Construction of New Substructures Beneath Existing Bridges

Final Report
April 2019

BRIDGE ENGINEERING CENTER

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Highway Research Board
(IHRB Project TR-716)
Iowa Department of Transportation
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The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
IHRB Project TR-716			
4. Title		**5. Report Date**	
Construction of New Substructures Beneath Existing Bridges		April 2019	
		6. Performing Organization Code	
7. Author(s)		**8. Performing Organization Report No.**	
Brent Phares (orcid.org/0000-0001-5894-4774), Seyedamin Mousavi (orcid.org/0000-0003-4203-8894), and Yaohua "Jimmy" Deng (orcid.org/0000-0003-0779-6112)		InTrans Project 17-599	
9. Performing Organization Name and Address		**10. Work Unit No. (TRAIS)**	
Bridge Engineering Center Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664		**11. Contract or Grant No.**	
12. Sponsoring Organization Name and Address		**13. Type of Report and Period Covered**	
Iowa Highway Research Board Iowa Department of Transportation 800 Lincoln Way Ames, Iowa 50010		Final Report	
		14. Sponsoring Agency Code	
		IHRB Project TR-716	
15. Supplementary Notes			
Visit www.intrans.iastate.edu for color pdfs of this and other research reports.			

16. Abstract

Accelerated bridge construction (ABC) has grown significantly in the last decade as an efficient method to rebuild bridges in the highway network. This method uses modern approaches in design, construction, and materials to reduce disruptions to traffic due to bridge construction.

In some cases, it is required to construct a new substructure beneath/within an existing bridge. There are various approaches to construct new foundations during ABC projects. The methods include spread footings, driven piles, drilled shafts, continuous flight augurs, and micropiles. Each method has its own advantages and disadvantages, which should be assessed for each ABC project.

For this research, each foundation method was reviewed by considering the specific features of the method that can be favorable to implement. To investigate new probable foundation construction approaches, a survey was distributed to state departments of transportation (DOTs). The survey included questions about the common bridge foundation approaches. According to the results, micropiles are the most commonly used piling approach, and there is no new method experienced by DOTs to establish foundations during ABC projects.

7. Key Words		18. Distribution Statement	
accelerated bridge construction (ABC)—bridge foundations—continuous flight augur—drilled shafts—driven piles—micropiles—spread footings		No restrictions.	
19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	61	NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Principal Investigator
Brent Phares, Director
Bridge Engineering Center, Iowa State University

Co-Principal Investigators
Yaohua Deng and Ping Lu

Authors
Brent Phares, Seyedamin Mousavi, and Yaohua "Jimmy" Deng

Sponsored by
Iowa Highway Research Board
and Iowa Department of Transportation
(IHRB Project TR-716)

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement
with the Institute for Transportation
(InTrans Project 17-599)

A report from
Bridge Engineering Center
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.instrans.iastate.edu

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EXECUTIVE SUMMARY

To minimize traffic impact during accelerated bridge construction (ABC) projects, it is sometimes desirable to construct the new substructure underneath an existing bridge prior to its demolition and road closure. Installing a new substructure under an existing bridge creates challenges during construction, primarily due to the low overhead space and stability concerns for the existing foundation.

A preliminary literature search revealed that documentation of the technical details for methods that can be used during the construction of new substructures underneath existing bridges are not readily available. This limited availability of documentation indicates the methods are not likely to be used by state departments of transportation (DOTs), local agencies, consultants, or contractors.

The objectives of this project included three main focus areas:

- Document through a literature search and survey, methods (including but not limited to multi-splicing and micropiles) for constructing new substructures beneath existing bridges
- Evaluate proven methods in terms of design considerations, constructability, and cost
- Document the project findings and develop method selection recommendations/guidelines

A literature review was first completed to obtain knowledge about different foundation methods and their application in ABC projects. The findings are presented as brief case studies in this report.

In the next step of this study, a survey was developed and distributed via email to investigate methods utilized by other DOTs in the construction of new foundations on ABC projects. The survey included questions about the common methods for bridge foundation construction.

Key Findings

Foundations for bridges are divided into two main categories: shallow foundations and deep foundations. Shallow foundations include spread footings and mats. Driven piles, drilled shafts, continuous flight auger piles, and micropiles are categorized as deep foundations. Each method has its own advantages and limitations.

Spread footings can be an economical and practical approach for bridge foundations, but this method is not applicable for high structural loads or weak soil conditions. Although ground conditions can be improved by different methods to accommodate spread footing foundations, that may not have economic justification.

Driven piles with various types of material, cross sections, and driving methods are one of the approaches in bridge foundation construction. Through-deck pile driving is a method that can be used on ABC projects when there is restricted space under the existing bridge.

Drilled shafts can provide proper axial and lateral resistance to loads induced from the superstructure. However, they can only be installed outside of the existing bridge footing, while there is also some newer equipment for spaces with low headroom.

Continuous flight augur piles are another approach to install piles for bridge foundations that can be utilized under existing bridges.

The last method from the deep foundation family is micropiles. Micropiles have a small diameter but can resist significant axial loads and moderate lateral loads. The installation equipment for micropiles is relatively small and can be mobilized easily. However, the cost of micropiles usually exceeds other piling systems.

Conclusions

According to the recorded information from the email survey, 47 DOT respondents opened the survey link and 19 states answered at least one of the questions.

- According to the survey results, state DOTs use common methods for bridge foundation construction on ABC projects, and there is no new method in use
- Using a soil strengthening method is not used in most states
- The continuous flight auger method does not appear to be a common method among state DOTS
- The average height for minimum headroom for micropiles is nearly 13 ft
- The average height for minimum headroom for a drilled shaft is nearly 27 ft
- The average height for minimum headroom for steel pile driving is nearly 35 ft
- The disruption of through-deck piling on traffic flow is evaluated as high

Implementation Readiness and Benefits

Documenting proven techniques for constructing new substructures beneath existing bridges and comparing their design considerations, constructability, and costs will help engineers determine the most appropriate application of these techniques. This could help engineers make more consistent, efficient, and cost-effective decisions and reduce the risk in using the techniques on ABC projects.

CHAPTER 1:INTRODUCTION

1.1 Background

To minimize traffic impact during accelerated bridge construction (ABC) projects, it is sometimes desirable to construct the new substructure underneath an existing bridge prior to its demolition and road closure. Installing a new substructure under an existing bridge creates challenges during construction, primarily due to the low overhead space and stability concerns for the existing foundation.

A variety of approaches have been used to either construct new or rehabilitate existing bridges with new foundations. Some examples include use of spread footings, use of micropiles, and driving piles through holes in the existing deck. Each method has advantages and limitations.

A preliminary literature search revealed that documentation of the technical details for methods that can be used during the construction of new substructures underneath existing bridges are not readily available. This limited availability of documentation indicates the methods are not likely to be used by state departments of transportation (DOTs), local agencies, consultants, or contractors. Therefore, documenting proven techniques and comparing their design considerations, constructability, and costs are necessary to determine the most appropriate application of these techniques. This will assist engineers in attaining more consistent, efficient, and cost-effective decisions, and reduce the risk in using the new techniques.

1.2 Objective and Scope

The objectives of this project included three main focus areas:

- Document through a literature search and survey, methods (including but not limited to multi-splicing and micropiles) for constructing new substructures beneath existing bridges
- Evaluate proven methods in terms of design considerations, constructability, and cost
- Document the project findings and develop method selection recommendations/guidelines

CHAPTER 2:LITERATURE REVIEW AND EVALUATION

2.1 Introduction

ABC provides a cost-effective approach to rapidly replace an existing bridge and reduce the impacts on the mobility and safety of transportation systems. Due to the overall poor condition of bridges in the nation and ever-increasing demands of the traveling public, ABC has been attracting more and more interest over the past decade.

With ABC projects, it is sometimes necessary to build the new substructure beneath an existing bridge. This requires the contractor to deal with challenges associated with limited overhead space and in ensuring the stability of the existing foundation system. Several approaches have been used with the goal of solving these problems.

When soil conditions allow, spread footings are ideal given that excessive headroom is not required during construction. Spread footings can be built using traditional construction approaches. However, bedrock is seldom near the surface in Iowa and the utilization of spread footings are therefore not ideal in Iowa.

Piles are economically preferred in most cases in Iowa. However, the vertical clearance underneath a bridge is typically not enough to allow driving of traditional piles.

While multiple splicing of common-length piles seems a potential solution to reduce the required headroom, the current Iowa Department of Transportation (DOT) *Bridge Design Manual* does not allow pile splicing of piles with a length shorter than 55 ft and does not allow multiple splicing of piles with a length between 56 ft and 110 ft. A review of technical papers and reports and other states' practices will compile current information on approaches, techniques, and performance data related to multiple-pile splicing.

This chapter provides a general definition of accelerated bridge construction. Then, different solutions for bridge foundations are reviewed and assessed for ABC projects. To investigate probable new methods in foundation construction related to ABC projects and also gather information about common methods, a survey was distributed to state DOTs. The last section of this chapter is devoted to the survey and its results.

2.2 Accelerated Bridge Construction

ABC is a bridge construction method that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce on-site construction time (Culmo 2001). The key components of an ABC project, which make it different from conventional bridge construction, are reduction of on-site construction time and returning the bridge to service within a short period of time.

2.3 Conventional Construction Foundation Solutions for ABC Projects

With conventional construction for ABC projects, the foundation is the first structural element constructed and its performance has a significant effect on the overall performance of the structure. Generally, foundations are classified into two broad groups: shallow foundations and deep foundations (Coduto et al. 2011). Shallow foundations include spread footings (footer or simply footing) and mats. Driven piles, drilled shafts, continuous flight auger piles, and micropiles are categorized as deep foundations. The following sections briefly review different foundation types and assess the feasibility of each type for ABC projects.

2.3.1 *Shallow Foundations*

Spread footings are a general type of shallow foundation used in bridge construction. Compared to deep foundation methods, generally, spread footings are more economical. If the geomaterial and ultimate loading conditions are appropriate, spread footings can be one of the favorable choices for bridge foundations.

The main factors that make a spread footing suitable for ABC projects are that it does not need a large space or tall equipment to be constructed. However, shallow foundations are restricted in structural loads and ground conditions.

This method is not appropriate for situations in which the foundation experiences large uplift or lateral loads; also, it is not suitable for foundations subjected to large settlement, liquefaction, or scour. More detailed information about usage of spread footing foundations is provided in *Implementation Guidance for Using Spread Footings on Soils to Support Highway Bridges* (Abu-Hejleh et al. 2014).

In some situations, the ground condition is improved to supply adequate soil properties needed to use a shallow foundation. Generally, there are nine methods to improve ground condition (Schaefer et al. 2016):

- Vertical drains and accelerated consolidation
- Lightweight fills
- Deep compaction
- Aggregate columns
- Column-supported embankments
- Soil mixing
- Grouting
- Pavement support stabilization
- Reinforced soil structures

2.3.2 *Driven Piles*

When one or more upper soil layers are highly compressible and too weak to support loads transmitted by the superstructure, piles are used to transfer the load to underlying bedrock or a deep strong soil layer. The piles provide efficient resistance to both lateral and vertical loads.

Driven piles are the most commonly used deep foundation approach and one of the proven foundation systems used for transportation projects. Piles can be categorized by different aspects such as material, cross-section, and driving method. Primary pile materials include steel, concrete, and timber. However, plastic piles, including various composite materials such as polymer composites, polyvinyl chloride (PVC), and recycled materials, are used nowadays in special cases.

Considering their materials, piles can have various cross sections. Steel piles are generally either pipe piles or rolled steel H-section piles. Shell-type cross sections, such as Z or U profiles, are types of sheet pile. Pipe piles can be driven to the ground with their ends open or closed; open end pipe piles are available in diameters that range from 8 in. to 160 in. and closed end pipe piles typically range from 8 in. to 30 in. (Hannigan et al 2016). Typically, favored sections for H-piles are in 12 in. to 14 in.

Concrete-driven piles, with rectangular or octagonal cross sections, can be fabricated using ordinary reinforcement or pre-stressed cables. Prestressed piles can either be pre-tensioned or post-tensioned. Pre-tensioned piles are usually cast to their full length in permanent casting beds. Post-tensioned piles are usually manufactured in sections, most commonly cylindrical, and assembled and stressed to the required pile lengths at the manufacturing plant or on the job site. Reinforced concrete piles are more susceptible to damage during handling and driving because of tensile stresses compared to prestressed piles. However, reinforced concrete piles are easier to splice than prestressed piles (Hannigan et al 2016).

Driving piles are categorized into main three groups: impact driving, vibrodriving, and pressing. With impact driving methods, the pile is driven into the ground under the blow of a hammer. The earliest method was simply a falling weight creating an impact on top of the pile. Air and diesel hammers are also popular types of hammers that use explosive force to drive the pile. Nowadays, hydraulic hammers are more efficient and less noisy than previous diesel types.

With the vibrodriving method, an oscillating driver is clasped to the pile top. By inducing vibration on top of the pile, friction along the sides of the pile is reduced and the pile is inserted into the ground by application of force resulting from the vibrator's weight. This method can be used for various steel profiles or sheet piles.

With the pressing (or press-in) method, neither impact nor vibration is used. Instead, piles are driven into the ground under the static force of hydraulic jacks. This method is very efficient for sensitive sites, such as city areas, since it does not generate noise. This method is one of the commonly used methods for sheet piling. However, with progress in pile driving technology, this method is used for various types of piles. Figure 2-1 illustrates prestressed concrete piles being driven using the press-in method.

A.P. van den Berg

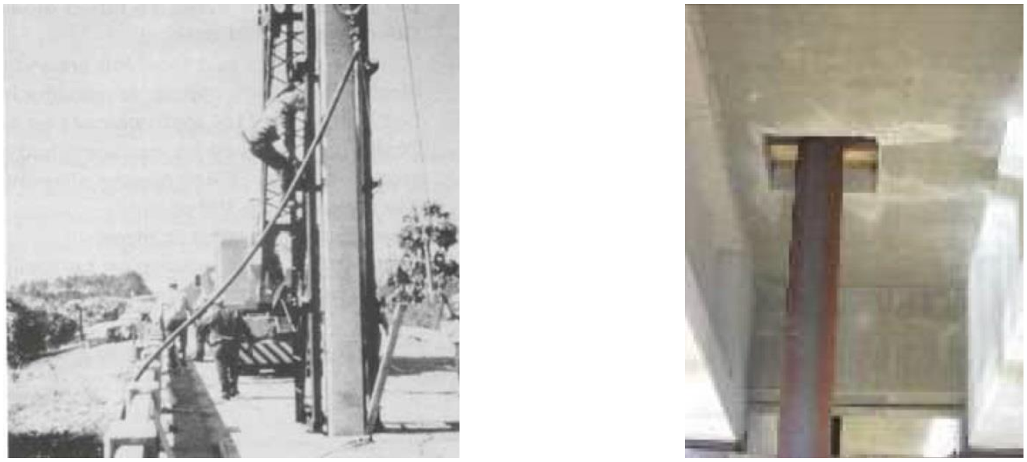
Figure 2-1. Concrete pile driving by press-in method

In the pile driving process, if the soil property is not appropriate, driving assistance methods can be utilized. Jetting and pre-auguring are two favored methods for pile driving assistance that can significantly improve the constructability of the project.

Jetting involves delivering a water jet to the soil at the pile toe, reducing friction between the pile and soil. Pre-auguring includes using a continuous flight auger to penetrate the ground along the pile line in advance of pile installation. Both methods change the in situ soil properties around the piles and the impact of their use needs to be considered in the design process. Figure 2-2 shows the application of pre-auguring for press-in sheet piling in a hard ground stratum, such as a sandy gravel layer with a boulders and rock layer.

Figure 2-2. Sheet pile driving with pre-auguring

Since pile driving tools are typically tall and need notable headroom, one of the methods that can be implemented in ABC projects is driving piles through the bridge deck. This is accomplished by cutting holes in the deck and driving the piles through the holes. Given that piles are driven from the deck, the deck must be capable of supporting the necessary pile-driving equipment. It can also disrupt the traffic flow in some cases. Figure 2-3 shows typical usage of through-deck piling.



Wilbur Smith Associates   Monnier et al. 2015

Figure 2-3. Pile driving process through deck (left) and pile driven through deck (right)

2.3.3 *Drilled Shafts*

A drilled shaft foundation is formed by excavating a hole in the ground. The typical diameter of hole-drilled shaft ranges from 3 ft to 12 ft, considering the soil or rock into which the foundation is formed. After boring the hole, a cast-in-place reinforced concrete member is constructed inside the hole. This kind of foundation can support axial forces through a combination friction action and end bearing resistance. The large diameter reinforced concrete member is also able to provide adequate resistance to lateral and overturning loads.

Drilled shafts are fairly commonly used for transportation structures and bridges to depths of up to 200 ft in the US, but can extend to depths of as much as 300 ft or more (Brown et al. 2010).

Drilled shafts can be used in ABC projects. It is possible to drill shafts outside the existing bridge footing, which is illustrated in Figure 2-4.

Brown et al. 2010

Figure 2-4. Using drilled shafts out of bridge footprint

There is also some construction equipment that can install drilled shafts in spaces with limited headroom (see Figure 2-5).

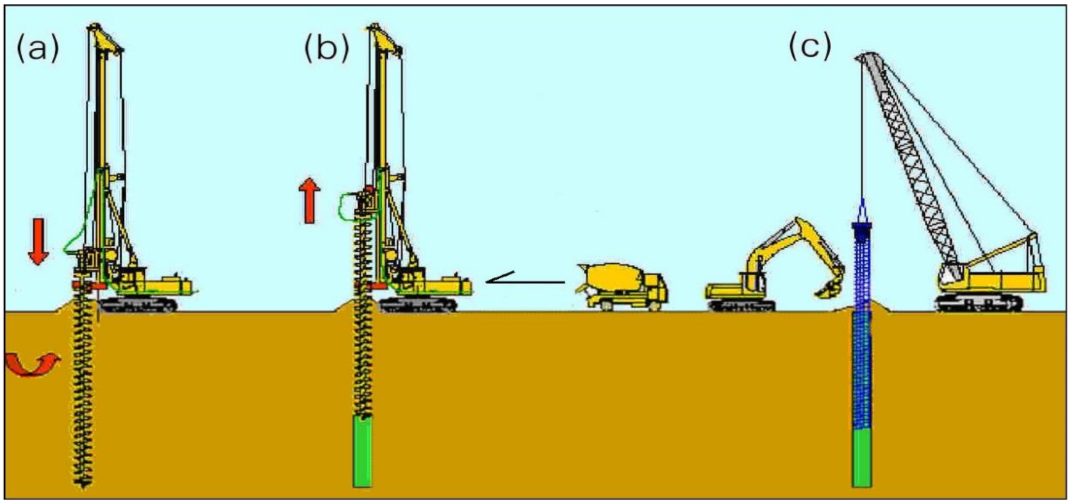
A.H. Beck Foundation Company

Figure 2-5. Shaft drilling in low headroom

More detailed information about usage of shallow foundations in highway bridges is provided in *Drilled Shafts: Construction Procedures and LRFD Design Method* (Brown et al. 2010).

2.3.4 *Continuous Flight Auger*

This method is a kind of deep foundation in which piles are constructed to the intended depth using a continuous flight auger. Figure 2-6 shows the various steps of the continuous flight auger (CFA) piling method.



Brown et al 2007

Figure 2-6. Steps of continuous flight auger pile construction

In this process, an auger is drilled into the ground and continuous filling of the auger flight with soil can provide stability for the drilled hole (Figure 2-6a). After reaching a predetermined depth, the auger is withdrawn, and the free hole is placed with concrete or grout (Figure 2-6b). Filling the hole is done by pumping the concrete/grout mix through the pipe located at the center of the auger. Simultaneous pumping of the grout or concrete and withdrawing the auger continues until the hole is filled. At this stage, reinforcement is placed into the hole filled with fluid concrete/grout immediately after withdrawal of the auger.

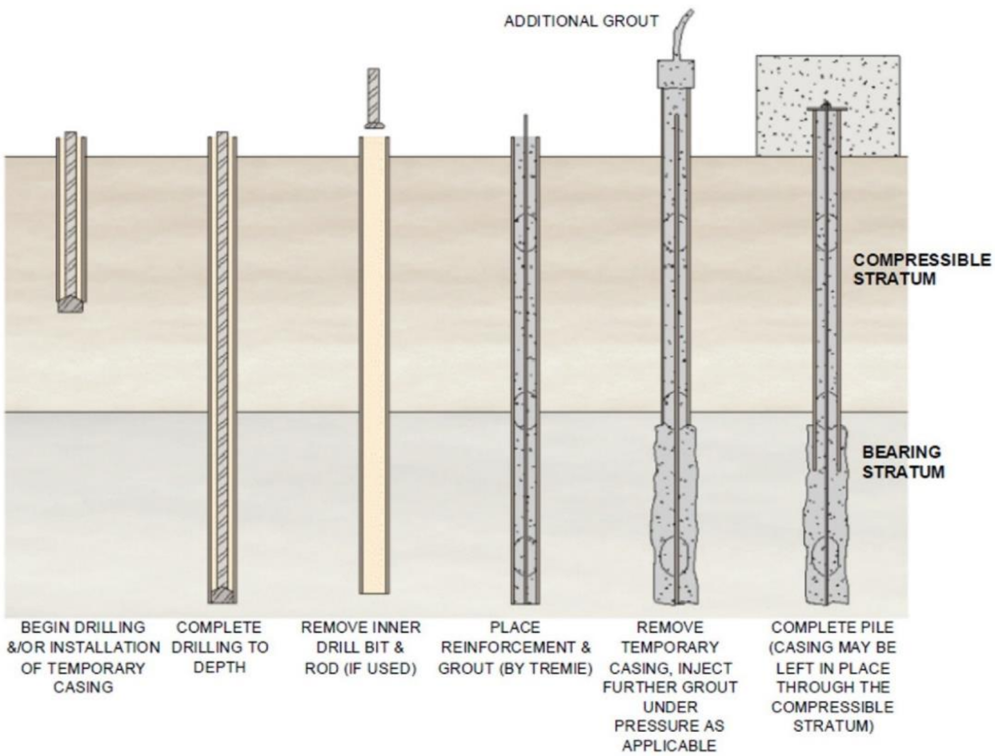
CFA piles can be a practicable foundation solution for ABC projects. There is also some installation equipment that can provide drilled shafts in spaces with limited headroom (see Figure 2-7).

Figure 2-7. Equipment used for low headroom continuous flight auger piles

More detailed information about usage of shallow foundation in highway bridges is provided in *Design and Construction of Continuous Flight Augur (CFA) Piles* (Brown et al. 2007).

2.3.5 *Micropiles*

This kind of deep foundation method includes small-diameter piles with diameters less than 12 in. With micropiles, the ground is drilled using a temporary casing to stabilize the soil. After reaching the predetermined depth, the drill bit is removed and the reinforcement and grout are placed inside the hole. Finally, the temporary casing is removed and additional grout is injected. In some cases, a permanent steel casing can be used in combination with the steel reinforcing member to provide additional lateral, as well as axial, capacity (Rabeler et al. 2000). The piling process is illustrated in Figure 2-8.



Sabatini et al. 2005

Figure 2-8. Steps of micropile construction process

Micropiles can resist relatively significant axial loads and moderate lateral loads (Sabatini et al. 2005). To improve their lateral load deficiency, they can be installed at any angle (battered). Micropile installation causes low disturbance to adjacent structures. However, they are vulnerable to buckling due to their being slender, and this issue should be considered in design.

The installation equipment for this piling method is relatively small and can be mobilized in limited areas and low headroom conditions. Figure 2-9 shows a typical usage of micropiles in a low headroom construction project.

Sabatini et al. 2005

Figure 2-9. Using micropiles in low headroom project

The installation requirements for micropiles make them an appropriate choice for ABC projects. However, the cost of micropiles usually exceeds conventional piling systems, and especially driven piles. Under certain combinations of circumstances, micropiles can be the cost-effective choice and sometimes the only feasible constructible option (Armour et al. 2000).

2.4 State DOT Survey

In previous sections, various systems for bridge foundations were reviewed and their implementation for ABC projects were briefly described. To investigate further, a survey was distributed to the state bridge engineers within each state DOT via email. The purpose of this survey was to identify probable new foundation construction methods used by other state DOTs.

2.4.1 *Survey Questions*

The survey was comprised of the following eight questions.

1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?

2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges? (you can select more than one choice)
Spread footings, Micropiles, Multiple-spliced driven steel piles, Drilled shafts

3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases?

4- According to your experience, what was the minimum headroom (ft) where micropiles were used?

5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within the existing bridge?

6- According to your experience, what was the minimum headroom (ft) where drilled shafts were used beneath/within existing bridge?

7- How do you assess the disruption of the through-deck driven pile method on the traffic flow?

8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?

2.4.2 *Survey Results Summary*

According to the recorded information from the email survey, 47 DOT respondents opened the survey link and 19 states answered at least one of the questions. This section summarizes the results collected from those respondents.

1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?

Yes	8 (80%)
No	2 (20%)

2- What type of foundation solutions do your agency use when constructing a new foundation beneath/within existing bridges?

Spread footings	Micro-piles	Multiple-spliced driven steel piles	Through-deck driven steel piles	Continuous flight auger piles	Drilled shafts	Other
7	14	5	7	0	8	0

3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases?

Yes	1 (12%)
No	7 (88%)

4- According to your experience, what is the minimum headroom (ft) where micropiles can be used?

Delaware	13
Illinois	10
Maryland	15
Missouri	8
Pennsylvania	14.5
Texas	16
Average	12.75

5- According to your experience, what is the minimum headroom (ft) where continuous flight auger (CFA) piles can be used beneath/within an existing bridge?
No answer

6- According to your experience, what is the minimum headroom (ft) where drilled shafts can be used beneath/within an existing bridge?

Delaware	50
Illinois	10
Texas	20
Average	26.67

7- How would you characterize the disruption of the through-deck driven pile method on traffic flow?

Illinois	High
Louisiana	Moderate
Maryland	Moderate
Michigan	High
Missouri	High
Pennsylvania	High
Washington	Low

8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?

Illinois	30
Pennsylvania	40
Average	35

CHAPTER 3:CASE STUDIES

3.1 Introduction

In the previous chapter, common methods for constructing new foundations beneath existing bridges were introduced. Also, the results of a survey that was distributed to find out more about various aspects of the methods were presented. This chapter provides case studies utilizing the methods on projects to overcome the challenges of constructing a new foundation beneath the existing bridge. The case study projects include different goals—from complete renewal of a bridge using an ABC methodology to retrofitting and rehabilitating the damaged foundation of a bridge.

3.2 Charlotte Avenue Bridge Replacement, Nashville, Tennessee, 2015

The two bridges at the Charlotte Avenue crossing in Nashville, Tennessee, were completely replaced in the Tennessee DOT (TDOT) Fast Fix 8 Project. The existing bridges were three-span continuous K-frame structures supported on thrust blocks. The total bridge length was about 200 ft and the beam depth was 36 in. (Kniazewycz and Mackie 2017). Figure 3-1 shows two views of the existing bridges.

Kniazewycz and Mackie 2017

Figure 3-1. Existing Charlotte Avenue bridges

The new bridges included a single span with two steel plate girder units and a composite concrete deck. Given the bed rock was only 8 ft from the road elevation and was shallow enough, an isolated spread footings foundation was selected as an economical approach for the abutment's foundation (Kniazewycz and Mackie 2017).

To construct the new foundation for the abutments, the existing end fills were excavated. To stabilize the existing abutment's fill, soil nailing was utilized, as illustrated in Figure 3-2.

Kniazewycz and Mackie 2017

Figure 3-2. Excavation and soil stabilization beneath the existing bridge

Leveling concrete was placed during excavation to bring the working level up to the roadway. As shown in Figure 3-3, construction of the new substructures took place under the existing bridges.

Kniazewycz and Mackie 2017

Figure 3-3. Construction of new substructures beneath the bridges

The superstructures were replaced during a weekend road closure utilizing ABC methods.

3.3 Pennsylvania Turnpike Bridge NB-355 at Milepost A-57.66, Pennsylvania, 2017

The existing Pennsylvania Turnpike (I-476) northeast extension bridge over Crackersport Road (milepost A-57.66) in Lehigh County, Pennsylvania, was a dual three-span structure with a 42 ft 0 in. length for each span girder superstructure (Figure 3-4).

Carper et al. 2017

Figure 3-4. Existing NB-355 bridge at milepost A57.66

The bridge had continuous reinforced concrete abutments and independent reinforced concrete piers with circular pile foundations. The bridge had extensive deck and pier deterioration and also needed to be widened. The solution was complete replacement of the bridge.

The new bridge was a dual single-span superstructure 115 ft 0 in. long. To construct the new superstructure, temporary bents were used along each side of the turnpike. The new reinforced concrete abutments and wingwalls were founded on micropiles and constructed in front of the existing abutments while traffic was maintained on the existing bridge. The micropiles had a 9.625 in. diameter, 85 ft 0 in. depth, and 5 ft 0 in. spacing length. The micropiles were installed with only 16 ft of overhead clearance. Figure 3-5 shows the micropile installation procedure.

Carper et al. 2017

Figure 3-5. Installing micropiles beneath existing bridge

The existing bridge and piers were demolished in a weekend 55-hour closure, and the new superstructure was slid laterally into place using ABC methods. Figure 3-6 (left) provides a view during the bridge's superstructure replacement and Figure 3-6 (right) shows the completed bridge.

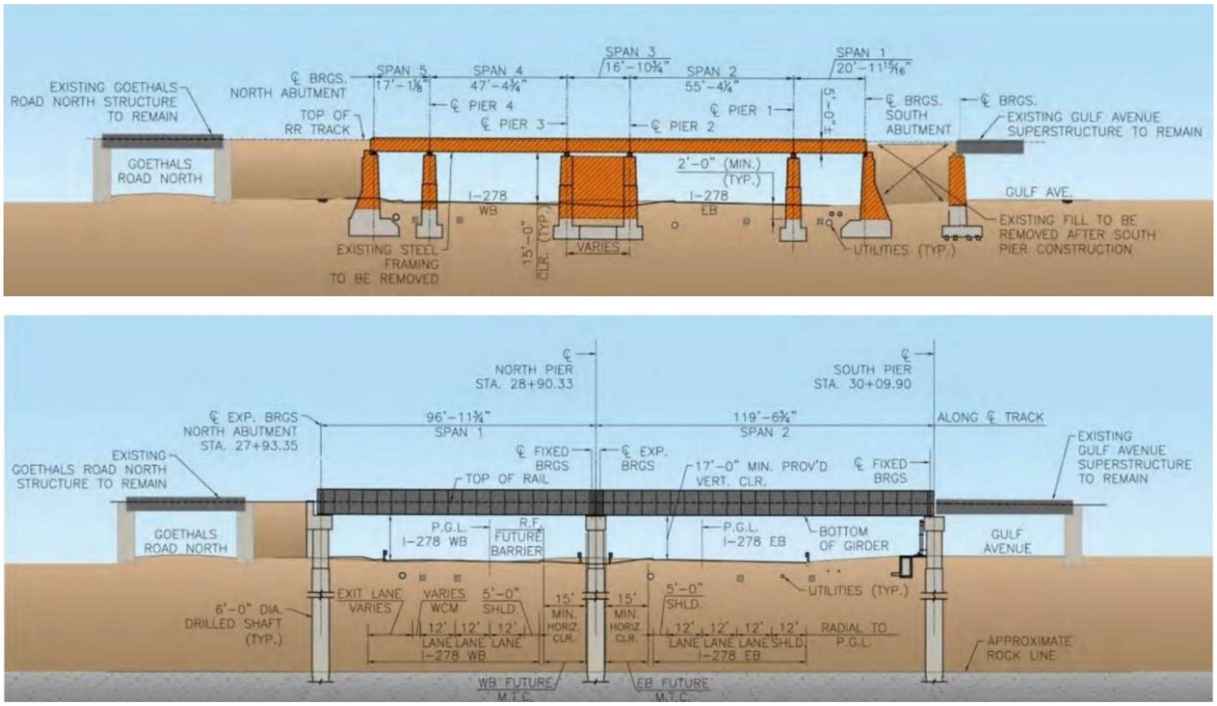
Carper et al. 2017

Figure 3-6. Slide-in procedure of new substructure (left) and new NB-355 bridge at milepost A57.66

3.4 Travis Spur Rail Bridge Replacement, Staten Island, New York, 2017

The Travis Spur Rail Bridge (TSRB) is part of the Staten Island Railroad (SIRR) owned by the City of New York. The section of the TSRB over eastbound and westbound I-278 was built in 1930 and was a five-span, through-girder bridge with a ballasted track. The steel superstructure was set on reinforced concrete piers and abutments on spread footings.

Since I-278 in the vicinity of the TSRB was widened and re-configured, a new bridge configuration was needed to accommodate the geometrical changes. As a result, the old five-span bridge was removed and a new two-span through-girder bridge was constructed. Figure 3-7 shows the original and new elevation views of the bridge.



Kang et al. 2017

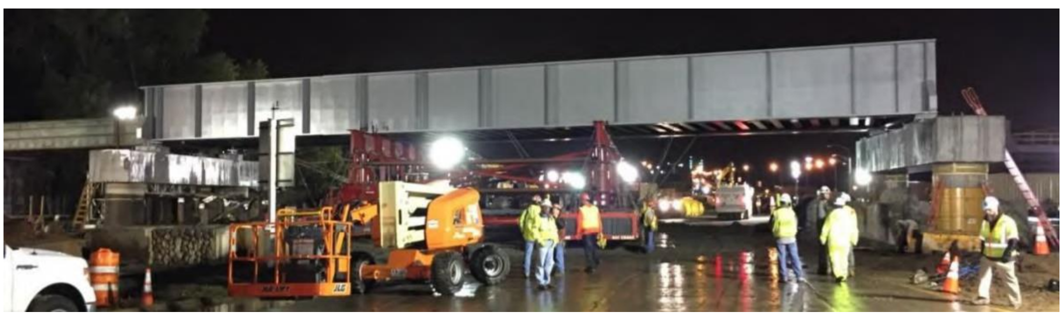
Figure 3-7. Travis Spur Rail Bridge old elevation (top) and new elevation (bottom)

The superstructure of the new bridge included welded steel plate girders. The substructure units were precast concrete abutments and pier caps on cast-in-place 5 ft 6 in.-diameter double columns supported on a 6-ft diameter drilled shaft. The contractor chose to use a larger-than-required drilled shaft size for economic reasons because that sized shaft was being used on many of the foundations at the new Goethals Bridge's New York approach spans, thus allowing for re-use of forms and tooling (Kang et al. 2017). The depth of the drilled shafts at the north abutment, north pier, and south pier were 42 ft 6 in., 42 ft 6 in., and 49 ft, respectively.

ABC techniques were used to replace the entire original five-span bridge with a new, two-span bridge over a single weekend. The shafts and columns were constructed on either side of the existing substructure prior to closure. Figure 3-8 shows precast pier cap installation and Figure 3-9 shows the superstructure's replacement.

Kang et al. 2017

Figure 3-8. Pre-cast pier cap installation



Kang et al. 2017

Figure 3-9. Superstructure replacement

3.5 I-495 Emergency Repair Project, Wilmington, Delaware

This project required 32 drilled shafts each with a 4 ft diameter and up to a 168 ft depth to repair a failing bridge over the Christina River in Wilmington, Delaware. The bridge was 40 years old and carried about 90,000 vehicles a day (A.H. Beck Foundation Co., Inc.). All shafts were drilled underneath the existing bridge, with only 50 ft of headroom space.

To prevent excessive vibration resulting in additional damage to the bridge, oscillators were used to start the permanent casing, the shafts were excavated using bentonite slurry down to rock, and the remainder of the casing was then welded together and driven with vibratory hammers (A.H. Beck Foundation Co., Inc.).

The 50 kips full-length reinforcing cages were lifted over the deck of the bridge, lowered through cut outs in the concrete decking, and installed in the excavated drilled shaft below (A.H. Beck Foundation Co., Inc.). Figure 3-10 shows the installation of shafts beneath the existing bridge.

A.H. Beck Foundation Co., Inc.

Figure 3-10. Installation of shafts beneath the existing bridge

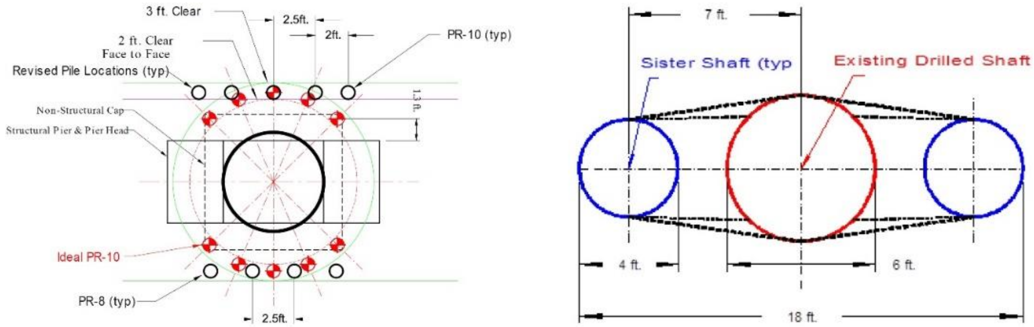
3.6 Lee Roy Selmon Crosstown Expressway, Tampa, Florida, 2004

In April 2004, during construction of a 5-mile elevated section of the Lee Roy Selmon Crosstown Expressway in Tampa, Florida, Pier No. 97 plunged 11 ft causing a collapse of two sections of the bridge (see Figure 3-11).

Dapp et al. 2013

Figure 3-11. Collapse of bridge under construction due to foundation failure

More investigation showed that the drilled shaft foundation had inadequate capacity to carry loads and 27 of the constructed bents had the same deficiency and needed remediation. Constructing sister shafts and utilizing micropiles were the two methods selected to strengthen the system. Sister shafts (sometimes called straddle shafts) is a method for supplementing or replacing a defective drilled shaft. Figure 3-12 shows the sister shaft and micropile layout used to upgrade the foundation of the bridge.



Dapp et al. 2013

Figure 3-12. Foundation upgrading solutions: micropile layout (left) and drilled shaft layout (right)

Both shafts and micropiles were installed under the existing bridge, with as little as 18 ft headroom. Low clearance installation equipment designed and manufactured by A.H. Beck Foundation Co., Inc. was used. Figure 3-13 shows the installation of the new shafts and micropiles under the bridge.

Dapp et al. 2013

Figure 3-13. Shaft drilling under the bridge (left) and micropile installation under the bridge (right)

3.7 De Diego Bridge Modifications, Puerto Rico

This project was to construct new soldier pier retaining walls as protection for existing bridge abutments. A total of 67 50-in.-diameter soldier piers with a 50 ft depth were constructed under 13 ft of overhead clearance (A.H. Beck Foundation Co., Inc.). Each soldier pier had #24 to #18 vertical full-length reinforcing bars that had to be spliced together in sections as each went into the shaft. Figure 3-14 shows the construction of the new shafts beneath the bridge.

A.H. Beck Foundation Co., Inc.

Figure 3-14. Constructing drilled shafts beneath existing bridge

3.8 Railway Bridge Foundation Repair, Columbus, Ohio

In Columbus, Ohio, one of the pier foundations supporting a railroad bridge was in a poor condition due to scour and needed immediate repair. The original foundation was supported on timber piles with a concrete footer. To repair the foundation, 35 micropiles with a depth of 85 ft were installed around the original footer. To construct a larger concrete encasement footer, 25-ft long PZC 18 sheet piles were driven. Because of limited overhead clearance (only 15 ft) and the proximity to the damaged foundation, before installing micropiles, sheet piles were driven using equipment capable of applying up to 130 metric tons of press-in force. Sheet piles had to be spliced and welded together underneath the girder. Figure 3-15 shows the pile driving procedure beneath the existing bridges and the micropiles installed in around the old foundation.

Takuma and Sakai 2018

Figure 3-15. Pile driving procedure beneath the existing bridge (left) and micropiles installed around the old foundation (right)

3.9 Togawa Rail Bridge Foundation Repair, Japan

The Togawa Bridge is located approximately 100 miles north of downtown Tokyo, Japan. It was built in 1947 with two spans. One of the spans included a 82.7-ft long plate girder while the other had a 203-ft long truss (Takuma and Sakai 2018). Figure 3-16 provides a view of this bridge.

Takuma and Sakai 2018

Figure 3-16. Togawa rail bridge, Japan

Due to heavy scour caused by flooding, one of the pier foundations needed emergency repair. Considering the historical significance and low headroom under the bridge, the Gyropress piling method was chosen for installing pipe piles around the existing foundation to prevent probable damage during pile driving operations (see Figure 3-17).

Takuma and Sakai 2018

Figure 3-17. Pile driving using Gyropress method under the bridge

With this method, a combination of press-in and rotational force is utilized to install the pipe piles. The driving equipment is mounted on top of the previously driven piles and can move forward automatically after completing the driving of each pile.

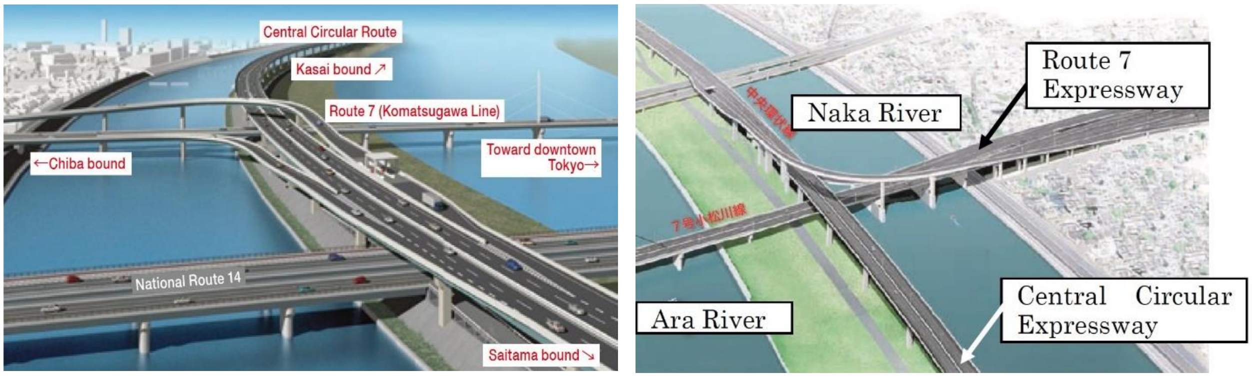
For this project, 36 pipe piles were driven and 22 of them were spliced two or three times each due to the limited headroom, while those outside the bridge were spliced once or installed as a whole, considering the overhead clearance at each pile location. Figure 3-18 provides a view of a completed new footing.

Takuma and Sakai 2018

Figure 3-18. Completed new footing

3.10 Komatsugawa Junction, Tokyo, Japan

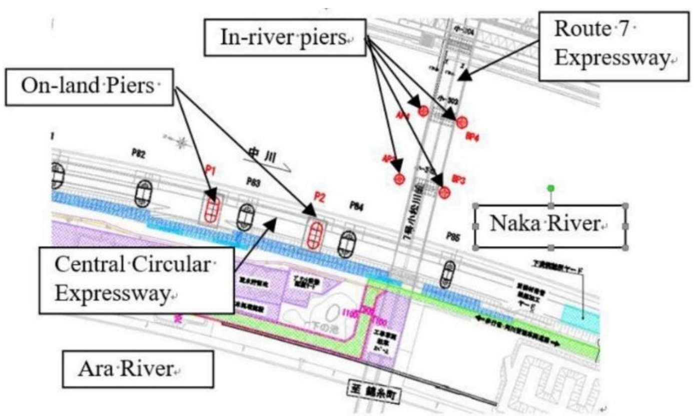
Komatsugawa Junction is located nearly 8 miles from Tokyo, Japan. To connect the east-west Route 7 and central circular expressway, a new connecting ramp and frontage road were designed and constructed. Figure 3-19 provides a general view of the location.



Takuma et al. 2017

Figure 3-19. Komatsugawa Junction location

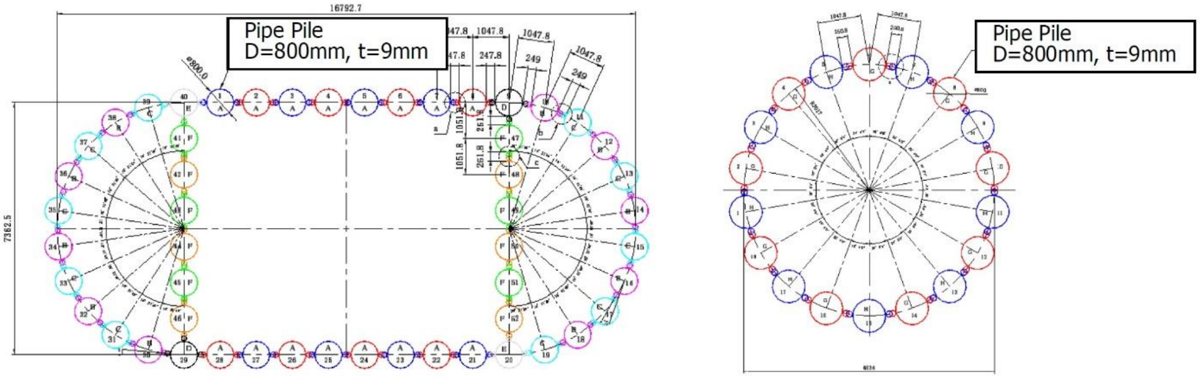
To connect ramp lanes between the two expressways, six new piers were constructed with two of them on the riverbank and four in the river. Figure 3-20 shows the positions of the new piers.



Takuma et al. 2017

Figure 3-20. Positions of new piers constructed on Komatsugawa Junction project

Construction of the new piers required the installation of a new foundation for each. Pipe piles were selected as the deep foundation for all piers. The on-land pile groups were arranged in a quasi-oval configuration while the in river piles had a circular layout (see Figure 3-21).



Takuma et al. 2017

Figure 3-21. New foundation configuration: on-land pier foundation (left) and in-water pier foundation (right)

The pipe piles had a 35 in. diameter with the wall thickness varying from 0.35 to 0.71 in. Depending on the pile group position, the length of the piles varied from 167 ft to 195 ft.

To minimize vibration and noise during pile driving operations, the Gyropress pile driving method was utilized on this project. The two on-land piers needed to be constructed under the Route 7 expressway as shown in Figure 3-22.

Takuma et al. 2017

Figure 3-22. Pile driving using Gyropress method under the bridge

Due to limited available overhead under the bridge, 195-ft piles were installed in five splices with the maximum length of 34 ft each.

CHAPTER 4:SUMMARY AND CONCLUSIONS

4.1 Summary

The research presented in this report started with a brief description of ABC. This method is based on modern approaches for design, construction, and material selection for bridge construction with the goal of reducing traffic interruptions. Similar to other facilities, bridge construction usually needs the foundation to be in place before other elements. The main issue in constructing the foundation in an ABC project is low headroom available for construction activities.

A literature review was completed with the goal of obtaining knowledge about different foundation methods and their application in ABC projects. Foundations for bridges are divided into two main categories: shallow foundations and deep foundations. Shallow foundations include spread footings (footer or simply footing) and mats. Driven piles, drilled shafts, continuous flight auger piles, and micropiles are categorized as deep foundations.

Spread footings can be an economical and practical approach for bridge foundations, but this method is not applicable for high structural loads or weak soil conditions. Although ground conditions can be improved by different methods to accommodate spread footing foundations, that may not have economic justification.

Driven piles with various types of material, cross sections, and driving methods are one of the approaches in bridge foundation construction. Through-deck pile driving is a method that can be used on ABC projects when there is restricted space under the existing bridge.

Drilled shafts can provide proper axial and lateral resistance to loads induced from the superstructure. However, they can only be installed outside of the existing bridge footing, while there is also some newer equipment for spaces with low headroom.

Continuous flight augur piles are another approach to install piles for bridge foundations that can be utilized under existing bridges.

The last method from the deep foundation family is micropiles. Micropiles have a small diameter but can resist significant axial loads and moderate lateral loads. The installation equipment for micropiles is relatively small and can be mobilized easily. However, the cost of micropiles usually exceeds other piling systems.

In the next step of this research, a survey was created to investigate methods utilized by other DOTs in the construction of new foundations on ABC projects. The survey included questions about the common methods for bridge foundation construction.

4.2 Conclusions

Based on the completed study presented within this report, the following conclusions were drawn:

- According to the survey results, state DOTs use common methods for bridge foundation construction on ABC projects, and there is no new method in use
- Using a soil strengthening method is not used in most states
- The continuous flight auger method does not appear to be a common method among state DOTS
- The average height for minimum headroom for micropiles is nearly 13 ft
- The average height for minimum headroom for a drilled shaft is nearly 27 ft
- The average height for minimum headroom for steel pile driving is nearly 35 ft
- The disruption of through-deck piling on traffic flow is evaluated as high

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APPENDIX: SURVEY RESPONSES BY STATE

According to the recorded information from the email survey, 47 DOT respondents opened the survey link, 24 of them provided their contact information, and 19 answered at least one of the questions. This appendix includes the responses from those 19 states in alphabetical order.

California

State	***California***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Micropiles, Multiple-spliced driven steel piles, Through-deck driven steel piles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Delaware

State	***Delaware***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*~13 ft*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*N/A*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*50 ft*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*N/A*

Georgia

State	***Georgia***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Micropiles*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Illinois

State	***Illinois***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Multiple-spliced driven steel piles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*10 ft*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*10 ft*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*High*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*30 ft*

Kansas

State	***Kansas***	
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*No*	
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Other (please specify)*	*We have not constructed a new foundation under an existing bridge.*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*	
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*	
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*	
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*	
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*	
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*	

Kentucky

State	***Kentucky***	
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*	
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Through-deck driven steel piles, Other (please specify)*	*Through pavement (lane at a time) behind existing bents*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*	
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*	
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*	
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*	
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*	
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*	

Louisiana

State	***Louisiana***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Through-deck driven steel piles*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*Moderate*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Maryland

State	***Maryland***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Through-deck driven steel piles*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*15'*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*NA*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*NA*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*Moderate*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*NA*

Michigan

State	***Michigan***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Micropiles*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*10*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*No experience*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*No experience*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*High*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*No experience*

Minnesota

State	***Minnesota***	
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*	
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Through-deck driven steel piles, Other (please specify)*	*Piles driven outside plan of existing bridge*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*	
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*	
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*	
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*	
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*	
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*	

Missouri

State	***Missouri***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Micropiles, Through-deck driven steel piles*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*8 ft*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*High*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

New York

State	***New York***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Micropiles, Multiple-spliced driven steel piles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Ohio

State	***Ohio***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Oklahoma

State	***Oklahoma***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Pennsylvania

State	***Pennsylvania***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Multiple-spliced driven steel piles*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*14.5 ft*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*N/a*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*N/a*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*High*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*40 ft*

Tennessee

State	***Tennessee***	
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Spread footings, Micropiles, Through-deck driven steel piles, Other (please specify)*	*Strengthening of existing substructures for new superstructure loads*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*	
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*	
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*	
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*	
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*	
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*	
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*	

Texas

State	***Texas***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*Yes*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*No*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*16 ft*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*No*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*20 ft*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*We haven't used this option*

Utah

State	***Utah***
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Micropiles, Multiple-spliced driven steel piles, Drilled shafts*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*

Washington

State	***Washington***	
1- Does your agency have experience with the construction of new substructures beneath/within existing bridges?	*	
2- What type of foundation solutions does your agency use when constructing a new foundation beneath/within existing bridges (you can select more than one choice)?	*Spread footings, Micropiles, Other (please specify)*	*not used yet*
3- If your agency has used the spread footing method, do you have experience using soil strengthening in these cases? - Selected Choice	*Yes (please specify the method)*	*N/A*
4- According to your experience, what was the minimum headroom (ft) where micropile was used?	*	
5- According to your experience, what was the minimum headroom (ft) where continuous flight auger (CFA) pile was used beneath/within existing bridge?	*	
6- According to your experience, what was the minimum headroom (ft) where drilled shaft was used beneath/within existing bridge?	*	
7- How do you assess the disruption of "Through-Deck Driven Pile" method on the traffic flow:	*Low*	
8- If your agency allows using multiple-spliced steel piles, what is the minimum headroom (ft) required for steel pile driving?	*	

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