Implementation of Redundancy Terms under 2022 NBIS

23 U.S.C. 144 (b), Section 650.305 REGARDING REDUNDANCY

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Background

The newly implemented FHWA National Bridge Inspection Standards (NBIS), published in May 2022, establish new terms that govern the classification of steel bridge members subjected to tension, specifically in terms of how redundancy is achieved and discontinues the use of the term "fracture critical." The new terms define the different forms of redundancy as defined in the Title 23 Code of Federal Regulations (CFR) *Part 650.305 Subpart C, National Bridge Inspection Standards (NBIS)*, as follows:

- **System Redundancy:** A redundancy that exists in a bridge system without load path redundancy, such that fracture of the cross section at one location of a primary member will not cause a portion of or all of the bridge to collapse.
- **Internal Redundancy:** A redundancy that exists within a primary member cross-section without load path redundancy, such that fracture of one component will not propagate through the entire member, is discoverable by the applicable inspection procedures, and will not cause a portion of or the entire bridge to collapse.
- **Load Path Redundancy:** A redundancy exists based on the number of primary load-carrying members such that fracture of the cross section at one location of a member will not cause a portion of or the entire bridge to collapse. AASHTO and FHWA consider bridges with three or more primary load-carrying members to be load path redundant.

When none of the above forms of redundancy are identified by the engineer, the member is to be identified as a Nonredundant Steel Tension Member (NSTM). *Per NBIS Part 650.305 Definitions*, a Nonredundant Steel Tension Member (NSTM) is defined as follows:

> *A primary steel member fully or partially in tension, and without load path redundancy, system redundancy or internal redundancy, whose failure may cause a portion of or the entire bridge to collapse.*

Historically, it was implied that Load Path Redundancy was the only type of redundancy recognized by previous editions of Title 23 Code of Federal Regulations Part 650. A common example of such can be found in a typical multi-girder cross section where several parallel beams support the span. These members are defined *herein* as Load Path Redundant Members (LPRMs). As a result, members were previously either defined as redundant *(when load path redundancy was present)* or nonredundant *(when it was not)*. When a member was determined to be, 1) nonredundant, 2) steel, and 3) to be in tension, or portion thereof in tension, such members were defined as Fracture Critical Members (FCMs). Primary members determined to be FCMs were to be identified as such on contract plans. Fabrication was to be in accordance with Clause 12 of the AASHTO/AWS D1.5 along with additional in-service inspection requirements. This discussion is only focused on design, fabrication, and material selection requirements. Ramifications for in-service inspections are not discussed herein.

Based on over a decade of research, the most recent version (2022) of the CFRs allows for the other forms of redundancy to be explicitly considered with FHWA approval of the procedure. Thus, both internal redundancy at the member level, as well as overall system redundancy, may be utilized. Common examples of internal redundancy include truss members, or steel bent caps, that are fabricated from angles and plates that are riveted or bolted together whereby it can be shown that fracture of an individual component does not lead to complete member failure. These members are now referred to as Internally Redundant Members (IRMs). An example of system redundancy can often be found in continuous span twin tub girder bridges, where only two main girders are present, but sufficient redundancy is demonstrated through analysis showing the bridge effectively redistributes load after a main girder is assumed to have failed without collapse. These members are now referred to as System Redundant Members (SRMs).

Fabrication Requirements

The steel bridge industry has over 40 years of experience with the special fabrication rules associated with labeling a member as an FCM. Similarly, there are certain fabrication requirements associated with the new member types, specifically the NSTM, SRM, and IRM that need to be understood and conveyed to the fabricator to avoid unnecessary costs and confusion.

The requirements for new fabrication are summarized in Table 1 and are based on existing and newly planned revised provisions contained in the AASHTO *LRFD Bridge Design Specifications* and applicable AASHTO *Guide Specifications*.

Table 1. Requirements for fabrication

Member Classification	Fracture Control Practice Required?	A709 CVN Requirements? (2021)	Identification on Design Drawings?
LPRM	NO	A709 Table 11	NO
NSTM*	YES	A709 Table 12	YES
SRM	YES	A709 Table 12	YES
IRM**	YES	A709 Table 12	YES

*Formerly referred to as FCM
**Primary plate components in newly designed IRMs

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As stated, members or portions thereof classified as FCMs have been required to be clearly identified on the design drawings. As noted in Table 1, the fabrication requirements for NSTMs, SRMs, and IRMs are the same as they were for FCMs. While it may take a short time for industry to become completely familiar with these new terms, the general requirements for materials and fabrication have not changed.

Implementation for Fabricators

It can be simply stated that, in terms of material and fabrication, NSTM = SRM = IRM = FCM.

In a short period of time, it is expected that these new terms will become routine. In the meantime, engineers should be expected to add a basic general note that defines what is required for fabrication. For example, a note for SRMs may read:

> *"All members, or portions thereof, identified on the design drawings as SRM shall be fabricated in accordance with all requirements of Fracture Control (FC) practices."*

DOTs and associations, such as AASHTO, AREMA, ASTM, and AWS, also need to transition from "fracture critical" to the new NBIS terms. For AASHTO, AREMA, and ASTM, the operative terms would be "NSTM," "SRM," and "IRM." For AASHTO/AWS, the term "FC" could be retained with modified meaning of "Fracture Control." The recommended approach is to use the terms NSTM, SRM, and IRM throughout the design documents and include a general statement that describes how the requirements for SRMs and IRMs relate to NSTMs. The recommended practices for addressing these terminology changes are as follows:

1. If a tension member is not load path redundant, then the Engineer of Record (EOR) must designate it as NSTM, SRM, or IRM on the design drawings, as appropriate.
2. When using the labels NSTM, SRM, or IRM, the EOR will designate the tension zones within each member where special Fracture Control practices apply.
3. When NSTM, SRM, or IRM is designated on contract drawings, fabricators must then use special Fracture Control practices (former fracture critical member practices) for material and fabrication for the tension zones designated as such by the EOR.
4. Fabricator shop drawings will have a note saying that NSTM, SRM, or IRMs shall be fabricated to special Fracture Control practices.
5. Elsewhere in the shop drawings, the fabricator will use "Fracture Control" or "FC" to indicate application of special Fracture Control practices.
6. When NSTM, SRM, or IRM is used on design drawings, fabricators will order material meeting special Fracture Control practices for the tension zones identified by the EOR.
7. Material purchase orders and material test reports for ASTM A709 will continue to use the "F" designation. For other materials, these documents will designate any special Fracture Control requirements.
8. Since existing welding and repair procedures and existing welder qualifications may carry the FC designation, use notes like this on shop drawings:
   a) Welding and repair procedures approved for FC requirements are approved for use on materials and components designated as SRM, IRM, or NSTM.
   b) Welders qualified for FC requirements are qualified for work on materials designated as SRM, IRM, or NSTM.

Implementation for Designers

The AASHTO Technical Committee for Steel Design (T-14) is currently identifying how the new NBIS terminology impacts the 9th edition of the AASHTO *LRFD Bridge Design Specification*s, as well as the *Guide Specifications* for SRMs and IRMs. Proposed changes to the current *Specifications* language will be submitted to the AASHTO Committee on Bridges and Structures for approval in the upcoming annual meeting in 2023. Approved revisions will appear in the 10th edition to be published in 2024. In the interim, the authors are offering the following suggestions and recommendations to AASHTO T-14 and the engineering community:

1. Add language in the specifications requiring members designed as NSTMs, SRMs, and IRMs to be specifically labeled as such on the contract plans.
2. In accordance with CFR 650.313, owners may elect to continue to design bridges as non-redundant systems, labeling appropriate members as NSTM and accepting the more rigorous field inspection requirements outlined in the NBIS regulations. As an option, owners may elect to design bridges in accordance with the *Guide Specifications* for System Redundant or Internally Redundant bridge systems which will allow these bridges to be inspected as required, outlined in CFR 650.313 and providing that the owner follow the conditional requirements described in bullet 3., below.
3. The NBIS requires that owners develop and submit a formal request to FHWA for approval of procedures using a nationally recognized method to evaluate for system or internal redundancy along with field inspection protocols for each. The specific requirements of the application are provided in the newly published CFR 650.313 Rulemaking document. FHWA will review the procedures for approval based upon conformance with the nationally recognized method. Once the procedure has been reviewed and approved by FHWA, owners and designers may design SRMs and IRMs without additional FHWA approval, meaning there is not project-level approval required for each design thereafter, so long as the approved procedure is followed. Requirements for the formal request are outlined in 23 CFR 650.313 (f)(i). Consistent with CFR 650.313 (f)(1)(i)(B), as stated in their dated May 9, 2022, FHWA considers the AASHTO *Guide Specifications for Analysis and Identification of Fracture Critical Members and System Redundant Members* [At the time of this writing plans are in place to rename this as, "AASHTO *Guide Specifications for Analysis and Identification of Nonredundant Steel Tension Members and System Redundant Members*"] and AASHTO *Guide Specifications for Internal Redundancy of Mechanically-Fastened Built-up Steel Members* to be nationally recognized methods. Note that failure to properly maintain the condition of the bridge, or significant inspection findings left unrepaired, may cause the SRM or IRM classification to be changed to NSTM. A thorough review of CFR 650.313 is recommended before choosing this design approach.

4. As a point of clarification, FHWA issued a memo on May 9, 2022, stating that bridges with three or more primary load-carrying members are load path redundant. In 2022 the AASHTO Committee on Bridges and Structures approved a change to the commentary of the AASHTO *LRFD Bridge Design Specifications* that will appear in the 10th Edition stating that an example of load path redundancy is a three-girder system at spacing not exceeding 16-ft. This spacing is based on engineering judgement but may serve as a good rule of thumb to guide engineers. Three-girder systems are suitable as superstructures, straddle beams and bent caps. Load path redundant member require no prior approvals from FHWA and less rigorous fabrication and in-service field inspection requirements than do NSTMs, SRMs, and IRMs.
5. Labeling members as NSTM, SRM, or IRM on contract plans automatically invokes the fabrication requirements found in the AASHTO/AWS D1.5 specifications and any state-mandated fabrication specifications. No further repetition of the special fracture control fabrication practices is required on the contract plans. Improvised notes attempting to reiterate these practices may only lead to confusion and miscommunication and is not recommended.
6. The Engineer shall have the responsibility for classifying primary members fully or partially in tension, that are without load path redundancy as NSTM, SRM, or IRM. For flexural members, only the portions of the member located in the tension zones under Strength Load Combination I should be classified as NSTM, SRM, or IRM and only the limits of the areas in tension should be so designated on the contract plans. Special fracture control practice need only apply within the zones so designated, except for bearing sole plates and attachments having a length in the direction of the tension stress greater than 4-inches that are welded to a tension area of a component or member without load path redundancy. Requiring otherwise only adds cost and does not enhance safety.
7. Secondary members and primary diaphragm or cross-frame members in horizontally curved bridges should not be classified as NSTMs, SRMs, or IRMs. To do otherwise only adds cost and does not enhance safety.
8. As mentioned above, AASHTO and FHWA are moving away from using the term Fracture Critical and Fracture Critical Member on contract plans. Fabricators will continue to address special material and fabrication practices for NSTMs, SRMs, and IRMs as "Fracture Control" on their shop plans. The term "fracture control" will appear on material purchase orders, material test reports, welding procedures, repair procedures and material tracking marks.
9. Design procedures applicable to SRMs and IRMs require a distinct analysis that includes an evaluation in the "Faulted State". Nonetheless, any welding permitted, such as shop splices of main member materials or attachments, not otherwise exempted in the *Specifications*, are subject to the Fracture Control Plan requirements found in the AASHTO/AWS D1.5 and elsewhere. The rationale for this requirement is enhanced safety at an acceptable cost.

Summary

During the past decade there has been considerable research and interest in the topic of redundancy and fracture-critical members. As a result, new methods of analysis have been developed and what was formerly identified as an FCM has been reevaluated thereby allowing more rational treatment of steel tension members. The integrated approaches now available to owners and designers, partially discussed in this document, can ensure fracture is no more likely than any other limit state; ultimately, allowing for a better allocation of owner resources without compromising steel bridge safety. While some changes to typical practice will be required, the long-term benefits to the industry will far outweigh any short-term concerns with respect to implementation.

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