CASE STUDY: LARGE DIAMETER HELICAL PILE FOUNDATION FOR HIGH VOLTAGE TRANSMISSION TOWERS IN SOFT GLACIAL DEPOSITS

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ABSTRACT

This paper presents the results of a static load testing program completed on helical pile foundations for the replacement of high voltage transmission line tower structures. The foundations were part of the Northeast Grid Reliability Project (NGRP) for the Public Service Electric & Gas Company (PSE&G) near Newark, New Jersey. Structure foundations "anchor bolts down" was a design build contract model with the superstructure as bid-build.

The general soil stratigraphy along the alignment consisted of fill over about 10 ft of organic deposits underlain by up to 260 ft of normally consolidated glacial lake clays and silts. Project challenges included working under/adjacent the existing live high voltage lines, narrow site access due to environmental permits, foundations in tidally influenced area, and pile projections on the order of 10 feet to meet the 10 year flood level requirements.

A total of ten static load tests (compression, tension, and lateral) were completed on 60 ft and 90 ft long piles, using both welded and mechanical pile splices. To evaluate pile-soil setup in the sensitive fine grained soil and determine representative longer term installation torque factors (Kt) for the production piles, the static load tests were performed 7 to 49 days after pile installation.

Helical piles with mechanical splices were installed for the varying structure foundations including tangent and heavy deadend to a deadend monopole. Installation of 448 production piles (34,320 linear ft) was completed in three months. The installation timeline was critical to meeting the semi-annual PSEG shutdown for switching the old and new structures. Helical piles employing a mechanical splice resulted in an efficient and effective foundation solution for the conditions encountered on the project.

INTRODUCTION

NGRP consisted of three project sections beginning in North Arlington, NJ and terminating in Kearny, NJ. The project alignment spanned low lying inundated wetlands and industrial areas. Figure 1a illustrates the project alignment. Helical pile foundations were selected for a total of 17 structures. Fifteen structures were located in Section 2 and two structures were in Section 5. Three types of helical piles were designed to meet the variety of foundation loadings, sub-surface soil conditions, and the allowable horizontal and vertical movement of 1.0 inch. The focus of this paper is the transmission towers supported by helical piles and the static load testing program.

The initial test program consisted of two test sites, herein referred to as TP1 and TP2, did not consider a pile-soil setup time between the end of installation and static load testing similar to a driven pile in sensitive fine grained soil. The results of the initial static load testing and installation presented two challenges to the project team. First, the axial compression and tension capacities from the static load tests were about one-third less than the predicted capacity from the static analysis, indicating more piles would be required than had been budgeted. Second, the production rate of the pile installation was substantially slower due to the welding requirements and field conditions, indicating the team would have to mobilize more equipment and personnel than had been budgeted to meet the scheduled shutdown.

To address these issues a third test site (TP3) was selected for static load testing. TP3 was located at the adjacent structure to TP1 about 700 to 800 ft southeast. TP3 utilized a mechanical connection, developed by Almita, to minimize the splice time of the pile segments and included a waiting period of approximately two weeks between installation and testing to evaluate potential pile-soil setup. Figures 1b and 1c illustrate the test site locations.

The completed static load test program allowed the project team to establish site specific pile capacity to installation torque ratios (Kt) for tension and compression. A total of 448 helical piles were installed within a timeline of approximately 3 months to meet the schedule.

GEOTECHNCIAL INVESTIGATION AND SUBSURFACE SOIL CONDITION

Paulus, Sokolowski and Sartor, LLC carried out site specific geotechnical investigation including boring and CPT soundings close to the proposed new structure locations. Portions of the alignment were inaccessible and therefore no borings or CPTs were performed near approximately half of the structures. All of the borings and CPTs were drilled on land, so additional consideration was necessary for structures located in the water 20 to 50 ft from the boring location. Standard penetration testing (SPT) was completed in boreholes from ground surface into the glacial lake deposits. Below that depth, drilling was continued without sampling to determine the depth of glacial till deposits. CPT soundings were also completed at selected locations adjacent to the borings to refusal depths. Laboratory testing on the collected samples consisted of Atterberg limits, moisture contents, unconfined compression testing, consolidation testing, soil corrosivity tests and chemical analysis.

Soil stratigraphy along the alignment was generally consistent with fine grained glacial lake deposits overlying glacial till or bedrock. The uppermost stratum (at the static load test locations) consisted of fine to coarse sand fill with construction and/or household debris underlain by layers of organic material, alluvial sand, glacial lake deposits and glacial till. Many of the locations were in inundated areas of the meadowlands and therefore the fill was not always present. The combined depth of the fill, organics and alluvial sand was generally 30 ft or less. According to the borings and CPTs, the depth of the glacial lake deposits was typically greater than 100 ft but ranged from 75 ft to more than 200 ft. The glacial lake deposits generally consisted of clayey silt to silty clay with thin layers or lenses of silt and fine sand.

Soil stratigraphy at test locations TP1 and TP3 were similar with the glacial till at depths of about 200 ft. The borings near TP 2 presented glacial till at a depth of 75 ft. Undrained shear strength estimated from N-values and CPTs are presented in Figure 2 along with the design profile. Design undrained shear strength for locations 1 and 3 were estimated using SHANSEP strength relationship. Design undrained shear strength parameters for location 2 were calculated from SPT completed in the glacial lake deposits. A CPT was not performed in the area of TP2.

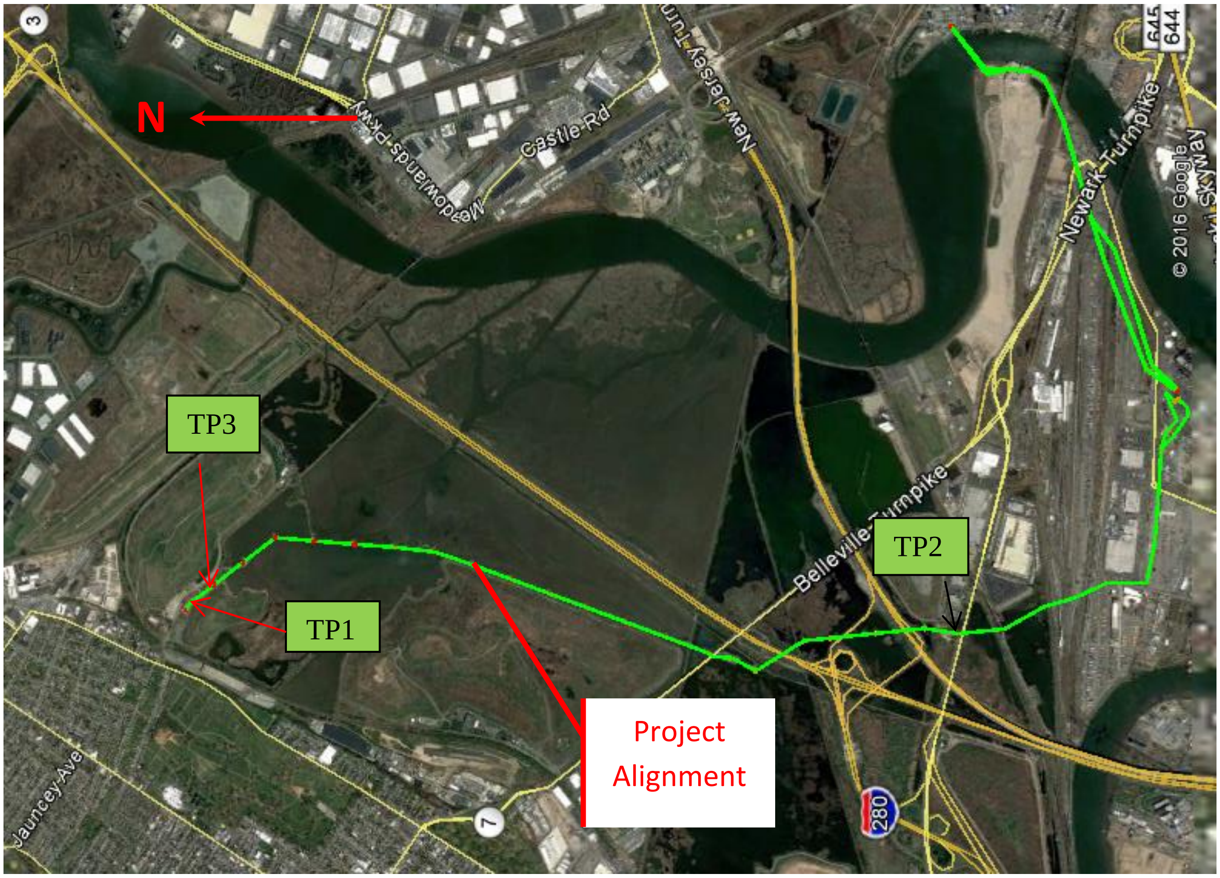


Figure 1a. NGRP Project Alignment, 4045'54.21" N 7405'44.39". Google Earth. June 25, 2016. April 6, 2017.

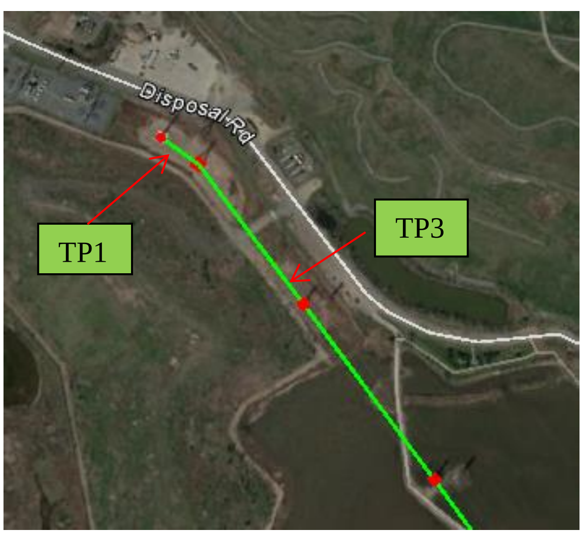
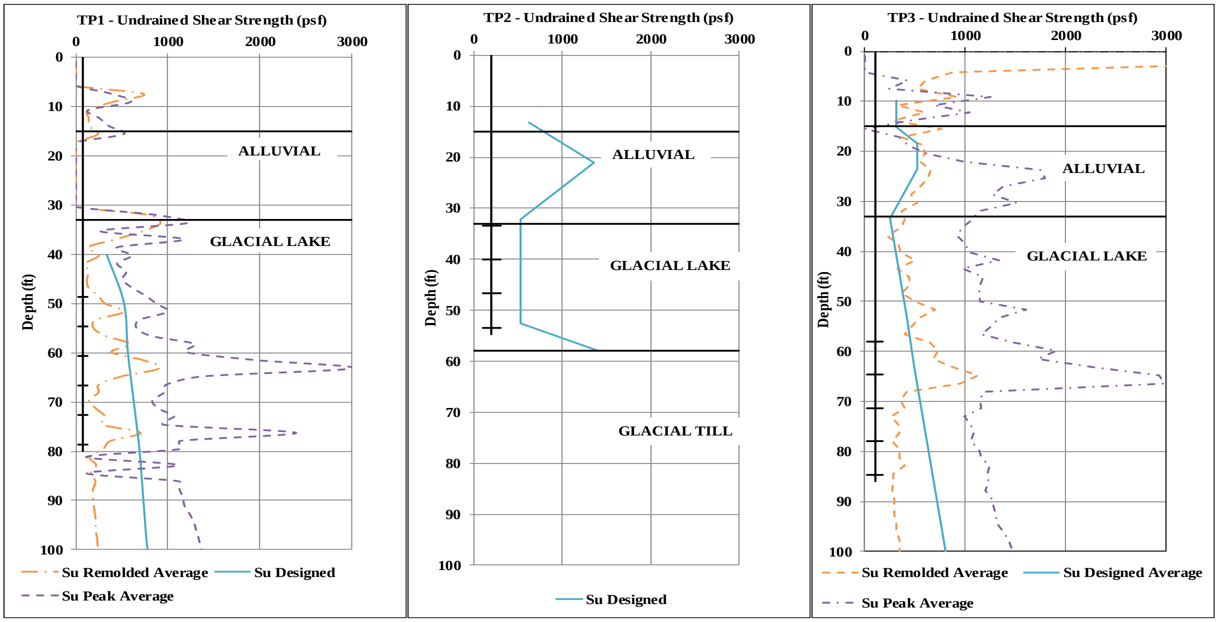


Figure 1b. – Zoomed in view of TP1 and TP3.

Figure 1c. – Zoomed in view of TP2

Groundwater was approximately 2 ft below the ground surface based on the dissipation tests completed during CPT testing at TP1 and TP2. Groundwater depth at TP3 was not established accurately due to use of mud rotary drilling. The groundwater was assumed at ground surface for helical pile design for all test locations.



(a) (b) (c)

Figure 2: Peak, remolded, and design undrained shear strength: a) TP1, b) TP2, and c) TP3

HELICAL PILE DESIGN

Aside from one monopole structure, the typical structure was a four legged lattice tower. Each leg was designed with a separate pile cap consisting 4 to 11 helical piles. The center pile was vertical and the peripheral piles were battered at angles of 3 to 15 degrees. All piles were manufactured in 30 ft lengths, so total pile lengths were either 60 or 90 ft long and utilized 36 inch or 40 inch diameter helices as the bearing elements. Varying helix diameters were not used on individual piles or structures. The helices began approximately one foot above the pile tip and were spaced at two times the helix diameter. The static analysis used traditional helical pile capacity analysis evaluating both individual bearing and cylindrical shear failure modes. The lower of the two calculated values was used.

Since a static load test was planned a factor of safety of 2 was used in the design and static analysis. The factor of safety was applied to the extreme loading conditions, not just the service load as is customary for buildings and/ traditional infrastructure design according to allowable stress design (ASD). In addition to the factor of safety of 2, the owner required an additional factor of 1.1 and 1.25 be applied to the factor of safety for lattice and monopole structures, respectively. Meaning the required factor of safety increased to 2.2 and 2.5 for the lattice and monopole foundations, respectively. The concept of the additional load factors or higher safety factors is to help ensure that the superstructure fails before the foundation, since it is typically more economical to replace the super structure as opposed to the foundation.

STATIC LOAD TEST PROGRAM

One of the main purposes of the static load test program was to establish an installation torque to capacity ratio, which is typical of helical pile projects. The relationship between ultimate pile capacity (Qt), torque (T) and an empirical torque factor (Kt) can be expressed as:

$$Qt = Kt \times T$$

The Kt factor established by the load test program is then used for the production pile installation as a quality control /quality assurance measure.

The initial test program at TP1 and TP2 was based on the different helical pile designs, structures and load conditions. Each site had a dedicated pile installed for static axial compression, tension and lateral load tests. TP1 was located in Section 2 and consisted of a 90 ft long helical piles with six – 36 inch-diameter helices. TP2 was located in Section 5 and consisted of 60 ft long helical piles with four -40 inch diameter helices. TP3 consisted of a 90 ft long helical pile with five-40 inch-diameter helices. Table 1 summarizes the test pile configuration. Test sites TP1 and TP2 did not have specified wait times between installation and testing. The set-up time of seven days or less for these two sites were purely the product of pile installation time, relocation of equipment and work not being performed on weekends.

TP3 utilized a mechanical connection, developed by Almita, to minimize the splice time of the piles and includeda wait period of approximately two weeks between installation and testing to evaluate potential pile-soil setup. At the completion of the load testing at TP3, the test piles and reaction piles were extracted for inspection of the mechanical connection. The mechanical connection and its components were inspected for any deformation or damage due to the torque applied during installation, removal or loading applied during the static load testing. The performance of the connection was found to be satisfactory, and was employed for all production piling.

Table 1: Summary of test pile configuration

Test Pile	Pile Length, ft	Pile Dia, in	Pile Wall Thk, in	Helix Dia, in	Helix Thk, in	No. of Helices
TP1	90	12.75	0.5	36	1	6
TP2	60	12.75	0.5	40	1	4
TP3	90	12.75	0.5	40	1	5

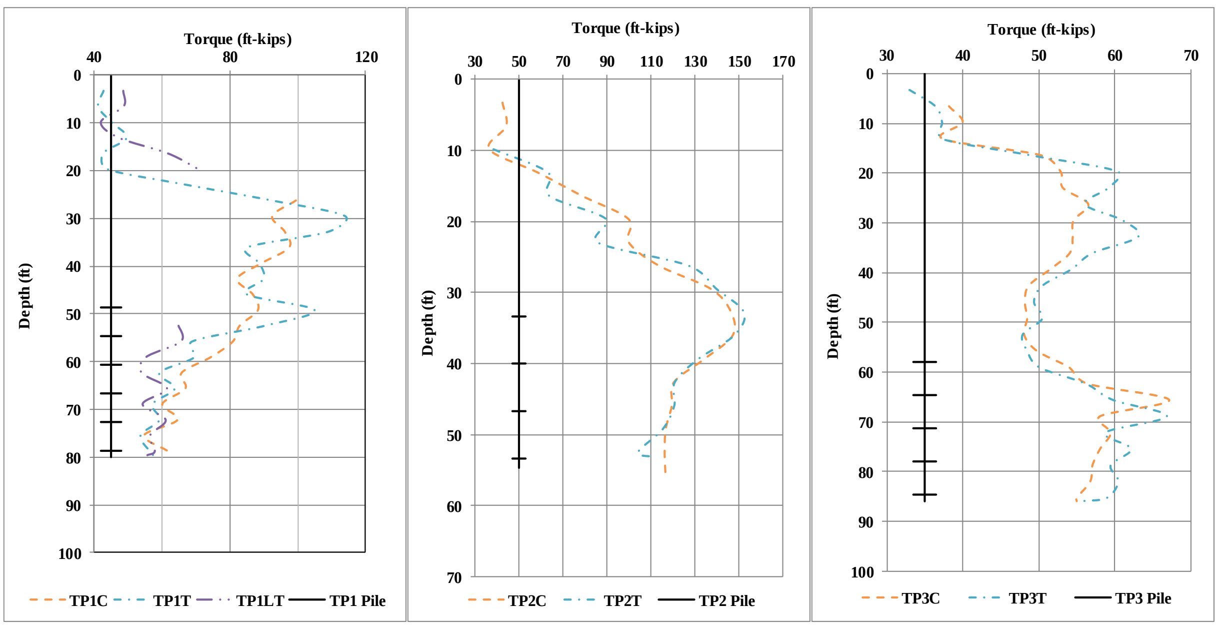
INSTALLATION MONITORING

The test piles and reaction piles were installed using a drive unit mounted to a tracked excavator. The drive unit contains a hydraulic motor that provides a maximum torque of 250 ft-kip to rotate the helical pile into the ground. Installation torque profiles are provided in Figure 3. Torque was recorded continuously by a data logging system on the install machine. The final torque was determined by taking an average of the recorded installation torque over the final 6 feet of embedment.

The near-surface conditions varied between the test sites. At TP1 dry, un-compacted sand was placed around the pile shaft during installation of the final section. At TP2 no backfill of any type was placed around the pile shaft and at TP3 loose woodchips were placed around the pile shaft after installation. The fill was used to fill holes and provide a safe working surface for setup and execution of the load tests. Groundwater was within a foot of the ground surface at TP2 and TP3. Groundwater at TP1 was approximately 3 feet below the ground surface.

TEST SETUP

The static load tests were performed in general accordance with ASTM D1143-07, D3689-07, and D3966. The quick method was used for the compression and tension tests with 10 minute load durations. At the request of the owner, a one-hour hold at the maximum test load was performed. Displacement monitoring was accomplished with Linear Variable Displacement Transducers (LVDT), as well as mechanical dial gauges for backup. A custom data logger system was used to automatically record the hydraulic jack pressure, the load cell, and the LVDTs at thirty second intervals. The data was also manually recorded at 1, 5 and 10 minute intervals as backup.



(a) (b) (c)

Figure 3: Test pile installation torque profiles; a) TP1; b) TP2; c) TP3

AXIAL TEST RESULTS

Load-displacement curves were prepared for each compression and tension test completed. Analysis was completed using the Brinch-Hansen 90% pile ultimate failure criteria. Load displacement curves for axial tests are shown in Figures 4 and 5. Compression and uplift capacities of the test piles and corresponding load at 1.0 inch displacement are summarized in Table 2. The "C" or "T" indicates compression or tension test. Test pile TP1-LT was originally the lateral test pile at site TP1 and was later tested in tension 49 days after it had been installed.

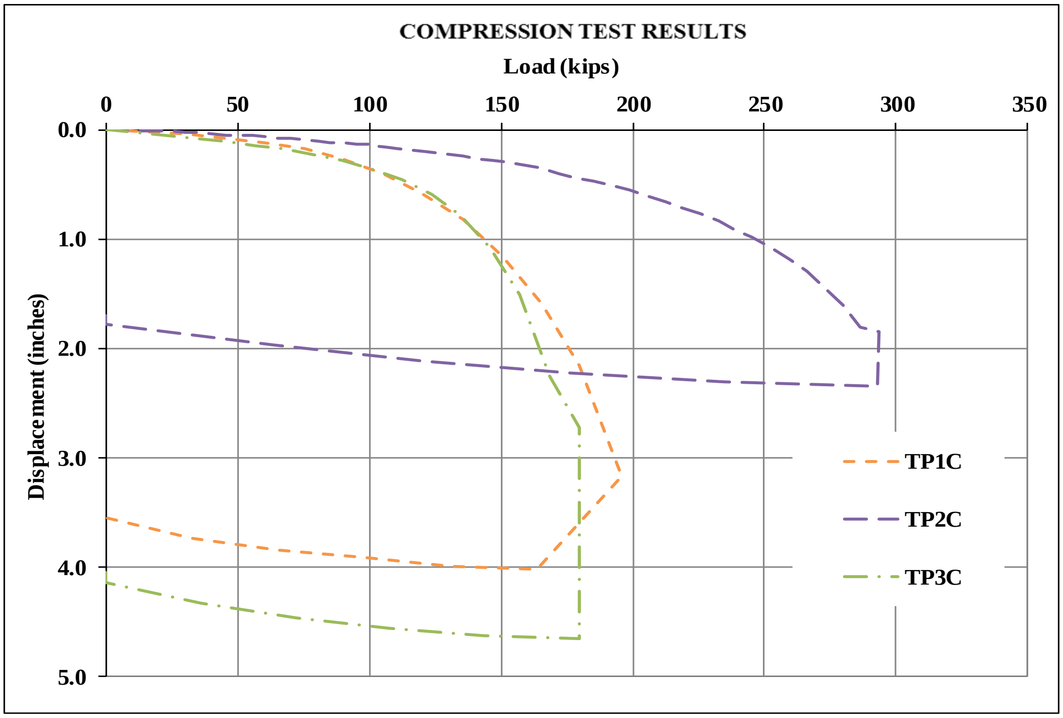


Figure 4: Compression test results

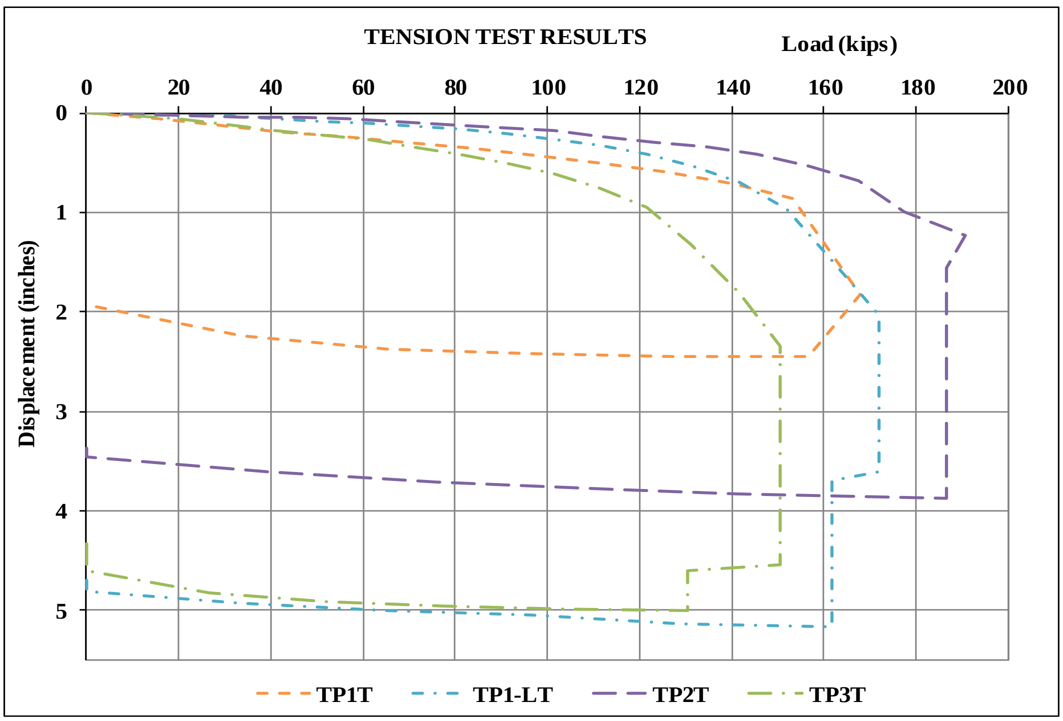


Figure 5: Tension test results

Table 2: Summary of compression and tension load tests

Test Pile	Set-up Time (days)	Ultimate Capacity (kips)	Capacity at 1.0” Displacement (kips)	Displacement at Ultimate Capacity (in)	Displacement at Ultimate Capacity as %age of Helix Dia.
TP1-C	6	193	149	4.0	11.1
TP1-T	7	168	156	2.0	5.5
TP1-LT	49	172	153	2.0	5
TP2-C	6	293	246	2.0	5
TP2-T	2	188	177	1.5	3.75
TP3-C	15	180	144	2.7	6.75
TP3-T	13	151	123	2.3	5.75

Compression load tests were carried out on piles TP1-C, TP2-C, and TP3-C at 6 to 15 days after installation. The performance of test piles TP1-C and TP3-C was similar up to a compressive load of 150 kips. Settlement of both piles started increasing at a faster rate associated with plunging failure beyond 2 inches of displacement. Compression capacity of TP1-C was slightly more than TP3-C. The compression test at TP2-C was terminated prior to achieving failure load.

Tension load tests were carried out on piles TP1-T, TP1-LT, TP2-T, and TP3-T at 2 to 49 days after installation. Two tension tests were completed at TP1 (TP1-T and TP1-LT) at 7 and 49 days after installation.

The initial response of all piles to loading was relatively linear in compression and tension testing. As a result, the measured displacement at around 150 kips was close to 1.0 inch for all piles. The displacement of test piles TP1-C and TP3-C was greater than TP2-C when approaching the failure load.

Although the ultimate capacity of TP3-C was slightly less than TP1-C, the resulting Kt factor was about 6% greater, indicating an increase in capacity versus time when relating capacity to installation torque. Higher axial capacities for TP2-C are due to encountering more competent soils, as indicated by the torque readings.

The tension test data indicated an increase in Kt factor from 1.7 at 2 days to 2.7 at seven days of setup. There was not a significant increase in the Kt factor from seven to 13 days. The 49 day tension test at TP1-LT at 49 resulted in a Kt factor 3 indicating increasing trend of Kt. The increased Kt factor was about 8% between the 13 day and 49 day test time. The Kt factor for compression and tension of the test piles are summarized in Table 3.

Table 3: Capacity to Installation Torque Ratio - Kt

Test Pile	Set-up time (days)	Capacity (kips)	Final Torque (ft-kips)	Kt (1/ft)
TP1-C	6	193	62.4	3.1
TP1-T	7	168	61.4	2.7
TP1-LT	49	172	58.1	3.0
TP2-C	6	293	123.7	2.4 (1)
TP2-T	2	188	111.1	1.7
TP3-C	15	180	55.0	3.3
TP3-T	13	151	55.0	2.8

(1): The compression test on TP2-C was terminated prior to reaching pile failure; the resulting Kt factor is therefore artificially low.

Figure 6 illustrates the change in Kt with increasing soil setup time. Based on the observed trend, an appropriate correlation between installation torque and long term capacity was to select Kt factors of 3.0 and 3.5 for tension and compression, respectively.

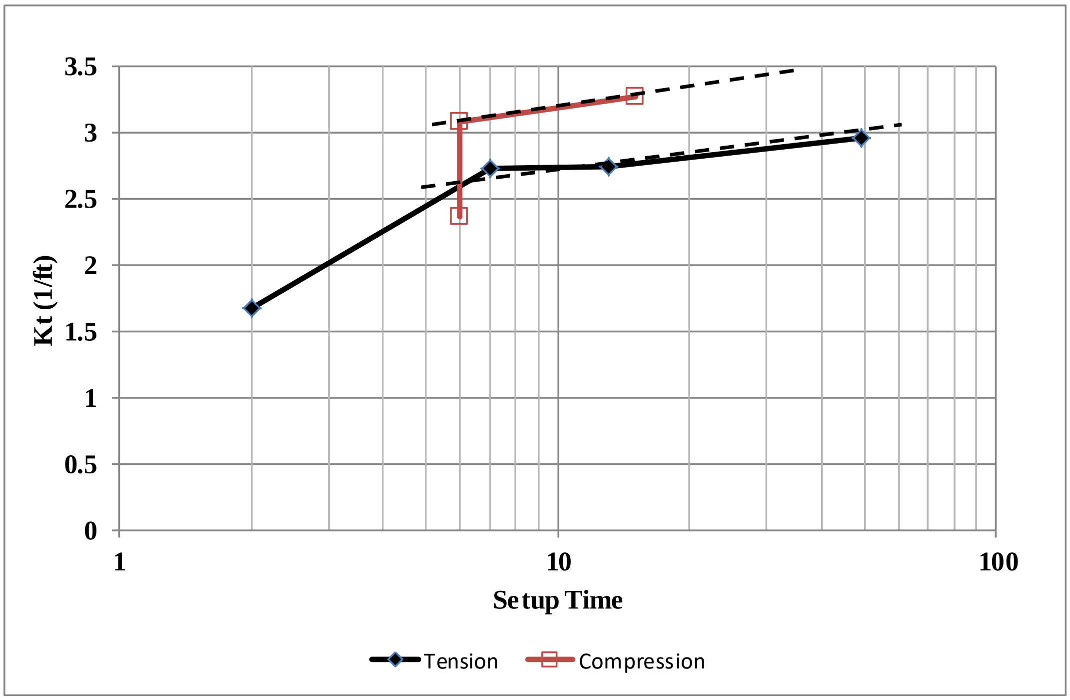


Figure 6: Torque Factor, Kt vs set-up time

SUMMARY AND CONCLUSIONS

The results of the static load test program allowed the project team to develop site specific Kt factors for the production pile quality assurance / quality control program. The evaluation of pile-soil setup over longer periods permitted the team to optimize the design and limit the amount of re-design and additional required piles.

The mechanical connections used on 18 connections did not show any adverse effects from install, load testing and removal. This helped the project team meet the production rates required to get the foundations installed according to the project schedule shutdowns.

REFERENCES

Brinch Hansen, J., 1963. Hyperbolic Stress-Strain Response, Cohesive Soils, Journal of Soil Mechanics Foundation Division, ASCE, Vol. 89, No. SM4, pp. 241 – 242.

Butler, H. D. and Hoy, H. E., 1977. User's Manual for the Texas Quick-Load Method for Foundation Load Testing, Federal Highway Administration, Office of Development, Washington, DC., 59 pp.

Davisson, M. T., 1972. High Capacity Piles, Proceedings, Lecture Series Innovations in Foundation Construction, ASCE, Illinois Section, Chicago, 1972, 52 pp.

International Code Council, Inc., 2009. 2009 International Building Code (IBC).

ASTM D1143/D 1143M-07 – Test Methods for Deep Foundations Under Static Axial Compressive Load (ASTM International, 2007a).

ASTM D3689-07 – Test Methods for Deep Foundations Under Static Axial Tensile Load (ASTM International, 2007b).

ASTM D3966/D3966M-07 – Test Methods for Deep Foundations Under Lateral Load (ASTM International, 2007).