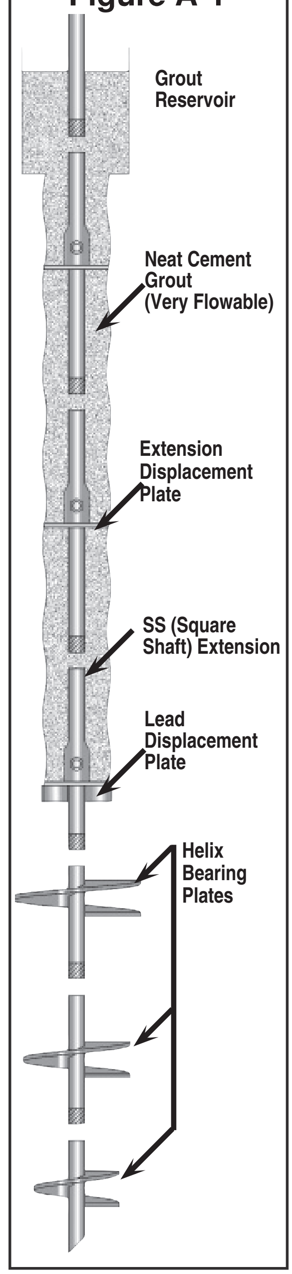
Addendum – HELICAL PULLDOWN™ Micropile (HPM)

Introduction

The HPM is a system for constructing a grout column around the shaft of a standard Helical Screw Foundation (see Figure A-1).

To begin the process, a helical screw foundation is placed into the soil by applying torque to the shaft. The helical shape of the bearing plates creates a significant downward force that keeps the foundation advancing into the soil. After the Lead Section with the helical plates penetrates the soil, a Lead Displacement Plate and Extension are bolted onto the shaft. Resuming torque on the assembly advances the helical plates and pulls the displacement plate downward, forcing soil outward to create a cylindrical void around the shaft. From a reservoir at the surface, a flowable grout immediately fills this void, surrounding the shaft. Additional extensions and displacement plates are added until the helical bearing plates reach the minimum depth required or competent load-bearing soil. This displacement pile system does not require removing spoils from the site.

Figure A-1

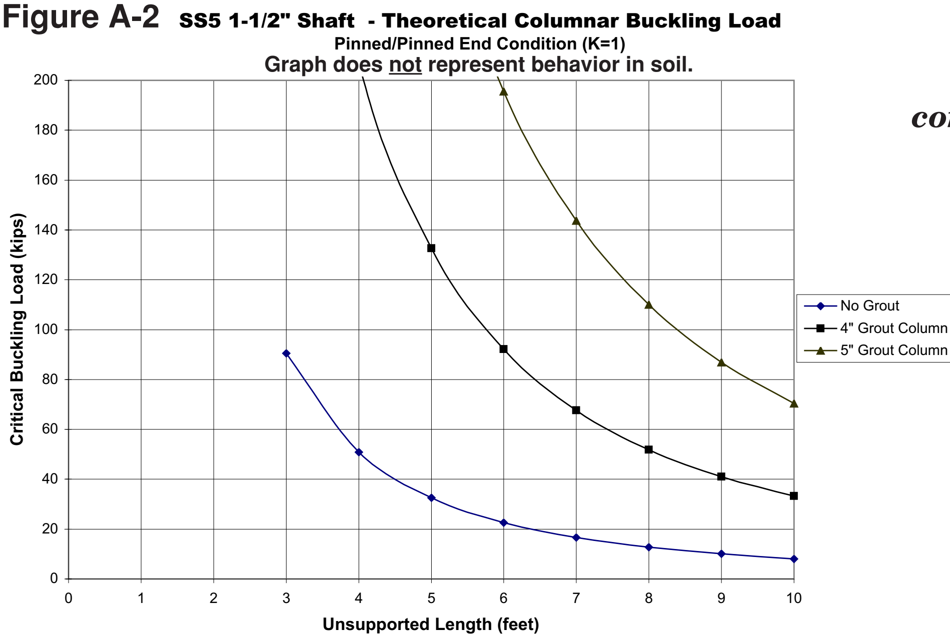


Advantages of the HELICAL PULLDOWN™ Micropile

Resistance to Buckling in Soft/Loose Soils

When soft or loose soils (SPT blow count < 5, clay with C < 600 psf and sand with $\phi < 25°$ or dry unit weights < 85 pcf) are encountered, the HPM eliminates slenderness (L/R) or buckling concerns. Figure A-2 illustrates the Theoretical Columnar Buckling Load of three unsupported (not embedded in soil) foundations, including: standard SS5 shaft without grout, SS5 shaft with a 4-inch diameter grout column, and an SS5 shaft with a 5-inch diameter grout column. As seen on the graph, grout significantly increases the column buckling load. Note that helical screw foundations are typically embedded in soil and that graph A-2 is for illustrative purposes only. For more information on shaft buckling, refer to Step 6.

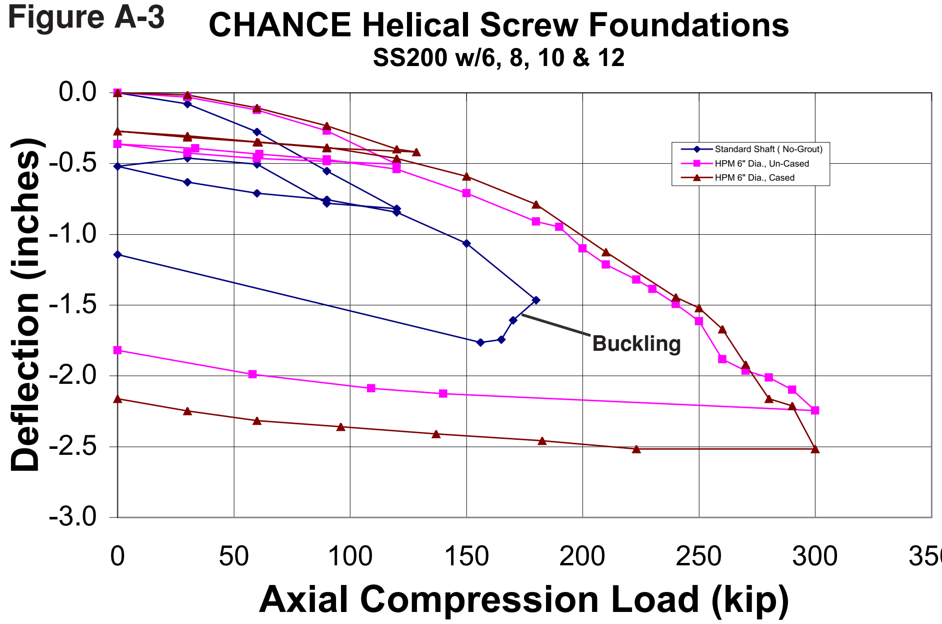
Figure A-2 SS5 1-1/2" Shaft - Theoretical Columnar Buckling Load



continued on next page . . .

Figure A-3 is a graph that compares actual grouted and ungrouted SS200 helical screw foundations. The ungrouted shaft buckled at 180 kip (800 kN) while the grouted shafts, loaded to 300 kip (1335 kN), did not buckle.

Figure A-3

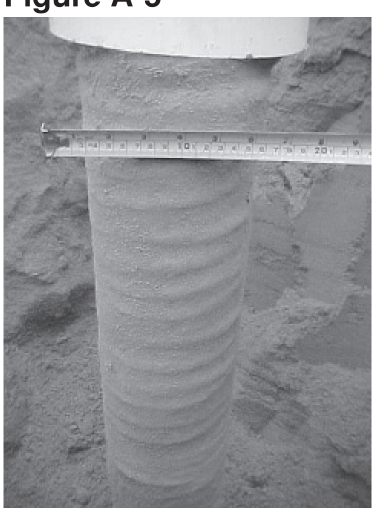


Frictional Capacity

Capacity is developed through friction between the grout column and the surrounding soil. Figures A-4 and A-5 show HPM grout columns that were installed into clay and sand respectively. The corrugated appearance of the grout columns provides an excellent surface for grout-to-soil load transfer. The HPM can be used in areas where a competent load-bearing stratum is not available, see Figure A-6. An HPM can also be used as a composite pile, developing capacity from both end bearing and friction, see Figure A-7.

Figure A-4

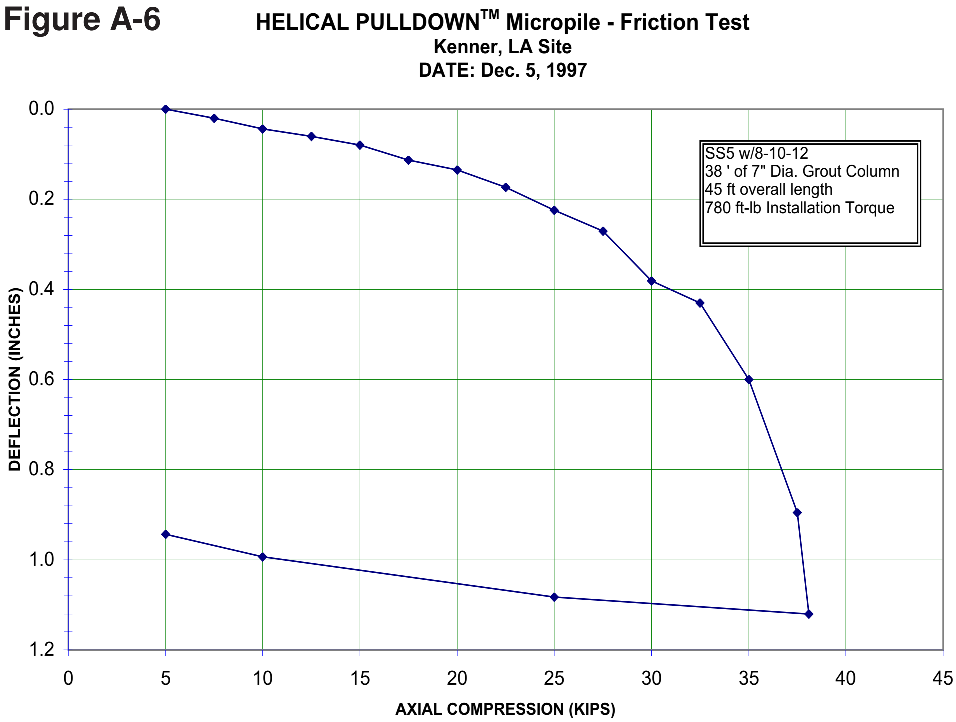
Figure A-5



Increased Mechanical Capacity

The ultimate compression capacity of the standard helical screw foundation is typically limited by the strength of the connection bolt. With an HPM, grout fills the voids in the coupling (see Figure A-8) and reduces the stress on the connection bolt. Notice the strain deformation on the SS200 coupling bolt in Figure A-9. This bolt was taken from a standard helical screw

Figure A-6



foundation (without grout) that was loaded in compression to 180 kip (800 kN). In comparison, Figure A-10 is an SS200 bolt from an HPM that was loaded in compression to 300 kip (1335 kN) with no visible signs of deformation. With grout in the coupling, the stress on the connection bolt is clearly reduced, allowing compression loads up to the Ultimate Compression Capacity of the shaft to be applied to the foundation. See Step 8, Table 8.5 for Mechanical Ratings.

Figure A-7 Farmington - Compression Test

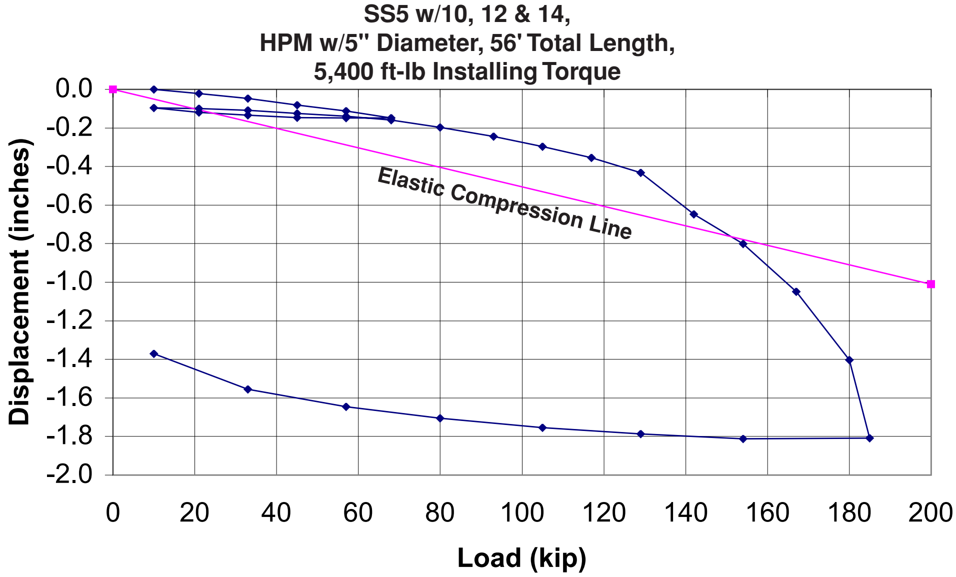
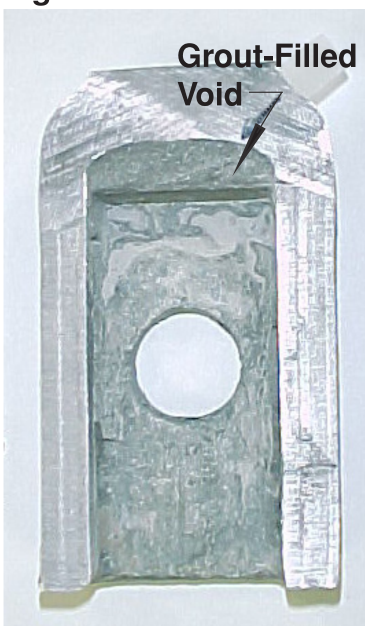


Figure A-8



Stiffer Helical Screw Foundation

Axial deflection per unit load is typically less for an HPM than standard helical screw foundations. The square shaft (SS) coupling requires clearance so that it fits over the proceeding shaft. With a HPM, grout fills these clearance spaces and "locks" the coupling-shaft connection. Also, the grout column encapsulates the square shaft providing a larger section to distribute the load, resulting in less elastic compression. The overall result is a stiffer pile.

Figure A-9, without Grout

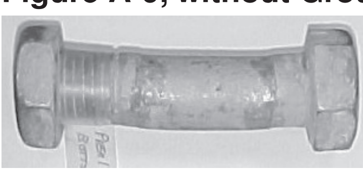
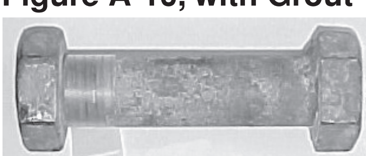


Figure A-10, with Grout



Quality

The HPM is a patented system and must be installed by Hubbell/A.B. Chance Company authorized dealers. These dealers have satisfied the certification requirements relating to both technical aspects and installation techniques.

Figure A-11

Corrosion

Corrosion concerns occasionally cause objection to the use of helical screw foundation technology even though past findings suggest that most concerns are unfounded (see Step 7, Corrosion Guide). If corrosion is a problem, either real or perceived, traditional solutions (anodes, coatings, thicker sections) can increase the cost of a project. The grout column provides additional corrosion protection to the steel shaft from naturally occurring corrosive soils. These may include organic soils such as peat, or other corrosive environments like slag, ash, swamp, chemical waste, or other man-made material. Figure A-11 is a cross-section of an HPM with microsil grout. Microsil type grouts with silica fume offer extremely low chloride permeability, extremely low water intrusion and high electrical resistivity. These characteristics help to minimize corrosion.

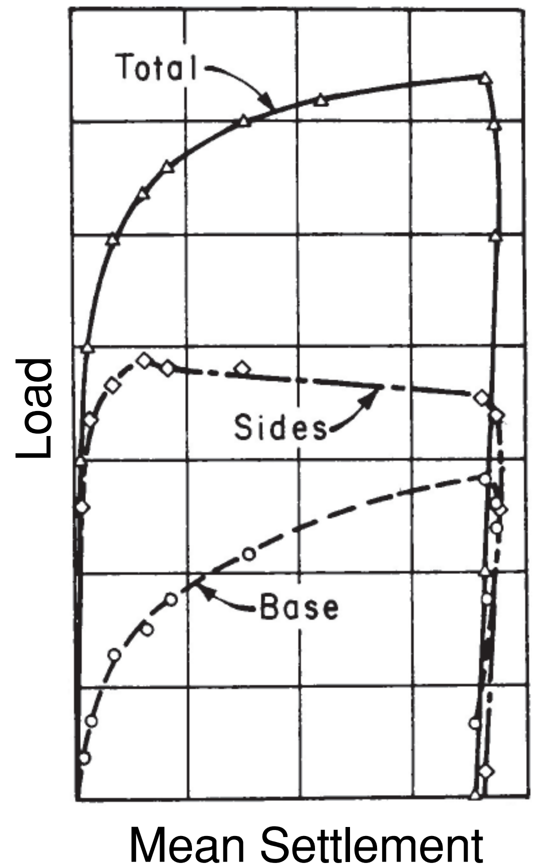
Determining Capacity of a HELICAL PULLDOWN™ Micropile

The total capacity of a HPM is equal to the sum of the bearing capacity on each helix plus the friction generated along the grout-soil interface.

$$Q_t = \sum Q_h + Q_f$$

Where: Q_t = Total Capacity
$\sum Q_h$ = Sum of bearing capacity on each individual helix (see Step 4)
Q_f = Total friction generated between the grout column and the soil

Table A-12 (Reese & Wright, 1977)



To effectively design HELICAL PULLDOWN™ Micropiles, one must first understand the soil-structure interaction of friction and end-bearing piles. The total pile capacity at a given load is typically not divided into equal parts of friction and end bearing. Figure A-12 shows Load-Settlement Curves demonstrating the relative development of side and base resistance. Maximum side resistance (friction) is mobilized after downward displacement of from 0.5 to greater than 3 percent of the shaft diameter, with a mean of approximately 2 percent [Reese, Wright (1977)]. This side resistance or friction continues almost equal to the ultimate value during further settlement. No significant difference is found between cohesive and cohesionless soil except that further strain in clay sometimes results in a decrease in shaft resistance to a residual value. In contrast, the point (end bearing) resistance develops slowly with increasing load and does not reach a maximum until settlements have reached on the order of 10 percent of the diameter of the base (largest helix) [Terzaghi, Peck (1948)]. Hubbell/A.B. Chance Company uses 8 percent of the largest helix diameter plus the elastic compression, i.e. $0.08D_h + PL/AE$ (see Step 11, Static Load Testing) as the method to determine the ultimate capacity of an end-bearing deep foundation. An HPM initially responds to load with a stiff load/deflection profile as the friction capacity is mobilized. As the load continues to increase, friction capacity becomes fully mobilized and the end-bearing resistance increases. This will continue until the end bearing capacity is fully mobilized. The net result is a stiff initial response to load followed by an ultimate capacity that is generally much higher than could be achieved with a standard ungrouted helical screw foundation.

Friction Capacity Calculation

General Equation:

$$Q_f = \sum[\pi D f_s \Delta L_f]$$

Where: D = diameter of grouted pile column

f_s = sum of friction and adhesion between soil and pile

ΔL_f = incremental pile length over which πD and f_s are taken as constant

There are several empirical methods to calculate friction, including the following two.

1. Gouvenot Method

Gouvenot reported a range of values for skin friction based on a number of field load tests.

The soil conditions are divided into three categories based on friction angle (ϕ) and cohesion (C).

The following equations used to calculate f_s are:

Type I: Sands and gravels with $35° < \phi < 45°$ and $C = 0$:

$$f_s = \sigma_o \tan \phi$$

Where: σ_o = mean normal stress for the grout column

Type II: Mixed soils—fine loose silty sands with $20° < \phi < 30°$ and sandy clays with 205 psf < C < 1024 psf (9.8 kPa < C < 49 kPa):

$$f_s = \sigma_o \sin \phi + C \cos \phi$$

Type III: Clays with 1024 psf < C < 4096 psf (49 kPa < C < 196 kPa):

$$f_s = C$$

Where: 1024 psf < C < 2048 psf (49kPa < C < 98kPa)

And f_s = 2048 psf (98kPa)

Where: 2048 psf < C < 4096 psf (98 kPa < C < 196 kPa)

This analysis assumes a uniform shaft diameter for each soil layer and, if required, the friction capacity of the pile near the surface can be omitted.

2. Department of Navy Design Manual 7 Method

For Cohesive Soils: (α Method)

$$Q_f = \sum[\pi D C_a \Delta L_f]$$

Where: C_a = Adhesion factor

*Recommended Values of Adhesion			
Pile Type	Consistency of Soil	Cohesion, C (PSF)	Ahesion, C_a (PSF)
Timber or Concrete	Very Soft	0 – 250	0 – 250
	Soft	250 – 500	250 – 480
	Medium Stiff	500 – 1000	480 – 750
	Stiff	1000 – 2000	750 – 950
	Very Stiff	2000 – 4000	950 – 1300
Steel	Very Soft	0 – 250	0 – 250
	Soft	250 – 500	250 – 460
	Medium Stiff	500 – 1000	460 – 700
	Stiff	1000 – 2000	700 – 720
	Very Stiff	2000 – 4000	720 - 750

*From: Department of Navy Design Manual 7, Soil Mechanics, Foundations and Earth Structures.

For Cohesionless Soils: (α Method)

$$Q_f = \sum[\pi D(qK\tan\delta)\Delta L_f]$$

Where: q = effective vertical stress on element ΔL_f

K = coefficient of lateral earth pressure ranging from K_o to about 1.75 depending on volume displacement, initial soil density, etc. Values close to K_o are generally recommended because of long-term soil creep effects. As a default, use K_o = 1.

δ = effective friction angle between soil and pile material.

Alternate Method

$$Q_f = \sum[\pi D(S)\Delta L_f]$$

Where: S = Average Friction Resistance on Pile Surface Area = $P_o\tan\phi$

P_o = Average Overburden Pressure

	Angle of Internal Friction (degrees)				
	20	25	30	35	40
P_o (PSF)	*S = Average Friction Resistance on Pile Surface (PSF)				
500	182	233	289	350	420
1000	364	466	577	700	839
1500	546	699	866	1050	1259
2000	728	933	1155	1400	1678
2500	910	1166	1443	1751	2098
3000	1092	1399	1732	2100	2517
3500	1274	1632	2021	2451	2937
4000	1456	1865	2309	2801	3356

*Values in chart are for straight concrete piles.
From: Dept. of Navy Design Manual 7, Soil Mechanics, Foundations and Earth Structures.

Design Example:
Determine the capacity of the following HELICAL PULLDOWN™ Micropile installed into soil described on Soil Boring A-1, at end of this Step.

SS5 1½ x 1½ Square Shaft
Helix Configuration: 8, 10 & 12
Total Depth: 40 ft
Grout Column: 5 inch dia x 31 ft

End Bearing Calculation, $\sum Q_h$ (see Step 4)

Table A-1 **HeliCAP SUMMARY REPORT**

Job Name: Medina, MN Demonstration
Job Number: Stannard Soil Anchor Systems
Boring No: B-1
Anchor Use: Compression

C:\Documents and Settings\glseider\My Document:
8/19/2002 1:31:05 PM
Water Table Depth: 15 ft

Capacity Summary

Anchor Number	Anchor Family	Helix Depth (ft)	Helix Capacity (kips)	Total Anchor Capacity (kips)	Recommended Ultimate Capacity (kips)	Torque (ft-lbs)
Anchor 1	Angle: 90 Datum Depth: 0 Length: 40					
12" helix	SS 5	35	17.9t 19.9c			
10" helix	SS 5	37.5	14.3t 14.8c	41.9t	41.9t	4263
8" helix	SS 5	39.5	9.6t 9.8c	44.7c	44.7c	

Summary: Compression Capacity, $\sum Q_h = 44.7$ kip

Table A-2 **Friction Calculation**
See Soil Boring A-1, at end of this Step.

Depth (ft)	Soil	"N" blows	Estimated Cohesion (lb/ft²)	Estimated φ	Effective Unit Weight (lb/ft³)	Average Overburden (lb/ft²)	Adhesion/ Friction (lb/ft²)	Side Friction (lb)
0 - 9	clay	6	750	-	92		682	8040
9 - 15	clay	2	250	-	84		250	1965
15 - 18	clay	1	125	-	20		125	491
18 - 22	sand	5	-	29	23	1438	798	3192
22 - 28	clay	7	875	-	32		682	5364
28 - 31	sand	8	-	30	38	1733	1001	3003

Note: **Total 22055**

$\phi = 0.28N + 27.4$ } from Step 4
$c = (N \times 1000)/8$ }

Area = $\pi 5/12 = 1.31$ ft²/ft

Summary: Friction Capacity, Q_f = 22.1 kip

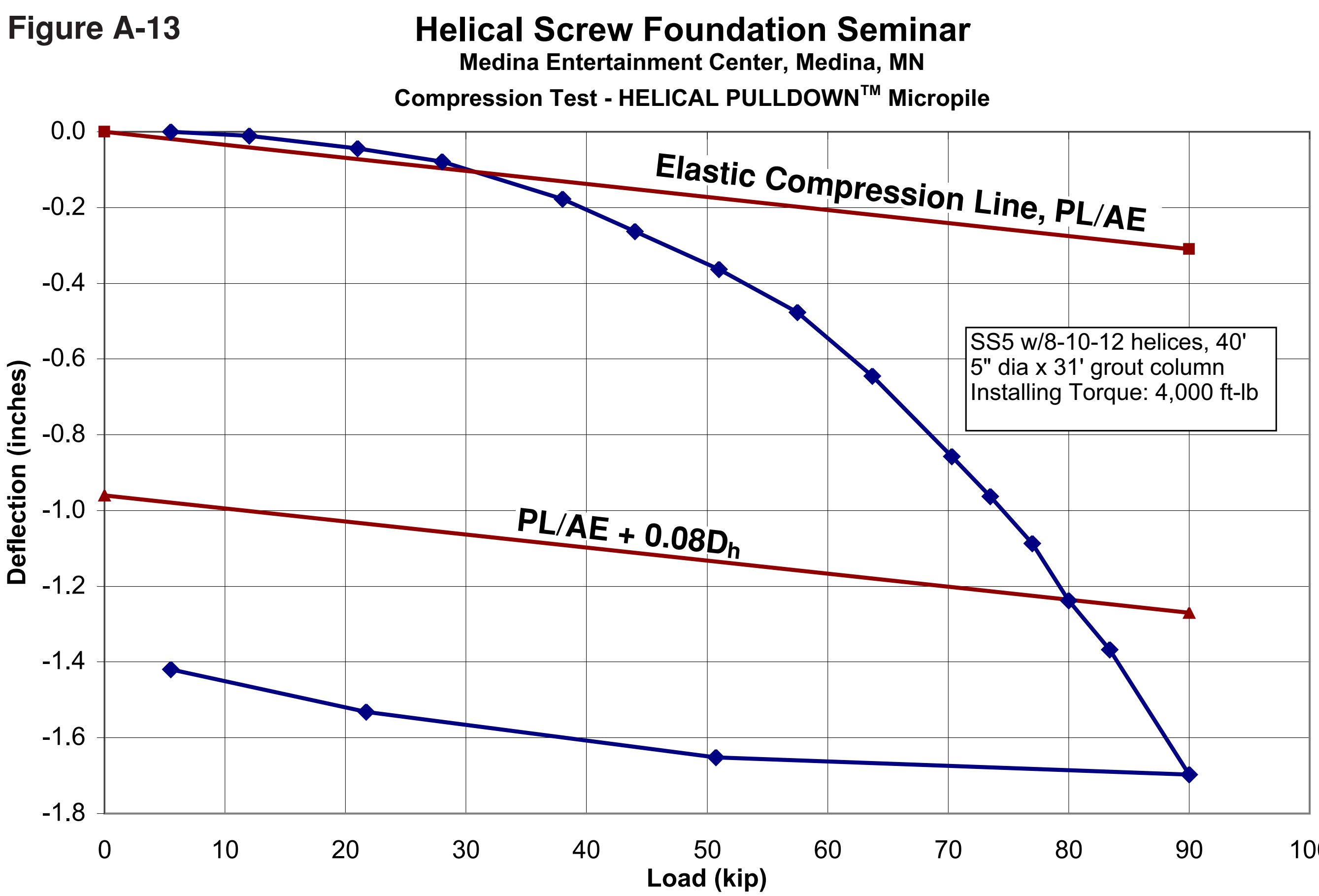
Total Capacity, Q_t

$$Q_t = \sum Q_h + Q_f$$
$$= 44.7 + 22.1$$
$$= 66.8 \text{ kip}$$

Review of Compression Test

Figure A-13 is a load deflection plot from the actual compression test on the helical screw foundation installed into the soil described in Soil Boring A-1. From the plotted data, the Ultimate Capacity (based on 0.08Dh + PL/AE) was 80 kip, compared to the calculated Total Capacity of 66.8 kip. This calculated value provides a conservative approach to determining the ultimate capacity of an HPM.

Figure A-13



MINNESOTA DEPARTMENT OF TRANSPORTATION - GEOTECHNICAL SECTION

LABORATORY LOG & TEST RESULTS - SUBSURFACE EXPLORATION

UNIQUE NUMBER

U.S. Customary Units

State Project	Bridge No. or Job Desc.	Trunk Highway/Location	Boring No.	Ground Elevation
		Anchor Demonstration - Medina, MN	1	

Location

Co. Coordinate: X= Y= (ft.)

Latitude (North)= Longitude (West)=

Drill Machine 91

Hammer CME Automatic Calibrated

SHEET 1 of 2

Drilling Completed 7/16/01

DEPTH	Depth / Elev.	Classification	SPT N60	MC (%)	COH (psf)	γ (pcf)	Other Tests Or Remarks
0–9.5	9.5	FILL, mixture of sandy lean clay, clayey sand, a little gravel, brown and gray	8, 4				
9.5–12.0	12.0	SAPRIC PEAT, black, soft (PT)	2				
12.0–18.0	18.0	ORGANIC CLAY, grayish brown, very soft (OH)	WH				
18.0–22.0	22.0	SILTY SAND, fine grained, gray, waterbearing, loose, lenses of lean clay (SM)	5				
22.0–28.0	28.0	LEAN CLAY, gray, firm (CL)	7				
28.0–35		CLAYEY SAND, a little gravel, gray, firm to stiff to very stiff, lenses of sand (SC/CL)	8				

Rock REC (%) | RQD (%) | ACL (ft) | Core Breaks | Formation or Member

Index Sheet Code 3.0

(Continued Next Page)

Soil Class:LR Rock Class: LR Edit: Date: 7/19/01

R:\DATA\GINTW\200101-C0\/\ER.GPJ

MINNESOTA DEPARTMENT OF TRANSPORTATION - GEOTECHNICAL SECTION
LABORATORY LOG & TEST RESULTS - SUBSURFACE EXPLORATION

UNIQUE NUMBER

U.S. Customary Units

Mn/DOT GEOTECHNICAL SECTION - LOG & TEST RESULTS — *SHEET 2 of 2*

State Project	Bridge No. or Job Desc.	Trunk Highway/Location	Boring No.	Ground Elevation
		Anchor Demonstration - Medina, MN	1	

DEPTH	Depth / Elev.	Lithology	Classification	Drilling Operation	SPT N60 / REC (%)	MC (%) / RQD (%)	COH (psf) / ACL (ft)	γ (pcf) / Core Breaks	Soil / Rock	Other Tests Or Remarks / Formation or Member
35					11					
40			CLAYEY SAND, a little gravel, gray, firm to stiff to very stiff, lenses of sand (SC/CL)		11					
45					12					
50					15					
55					17					
60					20					
	64.0		Bottom of Hole - 64'							

Soil Class: LR Rock Class: LR Edit: Date: 7/19/01
R:\DATA\GINTW\2001\01-00868.GPJ

References

1. Gouvenot, D., "Essais En France et a L'Etranger sur le Frottement Lateral en Fondation: Amelioration par Injection," Travaux, 464,Nov, Paris, France, 1973
2. Reese, L.C. and Wright, S.J., *Drilled Shaft Design and Construction Guidelines Manual*, U.S. Department of Transportation, Federal Highway Administration, 1977
3. Terzaghi, K. and Peck, R.B. , *Soil Mechanics in Engineering Practice*, John Wiley and Sons, Inc., 1967