LARGE DIAMETER HELICAL PILES FOR REFINERY EXPANSION

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ABSTRACT

A refinery expansion project for Marathon Petroleum Company in Southern Louisiana required existing medium to large pipe racks to be expanded for additional capacity. Foundation modifications were necessary in order to add levels to the existing pipe racks. New piles were added and existing pile cap foundations were expanded. Several different pile types were considered. Custom designed large diameter helical piles were chosen, because they can be installed quickly with low overhead restrictions, produce minimal soil spoils, and are cost effective. The load capacity required for piles was higher than typical, off-the-shelf helical piles. In particular, the lateral load capacity demand was high due to wind loads of a hurricane prone region. Methods used to design and size helical piles are summarized including capacity to torque ratio estimation for composite helical piles. Pile load testing was performed in order to confirm design capacities of the helical piles under axial and lateral loading. Measured axial and lateral deflections compared well with predicted values. This case history evaluates the effectiveness of modern helical pile design methods within the context of a real and practical example.

Keywords: helical piles, lateral load, pile testing, foundations, headroom, pipe racks, non-building structures

INTRODUCTION

As the capacity of modern installation equipment increases, large-diameter helical piles are being used to support higher loads in more diverse applications. Currently, large-diameter high-capacity helical piles are used for electrical power transmission, power generation, high-rise buildings, bridges, and industrial applications. This case study regards a 2.5-mile pipe rack modification project within an existing refinery. One of the many challenges for engineering and construction of refinery revamp projects is determining how to effectively expand the capacity of existing foundations for additional equipment, piping, and other facilities. Custom designed large-diameter helical piles provided an effective solution to the challenges faced when expanding the capacity of existing pipe racks.

In previous paper by Wey, et al. (2017), the overall project was briefly described along with the need for a safe, reliable, low-headroom solution involving helical piles that does not produce drill spoil. A description of the helical pile design and load testing program was provided with particular emphasis on vertical and lateral pile head movements, prediction, and tolerance for refinery equipment. Results of load tests were shown to compare well with design predictions. Test loads were held for an extended period showing minimal pile movement, which supported that helical piles are not prone to creep under sustained static loads. Also discussed in the previous paper was the importance of early clarification with regard to governing building codes and pile performance expectations.

This paper differs from the previous document by focusing less on design and more on installation obstacles and how they were overcome by the contractor. Also discussed are field quality control and the development of final pile termination criteria. Helical piles selected for the project consisted of a 5.5-inch diameter shaft with four 24-inch diameter helical bearing elements transitioning to a 13.4-inch diameter casing for the upper 16 feet. Composite helical piles, which are those with varying shaft size, have been used for several decades (Perko, 2009). However, little has been published regarding the installation torque produced by composite helical piles. Torque is often used as a final termination criterion for helical pile installation. Estimation of torque is valuable for sizing equipment and pile design.

In the past, one or two static load tests have been used to establish a project site specific capacity to torque ratio, K_t, for a particular helical pile design. The authors argue that one or two tests do not represent a statistically significant measure of pile performance that properly captures variability of a given site. For this reason, the authors advocate establishing capacity to torque ratios using well-known and published average values for a particular pile shaft lead section, evaluating the effect of the upper section, combining the required torque for both lead and upper section, and then conducting static load tests to verify the ratio K_t. This paper describes steps used to establish the termination torque for the composite helical piles used on this project. Three static load tests were performed as a final step in the process to verify the final K_t values.

SITE CONDITIONS

The project site is located within an existing developed refinery operated by Marathon Petroleum Company in Garyville, Louisiana. The approximately 2.5 miles of pipe rack, depicted by the yellow lines in Fig. 1, weave between existing tanks and processing units. A snapshot showing the existing pipe rack is provided in Fig. 2. The congested nature of existing well-developed industrial facilities is represented in the photograph. Refinery revamp work presents many challenges including low overhead restrictions, limited access, noise and vibration concerns. In many refineries, drill spoils often need to be hauled away and require special disposal. Perhaps the most important criteria for refinery revamp work are that interruptions to processing must be minimized, and safety of workers and existing equipment is paramount.

The generalized soil profile in this area of Louisiana consists of recent deposits of medium stiff clays and sands with an average unconfined compressive strength of 0.5 tsf overlying a Pleistocene age stiff clay at a depth of about 40 feet below the ground surface. The Pleistocene clay has a lower bound unconfined compressive strength on the order of 1.2 tsf. Groundwater is present only a few feet below ground surface.

Table 1 shows pile design loads. Design lateral and overturning loads are primarily from hurricane winds due to the proximity to the Gulf coast. A robust lateral load capacity was required for the piles because the additional height of pipe racks would significantly increase the wind profile. Allowable deflection under lateral loads was determined from an analysis of the equipment to be supported and its tolerance for movement. Allowable deflection will vary depending on type, height, and configuration of petro-chemical processing equipment and piping.

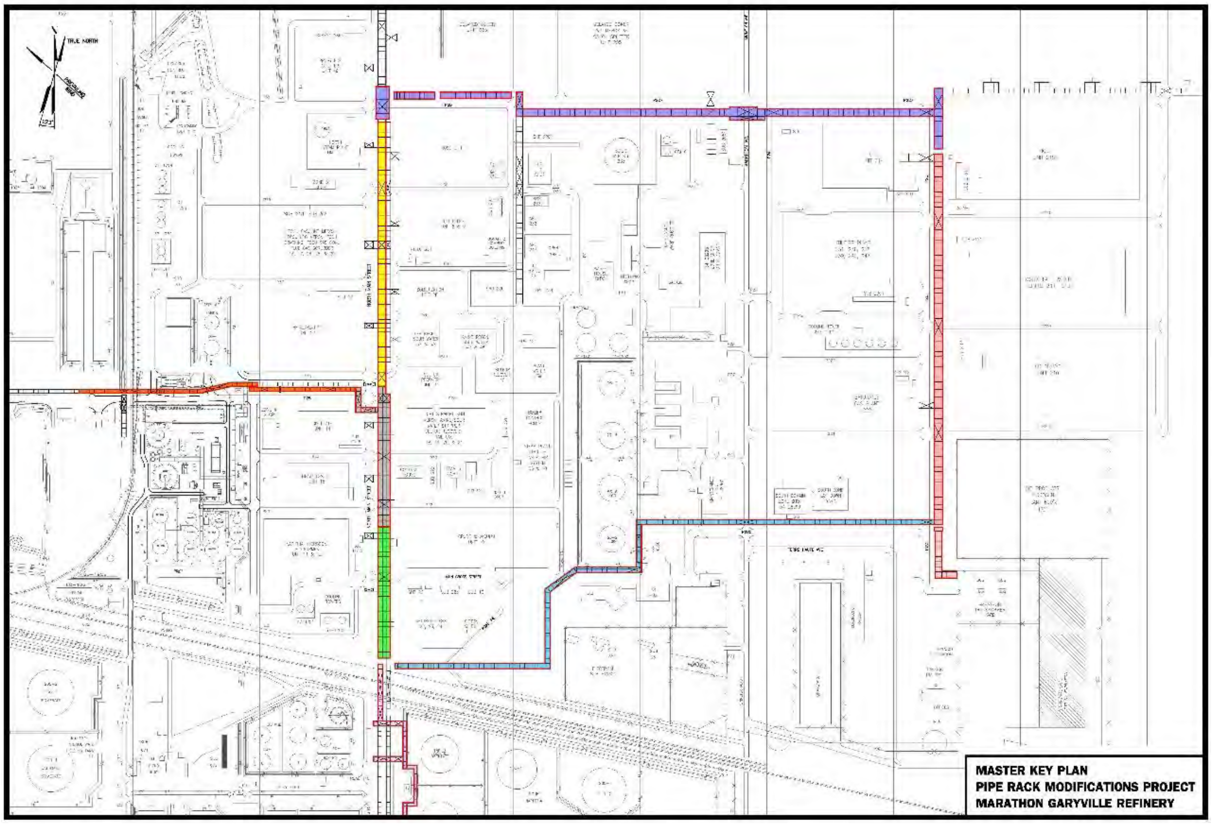

Fig. 1. Location of Pipe Rack Augmentation Work

PILE SELECTION

There were three different pile types initially considered in the project; 16-inch diameter auger-cast piles, 16-inch square pre-stressed concrete driven piles, and helical piles. Each of these piles was required to support the loads shown in Table 1. Low-overhead auger-cast piles are very labor intensive and produce a large quantity of spoils for disposal. A photograph of a typical low-overhead auger-cast pile drilling machine is shown in Fig. 3. Driven piles require high headroom for installation with additional risk of disturbing or damaging existing pipes, duct banks, or foundations.

Table 1. Expansion Pile Design Loads

Type of Loading	Axial Compression	Axial Tension	Lateral (horizontal) load (based on free-head) [5/8-in deflection]
Sustained (dead and Live)	60 kips	45 kips	9 kips
Transient (wind or seismic)	80 kips	60 kips	12 kips

The selected pile type was base upon constructability and cost effectiveness. The modification to the existing pipe racks required the pile to be installed in locations with low overhead obstructions and limited access. Overhead obstructions were typically about 15 feet above grade; however, some obstructions were as low as 10 feet above grade. Minimizing the number of new pile rows in order to mitigate the group pile shear reduction factor was a challenge for the engineers because of the existing conditions including existing battered precast piles. Underground obstructions were carefully avoided by studying existing underground drawings, exploratory trenching, and hydro-excavation pilot holes at the location of piles.

Helical piles were chosen for the speed of installation in low-overhead conditions which played a role in being the most economical solution. Helical piles minimized spoils while providing the optimum pile layout with the aid of high torque, low RPM motors, which allow advancement with minimal soil disturbance. A photograph of a typical low-headroom helical pile installation is shown in Fig. 4.

In order to provide best economy and efficient use of materials, a composite helical pile was chosen consisting of an upper 16 feet long, 13-3/8" diameter by 3/8" wall steel casing coupled to a lower section consisting of 5.5" diameter by 0.47" wall high-strength steel shaft with four 24" diameter helical bearing elements. Each helix has a 6" pitch. A schematic diagram of the selected pile is shown in Fig. 5. Helical pile properties and installation criteria are summarized in Table 2. Determination of helix size and quantity was discussed in Wey, et al. (2017). How the design team arrived at the final installation torque used for pile termination is described in the next section.

Fig. 2. Photograph Showing a Portion of Existing Exaggerated 3-Story Tall Pipe Racks Subject to Expansion (Courtesy of Fluor Corporation)

Fig. 3. Low Overhead Auger Cast Pile Installation (Courtesy of Fluor Corporation)

Fig. 4. Low Overhead Helical Pile Installation (Courtesy of Cajun Deep Foundations, LLC)

Table 2. Helical Pile Installation Criteria

Shaft size	Helix	Pitch	Installation Torque	Anticipated Length	Minimum Casing Length	Batter Angle
13.38” x 3/8 5.5” x 0.47”	4qty 24”dia.	6”	41,560 ft-lbs	46-ft to 54-ft	16-ft	0

TERMINATION CRITERIA

Installation torque is commonly used as a termination criterion for helical piles. It has been known since the 1970's that installation torque indicates average soil strength at the depth of the helical bearing elements and, therefore, pile capacity (Cherry and Perko, 2013). Capacity to torque ratios, K_t, are a function of shaft diameter. A common formula for estimating K_t values for different diameter helical piles is as follows (ICC-ES, 2016 and Perko, 2009),

$$K_t = 22.285\ (d_{eff})^{-0.9195}$$

where d_{eff} is the effective shaft diameter in inches. The units of K_t are ft^{-1}.

Based on the above formula, the lead section of the helical piles for this project has a capacity to torque ratio of 4.7 ft^{-1}. In order to achieve the project required capacity of 80 kips with a factor of safety of 2.0, final installation torque is found by taking ultimate capacity divided by the capacity to torque ratio,

$$80 \text{ kips} \times 2.0 = 160 \text{ kips}$$

$$160{,}000 \text{ lbs}/4.7 \text{ ft}^{-1} = 34{,}000 \text{ ft-lbs}$$

However, the upper larger-diameter casing section will affect the installation torque. The effect of the casing on installation torque was accounted for in two ways:

First, the theoretical torque produced by the casing was determined by multiplying the adhesion of the upper soils by the surface area of the casing times the radius of the casing. Adhesion was taken as the undrained shear strength times 2/3 to account for soil-to-steel friction. For an undrained shear strength of the upper soils of 0.5 tsf, one arrives at 9,800 ft-lbs of additional torque due to the casing.

Second, six field installation tests were conducted. In the first four tests, a 5.5" diameter shaft with helical bearing elements was installed to a depth of 21 feet while recording torque at 3-foot intervals. The next two tests consisted of a 15-foot long lead section with 5.5" diameter shaft and a 16-foot long section of casing with 13.38" diameter. As can be seen from the results shown in Fig. 6, the average increase in installation torque at 21 feet was 7,560 ft-bs, or roughly 77% of theoretical. Pore pressures generated during installation likely resulted in the observed difference.

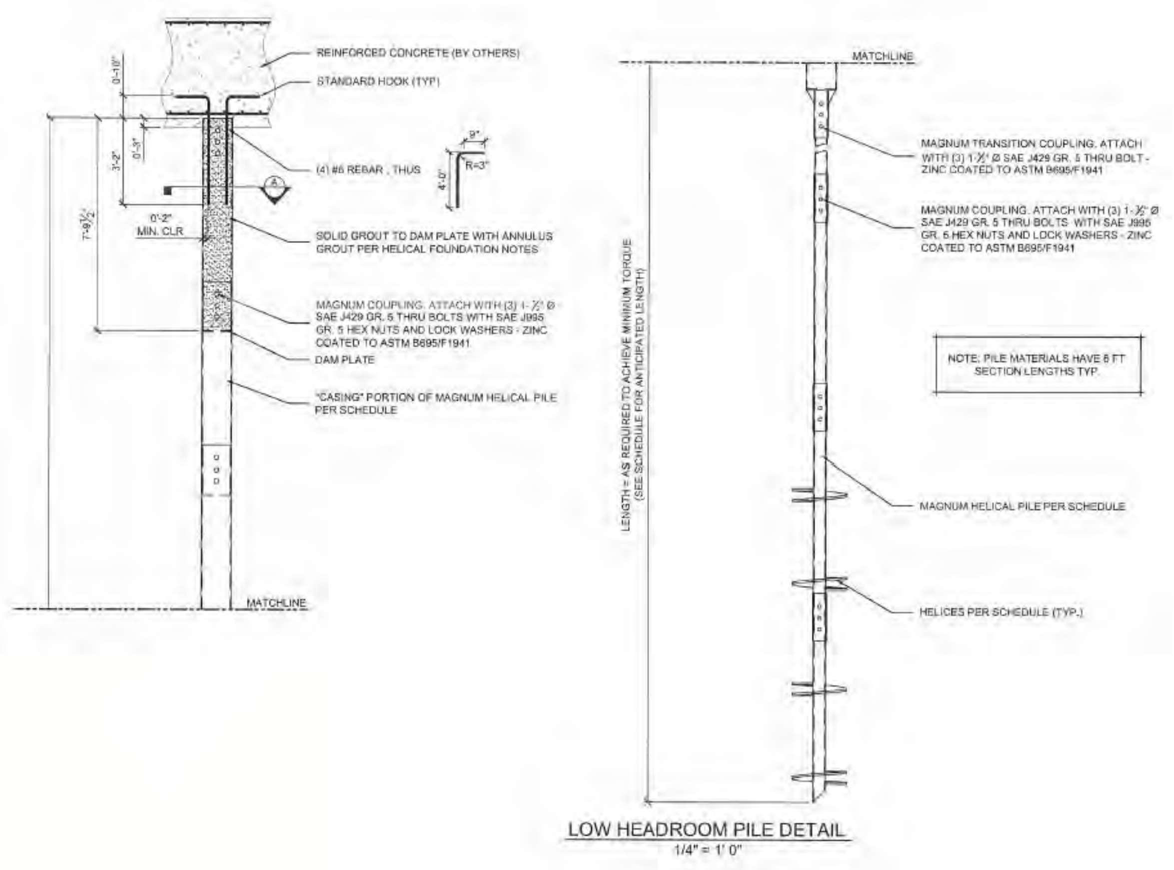

Fig. 5. Pile Schematic Details (Courtesy of Magnum Geo-Solutions, LLC)

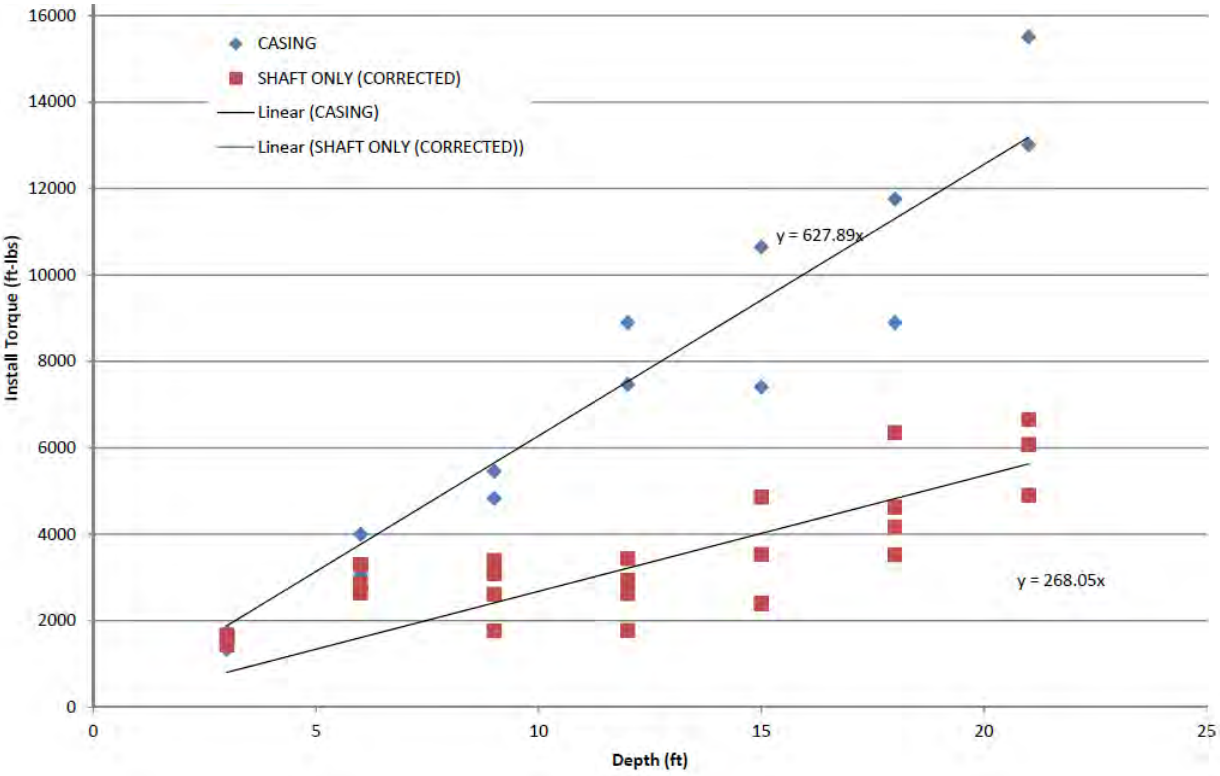

Fig. 6. Casing Installation Torque Field Tests

Final installation torque required for the helical piles on this project was computed by adding the required torque from the empirical K_t value for the lead section (34,000 ft-lbs) and the torque anticipated form the upper casing (7,560 ft-lbs) for a total of 41,560 ft-lbs as shown in Table 2.

Three axial compression, three axial tension, and two lateral load tests were performed per ASTM Standards on the helical piles to verify design. The "maintained" load procedure was followed so each increment was held for an extended time period. A photograph of one of the compression load tests is shown in Fig. 7. The load tests and results were described in Wey, et al. (2017). Pile load tests were conducted on site with the sacrificial helical piles matching the size and configuration used for the final design on the project. After load testing, the reaction piles and helical test piles were removed by unscrewing the piles and backing them out of the ground. Remaining holes were backfilled from the surface. In general, the installation depth and final torque matched design predictions very well. Load tests confirmed pile capacity and the capacity to torque ratio.

INSTALLATION

Helical piles were installed by Cajun Deep Foundations, LLC of Baton Rouge, Louisiana with a CAT 323F excavator equipped with a two speed, 110,000 ft-lb Digga torque motor and a Digga jib attachment for added reach. Despite challenging conditions, overhead constraints, and access restrictions, the contractor was able to install an average of 15 piles per work day. Helical pile sections ranged from 15 feet with no overhead restrictions to as short as 4 feet where low overhead conditions prevailed. Helical pile sections were bolted together. All piling materials were manufactured by Magnum Piering, Inc. of Cincinnati, Ohio and trucked to the site in weekly recurring shipments. Approximately 1,200 piles were installed.

Fig. 7. Compression Load Test (Courtesy of Magnum Piering, Inc.)

Photos showing examples of the challenging installation conditions are contained in Figures 8 through 10. The image in Fig. 8 shows the installation machine set outside of the pipe rack area with jib arm reaching between existing braces to the pile location below. The image in Fig. 9 shows the same installation machine reaching over an existing low pipe rack and alongside the existing taller pipe rack. The image in Figure 10 shows the hydraulic machine parked under the existing pipe rack and installing a pile within inches of an array of vertical pipes.

Installation torque was measured using a redundant system consisting of a wireless in-line torque sensor and differential hydraulic pressure. Torque and depth readings were obtained every 3 feet during installation. On occasions where the installation torque was close to the required final torque at the anticipated depth, the piles were rested for 3 days or more and then re-torqued. Most conventional helical piles with slender shaft do not exhibit pile freeze except in sensitive clays (Perko, 2009). Pile freeze is defined as an increase in capacity with time caused by changing effective stress. Pile freeze is predominantly due to soil displacement and pore pressure generation during installation. Slender shaft helical piles are a low-displacement pile. On this project, the helical piles did exhibit significant pile freeze most likely caused by the large diameter upper casing and moderately long shaft. Anecdotal evidence from field inspectors suggests pile freeze was generally on the order of 25 to 50% and sometimes as large as 100% of the final installation torque.

Fig. 8. Limited Access Helical Pile Installation (Courtesy of Cajun Deep Foundations, LLC)

Fig. 9. Cross Equipment Helical Pile Installation (Courtesy of Cajun Deep Foundations, LLC)

Fig. 10. Confined Area Helical Pile Installation (Courtesy of Cajun Deep Foundations, LLC)

CONCLUSIONS

This paper regards a case study of a recently completed onshore pipe rack revamp project in the United States in a hurricane prone region. A number of conclusions were presented in Wey, et al. (2017) including factors that make helical piles beneficial in existing refineries namely low overhead restrictions, contaminated soils, construction schedule, and restrictions with importing materials. That paper explained how the design team accurately predicted pile head deflections under axial and lateral loads. The importance of maintained load tests also was discussed.

In this paper, steps were taken by the design team to develop pile termination criteria. Specifically, capacity to torque ratio was derived for a composite shaft helical pile by adding the anticipated torque of the upper casing to the empirical torque required for the lead section. Load tests confirmed pile capacity and the capacity to torque ratio. The piles on this project exhibited significant pile freeze. Helical piles that did not reach required torque during initial installation at the design depth were successfully re-torqued.

Use of helical piles to support large refinery equipment has been slow to acceptance due to the lack of history and experience. Case studies are needed to support use of large helical piles for refinery work. A greater understanding of the expected settlements under operating loads and long-term resistance to corrosion will help decision makers feel more comfortable with the choice of helical piles for refinery work.

REFERENCES

Cherry, J.A. and Perko, H.A. (2013) "Helical Pile Deflection and Reliability", DFI Magazine, Jan/Feb Edition, New Jersey

ICC Evaluation Services, Inc. (2016) "AC358 Acceptance Criteria for Helical Foundation Systems and Devices", International Code Council, Wittier, CA

Perko, H.A. (2009) *Helical Piles: A Practical Guide to Design and Installation*, Wiley & Sons, New York

Wey, E., Murray, P., Perko, H., Mondoy, M. and Volpe, P. (2017) "Custom Helical Pile Use for Refinery Revamp: A Case Study", Proceedings of the SEI Structures Congress, Denver, CO, Structural Engineering Institute, ASCE Press, Reston, VA