Economical Steel Bridge Design & Skewed Bridge Considerations

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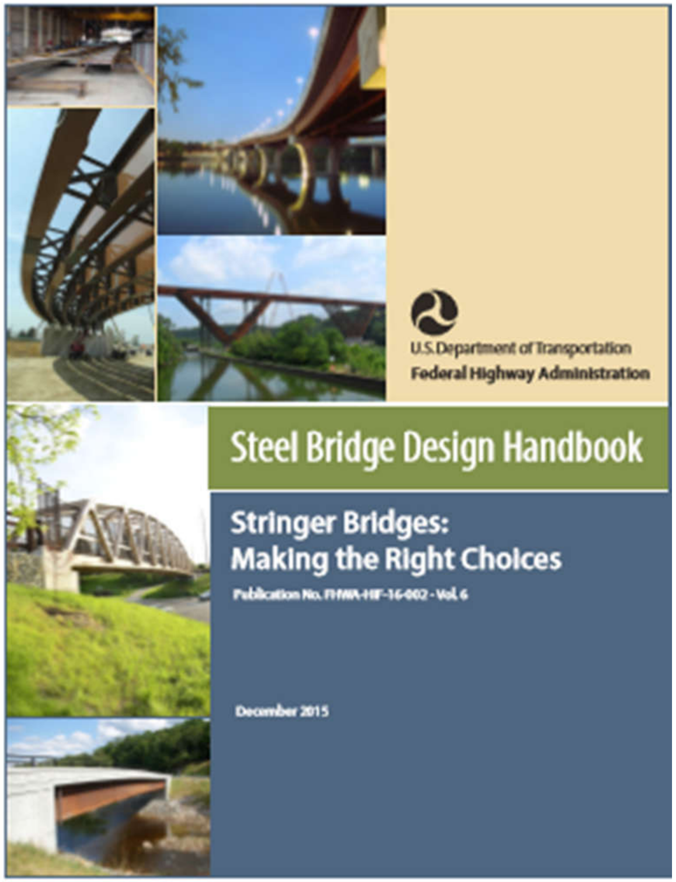

U.S. Department of Transportation
Federal Highway Administration

Steel Bridge Design Handbook

**Stringer Bridges:
Making the Right Choices**

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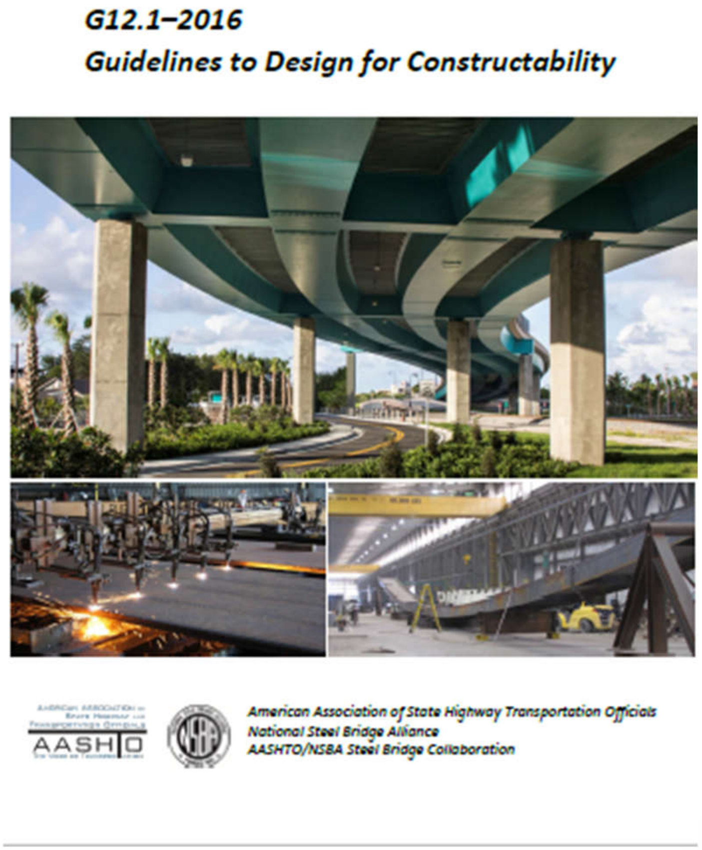

G12.1–2016
Guidelines to Design for Constructability

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Topics on Steel Girder Design

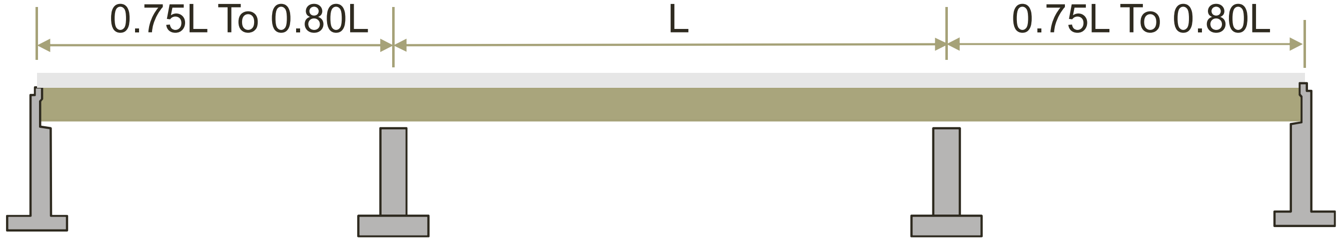
SPAN ARRANGEMENT CONSIDERATIONS

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

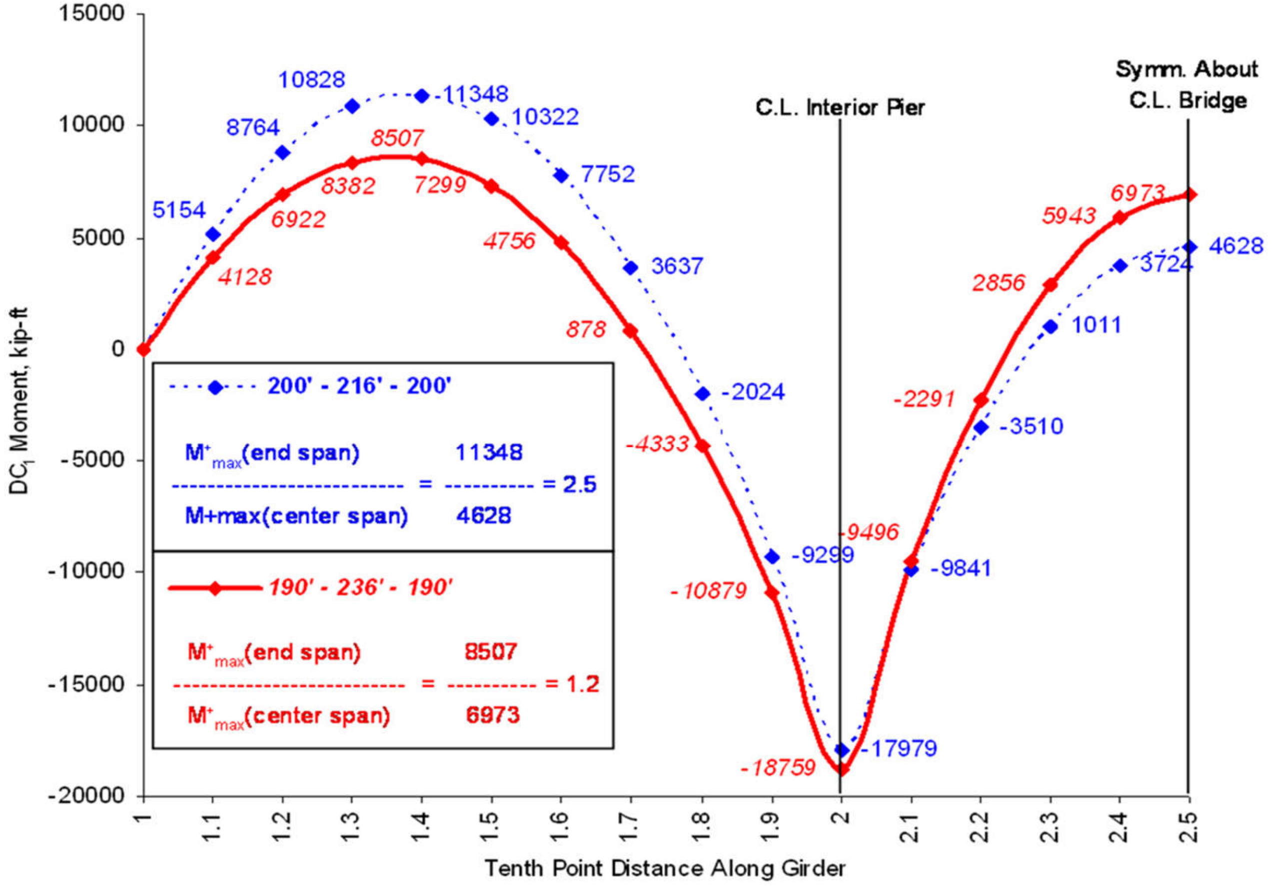
- End spans ideally 75% - 80% of center span



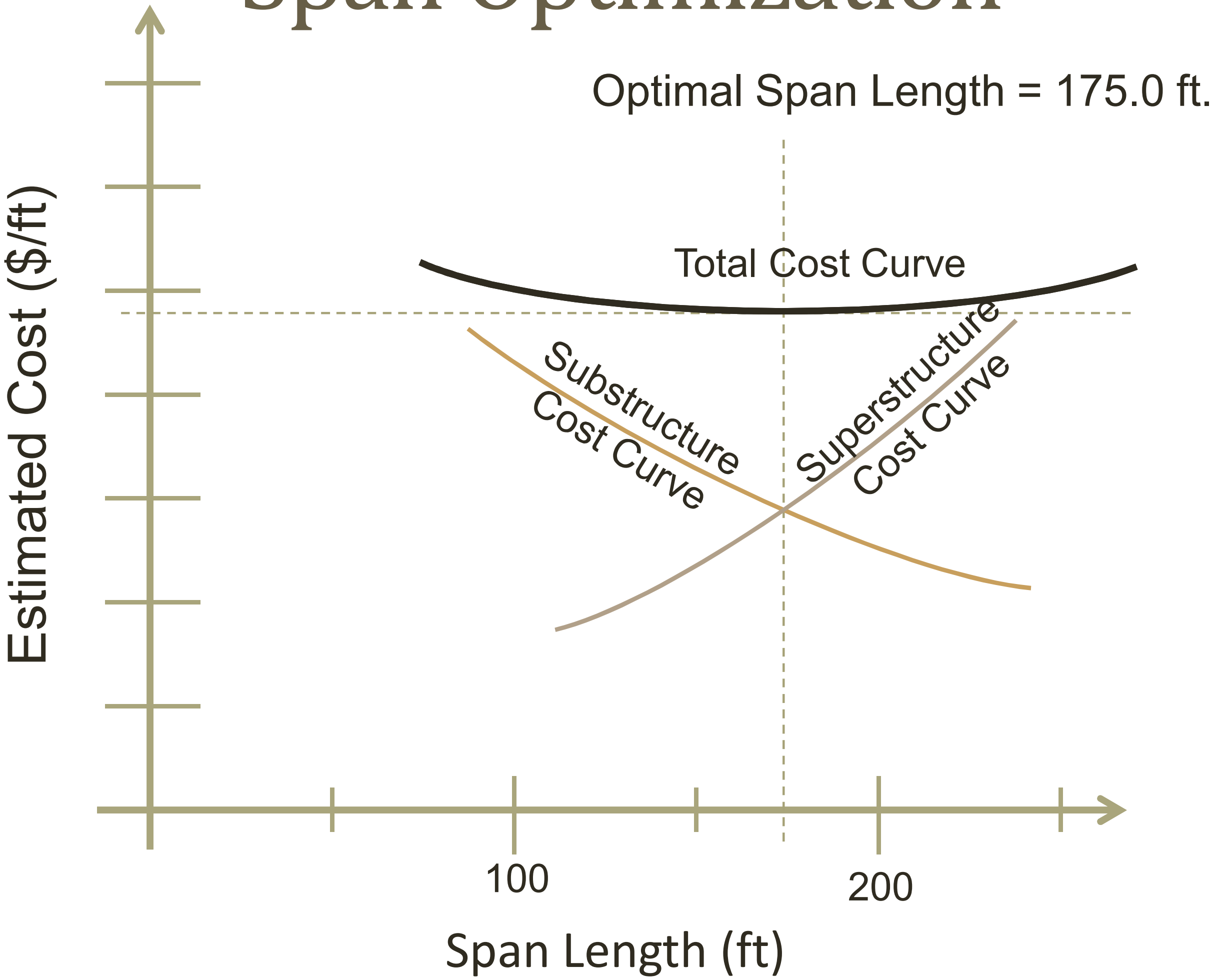
Balanced Span Arrangement

- Yields approximately equal maximum positive moments in the end and interior spans

Balanced Spans



Span Optimization



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

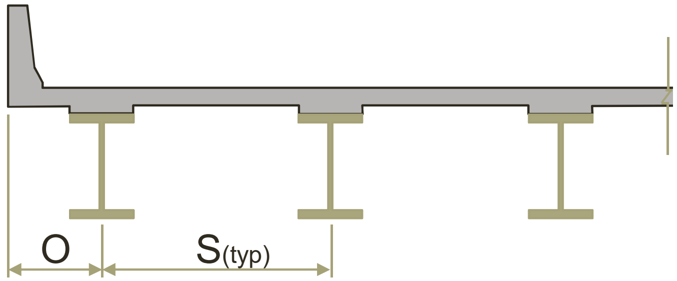
Future Redecking Under Traffic

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

- Skewed and horizontally curved girder bridges can be particularly problematic during redecking

Deck Overhangs

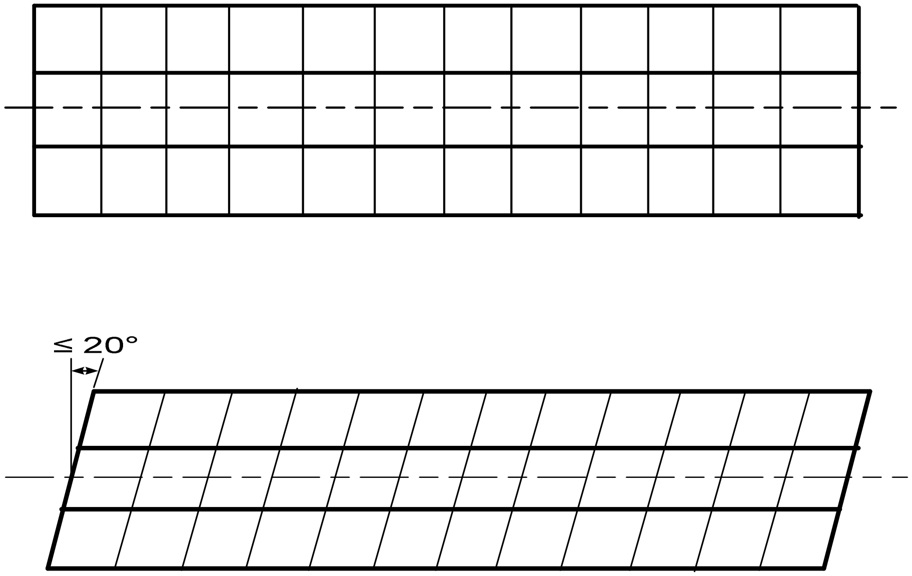
- Goal – economical cross-section
  - Balance spacing & overhang so that interior/exterior girders are nearly the same size



Deck Overhangs

Dead Load Distribution

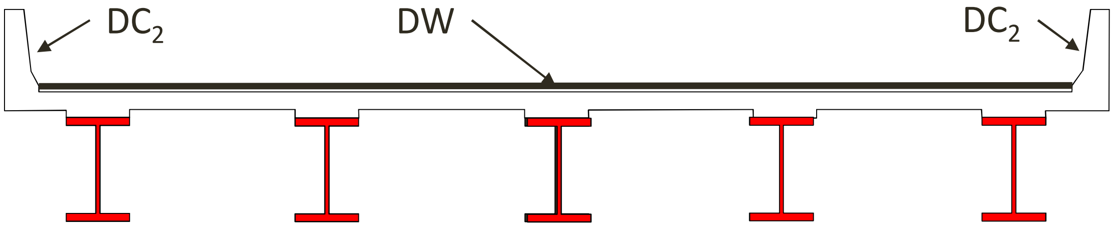
- For the cases shown, distribute the noncomposite DC_1 loads equally to each girder (vs. tributary area)



Deck Overhangs

Dead Load Distribution

- Assign a larger percentage of the composite DC_2 loads to the exterior girders & the adjacent interior girders



- Distribute wearing surface load DW equally to all the girders

Deck Overhangs

Live Load Distribution

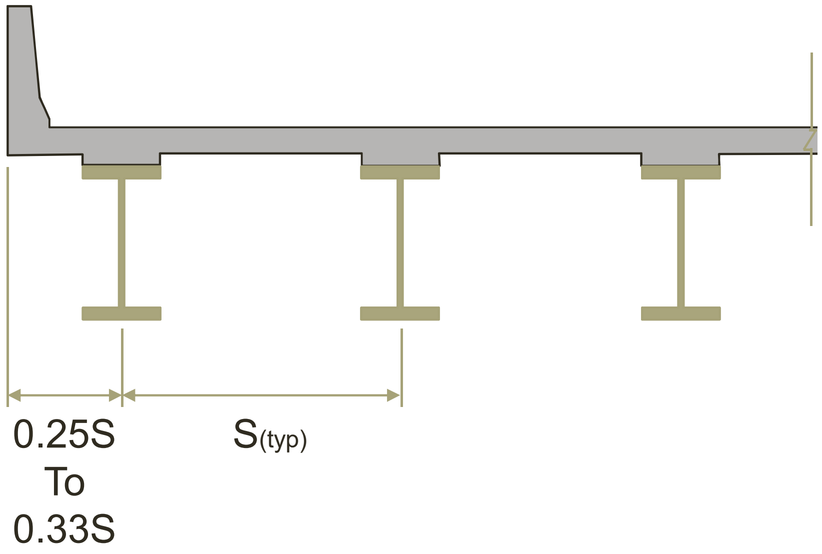
- Apply special cross-section analysis to determine the live load distribution to the exterior girders
  - Assumes the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge:

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

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



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

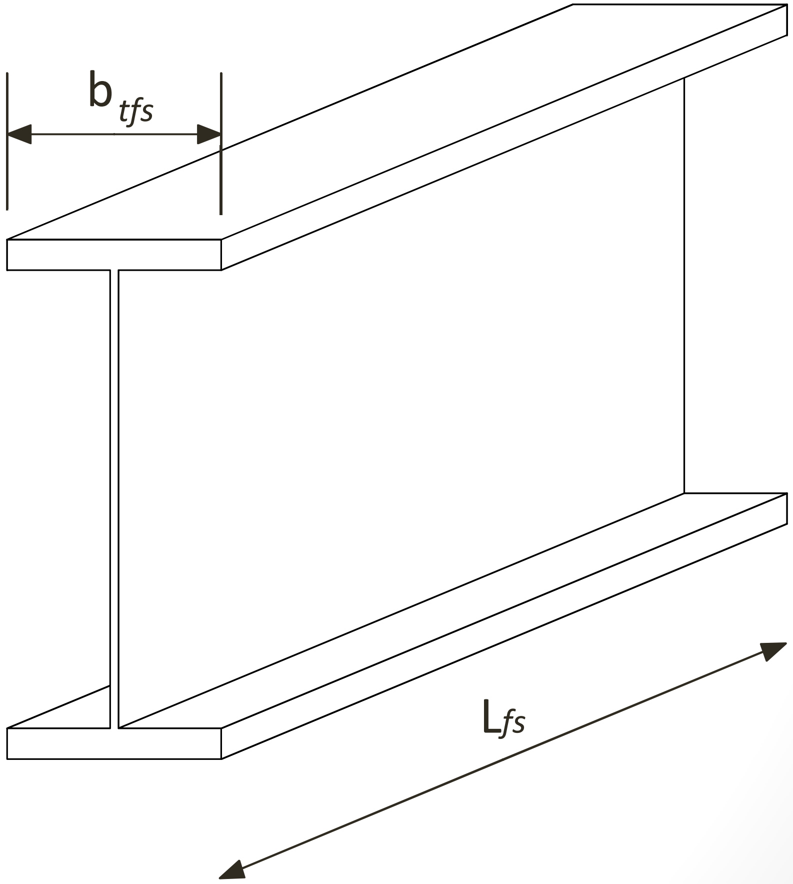
L/b Ratio

- **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.)

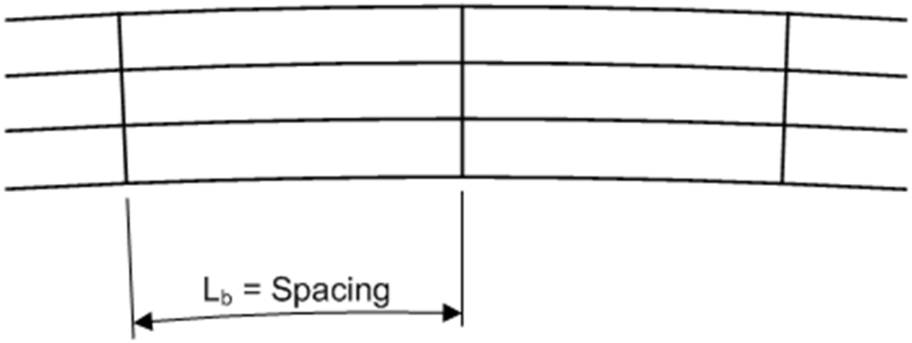
L_{fs} = length of unspliced girder field section (in.)



Cross-Frame & Diaphragm Spacing Requirements

Based on rational analysis

- Nearly uniform spacing desirable
- Satisfy flange resistance requirements



Cross-Frame Spacing Trade-Offs

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

    vs.
  - Higher cross-frame cost
- Larger spacing
  - Lower cross-frame cost

    vs.
  - Larger cross-frame forces
  - Larger lateral flange moments
  - Lower compression-flange capacity

Preliminary Cross-Frame Spacing

Simple Spans & Positive Moment Regions in End Spans	18 to 25 ft
Positive Moment Regions in Interior Spans	24 to 30 ft
Negative Moment Regions	18 to 24 ft

Topics on Steel Girder Design

I-GIRDER PROPORTIONING CONSIDERATIONS

I-Girder Web Proportioning

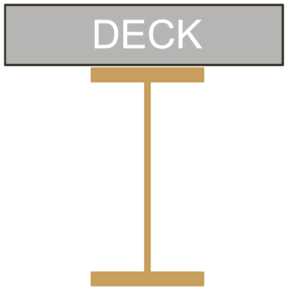
Optimum Web Depth

- **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

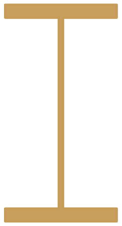
Span-to-Depth Ratio

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



Simple Spans	0.040L
Continuous spans	0.032L

Suggested Minimum Overall Depth for Composite I-beam

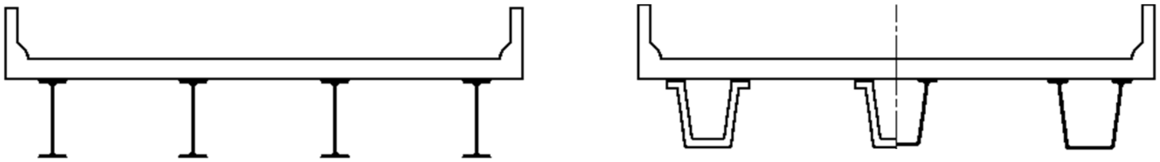


Simple Spans	0.033L
Continuous spans	0.027L

Suggested Minimum Depth for I-beam

LRFD SIMON
SOFTWARE SOLUTION FOR PRELIMINARY BRIDGE DESIGN

- 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

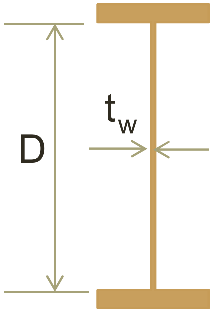
```
DEPTH VARIATION ANALYSIS
========================

                                        Depth     Weight      Cost
           Filename                     Inch       Tons        $
   -------------------------          ----------  ----------  ----------
  SIMONTUTORIAL_BELOW3                  61.00     245.67     513546
  SIMONTUTORIAL_BELOW2                  63.00     242.74     508186
  SIMONTUTORIAL_BELOW1                  65.00     243.00     509408
  SIMONTUTORIAL                         67.00     239.88     502815
  SIMONTUTORIAL_ABOVE1                  69.00     240.66     504648
  SIMONTUTORIAL_ABOVE2                  71.00     242.04     507768
  SIMONTUTORIAL_ABOVE3                  73.00     248.12     518250
```

I-Girder Web Proportioning

Web Thickness

- Web Thickness (Art. 6.10.2.1)



Without Longitudinal Stiffeners	$\frac{D}{t_w} \leq 150$
With Longitudinal Stiffeners	$\frac{D}{t_w} \leq 300$

- ½" minimum thickness preferred by fabricators

I-Girder Flange Proportioning

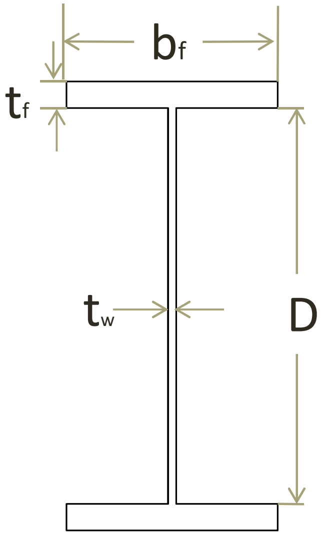
- Proportioning Requirements (Art. 6.10.2.2):

$$\frac{b_f}{2t_f} \leq 12$$

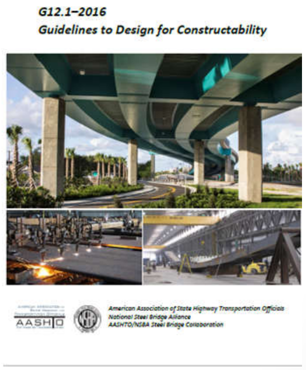
$$b_f \geq \frac{D}{6}$$

$$t_f \geq 1.1\, t_w$$

$$0.1 \leq \frac{I_{yc}}{I_{yt}} \leq 10$$



$$b_{tfs} \geq \frac{L_{fs}}{85}$$



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Fabricators prefer: $b_f \geq 12$ in.; $t_f \geq 0.75$ in.

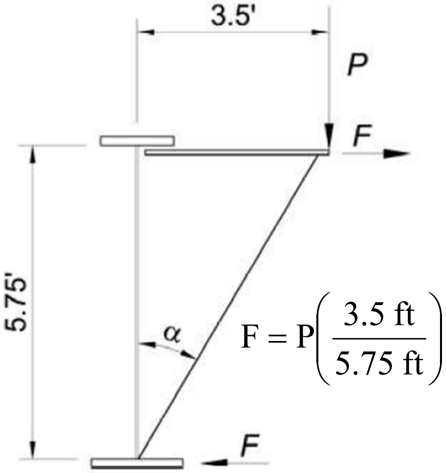
I-Girder Flange Proportioning

Deck Overhang Loads

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

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

$$f_{bu} + \frac{1}{3} f_{\ell} \leq \phi_f F_{nc}$$



$$F = P\left(\frac{3.5\text{ ft}}{5.75\text{ ft}}\right)$$

$$M_{\ell} = \frac{FL_b^2}{12}$$

$$f_{\ell} = \frac{M_{\ell}}{\left(t_f b_f^2/6\right)}$$

I-Girder Flange Proportioning

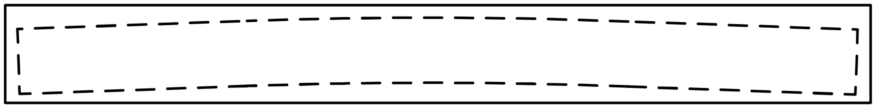
Sizing Flanges for Efficient Fabrication

- 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

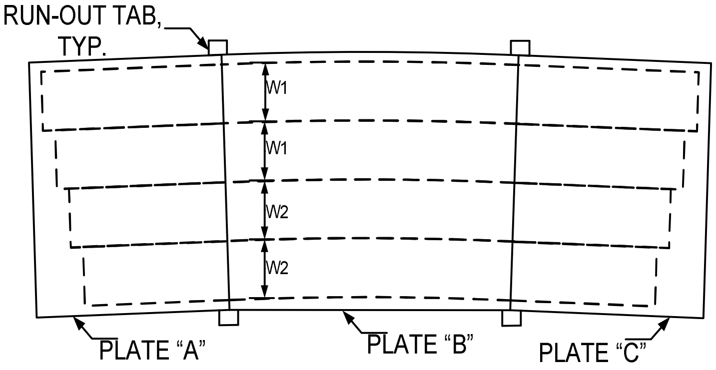
I-Girder Flange Proportioning

Sizing Flanges for Efficient Fabrication

- Weld shop splices after cutting individual flanges from a single plate



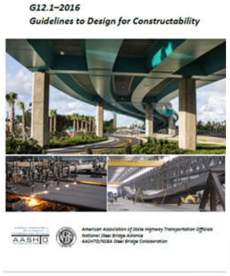
- Cut multiple flange plates from slab welded plates



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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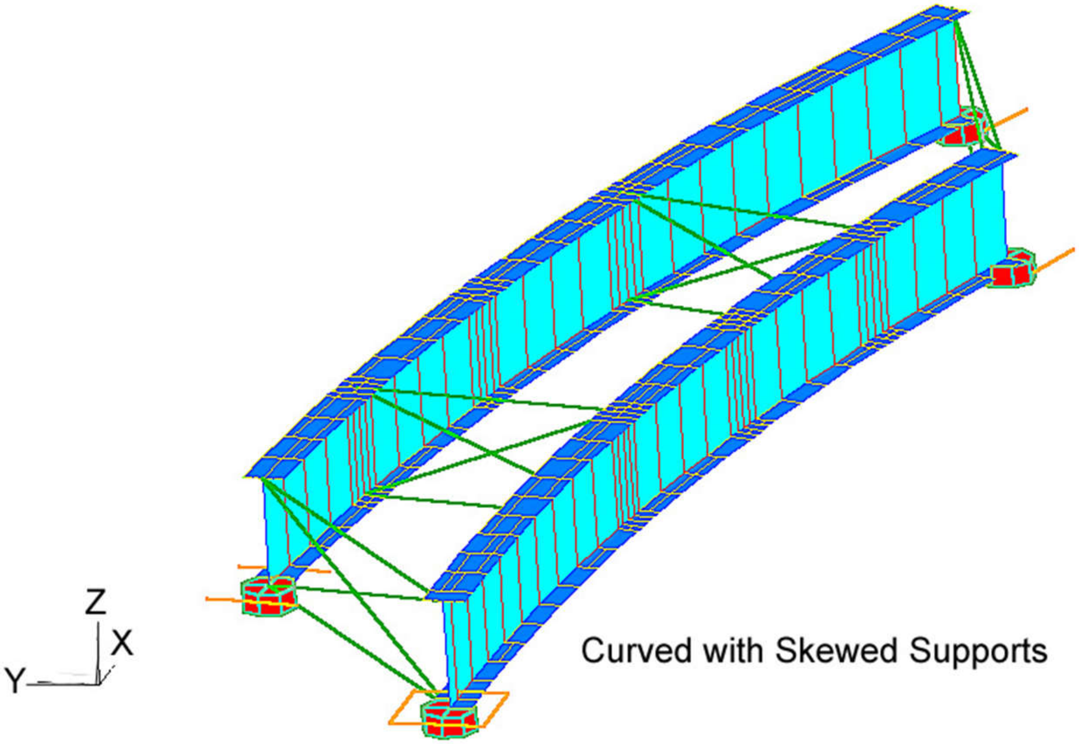
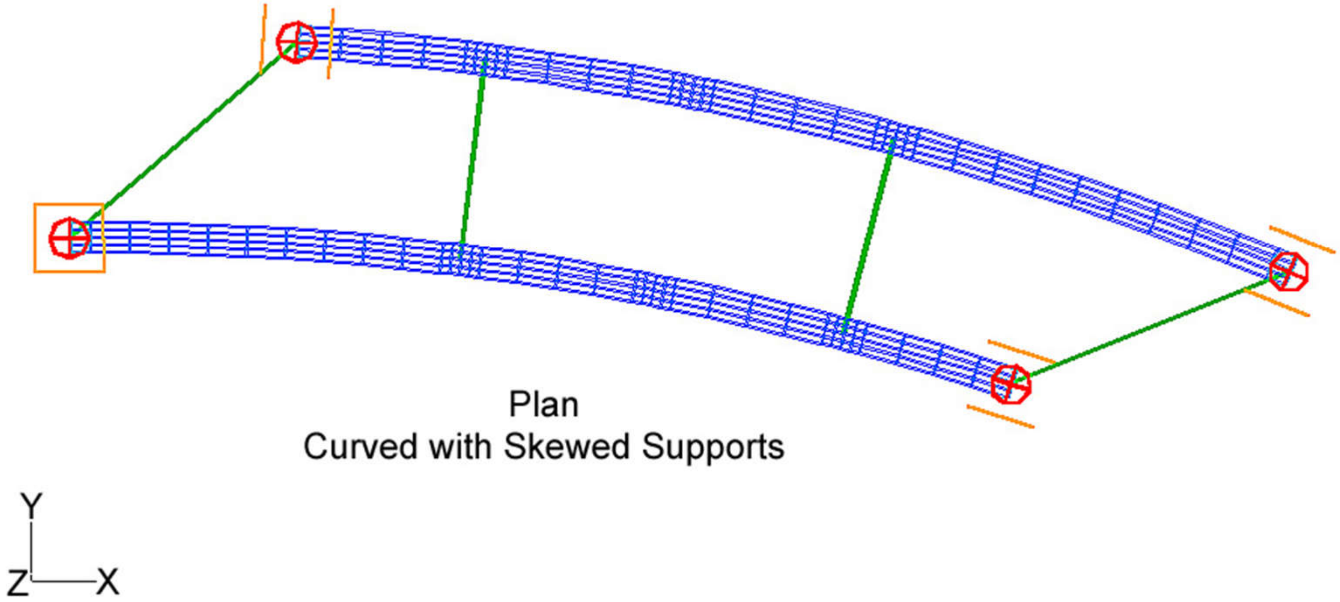
Skewed Supports

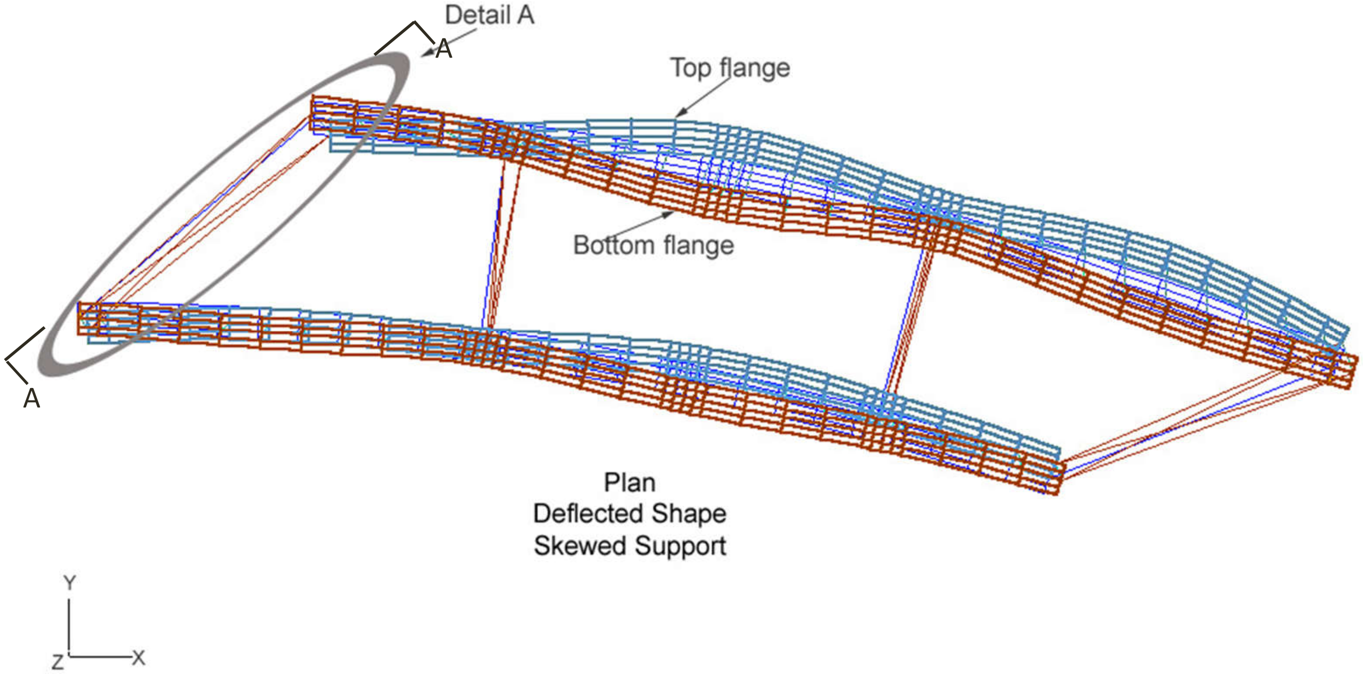
- Skewed supports are frequently required to span highways and streams not perpendicular to the bridge alignment
- Allow for reduced girder span lengths and bridge deck area, as well as reduced girder depths
- Increased torsion in the girders, larger than normal cross-frame forces, unique thermal movements, large differential deflections, longer abutments and piers
- The significance of skew increases with increasing skew and bridge width



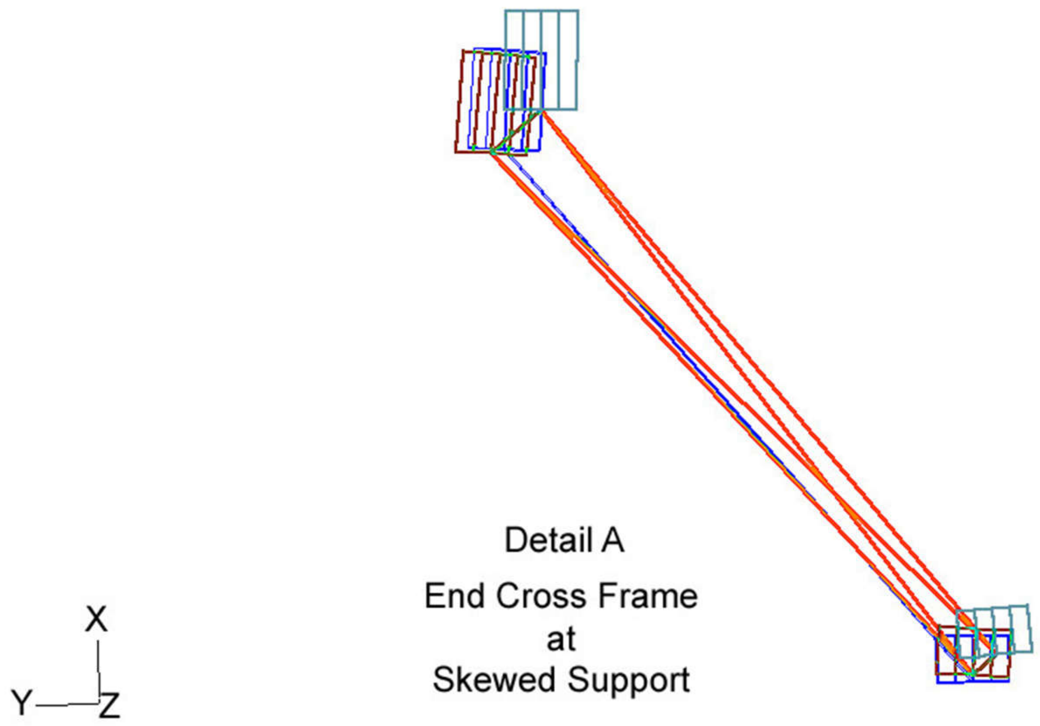
Curved with Skewed Supports


Plan

Curved with Skewed Supports

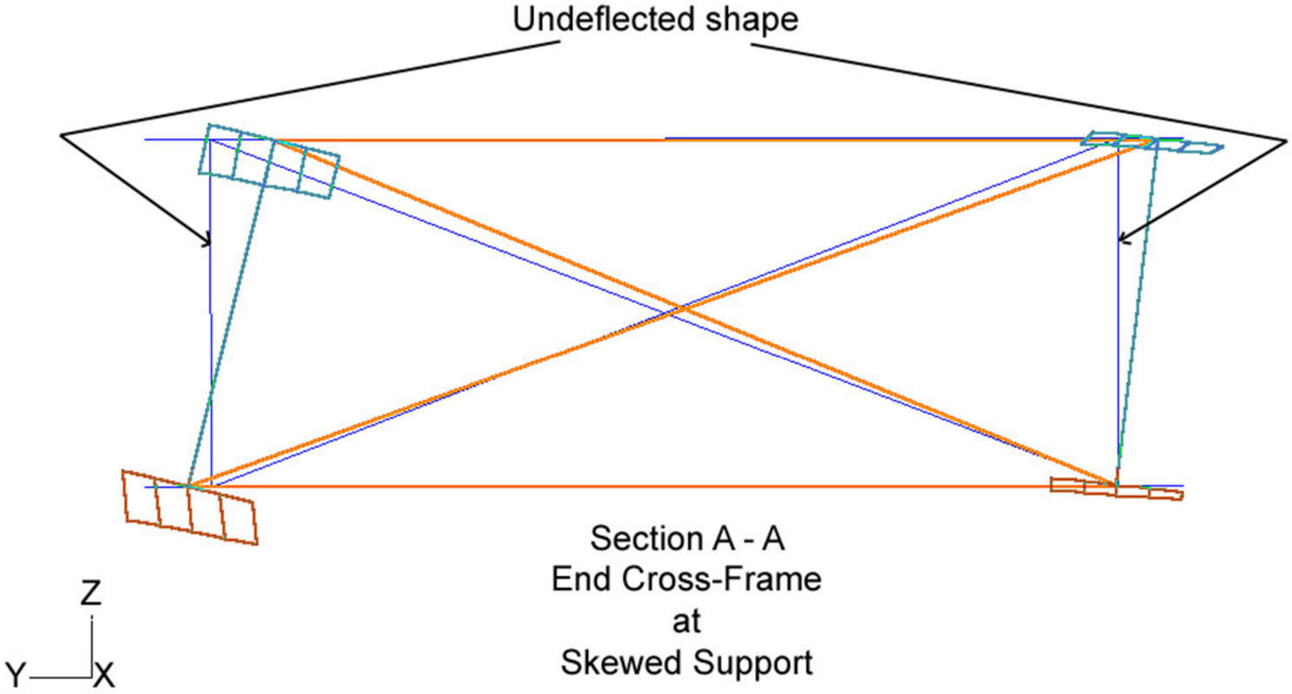


Plan
Deflected Shape
Skewed Support

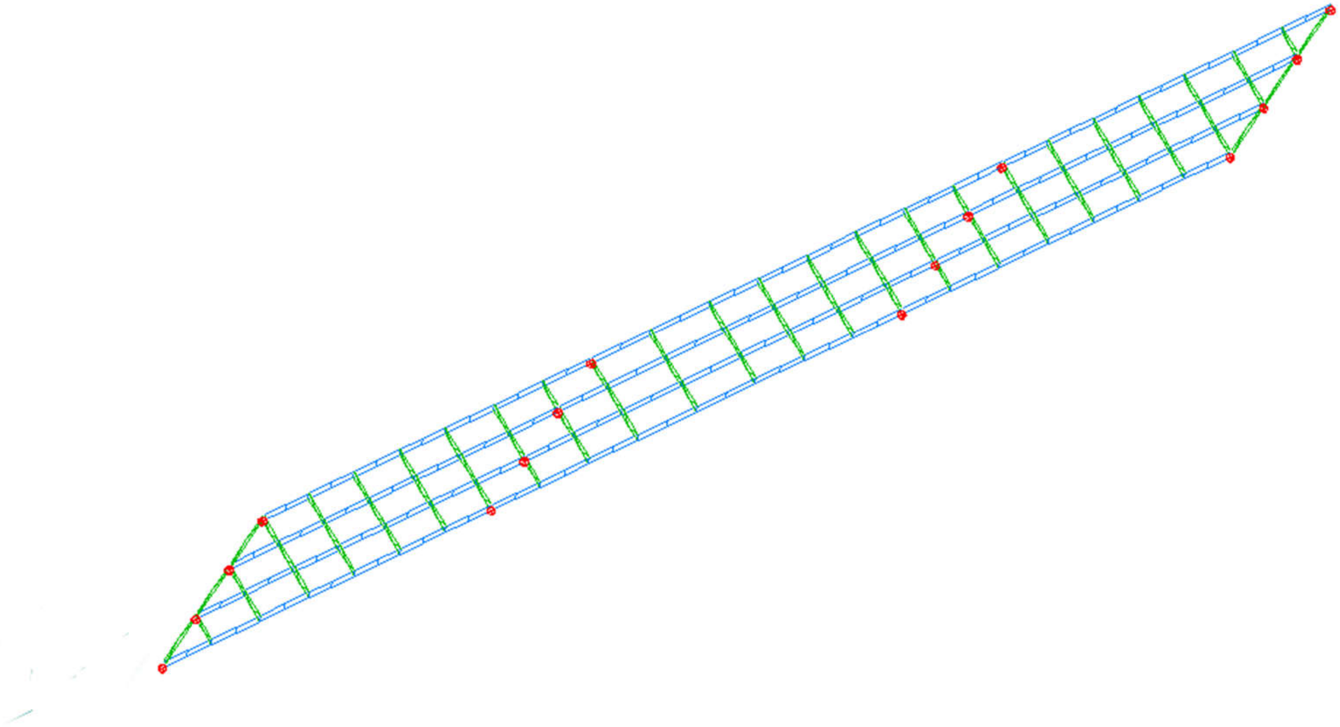


Detail A

End Cross Frame
at
Skewed Support

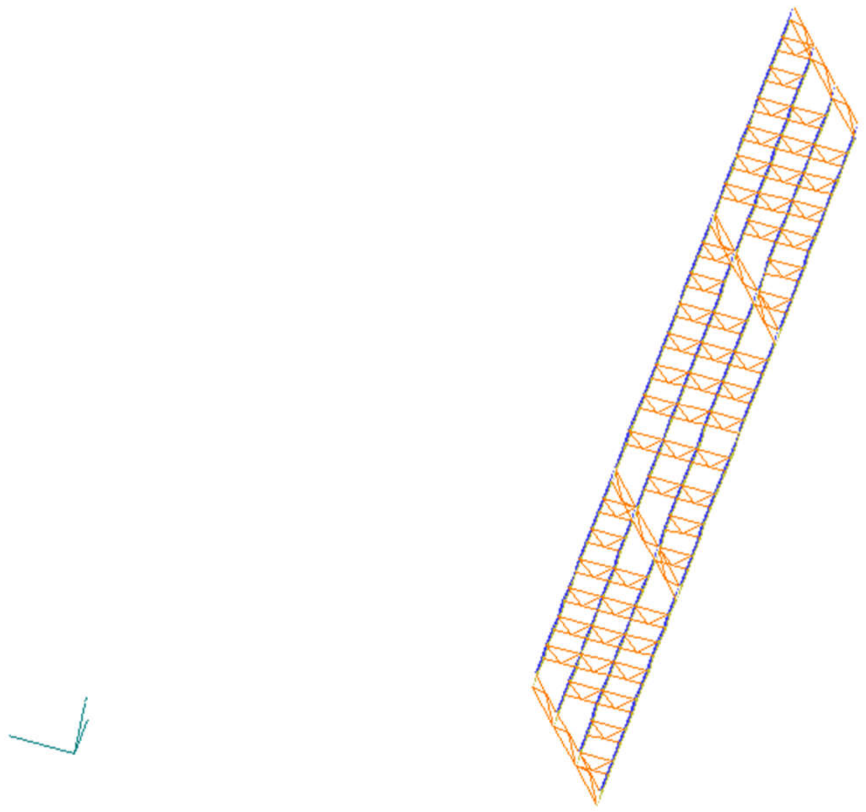


Section A - A
End Cross-Frame
at
Skewed Support



Skewed Example Bridge Dead Load (DC_1) Deflections

DC_1 (unfactored) in.	*Spans 1&3* Right Bridge Line Girder Analysis	*Spans 1&3* Right Bridge 3D Analysis	*Span 1* Skewed Bridge 3D Analysis	*Span 2* Skewed Bridge 3D Analysis	*Span 3* Skewed Bridge 3D Analysis
G1	-3.15	-3.11	-4.18	-3.67	-2.56
G2	-3.15	-3.16	-3.12	-3.40	-2.57
G3	-3.15	-3.16	-2.57	-3.40	-3.12
G4	-3.15	-3.11	-2.56	-3.67	-4.18



Dead Load (DC_1) Deflections Discontinuous Cross-Frames

DC_1 (unfactored) in.	***Spans 1&3*** Right Bridge Line Girder Analysis	***Spans 1&3*** Right Bridge 3D Analysis	***Span 1*** Skewed Bridge 3D Analysis	***Span 2*** Skewed Bridge 3D Analysis	***Span 3*** Skewed Bridge 3D Analysis
G1	-3.15	-3.11	-3.68	-2.82	-3.01
G2	-3.15	-3.16	-2.81	-2.46	-2.61
G3	-3.15	-3.16	-2.61	-2.46	-2.81
G4	-3.15	-3.11	-3.01	-2.82	-3.68

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_ℓ to use for the preceding cases.

?? QUESTIONS ??