Author: **Corson, Cory R.**

Title: ***Developing WisDOT Standard Specifications for Helical Piles***

The accompanying research report is submitted to the **University of Wisconsin-Stout**, **Graduate School** in partial completion of the requirements for the

Graduate Degree/ Major: MS Construction Management

Research Advisor: Tim Becker, Associate Professor

Submission Term/Year: Summer 2019

Number of Pages: 58

Style Manual Used: American Psychological Association, 6th edition

☒ **I have adhered to the Graduate School Research Guide and have proofread my work.**

☒ **I understand that this research report must be officially approved by the Graduate School.** **Additionally, by signing and submitting this form, I (the author(s) or copyright owner) grant the University of Wisconsin-Stout the non-exclusive right to reproduce, translate, and/or distribute this submission (including abstract) worldwide in print and electronic format and in any medium, including but not limited to audio or video. If my research includes proprietary information, an agreement has been made between myself, the company, and the University to submit a thesis that meets course-specific learning outcomes and CAN be published. There will be no exceptions to this permission.**

☒ **I attest that the research report is my original work (that any copyrightable materials have been used with the permission of the original authors), and as such, it is automatically protected by the laws, rules, and regulations of the U.S. Copyright Office.**

☒ **My research advisor has approved the content and quality of this paper.**

STUDENT:

NAME: Cory R. Corson **DATE: September 6, 2019**

ADVISOR: (Committee Chair if MS Plan A or EdS Thesis or Field Project/Problem):

NAME: Dr. Tim Becker **DATE: September 6, 2019**

This section for MS Plan A Thesis or EdS Thesis/Field Project papers only

Committee members (other than your advisor who is listed in the section above)

1. **CMTE MEMBER'S NAME:** **DATE:**
2. **CMTE MEMBER'S NAME:** **DATE:**
3. **CMTE MEMBER'S NAME:** **DATE:**

This section to be completed by the Graduate School

This final research report has been approved by the Graduate School.

Director, Office of Graduate Studies: **DATE:**

Corson, Cory R. ***Developing WisDOT Standard Specifications for Helical Piles***

Abstract

The definition and integration of universal provisions for new standard bid items in WisDOT Standard Specifications is recognized as a challenging assignment. Before a proposed specification can be implemented, delineating material, construction, and compensatory language that can be universally applied across all projects must be established. The following work initiates discussion and research for implementing the first-ever standard specification for helical piles to be included in WisDOT's Standard Specification.

For the purpose of the study, data was collected from two special provisions accepted by WisDOT, one IowaDOT special provision, and three proprietary specifications created by independent helical pile manufactures. From this pool of information, research was conducted to verify the appropriateness of the various material requirements and the construction techniques to meet WisDOT's needs. Furthermore, the proposed standard was compared against like-kind specifications to ensure procurement and material specifications were analogous.

The research contained in this work results in a baseline specification for which WisDOT may conduct further research and product testing. The research does not prove or disprove engineer calculations and should carefully be reviewed before acceptance. The end product of this work is intended to provide designers and contractors with adequate guidance to design and construct helical piles.

Acknowledgments

The ability to pursue continuing education, while working full-time and serving my country has been invaluable to my personal and professional development and is attributed to the program delivered by the University of Wisconsin System and the University of Wisconsin Stout. With continued support from friends, family, advisors, and colleagues, I was able to complete my masters program in Construction Management at the University of Wisconsin Stout.

I would like to thank my advisor, Dr. Tim Becker, for his continued support and guidance throughout the graduate component of my academic career. His background in the construction industry was instrumental in helping me understand current practices in the industry and he explained how innovation is what drives the future in a progressive and continually evolving field of study. His relentless dedication toward communication, encouragement, and accountability ensured I remained motivated to complete my work. Regardless of the obstacles that I faced, he provided me with tools and resources necessary to make sure I was successful.

A special thank you is owed to Mr. Tom Miller of SX Foundations. My interest in helical piles stems from a 2016 project where I was the project engineer, and helical piles were proposed and accepted as a cost reduction incentive. Following the successful implementation, Tom was instrumental in connecting me with helical pile manufacturer. He also provided numerous resources used to collect information for the subsequent proposed specification.

Lastly, I would like to thank my family and friends that have supported me throughout my academic career and motivated me along the way.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

Innovation in the highway construction industry presents itself in many forms from new products to improve construction practices. Enhancements in environmental sustainability, safety, and efficiency are universally welcomed; however, the leading issue with integrating new ideas is gaining industry acceptance to become standardized. The ensuing research expresses the importance of standardizing the design and construction of helical pile foundations within the Wisconsin Department of Transportation's Standard Specifications.

The initial application for helical foundations was conceptualized in the late 1800s as a simple mechanism used for supporting structures in unstable soils. Known as helical screws or screw-piles, these large-scale mechanisms utilized the same mechanical principles as a typical screw; however, screw-piles were used to support foundations of a significantly greater magnitude. Although the fundamental principles have not changed, the complexity and diversity of the modern helical foundation has allowed it to be applied across numerous construction disciplines and various engineering applications.

The Wisconsin Department of Transportation, commonly referred to as the department, is the governing agency responsible for oversight of the state's transportation networks. As a self-governing agency with oversight from the Federal Highway Administration and Federal Department of Transportation, the department is responsible for transportation projects from inception through completion. With respect to the design and construction of transportation infrastructure, one of the department's responsibilities includes developing and revising standard specifications. Standard specifications are an annual publication containing approved direction and contract language to be followed through the design and construction of department infrastructure projects. The complete standard specification is organized into seven parts that categorize unique specifications based on the type of construction. Each part contains a number of sections that are specific to an item or group of items. Individual items include five subsections: General, Materials, Construction, Measurement, and Payment. Respective sections depict guidelines required for compliance with department criterions.

Implementing new standards is a detailed process performed by both federal and state Departments of Transportation. The elaborate deliberation over the importance and necessity of adding a standard is debated before resources are allocated for research and development. Following an agreement that a standard is needed, a considerable amount of resources are expended collecting qualitative and quantitative data from lab and field research. From this research, a draft specification is developed using conclusions from the data collected. When the draft standard is presented to the department, it will go through extensive review before it is either added to the standard specification or returned for further review.

Detailed guidance with respect to design and construction of helical piles has yet been published within the department's standard specification, and therefore potentially indicates one or more of the following issues: Helical piles have not attained sufficient industry acceptance, there is inconclusive research to derive a standard, and the various engineering applications result in uncertainty in defining common material and construction practices. Projects that have incorporated standards for helical piles on projects did so by publishing special provisions. Special provisions are supplemental, contract-specific documents used to distribute requirements for items not covered in the standard specification. Although effective for project-specific requirements, special provisions are not consistent from one project to the next. This creates additional department validation to ensure the special provision is acceptable. With a standard specification the department would be able to ensure helical pile deliverables are consistent from one project to the next with some variance in size, quantity, and configuration based on project-specific criteria.

The proceeding research will evaluate historically accepted special provisions articles used for the design and construction of helical piles and analyze recent research conducted in order to define an initial outline for standard specification integration. The aforementioned outline will be prepared using the Wisconsin Department of Transportation Standard Specification format and will be provided to the department for future review and acceptance.

Statement of the Problem

Before helical foundations can become a standardized item in the Wisconsin Department of Transportation standard specification, identification of universal material requirements and specific construction practices needs to be developed. Without a clear standard specification for the implementation of helical piles, designers and contractors are not provided with adequate guidance for design and construction.

Purpose of the Study

The subsequent evaluation of current practices and recent research will be assessed to determine suitable applications for helical piles, identify potential material requirements, and investigate general installation procedures. The findings of this research will then be used to develop an initial standardized helical pile specification with the intent that the department incorporates it into future editions of the published standard specification.

The objectives of this study are to:

1. Analyze approved special provisions for helical foundations.
2. Evaluate manufacturer-proposed helical pile specifications.
3. Determine areas for future research.

Assumptions of the Study

The assumptions of this study are:

1. The Wisconsin Department of Transportation will use the research provided within this work to justify further research and derive a standardized specification for helical piles.

Definition of Terms

The subsequent professional organizations are involved in the development of material and construction standards and are recognized across their respective industries. Their abbreviations are frequently used throughout this work.

American Society of Civil Engineers (ASCE). Provides technical and professional standards and is the authoritative source for codes and standards that protect the public.

American Welding Society (AWS). Provides industry knowledge, resources and tools pertaining to the science, technology, and application of welding, allied joining and cutting processes.

Federal Highway Administration (FHWA). Provides research, regulations, and technical standards to state and local agencies on transportation safety and policies.

International Building Code (IBC). Provides building codes and regulations as well as design standards and considerations for the construction industry.

Society of Automotive Engineers (SAE). Provides technical and professional standards for the aerospace, automotive and commercial-vehicle industries.

Limitations of the Study

The limitations of this study are:

1. This research will propose a draft specification based on observed trends and manufacturer recommendations, and should not be regarded as the final accepted standard specification.
2. The study will not prove or disprove structural or geotechnical calculations.
3. Implementing change within the department standard specifications requires a process of influence outside of the scope of this study.

Methodology

The following research will examine the requirements necessary to successfully draft the first standard specification for helical piles. This will be accomplished by analyzing historically accepted special provisions from WisDOT and IowaDOT projects, the examination of feedback from industry leaders who currently design helical piles for the department, and by means of integrating previously accepted standards from the International Building Code, (IBC). The result will be a standard specification for helical piles that can be presented to WisDOT for analysis and incorporation into future published editions of the Standard Specifications for Highway and Structure Construction.

Chapter II: Literature Review

This chapter summarizes relevant literature regarding the need for implementing a helical pile standard. It presents sustainability, safety, and efficiency benefits and examines content employed in past WisDOT, IowaDOT, and manufacturers' special provisions that can be used as a specification framework. The cited work has been collected from scholarly journals, published research articles, and independent helical pile manufacturers.

Justification for a Standard

In an article published in Soil Mechanics and Foundation Engineering, Ponomarenko and Baranov's (2013) supported helical piles as a promising foundation substitute for alternative pile types; however, noted that regulatory literature currently utilized in the field of pile-foundation design contains insufficient information for successful use of helical piles (Ponomarenko & Baranov's, 2013). Insufficient regulatory literature or standards can be attributed to the limited number of full-scale tests that have been performed on helical pile foundations, according to DiGioia (2012), leading to significant variations in reliability. DiGioia (2012) adds that a need exists to assemble currently available full-scale load test data for helical pile foundations and that additional full-scale tests should be conducted.

Helical piles have proven to be a viable foundation alternative for several engineering applications due to enhancements in environmental sustainability, construction safety, and installation efficiency (Bobbitt & Clemence, 1987; Helical Pile Association [HPA], 2016; International Society for Helical Foundations [ISHF], 2016; Perko, 2009). Each of these considerations is expanded upon in the following subsections though these benefits will not be included in the deliberation of the proposed specification.

Sustainability. Helical pile foundations have shown to reduce the environmental impact within the construction footprint. In foundation construction, the environmental impact on the surrounding setting can be measured in many ways; however, the two most significant measures include minimizing the construction footprint and eliminating the various forms of pollution.

Installing foundations without having an impact on the surrounding environment is crucial for structures constructed in environmentally sensitive areas as the fees to mitigate wetlands are costly. According to Kremer (2017), the cost for wetland credits can cost in excess of $70,000 per credit contingent on the species, size, and location of the wetland. The ability for helical pile installation with no site preparation, minimal spoils from installation, and no residual impacts on the surrounding area are some of the main benefits to helical pile foundation (HPA, 2016; ISHF, 2016; Perko, 2009). Site preparation, installation spoils, and site restoration are commonly associated with traditional foundations. Elimination of the identified impacts in environmentally sensitive areas saves money and ensures the structure can be constructed in a sustainable manner.

Noise and vibration pollution are among the most significant setbacks for traditional foundations. In an analysis on noise pollution at high rise building sites, De Araújo, Gusmão, Rabbani, and Fucale (2012), found that noise levels exceeded the maximum decibel limit in 68 of the 71 locations during installation driven-piles; however, helical foundations were able to be installed without similar results (De Araújo, Gusmão, Rabbani, & Fucale, 2012). Vibration pollution is also a concern that affects humans, structures, and wildlife. Woods (2007) observed the consequences of ground-borne vibrations in that it resulted in the generation of physiological stress in humans and wildlife. In addition, the impacts from pile driving make buildings susceptible to various levels of damage from fatigue cracking to destruction of building components (Woods, 2007).

Construction safety. Traditional pile driving operations are notorious for triggering injuries and fatalities among laborers and operators involved with construction operations. Structural iron and steelworkers, to include pile drivers, ranked number seven on TIME magazine's most dangerous jobs in America for 2014. According to Johnson (2016), the rate of fatal injuries was 25.2 per 100,000 people for structural iron and steelworkers. The Department of Labor's Occupational Safety and Health Organization, (OSHA), division is responsible for collecting, reviewing, and reporting workplace conditions, injuries, and fatalities. According to a 2018 study, OSHA reported that 81 injuries and fatalities were reported and sustained from pile-driving operations in the United States since 1984 in comparison to one reported incident involving helical pile installations. OSHA (2018) acknowledges the majority of the risks associated with pile driving operations were the workers' proximity to hazards and site working conditions. Since workers are required to be in direct contact with piles during installation, the leading causes of pile driving incidents include caught-in/between, fall, and struck-by (OSHA, 2018). In an assessment of the ergonomic hazards associated with pile driving operations, Dasgupta, Fulmer, Jing, and Buchholz (2012) found that the accumulation of musculoskeletal stressors is derived from unsuitable ground conditions in addition to awkward working positions. The installation procedure for helical piles removes workers from the installation point and significantly reduces the probability of injury and death.

Installation efficiency. The ability to complete work in an efficient manner minimizes construction costs. According to the ISHF (2016), helical piles have the ability to advance at approximately 30 seconds per foot, and once the installation is complete, the pile is able to support loads from the overlying structure immediately. In contrast, additional measures are required to prepare pile-driven, drilled shaft, and cast-in-place foundations; such as cure time for concrete. Perko (2009) attributes an increase in installation efficiency to the various methods of installation, equipment versatility, and the ability for helical pile foundations to be installed in virtually any location.

Helical pile foundations present arguable advantages over traditional foundations when it comes to sustainability, construction safety, and installation efficiency. The next step in creating a new standard specification is developing the standard and determining the requirements that need to be identified.

Developing the Standard

Material requirements and construction procedures for helical pile design, layout, installation, and measurement are exclusively defined in special provisions when being used on WisDOT projects. This section examines three known special provisions from past WisDOT and IowaDOT projects in an attempt to identify similarities that may be useful in developing a standard. They are:

Project 4996-01-58 Taylor Drive, Kohler Memorial Drive – Crocker Ave.

Project 5992-08-85 Lower Yahara River Phase One, Capital City Trail – McDaniel Park

Project NHSN-030-1(161)--2R-43 Harrison County

A review of the aforementioned special provisions will also contain supplementary information from various organizations and research devoted to the development of helical pile foundations.

The material and construction sections contain the majority of the valuable content in a specification. These sections contain important resources used to assist designers and contractors as they present acceptable standards that must be followed for the work to be accepted by the department. Other sections include general, measurement, and payment, which will not be discussed as the formats have been previously established by the department.

Materials. The materials section contains a composite list of specific standards and testing requirements unique to the manufacturing of helical pile assemblies to ensure that the final product is satisfactory. Typical assemblies include, but are not limited to, the driver interface (bracket), shaft extensions, couplings, helix plates and pilot points (See **Error! Reference source not found.**).

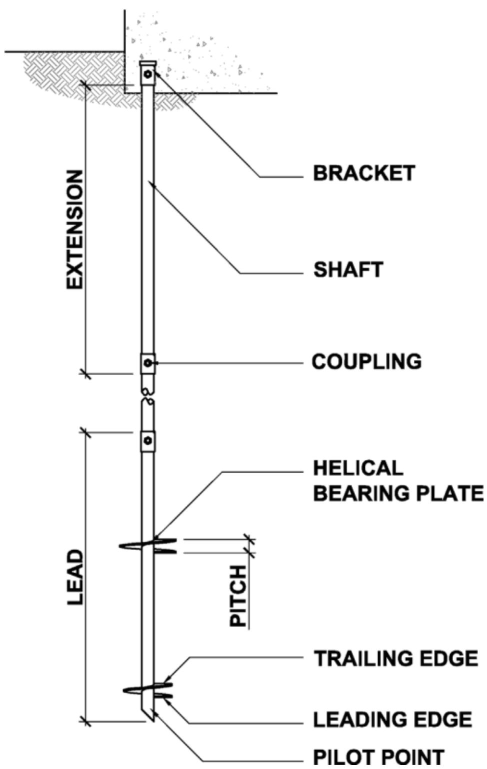

Figure 1. Helical pile components. (From Helical Piles: A Practical Guide to Design and Installation, by H. Perko, 2009)

Additional subsections organize relevant requirements for these individual components. The first subsection typically identifies unique standards that are to be used for selecting material and testing procedures. Department specifications often extract standards form the American

Society for Testing and Materials, (ASTM), as they are experts in material research and testing. The Taylor Drive and Yahara River projects use similar standards for identifying material requirements. A list of the specific standards are presented in Appendix A. Each of these standards is recognized by the International Code Council's, (ICC), Acceptance Criteria for Helical Foundation Systems and Devices (2007) and IBC (2015). These standards assist designers in determining the size, orientation, and material composition of foundation components in addition to specifying testing required for material acceptance.

In addition to the aforementioned material requirements, the Federal Highway Administration, (FHWA), operating under the U.S. Department of Transportation, enforces a special requirement for all steel or iron products used on department projects. The Buy America Act was established to ensure that all steel and iron products must be smelted, rolled, and manufactured from domestic materials (FHWA, 2016). This requirement, although not specifically referenced in each specification, respectively, would be applicable to the helical pile specification.

Subsections within the special provisions for the three identified department projects include detailed requirements for design and submittals. The design requirements are unique to the project and cannot be generalized. The IBC (2015) identifies that design requirements and materials must represent findings of a professional assessment as each foundation possesses unique design characteristics. This process begins with a comprehensive structural and geotechnical assessment. The results of this assessment are used to determine the dimensions, configuration, and orientation of the foundation.

The submittals associated with helical pile foundation installations include design calculations and drawings, construction procedures, material reports, equipment calibration reports, and installation records (Taylor Drive & Yahara River, 2015). These submittals are provided to the field engineer prior to work commencing for review and acceptance.

Construction. Standardized installation procedures are not likely achievable as the individual procedures are expected to be unique to the particular foundation. The department, however, can develop standard methods to ensure the installation meets the requirements specific to the design requirements as seen in the special provision for the identified department projects. As it is a required submittal, construction procedures have to be established and verified by the department prior to installation. These predesignated procedures, which are contingent on ASCE 20-96, should be approved for proper installation.

The department must also define the requirements essential for installation. Specifying minimum requirements for installation equipment and tooling will ensure that results, regardless of the installer, are consistent. Supplementary requirements added by section 1810.4.11 (IBC, 2015) and 4.2.1 (ICC, 2014) guarantee that the foundation should be installed correctly if followed. The specific limits of installation are subject to the design criteria; therefore, the information provided in a standard specification can only refer the installers to these documents.

The collection of installation records is the most effective way to determine if the foundation is installed according to the designed requirements. It is also imperative that equipment calibration is performed regularly to ensure the observed readings are representative of the actual results (ICC, 2014). Equipment verification checks should be an integral part of the installation and a standard should be set to determine the consistency of the equipment. The ICC provides a standardized procedure for performing verification checks (ICC, 2014).

The objective of a unified helical pile specification is justified within this chapter as expressed by federal, state, and private entities on the grounds of sustainability, safety, and efficiency. In developing a standard specification, the requirements of all invested contributors must be accounted for in order to gain lateral acceptance. This includes extracting information contained within past department special provisions, current manufacturer specifications, and industry standards to aid in the compilation of the first universally accepted specification framework.

Chapter III: Methodology

Assembling, deducing, and validating collections of special provisions, manufacturer specifications, and industry standards present certain challenges. Individually, each entity making a claim to a, “best practice,” endorses arguments that their respective specification works best with their product; however, collectively the definitive parallels in specifications do not always align. Therefore, it was concluded that the most effective method for determining a suitable specification for Wisconsin Department of Transportation would be to collect creditable material and construction specifications, determine a hierarchy of precedence, and eliminate redundancies where possible.

Analysis Framework

The methodology used to draft what is believed to be the first helical pile specification for the department is shown below (See **Error! Reference source not found.**). This chapter e xamines how information was assembled, reasoned, and validated in the process of refining the proposed specification.

Figure 2. Research methodology data collection procedures.

The five-step process presented in **Error! Reference source not found.** provided the f ramework necessary to ensure the collected research was clearly organized, logically evaluated, and properly cited to allow ensuing research. In the following subsections, each abbreviation is further defined and elaborates on what work was performed to satisfy the intent of the research.

Justify a standard. The efforts dedicated to this research paper would be irrelevant if a standard was not first justified. Given the collection of scholarly studies, professional research, and published work presented in chapter 2, it is evident that an argument exists based on construction sustainability, safety, and efficiency. Helical piles also unarguably provide monetary savings to the customer. An indication that the department is invested in helical piles is made known by the recent re-emergence of helical piles on construction projects. It is fair to speculate that further acceptance will be achieved with the development of a standard specification.

Develop a baseline. To prevent the results of this research from being subjective, the basis for analysis will remain consistent between the various specification sources. Each source will be organized into the five subsections found within a typical WisDOT standard specification: General, Materials, Construction, Measurement, and Payment. As previously discussed, this research will only compare and analyze the Materials and Construction subsections; however, the proposed specification will include the other subsection. A hierarchy of precedence will be established to define which standards hold greater value over others.

The hierarchy of precedence established for this research follows industry standards. As represented below (See **Error! Reference source not found.**), building codes and criteria take p recedence over all other standards. Codes and criteria set the foundation that must be followed by federal, state, and local levels. The succeeding are professional organizations. Organizations such as ASCE, AWS and SAE have precedence over federal and state administrations as they set industry standards based on their respective fields rather than standards based on internallydriven requirements. Federal and state administrations followed by manufacturer specifications make up the remaining steps of the hierarchy with increasing levels of specialization within the standard at each respective level. The Wisconsin Department of Transportation, Bureau of Technical Services is responsible for developing and refining new and existing specifications in accordance with industry and department codes and criteria. Initiating research and development for a helical pile standard specification would have to be pushed from the field or initialized from within.

Figure 3. Hierarchy of organization precedence.

It is important to note that within the Wisconsin Department of Transportation, there is an administration-defined hierarchy within, as discussed in chapter 1. The order of precedence within department contract documents in increasing order of importance are: Standard Specifications, Additional Special Provisions, Plans, Special Provisions, and Addenda. It is important to recognize these hierarchies, as they contribute to the analysis and validation of standards used in chapter 4.

Integrate and compare existing standards. Established specifications, standards, code, and criteria were collected from department special provisions, proprietary manufacturers, and from IBC and UFC guidance. After each respective source was organized into the aforementioned subcategories, the real work began with the process of analyzing and validating the information. A critical part of the analysis was spent identifying redundant information; otherwise, specifications called-out in other related pre-existing specifications. The remaining information was compiled for validation against other specifications and rated against the hierarchy of precedence.

Critical content review. Baseline material and construction standards were derived from observed trends across specifications and recommendations throughout the hierarchy of precedence. If one standard was outlying from the others, a more thorough examination was initiated. Construction specifications were interpreted differently with each standard yet defined basic specification language that would be suited for a standard. Levels of details that cannot be defined by this research will be left to the project design engineers for clarification.

Draft a standard. The specification presented in Appendix A is an accumulation of carefully selected special provisions, manufacturer specifications, and industry standards. The final product is intended to deliver a universally accepted standard specification for helical piles. It not only tactfully mirrors the format, language, and detail of other WisDOT specifications of its kind, but it also provides clear requirements without patent ambiguities.

Baseline Sources

Prior to refining, categorizing, and validating specific requirements within the specification, general provisions needed to be collected. To accomplish this, a collection of codes and criterion, special provisions, and manufacturer specifications were compiled. The sources used to establish the baseline standard are listed below (See **Error! Reference source not found.**). The intent was to collect as many reputable specifications that are available, analyze their content, and extract the useful data needed to create a draft specification.

Code and Criteria	International Building Code, IBC
	Unified Facilities Code, UFC
WisDOT Special Provision	Project 4996-01-58 Taylor Drive, Kohler Memorial Drive – Crocker Ave.
	Project 5992-08-85 Lower Yahara River, Capital City Trail – McDaniel Park
IowaDOT Special Provision	Project NHSN-030-1(161)--2R-43 Harrison County
Manufacturer Specification	EBS Geostructural, Inc.
	Supportworks, Inc.
	MacLean Dixie Anchoring Systems
	Magnum Piering Inc.

Figure 4. Sample specification sources.

Specific requirements were evaluated once the general format was identified. The sources in **Error! Reference source not found.** were selected based on their availability and the comparative information they provided.

Data Analysis

The data analysis performed in this research extrapolates qualitative data rather than quantitative; therefore, data samples consist of gathered material and construction requirements in lieu of statistical models, predictive analytics, and trend correlations. To explain how this procedure works, an example analysis used to determine the requirements for helical pile coatings is provided in **Error! Reference source not found.**. Note the specification sources in the left column and the correlating standard from that source in the right column. This structure will be used to collect extracted material standards from the previously acknowledged sources. After the requirements have been identified, a synopsis discussing the results will be provided. If the results are unanimous, the standard will be incorporated into the draft standard in

Appendix A however, if one or more of the specifications do not agree, an investigation and interpretation will be provided.

Table 1

Data Analysis Example for Helical Pile Coatings

Source	Standard
WisDOT - Project 4996-01-58	ASTM A153
WisDOT - Project 5992-08-85	ASTM A153
IowaDOT - Project NHSN-030-1(161)--2R-43	Not Defined
EBS Geostructural, Inc.	ASTM A153
Supportworks, Inc.	ASTM A153
MacLean Dixie Anchoring Systems	ASTM A153

Construction standards will be evaluated by means of semantic interpretation. This means that each source's construction requirements section will be defragmented to extract relevant information that may be worthwhile in the draft specification. Again, any trend in the data will be examined and include commentary to summarize the findings.

The objective of this research was not intended to develop an independent helical pile specification. The methodology used identified patterns in the specifications that already exist. It also determined if the same requirements and language are being used and developed a standard specification for the Wisconsin Department of Transportation that best suits the department's requirements.

Chapter IV: Results

A sample of historical department and manufacturer specifications were collected to populate a list of material and construction standards so that trends and ambiguities could be determined. It was important to the research that helical pile specifications be refined to those used in Wisconsin or in similar geotechnical, geographical, and climatic conditions. Fortunately, a range was established and valuable data was collected. This section evaluated these material and construction standards and supported the development of the proposed WisDOT helical pile specification.

Material Analysis

Material specifications and standards are developed by independent laboratories and research centers to ensure physical properties, testing, and acceptance is uniform across each of the industries. The American Society for Testing and Materials, (ASTM), is the industry leader in creating and ensuring such standards remain current. Helical pile manufacturers, designers, and installers recognize ASTM standards as they are universally accepted across the transportation and building industries. Other standards established by the American Iron and Steel Institute, (AISI), Society of Automotive Engineering, (SAE), and American Welding Society, (AWS), provide supplementary guidance on specific material criteria with respect to their unique trades. Various standards were revealed with respect to helical pile material standards. These standards were extracted from their source and complied in this section to determine trends and ambiguities for analysis.

Lead/extension shafts. The helical pile shaft is the second-most critical component of the helical pile. It not only supports the torsional loading on the pile put on it by the installation equipment, but it also transfers the load from each helical plate to the exposed bracket or mounting surface. Lead and extension shafts can be constructed with aluminum or steel; however, most helical piles use steel construction based on constructability and cost. Leads contain the initial configuration of helical plates and the pilot point (See Figure 1). Extensions may or may not contain helical plates and are used to extend the pile until the desired bearing is achieved.

Table 2

Lead and Extension Standards

Source	Standard
WisDOT - Project 4996-01-58	ASTM A53, A252, A500, A618
WisDOT - Project 5992-08-85	ASTM A53, A252, A500, A618
IowaDOT - Project NHSN-030-1(161)--2R-43	ASTM A53, A252, A500, or A618.
EBS Geostructural, Inc.	ASTM A500, or A618
Supportworks, Inc.	ASTM A500 Grade B or C
MacLean Dixie Anchoring Systems	ASTM A500

ASTM A53 defines chemical and mechanical properties for seamless and welded black and hot-dipped galvanized steel pipe. ASTM A252 further defines mechanical properties for normal wall cylindrical steel pipe piles that are to be used as load-carrying members or concrete-filled piles. ASTM A500 appears in each specification and is all-inclusive of the chemical and physical properties of cold-formed welded and seamless carbon steel shapes for use for buildings, bridges, and general construction purposes. ASTM A618 defines chemical and physical properties for hot-formed welded and seamless high-strength low-alloy shapes for building, bridges, and general construction (ASTM, 2019).

The results show that WisDOT and IowaDOT identify similar material standards as do the three manufacturer specifications. The one standard that stands out and is in each source is ASTM A500. Theoretically, WisDOT and IowaDOT write specifications so as not to restrict contractors from exploring varying means and methods to furnish a helical pile that satisfies the design requirement. ASTM A53, A252 and A618 provide fundamental requirements for different types of steel pipe; whereas, ASTM A500 references the other specifications. Furthermore, manufacturer specifications define the standards that are applicable to their product rather than the generalized state specifications. Even though it is convenient to minimize the number of standards in a specification, it is important for standard specification to retain a level of generalization; therefore, ASTM A53, A252, A500, A618 will be included in the proposed specification.

Helical bearing plates. Bearing plates are the most critical component of the helical pile as they carry the majority of the bearing forces placed on the pile. Bearing plates are constructed in different configurations according to diameter, thickness, number of spirals and pitch (See **Error! Reference source not found.**). Configurations are typically proprietary based on the p ile manufacture and vary from model-to-model and between manufacturers. Geotechnical calculations are required to determine the configuration of bearing plates based on soil classification, soil consistency, required bearing, and soil chemical/physical characteristics.

Figure 5. Helical bearing plate. (From Helical Piles: A Practical Guide to Design and Installation, by H. Perko, 2009)

Table 3

Helical Bearing Plate Standards

Source	Standard
WisDOT - Project 4996-01-58	ASTM A36, A572, A1011, A1018 or A656
WisDOT - Project 5992-08-85	ASTM A36, A572, A1011, A1018 or A656
IowaDOT - Project NHSN-030-1(161)--2R-43	ASTM A36, A572, A1018, or A656
EBS Geostructural, Inc.	Not Identified
Supportworks, Inc.	ASTM A572 Grade 50
MacLean Dixie Anchoring Systems	ASTM 1011/1018

ASTM A36 and ASTM A572 define chemical and mechanical properties for carbon structural and high-strength structural steel shapes, plates, and bars in riveted, bolted, or welded construction for use in buildings, bridges and general construction purposes respectively. ASTM A656 delineates the three types and four strength grades of high strength low-alloy, hot-rolled structural steel plates. ASTM A1011 outlines chemical and mechanical properties for hot-rolled, carbon, structural, high-strength low-alloy, high-strength low-alloy with improved formability, and ultra-high-strength steel sheet and strip, in coils and cut lengths. ASTM A1018 defines chemical and mechanical properties for hot-rolled, heavy-thickness steel sheet, and strip coils (ASTM, 2019).

As seen with the lead/extension shaft requirements, Wisconsin and Iowa departments provide a general range of standards that encompass the common material types; whereas, the manufacturers refine their specification to reflect the type and grade of material used with respect to their product. The standards referenced in the manufacturer specifications directly match one or more of the department standards. Once again, this trend is attributed to the belief that departments seek not to limit material choices for manufacturers. A significant trend worth pointing out is the minimum yield strength and plate thickness specified by WisDOT, IowaDOT, Supportworks, and MacLean Dixie. Each define an allowable choice of 3/8 or 1/2 inch plate thickness and stipulates the minimum yield strength must exceed 50 ksi. Short of specific geotechnical data, the minimum plate thickness and yield strength will be defined in the proposed specification to guarantee physical performance. Specific material standards cannot clearly be derived from the range of specifications; therefore, the proposed specification will list each standard. The department must rely on the manufacturer to use the applicable standards that meet the performance requirements of the foundation design.

Couplings/connections. In an effort to consolidate like-items, helical pile couplings and connections were combined into one material category. Each features functions as a significant component in the helical pile assembly although they serve different purposes. Couplings join lead and extension shafts (See **Error! Reference source not found.** Left). There are several v ariations of couplings that are typically proprietary to the pile manufacture. The example provided is manufactured MacLean Dixie Anchoring Systems. Connections are used to attach structural members or load-transfer devices by means of brackets, flanges, and other shapes. The example provided shows a beam saddle for supporting a timber plank (See **Error! Reference source not found.** Right).

Figure 6. Sample coupling and connection. (From Helical Piles: A Practical Guide to Design and Installation, by H. Perko, 2009)

Another component not included in this category yet shares comparable material standards are pilot points. Pilot points are common in predominantly gravel soils and are used to guide the pile through irregular material while protecting the integrity of the lead section. As such, not all pile manufacturers use pile points. The most common is an open-point pile (See **Error! Reference source not found.**), as it increases the bearing capacity due to internal surface friction.

Table 4

Coupling/Connection Standards

Source	Standard
WisDOT - Project 4996-01-58	ASTM A36/A36M or A572, A513
WisDOT - Project 5992-08-85	ASTM A36/A36M or A572, A513
IowaDOT - Project NHSN-030-1(161)--2R-43	ASTM A36 or A572 Grade 50
EBS Geostructural, Inc.	Not Identified
Supportworks, Inc.	ASTM A513 Type 5, Grade 1026
MacLean Dixie Anchoring Systems	AISI 8620 or SC1045 per ASTM A958

ASTM A36 and ASTM A572 define chemical and mechanical properties for carbon structural and high-strength structural steel shapes, plates, and bars in riveted, bolted, or welded construction for use in buildings, bridges and general construction purposes respectively. ASTM A513 categorizes the six types of electric-resistance-welded carbon and alloy steel mechanical tubing produced by hot- or cold-rolling. ASTM A958 defines chemical and mechanical properties for carbon and low-alloy steel castings (ASTM, 2019).

Many of the material standards cited for helical bearing plates are cited for couplings and connections, such as the chemical and mechanical properties. The sole ambiguity is ASTM A958, cited by MacLean Dixie Anchoring Systems, that sources low-alloy steel castings. As noted before, this is likely based on their trademarked product. In the interest of remaining impartial to individual manufacturer products, the proposed specification will include each of the standards listed. Again worth noting are the additional requirements in the IowaDOT, MacLean Dixie and SupportWorks specifications. IowaDOT stipulates that couplings shall be hot upset forged sockets or hot forge expanded sockets with a minimum yield strength; MacLean Dixie specifies that couplings must be square, not round with minimum yield and tensile strengths; and SupportWorks provides minimum dimensions with minimum yield and tensile strengths. The proposed specification should specify minimum requirements without indirectly pre-selecting one manufacturer over another. It is ultimately the manufacturer's responsibility to provide a product that will satisfy the project-specific design requirements.

Hardware. The structural capacity of a helical pile is as strong as the weakest component. Improper selection of hardware material and sizing is credited for the majority of the failures observed. Hardware failure is extremely common at the coupling during installation and contributes to decreasing structural capacity and even helical pile failure. Couplings and hardware are placed under punishing strain during installation due to the torque required to drive the helical pile into the ground. When failure occurs, it is common to find that the bolts at the coupling have been sheared off or the coupling has been deformed. That is why an independent section is devoted to hardware standards.

Table 5

Hardware Standards

Source	Standard
WisDOT - Project 4996-01-58	ASTM A193 or ASTM A320
WisDOT - Project 5992-08-85	ASTM A193 or ASTM A320
IowaDOT - Project NHSN-030-1(161)--2R-43	ASTM A193, A320, or SAE J429
EBS Geostructural, Inc.	Not Identified
Supportworks, Inc.	ASTM A307
MacLean Dixie Anchoring Systems	ASTM A325, SAE J429 or ASTM A354

ASTM A193 defines chemical, mechanical, and testing requirements for alloy steel and stainless steel bolting materials for high-temperature or high-pressure use. ASTM A320 defines chemical, mechanical, and testing requirements for alloy steel bolting materials for low-temperature service. ASTM A307 defines the chemical and mechanical requirements for Grade A, B and, C carbon steel bolts and studs in specified sizes. ASTM A325 was superseded by ASTM F3125 in 2016 and defined the chemical, physical, and mechanical requirements for quenched and tempered bolts manufactured from steel and alloy steel. ASTM A354 defines the chemical, and mechanical requirements of quenched and tempered alloy steel bolts, studs, and other externally threaded fasteners (ASTM, 2019). SAE J429 defines mechanical and material requirements for steel bolts in sizes up to 1-1/2 inch (SAE, 2019).

The range of standards to consider with regard to hardware seems to vary depending on the specification. Wisconsin and Iowa department special provisions agree that ASTM A193 and ASTM A320 are suited for bolting hardware. IowaDOT includes the SAE standard that is seen in the manufacturer specifications. More than 50 standards are listed on the ASTM website with respect to bolts, nuts, washers, and other hardware. Without knowing the specific details of the design or manufacturer requirements of the helical pile, it is nearly impossible to isolate a single or group of standards that must be followed. Therefore, it is recommended that the hardware standards be left vague in the proposed specification and left to the manufacturer to identify materials and appropriate standards to be used with their product.

Finishes/coatings. The final process in helical pile manufacturing is the application of a protectant treatment to ensure the chemical and physical characteristics of the pile remains as manufactured. Finishes and coatings prevent uncontrollable deterioration or breakdown of metals by means of galvanizing, cathodic protection, anodizing, painting/powder coating and nickel plating. Selecting the proper protective for helical piles is critical as piles commonly make contact with corrosive elements in the groundwater, soils, and the natural environment.

Table 6

Finishes/Coatings Standards

Source	Standard
WisDOT - Project 4996-01-58	ASTM A153
WisDOT - Project 5992-08-85	ASTM A153
IowaDOT - Project NHSN-030-1(161)--2R-43	Not Defined
EBS Geostructural, Inc.	ASTM A153
Supportworks, Inc.	ASTM A153
MacLean Dixie Anchoring Systems	ASTM A153

ASTM A153 defines standards for hot-dip zinc galvanizing application, delineates galvanizing grades based on thickness, outlines procedural techniques, and identifies testing requirements (ASTM, 2019). The range of standards unanimously cite ASTM A153 as the standard for a helical pile protectant treatment, inclusive to not only the helical pile assembly but also the hardware. Given the unanimous results from the independent specifications, it can easily be determined that ASTM A153 if the preferred treatment type; however, the proposed specification should allow other solutions if they can be proven effective.

Submittals. Action submittals are required by the department prior to construction to demonstrate that the contractor understands the material and construction requirements defined in the specification. After submittals are reviewed by the field-engineer, department or department-consulted staff, they will verify that the furnished materials and construction practices used by the contractor match their initial submittals. Material and construction submittals are retained with project records once the project is complete. Action submittals will vary based on the project if defined in special provisions; however, they must be consistent for items within the standard specification. From the special provisions and manufacturer specifications collected, action submittals for helical piles include calculations and drawings, construction procedures, shop drawings, material test reports, calibration reports, and installation records. These submittal requirements are consistent across the range of specifications.

The ability to define an explicit pool of material standards proved to be challenging as helical pile manufacturers continue to develop products that outperform their competitors. This section evaluated a vast number of material specifications that were independent amongst manufacturers. Uniformity was nevertheless demonstrated between department specifications. Despite the fact that manufacturers are able to concentrate specifications appropriate for their product, state departments cannot risk limiting competition by defining specific material standards. The department can, however, set minimum performance standards. This allows the manufacturers to tailor their products and affords the department a level of comfort in that the delivered product will likely perform.

Construction Analysis

Construction standards are developed and implemented based on industry criteria and common practice. Unlike material standards that are incorporated by independent laboratories and research centers, construction standards are profoundly influenced by contractor organizations and manufacturer endorsements. Given performance requirements, contractors and manufacturers collectively determine best-practice techniques to meet these requirements. When construction practices and manufacturer recommendations have been vetted in the field, they are analyzed by the industry and either adapted into standards or rejected for further development. For the design and installation of helical pile foundations, ASCE 20-96, Standard Guidelines for the Design and Installation of Pile Foundations, offers a collection of design and installation procedures. In conjunction with ASCE 20-96, the department and manufacturer specifications collected in the previous section were used to evaluate appropriate construction practices for implementation into the proposed standard specification. From these sources, it was found that separate subsections existed for site conditions, installation equipment, installation tooling, installation procedures, and termination criteria and tolerances. Each subsection listed warrants further clarification before the content is included in the proposed specification.

Site conditions. Helical pile design and construction requires a detailed site investigation prior to design kick-off. As part of the design process, a site investigation can include specifics like product feasibility, geotechnical investigation, and capacity determination. Before helical piles can be considered, designers must determine what type of foundation best suits the proposed structure. Designers will consider the location of the project, identify environmental concerns, and evaluate the owner's objectives. If helical piles fit the constraints of the design, a geotechnical investigation will follow to include soil borings and samples. A geotechnical analysis provides the designer with valuable data necessary to define soil characteristics, identify potential conflicts, and drive the size and shape of the helical pile. Equally important in the design of the helical pile is understanding the bearing capacity that the pile must support. All this information is collected and analyzed prior to the production of the first helical pile. The site investigation during construction includes, but is not limited to, scheduling conflicts, unforeseen site conditions, and construction permitting. Field engineers must ensure subsequent structure construction begins following pile installation. Abandoned piles posture safety concerns, are susceptible to damage from surrounding operations, and change the pile's response to loading. Unforeseen site conditions are common during subsurface construction. Subsurface rocks, abandoned utilities, and other obstructions are found on almost every construction site. Although differing/unforeseen site conditions are covered in Part 1 of the WisDOT standard specification, the proposed specification will make reference to the specific section. If not completed during design, contractors must be aware of all construction, environmental, and specialized permits required for helical pile installation. A blanket statement to make the contractor aware of necessary permits will be added to the proposed specification. Failure to perform routine site visits or to document existing conditions contributes to errors and omissions for designers and costly change orders for the department.

Installation equipment. Helical pile installation follows the basic mechanical principles of a screw, one of the six fundamental simple machines. The way a screwdriver manipulates a screw, a helical pile requires a mechanical, pneumatic, or hydraulic-powered compound machine to assist in installation. The department special provisions reference the use of a rotary-type, hydraulic-power-driven torque motor to install helical piles. An example of a hydraulic torque motor used to install helical piles (see **Error! Reference source not found.**), uses an excavator's h ydraulic system to drive the torque motor in a rotary motion. Attaching the torque motor to an excavator allows greater maneuverability and provides enough crowd to advance the pile. The applied torque is measured using specialized tooling, and live readouts are displayed to the operator and crew by means of stationary and handheld devices. An example of a rotary-type, hydraulic-power-driven torque motor used to install helical on WisDOT Project 4996-01-58 – Taylor Drive is shown below.

Figure 7. Rotary type, hydraulic-powered torque motor.

Test piles are conducted prior to the installation of the foundation piles to ensure the installation equipment meets the torque requirements required to achieve bearing. The results are submitted as part of the material submittals to ensure the bearing capacity under normal conditions will be achieved. Since the helical piles are engineered to meet the geotechnical requirements of the pile, the departments took an extra precaution and stipulated that the toque motor shall be capable of exceeding the capacity of the shaft by 15%. This ensures the equipment is properly sized for installation. The manufacturer specifications follow the same procedures and essentially read word-for-word. Although equipment characteristics may vary between projects, the method of installation remains the same.

Installation tooling. Department special provisions and manufacture model specifications delineate subsections for installation equipment and tooling despite how to work together to distribute the installation force. Installation tooling commonly refers to the torque indicator and Kelly Bar Adapter, (KBA), which are fastened to the torque motor and used to measure and transfer mechanical energy. The torque indicator and KBA are located between the motor and shaft coupling (see Figure 7). Torque indicators present real-time readouts by means of analog or digital gauges that are directly linked to the fixed or handheld devices. The relationship between torque and bearing is established using pre-determined calculations; therefore, when a given torque is applied, the relative bearing can be assumed. Minimum requirements for torque indicators are contained within the sample specifications. The indicator must be capable of providing continuous measurements in increments of less than 500 foot-pounds. Torque indicator calibration is a required action submittal and the results are verified with the test pile. The function of the KBA is to mate the torque motor to the shaft coupling in addition to providing a torque increase using basic mechanical properties. To conceptualize the mechanical principles, the KBA is to the torque motor as a socket is to the ratchet. The proposed specification will incorporate these requirements as they collectively appear in the independent specifications.

Installation procedures. General procedures for helical pile installation can be categorized into three phases: pre-installation, production, and post-installation. Each phase contains actions that promote overall installation success. During pre-installation, it is vital that contractors review plans, specifications, and manufacturer recommendations for installation. In addition, they must locate underground and overhead utilities, obtain necessary construction permits, and layout pile locations per project plans. It is equally important for contractors to meet with the field engineer to ensure action submittals were reviewed, and potential conflicts are discussed. Installation should be postponed until all conflicts are resolved. During production, it is of the utmost importance that the contractor installs each helical pile in accordance with the manufacturer's recommendations; otherwise, the contractor assumes liability for product performance. The manufacturer provides helical piles capable of exceeding the performance requirements specified within the plan; therefore, all performance-based risk is covered under the manufacturer's warranty. Post-installation actions include completing installation records, measuring quantities, and load testing for hand-picked projects. Installation records at a minimum include pile number, date installed, final torque, final capacity, number of extensions, total length, cut-off length, net depth, and comments. The installation records are used as payment justification and retained with the project records. A small number of projects are selected for post-installation load testing. The requirement must be defined in the specification or can be performed if required for conflict resolution.

Termination criteria and tolerances. Helical pile termination criteria are derived from structural and geotechnical calculations and are included in the structure plans that are provided to the contractor prior to construction. The design engineer determines the minimum requirements for bearing capacity and minimum depth based on performance requirements. From the plans, the contractor takes the required bearing capacity and determines the torque requirement knowing the torque-bearing relationship of their installation equipment. Installation can then be terminated once the pre-determined criteria targets are satisfied. Upon termination, the average torque is calculated using the average torque readings over the last three feet of penetration, at one-foot intervals. The final torque, used to determine the pile's ultimate bearing capacity, is calculated by averaging the average torque readings from the final three revolutions. The contractor must ensure the installation torque does not exceed the torsional capacity of the lead or extension shafts to prevent damage to the helical pile assembly. If pile refusal is observed before the minimum depth is reached, the contractor should refer to the manufacturer's installation recommendations and consult the field engineer. The contractor is to follow the same procedure if the minimum torque is not achieved at the plan depth.

Upon completion, the helical pile should be installed as close to the specified location as geospatially defined in the plan. Installation tolerances are specified in the plans since tolerances for foundations will vary from boardwalk piers. Unless otherwise specified, typical ranges for horizontal, vertical, and zenith tolerance are ±2 inches, ±1 inch, and ±5 degrees respectfully. Installation results must be recorded after each pile is installed. The results are submitted to the field engineer as a required action submittal before final payment. At the risk of being redundant, the primary takeaway from the construction analysis section is the importance of following the manufacturer's recommendations when installing helical piles. The department and contractor must rely on the shop drawings and products provided by the manufacturer to perform as intended. The proposed specification will contain references to common installation practices in the construction subsection; however, it will commonly refer to the manufacturer specifications for most construction recommendations.

After reviewing the range of material and construction specifications, it is apparent that specific requirements are refined to the helical pile manufacturer. Although each of the specifications collected were unique, there is evidence that relationships can be identified and isolated to derive a standard. Material standards are comparable when helical piles are constructed in the same manner as seen in the linear comparisons. When the pile dimensions and configurations are consistent, the standards align. Construction procedures hold greater tolerances concerning a universal language. Each specification evaluated confirms that it is the helical pile manufacturer's responsibility to ensure their individual product meets the requirements in the proposed design. There is evidence that material and construction language can be standardized using performance requirements. Through such, the standard specification provides autonomy to the manufacturer while ensuring minimum requirements are achieved. Although the proposed specification will not be all-inclusive, it lays the foundation for future research and development.

Chapter V: Conclusion

Before helical piles can be included in the WisDOT standard specification, universal material requirements and specific construction practices needed to be identified. In addition, external factors such as geotechnics, geospatial interference, and environmental factors need to be considered. Without a clear standard in place, designers and contractors are unclear of the design and construction requirements. Since their conceptualization in the late 1800s, helical piles have yet to gain the backing needed for WisDOT to allocate resources toward the research and development of a helical pile standard specification. Special provisions have historically been the preferred mode to disseminate contract requirements regarding helical pile use to the field. At the beginning of this study, an argument was made for a helical pile standard. Current practices, identified material requirements, and investigated installation procedures using department and manufacturer specifications were reviewed. As a result, a proposed standard specification was developed and intended for use by designers and contractors for the employment of helical piles. This chapter reviews the significant findings from the research and suggests recommendations for forthcoming specification developments.

The literature suggested there are significant benefits to justify the development of a standard specification. Helical piles prove to be a superior alternative to traditional foundations such as driven-pile, drilled shaft, and cast-in-place, with respect to sustainability, construction safety, and installation efficiency. The use of department special provisions and manufacturer model specifications provide sufficient qualitative data to distinguish trends in material and construction standards. Further investigation revealed industry standards are reflected in these sources; therefore, none of the sources needed to be excluded from the study. While special provisions are effective at delivering critical contractual information, standard specifications eliminate variance from one special provision to the next. An adequate sum of qualitative data was extracted to define the framework for the standard specification using previously published department special provisions and manufacturer model specifications. The proposed specification, Section 560, contains contract-specific language, covering all five subsections and reads similar to the specifications around it. The goal was to present a specification that ensured continuity with coexisting specifications. The result is a specification that leaves much to be determined by the manufacturer and contractor-provided shop drawings. Although a contract-driven specification creates speculation as to why a standard specification is needed, it encourages ingenuity while establishing minimum performance standards.

The anticipation that the proposed specification will be adopted, or at a minimum gain the attention of WisDOT Bureau of Technical Services, future research could be conducted to evaluate the impending effectiveness of the standard. Moreover, with respect to construction costs and installation productivity, it will provoke conversation as to where quantitative research can be collected. This research could have included more input from leaders in the helical pile industry to more accurately understand the difficulties they experience when working with WisDOT. The opportunity may surface reasons why a standard has yet to be recognized or implemented. Establishing bilateral lanes of communication between WisDOT and the contractors will undoubtedly promote good working relationships and mutual respect.

References

American Society for Testing and Materials. (2019). Standards. Retrieved from https://www.astm.org/

American Society of Civil Engineers. (2019). ASCE 20-96, Standard Guidelines for the Design and Installation of Pile Foundations. Retrieved from https://ascelibrary.org/doi/book/10.1061/9780784402191

Bobbitt, D.E., and Clemence, S.P. 1987. Helical anchors: Application and design criteria. In Proceedings of the 9th Southeast Asian Geotechnical Conference, Bangkok, Thailand, pp. 6-105–6-120.

Dasgupta, P. S., Fulmer, S., Jing, X., & Buchholz, B. (2012). Assessing the ergonomic hazards for Pile Drivers, *Work, 43*(4), 417-425. doi:10.3233/WOR-2012-1459

De Araújo, A.G., Gusmão, A. D., Rabbani, E. R. K., & Fucale, S. P. (2012). Mapping of Noise Impact Provoked by the Execution of Foundation Piles at High Rise Building Sites, *Work, 41*(1). doi:10.3233/WOR-2012-0596-3291

DiGioia, A. (2012). Put Foundations to the Test. *Transmission & Distribution World, 64*(1), 72.

EBS Geostructural Inc. (2019). Helical Pile Specifications: 31 66 00 Helical Pile/Anchor Deep Foundation; Model specification. Retrieved from https://www.ebsgeo.com/helical-piles/specifications

Elkasabgy, M., & El Naggar, M. H. (2015). Axial compressive response of large-capacity helical and driven steel piles in cohesive soil. *Canadian Geotechnical Journal, 52*(2), 224-243. doi:10.1139/cgj-2012-0331

Federal Highway Administration. (2016). Construction Program Guide: Buy America. Retrieved from https://www.fhwa.dot.gov/construction/cqit/buyam.cfm

International Code Counsel, Inc. (2007). Acceptance Criteria for Helical Foundation Systems and Devices: AC358. Retrieved from http://www.helicalpileworld.com/ac358.pdf

International Code Counsel, Inc. (2015). IBC "International Building Code" (6th ed). Country Club Hills, IL.

International Society for Helical Foundations. (2016). Potential advantages and limitations of screw-piles and helical anchors. Retrieved from http://helicalfoundations.org/faqs-2/advantages-and-limitations-of-screws/

Helical Anchors Incorporated. (2014). Engineering Design Manual. Retrieved from http://www.helicalanchorsinc.com/wp-content/uploads/2015/06/Helical-Anchor-Inc-Engineering-Manual-Rev-02.pdf

Helical Pile Association. (2016). Helical Piles. Retrieved from http://www.helicalpileassociation.com/piles-piers/helical-piles/

Johnson, D. (2016). The Most Dangerous Jobs in America. Time Inc. Retrieved from http://time.com/4326676/dangerous-jobs-america/

Kremer, R. (2017). Wetland Restoration As A Business: Wisconsin's Growing Mitigation Industry. State of Change: Water, Food, and the Future of Wisconsin. Retrieved from https://www.wpr.org/wetland-restoration-business-wisconsin%E2%80%99s-growing-mitigation-industry

MacLean Power Systems. (2019). MacLean-Dixie Anchoring Systems: Helical Steel Piles. Retrieved from https://www.macleanpower.com/UserFiles/File/Civlil_Anchor_Postings/MacLean_Dixie_Anchoring_Systems_Specifications0602.pdf

Magnum Piering Inc.. (2019). DOT Format Model Specifications for Helical Piles and Helical Anchors. Retrieved from http://www.magnumpiering.com/products/performance-helical-piles-and-anchor-specs-in-dot-format/

Occupational Safety and Health Organization. (2018).

Perko, H. (2009). Helical Piles: A Practical Guide to Design and Installation. Hoboken, NJ, USA: John Wiley & Sons

Ponomarenko, Y., & Baranov, E. (2013). Peculiarities of regulatory documents for design of foundations formed from helical anchors and piles. *Soil Mechanics and Foundation Engineering, 50*(1), 38-41.

Society of Automotive Engineering. (2019). Standards. Mechanical and Material Requirements for Externally Threaded Fasteners J429_199901. Retrieved from https://www.sae.org/standards/content/j429_199901/

Supportworks, Inc. (2018). Helical Pile Model Specification: Model Specification for Helical Pile Foundations Compression Applications, Doc. 14FSI-001-Rev.2. Retrieved from https://commercial.supportworks.com/technical-information/sample-specifications.html

Woods, R. D. (1997). Dynamic Effects of Pile Installations on Adjacent Structures, NCHRP Synthesis of Highway Practice, 253, p. 1-86.

Appendix A: Proposed Standard Specification

Section 560 Helical Piles

560.1 Description

(1) This section describes the furnishing of all designs, materials, tools, equipment, labor including supervision, and installation techniques necessary to install Helical Piles as detailed on the drawings including connection details.

560.1.1 References

ASTM A29/A29M Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished.
ASTM A36/A36M Structural Steel.
ASTM A53 Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless.
ASTM A153 Zinc Coating (Hot Dip) on Iron and Steel Hardware.
ASTM A193/A193M Alloy-Steel and Stainless Steel Bolting Materials for High Temperature Service.
ASTM A252 Welded and Seamless Steel Pipe Piles.
ASTM A307 Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength
ASTM A320/A320M Alloy-Steel Bolting Materials for Low Temperature Service.
ASTM A325 Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength.
ASTM A500 Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes.
ASTM A512 Cold-Drawn Buttweld and Seamless Carbon Steel Mechanical Tubing.
ASTM A513 Standard Specification for Electric Resistance Welded Carbon and Alloy Steel Mechanical Tubing.
ASTM A536 Standard Specifications for Ductile Iron Castings
ASTM A354 Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners.
ASTM A572 HSLA Columbium-Vanadium Steels of Structural Quality.
ASTM A607 Steel, Sheet and Strip, High-Strength, Low-Alloy, Columbium or Vanadium, or Both, Hot-Rolled and Cold-Rolled.
ASTM A618 Hot-Formed Welded and Seamless High-Strength Low-Alloy Structural Tubing.
ASTM A635 Steel, Sheet and Strip, Heavy-Thickness Coils, Carbon, Hot-Rolled.
ASTM A656 Hot-Rolled Structural Steel, High-Strength Low-Alloy Plate with Improved Formability.
ASTM A958 Standard Specification for Steel Castings, Carbon, and Alloy, with Tensile Requirements, Chemical Requirements Similar to Wrought Grades.
ASTM A1011 Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability.
ASTM A1018 Steel, Sheet and Strip, Heavy Thickness Coils, Hot Rolled, Carbon, Structural, High-Strength Low-Alloy, Columbium or Vanadium, and High-Strength Low-Alloy with Improved Formability.
AWS D1.1 Structural Welding Code – Steel.
SAE J429 Mechanical and Material Requirements for Externally Threaded Fasteners.

560.2 Materials

(1) Submit a list of all proposed materials to be included in the Helical Pile construction.

560.2.1 Design Requirements

(1) Design Helical Piles to meet the specified loads and acceptance criteria as shown on the drawings. The geotechnical report, including logs of soil borings as shown on the boring location plan, shall be considered representative of the in-situ subsurface conditions likely to be encountered on the project site. The required soil parameters (c, f, g, or N-values) are provided in the geotechnical report. Specify the overall length and installed torque of a Helical Pile such that the required in-soil capacity is developed by end-bearing on the helix plate(s) in an appropriate strata(s).

560.2.2 Central Steel Shaft

(1) Submit a certified report of test or analysis as specified in 506.3.21 at or before pile delivery unless the engineer directs or allows otherwise. Ensure that piles have marks tying them to a specific test report, or absent marks, certifying that all material furnished is represented by a submitted test report. Provide marks or certifications for each piece of a pile fabricated from multiple pieces.

(2) Use a round shaft for the central steel shaft consisting of lead sections, helical extensions, and plain extensions and shall conform to one or more of the following specifications: ASTM A53, A252, A500, A618, or equal.

560.2.3 Helical Bearing Plate

(1) Use hot-rolled carbon steel sheet, strip, or plate-formed on matching metal dies to true helical shape and uniform pitch. The leading edge of all helices must be in the same plane

(2) Helical plates shall be either ⅜ or ½ inch thick and shall conform to one or more of the following specifications: ASTM A36, A572, A1011, A1018, A656, or equal.

560.2.4 Couplings

(1) Form the couplings as either an integral part of the plain with helical extension material as hot-forged expanded sockets or as internal sleeve wrought steel connectors. They shall conform to one or more of the following specifications: ASTM A36/A36M, A572, A513, A958, or equal.

(2) The steel connectors must be square engagement with connecting bolts not subject to shear or bending during installation.

560.2.5 Hardware

(1) Connect the central steel shaft sections using the size and type of bolts conforming to one or more of the following specifications: ASTM A193, A307, A320, A325, A354, SAE J429 or equal.

(2) Coupling hardware shall have a Class C, hot-dipped, zinc coating that complies with ASTM A153.

560.2.6 Plates, Shapes, or Pile Caps

(1) For the pile caps, use a welded assembly consisting of structural steel plates and shapes designed to fit the pile and transfer of the applied load. Use structural steel plates and shapes for Helical Pile top attachments conforming to ASTM A36 or ASTM A572 Grade 50.

560.2.7 Corrosion Protection

(1) Hot-dip galvanize material according to ASTM A153 or A123 as specified after fabrication.

560.2.8 Submittals

560.2.8.1 Calculations and Drawings

(1) Submit to the engineer for review and approval all working drawings, shop drawings, and design documents for the Helical Piles and components intended for use at least 14 calendar

days prior to planned start of construction. All submittals shall be signed and sealed by a professional engineer registered in the State of Wisconsin and knowledgeable of the specific site conditions and requirements.

560.2.8.2 Construction Procedures

(1) Submit to the engineer for review and approval a detailed description of the construction procedures proposed for use. This shall include a list of major equipment to be used.

Include the following on the working drawings:

- Helical Pile number, location and pattern by assigned identification number.
- Helical Pile design load.
- Type and size of central steel shaft.
- Helix configuration (number and diameter of helix plates).
- Minimum effective installation torque.
- Minimum overall length.
- Inclination of Helical Pile.
- Cut-off elevation.
- Helical Pile attachment to structure relative to pile cap.

560.2.8.3 Shop Drawings

(1) Submit to the engineer for review and approval all shop drawings for Helical Pile components including corrosion protection and pile-top attachments. These includes Helical Pile lead/starter and extension section identification (manufacturer's catalog numbers).

560.2.8.4 Mill Test Reports

(1) Submit a certified report of test or analysis as specified in 506.3.21 at or before pile delivery unless the engineer directs or allows otherwise. Ensure that piles have marks tying them to a specific test report, or absent marks, certify that all material furnished is represented by a submitted test report.

(2) Provide marks and certifications for each component of the pile fabricated from multiple sources.

(3) Provide the ultimate strength, yield strength, % elongation, and chemistry composition.

560.2.8.5 Calibration Reports

(1) Submit to the engineer for review and approval copies of calibration reports for each torque indicator or torque motor, and all load test equipment to be used on the project. Perform the calibration tests within 45 working days of the date submitted. Do not proceed with Helical Pile installation until the engineer has received the calibration reports. Include, at a minimum, the following information in the calibration reports:

- Name of project and contractor
- Name of testing agency
- Identification (serial number) of device calibrated
- Description of calibrated testing equipment
- Date of calibration
- Calibration data

(2) Do not begin work until all the submittals have been received and approved by the engineer. Allow the engineer a reasonable time to review, comment, and return the submittal package after a complete set has been received. All costs associated with incomplete or unacceptable submittals shall be the responsibility of the contractor.

560.2.8.6 Installation Records

(1) Submit to the engineer copies of Helical Pile installation records within 24 hours after each installation is completed. Submit formal copies on a weekly basis. Include, at a minimum, the following information in the installation records:

- Name of project and contractor.
- Name of contractor's supervisor during installation.
- Date and time of installation.
- Name and model of installation equipment.
- Type of torque indicator used.
- Location of Helical Pile by assigned identification number.
- Actual Helical Pile type and configuration – including lead section (number and size of helix plates), number and type of extension sections (manufacturer's SKU numbers).
- Helical Pile installation duration and observations.
- Total length of installed Helical Pile.
- Cut-off elevation.
- Inclination of Helical Pile.
- Installation torque at one-foot intervals for the final 10 feet.
- Comments pertaining to interruptions, obstructions, or other relevant information.
- Rated load capacities.

560.3 Construction

(1) Install Helical Piles that will sustain the load capacities as detailed on the drawings. Install all Helical Piles in the presence of the engineer unless the engineer informs the contractor otherwise. Provide the engineer the right of access to any and all field installation records and test reports.

560.3.1 Site Conditions

(1) Prior to commencing Helical Pile installation, inspect the work of all other trades and verify that said work is completed to the point where Helical Piles may commence without restriction.

(2) Verify that all Helical Piles are installed according to all pertinent codes and regulations regarding such items as underground obstructions, right-of-way limitations, utilities, etc.

(3) In the event of a discrepancy, notify the engineer. Do not proceed with Helical Pile installation in areas of discrepancies until said discrepancies have been resolved.

560.3.2 Installation Equipment

(1) Use rotary-type, hydraulic-power-driven torque motor with clockwise and counter-clockwise rotation capabilities. The torque motor shall be capable of continuous adjustment to revolutions per minute (RPM's) during installation. Percussion drilling equipment shall not be permitted. The torque motor shall have torque capacity 15% greater than the torsional strength rating of the central steel shaft to be installed.

(2) Use equipment capable of applying adequate down pressure (crowd) and torque simultaneously to suit project soil conditions and load requirements. Use equipment capable of continuous position adjustment to maintain proper Helical Pile alignment.

560.3.3 Installation Tooling

(1) Use installation tooling consisting of a Kelly Bar Adapter (KBA) and round shaft drive tools according to the manufacturers written installation instructions.

(2) Use a torque indicator during Helical Pile installation. The torque indicator can be an integral part of the installation equipment or externally mounted in-line with the installation tooling. Use a torque indicator with the following characteristics:

- Capable of providing continuous measurement of applied torque throughout the installation.
- Capable of indicating torque measurements in increments of at least 500 ft-lb.
- Capable of being calibrated prior to pre-production testing or start of work. Torque indicators which are an integral part of the installation equipment shall be calibrated on-site. Calibrate torque indicators which are mounted in-line with the installation tooling either on-site or at an appropriately equipped test facility. Calibrate indicators that measure torque as a function of hydraulic pressure at normal operating temperatures.

(3) Re-calibrate installation tooling if in the opinion of the owner and/or contractor believes reasonable doubt exists as to the accuracy of the torque measurements.

560.3.4 Installation Procedures

(1) Install Helical Piles using a technique consistent with the geotechnical, logistical, environmental, and load carrying conditions of the project and as recommended by the manufacturer.

(2) Position the lead section at the location as shown on the working drawings. Battered Helical Piles can be positioned perpendicular to the ground to assist in initial advancement into the soil before the required batter angle shall be established. Engage the Helical Pile sections and advanced into the soil in a smooth, continuous manner at a rate of rotation of 5 to 20 RPM's. Provide extension sections to obtain the required minimum overall length and installation torque as shown on the working drawings. Connect sections together using coupling bolt(s) and nut torqued to 40 ft-lb.

(3) Apply sufficient down pressure to uniformly advance the Helical Pile sections approximately 3 inches per revolution. Adjust the rate of rotation and magnitude of down pressure for different soil conditions and depths.

560.3.5 Termination Criteria

(1) Do not exceed the torsional strength rating of the central steel shaft as the torque is measured during the installation.

(2) Satisfy the minimum installation torque and minimum overall length criteria as shown on the working drawings prior to terminating the Helical Pile installation. Torque is to be measured according to manufacturer's specifications.

(3) The following options will be allowed if the torsional strength rating of the central steel shaft and/or installation equipment has been reached prior to achieving the minimum overall length required:

- Terminate the installation at the depth obtained, subject to the review and acceptance of the engineer, or:
- Remove the existing Helical Pile and install a new one with fewer and/or smaller diameter helix plates. Obtain approval from engineer for the new helix configuration. If re-installing in the same location, terminate the top-most helix of the new Helical Pile at least 3 feet beyond the terminating depth of the original Helical Pile.
- Do not re-use Helical Pile shaft material that has been permanently twisted during a previous installation.

- The following options will be allowed if the minimum installation torque as shown on the working drawings is not achieved at the minimum overall length, and there is no maximum length constraint:
- Install the Helical Pile deeper using additional extension sections until the minimum installation torque criterion is met, or:
- Remove the existing Helical Pile and install a new one with additional and/or larger diameter helix plates. Obtain approval from the engineer for the new helix configuration. Terminate the top-most helix of the new Helical Pile at least 3 feet beyond the terminating depth of the original Helical Pile if re-installing in the same location.
- De-rate the load capacity of the Helical Pile and install additional Helical Pile(s). Obtain approval from the engineer for the de-rated capacity and additional Helical Pile location.

(4) Terminate the installation and remove if the Helical Pile is refused or deflected by a subsurface obstruction. Remove the obstruction, if feasible, and re-install the Helical Pile. If the obstruction cannot be removed, install the Helical Pile at an adjacent location, subject to review and acceptance of the engineer.

(5) If the torsional strength rating of the central steel shaft and/or installation equipment has been reached prior to proper positioning of the last plain extension section relative to the final elevation, the contractor may remove the last plain extension and replace it with a shorter length extension. If it is not feasible to remove the last plain extension, the contractor may cut said extension shaft to the correct elevation. Do not reverse (back-out) the Helical Pile to facilitate extension removal.

(6) Use the average torque from the last three feet of penetration as the basis of comparison with the minimum installation torque as shown on the working drawings. The average torque is defined as the average of the last three readings recorded at one-foot intervals.

560.3.6 Dimension Tolerance

(1) Install Helical Piles to the following tolerances:

- Centerline of Helical Pile shall not be more than 3 inches from indicated plan location.
- Helical Pile plumbness shall be within 2 deg of design alignment
- Top elevation of Helical Pile shall be within ± 1 inch of the design vertical elevation.
- Deflection in the connection between shaft sections shall be less than 1-inch in 5-feet of length.

560.4 Measurement

(1) The department will measure the Helical Pile bid item by the linear foot acceptably completed, measured as the length of piling installed and left in place below the cutoff elevation.

560.5 Payment

(1) The department will pay for measured quantities at the contract unit price under the following bid item:

ITEM NUMBER	DESCRIPTION	UNITS
560.1XXX-9XXX	Helical Pile (Size)	LF

(2) Payment is full compensation for preparing and providing all submittals; and furnishing all labor, equipment, and materials required for the installation of helical piles.

(3) The department will not entertain a change order request for a differing site condition under 104.2.2.2 or for a quantity change under 104.2.2.4.3 for the Piling bid items. Instead the department will adjust pay under the Piling Quantity Variation administrative item if the total driven length of each size is less than 85 percent of, or more than 115 percent of the contract quantity as follows:

PERCENT OF CONTRACT LENGTH DRIVEN	PAY ADJUSTMENT
< 85	(85% contract length - driven length) x 20% unit price
> 115	(driven length - 115% contract length) x 5% unit price

Appendix B: Specification References

ASTM A29/A29M Steel Bars, Carbon and Alloy, Hot-Wrought and Cold Finished.
ASTM A36/A36M Structural Steel.
ASTM A53 Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless.
ASTM A153 Zinc Coating (Hot Dip) on Iron and Steel Hardware.
ASTM A193/A193M Alloy-Steel and Stainless Steel Bolting Materials for High Temperature Service.
ASTM A252 Welded and Seamless Steel Pipe Piles.
ASTM A320/A320M Alloy-Steel Bolting Materials for Low Temperature Service.
ASTM A325 Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength.
ASTM A500 Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes.
ASTM A512 Cold-Drawn Buttweld and Seamless Carbon Steel Mechanical Tubing.
ASTM A513 Standard Specification for Electric Resistance Welded Carbon and Alloy Steel Mechanical Tubing.
ASTM A536 Standard Specifications for Ductile Iron Castings
ASTM A572 HSLA Columbium-Vanadium Steels of Structural Quality.
ASTM A607 Steel, Sheet and Strip, High-Strength, Low-Alloy, Columbium or Vanadium, or Both, Hot-Rolled and Cold-Rolled.
ASTM A618 Hot-Formed Welded and Seamless High-Strength Low-Alloy Structural Tubing.
ASTM A635 Steel, Sheet and Strip, Heavy-Thickness Coils, Carbon, Hot-Rolled.
ASTM A656 Hot-Rolled Structural Steel, High-Strength Low-Alloy Plate with Improved Formability.
ASTM A958 Standard Specification for Steel Castings, Carbon, and Alloy, with Tensile Requirements, Chemical
Requirements Similar to Wrought Grades.
ASTM A1011 Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability.
ASTM A1018 Steel, Sheet and Strip, Heavy Thickness Coils, Hot Rolled, Carbon, Structural, High-Strength Low Alloy, Columbium or Vanadium, and High-Strength Low-Alloy with Improved Formability.
AWS D1.1 Structural Welding Code – Steel.
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations.
SAE J429 Mechanical and Material Requirements for Externally Threaded Fasteners.