

Investigation of the Efficacy of Helical Pile Foundation Implementation in Accelerated Bridge Construction Projects – Phase I

**Final Report
July 2021**



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16. Abstract The main objective of this research was to investigate the efficacy of the use of helical pile foundations for accelerated bridge construction (ABC) projects. The focus of the research was helical pile use to accelerate foundation construction on bridge projects. The capacity of helical piles is on par with several other deep foundation technologies. Installers tout the simplicity and speed of installation, along with the ability to work within areas of limited size with smaller equipment. The required equipment for installation (skid steer, backhoe, or excavator) lends itself to quick deployment and being an economical solution (i.e., excavator vs. crane), an advantage for any bridge project, but particularly for low-volume roads where budgetary considerations tend to be a specific priority. This report includes details on the current state-of-the-practice for helical piles, the potential adoption of helical piles for ABC projects, other key project considerations, and recommendations for further study/research. This report includes a literature review, contractor/installer questions and answers, a cost comparison, and images from a helical pile installation demonstration. It also provides a decision making framework, which includes two tools: a process flowchart of questions and answers and a table matrix of questions and considerations categorized by site and constructability, geotechnical, and design. The References section includes a list of webinar resources at the end of it.					
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INTRODUCTION

Background

Accelerated bridge construction (ABC) has been used at an increasing rate by transportation agencies over the past decade given the need to reduce the impact of bridge construction on the traveling public and increase the safety of workers is important. Many advances have been made in the construction methodology, especially with respect to bridge decks, superstructures, and, to a lesser extent, substructures. Of the many advances that have been made, few have specifically been directed at the accelerated construction of foundations of bridge structures. For this reason, opportunities still exist to decrease project duration and reduce disruption to road users with the adoption of newer or lesser-used foundation technologies.

One such technology is helical piles. Research is needed to identify the efficacy of using helical pile foundations for ABC projects. Helical pile installers tout the simplicity and speed of installation, along with the ability to work within areas of limited size with smaller equipment.

The number of current standard foundation options for bridge substructures is limited, thus reducing the potential time savings afforded through newer, less-common technologies. Although acceleration of bridge construction projects has greatly progressed, the potential for additional time savings still exists through the use of other methods, such as helical piles. In addition to relatively rapid installation, the use of helical piles offers immediate capacity determination using torque ratios upon installation and small maneuverable equipment.

Helical pile foundations have become commonplace in new commercial building construction and foundation repair applications with many foundation installers now offering this technology as one of their services. However, few bridge projects have been completed using helical piles despite their high capacities and speed of installation. The required equipment for installation (skid steer, backhoe, or excavator) lends itself to quick deployment and being an economical solution (i.e., excavator vs. crane), which is an advantage for any bridge construction project, for any bridge construction project, but particularly for low-volume roads where budgetary considerations tend to be a specific priority.

Research Approach and Objectives

To address the efficacy of helical pile use on ABC projects, the project activities were divided into multiple tasks. The tasks include the following list, and the objectives of these tasks follow.

1. Literature Review
2. Information Collection and System Comparison
3. Decision-Making Framework
4. Final Report

Task 1 – Literature Review

The research team compiled related information available in industry guides, journals, conference proceedings, technical reports, and online resources in a concise and comprehensive summary. The main objective of this task was to obtain a greater understanding of helical pile use and its potential application to ABC projects.

Task 2 – Information Collection and System Comparison

While Task 1 focused on extracting relevant material from documented sources, Task 2 involved gathering information from helical pile foundation system designers, installers, and contractors. The goal was to gather information primarily on capacity (vertical and lateral), speed of installation, and cost associated with helical pile installation.

In addition, similar information was gathered on completed ABC project foundation systems for the sake of comparison. Numerous ABC projects have been completed over the past several years in diverse geographical areas, the information from which sufficient detail can be gathered to assess the cost of their respective foundation systems. In any case for comparison, efforts were made to determine the equivalent helical pile system for the sake of accuracy.

Task 3 – Decision Making Framework

Using the information gathered in Tasks 1 and 2, the researchers completed a comparative analysis (of capacity and costs) between helical piles and foundation systems currently used for ABC projects and created a decision-making framework for using helical piles versus another foundation system.

The framework is two-fold in format: First, a high-level basic flowchart guiding the consideration of helical pile use was developed resulting in a yes, no, or maybe decision to proceed; second, an extended question and discussion table matrix was created to provide greater detail of the factors to consider when selecting the foundation type.

The intended user of each may be the same or different based on the responsibility one holds to the project (i.e., preliminary concept vs. design details). For the sake of project efficiency, it is intended for these tools to be used at the beginning of a new ABC project. However, the guidance would hold true throughout the project and could be used even beyond the contract award in the case of value engineering.

Task 4 – Summary of Information

The efforts associated with Tasks 1, 2, and 3 were summarized to define the benefits and drawbacks of helical pile technology and highlight the overall project discoveries, specifically how ABC projects may be affected by implementing additional foundation strategies.

Task 5 – Final Report

The project findings from the previously defined tasks were compiled into this final report. This report includes the identified current state-of-the-practice for helical piles, the potential adoption of helical piles for ABC projects, other key project considerations, and recommendations for further study/research.

Chapter 2 covers the Literature Review including history, installation, bearing, pullout, and torque ratio capacities, sizing, lateral load resistance, life expectancy, and environmental sustainability. It also covers economics, codes and acceptance criteria, and design guides.

Chapter 3 covers Information Collection, including contractor/installer questions and answers, a cost comparison, and images from a helical pile installation demonstration.

Chapter 4 provides a Decision Making Framework, including two tools: a process flowchart of questions and answers and a table matrix of questions and considerations categorized by site and constructability, geotechnical, and design.

Chapter 5 covers the Summary and Conclusions, along with Recommendations for Additional Research.

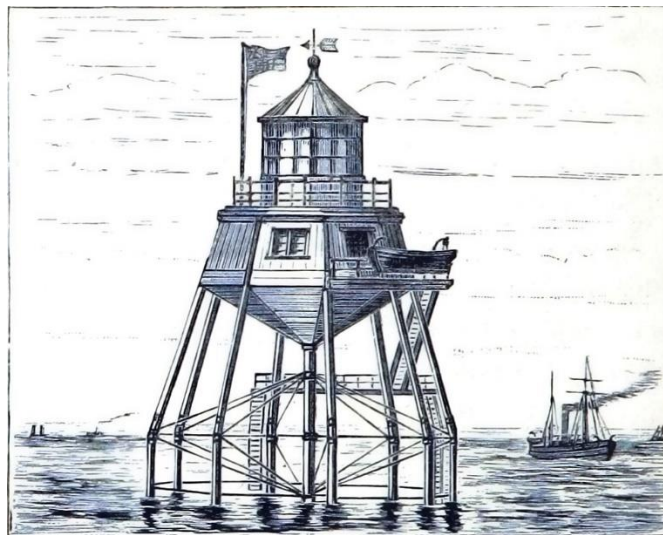
Finally, the References section includes a list of Webinar Resources at the end of it.

LITERATURE REVIEW

Numerous resources were identified that provided valuable information for this review. Howard Perko's book, *Helical Piles: A Practical Guide to Design and Installation* (Perko 2009), was found to be a resource of significant value. The book is quite comprehensive and covers many aspects of helical pile technology in great detail, much beyond what can be summarized here. Anyone looking for additional information should seek out this resource.

History

Alexander Mitchell, a European civil engineer, is credited with the first recorded use of helical piles in 1836. It was his solution to better found marine structures on weak soils. Prior to this time, Mitchell patented his invention in London in 1833 calling it a screw pile. Installation of the pile was completed using human and animal power using a large wooden handle wheel called a capstan. In 1838, the Maplin Sands Lighthouse was founded on nine screw piles 22 ft deep with a 4 ft diameter helix at the base and 5 in. diameter shafts (see Figure 1).



From the Mechanical Curator collection released to Flickr Commons by the British Library

Figure 1. Maplin Sands Lighthouse founded on screw piles

The use of screw piles continued on many marine structures (piers, lighthouses, etc.) throughout the mid to late 1800s, and their use gained traction in locations outside of Europe including the United States. More than 100 lighthouses were constructed on helical pile foundations along the East Coast and the Gulf Coast between the 1850s and 1890s.

At the turn of the century until the 1950s, the use of helical piles declined with the advancement of mechanical pile driving equipment and drilling equipment. Helical pile use became primarily for anchor applications until around 1980 when the first compression use of modern helical piles in the United States was recorded by the engineer, Stan Rupiper.

Advances in helical pile technology have accelerated in recent decades with many new patents being awarded. Accordingly, modern day applications for helical piles are vast in number. These include applications for residential homes, utility towers, commercial buildings, piers, decks, etc. Simply stated, the ability for helical piles to support loads and be installed in areas that are otherwise difficult for other foundation technology installations has become attractive to engineers and owners of all types of projects. The continued use of helical piles is predictably high and the knowledge base is continually growing.

Installation

Equipment

The list of equipment necessary to install helical piles is relatively short. A hydraulic machine such as a backhoe (see Figure 2), forklift, or skid-steer, among others, can be used with a torque motor capable of producing high torques at low speeds to install piles.



Justin Dahlberg, Bridge Engineering Center

Figure 2. Helical pile installation equipment

The torque motor should also be capable of clockwise and counterclockwise rotations and produce torques from 4,500 ft-lb for smaller piles up to 80,000 ft-lb for larger piles. The size of the hydraulic machine should be matched with the size of the torque motor, and the torque motor size should be matched with the piles being installed to ensure enough torque is provided without overstressing the piles.

A torque indicator should be used either in line with the torque motor and helical pile or as part of the hydraulic system of the machine. Applied torque is correlated to the capacity of the pile and provides surety with respect to the ultimate capacity.

Procedure

Once the torque motor and torque indicator have been properly attached to the hydraulic machine, the helical pile lead section is coupled to the assembly with a drive pin. The lead section is positioned at its location of installation and the plumbness or inclination is checked from multiple vantage points.

A downward force, or crowd, is applied to the pile by the hydraulic machine forcing the tip into the ground. Once this is complete, the hydraulic machine can advance the pile into the ground until the point at which an extension is required.

An extension is coupled to the top of the installed section with connection bolts and to the hydraulic assembly with the drive pin. The process repeats until sufficient depth has been achieved to provide the capacity specified.

It is recommended that piles be installed without start and stops and at a rate of rotation less than 30 rpm. Faster rates can create an auguring effect if advancing into hard soils from soft ones.

Safety

Marking utilities and being aware of overhead power lines must be done prior to installation commencing. Installing piles through underground utilities, especially electric or gas, or contacting overhead power lines could result in death.

Proper maintenance of hydraulic components reduce the risk of breakage. Bursting hydraulic lines can cause injury or death if someone is struck.

Installation can best be safely completed using a minimum of two workers with one worker operating the hydraulic machine while the other serves as a spotter, moves the pile sections, and completes the coupling and decoupling as necessary. The spotter also checks for plumbness and correct positioning. The hydraulic machine operator and spotter should have a clear site line to one another to communicate quickly with hand signals.

Taking precautions against heavy equipment rollover is another essential to ensuring safe installation. An advantage to using helical piles is the ability to install them in locations that many other machines may not be able to access. However, this creates a risk for machine operators if the proper attention is not paid to safety on the site.

Personal protective equipment, such as hard hats, boots, eye protection, and ear protection should also be worn at all times to reduce the risk of injury.

Torque Measurement

Measuring torque during installation is critical to evaluating the capacity of the helical pile. Methods for measuring torque are numerous, with many recent advances.

One method is the use of a shear pin indicator, where two adjoining circular plates are fixed together using varying numbers of calibrated shear pins. Once the torque has reached the capacity of the pins, the pins will shear and the plates will freely rotate about one another. This method is good for limiting the maximum shear but does not give a continuous shear readout during installation.

A mechanical dial gage equipment with an internal strain transducer has been used with reasonable accuracy. A continuous torque reading is displayed, although the display continuously rotates with the torque motor making it difficult to read.

A load cell is similarly equipped with a strain gauge on its steel housing. A data acquisition device records the strain and converts the reading to torque, which is most often displayed to the operator in the hydraulic machine. Expense and fragility are the disadvantages to using load cells. However, newer battery-powered load cells remove the possibility of wire entanglement during installation.

Other devices measure inline pressure differential in the hydraulic hoses leading to and from the torque motor. This differential is converted to torque for the operator to observe.

Inspection

The frequency of inspection for helical pile installation can vary depending on the needs of the project and the willingness of the owner to invest in an inspection program. Some projects require inspection on all installed piles, while others may only require a small percentage be inspected.

The subsurface conditions may also dictate the level of inspection required, since highly variable conditions will likely result in variable torque readings at differing elevations. The variability may require modifications to the as-planned installation.

At a minimum, the torque and depth during installation during installation and the final depth should be logged for each pile. Deviations from the plan should be recorded for as-built files.

Bearing Capacity

Subsurface conditions are used to determine the shaft size and total number of helices on the shaft to achieve the required bearing capacity. Two methods are used to determine the helix spacing: individual bearing and cylindrical shear.

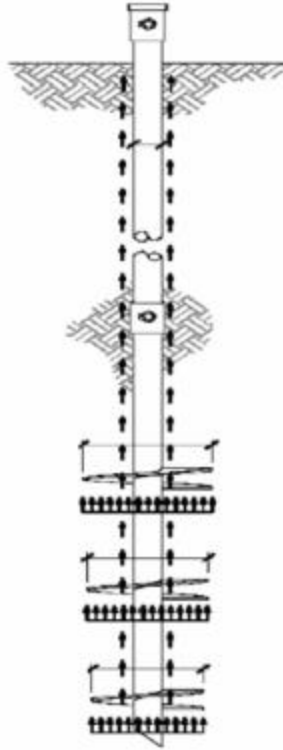
A relatively wide helical spacing dictates that the helices act independently, and the total bearing capacity is simply the sum of that from each. Alternatively, if the spacing is relatively narrow, the helices act as a group. The total bearing capacity is the sum of the bottom helix and the side friction comprised of the projected cylinder between each of the helices.

The closeness of the helical bearing plates is relative based on the diameter of the helices and the surrounding soil conditions. The ideal spacing of helical bearing plates occurs where the calculated individual method and the cylindrical method capacities are equal. This creates efficiency by minimizing the shaft length and number of helices required.

For smaller shaft sizes (1.5 in. square to 3.5 in.² in diameter), the optimal spacing is often taken as two to three times the average diameter of the helical bearing plates. The helical bearing plates should be spaced with respect to the pitch to ensure the same path during installation.

Individual Bearing Method

The distribution of forces is assumed to be a uniform pressure distribution on the underside of each helical bearing plate. Additionally, adhesion stresses are assumed on the shaft along its length (see Figure 3).



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Figure 3. Individual bearing method

The ultimate bearing capacity is the sum of individual bearing capacities for each helical bearing plate plus the adhesion along the shaft, as given by this equation:

$$P_u = \sum_n q_{ult} A_n + \alpha H (\pi d)$$

where:

q_{ult} is the ultimate bearing pressure

A_n is the area of the nth helical bearing plate

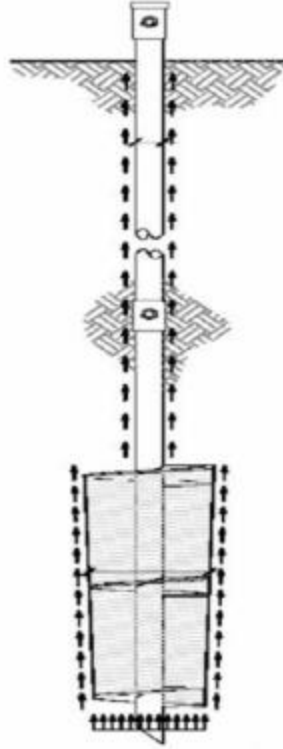
α is the adhesion between the soil and the shaft

H is the length of the helical pile shaft above the top helix

d is the diameter of a circle circumscribed around the shaft

Cylindrical Shear Method

For the cylindrical shear method, it is assumed that the entire volume of soil between the top and bottom helical bearing plates is mobilized. In this case, the lead helix is subjected to a uniform pressure on its bottom side, and the soil between the helices is subjected to shear interaction with the surrounding soils. Furthermore, adhesion stresses act along the length of the helical pile shaft located above the top helix (see Figure 4).



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Figure 4. Cylindrical shear method

Ultimate bearing capacity is found by taking the sum of shear stress along the cylinder, adhesion along the shaft, and bearing capacity of the bottom helix, as given by the following:

$$P_u = q_{ult}A_1 + T(n - 1)s\pi d_{AVG} + \alpha H(\pi d)$$

where:

A_1 is the area of the bottom helix

T is the soil shear strength

H is the length of shaft above the top helix

d is the diameter of the pile shaft

$(n - 1)s$ is the length of soil between the helices

All other parameters are the same as those for the individual bearing method.

Limit State Analysis

The ultimate capacity should be determined by calculating capacities for both the individual bearing method and cylindrical shear method and using the lower capacity value. The shaft adhesion portion of the previous equations is often ignored due to several reasons including the following: square shaft helical piles form an annulus around the shaft reducing soil to shaft

contact and the wobble of the shaft upon insertion can similarly create voids between the shaft and soil. Also note that adhesion to the shaft has been found to be a greater contributor to the ultimate capacity in deep, larger-diameter shafts.

Pile Deflection/Settlement

Helical piles designed with a minimum factor of safety of 2.0 have been found to have maximum settlements of about 1/2 to 1 in. under typical design loads (e.g., buildings). This assumes good bearing material with a blow count of 20 or greater. Highway bridge foundation loads can be greater than building foundations and, accordingly, may require longer helical piles. The structural engineer should understand the settlement limits for the bridge structure as there may be elastic shortening effects that result in larger deflections (measured at the top of the helical pile), even with properly sized helical plates to match soil conditions.

Pullout Capacity

Pullout capacity is determined similarly to the bearing capacity when downward forces are applied assuming the piles have been installed at a depth that ensures a deep mode of behavior. The individual bearing method and cylindrical shear method are both applicable, although the forces are reversed. The bearing stress moves to the top of the individual helices with the individual bearing method, and the bearing stress moves to the top helix with the cylindrical shear method.

A helical pile not installed deeply enough (too shallowly) will not have sufficient resistance to avoid pullout. Deep-mode behavior ensures that the minimum embedment of helical piles subject to tension forces is the depth at which the weight of a cone of soil above the shallowest helix is sufficient to provide the necessary pullout pressure. This is conservative, because it assumes a geometrical vertex at the shallowest helix. More rigorous and precise methods of determining the total weight of soil engaged during pullout exist and can be used.

Capacity to Torque Ratio

In situ strength of helical piles is correlated to installation torque. Similar to that using the plate penetrometer test, the torque required to advance a pile into the ground is indicative of soil consistency and strength.

The ultimate axial capacity of helical piles was first provided in a calculation by Hoyt and Clemence (1989). The relationship is as follows:

$$P_u = K_t T$$

The parameter K_t is known as the capacity-to-torque ratio having units of ft^{-1} and was found to be a constant most closely related to the shaft diameter. Since the early studies and development of

the K_t factor by Hoyt and Clemence, in which more than 90 pullout load tests at 24 different sites with varying soil types were completed, many other pile load tests have been completed with final installation torque recorded. The cumulative data show good correlation to the K_t parameter originally developed.

The differences in the tension and compression capacity correlation with installation torque is noteworthy. K_t values tend to be about 10% higher in compression than in tension, although it has become common practice to assume the same K_t value for compression and tension applications given the inherent variability due to soil conditions.

The ultimate capacity calculation based on the installation torque was shown to correlate well with the cylindrical shear method and individual bearing method, although these methods tend to more conservatively predict actual capacity. In other words, using the capacity-to-torque ratio often results in a greater predicted capacity than when using either of the two other methods.

Installers should also be aware of factors that may affect the ultimate capacity determined by the capacity-to-torque ratio. For example, helical piles can begin to auger the soil instead of advancing through the soil, especially when exiting a softer layer and entering a harder layer. The reduction in torque results in a lower and more conservative ultimate capacity. Augering can also occur when the helical bearing plates are not properly positioned and, succeeding plates do not follow the same path as the leading plate.

The capacity-to-torque method does not apply when piles terminate on bedrock or other hard material when piles are installed such that the top helix is less than 5 helix diameters below the surface (Pack 2000). Rather, a load test or limit state calculations are typically used to determine the ultimate capacity. The strength of the pile may govern which method to use.

Sizing

The allowable capacity is determined by applying a factor of safety to the ultimate capacity. It is typical for a factor of safety of 3.0 to be used for deep foundation designs. However, for helical piles, a factor of safety of 2.0 is more typical when capacity is verified through torque correlations. This has been statistically justified based on the measured and predicted capacity of more than 100 load tests. An even lower factor of safety may be justified when a load testing program is employed.

To determine the size of helical piles, take into account the soil conditions for which the piles will be installed and the anticipated loads. Using this information, the shaft size and shape along with the size and number of helical bearing plates can be determined. Several iterations may be required to optimize the design.

Commercially available software has been developed to allow a design engineer to evaluate several possibilities and configurations (e.g., Ramjack Foundation Solutions HeliCAP Helical Capacity Design Software from Chance for Hubbell Power Systems, Inc.). Each of the software

programs uses the individual bearing method for calculating the ultimate capacity and allows for numerous soil stratum to be defined.

Statistics show that using a combination of limit state analysis and torque correlations with a factor of safety of 2.0 provide a reliability of 99.7% (capacity > demand). Whereas, using limit state analysis or torque correlations singly reduces the probability to near 90% or 97%, respectively. A prudent practice is to use traditional limit state methods to size helical piles, and, then, verify the capacity using torque correlation.

Lateral Load Resistance

Helical piles with tubular shafts and rigid couplings are best suited to support lateral loads. Analysis is considered in two categories, rigid pile analysis and flexible pile analysis, depending on the installed configuration. Brom's Method is used for the former and L-Pile for the latter. The analysis for each takes the soil type into consideration.

The lateral soil pressure on a single pile in ground under lateral loads is on the order of two to three times greater than the Rankine passive earth pressure. The lateral stress distributions will overlap and be additive when the piles are spaced closer than three shaft diameters apart. Helical piles are often spaced to avoid group efficiency effects.

The lateral load capacity of helical piles can be increased by installing them at a batter angle. Where resistance to vertical and horizontal loads is required of helical piles, the batter angle can be optimized. Alternatively, two or more piles can be used to resist vertical and lateral forces individually. Tie-back anchors are helical piles installed at a shallow angle and are used to resist the horizontal loads in combination with vertically installed piles that are used to resist vertical loads.

Life Expectancy

Galvanic corrosion can occur if the proper care to avoid contact and/or electric coupling of dissimilar metals is not taken. Zinc-coated steel and bare steel should not be used in the same helical piling system. Otherwise, helical piling may become a sacrificial anode to a bare steel structure. Electric isolation between the helical piles and bare steel and concrete reinforcing steel is paramount to avoiding galvanic corrosion. It is recommended to use the same material with the same protective coating and to use one corrosion rate for the entire pile system.

Zinc coatings have shown to reduce underground corrosion rates by as much as 50 to 98%. Several methods of coating with zinc exist, although mechanical plating, electroplating, and batch hot-dip galvanizing are the three recognized methods in the acceptance of helical piles.

Batch hot-dip galvanizing has been most commonly used in the production of helical piles. Coating are typically 3.5 to 4 mils thick. They result in a zinc iron alloy that is harder than steel, yet they remain reasonably flexible.

Pits and scratches in zinc coatings can occur upon installation. Galvanic corrosion protects exposed steel in areas up to 1/8 in. wide.

Perko (2004) showed, through the analysis of corrosion data, the life expectancy of a 0.25 in. thick-wall helical pile both bare and galvanized steel in four categories of soil corrosivity: severe, high, moderate, and low. With a 98% probability, the life expectancies were for bare/galvanized 30/75, 70/170, 55/140, and 325/810 years, respectively, for each of the four soil categories (severe, high, moderate, and low). The life expectancy was based on the sample wall thickness reduction of one-third using a minimum factor of safety of 1.5.

Corrosion of zinc-coated steel in water and air vary based on the environment. Marine environments are generally more corrosive and, thus, require maintenance sooner than those unexposed to those environments. It is unlikely, however, that many helical piles would remain exposed given their intended purpose and design.

Environmental Sustainability

More owners and engineers are becoming increasingly attentive to the environmental sustainability of construction methods and materials used on their projects. In comparison to other deep foundation technologies, helical piles are competitive and often surpass others on the scale of sustainability.

Environmental disturbance is minimized without the need for soil removal. The carbon footprint is reduced in many ways including a more efficient use of raw materials and fewer truck trips to and from a construction site. Fewer trips result in less pollution and wear on roadways. Additionally, the equipment required to install helical piles is often smaller and the time to install them is often less requiring less fuel.

Economics

The unit cost of installed and furnished helical piles can vary with required capacity, depth, and corrosion protection, as well as distance to the site, competition, quantity, and schedule. Due to geographical differences in availability of different foundation systems, the question as to the cost of a helical pile foundation cannot be answered quantitatively with any certainty (Perko 2009), while helical pile costs are within the general realm of deep foundation costs. A designer should inquire about the overall cost specific to their market.

Helical piles are best used where pile loads generally do not exceed 30 tons, although heavier duty piles can be employed. The economy of helical piles increases with the total number of piles due to the speed of installation and the savings associated with an expedited schedule.

Measurement and Payment

Lump Sum: The benefit to the owner is that the costs are fixed, although the contractor will likely be conservative to reduce the financial risk, since the disadvantage to the contractor is the potential for longer piles to reach the required strength. The method lends itself well to design-build contracts. Loads and locations are provided to the pile contractor and the pile design and attachment to the structure are under the contractor's responsibility.

Price per Pile: The same advantages and disadvantages of lump sum exist, although the added benefit of the price for adding or subtracting piles is made by prior agreement.

Price per Foot: This method is preferred by contractors due to the variability of subsurface conditions. The owner can benefit by shorter overall pile lengths or, conversely, be required to pay for additional installed pile lengths. Specifications and scope should be narrow to accurately compare bids, although allowances for field modifications should be made.

Time and Materials: Payment is made on a unit rate basis for hourly rates, materials, and equipment rental. This method is useful on projects with limited subsurface information and in design-build approaches. The owner, engineer, pile designer, and contractor can work together to optimize time and materials. It is more difficult, however, for the owner to estimate total project costs. The contract could be written with a guaranteed maximum cost and incentives for early completion.

Codes, Acceptance Criteria, and Design Guides

To date, the pursuit of helical pile use has primarily been directed at the vertical construction industry, which leans primarily on the private sector. Accordingly, the lion share of effort towards research, design, and development of the technology and its adoption into governing building codes has not specifically engaged the bridge design community. Despite this fact, advances in the recent past will prove to benefit the bridge design community, since the deep foundation methodology has largely been proven. In the following sections, a brief summary of building code history and acceptance criteria are provided.

International Building Code

The 2009 edition of the International Building Code (IBC) was the first U.S. code to directly address the use of helical piles (International Code Council [ICC] 2009). Within Chapter 18 – Soils and Foundations, it is stated that “Helical piles shall be designed and manufactured in accordance with accepted engineering practice to resist all stresses induced by installation into the ground and service loads.” Instruction for determining allowable axial and lateral loads are then provided (Deep Foundations Institute [DFI] 2019).

The current version of the IBC maintains similar language with respect to design and detailing, prescribes the maximum allowable stress for compression and tension applications

$(0.6F_y \leq 0.5F_u)$, and prescribes the allowable axial design load (ICC 2021). The code further specifies that “helical piles shall be installed to specified embedment depth and torsional resistance criteria as determined by a registered design professional. The torque applied during installation shall not exceed the maximum allowable installation torque of the helical pile.”

International Code Council Acceptance Criteria (AC358)

ICC *Acceptance Criteria for Helical Pile Systems and Devices (AC358)* provides the testing protocols to quantify performance characteristics of helical pile elements (ICC-Evaluation Service 2007, 2016). AC358 was most recently updated in 2016 to include 4.5 in. diameter round shafts and smaller hollow square shafts. Previously, it only covered small diameter helical piles that are 3.5 in. or smaller.

The development of acceptance criteria was seen as necessary to create standards and minimum requirements for the manufacturers of helical piles. The approval process now includes review of field and laboratory testing by an independent laboratory, calculation submittals, quality management documents, and other manufacturer information.

A report is issued to manufacturers when AC358 requirements are satisfied and when the structural and installation torque-to-capacity relationships have been confirmed by independent agencies (DFI 2019).

Helical Pile Foundation Design Guide

In 2019, the Deep Foundations Institute (DFI) Helical Piles and Tiebacks Committee published the *Helical Pile Foundation Design Guide* (DFI 2019). It was written with engineers, contractors, building officials, and other construction trade practitioners in mind. The guide was prepared for the design and review of helical pile foundation and helical anchor projects. More so, it was prepared to be easily understood and helpful during preliminary design and selection of helical piles. This guide, along with its cited references, provides a wealth of information necessary for any helical pile project.

INFORMATION COLLECTION

Information was collected from helical system designers, installers, and contractors. The goal was to gather information primarily on capacity (vertical and lateral), speed of installation, and cost associated with helical pile installation. Additional information was gathered from the Iowa Department of Transportation (DOT) with respect to the foundation costs associated with three completed ABC projects.

Contractor/Installer Questions and Responses

An engineer from Atlas Foundation Company, a Midwest helical pile installer, was asked the following questions (Q1 through Q8) and his corresponding answers (A1 through A8) follow each question.

Q1) What can be typically expected for duration for installation of helical piles for a bridge foundation and how does this compare to other commonly used foundation types (e.g., H-pile, augercast piles, etc.)?

A1) Commonly, helical pile installation can be faster than the other methods. The equipment used for installation is typically one machine and does not require an additional crane typical for many pile projects; there are no drill spoils to remove; and, if encasement of a smaller helical shaft in a grout column is required, the grout is placed at the time of installation and no casing is required.

Q2) Is there a general sense to the overall cost advantages of using helical piles for bridge foundations when accounting for materials, labor, and time?

A2) Based on geotechnical conditions and the load capacity required, helical piles can be more cost effective than H-piles or cast-in-place (CIP) drilling methods. H-pile and helical pile material costs can be comparable; CIP cost is typically less. Labor and mobilization cost for helical installation is less, and installation time for helical piles is less.

Q3) Does the use of helical piles alter in any significant way how the remaining bridge foundation structure is constructed?

A3) It depends on the geotechnical conditions and loading you are dealing with. If a grouping of helical piles is required to support a load, the footprint of the pile cap may need to be enlarged from a typical pile or CIP to incorporate the piles. Center to center pile spacing between helical piers should be at a minimum of 3 to 4 times the largest helix diameter.

Q4) Is there a range for compressive loads that tends to be the “sweet spot” for helical piles? That is, where do they make most economic sense as a function of capacity?

A4) This is project specific, and I don't have a solid answer for this one. I know of at least one project where an axial compressive load of 500 kips was supported on a single pile. Was this cost effective? I don't know. The geotechnics of the site and project loads typically guide the foundation selection. A helical pile is an end bearing pile, and shear strength along the shaft is commonly not considered. The shaft can be grouted during installation of the pile turning it into an end bearing micropile, where the shear strength along the shaft significantly increases the capacity of the pile.

Q5) What type of contracts are best suited for helical pile installation? Allowable contract methodologies within DOTs vary state by state, meaning some may be more amenable to helical pile use.

A5) Most commonly, the process is to evaluate the project soils report and establish a bid depth based on the evaluation of the request for proposals. Change orders due to depth variations where capacity is achieved during construction should be based on over- and under-runs shown in proposal documents.

Q6) Helical piles are accepted into the IBC, but not in the current American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Design Specifications. Have there been actions to introduce piles into the bridge design code? If so, what are they? If not, what are the reasons?

A6) Not that I am aware of. I recently corresponded with Gary Seider, the immediate past chair of the DFI Helical Piles and Tiebacks Committee, and he said the following: "No is the direct answer. I don't know why it is hasn't been pursued. Probably because no one has invested the time and money to start the process. The main focus of the industry for the last several years has been the IBC and the DFI Design Guide."

Q7) What standard guide specifications exist for helical pile use on bridge structures?

A7) The DFI Helical Piles and Tiebacks Committee Design Guide is a good place to start.

IPENZ Engineers New Zealand – Practice Note 28 – Screw Piles: Guidelines for Design, Construction, and Installation. 2015.

DFI Helical Pile Foundation Design Guide. 2019. Gary L. Seider – Hubbell Power Systems, Inc. Chairman.

Canadian Foundation Engineering Manual – 4th Edition. Canadian Geotechnical Society. 2006.

Q8) What information would you want a bridge engineer/owner to know when selecting a deep foundation type that would convince them a helical pile system performs as well as other deep foundation systems?

A8) This is not a new system and has been used for decades for support of critical infrastructure, including pedestrian bridges, county road bridges, and larger highway bridge piers and abutments.

Cost Comparison

Iowa is home to several completed ABC projects. Plan sets and bid tabulations were acquired for three projects covered in this section and used to generally compare the costs of deep foundation materials and installation to the estimated costs of helical piles. The helical pile cost information is presented in today's dollars, whereas the completed projects are presented in the dollars for their respective construction dates. As with all comparative estimates, the actual cost can vary, and these costs should be viewed as approximate figures.

It is quite probable that an optimized solution using helical piles would differ from the as-built structure had they been the original deep foundation solution of choice. This would likely result in an increase in the total number of piles used while still allowing similar prefabricated abutment construction. High-capacity helical piles exist that have capacities near that of H-piles. Even so, the advantage of using helical piles often comes with using a greater number with lesser individual capacity. The required capacities are often achieved at depths much less than what would be required of driven piles, so comparing the cost per foot assuming the same driven depth can be misleading when evaluating total cost.

A prominent Midwest helical pile installer indicated the installed cost of helical piles can range from \$35/LF to \$75/LF on a project limited to between 20 and 30 total piles. Cost reduction can be realized with a greater number of installed piles. The cost is also a function of the size of the helical piles required; greater individual loads per pile require larger sized piles, and, thus, additional material cost is incurred. The opposite is true of piles with reduced demand. It was stated that the cost per kip of demand for helical piles is often lower than that of H-piles. As an example, a 50 kip capacity helical pile will cost less than a 50 kip capacity H-pile.

Additionally, it was stated that piles with an ultimate capacity up to 200 kips are typically installed with small to midsized hydraulic equipment (backhoe, excavator, etc.), and those with capacities greater than 200 kips are typically installed with larger equipment (large excavator or crane). The use of large capacity helical piles is not uncommon, and there are many installers around the country, but it may be advantageous to maintain use of piles with an ultimate capacity less than 200 kips to achieve greater economy. Table 1 provides the ultimate capacities of many commonly used helical pile sizes.

Table 1. Ultimate strength of common helical pile sizes

Pile Size Designation	Ultimate Capacity	Pile Size Designation	Ultimate Capacity
SS5 – 1 1/2 in.	55 kips	RS2875.203	49.5 kips
SS150 – 1 1/2 in.	70 kips	RS2875.76	72 kips
SS175 – 1 3/4 in.	110 kips	RS3500.300	91 kips
SS200 – 2 in.	150 kips	–	–
SS225 – 2 1/4 in.	200 kips	–	–

Source: Chance/Atlas 2018

Keg Creek Bridge (2011)

The bridge on US 6 over Keg Creek in Pottawattamie County, Iowa, is a 210 ft long by 44 ft wide steel modular bridge constructed in the fall of 2011. The substructure is composed of integral concrete abutments supported on steel H-piling and two, two-column concrete piers supported on drilled shafts keyed into bedrock. The superstructure is a three-span, continuous modular weathering steel welded girder structure with a cast concrete deck.

The substructure pile caps and wing walls at each abutment were precast offline, picked, and set over the top of driven H-piles. The pile caps and wing walls were formed with 1 ft 9 in. diameter, full-depth grout pockets aligning with the H-piles. Once the pile cap was set into place, the grout pockets were filled with self-consolidating concrete. The pile layout is shown in Figure 5.

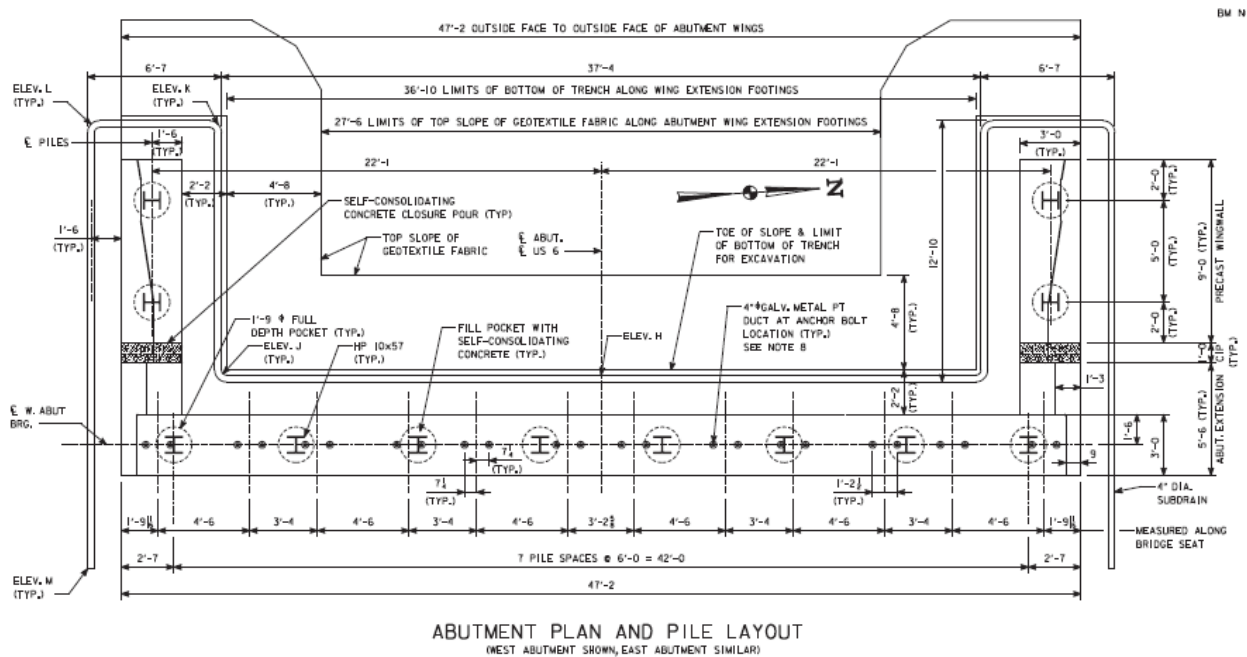


Figure 5. Keg Creek Bridge abutment plan and pile layout

Plan notes respective to the piles are presented in Figure 6.

NOTES:

1. FINAL PILE POSITIONS SHALL NOT DEVIATE FROM THE LOCATIONS DESIGNATED IN THESE PLANS BY MORE THAN 3" IN ANY DIRECTION.
2. FOR SECTION A-A, SEE DESIGN SHEET 12.
3. PILES SHALL BE DRIVEN TO ROCK. PILE DESIGN BEARING IS 65 TONS.
4. FOR ABUTMENT BACKFILL PROCESS AND NOTES, SEE DESIGN SHEET 12.
5. FOR WING ARMORING AND SUBDRAIN DETAILS, SEE DESIGN SHEET 17.
6. PRECAST CONCRETE ABUTMENT SHALL CONFORM TO PRECAST CONCRETE SUBSTRUCTURE ELEMENTS SPECIAL PROVISIONS.
7. USE 1'-9" GALVANIZED CORRUGATED METAL PIPE FOR POCKETS.
8. GALVANIZED METAL PT DUCTS SHALL BE USED AT ALL ANCHOR BOLT LOCATIONS EXCEPT THOSE THAT FALL IN PILE POCKETS. THESE LOCATIONS SHALL BE FIELD DRILLED ONCE POCKET CONCRETE HAS ACHIEVED 3000 PSI COMPRESSIVE STRENGTH. GROUT $1\frac{1}{2}$ " DIA. x $1'-7\frac{1}{2}$ " SWEDGED ANCHORS IN FIELD. SEE DESIGN SHEET NO. 34.
9. 12 - 80'-0" HP 10x57 STEEL BEARING PILING AT SOUTH ABUTMENT.
10. 12 - 80'-0" HP 10x57 STEEL BEARING PILING AT NORTH ABUTMENT.

Figure 6. Keg Creek Bridge foundation notes

Specific attention is given to Notes #3, #9, and #10, where the pile design bearing is shown to be 65 tons and the total number and depth of piles at each abutment are indicated.

It is assumed the substructure layout would not require change if helical piles would be used in place of the H-piles, especially if a higher capacity helical pile was selected. However, the possibility exists to use a greater number of lesser capacity helical piles but maintain the same pile-in- corrugated metal pipe (CMP) void form detail.

Massena Bridge (2013)

Located on US 92 over a small stream immediately west of Massena, Iowa, the bridge is a single-span, 124 ft long by 44 ft wide. The substructure is composed of prefabricated abutment footings locked to driven steel piles. The superstructure is composed of precast, prestressed concrete girders and a CIP deck superstructure. The bridge was constructed in the fall of 2013 using slide-in construction methods.

The substructure is composed of prefabricated abutment footings with 2 ft 3 in. diameter CMP block-outs placed over driven HP 14 x 117 steel piles with 11 total per side. The footings measure 47 ft 2 in. by 4 ft 0 in. and 3 ft 0 in. tall. The block-outs are full depth and filled with a highly flowable concrete chip mix. A plan view of the abutment piles and footing is shown in Figure 7 with foundation notes in Figure 8.

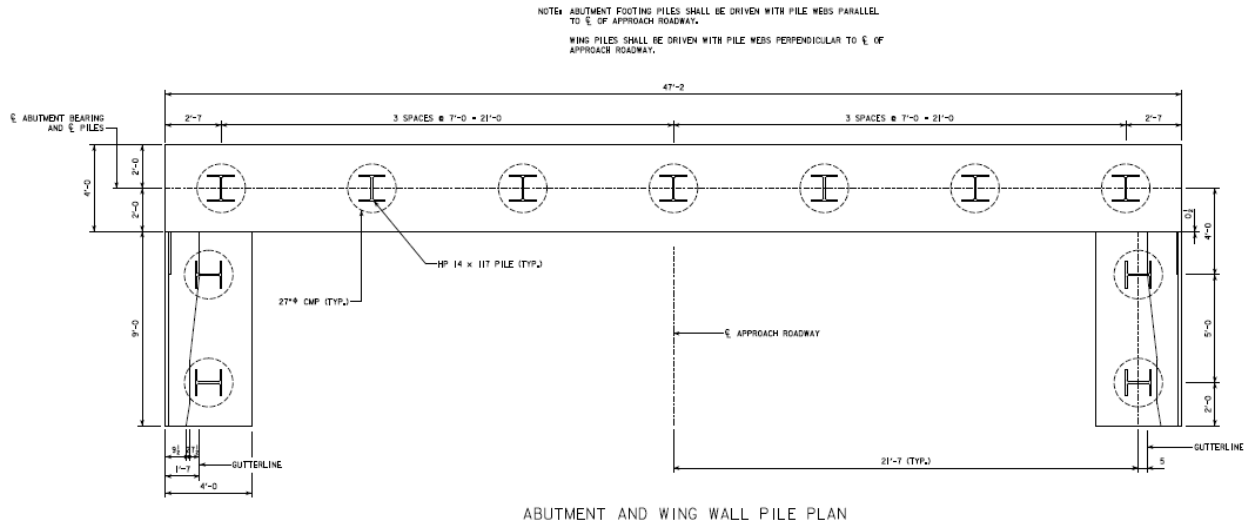


Figure 7. Massena Bridge abutment plan and pile layout

ABUTMENT NOTES:

THE CONTRACT LENGTH OF 95'-0 FOR THE EAST AND WEST ABUTMENT PILES IS BASED ON A COHESIVE SOIL CLASSIFICATION, A TOTAL FACTORED AXIAL LOAD PER PILE (PU) OF 237 KIPS AND A GEOTECHNICAL RESISTANCE FACTOR (PHI) OF 0.65.

THE NOMINAL AXIAL BEARING RESISTANCE FOR CONSTRUCTION CONTROL WAS DETERMINED FROM A COHESIVE SOIL CLASSIFICATION AND A GEOTECHNICAL RESISTANCE FACTOR (PHI) OF 0.65.

THE REQUIRED NOMINAL AXIAL BEARING RESISTANCE FOR EAST AND WEST ABUTMENT PILES IS 182 TONS AT END OF DRIVE (EOD) OR RETAP. THE PILE CONTRACT LENGTH SHALL BE DRIVEN AS PER PLAN UNLESS PILES REACH REFUSAL. CONSTRUCTION CONTROL REQUIRES A WEAP ANALYSIS WITH BEARING GRAPH.

MINIMUM CLEAR DISTANCE FROM FACE OF CONCRETE TO NEAR REINFORCING BAR IS TO BE 2" UNLESS OTHERWISE NOTED OR SHOWN.

FINAL PILE HEAD POSITION SHALL NOT DEVIATE FROM THE LOCATION DESIGNATED IN THESE PLANS BY MORE THAN 3" IN ANY DIRECTION IN ORDER TO ALLOW THE PRECAST ABUTMENT FOOTING AND WINGS TO BE INSTALLED.

Figure 8. Massena Bridge foundation notes

The factored axial load per abutment pile on this bridge was greater than that of the other two bridges covered in this section. This loading would require use of higher capacity helical piles if the same layout was maintained or multiple lower capacity piles if the layout was modified. Regardless, there is opportunity for the foundation plan to be optimized when considering the number of piles and final layout.

Little Silver Creek (2015)

Located on IA 92 over Little Silver Creek near Treynor, Iowa, the Little Silver Creek Bridge is a three-span, 234 ft long by 44 ft wide steel modular bridge constructed in 2015. The substructure is composed of integral concrete abutments supported on steel H-piling and two concrete-

encased, H-pile piers with concrete caps. The superstructure is a three-span continuous modular weathering steel welded girder structure with a cast concrete deck.

The substructure pile caps and wing walls at each abutment were precast offline, picked, and set over the top of driven H-piles. The pile caps and wing walls were formed with 1 ft 9 in. diameter, full-depth grout pockets aligning with the H-piles. Once each pile cap was set into place, the grout pockets were fill with high early-strength self-consolidating concrete. The pile layout is shown in Figure 9.

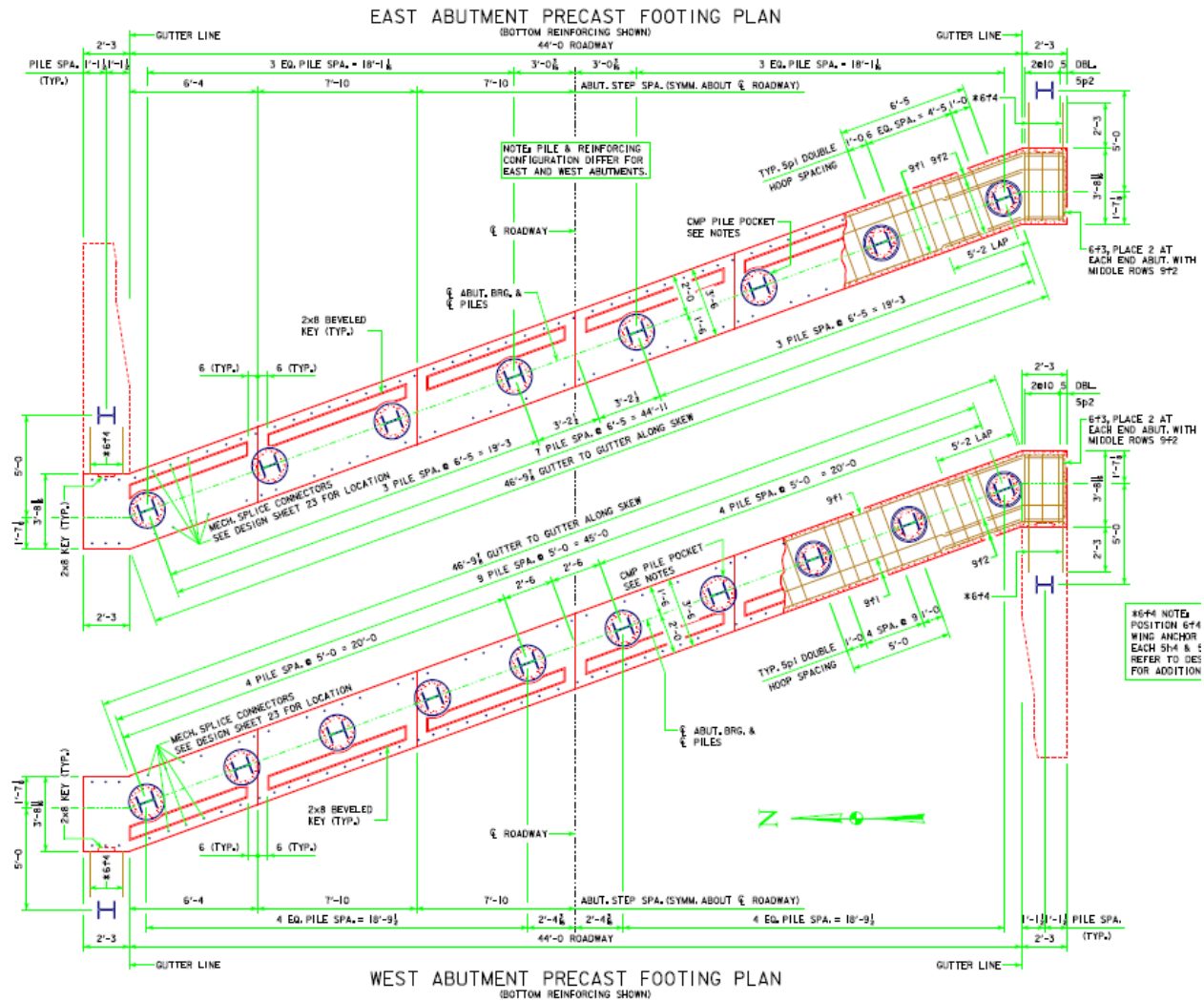


Figure 9. Little Silver Creek Bridge abutment plan and pile layout

The pile notes are shown in Figure 10, and the abutment pile summary is shown in Figure 11. Together, they show the size, bearing requirements, and quantity of piles planned for the abutments.

9	2501-0201057	PILES, STEEL, HP 10 X 57 PILES SHALL BE DRIVEN UNTIL DESIGN BEARING IS ACHIEVED AND THE PILES EXCEED THE MINIMUM DRIVING LENGTH NOTED IN THE PLANS. THESE REQUIREMENTS SUPERSEDE THE REQUIREMENTS NOTED IN SECTION 2501.03,0,2 OF THE STANDARD SPECIFICATIONS. SPLICES BETWEEN INDIVIDUAL LENGTHS OF PILE SHALL CONSIST OF FULL PENETRATION WELDS IN ACCORDANCE WITH SECTION 2501.03,2 OF THE STANDARD SPECIFICATIONS.
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Figure 10. Little Silver Creek Bridge pile notes

PILES, STEEL, HP 10 X 57 SUMMARY			
ITEM		EST. QTY	BID QTY.
WEST ABUTMENT	(12 @ 100 LF)	1,200	1,200
EAST ABUTMENT	(10 @ 100 LF)	1,000	1,000
TOTAL (LF)		2,200	2,200

Figure 11. Little Silver Creek Bridge pile estimated quantities

Additional pile notes are provided in Figure 12, stating the required nominal axial bearing resistance and construction control measures.

PILE NOTES:

THE CONTRACT LENGTH OF THE ABUTMENT PILES IS BASED ON THE DESIGN PARAMETERS LISTED IN THE "ABUTMENT PILE DESIGN (LRFD)" TABLE.

THE REQUIRED NOMINAL AXIAL BEARING RESISTANCE FOR ABUTMENT PILES AT END OF DRIVE (EOD) IS BASED ON THE PARAMETERS LISTED IN THE "ABUTMENT PILE CONST. CONTROL (LRFD)" TABLE. NOMINAL AXIAL BEARING RESISTANCE VALUES ARE BASED ON SOIL ELEVATION EQUAL TO THE BOTTOM OF FOOTING ELEVATION AT THE TIME OF PILE DRIVING.

ABUTMENT PILES SHALL BE DRIVEN UNTIL REQUIRED NOMINAL AXIAL BEARING RESISTANCE IS ACHIEVED AND THE PILES EXCEED THE MINIMUM DRIVING LENGTH NOTED IN THE TABLE (MEASURED FROM TOP OF PILE, AS EMBEDDED IN FOOTING). THESE REQUIREMENTS SUPERSEDE THE REQUIREMENTS NOTED IN SECTION 2501.03.0.2 OF THE STANDARD SPECIFICATIONS. CONSTRUCTION CONTROL REQUIRES A WEAP ANALYSIS WITH BEARING GRAPH. PILE DRIVING OPERATIONS SHALL CEASE AND THE ENGINEER SHALL BE CONTACTED IF PILES REACH PRACTICAL REFUSAL PRIOR TO ACHIEVING THE MINIMUM DRIVING LENGTH.

ABUTMENT PILE DESIGN (LRFD)		
DESIGN PARAMETER	W. ABUT.	E. ABUT.
SOIL CLASSIFICATION	COHESIVE	COHESIVE
GEOTECH. RESIST. FACTOR, "PHI" - SOIL	0.65	0.65
TOTAL FACTORED AXIAL LOAD, "PU" (KIPS)	137	137
NO. PILES	12	10
PILE TYPE (STEEL HP-SECTION)	HP 10 X 57	HP 10 X 57
CONTRACT LENGTH (FT)	100	100

ABUTMENT PILE CONST. CONTROL (LRFD)		
DESIGN PARAMETER	W. ABUT.	E. ABUT.
SOIL CLASSIFICATION	COHESIVE	COHESIVE
GEOTECH. RESIST. FACTOR, "PHI" - SOIL	0.65	0.65
NOMINAL AXIAL BEARING RESISTANCE (TONS)	105	105
MINIMUM DRIVING LENGTH (FT)	80	80

THIS PROJECT USES LOAD AND RESISTANCE FACTOR DESIGN (LRFD) METHODOLOGY FOR DETERMINING PILE CONTRACT LENGTH AND NOMINAL AXIAL BEARING RESISTANCE. NOMINAL AXIAL BEARING RESISTANCES WILL BE LARGER THAN BEARING VALUES IN THE PAST, BUT CONSTRUCTION CONTROL BLOW COUNTS WILL BE APPROXIMATELY THE SAME. A WEAP ANALYSIS AND BEARING GRAPH WILL BE PROVIDED BY THE OFFICE OF CONSTRUCTION THAT GIVES THE RELATIONSHIP BETWEEN REQUIRED NOMINAL AXIAL BEARING RESISTANCE AND BLOW COUNT.

FOR THE CONTRACTOR'S BIDDING PURPOSES, PARTICULARLY FOR SIZING OF THE PILE DRIVING HAMMER, THE APPROXIMATE PREVIOUS DESIGN METHODOLOGY BEARING VALUES AT END OF DRIVE (EOD) ARE GIVEN BELOW. THESE VALUES SHALL NOT BE USED FOR CONSTRUCTION CONTROL AND ARE GIVEN ONLY FOR COMPARATIVE PURPOSES.

APPROXIMATE BEARING USING PREVIOUS DESIGN METHODOLOGY:

W. ABUT: 47 TONS
 E. ABUT: 47 TONS

Figure 12. Additional Little Silver Creek Bridge pile notes

Similar to the Keg Creek Bridge, it is assumed that the substructure layout would not require change if helical piles were used in place of the H-piles, especially if a higher capacity helical pile was selected. However, the possibility exists to use a greater number of lesser capacity helical piles but maintain the same pile-in-CMP void form detail.

Construction Costs

Table 2 presents the as-built pile construction costs for these three ABC projects completed in Iowa.

Table 2. As-built pile construction costs

Bridge	Piles Used	Quantity	Unit Price	Extension	Factored Axial Load per Pile
Keg Creek (2011)	HP 10x57	1,920 LF (24@80 ft)	\$48/LF	\$92,160	130 kips
Massena (2013)	HP 14x117	2,090 LF (22@95 ft)	\$80/LF	\$167,200	237 kips
Little Silver Creek (2015)	HP 10x57	2,200 LF (22@100 ft)	\$51/LF	\$112,200	137 kips

To reiterate, the total costs correspond to the year in which each bridge was constructed. Each project used H-piles ranging from HP 10x57 to HP 14x117 in size. The total cost per foot installed ranged from \$48/LF to \$80/LF. It can be assumed the total cost is at least marginally higher in today's dollars. Comparing this range of costs to that given by the helical pile installer for helical piles (\$35/LF to \$75/LF) indicates a comparable cost for each deep foundation option.

Installation Demonstration

In conjunction with this project, the designer/installer who was preliminarily contacted for information provided an opportunity to the research team to observe the installation of a group of helical piles. These piles were installed in a location where the soil stratum was composed primarily of stiff to very stiff, sandy lean clay. The four piles were installed at the corners of an 8 ft 0 in. x 6 ft 0 in. box. The required allowable capacity was 80 kips.

The design was completed by the designer/installer using the soil boring logs provided. The design resulted in using Chance SS200 2 in. helical piers. The lead section helix configurations were 8 in., 10 in., to 12 in. diameter, with a 5 ft nominal base length. All piles were installed using an 18,000 ft-lb torque head. All material was galvanized per ASTM A153. Previous testing and factory recommendations assumed a ratio of ultimate capacity to torque of 10:1. All foundations were terminated with DYWIDAG bar adapters, bar, dished plates, and hex nuts.

A summary of the final installation lengths and capacities is provided in Table 3.

Table 3. Demonstration piles installation log

Helical Pier		Extensions		No. of Helices	Final PSI	Final 3 ft Torque (ft-lbs)	Total Length (ft)	Cut Off (ft)	Final Length (ft)	Skin Friction (kips)	Allowable End Bearing Capacity (kips)	Allowable Friction Capacity (kips)	Combined Allowable Capacity (kips)
No.	Size	10 ft											
1	2	2		3	2,800	14,300	25	0.0	25.0	10.2	71.5	10.2	81.7
2	2	8		3	2,200	6,600	85	0.0	85.0	50.9	33.0	50.9	83.9
3	2	8		3	2,200	6,600	85	0.0	85.0	50.9	33.0	50.9	83.9
4	2	8		3	2,200	6,600	85	0.0	85.0	50.9	33.0	50.9	83.9

The installation log is a good example of the inherent adaptability of helical piles during installation. While Pile No. 1 was being installed, a hardened subsurface layer was encountered. The pile length, in comparison to the others, was substantially shorter. Despite this fact, the required capacity was still met with a greater attribution to end bearing capacity in lieu of the skin friction, which the others primarily rely on. The capacity could be determined real-time in the field given the capacity is a function of the torque ratio.

Images of the installation are shown in Justin Dahlberg, Bridge Engineering Center

Figure 13 through Figure 21, which include the lead sections, extensions, torque motor, and other installation equipment.



Justin Dahlberg, Bridge Engineering Center

Figure 13. Preliminary pile location layout



Justin Dahlberg, Bridge Engineering Center

Figure 14. Lead helix sections (8 in., 10 in., and 12 in.)



Justin Dahlberg, Bridge Engineering Center

Figure 15. Tips of lead sections



Justin Dahlberg, Bridge Engineering Center

Figure 16. Extension sections



Justin Dahlberg, Bridge Engineering Center

Figure 17. Placement of lead section



Justin Dahlberg, Bridge Engineering Center

Figure 18. Lowering of the torque motor to engage the lead section



Justin Dahlberg, Bridge Engineering Center

Figure 19. Beginning of lead section installation



Justin Dahlberg, Bridge Engineering Center

Figure 20. Small-sized excavator (CAT 311) equipped with torque motor



Justin Dahlberg, Bridge Engineering Center

Figure 21. Continuation of installation with extension added

DECISION MAKING FRAMEWORK

Several deep foundation options exist from which engineers can select. It is likely one or two options have been the most commonly selected based on historical use and proven functionality. Introducing another option can introduce uncertainty if a suitable decision making framework is not available to the engineer. In such cases, the default will be to consider previously used deep foundation options.

Two tools to help direct the decision in consideration of helical piles were developed and are presented in this chapter. First, the flowchart (Figure 22) provides a systematic step-through of questions and instructions to conclude whether the use of helical piles or another deep foundation system is most suitable.

Second, a matrix of questions (Table 4) is provided to help direct the engineer toward a decision of helical pile suitability. The questions are categorized by 1) Site and Constructability, 2) Geotechnical, and 3) Design Considerations. A response of Yes, No, Maybe, or N/A should be provided for each question.

Any questions answered as other than Yes do not discount helical piles from being used. Rather, additional considerations should be evaluated before a final decision is made. The commentary provided for each question provides additional information and instruction to assist the user in their decision.

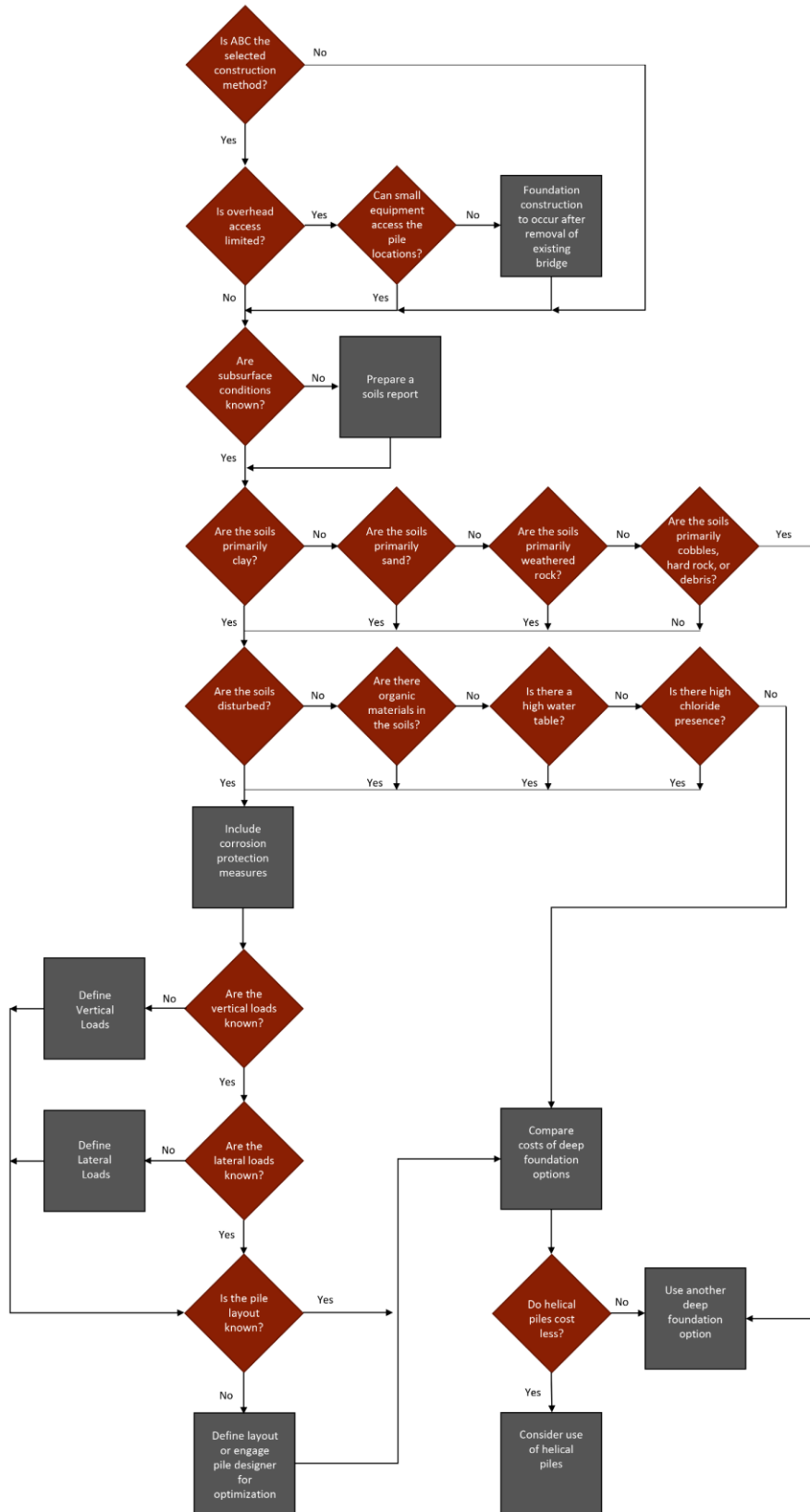


Figure 22. Flowchart for use of helical piles or another deep foundation system

Table 4. Questions for helical pile suitability

Question	Yes	No	Maybe	N/A	Commentary
Site and Constructability					
Does the site topography allow access for multiple types of smaller equipment? (mini-excavator, rubber-tired backhoe, small-tracked machine)					Helical piles can be and are most often installed without the use of larger equipment—an advantage to using helical piles if site access for larger equipment is difficult.
Does the schedule require accelerated construction of deep foundations?					Helical pile installation can be completed more quickly than more traditional deep foundation options.
Are there overhead obstructions?					Overhead obstructions may limit or prohibit the use of larger equipment. Helical piles can be installed in low-overhead-clearance conditions.
Can welding and torch cutting be safely conducted on site?					Welding and/or torch cutting may be necessary to complete helical pile installation and should be considered if these activities can be safely completed.
Can large equipment access the site? (excavator)					In some instances of high-capacity helical piles, a larger excavator may be required for installation.
Geotechnical					
Are the subsurface conditions known?					A soils report will provide the necessary information for helical pile design. Unknown subsurface conditions do not necessarily prohibit helical pile use. Rather, uncertainty will be introduced into preliminary design.
Is the soil cohesive (clay)?					Helical pile use is conducive to cohesive soils.
Is the soil non-cohesive (sands and gravels)?					Helical pile use is conducive to non-cohesive soils.
Is there a presence of cobbles, hard rock, or debris?					The presence of cobbles, hard rock, or debris does not necessarily prohibit the use of helical piles, but special attention should be paid to these soil conditions given a more suitable foundation option may exist. Typical penetration limits for helical piles are 70 psf ultimate bearing pressure.
If weathered rock is present, is the strength known?					Weathered rock can provide additional end bearing capacity to helical piles.
Is corrosion protection of the piles required?					It is typical for helical piles to be corrosion-protected prior to onsite delivery. This affords the piles more protection against corrosive environments.
Will the piles be installed into disturbed soils?					The oxygen content in disturbed soils is greater, which can lead to increased corrosion rates of unprotected steel.
Will the piles be installed into soils that contain cinders or high concentrations of organic materials?					Organic material can increase the rate of corrosion on bare and protected steel. Adding sacrificial thickness in severe conditions is common.

Question	Yes	No	Maybe	N/A	Commentary
Is the pile being installed into soils where the water table fluctuates and has appreciable salt content?					Corrosion of steel is accelerated in partial submersion zones. Sacrificial thickness and hot-dipped zinc galvanization can be used to protect the piles.
Design Considerations					
Is there a governing code for helical pile use/installation at the location of the bridge?					
Are the vertical loads for the foundation structure known or reasonably estimated?					Helical piles come in numerous sizes. The capacity is a function of size and soil conditions.
Are the lateral loads for the foundation structure known or reasonably estimated?					Battered helical piles can be used in cases where the lateral loads are significant.
Are overturning loads for the foundation structure known or reasonably estimated?					Helical piles offer significant tensile load capacity.
Is there a preferred pile layout?					Helical piles are generally adaptable to any preferred layout. However, the layout and pile size can be optimized if a specific layout is not required.
Is there a tolerable maximum displacement?					Helical piles offer similar maximum displacements as other deep foundation options.
Will multiple piles in single locations be allowed in the event of large loads?					Where large loads exist, helical pile sizes can be increased or multiple smaller piles can be used.
Will the pile layout be prescribed by the bridge designer?					A prescribed pile layout can be restrictive to a helical pile designer. Collaboration between the bridge designer and pile designer is recommended.
Can the pile spacing be optimized by the pile designer?					It is recommended that the helical pile designer be involved early on in order to optimize the pile size and layout.
Will battered piles be allowed to resist lateral loads?					Battered piles reach beyond the plan dimensions of the pile layout and should be coordinated with other underground objects.
Can the foundation reinforcement be readily kept free from touching the helical piles?					Steel reinforcement in contact with steel piles, including helical piles, has the potential to increase corrosive action. Ensuring non-contact where the pile terminates into the footing reduces the potential.
Totals:					

SUMMARY AND CONCLUSIONS

ABC can benefit from the accelerated construction of foundations of bridge structures. There are opportunities to further decrease project duration and reduce disruption to road users with the adoption of newer or lesser-used foundation technologies.

One such technology is helical piles. Helical pile foundations have become commonplace in new commercial building construction and foundation repair applications with many foundation installers now offering this technology as one of their services. Installers tout the simplicity and speed of installation, along with the ability to work within areas of limited size with smaller equipment. The required equipment for installation (skid steer, backhoe, or excavator) lends itself to quick deployment and being an economical solution (i.e., excavator vs. crane), an advantage for any bridge project, but particularly for low-volume roads where budgetary considerations tend to be a specific priority.

From a design perspective, the technology is fairly well-defined. There has been extensive research and development of helical piles completed, which includes such things as pile configuration, soil interaction, durability, etc. Design guides have been published and several design software packages exist to assist the designer. The load carrying capacity is well-known and is also verifiable by correlating the capacity to the torque of the installation equipment. The capacity of helical piles is on par with several other deep foundation technologies. Helical piles have been proven effective in the building industry and their use has been codified in the US since 2009.

In recent history, a concerted effort was put forth to introduce this deep foundation option to the building industry by many individuals and organizations. Conversely, minimal effort has been allocated to doing the same for the bridge industry. This is not for lack of potential application, but rather a need to focus the effort in one area to effectively move it forward. One nationally recognized leading expert of helical pile use has suggested this was the case and recognized the opportunity for use in bridge foundation structures.

A comparison of deep foundation costs of three completed ABC projects in Iowa to the expected helical pile costs shows the costs of helical piles (\$35/LF to \$75/LF) to be within the range of that for the H-piles (\$48/LF to \$80/LF) previously installed. Costs are ultimately dependent on the soils present and number of piles required to resist the load. However, generally speaking, past projects are a good indicator of future expectations. It is likely the remaining portions of the substructure would maintain the same or with slightly modified connection detailing, so any deviation in costs is substantially in the deep foundation elements.

Decision making tools were developed for the owner and/or engineer in the form of a flowchart and a table matrix. Together, these tools help direct decision making with respect to the suitability of helical piles as a deep foundation option. A series of questions was produced to draw attention to the particular points of emphasis that must be considered when choosing helical piles.

Recommendations for Additional Research

This report gives an overview of helical pile technology, its costs, and where it is most suitable. Given this information, it is clear there can be widespread application on bridge projects. However, implementing this technology on a more regular basis on bridge projects will require the development of a bridge-specific design guide for helical pile use on ABC projects.

Furthermore, a demonstration project would be beneficial to prove the efficacy of helical pile use on bridge projects. Working together with key stakeholders (owners, engineers, and contractors), plans and specifications would be developed and would establish a starting point for these documents going forward.

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Webinar Resources

- Seider, G. May 28, 2020. *Innovations in Piling III*. Webinar. Hubbell University.
- Seider, G. September 24, 2020. *Innovations in Piling IV*. Webinar. Hubbell University.
- Seider, G. March 25, 2021. *Innovations in Piling V – Square vs. Round Shaft*. Webinar. Hubbell University.
- Seider, G. April 28, 2021. *Precision Design with HeliCAP*. Webinar. Hubbell University.

