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**Bridge Erection –
A Construction Engineer’s Perspective**
January 21, 2020



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Course Description

Bridge Erection – A Construction Engineer’s Perspective
January 21, 2020

To properly bid a bridge project, contractors have the responsibility to evaluate the site, the structure, and the specifications to develop a process for how they are going to build it. There can be confusion about the division of responsibility for ensuring a bridge is constructable. The speakers will review the thinking, planning, and strategies behind the development of a bid from a contractor/construction engineering team’s perspective. They will also discuss how the current AASHTO specifications divide the responsibilities for ensuring bridge constructability, and the development of design loads for temporary structures during bridge erection.



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Learning Objectives

- List the issues that the construction engineer must consider when assessing the constructability of a bridge.
- Describe the responsibilities for the design engineer and contractor when documenting the erection plans for both conventional and complex steel bridges.
- Identify sources of construction loads and how to determine their load demands.
- Explain how the variables of environmental load duration and risk affect the stability of bridges and temporary structures during construction.



Bridge Erection – A Construction Engineer’s Perspective January 21, 2020

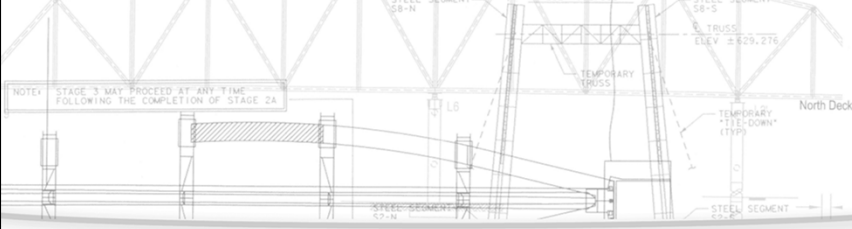


Dave Rogowski, PE
Principal / Owner
Genesis Structures
Kansas City, MO





Josh Crain, PE, SE
Senior Engineer
Genesis Structures
Kansas City, MO





BRIDGE ERECTION
A CONSTRUCTION ENGINEER’S PERSPECTIVE
American Institute of Steel Construction (AISC)



Presentation Overview



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



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Presentation Overview

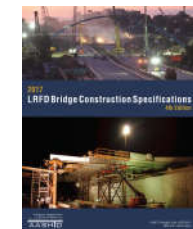
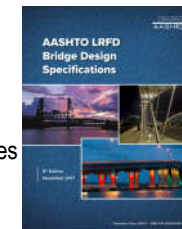
- **Contractors and the 3-C’s**
 - Constructability
 - Costs
 - Competition
- Constructability of Superstructures
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions



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Presentation Overview




- Contractors and the 3-C’s
- **Constructability of Superstructures**
 - Review of AASHTO Expectations
 - Review of Minimum Checks
- Design Loads for Temporary Structures
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions



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Presentation Overview


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


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Presentation Overview


- Contractors and the 3-C's
- Constructability 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



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Presentation Overview

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



Owners
Designer Engineers


Construction Engineers
Contractors



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Presentation Overview

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



Owners
Designer Engineers


Construction Engineers
Contractors




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Side Note


- Steel/Precast



Simple 3-Span Precast Girder Bridge




Simple 3-Span Continuous Steel Girder Bridge



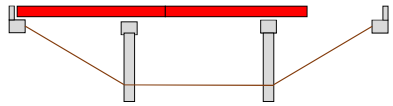
17

Side Note


- Steel/Precast
- Similar
 - Short Spans (<200 ft) / Conventional



Simple 3-Span Precast Girder Bridge




Simple 3-Span Continuous Steel Girder Bridge




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Side Note


- Steel/Precast
- Similar
 - Short Spans (<200 ft) / Conventional



Simple 3-Span Precast Girder Bridge



Simple 3-Span Continuous Steel Girder Bridge



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Side Note

- Steel/Precast
- Similar But Different
 - Short Spans (<200 ft) / Conventional
 - Long Spans (>200 ft) / Complex



Spliced Precast



Spliced Steel




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Contractors & The 3-C's

- Constructability
 - Assessing site to determine direction and sequence of construction
 - Work from fixed pier preferred but not always possible
 - Working from one abutment to the other preferred but not always possible
 - Crane locations may be limited so girder erection must be planned ahead
 - Access may not be available so it has to be created
 - Access may not be available therefore dictating the construction method
 - Worker access must also be considered
 - Crane Sizing and Access
 - Girder Delivery

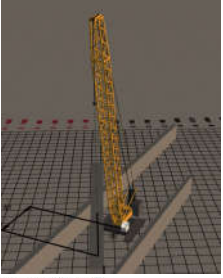


nearmap.com


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3D Lift Plan

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Whittier Memorial Bridge, Newburyport and Amesbury, MA


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Kate Shelly Replacement Bridge, Boone, IA




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US 20 - Iowa River Bridge




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Crum Creek Viaduct, Swarthmore, PA




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Crum Creek Viaduct, Swarthmore, PA




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Contractors & The 3-C's

- Constructability
 - Assessing site to determine direction and sequence of construction
 - Crane Sizing and Access
 - What are the maximum picks?
 - What is the maximum pick radius?
 - Does the crane have clearance to make the pick?
 - Does a traditional crane even make sense?
 - How high are the girders from the base of the crane and what is the length of the required reach?
 - Land vs. water (same cranes have different capacities)?
 - Sometimes it takes an assist crane to set up the main crane
 - At the end of the day, safety is #1 priority
 - Girder Delivery



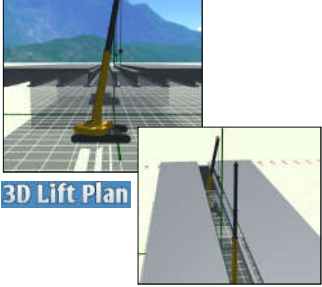
K7 over US24, Blue Springs, KS




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Whittier Memorial Bridge, Newburyport and Amesbury, MA




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Cleveland Innerbelt, Cleveland, OH



32

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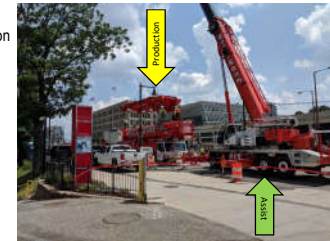
South Omaha Bridge – 4100 Ringer Crane



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Images Courtesy of: www.cranespy.com



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Contractors & The 3-C’s

- Constructability
 - Assessing site to determine direction and sequence of construction
 - Crane Sizing and Access
 - Girder Delivery
 - Trucks deliver directly within reach of the crane
 - Cranes may have to receive load and then walk with a load
 - Crawler – Yes
 - Hydraulic on Outriggers – No
 - How are girders delivered to the site?
 - Girder length, weight or delivery position may require two cranes
 - Sometimes the girders are too tall so they are delivered horizontally and require to be unloaded, set down and then tripped to vertical (two extra crane moves)



Boone County, IA



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Contractors & The 3-C’s

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Sandy Hook Sub Division, UPRR, MO



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Prairie Star Parkway, Lenexa, KS



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Contractors & The 3-C’s

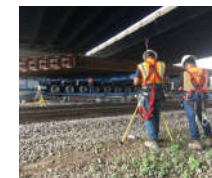
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Hole In The Wall, Fort Worth, TX



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Contractors & The 3-C’s

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MLK Bridge Replacement, Toledo, OH



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Contractors & The 3-C’s

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Fore River, Quincy, MA



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Contractors & The 3-C’s

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



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Contractors & The 3-C’s

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Cleveland Innerbelt, Cleveland, OH



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Contractors & The 3-C's


- Constructability (Cont.)
 - **Rigging and Segment Stability**
 - Picking girders (flange grabs, underslung slings, bolted/welded picking eyes)
 - Picking girders (spreader beams and picking trees)
 - Single Girder Picks vs. Paired Girder Picks
 - Temporary Top Flange Lateral Bracing (Stability Truss) to Erect
 - Temporary Lateral Bracing to Stabilize before Decking
 - Temporary Towers
 - Environmental Conditions
 - Overhangs
 - Demolition


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Contractors & The 3-C's

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Cleveland Innerbelt, Cleveland, OH




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Contractors & The 3-C's

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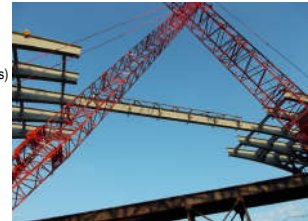
Comm. Ave Bridge, Boston, MA




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Contractors & The 3-C's

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Cleveland Innerbelt, Cleveland, OH



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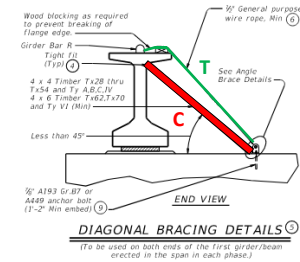


CSVT Project, Pennsylvania



Contractors & The 3-C’s

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Contractors & The 3-C’s

- Constructability (Cont.)
 - Rigging and Segment Stability
 - **Temporary Towers**
 - Length of spans, number of girder segments in a span, the curvature of the girder, crane size, crane and delivery access all factor into the need
 - Pre-Manufactured
 - Built to fit the Need
 - Some are so unique there may not be a possible re-use
 - Environmental Conditions
 - Overhangs
 - Demolition



I-94 & I-69 Interchange, Port Huron, MI



Contractors & The 3-C’s

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Whittier Memorial Bridge, Newburyport and Amesbury, MA



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Cleveland Innerbelt, Cleveland, OH



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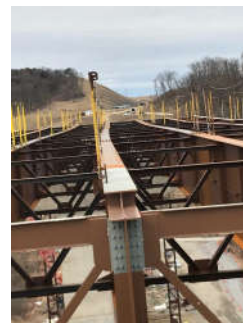


Cleveland Innerbelt, Cleveland, OH



Contractors & The 3-C's

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 - Temperature can affect the erected structure (especially orientation of the girders and time of day)
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Blennerhassett Island Bridge, Parkersburg, WV



Contractors & The 3-C's

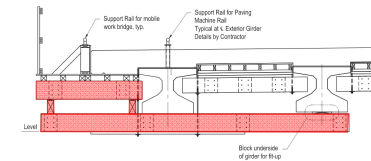
- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Overhangs
 - Bracket Type
 - Special Conditions
 - Finishing Machine
 - Demolition



57

Contractors & The 3-C's

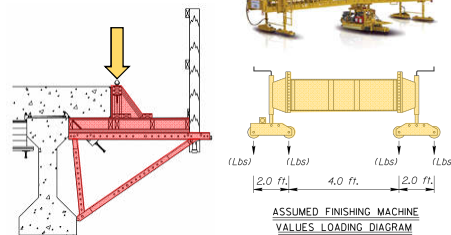
- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Overhangs
 - Bracket Type
 - Special Conditions
 - Finishing Machine
 - Demolition



58

Contractors & The 3-C's

- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Overhangs
 - Bracket Type
 - Special Conditions
 - Finishing Machine
 - Demolition



59

Contractors & The 3-C's




- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Demolition
 - How do we need to remove the bridge?
 - How does this bridge want to come down? Safely!!!
 - How do we get rid of the debris?



60

Contractors & The 3-C's





- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Demolition
 - How do we need to remove the bridge?
 - How does this bridge want to come down? Safely!!!
 - How do we get rid of the debris?

61

Contractors & The 3-C's

- Constructability (Cont.)
 - Rigging and Segment Stability
 - Temporary Towers
 - Environmental Conditions
 - Demolition
 - How do we need to remove the bridge?
 - How does this bridge want to come down? Safely!!!
 - How do we get rid of the debris?

62

Contractors & The 3-C's

- Costs
 - Crane Rental/Mobilization
 - Size of crane
 - Duration of time on site
 - Shared needs vs. multiple crane sizes
 - Material
 - Labor Forces
 - Temporary Structures
 - Crane Work Platforms
 - Finishes/Coatings
 - Schedule










63

Contractors & The 3-C's




- Costs
 - Crane Rental/Mobilization
 - Material
 - Costs can fluctuate with demand
 - Expediting delivery schedules will generally increase costs
 - When contractors are asked to hold prices for extended periods cost can increase
 - Labor Forces
 - Temporary Structures
 - Crane Work Platforms
 - Finishes/Coatings
 - Schedule

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Contractors & The 3-C's





- Costs
 - Crane Rental/Mobilization
 - Material
 - Labor Forces
 - Union vs. Non-Union Locations
 - Laborers, Operators, Project Managers, Project Engineers
 - Temporary Structures
 - Crane Work Platforms
 - Finishes/Coatings
 - Schedule

65

Contractors & The 3-C's

- Costs
 - Crane Rental/Mobilization
 - Material
 - Labor Forces
 - Temporary Structures
 - Foundations, Erect, Remove, Temporary Lane Closures
 - Top Flange Bracing (stability trusses)
 - Bottom Flange Lagging – DOT requirements
 - Crane Work Platforms
 - Finishes/Coatings
 - Schedule








66

Contractors & The 3-C's

- Costs
 - Crane Rental/Mobilization
 - Material
 - Labor Forces
 - Temporary Structures
 - Crane Work Platforms
 - Crane Mats
 - Grading to Level Zones/Temporary Access Roads
 - Barges/Bulkheads/Trestles for water operations
 - Finishes/Coatings
 - Schedule







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Contractors & The 3-C's

- Costs
 - Crane Rental/Mobilization
 - Material
 - Labor Forces
 - Temporary Structures
 - Crane Work Platforms
 - Finishes/Coatings
 - Steel – Weathering, Primed & Painted, Metalized, Primed, Painted over Metalized (extreme cases)
 - Precast - Some DOT's paint precast for aesthetics
 - Schedule







68

Contractors & The 3-C's

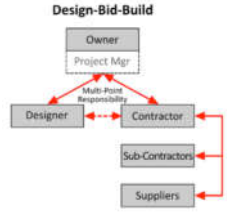

- Costs
 - Crane Rental/Mobilization
 - Material
 - Labor Forces
 - Temporary Structures
 - Crane Work Platforms
 - Finishes/Coatings
 - Schedule
 - Time is money >>> the more temporary works, the longer the erection schedule
 - Time is money >>> the more special care required in the field, the longer the erection schedule
 - Time is money >>> repairs to steel finishes or precast concrete corners can be expensive and extend the project schedule

69

Contractors & The 3-C's

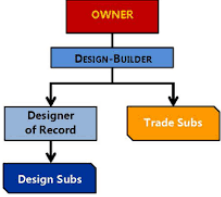

- Competition
 - Traditional Design-Bid-Build Project Delivery
 - What are my competitors doing?
 - What special equipment do my competitors own that I have to lease/purchase?
 - What location advantages do my competitors have?
 - Design Build Project Delivery
 - Construction Manager General Contractor (CMGC) Project Delivery

70

Contractors & The 3-C's

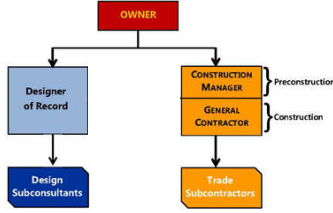

- Competition
 - Traditional Design-Bid-Build Project Delivery
 - Design Build Project Delivery
 - Best Idea and Price will win
 - The idea phase is pre-bid and may or may not be fully disclosed to the DOT's (ATC's)
 - Contractors/Designers
 - Sometimes missing is the Construction Engineer that is "bi-lingual"
 - Engineer who can speak the language of the Designer and the Contractor
 - Construction Manager General Contractor (CMGC) Project Delivery

71

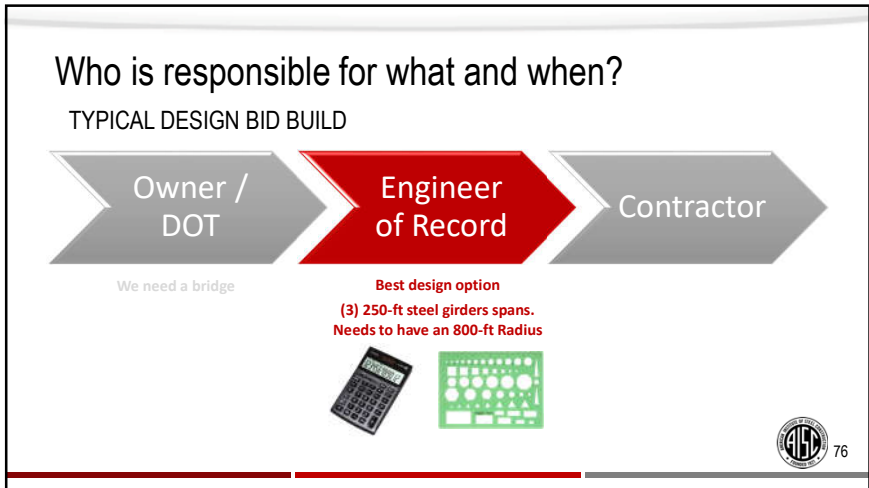
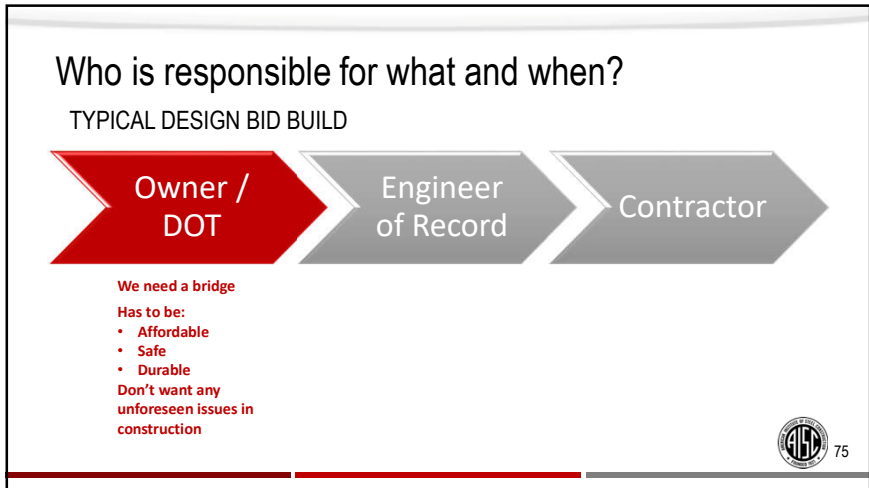
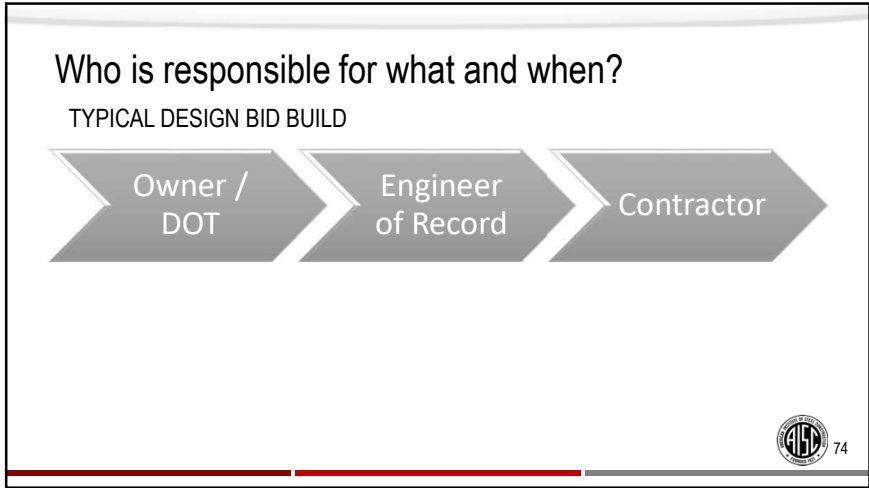
Contractors & The 3-C's

- Competition
 - Traditional Design-Bid-Build Project Delivery
 - Design Build Project Delivery
 - Construction Manager General Contractor (CMGC) Project Delivery
 - Best Ideas are Discussed between Contractor/Designer/Owners after team selection
 - The idea phase is pre-final bid but costs and schedule and design are discussed with the owner's full knowledge

72

Constructability of Superstructures



Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

The diagram shows a sequence of three chevron-shaped boxes pointing right. The first is grey and labeled 'Owner / DOT' with the text 'We need a bridge' below it. The second is grey and labeled 'Engineer of Record' with 'Best design option' below it. The third is red and labeled 'Contractor' with 'This is how I would build it. Going to cost you this much' below it. A small image of a piggy bank on a calculator is positioned below the Contractor box.

Owner / DOT
We need a bridge

Engineer of Record
Best design option

Contractor
This is how I would build it.
Going to cost you this much

77

Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

The diagram is similar to slide 77 but includes a red arrow pointing from the Engineer of Record box to the Contractor box, labeled 'Contract Plans'. Above this arrow, text reads 'Essential Information Exchanged / Costs Established'.

Owner / DOT

Engineer of Record

Contractor

Contract Plans

Essential Information Exchanged /
Costs Established

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

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Who is responsible for what and when?

- When is a bridge complex enough so engineering is required to ensure constructability 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?

79

AASHTO Specifications

AASHTO LRFD Bridge Design Specifications

2017 LRFD Bridge Construction Specifications

AASHTO Bridge Design Spec.

AASHTO Bridge Construction Specs.

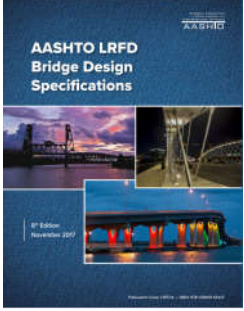
80

AASHTO Bridge Design Specifications





81

AASHTO Bridge Design Specifications



Key Sections:

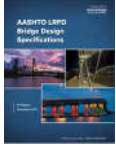


- Chapter 2
General Design and Location Features
 - 2.5.3 – Constructibility
- Chapter 5
Concrete Structures
 - 5.12 – Provisions for Structure Components and Types
- Chapter 6
Steel Structures
 - 6.10.3 – Steel I-Section Constructibility
 - 6.11.3 – Box Section



82

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.


83

Precast Beams

5.12.3.2—Precast Beams

5.12.3.2.1—Precast Beams

ship... of prestressed girders for... the responsibility of the...
contract... the responsibility of the...






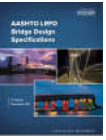

84

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 documents, including elevations and reactions. The construction method during which the temporary supports are removed shall also be shown on the contract documents.

The contract documents shall indicate alternative methods of construction and the Contractor's responsibility for each. The Contractor shall be responsible for the construction method or to the design shall comply with the requirements of Article 5.12.5.5.

85

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 erected supporting itself and subsequently removed shall also be shown in the contract documents.

The contract documents shall indicate alternative methods of construction and the Contractor's responsibility for each. The Contractor shall be responsible for the construction method or in the design shall comply with the requirements of Article 5.12.5.5.








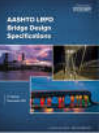



86

Segmental Concrete Bridges

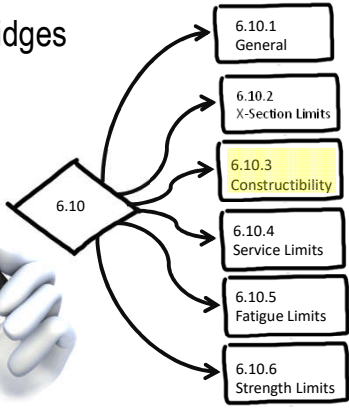


Table 5.12.5.3.3-1—Load Factors and Tensile Stress Limits for Construction Load Combinations

Load Combination	LOAD FACTORS														STRESS LIMITS				See Note				
	Dead Load		Live Load		Wind Load		Other Loads				Earth Loads	Flexural Tension		Principal Tension									
	DC	DF	LL	W	W ₁	W ₂	W ₃	W ₄	W ₅	W ₆		W ₇	W ₈		W ₉	W ₁₀	W ₁₁	W ₁₂					
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	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√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	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√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	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√f _c	—
d	1.0	1.0	0.0	1.0	1.0	0.0	0.7	1.0	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√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	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√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	1.0	1.0	1.0	1.0	1.0	1.0	0.190√f _c	0.220√f _c	0.110√f _c	0.126√f _c	3

87

Steel I-Girder Bridges

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Steel I-Girder Bridges - Constructibility

6.10.3—Constructibility


6.10.3.1—General

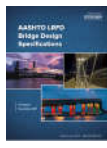
The provisions of [Article 2.5.3](#) shall apply. In addition to providing adequate strength, nominal yielding or reliance on post-buckling resistance shall not be permitted for main load-carrying members during critical stages of construction, except for yielding of the web in hybrid sections. This 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 D6.3](#).

Conventional





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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_r is equal to zero. For sections with compact or noncompact webs, [Eq. 6.10.3.2.1-3](#) shall not be checked.

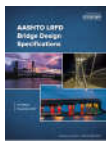
$$f_{bu} + f_r \leq \phi_f R_b F_{yc} \quad (6.10.3.2.1-1)$$


$$f_{bu} + \frac{1}{3} f_r \leq \phi_f F_{uc} \quad (6.10.3.2.1-2)$$

and

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

What are critical stages of construction?



 90

Steel I-Girder Bridges - Constructibility

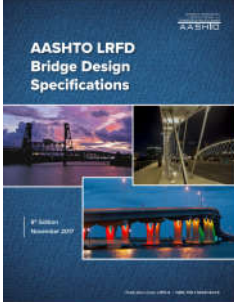
6.10.3.4—Deck Placement


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.



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Steel I-Girder Bridges - Constructibility

6.10.3.4—Deck Placement


6.10.3.4.1—General

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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.aistheonbridge.org

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Steel I-Girder Bridges - Constructibility

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>

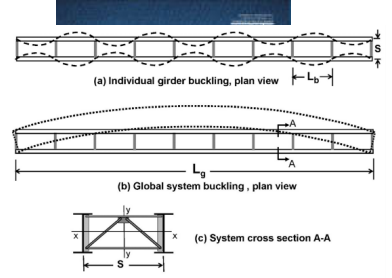


Steel I-Girder Bridges– System Stability

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

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

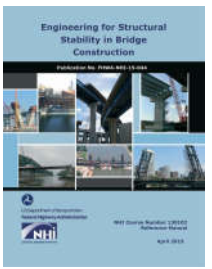
- AASHTO check of narrow 2 or 3 girder system stability during deck pouring
- If $M_{gt} > 0.7 M_{gs}$ design has following options:
 - Add flange lateral bracing
 - Increase system stiffness
- Verify with owner that second order displacements are within acceptable tolerances



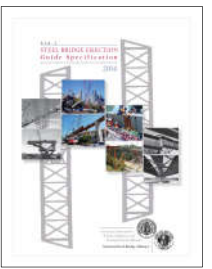
Images Courtesy of: Engineering for Structural Stability in Bridge Construction



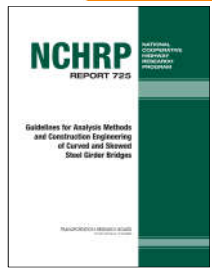
Useful Resources - Erection Analysis



FHWA-NHI-15-044
ALL MATERIAL TYPES



NSBA / AASHTO S10.1



NCHRP Report 725

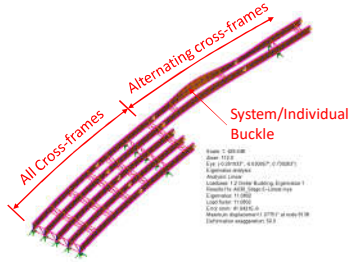
STEEL BRIDGE
SPECIFIC GUIDES



Steel I-Girder Bridges - System Stability



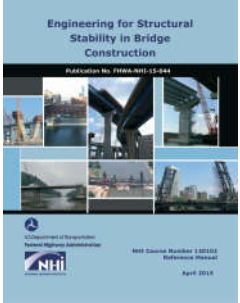

$$M_{CG} = C_b \frac{\pi^2 s E}{L^2} \sqrt{I_y I_x} \quad \text{Eq. 3}$$



Guidelines for Analysis Methods
and Construction Engineering
of Curved and Skewed
Steel Girder Bridges



Steel I-Girder Bridges - System Stability DETOUR

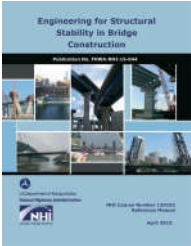

$$M_{gs} = \frac{\pi^2 SE}{L_g^2} \sqrt{I_y I_x} \quad \text{Equation 5-12}$$



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:

- Lifting of girders/members Contractor / Construction Engineer
- 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





Critical Stages of Construction DETOUR


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Fulbright Expressway, Fayetteville, AR




Critical Stages of Construction DETOUR


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




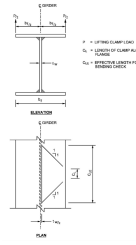

Critical Stages of Construction

DETOUR →

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Critical Stages of Construction

DETOUR →


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- Application of the deck overhang bracket loads to the fascia girders during the deck placement



Gateway Interchange Flyovers, Johnson County, KS



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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:

- Lifting of girders/members **Contractor / Construction Engineer**
- 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 Harrington Lake, Mercer and Garrard Counties, KY



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Critical Stages of Construction

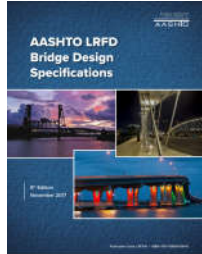

DETOUR →

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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?





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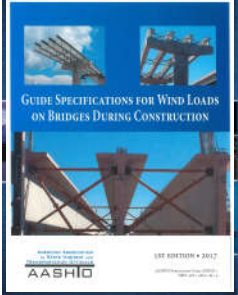
Check of Completed Bridge Prior to Deck Pour


DETOUR

- AASHTO design specifications currently do not include section on winds on a completed structure prior to pouring deck
- Designer could refer to “AASHTO Guide Specifications for Wind Loads on Bridges During Construction”



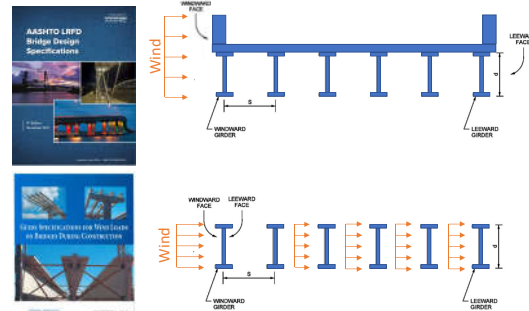
COMPONENT TYPE	CONSTRUCTION CONDITION	FORCE COEFFICIENT (C _d)
I-Girder Bridge Superstructure	Deck forms not in place	2.2 (1)
	Deck forms in place	1.1
U-Girder and Box-Girder Superstructure	Deck forms not in place	1.5
	Deck forms in place	1.1
Flat Slab or Segmental Box-Girder Superstructure	Any	1.1




 105

Wind During Erection


DETOUR



 106

Wind During Erection

DETOUR




$$P_z = 2.56 \times 10^{-6} V^2 K_z GC_D$$

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

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

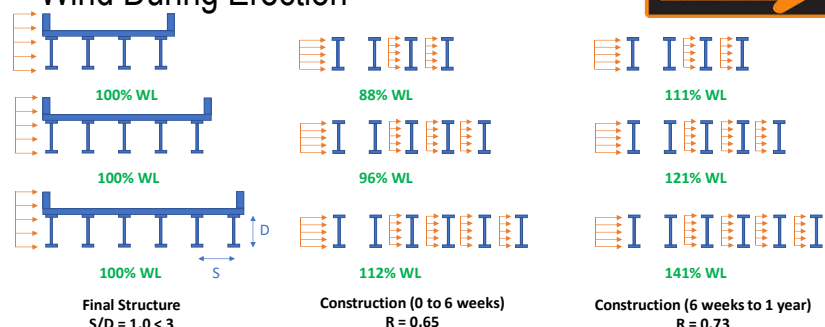
	R
0-6 weeks	0.65
6 weeks to 1 year	0.73
>1-2 years	0.75
>2-3 years	0.77
>3-7 years	0.84

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


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Wind During Erection

DETOUR



Final Structure S/D = 1.0 < 3	Construction (0 to 6 weeks) R = 0.65	Construction (6 weeks to 1 year) R = 0.73
100% WL	88% WL	111% WL
100% WL	96% WL	121% WL
100% WL	112% WL	141% WL

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PennDOT Requirements

DETOUR

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

LATERAL STABILITY BRACING
DESIGN CRITERIA FOR GIRDER BRIDGES
PRIOR TO DECK COMPLETION*

THE CRITERION IN THIS STANDARD APPLIES ONLY TO COMPLETELY ERECTED STEEL SUPERSTRUCTURE, WITHOUT THE DECK. THE STABILITY OF PARTIAL AND COMPLETED GIRDERS IN THE VARIOUS STAGES OF ERECTION PRIOR TO INSTALLATION OF ALL GIRDERS AND DIAPHRAGMS IS THE RESPONSIBILITY OF THE CONTRACTOR AS SPECIFIED IN PUBLICATION 408 SECTION 1050.31 (a). (APPLIES TO TANGENT, SKEWED AND CURVED BRIDGES. APPLIES TO SINGLE AND MULTI-SPAN BRIDGES.)

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PennDOT Requirements

DETOUR

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

Provides Design Wind Pressures & Load Combinations

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

CONSTRUCTION DURATION APPROXIMATE PERCENT ADDED GIRDER LEVEL (%)	0-1 WEEKS		3-4 WEEKS		5-6 WEEKS		7-8 WEEKS	
	WIND	LEeward	WIND	LEeward	WIND	LEeward	WIND	LEeward
10	20	21	20	20	20	20	20	20
25	21	22	21	21	21	21	21	21
50	22	23	22	22	22	22	22	22
75	23	24	23	23	23	23	23	23
90	24	25	24	24	24	24	24	24
95	25	26	25	25	25	25	25	25
100	26	27	26	26	26	26	26	26

110

PennDOT Requirements

DETOUR

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

1. PROVIDE LATERAL BRACING FOR BRIDGES WITH SPANS IN EXCESS OF 300 FT. TO AID IN CONSTRUCTION OF THE BRIDGE. DESIGN BRACING FOR THE SPECIFIED WIND LOADS.
2. EVALUATE THE NEED FOR LATERAL BRACING FOR SPANS IN EXCESS OF 200 FT. BASED ON LATERAL DEFLECTION.

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Critical Stages Deflection Criteria

DETOUR

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD

STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA
AND DETAILS

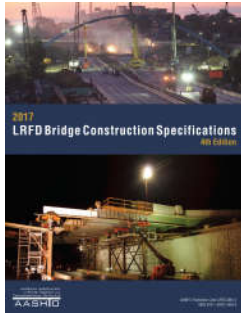
4. EVALUATE LATERAL DEFLECTION OF STEEL SUPERSTRUCTURE FOR A PERMISSIBLE DEFLECTION OF L/150. PROVIDE BRACING IF DEFLECTION LIMIT IS EXCEEDED. AN ACCEPTABLE ANALYSIS METHOD IS A HAND CALCULATION FOR A SINGLE FASCIA GIRDER (NON COMPOSITE) OR A GRID ANALYSIS FOR THE ENTIRE STEEL SUPERSTRUCTURE FRAMING. THE DIAPHRAGM ACTION OF THE STAY-IN-PLACE FORMS SHALL BE NEGLECTED. FINALLY, IF A GRID ANALYSIS IS USED, THE DIAPHRAGM/GIRDER CONNECTION SHALL BE MODELED AS A PIN IN THE PLANE OF THE GRID. IT IS CONSERVATIVE TO ASSUME PINNED DIAPHRAGM TO GIRDER CONNECTIONS. A MORE RIGOROUS ANALYSIS MODELING PARTIAL FIXITY AT THE CONNECTIONS CONSISTENT WITH THE CONNECTION DETAILING IS ACCEPTABLE.

- State Specific (PennDOT)
- No AASHTO Criteria

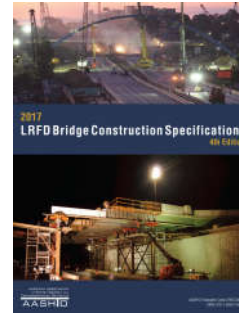
112



AASHTO Bridge Construction Specifications



AASHTO Bridge Construction Specifications



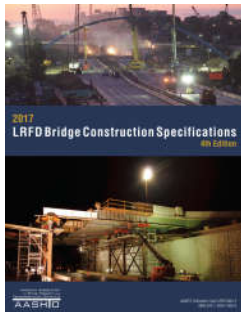
Key Sections:

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

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 the bridge members, and weight of the bridge members. The drawings shall be complete in all respects and shall be required to demonstrate that the stresses 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 deck placement, and which shall include the Contractor’s construction plan on the plan shown in the construction plan. If the plan may be developed entirely on the ground, it shall demonstrate the general arrangement and individual components during construction, including while supported by temporary jacks. The Contractor’s construction plan shall be stamped by a Professional Engineer and be accepted by the Owner.




Gateway Interchange Flyovers, Johnson County, KS

Complex

 117


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

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Constructability Summary

Structure Classification	Material	Structure Type	EOR Responsibility
			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

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Constructability Summary

Structure Classification	Material	Structure Type	EOR Responsibility	Contractor Responsibility	
				Suggested Construction Plan	Erection Plan 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

 120

Constructability Summary

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



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



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

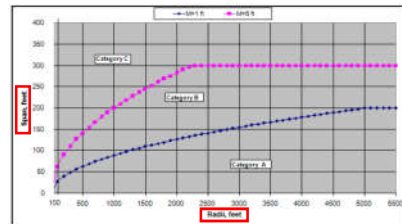
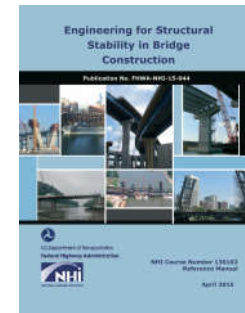


FIGURE 736-1
Special Requirements for Bridge Designers to Designate Erection Plan Categories
The initial Category is based on the chart which considers the length of the longer span, the curvature of the bridge and the skew angle.
If skew is greater than 30°, raise up one Category (A to B or B to C).
If structure crosses water or a railroad, require Category B or an equivalent.
If the Contractor uses interwork bents or strongbacks 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.

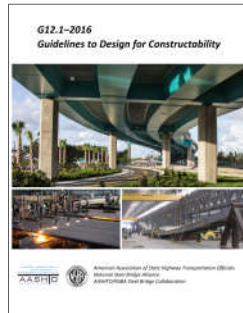


Erection Classification - Survey

- Survey of AASHTO member states for engineering requirements for structural safety during erection
- 33 states responded to survey
- Past issues related to girder erection
- Threshold for when submittal of erection plans required for review



Useful Resources - Constructability



- G12.1-2016 - NSBA / AASHTO Collaboration
- Great resource to ensure a bridge is easy to fabricate and connections are constructable
- Does not cover erection analysis



Construction Engineer’s Literature Review

Design Specifications



Erection Guides/Specifications



Design Loads



Construction Engineer’s Literature Review

Temporary Works



Rigging Hardware



Demolition Guides



Design Loads for Temporary Structures

Equipment Loads

- Almost every bridge structure requires some form of temporary works to erect
- All temporary works require design and planning to accommodate construction loads
- Construction loads are not as easily defined as perhaps for a permanent structure
- Construction Engineers must follow a set of base guidelines and principles but many times work together with their contractor clients to properly educate them on the pro’s/con’s of a minimum design level vs. risk



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“Calculated risks are risks with a plan.”



Equipment Loads

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Equipment Loads **Manufacturer's Provide Data Right?**

134

Equipment Loads **Manufacturer's Provide Data Right?**

135

Excavator/Drill Rigs – Need to Develop Loading

Ground Pressure General Operation =	1150	psf (impact included)
=	7.986	psi
Max. Pressure Under Track =	2488	psf (impact included)
=	17.277	psi
Min. Pressure Under Track =	0	psf (impact included)
=	0.000	psi

Back Calculate an "Effective" Track Pressure for Different Loads/Reaches/Swings

136

Excavator/Drill Rigs – Need to Develop Loading

What is the attachment/pick weight?

Ground Pressure General Operation =	1150	psf (impact included)
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Back Calculate an “Effective” Track Pressure for Different Loads/Reaches/Swings

137

Excavator/Drill Rigs – Need to Develop Loading

What is the attachment/pick weight?
Where is Center of Gravity?

Ground Pressure General Operation =	1150	psf (impact included)
=	7.986	psi
Max. Pressure Under Track =	2488	psf (impact included)
=	17.277	psi
Min. Pressure Under Track =	0	psf (impact included)
=	0.000	psi

Back Calculate an “Effective” Track Pressure for Different Loads/Reaches/Swings

138

Excavator/Drill Rigs – Need to Develop Loading

What is the attachment/pick weight?
Where is Center of Gravity?
What is Machine Capacity?

Ground Pressure General Operation =	1150	psf (impact included)
=	7.986	psi
Max. Pressure Under Track =	2488	psf (impact included)
=	17.277	psi
Min. Pressure Under Track =	0	psf (impact included)
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Back Calculate an “Effective” Track Pressure for Different Loads/Reaches/Swings

139


Track Loads >>> Uniform Load or Point Loads

140

IMPACT





 <p>Excavator Vertical = Up to 40% Lateral = 10% Equip Wt</p> <p>Crane Vertical = 10% Load New Vertical = 20% Load Demo Lateral = None</p>	 <p>Excavator Vertical = Per Manuf Lateral = 10% Equip Wt</p> <p>Crane Vertical = 0% Load New Vertical = 20% Load Demo Lateral = None</p>	 <p>Excavator Vertical = 30% * Lateral = Silent</p> <p>Crane Vertical = 30% * Lateral = Silent</p>	 <p>Excavator Vertical = 30% * Lateral = Silent</p> <p>Crane Vertical = 30% * Lateral = Silent</p>
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* Or Per Manuf




141

IMPACT

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* Or Per Manuf

IMPACT >>> Ideal vs... Actual >>> Up to Operations




142

Environmental Loads

- **Mother Nature**
 - Affects Permanent Structures
 - Affects Temporary Structures
- All temporary works require design and planning to accommodate environmental loads
 - Unless specified, what level of design is required?
 - Duration vs. Risk Assessment?
- Construction Engineers must follow a set of base guidelines and principles but many times work together with their contractor clients to properly educate them on the pros/cons of a minimum design level vs. risk



Wind
 Temperature
 Seismic
 Stream Flow
 Ice
 Debris
 Scour



143

Environmental Loads



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 - Affects Temporary Structures
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144

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145

Environmental Loads



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146

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147

Bridge Demolition and Re-Decking

Bridge Demolition and Re-Decking

- Thousands of bridges in our current infrastructure need to be replaced and/or rehabilitated
- This “need” for bridge replacement generates a need for safe demolition practices
- Currently is no “formal” code that specifically addresses any minimum design criteria to properly analyze a structure that is being taken out of service.
- Genesis is part of a group of engineers and contractors working towards the development of a “Best Practices” guideline for starters



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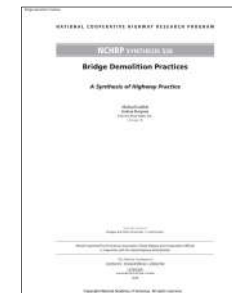


Lewis and Clark Viaduct, Kansas City, MO



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NCHRP Demo Practice Guides



Bridge Demolition and Re-Decking

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153

Complications of Bridge Demolition

- Similar to erecting a bridge, structure stiffness and resistance change depending on stage



Lewis and Clark Viaduct, Kansas City, MO



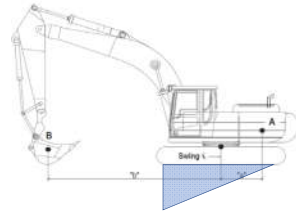
I-75 Deck Replacement, Detroit, MI



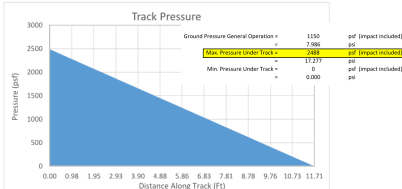
154

Complications of Bridge Demolition

- Similar to erecting a bridge, structure stiffness and resistance change depending on stage
- Method for determination of load effects from equipment demolishing a structure is not standardized

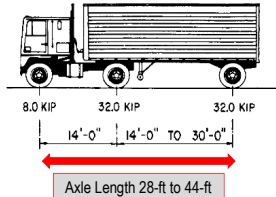


What level of dynamic effects do you include?
Does it vary by deck removal method?



155

Demolition Equipment - Weight



AASHTO 3.6.1.2.2 - DESIGN TRUCK
(72,000 lbs)
On a composite structure





EXCAVATOR
CAT 349 (120,000 lb)
On a partially composite to noncomposite structure




156

Deck Removal Methods

- Breaker / Hammer
 - Contractor preference (quick)
 - Can damage flanges / cross frames
 - Protection under bridge may be required

Comm Ave Bridge, Boston, MA



157

Deck Removal Methods

- Shear
 - Punch hole in deck with breaker/hammer and shear the rest
 - Multiple Uses:
 - Deck removal
 - Girder/material picking
 - Girder Processing







I40 Fast Fix 8, Nashville, TN




158

Deck Removal Methods

- Slab Crab / Bucket with Thumb
 - Time Consuming (Deck Cutting)
 - More Controlled
 - Protection under bridge minimal
 - Common for more complex bridges




Paseo Suspension Bridge, Kansas City, MO




159

Deck Removal Methods

- Slab Crab / Bucket with Thumb
 - Time Consuming (Deck Cutting)
 - More Controlled
 - Protection under bridge minimal
 - Common for more complex bridges

I-75 Deck Replacement, Detroit, MI



160

Changing Structural Integrity – Intentional

Precutting cross-frames Prior to girder removal

Precutting or scoring deck prior to panelized deck removal

Comm. Ave Bridge, Boston, MA

I-75 Deck Replacement, Detroit, MI

161

Changing Structural Integrity – Unintentional

Deck removal technique can damage structure supporting excavators

ORB Downtown, Louisville, KY

162

Direction of Removal Matters!

← Direction of Removal indicated on plans

Span 1 Span 2 Span 3

Direction of Removal performed in field →

Span 1 Span 2 Span 3

Girder began to roll because increased demand with loss of support

163

Changing Structural Integrity – Unintentional

Steel Girders

Composite Deck

Abut 1 Span 1 Span 2 Span 3 Span 4 Abut 2

Integral Abutments

P1 P2 P3

164

Changing Structural Integrity – Unintentional

Abut 1 Span 1 Span 2 Span 3 Span 4 Abut 2

Integral Abutments

P2 P3

165

Changing Structural Integrity – Unintentional

H70 Bridge Re-decking, Kansas City, MO

166

Demolition Summary

- Demolition is often an overlooked portion of projects with minimal formalized requirements
- Demolition engineering / analysis can be as complicated as erection engineering, and at times can be higher risk
- Goal to establish minimum requirements to increase quality and safety across industry

White River Truss Demolition, Prairie County, AR

167

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- Demolition engineering / analysis can be as complicated as erection engineering, and at times can be higher risk
- Goal to establish minimum requirements to increase quality and safety across industry

Fore River Lift Span Demolition, Quincy, MA

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Demolition Summary

- Demolition is often an overlooked portion of projects with minimal formalized requirements
- Demolition engineering / analysis can be as complicated as erection engineering, and at times can be higher risk
- Goal to establish minimum requirements to increase quality and safety across industry



K Bridge Lift Span Demolition, New York, NY



Conclusions / Thoughts

Conclusions/Thoughts – Const. Eng. Perspective

- Perfect World
- Design-Bid-Build Contract Plans
- Temporary Works are NOT permanent structures



Conclusions/Thoughts – Const. Eng. Perspective

- Perfect World
 - Design Engineers need to be experts in design and be aware of construction engineering challenges
 - Construction engineers need to be experts in temporary works and maintain an understanding of AASHTO
 - Design Engineers/Owners should not be afraid to reach out to construction engineering firms
 - AASHTO could formally categorize steel girder bridges into erection categories...currently up to DOTs
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 - *The industry can benefit from a front end and back end service*
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Conclusions/Thoughts – Const. Eng. Perspective

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- **Design-Bid-Build Contract Plans**
 - **Contractor is responsible for erecting parts and pieces to achieve a fully erected structure**
 - Contract plans should provide a design that is stable and safe once the superstructure is fully erected
 - Contract plans should provide a viable "suggested" erection sequence (or at a min deck pour sequence)
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Conclusions/Thoughts – Const. Eng. Perspective

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- Design-Bid-Build Contract Plans
- **Temporary Works are NOT permanent structures**
 - **Temporary works support the structure in their most unstable periods of time as well as equipment needed to erect the structure**
 - Temporary works may only need to work for 15 minutes or could work as long as six to twelve months (or longer in the case of trestles/barges supporting equipment)
 - The design loads/guidelines of temporary works are not as well defined as those for the permanent structures ... This needs to be recognized by the EOR when developing erection submittal specifications and reviewing contractor submittals.



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Questions?



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AISC | Questions?



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