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Foreword

The Steel Bridge Design Handbook covers a full range of topics and design examples to provide bridge engineers with the information needed to make knowledgeable decisions regarding the selection, design, fabrication, and construction of steel bridges. The Handbook has a long history, dating back to the 1970s

TECHNICAL REPORT DOCUMENTATION PAGE

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2.0 GENERAL

The NBIS regulations define load rating as “The determination of the live load carrying capacity of a bridge using as-built bridge plans and supplemented by information gathered from the latest field inspection.” Load ratings are expressed as a rating factor (RF) or as a tonnage for a particular vehicle. Emphasis in load rating is on the live-load capacity and dictates the approach of determining rating factors instead of the design approach of satisfying limit states.

The rating factor is the multiple of the vehicular live-load effect (for example, moment or shear) that the bridge can carry when the limit-state under investigation is satisfied. The weight of the live-load in tons multiplied by the rating factor is the tonnage that the bridge can safely carry.

Superstructure spans, including the main or primary components of the span and their connections, should be load rated to identify the governing component. The sudden collapse of the I-35W highway bridge in Minneapolis, Minnesota in August of 2007, reiterated the need to load rate connections as well as the members. The National Transportation Safety Board (NTSB) with the aid of the Federal Highway Administration (FHWA) determined that the probable cause of the deck-truss bridge collapse was inadequate load-carrying capacity of gusset plates connecting some truss members together due to a design error [2]. In response, the FHWA developed guidelines for the load rating of such gusset plates [3]. Additionally, the most recent version of the AASHTO Manual for Bridge Evaluation, Third Edition with 2019 Interims (MBE) [4] provides guidelines for the load rating of gusset plates.

4.0 ASSUMPTIONS

The load carrying capacity of an existing bridge is based upon its present condition. In general, the bridge will be inspected biennially. The condition of the bridge is captured and the load carrying capacity may be recalculated when the bridge condition or loading has changed. The routine updating to bridge ratings following new findings during field inspections is critical considering capacity often decreases with time due to deterioration, live loads historically increase with time, and dead loads may increase through repairs and rehabilitations.

In order to obtain accurate load ratings, thorough inspections documenting the necessary data required is critical. General descriptions of conditions are not adequate to assess the current load-carrying capacity of the structure. Per MBE Article Commentary C6.1.1, “a load rating of a bridge should not be undertaken without a recent thorough field inspection which:

6.0 LOAD AND RESISTANCE FACTOR RATING (LRFR)

6.1

The LRFR methodology consists of three distinct levels of evaluation:

1) design-load rating (first level evaluation),
2) legal-load rating (second level evaluation), and
3) permit-load rating (third level evaluation).

The results of each evaluation serve specific purposes and also inform the need for further evaluations. Each of the above evaluations is performed for a specific live load model with specifically calibrated load factors aimed at maintaining uniform and acceptable levels of reliability in the various evaluations.

6.1.1 General Load-Rating Equation

The general load-rating equation for rating factor, RF, may be rewritten for steel bridges as follows, considering permanent loads other than dead load to be non-existent:

$$RF = \frac{C - {}_{DC}\,DC - {}_{DW}\,DW}{{}_{L}\,LL\,IM}$$

For the strength limit states:

$$C = {}_{c}\,{}_{s}\,R_n$$

Where the following lower limit applies:

$${}_{c}\,{}_{s} \geq 0.85$$

For the service limit states:

$$C = f_R$$

where:

RF	=	Rating factor
C	=	Capacity
f_R	=	Allowable stress specified in the AASHTO LRFD BDS
R_n	=	Nominal member resistance (as inspected)
DC	=	Dead-load effect due to structural components and attachments
DW	=	Dead-load effect due to wearing surface and utilities
LL	=	Live-load effect
IM	=	Dynamic load allowance

γ_{DC} = LRFD load factor for structural components and attachments
γ_{DW} = LRFD load factor for wearing surfaces and utilities
γ_{L} = Evaluation live-load factor
$_{c}$ = Condition factor
$_{s}$ = System factor
= LRFD resistance factor

6.1.2 Condition Factors

The condition factors, $_{c}$, given in Table 1 (See Tables 6A.4.2.3-1 and C6A.4.2.3-1 of the MBE) are only applied to strength limit-state ratings. The application of condition factors is optional based on the owner's preference.

Table 1 Condition Factors

Structural Condition of Member	NBI Condition Rating	φ_c
Good or Satisfactory	6 or higher	1.00
Fair	5	0.95
Poor	4 or lower	0.85

6.1.3 System Factors

System factors are multipliers related to the level of redundancy of the complete superstructure system. Less redundant structural systems are penalized by requiring their members to provide higher safety levels than those of similar members in bridges with redundant configurations. System factors, $_{s}$, are given in Table 2 See Table 6A.4.2.4-1 of the MBE) for various structure and member types.

Just as for the condition factors, the system factors are only applied to strength limit states. A system factor of 1.0 is used when checking shear at the strength limit state.
Like the condition factors, the application of system factors may be considered optional based on the bridge owner's preference. However, when rating nonredundant superstructures for legal loads using generalized load factors given in MBE Article 6A.4.4.2.3 (see Table 5), the system factors shown in Table 2 can be used to reflect a more consistent evaluation of the level of

Table 2 System Factors

Superstructure Type	φ_s

6.2.3 Limit States

Strength I and Service II load combinations should be checked for the design loading. These limit states are as discussed in NSBA's *Steel Bridge Design Handbook: Limit States* [9] for design.

6.2.4 Load Factors

The evaluation live load factors for the design-load rating level are as given in Table 3 above.

6.3

6.3.1 General

Federal Bridge Formula B sets weight limits on groups of axles that current legal loads are required to obey. The Fixing America's Surface Transportation Act (FAST Act), signed into law in December of 2015, exempted emergency vehicles from meeting the nationwide interstate truck weight limits set by Federal Bridge Formula B and created an opportunity for these vehicles to impose greater load effects in certain bridges than previously established legal loads. Subsequently, the FHWA issued a memorandum titled "Load Rating for the FAST Act's Emergency Vehicles," dated November 3, 2016 [10], to provide guidance on the load rating and posting of bridges for emergency vehicles.

6.3.2 Live Load

The memorandum established two new emergency vehicle configurations known as EV2 and EV3; see Figure 1 and Figure 2, respectively [11]. These two vehicles produce load effects in typical bridges that envelope the effects of the vehicles covered by the FAST Act.

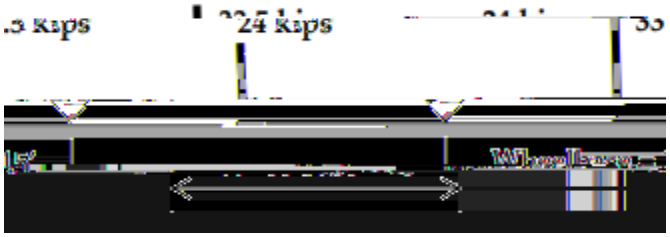

Figure 1 Emergency Vehicle Type EV2*

6.3.3 Limit States

The emergency vehicle load ratings should be determined at the legal load rating level with exception to the multiple presence and load factors discussed in the following subsection. As such, the Strength I and Service II limit-state load combinations are mandatory. These limit states are as discussed in the NSBA's *Steel Bridge Design Handbook: Limit States* [9].

6.3.4 Load Factors and Multiple Presence

The FHWA memorandum provides specific guidance regarding multiple presence and live load factors that differs from other legal loads. A load factor of 1.3 may be used and, if necessary when combined with other unrestricted legal loads for rating purposes, the emergency vehicle may only be considered in a single lane of one direction of a bridge. For a one-lane bridge, the 1.2 multiple presence factor may be divided out. Refer to the FHWA Questions and Answers document for further guidance [11].

6.4

6.4.1 General

Legal-load ratings establish the need for posting or bridge strengthening when the controlling rating factor, RF, associated with the legal loads is less than 1.0. This live-load capacity corresponds to a minimum target reliability index, β_T, of 2.5. Bridges with a rating factor, RF, greater than 1.0 for legal loads may be evaluated for overweight permit loads.

6.4.2 Live Load

There are two main categories of legal loads that comply with federal weight laws:

1. Routine commercial vehicles, and

2. Specialized hauling vehicles (SHVs)

The factor used to address dynamic load allowance should be as specified in the AASHTO LRFD BDS except for longitudinal members with spans greater than 40 ft, where the dynamic load allowance may be decreased based upon the observed riding surface condition as provided in the Commentary to Article 6A.4.4.3 of the MBE.

6.4.3 Limit States

The Strength I and Service II limit-state load combinations are mandatory for legal-load ratings. These limit states are as discussed in the NSBA's *Steel Bridge Design Handbook: Loads and Combinations* [8] for design.

6.4.4 Load Factors

The evaluation live-load factors for legal-load rating at the Strength I limit state load combination are a function of the average daily truck traffic (ADTT). The evaluation live-load factor for the Service II limit-state load combination is 1.30 as shown in Table 3.

6.4.4.1 Routine Commercial Vehicles

The evaluation live-load factors for routine commercial vehicles at the Strength I limit-state load combination are given in Table 5 g0 G[(e)4(va)4(luation l)-3l2300000912 0 612 792 rehc73Tm0 g0 Gm1 224.93

Load factors by permit type and traffic conditions on the bridge are specified for reviewing the safety inherent with the passage of the overweight truck. Guidance is also provided on the serviceability that may be checked when reviewing permit applications.

6.5.2 Live Load

The actual permit vehicle's gross vehicle weight and axle configuration will be the live load used in the permit-load evaluation.

The MBE categorizes permit loads into two classes:

1. Routine/annual permits, and
2. Special (limited crossing) permits.

Routine or annual permits are usually valid for unlimited trips over a period of time, up to one year.

Special permits are usually valid for a single trip, or for a limited number of trips, for a vehicle of specified configuration, axle weights, and gross weight. Special permit vehicles are usually heavier than those vehicles issued annual permits.

For spans up to 200 ft, only the permit vehicle is considered present in the lane. For span lengths between 200 and 300 ft and when checking negative moments in continuous span bridges, an additional lane load is applied to simulate closely following vehicles. The lane load should be taken as 0.2 kips per linear feet in each lane. The lane load may be superimposed on the permit vehicle (for ease of analysis) and is applied to those portions of the span where the loading effects add to the permit load effects.

6.5.3 Limit States

Permits are checked using the Strength II limit-state load combination with the Service II limit-state load combination optional for steel bridges to limit potential permanent deformations. These limit states are as discussed in the NSBA's *Steel Bridge Design Handbook: Loads and Combinations* [8] for design.

6.5.4 Load Factors

6.5.4.1 Routine/annual Permits

Routine permit-load rating uses the multi-lane distribution factors (DFs) of the AASHTO LRFD BDS. This assumes simultaneous side-by-side presence of two equally heavy vehicles in each lane.

The evaluation live-load factors for routine or annual permits are given in Table 7, below (See Table 6A.4.5.4.2a-1 of the MBE).

Table 8 Special Permit Evaluation Live Load Factors for Strength II for Steel Bridges

Trip Type	Traffic Condition	Distribution Factor (DF)	ADTT (One Direction)	Load Factor (All Weights)
Single	Escorted with no other vehicles on the bridge	One Lane	N/A	1.10
Single	Mix with traffic (other vehicles may be on the bridge)	One Lane	All ADTTs	1.20

7.0 RATING EXAMPLES

Up-to-date rating examples are included in an appendix to the MBE. These examples are continually updated with any interim revisions to the MBE.

The rating examples are summarized in Table 9 below

8.0 REFERENCES

1. NTSB, *Collapse of U.S. 35 Highway Bridge, Point Pleasant*, West Virginia, December 15, 1967, HAR-71-01, National Transportation Safety Board, August 1971.

2. NTSB, *Collapse of I-35W Highway Bridge Minneapolis*, Minnesota August 1, 2007, HAR-08-03, National Transportation Safety Board, November 2008.

3. FHWA, *Load Rating Guidance and Examples for Bolted and Riveted Gusset Plates in Truss Bridges*, FHWA-IF-09-014, Federal Highway Administration, February 2009.