
Photo: 2020 Prize Bridge National Winner – Manning Crevice (Idaho) – Photo Credit: Ken Saindon

Using the New Guide to Streamline Design

Brandon Chavel, PhD, PE – Director of Market Development

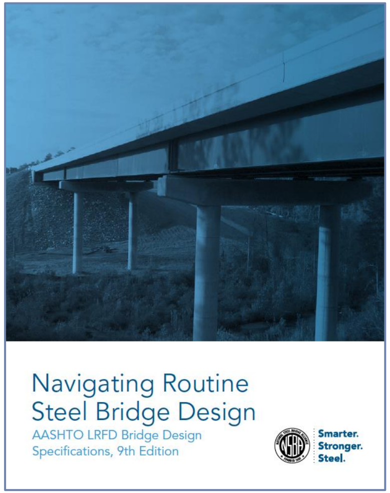
National Steel Bridge Alliance

Smarter.
Stronger.
Steel.

Using the New Guide

- Let’s now talk about how one can use this guide as they walk through a design…..

- As a reminder, the New Guide is not meant to be read cover to cover!



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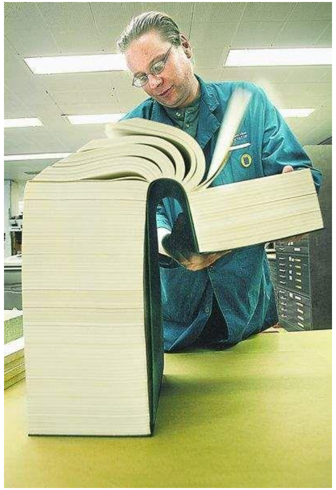
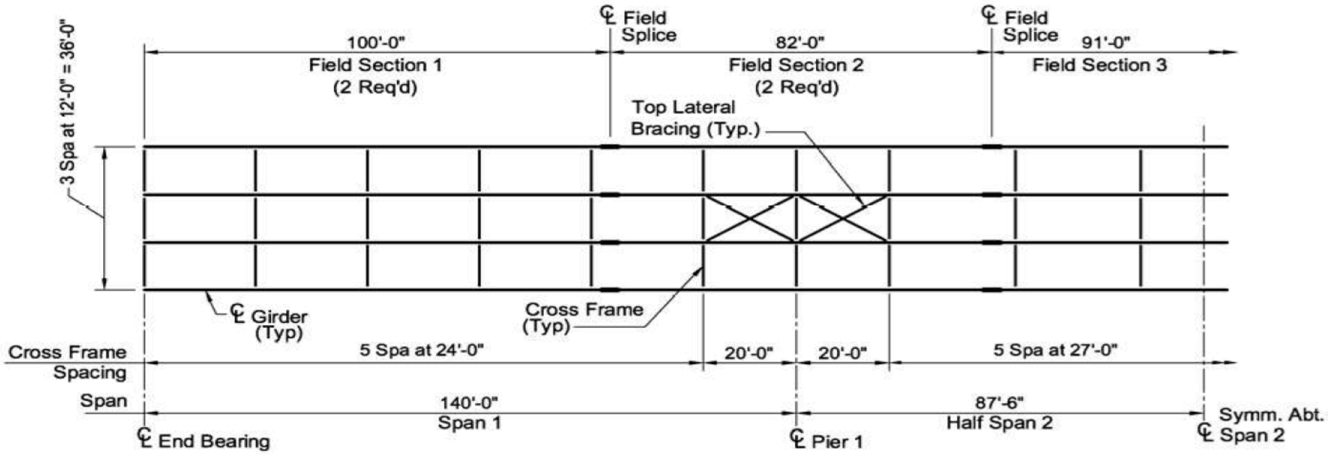
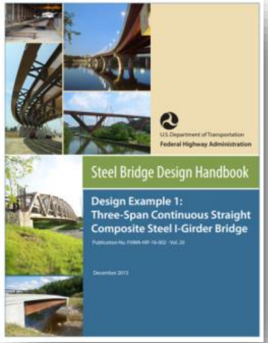


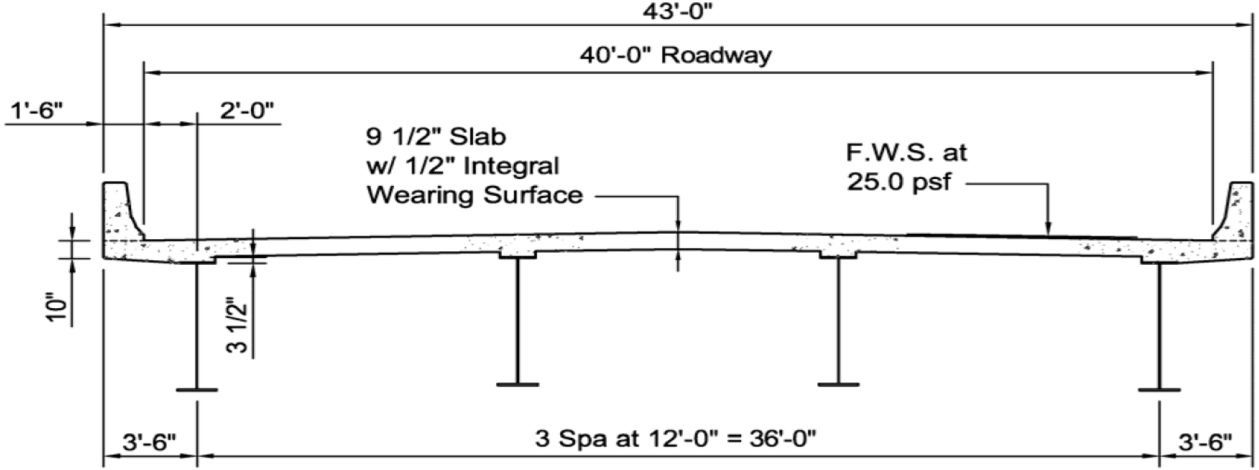
Walk-Through Example

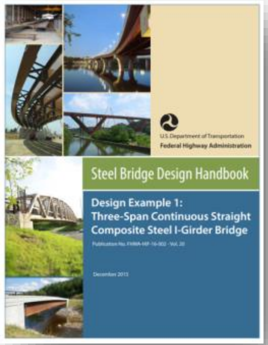




- Spans @ 140’ – 175’ – 140’
- Cross frames @ 24’ and 20’ centers (end spans)
- Cross frames @ 27’ and 20’ centers (center span)
- Field section lengths: 100’ (end spans), 91’ (center span) and 82’ (over piers)

Walk-Through Example

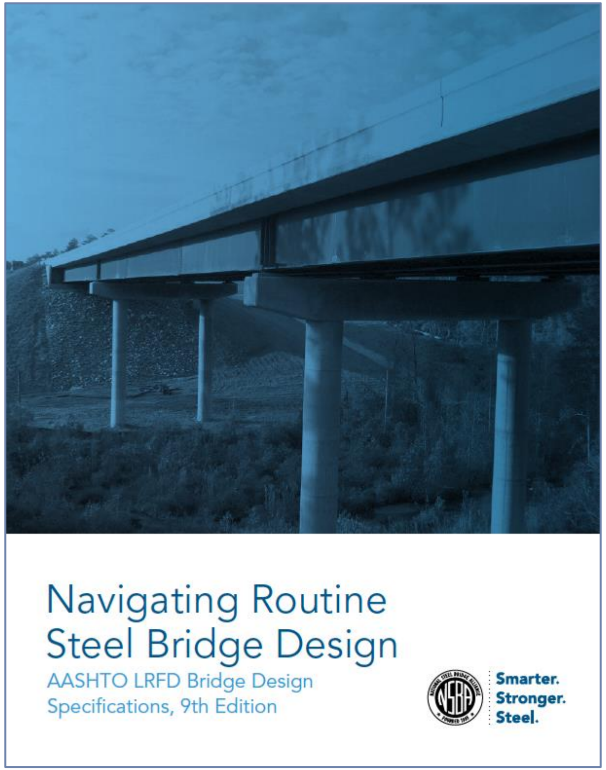




- 12 ft girder spacing
- 9-½″ deck thickness (9″ structural thickness)
- 3-½″ deck haunch; future wearing surface = 25 psf;
- Barriers are 520 lb/ft each
- Overhangs: 3.5 ft

Presentation Outline

- Live Load Force Effects - Flexure
- Girder Flexure Design
  - General
  - Constructability
- Splice Design
- Summary



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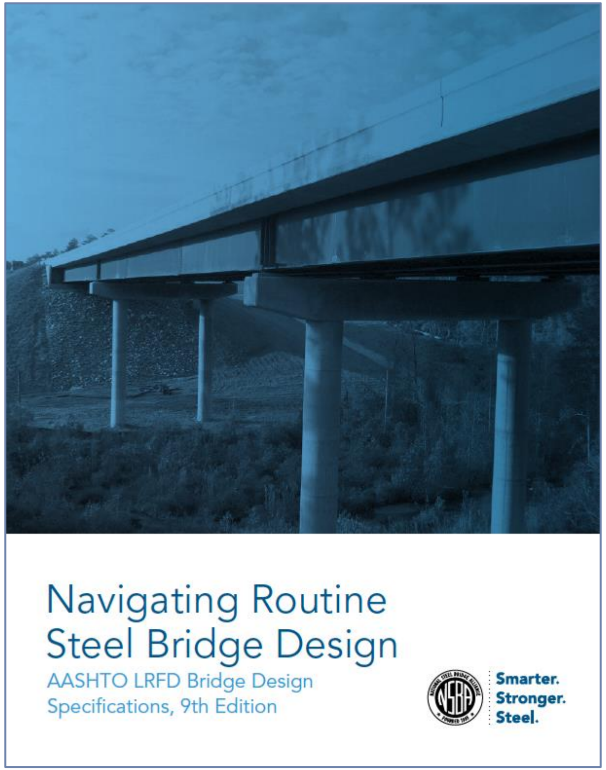


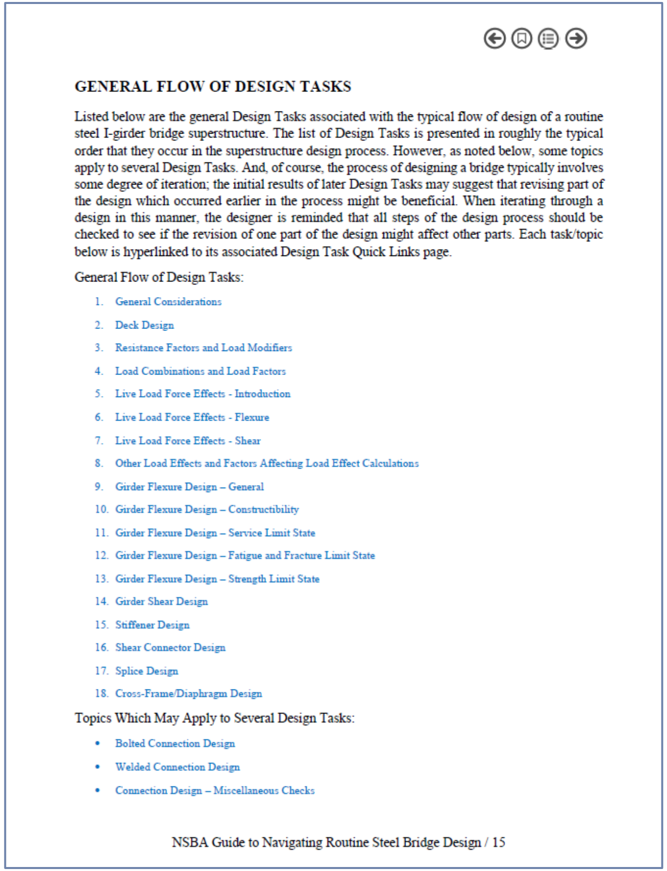
Live Load Force Effects - Flexure

Objective – Live load distribution factors for flexure

Start with General Flow of Design Tasks

Click on:

6. Live Load Force Effects - Flexure



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:

1. General Considerations
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
7. Live Load Force Effects - Shear
8. Other Load Effects and Factors Affecting Load Effect Calculations
9. Girder Flexure Design – General
10. Girder Flexure Design – Constructibility
11. Girder Flexure Design – Service Limit State
12. Girder Flexure Design – Fatigue and Fracture Limit State
13. Girder Flexure Design – Strength Limit State
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

Live Load Force Effects – Flexure

Design Task Links Page

LIVE LOAD FORCE EFFECTS - FLEXURE

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

- Determine distribution factors for moment, considering:
  - Interior beams with concrete decks (4.6.2.2.2b)
  - Exterior beams (4.6.2.2.2d)
  - Skewed bridges (4.6.2.2.2e)

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

For more explanation and examples of the determination of live load force effects with regards to flexure, see:

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Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It can automatically calculate the live load distribution factors necessary for the analysis, 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.

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Live Load Force Effects – Flexure

LIVE LOAD FORCE EFFECTS - FLEXURE

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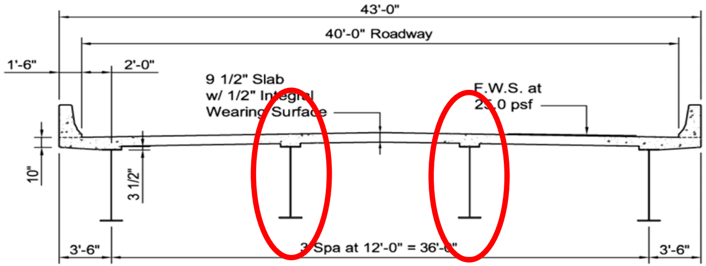
Live Load Force Effects – Flexure

Determination and Discussion

Interior Girders



4.6.2.2.2b Interior Beams with Concrete Decks

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

Discussion:

This Article addressed the live load distribution factor for moment on interior beams. The equations in the third row of Table 4.6.2.2.2b-1 ("Concrete Deck or Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-beams, T- and Double T-sections") are the only equations applicable for calculation of live load distribution factors for moment on interior beams of routine steel I-girder bridges. The routine steel I-girder bridges covered by this Guide satisfy the limitations specified in the table for the use of these distribution factors.

Note that the live load distribution factor equations of Table 4.6.2.2.2b-1 inherently include consideration of multiple presence (Article 3.6.1.1.2) as discussed in this Article, in Article 3.6.1.1.2, and associated Commentary for both articles (see also the Discussion of Article 3.6.1.1.2 in this Guide). When evaluating the live load distribution for interior girders at the strength and service limit states, the live load distribution factors calculated from the formulas given in the table should not be modified to account for multiple presence. However, as discussed in the Commentary for Article 3.6.1.1.2 and in the Discussion of Article 3.6.1.1.2 in this Guide, the multiple presence factor of 1.20 should be removed from the one-lane-loaded live load distribution factor for interior girders calculated from the formula given in the table for evaluation of the fatigue limit state.

Section 4.4.2 of the Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures provides an extensive and helpful discussion of the AASHTO LRFD BDS approximate live load distribution factors for moment in interior girders, including example calculations.

Most commercial line girder analysis programs (such as NSBA's LRFD Simon line-girder analysis and design program) automatically calculate the live load distribution factors necessary for the analysis. Users should verify the capabilities, assumptions, and general correctness of any program's calculations of the live load distribution factors prior to initial use.

Live Load Force Effects – Flexure

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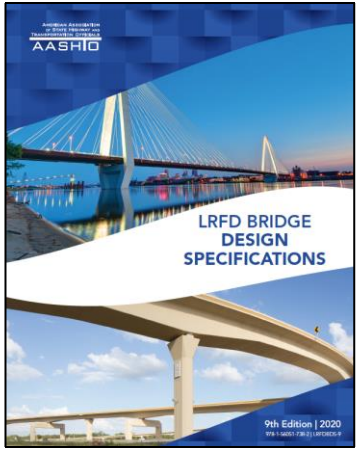
Partially Applicable: Parts of the Article are applicable to the design of routine steel I-girder bridges, other parts are not applicable.

Equations in 3rd Row of Table 4.6.2.2.2b-1 are only ones applicable to our example bridge.

Live Load Force Effects - Flexure

Table 4.6.2.2.2b-1—Live Load Distribution Factor for Moment in Interior Beams

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	Distribution Factors	Range of Applicability
Wood Deck on Wood or Steel Beams	a, l	See Table 4.6.2.2.2a-1	
Concrete Deck on Wood Beams	l	One Design Lane Loaded: $S/12.0$ Two or More Design Lanes Loaded: $S/10.0$	$S \leq 6.0$
Concrete Deck or Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T- and Double T-Sections	a, e, k and also i, j if sufficiently connected to act as a unit	One Design Lane Loaded: $0.06+\left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12.0Lt_s^3}\right)^{0.1}$ Two or More Design Lanes Loaded: $0.075+\left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12.0Lt_s^3}\right)^{0.1}$	$3.5 \leq S \leq 16.0$ $4.5 \leq t_s \leq 12.0$ $20 \leq L \leq 240$ $N_b \geq 4$ $10{,}000 \leq K_g \leq 7{,}000{,}000$
		use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$



Live Load Force Effects – Flexure

4.6.2.2.2b Interior Beams with Concrete Decks

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Important Notes!

- *MPFs included in LLDF from Table 4.6.2.2.2b-1*
- *For Fatigue, MPF of 1.20 should be removed from the one-lane-loaded LLDF*

Live Load Force Effects – Flexure

4.6.2.2.2b Interior Beams with Concrete Decks

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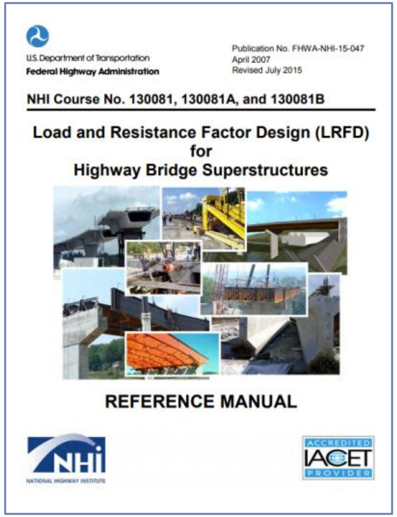

Live Load Force Effects – Flexure

Design Task Links Page

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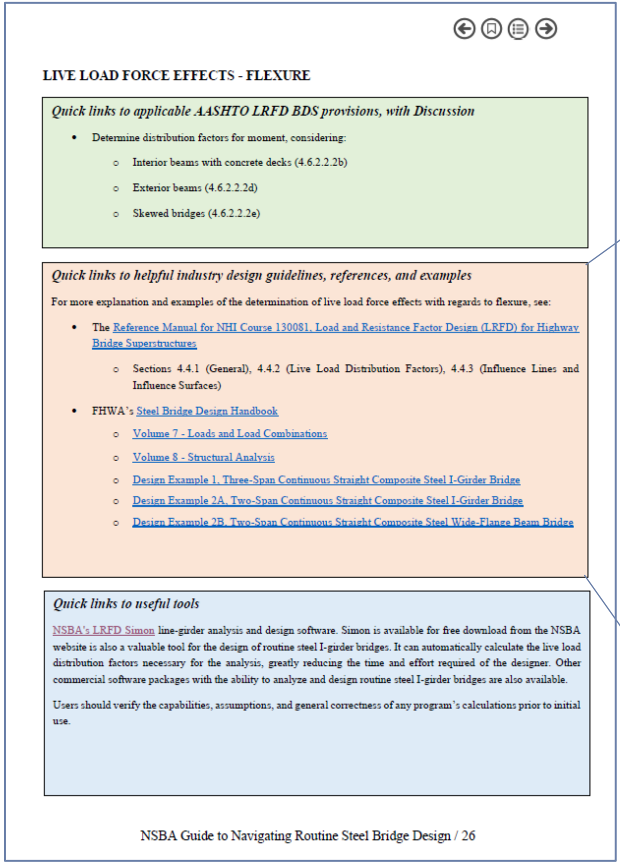

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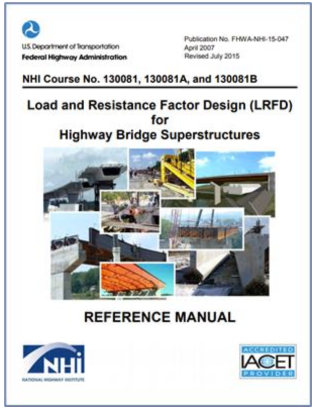

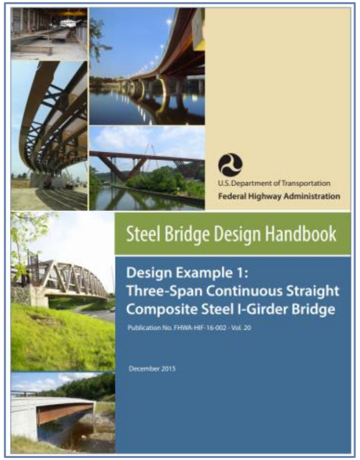

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  - Sections 4.4.1 (General), 4.4.2 (Live Load Distribution Factors), 4.4.3 (Influence Lines and Influence Surfaces)
- FHWA's Steel Bridge Design Handbook
  - Volume 7 - Loads and Load Combinations
  - Volume 8 - Structural Analysis
  - Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It can automatically calculate the live load distribution factors necessary for the analysis, 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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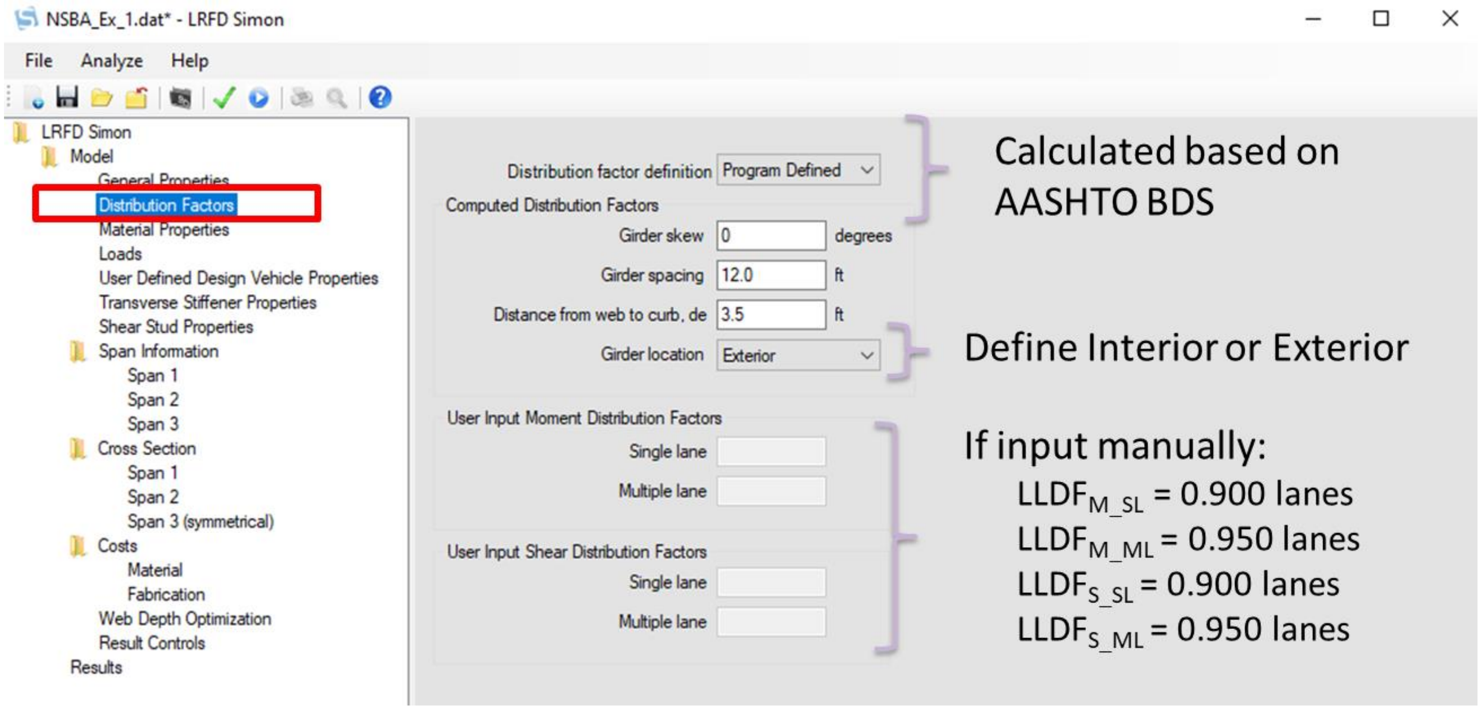
Live Load Force Effects - Flexure

- NSBA's LRFD SIMON



Calculated based on AASHTO BDS

Define Interior or Exterior

If input manually:

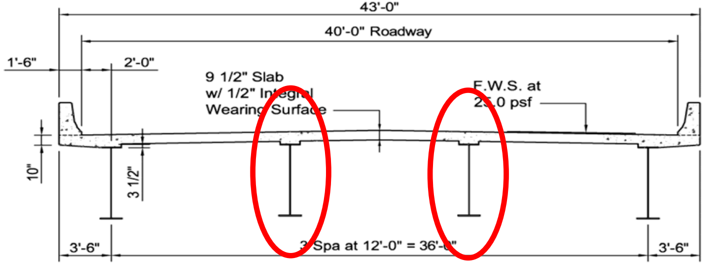
$LLDF_{M\_SL}$ = 0.900 lanes

$LLDF_{M\_ML}$ = 0.950 lanes

$LLDF_{S\_SL}$ = 0.900 lanes

$LLDF_{S\_ML}$ = 0.950 lanes

Live Load Force Effects - Flexure



One lane loaded:

$$0.06+\left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12.0Lt_S^3}\right)^{0.1}$$

$$0.06+\left(\frac{12.0}{14}\right)^{0.4}\left(\frac{12.0}{140.0}\right)^{0.3}\left(\frac{1.81\,x\,10^6}{12.0(140.0)(9.0)^3}\right)^{0.1}=0.528\ \text{lanes}$$

Two or more lanes loaded:

$$0.075+\left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12.0Lt_S^3}\right)^{0.1}$$

$$0.075+\left(\frac{12.0}{9.5}\right)^{0.6}\left(\frac{12.0}{140.0}\right)^{0.2}\left(\frac{1.81\,x\,10^6}{12.0(140.0)(9.0)^3}\right)^{0.1}=0.807\ \text{lanes (governs)}$$

Live Load Force Effects – Flexure

Design Task Links Page

LIVE LOAD FORCE EFFECTS - FLEXURE

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

- Determine distribution factors for moment, considering:
  - Interior beams with concrete decks (4.6.2.2.2b)
  - Exterior beams (4.6.2.2.2d)
  - Skewed bridges (4.6.2.2.2e)

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

For more explanation and examples of the determination of live load force effects with regards to flexure, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 4.4.1 (General), 4.4.2 (Live Load Distribution Factors), 4.4.3 (Influence Lines and Influence Surfaces)
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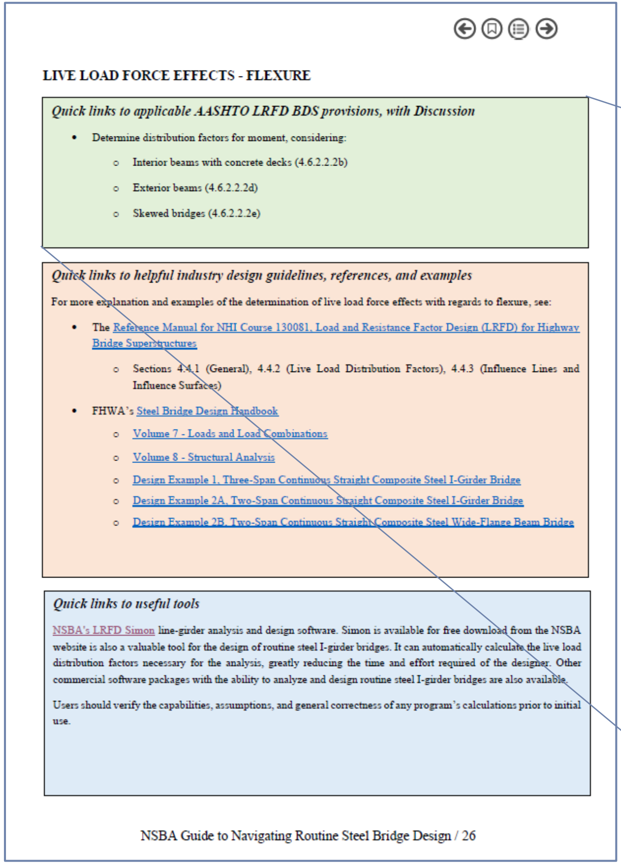
Users should verify the capabilities, assumptions, and general correctness of any program's calculations prior to initial use.

Live Load Force Effects – Flexure



LIVE LOAD FORCE EFFECTS - FLEXURE

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

- Determine distribution factors for moment, considering:
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  - Skewed bridges (4.6.2.2.2e)

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For more explanation and examples of the determination of live load force effects with regards to flexure, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
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Users should verify the capabilities, assumptions, and general correctness of any program's calculations prior to initial use.

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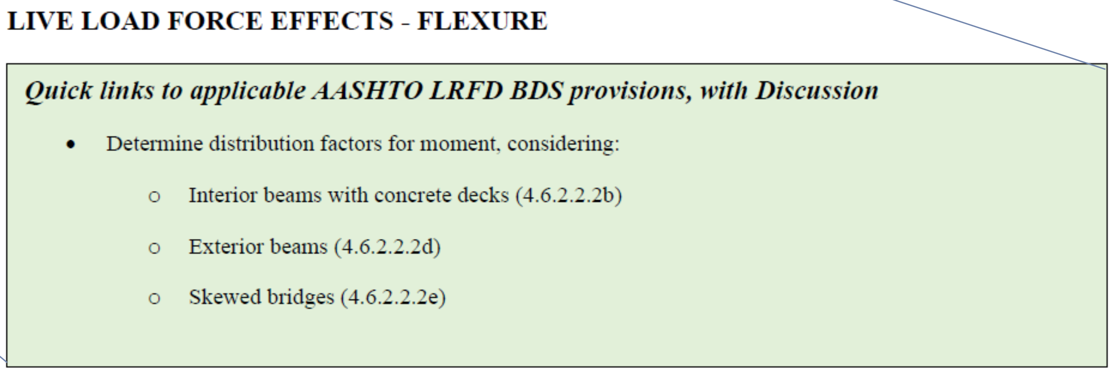


LIVE LOAD FORCE EFFECTS - FLEXURE

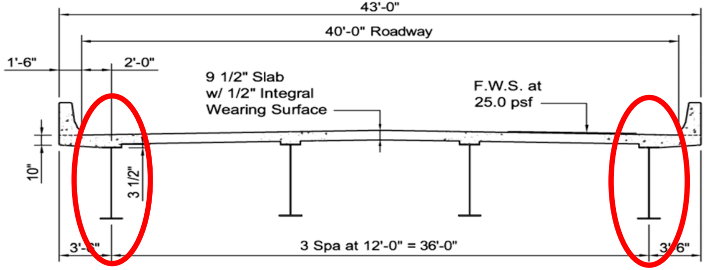
Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

- Determine distribution factors for moment, considering:
  - Interior beams with concrete decks (4.6.2.2.2b)
  - Exterior beams (4.6.2.2.2d)
  - Skewed bridges (4.6.2.2.2e)

Live Load Force Effects – Flexure

Determination and Discussion

Exterior Girders



4.6.2.2.2d Exterior Beams

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

Discussion:

This Article addressed the live load distribution factor for moment on exterior beams. The equations the third row of Table 4.6.2.2.2d-1 ("Concrete Deck or Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-beams, T- and Double T-sections") are the only equations applicable for calculation of live load distribution factors for moment on exterior beams of routine steel I-girder bridges. The routine steel I-girder bridges covered by this Guide satisfy the limitations specified in the table for the use of these distribution factors.

Note that the live load distribution factor equations of Table 4.6.2.2.2d-1 inherently include consideration of multiple presence (Article 3.6.1.1.2) as discussed in this Article, in Article 3.6.1.1.2, and associated Commentary for both articles (see also the Discussion of Article 3.6.1.1.2 in this Guide). When evaluating live load distribution for exterior girders at the strength and service limit states, the live load distribution factor calculated from the formula given in the table for the case of two or more lanes loaded should not be modified to account for multiple presence.

For situations where only one design lane is loaded, the lever rule is used to calculate the distribution factor for moment in an exterior girder. For further description of the lever rule, see the Commentary for Article 4.6.2.2.1. The provisions of Article 3.6.1.1.1 regarding the placement of the design lanes and the placement of the wheel loads within those lanes should be followed when utilizing the lever rule. When evaluating the live load distribution for exterior girders for one-lane loaded at the fatigue limit state utilizing the lever rule, the multiple presence factor of 1.2 should not be applied. When evaluating the live load distribution for exterior girders utilizing the lever rule for situations where only one design lane is loaded at the strength and service limit states, the appropriate multiple presence factor specified in Table 3.6.1.1.2-1 must be applied. The presence or absence of cross-frames or diaphragms is not considered when calculating distribution factors using the lever rule, which only considers the deck acting as a lever supported by the exterior and first interior girder.

In addition, this Article specifies that for steel bridge cross-sections with cross-frames or diaphragms, the live load distribution factor for the exterior girder *is not to be taken less than* that which would be obtained by assuming the cross-section deflects and rotates as a rigid cross-section. This special analysis is specified because the empirical distribution factors for moment given in the specification table were determined without consideration of cross-frames or diaphragms; hence, while they are conservative for interior girders, they are generally unconservative for exterior girders in steel multi-girder bridges. Therefore, the distribution factor for moment in the exterior girders determined from this special analysis will usually control and should always be employed for routine steel I-girder bridges since the exterior girder is typically the critical girder for moment. It is recommended that Eq. C4.6.2.2.2d-1 be used to satisfy this assumption; the equation should be evaluated for one lane loaded and also for two or more lanes loaded (up to the total number of design lanes the design roadway width can accommodate). The provisions of Article 3.6.1.1.1 regarding the placement of the design lanes and the placement of

NSBA Guide to Navigating Routine Steel Bridge Design / 95

the wheel loads within those lanes should also be followed. When evaluating the live load distribution for exterior girders for one-lane loaded at the fatigue limit state utilizing the special analysis, the multiple presence factor of 1.2 should not be applied. When evaluating the live load distribution for exterior girders for any number of design lanes loaded at the strength and service limit states utilizing the special analysis, the appropriate multiple presence factor specified in Table 3.6.1.1.2-1 must be applied.

Section 4.4.2 of the Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures provides an extensive and helpful discussion of the AASHTO LRFD BDS approximate live load distribution factors for moment in exterior girders, including example calculations utilizing the specification formulas, the lever rule, and the special rigid cross-section analysis.

Most commercial line girder analysis programs (such as NSBA's LRFD Simon line-girder analysis and design program) automatically calculate the live load distribution factors necessary for the analysis. Users should verify the capabilities, assumptions, and general correctness of any program's calculations of the live load distribution factors prior to initial use. Note that the LRFD Simon program does not currently perform the special rigid cross-section analysis.

Live Load Force Effects - Flexure

4.6.2.2.2d Exterior Beams

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

Discussion:

This Article addressed the live load distribution factor for moment on exterior beams. The equations the third row of Table 4.6.2.2.2d-1 ("Concrete Deck or Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-beams, T- and Double T-sections") are the only equations applicable for calculation of live load distribution factors for moment on exterior beams of routine steel I-girder bridges. The routine steel I-girder bridges covered by this Guide satisfy the limitations specified in the table for the use of these distribution factors.

Note that the live load distribution factor equations of Table 4.6.2.2.2d-1 inherently include consideration of multiple presence (Article 3.6.1.1.2) as discussed in this Article, in Article 3.6.1.1.2, and associated Commentary for both articles (see also the Discussion of Article 3.6.1.1.2 in this Guide). When evaluating live load distribution for exterior girders at the strength and service limit states, the live load distribution factor calculated from the formula given in the table for the case of two or more lanes loaded should not be modified to account for multiple presence.

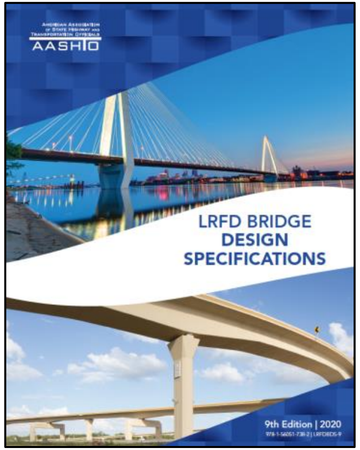
For situations where only one design lane is loaded, the lever rule is used to calculate the distribution factor for moment in an exterior girder. For further description of the lever rule, see

Equations in 3rd Row of Table 4.6.2.2.2d-1 are only ones applicable to our example bridge.

Live Load Force Effects - Flexure

Table 4.6.2.2.2d-1—Live Load Distribution Factor for Moment in Exterior Longitudinal Beams

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	One Design Lane Loaded	Two or More Design Lanes Loaded	Range of Applicability
Wood Deck on Wood or Steel Beams	a, l	Lever Rule	Lever Rule	N/A
Concrete Deck on Wood Beams	l	Lever Rule	Lever Rule	N/A
Concrete Deck or Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T- and Double T-Sections	a, e, k and also i, j if sufficiently connected to act as a unit	Lever Rule	$g = e\, g_{interior}$ $e = 0.77 + \frac{d_e}{9.1}$	$-1.0 \leq d_e \leq 5.5$
			use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$



Live Load Force Effects - Flexure

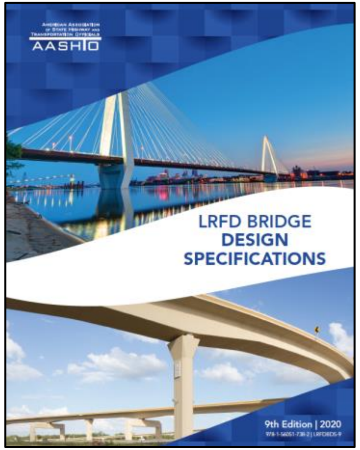
exterior and first interior girder.

In addition, this Article specifies that for steel bridge cross-sections with cross-frames or diaphragms, the live load distribution factor for the exterior girder *is not to be taken less than* that which would be obtained by assuming the cross-section deflects and rotates as a rigid cross-section. This special analysis is specified because the empirical distribution factors for moment given in the specification table were determined without consideration of cross-frames or diaphragms; hence, while they are conservative for interior girders, they are generally unconservative for exterior girders in steel multi-girder bridges. Therefore, the distribution factor for moment in the exterior girders determined from this special analysis will usually control and should always be employed for routine steel I-girder bridges since the exterior girder is typically the critical girder for moment. It is recommended that Eq. C4.6.2.2.2d-1 be used to satisfy this assumption; the equation should be evaluated for one lane loaded and also for two or more lanes loaded (up to the total number of design lanes the design roadway width can accommodate). The provisions of Article 3.6.1.1.1 regarding the placement of the design lanes and the placement of the wheel loads within those lanes should also be followed. When evaluating the live load distribution for exterior girders for one-lane loaded at the fatigue limit state utilizing the special analysis, the multiple presence factor of 1.2 should not be applied. When evaluating the live load distribution for exterior girders for any number of design lanes loaded at the strength and service limit states utilizing the special analysis, the appropriate multiple presence factor specified in Table 3.6.1.1.2-1 must be applied.

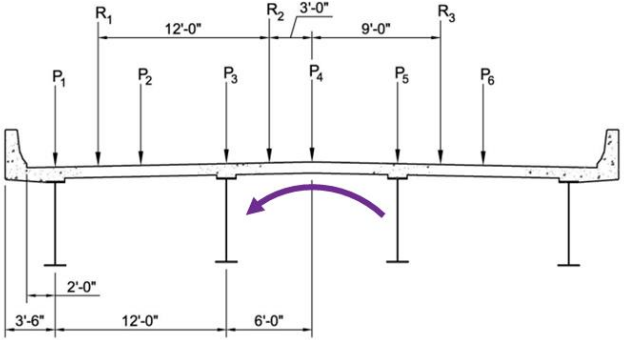
For exterior girders it is suggested to consider the Special Analysis of Eq. C4.2.2.2d-1.

Live Load Force Effects - Flexure

- Special Analysis (C4.6.2.2.2d - Commentary)
  - Assuming the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge, distribution factors for the exterior girder are also computed for one, two and three lanes loaded using the following formula



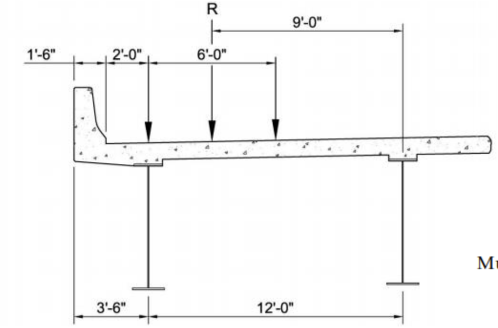
$$R = \frac{N_L}{N_b} + \frac{X_{ext}\sum^{N_L} e}{\sum^{N_b} x^2} \quad \text{(C4.6.2.2.2d-1)}$$



Live Load Force Effects - Flexure

Table 4.6.2.2.2d-1

One lane loaded: Use the lever rule (Table 4.6.2.2.2d-1)



$$\frac{9.0}{12.0} = 0.750$$

Multiple presence factor $m = 1.2$ (Table 3.6.1.1.2-1)

$$1.2(0.750) = 0.900 \text{ lanes}$$

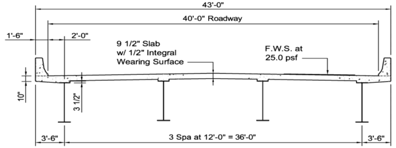
Two or more lanes loaded: Modify interior-girder factor by *e* (Table 4.6.2.2.2d-1)

$$e = 0.77 + \frac{d_e}{9.1}$$

$$e = 0.77 + \frac{2.0}{9.1} = 0.990$$

$$0.990(0.807) = 0.799 \text{ lanes}$$

Eq. C4.2.2.2d-1



Multiple presence factors (Table 3.6.1.1.2-1):

1 lane:	$m_1 = 1.2$
2 lanes:	$m_2 = 1.0$
3 lanes:	$m_3 = 0.85$

Referring to Figure 6:

One lane loaded:

$$R = \frac{1}{4} + \frac{(12.0+6.0)(12.0+3.0)}{2(18.0^2+6.0^2)} = 0.625$$

$$m_1R = 1.2(0.625) = 0.750 \text{ lanes}$$

Two lanes loaded:

$$R = \frac{2}{4} + \frac{(12.0+6.0)(12.0+3.0+3.0)}{2(18.0^2+6.0^2)} = 0.950$$

$$m_2R = 1.0(0.950) = 0.950 \text{ lanes (governs)}$$

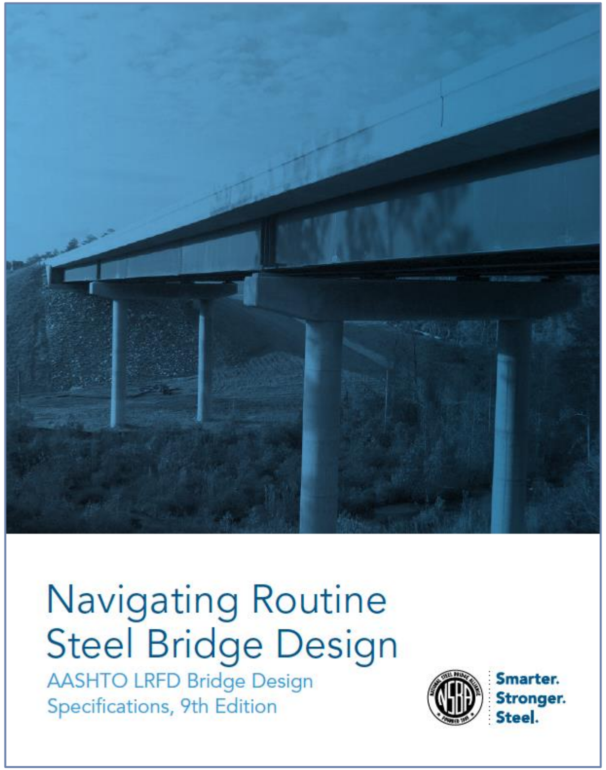
Three lanes loaded:

$$R = \frac{3}{4} + \frac{(12.0+6.0)(12.0+3.0+3.0-9.0)}{2(18.0^2+6.0^2)} = 0.975$$

$$m_3R = 0.85(0.975) = 0.829 \text{ lanes}$$

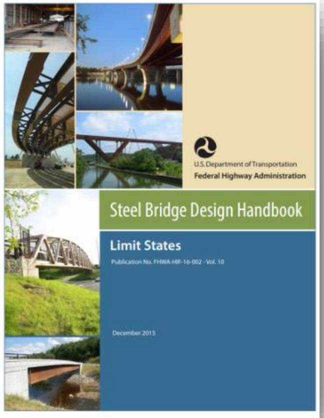
Presentation Outline

- Live Load Force Effects - Flexure
- **Girder Flexure Design**
  - **General**
  - Constructability
- Splice Design
- Summary



Girder Flexure Design

- AASHTO LRFD Limit States
  - Constructability*
  - Service
  - Fatigue
  - Strength
  - Extreme Event



** Not an AASHTO defined limit state, but often treated similarly (invoked under Strength Limit State).*

For more information, see FHWA SBDH Volume 10, Limit States

Girder Flexure Design

- General Flow of Design Tasks

Note that the Guide tells me that the Extreme Event Limit State is "beyond the scope of superstructure design" for routine bridges (Design Task Item 1, General Considerations).

General Flow of Design Tasks:

1. General Considerations
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
7. Live Load Force Effects - Shear
8. Other Load Effects and Factors Affecting Load Effect Calculations
9. Girder Flexure Design – General
10. Girder Flexure Design – Constructibility
11. Girder Flexure Design – Service Limit State
12. Girder Flexure Design – Fatigue and Fracture Limit State
13. Girder Flexure Design – Strength Limit State
14. Girder Shear Design
15. Stiffener Design
16. Shear Connector Design
17. Splice Design
18. Cross-Frame/Diaphragm Design

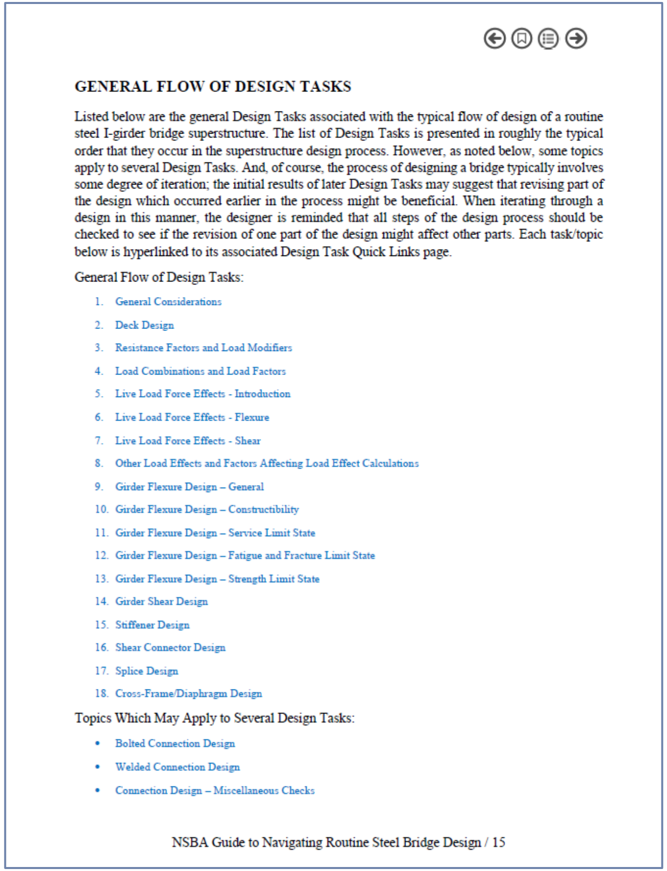
Girder Flexure Design

Objective – Perform Girder Flexure Design for Constructability

Start with General Flow of Design Tasks

Start with:

9. Girder Flexure Design - General



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:

1. General Considerations
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
7. Live Load Force Effects - Shear
8. Other Load Effects and Factors Affecting Load Effect Calculations
9. Girder Flexure Design – General
10. Girder Flexure Design – Constructibility
11. Girder Flexure Design – Service Limit State
12. Girder Flexure Design – Fatigue and Fracture Limit State
13. Girder Flexure Design – Strength Limit State
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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Girder Flexure Design - General

Design Task Links Page

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
- Flange Stresses and Member Bending Moments (6.10.1.6)
- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

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

For more explanation and examples of flexure design, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
- FHWA's Steel Bridge Design Handbook
  - Volume 1 – Bridge Steels and Their Mechanical Properties
  - Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge
- The Reference Manual for NHI Course 130102, Engineering for Structural Stability in Bridge Construction

In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the stresses in the section in accordance with the provisions of the AASHTO LRFD BDS, greatly reducing the time and effort required of the designer. NOTE that the Simone software currently does not include the capability to design the girders using the provisions of Appendix A6 to account for the ability of certain compact and noncompact web I-sections to develop flexural resistances significantly greater than the yield moment, M_y. 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.

Girder Flexure Design - General

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
- Flange Stresses and Member Bending Moments (6.10.1.6)
- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

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

For more explanation and examples of flexure design, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
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  - Volume 1 – Bridge Steels and Their Mechanical Properties
  - Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge
- The Reference Manual for NHI Course 130102, Engineering for Structural Stability in Bridge Construction

In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the stresses in the section in accordance with the provisions of the AASHTO LRFD BDS, greatly reducing the time and effort required of the designer. NOTE that the Simone software currently does not include the capability to design the girders using the provisions of Appendix A6 to account for the ability of certain compact and noncompact web I-sections to develop flexural resistances significantly greater than the yield moment, M_y. 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.

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
- Flange Stresses and Member Bending Moments (6.10.1.6)
- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

Girder Flexure Design - General

Determination and Discussion

6.10.1.1.1 *Stresses*

6.10.1.1.1a *Sequence of Loading*

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

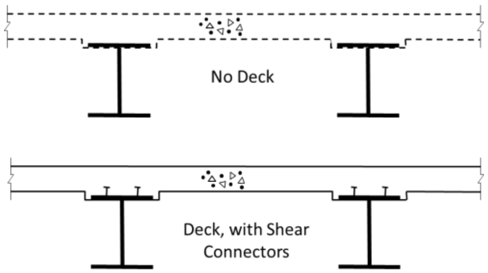
Discussion:

This Article describes for a composite section the necessary accumulation of the elastic stresses due to the applied dead and live loads acting on different sections; that is, the noncomposite component dead loads (referred to herein as DC_1 loads) acting on the bare steel section, the composite component dead loads (referred to herein as DC_2 loads) acting on the long-term (3*n*) transformed composite section to account for the effects of concrete creep, the wearing surface and utility loads (referred to as DW loads) acting on the long-term (3*n*) transformed composite section, and the live loads plus the dynamic load allowance (LL+IM) acting on the short-term (*n*) transformed composite section. The calculation of the long-term and short-term transformed composite sections is described in Articles 6.10.1.1.1b and 6.10.1.1.1c (see the Discussion of Articles 6.10.1.1.1b and 6.10.1.1.1c in this Guide). The accumulation of the elastic stresses must be accounted for in the design of steel I-girder bridges at the service and strength limit states (and in some cases involving the dead loads at the fatigue limit state).

This accumulation of the elastic stresses reflects the assumption that the routine steel I-girder bridges covered by this Guide are built using unshored construction, in which no support of the steel beams or girders (other than at permanent support points) is provided during the concrete deck construction, including no temporary supports. As a result, the bare steel beams or girders resist the permanent load applied before the concrete deck hardens and the composite girder section (steel girder alone, steel girder plus the composite concrete deck, or steel girder plus the longitudinal deck reinforcement, as applicable – see the Discussion of Articles 6.10.1.1.1b and

States which loads are applied to which section and which section properties to use….

- *DC_1 ➔ Bare Steel*
- *DC_2 ➔ Long-term transformed composite section (3n)*
- *DW ➔ Long-term transformed composite section (3n)*
- *(LL+IM) ➔ Short-term transformed composite section (n)*



Girder Flexure Design - General

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
- Flange Stresses and Member Bending Moments (6.10.1.6)
- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

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

For more explanation and examples of flexure design, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
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In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the stresses in the section in accordance with the provisions of the AASHTO LRFD BDS, greatly reducing the time and effort required of the designer. NOTE that the Simone software currently does not include the capability to design the girders using the provisions of Appendix A6 to account for the ability of certain compact and noncompact web I-sections to develop flexural resistances significantly greater than the yield moment, M_y. 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.

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
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- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

Girder Flexure Design - General

Determination and Discussion

D6.1 PLASTIC MOMENT

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

Discussion:

The plastic moment, M_p, is defined in the AASHTO LRFD BDS as the resisting moment about the major axis of a fully yielded cross-section. M_p is used as a theoretical measure of the maximum potential flexural resistance at the strength limit state of a noncomposite or composite section satisfying specific steel grade, flange and web slenderness, compression-flange bracing and ductility requirements, as applicable. For sections that can achieve the full plastic-moment resistance, it is assumed that the section is completely elastic up to M_p and then rotates inelastically at M_p with no increase in the moment resistance. The effects of strain hardening are conservatively ignored. This idealized moment-rotation behavior is termed elastic-perfectly plastic behavior. In the AASHTO LRFD BDS, composite sections in straight bridges in regions of positive flexure that can achieve flexural resistances at or near M_p are termed compact sections (see the Discussion of Article 6.10.6.2.2 in this Guide). Composite sections in regions of negative flexure and noncomposite sections subject to positive or negative flexure in straight bridges that can achieve flexural resistances of M_p are termed compact web sections and are less commonly used (see the Commentary for Article 6.10.6.2.3 and the Discussion of Article 6.10.6.2.3 in this Guide for further discussion on the definition and categorization of compact web, noncompact web, and slender web sections).

M_p is calculated as the moment of the plastic forces acting on the cross-section about the plastic neutral axis (*PNA*). For sections subject to flexure only, M_p may be calculated as the moment of the plastic forces about any axis parallel to the *PNA*. Plastic forces in steel portions of the cross-section are calculated using the yield strengths of the flanges, web, and longitudinal reinforcing steel, as appropriate. Plastic forces in concrete portions of the cross-section (in compression only) are based on a rectangular stress block, with the magnitude of the compressive stress taken equal to $0.85f'_c$. Concrete in tension is neglected. Equations to calculate these plastic forces are given in this Article. The position of the *PNA* is calculated based on the equilibrium condition that there is no net axial force acting on the cross-section.

For composite sections, the stress distribution in the cross-section at M_p is assumed independent of the manner in which the stresses are induced into the beam. Also, creep and shrinkage are assumed to have no effect on the internal stress distribution at M_p. Thus, when checking the flexural

Conditionally Applicable: Some or all of the Article may be applicable to the design of routine steel I-girder bridges depending on the circumstances

Background discussion on the plastic moment, M_p.

Girder Flexure Design - General

GIRDER FLEXURE DESIGN – GENERAL

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure, considering the following general topics:

- Composite Section Stresses (6.10.1.1.1a, 6.10.1.1.1b, 6.10.1.1.1c, 6.10.1.1.1d, 6.10.1.1.1e)
- Flange Stresses and Member Bending Moments (6.10.1.6)
- Fundamental Section Properties (D6.1, D6.2.1, D6.2.2, D6.2.3, D6.3.1, D6.3.2)
- Materials (6.4)
- Material Thickness (6.7.3)

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For more explanation and examples of flexure design, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
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  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge
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Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the stresses in the section in accordance with the provisions of the AASHTO LRFD BDS, greatly reducing the time and effort required of the designer. NOTE that the Simone software currently does not include the capability to design the girders using the provisions of Appendix A6 to account for the ability of certain compact and noncompact web I-sections to develop flexural resistances significantly greater than the yield moment, M_y. 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.

Quick Links to Guidelines, References, & Examples

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

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  - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
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In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Girder Flexure Design - General

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

For more explanation and examples of flexure design, see:

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    - Sections 6.4.5.2 (Plastic Moment), 6.4.5.3 (Yield Moment), 6.4.5.4.1 (Depth of Web in Compression in the Elastic Range), 6.4.5.4.2 (Depth of Web in Compression at the Plastic Moment), and 6.5.2 (LRFD Flexural Design Resistance Equations)
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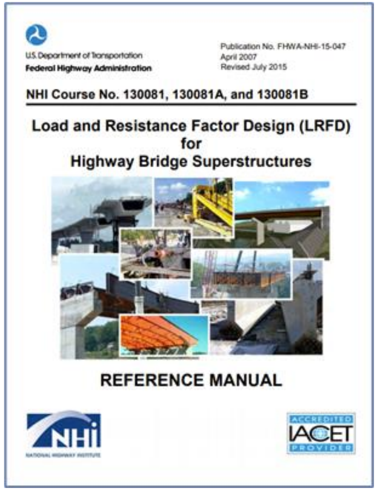
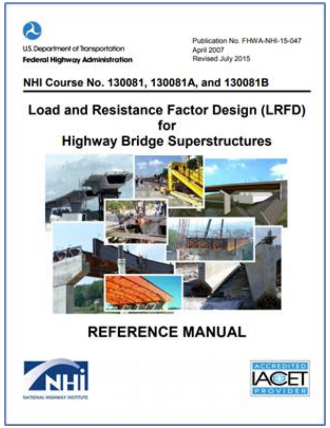
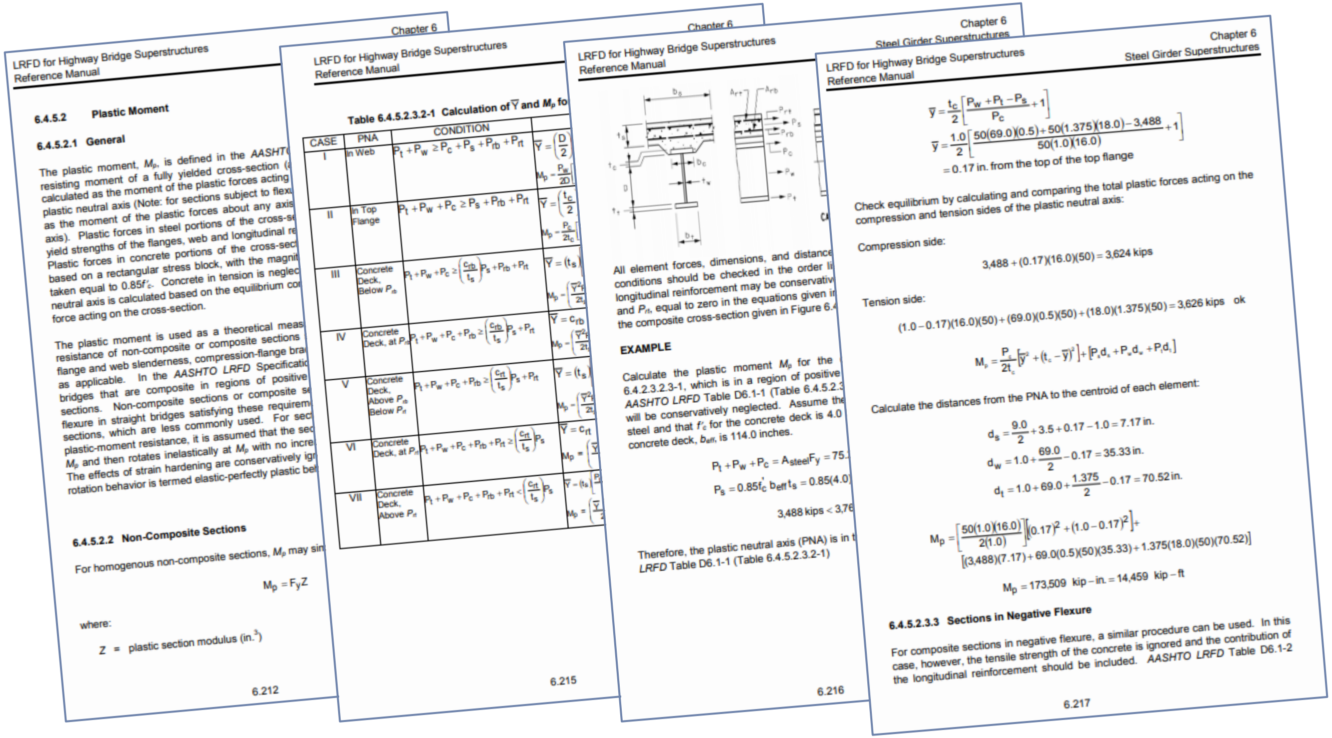


Girder Flexure Design - General





Girder Flexure Design – General (Example)

Section Properties

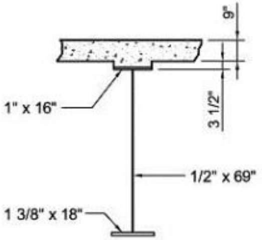


Figure 12: Section 1-1

Table 3 Section 1-1: Steel Only Section Properties

Component	A	d	Ad	Ad^2	I_o	I
Top Flange 1" x 16"	16.00	35.00	560.0	19,600	1.33	19,601
Web ½" x 69"	34.50				13,688	13,688
Bottom Flange $1^3/8$" x 18"	24.75	−35.19	−871.0	30,649	3.90	30,653
	75.25		−311.0			63,942
					−4.13(311.0) =	−1,284
					I_{NA} =	62,658 in.^{4}

$$d_s = \frac{-311.0}{75.25} = -4.13\text{ in.}$$

$$d_{TOP\,OF\,STEEL} = 35.50 + 4.13 = 39.63\text{ in.} \qquad d_{BOT\,OF\,STEEL} = 35.88 - 4.13 = 31.75\text{ in.}$$

$$S_{TOP\,OF\,STEEL} = \frac{62{,}658}{39.63} = 1{,}581\text{ in.}^3 \qquad S_{BOT\,OF\,STEEL} = \frac{62{,}658}{31.75} = 1{,}973\text{ in.}^3$$

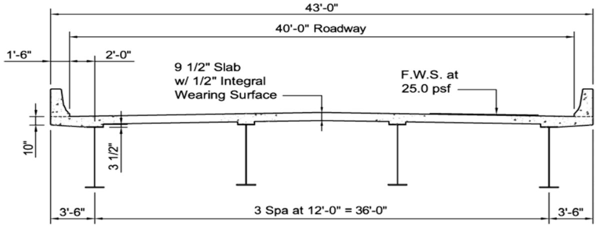


Table 4 Section 1-1: Long-term (3n = 24) Composite Section Properties

Component	A	d	Ad	Ad^2	I_o	I
Steel Section	75.25		−311.0			63,942
Concrete Slab 9" x 114"/ 24	42.75	42.50	1,817	77,217	288.6	77,506
	118.0		1,506			141,448
					−12.76(1,506) =	−19,217
					I_{NA} =	122,231 in.^{4}

$$d_{3n} = \frac{1{,}506}{118.0} = 12.76\text{ in.}$$

$$d_{TOPOFSTEEL} = 35.50 - 12.76 = 22.74\text{ in.} \qquad d_{BOTOFSTEEL} = 35.88 + 12.76 = 48.64\text{ in.}$$

$$S_{TOP\,OF\,STEEL} = \frac{122{,}231}{22.74} = 5{,}375\text{ in.}^3 \qquad S_{BOT\,OF\,STEEL} = \frac{122{,}231}{48.64} = 2{,}513\text{ in.}^3$$

Table 5 Section 1-1: Short-term (n = 8) Composite Section Properties

Component	A	d	Ad	Ad^2	I_o	I
Steel Section	75.25		−311.0			63,942
Concrete Slab 9" x 114"/ 8	128.25	42.50	5,451	231,652	865.7	232,518
	203.5		5,140			296,460
					−25.26(5,140) =	−129,836
					I_{NA} =	166,624 in.^{4}

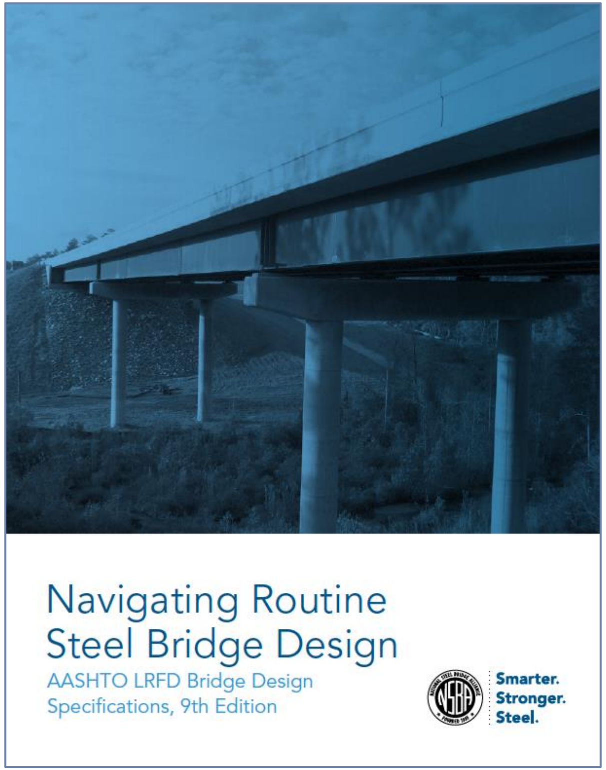
$$d_n = \frac{5{,}140}{203.5} = 25.26\text{ in.}$$

$$d_{TOPOFSTEEL} = 35.50 - 25.26 = 10.24\text{ in.} \qquad d_{BOTOFSTEEL} = 35.88 + 25.26 = 61.14\text{ in.}$$

$$S_{TOP\,OF\,STEEL} = \frac{166{,}624}{10.24} = 16{,}272\text{ in.}^3 \qquad S_{BOT\,OF\,STEEL} = \frac{166{,}624}{61.14} = 2{,}725\text{ in.}^3$$

Presentation Outline

- Live Load Force Effects - Flexure
- **Girder Flexure Design**
  - General
  - **Constructability**
- Splice Design
- Summary



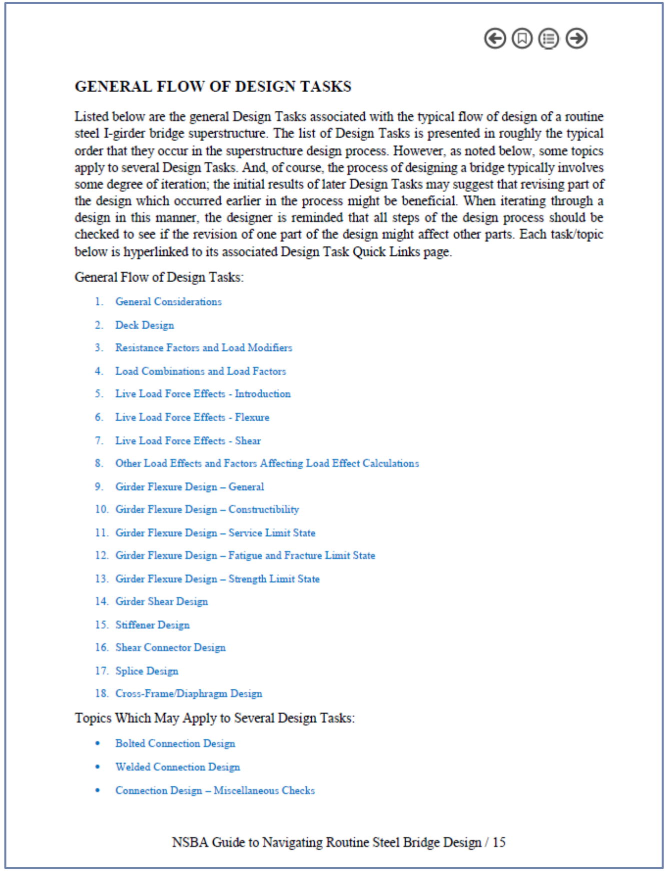
Girder Flexure Design - Constructability

Objective – Perform Girder Flexure Design for Constructability

Back to General Flow of Design Tasks

Click on:

10. Girder Flexure Design - Constructability



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:

1. General Considerations
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
7. Live Load Force Effects - Shear
8. Other Load Effects and Factors Affecting Load Effect Calculations
9. Girder Flexure Design – General
10. Girder Flexure Design – Constructibility
11. Girder Flexure Design – Service Limit State
12. Girder Flexure Design – Fatigue and Fracture Limit State
13. Girder Flexure Design – Strength Limit State
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

NSBA Guide to Navigating Routine Steel Bridge Design / 15

Girder Flexure Design - Constructability

Design Task Links Page

GIRDER FLEXURE DESIGN – CONSTRUCTIBILITY

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure with regards to constructibility, considering the following:

- Constructibility (6.10.3.1, 6.5.4.1), Flowchart (C6.4.1)
- Flexure (6.10.3.2, 6.10.1.8, 6.10.1.9, 6.10.1.10.1, 6.10.8.2, A6.3.3—optional)
- Shear (6.10.3.3)
- Deck placement (6.10.3.4)
- Dead load deflections (6.10.3.5)
- Tension flanges with holes (6.10.1.8)

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

For more explanation and examples of flexure design with regards to constructibility, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 1.3 (Limit States), 6.4.5.5 (Web Bend Buckling Resistance), 6.5.3 (LRFD Constructibility Design), and 6.5.6 (LRFD Strength Limit State for Flexure)
- FHWA's Steel Bridge Design Handbook
  - Volume 10 - Limit States
  - Volume 11 - Design for Constructability
  - Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge
- The AASHTO-NSBA Steel Bridge Collaboration Guidelines
  - G12.1-2020 Guidelines to Design for Constructability and Fabrication

In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

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

Girder Flexure Design - Constructability

GIRDER FLEXURE DESIGN – CONSTRUCTIBILITY

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure with regards to constructibility, considering the following:

- Constructibility (6.10.3.1, 6.5.4.1), Flowchart (C6.4.1)
- Flexure (6.10.3.2, 6.10.1.8, 6.10.1.9, 6.10.1.10.1, 6.10.8.2, A6.3.3—optional)
- Shear (6.10.3.3)
- Deck placement (6.10.3.4)
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  - Sections 1.3 (Limit States), 6.4.5.5 (Web Bend Buckling Resistance), 6.5.3 (LRFD Constructibility Design), and 6.5.6 (LRFD Strength Limit State for Flexure)
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GIRDER FLEXURE DESIGN – CONSTRUCTIBILITY

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Design girders for flexure with regards to constructibility, considering the following:

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- Shear (6.10.3.3)
- Deck placement (6.10.3.4)
- Dead load deflections (6.10.3.5)
- Tension flanges with holes (6.10.1.8)

Girder Flexure Design - Constructability

Determination and Discussion

C6.4.1 Flowchart for LRFD Article 6.10.3

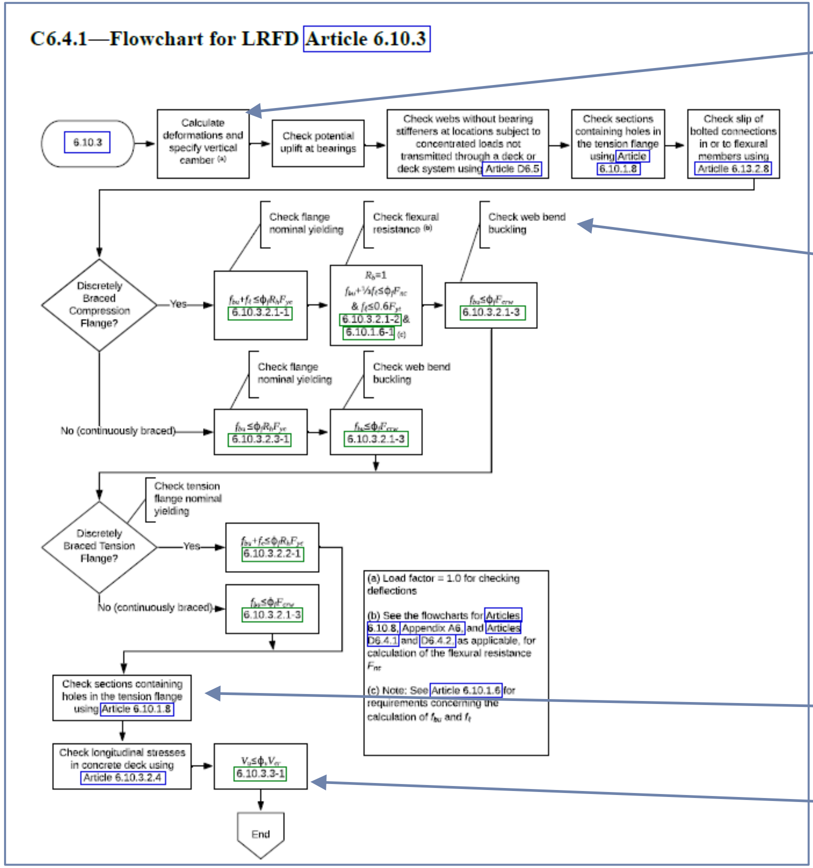
Determination of applicability, *All Routine Steel I-girder Bridges*: Applicable.

Discussion:

The flowchart provided in this Article is helpful to guide the Engineer through the provisions of Article 6.10.3 dealing with the design for constructibility (see the Discussion of Article 6.10.3 in this Guide). This flowchart is applicable to the routine steel I-girder bridges covered by this Guide and is strongly recommended for use in conjunction with this Guide.

"Strongly recommended for use..."

Girder Flexure Design - Constructability

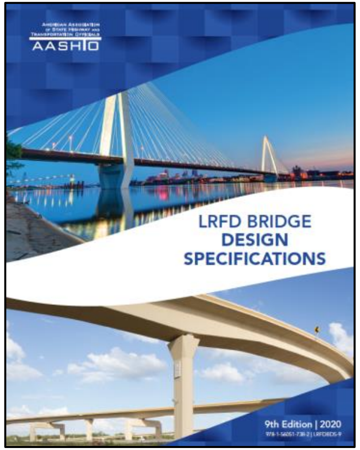


Dead Load Deflection, 6.10.3.5

Flexure Checks, 6.10.3.2

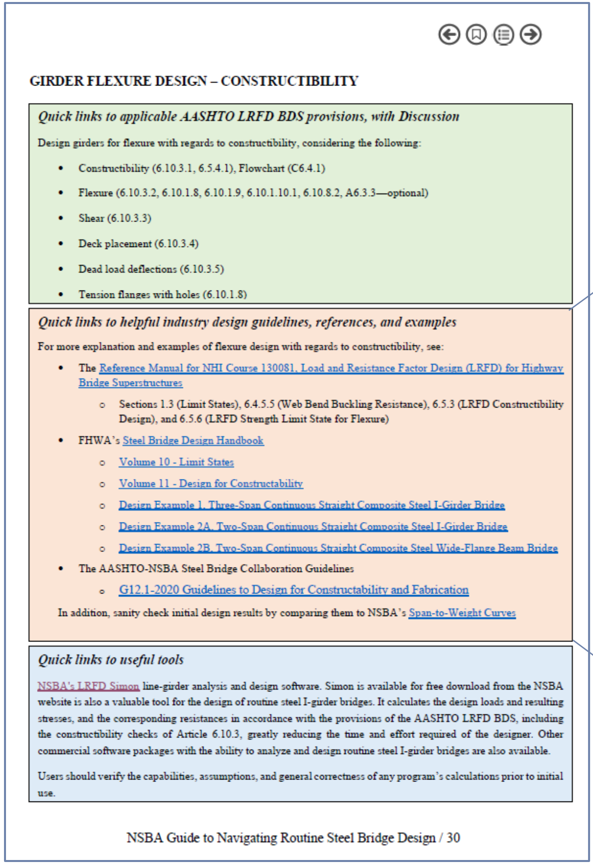
Holes in Tension Flange, 6.10.1.8

Shear Checks, 6.10.3.3



Girder Flexure Design - Constructability

Quick Links to Guidelines, References, & Examples



GIRDER FLEXURE DESIGN – CONSTRUCTIBILITY

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure with regards to constructibility, considering the following:

- Constructibility (6.10.3.1, 6.5.4.1), Flowchart (C6.4.1)
- Flexure (6.10.3.2, 6.10.1.8, 6.10.1.9, 6.10.1.10.1, 6.10.8.2, A6.3.3—optional)
- Shear (6.10.3.3)
- Deck placement (6.10.3.4)
- Dead load deflections (6.10.3.5)
- Tension flanges with holes (6.10.1.8)

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

For more explanation and examples of flexure design with regards to constructibility, see:

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
  - Sections 1.3 (Limit States), 6.4.5.5 (Web Bend Buckling Resistance), 6.5.3 (LRFD Constructibility Design), and 6.5.6 (LRFD Strength Limit State for Flexure)
- FHWA's Steel Bridge Design Handbook
  - Volume 10 - Limit States
  - Volume 11 - Design for Constructability
  - Design Example 1, Three-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2A, Two-Span Continuous Straight Composite Steel I-Girder Bridge
  - Design Example 2B, Two-Span Continuous Straight Composite Steel Wide-Flange Beam Bridge
- The AASHTO-NSBA Steel Bridge Collaboration Guidelines
  - G12.1-2020 Guidelines to Design for Constructability and Fabrication

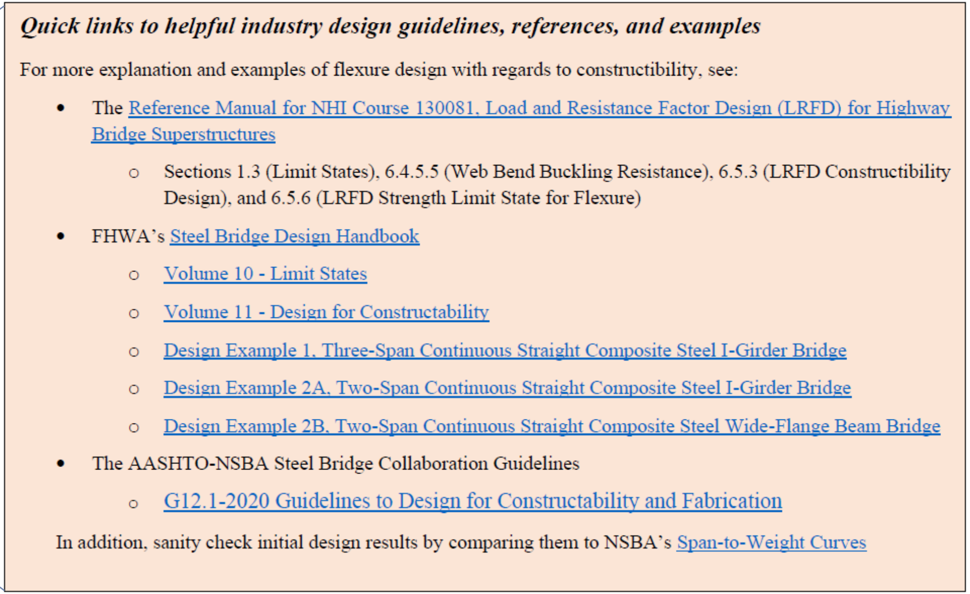
In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the design loads and resulting stresses, and the corresponding resistances in accordance with the provisions of the AASHTO LRFD BDS, including the constructibility checks of Article 6.10.3, 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.

NSBA Guide to Navigating Routine Steel Bridge Design / 30



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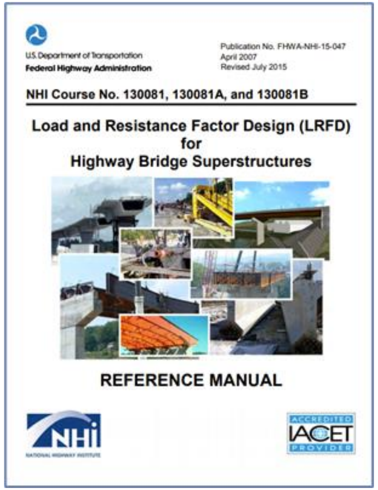
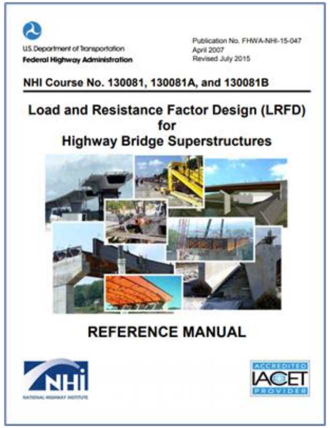
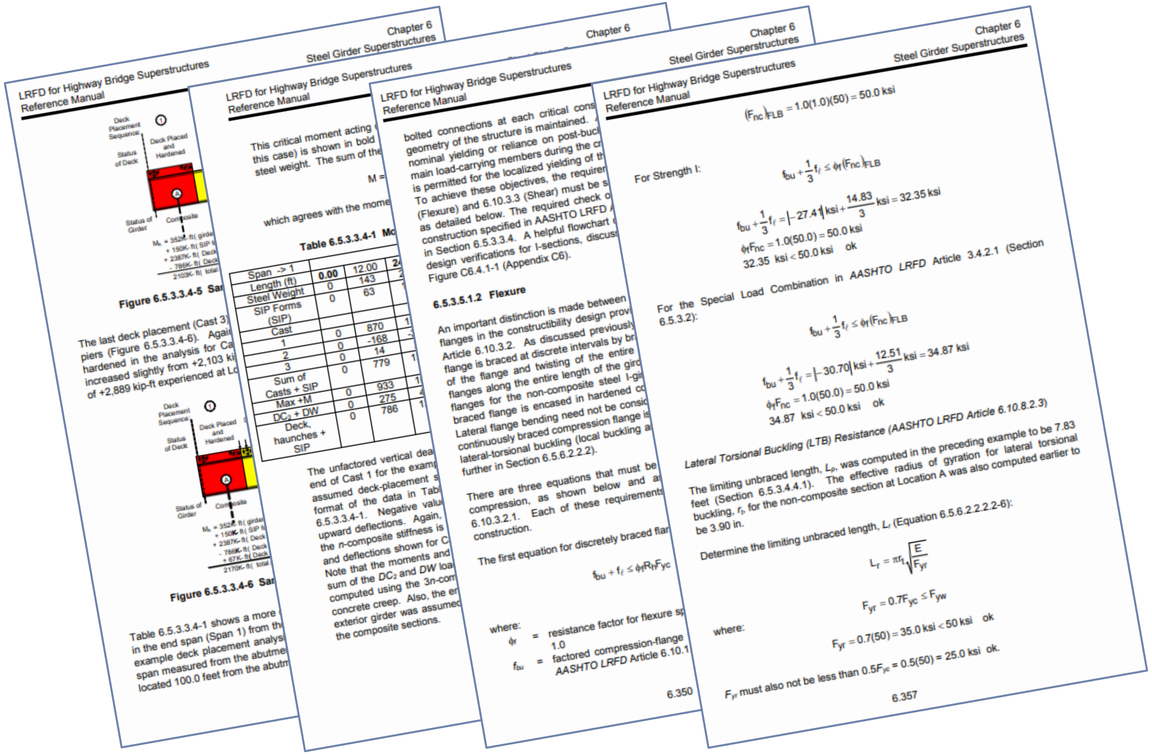


Girder Flexure Design - Constructability





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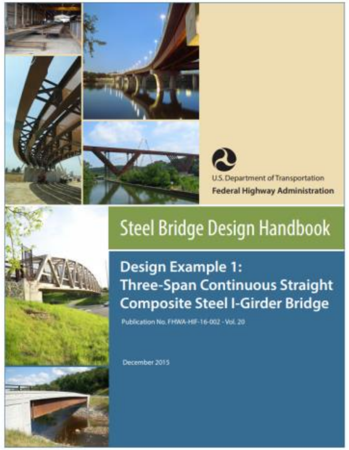

Girder Flexure Design - Constructability

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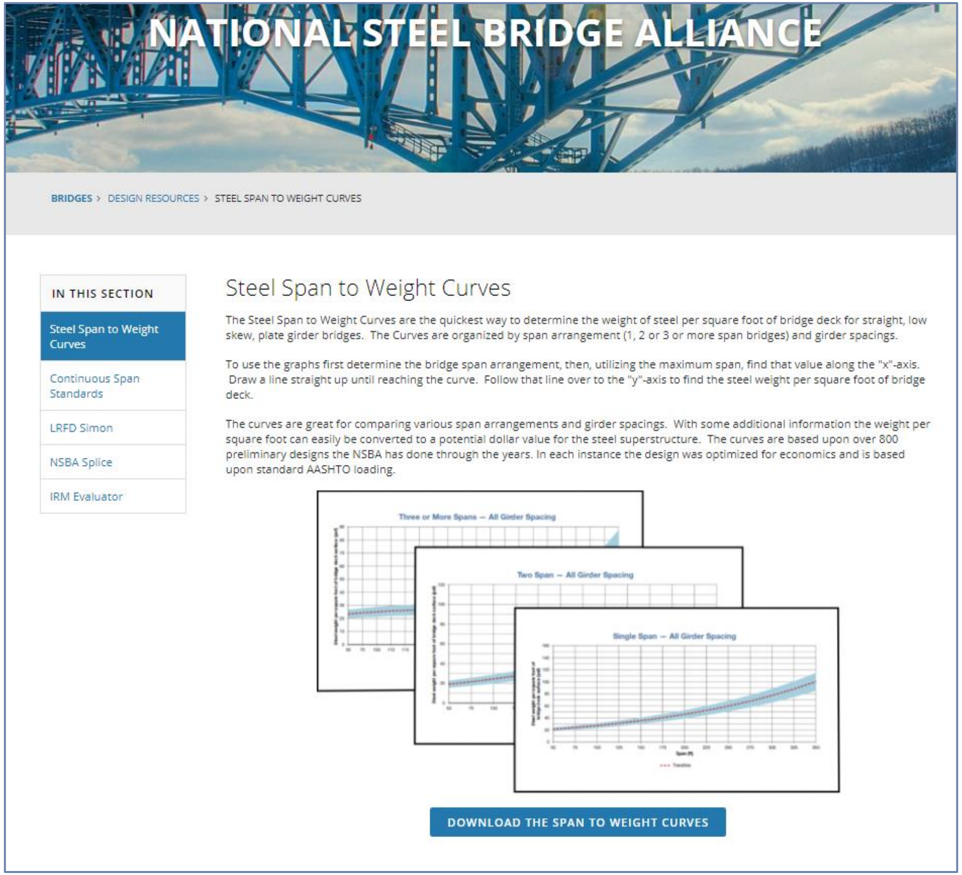
Girder Flexure Design - Constructability



NATIONAL STEEL BRIDGE ALLIANCE

BRIDGES › DESIGN RESOURCES › STEEL SPAN TO WEIGHT CURVES

IN THIS SECTION

- Steel Span to Weight Curves
- Continuous Span Standards
- LRFD Simon
- NSBA Splice
- IRM Evaluator

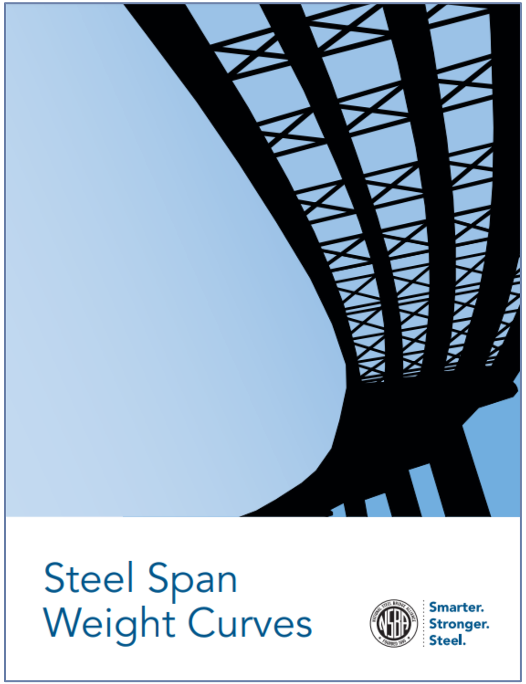
Steel Span to Weight Curves

The Steel Span to Weight Curves are the quickest way to determine the weight of steel per square foot of bridge deck for straight, low skew, plate girder bridges. The Curves are organized by span arrangement (1, 2 or 3 or more span bridges) and girder spacings.

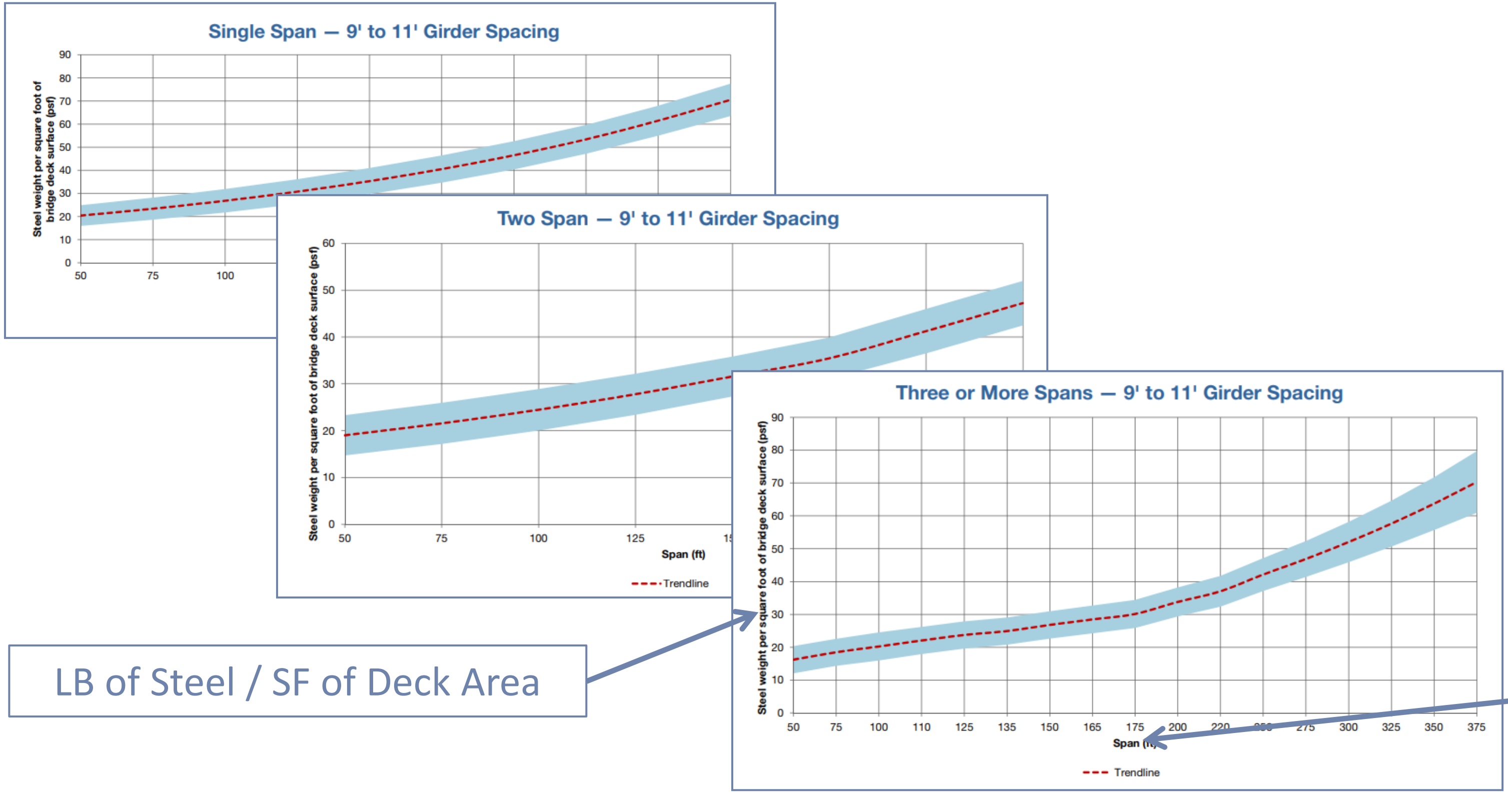
To use the graphs first determine the bridge span arrangement, then, utilizing the maximum span, find that value along the "x"-axis. Draw a line straight up until reaching the curve. Follow that line over to the "y"-axis to find the steel weight per square foot of bridge deck.

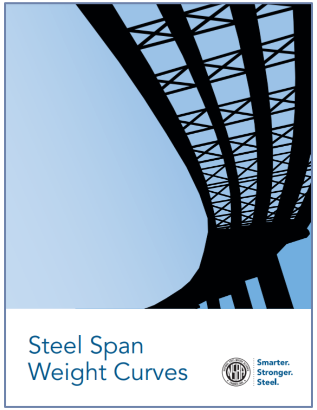
The curves are great for comparing various span arrangements and girder spacings. With some additional information the weight per square foot can easily be converted to a potential dollar value for the steel superstructure. The curves are based upon over 800 preliminary designs the NSBA has done through the years. In each instance the design was optimized for economics and is based upon standard AASHTO loading.

DOWNLOAD THE SPAN TO WEIGHT CURVES



Girder Flexure Design - Constructability

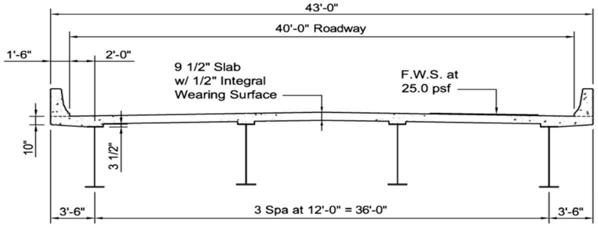




LB of Steel / SF of Deck Area

Max. Span Length

Girder Flexure Design – Constructability



Deck Placement Sequence

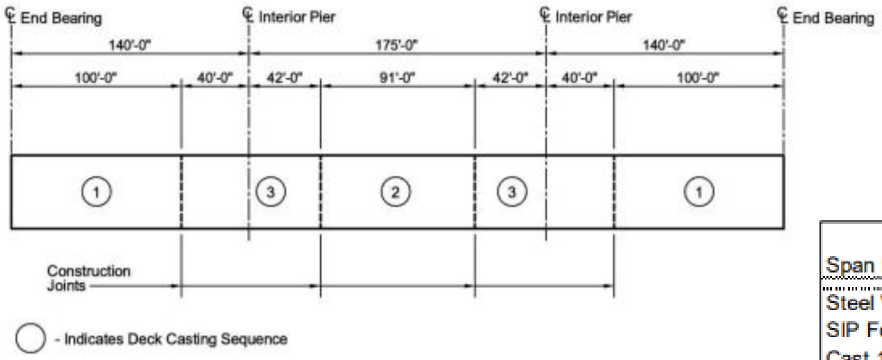
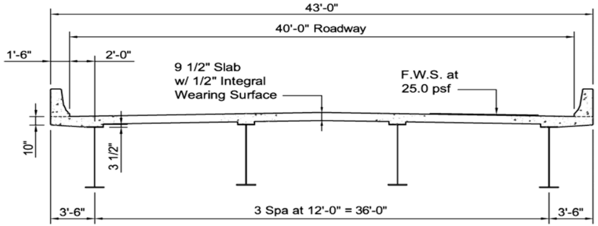


Table 11 Moments from Deck-Placement Analysis

	Span 1 - Unfactored Dead-Load Moments (kip-ft)									
Span Length (ft)	0	12	24	42	48	56	72	84	96	100
Steel Weight	0	143	250	341	353	352	296	206	74	21
SIP Forms (SIP)	0	63	110	147	151	150	124	84	27	4
Cast 1	0	870	1544	2189	2306	2387	2286	1983	1484	1275
Cast 2	0	-168	-336	-589	-673	-786	-1010	-1179	-1347	-1403
Cast 3	0	14	28	50	57	67	86	101	115	120
Sum of Casts + SIP										
After Cast 1	0	933	1654	2336	2457	2537	2410	2067	1511	1279
After Cast 2	0	765	1318	1747	1784	1751	1400	888	164	-124
After Cast 3	0	779	1346	1797	1841	1818	1486	989	279	-4
Max. + M	0	933	1654	2336	2457	2537	2410	2067	1511	1279
DC_2 + DW	0	275	447	643	661	657	551	386	148	52
Deck, hauches, SIP	0	786	1360	1822	1870	1850	1528	1038	335	53

Girder Flexure Design – Constructability



- Local Buckling Resistance, 6.10.8.2.2
  - Positive Moment

For STRENGTH I:

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f (F_{nc})_{FLB}$$

$$f_{bu} + \frac{1}{3} f_\ell = |-27.41| \text{ ksi} + \frac{14.83}{3} \text{ ksi} = 32.35 \text{ ksi}$$

$$\phi_f (F_{nc})_{FLB} = 1.0(50.0) = 50.0 \text{ ksi}$$

$32.35 \text{ ksi} < 50.0 \text{ ksi}$ ok

(Ratio = 0.647)

For STRENGTH III:

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f (F_{nc})_{FLB}$$

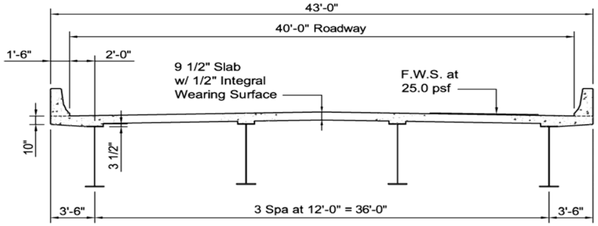
$$f_{bu} + \frac{1}{3} f_\ell = |-3.34| \text{ ksi} + \frac{9.70}{3} \text{ ksi} = 6.57 \text{ ksi}$$

$$\phi_f (F_{nc})_{FLB} = 1.0(50.0) = 50.0 \text{ ksi}$$

$6.57 \text{ksi} < 50.0 \text{ksi}$

(Ratio = 0.131)

Girder Flexure Design – Constructability



- Lateral Torsional Buckling Resistance, 6.10.8.2.3
  - Positive Moment

For STRENGTH I:

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f (F_{nc})_{LTB}$$

$$f_{bu} + \frac{1}{3} f_\ell = |-27.41| \text{ ksi} + \frac{14.83}{3} \text{ ksi} = 32.35 \text{ ksi}$$

$$\phi_f (F_{nc})_{LTB} = 1.0(38.75) = 38.75 \text{ ksi}$$

32.35 ksi < 38.75 ksi ok

(Ratio = 0.835)

For STRENGTH III:

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f (F_{nc})_{LTB}$$

$$f_{bu} + \frac{1}{3} f_\ell = |-3.34| \text{ ksi} + \frac{9.70}{3} \text{ ksi} = 6.57 \text{ ksi}$$

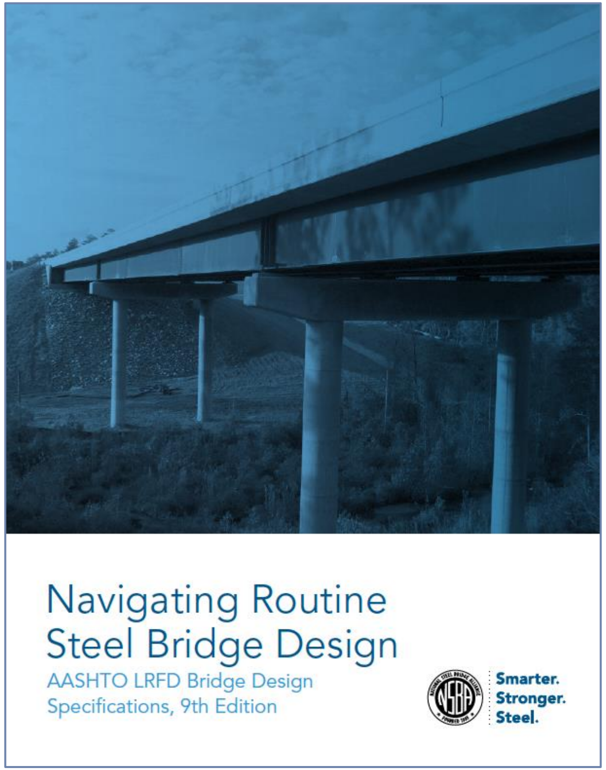
$$\phi_f (F_{nc})_{LTB} = 1.0(38.75) = 38.75 \text{ ksi}$$

6.57ksi < 38.75ksi

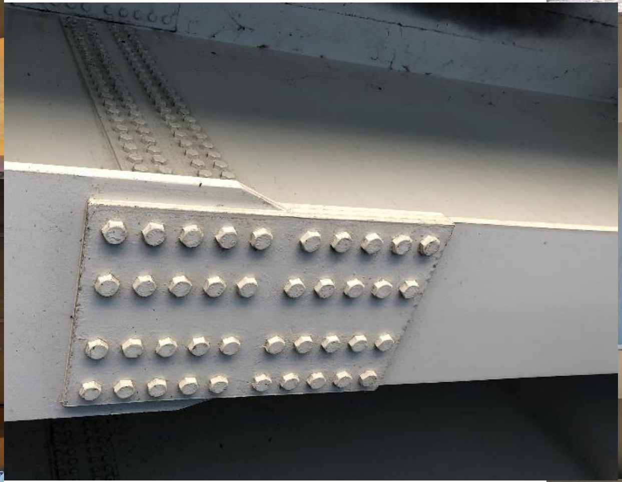
(Ratio = 0.170)

Presentation Outline

- Live Load Force Effects - Flexure
- Girder Flexure Design
  - General
  - Constructability
- **Splice Design**
- Summary



Splice Design



Splice Design

Objective – Perform Girder Field Splice Design

Back to General Flow of Design Tasks

Click on:

17. Splice Design

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:

1. General Considerations
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
7. Live Load Force Effects - Shear
8. Other Load Effects and Factors Affecting Load Effect Calculations
9. Girder Flexure Design – General
10. Girder Flexure Design – Constructibility
11. Girder Flexure Design – Service Limit State
12. Girder Flexure Design – Fatigue and Fracture Limit State
13. Girder Flexure Design – Strength Limit State
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

Splice Design

Design Task Links Page

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)

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

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

- The Reference Manual for NHI 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 G12.1-2020 Guidelines to Design for 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

Quick links to useful tools

The NSBA Splice Microsoft Excel-based bolted field splice design spreadsheet is available for free download from the NSBA website is also 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.

Splice Design

SPLICE DESIGN

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

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

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SPLICE DESIGN

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- Minimum thickness requirements (6.7.3)

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

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Splice Design

Determination and Discussion

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 designed at a minimum for 100 percent of the individual design resistances of the flange and web; that is, the individual flange splices are designed for the smaller design yield resistance of the corresponding flanges on either side of the splice (see the Discussion of Article 6.13.6.1.3b in this Guide), and the web splice is designed for the smaller factored shear resistance of the web on either

General parts of a splice:

- *Top flange splice plates*
- *Web splice plates*
- *Bottom flange splice plates*
- *Filler plates*

Flange splices:

- *1 plate on outside of flanges*
- *2 smaller plates on inside of flange*

Web splice:

- *Two plates, one each side of web*

Splice Design

Determination and Discussion

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.

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Minimum Design forces:

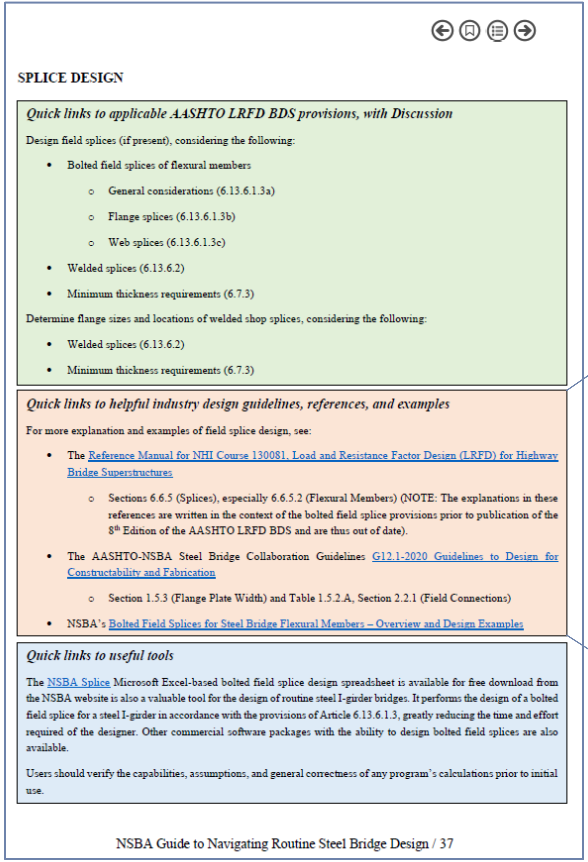
Bolted flange and web splices are designed for a minimum of 100 percent of the individual design resistances

Flange splice: smaller design yield resistance of flange on either side of the splice.

Web splice: smaller factored shear resistance of web on either side of the splice

Splice Design

Quick Links to Guidelines, References, & Examples



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)

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

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

- The Reference Manual for NHI Course 130081, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures
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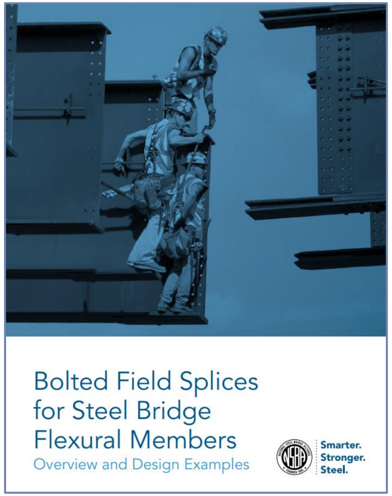
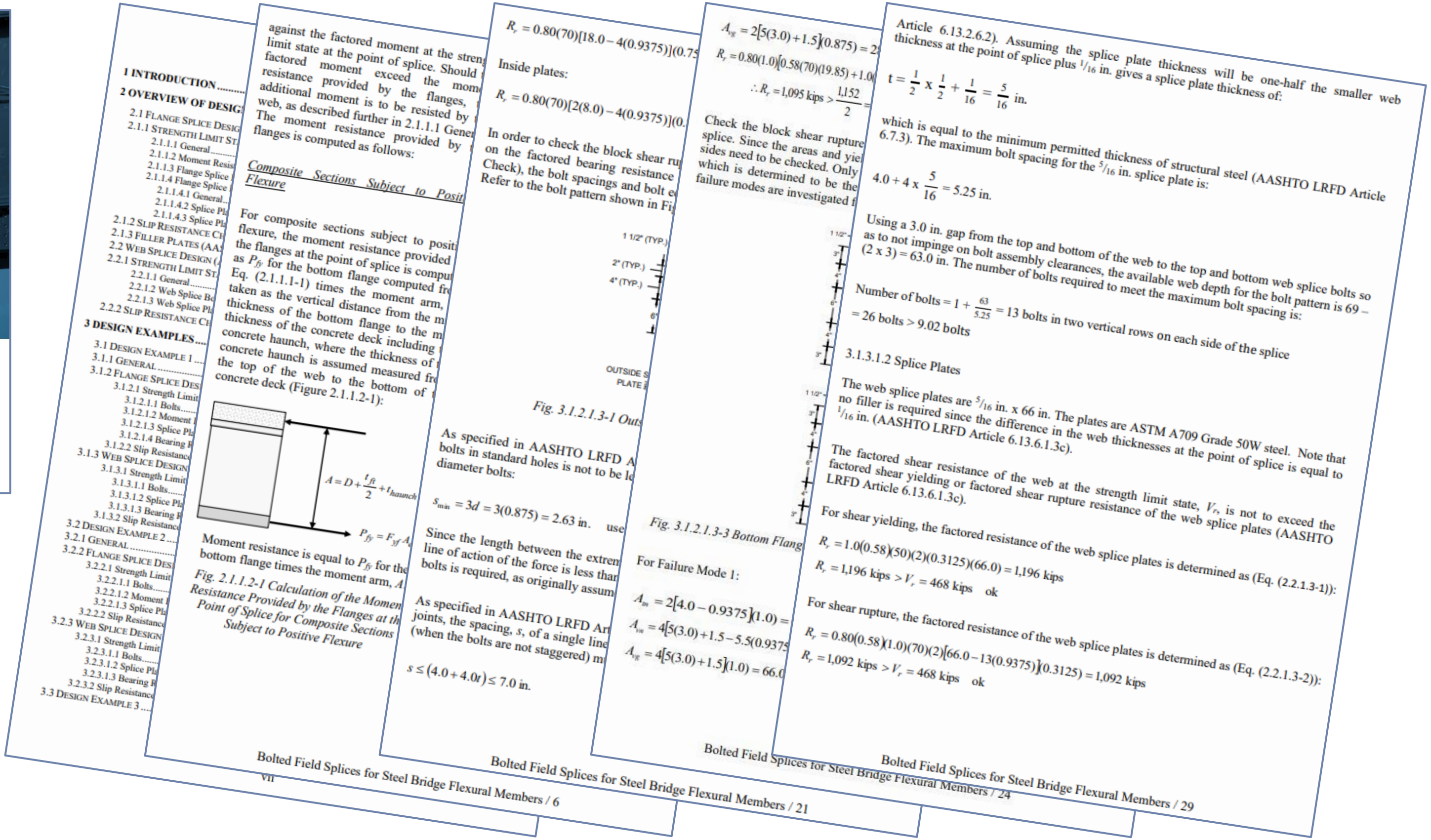
Splice Design





Article 6.13.2.6.2). Assuming the splice plate thickness will be one-half the smaller web thickness at the point of splice plus 1/16 in. gives a splice plate thickness of:

$t = \frac{1}{2} \times \frac{1}{2} + \frac{1}{16} = \frac{5}{16}$ in.

which is equal to the minimum permitted thickness of structural steel (AASHTO LRFD Article 6.7.3). The maximum bolt spacing for the 5/16 in. splice plate is:

$4.0 + 4 \times \frac{5}{16} = 5.25$ in.

Using a 3.0 in. gap from the top and bottom of the web to the top and bottom web splice bolts so as to not impinge on bolt assembly clearances, the available web depth for the bolt pattern is 69 – (2 x 3) = 63.0 in. The number of bolts required to meet the maximum bolt spacing is:

Number of bolts $= 1 + \frac{63}{5.25} = 13$ bolts in two vertical rows on each side of the splice $= 26$ bolts > 9.02 bolts

3.1.3.1.2 Splice Plates

The web splice plates are 5/16 in. x 66 in. The plates are ASTM A709 Grade 50W steel. Note that no filler is required since the difference in the web thicknesses at the point of splice is equal to 1/16 in. (AASHTO LRFD Article 6.13.6.1.3c).

The factored shear resistance of the web at the strength limit state, V_r, is not to exceed the factored shear yielding or factored shear rupture resistance of the web splice plates (AASHTO LRFD Article 6.13.6.1.3c).

For shear yielding, the factored resistance of the web splice plates is determined as (Eq. (2.2.1.3-1)):

$R_r = 1.0(0.58)(50)(2)(0.3125)(66.0) = 1{,}196$ kips

$R_r = 1{,}196$ kips $> V_r = 468$ kips ok

For shear rupture, the factored resistance of the web splice plates is determined as (Eq. (2.2.1.3-2)):

$R_r = 0.80(0.58)(1.0)(70)(2)[66.0 - 13(0.9375)](0.3125) = 1{,}092$ kips

$R_r = 1{,}092$ kips $> V_r = 468$ kips ok

Bolted Field Splices for Steel Bridge Flexural Members / 29

Bolted Field Splices for Steel Bridge Flexural Members / 6

Bolted Field Splices for Steel Bridge Flexural Members / 21

Bolted Field Splices for Steel Bridge Flexural Members / 24

Splice Design

GIRDER FLEXURE DESIGN – CONSTRUCTIBILITY

Quick links to applicable AASHTO LRFD BDS provisions, with Discussion

Design girders for flexure with regards to constructibility, considering the following:

- Constructibility (6.10.3.1, 6.5.4.1), Flowchart (C6.4.1)
- Flexure (6.10.3.2, 6.10.1.8, 6.10.1.9, 6.10.1.10.1, 6.10.8.2, A6.3.3—optional)
- Shear (6.10.3.3)
- Deck placement (6.10.3.4)
- Dead load deflections (6.10.3.5)
- Tension flanges with holes (6.10.1.8)

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

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  - Sections 1.3 (Limit States), 6.4.5.5 (Web Bend Buckling Resistance), 6.5.3 (LRFD Constructibility Design), and 6.5.6 (LRFD Strength Limit State for Flexure)
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In addition, sanity check initial design results by comparing them to NSBA's Span-to-Weight Curves

Quick links to useful tools

NSBA's LRFD Simon line-girder analysis and design software. Simon is available for free download from the NSBA website is also a valuable tool for the design of routine steel I-girder bridges. It calculates the design loads and resulting stresses, and the corresponding resistances in accordance with the provisions of the AASHTO LRFD BDS, including the constructibility checks of Article 6.10.3, 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.

NSBA Guide to Navigating Routine Steel Bridge Design / 30

Quick links to useful tools

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Splice Design

BRIDGES > DESIGN RESOURCES > NSBA SPLICE

IN THIS SECTION

- Steel Span to Weight Curves
- Continuous Span Standards
- LRFD Simon
- NSBA Splice
- IRM Evaluator

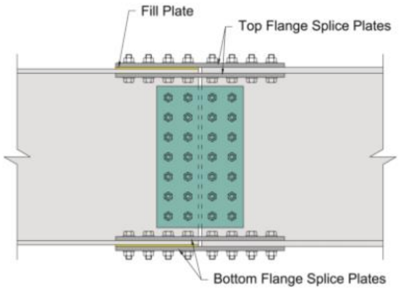
UPDATED: NSBA Splice

NSBA Splice takes the time-consuming task of designing and checking a bolted splice connection and rewrites 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 AASHTO LRFD 8th 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**.

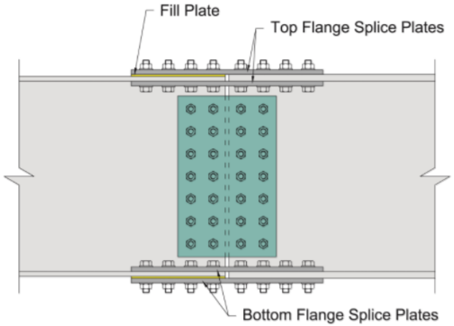
DOWNLOAD NSBA SPLICE

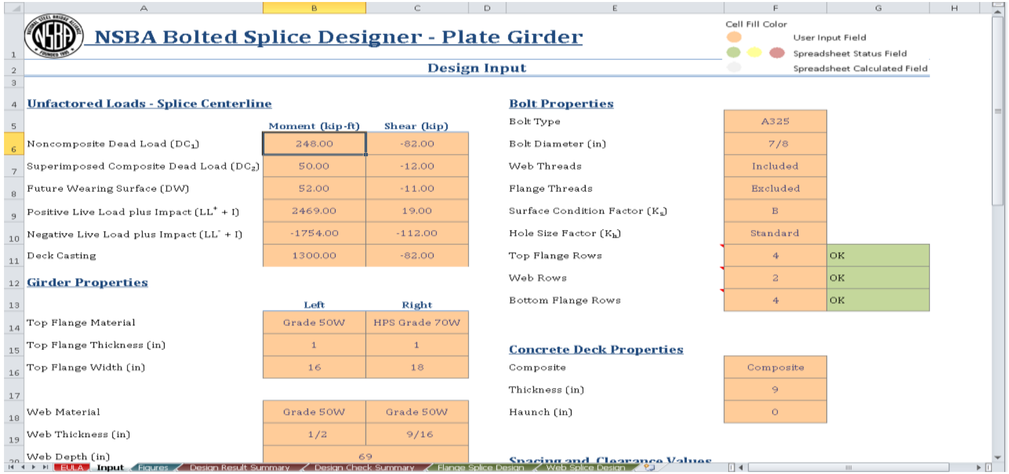
The current version of NSBA Splice (v3.12) was released on April 22, 2021 (Release Notes).



Splice Design

- NSBA Splice Spreadsheet
  - SPREADSHEET!
  - Allows the designer to quickly analyze various bolted splice connections to determine the most efficient bolt quantity and configuration.
  - Updated for AASHTO LRFD 9th Edition





NSBA Bolted Splice Designer - Plate Girder

Cell Fill Color
User Input Field
Spreadsheet Status Field
Spreadsheet Calculated Field

Design Input

Unfactored Loads - Splice Centerline

	Moment (kip-ft)	Shear (kip)
Noncomposite Dead Load (DC_1)	248.00	-82.00
Superimposed Composite Dead Load (DC_2)	50.00	-12.00
Future Wearing Surface (DW)	52.00	-11.00
Positive Live Load plus Impact (LL^+ + I)	2469.00	19.00
Negative Live Load plus Impact (LL^- + I)	-1754.00	-112.00
Deck Casting	1300.00	-82.00

Girder Properties

	Left	Right
Top Flange Material	Grade 50W	HPS Grade 70W
Top Flange Thickness (in)	1	1
Top Flange Width (in)	16	18
Web Material	Grade 50W	Grade 50W
Web Thickness (in)	1/2	9/16
Web Depth (in)	69	

Bolt Properties

Bolt Type	A325	
Bolt Diameter (in)	7/8	
Web Threads	Included	
Flange Threads	Excluded	
Surface Condition Factor (K_s)	B	
Hole Size Factor (K_h)	Standard	
Top Flange Rows	4	OK
Web Rows	2	OK
Bottom Flange Rows	4	OK

Concrete Deck Properties

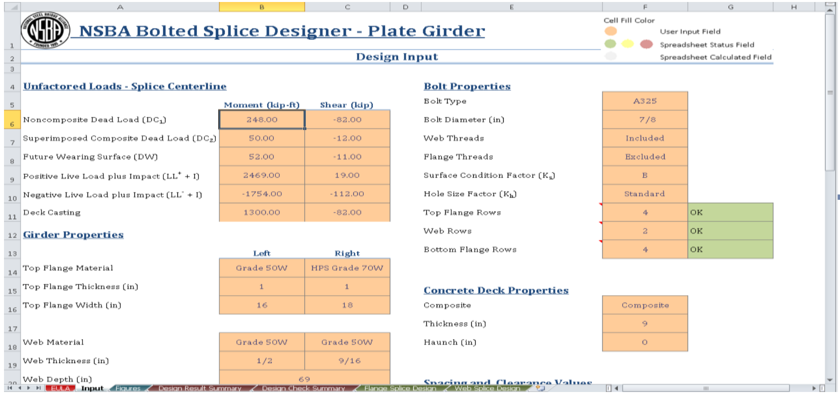
Composite	Composite
Thickness (in)	9
Haunch (in)	0

Spacing and Clearance Values

EULA | Input | Figures | Design Result Summary | Design Check Summary | Flange Splice Design | Web Splice Design

Splice Design

- Example Bridge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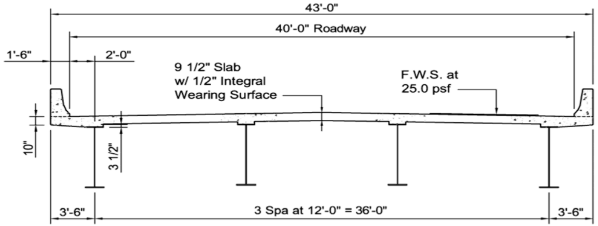
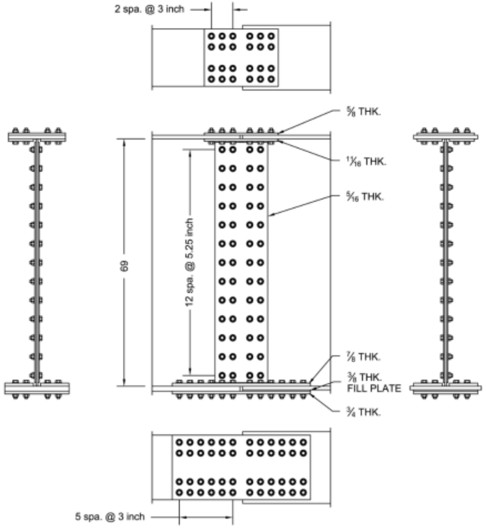
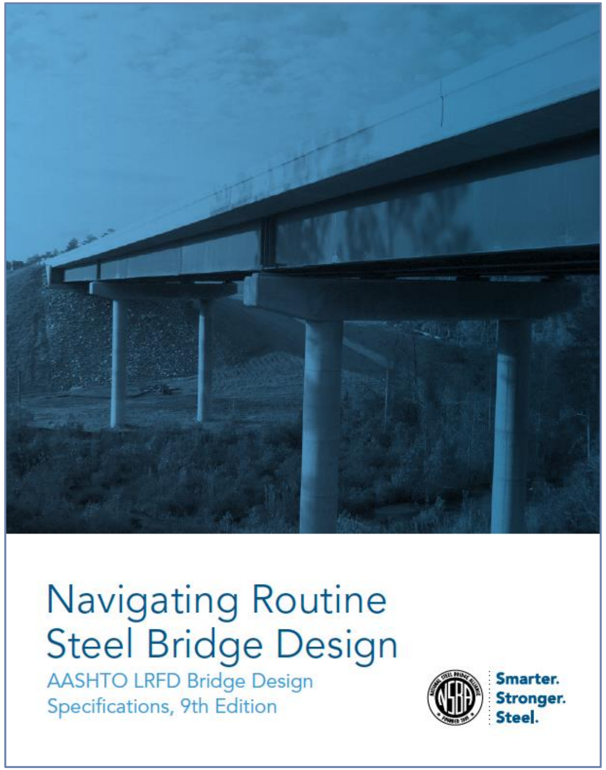




Presentation Outline

- Live Load Force Effects - Flexure
- Girder Flexure Design
  - General
  - Constructability
- Splice Design
- **Summary**



Summary

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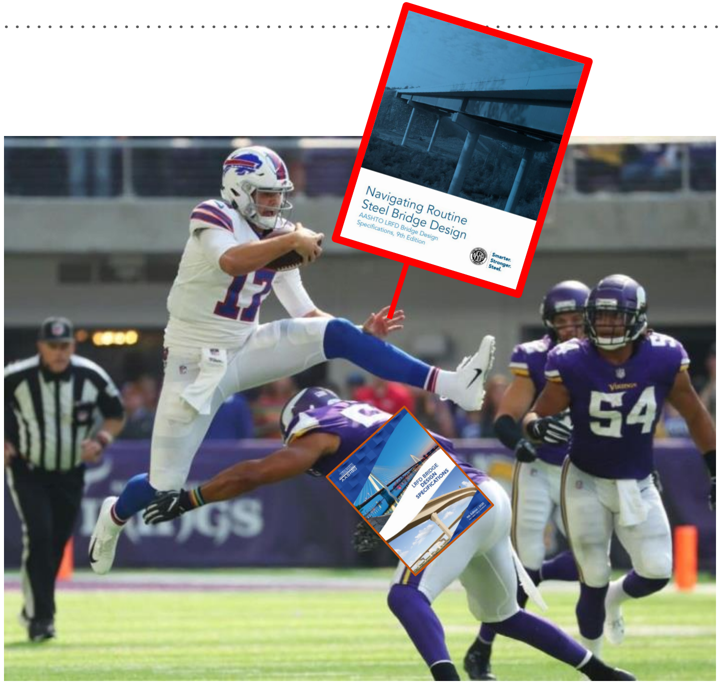
Questions……



- ***Download the new Guide at:***
  - ***www.aisc.org/nsba***

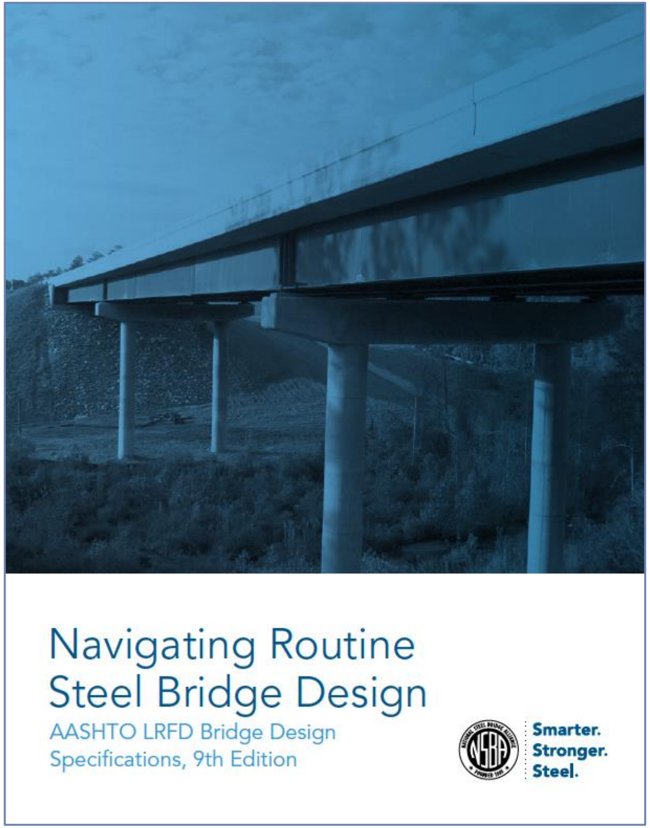



Photo: 2020 Prize Bridge National Winner – Manning Crevice (Idaho) – Photo Credit: Ken Saindon

Using the New Guide to Streamline Design

Brandon Chavel, PhD, PE – Director of Market Development

National Steel Bridge Alliance

Smarter.
Stronger.
Steel.