Research Paper

Helical Pile Capacity-to-torque Correlation: A More Reliable Capacity-to-torque Factor Based on Full Scale Load Tests

Moncef Souissi1*, James A. Cherry2, and Tom Siller3

Abstract: The capacity-to-torque ratio, $K_t$, has been used in the design of helical piles and anchors for over half a century. Numerous research efforts have been conducted to accurately predict this capacity-to-torque ratio. However, almost of all these $K_t$ factors are based on shaft geometry alone. The capacity-to-torque ratio described herein was found to depend on the shaft diameter, shaft geometry, helix configuration, axial load direction, and installation torque. In this study, 799 full scale static load tests in compression and tension were conducted on helical piles of varying shaft diameters, shaft geometry, and helix configurations in different soil types (sand, clay, and weathered bedrock). The collected data were used to study the effect of these variables on the capacity-to-torque ratio and resulted in developing a more reliable capacity-to-torque ratio, $K_m$, that considers the effect of the variables mentioned above. The study shows that the published $K_t$ values in AC358 (ICC-ES Acceptance Criteria for Helical Piles Systems and Devices) underestimate the pile capacity at low torque and overestimate it at high torque. In addition, and based on probability analysis, the predicted capacity using the modified $K_m$ results in a higher degree of accuracy than the one based on the published $K_t$ values in AC358.

Keywords: helical pile, capacity torque ratio, ultimate capacity, helix configuration, shaft geometry, compression, tension, AC358

Introduction and Background

The relationship between the installation torque and pile capacity has been a widely accepted method in the helical pile industry for predicting the ultimate capacity, as well as a quality control and assurance tool. The traditional capacity-to-torque correlation method is an empirical one that relates the ultimate pile geotechnical capacity to the installation torque via an empirical constant, capacity-to-torque ratio, $K_t$. This method has been used since the 1960's. It has gained popularity since the study performed by Hoyt and Clemence (1989). Based on their work, the common denominator was a parameter referred to as the capacity-to-torque ratio, $K_t$, used in the following equation to predict the pile capacity based on the final installation torque:

$$ Q = K_t T $$

Where:

- $Q$: ultimate capacity of the helical pile [lbs. (N)]
- $K_t$: capacity-to-torque ratio based on the pile shaft size [ft$^{-1}$ (m$^{-1}$)]
- $T$: final installation torque [ft-lb (m-N)]

The results analyzed by Hoyt and Clemence were solely based on tension tests, where the ultimate capacity is defined as the applied load that caused a net deflection of the pile head equal to 10% of the average helix diameter. The capacity-to-torque ratio, $K_t$, in the above equation has been equally applied for both tension and compression, although, it is well known in the industry that the $K_t$ value in compression should be slightly higher than the $K_t$ value in tension. Both directions of loading mobilize some shear resistance in disturbed soil along the length of shaft. However, in tension loading all helices bear against disturbed soil whereas in compression the bottom helix bears against undisturbed soil. In addition, the capacity-to-torque ratio, $K_t$, from the Hoyt and Clemence study was determined as a function of the shaft diameter only.

In 2007, ICC-ES published Acceptance Criteria for Helical Pile Systems and Devices (AC358). This criterion was developed by an Ad-Hoc committee consisting of several helical pile manufacturers seeking ICC-ES approval of their products. AC358 also specifies constant $K_t$ values to be used with specific shaft effective diameters. In AC358, $K_t$ values range from 10 ft$^{-1}$ (33 m$^{-1}$) for 1.5-inch (38 mm) square bars to 5.5 ft$^{-1}$ (18 m$^{-1}$) for 4.5 inch (114 mmm) outside diameter rounds shafts.

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Perko (2009) presented an empirical relationship between capacity and torque. The capacity-to-torque ratio, $K_t$, was obtained from the analysis of 197 load tests (compression and tension). Perko applied an exponential regression analysis to the test data and the best-fit empirical equation, relating $K_t$ to the shaft effective diameter was obtained as given by the equation below:

$$K_t = \frac{\lambda_k}{(d_{eff}^{0.92})}$$  \hspace{1cm} (2)

Where:
- $\lambda_k$: fitting factor equal to 22 in$^{0.92}$/ft [14.33 mm$^{0.92}$/m]
- $d_{eff}$: effective shaft diameter (in) [mm]

Where $d_{eff}$ is the outside diameter for round shafts or diagonal distance between corners for square shafts.

Filho (2014), conducted tension tests on instrumented helical anchors to investigate the capacity-to-torque ratio, $K_t$. His main conclusion was that $K_t$ was found to depend on load distribution along the anchor length (% of shaft resistance), lead shaft diameter, and the number of helices.

Lutenegger (2019) explains $K_t$ values are not constant but dependent upon a number of variables, one of which is the outside shaft diameter (D). Lutenegger’s simple model for plain pipe piles, without helices, showed that $K_t$ factors decrease as the pipe pile diameter increases.

$$K_t = \frac{2}{D}$$  \hspace{1cm} (3)

In this study, instead of using the traditional plot of the ratio of measured capacity to installation torque (Q/T) vs shaft diameter (D) to determine the empirical $K_t$ factor, the measured pile capacity (Q) was plotted against the ratio of the effective pile diameter to the final installation torque (D/T). This approach shows better correlation as indicated by the coefficient of determination $R^2$. Based on this new relationship, the effect of helix configuration, axial load direction, shaft geometry, shaft diameter, and installation torque were analyzed and incorporated into a new capacity-to-torque relationship.

**Testing Program and Data Collection**

The testing program began around 2008, just after the first publication of the acceptance criteria AC358 in 2007 by ICC-ES. The purpose of this criteria was to provide helical pile manufacturers with guidelines for demonstrating that the helical product is compliant with applicable codes. AC358 establishes standardized requirements for helical pile systems to be recognized in an ICC-ES evaluation report (ESR). All compression and tension tests were performed according to ASTM D1143/1143M-07 and ASTM D3689-07 as required per AC358. Table 1 shows the total test samples used in this study with details of the helix configuration and axial load direction where RCS is round corner square shaft and O.D. is the outside diameter of round hollow structural members. The helix sizes range from 8 inches (203 mm) to 19 inches (483 mm).

**Test Sites**

Full scale load testing was predominantly conducted along the front range corridor of Colorado in the vicinity of Fort Collins, Loveland, Windsor, and Platteville. Test sites were investigated as required by AC358. Soil profiles are described in Table 2 shown below.

**Table 1. Test samples (Courtesy of CTL|Thompson, Inc.)**

<table>
<thead>
<tr>
<th>Shaft Size (in, mm)</th>
<th>Helix configuration</th>
<th>No of compression tests</th>
<th>No of Tension Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.5, 38) RCS</td>
<td>Single</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>(1.75, 44.5) RCS</td>
<td>Single</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>(1-7/8, 47.6) O.D</td>
<td>Single</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>(2-3/8, 60) O.D</td>
<td>Single</td>
<td>35</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>31</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>44</td>
<td>51</td>
</tr>
<tr>
<td>(3.0, 76) O.D</td>
<td>Single</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>(3.5, 89) O.D</td>
<td>Single</td>
<td>55</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>(4.5, 114) O.D</td>
<td>Single</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Triple</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>440</td>
<td>359</td>
</tr>
</tbody>
</table>

**Table 2. Test site soil description**

<table>
<thead>
<tr>
<th>Test Site</th>
<th>Soil Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fort Collins and Loveland clay</td>
<td>about 20 feet (6 m) of sandy to slightly sandy clay (moist, stiff to very stiff) over weathered claystone bedrock (medium hard to very hard)</td>
</tr>
<tr>
<td>Plateville sand</td>
<td>about 20 feet (6 m) of silty sand (medium dense) over weathered claystone (medium hard to hard)</td>
</tr>
<tr>
<td>Fort Collins sand</td>
<td>about 15 feet (4.6 m) of clayey to silty sand (medium dense) over sandstone (hard to very hard)</td>
</tr>
<tr>
<td>Windsor sand</td>
<td>about 17 feet (5.2 m) of clean sand (very loose to loose) with occasional gravel</td>
</tr>
</tbody>
</table>
Axial Load Tests
Throughout the testing program, the installation of the helical piles was performed in accordance with the requirements of AC358 and manufacturer’s installation instructions. In this study, the torque used in the evaluation of ultimate capacity was the final termination torque.

During testing of the piles, both the total deflection and applied load were recorded according to the procedure described in section 8.2 of the quick load test method in ASTM D1143 and ASTM D3689 for compression and tension, respectively. The recorded data was then plotted with applied load on the x-axis and pile deflection on the y-axis. The total deflection, the net deflection, and the maximum allowable deflection described in AC358 were all plotted on the same graph for each test pile. Total deflection is the measured total movement of the pile during testing. Net deflection is the total measured movement minus the elastic shortening or elastic lengthening of the pile and was determined using the following formula:

Net deflection = Total deflection – (PL/AE)

Where P is the applied load [lb,(N)], L is the pile length [in,(m)], A is the cross sectional area of the pile [in²(m²)], and E is the steel modulus of elasticity [Ksi,(N/m²)]. The maximum allowable net deflection per AC358 is equal to 10% of the average diameter (in) of the helix configuration. In all tests, the ultimate pile capacity was determined based on the 10% net deflection, also known as the modified Davisson method, as advocated by the helical pile industry (Perko, 2009). Figures 1 and 2 show the load test set up for compression and tension, respectively. Figure 3 shows the results of a tension load test and how the ultimate pile capacity is determined based on the 10% net deflection method. The test was conducted on a 2-7/8" (73 mm) O.D shaft with a triple 8"/10"/12" (203 mm/254 mm/305 mm) helix configuration, installed to a final torque of 8,800 ft-lb (11,933 N.m).

Figure 1. Compression test (courtesy of CTL|Thompson, Inc)

Figure 2. Tension test (courtesy of CTL|Thompson, Inc)

Figure 3. Load deflection curve, tension. (Courtesy of CTL|Thompson, Inc.)
Data Analysis

Historically, the $K_t$ values relating the final installation torque to ultimate pile capacity, were based on shaft diameter only. It is reasonable, as a starting point, to plot the measured $K_t$ values versus the effective shaft diameter to determine how close the test data are to the fitted regression line. Figure 4 shows the plot of the measured $K_t$ values versus the effective diameter for all shaft sizes (compression and tension). The measured $K_t$ values were obtained from the ratio of the measured ultimate capacity (based on 10% net deflection limit) to the final installation torque for each test. The effective diameter is as defined previously.

Figure 4 shows that the data is very scattered and that the coefficient of determination $R^2$ is very low, which is an indication that the statistical correlation, based on shaft size only, is not strong.

In this study, instead of using the $K_t$ value as the dependent variable, the measured ultimate capacity ($Q$) is plotted against the ratio of the shaft effective diameter to the final installation torque ($D/T$). Figures 5, 6 and 7 show the plots of the measured ultimate capacity ($Q$) versus the ratio of the effective shaft diameter to the final installation torque ($D/T$) for all shaft sizes (square and round), round shafts only, and square shafts only, respectively.

Figures 5 through 7 show a trend of how the measured pile capacity is changing with effective diameter to torque ratio. This trend was also found in other data groups such as single helix compression or tension and multi helix compression.
or tension. The plotted test points are not as scattered as the ones shown in Figure 4, using measured \( K_t \) values vs effective diameter. In addition, the coefficients of determination \( R^2 \) for all graphs are higher than the one in figure 4 indicating a better correlation.

From the regression analysis of the data, the best-fit equation obtained could be written in the form of:

\[
Q = \alpha (D/T)^\beta
\]

(4)

Where:

- \( Q \): Ultimate capacity of the pile [Kips, (N)]
- \( D \): Effective diameter [in,(m)]
- \( T \): Final installation torque [Kip-ft,(N-m)]
- \( \beta \): Regression fitting factor
- \( \alpha \): Regression fitting factor \([(\text{Kip} \cdot \text{Kip-ft/in})^\beta),\text{N} \cdot \text{(N-m/m)}^\beta]\)

Different relationships for \( Q \) were developed based on the shaft shape (square versus round), loading direction (tension versus compression) and helix configuration (single helix versus multi-helix.) The test data was organized and analyzed as follows:

1. **Round shafts:**
   - Round Multi-Helix Compression (RMHC)
   - Round Single-Helix Compression (RSHC)
   - Round Multi-Helix Tension (RMHT)
   - Round Single-Helix Tension (RSHT)
2. Square shafts:
   - Square Multi-Helix Compression (SMHC)
   - Square Single-Helix Compression (SSHC)
   - Square Multi-Helix Tension (SMHT)
   - Square Single-Helix Tension (SSHT)

Both round and square shafts had 4 cases evaluated. In each case, the test data was plotted as ultimate capacity (Q) versus effective diameter to torque ratio (D/T). Figures 8 and 9 show example plots for round shafts, multi-helix compression (RMHC) and square shafts multi-helix compression (SMHC), respectively. In all eight cases, the best-fit empirical equation is a power function similar to equation (4), but with different α and β fitting factors, which is expected.

Since all the empirical equations for each case are in the form of Equation (4), it is reasonable and simpler to use one single equation that includes the effect of the variables previously mentioned. The proposed general formula was derived as follows. The equation used for this derivation is the one obtained from the analysis of all-round shafts, including both compression and tension consistent with current practice of not differentiating between loading direction. The variables: loading direction, shaft shape, and helix configuration are then accommodated through coefficients applied to this baseline equation, as described below. This equation was selected because it has the highest coefficient of determination (R²), Figure 6.

\[ \text{Capacity (Q)} = 28.242(D/T)^{-0.774} \]  

(5)
The empirical equation obtained from each plot of the eight configurations given above is divided by Equation 5. The average of these ratios is called the \( \lambda \) factor, which reflects the effect of the variables identified previously. In addition, and in each case, the standard deviation (STDV) and coefficient of variance (CV) are determined to validate the results. Table 3 above shows the results used to determine the \( \lambda \) factor.

The two statistical parameters (STDV, CV) given in Table 3 are very small. This is an indication that all the data points are very closely clustered around the mean. Hence, taking the \( \lambda \) factor to be the average is statistically justified.

Incorporating \( \lambda \) into the capacity Equation (5), gives the general formula that considers the effect of all the variables discussed before. The adjusted ultimate soil capacity (\( Q' \)) which accounts for the eight configurations, is then determined as:

\[
Q' = \lambda \cdot Q
\]  

(6)

Rearranging Equation 5 and solving for \( K_m \) where \( K_m \) is the proposed modified torque factor that considers the effects of helix configuration, axial loading direction and shaft size and shape results in:

\[
K_m = \lambda \cdot 28.242 \cdot (D^{-0.774}/T^{0.226})
\]  

(7)

### Results and Discussion

In helical pile design, the working load and factor of safety are usually specified by the project design engineer. The required installation torque could be determined by solving Equations (5-7) for the final installation torque, which is given by:

\[
T = D[(0.0354(Q/\lambda))^{1.292}]
\]  

(8)

Figure 10 and 11 are generated for a 2-7/8" (73 mm) O.D round shaft and a 1.5" (38 mm) RCS shaft, two very common shaft sizes in the helical pile industry, to compare the proposed modified capacity-to-torque ratio, \( K_m \), with other published values.

Figures 10 and 11, show that the proposed modified capacity-to-torque ratio, \( K_m \), decreases as the installation torque increases, unlike the historical \( K_t \) value, which remains constant for a given shaft size. Also, helix configuration, load direction, and shaft geometry affect the capacity-to-torque correlation.

To evaluate the reliability of the predicted capacity, based on equation (6), a similar approach to that taken by Hoyt and Clemence (1989) is used. Consistent with their approach, the measured capacity is compared to the predicted capacity divided by a factor of safety of 2. This same approach is also used in AC358 to evaluate the \( K_t \) value of helical pile products.

For each \( \lambda \), the probability is evaluated twice. One is based on AC358 predicted capacity using the historical \( K_t \) values. The other one is based on predicted capacity using Equation (6) developed herein. Note, both already incorporate a factor of safety of 2, as described above. In each case, a histogram of measured capacity divided by the predicted capacity is plotted. The histogram gives a first indication of the nature of the data distribution—whether it is normally distributed or log-normally distributed. The type of distribution leads to the use of the proper density function for probability determination. Figure 12 shows an example histogram plot of raw data for the round multi-helix configuration in compression (RMHC) using Equation (6).

All histograms showed that the collected data is not normally distributed, instead the distribution is skewed to the right from the mean and that all data is positive (zero is the minimum). This suggests that the data follows a lognormal distribution. By definition, a random variable is log-normally distributed if the logarithm of the variable is normally distributed. To validate that the raw data is long normally distributed, the logarithm of the raw data was computed and analyzed in each case. Figure 13 shows a histogram for RMHC...
on the logarithm of the raw data values - this distribution is typical of the other configurations.

From Figure 13, the data appear to be normally distributed around the mean on a logarithmic scale, with the exception of some outliers on the left side. This is an indication that the raw data is log-normally distributed. Again, Figure 13 is representative of the data from all eight configurations.

Since the distribution of the analyzed collected data has been shown to follow a lognormal distribution, the probability of the measured capacity being greater than half of the predicted capacity, is determined using the cumulative lognormal distribution function. The probability was determined for both predicted capacities based on AC358 $K_t$ values and the newly developed modified $K_m$. 
The reliability function using the log-normal distribution is defined as:

$$R(x) = 1 - \Phi[(\ln(x) - \mu)/\sigma]$$

(9)

Where:

- $\Phi$: Standard normal cumulative distribution function
- $\mu$: Mean of the logarithm of the data
- $\sigma$: Standard deviation of the logarithm of the data
- $x$: Ratio of $Q$ measured to $Q$ predicted

The probabilities computed for the eight different cases (different $\lambda$) are shown in Table 4.

Table 4 shows that the probability based on modified $K_m$ is generally higher than the one based on AC358 $K_t$, especially in the case of square shafts and tension. This indicates that the newly developed formula is an improvement over the traditional used $K_t$ values as depicted both by its accuracy (smaller standard deviation) and reliability (higher probability).
Table 4. Probability of $Q$ measured higher than 0.5 $Q$ predicted

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>STDV</th>
<th>Max</th>
<th>Min</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMHC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.056</td>
<td>0.349</td>
<td>2.708</td>
<td>0.121</td>
<td>98.30</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>1.275</td>
<td>0.666</td>
<td>5.530</td>
<td>0.134</td>
<td>99.30</td>
</tr>
<tr>
<td>RMHT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.037</td>
<td>0.276</td>
<td>2.137</td>
<td>0.121</td>
<td>99.30</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>0.937</td>
<td>0.277</td>
<td>2.222</td>
<td>0.095</td>
<td>98.30</td>
</tr>
<tr>
<td>RSHC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.059</td>
<td>0.385</td>
<td>2.866</td>
<td>0.351</td>
<td>97.80</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>1.286</td>
<td>0.801</td>
<td>5.553</td>
<td>0.516</td>
<td>96.90</td>
</tr>
<tr>
<td>RSHT</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.029</td>
<td>0.268</td>
<td>1.982</td>
<td>0.441</td>
<td>99.50</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>0.908</td>
<td>0.241</td>
<td>2.222</td>
<td>0.366</td>
<td>98.60</td>
</tr>
<tr>
<td>SMHC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.061</td>
<td>0.367</td>
<td>2.205</td>
<td>0.300</td>
<td>97.40</td>
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<tr>
<td>AC358, $K_i$</td>
<td>1.007</td>
<td>0.410</td>
<td>2.779</td>
<td>0.315</td>
<td>94.90</td>
</tr>
<tr>
<td>SMHT</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.067</td>
<td>0.392</td>
<td>2.464</td>
<td>0.406</td>
<td>99.30</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>0.887</td>
<td>0.344</td>
<td>2.370</td>
<td>0.308</td>
<td>97.40</td>
</tr>
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<td>SSHC</td>
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<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.059</td>
<td>0.398</td>
<td>2.404</td>
<td>0.515</td>
<td>98.00</td>
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<tr>
<td>AC358, $K_i$</td>
<td>0.950</td>
<td>0.428</td>
<td>2.779</td>
<td>0.407</td>
<td>93.30</td>
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<tr>
<td>SSHT</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Modified, $K_m$</td>
<td>1.087</td>
<td>0.567</td>
<td>3.009</td>
<td>0.697</td>
<td>96.50</td>
</tr>
<tr>
<td>AC358, $K_i$</td>
<td>0.793</td>
<td>0.461</td>
<td>2.370</td>
<td>0.447</td>
<td>80.7</td>
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</table>

Conclusions

A proposed capacity torque relationship is developed, and it considers the effects of shaft diameter, shaft geometry, installation torque, helix configuration and axial load direction. The followings are the major conclusions of this study:

1. Historical $K_i$ values are more conservative at low torque and less conservative at high torque as compared to the proposed capacity-to-torque ratio $K_m$.
2. The proposed capacity formula, which takes into consideration installation torque, shaft diameter, and other adjustment factors ($\lambda$), is generally more reliable, as demonstrated by the higher probabilities in Table 4, than the AC358 capacity torque correlation method.

Limitations and Recommendations

The results herein were based on shaft sizes in Table 1 and with product specifications as described in Table 3 of AC358. Therefore, one should proceed with caution when using this new relationship for products different from the ones used in this study. Also, careful consideration should be given to local soil conditions that are different from the ones described above.

Most of the tests were conducted at about 30% to 70% of the shaft maximum torque capacity, which could possibly result in an empirical relationship that is more skewed toward this data range. To more accurately study the effects of the installation torque, future investigations should consider the magnitude of the installation torque equally over a wider range of the shaft rating torque. One recommendation is to conduct tests installed at torques ranging from 10% to 100% of the product rating torque at an increment of 10%. Additionally, more research is needed to investigate the effects of soil type and condition which may lead to include adjustment factors for soil (i.e. $\lambda_{soil}$).

References


International Accreditation Services (IAS), Brea, California. www.iasonline.org

