NSBA Guide to Navigating Routine Steel Bridge Design

Domenic Coletti, PE
Agenda

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The current situation...

- The AASHTO LRFD BDS is comprehensive
- The AASHTO LRFD BDS is thick (1900+ pages)
- The AASHTO LRFD BDS is a bit overwhelming
- Not everything in the BDS applies to every structure

Bottom line...

- A way to identify just the provisions applicable to routine steel I-girder bridge design would be nice
Background of the Guide

Result
- AISC hired HDR in 2019 to create a guide
- **NSBA Guide to Navigating Routine Steel Bridge Design**

Authors
- Mike Grubb (MA Grubb & Associates)
- Domenic Coletti (HDR)
- Tony Ream (HDR)
- Al Nelson (HDR)

Peer Reviewers
- Too many to name... representatives from NSBA, owner-agencies, and both large and small consulting design firms
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Basic Themes

• Filter for the AASHTO LRFD BDS
• Discussion of the AASHTO LRFD BDS
• Audience = designers with less steel bridge experience
Concept for the Guide

Key Ideas

- Definition of a “Routine Steel I-Girder Bridge”
- Applicability Determinations
- Discussions
- The role of the Guide vs. the BDS
Concept for the Guide

Definition of a “Routine Steel I-Girder Bridge”

- Straight girders, straight deck, little or no skew
- Constant width, constant depth
- Spans < 200’
- Stringer-type cross-section with at least 4 girders
- Contiguous truss-type cross-frames or solid diaphragms
- Composite concrete deck

LINE GIRDER ANALYSIS
Concept for the Guide

Definition of a “Routine Steel I-Girder Bridge”

DEFINITION CHECKLIST FOR A “ROUTINE STEEL I-GIRDER BRIDGE”

Answer all questions with “Yes” or “No”. If any questions are answered “No”, the bridge does not satisfy the definition of a routine steel I-girder bridge for the purposes of this Guide. For further detail on any of these criteria, please see the preceding section of the Guide: DEFINITION OF A “ROUTINE STEEL I-GIRDER BRIDGE”

If a given bridge somehow falls partially outside the limits of the definition of a “routine steel I-girder bridge”, or outside the exclusions of this scope, this Guide may still provide value to designers; in such cases, senior bridge engineers with extensive experience in steel bridge design should be consulted when determining if and how to apply any of the recommendations provided herein.

☐ Are the girders straight (non-curved)?
☐ Is the deck straight?
☐ Is the skew not more than 20 degrees?
☐ Are all supports parallel (or within 10 degrees of being parallel)?
☐ Are the cross-frames contiguous?
☐ Are the girders parallel?
☐ Is the deck constant width?
☐ Is the Skew Index (Eq. 4.6.3.3.2-2) less than or equal to 0.30?
☐ Do the girders have a constant web depth?
Concept for the Guide

Definition of a “Routine Steel I-Girder Bridge”
Concept for the Guide

Definition of a “Routine Steel I-Girder Bridge”
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Definition of a “Routine Steel I-Girder Bridge”
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Applicability Determinations

The various Determinations are defined as follows:

1. **Applicable:** The Article, in its entirety, is fully applicable to the design of routine steel I-girder bridges

2. **Partially Applicable:** Parts of the Article are applicable to the design of routine steel I-girder bridges, other parts are not applicable; see the Discussion for explanation

3. **Conditionally Applicable:** Some or all of the Article may be applicable to the design of routine steel I-girder bridges depending on the circumstances; see the Discussion for explanation

4. **Not Applicable:** None of the Article is applicable to the design of routine steel I-girder bridges

5. **Beyond Scope of Superstructure Design:** Some or all of the Article may be applicable to some aspect of the design of routine steel I-girder bridges, but is not applicable to superstructure design; see the Discussion for explanation
Concepts of the Guide

Discussions

- Guide “Discussions” are differentiated from AASHTO “Commentary”
- Discussions explain why the Determination is what it is
- Discussions offer helpful application suggestions
- Discussions include references and links to other industry design guidelines and design aids
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Delivery Formats

• PDF of the Guide
  • Use as an interactive design aid
  • Index of design tasks
  • Design Task Quick Links
  • Internal hyperlinks and bookmarks to aid navigation
  • External hyperlinks to many free resources
• Eventual web-based interactive design aid
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General Flow of Design Tasks

GENERAL FLOW OF DESIGN TASKS

Listed below are the general Design Tasks associated with the typical flow of design of a routine steel I-girder bridge superstructure. The list of Design Tasks is presented in roughly the typical order that they occur in the superstructure design process. However, as noted below, some topics apply to several Design Tasks. And, of course, the process of designing a bridge typically involves some degree of iteration; the initial results of later Design Tasks may suggest that revising part of the design which occurred earlier in the process might be beneficial. When iterating through a design in this manner, the designer is reminded that all steps of the design process should be checked to see if the revision of one part of the design might affect other parts. Each task/topic below is hyperlinked to its associated Design Task Quick Links page.

General Flow of Design Tasks:

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2. Deck Design
3. Resistance Factors and Load Modifiers
4. Load Combinations and Load Factors
5. Live Load Force Effects - Introduction
6. Live Load Force Effects - Flexure
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12. Girder Flexure Design – Fatigue and Fracture Limit State
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14. Girder Shear Design
15. Stiffener Design
16. Shear Connector Design
17. Splice Design
18. Cross-Frame/Diaphragm Design

Topics Which May Apply to Several Design Tasks:

- Bolted Connection Design
- Welded Connection Design
- Connection Design – Miscellaneous Checks
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Design Task Quick Links pages

**SPICE DESIGN**

**Quick Links to applicable AASHTO LRFD B RBs provisions, with Discussion**

Design field splice of members, considering the following:

- Design field splices of members:
  - Axial compression (6.10.6.1.4(a))
  - Flexure or shear (6.10.6.1.5(b))
  - Web splices (6.10.6.1.3(c))
- Welded splices (6.10.6.2)
- Minimum thickness requirements (6.7.2)

Determine design sizes and locations of welded shop splices, considering the following:

- Welded splices (6.10.6.2)
- Minimum thickness requirements (6.7.2)

**Quick Links to helpful industry design guidelines, references, and examples**

For more explorations and examples of field splice design, see:

- The Reference Manual for Bridge Design (RM BD); Load and Resistance Factor Design (LRFD) for Highway Bridges (5th Edition)
  - Sections 6.6.1 (Ballas), especially 6.6.2 (Theodore Marsham) (NOTE: The explanations in these references are written in the context of the bolted field splice provisions prior to publication of the 5th Edition of the AASHTO LRFD and are no longer valid).
- The AASHTO/AASCE Steel Bridge Construction Handbook (G13-08) Guideline on Design for Construction Fabrication and Fabrication
  - Section 1.5.3 (Hinge Plate Width) and Table 1.5.2.1, Section 3.2.1 (End Connections)
- RSMA’s Field Joint Options for Steel Bridge Structural Members: Overview and Design Examples

**Quick Links to useful tools**

The USDA, Agency’s 3D-based bolted field splice design spreadsheet is available for free-download from the USDA website. It is a valuable tool for the design of various steel-girder bridges. Implement the design of bolted field splice for internal girders in accordance with provisions of Article 6.10.6.3.3, greatly reducing the time and effort required of this designer. Other commercial software packages with the ability to design bolted field splices are also available.

Users should verify the capabilities, assumptions, and general consistency of any program’s calculations prior to initial use.
SPLICE DESIGN

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design field splices (if present), considering the following:

- Bolted field splices of flexural members
  - General considerations (6.13.6.1.3a)
  - Flange splices (6.13.6.1.3b)
  - Web splices (6.13.6.1.3c)
- Welded splices (6.13.6.2)
- Minimum thickness requirements (6.7.3)

Determine flange sizes and locations of welded shop splices, considering the following:

- Welded splices (6.13.6.2)
- Minimum thickness requirements (6.7.3)
6.13.6.1.3  Flexural Members

6.13.6.1.3a  General

Determination of applicability, All Routine Steel I-girder Bridges: Applicable.

Discussion:

A splice is defined as a group of bolted connections (or a welded connection) sufficient to transfer the moment, shear, axial force or torque between two structural elements joined at their ends to form a single, longer element. Bolted splices are typically used to connect member sections together in the field; hence, the term “field splice” is often used. The provisions of this Article cover general provisions for the design of bolted field splices for members subject to flexure, and hence, are applicable to the routine steel I-girder bridges covered by this Guide.

Bolted beam or girder field splices generally include top flange splice plates, web splice plates and bottom flange splice plates. In addition, if the plate thicknesses on one side of the joint are different than those on the other side, filler plates are used to match the thicknesses within the splice (see the Discussion of Article 6.13.6.1.4 in this Guide). For the flange splice plates, there is typically one plate on the outside of the flange and two smaller plates on the inside of the flange; one on each side of the web. For the web splice plates, there are two plates; one on each side of the web, with at least two rows of high-strength bolts over the depth of the web used to connect the splice plates to the member.

As required by Articles 6.13.6.1.3b and 6.13.6.1.3c, bolted flange and web splice connections are
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Quick links to helpful industry design guidelines, references, and examples

For more explanation and examples of field splice design, see:

- The Reference Manual for NIJ Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 6.6.5 (Splices), especially 6.6.5.2 (Flexural Members) (NOTE: The explanations in these references are written in the context of the bolted field splice provisions prior to publication of the 8th Edition of the AASHTO LRFD BDS and are thus out of date).
- The AASHTO-NSBA Steel Bridge Collaboration Guidelines Constructability and Fabrication
  - Section 1.5.3 (Flange Plate Width) and Table 1.5.2.A, Section 2.2.1 (Field Connections)
- NSBA’s Bolted Field Splices for Steel Bridge Flexural Members – Overview and Design Examples
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Guidelines to Design for Constructability and Fabrication

G12.1-2020
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Quick links to useful tools

The NSBA Splice, a Microsoft Excel-based bolted field splice design spreadsheet, is available for free download from the NSBA website and is a valuable tool for the design of routine steel I-girder bridges. It performs the design of a bolted field splice for a steel I-girder in accordance with the provisions of Article 6.13.6.1.3, greatly reducing the time and effort required of the designer. Other commercial software packages with the ability to design bolted field splices are also available.

Users should verify the capabilities, assumptions, and general correctness of any program’s calculations prior to initial use.
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**NSBA Splice**

NSBA Splice takes the time-consuming task of designing and checking a bolted splice connection and automates the process with a simple input page and output form. NSBA Splice can be incorporated as a design tool on plate girder bridges, allowing the designer to quickly analyze various bolted splice connections to determine the most efficient bolt quantity and configuration. Based upon the updated ANSI/AISC 360-10 edition, Splice allows the user to explore the effects of bolt spacing, bolt size, strength, and connection dimensions on the overall splice design.

Splice is presented in an easy-to-understand Microsoft Excel spreadsheet format allowing users with Microsoft Excel 2010 or later to access and use. The download includes the design spreadsheet as well as two completed examples drawn from the inputs and solutions for Examples 1 and 2 presented in Bolted Field Splices for Steel Bridge Flexural Members.

**DOWNLOAD NSBA SPlice**

The current version of NSBA Splice (v.1.1) was released on February 22, 2021 (Release Notes).

- Fill Plate
- Top Flange Splice Plates
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SPLICE DESIGN

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design field splices (if present), considering the following:

- Bolted field splices of flexural members
  - General considerations (6.13.6.1.3a)
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**General Considerations**

General considerations prior to beginning a detailed structural design include understanding the DINF Design philosophy and the concept of limit states design. Selecting basic design parameters such as target gage depth and spacing, identifying superstructure materials, and ensuring whether or not to make the deck composite with the girders. The following Design Tasks apply—each task is hyperlinked to its associated Design Task Quick Links page.

- **General Considerations**

**Deck Design**

The design of decks for reaction and bridle bridges is beyond the scope of this Guide. See the Design Guidelines for Highway Bridges (ASCE/SEI 350-14) for more information on the design of decks.

- **Deck Design**

**Loads**

The identification and calculation of various load effects is typically accomplished early in the design process. It is difficult to design the superstructure of a reaction and bridle bridge if the applicable loads are not known. The process of determining these loads begins with identification of the applicable load cases, definition of their associated load combinations, and specification of the various load modelling and load factors. Resistance factors are typically identified and quantified as well. Then the specific loading effects are calculated. The following Design Tasks apply—each task is hyperlinked to its associated Design Task Quick Links page.

- Resistance Factors and Load Modifiers
- Limit Combinations and Load Factors
- Live Load Force Effects—Individual
- Live Load Force Effects—Total
- Live Load Force Effects—Other
- Other Load Effects and Factors Affecting Load Effect Calculations
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Girder Design
Once the loads are defined, girder design follows. Various limit states must be addressed in girder design. Design tasks must reflect the most common or composite nature of the service that the structure will be subjected to. These tasks should be completed in a logical order. The following Design Tasks apply to girder design.

- Girder Design - Service Limit State
- Girder Design - Fatigue and Fracture Limit State
- Girder Design - Strength Limit State

Once the initial girder design is completed, shoring design of the web follows. It may be appropriate or necessary to iterate back through one or more girder design tasks. The following Design Tasks apply to girder design.

- Shoring Design

Design of Details and Bracing
Once the basic girder design is established, design of details and bracing can begin. The design of several details is associated directly with the girders, including cut-out design, shoring connection design, and welded field splice design. The following Design Tasks apply to the design of pre-tensioned details - each task is hyperlinked to its associated Design Task Quick Links page.

- Cut-out Design
- Shoring Connection Design
- Splice Design

Note that the detailing members (cross-members or diaphragms) can be designed. The following Design Task applies to bracing design - the task is hyperlinked to its associated Design Task Quick Links page.

- Cross-Member/Splicing Design

Connection Design Topics
Several design topics related to connections design are applicable in one or more Design Tasks. These topics are presented here for convenience. The following Design Tasks apply to these connection design topics - each task is hyperlinked to its associated Design Task Quick Links page.

- Welded Connection Design
- Connection Design - Miscellaneous Checks
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Girder Design
Once the loads are defined, girder design follows. Various limit states must be addressed in girder flexure design, and the design must reflect the noncomposite or composite nature of the superstructure at the time each load is applied.

Generally, it is most efficient to perform the flexural design first, and then design for shear afterwards. The following Design Tasks apply to girder flexure design – each task is hyperlinked to its associated Design Task Quick Links page.

- Girder Flexure Design – General
- Girder Flexure Design – Constructibility
- Girder Flexure Design – Service Limit State
- Girder Flexure Design – Fatigue and Fracture Limit State
- Girder Flexure Design – Strength Limit State

Once the initial flexure design is completed, shear design of the web follows. It may be appropriate or necessary to iterate back through more than one cycle of flexure design and shear design. The following Design Task applies to girder shear design – the task is hyperlinked to its associated Design Task Quick Links page.

- Girder Shear Design

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Design of Details and Bracing
Once the basic girder design is established, design of details and bracing can begin. The design of several details is associated directly with the girders, including stiffener design, shear connector design, and bolted field splice design. The following Design Tasks apply to the design of girder-related details – each task is hyperlinked to its associated Design Task Quick Links page.

- Stiffener Design
- Shear Connector Design
- Splice Design

Next the bracing members (cross-frames or diaphragms) can be designed. The following Design Task applies to bracing design – the task is hyperlinked to its associated Design Task Quick Links page.

- Cross-Frame/Diaphragm Design

Quick links to helpful industry design guidelines, references, and examples

- The Reference Manual for NBI Course 136152, Design and Evaluation of Steel Bridges for Fatigue and Fatigue
  Section 6.3.4.3 (New Study)
- The Reference Manual for NBI Course 139081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  Section 9.8.2 (New Connections)
- AASHTO LRFD Bridge Design
  Design Examples: Three-Span Continuous Bridge, Girder Bridge
  Design Examples: Three-Span Continuous Bridge, Splice Bridge
  Design Examples: Three-Span Continuous Bridge, Shear Connector Bridge

Quick links to useful tools

NSRAs LRFD Bridge Shear analysis and design software license is available for free downloaded from the NSRA website in order to validate the design of our steel girders. It provides design calculations including the structural steel and maximum of, analyze degrees of stress, strength, and stress service stress, and the requirements of the AASHTO LRFD Bridge Design Specifications. The software package includes the following analysis procedures and software tools are available.

Users should verify the capabilities, assumptions, and general execution of the program's calculations prior to initial use.

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SHEAR CONNECTOR DESIGN

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design shear connectors for the fatigue and strength limit states, considering the following:

- General provisions (6.10.10.1, 6.10.10.1.1, 6.10.10.1.2, 6.10.10.1.3, 6.10.10.1.4)
- Fatigue resistance (6.10.10.2)
- Special requirements for points of permanent load contraflexure (6.10.10.3)
- Strength limit state (6.10.10.4.1, 6.10.10.4.2, 6.10.10.4.3)
6.10.10.2  Fatigue Resistance

Determination of applicability, *All Routine Steel I-girder Bridges*: Partially applicable.

Discussion:

The provisions of this Article are used to determine the fatigue resistance of an individual shear connector, \( Z_f \). \( Z_f \) is used in the calculation of the required pitch, \( p \), at the fatigue limit state (Article 6.10.10.1.2). Only the provisions for stud shear connectors should be considered applicable to the routine I-girder bridges covered by this Guide.

When the 75-year single lane Average Daily Truck Traffic (ADTT)\(_{SL}\) (Article 3.6.1.4.2) is greater than or equal to 1,090 trucks per day, the fatigue shear resistance for infinite life determined from Eq. 6.10.10.2-1 is used for \( Z_f \). Otherwise, the fatigue shear resistance for finite life determined from Eq. 6.10.10.2-2 is used for \( Z_f \). For a fatigue design life other than 75 years and/or a number of stress cycles per truck passage (\( n \) from Table 6.6.1.2.5-2) other than 1.0, see the specification Commentary for this Article.
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For more explanation and examples of the determination of the design of shear connectors at the fatigue and strength limit states, see Section 6.3.6.3 of Reference Manual for NHI Course 130122, Design and Evaluation of Steel Bridges for Fatigue and Fracture, Section 6.6.2 of Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures as well as FHWA’s Steel Bridge Design Handbook, Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge, Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge, and Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge.

The NSBA's LRFD Simon line-girder analysis and design software available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It performs design calculations addressing the demand on, and resistance of, shear connectors at the fatigue and strength limit states in accordance with the provisions of the AASHTO LRFD BDS, greatly reducing the time and effort required of the designer. Other commercial software packages with the ability to analyze and design routine steel I-girder bridges are also available. Users should verify the capabilities, assumptions, and general correctness of any program’s calculations prior to initial use.
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6.10.10.2 Fatigue Resistance

Determination of applicability, *All Routine Steel I-girder Bridges*: Partially applicable.

Discussion:

The provisions of this Article are used to determine the fatigue resistance of an individual shear connector, $Z_r$. $Z_r$ is used in the calculation of the required pitch, $p$, at the fatigue limit state (Article 6.10.10.1.2). Only the provisions for stud shear connectors should be considered applicable to the routine I-girder bridges covered by this Guide.

When the 75-year single lane Average Daily Truck Traffic ($ADTT_{SL}$) (Article 3.6.1.4.2) is greater than or equal to 1,090 trucks per day, the fatigue shear resistance for infinite life determined from Eq. 6.10.10.2-1 is used for $Z_r$. Otherwise, the fatigue shear resistance for finite life determined from Eq. 6.10.10.2-2 is used for $Z_r$. For a fatigue design life other than 75 years and/or a number of stress cycles per truck passage ($n$ from Table 6.6.1.2.5-2) other than 1.0, see the specification Commentary for this Article.
Agenda

Background of the Guide

Concept for the Guide

Content of the Guide

Summary
Summary

Background of the Guide
Concept for the Guide
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Questions

NSBA’s new guide, *Navigating Routine Steel Bridge Design*, is intended to:

A. Replace the AASHTO LRFD BDS
B. Replace the FHWA Steel Bridge Design Handbook
C. Replace the NHI course Reference Manuals
D. Replace the AASHTO/NSBA Steel Bridge Collaboration Guidelines
E. Complement all of the above
Questions

True or False:
All bridge engineers should you read NSBA’s new guide, “Navigating Routine Steel Bridge Design,” from cover to cover.

NSBA’s new guide, *Navigating Routine Steel Bridge Design*, includes links directly to numerous references and resources. How many of them are free?
A. All of them
B. None of them
C. About 37.64% of them