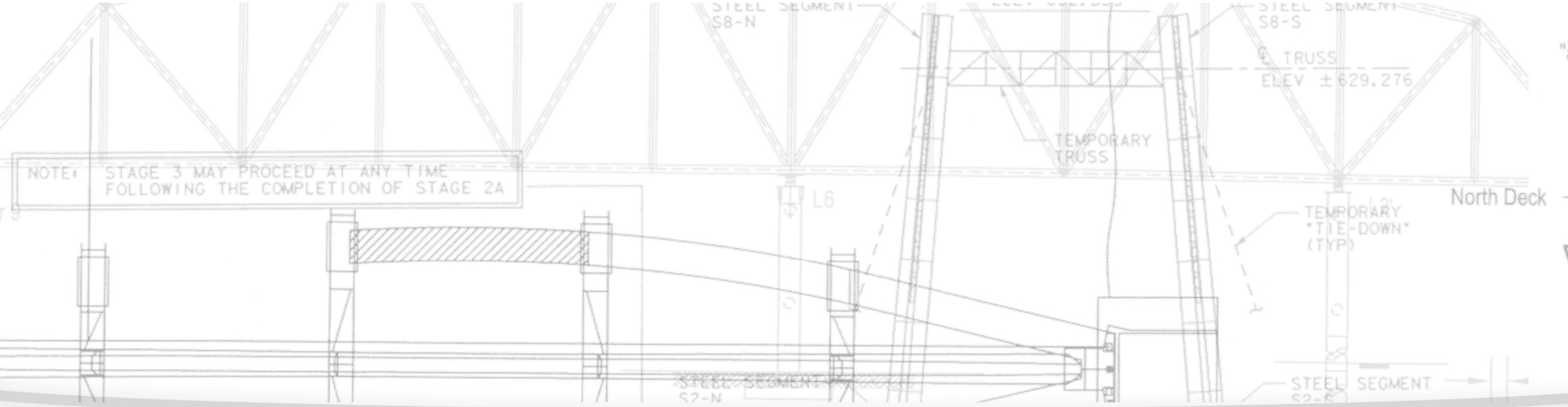


ENGINEERING FOR STABILITY DURING CONSTRUCTION

A CONSTRUCTION ENGINEER'S PERSPECTIVE

University of Minnesota

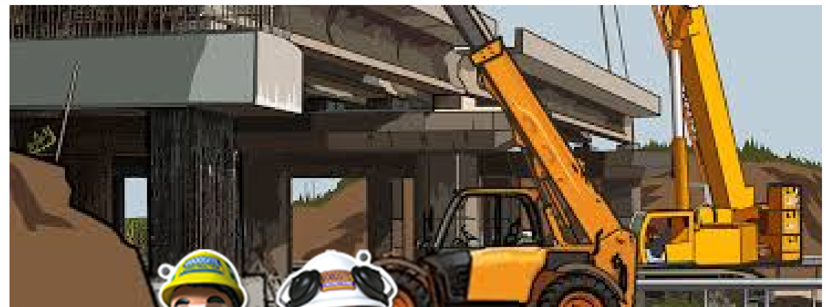
Structural Engineering Webinar – February 7, 2023

Presentation Overview

- Contractors and the 3-C’s
- Constructibility of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions

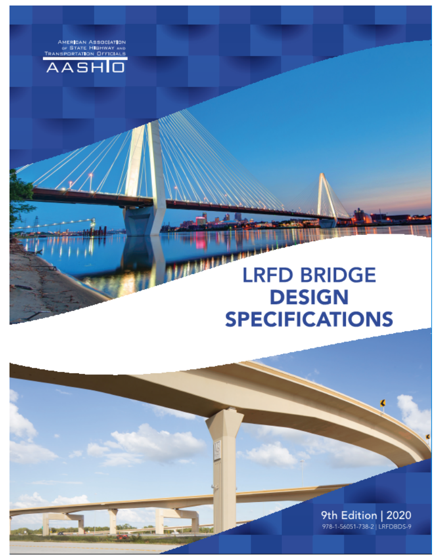
Presentation Overview

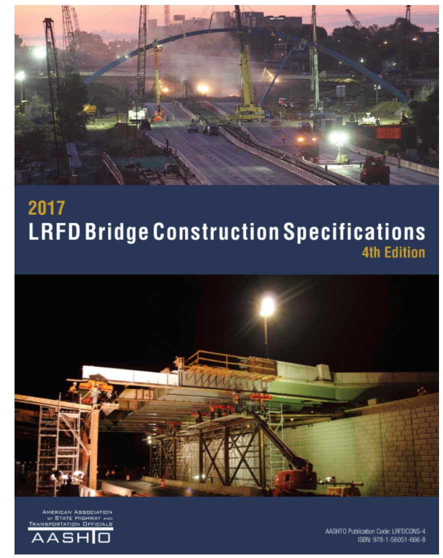
- Contractors and the 3-C's
  - Constructibility
  - Costs
  - Competition
- Constructibility of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions



Presentation Overview

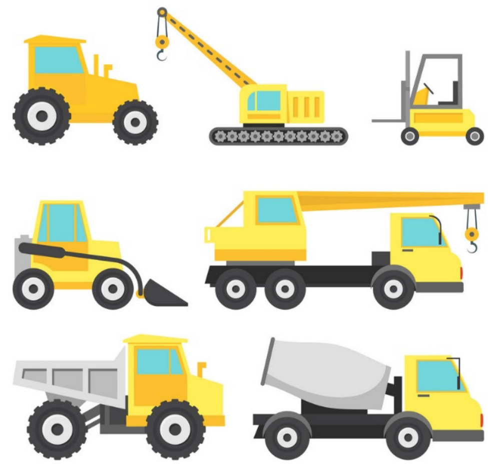
- Contractors and the 3-C's
- Constructibility of Superstructures
  - Review of AASHTO Expectations
  - Review of Minimum Checks
  - Steel Girder Erection
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions

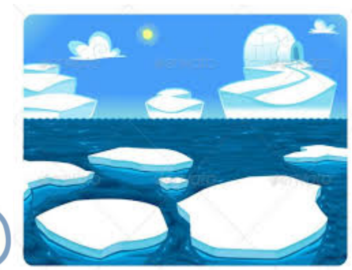




Presentation Overview

- Contractors and the 3-C's
- Constructibility of Superstructures
- Design Loads for Temporary Structures
  - Equipment
  - Environment
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions





Presentation Overview

- Contractors and the 3-C's
- Constructibility of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
  - Stability of girders with equipment removing concrete decks
  - Most Demos/Re-decking for Bridges Designed with ASD
  - How will LRFD designed bridges hold up?
- Conclusions/Suggestions

Sarah Long Demolition, Portsmouth, NH

I-75 Deck Replacement, Detroit, MI

Presentation Overview

- Contractors and the 3-C's
- Constructibility of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions

Owners
Designer Engineers

Construction Engineers
Contractors

Presentation Overview

- Contractors and the 3-C's
- Constructibility of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions

Presentation Overview

- Definitions
- Who is Responsible, and for What and When?
- Resources available
- Deeper dive into what AASHTO says
- Compare other resources
- Steel Girder Erection

Age old question…

Constructibility

6.10.3—Constructibility

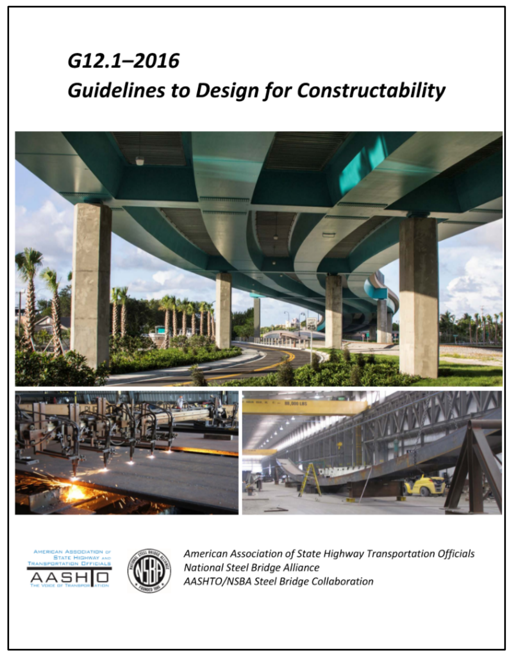
6.10.3.1—General

The provisions of Article 2.5.3 shall apply. In addition to providing adequate strength, nominal yielding or reliance on post-buckling resistance shall not be permitted for main load-carrying members during critical stages of construction, except for yielding of the web in hybrid sections. This shall be accomplished by satisfying the requirements of Articles 6.10.3.2 and 6.10.3.3 at each critical construction stage. For sections in positive flexure that are composite in the final condition, but are noncomposite during construction, the provisions of Article 6.10.3.4 shall apply. For investigating the constructibility of flexural members, all loads shall be factored as specified in Article 3.4.2. For the calculation of deflections, the load factors shall be taken as 1.0.

Potential uplift at bearings shall be investigated at each critical construction stage.

Webs without bearing stiffeners at locations subjected to concentrated loads not transmitted through a deck or deck system shall satisfy the provisions of Article D6.5.

Constructability


G12.1–2016
Guidelines to Design for Constructability

AASHTO

American Association of State Highway Transportation Officials
National Steel Bridge Alliance
AASHTO/NSBA Steel Bridge Collaboration

Constructibility:
The condition of being constructible.
"Is Constructible"
or
"It is Not Constructible"
or
"Leave me alone, I'm checking to see it it's constructible"

Constructability:
Project Management technique to Review the construction process.
Use an "a" anytime you can also use the phrase "Constructability review" in the same sentence.

Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT → Engineer of Record → Contractor

We need a bridge

Has to be:

- **Affordable**
- **Safe**
- **Durable**

Don't want any unforeseen issues in construction

Who is responsible for what and when?

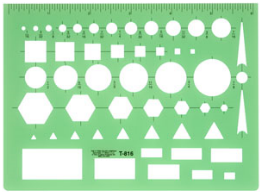
TYPICAL DESIGN BID BUILD

Owner / DOT → Engineer of Record → Contractor

We need a bridge

Best design option

Number of steel girders spans.
Needs to have an 800-ft Radius
Expansion Joints? Etc…



Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT → **Engineer of Record** → **Contractor**

We need a bridge

Best design option

This is how I would build it.
It's Going to cost you this much

Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

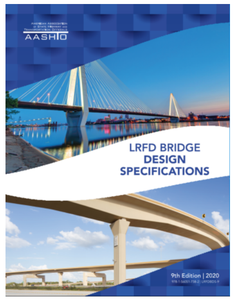
- **Contract Plans = Defines responsibilities of all parties (bidding / fabricating / erecting structure)**

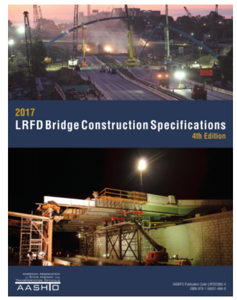
Who is responsible for what and when?

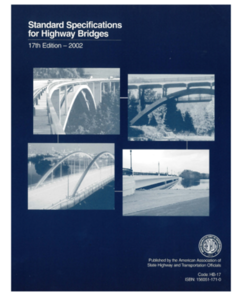
- When is a bridge so complex that special engineering is required to ensure constructibility or stability during erection?
- When should a Department of Transportation (DOT) / Engineer of Record (EOR) make Contractors aware of limitations during construction?
- When does the DOT / EOR owe a Contractor a suggested erection sequence?
- What do the AASHTO Specifications say?

Construction Engineer’s Literature Review

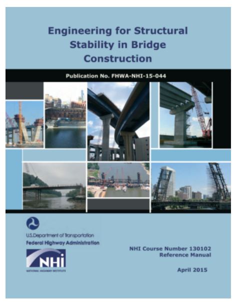
Design Specifications

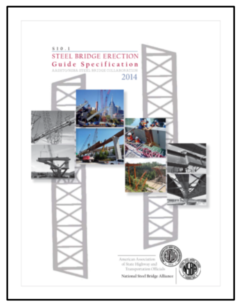


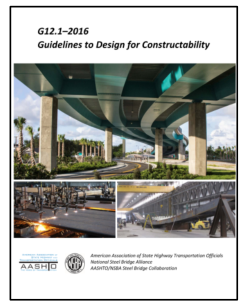


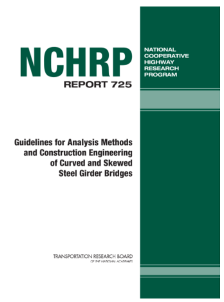


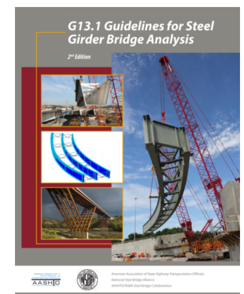
Erection
Guides/Specifications



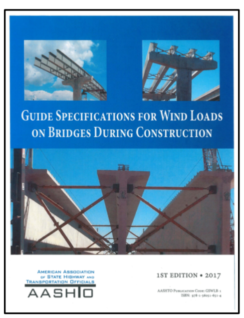


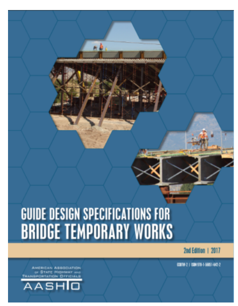


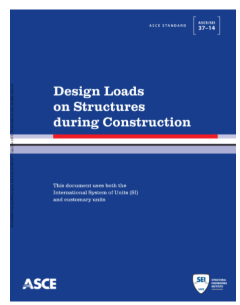


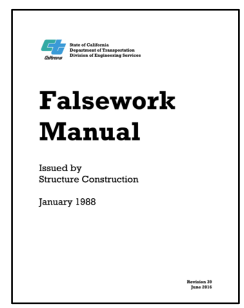


Design Loads



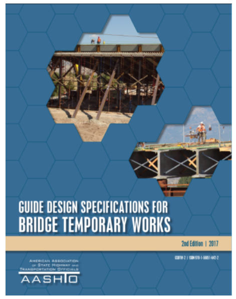


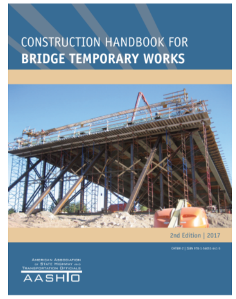


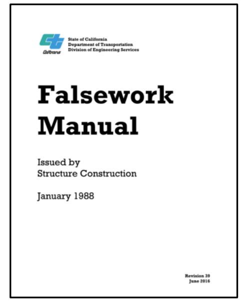


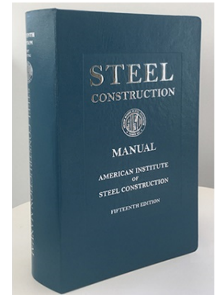
Construction Engineer's Literature Review

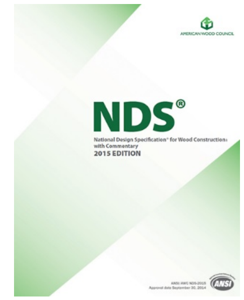
Temporary Works

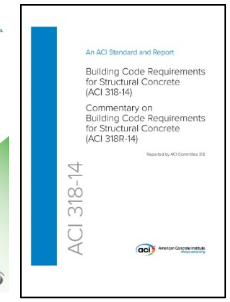




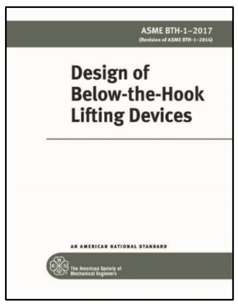


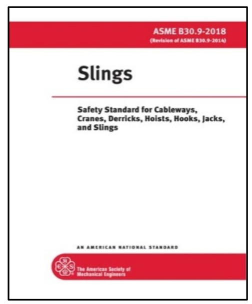




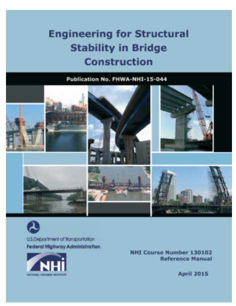


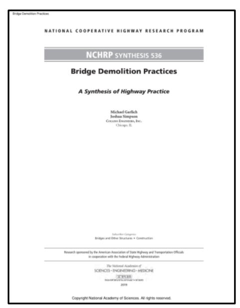
Rigging Hardware

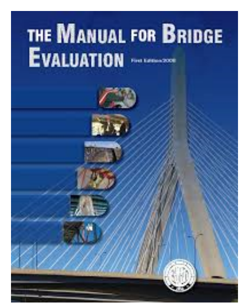




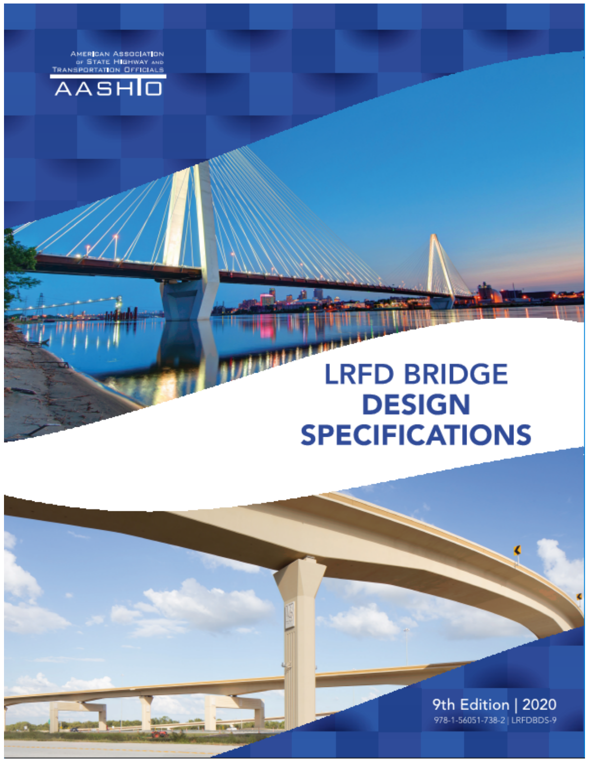
Demolition Guides



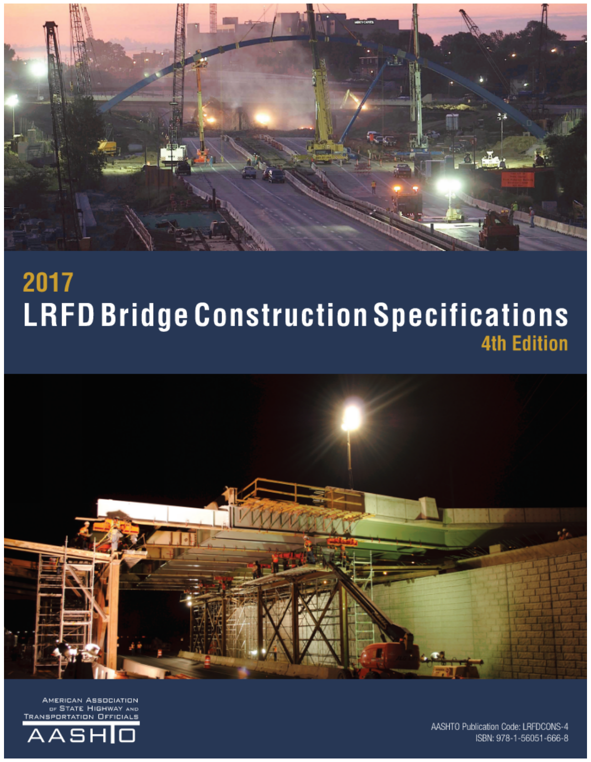




AASHTO Specifications

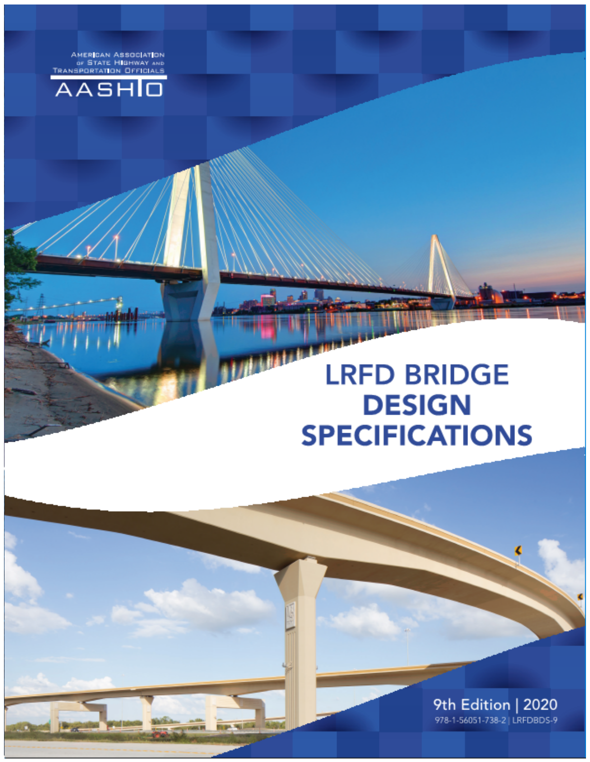


AASHTO Bridge Design Spec.

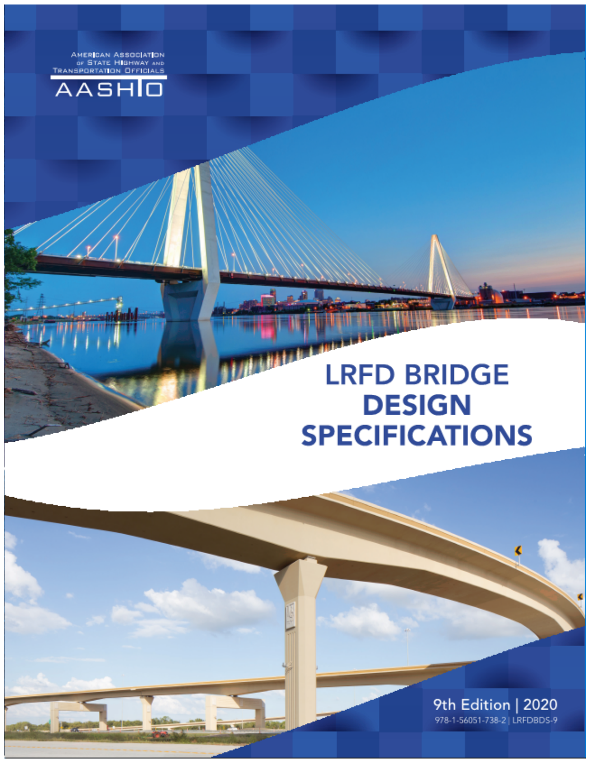


AASHTO Bridge Construction Specs.

AASHTO Bridge Design Specifications



AASHTO Bridge Design Specifications



Key Sections:

Chapter 2
General Design and Location Features

- 2.5.3 – Constructibility

Chapter 5
Concrete Structures

- 5.12 – Provisions for Structure Components and Types

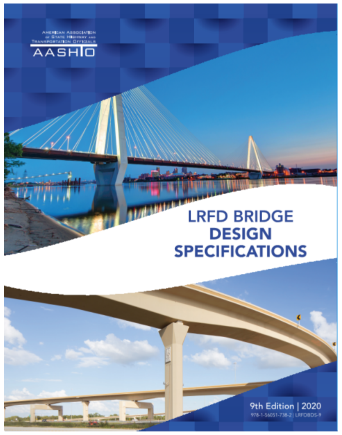
Chapter 6
Steel Structures

- 6.10.3 – Steel I-Section Constructibility
- 6.11.3 – Box Section

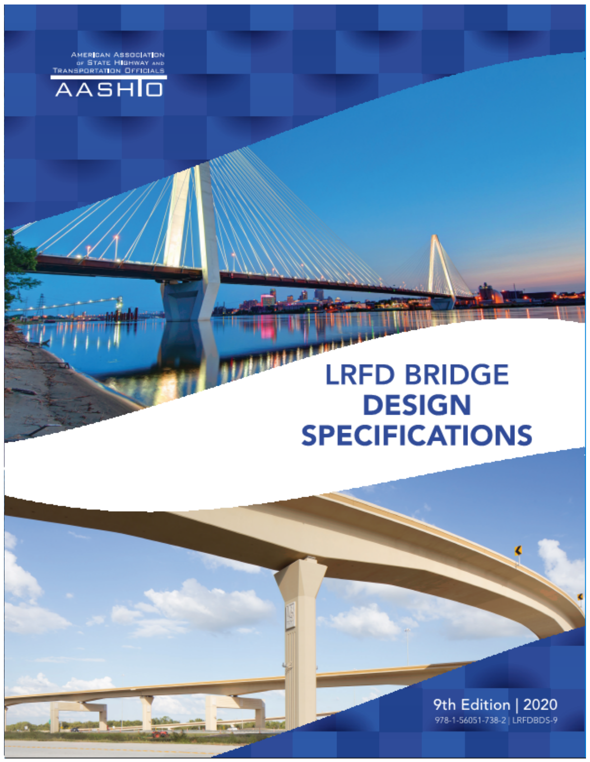
AASHTO – Constructibility

- *2.5.3: This section specifies, "Bridges should be designed in a manner such that fabrication and erection can be performed without undue difficulty or distress and that locked in construction force effects are within tolerable limits."*

- *2.5.3 (Cont.): Where the bridge is of unusual complexity, such as that would be unreasonable to expect an experienced contractor to predict and estimate a suitable method of construction while bidding the project, at least one feasible construction method shall be indicated in the contract documents. If the design requires some strengthening and/or temporary bracing or support during erection by the selected method, indication of the need thereof shall be indicated in the contract documents.*



AASHTO Bridge Design Specifications



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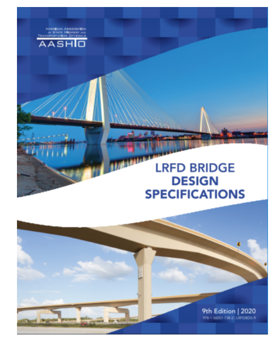
- 6.11.3 – Box Section

Precast Beams

5.12.3.2—Precast Beams

5.12.3.2.1—Preservice C…itions

The r… prestressed girders for shipping … responsibility of the contractor.

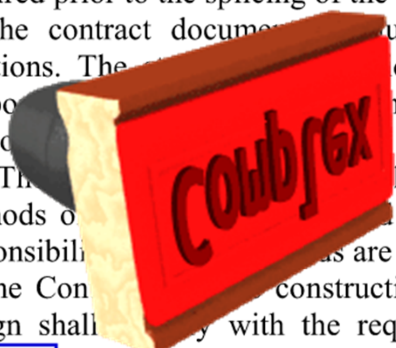


Spliced Precast Girders

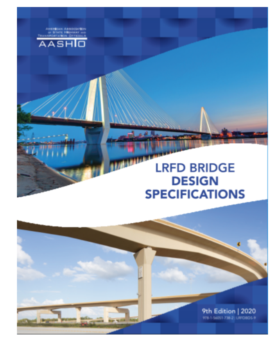
5.12.3.4—Spliced Precast Girders

The method of construction assumed for the design shall be shown in the contract documents. All supports required prior to the splicing of the girder shall be shown on the contract docum… uding elevations and reactions. The … on during which the tempo… hall also be shown on the co…

Th… l indicate alternative methods o… and the Contractor's responsibili… s are chosen. Any changes by the Con… construction method or to the design shall … with the requirements of Article 5.12.5.5.



Images Courtesy of: www.post-tensioning.org

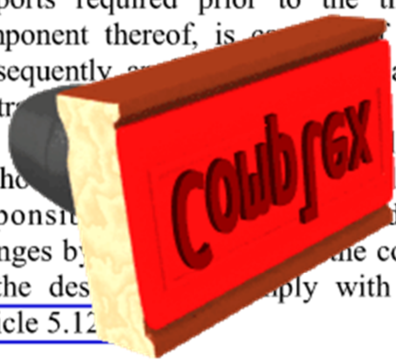


Segmental Concrete Bridges

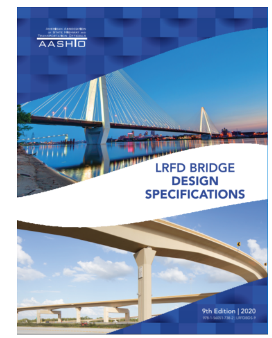
5.12.5—Segmental Concrete Bridges

The method of construction assumed for the design shall be shown in the contract documents. Temporary supports required prior to the time the structure, or component thereof, is c… supporting itself and subsequently a… also be shown in the contr…

…l indicate alternative metho… and the Contractor's responsi…ds are chosen. Any changes b… the construction method or in the des… ply with the requirements of Article 5.12…



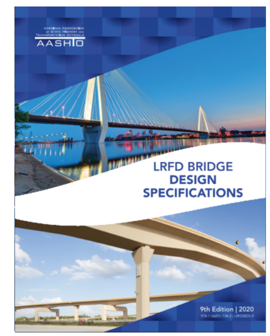
Images Courtesy of: http://www.asbi-assoc.org/



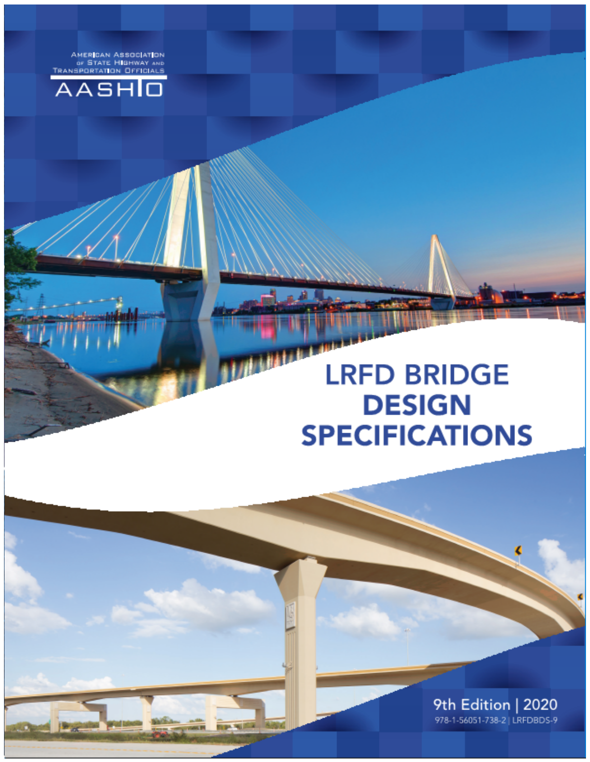
Segmental Concrete Bridges

Table 5.12.5.3.3-1—Load Factors and Tensile Stress Limits for Construction Load Combinations

Load Combination	LOAD FACTORS															STRESS LIMITS				See Note
	Dead Load			Live Load			Wind Load			Other Loads					Earth Loads	Flexural Tension		Principal Tension		
	DC *DW*	*DIFF*	*U*	*CEQ* *CLL*	*IE*	*CLE*	*WS*	*WUP*	*WE*	*CR*	*SH*	*TU*	*TG*	A AI *WA*	*EH* *EV* *ES*	Excluding "Other Loads"	Including "Other Loads"	Excluding "Other Loads"	Including "Other Loads"	
a	1.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	—
b	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	—
c	1.0	1.0	0.0	0.0	0.0	0.0	0.7	0.7	0.0	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	—
d	1.0	1.0	0.0	1.0	0.0	0.0	0.7	1.0	0.7	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	1
e	1.0	0.0	1.0	1.0	1.0	0.0	0.3	0.0	0.3	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	2
f	1.0	0.0	0.0	1.0	1.0	1.0	0.3	0.0	0.3	1.0	1.0	1.0	γ_{TG}	1.0	1.0	$0.190\sqrt{f'_c}$	$0.220\sqrt{f'_c}$	$0.110\sqrt{f'_c}$	$0.126\sqrt{f'_c}$	3



AASHTO Bridge Design Specifications



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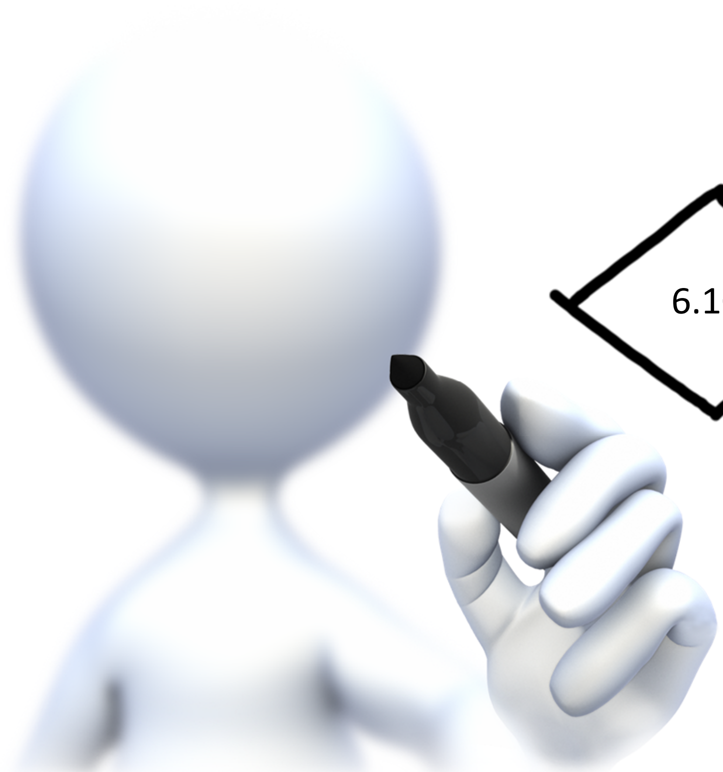
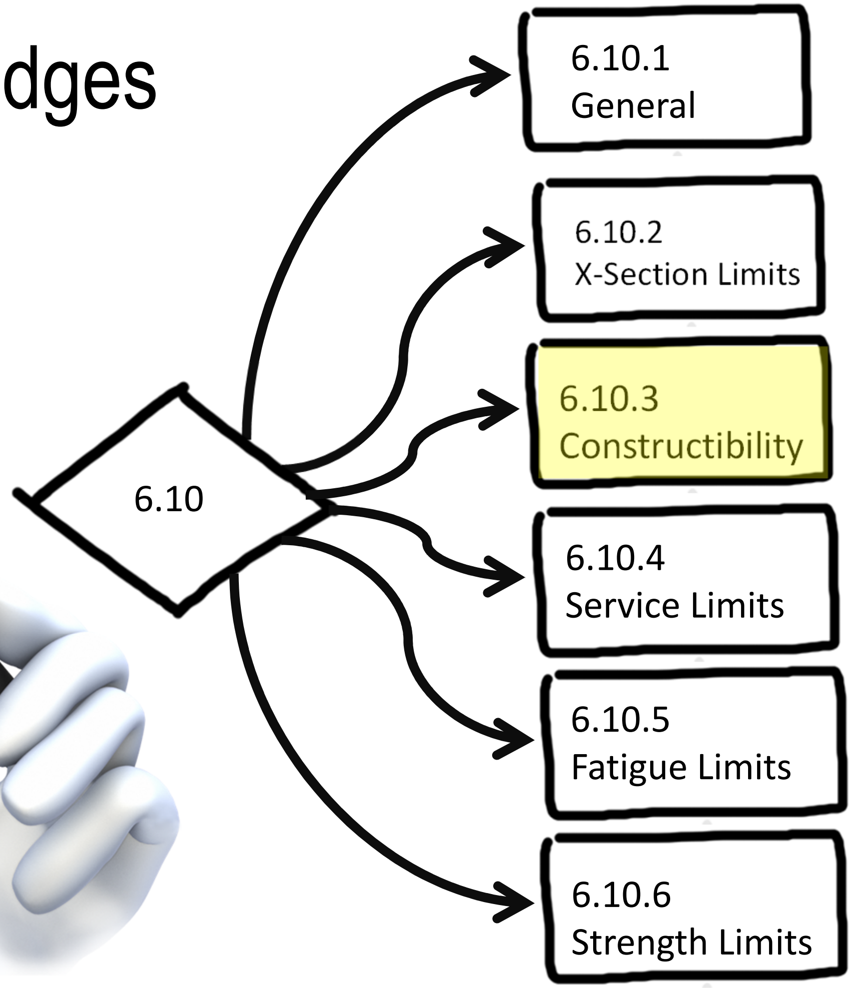
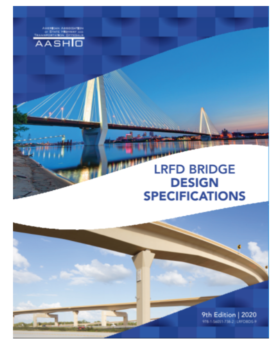
Steel I-Girder Bridges







Steel I-Girder Bridges - Constructibility

6.10.3—Constructibility

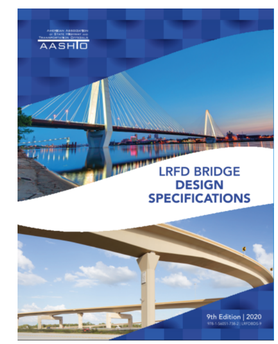
6.10.3.1—General

The provisions of Article 2.5.3 shall apply. In addition to providing adequate strength, nominal yielding or reliance on post-buckling resistance shall not be permitted for main load-carrying members during critical stages of construction, except for yielding of the web in hybrid sections. This shall be accomplished by satisfying the requirements of Articles 6.10.3.2 and 6.10.3.3 at each critical construction stage. For sections in positive flexure that are composite in the final condition, but are noncomposite during construction, the provisions of Article 6.10.3.4 shall apply. For investigating the constructibility of flexural members, all loads shall be factored as specified in Article 3.4.2. For the calculation of deflections, the load factors shall be taken as 1.0.

Potential uplift at bearings shall be investigated at each critical construction stage.

Webs without bearing stiffeners at locations subjected to concentrated loads not transmitted through a deck or deck system shall satisfy the provisions of Article D6.5.

- *2.5.3: This section specifies, "Bridges should be designed in a manner such that fabrication and erection can be performed without undue difficulty or distress and that locked in construction force effects are within tolerable limits."*
- *2.5.3 (Cont.): Where the bridge is of unusual complexity, such as that would be unreasonable to expect an experienced contractor to predict and estimate a suitable method of construction while bidding the project, at least one feasible construction method shall be indicated in the contract documents. If the design requires some strengthening and/or temporary bracing or support during erection by the selected method, indication of the need thereof shall be indicated in the contract documents.*



Steel I-Girder Bridges - Constructibility

6.10.3.2.1—Discretely Braced Flanges in Compression

For critical stages of construction, each of the following requirements shall be satisfied. For sections with slender webs, Eq. 6.10.3.2.1-1 shall not be checked when f_ℓ is equal to zero. For sections with compact or noncompact webs, Eq. 6.10.3.2.1-3 shall not be checked.

$$f_{bu} + f_\ell \leq \phi_f R_h F_{yc},$$

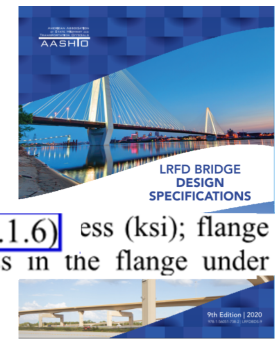
$\bar{F}_{crw}$ = nominal web bend-buckling resistance (ksi) (6.10.1.9.1) …ge (ksi) (6.10.1.6) …ess (ksi); flange lateral bending stress due to the Service II loads (ksi); lateral bending stress in the flange under

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f F_{nc}, \quad (6.10.3.2.1\text{-}2)$$

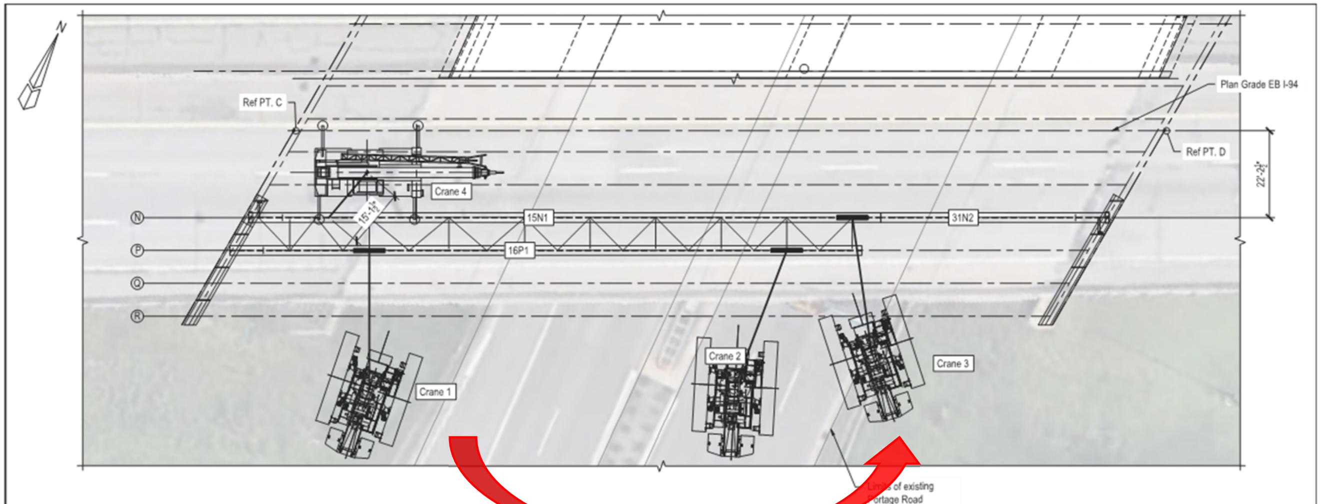
and

$$f_{bu} \leq \phi_f F_{crw} \quad (6.10.3.2.1\text{-}3)$$

New term - What are construction?



Steel I-Girder Bridges - Constructibility



STEP 7

Notes:
1. See sheet G01-201 for notes.
2. Crane Loads shown in Table T1 shall not be exceeded by more than 5 kips.
3. Crane Loads shown in Table T1 are required minimum support loads for girder stability.
4. See General Notes for details of cross-frame and lateral bracing installation.

NOTE:
Erection operations for Stage 1A/1B Steps 1-11 shall be completed in a single working day.

Step 7:
1. Install cross-frames and lateral bracing members connecting Girder Segment 15N1 and Girder Segment 16P1 while continuing to hold load on all four cranes. Utilize a separate rig (not shown) as needed for installation of cross-frames and lateral bracing members.

Crane # (--)	Crane ID (--)	Lift Type (--)	Approximate Load (kip)	Weight of Rigging (kip)	Total Crane Load (kip)	Maximum Radius (ft)	Approximate Utilization (--)
1	HC165	TCL	48.0	6.0	54.0	50	78%
2	HC165	TCL	57.0	6.0	63.0	50	91%
3	HC165	CST	89.0	7.2	96.2	35	84%
4	Grove	CST	34.0	3.0	37.0	30	88%

CRANE OPERATION DATA

NO.	DATE	REMARKS	BY

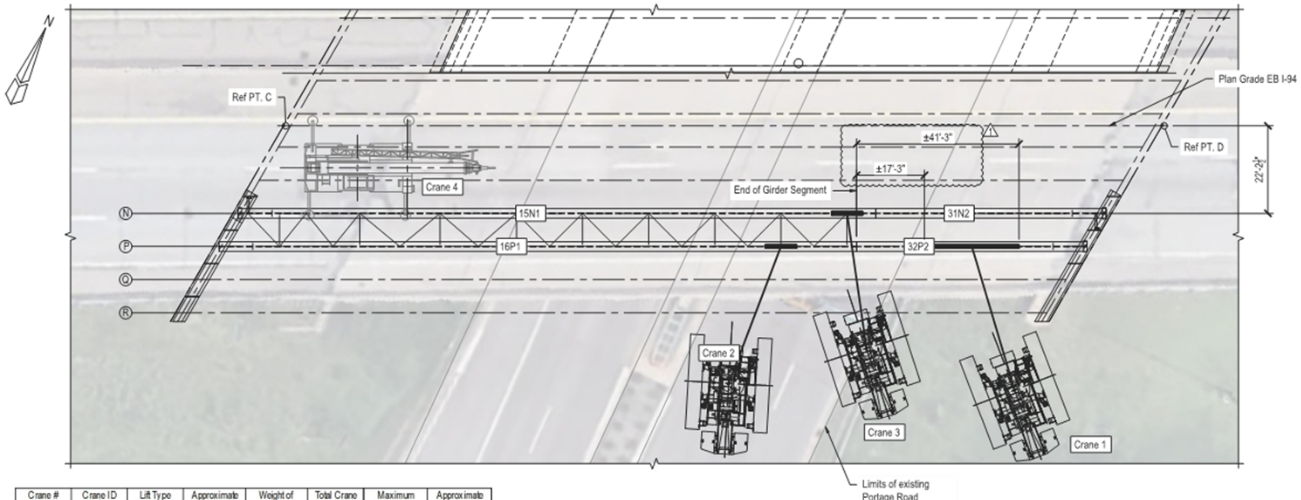
ERECTION - STAGE 1A/1B
GIRDER ERECTION

GENESIS STRUCTURES, INC.
104. W. 9TH, SUITE 200
KANSAS CITY, MO. 64105
(P) 816-421-1520
www.genesisstructures.com

DRAWN BY: ZB CHCK'D BY: JPB
DATE: 11-04-21
PROJECT: 1208 - I-94 OVER PORTAGE ROAD
SHEET NO.: G01-207

What are critical stages of construction?

Steel I-Girder Bridges - Constructibility



Crane #	Crane ID	Lift Type	Approximate Load	Weight of Rigging	Total Crane Load	Maximum Radius	Approximate Utilization
(--)	(--)	(--)	(kip)	(kip)	(kip)	(ft)	(--)
1	HC165	CST	35.0	5.3	40.3	50	58%
2	HC165	CST	69.0	6.0	75.0	40	79%
3	HC165	SCL	100.0	7.2	107.2	35	93%
4	Grove	--	--	--	--	--	--

CRANE OPERATION DATA
Load Data for Setting of Girder on Bearing and Field Splice Install

Crane #	Crane ID	Lift Type	Approximate Load	Weight of Rigging	Total Crane Load	Maximum Radius	Approximate Utilization
(--)	(--)	(--)	(kip)	(kip)	(kip)	(ft)	(--)
1	HC165	CST	6.0	5.3	11.3	50	16%
2	HC165	CST	6.0	6.0	12.0	50	17%
3	HC165	SCL	9.0	7.2	16.2	50	23%
4	Grove	--	--	--	--	--	--

CRANE OPERATION DATA
Load Data for Girder Support & Crane Load Reduction

STEP 9

Notes:
1. See sheet G01-201 for notes.
2. Crane Loads shown in Table T1 and T2 shall not be exceeded by more than 5 kips.
3. Crane Loads shown in Table T1 and T2 are required minimum support loads for girder stability.
4. See General Notes for details of field splice installation.

NOTE:
Erection operations for Stage 1A/1B Steps 1-11 shall be completed in a single working day.

Step 9 - Erection Sequence:
1. Hold load on Crane 2 and Crane 3.
2. Erect Girder Segment 32P2 using SCL a shown.
3. While holding load on all cranes, assemble bolted field splice.
4. Following assembly of the bolted field splice, reduce supported crane loads. See Table T2 for information.

ERECTION - STAGE 1A/1B
GIRDER ERECTION

GENESIS STRUCTURES, INC.
104. W. 9TH, SUITE 200
KANSAS CITY, MO. 64105
(P) 816-421-1520
www.genesisstructures.com

DRAWN BY: ZB | CHCK'D BY: JPB | DATE: 11-04-21

PROJECT: 1208 - I-94 OVER PORTAGE ROAD | SHEET NO.: G01-209

NO.	DATE	REMARKS	BY
1	11-29-21	RIGGING REVISION	ZB

What are critical stages of construction?

We generally consider all stages as critical stages.

Steel I-Girder – Deck Placement

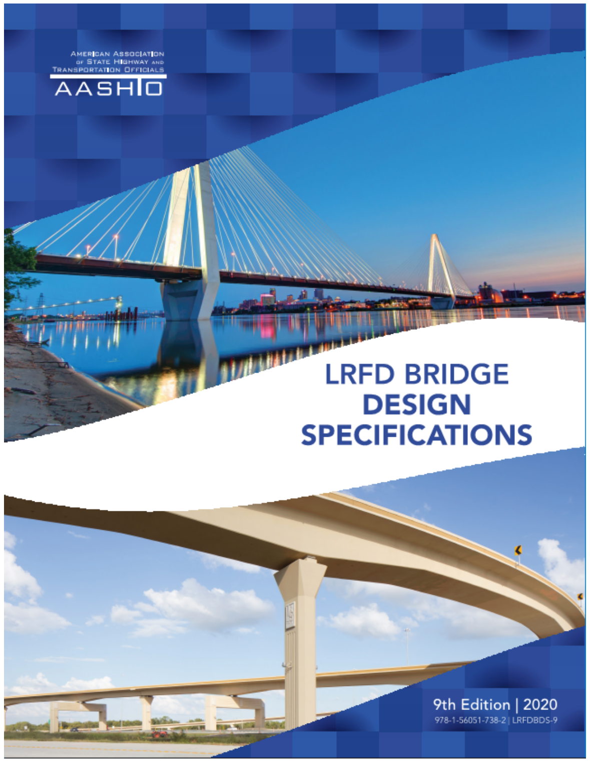
6.10.3.4—Deck Placement

6.10.3.4.1—General

Sections in positive flexure that are composite in the final condition, but are noncomposite during construction, shall be investigated for flexure according to the provisions of Article 6.10.3.2 during the various stages of the deck placement.

Geometric properties, bracing lengths and stresses used in calculating the nominal flexural resistance shall be for the steel section only. Changes in load, stiffness and bracing during the various stages of the deck placement shall be considered.

The effects of forces from deck overhang brackets acting on the fascia girders shall be considered.



Steel I-Girder – Deck Pour Sequence

6.10.3.4—Deck Placement

6.10.3.4.1—General

Sections in positive flexure that are composite in the final condition, but are noncomposite during construction, shall be investigated for flexure according to the provisions of Article 6.10.3.2 during the various stages of the deck placement.

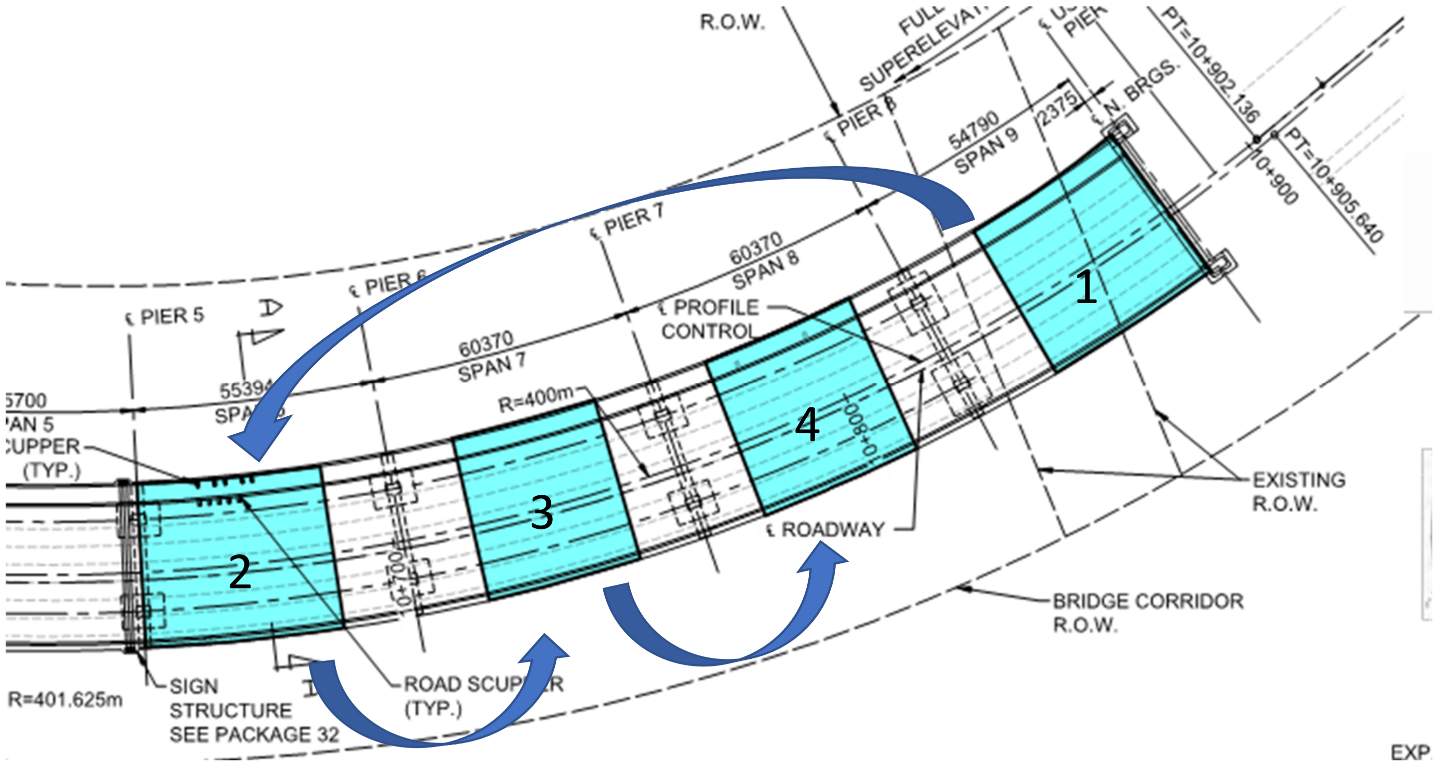
Geometric properties, bracing lengths and stresses used in calculating the nominal flexural resistance shall be for the steel section only. Changes in load, stiffness and bracing during the various stages of the deck placement shall be considered.

The effects of forces from deck overhang brackets acting on the fascia girders shall be considered.

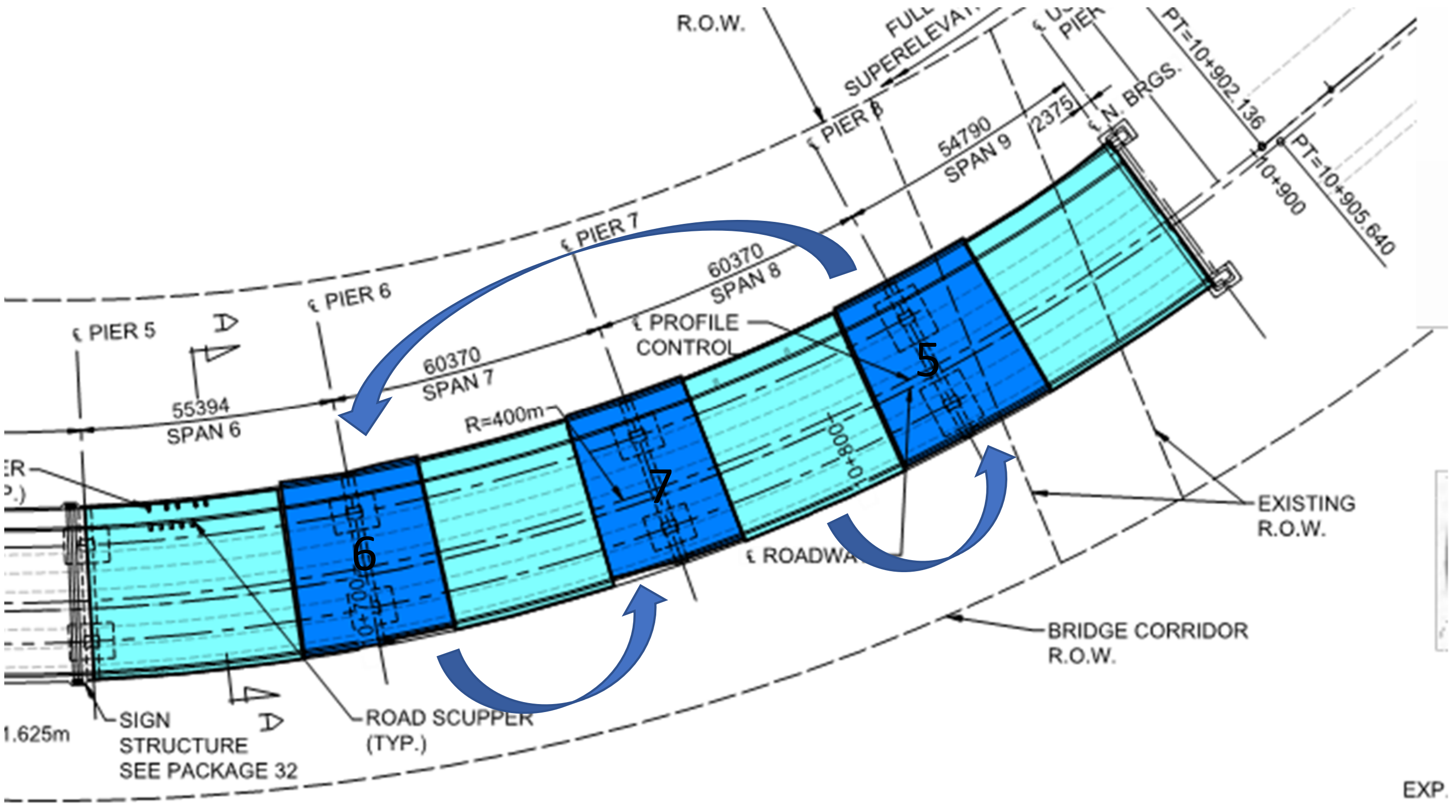
Following pour sequence is important!

Images Courtesy of: www.sellwoodbridge.org

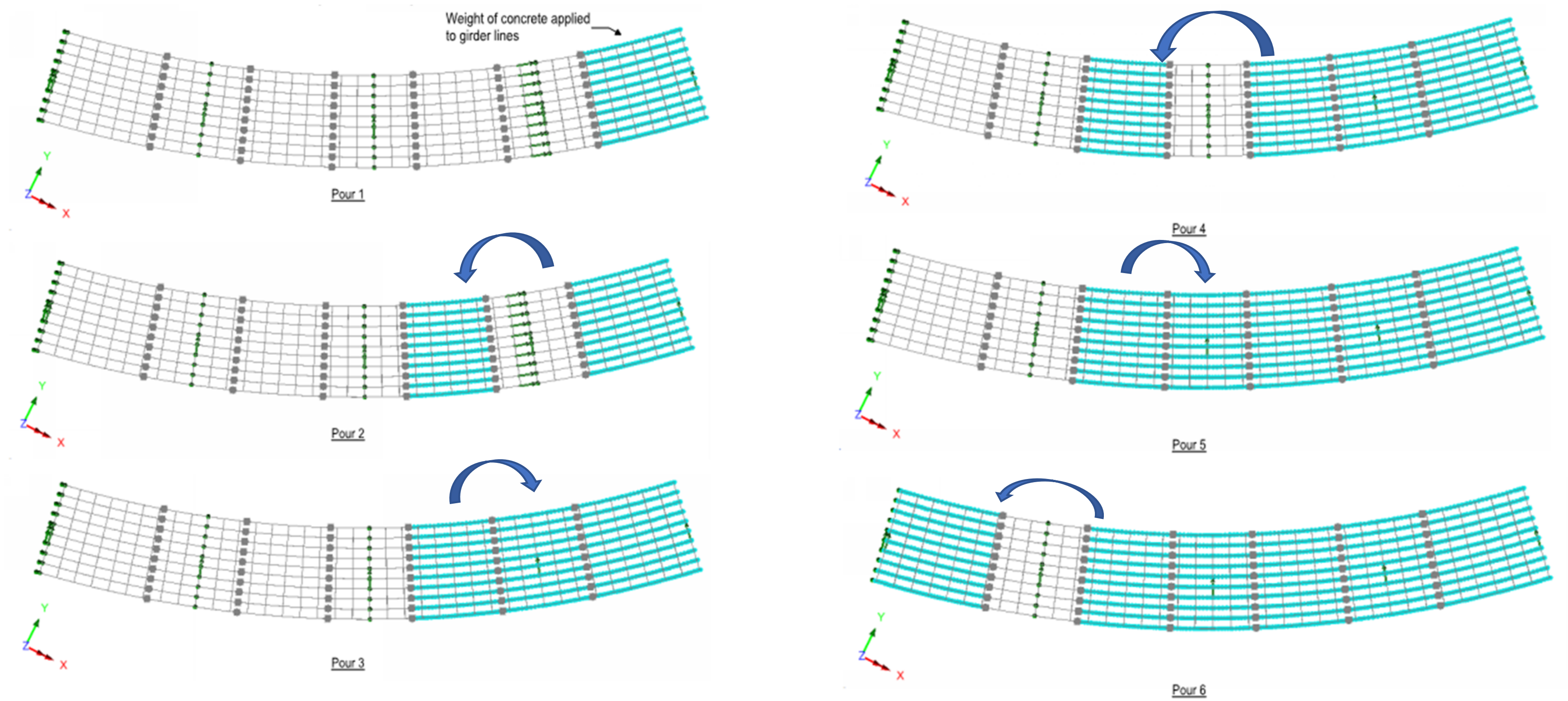
Steel I-Girder – Deck Placement



Steel I-Girder – Deck Placement



Steel I-Girder – Contractor Preferred



Steel I-Girder – Deck Pour Overhang Effects

6.10.3.4—Deck Placement

6.10.3.4.1—General

Sections in positive flexure that are composite in the final condition, but are noncomposite during construction, shall be investigated for flexure according to the provisions of Article 6.10.3.2 during the various stages of the deck placement.

Geometric properties, bracing lengths and stresses used in calculating the nominal flexural resistance shall be for the steel section only. Changes in load, stiffness and bracing during the various stages of the deck placement shall be considered.

The effects of forces from deck overhang brackets acting on the fascia girders shall be considered.

Images Courtesy of: https://www.gamcoform.com/overhang-bracket

Steel I-Girder – Deck Pour Overhang Effects

6.10.3.4—Deck Placement

6.10.3.4.1—General

Sections in positive flexure that are composite in the final condition, but are noncomposite during construction, shall be investigated for flexure according to the provisions of Article 6.10.3.2 during the various stages of the deck placement.

Geometric properties, bracing lengths and stresses used in calculating the nominal flexural resistance shall be for the steel section only. Changes in load, stiffness and bracing during the various stages of the deck placement shall be considered.

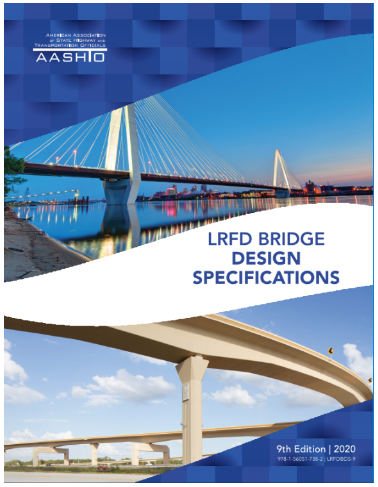
The effects of forces from deck overhang brackets acting on the fascia girders shall be considered.

Overhang torsional analysis guidance included in commentary. C

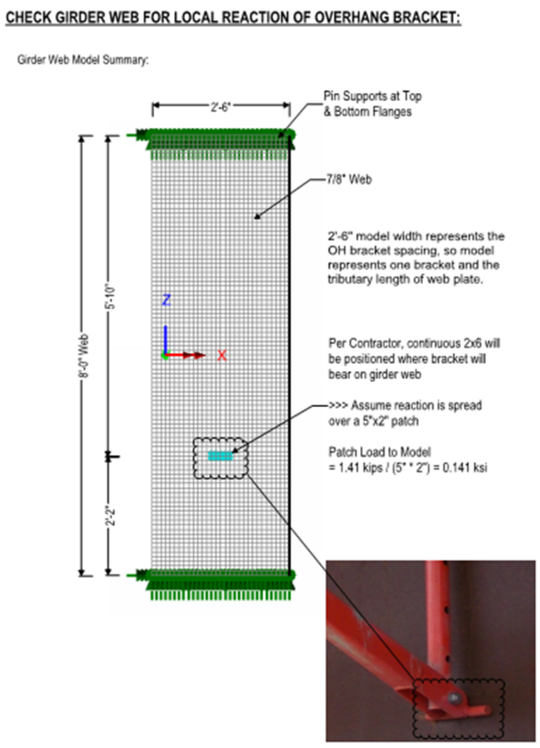
C6.10.3.4.1

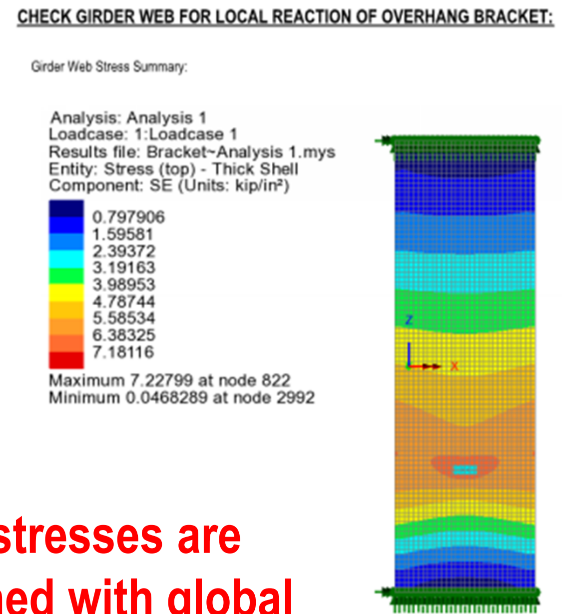
During construction of steel girder bridges, concrete deck overhang loads are typically supported by cantilever forming brackets typically placed at 3.0 to 4.0 ft spacings along the exterior members. The eccentricity of the deck weight and other loads acting on the overhang brackets creates applied torsional moments on the exterior members. As a result, the following issues must be considered in the design of the exterior members:

- The applied torsional moments bend the exterior girder top flanges outward. The resulting flange lateral bending stresses tend to be largest at the brace points at one or both ends of the unbraced length. The lateral bending stress in the top flange is tensile at the brace points on the side of the flange opposite from the brackets. These lateral bending stresses should be considered in the design of the flanges.
- The horizontal components of the reactions on the cantilever-forming brackets are often transmitted directly onto the exterior girder web. The girder web may exhibit significant plate bending deformations due to these loads. The effect of these deformations on the vertical deflections at the outside edge of the deck should be considered. The effect of the reactions from the brackets on the cross-frame forces should also be considered.
- Excessive deformation of the web or top flange may lead to excessive deflection of the bracket supports causing the deck finish to be problematic.



Steel I-Girder – Deck Pour Overhang Effects





These stresses are combined with global bending stresses to evaluate the combined effects.

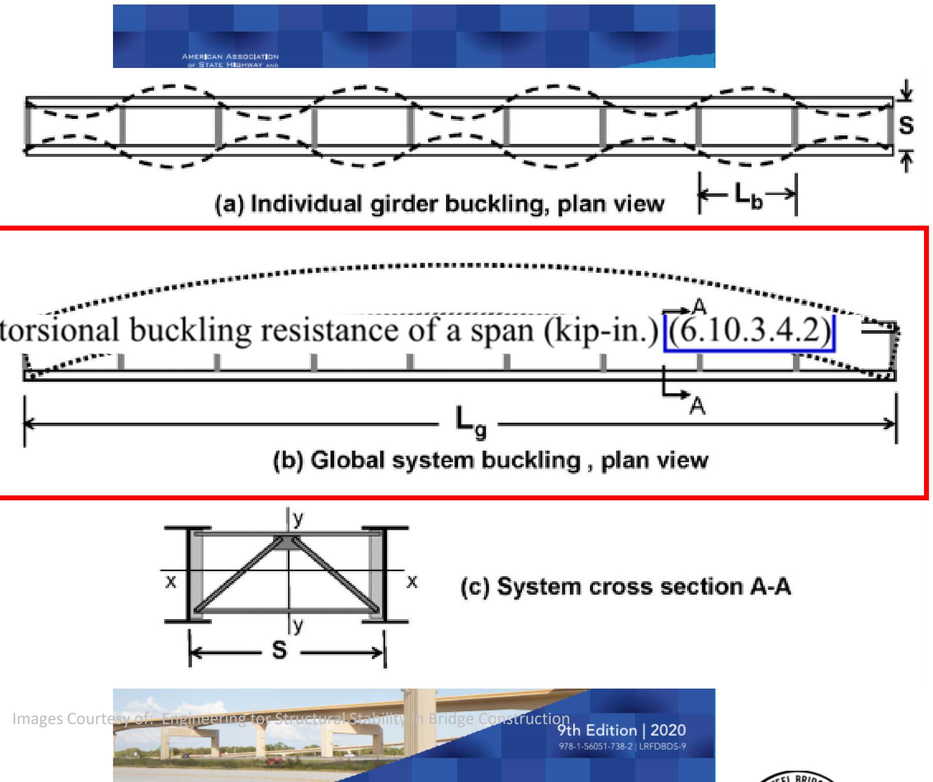
Steel I-Girder – System Stability During Deck Pour

6.10.3.4.2—Global Displacement Amplification in Narrow I-Girder Bridge Units

$$M_{gs} = C_{bs} \frac{\pi^2 w_g E}{L^2} \sqrt{I_{eff} I_x} \qquad (6.10.3.4.2\text{-}1)$$

M_{gs} = elastic global lateral–torsional buckling resistance of a span (kip-in.) (6.10.3.4.2)

- AASHTO check of narrow 2 or 3 girder system stability during deck pouring
- If Mult > 0.7 Mgs design has following options:
  - Add flange lateral bracing
  - Increase system stiffness
  - Verify with owner that second order displacements are within acceptable tolerances



Images Courtesy of: Engineering for Structural Stability in Bridge Construction

NYSDOT - Steel I-Girder Bridges - Constructibility

NEW YORK STATE OF OPPORTUNITY. Department of Transportation	ENGINEERING INSTRUCTION	EI 21-004
Title: **NYSDOT LRFD BRIDGE DESIGN SPECIFICATIONS - 2021**		
	Approved: James Flynn III, PE, Deputy Chief Engineer (Structures)	2-2-21 Date

ADMINISTRATIVE INFORMATION:

- This Engineering Instruction (EI) is effective beginning with projects submitted for the letting of September 1, 2021
- This EI supersedes EI 19-001 "NYSDOT LRFD BRIDGE DESIGN SPECIFICATIONS - 2019"
- Disposition of Issued Materials: The technical information transmitted by this EI will be incorporated into the next revision of the NYSDOT Bridge Manual

PURPOSE: This EI officially adopts the NYSDOT LRFD Bridge Design Specifications – 2021 for use in New York State and announces the availability of "NYSDOT LRFD Blue Pages" dated January 2021.

TECHNICAL INFORMATION: The *AASHTO LRFD Bridge Design Specifications - 9th Edition, 2020*, together with the "NYSDOT LRFD Blue Pages" dated January 2021 constitute the NYSDOT LRFD Bridge Design Specifications.

- The LRFD specifications will continue to be used for the design of all new and replacement bridges for NYSDOT. This includes both superstructure designs and substructure designs. This EI does not discontinue use of the NYSDOT Standard Specifications for Highway Bridges – 2003. Both specifications will continue to be used until further notice. The existing NYSDOT Standard Specifications for Highway Bridges - 2003 will be used when necessary for the repair and rehabilitation of structures. The NYSDOT Standard Specifications for Highway Bridges – 2003 consists of the *AASHTO Standard Specifications for Highway Bridges - 17th Edition* plus the "NYSDOT Blue Pages", issued by EB 02-038 and EB 03-016.
- The NYSDOT Design Permit Vehicle has been removed from the NYSDOT LRFD Blue Pages.
- Currently, NYSDOT overload permitting and bridge posting policies require that new and replacement bridges be load rated using the Load Factor Design (LFD) or Allowable Stress Design (ASD) methods. For this reason, load ratings will continue to be computed by the LFD or ASD method and shown on the contract plans. Also, load rating factors for all new, replacement, and rehabilitated bridges will be computed by the Load and Resistance Factor Rating (LRFR) method and shown on the contract plans. LRFR ratings shall be shown at the Inventory and Operating levels as rating factors of the AASHTO HL-93 live load. Once overload permitting and bridge posting policies are revised to accommodate LRFR, load ratings using the LFD and ASD methods will be discontinued.

Designer shall check:

- **Splice Locations**
- **Shipping Length**
- **Shipping Width**
- **Stability during erection**
- **Web slenderness**
- **LTB resistance**

6.10.3.1a Stability During Erection

The designer shall check all girders for stability during erection. To make this check, the designer shall specify and design splice locations when girders need to be erected in multiple segments. The maximum shipping length of steel girder segments is ordinarily limited to 140 ft. The maximum shipping width of steel girder segments is ordinarily limited to 16 ft., however any width greater than 12 ft. will require an escort. Shipping widths instead of lengths may control the location of splices for steel curved girders. Further guidance on splice locations and shipping lengths can be found in Section 8 of NYSDOT Bridge Manual.

Girder segments shall be checked for all conditions where they are simply supported. The fully assembled girder shall also be checked for stability for its full length under dead load only. This condition will exist when the first fully assembled girder is erected in one piece without the use of any falsework and before any bracing is in place.

If the girder segment or fully assembled girder meets the provisions of Article 6.10.6.2.3 for web slenderness, the check shall be made according to Article A6.3.3 Lateral Torsional Buckling Resistance. If it does not meet these provisions, the check will be made according to Article 6.10.8.2.3.

In making the stability check, the load factor for the weight of the girder shall be taken as 1.25 in accordance with Article 3.4.2, Load Factors for Construction Loads.

If the girder segment or fully assembled girder does not meet the stability check, the designer shall either:

a. Increase the girder size to meet the stability check.
OR
b. Place Steel Erection Note #A1 on the plans

6.10.3.1a (continued)

This choice shall be based on an economic analysis comparing the cost of providing additional steel versus the cost of providing additional bracing, falsework, or holding cranes. Site conditions will need to be investigated to determine the feasibility of various erection methods.

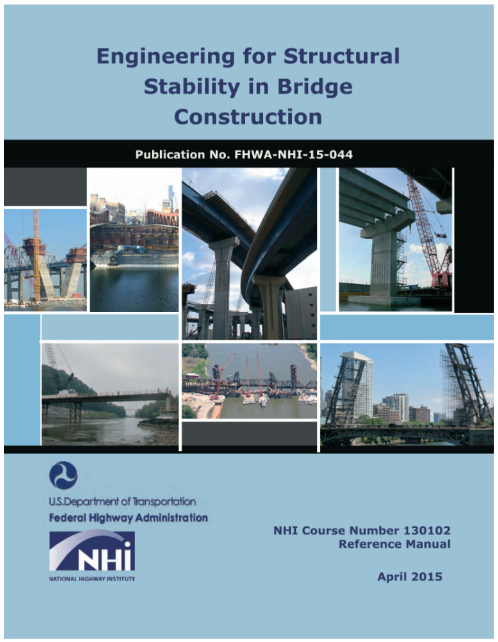
Steel Erection Notes

A1. The Contractor shall provide for the stability of structural steel during all phases of erection and construction, as provided in Subsection 204 of the New York State Steel Construction Manual (SCM). The girders on this bridge shall be stabilized during erection by use of falsework, temporary bracing, compression flange stiffening trusses, choosing alternate picking points, or by use of a holding crane until a sufficient number of girders have been erected and cross frames installed. The methods used by the contractor shall be documented on the erection drawings with all supporting stability calculations submitted and stamped by a licensed New York State Professional Engineer and submitted to the DCES in accordance with the SCM.

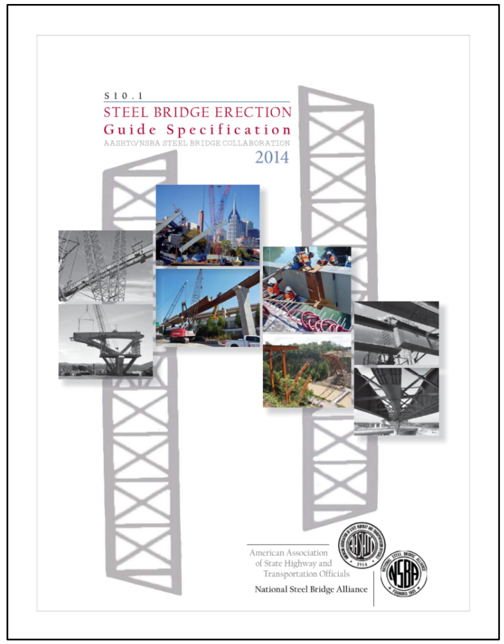
If the girder segments and fully assembled girders meet the stability check, then Steel Erection Note #A2 shall be placed on the plans.

A2. The contractor shall provide for the stability of structural steel during all phases of erection and construction, as provided in Subsection 204 of the New York State Steel Construction Manual (SCM). The methods used by the contractor shall be documented on the erection drawings with all supporting stability calculations submitted and stamped by a licensed New York State Professional Engineer and submitted to the DCES in accordance with the SCM.

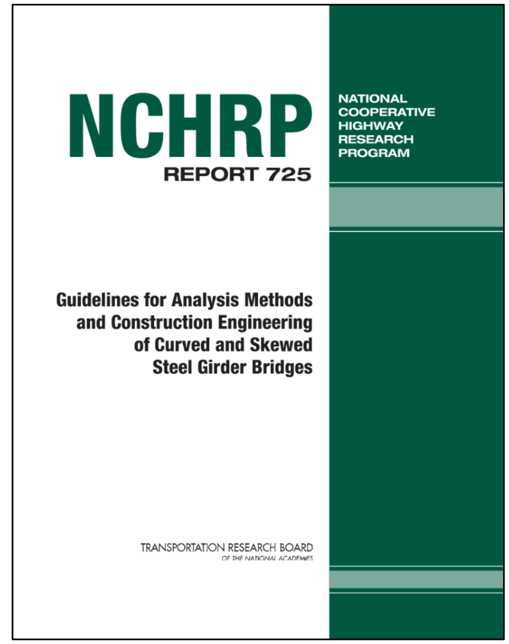
Useful Resources – System Stability



FHWA-NHI-15-044
ALL MATERIAL TYPES



NSBA / AASHTO S10.1

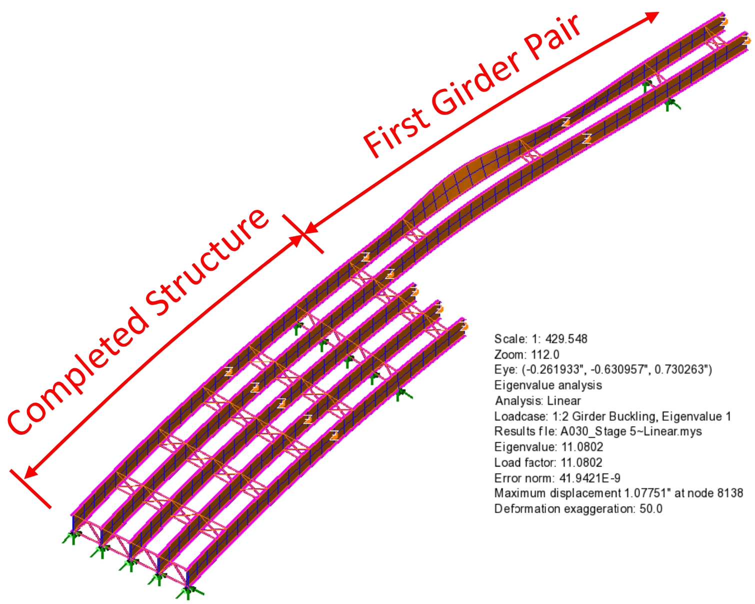


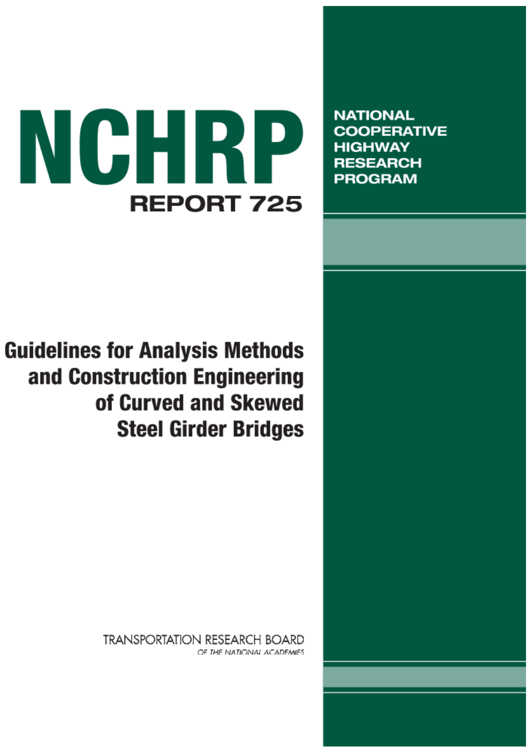
NCHRP Report 725

STEEL BRIDGE SPECIFIC GUIDES

Steel I-Girder Bridges - System Stability

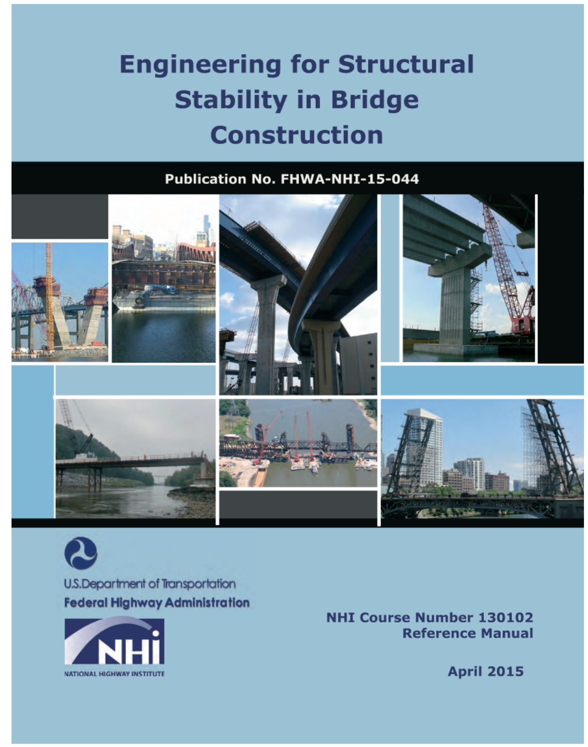
$$M_{crG} = C_b \frac{\pi^2 sE}{L_s^2} \sqrt{I_{ye} I_x} \qquad \text{Eq. 3}$$





Steel I-Girder Bridges - System Stability

$$M_{gs} = \frac{\pi^2 SE}{L_g^2}\sqrt{I_y I_x}$$ **Equation 5-12**



Critical Stages of Construction

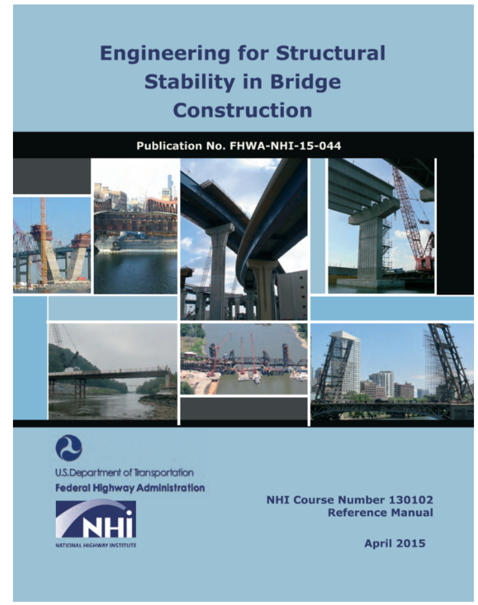
7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed

Contractor / Construction Engineer

- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement



Critical Stages of Construction

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The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

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- Lifting of girders/members
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- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement

Fulbright Expressway, Fayetteville, AR

Critical Stages of Construction

DETOUR

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

Contractor / Construction Engineer

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY

Critical Stages of Construction

DETOUR

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

Contractor / Construction Engineer

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement

Gateway Interchange Flyovers, Johnson County, KS

Critical Stages of Construction

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

Contractor / Construction Engineer

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement

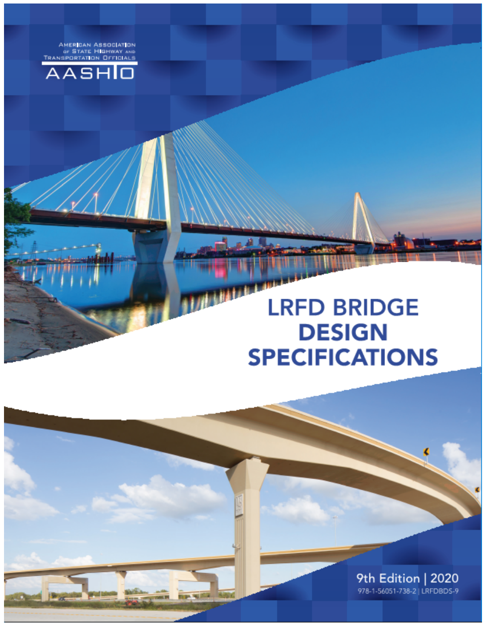
KY 152 over Herrington Lake, Mercer and Garrard Counties, KY

Critical Stages of Construction

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement



AASHTO dictates these stages shall be considered by Design Engineer

Should be considered by Design Engineer
What design reference should a designer use to evaluate?

Wind on Completed Bridge Prior to Deck Pour

- AASHTO design specifications currently do not include section on winds on a completed structure prior to pouring deck
- Designer could use "AASHTO Guide Specifications for Wind Loads on Bridges During Construction"
- Other state specific references are available

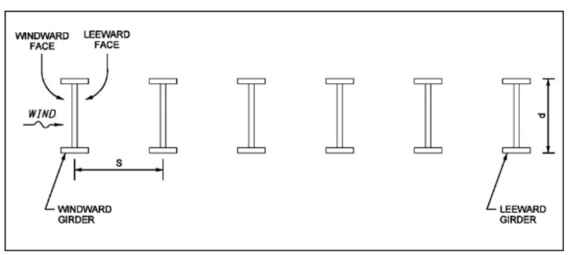
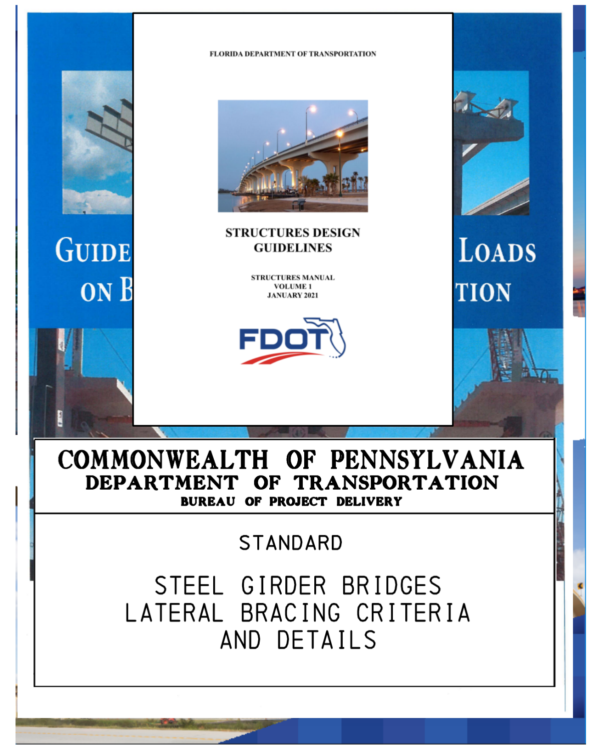
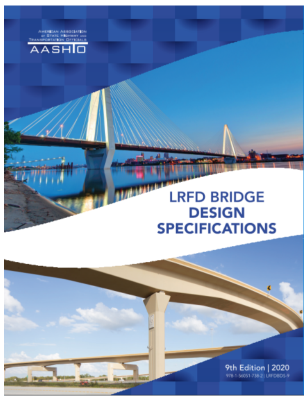


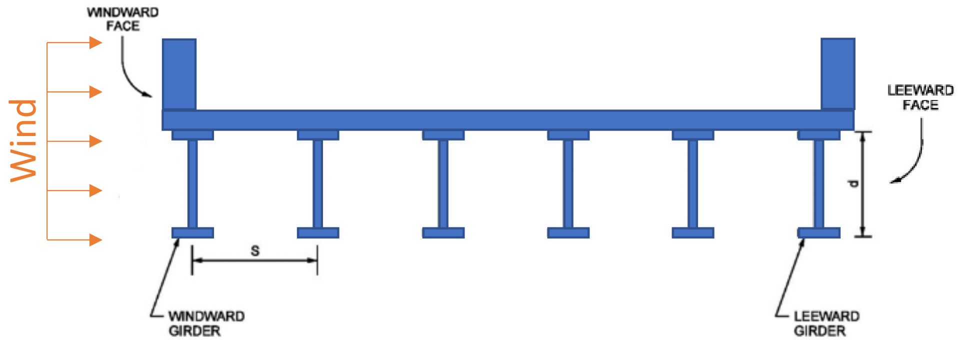
Figure 7-12 Girder Wind Load Terminology

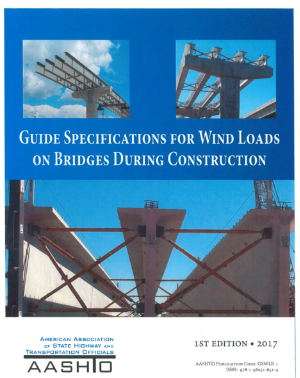
COMPONENT TYPE	CONSTRUCTION CONDITION	FORCE COEFFICIENT (C_f)
I-Shaped Girder Superstructure	Deck forms not in place	2.2 (1)
	Deck forms in place	1.1
U-Shaped and Box-Girder Superstructure	Deck forms not in place	1.5
	Deck forms in place	1.1
Flat Slab or Segmental Box-Girder Superstructure	Any	1.1

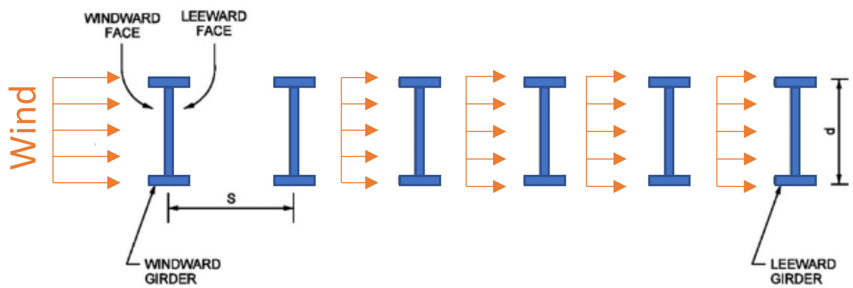


AASHTO - Wind During Erection

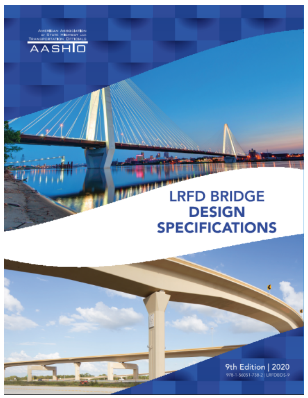






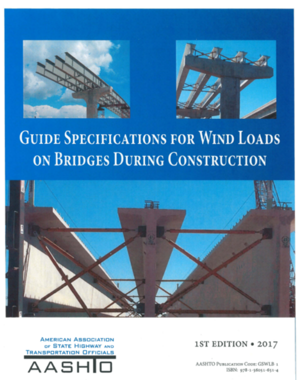


AASHTO - Wind During Erection



$$P_Z = 2.56 \times 10^{-6} V^2 K_z G C_D$$

Component		Drag Coefficient, C_D Windward	Drag Coefficient, C_D Leeward
I-Girder and Box-Girder Bridge Superstructures		1.3	N/A
Trusses, Columns, and Arches	Sharp-Edged Member	2.0	1.0
	Round Member	1.0	0.5
Bridge Substructure		1.6	N/A
Sound Barriers		1.2	N/A



$$P_z = 2.56 \times 10^{-6} V^2 R^2 K_z G C_D$$

	R
0-6 weeks	0.65
6 weeks to 1 year	0.73
>1-2 years	0.75
>2-3 years	0.77
>3-7years	0.84

Rolled I-Beams	2.2
Concrete I-Beams	2.0
Closed and Open Box-Girders	2.1
Round Members	1.0

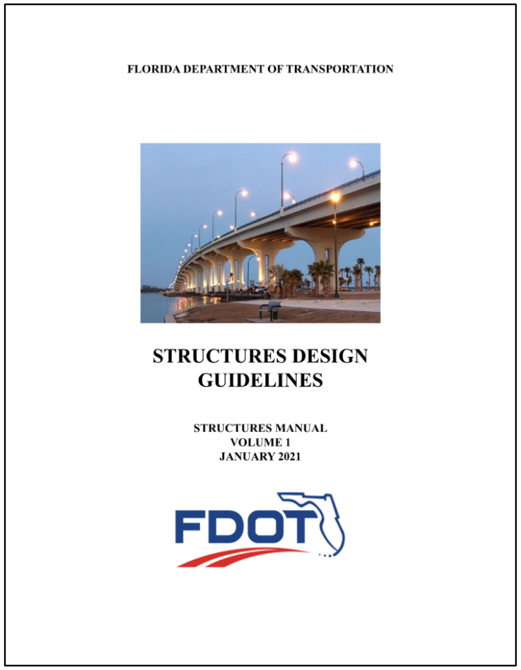
AASHTO - Wind During Erection

Final Structure
S/D = 1.0 < 3

Construction (0 to 6 weeks)
R = 0.65

Construction (6 weeks to 1 year)
R = 0.73

FDOT – Wind During Erection


FLORIDA DEPARTMENT OF TRANSPORTATION

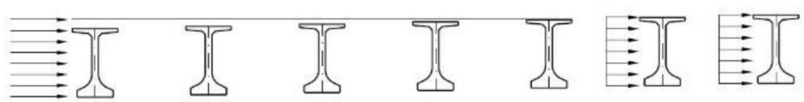
STRUCTURES DESIGN GUIDELINES

STRUCTURES MANUAL
VOLUME 1
JANUARY 2021

FDOT

Table 2.4.3-2 Drag Coefficient During Construction

	Component Type	Drag Coefficient (C_D)				
		S/D ≤ 3		S/D > 3		
		Beams/ Girders 1-5	Beam/ Girder 6+	Beam/ Girder 1	Beam/ Girder 2	Beam/ Girder 3+
Superstructure	I-Shaped Steel Girder	2.2	1.1	2.5	0	1.1
Superstructure	I-Shaped Concrete Beam/Girder	2.0	1.0	2.0	0	1.0
Superstructure	U-Shaped Beam/ Girder or Steel Box Girder	2.2				
Superstructure	Flat Slab or Segmental Box Girder	1.5				
Substructure		1.6				



- Based on research at University of Florida, Funded by FDOT
- Drag Coefficients and Gust Factors vary from AASHTO w/ AASHTO being more conservative

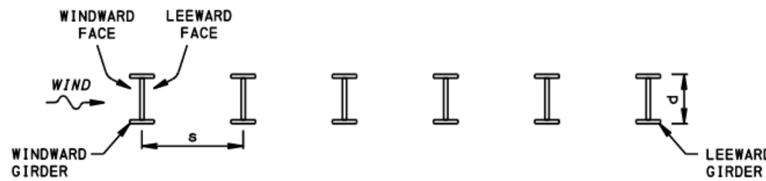
PennDOT – Wind Prior to Deck Pour

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

MINIMUM DESIGN WIND PRESSURE(PSF)
FOR LATERAL BRACING DURING CONSTRUCTION



CONSTRUCTION DURATION	0-6 WEEKS		6 WEEKS-1 YEAR		1-2 YEARS	
SUPERSTRUCTURE HEIGHT ABOVE GROUND LEVEL (FT.)	s/d≤2	2<s/d≤4	s/d≤2	2<s/d≤4	s/d≤2	2<s/d≤4
0-15	19	21	26	28	29	32
20	20	22	27	30	31	34
25	21	23	28	31	32	35
30	22	24	30	32	34	37
40	24	26	31	34	36	39
50	25	27	33	36	38	41
60	26	28	34	37	39	42
70	27	29	35	39	40	44
80	28	30	37	40	42	45
90	28	31	38	41	43	47
100	29	31	38	42	43	47

- Guidance for wind on completed structure prior deck placement
- Not meant for staged construction analysis
- Provides general rules for designer

PennDOT – Wind Prior to Deck Pour

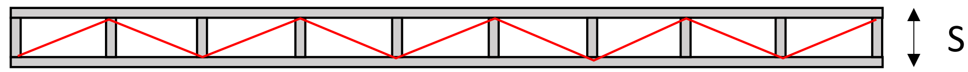
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

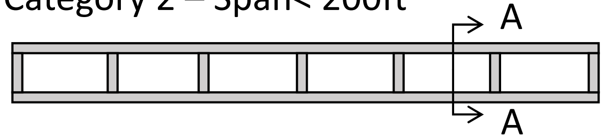
Lateral Bracing Requirements Based on Span Length

Category 1 - Span > 300ft

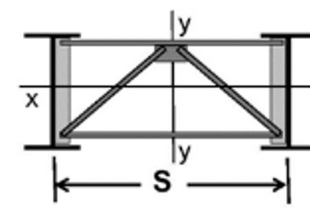


Lateral Bracing Required

Category 2 – Span< 200ft

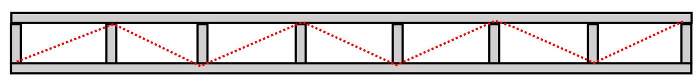


No Lateral Bracing Required



Section A-A

Category 3 – 200 ft < Span < 300ft



Evaluate Need Based on Lateral Deflection

PennDOT – Wind Prior to Deck Pour

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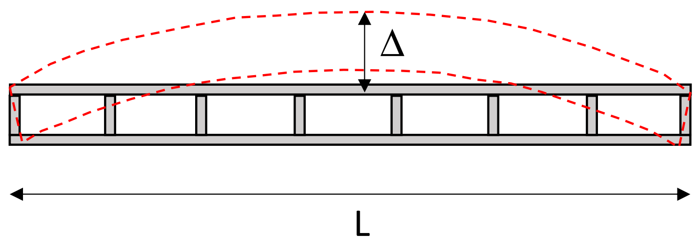
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

Lateral Bracing Requirements Based on Span Length (Cont.)

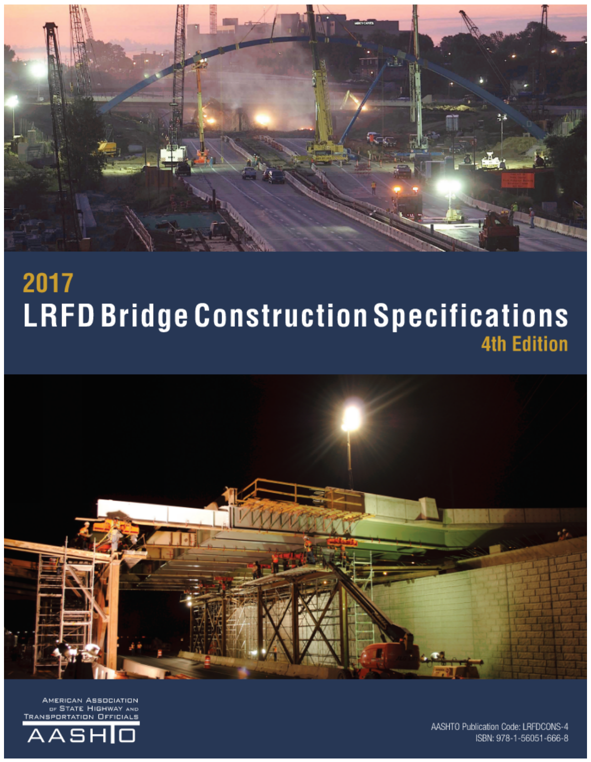
Category 3 – 200 ft < Span < 300ft



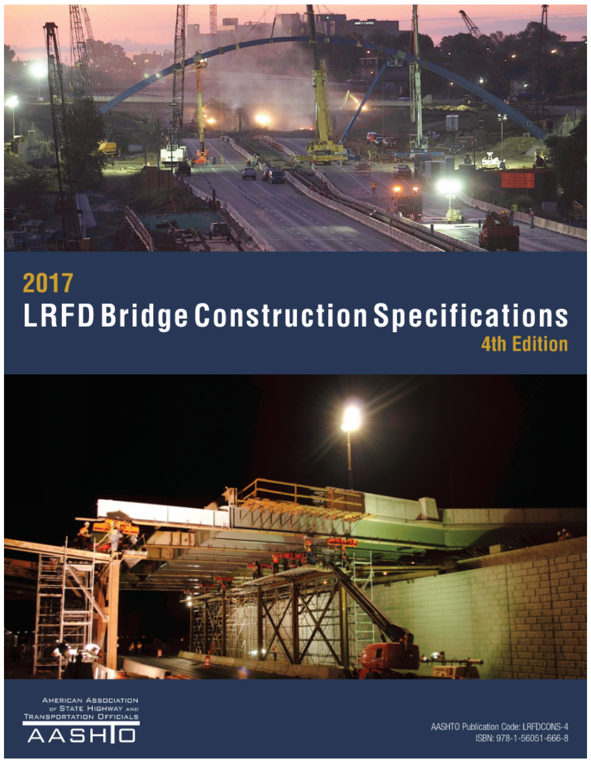
Δ - Displacement Wind no Deck < Must be less than L/150

Otherwise lateral bracing required

AASHTO Bridge Construction Specifications



AASHTO Bridge Construction Specifications



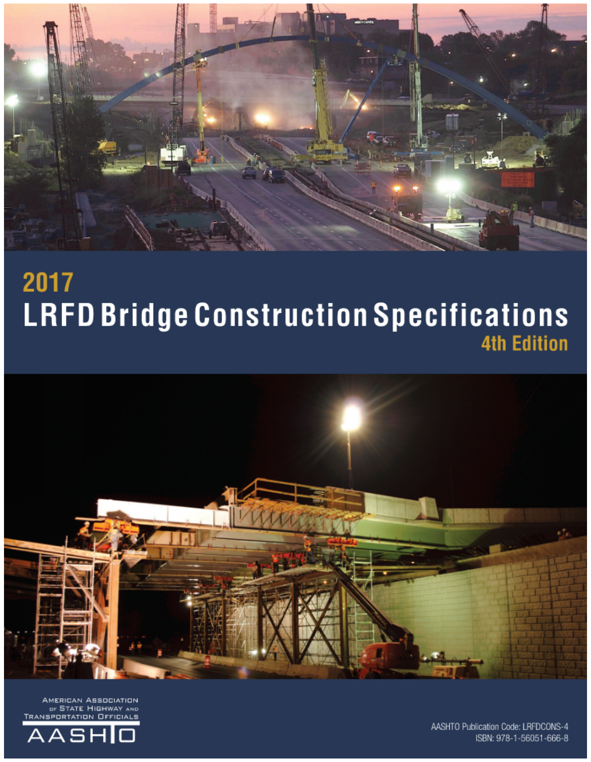
Key Sections:

Chapter 8

Concrete Structures

- 8.13 – Precast Concrete Members
- 8.16 – Special Provisions for Segmental Bridges

AASHTO Bridge Construction Specifications



Key Sections:

Chapter 8

Concrete Structures

- 8.13 – Precast Concrete Members
- 8.16 – Special Provisions for Segmental Bridges

Chapter 11

Steel Structures

- 11.2 – Erection Drawings
- 11.8 – Additional Provisions for Curved Girders

Steel Girder Bridges Erection Requirements

11.2.2—Erection Drawings

The Contractor shall submit drawings illustrating fully the proposed method of erection. The drawings shall show details of all falsework bents, bracing, guys, dead-men, lifting devices, and attachments to the bridge members: sequence of erection, location of cranes and barges, crane capacities, location of lifting points on the bridge members, and weights of the members. The drawings shall be complete in detail for all anticipated phases and conditions during erection. Calculations may be required to demonstrate that factored resistances are not exceeded and that member capacities and final geometry will be correct.

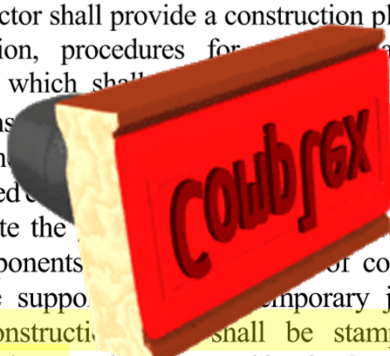
Comm. Ave Bridge, Boston, MA

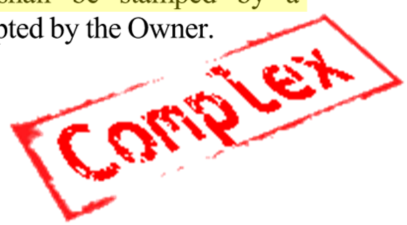
Curved Steel Girder Bridges

11.8—ADDITIONAL PROVISIONS FOR CURVED STEEL GIRDERS

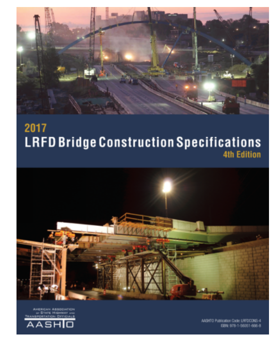
11.8.2—Contractor's Construction Plan for Curved Girder Bridges

The Contractor shall provide a construction plan which details fabrication, procedures for … and deck placement, and which shall … in as the Contractor's cons… ased on the plan shown in th… rovided, or may be developed … er event, it shall demonstrate the … ucture and individual components … of construction, including while suppo… mporary jacks. The Contractor's constructi… shall be stamped by a Professional Engineer and be accepted by the Owner.



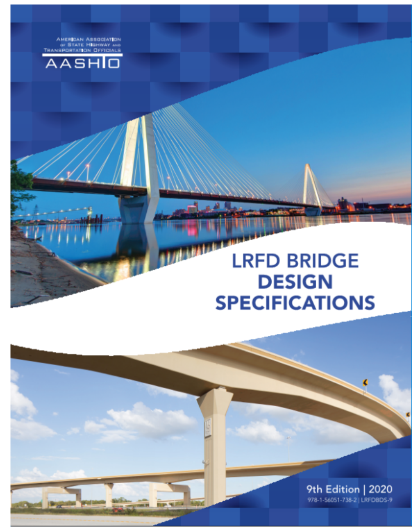


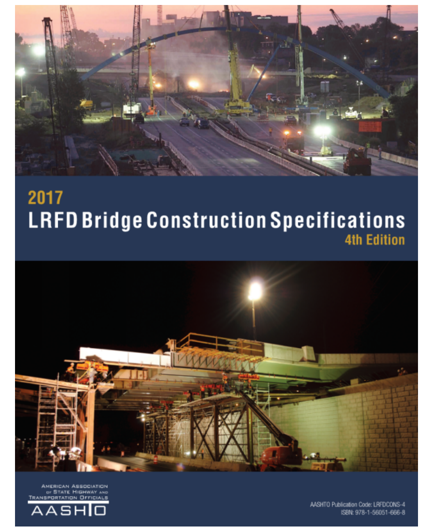
Gateway Interchange Flyovers, Johnson County, KS



Constructability Summary

- AASHTO Specifications clearly distinguish between complex and conventional for concrete girder bridges …Mostly out of necessity
- AASHTO Specifications are not as clear for steel girder bridges (I-Girder / Box Girder)
- DOT guides have made effort to address





NYSDOT - Steel I-Girder Bridges - Constructibility

New York State

DEPARTMENT OF TRANSPORTATION

BRIDGE MANUAL

2021

NEW YORK STATE OF OPPORTUNITY. | Department of Transportation

Kathy Hochul
Governor

NEW YORK STATE

STEEL CONSTRUCTION MANUAL

4TH EDITION

ANDREW M. CUOMO
GOVERNOR

PAUL KARAS
ACTING COMMISSIONER

Department of Transportation, Office of Structures
January 2018

NEW YORK STATE OF OPPORTUNITY. Department of Transportation	ENGINEERING INSTRUCTION	EI 21-004
Title: **NYSDOT LRFD BRIDGE DESIGN SPECIFICATIONS - 2021**		
Approved: James Flynn III, PE, Deputy Chief Engineer (Structures)	2-2-21 Date	

ADMINISTRATIVE INFORMATION:

- This Engineering Instruction (EI) is effective beginning with projects submitted for the letting of September 1, 2021
- This EI supersedes EI 19-001 "NYSDOT LRFD BRIDGE DESIGN SPECIFICATIONS - 2019"
- Disposition of Issued Materials: The technical information transmitted by this EI will be incorporated into the next revision of the NYSDOT Bridge Manual

PURPOSE: This EI officially adopts the NYSDOT LRFD Bridge Design Specifications – 2021 for use in New York State and announces the availability of "NYSDOT LRFD Blue Pages" dated January 2021.

TECHNICAL INFORMATION: The *AASHTO LRFD Bridge Design Specifications - 9th Edition, 2020*, together with the "NYSDOT LRFD Blue Pages" dated January 2021 constitute the NYSDOT LRFD Bridge Design Specifications.

- The LRFD specifications will continue to be used for the design of all new and replacement bridges for NYSDOT. This includes both superstructure designs and substructure designs. This EI does not discontinue use of the NYSDOT Standard Specifications for Highway Bridges – 2003. Both specifications will continue to be used until further notice. The existing NYSDOT Standard Specifications for Highway Bridges - 2003 will be used when necessary for the repair and rehabilitation of structures. The NYSDOT Standard Specifications for Highway Bridges – 2003 consists of the *AASHTO Standard Specifications for Highway Bridges - 17th Edition* plus the "NYSDOT Blue Pages", issued by EB 02-038 and EB 03-016.

- The NYSDOT Design Permit Vehicle has been removed from the NYSDOT LRFD Blue Pages.

- Currently, NYSDOT overload permitting and bridge posting policies require that new and replacement bridges be load rated using the Load Factor Design (LFD) or Allowable Stress Design (ASD) methods. For this reason, load ratings will continue to be computed by the LFD or ASD method and shown on the contract plans. Also, load rating factors for all new, replacement, and rehabilitated bridges will be computed by the Load and Resistance Factor Rating (LRFR) method and shown on the contract plans. LRFR ratings shall be shown at the Inventory and Operating levels as rating factors of the AASHTO HL-93 live load. Once overload permitting and bridge posting policies are revised to accommodate LRFR, load ratings using the LFD and ASD methods will be discontinued.

LRFD Blue Pages

Alternate Erection Classification Example - KDOT

- KDOT Section 737 provides erection category system based on complexity
- Accounts for span length, skew and curvature
- Based on category, which designer can indicate on Contract Plans, the level of erection considerations may be required.
- Everyone is on even playing field during bid phase

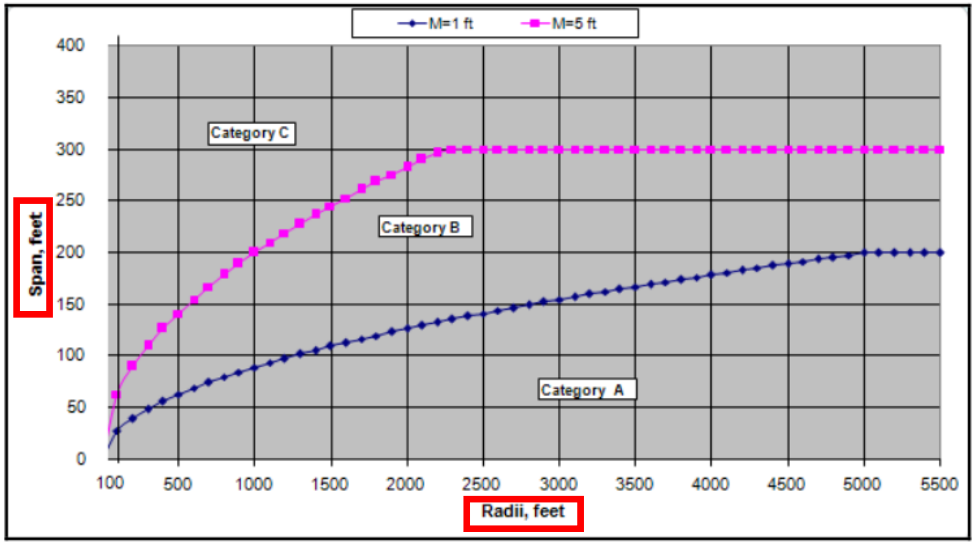


FIGURE 736-1

Special Requirements for Bridge Designers to Designate Erection Plan Categories

The initial Category is based on the chart which considers the length of the longest span, the curvature of the bridge and the skew angle.

If skew is greater than 30°, move up one Category (A to B or B to C).

If a structure crosses traffic or a railroad, require Category B as a minimum.

If the Contractor uses falsework bents or strong-backs for the field erection, Category C Erection Plans are required.

The designer may elevate a structure to the necessary Category based upon engineering judgment and unique circumstances.

Constructability Summary

Structure Classification	Material	Structure Type
Conventional	Concrete	Precast Beams
	Steel	Shorter Straight Spans (< 200-ft)
Complex	Concrete	Spliced Prestressed Beams / Segmental
	Steel	Long Spans (> 200-ft) / Curved / High Skew

Constructability Summary

			EOR Responsibility
Structure Classification	**Material**	**Structure Type**	**Suggested Construction Plan**
Conventional	Concrete	Precast Beams	No
	Steel	Shorter Straight Spans (< 200-ft)	No
Complex	Concrete	Spliced Prestressed Beams / Segmental	Yes
	Steel	Long Spans (> 200-ft) / Curved / High Skew	Sometimes

Constructability Summary

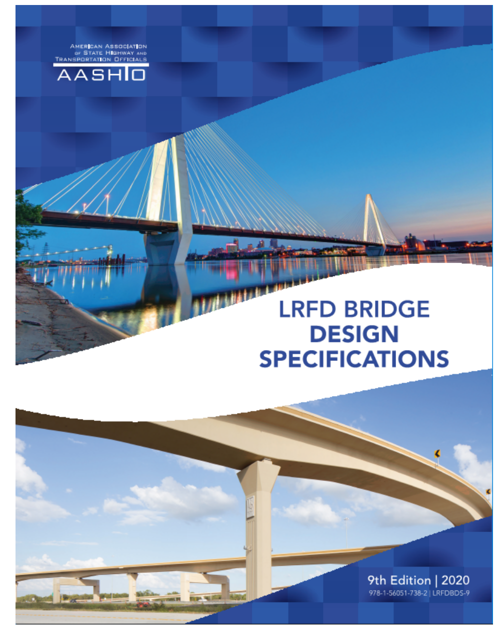
			EOR Responsibility	Contractor Responsibility	
Structure Classification	**Material**	**Structure Type**	**Suggested Construction Plan**	**Erection Plan Required?**	**Engineering Required?**
Conventional	Concrete	Precast Beams	No	Yes	DOT Dependent
	Steel	Shorter Straight Spans (< 200-ft)	No	Yes	DOT Dependent
Complex	Concrete	Spliced Prestressed Beams / Segmental	Yes	Yes	Yes
	Steel	Long Spans (> 200-ft) / Curved / High Skew	Sometimes	Yes	Yes

Critical Stages of Construction

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
- All girders and bracing installed prior to the deck placement *[total structure stable in wind]*
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement



AASHTO (Industry) should clarify that all girder systems should be evaluated by the Design Engineer for wind loading prior to slab pour

AASHTO T-14 Addition

Add the following new Article C4.6.2.7.3:

C4.6.2.7.3

The provisions of Articles 4.6.2.7.1 and 4.6.2.7.2 were developed for girder bridges after the deck is placed. The response of these structures to wind loads during construction before the deck placement is completed is significantly different from that of the completed bridge. The flow of wind around the structure and the resulting wind pressure acting on the individual girders is different. Another significant difference between bridges during construction and bridges in service is the short length of time expected between the erection of the girders and the placement of the deck. For the same probability of exceedance, the design wind speed decreases with the decrease in the time between the girder erection and the deck placement.

The *AASHTO Guide Specifications for Wind Loads on Bridges During Construction* modify the preceding wind-load provisions to account for these differences between completed bridges and bridges during construction. To determine if any wind bracing is necessary, the Guide Specifications may be used to perform an investigation of the inactive work zone wind load case between the completed erection of the girders and the placement of the concrete deck assuming no wind bracing is provided in the plane of either flange. These Specifications may also be used to perform an investigation of the active work zone wind load case during the placement of the deck, if desired.

AASHTO T-14 Addition

ANTICIPATED EFFECT ON BRIDGES:

The proposed addition of Commentary Article C4.6.2.7.3 alerts designers to consider using the *AASHTO Guide Specifications for Wind Loads on Bridges During Construction* to evaluate the need for wind bracing in I- and box-section bridges during construction in lieu of the provisions of Articles 4.6.2.7.1 and 4.6.2.7.2, which were developed for girder bridges after the deck is placed. The Guide Specifications allow for a more rational evaluation of the inactive work zone wind load case between the completed erection of the girders and the placement of the concrete deck assuming no wind bracing is provided in the plane of either flange and also the active wind load case during the deck placement, if desired, to determine if there is a need for any lateral wind bracing. The designer is also alerted to consider using the *PCI Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders* to evaluate the stability of precast, prestressed concrete bridge girders seated on bearing pads and subject to wind loads during construction.

Does not address deflection limit states

Steel Girder Erection

Through the Eyes of a Construction Engineer

Steel Girder Erection

- Compression Flange Slenderness Requirements
- Picking Girders
- Staged Construction Evaluation
- Temporary Works

Compression Flange Requirements

b/t RATIO

- Compression flange slenderness (b/t) has a major impact on plate girder constructability.
  - Stability of Girders while Hoisting
  - Stability of Partially Constructed Girder Systems

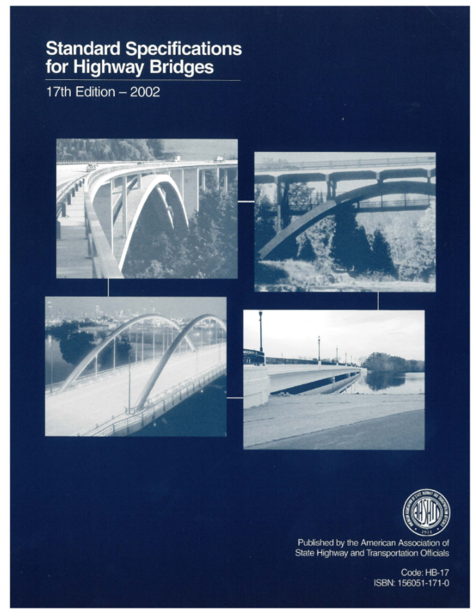
Typically not considered by designers

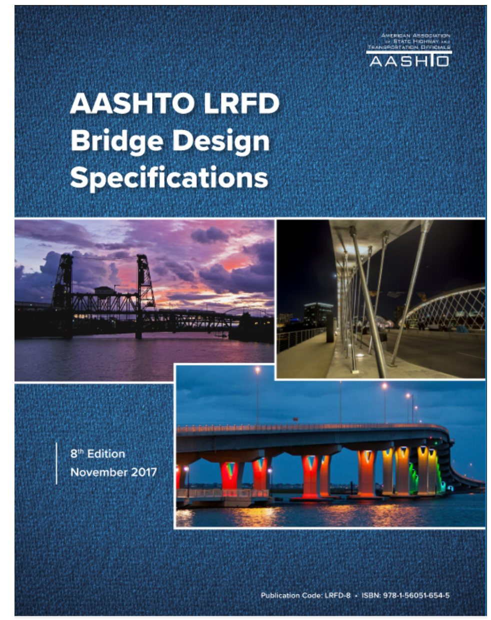
- Prior to deck pour, the flanges provide the only means of stiffness between cross-frames.
- Changes to AASHTO requirements have allowed compression flanges to be more "optimized"

AASHTO History

b/t RATIO

- ASD (Allowable Stress Design)
- LFD (Load Factor Design)
- LRFD (Load Resistance Factor Design)





ASD (Allowable Stress Design)

σ.allowable ≥ σ.demand

1930's

LFD (Load Factor Design)

$$R_n \geq effects\ of \sum \gamma_i Q_i$$

1970's

LRFD (Load Resistance Factor Design)

$$\phi R_n \geq effects\ of \sum \gamma_i Q_i$$

1994

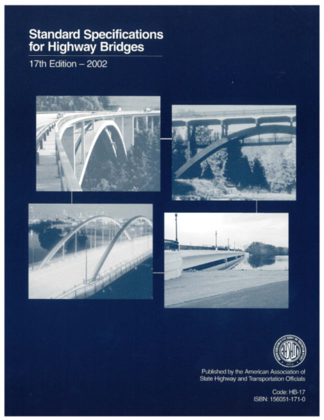
Images Courtesy of:

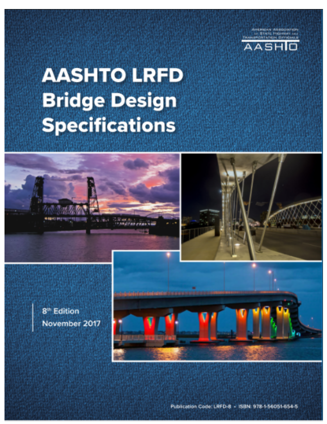
https://imgur.com/gallery/Yg6XWqB
https://www.biography.com/news/saturday-night-fever-40th-anniversary
https://csengineermag.com/article/john-kulicki-setting-new-standards/

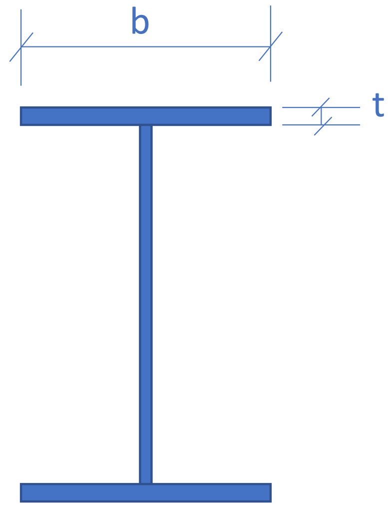
Compression Flange Requirements

b/t RATIO

- ASD
- LFD
- LRFD







Flange Proportion Limit
$b/t \leq 24$

Golden Rule

ASD - Compression Flange Requirements

b/t RATIO

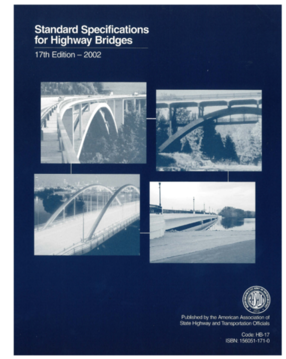
10.34.2.1.3 The ratio of compression flange plate width to thickness shall not exceed the value determined by the formula

$$\frac{b}{t} = \frac{3{,}250}{\sqrt{f_b}} \quad \text{but in no case shall b/t exceed 24} \qquad (10\text{-}19)$$

10.34.2.1.4 Where the calculated compressive bending stress equals .55 F_y the (b/t) ratios for the various grades of steel shall not exceed the following:

36,000 psi, Y.P. Min. b/t = 23
50,000 psi, Y.P. Min. b/t = 20
70,000 psi, Y.P. Min. b/t = 17
90,000 psi, Y.P. Min. b/t = 15
100,000 psi, Y.P. Min. b/t = 14

- b/t limit is function of applied stress (f_b)
- Defines maximum flange width to thickness limits when fb = 0.55fy



LFD - Compression Flange Requirements

b/t RATIO

10.48.1.1 Compact sections shall meet the following requirements: (For certain frequently used steels these requirements are listed in Table 10.48.1.2A.)

(a) Compression flange

$$\frac{b}{t} \leq \frac{4{,}110}{\sqrt{F_y}} \qquad (10\text{-}93)$$

TABLE 10.48.1.2A Limitations for Compact Sections

F_y (psi)	36,000	50,000	70,000
b/t	21.7	18.4	15.5
D/t_w	101	86	72
L_b/r_y (M_l/M_u = 0*)	100	72	51
L_b/r_y (M_l/M_u = 1*)	39	28	20

* For values of M_l/M_u other than 0 and 1, use Equation (10-96).

TABLE 10.48.2.1A Limitations for Braced Noncompact Sections

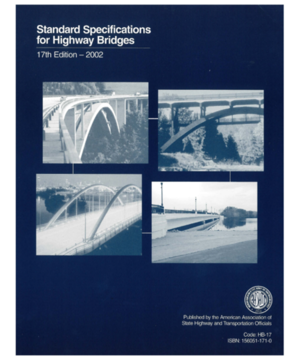
F_y (psi)	36,000	50,000	70,000	90,000	100,000
b/t *	23.2	19.7	16.6	14.7	13.9
$\frac{L_b d}{A_f}$	556	400	286	222	200
D/t_w	Refer to Articles 10.48.5.1, 10.48.6.1, 10.49.2, or 10.49.3, as applicable. For unstiffened webs, the limit is 150.				

* Limits shown are for $F_{cr} = F_y$. Refer also to Articles 10.48.2 and 10.48.2.1(a).

10.48.2.1 The above equations are applicable to sections meeting the following requirements:

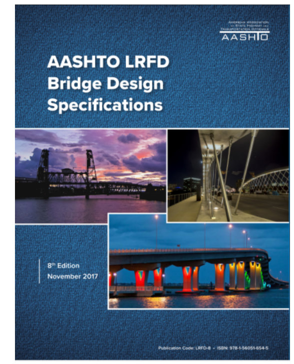
(a) Compression flange

$$\frac{b}{t} \leq 24 \qquad (10\text{-}100)$$



LRFD - Compression Flange Requirements

b/t RATIO



6.10.2.2—Flange Proportions

Compression and tension flanges shall be proportioned such that:

$$\frac{b_f}{2t_f} \leq 12.0, \quad (6.10.2.2\text{-}1)$$

→ bf / tf < 24

$$b_f \geq D/6, \quad (6.10.2.2\text{-}2)$$

$$t_f \geq 1.1t_w, \quad (6.10.2.2\text{-}3)$$

and:

$$0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 10 \quad (6.10.2.2\text{-}4)$$

LRFD - Compression Flange Requirements

b/t RATIO

6.10.8.2.2—Local Buckling Resistance

The local buckling resistance of the compression flange shall be taken as:

- If $\lambda_f \le \lambda_{pf}$, then:

$$F_{nc} = R_b R_h F_{yc} \quad (6.10.8.2.2\text{-}1)$$

- Otherwise:

$$F_{nc} = \left[1 - \left(1 - \frac{F_{yr}}{R_h F_{yc}}\right)\left(\frac{\lambda_f - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right] R_b R_h F_{yc} \quad (6.10.8.2.2\text{-}2)$$

in which:

λ_f = slenderness ratio for the compression flange

$$= \frac{b_{fc}}{2t_{fc}} \quad (6.10.8.2.2\text{-}3)$$

λ_{pf} = limiting slenderness ratio for a compact flange

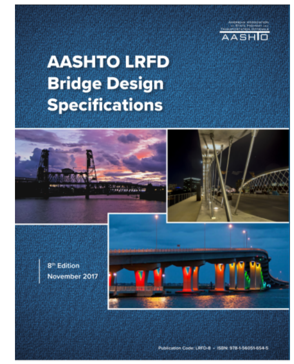
$$= 0.38\sqrt{\frac{E}{F_{yc}}} \quad (6.10.8.2.2\text{-}4)$$

λ_{rf} = limiting slenderness ratio for a noncompact flange

$$= 0.56\sqrt{\frac{E}{F_{yr}}} \quad (6.10.8.2.2\text{-}5)$$

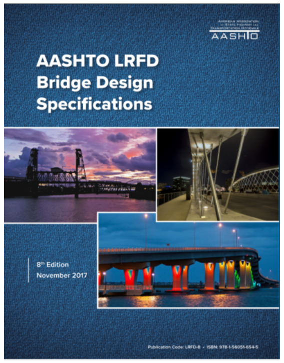
$b_f / 2t_f < \lambda_{pf}$

$b_f / t_f < 2\lambda_{pf}$



Compression Flange Requirements

b/t RATIO



- ASD or LFD Non-Compact

  $\frac{b}{t} = \frac{3,250}{\sqrt{f_b}}$ let fb = 0.55fy

- LFD Compact

  $\frac{b}{t} \le \frac{4,110}{\sqrt{F_y}}$

- LRFD

  $2 \text{ x } 0.38\sqrt{\frac{E}{F_{yc}}}$

- ASD / LFD / LRFD

  $\frac{b}{t} \le 24$

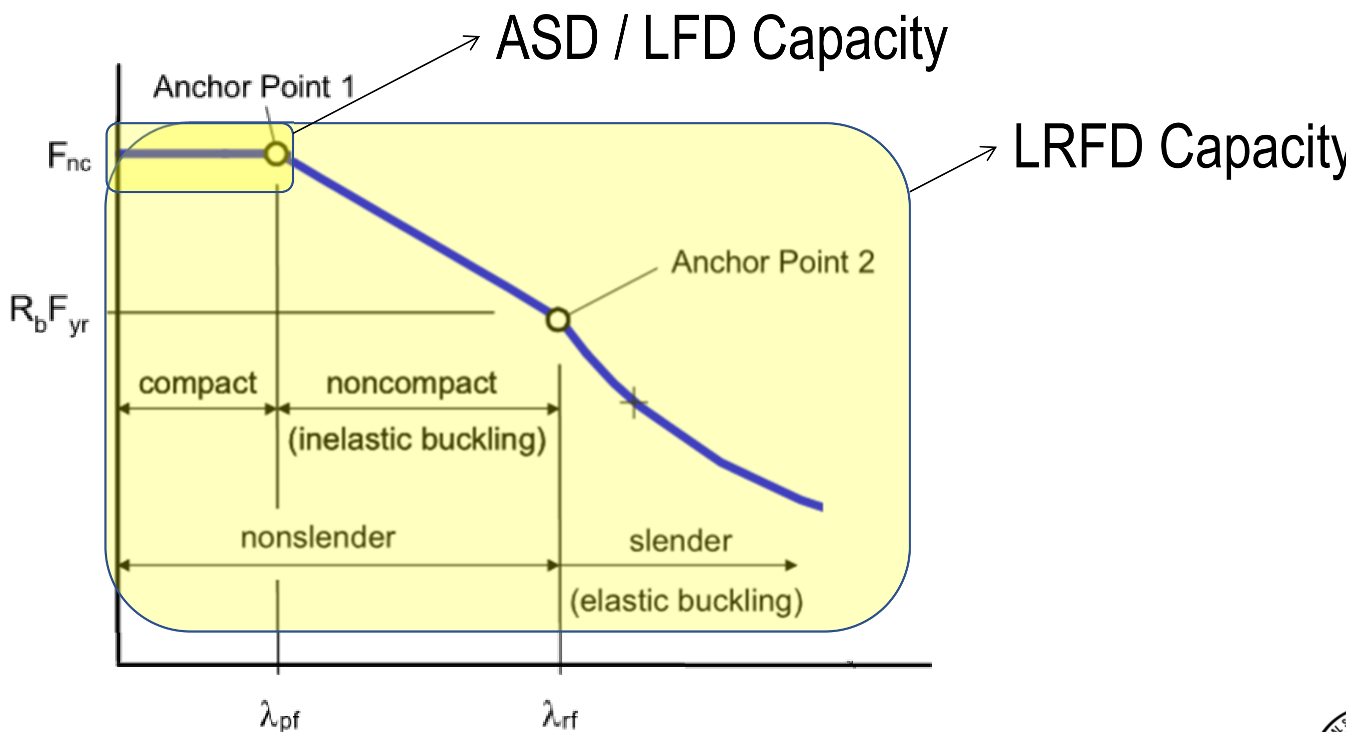
fy (ksi)	ASD or LFD Non-Compact	LFD Compact	LRFD
36	23.1	21.7	21.6
50	19.6	18.4	18.3
70	16.6	15.5	15.5
90	14.6	13.7	13.6
100	13.9	13.0	12.9

ASD & LFD Hard Limit

LRFD Limit for when LB must be considered

Compression Flange Requirements

b/t RATIO



Compression Flange Requirements

b/t RATIO

- Governing codes have become more refined (& complicated) in the calculation of both member capacity and load demands.
- Computer power allows for more refined analysis.
- This has in turn allowed for more "efficient" structures.
- Results in potentially larger compression flange b/t ratios.
  - Final bridge condition may be adequate
  - More difficult to erect.
- More "efficient" structures do NOT always result in project cost savings.

Steel Girder Erection

PICKING

- Compression Flange Slenderness Requirements
- Picking Girders
  - Single Girder vs Paired Girder
  - Curved Girder
  - Rigging Options
- Staged Construction Evaluation
- Temporary Works

Critical Stages of Construction

PICKING

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

- Lifting of girders/members
- Placement of the initial girder and any associated temporary bracing used to hold the girder in place
- First pair of girders set with permanent bracing installed
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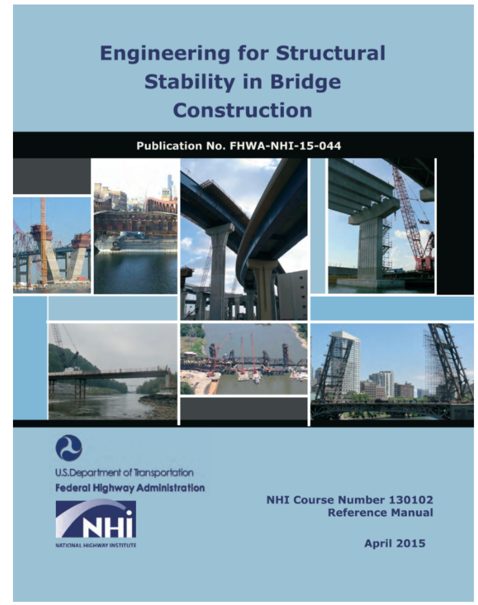
- All girders and bracing installed during the deck placement
- Application of the deck overhang bracket loads to the fascia girders during the deck placement



Single vs. Paired Girder Pick

PICKING

Comm. Ave Bridge, Boston, MA

Comm. Ave Bridge, Boston, MA

Single Girder Pick Advantages

PICKING

- Smaller Crane
  - Lighter pick load
- Larger Radius
  - Site constraints may dictate
- Simpler Rigging
  - No transverse spreaders
- Expedited Installation
  - One field splice connection

Comm. Ave Bridge, Boston, MA

Paired Girder Pick Advantages

PICKING

- More Ground Assembly
  - Cross frame connections
- More Stable while Hoisted
  - Reduced lateral torsional buckling concerns
- But….
  - More complicated rigging
  - More difficult fitup of splices

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY

Curved Girder Pick

PICKING

Fulbright Expressway, Fayetteville, AR

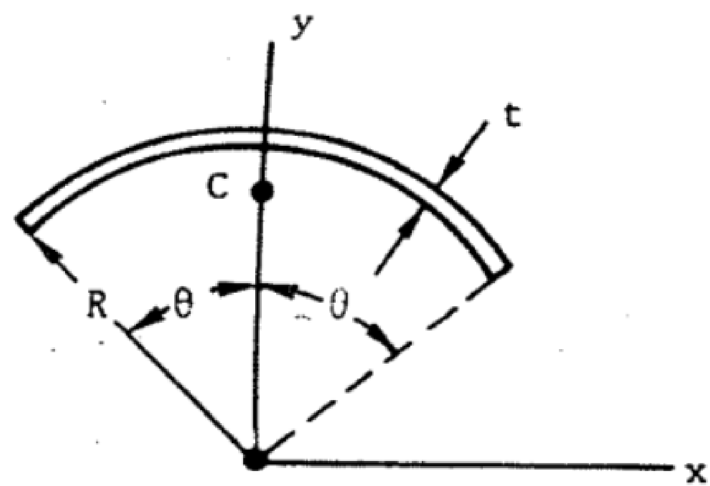
Gateway Interchange Flyovers, Johnson County, KS

Curved Girder Pick

PICKING

Girder Center of Gravity

28. Sector of Thin Annulus



$$x_C = 0$$

$$y_C = R\frac{\sin\theta}{\theta}$$

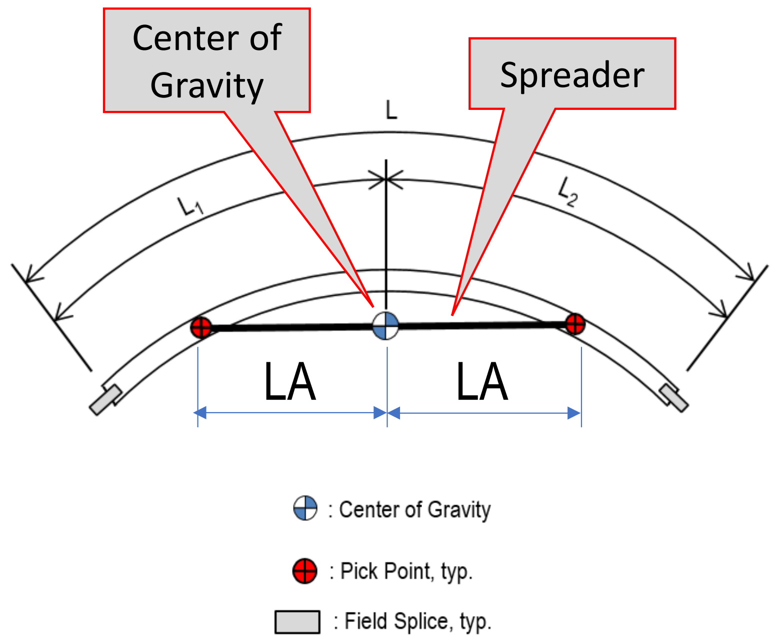
Curved Girder Pick

PICKING

Girder Center of Gravity for fabricated steel

- Span Lengths
- Changing Girder Cross Section
  - Shop Splices
- Field Splices
  - Installed or not installed
- Cross Frames
  - Installed or not installed

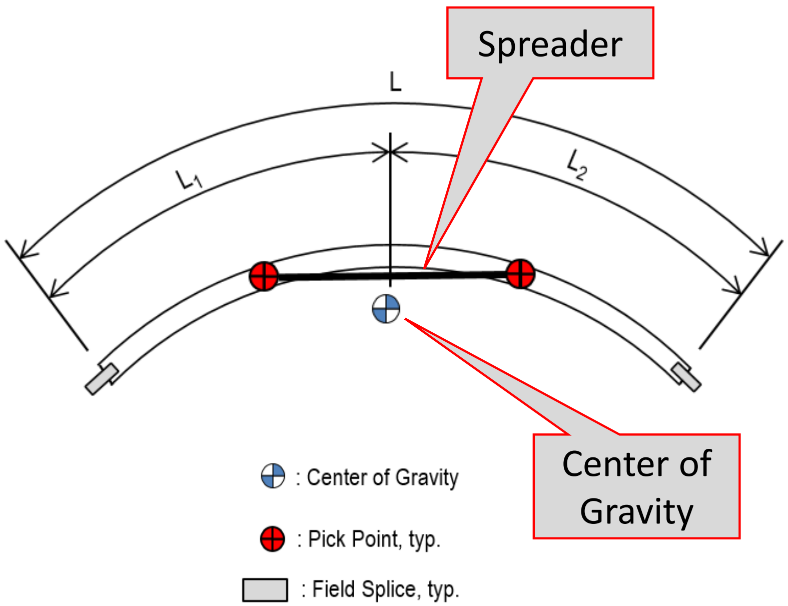
Ideal Spreader Length



Curved Girder Pick

PICKING

Spreader Shorter Than Ideal Length



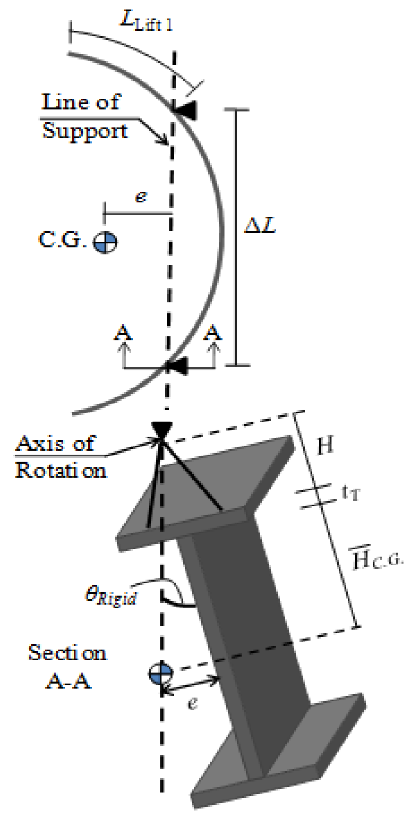
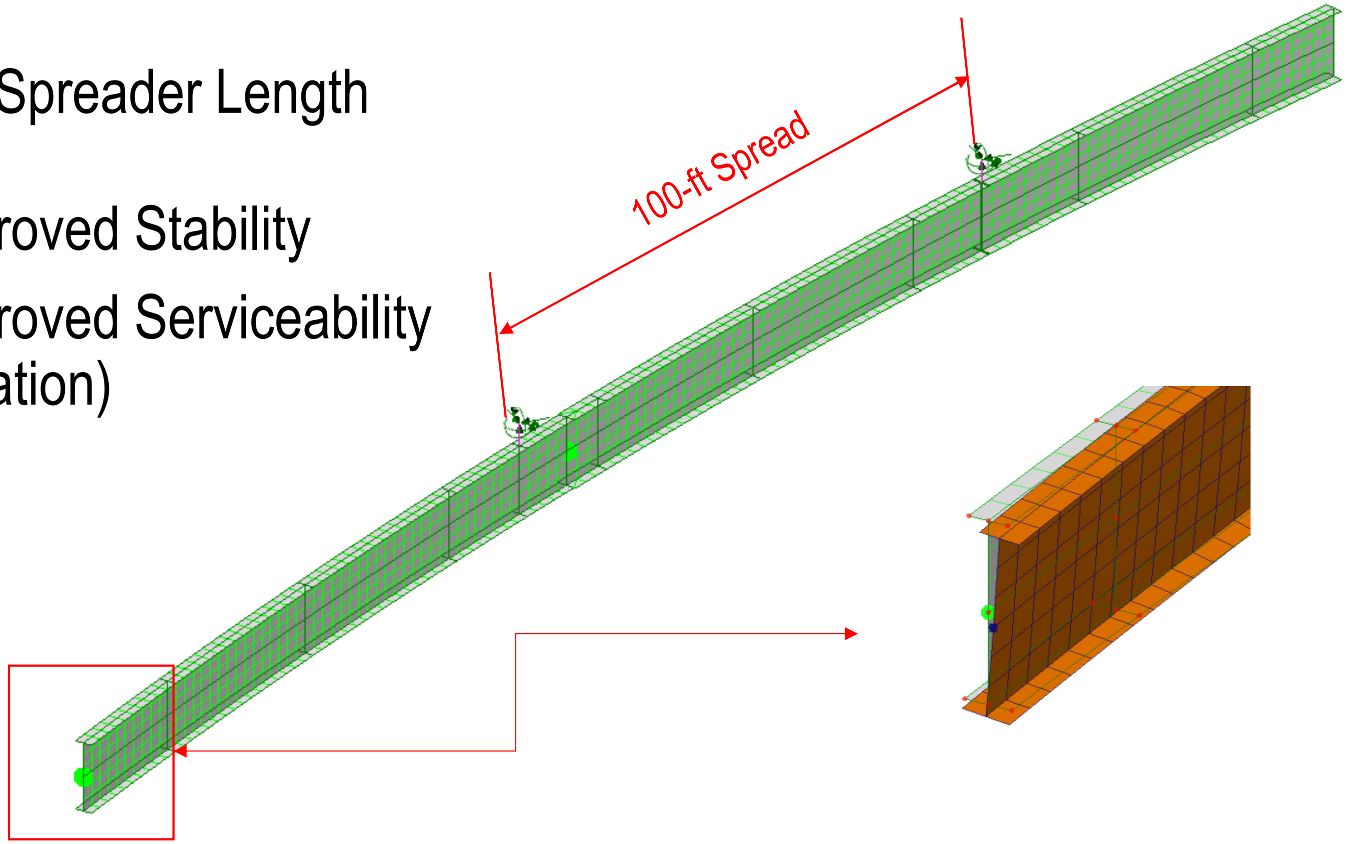


Image Courtesy of: UTLift

Curved Girder Pick

Ideal Spreader Length

- Improved Stability
- Improved Serviceability (rotation)

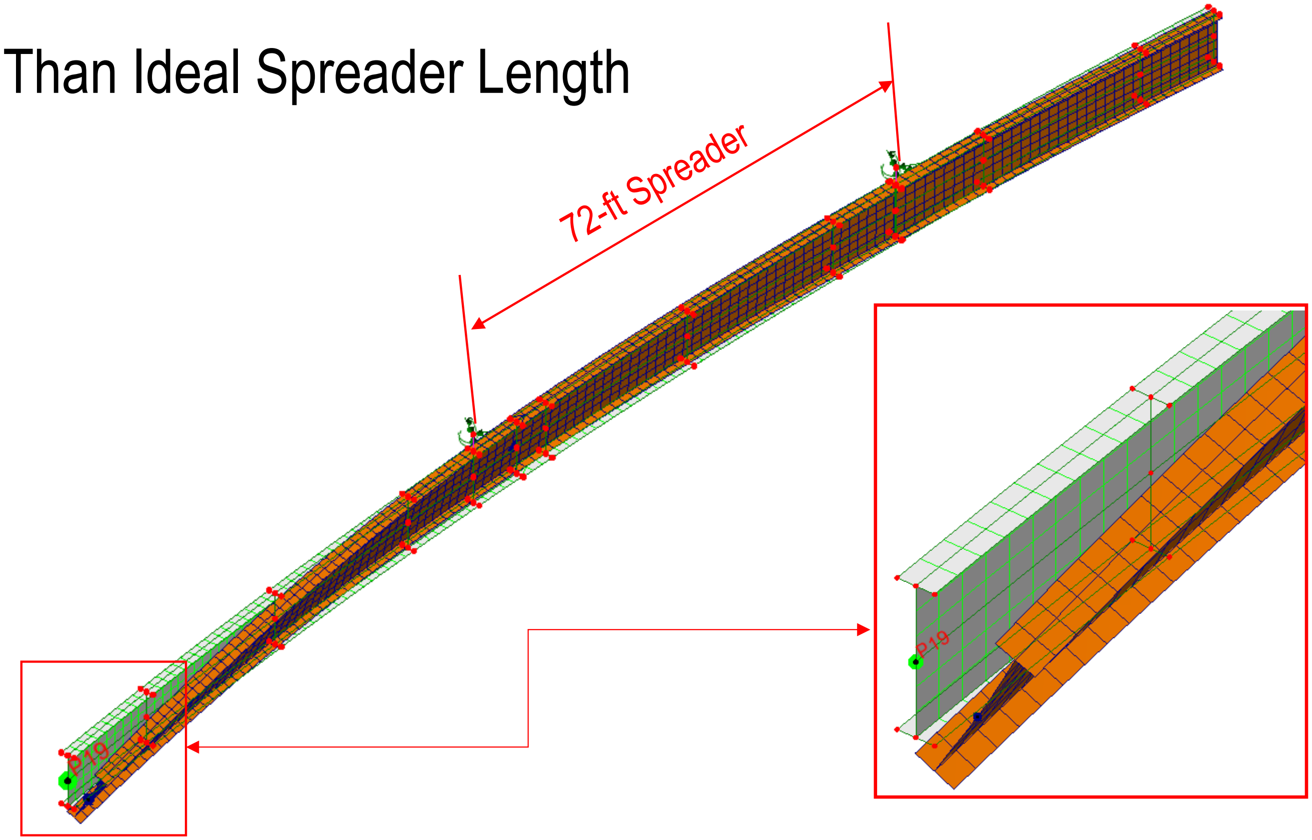


9" Lateral Displacement

Curved Girder Pick

PICKING

Shorter Than Ideal Spreader Length

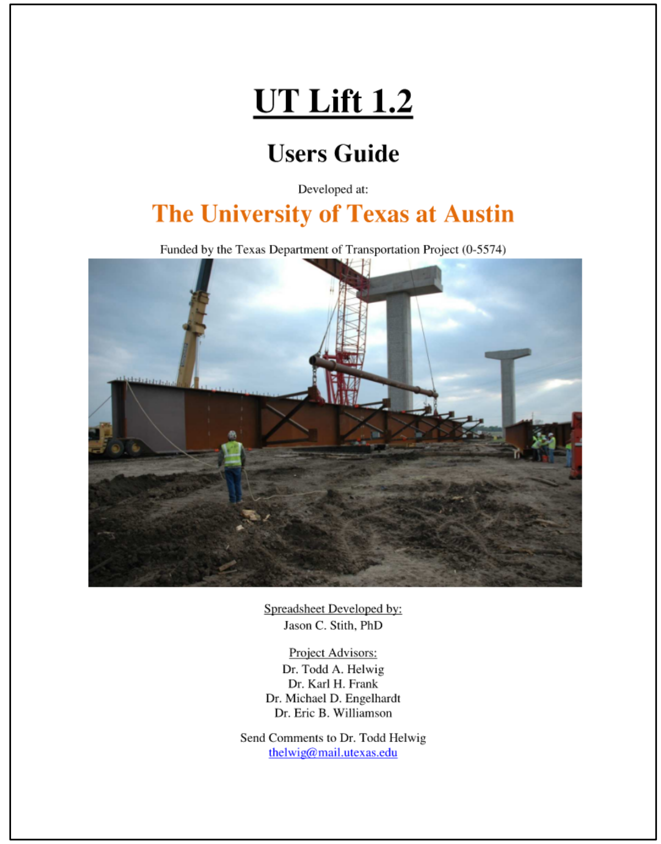


20" Lateral Displacement

Curved Girder Pick – UT Lift

PICKING

- UT Lift Software used for curved girder hoisting analysis



UT Lift 1.2

Users Guide

Developed at:

The University of Texas at Austin

Funded by the Texas Department of Transportation Project (0-5574)

Spreadsheet Developed by:
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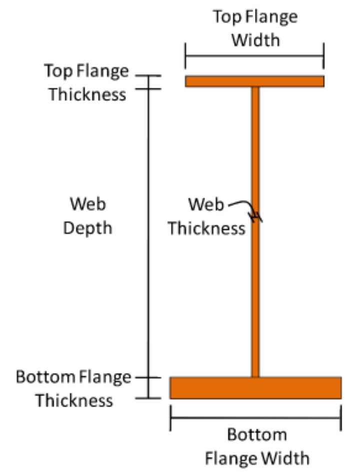
Dr. Michael D. Engelhardt
Dr. Eric B. Williamson

Send Comments to Dr. Todd Helwig
thelwig@mail.utexas.edu

Curved Girder Pick – UT Lift

PICKING

- Input:
  - Girder section properties
  - Curve radius
  - Cross-frame information, if applicable
- Output:
  - Pick weight and C.G.
  - Ideal spread between pick points
  - Max girder picking stresses
  - Girder twist
  - Girder Demand/Capacity (D/C) Ratio



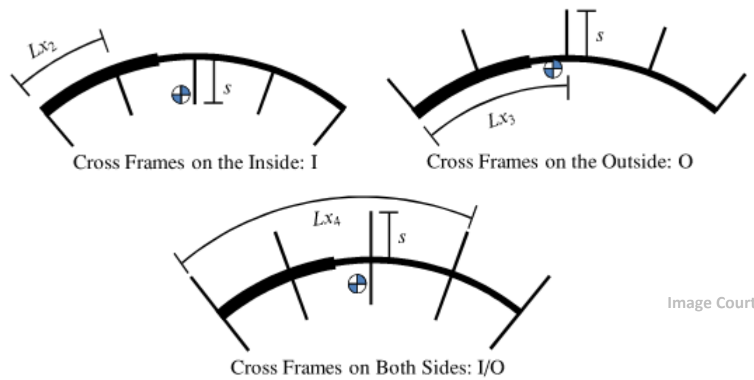


Image Courtesy of: UTLift

Curved Girder Pick – UT Lift

PICKING

- Input:
  - Girder section properties
  - Curve radius
  - Cross-frame information, if applicable
- Output:
  - Pick weight and C.G.
  - Ideal spread between pick points
  - Max girder picking stresses
  - Girder twist
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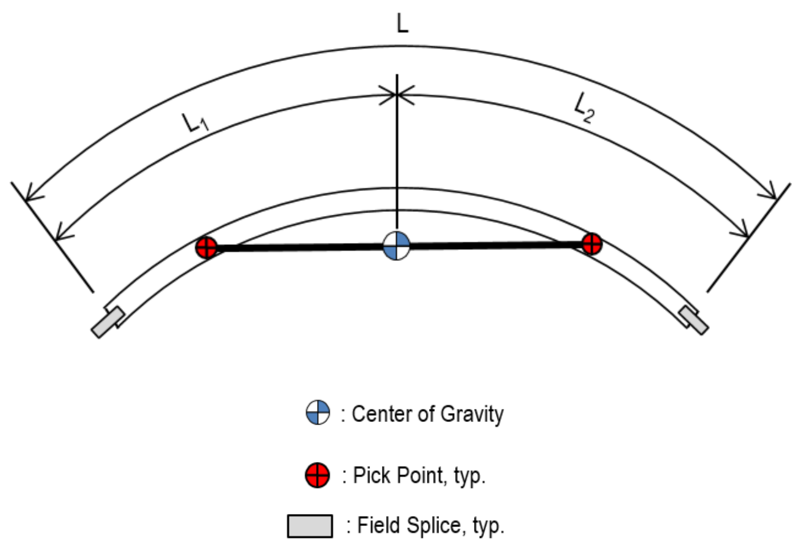
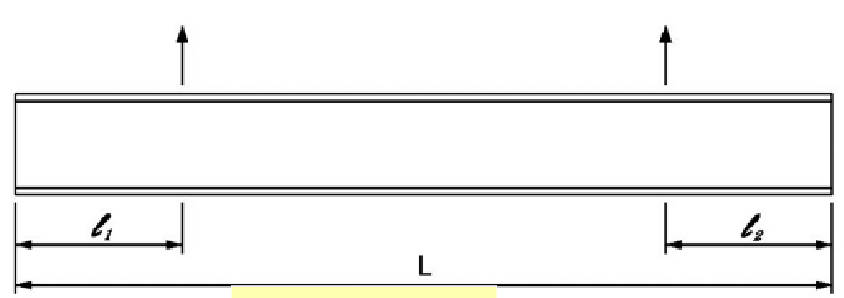


Curved Girder Pick – UT Lift

PICKING



$$L_{LIFT} = \frac{\ell_1 + \ell_2}{2}$$

$$M_u < \phi_b M_{cr} = \phi_b C_{bL} \frac{\pi}{L_b} \sqrt{E I_y G J + E^2 I_y C_w \left(\frac{\pi^2}{L_b^2} \right)}$$

Equation 7-7

L_b = Unbraced length = L (total length of girder segment)

$$C_{bL} = 2.0 \; for \; \frac{L_{Lift}}{L} \leq 0.225$$

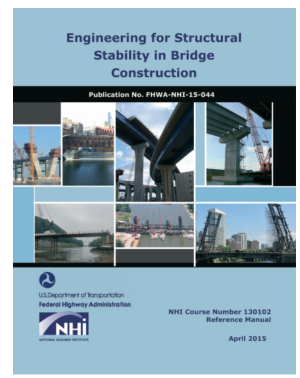
Equation 7-8

$$C_{bL} = 6.0 \; for \; 0.225 < \frac{L_{Lift}}{L} < 0.3$$

Equation 7-9

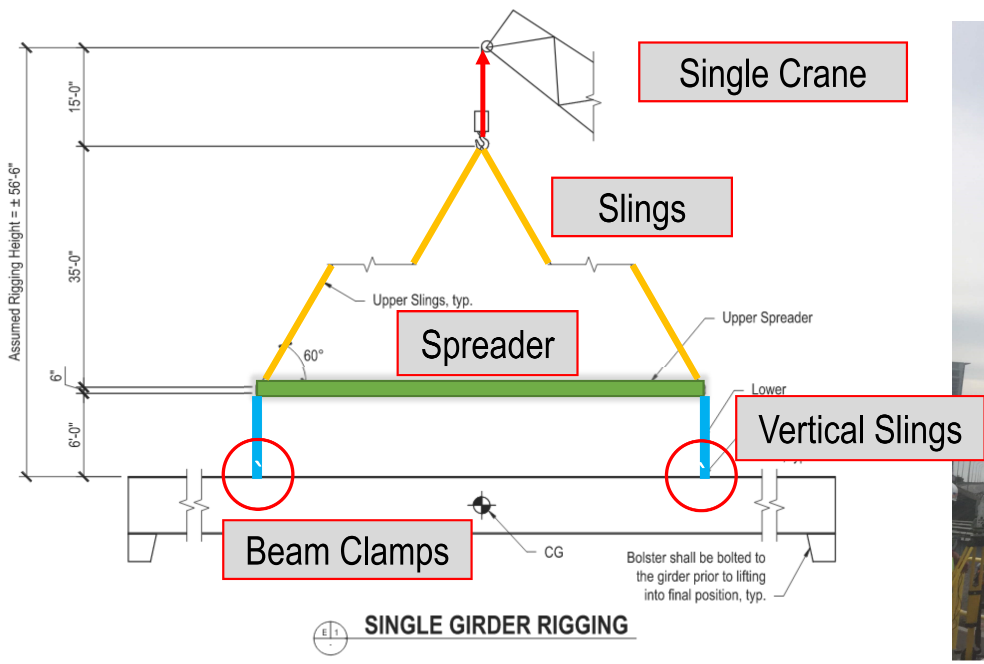
$$C_{bL} = 4.0 \; for \; \frac{L_{Lift}}{L} \geq 0.3$$

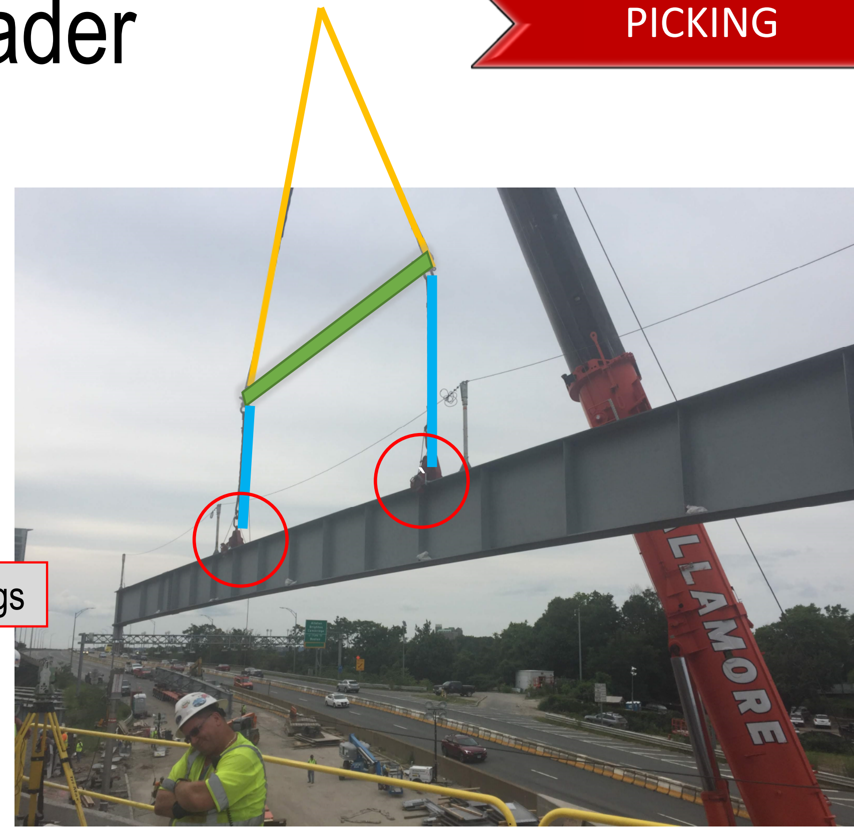
Equation 7-10



Rigging – Single Girder Spreader

PICKING

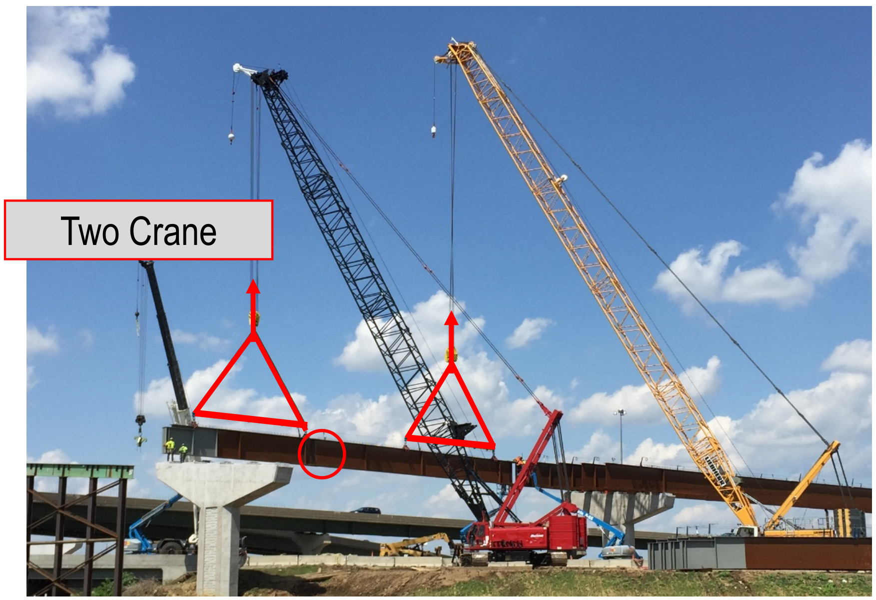




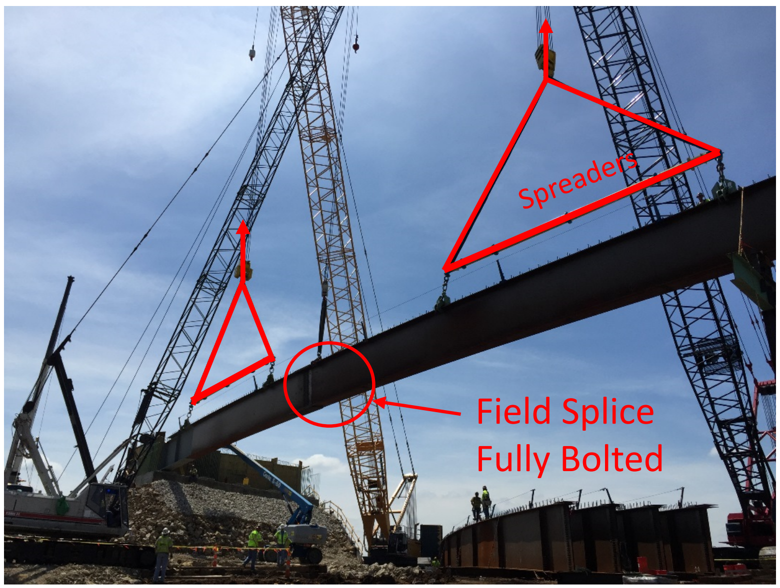
Comm. Ave Bridge, Boston, MA

Rigging – Single Girder Spreader

PICKING



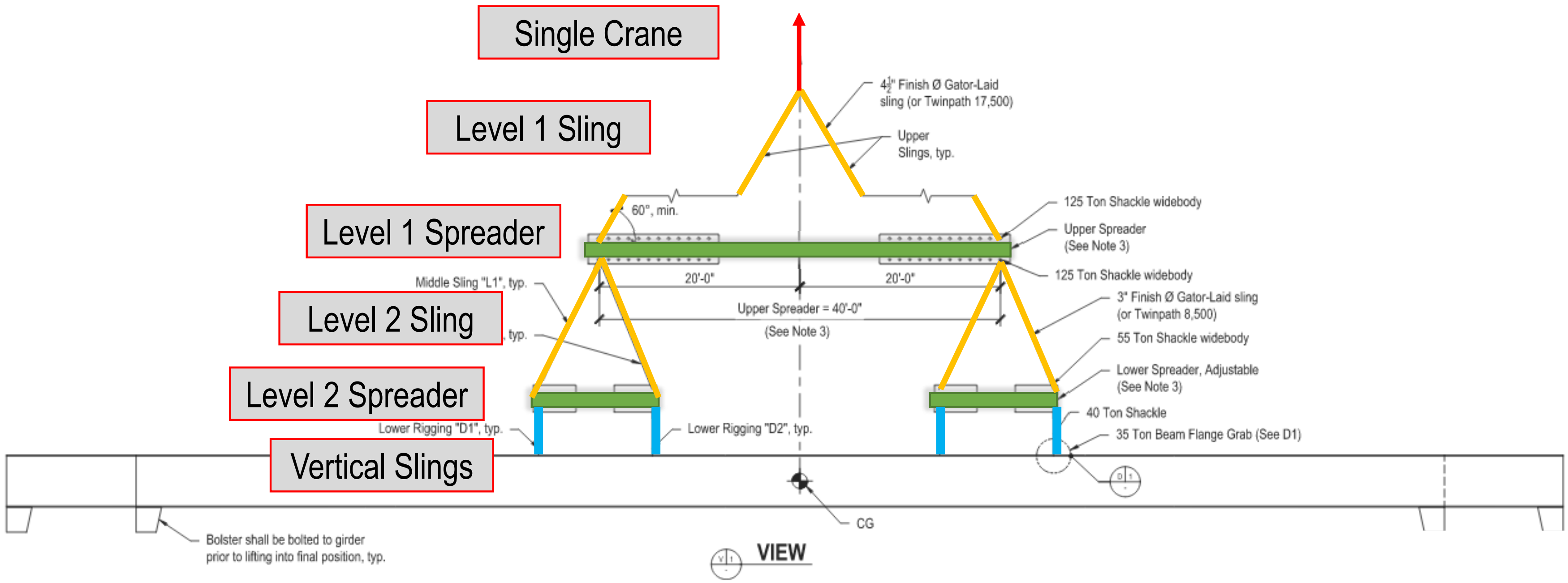
Gateway Interchange Flyovers, Johnson County, KS



Gateway Interchange Flyovers, Johnson County, KS

Rigging – Multi-Level Spreaders

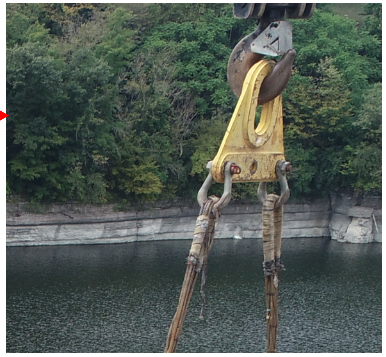
PICKING



Load Equalizers – Lifting Triangles

PICKING

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY



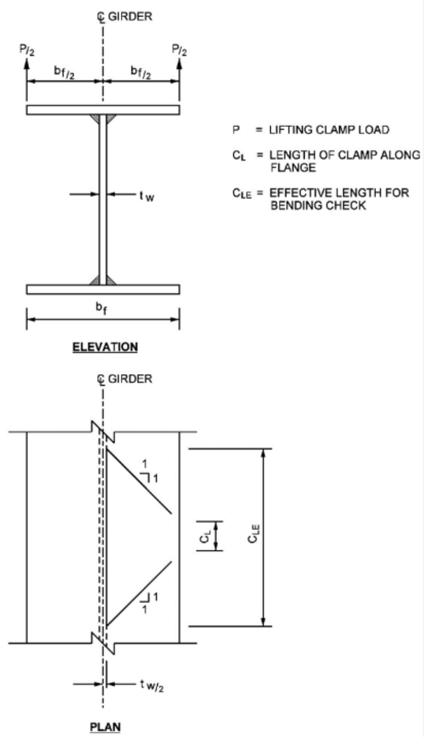
Beam Clamps

PICKING

Fulbright Expressway, Fayetteville, AR

Beam Clamps

PICKING

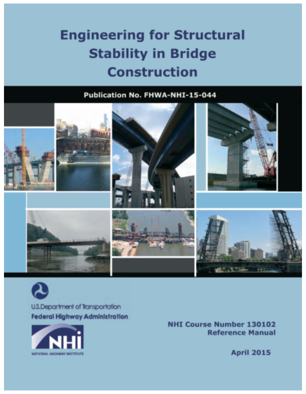


$$f_{lb} = \frac{R_c k}{\left(b_f + C_L\right)\left(t_f\right)^2 / 6}$$

Equation 7-23

$$f_{lb} \leq 0.75\, F_{yf}$$

Equation 7-24



Where:

R_c = service level concentrated force at each flange edge (kip)

F_{yf} = specified minimum flange yield stress (ksi)

b_f = flange width (in)

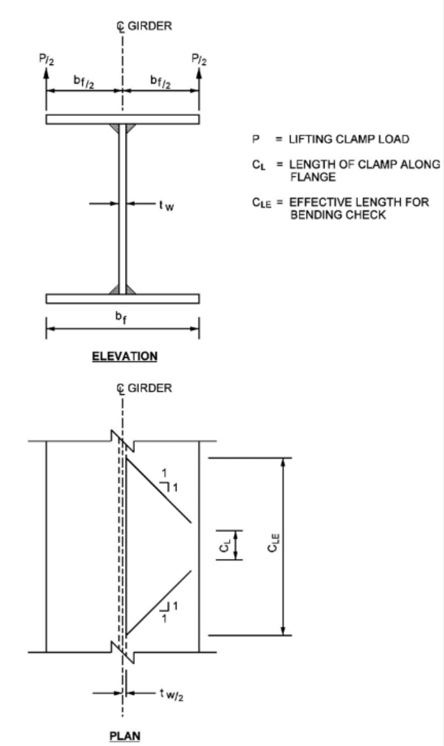
t_f = flange thickness (in)

C_L = length of clamp along flange (in)

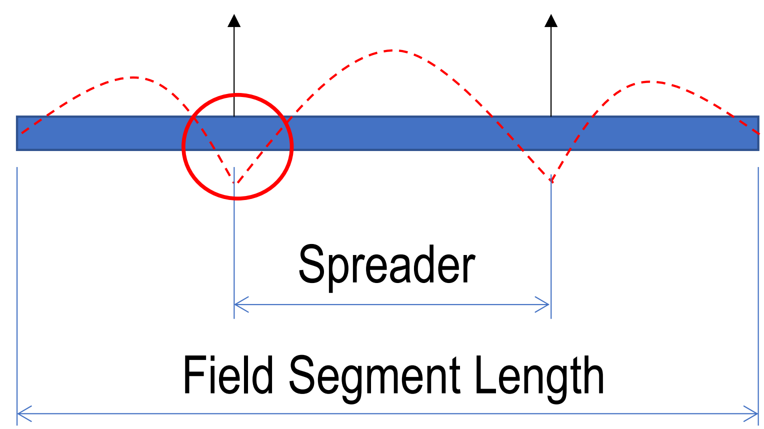
k = distance from outer face of flange to web toe of fillet (in)

Beam Clamps

PICKING



Global Strong Axis Bending Moment



Steel Girder Erection

- Compression Flange Slenderness Requirements
- Picking Girders
- Staged Construction Evaluation
  - Check for critical stages of stability concerns
  - Check stage specific demands with stage specific capacity
  - Perform detailed finite element model buckling analysis
- Temporary Works

Critical Stages of Construction

STAGED CONST.

7.2.2 Critical Erection Stages

The erection plan and supporting engineering calculations must address both strength and stability at each stage of erection. Deformations associated with each stage should also be evaluated. Critical erection stages for the girder bridge structure during construction normally consist of at least the following:

- Lifting of girders/members
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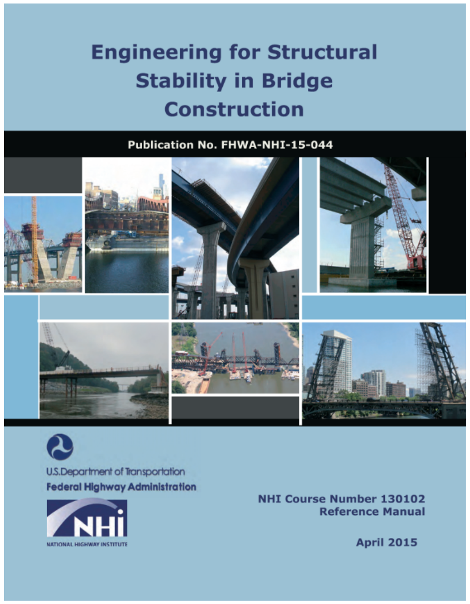


Critical Stages of Construction

STAGED CONST.

6.10.3.2.1—Discretely Braced Flanges in Compression

For critical stages of construction, each of the following requirements shall be satisfied. For sections with slender webs, Eq. 6.10.3.2.1-1 shall not be checked when f_ℓ is equal to zero. For sections with compact or noncompact webs, Eq. 6.10.3.2.1-3 shall not be checked.

$$f_{bu} + f_\ell \leq \phi_f R_h F_{yc}, \quad (6.10.3.2.1\text{-}1)$$

$$f_{bu} + \frac{1}{3} f_\ell \leq \phi_f F_{nc}, \quad (6.10.3.2.1\text{-}2)$$

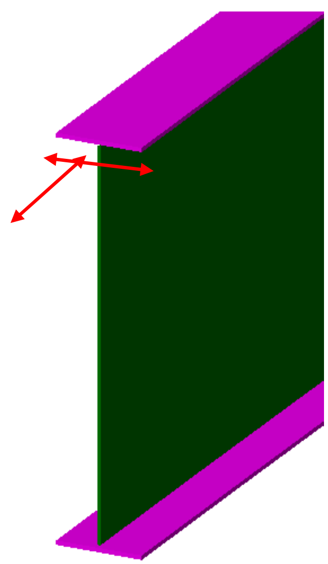
and

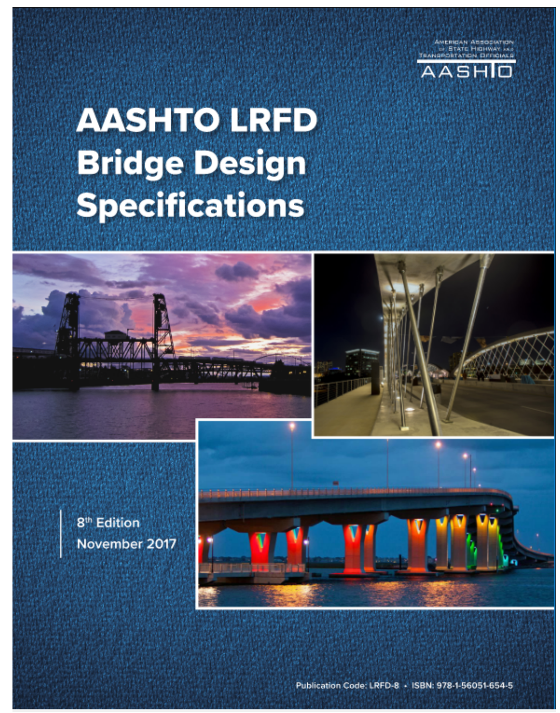
$$f_{bu} \leq \phi_f F_{crw} \quad (6.10.3.2.1\text{-}3)$$

6.10.3.2.2—Discretely Braced Flanges in Tension

For critical stages of construction, the following requirement shall be satisfied:

$$f_{bu} + f_\ell \leq \phi_f R_h F_{yt} \quad (6.10.3.2.2\text{-}1)$$





Critical Stages of Construction

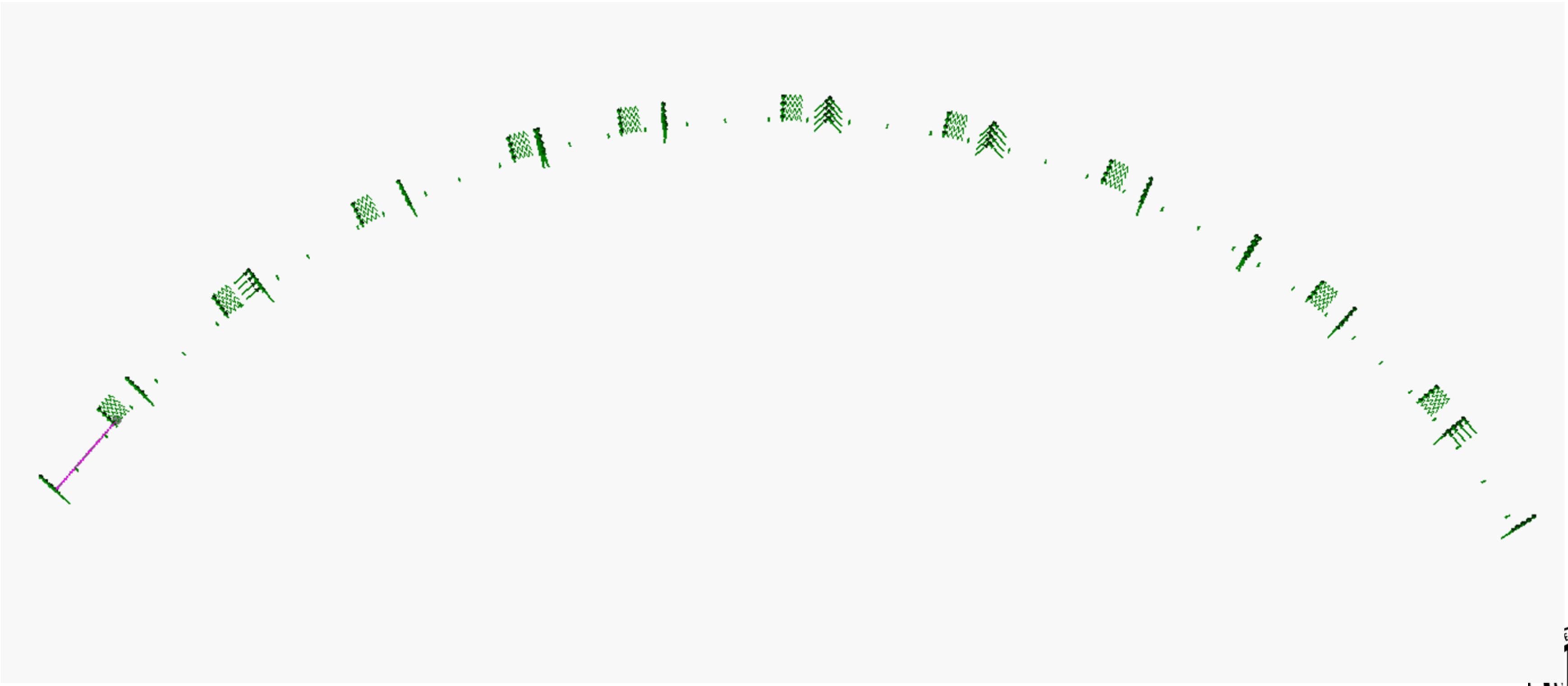
STAGED CONST.

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY

Gateway Interchange Flyovers, Johnson County, KS

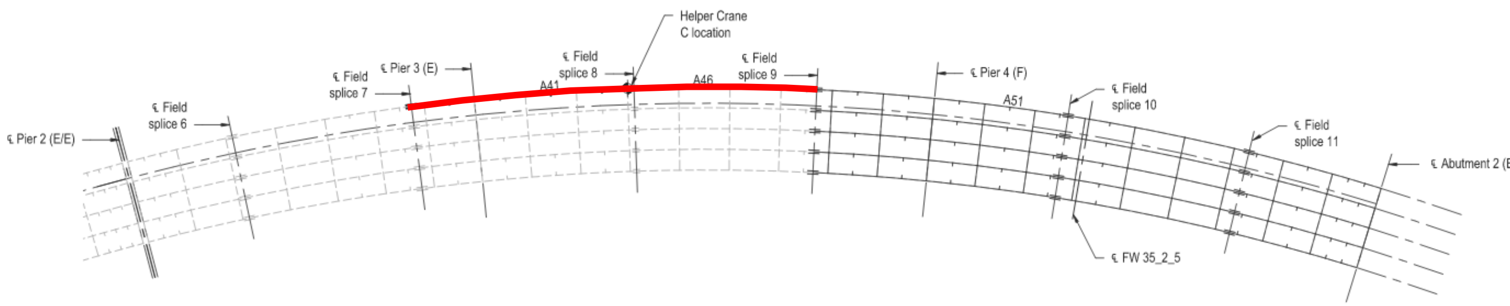
Staged Construction Evaluation

STAGED CONST.



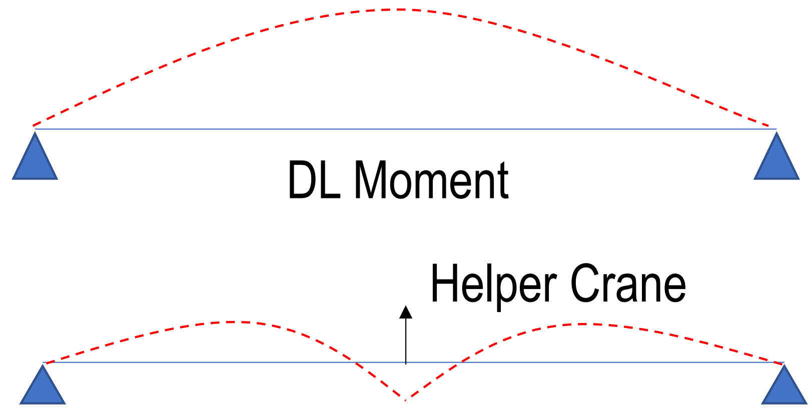
Single Girder Stability

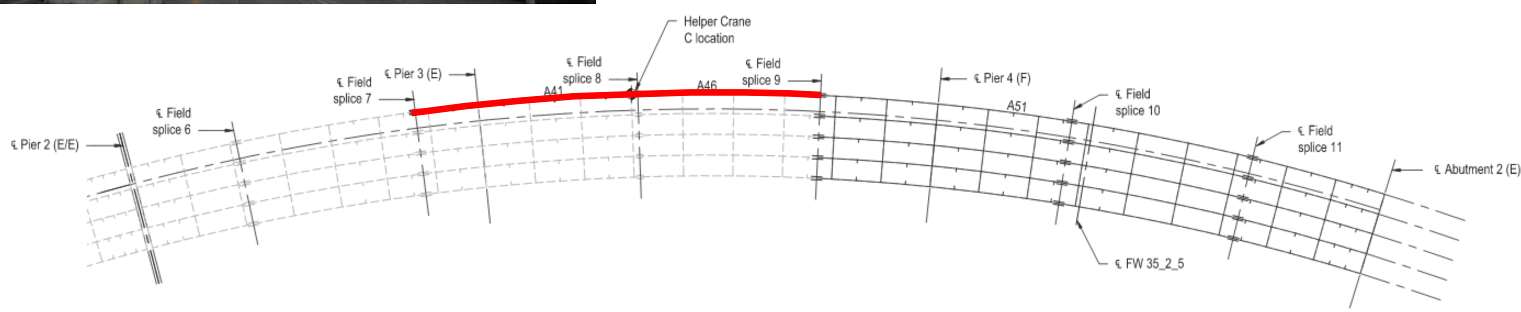
STAGED CONST.



Single Girder Stability

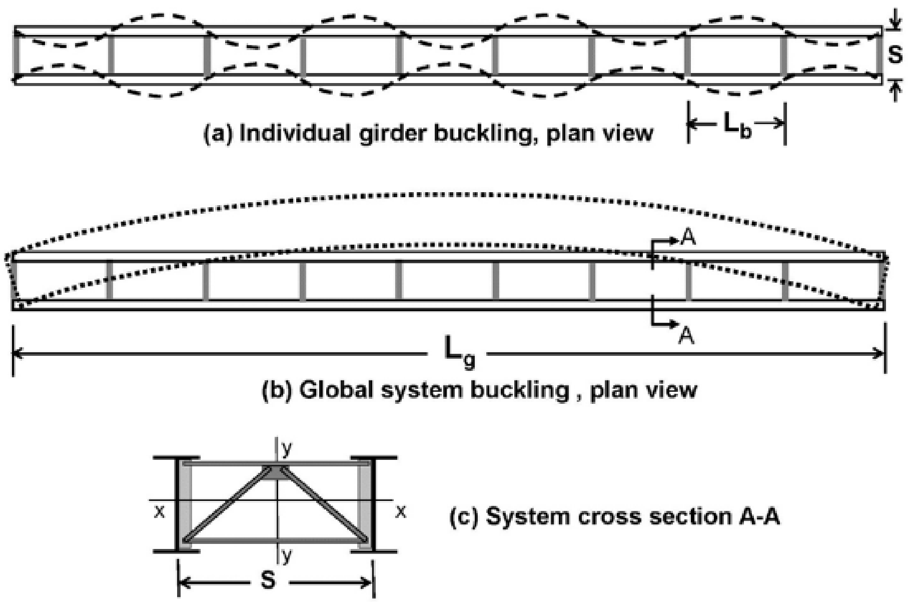
STAGED CONST.

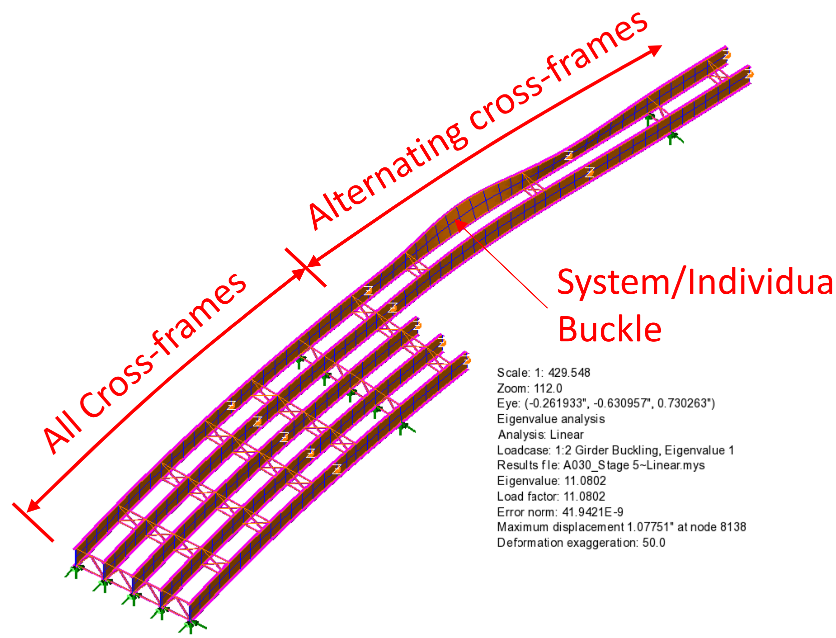




Girder System Stability

STAGED CONST.





Images Courtesy of: Engineering for Structural Stability in Bridge Construction

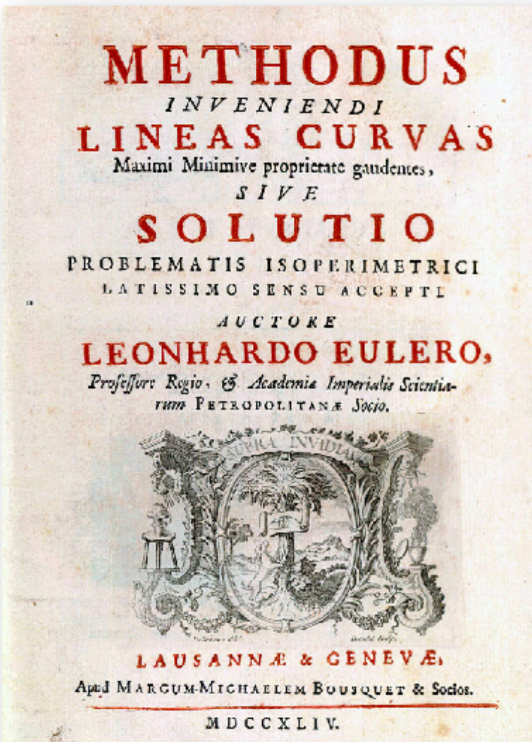
Girder System Stability

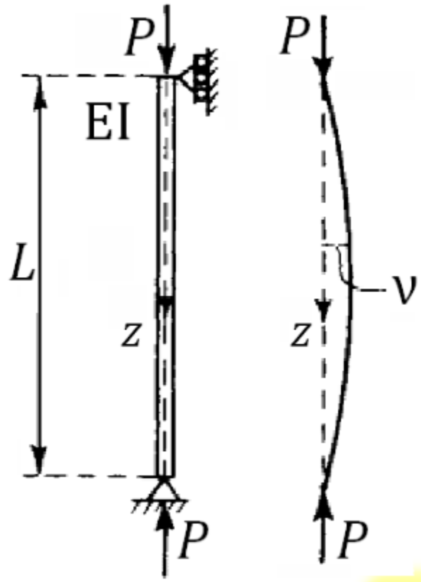
STAGED CONST.

Images Courtesy of: edmontonsun.com

Eigenvalue & 2nd Order Nonlinear Analysis

STAGED CONST.


METHODUS
INVENIENDI
LINEAS CURVAS
Maximi Minimive proprietate gaudentes,
SIVE
SOLUTIO
PROBLEMATIS ISOPERIMETRICI
LATISSIMO SENSU ACCEPTI
AUCTORE
LEONHARDO EULERO,
Professore Regio, & Academiae Imperialis Scientiarum PETROPOLITANÆ Socio.
LAUSANNÆ & GENEVÆ,
Apud MARCUM-MICHAELEM BOUSQUET & Socios.
MDCCXLIV.



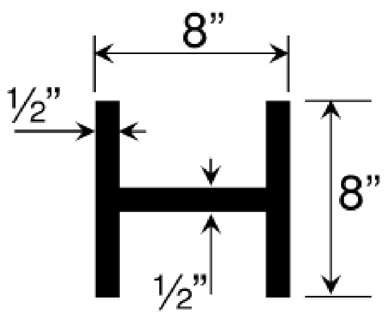
$$P_e = \frac{\pi^2 EI}{L^2}$$

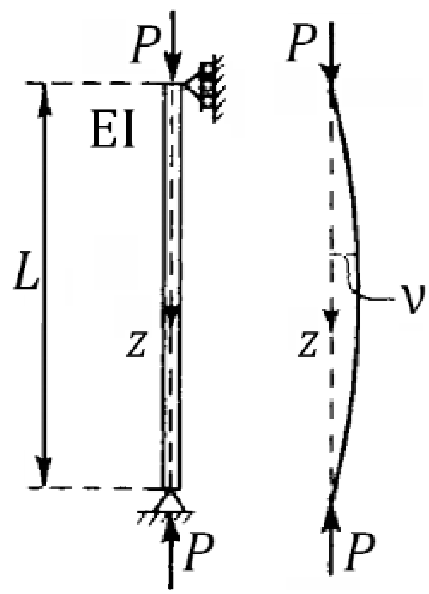
Reference:

LUSAS

Eigenvalue Analysis

STAGED CONST.





$A_g = 11.5\ in^2$
$I_{zz} = 42.74\ in^4$
$L = 18'$
$E = 29,000\ ksi$

$$P_e = \frac{\pi^2 \times 29,000 \times 42.74}{(18 \times 12)^2} = 262\,kip$$

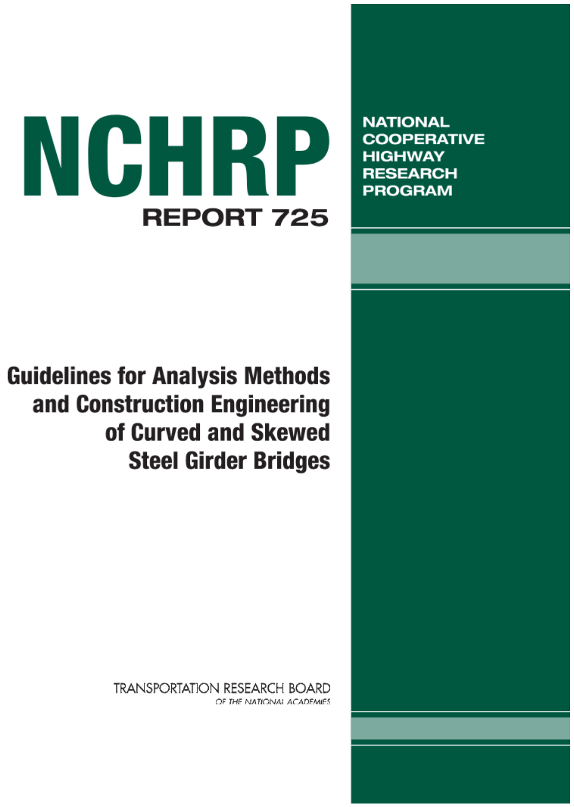
Reference:

P = 1 kip
Eigenvalue = 262
FOS = 262

P = 262 kip
Eigenvalue = 1
FOS = 1

Eigenvalue & 2nd Order Nonlinear Analysis

STAGED CONST.

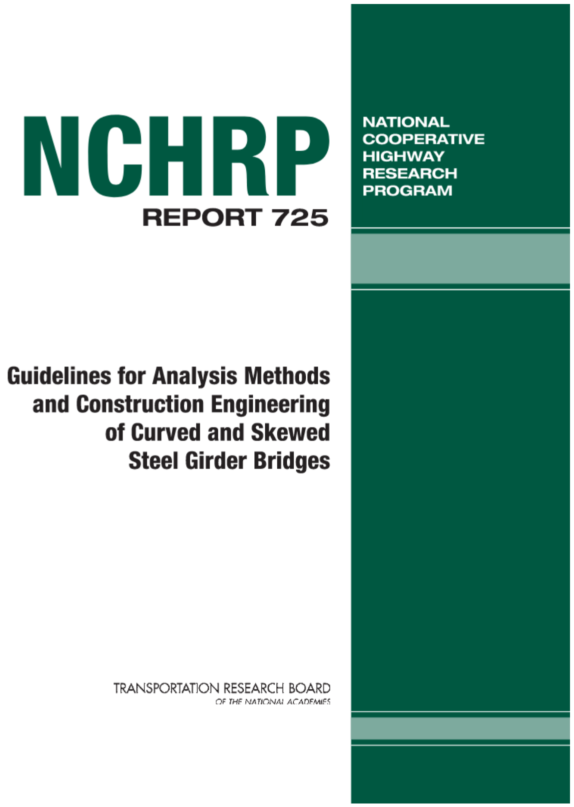


$$AF_G = \frac{1}{1 - \dfrac{M_{\max G}}{M_{crG}}}$$

- AF_G = Amplification Factor = System Stability Indicator
- M_{maxG} = Maximum Total Moment support by bridge unit
- M_{crG} = Elastic global buckling moment of the bridge
- M_{crG} / M_{maxG} = Eigenvalue
- Equation uses M_{maxG} / M_{crG} = 1/Eigenvalue

Eigenvalue & 2nd Order Nonlinear Analysis

STAGED CONST.



$$AF_G = \frac{1}{1 - \frac{M_{\max G}}{M_{crG}}}$$

- Second order effects may be neglected
  - $AF_G < 1.10$
  - Eigenvalue > 11
- Second order 3D FEM recommended
  - $AF_G > 1.25$
  - Eigenvalue < 5

Eigenvalue & 2nd Order Nonlinear Analysis

STAGED CONST.

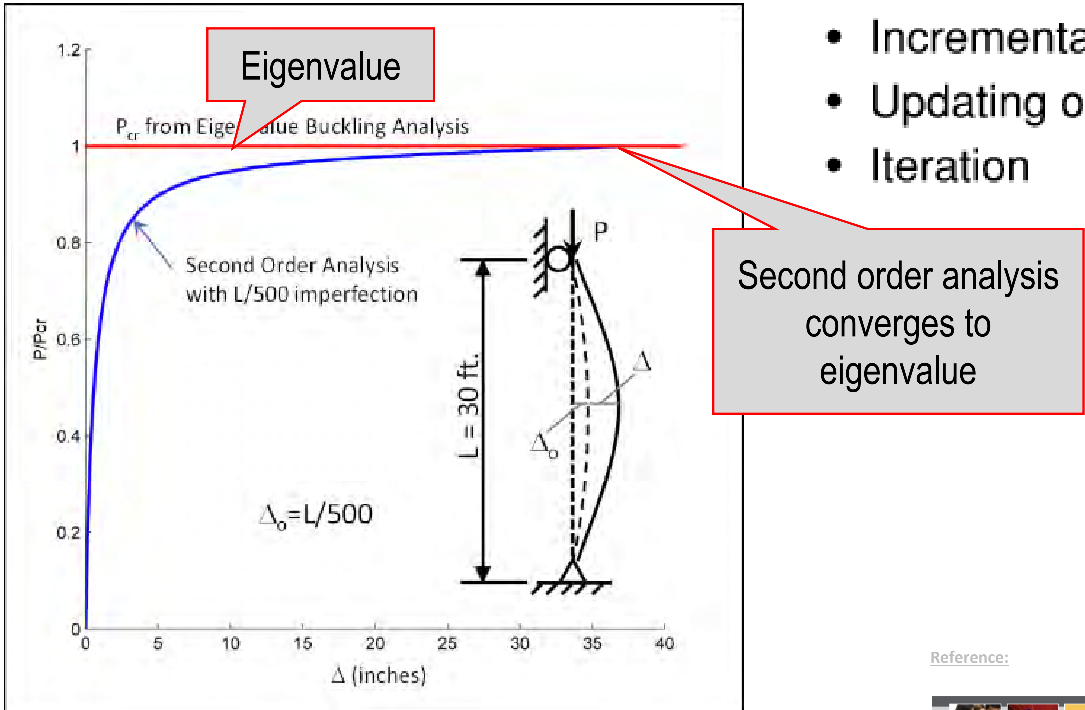
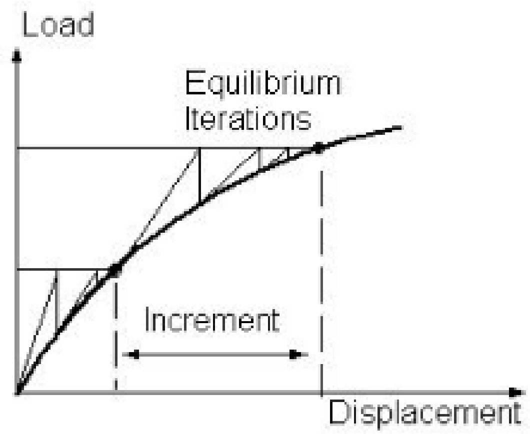


Figure 6-10 Second Order Analysis on Column with Initial Imperfection

- Incremental application of load
- Updating of stiffnesses
- Iteration



Images Courtesy of: Engineering for Structural Stability in Bridge Construction

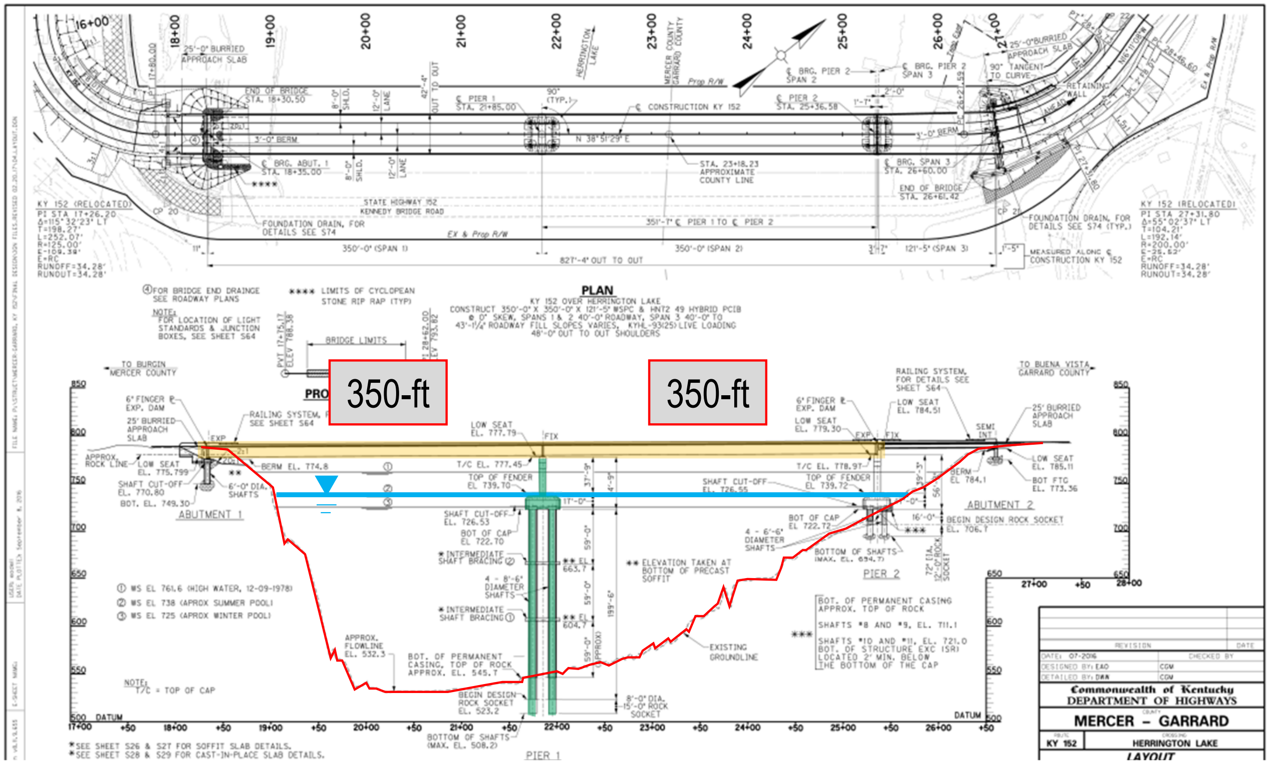
Reference:

LUSAS

System Buckling Case Study

STAGED CONST.

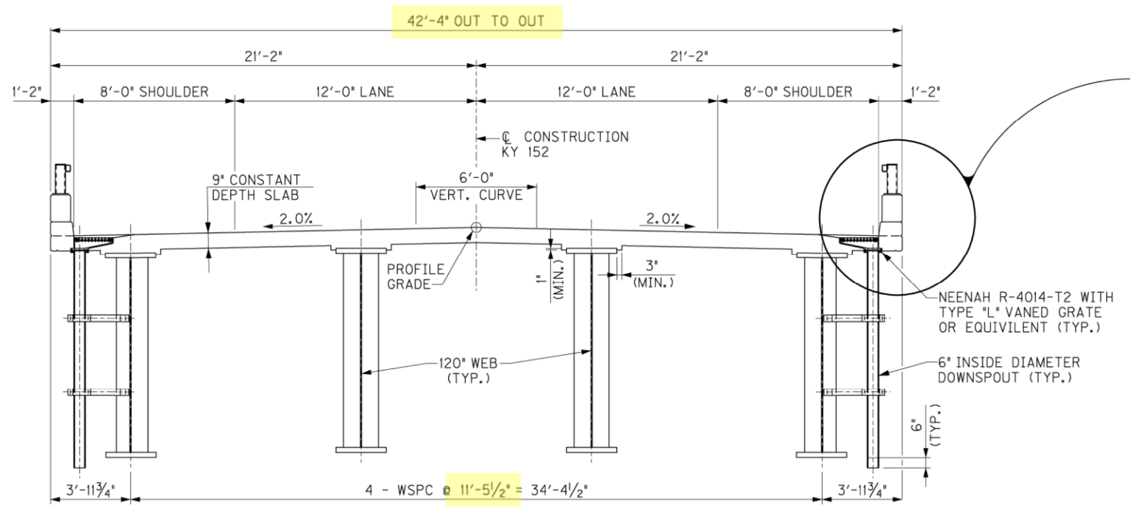
- Two Span Continuous Steel Plate Girder Bridge
- Span Length = 350'



System Buckling Case Study

STAGED CONST.

- Two Span Continuous Steel Plate Girder Bridge
- Span Length = 350’
- Girder Spa = 11’-5 1/2”
- Bridge Width = 42’-4”
- Very Long & Narrow



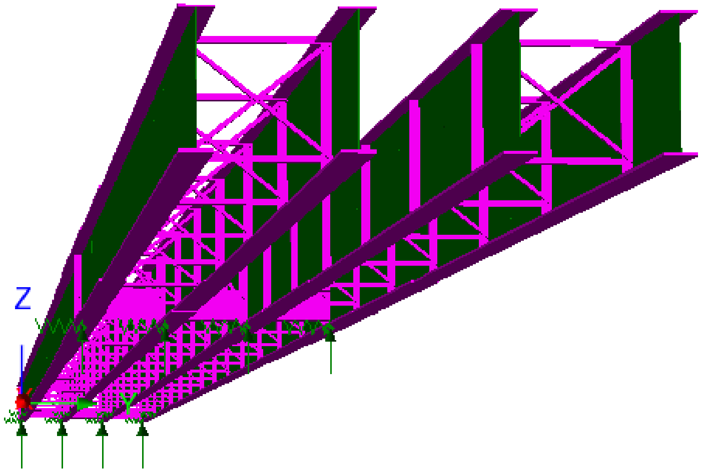
TYPICAL SECTION

(SPANS 1 & 2) LOOKING AHEAD

System Buckling Case Study

STAGED CONST.

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY



System Buckling Case Study

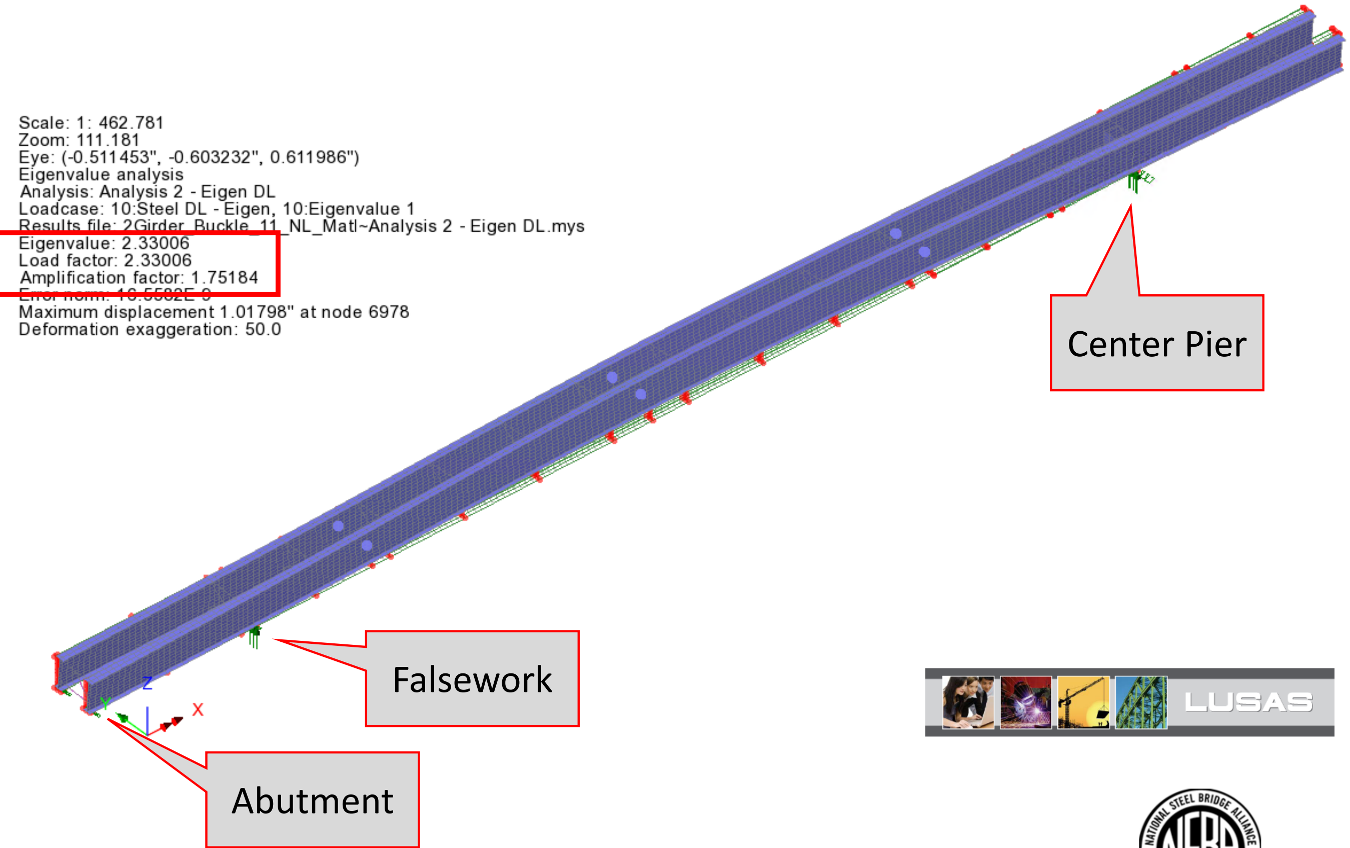
STAGED CONST.

- Eigenvalue Analysis

Eigenvalue = 2.33

$$AF_G = \frac{1}{1-\frac{1}{2.33}} = 1.75 > 1.25$$

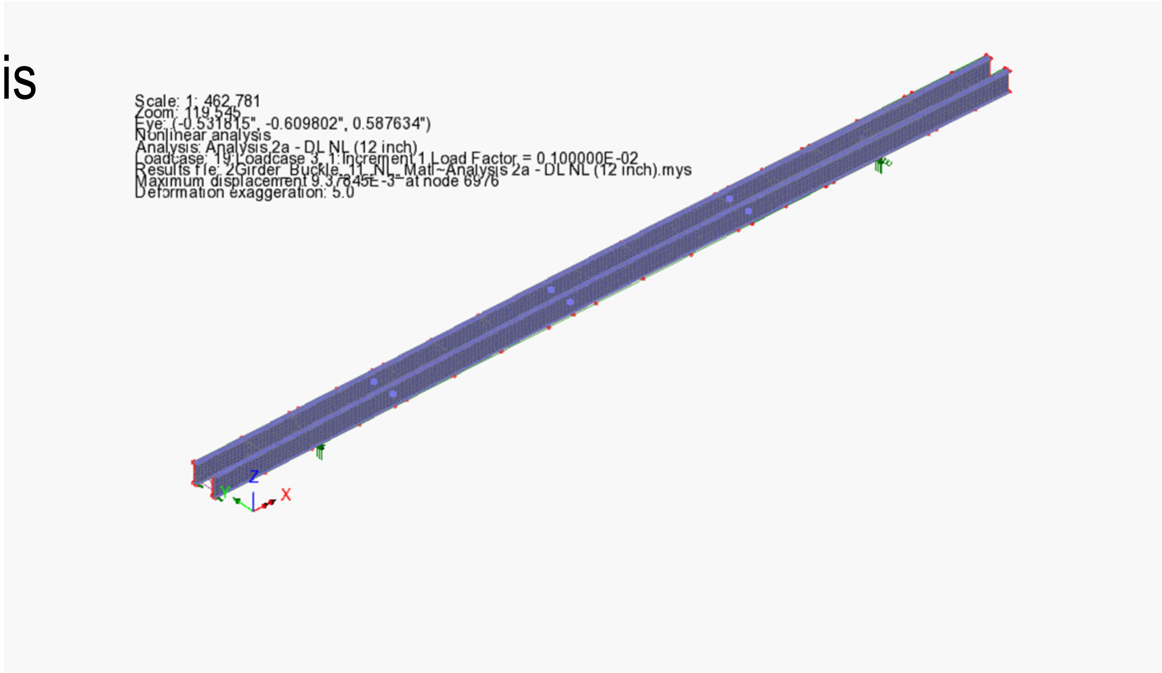
Second Order Analysis Req'd



System Buckling Case Study

STAGED CONST.

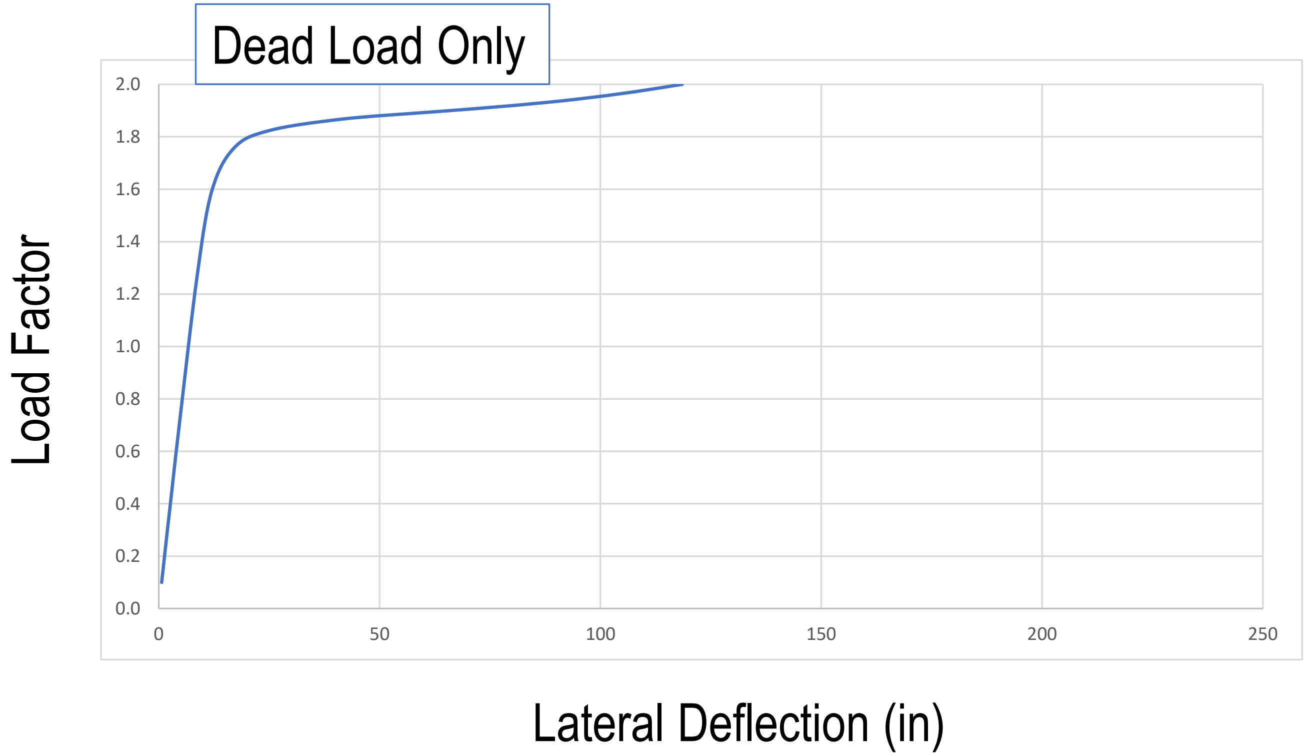
- 2nd Order Nonlinear Analysis
  - Increasing Load Factor
  - Key Point Deflection



LUSAS

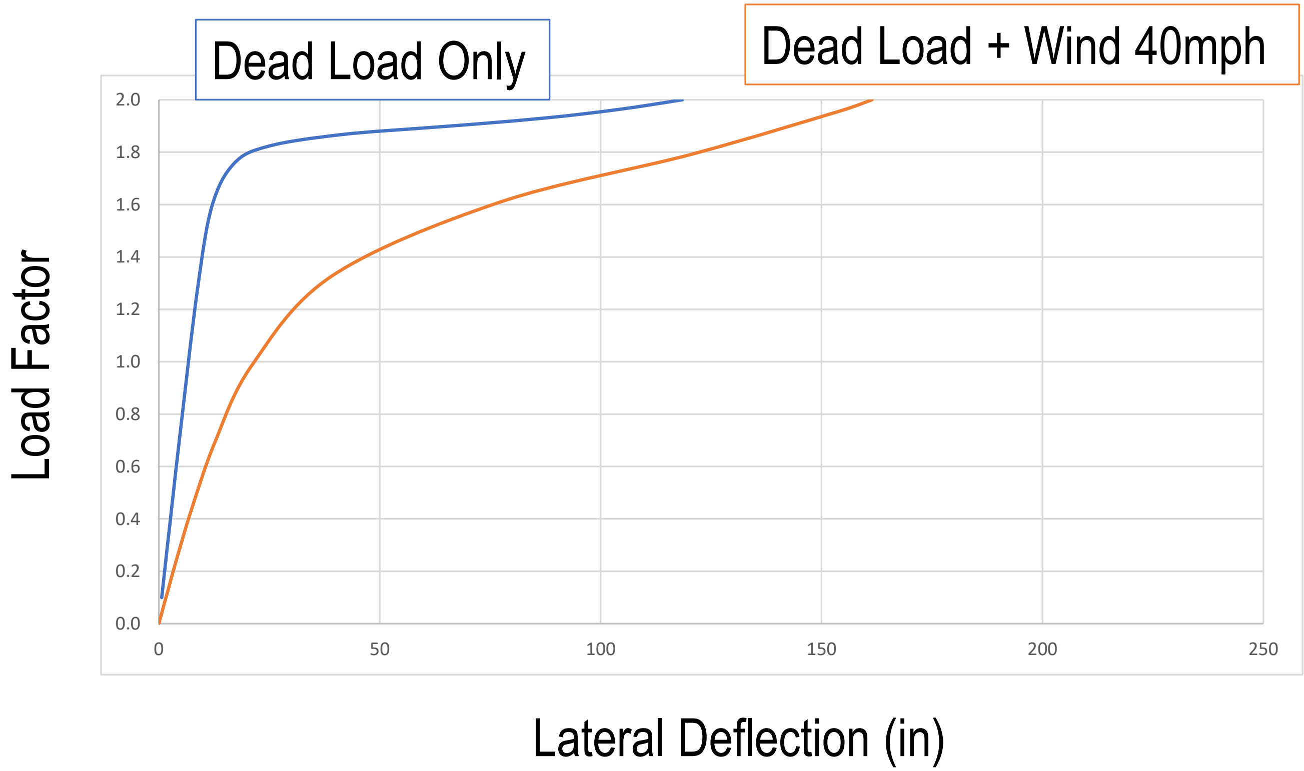
System Buckling Case Study

STAGED CONST.



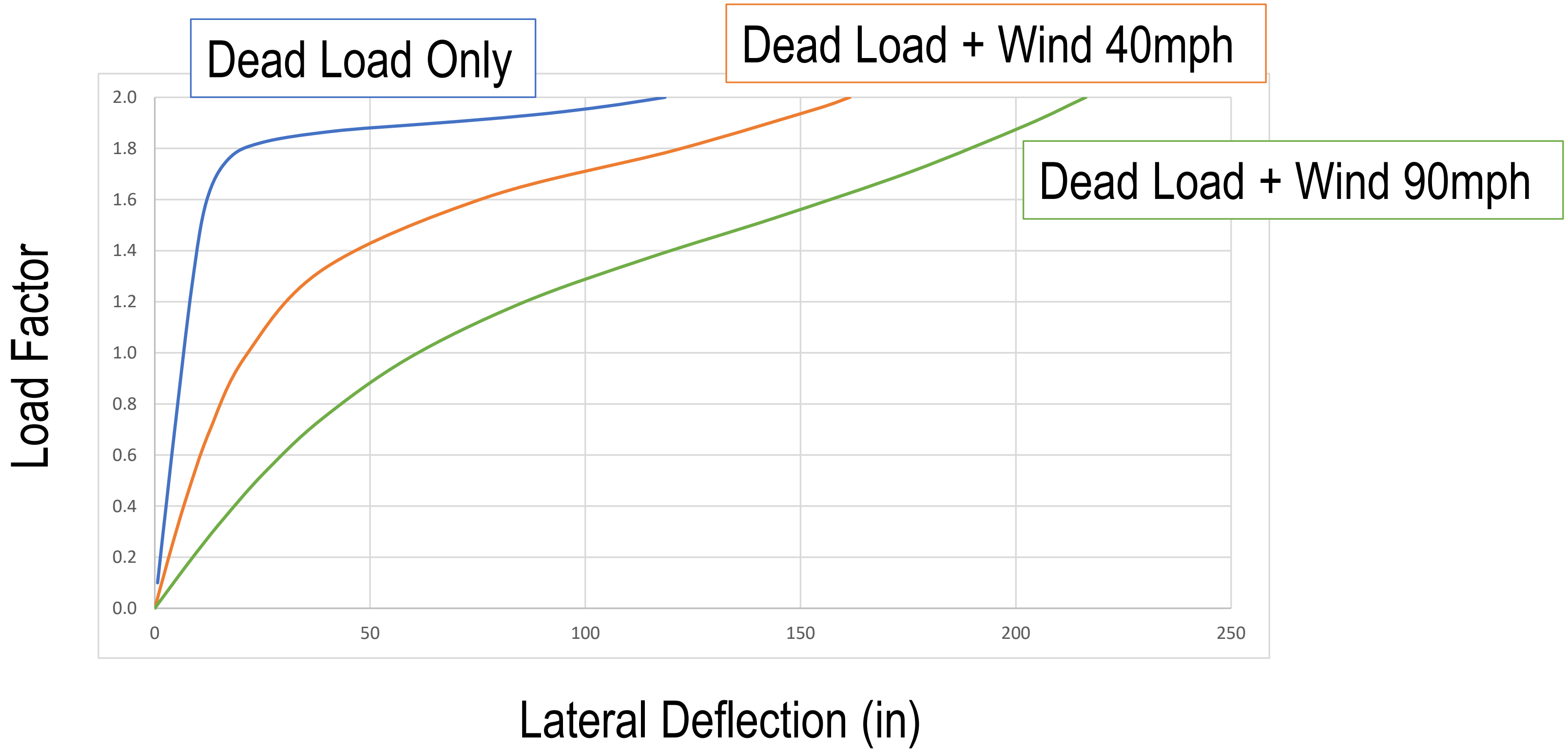
System Buckling Case Study

STAGED CONST.



System Buckling Case Study

STAGED CONST.



Steel Girder Erection

- Compression Flange Slenderness Requirements
- Picking Girders
- Staged Construction Evaluation
- Temporary Works
  - Falsework Towers
  - Geometry Control Studies
  - Girder Stiffening Truss

Falsework Towers

TEMP. WORKS

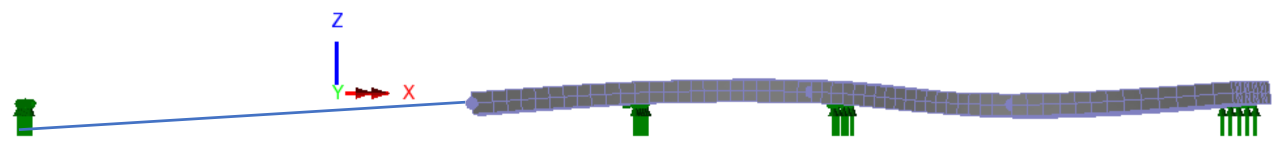
Gateway Interchange Flyovers, Johnson County, KS

Cleveland Innerbelt, Cleveland, OH

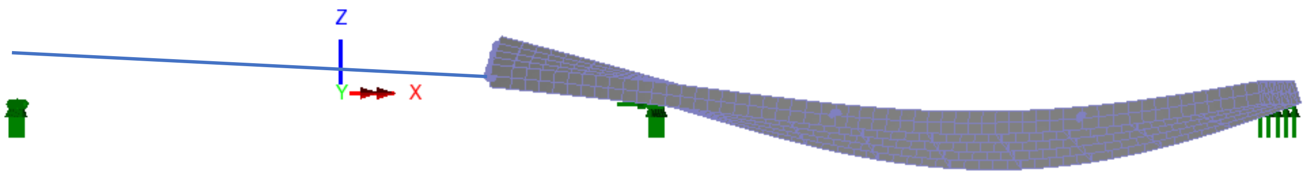
Geometry Control Studies

TEMP. WORKS

Negative Tip Deflection:



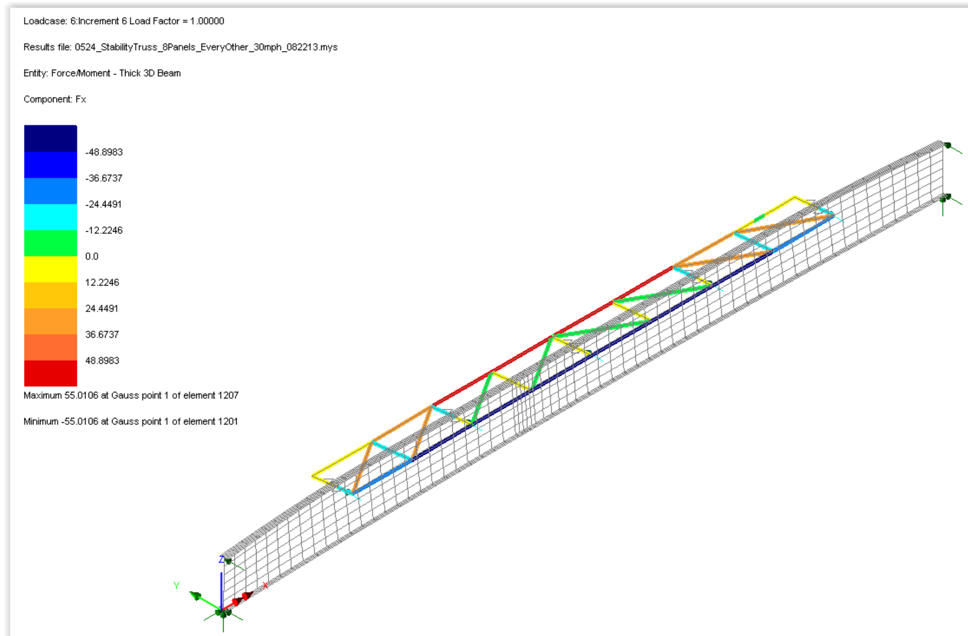
Positive Tip Deflection:



Girder Stiffening Truss

TEMP. WORKS

Whittier Memorial Bridge, Newburyport and Amesbury, MA



Questions?

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