DEVELOPMENT OF USER-FRIENDLY TOOLS AND DECISION-MAKING ALGORITHMS FOR SERVICE LIFE DESIGN OF ABC BRIDGES

Quarterly Progress Report
For the period ending February 28, 2021

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ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

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

1. Background and Introduction

Accelerated bridge construction (ABC) is a paradigm shift in the project planning where the necessity to lessen mobility impacts that occur due to onsite construction activities are given to a major priority. ABC techniques use innovative design and construction methods that are advantageous in a cost-effective and safe manner. Among the ABC techniques, prefabricated bridge elements are the most prominent methods. These are structural components that are manufactured offsite and shipped to the site upon the requirement that aims the reduction in onsite construction time, traffic disruption, improvement in product quality, and durability. An ABC application called closure joint is used to connect two adjacent prefabricated deck panels by casting filler material (i.e. normal concrete, polymer concrete, and ultra-high performance concrete) in between them with the use of different reinforcement details. The connections, however, can be affected by environmental and structural degradations. Consequently, durability issues have been encountered in closure joints. There are proof tested and approved ABC design methods available in the literature. The recent publication by ABC-UTC discussed the closure joint design methods to mitigate the durability in a comprehensive manner (Jahromi et al., 2020).

This project will design and implement a prototype web-based decision support tool to facilitate the use of existing manuals and bridge specifications in practice. We first derive decision-making algorithms and criteria presented in the guideline for service life design of longitudinal deck closure joints. We then translate them into UML (Unified Modeling Language) use cases and develop a series of well-designed interactive questions and user interfaces. This will allow users to walk through the service life process with the aids of visual elements, suggestions and tips, and make final design decisions, without much knowledge of probabilistic approaches.

2. Problem Statement

Implementation of ABC technology has been gaining great momentum by Federal Highway Administration (FHWA) and several state DOTs during the last two decades (Culmo, 2011). ABC methods minimize the construction activities performed in the field, reduce the detour time and traffic disruptions, and improve the safety of workers and the public. Methods typically used for ABC include prefabricated bridge elements and systems (PBES), lateral slides, and self-propelled modular transporters (SPMT). Prefabricated elements used for ABC will be connected using longitudinal or transverse closure joints. It is noted that many prefabricated decks with longitudinal closure joints have performed well. Connections of PBES are critical as the performance of connections under loads and natural environmental conditions can affect the service life of the bridges. In addition, some issues like leakage and cracking in prefabricated deck connections have been identified with respect to operational or production defects. Different ABC design methods have been developed to connect prefabricated deck panels (e.g. Jahromi et al., 2020; Haber and Graybeal, 2018; Graybeal, 2014; Li et al., 2009). These design methods and new solutions are in progress to be incorporated in AASHTO LRFD Bridge Design Specifications for ABC but are not available yet. However, the methods have been proof tested and verified by the bridge community including bridge engineering research group in FHWA, ABC-UTC, and several state DOTs.
Recently, ABC-UTC has published a guideline for service life design of longitudinal deck closure joints (Jahromi et al., 2020) which was a customized version of a project for Bridges with Service Life Beyond 100 Years. While the published ABC-UTC Guide is comprehensive, it is not user

friendly for bridge engineers and state DOTs to be used and implemented in their design. Therefore, a reliable decision support tool is required to assist stakeholders and engineers in choosing appropriate design options and solutions. To this end, we will develop a prototype web-based tool that provides customized design by applying the decision-making algorithm focusing primarily on service life and durability of closure joints. The proposed decision support tool will be implemented based on the general steps presented in the ABC-UTC design guide. It will be visual and allow users to easily navigate through the design options, design steps, on-site requirements, geometry, material properties, and modes of failures.

3. Objectives and Research Approach

Specific objectives of the projects are as follows:

- Develop a prototype web-based tool that will contain in a data base the entire information listed in the ABC-UTC Guide for Service Life Design of Longitudinal Deck Closure Joints and host it at FIU in a dedicated server.
- Develop a series of well-designed interactive questions and user interfaces that will allow the user to walk through service life process with the aids of visual elements, suggestions and tips.
- Allow, easily, the information in the data base, such as reported closure joint service life performance and types to be updated as information becomes available
- Develop decision making tools that will assist the user to make final design decisions, without having to know fully the theory behind probabilistic approaches that will be used in the decision-making process.

The project team first translates the design solutions, presented in the ABC-UTC Guide, into UML use case and state charts, and designs the interactive questions based on the decision-making criteria and probabilistic approaches. We then organize preliminary meetings with the research advisory panel to solicit their feedback and update the use case diagrams for the decision support tool. Once the information flow, decision algorithms, and system functionality are approved, we use Python, an object-oriented programming language, and available open-source libraries (e.g. Pandas, Scikit, Numpy, SQLite) to implement the user interfaces and algorithms. To facilitate the decision support tool deployment on FIU server, the project team works closely with the Office of Information Technology to allocate the required space and maintenance resources.

4. Description of Research Project Tasks

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

Task 1 – Architecture Design

The system architecture is the optimum way to understand the interaction among components. Our architecture comprises three components which include GUI, application server, and database server. The main components are shown in Fig. 1.

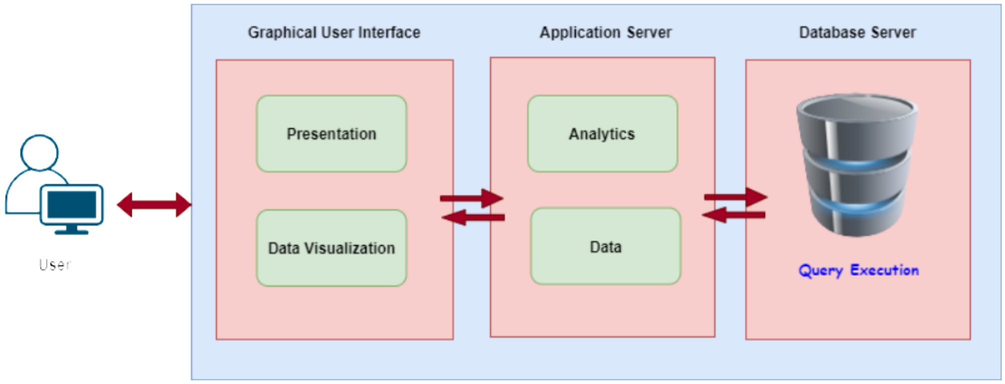


Fig. 1. System Architecture

Graphical User Interface: The user will be provided with an interface or frontend where the specific parameters need to be given by the user to assist in identifying the list of closure joints. The interface helps to establish the environment where the user can interact with the system by providing necessary inputs and getting the desired output.

Application Server: The application server is the middle tier of the system. It is a business logic application or set of applications on the local network. When an application server gets a request from the user, it then performs logical operations based on the designed algorithm.

Database Server: It is a crucial component where the query requested by the user will be processed at this stage. The database will be populated with the required information that allows the algorithm to process the data and make appropriate decisions.

The decision support tool will be deployed on the FIU server. The OU research team initiated communication with the Office of Information Technology at FIU to identify software requirements and allocate the required space and maintenance resources.

Task 2 – Content/Information Flow Identification, Algorithms and Analytics, Dashboard Design.

We designed UML use case diagrams, based on the published ABC-UTC Guide for service life design of longitudinal deck closure joints, to define interactive questions, systems functionalities, and required underlying decision algorithms.
The research team mainly focused on the identification of content flow and decision-making algorithms Fig. 2 illustrates the system use case diagram. The user is a primary actor who initiates the system. In our project, the database is the secondary actor which provides the necessary details to process the request. In this diagram, tasks or use cases are represented in three different colors to differentiate among tasks. Use cases represented in blue color are nothing but inputs/specifications that the user is required to provide in order to interact with the system. Use cases represented in orange color are outputs that the user receives as the result of the requested query. The rest of the use cases represents internal working process of the query.

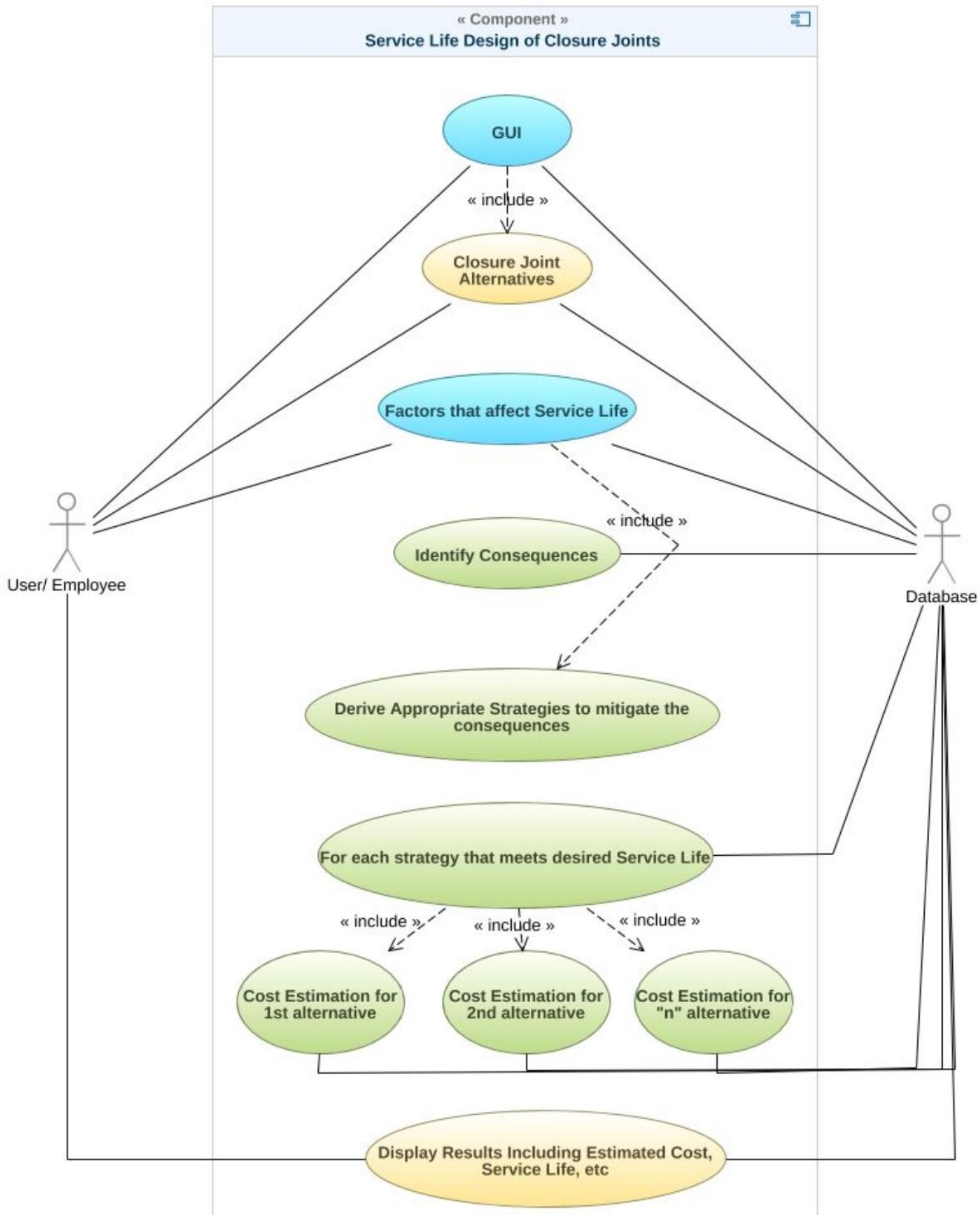


Fig. 2: UML Use case Diagram

Flow of Use cases: The interaction with the system starts once the user initiates the request through GUI by providing specifications through parameters. For each identified closure joint, with provided factors such as service loads, natural or manmade hazards that affect the service life of closure joints, the algorithm will determine appropriate mitigation strategies available in the guideline. For each derived alternative, the service life will be calculated based on Fick's law. For all alternatives, the estimated cost will be calculated and displayed along with the estimated service life. This allows for trade-off analysis and assists the user in making decisions.

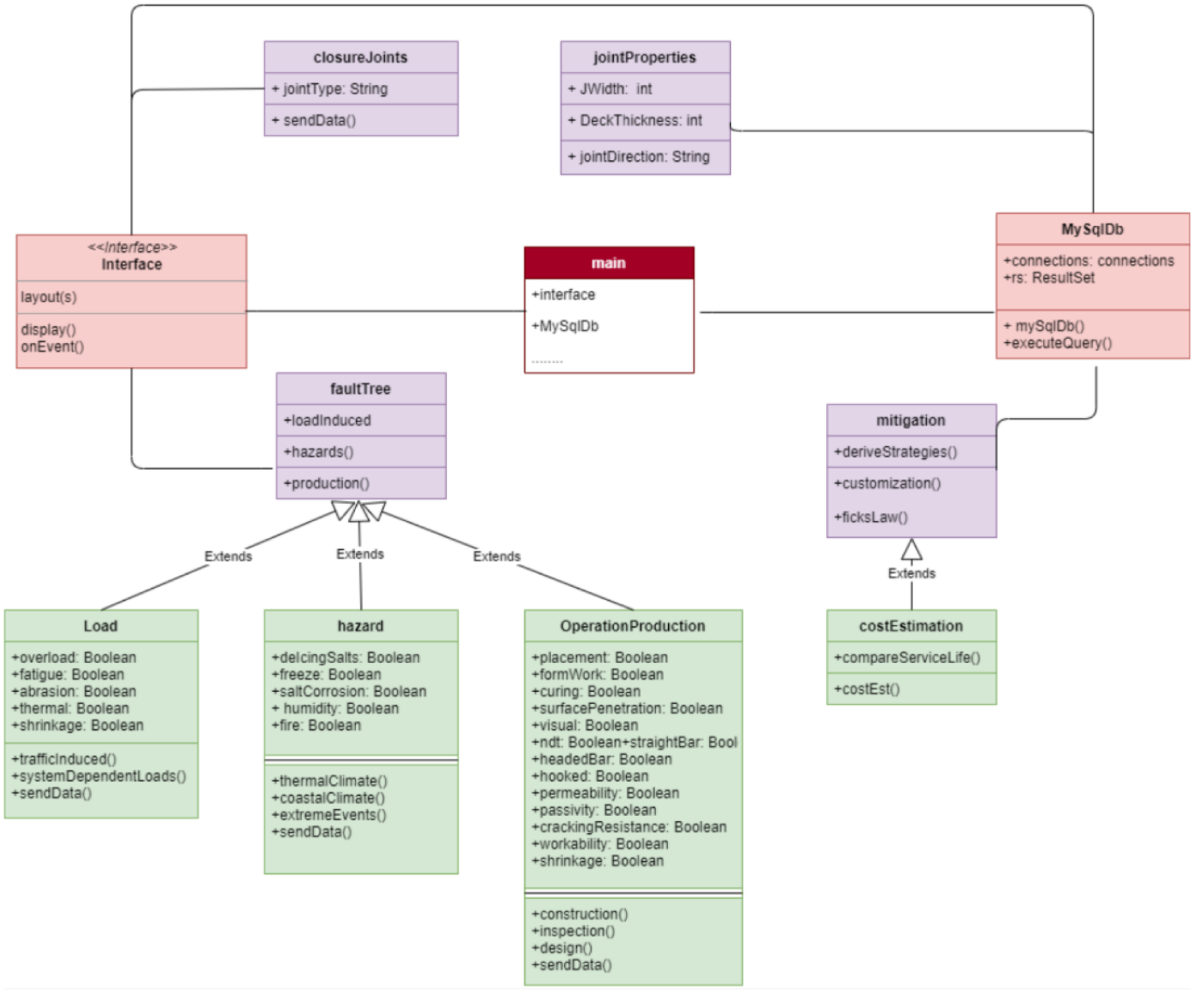


Fig. 3: UML Class Diagram

Fig. 3 illustrates a UML Class diagram such that each rectangular represents classes and their attributes. The number of classes of a system indicates the number of objects and its corresponding attributes. It can be observed that the above class diagram has main attributes such as joint properties, closure joints, mitigation strategies, cost analysis etc. Functions performs the operations of specific tasks.

To better understand the relationship between input parameters and mitigation strategies, the research team designed, developed, and tested an excel-based decision support tool based on the use case diagrams and identified attributes. The spreadsheet forms are presented in Appendix A. This tool has served as our reference point for developing the web-based tool in Task 3.

<u>Research advisory board:</u> Two members representing Oklahoma DOT and a consulting company were invited and joined the advisory panel.

4 Task 3 – Prototype Implementation.

We chose and utilized Django as our web-based platform, which is a Python-based open source framework. Its architecture is based on the model-view-controller design pattern (see Fig. 4). Django is a flexible and comprehensive platform which gives us the opportunity to add different levels of computational intelligence to the application. Django consist of front-end interface templates which play a major role in providing user-friendly environment. The View Logic component decides what kind of data to be delivered to the template by responding to inputs from the user. View holds functions with an associated template. Model is a primary source of information about stored data which contains the data fields and behavior of the stored data. Each attribute in the model also represents a database field. The database is then queried using the attributes.

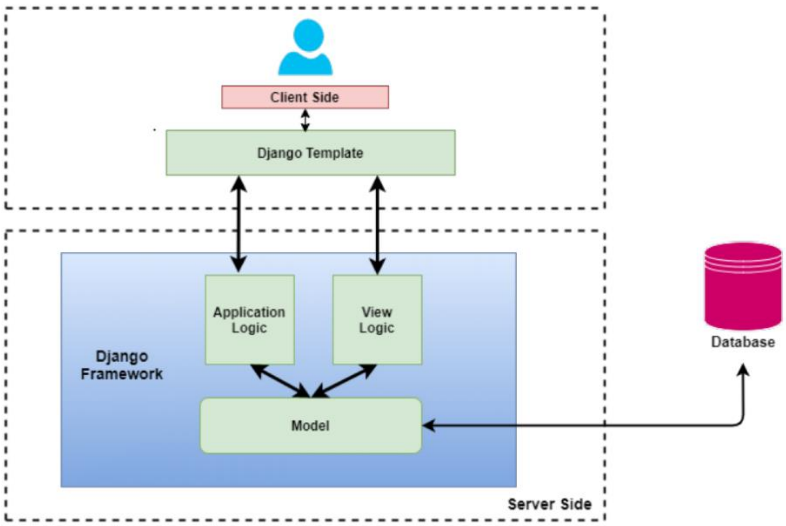


Fig. 4: Django Application Architecture (adapted from https://djangobook.com)

To enhance user's interaction, we improved GUIs (Graphical User Interfaces) including inputs, closure joints selection, and categories/ factors affecting the service life. The new versions of GUIs are presented in Appendix B. Some specific features we used for designing the forms are: (a) displaying the closure joints geometry/shape upon choosing the specific type of closure joint, (b) reducing/disabling duplicate parameters based on the chosen factors by the user, and (c) reducing the issue of global declarations and extra queries using Redis, a Python library, to share data among forms fields. In addition, we added a new dynamic form which produces all possible mitigation strategies based on user's inputs. Logging has also been introduced to collect information about the functionality of the application for various use cases.

Potential methods for how to include the effects of life cycle cost in the web-based tool were discussed further in Quarter 4.

5. Expected Results and Specific Deliverables

The expected deliverables are: (a) a prototype web-based tool; and (b) a manual (software documentation) which will guide users to make final design decisions, listed in the ABC-UTC Guide for Service Life Design of Longitudinal Deck Closure Joints. The interactive user interfaces will provide effective visual elements and suggestions to guide users, without fully knowing the theory behind probabilistic approaches.

6. Schedule

This project started in May, and the progress of tasks is shown in the table below. The PI left OU for George Mason University in August 2020. The decision was made to separate the PI's portion into a separate subcontract to allow the work to be completed. This process has taken longer than anticipated, which has prevented the PI from hiring a student to complete the remaining portions of the work. The PI has personally continued the work in collaboration with the OU team when possible, but limited progress has been made. A meeting is scheduled between the PI and ABC-UTC administrative personnel in March to discuss the path moving forward.

Item	% Completed
Percentage of Completion of this project to Date	50%

Project Tasks	Year 2020-2021											
	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb	Mar.	Apr.
T1. Architecture Design												
T2. Content identification, algorithms, analytics, dashboard												
T3. Prototype Implementation												
T4. Final Report												
						Work Performed						
						Work to be Performed						

7. References

M. Culmo, (2011), "Accelerated Bridge Construction: Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems: Final Manual", Federal Highway Administration, Office of Bridge Technology (Rep. No. FHWA-HIF-12-013). United States.

B. Graybeal, (2014), "Design and construction of field-cast UHPC connections", Federal Highway Administration (Rep. No. FHWA-HRT-14-084; HRDI-40/10-14 (750) E). United States.

Z. Haber, B. Graybeal, (2018), "Performance of Grouted Connections for Prefabricated Bridge Deck Elements", Federal Highway Administration (Rep. No. FHWA-HIF-19-003), United States.

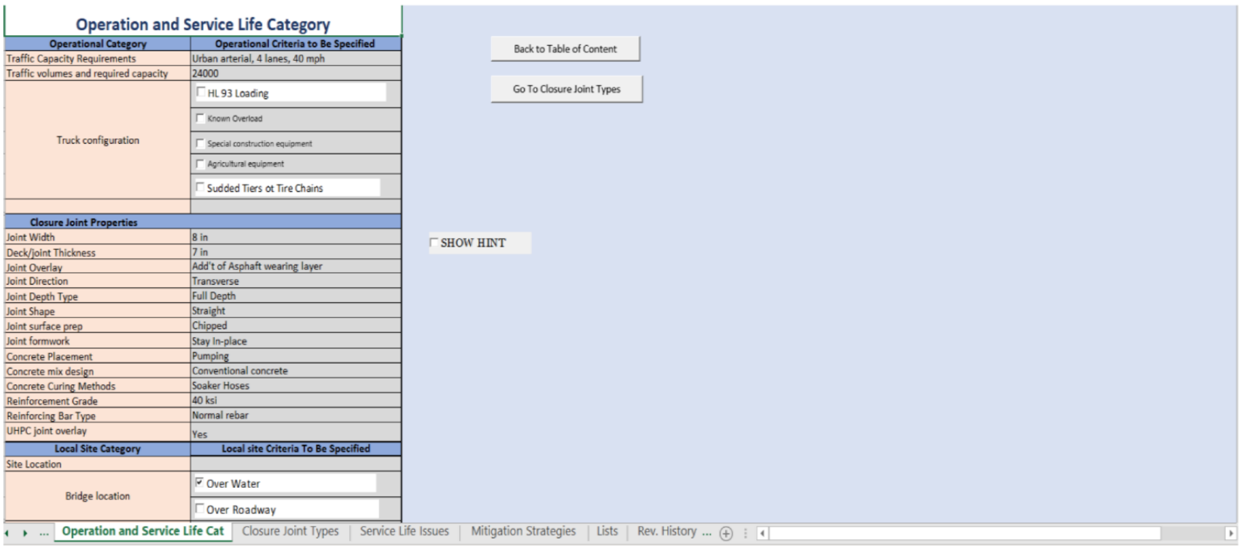
A. Jaberi Jahromi, A. Valikhani, I.M. Mantawy, A. Azizinamini, (2020), “Service Life Design of Deck Closure Joints in ABC Bridges: Guidelines and Practical Implementations” Frontiers in Built Environment, https://doi.org/10.3389/fbuil.2019.00152.

Li, L., Ma, Z., Griffey, M. E., & Oesterle, R. G, (2009), “Improved Longitudinal Joint Details in Decked Bulb Tees for Accelerated Bridge Construction: Concept Development”, ASCE Journal of Bridge Engineering, 15(3), 327-336.

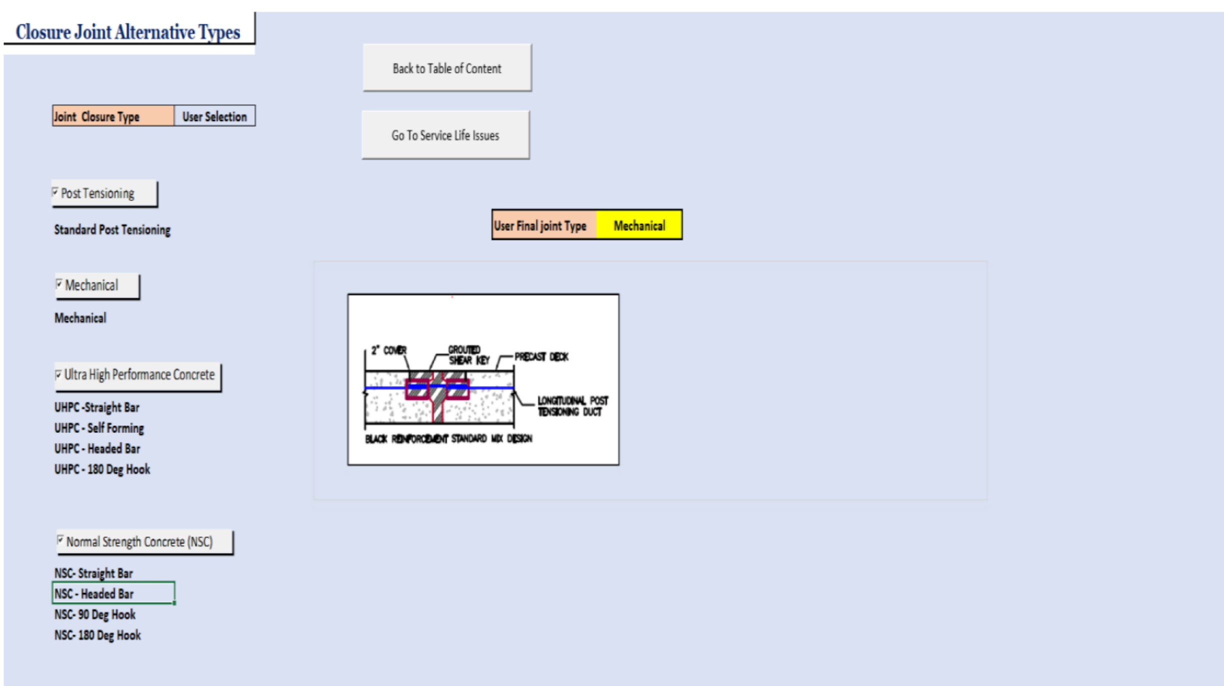
Appendix A

The following forms illustrate the Excel-based decision support tool.

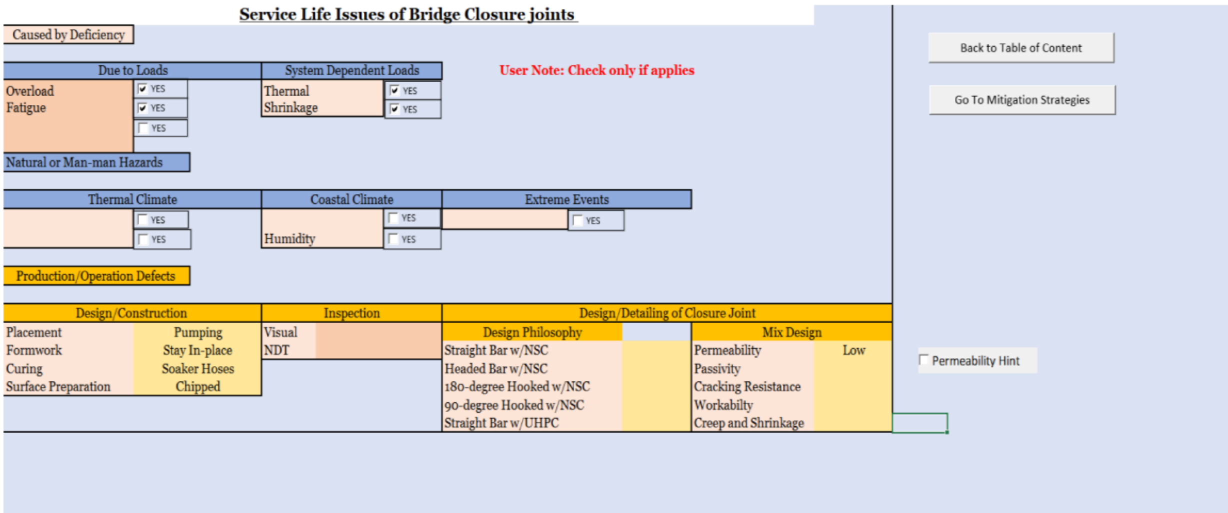
Form 1: Operational and Service Life Category



Form 2: Closure Joint Alternatives



Form 3: Service Life Issues of Closure Joints



Service Life Issues of Bridge Closure joints

Caused by Deficiency

Due to Loads | System Dependent Loads

User Note: Check only if applies

Overload YES
Fatigue YES
YES

Thermal YES
Shrinkage YES

Natural or Man-man Hazards

Thermal Climate | Coastal Climate | Extreme Events

YES
YES
Humidity YES
YES
YES

Production/Operation Defects

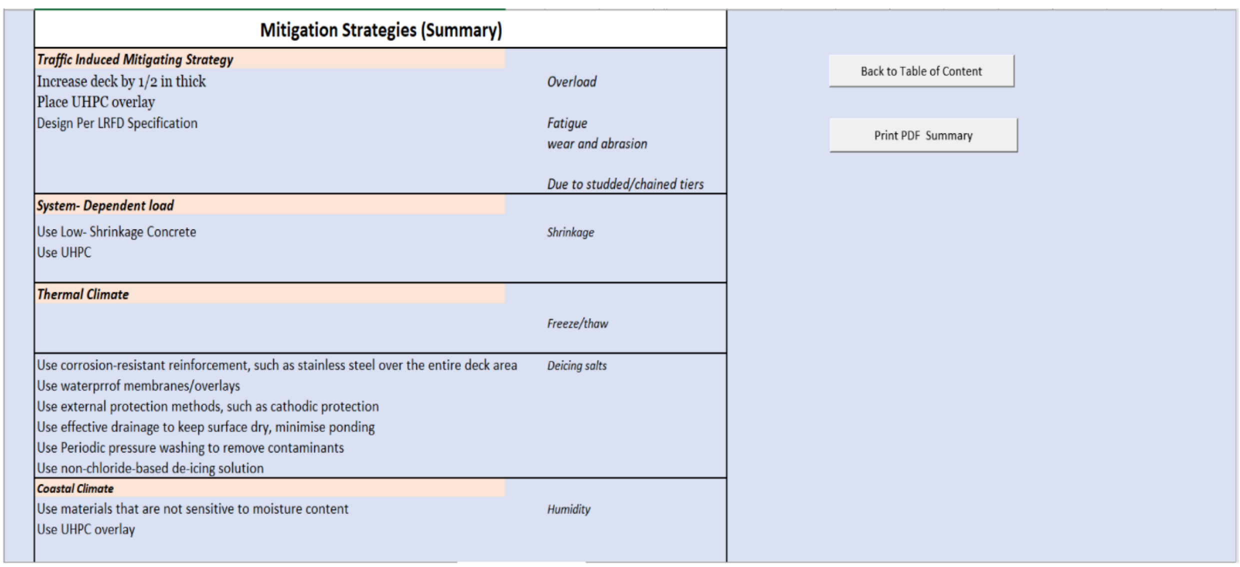
Design/Construction		Inspection		Design/Detailing of Closure Joint			
				Design Philosophy		Mix Design	
Placement	Pumping	Visual					
Formwork	Stay In-place	NDT		Straight Bar w/NSC		Permeability	Low
Curing	Soaker Hoses			Headed Bar w/NSC		Passivity	
Surface Preparation	Chipped			180-degree Hooked w/NSC		Cracking Resistance	
				90-degree Hooked w/NSC		Workabilty	
				Straight Bar w/UHPC		Creep and Shrinkage	

Back to Table of Content

Go To Mitigation Strategies

Permeability Hint

Form 4: Mitigation Strategies



Mitigation Strategies (Summary)

Traffic Induced Mitigating Strategy	
Increase deck by 1/2 in thick	*Overload*
Place UHPC overlay	
Design Per LRFD Specification	*Fatigue*
	wear and abrasion
	Due to studded/chained tiers
System- Dependent load	
Use Low- Shrinkage Concrete	*Shrinkage*
Use UHPC	
Thermal Climate	
	Freeze/thaw
Use corrosion-resistant reinforcement, such as stainless steel over the entire deck area	*Deicing salts*
Use waterprrof membranes/overlays	
Use external protection methods, such as cathodic protection	
Use effective drainage to keep surface dry, minimise ponding	
Use Periodic pressure washing to remove contaminants	
Use non-chloride-based de-icing solution	
Coastal Climate	
Use materials that are not sensitive to moisture content	*Humidity*
Use UHPC overlay	

Back to Table of Content

Print PDF Summary

Appendix B

The following forms illustrate the web-based decision support tool.

Input Form 1

ABC UTC

Service Life Design of Deck Closure Joints in ABC

Form -1

Joint Properties

Closure Joint Width Limitation: 8 Inches

Deck Thickness (Inches): Enter thickness in Inches

Reinforcing Bar Type: Ordinary Bar / Stainless Steel Bar / Epoxy Coated Bar

Joint Direction: Transverse / Longitudinal

Joint Depth: Partial / Full

Local Operational Requirements

Traffic Capacity Requirements: Enter in text format

Traffic Volume and Capacity: Enter in numeric format

Please select the Truck Configuration: HL - 93 Loading / Known Overload / Special Constructional Equipment / Agricultural Equipment / Studded Tires/ Tire Chains

Local Site Requirements

Site Location: Enter in text format

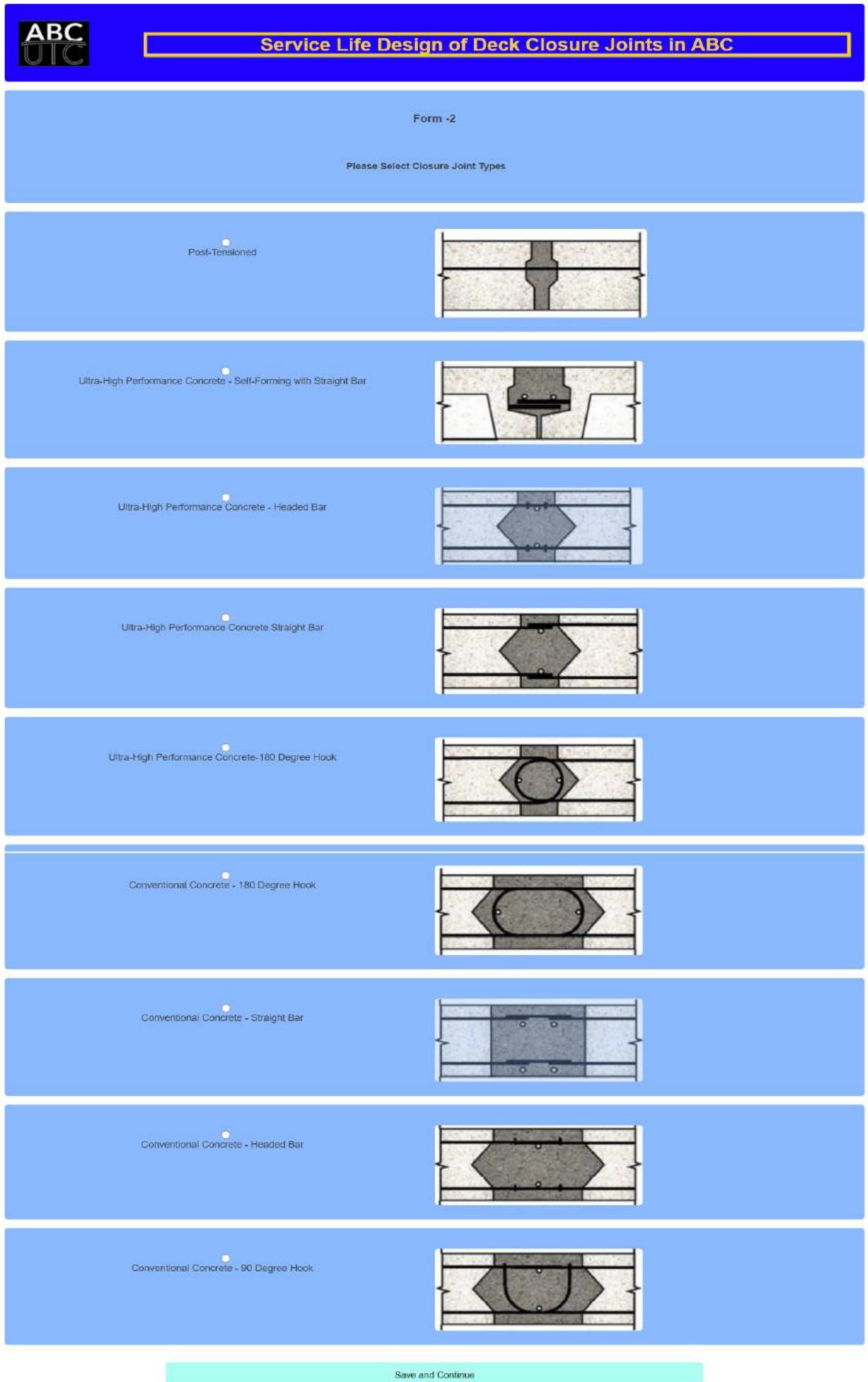
Bridge location: Over Roadway

Brideg Length: Enter in ft's

Brideg Curvature: Enter in ft's

Save and Continue

Input Form 2 (Selection of Closure Joints)



Input Forms 3 (Selection of factors affecting the service life of closure joints)

Service Life Design of Deck Closure Joints in ABC

Form -3

Factores that affect Service Life of Closure Joints. Please select the ones applicable

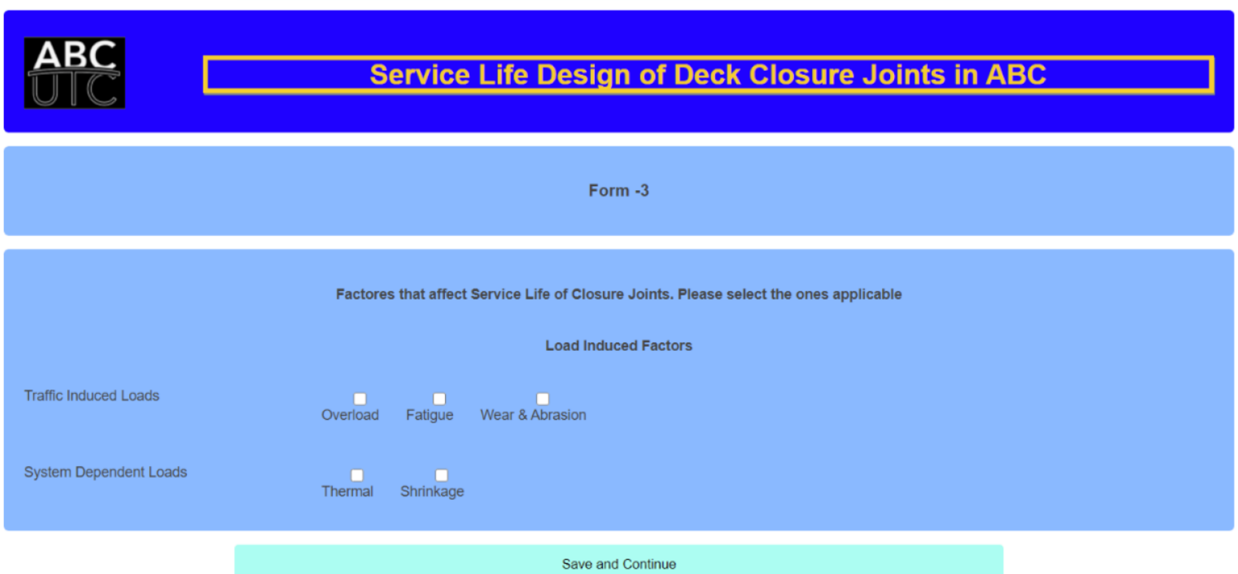
Natural or Man Made Hazards

Thermal Climate
De - Icing Salts
Freeze / Thaw

Coastal Climate
Salt Spary Corrosion
Humidity

Extreme Events
Fire

Save and Continue



Service Life Design of Deck Closure Joints in ABC

Form -3

Factores that affect Service Life of Closure Joints. Please select the ones applicable

Load Induced Factors

Traffic Induced Loads
Overload
Fatigue
Wear & Abrasion

System Dependent Loads
Thermal
Shrinkage

Save and Continue

ABC UTC

Service Life Design of Deck Closure Joints in ABC

Form -3

Factores that affect Service Life of Closure Joints. Please select the ones applicable

Production / Operation Defects - Inspection

Inspection

☐ Visual ☐ NDT

Production / Operation Defects - Design / Detailing of Closure Joints

Design / Detailing of Closure Joints- Design Philosophy

☐ Straight bar w/ NSC ☐ Headed bar w/ NSC ☐ 180-degree Hooked w/ NSC ☐ 90-degree Hooked w/ NSC ☐ Straight bar w/ UHPC

Design / Detailing of Closure Joints- Mix Design

☐ Permeability ☐ Passivity ☐ Cracking Resistance ☐ Workability ☐ Creep & Shrinkage

Save and Continue

ABC UTC

Service Life Design of Deck Closure Joints in ABC

Form -3

Factores that affect Service Life of Closure Joints. Please select the ones applicable

Production / Operation Defects - Construction

Plcaement

☐ Pumping ☐ Hopper ☐ Dumping From Concrete Trucks ☐ By Hand

Formwork

☐ Traditional Timber Forms ☐ Stay In Place

Curing

☐ Soaker Hose ☐ Wet Burlap ☐ Curing Compounds

Surface Preparation

☐ Wire Brushed ☐ Chipped ☐ Water Jetted

Save and Continue

Output Form (Mitigation Strategies)

Service Life Design of Deck Closure Joints in ABC

Suggested Mitigation Strategy

Mitigation Strategy for Fatigue:
Design Per LRFD Specification

Mitigation Strategy for Wear and Abrasion:
Implement membranes and overlays
Implement concrete mix design strategies

Mitigation Strategy for Shrinkage:
Use Low- Shrinkage Concrete Use UHPC

Mitigation Strategy for De icing:
Use corrosion-resistant reinforcement, such as stainless steel over the entire deck area Use waterprrof membranes/overlays
Use external protection methods, such as cathodic protection
Use effective drainage to keep surface dry, minimise ponding
Use Periodic pressure washing to remove contaminants
Use non-chloride-based de-icing solution

Mitigation Strategy for Humidity:
Use materials that are not sensitive to moisture content
Use UHPC overlay