Uplift Capacity of Helical Anchors in Soil

by
R.M. Hoyt, A.B. Chance Company
and
S.P. Clemence, Syracuse University

presented August 17, 1989
at the
12th International Conference
on Soil Mechanics
and Foundation Engineering
conducted in
Rio de Janeiro, Brazil

HUBBELL POWER SYSTEMS CHANCE A.B. Chance Company • Centralia, MO 65240 USA
Tele: 573-682-8414 Fax: 573- 682-8660

Bulletin 02-9001
Rev. 6/98

UPLIFT CAPACITY OF HELICAL ANCHORS IN SOIL

SYNOPSIS

Helical anchors have been used in various applications including transmission tower foundations, pipeline anchors and excavation bracings. Methods for predicting uplift capacity of anchors using geotechnical parameters are categorized into "cylindrical shear" and "individual bearing" methods. An empirical method for predicting capacity based on installation torque has been widely used in practice. The authors have analyzed numerous helical anchor tests to determine ultimate uplift capacities. Capacities based on the three methods were calculated for each anchor and compared to actual capacity. Ratios of actual to calculated capacities were computed and statistical analyses of the distributions of these ratios are presented. The results indicate that the torque correlation method yields more consistent results than either of the other two methods, although all three methods exhibit a wide range of values. The installation torque method may be used as an independent check of the other two to establish bounds of expected capacity.

INTRODUCTION

Helical anchors, also known as screw anchors, consist of one or more helical shaped circular plates (helices) affixed to a central hub. They are installed into soil with a turning moment supplied by standard truck or trailer mounted augering equipment. Uplift capacities up to 175,000 lb (775 kN) have been developed using multi-helix anchors, though capacities in the 20,000 lb (89 kN) to 100,000 lb (444 kN) range are more typical. These anchors have proven to be a cost effective means of providing tension anchorage for foundation and earth bracing systems where soil conditions permit their installation.

Recent emphasis on reliability-based design for electrical transmission lines has created a need to characterize the strength of their structural components as random variables, described by probability density functions (PDF's), rather than as unique values. The American Society of Civil Engineers (ASCE) suggests that strength design guides use a uniform 5% exclusion limit for all strength predicting equations to facilitate this process. A nominal value (Re) is said to be the e% exclusion limit of strength if the probability is e% that the actual strength will not be less than Re (Committee on Electrical Transmission Structures, 1984).

Uplift Capacity of Helical Anchors in Soil

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

UPLIFT CAPACITY PREDICTION

A survey of the literature indicates that a number of analytical methods exist for the analysis and design of individual plate anchors and shallow foundations subjected to uniaxial uplift forces (Adams and Hayes, 1967; Ali, 1968; and Meyerhof and Adams, 1968; and Vesic, 1971). Recent research by Mitsch and Clemence (1985) and Mooney, Adamczak, and Clemence (1985) has concentrated on predicting uplift capacity of helical anchors in sands, clays, and silts. The two most common methods used to predict the uplift capacity of multihelix anchors are the cylindrical shear and the individual bearing methods.

The cylindrical shear method assumes that a cylindrical shear surface connecting the uppermost and lowermost helices is formed (Figure 1). The uplift capacity is derived from shear resistance along this cylindrical surface and bearing resistance above the top helix.

The individual bearing method assumes that bearing failure occurs above each individual helix (Figure 2). The total uplift resistance is the sum of the individual capacities.

A third method often used for predicting uplift capacity is a correlation of installation torque and uplift capacity, analogous to the relationship of pile driving effort to pile capacity. This method was developed empirically and currently lacks explicit definition in traditional geotechnical concepts. It has, however, been used successfully in the construction of thousands of anchors over the past twenty years.

DATA COLLECTION AND ANALYSIS

Ninety-one multihelix anchor load tests detailed in the published literature (Adams and Klym, 1972; Clemence, 1984; Dames and Moore, 1980) and from the author's private files were analyzed for the current study. Uplift capacities were calculated using the cylindrical shear, individual bearing and, except for six cases where installation torque was not available, torque correlation methods.

The procedures used to calculate helix resistance by cylindrical shear were as presented in Mitsch and Clemence (1985) and Mooney, Adamczak, and Clemence (1985), modified for use with soil stratification in a manner comparable to that used by Lutenegger, Smith, and Kabir (1988). For individual bearing, the method presented in Klym, Radhakrishna, and Howard (1986) was adapted.

Uplift Capacity of Helical Anchors in Soil

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

Total anchor capacity can be calculated from installation torque as:

$$Q_u = K_t \times T$$

where

K_t = empirical factor
Q_u = uplift capacity
T = average installation torque

K_t = 10 ft^{-1} (33 m^{-1}) for all square-shaft anchors and round shaft anchors less than 3.5 in (89 mm) diameter, 7 ft^{-1} (23 m^{-1}) for 3.5 in diameter round-shaft anchors, and 3 ft^{-1} (9.8 m^{-1}) for anchors with 8.63 in (219 mm) diameter extension shafts. The installation torque should be averaged for the final distance of penetration equal to three times the diameter of the largest helix.

The first two of the above methods require knowledge of the properties of the soil in which the anchor is placed. Such properties are typically inferred from the results of in-situ and/or laboratory tests, a process often involving subjective evaluation and engineering judgement. This translation process and the quality of the soil test data used can control the outcome in geotechnical analyses to such an extent that the accuracy and precision of a given capacity algorithm can only be judged in the context of the whole process (see, for instance, Lutenegger, Smith, and Kabir, 1988).

The soil test data available for the anchor test sites was typical of that available for ordinary geotechnical projects. This included soil boring logs with standard penetration, unconfined compression, vane shear and pocket penetrometer test data. Empirical values for friction angle, cohesion and unit weight were derived from standard penetration test data using established correlations (see, for instance, Bowles, 1982).

All of the anchor tests used in this study were short term; most were strain-controlled and included a final loading step of imposing continuous deflection at a rate of approximately four inches (102 mm) per minute and measuring the resulting reaction. This load was taken as the ultimate capacity where the data was available.

The anchor tests used in this study were conducted at 24 different sites with sand, silt and clay soils all represented. The number of soil strata involved in the analyses varied from 1 to 10. In many cases, anchors of different types and at different depths were tested at a given site; however, no more than two data sets for the same anchor type at the same site and depth were used. Depth to diameter (H/D) varied from 5.1 to 134

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

and all anchors were analyzed as "deep". Angles of inclination varied from 0 to 50 degrees from vertical. None of the anchors showed any indication of having failed structurally during the tests, so the behavior exhibited can be presumed to have been controlled by soil strength.

The anchor types represented included those having 1.50 in (38 mm), 1.75 in (45 mm), and 2.00 in (51 mm) square and 3.50 in (89 mm) round shafts. Some of the latter had 8.63 in (219 mm) round shafts extending from the top helix to the surface. The number of helices varied from two to fourteen, and their diameters varied from 6 in (152 mm) to 20 in (508 mm). Interhelix spacings varied from 1.55 D to 4.50 D. Most commercially available multihelix anchors fall within these design limits.

RESULTS

Table 1 contains the minimum, maximum, mean and median values and standard deviations of the capacity ratios Q_{act}/Q_{calc} obtained.

Table 1
Uplift Capacity Ratios (Q_{act}/Q_{calc})

Method	Min.	Max.	Mean	Std. Dev.	Median
Cyl. Shear	0.07	7.29	1.50	1.18	1.15
Ind. Bearing	0.03	7.04	1.56	1.28	1.26
Inst. Torque	0.30	4.67	1.49	0.88	1.30

Figures 3-5 show histograms of these ratios. While discussions of reliability-based design often utilize Gaussian probability density functions (PDF's), it is apparent from the histograms that this data is not normally distributed. The right-skewness of the distributions, the fact that zero is the minimum possible value, and the fact that they represent random variables which are products of several secondary random variables, suggest the use of lognormal PDF's. Lognormal models, their defining parameters and 5% exclusion limits are also shown in Figures 3-5.

The Spearman coefficient of rank correlation (Rs) was computed for each pair of methods. This test showed a high degree of correlation (Rs = +0.90) between the cylindrical shear and individual bearing methods and a low degree of correlation between each of them and the torque correlation method (Rs = +0.02 and +0.14, respectively).

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

DISCUSSION OF RESULTS

All three algorithms as applied in this study exhibited the capability of overpredicting anchor capacity. If used in a traditional, deterministic design procedure, large factors of safety seem appropriate. In statistical design methods, the probability density functions shown in Figures 3-5 can be used directly. It should be emphasized that these results are representative of the complete calculation process, including the methods of soil property testing and interpretation, anchor capacity calculation, and load test interpretation.

Though all three sample means were quite close, the range and standard deviation were significantly lower for the torque correlation method than for the other two. This improved consistency may well be due to the removal of several secondary random variables from the prediction process. These would include soil testing errors, errors in translating soil properties between anchor and soil boring locations, and possible changes in soil properties between the times of boring and anchor testing (due, for instance, to a change in water table elevation). The installation torque correlation method does have a major drawback, however, in that it cannot be used until after the anchor has been installed. Thus it is more suited to on-site production control than design in the office.

The use of "engineering judgement" was intentionally minimized during this study so that any inherent differences in accuracy or precision of the various methods might not be masked. The Nq values of the individual bearing method and the soil test/property correlations used were selected because they have been used commercially in a computer program to predict anchor capacities by the individual bearing method for several years.

The relationship between actual and predicted capacities of anchors recommended using this computer program has not been as variable as this study indicates it should have been. Much of the data used in this study came from tests of anchors which had been recommended using this program. A review of these recommendations showed better correlations between actual and predicted capacity than between actual and that calculated for this study. The difference appears to have been that much judgement was used by the application engineer who prepared the recommendations in editing the soil test data for input to the program.

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

CONCLUSIONS

1. The cylindrical shear and individual bearing methods yield similar results in the calculation of multihelix anchor capacities at usual interhelix spacings.

2. The installation torque correlation method yields more consistent results than either of the other two methods. Its results are within the ranges exhibited by the theoretical methods but do not correlate well with them. It provides independent information which helps establish bounds of expected capacity.

3. Engineering judgement is crucial to the successful use of the individual bearing method unless high factors of safety are used. Presumably, it would also have a beneficial effect on the consistency of results using the cylindrical shear method.

Uplift Capacity of Helical Anchors in Soil

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

REFERENCES

Adams, J.I., and Hayes, D.C. (1967). The Uplift Capacity of Shallow Foundations, Ontario Hydro Research Quarterly, Vol. 19. No. 1.

Adams, J.I., and Klym, T.W. (1972). A Study of Anchorages for Transmission Tower Foundations, Canadian Geotechnical Journal. Vol. 9, No. 1.

Ali, M.S. (1968). Pullout Resistance of Anchor Plates and Anchor Piles in Soft Bentonite Clay, M.S. Thesis, Duke University, Durham, NC.

Bowles, J.E. (1982). Foundation Analysis and Design, 3rd Ed., pp. 100-101, McGraw-Hill, New York.

Clemence, S.P. (1984). The Uplift and Bearing Capacity of Helix Anchors in Soil, Vol. I, II, and III, Syracuse University.

Committee on Electrical Transmission Structures, 1984. Guidelines for Transmission Line Structural Loading, ASCE.

Dames and Moore (1980). Pullout Tests on Multi-Helix Screw Anchors, Shacklefords, Virginia, A report prepared for Virginia Electric Power Company.

Klym, T.W., Radhakrishna, H.S., and Howard, K. (1986). Helical Plate Anchors for Tower Foundations, Proc. Anchor Systems in Geotechnical Engineering, Canadian Geotechnical Society.

Lutenegger, A.J., Smith, B.L. and Kabir, M.G. (1988). Use of In Situ Tests to Predict Performance of Multihelix Anchors, Proc. Special Topics in Foundations, ASCE, Nashville.

Meyerhof, G.G., and Adams, J.I. (1968). The Ultimate Uplift Capacity of Foundations, Canadian Geotechnical Journal, Vol. 5, No. 4.

Mitsch, M.P., and Clemence, S.P. (1985). Uplift Behavior of Anchor Foundations in Soil, pp. 26-47, ASCE, New York.

Mooney, J.S., Adamczak, S. and Clemence, S.P. (1985). Uplift Behavior of Anchor Foundations in Soil, pp. 48-72, ASCE, New York.

Vesic, A.S. (1971). Breakout Resistance of Objects Embedded in Ocean Bottom, Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 97, No. SM9.

Uplift Capacity of Helical Anchors in Soil

R.M. Hoyt, Manager, Design Analysis, A.B. Chance Company, Centralia, MO USA

S.P. Clemence, Professor and Chairman, Civil Engineering Department, Syracuse University, Syracuse, New York, USA

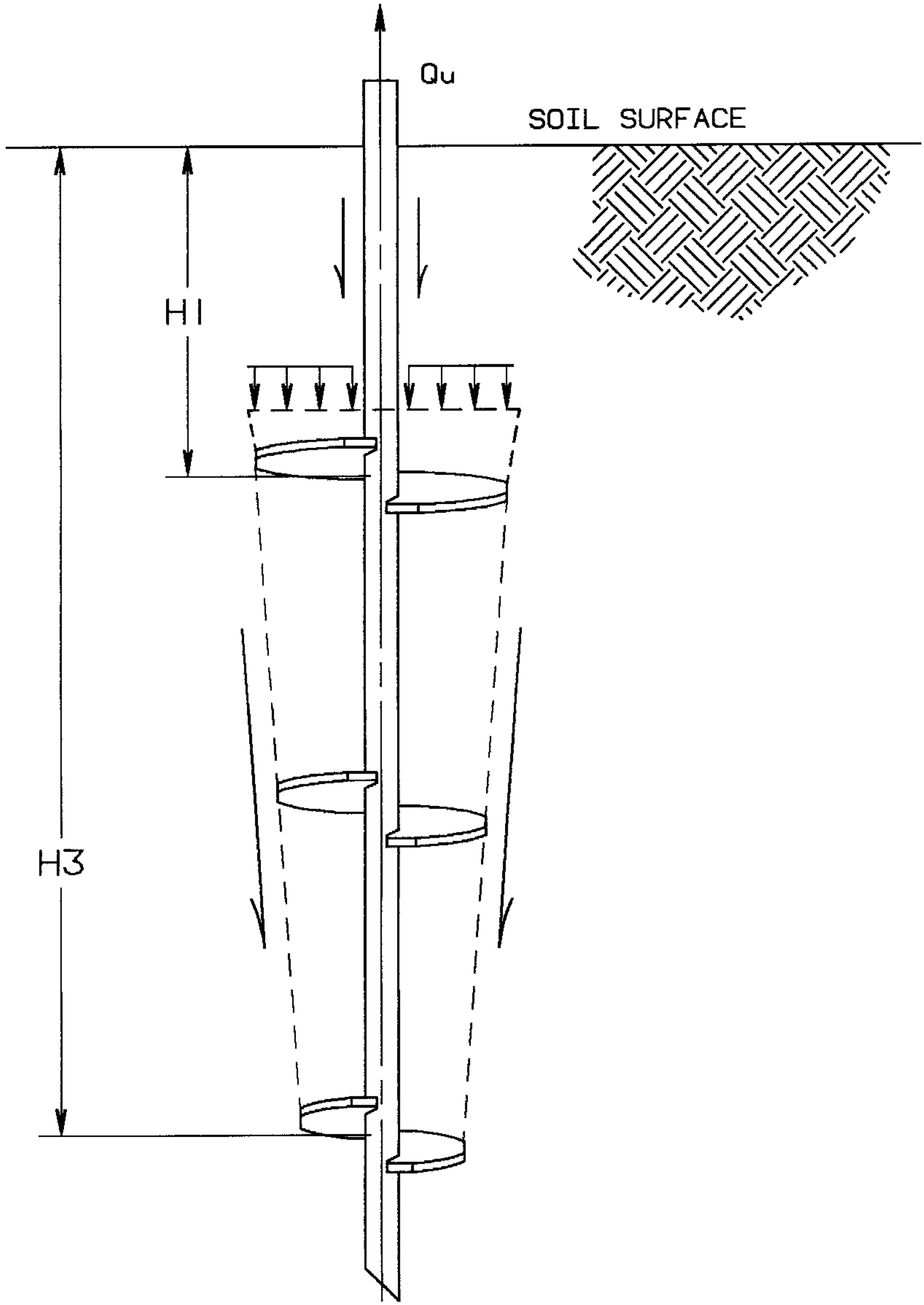

FIGURE 1 CYLINDRICAL SHEAR SURFACE

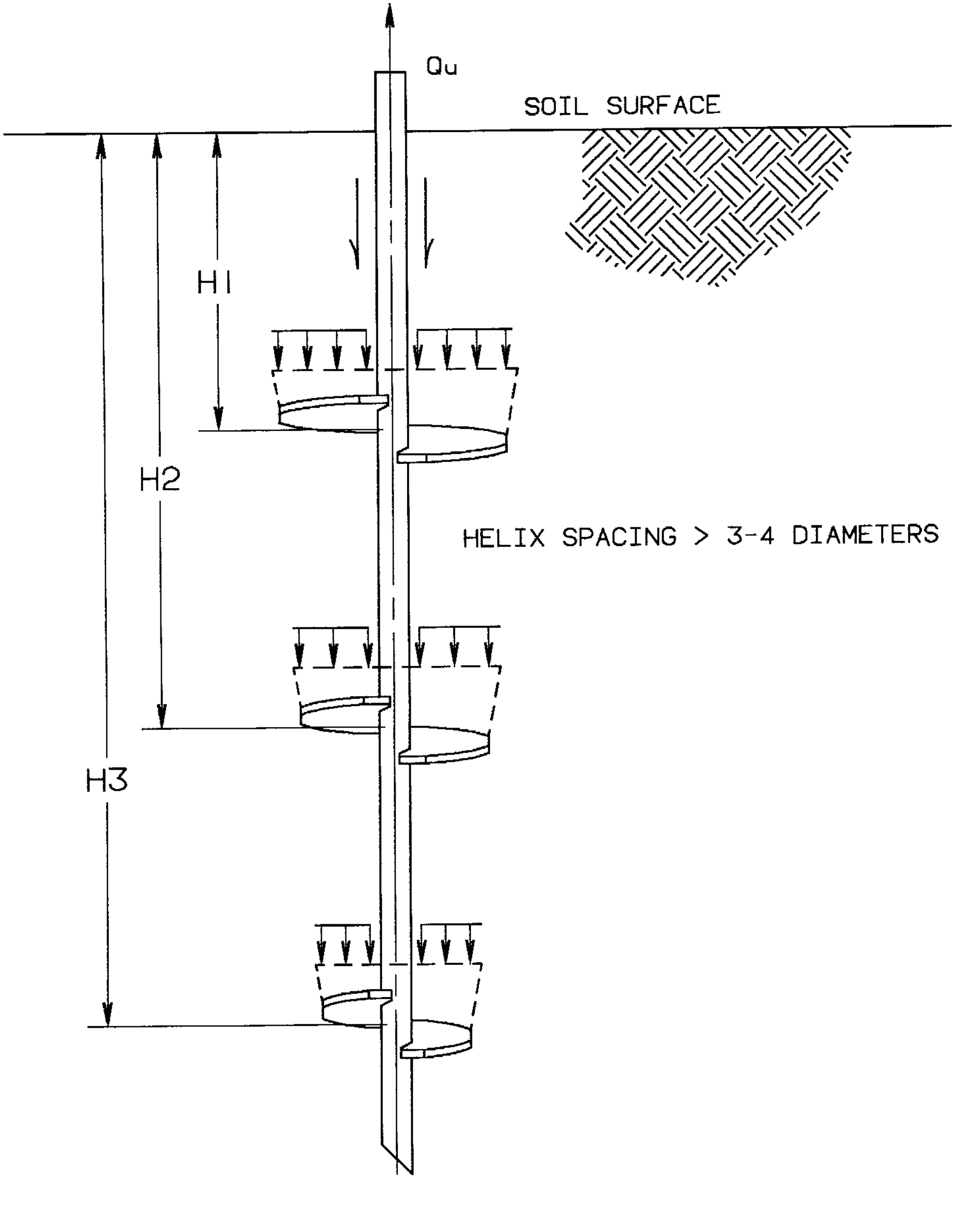

FIGURE 2 PLATE BEARING FAILURE INDIVIDUAL HELICES

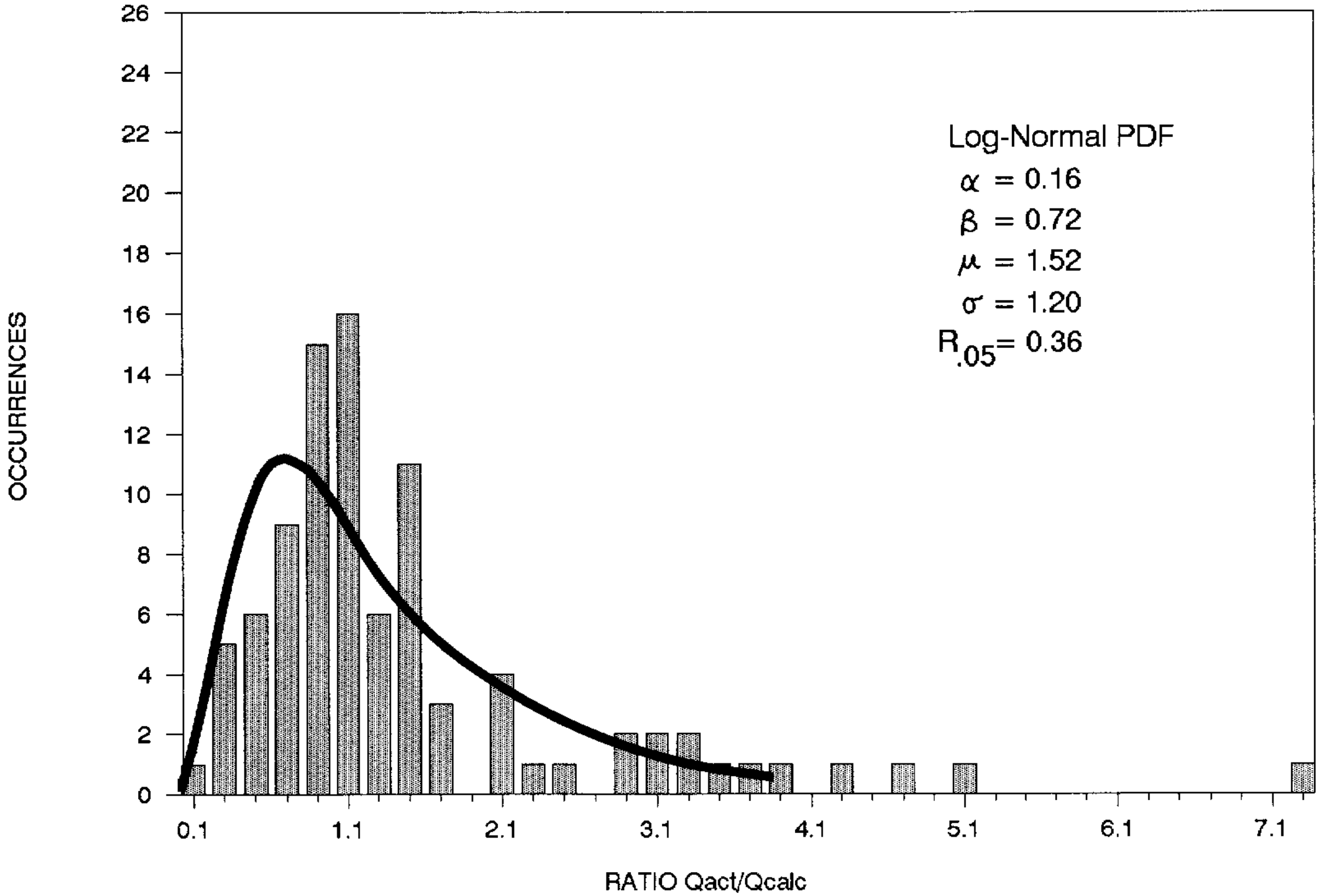

FIGURE 3: HISTOGRAM OF RATIOS OF ACTUAL/COMPUTED CAPACITY FOR CYLINDRICAL SHEAR METHOD

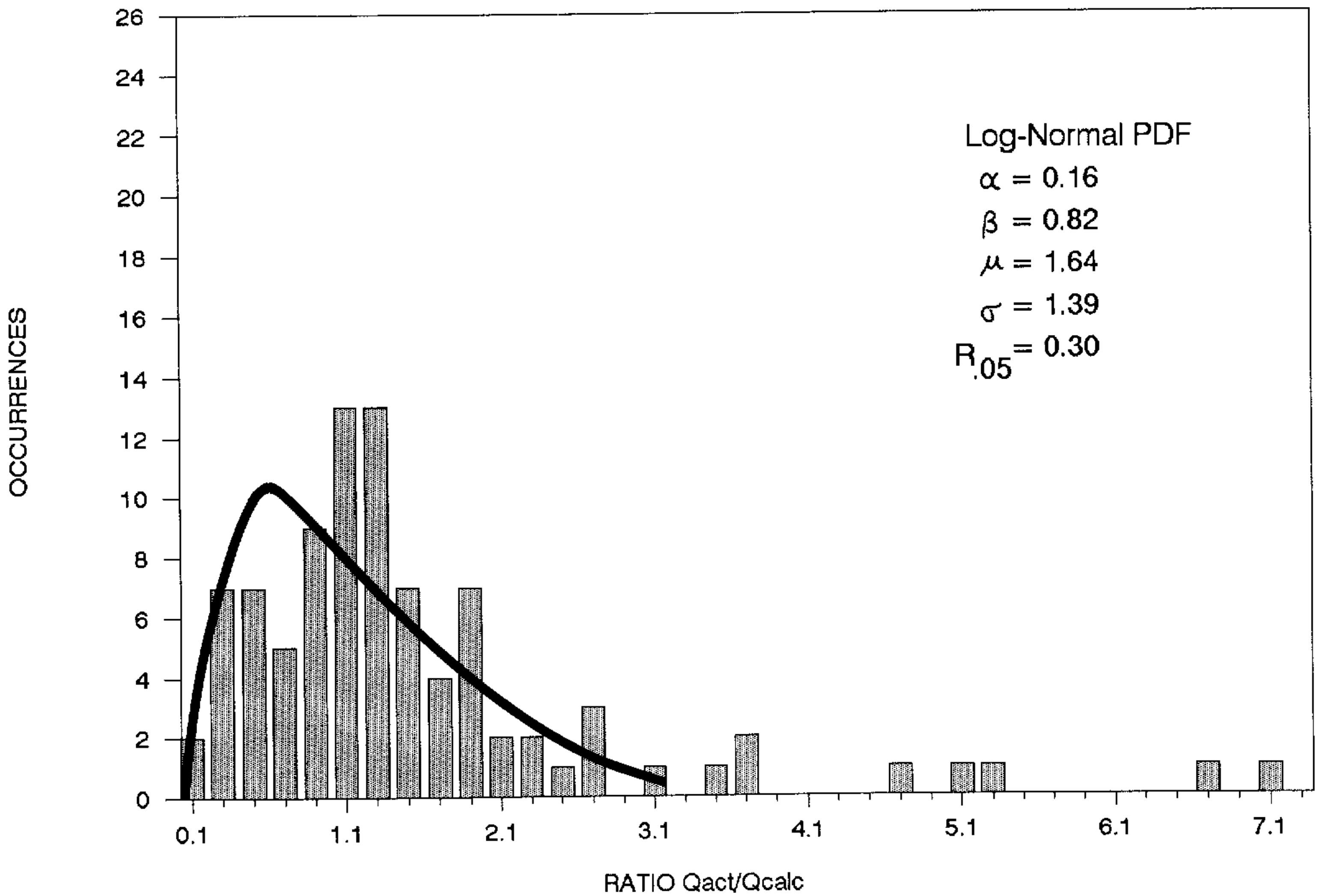

FIGURE 4: HISTOGRAM OF RATIOS OF ACTUAL/COMPUTED CAPACITY FOR INDIVIDUAL BEARING METHOD

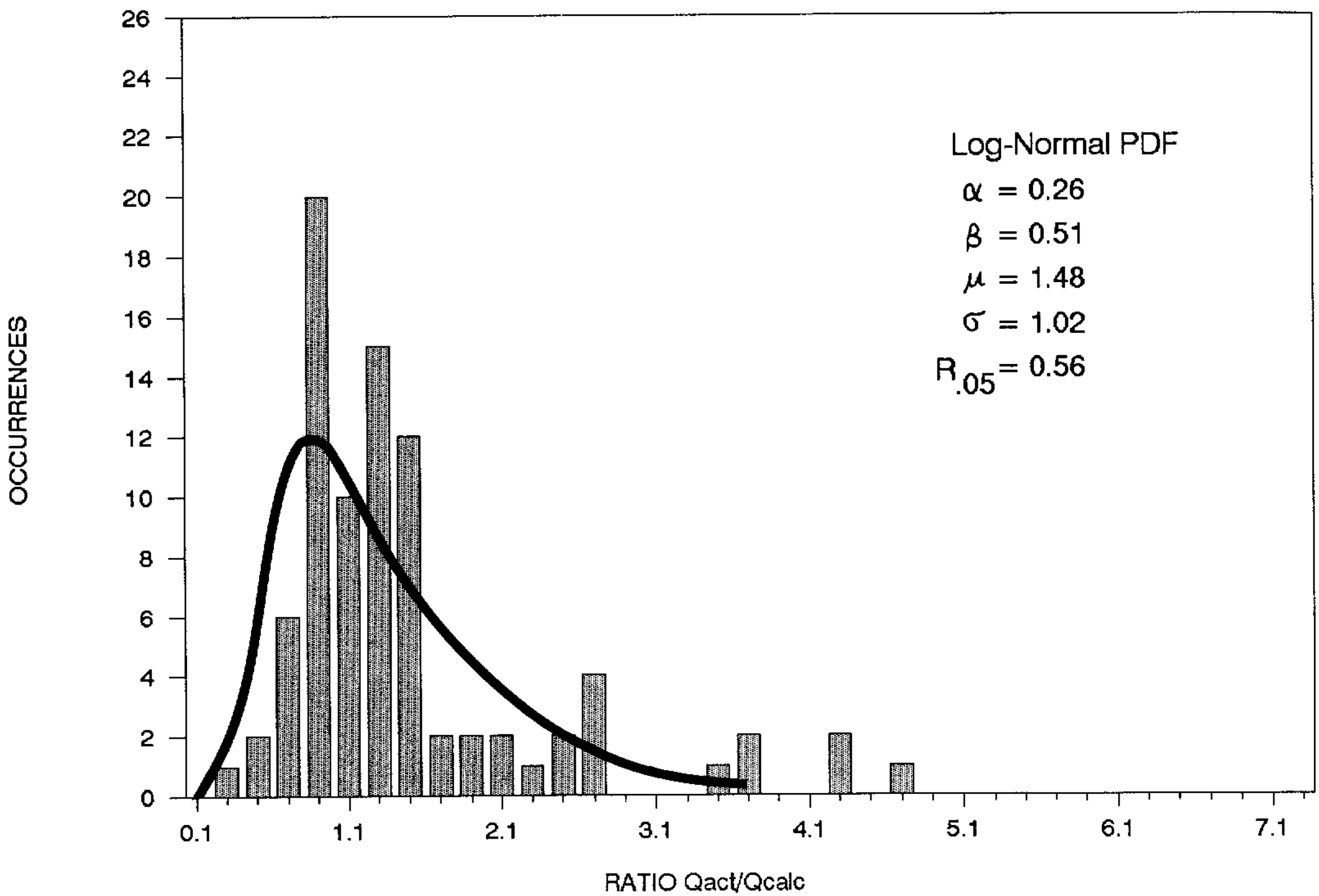

FIGURE 5: HISTOGRAM OF RATIOS OF ACTUAL/COMPUTED CAPACITY FOR TORQUE CORRELATION METHOD