MAINTENANCE GUIDELINES FOR STEEL BRIDGES

Addressing Fatigue Cracking and Details at Risk of Constraint-Induced Fracture

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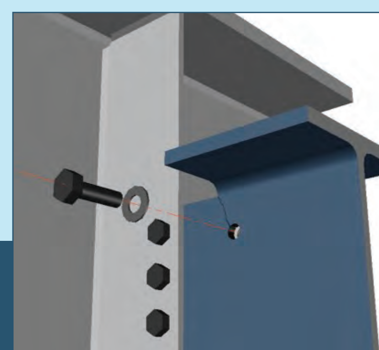

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Preface

This document presents guidelines developed by the AASHTO/NSBA Steel Bridge Collaboration. The primary goal of the Collaboration is to achieve steel bridge design and construction of the highest quality and value through standardization of the design, fabrication, and erection processes. Each document represents the consensus of a diverse group of professionals.

It is desired that Owners adopt and support Collaboration guidelines in their entirety to facilitate the achievement of standardization. It is understood, however, that local statutes or preferences may prevent full adoption of the guidelines recommended herein. In such cases, Owners may adopt these guidelines with the exceptions they feel are necessary.

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Executive Summary

Nearly thirty percent of the U.S. national bridge inventory (highway bridges) is made up of bridges having steel superstructures with an average age of about 48 years at the time of this writing. Fortunately, steel bridge superstructures lend themselves well to repair and retrofit methods that can improve and even eliminate fatigue and constraint-induced fracture (CIF) concerns, extending the service life for many years or even decades. Unfortunately, fatigue and fracture tend to be the least understood by engineers of the limit states affecting steel bridges. In some cases, this has led to repair or retrofit strategies that rendered a worse condition than existed prior to the attempted fix.

This document provides simple-to-follow guidelines for the maintenance actions to address fatigue cracking as well as details at risk of constraint-induced fracture (CIF) in steel bridges. It is a synthesis of best practices from published literature, project reports, and past and ongoing research projects, as well as input from industry professionals. Intended to be a very practical reference text, it is written with everyone in mind, from a maintenance contractor to an asset manager or design engineer, providing detailed descriptions of the driving causes of fatigue cracking and CIF in steel bridges and accepted methods for repair or retrofit. A number of case studies are discussed, giving context for the different detail susceptibilities and utilizing a mixture of real-world and rendered images to illustrate the problems and solutions. For each case, a suggested sequence of steps is also provided as a "how-to."

Appendix A contains quick reference tables with Harvey Ball ideograms that help users qualitatively identify appropriate repair or retrofit approaches for a type of detail. Some steel bridge details have multiple strategies that can be implemented and the tables are intended to give the reader a snapshot view of the benefits of each one, the degree of success it has had historically, and the level of ease (which translates to cost) with which the strategies can be implemented. Chapter 1 explains the ideogram tables in more detail.

Chapter 2 reviews several important general topics such as a brief history of steel bridge issues, the basics of fracture mechanics, and the basics of fatigue and fatigue evaluation. In addition, Chapter 2 also includes a section on the urgency of repairs, helping to ensure the reader considers factors that contribute to how urgently a repair or retrofit should be treated. Chapter 3 delves into some fundamental repair and retrofit techniques, such as grinding and hole drilling. These techniques are referred to many times throughout the rest of the guidelines. Chapter 4 introduces details commonly susceptible to load-induced fatigue, giving repair and retrofit strategies specific to those details. Load-induced fatigue is that caused by primary stresses and includes many of the details contained in the fatigue detail tables in the *AASHTO LRFD Bridge Design Specifications* (referred to as LRFD Design hereafter) (AASHTO, 2017). Chapter 5 transitions into distortion-induced fatigue caused by secondary stresses in steel structures. These are the most common types of fatigue cracks found in the steel bridge inventory. Chapter 6 covers the mechanics of constraint-induced fracture and details a number of effective retrofits that can be implemented to reduce or eliminate risk of fracture. And finally, Chapter 7 discusses several retrofit or repair concepts that may be in use, or being considered for use, that need additional research and development before being recommended.

CHAPTER 1
INTRODUCTION

The following is a synthesis of best practices from published literature, ongoing research activities, and input from industry professionals with the objective to provide guidelines for maintenance actions to address fatigue cracking in steel bridges. These Guidelines cover repair procedures, detailing techniques, maintenance recommendations, inspection recommendations, and preservation actions to repair and retrofit steel bridges in order to mitigate initiation of fatigue cracks on details known to have low fatigue resistance, control further growth of existing fatigue cracks, and reduce or eliminate the risk of CIF in steel bridges. The findings are primarily intended for highway bridges but are conceptually equally applicable to railroad bridges. In addition to fatigue, preemptive maintenance actions related to constraint-induced fracture (CIF) are also presented.

Fatigue and fracture tend to be the two limit states of steel bridges least understood when it comes to design, inspection, and especially for repair and retrofit. Although a wealth of research and case studies of fatigue damage and other failures related to steel bridge cracking exist in the literature, few university civil engineering programs offer courses on these topics. Only a limited number of professional short courses are offered which specialize in these topics, and even fewer reference manuals are available to practitioners. As a result, bridge owners and their consultants are often left to develop their own strategies. Unfortunately, experience has shown that some implemented repairs or retrofits have actually made the conditions worse due to the lack of understanding of what drives the development of fatigue cracks and how best to address it.

Detailed discussion is included regarding the cause or driving force behind various fatigue cracks observed in the field. As expected, the mitigation approaches have widely varied throughout the inventory, with some being more effective than others. During the literature review, which included a survey and conversations with industry leaders, the most effective retrofit strategies were identified for a given type of cracking. While the reader is encouraged to study these Guidelines to become fully familiar with the associated recommended retrofit strategy, ideograms were developed to assist the user in quickly selecting the most effective retrofit(s) for a given type of cracking. The approach follows that which is often used in publications that are used for rating and comparing cars or appliances. The concept is illustrated and explained in Table 1-1.

It is noted that there are often several "acceptable" retrofit strategies for a given type of cracking. Thus, assuming multiple approaches are known to be effective, other criteria, such as the required skills of the workforce or ease of installation, which generally translate into cost, should also be considered. Hence, the ideogram shown in Table 1-2 was prepared to provide a simple summary of these other factors which should be considered with each approach. While these tables explain the meaning of the ideograms, Appendix A contains the quick reference tables that help users qualitatively identify appropriate repair or retrofit approaches for a type of detail. Some steel bridge details have multiple strategies that can be implemented, and the tables are intended to provide a snapshot view of the benefits of each one, the degree of success it has had historically, and the level of ease with which the strategies can be implemented.

While the quick reference tables provided in Appendix A should not be used without reviewing the content of these Guidelines, they do provide a useful quick reference guide. Further, it is noted that some retrofits are inherently more challenging to install than others. For example, simple grinding is useful in removing a shallow nick or gouge, while retrofit and repair of a detail susceptible to CIF will require considerably more effort and possibly engineering analysis.

Table 1-1. Description of Ideograms Used in Repair and Retrofit Tables for Success of Performance

Success of Repair	
●	Well-documented successful performance in the laboratory and in the field. Significant increase in fatigue resistance or significant reduction of risk of fracture.
◑	Documented successful performance in the laboratory or in the field showing moderate fatigue resistance enhancement or reduction of risk of fracture.
○	Unknown or unproven long-term success or documented poor performance

Table 1-2. Description of Ideograms Used in Repair and Retrofit Tables for Ease of Installation

Ease of Installation	
●	Relatively easy to install with common hand tools (e.g., grinder, mag-drill) and minimal experience with iron work required.
◕	Decreased ease of installation, but still manageable with most common hand tools and beginner skill level in iron work.
◑	Some ease, requiring average working knowledge of repairing steel and/or specialized tools or training (e.g., ultrasonic impact machine, turn-of-nut wrench).
◔	Moderate effort required. Specialized training and tools required. Sound engineering judgement needed.
○	Significant effort required. Difficult to install, generally requiring expert knowledge. May also require engineering analysis.