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Lateral Capacity and Buckling Resistance of Helix Pier Foundations

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Abstract

A computer analysis was performed to determine the lateral strength and buckling resistance of helix foundations in various soil conditions. Several different helix pier configurations were considered including solid square shaft, standard pipe, and high strength structural tube. Results of lateral strength and buckling computations generally match those found previously by others using different methods.

The axial load required to buckle common sizes of helix pier shafts was determined for very soft clay, soft clay, very loose sand, and loose sand soil conditions. In contrast to conventional Euler theory, buckling of underground helix pier shafts was independent of the total length of the shaft. Buckling was found to occur over a 7 to 12 feet long section of shaft regardless of the remaining length of shaft within the same weak soil stratum.

The lateral capacity of helix foundations depends on shaft strength and near surface soil conditions. Computed lateral capacities of 3" O.D. high strength structural tube helix pier shafts with rigid connections varied considerably but were generally in the range of 3 to 6 kips for ½" of deflection in good soil conditions. These results are consistent with lateral load tests conducted by Magnum Piering, Inc. of West Chester, OH. The lateral capacities of square shaft helix pier foundations were not determined due to uncertainties associated with the free movement of forged upset couplings.

Introduction

The use of helix piers in compression for foundations has increased considerably over the last 20 years due to their ease of use and speed of installation. Other factors that contribute to the popularity of helix pier foundations are field verification of capacity through torque and simplicity of practical application in engineering designs. Despite their increased use, there remain unresolved concerns about their buckling resistance in weak soils and their lateral capacity.

The lateral capacity of helix piers in clays was studied by Prasad and Rao (1996). Laboratory tests were performed on small-scale helix piers embedded in clays. The ratio of length to helix blade diameter in these tests varied from 12 to 18. It was found that the presence of helix blades resulted in an increase in lateral capacity that was 1.2 to 1.5 times that of slender piles without helix blades.

Puri, Stephenson, and Dziedzic (1984) performed calculations based on elastic theory and nonlinear p-y type analysis on helix pier shafts embedded in soil and compared the results with previously published full-scale lateral load tests. It was found that the lateral capacity of helix pier shafts is controlled almost exclusively by the mechanical properties of the shaft for depths of helix pier embedment greater than three to five times the critical stiffness factor (6 to 10 feet for commonly manufactured helix foundations in stiff clay). A main conclusion of their study is that the helix pier foundations have some lateral capacity, and that capacity can be validly estimated using nonlinear p-y type analysis. A parameter was introduced to account for disturbance of the ground due to the installation process of helix piers. This parameter, C_u, was determined to be approximately 3.0 through correlations with lateral load test data. The effect of incorporating this parameter into p-y type analysis is to increase deflection under lateral loads directly through multiplication by C_u.

The buckling of square shaft helix piers used for underpinning was studied by Hoyt, R., Seider, G., Reese, L.C., Hon, M., and Wang, S. (1995). LPILE software was used to simulate underground buckling in different soil conditions. The results were found to be in agreement with full-scale field tests. Their results, which have been summarized below, indicated that the buckling capacity of helix pier shafts in soft clays decreased with shaft length. This is opposite of conventional Euler theory wherein the buckling capacity of slender columns generally decreases with increasing unsupported shaft length. A close examination of their results shows that the helix piers being modeled were failing due to overturning moments caused by bracket eccentricities rather than pure buckling. The main conclusion of their study was that buckling of deeply embedded square shaft helix piers with underpinning brackets occurs at less than 40 kips only in soft to very soft clay.

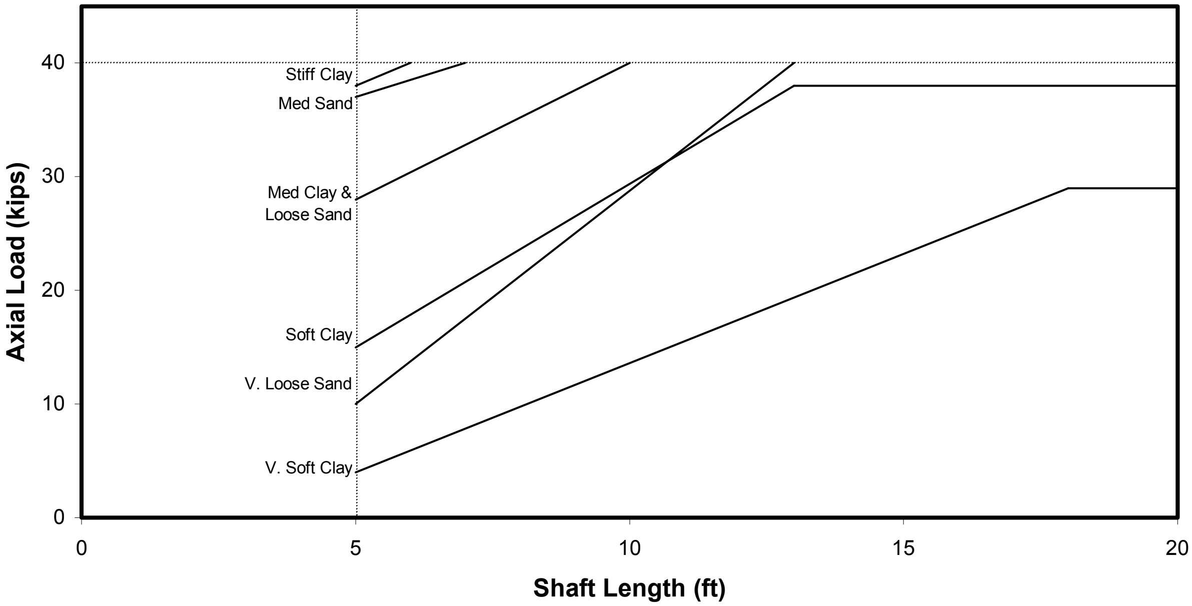

Fig. 1 Buckling Capacity of 1-1/2" Square Shaft Helix Piers Used for Underpinning
(Modified from Hoyt, et al., 1995)

Since helix piers are being used with increased frequency for new foundations, it would be beneficial to examine their buckling capacity without the stresses caused by bracket eccentricities. Often in construction, deep foundations must be relied upon for lateral as well as axial support. Hence, it is also of value to determine the lateral capacity of helix pier shafts. There are presently 5 to 6 helix pier manufacturing companies. Helix piers are available with different shaft configurations from square to tubular. Examination of the lateral capacity and buckling resistance of these different shaft sizes is also of interest.

Buckling Theory

Software for underground pile buckling computation is not readily available to the practicing engineer. One of the most widely used software packages for lateral pile analysis is LPILE by Reese and others. This software package incorporates a nonlinear discrete element p-y method of analysis to determine lateral pile deflections under various boundary conditions. It is difficult to apply LPILE to determine buckling capacity for pinned end conditions. However, a method using alternative boundary conditions is suggested as a valid approximation for buckling.

Recall that Euler's formula can be written as (Beer, F.P. and Johnston, E.R., 1981)

$$P_{cr} = \frac{\pi^2 EI}{L_e^{\,2}}$$

where P_{cr} is critical load, E is Modulus of Elasticity, I is area moment of inertia, and L_e is effective length. The effective length for a column with pinned end conditions is simply equal to the column length as shown on the left side of Fig. 2. Similarly, the effective length for a column with fixed slope and free translation top boundary conditions is shown on the right side of Fig. 2. Although buckling for the pinned end condition can not be determined readily using LPILE, the buckling condition with fixed slope and free translation conditions can be easily modeled. Since the elastic curve for the buckled portion of each of these conditions has the same effective length, it is suggested that the two configurations should yield approximately the same critical buckling load. Hence, buckling for different helix pier shafts was computed herein using the second model with fixed slope and free translation boundary conditions. Yet, the results are indicative of both conditions.

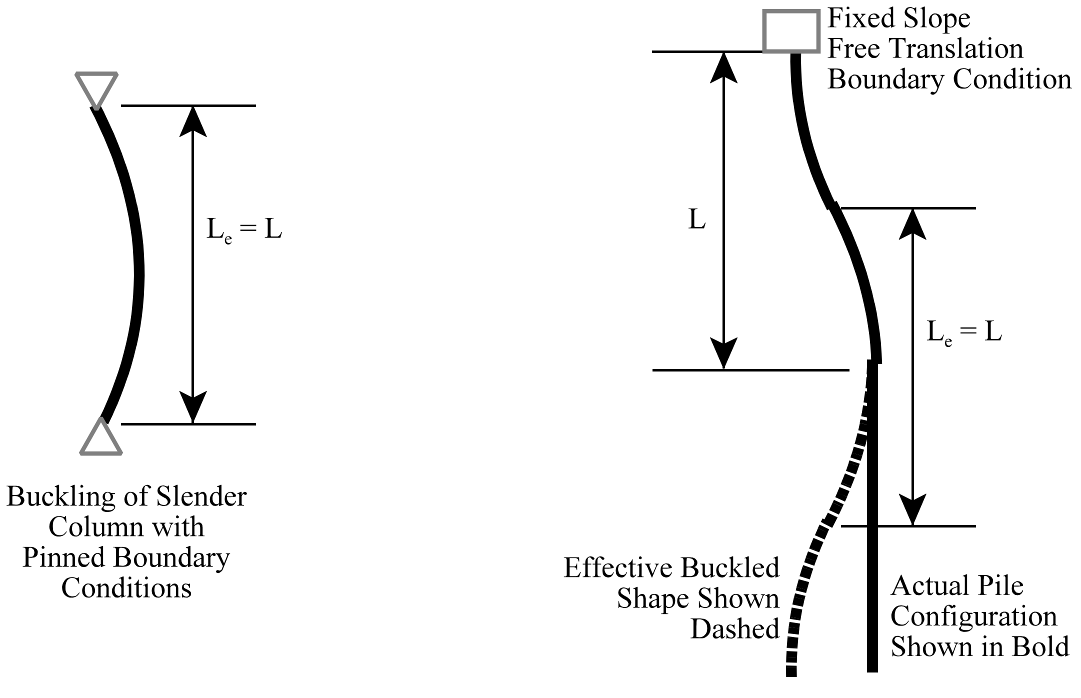

Fig. 2 Helix Pier Computational Buckling Model

Buckling Capacity Analysis

Buckling capacity of helix pier foundations was determined using LPILE software and the boundary conditions described above. Axial load was increased through successive iterations until helix pier failure occurred. Lateral load on the helix pier shafts was set equal to that caused by a departure from plumbness equal to 1.5% of the length. The soil conditions incorporated in the model are shown in Table 1. The model was applied to a variety of commonly available helix pier shaft configurations including 1.5"x1.5" and 1.75"x1.75" square shafts, 2.5" and 3.0" nominal diameter, schedule 80 pipe shafts, and 3.0" O.D., 0.12" and 0.25" thick wall, high strength structural tube shafts. The mechanical properties of these shafts are shown in Table 2.

Table 1 Input Soil Parameters

		SPT Blow Count *(blows/ft)*	Unit Weight *(pcf)*	Horiz. Mod. of Subgrade Reaction *(pci)*	Angle of Friction *(deg)*	Cohesion *(psf)*	Strain at 50% Peak Strength *(in/in)*
Sand	Very Loose	0-4	70	5	25	-	-
	Loose	4-10	96	25	29	-	-
	Medium	10-30	110	90	33	-	-
	Dense	30-50	130	225	39	-	-
Clay	Very Soft	0-2	82	30	-	200	0.06
	Soft	2-4	86	100	-	400	0.02
	Medium	4-8	92	500	-	800	0.01
	Stiff	8-15	104	1000	-	1500	0.005

Table 2 Input Helix Pier Shaft Properties

	1.5"x1.5" SQR BAR	1.75"x1.75" SQR BAR	3.0" O.D. 0.12 Wall HSST	2.5" Nom. Schd. 80 Pipe	3.0" O.D. 0.25 Wall HSST	3" Nom. Schd. 80 Pipe
Area Moment of Inertia (in^4)	0.42	0.78	1.06	1.92	2.06	3.89
Cross-Section Area (in^2)	2.25	3.06	1.02	2.25	2.16	3.02

It was determined that buckling is a critical constraint on the design capacity of helix piers only in very soft to soft clays and very loose to loose sands. Buckling capacity was in excess of manufacturer's recommended maximum allowable axial capacity of the helix piers in the other soil conditions. The results of buckling calculations are shown in Table 3. Allowable buckling capacity was determined from ultimate buckling capacity by application of a factor of safety of 1.5. The results in the table represent the maximum recommended axial design capacity for these helix pier shafts in the soil conditions shown. Buckling failure does not exclude the use of helix piers in weak soils. Rather, it is required that the design axial capacity be lower than or equal to these allowable limits in order to avoid buckling-type failure.

Table 3. Allowable Buckling Capacity of Helix Pier Foundations (F.S. = 1.5)

		1.5"x1.5" Square Bar	1.75"x1.75" Square Bar	3.0" O.D. 0.12 Wall HSST	2.5" Nom. Schd. 80 Pipe	3.0" O.D. 0.25 Wall HSST	3" Nom. Schd. 80 Pipe
Sand	Very Loose	23	28	38	51	64	79
	Loose	28	41	55	75	81	115
Clay	Very Soft	15	21	28	34	38	50
	Soft	28	38	50	63	68	89

The results determined in this study for 1.5"x1.5" square shaft helix piers in very soft to soft clay soils correspond well with those published by Hoyt, et al. (1995). As can be seen in Fig. 1, the ultimate buckling resistance of 1.5"x1.5" square shaft helix piers used for underpinning, as determined by Hoyt, et al. (1995), is approximately 28 kips for very soft clays and 37 kips for soft clay. Application of a factor of safety of 1.5 yields allowable buckling capacities of 19 and 25 kips, respectively. These values for the same shaft in similar soil conditions shown in Table 3 are 15 and 28 kips, respectively. The results determined in this study for 1.5"x1.5" square shaft helix piers in very loose to loose sand soils are less than those determined by Hoyt, et al. (1995). One reason for this difference is that the angle of internal friction for very loose sand used here was 25 deg instead of 28 deg as assumed by Hoyt. The difference in values for very loose to loose sands between the two studies could not be determined because buckling limits that occurred over 40 kips was not published by Hoyt.

Interestingly, the length of shaft affected by buckling in these soil conditions varied generally from 7 to 12 feet. Provided that at least this length of helix pier shaft was surrounded by weak soils, the buckling capacity was independent of any additional length bounded by weak soils. This contradicts traditional Euler buckling theory. The conclusion is made that underground buckling of helix pier shafts occurs at the capacities shown if there is at least 7 to 12 feet of weak soils. The buckling capacity of helix piers is not changed by the presence of more than 7 to 12 feet of week soils. The length of helix pier shafts used in this study was 30 feet. The length of shaft over which buckling occurred was determined by the depth where pier shaft deflections were insignificant.

The results show that confirm the conclusion of Puri, et al. (1984) that the lateral resistance of helix piers is significantly affected by the mechanical rigidity of the helix pier shaft. More rigid round helix pier shafts are able to support higher loads before buckling. Nonetheless, the practitioner should reference Table 3 in order to check the design capacity of all helix pier shafts when installation in weak soils is anticipated.

Lateral Capacity Analysis

In order to resist wind shear and earthquake loads, often large commercial and industrial structures supported by helix pier foundations must be braced laterally by either supplying foundation elements subject to passive soil resistance or by installing additional helix piers at a batter angle. However, helix pier foundations have some lateral capacity which may be incorporated to resist shear loads applied to lightly loaded structures so as to avoid the necessity of other measures.

The lateral capacity of 3.0" O.D., 0.25" thick wall, high strength structural tube helix pier foundations was determined using LPILE software. Fixed slope, free translation top end boundary conditions were incorporated in this analysis. These conditions are indicative of a pile that is rigidly fixed to a structure so as to resist bending moments. However, the entire foundation could translate laterally. The soil conditions used in the analysis were as shown in Table 1. Shaft mechanical properties were as shown in Table 2. The results of the analysis are given in Figs. 3 and 4.

The results of the LPILE analysis of the lateral capacity of these helix piers indicates that between 3,000 and 6,000 lbs of shear load can generally be applied in good soil conditions for ½" of allowable lateral movement. These loads are not large, however even 3,000 lbs is sufficient to support an example lateral wind pressure of 28 psf on an 8 ft x 8 ft section of wall or the lateral earth pressure behind a 4 feet tall x 9 ft long crawl space wall (a factor of safety of 1.7 was incorporated in the live loads used in these examples).

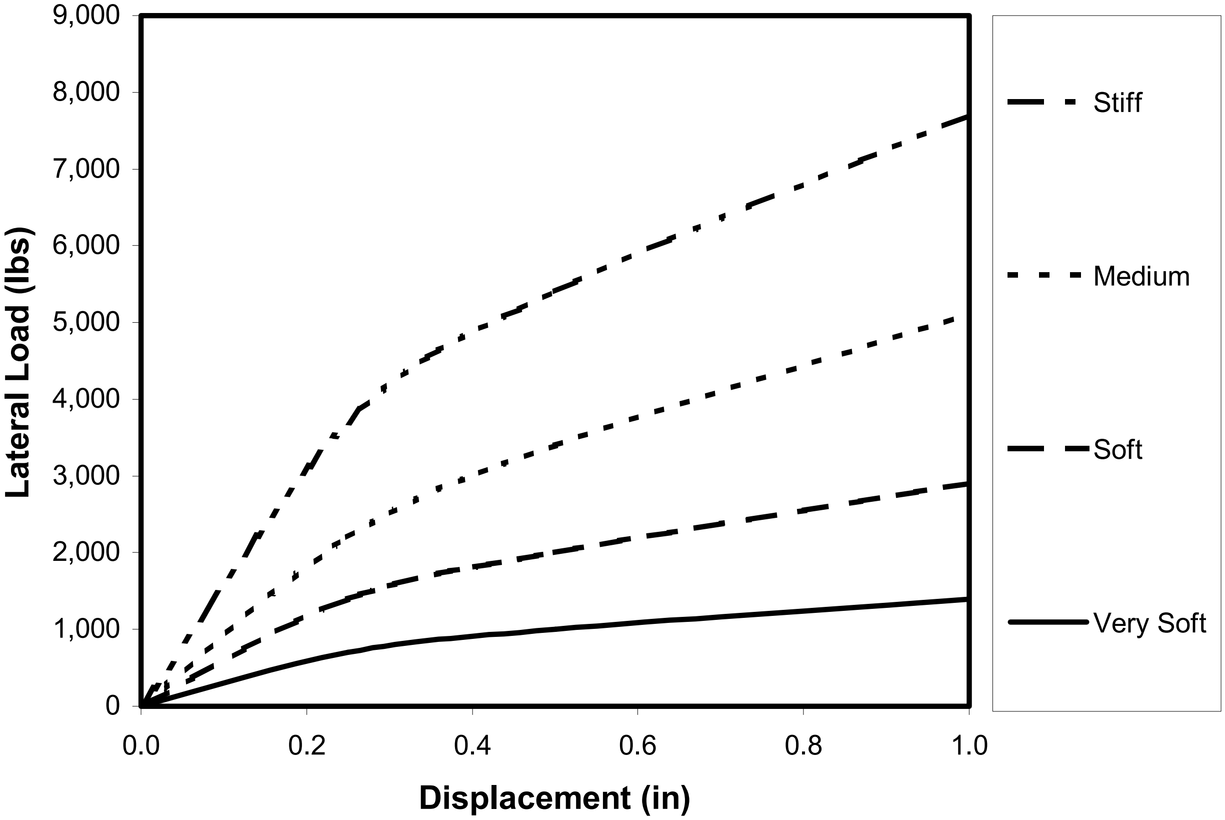

Fig. 3 Lateral Load Resistance of 3" O.D., 0.25" Wall HSST Helix Piers in Clays

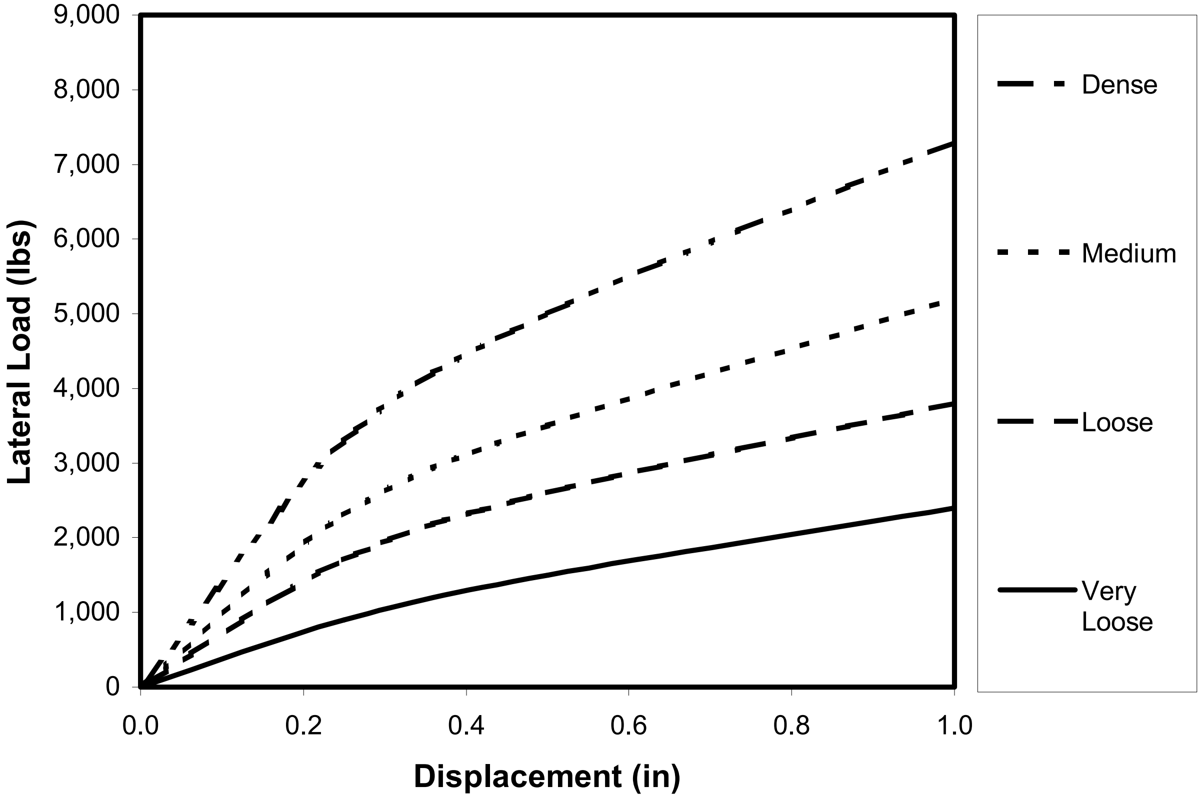

Fig. 4 Lateral Load Resistance of 3" O.D., 0.25" Wall HSST Helix Piers in Sands

Discussion

A parameter to account for disturbance of ground due to installation of helix blades per Puri, et al. (1984) was not taken into account. However, the lateral loads given in Figs. 3 and 4 have been confirmed in at least 5 separate load tests performed by Magnum Piering, Inc. in stiff clays. More study is recommended for various pier shaft configurations and soil conditions to determine positively if the soil disturbance parameter recommended by Puri is justified.

The free movement of forged upset couplings typically used with square shaft helix piers was not taken into account in the buckling computations. As suggested by Hoyt, et al. (1995), additional studies should be performed to determine the effect of these couplings on buckling capacity.

Conclusions

LPILE software was used to investigate the lateral strength and buckling resistance of helix foundations in various soil conditions. It is suggested that the analysis performed using fixed rotation, free translation end conditions is a valid estimation of the buckling resistance of helix pier shafts with pinned end conditions. Buckling was found to impart limits on the allowable axial load that can be applied to solid square shaft, standard pipe, and high strength structural tube helix pier foundation shafts in very soft to soft clays and very loose to loose sands. Buckling was not found to be important in more competent soil conditions. Buckling was found to occur over a 7 to 12 feet long section of shaft regardless of the remaining length of shaft within the same weak soil stratum. Results of buckling computations generally match those found previously by others using underpinning bracket reactions.

The lateral capacity of 3" O.D. high strength structural tube helix pier shafts with rigid connections was found to range from 3 to 6 kips for ½" of deflection in good soil conditions. These results are consistent with lateral load tests conducted by Magnum Piering, Inc. of West Chester, OH. Lateral capacity of 3 kips was shown to be of value in the design of residential and other lightly loaded structures.

References

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