Presentation Overview

- Contractors and the 3-C’s
- Constructibility of Superstructures
- Steel Girder Erection
- Precast Concrete Girder Erection
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions
Presentation Overview

- Contractors and the 3-C’s
  - Constructibility
  - Costs
  - Competition
- Constructibility of Superstructures
- Steel Girder Erection
- Precast Concrete Girder Erection
- 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/Precast – Similar
- Steel Girder Erection
- Precast Concrete Girder Erection
- 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/Precast – Similar…**but**…Different
    • Short Span (< 200ft) / Conventional
• Steel Girder Erection
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- Contractors and the 3-C’s
- **Constructibility of Superstructures**
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  - Steel/Precast – Similar…**but**…Different
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- Steel Girder Erection
- Precast Concrete Girder Erection
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- Conclusions/Suggestions
Presentation Overview

• Contractors and the 3-C’s
• Constructibility of Superstructures
  • Review of AASHTO Expectations
  • Review of Minimum Checks
  • Steel/Precast – Similar…*but*…Different
    • Long Span (> 200-ft) / Complex
• Steel Girder Erection
• Precast Concrete Girder Erection
• Bridge Demolition and/or Re-decking
• Conclusions/Suggestions
Presentation Overview

• Contractors and the 3-C’s
• Constructibility of Superstructures
• **Steel Girder Erection**
  • Compression Flange Requirements
  • Picking Girders
  • Staged Construction Evaluation
  • Temporary Works
• Precast Concrete Girder Erection
• Bridge Demolition and/or Re-decking
• Conclusions/Suggestions
Presentation Overview

- Contractors and the 3-C’s
- Constructibility of Superstructures
- Steel Girder Erection
- Precast Concrete Girder Erection
  - Picking Girders
  - Setting and Releasing Girders
- Bridge Demolition and/or Re-decking
- Conclusions/Suggestions

Spillway Bridge, Marion County, KS
Presentation Overview

• Contractors and the 3-C’s
• Constructibility of Superstructures
• Steel Girder Erection
• Precast Concrete Girder Erection
• 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
Presentation Overview

- Contractors and the 3-C’s
- Constructibility of Superstructures
- Steel Girder Erection
- Precast Concrete Girder Erection
- 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
• Steel Girder Erection
• Precast Concrete Girder Erection
• Bridge Demolition and/or Re-decking
• Conclusions/Suggestions
Contractors & the 3-C’s
Constructibility / Costs / Competition
Contractors & The 3-C’s

• Constructibility
  • 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 so it dictates the construction method
    • Worker access must also be considered
  • Crane Sizing and Access
  • Girder Delivery
Contractors & The 3-C’s

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  - Crane Sizing and Access
  - Girder Delivery
Contractors & The 3-C’s

• Constructibility
  • 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
Contractors & The 3-C’s

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Contractors & The 3-C’s

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Contractors & The 3-C’s

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  - Assessing site to determine direction and sequence of construction

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- **Girder Delivery**

Images Courtesy of: www.cranesy.com
Contractors & The 3-C’s

• Constructibility
  • 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 the tripped to vertical
    (two extra crane moves)

Whittier Memorial Bridge, Newburyport and Amesbury, MA
Contractors & The 3-C’s

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Contractors & The 3-C’s

- Constructibility (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

I40 Fast Fix 8, Nashville, TN
Contractors & The 3-C’s

• Constructibility (Cont.)
  • Rigging and Segment Stability
    • Picking girders (flange grabs, underslung slings, bolted/welded picking eyes)
    • Picking girders (spreader beams and picking trees)
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- Environmental Conditions
Contractors & The 3-C’s

- Constructibility (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 is no possible re-use
- Environmental Conditions
Contractors & The 3-C’s

• Constructibility (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
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Whittier Memorial Bridge, Newburyport and Amesbury, MA
Contractors & The 3-C’s

• Constructibility (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 is no possible re-use
  • Environmental Conditions

Cleveland Innerbelt, Cleveland, OH
Contractors & The 3-C’s

- Constructibility (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 is no possible re-use
  - Environmental Conditions

Cleveland Innerbelt, Cleveland, OH
Contractors & The 3-C’s

- **Constructibility (Cont.)**
  - Rigging and Segment Stability
  - Temporary Towers
  - Environmental Conditions
    - Temperature can affect the erected structure
      (especially orientation of the girders and time of day)
    - Wind impacts on erected girders
      (initial release, fully erected during deck forming)
    - Some DOT’s have strict wind criteria for permanent structures as well as during erection (PennDOT)
Contractors & The 3-C’s

- Constructibility (Cont.)
  - Rigging and Segment Stability
  - Temporary Towers
  - Environmental Conditions
    - Temperature can affect the erected structure (especially orientation of the girders and time of day)
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Blennerhasset Island Bridge, Parkersburg, WV
Contractors & The 3-C’s

• Constructibility (Cont.)
  • Rigging and Segment Stability
  • Temporary Towers
  • Environmental Conditions
    • Temperature can affect the erected structure (especially orientation of the girders and time of day)
    • Wind impacts on erected girders (initial release, fully erected during deck forming)
    • Some DOT’s have strict wind criteria for permanent structures as well as during erection (PennDOT)
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
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
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
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
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 for water operations
  • Finishes/Coatings
  • Schedule
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
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
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

Images Courtesy of:
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

Images Courtesy of:
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

Images Courtesy of:
https://www.fhwa.dot.gov/construction/contracts/acm/cmgc.cfm
Constructibility of Superstructures
Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT  
Engineer of Record  
Contractor
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 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

(3) 250-ft steel girders spans.
Needs to have an 800-ft Radius
Who is responsible for what and when?

**TYPICAL DESIGN BID BUILD**

- **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

3 C's
- **Constructibility**
- Steel Girder Erection
- Concrete Girder Erection
- Demolition
Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Contract Plans = Defines responsibilities of all parties (bidding / fabricating / erecting structure)
Constructibility of Superstructures

• When is a bridge complex enough so engineering is required to ensure constructibility or stability during erection?
• When should a 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?
AASHTO Specifications

3 C’s

- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition
AASHTO Bridge Design Specifications

AASHTO LRFD Bridge Design Specifications

3 C’s
  - Constructibility
  - Steel Girder Erection
  - Concrete Girder Erection
  - Demolition
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.
Precast Beams

5.12.3.2—Precast Beams

5.12.3.2.1—Preconditions

Shipment of prestressed girders for construction shall be the responsibility of the contractor.

Conventional
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 period during which the temporary supports shall also be shown on the contract documents.

The drawings shall indicate alternative methods of construction and the Contractor's responsibility for the costs as are chosen. Any changes by the Contractor in the construction method or to the design shall comply with the requirements of Article 5.12.5.5.
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 capable of supporting itself and subsequently assume its load shall also be shown in the contract documents.

Alternative methods of construction shall indicate the method retained and the Contractor's responsibility if any changes in methods are chosen. Any changes by the Contractor to the construction method or equipment shall comply with the requirements of Article 5.12.5.
### Segmental Concrete Bridges

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

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>DC</th>
<th>DW</th>
<th>DFF</th>
<th>U</th>
<th>CEQ</th>
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<th>IE</th>
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<th>WS</th>
<th>WUP</th>
<th>WE</th>
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<th>ES</th>
<th>EH</th>
<th>EV</th>
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<td>1.0</td>
<td>1.0</td>
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<td>0.220√f&lt;em&gt;c&lt;/em&gt;</td>
<td>0.110√f&lt;em&gt;c&lt;/em&gt;</td>
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<td>0.220√f&lt;em&gt;c&lt;/em&gt;</td>
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</tbody>
</table>

1, 2, 3

**3 C’s** 
- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition

70
Steel I-Girder Bridges

6.10

6.10.1 General
6.10.2 X-Section Limits
6.10.3 Constructibility
6.10.4 Service Limits
6.10.5 Fatigue Limits
6.10.6 Strength Limits
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 D.6.5.
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, \[ f_t \] shall not be checked when \[ f_t \] is equal to zero. For sections with compact or noncompact webs, \[ f_t \] shall not be checked.

\[ f_{bu} + f_t \leq \phi_f R_n F_{ye} \]  
(6.10.3.2.1-1)

\[ f_{bu} + \frac{1}{3} f_t \leq \phi_f F_{wc} \]  
(6.10.3.2.1-2)

and

\[ f_{bu} \leq \phi_f F_{crw} \]  
(6.10.3.2.1-3)

What are critical stages of construction?
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 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.

Following pour sequence is important!

Images Courtesy of: www.sellwoodbridge.org
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

\[ M_{gs} = C_{bs} \frac{\pi^2 w_g E}{L^2} \sqrt{I_{eff} I_x} \]  

(6.10.3.4.2-1)

- 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
Useful Resources - Erection Analysis

3 C’s
- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition

ALL MATERIAL TYPES

FHWA-NHI-15-044

NSBA / AASHTO S10.1

STEEL BRIDGE SPECIFIC GUIDES

NCHRP Report 725
Steel I-Girder Bridges - System Stability

\[ M_{crG} = C_b \frac{\pi^2 sE}{L_s^2} \sqrt{I_y e I_x} \]  
Eq. 3

- Simplified check for stages of erection
Steel I-Girder Bridges - System Stability

\[ M_{gs} = \frac{\pi^2 SE}{L_g^2} \sqrt{I_y I_x} \]

Equation 5-12

- Simplified check for stages of erection
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?
Check of 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 refer to “AASHTO Guide Specifications for Wind Loads on Bridges During Construction”.

![Girder Wind Load Terminology](image)

<table>
<thead>
<tr>
<th>COMPONENT TYPE</th>
<th>CONSTRUCTION CONDITION</th>
<th>FORCE COEFFICIENT (C_w)</th>
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<tbody>
<tr>
<td>I-Shaped Girder Superstructure</td>
<td>Deck forms not in place</td>
<td>2.2 (1)</td>
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<td>Deck forms in place</td>
<td>1.1</td>
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<tr>
<td>U-Shaped and Box-Girder Superstructure</td>
<td>Deck forms not in place</td>
<td>1.5</td>
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<td></td>
<td>Deck forms in place</td>
<td>1.1</td>
</tr>
<tr>
<td>Flat Slab or Segmental Box-Girder Superstructure</td>
<td>Any</td>
<td>1.1</td>
</tr>
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</table>
Wind During Erection

- Wind During Erection
- Steel Girder Erection
- Concrete Girder Erection
- Demolition
Wind During Erection

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

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

**3 C’s**
- Constructability
- Steel Girder Erection
- Concrete Girder Erection
- Demolition

Nothing New Here…

\[ P_z = \frac{V^2}{K_z G C_D} \]

Drag Coefficient, \( C_D \)

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<tr>
<th>Component</th>
<th>Windward</th>
<th>Leeward</th>
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<td>I-Girder and Box-Girder Bridge Superstructures</td>
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<td>Sharp-Edged Member</td>
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<td>Sound Barriers</td>
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<th>Time Span</th>
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<tr>
<td>6 weeks to 1 year</td>
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<tr>
<td>&gt;1-2 years</td>
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<td>&gt;2-3 years</td>
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<td>&gt;3-7 years</td>
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</table>

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

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 1050.3(a). (Applies to tangent, skewed and curved bridges. Applies to single and multi-span bridges.)
PennDOT Requirements

**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

<table>
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<th>CONSTRUCTION DURATION</th>
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<th>1-2 YEARS</th>
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Provides Design Wind Pressures & Load Combinations
PennDOT Requirements

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.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

STANDARD
STEEL GIRDER BRIDGES
LATERAL BRACING CRITERIA AND DETAILS
Critical Stages Deflection Criteria

- State Specific (PennDOT)

### COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF PROJECT DELIVERY

<table>
<thead>
<tr>
<th>STANDARD</th>
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<tr>
<td>STEEL GIRDER BRIDGES</td>
</tr>
<tr>
<td>LATERAL BRACING CRITERIA</td>
</tr>
<tr>
<td>AND DETAILS</td>
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</table>

- No AASHTO Criteria

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.
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

Chapter 11
Steel Structures
- 11.2 – Erection Drawings
- 11.8 – Additional Provisions for Curved Girders
8.13—PRECAST CONCRETE MEMBERS

8.13.6—Erection

The Contractor shall be responsible for the safety of precast members during all stages of construction. Lifting devices shall be used in a manner that does not cause damaging, bending, or torsional forces. After a member has been erected and until it is secured to the structure, temporary braces shall be provided as necessary to resist wind or other loads.
Special Provisions for Segmental

• Contractor’s geometry control plan including the effect of time-dependent prestress losses and creep
• Additional requirements for construction procedure design calculations including falsework design

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.
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 be reviewed as the Contractor’s construction plan. The plan shown in the contract documents needed, or may be developed entirely. In any event, it shall demonstrate the general construction 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.
### Constructibility Summary

<table>
<thead>
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<th>Structure Classification</th>
<th>Material</th>
<th>Structure Type</th>
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<tbody>
<tr>
<td>Conventional</td>
<td>Concrete</td>
<td>Precast Beams</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Shorter Straight Spans (&lt; 200-ft)</td>
</tr>
<tr>
<td>Complex</td>
<td>Concrete</td>
<td>Spliced Prestressed Beams / Segmental</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Long Spans (&gt; 200-ft) / Curved / High Skew</td>
</tr>
</tbody>
</table>
## Constructibility Summary

<table>
<thead>
<tr>
<th>Structure Classification</th>
<th>Material</th>
<th>Structure Type</th>
<th>Suggested Construction Plan</th>
<th>EOR Responsibility</th>
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<td>Precast Beams</td>
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<td>Steel</td>
<td>Shorter Straight Spans (&lt; 200-ft)</td>
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<tr>
<td>Complex</td>
<td>Concrete</td>
<td>Spliced Prestressed Beams / Segmental</td>
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<tr>
<td></td>
<td>Steel</td>
<td>Long Spans (&gt; 200-ft) / Curved / High Skew</td>
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## Constructibility Summary

<table>
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<th>Suggested Construction Plan</th>
<th>Erection Plan Required?</th>
<th>Erection Engineering Required?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional</strong></td>
<td>Concrete</td>
<td>Precast Beams</td>
<td>No</td>
<td>Yes</td>
<td>DOT Dependent</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Shorter Straight Spans (&lt; 200-ft)</td>
<td>No</td>
<td>Yes</td>
<td>DOT Dependent</td>
</tr>
<tr>
<td><strong>Complex</strong></td>
<td>Concrete</td>
<td>Spliced Prestressed Beams / Segmental</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Long Spans (&gt; 200-ft) / Curved / High Skew</td>
<td>Sometimes</td>
<td>Yes</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>
Constructibility 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
Constructibility 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
Steel Girder Erection Classification – SDDOT/ NDDOT

- Standard Specifications indicate working drawings (which include erection plan) must be reviewed by Engineer
- No threshold defined for when an engineered erection plan would be required
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 76-1
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 beams 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 constructible
- 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
Construction Engineer’s Literature Review

Equipment Specifications

Hole in the Wall RR Bridge, Fort Worth, TX

Fore River Lift Bridge Replacement, Quincy, MA
Age old question...

Constructability

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.
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

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

• 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

• ASD (Allowable Stress Design)
• LFD (Load Factor Design)
• LRFD (Load Resistance Factor Design)
<table>
<thead>
<tr>
<th>Design Method</th>
<th>Equation</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD (Allowable Stress Design)</td>
<td>$\sigma_{\text{allowable}} \geq \sigma_{\text{demand}}$</td>
<td>1930’s</td>
</tr>
<tr>
<td>LFD (Load Factor Design)</td>
<td>$R_n \geq \text{effects of } \sum \gamma_i Q_i$</td>
<td>1970’s</td>
</tr>
<tr>
<td>LRFD (Load Resistance Factor Design)</td>
<td>$\phi R_n \geq \text{effects of } \sum \gamma_i Q_i$</td>
<td>1994</td>
</tr>
</tbody>
</table>

Images Courtesy of:
https://imgur.com/gallery/Yg6XWqB
https://csengineermag.com/article/john-kulicki-setting-new-standards/
Compression Flange Requirements

• ASD
• LFD
• LRFD

Flange Proportion Limit
\[ \frac{b}{t} \leq 24 \]
ASD - Compression Flange Requirements

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

\[ \frac{b}{t} = \frac{3.250}{\sqrt{f_b}} \]

but in no case shall \( b/t \) exceed 24

(10-19)

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 \( f_b = 0.55f_y \)
LFD - Compression Flange Requirements

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

\[
\frac{b}{t} \leq \frac{4.110}{\sqrt{F_y}}
\]  
(10-93)

<table>
<thead>
<tr>
<th>TABLE 10.48.1.2A Limitations for Compact Sections</th>
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</thead>
<tbody>
<tr>
<td>( F_y ) (psi)</td>
</tr>
<tr>
<td>( b/t )</td>
</tr>
<tr>
<td>( D/\tau_c )</td>
</tr>
<tr>
<td>( L_d/\tau_y ) (( M/M_c = 0^* ))</td>
</tr>
<tr>
<td>( L_d/\tau_y ) (( M/M_c = 1^* ))</td>
</tr>
</tbody>
</table>

* For values of \( M/M_c \) other than 0 and 1, use Equation (10-96).

<table>
<thead>
<tr>
<th>TABLE 10.48.2.1A Limitations for Braced Noncompact Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_y ) (psi)</td>
</tr>
<tr>
<td>( b/t ) *</td>
</tr>
<tr>
<td>( L_d/d )</td>
</tr>
<tr>
<td>( A_r )</td>
</tr>
<tr>
<td>( D/\tau_y )</td>
</tr>
</tbody>
</table>

* 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

\[
\frac{b}{t} \leq 24
\]  
(10-100)
6.10.2.2—Flange Proportions

Compression and tension flanges shall be proportioned such that:

\[
\frac{b_f}{2t_f} \leq 12.0, \quad \textbf{bf / tf < 24} \quad (6.10.2.2-1)
\]

\[
b_f \geq \frac{D}{6}, \quad (6.10.2.2-2)
\]

\[
t_f \geq 1.1t_w, \quad (6.10.2.2-3)
\]

and:

\[
0.1 \leq \frac{I_{yw}}{I_{ye}} \leq 10 \quad (6.10.2.2-4)
\]
LRFD - Compression Flange Requirements

6.10.8.2.2—Local Buckling Resistance

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

- If \( \lambda_f \leq \lambda_{pf} \), then:
  \[
  F_{nc} = R_x R_y F_{yc} \tag{6.10.8.2.2-1}
  \]

- Otherwise:
  \[
  F_{nc} = 
  1 - \left( 1 - \frac{F_{yc}}{R_x F_{yc} \left( \frac{\lambda_f - \lambda_{pf}}{\lambda_{pf} - \lambda_{pf}} \right)} \right) R_x R_y F_{yc} \tag{6.10.8.2.2-2}
  \]

in which:

- Slenderness ratio for the compression flange:
  \[
  \lambda_f = \frac{b_f}{2t_f} \tag{6.10.8.2.2-3}
  \]

- Limiting slenderness ratio for a compact flange:
  \[
  \lambda_{pf} = 0.38 \frac{E}{F_{yc}} \tag{6.10.8.2.2-4}
  \]

- Limiting slenderness ratio for a noncompact flange:
  \[
  \lambda_{nf} = 0.56 \frac{E}{F_{yc}} \tag{6.10.8.2.2-5}
  \]

bf /2tf < \lambda_{pf}

bf / tf < 2\lambda_{pf}
Compression Flange Requirements

- ASD or LFD Non-Compact
  \[ \frac{b}{t} = \frac{3.250}{\sqrt{f_y}} \]  
  let \( fb = 0.55fy \)

- LFD Compact
  \[ \frac{b}{t} \leq \frac{4.110}{\sqrt{f_y}} \]

- LRFD
  \[ 2 \times \frac{E}{\sqrt{f_y}} \]

- ASD / LFD / LRFD
  \[ \frac{b}{t} \leq 24 \]

### Table

<table>
<thead>
<tr>
<th>fy (ksi)</th>
<th>ASD or LFD Non-Compact</th>
<th>LFD Compact</th>
<th>LRFD</th>
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<tr>
<td>36</td>
<td>23.1</td>
<td>21.7</td>
<td>21.6</td>
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<tr>
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<td>18.3</td>
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<tr>
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<td>14.6</td>
<td>13.7</td>
<td>13.6</td>
</tr>
<tr>
<td>100</td>
<td>13.9</td>
<td>13.0</td>
<td>12.9</td>
</tr>
</tbody>
</table>

ASD & LFD Hard Limit

LRFD Limit for when LB must be considered
Compression Flange Requirements

ASD / LFD Capacity

LRFD Capacity

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition
Compression Flange Requirements

- 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

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

Comm. Ave Bridge, Boston, MA

Comm. Ave Bridge, Boston, MA
Single Girder Pick Advantages

- 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

- More Ground Assembly
  - Cross frame connections
- More Stable while Hoisted
  - Reduced lateral torsional buckling concerns
Curved Girder Pick

Fulbright Expressway, Fayetteville, AR

Gateway Interchange Flyovers, Johnson County, KS

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
Curved Girder Pick

Girder Center of Gravity

\[ x_C = 0 \]
\[ y_C = R \frac{\sin \theta}{\theta} \]
Curved Girder Pick

Girder Center of Gravity

- Span Lengths
- Changing Girder Cross Section
  - Shop Splices
- Field Splices
- Cross Frames

Ideal Spreader Length

- Center of Gravity
- Spreader

Diagram:

- LA
- LA

Legend:

- Center of Gravity
- Pick Point, typ.
- Field Splice, typ.
Curved Girder Pick

Spreader Shorter Than Ideal Length

Image Courtesy of: UTlift

Spreader

Center of Gravity

: Center of Gravity

: Pick Point, typ.

: Field Splice, typ.
Curved Girder Pick

Ideal Spreader Length

- Improved Stability
- Improved Serviceability (rotation)

9” Lateral Displacement

100-ft Spread

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
Curved Girder Pick

Shorter Than Ideal Spreader Length

20” Lateral Displacement

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
Curved Girder Pick – UT Lift

- 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 (0-5576)

Spreadsheet Developed by:
Jason C. Sith, PhD

Project Advisors:
Dr. Todd A. Helwig
Dr. Karl H. Frank
Dr. Michael O. Englebank
Dr. Eric B. Williamson

Send Comments to Dr. Todd Helwig:
tmhelwig@newmail.utsa.edu
Curved Girder Pick – UT Lift

- **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
Curved Girder Pick – UT Lift

• 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
Curved Girder Pick – UT Lift

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

- Unbraced length \( L_b = \) total length of girder segment

\[ L_{lift} = \frac{L_1 + L_2}{2} \]

Equation 7-7

\[ C_{bL} = 2.0 \text{ for } \frac{L_{lift}}{L} \leq 0.225 \]
\[ C_{bL} = 6.0 \text{ for } 0.225 < \frac{L_{lift}}{L} < 0.3 \]
\[ C_{bL} = 4.0 \text{ for } \frac{L_{lift}}{L} \geq 0.3 \]

Equations 7-8

Steel Girder Erection

Concrete Girder Erection

Demolition
Rigging – Single Girder Spreader

- Single Crane
- Slings
- Spreader
- Vertical Slings
- Beam Clamps

Comm. Ave Bridge, Boston, MA
Rigging – Single Girder Spreader

Two Crane

Field Splice Fully Bolted

Gateway Interchange Flyovers, Johnson County, KS

Gateway Interchange Flyovers, Johnson County, KS
Rigging – Multi-Level Spreaders

- Single Crane
- Level 1 Sling
- Level 1 Spreader
- Level 2 Sling
- Level 2 Spreader
- Vertical Slings

Bolster shall be bolted to girder prior to lifting into final position, typ.
Load Equalizers – Lifting Triangles

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

Fulbright Expressway, Fayetteville, AR

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition
Beam Clamps

Equation 7-23

\[ f_{lb} = \frac{R_k}{(b_f + C_L)(t_f)^3 / 6} \]

Equation 7-24

\[ f_{ub} \leq 0.75 F_{yf} \]

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

Global Strong Axis Bending Moment

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
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

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
- 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

6.10.3.2.1—Discreetly 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 \( f_t \) is equal to zero. For sections with compact or noncompact webs, Eq. 6.10.3.2.1-3 shall not be checked.

\[
f_{yw} + f_t \leq \phi_f R_f F_{yw}, \quad (6.10.3.2.1-1)
\]

\[
f_{yw} + \frac{1}{3} f_t \leq \phi_f F_{yw}, \quad (6.10.3.2.1-2)
\]

and

\[
f_{yw} \leq \phi_f F_{yw} \quad (6.10.3.2.1-3)
\]

6.10.3.2.2—Discreetly Braced Flanges in Tension

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

\[
f_{tw} + f_t \leq \phi_f R_f F_{tw}, \quad (6.10.3.2.2-1)
\]
Critical Stages of Construction

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

Gateway Interchange Flyovers, Johnson County, KS
Staged Construction Evaluation

3 C's
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
Single Girder Stability
Single Girder Stability

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition

STAGED CONST.

DL Moment
Helper Crane
DL Moment Reduced
Girder System Stability

3 C’s
- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition

Images Courtesy of: Engineering for Structural Stability in Bridge Construction
Girder System Stability

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition

Images Courtesy of: edmontonsun.com
Eigenvalue & 2\textsuperscript{nd} Order Nonlinear Analysis

\[ P_e = \frac{\pi^2 EI}{L^2} \]
Eigenvalue Analysis

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

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

P = 1 kip
Eigenvalue = 262
FOS = 262

P = 262 kip
Eigenvalue = 1
FOS = 1
Eigenvalue & 2nd Order Nonlinear Analysis

\[ AF_G = \frac{1}{1 - \frac{M_{\text{max}G}}{M_{\text{cr}G}}} \]

- \( AF_G \) = Amplification Factor = System Stability Indicator
- \( M_{\text{max}G} \) = Maximum Total Moment support by bridge unit
- \( M_{\text{cr}G} \) = Elastic global buckling moment of the bridge
- \( M_{\text{cr}G} / M_{\text{max}G} \) = Eigenvalue
Eigenvalue & 2\textsuperscript{nd} Order Nonlinear Analysis

\[ AF_G = \frac{1}{1 - \frac{M_{\text{max}G}}{M_{crG}}} \]

- 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

- Incremental application of load
- Updating of stiffnesses
- Iteration

Second order analysis converges to eigenvalue

Reference:
Second order analysis converges to eigenvalue buckling analysis.

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

Images Courtesy of: Engineering for Structural Stability in Bridge Construction
System Buckling Case Study

- Two Span Continuous Steel Plate Girder Bridge
- Span Length = 350’
System Buckling Case Study

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

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY
System Buckling Case Study

- Eigenvalue Analysis

\[ \text{Eigenvalue} = 2.33 \]

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

Second Order Analysis Req’d
System Buckling Case Study

- 2\textsuperscript{nd} Order Nonlinear Analysis
  - Increasing Load Factor
  - Key Point Deflection
System Buckling Case Study

Dead Load Only

Load Factor

Lateral Deflection (in)
System Buckling Case Study

Load Factor vs. Lateral Deflection (in)

- **Dead Load Only**
- **Dead Load + Wind 40mph**

<table>
<thead>
<tr>
<th>Lateral Deflection (in)</th>
<th>0.0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
<th>1.2</th>
<th>1.4</th>
<th>1.6</th>
<th>1.8</th>
<th>2.0</th>
</tr>
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<tbody>
<tr>
<td>Load Factor</td>
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<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition
System Buckling Case Study

- Load Factor
- Lateral Deflection (in)

- Dead Load Only
- Dead Load + Wind 40mph
- Dead Load + Wind 90mph

3 C’s
- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition

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

Gateway Interchange Flyovers, Johnson County, KS

Cleveland Innerbelt, Cleveland, OH

3 C’s

Constructibility

Steel Girder Erection

Concrete Girder Erection

Demolition
Geometry Control Studies

Negative Tip Deflection:

Positive Tip Deflection:
Girder Stiffening Truss

Whittier Memorial Bridge, Newburyport and Amesbury, MA
Precast Concrete Girder Erection
Through the Eyes of a Construction Engineer
Precast Concrete Girder Erection

- Precast Beam Bridge Considerations
- Precast Spliced Bridge Considerations
Precast Concrete Girder Erection

• Precast Beam Bridge Considerations
  • Single Crane Hoisting
  • Hoisting Stability
  • Roll-over Stability
  • Overhang Loading

• Precast Spliced Bridge Considerations
Precast Concrete Girder Erection

- Precast Beam Bridge Considerations
- Precast Spliced Bridge Considerations
  - Staged Construction Evaluation
  - Temporary Works
Precast Beam Bridge Considerations
3 C’s

Constructibility

Steel Girder Erection

Concrete Girder Erection

Demolition
Embed Loops

Typically (2) Crane Pick vertical at ends similar to fabricator

- Strength of strand based on:
  - Length of Embedment
  - Diameter of loop
  - Strength of Concrete

Images Courtesy of:
Engineering for Structural Stability in Bridge Construction
PCI 6th Edition Fabrication Design
Single Crane Hoisting Considerations

OPTION 1 - SPREADER

OPTION 2 - NO SPREADER

Common length of spreader for project can make this impractical.
Single Crane Hoisting Considerations

OPTION 1 - SPREADER

Shorter spreader can require need for additional tension reinforcement.

Images Courtesy of:
PCI 8th Edition Fabrication Design

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition

3 C’s
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Single Crane Hoisting Considerations

\[ F_h = \frac{W}{2 \tan(\phi)} \]

\[ W/2 = P \]

\[ T = \frac{P}{\sin \theta} \]

\[ F_h = \frac{P}{\tan \theta} \]

OPTION 2 - NO SPREADER

Images Courtesy of:
PCI 6th Edition Fabrication Design
Sweep Considerations

3 C’s

- Constructibility
- Steel Girder Erection
- Concrete Girder Erection
- Demolition
Roll Over Stability

- Roll over stability main concern when setting
- Construction winds main cause for starting rollover
- Rollover impacted by several factors:
  - Bearing flexibility
  - Slope of bottom of girder
  - Fabrication imperfections (sweep)
Diagonal Bracing Design

US50 Over BNSF RR, Lamar, CO
Sample Bracing Requirements

MINIMUM ERECTION AND BRACING REQUIREMENTS
PRESTRESSED CONCRETE I-GIRDERS AND I-BEAMS

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION
BUREAU OF DESIGN

STANDARD
PRESTRESSED CONCRETE BEAM BRACING NOTES

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition
Temporary Bracing – TxDOT

- Provides engineered details and minimum end and erection bracing requirements
- For span lengths < 150-ft
- For specific girder types

Forms can interfere with standard detail

**Temporary Bracing**

- Weld #5 bar to girder Bar R
- 1/2" Dia bolt with nut & washers
- 1-3 x 4 or 2-2 x 4 Timbers
- 2-2 x 8 Timbers (notched)

**FOR ERECTION BRACING, OPTION 2**

**HORIZONTAL BRACING DETAILS**

**DIAGONAL BRACING DETAILS**

(To be used on both ends of the first girder/beam erected in the span in each phase.)
Temporary Bracing – PennDOT

- Provides conceptual details for end and erection bracing
Other Considerations - Overhangs

Images Courtesy of:
http://www.texsunconcrete.com
http://www.daytonsuperior.com
Other Considerations - Overhangs

• Who is responsible for check of girder for overhang loads?
• AASHTO requires overhang check of steel I-Girder by designer. Concrete all on Contractor
• What do you check? Stability / Local Stresses / Torsion Stress / Deformation?

Images Courtesy of:
TxDOT New Standards, Amy Eskridge
Other Considerations - Overhangs

Suggested Designer Checklist:

1. Is girder tall enough to receive conventional overhang bracket?
2. Is girder(s) stable under overhang loading (for what screed load)?
3. Designer should indicate what has been checked for overhang forming in Contract Documents.
Precast Spliced Bridge Considerations
3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection  Demolition

Images Courtesy of:
www.post-tensioning.org
www.massman.net/project/rigolets-pass-bridge
Hoisting Considerations

- Spliced precast sections often too heavy for single crane pick
- Conventional 2 crane picks often utilized
- Rigging can become complicated for curved / rotated members (usually U-Shape sections) similar to steel
Setting Considerations

- Post tensioned I sections same stability concerns of prestressed simple spans.
- Spliced precast section can have drop in sections or could have FW towers at splice locations. Otherwise strong backs not required.
- Because span weights, FW towers often more substantial that steel alternate.
Releasing / Post Tensioning

- Post tensioning can add complexity/time to a girder erection but is achievable with the right team in place.
- Understanding of losses and time-dependent phenomenon required for final design and construction analysis including:
  - Steel relaxation
  - Concrete creep and shrinkage
  - Anchor losses

Images Courtesy of: www.halifen-moment.com
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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Complications of Bridge Demolition

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

Axle Length 28-ft to 44-ft
Tumbler Spacing 14-ft to 16-ft

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition
Deck Removal Methods

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

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

**Concrete Girder Erection**

Demolition

Comm. Ave Bridge, Boston, MA

I-40 Fast Fix 8, Nashville, TN
Deck Removal Methods

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

![Slab Crab](image1.png)

![Bucket with Thumb](image2.png)

Paseo Suspension Bridge, Kansas City, MO
Deck Removal Methods

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Slab Crab

Bucket with Thumb

I-75 Deck Replacement, Detroit, MI
Deck Removal Methods

- Grapple
  - Debris mover

Images Courtesy of: equipmentland & paladinattachments.
Girder Removal

Comm. Ave Bridge, Boston, MA

I40 Fast Fix 8, Nashville, TN

I40 Fast Fix 8, Nashville, TN
Changing Structural Integrity – Intentional

Precutting or scoring deck prior to panelized deck removal

Precutting cross-frames Prior to girder removal

Comm. Ave Bridge, Boston, MA

I-75 Deck Replacement, Detroit, MI
Changing Structural Integrity – Unintentional

Deck removal technique can damage structure supporting excavators

ORB Downtown, Louisville, KY
Direction of Removal Matters!

Direction of Removal indicated on plans

Direction of Removal performed in field

Girder began to roll because increased demand with loss of support
Changing Structural Integrity – Unintentional

3 C’s
Constructibility
Steel Girder Erection
Concrete Girder Erection
Demolition

Steel Girders
Composite Deck

Abut 1
Span 1
P1

Span 2

Span 3
P3

Span 4
Abut 2

Integral Abutments

Integral Abutments
Changing Structural Integrity – Unintentional

3 C's
- Constructibility
- Steel Girder Erection
- Concrete Girder Erection

Demolition
Changing Structural Integrity – Unintentional

3 C’s  Constructibility  Steel Girder Erection  Concrete Girder Erection

Demolition

I470 Bridge Re-decking, Kansas City, MO
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
Demolition Summary

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Demolition Summary – It can be pretty fun

Paseo Suspension Bridge, Kansas City, MO

Merchants Truss Bridge, St. Louis, MO
Time Lapse of Deck and Girder Removal
Conclusions / Suggestions
Conclusions/Suggestions – Contractor’s Perspective

- Perfect World
- Design-Bid-Build Contract Plans
- Precast & Steel
- Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
  • Everyone has an important role
    • Design Engineers need to be experts in design
    • Construction engineers need to be experts in temporary works

• Design-Bid-Build Contracts
• Precast & Steel
• Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
  • Everyone has an important role
    • Design Engineers need to be experts in design but must understand and appreciate the challenges that face construction engineers and contractors.
    • Construction engineers need to be experts in temporary works and must maintain a full working knowledge and understanding of design provisions in AASHTO

• Design-Bid-Build Contracts
• Precast & Steel
• Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
  • Everyone has an important role
  • Design Engineers/Owners should reach out to construction engineering firms & contractors/fabricators
    • Genesis has been asked by engineering firms to provide constructability reviews but at the cost of being prohibited from then working with Contractors during the bid process

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    • Genesis has been asked by engineering firms to provide constructability reviews but at the cost of being prohibited from then working with Contractors during the bid process
    • The industry can benefit from a front end and back end constructibility review service
      • Design Engineer/Owners should have “general” conversations about possible erection methods/schemes with construction engineers
      • If Design Engineer/Owners want a more thorough review of the erection sequence, there should be proper budget allowance upfront in the design phases vs. becoming a last minute check at end of project when plans are already developed.

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Conclusions/Suggestions – Contractor’s Perspective

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  - Everyone has an important role
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    - Genesis has been asked by engineering firms to provide constructability reviews but at the cost of being prohibited from then working with Contractors during the bid process
    - The industry can benefit from a front end and back end service
    - AASHTO would formally categorize steel girder bridges into erection categories…currently up to DOTs

- Design-Bid-Build Contracts
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Conclusions/Suggestions – Contractor’s Perspective

- Perfect World

- 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 port sequence)
  - If the contractor strays from the “suggested”, all engineering in on them

- Precast & Steel

- Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
• Design-Bid-Build Contract Plans
• Precast & Steel – Basically Similar
  • Shorter more standard type bridges
    • Don’t necessarily require “Suggest Erection Sequences”
    • Don’t necessarily require formalized erection engineering submittals
    • Unless there are special site constraints

• Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

- Perfect World
- Design-Bid-Build Contract Plans
- Precast & Steel – Basically Similar
  - Shorter more standard type bridges
  - Complex bridges will require more formalized erection submittals
    - Do require “Suggest Erection Sequences”
    - Do require formalized erection engineering submittals
- Erecting Steel & Precast Girders
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
• Design-Bid-Build Contract Plans
• Precast & Steel
• Erecting Steel & Precast Girders
  • There is a lot of planning that goes into even a simple/typical/standard highway bridge structure
    • BOTH DURING DESIGN & DURING BIDDING
  • AASHTO “code writers” truly intended the specification to make sure designers to be responsible for the fully erected steel superstructure
Conclusions/Suggestions – Contractor’s Perspective

• Perfect World
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  • There is a lot of planning that goes into even a simple/typical/standard highway bridge structure
  • AASHTO “code writers” truly intended the specification to make sure designers to be responsible for the fully erected steel superstructure ..... *But it does not specifically say this*
Questions?

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