

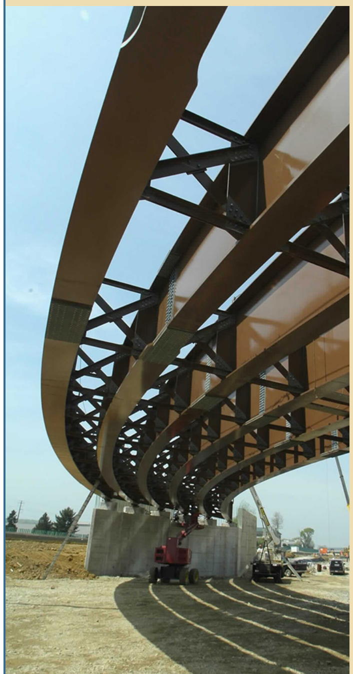


U.S. Department of Transportation
Federal Highway Administration

Steel Bridge Design Handbook

Load Rating of Steel Bridges

Publication No. FHWA-IF-12-052 - Vol. 18

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Steel Bridge Design Handbook: Load Rating of Steel Bridges

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16. Abstract

Load rating is defined 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 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. Existing highway bridges are rated to prioritize a bridge owner's needs, assure the traveling public's safety, and facilitate the passage of goods. Bridges that cannot safely carry statutory loads, based on a load-rating evaluation, should be load posted, rehabilitated or replaced. This module informs designers of load ratings, and discusses the LRFR methodology used for load rating evaluation.

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Steel Bridge Design Handbook: Load Rating of Steel Bridges

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FOREWORD

It took an act of Congress to provide funding for the development of this comprehensive handbook in steel bridge design. This 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 is based on the Fifth Edition, including the 2010 Interims, of the AASHTO LRFD Bridge Design Specifications. The hard work of the National Steel Bridge Alliance (NSBA) and prime consultant, HDR Engineering and their sub-consultants in producing this handbook is gratefully acknowledged. This is the culmination of seven years of effort beginning in 2005.

The new *Steel Bridge Design Handbook* is divided into several topics and design examples as follows:

- Bridge Steels and Their Properties
- Bridge Fabrication
- Steel Bridge Shop Drawings
- Structural Behavior
- Selecting the Right Bridge Type
- Stringer Bridges
- Loads and Combinations
- Structural Analysis
- Redundancy
- Limit States
- Design for Constructibility
- Design for Fatigue
- Bracing System Design
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- Bearings
- Substructure Design
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- Corrosion Protection of Bridges
- Design Example: Three-span Continuous Straight I-Girder Bridge
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- Design Example: Three-span Continuous Straight Tub-Girder Bridge
- Design Example: Three-span Continuous Curved I-Girder Beam Bridge
- Design Example: Three-span Continuous Curved Tub-Girder Bridge

These topics and design examples are published separately for ease of use, and available for free download at the NSBA and FHWA websites: http://www.steelbridges.org, and http://www.fhwa.dot.gov/bridge, respectively.

The contributions and constructive review comments during the preparation of the handbook from many engineering processionals are very much appreciated. The readers are encouraged to submit ideas and suggestions for enhancements of future edition of the handbook to Myint Lwin at the following address: Federal Highway Administration, 1200 New Jersey Avenue, S.E., Washington, DC 20590.

M. Myint Lwin, Director
Office of Bridge Technology

1.0 BACKGROUND

The U.S. 35 “Silver Bridge” between Point Pleasant, West Virginia, and Kanauga, Ohio, collapsed in 1967, killing 46 people and injuring 9 when the bridge fell into the Ohio River or onto the Ohio shore (1).

The Silver Bridge collapse, the first major collapse since the Tacoma Narrows Bridge collapsed in 1940, prompted national concern about bridge safety and led to the establishment of the National Bridge Inspection Standards (NBIS) under the Federal-aid Highway Act of 1968 and the Special Bridge Replacement Program under the Federal-aid Highway Act of 1970.
Load rating is required by NBIS regulations. The regulations state “Rate each bridge as to its safe loading capacity in accordance with the AASHTO manual. Post or restrict the bridge in accordance with the AASHTO Manual or in accordance with state law, when the maximum unrestricted legal loads or State routine permit loads exceed that allowed under the operating rating or equivalent rating factor.”

The NBIS regulations apply to all structures defined as highway bridges located on all public roads. They apply to all publicly owned highway bridges longer than twenty feet located on public roads. Railroad/pedestrian structures that do not carry highways are not covered by the NBIS regulations.

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.

All superstructure spans, and main or primary components of the span and their connections shall be load rated until the governing component is established. 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).

3.0 PURPOSES

Existing highway bridges are rated to:

- prioritize an owner's needs,
- assure the traveling public's safety, and
- facilitate the safe passage of goods.

Owners rate bridges upon completion of original construction and whenever a change in condition suggests that the current rating may have changed.

Bridges that cannot safely carry statutory loads, based on a load-rating evaluation, should be load posted, rehabilitated or replaced.

Bridge load ratings reported to the NBI weigh heavily in the determination of the Sufficiency Rating (SR). Federal resource allocation determinations utilize the SR to prioritize and distribute funds among the States to replace, rehabilitate and maintain our nation's highway bridges. States, in addition, use the ratings in prioritizing projects for repair, rehabilitation or replacement, distributing bridge funds to local governments, determine load-posting needs, and for issuing overload permits.

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.

Capacity often decreases with time due to deterioration. Live loads historically increase with time. Dead loads may increase through repairs and rehabilitations.

5.0 EVALUATION METHODS

5.1 Background

Several philosophies are available to rate bridges through various design methodologies.

Bridge design and rating methodology has evolved over time from allowable stress design (ASD) through load factor design (LFD) to load and resistance factor design (LRFD). While bridges are designed using the LRFD philosophy of the *AASHTO LRFD Bridge Design Specifications, 5th Edition* (referred to herein as the LRFD Specifications) (4), bridges may be rated using either the load factor rating (LFR) or load and resistance factor (LRFR) methodology.

5.2 Evolution of Rating Specifications

Traditionally, existing bridges were rated using the evaluation methodologies of the AASHTO Manual for Conditional Evaluation of Bridges (5), the ASR or LFR methodologies. These evaluation methodologies are analogous to the design methodologies of the AASHTO LRFD Construction Specifications (6).

National Cooperative Highway Research Program (NCHRP) Project 12-46 developed an evaluation methodology analogous to the LRFD methodology of the AASHTO LRFD Bridge Design Specifications, 5th Edition (4). This reliability-based rating method is termed LRFR. This rating procedure was included in the AASHTO Manual for the Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges (7).

With the publication of the AASHTO Manual for Bridge Evaluation (referred to herein as the MBE) (8), the LRFR methodology was added to the ASR and LFR methodologies in one all-encompassing document. The MBE replaces both the AASHTO Manual for Condition Evaluation of Bridges and the AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges. It serves as a single standard for the evaluation of all highway bridges.

5.3 Comparisons

AASHTO Technical Committee T-18, Bridge Management, Evaluation and Rehabilitation, commissioned a research project to investigate the validity of the LRFR methodology. The objective of National Cooperative Highway Research Program (NCHRP) Project 20-07 Task 122 (9) was to provide explicit comparisons between the ratings produced by the LRFR and LFR methodologies. The comparisons are based upon flexural-strength ratings. For girder-type bridges, the rating comparisons further concentrate on the interior girder. The study compared 74 example bridges provided by the NYSDOT and WYDOT.

The reliability or safety of the example bridges was established through Monte-Carlo simulation. For each example bridge, 1,000,000 Monte Carlo simulations are made. The resultant reliability indices are independent of the rating methodology as they represent inherent bridge safety.

Twenty six of the bridges in the 74 bridge database demonstrated a failure rate of more than 10 failures out of 1,000,000 simulations, or a reliability index less than about 4.25. A plot, from the National Cooperative Highway Research Program (NCHRP) Project 20-07 Task 122 (9), comparing the reliability index, β, versus the design-load inventory-rating factors for both LRFR and LFR is given in Figure 1. In the figure, LRFR rating factors are represented by diamonds, while LFR rating factors are represented by squares. Little correlation with the inherent reliability indices is demonstrated by the LFR rating factors while a strong, more linear correlation is demonstrated by the LRFR rating factors. This comparison demonstrates the strong superiority of the LRFR methodology in predicting the reliability or safety of existing bridges.

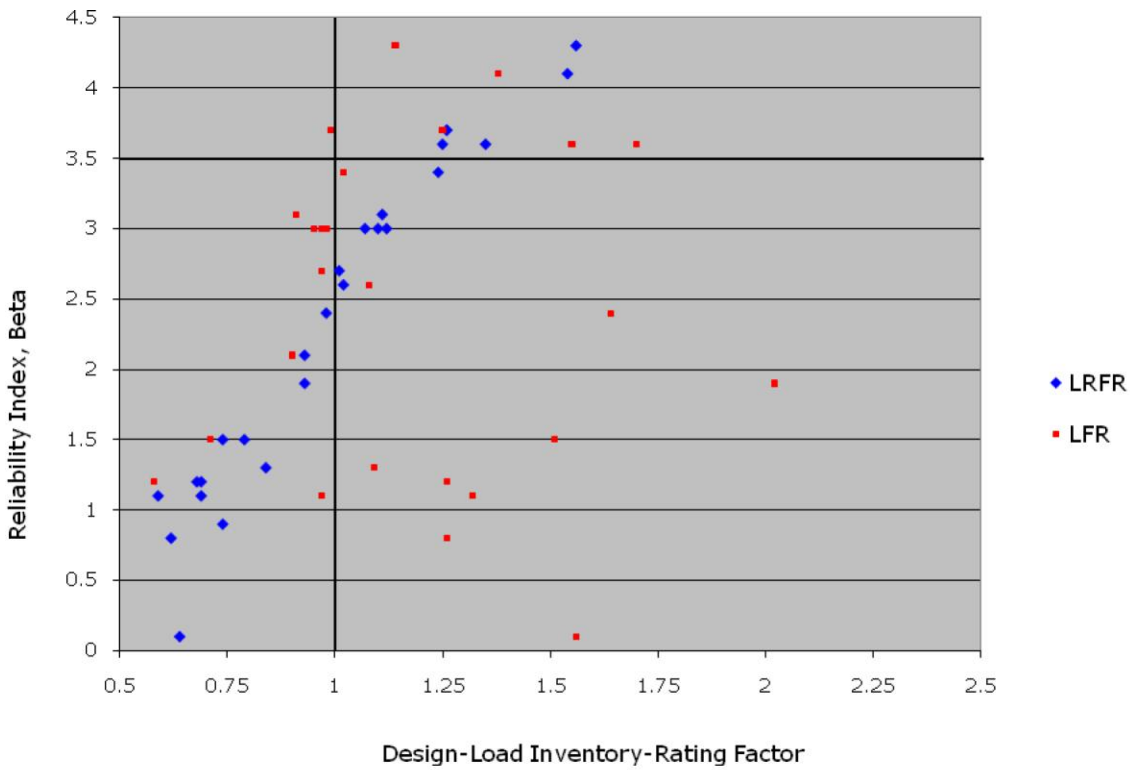

Figure 1 Design-Load Inventory-Rating Factor, RF, versus Reliability Index, β

5.4 Federal Highway Administration Policy

The Federal Highway Administration (FHWA) considers LRFR as the preferred load-rating methodology for all existing bridges. Further, the FHWA has adopted a policy that starting October 1, 2010, bridges designed with LRFD be load rated with LRFR (8).

As such, only the preferred load rating methodology, LRFR, will be discussed herein. This methodology has been demonstrated to be most representative of the quantified safety of the bridge in terms of reliability index or probability of failure as shown in Figure 1 above.

6.0 LOAD AND RESISTANCE FACTOR RATING (LRFR)

6.1 General

The LRFR methodology consists of three distinct levels of evaluation:

1) design-load rating,
2) legal-load rating, and
3) permit-load rating.

The results of each evaluation serve specific purposes and also inform the need for further 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:

$$RF = \frac{C - \gamma_{DC}(DC) - \gamma_{DW}(DW)}{\gamma_L(LL + IM)}$$

For the strength limit states:

$$C = \phi_c \, \phi_s \, \phi \, R_n$$

Where the following lower limit shall apply:

$$\phi_c \, \phi_s \geq 0.85$$

For the service limit states:

$$C = f_R$$

where:

RF	=	Rating factor
C	=	Capacity
f_R	=	Allowable stress specified in the LRFD Specifications
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
ϕ_c = Condition factor
ϕ_s = System factor
ϕ = LRFD resistance factor

6.1.2 Condition Factors

The condition factors given in Table 1 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

Condition Description	NBI 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. Non-redundant bridges are penalized by requiring their members to provide higher safety levels than those of similar members in bridges with redundant configurations. System factors are given in Table 2 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 shall be 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.

Table 2 System Factors

Structure Type	System Factor
welded members in two-girder/truss/arch bridges	0.85
riveted members in two-girder/truss/arch bridges	0.90
multiple eyebar members in truss bridges	0.90
three-girder bridges with girder spacing less than or equal to 6 ft.	0.85
four-girder bridges with girder spacing less than or equal to 4 ft	0.95
all other girder bridges and slab bridges	1.00
floorbeams with spacing greater than 12ft. and non-continuous stringers	0.85
redundant stringer subsystems between floorbeams	1.00

6.1.4 Load Factors

The load factors for use in the general load rating equation are given in MBE Table 6A.4.2.2-1.

Evaluation live-load factors, γ_L, are specified for each level of evaluation. These factors for steel bridges are summarized in Table 3.

The MBE allows owners to specify live load factors other than those given in Table 3 if comparable target reliability is achieved with site-specific load factors.

The dead load factors are summarized in

Table 4.

Table 3 Evaluation Live-load Factors

Limit State	Rating Level			
	Design Load		Legal Load	Permit Load
	Inventory	Operating		
Strength I	1.75	1.35	see Table 5 & Table 6	–
Strength II	–	–	–	see Table 7& Table 8
Service II	1.30	1.00	1.30	1.00*

* The Service II limit-state load combination is optional for permit-load ratings.

Table 4 Dead Load Factors

Limit States	Component of Dead Load	
	DC	DW
Strength I & II	1.25	1.50
Service II	1.00	1.00

6.1.5 Levels of Evaluation

The various levels of evaluation are structured to be performed in a sequential manner, as needed, starting with the design-load rating. The logical progress of load rating checks provides labor saving in a manual load rating process. In cases where load rating is done by automated methods, bridge owners may find it expedient to define all load models for analysis in a single run and utilize the results as needed.

6.2 Design-Load Rating

6.2.1 General

The design-load rating level screens bridges to assess their vulnerability. At this level, the HL-93 live-load model of the LRFD Specifications is applied. The HL-93 live load model was initially developed as a notional representation of shear and moment produced by a group of vehicles routinely permitted on highways of various states under “grandfather” exclusions to weight laws.

The traditional inventory and operating levels are maintained within the design-load rating procedures. Bridges that pass HL-93 screening at the Inventory level will have adequate capacity for all AASHTO legal loads and State legal loads that fall within the exclusion limits described in the LRFD Specifications.

Bridges that pass HL-93 screening only at the Operating level will have adequate capacity for AASHTO legal loads, but may not rate (The rating factor, RF, is less than 1.0.) for all State legal loads, specifically those vehicles significantly heavier than the AASHTO trucks.

6.2.2 Live Load

The HL-93 notional live-load model of the LRFD Specifications discussed in the Steel Bridge Design Handbook module titled Loads and Combinations, including the dynamic load allowance, is applied in design-load rating to provide a convenient screening of existing bridges for all federal and state legal loads.

6.2.3 Limit States

Strength I and Service II load combinations shall be checked for the design loading. These limit states are as discussed in the Steel Bridge Design Handbook module titled Limit States 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 Legal-Load Rating

6.3.1 General

Legal-load ratings establish the need for posting or bridge strengthening when the rating factor, RF, 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, less than 1.0 for legal loads may be evaluated for overweight permit loads.

6.3.2 Live Load

There are two main categories of legal loads that comply with all federal weight laws so they are legal in all 50 states:

1. Routine commercial vehicles, and

2. Specialized hauling vehicles (SHVs)

Dynamic load allowance is as specified in the LRFD Specifications 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.

6.3.2.1 Routine Commercial Vehicle

The three AASHTO family of legal loads (Type 3, Type 3S2 and Type 3-3) are used in load rating for routine commercial traffic. They have only fixed axles. These legal loads model three portions of the federal bridge formula which control short, medium, and long span lengths. These AASHTO vehicles model many of the configurations of present truck traffic. They are appropriate for use as rating and posting vehicles as they satisfy the goal of providing uniform reliability over all span lengths. Additionally, they are widely used as truck symbols on load posting signs and provide continuity with past practice.

The traditional family of three AASHTO legal-load vehicles is shown schematically in Figures D6A-1, D6A-2 and D6A-3 of the MBE.

For span lengths up to 200 feet, the MBE requires that only a legal-load vehicle is considered for legal-load rating. For span lengths greater than 200 ft., critical load effects shall be generated through the application of an AASHTO Type 3-3 vehicle multiplied by 0.75 combined with a lane load of 0.2 kips per linear feet. The superposition of the Type 3-3 vehicle and the lane load results in uniform reliability for span lengths greater than 200 ft (See Figure D6A-4 of the MBE).

6.3.2.2 Specialized hauling vehicles (SHV's)

Since the adoption of the AASHTO family of three legal loads, the trucking industry has introduced specialized single unit trucks with closely-spaced multiple axles of maximum load up to 80,000 lbs, still satisfying the federal bridge formula. These trucks known as Specialized Hauling Vehicles (SHV) are legal in all states. SHVs commonly have axle groups with lift axles, which should be in the down position when the truck is loaded.

Short multi-axle single-unit trucks with liftable axles are not adequately modeled by the traditional family of three AASHTO legal loads. The adoption of these newer AASHTO legal loads to represent these new truck configurations ensures the safety of our bridges for all current legal traffic live loads. These new SHVs include the SU4, SU5, SU6 and SU7; shown schematically in Figure D6A-7 of the MBE.

6.3.2.3 Notional Rating Load (NRL)

Notional Rating Load (NRL) was developed to serve as a single load model that will envelop the load effects on simple and continuous span bridges of the most critical single-unit SHV configurations weighing up to 80 kips. It is termed "notional" because it does not represent a particular truck.

Bridges that rate (The rating factor, RF, is greater or equal to 1.0) for the NRL will have adequate load capacity for all legal SHVs up to 80 kips. Bridges that do not rate for the NRL should be investigated to determine posting needs using the specific SHVs discussed previously.

The NRL is shown schematically in Figure D6A-6 of the MBE.

6.3.3 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 module titled *Limit States* for design.

6.3.4 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.

6.3.4.1 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.

Table 5 Routine Commercial Vehicle Evaluation Live Load Factors for Strength I

ADTT	Load Factor
unknown or ≥ 5000	1.80
= 1000	1.65
≤ 100	1.40

6.3.4.2 Specialized Hauling Vehicles

The evaluation live-load factors for SHVs at the Strength I limit-state load combination are given in Table 6.

Table 6 Specialized Hauling Vehicle Evaluation Live Load Factors for Strength I

ADTT	Load Factor
UNKNOWN OR ≥ 5000	1.60
= 1000	1.40
≤ 100	1.15

6.4 Permit-Load Rating

6.4.1 General

Permit-load rating reviews the safety and serviceability of bridges in the review of permit applications for the passage of vehicles above the legally established weight limitations. This third level of rating should only be applied to bridges having sufficient capacity for legal loads. 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.

6.4.2 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 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 span lengths over 200 ft. and when checking negative moments in continuous span bridges, an additional lane load shall be applied to simulate closely following vehicles. The lane load shall 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.

6.4.3 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 Steel Bridge Design Handbook module titled Limit State for design.

6.4.4 Load Factors

6.4.4.1 Routine/annual Permits

Routine permit-load rating uses the multi-lane distribution factors (DFs) of the LRFD Specifications. 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.

The live-load factors for routine permits are reduced with increasing permit weight, compared to legal loads, to account for the small likelihood of such simultaneous events during the evaluation period. This reduction accommodates the conservative application of multi-lane DFs.

The live-load factors are derived to account for the possibility of simultaneous presence of heavy trucks on the bridge when the permit vehicle crosses the span. Thus, the load factors are higher for spans with higher average daily truck traffic (ADTT).

Table 7 Routine/annual-permit Evaluation Live Load Factors for Strength II

DF	ADTT	Load Factor Permit-load Weight ≤ 100 kips	 ≥ 150 kips
two or more lanes	≥ 5000	1.80	1.30
	= 1000	1.60	1.20
	≤ 100	1.40	1.10

For situations where the routine permit is below 100 kips, the live-load factors approach those given for evaluating legal loads. When the routine permit weight is above 100 kips, the live-load factors are reduced as shown in Table 7. This reduction reflects the lower probability of two simultaneously heavy vehicles equal to the permit weight crossing the span simultaneously.

Linear interpolation can be used for values of ADTT and weight between the various ADTT and weight limits of the tables.

6.4.4.2 Special Permits

The MBE provides evaluation live-load factors for special permits for use with the one-lane DF's of the *LRFD Specifications*. The permit live-load factor accounts for the probable weight of an adjacent random truck during a special permit crossing when the bridge is open to other traffic.

When performing a special permit-load rating, the single-lane multiple presence factor of 1.20 incorporated into the LRFD one-lane DF should be divided out as it specifically relates to the HL-93 live-load model..

The evaluation live-load factors for special permit-load rating at the Strength II limit-state load combination are given in Table 8 below.

Table 8 Specialized Hauling Vehicle Evaluation Live Load Factors for Strength I

Trip Type	Other Traffic	DF	ADTT	Load Factor
single	escorted, no other traffic	single lane	n/a	1.15
single	mixed with other traffic		≥5000	1.50
			=1000	1.40
			≤100	1.35
multiple			≥5000	1.85
			=1000	1.75
			≤100	1.55

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.

Table 9 Rating Examples in the MBE

Example Number	Description
A1	an interior girder of a simple-span composite-steel stringer bridge
A5	an interior girder of a four-span continuous straight welded steel plate-girder bridge
A6	selected members of a simple-span through Pratt steel truss bridge
A8	girder and floorbeam of a simple-span two-girder steel bridge

8.0 REFERENCES

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