American Association of State Highway and Transportation Officials
AASHTO

GUIDE SPECIFICATIONS FOR Analysis and Identification of Fracture Critical Members and System Redundant Members

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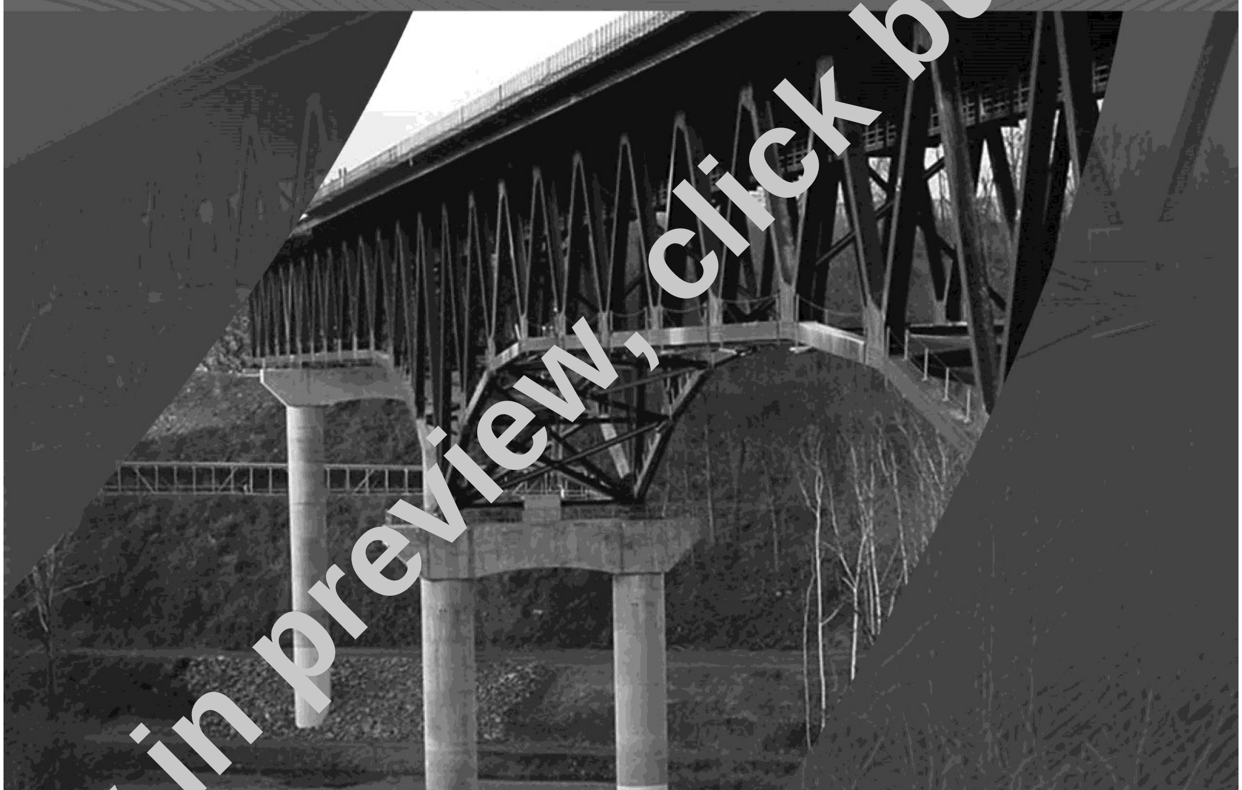
Analysis and Identification of Fracture Critical Members and System Redundant Members



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American Association of State Highway and Transportation Officials
444 North Capitol Street, NW, Suite 249
Washington, DC 20001
202-624-5800 phone/202-624-5806 fax
www.transportation.org

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FOREWORD

Fracture critical members (FCMs) are defined in the AASHTO *LRFD Bridge Design Specifications* (AASHTO, 2017) (referred to as LRFD Design hereafter) as steel primary members, or portions thereof, subject to tension whose failure would probably cause a portion of or the entire bridge to collapse. The decision to designate members as FCMs has often been made without considering actual system redundancy or performance of the structure following failure of an FCM. Prior to the development of the specifications contained herein, no standards existed on how to best perform a system analysis to determine performance and response in the event an FCM is assumed to have failed. NCHRP Report 883 (Connor et al., 2018) details the research conducted for NCHRP Project 12-87a, which was conceived and completed to address all of the important issues related to performing a credible system analysis to identify members in steel bridge structures that should truly be designated as FCMs. Members satisfying the provisions of this Guide Specification may be re-designated as System Redundant Members (SRMs) as defined in LRFD Design and in a FHWA Technical Memorandum dated June 20, 2012 (M. Myint Lwin, 2012). While the FHWA Memorandum states that system analysis shall only be applied to bridges that are fabricated to the Fracture Control Plan specified in Clause 12 of the AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* (AASHTO/AWS, 2015), the provisions contained herein may be applied to any steel bridge that satisfies the specified screening criteria. However, at present, special permission would need to be granted by the FHWA to designate members in such bridges as SRMs.

Clearly, the decision to designate members as fracture critical should not be made solely on the basis of the results from 3-D finite element system analysis. The decision also requires a thorough assessment of the overall fracture vulnerability of the bridge, including details, history, materials, condition, and other factors. Thus, while finite element analysis (FEA) may demonstrate that a given structure (new or existing) meets the performance criteria contained in these Guide Specifications, any future inspection strategy should depend on an overall assessment of the structure. The assessment would inherently include factors that are difficult to reliably incorporate in a FEA, such as material toughness, presence of fatigue cracks, detailing, residual stresses, age, traffic history, current condition, inspection history, etc. For example, a bridge with members traditionally designated as FCMs that possesses poor details and a history of fatigue cracking probably should not be exempted from in-depth inspection requirements for the entire life of the bridge based solely on system analysis. Alternately, it may be wasteful to perform fracture critical member inspections on a relatively new bridge that is constructed with high quality fabrication using high quality materials, and that is in good condition with details that are designed for infinite life. Thus, the user of this Guide Specification should consider future inspection strategies even when the structure is shown to satisfy the requirements of this Guide Specification. While this Guide Specification does not provide any direction on how to set any sort of future inspection strategies, research by Parr et al. (2010) and NCHRP Report 782 (Washer et al. 2014) provide useful guidance.

Throughout this Guide Specification, the condition during which an FCM is assumed to have failed is referred to as the "faulted state". It is in this condition that these Guide Specifications are intended to apply. These specifications are not applicable to rating or other evaluations when all members are intact. These Guide Specifications provide direction on overall modeling, element selection, and material models suitable for nonlinear FEA. Further, two reliability-based load combinations referred to as Redundancy I and Redundancy II have been developed to achieve target reliability indices in the faulted state. These load combinations were developed using the same procedures previously used to create the various load combinations utilized in the current LRFD Design. To determine if the bridge demonstrates sufficient performance in the faulted state, criteria for the strength and service limit states have been developed for comparison to the results of the FEA.

The assessment procedures included herein apply to typical steel bridges, such as simple span and continuous I-girder and tub girder bridges, through-girder bridges, truss bridges, and tied arch bridges. The Owner's/Engineer's discretion may be used to determine other bridge types to which these assessment procedures may or may not apply. It is noted that these assessment procedures were not developed for atypical structures, such as suspension bridges or cable-stayed bridges. It must be taken into account that the specified analysis procedures involve complex nonlinear FEA, which must only be performed by individuals experienced in such finite element modeling.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and the intent of this Guide Specification. The commentary is not intended to provide every detail as to the development of this Guide Specification, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions of this Guide Specification. The reader is encouraged to review NCHRP Report 883 (Connor et al., 2018), and the Interim Reports for NCHRP Project 12-87a, which include more complete details and background related to the development of these Guide Specifications.

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TABLE OF CONTENTS

SECTION 1: GENERAL INFORMATION **1**

1.1—SCOPE 1

1.2—APPROACH 2

1.3—DEFINITIONS 4

1.4—NOTATION 5

SECTION 2: SCREENING **9**

2.1—GENERAL 9

2.2—SCREENING CRITERIA 9

SECTION 3: FINITE ELEMENT ANALYSIS METHODOLOGY **11**

3.1—GENERAL 11

3.1.1—Software Requirements 11

3.1.2—Analysis Procedures 12

3.1.3—Minimum FCM/SRM Failure Scenarios 12

3.1.3.1—Girder Bridges (I-, Tub, Box, Wide Flange, and Through-Girder Bridges) 13

3.1.3.2—Truss Bridges 13

3.1.3.3—Tied-Arch Bridges 14

3.1.3.4—Floor Beams 14

3.1.3.5—Straddle Beams and Integral Cap Beams 14

3.2—LOADS 14

3.2.1—Dead Load 14

3.2.2—Live Load 15

3.2.2.1—Longitudinal Primary Members 15

3.2.2.2—Transverse Members 16

3.3—DYNAMIC AMPLIFICATION FOLLOWING SUDDEN MEMBER FAILURE 16

3.3.1—Simplified Procedure 16

3.3.2—Refined Procedure 17

3.4—LOAD COMBINATIONS 17

SECTION 4: MATERIAL MODELS 21

4.1—STRUCTURAL STEEL AND REINFORCING STEEL 21

4.2—REINFORCED CONCRETE 22

4.2.1—Concrete Compressive Behavior 22

4.2.2—Concrete Tensile Behavior 23

SECTION 5: MESHING REQUIREMENTS 25
5.1—GENERAL 25
5.2—STRUCTURAL STEEL MEMBERS 25
5.2.1—Secondary Steel Members 25
5.3—REINFORCED CONCRETE SLAB 26
5.3.1—Reinforced Concrete Slab Molding with Solid and Wire (Truss) Elements 26
5.3.2—Reinforced Concrete Slab Molding with Shell Elements 26
SECTION 6: INTERACTIONS AND CONSTRAINTS 29
6.1—CONTACT INTERACTION BETWEEN SLAB AND STRUCTURAL STEEL MEMBERS 29
6.2—COMPOSITE INTERACTION BETWEEN SLAB AND STRUCTURAL STEEL MEMBERS 29
6.2.1—Shear Behavior of Transversely Grouped Shear Studs 29
6.2.2—Tensile Behavior of Transversely Grouped Shear Studs 30
6.2.2.1—Initial Tensile Stiffness of Transversely Grouped Shear Studs 30
6.2.2.2—Tensile Strength of Transversely Grouped Shear Studs 32
6.2.2.3—Load-Displacement Relationships of Transversely Grouped Shear Studs in Tension 35
6.2.3—Combined Shear and Tension 37
6.3—CONNECTIONS OF STRUCTURAL STEEL MEMBERS 37
SECTION 7: APPLICATION OF LOADS AND BOUNDARY CONDITIONS 39
7.1—APPLICATION OF LOADS 39
7.2—SUPPORT CONDITIONS 39
SECTION 8: PERFORMANCE CRITERIA IN THE FAULTED STATE 41
8.1—GENERAL 41
8.2—STRENGTH REQUIREMENTS 41
8.2.1—Superstructure Considerations 41
8.2.2—Substructure Considerations 42
8.3—SERVICEABILITY REQUIREMENTS 42
SECTION 9: DETAILING REQUIREMENTS FOR NEW NON-REDUNDANT BRIDGES 45
9.1—GENERAL 45
9.2—STEEL SUPERSTRUCTURE 45
9.3—REINFORCED COMPOSITE CONCRETE DECK 45
SECTION 10: REFERENCES 47

SECTION 1
GENERAL INFORMATION

1.1—SCOPE

The provisions contained herein shall be used to evaluate system-level redundancy of a bridge after the failure of a member traditionally designated as an FCM. The results of the evaluation shall place such members into one of two categories:

- Fracture Critical Member (FCM)
- System Redundant Member (SRM)

An FCM may be re-designated as a SRM depending on the outcome of the evaluation using the performance criteria specified in Article 8.1. The primary tension members undergoing evaluation shall be identified on the contract plans as either SRMs or FCMs on new bridges, or as such in the bridge record file for existing bridges.

In the case of newly designed yet to be constructed bridges, both FCMs and SRMs shall be fabricated to satisfy the provisions of Clause 12 of the AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code*. The provisions of Article 9.1 shall also apply. For members which are entirely built-up from components attached using mechanical fasteners, the load-carrying components shall satisfy the Fracture-Critical Tension Component Impact Test Requirements specified in AASHTO M 270M/M 270 (ASTM A709/A709M).

Unless otherwise specified by the Owner, the assessment procedures included herein shall only be considered applicable to straddle beams and integral cap beams, and to the following steel-bridge structure types:

- Simple-span and continuous-span I-girder (rolled or fabricated plate sections) and tub-girder bridges (including curved and/or skewed bridges);
- Through-girder bridges;
- Truss bridges; and
- Tied-arch bridges.

C1.1

The provisions described herein are applicable to existing or newly designed but yet to be constructed steel bridges that are classified as non-redundant and that possess members that are traditionally classified as Fracture Critical Members (FCMs). Traditionally, simple static structural analysis models, experience, and/or engineering judgement have been the typical tools used to identify FCMs. However, it has been shown that steel bridges with members traditionally classified as fracture critical may possess significant reserve strength after the failure of such a member (Cha et al., 2014; Connor et al., 2005; Connor et al., 2018; and Neuman, 2009).

These provisions are primarily based on the work reported in NCHRP Report 883 (Connor et al., 2018), in which a finite element methodology was developed to assess whether the failure of a member traditionally classified as fracture critical would result in excessive strain in the remaining members, collapse, or loss of serviceability.

The objective of these provisions is to provide guidance on how to best perform FEA to evaluate the redundancy of an existing bridge or a bridge under design after the assumed failure of a member traditionally designated as an FCM. Members satisfying these provisions may be re-designated as System Redundant Members (SRMs) as defined in LRFD Design (AASHTO, 2017), and in an FHWA Technical Memorandum dated June 20, 2012 (M. Myint Lwin, 2012) SRMs need not be subject to the inspection protocols for FCMs as described in 23 CFR 650.305(FHWA/DOT, 2017).

In the majority of cases, research and in-service performance have demonstrated that conventional bridge designs have provided sufficient redundant capacity after the failure of a member traditionally designated as an FCM. Therefore, while adjustments to a new design may need to be made to satisfy the performance criteria specified herein, these provisions are not intended to be used as the primary basis for the design of a new structure.

While the analysis may indicate adequate system redundancy, the special fabrication requirements associated with the provisions of the Fracture Control Plan (FCP) specified in Clause 12 of the AASHTO/AWS D1.5M/D1.5 *Bridge Welding Code* (AASHTO/AWS,