





Office of Structures

## **Flange Lateral Bending**



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## **Presentation Topics**

- NYSDOT Skewed Steel I-Girder Analysis Requirements
- Literature Review
- Modified Line Girder Analysis
- BrDR Enhancement



## **Skewed Steel I-Girder Bridges**

- Current NYSDOT policy: line girder analysis for skews less than 45 degrees
- Determine if revisions to current analysis and detailing policies are needed based on literature review



## Excerpts from LRFD BDS C6.10.1

- Significant flange lateral bending may be caused by wind, by torsion from eccentric concrete deck overhang loads acting on cantilever forming brackets placed along exterior girders, and by the use of discontinuous crossframes, i.e., not forming a continuous line between multiple girders, in conjunction with skews exceeding 20 degrees.
  - 4<sup>th</sup> Edition, 2007 and possibly earlier editions



## Excerpts from LRFD BDS C6.10.1

- Lateral flange bending in the exterior girders is substantially reduced when cross-frames or diaphragms are placed in discontinuous lines over the entire bridge due to the reduced cross-frame or diaphragm forces.
- An examination of cross-frame or diaphragm forces is also considered prudent in all bridges with skew angles exceeding 20 degrees.
  - 5<sup>th</sup> Edition, 2010



### **Literature Review**

## Straight Steel I-Girder Bridges with Skew Index Approaching 0.3 (FDOT Report)

To maximize engineering effectiveness, appropriate tools must be matched to the task. Straight skewed steel I-girder bridges have been designed traditionally using simplified 1D line girder analysis (LGA) methods. Modern 2D grid and 3D finite element analysis (3D FEA) procedures can capture the component and system response of these types of structures at a -higher resolution than the traditional approach.



## Straight Steel I-Girder Bridges with Skew Index Approaching 0.3 (FDOT Report)

However, these refined analysis tools require more expensive software and greater time to execute and interpret the higher resolution analysis models. It is broadly recognized that LGA is appropriate and sufficient for the design of straight non-skewed girder bridges



### **Literature Review**

## Straight Steel I-Girder Bridges with Skew Index Approaching 0.3 (FDOT Report)

- The objectives of this research were to better understand the behavior of straight steel Igirder bridges with small to moderate skew, and to define and potentially extend the limits at which LGA provides an effective structural engineering solution for these bridge types.
- Comparative parametric 3D FEA and LGA studies were conducted on 26 bridges having a skew index up to and slightly larger than 0.3...

## Straight Steel I-Girder Bridges with Skew Index Approaching 0.3 (FDOT Report)

The results showed that routine LGA models using equal distribution of dead loads to the girders and established AASHTO live load distribution factors provide a fast and sufficient solution for straight steel I-girder bridges with skew index up to 0.45 and skew up to 50 degrees within certain qualifications.



## Skew Index - LRFD BDS Eq. 4.6.3.3.2-2

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

 $I_S$  = bridge skew index, taken equal to the maximum of the values of Eq. 4.6.3.3.2-2 determined for each span of the bridge

 $L_s$  = span length at the centerline (ft)

- $w_g$  = maximum width between the girders on the outside of the bridge cross-section at the completion of the construction or at an intermediate stage of the steel erection (ft)
- $\theta$  = maximum skew angle of the bearing lines at the end of a given span, measured from a line taken perpendicular to the span centerline (degrees)

## **Revisions to Analysis Requirements**

- Base need for refined analysis on both skew and skew index
- Use a modified line girder analysis to capture skew effects when appropriate
- ⇒ If 20° <  $\theta$  ≤ 45° and I<sub>s</sub> ≤ 0.3 use modified line girder analysis per FDOT Report BE535 for girders, diaphragms, and connections
- If θ > 45° or I<sub>s</sub> > 0.3 use 3D FEA for girders, diaphragms, bracing, and connections



## **Modified Line Girder Analysis**

- Increase the calculated Strength I girder vertical reactions at the obtuse corners of simple spans, and at the fascia girders in continuous spans, by a multiplicative factor of 1.10.
- Include flange lateral bending stresses in the analysis of girders and girder splices when applicable.
- Include additional diaphragm forces that result from the skewe and th
   Do no
- Do no Fifed in Article And Ar
- Determine girder live load deflections using the Live Load Distribution Factors for moment as specified in the NYSDOT LRFD Bridge Design Specifications rather than assuming all girders deflect equally.

g Ranges	Tasks	Hours	not use
		Hours	
A Lateral Support	1 Mockups for implementation	0	- n ×
	2. Database, Data Access, Payload, Service, and Domain classes		
	a. Database design and implementation	40	- 0
Dennes Locations Steams Intending	b. Generate Data Access, Payload, Service, and Domain classes	43	vised table
Ranges Locations Flange lateral bending	c. Bridge validation for diaphragm locations	9	niscu tuble.
Lateral bending stress description			
Load case Descripti	3. User Interface		
Skew effects	a. 2 new control options for steel member alternatives	12	Consider Consider
Deck overhang brackets * A	b. Girder system superstructure definition's steel plate, rolled, and built-up member alternativ		review rating
	i. Lateral Support window's Lateral bending tab (4 grids)	71	
	ii. Diaphragm selections and validation	12	
	c. Girder line superstructure definition's steel plate, rolled, and built-up member alternatives		
Lateral bending stress load case: Skew ef	i. Bracing Ranges window's Lateral bending tab (4 grids)	71	
Lateral bending stress ioad case. Sherr en	ii. Diaphragm selections and validation	12	
Lateral bending stress input.   Onlation	d. Add Diaphragm Locations dialog	31	New Duplicate Dele
Diaphragm Support Distance			
number (ft)	4. Estimate stresses due to skew effects	43	
1-2 × 1 2500	7		
2-2 - 1 35.00	5. AASHTO LRFD and LRFR Engine (Line Girder and 3D FEM)		
	a. Model Domain and Element Domain	62	Girder reaction
Cinden autom format (Day a	b. Apply girder reaction adjustment factor at obtuse corners	62	factor
Girder line format "Diaphrag	c. Specification Controller	124	1
Girder inte format Diaphragi	d. Specification articles - LRFD 6.10.1.6, 6.10.3.2, 6.10.7.1.1, 6.10.8.1.1 (9th Edition only),	186	2
	A6.1.1, A6.1.2; MBE 6A.4.2.1.fl		
	6. Load Rating Tool (Line Girder)	62	
Add diaphragm			
locations	Help (BrDR Help and Method of Solution)	9	
Support Girder reaction	Report Tool	9	
adjustment factor	API	6	
2 1.10	Test Scripts	6	
3	NSG	0	
	General Preferences	16	
Analysis defaults to 1.0 if not	e 508 Compliance	0	
,	Automated UI Testing	0	
	Automated Regression Testing	3	
	SubTotal	889	
	Testing 19.9 Sonvice Unite	178	
		1067	
	Cost	\$ 188,000	

A Member Alternative Description	- 🗆 X
Member alternative: G1	
Description Specs Factors Engine Import Control options	
Doints of interest	Points of interest
Generate at tenth points	Generate at tenth points
Generate at section change points	Generate at section change points
Generate at user-defined points	Generate at user-defined points
Generate at stiffeners	Generate at stiffeners
Allow moment redistribution	✓ Allow moment redistribution
Use Appendix A6 for flexural resistance	Use Appendix A6 for flexural resistance
Allow plastic analysis	Allow plastic analysis
Ignore long. reinf. in negative moment capacity	Evaluate remaining fatigue life
Consider deck reinf. development length	Ignore long. reinf. in negative moment capacity
Must consider user input lateral bending stress	✓ Include field splices in rating
Consider concurrent moments in Cb calculation	Consider deck reinf. development length
Distribution factor application method	Consider tension-field action in stiffened web end panels
By axle	Must consider user input lateral bending stress
O By POI	Consider concurrent moments in Cb calculation



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🕂 Member Loads 🏹 Supports	Ranges Locations Flange lateral bending												\$ ×	( Repo		
· I G1 (E) (C)	Lateral bending stress load cases															
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		Overhang	bracke	et dead load		Constructio	on (Stage 1)	D,DC	~	<ul> <li>Image: A set of the set of the</li></ul>				-		
····· 💋 Splice Locations	(	Overhang	bracke	et constructio	n load	Constructio	on (Stage 1)	Cons	~	$\checkmark$						
Haunch Profile	> :	Skew effec	ct			Proportion	ed (Stage 1 + 🚿	DL+LL	~				<ul> <li>Image: A start of the start of</li></ul>			
Lateral Support																
Stiffener Kanges     Stiffener Kanges     Stiffener Loca     Stiffener Loca     Stiffener Loca     Stiffener Kanges     Stiffener	Add case	Add default load case descriptions Delete Delete														
		Diaphragm		Support	Distance	Unfactored lateral bending stress (ksi)				Sup	Girc port ac	ler reaction ljustment factor				
				number	(11)	Top flange	Bottom flange				1	1.10		•		
		1-1	~	1	0.00	8.000	8.000	í	ì		2	1.10				
		1-2	$\sim$	1	3.85	8.000	8.000				3	1.10				
,		1-3	$\sim$	1	19.85	2.000	2.000	Add Diaphragm Locations								×
	_	1-4	~	1	35.85	2.000	2.000	_								
	_	1-5	~	1	51.85	2.000	2.000	Estir	Estimate stresses due to skew effects							
	_	1-6	~	1	67.85	2.000	2.000	Estimatio	on m	ethod:	AASHTO O Based on FDOT Report BE535, (					
		1-7	~	1	83.85	2.000	2.000	Diaphra	am la	wout:	Contigue		ared			
		1-8	$\sim$	1	99.85	4.000	4.000	Diapina	911110	Jour	contigue		ninaous, staggi	and a		
	_	1-9	~	1	120.00	8.000	8.000									
		1-10	~	2	3.85	8.000	8.000									
	_	1-11	~	2	19.85	2.000	2.000							Add	Can	cel
		Add dia locat	phragi tions	m		New	Duplicate	Delete						V		
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### Table from FDOT Report BE535

## Table 12. Summary of recommended estimations of the unfactored flange lateral bending stresses, $f_{\ell}$

				-		$f_\ell$ (ksi)	
Bridge Category	Cross-frame Framing Arrangement	Orientation of Intermediate Cross-frames	Girder	Location	$O_{min}/b_f$ < 4	$O_{min}/b_f \ge 4$	AASHTO C6.10
1	Contiguous	Parallel to	Exterior	- All -	0	0	0
	contiguous	skew	Interior	1 111	0	0	0
2/3		Perpendicular	Exterior	At or near supports	8	4	7.5
	Contiguous	to girders	Exterior	Throughout the span	0	0	0
	Contiguous	Perpendicular	Interior	At or near supports	10	5	10
		to girders	Interior	Throughout the span	0	0	0
		Perpendicular to girders	Exterior	At or near supports	8	4	7.5
2/3	Staggarad		Exterior	Throughout the span	3	2	2
	Staggered	Perpendicular to girders	Interior	At or near supports	10	5	10
		-	interior	Throughout the span	15	10	10

## **Diaphragm Offsets**

# AASHTO recommends minimum offset ≥ 4x bottom flange width



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#### 💕 AASHTOWare BrDR - Help

Image: Image

#### Lateral Support: Flange Lateral Bending

This tab allows you to define user input flange lateral bending stresses to consider in the specification checking. Enter the required information and click another tab or the **OK** button.

#### Engine Related Help

#### Lateral bending stress load cases Load case name Enter a name for the load case.

**Description** Enter a brief description for the load case.

#### Stage

Select the stage for the load case from the drop down menu. For stresses assigned to the proportioned (Stage 1 + Stage 3) stage, the entered stresses are proportioned to dead and live load in the same proportion as the unfactored major-axis dead and live moments at the section under consideration.

#### Туре

Select the load case type for the load case from the drop down menu.

#### Include in analysis

#### Line girder

Check this box to include flange lateral bending stresses for this load case in a line girder analysis.

#### 3D FEM

Check this box to include flange lateral bending stresses for this load case in a 3D FEM analysis.



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Framing Plan



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#### Span 1 – Exterior Girder Unfactored FLB



#### Without Flange Lateral Bending

#### 📴 Spec Check Detail for 6A.4.2.1 General Load Rating Equation - Steel Flexure Stress

Bottom Flan	ottom Flange LTB Rating												
Load	Load Combo	Limit State	Component	Flexure Type	Location	fDL1 (ksi)	fDL2 (ksi)	fLL (ksi)	User Input fl DL User (ksi)	actored Stres Input fl LL (ksi)	fR (ksi)	RF	Capacity (Ton)
DesignInv	1	STR-I	Bot Flange	Neq	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignInv	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-14.39	0.00	0.00	-50.00	1.953	70.33
DesignOp	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignOp	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-11.10	0.00	0.00	-50.00	2.532	91.16
DesignInv	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignInv	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-12.40	0.00	0.00	-50.00	2.267	81.61
DesignOp	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignOp	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-9.57	0.00	0.00	-50.00	2.938	105.79
DesignInv	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignInv	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-19.22	0.00	0.00	-50.00	1.463	52.66
DesignOp	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignOp	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-14.83	0.00	0.00	-50.00	1.896	68.26

#### With Flange Lateral Bending

#### 📴 Spec Check Detail for 6A.4.2.1 General Load Rating Equation - Steel Flexure Stress

Bottom Fla	nge LTB	Rating											
Load	Load Combo	Limit State	Component	Flexure Type	Location	fDL1 (ksi)	fDL2 (ksi)	fLL (ksi)	User Input fl DL Use: (ksi)	actored Stre Input fl LL (ksi)	fR (ksi)	RF	Capacity (Ton)
DesignInv	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignInv	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-14.39	-6.65	-4.69	-50.00	1.514	54.51
DesignOp	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignOp	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-11.10	-6.65	-3.62	-50.00	1.993	71.75
DesignInv	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignInv	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-12.40	-6.97	-4.24	-50.00	1.755	63.19
DesignOp	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignOp	2	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-9.57	-6.97	-3.27	-50.00	2.304	82.94
DesignInv	- 3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignInv	r 3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-19.22	-5.98	-5.63	-50.00	1.149	41.38
DesignOp	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	-10.00	0.00	-50.00	99.000	3564.00
DesignOp	3	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	-14.83	-5.98	-4.34	-50.00	1.516	54.59







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