Economical Steel Bridge Design & Skewed Bridge Considerations

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Topics on Steel Girder Design

SPAN ARRANGEMENT CONSIDERATIONS
Structural Unit Lengths

• Single multi-span unit preferred over many simple spans or several continuous-span units
• Eliminating simple spans and deck joints provides savings in:
  • Bearings
  • Cross-frames
  • Expansion devices
Balanced Spans

• End spans ideally 75% - 80% of center span

Yields approximately equal maximum positive moments in the end and interior spans
Balanced Spans
Span Optimization

Optimal Span Length = 175.0 ft.

Estimated Cost ($/ft)

Span Length (ft)
Topics on Steel Girder Design

CROSS-SECTION LAYOUT CONSIDERATIONS
Girder Spacing

Benefits of minimizing number of girder lines:

• Fewer girders to fabricate, inspect, coat, ship and erect
• Fewer bearings to purchase, install and maintain
• Fewer bolts and welded flange splices
• Reduced fabrication and erection time
• Stiffer structure with smaller relative girder deflections
• Reduced out-of-plane rotations
Girder Spacing
Future Redecking Under Traffic

• **Issues to consider:**
  - Girder capacity
  - Stability
  - Uplift
  - Cross-frame forces

• Skewed and horizontally curved girder bridges can be particularly problematic during redecking
Deck Overhangs

- Goal – economical cross-section
  - Balance spacing & overhang so that interior/exterior girders are nearly the same size
Deck Overhangs
Dead Load Distribution

- For the cases shown, distribute the noncomposite DC₁ loads equally to each girder (vs. tributary area)
Deck Overhangs
Dead Load Distribution

• Assign a larger percentage of the composite DC₂ loads to the exterior girders & the adjacent interior girders

• Distribute wearing surface load DW equally to all the girders
Deck Overhangs
Live Load Distribution

- Apply special cross-section analysis to determine the live load distribution to the exterior girders

- Assumes the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge:

\[
R = \frac{N_L}{N_b} + \frac{X_{\text{ext}} \sum N_L e}{\sum N_b x^2}
\]

Eq. (C4.6.2.2.2d-1)
Deck Overhangs

- Total factored moment tends to be larger in exterior girders (also subject to overhang loads)
- Limit size of deck overhangs accordingly

\[ \text{S (typ)} \]

\[
\begin{align*}
0.25S & \quad \text{To} \\
0.33S & \\
\end{align*}
\]
Topics on Steel Girder Design

FRAMING-PLAN LAYOUT CONSIDERATIONS
Field-Section Size

• Field sections are girder sections fabricated and shipped to the bridge site
• Handling and shipping requirements affect the field section lengths selected for design
Field-Section Size
I-Girders

- Shipment by truck is the most common means
  - 175 ft. Possible, 80 ft. Comfortable
  - 100 Tons Maximum, 40 Tons No Permit
  - 16 ft. Width Maximum
  - 10 ft. Height
Field-Section Size
L/b Ratio

• L/b Ratio (Art. C6.10.2.2):

\[ b_{tfs} \geq \frac{L_{fs}}{85} \]

\( b_{tfs} = \) smallest top flange width within the unspliced girder field section (in.)

\( L_{fs} = \) length of unspliced girder field section (in.)
Cross-Frame & Diaphragm Spacing Requirements

Based on rational analysis

• Nearly uniform spacing desirable
• Satisfy flange resistance requirements

\[ L_b = \text{Spacing} \]
Cross-Frame Spacing Trade-Offs

- **Closer spacing**
  - Lower cross-frame forces
  - Lower lateral flange moments
  - Higher compression-flange capacity
  - Higher cross-frame cost

- **Larger spacing**
  - Lower cross-frame cost
  - Larger cross-frame forces
  - Larger lateral flange moments
  - Lower compression-flange capacity
## Preliminary Cross-Frame Spacing

<table>
<thead>
<tr>
<th>Region</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Spans &amp; Positive Moment Regions in End Spans</td>
<td>18 to 25 ft</td>
</tr>
<tr>
<td>Positive Moment Regions in Interior Spans</td>
<td>24 to 30 ft</td>
</tr>
<tr>
<td>Negative Moment Regions</td>
<td>18 to 24 ft</td>
</tr>
</tbody>
</table>
Topics on Steel Girder Design

I-GIRDER PROPORTIONING CONSIDERATIONS
I-Girder Web Proportioning
Optimum Web Depth

• **Optimum Web Depth**
  - Not always possible to achieve optimum depth due to clearance issues or unbalanced spans
  - Provides minimum cost girder in absence of depth restrictions
  - Function of many factors – elusive for composite girders
  - May be established based on series of designs with different web depths to arrive at an optimum depth based on weight and/or cost factors
I-Girder Web Proportioning
Span-to-Depth Ratio

- Span-to-Depth Ratio (Art. 2.5.2.6.3)

**Suggested Minimum Overall Depth for Composite I-beam**

<table>
<thead>
<tr>
<th>Simple Spans</th>
<th>0.040L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous spans</td>
<td>0.032L</td>
</tr>
</tbody>
</table>

**Suggested Minimum Depth for I-beam**

<table>
<thead>
<tr>
<th>Simple Spans</th>
<th>0.033L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous spans</td>
<td>0.027L</td>
</tr>
</tbody>
</table>
• Steel Girder Analysis AND Preliminary Design Program
• I-Girders AND Box Girders

• FREE OF CHARGE!

www.steelbridges.org  Design Resources
What Does LRFD SIMON Do?

• Line girder analysis of steel beams
  ➢ Based on user-defined or program-defined distribution factors

• Iterative design

• Complete AASHTO LRFD code checking (8th Edition)

• Cost analysis based on user-input cost factors

• Customizable processes and output
LRFD SIMON Capabilities

- Simple span or up to 12 continuous spans
- 20 nodes per span
- 1/10th point influence lines
- Partial or full-length dead loads
- AASHTO or user-defined live loads
- Transversely stiffened webs with or without longitudinal stiffeners or unstiffened webs
- Bearing stiffeners
- Parabolic or linear web haunches
- Homogenous or hybrid cross-sections
LRFD SIMON – Optimization Approach

• Automatic incremental design changes to achieve convergence
• Alternatively, can run program for one design cycle for evaluation & make design changes manually
• User must still control what options are explored
  ➢ Web depth? Stiffened?
  ➢ Flange size ranges
  ➢ Material grade(s)
• Successful run does not necessarily mean a good design
• “Best” solution still depends on the Engineer
# I-Girder Web Proportioning

## Web Depth Optimization – LRFD SIMON

### DEPTH VARIATION ANALYSIS

<table>
<thead>
<tr>
<th>Filename</th>
<th>Depth</th>
<th>Weight</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMONTUTORIAL_BELOW3</td>
<td>61.00</td>
<td>245.67</td>
<td>513546</td>
</tr>
<tr>
<td>SIMONTUTORIAL_BELOW2</td>
<td>63.00</td>
<td>242.74</td>
<td>508186</td>
</tr>
<tr>
<td>SIMONTUTORIAL_BELOW1</td>
<td>65.00</td>
<td>243.00</td>
<td>509408</td>
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<tr>
<td>SIMONTUTORIAL</td>
<td>67.00</td>
<td>239.88</td>
<td>502815</td>
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<tr>
<td>SIMONTUTORIAL_ABOVE1</td>
<td>69.00</td>
<td>240.66</td>
<td>504648</td>
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<tr>
<td>SIMONTUTORIAL_ABOVE2</td>
<td>71.00</td>
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<tr>
<td>SIMONTUTORIAL_ABOVE3</td>
<td>73.00</td>
<td>248.12</td>
<td>518250</td>
</tr>
</tbody>
</table>
I-Girder Web Proportioning

Web Thickness

- Web Thickness (Art. 6.10.2.1)

<table>
<thead>
<tr>
<th></th>
<th>Without Longitudinal Stiffeners</th>
<th>With Longitudinal Stiffeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{D}{t_w} )</td>
<td>( \leq 150 )</td>
<td>( \leq 300 )</td>
</tr>
</tbody>
</table>

- \( \frac{1}{2} \)" minimum thickness preferred by fabricators
I-Girder Flange Proportioning

• Proportioning Requirements (Art. 6.10.2.2):

\[ \frac{b_f}{2t_f} \leq 12 \]

\[ b_f \geq \frac{D}{6} \]

\[ t_f \geq 1.1 \, t_w \]

\[ \frac{1}{l_{yc}} \leq 10 \leq \frac{1}{l_{yt}} \]

Fabricators prefer: \( b_f \geq 12 \text{ in.}; t_f \geq 0.75 \text{ in.} \)
I-Girder Flange Proportioning
Deck Overhang Loads

- Deck Overhang Loads:
  - Significant effects on exterior girders
  - Amplified top flange lateral bending stresses may be 10 to 15 ksi

\[
f_{bu} + f_{\ell} \leq \phi_f R_h F_{yc}
\]

\[
f_{bu} + \frac{1}{3} f_{\ell} \leq \phi_f F_{nc}
\]
I-Girder Flange Proportioning
Sizing Flanges for Efficient Fabrication

• Minimum plate size from mill is 48”
• Most economical plate size from mill is 72" to 96"
• Consider sizing flanges so that as many pieces as possible can be obtained from a wide plate of a given grade and thickness with minimal waste
• Limit the number of different flange plate thicknesses specified for a given project
I-Girder Flange Proportioning  
Sizing Flanges for Efficient Fabrication

- Weld shop splices after cutting individual flanges from a single plate
- Cut multiple flange plates from slab welded plates
I-Girder Flange Proportioning
Flange Thickness Transitions

• Affected by plate length availability and economics of welding and inspecting a splice vs. extending a thicker plate
  • Optimal ordered plate lengths usually ≤ 80 feet
  • A welded I-girder flange splice is equivalent to 800 to 1,200 lbs of steel plate
• Three or fewer flange thicknesses per flange (or two shop splices) should be used in a typical field section
• Reduce flange area by no more than one-half the area of the thicker plate at shop splice
Skewed Supports

• Skewed supports are frequently required to span highways and streams not perpendicular to the bridge alignment

• Allow for reduced girder span lengths and bridge deck area, as well as reduced girder depths

• Increased torsion in the girders, larger than normal cross-frame forces, unique thermal movements, large differential deflections, longer abutments and piers

• The significance of skew increases with increasing skew and bridge width
Detail A
End Cross Frame
at
Skewed Support
Skewed Example Bridge
Dead Load (DC₁) Deflections

<table>
<thead>
<tr>
<th>DC₁ (unfactored) in.</th>
<th>Spans 1&amp;3 Right Bridge Line Girder Analysis</th>
<th>Spans 1&amp;3 Right Bridge 3D Analysis</th>
<th>Span 1 Skewed Bridge 3D Analysis</th>
<th>Span 2 Skewed Bridge 3D Analysis</th>
<th>Span 3 Skewed Bridge 3D Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>-3.15</td>
<td>-3.11</td>
<td>-4.18</td>
<td>-3.67</td>
<td>-2.56</td>
</tr>
<tr>
<td>G3</td>
<td>-3.15</td>
<td>-3.16</td>
<td>-2.57</td>
<td>-3.40</td>
<td>-3.12</td>
</tr>
<tr>
<td>G4</td>
<td>-3.15</td>
<td>-3.11</td>
<td>-2.56</td>
<td>-3.67</td>
<td>-4.18</td>
</tr>
</tbody>
</table>
# Dead Load (DC₁) Deflections

Discontinuous Cross-Frames

<table>
<thead>
<tr>
<th>DC₁ (unfactored) in.</th>
<th>Span 1&amp;3 Right Bridge Line Girder Analysis</th>
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<th>Span 1 Skewed Bridge 3D Analysis</th>
<th>Span 2 Skewed Bridge 3D Analysis</th>
<th>Span 3 Skewed Bridge 3D Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>-3.15</td>
<td>-3.11</td>
<td>-3.68</td>
<td>-2.82</td>
<td>-3.01</td>
</tr>
<tr>
<td>G2</td>
<td>-3.15</td>
<td>-3.16</td>
<td>-2.81</td>
<td>-2.46</td>
<td>-2.61</td>
</tr>
<tr>
<td>G3</td>
<td>-3.15</td>
<td>-3.16</td>
<td>-2.61</td>
<td>-2.46</td>
<td>-2.81</td>
</tr>
<tr>
<td>G4</td>
<td>-3.15</td>
<td>-3.11</td>
<td>-3.01</td>
<td>-2.82</td>
<td>-3.68</td>
</tr>
</tbody>
</table>
Skew Effects

Flange Lateral Bending

• Flange lateral bending should be considered where discontinuous cross-frames are used in conjunction with skews exceeding 20°.
• Lateral bending is usually smaller in the exterior girders than in the interior girders in these cases.
• Flange lateral bending in these cases is probably best handled by a direct structural analysis of the entire superstructure.
• In lieu of a refined analysis, Article C6.10.1 suggests total unfactored flange lateral bending stresses $f_\ell$ to use for the preceding cases.
?? QUESTIONS ??