There's always a solution in steel.

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Course Description

Application of NSBA Design Resources in a Design

February 22, 2018

There are several published references that can be used to aid in the development of efficient and economical steel-girder bridge superstructure designs. This presentation will demonstrate how to best employ the available references when designing a steel-girder bridge superstructure. There will be a dedicated focus on the AASHTO/NSBA Steel Bridge Collaboration Guideline documents, the FHWA Steel Bridge Design Handbook, and other NSBA published documents, such as the Continuous Span Standards, the Steel Span to Weight Curves, Bolted Field Splice Design Examples, and two Steel I-Girder Bridge Fit documents.

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Learning Objectives

- Identify the AASHTO/NSBA Steel Bridge Collaboration Guideline documents available on the NSBA website.
- Identify how to best employ the available references in the design of a steel-girder superstructure.
- List the design steps of a steel-girder superstructure.
- Identify the advantages of wider girder spacing.

7

There's always a solution in steel.

Application of NSBA Design Resources in a Design
February 22, 2018

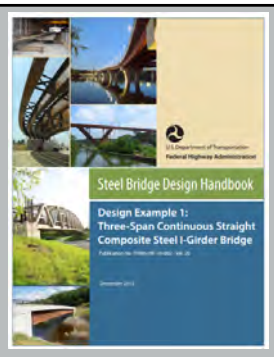
Presented by
Brandon Chavel, PhD, PE
HDR
Cleveland, OH

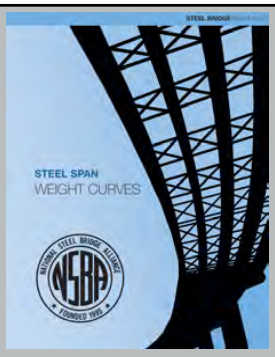
structural STEEL

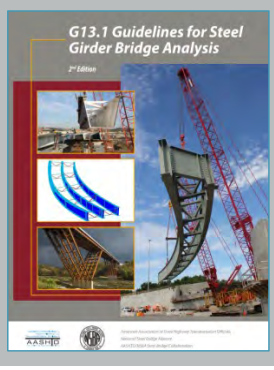
Application of NSBA Design Resources in a Design

Brandon Chavel, PhD, PE

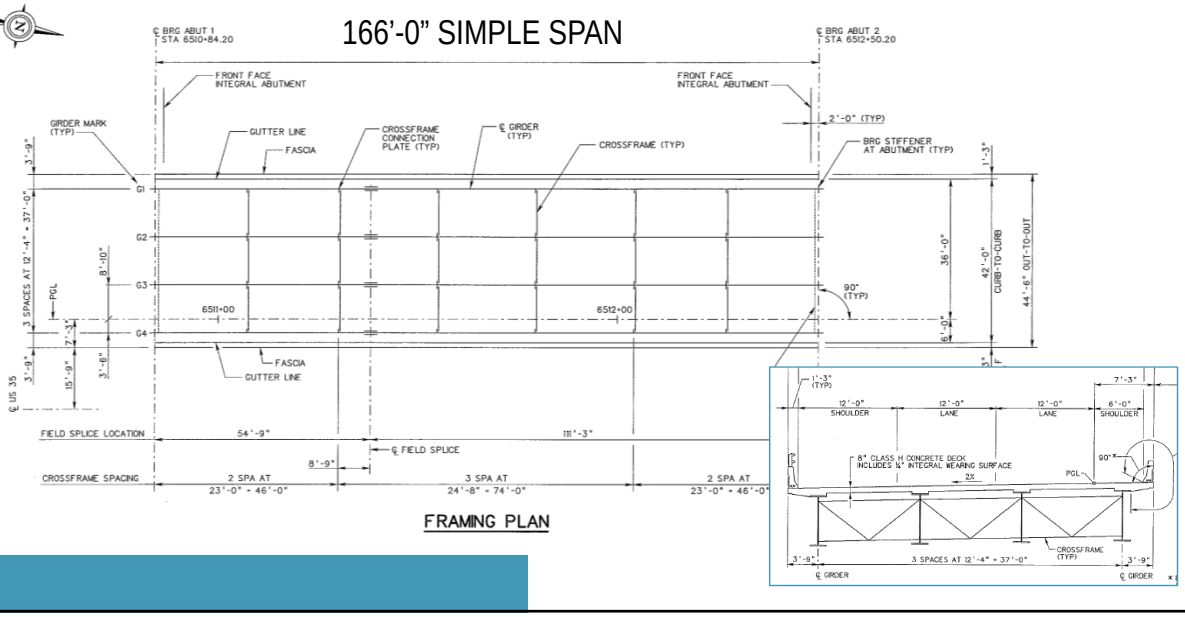
February 22, 2018







What resources can help me design this steel girder bridge?



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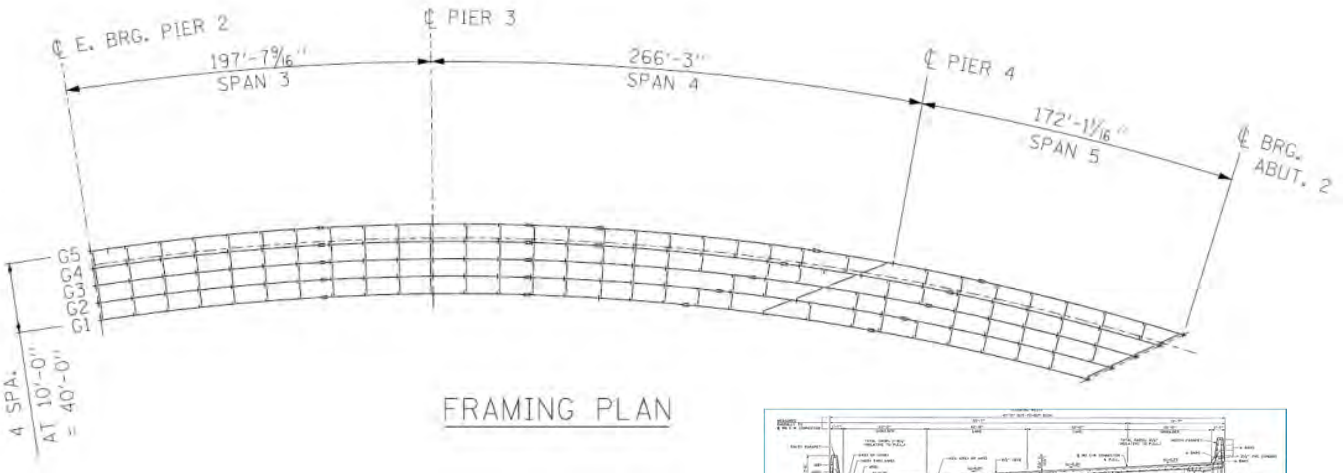
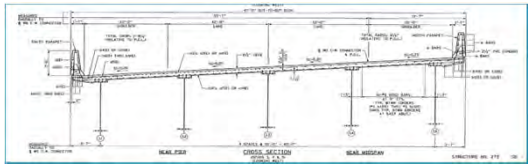
Or, this steel girder bridge?





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Modern Steel Construction - November 2017

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2018 World Steel Bridge Symposium

- 2018 World Steel Bridge Symposium
  - April 11 – 14
  - Baltimore Convention Center - Baltimore, Maryland
  - Co-located with AISC Steel Conference – NASCC
- 2 Concurrent Bridge Tracks
  - 25 Bridge Sessions
  - 64 Speakers

World Steel Bridge Symposium
Baltimore || 4.11–13.18

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Presentation Outline

- Available References
  - Design Specifications and Codes
  - AASHTO/NSBA Collaboration
  - FHWA Steel Bridge Handbook
  - NSBA Design & Technical Resources
  - Other FHWA Technical Resources
  - NSBA Design Tools
- Example of How To Use These References
- Summary

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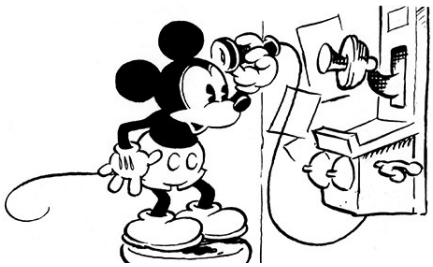
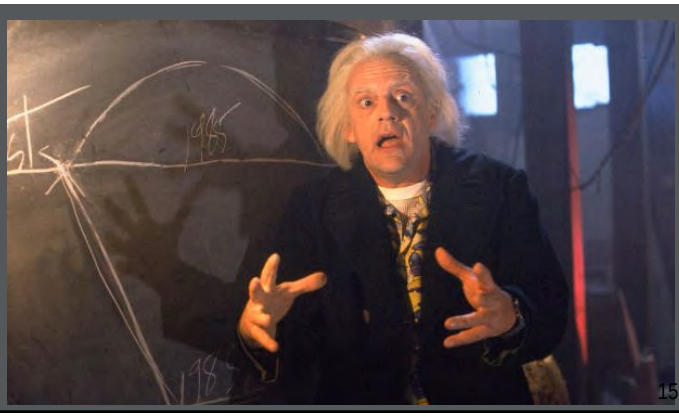
Knowledge Base

- Before we get started……
- Guidelines and such are no substitute for talking with the experienced engineers in your office, or with colleagues, fabricators, or NSBA!!!!





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Presentation Outline

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  - FHWA Steel Bridge Handbook
  - NSBA Design & Technical Resources
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  - NSBA Design Tools
- Example of How To Use These References
- Summary

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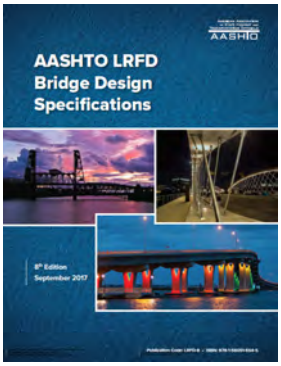
Design Specifications and Codes

- AASHTO LRFD Bridge Design Specifications
  - 8th Edition was released in November 2017
- State DOT Structure Design Manuals
- State DOT Standard Drawings
- AISC Steel Construction Manual
  - 15th Edition



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Presentation Outline

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  - FHWA Steel Bridge Handbook
  - NSBA Design & Technical Resources
  - Other FHWA Technical Resources
  - NSBA Design Tools
- Example of How To Use These References
- Summary

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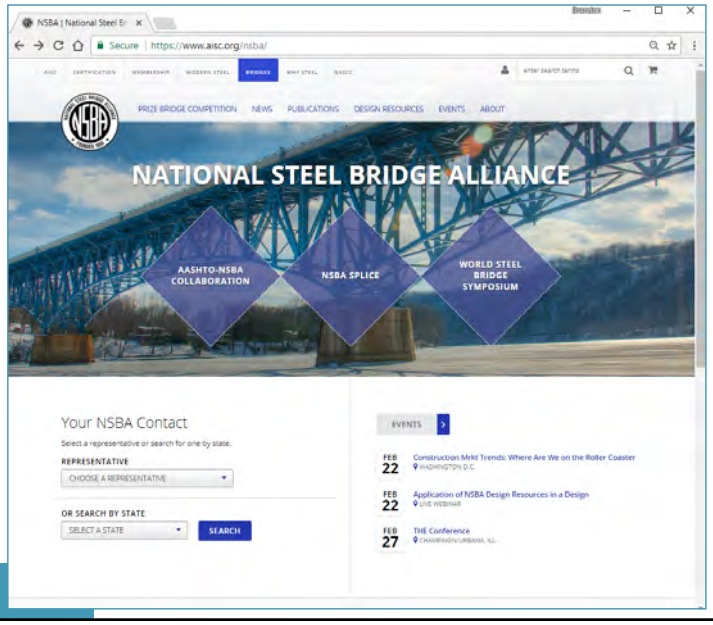
AASHTO/NSBA Steel Bridge Collaboration

- https://www.steelbridges.org/



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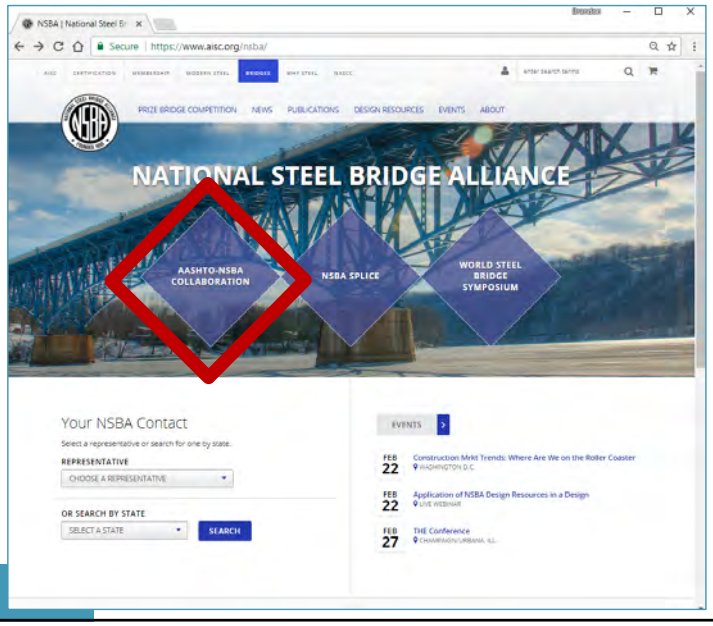
AASHTO/NSBA Steel Bridge Collaboration

- https://www.steelbridges.org/



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AASHTO/NSBA Steel Bridge Collaboration

- https://www.aisc.org/nsba/nsba-publications/aashto-nsba-collaboration/
- *Provides a forum where professionals can work together to improve and achieve the quality and value of steel bridges through standardization of design, fabrication and erection.*

- Specifications and Guidelines
  - Specifications:
    - Written in "spec language"
    - Can be adopted as a contract document
  - Guidelines:
    - Written as a reference
    - Consensus of the steel industry
- ALL ARE FREE!!!

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AASHTO/NSBA Steel Bridge Collaboration

- Variety of Collaboration Standards for Engineers
  - Guidelines for Design Details (G1.4-2006)
  - Guidelines for Design for Constructability (G12.1-2016)
  - Guidelines for Steel Girder Bridge Analysis (G13.1-2014)
  - Steel Bridge Erection Guide Specification (S10.1-2014)
  - Steel Bridge Bearing Design and Detailing Guidelines (G9.1-2004)
  - Design Drawings Presentation Guidelines (G1.2-2003)
  - Shop Drawing Approval Review/Approval Guidelines (G1.1-2000)

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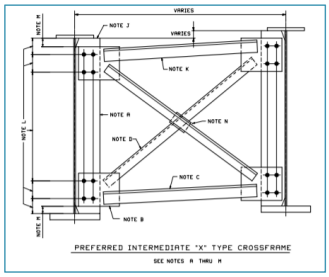
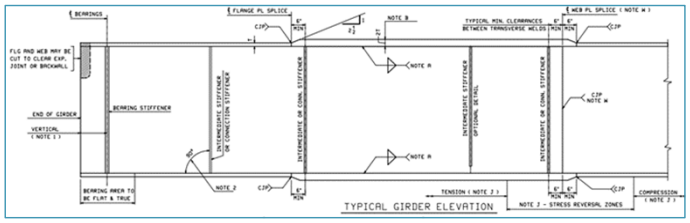
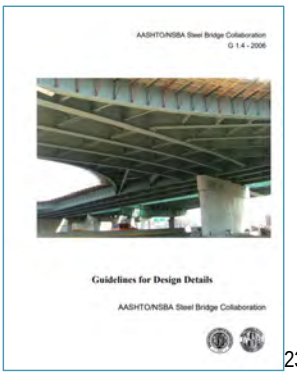
AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Design Details (G1.4-2006)**
  - Collection of sample design details that allow for the economical fabrication and erection of bolted splices, crossframes, and stiffeners.
  - When in doubt regarding a specific design detail, this should be the engineer's first reference.







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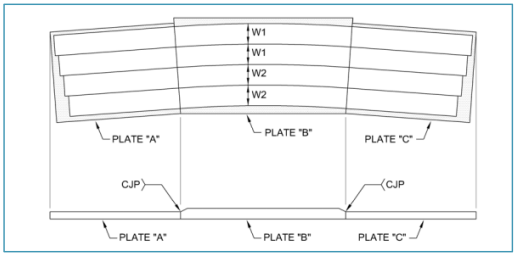
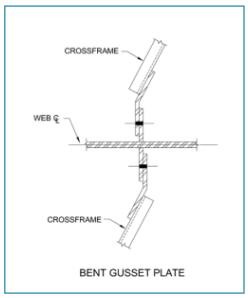
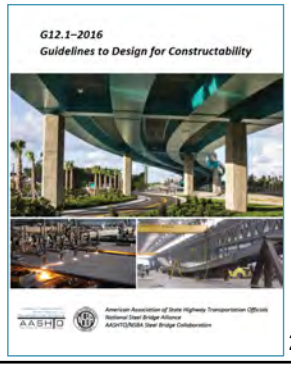
AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Design for Constructability (G12.1-2016)**
  - Provides engineers with design and detailing recommendations to help make steel girder type bridges more easily fabricated and constructible.
  - Refer to this guideline for a better understanding of certain details can affect fabrication, and for general guidance to make better informed decisions during design.







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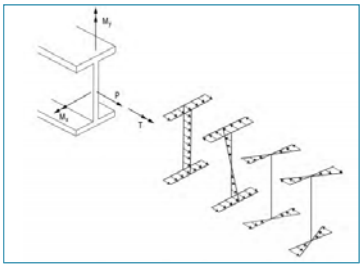
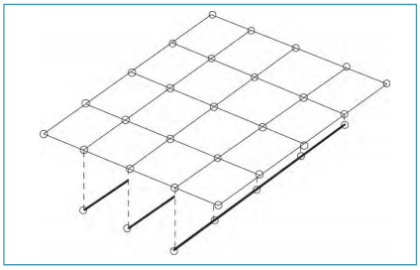
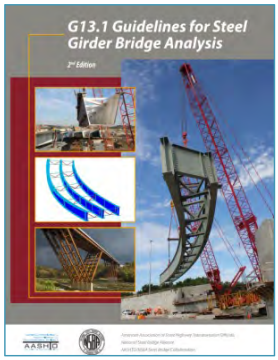
AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Provides the most comprehensive presentation and discussion regarding analysis techniques associated with steel girder bridges.
  - Discussion on line girder, 2D, and 3D analysis methods, while also helping engineers determine the appropriate level of analysis based on a bridge's geometric aspects.







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AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Table B.2-1 Matrix for Recommended Level of Analysis

Major Axis Bending Stress

Vertical Displacements

Cross Frame Forces

Flange Lateral Bending

Girder Layover at Bearings

Response	Geometry	Worst-Case Scores			Mode of Scores		
		Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]	Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]
Major-Axis Bending Stresses	C ($I_C \le 1$)	B	B	A	A	B	A
	C ($I_C > 1$)	D	C	A	B	C	A
	S ($I_S < 0.30$)	B	B	A	A	A	A
	S ($0.30 \le I_S < 0.65$)	B	C	A	B	B	A
	S ($I_S \ge 0.65$)	D	D	A	C	C	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	D	F	A	B	C	A
Vertical Displacements	C ($I_C \le 1$)	B	C	A	A	B	A
	C ($I_C > 1$)	F	D	A	F	C	A
	S ($I_S < 0.30$)	B	A	A	A	A	A
	S ($0.30 \le I_S < 0.65$)	B	B	A	A	B	A
	S ($I_S \ge 0.65$)	D	D	A	C	C	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	F	F	A	F	C	A
Cross-Frame Forces	C ($I_C \le 1$)	C	C	B	B	B	A
	C ($I_C > 1$)	F	D	B	C	C	A
	S ($I_S < 0.30$)	NA[a]	NA[a]	B	NA[a]	NA[a]	A
	S ($0.30 \le I_S < 0.65$)	F[b]	NA[c]	B	F[b]	NA[c]	A
	S ($I_S \ge 0.65$)	F[b]	NA[c]	B	F[b]	NA[c]	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	F[b]	NA[c]	B	F[b]	NA[c]	A
Flange Lateral Bending Stresses	C ($I_C \le 1$)	C	C	C	B	B	B
	C ($I_C > 1$)	F	D	C	C	C	B
	S ($I_S < 0.30$)	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]
	S ($0.30 \le I_S < 0.65$)	F[b]	NA[e]	C	F[b]	NA[e]	B
	S ($I_S \ge 0.65$)	F[b]	NA[e]	C	F[b]	NA[e]	B
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	F[b]	NA[e]	C	F[b]	NA[e]	B
Girder Layover at Bearings	C ($I_C \le 1$)	NA[f]	NA[f]	NA[f]	NA[f]	NA[f]	NA[f]
	C ($I_C > 1$)	NA[f]	NA[f]	NA[f]	NA[f]	NA[f]	NA[f]
	S ($I_S < 0.30$)	B	A	A	A	A	A
	S ($0.30 \le I_S < 0.65$)	B	B	A	A	B	A
	S ($I_S \ge 0.65$)	D	D	B	C	C	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	F	F	B	F	C	A

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AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Table B.2-1 Matrix for Recommended Level of Analysis

Response	Geometry	Worst-Case Scores			Mode of Scores		
		Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[5]	Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[5]
Major-Axis Bending Stresses	C ($I_C \le 1$)	B	B	A	A	B	A
	C ($I_C > 1$)	D	C	A	B	C	A
	S ($I_S < 0.30$)	B	B	A	A	A	A
	S ($0.30 \le I_S < 0.65$)	B	C	A	B	B	A
	S ($I_S > 0.65$)	D	D	A	C	C	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	D	F	A	B	C	A

Connectivity Index

$$I_C = \frac{15000}{R(n_{cf}+1)m}$$

Skew Index

$$I_S = \frac{w \tan\theta}{L_s}$$

AASHTO LRFD Eq. 4.6.3.3.2-2

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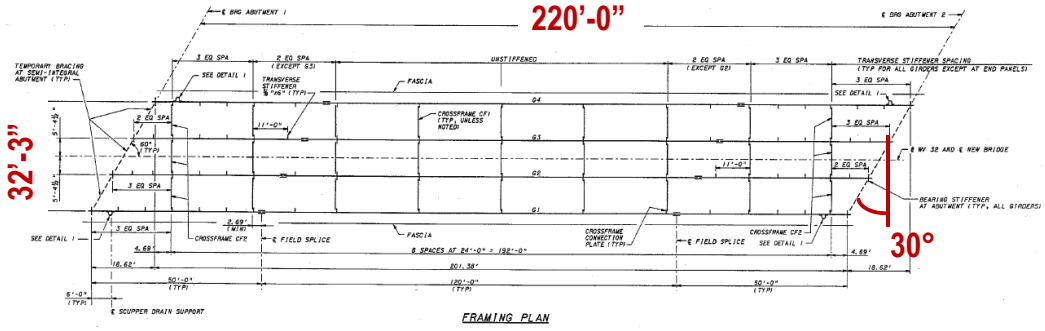
AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Example using Table B.2-1 Matrix for Recommended Level of Analysis



$$I_S = \frac{w \tan\theta}{L_S} = \frac{32.25 \tan(30°)}{220.0} = 0.08$$

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AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Table B.2-1 Matrix for Recommended Level of Analysis

Response	Geometry	Worst-Case Scores			Mode of Scores		
		Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]	Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]
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	S ($I_S > 0.65$)	D	D	A	C	C	A
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$$I_S = \frac{w \tan\theta}{L_S} = \frac{32.25 \tan(30°)}{220.0} = 0.08$$

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AASHTO/NSBA Steel Bridge Collaboration

- **Guidelines for Steel Girder Bridge Analysis (G13.1-2014)**
  - Table B.2-1 Matrix for Recommended Level of Analysis

Response	Geometry	Worst-Case Scores			Mode of Scores		
		Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]	Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[†]
Vertical Displacements	C ($I_C \leq 1$)	B	C	A	A	B	A
	C ($I_C > 1$)	F	D	A	F	C	A
	S ($I_S < 0.30$)	B	A	A	A	A	A
	S ($0.30 \leq I_S < 0.65$)	B	B	A	A	B	A
	S ($I_S > 0.65$)	D	D	A	C	C	A
	C&S ($I_C > 0.5$ & $I_S > 0.1$)	F	F	A	F	C	A

$$I_S = \frac{w \tan\theta}{L_S} = \frac{32.25 \tan(30°)}{220.0} = 0.08$$

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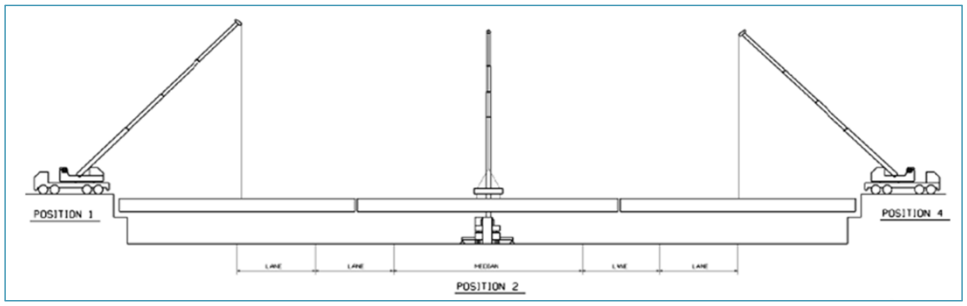
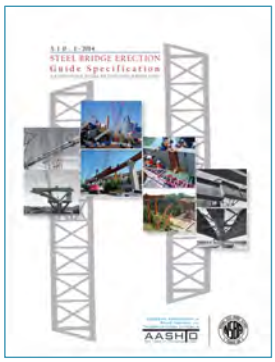
AASHTO/NSBA Steel Bridge Collaboration

- **Steel Bridge Erection Guide Specification (S10.1-2014)**
  - Specification, thus could be adopted by owners in whole, or in parts.
  - Covers all aspects of steel girder bridge erection, including transportation and jobsite storage of girders, bolted connections, inspection, repairs, and guidance for erection engineering computations.





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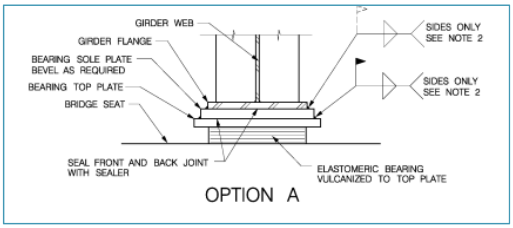
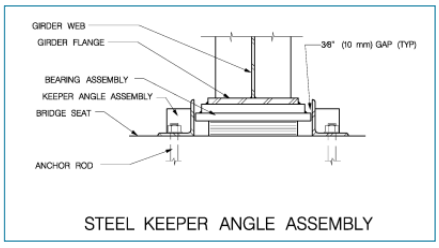
AASHTO/NSBA Steel Bridge Collaboration

- **Steel Bridge Bearing Design and Detailing Guidelines (G9.1-2004)**
  - Presents steel bridge bearing details that are cost effective, functional, and durable.





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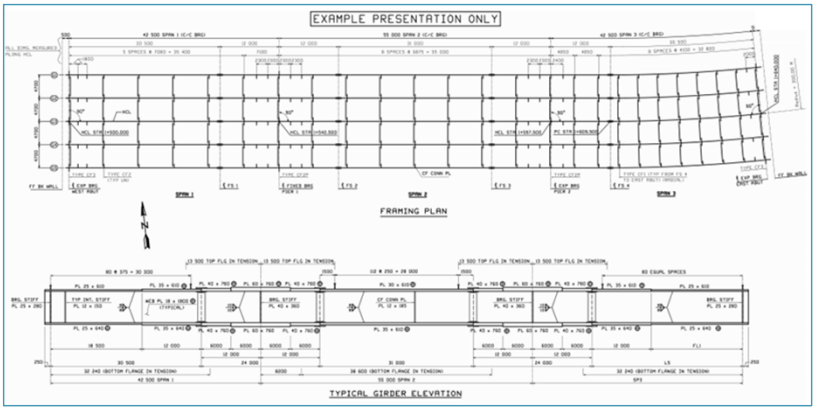
AASHTO/NSBA Steel Bridge Collaboration

- **Design Drawings Presentation Guidelines (G1.2-2003)**
  - Provides advice on the minimum information required to detail and fabricate a steel structure. Sample drawings illustrating the needed information are provided.



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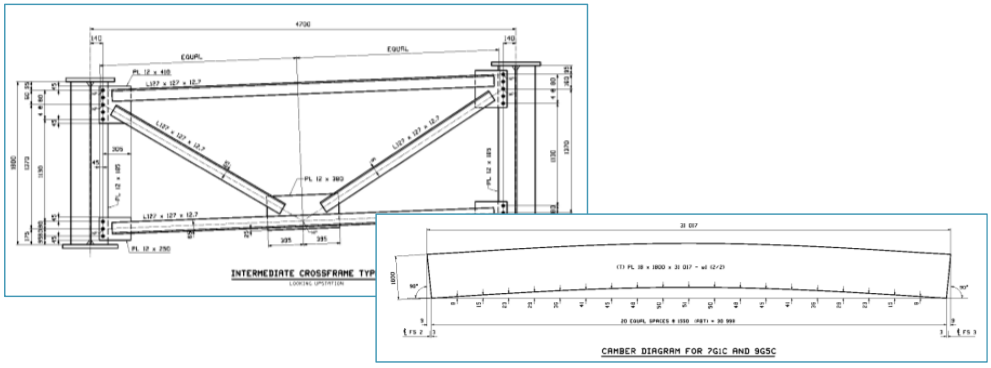
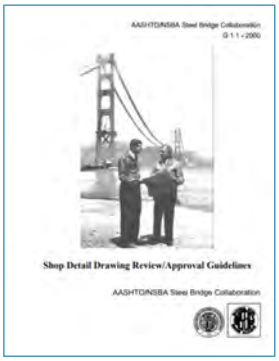
AASHTO/NSBA Steel Bridge Collaboration

- **Shop Drawing Approval Review/Approval Guidelines (G1.1-2000)**
  - Provides owners and engineers with typical guidelines, as well as an overall framework of responsibilities for the approval of shop drawings. A checklist of common items that should typically be reviewed is provided.





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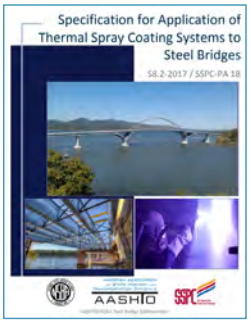
AASHTO/NSBA Steel Bridge Collaboration

- **Other Useful Collaboration Documents**
  - Steel Bridge Fabrication Guide Specification (S2.1-2016)
  - Steel Bridge Fabrication QC/QA Guide Specification (S4.1-2002)
  - Guide Specification for Application of Coating Systems (S8.1-2014)
  - Shop Detail Drawing Presentation Guidelines (G1.3-2002)
  - Specification for Application of Thermal Spray Coatings for Steel Bridges (S8.2-2017)



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Presentation Outline

- Available References
  - Design Specifications and Codes
  - AASHTO/NSBA Collaboration
  - FHWA Steel Bridge Handbook
  - NSBA Design & Technical Resources
  - Other FHWA Technical Resources
  - NSBA Design Tools
- Example of How To Use These References
- Summary

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FHWA Steel Bridge Design Handbook

- FHWA Office of Bridges and Structures - http://www.fhwa.dot.gov/bridge/
- 25 Volumes
  - 19 Written Chapters
  - 6 Design Examples
- Updated for AASHTO LRFD 7th Edition
- FREE!!!

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FHWA Steel Bridge Design Handbook

- **History of the Handbook**
- **Highway Structures Handbook**
  - US Steel, 1970's
- **AISC**
  - Several updated chapters over several years
  - LFD and LRFD design examples
- **NSBA**
  - Update for LRFD and a few new chapters
- **FHWA**
  - Provided funding to update and complete in 2012
  - Updated again in 2016

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FHWA Steel Bridge Design Handbook

Chapters

1. **Bridge Steels and Their Mechanical Properties**
2. Steel Bridge Fabrication
3. Steel Bridge Shop Drawings
4. **Structural Behavior of Steel**
5. **Selecting the Right Bridge Type**
6. **Stringer Bridges: Making the Right Choices**
7. Loads and Load Combinations
8. Structural Analysis
9. Redundancy

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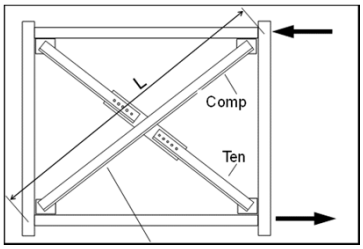
FHWA Steel Bridge Design Handbook

Chapters (cont'd)

10. Limit States
11. Design for Constructibility
12. **Design for Fatigue**
13. **Bracing System Design**
14. Field Splice Design
15. Bearing Design
16. Substructure Design
17. Bridge Deck Design
18. Load Rating of Steel Bridges
19. Corrosion Protection of Steel Bridges



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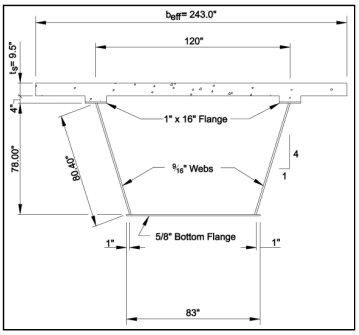
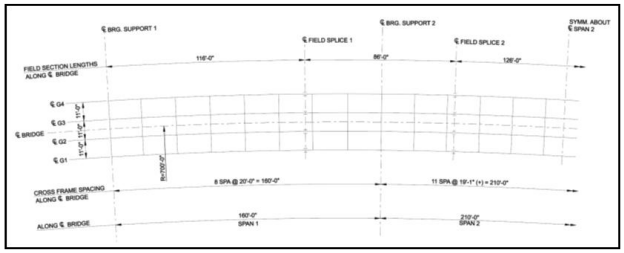
FHWA Steel Bridge Design Handbook

Design Examples

20. **3-span Straight Steel I-Girder Bridge**
21. 2-span Straight Steel I-Girder Bridge
22. 2-span Straight Steel Wide-Flange Beam Bridge
23. 3-span Straight Steel Tub-Girder Bridge
24. **3-span Curved Steel I-Girder Bridge**
25. 3-span Curved Steel Tub-Girder Bridge





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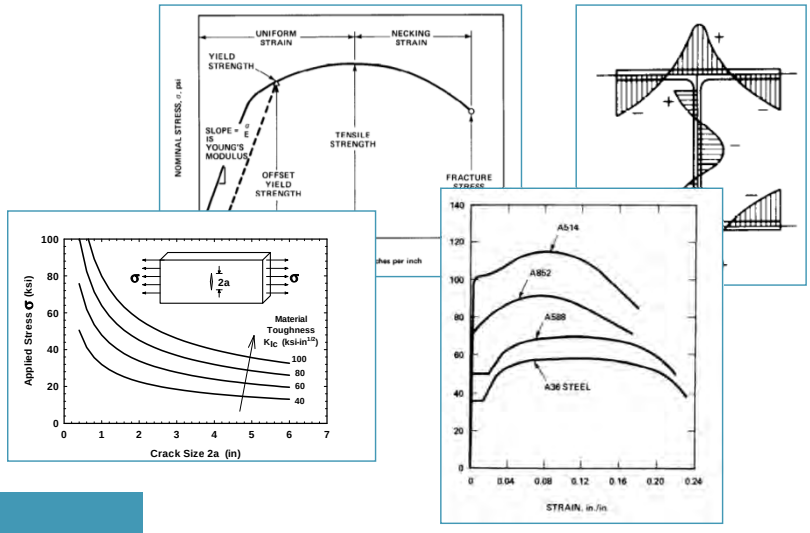
FHWA Steel Bridge Design Handbook

Vol. 1 - Bridge Steels and Their Mechanical Properties

- **Includes:**
  - Product Specifications
  - Steel Manufacturing
  - Mechanical Properties
  - Weldability & Fabrication
  - Corrosion Resistance



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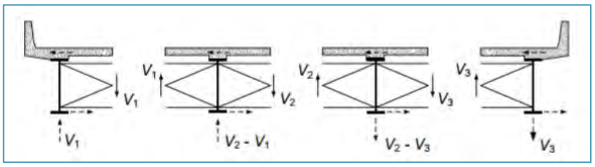
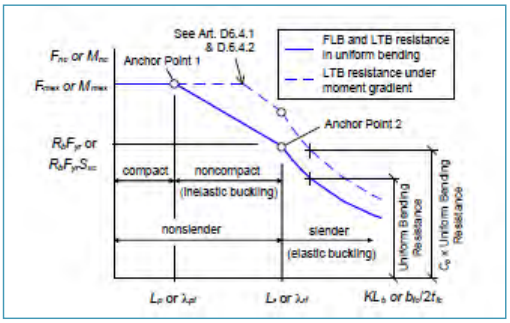
FHWA Steel Bridge Design Handbook

Vol. 4 – Structural Behavior of Steel

- **Includes:**
  - Member Behavior and Strength Design
  - Tension Members
  - Compression Members
  - I-section Flexural Members
  - Combined Flexural and Torsion
  - Box-Section Flexural Members
  - Miscellaneous Flexural Members
  - Combined Flexure and Axial Load





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FHWA Steel Bridge Design Handbook

Vol. 5 – Selecting the Right Bridge Types

Vol. 6 – Stringer Bridges: Making the Right Choices

- **Includes:**
  - Discussion on Various Bridge Types and when appropriate
  - Details encountered in composite deck girders
  - Welded plate girders and rolled beams
  - Specific design details

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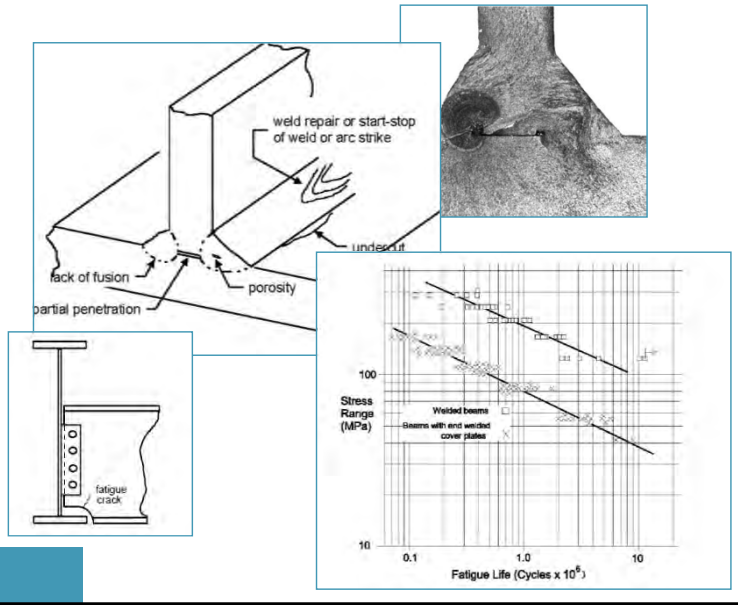
FHWA Steel Bridge Design Handbook

Vol. 12 – Design for Fatigue

- **Includes:**
  - Historical Perspective
  - Crack Growth
    - Load-Induced
    - Distortion Induced
  - AASHTO Provisions
    - Infinite Life Design
    - Finite Life Design
  - Fracture Control



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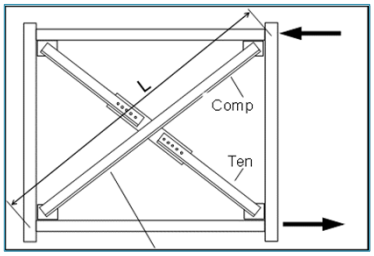
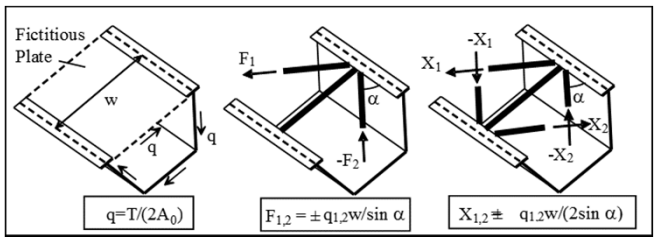
FHWA Steel Bridge Design Handbook

Vol. 13 – Bracing System Design

- **Includes:**
  - Bracing of I-Girders
    - Stability & Strength / Skew Effects
    - System Buckling
  - Bracing of Tub Girders
    - Top Lateral Bracing
    - Intermediate Bracing
  - Bracing Member Design
    - Compression & Tension / WT's & angles / Connections





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Presentation Outline

- Available References
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  - FHWA Steel Bridge Handbook
  - NSBA Design & Technical Resources
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  - NSBA Design Tools
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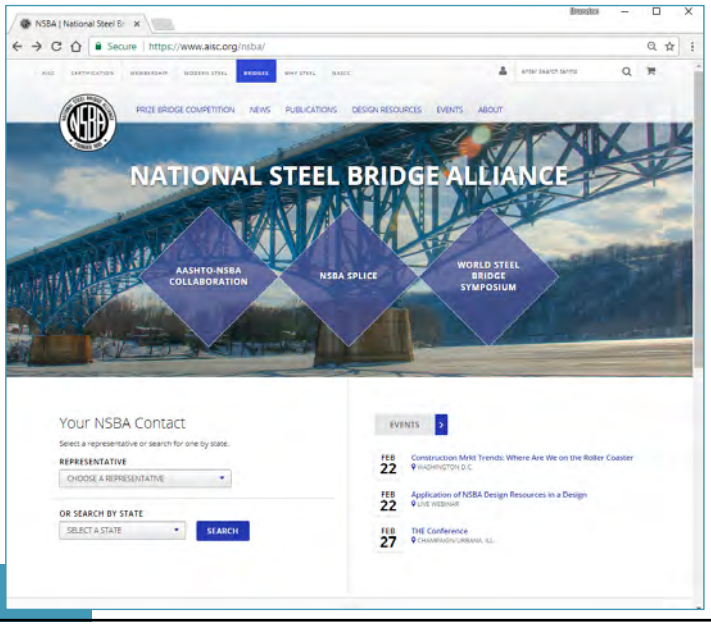
NSBA Design Resources

- https://www.steelbridges.org/



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NSBA Design Resources

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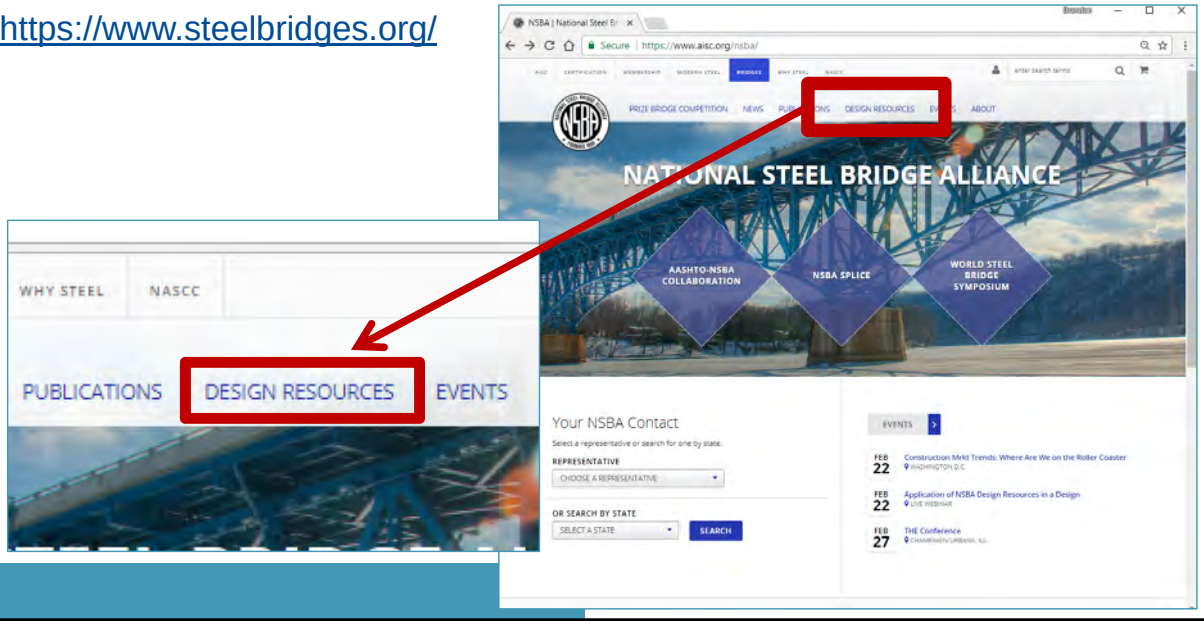

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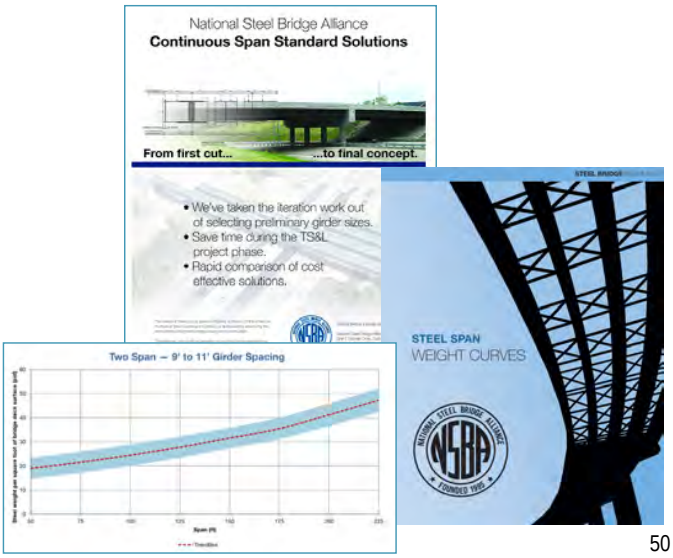
NSBA Design Resources

- https://www.aisc.org/nsba/design-resources/
- Continuous Span Standards
  - Assist engineers during the TS&L phase:
    - Flange plate sizes and lengths
    - Web plate sizes and lengths
    - Diaphragm spacing
    - Stiffener locations
    - Girder weights
    - Shear connector spacing
    - Steel DL and Total DL camber tables
- Steel Span Weight Curves



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NSBA Design Resources

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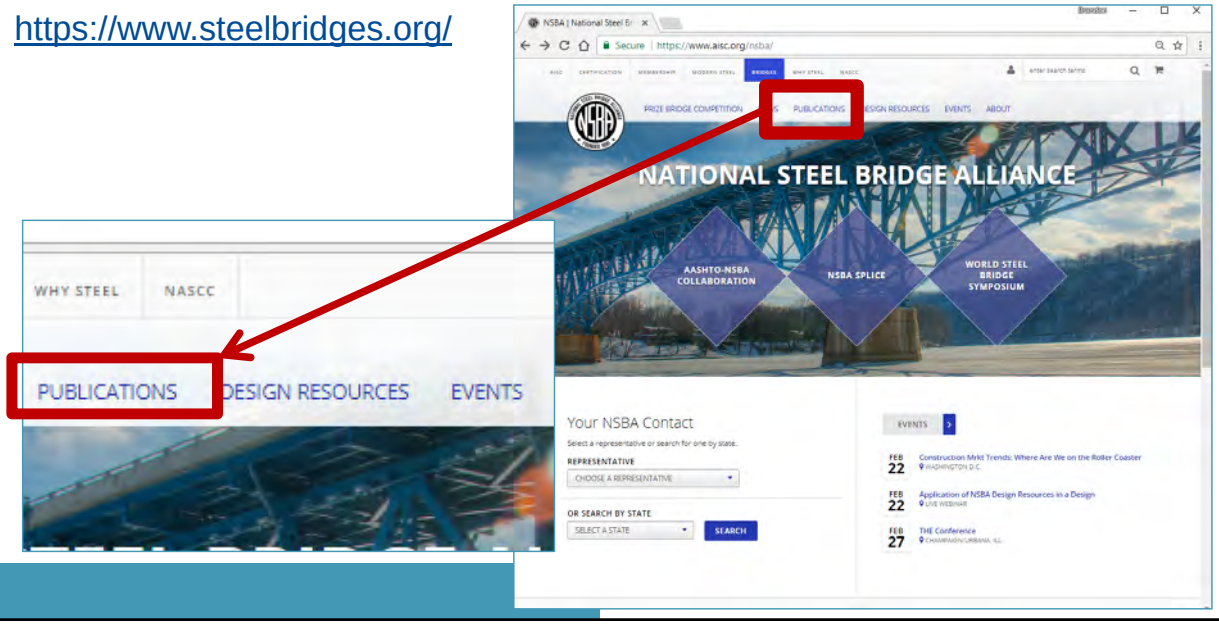

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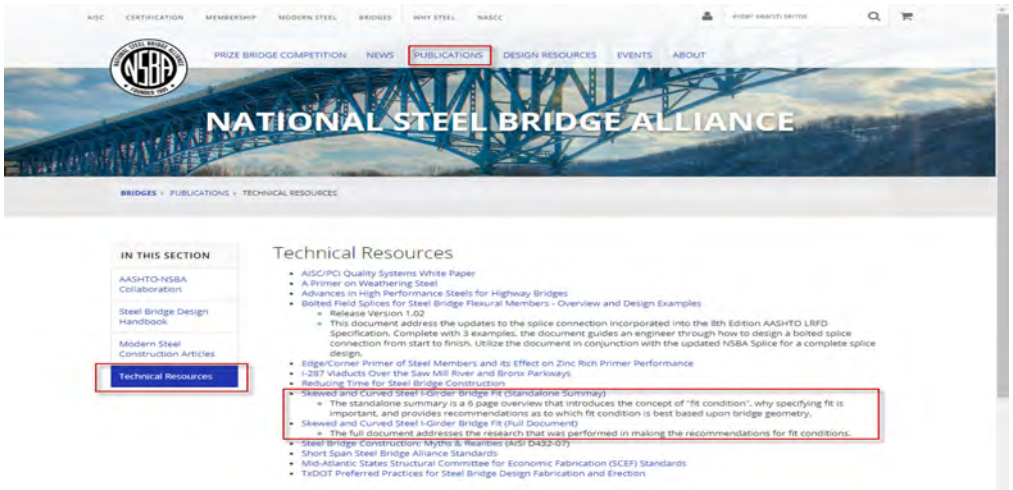
NSBA Design Resources

- https://www.steelbridges.org/



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NSBA Technical Resources

- Practical Steel Tub Girder Design
- A Fatigue Primer for Structural Engineers
- Moments, Shears, and Reactions

- Bolted Field Splices
  - AASHTO LRFD 8th Edition

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NSBA Technical Resources

- Bolted Field Splices

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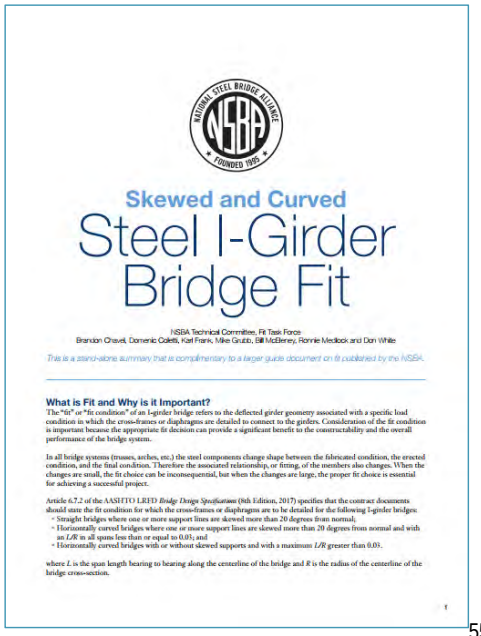
NSBA Technical Resources

- Skewed and Curved Steel I-Girder Bridge Fit
  - Standalone Summary (6 pages)
  - Full Document (47 pages)

  - Explains Fit Conditions
    - No Load Fit
    - Steel Dead Load Fit
    - Total Dead Load Fit

  - Provides Recommended Fit Conditions for
    - Skewed Bridges
    - Curved Bridges
    - Curved Bridges with Skewed Supports


Skewed and Curved
Steel I-Girder Bridge Fit

NSBA Technical Committee, Fit Task Force:
Brandon Chavel, Domenic Colletti, Karl Frank, Mike Grubb, Bill McBerey, Ronnie Medlock and Don White

This is a stand-alone summary that is complimentary to a larger guide document on fit published by the NSBA.

What is Fit and Why is it Important?

The "fit" or "fit condition" of an I-girder bridge refers to the deflected girder geometry associated with a specific load condition in which the cross-frames or diaphragms are detailed to connect to the girders. Consideration of the fit condition is important because the appropriate fit decision can provide a significant benefit to the constructability and the overall performance of the bridge system.

In all bridge systems (trusses, arches, etc.) the steel components change shape between the fabricated condition, the erected condition, and the final condition. Therefore the associated relationship, or fitting, of the members also changes. When the changes are small, the fit choice can be inconsequential, but when the changes are large, the proper fit choice is essential for achieving a successful project.

Article 6.7.2 of the AASHTO LRFD *Bridge Design Specifications* (8th Edition, 2017) specifies that the contract documents should state the fit condition for which the cross-frames or diaphragms are to be detailed for the following I-girder bridges:

- Straight bridges where one or more support lines are skewed more than 20 degrees from normal;
- Horizontally curved bridges where one or more support lines are skewed more than 20 degrees from normal and with an L/R in all spans less than or equal to 0.03; and
- Horizontally curved bridges with or without skewed supports and with a maximum L/R greater than 0.03.

where L is the span length bearing to bearing along the centerline of the bridge and R is the radius of the centerline of the bridge cross-section.

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  - NSBA Design Tools
- Example of How To Use These References
- Summary

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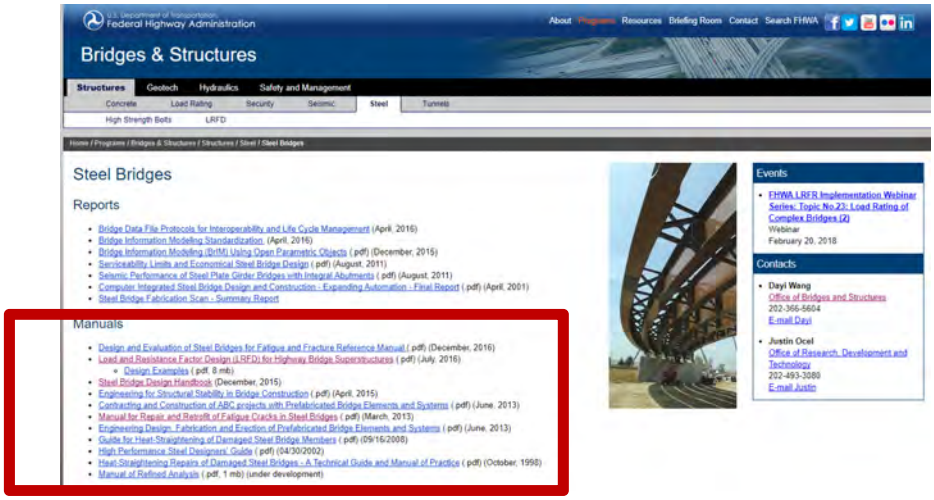
Other FHWA Technical Resources

- FHWA Office of Bridges and Structures - http://www.fhwa.dot.gov/bridge/



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Other FHWA Technical Resources

- FHWA Office of Bridges and Structures - http://www.fhwa.dot.gov/bridge/

Manuals

- Design and Evaluation of Steel Bridges for Fatigue and Fracture Reference Manual (.pdf) (December, 2016)
- Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures (.pdf) (July, 2016)
  - Design Examples (.pdf, 8 mb)
- Steel Bridge Design Handbook (December, 2015)
- Engineering for Structural Stability in Bridge Construction (.pdf) (April, 2015)
- Contracting and Construction of ABC projects with Prefabricated Bridge Elements and Systems (.pdf) (June, 2013)
- Manual for Repair and Retrofit of Fatigue Cracks in Steel Bridges (.pdf) (March, 2013)
- Engineering Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems (.pdf) (June, 2013)
- Guide for Heat-Straightening of Damaged Steel Bridge Members (.pdf) (09/16/2008)
- High Performance Steel Designers' Guide (.pdf) (04/30/2002)
- Heat-Straightening Repairs of Damaged Steel Bridges - A Technical Guide and Manual of Practice (.pdf) (October, 1998)
- Manual of Refined Analysis (.pdf, 1 mb) (under development)

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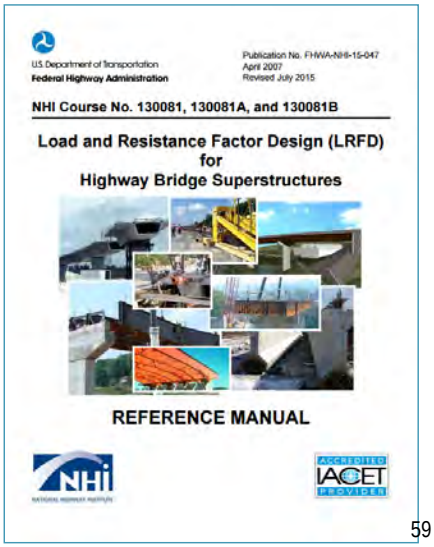
Other FHWA Technical Resources

- FHWA Office of Bridges and Structures - http://www.fhwa.dot.gov/bridge/
  - LRFD for Highway Superstructures Reference Manual
  - http://www.fhwa.dot.gov/bridge/pubs/nhi15047.pdf
  - AASHTO LRFD 7th Edition, 2015 Interims
  - Chapters include
    - General Design and Location Features
    - Loads and Load Factors
    - Structural Analysis
    - Steel Girder Superstructures
    - Decks and Deck Systems
    - Bearings and Joints
  - Design Example – 2 Span Steel Plate Girder



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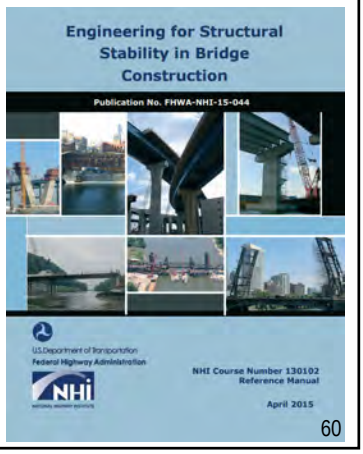
Other FHWA Technical Resources

- FHWA Office of Bridges and Structures
  - Manual for Repair and Retrofit of Fatigue Cracks in Steel Bridges
  - NHI Engineering for Structural Stability in Bridge Construction
  - Manual of Refined Analysis
    - In production
  - Guide for Heat-Straightening of Damaged Steel Bridge Members
  - Various Technical Advisories, Memos, and Ongoing Research
    - Clarification of Requirements for Fracture Critical Members (Memo)
    - Field Data Collection of Truck Spray (Research)



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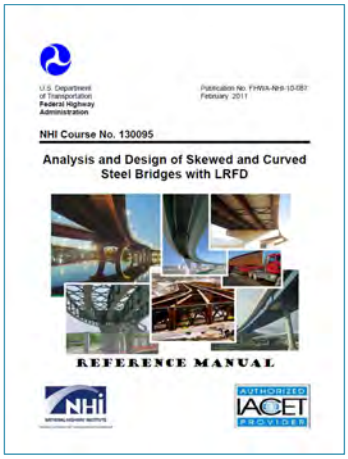
Other FHWA Technical Resources

- FHWA Office of Bridges and Structures
  - NHI Analysis and Design of Skewed and Curved Bridges with LRFD
    - Reference Manual you get when you take the NHI class 130095
  - AASHTO LRFD 5th Edition
  - Chapters include
    - Evolution of Curved Girder Design Specifications
    - Structural Analysis Topics
    - Design Considerations
    - Fabrication and Construction Considerations
    - Two Design Examples
      - » Skewed and Curved I-girder bridge
      - » Tub girder bridge



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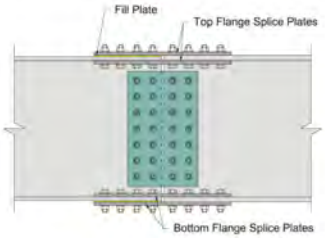
NSBA Design Tools

- SIMON Analysis Software
  - Line girder analysis software that can be used to analyze straight and low skew plate girder and tub girder bridges.
  - AASHTO LRFD 7th Edition
- NSBA Splice
  - SPREADSHEET!
  - Allows the designer to quickly analyze various bolted splice connections to determine the most efficient bolt quantity and configuration.
  - Updated for AASHTO LRFD 8th Edition



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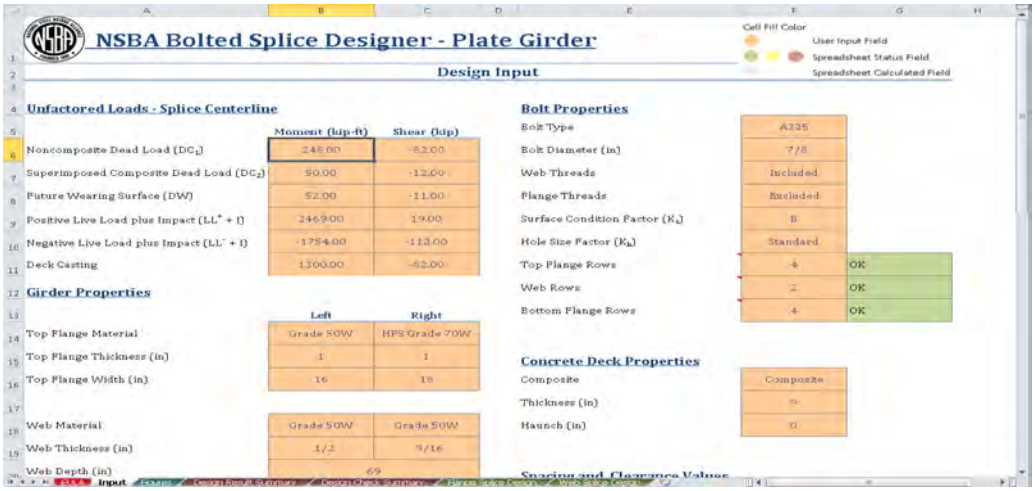
NSBA Design Tools

- NSBA Splice Spreadsheet


NSBA Bolted Splice Designer - Plate Girder

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	-113.00
Deck Casting	1300.00	-62.00

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

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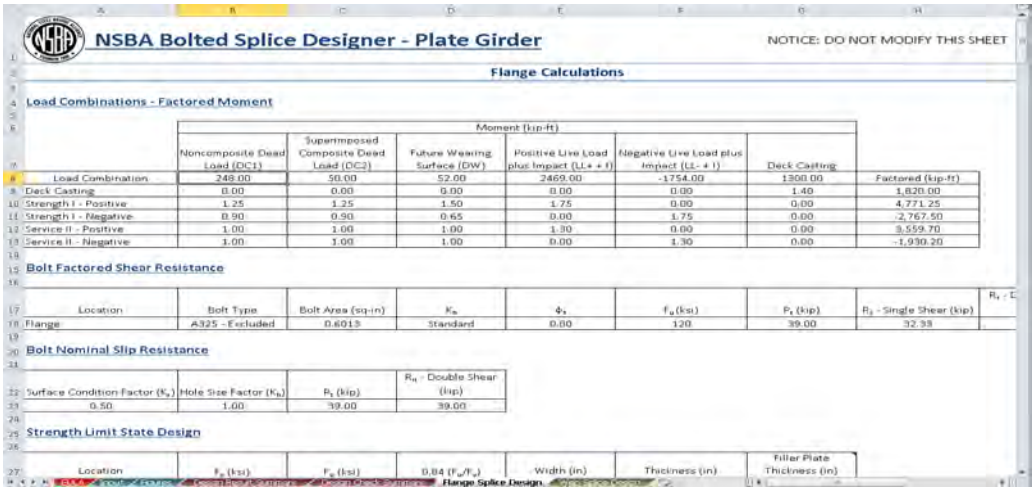
NSBA Design Tools

- NSBA Splice Spreadsheet



NSBA Bolted Splice Designer - Plate Girder

NOTICE: DO NOT MODIFY THIS SHEET

Flange Calculations

Load Combinations - Factored Moment

	Moment (kip-ft)						
Load Combination	Noncomposite Dead Load (DC1)	Superimposed Composite Dead Load (DC2)	Future Wearing Surface (DW)	Positive Live Load plus Impact (LL+ + I)	Negative Live Load plus Impact (LL- + I)	Deck Casting	Factored (kip-ft)
Deck Casting	248.00	50.00	52.00	2469.00	-1754.00	1300.00	
Strength I - Positive	0.00	0.00	0.00	0.00	0.00	1.40	1,820.00
Strength I - Negative	1.25	1.25	1.50	1.75	0.00	0.00	4,771.25
Service II - Positive	0.90	0.90	0.65	0.00	1.75	0.00	-2,767.50
Service II - Negative	1.00	1.00	1.00	1.30	0.00	0.00	3,559.70
	1.00	1.00	1.00	0.00	1.30	0.00	-1,930.20

Bolt Factored Shear Resistance

Location	Bolt Type	Bolt Area (sq-in)	K_h	ϕ_s	F_u (ksi)	P_r (kip)	R_s - Single Shear (kip)	R_r - D
Flange	A325 - Excluded	0.6013	Standard	0.80	120	39.00	32.33	

Bolt Nominal Slip Resistance

Surface Condition Factor (K_s)	Hole Size Factor (K_h)	P_t (kip)	R_n - Double Shear (kip)
0.50	1.00	39.00	39.00

Strength Limit State Design

Location	F_y (ksi)	F_u (ksi)	0.84 (F_y/F_u)	Width (in)	Thickness (in)	Filler Plate Thickness (in)

Flange Splice Design

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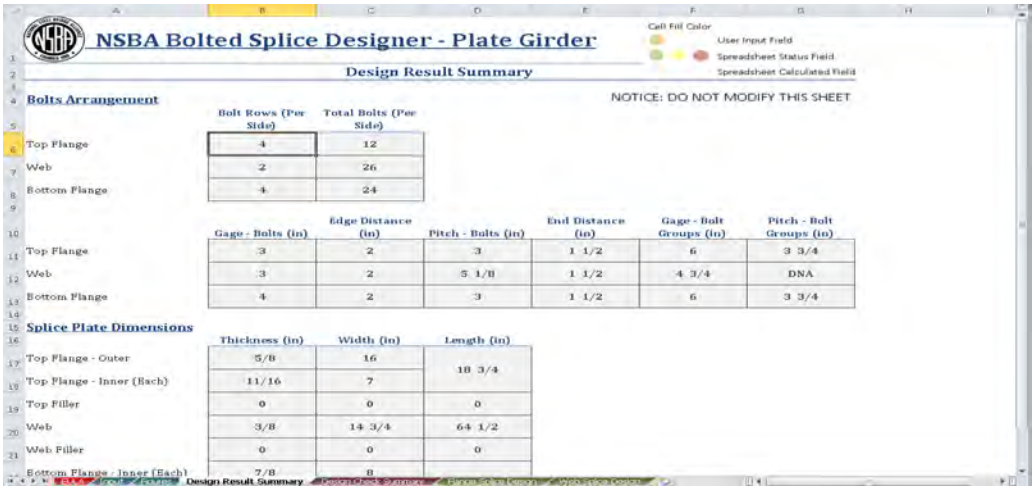
NSBA Design Tools

- NSBA Splice Spreadsheet



NSBA Bolted Splice Designer - Plate Girder

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Design Result Summary

NOTICE: DO NOT MODIFY THIS SHEET

Bolts Arrangement

	Bolt Rows (Per Side)	Total Bolts (Per Side)
Top Flange	4	12
Web	2	26
Bottom Flange	4	24

	Gage - Bolts (in)	Edge Distance (in)	Pitch - Bolts (in)	End Distance (in)	Gage - Bolt Groups (in)	Pitch - Bolt Groups (in)
Top Flange	3	2	3	1 1/2	6	3 3/4
Web	3	2	5 1/8	1 1/2	4 3/4	DNA
Bottom Flange	4	2	3	1 1/2	6	3 3/4

Splice Plate Dimensions

	Thickness (in)	Width (in)	Length (in)
Top Flange - Outer	5/8	16	18 3/4
Top Flange - Inner (Each)	11/16	7	
Top Filler	0	0	0
Web	3/8	14 3/4	64 1/2
Web Filler	0	0	0
Bottom Flange - Inner (Each)	7/8	8	

Design Result Summary

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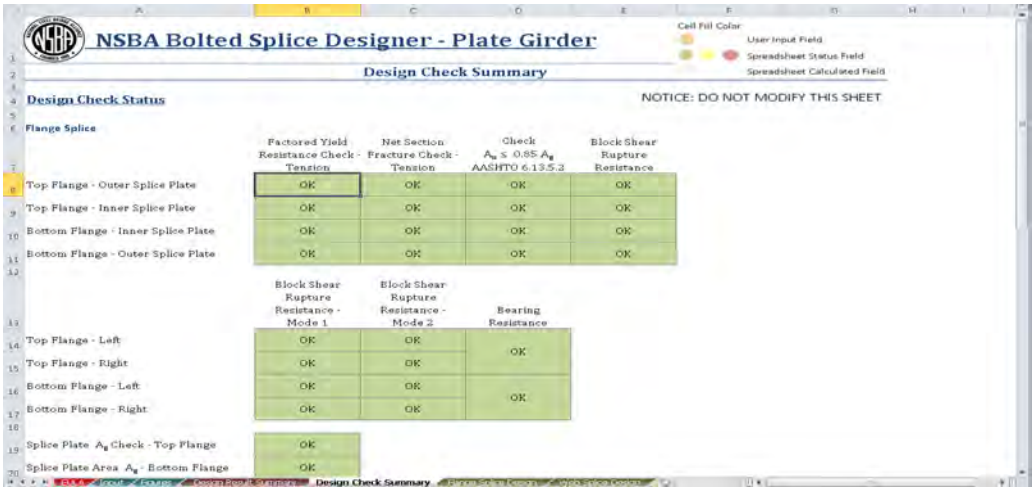
NSBA Design Tools

- NSBA Splice Spreadsheet



NSBA Bolted Splice Designer - Plate Girder

Design Check Summary

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Design Check Status

NOTICE: DO NOT MODIFY THIS SHEET

Flange Splice

	Factored Yield Resistance Check - Tension	Net Section Fracture Check - Tension	Check $A_n \geq 0.85 A_g$ AASHTO 6.13.5.3	Block Shear Rupture Resistance
Top Flange - Outer Splice Plate	OK	OK	OK	OK
Top Flange - Inner Splice Plate	OK	OK	OK	OK
Bottom Flange - Inner Splice Plate	OK	OK	OK	OK
Bottom Flange - Outer Splice Plate	OK	OK	OK	OK

	Block Shear Rupture Resistance - Mode 1	Block Shear Rupture Resistance - Mode 2	Bearing Resistance
Top Flange - Left	OK	OK	OK
Top Flange - Right	OK	OK	
Bottom Flange - Left	OK	OK	OK
Bottom Flange - Right	OK	OK	
Splice Plate A_g Check - Top Flange	OK		
Splice Plate Area A_g - Bottom Flange	OK		

Design Check Summary

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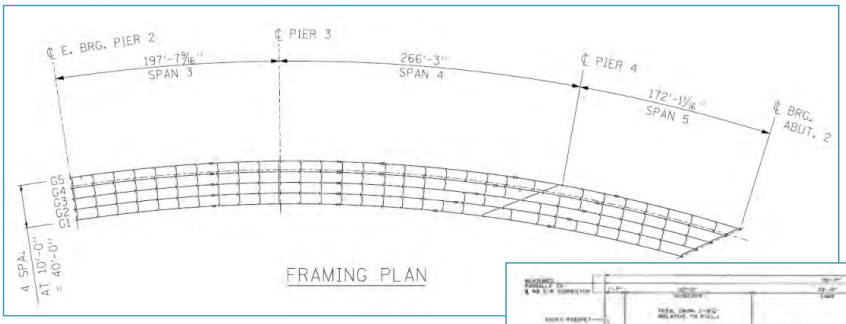
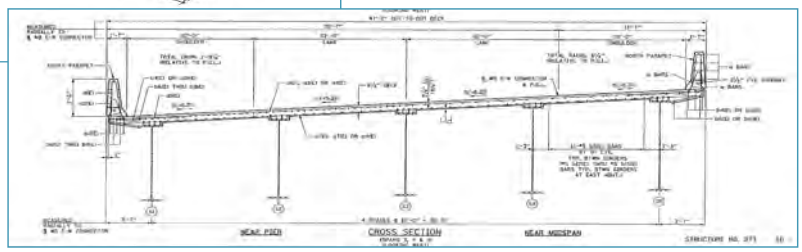
How Can I Use These Resources???

- Consider this bridge



General Geometric Features

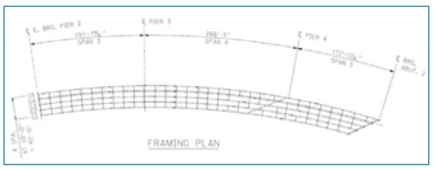
- *1400' radius @ CL*
- *Spans @ CL ~ 198' – 266' – 172'*
- *59º skew at Pier 4 and Abut 2*
- *47'-2" Out-to-Out*



69

How Can I Use These Resources???

- *Highlight Particular Items and How Resources can Help*
- Curved / Skewed Girder Behavior and Design
- Establish Framing Plan
  - Girder Spacing
  - Cross Frame Layout
- Level of Analysis
  - Where to Start?
- Cross Frame Connection Details
- Field Splice Design
- Fit up Condition
- Review of Design



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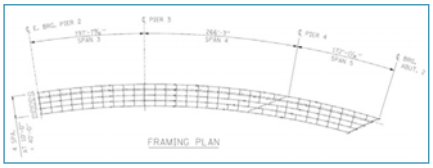

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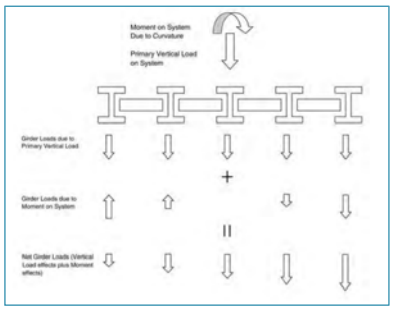
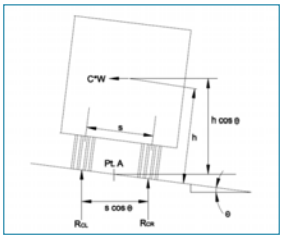
Curved / Skewed Girder Behavior and Design

- Behavior
  - Guidelines for Steel Girder Bridge Analysis (G13.1-2014)
  - FHWA SDBH – Vol. 4: Structural Behavior of Steel
- Design
  - FHWA SBDH – Vol. 20: 3-span Straight Steel I-Girder Bridge
  - FHWA SBDH – Vol. 24: 3-span Curved Steel I-Girder Bridge
  - FHWA/NHI Curved & Skewed Girder Course Reference Manual





Since $L_p < L_b < L_r$, use Eq. (6.10.8.2.3-2) to calculate the lateral torsional buckling resistance.

$$F_{nc} = C_b\left[1-\left(1-\frac{F_{yr}}{R_b F_{yc}}\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right]R_b R_h F_{yc} \le R_b R_h F_{yc} \qquad \text{Eq. (6.10.8.2.3-2)}$$

$$= 1.0\left[1-\left[1-\frac{0.7(50)}{1.0(50)}\right]\left(\frac{20-9.65}{36.2-9.65}\right)\right](1.0)(1.0)(50) = 44.15 \text{ ksi}$$

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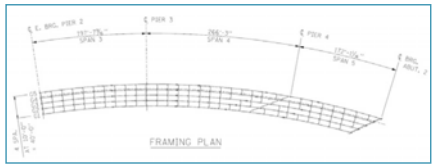

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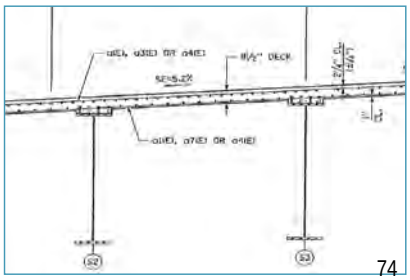
Establish a Framing Plan

- Determine Girder Spacing and Deck Overhang
  - AASHTO/NSBA Guidelines for Design for Constructability (G12.1-2016)
    - Article 1.2 – Girder Spacing
    - When selecting the number of girders consider:
      - » Owner preferences and limitations
      - » Cost of steel fabrication, transportation, and erection
      - » Deck thickness and forming methods
      - » Provisions for future widening
      - » Vertical clearances



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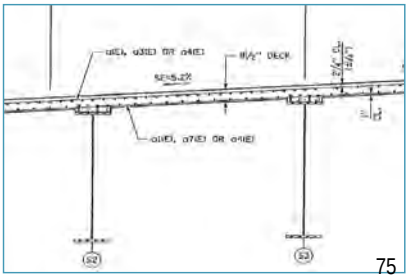
Establish a Framing Plan

- Determine Girder Spacing and Deck Overhang
  - AASHTO/NSBA Guidelines for Design for Constructability (G12.1-2016)
    - Article 1.2 – Girder Spacing
    - A wider spacing has benefits:
      - » Lower total structural steel weight
      - » Fewer girders to fabricate, inspect, handle, coat, transport and erect
      - » Fewer cross frames to fabricate, inspect, handle, coat, transport and erect
      - » Fewer bolts, connections, and bearings
      - » Reduced time of fabrication and erection
    - A wider spacing has to also consider:
      - » Thicker concrete deck resulting in more weight, concrete, rebar
      - » Methods for forming the deck
      - » Stability and redundancy of the structure during future re-decking
      - » Girder depth (deeper) and infringement on vertical clearance



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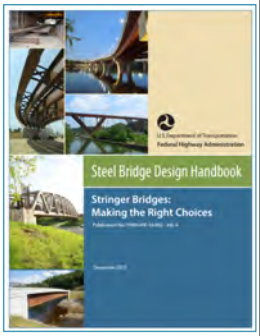
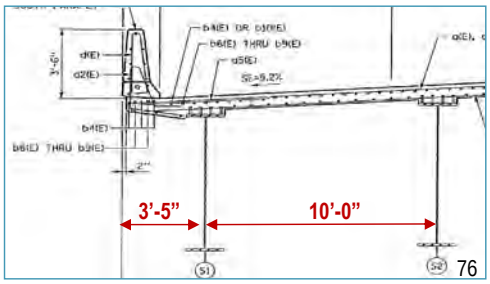
Establish a Framing Plan

- Determine Girder Spacing and Deck Overhang
  - FHWA SBDH – Vol. 6 Stringer Bridges: Making the Right Choices
    - Section 3.0
    - Deck Overhang ~ 30%-35% of girder spacing is most efficient
      - » Exterior and Interior Girder forces are reasonably balanced
  - Selection:
    - 5 Girders at 10’-0” Spacing
    - Deck Overhang = 3’-5”
    - Deck Overhang / Girder Spacing = 34%





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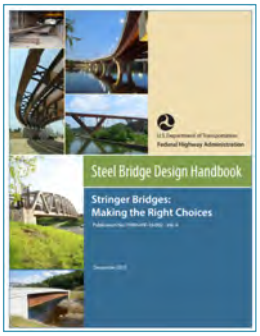
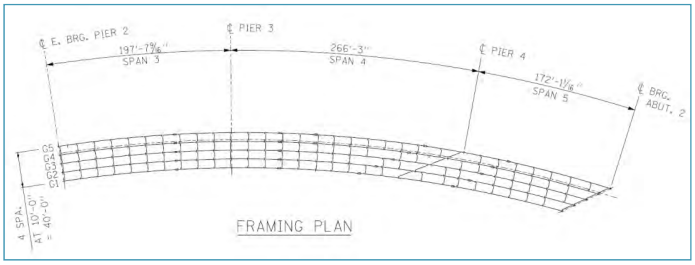
Establish a Framing Plan

- Determine Cross Frame Layout
  - FHWA SBDH – Vol. 6 Stringer Bridges: Making the Right Choices
    - Section 4.1
    - Discussion on past ASD and LRFD limits of 25’
    - LRFD does not specify limit, but generally don’t excessively exceed 25’
    - Primary load-carrying member in curved bridges
      - » Smaller radius of curvature, probably a smaller spacing of cross frames





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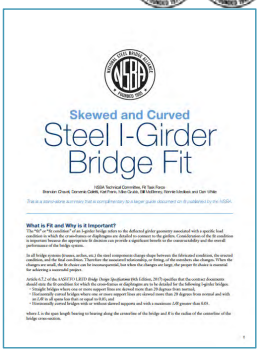
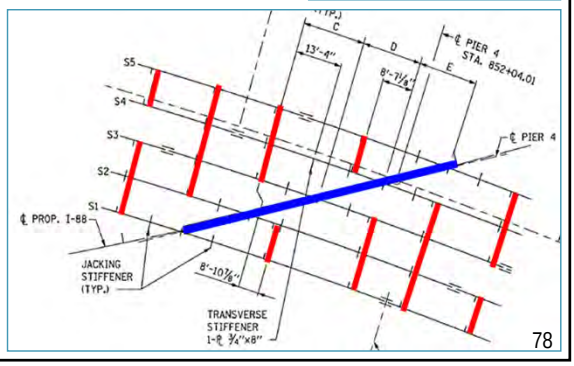
Establish a Framing Plan

- Determine Cross Frame Layout
  - Complications caused by Skew
  - AASHTO/NSBA Guidelines for Design for Constructability (G12.1-2016)
    - Article 2.2.6.5 – Reducing Demand on Cross Frames in Skewed Bridges
  - Steel I-Girder Bridge Fit (Full Document)
    - Section 4.4
      - » Discusses the use of staggered patterns
      - » Selectively omitting cross frames
      - » All to reduce transverse load paths near skewed supports





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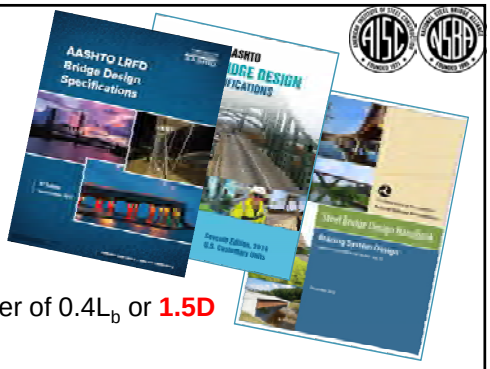
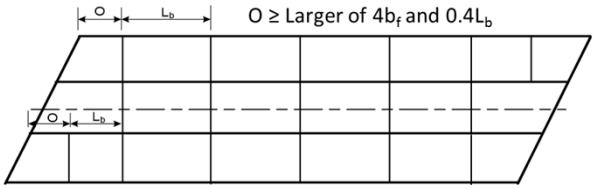
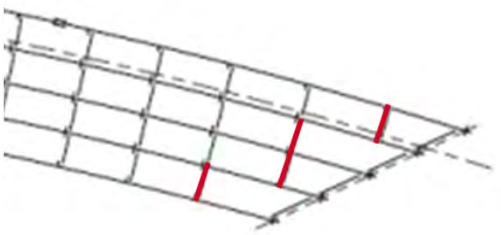
Establish a Framing Plan



- Determine Cross Frame Layout
  - When skew is greater than 20°:
    - AASHTO LRFD Article 6.7.4.2 (7th Edition)
      - » Locate 1st cross frame from skewed support by at least the larger of $0.4L_b$ or **1.5D**
    - AASHTO LRFD Article 6.7.4.2 (8th Edition)
      - » Locate 1st cross frame from skewed support by at least the larger of $0.4L_b$ or **$4b_f$**





  - FHWA SBDH – Vol. 13 Bracing System Design
    - Lean on Bracing Concepts

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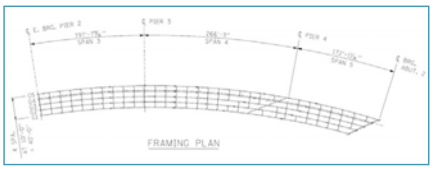

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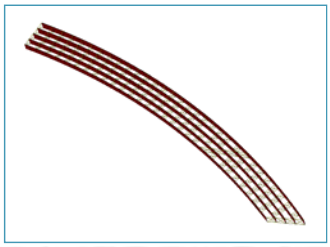
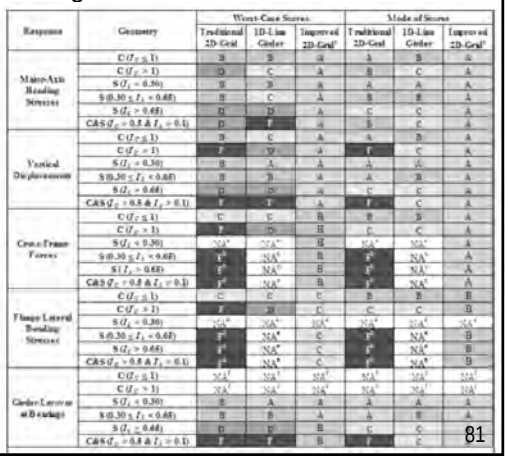
Level of Analysis

- Line Girder, 2D Grid, 3D Finite Element Analysis?
  - Guidelines for Steel Girder Bridge Analysis (G13.1-2014)
    - Section 1.1 and 1.2 – Analysis Methods in General
    - Section 4 – Analysis Guidelines for Specific Types of Steel Girder Bridges
    - Appendix B – Recommendations on Methods of Analysis
    - Appendix B – Table B-2





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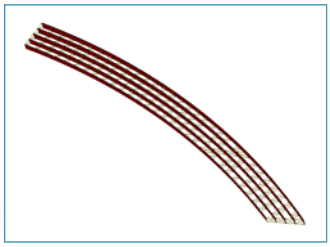
Level of Analysis

- Line Girder, 2D Grid, 3D Finite Element Analysis?
  - Guidelines for Steel Girder Bridge Analysis (G13.1-2014)



Response	Geometry	Worst-Case Scores			Mode of Scores		
		Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[1]	Traditional 2D-Grid	1D-Line Girder	Improved 2D-Grid[1]
Major-Axis Bending Stresses	$C(I_C \le 1)$	B	B	A	A	B	A
	$C(I_C > 1)$	D	C	A	B	C	A
	$S(I_S < 0.30)$	B	B	A	A	A	A
	$S(0.30 \le I_S < 0.65)$	B	C	A	B	B	A
	$S(I_S > 0.65)$	D	D	A	C	C	A
	$C\&S(I_C > 0.5 \;\&\; I_S > 0.1)$	D	F	A	B	C	A
Vertical Displacements	$C(I_C \le 1)$	B	C	A	A	B	A
	$C(I_C > 1)$	F	D	A	F	C	A
	$S(I_S < 0.30)$	B	A	A	A	A	A
	$S(0.30 \le I_S < 0.65)$	B	B	A	A	B	A
	$S(I_S > 0.65)$	D	D	A	C	C	A
	$C\&S(I_C > 0.5 \;\&\; I_S > 0.1)$	F	F	A	F	C	A
Cross-Frame Forces	$C(I_C \le 1)$	C	C	B	B	B	A
	$C(I_C > 1)$	F	D	B	C	C	A
	$S(I_S < 0.30)$	NA[2]	NA[2]	B	NA[2]	NA[2]	A
	$S(0.30 \le I_S < 0.65)$	F[3]	NA[2]	B	F[3]	NA[2]	A
	$S(I_S > 0.65)$	F[3]	NA[2]	B	F[3]	NA[2]	A
	$C\&S(I_C > 0.5 \;\&\; I_S > 0.1)$	F[3]	NA[2]	B	F[3]	NA[2]	A
Flange Lateral Bending Stresses	$C(I_C \le 1)$	C	C	C	B	B	B
	$C(I_C > 1)$	F	D	C	C	C	B
	$S(I_S < 0.30)$	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
	$S(0.30 \le I_S < 0.65)$	F[3]	NA[2]	C	F[3]	NA[2]	B
	$S(I_S > 0.65)$	F[3]	NA[2]	C	F[3]	NA[2]	B
	$C\&S(I_C > 0.5 \;\&\; I_S > 0.1)$	F[3]	NA[2]	C	F[3]	NA[2]	B
Girder Lateral Bending Stresses at Bearings	$C(I_C \le 1)$	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
	$C(I_C > 1)$	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]	NA[2]
	$S(I_S < 0.30)$	B	A	A	A	A	A
	$S(0.30 \le I_S < 0.65)$	B	B	A	A	B	A
	$S(I_S > 0.65)$	D	D	B	C	C	A
	$C\&S(I_C > 0.5 \;\&\; I_S > 0.1)$	F	F	B	F	C	A

$I_{C\_MAX} = 1.07$

$I_{S\_MAX} = 0.39$

Conclusion:
Use a 3D FEA

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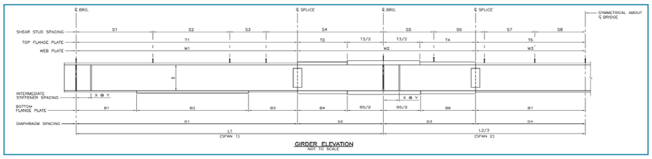
3D Analysis – Where to start?

- Where to get first cut at Girder Flange and Web Sizes
  - NSBA SIMON Analysis Software
    - Line Girder Analysis
    - Model girder with largest radius
    - Hold Performance Ratios to 80%-85% for a curved bridge
    - Hold Performance Ratios to ~75% for subject bridge
  - NSBA Continuous Span Standards
    - Based on Straight Girder Design
    - Increase flange sizes by 15%-20% for curved bridge
    - Increase flange sizes by ~25% for subject bridge



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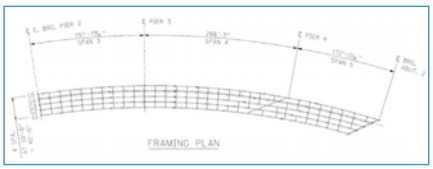

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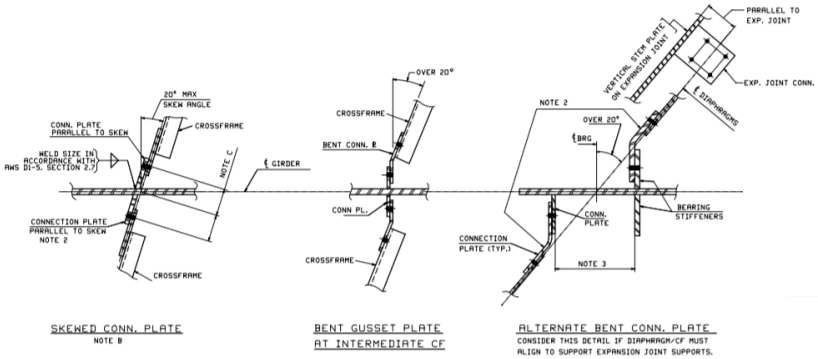
Cross Frame Connection Details

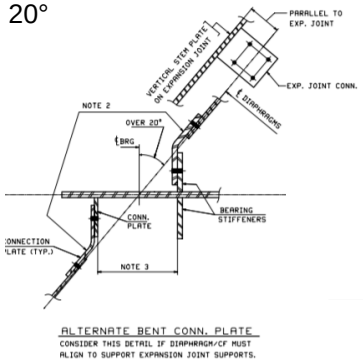
- Connection at Skewed Supports
  - Guidelines for Design Details (G1.4-2006)
    - Option A
      - » Skew < 20°
    - Option B
      - » Skew > 20°
    - Option C
      - » Skew > 20°
      - » Align to Support Exp. Joint



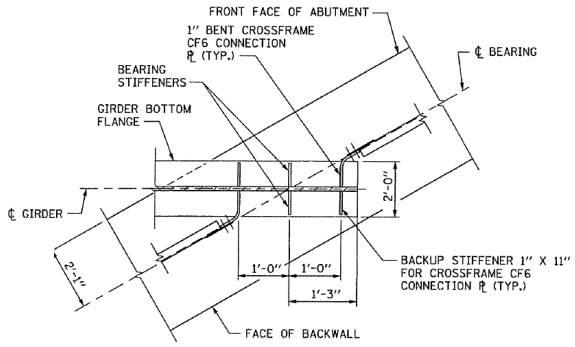
Option A Option B Option C

Cross Frame Connection Details

- Connection at Skewed Supports
  - Guidelines for Design Details (G1.4-2006)
    - Option C - Selected
      - » Skew > 20°



Option C



Actual Detail

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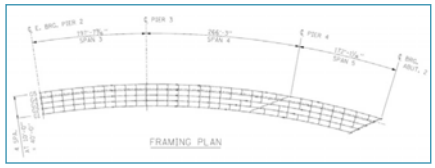

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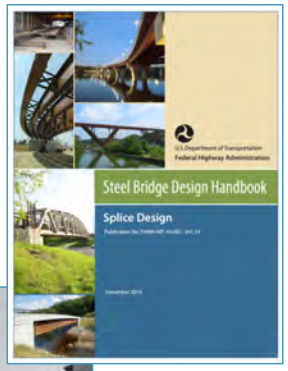
Field Splice Design

- FHWA SBDH – Vol. 9 Splice Design
  - AASHTO LRFD 7th Edition
  - In-Depth Discussion
  - Design Example
- NSBA Bolted Field Splices for Steel Bridge Flexural Members
  - AASHTO LRFD 8th Edition
  - Overview of Design Procedures
  - 3 Design Examples
- NSBA Splice Spreadsheet
  - AASHTO LRFD 8th Edition



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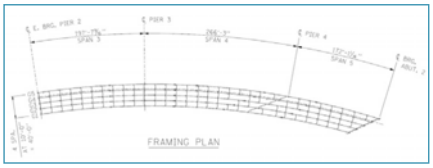

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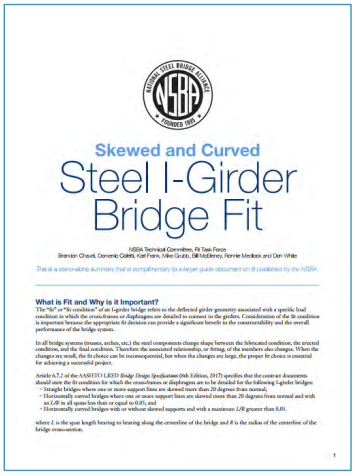
Fit-Up Condition

- NSBA Skewed and Curved Steel I-Girder Bridge Fit
  - Standalone Summary (6 pages)
  - L/R = 0.20
    - No-Load Fit is Recommended
    - Steel Dead Load Fit is Acceptable but consider locked-in force effects

Table 3 **Recommended Fit Conditions for Horizontally Curved I-Girder Bridges** $((L/R)_{MAX} > 0.03)$

Radial or Skewed Supports			
	Recommended	Acceptable	Avoid
$(L/R)_{MAX} \geq 0.2$	NLF[1]	SDLF[2]	TDLF
All other cases	SDLF	NLF	TDLF

Note 1: The recommendation transitions to NLF at or above a maximum *L/R* of 0.2 because research on these types of bridges (NCHRP 2015) shows that the increase in the cross-frame forces from SDLF detailing can become more significant as the degree of curvature increases.
Note 2: SLDF detailing is considered acceptable in these cases if the additive locked-in force effects are considered (see Design and Analysis section below).



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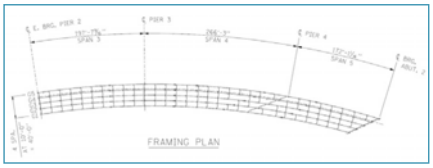
- Fit up Condition
- **Review of Design**



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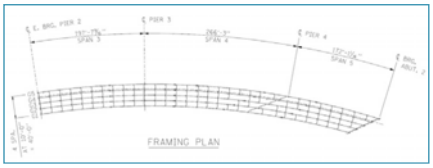
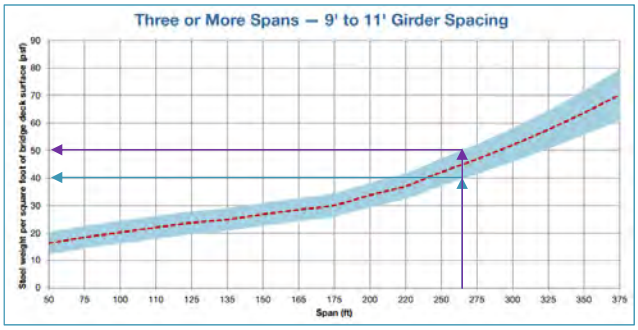
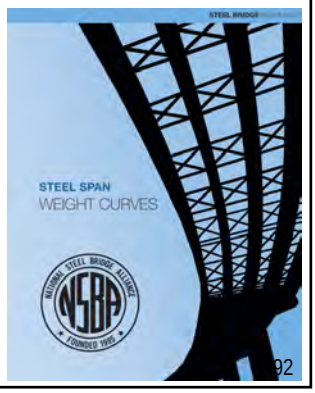
Review of Design

- Is there a way to “verify” the design?
  - Can compare the LB/SF with published data
- NSBA Steel Span Weight Curves
  - *Range of LB/SF for straight, low skew, plate girder bridges.*
  - *Can give a “ballpark” feel for the example bridge, apply a 30% factor for our bridge*







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Presentation Outline

- Available References
  - Design Specifications and Codes
  - FHWA Steel Bridge Handbook
  - AASHTO/NSBA Collaboration
  - NSBA Design & Technical Resources
  - Other FHWA Technical Resources
  - NSBA Design Tools
- Example of How To Use These References
- Summary

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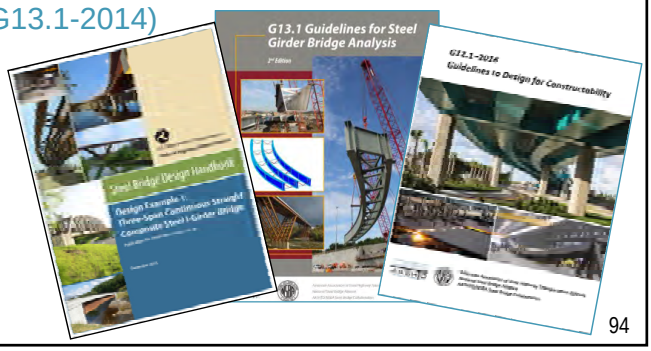
Summary

- Introduced / Reviewed Several Steel Bridge Design Resources
  - Design Specifications and Codes
  - FHWA Steel Bridge Handbook
  - AASHTO/NSBA Collaboration Guidelines and Specifications
    - Guidelines for Design Details (G1.4-2006)
    - Guidelines for Design for Constructability (G12.1-2016)
    - Guidelines for Steel Girder Bridge Analysis (G13.1-2014)
  - NSBA Design Resources
    - Continuous Span Standards
    - Steel Span Weight Curves



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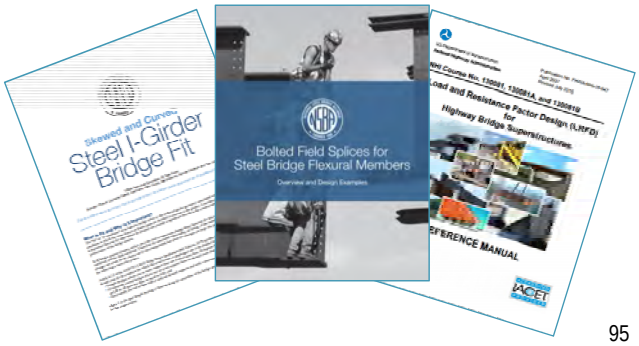
Summary

- Introduced / Reviewed Several Steel Bridge Design Resources
  - NSBA Technical Resources
    - NSBA Bolted Field Splices for Steel Bridge Flexural Members
    - NSBA Skewed and Curved Steel I-Girder Bridge Fit
  - Other FHWA Resources
    - FHWA/NHI Curved and Skewed Girder Course Reference Manual
  - NSBA Products
    - NSBA SIMON
    - NSBA Splice Spreadsheet



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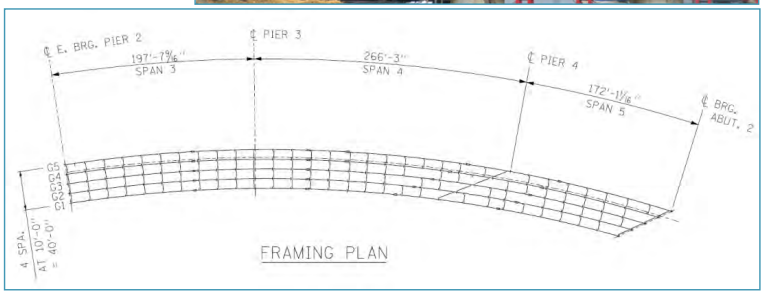
Summary

- Curved and Skewed Girder Example Bridge
  - Curved / Skewed Girder Behavior and Design
  - Establish Framing Plan
  - Level of Analysis
  - Cross Frame Connection Details
  - Field Splice Design
  - Fit-up Condition
  - Review of Design



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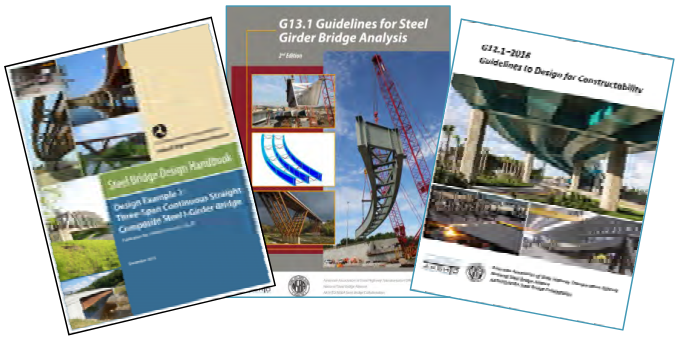
THANK YOU!



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Questions?

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PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

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There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.