Economical Steel Bridge Design, Skewed Bridge Design Considerations & Steel I-Girder Bridge Fit

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Topics on Steel Girder Design

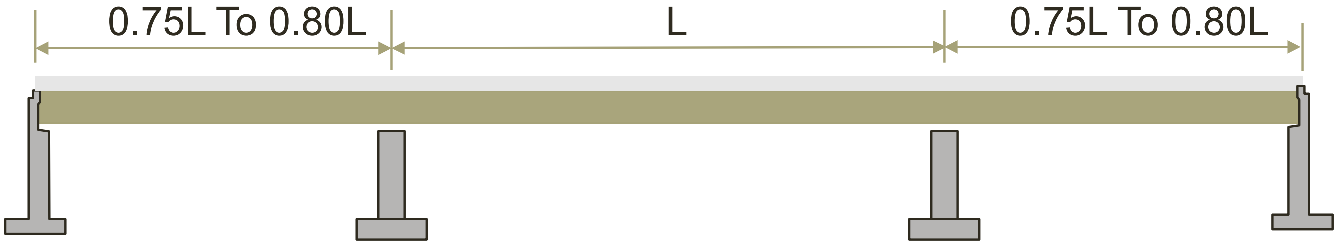
SPAN ARRANGEMENT CONSIDERATIONS

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

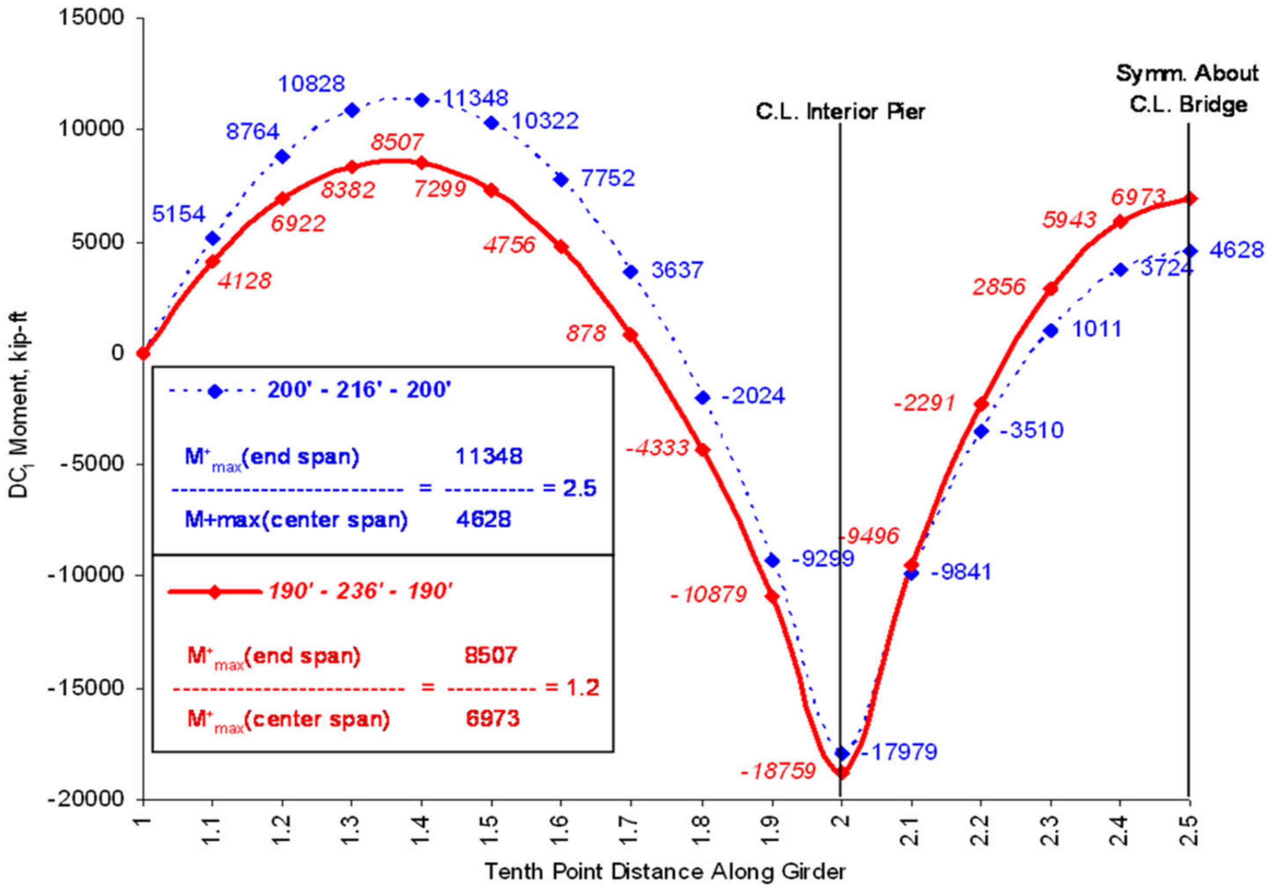
- End spans ideally 75% - 80% of center span



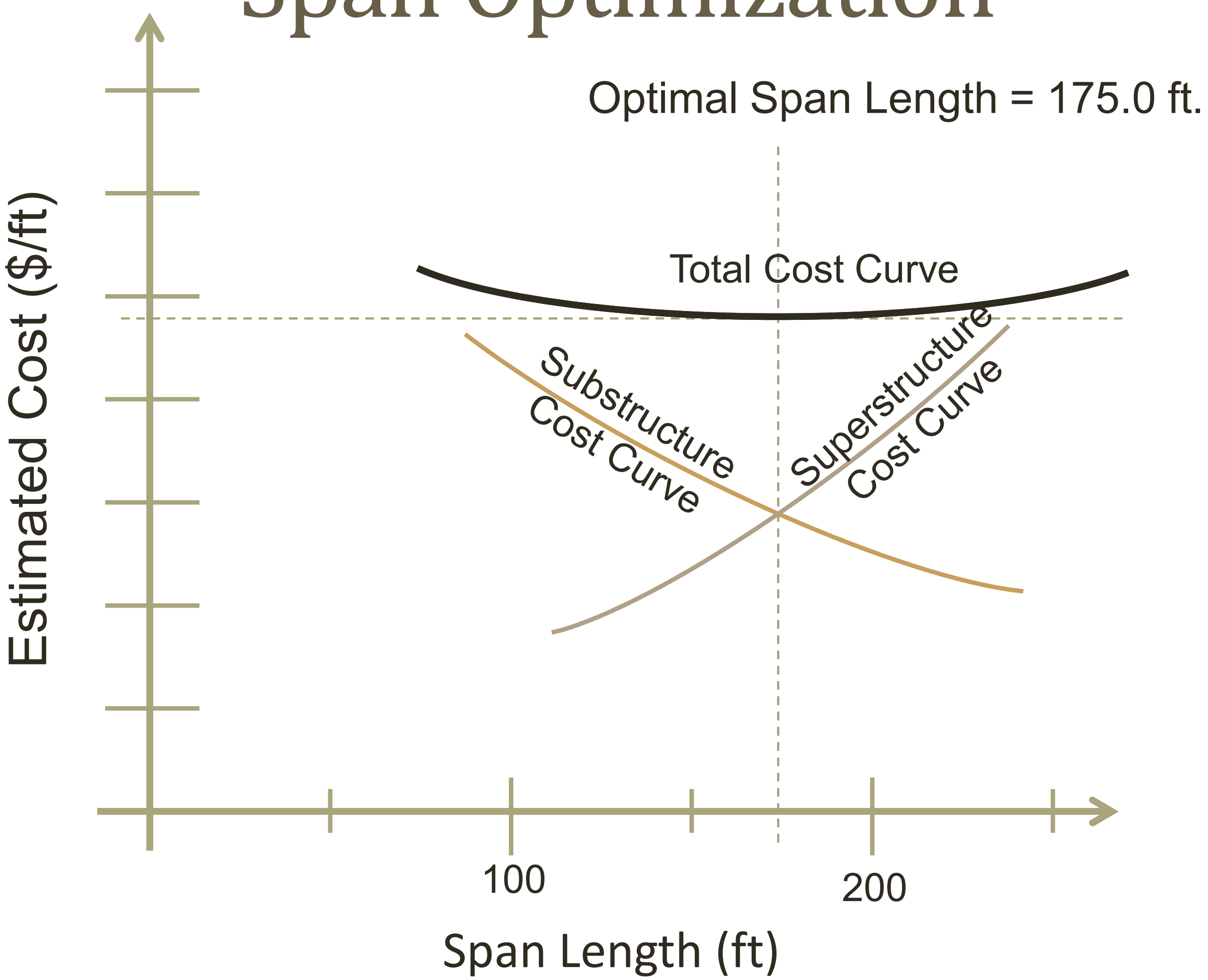
Balanced Span Arrangement

- 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

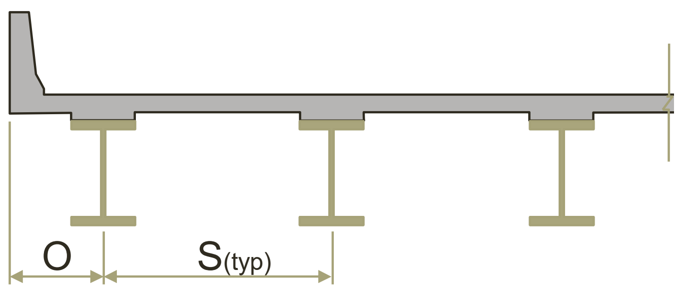
Girder Spacing
Future Redecking Under Traffic

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

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

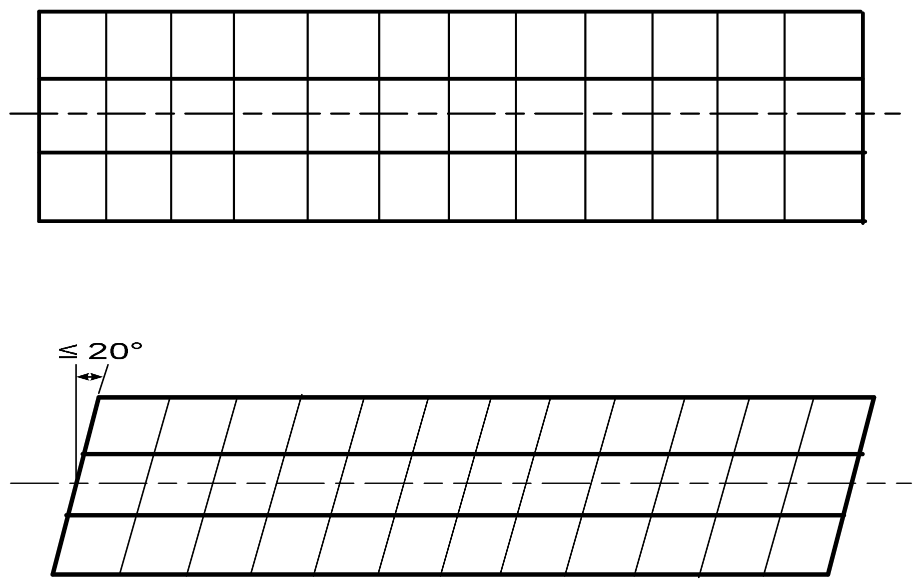
Deck Overhangs

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



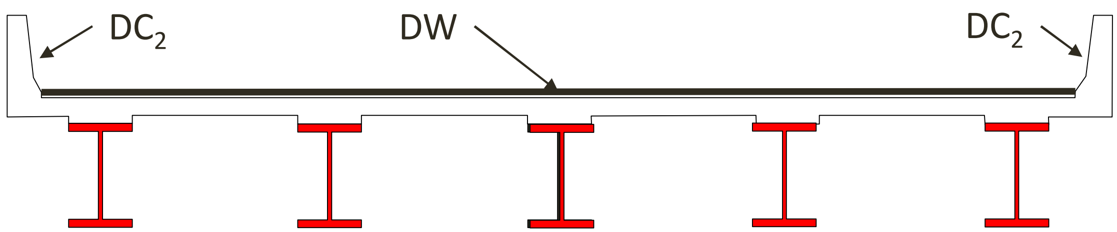
Deck Overhangs
Dead Load Distribution

- 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

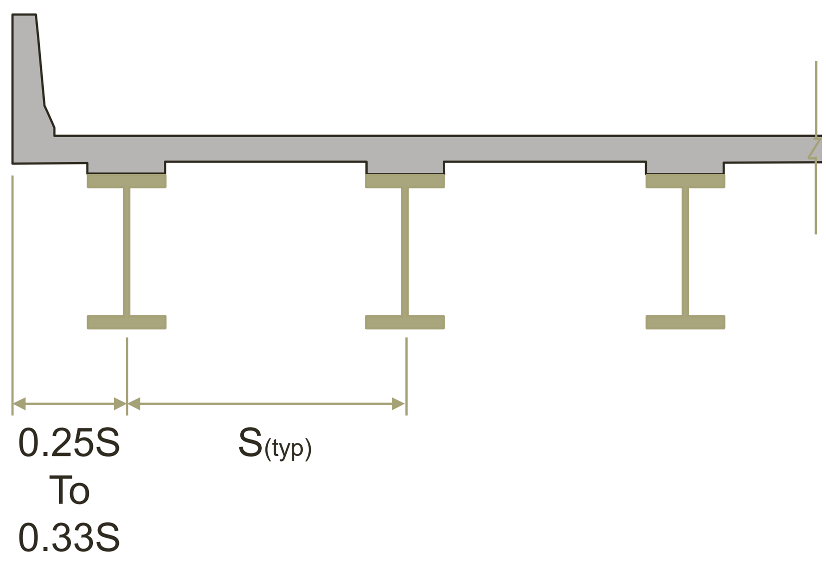
- Apply special cross-section analysis to determine the live load distribution to the exterior girders
  - Assumes the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge:

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

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

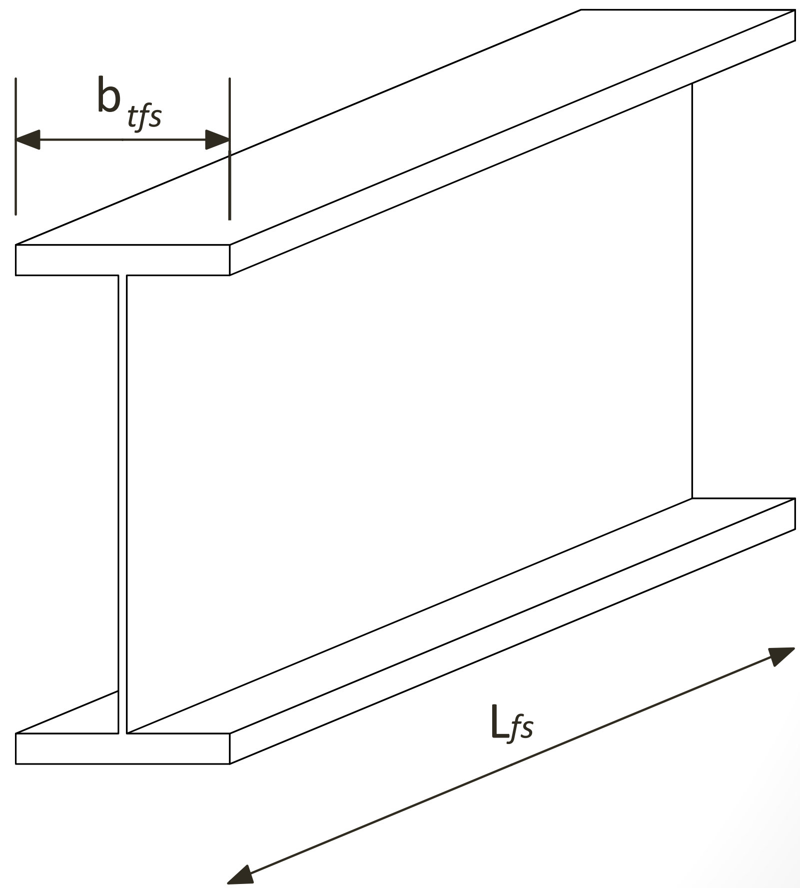
L/b Ratio

- **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.)

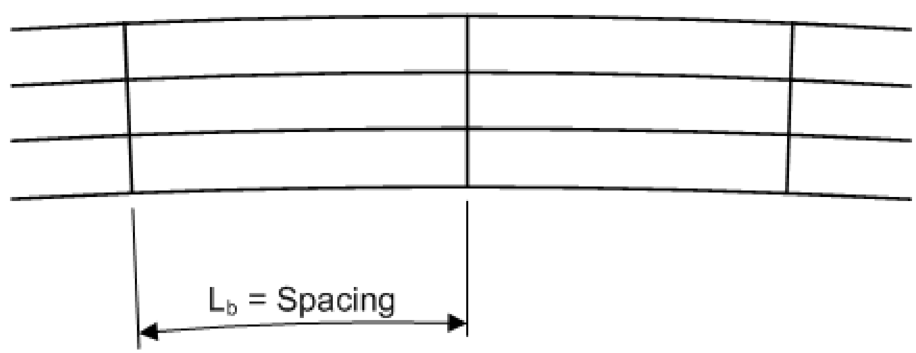
L_{fs} = length of unspliced girder field section (in.)



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

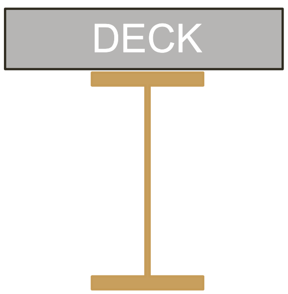
I-Girder Web Proportioning
Optimum Web Depth

- **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

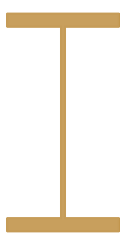
Span-to-Depth Ratio

- 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

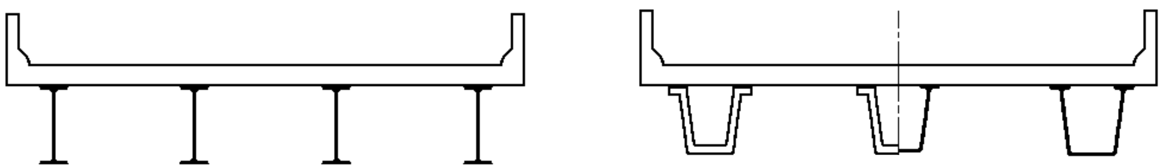


Simple Spans	0.033L
Continuous spans	0.027L

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



www.aisc.org/nsba → Design and Estimating

→ Design Resources and Software

What Does LRFD SIMON Do?

- Line girder analysis of steel beams
  - Based on user-defined or program-defined live load 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

I-Girder Web Proportioning
Web Depth Optimization – LRFD SIMON

DEPTH VARIATION ANALYSIS

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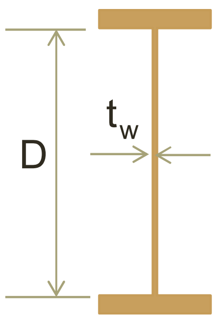
Filename	Depth Inch	Weight Tons	Cost $
SIMONTUTORIAL_BELOW3	61.00	245.67	513546
SIMONTUTORIAL_BELOW2	63.00	242.74	508186
SIMONTUTORIAL_BELOW1	65.00	243.00	509408
SIMONTUTORIAL	67.00	239.88	502815
SIMONTUTORIAL_ABOVE1	69.00	240.66	504648
SIMONTUTORIAL_ABOVE2	71.00	242.04	507768
SIMONTUTORIAL_ABOVE3	73.00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

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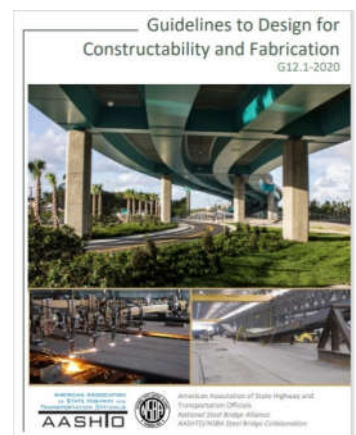


I-Girder Flange Proportioning

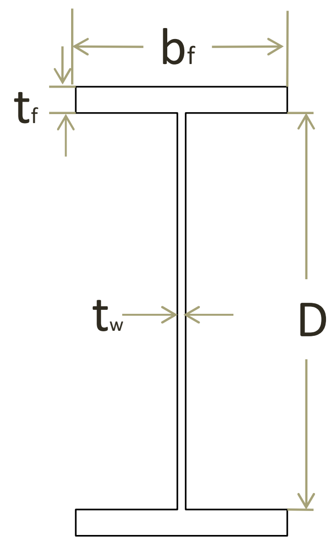
- Proportioning Requirements (Art. 6.10.2.2):

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

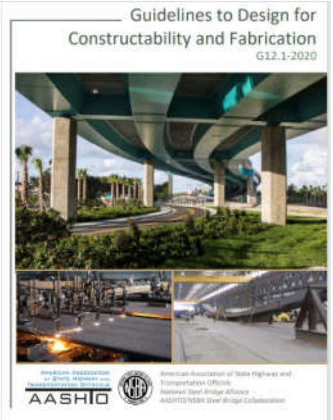
$$b_f \geq \frac{D}{6}$$

$$t_f \geq 1.1\, t_w$$

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



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



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

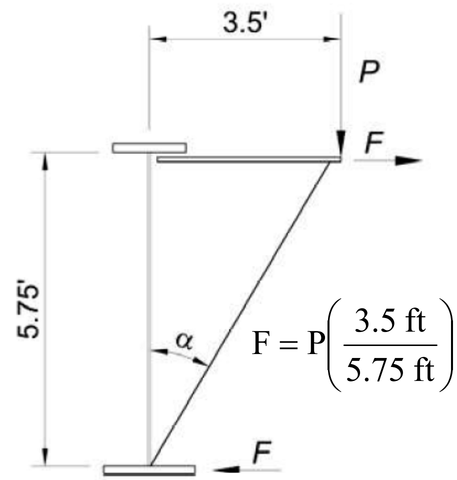
I-Girder Flange Proportioning

Deck Overhang Loads

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

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

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



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

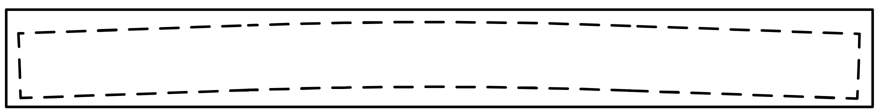
$$f_{\ell} = \frac{M_{\ell}}{\left(t_f b_f^2/6\right)}$$

I-Girder Flange Proportioning
Sizing Flanges for Efficient Fabrication

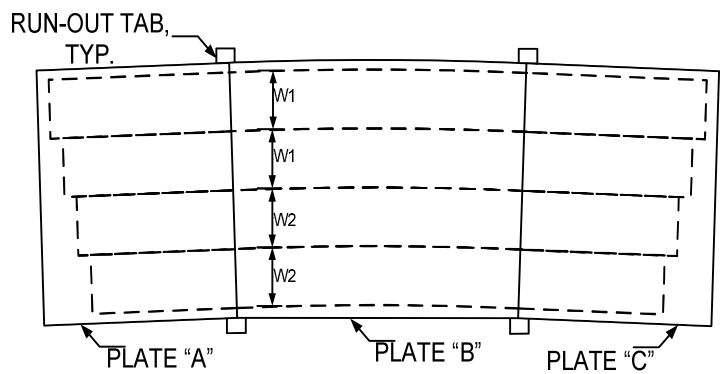
- Minimum plate size from mill is 60”
- Most economical plate size from mill is 72" to 96"
- Consider sizing flanges so that as many pieces as possible can be obtained from a wide plate of a given grade and thickness with minimal waste
- Limit the number of different flange plate thicknesses specified for a given project

I-Girder Flange Proportioning
Sizing Flanges for Efficient Fabrication

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

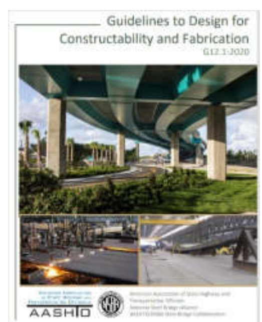


- Cut multiple flange plates from slab welded plates



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
  - 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

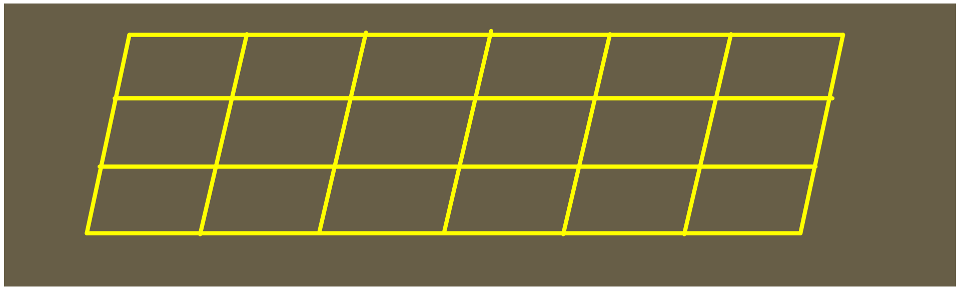


Skewed Supports

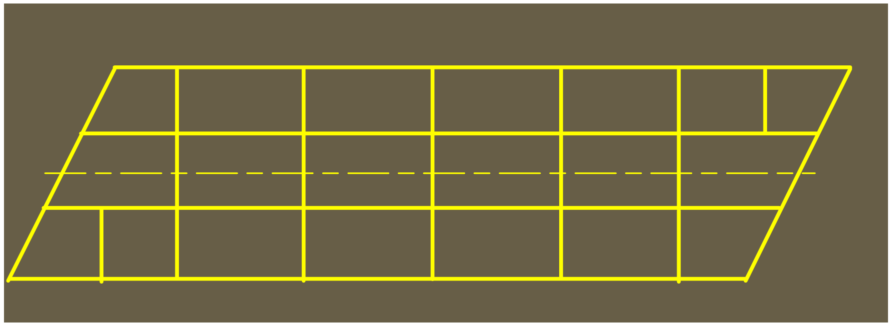
- Increased torsion in the girders, larger than normal cross-frame forces, unique thermal movements, large differential deflections, longer abutments and piers
- The significance of skew increases with increasing skew and bridge width

Skew Effects
Framing Arrangements - Layout

- Skews ≤ 20 degrees, may be placed parallel to supports

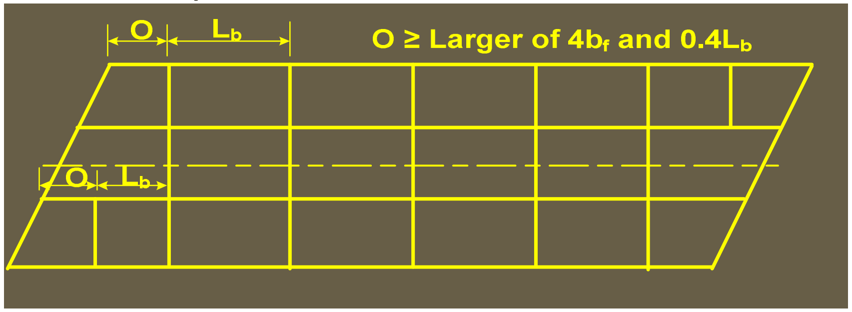


- Skews > 20 degrees, must be placed perpendicular to girders and may be placed in contiguous or discontinuous lines

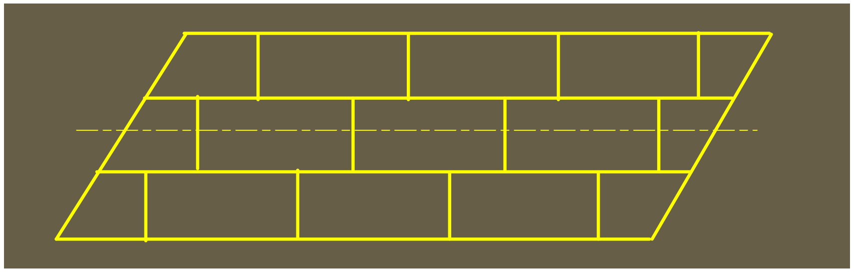


Skew Effects
Framing Arrangements - Layout

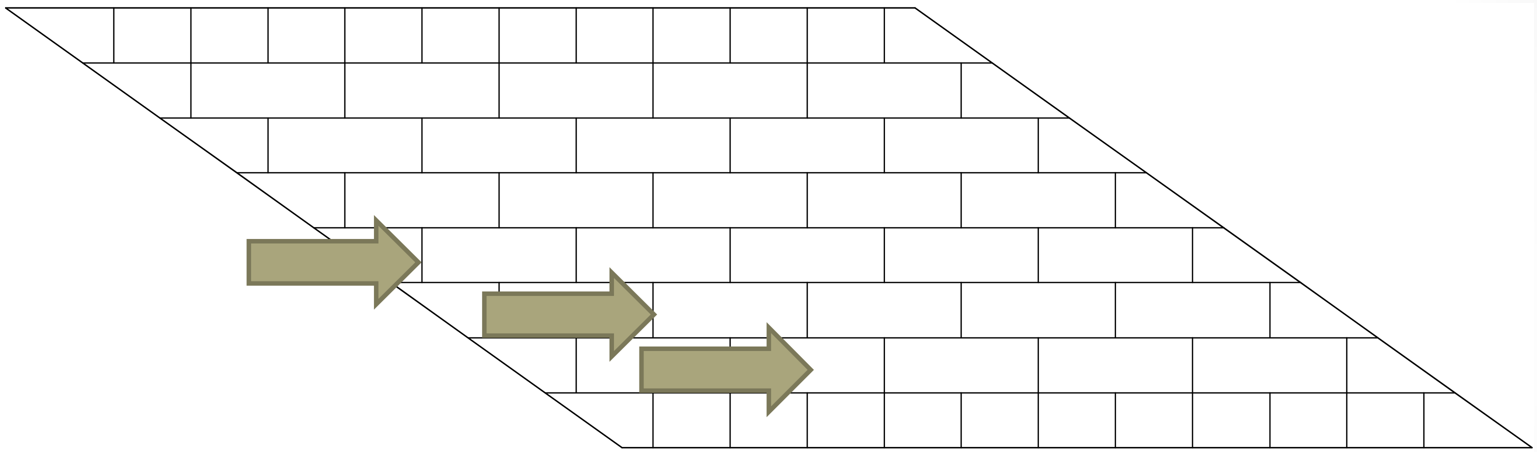
- Recommended minimum offset of cross-frames adjacent to skewed supports (discontinuous cross-frames)



- For skews > 20 degrees, it may be advantageous to stagger the cross-frames (discontinuous cross-frames)

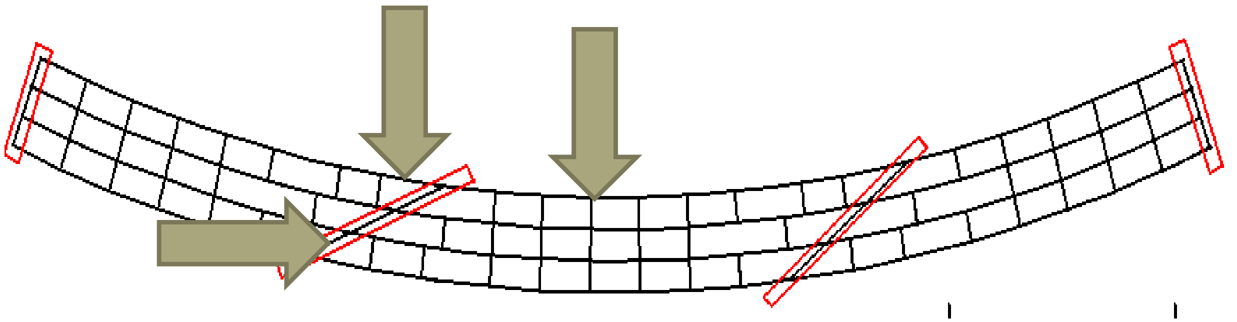


Skew Effects
Framing Arrangements - Layout



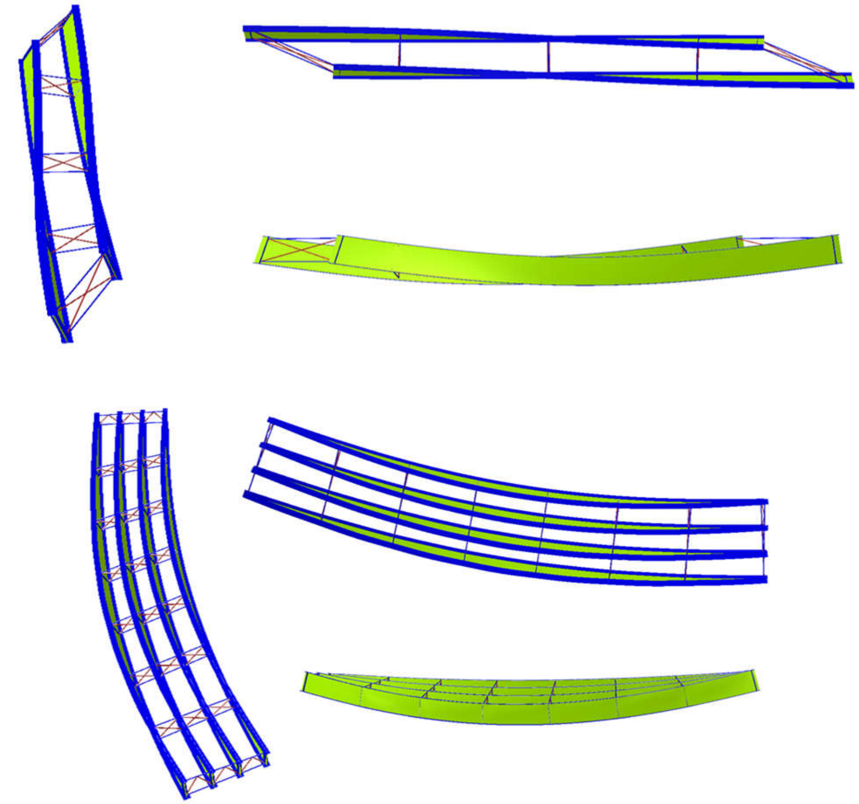
- Cross-frames adjacent to the bearing lines are placed at the same offset distance relative to the bearing lines.
- Other intermediate cross-frames placed at constant spacing.
- Every other cross-frame intentionally omitted within the bays between the interior girders.

Skew Effects
Framing Arrangements - Layout

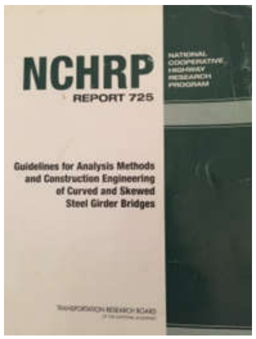


- Framing of a normal intermediate cross-frame into or near a bearing location along a skewed support line is strongly discouraged unless the cross-frame diagonals are omitted.
- At skewed interior piers & abutments, place cross-frames along the skewed bearing line, and locate intermediate cross-frames greater than or equal to the recommended minimum offset from the bearing lines.
- For curved I-girder bridges, provide contiguous intermediate cross-frame lines within the span in combination with the recommended offset at skewed bearing lines.

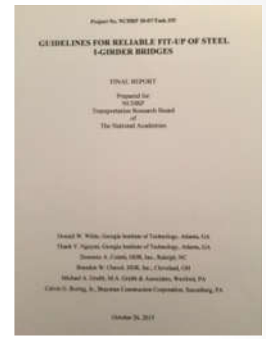
Twist due to Differential Girder Deflections



8^{th} Edition AASHTO LRFD (2017) Dead Load Camber – Article 6.7.2



- NCHRP Project 12-79: “Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges” (NCHRP Report 725)
- NCHRP Project 20-07, Task 355: “Guidelines for Reliable Fit-Up of Steel I-Girder Bridges”



- The contract documents should state the fit condition for which the cross-frames or diaphragms are to be detailed for the following I-girder bridges:
  - Straight bridges where one or more support lines are skewed more than 20 degrees from normal;
  - Horizontally curved bridges where one or more support lines are skewed more than 20 degrees from normal and with an *L*/*R* in all spans less than or equal to 0.03; and
  - Horizontally curved bridges with or without skewed supports and with a maximum *L*/*R* greater than 0.03.

Common Fit Conditions

Loading Condition Fit	Construction Stage Fit	Description
No-Load Fit (NLF)	Fully-Cambered Fit	The cross-frames are detailed to fit to the girders in their fabricated, plumb, fully-cambered position under zero load.
Steel Dead Load Fit (SDLF)	Erected Fit	The cross-frames are detailed to fit to the girders in their ideally plumb as-deflected positions under the self-weight of the steel at the completion of the erection.
Total Dead Load Fit (TDLF)	Final Fit	The cross-frames are detailed to fit to the girders in their ideally plumb as-deflected positions under the total dead load.

Girder Web Positions

No-Load Fit

	PLUMB	OUT-OF-PLUMB
NO-LOAD	●	
STEEL DL		●
TOTAL DL		●

Steel Dead Load Fit

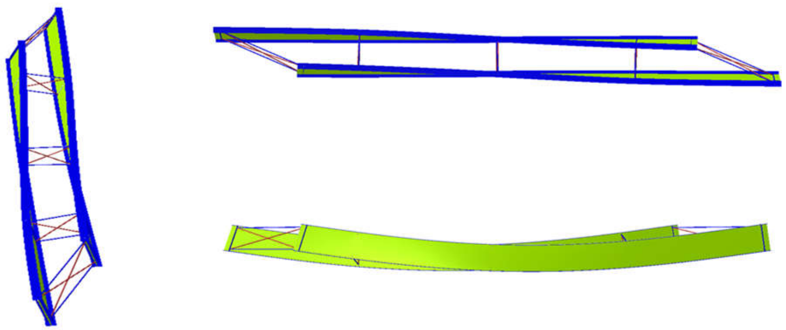
	PLUMB	OUT-OF-PLUMB
NO-LOAD		●
STEEL DL	●	
TOTAL DL		●

Total Dead Load Fit

	PLUMB	OUT-OF-PLUMB
NO-LOAD		●
STEEL DL		●
TOTAL DL	●	

Straight Skewed I-Girder Bridges

- When cross-frames are connected, the girders deflect vertically and simultaneously twist under the dead loads.



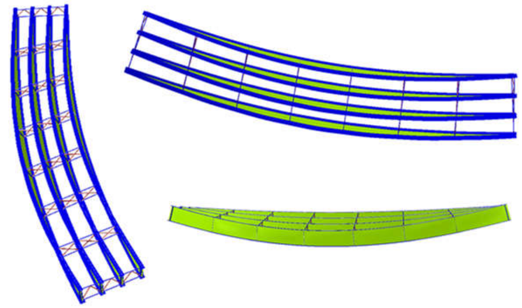
- If detailed for SDLF using these deflections, cross-frame connections to the girders can be completed with little forcing.
- If detailed for TDLF, Erector may need to apply force to complete the connections. In many cases, however, the girders can be twisted out-of-plumb with minimal force.

Straight Skewed I-Girder Bridges

- Locked-in forces due to the lack-of-fit detailed between the cross-frames and girders in the base No-Load geometry are reduced substantially (approximately offset) by the dead load effects.
- Locked-in forces tend to be largely opposite in sign (direction) to the internal dead load forces & stresses.
- NLF detailing is not typically used and should be avoided for straight skewed bridges.

Horizontally Curved I-Girder Bridges

- Cross-section subjected to significant internal torsional moments because resultant of the bridge vertical loads within the spans has an eccentricity relative to a straight chord between the supports.



- Resistance to the internal torsion is developed by interconnecting the girders by cross-frames.
- Since the overall bridge cross-section wants to rotate torsionally, some type of intermediate vertical support within the span is typically needed during the erection.

Horizontally Curved I-Girder Bridges

- Significant coupling between major-axis bending displacements and twisting or torsional displacements.
- Can exacerbate fit-up problems in some cases since more difficult to adjust the twist of the girders to connect them with the cross-frames.
- For SDLF or TDLF detailing, cross-frames are fabricated such that they twist the girders back in the opposite direction that they and the bridge cross-section want to roll.
- As such, SDLF and TDLF detailing tend to increase cross-frame forces, particularly in the diagonals.
- Locked-in cross-frame forces tend to be additive with the general cross-frame dead load effects.

Horizontally Curved I-Girder Bridges

- For SDLF detailing, the additional forces usually are not particularly large, and the cross-frame installation can be completed successfully in most cases.
- For TDLF detailing, the additional forces required to twist the girders and the resulting additive locked-in force effects can be more substantial.
- TDLF detailing should ***not*** be specified for curved bridges unless the supports are skewed, the spans are relatively small and the horizontal curvature is minor.

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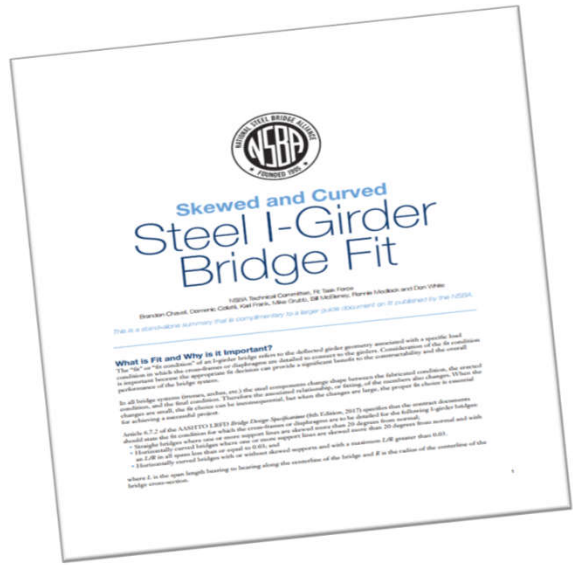
NSBA

Skewed and Curved

Steel I-Girder Bridge Fit

<u>NSBA</u>: www.aisc.org/nsba

Click on ‘Design and Estimating’ and then ‘Technical Resources & Research’

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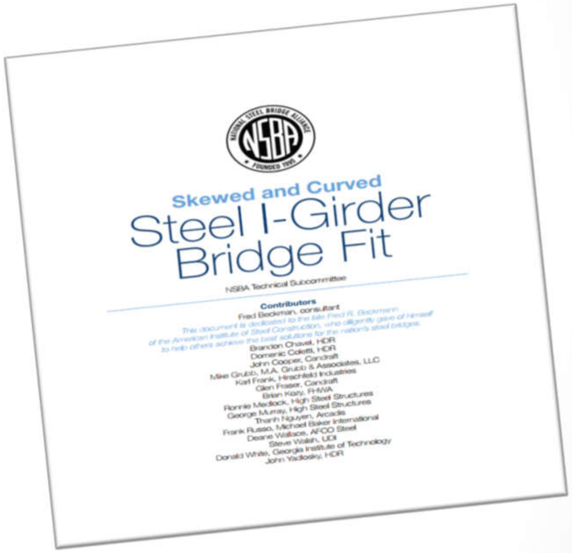
Skewed and Curved
Steel I-Girder
Bridge Fit
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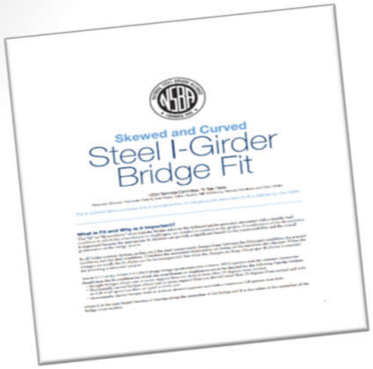
Skewed and Curved
Steel I-Girder
Bridge Fit

Recommended Fit Conditions for Straight I-Girder Bridges

(including Curved I-Girder Bridges with L/R in all spans ≤ 0.03)

Square Bridges and Skewed Bridges up to 20 deg Skew			
	Recommended	**Acceptable**	**Avoid**
Any span length	Any		None
Skewed Bridges with Skew > 20 deg and $I_s \le 0.30$ +/-			
	Recommended	**Acceptable**	**Avoid**
Any span length	TDLF or SDLF		NLF
Skewed Bridges with Skew > 20 deg and $I_s > 0.30$ +/-			
	Recommended	**Acceptable**	**Avoid**
Span lengths up to 200’ +/-	SDLF	TDLF	NLF
Span lengths greater than 200’ +/-	SDLF		TDLF & NLF

$$I_S = \frac{w_g \tan\theta}{L_s}$$

Recommended Fit Conditions for Horizontally Curved I-Girder Bridges

$((L/R)_{max} > 0.03)$

Radial or Skewed Supports			
	Recommended	**Acceptable**	**Avoid**
L/R ≥ 0.2	NLF	SDLF	TDLF
All other cases	SDLF	NLF	TDLF

- Total Dead Load Fit should not be specified for curved I-girder bridges with or without skew and with a maximum *L*/*R* greater than 0.03.
- Detail for a Steel Dead Load Fit, unless than maximum *L*/*R* is greater than or equal to 0.2.

?? QUESTIONS ??