NDT METHODS APPLICABLE TO HEALTH MONITORING OF ABC CLOSURE JOINTS

Quarterly Progress Report
For the period ending May 31, 2018

Submitted by:
Armin Mehrabi
Saman Farhangdoust
Sayed Feras Al Mosawi

Department of Civil and Environmental Engineering
Florida International University
Miami, FL

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

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

NDT METHODS APPLICABLE TO HEALTH MONITORING OF ABC CLOSURE JOINTS

1 INTRODUCTION

ABC comprises of precast elements of the bridge fabricated on site or away, moved to the bridge location and installed in place. Regardless of the fabrication and installation of precast-prefabricated elements, connections need to be established on site and in place. These connections, Closure Joints, are expected to provide continuity between adjoining elements for the purpose they are designed for. In all, the specific nature of the joint application, in-situ casting, curing, material incompatibility, cavities and steel congestion contribute to a higher potential for exposure and other detrimental effects with possible degradation in time, and therefore reducing the strength and serviceability of the joint and the structure. The long-term deflections and environmental loading will only exacerbate the situation. It is therefore critical to first assure the closure joint is in good health right after construction completes, and secondly to remain healthy in future.

2 STATEMENT OF PROBLEM

A variety of NDT methods have been utilized for evaluation of bridges including those with closure joints. However, a concerted attempt for categorization of these methods, comparison of capabilities, and selection of methods most applicable to closure joints is lacking. The main objective of this project is search, identification, and potential development of practical and economical methods for field inspection and damage detection of ABC closure joints, immediately after completion and periodically thereafter during its service life. The presence of defect may be readily identifiable by detecting significant anomalies in the response of the joint to NDT techniques. However, the overall approach to NDT evaluation of closure joints will also include constructing a signature response record of an intact joint to specific NDT technique at completion of construction. This base record will be used for comparison with future periodic (or on demand) inspections for determining the type and extent of potential damages. In conjunction with review of various NDT methods, it is the intent of this project to evaluate the promising NDT techniques, as much as the scope of project allows, and identify how best these techniques could be used to provide suitable practical methods for inspection, therefore health monitoring of the ABC structure. It is attempted to organize the project results in a manner to allow, in a separate follow-up project, development of field procedures, evaluation guidelines, and reporting methods and appraisal of methods for ease of use and suitability for integration into states bridge inspection programs.

3 RESEARCH APPROACH AND METHODS

The overall approach of this project is organized in three basic stages; search of background information for identification of detailed problems and available NDT methods, evaluation of methods for applicability to closure joints, and finally selection of the best methods and verification and necessary adaptation/modification in accordance with the objectives of this project. It is realized that the usefulness of data collected, practicality of approach, ease of use and quantifiable results are defining factors for acceptance, utility, and implementation of any inspection technique. It is also believed that instead of reinventing the wheel, the adaptation, albeit with modification and customization, of existing experiences and well-served practices from other industries/applications provide the maximum returns for the bridge engineering community. Lessons learnt over the past decades from the design, inspection, maintenance, and repair of ABC, and prior experiences would provide true and tried methods for minimizing experimentation with potential inspection methods. The project objectives will be met within the following approach and set of activities:

- A complete technological review to identify ABC closure joint problems and causes.
- In parallel to the published literature and technology practices, information may be collected, via surveys, from practices and experiences of owners and inspectors.
- Based on technological resources, candidate NDT methods will be categorized and NDT practices with promise for application to closure joints will be selected.
- The second stage will deal with verification of selected methods and their application on available specimens, and adaptation or modifications of methods if necessary.
- An outline of inspection procedure/protocol associated with selected methods will be developed.
- Reporting and communication of results with peers and advisory panel will be carried out in timely manner and at necessary juncture during the project.

4 DEFENITIONS

4.1 ACCELERATED BRIDGE CONSTRUCTION (ABC)

Accelerated Bridge Construction (ABC) is defined as design, planning and construction methods to organize and arrange construction activities for new bridges, as well as repair, replacing, and rehabilitating of existing bridges so that onsite construction time and mobility impacts are reduced, and public and worker’s safety is enhanced [1]–[3]. Among other features, the use of pre-fabricated modular bridge elements and assemblies are the most common aspect of the Accelerated Bridge Construction (ABC) [1], [4]. ABC addresses some of the major drawbacks of the conventional bridge construction methods including delays to allow concrete curing, time constraints due to sequential construction, traffic interruptions and safety issues, compromise in quality for in-situ activities, dependency on weather, etc. From a more practical standpoint, the most important of ABC potentials are:

- Reducing disruption to traffic
- Avoiding congestion
- Safer operation
- Alleviating public/workers exposure to construction activities
- Achieving higher quality control for precast elements
- Decreasing environmental impacts
- Better control over cost and schedule

Owing to these advantages, application of ABC methods is growing across the US (Fig. 1).

Figure 1: ABC superstructure positioning [5]

4.2 ABC CLOSURE JOINTS

Application of the Accelerated Bridge Construction (ABC) using prefabricated elements and assemblies necessitates the use of joints for connecting and integrating the bridge structure.

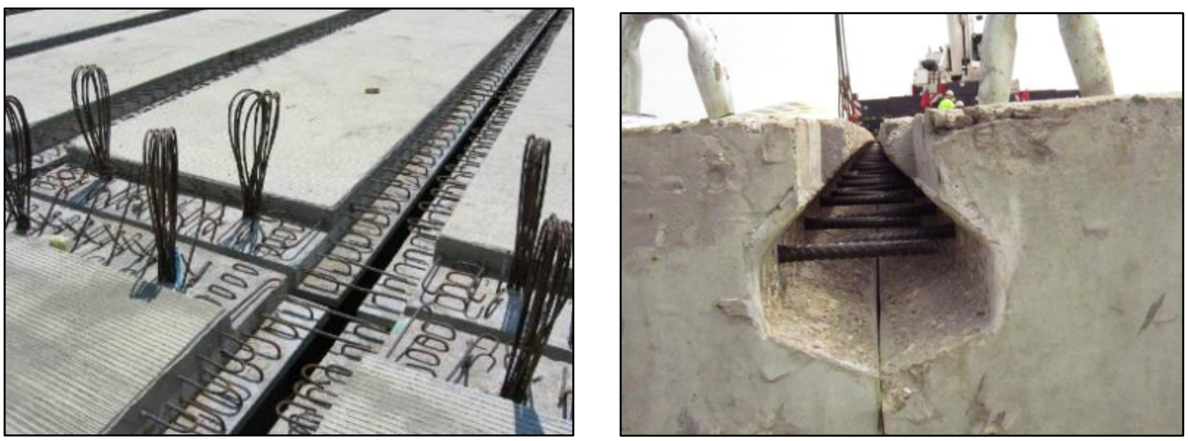


Figure 2: Examples of various types of ABC closure joints [6]–[9]

Closure joints normally refer to joints for connecting the bridge deck elements to each other and to the substructure. Other joints are used for connecting superstructure to substructure as well as substructure elements to each other (Fig. 2).

5 DESCRIPTION OF RESEARCH PROJECT TASKS

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

5.1 TASK 1 – TYPE, POTENTIAL DEFECTS, AND SERVICEABILITY PROBLEMS OF CLOSURE JOINTS

5.1.1 Literature Search

A review of available literature and data was being carried out to identify type, potential defects, failure modes and serviceability problems of the closure joints.

5.1.2 Categorization of Closure Joints

Five types of closure joints were identified to represent dominant groups according to anticipation of type of defects that could be present for these joints and overall configuration of joints influencing the use of specific NDT methods.

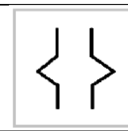
5.1.2.1 Type 1 Closure Joint

Type 1 Joint designation refers to linear joints known also as shearkey or keyway joint, and is normally used to join full-depth precast decks, while in some cases it is also used to join precast beams (Fig.3).

5.1.2.2 Type 2 Closure Joint

Type 2 Joint designation refers to linear joints that normally join full-depth precast decks to each other, and precast decks to precast concrete beams (Fig. 4).

Symbol Representing Joint



Sample Cross Section

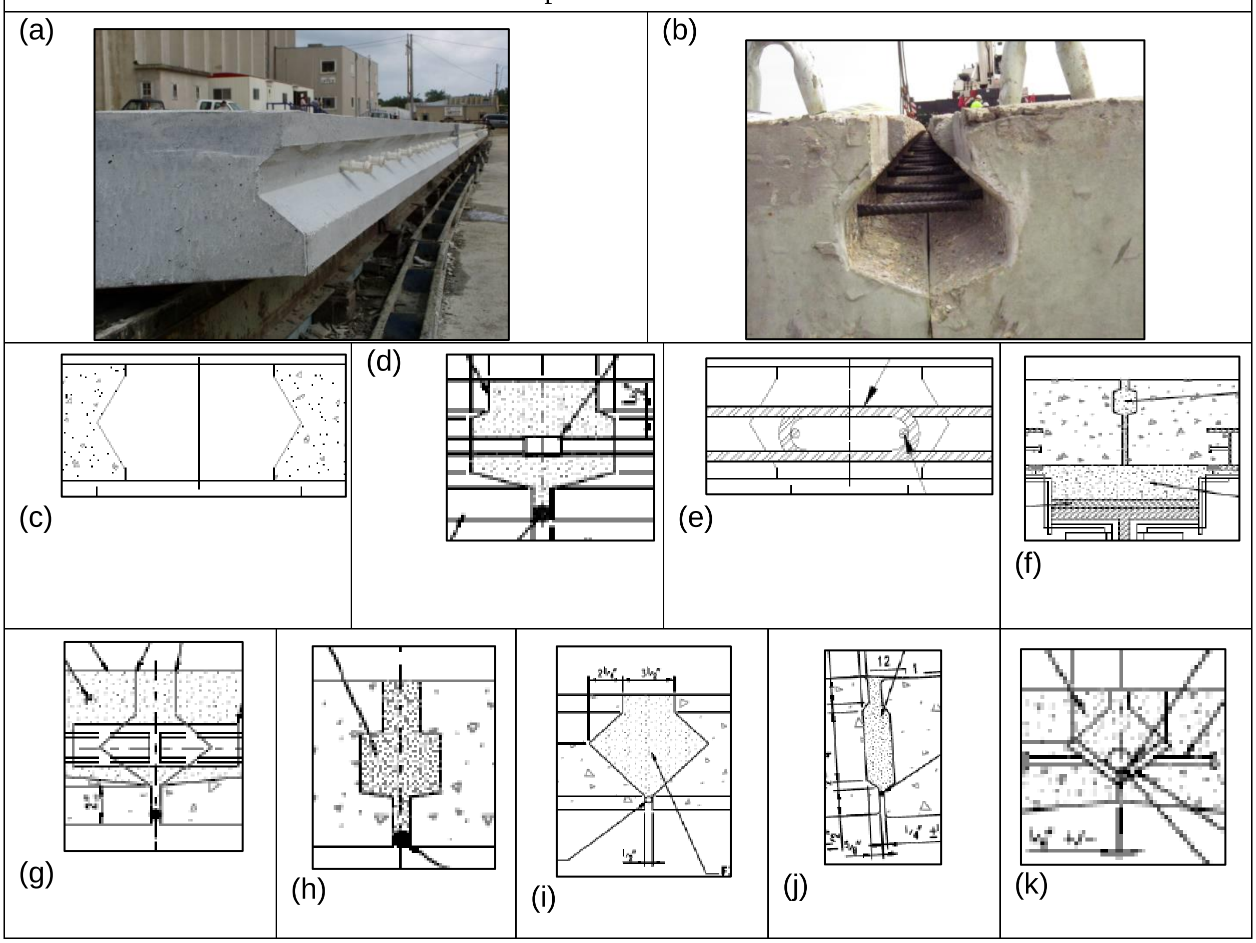
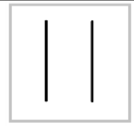


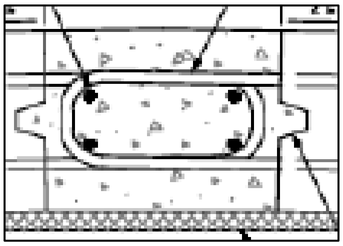
Figure 3: Type 1 Joint [6]–[8], [10], [11]

Symbol Representing Joint

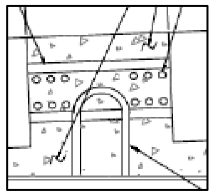


Sample Cross Section

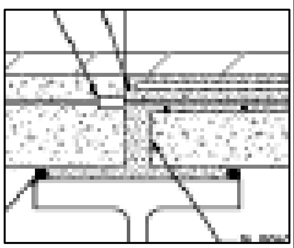
(a)



(b)

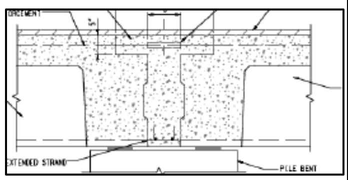


(c)

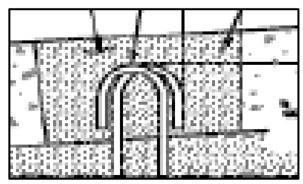


(d)

(e)



(f)



(g)

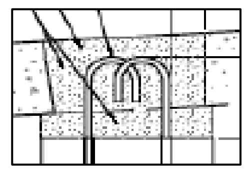


Figure 4: Type 2 Joint [7], [9]

5.1.2.3 Type 3 closure Joint

Type 3 Joint designation refers to linear joints that normally joining partial depth precast deck panels, butted decked precast girders, and in some cases P/C Slab Longitudinal connections to Steel Girder Superstructure [7] (Fig. 5).

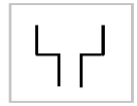
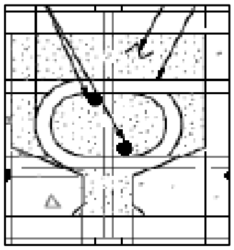
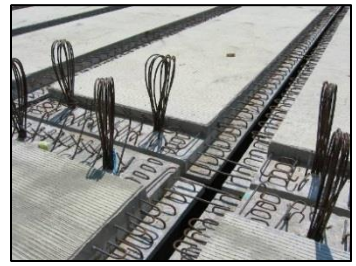
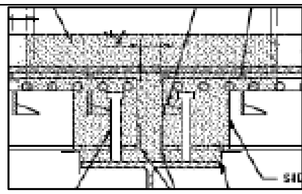
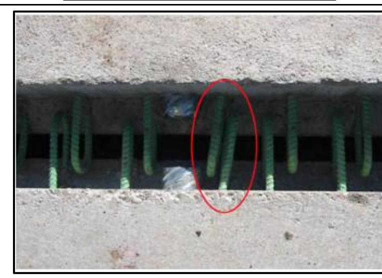
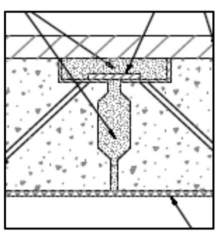
Symbol Representing Joint	
Sample Cross Section	
(a) 	(e) 
(b) 	(f) 
(c) 	(g) 
(d) 	

Figure 5: Type 3 Joint [7], [8], [12]

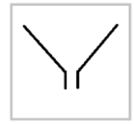
5.1.2.4 Type 4 closure Joint

Type 4 Joint designation refers to linear joints that normally joins two prestressed tee beams or double beam, and in some cases full or partial depth deck panels. The V shaped joint is cast in the longitudinal direction (Fig. 6).

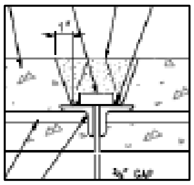
5.1.2.5 Type 5 of closure Joint

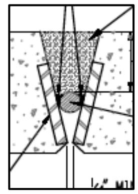
Type 5 Joint designation refers to box/recangular shaped joints that are known as blockouts. These joints are spaced throughout the decking and usually connect precast full depth decks to steel girders or concrete I-beams (Fig. 7).

Symbol Representing Joint



Sample Cross Section

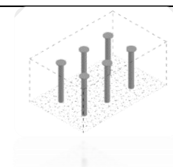
(a)


(b)


(c)

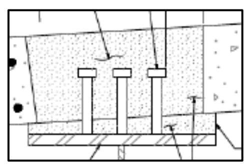

Figure 6: Type 4 Joint [7], [8], [12]

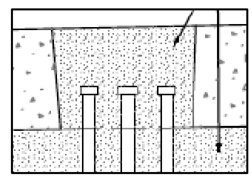
Symbol Representing Joint

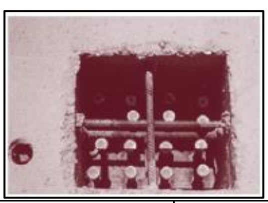


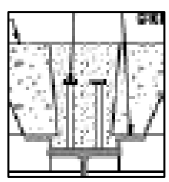
Sample Cross Section

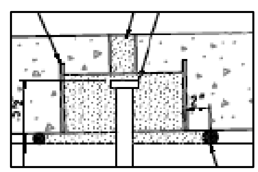
(a)

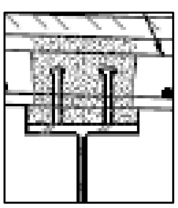

(b)


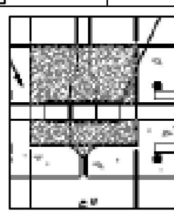
(c)


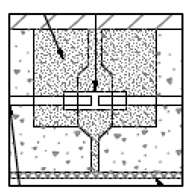
(d)


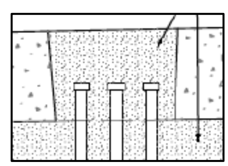
(e)


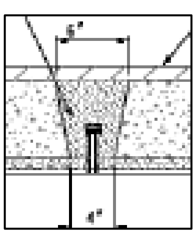
(f)


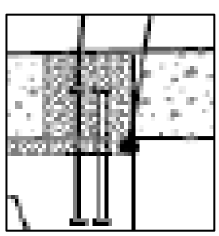
(g)


(h)


(i)


(j)


(k)


(l)


(m)


(n)


Figure 7: Type 5 Joint on a bridge deck [7], [9]

5.1.3 Reported and presumed defects and Anomalies

Defects and anomalies in closure joints are generally expected to follow those observed for concrete deck construction. Accordingly, unless a specific case is reported for closure joints that is different from those observed for bridge deck, defects and anomalies reported for bridge decks, with adaptation to the closure joints wherever possible, will be considered in this study. This can include lack of the cohesion or continuity in concrete or similar material in the closure joint such as;

- cracking,
- separation and delamination,
- voids and/or honeycombing filled with air or water,
- corrosion and loss of cross-section of reinforcing bars within the joints and their vicinity,
- leakage of surface water through joints,
- roughness,
- and abnormal appearance.

Figure 9: Shrinkage crack in the blockout type of ABC closure joint [13]

Figure 10: Longitude deck cracking of ABC closure joint [14]

5.1.4 Defects Etiology

According to observations from bridge inspections, most of the defects and damages/defects mentioned above can be caused by one or more of the issues with; Design, Material, Workmanship, Shrinkage, Mechanical and Environmental conditions. The relationships among the causes and effects were explored and an etiology was constructed for observed or expected defects in closure joints.

5.2 TASK 2 – CURRENT INSPECTION/NDT PRACTICES

It is intended to identify and combine the best practices from various applications of NDT to ABC including but not limited to those that are currently being used. The goal is to create standardized methods and techniques that would be similar or useable for inclusion within the customary bridge inspection practices.

5.2.1 Literature Review

A comprehensive study is being conducted on the technical literature focusing on NDT methods for field inspection and damage detection. The evaluation of methods for applicability to closure joints, and consequently, the selection of the most effective methods in accordance with the objectives of ABC closure joints are emphasized. Eighteen NDT methods in three distinctive groups considering to the potential in evaluating the ABC closure joints have been identified include:

1. NDT Methods potentially applicable to ABC closure Joints
    - Impact Echo Testing (IET)
    - Microwave Testing (MT)- Ground Penetrating Radar (GPR)
    - Pulse Velocity Testing (PVT) – Ultrasonic Testing (UT)
    - Phased Array Ultrasonic Testing (PAU)
    - Infrared Thermography Testing (ITT)
    - Acoustic Emission Testing (AE)
    - Impulse Response Testing (IRT)
    - Laser Testing (LT)
    - Radiographic Testing (RT)
    - Magnetic Flux Leakage Testing (MFL)
    - Visual Inspection (VI)
    - Global Structural Response Testing (GSR)
    - Chemical and Electrical Testing (CET)
2. Other Common NDT Methods
    - Penetrant Testing (PT)
    - Eddy Currant Testing (ET)
    - Magnetic Particle Testing (MPT)
3. Complementary to NDT Methods
    - Testing under Service Load (SL)
    - Automated Testing Platforms (ATP)

5.2.2 Promising Methods

Taking into account characteristics of the non-destructive methods discussed above, following methods can be viewed as promising for use in health monitoring of closure joints:

1. Impact Echo Testing (IET)
2. Microwave Testing (MT)- Ground Penetrating Radar (GPR)
3. Pulse Velocity Testing (PVT) – Ultrasonic Testing (UT)
4. Phased Array Ultrasonic Testing (PAU)
5. Infrared Thermography Testing (ITT)
6. Impulse Response Testing (IRT)
7. Laser Testing (LT)
8. Radiographic Testing (RT)
9. Magnetic Flux Leakage Testing (MFL)
10. Chemical and Electrical Testing (CET)

The promising NDT methods were compared based on an established criteria and results were tabulated.

6 REMAINING WORK

Laboratory and field verification work will be included in this study if the scope of work allows.

7 SCHEDULE

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

Table 5: Schedule

RESEARCH TASK	2017							2018								
	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Task 1 - Type, Potential Defects, and Serviceability Problems of Closure Joints																
Task 2 - Current Inspection/NDT Practices																
Task 3 - Selection of Applicable NDT Methods and Condition Assessment Approach																
Task 4 - Interim Report																
Task 5 - Verification of Selected Methods and adaptation/modification if necessary																
Task 6 - Final (Draft and Revised) Report submission																

8 REFERENCES

[1] Culmo, M. P., Sadasivam, S., Gransberg, D., Boyle, H., Deslis, A., Duguay, W., Rose, D., Mizioch, C. and Mallela, J., 2011, ‘Contracting and Construction of ABC Projects with Prefabricated Bridge Elements and Systems,’ Federal Highway Administration, Washington, D.C., Rep. FHWA-HIF-17-020.

[2] Mashal, M., White, S. and Palermo, A., 2012, ‘Concepts and Developments for Accelerated Bridge Construction and Dissipative Controlled Rocking,’ 15 WCEE LISBOA.

[3] Bowers, R., Klaiber, F. W., Kevern, S., Landau, C., Kieffer, R. and Nelson, J. S., 2007, ‘Construction and Testing of an Accelerated Bridge Construction Project in Boone County,’ Proceedings of the 2007 Mid-Continent Transportation Research Symposium.

[4] Jahromi, A. J., Dickinson, M., Valikhani, A. and Azizinamini, A., 2017, ‘Toward Development of Best Practices for Closure Joints in ABC Projects,’.

[5] Culmo, M. P., 2011, ‘Accelerated Bridge Construction - Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems,’ Federal Highway Administration, McLean, VA, Rep. FHWA-HIF-12-013.

[6] Adjacent precast box beam bridges,’ The Construction Specifier CSI, Available: https://www.constructionspecifier.com/adjacent-precast-box-beam-bridges/4/. [Accessed: 1-Jan-2018].

[7] Culmo, M. P., 2009, ‘Connection Details for Prefabricated Bridge Elements and Systems,’ Federal Highway Administration, Rep. FHWA-IF-09-010.

[8] Porter, S. D., Julander, J. L., Halling, M. W. and Barr, P. J., 2012, ‘Shear Testing of Precast Bridge Deck Panel Transverse Connections.’ Journal of Performance of Constructed Facilities, 26(4), 462-468.

[9] Russell, H., Ralls, M., Tang, B., Bhide, S., Brecto, B., Calvert, E., Capers, H., Dorgan, D., Matsumoto, E., Napier, C., and Nickas, W., 2005, ‘Prefabricated Bridge Elements and Systems in Japan and Europe,’ Federal Highway Administration, Rep. FHWA-P.

[10] French, C., Shield, C., Ma, Z. J, Klaseus, D., Smith, M., Eriksson, W., Zhu, P., Lewis, S. and Chapman, C. E., 2011, ‘Summary of Cast-In-Place Concrete Connections for Precast Deck Systems,’ National Academy of Sciences.

[11] Wipf, T., 2009, “Iowa’s Perspective on ABC,” FHWA ABC workshop International Bridge conference.

[12] Marin III, D., 2008, ‘Accelerated Bridge Construction,’ Iowa DOT ABC Workshop Bridge Devision Texas DOT.

[13] URS, 2014, ‘Lessons Learned After Construction: Bridge County Road Over I-80,’ Salt Lake City, Utah, Project No. IBHF-80-4(90)160.

[14] Attanayake. U., and Aktan, H., 2015, ‘First-generation ABC system, evolving design, and half a century of performance: Michigan side-by-side box-beam bridges,’ *J. Perform. Constr. Facil.*, vol. 29, no. 3, pp. 1–14.