Bridges Designed for Minimum Maintenance

Tech Transfer Summary

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TR-791: Bridges Designed for Minimum Maintenance

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Background & Problem Statement

Target service life designs of highway bridges have gained significant interest from state DOTs in recent years. The primary purpose of these efforts is to provide durability-based designs for bridges and bridge components that require minimal maintenance during the targeted service life of the structure. Such designs usually lead to better life cycle cost of the asset by avoiding costly maintenance during the targeted service life, and reduce traffic disruptions. Agencies commonly focus on designing bridges to achieve at least a 100-year service life, especially for signature bridges. However, a recent NCHRP report indicates that most bridges are replaced after 53 years, and for reasons other than having reached the end of their service life (NCHRP Project 20-07, Task 397).

The focus of this study is to explore strategies that can be employed to design bridges within Iowa to have minimal maintenance needs during their target service lives, and particularly in the first 50 years of service. These strategies are expected to improve cost efficiency by giving designers the flexibility to select a suitable target service life on a case-by-case basis instead of defaulting to a 100-year service life, and by helping designers identify design strategies expected to provide the desired durability in Iowa environments for the selected target service life based on the performance evaluations conducted within this study.

Objective

The primary objective of this study is to implement cost-effective bridge designs and techniques that require minimal (or no) maintenance during the first 50 years; through a targeted service life design approach. The study is intended to address principal maintenance activities for various bridge elements and subsystems that are typically completed for the different bridge types owned and maintained by Iowa DOT and local jurisdictions.

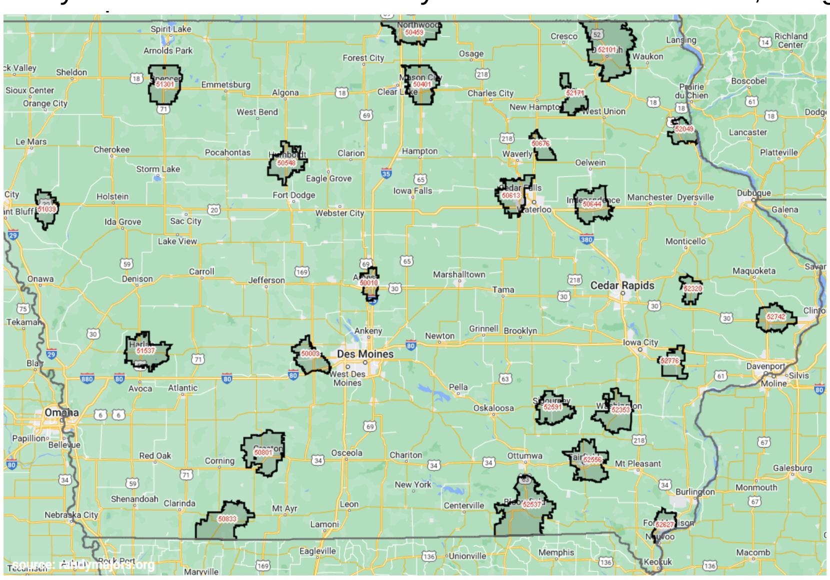
Research Description

This study consisted of a literature review on bridge service life design; analysis of the bridge maintenance data retained by the Iowa DOT; a survey of the types of bridge deterioration and maintenance needs experienced by local jurisdictions in Iowa; development of durable design strategies for reinforced concrete elements and structural steel superstructures based on a targeted service life design approach; and identification of recommended practices for improving the durability of other types of bridge elements. Available literature shows that the deterioration mechanisms that bridges may experience and effective protective strategies are generally known.

However, predicting future exposure conditions and the progression of deterioration in the long-term is challenging. Currently available service life models are limited to specific deterioration mechanisms, usually reinforcement corrosion. Further, the associated data collection and analysis may be too costly or require too much time to be practical for typical bridges. For such structures, and especially for deterioration mechanisms other than reinforcement corrosion, more practical service life design approaches are: (1) deemed-to-satisfy, in which a structure is expected to be exposed to conditions known to cause deterioration and, therefore, minimum design details, materials, and construction practices are specified to provide resistance towards the associated deterioration mechanism(s); and/or (2) avoidance-of-deterioration, which commonly involves using non-reactive materials not susceptible to the potential deterioration mechanisms, or avoiding exposure, e.g., through the elimination of vulnerable details or provision of an effective barrier between the structure and the exposure environment. As a result, this study focused on identifying appropriate deemed-to-satisfy and avoidance-of-deterioration strategies that could be conveniently applied by designers.

Bridge Maintenance Needs

The analysis of Iowa DOT bridge maintenance data and survey of bridge maintenance needs of local jurisdictions were performed in order to better understand the most common bridge maintenance actions and durability issues within Iowa that were logical to prioritize in this study. The Iowa DOT maintains two lists: (1) a list of recommended maintenance, for which data between 2011 and 2021 was available; and (2) a list of programmed work, for which data between 2001 and 2021 was available. The maintenance needs of the local agencies were determined through a survey instead of data analysis due to lesser availability of maintenance records; the geographical distribution of the survey respondents is shown in the map to the left. The following bridge elements were identified as requiring the most maintenance:



Map of Iowa highlighting the locations that responded to the survey of bridge maintenance needs of local jurisdictions.

1. Reinforced concrete members (decks, barriers, girders, pier caps, and pier columns),
2. Steel superstructures,
3. Joints,
4. Bearings,
5. Foundations,
6. Approach systems, and
7. Berm erosion.

Approach for Development of Durable Bridge Designs

A target service life design approach was identified as a desirable methodology for developing durable designs. This approach logically assumes that bridges designed for a greater target service life have a reduced risk of requiring maintenance within the first 50 years of service, which was the original goal of the project. The target service life design approach is also in closer alignment with the service life design methodology of the AASHTO *Guide Specification for Service Life Design of Highway Bridges* (2020), referred to as HBSLD-1. HBSLD-1 defines three service life categories, intended to represent a qualitative "good-better-best" model. For this study, the following target service life categories were defined:

- Normal – corresponding to a target service life of 75 years.
- Enhanced – corresponding to a target service life of 100 years.
- Maximum – corresponding to a target service life of 125 years.

Additionally, a "Baseline" category was defined as the expected service life of current standard designs and common practices used by the Iowa DOT or within Iowa.

Durable designs that are expected to provide the target service lives in the exposure conditions found across Iowa were identified based on service life modeling using WJE CASLE™ or quantitative service life prediction, when feasible. This was limited to modeling of chloride-induced corrosion of reinforced concrete members and corrosion prediction of steel superstructures, respectively. A quantitative service life analysis could not be conducted for foundations, and berm slopes, because models do not exist for these elements or because of insufficient data to inform Iowa-specific models at this time. As a result, the current standard designs for these elements and their maintenance needs were reviewed to identify recommended design and/or construction practices for avoiding or minimizing deterioration of these elements. Joints and bearings are unique in that they will require routine maintenance throughout the life of the structure. Because these elements cannot be expected to achieve the same service life as the bridge, and they cannot always be avoided, HBSLD-1 recommends assigning them the "Renewable" service life category, intended to capture elements that should be expected to be replaced within the service life of the structure. Approach slabs also are categorized as renewable elements in HBSLD-1. The target service life approach, therefore, was not applied to these elements, but the current designs and practices of the Iowa DOT were reviewed and good practices for minimizing maintenance needs associated with these elements were identified.

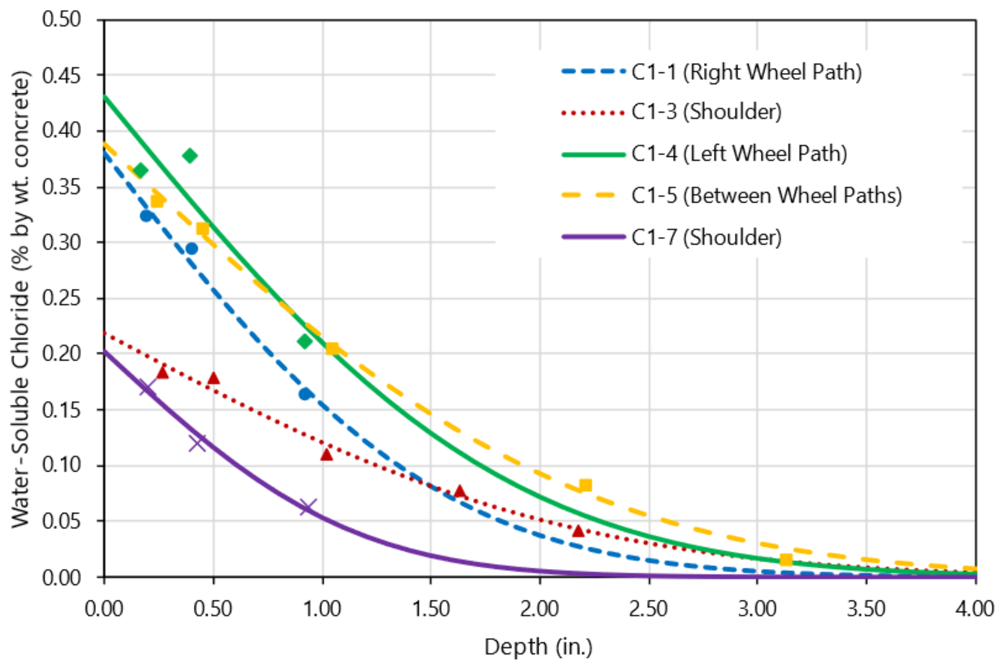
Element-Specific Service Life Design Considerations

Reinforced Concrete Members

The minimum combinations of concrete cover, concrete mix design, and reinforcing steel class that are expected to provide the target service lives based on service life modeling, given chloride exposure conditions in Iowa, were identified for each reinforced concrete member identified above; an example of these minimum combinations is shown below for bridge deck top surface exposure. To support this modeling effort, chloride exposure in Iowa was characterized by sampling 81 cores across 10 bridges.

Element / Surface	Chloride Exposure	Concrete Mix	Minimum Reinforcement Class Required for Service Life Target		
			Normal	Enhanced	Maximum
Bridge Deck - Top Surface; 2.5 in. cover (County Bridges)	Very High (9000 ppm)	No SCM	E	E	E
		Low SCM	E	E	E
		Moderate SCM	D	E	E
		Moderate SCM + SF	C	D	D
		High SCM	D	D	D
	High (6000 ppm)	No SCM	D	D	E
		Low SCM	D	D	D
		Moderate SCM	D	D	D
		Moderate SCM + SF	B	C	C
		High SCM	C	D	D
	Moderate (4000 ppm)	No SCM	D	D	D
		Low SCM	D	D	D
		Moderate SCM	C	C	D
		Moderate SCM + SF	B	B	C
		High SCM	B	C	C

Durable design strategies for the top surface of decks on county bridges in Iowa for achieving target service lives with respect to chloride-induced corrosion of reinforcing steel. SCM = supplementary cementitious material; SF = silica fume. Reinforcing classes A through E correspond to reinforcing steel with increasing resistance to chloride-induced corrosion, ranging from uncoated carbon steel (Class A) to stainless steel (Class D or E, depending on the alloy).



Chloride profile for bridge deck cores collected from FHWA No. 607890, a county highway bridge that was 20 years old at the time of coring.

These bridges represent a range of highway types and geographic areas throughout the state of Iowa. The average surface chloride concentrations assumed for "Very High," "High," and "Moderate" chloride exposure were identified based on chloride testing of the field cores.

While chloride-induced corrosion is expected to be the primary cause of deterioration of reinforced concrete members, reinforced concrete can also deteriorate due to other mechanisms, such as alkali-aggregate reaction and freeze-thaw deterioration. Widely accepted service life models are not available for these deterioration mechanisms currently, and deemed-to-satisfy and avoidance-of-deterioration strategies for addressing these deterioration mechanisms were provided instead.

Steel Superstructures

The combinations of corrosion-resistant steel type (i.e., weathering steel or low-chromium stainless steel), sacrificial steel thickness, coating type (i.e., galvanizing, metallizing, or duplex coating system), and coating extent (i.e., full coating or partial coating at vulnerable locations) that are expected to provide the target service lives based on corrosion service life prediction, given the corrosivity of atmospheres across Iowa, were identified. The atmospheric corrosivity classes of Iowa were determined based on the qualitative definitions of ISO 9223, *Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, determination and estimation*, and the most severe class expected to occur in Iowa was further subdivided into sites considered too aggressive for uncoated weathering steel (e.g., due to high levels of chlorides or persistent moisture) and sites where uncoated weathering steel is expected to exhibit increased atmospheric corrosion resistance. The corrosion protection strategies required to achieve the target service lives were determined based on performance reported in literature and an evaluation of the performance of uncoated weathering steel bridges in Iowa.

Implementation and Benefits

The contents and recommendations developed for the final report are intended to serve as guidance to the Iowa DOT and local bridge-owning agencies across Iowa for implementing durable bridge designs for typical bridges. Certain tables within the report identifying durable designs may be included in the Iowa DOT Bridge Design Manual. The recommendations within the report also identify the current practices within Iowa that should be continued, practices or requirements that should be added to specifications, and knowledge gaps that should be addressed to improve service life design practice in Iowa. The accessibility of this guidance aids in overcoming the barrier of increased initial design cost that might otherwise prevent service life design from being considered on such bridges. Widespread implementation of service life design will reduce bridge life cycle costs incurred by transportation agencies, improve service by decreasing traffic disruptions associated with maintenance, and support worker safety by reducing the time spent by in-house forces on bridges.