PROJECT TITLE: DEVELOPMENT OF GUIDELINES FOR SELECTION OF SUBSTRUCTURE FOR ABC PROJECTS

Quarterly Progress Report
For the period ending May 31, 2019

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ACCELERATED BRIDGE CONSTRUCTION
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Submitted to:
ABC-UTC
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1. Background and Introduction

The concept of Accelerated Bridge Construction (ABC) using precast and prefabricated bridge elements are gaining popularity among transportation agencies primarily to minimize traffic delays and costs. Some other benefits associated with the ABC techniques are reduced on-site construction time, reduced impact on mobility, better work zone safety and improved quality. Previously, the focus of the ABC techniques was limited to specific prefabricated bridge elements such as bridge decks and pier caps. However, with the recent advancement in construction methods, many projects are using precast and prefabricated elements for other bridge elements such as substructures and foundations. In case of a new bridge construction, substructure design by ABC technique will allow rapid construction to accommodate superstructure installation. For replacing an existing bridge, the substructure construction by ABC technique will cause minimum interference with existing bridge operation. Currently, a number of potential ABC technologies are available to design and construct bridge substructures and foundations. A guideline will help the transportation agencies to select the suitable techniques for their specific need.

2. Problem Statement

A number of previous studies are available focusing on the use of precast, prefabricated bridge superstructure elements. On contrary, only few studies can be found focusing on the design and construction of substructure and foundation by ABC method as most of the time it is assumed that the substructure already exists and ready to receive the load from superstructure. However, substructure construction can be the most time-consuming work for a bridge construction. There is a need to have specific guidelines for design and construction of substructures and foundations for new bridges to obtain full benefits of ABC method. Also, guidelines are needed for consideration of reusing, strengthening, and modification of substructure and foundations of an existing bridge. In addition, new, innovative and non-interruptive substructure and foundation design methods need to be explored and documented.

3. Research Approach and Methods

The overall approach of this project is to conduct an extensive literature search and document the ABC technologies available for design and construction of substructure and foundation. The current evaluation techniques of an existing substructure and foundation and problems associated with the evaluation techniques will also be investigated for replacing an existing bridge. Also, methods for strengthening or modifying an existing substructure will be discussed. The issues with the state-of-the art practices of ABC techniques for constructing a new bridge will be identified and potential solutions will be proposed based on the literature review. Attempts will be taken to present few examples of new and innovative techniques of substructure and foundation construction. A survey will be conducted to find out the challenges faced by stakeholders during construction of bridge. The acceptability of new practices such as installation of prefabricated foundation elements, retrofitting etc. will be investigated through this survey.

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Develop Outline for the Guideline

Proposed task description:

An outline will be proposed as a first step of developing a guide for substructure and foundation by ABC method. The outline will broadly encompass the topics related to substructure and foundation by ABC method such as ABC definitions, design methodologies for new and existing bridges, materials for bridge construction by ABC method, evaluation techniques of existing bridge elements and new methods of substructure and foundation construction. The outline will be updated periodically to prepare a comprehensive guide.

Description of work performed up to this period:

An initial outline has been developed. The outline was updated periodically, as needed.

Task 2 – Conduct Literature Search on Pertinent Topics.

Proposed task description:

A comprehensive literature review will be conducted focusing on the design and construction of substructure and foundation by ABC techniques. Sources of literature include, but not limited to TRB, FHWA, NCHRP, and DOTs. Other sources such as society journals will be consulted. Moreover, national and international conferences, symposia and workshops will be reviewed. The literature review will be continued throughout the duration of this project.

Description of work performed up to this period:

Based on the literature reviewed during the reporting period, “Chapter 2: ABC Definitions and Descriptions” and “Chapter 3: New Bridge Construction” were prepared. The following sections presents the foundation connections and selection and design considerations for new bridge foundation.

Foundation connections

Proper connections are required between different precast foundation elements to successfully transfer the load to subgrade soil and resist failure. Connections are required to ensure sufficient joint between precast footing to steel and concrete pile, precast footing to precast footing and precast box cofferdams. Details of different connections in foundation systems are discussed in the following sections.

Footing and Pile Systems: Prefabricated piles are most commonly used for bridges by state DOTs whereas the concept of prefabricated footings is comparatively new. The connection between the footing and pile system is important to transfer the load successfully.

Precast Footing to Subgrade Connections: The primary problem with the use of precast concrete footing is to properly seat the footing on the subgrade. Settlement or rocking of the foundation may be resulted from the inadequate seating on the subgrade. It can be eliminated by placing a flowable concrete or grout under the footing by using leveling bolts on the corners to lift the footing above the subgrade. In such cases, low grade concrete or flowable fill can be used as this is not a structural element. A sub-footing can also be used to create a level area for footings construction in bedrock [1]. Figure 1 presents the connections between precast footing and subgrade materials.

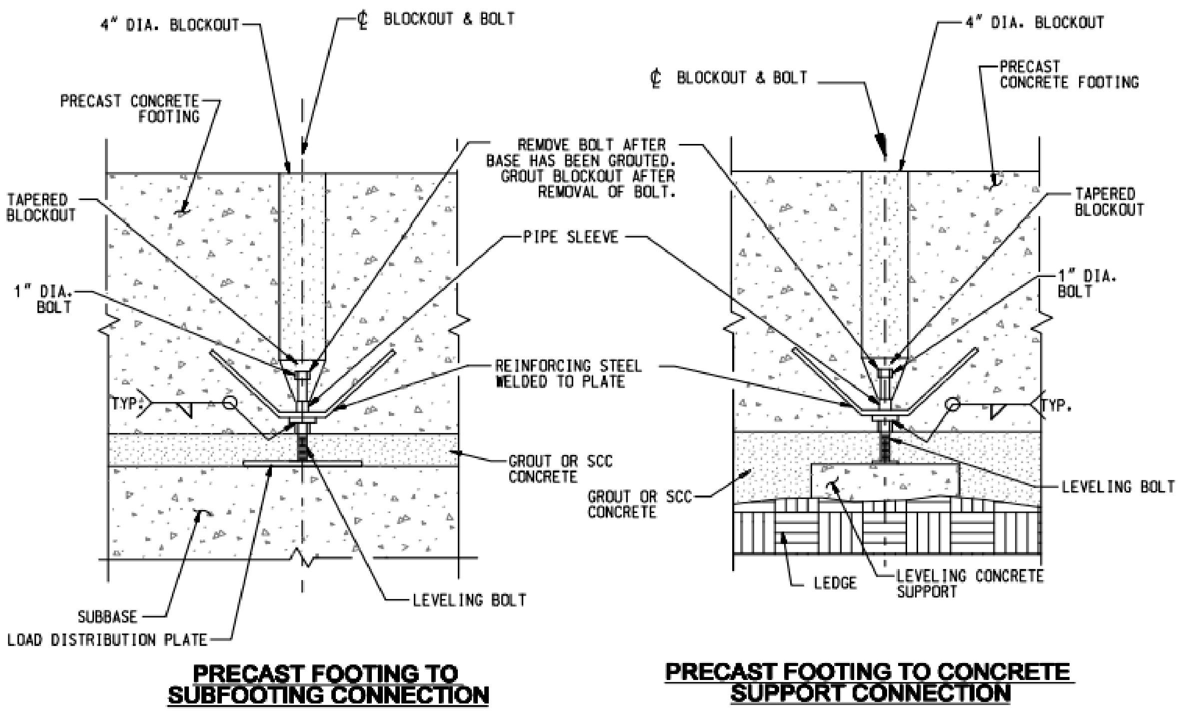

Figure 1 Details of Precast footing to subgrade Connection [1]

Precast Footing to Precast Footing Connections: The connection between adjacent footings elements may or may not need to be a structural connection, depending on the design. A simple grouted shear key can be used if there is no structural requirement for the connection. However, a small closure pour connection can be used if a moment connection is required (Figure 2). For this purpose, reinforcing steel are extended from footing elements and grout is poured in the formed area created by the two footing elements and the subgrade [1]. Figure 3 presents a photo of installation of a precast concrete footing with grouted shear connection on concrete sub-footing.

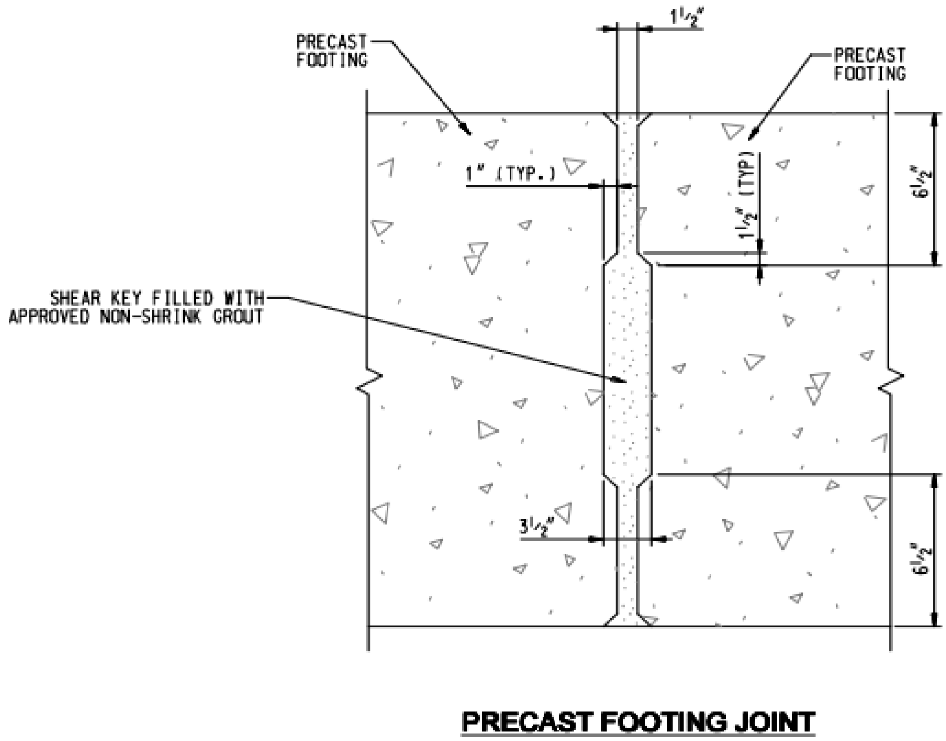

Figure 2 Precast concrete footing to precast concrete footing connection [1]

Figure 3 Installation of a precast concrete footing with grouted shear connection on concrete sub-footing [1]

Precast Footing to Steel Pile Connection: The connection details for precast concrete pier caps to steel pile mentioned in Section 2.5.1.2 can be used for precast footing to steel pile connections. However, uplift on the piles or moment capacity requirement may create problems for such connections. The pile end reinforcing steel can be welded and embedded in a closure pour to provide enough uplift capacity for this connection (Figure 4). Also, embedment of the pile top by at least 12 inches into the footing will help to achieve adequate moment capacity for this connection [1].

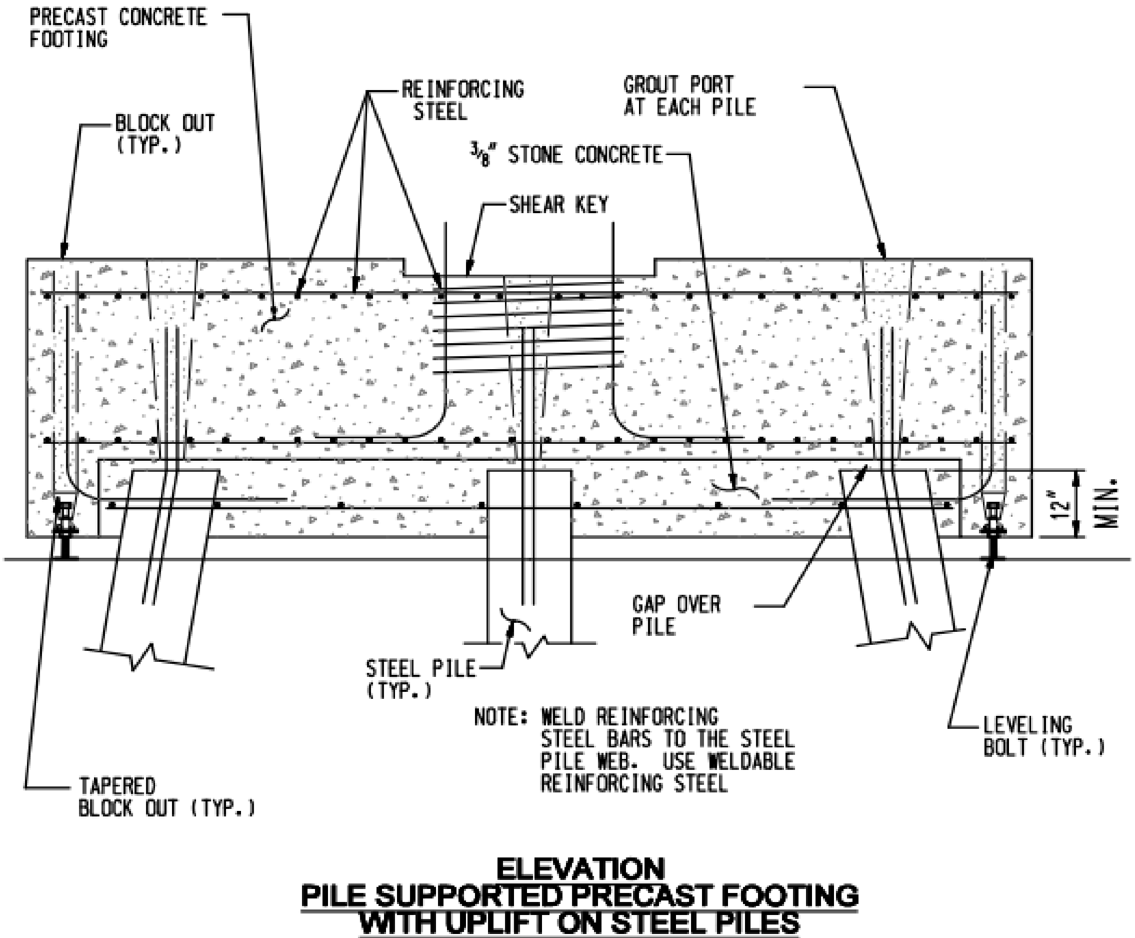

Figure 4 Connection between precast concrete footing and steel pile with uplift

Precast Footing to Precast Concrete Piles: Similar to steel pile connections, several states have developed connection details for precast concrete piles connected to precast concrete pier bents. There have also been concrete pile connection details developed for integral abutment bridges. Florida DOT has developed a connection for a hollow precast concrete pile to a precast footing to develop full moment capacity of the pile (Figure 5). The connection consists of a large blockout in the footing where a reinforcing steel cage is installed between the pile top and the blockout [1].

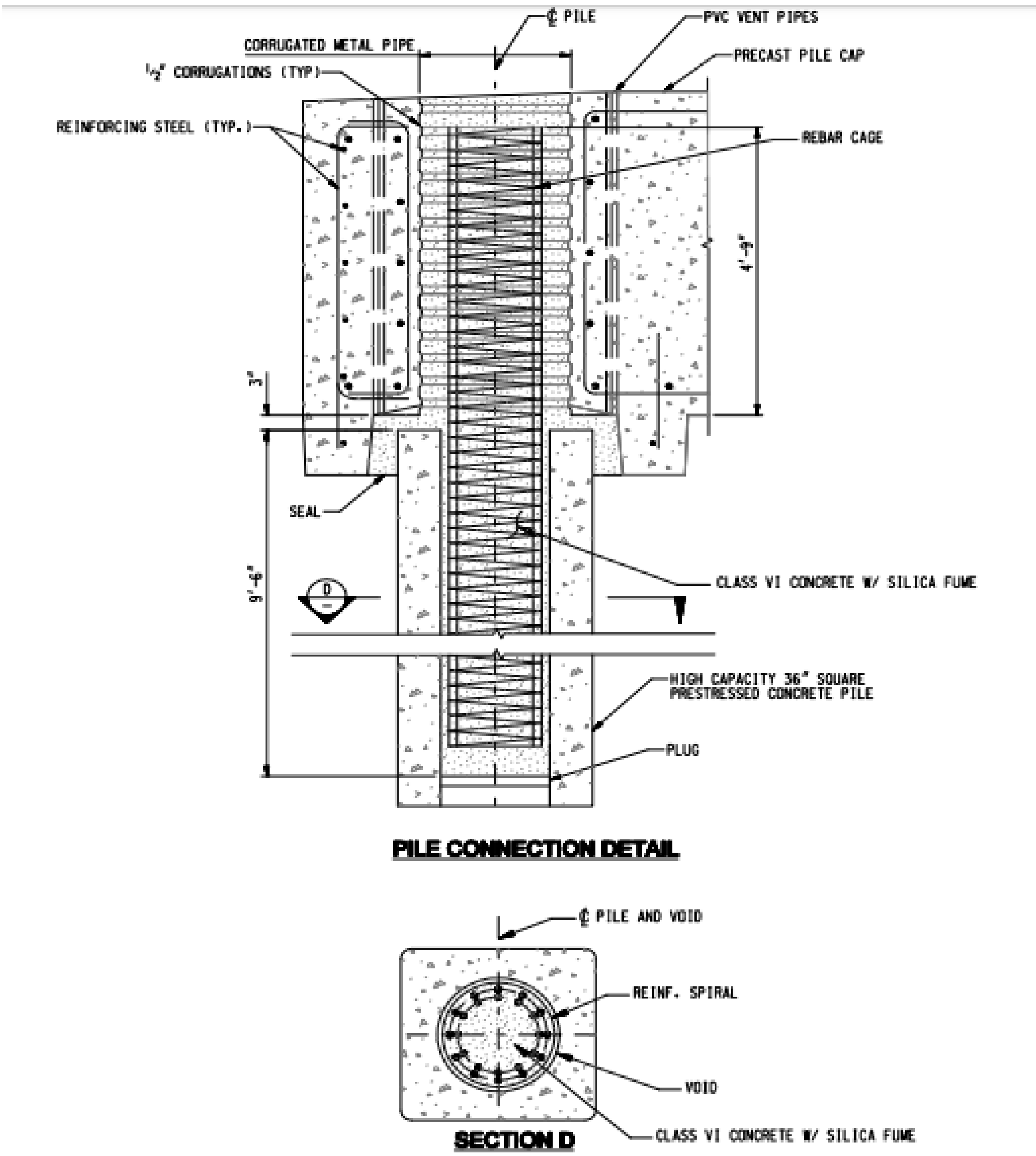

Figure 5 Connection details between concrete square pile and pile cap [1]

Precast Footing to Cast-in-place Pile or Drilled Shaft Connections: Till now, no connection between precast footing to cast-in-place piles or drilled shafts connected to precast concrete footings has been developed by any state DOT. However, the precast footing to concrete pile connection details could be adapted for use with cast-in-place concrete piles or drilled shafts.
Precast Pile to Precast Pile Connection: To accommodate variations in subsurface conditions, pile lengths for some pile types can be easily adjusted and spliced in the field. Many state DOTs have developed standard details for connecting precast driven piles that need to be spliced. Precast concrete pile industry has developed standard pile splicing details [2]. The Florida DOT

has developed a detail for splicing hollow square prestressed concrete piles (Figure 6). This detail consists of a reinforced concrete closure pour between pile elements.

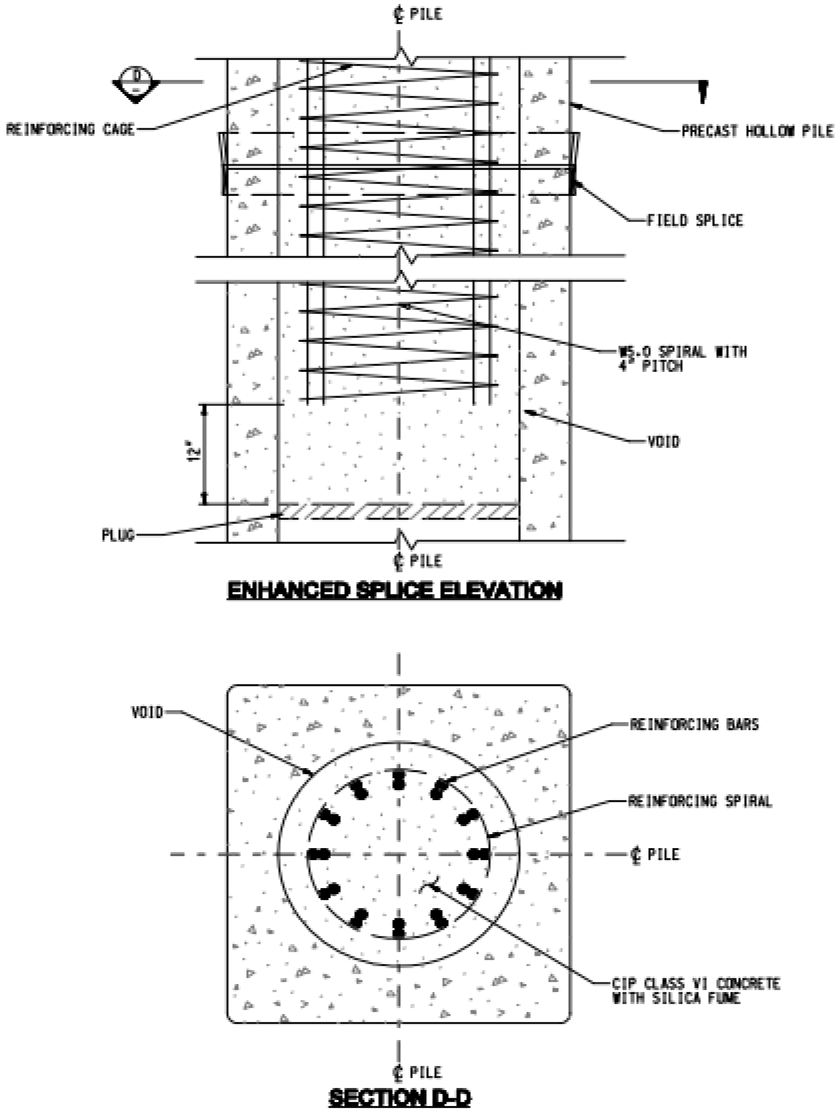

Figure 6 Connection between concrete square piles using splice

*Precast Pier Box Cofferdams: C*onstruction of the pier footings on piles is one of the biggest challenges during construction of piers over water. Precast concrete pier box is used to dewater the area where the drilled shaft connects to the bridge footing. Figure 7 presents the photo of the new Providence River Bridge in Providence, Rhode Island where a precast concrete pier boxes were hung from the 8 foot diameter drilled shafts to create dry space. The connection between the precast box and the drilled shaft was sealed with a small tremie pour around the drilled shaft.

Figure 7 Footing Reinforcing Placement in Providence River Bridge Pier Box

Selection and Design Considerations for Foundation

The selection and design of a proper foundation is critical to provide adequate support and satisfactory performance of bridge structure. Both shallow foundations and deep foundations should be considered to determine the most preferred foundation alternatives for a bridge [3]. Different deep foundation alternatives such as driven piles, drilled shafts, micropiles, continuous flight auger piles (CFA), proprietary and other deep foundations systems should be included as foundation alternatives in a given condition. However, deep foundations should not be the only choice for all bridges at any subsurface conditions. The selection of a bridge foundation should include considerations regarding engineering, economic and constructability pertinent to the particular site. According to the bridge design manuals of Wisconsin DOT [4] and Oregon DOT [5], the items need to be considered for selecting a bridge foundation are as follows:

- Ability to meet performance requirements, such as deformation, bearing resistance, uplift resistance, lateral resistance/deformation;
- Constructability of the foundation type by taking into account issues like traffic staging requirements, construction access, shoring required, cofferdams;
- Cost of foundation;
- Ability to meet the requirements of environmental permits, such as in-water work periods, confinement requirements, noise or vibration effects from pile driving or other operations, hazardous materials;
- Site constraints, such as overhead clearance, access, surface obstructions, and utilities;
- Impact of foundation construction on adjacent structures, or utilities, and the postconstruction impacts on such facilities; and
- Impact of the foundation installation on traffic and right-of-way.

An assessment needs to be made based on the above-mentioned factors to determine whether a shallow or a deep foundation is suitable to satisfy site-specific needs. Spread footings are typically cost effective than the deep foundation given the right set of conditions [4]. The depth to the bottom of the shallow foundation is generally less than or equal to twice the smallest dimension of the footing. Typical shallow foundations consist of spread footings to support single column or rafts/mat foundation to support multiple columns. Hard or dense soils with adequate bearing resistance is required for shallow foundation [5]. The size of the footings can get large in less dense soils such as medium dense sand or stiff clays depending on the loads and settlement requirements. Other than bearing capacity, foundation settlement and lateral loading constraints are the important factors govern the selection of shallow foundation. Other significant considerations for selection of shallow foundations include requirements for cofferdams, bottom seals, dewatering, temporary excavation support/shoring, over-excavation of unsuitable material, liquefaction, uplift loads, slope stability, available time to dissipate consolidation settlement prior to final construction, scour susceptibility, environmental impacts and water quality impacts [4]. Additional guidance for the selection of shallow foundation can be obtained from the FHWA publication, Selection of Spread Footings on Soils to Support Highway Bridge Structures [6]. When shallow foundations are not satisfactory, deep foundations should be considered. Deep foundations can transfer the loads from superstructure through shallow deposits to underlying deposits of more competent deeper bearing material. However, it is important to establish whether or not the site conditions require that a deep foundation must be used [3]. Figure 8 presents the typical situations proposed by Vesic [7] in which piles may be needed. Deep foundations should be considered if the inclined, lateral, or uplift loads and overturning moments could not be resisted using a shallow footing. Also, deep foundations are considered to mitigate concerns about scour, liquefaction, lateral spreading, excessive settlement and satisfy other site constraints. Bridge structures in areas of expansive or collapsible soils may require the use of deep foundation to resist undesirable seasonal movement of the structure [5].

An evaluation of the shallow foundation needs to be conducted if both shallow and deep foundation alternatives found to be technically feasible. The evaluation may include the dimensions and depth of shallow footings depending on the soil bearing capacity, the magnitude of settlement under anticipated loads, and a detailed cost analysis. The cost analysis may include factors, such as need for cofferdams, overall substructure cost, dewatering and foundation seals, construction time, construction risk and claims potential. The final selection of the foundation can be based on the comparative analysis of feasible alternatives [3].

Also, the selection of a deep foundation type depends on the soil type, stability under vertical and horizontal loading, long-term settlement, required method of foundation installation, substructure type, cost comparison and estimated length of pile foundation [4]. Most common types of deep foundations include driven pile, drilled shafts, micropiles and continuous flight auger piles. Driven piles are the most frequently-used type of deep foundation by many state DOTs. Different types of driven piles are available such as precast prestressed concrete piles, steel H piles and steel pipe piles. However, drilled shaft foundations are advantageous where a dense intermediate stratum needs to be penetrated to obtain the required bearing, uplift, or lateral resistance. Also, the drilled shaft foundation can be extended into a column to eliminate the need for a pile footing, pile casing or cofferdams. On the other hand, micropiles can be used as a foundation alternative where headroom is restricted, or foundation retrofittings are required for existing substructures. Another potential cost-effective foundation alternative of driven or drilled shaft piles can be CFA piles where lateral loads are minimal[3-5, 8, 9]. However, many DOTs have expressed concerns on the quality control of the construction of CFA pile [10]. Figure 9 presents the flow chart for the selection of foundation for new bridges based on the above discussion. The selection of foundation based on soil type and soil bearing capacity proposed by [11] is presented in Table 1.

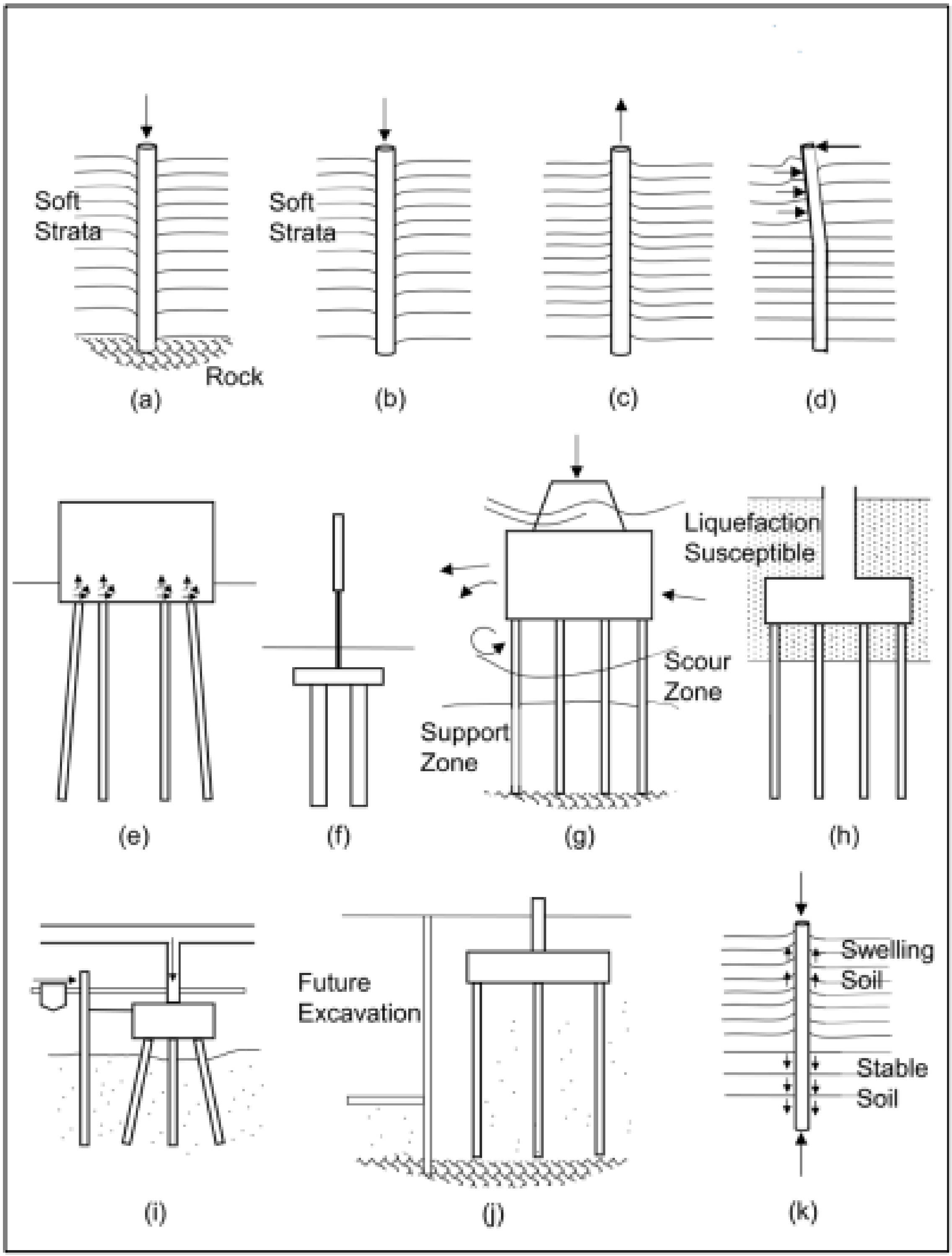

Figure 8 Situations to select deep foundation [7]

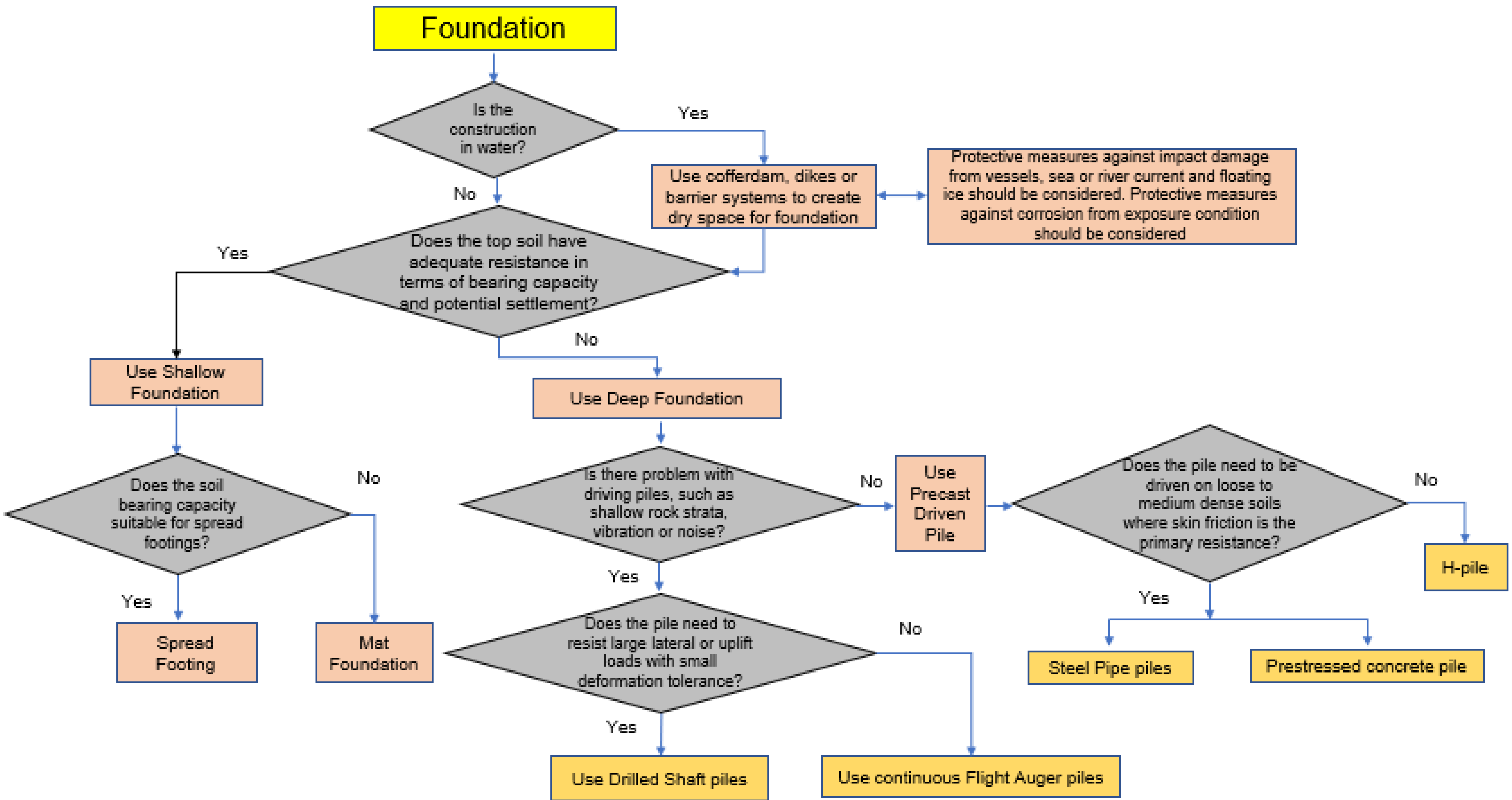

Figure 9 Flow chart for the selection of foundation for new bridges

Table 1 Foundation types based on soil conditions (Modified from Bowles [11])

Foundation Type	Applicable Soil Conditions	Non-suitable or Difficult Soil Conditions	Use
Spread footing, wall footings	Any conditions where bearing capacity is adequate for applied load. May use on single stratum; firm layer over soft layer, or weaker layer over firm layer. Check immediate, differential and consolidation settlements	Any conditions where foundations are supported on soils subject to excessive scour or liquefaction	Individual columns, walls, bridge piers
Mat foundation	Generally, soil bearing value is less than for spread footings. Over one-half area of structure covered by individual footings. Check settlements.	Same as footings	Same as spread and wall footings. Very heavy column loads. Usually reduces differential settlements and total settlements
Driven pile foundations	Poor surface and near surface soils. Geomaterials suitable for load support 15 to 300 feet below ground surface. Check settlement and lateral deformation of pile groups	Shallow depth to hard stratum. Sites where pile driving vibrations or heave would adversely impact adjacent facilities. Boulder fields	In groups to transfer heavy column and bridge loads to suitable soil and rock layers. Also, to resist uplift and/or lateral loads
Drilled shafts	Poor surface and near surface soils. Geomaterial suitable for load support located 25 to 300 feet below ground surface	Caving formations difficult to stabilize. Artesian conditions. Boulder fields. Contaminated soil. Areas with concrete delivery or concrete placement logistic problems	In groups to transfer heavy column loads. Mono shafts and small groups sometimes used. Cap sometimes eliminated by using drilled shafts as column extensions
Micropiles	Any soil, rock, or fill conditions including areas with rubble fill, boulders, and karstic conditions	High slenderness ratio may present buckling problems from loss of lateral support in liquefaction susceptible soils. Low lateral resistance. Offshore applications	Often used for seismic retrofitting, underpinning, very difficult drilling through overburden materials, in low head room situations, and for projects with noise or vibration restrictions
CFA Piles	Medium to very stiff clays, cemented sands or weak limestone, residual soils, medium dense to dense sands, rock overlain by stiff or cemented deposits	Very soft soils, loose saturated sands, hard bearing stratum overlain by soft or loose soils, karst conditions, areas with flowing water. Highly variable subsurface conditions. Conditions requiring long piles due to deep scour, liquefiable layers, or penetrating very hard strata or rock, offshore conditions	In groups to transfer heavy loads to suitable geomaterials. Projects with noise and vibration restrictions

Task 3- Identify Stakeholders and Conduct Survey.

Proposed task description:

A survey will be conducted to find out the state of the art practices of foundation design and construction methods by ABC method. Also, the challenges faced by engineers during construction of foundation will be investigated. The acceptability of new practices such as installation of prefabricated foundation elements, retrofitting etc. will be investigated through this survey. The questionnaire will be disseminated among DOTs and personals involve in research using ABC method.

Description of work performed up to this period:

A survey questionnaire form was prepared with consultation with FIU team members. The stakeholders for this survey was finalized. The survey questionnaire was disseminated with the help of AASHTO Committee on Bridge and Structures. A total of twenty responses were received while this report is being prepared.

Task 4- Analyze Literature Search and Survey Results

Proposed task description:

The literature reviewed for this project will be summarized and analyzed in order to prepare the guidelines for this project. A report will be prepared on the survey feedback and will be included in the final guideline.

Description of work performed up to this period:

The literature review conducted for this project is being analyzed to prepare the construction and design guidelines for bridge foundation by ABC technique. “Chapter 2: ABC Definitions and Descriptions” and “Chapter 3: New Bridge Construction” has been prepared based on the literature reviewed for this project. Also, the survey has been conducted with the help of AASHTO Committee on Bridge and Structures. A total of twenty responses were received while this report is being prepared. Following are the responses obtained related to Bridge Foundation:

ABC technology in bridge foundation construction

The following implementations of ABC technique in construction of bridge foundations were reported by different DOTs.

- North Carolina DOT: Micro-piles was used to support a single span bridge consisting of steel twin-girders with a precast deck.
- Missouri DOT: used Geosynthetic reinforcement soil integrated bridge system one time.
- Florida DOT: Auger-cast piles are being used on demonstration projects. Research is already underway to set quality and design requirements. In the future, trench box footing forms with lids w/ built-in traffic barriers designed to carry traffic used in conjunction with rapid auger cast pile construction is being considered for viaduct footing construction in the median of interstates. All of the technology should be in place within the next 5-10 years. All of this is to meet traffic restriction constraints of limiting the footing construction to

night-time windows and opening traffic every morning at 7:00 AM. Micro-piling is fairly typical foundation type for strengthening/retrofit existing footings and vibration sensitive applications for new construction. GRS is becoming more common for rural low volume bridge land applications in Florida.

- Montana DOT: they have used GRS-IBS on a couple of projects. The foundation types used for their largest ABC projects were not accelerated per se, but were installed such as to minimize traffic impacts prior to the full roadway closures necessary for the superstructure replacement.
- Nebraska DOT: Micro-piling and geosynthetic reinforcement with integrated soil system was used before but was not recommended on deep foundation with precast abutment since it will require too many sleeves.
- Iowa DOT: used GRS abutments.
- Wisconsin DOT: used GRS-IBS in several projects. This seems to have possibilities in the right situations.

Task 5- Identify Issues and Potential Solutions

Proposed task description:

Based on the literature review and survey results, issues with the state-of-the art practices of ABC techniques for constructing bridge foundation and substructure will be identified and potential solutions will be proposed.

Description of work performed up to this period:

Issues with the selection, design and construction of bridge foundation by ABC methods are being documented from literature. This section will be completed as soon as more information is available.

Task 6- Develop Draft Guideline

Proposed task description:

One of the deliverables from this project will be a draft guideline on design and construction of bridge foundation and substructure by ABC techniques. The guidelines will be based on the literature search and survey results. The guidelines will cover the topics mentioned in the Task 1.

Description of work performed up to this period:

The University of Oklahoma (OU) is currently preparing the draft guideline for bridge foundation. The draft will be disseminated for review by experts as soon as possible.

Task 7- Prepare Final Report

Proposed task description:

A final report will be prepared based on the outcome of the project. the final report and the draft guideline will be submitted to the ABC-UTC and other professionals for further review.

Description of work performed up to this period:

Not pursued during this reporting period.

5. Expected Results and Specific Deliverables

At the end of the project a user-friendly guideline on design and construction of bridge foundation and substructure by ABC techniques will be available for transportation authorities, engineers and other stakeholders. The specific deliverables from this project will be:

i. Progress reports at the end of every quarter
ii. A draft guideline on design and construction of bridge foundation and substructure by ABC techniques
iii. A final report

6. Schedule

Progress of tasks in this project is shown in the table below.

Research Task	2018												2019							
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Task 1 – Develop Outline for the Guideline																				
Task 2 – Conduct Literature Search on Pertinent Topics																				
Task 3- Identify Stakeholders and Conduct Survey																				
Task 4- Analyze Literature Search and Survey Results																				
Task 5- Identify Issues and Potential Solutions																				
Task 6- Develop Draft Guideline																				
Task 7- Prepare Final Report																				
		Work Performed							Work to be Performed											

7. References

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