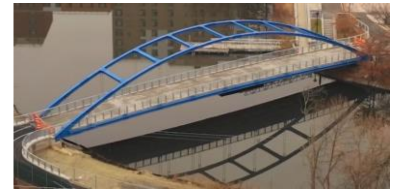


Flange Lateral Bending

Jim Scarlata, PE
Structures Design Bureau
Assistant Director

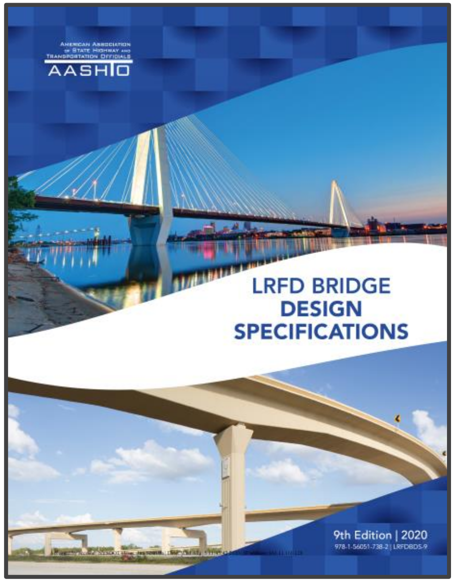
RADBUG Annual Meeting
August 6th, 2024

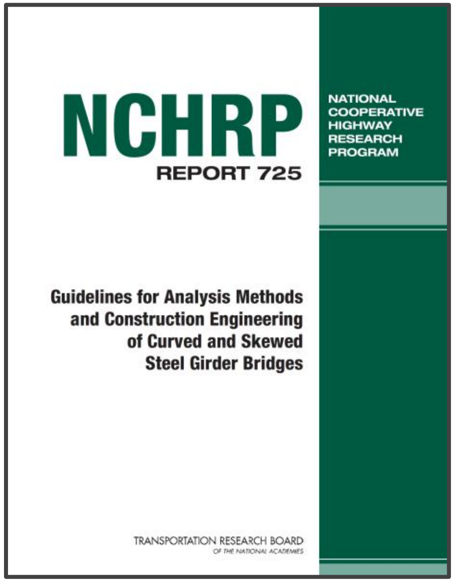
Presentation Topics

- 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






STRAIGHT STEEL I-GIRDER BRIDGES
WITH SKEW INDEX APPROACHING 0.3

Final Report

FDOT Contract No: BE535

Submitted to:

Florida Department of Transportation

Tallahassee, Florida

Project Manager: Vickie Young, PE

Submitted by:

Donald W. White and Ajit Kamath

Georgia Institute of Technology

John A Heath, PE, Brian K. Adams, PE, and Amrithraj Anand

Heath & Lineback Engineers, Inc.

November 2020

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.*

- 4th 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.*

- 5th Edition, 2010

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*

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 I-girder 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)

θ = 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

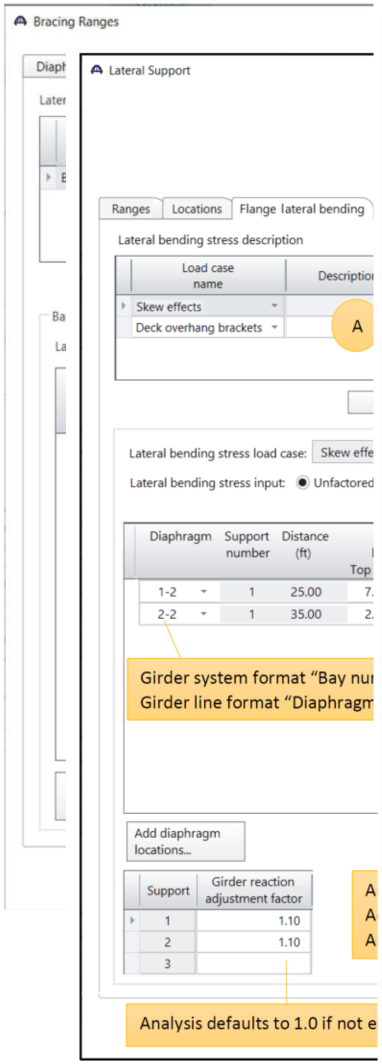
- Base need for refined analysis on both skew and skew index
- Use a modified line girder analysis to capture skew effects when appropriate
- **If $20° < \theta \leq 45°$ and $I_s \leq 0.3$** use modified line girder analysis per FDOT Report BE535 for girders, diaphragms, and connections
- **If $\theta > 45°$ or $I_s > 0.3$** 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 [illegible] hragms and th [illegible]
- Do no [illegible] ified in Article 4.6.2.2.2e of the *NYSDOT LRFD Bridge Design Specifications* when calculating Live Load Distribution Factors.
- 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.

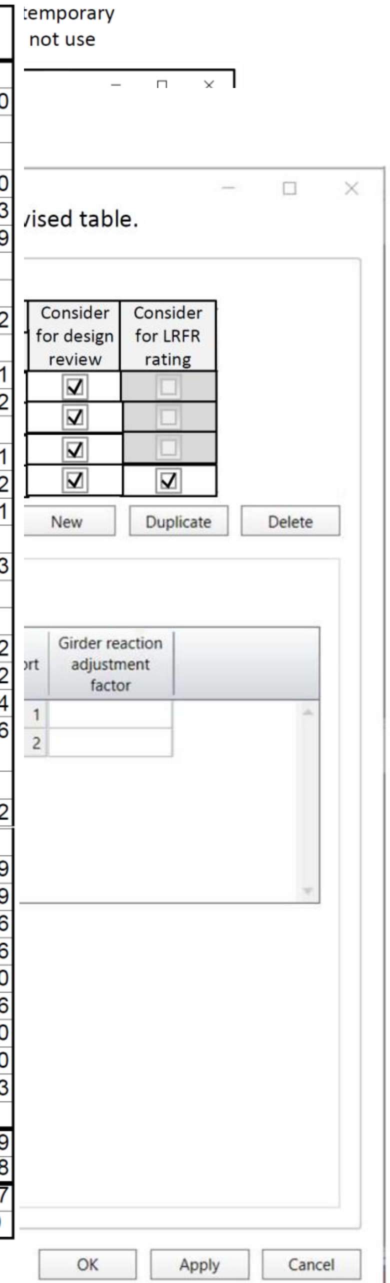
BrDR Enhancement

BrDR Enhancement

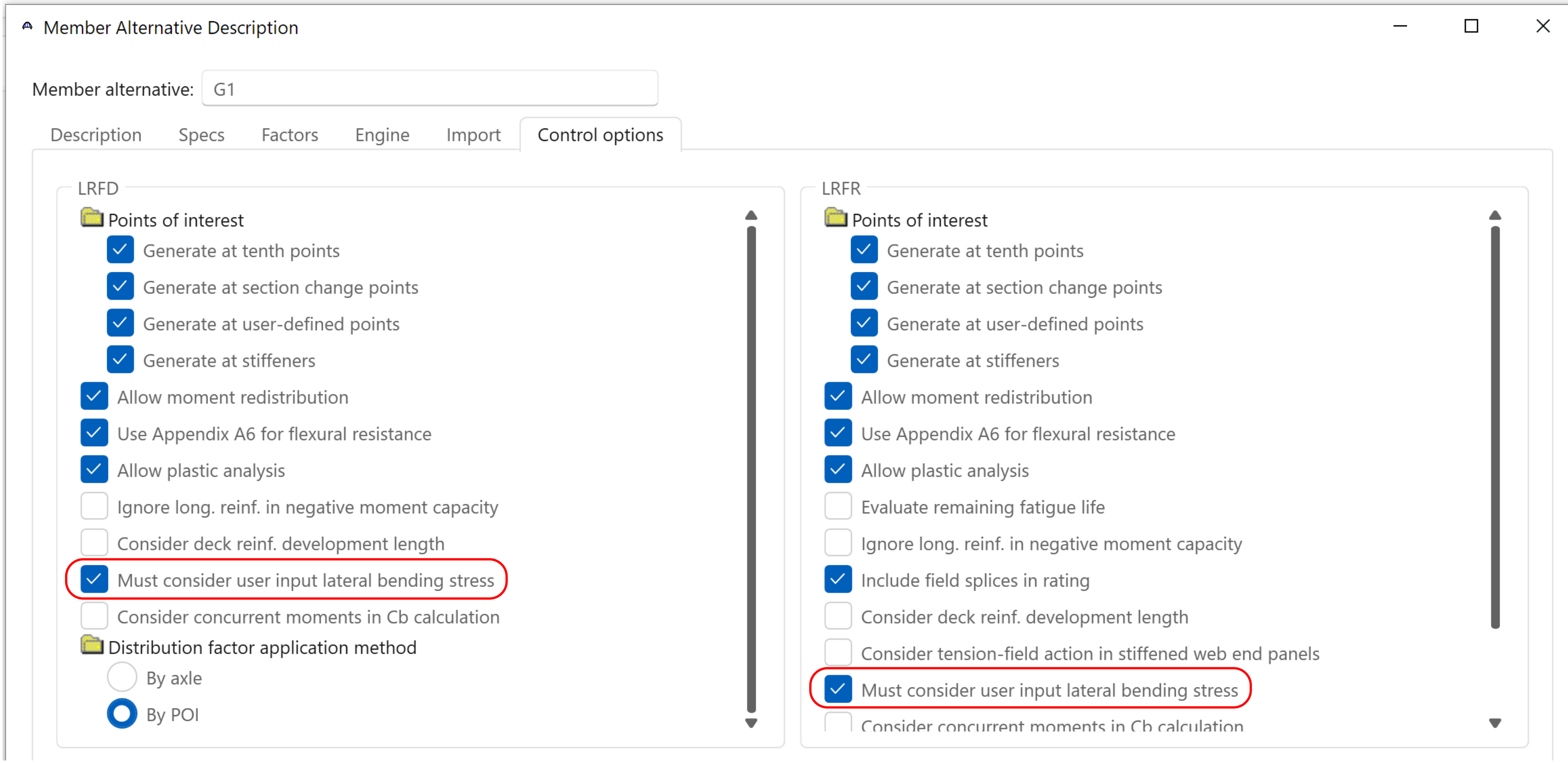


Tasks	Budget Hours
1. Mockups for implementation	0
2. Database, Data Access, Payload, Service, and Domain classes	
a. Database design and implementation	40
b. Generate Data Access, Payload, Service, and Domain classes	43
c. Bridge validation for diaphragm locations	9
3. User Interface	
a. 2 new control options for steel member alternatives	12
b. Girder system superstructure definition's steel plate, rolled, and built-up member alternativ	
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	
i. Bracing Ranges window's Lateral bending tab (4 grids)	71
ii. Diaphragm selections and validation	12
d. Add Diaphragm Locations dialog	31
4. Estimate stresses due to skew effects	43
5. AASHTO LRFD and LRFR Engine (Line Girder and 3D FEM)	
a. Model Domain and Element Domain	62
b. Apply girder reaction adjustment factor at obtuse corners	62
c. Specification Controller	124
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), A6.1.1, A6.1.2; MBE 6A.4.2.1.fl	186
6. Load Rating Tool (Line Girder)	62
Help (BrDR Help and Method of Solution)	9
Report Tool	9
API	6
Test Scripts	6
NSG	0
General Preferences	16
508 Compliance	0
Automated UI Testing	0
Automated Regression Testing	3
SubTotal	889
Testing	178
Total Hours	1067
Cost	$ 188,000

18.8 Service Units



BrDR Enhancement



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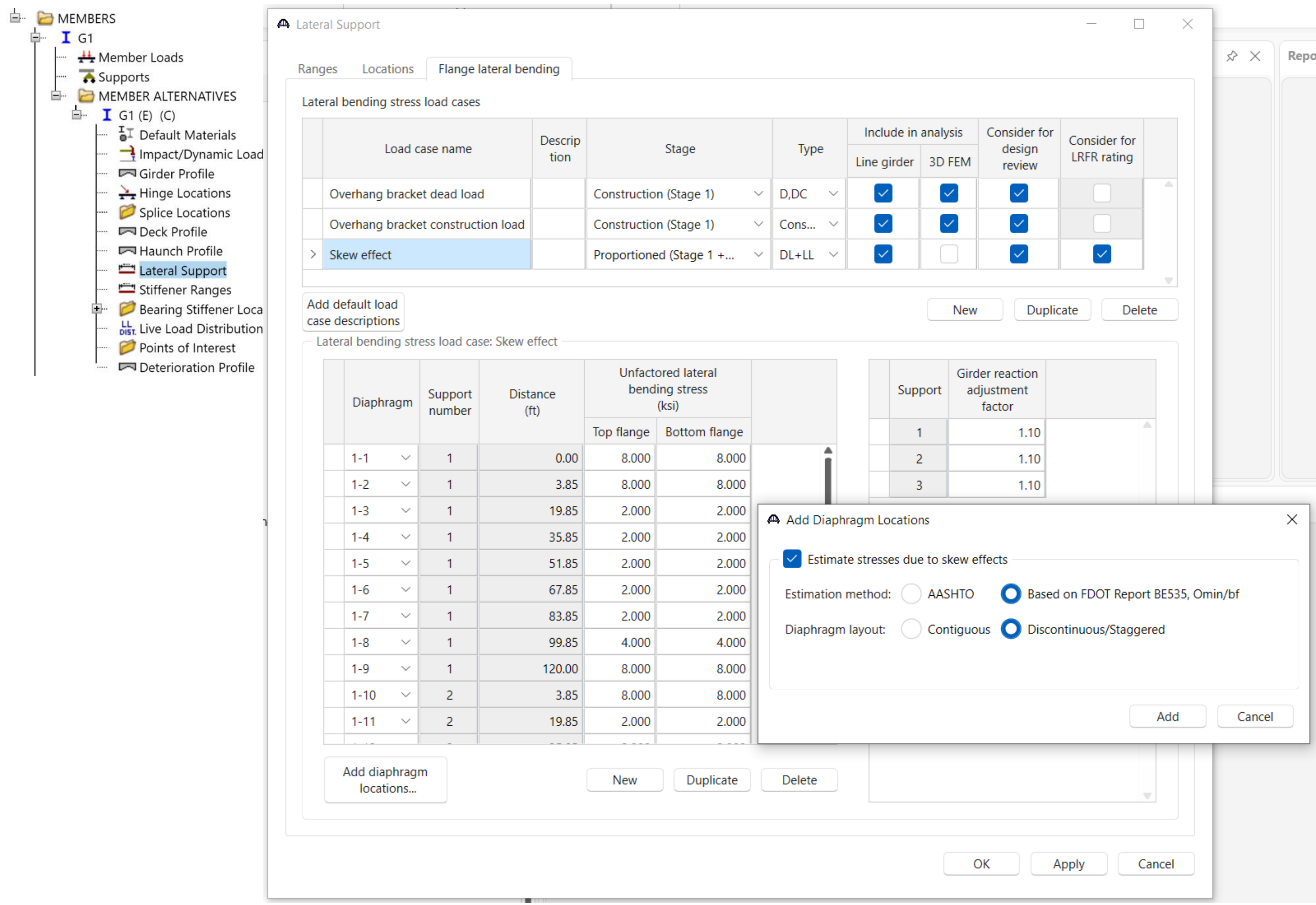


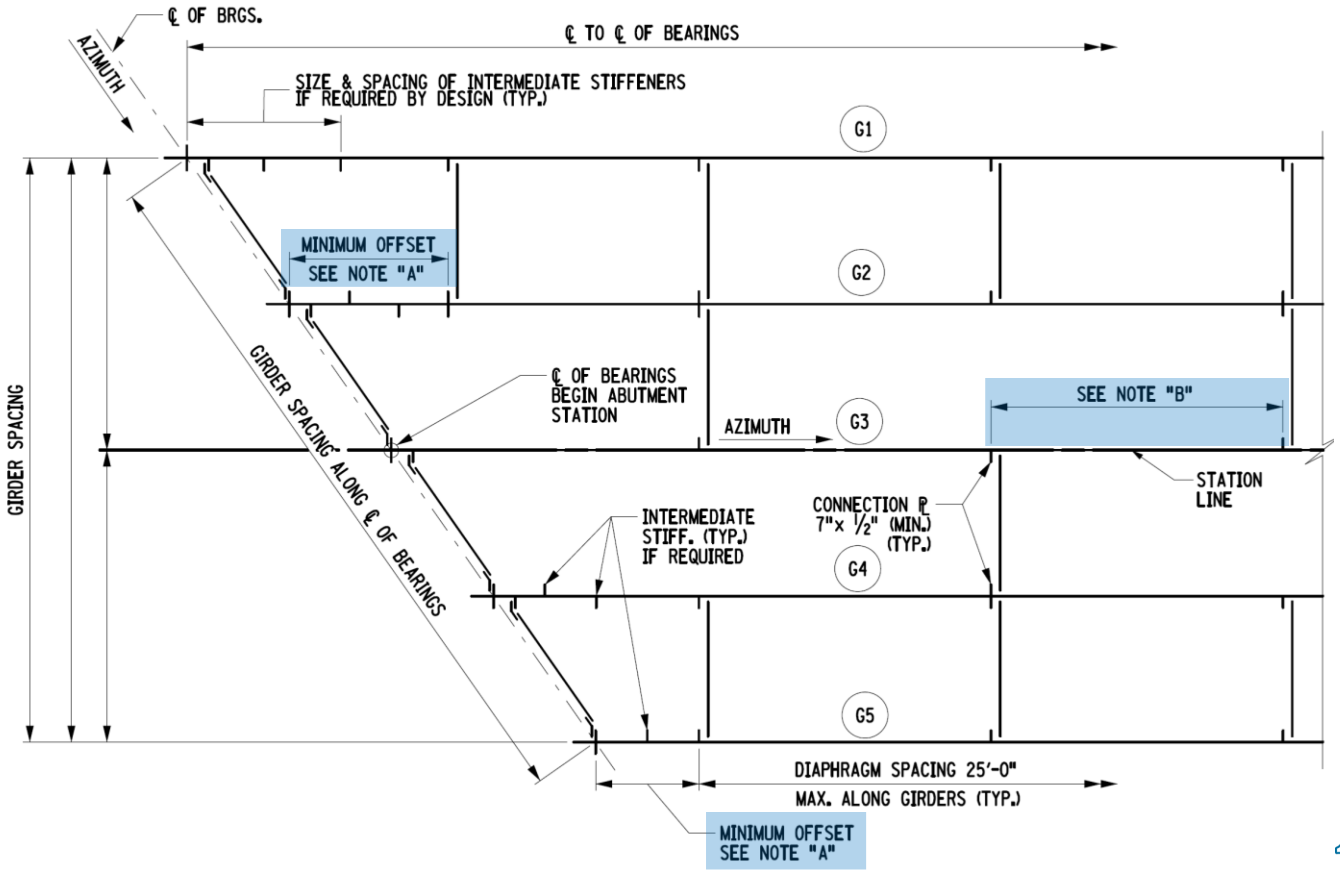
Table from FDOT Report BE535

Table 12. Summary of recommended estimations of the unfactored flange lateral bending stresses, f_ℓ

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

Diaphragm Offsets

- AASHTO recommends minimum offset ≥ 4x bottom flange width



AASHTOWare BrDR - Help

Show Back Print Options

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.

Type

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

Include in analysis

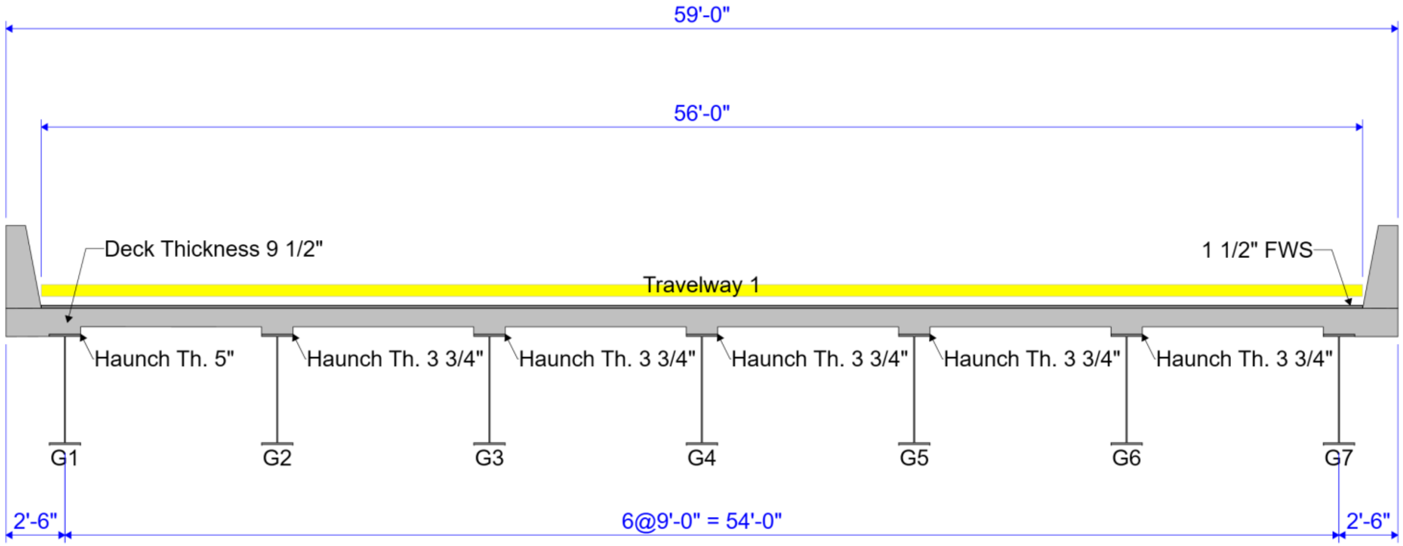
Line girder

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

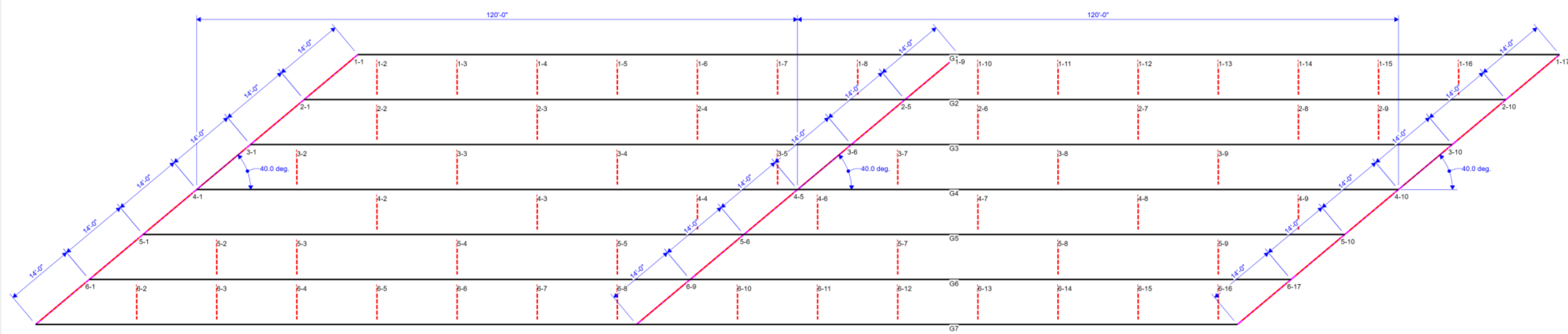
3D FEM

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

BrDR Enhancement



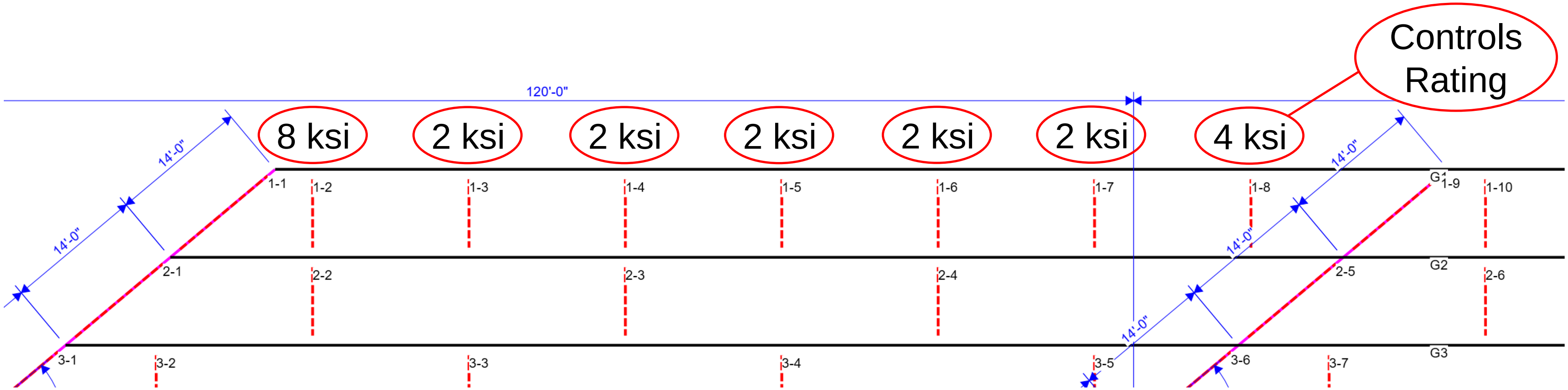
Typical Section



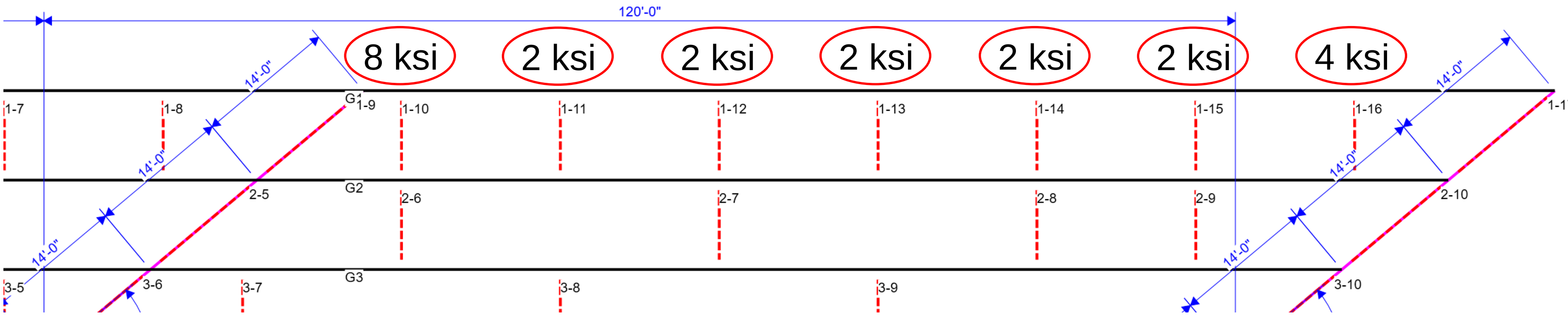
Framing Plan

NEW YORK STATE OF OPPORTUNITY. Department of Transportation

BrDR Enhancement



Span 1 – Exterior Girder Unfactored FLB



Span 2 – Exterior Girder Unfactored FLB

Without Flange Lateral Bending

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

Bottom Flange LTB Rating

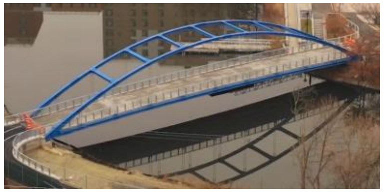
						Factored Stresses							
Load	Load Combo	Limit State	Component	Flexure Type	Location	fDL1 (ksi)	fDL2 (ksi)	fLL (ksi)	User Input fl DL (ksi)	User Input fl LL (ksi)	fR (ksi)	RF	Capacity (Ton)
DesignInv	1	STR-I	Bot Flange	Neg	120.00,L	-19.59	-2.30	0.00	0.00	0.00	-50.00	99.000	3564.00
DesignInv	1	STR-I	Bot 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

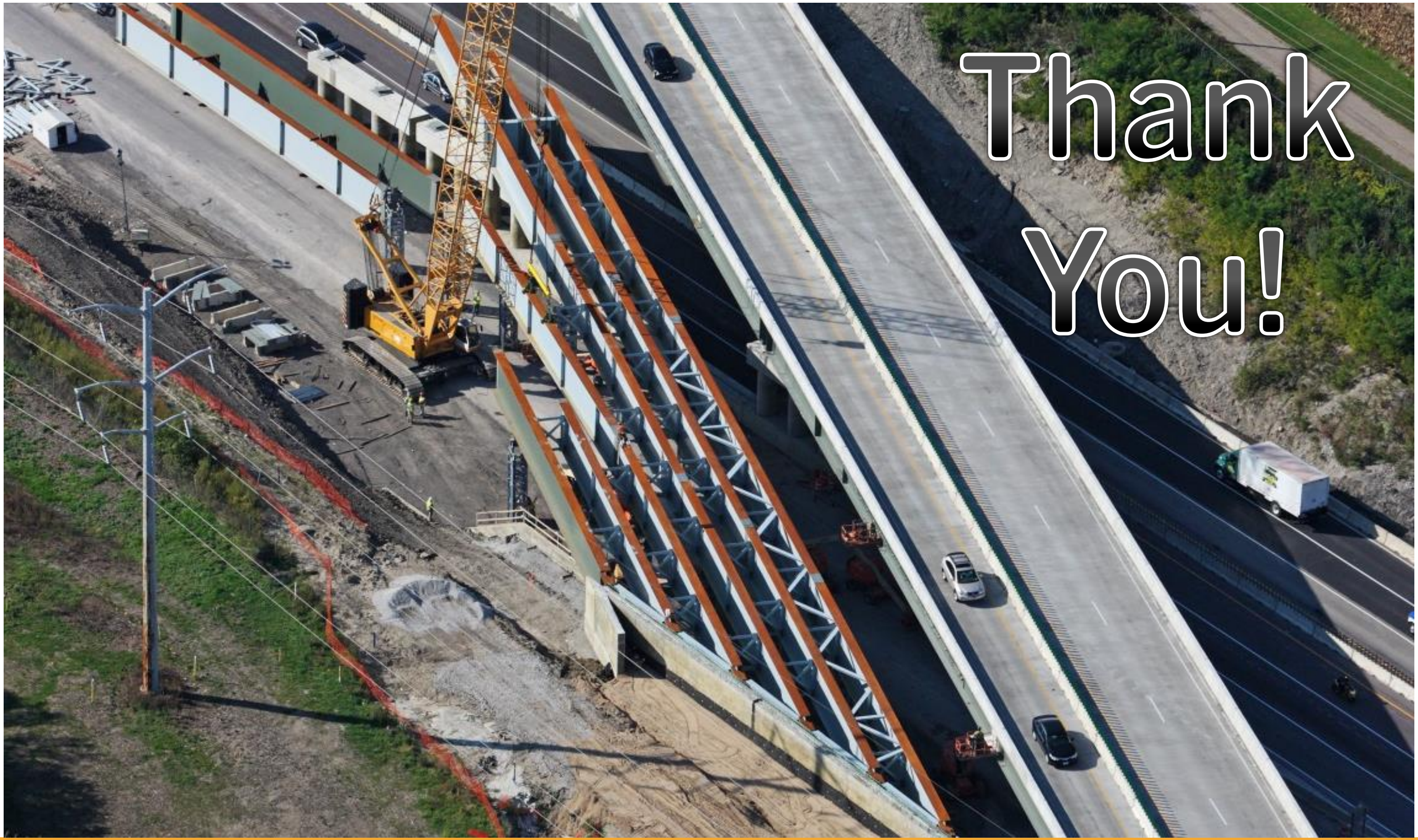
With Flange Lateral Bending

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

Bottom Flange LTB Rating

						Factored Stresses							
Load	Load Combo	Limit State	Component	Flexure Type	Location	fDL1 (ksi)	fDL2 (ksi)	fLL (ksi)	User Input fl DL (ksi)	User 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	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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