Note: This document was rescinded on 05/09/2022 by **Memorandum – Inspection of Nonredundant Steel Tension Members**

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: **ACTION:** Clarification of Requirements for Fracture Critical Members

Date: June 20, 2012

/s/ original Signed by

From: M. Myint Lwin, P.E., S.E.
Director, Office of Bridge Technology

In Reply Refer To: HIBT-10

To: Directors of Field Services
Federal Lands Highway Division Engineers
Division Administrators

RESCINDED

The purpose of this memo is to provide clarification of the FHWA policy for the classification of Fracture Critical Members. For design and fabrication, only Load Path Redundancy may be considered. For in-service inspection protocol, Structural Redundancy demonstrated by refined analysis is now formally recognized and may also be considered. Internal member redundancy is currently not recognized in the classification of Fracture Critical Members for either design and fabrication or in-service inspection. Finally, this memo introduces a new member classification, a System Redundant Member (SRM), which is a non-load-path-redundant member that gains its redundancy by system behavior.

Several States and FHWA Division Bridge Engineers have requested that we clarify our policy regarding the classification of Fracture Critical Members (FCMs). There are two primary implications related to identifying FCMs in bridges: 1) specification of proper materials and testing for design and fabrication, and 2) establishment of proper in-service inspection protocol. Clarification of our current policy and future direction is provided herein.

Definitions

The current National Bridge Inspection Standards (NBIS) definition for a FCM is ***"a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse."***

The AASHTO *Manual for Bridge Evaluation* (MBE), 2nd Edition, defines a FCM as ***"steel tension members or steel tension components of members whose failure would be expected to result in a partial or full collapse of the bridge."***

The AASHTO *LRFD Bridge Design Specifications* (LRFD), 6th Edition, defines a FCM as a ***"component in tension whose failure is expected to result in the collapse of the bridge or the inability of the bridge to perform its function."***

The NBIS and MBE definitions are substantially the same. FHWA agrees with either of the FCM definitions maintained by AASHTO but also recognizes the inconsistency in the language between the MBE and LRFD. FHWA interprets LRFD's use of ***"component in tension"*** to be a steel member in tension, or sub-element within a built-up member that is in tension. Also, FHWA interprets the phrase from LRFD "***inability of the bridge to perform its function"*** to mean the inability of the bridge to safely carry some level of traffic (Live Load) in its damaged condition. This live load may be less than the full design live load for the strength limit state load combination. The Load Factors and Combinations used to evaluate the damaged condition must be agreed upon between the Owner and Engineer and reviewed by FHWA.

Redundancy

FCMs by all definitions are an essential part of a non-redundant bridge system. LRFD defines Redundancy as "the quality of a bridge that enables it to perform its design function in a damaged state" and Redundant Member as "a member whose failure does not cause failure of the bridge." Redundancy can be provided in one or more of the following ways:

1) Load Path Redundancy
2) Structural Redundancy
3) Internal Member Redundancy

Load path redundancy is based on the number of main supporting members between points of support, usually parallel, such as girders or trusses. Structural redundancy can be provided by continuity in main members over interior supports or other 3-dimensional mechanisms. Internal member redundancy can be provided by built-up member detailing that provides mechanical separation of elements in an effort to limit fracture propagation across the entire member cross section.

Historically, for the purpose of identifying FCMs, redundancy has been defined primarily based on conservative consideration of load path redundancy alone, which is often determined by assessment of the number of parallel main members provided or the spacing of transverse members. More recently, experimental and analytical research has shown that bridges once assumed to be non-redundant (such as two girder or truss systems) actually may provide redundancy by 3-dimensional system behavior and lateral load redistribution. Also, engineers have begun to discover through modern analytical techniques that system redundancy may often exist, even though there are few apparent secondary load paths.

Identification of FCMs for Design and Fabrication

FCMs are identified on design plans to ensure fabrication of these members to a higher quality standard than typical members with load-path redundancy. The AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* requires steels used for FCMs to meet higher Charpy V-notch (CVN) toughness requirements and contain fine-grained material. Additional fabrication procedures and inspection and more strict shop certification is required to meet the AWS D1.5 Bridge Welding Code requirements for fracture critical fabrication. Collectively, these requirements are referred to as the Fracture Control Plan (FCP).

The FHWA expects that all members identified as FCMs **according to load path redundancy** be fabricated to meet the fracture critical requirements for quality. FHWA emphasizes that when identifying FCMs during design it is not the failure of only the element in tension that needs to be considered with regard to the performance of the damaged bridge, but rather the failure of the entire member containing that tension element. For example, a bridge girder in bending has two elements in tension, a flange and a portion of the web. For the purpose of the load path redundancy assessment, all three elements of the girder cross-section, tension flange, web and compression flange should be considered fractured.

With regard to the identification of FCMs for design purposes, the provisions of Section 6.6.2 of the LRFD state ***"The Engineer shall have the responsibility for determining which, if any, component is a FCM. Unless a rigorous analysis with assumed hypothetical cracked components confirms the strength and stability of the hypothetically damaged structure, the location of all FCMs shall be clearly delineated on the contract plans."***

Although FHWA accepts the use of such analysis to distinguish FCMs for in-service inspection protocol, this approach would not meet expectations of quality for materials and fabrication. Non-load path redundant members determined to be non-fracture critical through refined analysis will still be an important member for the structure. The fracture critical fabrication requirements are designed to provide a lower probability of fatigue crack initiation by reducing the frequency and size of defects in fabrication. Material and fabrication requirements developed for the FCP also increase the tolerance to cracks and other discontinuities in important members in tension or with tension elements. Therefore all non-load path redundant tension members shall be fabricated in accordance with the modern FCP of AASHTO and AWS to enhance safety and serviceability over the design life of the bridge.

Identification of FCMs for In-service Inspection Protocol

Currently available refined analysis techniques have provided a means to more accurately define FCMs for new designs and to re-evaluate existing bridge members that were previously classified as fracture critical on the record design documents. If refined analysis demonstrates that a structure has adequate strength and stability sufficient to avoid partial or total collapse and carry traffic in the presence of a totally fractured member (by structural redundancy), the member does not need to be considered fracture critical for in-service inspection protocol. The assumptions and analyses conducted to support this determination need to become part of the permanent inspection records or bridge file so that it can be revisited and adjusted as necessary to reflect changes in bridge conditions or loadings. However, non-load path redundant tension members in existing bridges that were not fabricated to meet the modern FCP introduced in 1978 are not eligible for relief from fracture critical in-service inspection based on such refined analysis. The Owner must verify and document that the materials and fabrication specifications of any existing bridge being assessed for structural redundancy would meet the FCP.

This clarification provides full recognition of structural redundancy that is demonstrated by system response, but does not recognize redundancy from internal built-up details to affect the classification of a FCM. Although it is clear that there are potential added safety benefits to providing internally redundant detailing for certain important bridge members, the discovery of a partial section damage condition is unlikely without a fracture critical member, hands-on inspection. For example, if a tie-girder in a tied arch bridge made from a bolted, built-up box section were to develop a crack in one of the four plate elements, this condition would likely go undetected if only routine inspection was performed. As a result, FHWA cannot accept at this time the approach of using internally redundant detailing to demonstrate that a non-load path redundant member is not fracture critical.

Analysis Requirements

With regard to the level of rigor needed in using refined analysis to demonstrate redundancy, FHWA supports the requirements of LRFD Section 6.6.2 which are summarized by the commentary that reads:

"The criteria for a refined analysis used to demonstrate that part of a structure is not fracture-critical has not yet been codified. Therefore, the loading cases to be studied, location of potential cracks, degree to which the dynamic effects associated with a fracture are included in the analysis, and fineness of models and choice of element type should all be agreed upon by the Owner and the Engineer. The ability of a particular software product to adequately capture the complexity of the problem should also be considered and the choice of software should be mutually agreed upon by the Owner and the Engineer."

Modern analytical techniques have provided a means for engineers to more accurately assess bridge redundancy and identify fracture critical members, with full consideration of 3-D system behavior in damage scenarios. It is no longer necessary to identify FCMs by simple checking for load path redundancy alone, unless the State chooses to maintain such criteria. To demonstrate that a structure has adequate strength and stability sufficient to avoid partial or total collapse and carry traffic in the presence of a totally fractured FCM, a State must submit through the Division Office to the FHWA Office of Bridge Technology for review the detailed analysis and evaluation criteria that will be used to conduct the study. Once reviewed, these criteria can then be employed by the State systematically on their inventory.

Summary and System Redundant Members (SRM)

This memo has provided clarification and guidance for classification of FCMs for design/fabrication requirements and in-service inspection protocol. For in-service inspection protocol, owners may go beyond the simple, conservative definition of FCMs based on a load path redundancy assessment alone if the member was fabricated to meet the AWS FCP. Application of refined analysis techniques can be an effective strategy to address both the design and maintenance of FCMs in bridges and should be considered to optimize the use of available funding resources.

The interpretation of definitions and recognition of refined analysis provided herein has created a new member classification: a member that requires fabrication according to the AWS FCP, but need not be considered a FCM for in-service inspection. This memo defines this new member as a "System Redundant Member (SRM)." SRMs should be designated on the design plans with note to fabricate them in according with AWS Chapter 12. The criteria, assumptions, and the refined analysis used to determine the system redundancy condition must be retained and included in the inspection records or permanent bridge file. Changes in conditions of bridge elements or loading on the bridge could result in SRMs becoming FCMs in the future and requiring fracture critical inspection; therefore, it is vitally important to retain the refined analysis records and revise them as needed to account for these changes over the life of the structure. FHWA Divisions should work with their state partners to assure that their engineering practices align with the requirements given in this memo.

High Performance Steel (HPS) and use of internally redundant detailing both have the potential to further improve the fracture propagation resistance of FCMs and should be implemented where practical. The implications of such measures are the subject of ongoing research efforts.

Please work with your State transportation agency partner to assure that their engineering practices align with the guidance provided in this memorandum. If you have any questions or would like additional information, please contact Mr. Brian Kozy (202) 493-0341 (Brian.Kozy@dot.gov) or Mr. Joseph Hartmann (202) 366-4599 (Joey.Hartmann@dot.gov).

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