ENGINEERING FOR STABILITY DURING CONSTRUCTION
A CONSTRUCTION ENGINEER’S PERSPECTIVE
University of Minnesota
Structural Engineering Webinar – February 7, 2023
Presentation Overview

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

• Contractors and the 3-C’s
  • Constructibility
  • Costs
  • Competition

• Constructibility of Superstructures
• Design Loads for Temporary Structures
• Bridge Demolition and/or Re-decking
• Conclusions/Suggestions
Presentation Overview

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

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

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

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Presentation Overview

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

**Constructibility**

6.10.3—Constructibility

6.10.3.1—General

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

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

Webs without bearing stiffeners at locations subjected to concentrated loads not transmitted through a deck or deck system shall satisfy the provisions of Article 6.10.3.5.
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 unforeseen issues in construction
Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT

Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT

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

Contractor
Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

Owner / DOT  Engineer of Record  Contractor

We need a bridge  Best design option  This is how I would build it. It’s Going to cost you this much
Who is responsible for what and when?

TYPICAL DESIGN BID BUILD

- Owner / DOT
- Engineer of Record
- Contractor

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

Essential Information Exchanged / Costs Established
Who is responsible for what and when?

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

Design Specifications

Erection Guides/Specifications

Design Loads
Construction Engineer’s Literature Review

Temporary Works

Rigging Hardware

Demolition Guides
AASHTO Specifications

AASHTO Bridge Design Spec.

AASHTO Bridge Construction Specs.
AASHTO Bridge Design Specifications
AASHTO Bridge Design Specifications

Key Sections:

- **Chapter 2**
  General Design and Location Features
  - 2.5.3 – Constructibility

- **Chapter 5**
  Concrete Structures
  - 5.12 – Provisions for Structure Components and Types

- **Chapter 6**
  Steel Structures
  - 6.10.3 – Steel I-Section Constructibility
  - 6.11.3 – Box Section
AASHTO – Constructibility

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

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

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
Precast Beams

5.12.3.2—Precast Beams

5.12.3.2.1—Preservice Conditions

The prestress and posttensioning of precast prestressed girders for shipping and installation shall be the responsibility of the contractor.
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 support condition during which the temporary support shall also be shown on the contract documents.

The construction plans shall indicate alternative methods of construction and the Contractor's responsibility for these methods 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.

Images Courtesy of: www.post-tensioning.org
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 as the structure shall also be shown in the contract documents. The engineer may indicate alternative methods, and the Contractor's responsibility is to follow these methods if chosen. Any changes by the Contractor to the construction method or in the design shall comply with the requirements of Article 5.12.
Segmental Concrete Bridges

Table 5.12.3.3-1—Load Factors and Tensile Stress Limits for Construction Load Combinations

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>LOAD FACTORS</th>
<th>STRESS LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dead Load</td>
<td>Live Load</td>
</tr>
<tr>
<td>a</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>b</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>c</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>d</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>e</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>f</td>
<td>1.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

1, 2, 3 indicate different cases or conditions.
AASHTO Bridge Design Specifications

Key Sections:

Chapter 2
General Design and Location Features
• 2.5.3 – Constructibility

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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
Steel I-Girder Bridges

6.10

- 6.10.1 General
- 6.10.2 X-Section Limits
- **6.10.3 Constructibility** (highlighted)
- 6.10.4 Service Limits
- 6.10.5 Fatigue Limits
- 6.10.6 Strength Limits
Steel I-Girder Bridges - 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.

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

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

6.10.3.2.1—Discretely Braced Flanges in Compression

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

\[
f_{bu} + f_\ell \leq \phi_f R_{kc} \frac{F_{ew}}{w}, \quad \bar{F}_{crw} = \text{nominal web bend-buckling resistance (ksi)} \]

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

and

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

New term - What are critical stages of construction?
Steel I-Girder Bridges - Constructibility

What are critical stages of construction?
What are critical stages of construction?

We generally consider all stages as critical stages.
Steel I-Girder – Deck Placement

6.10.3.4—Deck Placement

6.10.3.4.1—General

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

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

The effects of forces from deck overhang brackets acting on the fascia girders shall be considered.
Steel I-Girder – Deck Pour Sequence

6.10.3.4—Deck Placement

6.10.3.4.1—General

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

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

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

Following pour sequence is important!

Images Courtesy of: www.sellwoodbridge.org
Steel I-Girder – Deck Placement
Steel I-Girder – Deck Placement
Steel I-Girder – Contractor Preferred
Steel I-Girder – Deck Pour Overhang Effects

6.10.3.4—Deck Placement

6.10.3.4.1—General

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

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

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

Images Courtesy of: https://www.gamcoform.com/overhang-bracket
Steel I-Girder – Deck Pour Overhang Effects

6.10.3.4—Deck Placement

6.10.3.4.1—General

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

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

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

Overhang torsional analysis guidance included in commentary. C

C6.10.3.4.1

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

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

These stresses are combined with global bending stresses to evaluate the combined effects.
Steel I-Girder – System Stability During Deck Pour

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

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

(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
Designer shall check:

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

6.10.3.1a Stability During Erection

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

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

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

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

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

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

6.10.3.1a (continued)

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

Steel Erection Notes

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

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

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

FHWA-NHI-15-044
ALL MATERIAL TYPES

NSBA / AASHTO S10.1
STEEL BRIDGE SPECIFIC GUIDES

NCHRP Report 725
GUIDELINES FOR ANALYSIS METHODS AND CONSTRUCTION ENGINEERING OF CURVED AND SKewed STEEL GIRDER BRIDGES

44
Steel I-Girder Bridges - System Stability

\[ M_{crG} = C_b \frac{\pi^2 s E}{L_s^2} \sqrt{I_y e I_x} \]  
Eq. 3
Steel I-Girder Bridges - System Stability

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

Equation 5-12
Critical Stages of Construction

7.2.2 Critical Erection Stages

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

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

Contractor / Construction Engineer
Critical Stages of Construction

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

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY
Critical Stages of Construction

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

Gateway Interchange Flyovers, Johnson County, KS
Critical Stages of Construction

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Critical Stages of Construction

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

AASHTO dictates these stages shall be considered by Design Engineer. Should be considered by Design Engineer.

What design reference should a designer use to evaluate?
Wind on Completed Bridge Prior to Deck Pour

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

<table>
<thead>
<tr>
<th>COMPONENT TYPE</th>
<th>CONSTRUCTION CONDITION</th>
<th>FORCE COEFFICIENT (Cₚ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-Shaped Girder Superstructure</td>
<td>Deck forms not in place</td>
<td>2.2 (1)</td>
</tr>
<tr>
<td></td>
<td>Deck forms in place</td>
<td>1.1</td>
</tr>
<tr>
<td>U-Shaped and Box-Girder Superstructure</td>
<td>Deck forms not in place</td>
<td>1.5</td>
</tr>
<tr>
<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>
</tbody>
</table>

Figure 7-12 Girder Wind Load Terminology
AASHTO - Wind During Erection

- Wind acting on the structure.
- Windward face and leeward face of girders.
- Diagram showing wind forces and directions.

[Images and diagrams related to bridge design and wind loads during erection.]
AASHTO - Wind During Erection

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

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

<table>
<thead>
<tr>
<th>Component</th>
<th>Drag Coefficient, ( C_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-Girder and Box-Girder Bridge Superstructures</td>
<td>Windward 1.3, Leeward N/A</td>
</tr>
<tr>
<td>Trusses, Columns, and Arches</td>
<td>Sharp-Edged Member 2.0, Round Member 1.0</td>
</tr>
<tr>
<td>Bridge Substructure</td>
<td>1.6, N/A</td>
</tr>
<tr>
<td>Sound Barriers</td>
<td>1.2, N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6 weeks</td>
</tr>
<tr>
<td>6 weeks to 1 year</td>
</tr>
<tr>
<td>&gt;1-2 years</td>
</tr>
<tr>
<td>&gt;2-3 years</td>
</tr>
<tr>
<td>&gt;3-7 years</td>
</tr>
</tbody>
</table>

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

Final Structure
S/D = 1.0 < 3

Construction (0 to 6 weeks)
R = 0.65

Construction (6 weeks to 1 year)
R = 0.73
Based on research at University of Florida, Funded by FDOT

- Drag Coefficients and Gust Factors vary from AASHTO w/ AASHTO being more conservative

### Table 2.4.3-2 Drag Coefficient During Construction

<table>
<thead>
<tr>
<th>Component Type</th>
<th>S/D ≤ 3</th>
<th>S/D &gt; 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beams/ Girders 1-5</td>
<td>Beam/ Girder 6+</td>
</tr>
<tr>
<td>I-Shaped Steel Girder</td>
<td>2.2</td>
<td>1.1</td>
</tr>
<tr>
<td>I-Shaped Concrete Beam/Girder</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>U-Shaped Beam/ Girder or Steel Box Girder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat Slab or Segmental Box Girder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substructure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PennDOT – Wind Prior to Deck Pour

- Guidance for wind on completed structure prior to deck placement
- Not meant for staged construction analysis
- Provides general rules for designer
PennDOT – Wind Prior to Deck Pour

Lateral Bracing Requirements Based on Span Length

Category 1 - Span > 300ft

Lateral Bracing Required

Category 2 – Span< 200ft

No Lateral Bracing Required

Category 3 – 200 ft < Span < 300ft

Evaluate Need Based on Lateral Deflection
PennDOT – Wind Prior to Deck Pour

Lateral Bracing Requirements Based on Span Length (Cont.)

Category 3 – 200 ft < Span < 300ft

\[ \Delta \] - Displacement Wind no Deck < Must be less than \( \frac{L}{150} \)

Otherwise lateral bracing required
AASHTO Bridge Construction Specifications
AASHTO Bridge Construction Specifications

Key Sections:

Chapter 8
Concrete Structures

- 8.13 – Precast Concrete Members
- 8.16 – Special Provisions for Segmental Bridges
AASHTO Bridge Construction Specifications

Key Sections:

Chapter 8
Concrete Structures
- 8.13 – Precast Concrete Members
- 8.16 – Special Provisions for Segmental Bridges

Chapter 11
Steel Structures
- 11.2 – Erection Drawings
- 11.8 – Additional Provisions for Curved Girders
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.
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 assembly and deck placement, and which shall be consistent with the plan shown in the plans and specifications provided, or may be developed by the Contractor at the Contractor’s option. The plan shall demonstrate the design of the structure and individual components of the system of construction, including while supports and 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
Constructability Summary

• AASHTO Specifications clearly distinguish between complex and conventional for concrete girder bridges …Mostly out of necessity

• AASHTO Specifications are not as clear for steel girder bridges (I-Girder / Box Girder)

• DOT guides have made effort to address
NYSDOT - Steel I-Girder Bridges - Constructibility
Alternate Erection Classification Example - KDOT

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

**FIGURE 736-1**
Special Requirements for Bridge Designers to Designate Erection Plan Categories

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

- If the skew is greater than 30°, move one Category (A to B or B to C).
- If the bridge crosses a river or a highway, refer Category B as a minimum.
- If the Contractor uses falsework bents or string-backs for the field erection, Category C Erection Plans are required.
- The designer may elevate a structure to the necessary Category based upon engineering judgment and unique circumstances.
## Constructability Summary

<table>
<thead>
<tr>
<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>
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</tbody>
</table>
## Constructability Summary

<table>
<thead>
<tr>
<th>Structure Classification</th>
<th>Material</th>
<th>Structure Type</th>
<th>EOR Responsibility</th>
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<tbody>
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</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Shorter Straight Spans (&lt; 200-ft)</td>
<td>No</td>
</tr>
<tr>
<td>Complex</td>
<td>Concrete</td>
<td>Spliced Prestressed Beams / Segmental</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>Long Spans (&gt; 200-ft) / Curved / High Skew</td>
<td>Sometimes</td>
</tr>
</tbody>
</table>
## Constructability Summary

<table>
<thead>
<tr>
<th>Structure Classification</th>
<th>Material</th>
<th>Structure Type</th>
<th>Suggested Construction Plan</th>
<th>Erection Plan Required?</th>
<th>Engineering Required?</th>
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<td>Conventional</td>
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<td>Precast Beams</td>
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<td>Yes</td>
<td>DOT Dependent</td>
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<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>Complex</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>Yes</td>
</tr>
</tbody>
</table>
Critical Stages of Construction

7.2.2 Critical Erection Stages

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

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

AASHTO (Industry) should clarify that all girder systems should be evaluated by the Design Engineer for wind loading prior to slab pour
Add the following new Article C4.6.2.7.3:

\[ C4.6.2.7.3 \]

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

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

Article 4.3.2.4 of the Guide Specifications provides an approximate approach for calculating the lateral wind load...
ANTICIPATED EFFECT ON BRIDGES:

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

Does not address deflection limit states
Steel Girder Erection
Through the Eyes of a Construction Engineer
Steel Girder Erection

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

- 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 Approach</th>
<th>Date</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASD (Allowable Stress Design)</td>
<td>1930’s</td>
<td><img src="https://imgur.com/gallery/Yg6XWq8" alt="Image" /></td>
</tr>
<tr>
<td>( \sigma_{\text{allowable}} \geq \sigma_{\text{demand}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFD (Load Factor Design)</td>
<td>1970’s</td>
<td><img src="https://www.biography.com/news/saturday-night-fever-40th-anniversary" alt="Image" /></td>
</tr>
<tr>
<td>( R_n \geq \text{effects of } \sum \gamma_i Q_i )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD (Load Resistance Factor Design)</td>
<td>1994</td>
<td><img src="https://csengineermag.com/article/john-kulicki-setting-new-standards/" alt="Image" /></td>
</tr>
<tr>
<td>( \phi R_n \geq \text{effects of } \sum \gamma_i Q_i )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

\[
\frac{b}{t} = \frac{3.250}{\sqrt{f_b}} \quad \text{but in no case shall } \frac{b}{t} \text{ exceed 24}
\]  

(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 \( f_b = 0.55 f_y \)
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 10.48.1.2A Limitations for Compact Sections

<table>
<thead>
<tr>
<th>( F_y ) (psi)</th>
<th>36,000</th>
<th>50,000</th>
<th>70,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{b}{t} )</td>
<td>21.7</td>
<td>18.4</td>
<td>15.5</td>
</tr>
<tr>
<td>( D/\rho_0 )</td>
<td>101</td>
<td>86</td>
<td>72</td>
</tr>
<tr>
<td>( L_0/\gamma ) (( M_0/M_n = 0^* ))</td>
<td>100</td>
<td>72</td>
<td>51</td>
</tr>
<tr>
<td>( L_0/\gamma ) (( M_0/M_n = 1^* ))</td>
<td>39</td>
<td>28</td>
<td>20</td>
</tr>
</tbody>
</table>

* For values of \( M/M_0 \) other than 0 and 1, use Equation (10-96).

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:

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

\[b_f \geq D/6, \quad (6.10.2.2-2)\]

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

and:

\[
0.1 \leq \frac{I_{x_c}}{I_{y_l}} \leq 10 \quad (6.10.2.2-4)
\]
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:
  \[
  F_{nc} = R_b R_k F_{yc}
  \]  
  (6.10.8.2.2-1)

- Otherwise:
  \[
  F_{nc} = \left[1 - \frac{F_{yc}}{R_b F_{yc}} \left(\frac{\lambda_f - \lambda_{pf}}{\lambda_{of} - \lambda_{pf}}\right)\right] R_b R_k F_{yc}
  \]  
  (6.10.8.2.2-2)

\[b f / 2 t f < \lambda_{pf}\]
\[b f / t f < 2 \lambda_{pf}\]

in which:

- \(\lambda_f\) = slenderness ratio for the compression flange
  \[\lambda_f = \frac{b_f}{2 t_f}\]  
  (6.10.8.2.2-3)

- \(\lambda_{pf}\) = limiting slenderness ratio for a compact flange
  \[\lambda_{pf} = \frac{0.38 \sqrt{E}}{F_{yc}}\]  
  (6.10.8.2.2-4)

- \(\lambda_{of}\) = limiting slenderness ratio for a noncompact flange
  \[\lambda_{of} = \frac{0.56 \sqrt{E}}{F_{yc}}\]  
  (6.10.8.2.2-5)
Compression Flange Requirements

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

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

- **LRFD**
  \[ 2 \times 0.38 \sqrt{\frac{E}{F_{yc}}} \]

- **ASD / LFD / LRFD**
  \[ \frac{b}{t} \leq 24 \]
Compression Flange Requirements

- ASD / LFD Capacity
- LRFD Capacity

Graph showing flange requirements with parameters such as $F_{nc}$, $R_b F_{yr}$, $\lambda_{pf}$, and $\lambda_{rf}$.
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

• But….  
  • More complicated rigging  
  • More difficult fitup of splices

KY 152 over Herrington Lake, Mercer and Garrard Counties, KY
Curved Girder Pick

Fulbright Expressway, Fayetteville, AR

Gateway Interchange Flyovers, Johnson County, KS
Curved Girder Pick

Girder Center of Gravity

28. Sector of Thin Annulus

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

Girder Center of Gravity for fabricated steel

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

Spreader Shorter Than Ideal Length

Image Courtesy of: UTLift
Curved Girder Pick

Ideal Spreader Length

- Improved Stability
- Improved Serviceability (rotation)

9” Lateral Displacement

100-ft Spread
Curved Girder Pick

Shorter Than Ideal Spreader Length

72-ft Spreader

20” Lateral Displacement
Curved Girder Pick – UT Lift

• UT Lift Software used for curved girder hoisting analysis
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

\[ M_u < \phi_b M_{cr} = \phi \frac{C_{bl}}{L_b} \sqrt{\frac{\pi^2}{L_b} \left( \frac{E l_G J}{E l_G J} + E^2 I_g C_w \left( \frac{\pi^2}{L_b^2} \right) \right)} \]

\[ L_b = \text{Unbraced length} = L \text{ (total length of girder segment)} \]

\[ C_{bl} = \begin{cases} 2.0 & \text{for } \frac{L_{lift}}{L} \leq 0.225 \\ 6.0 & \text{for } 0.225 < \frac{L_{lift}}{L} < 0.3 \\ 4.0 & \text{for } \frac{L_{lift}}{L} \geq 0.3 \end{cases} \]
Rigging – Single Girder Spreader

Beam Clamps

Singles

Spreader

Vertical Slings

Single Crane

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

Two Crane

Gateway Interchange Flyovers, Johnson County, KS

Spreader

Field Splice Fully Bolted

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 together 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
Beam Clamps

\[ f_{dp} = \frac{R \cdot k}{(b_f + C_L)(t_f)^2/6} \]

\[ f_{st} \leq 0.75 \cdot F_{sy} \]

Where:
- \( R_c \) = service level concentrated force at each flange edge (kip)
- \( F_{sy} \) = 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

Spreader

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

\[
f_{cu} + f_c \leq \phi_f R_f F_w, \quad (6.10.3.2.1-1)
\]

\[
f_{cu} + \frac{1}{3} f_c \leq \phi_f F_w, \quad (6.10.3.2.1-2)
\]

and

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

6.10.3.2.2—Discretely Braced Flanges in Tension

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

\[
f_{ct} + f_c \leq \phi_f R_f F_m \quad (6.10.3.2.2-1)
\]
Critical Stages of Construction

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

Gateway Interchange Flyovers, Johnson County, KS
Staged Construction Evaluation
Single Girder Stability
Single Girder Stability

DL Moment

Helper Crane

DL Moment Reduced

STAGED CONST.
Girder System Stability

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

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

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

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

- \( P = 1 \text{ kip} \)
- Eigenvalue = 262
- FOS = 262

- \( P = 262 \text{ kip} \)
- Eigenvalue = 1
- FOS = 1
Eigenvalue & 2\textsuperscript{nd} 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
- \( \frac{M_{\text{cr}G}}{M_{\text{max}G}} = \text{Eigenvalue} \)
- Equation uses \( \frac{M_{\text{max}G}}{M_{\text{cr}G}} = \frac{1}{\text{Eigenvalue}} \)
Eigenvalue & 2nd Order Nonlinear Analysis

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

- Second order effects may be neglected
  - \( AF_G < 1.10 \)
  - Eigenvalue > 11
- Second order 3D FEM recommended
  - \( AF_G > 1.25 \)
  - Eigenvalue < 5
Eigenvalue & 2\textsuperscript{nd} Order Nonlinear Analysis

- Incremental application of load
- Updating of stiffnesses
- Iteration

Second order analysis converges to eigenvalue

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

Eigenvalue $= 2.33$

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

Second Order Analysis Req’d

Center Pier

Abutment

Falsework

STAGED CONST.
System Buckling Case Study

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

![Graph showing Lateral Deflection (in) vs Load Factor with a blue line labeled Dead Load Only.](image)

- Load Factor
- Lateral Deflection (in)

Dead Load Only
System Buckling Case Study

Load Factor vs. Lateral Deflection (in)

- Dead Load Only
- Dead Load + Wind 40mph
System Buckling Case Study

Load Factor

Lateral Deflection (in)

Dead Load Only

Dead Load + Wind 40mph

Dead Load + Wind 90mph
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
Geometry Control Studies

Negative Tip Deflection:

Positive Tip Deflection:
Girder Stiffening Truss

Whittier Memorial Bridge, Newburyport and Amesbury, MA
Questions?

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