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

Quarterly Progress Report
For the period ending August 31, 2019

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ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
Florida International University
Miami, FL

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 4: Existing Bridge Replacement” was prepared. The following sections presents the OU part “Chapter 4: Existing Bridge Replacement”.

Evaluation of existing foundation for potential reuse

The evaluation of a foundation for potential reuse can be divided into four steps such as desk study, integrity assessment, durability assessment and capacity assessment. Table 1 presents the details of each step for the evaluation process [1]. Before considering a foundation for potential reuse, it is important to collect as much existing data on the foundation as possible during the desk study. This is a cost-effective method of collecting information and will provide a preliminary determination of the current state and past performance of the foundation. Important documents can be collected during this step includes, but not limited to design drawings, installation records, inspection reports, test data, and maintenance records. This information can be used in determining the tests required to be performed in determining foundation shape, structural integrity, capacity and remaining life. Detailed investigation is carried out based on the findings of the desk study. The knowledge from the desk study and the detailed investigation is combined to assemble all the required information for the foundation reuse (Figure 1).

Table 1 Assessment process for a foundation reuse candidate [1]

Assessment Portion	Tasks
Desk Study	Collect and review design drawings, installation records, soil boring history, soil test data, QA/QC records, inspection history, hazard history, and other reports.
Integrity Assessment	Determine material properties of foundation structures. Assess component damage and deterioration. Identify uncertain details, such as pile length and subsurface dimensions. Evaluate geotechnical performance, including settlement, geo-hazards, slope stability, and other changes to geotechnical system.
Durability Assessment	Assess current state of the bridge and level of deterioration. Assess environmental factors at the bridge that may lead to future deterioration of elements. Estimate remaining service life. Identify potential life cycle costs of durability issues identified and the life cycle costs of repair measures identified
Capacity Assessment	Determine new loads on the foundation. Determine capacity of existing components, accounting for integrity and durability assessments. Determine capacity of footings and deep foundations, performing load testing if necessary

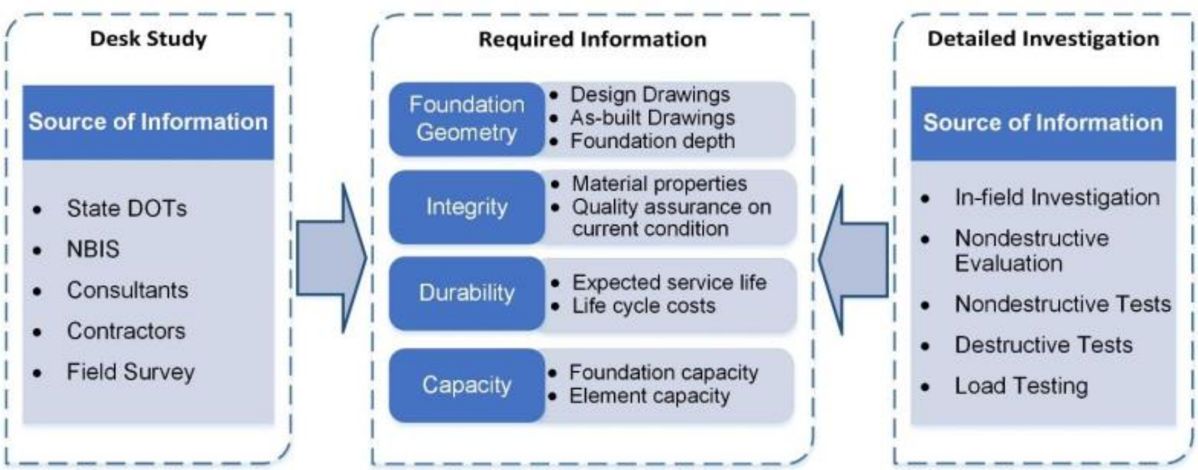

Figure 1 Required information for a comprehensive reuse assessment [1]

Integrity Assessment

The integrity assessment of foundation for potential reuse primarily focuses on identifying any damage, deterioration, or adverse conditions that may have reduced the capacity of the current foundation element. During the integrity assessment step, a review of the documentation such as foundation inspection reports, previous repairs, and any reported extreme loading events, including flooding and scour, geo-hazards, seismic, fire, and impacts will help identify the potential deficiencies or modes of failure. Additional testing required for assessing integrity of different foundation elements can be performed during this step to accurately determine the in-situ conditions. Figure 2 presents the flowchart of integrity assessment that may be considered during a reuse investigation for different material types. The evaluation of the above ground foundation components is similar to the evaluation of substructure components of the bridge. Therefore, the integrity assessment process for the below ground components are described in the following section.

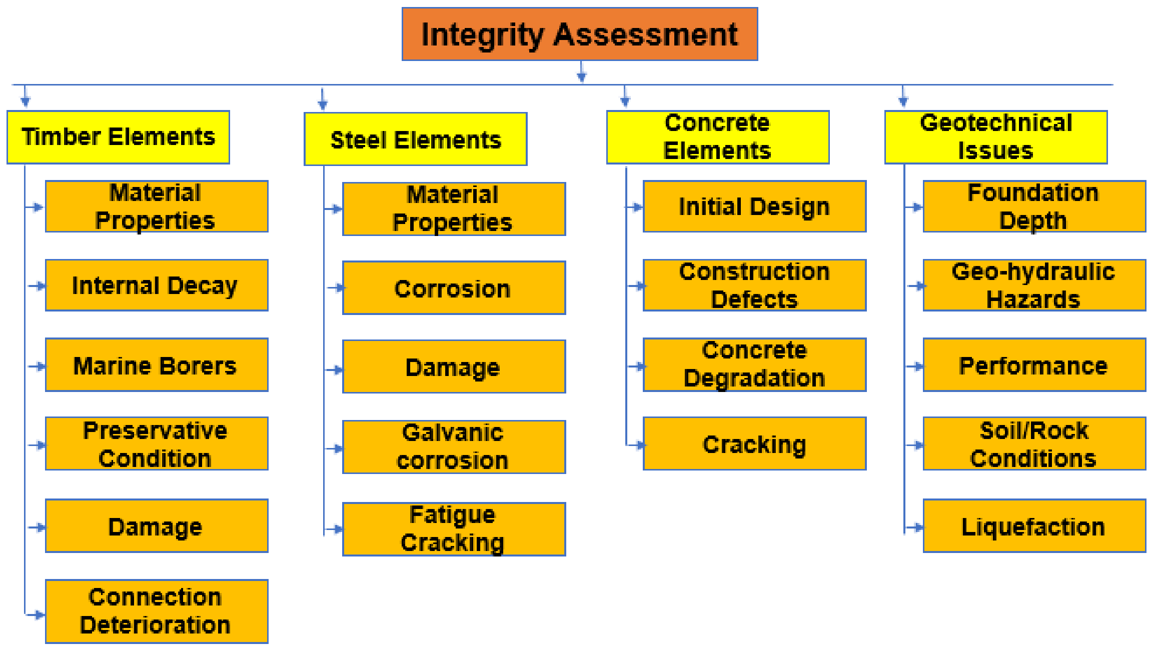

Figure 2 Flow chart of integrity assessment for different foundation materials [1]

Structural integrity of below ground elements

The evaluation of below the ground foundation components are difficult as these cannot be directly observed without excavation. Therefore, the evaluation process heavily depends on non-destructive (NDT) methods capable of indirectly detecting the geometry of buried elements as well as any damage to buried elements. Foundation depth is one of the important factors in deciding foundation's candidacy for reuse. Generally, foundations with unknown depths are not considered for reuse, as significant investigation may be needed as part of the reuse investigation. However, known foundations may still have missing important documents such as design plans, material properties, as-built plans, boring logs, or installation logs. The risks associated with reusing these foundations can be minimized by using technologies, such as core-hole logging, surface NDT methods, borehole NDT methods, and exposure of elements with test pits.

Detecting damage of underground piles, specifically driven piles is important for determining the suitability of the pile foundation for reuse. Driven concrete piles can get damaged during installation, especially while driving through excessively hard material. The historical performance data of the pile foundation may provide an idea about the damage of the foundation. However, it is possible that a pile group might perform adequately with a damaged pile. Reviewing the driving logs of the entire installation is the most effective technique for managing this risk of damaged foundation. Also, various NDT technologies can identify damage in underground piles. Also, drilled shaft foundations, which are being considered for reuse, needs to be checked for construction defects. Construction defects of drilled shafts, such as honeycombing, cold joints (lift lines), voids, soil intrusions (decrease in diameter), caving, bulbing (increase in diameter), poor-quality concrete (weak zones), and soft bottom [2] may lower the capacity of the section and become focal points for corrosion or other deterioration. Construction defects can be determined by cross-hole sonic logging (CSL) or other NDT methods on new drilled shafts.

The properties and conditions of below ground portions of foundations can be determined by using surface NDT methods. The methods do not generally require excavation or boreholes to perform. A summary of various surface NDT methods are presented in Table 2 [3].

Table 2 Structural integrity assessment technologies for below ground elements for reuse of bridge foundation [3]

Methods	Issues addresses
Surface NDT Methods	
Sonic echo (SE) testing	Performed on timber elements to locate voids and determine foundation depth.
Bending Wave Methods	To determine the unknown depth of the foundation or large defects
Ultra-seismic testing (US)	To determine large defective zones or pile tips can be measured
Seismic wave reflection surveys	To determine the depth of foundation elements
Borehole Investigation Methods	
Parallel seismic (PS) testing	To determine gross structural integrity and depth of driven piles or drilled shafts
Induction field testing	To detect the presence of metal objects, like steel or reinforced concrete
Borehole radar and sonic methods	The depth of the bottom of the foundation can be determined
Vertical Coring and Wireline Geophysical Logging	
Wireline logging	To measure material properties, to locate defects and cracking, and to identify local zones of weaker concrete
Cross-hole Sonic Logging (CSL)	Areas of cracked or weakened concrete can be determined

Durability and remaining life

The future lifespans of the foundation elements are determined by conducting durability assessment. Durability issues may include corrosion of reinforcing steel or steel elements, spalling, abrasion, rotting of timber elements, degradation of masonry joints, and other forms of progressive deterioration. Foundation elements, such as driven piles, drilled shafts, abutments, wingwalls, and pile caps are mostly comprised of reinforced concrete, where steel rebar is used to provide tensile strength, shear resistance, and flexure capacity. Corrosion of the reinforcing steel and degradation of the cover concrete are the two important durability concerns for reinforced concrete. Since steel expands as it corrodes, even a small amount of corrosion can cause cracking or spalling of the cover concrete, making the reinforcement even more susceptible to corrosion. The causes of concrete degradation and reinforcement corrosion for reinforced concrete foundation elements are presented in Figure 3 [4]. Cracking of the concrete cover is one of the most common causes of reinforcement corrosion which can be initiated by several causes: shrinkage/drying, flexural cracking (in tensile areas), shear cracking, temperature fluctuations, freeze-thaw cycling, impacts/damage, or poor initial quality. cracking allows for ingress of water, chlorides, and contaminants that initiate corrosion in the reinforcement steel. Chemical attacks (from acids, sulfates or pure water), abrasion and erosion by water can degrade the concrete cover, potentially exposing reinforcement. Also, Freeze thaw cycling can result in a reduction in concrete strength over time and eventual exposure of reinforcement.

The service life of steel foundation elements can be degraded due to rusting or corrosion. Corrosion of steel can be prevented by using paint coatings, rust (in the case of weathering steel), and coal tar epoxy or by use of a sacrificial thickness of steel. Also, the timber elements of the foundation can experience rapid loss in strength if become susceptible to biological attack from boring insects or fungi.

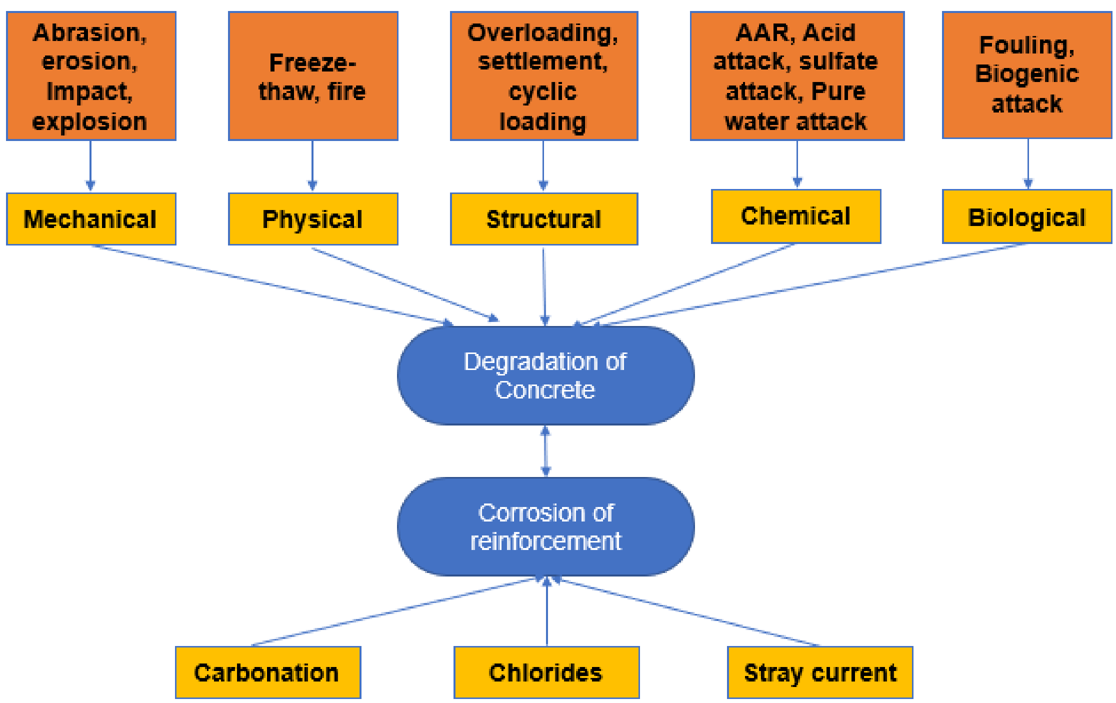

Figure 3 Causes of deterioration of reinforced concrete structures [4]

Field Measurement and Testing

Different available durability related testing for concrete elements are presented in Table 3. A number of testing methods, ranging from simple visual and physical inspection to NDE/NDT, to sample removal and testing are available for assessing durability of concrete elements. The focuses of these tests are to determine the extent of cracking present, the presence and rate of reinforcement corrosion, the extent of carbonation, and the extent of chloride ingress into the cover concrete.

Table 3 Durability related testing for concrete elements [1]

Available testing	Issue identified during preliminary evaluation	Notes
Cover Measurement	Corrosion, chloride exposure, carbonation	Determine cover thickness important to evaluation of other durability issues.
Chloride Testing	Exposure to chlorides	Determine profile of chloride diffusion into cover concrete. Initial chloride testing can be limited to surface and depth samples, to ascertain the magnitude of bound and unbound chlorides
pH testing	Carbonation	Perform pH testing on extracted cores to determine depth of carbonation penetration
Half-cell potentials	Active corrosion	Perform half-cell potential testing in areas of suspected corrosion
Electrical Resistivity	Potential for corrosion	Useful for finding areas of corrosion or areas susceptible to corrosion

The extent of corrosion in steel foundation element can be found through visual and physical inspection using calipers, ultrasonic thickness gauges, or other measurement devices. However, for underground foundation elements, these types of durability assessment may be difficult, requiring the installation of test pits to expose the element. Underground elements at areas of low pH, high sulfate or chloride content, alternating wet/dry cycles, and differential soil layers exhibited higher susceptibility to corrosion.

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 and 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 4: Existing Bridge Replacement” has been prepared based on the literature reviewed for this project. Also, the survey was conducted with the help of AASHTO Committee on Bridge and Structures. The responses of the survey were presented in previous quarterly report.

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.

Item	% Completed
Percentage of Completion of this project to Date	70%

Research Task	2018												2019										
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
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

1. Agrawal, A., et al., *Foundation Reuse for Highway Bridges*. 2018.
2. Jalinoos, F., et al., *Defects in Drilled Shaft Foundations: Identification, Imaging, and Characterization.* Publication No. FHWA-CFL/TD-05-003, Federal Highway Administration, 2005.
3. Wightman, W., et al., *Application of geophysical methods to highway related problems*. 2004.
4. Bertolini, L., et al., *Corrosion of steel in concrete*. Vol. 392. 2013: Wiley Online Library.