DEVELOPMENT OF GUIDE FOR SELECTION OF SUBSTRUCTURE FOR ABC PROJECTS

Quarterly Progress Report

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1 Background and Introduction

While much attention has been paid to means and methods of accelerated construction of the bridge superstructure, little has been done to provide proper guidance to designers and bridge owners on the selection of type, design and construction of the substructure. The primary objective is to provide guidelines for decision making by the designers and bridge owners for the selection of substructure and foundation for new bridges and replacement of existing bridges using the ABC methods, including evaluation, retrofitting, design, and construction. The project will include a comprehensive review of the current practice and compilation of available ABC methods for substructures and superstructures. This review should result in categorization of sub- and superstructures that are best match. Efforts will be divided into two major categories: new bridge construction and existing bridge replacement. An attempt will be made to identify issues and obstacles preventing the adoption of ABC substructures for bridge projects, and exploring solutions for facilitating a wider use of ABC substructure. Development of the Guide would rely on information from various sources including open literature, survey of experts and stakeholders, input of ABC-UTC Advisory Board members, and other domain experts nationally and globally. Information obtained from these sources will be reviewed and synthesized carefully and organized systematically. Gaps in the knowledge will be evident from this synthesis. This research project is a collaborative project between Florida International University and the Oklahoma University. FIU will focus its work on substructure and lead the development of the guideline, and OU will focus its activities on foundation related subjects and provide support to FIU on other tasks.

2 Problem Statement

The aim of accelerated bridge construction (ABC) is to reduce the impact of bridge construction on the public and bridge usage by reducing the construction time, especially when replacement of an existing bridge is involved. In addition to reducing construction time significantly, ABC has been found to enhance safety and reduce congestion. Although much work has been done in the past to investigate the design, configuration, and erection methods for bridge superstructure, very limited studies have addressed substructures and foundations (in this proposal “substructure and Foundation” and “substructure” are used interchangeably). Often, it is assumed that the bridge substructure and foundation are ready to receive the superstructure. Based on field experience, site-specific testing, design and construction of foundations and substructures can be the most time-consuming part of bridge construction. An informed and educated decision on the type of foundation and substructure may define the viability and economic feasibility of the entire ABC project. In the proposed study, the research team seeks to develop a Guide that can be readily used by practitioners for the selection of substructures and foundations for different ABC projects. The Guide will include parameters in design and construction of substructure and foundation including type, geometry, location, superstructure and bridge configurations, and design methodology. Issues related to construction of new bridges and replacement of existing bridges will be addressed including evaluation and strengthening of existing substructure and foundation for potential reuse. In addition to developing the Guide, the proposed study will identify gaps in existing knowledge and practice and make recommendations for future studies to address these gaps.

3 Research Approach and Methods

The primary objective of this project is to provide guidelines for decision making by the designers and bridge owners for the selection of substructure and foundation for new bridges and replacement of existing bridges using the ABC methods, including evaluation, retrofitting, design, and construction. The decision will depend strongly on the type and configuration of the superstructure intended for the bridge. From compatibility and conformity considerations, the decision on the type and design of both substructure and superstructure needs to be done concurrently. Geometric parameters such as span length, bridge width and bridge clearance are also important parameters in the selection of substructure type. This study may also review new types of substructures and/or closure joints and connection types for better performance and service life of the bridge. As noted in the Problem Statement, the evaluation of substructure and foundation of existing bridges for their structural capacity and functional adequacy and decision on reuse or replacement will be an important part of this study.

Development of the guide would rely on information from the following sources: (i) open literature; (ii) survey of experts and stakeholders; (iii) input of ABC-UTC Advisory Board members; and (iv) other domain experts nationally and globally. Information obtained from these sources will be reviewed and synthesized carefully and organized systematically in the form of a guide. Gaps in the knowledge will be evident from the synthesis.

The project team will attempt to present the information in the form of a decision tree or a flow chart that links the selection decisions to input parameters and assessment tools. Ideally, the Guide will start with a decision tree that introduces the various aspects that influence the selection and design. Subsequent chapters will elaborate on each aspect. Figure 1 is a sample preliminary flowchart that can help streamline the Guide that could form a framework for development of a more elaborate flowchart.

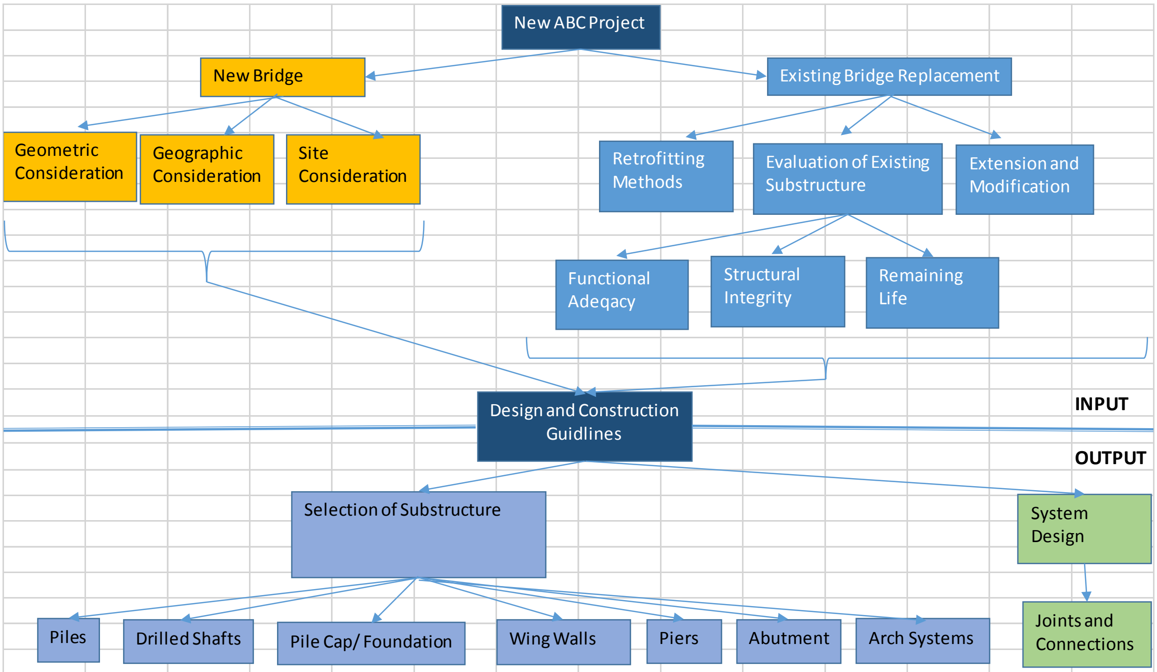


Figure 1: Sample Preliminary Flow Chart

4 Description of Research Project Tasks

An overview of the study tasks is given below. The project is a collaborative effort with active participation of Florida International University (FIU) and Oklahoma University (OU).

4.1 Task 1 – Draft Outline

A draft outline of the Guide for the selection of substructure and foundation for ABC projects has been developed collaboratively by the research teams at FIU and OU. FIU and OU performed this task collaboratively where FIU will focus its efforts on the substructure and superstructure portion of the outline, and OU on the foundation portion. A daft outline is attached to this report as Appendix A. For the next period, the project team will work to finalize the outline of the guideline.

4.2 Task 2 – Conduct Literature Search on Topics Identified in the Draft Outline

A comprehensive literature search is underway on the topics identified in the guideline. Sources of literature includes, but not limited to, ABC-UTC Archives, TRIS, TRB, FHWA, NCHRP, and DOTs. Other sources such as society journals (ASCE, ASTM), Asphalt Institute (AI), Western Research Institute (WRI), and NCAT will also be consulted. The literature search will identify existing best practices for design and selection of substructure and foundation for ABC projects. The topics include the following:

- Existing superstructure elements and construction methods and their categorization with respect to adaptability to substructure; (to be performed by FIU)

- Existing substructure elements and construction methods, and current practices for selection of type, design and construction methods; (to be performed by FIU)
- Foundation types, design, and construction; (to be performed by OU)
- Methods for evaluation and rating of existing foundations and substructures for potential reuse (FHWA study); (OU will focus on foundation and FIU on substructure)
- Retrofitting and strengthening methods. (OU will focus on foundation and FIU on substructure)

4.2.1 Definitions

ABC bridges in general can be divided into superstructure, substructure, and foundation subsystems (Figure 2). Superstructure refers to deck and girders and everything above the deck. The substructure refers to elements that hold the superstructure like piers, abutments, and wing walls, basically, everything below the superstructure bearing and above the foundation. Foundation is a part of substructure that transfers loads from the bridge to the earth and strata, it can be shallow or deep, and includes footings, pile caps, piles, etc. The ABC bridge elements and components are connected to each other using joints and connections which normally establishes in-situ. It is realized that an alternative definition exists referring to everything below deck bearing as substructure including the foundation. However, this report subscribes to a definition of substructure that includes bridge components below the deck bearing and above the foundation. This helps to better distinguish the role of substructure and foundation as well as better definition for the scope of work by parties performing the project.

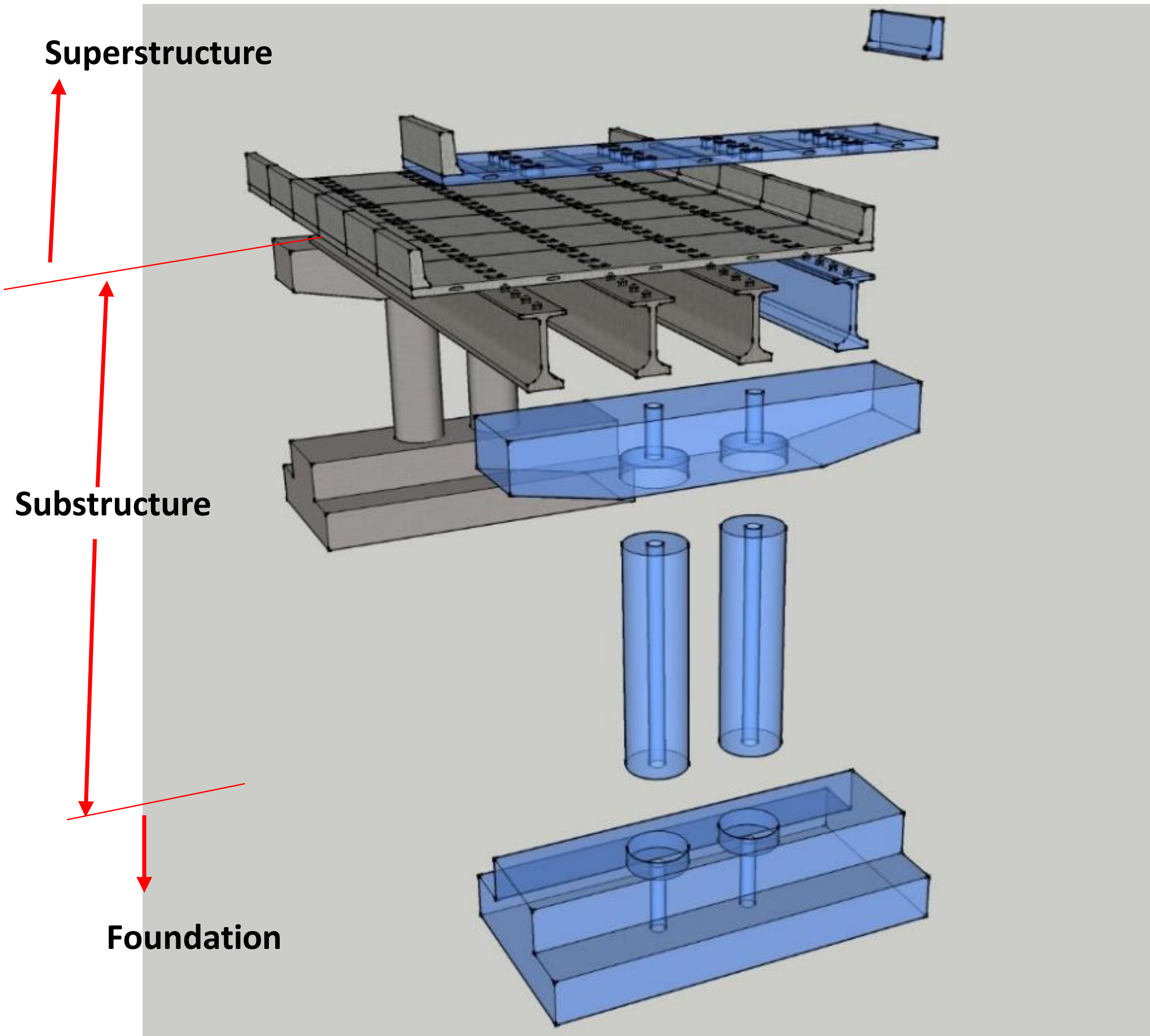


Figure 2: ABC bridge components

4.2.2 Superstructure

The superstructure referes to all the parts that are above the bridge bearing and provide horizontal span. These elements carry loads from the deck span and provide the riding surface [1]. Superstructure includes girder and deck slab, miscellaneous elements, barriers, and railing (Figure 3).

The deck elements include road lanes, walkway, and sideways. The deck panel construction can be fully or partially precast (Figure 4).

The girders are elements that are bearing the slab loads and transferring them to the column and foundation (Figure 5). The term girder sometimes called interchangeably as beam in bridge construction and design. Box girder and plate girder are the two shape of girders commonly use in ABC bridge construction [2].

The miscellaneous elements of the superstructure include the drainage assembly, lightning, expansion joints, and deck overlay or riding surface of the bridge. The deck overlay can be surface of the bridge without any overlay, or can be overlaied with asphalt pavement. The drainage assembly can be installed to prefabricated deck elements or the standard methods that use for conventional bridges applied to ABC bridges to drain the water [3].

The barriers for ABC bridges can be designed and constructed with prefabricated deck, cast in place, or attached to the deck by the bolt (Figure 6). The FHWA provided a manual that defines the barrier and railing requirements for bridges [4]. This manual requires crash testing for barriers. However, there is no available crash tested prefabricated barrier [2]. A prefabricated railing system has been developed recently by Iowa State University researchers as part of ABC-UTC projects verified with static/push over testing. Next phase of the project, aims at verification through crash testing [5](Figure 7).

Literature review continues to identify all variations of prefabricated superstructure elements, subsystems.

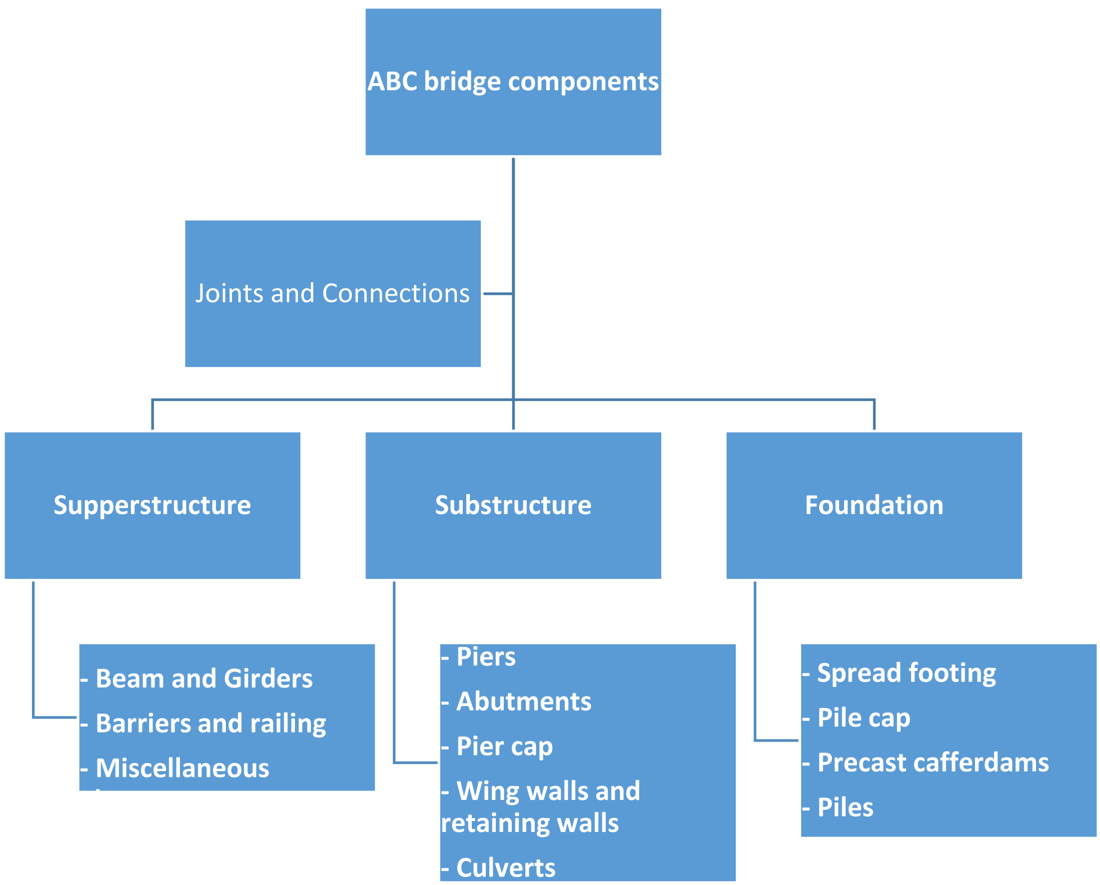


Figure 3: ABC bridge components

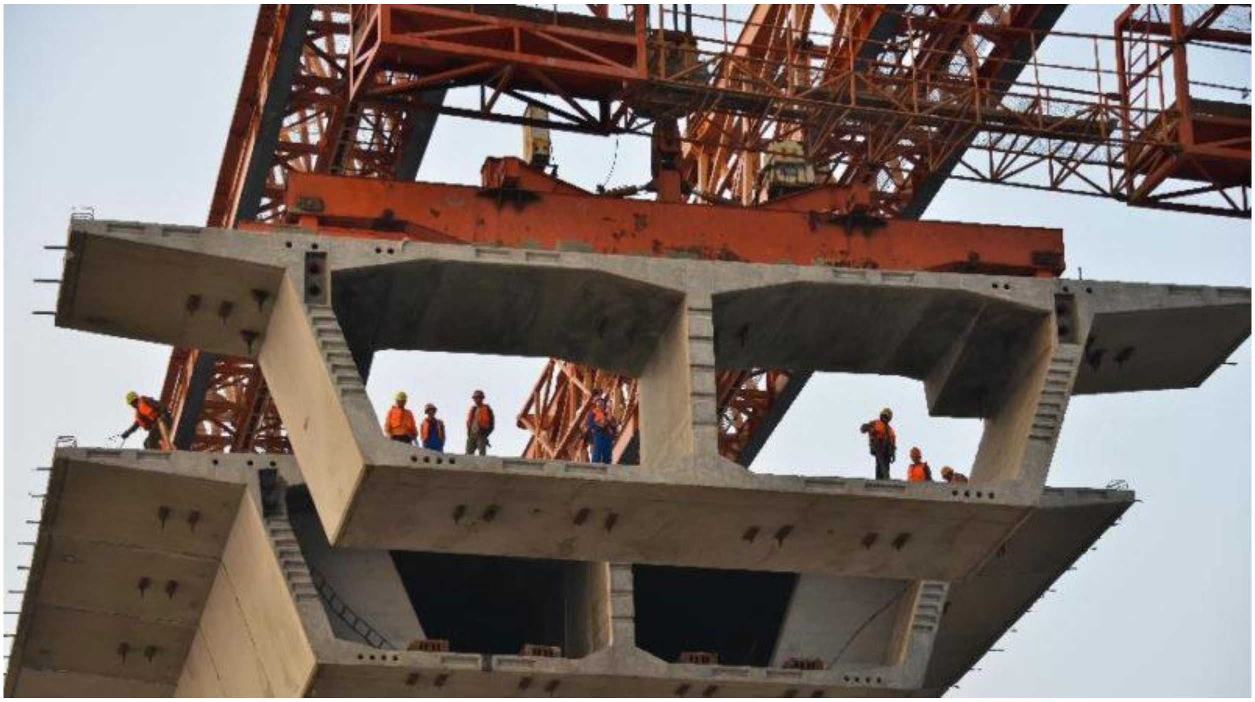


Figure 4: Prefabricated deck panel [2]

Figure 5: Steel girder [2]

Figure 6: Prefabricated deck panel with barrier (Utah DOT) [2]

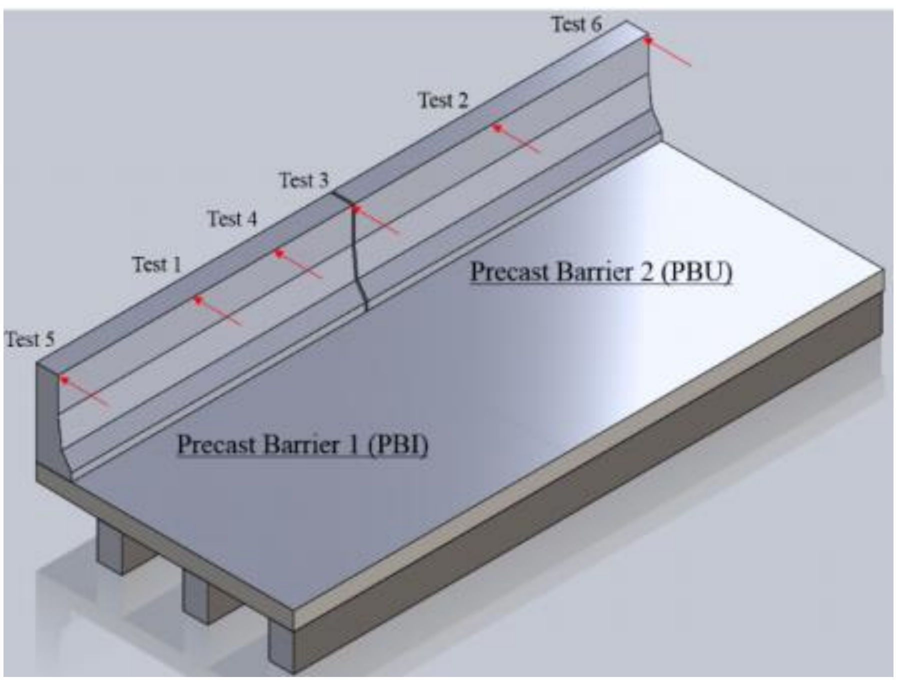


Figure 7: 3D model of prefabricated deck panel with barrier lab set-up at Iowa State University[5]

4.2.3 Substructure

Substructure elements transfer vertical and horizontal loads from superstructure into the foundation. Piers, pier cap, abutments, culvert, wing walls, and retaining walls are the substructure elements (Figure 8) [2].

Piers are vertical elements that support deck span at intermediate points. This element transfers loads to the foundation and resists to horizontal loads using its shear resistance mechanism. Piers that consist of more than one column are called pier bent (Figure 9)[2].

Abutments are elements that are used to retain the earth and embankment, sustain the superstructure live and dead load, retain the earth or embankment lateral pressure, and resist sliding and overturning due to the embankment. In fact, abutments play both pier and retaining wall function. Abutments are constructed at the beginning or end of the bridge span where superstructure rest on land (Figure 10) [2].

Retaining wall and wing wall are the abutment extension to retain the earth pressure in approach bank embankment. These walls are constructed at the abutment and are designed to resist earth pressure from backfill, surcharge from the live load, and hydrostatic load from saturated soil. If these walls are not constructed, the earth stays in natural angle response (Figure 11) [2].

Pier caps provide enough space for sitting of girders to transfer loads from superstructure to substructure and distribute the loads from bearing to piers (Figure 12) [2].

Culvert is used to convey stormwater and sewage. To design and construct the precast culvert, standard specification of ASTM C5177 entitled "Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD" can be used [3]. Culverts can be four-sided (box), three-sided or arch section. Concrete box culvert has a rectangular cross-section [6]. Three sided culverts have a rectangular cross-section with varying wall thickness or have an arched structure. Three sided or arched culverts need a separate foundation to support them (Figure 13) [6].

Literature review continues to identify all variations of prefabricated substructure elements and subsystems.

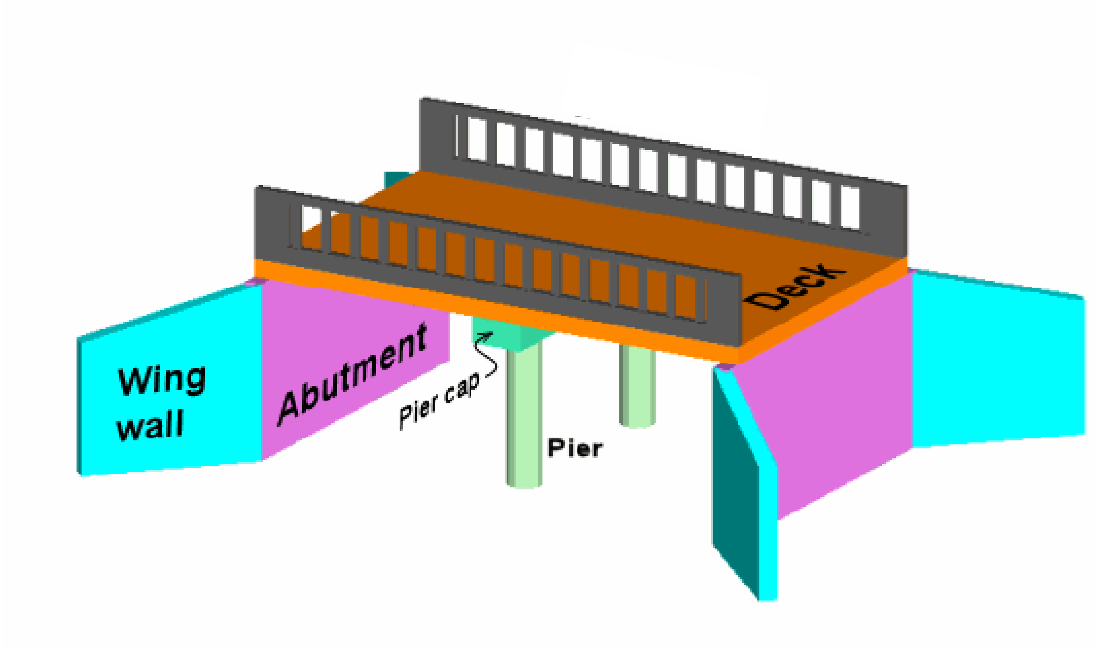


Figure 8: Substructure elements

Figure 9: Prefabricated pier bent [2]

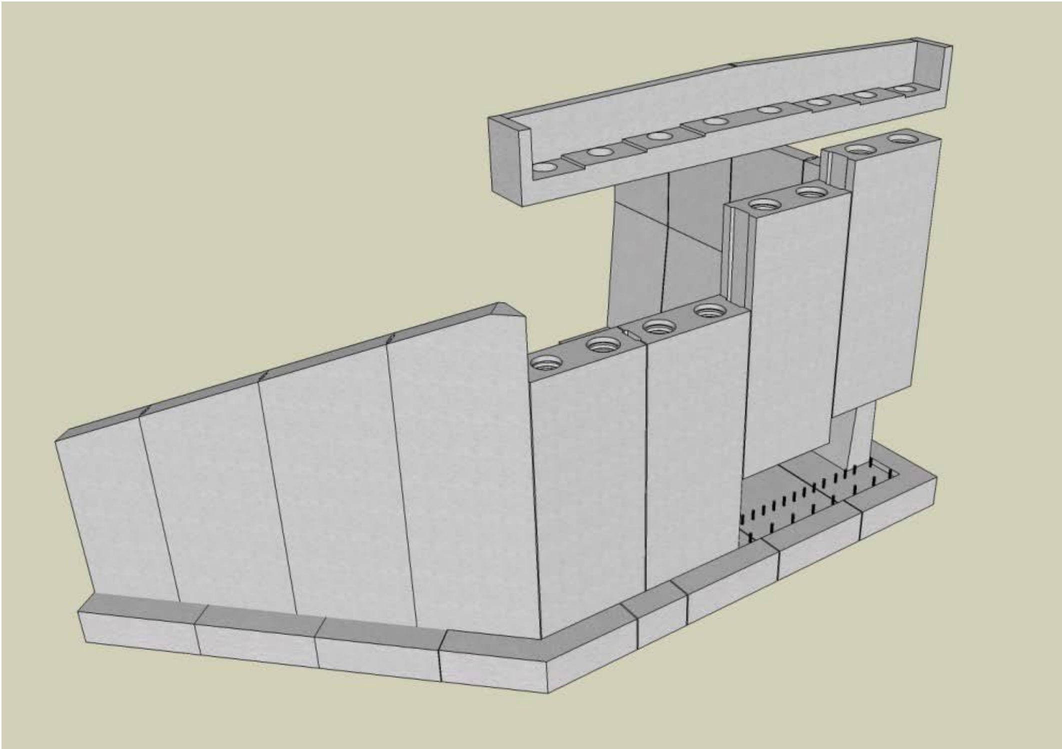


Figure 10: Prefabricated cantilever abutment [2]

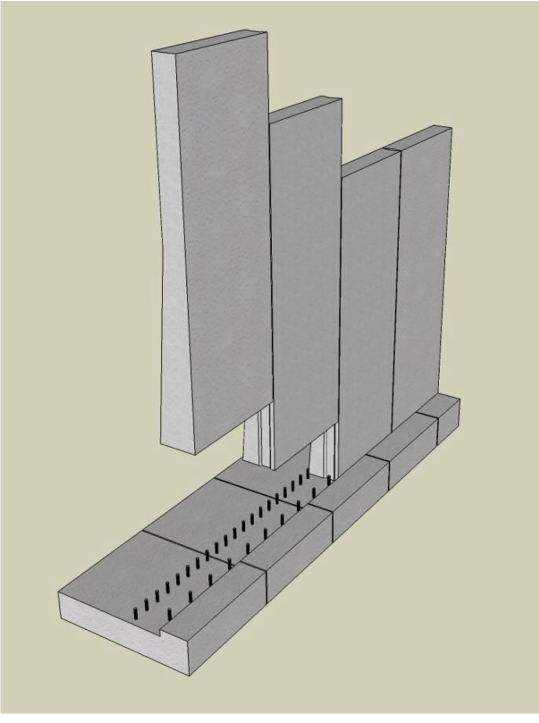


Figure 11: Prefabricated cantilever wing wall [2]

Figure 12: Pier cap [2]

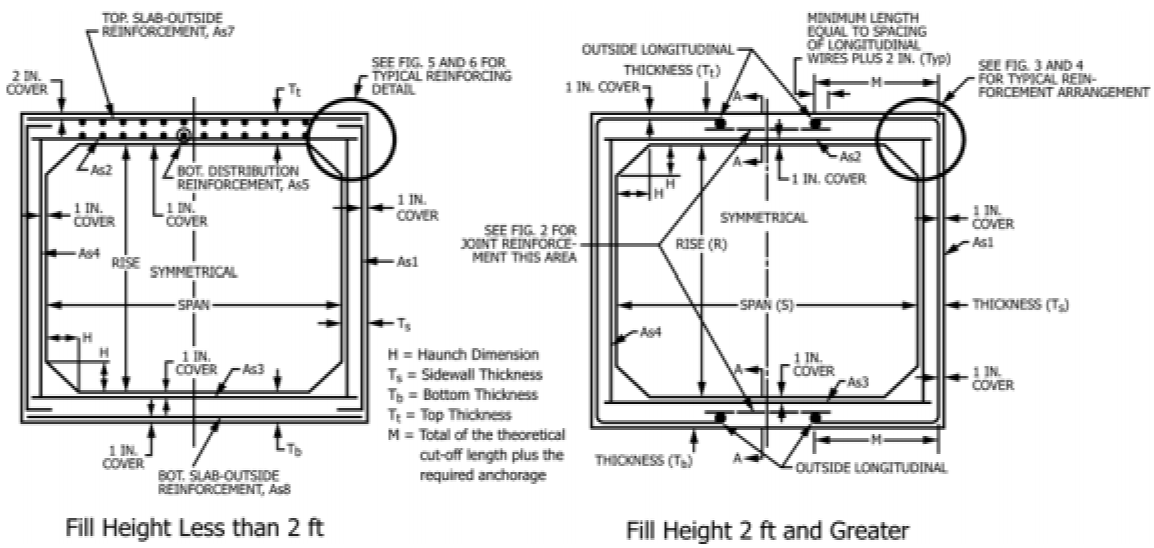


Figure 13: Precast box culvert section [3]

4.2.4 Foundation

Foundation function is to transfer load from the abutment, pier, and wing wall into the earth and strata [2]. When the soil near the surface is adequately stable and can provide bearing for the bridge load, spread footing can be used as the bridge foundation. However, when the surface soil is not stable enough, deep foundation such as piles should be used under the footing to transfer the load under the surface of the soil to provide enough support to bridge loads. Also, the bridge foundations should be deep enough to prevent scouring due to water current. Precast pile cap beam can be used to connect pier and columns to the precast pile (Figure 14). Precast box cofferdam can be used to dewater the location where the pile in connecting the footing (Figure 15). This structure can sit over the shaft and be sealed to provide a dry condition in construction footing. Also, this structure can provide additional corrosion protection to the footing. This section will be covered in more details by Oklahoma University.

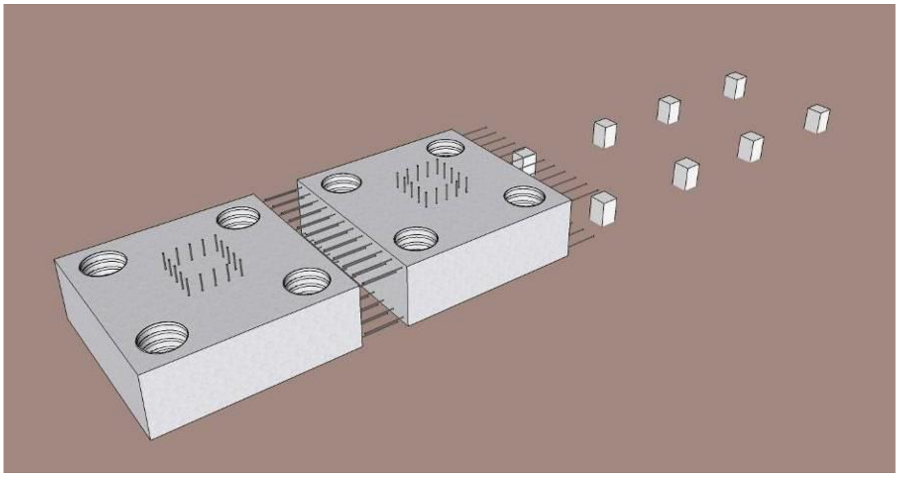


Figure 14: Prefabricated pile cap footing [2]

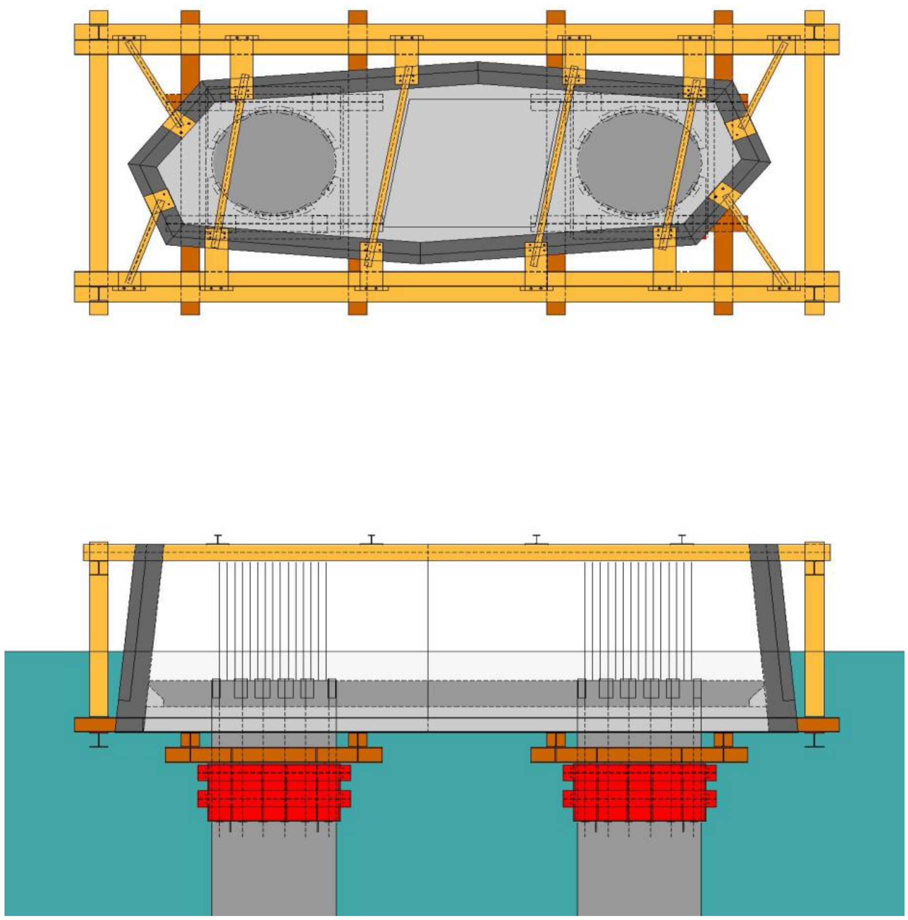


Figure 15: Precast concrete box cofferdam [2]

4.2.5 Joints and Connections

In an ABC bridge construction, joints and connections are needed to attach the prefabricated elements to each other and between foundation, substructure and superstructure. The design and details of joints and connections in bridges that use prefabricated elements should at a minimum satisfy the same conditions as connections in cast-in-place bridges to provide enough durability and integrity for the structure [7]. Joints connecting deck elements are normally referred to as closure joints (Figure 16). "Emulating connection detailing" and design is used to make the precast structural elements behave as they are monolithic [8]. Accordingly, various connection types have been developed and validated for prefabricated elements including welded ties, mechanical couples, small closure pours, closure joints, socket and pockets, and grouted tubes with reinforcing dowels.

Within a substructure, joints are used to connect columns, piers, or walls to a cap beam [9]. It is easy to access this connection for inspection. It can experience high shear and bending moment, especially during lateral loading, e.g., earthquake. In the longitudinal direction, it may experience high deformation due to thermal expansion of the deck slab. Connection of piers to pier cap can be accommodated using slots or sleeves in the cap to receive the extended reinforcing bars from pier, or a complete opening (socket) can be left in the cap to receive the bars. Also, a thin layer of grout may be used between cap beam and column to provide a uniform bearing (Figure 17-18) [10].

In-situ joints are also used to connect the columns/piers or walls from substructure to the spread foundation or pile cap [9]. This type of connection is usually located at the ground level near the expected plastic hinge location, and normally experiences high shear and bending moment. Proper seating of spread footing on subgrade for uniform bearing is usually challenging and may require leveling means. Closure pours may be used to connect adjacent footings to each other. When connection of precast footing to steel or reinforced concrete piles is required, connection methods similar to that used for connecting pier cap to the column can be used. Some states, including Florida have developed specific details and designs for connecting columns, piers, and piles to the cap beams and pile caps usually develop the full moment capacity.

Literature review continues to identify all variations of prefabricated substructure elements and subsystems.

Figure 16: Examples of deck closure joints

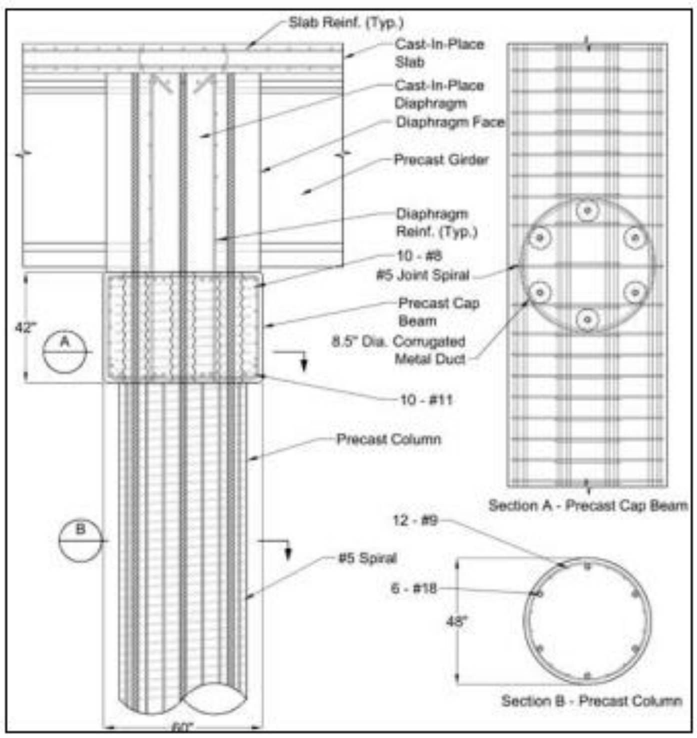


Figure 17: Example of cap beam to column connection [11]

Figure 18: Prefabricated bent cap connecting to piers [12]

4.3 Task 3 – Identify Stakeholders and Conduct Survey

The FIU and OU research team members will work collaboratively among themselves and with the ABC-UTC leadership to identify stakeholders for this study. The stakeholders would include, but not limited to, state DOTs (bridge divisions, construction divisions, and maintenance divisions), bridge designers, contractors, academic institutions, and TRB committees. A survey of the stakeholders will be prepared and conducted to identify existing practices that are not available in the open literature (Task 2). Online instruments such as Survey Monkey and Google Frame could be used in conducting the survey. Statistical analyzes of results (for multiple choice questions) are automatically conducted by these instruments. This task will be performed collaboratively by FIU and OU.

4.4 Task 4 – Analysis of Literature Search and Survey Results

Information from the literature search (Task 2) and the survey (Task 3) will be analyzed carefully to document existing practices, best practices, issues, and other important factors such as cost, service life, construction/retrofitting time, and durability. Outcomes of this task will be instrumental to the development of the Guide. FIU will focus on substructure and OU on foundation.

4.5 Task 5 – Identification of Issues and Potential Solutions

Findings of Tasks 3, 4 and 5 will be used to identify the issues related to design and implementation of ABC substructures and foundations and the knowledge gaps. They will also help identify issues hindering the design and use of ABC substructures. To the extent permitted by the scope of this project and the limited budget, solutions to these issues will be explored by the FIU and OU research teams. FIU will focus on substructure issues and OU on foundation issues.

4.6 Task 6 – Develop Draft Guide

Based on the outcomes of Tasks 1 through 5, a draft Guide will be compiled and submitted for review by the Advisory Panel. The draft will be revised based on the review comments. FIU will lead this task with the support from OU.

4.7 Task 7 – Final Report

A comprehensive final report will be prepared and submitted. In addition to discussing the Guide, the process used in the development of the Guide will be included. FIU will lead this task

5 Expected Results and Specific Deliverables

5.1 ABC-UTC Guide for Selection of Substructure and Foundation for ABC Projects

The main deliverable for this project is a Guide for selection of substructure and foundation for ABC projects.

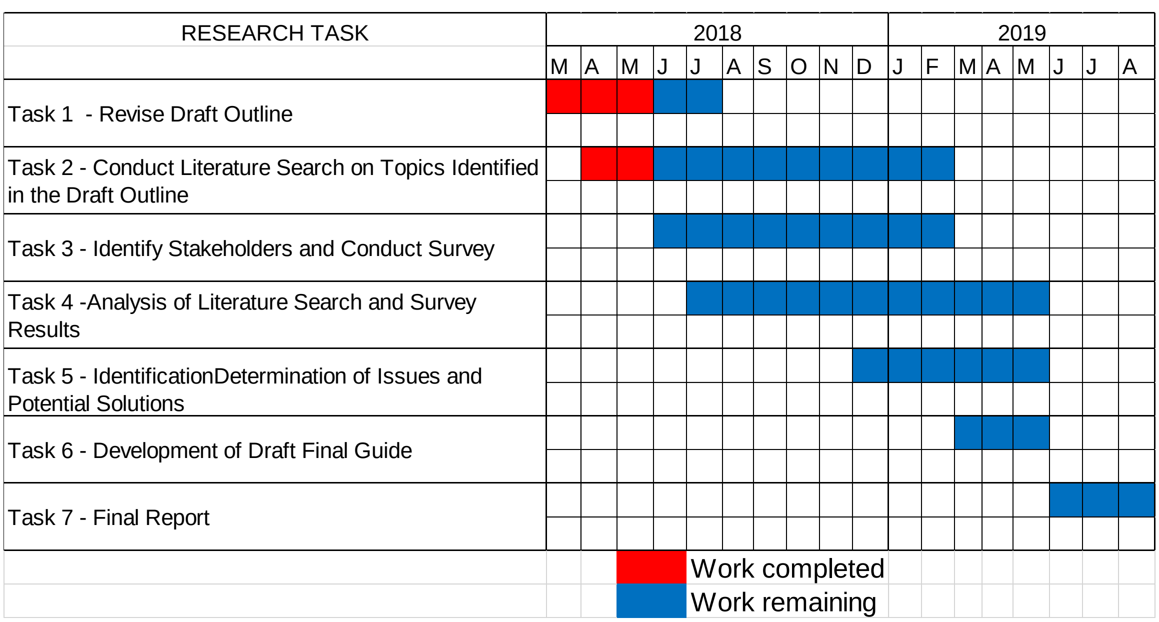
5.2 A five-minute Video Summarizing the Project

A short video will be prepared describing the guide developed in this project.

This research work and the Guide to be developed are directly applicable to the selection, design, and construction of ABC projects, including new bridges and replacement of existing bridges. Designers, bridge owners, and other stakeholders should be able to use this Guide to determine the substructure that best serves their purposes.

6 Schedule

The bar-chart below shows the schedule and work progress.



7 References

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Appendix A

ABC-UTC

DRAFT GUIDELINES FOR ABC SUBSTRUCTURES AND FOUNDATIONS

1. **INTRODUCTION**
   - **BACKGROUND**
   - **PURPOSE OF THE GUIDELINE**
   - **INTENDED USERS**
   - **GUIDELINE ORGANIZATION**
   - **HOW TO USE THE GUIDELINE**

- **ABC – DEFINITIONS AND DESCRIPTIONS**
  - **ABC BRIDGE COMPONENTS**
    - **SUPERSTRUCTURE**
    - **SUBSTRUCTURE**
    - **FOUNDATION**
    - **JOINTS AND CONNECTIONS**
  - **CONSTRUCTION METHODS**
  - **POTENTIAL ISSUES WITH DESIGN AND CONSTRUCTION**
    - **SUPERSTRUCTURE**
    - **SUBSTRUCTURE**
    - **FOUNDATION**
    - **JOINTS AND CONNECTIONS**

- **NEW BRIDGE CONSTRUCTION**
  - **SELECTION AND DESIGN CONSIDERATIONS FOR SUBSTRUCTURE**
  - **SELECTION AND DESIGN CONSIDERATIONS FOR FOUNDATION**
  - **CATEGORIZATION OF SUPERSTRUCTURE TYPES**
  - **CATEGORIZATION OF BRIDGES BASED ON GEOMETRIC PARAMETERS**
  - **CATEGORIZATION OF BRIDGES BASED ON GEOGRAPHIC PARAMETERS**
  - **SUITABILITY OF SUBSTRUCTURE AND FOUNDATION TYPES WITH RESPECT TO SUPERSTRUCTURE AND BRIDGE CONFIGURATION**

- **EXISTING BRIDGE REPLACEMENT**
  - **TYPE AND DESIGN OF EXISTING SUBSTRUCTURE**
  - **TYPE AND DESIGN OF EXISTING FOUNDATIONS**
  - **EVALUATION OF EXISTING SUBSTRUCTURE FOR POTENTIAL REUSE**

- STRUCTURAL CAPACITY

- **4.3.1.1 None Destructive Evaluation**
- **4.3.1.2 Field Testing**
- **4.3.1.3 Modeling and Analysis**
    - FUNCTIONAL ADEQUACY
    - INTEGRITY AND REMAINING SERVICE LIFE
    - HYDRAULIC ISSUES
    - SEISMIC CONSIDERATIONS
    - OTHER CONSIDERATIONS

- **EVALUATION OF EXISTING FOUNDATION FOR POTENTIAL REUSE**
    - STRUCTURAL CAPACITY
        - **NDE**
        - **Field Testing**
        - **Modeling and Analysis**
    - FUNCTIONAL ADEQUACY (WIDTH, HEIGHT, TRAFFIC, ETC.)
    - INTEGRITY AND REMAINING SERVICE LIFE
    - HYDRAULIC ISSUES
    - SEISMIC CONSIDERATIONS
- **SUITABILITY OF SUBSTRUCTURE AND FOUNDATION TYPES WITH RESPECT TO SUPERSTRUCTURE AND BRIDGE CONFIGURATION**
- **DECISION MAKING FOR REPLACEMENT, REUSE, OR RETROFITTING/ STRENGTHENING OF EXISTING FOUNDATIONS AND SUBSTRUCTURES**

4.6.1 LIFE CYCLE COST ANALYSIS

4.6.1.1 CONSTRUCTION COST

4.6.1.2 MAINTENANCE COST

4.6.1.3 SERVICE COST

4.6.2 SOCIAL IMPACTS

- **METHODS OF RETROFITTING/ STRENGTHENING**
    - SUBSTRUCTURE
    - FOUNDATIONS
- **EXTENSION OR AMENDING TO THE EXITING SUBSTRUCTURE AND/OR FOUNDATION**

- **SUBSTRUCTURE**
- **FOUNDATIONS**

- **DESIGN AND CONSTRUCTION GUIDELINES**
  - **DESIGN METHODOLOGY**
    - **DESIGN METHODS**
    - **SYSTEM DESIGN**
    - **COMPONENT DESIGN**
  - **PIERS**
    - **OPEN FRAME BENTS**
    - **WALL PIERS**
    - **SEISMIC CONSIDERATIONS**
    - **PIER ELEMENTS**
  - **ABUTMENTS**
    - **CANTILEVER**
    - **SPILL-THROUGH**
    - **GRS**
    - **INTEGRAL ABUTMENTS**
    - **SEISMIC CONSIDERATIONS**
    - **ABUTMENT SYSTEMS**
  - **WING WALLS AND RETAINING WALLS**
    - **PRECAST CONCRETE CANTILEVER**
    - **MODULAR PRECAST**
    - **WING WALL AND RETAINING WALL SYSTEMS**
  - **MODULAR CULVERT/ARCH SYSTEM**
    - **PRECAST ARCH AND 3-SIDED FRAME**
    - **STEEL ARCHES AND PIPES**
    - **BOX CULVERTS**
  - **FOUNDATIONS**
    - **DEEP FOUNDATIONS**

      5.6.1.1 Pile

      - **5.6.1.2 Drilled Shaft**

- **PREFABRICATED FOUNDATION ELEMENTS**
  - **5.6.2.1 Spread Footing**
  - **5.6.2.2 Pile Cap Footing**
  - **5.6.2.3 Precast Pier Box Cofferdams**

- **JOINTS AND CONNECTIONS**
  - **SUBSTRUCTURE CONNECTIONS**
  - **FOUNDATION CONNECTIONS**
  - **FOOTING AND PILE SYSTEMS**
  - **CONTINUITY CONSIDERATIONS**
- **STRENGTHENING OF EXISTING SUBSTRUCTURE/FOUNDATION**
  - **EXTENSION OF PIER CAPS**
  - **EXTENSION OF FOOTING**
  - **ADDITIONAL PILES AND PIERS**
  - **JACKETING**
  - **POST-TENSIONING**
  - **SOIL STABILIZATION**

- **NEW CONCEPTS FOR IMPROVING EXISTING SUBSTRUCTURE SYSTEMS**
  - **NEW SYSTEMS**
  - **NEW MATERIALS**

- **CASE STUDIES (subject to material availability)**