown to adjust to the reported soil composition:

P_u = Helical Plate Area x (30% strength of clay + 70% strength of sand)

$P_u = \Sigma A_H (0.30\ c\ N_c + 0.70\ q\ N_q)$

The result of the analysis will be a helical pile capacity that is lower than if it was embedded in only sand, but greater than if embedded only in clay.

Keep in mind that when dealing with incomplete data, it is wise to add a sufficient factor of safety to the result or to choose the percentage for the cohesionless soil component at the lower end of the range provided in Table 8.

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Effects of Water Table Fluctuations and Freeze Thaw Cycle

When designing helical anchors, the amount of water present in the soil at the time of installation, and possible moisture changes in the future, must be considered. If the anchor is installed near the water table, the capacity of the anchor can dramatically change with the changing level of the water table.

Cohesionless soil is buoyed by the water when the soil around the helical pile or anchor becomes saturated. This buoyancy of the soil particles in the soil reduces the load capacity of the anchor. A different situation exists if the anchor is just below the water table and dry conditions cause the water table to drop. As the water drains from between the soil particles, the soil around the helical plates could begin to consolidate. This soil consolidation may cause the anchor to creep and require adjustment.

It is also important to know the maximum frost depth along with the range of depth for the water table at the job site to insure a solid and stable installation. Anchors should always be installed below the lowest recorded frost depth to a depth of more than three diameters of the uppermost plate. In most cases this is usually means installing the helical plates three to four feet below the lowest expected frost depth. The reasoning here is that when the soil thaws and the ice changes to water, the soil can become saturated. From the discussion above about installations made near the water table, a similar situation exists with thawing frost. Load capacity could reduce because saturated soil cannot support as much load as damp to dry soil. Clay soil is especially vulnerable and can become plastic when saturated. A saturated cohesive soil might simply flow around the helical plates and could cause creep or failure. In addition, freezing water within the pores of the soil can lead to upward pressure on the helical plates resulting in movement and/or loss of strength when the plates are terminated within the freeze-thaw zone.

Monitoring the installation torsion on the shaft (Discussed below and in Chapter 2) can predict the performance of the anchor at the time of installation, but changes in the soil moisture can affect the product's long term holding ability.

Budgetary Capacity Estimates by "Quick and Rough" Design Method

Many installers and engineers are familiar with the *Soil Classification Table* that other manufacturers use for budgetary helical anchor designs. This table "classifies" soil into eight soil groups ranging from solid rock down to very soft clays, organics and peats. These Soil Classifications are used for reference to estimate expected pile capacities indicated by graphs or tables.

Table 9 below is the *Soil Classification Table* that relates the classification levels offered by other manufacturers along with anticipated values for Standard Penetration Tests, "N", likely to be found within each classification. The *Holding Capacity Graphs* 2 through 5 that follow were developed to provide rough estimates of holding capacities for various sizes and combinations of helical plates attached to Torque Anchor™ shafts and installed into these soil classifications.

It must be clearly understood that Graphs 2 through 5 are provided to help offer a general estimated load capacity for a pile or anchor configuration installed into a soil that fits within a certain soil classification. The graphs are not intended to be a substitute for engineering judgement and design calculations detailed earlier that rely upon specific soil data relative to the project. Table 10 and Graphs 2 through 5 represent general trends of capacity through different *homogeneous* soil classifications. The graphs are based upon conservative estimates.

Graphs 2 - 5 represent the ultimate capacity of the helical plate configuration in the soil, and one must always apply a suitable factor of safety to the service load before using these tables to insure reliability of any tieback or pile installation.

In very dense soil or rock stratum when rotation of the helical anchor shaft does not advance the product into the soil, the helical plates are not able to fully embed and cannot achieve the capacity level predicted by Terzaghi's bearing capacity formula (Equation 1). The graphs disregard soil classifications zero through class 2 because these soils are usually too dense for the

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Torque Anchors™ to advance without pre-drilling,

Likewise, soil class 8 was not represented in the graphs because class 8 soils usually contain significant amounts of organics or fill materials. The organics may continue to decay and/or soil with organics and/or fill may not be properly consolidated and are therefore not considered suitable for long term support.

Graphs 2 through 5 presented here also show a shaded area for Class 7 soils and part of Class 6 soils. This is to alert the user that, in some cases, soils that fall within these shaded areas of the graphs may not be robust enough to support heavy loads. If the soil in the shaded areas contain fill; the fill could contain rocks, cobbles, trash, and/or construction debris. In addition, these soils may not be fully consolidated and/or could contain organic components. Any of these could allow for creep of a foundation element embedded within the stratum. This could cause a serious problem for permanent or critical installations. When such weak soils are encountered, it is strongly recommended that the anchor or pile be driven deeper so that the Torque Anchor™ will penetrate beyond all weak and possibly unstable soil into a more robust and stable soil stratum underlying these undesirable strata.

It is also important to understand that the Graphs 2 through 5 below do not take into consideration the size of the shaft or type of shaft being used in conjunction with the helical plate configurations. As a result, these graphs could suggest holding capacities well above the "Useable Torsional Capacity" of the helical shafts shown in Table 2.

Where the graph line is truncated at the top of the graph for a particular helical plate configuration, one should not try to extrapolate a higher capacity than indicated by the top line because these plate configurations have reached the ultimate mechanical capacity for that particular configuration being represented. It might be possible to achieve higher capacities with a given configuration presented in the graphs if one orders the Torque Anchor™ with one-half inch thick helical plates instead of the standard three-eighths inch thickness. Please check with ECP or your engineer to determine if using thicker helical plates could achieve a higher ultimate capacity requirement on a particular project.

Table 9. SOIL CLASSIFICATIONS

Class	Soil Description	Geological Classification	Standard Penetration Test Range - "N" (Blows per foot)
0	Solid Hard Rock (Unweathered)	Granite; Basalt; Massive Sedimentary	No penetration
1	Very dense/cemented sands; Coarse gravel and cobbles	Caliche	60 to 100+
2	Dense fine sands; very hard silts and/or clays	Basal till; Boulder clay; Caliche; Weathered laminated rock	45 to 60
3	Dense sands/gravel, hard silt and clay	Glacial till; Weathered shale; Schist, Gneiss; Siltstone	35 to 50
4	Medium dense sand/sandy gravels; very stiff /hard silt/clay	Glacial till; Hardpan; Marl	24 to 40
5	Medium dense coarse sand and sandy gravel; Stiff/very stiff silt and clay	Saprolites; Residual soil	14 to 25
6	Loose/medium dense fine/coarse sand; Stiff clay and silt	Dense hydraulic fill; Compacted fill; Residual soil	7 to 15
7	Loose fine sand; soft/medium clay; Fill	Flood plain soil; Lake clay; Adobe; Clay gumbo; Fill	4 to 8
8	Peat, Organic silts, Fly ash, Very loose sand; Very soft/soft clay	Unconsolidated fill; Swamp deposits; Marsh soil	WOH to 5 (WOH = Weight of Hammer)

Notes:

1. Soils in class "0", class "1" and a portion of class "2" are generally not suitable for tieback anchorage because the helical plates are unable to advance into the very dense/hard soil or rock sufficiently for anchorage.
2. When installing anchors into soils classified from "7" and "8", it is advisable to continue the installation deeper into more dense soil classified between "3" and "5" to prevent creep and enhanced anchor capacity.
3. Shaft buckling must be considered when designing compressive anchors that pass through Class 8 soils.

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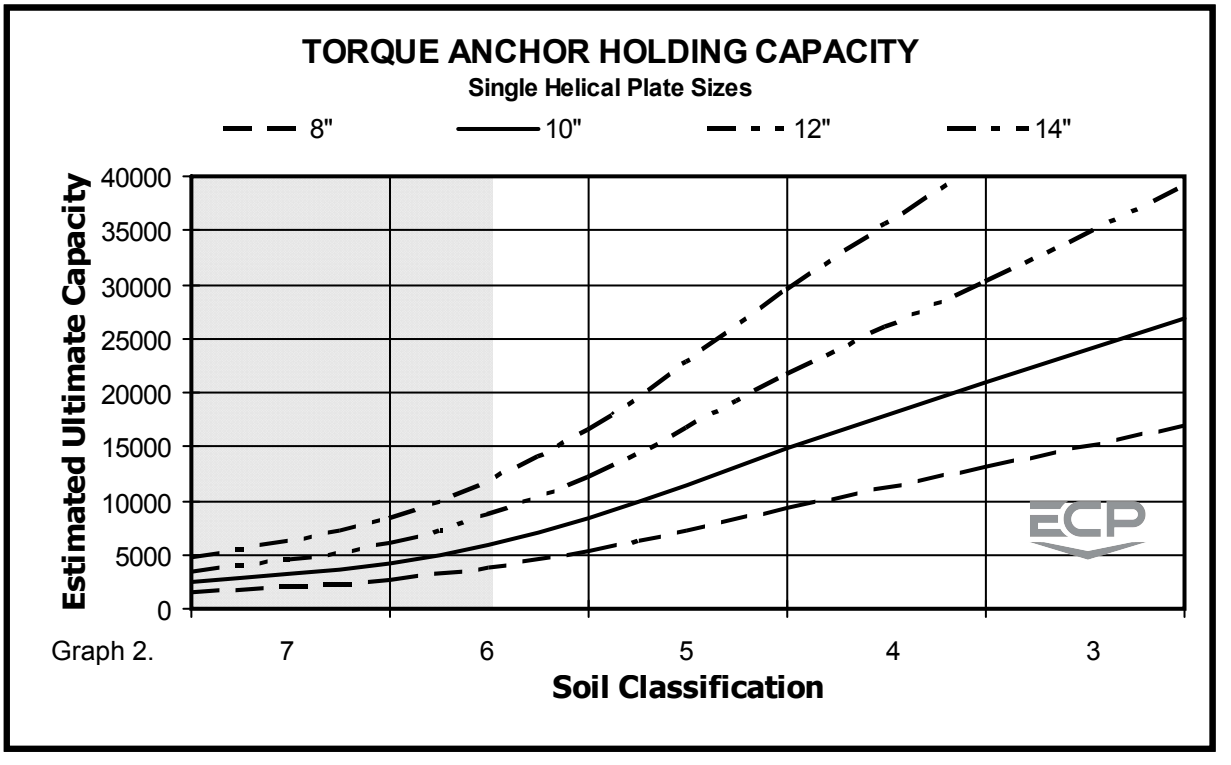
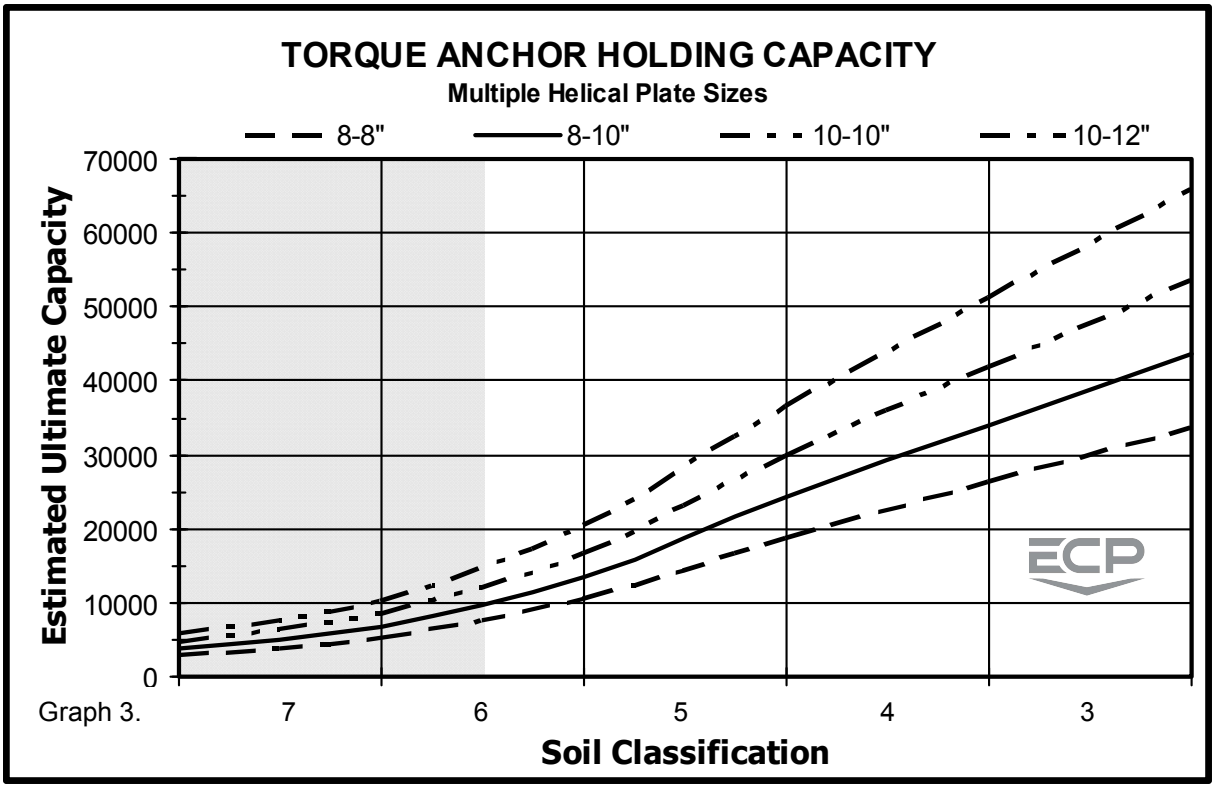


Graph 2.



Graph 3.

Note: It is advisable not to install Torque Anchors™ into Soil Classes in the shaded area for better stability and performance. In situations where this is not possible, we recommend increasing the factor of safety for a safer design. Installing the Torque Anchors™ to an underlying stratum that has a higher bearing capacity and a more stable soil classification is recommended.

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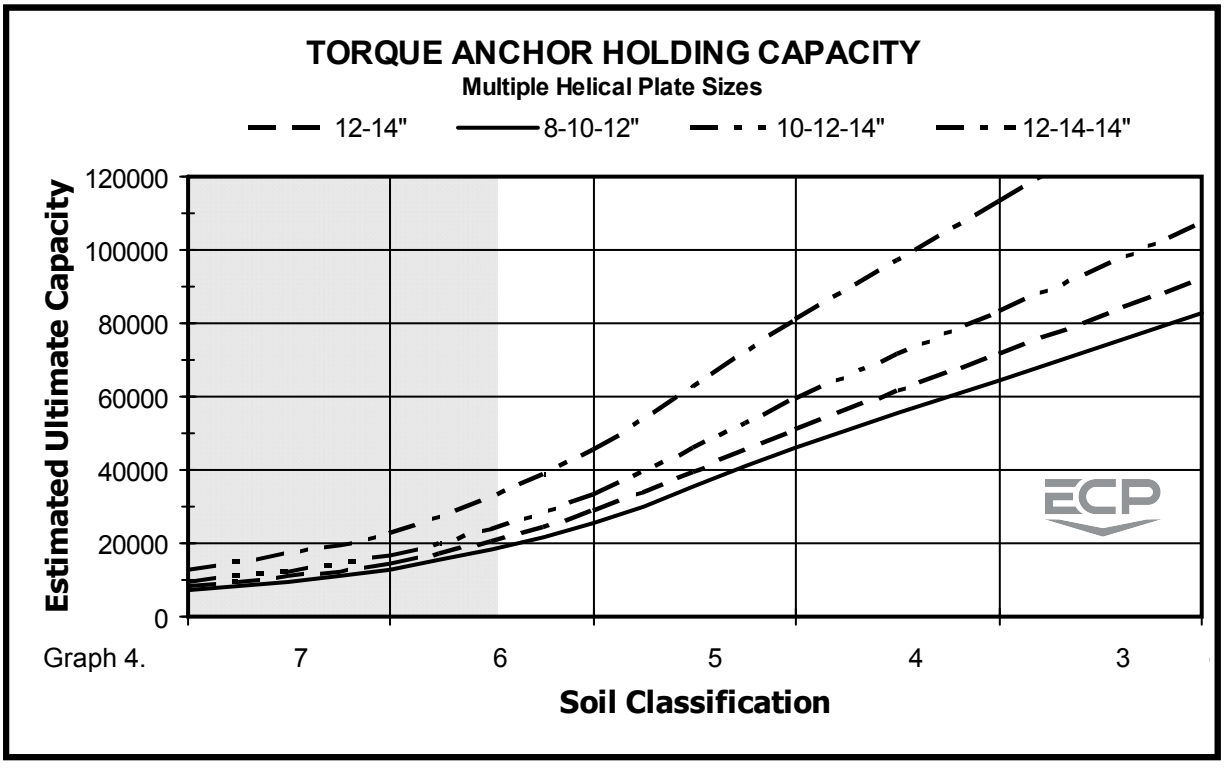
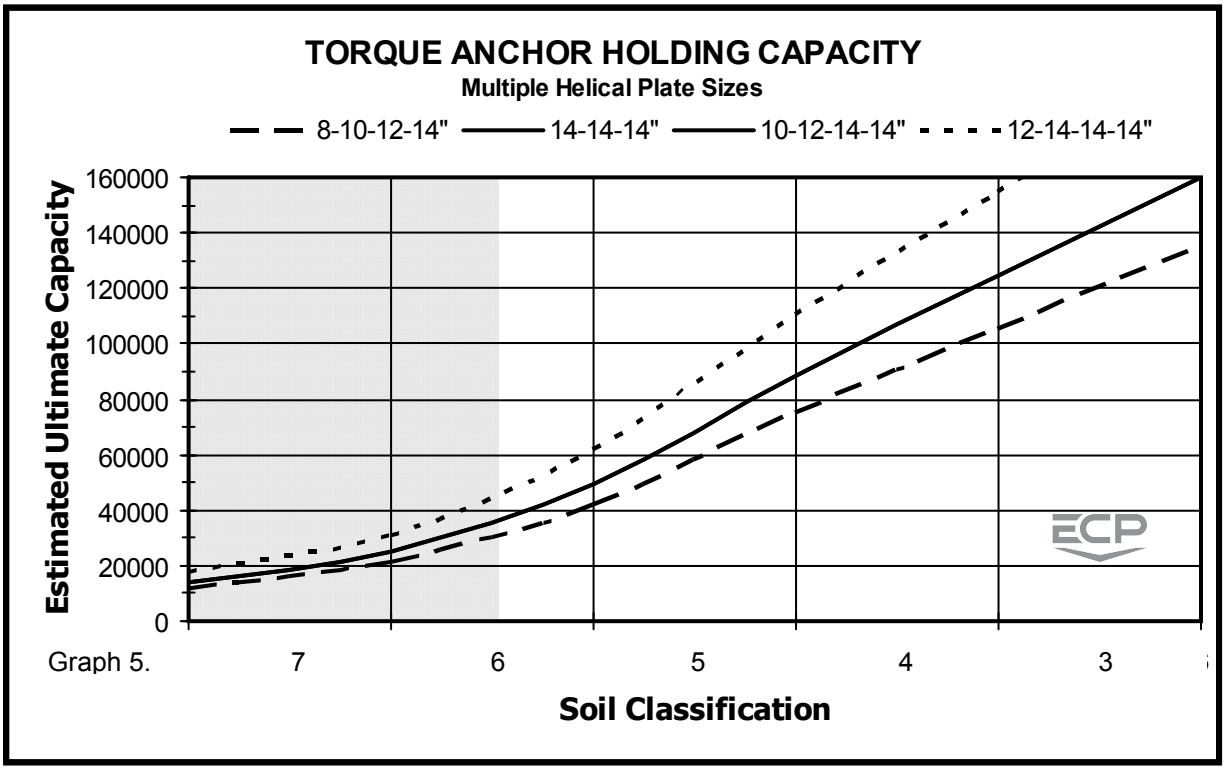


Graph 4.



Graph 5.

Note: It is advisable not to install Torque Anchors™ into Soil Classes in the shaded area for better stability and performance. In situations where this is not possible, we recommend increasing the factor of safety for a safer design. Installing the Torque Anchors™ to an underlying stratum that has a higher bearing capacity and a more stable soil classification is recommended.

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Torque Anchor™ Holding Capacity

The capacity of a helical product can be estimated by accurately measuring the installation shaft torsion. Several methods are commonly used. Transducers attached to the hydraulic lines, strain gauge monitors, shear pins and monitoring pressure differential across the installation motor are all common ways to determine installation torque being applied to the anchor shaft. The average recorded shaft torsion must be at or above the torque requirement during the final three feet of installation to confirm meeting the installation torque requirement. By continuing to install the helical product beyond first reaching the shaft torsion requirement insures that all anchor plates are sufficiently embedded into the target soil and this reduces the chance of creep, settlement or pullout in the future.

Field load testing is required to verify the actual load capacity. During a field test, the helical product is loaded in the direction of the intended compressive or tensile load and at the intended installation angle. ASTM D1143 and ASTM 3689 field load tests measure the ultimate capacity of the helical product when fully loaded. There is normally a small shaft movement when a helical product is initially loaded due to "seating" the plates into the soil. This movement is normally not considered in the test measurement. Before beginning the field load test, a small initial "seating" load of 1,500 to 2,000 pounds is usually applied to the pile or anchor prior to commencing test procedures. During testing, the load on the helical shaft is incrementally increased and after applying each load increment the movement at the top of the shaft is measured against a fixed point. If creep occurs only during the application of the incremental load, the test can continue immediately after measuring the initial creep increment. As the load increases and nears ultimate capacity, the pile or anchor may continue to slowly move for a period of time after the incremental load was applied. During this time the incremental load on the helical product must be maintained as the shaft continues to creep. The total deflection shall not be determined until the movement ceases and the pile or anchor becomes stable. If after 15 to 20 minutes, the movement is continuing or the total measured creep exceeds the established limit for acceptance, the useful capacity of the pile or anchor has been exceeded. The load increment prior to this final load increment shall be recorded as the ultimate capacity of the product. Load capacity is discussed in greater detail in Chapter 2.

Soil type will affect the performance of the helical product during field testing. For example, piles or anchors installed in clay will show minimal creep with increasing load and then suddenly and continuously start moving. Cohesionless soils, on the other hand, usually will produce a more predictable load to creep curve.

Installation Torque

Shaft torsion during installation can provide a reasonably accurate estimate of the expected ultimate capacity of the helical product. The relationship between the shaft torsion during installation and the ultimate capacity of the pier or anchor is empirical and was developed from results from thousands of tests. When one applies rotational torsion to a shaft at grade, some of the torque energy is lost before it reaches the helical plates at the bottom end of the shaft. This is due to friction between the shaft and the soil.

Figure 2, below, illustrates that not all of the torque applied to the shaft by the motor reaches the helical plates. The actual torque applied to the helical plates is $T_{Plates} = T_{Motor} - T_{Shaft}$. The friction generated between the circumference of the shaft and the soil is directly related to the shaft configuration and size along with the properties of the soil. Because of this loss of efficiency in transmitting the motor torque down to the plates, an empirical *Soil Efficiency Factor* ("k") must be employed to arrive at a reasonable estimate of pile or anchor ultimate capacity.

Shaft torsion should always be monitored during

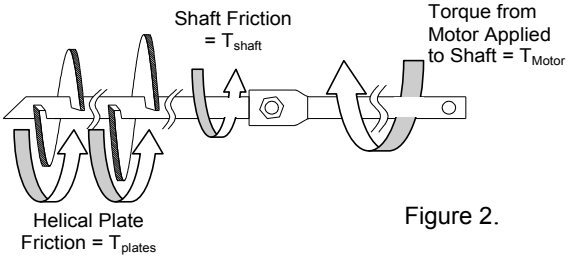

Figure 2.

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the installation of helical screw piles and anchors. Generally, the ultimate holding capacity of the typical *solid square shaft helical product* within a given soil stratum is ten times the average shaft torsion measured over the final three feet of installation.

When estimating the anchor's capacity, one must not consider any torque readings on an anchor when it is stalled or encountering obstructions; instead average the readings three feet before the stall. Likewise the shaft torsion readings on an anchor that spins upon encountering very dense soil cannot be used. When a tension anchor spins, it must be removed and repositioned. The torsion measurements on the new placement shall be averaged over three feet, but the anchor shall not be installed to the spin depth.

Due to larger friction between the soil and tubular shaft configurations, one cannot use the ten to one relationship mentioned above to estimate ultimate capacity of tubular shafts.

A more detailed discussion of the relationship between torque on the shaft and anchor capacity is presented in the next section.

Helical Torque Anchor™ Design Considerations

Projected Areas of Helical Plates: When determining the capacity of a screw pile in a given soil, knowledge of the projected total area of the helical plates is required. This projected area is the summation of the areas of the helical plates in contact with the soil less the cross sectional area of the shaft. Table 10 provides projected areas in square feet of bearing area for various plate diameters on different shaft configurations.

Table 10. Projected Areas* of Helical Torque Anchor™ Plates

Helical Plate	6" Dia.	8" Dia.	10" Dia.	12" Dia.	14" Dia.	16" Dia.
Shaft	**Projected Area – ft²**					
1-1/2" Sq.	0.181	0.333	0.530	0.770	1.053	1.381
1-3/4" Sq.	0.175	0.328	0.524	0.764	1.048	1.375
2-1/4" Sq.	0.161	0.314	0.510	0.750	1.034	1.361
2-7/8" Dia	0.151	0.304	0.500	0.740	1.024	1.351
3-1/2" Dia	0.130	0.282	0.478	0.719	1.002	1.329
4-1/2" Dia	0.086	0.239	0.435	0.675	0.959	1.286

* Projected area is the face area of the helical plate less the cross sectional area of the shaft.

Important: When a 90^0 spiral cut leading edge is specified, the projected areas listed in Table 10 will be reduced by approximately 20%.

Allowable Helical Plate Capacity: When conducting a preliminary design, one must also be aware of the mechanical capacity of the helical plate and the shaft weld strength. Average capacities of plates are given in Table 11. Actual capacities are generally higher than shown for smaller diameter helical plates. Capacities are also slightly higher when the helices are mounted to larger diameter tubular shafts.

Table 11. Average Ultimate Mechanical Helical Plate Capacities

6" through 14" Diameter Plates		
Helical Plate Thickness	Average Ultimate Load	Average Service Load
3/8"	40,000 lb	20,000 lb
1/2"	50,000 lb	25,000 lb
16" Diameter Plate		
1/2"	40,000 lb	20,000 lb

Designs using 12" to 14" diameter plates on square bar shafts will have ultimate mechanical capacities that are slightly lower than shown in Table 11. This variance is usually not a concern except when a small shaft is highly loaded with only a single or double helix configuration.

Relationships between Installation Torque and Torque Anchor™ Capacity: Estimating the capacity of a given screw pile based upon the installation torque has been used for many years.

Unless a load test is performed on site to determine a specific value for the relationship between installation shaft torsion and ultimate product capacity, commonly referred to as *Soil Efficiency Factor,* "k", a conservative value should be selected when designing. While

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values for "k" have been reported from 2 to 20, most projects will produce a value of "k" in the 6 to 14 range. Earth Contact Products suggests using the values for "k" as shown in Table 12 when estimating Torque Anchor™ ultimate capacities.

Table 12. Soil Efficiency Factor "k"

Torque Anchor™ Type	Typically Encountered Range "k"	Suggested Average Value, "k"
1-1/2" Sq. Bar	9 - 11	10
1-3/4" Sq. Bar	9 - 11	10
2-1/4" Sq. Bar	10 - 12	11
2-7/8" Diameter	8 - 9	8-1/2
3-1/2" Diameter	7 - 8	7-1/2
4-1/2" Diameter	6 - 7	6-1/2

It is important to understand that the value of "k" is a measure of friction during installation as illustrated in Figure 2 on page 25 above. This friction has a direct relationship between the soil properties and anchor design. For example, "k" for clay soil would usually be greater than for dry sand. The "k" for a square bar is generally higher than for a tubular pile. Keep in mind that the suggested values in Table 12 are only guidelines. Graph 6 illustrates how the *Soil Efficiency Factor*, "k" affects the ultimate capacity of a pile or anchor. It can be seen that the ultimate capacity varies significantly when the same torque is applied to each different shaft configuration.

It is also important to refer to Table 2 for the *Useable Torque Strength* values to avoid shaft fractures during installation.

Equation 2: Helical Installation Torque

$$T = (P_u \text{ or } T_u) / k \quad \text{or} \quad (P_u \text{ or } T_u) = k \times T$$

Where,
T = Final Installation Torque - (ft-lb)
(Averaged Over the Final 3 to 5 Feet)
P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
k = Empirical Torque Factor - (ft^{-1})

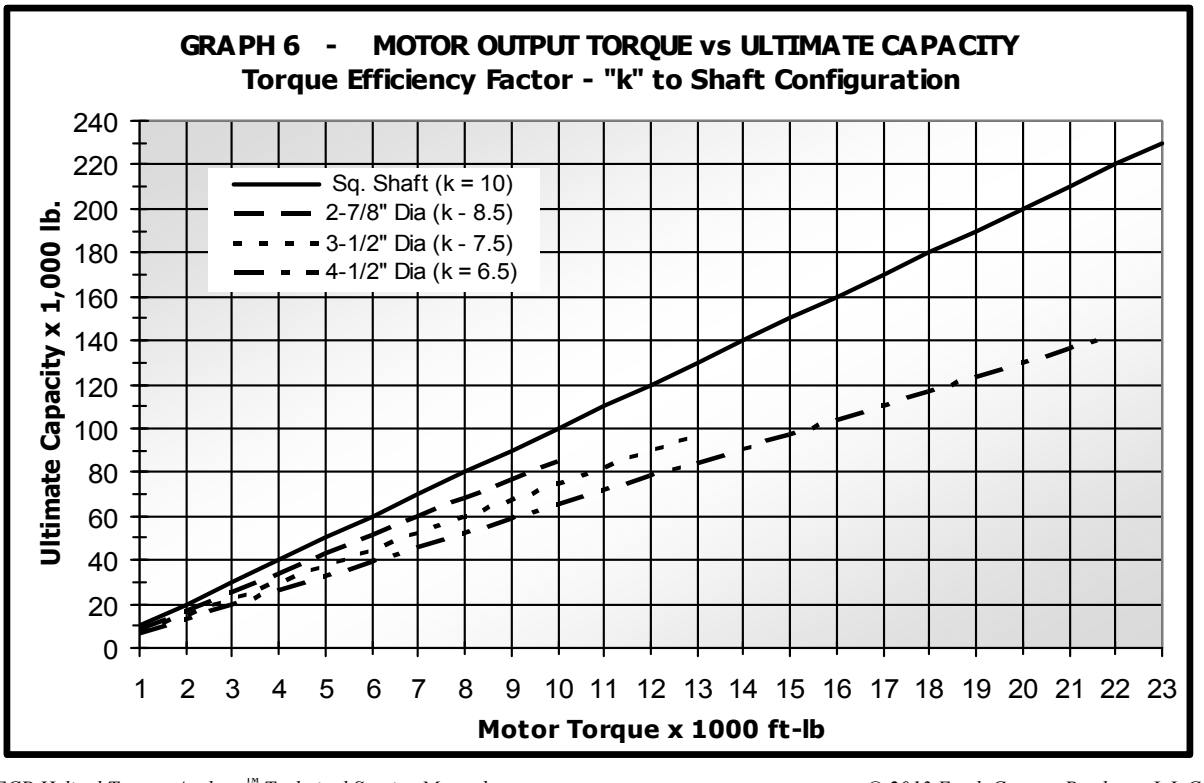
An appropriate factor of safety of 2.0, minimum, must always be applied when using design or working loads with Equation 3.

To determine *Soil Efficiency Factor*, "k" from field load testing, Equation 2 can be rewritten as:

Equation 2a: Soil Efficiency Factor

$$k = (P_u \text{ or } T_u) / T$$

Where,
k = Empirical Torque Factor - (ft^{-1})
P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
T = Final Installation Torque - (ft-lb)



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Always verify capacity by performing a field load test on any critical project.

Torque Anchor™ Spacing – "X": Equation 3 is used to determine the center-to-center spacing of Torque Anchors™.

Equation 3: Torque Anchor™ Spacing
"X" = P_u/(w) x (FS) or P_u = ("X") x (w) x (FS)

Where,
"X" = Product Spacing - (ft)
P_u = Ultimate Capacity - (lb)
w = Distributed Load on Foundation or Wall (lb/ft)
FS = Factor of Safety (Typically 2.0 – Foundations or Permanent Walls and 1.5 for Temporary Walls)

Plate Embedment in Tension Applications: When a pile must resist uplift or tension loads, the pile must be adequately embedded into the bearing stratum to offer resistance to pull out.

The pile must first qualify as a deep foundation, defined as being installed to a depth from intended surface elevation of no less than six times the diameter of the largest and shallowest helical plate (**6 x $d_{Largest}$**). In addition, to insure that the pile is fully embedded, the required terminal torsion applied to the shaft must have been an average of the torsion developed over a distance of no less than three times the diameter of the uppermost (largest) plate (3 x $d_{Largest}$).

Preventing "Punch Through": A soil boring on occasion may report a layer of competent soil overlaying a weak and softer stratum of soil. , One must consider the possibility that the Torque Anchor™ could "punch through" to the weaker soil when fully loaded in situations when designing the Torque Anchor™ to achieve axial compressive bearing in any competent soil situated directly above a weaker soil stratum.

When designing a pile in such situations, it is recommended that a distance greater than five times the diameter of the lowest (smallest) helical plate (5 x d_{Lowest}) exist below the lowest Torque Anchor™ to prevent "punching through" to the stratum of weaker soil and possibly failing.

Tieback Design Considerations

One of the most common applications for helical tieback anchors is for supplemental basement wall support. Many basement walls show signs of inwardly bulging, have horizontal tension fractures and/or have rotated inwardly.

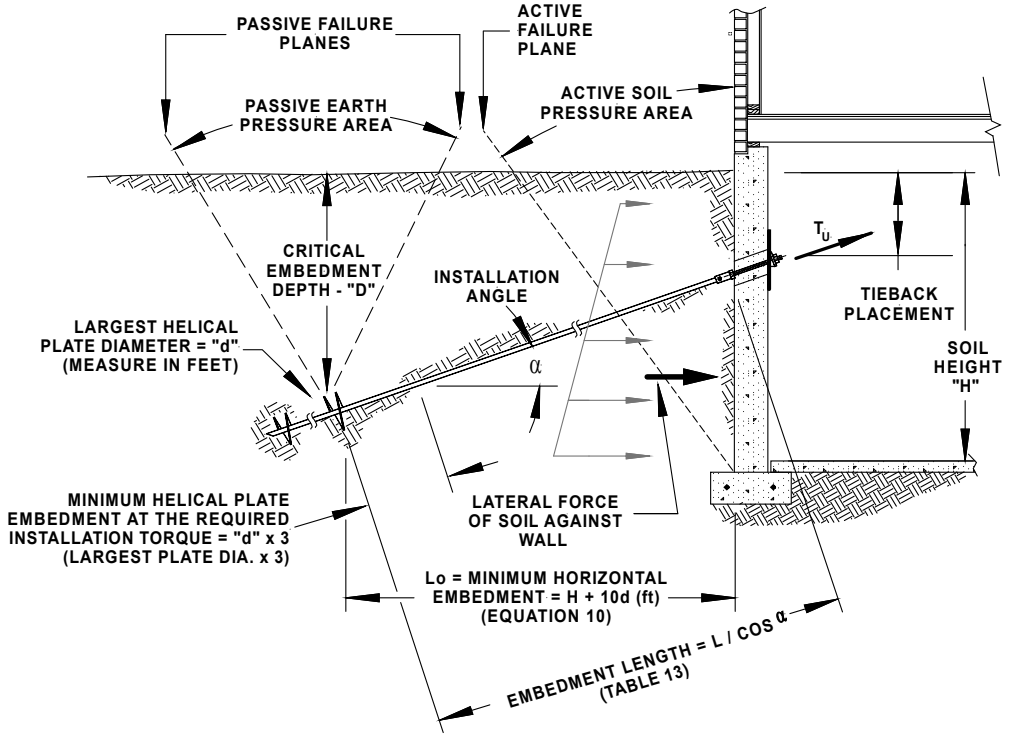

Figure 3. Elements of Tieback Design

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Consolidation of the fill soil, inoperative drain tiles, plumbing leaks, ponding water on the surface near the basement wall, or other environmental factors are largely the cause of the distress seen in many basement wall failures. When ECP Helical Torque Anchors™ are installed and anchored into the soil; two repair options are available:

1. The tieback is designed and loaded to support or supplement the wall structure. Soil is not removed from behind the wall; therefore, the wall can be only supported and not restored.
2. The soil behind the wall is removed and the tieback anchor is used to restore the wall to near its original position. Proper granular material must be used as backfill against the wall after restoration along with a proper ground water drainage system for stability.

The wall will always be exposed to active pressure from the soil and possible hydraulic force from water. For the Torque Anchor™ to properly develop resistance against this active pressure, the anchor must be installed beyond this active soil area. Once beyond this area, the tieback can develop passive earth pressure against the helical plate(s). Figure 3, above, shows the general layout for a tieback project and design elements for the embedment of the helical plates for proper support.

It is most important that any basement wall repair include an investigation, and any remedial work required to prevent any future conditions where the soil behind the wall can become saturated. If the drainage work is not accomplished immediately following tieback installation, the design must assume that there will be hydraulic pressure against the wall. An engineer can determine if the wall has sufficient structural integrity to support these combined loads if drainage corrections are not implemented.

Design of retaining walls is very complicated and requires engineering input. This manual has greatly simplified the equations so that the reader can quickly and relatively easily obtain an estimate of the reaction force required to stabilize and support a failing retaining wall. This material should be used with caution for new construction retaining walls or basement wall designs.

Placement of Tiebacks: The vertical placement of the tieback is dictated by the height of the soil against the wall. It is recommended that the tieback be installed close to the point of maximum bulging of the wall and/or close to the most severe horizontal crack in the wall. When the wall is constructed of blocks, or where a concrete wall is severely distressed, vertical steel supports and/or horizontal waler beams must be used to provide even distribution of the reaction force of the anchor across the face of the wall.

The typical vertical mounting location for tieback anchors is 20% to 50% of the distance down from the elevation where the soil touches down to the wall to the bottom of the wall. Seek engineering assistance for walls taller than 12 feet and/or more complicated projects.

Hydrostatic Pressure: If water is present or suspected behind a basement or retaining wall, the additional force of the hydrostatic pressure must be added to the load requirements of the tieback anchor.

When soil and/or subsurface conditions are unknown, it MUST be assumed in the design that water pressure is present.

Basement Tieback Applications: If a basement wall fails because of insufficient structural integrity, improper fill against the wall and/or improper compaction of the fill, then Equation 4 may be used for approximating the load per lineal foot against the basement wall. This equation assumes that no hydrostatic pressure is present. Please refer to Figures 3 & 4.

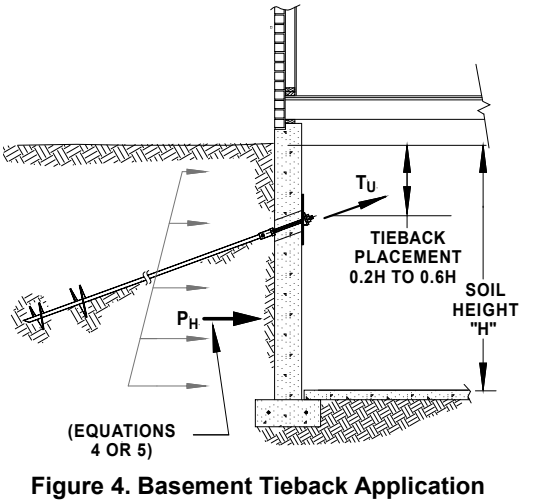

Figure 4. Basement Tieback Application

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Equation 4: Basement Wall Load
$P_H = 18 \times (H^2)$ (No Water Pressure)

When water pressure is present behind the basement wall or if it is not known if hydrostatic pressure exists, Equation 5 should always be used to estimate the load.

Equation 5: Basement Wall Load
$P_H = 45 \times (H^2)$ (Water is Present)

Where:
P_H = Soil Load on Wall - (lb/lineal foot)
H = Height of Backfill - (ft)

Simple Retaining Wall Tieback Applications: Similarly, if a retaining wall fails because of insufficient structural capacity, improper fill against the wall and/or consolidation of the fill, then Equation 6 may be used to approximate the load per lineal foot of retaining wall. If the soil at the top of the wall is level as shown in Figure 5, then the value of "S" in Equations 6 & 7 becomes zero. **This equation assumes that no hydrostatic pressure present**. (Refer to Figures 3 and 5.)

Simple Retaining Wall Tieback Applications with Soil Surcharge: A load on a retaining wall with a simple soil surcharge load such as shown in Figure 6 may also be approximated using Equations 6 & 7. One must first estimate the surcharge height, "S" as shown.

Equation 6: Simple Retaining Wall Load
$P_H = 24 \times (H + S)^2$ (No Water Pressure)

Equation 7: Simple Retaining Wall Load
$P_H = 50 \times (H + S)^2$ (Water is Present)

Where:
P_H = Soil Load on Wall - (lb/lineal foot)
H = Height of Backfill - (ft)
S = Height of Soil Surcharge - (ft)

When water pressure is present behind the retaining wall of it is unknown if hydrostatic pressure exists, Equation 7 must be used to estimate the load on the retaining wall.

Ultimate Tieback Capacity Selection: To determine the ultimate tieback capacity requirement, multiply the soil force against the wall by the selected center to center tieback spacing appropriate for the existing or planned wall construction and loading.

Equation 8: Ultimate Tieback Capacity
$T_U = (P_H) \times$ ("X") x FS

Where:
T_U = Ultimate Tieback Capacity Tension – (lb)
P_H = Foundation Load or Force on Wall – (lb/lin.ft)
FS = Factor of Safety (Typically 2.0 - Permanent Walls and 1.5 for Temporary Walls)
"X" = Center to Center Spacing of Tiebacks – (ft)

It is highly recommended to consult a registered professional engineer when more complex surcharge loads such as a structure, parking lot, road, etc. is located on the surface near the top of the retaining wall.

Horizontal Embedment Length – "L_0": The

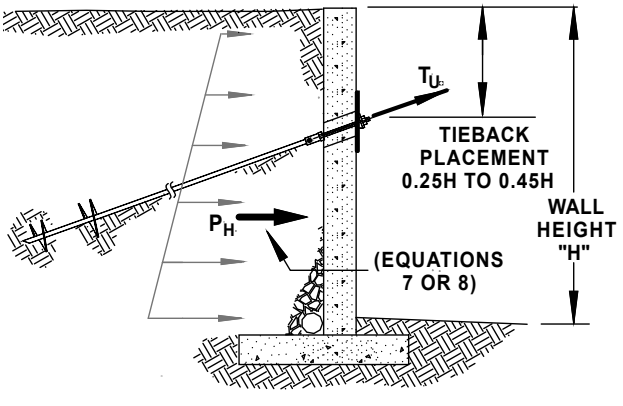

Figure 5. Simple Retaining Wall Tieback Application

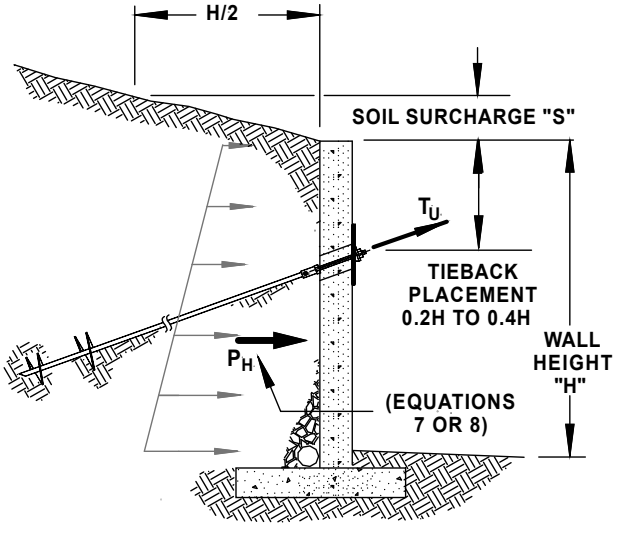

Figure 6. Simple Retaining Wall with Soil Surcharge

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Helical Torque Anchor™ must be installed into soil a sufficient distance away from the wall so that the helical plate(s) can fully develop anchoring capacity beyond any failure planes. (See Figure 3.)

Equation 9: Horizontal Embedment

$$L_0 = H + 10d_{largest}$$

Where:

L_0 = Minimum Horizontal Embedment Length from Wall to the Shallowest Plate – (ft)

H = Height of Soil Against Wall - (ft)

$d_{largest}$ = Diameter Of Largest Plate - (ft)

Installation Angle – "α": Typically in tieback applications, Torque Anchors™ are installed at downward angles of 5^0 to 30^0 measured from horizontal. Most often the designer calls for installed angles between 10^0 and 20^0. The smaller the angle, the less shaft material is required to reach a suitable horizontal embedment length; however, a large enough installation angle is required to reach critical depth, "D", which insures that a shallow embedment failure cannot occur. (See Figure 3.)

Table 13 provides equations to obtain minimum horizontal embedment length when the anchor is installed at various downward angles.

Critical Embedment Depth – "D": In tension applications there is a shallow failure mechanism for screw piles. The anchor fails when the soil suddenly erupts from insufficient soil overburden on the anchor. To prevent such failures, Torque Anchors™ must be installed to a sufficient embedment depth to be considered a deep foundation. This is illustrated in Figure 3 on Page 28.

As a general rule of thumb, many designers use six times the diameter of the largest plate as the minimum vertical depth from the surface elevation as the critical embedment depth for the anchor to be considered a deep foundation.

Table 13. Angular Embedment Length

Installation Angle "α" (Downward From Horizontal)	Length "L" of installed product required to reach the proper embedment length
10^0	$L_{10} = [H + (10\ d_{largest})] \times 1.015$
15^0	$L_{15} = [H + (10\ d_{largest})] \times 1.035$
20^0	$L_{20} = [H + (10\ d_{largest})] \times 1.064$
25^0	$L_{25} = [H + (10\ d_{largest})] \times 1.103$
30^0	$L_{25} = [H + (10\ d_{largest})] \times 1.155$

H = Height of Backfill (ft) $d_{largest}$ = Largest Plate Dia. (ft)

Torque Anchor™ Installation Limits

Shaft Strength: The data in Table 2 gives the strength ratings for various shaft configurations in axial tension, compression and shaft torsion. **The values are from mechanical testing and not from tests in the soil.** Because Torque Anchor™ products are installed by rotating them into the soil; the installation torsion can limit the ultimate strength of the product.

The *Useable Torsional Strength* column in Table 2 indicates the maximum installation torque that should be intentionally applied to the Torque Anchor™ shaft during installation in homogeneous soil. The risk of product failure dramatically increases when one exceeds these limits.

When choosing a product for a project, the designer should select a product that has an adequate margin of torsional strength above the torque required for embedment. This margin will allow for increases in torque during the final embedment length after the initial torsional resistance criterion has been met. In addition, fractures from unexpected impact loading can and often occur during installation, especially in obstruction laden soils.

It is recommended that a margin of at least 30% above the required installation torque be allowed to insure proper embedment and to prevent shaft impact fractures.

It is important to also understand that the empirical torsional factor "k" reduces the practical limit on the ultimate capacity that can be developed in the soil. This is especially important when designing with larger tubular products because large tubular shafts pass through the soil less efficiently than smaller tubular shafts and solid square bars.

Shaft Stiffness: When the tubular Torque Anchor™ is installed through soft soils that display a Standard Penetration Test value "N" ≤ 4 blows per foot ("N" ≤ 5 for square shafts), the possibility of shaft buckling must be considered

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in assessing the axial compressive capacity of the pile.

It is important to remember that tubular shafts provide superior resistance to buckling than solid square bars when used in axial compression applications.

This is because tubular shafts have greater flexural stiffness. (They have a larger moment of inertia.) In general tubular pile configurations the larger shaft diameter will provide greater resistance to lateral deflection or buckling within the soil.

Table 14 Torque Anchor™ Shaft Stiffness Comparisons

Torque Anchor™ Shaft Configuration	Cross Section Area - in^2	Moment of Inertia - in^4 (Stiffness)	Pier Stiffness Relative to TA-288
TA-150 (1-1/2" Square)	2.21	0.40	22%
TA-175 (1-3/4" Square)	3.00	0.74	40%
TA-225 (2-1/4" Square)	5.00	2.04	110%
TA-288L (2-7/8" Dia x 0.203")	1.70	1.53	82%
TA-288 (2-7/8" Dia x 0.262")	**2.08**	**1.85**	**100%**
TA-350 (3-1/2" Dia x 0.300")	3.02	3.89	206%
TA-450 (4-1/2" Dia x 0.337")	4.41	9.61	519%

Table 14 illustrates how tubular piles have superior shaft stiffness when compared to solid square bars. It is interesting to note that the 2-7/8" diameter tubular Torque Anchor™ with a wall thickness of 0.262 inches costs approximately the same as a Torque Anchor™ fabricated from 1-3/4" solid square bar stock. Please notice in Table 14 that the 1-3/4" solid square bar is only 40% as stiff as the 2-7/8" diameter tubular product. It is clear that the 2-7/8" tubular product is the better choice when designing foundation piles that are to be loaded in axial compression.

Another situation where shaft buckling should be considered is where there are both axial compression and lateral forces acting upon the pile. Normally when the pile terminates within a footing, this is not a problem. When the pile is not fixed at the surface, there may be factors present that affect buckling. These factors include shaft diameter, length, soil density and strength, and pile cap attachment.

Buckling Loads In Weak Soil: Whenever a slender shaft does not have adequate lateral soil support, the load carrying capacity of the shaft is reduced as shaft buckling becomes an issue. In the case of tubular Torque Anchors™, the full ultimate capacity is available provided the soil through which the pile penetrates maintains a value for "N" ≥ 4 blows per foot or greater as reported on a Standard Penetration Test for the entire length of the pile embedment. The pile must also be secured to a suitable footing at grade level to prevent lateral forces transmitting to the top of the pile.

Whenever one encounters weak soils such as peat or other organic soils, improperly consolidated soil, or where the pile may become fully exposed from the soil due to erosion; the pile will not be able to support the full rated capacity listed in Table 2.

In addition to the amount of lateral soil support on the shaft, both the length of the pile pipe that is exposed to insufficient lateral support and the stiffness of the slender shaft will affect the reduction in allowable capacity.

It should be noted that solid square shafts are only recommended to be installed through soils having SPT, "N" values greater or equal to five blows per foot.

The reason for this is the shaft offers very little strength against buckling when subjected soils with SPT blow less than five. When designing piles in axial compression that must penetrate weak soils, it is good practice to consider tubular products for the application.

The most accurate way to determine the buckling load of a helical pile shaft in weak soil is by performing a buckling analysis by finite differences. There are several specialized computer programs that can perform this analysis and allow the introduction of shaft properties and soil conditions that can vary with depth. Another, less accurate method of estimating critical buckling is by Davisson Method, "*Estimating Buckling Loads for Piles"* (1963). In this method, Davisson assumes various combinations of pile head and tip

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boundary conditions with a constant modulus of sub-grade reaction, "k_H" with depth. Load transfer to the soil due to skin friction is assumed to not occur and the pile is straight. Davisson's formula is shown as Equation 10 below.

Equation 10: Critical Buckling

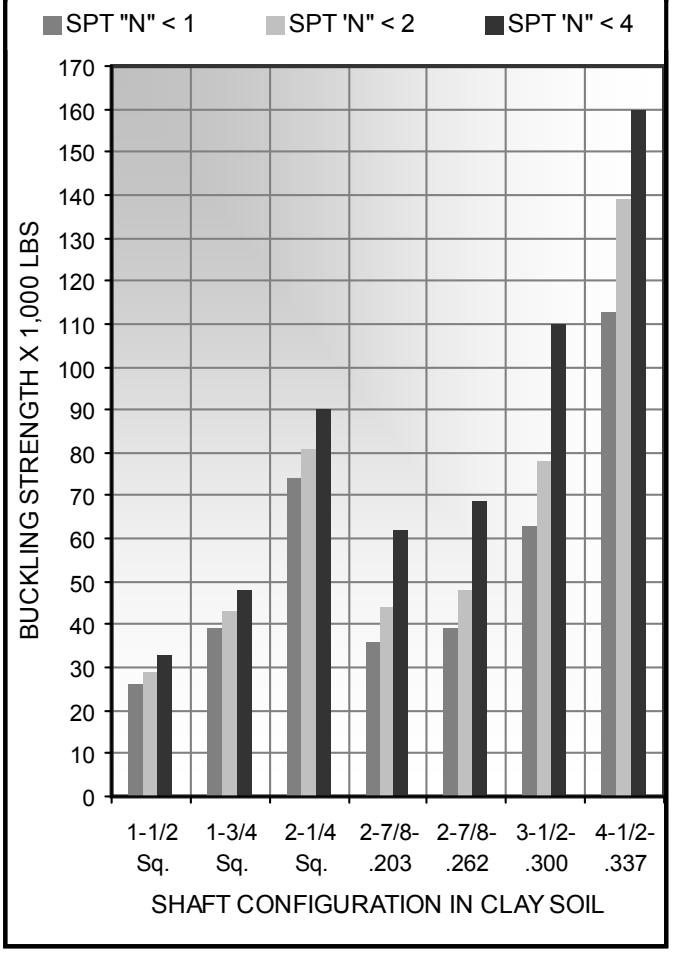
$$P_{cr} = U_{cr}\, E_p\, I_p / R^2$$

Where:

P_{cr} = Critical Buckling Load – lb
U_{cr} = Dimensionless ratio (Assume = 1)
E_p = Shaft Mod. of Elasticity = 30 x 10^6 psi
I_p = Shaft Moment of Inertia = in^4
$R = \sqrt[4]{E_p\, I_p / k_H\, d}$
d = Shaft Diameter – in

Computer analysis of shaft buckling is the recommended method to achieve the most accurate results. Many times, however, one must have general information to prepare a preliminary design or budget proposal. Table 15 below provides conservative working load estimates for various shaft sizes penetrating through different types of weak homogeneous soils. Graph 7 presents a visual representation of critical buckling loads that will quickly identify shaft configurations with Insufficient Buckling Strength when passing through soft soils that do not adequately support the shaft.

GRAPH 7 - CONSERVATIVE CRITICAL BUCKLING LOAD FOR BUDGET ESTIMATES



Allowable Compressive Loads - Pile in Air: Graph 8 shows the reduction in allowable axial compressive loading relative to the length of the pier shaft that is without lateral support. Table 14 illustrates that the 4-1/2" diameter tubular Torque Anchor™ provides an axial stiffness of more than five times that of a 2-7/8" diameter shaft. In addition, Graph 8 demonstrates that the 4-1/2" diameter pile has an ultimate capacity of more than four times that of the 2-7/8" diameter shaft when each shaft has ten feet of exposed column height without any lateral support. When one compares the buckling capacity of the 4-1/2" and diameter shaft to the 1-3/4" solid square shaft, the 4-1/2" diameter tubular shaft has more than three times the capacity. The same comparison between the 3-1/2" diameter shaft and the 1-3/4" solid square shaft, the 3-1/2 shaft has 1.6 times greater buckling capacity.

Table 15 Working Loads Under Buckling Conditions For Budgetary Estimating (Factor of Safety = 2)

Shaft Size	Uniform Soil Condition			
	Organics N ≤ 1	Very Soft Clay N = 1 - 2	Soft Clay N = 2 - 4	Loose Sand N = 2 - 4
1-1/2" Sq	14,000 lb	16,000 lb	23,000 lb	18,000 lb
1-3/4" Sq.	20,000 lb	24,000 lb	34,000 lb	27,000 lb
2-1/4" Sq.	38,000 lb	45,000 lb	64,000 lb	52,000 lb
2-7/8" Dia x 0.203"	19,000 lb	22,000 lb	31,000 lb	25,000 lb
2-7/8" Dia x 0.262"	20,000 lb	24,000 lb	34,000 lb	28,000 lb
3-1/2" Dia x 0.300"	33,000 lb	39,000 lb	55,000 lb	45,000 lb
4-1/2" Dia x 0.337"	59,000 lb	69,000 lb	98,000 lb	80,000 lb

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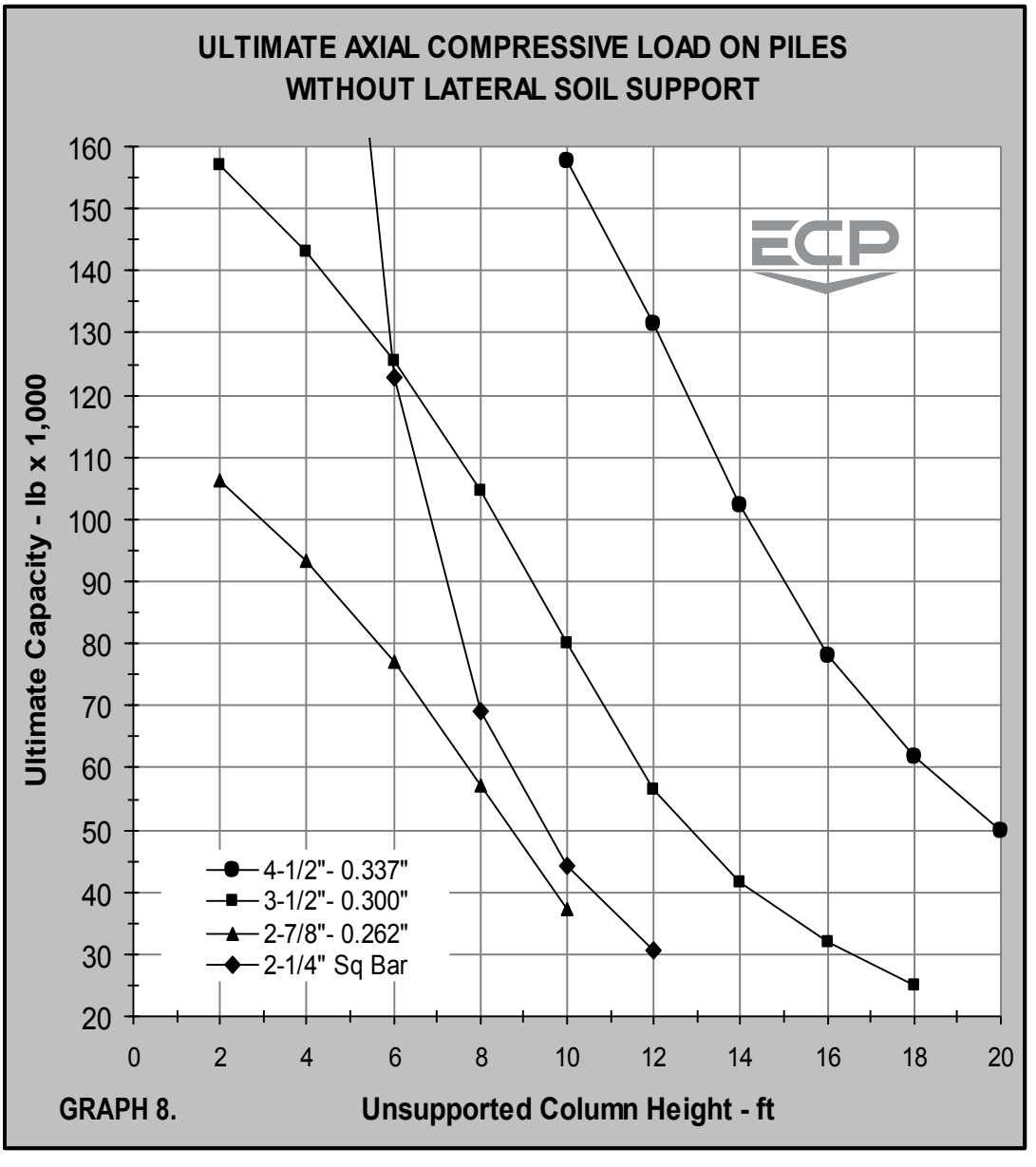
Each design where shaft buckling is possible requires specific information involving the structure and soil characteristics at the site. We strongly recommend that the final structural design be prepared or reviewed and approved by a geotechnical and structural engineer.



GRAPH 8.

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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Chapter 2

ECP Helical Torque Anchors™

Installation Guidelines and Testing Procedures

- **Hydraulic Torque Motors**
- **Installation Procedures**
- **Field Testing of Torque Anchors™**

EARTH CONTACT PRODUCTS
"Designed and Engineered to Perform"

Earth Contact Products, LLC reserves the right to change design features, specifications and products without notice, consistent with our efforts toward continuous product improvement. Please check with Engineering Department, Earth Contact Products to verify that you are using the most recent information and specifications.

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Helical Torque Anchors™ are usually installed with a hydraulic motor and reduction gear box assembly. Some motors offer a two speed gear box, which allows the installer to increase the advancement the Torque Anchor™ through the upper strata of the soil. Once approximately 75% of the design installation torque has been reached, the rotational speed is reduced to between 5 and 10 rpm until the final torque is maintained for required embedment distance.

Installation Torque

Installation torque on the shaft, the *Soil Efficiency Factor* ("k") and Table 12 were introduced and discussed in Chapter 1. These are reproduced for reference below.

Shaft torsion during installation can provide a reasonably accurate estimate of the ultimate capacity of the installed helical screw product. The relationship between the shaft torsion during installation and the ultimate helical product capacity is empirical and was developed from results from thousands of tests. When one applies rotational torsion to the end of the shaft at grade level, some of the torque energy is lost before it reaches the helical plates at the bottom end of the shaft. This loss of torque is due to friction between the shaft and the soil.

In the sketch below, notice that not all of the torque applied to the shaft by the motor reaches the helical plates. The actual torque applied to the helical plates is $T_{Plates} = T_{Motor} - T_{Shaft}$. The friction generated between the surface area of the shaft and the soil is directly related to the tyoe if shaft and shaft size along with the properties of the soil. Because of this loss of torque in transmitting the motor torque to the plates, an empirical *Soil Efficiency Factor* ("k") must be employed to arrive at a reasonable estimate of pile or anchor ultimate capacity.

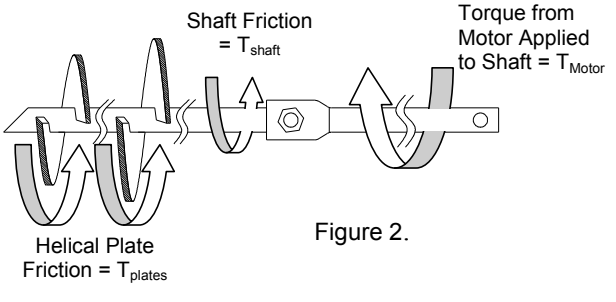

Figure 2.

Soil Efficiency Factor – "k": This is the relationship between installation torque and ultimate capacity of the installed Torque Anchor™. Estimating the ultimate capacity of helical foundation product based upon the installation torque has been used for many years.

Unless a load test is performed to create a site specific value for the *Soil Efficiency Factor* ("k"), a value must be estimated when designing. While values for "k" have been reported from 2 to 20, most projects will produce a value of "k" in the 6 to 14 range. Earth Contact Products offers a range of values for *Soil Efficiency Factors* ("k") in Table 12. Graph 6 on Page 40 also illustrates this. These values may be used for estimating empirical ultimate capacities of installed Torque Anchors™. These values may be used until a field load test can provide a more accurate site specific value for "k". Table 12 lists typical values of "k" for successful estimations of ultimate capacities of Torque Anchors™ based upon the output torque at the installation motor shaft.

Table 12. Soil Efficiency Factor "k"

Torque Anchor™ Type	Typically Encountered Range "k"	Suggested Average Value, "k"
All Square Shafts	9 - 11	10
2-7/8" Diameter	8 - 9	8-1/2
3-1/2" Diameter	7 - 8	7-1/2
4-1/2" Diameter	6 - 7	6-1/2

Understand that the value of the *Soil Efficiency Factor* ("k") is an estimation of friction loss during installation. The amount of friction loss has a direct relationship to soil properties and the anchor shaft.

The "k" value for square bars is generally higher than for tubular shafts. Keep in mind that the suggested values in Table 12 are only guidelines.

It is also important to refer to Table 2 at the beginning of Chapter 1 for the *Useable Torsional Strength* that can be applied to a specific anchor shaft. Being mindful of the torsional strength of the shaft will help to avoid shaft fractures during installation.

Failure to verify that the shaft configuration has

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sufficient reserve torsional capacity could result in an unexpected shaft fracture during installation especially in soils containing debris, rocks and cobbles.

Equation 4: Installation Torque
$$T = (T_u \text{ or } P_u) / k \text{ or } (T_u \text{ or } P_u) = k \times T$$

Where,
T = Final Installation Torque - (ft-lb)
(Averaged Over the Final 3 to 5 Feet)
$T_u = P_u$ = Ultimate Capacity - (lb)
(Measured from field load tests)
k = Soil Efficiency Factor - (ft^{-1})

To determine the site specific *Soil Efficiency Factor,* ("k") from field load testing, Equation 4 is rewritten as:

Equation 4a: Soil Efficiency Factor
$$k = (T_u \text{ or } P_u) / T$$

Where,
k = Soil Efficiency Factor - (ft^{-1})
$T_u = P_u$ = Ultimate Capacity - (lb)
(Calculated or measured from field load tests)
T = Final Installation Torque - (ft-lb)

An appropriate factor of safety must always be applied to the design or working loads when using Equation 4 and 4a.

Determining Installation Torque

Shaft torsion can be determined several ways:

- **Twisting of the Solid Square Bar** – This method of torque control is the least accurate method to determine the torsion that is being applied to the shaft. The reason this method is inaccurate and not recommended is because the point at which twisting occurs will vary with fluctuations in the steel chemistry used to make the bar, the differences in torsional strength from bar to bar within a mill run of bars and the tolerances in the steel compositions from mill run to mill run of similar bars. The length of shaft can also affect the number of twists for a given shaft torque. ECP does not recommend using this method to determine installation torque.
- **Shear Pin Hub** – This device uses a hub that attaches between the motor and the anchor shaft. Maximum shaft torsion is determined by inserting a number of shear pins between the flanges of the hub. Each pin usually represents 500 ft-lbs. Based upon the total number of pins used, one can restrict the maximum torsion that can be applied to the shaft. When the desired torsion is reached, the pins shear and the hub no longer transmits torsion to the helical anchor shaft. For this device to accurately predict ultimate capacity, the soil into which the screw anchor is installed must be homogeneous and with no obstructions. The shear pin hub, by nature, tends to overestimate the shaft torsion. If, during installation, the helical plates encounter an obstruction or something that causes a spike in the shaft torque, the shear pins become deformed and weakened. In addition, if the target stratum rapidly becomes very dense, the shear pins may break before all plates have been properly embedded. This is especially important in tension applications where the desired shaft torsion should be averaged over a distance of at least three feet before terminating the installation. Earth Contact Products does not endorse the shear pin hub and considers it a less desirable way to measure shaft torsion.
- **Single Pressure Gauge** – Many operators install a single pressure gauge at the inlet to the hydraulic gear motor. This is a dangerous practice and not recommended because in nearly every hydraulic system there is back pressure. This back pressure represents energy that enters the gear motor, but is not used by the motor. The back pressure simply causes the oil to flow back into the system and to the reservoir. Typically, back pressures range from 200 to 500 psi. In some cases it is higher.

  The danger in using a single gauge to estimate shaft torsion is that the back pressure is unknown. As a result, the shaft torsion on the shaft is overestimated, which results in an anchor capacity prediction that is overstated.

  Anchors installed with a single gauge system, in general, will not produce as much capacity as expected and could fail.
- **Dual Pressure Gauges** -- One of the most common ways to determine motor output torque is to measure the difference between the input pressure and output pressure across the motor. When using two gauges installed one on each port of the gear motor, the actual pressure drop across the motor is known. This is a theoretical representation of the amount of

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hydraulic energy that was used by the motor. Once the pressure differential is determined, the output shaft torque can be estimated from motor performance data that is provided by the motor manufacturer. It is especially important to have the gauges calibrated regularly. Gauges can become damaged and rendered inaccurate in the field.

- **Strain Gauge Monitor** (Torque Transducer) This device provides a direct display of installation torque being applied to the shaft; it also provides a recorded history of the shaft torsion through the entire depth of installation. This system consists of three parts; a Torque Analyzer Rotor installed on the flanged coupling between the motor and anchor shaft, a Torque Analyzer PDA indicator and a battery charger.

  The unit is extremely rugged and ideal for field based applications. The strain gauge monitor measures the torque applied between two flanges located between the motor output shaft and the helical anchor shaft. This data is transmitted to a hand held PDA readout device for display and logging. This method of measuring the torque applied is highly accurate (+/- 0.25%). The torque sensor is built into the housing of the flanges and the data is transferred by a wireless transmitter fitted into the housing.

  The data is captured by the PDA and is recorded as a text file that can be viewed or downloaded to any computer software for further analysis such as Microsoft Excel.

  This unit is the most accurate and the most rapid way to monitor and record installation torque. It is highly recommended.

Converting Motor Pressure To Shaft Torque

When a pressure differential is measured across the motor ports, it must be converted to motor output shaft torque. This can be accomplished by using Torque Motor Output Curves for the specific motor being used on site, or one can use a motor specific *Torque Motor Conversion Factor,* ("K"). Both are available from the motor manufacturer.

Torque Motor Conversion Factor – "K": Each motor has a unique *Torque Motor Conversion Factor*, which is the relationship between the differential pressure measured across the hydraulic ports of the motor and the shaft output torque of the motor. This factor, which is referred to as "K", may be used to calculate the output torque of a motor. In Table 16 on the following page, hydraulic gear motor manufacturers' data for several commonly used hydraulic torque motors have been provided. The important column in this table is the *Torque Motor Conversion Factor* ("K").

(Do not confuse the *Torque Motor Conversion Factor*, "K", with the *Soil Efficiency Factor,* "k", which is the measure of the soil friction on the shaft.)

Equation 11 below is used to convert pressure differential into motor shaft output torque.

Equation 11: Motor Output Torque

$$T = K \times \Delta P$$

Where,
T = Hydraulic Motor Output Torque - ft-lb
K = Torque Motor Conversion Factor – (Table 16)
$\Delta P = p_{in} - p_{out}$ = Motor Pressure Differential

When determining the installation torque from hydraulic pressure differentials, it is imperative that the motor outlet pressure be subtracted from the motor inlet pressure prior to referring to any tables or charts that convert differential motor pressure to output shaft torque.

In Table 16 presents the *Torque Motor Conversion Factor,* ("K") for some commonly used hydraulic torque motors.

Caution: Determining output shaft torsion when operating at very low motor output torque should be approached with caution. Hydraulic torque motor curves are not exactly linear. Errors are possible at the low end of the motor output curve when using a fixed value of "K".

Caution: It is very important to capture the pressure differential across the motor directly at the motor ports.

If the pressure measurement connections are made at other locations, the differential pressure reading may be inaccurate and could result in incorrect estimates of motor shaft torsions. Finally, the accuracy of the data is only as accurate as the gauges. Calibrate the pressure gauges regularly to insure accurate results.

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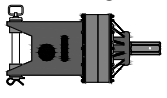
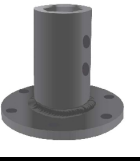
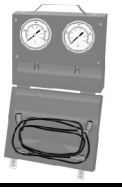
Table 16. Hydraulic Torque Motor Specifications									
Illustration	Model Number	Graph No.	Torque Output ft-lb	Motor Torque Conversion	Maximum Pressure psi	Max. Flow gpm	Output Speed rpm	Hex Output Shaft	Weight lb.
PRO-DIG	L6K5	10	6,335	**2.53**	2,500	16	13.8	2”	132
	L7K5	9	7,644	**2.55**	3,000	35	32.8	2-1/2	363
	X9K5	9	9,663	**3.22**	3,000	35	26	2-1/2	365
	X12K5	9	12,612	**4.20**	3,000	40	23.5	2-1/2”	366
	T12K	10	5,597/ 12,128	**2.24/4.85**	2,500	65	70/32	2-1/2” or 2-3/4	382
	X16K5	11	16,563	**5.52**	3,000	40	17.9	3”	565
	X20K	11	20,670	**6.89**	3,000	40	14.3	3”	571
Eskridge 	B26 16:1	12	4,500	**1.5**	3,000	10	10	2” Dia Keyed	68
	B5016-21F54	12	5,000	**1.71**	3,000	20	24	2”	150
	77BA	13	12,000	**5.0**	2,400	40	19	2-1/2”	250

IMPORTANT: Torque Motor Conversion Factor, “K”, tends to become lower than shown in this table when pressure differentials are below 1,000 psi. As a safety guideline, use only 90% of the “K” shown when pressure differentials are between 750 and 900 psi; use 80% of “K” shown for pressure differentials between 500 and 750 psi.

Torque Motor Accessories

DT-150-5 1.50 inch Sq. Shaft Drive Tool	DT-175-5 1.75 inch Sq. Shaft Drive Tool	DT-200-5 2 inch Hex Drive Tool	DT-250-5 2.50 inch Hex Drive Tool
			
DT-288-L-5 2.88 inch Drive Tool (Two Hole)	**DT-288-5 2.88 inch Drive Tool (Three Hole)**	**DT-350-5 & DT-350-7* 3-1/2 inch Dia. Drive Tool**	**Link Arm**
Pipe Install Tool	**Hydraulic Motor Pressure Monitor**	**Shear Pin Torque Indicator**	**Smart Anchor Monitor**
			

* DT-350-7 Drive Tool. Similar to DT-350-5 but with 7-5/8” flange (Not Shown)

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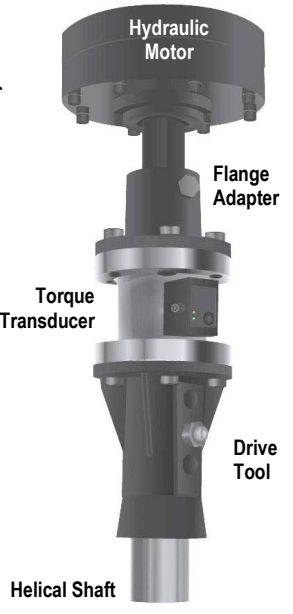
ECP Smart Anchor Monitor (SAM) and Assembly Configuration

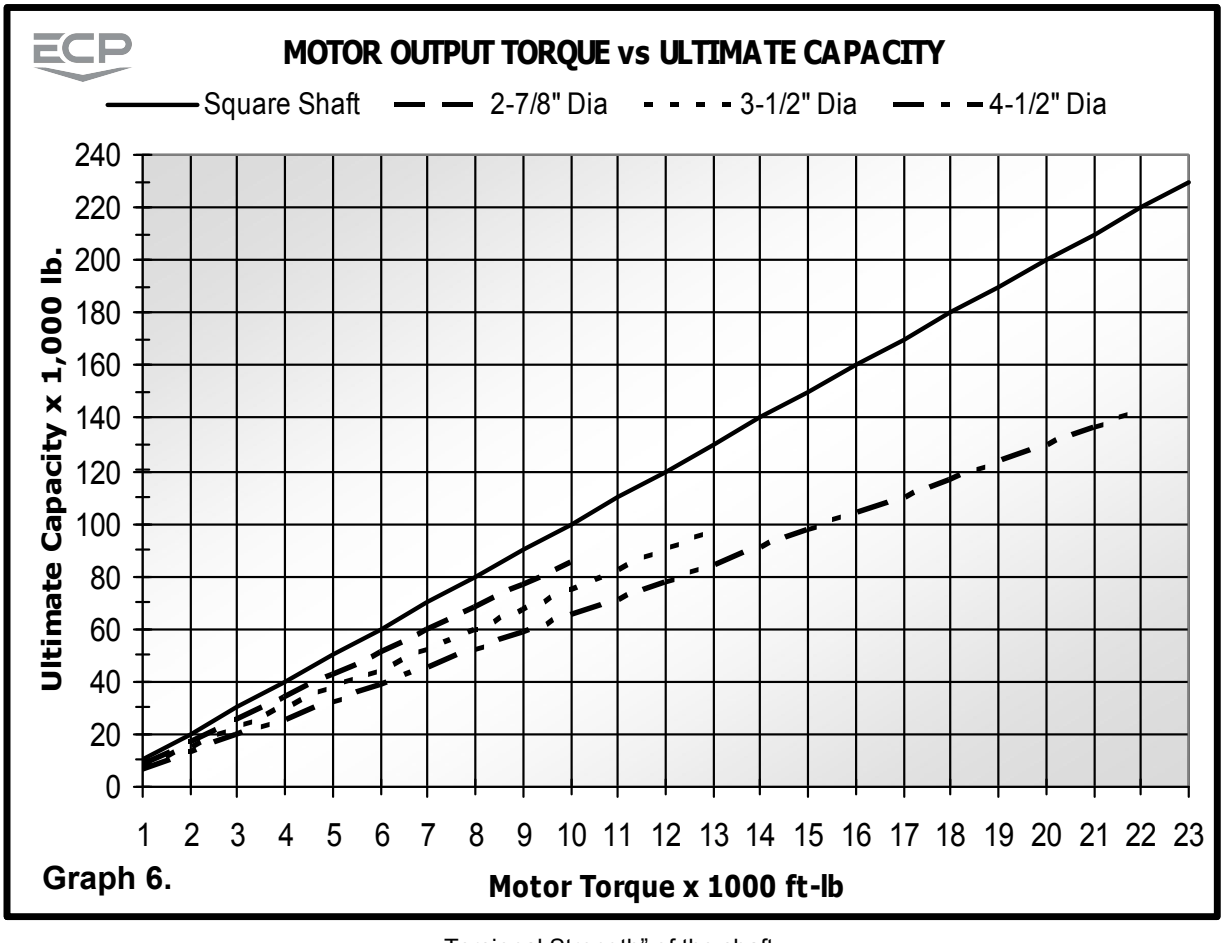


The torque transducer is assembled between the hydraulic gear motor and the Torque Anchor™ shaft that is to be monitored during installation. This state of the art tool provides the state of the art helical anchor monitoring and recording.

- Highly accurate (+/-0.25%) torque monitoring capabilities
- Angle and depth monitoring
- GPS data recorder for exact location of the anchor
- Multiple wireless PDA's can be used to view one drive
- Data can be exported to third party software
- Shaft RPM Indicator
- Calibrated to NIST (National Institute of Standards & Technology Certification)
- Extremely rugged design
- No mechanical parts

This quick reference can be used to estimate the ultimate capacity of a Torque Anchor™ when the motor output torque and the shaft configuration are known.

Caution: When using the Solid Square Shaft curve, do not exceed the "Useable Torsional Strength" of the shaft.



Graph 6.

ECP Hydraulic Torque Motor Performance Curves

The graphs on the following pages are hydraulic motor performance curves for Pro-Dig and Eskridge gear motors that are normally in stock at ECP and ready for immediate delivery. Motor performance curves provide a quick source for motor torque output based upon the actual pressure differential across the motor ports.

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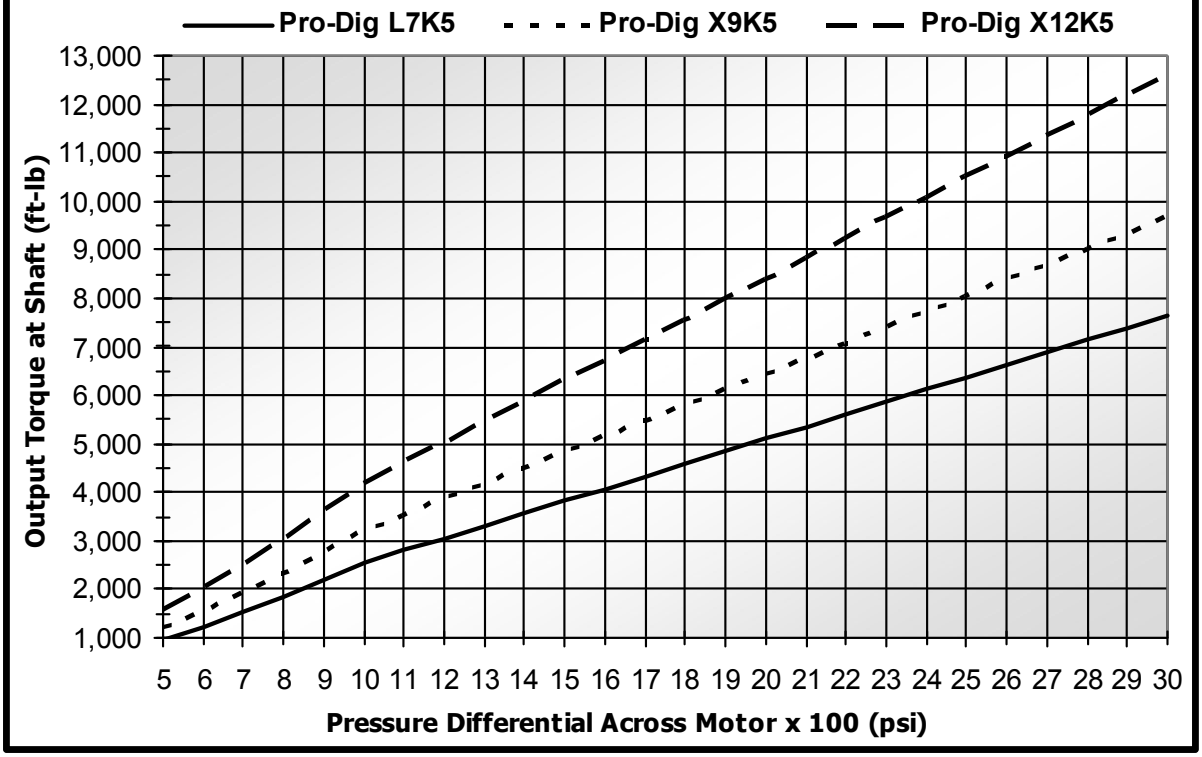
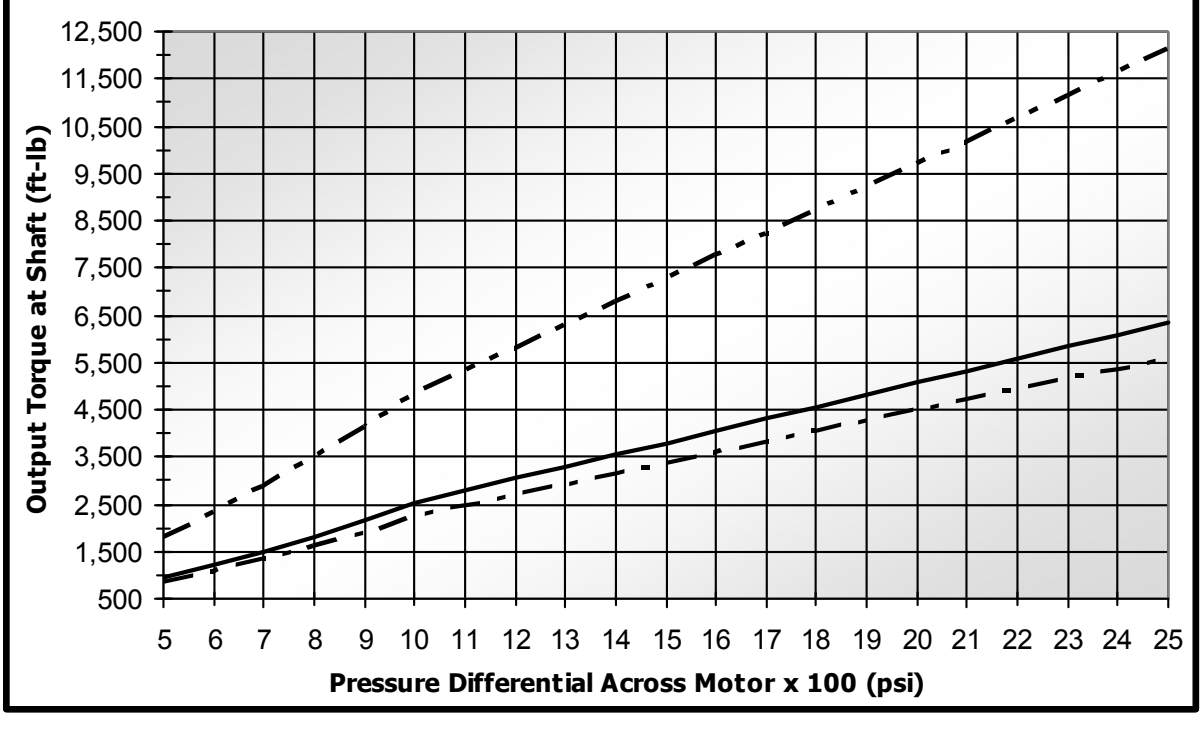
GRAPH 9. PRO-DIG SINGLE SPEED GEAR MOTORS - DIFFERENTIAL PRESSURE AT MOTOR VS. MOTOR OUTPUT TORQUE FOR



GRAPH 10. PRO-DIG SINGLE AND TWO SPEED GEAR MOTORS DIFFERENTIAL PRESSURE AT MOTOR VS. MOTOR OUTPUT TORQUE



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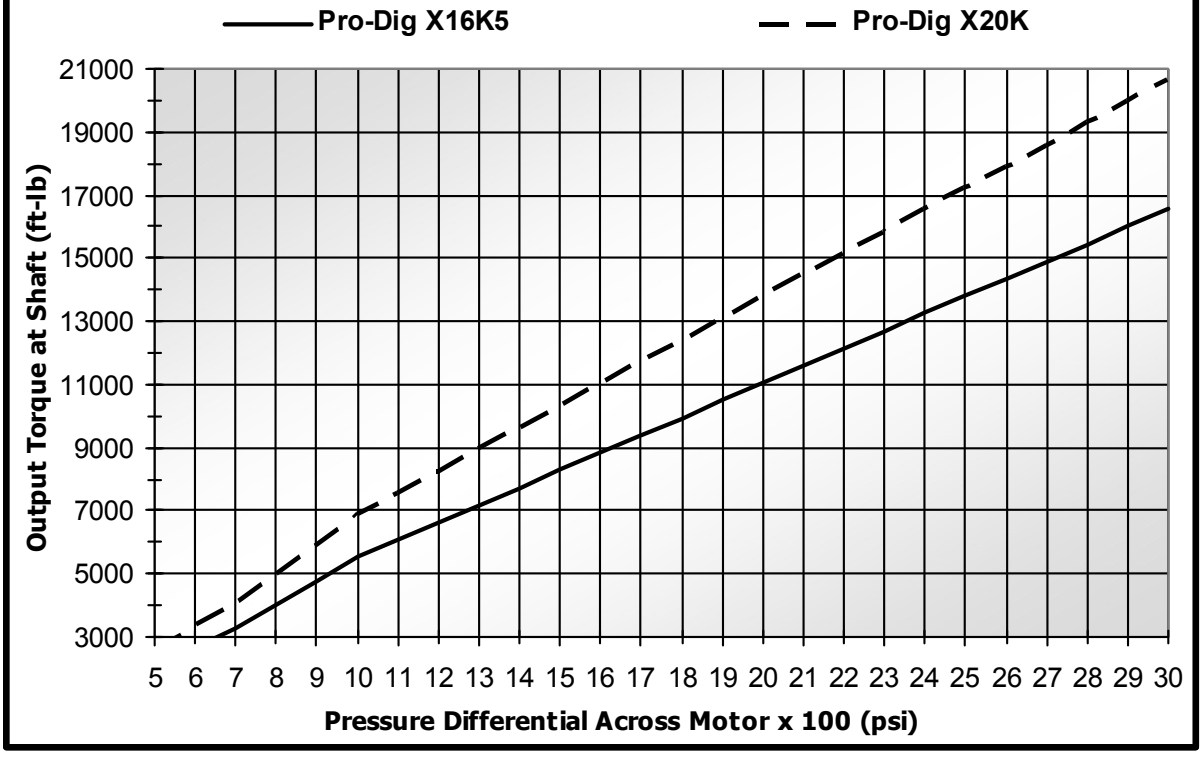
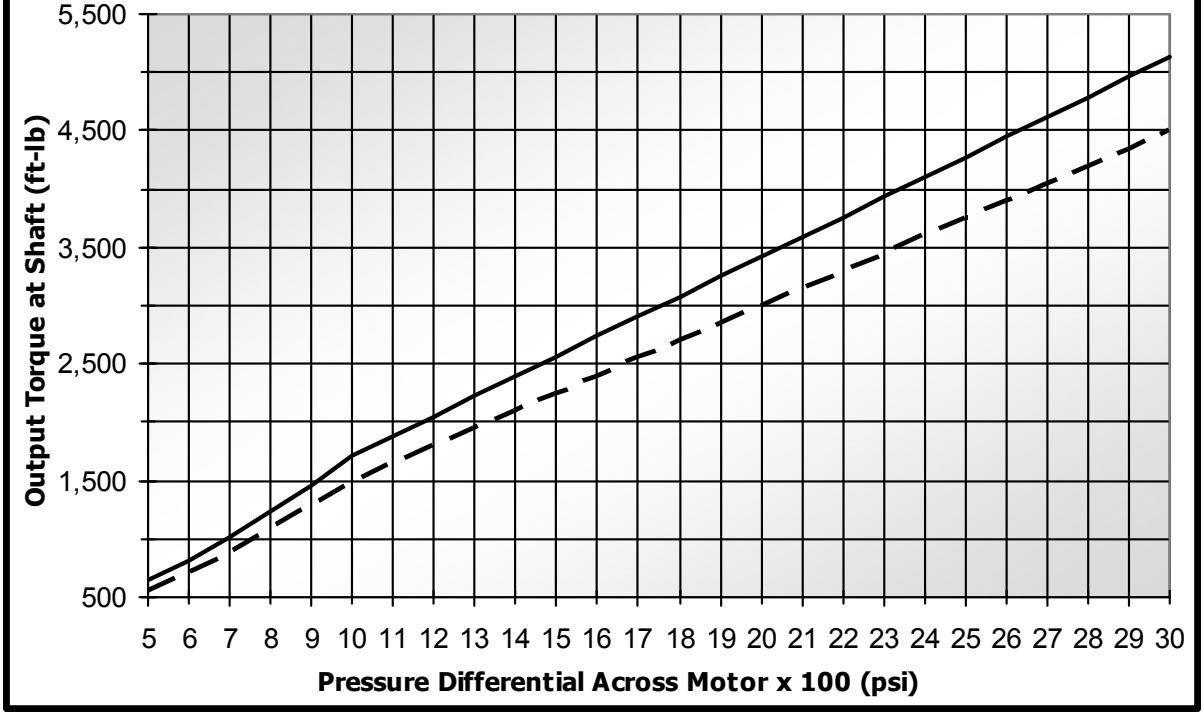
GRAPH 11. PRO-DIG SINGLE SPEED GEAR MOTORS - DIFFERENTIAL PRESSURE AT MOTOR VS. MOTOR OUTPUT TORQUE



GRAPH 12. ESKRIDGE SINGLE SPEED GEAR MOTORS - DIFFERENTIAL PRESSURE AT MOTOR VS. MOTOR OUTPUT TORQUE



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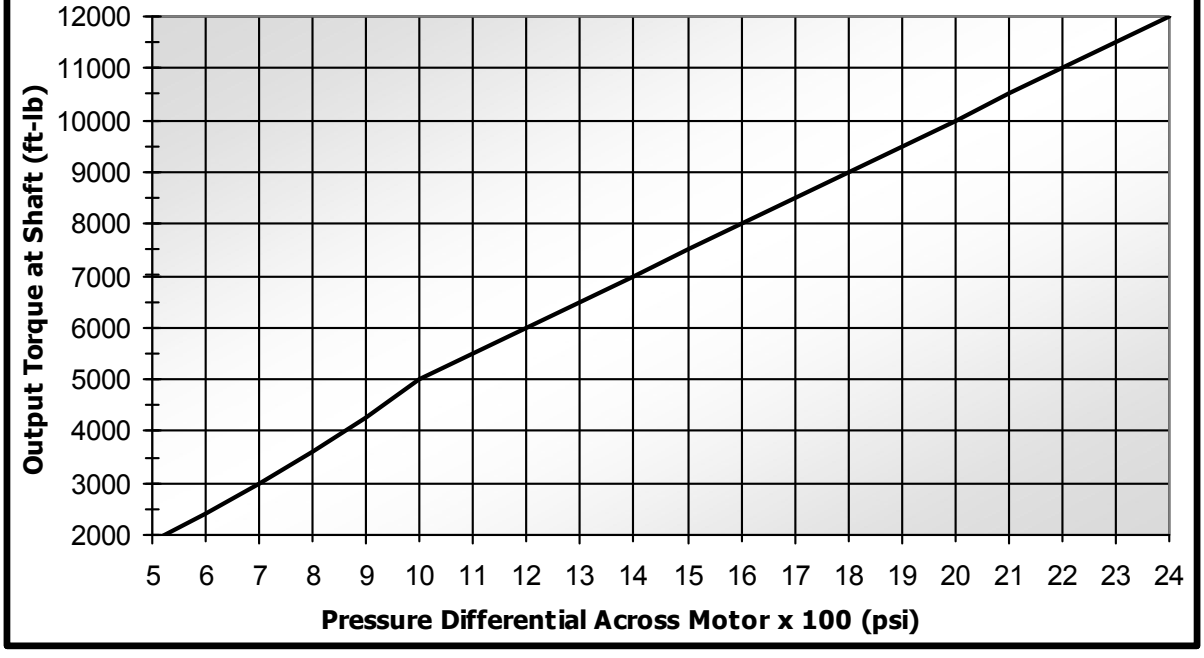
GRAPH 13. ESKRIDGE 77BA SINGLE SPEED GEAR MOTOR
DIFFERENTIAL PRESSURE AT MOTOR VS. MOTOR OUTPUT TORQUE



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Structural Compressive Pile and/or Tensile Helical Anchor Installation Procedure

General Considerations:

- Prepare site for safe working conditions.
- Thoroughly investigate the site for any and all underground utilities before excavating.
- Excavate as required for installation of the product.
- Install ECP Helical Torque Anchor™ to depth and torque specifications
- Cut to length and install the pile cap or wall support assembly as required
- Load test to verify design and capacity of the product and installation
- Remove equipment from work area and clean work area

Installation Plan:

The torque anchors shall be installed as shown on the written new construction or repair plan that was prepared by the engineer or the installer, and submitted to the owner or their representative. The plan shall include, but not be limited to:

- Size and number of placements
- Helical plate configuration on the helical torque anchor™
- Spacing between helical torque anchors™
- Minimum depth of embedment
- Minimum target torque requirement
- Load testing requirements

STEP 1 – Installation Requirements:

- The minimum average installation torque and the minimum length shown on the plans shall be satisfied prior to termination the installation. The installation torque shall be an average of the installation torque recorded during a minimum of the last three feet of installation.
- The torsional strength rating of the torque anchor™ shall not be exceeded during installation. If the torsional strength limit for the torque anchor™ has been reached, but the anchor has not reached the target depth, the following modifications are acceptable:
    A. If the torsional strength limit is achieved prior to reaching the target depth, the installation may be acceptable if reviewed and approved by the engineer and/or owner.
    B. The installer may remove the torque anchor™ and install a new one with fewer and/or smaller diameter helical plates with review and approval by the engineer and/or owner
- If the target is achieved, but the torsional requirement has not been met; the installer may do one of the following subject to the review and approval of the engineer and/or owner:
    A. Install the torque anchor™ deeper to obtain the required installation torsion.
    B. The installer may remove the torque anchor™ and install a new one with an additional helical plate and/or larger diameter helical plates.
    C. Reduce the load capacity of the placement and provide additional helical torque anchors™ at closer spacing to achieve the required total support for the project.
- If the torque anchor™ hits an obstruction or is deflected from its intended path, the installation shall be terminated and the anchor removed. Either the obstruction must be removed or the torque anchor™ relocated as directed by the engineer and/or owner and the installation resumed.
- In no case shall a torque anchor™ be backed out and reinstalled to the same depth. If an anchor must be removed for any reason, it must be installed to a deeper embedment of at least three feet.
- After meeting the installation requirements, the installer may remove the final plain extension section and replace it with a shorter one to obtain the design elevation, or he may cut the extension to length. The cut shall be smooth and at 90 degrees to the axis of the shaft. It is not permissible to reverse the installation to reach the desired coupling elevation.

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STEP 2 – Torque Anchor™ Installation:

The hydraulic installation motor shall be installed on a suitable machine capable providing the proper installation angle, reaction against installation torque, and downward force (crowd). The lead section shall be positioned with the shaft at the proper installation angle(s) at the designated location(s). The opposite end shall be attached to the hydraulic installation motor with a pin(s) and retaining clip(s).

If using portable equipment, the torque reaction bar MUST be properly secured against movements in all directions. Torque Anchor™ lead sections shall be placed at the locations indicated on the plans. The lead section shall be advanced into the soil in a smooth and continuous manner using sufficient force for uniform advancement. The installer shall have knowledge of the desired pressure differential that will produce the desired terminal installation torque approved by the engineer before beginning the installation.

Once the lead is installed, the motor shall be unpinned from the lead. One or more extensions shall be installed and securely bolted in place with the hardware supplied by the manufacturer.

The torque anchor™ shall be continued to be driven to the average design torque until the bottom end of the torque anchor™ is at the design depth. Once the design torque at the design depth has been achieved, the installation motor shall be removed from the torque anchor™.

STEP 3 – Documentation:

The installer shall carefully monitor the torque applied to the anchor as it is installed. It is recommended that the installation torque be recorded at one foot intervals, but should never exceed every two feet. The data may be collected from electronic torsion monitoring equipment that has been calibrated to the installation motor being used. Installation torque may also be monitored by noting the differential pressure across the installation motor and determining the torque from the manufacturer's published torque curves.

At the conclusion of the installation, the raw field data shall be converted into an installation report that includes the location of each placement, the installation depth, installation torque readings at intervals and the averaged installation torque over the final three feet.

STEP 4 – Torque Anchor™ Termination:

- **Pile Cap or Bracket** – The pile cap, slab pier bracket, utility bracket, or porch bracket shall be installed by placing the appropriate sleeve over the torque anchor™ shaft. If the foundation will be subjected to uplift, the pile cap shall be bolted to the torque anchor shaft using bolt(s) and nut(s) supplied by the manufacturer having the same diameter and strength rating as used to couple the pile sections.
- **Transition** – The transition is sometimes used for equipment anchorage. The transition shall be bolted to the end of the torque anchor™ using the hardware supplied by the manufacturer. All-thread bar shall be attached between the transition and the equipment base. If required, the installer may place a center-hole ram over the continuously threaded bar to preload pile in tension as specified. The mounting nuts shall then be tightened securely to maintain the preload. In less critical applications the wall plate nuts may be tightened to a torque specified by the engineer or owner.

STEP 5 – Clean up:

Remove all scrap and other construction debris from the site. Remove all tools and equipment, clean them and store them. Any disturbed soils in the area of work shall be restored to the dimensions and condition specified by the engineer and/or owner. Dispose of all construction debris in a safe and legal manner.

End Procedure

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TORQUE ANCHOR™ INSTALLATION RECORD

Job Name:		Date:	
Job Address:		Placement Number: (Show On Sketch)	
Installing Crew:			
Torque Motor Make:	Model No:	Torque Conversion: "K" =	Maximum Motor Output: ft-lb
Press. Gauge Make: Max psi =		Strain Ga. Make: Max. Torque =	
Motor Back Pressure = psi	Machine Motor is Mounted to:		
ECP Torque Anchor™ Lead Designation:		Plate Sizes: 1. 2. 3. 4. 5. Shaft Size: ☐ Sq. ☐ Tubular	

Depth From Grade To Tip (ft)	Δ Pressure (psi)	Torque (ft-lb)	Depth From Grade To Tip (ft)	Δ Pressure (psi)	Torque (ft-lb)
1			21		
2			22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

NOTES:

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Many projects require field testing to verify capacity, in other cases a field test can provide valuable information. Not only will the load test verify that the anchor or pile has achieved the capacity requirement, a field load test on the job site can provide a precise *Soil Efficiency Factor*, "k", for the particular shaft configuration being installed at this specific site.

In the utility industry, guy anchors do not have to meet such stringent requirements as permanent structural supports. In general, the amount of creep allowed in guy wire applications is typically four to six inches. When testing support for permanent structures, a factor of safety of 2.0 is most commonly accepted by engineers for building foundations, structural supports and other permanent anchorages such as retaining walls. The testing procedures are the same, whether the maximum movement of the anchor of four inches is allowed for guy applications or the ECP recommended allowable maximum of one inch of movement for permanent structural support applications.

In this section the test procedures closely conform to ASTM D1143 and D3689 specifications.

It is recommended that any field load test for compressive bearing or tension anchor resistance be conducted under the supervision of a Registered Professional Engineer.

The increments and failure criteria provided below in our *"Basic Procedure for Quick Tests"* outlines are conservative and designed for tests on supports for permanent buildings and retaining walls.

When determining acceptable criteria for guy wire anchorage or for other temporary anchorages, the failure criterion could differ from the test procedures presented here because significantly more creep is usually acceptable in guy anchor applications. For this reason, the engineer in charge should be consulted to modify the test procedure, the load increments, time intervals, measurement procedures, and the acceptable ultimate deflection that is consistent with the specific project and load conditions. If the result of load testing suggests less than the ultimate load requirement has been achieved, the responsible engineer may choose to adjust the product spacing and/or increase the depth of anchor installation and/or modify the projected helical plate area on the shaft in order to achieve a higher capacity and/or the desired factor of safety and acceptable shaft deflection.

The first procedural outline is based closely on the ASTM D1143 and D3689 testing procedures. The "Quick Test" procedure outlined below will more quickly produce an estimate of actual anchor performance on the job site. This load test will provide a more accurate ultimate load capacity than by relying only upon the *Soil Efficiency Factor*, "k" of the shaft as it penetrates the soil.

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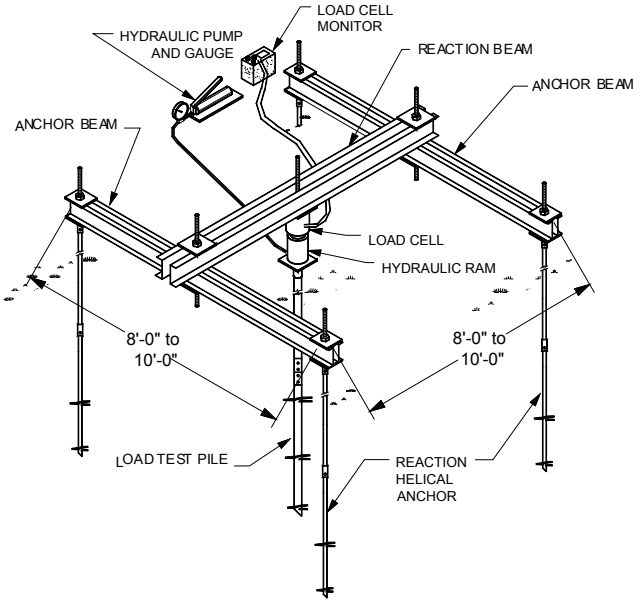
Basic Procedure for Quick Tension or Compression Tests

1. Determine the depth to the target stratum of soil from the geotechnical site investigation report that includes boring logs. Use this data to select a pile design capacity, ultimate capacity and estimate the installation torque at the target stratum and depth.
2. Set the spacing and install the four reaction piles at the test site. The recommended spacing between the test pile and the reaction piles is 5D where D = diameter of the largest helical plate.
3. Install the test helical product pile at the center between the reaction piles to the target depth and torque resistance.
4. Mount the two anchor beams on the four reaction piles and the reaction beam between the anchor beams and level.
5. Install a load cell (or certified pressure gauge) and hydraulic ram. The center-hole load ram must be mounted below the reaction beam for a bearing (compression) test and above the reaction beam for an anchor (tension) test.
6. Set the deflection measuring devices. Deflection measuring devices can include dial gauges (accuracy to 0.001") with minimum travel of one inch greater than the acceptable deflection mounted on a reference beam, a transit level surveying system, or other types of devices as may be specified by the Engineer.



7. Apply a small seating/alignment load, usually 5% of the ultimate load. Hold the seating load constant for a minimum of four minutes or until no further displacement is measured.
8. Set the deflection measuring device(s) to zero in preparation to starting the test.
9. Apply the first load increment of 5% of the ultimate load and hold that load constant for a minimum of four minutes to a maximum of 15 minutes. Monitor the incremental deflection (Δd) at intervals of 30 sec., 1, 2, and 4 minutes (per the "quick" test procedure of ASTM) and at longer intervals of 8 and 15 minutes when permitted. The monitoring may be stopped after 4 or 15 minutes as long as the rate of deflection is less than 0.002" per minute. If Δd (at 15 minutes) < 0.330", proceed to the next 5% load increment and repeat Step 9 until the ultimate load is reached or failure occurs by excessive deflection (vertical deformation).
10. Once the maximum loading condition is reached, unloading commences with two to five unloading decrements that are approximately equal. Hold each decrement for a minimum of four minutes to a maximum of 15 minutes recording the movement at each decrement. A frequently used failure criteria for permanent support of physical structures is "d" > 1.0" to define the ultimate acceptable load with a permanent deflection of "d" < 0.5" after unloading.

A failure criterion is often different than outlined in this typical procedure. The failure criteria should be reviewed and established by the project engineer <u>prior to testing</u>. He can provide project specific test acceptance conditions for the installation. Acceptance criteria are sometimes quite different for applications such as guy wire anchorage and for temporary tension anchors. Discuss test procedures with the Engineer of Record on the project.

A plot of load versus pile deflection "d" is often prepared after testing to determine the acceptable ultimate and working load capacities of the anchor, and for review of the actual performance of the helical pile or anchor in the soil under changing load conditions.

End Test Procedure

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FIELD LOAD TEST REPORT

PROJECT DATA	Load Test Log No. of	Date:	Zip Code:
	Project No.	Address:	
	Project Name:		
	Load Type: (Compression, Tension or Lateral)		
	Project Ultimate Load:	Project Working Load:	
PRODUCT TESTED	Helical Product No:	Shaft Size:	
	Part No.	Part No.	
	Part No.	Part No.	
LOAD TEST EQUIPMENT INFORMATION	Load Test Cylinder Capacity:	Effective Cylinder Area:	
	Manufacturer:	Cylinder Part Number:	

Test Load Increment Number	Load Force (lbs)	Hydr. Press. (psi)	Load Cell Reading	Initial Dial Reading	Instrument Reading or Dial Gauge Reading (.001 in.)					
					30 sec.	1 min.	2 min.	4 min.	8 min.	15 min.
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										

FAILURE LOAD lbs.	**MODE OF FAILURE:**
COMMENTS:	

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Chapter 3

ECP Helical Torque Anchors™ Design Examples

- **Heavy Weight New Construction**
- **Light Weight New Construction**
- **Basement Wall Tieback Anchors**
- **Retaining Wall Tieback Anchors**
- **Foundation Restoration**
- **Motor Output Torque**
- **Ultimate Capacity from Field Data**

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Design Example 1 – Heavy Weight New Construction – Cohesionless Soil

Structural Details:

- New Building – 2 story house with basement
- Estimated weight 3,700 lb/ft
- Working load on foundation piles – 30,000 lb
- Top of pile to be 12" above the soil surface
- Soil data:
  6 feet of sandy clay fill (CL), stiff
  Density = 110 pcf
  30 feet of medium grained, well graded sand (SW), medium dense, SPT "N" = 22
  Density = 120 pcf $\phi = 34^0$
  Water table = 14 ft
  Recommended target depth = 18 ft.

Torque Anchor™ Design:

1. Select the proper capacity equation and collect the known information.

Because the soil on the site is cohesionless, Equation 1b from Chapter 1 is used:

$\mathbf{P_u = \Sigma A_H (q\ N_q)}$ Where:

P_w = 30,000 lb
FS = Factor of Safety = 2.0

$\mathbf{P_u} = P_w$ x FS = 30,000 lb x 2.0 = **60,000 lb**.

$\mathbf{h_{mid} = 18\ ft}$.

(Choose the target depth to be 18 ft. This is the measurement from the surface to midway between the helical plates.)

$q = \gamma \times h_{mid}$

$\mathbf{q}$ = (110 lb/ft^3 x 6 ft) + (120 lb/ft^3 x 8 ft) + (120 – 62) lb/ft^3 x 4 ft) = **1,852 lb/ft^2**

$\mathbf{N_q = 24}$ "N" = 22 (Chapter 1 - Table 7)

Use Equation 1b to solve for the helical plate area that is needed.

$\mathbf{\Sigma A_H = P_u / (q\ N_q)}$

$\mathbf{\Sigma A_H =}$ 60,000 lb / 1,852 lb/ft^2 x 24

$\mathbf{\Sigma A_H = 1.35\ ft^2}$

2. Select the ECP Helical Torque Anchor™ suitable to support the load.

Referring to Chapter 1, Table 2 the 2-7/8" diameter x 0.262 wall thickness tubular pile shaft is selected as most economical for this application. Our project requires 60,000 pounds of compressive strength. The selected pile shaft has a *Compressive Load Limit* of 100,000 pounds and a *Useable Torsional Strength* of 9,500 ft-lbs.

Referring to Chapter 1, Table 10 the combination of helical plates is selected from the row opposite the 2-7/8" shaft size. At least 1.35 ft^2 of bearing area is needed to support an ultimate capacity of 60,000 pounds. The data

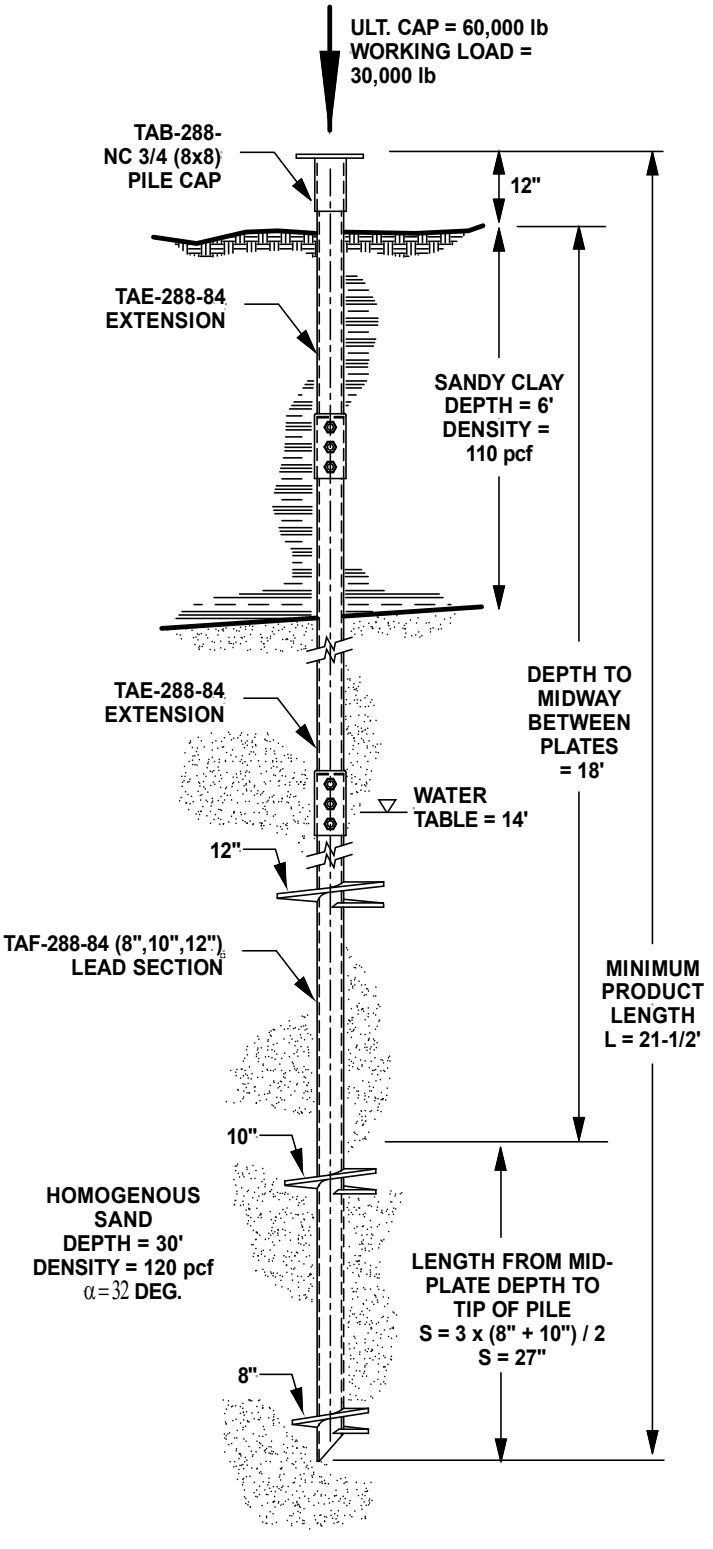

Figure 7. Design Example 1 & 2

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from the 2-7/8" diameter shaft on Table 10 in Chapter 1 is reproduce here:

6" Dia. = 0.151 ft^2
8" Dia. = **0.304** ft^2
10" Dia. = **0.500** ft^2
12" Dia. = **0.740** ft^2
14" Dia. = 1.024 ft^2

Select the combination of 8", 10", and 12" diameter plates on the 2-7/8" diameter tubular shaft.

$\mathbf{\Sigma A_H}$ = 0.304 + 0.500 + 0.740 = **1.544 ft^2**

$\mathbf{\Sigma A_H}$ = **1.54 ft^2** > 1.35 ft^2

This plate combination provides a total area of 1.54 ft^2, which exceeds the required plate area of 1.35 ft^2, arrived at from Equation 2b.

Designation for the selected Torque Anchor™ configuration is found in the product list on Page 7. The product selected is:

TAF-288-84 08-10-12

3. Installation Torque: Equation 2 in Chapter 1 calculates the estimated installation torque.

Equation 2: $T = P_u / k$, Where,

P_u = 60,000 lb. (30,000 Working Load x 2.0)
K = 8.5 (Chapter 1 - Table 12)

T = 60,000 lb / 8.5 ft^{-1}

T = 7,100 ft-lb

4. Torque Anchor™ Capacity Verification: A review of Table 2 in Chapter 1 indicates that the 2-7/8" diameter Torque Anchor™ has a *Useable Torsional Strength* of 9,500 ft-lb. The torque requirement of 7,500 ft-lb is 21% below the torsional limit of the shaft. The selection should work for this application based upon the soil report stating that the soil is sandy clay fill and homogenous sand with no mention of rocks, debris or other obstructions. A review of Table 11 in Chapter 1 shows that three 3/8" thick helical plates have a mechanical ultimate capacity of 120,000 pounds (40,000 lb x 3), which is double our requirement for this installation, so the mechanical capacity of the pile assembly exceeds the project requirements.

5. Installed Product Length. The installed length required to accomplish this design is a summation of all the lengths previously provided and determined.

A. The pile cap is placed **1 ft.** above grade level
B. h_{mid} = **18 ft.**
C. Length from mid-plate to pile tip
(Recall that the helical plates are spaced at three times the diameter of the nearest lower plate.)

h_{tip} = [(3 x 8" dia)+(3 x 10" dia)]/2 = 27"

h_{tip} = 2-1/2 ft (Round up to 30".)

L = 1 ft + 18 ft + 2-1/2 ft

L = 21-1/2 feet

6. Torque Anchor™ Specifications:
The specified Torque Anchor™ assembly will consist of the following:

- **TAF-288-84 08-10-12** This is a 2-7/8" diameter tubular product, having a standard length of 7 feet long, with an 8", a 10", and a 12" diameter plates that are 3/8" thick,
- **TAE-288-84** Extension, which is 7 feet long and includes coupling hardware. The coupling overlaps the previous section by 6 inches, which provides an effective length of the extension section at 6-1/2 feet. – Two extension sections are required
- **TAE-288-60** Extension, which is 5 feet long with coupling hardware. The coupling overlaps the previous section by 6 inches, which provides an effective extension length of 4-1/2 feet. – (One extension may be required.)
- **TAB-288 NC** Pile Cap that fits over the 2-7/8" diameter tubular shaft and has a 3/4" x 8" x 8" bearing plate.

The total length of the assembled products from the list is actually 24-1/2 feet long. The Torque Anchors™ shall be installed to minimum depth of 21-1/2 feet at the locations designated on the plan and must develop a sufficient compressive strength as determined by the minimum average installation torque of 7,100 ft-lb at this specified target depth or lower.

End Design Example 1

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Design Example 1A – Heavy Weight New Construction – "Quick and Rough" Method

Design Details:

- Compressive Service Load = 30,000 lbs at each pile. (See Figure 7 above.)
- The soil information about the site indicated 6 feet of stiff sandy clay fill (CL) followed by 30 feet medium dense sand (SP)

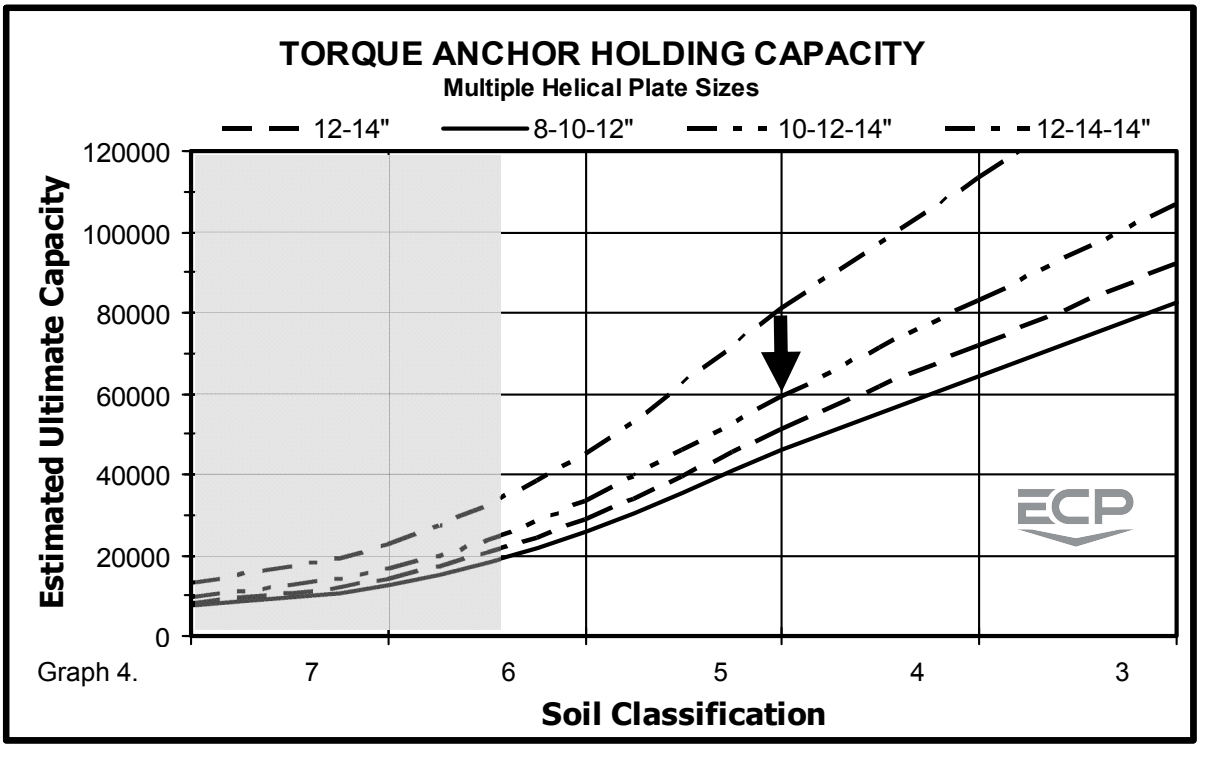
ECP Torque Anchor™ Design: The soil data provides only a rough description of the soil on the site with no SPT, "N", values or any indication of water table. The quick estimating method for designing the compression piles to support the structure is used. The thorough analysis for this project using the bearing capacity equations was demonstrated in Design Example 1 above. Comparison between the results of the two methods will be discussed.

1. Determine the Soil Class. Referring to the *Soil Classification Table* (Chapter 1 - Table 9) a Soil Class between 4 and 5 is selected based upon the description of the soil.

2. Ultimate Helical Pile Capacity. The engineer provided the Service Load (or working load) on this project based upon his knowledge of the calculated structural loading. Because the pile must have the capability to support more than just the service capacity, a Factor of Safety must be added to the Service Load to obtain the Ultimate Capacity of the pile design. In this case, a factor of safety of 2.0 is used to arrive at 60,000 pounds per pile ultimate capacity.

3. Select the proper compression pile from the estimated capacity graphs. Referring to Graph 4 from Chapter 1 (reproduced below), notice that the capacity line for a Torque Anchor™ with 10", 12" and 14" diameter helical plates attached crosses between Soil Class 4 & 5 at 60,000 pounds. The 10", 12" and 14" diameter plate configuration is selected for the design.

4. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 in Chapter 1 and select the 2-7/8 inch diameter tubular shaft that has sufficient capacity to support the load, and has sufficient torsional shaft strength for installation. The required ultimate capacity for each pile is 60,000 lbs. The 2-7/8 inch tubular product, with 0.262 inch wall thickness, has an *Axial Compressive Load Limit* rating of 100,000 pounds and a *Practical Load Limit based on Torsional Strength* of 80,000 pounds assuming a *Useable Torsional Strength* of 9,500 ft-lbs. The 2-7/8 inch diameter, 0.262 inch wall helical pile provides suitable torsional capacity and a sufficient practical load limit to exceed the ultimate load requirement of 60,000 pounds. The choice is verified.



Graph 4.

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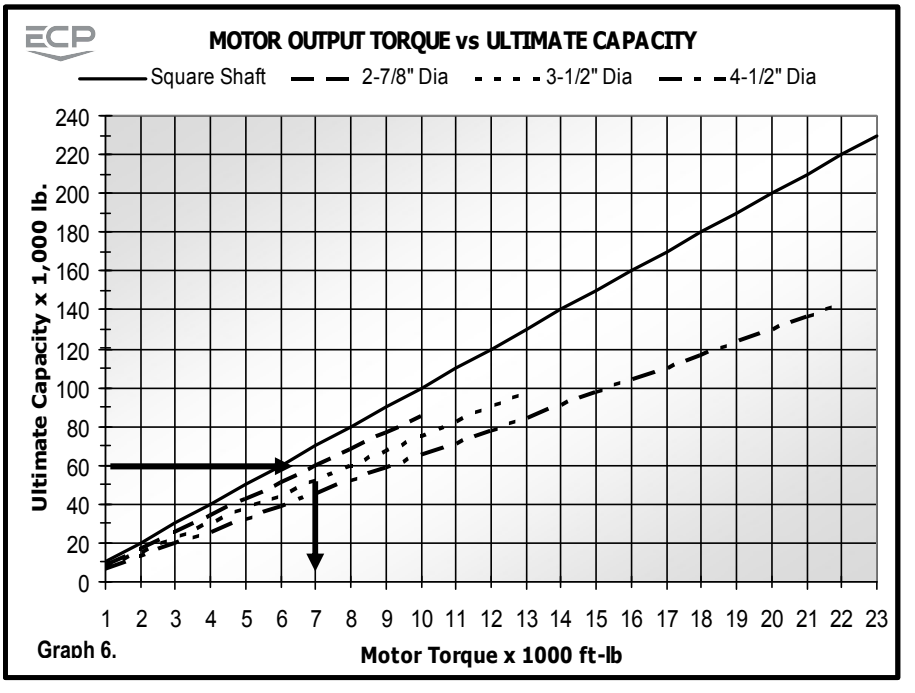
5. Installation Torque. Use Graph 6 from Chapter 2 or Equation 2 from Chapter 1 to determine the installation torque requirement for these piles.

Find a capacity of 60,000 pounds on the left side of Graph 6 and move horizontally to where the graph line for 2-7/8 inch diameter shafts intersects with 60,000 pounds. Read down to determine that the motor torque requirement is 7,000 ft-lb.

T = 7,000 ft-lb, min.



Graph 6.

Calculation from Equation 2 shows a comparison of results between the formula and the graph.

Equation 2: $\mathbf{T = P_u / k}$, Where,

P_u = 60,000 lb k = 8.5 (Table 12)

$T = 60{,}000 \text{ lb} / 8.5 \text{ ft}^{-1} = 7{,}059$ ft-lb

T = 7,100 ft-lb (Not a significant difference)

6. <u>Minimum</u> Embedment Depth. The minimum depth requirement from the surface to the shallowest plate on the pile must be at least six times the diameter of the 14" dia. top helical plate. (Chapter 1, Page 16)

D = 6 x (14 in / 12 in/ft) = 7 feet

D = Minimum Vertical Depth = 7 feet.

7. <u>Minimum</u> Required Shaft Length. Helical plates are spaced at three times the diameter of the next lower plate. The selected configuration was 10-12-14. The additional shaft length from the plate closest to the surface to the pile tip must be determined and added to minimum vertical depth just determined.

L = 7' + L_{tip} (Length from 10" to the 12" plates) + (Length from 12" to the 14" plate)

L = 7' + (3 x 10" Dia)/12" + (3 x 12" Dia)/12"

L = 7' + 2.5'+ 3' = 12-1/2 ft + 1 ft above grade provides the minimum shaft length

<u>Minimum</u> Shaft Length = 13-1/2 ft

The least amount of shaft needed for this project would be a 7 foot lead section plus a 7 foot extension (with a coupled length of 6-1/2 feet) provides 13-1/2 feet total.

8. Torque Anchor™ Specifications. The minimum pile assembly shall consist of:

- **TAF-288-84 10-12-14** – 2-7/8" diameter tubular shaft with 0.262" wall thickness that has a 10", a 12" and a 14" diameter plate on the 7'-0" long shaft,
- **TAE-288-84** extension – 7' extension & hardware. (Additional extensions will likely be needed to reach required shaft torsion.)

End of Example 1A

Review of Results of Example 1 & 1A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested a larger pile than predicted the calculations. The "Quick and Rough" system was designed to be conservative and this example demonstrates this. It is likely that the pile design of Example 1A will reach the required shaft torque at more shallow depth than the 8-10-12 pile. The pile must terminate at least 12-1/2 feet below grade to accurately predict capacity. <u>Termination at this shallow depth may not be acceptable to the engineer because the water table located at 14 feet below grade</u>. (Not mentioned in the soil data in this example.) This type of problem can appear when using incomplete soil data and *Torque Anchor™ Capacity Graphs* to obtain a "Quick and Rough" design.

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Design Example 1B – Heavy Weight New Construction – Weak Soil

In this variation, the same construction load and soil conditions prevail as stated in Design Example 1 with the exception that five feet of very weak soil now exists directly below the surface.

Additional Design Details:

- The soil data revealed a least five feet of very loose sand fill and very soft clay organic soil near the surface.
- Standard Penetration Test values for this weak layer were, "N" = 1 to 3 blows per foot - Soil Class = 8
- Below 5 feet the soil profile is the same as shown in Design Example 1.

ECP Torque Anchor™ Design: The soil data here suggests that below the initial five feet of very weak soil, the soil profile is similar to the soil in Design Example 1. Referring to Example 1, it can be recalled that the pile configuration required supporting the 60,000 pound ultimate load on pile using an 8-10-12 inch diameter plate configuration. The 2-7/8 inch diameter tubular shaft, with 0.262 inch wall thickness, had a sufficient *Axial Compressive Load Limit* to support the design load and sufficient *Useable Torsional Strength* to install the pile under the soil conditions represented in Design Example 1.

Knowing that there exists a layer of extremely weak (Class 8) soil near the surface on this site is important information because helical piles have slender shafts and require sufficient lateral soil support against the shaft to prevent shaft buckling under full load.

1. Determine the Buckling Strength. Table 2 in Chapter 1 lists the *Axial Compression Load Limits* for helical pile shafts when the shafts are installed into soil that provides sufficient lateral support along the pile shaft. Testing has suggested that shaft buckling is not an issue when the soil has a SPT value, "N" $\geq$ 5 blows per foot for solid square shafts and "N" $\geq$ 4 blows per foot for tubular shafts.

In this design example there exists a five foot layer of very weak Class 8 soil consisting of loose sand and soft organic clay located just under the surface. These very weak soils overlay inorganic clay that is able to support the required load where the soil will provide sufficient lateral shaft support. However, an *Axial Compressive Load Limit* of 100,000 pounds shown in Table 2 for a 2-7/8 inch diameter with 0.262 inch wall tubular shaft is not valid when this shaft passes through the Class 8 soil with SPT values reported to be between 1 and 3 blows per foot.

Instead of using Table 2 from Chapter 1 for the compressive load limit on the shaft, one must understand that the upper layer of soil is not able to provide sufficient lateral support to the shaft to prevent bucking. Table 15 in Chapter 1 *Conservative Critical Buckling Load Estimates* (reproduced below) demonstrates this quite clearly for various soil strengths and types. Referring to Table 15, it can be seen that the estimated buckling strength for the 2-7/8 inch diameter, 0.262 inch wall helical Torque Anchor™ shaft when it passes through soil consisting of very loose sand fill and soft organic clay having SPT values that range from "N" = 1 to 3 blows per foot is only 48,000 pounds.

This soil is not capable of lateral shaft support for 60,000 pound ultimate compressive load without concern for the shaft buckling within the weak upper level soils.

Table 15 Conservative Critical Buckling Load Estimates

Shaft Size	Uniform Soil Condition			
	Organics N ≤ 1	**Very Soft Clay N = 1 - 2**	Soft Clay N = 2 - 4	Loose Sand N = 2 - 4
1-1/2" Sq	26,000 lb	29,000 lb	33,000 lb	37,000 lb
1-3/4" Sq.	39,000 lb	43,000 lb	48,000 lb	55,000 lb
2-1/4" Sq.	74,000 lb	81,000 lb	90,000 lb	104,000 lb
2-7/8" Dia x 0.203"	36,000 lb	44,000 lb	62,000 lb	51,000 lb
~~**2-7/8" Dia x 0.262"**~~	39,000 lb	~~**48,000 lb**~~	69,000 lb	56,000 lb
3-1/2" Dia x 0.300"	63,000 lb	**78,000 lb**	110,000 lb	90,000 lb
4-1/2" Dia x 0.337"	113,000 lb	139,000 lb	160,000 lb	160,000 lb

2. Select a Pile Shaft with Suitable Buckling Strength. The axial ultimate compressive capacity requirement for this project is 60,000

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pounds on pile shaft. The selected shaft from Design Example 1 must be changed to a stiffer shaft to be able to successfully pass through the very week upper soil strata without buckling. A larger diameter tubular shaft is able to offer more shaft stiffness called Moment of Inertia or resistance to buckling. Referring once again to Table 15 (above); notice the row labeled "3-1/2 inch dia. x 0.300" shows a conservative estimated buckling load capacity of 78,000 pounds for the larger diameter shaft. Because there exists very weak soil near the surface in this example, the pile shaft diameter must be increased to provide resistance to shaft buckling when the fully loaded pile passes through these weak soils.

3. Torque Anchor™ Specifications. The Torque Anchor™ plate configuration remains as originally determined in Design Example 1 to support the structural load, but the shaft diameter must be increased to the 3-1/2 inch diameter, 0.300 inch wall tubular shaft for increased buckling strength:

- **TAF-350-84 08-10-12** Lead Section
- **TAE-350-84** Extension Section (2 required)
- **TAE-350-60** Extension Section
- **TAB-350 NC** Pile Cap that fits over the 3-1/2" tubular shaft and has a 3/4" x 8" x 8" bearing plate.

4. Installation Torque. The larger diameter tubular shaft now required passes through the soil less efficiently. This soil friction effect was fully discussed at the beginning of Chapter 2. As a result, when the design requires a change in shaft size, the installation torque requirement must be recalculated and will be higher for larger diameter shafts.

A check of Table 12 in Chapter 1 shows that the 3-1/2 inch diameter shaft has a recommended efficiency factor, "k" = 7-1/2 as compared to "k" = 8-1/2 that was used to estimate installation shaft torsion requirement for the 2-7/8 inch diameter tubular shaft.

Use Equation 4 introduced in Chapter 1 and repeated in Chapter 2 to calculate the new installation torque requirement for the larger diameter pile shaft.

Equation 5: $\mathbf{T = P_u / k}$, Where,
P_u = 60,000 lb
k = 7.5 (Table 12 – Chapter 1 & 2)

$T = 60{,}000 \text{ lb} / 7.5 \text{ ft}^{-1} = 8{,}000 \text{ ft-lb}$

T = 8,000 ft-lb, minimum

Earth Contact Products recommend that a Registered Professional Engineer conduct the evaluation and design of Helical Torque Anchors™ where shaft buckling may occur due to the shaft being installed through weak soil or in cases where the shaft is fully exposed without lateral shaft support.

End of Example 1B

Review of Results of Example 1 & 1B

It is very important to remember that buckling is an issue when a pile shaft passes through weak soils anywhere along the length of the shaft. The key numbers to remember here when looking at soil data are the Standard Penetration Test, "N", values throughout the depth of the borings. Watch for soil strata that are weaker than "N" < 4 blows per foot for solid square shaft installations and "N" < 5 blows per foot for tubular shafts. When such weak soils may be encountered, a check of the buckling strength of the selected shaft diameter is necessary.

Whenever the shaft must extend above ground in the air or in water without any later support at all, On the last page of Chapter 1, Graph 8 is provided to give ultimate load estimates for various shaft configurations relative to the length of exposed and unsupported column height.

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Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007. Fax at 913 393-0008.

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Design Example 2 – Light Weight New Construction – Cohesive Soil

Structural Details:

- New building – single story brick veneer house on monolithic concrete slab on grade
- The estimated weight is 1,269 lb/lineal ft on the 18" tall steel reinforced perimeter beam
- The client wants Torque Anchors™ on the perimeter of the structure because of lot fill.
- Top of shaft to be one foot below soil surface
- Soil data:
  4 feet of poorly compacted fill – "N" = 5
  6 feet of silty clay (CH) – "N" = 5 to 7
  15 feet of very stiff clay (CL) –
  "N"= 25 to 30 blows per foot.

Torque Anchor™ Design:

1. Select suitable pile spacing and working load from the description of the foundation beam. Use Equation 3 from Chapter 1 to determine the working load on the helical pile. From Graph 2 - Chapter 6, for an 18" beam choose "X" = 7 ft.

Equation 3: P_u = ("X") x (w) x (FS):

Where,
P_u = Ultimate Capacity of Torque Anchor™ (lb)
w = Foundation Load (lb/ft)
= 1,269 lb/lineal foot
FS = 2.0
"X" = Product Spacing = 7 ft

$\mathbf{P_U}$ = 1,269 lb/ft x 7 ft x 2.0

$\mathbf{P_U}$ = 17,766 lb (Use 18,000 lb.)

$\mathbf{P_U}$ = **18,000 lb**

2. Select the proper ultimate capacity equation and collect the known information. Because the soil on the site is cohesive (clay), Equation 1a from Chapter 1 is used:

Equation 1a: $\Sigma A_H = P_u / (9c)$ Where:

P_u = 18,000 lb
c = 3,400 lb/ft^2 (Table 5 – Assume "N" = 27 bpf)

$\mathbf{\Sigma A_H}$ = P_u / (9 x 3,400)

$\mathbf{\Sigma A_H}$ = 18,000 lb / 30,600 lb/ft^2

$\mathbf{\Sigma A_H = 0.59\ ft^2}$

3. Select the ECP Helical Torque Anchor™ suitable to support the load. The requirement states an ultimate compressive capacity of 18,000 lb. Referring to Table 2 in Chapter 1 the 1-1/2" solid square pile shaft is an economical choice because it has an *Axial Compressive Load Limit* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

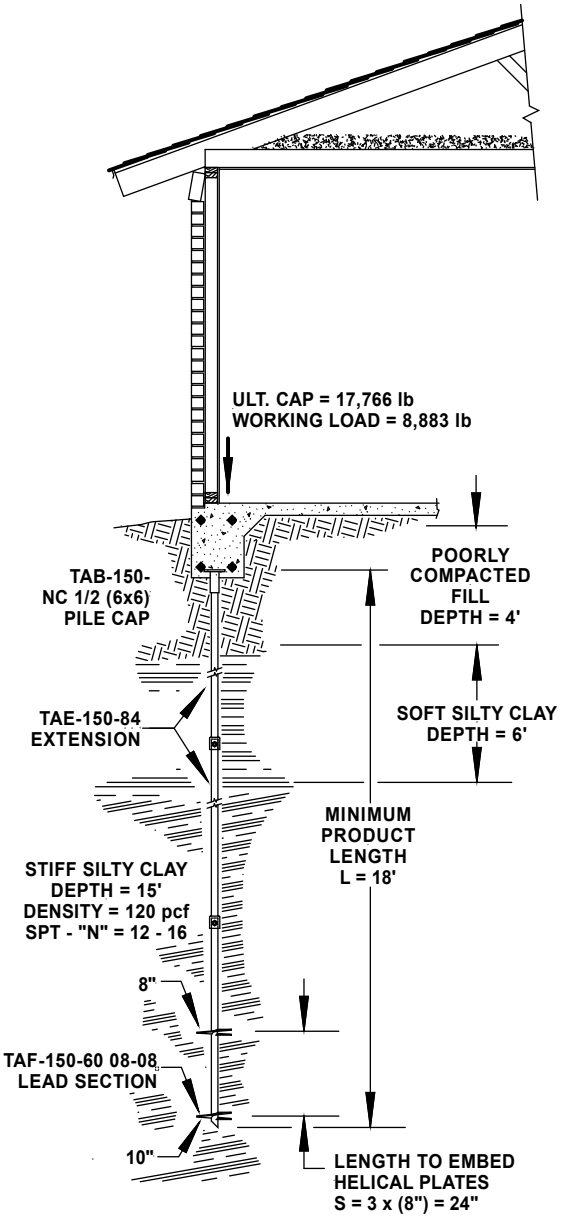

Figure 8. Design Example 2

Referring to Table 10 – Chapter 1, select a combination of plates from the row opposite the 1-1/2" square shaft size. At least 0.59 ft^2 of bearing area is required:

6" Dia. = 0.181 ft^2
8" Dia. = **0.333** ft^2
10" Dia. = 0.530 ft^2
12" Dia. = 0.770 ft^2

The combination of 8 inch diameter plates on the 1-1/2" solid square shaft is selected.

$\mathbf{\Sigma A_H}$ = 0.333 + 0.333 = **0.67 ft^2** > 0.59 ft^2 - O.K.

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This plate combination provides a total area of 0.67 ft^2, which exceeds the required 0.59 ft^2. As an alternate, a single 12" diameter plate could be selected with a projected area of 0.77 ft^2.

The product designation for the standard length Torque Anchor™ product is selected from the standard product listing on Page 5:

TAF-150-60 08-08

4. Installation Torque: Equation 2 in Chapter 1 gives an estimation of the required installation shaft torsion. It is determined as follows:

Equation 2: $T = P_u / k$

Where,

P_u = 18,000 lb

k = 10 (Table 12)

T = 18,000 lb / 10 ft^{-1}

T = 1,800 ft-lb

5. Torque Anchor™ Capacity Verification: A review of Table 2 in Chapter 1 indicates that the 1-1/2" solid square bar Torque Anchor™ has a *Useable Torsional Strength* of 7,000 ft-lb, which is nearly four times the required installation torque. There was no mention of rocks, debris or other obstructions in the project information. This is excellent product for this project. Table 9 in Chapter 1 shows the *Ultimate Mechanical Helical Plate Capacity* of 80,000 pounds (40,000 lb x 2) for the two 3/8" thick helical plates. The mechanical capacity of the selected pile configuration is more than adequate.

6. Installed Product Length. The stiff silty clay has been targeted as the soil where the helical plates will be founded. A depth of 18 feet is selected to set the plates below the weaker soils. This places the plates within the middle of the very stiff clay stratum. The installed length required to accomplish this design depth is:

- The depth from the surface to bearing = 18 ft.
- The pile cap is specified at one foot below grade level = 18 ft – 1ft = **17 feet**

The distance to midway between the twin 8 inch plates is 1 ft. (8" x $3D_{8"}$ = 24 in/2 = 12 inches)

The minimum shaft length requirement is:

L = 17 ft + 1 ft = 18 ft

7. Torque Anchor™ Specifications: The Torque Anchor™ assembly is specified from the standard products listed near the beginning of Chapter 1:

- **TAF-150-60 08-08**, which is a 1-1/2" solid square bar product on a standard 5 foot long shaft, with twin 8 inch diameter 3/8" thick plates
- **TAE-150-84** Extension, which is 7 feet long, but the coupling overlaps 3 inches providing an effective length of 6'-9" The extension includes coupling hardware. Two extensions are required.
- **TAB-150 NC** Pile Cap that fits over the 1-1/2" square bar and has a 1/2" x 6" x 6" bearing plate.

The total length of the assembled products from above is exactly 18-1/2 feet long. Placements shall be 7 feet on center along the perimeter grade beam and must develop an average installation torque of 1,800 ft-lb or more at the target depth of 18 feet. It is recommended that additional extension be on hand in case the shaft torque requirement is not achieved at 18 feet.

End Design Example 2

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Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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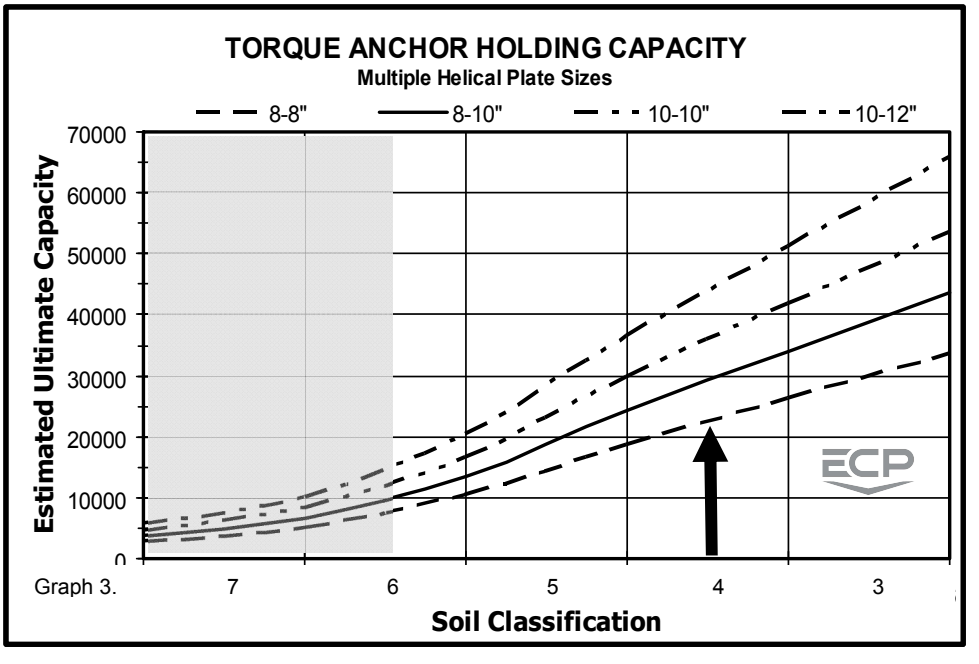
Design Example 2A – Light Weight New Construction – "Quick and Rough" Method

Design Details from Design Example 2:

- The ultimate capacity on each pile spaced at 7 feet on center is 18,000 pounds
- Top of shaft to be one foot below soil surface
- Soil data:
  4 feet of poorly compacted fill followed by 6 feet of silty clay (CH) over 15 feet of very stiff clay (CL)

ECP Torque Anchor™ Design: Because this is a compressive load application and there is some poorly compacted fill exists the selection of Soil Class must be conservative.

1. Determine the Soil Class.
Referring to the Soil Classification Table (Table 9 – Chapter 1) and noticing that the clay on the site is very stiff, Soil Class 4 is selected. The poorly compacted fill should not be a problem at this light loading as long as the helical plates are founded into the underlying very stiff clay.



Graph 3.

2. Select the proper compression pile configuration from the estimated capacity graphs. Referring to Graph 3 from Chapter 1 (reproduced right), notice that the capacity line for an anchor with two 8" diameter helical plates attached crosses the midpoint of Soil Class 4 at 22,000 lb. The 8" – 8" diameter plate configuration is selected for the design.

3. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 in Chapter 1 to find a shaft with a suitable *Axial Compression Load Limit* and sufficient *Useable Torsional Strength.* The 1-1/2 inch solid square shaft has an *Axial Compression Load Limit* rating of 70,000 pounds based upon an installation torsional limit of 7,000 ft-lbs. The selected pile shaft provides suitable *Useable Torsional Strength* and a sufficient practical load limit to exceed the ultimate job load requirement of 18,000 pounds. Table 9 in Chapter 1 shows the *Ultimate Mechanical Helical Plate Capacity* of 80,000 pounds (40,000 lb x 2) for the two 3/8" thick helical plates. The selected and verified pile configuration is TAF-150-60 08-08 and is smaller than recommended from the earlier calculations in Design Example 2.

4. Installation Torque. Use Graph 6 from Chapter 2, please see Graph 6 on next page (or Equation 2 from Chapter 1) to determine the installation torque requirement for these piles. The ultimate capacity requirement is 18,000 pounds. Find this value on the left side of Graph 6 and find the intersection of 18,000 pounds with the graph line for solid square shafts. Then read down to determine the motor torque requirement of 1,800 ft-lb.

T = 1,800 ft-lb, minimum

Calculating the installation torque from Equation 2: (shown here for comparison)

Equation 3: $\mathbf{T = P_u / k}$, Where,
P_u = 18,000 lb k = 10 (Table 12)
$T = 18{,}000 \text{ lb} / 10 \text{ ft}^{-1} = 1{,}800 \text{ ft-lb}$
T = 1,800 ft-lb, minimum – O.K.

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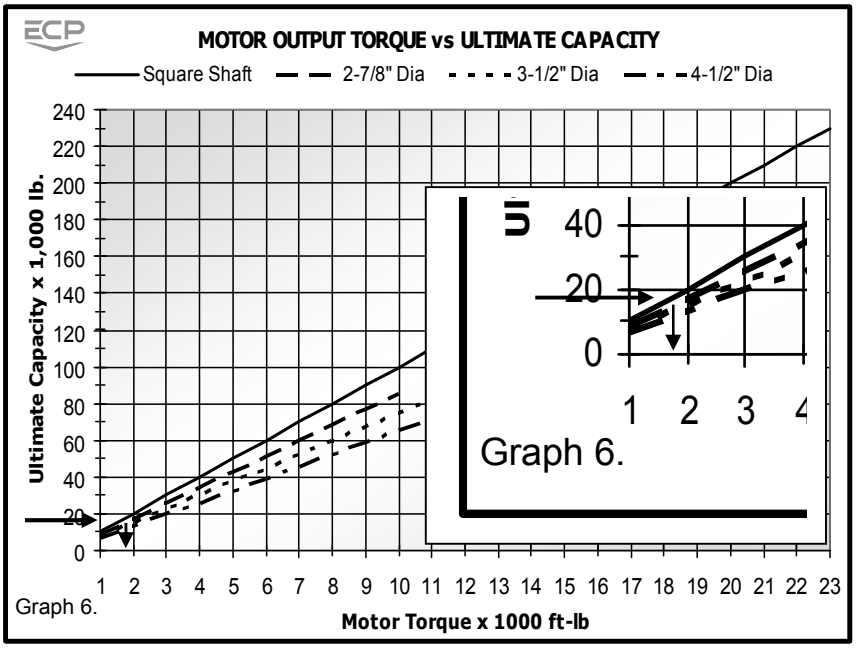
5. Minimum Embedment Depth. In Chapter 1, Page 16 of this manual, there is a discussion about helical products being deep foundation elements. The formulas presented herein are based upon "deep foundation theory". For the results of the calculations, tables and graphs to be accurate, there must be sufficient soil burden over the anchor or pile. Deep foundation theory dictates that the minimum depth from the surface to the shallowest plate must exceed six times the largest diameter.



Graph 6.

Minimum Embedment Depth:

$D = 6 \times d_{\text{largest plate.}} = 6 \times (8 \text{ in}/12 \text{ in}) =$ **4 ft***

*Notice: The soil information provided on this project stated at least 10 feet of soft soil existed below the surface before reaching stiff to very stiff clay. **The "Minimum Vertical Depth" for this design is invalid and the pile must be installed deeper than ten feet.**

D = Minimum Vertical Depth > 10 feet

6. Minimum Required Shaft Length. The shaft length between the two 8" plates must be determined and added to the 10 foot, minimum vertical depth. In addition, the engineer stated that the termination point for the pile caps shall be one foot below grade.

$L = 10' - 1' + (3D_{8"})/2 = 10$ ft

L = 10 ft*

The least amount of shaft required to exceed the minimum depth is a 5 foot lead and a 7 foot extension.

*Because the soil profile is known to be weak near the surface, a 10 foot long extension should be considered because it offers a depth of 15-3/4 feet (14-3/4 feet of shaft plus 1 ft depth to the pile cap. Additional extensions could be required if the torsion requirement of 1,800 ft-lb is not achieved between 10 ft and 15-3/4 ft depth.

7. Torque Anchor™ Selection:

- **TAF-150-60 08-08** – 1-1/2 inch solid square shaft that has two 8" diameter plate on the 5'-0" long shaft,
- **TAE-150-120** extension – 10' extension section & hardware, (9'-9" effective length). It recommended to have additional extensions on hand should the target shaft torsion not be achieved at 15-3/4 feet below grade.
- **TAB-150 NC** Pile Cap that fits over the 1-1/2" square bar and has a 1/2" x 6" x 6" bearing plate.

End of Example 2A

Review of Results of Example 2 & 2A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested the same pile design as determined by the calculated analysis. Therefore the TAF-150 08-08 is a valid design and should work well on this project. Recall that the calculated analysis used 18 feet dept to bearing.

* Example 2A, "Quick and Rough" method is not able to compensate for the fill soil near the surface. Recall that the graphs are based upon capacities of helical piles installed into ***homogeneous soil***, which means that the soil is consistent at all depths. Clearly this is not the case in this example because of the fill soil. A pile installation deeper than 15-3/4 feet might be required to support the load.

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Design Example 3 – Basement Wall Tieback Anchor -- Cohesive Soil

Structural Details:

- Cast concrete basement wall is 8 feet tall and 10 inches thick.
- Unknown soil backfill against the wall is 7 feet high
- The only soil information about the site is that there exists inorganic clay (CL), stiff to very stiff – 115 pcf

Torque Anchor™ Design: Because there is so little information about the soil on this project, the designer will have to make judgments about the conditions on the site.

1. Estimate the lateral soil force against the wall. Equation 5 presented in Chapter 1 is selected because hydrostatic pressure must be assumed as part of the reason for the damage to the wall.

$\mathbf{P_H = 45 \times (H^2)}$

Where, H = 7 ft

$P_H = 45 \times (49) = 2{,}205$

$\mathbf{P_H = 2{,}205}$ **lb/lineal foot**

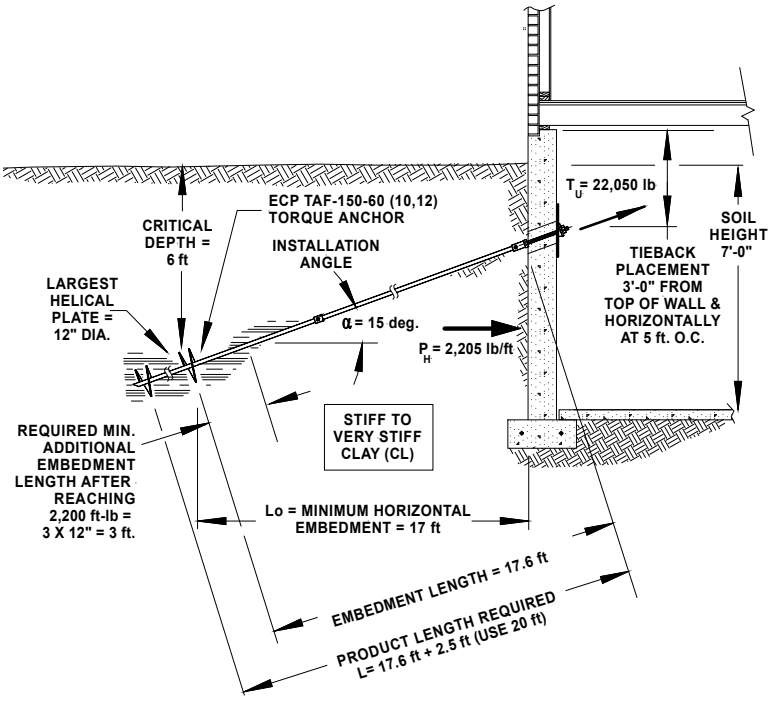

Figure 9. Design Example 3

2. Ultimate Tieback Capacity. Choose a Torque Anchor™ spacing of 5 ft on center as typical for a damaged basement wall of unknown construction. Use Equation 8 from Chapter 1 to determine the Ultimate Capacity on the Torque Anchor™.

Equation 8: $\mathbf{T_u = (P_H) \times (\text{“X”}) \times FS}$, Where:

T_u = Ultimate Tieback Capacity – lb
P_H = Horizontal Soil Force on Wall – lb/lin.ft
FS = Factor of Safety (Typically 2:1 permanent support and 1.5:1 for temporary support)
“X” = Center to Center Spacing of Tiebacks - ft

In this example, the ultimate capacity becomes:

$\mathbf{T_u} = 2{,}205 \text{ lb} \times 5 \text{ ft} \times 2$

$\mathbf{T_u = 22{,}050 \text{ lb}}$

3. Select the proper bearing capacity equation and collect the known information.

Because the soil on the site is cohesive, Equation 1a – Chapter 1 is used:

Equation 1a: $\mathbf{\Sigma A_H = T_u / (9c)}$, Where:

$\mathbf{T_u = 22{,}050 \text{ lb}}$
$\mathbf{c = 2{,}000 \text{ lb/ft}^2}$
(Table 5 - Chapter 1 – Stiff to Very Stiff Clay)

$\mathbf{\Sigma A_H} = T_u / (9 \times 2000 \text{ lb/ft}^2)$

$\mathbf{\Sigma A_H} = 22{,}050 \text{ lb} / 18{,}000 \text{ lb/ft}^2$

$\mathbf{\Sigma A_H = 1.23 \text{ ft}^2}$

4. Select the ECP Helical Torque Anchor™ configuration suitable to support the load.

Referring to Table 2 – Chapter 1 choose the 1-1/2” solid square pile shaft. An ultimate tensile strength for this job is 22,050 lb and the 1-1/2 inch solid square shaft an *Ultimate Limit Tension Strength* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

Referring to Table 10 – Chapter 1 (reproduced on next page), a combination of plates is selected from the projected plate areas in the row opposite the 1-1/2” solid square shaft size. At least 1.23 ft^2 of bearing area is needed:

6” Dia. = 0.181 ft^2 8” Dia. = 0.333 ft^2
10” Dia. = **0.530** ft^2 12” Dia. = **0.770** ft^2
14” Dia. = 1.053 ft^2

$\mathbf{\Sigma A} = 0.530 + 0.770 = \mathbf{1.30 \text{ ft}^2}$

The combination of 10” and 12” diameter plates on the 1-1/2” solid square shaft provides a total area of 1.30 ft^2, which exceeds our requirement of 1.23 ft^2.

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Table 10. Projected Areas* of Helical Torque Anchor™ Plates						
Helical Plate	6" Dia.	8" Dia.	10" Dia.	12" Dia.	14" Dia.	16" Dia.
Shaft	Projected Area – ft^2					
1-1/2" Sq.	0.181	0.333	0.530	0.770	1.053	1.381
1-3/4" Sq.	0.175	0.328	0.524	0.764	1.048	1.375
2-1/4" Sq.	0.161	0.314	0.510	0.750	1.034	1.361
2-7/8" Dia	0.151	0.304	0.500	0.740	1.024	1.351
3-1/2" Dia	0.130	0.282	0.478	0.719	1.002	1.329
4-1/2" Dia	0.086	0.239	0.435	0.675	0.959	1.286

* Projected area is the face area of the helical plate less the cross sectional area of the shaft.

The Torque Anchor™ tieback product designation **TAF-150-60 10-12** is selected from the Standard Product Tables near the beginning of Chapter 1. This anchor configuration will provide the 22,050 pound ultimate capacity required for tension support when spaced at 5 feet center to center along the wall.

5. Installation Torque. Use Equation 2 from Chapter 1, or use Graph 6 from Chapter 2 shown in the example above to calculate the installation torque requirement for this anchor.

Equation 2: $T = T_u / k$, Where,

T_u = 22,050 lb

k = 10 (Table 12, below from Chapters 1 & 2)

$T = 22{,}050 \text{ lb} / 10 \text{ ft}^{-1}$

T = 2,200 ft-lb

The torque must be developed for a long enough distance to insure that the helical plates are properly embedded to develop the required tension capacity. The torque requirement must be averaged over a distance of at least three times the diameter of the largest plate. The 2,200 ft-lbs must be continuous for a minimum distance of 3 feet (12" diameter plate x 3 dia.) before terminating the installation.

Table 12. Soil Efficiency Factor "k"		
Torque Anchor™ Type	Typically Encountered Range "k"	Suggested Average Value, "k"
1-1/2" Sq. Bar	9 - 11	10
1-3/4" Sq. Bar	9 - 11	10
2-1/4" Sq. Bar	10 - 12	11
2-7/8" Diameter	8 - 9	8-1/2
3-1/2" Diameter	7 - 8	7-1/2
4-1/2" Diameter	6 - 7	6-1/2

6. Minimum Horizontal Embedment: Determine the *Minimum Embedment Length* from Equation 9 in Chapter 1. (Also see Figure 3 – Chapter 1, which is reproduced on next page for reference.)

$L_0 = H + (10 \times d_{Largest})$ Where,

H = Height of Soil (7 ft)

$d_{Largest}$ = Largest Plate Dia. (12 in = 1 ft)

$L_0 = 7 \text{ ft} + (10 \times 1 \text{ ft})$

L_0 = 17 feet

Min. Horizontal Embedment = 17 feet

7. Calculate the Critical Depth:

Use 6 x $d_{Largest\ plate.}$ (Discussed Page 31)

6 x 1 (ft) = 6 feet (See Figure 3, below.)

Critical Depth = 6 feet.

8. Select Installation Angle and Determine Product Length. Position the anchors to penetrate the wall at two feet below the soil surface. **(Note: This is three feet from top of basement wall.)** From Step 7 it was determined that the Critical Depth, "D", of 6 feet is required, which means that the 12" diameter plate must terminate at least 4 feet lower than where the anchor shaft penetrated the wall. Select an installation angle of 15^0 and determine the minimum installed product length that will provide the additional 4 feet of soil depth required at the 12" plate to achieve critical depth.

This can be determined as follows:

$L_{15\ deg} = (4 \text{ ft} / \text{sine } 15^0)$

$L_{15\ deg} = 4 \text{ ft} / 0.259 =$ **15-1/2 ft**

The minimum distance from the wall to the 12" plate when installed at a 15^0 downward angle is 15-1/2 feet to insure meeting the critical depth requirement of 6 feet. Comparing the minimum horizontal embedment length of 17 feet from Step 6 to the 15-1/2 foot length required for obtaining Critical Depth at 15^0 installation angle; it is clear that 17 feet of horizontal length of embedment from the wall is the controlling distance. The additional length of shaft required to get to the 10 inch diameter plate to the required distance of 17 feet at a shaft installation angle of 15^0 downward must be calculated.

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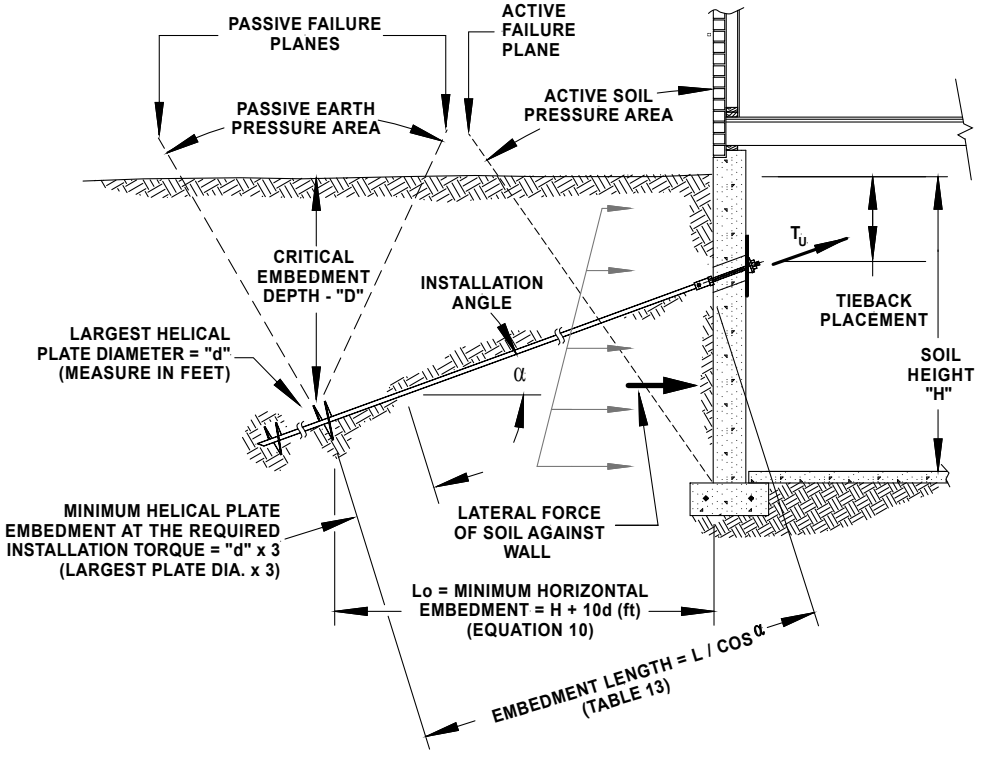

Figure 3. Elements of Tieback Design

Use the equation shown in Chapter 1 on Table 13 for a 15^0 downward angle.

$\mathbf{L_{15\ deg}}$ = [H + (10 $d_{largest}$)] x 1.035

$\mathbf{L_{15\ deg}}$ = [7 ft + (10 x 1 ft] x 1.035 = **17.6 feet**

Total Shaft Length Needed:

$\mathbf{L_{Total}} = \mathbf{L_{15}} + L_{Tip}$ (Where $L_{Tip} = 3D_{10"}$)

$\mathbf{L_{Total}}$ = 17.6 ft + (3 x 10")/12"

$\mathbf{L_{Total}}$ = 17.6 ft + 2.5 ft = **20.1 ft**

Use L_{Total} = 20 ft $\alpha = 15^0$

Specify required product length by selecting standard product assembled lengths exceeding 20' long.

8. Torque Anchor™ Specifications. The Torque Anchor™ assembly will consist of products selected from the Standard Product Selection near the beginning of Chapter 1.

- **TAF-150-60 10-12** -- 1-1/2" solid square bar with a 10" and a 12" diameter plate attached to a standard 5'-0" long shaft length.
- **TAE-150-60** extension – 5' extension bar & hardware are specified for ease of installation in the basement. (4'-9" effective length). Three extensions are required. (Possibly four extensions could be needed for if insufficient shaft torsion is measured at 20 ft.)
- **TAT-150** – Light Duty Transition that connects from 1-1/2" square bar to a 22" length of continuous threaded rod, with hardware.
- **PA-SWP** – Stamped steel wall plate that measures 11" x 16"

The length of all of the Torque Anchor™ shafts plus the threaded bar that penetrates the wall is 19'-3" + 20" = 20'–11". The anchors shall mount along the wall on 5 feet on center at 3 feet from the top of the basement wall. (Two feet below soil level) The anchors are angled down at 15^0. The tieback must be installed to a minimum shaft length of 20 feet and must develop an average installation torque of 2,200 ft-lb or greater for a minimum distance of at least 3 feet after reaching 17 feet, otherwise the anchor must be driven deeper using additional extension sections until the torque requirement is satisfied.

End of Example 3

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Design Example 3A – Basement Wall Tieback Anchor – "Quick and Rough Method"

Mandatory Installation Requirements
Before beginning a complicated basement tieback anchor design like Design Example 3A using the "Quick and Rough" method with only general information and data from graphs and tables; the following **Mandatory Installation Requirements** MUST ALWAYS BE DEFINED in the final design before the "Quick and Rough" method will be successful.

Before performing a "Quick and Rough Design" for a basement tieback system, the following items MUST be defined and included for a "Safe Use" design:

1. The anchor must penetrate the wall at between 3 and 5 feet from the floor of an 8 foot tall basement wall. (This is also valid for a 9 foot basement wall with no more than eight feet of soil overburden.
2. There must be at least two feet of soil above the penetration point for the tiebacks.
3. Ground water must be assumed present behind the wall.
4. Unless otherwise given, the working soil load on the wall shall be assumed to be 3,250 lb/lin.ft. of wall. To obtain the load on each placement, multiply 3,250 lb/lineal ft by a Factor of Safety = 2 and by the spacing of the anchors on the wall (feet).
5. Unless otherwise given, the maximum spacing of tiebacks shall be no more than 5 feet on center with a downward angle 15^0.
6. A minimum installed shaft length of 22 feet from the wall to the tip of the tieback assembly shall be used when the largest helical plate on the shaft is 12 inches diameter. If the largest plate diameter is 14 inches the minimum installed shaft length at a 15^0 downward is 25 feet.

IMPORTANT: If the tieback reaches maximum torque before obtaining the length requirement, the helical plate area MUST be reduced and the anchor MUST be installed to the minimum length stated above, or the possibility that the anchor will load the wall and fail exists.

If any of the conditions are encountered that are substantially different from what is normally encountered, an analysis and design shall be performed by a Registered Professional Engineer, or the engineer needs to review and approve your design.

Structural Details: The only data available:

- Cast concrete basement wall is 8 feet tall and 10 inches thick.
- Backfill against the wall is 7 feet - Unknown soil
- The only soil information given: There exists inorganic clay (CL), stiff to very stiff – 115 pcf in the area

1. Determine the Soil Class. Referring to the Soil Classification Table (Chapter 1 - Table 9) the soil class of 4 - 5 is selected based upon the soil description being "stiff to very stiff clay".

2. Ultimate Helical Pile Capacity. In this design the largest spacing allowed is selected – five feet on center. The Ultimate Design Load for the project is estimated at:
T_u = 3,250 lb/lin ft x 2 x 5 ft =
T_u = **32,500 lb** per anchor

3. Select the proper tieback anchor from the estimated capacity graphs. Referring to Graph 3 from Chapter 1 (reproduced on next page), notice that the capacity line for an anchor with an a 10" and 12" diameter helical plate suggests a capacity in excess of at 32,500 lb at Soil Class between 4 - 5. The 10"-12" diameter plate configuration is selected for the design.

4. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 to verify that the 1-1/2 inch solid square shaft has sufficient capacity to support the tensile load, and has sufficient torsional shaft strength for installation. The required ultimate capacity for each anchor is 32,500 lbs. (Step 2.) The 1-1/2 inch solid square shaft has an *Ultimate Limit Tension Strength* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs. The selected helical pile provides suitable torsional capacity and a sufficient practical load limit to exceed the ultimate load requirement of 32,500 pounds. The choice is verified.

5. Installation Torque. Use Equation 2 from Chapter 1, (or Graph 6 demonstrated in Design

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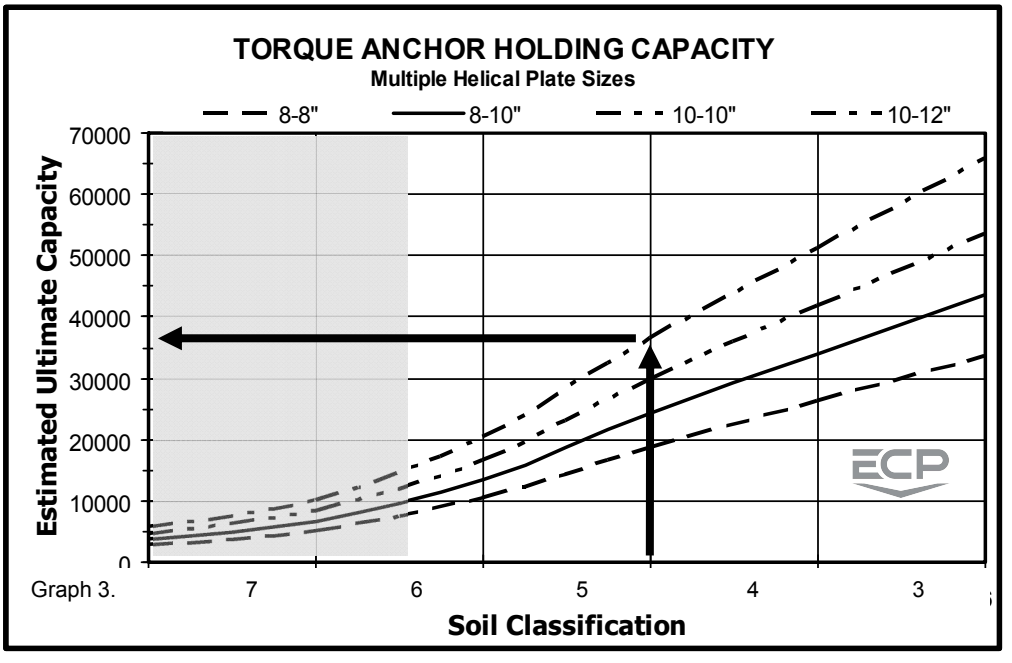

Graph 3.

Example 2A) to calculate the installation torque requirement for this pile.

Equation 2: $T = P_u / k$, Where,

P_u = 32,500 lb

k = 10 (See Table 12 in Design Example 3)

$T = 32{,}500 \text{ lb} / 10 \text{ ft}^{-1} = 3{,}250 \text{ ft-lb}$

T = 3,300 ft-lb, minimum

6. Torque Anchor™ Specifications.

- **TAF-150-84 10-12** – 1-1/2 inch round corner solid square shaft that has a 10 inch diameter and a 12" diameter plate attached to a 7'-0" long shaft,
- **TAE-150-60** extension – 5'-0 extension section & hardware. This extension has a coupled length of 4'-9". The installation will need four extensions to exceed 22 feet total length.
- **TAT-150** – Light Duty Transition that connects from 1-1/2" square bar to a 20" length of continuous threaded rod, with hardware.
- **PA-SWP** – Stamped steel wall plate that measures 11" x 16"

The items shown below are from the list of **Mandatory Installation Requirements** at the beginning of this example. **These requirements MUST always be included** when designing "Quick and Rough" basement tieback projects.

7. Mandatory Installation Requirements:

- **Anchors shall be installed at 3 to 6 feet from the floor of the standard 8 foot basement wall.**
- **Anchors shall have a minimum of two feet of soil cover from point of penetration of the wall to the ground surface.**
- **Anchors shall be installed with a declination of 15^0.**
- **These anchors with 12" diameter largest helical plates shall be installed to a length not less than 22 feet.**
- **Anchors shall achieve installation shaft torsion of at least 3,300 ft-lb over the final three feet of installation prior to termination.**

End of Example 3A

Review of Results of Example 3 & 3B

One can see that the result obtained by the "Quick and Rough" analysis suggested a similar anchor configuration as predicted by using the bearing capacity equation. Because this is a general use "Quick and Rough Design" there are design parameters put in place to cover most situations with an eight foot tall basement wall (or nine foot wall with no more than eight feet of soil overburden). In addition, many installation requirements MUST be followed to provide a safe design when a "Quick and Rough" design method is used. These installation requirements were explained in the Design Example 3B. If the job not typical, consult a Registered Professional Engineer.

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Design Example 4 – Retaining Wall Tieback Anchor -- Cohesionless Soil

Structural Details:

- New construction steel reinforced cast concrete retaining wall – 12 ft tall
- Backfilled with granular fill at the wall with free flow drainage tiles at the footing
- The soil information about the site indicated medium to coarse gravelly sand (SP), Medium dense – 130 pcf
- Standard Penetration Blow count "N" = 20 blows per foot at 10 feet deep
- $\Phi = 32^0$

1. Estimate the lateral soil force against the wall. Equation 6 in Chapter 1 is selected because the design specifies that the hydrostatic pressure is relieved by the drainage system.

Equation 6: $P_H = 24 \times (H^2)$, Where, H = 12 ft.

P_H = 24 x (12' x 12') = 3,456 (Use 3,500)

P_H = 3,500 lb/lineal foot

2. Select a Torque Anchor™ and make an analysis to see if it is suitable. In this example the TAF-175-60 08-10-12 is tried, a 1-3/4" solid square bar product with an 8", 10" and a 12" diameter helical plate attached. From the soil data available the soil is cohesionless; Equation 1b from Chapter 1 is used:

Equation 1b: $T_u = \Sigma A_H (q\ N_q)$ Where,

$A_{8"}$ = 0.328 ft^2 (From Table 10 – Chapter 1)
$A_{10"}$ = 0.524 ft^2 (See also pg 63 above.)
$A_{12"}$ = 0.764 ft^2

ΣA_H = 0.328 + 0.524 + 0.764 = **1.62 ft^2**

q = γ x h_{mid}

h = Design Embedment = 10 ft. is selected
(This is the measurement from the ground surface to where the 12" diameter helical plate is located when the tieback is fully installed - See Figure 10, below.)

γ = Soil density = **130 lb/ft^3**

N_q = **23** ("N" = 20 & $\Phi = 33^0$) Table 7 Chapter 1

T_u = 1.62 ft^2 x (130 lb/ft^3 x 10 ft) x (23)

T_u = 48,438 lb

3. Torque Anchor™ Spacing. Determine the Torque Anchor™ spacing along the wall for the configuration selected. Use Equation 4 from Chapter 1.

Equation 4: "X" = T_u / [P_H x (FS)], Where,
"X" = Product Spacing
T_u = Ultimate Capacity on Torque Anchor™
P_H = Lateral Force on Wall (lb/lin.ft)
FS = Factor of Safety (Typically 2.0:1)

"X" = 48,438 lb/[3,500 lb/lin.ft x 2 (FS)] = **6.9'**

4. Installation Torque & Embedment. Use Equation 3 – Chapter 1 to calculate the installation torque for this anchor.

Equation 3: $T = T_u / k$ Where,
T_u = 48,438 lb (Step 3)
k = 10 (Table 12 – Chapter 1)

T = 48,438 lb/10 ft^{-1} = 4,844 ft-lb.

T = 4,900 ft-lb

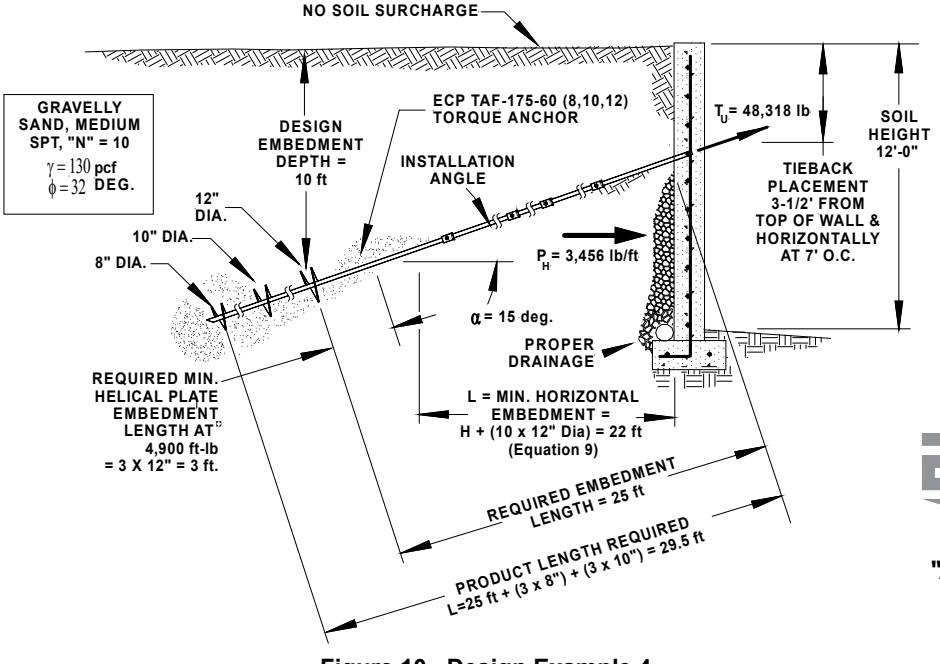

Figure 10. Design Example 4.

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The torque must be developed for a distance great enough to insure that the helical plates are properly embedded to develop adequate tension capacity. The torque requirement must be averaged over a minimum distance of at least three times the diameter of the largest plate. The installer must average at least 4,900 ft-lbs through a distance of 3 feet. (Three times the 12" diameter plate.)

5. Select Installation Angle and Product Length. The anchors penetrate the wall at 3-1/2 feet below the soil surface. (This is approximately 0.3 times the wall height.) Recall that embedment depth was selected at 10 ft in Step 2. This means that the depth below the soil surface to the location of the 12" helical plate must be at least 10 feet. Try using an installation angle of 15^0 and determine the product length that will provide the 10 feet of vertical embedment required. (The required depth of embedment is 10 ft. Recall that the distance from the top of grade level to where the anchors will penetrate the wall is 3-1/2 feet. The additional depth required by the anchor is 6-1/2 feet (10 ft - 3-1/2 ft) = 6-1/2 feet.)

The shaft length required at 15^0 to achieve the 6-1/2 foot vertical depth is calculated using the equation given in Table 13 in Chapter 1 for a declination angle of 15^0.

$\mathbf{L_{15}}$ = (6-1/2 ft/sine 15^0) = 6-1/2 ft/0.259 = **25 ft**

The minimum shaft length at 15^0 installation angle is 25 feet, which will insure that the 12" diameter plate is located at a total embedment depth of 10 feet below the surface.

Comparing the *Minimum Horizontal Embedment* length from Equation 9 to the *Minimum Embedment Depth* (Step 5):

$\mathbf{L_0}$ = 12 + [10 x 1'] = **22 ft**.

It is clear that L_{15} = 25 ft (Length to insure required 10' soil embedment depth determined in Step 5) exceeds the *Minimum Horizontal Embedment* requirement.

The 10 ft depth of embedment also exceeds the Critical Depth, "D" = 6 x d_{12} = 6 x 12"/12 = **6 ft**

L_{15} = 25' > L_0 = 22' using D = 6

Use L_{15} = 25 ft

Minimum Required Shaft Length:

L = L_{15} + L_{Tip} (Distance shallowest plate to tip)

Where: $L_{Tip} = (3 \times d_{plate\ 1}) + (3 \times d_{plate\ 2})$

L_{Tip} = [(3D x 8" dia)+(3D x 10" dia)]/12

L_{Tip} = 4-1/2 ft

L = L_{15} + L_{Tip} = 25 ft + 4-1/2 ft = **29-1/2 ft**

L = 29-1/2 feet **$\alpha = 15^0$**

6. Torque Anchor™ Capacity Verification: A review of Table 2 – Chapter 1 indicates that the 1-3/4" solid square bar Torque Anchor™ has a *Ultimate Limit Tension Strength* of 100,000 lb and a *Useable Torsional Strength* of 10,000 ft-lb. The project ultimate tension capacity and torsional requirement are approximately one-half of the mechanical and torsional capacity of the product. There was no mention about rocks, debris or other obstructions in the soil so installation should be smooth. A check of Table 11 – Chapter 1 indicates that three 3/8" thick helical plates have an ultimate capacity of 120,000 pounds (3 x 40,000 lb), so the total mechanical capacity of the anchor is satisfactory.

7. Torque Anchor™ Specifications. The required Torque Anchor™ assembly consists of:

- **TAF-175-84 08-10-12** - 1-3/4" solid square bar, on a standard 7' long shaft with 8", 10" & 12" dia. plates,
- **TAE-175-84** extensions - 7 feet long & hardware (6'-9" effective length) – **Three extensions are required**.
- **TAE-175-60** extensions - 5' long with hardware (4'-9" effective length) – **One extension is required.**
- **TAB-175 T** Tension Pile Cap – 3/4" x 8" x 8" pile cap with bolt and nut. The pile cap bolts to the anchor shaft and will be incorporated into the concrete new construction wall.

The actual assembled length of the specified Torque Anchor™ system is 32 ft.

The anchors shall mount along the wall at 7 feet center to center at a distance of 3-1/2 feet from the top of the proposed wall. The anchors shall be installed at a downward angle of 15^0 from horizontal. The tiebacks must be installed to a length greater than 29-1/2 feet and must develop an average installation torque of 4,900 ft-lb or more for a minimum distance of at least 3 feet beyond an installed length of 26 feet, otherwise the anchor shall be driven deeper until this torque requirement is satisfied.

End of Example 4

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Design Example 5 – Foundation Restoration – Cohesive Soil

Structural Details:

- Two story wood frame house with wood composition siding.
- Foundation consists of 20" wide by 18" tall steel reinforced concrete perimeter beam with a 4" thick concrete slab cast with the perimeter beam.
- The corner of structure has settled 2"
- Top of pile will be 12" below the soil surface
- Soil data: There are two feet of consolidating, poorly compacted fill overlaying 20 feet of inorganic clay (CL), stiff.
- SPT "N" blow count was measured between 8 to 12 blows per foot increasing with depth

Torque Anchor™ Design:

1. Determine the foundation load: Breaking down weights of structural elements can be found in the *Simplified Tables of Structural Foundation Loads* in Tables 2 through 9 in Chapter 5, ECP Steel Piers™ Design, later in this manual. The foundation loads are estimated below:

Footing – 20" x 18"	360 lb/lf
Slab Floor, Carpet & Pad	195
Wood Frame Walls – 2 Story	176
2nd Floor – 14' Span, Carpet & Pad	98
Roof – 6" in 12" Composition, 14' Span	171
Total Dead Load	**1,000 lb/lf**
Live Load – Slab	120
Live Load – 2nd Floor, 14' Span	180
Total Live Load	**300 lb/lf**

w = Distributed Load = 1,000 + 300 = 1,300 lb/lf

w = 1,300 lb/lineal foot

2. Select a Suitable Pile Spacing and Determine Ultimate Torque Anchor™ Load: This is not a heavy structure, so for economy the solid square bar Torque Anchor™ configuration is chosen for this restoration along with Utility Brackets to transfer the structural load to the pile shaft. Using Graph 2 in Chapter 5, select pile spacing, "X", at 7-1/2 feet on the perimeter beam. (Note arrow on graph.) Determine the working load on the piles from Equation 4 – Chapter 1.

Equation 4. P_u = "X" x w x (FS):

Where,

"X" = Product Spacing = 7-1/2 feet (Selected)

w = 1,300 lb/lineal foot (Step 1)

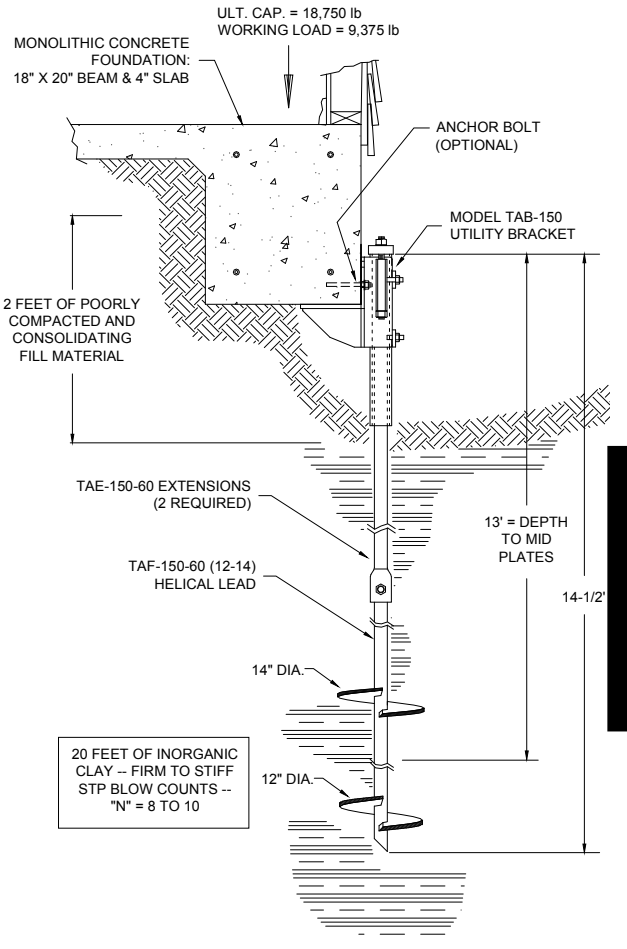


Figure 13. Design Example 5.

FS = Factor of Safety (Use 2.0)

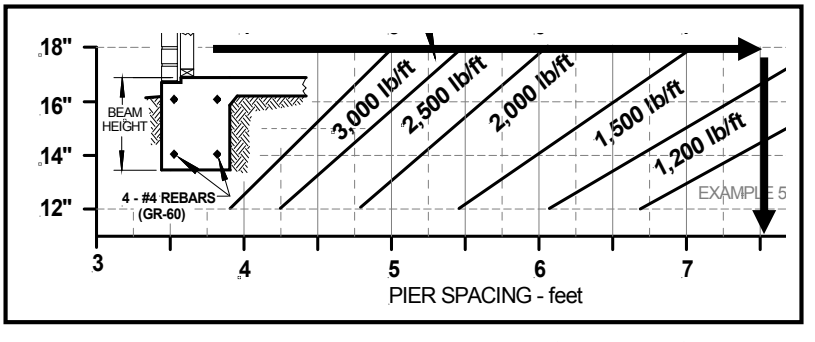
P_u = 7-1/2 ft x 1,300 lb/ft x 2 = 19,500 lb

3. Determine the helical plate area required from the known information: Because the soil on the site is cohesive, Equation 1a from Chapter 1 is used:

Equation 1a: $\Sigma A_H = P_u$ / (9c) Where:

P_u = 19,500 lb (Step 2)

c = 1,250 lb/ft² Average "N" = 10 (assumed) (Table 5 - Chapter 1)



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$\Sigma A_H = P_u / (9 \times 1{,}250) =$ 19,500 lb / 11,250 lb/ft^2

$\Sigma A_H = 1.73$ ft^2

4. Select the ECP Helical Torque Anchor™ suitable to support the load.

Referring to Table 2 – Chapter 1 the 1-1/2" solid square pile shaft is selected. It has an *Axial Compression Load Limit* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

Referring to Table 10 – Chapter 1, we will select our combination of plates from the list opposite the 1-1/2" shaft size. We must provide at least 1.67 ft^2 of bearing area:

6" Dia. = 0.181 ft^2
8" Dia. = 0.333 ft^2
10" Dia. = 0.530 ft^2
12" Dia. = **0.770** ft^2
14" Dia. = **1.053** ft^2

The combination of 12" & 14" diameter plates on the 1-1/2" solid square shaft provides a total area of 1.82 ft^2.

TAF-150-60 12-14

5. Installation Torque. Use Equation 2 – Chapter 1 to calculate the installation torque for this anchor.

$T = T_u / k$ Where,

T_u = 19,500 lb (Step 2)
k = 10 (Table 12 – Chapter 1)

T = 19,500 lb / 10 ft^{-1}

T = 1,950 ft-lb – **Use 2,000 ft-lb**

6. Torque Anchor™ Capacity Verification: A review of Table 2 – Chapter 1 indicates that the 1-1/2" solid square bar Torque Anchor™ has a *Useable Torsional Strength* of 7,000 ft-lb, which is more than adequate for this application. The product selection should work based upon the soil report stating that the firm to stiff clay becomes more dense as the depth increases. There was no mention of rocks, debris or other obstructions. Table 11 – Chapter 1 verifies that two 3/8" thick helical plates have a mechanical ultimate capacity of 80,000 pounds. The mechanical capacity of the pile is excellent.

7. Installed Product Length. Termination depth is targeted in the stiff silty clay where the helical plates will be situated. The data indicates that the soil has a variance in the Standard Penetration Test (SPT) blow count, "N", between 8 and 12 blows per foot. It is estmated that the pile would reach the desired shaft torsion at a mid-plate depth of about 13 feet.

Minimum Required Shaft Length:

$L = h_{mid} + L_{Tip} - h_F$

Where:

h_{mid} **= 13 ft** (The depth from the surface to midway between plates on the shaft.)

$L_{Tip} = (3D_{Plate\ 1}) / 2$

L_{Tip} = (3 x 12" dia / 2 = 18 in

L_{Tip} = **1-1/2 ft**

h_F = **-1 ft** (The pile cap will terminate at the Utility Bracket approximately 12 inches below grade level.)

L = 13 ft + 1-1/2 – 1 ft

L = 13-1/2 feet = Shaft length estimate

8. Torque Anchor™ Specifications: Specify the necessary Torque Anchor™ components:

- **TAF-150-60 12-14** - 1-1/2" solid square bar lead section on a standard length 5 feet long shaft with a 12" and 14" diameter plate.
- **TAE-150-60** Extension – 1-1/2" solid square bar extension 5 feet long with hardware, **2 required** (The coupling overlaps 3 inches providing an effective length of 4'-9")
- **TAB-150-SUB-150** Utility Bracket. This foundation bracket fits over the 1-1/2" square bar and mounts to the perimeter beam. The bearing plate provides 68-1/4 in^2 at the bottom of the foundation for load transfer.

The total length of the assembled Torque Anchor™ is 14-1/2 ft.

The Torque Anchors™ shall be spaced at 7-1/2 feet center to center along the perimeter grade beam and must develop an average installation torque of 2,000 ft-lb or more during the last 3 feet of the installation. Depth is 13-1/2 feet.

Note: It is recommended to order additional extension sections because the target torque might not be achieved at 13-1/2 feet.

9. Foundation Restoration. Once all of the Torque Anchor™ piles have been installed and the Utility Brackets mounted, the structure may be restored to as close to the original elevation as the construction will permit.

- A pile cap, lift assembly and hydraulic jack are installed at each placement.

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- All hydraulic jacks are connected to a hand pump and gauge through a manifold system that distributes equal pressure to all jacks.
- The hand pump is actuated, transferring the structural load from the soil below the footing to the Torque Anchor™ shafts. As the structure responds and a portion of the foundation reaches the desired elevation, the jack(s) supporting the restored area(s) are isolated and the pressure at the jack(s) recorded.
- The restoration process continues until the structure is satisfactorily restored, and all jacks have been isolated and their pressures recorded.
- All installation and restoration data is transferred to a Project Installation Report. This report should include, but is not limited to, project identification, equipment used, product installed, final installation torque, installed depth, lifting force required to restore the structure and lift measurement. This data must be recorded for each placement.
- Review the report and calculate actual factors of safety on the installation to see if the design requirements have been satisfied.

10. Actual Load vs. Calculated Load and Installed Factor of Safety: The installation data must be compared to the calculated values. This enables the designer to verify the accuracy of the design. In addition, actual project factors of safety should be verified, as shown below.

The actual factor of safety for each pile installation is calculated, a slight variation of the typical factor of safety formula is used.

Equation 12: Project Factor of Safety

$$FS_{job} = P_{u\text{-}job} / P_{w\text{-}job}$$

Where:

$P_{u\text{-}job}$ = Installed Estimated Ult. Capacity – lb
($P_{u\text{-}job}$ = Installation Torque x k)

$P_{w\text{-}job}$ = Lifting Force to Restore – lb
($P_{w\text{-}job}$ = Jack Pressure x Cylinder Area)

The Project Installation Report data is used to calculate the actual factors of safety for each Torque Anchor™ placement:

$\mathbf{FS_{Actual} = T_{Final} \times k}$ (Table 12)$/ \mathbf{P_{Lift}}$

Pile 1: FS = (2,000 ft-lb x 10 ft^{-1}) lb / 9,000 lb
$FS_{pile\ 1}$ = 2.22

Pile 2: FS = (1,950 ft-lb x 10 ft^{-1}) lb / 9,400 lb
$FS_{pile\ 2}$ = 2.07

Pile 3: FS = (2,050 ft-lb x 10 ft^{-1}) lb / 7,700 lb
$FS_{pile\ 3}$ = 2.66

PROJECT INSTALLATION REPORT

Project Name: Design Example 5
Project Address: 123 Anywhere, Mid-America, USA

Products Installed: TAF-150-60 10-12 Lead
TAE-150-60 Extensions
TAB-150-SUB Utility Bracket

Torque Motor: Model LW6K – 6,000 ft-lb
Lifting Jack: Model RC254 – 25 Ton

Calculated Ultimate Pile Capacity: **P_u = 19,500 lb**
Calculated Working Pile Load: **P_w = 9,750 lb**

Placement Identification	Pile 1	Pile 2	Pile 3
Final Install Torque, ft-lb	2,000	1,950	2,050
Pile Depth, ft	18.5	16	16.5
Force to Lift, lb	9,000	9,400	7,700
Amount of Lift, in	1-1/2	1-3/4	2
Actual Factor of Safety	2.22	2.07	2.66

Soil tends to be non-homogeneous and normally installation torque varies from point to point on a project; in addition, the load on a footing is usually not uniform due to different architectural elements in the design of the structure. Pile 2 had slightly lower shaft torsion than required and had a slightly higher working load. This resulted in the lowest Factor of Safety. Pile three was on a lightly loaded part of the building an had a large Factor of Safety.

End Design Example 5

Review of Results of Example 5

Comparing the calculated design working load of 8,818 lb per pile (P_w = w (Step 1) x "X" (Step 2) = 1,300 lb/ lineal ft x 7-1/2 ft = 9,750 lb) to the actual lifting forces one can see that all working pile loads are slightly lower than predicted by the calculations. These differences between calculated and actual working loads are not significant and are related to the fact that actual loads on the footing are not uniform along the footing. The actual factors of safety for the installation on this project demonstrate that the project has actual factor of safeties within normal tolerances. The project has a safe design.

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Design Example 5A – Foundation Restoration – "Quick and Rough" Method

Design Details from Design Example 5:

- Two story wood frame house with slab foundation and wood composition siding.
- Foundation consists of 20" wide by 18" tall steel reinforced concrete perimeter beam
- Top of pile to be 12" below the soil surface
- Soil data: Two feet of consolidating poorly compacted fill was found overlaying 20 feet of inorganic clay (CL), firm to stiff.

ECP Torque Anchor™ Design:

1. Determine the foundation load: Use Table 2, *Ranges for Typical Average Residential Building Loads* that can be found in Chapter 5 of this manual. A portion of Table 2 from Chapter 5 is shown below. (This table does not include snow loads. Snow loads must be added for the job location.)

Table 2. Ranges for Typical Average Residential Building Loads

Building Construction (Slab On Grade)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing -- Footing with Slab	DL 750 – 850 lb/ft LL 100 – 200 lb/ft
One Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,000 – 1,200 lb/ft LL 100 – 200 lb/ft
Two Story Wood/Metal/Vinyl Walls with Wood Framing – Footing with Slab	DL 1,050 – 1,550 lb/ft LL 300 – 475 lb/ft
Two Story 1st Floor Masonry, 2nd Wood/Metal/Vinyl with Wood Framing – Footing with Slab	DL 1,300 – 2,000 lb/ft LL 300 – 475 lb/ft
Two Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,600 – 2,250 lb/ft LL 300 – 475 lb/ft

From the description of the project, the total foundation load (except snow loads) can be roughly estimated for this structure from Table 2. The portion of Table 2 reproduced is for slab on grade foundation loads, which is the type of foundation on this project that supports a two story residence that has wood composition siding.

To determine the estimated foundation load, look down the first column until the "Two Story" description that most closely matches the job house is found. Reading across to the other column provides a range of foundation dead load weights for this kind of residential structure. Dead loads range between 1,050 and 1,550 lb/lin.ft and the live load estimates run from 300 to 475 lb/lin.ft.

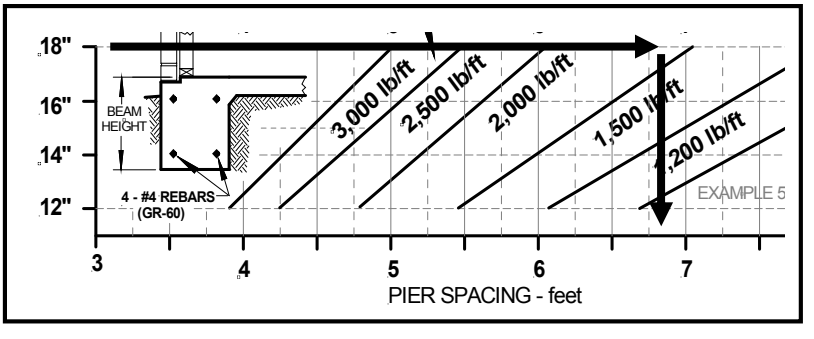
A judgment about the quality of construction is used to select the foundation loads from within the ranges. For Design Example 5A careful judgment about the construction suggests using DL = 1,200 lb/lin.ft and LL = 375 lb/lin.ft. The average perimeter loading to be used for the "Quick and Rough" design is 1,575 lb/lin.ft.

2. Determine the Soil Class. The soil was reported only as still clay. Referring to the *Soil Classification Table* - Table 9 (Chapter 1), Soil Class 6 is selected. Keep in mind that little soil information available and there is concern about the poorly compacted fill near the surface.

3. Select a Suitable Pile Spacing and Determine Ultimate Torque Anchor™ Load: This is not a heavy structure so the solid square bar Torque Anchors™ configuration is chosen for this restoration along with Utility Brackets are the most economical products to use to transfer the structural load from the foundation to the pile shaft. Use Graph 2 from Chapter 6, to select pile spacing, "X". (See below)

A loading of 1,575 lb/lin. ft is slightly higher than the 1,500 lb/ft line on the graph. This line will be used to select the spacing and then the spacing will be adjusted to reflect the load higher than the graph curve. Read across from the 18 inch footing height to an estimated 1,575 lb/ft position, then drop down to see the pile spacing of 6-3/4 feet. 6-3/4 feet center to center is selected for "Safe Use" design.

"X" = 6-3/4 feet



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4. Determine Ultimate Torque Anchor™ Load: Use Equation 3 from Chapter 1 to determine the ultimate capacity per pile:

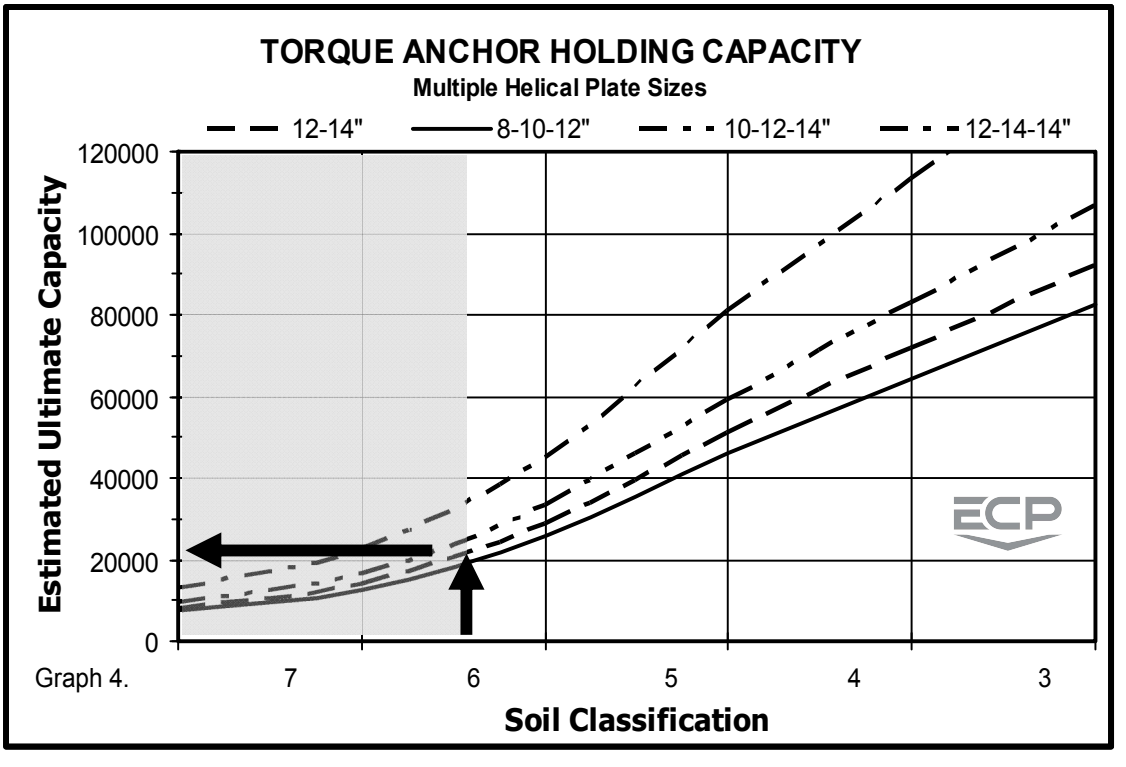
Equation 3. P_u = ("X") x (w) x (FS):

Where,
"X" = Product Spacing = 6-3/4 feet
w = 1,575 lb/lineal foot (Step 1)
FS = Factor of Safety (Use 2.0)

P_u = 6-3/4 ft x 1,575 lb/ft x 2 = 21,263 lb

5. Select the proper pile configuration: Referring to Graph 4 from Chapter 1 (reproduced below), notice that the capacity line for 12" and 14" diameter helical plates attached to shaft crosses just above 20,000 pounds at the center of Soil Class 6. The 12" and 14" diameter plate configuration is selected for the design.

6. Check Shaft Strengths and Torsional Strengths to see which shaft is suitable: Refer to Table 2 in Chapter 1 to find a shaft with a suitable *Axial Compression Load Limit* and sufficient *Useable Torsional Strength.* The 1-1/2 inch solid square shaft is selected because it has an *Axial Compression Load Limit* rating of 70,000 pounds based upon an installation torsional limit of 7,500 ft-lbs. This pile exceeds the ultimate job load requirement of 21,263 pounds. The selected and verified pile configuration is TAF-150-60 12-14.



Graph 4.

7. Installation Torque. Use Graph 6 from Chapter 2, shown next page to determine the installation torque requirement for the piles. The Ultimate Capacity requirement is 21,263 pounds. Find 22,000 pounds at the left side of Graph 6 look horizontally to the graph line for solid square shafts, read down to torque of 2,200 ft-lb.

T = 2,200 ft-lb, minimum

Just for comparison, the installation torque is calculated: from Equation 2 in Chapter 1:
Equation 2: $T = P_u / k$, (from Chapter 1)
P_u = 21,263 lb k = 10 (Table 12)
T = 21,263 lb/10 ft^{-1} = 2,127 ft-lb **T = 2,200 ft-lb**

8. Installed Product Length. Termination depth is the stiff clay. It is likely that the pile would reach the desired shaft torsion at a depth somewhere beyond the unconsolidated soil near grade. The minimum depth is the summation of the *Critical Depth* (Chapter 1, page 16) plus the distance to the lowest plate.

Minimum Required Shaft Length:

$L_{min} = D_{Critical} + L_{Tip}$ Where:

$D_{Ccritical}$ = 14" dia./12" x 6 ft (Page 16)
(Critical Depth = 6 x diameter of largest plate.)

L_{Tip} = 12" dia./12" x 3 = 3 ft
(Plates spaced at 3 x diameter.)

L_{min} = (14"/12" x 6') + (12"/12" x 3) = **10 ft**

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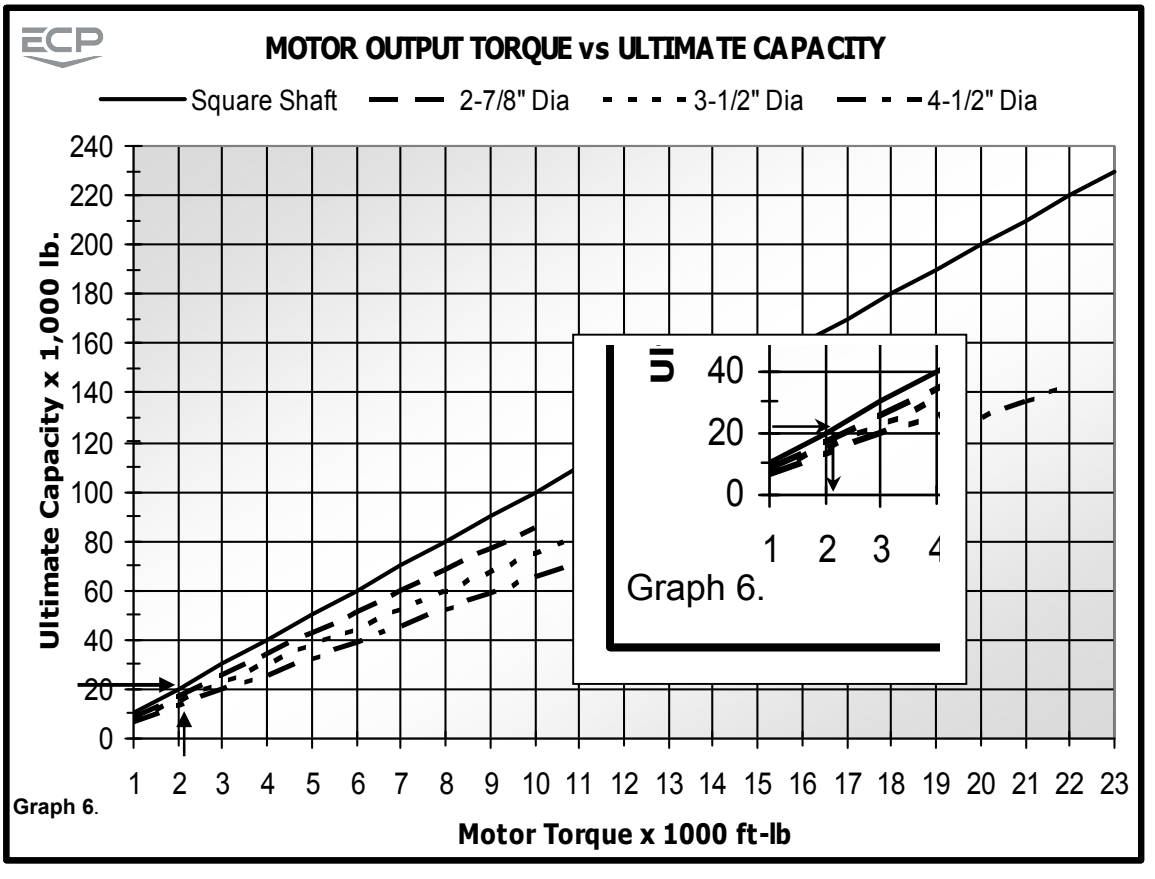

"Safe Use" design suggests that the piles be installed deeper than ten feet below grade because there is weak and consolidating fill soil near the surface. A longer standard shaft length of 12 feet, minimum, is selected.

9. Torque Anchor™ Specifications: The selected Torque Anchor™ assembly is specified:

- **TAF-150-60 12-14** – 1-1/2 inch solid square shaft that has a 12" and a 14" diameter plate on the 5'-0" long shaft,
- **TAE-150-84** extension – 7 foot extension section & hardware. (6'-9" effective length)
- **TAB-150-SUB** Utility Bracket This foundation bracket fits over the 1-1/2" square bar and mounts to the perimeter beam. The bearing plate provides 68-1/4 in^2 at the bottom of the foundation for load transfer.
- It is recommended that additional extensions (**TAE-150-60** extension – 5 foot extension section & hardware - 4'-9" effective length or **TAE-150-84** extension – 7 foot extension section & hardware - 6'-9" effective length) be on hand in case the shaft torque requirement is not achieved at 12 feet.

End of Example 5A

Review of Results of Example 5 & 5A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested the same pile that was determined by the analysis that used the bearing capacity equations. There were some variations in the design because a higher footing load and higher installation torque were predicted by the "Quick and Rough" method. This was caused in part by the higher ultimate load suggested by the "Quick and Rough" tables and graphs from Chapter 5. Once again, similar results were determined from the "Quick and Rough" design method, but good judgment estimating the quality of construction is most important in selecting proper data from the tables and graphs for more accurate results.

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Design Example 6 – Motor Output Torque

The heavy weight new construction pile design presented in Design Example 1 required shaft torsion of 7,100 ft-lb be applied to the 2-7/8 inch diameter Torque Anchor™ shaft to achieve the ultimate capacity requirement of 60,000 pounds. In Design Example 1B, where weak soil was present, the torsion requirement was determined to be 8,000 ft-lb on a 3-1/2 inch diameter tubular shaft to be able to achieve the same 60,000 pound ultimate pile capacity.

Project Details Provided from the Field:

- New Building – 2 story house with basement
- Ultimate Capacity = 60,000 lb
- Torque Motor Available = Pro-Dig X12K5
- Design 1 – Avg. Pressures at termination depth - 2-7/8" dia = 1,900 psi at inlet & 200 psi at outlet
- Design 1B – Avg. pressures at termination depth, 3-1/2" dia = 2,150 psi at inlet & 200 psi at outlet
- Pressures averaged over final three feet of depth

Equation 11 introduced in Chapter 2 is used to convert pressure differential across the hydraulic gear motor into shaft output torque.

Equation 12: Motor Output Torque
$$T = K \times \Delta P$$

1. Differential Pressures: Before using Equation 11, the pressure differential, or ΔP, from the field must be determined. The *Motor Torque Conversion Factor* – "K" must also be identified for the Pro-Dig X12K5.

The Pressure Differential across the motor is determined as follows:

ΔP = Inlet psi – Outlet psi

$\Delta P = p_{in} - p_{out}$

ΔP from Design Example 1:

$\Delta P_{Example\ 1}$ = 1,900 psi – 200 psi

$\Delta P_{Example\ 1}$ = **1,700 psi**

ΔP from Design Example 1B:

$\Delta P_{Example\ 1B}$ = 2,150 psi – 200 psi

$\Delta P_{Example\ 1B}$ = **1,950 psi.**

2. Motor Torque Conversion Factor, "K": The *Motor Torque Conversion Factor* – "K" is found on Table 16 in Chapter 2. (A portion of the table is shown below.) Looking in the *"Model Number"* column of Table 16, the X12K5 Torque Motor data is found. Reading to the right the value for the *Motor Conversion Factor*, "K", for this motor is determined to be "K" = 4.20.

3. Motor Output Torque: Once the differential pressure across the hydraulic torque motor has been calculated (Step 1) and the value for "K" determined (Step 2), the values can be used in Equation 11 to determine the actual torque that was applied to the pile shaft at termination depth.

Equation 11: Motor Output Torque
$$T = K \times \Delta P$$

Where,
T = Hydraulic Motor Output Torque - ft-lb
K = Torque Motor Conversion Factor – (Table 16)
$\Delta P = p_{in} - p_{out}$ = Motor Pressure Differential

Confirm proper installation torque for Design Example 1.

$T_{Example\ 1}$ = 4.20 x 1,700 psi

$T_{Example\ 1}$ = **7,140 ft-lb**

7,140 ft-lb > 7,100 ft-lb - O.K.

Confirm proper installation torque for Design Example 2.

$T_{Example\ 1B}$ = 4.20 x 1,950

$T_{Example\ 1B}$ = **8,190 ft-lb**

8,190 ft-lb > 8,000 ft-lb - O.K.

End Design Example 6

Table 16. Hydraulic Torque Motor Specifications

Illustration	Model Number	Torque Output ft-lb	Motor Torque Conversion Factor – "K"	Maximum Pressure psi
PRO-DIG	L6K5	6,335	**2.53**	2,500
	L7K5	7,644	**2.55**	3,000
	X9K5	9,663	**3.22**	3,000
	X12K5	12,612	**4.20**	3,000
	T12K	5,597/ 12,128	**2.24/4.85**	2,500

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Design Example 6A – Motor Output Torque "Quick and Rough Method"

The heavy weight new construction pile design presented in Design Example 1 specified that when installed on the site, torsion of 7,100 ft-lb was needed on the 2-7/8 inch diameter Torque Anchor™ shaft to reach the ultimate capacity requirement of 60,000 pounds.

In Design Example 1B where weak soil was present the torsion requirement increased to 8,000 ft-lb on the 3-1/2 inch diameter tubular shaft to achieve the same 60,000 pound ultimate pile capacity.

Determine Motor Output Torque: Graph 9 introduced in Chapter 2 is used to convert pressure differential across the hydraulic gear motor into shaft output torque. Referring to Graph 9 (reproduced below); the output torque of the X12K5 motor can be determined once the pressure differentials across the installation motor are determined.

ΔP = Inlet psi – Outlet psi

$\Delta P = p_{in} - p_{out}$

ΔP from Design Example 1:

$\Delta P_{Example\ 1}$ = 1,900 psi – 200 psi

$\Delta P_{Example\ 1}$ = **1,700 psi**

ΔP from Design Example 1B:

$\Delta P_{Example\ 1B}$ = 2,150 psi – 200 psi

$\Delta P_{Example\ 1B}$ = **1,950 psi**

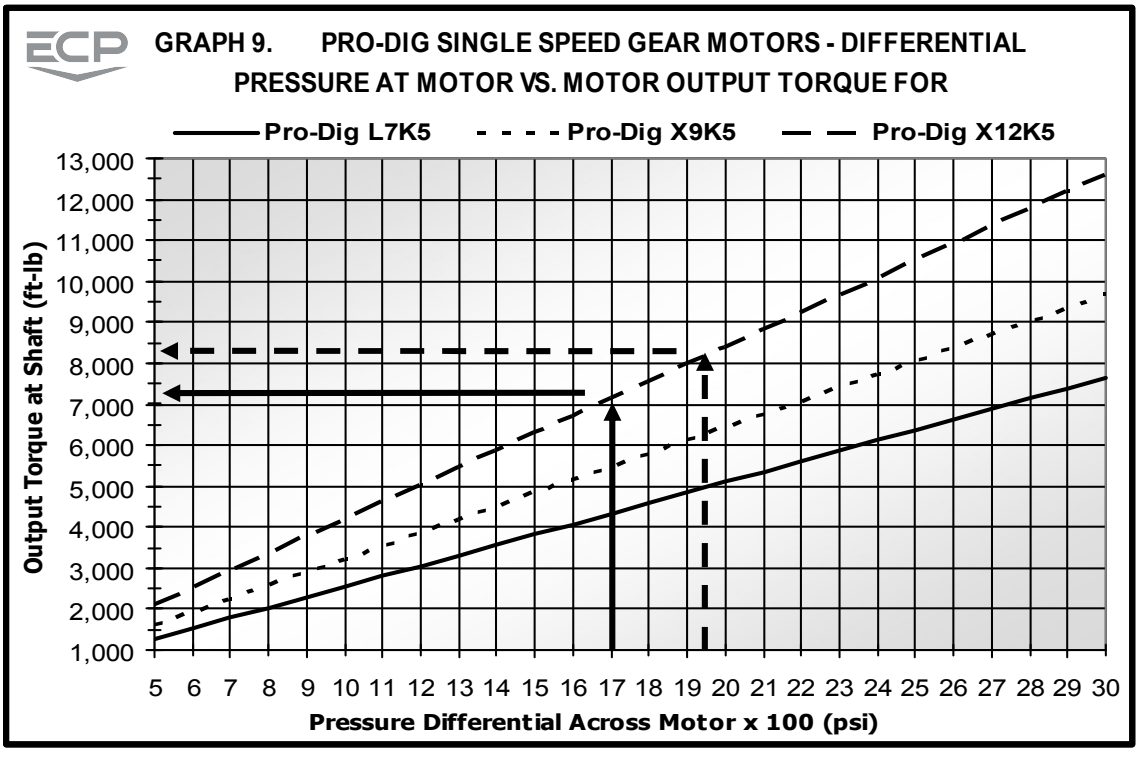
With the actual field measured pressure differentials calculated, one can find the actual installation motor torque at pile termination depth on Graph 9. Locate 1,700 psi and 1,950 psi values at the bottom of the graph. Then read upward until the motor curve line for the X12K5 motor is reached. Read horizontally to the left where the *Output Torque at the Shaft"* where can be found.

Design Example 1 output shaft torsion is determined to be estimated at **7,250 ft-lbs**.

Design Example 1B had a pressure differential of 1,950 psi pressure differential, which produced an output torque estimated at **8,200 ft-lb**.

Proper installation shaft torque is confirmed for Design Examples 1 and 1B

End Design Example 6A



Review of Results of Example 6 & 6A

One can see that the result obtained by the "Quick and Rough" analysis suggested the shaft torsion from field data was sufficient to provide the load capacity. The calculated method and the "Quick and Rough" solutions for the actual installation shaft torque values were similar.

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Design Example 7 – Ultimate Capacity from Field Data

In this exercise the anticipated ultimate capacities of the pile designs from Design Example 1 and 1B will be determined. This information will be used to confirm that the installed piles meet or exceed the design requirements set out in the original designs

Equation 2 from Chapter 1 is used to calculate the ultimate compressive capacity of the pile based upon data provided from the field. Recall that the *Design Example 1 - Heavy Weight New Construction Project* required an ultimate capacity at each pile of 60,000 pounds.

Equation 2: Helical Pile Ultimate Capacity

$$P_u = k \times T$$

Where,
P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
T = Final Installation Torque - (ft-lb)
(Averaged Over the Final 3 to 5 Feet)
k = Empirical Torque Factor - (ft^{-1})

Calculating the ultimate pile capacity using data from Design Example 1:

Ultimate Capacity of the 2-7/8" diameter, 0.262 wall piles installed in Example 1 ($P_{u\text{-Example 1}}$):

Where,
k = 8.5 (Table 12)
$T_{Example\ 1}$ = 7,140 ft-lb (Design Example 6)

P_u = 8.5 x 7,140 = 60,690 lb

P_u = <u>60,690 lb</u> > 60,000 lb O.K.

Calculating the ultimate pile capacity using data from Design Example 1B:

Ultimate Capacity of the 3-1/2" diameter piles with 0.300 inch wall thickness that were installed in Design Example 1B = $P_{u\text{-Example 1B}}$:

Where,
k = 7.5 (Table 12)
$T_{Example\ 1B}$ = 8,190 ft-lb (Design Example 6)

P_u = 7.5 x 8,190 = 61,425 lb

P_u = <u>61,425 lb</u> > 60,000 lb O.K.

The results of the calculations confirm the ultimate capacity determined from the field data exceeds the design ultimate capacity stated in the specifications of Design Examples 1 and 1B.

End Design Example 7

Design Example 7A – Ultimate Capacity from Field Data – "Quick and Rough" Method

This exercise will determine the ultimate pile capacity based upon field data using the "Quick and Rough" method. The comparison between the calculated design specifications and the actual field capacity will verify whether the pile installation is satisfactory.

Design Example 6A determined that the output torque at the motor shaft was 7,250 ft-lb at the termination of the pile installation. Graph 7 from Chapter 2 (shown on the next page) provides a method to demonstrate the ultimate capacity of the installed helical product. A comparison to the design requirement will determine if the installed pile capacity exceeds the specified ultimate capacity.

Estimate the location on the horizontal axis for shaft torsion of 7,250 ft-lb slightly to the right of the 7,250 ft-lb grid line and read up to the plot line for the 2-7/8 inch diameter shaft configuration. The legend near the top of the graph provides choices between square shafts and various tubular shafts. Read upward from the 7,250 ft-lb "*Motor Torque*" line until the bold dashed line that represents the 2-7/8 inch diameter shaft configuration is encountered. Then move horizontally to the vertical axis at left to see if installed pile ultimate capacity exceeds 60,000 pounds.

Looking carefully at the point where the horizontal plot intersects the *"Ultimate Capacity"* axis, the field generated shaft torsion at the termination of the pile installation shows to be slightly above 60,000 lb. This verifies that the actual installed pile capacity exceeds design specifications.

End Design Example 7

Review of Results of Example 7 & 7A

The value in using the "Quick and Rough" method is that it provides rapid results from the graphs. This method cannot tell exactly how much the field installation exceeded the design requirements, but it confirms whether the installation meets or exceeds specificaitons. If the engineer wants to know the actual installed ultimate capacity, then it must be calculated.

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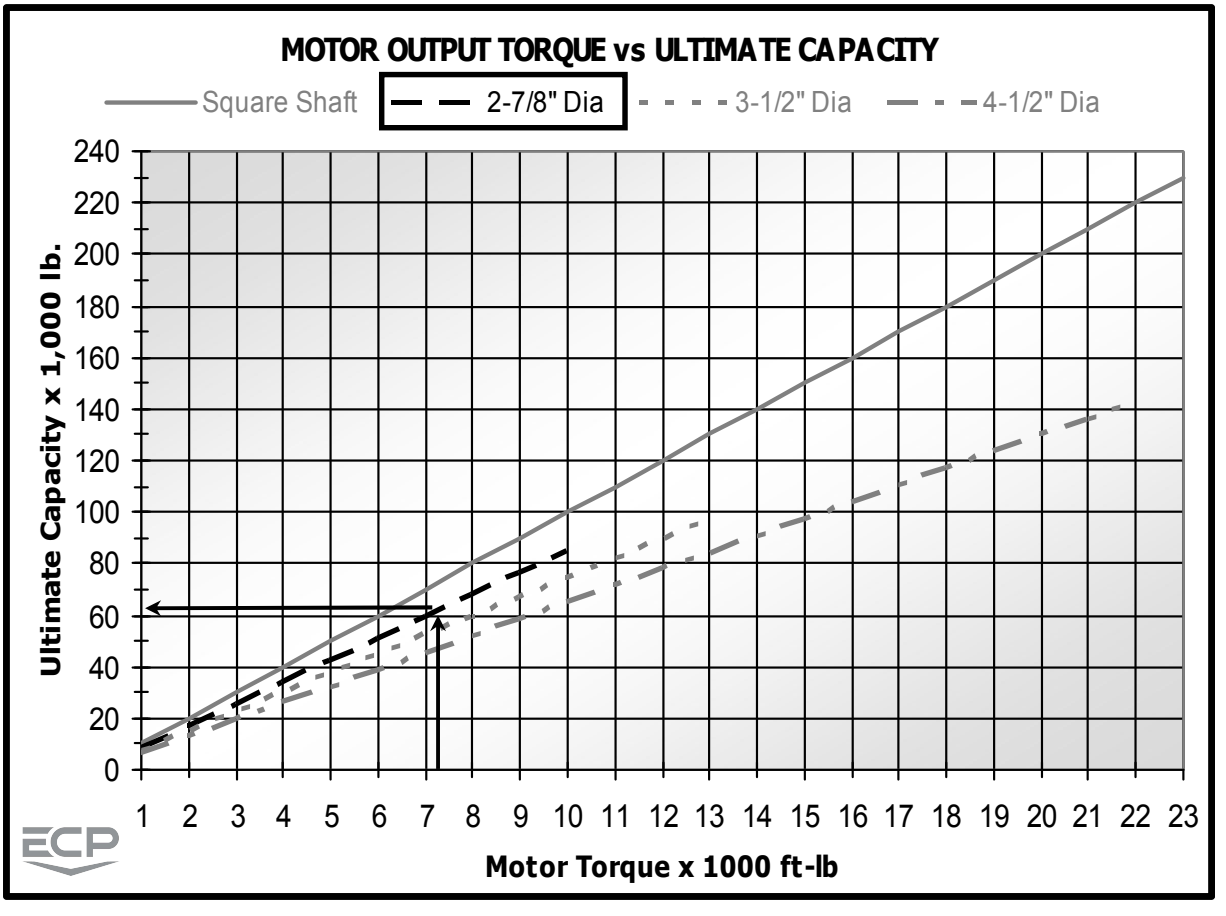

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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Chapter 3

ECP Helical Torque Anchors™ Design Examples

- **Heavy Weight New Construction**
- **Light Weight New Construction**
- **Basement Wall Tieback Anchors**
- **Retaining Wall Tieback Anchors**
- **Foundation Restoration**
- **Motor Output Torque**
- **Ultimate Capacity from Field Data**

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Design Example 1 – Heavy Weight New Construction – Cohesionless Soil

Structural Details:

- New Building – 2 story house with basement
- Estimated weight 3,700 lb/ft
- Working load on foundation piles – 30,000 lb
- Top of pile to be 12" above the soil surface
- Soil data:
  6 feet of sandy clay fill (CL), stiff
  Density = 110 pcf
  30 feet of medium grained, well graded sand (SW), medium dense, SPT "N" = 22
  Density = 120 pcf $\phi = 34^0$
  Water table = 14 ft
  Recommended target depth = 18 ft.

Torque Anchor™ Design:

1. Select the proper capacity equation and collect the known information.

Because the soil on the site is cohesionless, Equation 1b from Chapter 1 is used:

$\mathbf{P_u = \Sigma A_H (q\ N_q)}$ Where:

P_w = 30,000 lb
FS = Factor of Safety = 2.0

$\mathbf{P_u} = P_w$ x FS = 30,000 lb x 2.0 = **60,000 lb**.

$\mathbf{h_{mid} = 18\ ft}$.

(Choose the target depth to be 18 ft. This is the measurement from the surface to midway between the helical plates.)

$q = \gamma \times h_{mid}$

$\mathbf{q}$ = (110 lb/ft^3 x 6 ft) + (120 lb/ft^3 x 8 ft) + (120 – 62) lb/ft^3 x 4 ft) = **1,852 lb/ft^2**

$\mathbf{N_q = 24}$ "N" = 22 (Chapter 1 - Table 7)

Use Equation 1b to solve for the helical plate area that is needed.

$\mathbf{\Sigma A_H = P_u / (q\ N_q)}$

$\mathbf{\Sigma A_H =}$ 60,000 lb / 1,852 lb/ft^2 x 24

$\mathbf{\Sigma A_H = 1.35\ ft^2}$

2. Select the ECP Helical Torque Anchor™ suitable to support the load.

Referring to Chapter 1, Table 2 the 2-7/8" diameter x 0.262 wall thickness tubular pile shaft is selected as most economical for this application. Our project requires 60,000 pounds of compressive strength. The selected pile shaft has a *Compressive Load Limit* of 100,000 pounds and a *Useable Torsional Strength* of 9,500 ft-lbs.

Referring to Chapter 1, Table 10 the combination of helical plates is selected from the row opposite the 2-7/8" shaft size. At least 1.35 ft^2 of bearing area is needed to support an ultimate capacity of 60,000 pounds. The data

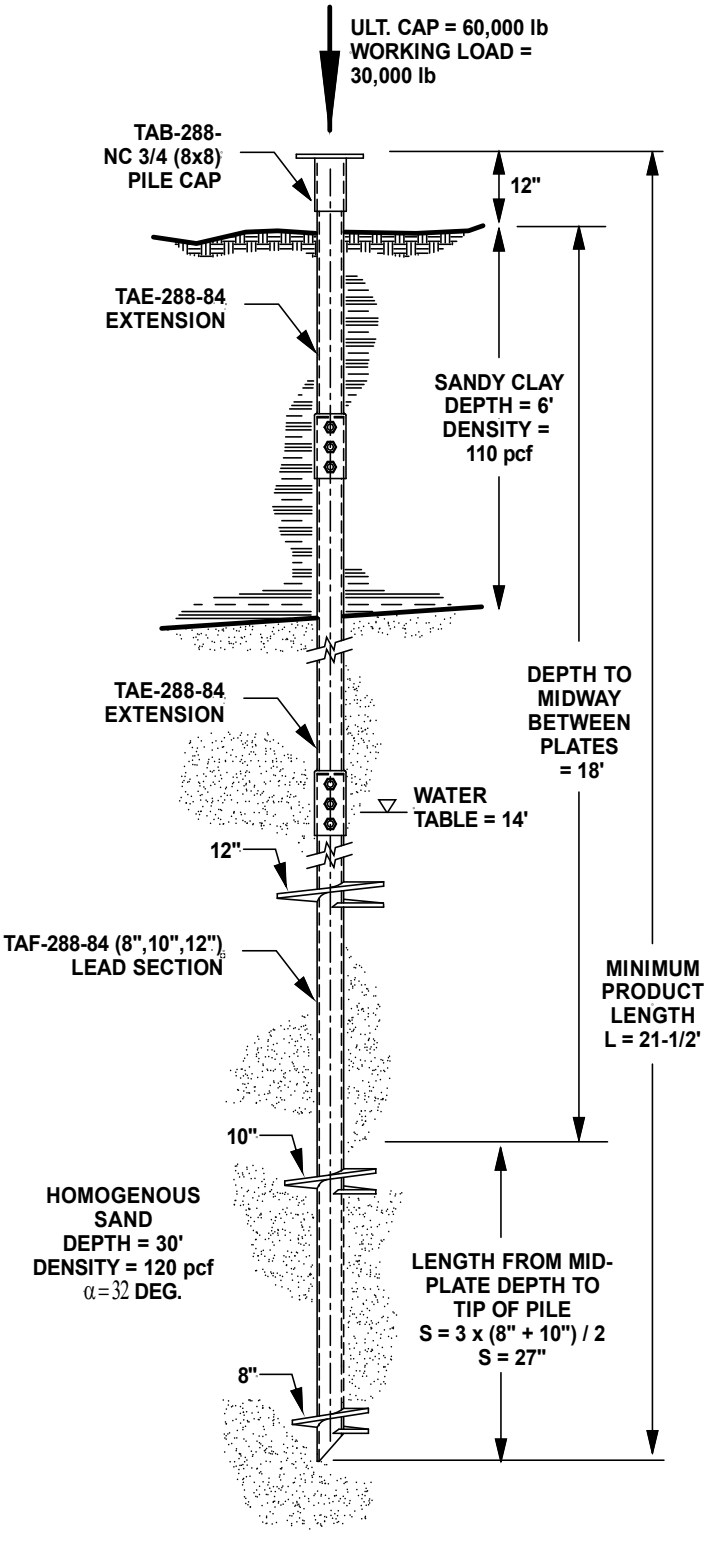

Figure 7. Design Example 1 & 2

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from the 2-7/8" diameter shaft on Table 10 in Chapter 1 is reproduce here:

6" Dia. = 0.151 ft^2
8" Dia. = **0.304** ft^2
10" Dia. = **0.500** ft^2
12" Dia. = **0.740** ft^2
14" Dia. = 1.024 ft^2

Select the combination of 8", 10", and 12" diameter plates on the 2-7/8" diameter tubular shaft.

$\mathbf{\Sigma A_H}$ = 0.304 + 0.500 + 0.740 = **1.544 ft^2**

$\mathbf{\Sigma A_H}$ = **1.54 ft^2** > 1.35 ft^2

This plate combination provides a total area of 1.54 ft^2, which exceeds the required plate area of 1.35 ft^2, arrived at from Equation 2b.

Designation for the selected Torque Anchor™ configuration is found in the product list on Page 7. The product selected is:

TAF-288-84 08-10-12

3. Installation Torque: Equation 2 in Chapter 1 calculates the estimated installation torque.

Equation 2: $T = P_u / k$, Where,

P_u = 60,000 lb. (30,000 Working Load x 2.0)
K = 8.5 (Chapter 1 - Table 12)

T = 60,000 lb / 8.5 ft^{-1}

T = 7,100 ft-lb

4. Torque Anchor™ Capacity Verification: A review of Table 2 in Chapter 1 indicates that the 2-7/8" diameter Torque Anchor™ has a *Useable Torsional Strength* of 9,500 ft-lb. The torque requirement of 7,500 ft-lb is 21% below the torsional limit of the shaft. The selection should work for this application based upon the soil report stating that the soil is sandy clay fill and homogenous sand with no mention of rocks, debris or other obstructions. A review of Table 11 in Chapter 1 shows that three 3/8" thick helical plates have a mechanical ultimate capacity of 120,000 pounds (40,000 lb x 3), which is double our requirement for this installation, so the mechanical capacity of the pile assembly exceeds the project requirements.

5. Installed Product Length. The installed length required to accomplish this design is a summation of all the lengths previously provided and determined.

A. The pile cap is placed **1 ft.** above grade level
B. h_{mid} = **18 ft.**
C. Length from mid-plate to pile tip
(Recall that the helical plates are spaced at three times the diameter of the nearest lower plate.)

h_{tip} = [(3 x 8" dia)+(3 x 10" dia)]/2 = 27"

h_{tip} = 2-1/2 ft (Round up to 30".)

L = 1 ft + 18 ft + 2-1/2 ft

L = 21-1/2 feet

6. Torque Anchor™ Specifications:
The specified Torque Anchor™ assembly will consist of the following:

- **TAF-288-84 08-10-12** This is a 2-7/8" diameter tubular product, having a standard length of 7 feet long, with an 8", a 10", and a 12" diameter plates that are 3/8" thick,
- **TAE-288-84** Extension, which is 7 feet long and includes coupling hardware. The coupling overlaps the previous section by 6 inches, which provides an effective length of the extension section at 6-1/2 feet. – Two extension sections are required
- **TAE-288-60** Extension, which is 5 feet long with coupling hardware. The coupling overlaps the previous section by 6 inches, which provides an effective extension length of 4-1/2 feet. – (One extension may be required.)
- **TAB-288 NC** Pile Cap that fits over the 2-7/8" diameter tubular shaft and has a 3/4" x 8" x 8" bearing plate.

The total length of the assembled products from the list is actually 24-1/2 feet long. The Torque Anchors™ shall be installed to minimum depth of 21-1/2 feet at the locations designated on the plan and must develop a sufficient compressive strength as determined by the minimum average installation torque of 7,100 ft-lb at this specified target depth or lower.

End Design Example 1

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Design Example 1A – Heavy Weight New Construction – "Quick and Rough" Method

Design Details:

- Compressive Service Load = 30,000 lbs at each pile. (See Figure 7 above.)
- The soil information about the site indicated 6 feet of stiff sandy clay fill (CL) followed by 30 feet medium dense sand (SP)

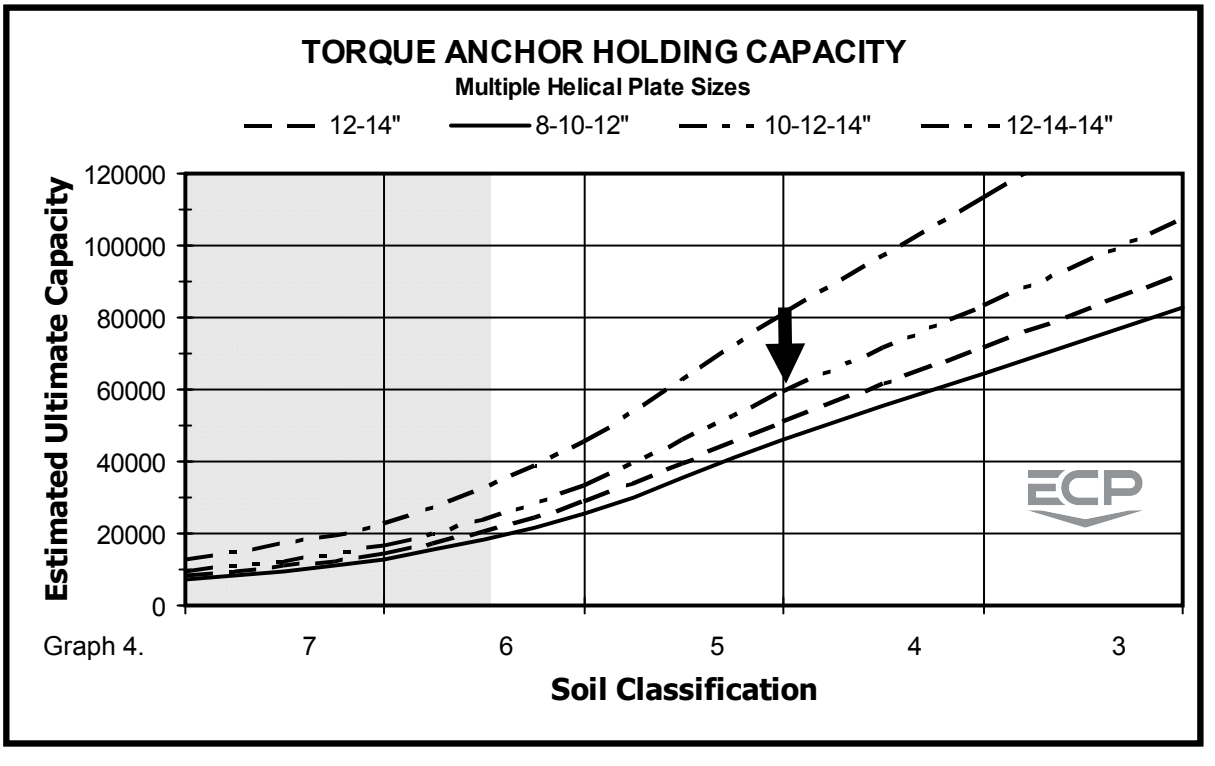
ECP Torque Anchor™ Design: The soil data provides only a rough description of the soil on the site with no SPT, "N", values or any indication of water table. The quick estimating method for designing the compression piles to support the structure is used. The thorough analysis for this project using the bearing capacity equations was demonstrated in Design Example 1 above. Comparison between the results of the two methods will be discussed.

1. Determine the Soil Class. Referring to the *Soil Classification Table* (Chapter 1 - Table 9) a Soil Class between 4 and 5 is selected based upon the description of the soil.

2. Ultimate Helical Pile Capacity. The engineer provided the Service Load (or working load) on this project based upon his knowledge of the calculated structural loading. Because the pile must have the capability to support more than just the service capacity, a Factor of Safety must be added to the Service Load to obtain the Ultimate Capacity of the pile design. In this case, a factor of safety of 2.0 is used to arrive at 60,000 pounds per pile ultimate capacity.

3. Select the proper compression pile from the estimated capacity graphs. Referring to Graph 4 from Chapter 1 (reproduced below), notice that the capacity line for a Torque Anchor™ with 10", 12" and 14" diameter helical plates attached crosses between Soil Class 4 & 5 at 60,000 pounds. The 10", 12" and 14" diameter plate configuration is selected for the design.

4. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 in Chapter 1 and select the 2-7/8 inch diameter tubular shaft that has sufficient capacity to support the load, and has sufficient torsional shaft strength for installation. The required ultimate capacity for each pile is 60,000 lbs. The 2-7/8 inch tubular product, with 0.262 inch wall thickness, has an *Axial Compressive Load Limit* rating of 100,000 pounds and a *Practical Load Limit based on Torsional Strength* of 80,000 pounds assuming a *Useable Torsional Strength* of 9,500 ft-lbs. The 2-7/8 inch diameter, 0.262 inch wall helical pile provides suitable torsional capacity and a sufficient practical load limit to exceed the ultimate load requirement of 60,000 pounds. The choice is verified.



Graph 4.

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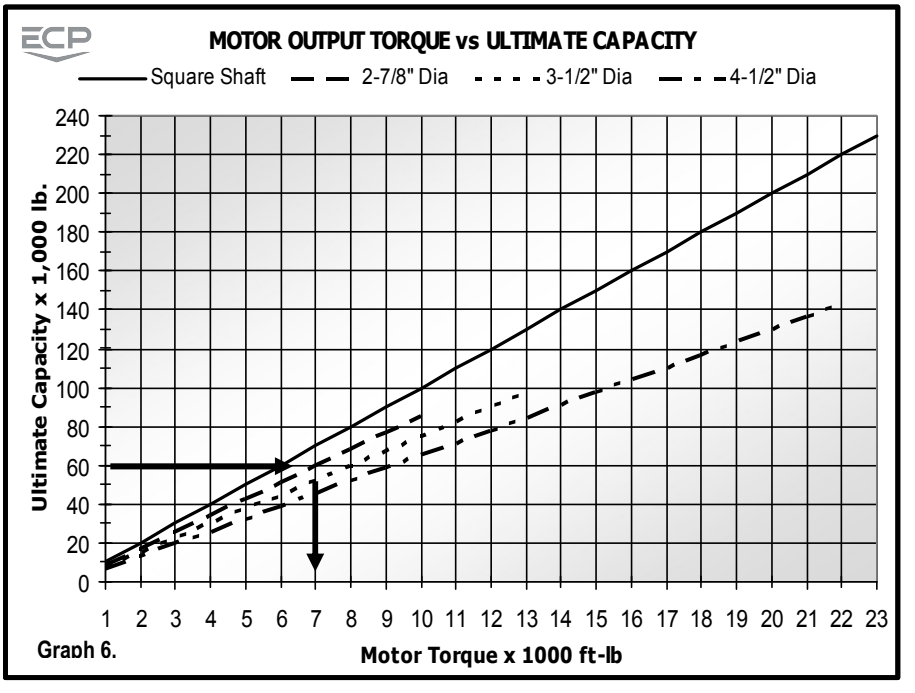
5. Installation Torque. Use Graph 6 from Chapter 2 or Equation 2 from Chapter 1 to determine the installation torque requirement for these piles.

Find a capacity of 60,000 pounds on the left side of Graph 6 and move horizontally to where the graph line for 2-7/8 inch diameter shafts intersects with 60,000 pounds. Read down to determine that the motor torque requirement is 7,000 ft-lb.

T = 7,000 ft-lb, min.



Graph 6.

Calculation from Equation 2 shows a comparison of results between the formula and the graph.

Equation 2: $\mathbf{T = P_u / k}$, Where,

P_u = 60,000 lb k = 8.5 (Table 12)

T = 60,000 lb / 8.5 ft^{-1} = 7,059 ft-lb

T = 7,100 ft-lb (Not a significant difference)

6. <u>Minimum</u> Embedment Depth. The minimum depth requirement from the surface to the shallowest plate on the pile must be at least six times the diameter of the 14" dia. top helical plate. (Chapter 1, Page 16)

D = 6 x (14 in / 12 in/ft) = 7 feet

D = Minimum Vertical Depth = 7 feet.

7. <u>Minimum</u> Required Shaft Length. Helical plates are spaced at three times the diameter of the next lower plate. The selected configuration was 10-12-14. The additional shaft length from the plate closest to the surface to the pile tip must be determined and added to minimum vertical depth just determined.

L = 7' + L_{tip} (Length from 10" to the 12" plates) + (Length from 12" to the 14" plate)

L = 7' + (3 x 10" Dia)/12" + (3 x 12" Dia)/12"

L = 7' + 2.5'+ 3' = 12-1/2 ft + 1 ft above grade provides the minimum shaft length

<u>Minimum</u> Shaft Length = 13-1/2 ft

The least amount of shaft needed for this project would be a 7 foot lead section plus a 7 foot extension (with a coupled length of 6-1/2 feet) provides 13-1/2 feet total.

8. Torque Anchor™ Specifications. The minimum pile assembly shall consist of:

- **TAF-288-84 10-12-14** – 2-7/8" diameter tubular shaft with 0.262" wall thickness that has a 10", a 12" and a 14" diameter plate on the 7'-0" long shaft,
- **TAE-288-84** extension – 7' extension & hardware. (Additional extensions will likely be needed to reach required shaft torsion.)

End of Example 1A

Review of Results of Example 1 & 1A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested a larger pile than predicted the calculations. The "Quick and Rough" system was designed to be conservative and this example demonstrates this. It is likely that the pile design of Example 1A will reach the required shaft torque at more shallow depth than the 8-10-12 pile. The pile must terminate at least 12-1/2 feet below grade to accurately predict capacity. <u>Termination at this shallow depth may not be acceptable to the engineer because the water table located at 14 feet below grade</u>. (Not mentioned in the soil data in this example.) This type of problem can appear when using incomplete soil data and *Torque Anchor™ Capacity Graphs* to obtain a "Quick and Rough" design.

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Design Example 1B – Heavy Weight New Construction – Weak Soil

In this variation, the same construction load and soil conditions prevail as stated in Design Example 1 with the exception that five feet of very weak soil now exists directly below the surface.

Additional Design Details:

- The soil data revealed a least five feet of very loose sand fill and very soft clay organic soil near the surface.
- Standard Penetration Test values for this weak layer were, "N" = 1 to 3 blows per foot - Soil Class = 8
- Below 5 feet the soil profile is the same as shown in Design Example 1.

ECP Torque Anchor™ Design: The soil data here suggests that below the initial five feet of very weak soil, the soil profile is similar to the soil in Design Example 1. Referring to Example 1, it can be recalled that the pile configuration required supporting the 60,000 pound ultimate load on pile using an 8-10-12 inch diameter plate configuration. The 2-7/8 inch diameter tubular shaft, with 0.262 inch wall thickness, had a sufficient *Axial Compressive Load Limit* to support the design load and sufficient *Useable Torsional Strength* to install the pile under the soil conditions represented in Design Example 1.

Knowing that there exists a layer of extremely weak (Class 8) soil near the surface on this site is important information because helical piles have slender shafts and require sufficient lateral soil support against the shaft to prevent shaft buckling under full load.

1. Determine the Buckling Strength. Table 2 in Chapter 1 lists the *Axial Compression Load Limits* for helical pile shafts when the shafts are installed into soil that provides sufficient lateral support along the pile shaft. Testing has suggested that shaft buckling is not an issue when the soil has a SPT value, "N" $\geq$ 5 blows per foot for solid square shafts and "N" $\geq$ 4 blows per foot for tubular shafts.

In this design example there exists a five foot layer of very weak Class 8 soil consisting of loose sand and soft organic clay located just under the surface. These very weak soils overlay inorganic clay that is able to support the required load where the soil will provide sufficient lateral shaft support. However, an *Axial Compressive Load Limit* of 100,000 pounds shown in Table 2 for a 2-7/8 inch diameter with 0.262 inch wall tubular shaft is not valid when this shaft passes through the Class 8 soil with SPT values reported to be between 1 and 3 blows per foot.

Instead of using Table 2 from Chapter 1 for the compressive load limit on the shaft, one must understand that the upper layer of soil is not able to provide sufficient lateral support to the shaft to prevent bucking. Table 15 in Chapter 1 *Conservative Critical Buckling Load Estimates* (reproduced below) demonstrates this quite clearly for various soil strengths and types. Referring to Table 15, it can be seen that the estimated buckling strength for the 2-7/8 inch diameter, 0.262 inch wall helical Torque Anchor™ shaft when it passes through soil consisting of very loose sand fill and soft organic clay having SPT values that range from "N" = 1 to 3 blows per foot is only 48,000 pounds.

This soil is not capable of lateral shaft support for 60,000 pound ultimate compressive load without concern for the shaft buckling within the weak upper level soils.

Table 15 Conservative Critical Buckling Load Estimates

Shaft Size	Uniform Soil Condition			
	Organics N ≤ 1	**Very Soft Clay N = 1 - 2**	Soft Clay N = 2 - 4	Loose Sand N = 2 - 4
1-1/2" Sq	26,000 lb	29,000 lb	33,000 lb	37,000 lb
1-3/4" Sq.	39,000 lb	43,000 lb	48,000 lb	55,000 lb
2-1/4" Sq.	74,000 lb	81,000 lb	90,000 lb	104,000 lb
2-7/8" Dia x 0.203"	36,000 lb	44,000 lb	62,000 lb	51,000 lb
~~**2-7/8" Dia x 0.262"**~~	39,000 lb	~~**48,000 lb**~~	69,000 lb	56,000 lb
3-1/2" Dia x 0.300"	63,000 lb	**78,000 lb**	110,000 lb	90,000 lb
4-1/2" Dia x 0.337"	113,000 lb	139,000 lb	160,000 lb	160,000 lb

2. Select a Pile Shaft with Suitable Buckling Strength. The axial ultimate compressive capacity requirement for this project is 60,000

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pounds on pile shaft. The selected shaft from Design Example 1 must be changed to a stiffer shaft to be able to successfully pass through the very week upper soil strata without buckling. A larger diameter tubular shaft is able to offer more shaft stiffness called Moment of Inertia or resistance to buckling. Referring once again to Table 15 (above); notice the row labeled "3-1/2 inch dia. x 0.300" shows a conservative estimated buckling load capacity of 78,000 pounds for the larger diameter shaft. Because there exists very weak soil near the surface in this example, the pile shaft diameter must be increased to provide resistance to shaft buckling when the fully loaded pile passes through these weak soils.

3. Torque Anchor™ Specifications. The Torque Anchor™ plate configuration remains as originally determined in Design Example 1 to support the structural load, but the shaft diameter must be increased to the 3-1/2 inch diameter, 0.300 inch wall tubular shaft for increased buckling strength:

- **TAF-350-84 08-10-12** Lead Section
- **TAE-350-84** Extension Section (2 required)
- **TAE-350-60** Extension Section
- **TAB-350 NC** Pile Cap that fits over the 3-1/2" tubular shaft and has a 3/4" x 8" x 8" bearing plate.

4. Installation Torque. The larger diameter tubular shaft now required passes through the soil less efficiently. This soil friction effect was fully discussed at the beginning of Chapter 2. As a result, when the design requires a change in shaft size, the installation torque requirement must be recalculated and will be higher for larger diameter shafts.

A check of Table 12 in Chapter 1 shows that the 3-1/2 inch diameter shaft has a recommended efficiency factor, "k" = 7-1/2 as compared to "k" = 8-1/2 that was used to estimate installation shaft torsion requirement for the 2-7/8 inch diameter tubular shaft.

Use Equation 4 introduced in Chapter 1 and repeated in Chapter 2 to calculate the new installation torque requirement for the larger diameter pile shaft.

Equation 5: $\mathbf{T = P_u / k}$, Where,
P_u = 60,000 lb
k = 7.5 (Table 12 – Chapter 1 & 2)

$T = 60{,}000 \text{ lb} / 7.5 \text{ ft}^{-1} = 8{,}000 \text{ ft-lb}$

T = 8,000 ft-lb, minimum

Earth Contact Products recommend that a Registered Professional Engineer conduct the evaluation and design of Helical Torque Anchors™ where shaft buckling may occur due to the shaft being installed through weak soil or in cases where the shaft is fully exposed without lateral shaft support.

End of Example 1B

Review of Results of Example 1 & 1B

It is very important to remember that buckling is an issue when a pile shaft passes through weak soils anywhere along the length of the shaft. The key numbers to remember here when looking at soil data are the Standard Penetration Test, "N", values throughout the depth of the borings. Watch for soil strata that are weaker than "N" < 4 blows per foot for solid square shaft installations and "N" < 5 blows per foot for tubular shafts. When such weak soils may be encountered, a check of the buckling strength of the selected shaft diameter is necessary.

Whenever the shaft must extend above ground in the air or in water without any later support at all, On the last page of Chapter 1, Graph 8 is provided to give ultimate load estimates for various shaft configurations relative to the length of exposed and unsupported column height.

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Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007. Fax at 913 393-0008.

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Design Example 2 – Light Weight New Construction – Cohesive Soil

Structural Details:

- New building – single story brick veneer house on monolithic concrete slab on grade
- The estimated weight is 1,269 lb/lineal ft on the 18" tall steel reinforced perimeter beam
- The client wants Torque Anchors™ on the perimeter of the structure because of lot fill.
- Top of shaft to be one foot below soil surface
- Soil data:
  4 feet of poorly compacted fill – "N" = 5
  6 feet of silty clay (CH) – "N" = 5 to 7
  15 feet of very stiff clay (CL) –
  "N"= 25 to 30 blows per foot.

Torque Anchor™ Design:

1. Select suitable pile spacing and working load from the description of the foundation beam. Use Equation 3 from Chapter 1 to determine the working load on the helical pile. From Graph 2 - Chapter 6, for an 18" beam choose "X" = 7 ft.

Equation 3: P_u = ("X") x (w) x (FS):

Where,
P_u = Ultimate Capacity of Torque Anchor™ (lb)
w = Foundation Load (lb/ft)
= 1,269 lb/lineal foot
FS = 2.0
"X" = Product Spacing = 7 ft

$\mathbf{P_U}$ = 1,269 lb/ft x 7 ft x 2.0

$\mathbf{P_U}$ = 17,766 lb (Use 18,000 lb.)

$\mathbf{P_U}$ = **18,000 lb**

2. Select the proper ultimate capacity equation and collect the known information. Because the soil on the site is cohesive (clay), Equation 1a from Chapter 1 is used:

Equation 1a: $\Sigma A_H = P_u / (9c)$ Where:

P_u = 18,000 lb
c = 3,400 lb/ft^2 (Table 5 – Assume "N" = 27 bpf)

$\mathbf{\Sigma A_H}$ = P_u / (9 x 3,400)

$\mathbf{\Sigma A_H}$ = 18,000 lb / 30,600 lb/ft^2

$\mathbf{\Sigma A_H = 0.59\ ft^2}$

3. Select the ECP Helical Torque Anchor™ suitable to support the load. The requirement states an ultimate compressive capacity of 18,000 lb. Referring to Table 2 in Chapter 1 the 1-1/2" solid square pile shaft is an economical choice because it has an *Axial Compressive Load Limit* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

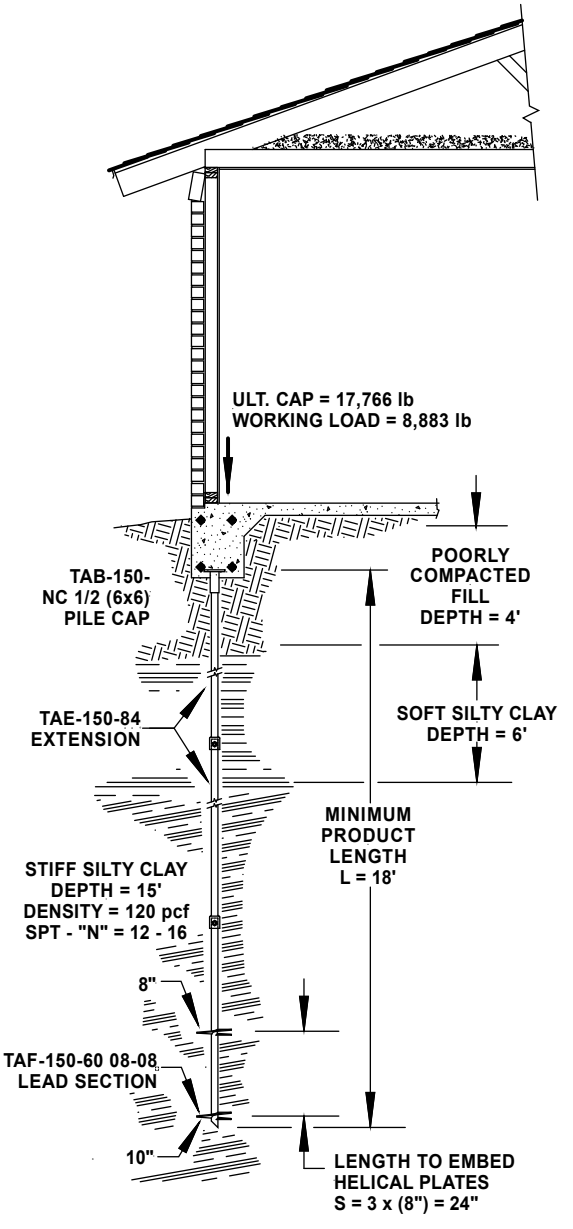

Figure 8. Design Example 2

Referring to Table 10 – Chapter 1, select a combination of plates from the row opposite the 1-1/2" square shaft size. At least 0.59 ft^2 of bearing area is required:

6" Dia. = 0.181 ft^2
8" Dia. = **0.333** ft^2
10" Dia. = 0.530 ft^2
12" Dia. = 0.770 ft^2

The combination of 8 inch diameter plates on the 1-1/2" solid square shaft is selected.

$\mathbf{\Sigma A_H}$ = 0.333 + 0.333 = **0.67 ft^2** > 0.59 ft^2 - O.K.

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This plate combination provides a total area of 0.67 ft^2, which exceeds the required 0.59 ft^2. As an alternate, a single 12" diameter plate could be selected with a projected area of 0.77 ft^2.

The product designation for the standard length Torque Anchor™ product is selected from the standard product listing on Page 5:

TAF-150-60 08-08

4. Installation Torque: Equation 2 in Chapter 1 gives an estimation of the required installation shaft torsion. It is determined as follows:

Equation 2: $T = P_u / k$

Where,

P_u = 18,000 lb

k = 10 (Table 12)

T = 18,000 lb / 10 ft^{-1}

T = 1,800 ft-lb

5. Torque Anchor™ Capacity Verification: A review of Table 2 in Chapter 1 indicates that the 1-1/2" solid square bar Torque Anchor™ has a *Useable Torsional Strength* of 7,000 ft-lb, which is nearly four times the required installation torque. There was no mention of rocks, debris or other obstructions in the project information. This is excellent product for this project. Table 9 in Chapter 1 shows the *Ultimate Mechanical Helical Plate Capacity* of 80,000 pounds (40,000 lb x 2) for the two 3/8" thick helical plates. The mechanical capacity of the selected pile configuration is more than adequate.

6. Installed Product Length. The stiff silty clay has been targeted as the soil where the helical plates will be founded. A depth of 18 feet is selected to set the plates below the weaker soils. This places the plates within the middle of the very stiff clay stratum. The installed length required to accomplish this design depth is:

- The depth from the surface to bearing = 18 ft.
- The pile cap is specified at one foot below grade level = 18 ft – 1ft = **17 feet**

The distance to midway between the twin 8 inch plates is 1 ft. (8" x $3D_{8"}$ = 24 in/2 = 12 inches)

The minimum shaft length requirement is:

L = 17 ft + 1 ft = 18 ft

7. Torque Anchor™ Specifications: The Torque Anchor™ assembly is specified from the standard products listed near the beginning of Chapter 1:

- **TAF-150-60 08-08**, which is a 1-1/2" solid square bar product on a standard 5 foot long shaft, with twin 8 inch diameter 3/8" thick plates
- **TAE-150-84** Extension, which is 7 feet long, but the coupling overlaps 3 inches providing an effective length of 6'-9" The extension includes coupling hardware. Two extensions are required.
- **TAB-150 NC** Pile Cap that fits over the 1-1/2" square bar and has a 1/2" x 6" x 6" bearing plate.

The total length of the assembled products from above is exactly 18-1/2 feet long. Placements shall be 7 feet on center along the perimeter grade beam and must develop an average installation torque of 1,800 ft-lb or more at the target depth of 18 feet. It is recommended that additional extension be on hand in case the shaft torque requirement is not achieved at 18 feet.

End Design Example 2

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Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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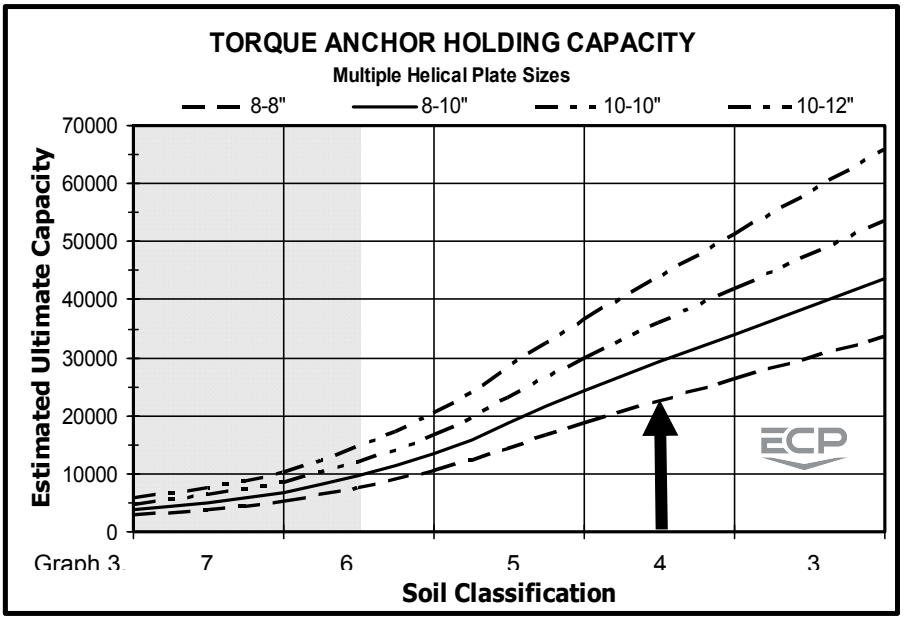
Design Example 2A – Light Weight New Construction – "Quick and Rough" Method

Design Details from Design Example 2:

- The ultimate capacity on each pile spaced at 7 feet on center is 18,000 pounds
- Top of shaft to be one foot below soil surface
- Soil data:
  4 feet of poorly compacted fill followed by 6 feet of silty clay (CH) over 15 feet of very stiff clay (CL)

ECP Torque Anchor™ Design: Because this is a compressive load application and there is some poorly compacted fill exists the selection of Soil Class must be conservative.

1. Determine the Soil Class.
Referring to the Soil Classification Table (Table 9 – Chapter 1) and noticing that the clay on the site is very stiff, Soil Class 4 is selected. The poorly compacted fill should not be a problem at this light loading as long as the helical plates are founded into the underlying very stiff clay.



2. Select the proper compression pile configuration from the estimated capacity graphs. Referring to Graph 3 from Chapter 1 (reproduced right), notice that the capacity line for an anchor with two 8" diameter helical plates attached crosses the midpoint of Soil Class 4 at 22,000 lb. The 8" – 8" diameter plate configuration is selected for the design.

3. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 in Chapter 1 to find a shaft with a suitable *Axial Compression Load Limit* and sufficient *Useable Torsional Strength.* The 1-1/2 inch solid square shaft has an *Axial Compression Load Limit* rating of 70,000 pounds based upon an installation torsional limit of 7,000 ft-lbs. The selected pile shaft provides suitable *Useable Torsional Strength* and a sufficient practical load limit to exceed the ultimate job load requirement of 18,000 pounds. Table 9 in Chapter 1 shows the *Ultimate Mechanical Helical Plate Capacity* of 80,000 pounds (40,000 lb x 2) for the two 3/8" thick helical plates. The selected and verified pile configuration is TAF-150-60 08-08 and is smaller than recommended from the earlier calculations in Design Example 2.

4. Installation Torque. Use Graph 6 from Chapter 2, please see Graph 6 on next page (or Equation 2 from Chapter 1) to determine the installation torque requirement for these piles. The ultimate capacity requirement is 18,000 pounds. Find this value on the left side of Graph 6 and find the intersection of 18,000 pounds with the graph line for solid square shafts. Then read down to determine the motor torque requirement of 1,800 ft-lb.

T = 1,800 ft-lb, minimum

Calculating the installation torque from Equation 2: (shown here for comparison)

Equation 3: $\mathbf{T = P_u / k}$, Where,
P_u = 18,000 lb k = 10 (Table 12)

$T = 18{,}000 \text{ lb} / 10 \text{ ft}^{-1} = 1{,}800 \text{ ft-lb}$

T = 1,800 ft-lb, minimum – O.K.

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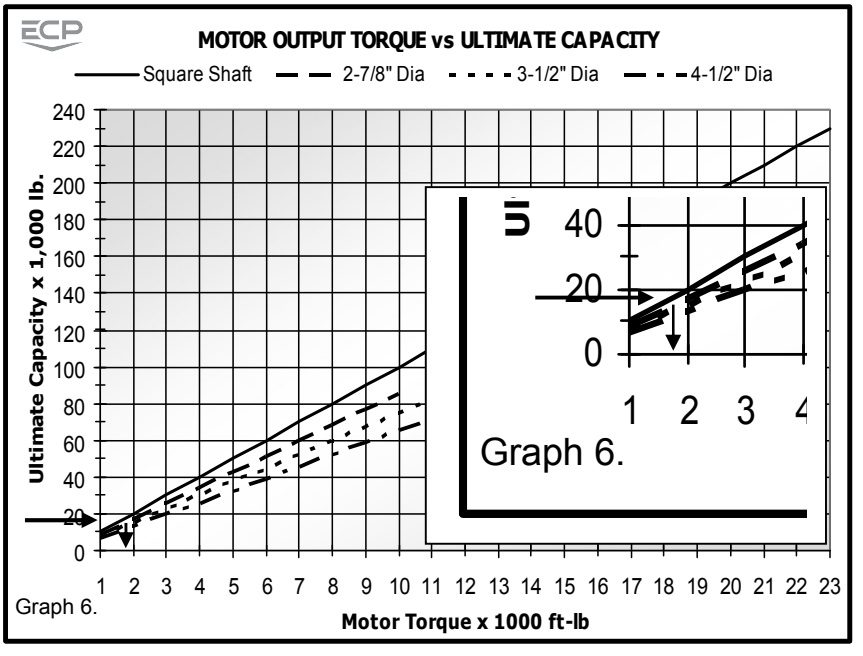
5. Minimum Embedment Depth. In Chapter 1, Page 16 of this manual, there is a discussion about helical products being deep foundation elements. The formulas presented herein are based upon "deep foundation theory". For the results of the calculations, tables and graphs to be accurate, there must be sufficient soil burden over the anchor or pile. Deep foundation theory dictates that the minimum depth from the surface to the shallowest plate must exceed six times the largest diameter.



Graph 6.

Minimum Embedment Depth:

$D = 6 \times d_{\text{largest plate.}} = 6 \times (8 \text{ in}/12 \text{ in}) =$ **4 ft***

*Notice: The soil information provided on this project stated at least 10 feet of soft soil existed below the surface before reaching stiff to very stiff clay. **The "Minimum Vertical Depth" for this design is invalid and the pile must be installed deeper than ten feet.**

D = Minimum Vertical Depth > 10 feet

6. Minimum Required Shaft Length. The shaft length between the two 8" plates must be determined and added to the 10 foot, minimum vertical depth. In addition, the engineer stated that the termination point for the pile caps shall be one foot below grade.

$L = 10' - 1' + (3D_{8"})/2 = 10$ ft

L = 10 ft*

The least amount of shaft required to exceed the minimum depth is a 5 foot lead and a 7 foot extension.

*Because the soil profile is known to be weak near the surface, a 10 foot long extension should be considered because it offers a depth of 15-3/4 feet (14-3/4 feet of shaft plus 1 ft depth to the pile cap. Additional extensions could be required if the torsion requirement of 1,800 ft-lb is not achieved between 10 ft and 15-3/4 ft depth.

7. Torque Anchor™ Selection:

- **TAF-150-60 08-08** – 1-1/2 inch solid square shaft that has two 8" diameter plate on the 5'-0" long shaft,
- **TAE-150-120** extension – 10' extension section & hardware, (9'-9" effective length). It recommended to have additional extensions on hand should the target shaft torsion not be achieved at 15-3/4 feet below grade.
- **TAB-150 NC** Pile Cap that fits over the 1-1/2" square bar and has a 1/2" x 6" x 6" bearing plate.

End of Example 2A

Review of Results of Example 2 & 2A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested the same pile design as determined by the calculated analysis. Therefore the TAF-150 08-08 is a valid design and should work well on this project. Recall that the calculated analysis used 18 feet dept to bearing.

* Example 2A, "Quick and Rough" method is not able to compensate for the fill soil near the surface. Recall that the graphs are based upon capacities of helical piles installed into ***homogeneous soil***, which means that the soil is consistent at all depths. Clearly this is not the case in this example because of the fill soil. A pile installation deeper than 15-3/4 feet might be required to support the load.

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Design Example 3 – Basement Wall Tieback Anchor -- Cohesive Soil

Structural Details:

- Cast concrete basement wall is 8 feet tall and 10 inches thick.
- Unknown soil backfill against the wall is 7 feet high
- The only soil information about the site is that there exists inorganic clay (CL), stiff to very stiff – 115 pcf

Torque Anchor™ Design: Because there is so little information about the soil on this project, the designer will have to make judgments about the conditions on the site.

1. Estimate the lateral soil force against the wall. Equation 5 presented in Chapter 1 is selected because hydrostatic pressure must be assumed as part of the reason for the damage to the wall.

$\mathbf{P_H = 45 \times (H^2)}$

Where, H = 7 ft

$P_H = 45 \times (49) = 2{,}205$

$\mathbf{P_H = 2{,}205}$ **lb/lineal foot**

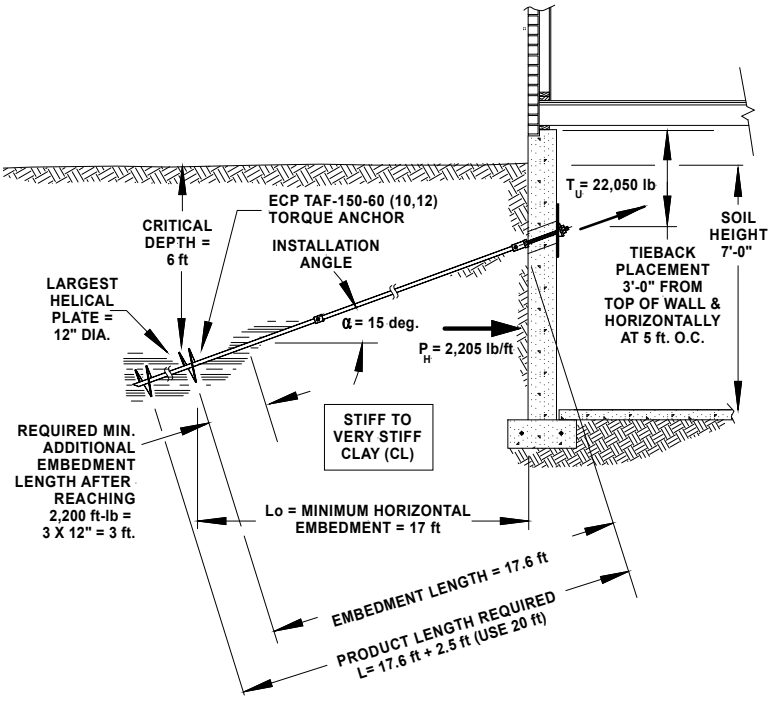

Figure 9. Design Example 3

2. Ultimate Tieback Capacity. Choose a Torque Anchor™ spacing of 5 ft on center as typical for a damaged basement wall of unknown construction. Use Equation 8 from Chapter 1 to determine the Ultimate Capacity on the Torque Anchor™.

Equation 8: $\mathbf{T_u = (P_H) \times (\text{“X”}) \times FS}$, Where:

T_u = Ultimate Tieback Capacity – lb
P_H = Horizontal Soil Force on Wall – lb/lin.ft
FS = Factor of Safety (Typically 2:1 permanent support and 1.5:1 for temporary support)
“X” = Center to Center Spacing of Tiebacks - ft

In this example, the ultimate capacity becomes:

$\mathbf{T_u} = 2{,}205 \text{ lb} \times 5 \text{ ft} \times 2$

$\mathbf{T_u = 22{,}050 \text{ lb}}$

3. Select the proper bearing capacity equation and collect the known information.

Because the soil on the site is cohesive, Equation 1a – Chapter 1 is used:

Equation 1a: $\mathbf{\Sigma A_H = T_u / (9c)}$, Where:

$\mathbf{T_u = 22{,}050 \text{ lb}}$
$\mathbf{c = 2{,}000 \text{ lb/ft}^2}$
(Table 5 - Chapter 1 – Stiff to Very Stiff Clay)

$\mathbf{\Sigma A_H} = T_u / (9 \times 2000 \text{ lb/ft}^2)$

$\mathbf{\Sigma A_H} = 22{,}050 \text{ lb} / 18{,}000 \text{ lb/ft}^2$

$\mathbf{\Sigma A_H = 1.23 \text{ ft}^2}$

4. Select the ECP Helical Torque Anchor™ configuration suitable to support the load.

Referring to Table 2 – Chapter 1 choose the 1-1/2” solid square pile shaft. An ultimate tensile strength for this job is 22,050 lb and the 1-1/2 inch solid square shaft an *Ultimate Limit Tension Strength* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

Referring to Table 10 – Chapter 1 (reproduced on next page), a combination of plates is selected from the projected plate areas in the row opposite the 1-1/2” solid square shaft size. At least 1.23 ft^2 of bearing area is needed:

6” Dia. = 0.181 ft^2 8” Dia. = 0.333 ft^2
10” Dia. = **0.530** ft^2 12” Dia. = **0.770** ft^2
14” Dia. = 1.053 ft^2

$\mathbf{\Sigma A} = 0.530 + 0.770 = \mathbf{1.30 \text{ ft}^2}$

The combination of 10” and 12” diameter plates on the 1-1/2” solid square shaft provides a total area of 1.30 ft^2, which exceeds our requirement of 1.23 ft^2.

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Table 10. Projected Areas* of Helical Torque Anchor™ Plates						
Helical Plate	**6" Dia.**	**8" Dia.**	**10" Dia.**	**12" Dia.**	**14" Dia.**	**16" Dia.**
Shaft	**Projected Area – ft²**					
1-1/2" Sq.	0.181	0.333	0.530	0.770	1.053	1.381
1-3/4" Sq.	0.175	0.328	0.524	0.764	1.048	1.375
2-1/4" Sq.	0.161	0.314	0.510	0.750	1.034	1.361
2-7/8" Dia	0.151	0.304	0.500	0.740	1.024	1.351
3-1/2" Dia	0.130	0.282	0.478	0.719	1.002	1.329
4-1/2" Dia	0.086	0.239	0.435	0.675	0.959	1.286

* Projected area is the face area of the helical plate less the cross sectional area of the shaft.

The Torque Anchor™ tieback product designation **TAF-150-60 10-12** is selected from the Standard Product Tables near the beginning of Chapter 1. This anchor configuration will provide the 22,050 pound ultimate capacity required for tension support when spaced at 5 feet center to center along the wall.

5. Installation Torque. Use Equation 2 from Chapter 1, or use Graph 6 from Chapter 2 shown in the example above to calculate the installation torque requirement for this anchor.

Equation 2: $T = T_u / k$, Where,

T_u = 22,050 lb

k = 10 (Table 12, below from Chapters 1 & 2)

$T = 22{,}050 \text{ lb} / 10 \text{ ft}^{-1}$

T = 2,200 ft-lb

The torque must be developed for a long enough distance to insure that the helical plates are properly embedded to develop the required tension capacity. The torque requirement must be averaged over a distance of at least three times the diameter of the largest plate. The 2,200 ft-lbs must be continuous for a minimum distance of 3 feet (12" diameter plate x 3 dia.) before terminating the installation.

Table 12. Soil Efficiency Factor "k"		
Torque Anchor™ Type	**Typically Encountered Range "k"**	**Suggested Average Value, "k"**
1-1/2" Sq. Bar	9 - 11	10
1-3/4" Sq. Bar	9 - 11	10
2-1/4" Sq. Bar	10 - 12	11
2-7/8" Diameter	8 - 9	8-1/2
3-1/2" Diameter	7 - 8	7-1/2
4-1/2" Diameter	6 - 7	6-1/2

6. Minimum Horizontal Embedment: Determine the *Minimum Embedment Length* from Equation 9 in Chapter 1. (Also see Figure 3 – Chapter 1, which is reproduced on next page for reference.)

$L_0 = H + (10 \times d_{Largest})$ Where,

H = Height of Soil (7 ft)

$d_{Largest}$ = Largest Plate Dia. (12 in = 1 ft)

$L_0 = 7 \text{ ft} + (10 \times 1 \text{ ft})$

L_0 = 17 feet

Min. Horizontal Embedment = 17 feet

7. Calculate the Critical Depth:

Use 6 x $d_{Largest\ plate.}$ (Discussed Page 31)

6 x 1 (ft) = 6 feet (See Figure 3, below.)

Critical Depth = 6 feet.

8. Select Installation Angle and Determine Product Length. Position the anchors to penetrate the wall at two feet below the soil surface. **(Note: This is three feet from top of basement wall.)** From Step 7 it was determined that the Critical Depth, "D", of 6 feet is required, which means that the 12" diameter plate must terminate at least 4 feet lower than where the anchor shaft penetrated the wall. Select an installation angle of 15^0 and determine the minimum installed product length that will provide the additional 4 feet of soil depth required at the 12" plate to achieve critical depth.

This can be determined as follows:

$L_{15\ deg} = (4 \text{ ft} / \sin 15^0)$

$L_{15\ deg} = 4 \text{ ft} / 0.259 =$ **15-1/2 ft**

The minimum distance from the wall to the 12" plate when installed at a 15^0 downward angle is 15-1/2 feet to insure meeting the critical depth requirement of 6 feet. Comparing the minimum horizontal embedment length of 17 feet from Step 6 to the 15-1/2 foot length required for obtaining Critical Depth at 15^0 installation angle; it is clear that 17 feet of horizontal length of embedment from the wall is the controlling distance. The additional length of shaft required to get to the 10 inch diameter plate to the required distance of 17 feet at a shaft installation angle of 15^0 downward must be calculated.

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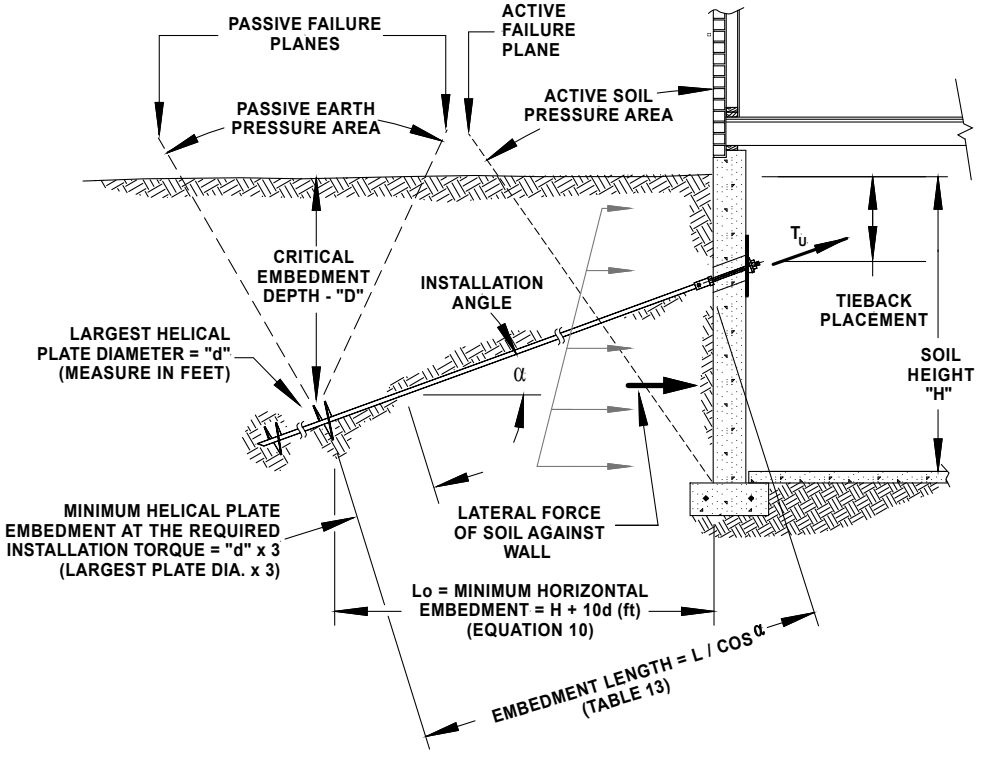

Figure 3. Elements of Tieback Design

Use the equation shown in Chapter 1 on Table 13 for a 15^0 downward angle.

$\mathbf{L_{15\ deg}}$ = [H + (10 $d_{largest}$)] x 1.035

$\mathbf{L_{15\ deg}}$ = [7 ft + (10 x 1 ft] x 1.035 = **17.6 feet**

Total Shaft Length Needed:

$\mathbf{L_{Total}} = \mathbf{L_{15}} + L_{Tip}$ (Where $L_{Tip} = 3D_{10"}$)

$\mathbf{L_{Total}}$ = 17.6 ft + (3 x 10")/12"

$\mathbf{L_{Total}}$ = 17.6 ft + 2.5 ft = **20.1 ft**

Use L_{Total} = 20 ft $\alpha = 15^0$

Specify required product length by selecting standard product assembled lengths exceeding 20' long.

8. Torque Anchor™ Specifications. The Torque Anchor™ assembly will consist of products selected from the Standard Product Selection near the beginning of Chapter 1.

- **TAF-150-60 10-12** -- 1-1/2" solid square bar with a 10" and a 12" diameter plate attached to a standard 5'-0" long shaft length.
- **TAE-150-60** extension – 5' extension bar & hardware are specified for ease of installation in the basement. (4'-9" effective length). Three extensions are required. (Possibly four extensions could be needed for if insufficient shaft torsion is measured at 20 ft.)
- **TAT-150** – Light Duty Transition that connects from 1-1/2" square bar to a 22" length of continuous threaded rod, with hardware.
- **PA-SWP** – Stamped steel wall plate that measures 11" x 16"

The length of all of the Torque Anchor™ shafts plus the threaded bar that penetrates the wall is 19'-3" + 20" = 20'–11". The anchors shall mount along the wall on 5 feet on center at 3 feet from the top of the basement wall. (Two feet below soil level) The anchors are angled down at 15^0. The tieback must be installed to a minimum shaft length of 20 feet and must develop an average installation torque of 2,200 ft-lb or greater for a minimum distance of at least 3 feet after reaching 17 feet, otherwise the anchor must be driven deeper using additional extension sections until the torque requirement is satisfied.

End of Example 3

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Design Example 3A – Basement Wall Tieback Anchor – "Quick and Rough Method"

Mandatory Installation Requirements
Before beginning a complicated basement tieback anchor design like Design Example 3A using the "Quick and Rough" method with only general information and data from graphs and tables; the following **Mandatory Installation Requirements** MUST ALWAYS BE DEFINED in the final design before the "Quick and Rough" method will be successful.

Before performing a "Quick and Rough Design" for a basement tieback system, the following items MUST be defined and included for a "Safe Use" design:

1. The anchor must penetrate the wall at between 3 and 5 feet from the floor of an 8 foot tall basement wall. (This is also valid for a 9 foot basement wall with no more than eight feet of soil overburden.
2. There must be at least two feet of soil above the penetration point for the tiebacks.
3. Ground water must be assumed present behind the wall.
4. Unless otherwise given, the working soil load on the wall shall be assumed to be 3,250 lb/lin.ft. of wall. To obtain the load on each placement, multiply 3,250 lb/lineal ft by a Factor of Safety = 2 and by the spacing of the anchors on the wall (feet).
5. Unless otherwise given, the maximum spacing of tiebacks shall be no more than 5 feet on center with a downward angle 15^0.
6. A minimum installed shaft length of 22 feet from the wall to the tip of the tieback assembly shall be used when the largest helical plate on the shaft is 12 inches diameter. If the largest plate diameter is 14 inches the minimum installed shaft length at a 15^0 downward is 25 feet.

IMPORTANT: If the tieback reaches maximum torque before obtaining the length requirement, the helical plate area MUST be reduced and the anchor MUST be installed to the minimum length stated above, or the possibility that the anchor will load the wall and fail exists.

If any of the conditions are encountered that are substantially different from what is normally encountered, an analysis and design shall be performed by a Registered Professional Engineer, or the engineer needs to review and approve your design.

Structural Details: The only data available:

- Cast concrete basement wall is 8 feet tall and 10 inches thick.
- Backfill against the wall is 7 feet - Unknown soil
- The only soil information given: There exists inorganic clay (CL), stiff to very stiff – 115 pcf in the area

1. Determine the Soil Class. Referring to the Soil Classification Table (Chapter 1 - Table 9) the soil class of 4 - 5 is selected based upon the soil description being "stiff to very stiff clay".

2. Ultimate Helical Pile Capacity. In this design the largest spacing allowed is selected – five feet on center. The Ultimate Design Load for the project is estimated at:
T_u = 3,250 lb/lin ft x 2 x 5 ft =
T_u = **32,500 lb** per anchor

3. Select the proper tieback anchor from the estimated capacity graphs. Referring to Graph 3 from Chapter 1 (reproduced on next page), notice that the capacity line for an anchor with an a 10" and 12" diameter helical plate suggests a capacity in excess of at 32,500 lb at Soil Class between 4 - 5. The 10"-12" diameter plate configuration is selected for the design.

4. Check the Shaft Strength and Torsional Strength to see which shaft is suitable. Refer to Table 2 to verify that the 1-1/2 inch solid square shaft has sufficient capacity to support the tensile load, and has sufficient torsional shaft strength for installation. The required ultimate capacity for each anchor is 32,500 lbs. (Step 2.) The 1-1/2 inch solid square shaft has an *Ultimate Limit Tension Strength* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs. The selected helical pile provides suitable torsional capacity and a sufficient practical load limit to exceed the ultimate load requirement of 32,500 pounds. The choice is verified.

5. Installation Torque. Use Equation 2 from Chapter 1, (or Graph 6 demonstrated in Design

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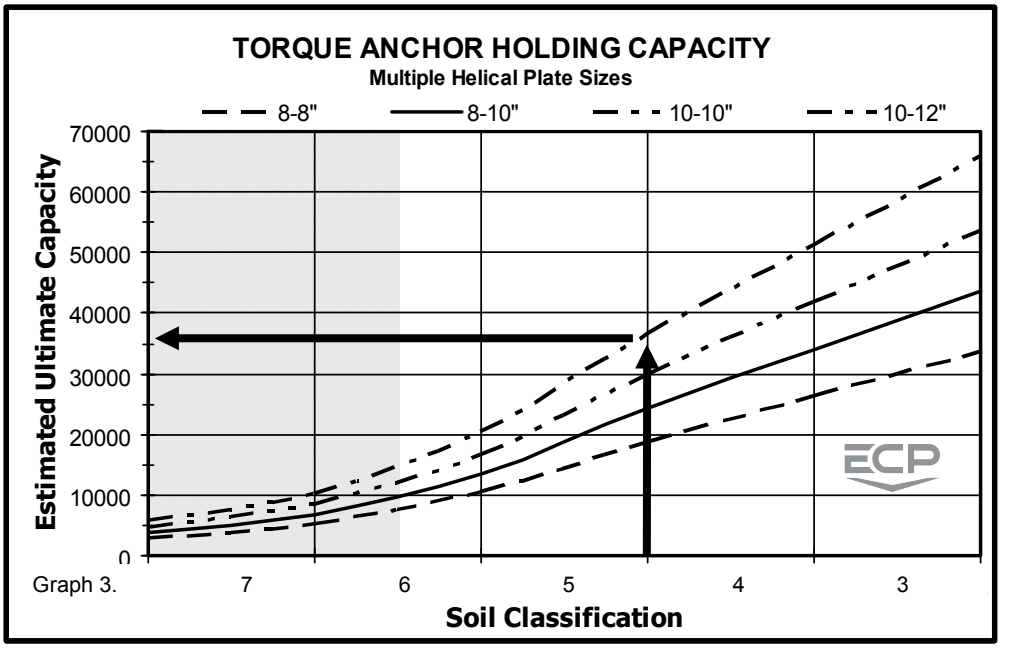

Graph 3.

Example 2A) to calculate the installation torque requirement for this pile.

Equation 2: $T = P_u / k$, Where,

P_u = 32,500 lb

k = 10 (See Table 12 in Design Example 3)

$T = 32{,}500 \text{ lb} / 10 \text{ ft}^{-1} = 3{,}250 \text{ ft-lb}$

T = 3,300 ft-lb, minimum

6. Torque Anchor™ Specifications.

- **TAF-150-84 10-12** – 1-1/2 inch round corner solid square shaft that has a 10 inch diameter and a 12" diameter plate attached to a 7'-0" long shaft,
- **TAE-150-60** extension – 5'-0 extension section & hardware. This extension has a coupled length of 4'-9". The installation will need four extensions to exceed 22 feet total length.
- **TAT-150** – Light Duty Transition that connects from 1-1/2" square bar to a 20" length of continuous threaded rod, with hardware.
- **PA-SWP** – Stamped steel wall plate that measures 11" x 16"

The items shown below are from the list of **Mandatory Installation Requirements** at the beginning of this example. **These requirements MUST always be included** when designing "Quick and Rough" basement tieback projects.

7. Mandatory Installation Requirements:

- **Anchors shall be installed at 3 to 6 feet from the floor of the standard 8 foot basement wall.**
- **Anchors shall have a minimum of two feet of soil cover from point of penetration of the wall to the ground surface.**
- **Anchors shall be installed with a declination of 15^0.**
- **These anchors with 12" diameter largest helical plates shall be installed to a length not less than 22 feet.**
- **Anchors shall achieve installation shaft torsion of at least 3,300 ft-lb over the final three feet of installation prior to termination.**

End of Example 3A

Review of Results of Example 3 & 3B

One can see that the result obtained by the "Quick and Rough" analysis suggested a similar anchor configuration as predicted by using the bearing capacity equation. Because this is a general use "Quick and Rough Design" there are design parameters put in place to cover most situations with an eight foot tall basement wall (or nine foot wall with no more than eight feet of soil overburden). In addition, many installation requirements MUST be followed to provide a safe design when a "Quick and Rough" design method is used. These installation requirements were explained in the Design Example 3B. If the job not typical, consult a Registered Professional Engineer.

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Design Example 4 – Retaining Wall Tieback Anchor -- Cohesionless Soil

Structural Details:

- New construction steel reinforced cast concrete retaining wall – 12 ft tall
- Backfilled with granular fill at the wall with free flow drainage tiles at the footing
- The soil information about the site indicated medium to coarse gravelly sand (SP), Medium dense – 130 pcf
- Standard Penetration Blow count "N" = 20 blows per foot at 10 feet deep
- $\Phi = 32^0$

1. Estimate the lateral soil force against the wall. Equation 6 in Chapter 1 is selected because the design specifies that the hydrostatic pressure is relieved by the drainage system.

Equation 6: $P_H = 24 \times (H^2)$, Where, H = 12 ft.

P_H = 24 x (12' x 12') = 3,456 (Use 3,500)

P_H = 3,500 lb/lineal foot

2. Select a Torque Anchor™ and make an analysis to see if it is suitable. In this example the TAF-175-60 08-10-12 is tried, a 1-3/4" solid square bar product with an 8", 10" and a 12" diameter helical plate attached. From the soil data available the soil is cohesionless; Equation 1b from Chapter 1 is used:

Equation 1b: $T_u = \Sigma A_H (q\ N_q)$ Where,

$A_{8"}$ = 0.328 ft^2 (From Table 10 – Chapter 1)
$A_{10"}$ = 0.524 ft^2 (See also pg 63 above.)
$A_{12"}$ = 0.764 ft^2

ΣA_H = 0.328 + 0.524 + 0.764 = **1.62 ft^2**

q = γ x h_{mid}

h = Design Embedment = 10 ft. is selected
(This is the measurement from the ground surface to where the 12" diameter helical plate is located when the tieback is fully installed - See Figure 10, below.)

γ = Soil density = **130 lb/ft^3**

N_q = **23** ("N" = 20 & $\Phi = 33^0$) Table 7 Chapter 1

T_u = 1.62 ft^2 x (130 lb/ft^3 x 10 ft) x (23)

T_u = 48,438 lb

3. Torque Anchor™ Spacing. Determine the Torque Anchor™ spacing along the wall for the configuration selected. Use Equation 4 from Chapter 1.

Equation 4: "X" = T_u / [P_H x (FS)], Where,
"X" = Product Spacing
T_u = Ultimate Capacity on Torque Anchor™
P_H = Lateral Force on Wall (lb/lin.ft)
FS = Factor of Safety (Typically 2.0:1)

"X" = 48,438 lb/[3,500 lb/lin.ft x 2 (FS)] = **6.9'**

4. Installation Torque & Embedment. Use Equation 3 – Chapter 1 to calculate the installation torque for this anchor.

Equation 3: $T = T_u / k$ Where,
T_u = 48,438 lb (Step 3)
k = 10 (Table 12 – Chapter 1)

T = 48,438 lb/10 ft^{-1} = 4,844 ft-lb.

T = 4,900 ft-lb

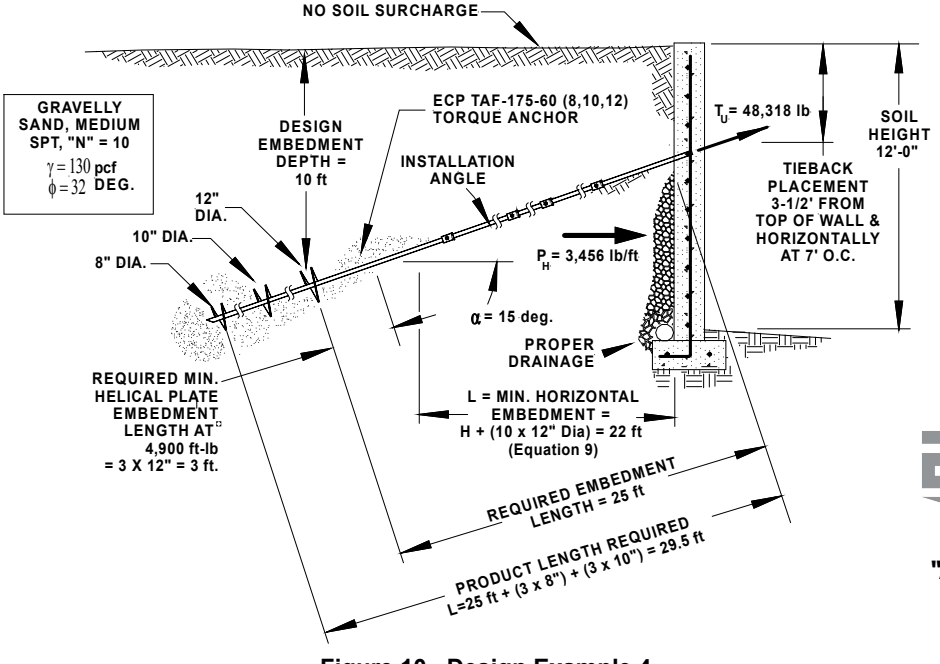

Figure 10. Design Example 4.

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The torque must be developed for a distance great enough to insure that the helical plates are properly embedded to develop adequate tension capacity. The torque requirement must be averaged over a minimum distance of at least three times the diameter of the largest plate. The installer must average at least 4,900 ft-lbs through a distance of 3 feet. (Three times the 12" diameter plate.)

5. Select Installation Angle and Product Length. The anchors penetrate the wall at 3-1/2 feet below the soil surface. (This is approximately 0.3 times the wall height.) Recall that embedment depth was selected at 10 ft in Step 2. This means that the depth below the soil surface to the location of the 12" helical plate must be at least 10 feet. Try using an installation angle of 15^0 and determine the product length that will provide the 10 feet of vertical embedment required. (The required depth of embedment is 10 ft. Recall that the distance from the top of grade level to where the anchors will penetrate the wall is 3-1/2 feet. The additional depth required by the anchor is 6-1/2 feet (10 ft - 3-1/2 ft) = 6-1/2 feet.)

The shaft length required at 15^0 to achieve the 6-1/2 foot vertical depth is calculated using the equation given in Table 13 in Chapter 1 for a declination angle of 15^0.

$\mathbf{L_{15}}$ = (6-1/2 ft/sine 15^0) = 6-1/2 ft/0.259 = **25 ft**

The minimum shaft length at 15^0 installation angle is 25 feet, which will insure that the 12" diameter plate is located at a total embedment depth of 10 feet below the surface.

Comparing the *Minimum Horizontal Embedment* length from Equation 9 to the *Minimum Embedment Depth* (Step 5):

$\mathbf{L_0}$ = 12 + [10 x 1'] = **22 ft**.

It is clear that L_{15} = 25 ft (Length to insure required 10' soil embedment depth determined in Step 5) exceeds the *Minimum Horizontal Embedment* requirement.

The 10 ft depth of embedment also exceeds the Critical Depth, "D" = 6 x d_{12} = 6 x 12"/12 = **6 ft**

L_{15} = 25' > L_0 = 22' using D = 6

Use L_{15} = 25 ft

Minimum Required Shaft Length:

L = L_{15} + L_{Tip} (Distance shallowest plate to tip)

Where: $L_{Tip} = (3 \times d_{plate\ 1}) + (3 \times d_{plate\ 2})$

L_{Tip} = [(3D x 8" dia)+(3D x 10" dia)]/12

L_{Tip} = 4-1/2 ft

L = L_{15} + L_{Tip} = 25 ft + 4-1/2 ft = **29-1/2 ft**

L = 29-1/2 feet **$\alpha = 15^0$**

6. Torque Anchor™ Capacity Verification: A review of Table 2 – Chapter 1 indicates that the 1-3/4" solid square bar Torque Anchor™ has a *Ultimate Limit Tension Strength* of 100,000 lb and a *Useable Torsional Strength* of 10,000 ft-lb. The project ultimate tension capacity and torsional requirement are approximately one-half of the mechanical and torsional capacity of the product. There was no mention about rocks, debris or other obstructions in the soil so installation should be smooth. A check of Table 11 – Chapter 1 indicates that three 3/8" thick helical plates have an ultimate capacity of 120,000 pounds (3 x 40,000 lb), so the total mechanical capacity of the anchor is satisfactory.

7. Torque Anchor™ Specifications. The required Torque Anchor™ assembly consists of:

- **TAF-175-84 08-10-12** - 1-3/4" solid square bar, on a standard 7' long shaft with 8", 10" & 12" dia. plates,
- **TAE-175-84** extensions - 7 feet long & hardware (6'-9" effective length) – **Three extensions are required**.
- **TAE-175-60** extensions - 5' long with hardware (4'-9" effective length) – **One extension is required.**
- **TAB-175 T** Tension Pile Cap – 3/4" x 8" x 8" pile cap with bolt and nut. The pile cap bolts to the anchor shaft and will be incorporated into the concrete new construction wall.

The actual assembled length of the specified Torque Anchor™ system is 32 ft.

The anchors shall mount along the wall at 7 feet center to center at a distance of 3-1/2 feet from the top of the proposed wall. The anchors shall be installed at a downward angle of 15^0 from horizontal. The tiebacks must be installed to a length greater than 29-1/2 feet and must develop an average installation torque of 4,900 ft-lb or more for a minimum distance of at least 3 feet beyond an installed length of 26 feet, otherwise the anchor shall be driven deeper until this torque requirement is satisfied.

End of Example 4

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Design Example 5 – Foundation Restoration – Cohesive Soil

Structural Details:

- Two story wood frame house with wood composition siding.
- Foundation consists of 20" wide by 18" tall steel reinforced concrete perimeter beam with a 4" thick concrete slab cast with the perimeter beam.
- The corner of structure has settled 2"
- Top of pile will be 12" below the soil surface
- Soil data: There are two feet of consolidating, poorly compacted fill overlaying 20 feet of inorganic clay (CL), stiff.
- SPT "N" blow count was measured between 8 to 12 blows per foot increasing with depth

Torque Anchor™ Design:

1. Determine the foundation load: Breaking down weights of structural elements can be found in the *Simplified Tables of Structural Foundation Loads* in Tables 2 through 9 in Chapter 5, ECP Steel Piers™ Design, later in this manual. The foundation loads are estimated below:

Footing – 20" x 18"	360 lb/lf
Slab Floor, Carpet & Pad	195
Wood Frame Walls – 2 Story	176
2nd Floor – 14' Span, Carpet & Pad	98
Roof – 6" in 12" Composition, 14' Span	171
Total Dead Load	**1,000 lb/lf**
Live Load – Slab	120
Live Load – 2nd Floor, 14' Span	180
Total Live Load	**300 lb/lf**

w = Distributed Load = 1,000 + 300 = 1,300 lb/lf

w = 1,300 lb/lineal foot

2. Select a Suitable Pile Spacing and Determine Ultimate Torque Anchor™ Load: This is not a heavy structure, so for economy the solid square bar Torque Anchor™ configuration is chosen for this restoration along with Utility Brackets to transfer the structural load to the pile shaft. Using Graph 2 in Chapter 5, select pile spacing, "X", at 7-1/2 feet on the perimeter beam. (Note arrow on graph.) Determine the working load on the piles from Equation 4 – Chapter 1.

Equation 4. P_u = "X" x w x (FS):

Where,

"X" = Product Spacing = 7-1/2 feet (Selected)

w = 1,300 lb/lineal foot (Step 1)

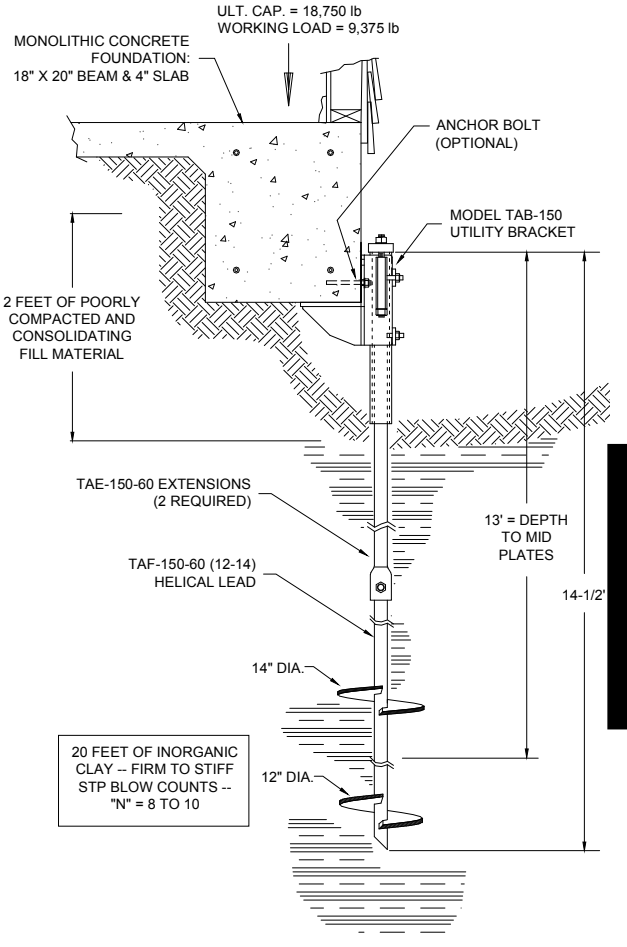


Figure 13. Design Example 5.

FS = Factor of Safety (Use 2.0)

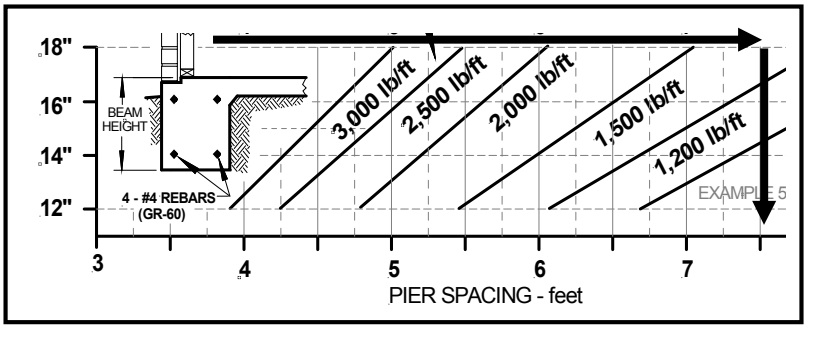
P_u = 7-1/2 ft x 1,300 lb/ft x 2 = 19,500 lb

3. Determine the helical plate area required from the known information: Because the soil on the site is cohesive, Equation 1a from Chapter 1 is used:

Equation 1a: $\Sigma A_H = P_u$ / (9c) Where:

P_u = 19,500 lb (Step 2)

c = 1,250 lb/ft² Average "N" = 10 (assumed) (Table 5 - Chapter 1)



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$\Sigma A_H = P_u / (9 \times 1{,}250) =$ 19,500 lb / 11,250 lb/ft^2

$\Sigma A_H = 1.73$ ft^2

4. Select the ECP Helical Torque Anchor™ suitable to support the load.

Referring to Table 2 – Chapter 1 the 1-1/2" solid square pile shaft is selected. It has an *Axial Compression Load Limit* rating of 70,000 pounds and a *Useable Torsional Strength* of 7,000 ft-lbs.

Referring to Table 10 – Chapter 1, we will select our combination of plates from the list opposite the 1-1/2" shaft size. We must provide at least 1.67 ft^2 of bearing area:

6" Dia. = 0.181 ft^2
8" Dia. = 0.333 ft^2
10" Dia. = 0.530 ft^2
12" Dia. = **0.770** ft^2
14" Dia. = **1.053** ft^2

The combination of 12" & 14" diameter plates on the 1-1/2" solid square shaft provides a total area of 1.82 ft^2.

TAF-150-60 12-14

5. Installation Torque. Use Equation 2 – Chapter 1 to calculate the installation torque for this anchor.

$T = T_u / k$ Where,

T_u = 19,500 lb (Step 2)
k = 10 (Table 12 – Chapter 1)

T = 19,500 lb / 10 ft^{-1}

T = 1,950 ft-lb – **Use 2,000 ft-lb**

6. Torque Anchor™ Capacity Verification: A review of Table 2 – Chapter 1 indicates that the 1-1/2" solid square bar Torque Anchor™ has a *Useable Torsional Strength* of 7,000 ft-lb, which is more than adequate for this application. The product selection should work based upon the soil report stating that the firm to stiff clay becomes more dense as the depth increases. There was no mention of rocks, debris or other obstructions. Table 11 – Chapter 1 verifies that two 3/8" thick helical plates have a mechanical ultimate capacity of 80,000 pounds. The mechanical capacity of the pile is excellent.

7. Installed Product Length. Termination depth is targeted in the stiff silty clay where the helical plates will be situated. The data indicates that the soil has a variance in the Standard Penetration Test (SPT) blow count, "N", between 8 and 12 blows per foot. It is estimated that the pile would reach the desired shaft torsion at a mid-plate depth of about 13 feet.

Minimum Required Shaft Length:

$L = h_{mid} + L_{Tip} - h_F$

Where:

h_{mid} = 13 ft (The depth from the surface to midway between plates on the shaft.)

$L_{Tip} = (3D_{Plate\ 1}) / 2$

L_{Tip} = (3 x 12" dia / 2 = 18 in

L_{Tip} = **1-1/2 ft**

h_F = **-1 ft** (The pile cap will terminate at the Utility Bracket approximately 12 inches below grade level.)

L = 13 ft + 1-1/2 – 1 ft

L = 13-1/2 feet = Shaft length estimate

8. Torque Anchor™ Specifications: Specify the necessary Torque Anchor™ components:

- **TAF-150-60 12-14** - 1-1/2" solid square bar lead section on a standard length 5 feet long shaft with a 12" and 14" diameter plate.
- **TAE-150-60** Extension – 1-1/2" solid square bar extension 5 feet long with hardware, **2 required** (The coupling overlaps 3 inches providing an effective length of 4'-9")
- **TAB-150-SUB-150** Utility Bracket. This foundation bracket fits over the 1-1/2" square bar and mounts to the perimeter beam. The bearing plate provides 68-1/4 in^2 at the bottom of the foundation for load transfer.

The total length of the assembled Torque Anchor™ is 14-1/2 ft.

The Torque Anchors™ shall be spaced at 7-1/2 feet center to center along the perimeter grade beam and must develop an average installation torque of 2,000 ft-lb or more during the last 3 feet of the installation. Depth is 13-1/2 feet.

Note: It is recommended to order additional extension sections because the target torque might not be achieved at 13-1/2 feet.

9. Foundation Restoration. Once all of the Torque Anchor™ piles have been installed and the Utility Brackets mounted, the structure may be restored to as close to the original elevation as the construction will permit.

- A pile cap, lift assembly and hydraulic jack are installed at each placement.

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- All hydraulic jacks are connected to a hand pump and gauge through a manifold system that distributes equal pressure to all jacks.
- The hand pump is actuated, transferring the structural load from the soil below the footing to the Torque Anchor™ shafts. As the structure responds and a portion of the foundation reaches the desired elevation, the jack(s) supporting the restored area(s) are isolated and the pressure at the jack(s) recorded.
- The restoration process continues until the structure is satisfactorily restored, and all jacks have been isolated and their pressures recorded.
- All installation and restoration data is transferred to a Project Installation Report. This report should include, but is not limited to, project identification, equipment used, product installed, final installation torque, installed depth, lifting force required to restore the structure and lift measurement. This data must be recorded for each placement.
- Review the report and calculate actual factors of safety on the installation to see if the design requirements have been satisfied.

10. Actual Load vs. Calculated Load and Installed Factor of Safety: The installation data must be compared to the calculated values. This enables the designer to verify the accuracy of the design. In addition, actual project factors of safety should be verified, as shown below.

The actual factor of safety for each pile installation is calculated, a slight variation of the typical factor of safety formula is used.

Equation 12: Project Factor of Safety

$$FS_{job} = P_{u\text{-}job} / P_{w\text{-}job}$$

Where:

$P_{u\text{-}job}$ = Installed Estimated Ult. Capacity – lb
($P_{u\text{-}job}$ = Installation Torque x k)

$P_{w\text{-}job}$ = Lifting Force to Restore – lb
($P_{w\text{-}job}$ = Jack Pressure x Cylinder Area)

The Project Installation Report data is used to calculate the actual factors of safety for each Torque Anchor™ placement:

$\mathbf{FS_{Actual} = T_{Final} \times k}$ (Table 12)$/ \mathbf{P_{Lift}}$

Pile 1: FS = (2,000 ft-lb x 10 ft^{-1}) lb / 9,000 lb
$FS_{pile\ 1}$ = 2.22

Pile 2: FS = (1,950 ft-lb x 10 ft^{-1}) lb / 9,400 lb
$FS_{pile\ 2}$ = 2.07

Pile 3: FS = (2,050 ft-lb x 10 ft^{-1}) lb / 7,700 lb
$FS_{pile\ 3}$ = 2.66

PROJECT INSTALLATION REPORT

Project Name: Design Example 5
Project Address: 123 Anywhere, Mid-America, USA

Products Installed: TAF-150-60 10-12 Lead
TAE-150-60 Extensions
TAB-150-SUB Utility Bracket

Torque Motor: Model LW6K – 6,000 ft-lb
Lifting Jack: Model RC254 – 25 Ton

Calculated Ultimate Pile Capacity: **P_u = 19,500 lb**
Calculated Working Pile Load: **P_w = 9,750 lb**

Placement Identification	Pile 1	Pile 2	Pile 3
Final Install Torque, ft-lb	2,000	1,950	2,050
Pile Depth, ft	18.5	16	16.5
Force to Lift, lb	9,000	9,400	7,700
Amount of Lift, in	1-1/2	1-3/4	2
Actual Factor of Safety	2.22	2.07	2.66

Soil tends to be non-homogeneous and normally installation torque varies from point to point on a project; in addition, the load on a footing is usually not uniform due to different architectural elements in the design of the structure. Pile 2 had slightly lower shaft torsion than required and had a slightly higher working load. This resulted in the lowest Factor of Safety. Pile three was on a lightly loaded part of the building an had a large Factor of Safety.

End Design Example 5

Review of Results of Example 5

Comparing the calculated design working load of 8,818 lb per pile (P_w = w (Step 1) x "X" (Step 2) = 1,300 lb/ lineal ft x 7-1/2 ft = 9,750 lb) to the actual lifting forces one can see that all working pile loads are slightly lower than predicted by the calculations. These differences between calculated and actual working loads are not significant and are related to the fact that actual loads on the footing are not uniform along the footing. The actual factors of safety for the installation on this project demonstrate that the project has actual factor of safeties within normal tolerances. The project has a safe design.

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Design Example 5A – Foundation Restoration – "Quick and Rough" Method

Design Details from Design Example 5:

- Two story wood frame house with slab foundation and wood composition siding.
- Foundation consists of 20" wide by 18" tall steel reinforced concrete perimeter beam
- Top of pile to be 12" below the soil surface
- Soil data: Two feet of consolidating poorly compacted fill was found overlaying 20 feet of inorganic clay (CL), firm to stiff.

ECP Torque Anchor™ Design:

1. Determine the foundation load: Use Table 2, *Ranges for Typical Average Residential Building Loads* that can be found in Chapter 5 of this manual. A portion of Table 2 from Chapter 5 is shown below. (This table does not include snow loads. Snow loads must be added for the job location.)

Table 2. Ranges for Typical Average Residential Building Loads

Building Construction (Slab On Grade)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing -- Footing with Slab	DL 750 – 850 lb/ft LL 100 – 200 lb/ft
One Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,000 – 1,200 lb/ft LL 100 – 200 lb/ft
Two Story Wood/Metal/Vinyl Walls with Wood Framing – Footing with Slab	DL 1,050 – 1,550 lb/ft LL 300 – 475 lb/ft
Two Story 1st Floor Masonry, 2nd Wood/Metal/Vinyl with Wood Framing – Footing with Slab	DL 1,300 – 2,000 lb/ft LL 300 – 475 lb/ft
Two Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,600 – 2,250 lb/ft LL 300 – 475 lb/ft

From the description of the project, the total foundation load (except snow loads) can be roughly estimated for this structure from Table 2. The portion of Table 2 reproduced is for slab on grade foundation loads, which is the type of foundation on this project that supports a two story residence that has wood composition siding.

To determine the estimated foundation load, look down the first column until the "Two Story" description that most closely matches the job house is found. Reading across to the other column provides a range of foundation dead load weights for this kind of residential structure. Dead loads range between 1,050 and 1,550 lb/lin.ft and the live load estimates run from 300 to 475 lb/lin.ft.

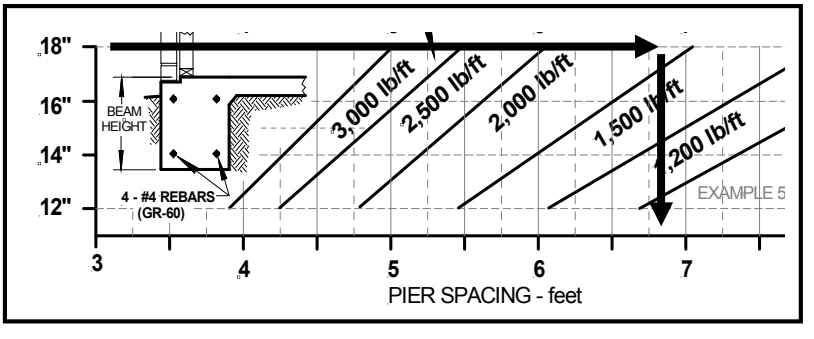
A judgment about the quality of construction is used to select the foundation loads from within the ranges. For Design Example 5A careful judgment about the construction suggests using DL = 1,200 lb/lin.ft and LL = 375 lb/lin.ft. The average perimeter loading to be used for the "Quick and Rough" design is 1,575 lb/lin.ft.

2. Determine the Soil Class. The soil was reported only as still clay. Referring to the *Soil Classification Table* - Table 9 (Chapter 1), Soil Class 6 is selected. Keep in mind that little soil information available and there is concern about the poorly compacted fill near the surface.

3. Select a Suitable Pile Spacing and Determine Ultimate Torque Anchor™ Load: This is not a heavy structure so the solid square bar Torque Anchors™ configuration is chosen for this restoration along with Utility Brackets are the most economical products to use to transfer the structural load from the foundation to the pile shaft. Use Graph 2 from Chapter 6, to select pile spacing, "X". (See below)

A loading of 1,575 lb/lin. ft is slightly higher than the 1,500 lb/ft line on the graph. This line will be used to select the spacing and then the spacing will be adjusted to reflect the load higher than the graph curve. Read across from the 18 inch footing height to an estimated 1,575 lb/ft position, then drop down to see the pile spacing of 6-3/4 feet. 6-3/4 feet center to center is selected for "Safe Use" design.

"X" = 6-3/4 feet



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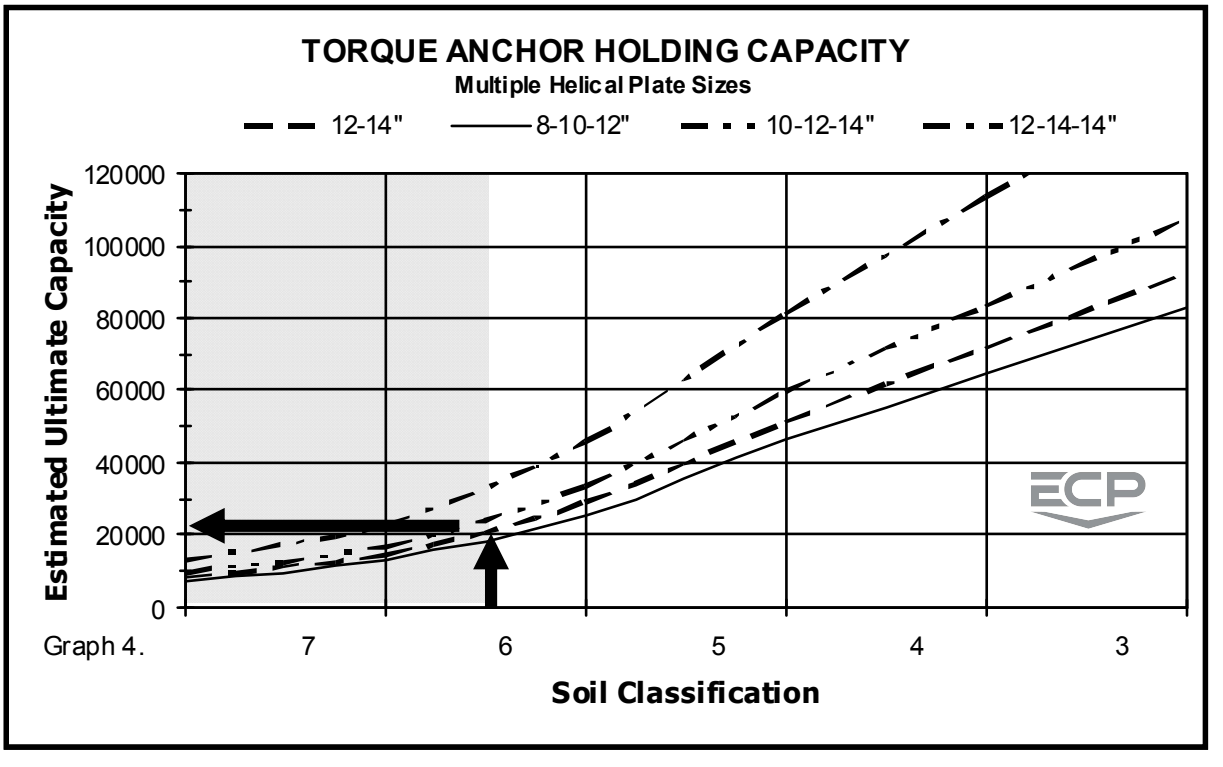
4. Determine Ultimate Torque Anchor™ Load: Use Equation 3 from Chapter 1 to determine the ultimate capacity per pile:

Equation 3. P_u = ("X") x (w) x (FS):

Where,
"X" = Product Spacing = 6-3/4 feet
w = 1,575 lb/lineal foot (Step 1)
FS = Factor of Safety (Use 2.0)

P_u = 6-3/4 ft x 1,575 lb/ft x 2 = 21,263 lb

5. Select the proper pile configuration: Referring to Graph 4 from Chapter 1 (reproduced below), notice that the capacity line for 12" and 14" diameter helical plates attached to shaft crosses just above 20,000 pounds at the center of Soil Class 6. The 12" and 14" diameter plate configuration is selected for the design.



Graph 4.

6. Check Shaft Strengths and Torsional Strengths to see which shaft is suitable: Refer to Table 2 in Chapter 1 to find a shaft with a suitable *Axial Compression Load Limit* and sufficient *Useable Torsional Strength.* The 1-1/2 inch solid square shaft is selected because it has an *Axial Compression Load Limit* rating of 70,000 pounds based upon an installation torsional limit of 7,500 ft-lbs. This pile exceeds the ultimate job load requirement of 21,263 pounds. The selected and verified pile configuration is TAF-150-60 12-14.

7. Installation Torque. Use Graph 6 from Chapter 2, shown next page to determine the installation torque requirement for the piles. The Ultimate Capacity requirement is 21,263 pounds. Find 22,000 pounds at the left side of Graph 6 look horizontally to the graph line for solid square shafts, read down to torque of 2,200 ft-lb.

T = 2,200 ft-lb, minimum

Just for comparison, the installation torque is calculated: from Equation 2 in Chapter 1:
Equation 2: $T = P_u / k$, (from Chapter 1)
P_u = 21,263 lb k = 10 (Table 12)
T = 21,263 lb/10 ft^{-1} = 2,127 ft-lb **T = 2,200 ft-lb**

8. Installed Product Length. Termination depth is the stiff clay. It is likely that the pile would reach the desired shaft torsion at a depth somewhere beyond the unconsolidated soil near grade. The minimum depth is the summation of the *Critical Depth* (Chapter 1, page 16) plus the distance to the lowest plate.

Minimum Required Shaft Length:

$L_{min} = D_{Critical} + L_{Tip}$ Where:

$D_{Ccritical}$ = 14" dia./12" x 6 ft (Page 16)
(Critical Depth = 6 x diameter of largest plate.)

L_{Tip} = 12" dia./12" x 3 = 3 ft
(Plates spaced at 3 x diameter.)

L_{min} = (14"/12" x 6') + (12"/12" x 3) = **10 ft**

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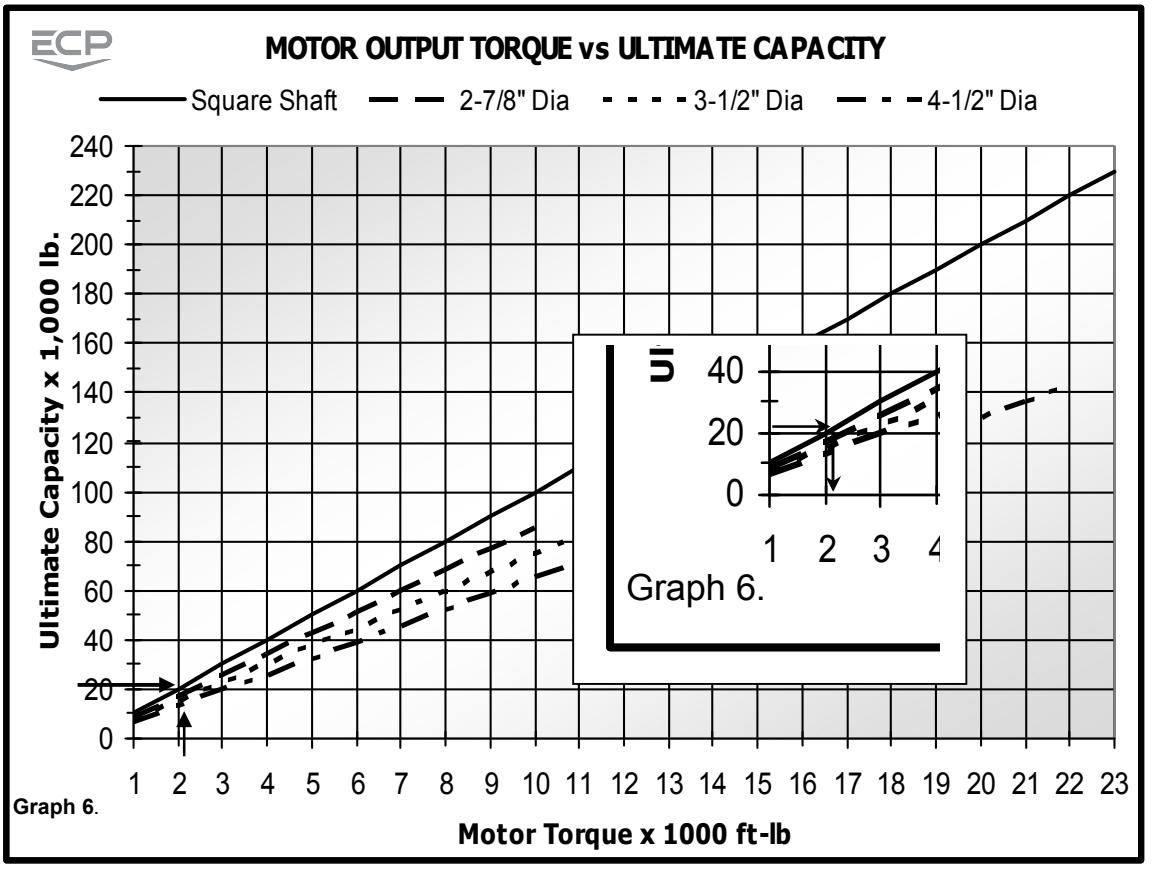

"Safe Use" design suggests that the piles be installed deeper than ten feet below grade because there is weak and consolidating fill soil near the surface. A longer standard shaft length of 12 feet, minimum, is selected.

9. Torque Anchor™ Specifications: The selected Torque Anchor™ assembly is specified:

- **TAF-150-60 12-14** – 1-1/2 inch solid square shaft that has a 12" and a 14" diameter plate on the 5'-0" long shaft,
- **TAE-150-84** extension – 7 foot extension section & hardware. (6'-9" effective length)
- **TAB-150-SUB** Utility Bracket This foundation bracket fits over the 1-1/2" square bar and mounts to the perimeter beam. The bearing plate provides 68-1/4 in^2 at the bottom of the foundation for load transfer.
- It is recommended that additional extensions (**TAE-150-60** extension – 5 foot extension section & hardware - 4'-9" effective length or **TAE-150-84** extension – 7 foot extension section & hardware - 6'-9" effective length) be on hand in case the shaft torque requirement is not achieved at 12 feet.

End of Example 5A

Review of Results of Example 5 & 5A

One can see that the result obtained by the "Quick and Rough" analysis clearly suggested the same pile that was determined by the analysis that used the bearing capacity equations. There were some variations in the design because a higher footing load and higher installation torque were predicted by the "Quick and Rough" method. This was caused in part by the higher ultimate load suggested by the "Quick and Rough" tables and graphs from Chapter 5. Once again, similar results were determined from the "Quick and Rough" design method, but good judgment estimating the quality of construction is most important in selecting proper data from the tables and graphs for more accurate results.

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Design Example 6 – Motor Output Torque

The heavy weight new construction pile design presented in Design Example 1 required shaft torsion of 7,100 ft-lb be applied to the 2-7/8 inch diameter Torque Anchor™ shaft to achieve the ultimate capacity requirement of 60,000 pounds. In Design Example 1B, where weak soil was present, the torsion requirement was determined to be 8,000 ft-lb on a 3-1/2 inch diameter tubular shaft to be able to achieve the same 60,000 pound ultimate pile capacity.

Project Details Provided from the Field:

- New Building – 2 story house with basement
- Ultimate Capacity = 60,000 lb
- Torque Motor Available = Pro-Dig X12K5
- Design 1 – Avg. Pressures at termination depth - 2-7/8" dia = 1,900 psi at inlet & 200 psi at outlet
- Design 1B – Avg. pressures at termination depth, 3-1/2" dia = 2,150 psi at inlet & 200 psi at outlet
- Pressures averaged over final three feet of depth

Equation 11 introduced in Chapter 2 is used to convert pressure differential across the hydraulic gear motor into shaft output torque.

Equation 12: Motor Output Torque
$$T = K \times \Delta P$$

1. Differential Pressures: Before using Equation 11, the pressure differential, or ΔP, from the field must be determined. The *Motor Torque Conversion Factor* – "K" must also be identified for the Pro-Dig X12K5.

The Pressure Differential across the motor is determined as follows:

ΔP = Inlet psi – Outlet psi

$\Delta P = p_{in} - p_{out}$

ΔP from Design Example 1:

$\Delta P_{Example\ 1}$ = 1,900 psi – 200 psi

$\Delta P_{Example\ 1}$ = **1,700 psi**

ΔP from Design Example 1B:

$\Delta P_{Example\ 1B}$ = 2,150 psi – 200 psi

$\Delta P_{Example\ 1B}$ = **1,950 psi.**

2. Motor Torque Conversion Factor, "K": The *Motor Torque Conversion Factor* – "K" is found on Table 16 in Chapter 2. (A portion of the table is shown below.) Looking in the *"Model Number"* column of Table 16, the X12K5 Torque Motor data is found. Reading to the right the value for the *Motor Conversion Factor*, "K", for this motor is determined to be "K" = 4.20.

3. Motor Output Torque: Once the differential pressure across the hydraulic torque motor has been calculated (Step 1) and the value for "K" determined (Step 2), the values can be used in Equation 11 to determine the actual torque that was applied to the pile shaft at termination depth.

Equation 11: Motor Output Torque
$$T = K \times \Delta P$$

Where,
T = Hydraulic Motor Output Torque - ft-lb
K = Torque Motor Conversion Factor – (Table 16)
$\Delta P = p_{in} - p_{out}$ = Motor Pressure Differential

Confirm proper installation torque for Design Example 1.

$T_{Example\ 1}$ = 4.20 x 1,700 psi

$T_{Example\ 1}$ = **7,140 ft-lb**

7,140 ft-lb > 7,100 ft-lb - O.K.

Confirm proper installation torque for Design Example 2.

$T_{Example\ 1B}$ = 4.20 x 1,950

$T_{Example\ 1B}$ = **8,190 ft-lb**

8,190 ft-lb > 8,000 ft-lb - O.K.

Table 16. Hydraulic Torque Motor Specifications

Illustration	Model Number	Torque Output ft-lb	Motor Torque Conversion Factor – "K"	Maximum Pressure psi
PRO-DIG	L6K5	6,335	**2.53**	2,500
	L7K5	7,644	**2.55**	3,000
	X9K5	9,663	**3.22**	3,000
	X12K5	12,612	**4.20**	3,000
	T12K	5,597/ 12,128	**2.24/4.85**	2,500

End Design Example 6

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Design Example 6A – Motor Output Torque "Quick and Rough Method"

The heavy weight new construction pile design presented in Design Example 1 specified that when installed on the site, torsion of 7,100 ft-lb was needed on the 2-7/8 inch diameter Torque Anchor™ shaft to reach the ultimate capacity requirement of 60,000 pounds.

In Design Example 1B where weak soil was present the torsion requirement increased to 8,000 ft-lb on the 3-1/2 inch diameter tubular shaft to achieve the same 60,000 pound ultimate pile capacity.

Determine Motor Output Torque: Graph 9 introduced in Chapter 2 is used to convert pressure differential across the hydraulic gear motor into shaft output torque. Referring to Graph 9 (reproduced below); the output torque of the X12K5 motor can be determined once the pressure differentials across the installation motor are determined.

ΔP = Inlet psi – Outlet psi

$\Delta P = p_{in} - p_{out}$

ΔP from Design Example 1:

$\Delta P_{Example\ 1}$ = 1,900 psi – 200 psi

$\Delta P_{Example\ 1}$ = **1,700 psi**

ΔP from Design Example 1B:

$\Delta P_{Example\ 1B}$ = 2,150 psi – 200 psi

$\Delta P_{Example\ 1B}$ = **1,950 psi**

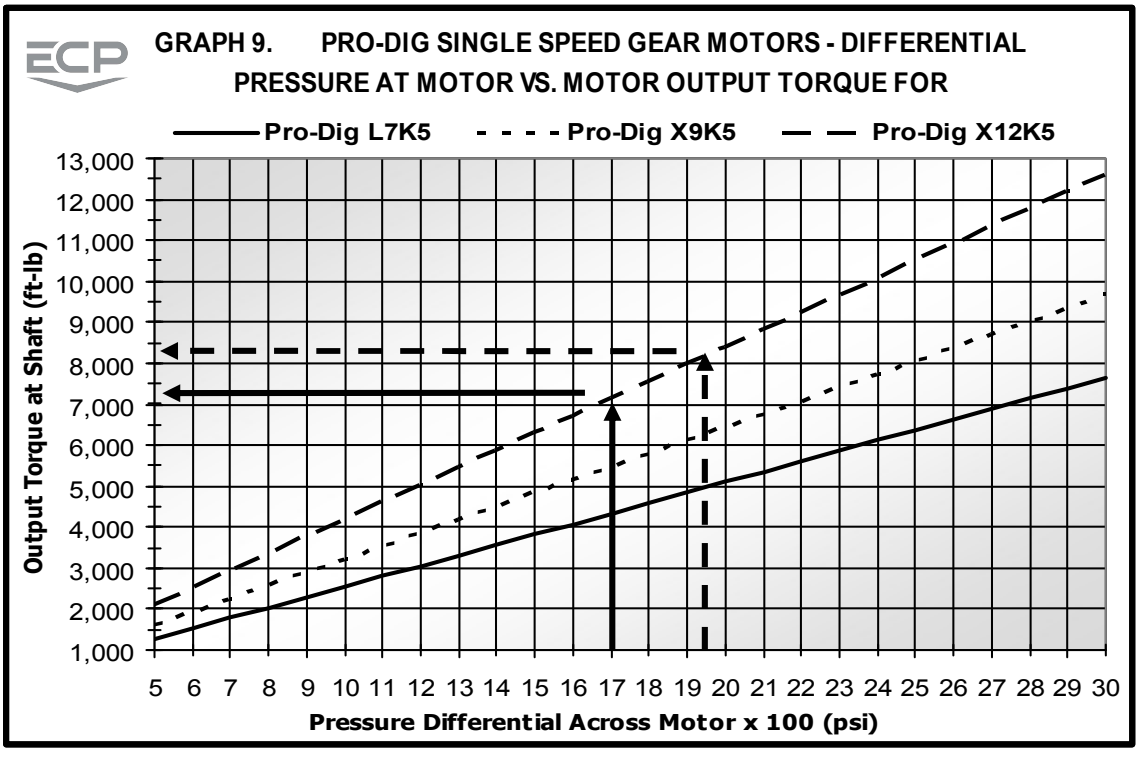
With the actual field measured pressure differentials calculated, one can find the actual installation motor torque at pile termination depth on Graph 9. Locate 1,700 psi and 1,950 psi values at the bottom of the graph. Then read upward until the motor curve line for the X12K5 motor is reached. Read horizontally to the left where the *Output Torque at the Shaft"* where can be found.

Design Example 1 output shaft torsion is determined to be estimated at **7,250 ft-lbs**.

Design Example 1B had a pressure differential of 1,950 psi pressure differential, which produced an output torque estimated at **8,200 ft-lb**.

Proper installation shaft torque is confirmed for Design Examples 1 and 1B

End Design Example 6A



Review of Results of Example 6 & 6A

One can see that the result obtained by the "Quick and Rough" analysis suggested the shaft torsion from field data was sufficient to provide the load capacity. The calculated method and the "Quick and Rough" solutions for the actual installation shaft torque values were similar.

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Design Example 7 – Ultimate Capacity from Field Data

In this exercise the anticipated ultimate capacities of the pile designs from Design Example 1 and 1B will be determined. This information will be used to confirm that the installed piles meet or exceed the design requirements set out in the original designs

Equation 2 from Chapter 1 is used to calculate the ultimate compressive capacity of the pile based upon data provided from the field. Recall that the *Design Example 1 - Heavy Weight New Construction Project* required an ultimate capacity at each pile of 60,000 pounds.

Equation 2: Helical Pile Ultimate Capacity

$$P_u = k \times T$$

Where,
P_u or T_u = Ult. Capacity of Torque Anchor™ - (lb)
T = Final Installation Torque - (ft-lb)
(Averaged Over the Final 3 to 5 Feet)
k = Empirical Torque Factor - (ft^{-1})

Calculating the ultimate pile capacity using data from Design Example 1:

Ultimate Capacity of the 2-7/8" diameter, 0.262 wall piles installed in Example 1 ($P_{u\text{-Example 1}}$):

Where,
k = 8.5 (Table 12)
$T_{Example\ 1}$ = 7,140 ft-lb (Design Example 6)

P_u = 8.5 x 7,140 = 60,690 lb

P_u = <u>60,690 lb</u> > 60,000 lb O.K.

Calculating the ultimate pile capacity using data from Design Example 1B:

Ultimate Capacity of the 3-1/2" diameter piles with 0.300 inch wall thickness that were installed in Design Example 1B = $P_{u\text{-Example 1B}}$:

Where,
k = 7.5 (Table 12)
$T_{Example\ 1B}$ = 8,190 ft-lb (Design Example 6)

P_u = 7.5 x 8,190 = 61,425 lb

P_u = <u>61,425 lb</u> > 60,000 lb O.K.

The results of the calculations confirm the ultimate capacity determined from the field data exceeds the design ultimate capacity stated in the specifications of Design Examples 1 and 1B.

End Design Example 7

Design Example 7A – Ultimate Capacity from Field Data – "Quick and Rough" Method

This exercise will determine the ultimate pile capacity based upon field data using the "Quick and Rough" method. The comparison between the calculated design specifications and the actual field capacity will verify whether the pile installation is satisfactory.

Design Example 6A determined that the output torque at the motor shaft was 7,250 ft-lb at the termination of the pile installation. Graph 7 from Chapter 2 (shown on the next page) provides a method to demonstrate the ultimate capacity of the installed helical product. A comparison to the design requirement will determine if the installed pile capacity exceeds the specified ultimate capacity.

Estimate the location on the horizontal axis for shaft torsion of 7,250 ft-lb slightly to the right of the 7,250 ft-lb grid line and read up to the plot line for the 2-7/8 inch diameter shaft configuration. The legend near the top of the graph provides choices between square shafts and various tubular shafts. Read upward from the 7,250 ft-lb "*Motor Torque*" line until the bold dashed line that represents the 2-7/8 inch diameter shaft configuration is encountered. Then move horizontally to the vertical axis at left to see if installed pile ultimate capacity exceeds 60,000 pounds.

Looking carefully at the point where the horizontal plot intersects the *"Ultimate Capacity"* axis, the field generated shaft torsion at the termination of the pile installation shows to be slightly above 60,000 lb. This verifies that the actual installed pile capacity exceeds design specifications.

End Design Example 7

Review of Results of Example 7 & 7A

The value in using the "Quick and Rough" method is that it provides rapid results from the graphs. This method cannot tell exactly how much the field installation exceeded the design requirements, but it confirms whether the installation meets or exceeds specificaitons. If the engineer wants to know the actual installed ultimate capacity, then it must be calculated.

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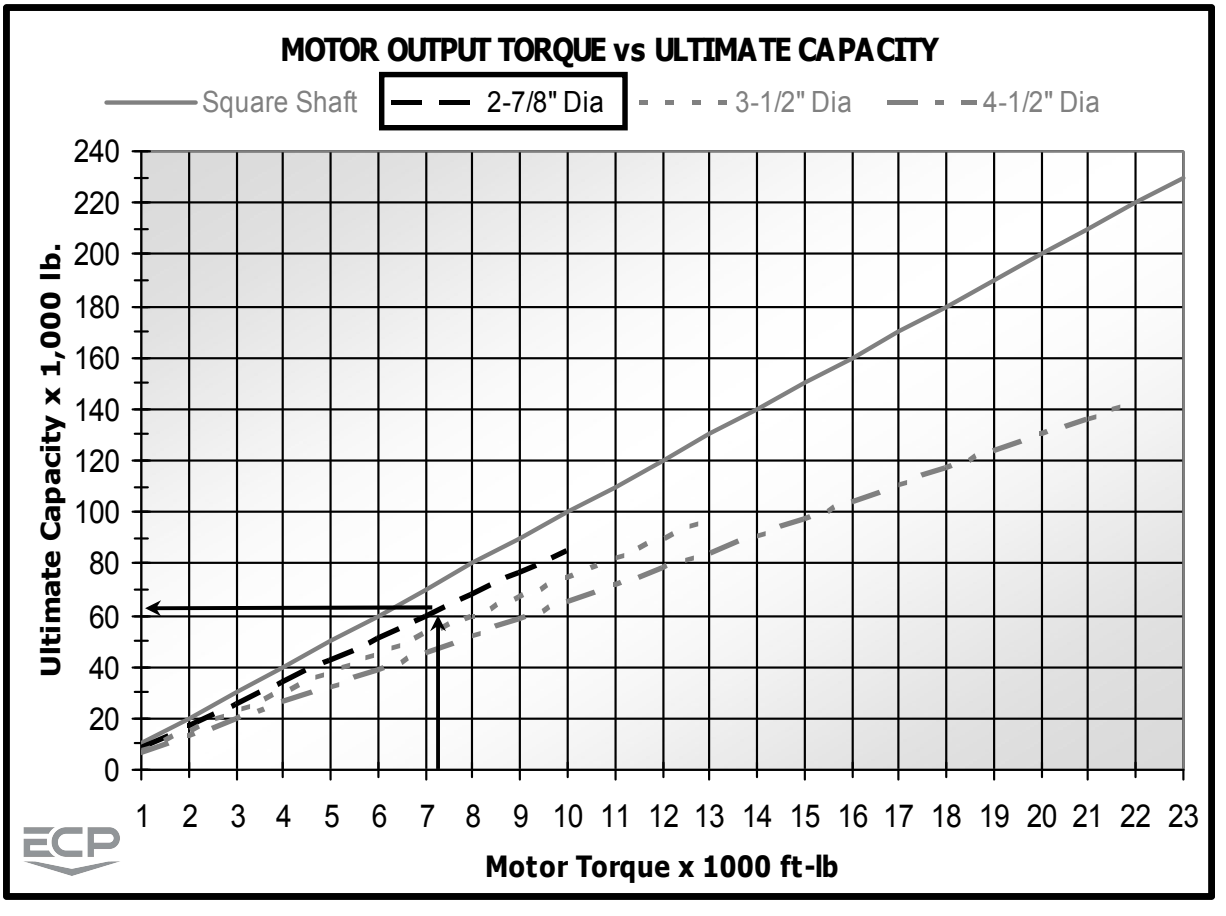

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to prepare preliminary designs, installation procedures, load testing, and documentation of each placement when using ECP Torque Anchors™. If you have questions or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call us at 913 393-0007, Fax at 913 393-0008.

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Chapter 4

ECP Torque Anchors™
Introduction to ECP Helical Soil Nails

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Before one can begin a discussion of soil nailing, a clear understanding of the difference between soil nails and tieback anchors is required. Many times one hears the term "Soil Nail" and "Tiebacks" used interchangeably and this demonstrates a lack of understanding of the products.

Suppose that a construction project requires an excavation where the side of a soil cut cannot be provided with a stable slope. Figure 1 illustrates the soil cut and excavation for this project.

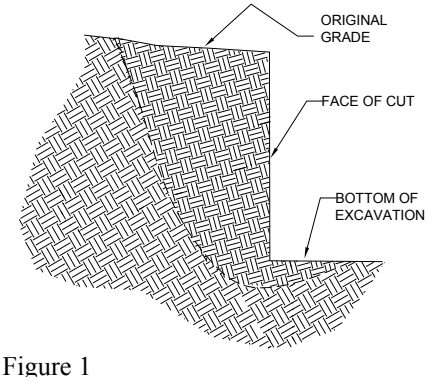

Figure 1

One can easily understand that without some kind of containment of the soil at the face of the cut, a collapse of the soil along a failure plane is likely to occur. This failure can happen very quickly and without warning. The failure might look something like Figure 2. The unstable soil moves to the bottom of the excavation leaving a natural and stable slope for the remaining soil. This interface between the stable and unstable soil is called a slip plane.

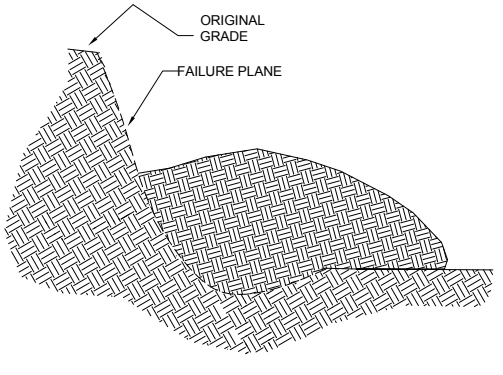

Figure 2

The most common way to prevent this kind of soil failure is to provide lateral support to the unstable soil situated in front of the slip plane. One common way to do this is with a retaining wall and tieback anchors. The tiebacks work together with the structural retaining wall to provide sufficient lateral support to retain the unstable soil mass. The retaining wall must be designed and constructed to provide rigid support for the soil mass over the distance between the tieback anchor placements. One often sees tieback anchors spaced eight to twelve feet apart along the length of the retaining wall. The spacing and number of anchors depends upon the wall height, surcharge loads and properties of the retained soil. Tieback anchors must be driven into the soil to a depth that is sufficient to provide tension resistance in the anchor shaft that is equal to the soil forces pushing against the retaining wall. A typical soil cut with a retaining wall is illustrated in Figure 3.

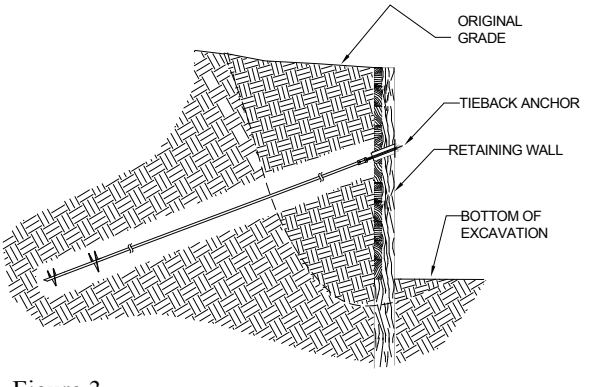

Figure 3

In many construction projects soil nails are used to retain the unstable soil mass.

To accomplish this, soil nails are installed in an evenly spaced close geometric pattern without the massive retaining wall structure. When constructing a soil nail stabilization project, the soil nail placement spacing and the incremental excavation depth must be accomplished with incremental excacations that typically measure 4 to 6 feet until the final depth of cut is accomplished.

Usually only one depth increment can be completed per day. Immediately following the incremental excavation of the soil and the installation of the soil nails, the vertical face of the soil cut is covered with steel mesh reinforcement and a coating of shotcrete.

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Soil nails are passive structural elements and are not tensioned after installation. The soil nail achieves pullout resistance from within the sliding soil mass in front of the slip plane and the stable soil mass located behind the slip plane. The geometric system of soil nail placements

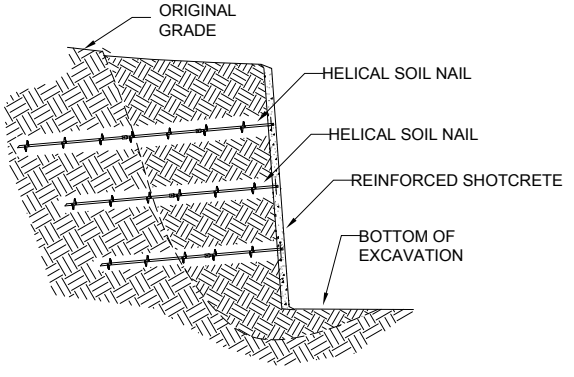

Figure 4

creates an internally reinforced soil mass that is stable. Figure 4 shows a sketch of a typical soil nail installation.

Notice that each soil nail shaft has a great number of helical plates with each plate the same diameter. These helical plates are evenly spaced along the entire length of the shaft. By comparison, a tieback anchor has one or more helical plates situated at the tip of the tieback. Helical plates on tieback anchors generally have increasing diameters as one moves away from the tip of the anchor. Once a tieback anchor lead section is installed, extensions without helical plates are used to extend the helical plates at the tip of the anchor to the target depth. This characteristic of tieback anchors is clearly shown in Figure 3. When comparing the two products, soil nails always have identical, evenly spaced, small diameter helical plates along the entire length of shaft from beginning to end.

Soil nails may be the product of choice in applications where the vibrations from installing sheet piling or "H" piles may cause structural distress to nearby structures. Soil nails are generally installed to a shallower depth than tiebacks, which might be an advantage if deeply installed tiebacks have to cross property lines and/or terminate under structures owned by other parties; or where otherwise obstructed.

Soil nails work very efficiently in medium dense to dense sand with Standard Penetration Test values, "N" > 7 blows per foot. They also are suited for low plasticity cohesive soil (clays) with SPT values, "N" $\geq$ 8 blows per foot, which also have soil cohesion values exceeding 1,000 psf through the entire depth of soil to be stabilized.

ECP Soil Nail Components

ECP Soil Nail products consist of a shaft fabricated from either 1-1/2 inch or 1-3/4 inch solid square steel bar. Welded along the entire length of the soil nail shaft are identically sized helical plates measuring six or eight inches diameter with a plate thickness of 3/8 inch. The available lead shaft lengths for ECP Soil Nails are nominally five or seven feet long; however, other lengths may be specially fabricated. Soil nail extensions are also available in nominal lengths of five and seven feet. The extensions shall also contain evenly spaced helical plates of the same diameter as the lead section. Soil nail extensions are supplied with integral couplings and hardware for attachment to already installed lead or other extensions allowing the soil nail assembly to reach the designed embedment length requirement.

Soil nails may be terminated with a large flat wall plate or an assembly of reinforcing bars welded to a small wall plate. The wall plates will eventually be embedded into the reinforced shotcrete wall covering.

Product Benefits

- **Quickly Installed Using Rotary Hydraulic Torque Motor**
- **Installs With Little Or No Vibration**
- **Installs In Areas With Limited Access**
- **No Post-Tensioning – Immediate Support**
- **No Need for "H" Piles, Sheet Piling, or Walers**
- **In Temporary Applications, Soil Nail Removal and Reuse is Possible**

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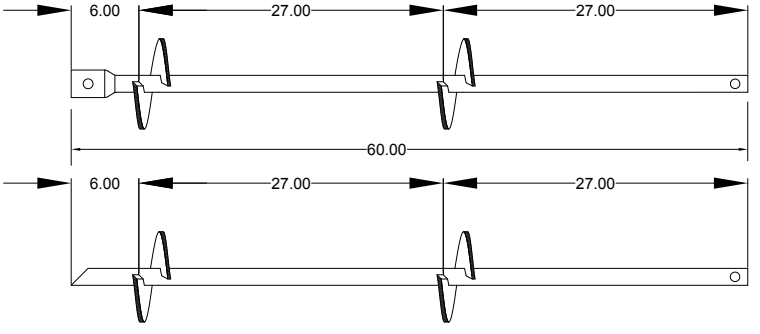
ECP Square Shaft Soil Nails



EARTH CONTACT PRODUCTS
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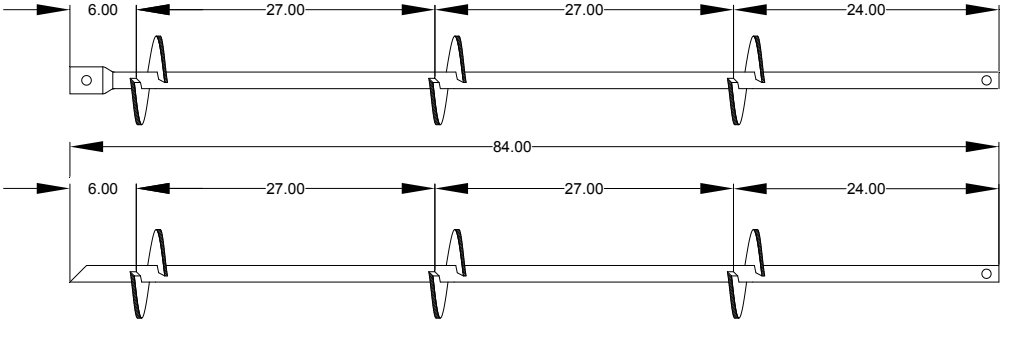
ECP Soil Nail Product Configurations

Part Number	Shaft Size	Torque Limit*	Plate Size	Number Plates	Shaft Length
TAS-150-60 06-06 Lead	1-1/2" Square	7,000 ft-lb	6" Diameter	2	5'- 0"
TAS-175-60 06-06 Lead	1-3/4" Square	10,000 ft-lb			
TAS-150-60 08-08 Lead	1-1/2" Square	7,000 ft-lb	8" Diameter	2	5'- 0"
TAS-175-60 08-08 Lead	1-3/4" Square	10,000 ft-lb			
TASE-150-60 06-06 Extension	1-1/2" Square	7,000 ft-lb	6" Diameter	2	5'- 0"
TASE-175-60 06-06 Extension	1-3/4" Square	10,000 ft-lb			
TASE-150-60 08-08 Extension	1-1/2" Square	7,000 ft-lb	8" Diameter	2	5- 0"
TASE-175-60 08-08 Extension	1-3/4" Square	10,000 ft-lb			



Part Number	Shaft Size	Torque Limit*	Plate Size	Number Plates	Shaft Length
TAS-150-84 06-06-06 Lead	1-1/2" Square	7,000 ft-lb	6" Diameter	3	7'- 0"
TAS-175-84 06-06-06 Lead	1-3/4" Square	10,000 ft-lb			
TAS-150-84 08-08-08 Lead	1-1/2" Square	7,000 ft-lb	8" Diameter	3	7'- 0"
TAS-175-84 08-08-08 Lead	1-3/4" Square	10,000 ft-lb			
TASE-150-84 06-06-06 Extension	1-1/2" Square	7,000 ft-lb	6" Diameter	3	7'- 0"
TASE-175-84 06-06-06 Extension	1-3/4" Square	10,000 ft-lb			
TASE-150-84 08-08-08 Extension	1-1/2" Square	7,000 ft-lb	8" Diameter	3	7- 0"
TASE-175-84 08-08-08 Extension	1-3/4" Square	10,000 ft-lb			

Note: Custom fabrication of soil nail products to your specifications is available – Inquire for pricing and delivery.
All helical plates are 3/8" thick and spaced as shown above.
Extensions supplied with integral coupling and SAE J429 grade 8 bolts and nuts.
Product is hot dip galvanized per ASTM A123 grade 100.
Soil Nail products available as special order – Allow extra time for processing.

*** Please see "IMPORTANT NOTE" on Table 17, Page 83**

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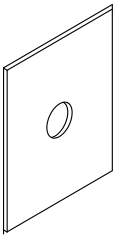
ECP Soil Nail Terminations

Wall Plate



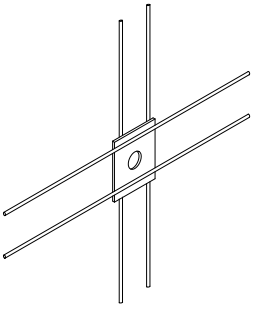
TAS-150 WP 12-12 – Wall Plate to fit 1-1/2" square Soil Nail shaft. 1/2" x 12" x 12" with 2-1/8" dia. hole

TAS-175 WP 12-12 – Wall Plate to fit 1-3/4" square Soil Nail shaft. 1/2" x 12" x 12" with 2-3/8" dia. hole

TAS-150 WPR – Wall Plate to fit 1-1/2" square Soil Nail shaft. 3/8" x 6" x 6" with 2-1/8" dia. hole, and four #4 rebar by 36" long

TAS-175 WPR 3/8 – Wall Plate to fit 1-3/4" square Soil Nail shaft. 3/8" x 6" x 6" with 2-3/8" dia. hole, and four #4 rebar by 36" long.

Wall Plate with Rebar



Product Limitations

Soil nails are designed to attain pullout resistance from within the sliding soil mass along with the resistance from the stable soil behind the movement plane. As a result of this tensioning, one must anticipate movements horizontally and vertically at the top of the excavation on the order of 1/8 inch movement for each five feet of excavation. These movements are normally not of concern unless a building is situated close to the proposed soil cut. Creep of the soil mass after the initial soil movement is usually not a problem; however when the soil liquidity index is > 0.2, a soil nail matrix is not recommended.

Soil nails may not be suitable in situations where the soil report indicates the presence of weathered rock anywhere within the area to be stabilized. Soil nails are also not recommended in loose sand with SPT value of "N" < 7 blows per foot. The use of soil nails must be approached with caution where highly plastic clays and silts are present within the soil mass. Soil nails are not recommended for low plasticity clay soil having SPT value of "N" $\leq$ 6 blows per foot.

The practical limit for excavations using the soil nail stabilization technique is approximately 20 feet; although under ideal soil conditions, excavations as deep as 25 feet deep have been reported.

When designing soil stabilization with surcharge loads near the top of the excavation such as buildings, roads, soil overburden, etc, the surcharge loads must be included with the weight of the soil mass being retained. With an expected slump of 1/8 inch for each five feet of excavation, one should consider stabilizing the perimeter footing of nearby structures whenever the excavation exceeds 10 to 12 feet because lateral and vertical movements on the order of 1/4 to 3/8 inch could cause structural damage to existing structures nearby.

Table 17. CAPACITIES OF ECP SOIL NAILS

Shaft Size	Shaft Configuration	Ultimate-Limit Tension Strength	Useable Torsion
1-1/2" Square	Solid Bar	70,000 lb.	7,000 ft-lb
1-3/4" Square	Solid Bar	100,000 lb.	10,000 ft-lb

IMPORTANT NOTE:
The capacities listed are mechanical ratings. One must understand that the actual installed load capacities are dependent upon the actual soil conditions on a specific job site and the strength of the termination connection. The *Useable Shaft Torsional Strengths* given here are the maximum values that should be applied to the product. Furthermore, these torsional ratings assume homogeneous soil conditions and proper alignment of the drive motor. In homogeneous soils it might be possible to achieve 90% to 95% of the ultimate torsional strength shown in the table.

The designer should select a product that provides adequate additional torsional capacity for the specific project and soil conditions.

Each soil nail design requires very specific and detailed information involving the soil characteristics at the site and surcharge loads, if any. Each design is complicated and highly technical. The design and specifications should only be prepared by a Registered Professional Engineer trained in soil nail design and familiar with the specific job site.

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Soil nails not only look different from Torque Anchor™ tiebacks they are designed differently. It is important to understand the dramatic differences in these products before working with soil nails.

For soil nails to be effective, they must have equal diameter helical plates spaced evenly along the entire length of shaft.

Remember that soil nails are not tensioned to gain strength; they gain pullout resistance from within the sliding soil mass that is located in front of the slip plane. The concept is rather simple to understand. As the soil mass begins to slip downward and outward, the sliding soil creates a force against the back side of the helical plates embedded within this sliding soil mass. The force generated by the sliding soil against these helical plates is resisted equally, and in the opposite direction, on the front side of the remaining helical plates that are embedded within the stable soil behind the slip plane. Figure 5 illustrates the way that the forces are developed along the Soil Nail shaft.

The forces developed within the soil nail system remove the structural requirement for an exterior retaining wall. In most cases the soil nails wall plates are embedded directly into the shotcrete coating. There is no need for sheet piles, "H" piles or wales. The soil mass is stabilized by the matrix of soil nails, therefore only the thin shotcrete wall is necessary.

Soil nails are installed in a geometrical matrix to distribute the load evenly; and as such, soil nails are more lightly loaded than tieback anchors.

Some engineers might specify a small "seating" load be applied to the soil nail after installation to remove slack in the couplings; but in general practice, soil nails are usually not tensioned after installation because tensioning can change the balance of stresses on the helices.

Soil nailing is a passive restraint system, meaning that the soil nails are not post-tensioned, the unstable soil mass has to slump slightly before the soil nail system can develop internal forces to resist the soil movements.

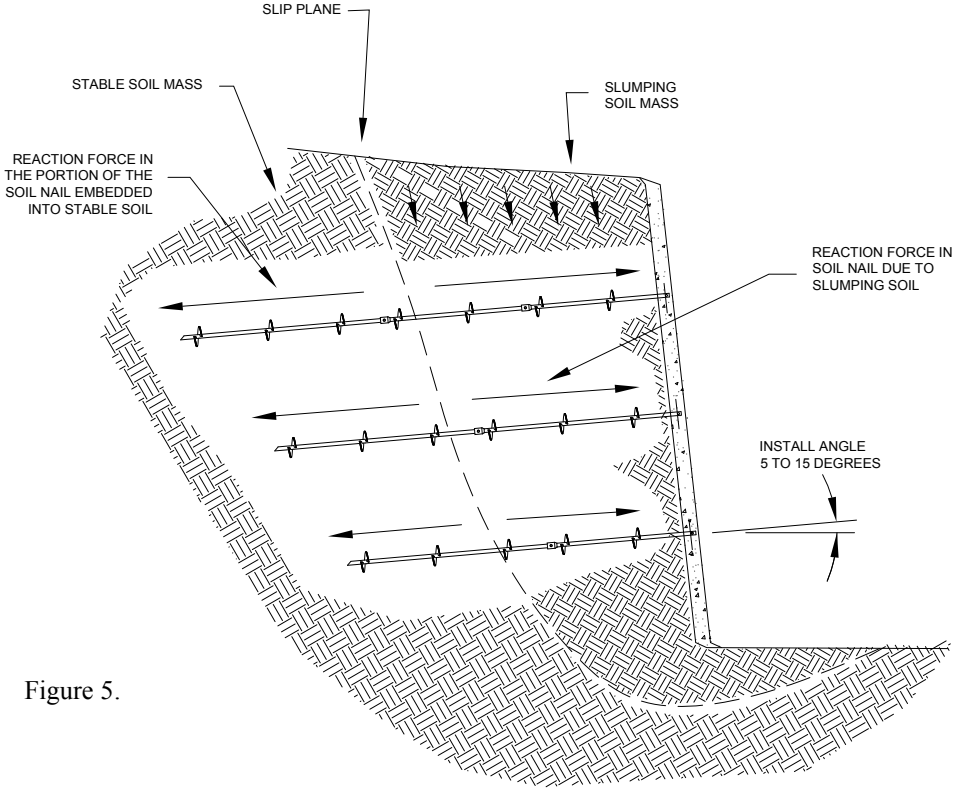

Figure 5.

Soil nailed walls can be expected to deflect both downward and outward during the slumping of the soil mass. Expected movements of approximately 1/8" of vertical and horizontal movement of the top of the wall for each five feet of excavation are common.

These movements are normally not a concern except when an existing structure is situated near the

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top of the excavation. The soil overburden load from a nearby structure can be reduced by pro-viding supple-mental foundation support to the perimeter beam and/or column footings of the existing structure. ECP Steel Piers™ are recommended to transfer the structural load of the existing build-ing foundation to the deep support provided by ECP Steel Piers™. The ECP Steel Piers™ not only reduce the surcharge on the soil mass, they prevent vertical settlement of the existing footing as the slight movement of the soil mass occurs during the tensioning of the soil nail matrix. If there are concerns with regard to lateral movements of the building's footings, the designer has the ability to prevent lateral footing movements of the existing structure by using Torque Anchor™ tieback anchors along with ECP Steel Piers™ to provide both lateral and vertical stability to the building's footing.

Figure 6 shows details of a typical soil nail installation. Usually four to five feet of soil is excavated and immediately followed by the installation of the first row of soil nails. Notice that the first row has the longest shaft length because the distance to the slip plane is the greatest. The soil nail is not installed to a specified torsion requirement like tieback anchors; rather the length of embedment, the installation angle and center to center spacing are the important elements in soil nail installations.

Once all of the soil nails situated within the first excavation increment are installed, one-half of the required thickness of shotcrete is placed on the wall followed immediately by the installation of the wall plates and reinforcing steel mesh. The reinforcing mesh is cut long enough to provide suitable splice overlap at the next increment of soil excavation. A surface coating of shotcrete is installed over the steel reinforcement to provide the final thickness of concrete specified by the engineer. All work is then left to cure prior to the next depth increment excavation.

Prior to the beginning the next excavation increment (usually the next day), the amount of slump at the top of the excavation must be measured to insure that the recently installed soil nails are performing as intended. When approved, the next depth increment can be excavated followed by the installation of the next

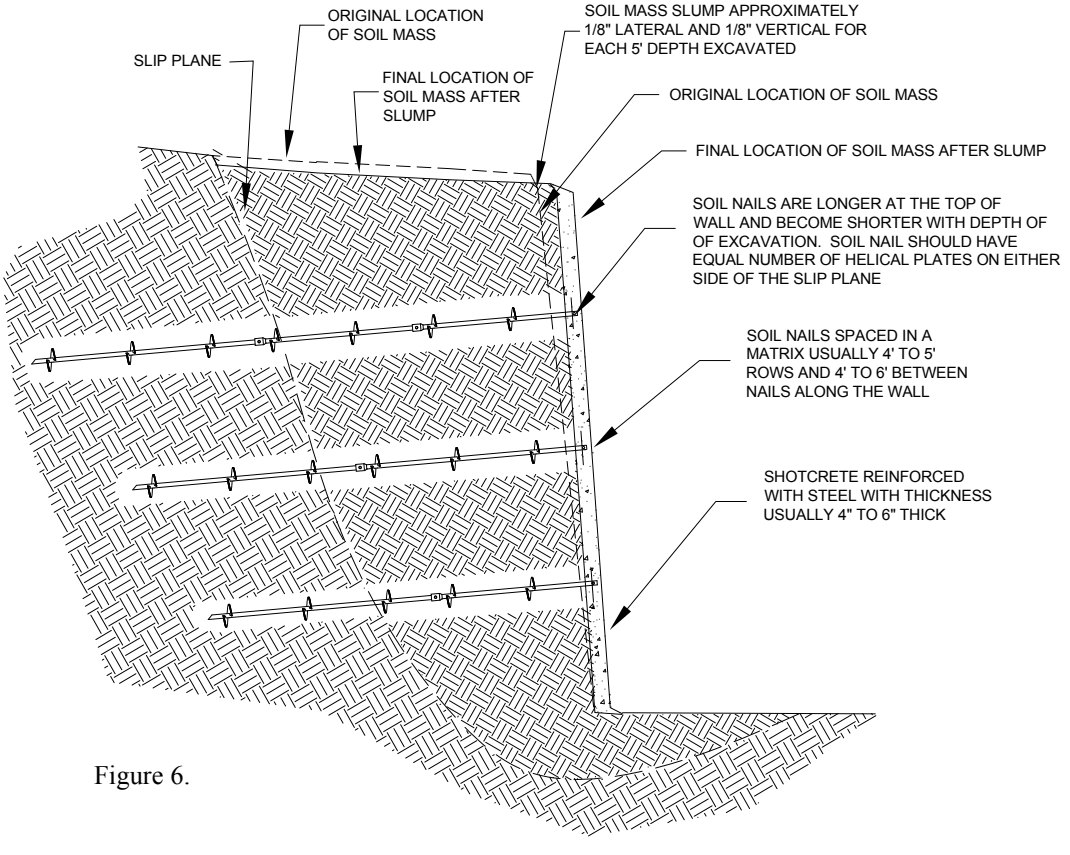

Figure 6.

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row of soil nails followed by the immediate installation of the first layer of shotcrete. The only difference between the initial and subsequent incremental excavations is that the new layers of shotcrete and steel must be interlocked to the previous work to provide continuity to the wall.

Shotcrete

Shotcrete is a process where Portland cement concrete, or mortar, is propelled under air pressure onto a surface. ECP recommends the wet process where the dry ingredients are mixed with water and then sent to the spray nozzle as opposed to "Gunite" where the materials are mixed as they leave the nozzle. Shotcrete deposits more concrete with less rebound upon impact than "Gunite".

Engineering Design and Supervision

Design should involve professional geotechnical and engineering input. Each soil nail design requires very specific and detailed information involving the soil characteristics at the site and surcharge loads, if any. Each design is complicated and highly technical. The final design and specifications should only be prepared by a Registered Professional Engineer trained in soil nail design and familiar with the specific job and job site.

The photographs show ECP Soil Nail installation and Shotcrete application.

Field Documentation

It is very important for the installer to be aware that soil nailing projects involve risk; and as such, close communications with the engineer and attention to detail is extremely important. The data collected on site will assist the engineer to determine if the project is progressing according to plan. Field data should be recorded on each soil nail product installed. Usually, the field superintendent is the person responsible for recording field data. This raw field data is normally compiled at the end of the day into a *Daily Installation Report*. This report should be assembled in a form that is easy to read and understand. At the start of each day the *Daily Installation Report* from the previous day should be provided to the engineer prior to his field measurements and before beginning the next excavation increment. ECP suggests reporting

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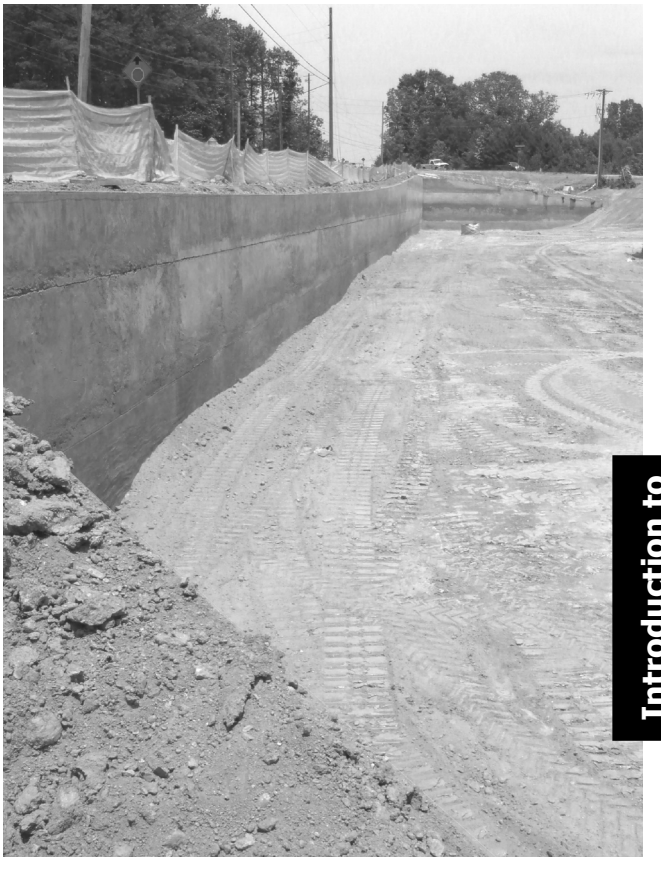
the following data on each installed soil nail to the engineer each day:

1. A diagram with the numbered locations of the installed ECP Soil Nail for reference
2. ECP Soil Nail product part numbers of the items that were installed
3. The elevation from the surface to the soil nail entry point
4. The soil nail installation angle
5. The installed length of the soil nail
6. The installation torque required to advance the soil nail into the soil recorded at one foot intervals
7. Notes should be made on the torsion log for each soil nail placement to report the presence of non-uniform soil or if the soil nail encounters an obstruction during installation

Two skid steer machines are shown above installing a second row of ECP Soil Nails.



A view of a finished ECP Soil Nail retaining wall.

NOTE: Technical Design Assistance Is Not Offered For Soil Nail Projects

Soil Nail design should only be performed after a thorough soil investigation by a registered professional engineer because soil nail projects carry the risk of severe failure. All field installation procedures should be performed under the direct supervision of the design engineer of record on site. As these types of projects require extremely detailed soil reports, extensive engineering calculations, and intimate knowledge of the job site, ECP is unable offer complementary preliminary designs for soil nail projects.

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Chapter 5

ECP Steel Piers™

Technical Design Manual

- **PPB-166 Slab Bracket System**
- **PPB-200 Under Footing Pier System**
- **PPB-250 Under Footing Pier System**
- **PPB-300 ECP Steel Pier™ System**
- **PPB-350 ECP Steel Pier™ System**
- **PPB-400 ECP Steel Pier™ System**

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Earth Contact Products, LLC reserves the right to change design features, specifications and products without notice, consistent with our efforts toward continuous product improvement. Please check with Engineering Department, Earth Contact Products to verify that you are using the most recent information and specifications.

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Introduction

The ECP Steel Pier™ belongs to a family of underpinning products that are sometimes referred to as micropiles, push piers, or resistance piers. These underpinning products are hydraulically driven into the soil using the structural weight of the building as a reaction force. A friction reduction collar is attached to the bottom end of the lead section of pier pipe. The purpose of the collar is to create an opening in the soil that has a larger diameter than the pier pipe that follows. This dramatically reduces the skin friction on the pier pipe as it is driven into the soil. This feature allows the installer to load test and to verify that the pier has encountered firm bearing stratum or rock that is suitable to support the design load.

The ECP Steel Pier™ like other resistance piers is an end-bearing pier that does not rely upon, nor requires, skin friction to produce support. Each pier is field load tested after it is installed. The piers are able to develop a factor of safety because the piers are installed and load tested individually using the structural weight from a large part of the building as a reaction force. The ability of the system to develop a significant factor of safety comes from the much higher load the pier during pier installation and a lower load when the lifting load is transferred to the pier during restoration. The piers are driven one at a time using the weight of the entire structure as the reaction during the installation. During load transfer and restoration, hydraulic jacks are placed at multiple pier locations, which places only the lower design/working load on each pier.

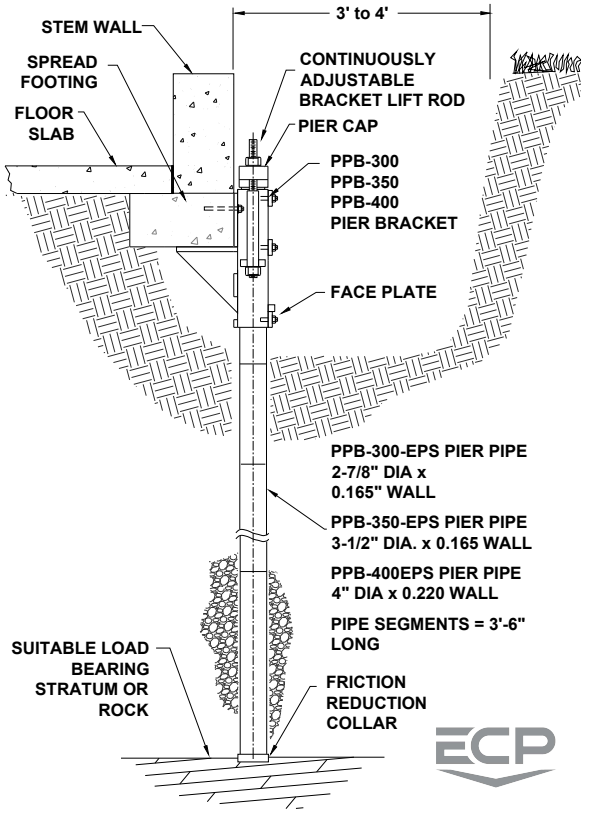

Figure 1. Typical configuration for the ECP Steel Pier™ System with Type PPB Utility Bracket attachment to the footing.

A building with substantial construction and rigidity can develop greater factor safety on each pier than a structure with a weaker, more flexible structure.

Features and Innovations

The patented ECP Steel Pier™ is the fourth generation of a product invented by Don May dating back to the 1970's. This resistance steel pier incorporates many advances over previous versions. An important improvement to the ECP Steel Pier™ system is a reduction in the eccentricity between centerline of the pier pipe and the foundation bracket. This means that there is less moment (twisting) at the pier bracket when in is loaded. This feature translates to greater load capacities. The system offers nearly unlimited elevation recovery as the adjustment of the pier bracket elevation is accomplished by hex nuts attached to continuously threaded rods as opposed to the limitations imposed by the use of shims and pins on other systems. The ECP Steel Pier™ is also more "installer friendly" because the inner chamber of the drive stand is quickly accessible by temporarily removing face plates on the pier bracket and drive stand. In addition, a pier alignment guide is integral with one of the drive stand face plates. The addition of a retaining plate that safely secures the heavy hydraulic drive cylinder to the drive stand is a large advancement for operator safety. The drive cylinder had a tendency to work loose in earlier designs. Other than a control sleeve that

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is only used on the PPB-350, all of the pier brackets are designed to securely align and guide the pier pipe without additional tools.

Another innovation on the ECP PPB-300 & PPB-350 Steel Pier™ Systems is the patented "Inertia Sleeve". This state of the art method of increasing the moment of inertia (stiffness) of the pier pipe and the "Inertia Sleeve" strengthens the coupled joints, which is unmatched in the industry. The pier pipe and "Inertia Sleeve" combination produces a more rigid pier system with a higher moment of inertia (stiffness) than the pier pipe alone.

The "Inertia Sleeve" does not carry any of the axial compressive pier load; the function of this product is only to increase pier stiffness in weak soils to prevent buckling. (See Figure 3, next page)

The "Inertia Sleeve" consists of a piece of pipe that fits snugly inside the existing pier pipe. At one end the "Inertia Sleeve" has a nine inch long coupling that fits through, and spans across, the coupled pier joint. The "Inertia Sleeve" is installed concurrent with the pier pipe installation and only takes the time necessary to pick up the "Inertia Sleeve" product and to let it drop by gravity into the current pier section prior to installing the next section of pier pipe.

The installed cost of this pier strengthening product is hardly more than the purchase price of the "Inertia Sleeve" product, yet it creates a stiffer pier system that is more resistant to buckling when installed through weak soil.

Product Benefits

- **Ultimate-Limit Capacities: Up to 115,000 lb.**
- **Proof Test Loads: Up to 86,000 lb.**
- **Standard Lift – 4" Fully Adjustable**
- **Greater Lift Capability With Optional Longer Bracket Rods**
- **Installs From Outside or Inside the Structure**
- **Installs With Portable Hydraulic Equipment**
- **Installs With Little or No Vibration**
- **Friction Reduction Collar On Lead Pier Section Reduces Skin Friction**
- **Installs To Rock or Verified End Bearing Stratum**
- **100% of Piers Are Field Load Tested to Verify Capacity During Installation**
- **Manufacturer's Warranty**

Pier Installation Sequences

Quiet vibration free hydraulic equipment is used to install ECP Steel Piers™. All installation equipment is portable and can be carried in a wheelbarrow. After all of the piers are installed and load tested, the structure can be immediately restored by transferring the structural load to the piers. There are no days wasted waiting for concrete to cure and no soil to transport from the site. A measured factor of safety is verified, as the piers are 100% load tested to a force greater than the actual working load prior to being put in service.

Projects are usually completed in days, not weeks. Should geologic conditions change, the piers can be easily inspected, tested and/or adjusted.

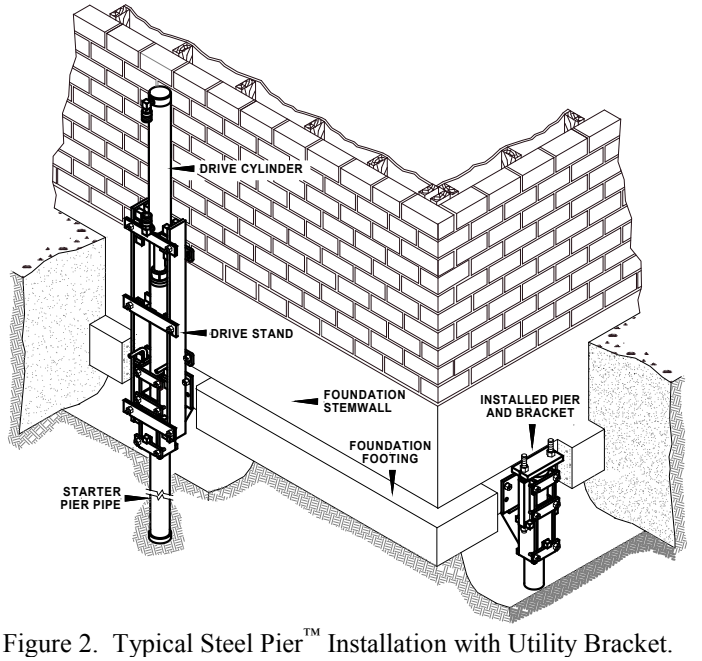

Figure 2. Typical Steel Pier™ Installation with Utility Bracket.

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PPB Utility Bracket Installation

The following nine steps illustrate the typical installation procedure for the PPB-300, PPB-350 or PPB-400 Utility Bracket. Figure 2 shows a structure with a spread footing. The detail on the left side of Figure 2 illustrates the configuration used when installing the resistance pier system and driving the pier pipe. On the right side of Figure 2 is the configuration of the installed pier system following the transfer of the structural load to the pier. Please contact ECP engineering department for *ECP Typical Specifications* that provide the specific and detailed product installation requirements and procedures.

1. **Site survey:** Pier placements are determined and locations of all underground utilities are verified.
2. **Excavation:** Small excavations are dug for access at each placement location. The excavation required at the foundation is usually about 3 feet square.
3. **Preparation of the foundation:** The footing is notched (if required) to situate the pier bracket under the stem wall. The bearing area under the footing is chipped a smooth and level condition and the face of the stem wall is adjusted to vertical (plumb) at the point of bracket attachment.
4. **Utility Bracket Attachment:** The utility bracket is secured to the footing using two anchor bolts. Then the drive stand and the hydraulic cylinder are mounted to the bracket. (Shown on left side of Figure 2.)
5. **Pier Pipe Installation:** The piers may be installed from outside or inside the structure. The pier pipe is advanced into the soil using a small portable high-pressure hydraulic pump. The pier pipe is 3-1/2 feet long so low overhead clearance is not a problem during installation. Pier installation continues until rock or suitable bearing is encountered below the unstable soil near the surface.
6. **Proof Load Test:** Every pier is load tested to insure that rock or other firm bearing is verified to be substantial enough to withstand a load greater than required to restore and support the structure. The structure provides the reaction force for installing and testing. Typically Factor of Safeties from 1.25 to 3.0 can typically be generated.
7. **Preparations for Restoration:** Once all piers have been installed, load tested, and the installation data recorded; lifting head assemblies and hydraulics are placed at the placements, which are connected to one or more manifolds and hydraulic hand pumps.
8. **Restoration:** Under careful supervision, the structural load is transferred from the failing soil under the foundation to the steel pier system. The structure is gently and evenly lifted to the specified design elevation. The nuts at the pier caps are secured at each placement and the lifting equipment is removed. (Please see Figure 1.)
9. **Clean Up:** The soil that was excavated at each pier placement location is replaced and compacted. The site is left clean and neat.

PPB Utility Bracket Components

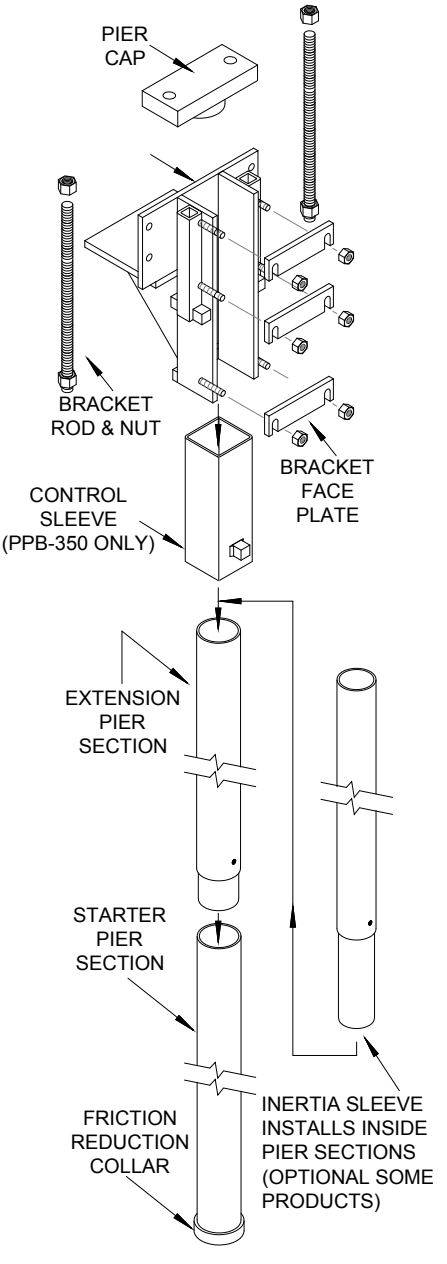

Figure 3. Component configuration for typical PPB-300, PPB-350 & PPB-400 Utility Brackets

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PPB-166 Slab Jack Installation

The following nine steps illustrate the typical installation procedure for the ECP PPB-166 Slab Jack Bracket. Figure 4 shows the configuration used to install the pier pipe and the installation tools mounting configuration. Please contact ECP engineering department for *ECP Typical Specifications* that provide the specific and detailed product installation requirements and procedures.

1. **Site survey:** Pier placements are determined and locations of all underground utilities verified.
2. **Core Drill/Excavation**: Core drill an eight inch diameter hole through the slab. Excavate soil below hole to a depth of 14 to 16 inches.
3. **PPB-166 Bracket Placement:** The Bearing Plate shall be temporarily placed on the soil at the bottom of the hole and aligned with the center of the hole in the concrete. The drive stand and hydraulic cylinder are connected to the bracket using 3/4 inch diameter B7 all-thread rods.
4. **Pier Pipe Installation:** Each three foot long section of pier pipe is advanced into the soil using a portable high-pressure hydraulic pump. Overhead clearance is usually not a problem when using short pier sections. The pier pipe is advanced into the soil until rock or suitable bearing is encountered below the failing unstable soil directly under the slab.
5. **Proof Load Test:** Every pier is load tested to insure that rock or other firm bearing is verified to be substantial enough to withstand a load greater than required to restore and support the slab. Some slabs can provide sufficient reaction force for installation and testing, but supplement weights around the access hole are sometime necessary to develop addition reaction force and to reduce slab stress cracks. Tests typically apply no more than 75% of the ultimate capacity.
6. **Preparations for Restoration:** Once pier pipe has been installed, load tested, and the data recorded for all placements; the all of the bearing plates, lifting head assemblies and hydraulics are installed on the piers.

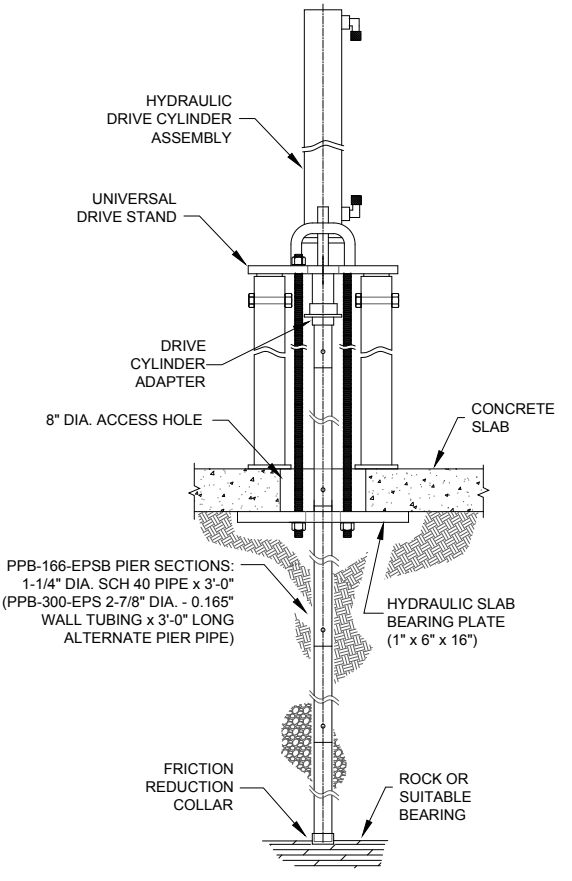

Figure 4. PPB-166 Slab Jack installation configuration

Hydraulic rams are connected to one or more manifolds and hydraulic hand pumps.

7. **Restoration:** Under careful supervision, the load is transferred from the failing soil under the slab to the steel pier system. The slab is gently and evenly lifted to as close to the original elevation as the construction will allow or to the specified elevation. The nuts at the pier caps are secured at each placement, and then the lifting equipment is removed.
8. **Filling the Voids:** A lean concrete mud slurry (2-1/2 sack mix) shall always be pumped under low pressure to fill all voids created when the slab was lifted.
9. **Clean Up:** The soil that was excavated from each pier placement shall be removed and disposed of in a safe and legal manner. The core drilled holes shall be filled with structural concrete and finished to match the existing floor. The site shall be left clean and neat.

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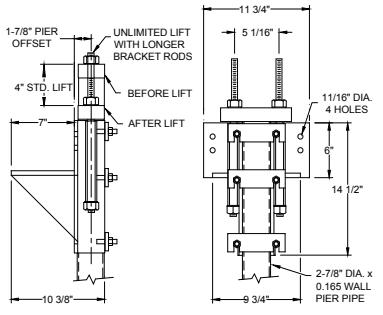
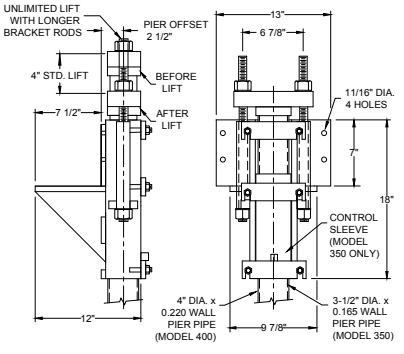
ECP Steel Pier™ – Product Configurations

A. PPB-300 Utility Bracket



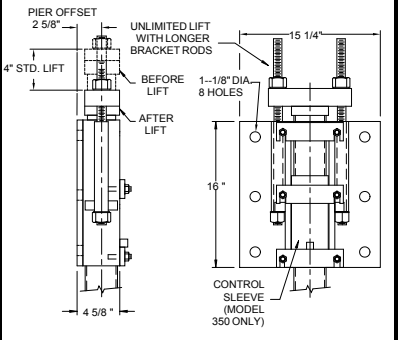
Ultimate-Limit Bracket Capacity
79,000 pounds

B. PPB-350-400 Utility Bracket



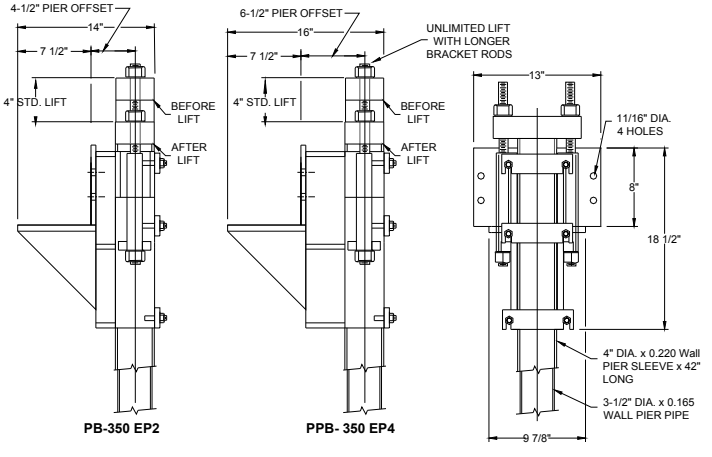
Ultimate-Limit Bracket Capacity
99,000 pounds

C. PPB-350-400-WM Wall Bracket



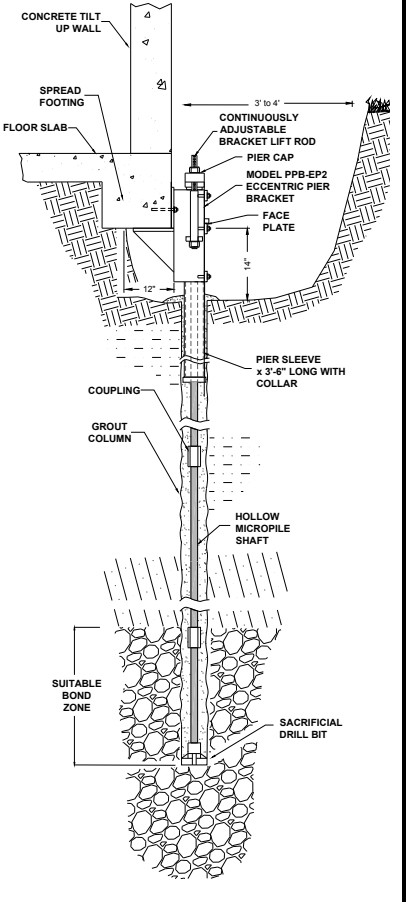
Ultimate-Limit Capacity
Std. Bracket: 107,000 pounds
PPB-400 WM HD Bracket
115,000 pounds (Not Shown)

D. PPB-350-EP2 & PPB-350-EP4 Eccentric Bracket



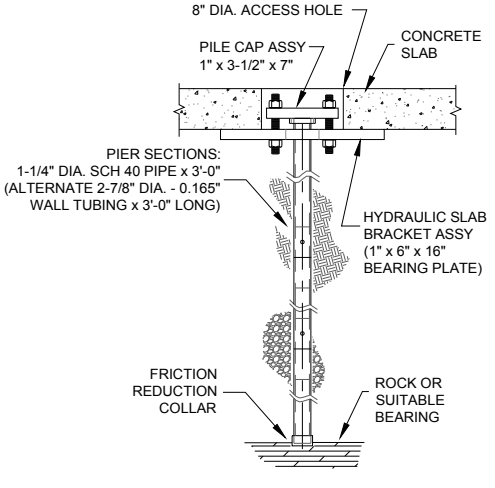
Ultimate-Limit Bracket Capacity: EP2 - 68,000 lb – EP4 - 55,000 lb

E. PPB-350-MP2 Micro Pile



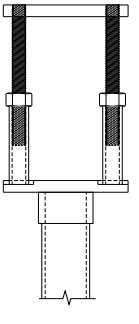
Ultimate-Limit Bracket Capacity
68,000 pounds

F. PPB-166 Slab Jack Bracket Assembly



Ultimate-Limit Bracket Capacity: 22,000 lb
(Pier Pipe Sold Separately)

G. PPB-200 & PPB-250 Under Footing Bracket



Ultimate-Limit Bracket Capacities:

PPB-200 - 50,000 pounds
PPB-250 - 54,000 pounds
(PPB-250 similar, not shown)

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Table 1. ECP Steel Resistance Pier System Ratings					
Fig	Product Designation – Pipe Size	Ultimate-Limit [1] Bracket Only Capacity	Ultimate-Limit [1] Mechanical System Capacity	Maximum Drive Force - "Proof Test" [2]	Recommended Design / Service Load
A	PPB-300 Steel Pier – 2-7/8" dia x 0.165" Wall	79,000 lb	68,000 lb	51,000 lb	34,000 lb
B	PPB-350 Steel Pier – 3-1/2" dia x 0.165" Wall	99,000 lb	86,000 lb	64,500 lb	43,000 lb
B	PPB-400 Steel Pier – 4" dia x 0.220" Wall	99,000 lb	99,000 lb	74,000 lb	49,500 lb
C	PPB-350-WM – 3-1/2" dia x 0.165" Wall	107,000 lb	86,000 lb	64,500 lb	43,000 lb
C	PPB-400-WM – 4" dia x 0.220" Wall	107,000 lb	107,000 lb	80,000 lb	53,500 lb
--	PPB-400- WMHD – 4" dia x 0.220" Wall	115,000 lb	115,000 lb	86,000 lb	57,500 lb
D	PPB-350-EP2 – 3-1/2" dia x 0.165" Wall	68,000 lb	53,000 lb	39,750 lb	26,500 lb
D	PPB-400-EP2 – 4" dia x 0.220" Wall	68,000 lb	54,000 lb	40,500 lb	27,000 lb
D	PPB-350-EP4 – 3-1/2" dia x 0.165" Wall	55,000 lb	42,000 lb	31,500 lb	21,000 lb
E	PPB-350-MP2 – Micro Pile Bracket	68,000 lb	Note: Capacity depends upon drill dia, bar dia & grout strength		
F	PPB-166 – Slab Jack – 1-1/4" Sch. 40[3]	22,000 lb	22,000 lb	16,500 lb	11,000 lb
G	PPB-200 – Ftg Bracket – 2-7/8" dia x 0.165" Wall	50,000 lb	50,000 lb	37,500 lb	25,000 lb
--	PPB-250 – Ftg Bracket – 2-7/8" dia x 0.165" Wall	54,000 lb	54,000 lb	40,500 lb	27,000 lb

1. Unfactored Failure Limit, use as nominal, "P_n" value per design codes 2. Maximum recommended load to confirm suitable end bearing capacity of pipe
3. Alternate pier pipe – 2-7/8" dia x 0.165" Wall

"Suitable Load Bearing Stratum"

While field load testing of each resistance pier verifies that the pier has encountered suitable end bearing, several definitions can be found for the word "*Rock*". Many times when a soil boring log is available one may want to estimate the approximate depth to load bearing. Presented here are guidelines to assist with the estimating depth to suitable bearing.

When material described in a soil boring reflects a Standard Penetration Test, "N", greater than 50 blows per foot, we generally consider the material to be "rock" or a very hard soil stratum. Field load tests over the years have confirmed that resistance piers will provide long term support in strata such as these. In many cases suitable bearing can be achieved in less dense material depending upon the pile loading requirements, the type of soil and the soil density.

Thousands of comparisons between soil boring logs and field load tests suggest that *Suitable Load Bearing* is generally achieved in soils where "N" > 35 blows per foot at the termination depth.

Why Determine Structural Loads?

Before one can begin to prepare a foundation underpinning design, an accurate estimate of the foundation loading is required. All loads that are placed upon a structure eventually transfer to the soil through the foundation. Many times all of these loads are not considered during the design. This can lead to an underestimation of the total structural load on the foundation. The result may be a design that has insufficient strength to support and restore the structure. Several problems surface when underestimated structural loads are used for the project design. The first indication of a problem is when the structure cannot be lifted, whereby the contractor usually tries to explain away the problem by saying that he is only trying to "stabilize" the structure or that there is too much "suction" under the slab. Other indications of underestimated foundation loads are the appearance of new foundation fractures and/or continued settlement of the underpinning piers after project completion.

The cost to the foundation contractor due to improperly estimating structural loads can be high. First and foremost is the likelihood of a customer complaint and lack of referrals. In addition, expensive callbacks cut into the company's profits. Finally, the long term solution usually involves installing additional underpinning between the existing piers, which means that the project could easily cost the contractor twice as much as originally planned.

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Simplified Tables of Structural Foundation Loads

When attempting a foundation load calculation for the first time, it often seems complicated and imposing. Once the basics are learned, estimating structural loads is quite easy. The simplest way to prepare a foundation load estimate is to break the structure into components, determine the estimated weight for each component and then add all of the results together. The simplified tables below have been prepared for the most common residential structural elements. (See note regarding Building Codes after Table 7 below.)

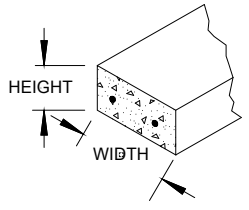

Table 2. Reinforced Concrete Spread Footings

WIDTH / HEIGHT	8”	12”	15”	18”	20”	24”
	Perimeter Weight – lb/ft					
6”	24	72	90	108	120	144
9”	72	108	135	162	180	216
12”	96	144	180	216	240	288
15”	120	180	225	270	300	360
18”	144	216	270	324	360	432
20”	160	240	300	360	400	480
24”	192	288	360	432	480	576

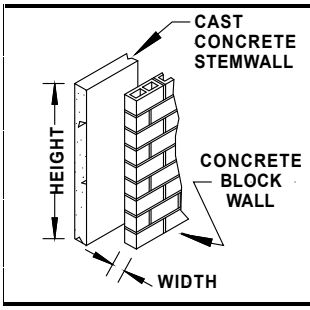

Table 3. Walls, Stem Walls, Basement Walls

WALL WIDTH / WALL HEIGHT	18”	24”	36”	48”	96”	108”
	Perimeter Weight – lb/ft					
6” Conc. Block	65	86	129	172	344	387
8” Conc. Block	83	110	165	220	440	495
8” Cast Concrete	144	192	288	384	768	964
10” Cast Concrete	180	240	360	480	960	1,080
12” Cast Concrete	216	288	432	576	1,152	1,296

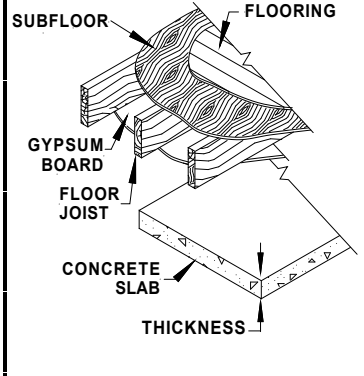

Table 4. Wood Floors & Concrete Slabs

Wood Floor – Span To Girder (2 X 6 or 2 X 8 Joist Framing @ 12” O.C.)	8’	10’	12’	14’	16’
	Perimeter Weight – lb/ft				
3/4” Sub Floor , 3/4” Hardwood & 1/2” Gypsum	48	60	78	91	96
1-1/2” Sub Floor, Carpet, Pad & 1/2” Gypsum	52	65	84	98	104
1-1/2” Sub Floor, 1/4” Ceramic Tile, 1/2” Gypsum	64	80	102	119	128

Concrete Slab	Perimeter Weight
4” Slab – Unfinished	191 lb/ft
4” Slab, Carpet & Pad	195 lb/ft
4” Slab & 1/4” Ceramic Tile	198 lb/ft
6” Slab – Unfinished	432 lb/ft

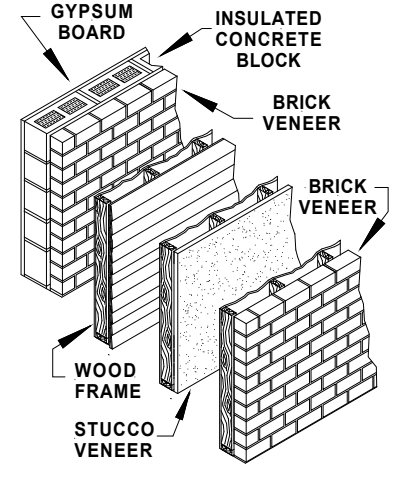

Table 5.	**Exterior Walls** (8 ft tall)	Perimeter Weight
Conc. Block	8” Heavy Weight Concrete Block, 1/2” Drywall & Insulation Fill (Not Illustrated)	425 lb/ft
Conc. Block Brick Veneer	8” Heavy Weight Concrete Block, Clay Brick, 1/2” Drywall & Insulation Fill	815 lb/ft
Wood Frame	1/2” Ship Lap or Plywood, 1/2” Sheathing, 2 x 4 Studs @ 16” o.c., 1/2” Drywall & 3-1/2” Insulation	88 lb/ft
Stucco Veneer	1-1/2” Concrete Stucco, 2 x 4 Studs @ 16” o.c., 1/2” Drywall & 3-1/2” Insulation	200 lb/ft
Brick Veneer	Clay Brick, 1/2” Sheathing, 2 x 4 Studs @ 6” o.c., 1/2” Drywall & 3-1/2” Insulation	390 lb/ft

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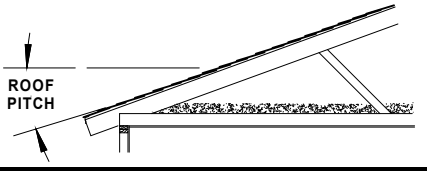
Table 6.	Roof & Ceiling				
	**Roof** -- Rafter Framing (2 X 6 or 2 X 8 @ 12" O.C.), 1/2" Wafer Decking, 15# Felt, & 240# Asphalt Shingles (1' Roof Overhang) **Ceiling** – Joist Framing (2 X 6 or 2 X 8 @ 12" O.C.), 1/2" Dry Wall & 10" Blown Insulation (No Attic Storage)				
ROOF PITCH \ SPAN TO INTERIOR SUPPORT	8'	10'	12'	14'	16'
	Perimeter Weight – lb/ft				
2" in 12"	91	116	143	164	185
3" in 12" or 4" in 12"	92	123	145	166	187
6" in 12"	95	127	149	171	193
12" in 12"	107	154	168	193	218

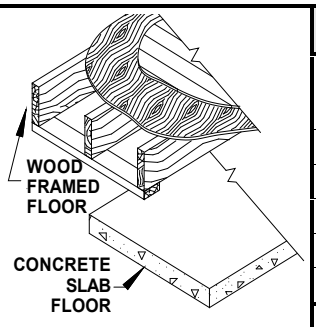


Table 7. Live Loads on Floors And Attics					
Residential Occupant Live Loads – Span to Interior Support or Girder	6'	8'	10'	12'	14'
	Perimeter Weight – lb/ft				
First Floor – Wood Framing -- 40 lb/ft^2	120	160	200	240	280
Second Floor -- 30 lb/ft^2	90	120	150	180	210
Habitable Attics -- 30 lb/ft^2	90	120	150	180	210
Uninhabitable Attics -- 20 lb/ft^2	60	80	100	120	140
4" Slab on Grade – 40 lb/ft^2	120				

Reference: Excerpts from American Standard Building Code Requirements for Minimum Design Loads in Buildings – A58.1 – 1955

Note: Building techniques and Codes vary across the country; these tables are only to be used as a general guide for structural load estimations on preliminary design work. When in doubt about the construction elements, add 10% to 20% to load estimate or increase factor of safety of the design to 2.2 to 2.5 for "Safe Use" Design.

Estimating Structural Loads

Two structural loads are usually specified in the design. "Dead Loads" are permanent weights that are always applied to the foundation. Examples of *Dead Loads* are loads associated with components like the roof framing, the floor structure and the masonry. "Live Loads" are weight on the foundation that can change. *Live Loads* are the weights associated with the occupants, storage, snow and wind pressure, etc. The goal is to achieve an accurate estimated weight along the perimeter of the structure where foundation restoration is needed. The easiest way to accomplish a foundation load estimate is to break the structure into components, estimate weight for each component and then add all of the results together. Tables 2 through 9 provide estimated component loads on a foundation perimeter. One only needs to inspect the structure and be familiar with typical building codes in the area to be able to use the tables provided to estimate the foundation load.

Benefits of Estimating Foundation Loads

- The design will be more accurate and there will be greater restoration success with less chance of a call back from the owner later.
- The designer will have greater confidence presenting his design to owners and engineers when he has prepared a load estimate.
- Pier placements are easily justified because the load analysis determines the pier placement design can provide immediate restoration and long term support.
- The owner will perceive the designer as being a more competent contractor because he is careful and thorough with the design, has attention to details, a solid design.
- Highly detailed proposals are generally more readily accepted than general repair outlines, which translate to more work for the company.
- There will be greater client satisfaction with the final product.

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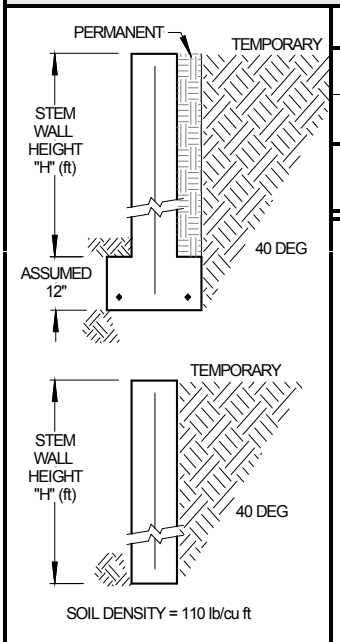
Table 8. Estimated Soil Loads on Footings



Permanent Soil Load on a Footing Toe – W_d

Soil Height Against Wall	2'	4'	6'	7'	8'	9'	10'
Soil Load per inch of Footing Width	18 lb	37 lb	55 lb	64 lb	73 lb	83 lb	92 lb

To determine the permanent soil load on a footing toe, multiply the actual width of the footing toe (in inches) by the unit weight shown above for the soil height against the wall.

Graph 1. Temporary Soil Load (One Side) – W_t

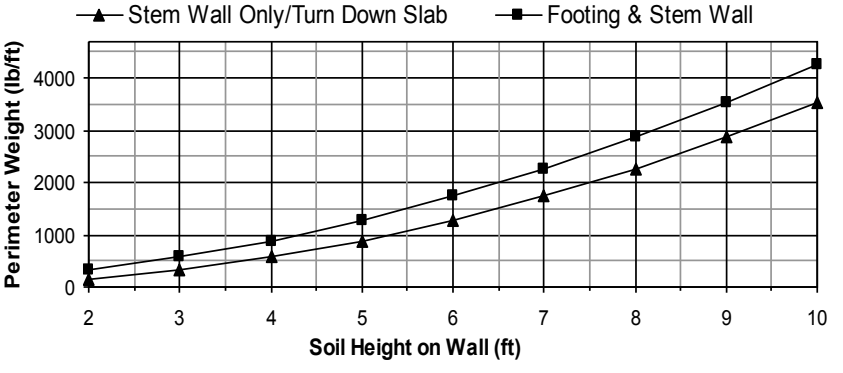


Table 9. Estimating Snow Loads*

0 – 18" Snow = 10 lb/ft²	19" – 38" Snow = 20 lb/ft²	39" – 57" Snow = 30 lb/ft²	58" – 76" Snow = 40 lb/ft²	77" – 96" Snow = 50 lb/ft²

Snow Load Along Perimeter Footing With Hip Style Roof – [(L x W) / 2 (L + W)] x (Snow Load Factor)

Snow Load Along Perimeter – Rafter Side of Roof With Gable Ends – (L x W / 2L) x (Snow Load)
– Gable End of Roof – [1.5 + (Roof overhang)] x (Snow Load)

L = Length of the perimeter wall to be underpinned -- W = Span of roof from exterior wall plus roof overhang

* Verify the locally approved Snow Load Factor with a Building Official in your area.

"Quick and Rough" Structural Load Estimating

Table 10 offers empirical load estimates over a range of typical residential construction techniques from light to heavily built structures. The estimated loads presented in Table 10 are rough load estimates. Please use this data only for determining quick budget estimates.

Table 10. Ranges for Typical Average Residential Building Loads*

Building Construction (Slab On Grade)	Estimated Foundation Load Range (DL = Dead – LL = Live)	Building Construction (Basement or Crawlspace & Footing)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing -- Footing with Slab	DL 750 – 850 lb/ft LL 100 – 200 lb/ft	**One Story** Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,250 – 1,500 lb/ft LL 300 – 475 lb/ft
One Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,000 – 1,200 lb/ft LL 100 – 200 lb/ft	**One Story** Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,500 – 2,000 lb/ft LL 300 – 475 lb/ft
Two Story Wood/Metal/Vinyl Walls with Wood Framing – Footing with Slab	DL 1,050 – 1,550 lb/ft LL 300 – 475 lb/ft	**Two Story** Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,400 – 1,900 lb/ft LL 600 – 950 lb/ft
Two Story 1st Floor Masonry, 2nd Wood/Metal/Vinyl with Wood Framing – Footing with Slab	DL 1,300 – 2,000 lb/ft LL 300 – 475 lb/ft	**Two Story** 1st Masonry, 2nd Wood/Metal/Vinyl – Wood Framing, Basement or Crawlspace & Footing	DL 1,650 – 2,200 lb/ft LL 600 – 950 lb/ft
Two Story Masonry Walls with Wood Framing – Footing with Slab	DL 1,600 – 2,250 lb/ft LL 300 – 475 lb/ft	**Two Story** Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,900 – 2,500 lb/ft LL 600 – 950 lb/ft

*** Table 10 load estimates DO NOT Include Snow Loads.**

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Estimating Commercial Building Loads

Because commercial construction and building use is so varied, it is not practical to produce tables similar to Table 2 through Table 7 for commercial structures, but using the typical weights of common building materials provided in Table 11, the designer may be able to determine perimeter and footing loads from knowledge about the construction materials and techniques used to construct the building needing repair; simply use the component weights below to create weights for the structural elements to the building.

Table 11. Weights of Building Materials

Materials	Weight lb/sq. ft.	Materials	Weight lb/sq. ft.	Materials	Weight lb/sq. ft.
Brick Masonry:		**Wood Framing:**		**Roof:**	
4" Brick	40	2x4 @ 12 – 16" o.c.	2	Asphalt	3
8" Brick	80	2x6 @ 12 – 16" o.c.	3	Wood	2
12" Brick	120	2x8 @ 12 – 16" o.c.	4	3-ply Felt & Gravel	5-1/2
Concrete: (per inch thick)		**Sheathing:**		**Insulation** (per inch)	
Standard Concrete	12.5	1/2" Wood	2	Blown	1/2
Slag Concrete	11.5	3/4" Wood	3	Batts	3/4
Lightweight Concrete	6 to 10	1/2" Gypsum	2	Rigid	1-1/2
Soil:	**lb/cu. ft.**	**Floors:**		**Hollow Conc. Block:**	
Clay (Dry)	63	Vinyl	1	4" Light Wt	21
Clay (Damp)	110	7/8" Hardwood	4	4" Heavy Wt	30
Sand, Gravel (Dry, Loose)	90 - 105	3/4" Softwood	2-1/2	6" Light Wt	30
Sand, Gravel (Dry, Packed)	100 - 120			6" Heavy Wt	43
Sand, Gravel (Wet)	118 - 120	Carpet & Pad	2	8" Light Wt	38
Earth (Dry, Loose)	76			8" Heavy Wt	55
Earth (Dry / Wet, Packed)	95 - 96	3/4" Ceramic Tile	10	12" Light Wt	55
Earth (Mud, Packed)	115	1" Terrazzo	13	4" Stone	55

Reference: Excerpts from American Institute of Steel Construction, "Manual of Steel Construction" - 1989

Determining Pier Spacing

When locating piers on a structure, two factors must be considered that can limit the center-to-center distance between piers. The spacing between piers cannot be so large such that:

- **The spacing between piers exceeds the pier capacity. (*Pier Strength Spacing*)**
- **The spacing between piers overloads the footing. (*Footing Strength Spacing*)**

Pier Spacing Based Upon *Pier Strength*

The strength of the pier system is usually of concern when supporting and restoring a heavy structure such as a commercial building or a heavy, two-story residence with a full basement. **"Safe Design" dictates that the designer applies a suitable factor of safety.** Table 1 provides a quick reference to selecting a *Recommended Design / Service Load*. In other cases the Factor of Safety may be dictated by the project. Equation 1 is used to determine the pier spacing relative to pier capacity.

Equation 1: Pier Spacing

$$\text{"X"} = P_{DSL} / P_L \quad \text{or} \quad P_{DSL} = \text{"X"} \times P_L$$

Where:
"X" = Pier Spacing (ft)
P_{DSL} = Recommended Design / Service Load (Table 1)
P_L = Estimated Lifting Load

Pier Spacing Based Upon *Footing Strength*

The strength of the footing is of great importance in lighter structures. These structures generally have small footings with little or no rigid stem wall for strength. If Equation 1 were used to estimate the spacing for a single story with slab on grade, the result would suggest pier spacing at a distance that the footing cannot span. In Design Examples 3 in Chapter 6, a typical light structure is shown. Using Equation 1 to estimate the pier spacing for the structure in Design Example 3 would suggest 27 foot pier spacing, but the concrete slab foundation simply cannot support such a long span

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between piers. Therefore, in this case, **the foundation strength determines the maximum pier spacing.**

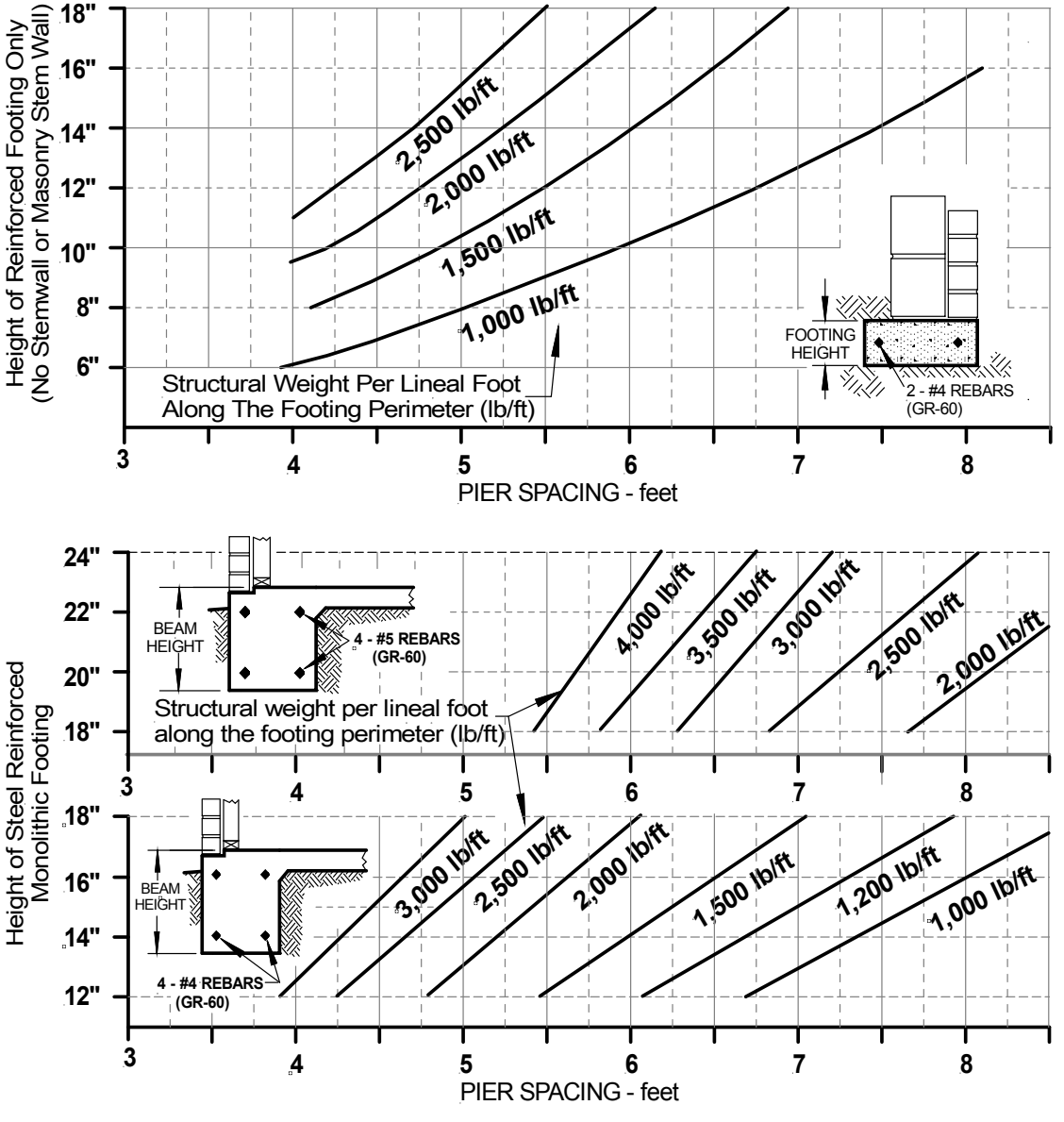
Graph 2 is provided to assist with estimating pier spacing when dealing with:

1. Monolithic ("turned down") footings and/or,
2. Steel reinforced spread footings with no stem wall or,
3. When hollow masonry stem walls are present.

Graph 3 is provided to help estimate pier spacing when estimating footings with steel reinforced footings with integral short concrete stem walls.

These graphs assume generally accepted construction techniques, adequate steel reinforcement that is properly embedded into the concrete, and concrete with a compressive strength of 3,000 psi or more after 28 days.

Graph 2. Graphs for Estimating Pier Spacing Based Upon Foundation Strength of Spread Footing or Monolithic Slab Only (No Stem Wall or Hollow Masonry Stem Walls)



Important: Building techniques and Building Codes vary across the country; the graphs presented here are to be used only as a general guide for spacing requirements, for preliminary designs, and for estimation purposes. It is recommended that a registered professional engineer conduct the final design and supervise the installation.

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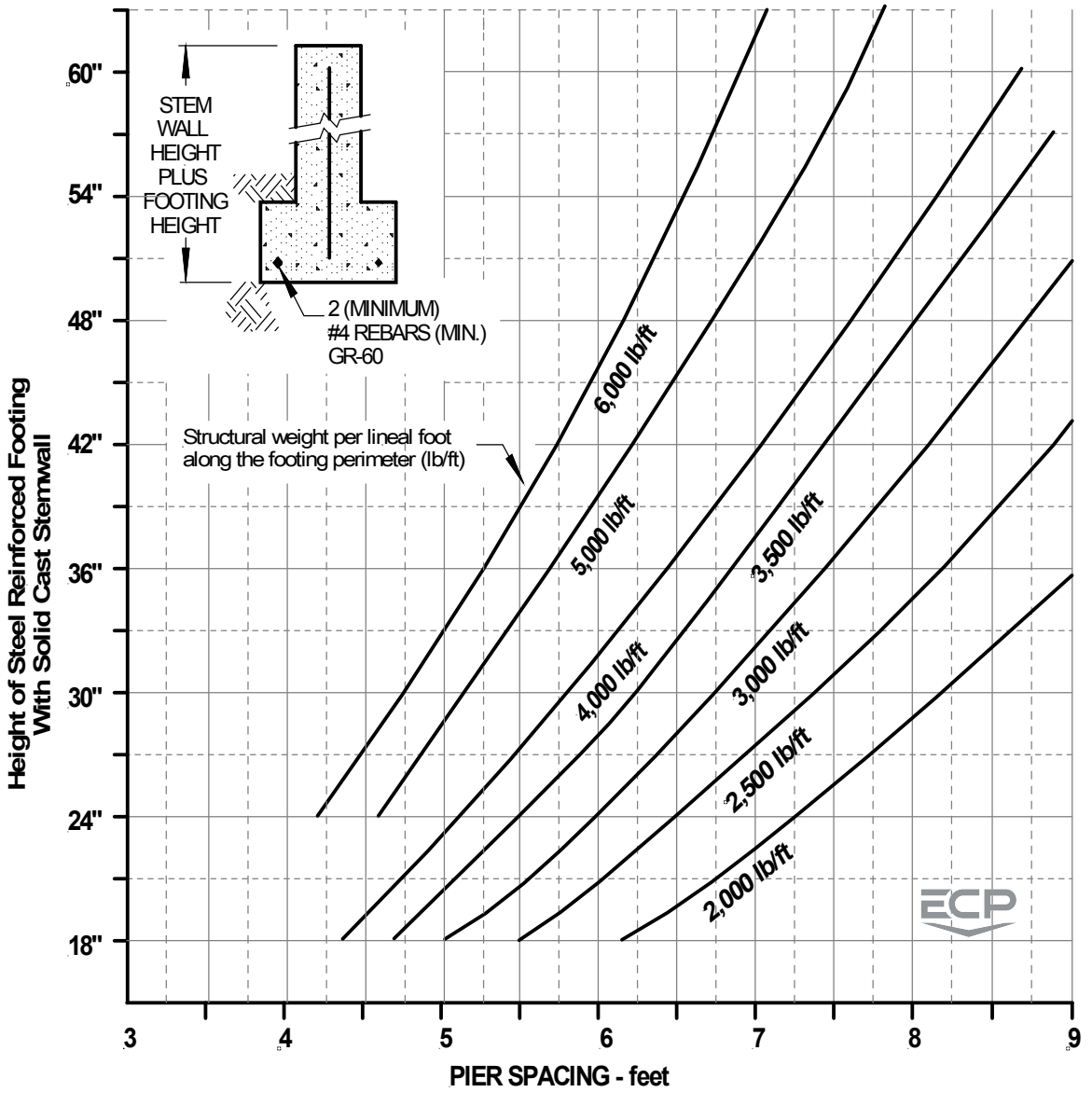
Graph 3. Graph for Estimating Pier Spacing Based Upon Foundation Strength of Spread Footing with Short Integrally Cast Concrete Stem Walls



Important: Building techniques and Building Codes vary across the country; the graphs presented here are to be used only as a general guide for spacing requirements, for preliminary designs, and for estimation purposes. It is recommended that a registered professional engineer conduct the final design and supervise the installation.

Technical Design Assistance

Earth Contact Products, LLC. has a knowledgeable staff that stands ready to help you with understanding how to design using ECP Steel Piers™, installation procedures, load testing, and documentation of each pier placement. If you have questions about structural weights, product selection or require engineering assistance in evaluating, designing, and/or specifying Earth Contact Products, please call 913 393-0007, Fax at 913 393-0008.

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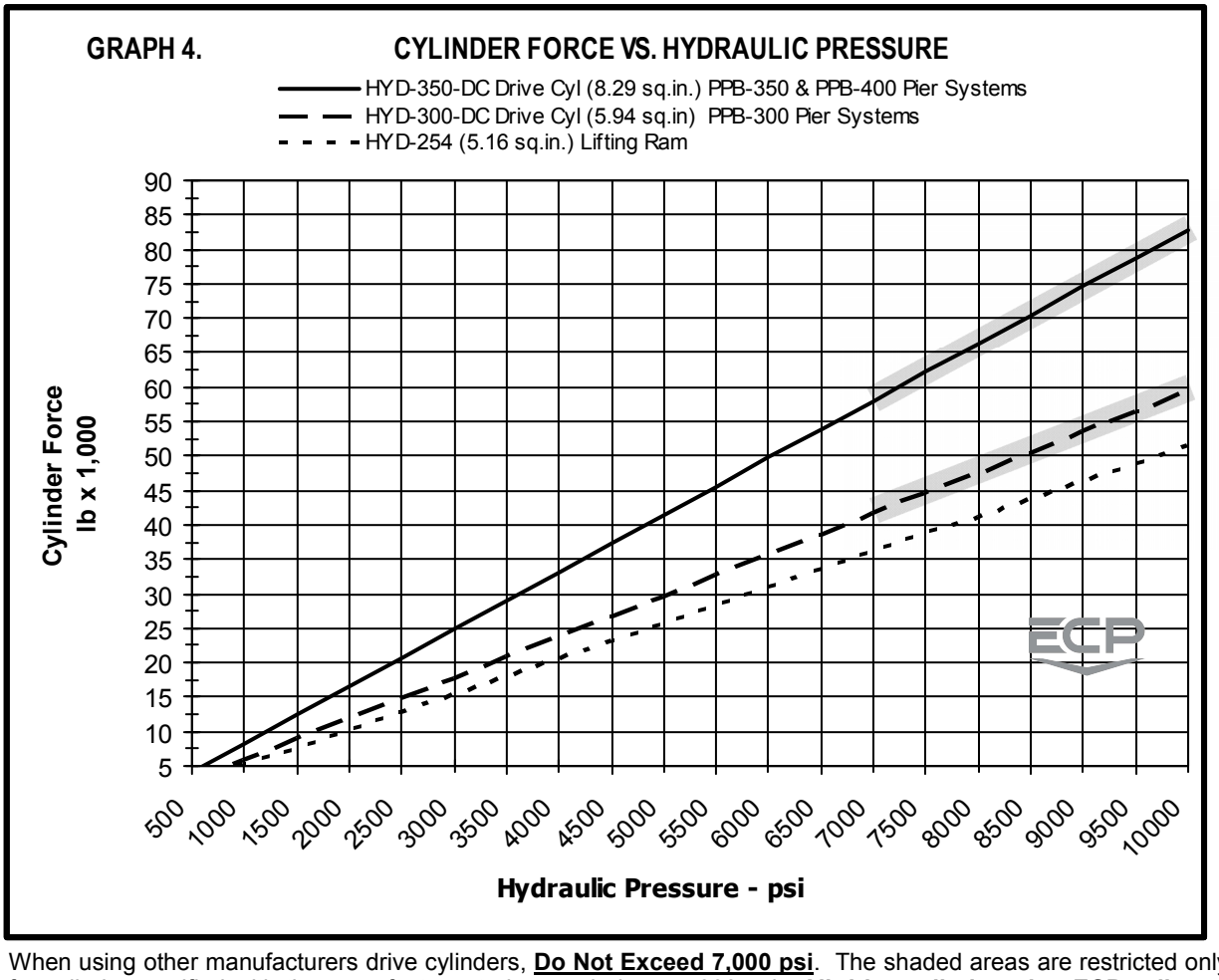
Pier Installation

Pier installation consists of forcing the pier pipe into the soil until end bearing resistance is encountered. Once this occurs, the strength of the bearing stratum is verified by load testing. The pier is subjected to a *proof load test* that is greater than the pier design (working) load.

Graph 4 below provides a quick reference to determine the actual downward force generated on the pier pipe at a various pressures on the drive cylinder.



When using other manufacturers drive cylinders, **Do Not Exceed 7,000 psi**. The shaded areas are restricted only for cylinders verified with the manufacturer to be rated above 7,000 psi. **All drive cylinders that ECP sells are rated to 10,000 psi.**

Caution!
Verify the manufacturer's recommended working pressure for the specific hydraulic drive cylinder to be used on a project prior to installing piers. When operating near the maximum cylinder pressure, the amount of actuator rod extension should be restricted to less than full length to prevent damage to the drive cylinder or actuator rod.

Equation 2: Hydraulic Cylinder Force

$$F_{Cyl} = A_{cyl} \times P_{cyl}$$

Where, F_{Cyl} = Cylinder force on pier – lb
P_{cyl} = Hydraulic Pressure -- psi
A_{cyl} = Effective Cylinder Area – in^2

- HYD-350-DC (3-1/2" & 4" dia)= 8.29 in^2
- HYD-300-DC (3" dia) = 5.94 in^2
- Lifting Ram = 5.16 in^2

Notice!
Earth Contact Products, LLC does not condone or recommend exceeding maximum working pressure ratings of hydraulic cylinders. Graph 4 shows maximum pressure allowed on ECP cylinders. Contact the cylinder manufacturer when in doubt about a pressure rating of other cylinders.

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Proof Testing and Project Documentation

The big advantage when using hydraulically installed ECP Steel Piers™ is that each pier is field *Proof Tested* to a load that is greater than force that is required to restore and support the structure. This *Proof Testing* of each and every pier placement verifies that firm bearing stratum or rock upon which the pier pipe is founded is sufficient to support the working load requirement plus a factor of safety.

It is recommended that the installer document the following data for each pier placement:

1. The installation force used to drive each 3-1/2 foot long section of pier pipe into the soil.
2. The *Proof Test* force that was applied against the bearing stratum. This force shall be either the force required to slightly lift the structure using just the drive cylinder or the application of the maximum allowable test load shown in Table 1, whichever is less.
3. The length of time the pier was subjected to the *Proof Test* loading.
4. The depth to load bearing
5. After all pier placements have been installed and *Proof Tested*, the force required at each placement to recover lost elevation to restore the structure shall be recorded.
6. The amount of lift at each placement.

At the end of the project, this data shall be compiled into a project report and retained by the installer for future reference. The installer should provide a copy of the project report to the engineer of record or owner's representative upon request.

Buckling Loads on the Pier Shaft in Weak Soil

Whenever a slender column (Pier Pipe) does not have adequate lateral support from the surrounding soil, the load carrying capacity of the column is reduced as buckling of the pipe column becomes a risk. In the case of ECP Steel Piers™, the full ultimate-limit capacity shown in Table 1 is available provided the soil through which the pier penetrates maintains a Standard Penetration Test value "N" $\geq$ 5 blows per foot through the entire depth of the pier installation. The pier must also be firmly secured to a foundation bracket at the footing.

The most accurate way to determine the buckling load of a pier shaft in weak soil is by performing a buckling analysis by finite differences. There are several specialized computer programs that can perform this analysis and allow the introduction of shaft properties and soil conditions that can vary with depth. Another, less accurate method of estimating critical buckling is by Davisson Method, "*Estimating Buckling Loads for Piles"* (1963). In this method, Davisson assumes various combinations of pile head and tip boundary conditions with a constant modulus of sub-grade reaction, "k_H". Load transfer to the soil due to skin friction is assumed negligible and the pile is assumed straight. Equation 3 is Davisson's formula.

Equation 3: Critical Buckling

$$P_{cr} = U_{cr}\, E_p\, I_p / R^2$$

Where:

P_{cr} = Critical Buckling Load – lb
U_{cr} = Dimensionless ratio (Assume = 1)
E_p = Shaft Mod. of Elasticity = 30 x 10^6 psi
I_p = Shaft Moment of Inertia = in^4
$R = \sqrt[4]{E_p\, I_p / k_H\, d}$
d = Shaft Diameter – in

Computer analysis of shaft buckling is the recommended method to achieve the most accurate results. Many times, however, one must have general information to prepare a preliminary design or budget proposal. Table 13, Page 106 below provides conservative critical buckling load estimates for various shaft sizes penetrating through different types of homogeneous soils.

Graph 5 on the following page presents visual representation of Buckling Strength of various pier configurations when fully exposed in air, or water, when no lateral shaft support is present.

It is recommended that a Registered Professional Engineer conduct the design of ECP Steel Piers™ where the pipe column is likely to be in weak soil and shaft buckling may occur.

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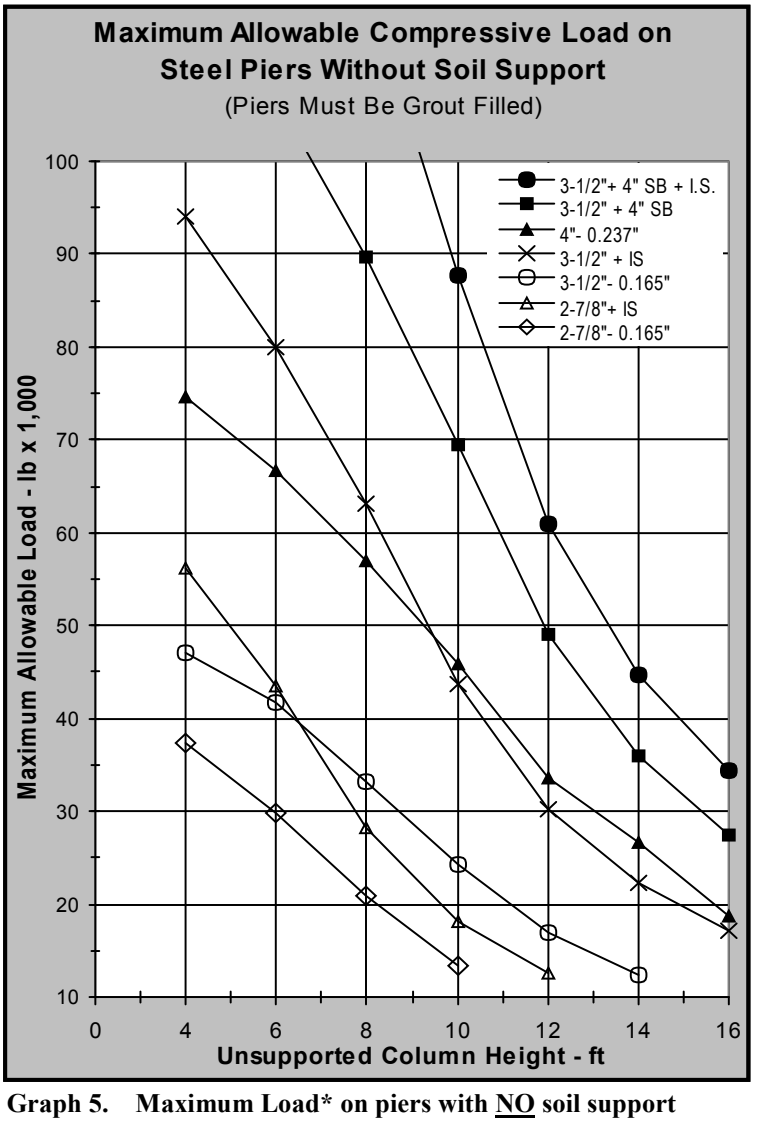
Allowable Compressive Loads - "P" in Air: Graph 5 shows the reduction in allowable axial compressive loading where the pier shaft has no lateral support.

Table 12 illustrates demonstrates how the ECP PPB-400-EPS (4 inch diameter) pier pipe provides an axial stiffness of more than 3-1/2 times that of a PPB-300-EPS (2-7/8 inch diameter) pier pipe. In addition, Graph 5 demonstrates that the PPB-400-EPS pier pipe has a maximum compressive load capacity of more than three times that of the PPB-300-EPS pier pipe when each has ten feet of exposed column height without any lateral support.

Whenever weak soil is encountered such as peat or other organic soils, improperly consolidated soil, or a situation where a portion of the pier shaft may become fully exposed; consideration MUST be given to the reduction in capacity brought on by the lack of lateral support to the pier pipe.



Graph 5. Maximum Load* on piers with NO soil support

In situations where insufficient lateral pier pipe support is provided by the soil, the pier is not able to support the full rated capacity. The length of pier pipe that is passing through the weak soil and the amount of stiffness provided by the pier pipe will affect the load capacity reduction that must be considered. **Pier pipe stiffness (Moment of Inertia) increases with increasing diameter.** Graph 5 shows reductions in allowable axial compressive loading relative to the exposed length of the pier pipe in air or water for various pier diameters and sleeved pier configurations. When ECP Steel Pier™ pipe is fully exposed or passes through very weak soils, we recommend installing sleeving over and/or inside the pier pipe to increase the bending strength of the pier; in addition, it is good practice for the designer to consider using a larger diameter pipe in weak soil applications.

Table 12 STEEL PIER SHAFT STIFFNESS COMPARISON

Steel Pier Pipe Configuration	Cross Section Area - in^2	Moment of Inertia - in^4 (Stiffness)	Pier Stiffness Relative to PPB-350-EPS
PPB-300-EPS (2-7/8" dia.)	1.41	1.29	0.55%
PPB-300-EPS + PPB-300-IP	2.65	1.81	0.77%
PPB-350-EPS (3-1/2" dia.)	1.68	2.35	100%
PPB-400-EPS (4" dia.)	2.60	4.66	198%
PPB-350-EPS + PPB-350-IP	3.46	4.22	180%
PPB-350-EPS + PPB-350-SB	4.27	7.01	298%
PPB-350-EPS + PPB-350-SB + PPB-350-IP	5.12	8.88	379%

EPS = Pier Pipe Section IP = Internal "Inertia" Sleeve SB = 4" External Sleeve

*** Caution: When selecting a pier configuration for a specific application, one must apply a factor of safety to the capacities shown on Graph 5 to insure "Safe Use" design.**

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Pier Sleeves

In areas of poor soil, the stiffness (axial moment of inertia) of the pier pipe and the strength of the coupled joints are of concern. Installing a pier sleeve or changing to a larger diameter pier pipe is required to prevent buckling. Poor soil conditions are generally recognized as:

- Soil having Standard Penetration Blow Counts less than or equal to five blows per foot ("N" ≤ 5) or,
- On projects where the pier pipe is exposed, or may become exposed

There are several ways to reinforce pier pipe in such situations. One of the simplest to slightly improve pier stiffness and to strengthen the coupled joints is to grout the pier pipe after installation. Many designers also require that the contractor install a reinforcing bar in the center of the pier pipe along with the grouting to improve joint strength.

"Inertia Sleeve" – Earth Contact Products offers a patented product called the *Inertia Sleeve* to improve shaft stiffness. This unique product is shown in Figure 5, and is the most economical way to quickly enhance the axial moment of inertia (stiffness) of the pier system. The *Inertia Sleeve* is easy to install, but must be installed concurrent with driving the pier pipe. One simply allows an *Inertia Sleeve* section to drop by gravity into the most recently installed section of pier pipe. This must be done prior to coupling together and driving the next section of pier pipe.

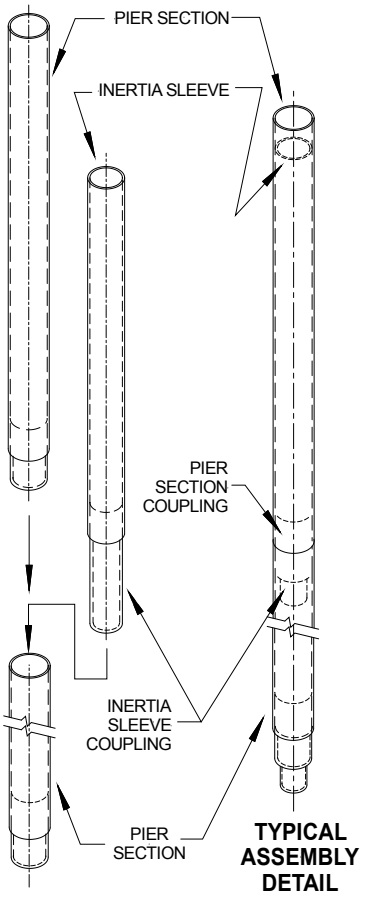

Figure 5. Details of ECP's patented PPB-300-IP and PPB-350-IP Internal "Inertia Sleeve" Assembly

The low cost *Inertia Sleeve* takes nearly no labor to install and instantly increases the rigidity and strength of the pier shaft through weak soil. The unique design of the patented "Inertia Sleeve" also strengthens the coupled joints. The coupling connection of the *Inertia Sleeve* fully passes through the pier pipe coupling and engages with the previously installed section of *Inertia Sleeve*. The couplings are therefore doubled and staggered, providing a strengthened coupled joint.

External Sleeve – Another means of increasing the axial moment of inertia of the pier shaft is to install external pier sleeving. Many designers like this method because it provides a significantly larger increase in pier rigidity than other methods. This is because the external sleeve increases the diameter of the pier shaft.

When installed, each external sleeve must be positioned such that the joints on the external sleeving are staggered and are not near the pier pipe couplings. The external sleeving must be hydraulically driven over the installed pier pipe prior to field load testing. The time required to drive the external pier sleeving is generally equivalent to the time required to initially install the pier pipe. Keep in mind, however, that external sleeving is only required at locations where the pier pipe is exposed with no lateral support or where the pier pipe passes through weak soil with insufficient lateral support on the pipe shaft.

Table 12 on the previous page presents shaft stiffness relative to different pier pipe configurations. It is interesting to note that the combination of the PPB-350-EPS, 3-1/2" diameter pier pipe, plus the PPB-350-IP *Inertia Sleeve* provides axial stiffness equal to 91% of the of the PPB-400 system (4" diameter) system. If the designer chooses PPB-350-SP (4" diameter exterior sleeve) over the PPB-350-EPS (3-1/2 inch diameter) pier pipe and grout fills pier pipe, the allowable load on the system will be 151% that of a simple PPB-400 (4" diameter) pier

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system. The cost savings should be very evident especially on projects that require extra rigidity only in the upper several feet of soil.

When specifying either type of pipe sleeve, the designer must extend the sleeving a minimum depth of three feet beyond the zone of weak soil and into the competent material.

For example, if a site has 6 feet of peat with Standard Penetration Test (SPT), "N", from 0 bpf ("Weight of Hammer") to 2 bpf that is overlaying sand with a SPT, "N" > 5 blows per foot; the designer should specify sleeving to a depth of at least 9 feet in order to provide adequate sleeve embedment beyond the 6 foot zone of weak soil that contains peat.

"Quick and Rough" Buckling Load Estimates for Weak Soil Conditions

A method for instantly estimating **Maximum Conservative Working Loads in Weak Soil** can be found in Table 13 below. General soil types and SPT, "N", values are provided in four columns. On the left side of Table 13 are available pier pipe and sleeving configurations. Read horizontally until the column with soil that most closely matches the soil conditions at the job site. At the intersection of the product line and soil column is the maximum **Design Load** (Working Load) for that pier or pier combination. If the capacity is unsufficient, drop down to a stiffer pier for the job.

Please note that the values given in Table 13 are working loads. A Factor of Safety of 2.0 has been applied to the loads in Table 13.

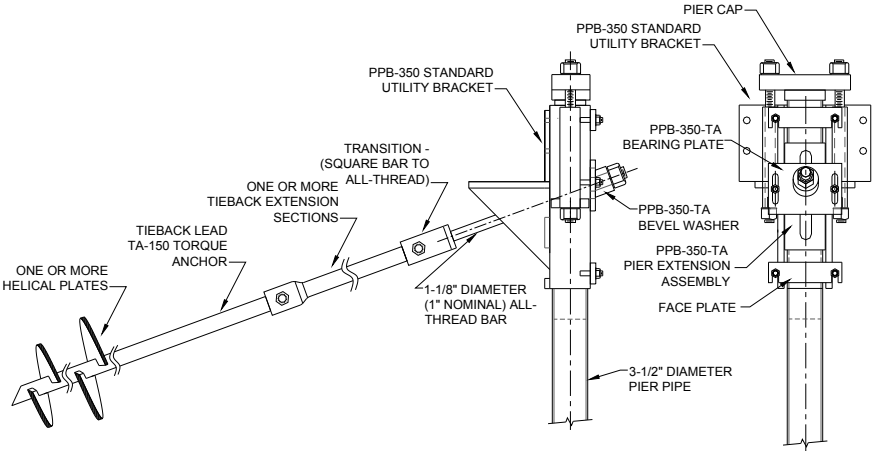
Table 13 Working Loads Under Buckling Conditions For Budgetary Estimating (Factor of Safety = 2)

Shaft Size	Uniform Soil Condition			
	Organics N < 1	Very Soft Clay N = 1 - 2	Soft Clay N = 2 - 4	Loose Sand N = 2 - 4
PPB-300-EPS (2-7/8" dia.)	19,000 lb	22,000 lb	31,000 lb	26,000 lb
PPB-300-EPS + PPB-300-IP	23,000 lb	27,000 lb	39,000 lb	32,000 lb
PPB-350-EPS (3-1/2" dia.)	26,000 lb	30,000 lb	43,000 lb	35,000 lb
PPB-400-EPS (4" dia.)	34,000 lb	40,000 lb	57,000 lb	46,000 lb
PPB-350-EPS + PPB-350-IP	36,000 lb	42,000 lb	59,000 lb	48,000 lb
PPB-350-EPS + PPB-350-SB	50,000 lb	58,000 lb	82,000 lb	67,000 lb
PPB-350-EPS + PPB-350-SB + PPB-350-IP	56,000 lb	66,000 lb	93,000 lb	76,000 lb

EPS = Pier Pipe Section IP = Internal "Inertia" Sleeve SB = 4" Ext Sleeve

ECP Steel Pier™ PPB-350 Utility Bracket System, TAF-150 Torque Anchor™ Tieback and PPB-350-TA Tieback Adapter Assembly

The PPB-350 Steel Pier System may be connected to a Helical Torque Anchor™ to provide lateral stabilization to the pier system. The connection is made with a PPB-350-TA Adapter Assembly. Please contact ECP for full specifications for the installation. Configuration details are shown below.



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Chapter 6

ECP Steel Piers™

Resistance Pier Design Examples

- **Calculate Foundation Load – Two Story Residence**
- **Calculate Maximum Pier Spacing for Design Example 1**
- **Adjusting for Pier Buckling in Weak Soil**
- **Determine Foundation Load – Single Story Slab on Grade**
- **Determining Maximum Pier Spacing**
- **Calculate the Foundation Load and Determine Pier Spacing – Three Story Office Building**
- **Estimating Drive Cylinder and Lifting Ram Pressures**
- **Determining Force Applied to Pier**

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"Designed and Engineered to Perform"

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Design Example 1 – Calculate Foundation Load

Two Story Brick with Full Basement

- The foundation consists of a 12" tall x 24" wide reinforced footing with a 10" thick x 8'-0" tall cast concrete basement wall. (footing toe = 7")
- The house is located in Indiana with 30+ inches of snow.
- The basement floor is 4" thick concrete.
- The soil depth to the basement floor elevation is 7 feet.
- The upper floors consist of 2 x 8 joists spaced 12" on center that span 12 feet to a steel beam supported by columns. The floors are carpeted.
- The house is 40' long x 24' wide with 2 x 4 studs on 16" centers, sheathing, insulation and drywall and brick veneer.
- The hip roof is framed with 2 x 8 rafters and 2 x 6 ceiling joists with a 3" in 12" pitch. There is no attic storage. There is 10" of blown insulation. The ceiling span is 12 feet plus a one foot roof overhang.

Calculate the Foundation Loads - Referring to the Load Tables in Chapter 6 estimate the foundation service (working) load, the live load and the temporary soil load.

1. **Dead Load** (DL):

Footing	=	288 lb/ lin. ft (Table 2)
Stem Wall	=	960 lb/ lin. ft (Table 3)
Slab	=	191 lb/ lin. ft (Table 4)
1st Floor	=	84 lb/ lin. ft (Table 4)
1st Exterior Wall	=	390 lb/ lin. ft (Table 5)
2nd Floor	=	84 lb/ lin. ft (Table 4)
2nd Exterior Wall	=	390 lb/ lin. ft (Table 5)
Roof & Ceiling	=	145 lb/ lin. ft (Table 6)
Perm. Soil Load	=	384 lb/ lin. ft [64# x 7" Toe] (Table 8)

Dead Load (DL) = **2,916 lb. per lineal foot**

2. **Live Loads** (LL):
   Live Load = 540 lb/ lin. ft (240+180+120) = 540 (Table 7)
   Snow Load = 150 lb/ lin. ft [(40x24)/2(40+24)] x (20#/sf) (Table 9)

   Live Load (LL) = **690 lb. per lineal foot**

3. **Working Load** (P_w) = Dead Load + Live Load
   Working Load (P_w) = 2,916 lb/lin. ft + 690 lb/lin. ft

   Working Load (P_w) = 3,606 lb. per lineal foot

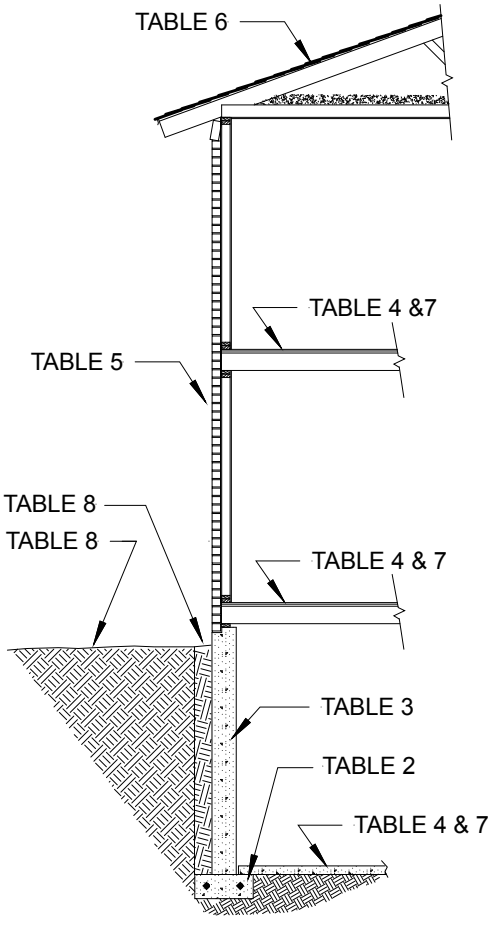

Figure 6. Load Estimate Sketch Example 1 & 1A.

4. **Lifting Load** (P_L) = Working Load + Temporary Soil Load
   Temp. Soil Load = 3,606 lb/lin. ft + 2,950 lb/lin. ft (Table 8-Graph 1 & reproduced below)

   Lifting Load (P_L) = **6,556 lb. per lineal foot** (See Note Pg 97)

5. **Factored Lifting Load** (P_{LF}) – The factored lifting load adds a percentage to the calculation to help compensate for possible omissions in the weight calculations, unexpected structural elements and the initial force to break the footing away from the surrounding soil. Depending upon confidence 10% to 20% is usually added.

   Factored Lifting Load (P_{LF}) = Lifting Load (P_L) + F.S. = 6,556 lb/lin. ft + 656 lb/lin.ft (10% F.S. Uncertainty)

   Factored Lifting Load (P_{LF}) = 7,212 lb. per lineal foot **(Use 7,200 pounds per lineal foot)**

END DESIGN EXAMPLE 1

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Design Example 1A – Calculate Foundation Load – "Quick and Rough" Method

Two Story Brick with Full Basement

- The house is 40' long x 24' wide with an 8'-0" tall cast concrete basement wall.
- The house is located in Indiana with 30+ inches of snow.
- The basement floor is concrete.
- The soil depth at the basement is 7 feet.

TABLE 10. Ranges for Typical Average Residential Building Loads*	
Building Construction (Basement or Crawlspace & Footing)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,250 – 1,500 lb/ft LL 300 – 475 lb/ft
One Story Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,500 – 2,000 lb/ft LL 300 – 475 lb/ft
Two Story Wood/Metal/Vinyl Walls with Wood Framing on Basement or Crawlspace and Footing	DL 1,400 – 1,900 lb/ft LL 600 – 950 lb/ft
Two Story 1st Masonry, 2nd Wood/Metal/Vinyl – Wood Framing, Basement or Crawlspace & Footing	DL 1,650 – 2,200 lb/ft LL 600 – 950 lb/ft
Two Story Masonry Walls with Wood Framing on Basement or Crawlspace and Footing	**DL 1,900 – 2,500 lb/ft LL 600 – 950 lb/ft**

1. Estimate the Dead Load and Live Load on the footing:

A. Using Table 10 from Chapter 5, select the column that most closely identifies the foundation construction. In this case the third column is selected because the house has a basement with a concrete slab floor.

B. Second, determine which of the five rows most closely describes the structure. In this case the closest match is the lowest row. (shaded) The construction of the house consists of two story framed construction with brick veneer siding.

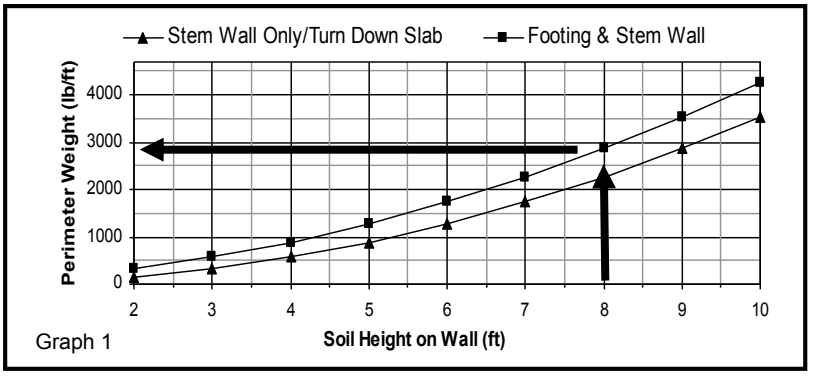
C. The Dead Load for a typical two story house of this description ranges from 1,900 to 2,500 lb/lin.ft and the Live Load averages between 600 and 950 lb/lin.ft. Based upon viewing the house and how robust is the construction and amount of contents, load selections are chosen within the ranges given.

D. The Snow Load is estimated at 150 lb/ lin. ft [(40'x24')/2(40+24')] x (20#/sf) (Chapter 5, Table 9)

Dead Load (DL) = 2,200 lb/lin.ft (selected) **Live Load (LL) = 750** lb/lin.ft (selected) **Snow Load 150** lb/lin.ft

2. Estimate the Temporary Soil Load on the footing:

The Temporary Soil Load may be estimated using Graph 1 presented in Chapter 5, shown here. The graph line that represents "Footing & Stem Wall" construction is selected because the footing construction is unknown. The Temporary Soil Load can be estimated by reading upward from a soil height of 8 feet (7' of soil on the basement wall + 1' for soil height against the side of the footing.) **Temporary Soil Load = 2,950 lb, lin.ft**



Graph 1

3. Factored Lifting Load (P_{LF}) = Dead Load + Live Load + Soil Load + Soil Load + Uncertainty Factor

Factored Lifting Load (P_{LF}) = 2,200 + 750 +150 + 2,950 lb/ft = **6.050 lb/ft** + 908 lb/lf (F.S. uncertainty: 15%)

Factored Lifting Load (P_{LF}) = 6,958 per lineal foot **(Use 7,000 pounds per lineal foot)**

END DESIGN EXAMPLE 1A

Review of Results of Design Examples 1 & 1A

One can see that the result obtained by the "Quick and Rough" analysis underestimated the foundation load by 3% compared to the more thorough weight analysis. Caution must be taken when using the "Quick and Rough" method because the load estimates are based upon where the designer believes the structural weight falls within the ranges provided. Choices made in this example were in the "middle range". It is quite evident that this structure is more robust than average construction, and loads should have been chosen nearer the higher end of the ranges and/or the Factor of Uncertainty increased.

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Design Example 2 -- Calculate the Maximum Pier Spacing for Design Example 1

- An inspection of the property suggests that the structure is well built and the foundation appears sound.
- A "Safe Use" Design Load of 43,000 pounds is selected with the use of the PPB-350 Steel Pier™. This represents a strong and economical pier for this project. (Table 1 – Chapter 5)
- A Factor of Safety of 2:1 is used.
- According to the analysis in Example 1 the structure requires a factored lifting force of 7,300 pounds per lineal foot of perimeter beam.

Equation 1 from Chapter 5 is used to determine the pier spacing relative to pier capacity.

Pier Spacing - "X" = $P_{SU\ Des}/P_L$ (Equation 1)

Where:

"X" = Pier Spacing (ft)

$P_{SU\ Des}$ = "Recommended Design Service Load" (Table 1 – Chapter 5) = 43,000 lbs

P_L = Estimated Lifting Load = 7,300 lb/lin.ft

"X" = 43,000 lb / 7,300 lb/ft (6,600 lb + 10%)

"X" = 5.9 feet

Use "**X" = 6 feet,** (maximum)

The pier placement design may now be prepared and a pricing estimate for this project is possible with piers spaced not to exceed 6 feet on center.

END DESIGN EXAMPLE 2

Design Example 2A – Adjusting for Pier Buckling in Weak Soil

- When discussing this project with the engineer, he mentions that consolidation of a layer of weak soil caused the settlement. Upon further investigations of the soil data, it is learned that there is approximately six feet of uncompacted loose fill with Standard Penetration Test values, "N" = 1 to 3 blows per foot.
- Below six feet, the soil is firm clay with SPT values exceeding "N" = 5 blows per foot.
- According to the analysis in Example 1 the structure requires a factored lifting force of 7,300 pounds per lineal foot of perimeter beam.

First Method: There are two ways to approach this new information. The first is to account for the reduction in pier pipe capacity and adjust the spacing accordingly.

In Example 2 it was determined that the Model 350 ECP Steel Pier™ installed at 6 feet on center would provide full foundation support with a factor of safety of 2:1.

1. Determine the *Working Load Under Buckling Conditions* for PPB-350 Steel Pier™:

Table 13, Chapter 5 shows that the Critical Buckling of the pier pipe for a PPB-350 in clay with SPT > 1 is 30,000 pounds, not the *Recomended Design/Service Load* shown in Table 1 in Chapter 5 = 43,000 pounds.

2. Calculate New Pier Spacing, "X":

"X" = $P_{SU\ Des}/P_L$ (Equation 1)

X" = 30,000 lb / 7,300 lb/ft = 4.11 ft

Use "**X" = 4 feet,** (maximum)

Second Method: Choose a new product configuration that offers a more rigid pier section and maintain the original pier placement spacing.

1. Find a Pier Configuration with a *Working Load Under Buckling Conditions* over 43,000 lb:

Table 13 from Chapter 5 reveals that the *Critical Buckling Loads* for all pier configurations. Notice that using a PPB-350-SB External Sleeve will provide working load capacity that is in excess of 43,000 lb.

Table 13 Working Loads Under Buckling Conditions For Budgetary Estimating (Factor of Safety = 2)

Shaft Size	Uniform Soil Condition	
	Organics N < 1	Very Soft Clay N = 1 - 2
PPB-300-EPS (2-7/8" dia.)	19,000 lb	22,000 lb
PPB-300-EPS + PPB-300-IP	23,000 lb	27,000 lb
PPB-350-EPS (3-1/2" dia.)	26,000 lb	30,000 lb
PPB-400-EPS (4" dia.)	34,000 lb	40,000 lb
PPB-350-EPS + PPB-350-IP	36,000 lb	42,000 lb
PPB-350-EPS + PPB-350-SB	50,000 lb	58,000 lb
3-1/2" + Inert. Slv. + 4" Slv	*99,000 lb*	66,000 lb

2. Specify the new pier pipe configuration:

Using the original placement spacing of 6 feet on center, the PPB-350-EPS Steel Pier™ shall be installed along with three sections of PPB-350-SB by 42 inches long external sleeve over the upper 10-1/2 feet of pier pipe. The three pieces PPB-350-SB sleeve shall be installed after the pier pipe has been installed to bearing, but prior to proof testing. Three sections of sleeve will reinforce the pier pipe through a distance of 10-1/2 feet (Minimum length needed is 6 ft + 3 ft into competent soil = 9 ft). The depth from the surface extends more than three feet beyond the depth of the weak fill soil.

END DESIGN EXAMPLE 2A

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Design Example 3 – Calculate Foundation Load

Single Story Slab on Grade

- The single story house is located in southern New Mexico
- The foundation consists of an 18" tall x 15" wide turned down footing reinforced with #4 rebars.
- The concrete slab floor is 4" thick and is carpeted.
- The exterior walls are 2 x 4 studs on 16" centers with sheathing, insulation and drywall. The exterior is typical brick veneer,
- The roof has a 3" in 12" pitch and is framed with 2 x 8 rafters and 2 x 6 ceiling joists. There is no attic storage, but there is 10" of blown in insulation. The span is 12 feet with a 2 foot overhang.

Calculate the Foundation Loads - Referring to the Load Tables in Chapter 5, estimate the foundation service (working) load, the live load and the temporary soil load.

1. **Dead Load** (DL):
   Footing = 270 lb./lineal foot (Table 2)
   Slab = 195 lb/ lin. ft (Table 4)
   Exterior Wall = 390 lb/ lin. ft (Table 5)
   Roof & Ceiling = 166 lb/ft (12' + 2' = 14') (Table 6)
   Perm. Soil Load = 0 lb/ lin. ft
   Dead Load (DL) = 1,021 lb. per lineal foot

2. **Live Loads** (LL):
   Live Load = 120 lb/ lin. ft (Table 7)
   Snow Load = 0 lb/ lin. ft
   Live Load (LL) = **120 lb. per lineal foot**

3. **Working Load** (P_w) = Dead Load + Live Load
   Working Load (P_w) = 1,021 lb/lin ft + 120 lb/lin ft
   Working Load (P_w) = 1,141 lb. per lineal foot

4. **Lifting Load** (P_L) = Working Load + Temporary Soil Load

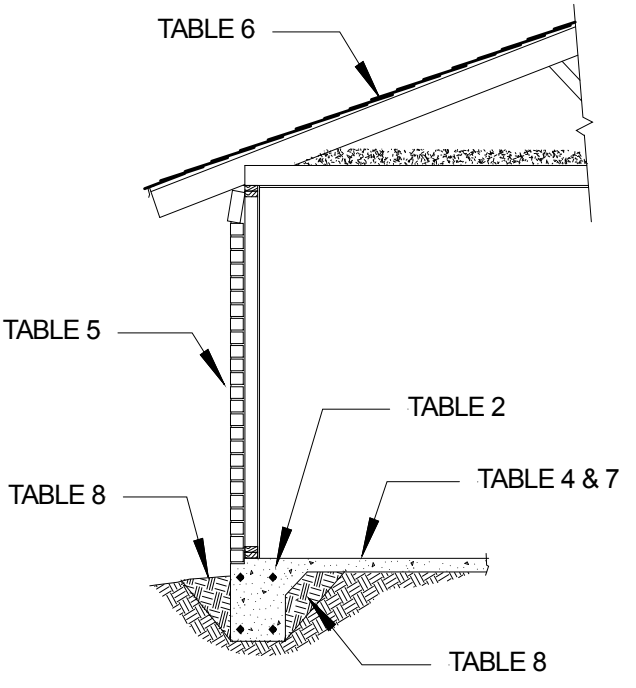

Figure 7. Sketch for Load Estimate Example 3 & 3A.

Temp. Soil Load = 80 lb/lin. ft x 2 (inside and outside turn down) (Table 8 – Graph 1 – estimate because graph does not go as low as 18 inches.)
Temp. Soil Load = 160 lb/lin.ft

Lifting Load (P_L) = **1,141 + 160 lb. per lineal foot**
Lifting Load (P_L) = **1,301 lb/lin.ft** (See Note Pg 129)

5. **Factored Lifting Load** (P_{LF}) = (P_L) + F.S.
   (P_{LF}) = 1,301 lb/lin,ft + 130 lb/lin.ft = 1,431 lb/ lin.ft
   F.S. uncertainty: 10% "Safe Use" Design
   Factored Lifting Load (P_{LF}) = 1,431 lb/lin.ft.
   (Use 1,450 lb/lin. ft)

END DESIGN EXAMPLE 3

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Design Example 3A – Calculate Foundation Load – "Quick and Rough" Method

Single Story Slab on Grade

1. Estimate footing Dead Load and Live Load:

A. Using Table 10 from Chapter 5 select the column that most closely identifies the foundation construction. (A portion of Table 10 is reproduced to the right.) In this case the first column is selected because the house has a slab on grade.

B. Second, determine which of the five rows most closely describes the structure. In this case the closest match is the second row. The construction of the house consists of single story framed construction with brick veneer siding.

C. The Dead Load for a typical single story house of this description ranges from 1,000 to 1,200 lb/lin.ft and the Live Load averages between 100 and 200 lb/lin.ft. Based upon viewing the quality of the construction and amount of contents, load values are chosen within these load ranges.

Table 10. Ranges for Typical Average Residential Building Loads*

Building Construction (Slab On Grade)	Estimated Foundation Load Range (DL = Dead – LL = Live)
One Story Wood/Metal/Vinyl Walls with Wood Framing -- Footing with Slab	DL 750 – 850 lb/ft LL 100 – 200 lb/ft
One Story Masonry Walls with Wood Framing – Footing with Slab	**DL 1,000 – 1,200 lb/ft** **LL 100 – 200 lb/ft**

Dead Load (DL) = 1,100 lb/lin.ft (selected)

Live Load (LL) = 150 lb/lin.ft (selected)

Temporary Soil Load is estimated at 80 lb/lin.ft inside and 80 lb/lin.ft outside of the turn down. Graph 1 in Table 8 was presented in Chapter 5. (A small version of Graph 1 was reproduced in Design Example 1A. One must estimate the temporary soil load value because the graph does not go as low as 18 inches.

Temporary Soil Load = 160 lb/lin.ft (estimated)

2. Estimated Lifting Load (P_L)
P_L = Dead Load + Live Load + Soil Load
P_L = 1,100 + 150 + 160 = **1,410 lb/lin.ft**

3. Factored Lifting Load (P_{LF}) = (P_L) + F.S.
Factor of Safety = 10% "Safe Use" design
(Structural loads were guessed from Table 10)
(P_{LF}) = **1,410 + 141 lb/lin.ft** (15%) = **1,551 lb/lin.ft**

END DESIGN EXAMPLE 3A

Review of Results of Design Examples 3 & 3A

The result obtained by the "Quick and Rough" analysis on Design Example 3A overestimated the foundation load by 7% when compared to the more thorough weight analysis. Once again the caution must taken when using the "Quick and Rough" method to select a load estimates. The values selected are based upon the designer's best estimate of where the actual structural weight falls within the ranges provided by the "Quick and Rough" Table 10. It must be kept in mind that the use of the "Quick and Rough" method returns estimates that can vary depending upon where the loads are selected within the ranges. With the "Quick and Rough" method providing a conservative estimate and the difference between the two methods of 100 lb/ft, one can see that the different results do not significantly affect foundation load estimate and ultimately the pier spacing. The "Quick and Rough" method has quickly returned a conservative and useful result.

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Design Example 4 – Calculate the Maximum Pier Spacing for Design Example 3

Because the structure in Example 3 has only a small footing with very light loads, the **foundation strength will limit the pier spacing**. The result of Example 3 suggested a line load of 1,450 lb/ft and Example 3A returned a load estimate of 1,551 lb/ft. For this example 1,500 lb/ft will be used.

To estimate the maximum spacing for pier placement, the lower portion of Graph 2 in Chapter 5 is used. A portion of Graph 2 is shown below. Referring to Graph 2 from Chapter 5, locate the line for an 18" tall monolithic footing in lowest graph and find the load line representing 1,500 lb/ft. Read downward to see the recommended maximum center-to-center pier spacing. It is slightly over seven feet, which will load the reinforcing steel in the concrete to yield strength. Prepare the preliminary design with a "safe" distance between placements.

Specify **"X" = 7 feet** (MAXIMUM)

The estimated pier load can now be calculated, and an ECP Steel Pier™ is selected for the project.

$\mathbf{P}_{SU\ Des}$ = ("**X**") x $\mathbf{P}_L$ (Chapter 5 - Equation 1),

Where;

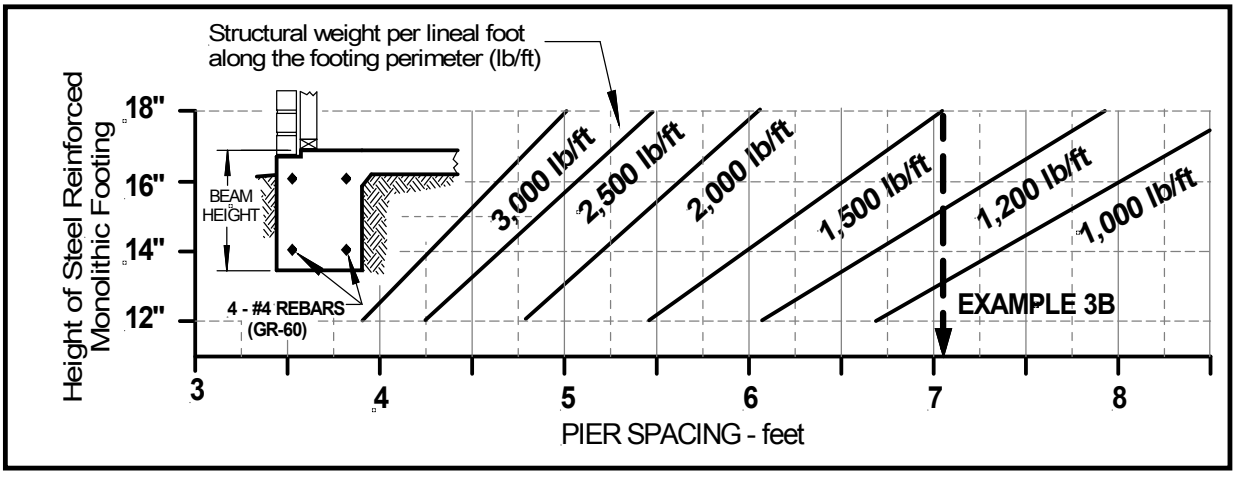
$\mathbf{P}_L$ = Lifting Load = 1,500 lb/lf

X = Pier spacing, feet

$\mathbf{P}_{SU\ Des}$ = **7** ft x **1,500** lb/ft = **10,500 lb**

The ECP Steel Pier™ PPB-300 is selected and when installed at a pier spacing of 7 feet, the piers enjoy a Factor of Safety rating of 6.5:1.

END DESIGN EXAMPLE 4



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Design Example 5 – Calculate the Foundation Load and Determine Pier Spacing

Three Story Office Building

- The three story structure has settled toward the corner. The largest elevation loss was measured at 1-1/2 inches. The engineer requested a pier design and placement proposal based on a steel pier system to support and restore the structure.
- The engineer specified a factor of safety of at least 2.0.
- The foundation consists of an 18" tall x 28" wide reinforced footing with a 10" thick x 3'-0" tall cast concrete stem wall. (Footing toe = 8") The first floor slab is 6" thick concrete.
- The upper floors are constructed of light weight concrete and the roof consists of multi-layer tar and gravel over an insulated metal roof deck.
- The exterior walls are 30 feet tall and consist of heavy weight concrete blocks that are filled and reinforced. The outer surface has a 1-1/2 inch thick simulated stucco covering. Inside the walls consist of steel studs, insulation, and pre-finished drywall.
- The engineer has calculated the dead load at 7,000 lb/lf on the heavy, load bearing side and 4,700 lb/lf on the adjacent wall. The live loads are estimated at 2,600 lb/lf and 1,800 lb/lf respectfully.

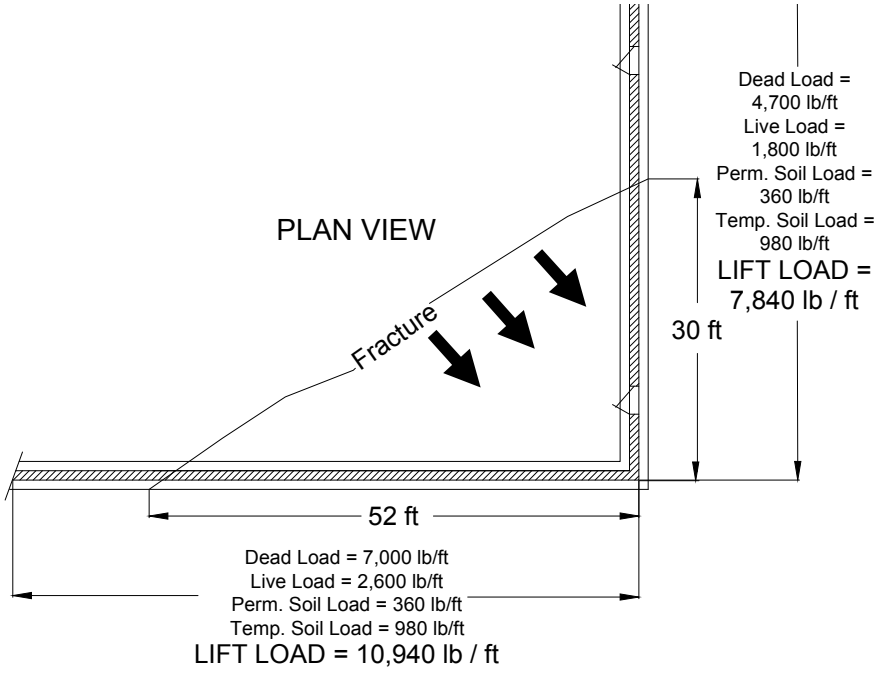

Figure 8. Sketch for Example 5.

1. Determine the Engineer's Working Loads:
Working Load (P_W) = Dead Load + Live Load

Side 1 - $P_{W\,1}$ = 7,000 + 2,600 = 9,600 lb/lf

Side 2 - $P_{W\,2}$ = 4,700 + 1,800 = 6,500 lb/lf

2. Adjust the Working Loads due to Soil Loads:
Reading through the information provided it was noticed that the engineer did not mention a temporary soil load in his working load calculations. A review of Table 8 presented in Chapter 5 provides soil load estimates that were omitted from the data.

It is necessary to consider the permanent and temporary soil loads when a structure must be lifted.

Permanent Soil Load on Footing Toe: Table 8 can be used to estimate the permanent soil load on the footing toes. There are 8 inches of footing toe inside and outside of the stem wall that will carry a permanent soil load. The soil height is assumed to be 2-1/2 feet above the top of the footing. Referring to Table 8, notice that there is no weight provided for a soil height of 2-1/2 feet. One solution is to use the permanent soil load for 2 feet and then add an additional load for 1/2 foot. Looking at the portion of Table 8 below, the weight for two feet of soil per inch of footing toe is 18 lb/in. To estimate the additional weight of 1/2 foot of soil, it is necessary to divide the weight of 2 feet of soil by 4 to arrive at the weight of 1/2 foot of permanent soil load. An additional weight of 4-1/2 lb/in of toe is the result of this calculation. Therefore, the estimated permanent soil load per inch of footing toe is 22-1/2 lb/in.

Permanent soil load on footing toes:

22.5 lb/ft x 8 inches x 2 toes = <u>360 lb/ft</u>

Table 8. Estimated Soil Loads on Footings

Permanent Soil Load on a Footing Toe – W_d							
Soil Height Against Wall	**2'**	4'	6'	7'	8'	9'	10'
Soil Load per inch of Footing Width	**18 lb**	37 lb	55 lb	64 lb	73 lb	83 lb	92 lb

To determine the permanent soil load on a footing toe, multiply the actual width of the footing toe (in inches) by the unit weight shown above for the soil height against the wall.

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Adjusted Working Load ($P_{W\text{-}Adj}$)

$P_{W\text{-}Adj}$ = **DL + LL + W_d**

Side 1 – $P_{W\text{-}Adj\ 1}$ = 9,600 + 360 lb/lin.ft
$P_{W\text{-}Adj\ 1}$ = 9,960 lb/ lin. ft

Side 2 – $P_{W\text{-}Adj\ 2}$ = 6,500 + 360 lb/lin. ft
$P_{W\text{-}Adj\ 2}$ = 6,860 lb/lin.ft

Temporary (Lifting) Soil Load:
In addition to the permanent soil load, lifting will include raising a temporary soil load that is resting against the stem wall (inside and outside). Table 8, Graph 1, Chapter 5 (shown below), suggests that the 2-1/2 foot temporary soil load is approximately 490 lb/ft or 980 lb/ft total.

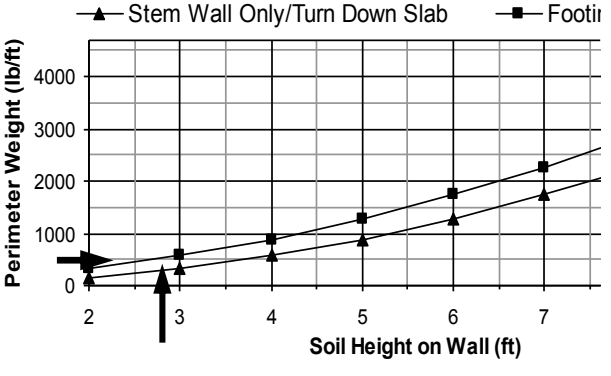
Estimated Actual Lifting Loads (P_L) = Adj. Working Load + Temp. Soil Load

$P_L = P_{W\text{-}Adj\ 1} + W_t$

$P_{L\text{-}Pier\ Side\ 1}$ = **9,960 + 980 = <u>10,940 lb/ft</u>**
$P_{L\text{-}Pier\ Side\ 2}$ = **6,860 + 980 = <u>7,840 lb/ft</u>**

Table 8. Estimated Soil Loads on Footings

Graph 1. Temporary Soil Load (One Side) – W_t



3. Select the Steel Pier System for the project:
The engineer specified a <u>minimum</u> factor of safety of 2.0 is required. Referring to the pier *Recommended Design / Service Load Ratings* on Table 1 in Chapter 5, the PPB-400 Steel Pier™ system was selected because it has a maximum "Safe Use" service load rating of 49,500 lb. Although this system is slightly more expensive than the PPB-350, this system will use fewer placements and incur lower labor costs.

4. Determine the pier spacing requirements.
By using Equation 1 from Chapter 5, the maximum pier spacing, "X", can be determined:

The pier spacing for each side of the structure is now calculated using Equation 1 from Chapter 6:

Equation 1: Pier Spacing
"X" = P_{DSL} / P_L or P_{DSL} = "X" x P_L

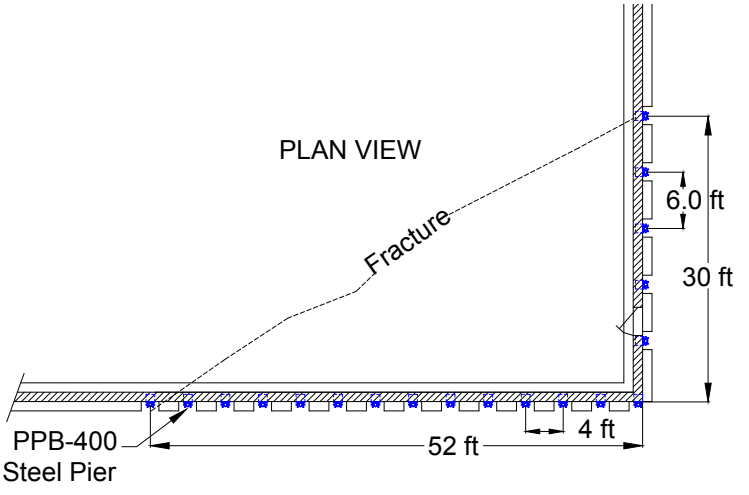


Figure 9. Pier Layout for Example 5.

Pier Spacing - "X" = P_{DSL} / P_L, Where,
"X" = Pier Spacing
P_{DSL} = 49,500 lb (Model 400 at 2.0 FS)
$P_{L\ 1}$ = 10,940 lb/ lf (Side 1)
$P_{L\ 2}$ = 7,840 lb/ lf (Side 2)

The pier spacing for each side of the structure is now calculated using Equation 1 from Chapter 6:

Pier Spacing = "X" = $P_{SU\ Des}$ / P_L

Side 1:
"X_1" = 49,500 lb/10,940 lb/lf = 4.52 ft
"**X_1**" = **Specify 4 feet on center** (Side 1)

Lifting Load on the Piers Side 1:
10,940 lb/ft x 4 ft = **<u>43,760 lb</u>**

Side 2:
"X_2" = 49,500 lb/7,840 lb/lf = 6.31ft
"**X_2**" = **Specify 6.0 feet on center** (Side 2)

Lifting Load on the Piers Side 2:
7,840 lb/ft x 6 ft = **<u>47,040 lb</u>**

5. Prepare a pier layout plan – See sketch above:
Piers along the lower side (heaviest load) are spaced 4 feet on center for a total of 14 placements along 52 lineal feet of foundation. This design places piers supports from the point of fracture up to, and including, the corner.

Piers on the right side (lighter load) are spaced at 6 feet on center for a total of 5 placements, which puts the first pier 6 feet up from the corner and the last pier at the foundation fracture.

Calculate the pier working loads:

$P_{W\text{-}Pier\ Side\ 1}$ = $P_{W\text{-}Adj\text{-}1}$ x 4 ft = **9,960 x 4 = <u>38,840 lb</u>**
$P_{W\text{-}Pier\ Side\ 2}$ = $P_{W\text{-}Adj\text{-}2}$ x 6 ft = **6,860 x 6 = <u>41,160 lb</u>**

A total of 19 PPB-400 ECP Steel Piers™ are proposed to support the structure and restore lost elevation. This design provides a continuous service load of approximately 38,840 pounds per pier on the heavy

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side at the bottom of the sketch, and provides continuous service load support of approximately 41,160 pounds per pier placement on the lighter side at the right side of the sketch.

The calculated working load values include the design live and dead loads provided by the engineer along with the permanent soil loads on the footing toes added.

6. Determine the Service Load and Lifting Force Factor of Safeties for the Steel Pier Design:

The *ECP Pier System Load Ratings*" on Table 1 in Chapter 5 for the PPB-400 Steel Pier™ system states that the "Safe Use" *Recommended Design / Service Load* rating is 49,500 pounds and the *Ultimate-Limit Mechanical System Capacity* is 99,000 pounds. This capacity is divided by the Service Loads determined in Step 6.

Factor of Safety = Ult. Capacity/Service Load

F.S.$_1$ = 99,000/38,840 = **2.5** (Side 1 - Working)

F.S.$_2$ = 99,000/41,160 = **2.4** (Side 2 - Working)

The factor of safety for lifting the structure can also be calculated:

This design satisfies the engineer's minimum factor of safety = 2.0, and also insures that there will be sufficient pier capacity to break the footing loose from the soil and lift the temporary soil load without exceeding "Safe Use" design. Divide the *Ultimate-Limit Mechanical System Capacity* by the Lifting Load determined in Step 4.

Factor of Safety = Ult. Capacity/Lifting Load

F.S.$_{L1}$ = 99,000/43,760 = **2.26** (Side 1- Lift)

F.S.$_{L2}$ = 99,000/47,040 = **2.10** (Side 2 – Lift)

7. Determine Field Proof Test Force Requirement for the Piers:

The design calls for the piers to support a maximum continuous working load of up to 41,160 pounds (From Step 6 – Side 2 Load). According to ECP guidelines, it is recommended to perform a proof test of each pile once the pile reaches firm bearing. The ECP field proof test loading recommendation is to load the pier to 1-1/2 times the anticipated working load or until slight lifting of the foundation is observed.

Proof Load = Working Load x 1.5

P_T = 41,160 lb x 1.5 = 61,740 lb

(Use Max. 62,000 lbs. for Proof Test)

Estimating Driving Cylinder Pressure:

It is a good idea to calculate the estimated hydraulic pressure that will provide the required test load on the pier, and an estimate of the hydraulic pressure requirement to recover the lost elevation while all of the project requirements and design data are at hand. This is valuable information for the field technicians.

The ECP HYD-350-DC Drive Cylinder has a piston area of 8.29 in^2 as stated in *Pier Installation, Load Testing & Project Documentation* in Chapter 5. To determine the pressure on the drive cylinder to produce the Proof Load of 62,000 pounds, Equation 2 is used:

Equation 2: Hydraulic Cylinder Force

$$\mathbf{F_{Cyl} = A_{cyl} \times P_{cyl}}$$

Where: F_{Cyl} = Cylinder force on pier = 62,000 lb

P_{cyl} = Hydraulic Pressure, psi

A_{cyl} = Effective Cylinder Area = 8.29 in^2

(HYD-350-DC Cylinder = 8.29 in^2)

Change Equation 2 to solve for the cylinder pressure:

$$\mathbf{P_{cyl} = F_{Cyl} / A_{cyl}} = 62{,}000 \text{ lb} / 8.29 \text{ in}^2$$

$$\mathbf{P_{cyl}} = 7{,}479 \text{ psi} - \underline{\mathbf{Use\ 7{,}500\ psi}}$$

Estimating Lifting Cylinder Pressures:

The necessary hydraulic pressure on the HYD-254 Lifting Ram that is sufficient to raise the structure is determined in a similar manner.

$$\mathbf{P_{cyl} = F_{Cyl} / A_{cyl}}$$

Where: F_{Cyl} = Max. lift force on pier:

Side 1: 43,760 lb

Side 2: 47,040 lb

P_{cyl} = Hydraulic Pressure -- psi

A_{cyl} = Effective Cylinder Area – 5.16 in^2

(HYD-254 Ram Area = 5.16 in^2)

Side 1: $\mathbf{P_{cyl}}$ = 43,760 lb / 5.16 in^2 = 8,480

$\mathbf{P_{cyl}} = \underline{\mathbf{8{,}500\ psi}}$

Side 2: $\mathbf{P_{cyl}}$ = 47,040 lb / 5.16 in^2 = 9,125

$\mathbf{P_{cyl}} = \underline{\mathbf{9{,}100\ psi}}$

The Proof Test pressure and the estimates for Lifting Cylinder Pressures shall be supplied to the field personnel to assist with the installation.

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Design Example 5A – Estimate the Drive Cylinder and Lifting Ram Pressures "Quick and Rough" Method for Design Example 5

"Quick and Rough" estimating can also determine the cylinder pressures required to "Proof Test" the piers and to determine the anticipated lifting pressure for restoration of the structure. Use Graph 4 from Chapter 5. (Reproduced below)

1. Begin by locating the Proof Test load requirement of 62,000 pounds at the left edge of the graph.

2. Read horizontally to the right until encountering the solid line (HYD-350-DC Cylinder). Read to the down to determine the Drive Cylinder pressure requirement.

P_{Cyl} = **7,500 psi.**

Similarly, the anticipated maximum pressure on the HYD-254 Lifting Ram is determined:

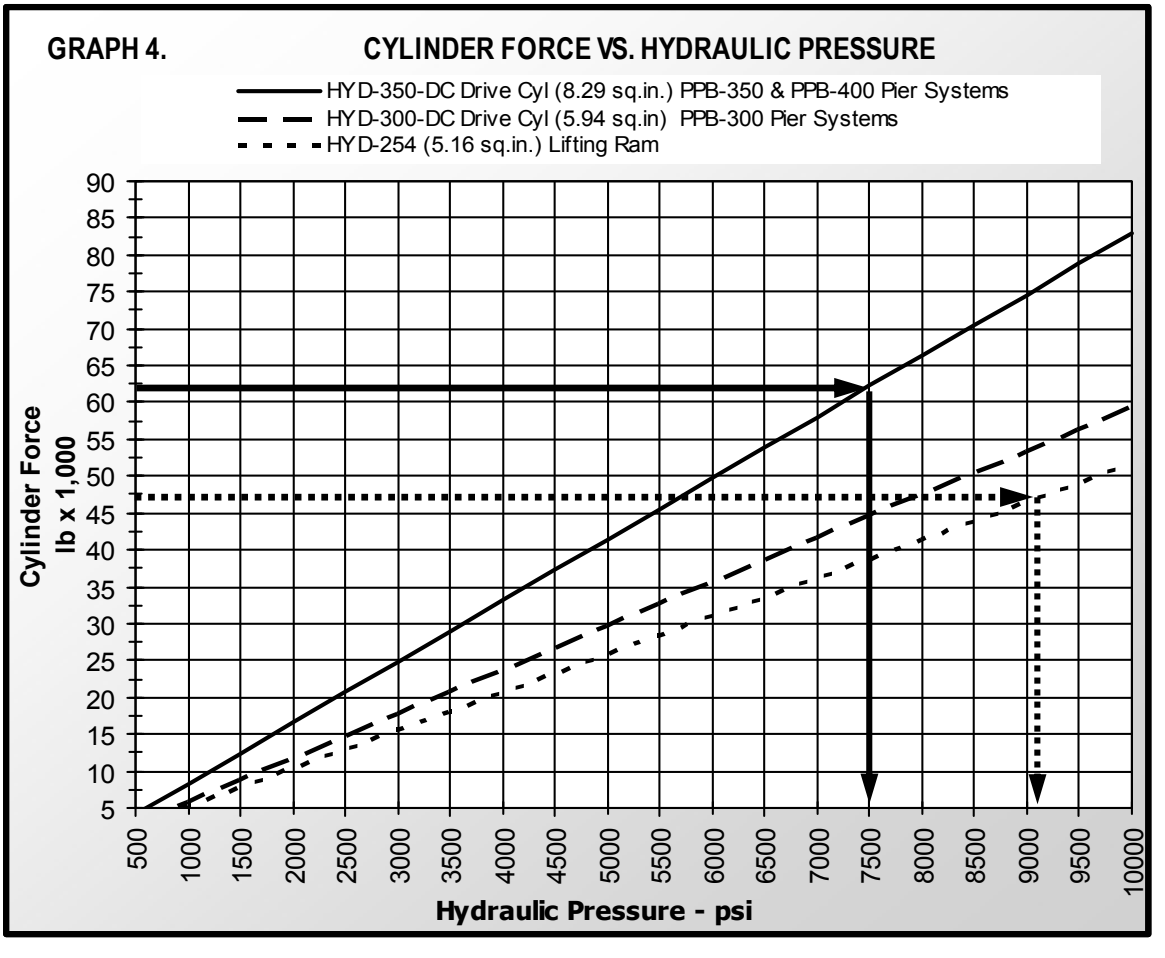
1. Begin by locating the proof test load requirement of 47,088 pounds at the left edge of the graph.

2. Read horizontally to the right until encountering the short dashed line (HYD-254 Lifting Ram). Read to the down to determine the estimated maximum pressure requirement.

P_{Cyl} = **9,100 psi.**

This information shall be supplied to the field personnel to assist with the installation.

END DESIGN EXAMPLE 5A



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Design Example 6 – Determining Force Applied to Pier from Field Data

For this example it is assumed that the technician in his field report states a driving pressure on a PPB-300-EPS pier pipe of 5,500 psi. The actual installation force on the pier pipe can be determined and submitted to the engineer.

Use Equation 2 from Chapter 5 to determine the downward force on the pier pipe:

Equation 2:	**Hydraulic Cylinder Force**
	$\mathbf{F_{Cyl} = A_{cyl} \times P_{cyl}}$

Where:

F_{Cyl} = Cylinder force on pier –lb
P_{cyl} = Hydraulic Pressure – 5,500 psi
A_{cyl} = Effective Cylinder Area – 5.94 in^2
(HYD-300-DC Cylinder = 5.94 in^2)

$\mathbf{F_{Cyl}}$ = 5.94 in^2 x 5,500 lb/in^2

$\mathbf{F_{Cyl}}$ = **32,670 lb.**

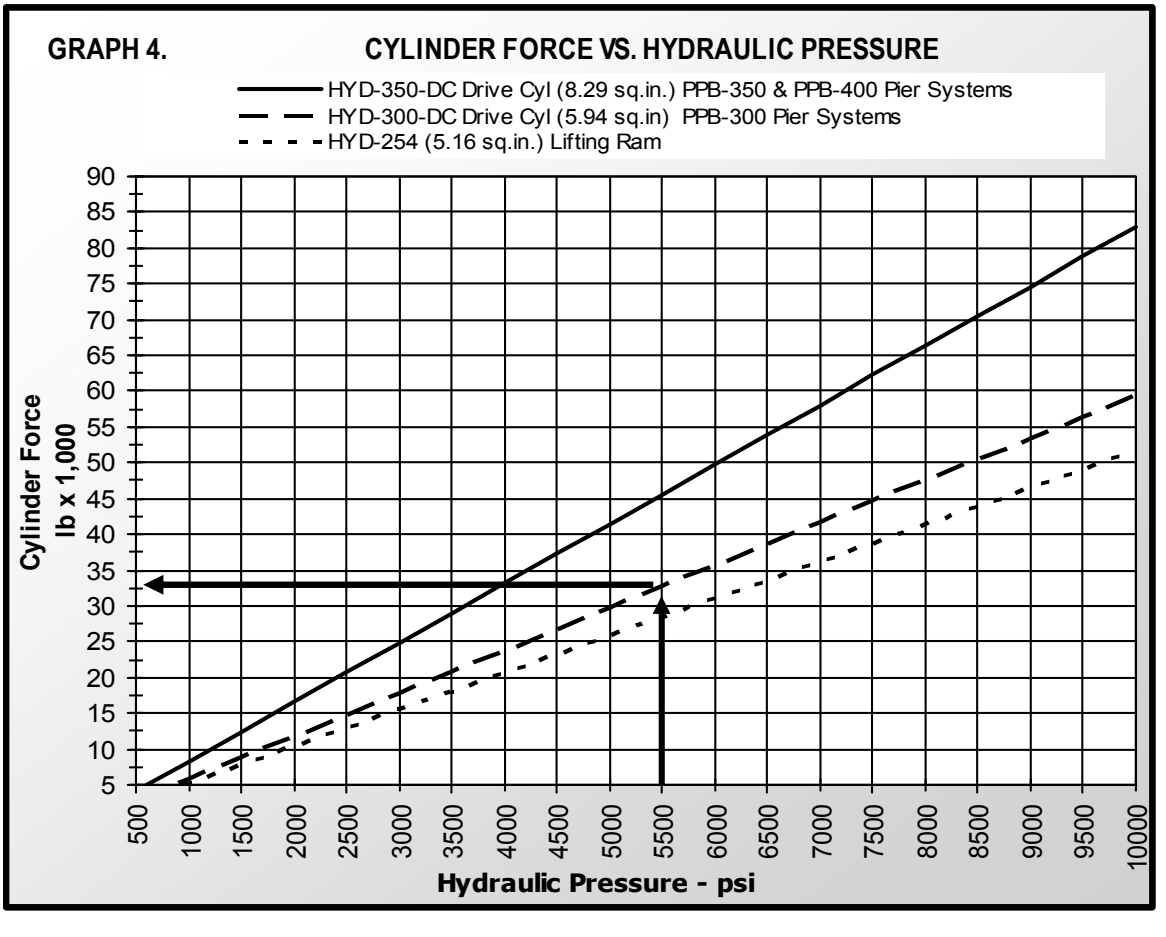
Design Example 6A – Determining Force Applied to Pier - "Quick and Rough" Method

"Quick and Rough" estimating can also determine the force on the pier when the cylinder pressure is known. Use Graph 4 from Chapter 5. (Reproduced below)

1. Begin by locating "5,500 psi" the pressure on the cylinder on the lower edge of the graph.
2. Read upward from the bottom of the graph until encountering the line with long dashes (HYD-300-DC Drive Cylinder). Read to the left to determine the force on the pier.

$\mathbf{F_{Cyl}}$ = **33,000 lb.**

END DESIGN EXAMPLE 6



Review of Results of Example 5A, 6 & 6A

The result obtained by the "Quick and Rough" analysis on these examples show that it is possible to obtain results very quickly that are relatively accurate. It is important to accurately lay out the lines on the graph to obtain best results. The "Quick and Rough" method returned useful results without requiring mathematical calculations.

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Chapter 7

Corrosion Life of Steel Foundation Products

Torque Anchors™
ECP Steel Piers™

EARTH CONTACT PRODUCTS
"Designed and Engineered to Perform"

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Corrosion Consideration

Corrosion is defined as the deterioration of a metallic structure due to its interaction with the surrounding environment.

Steel Underground - How Long Does It Last? Steel foundation supports are subjected to a range of corrosive forces that are quite different from steel exposed to atmospheric conditions. The performance of steel and galvanized structural steel elements underground are not as well understood as is the life expectancy of steel products in above ground applications.

For corrosion to initiate, steel requires not only oxygen but also the presence of dissolved salts in water. If either of these items is absent, corrosion will not occur.

The causes of corrosion on buried metallic structures are generally understood, but this knowledge base does not always permit an accurate prediction of a design life when placed in a corrosive environment. This chapter is not intended as a rigorous technical text; rather it provides knowledge to help the reader to establishing whether corrosion could be a critical factor in a specific foundation support application.

> A qualified engineer, knowledgeable in design for corrosion environments should be consulted when foundation support products are to be used in a known corrosive environment.

Corrosion occurs by an electrochemical process. In order for corrosion of an underground metallic structure to occur, there must be an electrical potential, an electrolyte (dissolved salts in water) and aeration present.

Difference in Electrical Potential: Corrosion is initiated by a difference in electric potential (electric charge) between two points on a metallic structure. This electrical potential can be caused by strains in the metal or between component parts, or contact with different soil types along the shaft, or non-homogeneities in metal, etc. A difference in electrical potential causes the development of "anodes" and "cathodes" along the surface of the metal. There must be an electrical connection between the anodes and cathodes for corrosion to occur.

Electrolyte: Water or moisture in the soil that surrounds the pile or pier shaft may contain dissolved chemical elements (ions) and serve as the electrical connection between different parts of the structural element. The water containing the dissolved chemical elements is called an electrolyte. The presence (or absence) of these ions, as well as their nature and concentration, determines the electrical conductivity, or resistivity, of the electrolyte.

Aeration: The availability of oxygen (aeration) in the soil surrounding the metal is also essential to the corrosion process. The process of wetting and drying of the soil causes oxygen to be present in the soil. It is also the reason that most corrosion occurs usually near the surface where the wet-dry cycle is more severe.

Under these conditions, metal ions will migrate from the anodic (+) locations on a metallic object and transfer to the cathodic (-) locations. It is this loss in metal at the anodic locations that results in the degradation of the underground metallic structure.

Controlling Factors for Corrosion

Soil Type: Some soil types are more corrosive than others. The physical and mineralogical composition of soils, which is a result of:

- Their origin, decomposition and deposition
- The plant life and its decomposition
- Topography of the land

All of these influence the soil's corrosivity potential. The soils having greatest concern are those which produce water soluble acid forming chemical elements such as carbonate, bicarbonate, chloride, nitrate and sulfate, or base (alkaline) forming chemical elements such as sodium, potassium, calcium and magnesium. The soils that have the highest corrosive potential, are soils described or classified by geotechnical engineers as silty, loamy, clay, organic (peats, cinders and ashes), and soils which are poorly aerated. Granular soils (sands and gravels) which are highly aerated can drain water away rapidly. In well drained soil the electrolyte is not constantly in contact with the steel and the corrosion process is reduced.

Soil Resistivity: The resistivity of the soil is one of the simplest checks for soil corrosivity. To obtain the soil resistivity, one passes a current

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through the soil and measures the resistivity of the soil. Generally, when the soil resistivity, measured in ohm-cm, is high; the rate of corrosion and loss of steel is low. Low soil resistivity occurs due to a number of factors, but fine-grained soils (silts, loams, clays, and peats) have low resistivity and the greatest corrosion susceptibility. Table 1 illustrates the average corrosivity for common soil types, and Table 2 provides a measure of the soil corrosivity based upon soil resistivity.

In general it can be said that sandy soils have the higher resistivity values and are generally considered the least corrosive. Clay soils generally have higher corrosivity and when clay soil is situated in an area of saline water, it can be highly corrosive to steel.

Soil resistivity can be measured in the field using a soil resistivity meter or by obtaining a soil sample from the site and testing it in a laboratory using a resistivity meter and a soil box. This equipment is generally available to the geotechnical engineer.

Soil pH: The measure of acidity or alkalinity in a solution is given as pH. Values of pH < 7 are considered acidic and values of pH > 7 to 14 are alkaline. Pure distilled water is neutral and has a pH = 7. pH is a measure of the degree of hydrogen ion concentration in the water. When a sample of soil is mixed with distilled water, the solution can then be tested with a pH meter to arrive at the soil pH number.

While soil corrosivity can exist within a broad range of soil conditions, the amount of acidity (organic reducing soils – pH < 7) or alkalinity of a soil (pH > 7), does influence corrosion susceptibility and rates. Most soils have a pH that falls within the range of pH 3-1/2 to pH 10.

Soils that are highly acidic (pH < 4-1/2) or alkaline (8 < pH < 10-1/2) have significantly higher corrosion rates than soils within the mid-range 4-1/2 < pH < 8.

Table 1. Soil Resistivity Ranges For General Soil Types

Soil Type	Resistivity Range (ohm-cm)	Soil Type	Resistivity Range (ohm-cm)
Gravel	40,000 to 200,000	Fine Silts & Organics	2,000 to 10,000
Sand	10,000 to 100,000	Loams	3,000 to 10,000
Silt	1,000 to 2,000	Humus	1,000 to 4,000
Clay with Silt	3,000 to 5,000	Ashes – Cinders	500 to 5,000
Clay	500 to 2,000	Peat	100 to 2,000
Heavy Plastic Clay	5,000 to 20,000	Marshy Deposit	50 to 300

Notes:
1. High soil moisture content decreases the resistivity making the soil more corrosive.
2. Freezing the soil dramatically raises the resistivity, thus reducing the corrosivity

Table 2. Soil Resistivity and Relative Corrosivity Rating

Resistivity (ohm-cm)	Corrosivity Rating
> 10,000	Non-Corrosive
5,000 to 9,999	Mildly Corrosive
3,000 to 4,999	Moderately Corrosive
1,000 to 2,999	Corrosive
500 to 999	Highly Corrosive
< 500	Extremely Corrosive

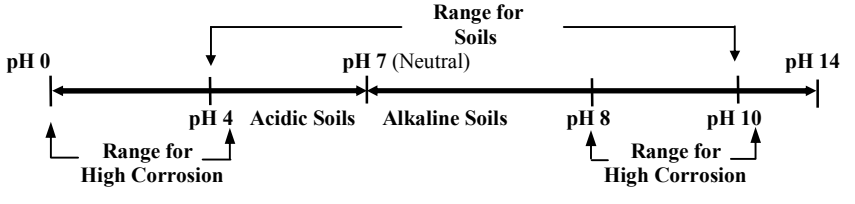

Figure 1. Corrosion of metals within soils can occur over a broad range of pH.

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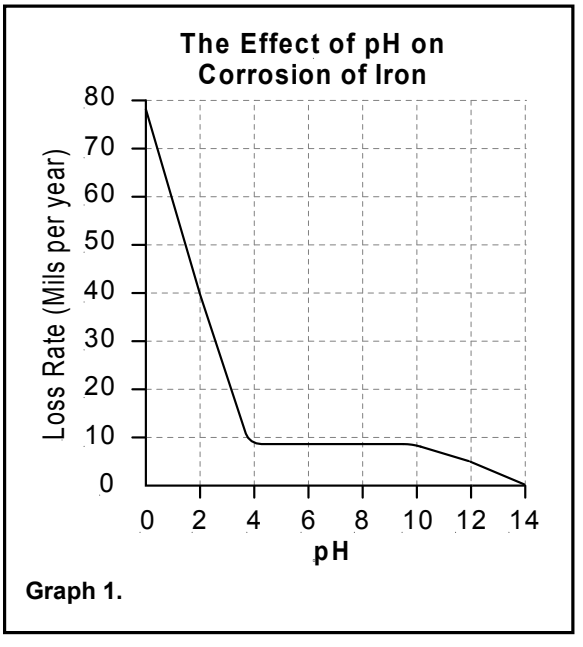
Alkaline soils that have a pH > 10-1/2 will have a significantly decreased corrosion rate due to passivation.

Corrosion Test Results: Doctors Laboratories, a division of the Royal Military College of Canada exposed iron to aerated water at room temperature and determined the corrosion rate as a function of the pH of the water.

As the water became highly acidic (pH < 4), the steel corroded more quickly than the steel did in a highly alkaline environment (pH > 10). It is also interesting to note that zinc used for galvanization provides the best protection to steel subjected to similar environments. Zinc provides the most effective protection through a range of 5.5 < pH < 12.5. In the absence of air, a zinc oxide film does not form on the zinc galvanized surface and corrosion can be more rapid when moisture is present.

The corrosion rate of steel in soil can range from less than 0.79 mils per year (0.0008 in/yr) under favorable conditions to more than 7.87 mils per year (0.0079 in/yr) in very aggressive soils. There are similarities in the corrosion rates of galvanized coatings. Under favorable conditions, the zinc may corrode at less than 0.20 mils per year under mild conditions to more than 0.98 mils in unfavorable soil conditions.

The results of the testing are illustrated in Graph 1. The data suggests that in the range of 4 < pH < 10 the corrosion rate of iron is independent of the acidity or alkalinity (pH) of the environment.

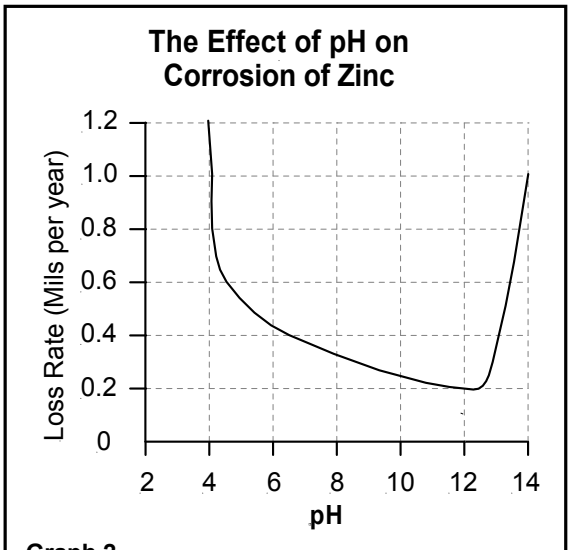


Graph 1.

In acidic conditions (pH < 4) the corrosion rate dramatically increases. The scientists concluded that the acidic conditions dissolve the iron oxide as it forms leaving the iron in direct contact with the water.

Zinc Galvanizing for Corrosion Protection: In Frank Porter's "Corrosion Resistance of Zinc and Zinc Alloys", he determined that dissolved chloride content in water is highly corrosive to zinc. When zinc is subjected to hard (alkaline) water, the insoluble salts in the water form a scale of calcium carbonate and zinc carbonate on the surface of the zinc coating that provides a protective barrier against attack from free chloride anions.

Frank Porter attributes this insoluble scale for the significantly increased corrosion free life of galvanized piles in soils where pH ranges between 5.5 and 12.5. Roathali, Cox and Littreal, the authors of "Metals and Alloys", 1963; presented data showing the corrosion rate of zinc is a function of pH. Excerpts from their data are presented in Graph 2.



Graph 2.

Oxygen Availability: In addition to soil moisture, free oxygen must be available to complete the corrosion process. Oxygen combines with the metal ions to form oxides, hydroxides and metal salts.

Corrosion rates will drop significantly when the steel structure is below a ground water table (GWT), and the water is relatively stagnant (low to no flow velocity) since available free oxygen is much reduced under these conditions.

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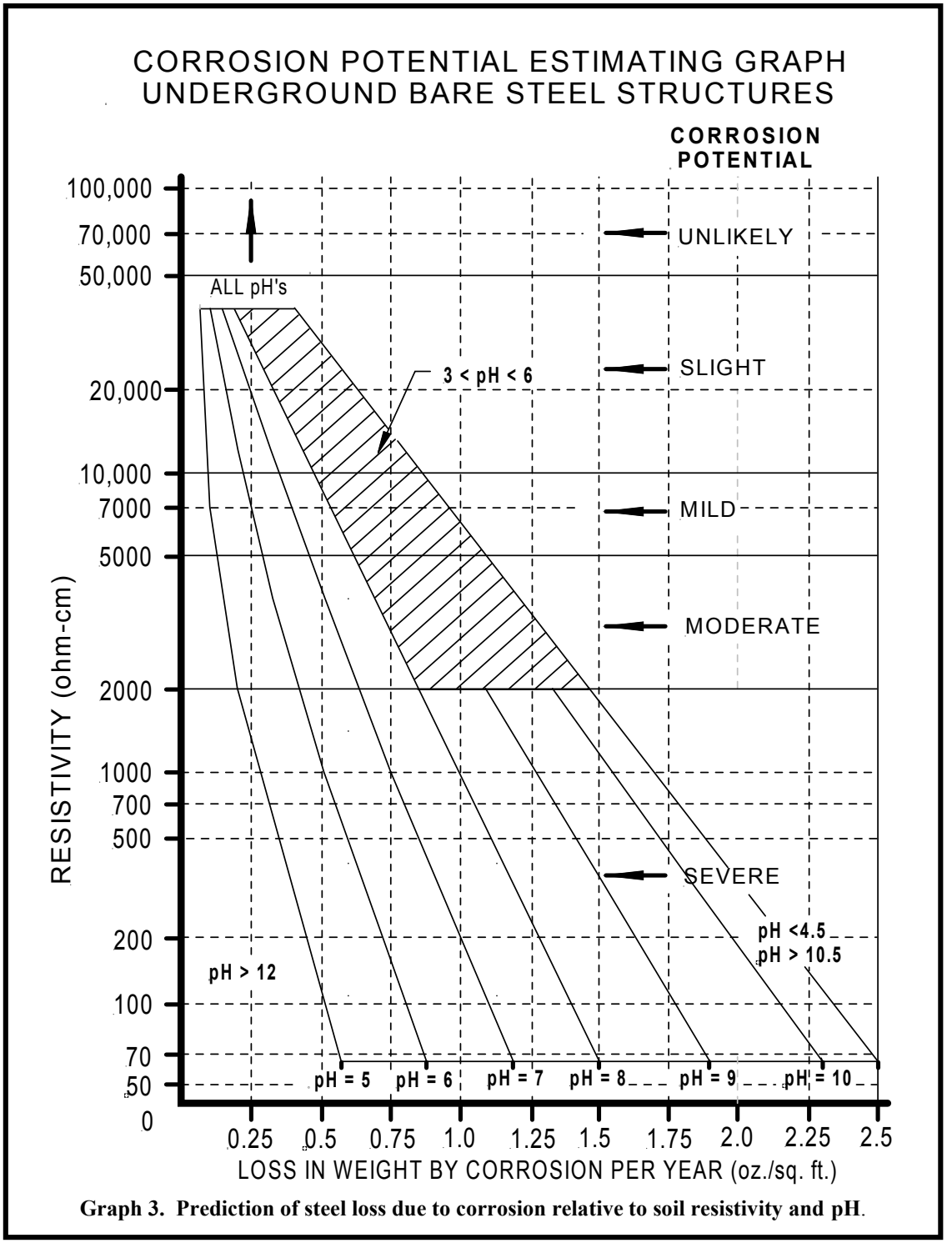
Estimating Corrosion Potential

There are a number of variables that influence the corrosion potential for underground metallic structures. Melvin Romanoff has conducted extensive field testing of buried metal structures to evaluate the corrosion levels related to the more significant variables. These results, published by Romanoff in "Underground Corrosion", National Bureau of Standards circular 579, Houston TX, 1989; along with data published in the proceedings of the "Eighth International Ash Utilization Symposium, Vol. 2", American Coal Ash Association, Washington, DC, October, 1987. These data were used to develop Graph 3, which allows during the design process for an empirical calculation to estimate losses due to corrosion.



Graph 3. Prediction of steel loss due to corrosion relative to soil resistivity and pH.

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If specific information on a soil is available to the designer (soil type, pH & resistivity), a preliminary estimate for metal corrosion loss of bare steel can be determined. The NBS publication can also be used to find a comparable soil and condition for estimating the rate of corrosion. It should be noted that when hot-dipped galvanizing is used as a form of corrosion protection, the resulting corrosion rate for steel (once the galvanized coating is lost due to corrosion) will be lower than the rates shown in Graph 3 on the previous page. (The estimated reduction rate of corrosion is in the 20% to 100% range).

Special Corrosion Conditions: Soil resistivity and pH are strong influencing factors on corrosion rates; however, there are other special soil conditions such as excessive salt content of water (seawater), velocity of water flow and atmospheric conditions, which may increase the corrosion rate. Uhilig's Corrosion Handbook, Edited by R. Winston Revie, 2nd Edition, provided the following reference material:

1. **Corrosion Rates in Seawater**
   (Pipe Piles, H-Piles, Etc.)
   a. Splash Zone (Average) = 6.9 oz/ft^2 / yr
   b. Tidal Zone (Average) = 2.0 oz/ft^2 / yr
   c. Immersed (Average) = 2.3 oz/ft^2 / yr
   d. Immersed Zone (Range) = 0.5 oz/ft^2 / yr to 9.0 oz/ft^2 / yr

2. **Influence Of Velocity In Fresh Water**

Velocity (m/s)	Corrosion Rate Multiplier
1/2 to 3	4
3 to 15	1.2 to 0.8

3. **Atmospheric Corrosion Rates**
   (Pipe Piles, H-Piles, Etc.)
   Atmospheric = 3.2 oz/ft^2 / yr (Average)
   (< 500 Meters to Seashore)

Soil Corrosion Ratings: In over 90% of foundation underpinning projects corrosion is not a problem, but one needs to recognize the warning signs of problem soils. The American Water Works Association developed a numerical rating to determine the severity of corrosion for cast iron pipes. While ECP products are not constructed from cast iron, a numerical rating system similar to the AWWA system was developed by ECP that provides guidance for steel foundation products in soil. The numerical corrosivity score is designed only as a guide to warn of a possible corrosive environment in which the life of galvanized steel product deterioration may be accelerated due to aggressive corrosion conditions.

Using the information gathered from a specific job site, an indication of the likelihood of corrosion is suggested based upon point values assigned to the three soil parameters linked to increased corrosion rates. Notice in Table 3 that the three elements that influence the rate of corrosion must be known before an assessment of soil corrosivity can be predicted from Table 4.

The sum of these point values gives the numerical corrosivity score for the site. The score suggests the likelihood of slight, moderate or high corrosion potential of the soil. As the score approaches 10, the soil becomes more aggressive. When the numerical corrosivity score equals 10 or higher, it is strongly recommended to seek the advice of an engineer familiar with corrosion to evaluate the project to determine what additional corrosion protective measures in addition to galvanization are required for extended service life.

Table 3. Numerical Corrosivity Score

Soil Parameter	
Soil Resistivity (ohm-cm)	**Points**
< 500	10
500 – 999	8
1,000 – 1,999	5
2,000 – 4,999	2
5,000 – 10,000	1
>10,000	0
pH	**Points**
2 – 4.5	6
5 – 6	0
7 – 9	2
10.5 -- 12	6
Moisture	**Points**
Tidal or Salt Water Exposure	5
Poor Drainage – Always Wet	2
Fair Drainage - Moist	1
Good Drainage – Usually Dry	0

Table 4. Soil Corrosion Potential

Unlikely			Slight		Mild		Moderate		Aggressive					Severe						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

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Depending upon the corrosion potential for a given soil environment, several alternatives are available to reduce the corrosion cycle and extend the performance life of the underground steel element. These control measures can be divided into general categories:

- **Passive Control** – for use in soils classified as having mild to moderate corrosion potential
- **Active Control** – for use in soils classified as having moderate to severe corrosion potential

Passive Control

Hot Dip Galvanizing: The products manufactured by Earth Contact Products that are offered with hot dip galvanizing are coated with molten zinc that contains not less than 98% pure zinc metal. The hot dip galvanization process meets or exceeds ASTM A123 Grade 100 which is 2.3 oz/ft^2 of zinc (3.9 mils minimum thickness) for steel plate, structural tubing or bar products..

Quadruple Layer Corrosion Protection: The pier pipe for ECP Steel Piers™ PPB-350 and PPB-300 foundation support systems are supplied with a triple step in-line process of corrosion protection as standard. This corrosion protection process consists of heating the clean steel tubing to 850^0 F and placing it in a bath of molten zinc. This process creates an extremely hard zinc-iron alloy upon which a uniform layer of pure zinc is deposited. Then the zinc is rendered inert against oxidation by a passivation process using a precisely controlled chromate bath. This passivation forms a complex layer of zinc chromate compounds that halts interaction of oxygen and water with the zinc to prevent premature corrosion.

After the chromate bath, in a continuous process, a clear polymer film is applied and cured to complete the corrosion protection system. This three step process provides four layers of corrosion protection:

1. a zinc-iron alloy layer,
2. a pure zinc galvanizing,
3. a layer of zinc chromate compounds,
4. a clear organic polymer film.

The quadruple layer corrosion protection process produces a strong and durable coating on the pier pipe that is smooth and shiny. The interior of the pipe is also coated with zinc-iron alloy, galvanizing and zinc chromate compounds.

Independent laboratory salt spray testing of this tubing from various manufacturers compared with standard galvanized schedule 40 pipe showed the in-line corrosion protection process lasted up to 33% longer.

The laboratory tests were conducted in accordance with ASTM B-117. Standard schedule 40 pipe is normally supplied with hot dip galvanize to ASTM-A123 Grade 75. Because no controlled in-soil corrosion testing is available for the in-line corrosion protected ECP products, a zinc equivalence of 3.0 mils or 1.7 oz/ft^2 (ASTM-A123 Grade 75) appears to be reasonable value to be used for conservatively estimating corrosion life of in-line corrosion protected pier pipe.

Thicker coatings (5 mils) have shown extended life, depending on the corrosion potential of the soil environment. The galvanized coating serves as an anode to provide cathodic protection to the steel. The results of the studies conducted by Romanoff and by Porter indicate that a galvanized (zinc) coating was effective in delaying the onset of corrosion in the buried steel structures. Typical conclusions drawn from this study for the 5 mil (3 oz/ft^2) galvanized coating includes:

- Adequate for more than 10 years corrosion protection for inorganic oxidizing soils.
- Adequate for more than 10 years corrosion protection for inorganic reducing soils.
- Insufficient for corrosion protection in highly reducing organic soils (pH < 4) and inorganic reducing alkaline soils or cinders (8 < pH < 10.5) lasted typically only 3 to 5 years.
- **It was also noted, however, that the use of a galvanized coating significantly reduced the rate of corrosion of the underlying steel structure once the zinc coating was destroyed**. This was observed in Romanoff's study where the rates of corrosion for the previously galvanized coated steel were less than the corrosion rates for never galvanized bare steel.

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Active Control

Cathodic Protection: As indicated previously, corrosion is an electrochemical process that involves a flow of direct electrical current from the anodic (corroding) areas of the underground metallic structure into the electrolyte and back onto the metallic structure at the cathodic (non-corroding) areas. In situations where helical piles or steel piers are to be placed in a soil environment classified as severely corrosive, Active Control technique of corrosion control should be used. This Active Control technique is termed *Active Cathodic Protection*.

The basic principle of *Active Cathodic Protection* is to apply an electrical current equal to and opposite to the electrical current generated by the corroding metallic structure, thus effectively eliminating the corrosion process on the foundation element.

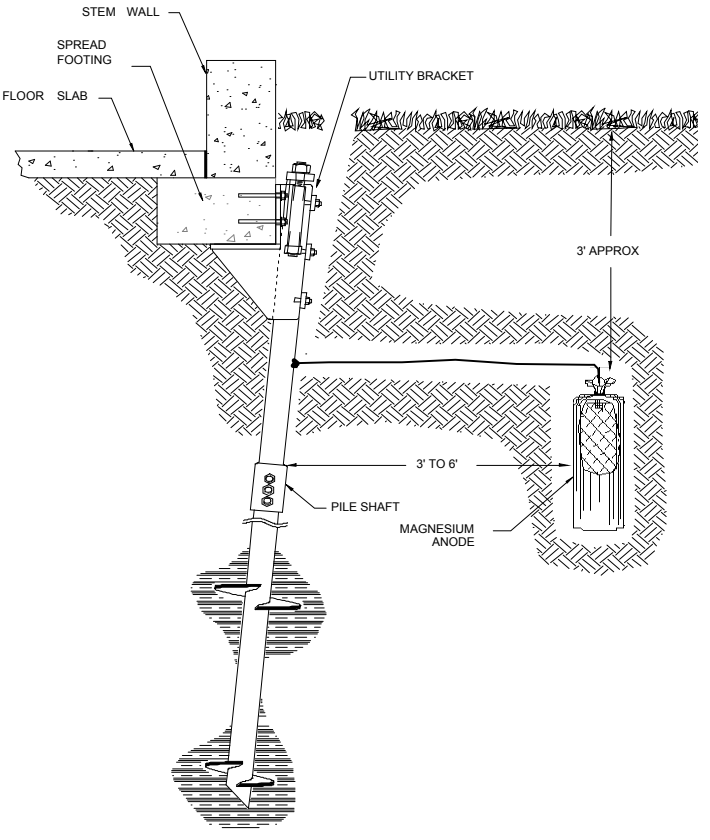

Figure 2. Active corrosion protection with a magnesium anode

Sacrificial Anodes: The sacrificial (galvanic) anode is attached to each underground metallic structure by an electrical conductor (cable) and the anode is placed within the common electrolyte (soil medium) adjacent to the foundation element. The sacrificial anode works best when only a small amount of electrical current is needed for corrosion control and/or when the soil resistivity is low. Anodes are usually installed about three feet below the surface and 3 to 6 feet from the steel subject to corrosion. Magnesium, zinc and aluminum are the most commonly used galvanic sacrificial anodes.

The use of cathodic protection using sacrificial anodes connected to underground metallic structures offers the following advantages:

- no external power supply is required
- low system cost for anode bags and installation
- minimum maintenance costs

The major variables are soil moisture content, resistivity of soil and pH. Each of these items influence the final selection of the cathodic protection system. Typical design life for the cathodic protection is 10 to 20 years, depending upon the size, length and type of the anode canister. After the anode is exhausted, a new anode needs to be installed. Otherwise the underground steel will begin to corrode.

Impressed Current: In areas that have the most severe corrosion potential and a large current is required, and in places with high resistance electrolytes; an impressed current system is generally recommended. This system requires a power source, rectifier and a ground bed of impressed current anodes. These systems require a continuous external power source to provide corrosion protection.

The majority of applications where foundation underpinning is installed will not require an active corrosion protection system. In most cases where there is corrosive soil and/or adverse electrolyte conditions, the sacrificial anode protection system will likely be the most economical approach. All corrosion protection systems require technical expertise and training to design and install the products for the specific job site conditions.

As long as the system is properly designed and installed; and the system remains in operation, the underground steel will have unlimited corrosion life.

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Corrosion Life Analysis

The estimated corrosion life is based on the following factors:

1. The life of the galvanized coating, (CL_G)
2. The life of a limited amount of steel loss in the pier wall without losing structural integrity of the pile, (CL_P) (The recommended allowance is 10 %.)
3. The life when cathodic protection is present, (Follow the life analysis provided by the sacrificial anode manufacturer.)

There is a high degree of variability in the performance life of steel piers and helical piles in the soil. Including, but not limited to:

- multiple strata soils through the depth of installation,
- soil variations within a given stratum
- variability of the water content of soil both vertically and seasonally
- presence or absence of salt ions in the soil due to leaching, etc.
- non-uniformity of the galvanized coating thickness and areas of stress concentration
- imperfections in the steel
- damage to the steel or galvanized coating
- presence or absence of stray currents

Corrosion Life of Galvanized Coating: The observed rates of corrosion for the galvanized coating were different (less) than that for bare steel in Romanoff's NBS study. Equation 1 can be used to estimate the corrosion (weight loss) rate for galvanized coatings.

Equation 1 - Corrosion Life Zinc:

$$CL_G = G / [0.25 - 0.12 \log_{10} (R/150)]$$

Where:

CL_G = Weight loss (oz/ft^2)/year
G = Amount of galvanize coating (oz/ft^2)
R = Soil resistivity (ohm-cm)

Corrosion Life of Steel Pier or Pile: Once the protection offered by the galvanized coating has been exhausted, the steel will begin to corrode and lose thickness. "Safe Use Design" states that a factor of safety of 2.0 or greater shall be used when designing foundation supports. With regard to corrosion loss, experience has shown that the structural integrity of the pier system is not be compromised should there be a corrosion loss of steel not exceeding ten per cent. This is because greater strength is needed for product installation than for support. The formula for estimating average time for ten percent corrosion loss in steel wall thickness (W_S x 0.10) is given in Equation 2, which estimates corrosion loss per year.

Equation 2 - Corrosion Loss Steel Shaft:

$$CL_P = W_{S\text{-}10\%} / K_C$$

Where:

CL_P = Life expectancy of steel tube (years)
$W_{S\text{-}10\%}$ = 10% shaft weight loss – (oz/ft^2)
$K_{C\text{-}1\ yr}$ = Corrosion loss per year - oz/ft^2

- $W_{S\text{-}10\%}$ is the amount of steel loss equal to 10 % of the wall thickness of a pile shaft can be determined by Equation 3.

Equation 3:

$$W_{S\text{-}10\%} = \mathbf{10\%} \times \mathbf{t} \text{ in} \times \mathbf{489.6} \text{ lb/ft}^3 \times \mathbf{16} \text{ oz/lb}$$

Where: **t** = Wall thickness of the tubular shaft or one-half the thickness of the solid bar - in.

- $K_{C\text{-}1\ yr}$ can be estimated from the data in Graph 3, which estimates of corrosion loss per year based upon the resistivity and pH.

It is important to remember that the corrosion life predicted by these equations provide an average life expectancy for the foundation support product when installed under the given conditions. Furthermore, at the end of the calculated corrosion life, there will be no loss of structural integrity or original design factor of safety.

From the end of the corrosion life predicted here, corrosion to the structural element will begin to reduce the factor of safety built into the design of the product. If left unprotected, corrosion will eventually cause failure sometime in the future.

Caution is required for predictions of performance life beyond 50 years. The equations above provide results that are average corrosion life predictions. The corrosion process is affected by variations in ground water adjacent to the pile or pier shaft. It is also affected by soil strata typically not homogenous, along with other factors such as dissolved minerals, imperfections in the galvanization, imperfections in the steel and/or damage to the products during shipping and installation, etc.

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"Quick and Rough" Corrosion Life Estimating

Corrosion Life Tables: The tables that follow were developed from Equations 1 and 2 presented earlier. The values for the pH used in the tables were based upon the values at which corrosion potential generally changes.

Corrosion of the Torque Anchor™ Shafts

The first two columns of Table 5 estimate the corrosion life of an ungalvanized Torque Anchor™ shaft before the pile deterioration affects capacity. This table estimates the time for corrosion to destroy ten percent of the of the pile shaft thickness. Determine the shaft configuration under the heading of the graph. Next, locate the row that most closely matches the soil pH on the job site. Read downward from the shaft configuration and horizontally from the selected pH value until the column and row intersect. This is the "Quick and Rough" estimate of corrosion life of the steel prior to any loss in capacity.

Life of Torque Anchor™ Galvanizing

The vast majority of steel foundation support products are specified with corrosion protection applied. At the far right column of Table 5 estimates the corrosion life of galvanized coating. Simply read horizontally across from the pH that most closely matches the pH at the job site until the estimated life of the galvanization is found at the far right column.

The Torque Anchor™ products are supplied with hot dip galvanizing that meets or exceeds ASTM A123, Grade 100. This puts a minimum of 2.3 oz/ft^2 of zinc, which is 3.9 mils (minimum) thickness.

TABLE 5. Sample ECP Torque Anchor® & Soil Nail Life Expectancy Estimates at Full Load

Soil pH	Plain Steel Life Expectancy at Full Load						Hot Dip Galvanize 2.3 oz/ft^2 - 3.9 Mils (ASTM A123 gr. 100)
	1-1/2" Square Bar	1-3/4" Square Bar	2-1/4" Square Bar	2-7/8" Dia x 0.262" Tube	3-1/2" Dia x 0.300" Tube	4-1/2" Dia x 0.337" Tube	
Soil Resistivity – 500 ohm-cm							
4.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	Add 12 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	48 yrs	57 yrs	63 yrs	
8	45 yrs	52 yrs	67 yrs	15 yrs	17 yrs	19 yrs	
10.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	
Soil Resistivity – 1,000 ohm-cm							
4.5	29 yrs	34 yrs	43 yrs	10 yrs	12 yrs	13 yrs	Add 15 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	57 yrs	67 yrs	73 yrs	
8	49 yrs	57 yrs	73 yrs	17 yrs	20 yrs	22 yrs	
10.5	29 yrs	34 yrs	43 yrs	11 yrs	12 yrs	13 yrs	
Soil Resistivity – 2,000 ohm-cm							
4.5	34 yrs	39 yrs	51 yrs	12 yrs	14 yrs	15 yrs	Add 20 years to life shown at left
5	125+ yrs	125+ yrs	150+ yrs	85 yrs	100 yrs	100+ yrs	
8	47 yrs	67 yrs	86 yrs	19 yrs	22 yrs	24 yrs	
10.5	34 yrs	39 yrs	51 yrs	12 yrs	14 yrs	15 yrs	
Soil Resistivity – 5,000 ohm-cm							
4.5	45 yrs	52 yrs	67 yrs	16 yrs	18 yrs	20 yrs	Add 34 years to life shown at left
5	150+ yrs	150+ yrs	175+ yrs	100+ yrs	100+ yrs	100+ yrs	
8	82 yrs	95 yrs	100+ yrs	29 yrs	33 yrs	37 yrs	
10.5	45 yrs	52 yrs	67 yrs	16 yrs	18 yrs	20 yrs	

IMPORTANT NOTES:

1. The tables above are designed to suggest to the reader basic life expectancies assuming homogeneous soil and constant soil moisture. These tables are not intended to be used in place of a corrosion analysis and design. This table is not to be considered a substitute for field measurements of pH and resistivity; and a site specific corrosion analysis.

IMPORTANT NOTES CONTINUED NEXT PAGE

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2. The life expectancies predicted in Tables 5 & 6 were calculated using recognized engineering principles and are for general information only. While believed to be accurate, this information should not be used or relied upon for any specific application without competent professional examination by a registered professional engineer and verified for accuracy or suitability to the application and site.

3. Reaching the end of the stated life does not indicate that the pile will fail; rather a slow reduction of the factor of safety will occur as the ultimate pile capacity decreases. Failure could occur in months or many years depending upon the soil conditions and the installed product.

4. The tables allow for ten percent of the cross section of the product to corrode away from the solid steel bars and ten per cent of wall thickness from the tubular sections. This extra material was required for torsional strength when installing the helical pile, or for field load testing the steel pier pipe. The helical pile or steel pier should retain the original design capacity with the full factor of safety intact even with this small amount of metal loss.

5. Variations in soil moisture content from season to season and year to year can adversely affect service life. Low field moisture content produces low corrosion rates even if corrosion elements are present. Stray currents from pipe lines, power lines, etc may also affect the life of the pile or pier. Corrosivity, resistivity and pH testing is always recommended in problem soils.

6. Hot Dip Galvanize process is assumed to meet or exceed ASTM A123 – Grade 100. The quadruple layer corrosion protection process found on the ECP Steel Pier pipe is assumed offer protection that is equivalent to ASTM A123 – Grade 75. The 4 inch diameter pier pipe is offered with optional galvanizing to ASTM A123 – GR 100.

7. Once the resistivity becomes higher than 1,000 ohm-cm, the galvanized solid square shaft helical pile product provides an excellent service life exceeding 44 years, when not subjected to soil pH values outside the range of Table 5 or to stray underground currents. Life expectancies exceeding 50 years can be expected for galvanized helical tubular products when the resistivity is above 5,000 ohm-cm.

8. As the predicted life expectancy increases beyond 40 years, the margin for error increases dramatically because the life expectancy estimates are calculated from empirical equations derived from field testing and projected beyond the length of time for the actual corrosion testing.

Corrosion Life of ECP Steel Piers™

Some ECP Steel Pier™ pipe is supplied with quadruple corrosion protection that is similar to ASTM A123, Grade 75. This is equivalent to 1.7 oz/ft^2 of zinc, or 3.0 mils thickness. The PPB-400-EPS pier pipe is supplied with Hot Dip Galvanizing to ASTM A123 – Grade 100. This pipe is also used for PPB-400-EPSB with a mill finish.

Table 6 (next page) is used to estimate corrosion life for the most commonly used ECP Steel Piers™. Because the PPB-300-EPS (2-7/8 inch diameter with 0.165 inch wall pier pipe) and the PPB-350-EPS (3-1/2 inch diameter with 0.165 pier pipe) are supplied with the factory applied quadruple corrosion protection, the values in Table 6 use the flow coat corrosion protection in the corrosion life estimates.

To obtain an estimate of the time that it will take for corrosion to destroy the corrosion protection coating on the pier pipe and ten percent of the wall thickness of the steel tube, locate the pier pipe configuration at the top of Table 6. Next, determine the soil pH that most closely matches the pH at the job site. Read downward from the pier pipe that will be used and horizontally from the selected pH value until the column and row intersect. This is the "Quick and Rough" estimate of the corrosion life expectancy of the ECP Steel Pier™ pipe for the particular job site.

The PPB-400-EPSB (4 inch diameter with 0.220 inch wall thickness mill finished pier pipe) and the PPB-400-EPS is the same pier pipe with Hot Dip Galvanization of 2.3 oz/ft^2 of zinc or 3.9 mils thickness to ASTM-A123, Grade 100. The corrosion life for these pier pipes is determined in the same manner as the other steel pier pipes. Locate the 4 inch diameter pier pipe at the top heading of the graph depending upon whether it has HDG or mill finish and read downward until the intersection with the row that represents the closest value of pH found on the job site.

It is important to remember that the corrosion life predicted by these tables provide an average life expectancy for the foundation support product when installed under the given conditions. Furthermore, at the end of the calculated corrosion life, there will be no loss of structural integrity or original design factor of safety for service load.

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TABLE 6. Sample ECP Steel Pier® Pipe Life Expectancy Estimates At Full Load				
Soil pH	**PPB-300-EPS** 2-7/8" Dia. Tube Quad-layer-coating (1.7 oz.ft^2 – 3.0 Mils)	**PPB-350-EPS** 3-1/2" Dia. Tube Quad-layer-coating (1.7 oz.ft^2 – 3.0 Mils)	**PPB-400-EPSB** 4" Dia. Tube (Mill Finish)	**PPB-400-EPS** 4" Dia. Tube HDG – (2.3 oz/ft^2 - 3.9 Mils ASTM A123 gr. 100)
Soil Resistivity – 500 ohm-cm				
4.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
5	40 yrs	40 yrs	40 yrs	53 yrs
8	19 yrs	19 yrs	13 yrs	25 yrs
10.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
Soil Resistivity – 1,000 ohm-cm				
4.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs
5	47 yrs	47 yrs	48 yrs	63 yrs
8	22 yrs	22 yrs	13 yrs	28 yrs
10.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs
Soil Resistivity – 2,000 ohm-cm				
4.5	22 yrs	22 yrs	10 yrs	39 yrs
5	69 yrs	69 yrs	72 yrs	92 yrs
8	27 yrs	27 yrs	17 yrs	37 yrs
10.5	22 yrs	22 yrs	10 yrs	39 yrs
Soil Resistivity – 5,000 ohm-cm				
4.5	35 yrs	35 yrs	13 yrs	47 yrs
5	97 yrs	97 yrs	95 yrs	100 yrs
8	43 yrs	43 yrs	25 yrs	59 yrs
10.5	35 yrs	35 yrs	13 yrs	47 yrs

Please see "Important Notes" on the two previous pages

Results of Field Tested Galvanized Coating Life

The National Bureau of Standard conducted testing of corrosion of metals in soils. As early as 1924, research on corrosion of galvanized pipe was in progress. In 1937 a zinc corrosion study began using 1-1/2 inch diameter galvanized steel pipe with a 5.3 mil (0.0053") zinc coating. The results from the testing are shown in Table 7. The test also found that the galvanization prevented pitting of the steel even after the zinc coating was completely consumed. The bare steel that was formally under the galvanization corroded at a much slower rate than comparable bare steel under identical conditions.

* Test of buried 1-1/2" diameter steel pipe with 5.3 mils of zinc galvanizing -- National Bureau of Standards – 1937.

** Life expectancy is only for galvanize coating and not any loss of steel.

Table 7. Corrosion of Galvanized* Steel Pipe* in Contact with Various Soils		
Inorganic Soils	**Zinc Loss /yr** (mil per year)	**Life of Zinc**** (years)
Acid Soils – Oxidizing		
Cecil Clay Loam	0.08	66
Hagerstown Loam	0.08	66
Susquehanna Clay	0.11	48
Acid Soils – Reducing		
Sharkey Clay	0.15	35
Acadia Clay	0.91	6
Alkaline Soils – Oxidizing		
Chino Silt Loam	0.15	35
Mohave Fine Gravelly Loam	0.15	35
Alkaline Soils – Reducing		
Docas Clay	0.22	24
Merced Silt Loam	0.10	53
Organic Acid Soil - Reducing		
Carlisle Muck	0.44	12
Tidal Mush	0.38	14
Muck	1.42	4
Rifle Peat	2.64	2
Cinders	1.64	3

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Manufacturer's Warranty

Earth Contact Products strives to provide quality foundation support products at competitive prices. We are proud that our products are providing long term foundation support to structures across the nation. We are so confident in our products that we offer a manufacturer's limited 25 year warranty against defects in materials and workmanship. The text of our warranty is shown below:

> *"Earth Contact Products, L.L.C. offers a 25 year warranty from the date of installation against any defects in manufacturing and workmanship on ECP Steel Piers™ and ECP Torque Anchors™ when installed by an authorized ECP installer in normal soil conditions*. Earth Contact Products, L.L.C. will furnish new product replacement, if any ECP Steel Pier™ or ECP Torque Anchor™ should fail to function due to defects in its quality of manufacturing material or workmanship. All replacement materials will be furnished F.O.B. from the point of manufacture. This is a product warranty provided by the manufacturer and does not include installation or service of the product. Installation and service shall be furnished by the selling contractor as a service warranty on his installation workmanship. This warranty covers only the quality of the manufactured product."*

Research shows that our products will meet or exceed this life expectancy in the vast majority of applications and soil environments. Because our products are sometimes exposed to extremely corrosive environments, we defined what we consider "normal" soil conditions below:

> **Normal Soil Condition is defined as soil having a resistivity greater than 2,000 ohm-cm and between pH 5 and pH 8. Excessive corrosion due to aggressive soil or corrosive environment is NOT considered a manufacturing defect. In corrosive environments, additional corrosion protection may be required for extended service life.*

If you suspect that the environment on a site would be corrosive to steel underpinning products, or if you require a service life exceeding 25 years, we strongly recommend that you request a site specific soil resistivity test at intervals to 20 feet below grade and soil pH values from a geotechnical engineer or soil testing laboratory.

Upon request, ECP offers complementary corrosion life analysis to determine the estimated service life for ECP products specified for a specific site when the request includes the required soil corrosivity data indicated above.

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Chapter 8

ECP Torque Anchors™ & ECP Steel Piers™

Corrosion Life Design Examples

- **Corrosion Life of Tubular Torque Anchor™**
- **Corrosion Life of ECP PPB Steel Piers™**

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Earth Contact Products, LLC reserves the right to change design features, specifications and products without notice, consistent with our efforts toward continuous product improvement. Please check with Engineering Department, Earth Contact Products to verify that you are using the most recent information and specifications.

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Design Example 1 – Corrosion Life of Tubular Torque Anchor™

Structural and Soil Details:

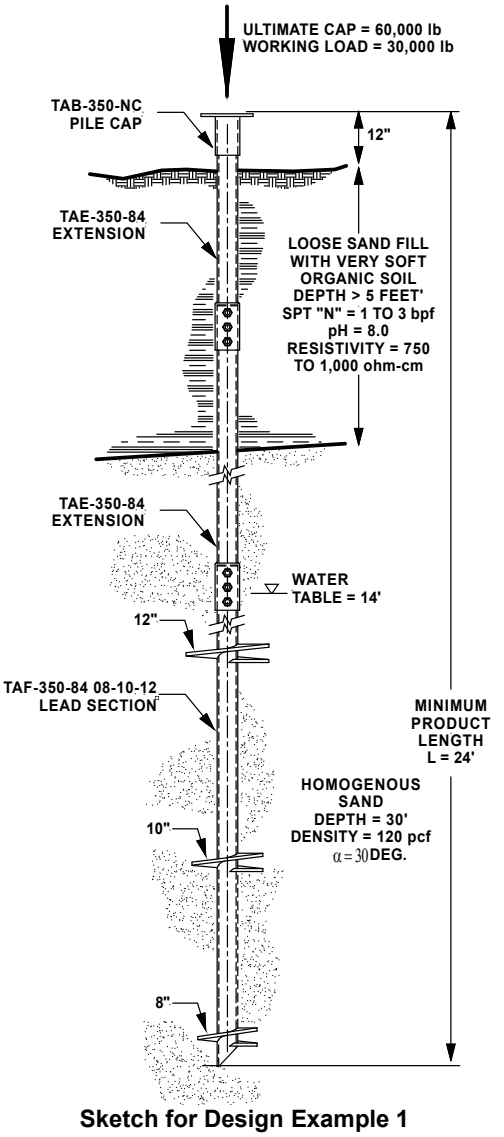
- Details are from Design Example 1, Chapter 3
- New Building – 2 story house with basement
- Estimated weight 3,700 lb/ft
- Working load on foundation piles – 30,000 lb
- Top of pile to be 12" above the soil surface.
- The soil data revealed a least five feet of very loose sand fill and very soft clay organic soil near the surface.
- Standard Penetration Test values for this weak layer were: "N" = 1 to 3 blows per foot - Soil Class = 8
- Below approximately five feet, a layer of very stiff inorganic clay (CL), with SPT, "N" = 20 blows per foot (average) exists as stated in Design Example 1 – Chapter 3 and the water table remains at 14 feet - Soil Class = 5
- Soil pH in the sand fill and soft organic soil was reported to be: pH = 8.0 and the resistivity measured from 750 to 1,000 ohm-cm to ten feet.
- The helical Torque Anchor™ required to support the load without bucking in the loose fill was determined to be TAF-350-84 08-10-12

ECP Corrosion Life Analysis: The equations provided in the previous chapter will be applied to estimate the average life expectancy of the hot dip galvanization and a time for a corrosion loss of 10% of wall thickness of the 3-1/2 inch diameter pile shaft.

The results from this analysis provide an estimate of average life expectancy. When dealing with soil conditions on a job site, there is always a degree of variability in the performance life of steel piles. In general, the following can affect the life of the pile in the soil:

- **Multiple strata nature of foundation soils**
- **Variability within the soil stratum**
- **Variability of the water content of soil both vertically and seasonally**
- **Presence or absence of salt ions in the soil due to leaching, etc.**
- **Non-uniformity of the galvanized coating thickness and areas of stress concentration**
- **Imperfections in the steel**
- **Presence or absence of stray currents**

This analysis considers the performance life of the galvanized coat along with the time required to corrode 10% of wall thickness of the pile shaft after the galvanized coating is exhausted.



Sketch for Design Example 1

1. Corrosion Evaluation of the Galvanized Coating: A soil study of the jobsite revealed that the upper stratum of soil has a reported Standard Penetration Test (SPT) - "N" = 1 to 3 blows per foot, the pH = 8.0 and the soil resistivity to a depth of ten feet ranges from 750 to 1,000 ohm-cm.

A *Corrosivity Score* for the soil on this site was determined to be 10. (See Tables 3 & 4 in Chapter 7) This suggests that the soil be considered to be *Aggressively Corrosive*. This corrosion potential raises a concern about corrosion effects on the useful life of the helical pile at this site.

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2. Estimated Life of Galvanized Coat. Estimate the average life of galvanized coating at the location that has the lowest soil resistivity. Use Equation 1 introduced in Chapter 7 to estimate the average life of the galvanized coating.

Equation 1 - Corrosion Life Zinc:
$$CL_G = G / [0.25 - 0.12 \log_{10} (R/150)]$$

Where:
CL_G = Weight loss (oz/ft^2)/year
G = 2.3 oz/ft^2 (HDG – ASTM A123 gr.100)
R = 750 ohm-cm (Lowest soil resistivity)

Determine CL_G using Equation 1:

$$CL_G = 2.3 / [0.25 - 0.12 \log_{10} (750/150)]$$
$$= 2.3 / [0.25 – 0.12 \log_{10} 5.0]$$
$$= 2.3 / [0.25 – 0.12 (0.699)$$
$$= 2.3 / 0.166$$

CL_G = <u>13.8 years</u>

3. Corrosion Life Estimated – Steel Loss: The formula for estimating average time for 10% loss of wall thickness of steel tube is given in Equation 2 from Chapter 7:

Equation 2 - Corrosion Life Steel Shaft:
$$CL_P = W_{S\text{-}10\%} / K_C$$

Where:
CL_P = Life expectancy of steel tube (years)
$W_{S\text{-}10\%}$ = 10% pile weight loss – (oz/ft^2)
K_C = Corrosion loss per year - oz/ft^2

- $W_{S\text{-}10\%}$ is the amount of steel loss equal to 10% of the wall thickness of a 3-1/2 inch diameter with 0.300 inch wall thickness must first be determined.

Equation 3:
$$W_{S\text{-}10\%} = 10\% [t"/12] \times 489.6 \text{ lb/ft}^3 \times 16 \text{ oz/lb}$$

Where: **t** = Wall thickness of shaft - inches

The pile shaft used for this example is a TAF-350 tubular shaft, which is 3-1/2 inches diameter with 0.300 inch wall thickness. Using Equation 3, the value of $W_{S\text{-}10\%}$ is calculated:

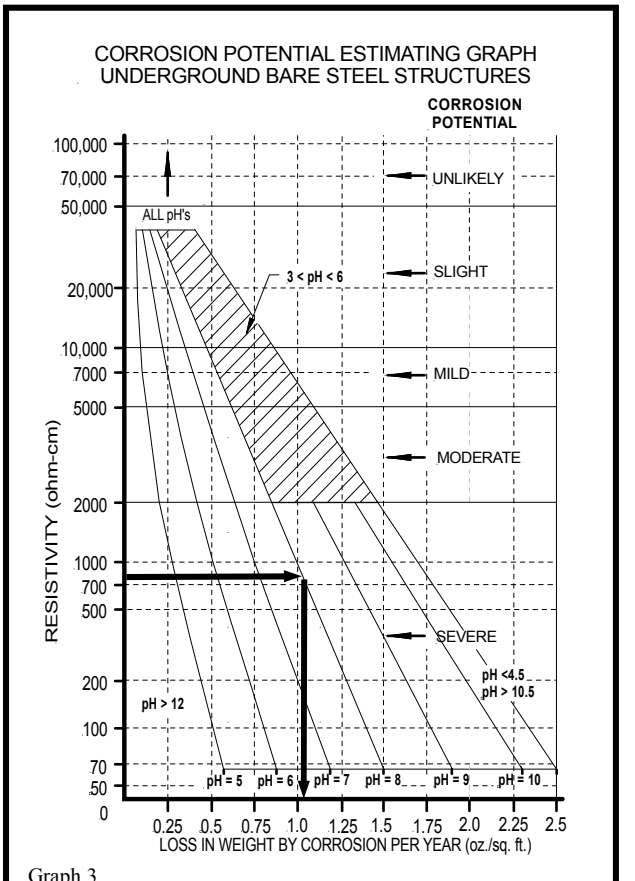
$W_{S\text{-}10\%}$ = 0.10 x [0.300"/12] x 489.6 x 16
$W_{S\text{-}10\%}$ = 19.6 oz/ft^2

Next, the corrosion loss rate (K_C) must be determined using Graph 3 presented in Chapter 7. It is reproduced at right for reference. Knowing that the lowest resistivity relates to highest rate of corrosion, locate 750 ohm-cm on the left axis. Reading horizontally to the right find the curved line that represents pH = 8.0. Reading directly downward, the corrosion loss in weight of steel per year is estimated to be 1.04 oz/ft^2.

Using Equation 2, the corrosion life for the steel tube is determined.

$CL_P = W_{S\text{-}10\%} / K_C$
Where:
CL_P = Life expectancy of steel tube (years)
$W_{S\text{-}10\%}$ = 19.6 oz/ft^2 (Weight loss of steel pier)
K_C = 1.04 oz/ft^2 (Corrosion loss per year.)

$CL_P = 19.6 / 1.04 =$ <u>18.8 years</u>



Graph 3.

4. Determine the corrosion life of the pile. The time for the galvanization to corrode and for ten percent corrosion loss of the steel is the average corrosion life expectancy of the steel pile shaft when installed at the job site.

Life = $CL_G + CL_P$ = 13.8 + 18.8 = <u>32.6 years</u>

Based upon the data and the assumptions, the analysis suggests that the Torque Anchor™ helical pile shafts specified for this project will support the design load, plus a full 2.0 factor of safety with no loss in capacity for an estimated <u>average corrosion life exceeding 30 years.</u>

Corrosion Life = <u>30+ years*</u>

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Design Example 1A – Corrosion Life of Tubular Torque Anchor™ "Quick and Rough Method"

All of the structural and soil data is the same as stated in Design Example 1 above.

1. Estimated Life of Steel. The estimated average amount of time for ten percent of the wall thickness of a TAF-350 tube to corrode can be estimated from Table 5 presented in Chapter 7, and reproduced below.

Many times the exact field resistivity and pH will not be found on Table 5. The average life will have to be estimated based from between the pH values in the table.

The resistivity was reported between 750 and 1,000 ohm-cm and the pH is 8. To estimate the corrosion life of the pile, it is necessary to find the pile configuration at the top of the table.

In determining corrosion life, conservative decisions should always be used.

The specified TAE-350 Torque Anchor™ shaft can be found at the sixth column from the left. There are two sub-tables; resistivity of 500 ohm-cm and 1,000 ohm-cm. A value half way between 500 and 1,000 ohm-cm (750 ohm-cm) will be used here. The soil pH = 8 is located at the left column. The corrosion life estimate is 17 years at 500 ohm-cm and pH = 8. The corrosion life at 1,000 ohm-cm and pH = 8 is 20 years.

An average value can estimate corrosion life at 750 ohm-cm between 17 and 20 years. The average value for steel corrosion life is:

$\mathbf{CL_P}$ = [17 + 20] years / 2 = **18.5 years**

2. Estimated Life of the galvanization. The average corrosion life of hot dip galvanize to ASTM A123 Grade 100 can be found at the right column. It is necessary determine the corrosion life at 750 ohm-cm resistivity, or midway between 12 and 15 years:

$\mathbf{CL_G}$ = [**12 yr** (500 Ω-cm)
+ 15 yr (1,000 Ω-cm] / **2 = 13.5 yrs**

3. Determine the corrosion life of the pile. The estimated average corrosion life expectancy of the steel pier when installed at the job site after all of the galvanizing is depleted and ten percent of the steel has been lost is the sum of the corrosion values from Steps 1 and 2.

Life = $\mathbf{CL_P}$ + $\mathbf{CL_G}$ = 18.5 + 13.5 = 32 years

Corrosion Life = 30+ years*

TABLE 5. Sample ECP Torque Anchor® & Soil Nail Life Expectancy Estimates at Full Load

Soil pH	Plain Steel Life Expectancy at Full Load						Hot Dip Galvanize 2.3 oz/ft² - 3.9 Mils (Minimum)
	1-1/2" Square Bar	1-3/4" Square Bar	2-1/4" Square Bar	2-7/8" Dia. x 0.262" Tube	3-1/2" Dia. x 0.300" Tube	4-1/2" Dia. x 0.337" Tube	
Soil Resistivity – 500 ohm-cm							
4.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	Add 12 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	48 yrs	57 yrs	63 yrs	
8	45 yrs	52 yrs	67 yrs	15 yrs	17 yrs	19 yrs	
10.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	
Soil Resistivity – 1,000 ohm-cm							
4.5	29 yrs	34 yrs	43 yrs	10 yrs	12 yrs	13 yrs	Add 15 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	57 yrs	67 yrs	73 yrs	
8	49 yrs	57 yrs	73 yrs	17 yrs	20 yrs	22 yrs	
10.5	29 yrs	34 yrs	43 yrs	11 yrs	12 yrs	13 yrs	

1

2

Review of Results of Example 1 & 1A

The result obtained by the "Quick and Rough" analysis and the result that was calculated are very close. Larger differences can be expected when making estimates for values that fall between the data boxes in the table.

*One must be cautioned not to consider the result of either analysis as an exact answer because the formulas were derived from empirical data. Both corrosion lives determined in Example 1 & 1A are accurate within the range of error and were rounded down to be conservative. Please review the *"Important Notes"* in Chapter 7.

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Design Example 2 – Corrosion Life of ECP Steel Pier™ Pipe

Structural and Soil Details:

- This settled structure was presented as Design Examples 1 and 2 in Chapter 6, but now there is a concern about corrosion.
- When discussing this project with the engineer, he mentions that consolidation of a layer of weak soil caused the settlement. Upon further investigations of the soil data, it is learned that there is approximately six feet of uncompacted loose fill with Standard Penetration Test values, "N" = 1 to 3 blows per foot.
- Below six feet of fill soil there is firm clay with SPT values exceeding "N" = 5 blows per foot.
- Further soil testing suggested that corrosion might be an issue on this job. The soil resistivity at five feet below grade was 700 ohm-cm and at a depth of ten feet below grade the resistivity climbed to 1,500 ohm-cm. Soil testing reported averaged value for pH = 5.5 down to ten feet.
- The underpinning specified in Design Example 2 was ECP PPB-350-EPS Steel Pier Pipe at the settled area.

ECP Corrosion Life Analysis: The equations provided in the previous chapter will be applied to estimate the average life expectancy of the hot dip galvanization and loss of 10% of wall thickness of the 3-1/2 inch diameter by 0.165 inch wall corrosion protected tube.

The result from this analysis provides an estimate of average life expectancy. When dealing with soil conditions on a job site, there is always a degree of variability in the performance life of steel piles. Please refer to the list in the shaded box presented in Design Example 1 above. The corrosion life analysis will consist of two parts; first is the corrosion live analysis of the zinc coating on the pier pipe, and second is the corrosion loss of 10% of the wall thickness of the pier pipe.

1. Corrosion Evaluation of the Galvanized Coating. A soil study of the five feet of fill material suggested that the fill may be corrosive. Reviewing Tables 3 and 4 in Chapter 7 a Corrosivity Score of 8 / 9 was suggested. This fill soil condition can be considered *"Moderately Corrosive*" to *"Aggressively Corrosive"*. The Standard Penetration Test (SPT), "N", results in the stratum of fill was reported as "N" = 1 to 3 blows per foot, the pH = 5.5 and the soil resistivity was 700 ohm-cm. These values from the soil study confirm the engineer's concern about corrosion effects on the ECP Steel Pier™.

2. Estimated Life of Galvanized Coat: The first calculation estimates the average life for the flow coat protection in soil with a resistivity of 700 ohm-cm. Use Equation 1 introduced in Chapter 7 to estimate the average life of the quadruple coat corrosion protection coating.

Equation 1 - Corrosion Life Zinc:

$$\mathbf{CL_G = G / [0.25 - 0.12 \log_{10} (R/150)]}$$

Where:
$\mathbf{CL_G}$ = Weight loss (oz/ft^2)/year
$\mathbf{G}$ = 1.7 oz/ft^2 (Flo Coat Zinc)
$\mathbf{R}$ = 700 ohm-cm (Soil resistivity)

Determine CL_G using Equation 1:

$$\mathbf{CL_G = 1.7 / [0.25 - 0.12 \log_{10} (700/150)]}$$
$$= 1.7 / [0.25 – 0.12 \log_{10} 4.67]$$
$$= 1.7 / [0.25 – 0.12 (0.669)$$
$$= 1.7 / 0.170$$
$$\mathbf{CL_G = 10.0 \text{ years}}$$

3. Estimated Life of Steel

The formula for estimating average time for 10% loss in steel wall thickness is given in Equation 2 from Chapter 7:

Equation 2 - Corrosion Life Steel Shaft:

$$\mathbf{CL_P = W_{S\text{-}10\%} / K_C}$$

Where:
$\mathbf{CL_P}$ = Life expectancy of steel tube (years)
$\mathbf{W_{S\text{-}10\%}}$ = 10% steel pier weight loss (oz/ft^2)
$\mathbf{K_C}$ = Corrosion loss per year- oz/ft^2

- $\mathbf{W_{S\text{-}10\%}}$ is the amount of steel loss equal to 10% of the wall thickness of a 3-1/2 inch diameter by 0.165 inch wall thickness is determined using Equation 3 for the value of W_S:

  $\mathbf{W_{S\text{-}10\%}}$ = **10% [t"/12] x 489.6** lb/ft^3 **x 16** oz/lb

  $\mathbf{W_S}$ = 0.10 x [0.165/12] x 489.6 x 16

  $\mathbf{W_S = 10.8 \text{ oz/ft}^2}$

- $\mathbf{K_C}$ is the corrosion loss rate and is determined using Graph 3 from Chapter 7.

The lowest resistivity is 700 ohm-cm and would create the highest rate of corrosion within the fill soil. Read from the left side of Graph 3 (shown below) horizontally to a point that represents a pH = 5.5. Then read directly down to determine the loss in weight of steel over a ten year period. A corrosion loss of 0.45 oz/ft^2 per year is determined.

Using Equation 2, the corrosion life for the steel tube is determined.

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$CL_P = W_{S\text{-}10\%} / K_C$

Where:

CL_P = Life expectancy of steel tube (years)

W_S = 10.8 oz/ft^2 (Weight loss of steel pier)

K_C = 0.45 oz/ft^2 (Corrosion loss per year.)

$CL_P = 10.8 / 0.45 = 24$ years

4. Determine the corrosion life of the pier. The corrosion live for the galvanization and for ten percent of the steel to be lost is the average corrosion life expectancy of the steel pier pipe when installed at this job site.

Life = $CL_G + CL_P = 10 + 24 = 34$ years

Based upon the data and the assumptions, the results of this analysis suggests that the ECP Steel Pier™ specified for this project will support the design load plus a factor of safety of 2.0 with no loss in capacity for an estimated average corrosion life of 34 years.

Corrosion Life = 34 years

BONUS: Suggest an Alternate Product for Longer Life

It is always to the advantage of the installer to offer a different product if he thinks it will benefit the client or engineer. The alternate product may or may not be satisfactory, but it does give the engineer another option to change to a product with a longer corrosion life.

The PPB-400-EPS Pier is a hot dip galvanized pier pipe that can be used with the same foundation bracket. The thicker zinc coating along with the larger diameter and thicker wall pier pipe can offer a significant increase in corrosion life with only a small added cost.

Estimated Life of Galvanized Coat on the PPB-400-EPS pipe:

Equation 1 - Corrosion Life Zinc:

$CL_G = G / [0.25 - 0.12 \log_{10} (R/150)]$

Where:

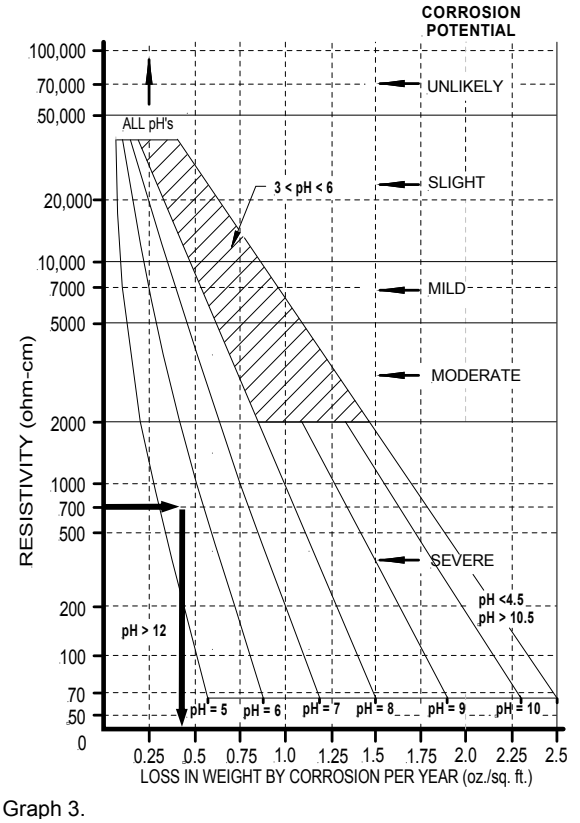
G = 2.3 oz/ft^2 (HDG – ASTM A123 gr. 100)

Determine **CL_G** using Equation 1:

$CL_G = 2.3 / [0.25 - 0.12 \log_{10} (700/150)]$

$= 2.3 / [0.25 – 0.12 (0.669)] = 2.3 / 0.170$

CL_G = 13.5 years



Graph 3.

Estimated Corrosion Life of Steel in PPB-400-EPS pipe:

The amount of steel loss equal to 10% of the 0.220 inch wall thickness of the 4 inch diameter pier pipe shall be determined.

$W_{S\text{-}10\%}$ = 0.10 x [0.220/12] x 489.6 x 16

$W_{S\text{-}10\%}$ = 14.4 oz/ft^2

Equation 2 - Corrosion Life of Steel Shaft:

$CL_P = W_{S\text{-}10\%} / K_C$

Where: $W_{S\text{-}10\%}$ = 14.4 oz/ft^2 (PPB-400-EPS 10% loss)

K_C = 0.45 oz/ft^2 (Corrosion loss per year.)

$CL_P = 14.4 / 0.45 = 32$ years

Determine the corrosion life of the PPB-400-EPS pier pipe. The time for the galvanization to be exhausted and for ten percent loss of the steel from the pipe is the average corrosion life expectancy of the alternate steel pier system when installed at this job site.

Life = $CL_G + CL_P = 13.5 + 32 = 45.5$ yrs

Corrosion Life = 45 years (See note pg 140)

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Design Example 2A – Corrosion Life of ECP Steel Pier™ Pipe "Quick and Rough Method"

All of the structural and soil data are the same as stated in Design Example 2 above.

Estimated Life of the PPB-350-EPS Pipe:

The estimated average corrosion life for the pier pipe installed in fill soil with resistivity of 700 ohm-cm and pH = 5.5 can be estimated from Table 6 in two steps.

1. Estimated Life - PPB-350-EPS Pier Pipe at pH = 5 and 700 Ω-cm: Notice in Table 6 the corrosion life at 500 ohm-cm is 40 years and the life increases to 47 years when the resistivity rises to 1,000 ohm-cm. The 700 ohm-cm resistivity at this site is approximately 2/5 of the difference between the two values given in Table 6, 1,000 Ω-cm = 47 years and 500 Ω-cm = 40 years. Estimate the corrosion at 700 Ω-cm as 2/5 times the difference of 7 years.

$\mathbf{CL_{pH=5.0}}$ = 40 years + (2/5 x 7 years)
$\mathbf{CL_{pH=5.0}}$ = 40 years + 2.8 years = **42.8 years**

2. Estimated Life - PPB-350 Pier at pH = 5.5 and 700 Ω-cm: An adjustment must also be made to adjust to the actual pH = 5.5. (Not pH = 5 shown in the tables) There are six increments of 0.5 pH between pH = 5 and pH = 8. The "ball park" estimate for reduction in corrosion life due to the higher pH = 5.5 on the site is determined:

$\mathbf{CL_{pH=5.0\ to\ 5.5}}$ = [40 yr (pH=5) -19 yr (pH=8)] / 6
$\mathbf{CL_{pH=5.0\ to\ 5.5}}$ = **3.5 years** (Life reduction)

By combining Step 1 and 2, the "Quick and Rough" corrosion life is determined:

$\mathbf{CL_P = CL_{pH=5}} - CL_{pH=5.0\ to\ 5.5}$
$\mathbf{CL_P}$ = 42.8 years – 3.5 years = **39.3 years**

Life PPB-350-EPS = 35 years (See note pg 140)

BONUS
Estimated Life of the PPB-400-EPS Pier:

1A. Estimated Life - PPB-400-EPS Pier Pipe at pH = 5 and 700 Ω-cm: Using the PPB-400-EPS pier system, the difference in corrosion life between resistivity 500 and 1,000 ohm-cm is found to be 10 years. Considering that 700 ohm-cm is 2/5 of the distance between 500 and 1,000 ohm-cm, the "Quick and Rough" estimated corrosion life for the Model 400-EPS pier pipe at pH 5.5 and 700 ohm-cm is 57 years.

$\mathbf{CL_{pH=5.0}}$ = 53 yrs + (2/5 x 10) yrs = **57 years**

2A. Estimated Life - PPB-400-EPS Pier Pipe at pH = 5.5 and 700 Ω-cm: An adjustment must also be made to account for the actual pH = 5.5 instead of pH = 5 shown in the tables. The number of increments of 0.5 pH between pH = 5 and pH = 8 is six. The reduction in corrosion life due to a higher pH = 5.5 is as follows:

$\mathbf{CL_{pH=5.0\ to\ 5.5}}$ = [53 yr (pH=5)–25 yr (pH=8)] / 6
$\mathbf{CL_{pH=5.0\ to\ 5.5}}$ = **4.7 years** (Life reduction)

By combining Steps 1A and 2A, the rough estimated corrosion life is determined:

$\mathbf{CL_P = CL_{pH=5.0} - CL_{pH=5.0\ to\ 5.5}}$
$\mathbf{CL_P}$ = 57 years – 4.75 years = **52.3 years**

Life PPB-400 = 50+ years (See note pg 140)

TABLE 6. Sample ECP Steel Pier® Pipe Life Expectancy Estimates At Full Load

Soil pH	PPB-300-EPS 2-7/8" Dia. Tube (Flow Coat – 1.7 oz.ft²)	PPB-350-EPS 3-1/2" Dia. Tube (Flow Coat – 1.7 oz.ft²)	PPB-400EPSB 4" Dia. Tube (Plain Steel)	PPB- 400-EPS 4" Dia. Tube (HDG – 2.3 oz/ft²)
Soil Resistivity – 500 ohm-cm				
4.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
5	40 yrs	40 yrs	40 yrs	53 yrs
8	19 yrs	19 yrs	13 yrs	25 yrs
10.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
Soil Resistivity – 1,000 ohm-cm				
4.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs
5	47 yrs	47 yrs	48 yrs	63 yrs
8	22 yrs	22 yrs	13 yrs	28 yrs
10.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs

1 2 1A 2A

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Review of Results of Example 2 & 2A

Bonus Solution:
The bonus solution was provided to illustrate that substituting a larger diameter pier pipe with a thicker wall and with a thicker galvanized coating; a substantial increase in corrosion life of the pier pipe can be achieved at very little increase in cost. In the calculated results for Design Example 2, the corrosion life increased by 33% simply by changing from the PPB-350-EPS (3-1/2" diameter) to the PPB-400-EPS (4" diameter) pier system. This recommendation to extend corrosion life by substituting a larger pipe that can be used in the same foundation bracket is less expensive than specifying and installing cathodic protection at each pier placement to increase the corrosion life. This substitution can save the customer money.

Discussion of the Results of Design Examples 2 & 2A:
The results obtained by the "Quick and Rough" analysis on this example over estimates the corrosion life expectancy compared to the calculated results for corrosion life. The inaccuracy is due to attempting to "read between the boxes" in the tables to determine a corrosion life when the soil at the project has a soil resistivity "between the lines". These two values, 700 ohm-cm and pH = 5.5, do not appear in the tables. The inaccuracy occurs because the change in life expectancy is not linear.

The error in the corrosion life prediction in Design Example 2A for the PPB-400 was more than 11% longer life when the Quick and Rough" method was used compared to the estimated corrosion life determined by calculations. **This clearly demonstrates a flaw in the "Quick and Rough" method of corrosion life estimating when it is necessary to extract data from "between the boxes".** To illustrate the point, one can see that the "Quick and Rough" Design Example 2A prediction estimated the corrosion life of the PPB-400 system to be 6.8 years greater than what was calculated from the empirical equations in Design Example 2. The interpolation "between the boxes" created this large variance that overestimated the product life.

Design Example 2A was designed as a complicated problem. The goal was to be able to demonstrate a simple method of linear interpolation to extract data from "between the boxes" on the tables. The linear interpolation method demonstrated in Design Example 2A caused the discrepancies between the two methods of corrosion life expectancies. The calculated method is the more accurate solution to Design Example 2A. The reason the calculated method is more accurate is because it uses the complicated relationship between "*Soil Resistivity", "Soil pH*", and *"Steel Loss by Corrosion"* in the corrosion life equations. One can be see how complicated these relationships are between the three parameters by looking at Graph 3, which is used in this manual to determine the *"Weight of Steel Loss by Corrosion"* for the steel support products installed in corrosive soils. Looking at Graph 3, notice that the resistivity data are logarithmically plotted on the left axis and the curved pH boundary lines in the body of the graph are not linear. The interpolations used in Design Example 2A assumed that the changes in life expectancy "between boxes" in Tables 5 and 6 are linear. The values are not linear and making the assumption of linear relationships created the variance in the life expectancies estimated by the "Quick and Rough" method.

The reader is cautioned to be very careful and conservative when reporting corrosion life expectancies that have been interpolated "between the boxes" when using the "Quick and Rough" method demonstrated here.

***** It was explained *in "Important Notes"* in Chapter 7 that once the estimated corrosion life exceeds 40 years; the results must be treated with caution.
It must also be kept in mind that when attempting to extract data from "between the boxes" in Tables 5 and 6 even greater variances may occur, so one must be very conservative with reporting the result when interpolation is involved.

Keep in mind that the results are only average corrosion life estimates and ECP recommends rounding down the results especially when predicted corrosion life estimates reach 40 years or results are obtained from interpolation during a "Quick and Rough" analysis.

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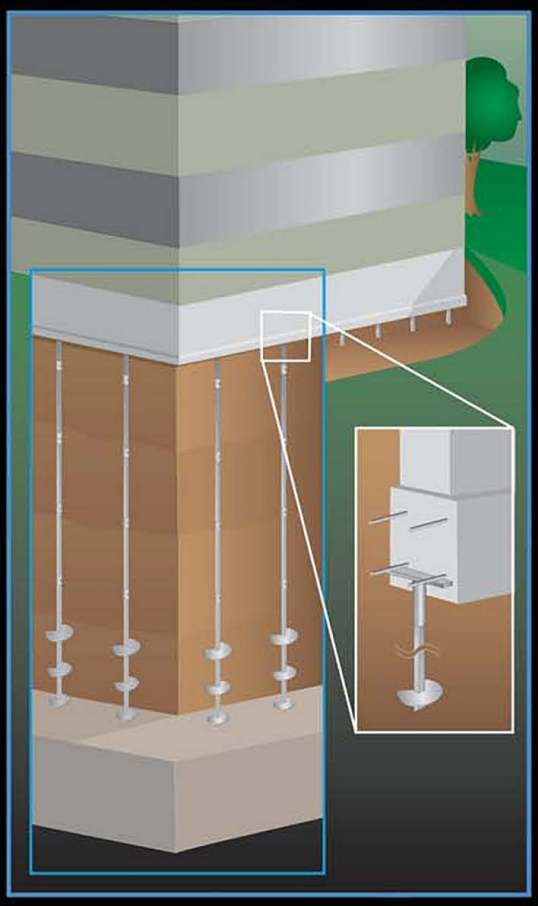

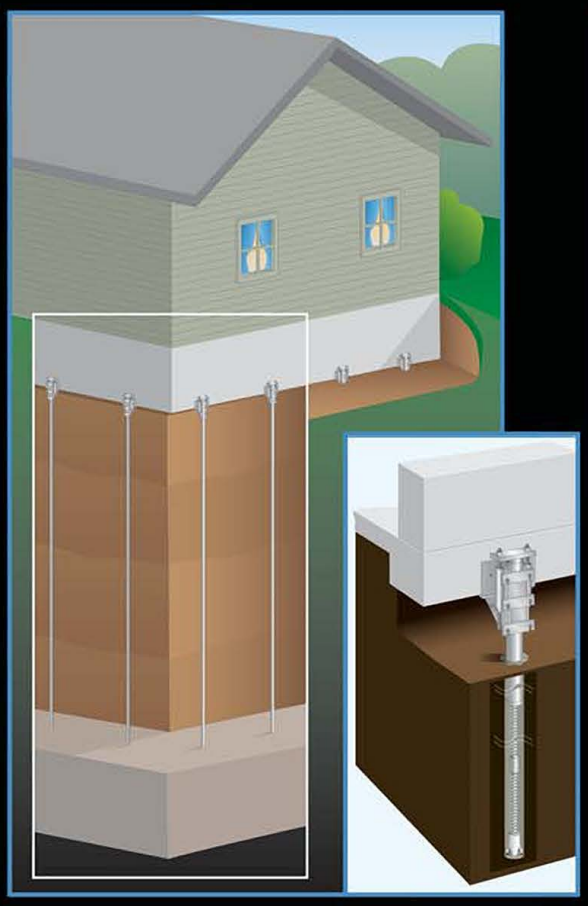

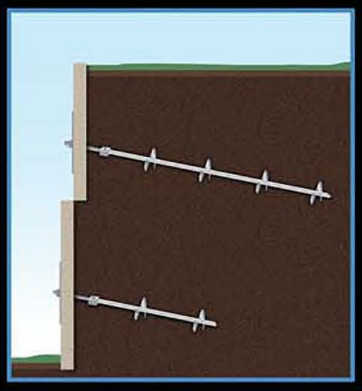

Earth Contact Products
15612 South Keeler Terrace • Olathe, Kansas 66062
Phone: 913-393-0007 • Fax: 913-393-0008 • Toll Free: 1-866-327-0007

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