Structural Load Rating Calculations

Volume 3

Section 3.14 to 3.24.5

CLINE AVENUE BRIDGE

S.R. 912 OVER THE INDIANA HARBOR CANAL
AT EAST CHICAGO, INDIANA
LAKE COUNTY

Prepared by:

URS

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	6.11.1 Results Comparison	6	PT	IC
	6.11.2 Tango Model	1	PT	IC
	6.11.3 Tango Input	16	PT	IC
	6.12 Ramp A			
	6.12.1 Results Comparison	9	PT	IC
	6.12.2 Tango Model	6	PT	IC
	6.12.3 Tango Input	23	PT	IC
	6.13 Ramp B			
	6.13.1 Results Comparison	9	PT	IC
	6.13.2 Tango Model	1	PT	IC
	6.13.3 Tango Input	8	PT	IC
	6.14 Ramp C			
	6.14.1 Results Comparison	9	PT	IC
	6.14.2 Tango Model	1	PT	IC
	6.14.3 Tango Input	12	PT	IC
	6.15 Ramp D			
	6.15.1 Results Comparison	9	PT	IC
	6.15.2 Tango Model	1	PT	IC
	6.15.3 Tango Input	7	PT	IC
	6.16 Temperature Gradient Comparison	10	PT	IC
	6.17 Permit Truck Live Load Comparison	10	PT	IC
	7 Transverse Analysis Verification			
	7.1 Summary	1	PT	N/A
	7.2 Minimum Live Load Moment at Edge of Cantilever			
	7.2.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.2.2 Brug Results	1	PT	N/A
	7.2.3 Homberg Chart Results	3	PT	N/A
	7.2.3.1 Homberg Charts – Fixed End Moment Beam	9	PT	N/A
	7.2.3.2 Homberg Charts – Continuous Beam	3	PT	N/A
	7.3 Minimum Live Load Moment at Edge of Web			
	7.3.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.3.2 Brug Results	1	PT	N/A
	7.3.3. Homberg Chart Results	2	PT	N/A

Job: Cline Avenue Load Rating
Item: Calculation Index
File: V:\Projects\Cline Avenue\Calc Index\[Calculation_Index.xls]Index

		Number of Pages	Designed	Checked
	7.3.3.1 Homberg Charts – Fixed End Moment Beam	2	PT	N/A
	7.3.3.2 Homberg Charts – Continuous Beam	3	PT	N/A
Volume 7A	7.4 Minimum Live Load Moment at Top Slab - Thickness Change Location			
	7.4.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.4.2 Brug Results	1	PT	N/A
	7.4.3 Homberg Chart Results	4	PT	N/A
	7.4.3.1 Homberg Charts – Fixed End Moment Beam	6	PT	N/A
	7.4.3.2 Homberg Charts – Continuous Beam	6	PT	N/A
	7.5 Maximum Live Load Moment at Top Slab - Thickness Change Location			
	7.5.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.5.2 Brug Results	1	PT	N/A
	7.5.3 Homberg Chart Results	4	PT	N/A
	7.5.3.1 Homberg Charts – Fixed End Moment Beam	7	PT	N/A
	7.5.3.2 Homberg Charts – Continuous Beam	6	PT	N/A
	7.6 Minimum Live Load Moment at Top Slab - Centerline			
	7.6.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.6.2 Brug Results	1	PT	N/A
	7.6.3 Homberg Chart Results	3	PT	N/A
	7.6.3.1 Homberg Charts – Fixed End Moment Beam	-	PT	N/A
	7.6.3.2 Homberg Charts – Continuous Beam	-	PT	N/A
	7.7 Maximum Live Load Moment at Top Slab - Centerline			
	7.7.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.7.2 Brug Results	1	PT	N/A
	7.7.3 Homberg Chart Results	2	PT	N/A
	7.7.3.1 Homberg Charts – Fixed End Moment Beam	4	PT	N/A
	7.7.3.2 Homberg Charts – Continuous Beam	3	PT	N/A
	7.8 Minimum Live Load Moment at Top of Web			
	7.8.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.8.2 Brug Results	1	PT	N/A
	7.8.3 Homberg Chart Results	2	PT	N/A
	7.8.3.1 Homberg Charts – Fixed End Moment Beam	-	PT	N/A
	7.8.3.2 Homberg Charts – Continuous Beam	-	PT	N/A
	7.9 Maximum Live Load Moment at Top of Web			
	7.9.1 Midas Results and Comparison	1	PT/DEM	N/A
	7.9.2 Brug Results	1	PT	N/A
	7.9.3 Homberg Chart Results	2	PT	N/A
	7.9.3.1 Homberg Charts – Fixed End Moment Beam	-	PT	N/A
	7.9.3.2 Homberg Charts – Continuous Beam	-	PT	N/A
	7.10 2D GTSTRUDL Analysis – Equivalent Loads on Continuous Beam	19	PT	N/A
	7.11 2D GTSTRUDL Analysis –Frame Model	20	PT	N/A
Volume 7E	**8 Review of Longitudinal Shear and Transverse Analysis**			
	8.1 Summary		RJB	N/A
	8.2 References for Interaction of Longitudinal Shear and Transverse Bending		RJB	N/A
	8.3 Initial Review of Transverse Analysis		RJB	N/A
	8.4 Revised Transverse Analysis Based on Revised Effective Span Length		RJB	N/A
	8.5 Review of Longitudinal Shear Analysis (MATHCAD Analysis)		RJB	N/A
	8.6 Comparison of the MCFT Shear Analysis - Tabularized Values (2007) Vs. Equations (2009)		RJB	N/A
Electronic Files	**8 Appendix A – GP Input Files - Geometry**		DEM	
	9 Appendix B - RM Input Files - Dead Load		DEM	
	10 Appendix C - RM Input Files - Live Load		DEM	
	10 Appendix D - Additional Longitudinal Rating Calculations		TSP	
	10 Appendix E - Brug Output Files		PT	

URS **EXHIBIT 4.7-2**

CALCULATION COVER SHEET

Client: Indiana DOT

Project Name: Cline Avenue LRFR Load Rating

Project/Calculation Number: Section 3.0

Title: LONGITUDINAL RATING

Total Number of Pages (including cover sheet): 870

Total Number of Computer Runs: See Section 3.0

Prepared by: Thomas S. Peake Date: 1/22/2009 & 10/1/09

Checked by: Independent Check by Daniel Mariscal and Richard Beaupre Date: 2/9/2009 & 10/1/09

Description and Purpose:
Includes LRFR longitudinal load rating analysis; service rating for flexure and principal stress; ultimate strength rating for flexure, shear and torsion.

Design Basis/References/Assumptions
Job Specific Criteria - See Section 1.2.

Remarks/Conclusions/Results:
None.

Calculation Approved by: _____
Project Manager/Date

Revision No.: Description of Revision: Approved by:

_____
Project Manager/Date

3.0 Longitudinal Rating

URS

Job : Cline Avenue Bridge **Project No.** 25626272.00001

Description: Longitudinal Rating Analysis **Computed By:** TSP

Description of Results **Checked By**: _____

The following calculations are a sample representation of the calculations used to produce the Load Rating Factor Tables found in each section of these calculations. All calculations shown in this section are for the **HL-93 Inventory** case. A pdf of the spreadsheet used to generate the graphs can be found in Appendix D of the calculations. Each section contains the following section for each segment or ramp of the Cline Avenue Bridge:

1) Rating Summary—minimum rating factors for each feature of the bridge, including transverse ratings.
2) Strength I Flexure—there are three graphs provided to show the capacity versus demand chart, calculated versus RM generated flexural demand, and calculated versus RM generated flexural capacity.
3) Strength I Shear—there are four graphs provided showing the shear demand versus capacity for maximum shear, minimum shear, maximum torsion, and minimum torsion. Each case shows an independent verification using MathCad for the HL-93 Operating case.
4) Service I Flexural (Service Stresses)—three graphs are provide to show the calculated stress versus allowable limits and two comparisons of RM generated service stresses versus calculated values.
5) Service I Principal Stresses—two graphs are provided to show the calculated stresses versus the allowable limits and calculated stresses versus RM generated stresses.

3.1 Global Rating Summary

URS

PROJECT: **Cline Avenue** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Global Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Posting Values | Posting Values

Cline Avenue Load Rating			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	0.82	1.06	0.81	0.86	0.75	0.94	0.94	0.87	0.87	0.73	0.82	0.75
		Shear	0.52	0.68	0.48	0.49	0.41	0.49	0.49	0.39	0.40	0.36	0.39	0.32
	Service	Flexure	0.28	1.10	0.99	1.01	0.93	1.00	0.99	0.91	0.92	0.83	0.89	0.80
		Principal Stress	0.73	0.82	0.75	0.76	0.86	0.78	0.78	0.68	0.68	0.52	0.58	0.49
Transverse	Strength	Top Slab Centerline	0.76	0.99	1.15	1.22	1.38	1.05	1.04	0.99	1.00	0.92	1.08	1.03
		Top Slab Thickness Change	0.56	0.73	0.81	0.81	0.72	0.66	0.68	0.58	0.60	0.50	0.58	0.50
		Top Slab Webs & Cantilever	1.16	1.51	1.61	1.85	1.73	1.43	1.38	1.43	1.47	1.38	1.58	1.33
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.56	0.57	0.52	0.47	0.47	0.38	0.46	0.38

Overall Rating Factor	0.28	0.64	0.41	0.32
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	25.83	76.80

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Global Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

Clear Posting Values | Posting Values

Cline Avenue Load Rating			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.09	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Shear	0.72	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Service	Flexure	0.34	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Principal Stress	0.73	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transverse	Strength	Top Slab Centerline	0.86	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Top Slab Thickness Change	0.56	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Top Slab Webs & Cantilever	1.89	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Transverse Web Bending	0.54	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Overall Rating Factor	0.34	0.70	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		25.20	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

3.2 Mainline Segment 1 Girder 1 Rating

3.2.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 1** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 1 Girder 1			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.52	1.97	1.42	1.48	1.39	1.75	1.74	1.69	1.71	1.49	1.63	1.45
		Shear	0.82	1.04	0.87	0.82	0.69	0.78	0.78	0.65	0.66	0.60	0.56	0.56
	Service	Flexure	0.46	1.52	1.35	1.41	1.30	1.37	1.36	1.29	1.29	1.17	1.27	1.15
		Principal Stress	1.31	1.33	1.15	1.16	0.99	1.01	1.01	0.83	0.83	0.77	0.69	0.69
Transverse	Strength	Top Slab Centerline	0.98	1.27	1.48	1.55	1.64	1.33	1.29	1.24	1.25	1.11	1.30	1.16
		Top Slab Thickness Change	0.56	0.73	0.81	0.81	0.72	0.66	0.68	0.58	0.60	0.50	0.58	0.50
		Top Slab Webs & Cantilever	1.85	2.40	2.33	2.31	1.90	1.92	2.01	1.68	1.68	1.39	1.60	1.37
		Transverse Web Bending	0.71	0.92	0.75	0.89	0.95	0.89	0.76	0.83	0.83	0.60	0.88	0.69

Overall Rating Factor	0.46	0.73	0.69	0.50
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	43.47	87.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 1** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

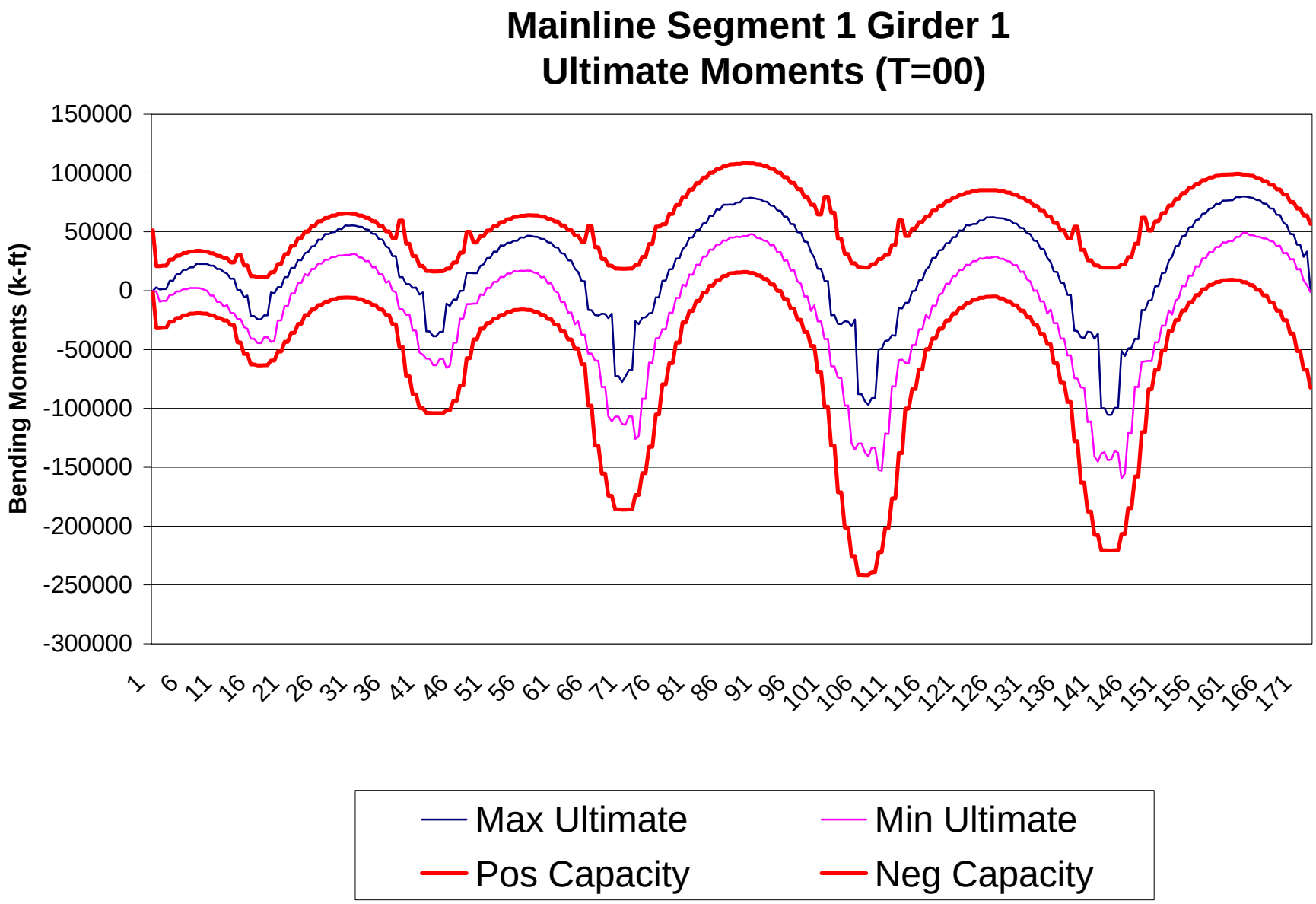
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 1 Girder 1			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	2.00	2.59										
		Shear	1.29	1.62										
	Service	Flexure	0.54	1.82										
		Principal Stress	1.84	1.86										
Transverse	Strength	Top Slab Centerline	0.98	1.27										
		Top Slab Thickness Change	0.56	0.73										
		Top Slab Webs & Cantilever	2.36	3.07										
		Transverse Web Bending	1.41	2.19										

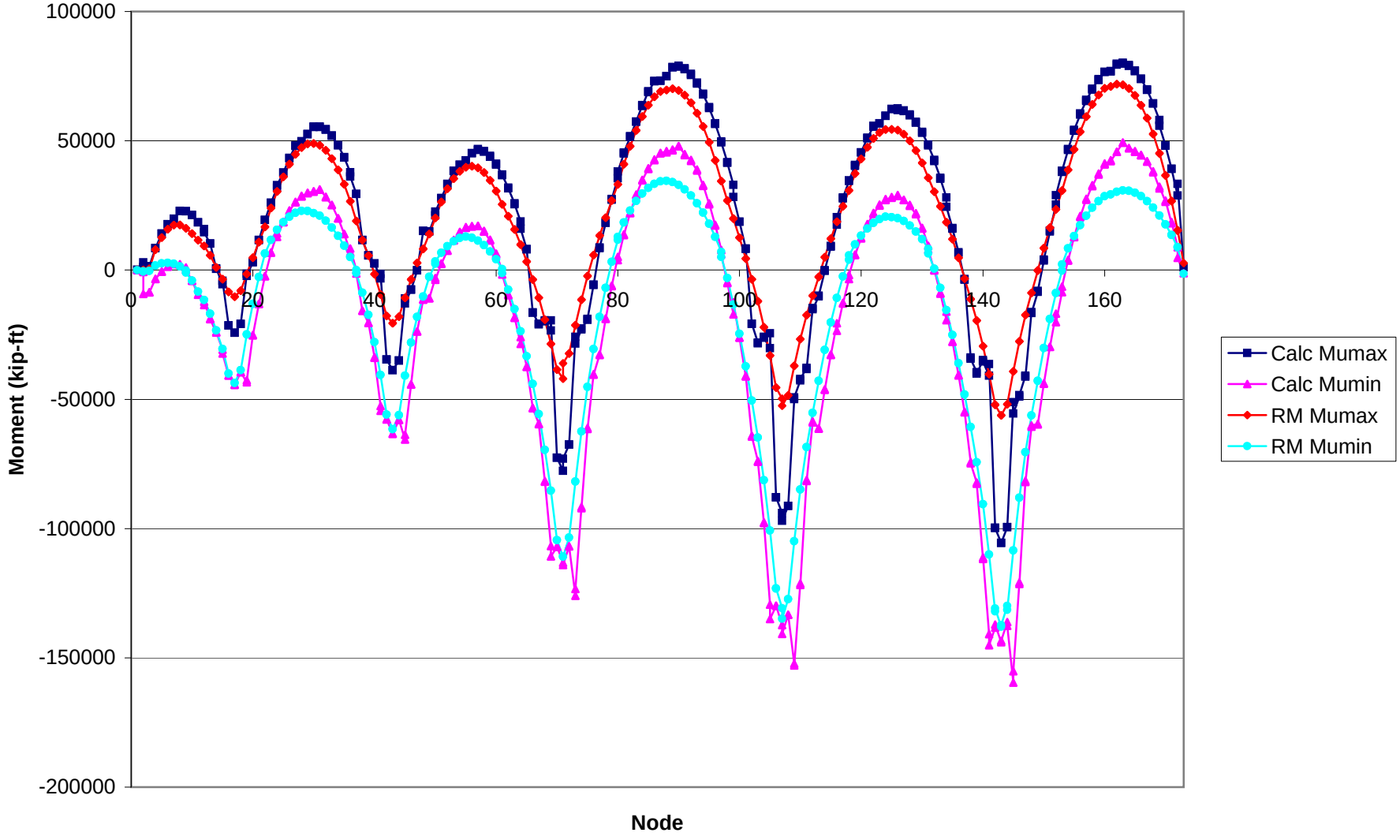
Overall Rating Factor	0.54	0.73	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

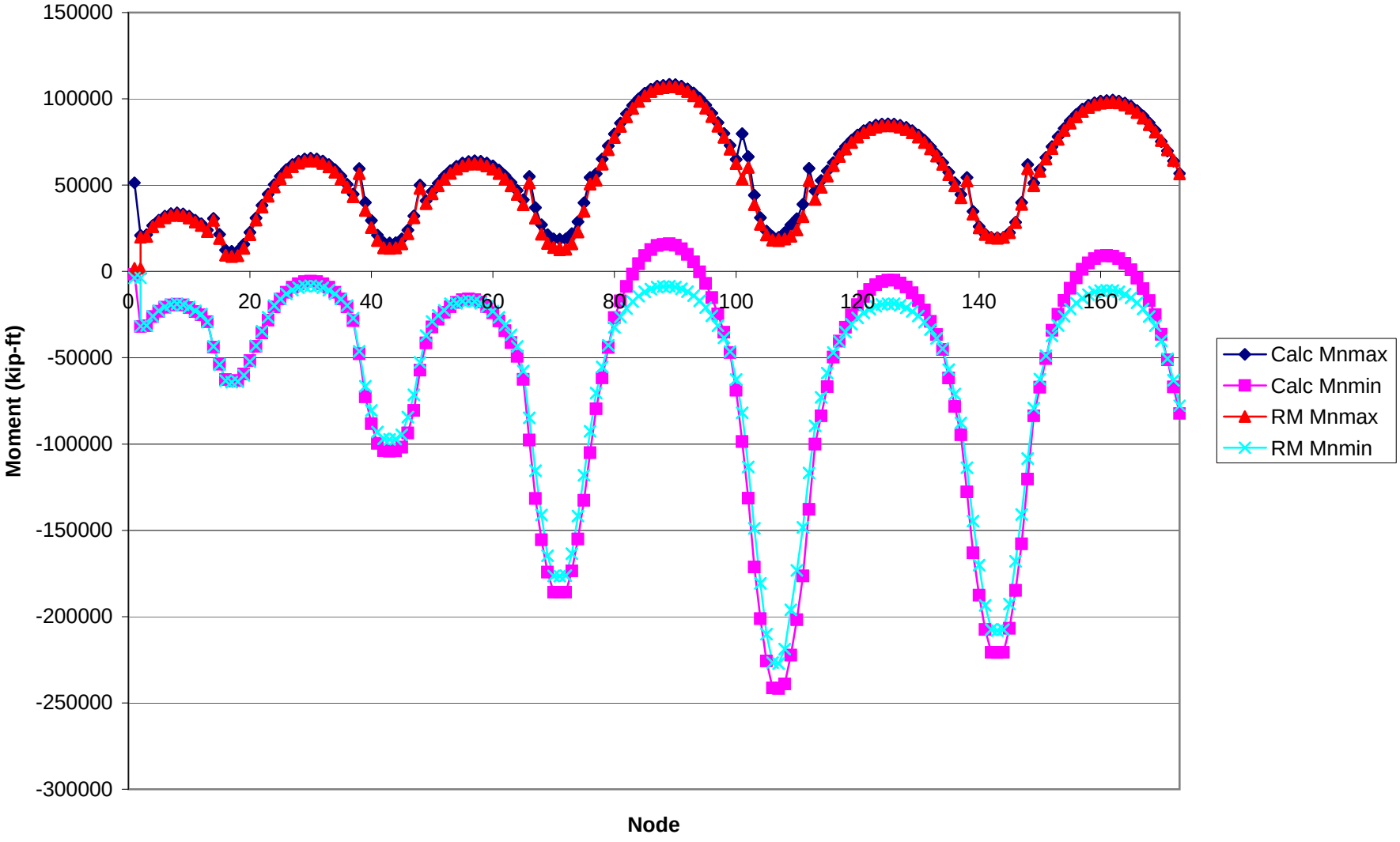
3.2.2 Strength I Flexure


Mainline Segment 1 Girder 1
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
-300000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

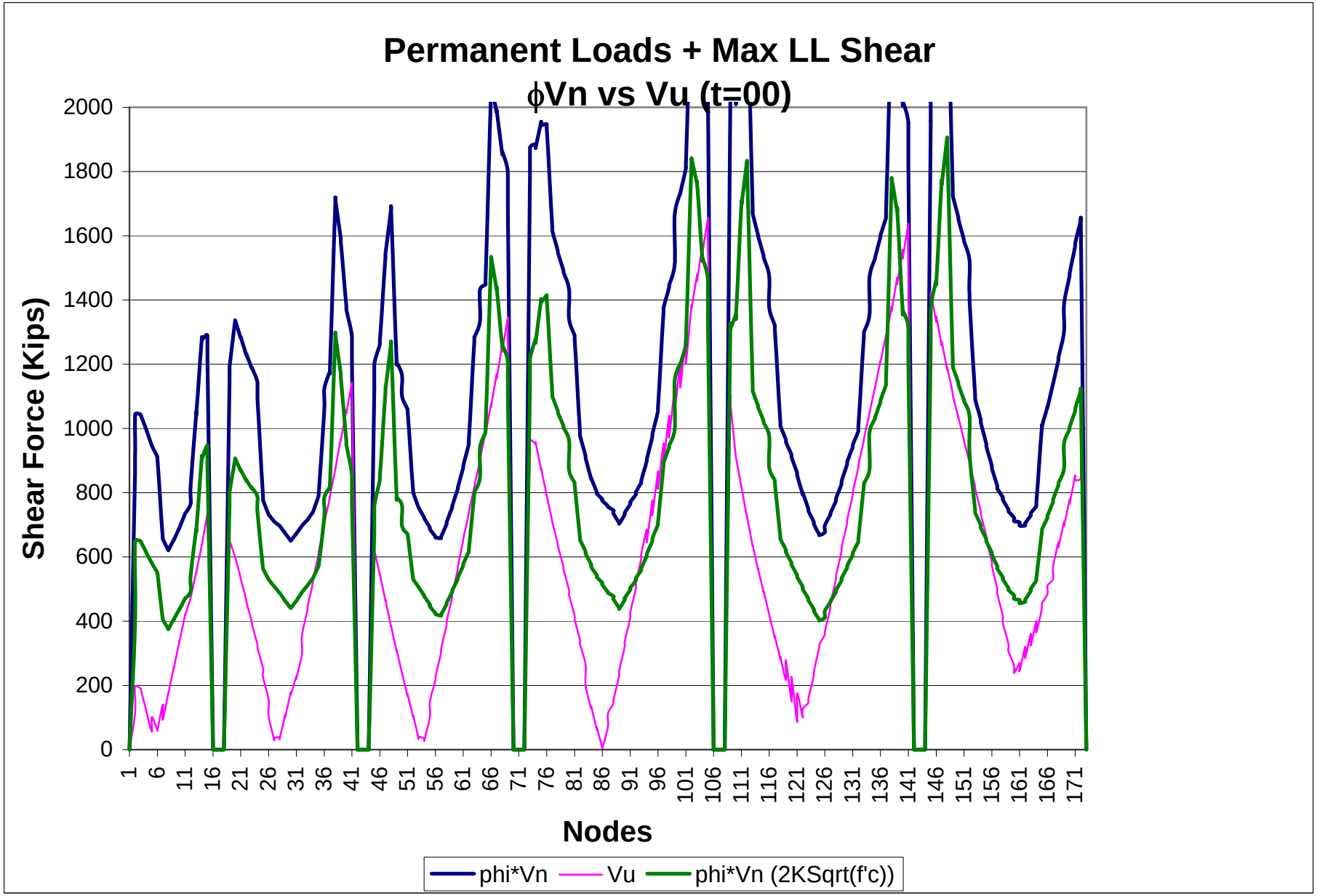
Mainline Segment 1 Girder 1 Flexural Demand, M_u

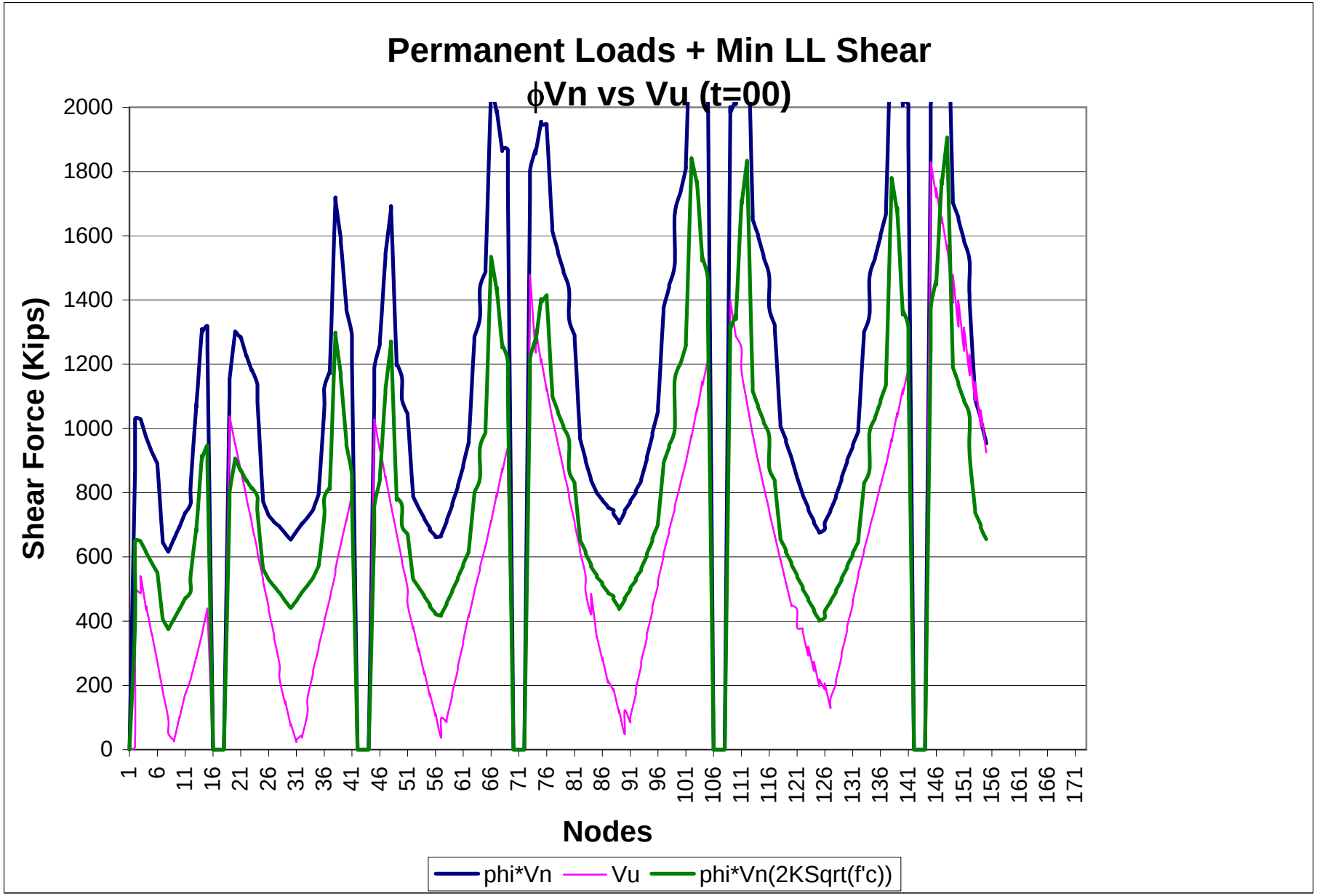


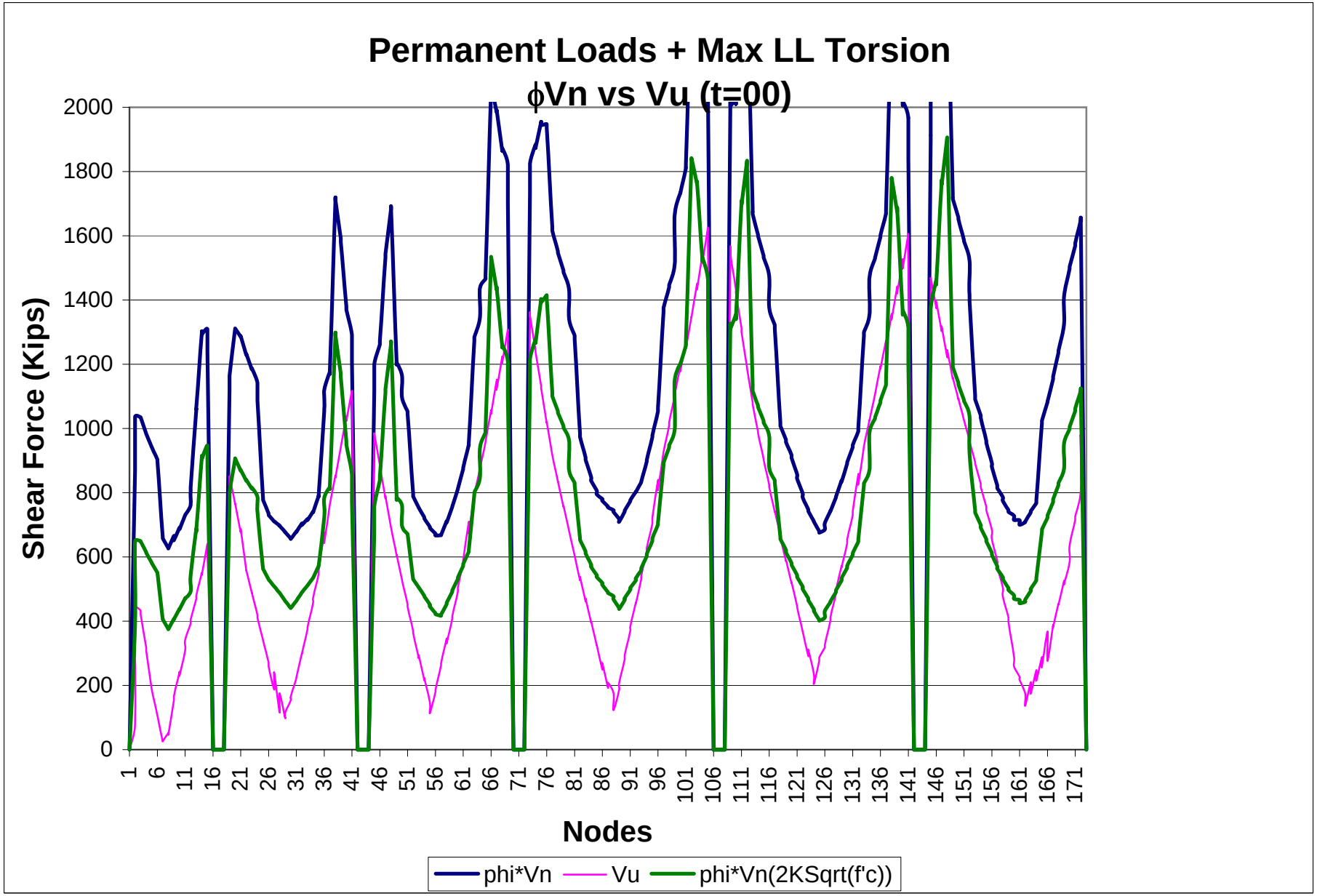
Mainline Segment 1 Girder 1 Flexural Strength, ϕM_n

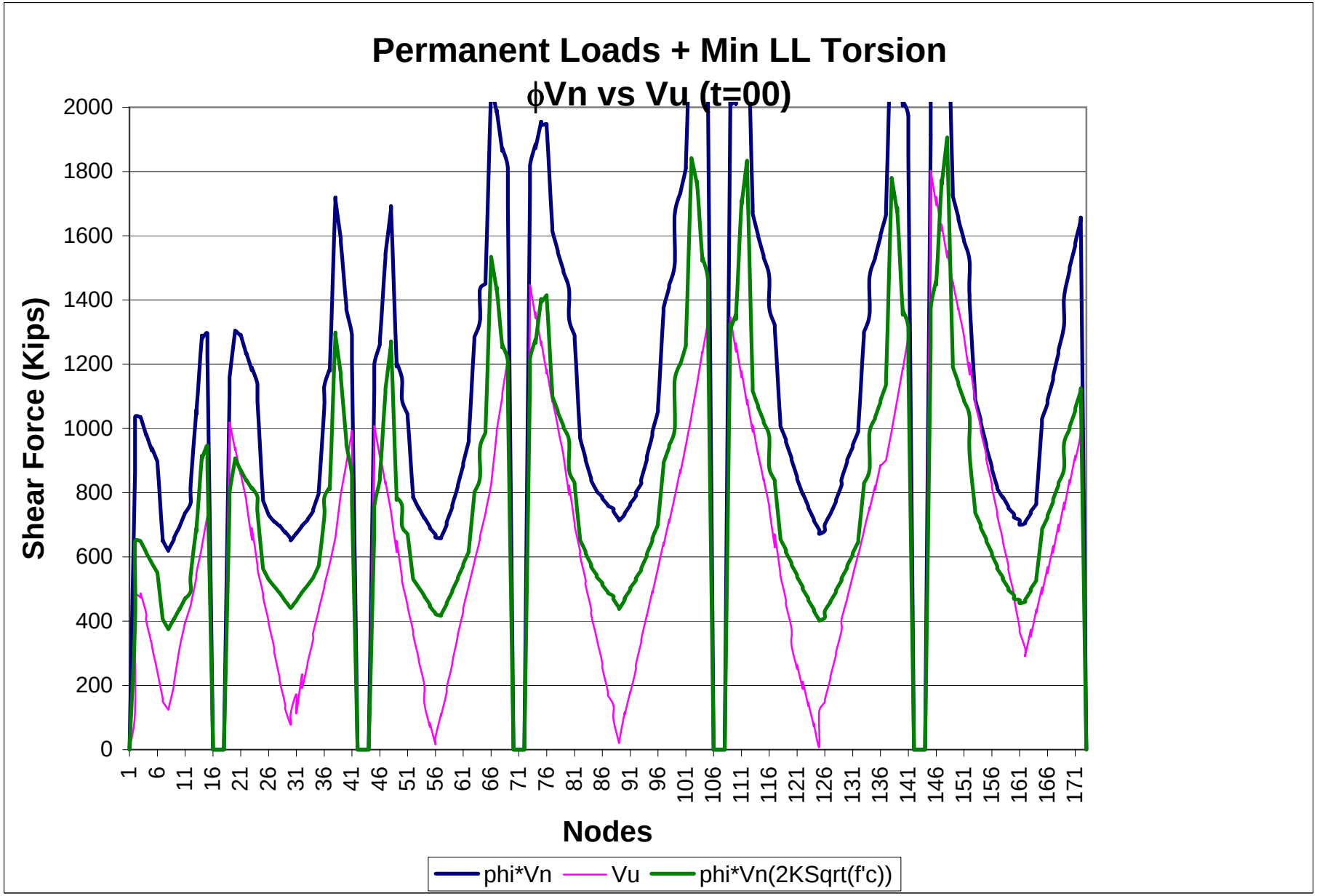


3.2.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001 | Page _____
Design: RJB | Date: 10/ 01 / 2009
Check: Ind Chk | Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 1 Gdr 1\

Node := 153 Position := Ahead $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -780 \cdot kips$	$M_{dc_x} = -2446 \cdot kip \cdot ft$	$T_{dc_x} = -11262\, ft \cdot kips$	$N_{dc_x} = -177 \cdot kips$	Dead Load
$V_{dw_x} = -102 \cdot kips$	$M_{dw_x} = 641 \cdot kip \cdot ft$	$T_{dw_x} = -502 \cdot kip \cdot ft$	$N_{dw_x} = -6 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 63 \cdot kips$	$M_{psec_x} = 18469 \cdot kip \cdot ft$	$T_{psec_x} = 1520 \cdot kip \cdot ft$	$N_{psec_x} = 218 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = 33\, kip$	$M_{crsh_x} = 3960 \cdot kip \cdot ft$	$T_{crsh_x} = 6202 \cdot kip \cdot ft$	$N_{crsh_x} = 625 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 76 \cdot kips$	$M_{LLvmax_x} = 5746 \cdot kip \cdot ft$	$T_{LLvmax_x} = -583 \cdot kip \cdot ft$	$N_{LLvmax_x} = 28 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -247 \cdot kips$	$M_{LLvmin_x} = 1608 \cdot kip \cdot ft$	$T_{LLvmin_x} = -1455 \cdot kip \cdot ft$	$N_{LLvmin_x} = 6 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -161 \cdot kips$	$M_{LLtmax_x} = 1750 \cdot kip \cdot ft$	$T_{LLtmax_x} = 1749 \cdot kip \cdot ft$	$N_{LLtmax_x} = 10 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -106 \cdot kips$	$M_{LLtmin_x} = 4255 \cdot kip \cdot ft$	$T_{LLtmin_x} = -2553 \cdot kip \cdot ft$	$N_{LLtmin_x} = 12 \cdot kips$	Min Live Load Torsion

URS

Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: RJB
Check: Ind Chk

Page
Date: 10/ 01 / 2009
Date: / /

Post Tensioning Forces:

$V_{prim_x} = 646 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10285 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = -30716 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1261 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -3 \cdot kips$

$M_{tu_x} = -399 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 4 \cdot kip \cdot ft$

$N_{tu_x} = -31 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 9566 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 21565 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.207 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 120.75 \cdot in$ Height of Box

$y_{bot_x} = 82.282 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.199 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.092 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.138 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.092 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 72.912 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 114 \cdot in$ Depth for Torsion

$A_{s_x} = 3.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 119 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -946 \cdot kips$	$T_{uvmax_x} = -10997 \cdot kip \cdot ft$	$M_{uvmax_x} = 26110\, ft \cdot kips$	$N_{uvmax_x} = 338 \cdot kips$
$V_{uvmin_x} = -1382 \cdot kips$	$T_{uvmin_x} = -12174 \cdot kip \cdot ft$	$M_{uvmin_x} = 20524\, ft \cdot kips$	$N_{uvmin_x} = 308 \cdot kips$
$V_{utmax_x} = -1266 \cdot kips$	$T_{utmax_x} = -7848 \cdot kip \cdot ft$	$M_{utmax_x} = 20715\, ft \cdot kips$	$N_{utmax_x} = 314 \cdot kips$
$V_{utmin_x} = -1192 \cdot kips$	$T_{utmin_x} = -13656 \cdot kip \cdot ft$	$M_{utmin_x} = 24097\, ft \cdot kips$	$N_{utmin_x} = 316 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.921\,ksi$

$K := \left| \begin{array}{l} \text{for } i \in 1..rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 5587 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \frac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \frac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 74.996 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 86.94 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$\varepsilon_{svmax_x} = -0.0004$

$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 545.512 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"Yes"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -200.424\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 76.264 \cdot kips$

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$$RF_{vpos} := \text{for } i \in y \;\; \begin{array}{l} V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)} \\ V_p \leftarrow \left|V_{prim_i}\right| \\ \phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases} \\ RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}} \\ RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases} \\ RF_{i,2} \leftarrow RF_{1_i} \\ RF_{i,3} \leftarrow RF_{2_i} \end{array}$$

$$RF$$

$$RF_{vpos_{x,1}} = 1.074$$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$$\varepsilon_{svmin} := \text{for } i \in y \;\; \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \;\; \text{if } \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \;\; \text{otherwise} \end{array}$$

$$\varepsilon$$

$$\varepsilon_{svmin_x} = -0.0004$$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 545.512 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinShear_x = \text{"Yes"}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -848.076\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -229.027 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.061$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.0004$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 545.512 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -848.076\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -183.566 \cdot kips$

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$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{tpos_{x,1}} = 1.074$$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{stmin_x} = -0.0004$$

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Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 545.512 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -848.076\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -180.868 \cdot kips$

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Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.074}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

URS

Project: Cline --Seg 1 Gdr 1
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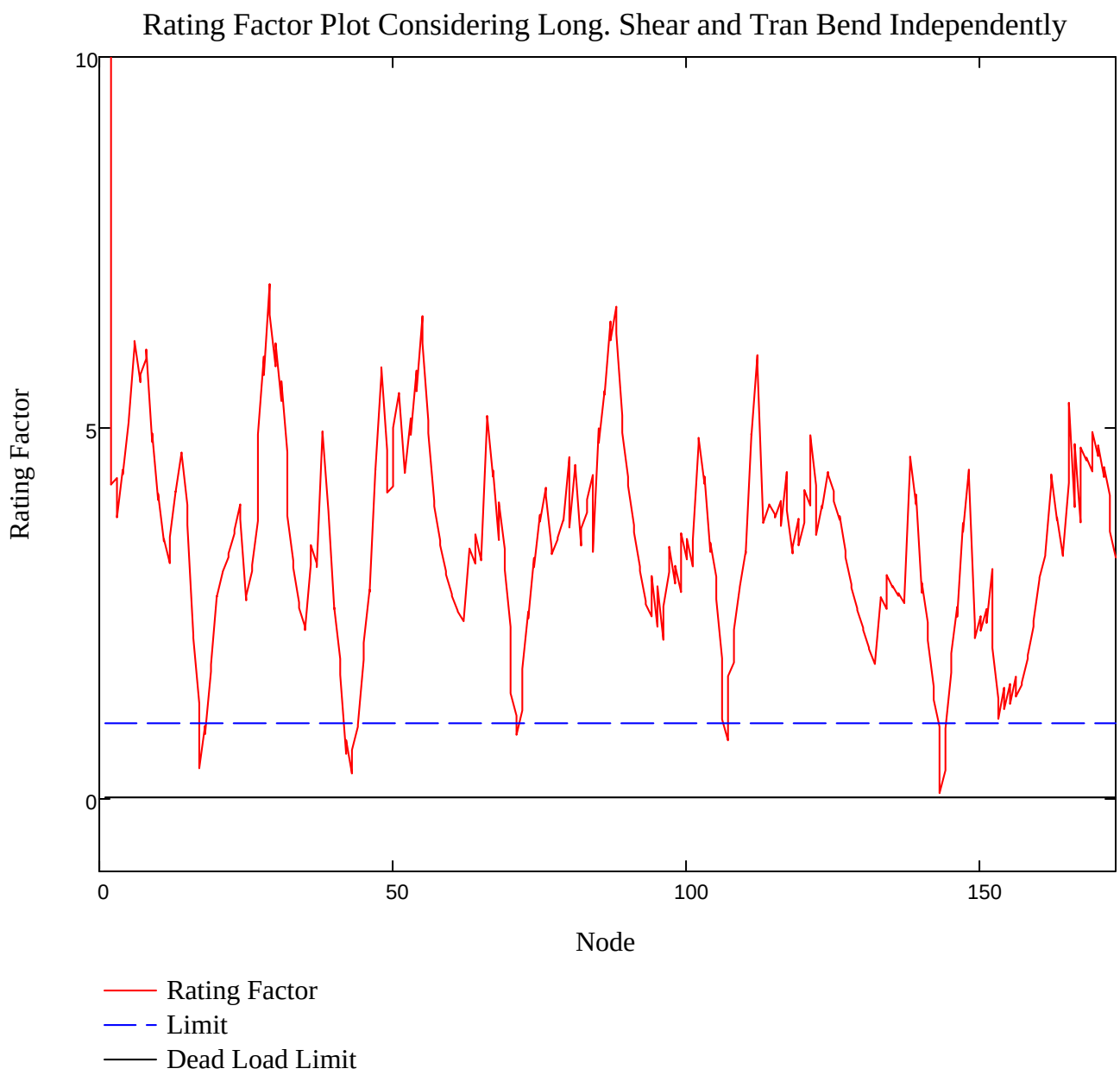

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.061$ at node $minRF_2 = 153$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 1.074$

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Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 131.593 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 61.144 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.234 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.108 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.521 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 12.4 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 10.714 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 12.4 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 171.844 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 936.321 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.243 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 10.71 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 343.688 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.091 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.486 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 10.714 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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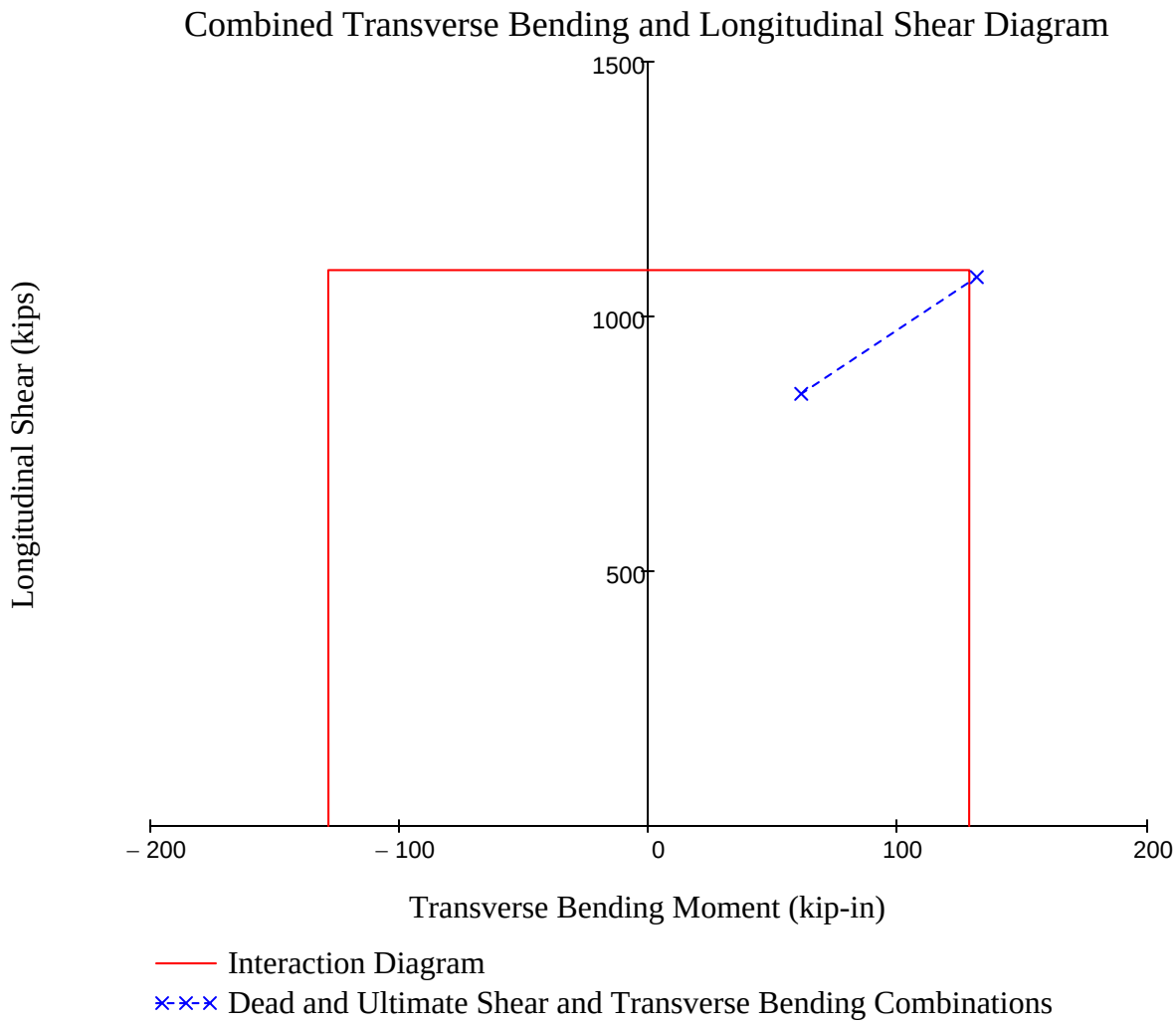


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 0.957$

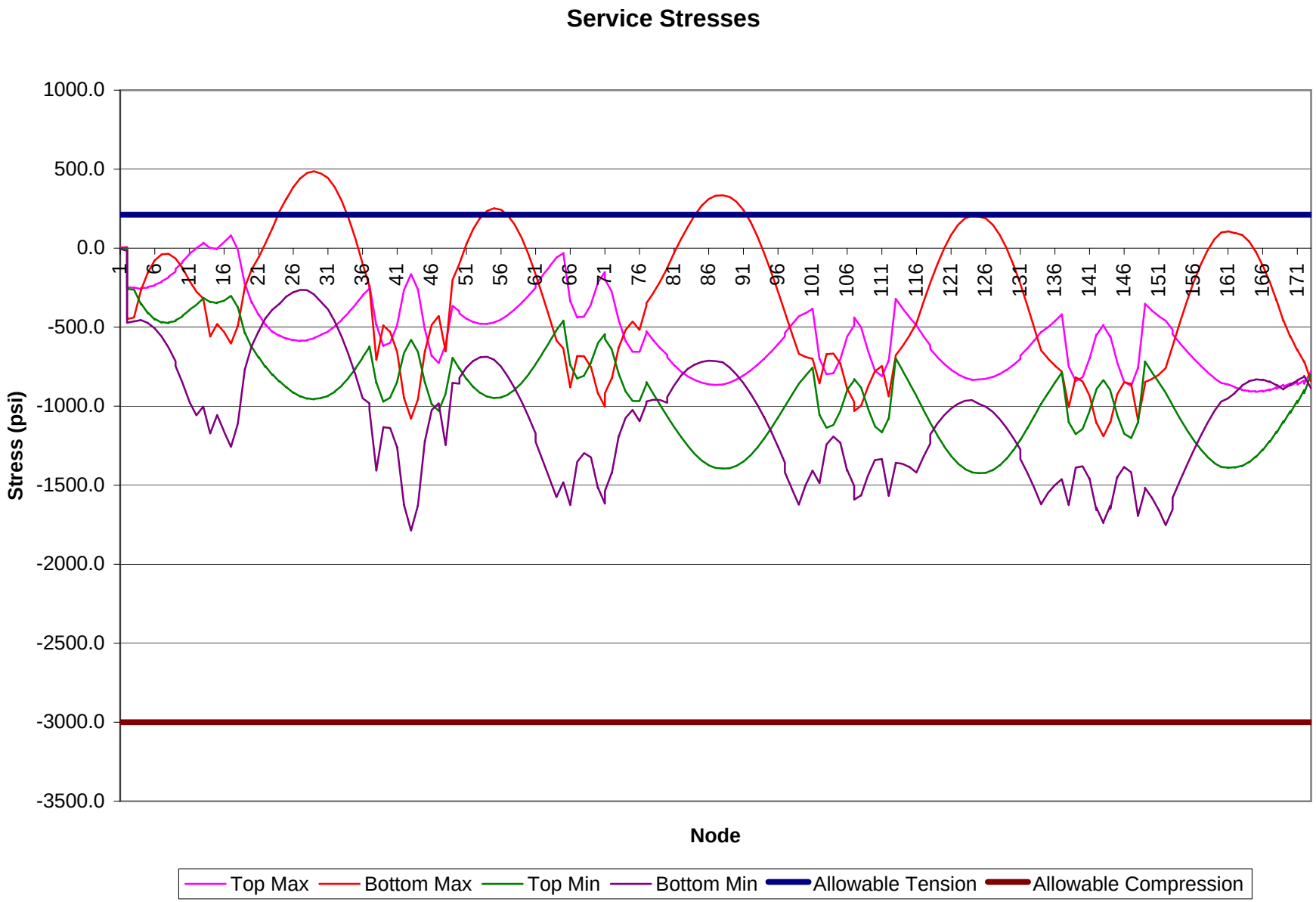
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

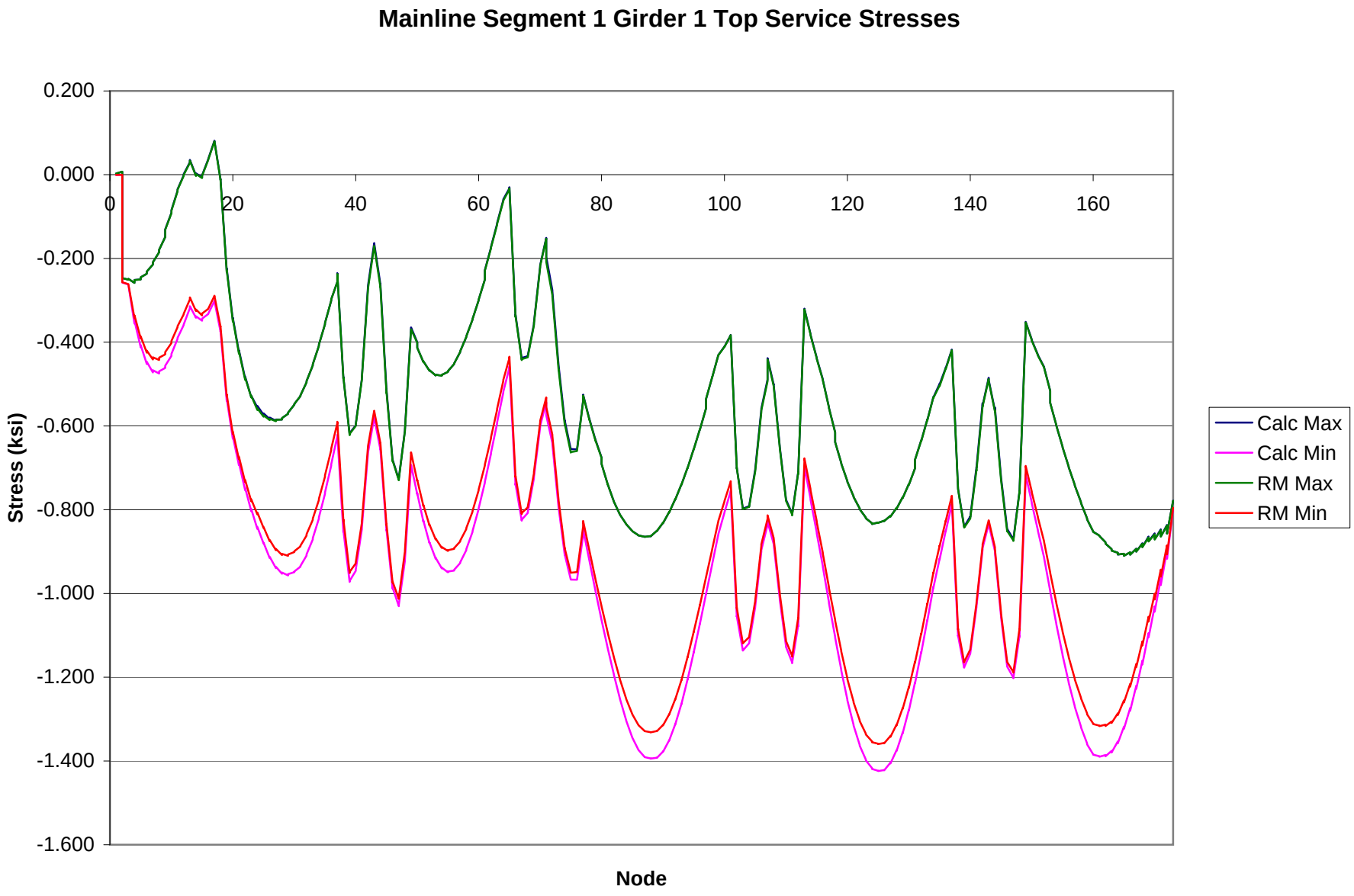
$RF_{shear} = 1.061$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

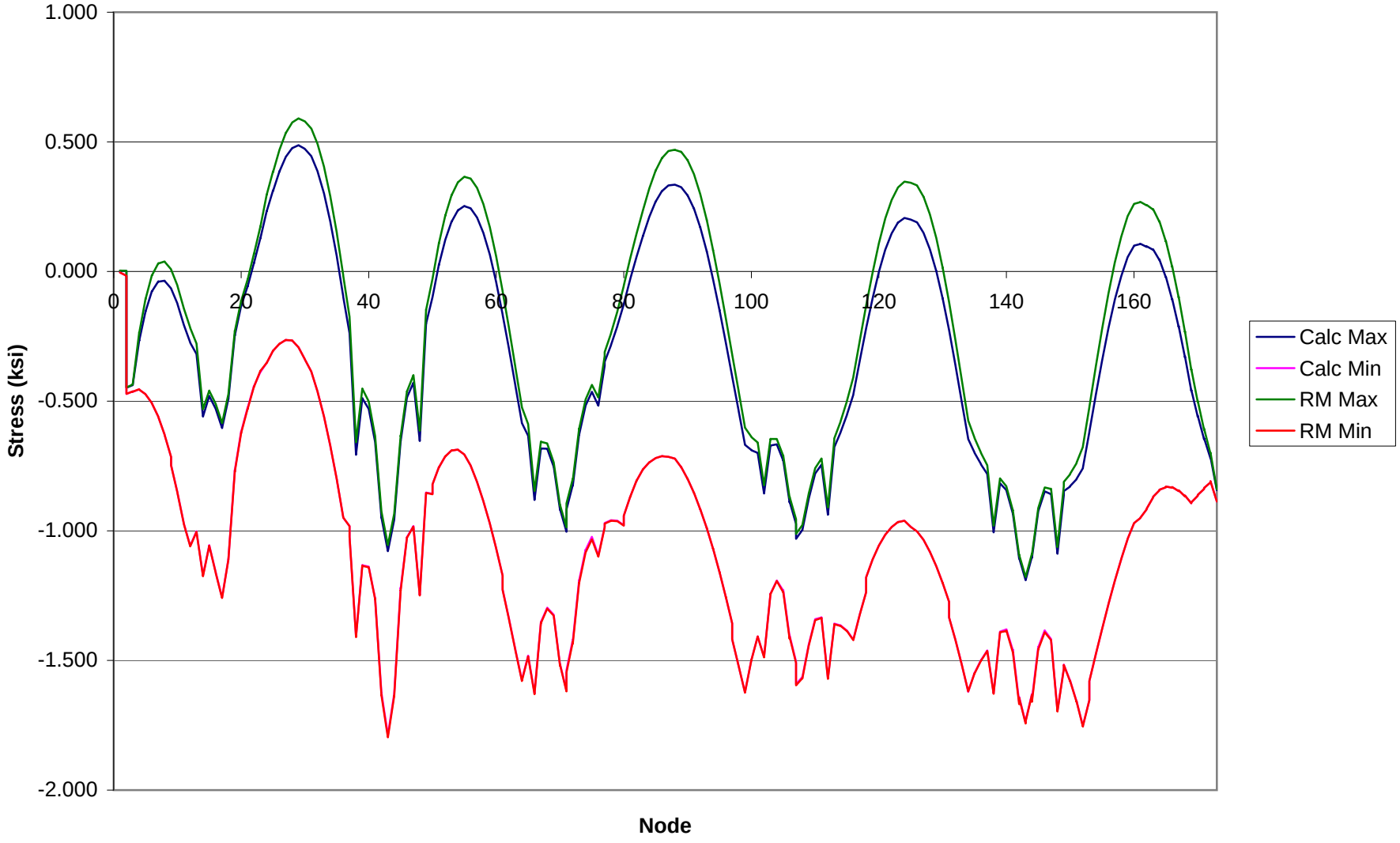
$RF_{torsion} = 1.323$

3.2.4 Service I Flexure (Service Stresses)

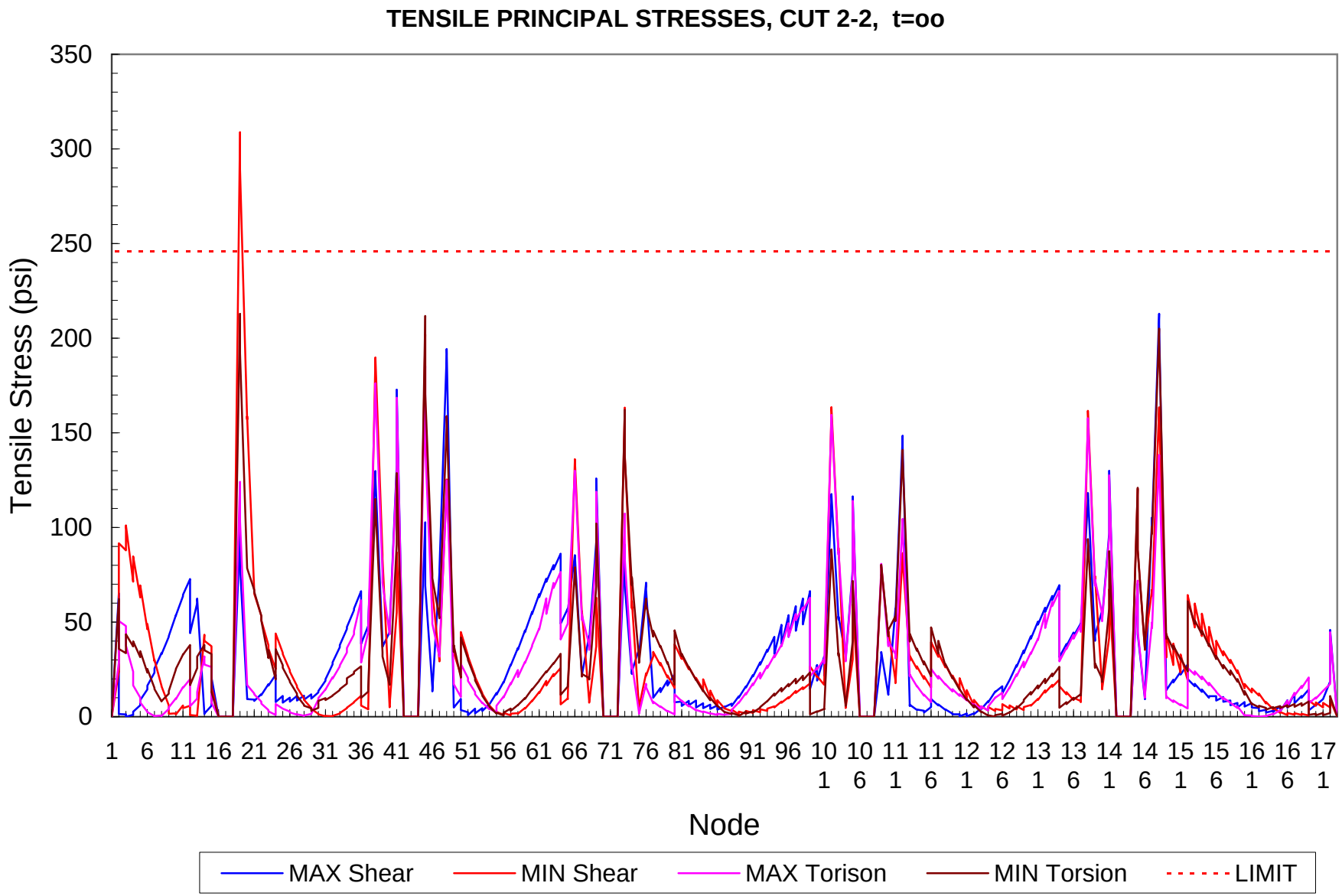

Service Stresses
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
156
161
166
171
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression


Mainline Segment 1 Girder 1 Top Service Stresses
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-1.400
-1.600
0
20
40
60
80
100
120
140
160
Stress (ksi)
Node
Calc Max
Calc Min
RM Max
RM Min

Mainline Segment 1 Girder 1 Bottom Service Stresses

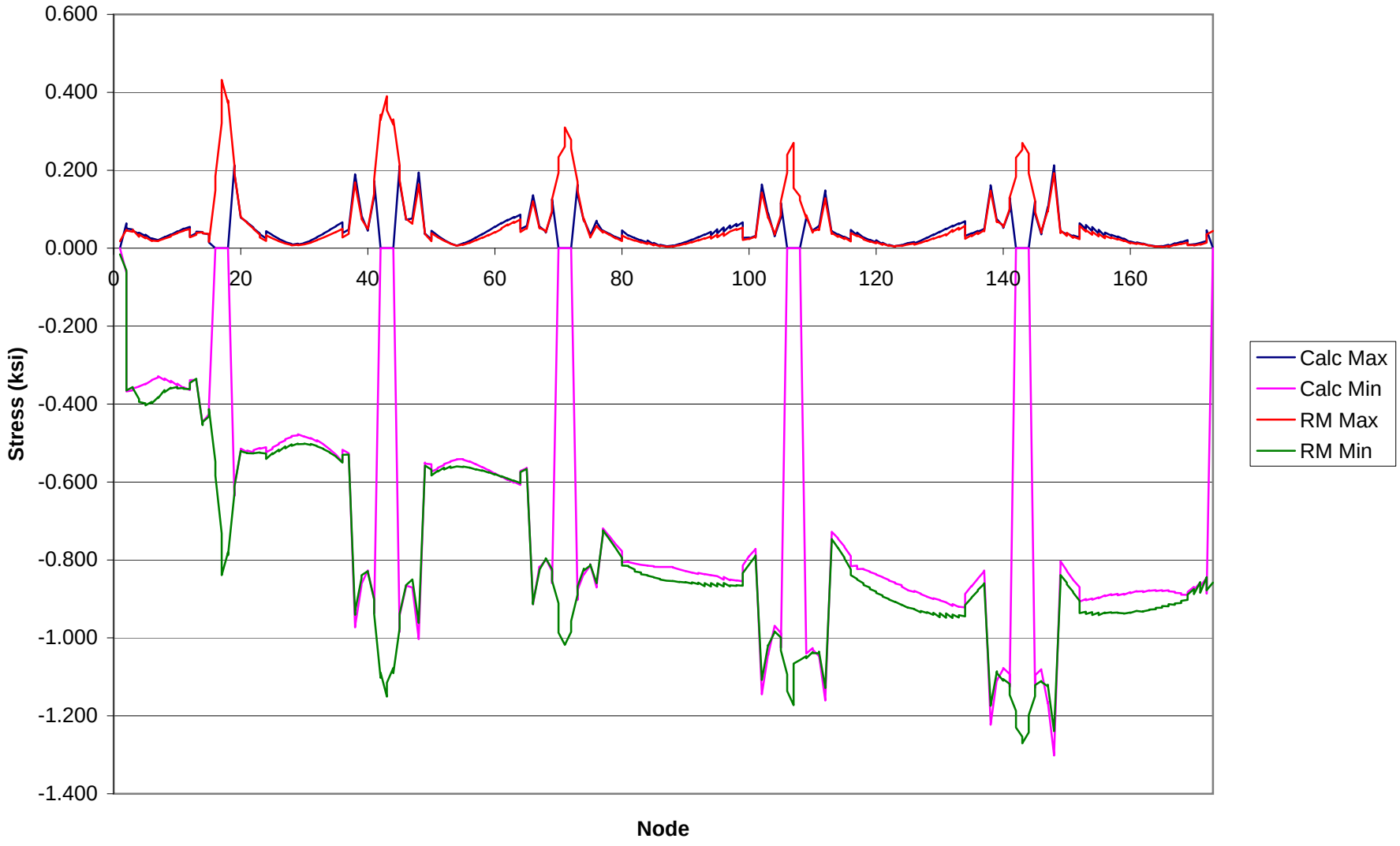


3.2.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.2.5/1

Mainline Segment 1 Girder 1 Principal Stresses



3.3 Mainline Segment 1 Girder 2 Rating

3.3.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 2** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 1 Girder 2			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.61	2.09	1.71	1.73	1.49	1.89	1.89	2.19	2.19	2.06	2.16	1.96
		Shear	1.59	2.06	1.46	1.47	1.27	1.58	1.58	2.01	2.03	1.80	1.96	1.66
	Service	Flexure	0.88	2.34	2.08	2.14	1.96	2.18	2.15	2.07	2.08	1.92	2.04	1.89
		Principal Stress	2.33	2.51	2.16	2.18	1.88	2.33	2.33	2.20	2.22	1.88	2.07	1.76
Transverse	Strength	Top Slab Centerline	0.98	1.27	1.48	1.55	1.64	1.33	1.29	1.24	1.25	1.11	1.30	1.16
		Top Slab Thickness Change	0.56	0.73	0.81	0.81	0.72	0.66	0.68	0.58	0.60	0.50	0.58	0.50
		Top Slab Webs & Cantilever	1.85	2.40	2.33	2.31	1.90	1.92	2.01	1.68	1.68	1.39	1.60	1.37
		Transverse Web Bending	0.71	0.92	0.75	0.89	0.95	0.89	0.76	0.83	0.83	0.60	0.88	0.69

Overall Rating Factor	0.56	0.73	0.72	0.50
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	45.36	87.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 2** CALCS BY: TSP DATE: 10/20/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

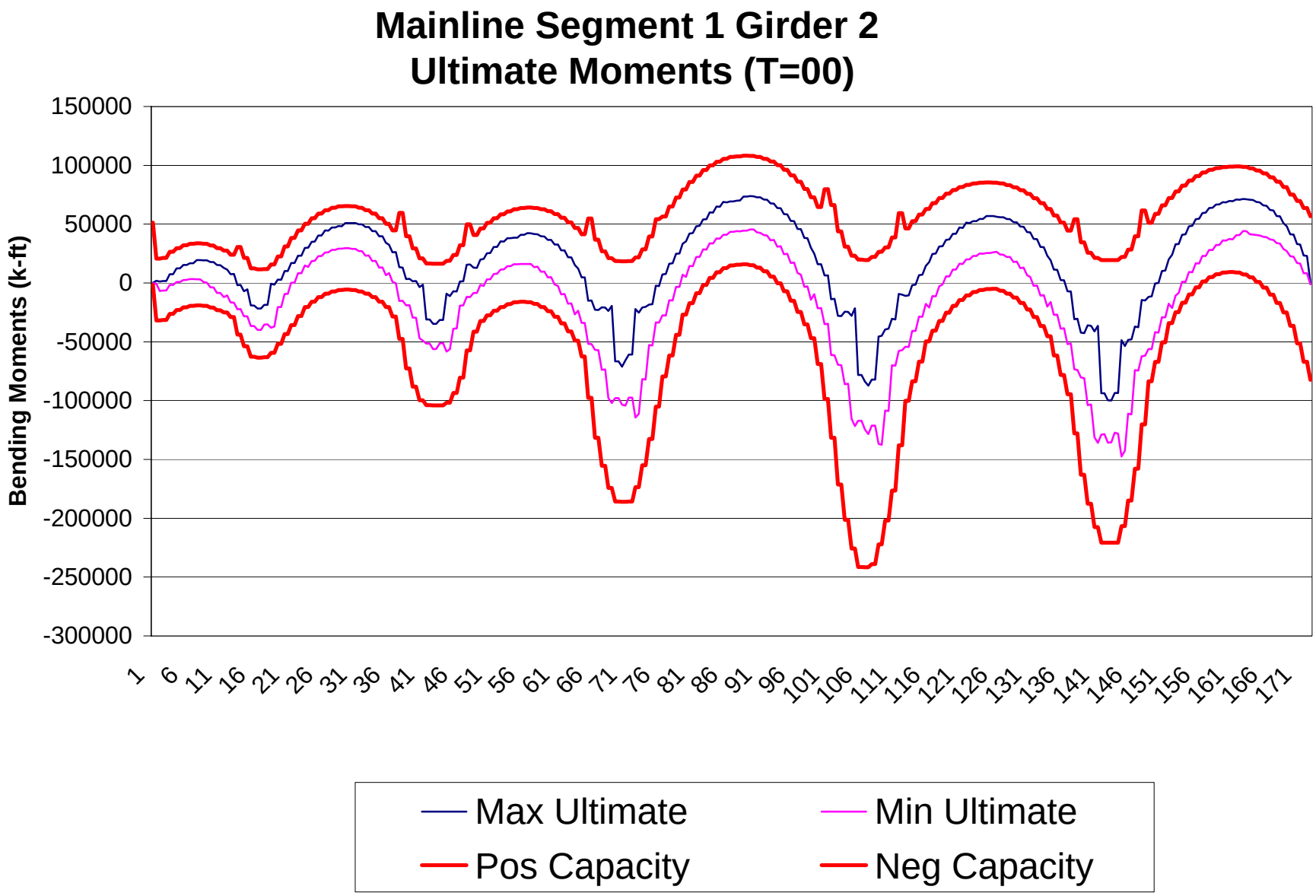
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 1 Girder 2			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36										
Longitudinal	Strength	Flexure	2.06	2.68										
		Shear	1.59	2.06										
	Service	Flexure	1.05	2.40										
		Principal Stress	2.33	2.51										
Transverse	Strength	Top Slab Centerline	0.98	1.27										
		Top Slab Thickness Change	0.56	0.73										
		Top Slab Webs & Cantilever	2.36	3.07										
		Transverse Web Bending	1.41	2.19										

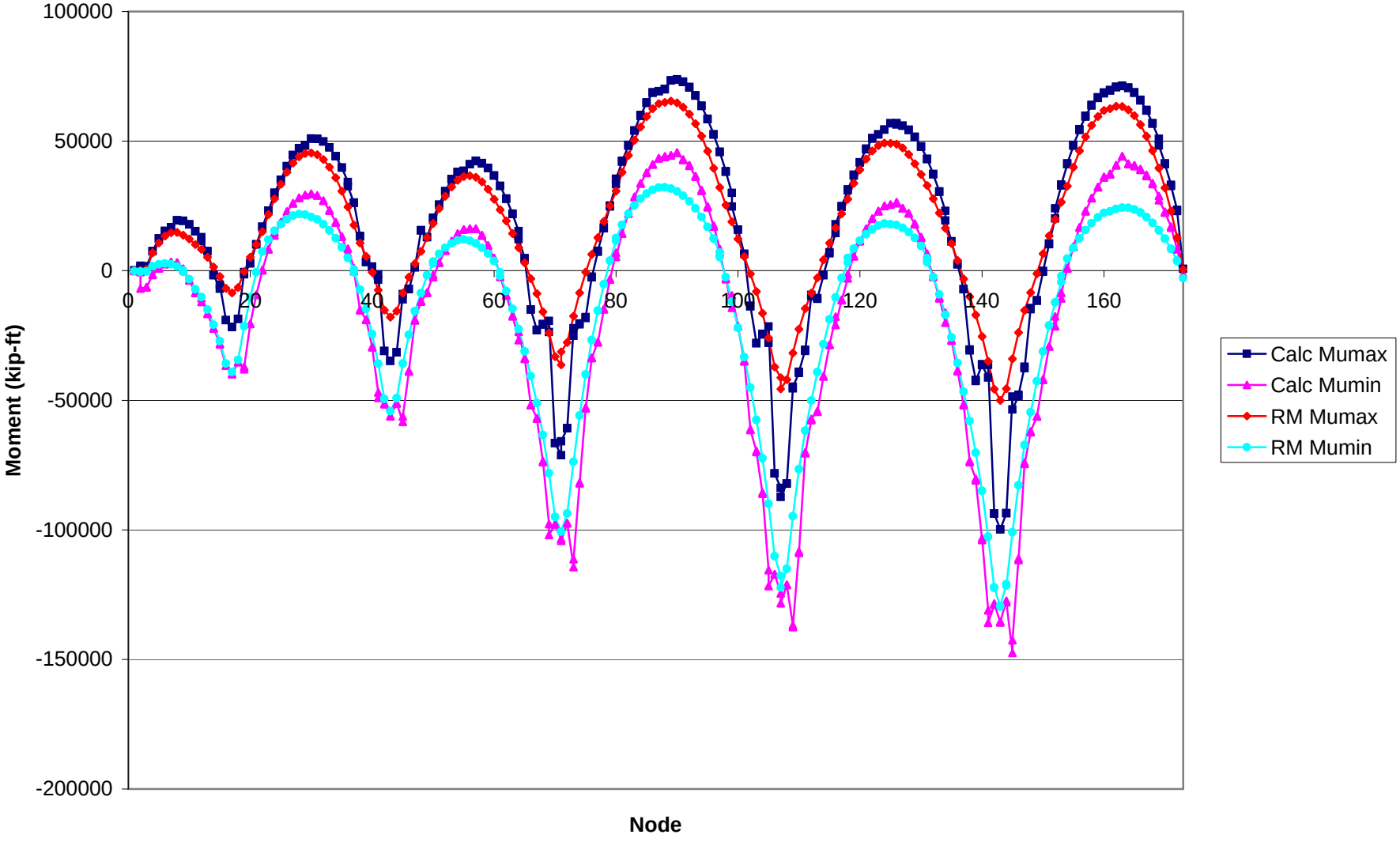
Overall Rating Factor	0.56	0.73	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

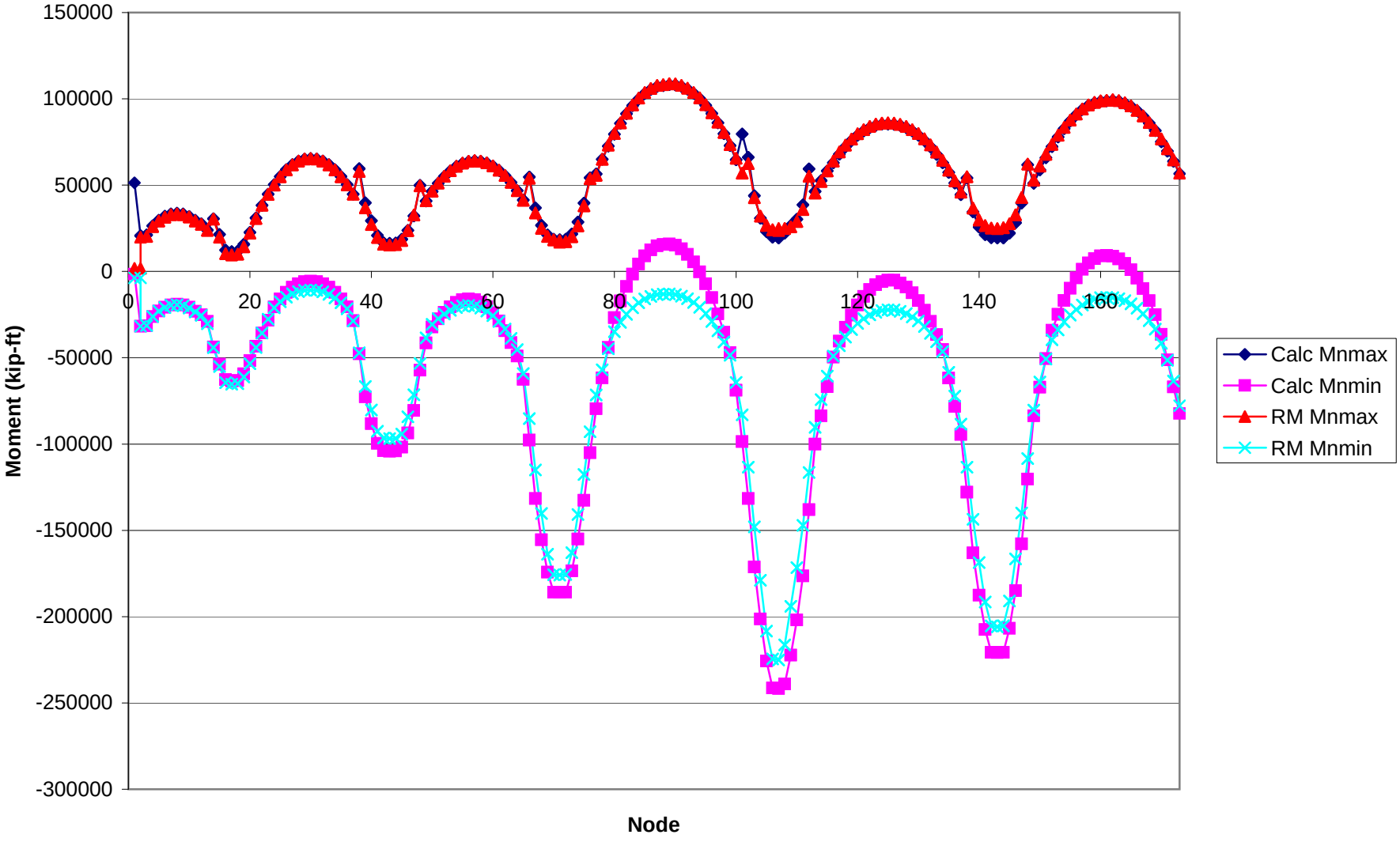
3.3.2 Strength I Flexure


Mainline Segment 1 Girder 2
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
-300000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

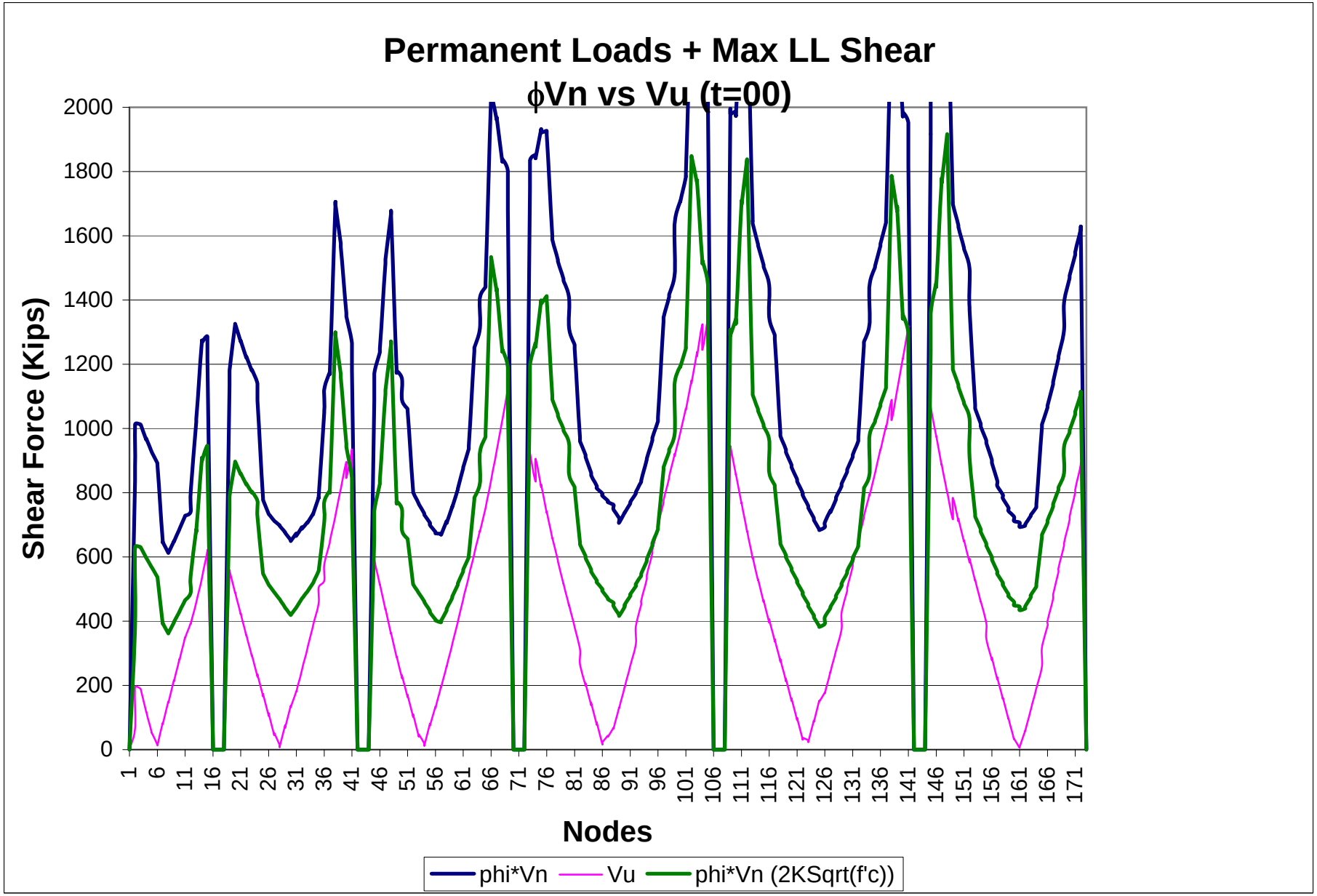
Mainline Segment 1 Girder 2 Flexural Demand, M_u

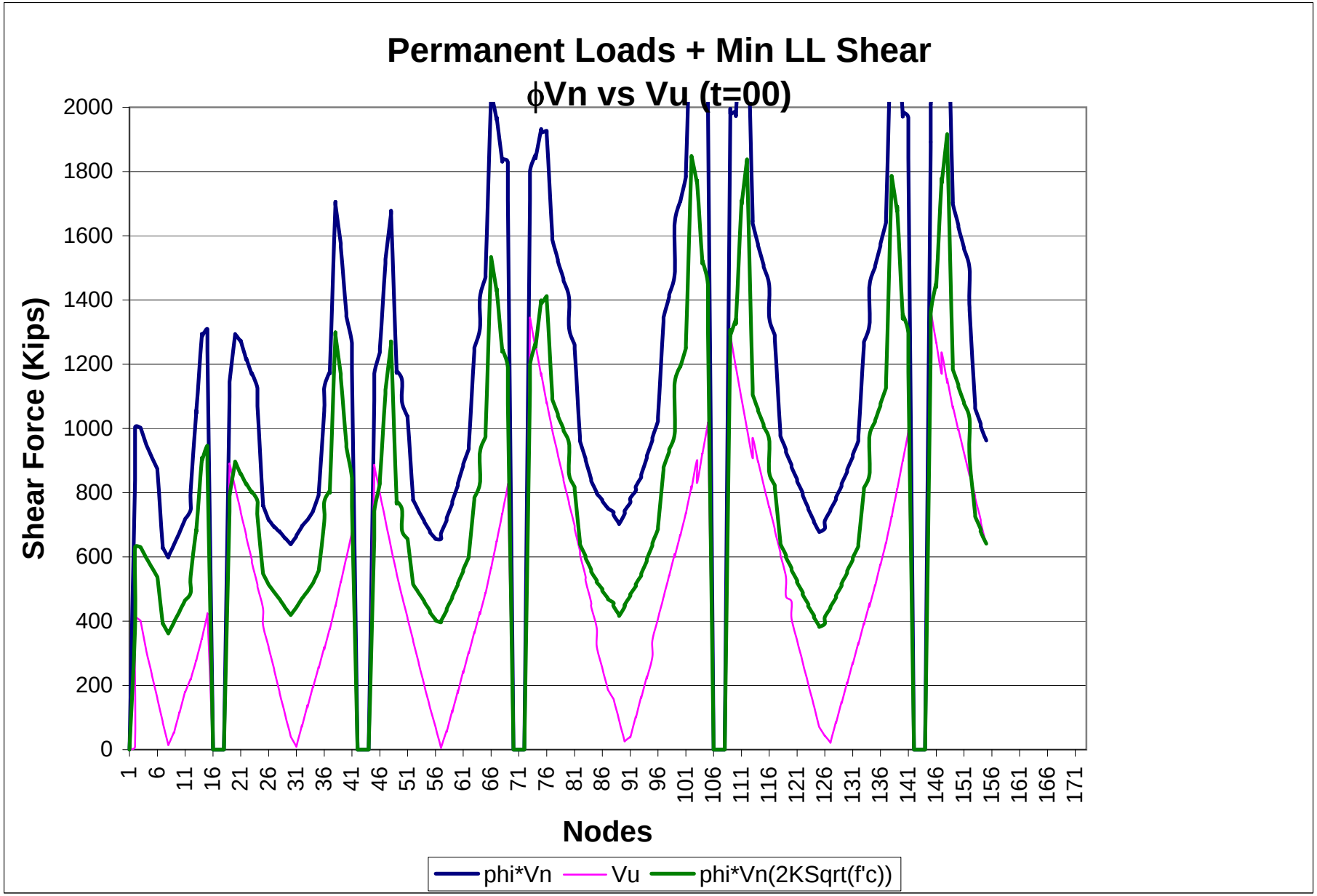


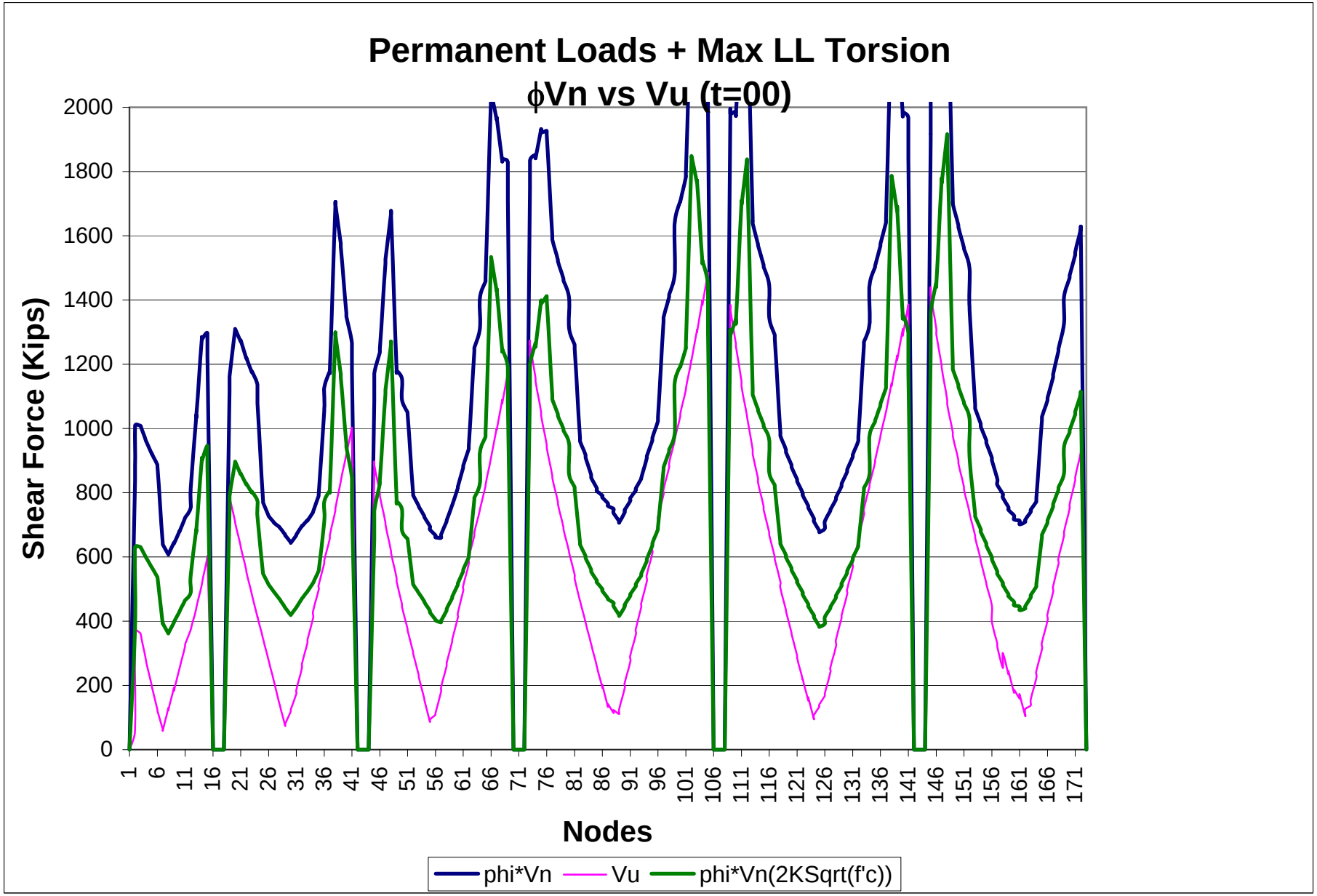
Mainline Segment 1 Girder 2 Flexural Strength, ϕM_n

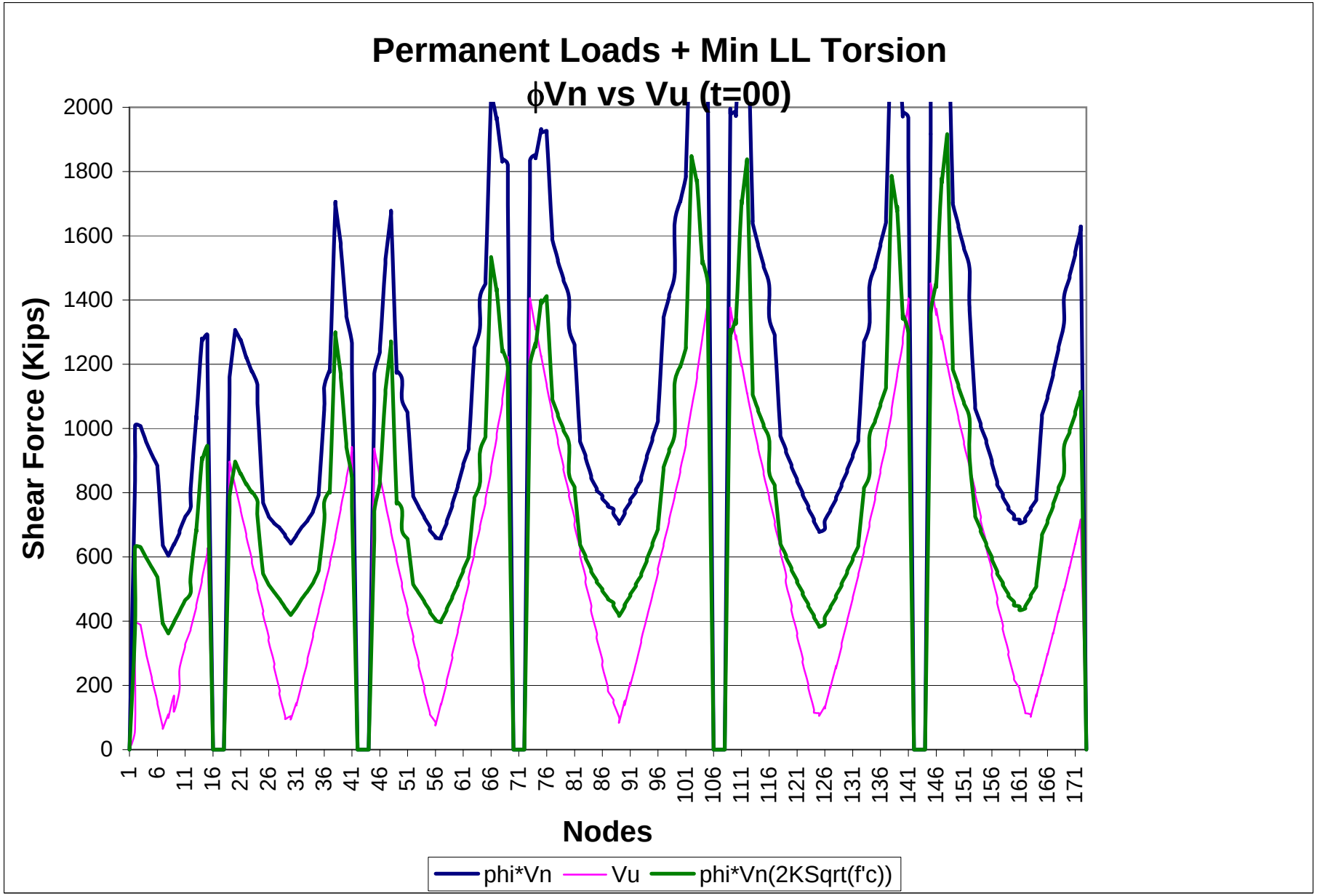


3.3.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

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Node := 45 Position := Back $b_{voverride}$:= 14

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -842 \cdot kips$	$M_{dc_x} = -21697 \cdot kip \cdot ft$	$T_{dc_x} = 114\, ft \cdot kips$	$N_{dc_x} = -13 \cdot kips$	Dead Load
$V_{dw_x} = -110 \cdot kips$	$M_{dw_x} = -3030 \cdot kip \cdot ft$	$T_{dw_x} = -3 \cdot kip \cdot ft$	$N_{dw_x} = -9 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -77 \cdot kips$	$M_{psec_x} = 6728 \cdot kip \cdot ft$	$T_{psec_x} = -516 \cdot kip \cdot ft$	$N_{psec_x} = 32 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -6\, kip$	$M_{crsh_x} = -1036 \cdot kip \cdot ft$	$T_{crsh_x} = -62 \cdot kip \cdot ft$	$N_{crsh_x} = -507 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 64 \cdot kips$	$M_{LLvmax_x} = 1779 \cdot kip \cdot ft$	$T_{LLvmax_x} = 132 \cdot kip \cdot ft$	$N_{LLvmax_x} = 8 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -273 \cdot kips$	$M_{LLvmin_x} = -4236 \cdot kip \cdot ft$	$T_{LLvmin_x} = -208 \cdot kip \cdot ft$	$N_{LLvmin_x} = 42 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -107 \cdot kips$	$M_{LLtmax_x} = -1973 \cdot kip \cdot ft$	$T_{LLtmax_x} = 3025 \cdot kip \cdot ft$	$N_{LLtmax_x} = 34 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -117 \cdot kips$	$M_{LLtmin_x} = -2470 \cdot kip \cdot ft$	$T_{LLtmin_x} = -3106 \cdot kip \cdot ft$	$N_{LLtmin_x} = 36 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = 322 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10294 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 22598 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1066 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -13 \cdot kips$

$M_{tu_x} = -439 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 0 \cdot kip \cdot ft$

$N_{tu_x} = -1 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 10726 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 18299 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 64.679 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.215 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.099 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.148 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.099 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 87.234 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 7.4 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -1211 \cdot kips$	$T_{uvmax_x} = -231 \cdot kip \cdot ft$	$M_{uvmax_x} = -23055\, ft \cdot kips$	$N_{uvmax_x} = -240 \cdot kips$
$V_{uvmin_x} = -1666 \cdot kips$	$T_{uvmin_x} = -690 \cdot kip \cdot ft$	$M_{uvmin_x} = -31175\, ft \cdot kips$	$N_{uvmin_x} = -195 \cdot kips$
$V_{utmax_x} = -1442 \cdot kips$	$T_{utmax_x} = 3675 \cdot kip \cdot ft$	$M_{utmax_x} = -28120\, ft \cdot kips$	$N_{utmax_x} = -205 \cdot kips$
$V_{utmin_x} = -1455 \cdot kips$	$T_{utmin_x} = -4602 \cdot kip \cdot ft$	$M_{utmin_x} = -28791\, ft \cdot kips$	$N_{utmin_x} = -203 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.857\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 7758 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 91.408 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 82.267 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0004$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 476.334 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -648.75\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 43.2 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 2.365$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.0004$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 476.334 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -648.75\,kip$

$V_{LLwebvmin_y} := \dfrac{1.35\,V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -184.275 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 2.365$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.0004$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 476.334 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -661.624\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -200.77 \cdot kips$

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$$RF_{tpos} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{tpos_{x,1}} = 2.186$$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$$\varepsilon_{stmin} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmin_x} = -0.0004$$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 476.334 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -661.624\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -210.962 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 2.08}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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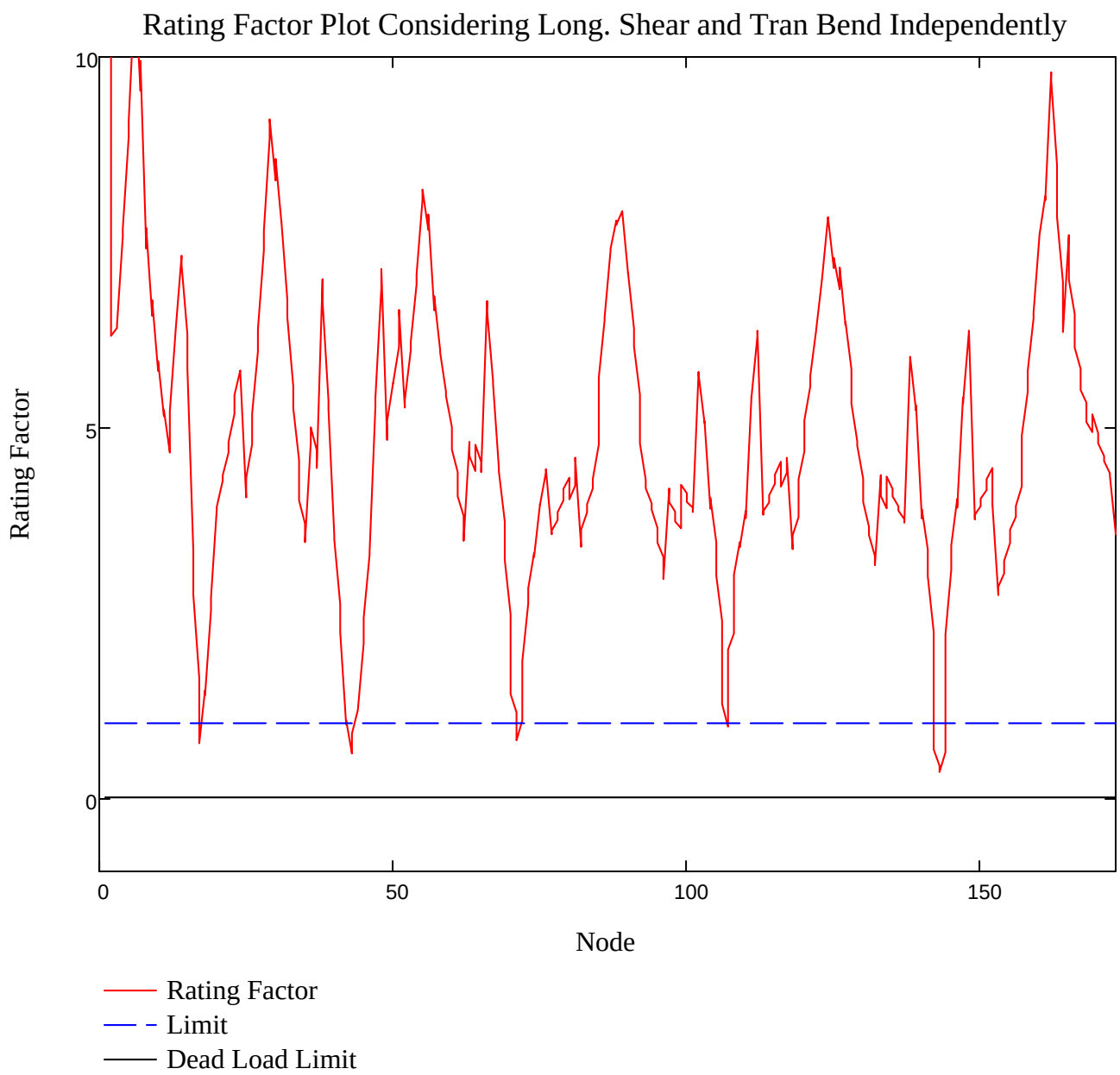

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.08$ at node $minRF_2 = 45$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.932$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 141.878 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 65.912 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.252 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.117 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.511 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 17.596 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 292.696 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 837.027 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 17.441 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 585.391 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.1 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.875 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 17.596 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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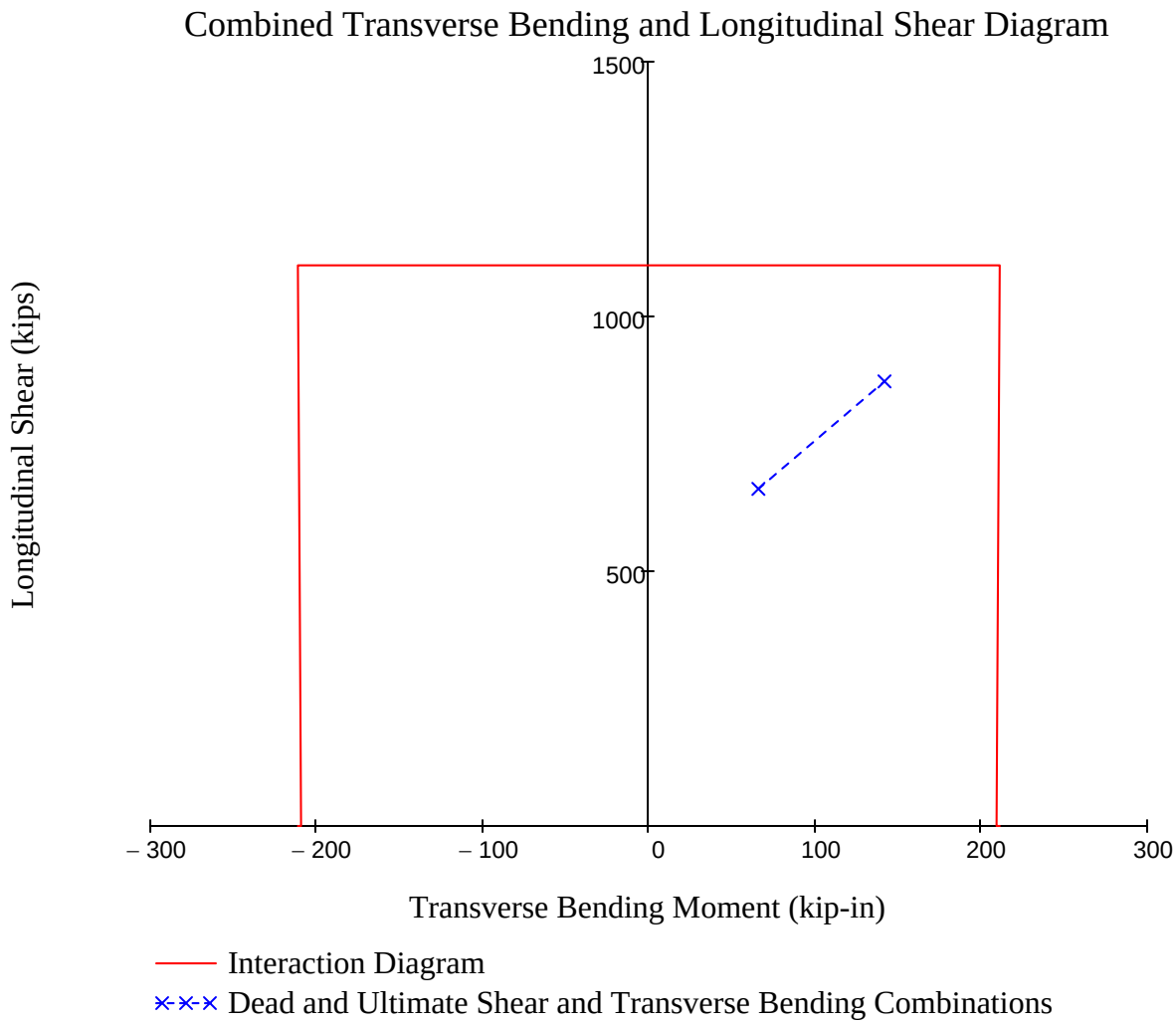


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.912$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

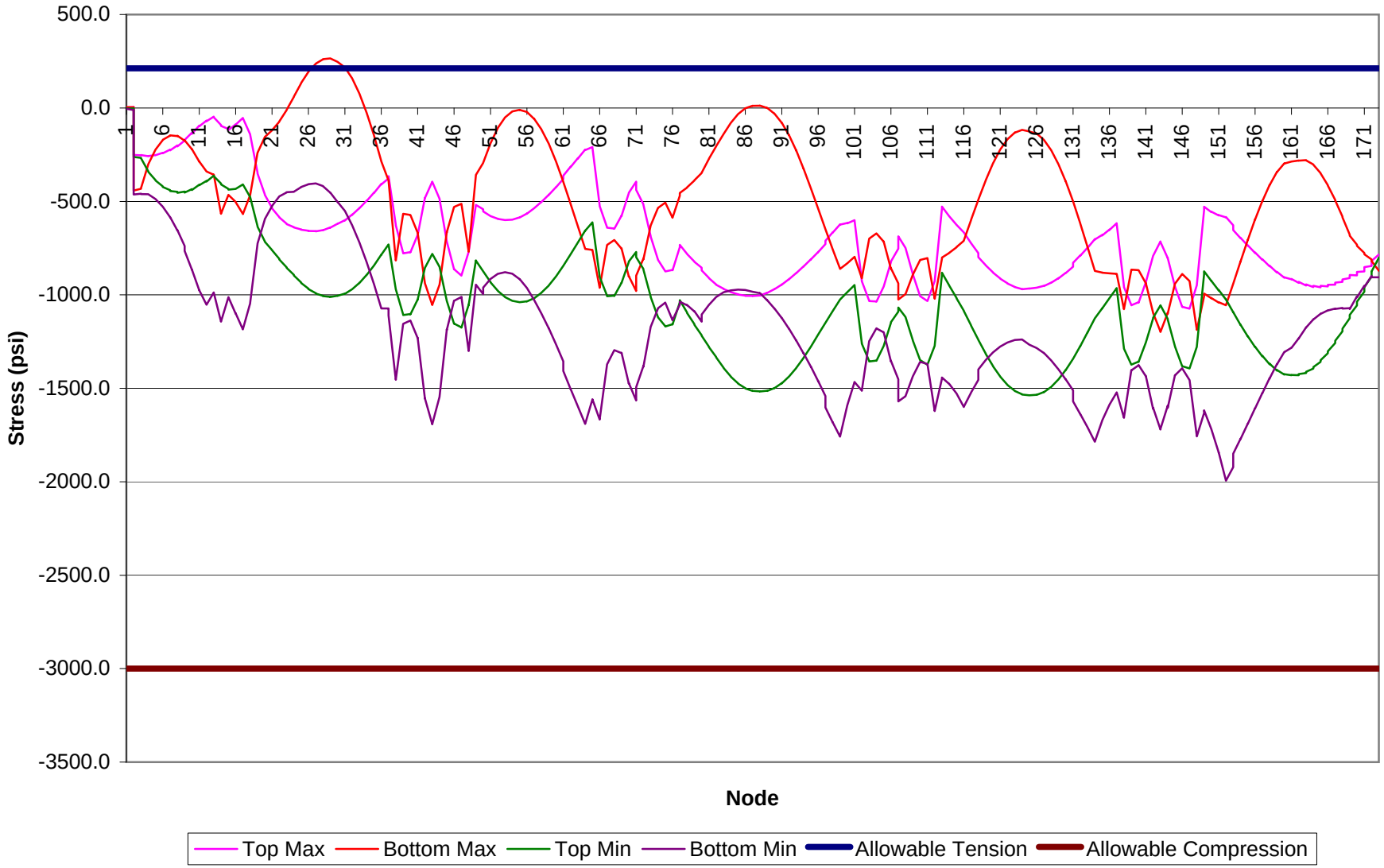
$RF_{shear} = 2.451$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

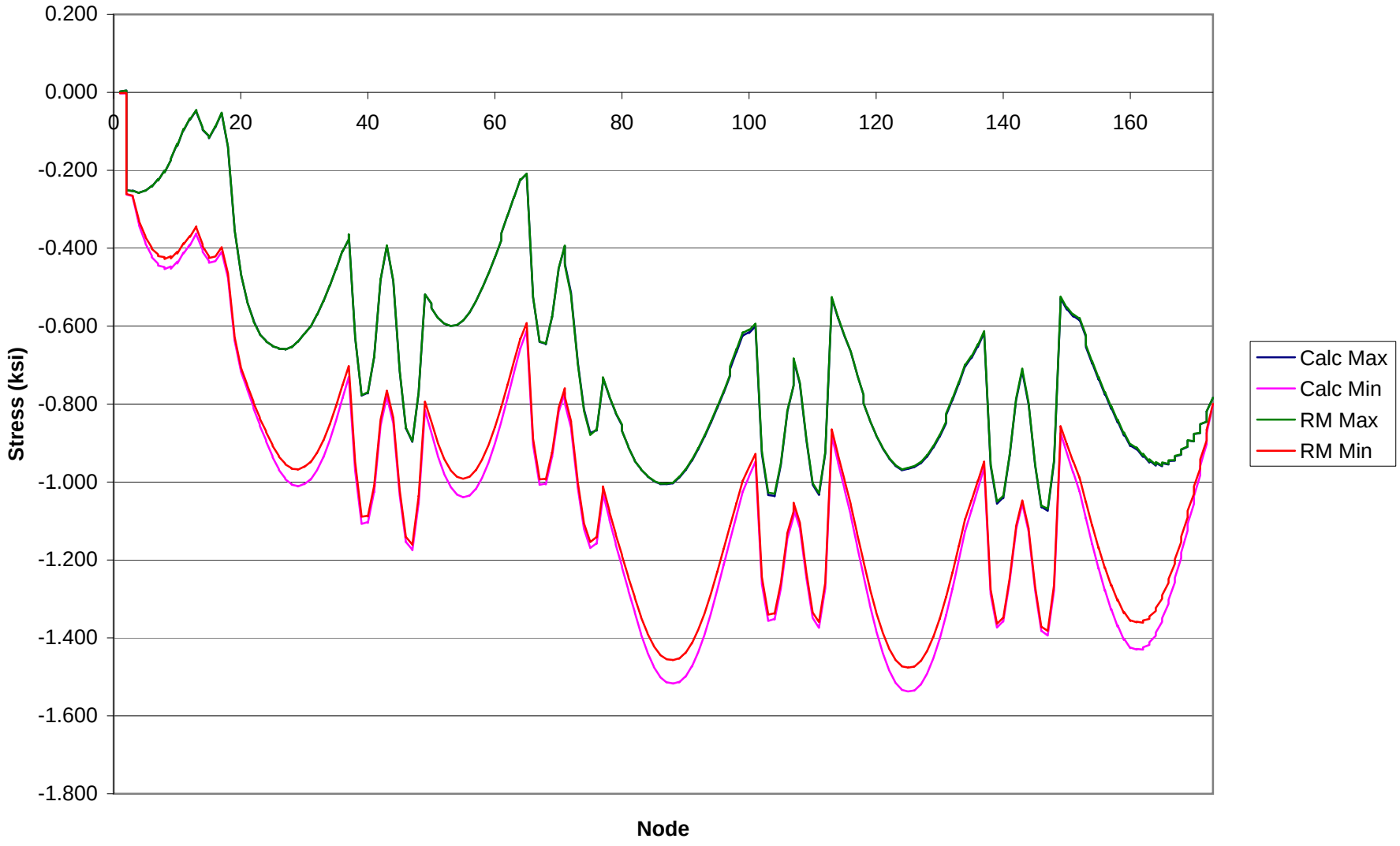
$RF_{torsion} = 2.08$

3.3.4 Service I Flexure (Service Stresses)

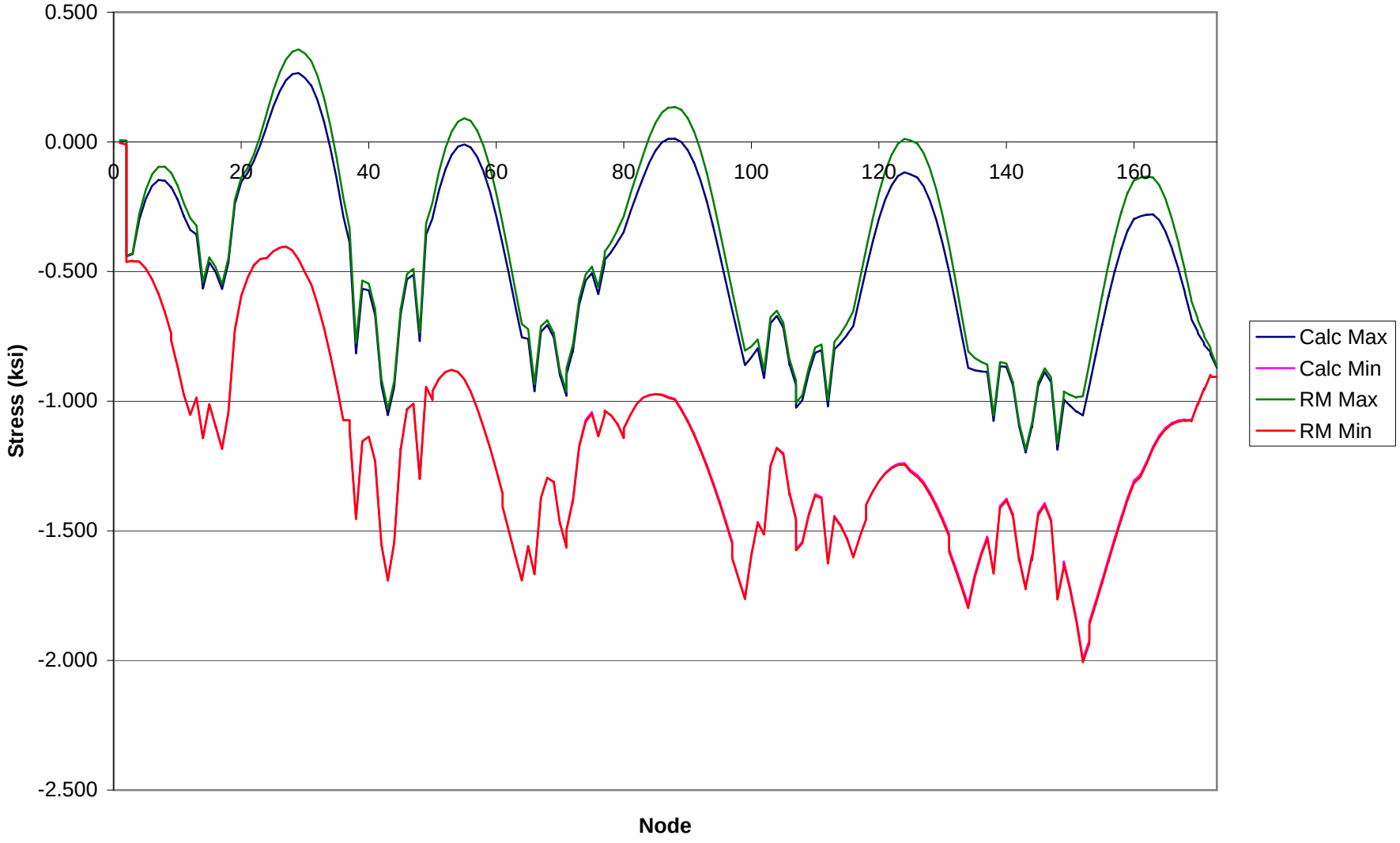
Service Stresses



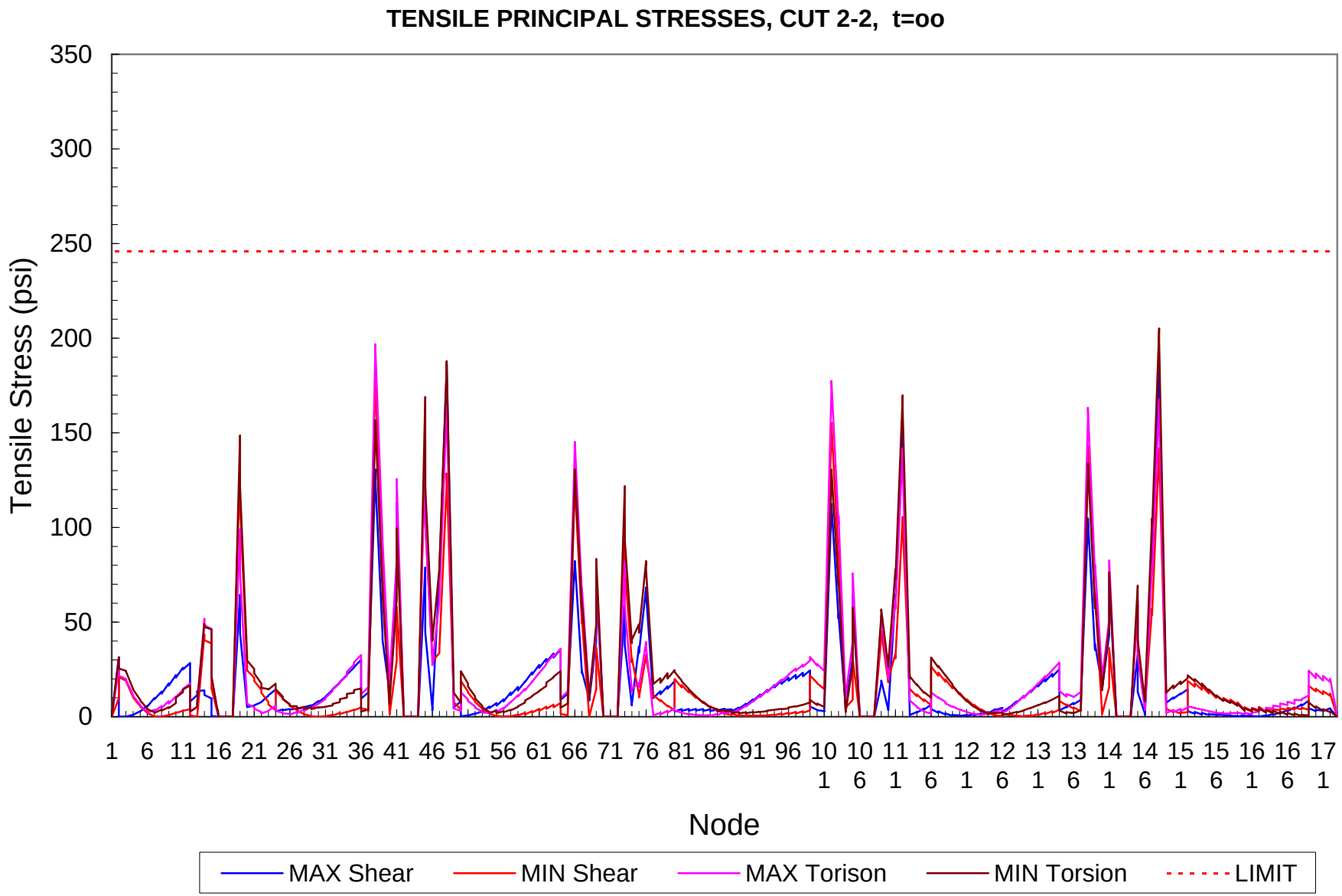
Mainline Segment 1 Girder 2 Top Service Stresses



Mainline Segment 1 Girder 2 Bottom Service Stresses

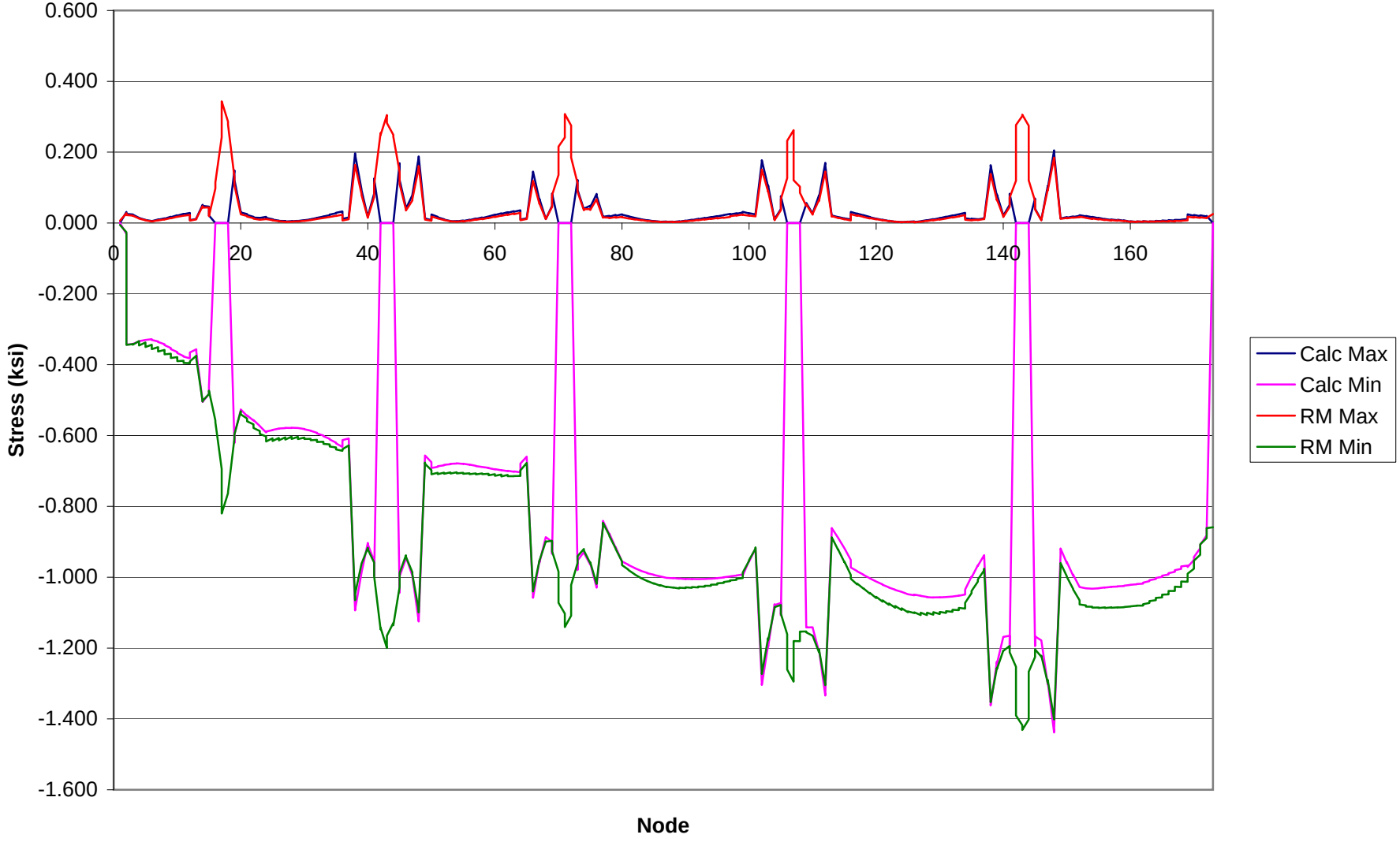


3.3.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.3.5/1

Mainline Segment 1 Girder 2 Principal Stresses



3.4 Mainline Segment 1 Girder 3 Rating

3.4.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 3** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 1 Girder 3			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.58	2.05	1.64	1.69	1.46	1.84	1.83	1.94	1.94	1.74	1.91	1.69
		Shear	1.47	1.91	1.34	1.37	1.26	1.37	1.36	1.13	1.13	1.06	1.01	0.95
	Service	Flexure	0.92	2.07	1.82	1.90	1.76	1.85	1.83	1.73	1.73	1.57	1.71	1.54
		Principal Stress	2.13	2.17	1.86	1.88	1.61	1.64	1.64	1.35	1.36	1.27	1.37	1.15
Transverse	Strength	Top Slab Centerline	0.98	1.27	1.48	1.55	1.64	1.33	1.29	1.24	1.25	1.11	1.30	1.16
		Top Slab Thickness Change	0.56	0.73	0.81	0.81	0.72	0.66	0.68	0.58	0.60	0.50	0.58	0.50
		Top Slab Webs & Cantilever	1.85	2.40	2.33	2.31	1.90	1.92	2.01	1.68	1.68	1.39	1.60	1.37
		Transverse Web Bending	0.71	0.92	0.75	0.89	0.95	0.89	0.76	0.83	0.83	0.60	0.88	0.69

Overall Rating Factor	0.56	0.73	0.72	0.50
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	45.36	87.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 1 Girder 3** CALCS BY: TSP DATE: 10/20/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

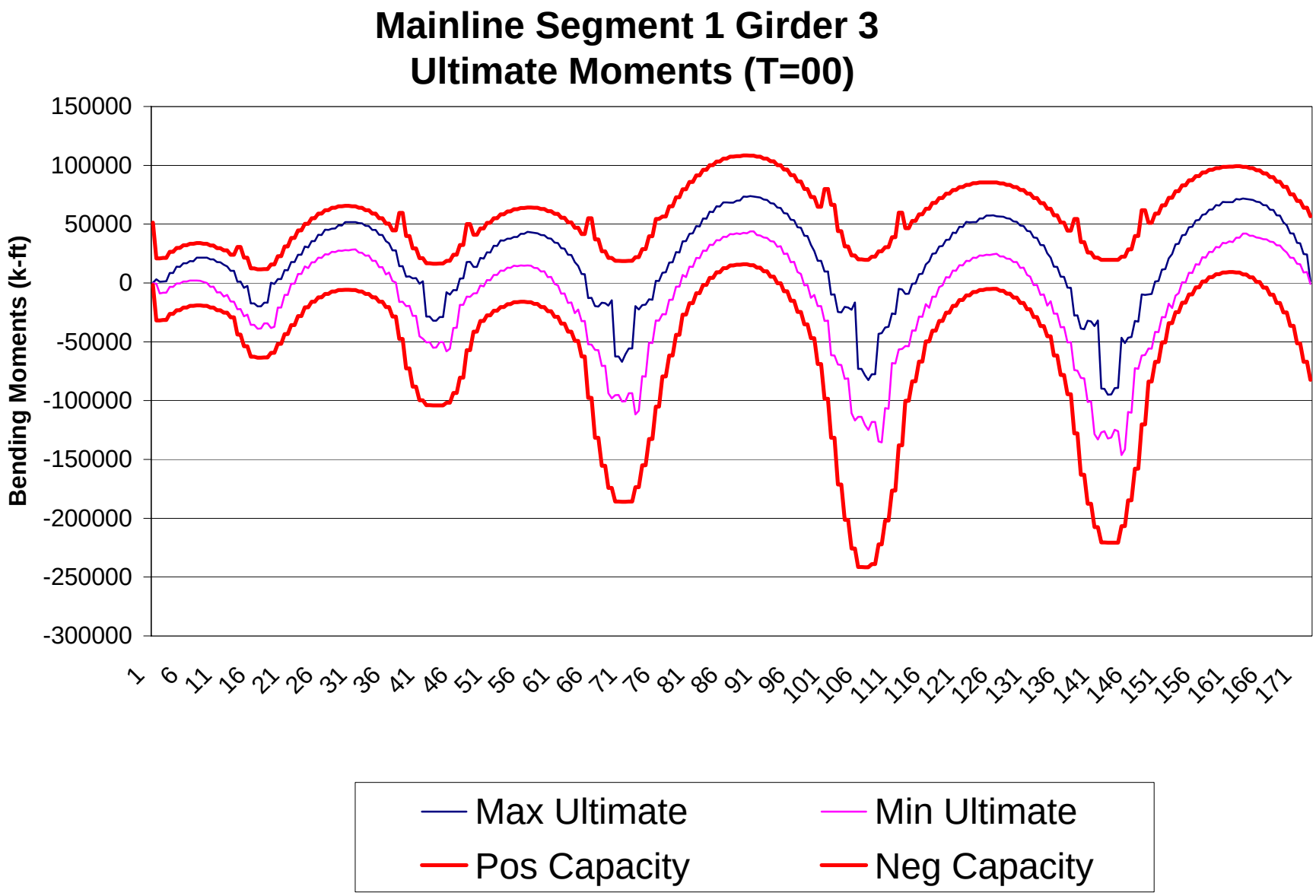
Clear Table | Fill Table | Posting Values

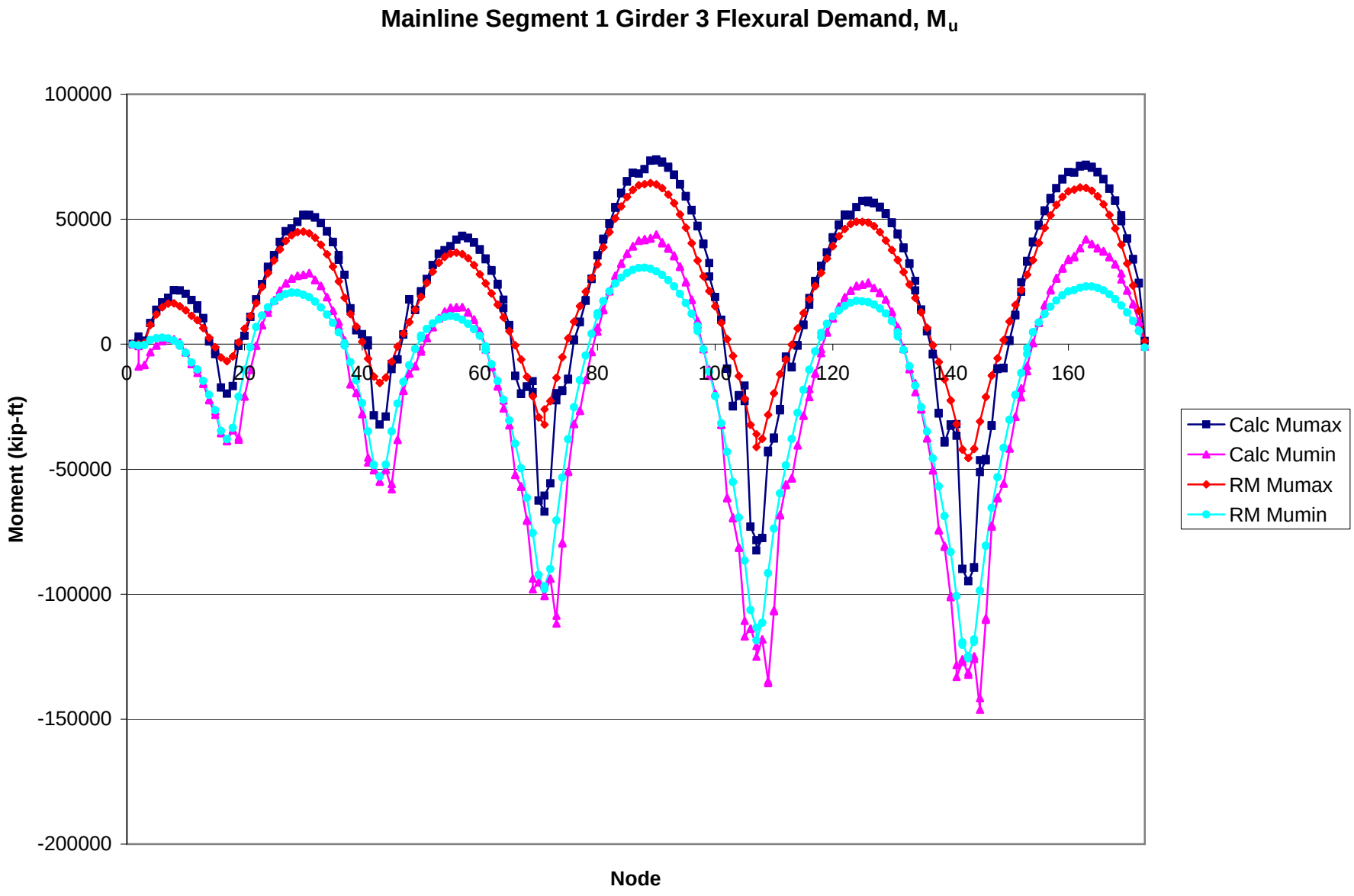
Cline Avenue Load Rating Mainline Segment 1 Girder 3			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	2.10	2.72										
		Shear	2.11	2.64										
	Service	Flexure	1.16	2.51										
		Principal Stress	2.99	3.03										
Transverse	Strength	Top Slab Centerline	0.98	1.27										
		Top Slab Thickness Change	0.56	0.73										
		Top Slab Webs & Cantilever	2.36	3.07										
		Transverse Web Bending	1.41	2.19										

Overall Rating Factor	0.56	0.73	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		26.28	0.00	0.00

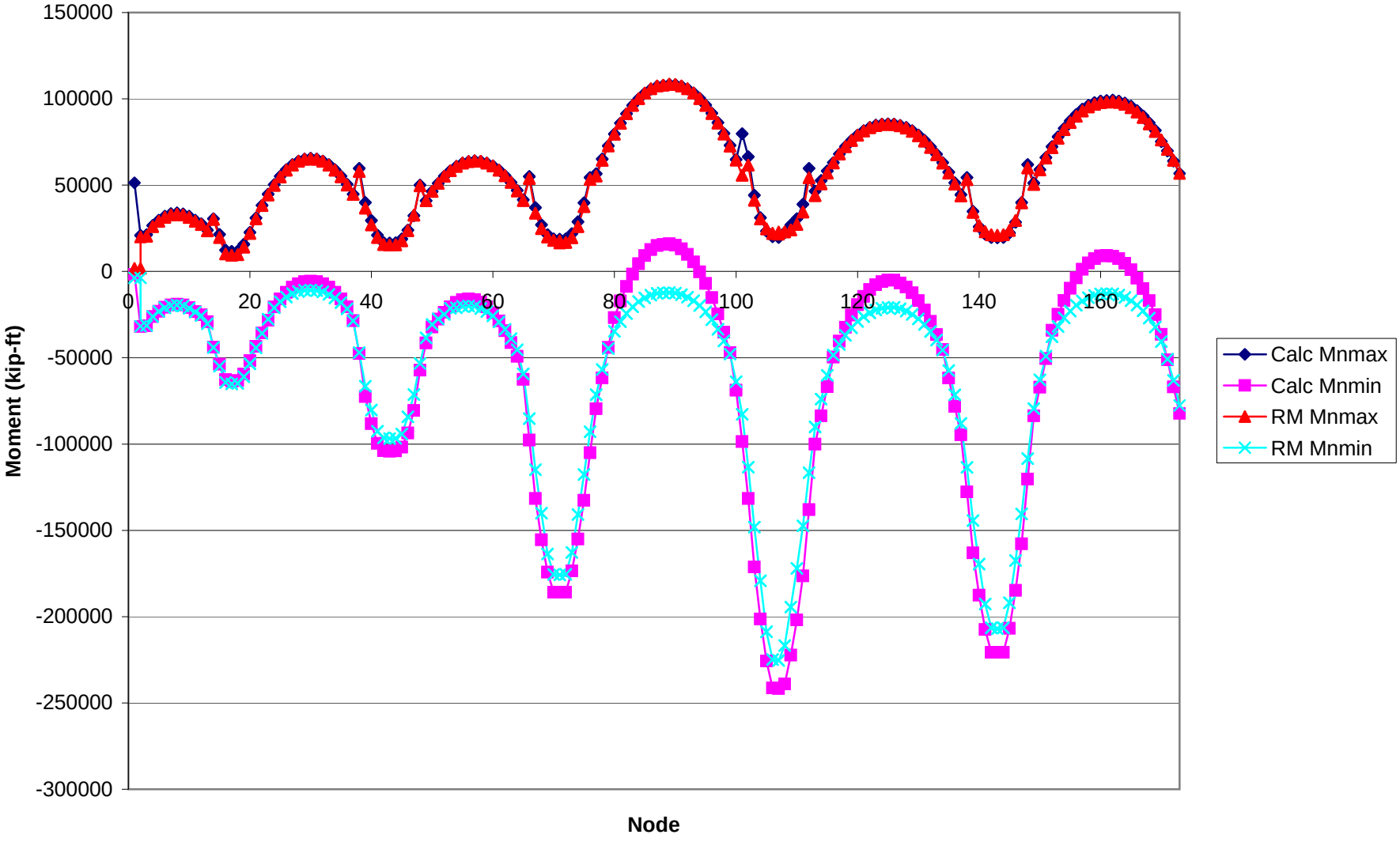
* Max number of lanes loaded = Per AASHTO LRFD

3.4.2 Strength I Flexure

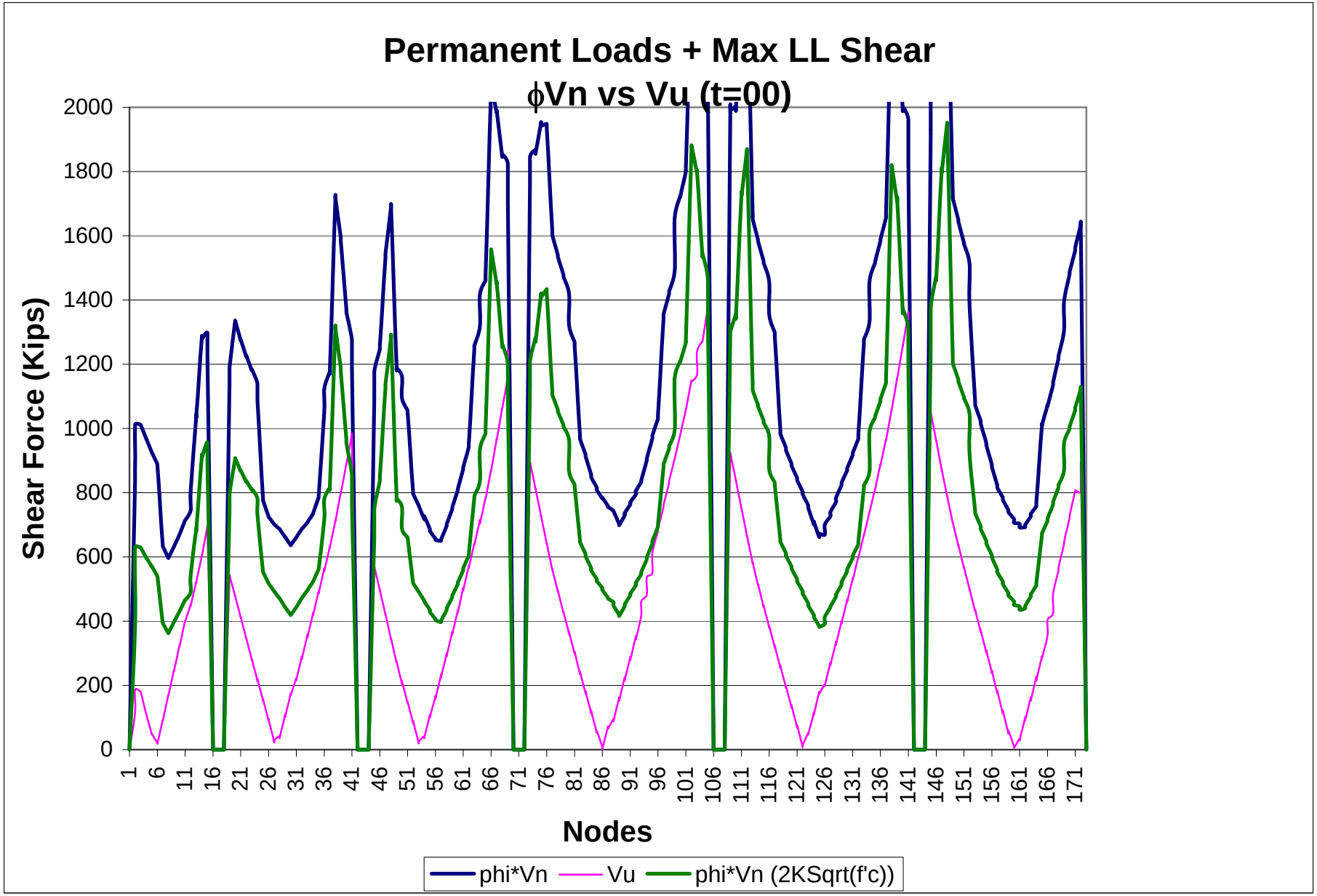

Mainline Segment 1 Girder 3
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
-300000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

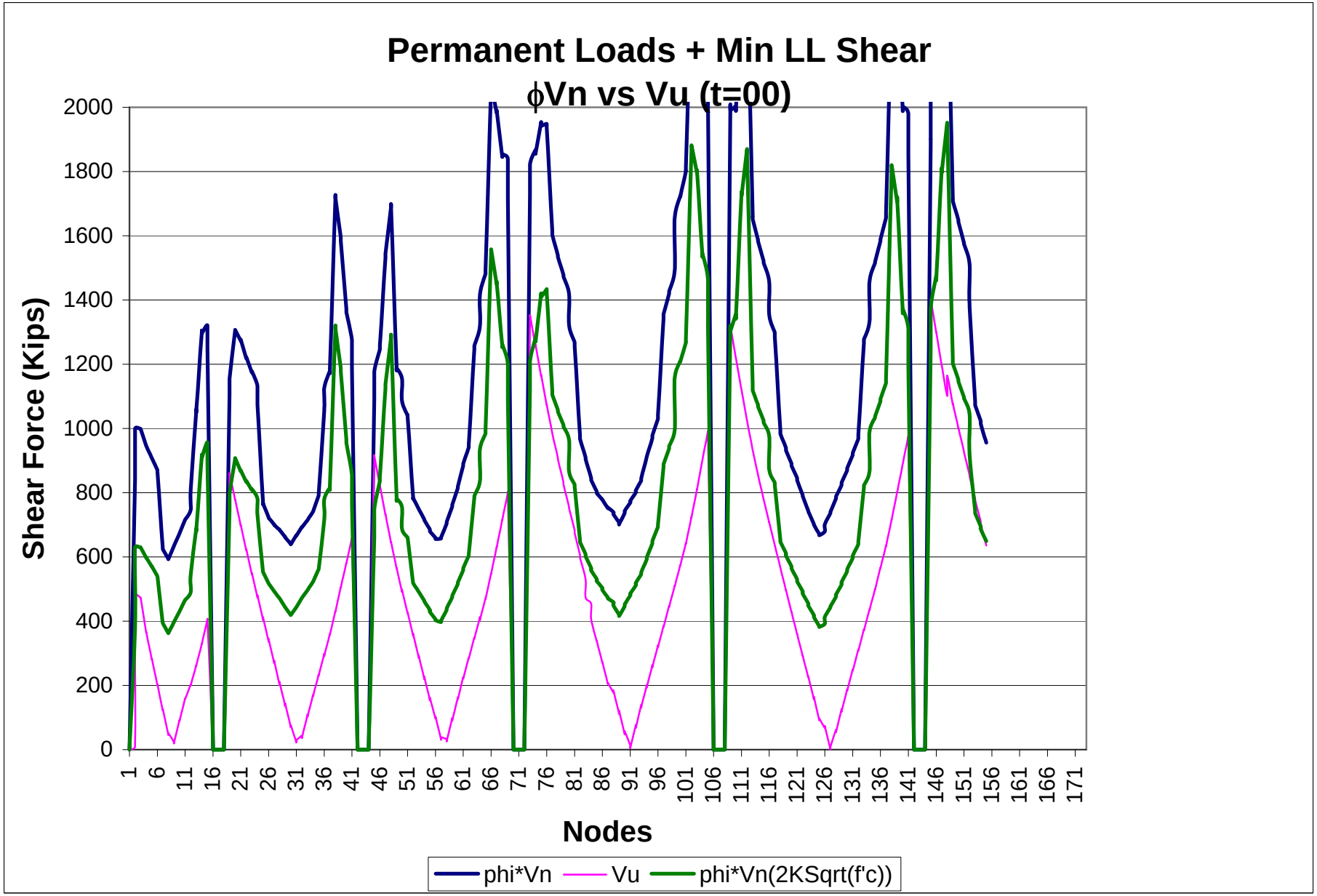

Mainline Segment 1 Girder 3 Flexural Demand, M_u
100000
50000
0
-50000
-100000
-150000
-200000
0
20
40
60
80
100
120
140
160
Moment (kip-ft)
Node
Calc Mumax
Calc Mumin
RM Mumax
RM Mumin

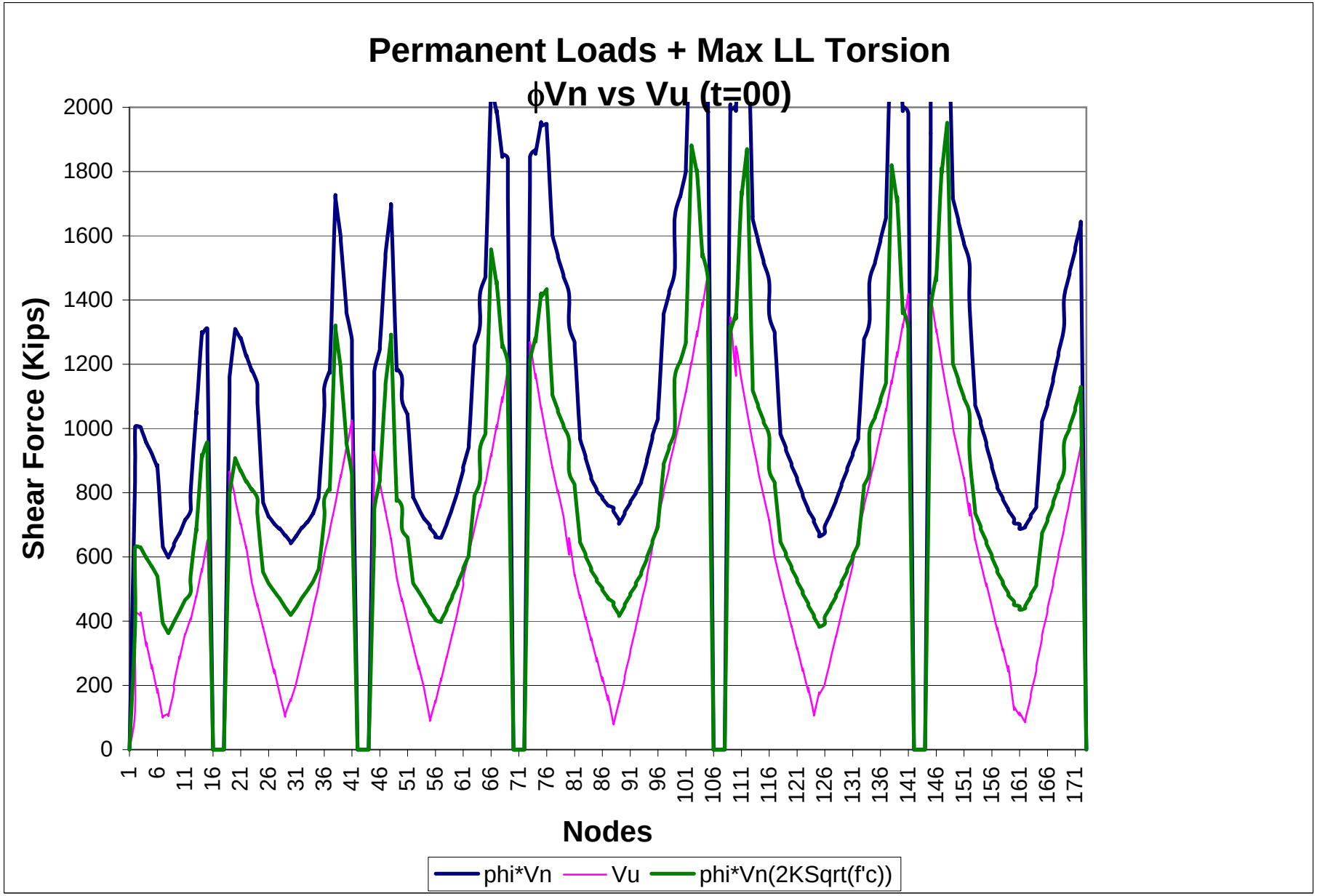
Mainline Segment 1 Girder 3 Flexural Strength, ϕM_n

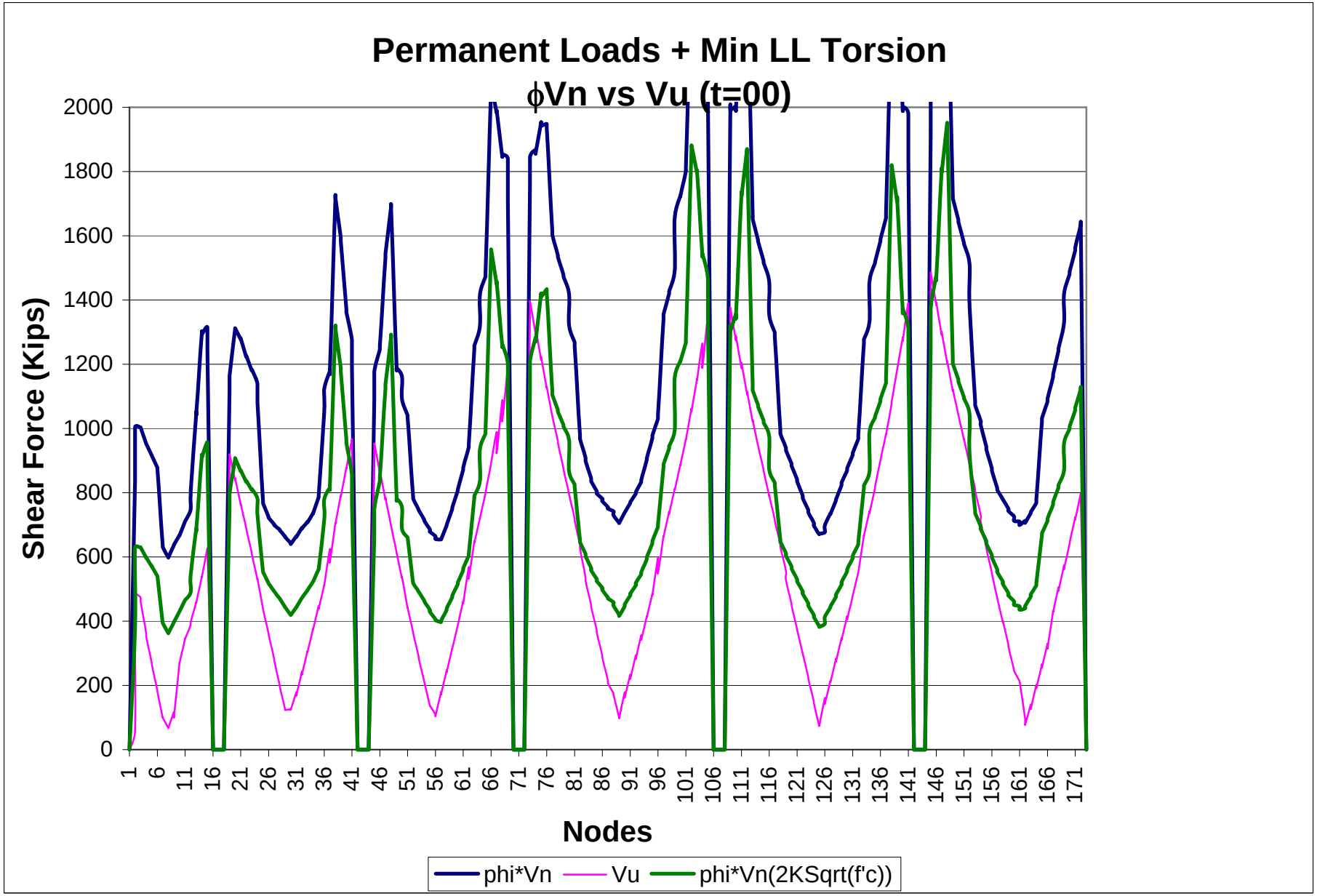


3.4.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Check: Ind Chk | Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 1 Gdr 3\

Node := 45 Position := Back $b_{voverride}$:= 14

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -830 \cdot kips$	$M_{dc_x} = -20952 \cdot kip \cdot ft$	$T_{dc_x} = 85\, ft \cdot kips$	$N_{dc_x} = 12 \cdot kips$	Dead Load
$V_{dw_x} = -114 \cdot kips$	$M_{dw_x} = -3111 \cdot kip \cdot ft$	$T_{dw_x} = 395 \cdot kip \cdot ft$	$N_{dw_x} = 14 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -48 \cdot kips$	$M_{psec_x} = 7901 \cdot kip \cdot ft$	$T_{psec_x} = -532 \cdot kip \cdot ft$	$N_{psec_x} = -32 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -5\, kip$	$M_{crsh_x} = -1295 \cdot kip \cdot ft$	$T_{crsh_x} = 103 \cdot kip \cdot ft$	$N_{crsh_x} = -345 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 67 \cdot kips$	$M_{LLvmax_x} = 1888 \cdot kip \cdot ft$	$T_{LLvmax_x} = 269 \cdot kip \cdot ft$	$N_{LLvmax_x} = 13 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -328 \cdot kips$	$M_{LLvmin_x} = -3807 \cdot kip \cdot ft$	$T_{LLvmin_x} = 635 \cdot kip \cdot ft$	$N_{LLvmin_x} = -55 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -202 \cdot kips$	$M_{LLtmax_x} = -2198 \cdot kip \cdot ft$	$T_{LLtmax_x} = 2075 \cdot kip \cdot ft$	$N_{LLtmax_x} = -40 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -207 \cdot kips$	$M_{LLtmin_x} = -2454 \cdot kip \cdot ft$	$T_{LLtmin_x} = -2590 \cdot kip \cdot ft$	$N_{LLtmin_x} = 11 \cdot kips$	Min Live Load Torsion

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Post Tensioning Forces:

$V_{prim_x} = 331 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10254 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 22332 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1076 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -13 \cdot kips$

$M_{tu_x} = -465 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = -17 \cdot kip \cdot ft$

$N_{tu_x} = 29 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 10771 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 18299 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 64.841 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.215 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.099 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.148 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.099 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 87.234 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 7.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Check: Ind Chk Date: / /

Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -1169 \cdot kips$	$T_{uvmax_x} = 581 \cdot kip \cdot ft$	$M_{uvmax_x} = -21054\, ft \cdot kips$	$N_{uvmax_x} = -151 \cdot kips$
$V_{uvmin_x} = -1702 \cdot kips$	$T_{uvmin_x} = 1076 \cdot kip \cdot ft$	$M_{uvmin_x} = -28742\, ft \cdot kips$	$N_{uvmin_x} = -243 \cdot kips$
$V_{utmax_x} = -1532 \cdot kips$	$T_{utmax_x} = 3019 \cdot kip \cdot ft$	$M_{utmax_x} = -26570\, ft \cdot kips$	$N_{utmax_x} = -223 \cdot kips$
$V_{utmin_x} = -1538 \cdot kips$	$T_{utmin_x} = -3278 \cdot kip \cdot ft$	$M_{utmin_x} = -26916\, ft \cdot kips$	$N_{utmin_x} = -154 \cdot kips$

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.855\,ksi$

$K := \left| \begin{array}{l} \text{for } i \in 1..rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 7758 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \frac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \frac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 91.373 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 82.236 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$

$\varepsilon_{svmax_x} = -0.0004$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 476.151 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -629.5\ kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 45.225 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 2.365$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.0004$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 476.151 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinShear_x = \text{"No"}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -629.5\ kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -221.4 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 2.144$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.0004$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 476.151 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -636.37\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -224.525 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{tpos_{x,1}} = 2.083$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

ε

$\varepsilon_{stmin_x} = -0.0004$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 476.151 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -636.37\ kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -249.785 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.873}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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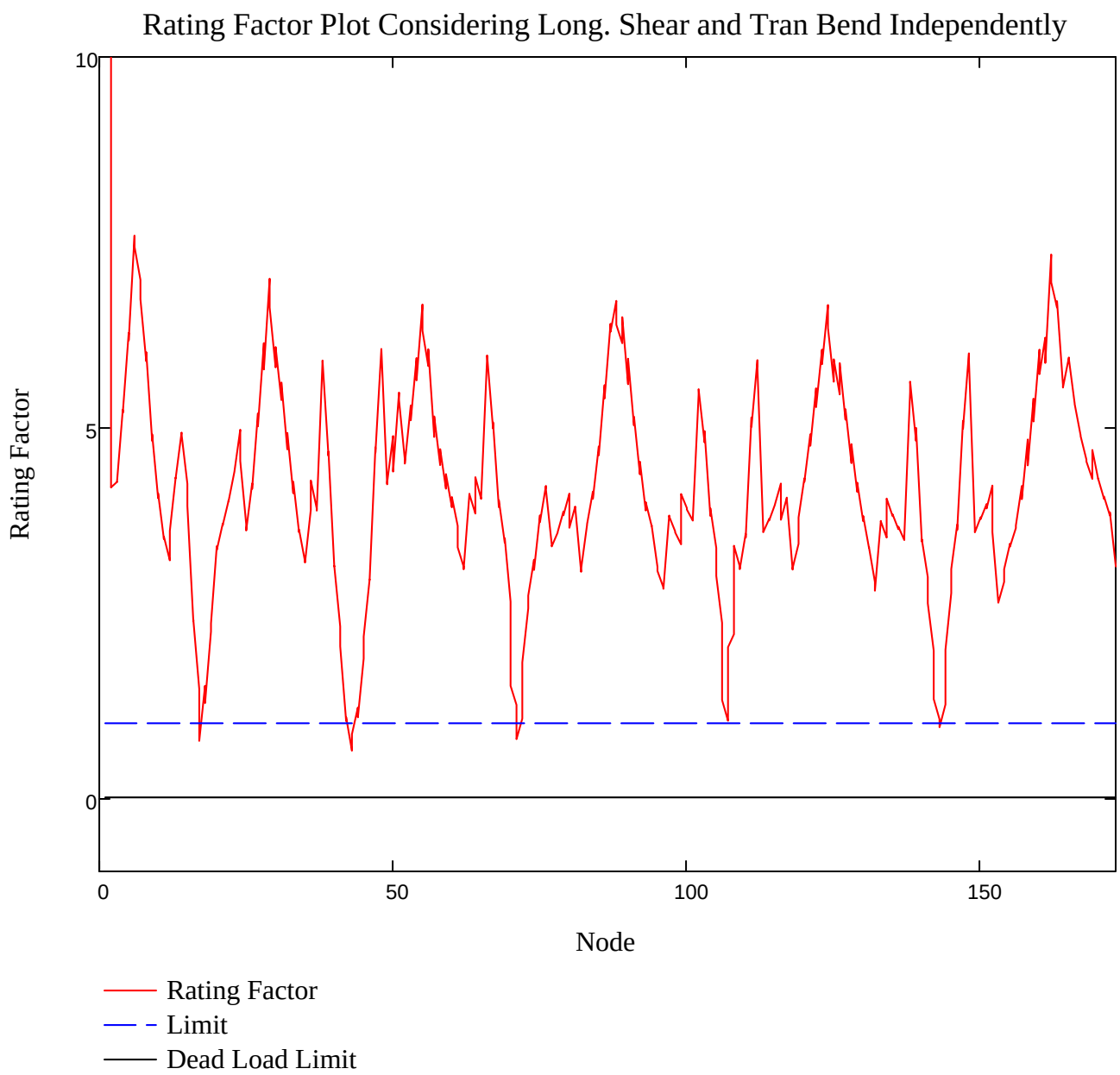

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.873$ at node $minRF_2 = 45$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.932$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 141.878 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 65.912 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.252 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.117 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.511 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 17.596 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 292.583 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 840.811 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 17.441 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 585.166 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.104 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.875 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 17.596 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad V_{n_i} \leftarrow \phi V_{n_i} \\ \quad V_{n_{7-i}} \leftarrow \phi V \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad M_{n_i} \leftarrow \phi M_{n_i} \\ \quad M_{n_{7-i}} \leftarrow -\phi M_{n_i} \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad M_{u_i} \leftarrow m_{rd_x} \\ \quad M_{u_{i+1}} \leftarrow m_{r_x} \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad V_{u_i} \leftarrow \left|V_d\right| \\ \quad V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \\ V_u \end{array} \right.$$

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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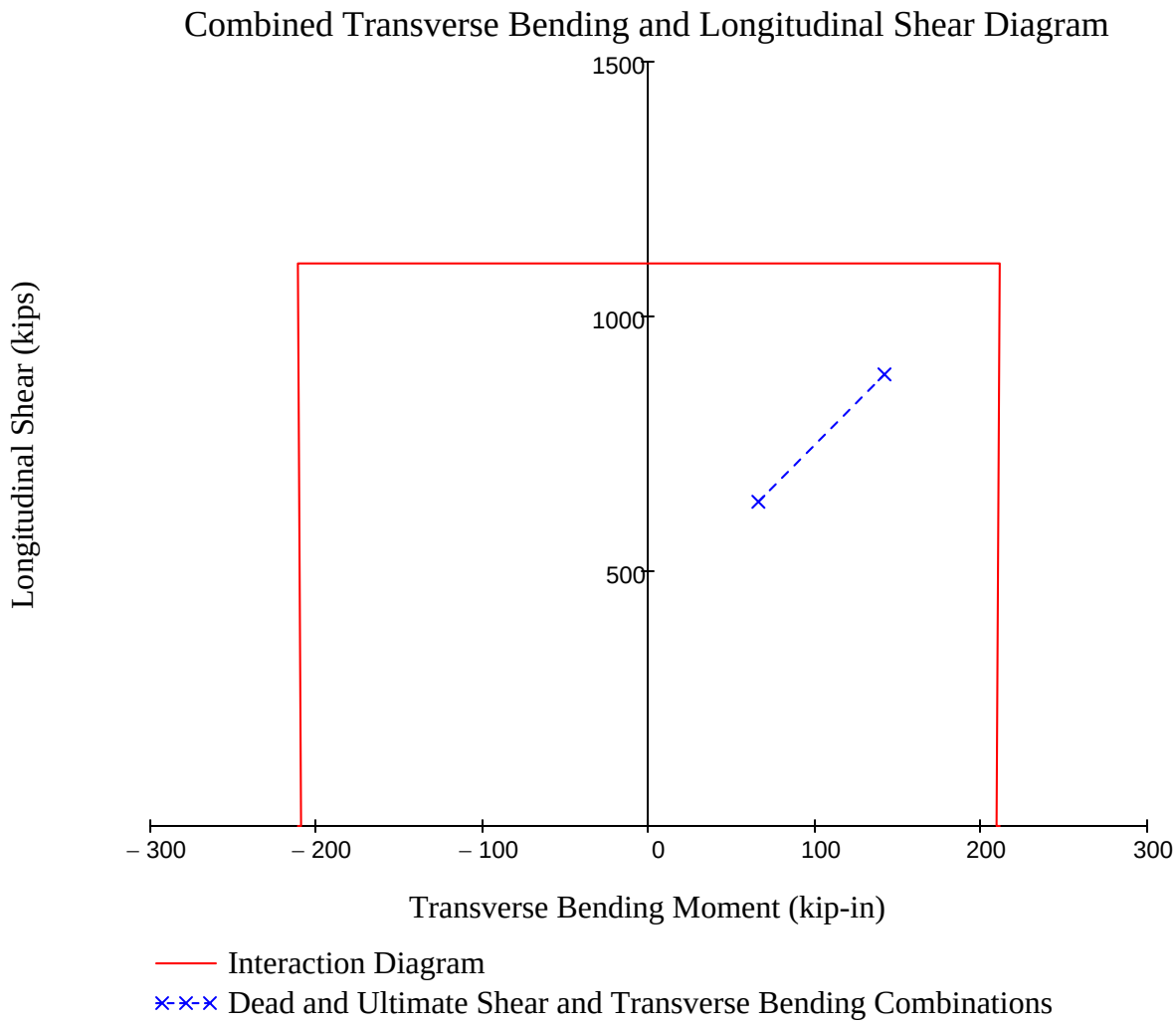


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.912$

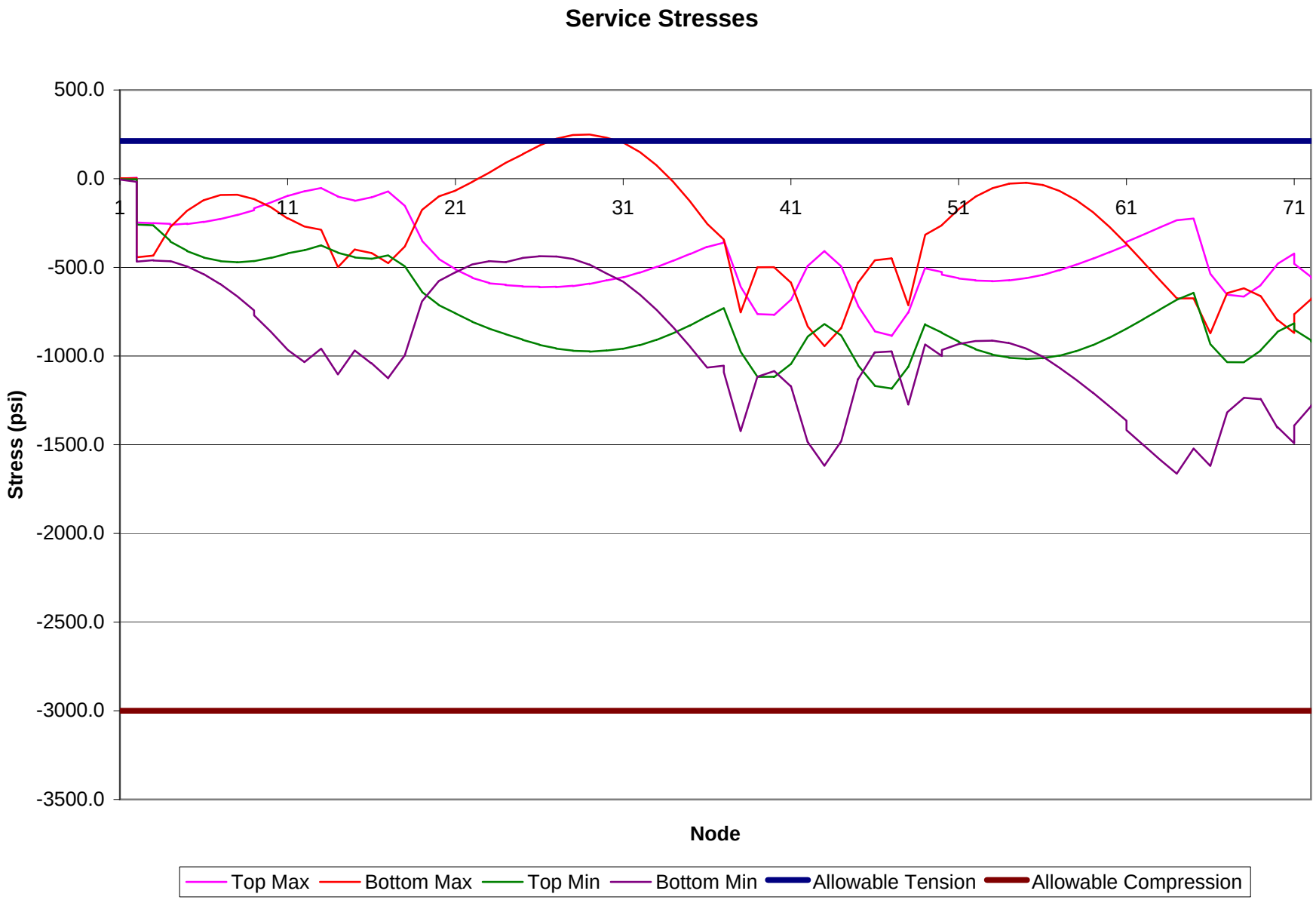
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 2.144$

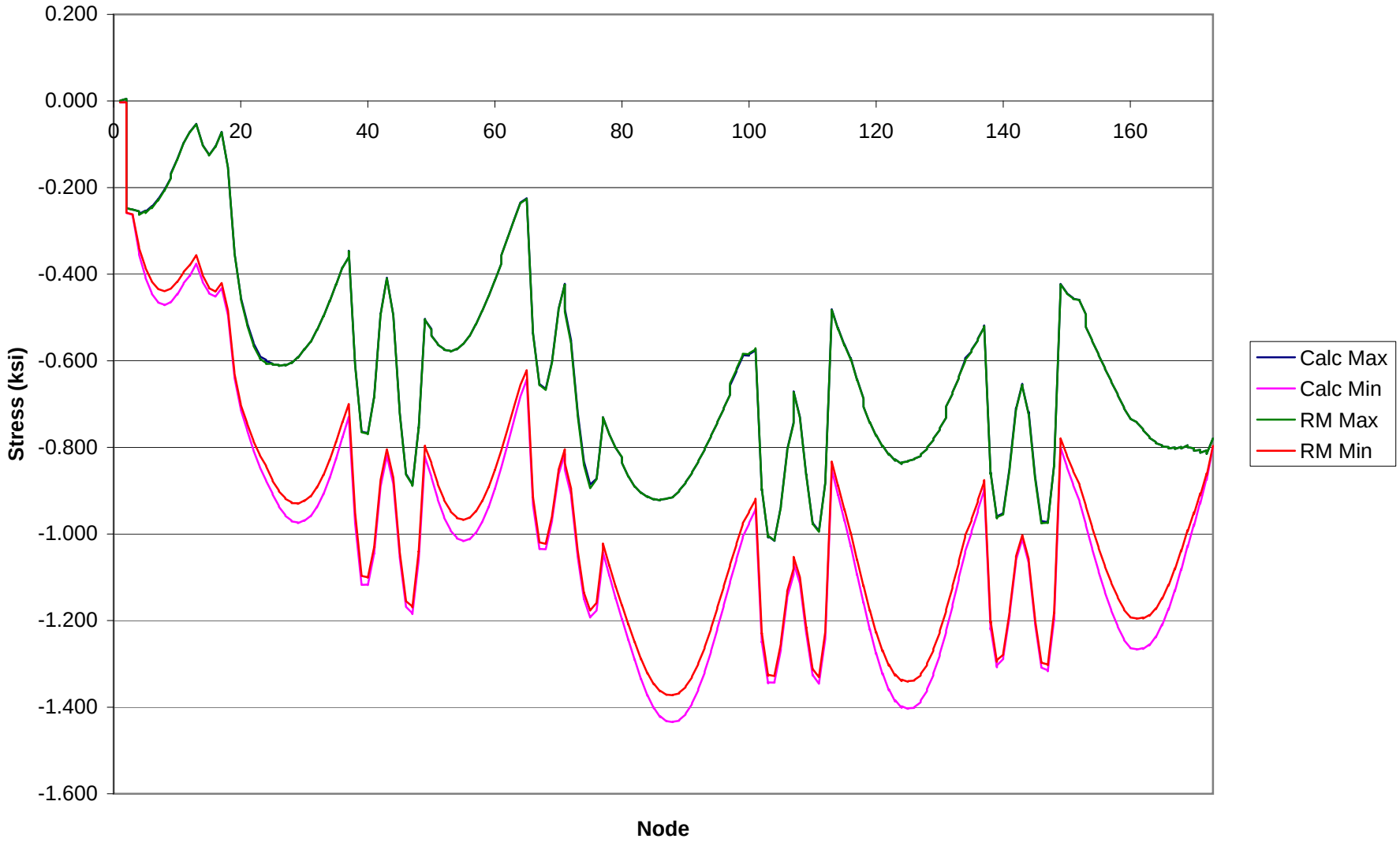
$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 1.873$

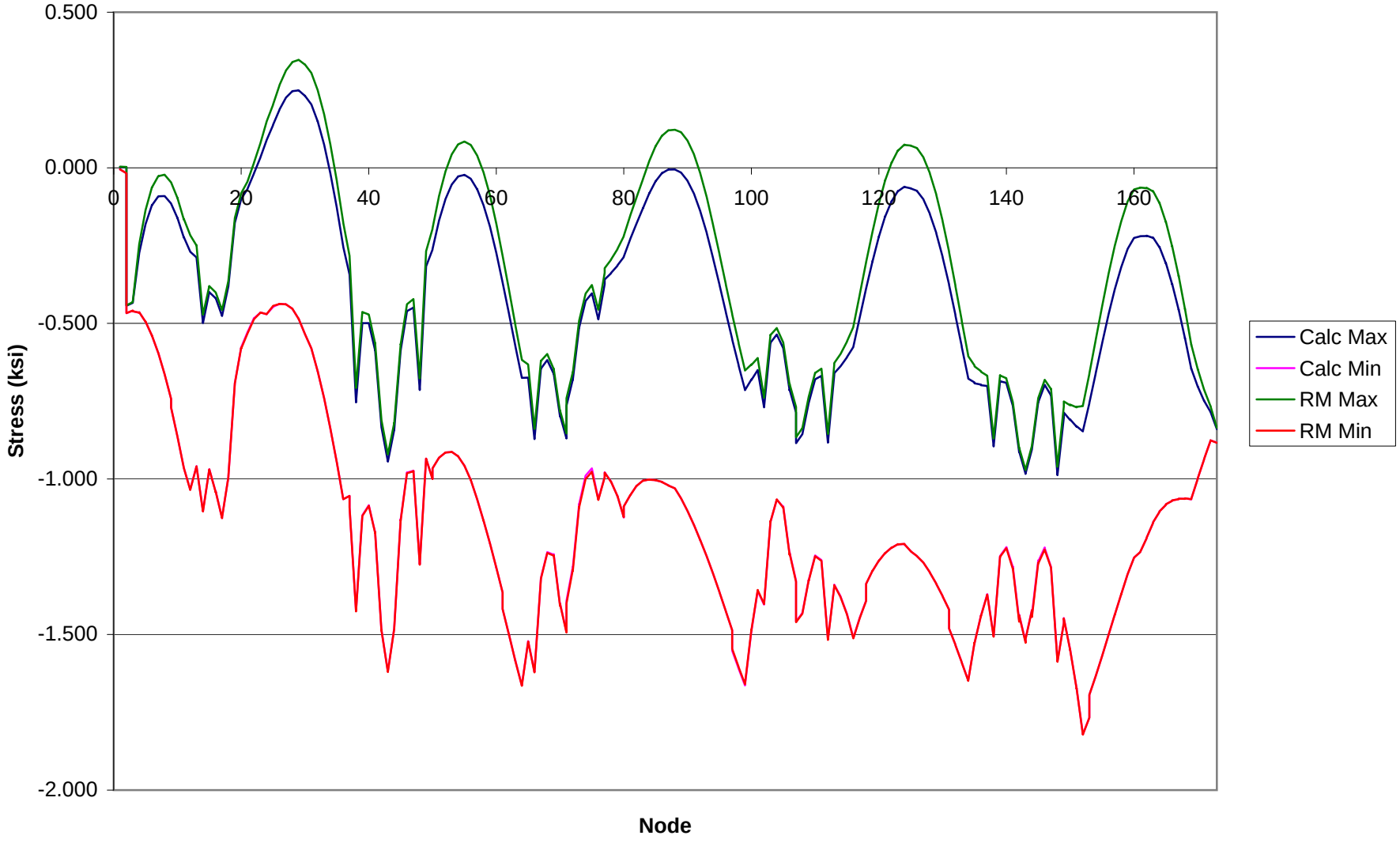
3.4.4 Service I Flexure (Service Stresses)


Service Stresses
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
1
11
21
31
41
51
61
71
Stress (psi)
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression

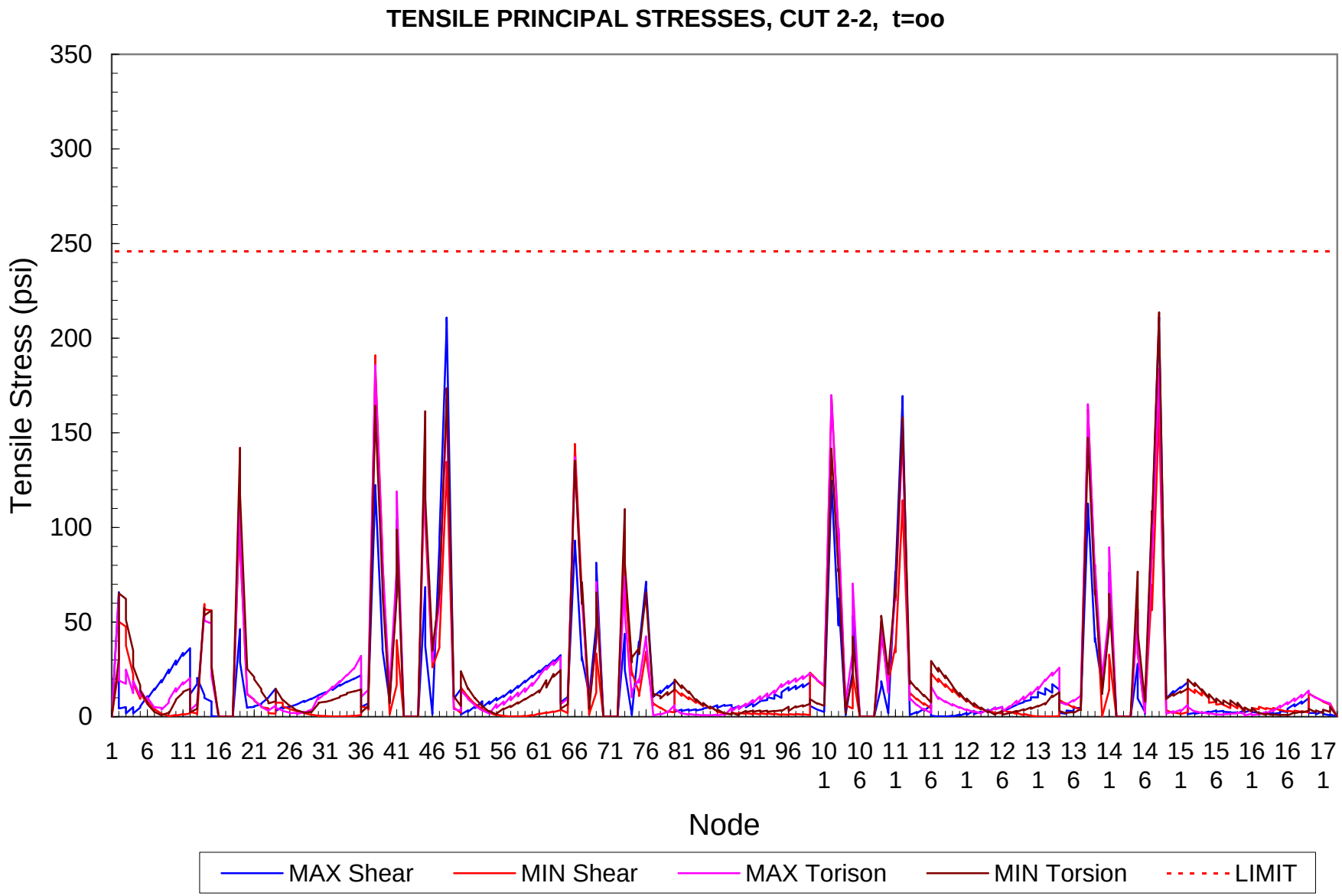
Mainline Segment 1 Girder 3 Top Service Stresses



Mainline Segment 1 Girder 3 Bottom Service Stresses

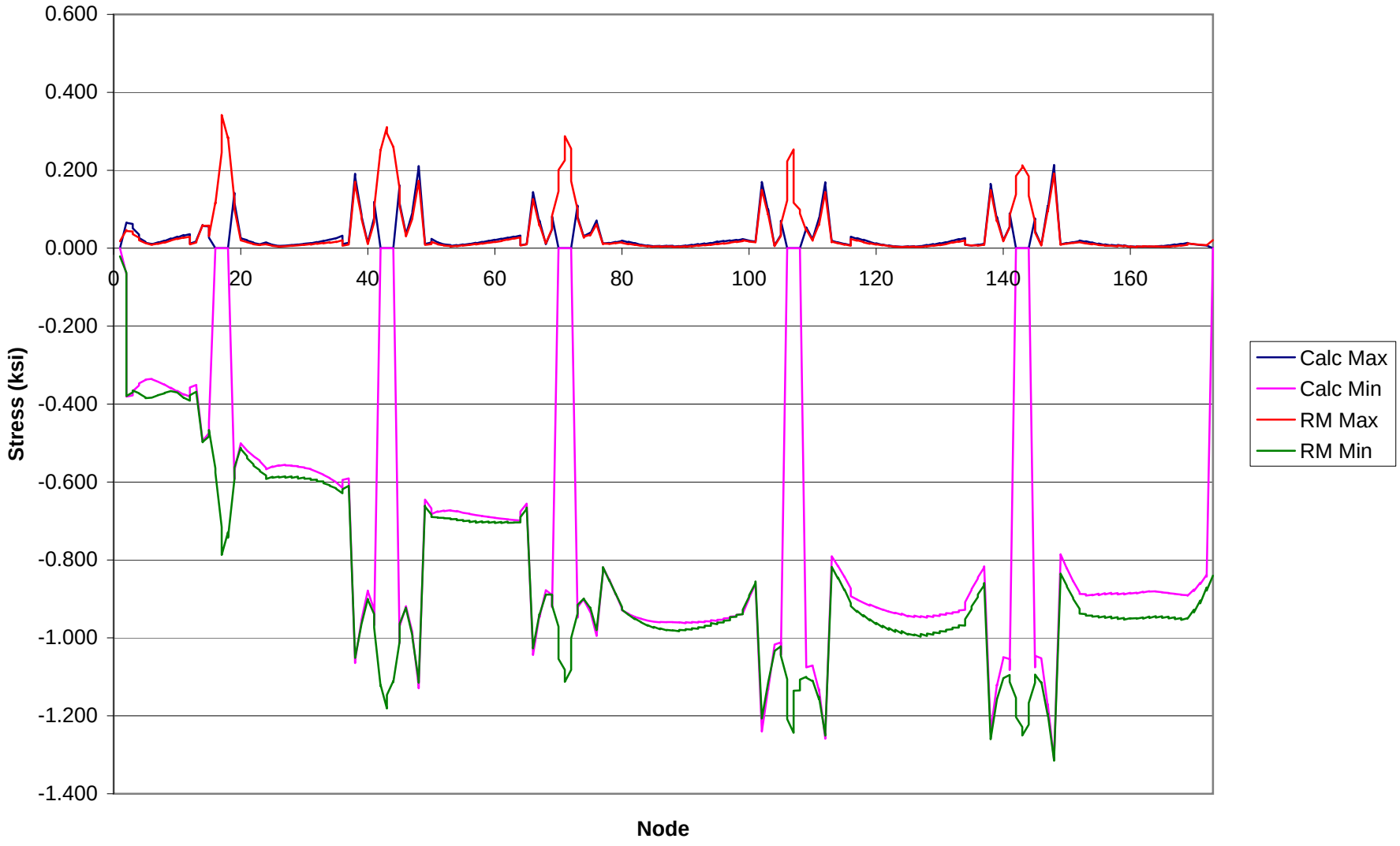


3.4.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166 171
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.4.5/1

Mainline Segment 1 Girder 3 Principal Stresses



3.5 Mainline Segment 2 EB Rating

3.5.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 2 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 2 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.81	2.35	1.70	1.74	1.54	2.06	2.05	1.83	1.83	1.63	1.76	1.54
		Shear	2.24	2.90	2.04	2.07	1.75	2.09	2.08	1.48	1.48	1.33	1.23	1.17
	Service	Flexure	0.70	1.33	1.20	1.22	1.09	1.21	1.20	1.09	1.10	1.00	1.06	0.95
		Principal Stress	3.13	3.14	2.83	2.84	2.37	2.52	2.52	2.09	2.09	1.85	1.71	1.67
Transverse	Strength	Top Slab Centerline	1.69	2.19	2.47	2.59	2.76	2.21	2.14	2.12	2.13	1.88	2.17	1.97
		Top Slab Thickness Change	1.78	2.31	2.54	2.59	2.59	2.38	2.41	2.20	2.31	1.84	2.36	1.89
		Top Slab Webs & Cantilever	1.85	2.40	2.36	2.93	2.90	2.85	2.25	2.27	2.32	1.81	2.65	2.00
		Web Transverse Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 2 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

Clear Table | Fill Table | Posting Values

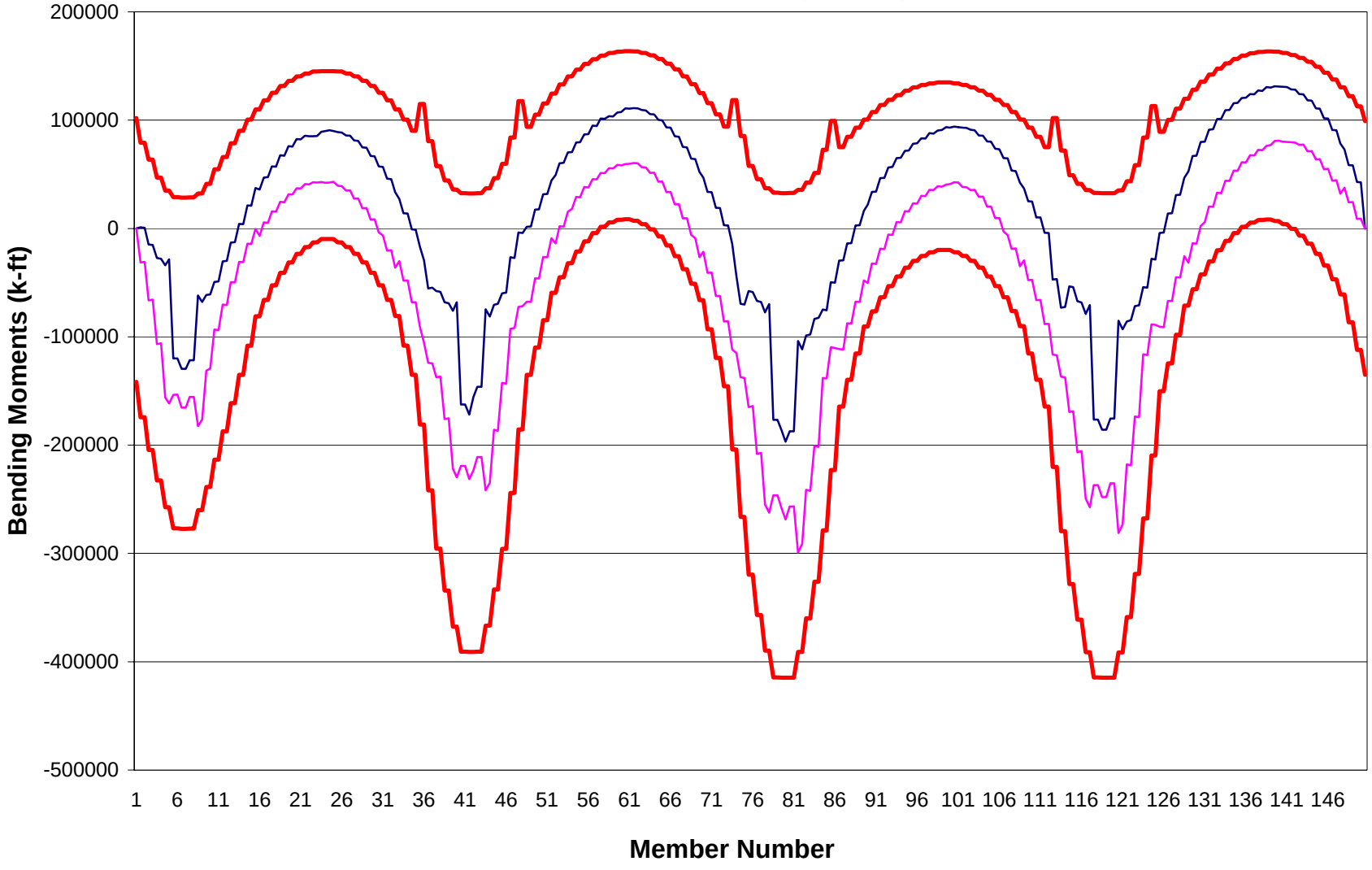
Cline Avenue Load Rating Mainline Segment 2 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.81	2.35										
		Shear	2.43	3.15										
	Service	Flexure	0.71	1.33										
		Principal Stress	3.30	3.32										
Transverse	Strength	Top Slab Centerline	1.69	2.19										
		Top Slab Thickness Change	2.23	2.89										
		Top Slab Webs & Cantilever	3.02	3.92										
		Transverse Web Bending	2.59	3.47										

Overall Rating Factor	0.71	1.33	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		47.88	0.00	0.00

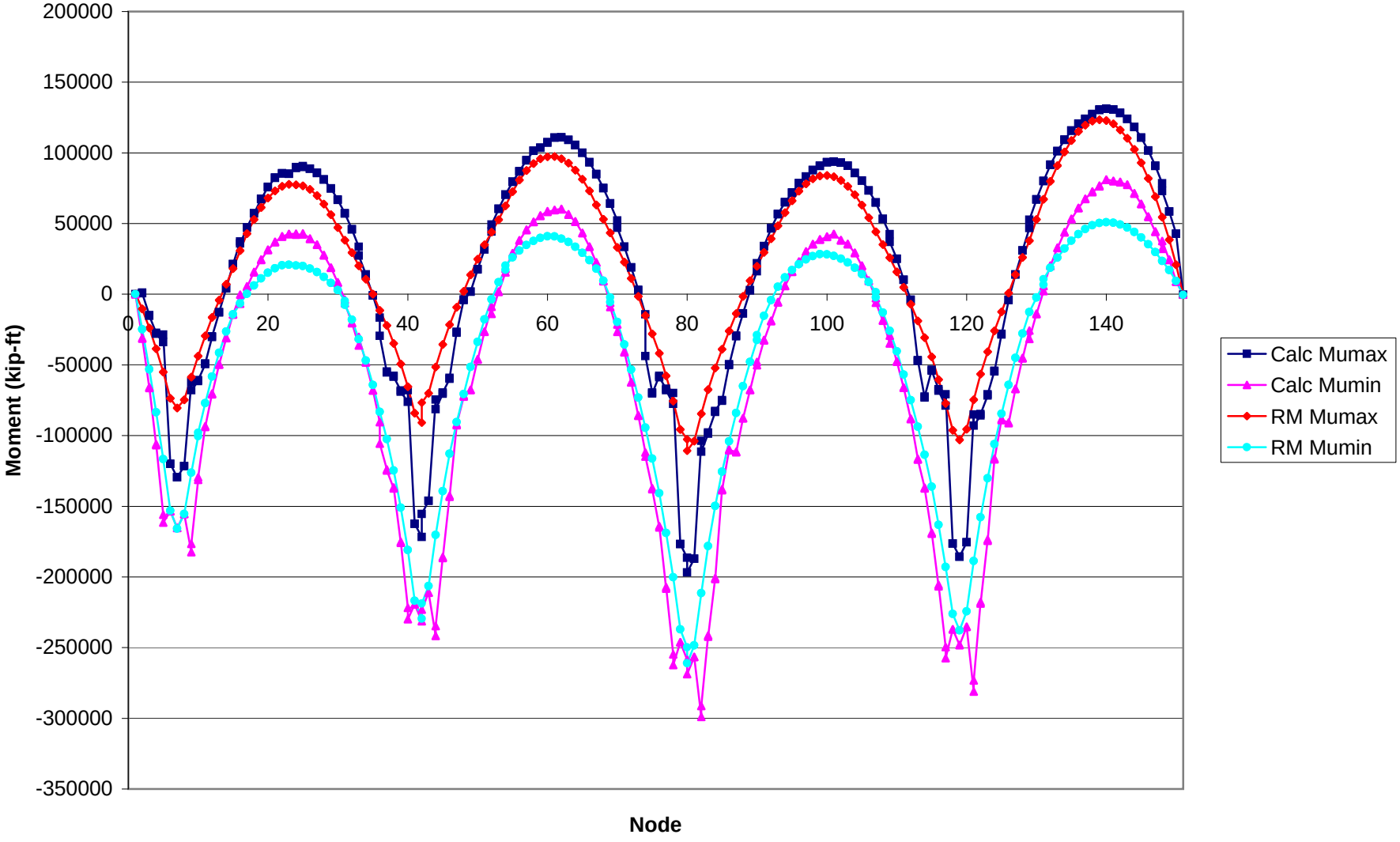
* Max number of lanes loaded = Per AASHTO LRFD

3.5.2 Strength I Flexure

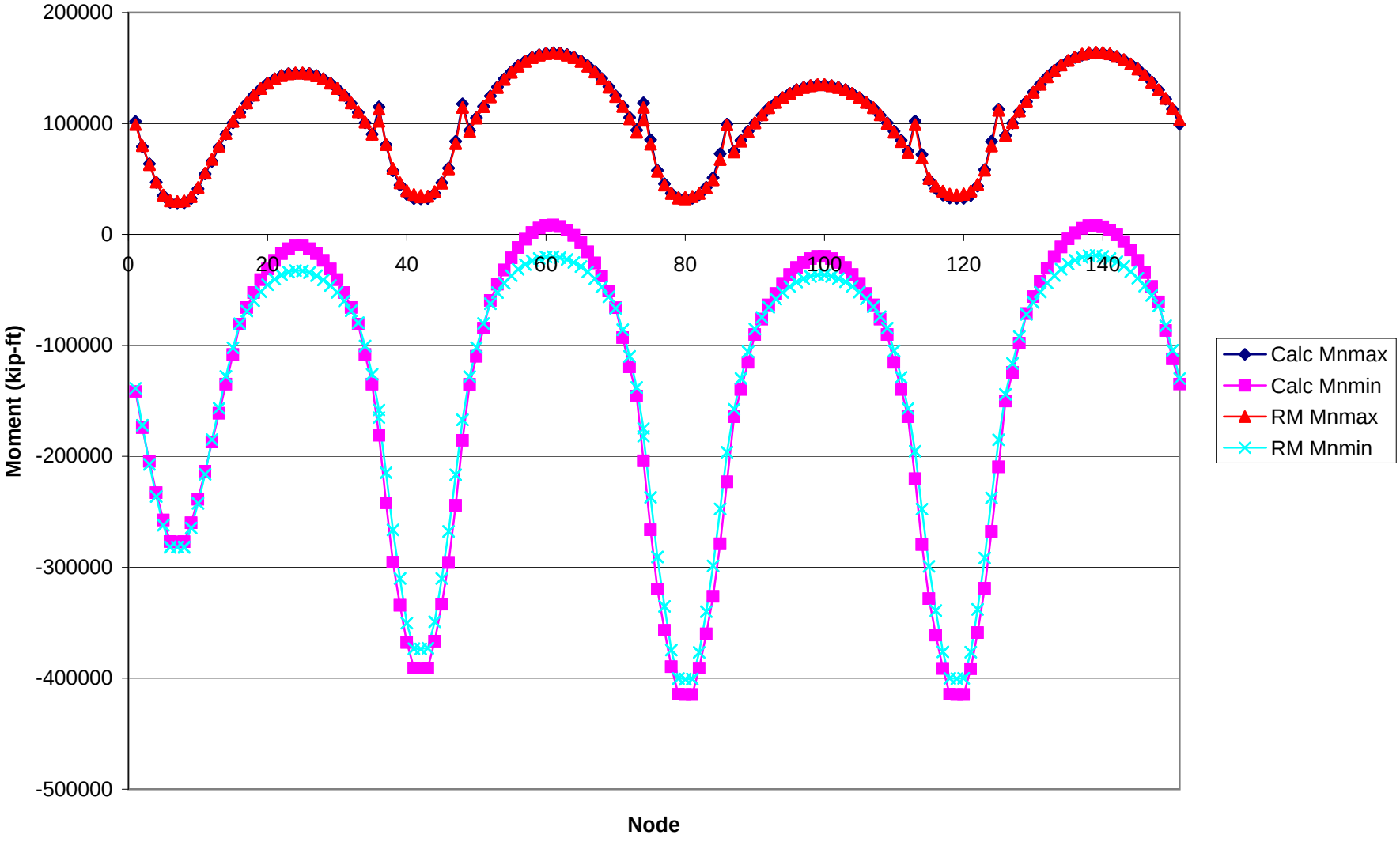
Mainline Segment 2 EB
Ultimate Moments (T=00)



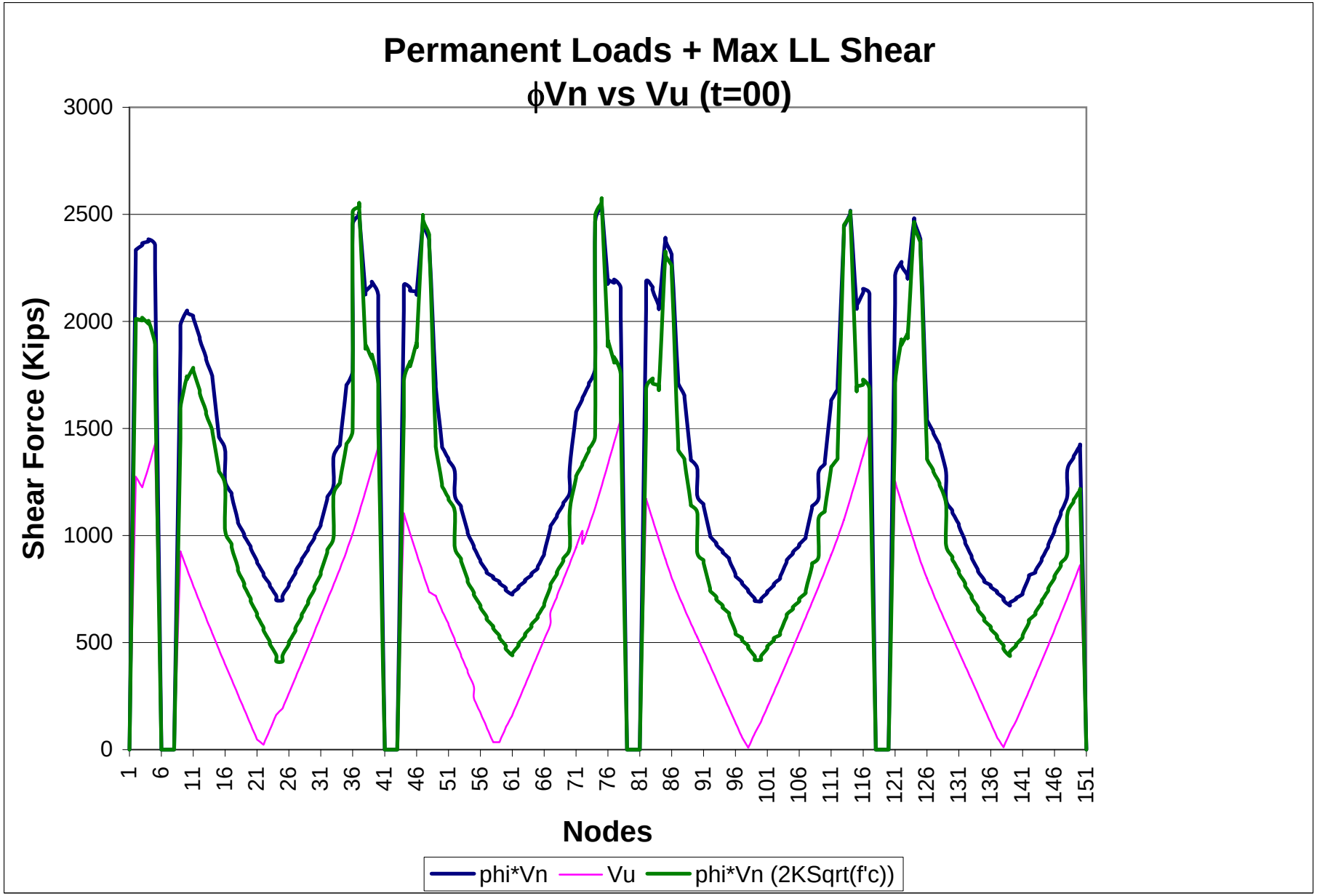
Mainline Segment 2 EB Flexural Demand, M_u

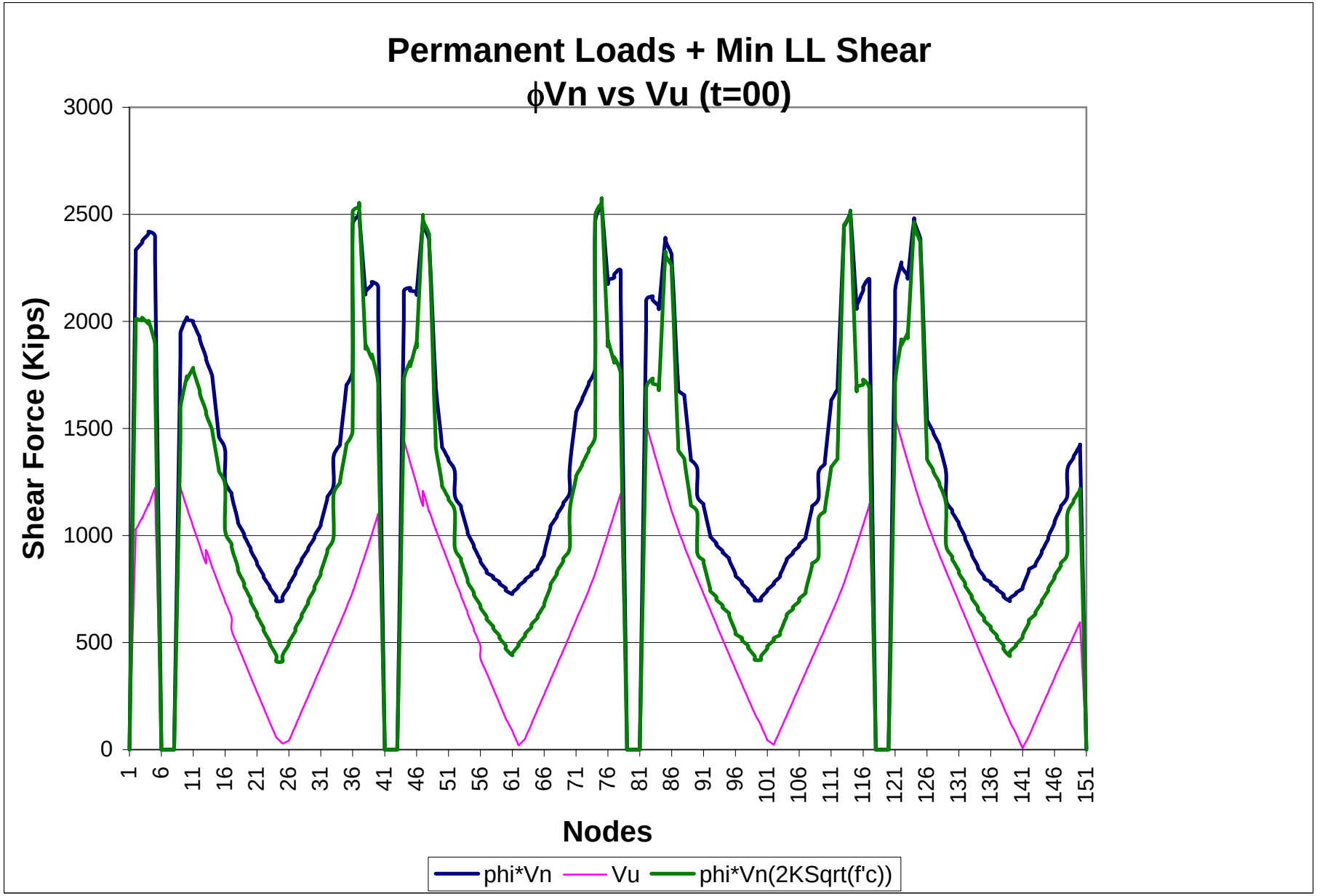


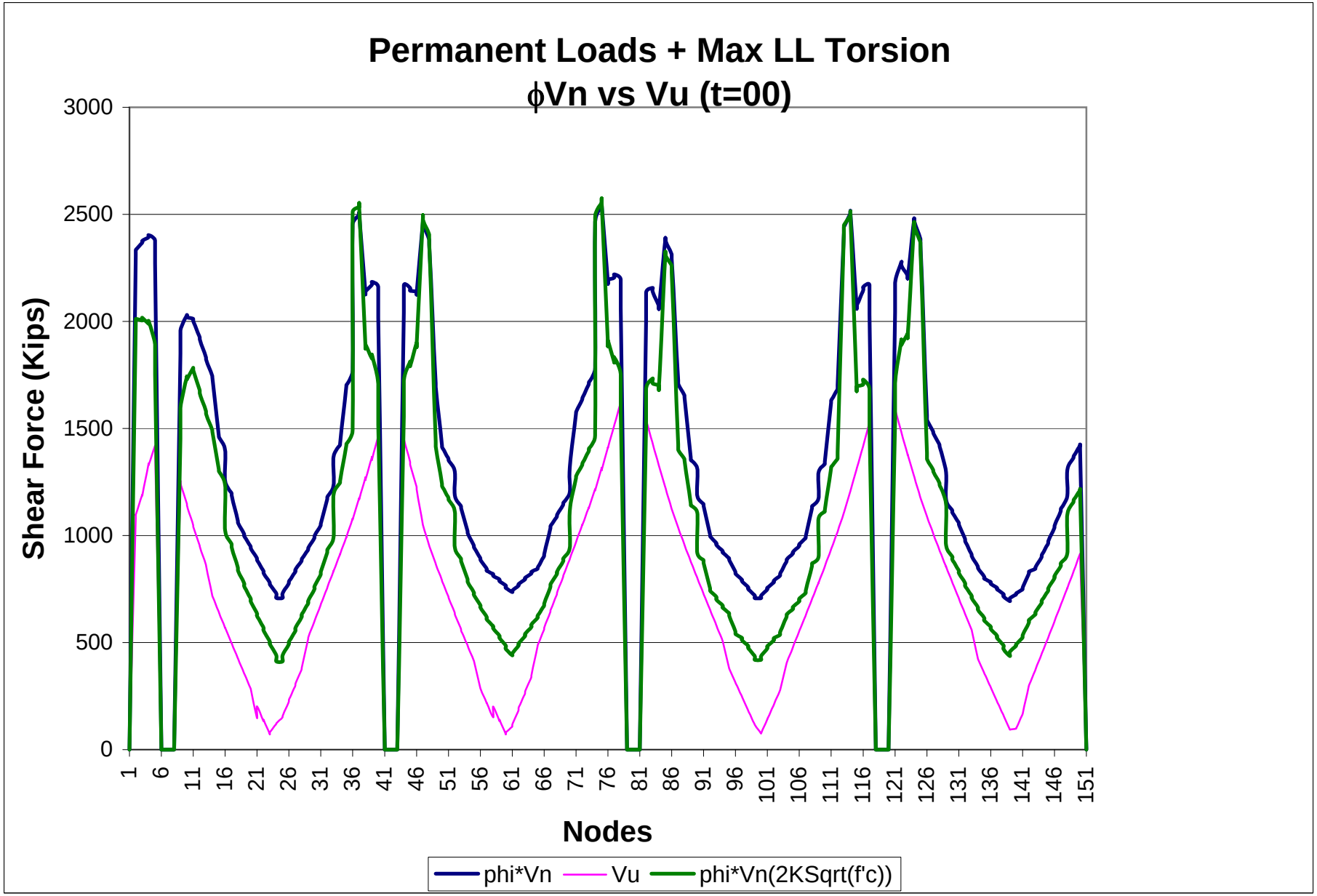
Mainline Segment 2 Flexural Strength, ϕM_n

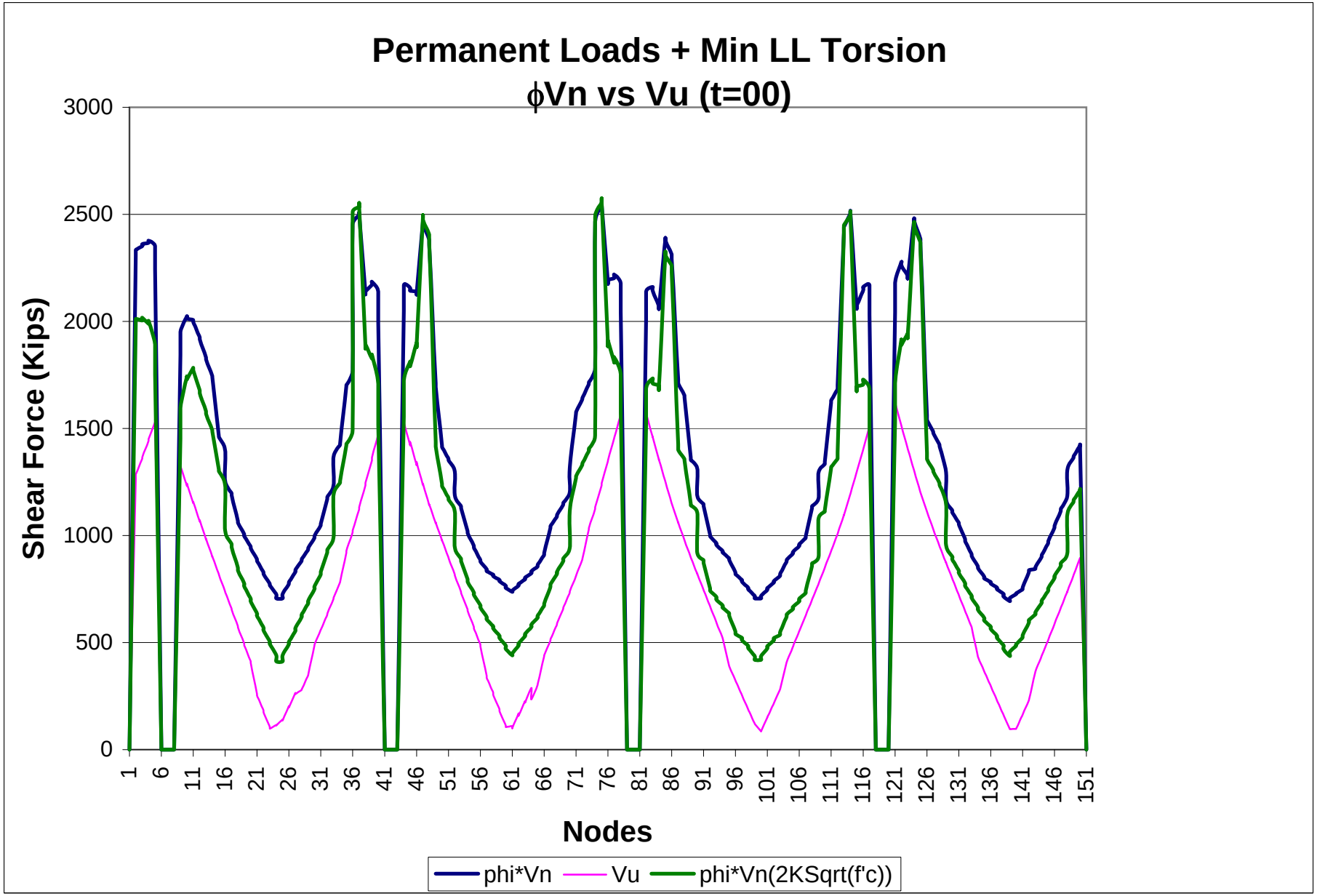


3.5.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 2 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Check: Ind Chk

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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 2 EB\

Node := 129 Position := Ahead $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -1368 \cdot kips$	$M_{dc_x} = 1054 \cdot kip \cdot ft$	$T_{dc_x} = -54\ ft \cdot kips$	$N_{dc_x} = -21 \cdot kips$	Dead Load
$V_{dw_x} = -181 \cdot kips$	$M_{dw_x} = -573 \cdot kip \cdot ft$	$T_{dw_x} = -366 \cdot kip \cdot ft$	$N_{dw_x} = -3 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 121 \cdot kips$	$M_{psec_x} = 20569 \cdot kip \cdot ft$	$T_{psec_x} = 9 \cdot kip \cdot ft$	$N_{psec_x} = 2 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -35\ kip$	$M_{crsh_x} = -5958 \cdot kip \cdot ft$	$T_{crsh_x} = 20 \cdot kip \cdot ft$	$N_{crsh_x} = -1 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 60 \cdot kips$	$M_{LLvmax_x} = 10129 \cdot kip \cdot ft$	$T_{LLvmax_x} = 168 \cdot kip \cdot ft$	$N_{LLvmax_x} = 1 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -358 \cdot kips$	$M_{LLvmin_x} = 874 \cdot kip \cdot ft$	$T_{LLvmin_x} = -7 \cdot kip \cdot ft$	$N_{LLvmin_x} = -6 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -245 \cdot kips$	$M_{LLtmax_x} = 5907 \cdot kip \cdot ft$	$T_{LLtmax_x} = 3674 \cdot kip \cdot ft$	$N_{LLtmax_x} = -4 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -246 \cdot kips$	$M_{LLtmin_x} = 5705 \cdot kip \cdot ft$	$T_{LLtmin_x} = -3686 \cdot kip \cdot ft$	$N_{LLtmin_x} = -4 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = 1068 \cdot kips$ Primary PT Shear

$N_{prim_x} = -15327 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = -30593 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1697 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -8 \cdot kips$

$M_{tu_x} = -1339 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 1 \cdot kip \cdot ft$

$N_{tu_x} = 0 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 15332 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 48999 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.207 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 127.938 \cdot in$ Height of Box

$y_{bot_x} = 83.035 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.243 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.15 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 121.086 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 121 \cdot in$ Depth for Torsion

$A_{s_x} = 7.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 126.188 \cdot in$ Depth of Mild Steel

URS

Project: Cline --Seg 2 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Check: Ind Chk | Date: / /

Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -1797 \cdot kips$	$T_{uvmax_x} = -371 \cdot kip \cdot ft$	$M_{uvmax_x} = 31722\, ft \cdot kips$	$N_{uvmax_x} = -28 \cdot kips$
$V_{uvmin_x} = -2361 \cdot kips$	$T_{uvmin_x} = -607 \cdot kip \cdot ft$	$M_{uvmin_x} = 19228\, ft \cdot kips$	$N_{uvmin_x} = -37 \cdot kips$
$V_{utmax_x} = -2209 \cdot kips$	$T_{utmax_x} = 4362 \cdot kip \cdot ft$	$M_{utmax_x} = 26022\, ft \cdot kips$	$N_{utmax_x} = -35 \cdot kips$
$V_{utmin_x} = -2210 \cdot kips$	$T_{utmin_x} = -5574 \cdot kip \cdot ft$	$M_{utmin_x} = 25750\, ft \cdot kips$	$N_{utmin_x} = -35 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.889\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 12695 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 69.917 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 92.115 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0004$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 577.986 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -626\ kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 27 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 0.705$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.0004$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 577.986 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -626\ kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -161.1 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 0.705$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.0004$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 577.986 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -634.853\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -183.739 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{tpos_{x,1}} = 0.705$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmin_x} = -0.0004$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 577.986 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -634.853\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -184.429 \cdot kips$

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Job No. 25626272.00001
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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 0.705}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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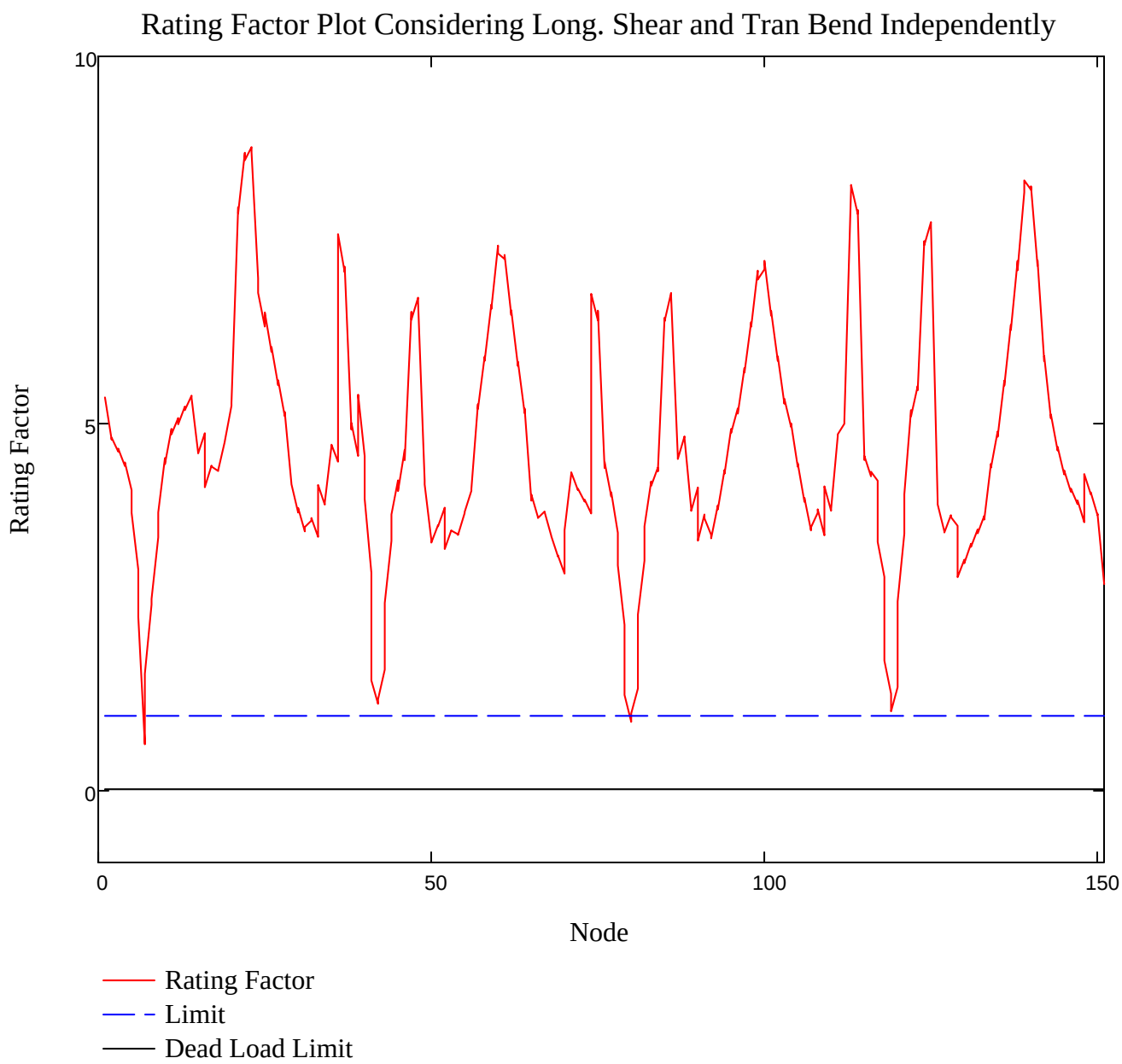

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.893$ at node $minRF_2 = 129$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.705$

URS

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 160.248 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 80.261 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.285 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.142 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.495 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 12.4 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 10.69 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 12.4 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 182.074 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 1.004 \times 10^3 \cdot kip$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.243 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 10.69 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 364.148 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.168 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.486 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 10.69 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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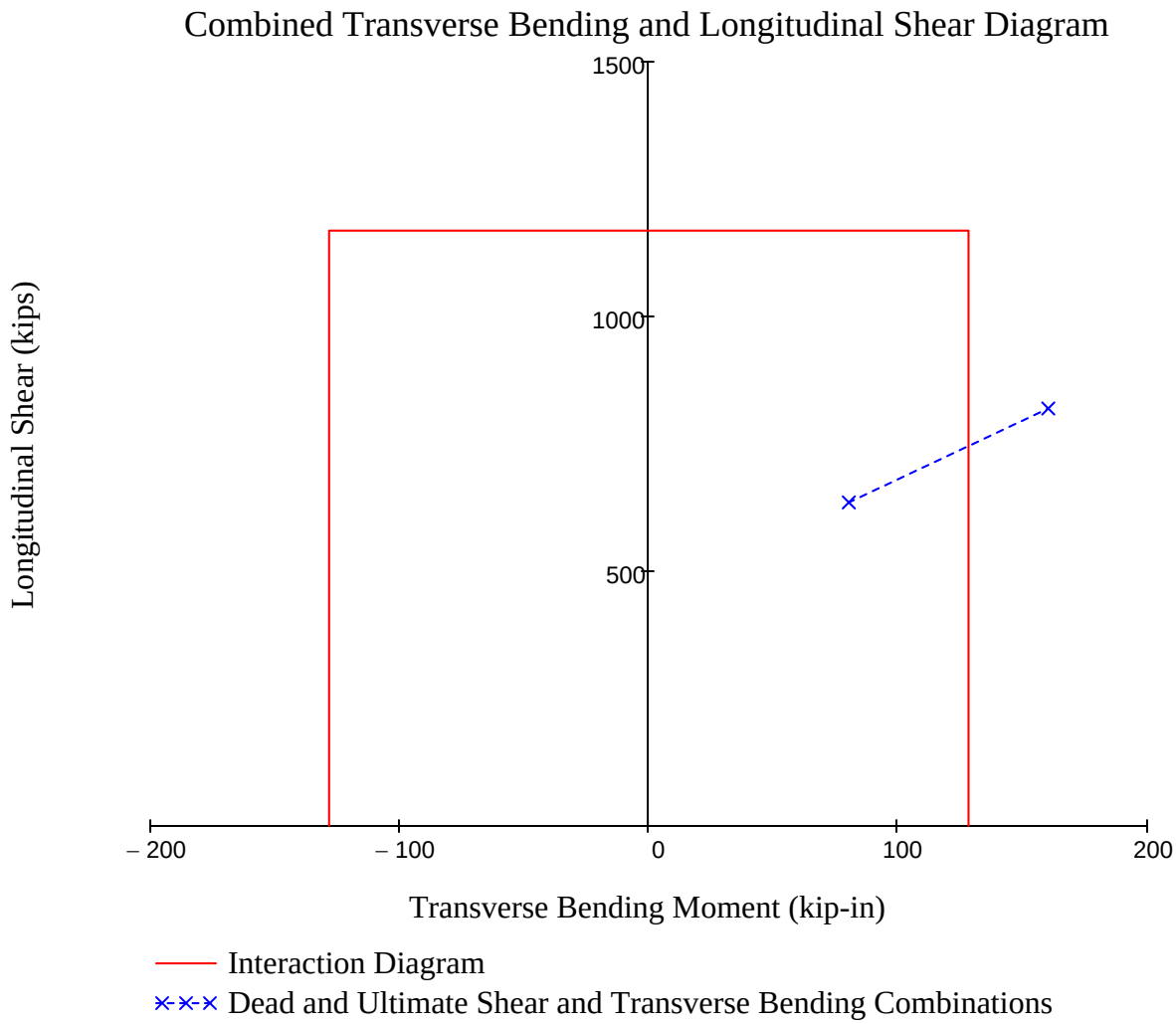


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 0.6$

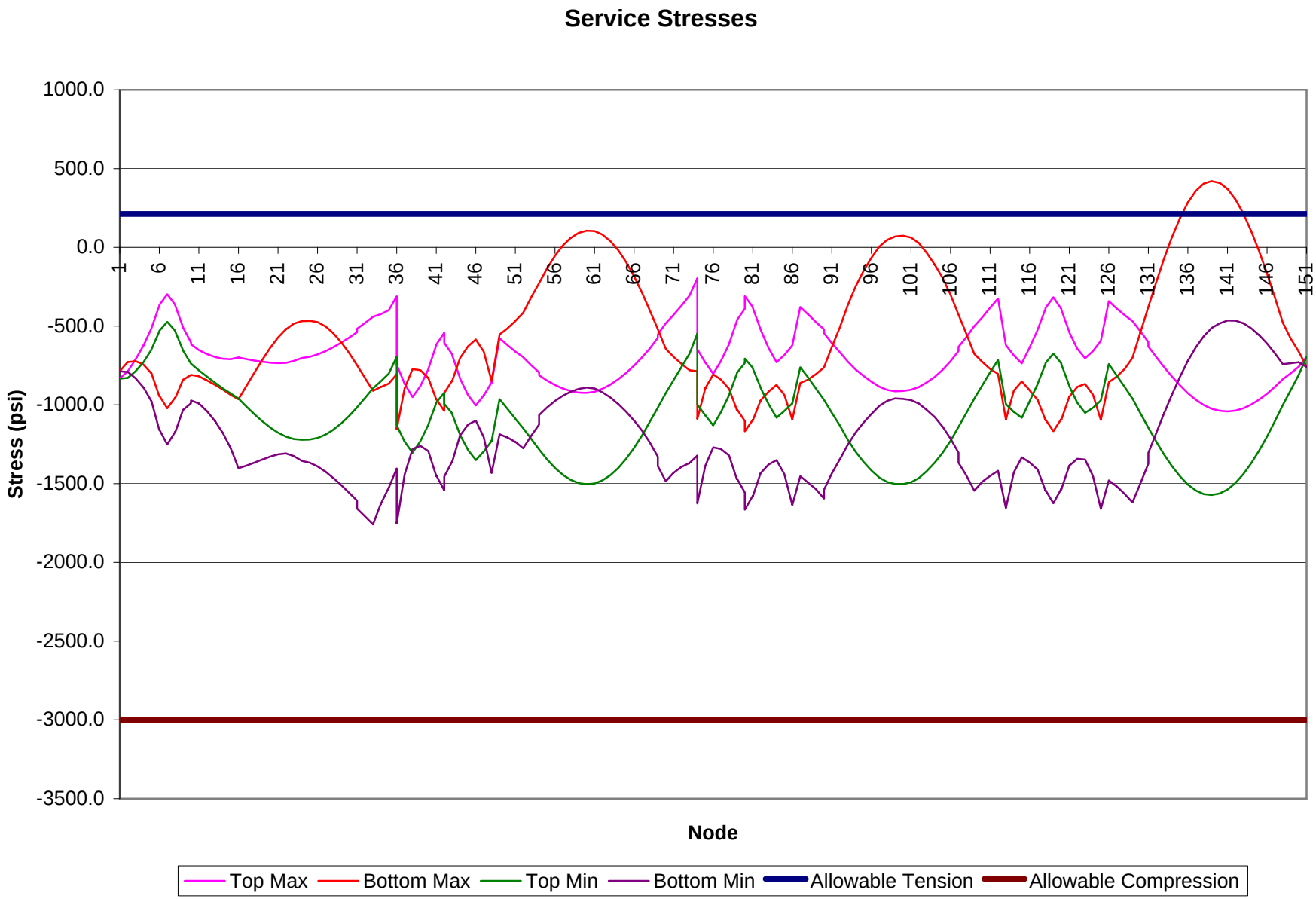
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 3.366$

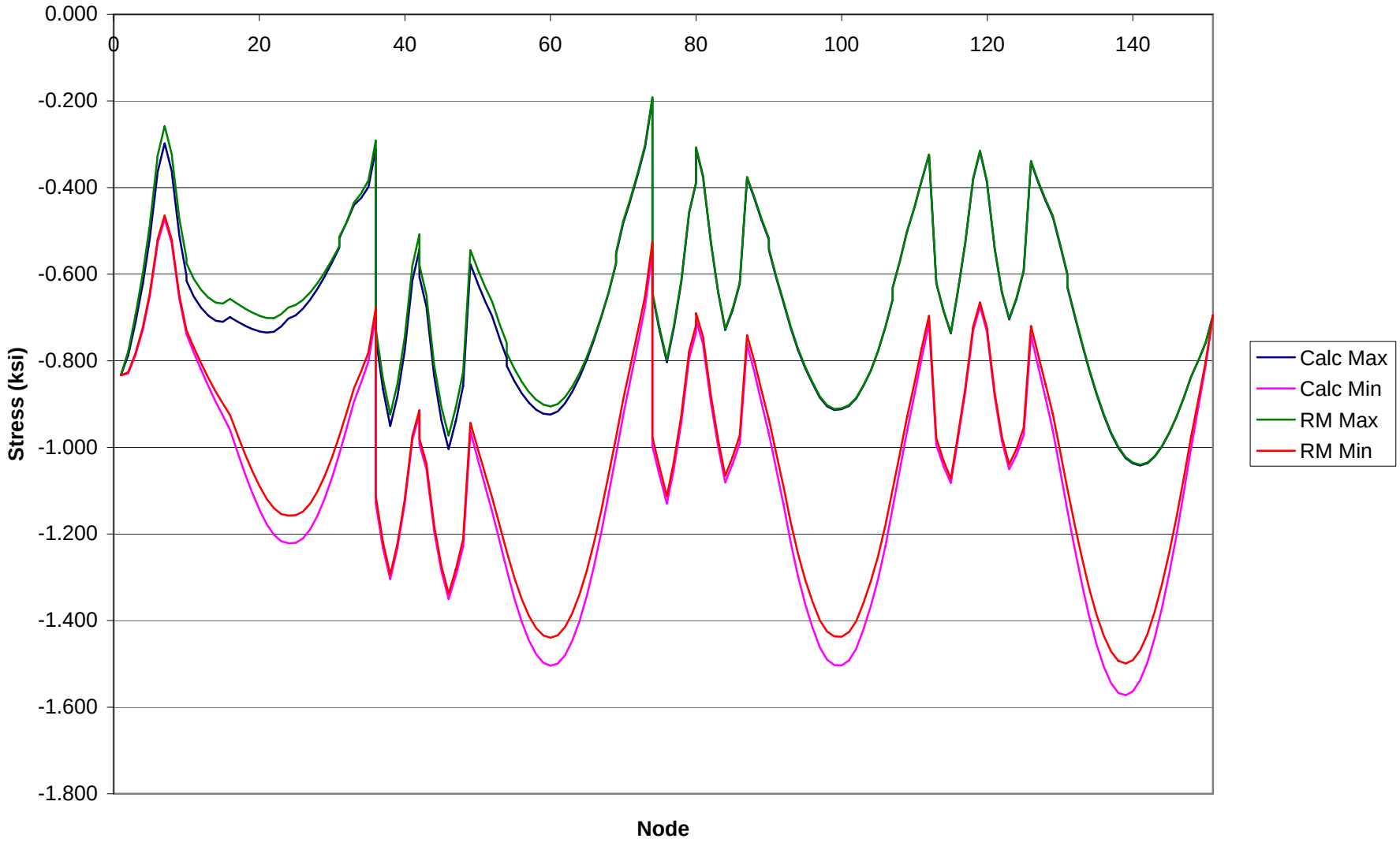
$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 2.893$

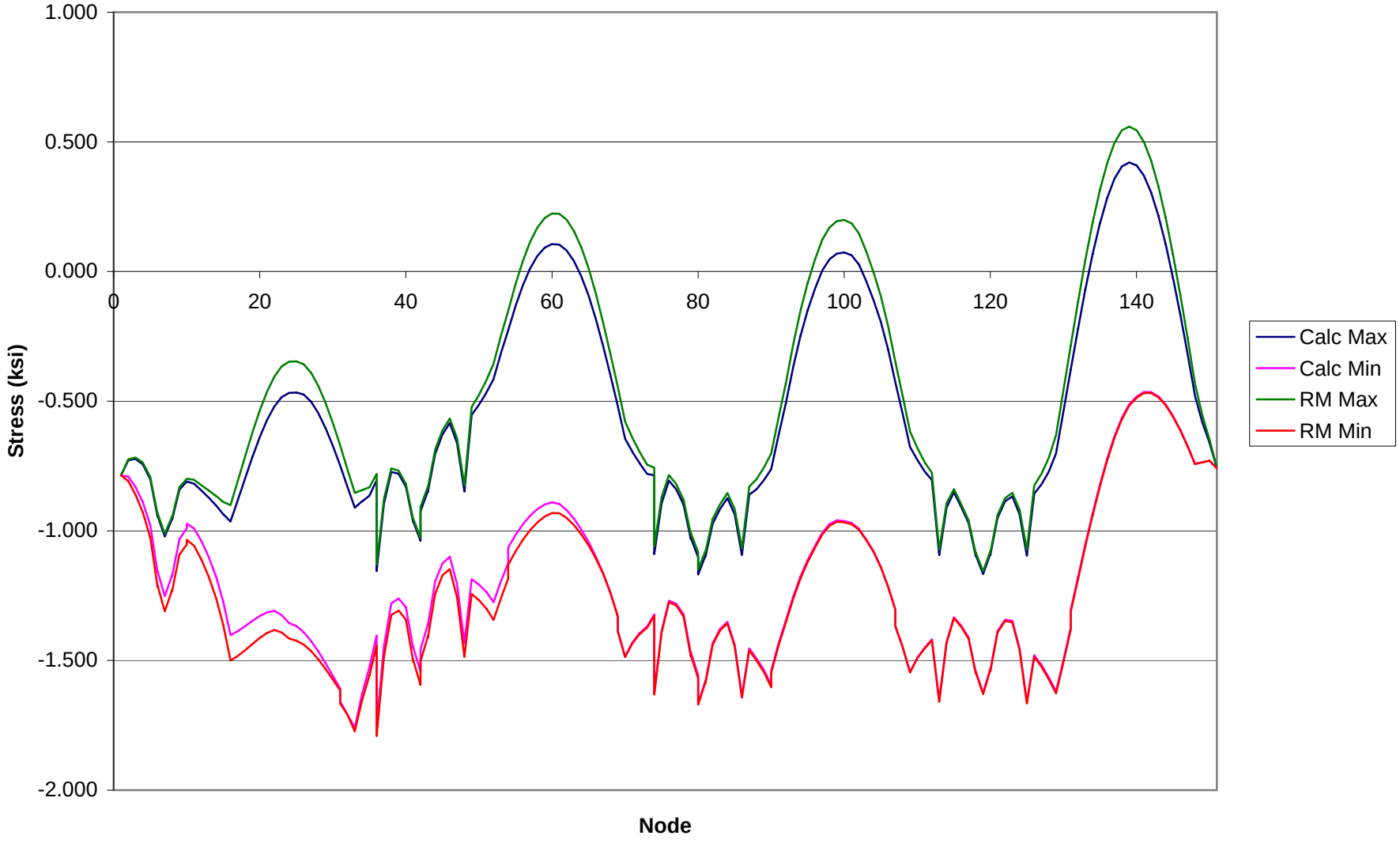
3.5.4 Service I Flexure (Service Stresses)


Service Stresses
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression

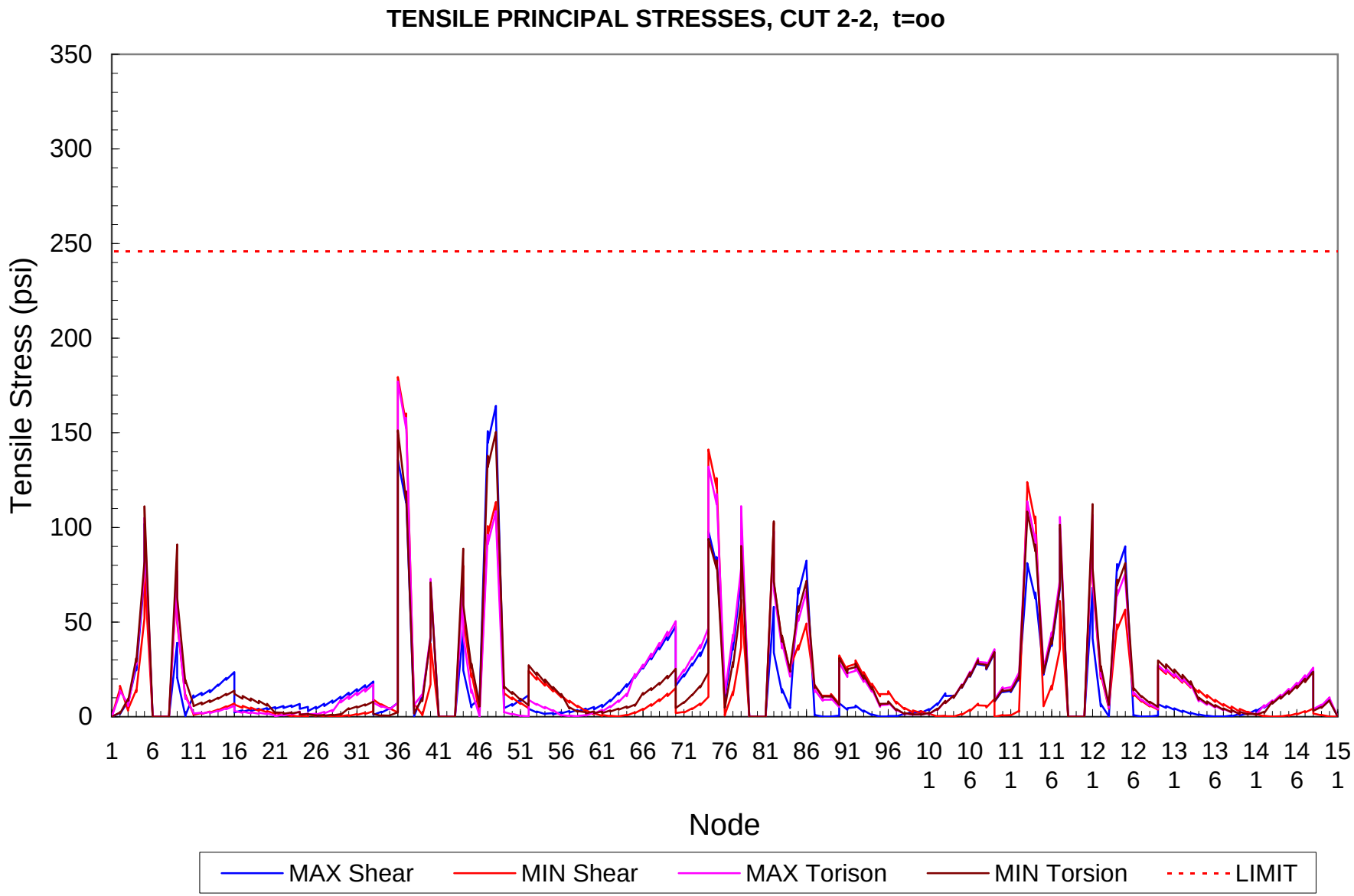
Mainline Segment 2 Top Service Stresses



Mainline Segment 2 Bottom Service Stresses

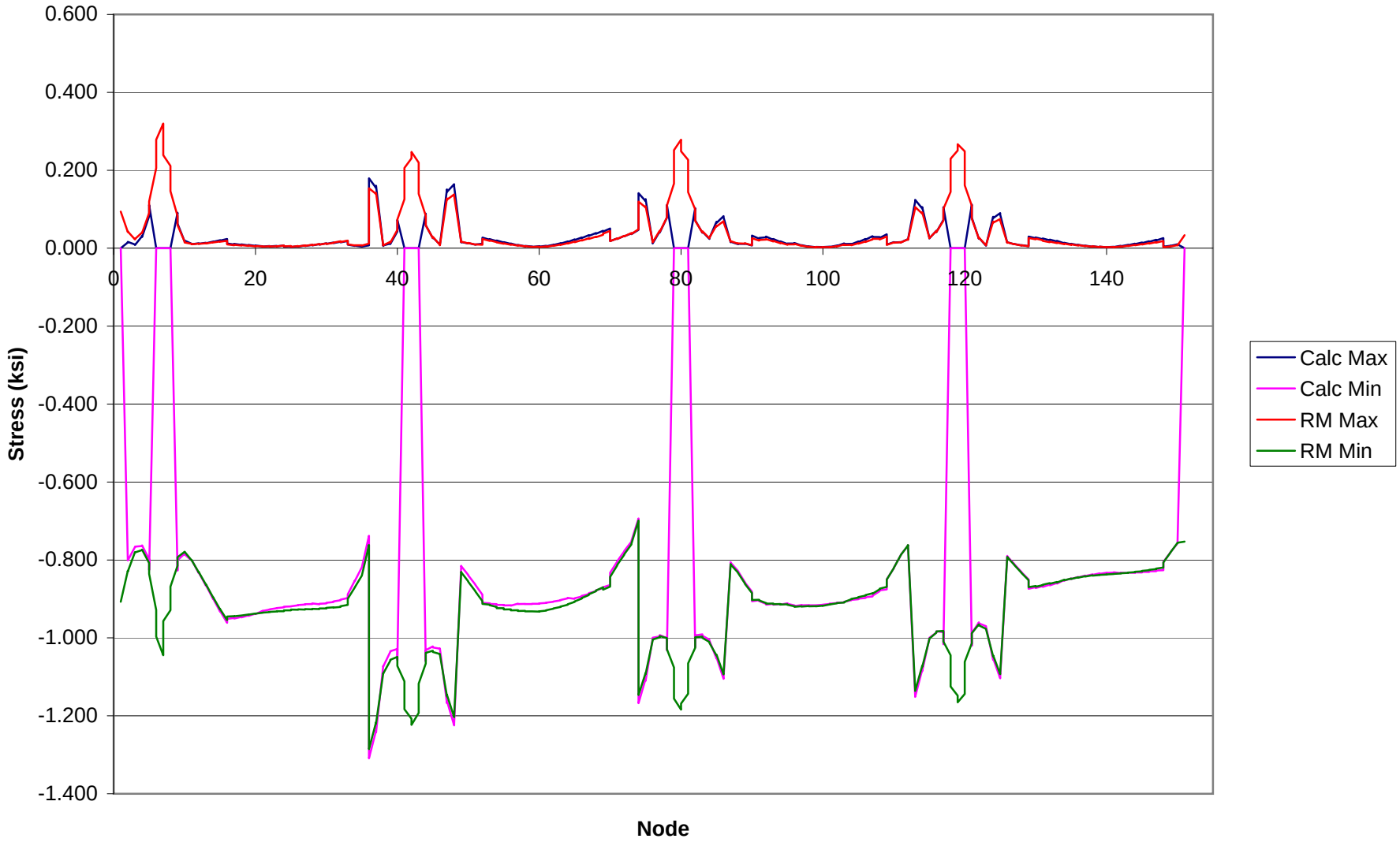


3.5.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.5.5/1

Mainline Segment 2 Principal Stresses



3.6 Mainline Segment 2 WB Rating

3.6.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 2 WB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 2 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.40	1.82	1.51	1.52	1.36	1.70	1.70	1.59	1.58	1.46	1.53	1.36
		Shear	1.77	2.32	1.68	1.69	1.44	1.68	1.68	1.29	1.28	1.11	0.97	0.97
	Service	Flexure	0.45	1.10	0.99	1.01	0.93	1.00	0.99	0.91	0.92	0.83	0.89	0.80
		Principal Stress	2.64	2.65	2.35	2.36	2.00	2.03	2.03	1.65	1.65	1.47	1.29	1.30
Transverse	Strength	Top Slab Centerline	1.65	2.13	2.30	2.43	2.48	2.07	2.00	1.95	1.95	1.71	1.97	1.77
		Top Slab Thickness Change	1.71	2.22	2.47	2.51	2.42	2.15	2.18	1.89	1.98	1.62	1.93	1.63
		Top Slab Webs & Cantilever	1.85	2.40	2.35	2.33	1.97	1.90	2.02	1.70	1.70	1.38	1.58	1.33
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.45	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 2 WB** CALCS BY: TSP DATE: 10/20/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

Clear Table | Fill Table | Posting Values

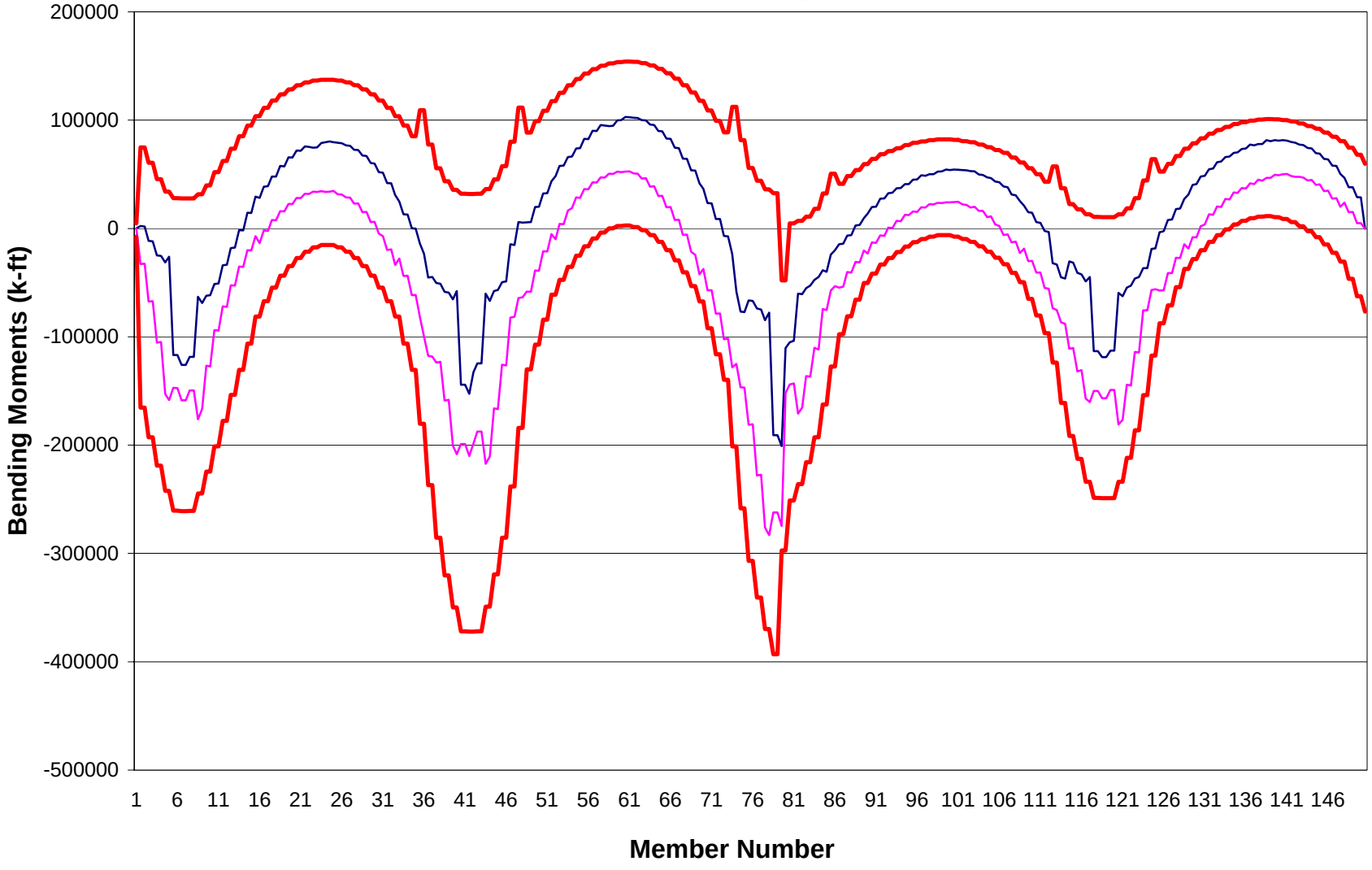
Cline Avenue Load Rating Mainline Segment 2 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.49	1.93										
		Shear	1.87	2.45										
	Service	Flexure	0.51	1.15										
		Principal Stress	3.22	3.23										
Transverse	Strength	Top Slab Centerline	1.65	2.13										
		Top Slab Thickness Change	1.71	2.22										
		Top Slab Webs & Cantilever	2.43	3.15										
		Transverse Web Bending	2.59	3.47										

Overall Rating Factor	0.51	1.15	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		41.40	0.00	0.00

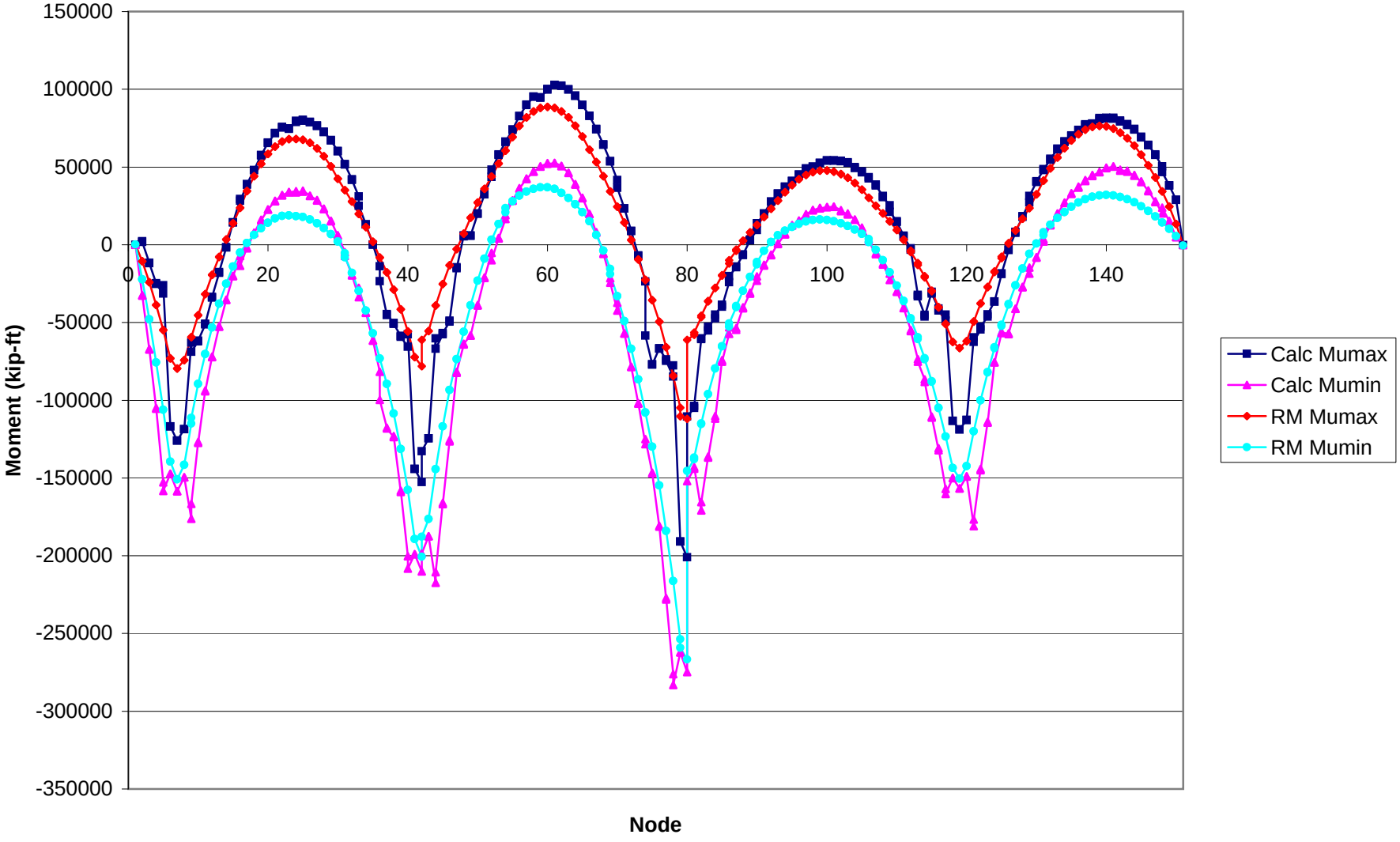
* Max number of lanes loaded = Per AASHTO LRFD

3.6.2 Strength I Flexure

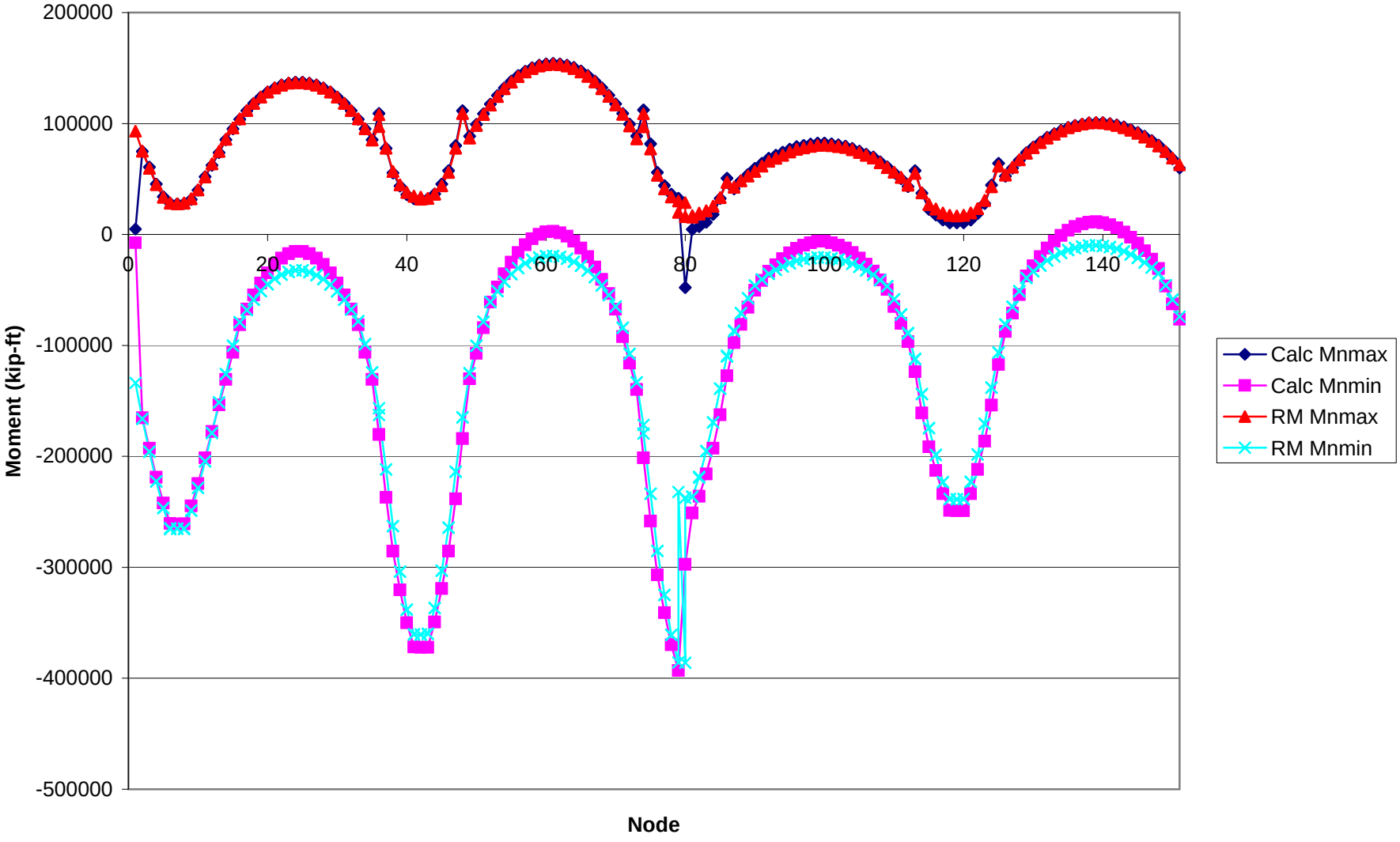
Mainline Segment 2 WB
Ultimate Moments (T=00)



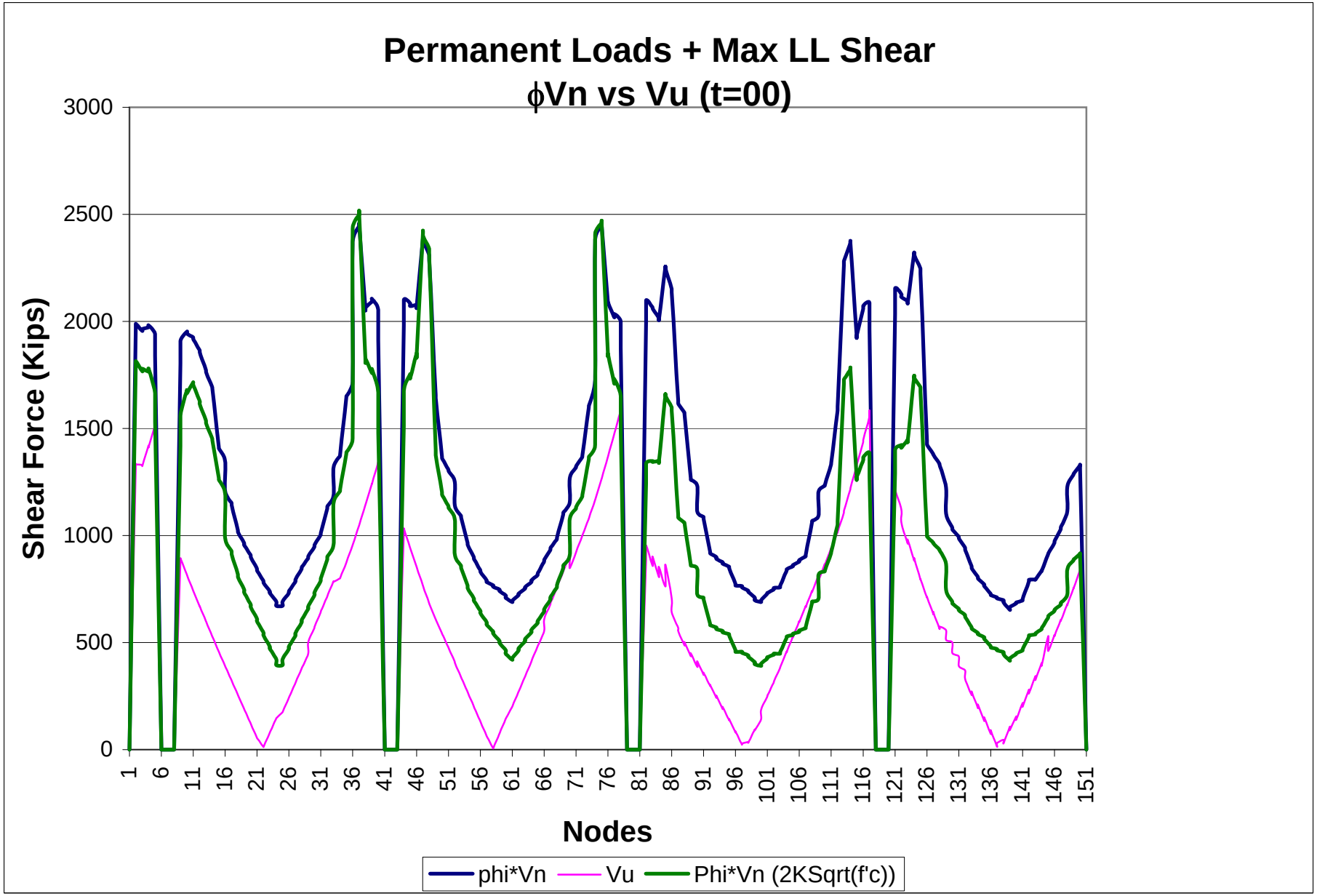
Mainline Segment 2 WB Flexural Demand, M_u

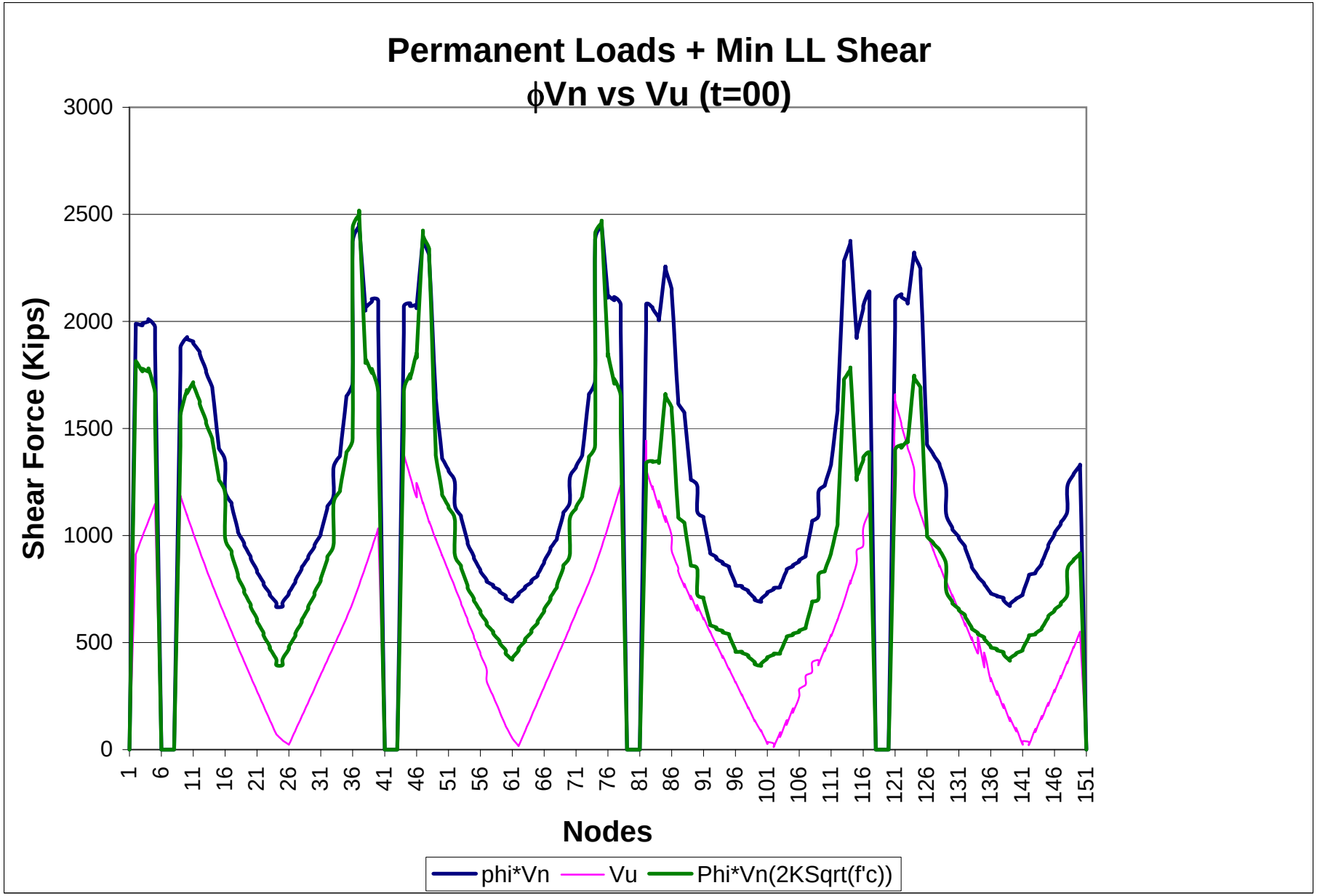


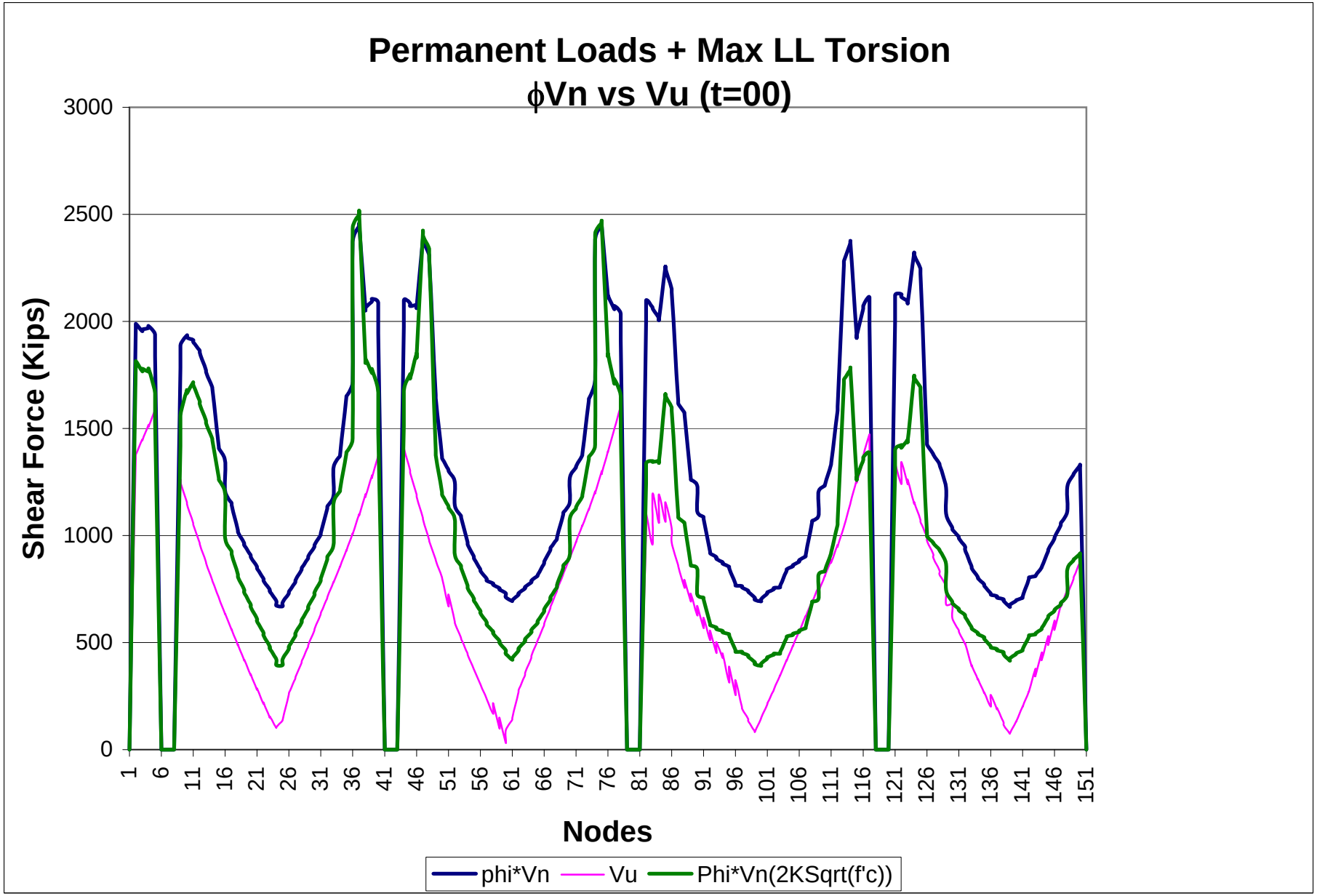
Mainline Segment 2 WB Flexural Strength, ϕM_n

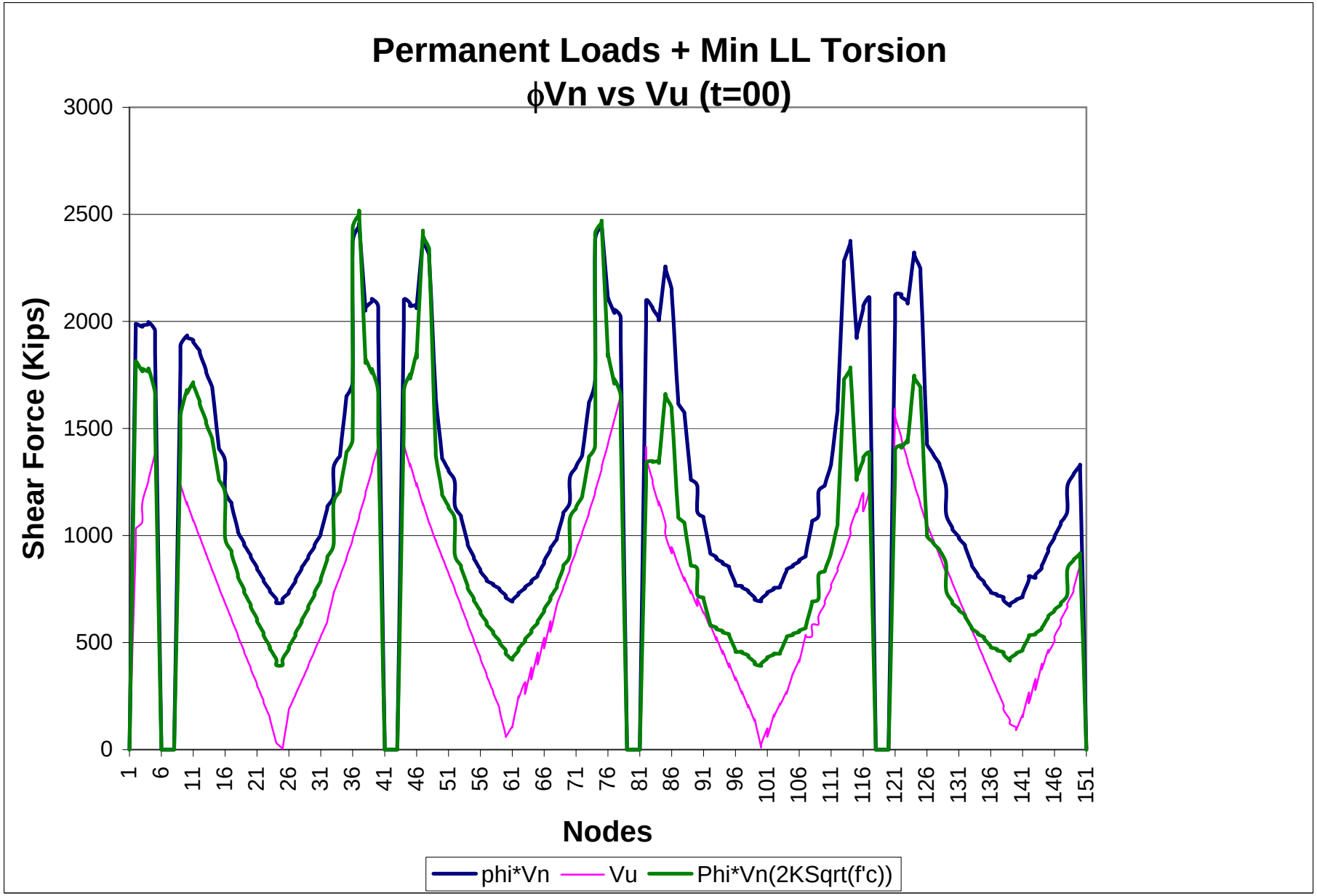


3.6.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
Phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
Phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
Phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Nodes
phi*Vn
Vu
Phi*Vn(2KSqrt(f'c))

URS

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Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 2 WB\

Node := 78 Position := Ahead $b_{voverride}$:= 14

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = 2613 \cdot kips$	$M_{dc_x} = -1 \times 10^5 \cdot kip \cdot ft$	$T_{dc_x} = -2847\, ft \cdot kips$	$N_{dc_x} = 138 \cdot kips$	Dead Load
$V_{dw_x} = 377 \cdot kips$	$M_{dw_x} = -18813 \cdot kip \cdot ft$	$T_{dw_x} = -752 \cdot kip \cdot ft$	$N_{dw_x} = -22 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 55 \cdot kips$	$M_{psec_x} = 22780 \cdot kip \cdot ft$	$T_{psec_x} = 2902 \cdot kip \cdot ft$	$N_{psec_x} = 115 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -50\, kip$	$M_{crsh_x} = 18264 \cdot kip \cdot ft$	$T_{crsh_x} = 1383 \cdot kip \cdot ft$	$N_{crsh_x} = -29 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 506 \cdot kips$	$M_{LLvmax_x} = -17123 \cdot kip \cdot$	$T_{LLvmax_x} = 1390 \cdot kip \cdot ft$	$N_{LLvmax_x} = -37 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -94 \cdot kips$	$M_{LLvmin_x} = 9883 \cdot kip \cdot ft$	$T_{LLvmin_x} = 71 \cdot kip \cdot ft$	$N_{LLvmin_x} = 39 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = 317 \cdot kips$	$M_{LLtmax_x} = -3295 \cdot kip \cdot ft$	$T_{LLtmax_x} = 5812 \cdot kip \cdot ft$	$N_{LLtmax_x} = -60 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = 356 \cdot kips$	$M_{LLtmin_x} = -9641 \cdot kip \cdot ft$	$T_{LLtmin_x} = -5320 \cdot kip \cdot ft$	$N_{LLtmin_x} = -10 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = -1343 \cdot kips$ Primary PT Shear

$N_{prim_x} = -20289 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 1 \times 10^5 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1676 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -5 \cdot kips$

$M_{tu_x} = -693 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = -92 \cdot kip \cdot ft$

$N_{tu_x} = -97 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 21178 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 65011 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 172.625 \cdot in$ Height of Box

$y_{bot_x} = 91.609 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.262 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.13 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.162 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.13 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 169.911 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 160 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 170.375 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = 4545 \cdot kips$	$T_{uvmax_x} = 783 \cdot kip \cdot ft$	$M_{uvmax_x} = -201195\ ft \cdot kips$	$N_{uvmax_x} = 190 \cdot kips$
$V_{uvmin_x} = 3735 \cdot kips$	$T_{uvmin_x} = -997 \cdot kip \cdot ft$	$M_{uvmin_x} = -164737\ ft \cdot kips$	$N_{uvmin_x} = 293 \cdot kips$
$V_{utmax_x} = 4290 \cdot kips$	$T_{utmax_x} = 6753 \cdot kip \cdot ft$	$M_{utmax_x} = -182527\ ft \cdot kips$	$N_{utmax_x} = 159 \cdot kips$
$V_{utmin_x} = 4342 \cdot kips$	$T_{utmin_x} = -8275 \cdot kip \cdot ft$	$M_{utmin_x} = -191094\ ft \cdot kips$	$N_{utmin_x} = 227 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.873\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 27562 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 156.128 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 140.515 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00024$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 28.157 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 5.858$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 695.053 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 1.287 \times 10^3\ kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 227.7 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})}$

$V_p \leftarrow |V_{prim_i}|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 1.838$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.00032$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.877 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.322$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 750.085 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmin_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left| T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 1.287 \times 10^3 \, kip$

$V_{LLwebvmin_y} := \dfrac{1.35 V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmin_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_x} = -42.3 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.838$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.00028$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 28.022 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.073$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 720.512 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"No"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 1.287 \times 10^3 \, kip$

$V_{LLwebtmax_y} := \dfrac{1.35 V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 142.65 \cdot kips$

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Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{tpos_{x,1}} = 1.838$$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left| M_{utmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| \left| V_{utmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left| M_{utmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| \left| V_{utmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{stmin_x} = -0.00026$$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 28.081 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 5.977$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 709.119 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 1303.394\ kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = 266.255 \cdot kips$

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Project: Cline --Seg 2 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.838}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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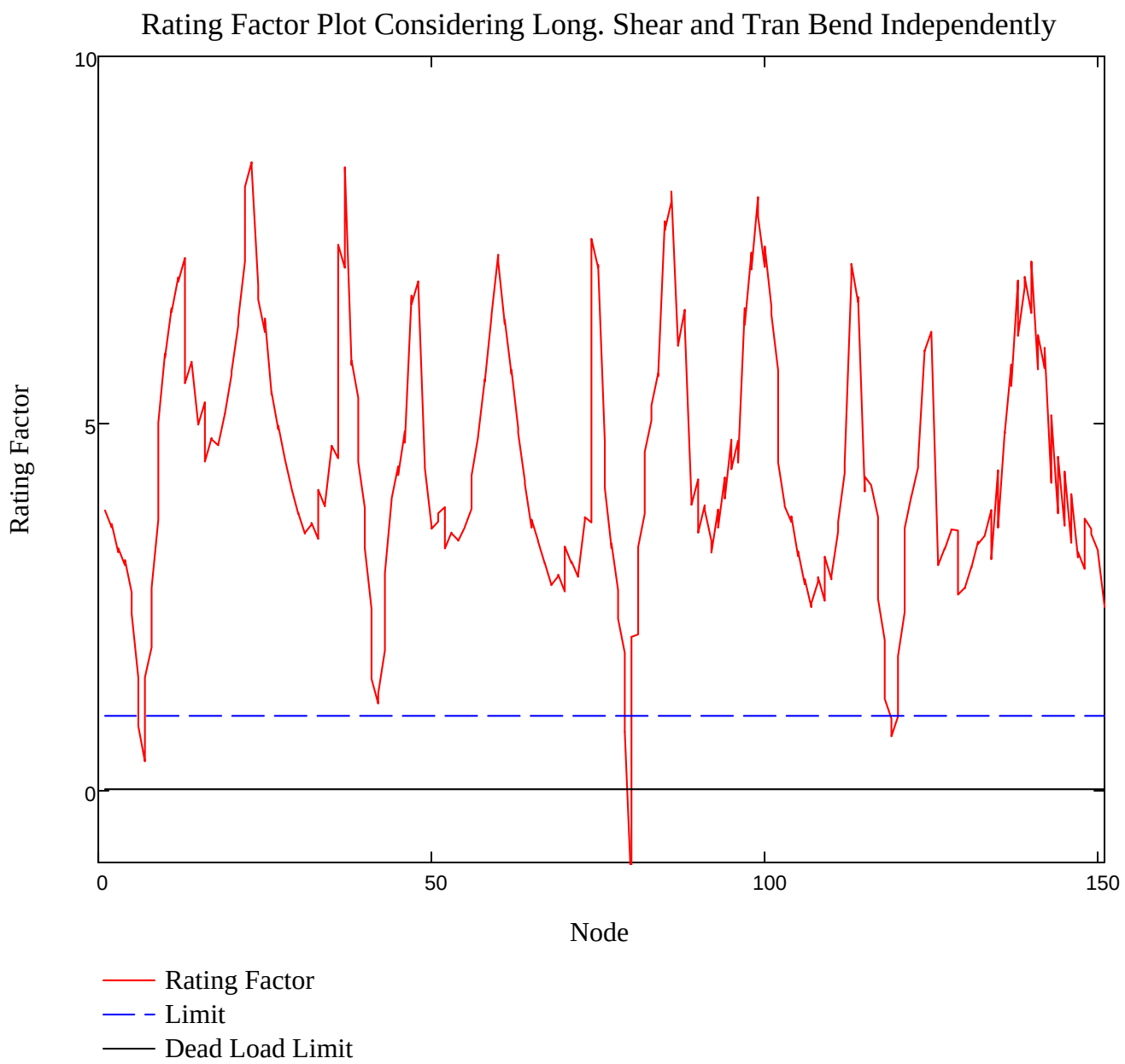

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.327$ at node $minRF_2 = 78$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.581$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 172.771 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 86.534 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.308 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.153 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.483 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 17.549 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 488.308 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 1.468 \times 10^3 \cdot kip$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 17.441 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 988.215 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.918 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.886 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 17.549 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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Project: Cline --Seg 2 WB
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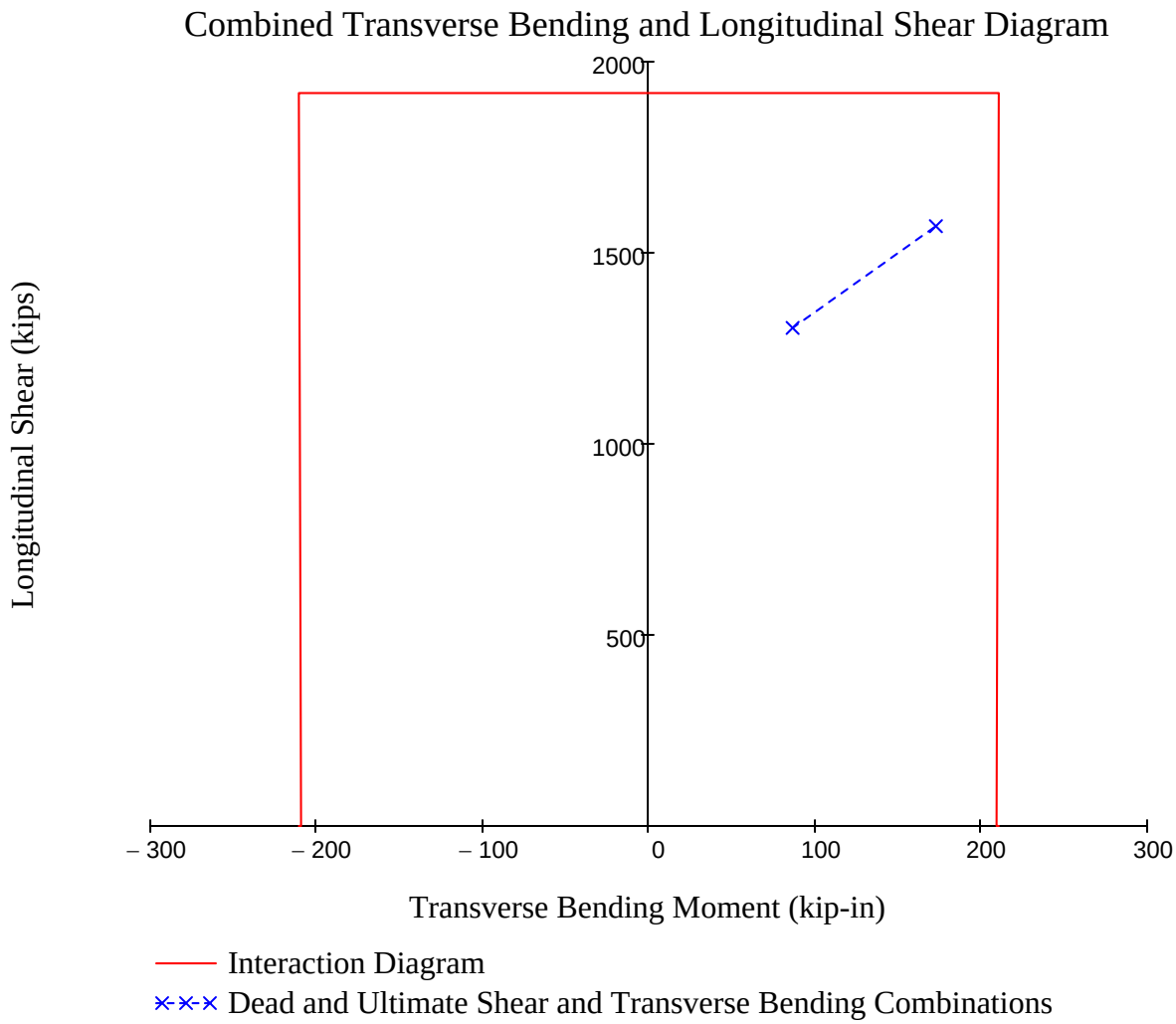


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.439$

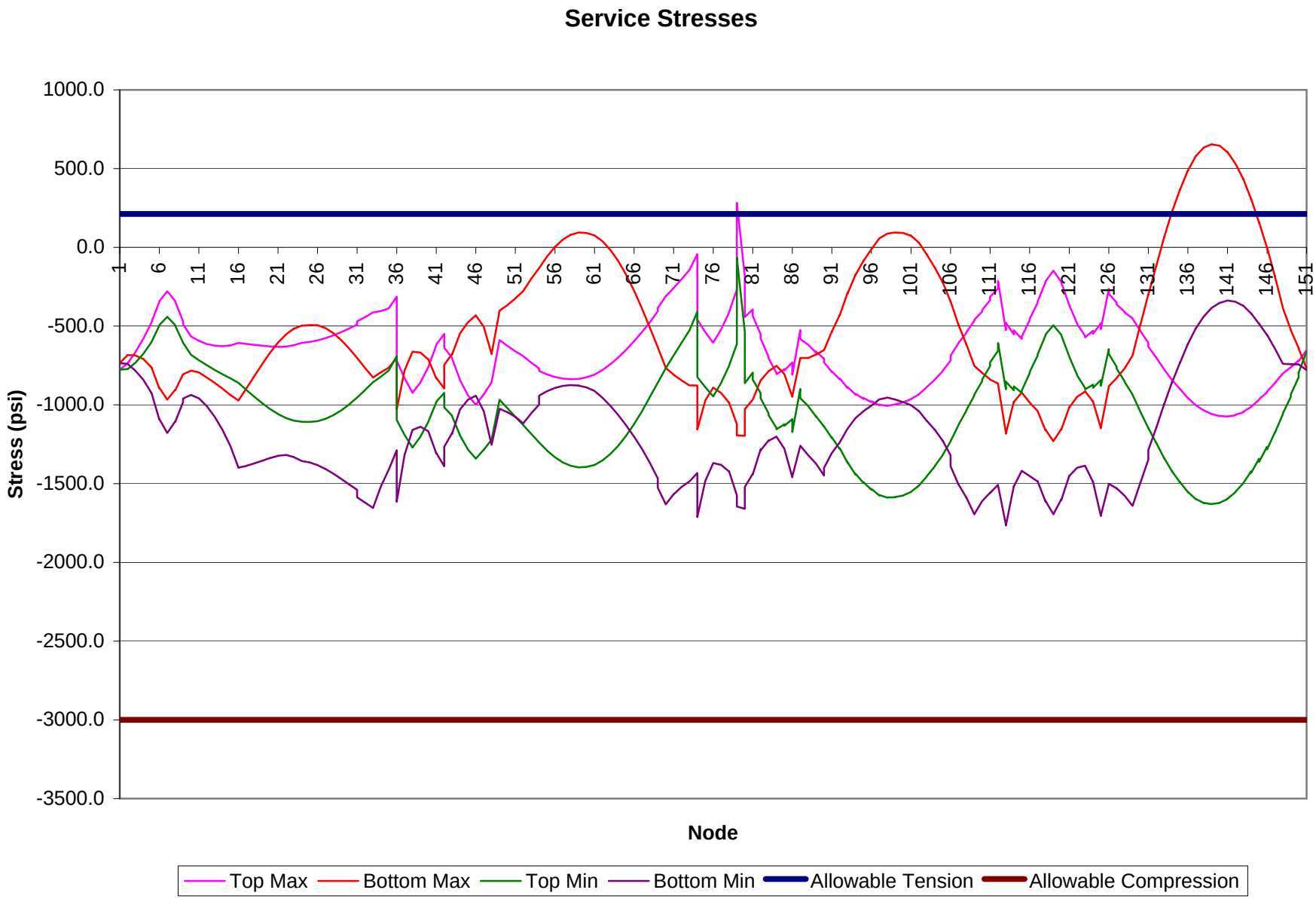
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 2.769$

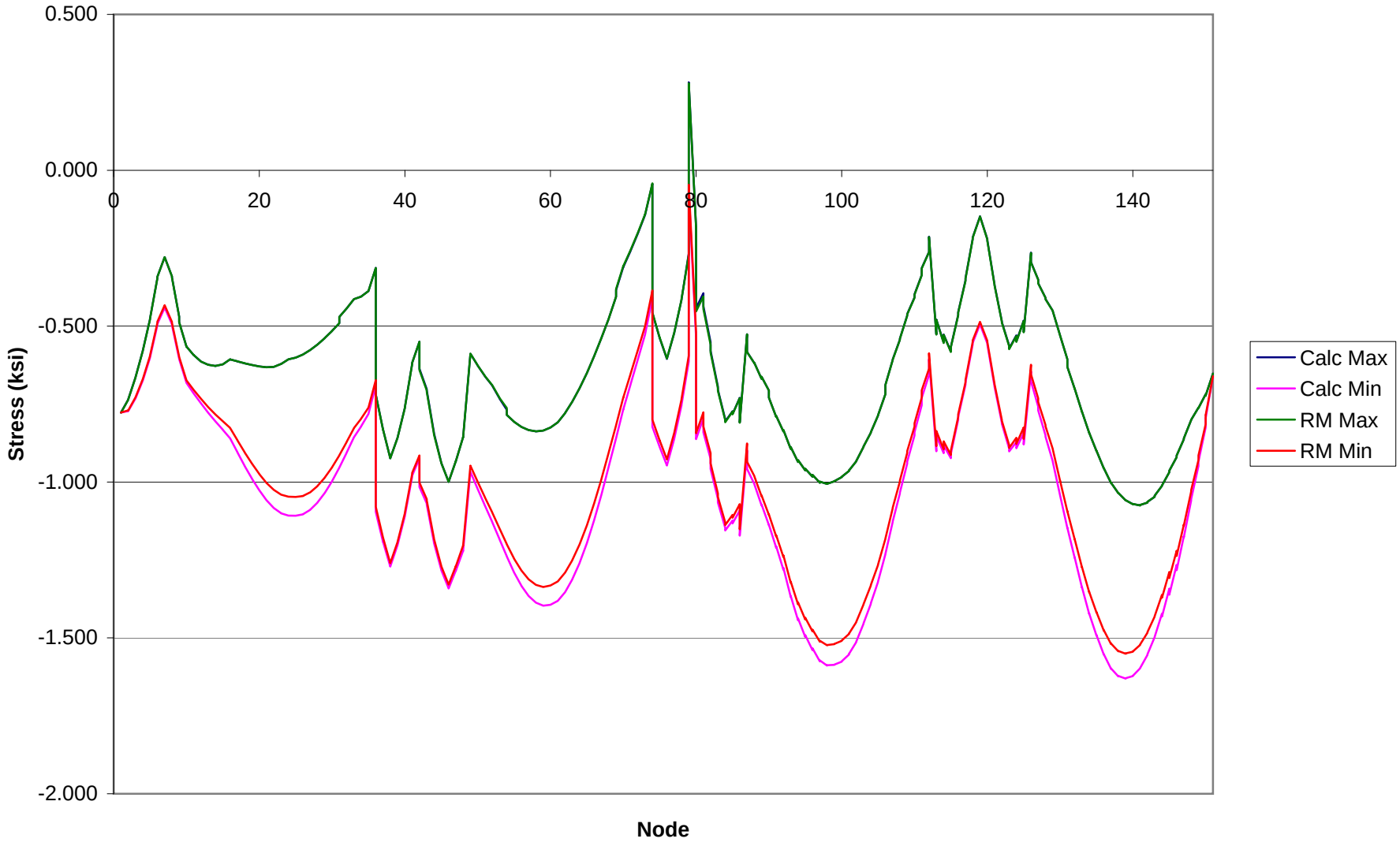
$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 2.308$

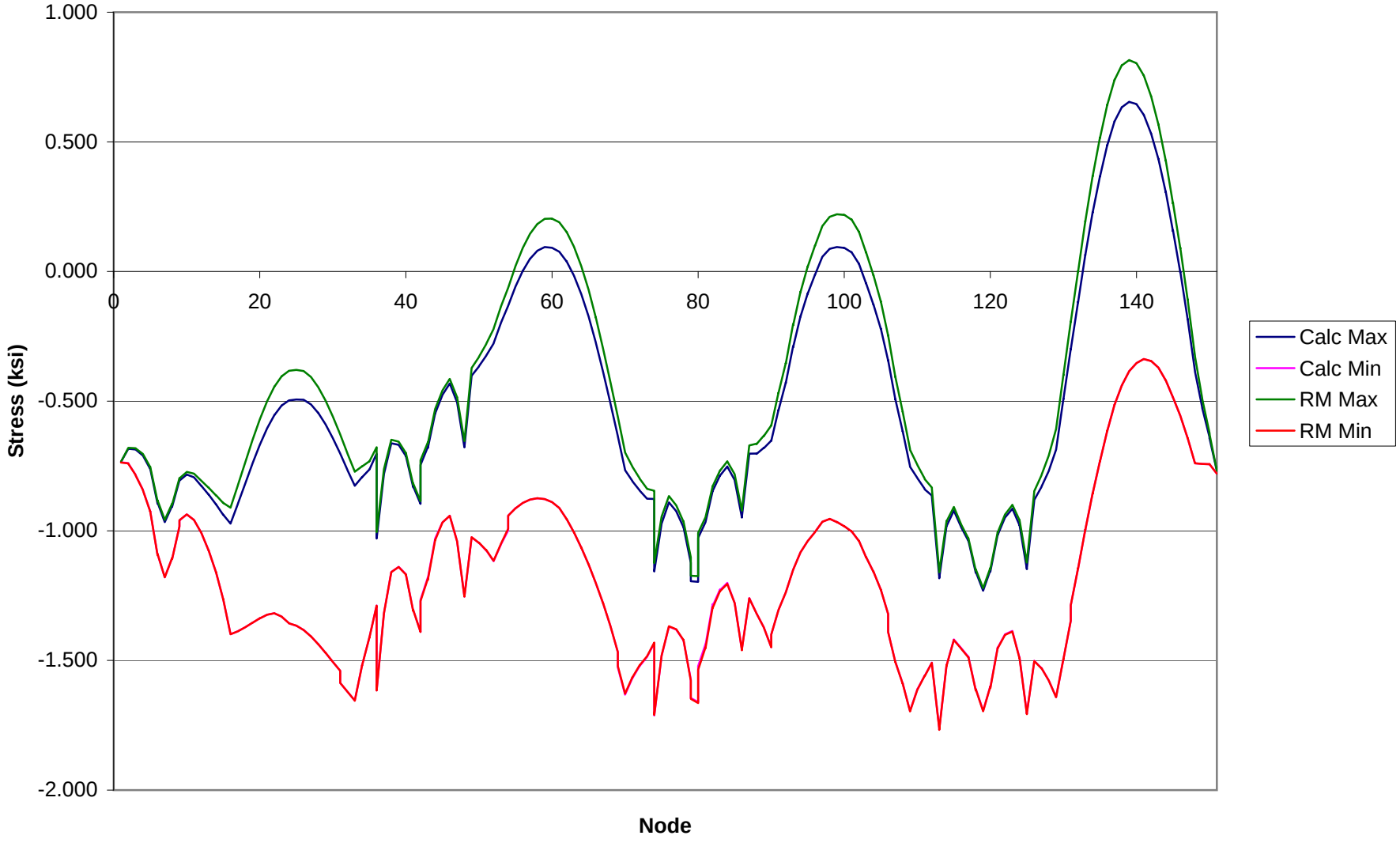
3.6.4 Service I Flexure (Service Stresses)


Service Stresses
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
141
146
151
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression

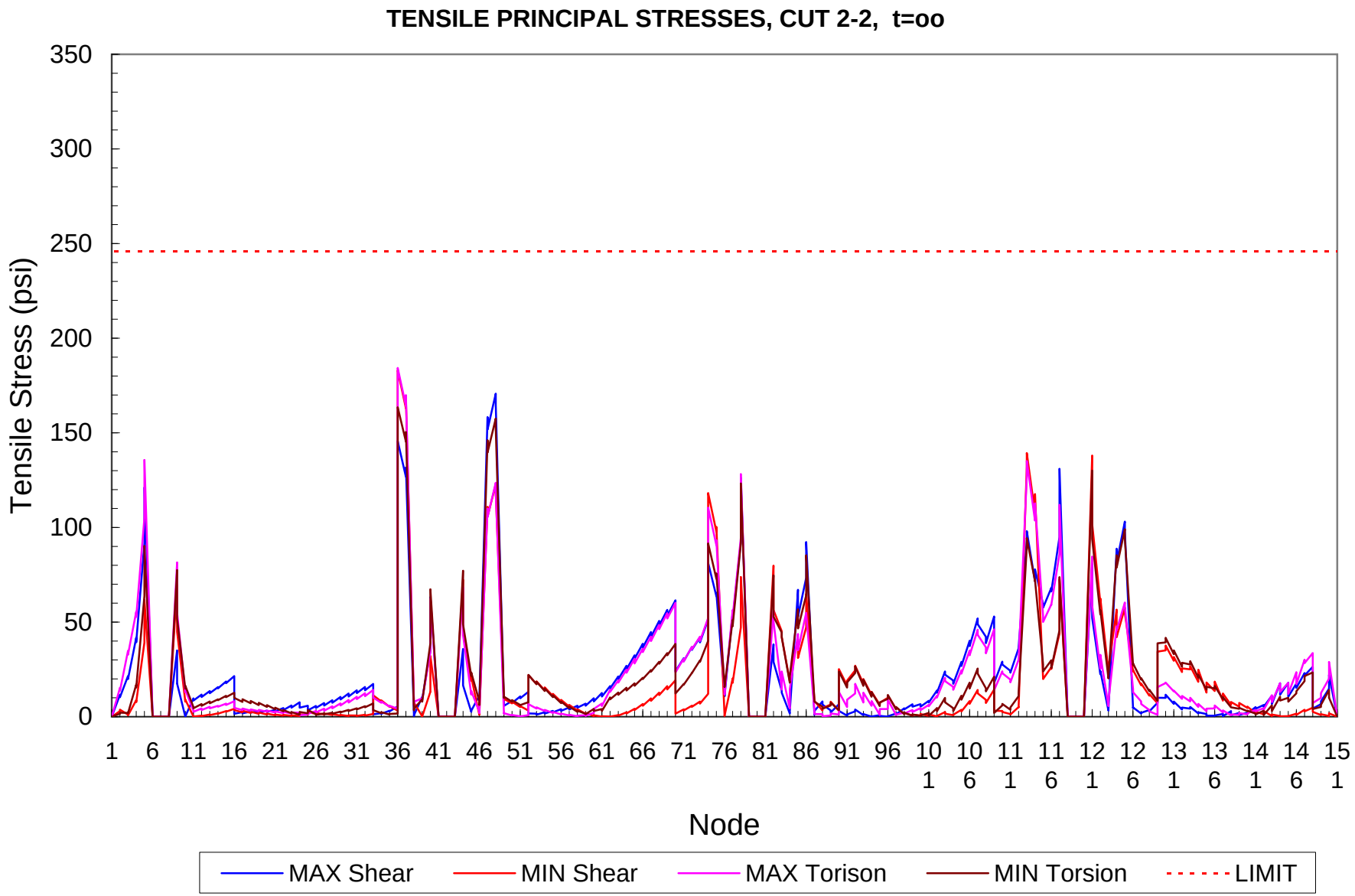
Mainline Segment 2 WB Top Service Stresses



Mainline Segment 2 WB Bottom Service Stresses

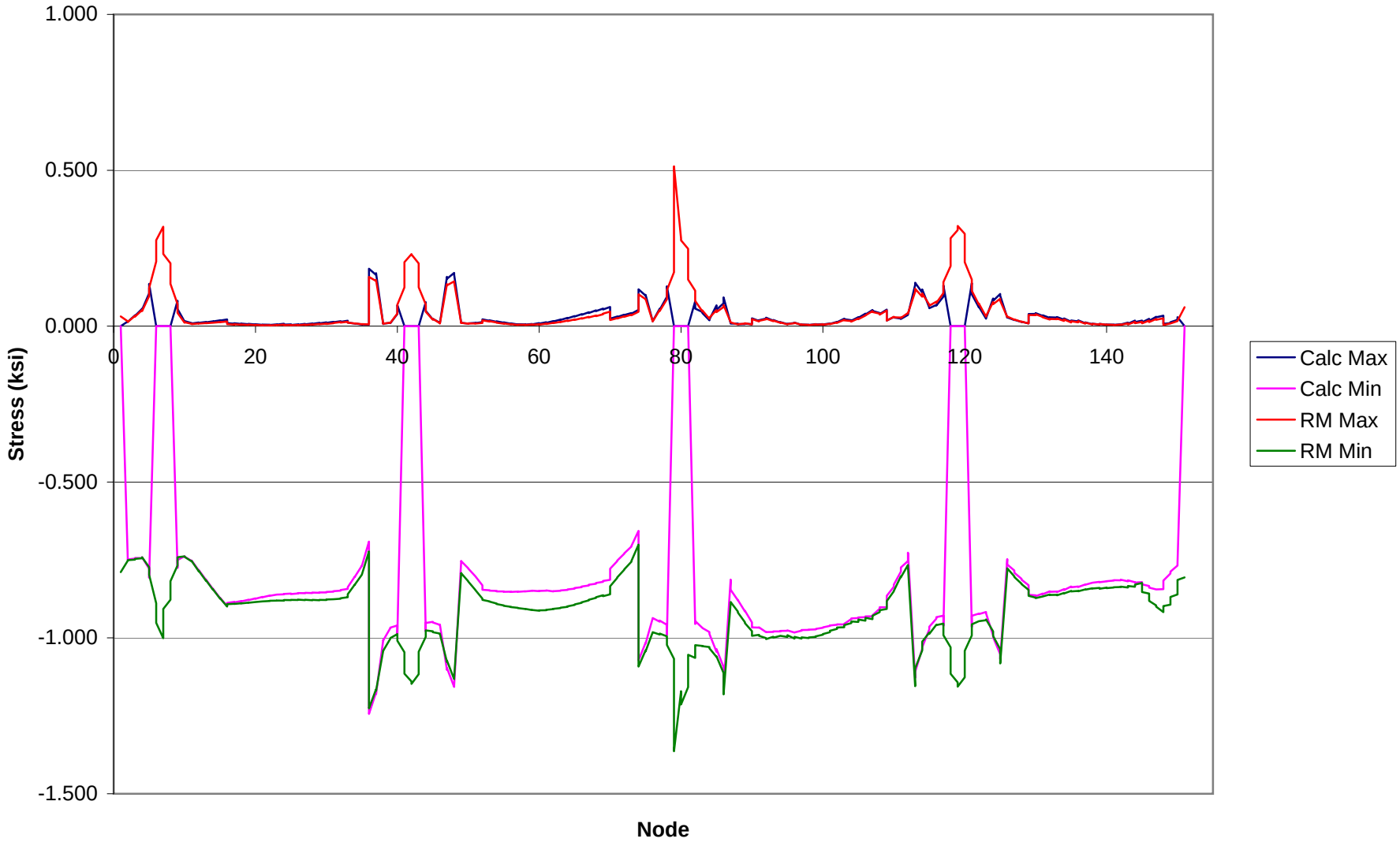


3.6.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.6.5/1

Mainline Segment 2 WB Principal Stresses



3.7 Mainline Segment 3 EB Rating

3.7.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 3 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 3 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.07	1.39	1.01	1.03	0.93	1.22	1.21	1.10	1.09	0.98	1.06	0.93
		Shear	0.69	0.90	0.65	0.66	0.58	0.65	0.65	0.52	0.52	0.44	0.43	0.40
	Service	Flexure	0.57	1.69	1.52	1.55	1.40	1.53	1.52	1.40	1.39	1.27	1.36	1.21
		Principal Stress	1.30	1.32	1.09	1.34	1.53	1.31	1.28	1.03	1.06	0.94	1.00	0.80
Transverse	Strength	Top Slab Centerline	1.65	2.13	2.30	2.43	2.48	2.07	2.00	1.95	1.95	1.71	1.97	1.77
		Top Slab Thickness Change	1.71	2.22	2.47	2.51	2.42	2.15	2.18	1.89	1.98	1.62	1.93	1.63
		Top Slab Webs & Cantilever	1.85	2.40	2.35	2.33	1.97	1.90	2.02	1.70	1.70	1.38	1.58	1.33
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 3 EB** CALCS BY: TSP DATE: 10/21/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

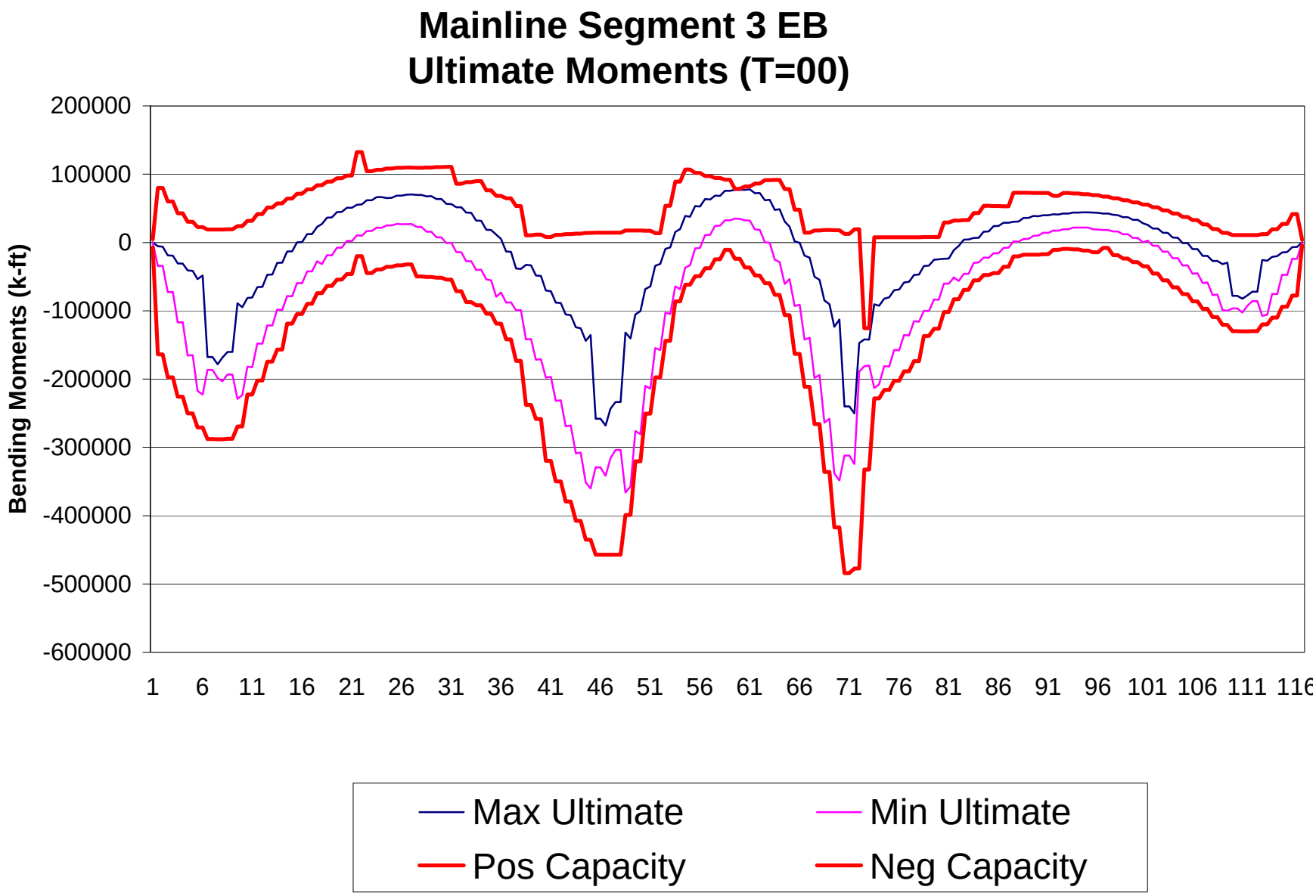
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 3 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.09	1.42										
		Shear	0.85	1.10										
	Service	Flexure	0.57	1.69										
		Principal Stress	1.65	1.68										
Transverse	Strength	Top Slab Centerline	1.65	2.13										
		Top Slab Thickness Change	1.71	2.22										
		Top Slab Webs & Cantilever	2.43	3.15										
		Transverse Web Bending	2.59	3.47										

Overall Rating Factor	0.57	1.10	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		39.60	0.00	0.00

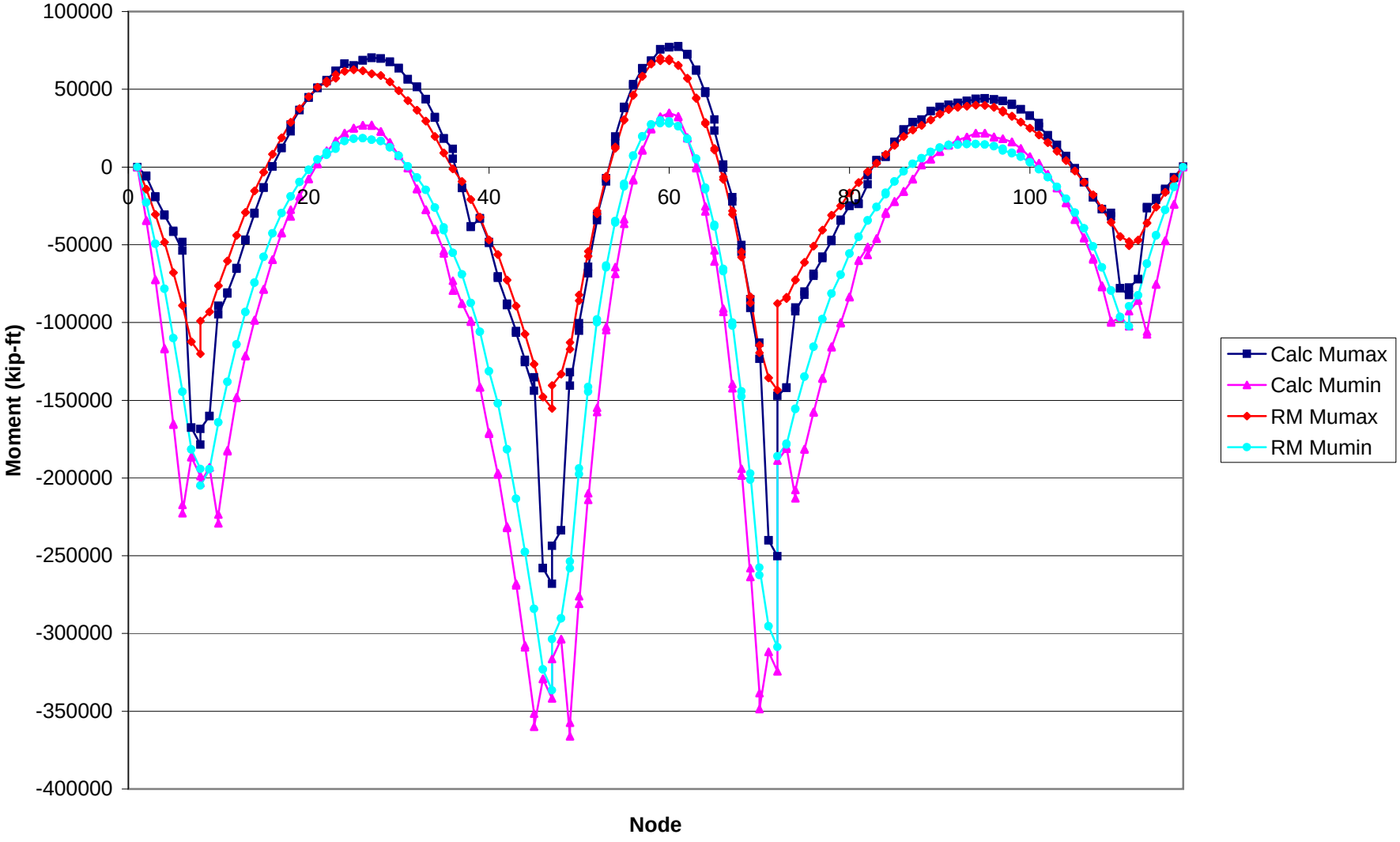
* Max number of lanes loaded = Per AASHTO LRFD

3.7.2 Strength I Flexure

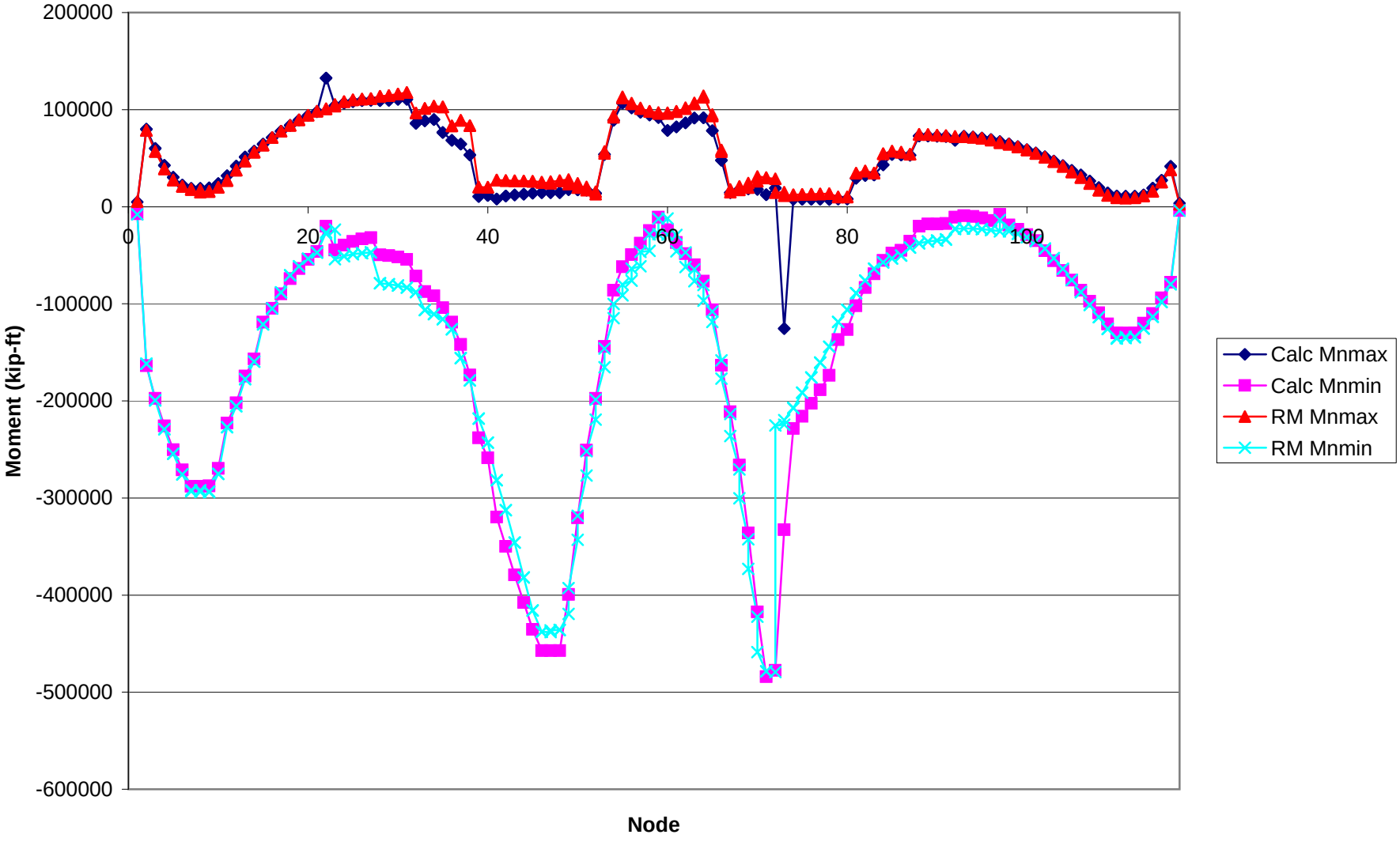

Mainline Segment 3 EB
Ultimate Moments (T=00)
Bending Moments (k-ft)
200000
100000
0
-100000
-200000
-300000
-400000
-500000
-600000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

3.7.2/1

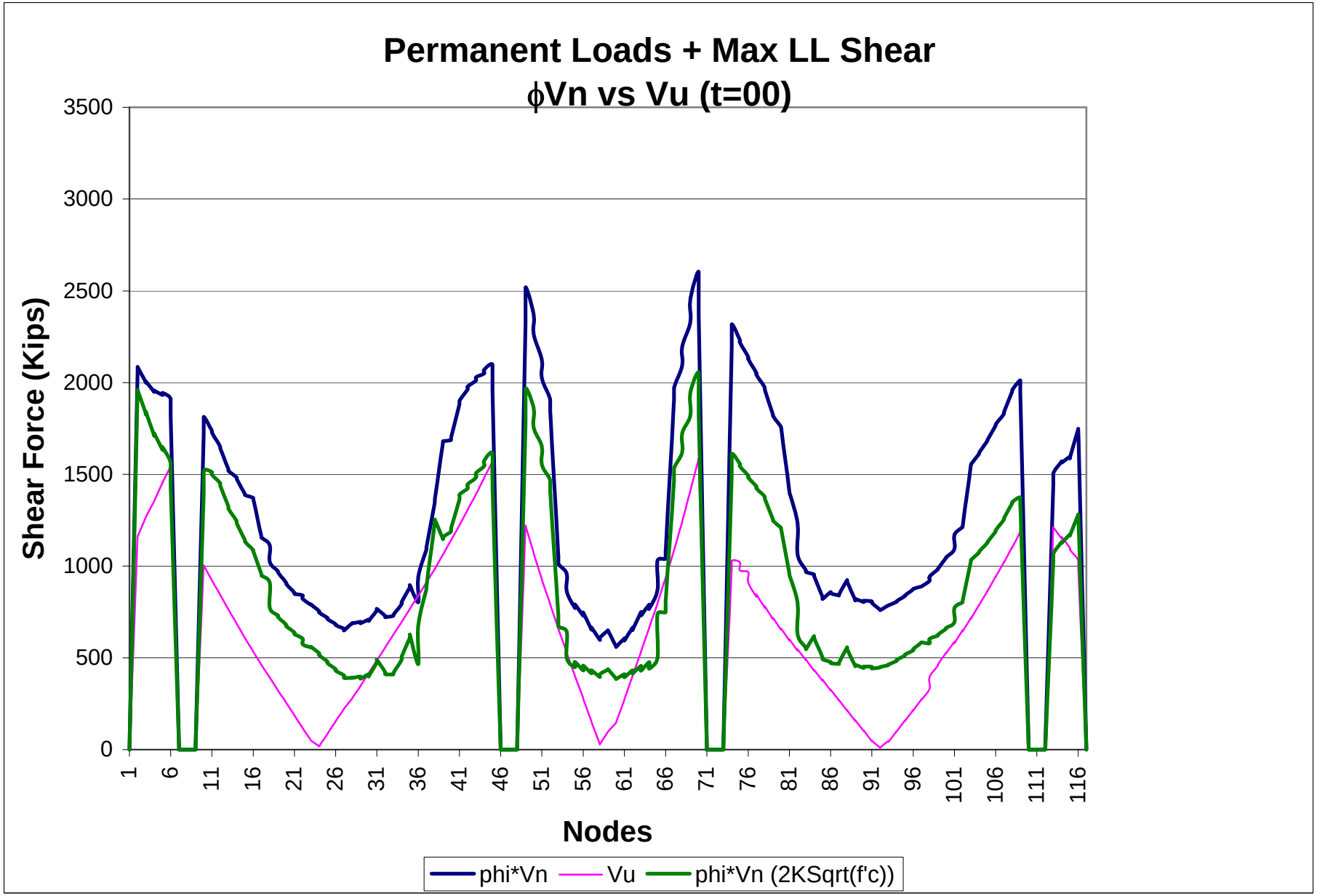
Mainline Segment 3 EB Flexural Demand, M_u

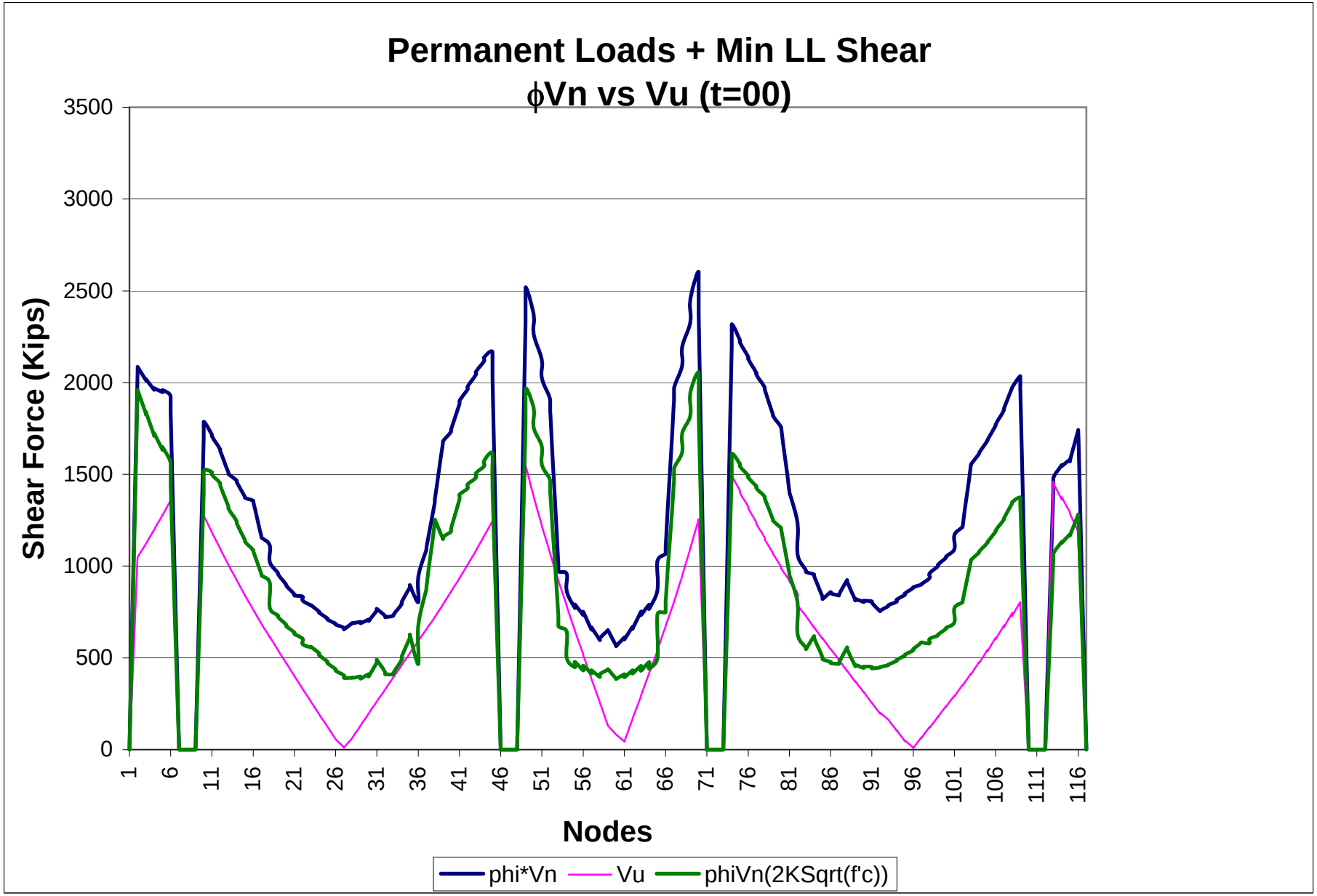


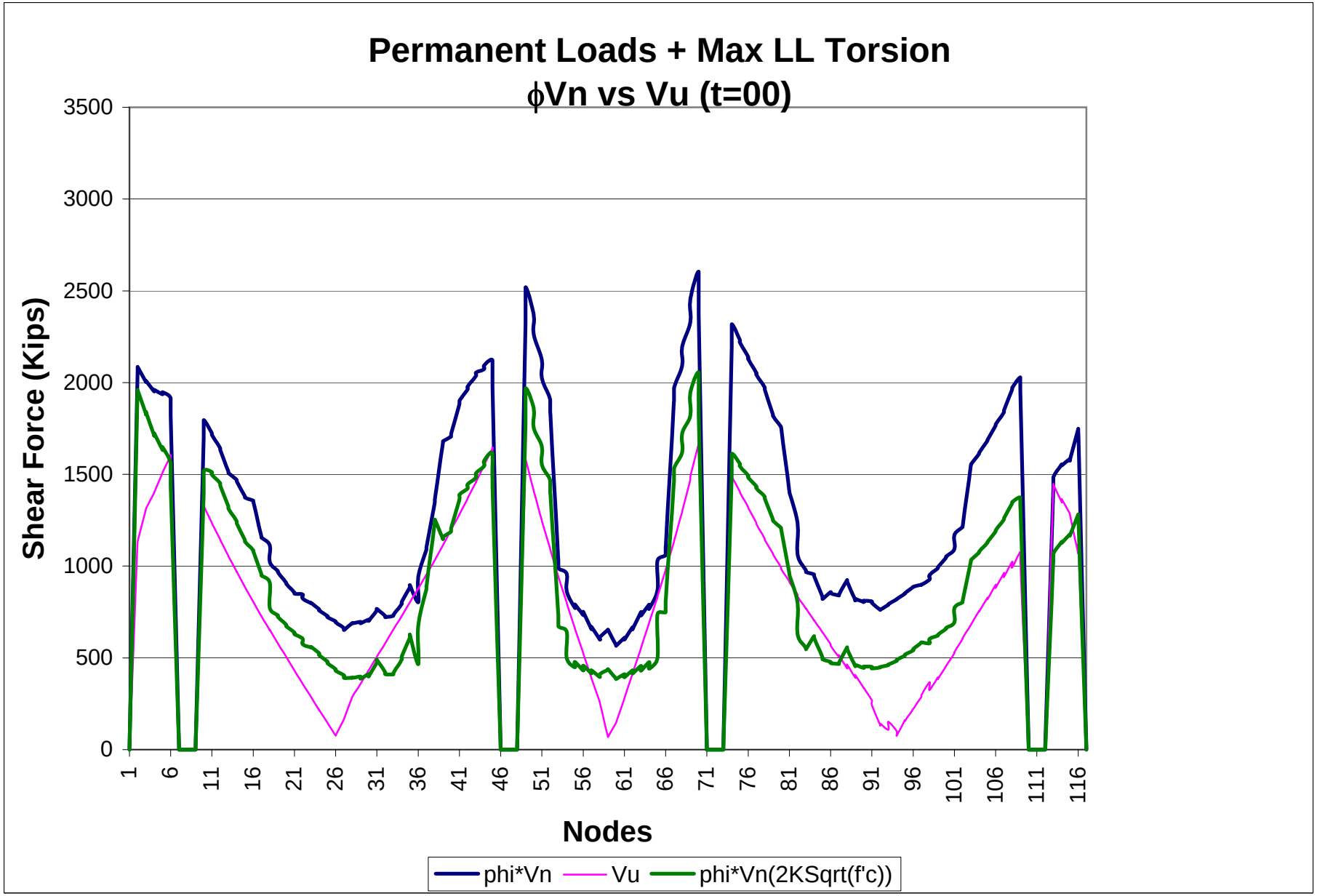
Mainline Segment 3 EB Flexural Strength, ϕM_n

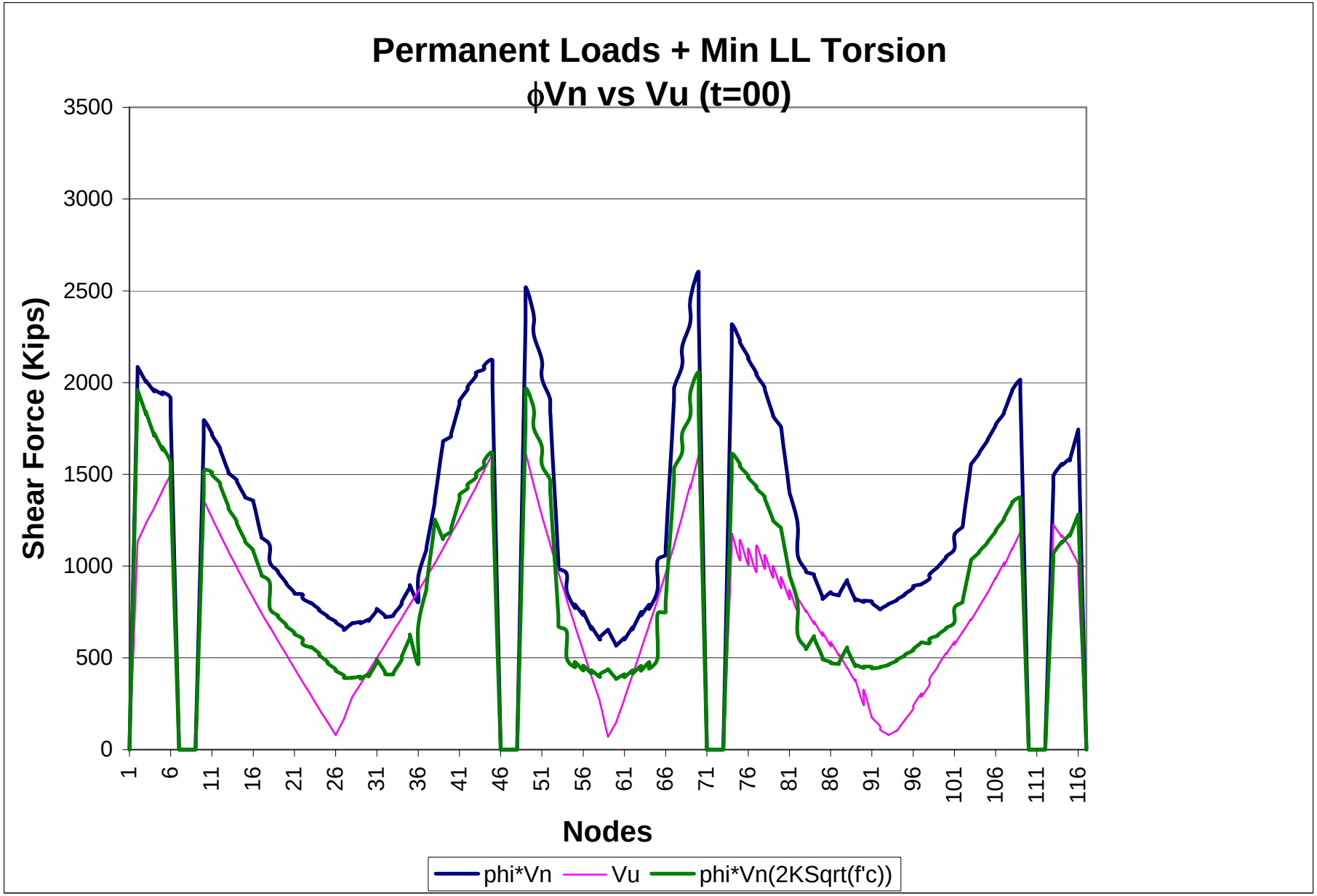


3.7.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3500
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3500
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phiVn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3500
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3500
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

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Node := 36 Position := Back $b_{voverride}$:= 14

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = 1354 \cdot kips$	$M_{dc_x} = -56585 \cdot kip \cdot ft$	$T_{dc_x} = -41\ ft \cdot kips$	$N_{dc_x} = -267 \cdot kips$	Dead Load
$V_{dw_x} = 161 \cdot kips$	$M_{dw_x} = -690 \cdot kip \cdot ft$	$T_{dw_x} = 347 \cdot kip \cdot ft$	$N_{dw_x} = -39 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -77 \cdot kips$	$M_{psec_x} = 26958 \cdot kip \cdot ft$	$T_{psec_x} = 4 \cdot kip \cdot ft$	$N_{psec_x} = 295 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = 26\ kip$	$M_{crsh_x} = 10432 \cdot kip \cdot ft$	$T_{crsh_x} = 5 \cdot kip \cdot ft$	$N_{crsh_x} = 274 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 371 \cdot kips$	$M_{LLvmax_x} = 1687 \cdot kip \cdot ft$	$T_{LLvmax_x} = -998 \cdot kip \cdot ft$	$N_{LLvmax_x} = -116 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -52 \cdot kips$	$M_{LLvmin_x} = 6518 \cdot kip \cdot ft$	$T_{LLvmin_x} = -148 \cdot kip \cdot ft$	$N_{LLvmin_x} = -39 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = 261 \cdot kips$	$M_{LLtmax_x} = 4113 \cdot kip \cdot ft$	$T_{LLtmax_x} = 3745 \cdot kip \cdot ft$	$N_{LLtmax_x} = -100 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = 261 \cdot kips$	$M_{LLtmin_x} = 4088 \cdot kip \cdot ft$	$T_{LLtmin_x} = -3742 \cdot kip \cdot ft$	$N_{LLtmin_x} = -100 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = -61 \cdot kips$ Primary PT Shear

$N_{prim_x} = -18980 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 7946 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1944 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -88 \cdot kips$

$M_{tu_x} = 3849 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 3 \cdot kip \cdot ft$

$N_{tu_x} = -290 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 15174 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 47477 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.207 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 124.188 \cdot in$ Height of Box

$y_{bot_x} = 80.713 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.262 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.13 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.155 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.13 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 127.813 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 117 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 121.938 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = 2371 \cdot kips$	$T_{uvmax_x} = -872 \cdot kip \cdot ft$	$M_{uvmax_x} = -37315\, ft \cdot kips$	$N_{uvmax_x} = -117 \cdot kips$
$V_{uvmin_x} = 1800 \cdot kips$	$T_{uvmin_x} = 276 \cdot kip \cdot ft$	$M_{uvmin_x} = -30793\, ft \cdot kips$	$N_{uvmin_x} = -13 \cdot kips$
$V_{utmax_x} = 2222 \cdot kips$	$T_{utmax_x} = 5532 \cdot kip \cdot ft$	$M_{utmax_x} = -34040\, ft \cdot kips$	$N_{utmax_x} = -95 \cdot kips$
$V_{utmin_x} = 2222 \cdot kips$	$T_{utmin_x} = -4576 \cdot kip \cdot ft$	$M_{utmin_x} = -34073\, ft \cdot kips$	$N_{utmin_x} = -95 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -1.103\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 12301 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 86.717 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 89.415 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0004$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $V_{cvmax_x} = 517.72 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 623.333\,kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 166.95 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 0.581$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.0004$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 517.72 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinShear_x = \text{"No"}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 623.333\,kip$

$V_{LLwebvmin_y} := \dfrac{1.35\,V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -23.4 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{vneg_{x,1}} = 0.581$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

ε

$\varepsilon_{stmax_x} = -0.0004$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 517.72 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmax_y}\left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 630.368\,kip$

$V_{LLwebtmax_y} := \dfrac{1.35\,V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmax_y}\left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 192.205 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{tpos_{x,1}} = 0.581$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

ε

$\varepsilon_{stmin_x} = -0.0004$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 517.72 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 630.368\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = 192.145 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 0.581}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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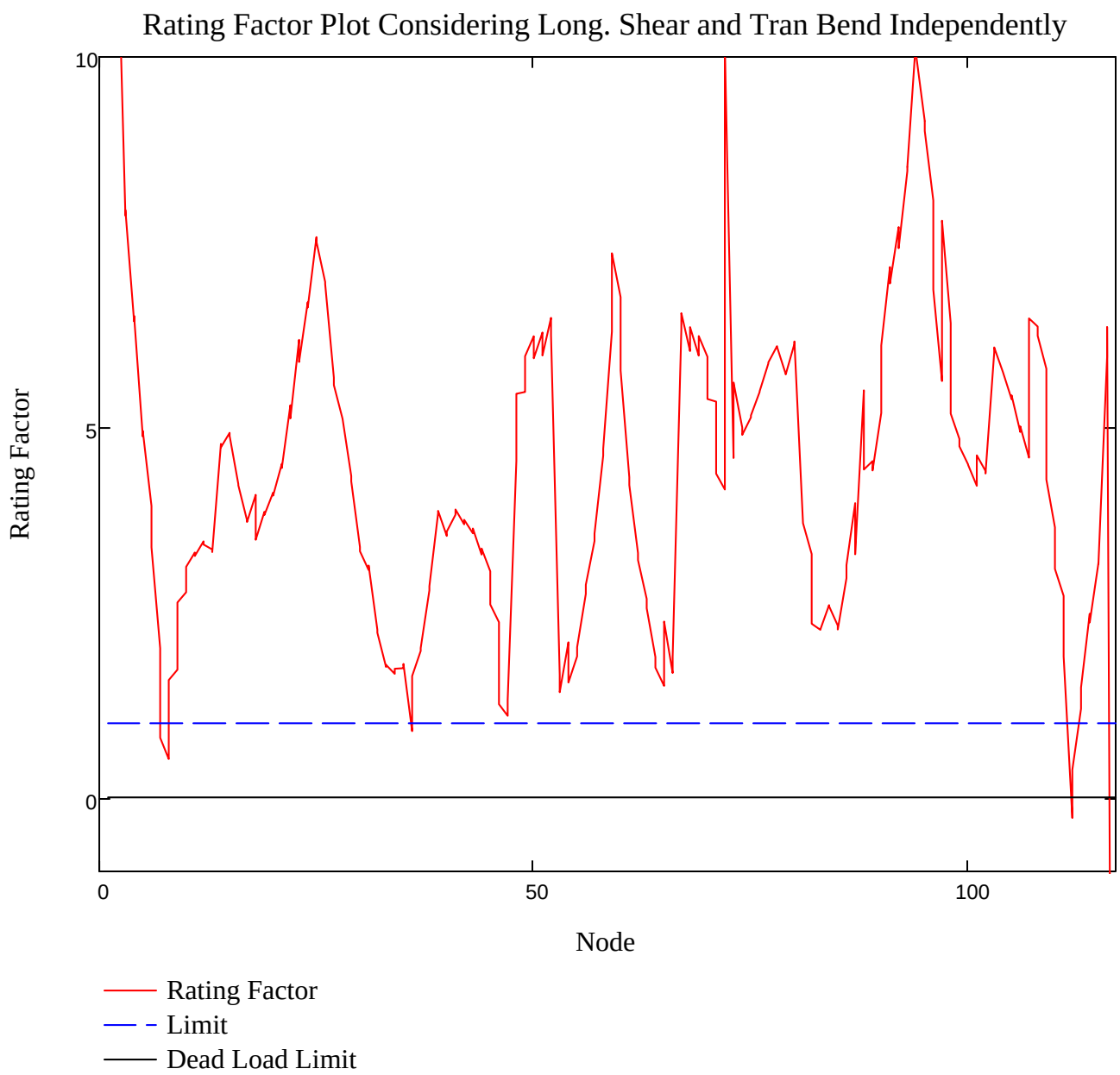

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.895$ at node $minRF_2 = 36$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.581$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 172.771 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 86.534 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.308 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.153 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.483 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 12.4 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 9.75 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 12.4 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 176.737 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 643.312 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.243 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 9.75 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 353.474 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 802.375 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.486 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 9.75 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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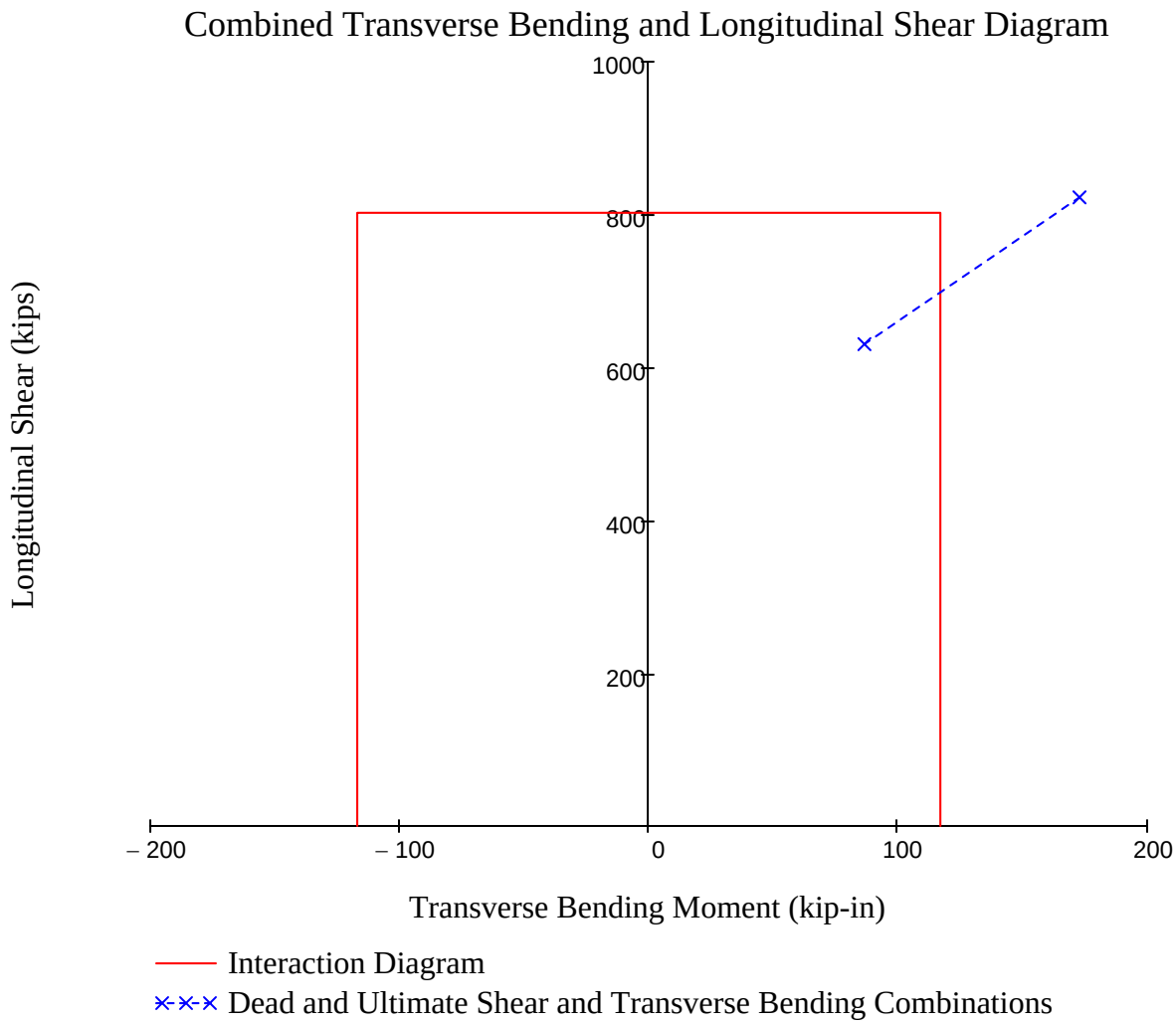


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 0.353$

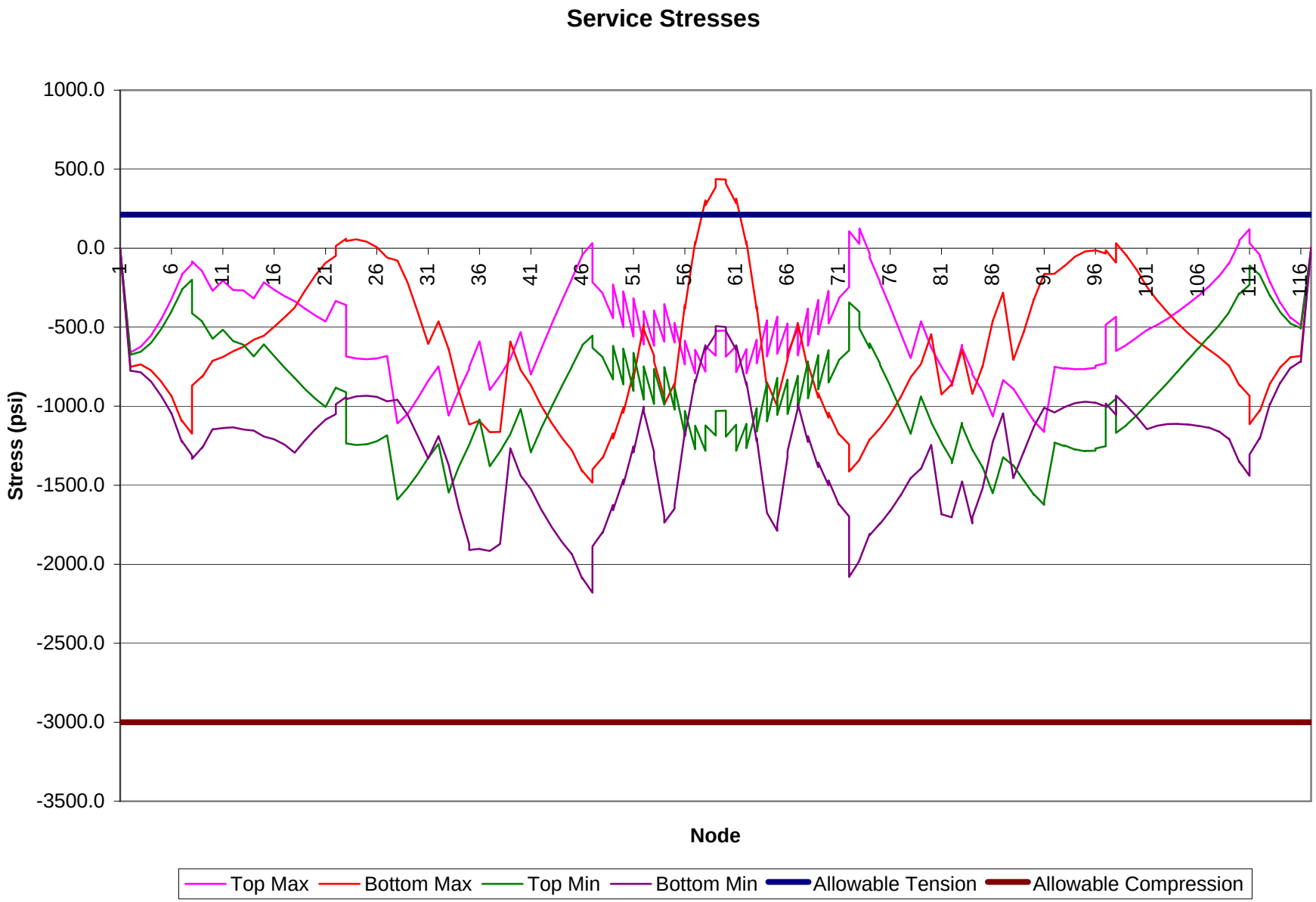
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

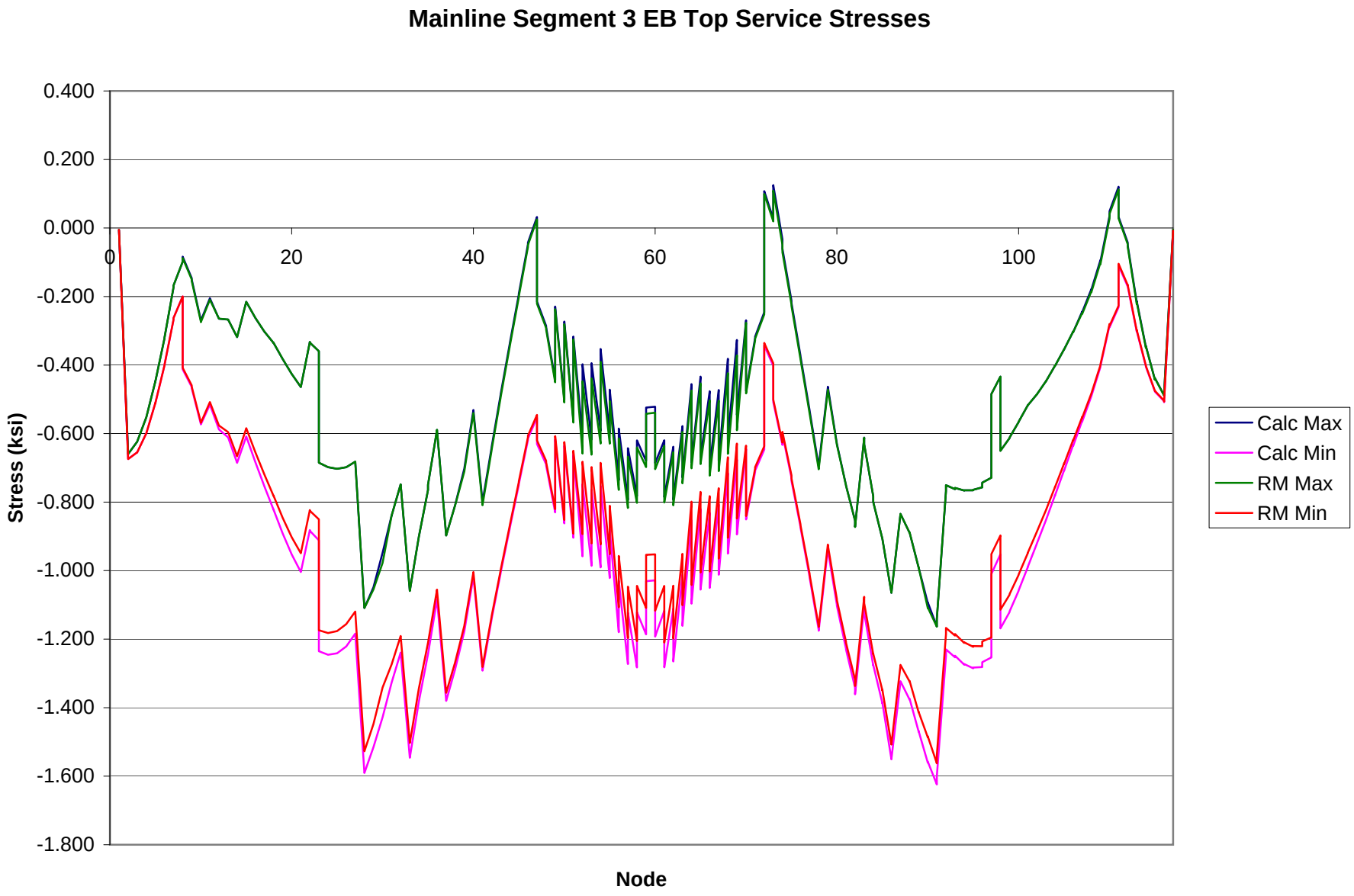
$RF_{shear} = 1.072$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

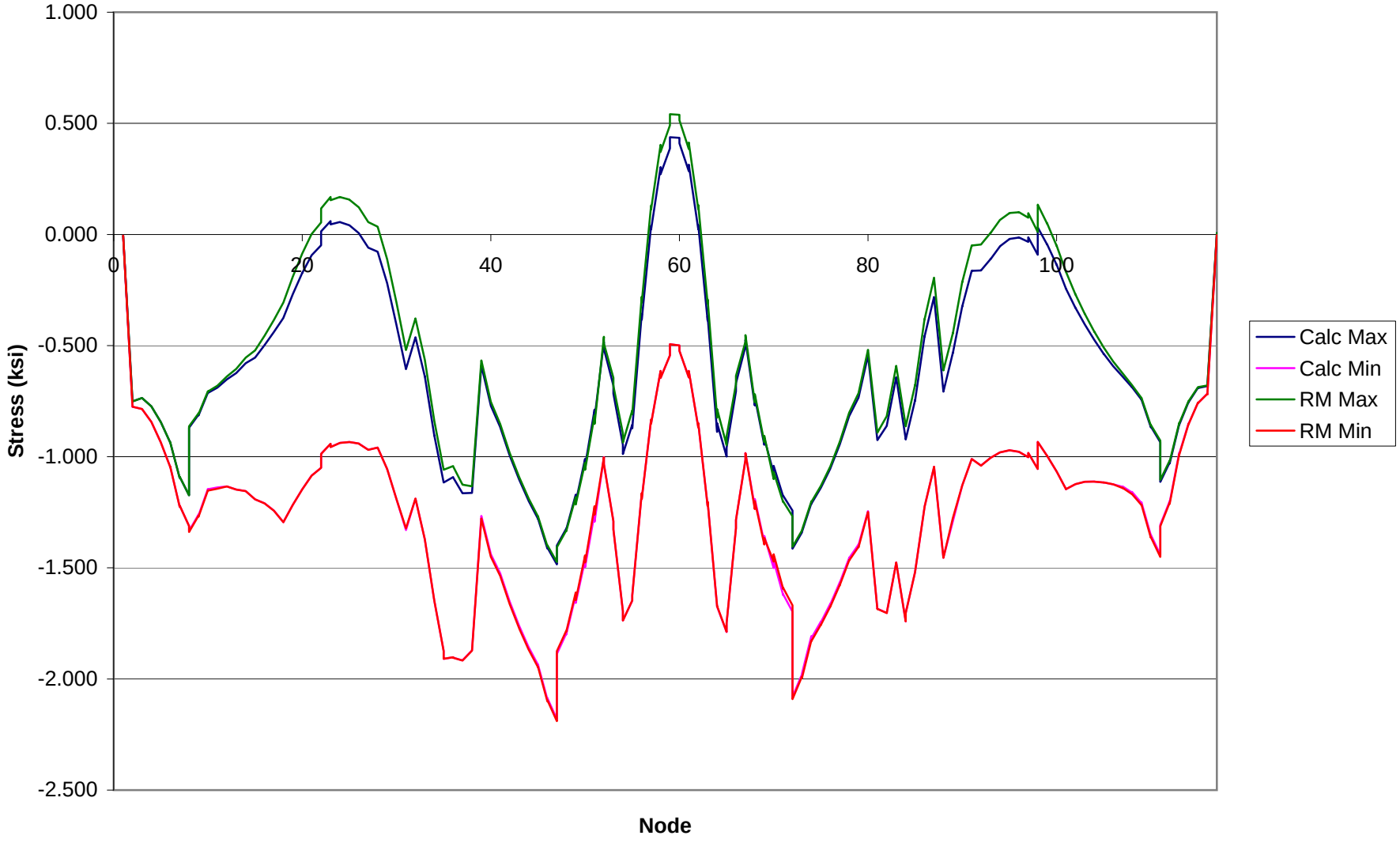
$RF_{torsion} = 0.895$

3.7.4 Service I Flexure (Service Stresses)

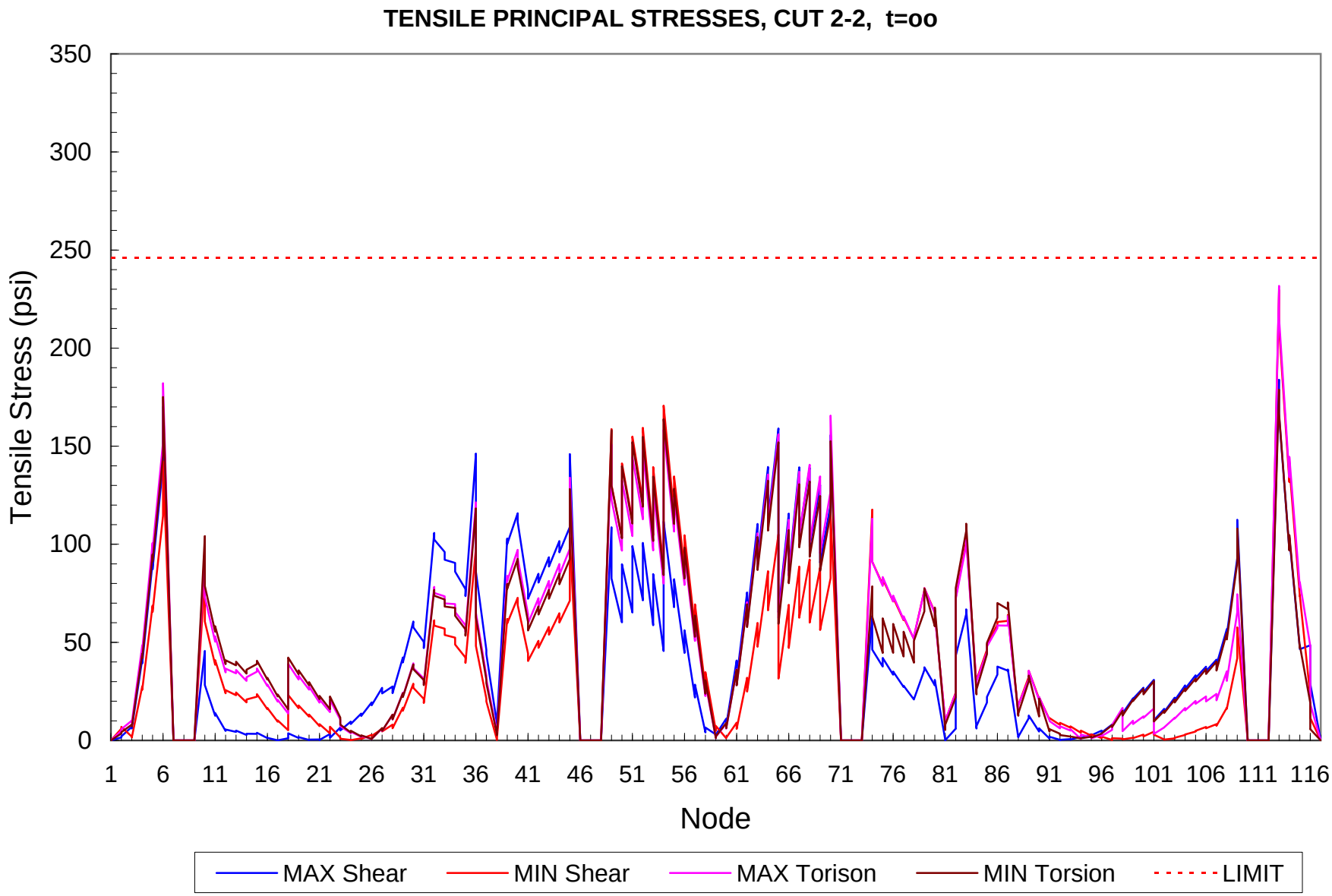

Service Stresses
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression


Mainline Segment 3 EB Top Service Stresses
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-1.400
-1.600
-1.800
0
20
40
60
80
100
Stress (ksi)
Node
Calc Max
Calc Min
RM Max
RM Min

Mainline Segment 3 EB Bottom Service Stresses

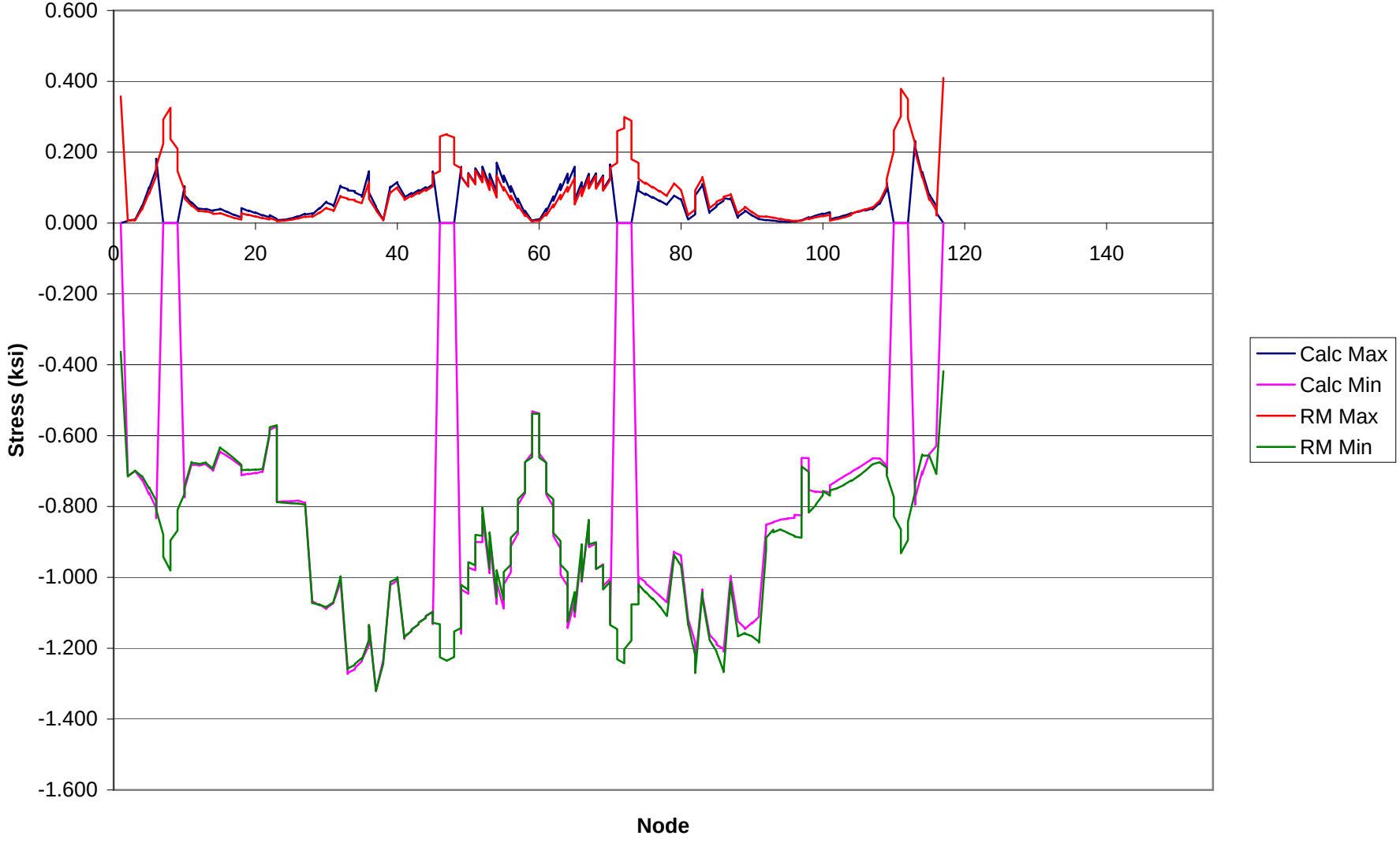


3.7.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.7.5/1

Mainline Segment 3 EB Principal Stresses



3.8 Mainline Segment 3 WB Rating

3.8.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 3 WB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 3 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	0.82	1.06	0.86	0.86	0.75	0.94	0.94	1.04	1.03	0.96	1.01	0.88
		Shear	0.52	0.68	0.48	0.49	0.41	0.49	0.49	0.39	0.40	0.36	0.39	0.32
	Service	Flexure	0.53	2.09	1.87	1.92	1.74	1.88	1.86	1.72	1.71	1.55	1.66	1.48
		Principal Stress	0.86	1.10	0.97	0.98	0.86	0.85	0.85	0.71	0.71	0.62	0.68	0.58
Transverse	Strength	Top Slab Centerline	0.86	1.11	1.29	1.35	1.46	1.16	1.13	1.09	1.10	0.98	1.15	1.03
		Top Slab Thickness Change	1.35	1.75	1.78	1.80	1.61	1.54	1.53	1.34	1.36	1.14	1.32	1.14
		Top Slab Webs & Cantilever	1.85	2.40	2.26	2.33	1.97	1.90	1.92	1.67	1.67	1.38	1.58	1.33
		Transverse Web Bendign	0.49	0.64	0.52	0.61	0.56	0.57	0.52	0.47	0.47	0.38	0.46	0.38

Overall Rating Factor	0.24	0.32	0.19	0.15
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		11.52	11.97	36.00

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 3 WB** CALCS BY: TSP DATE: 10/20/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

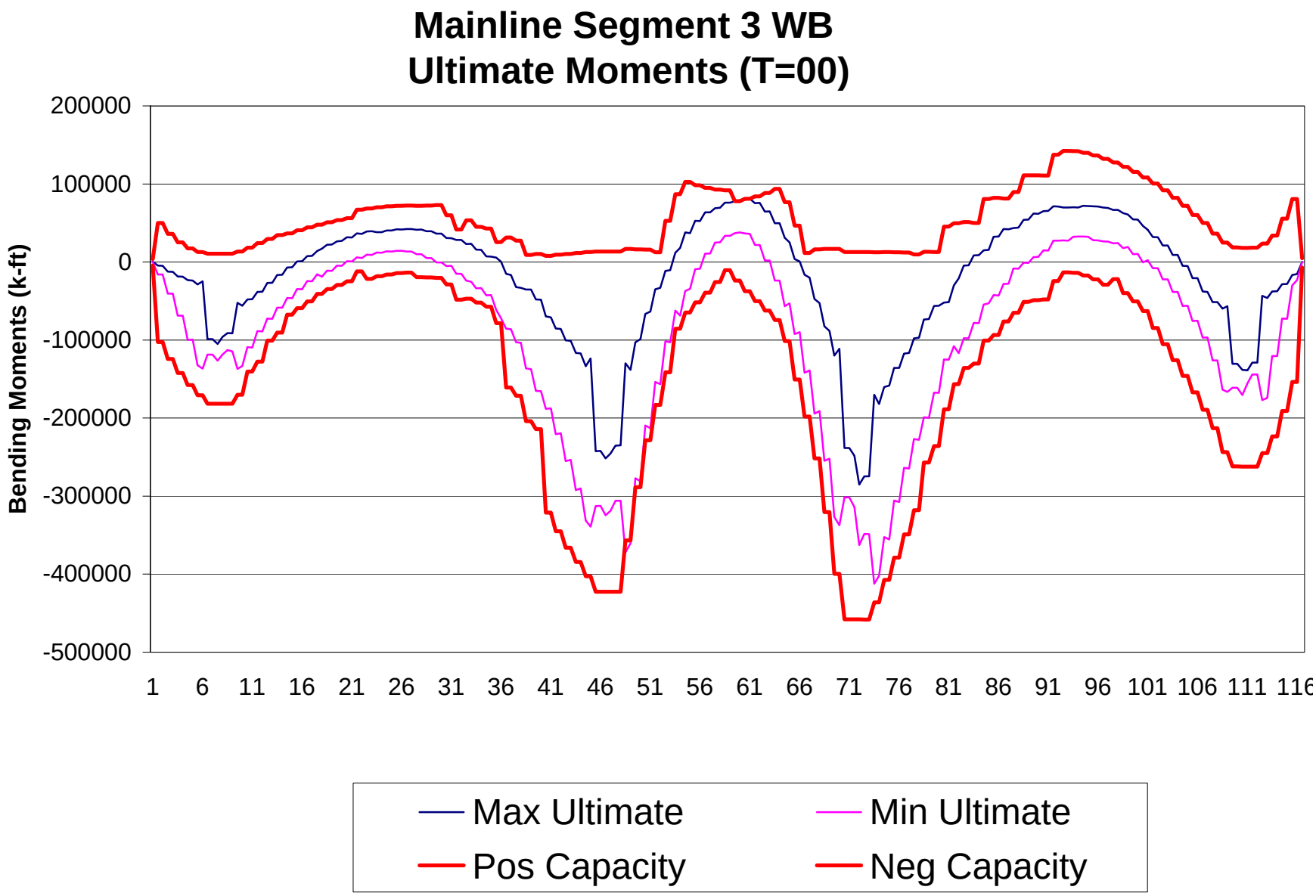
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 3 WB			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.09	1.42										
		Shear	0.72	0.90										
	Service	Flexure	0.66	2.13										
		Principal Stress	1.01	1.23										
Transverse	Strength	Top Slab Centerline	0.86	1.11										
		Top Slab Thickness Change	1.35	1.75										
		Top Slab Webs & Cantilever	1.89	2.45										
		Transverse Web Bending	0.54	0.70										

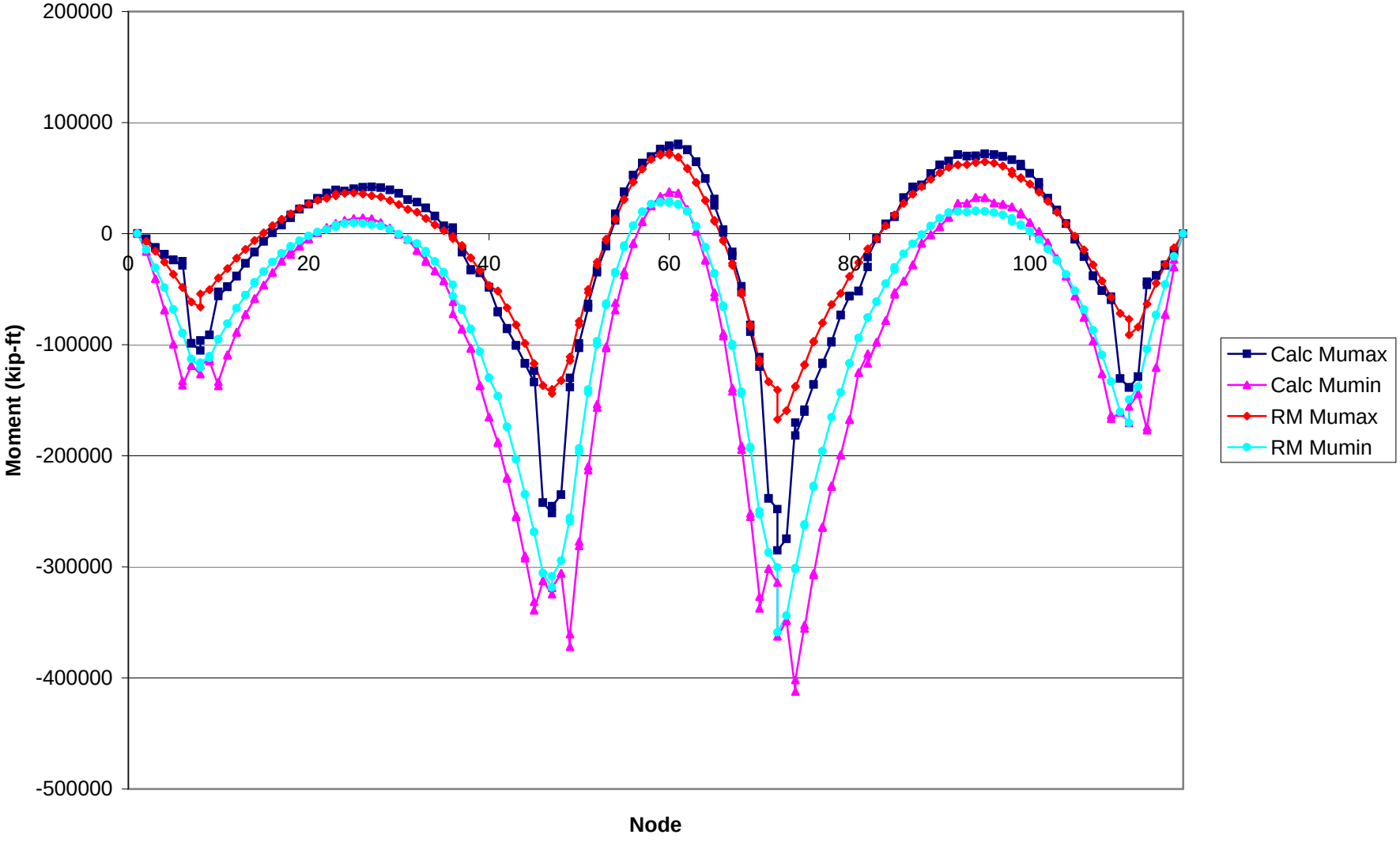
Overall Rating Factor	0.54	0.70	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		25.20	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

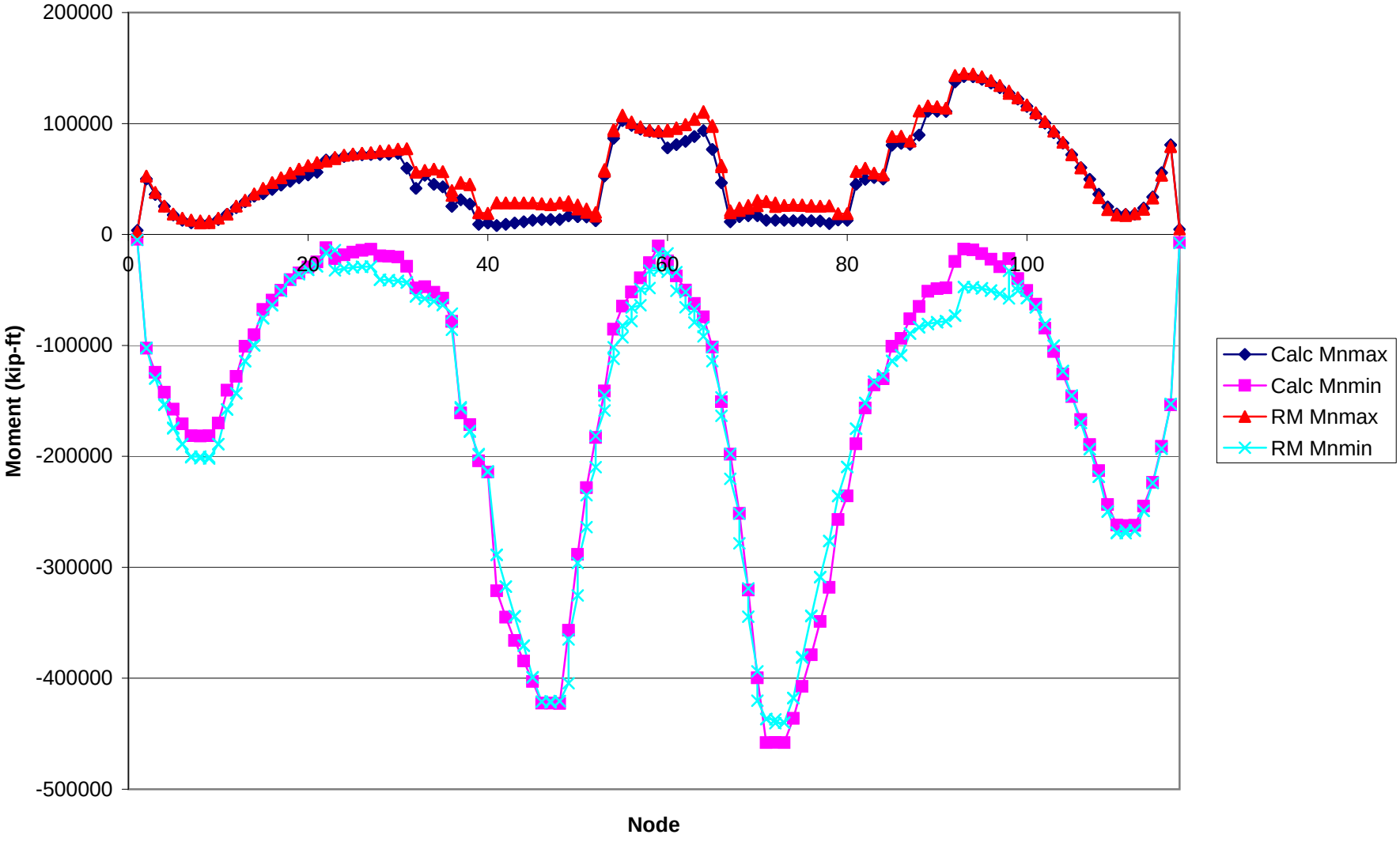
3.8.2 Strength I Flexure


Mainline Segment 3 WB
Ultimate Moments (T=00)
Bending Moments (k-ft)
200000
100000
0
-100000
-200000
-300000
-400000
-500000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

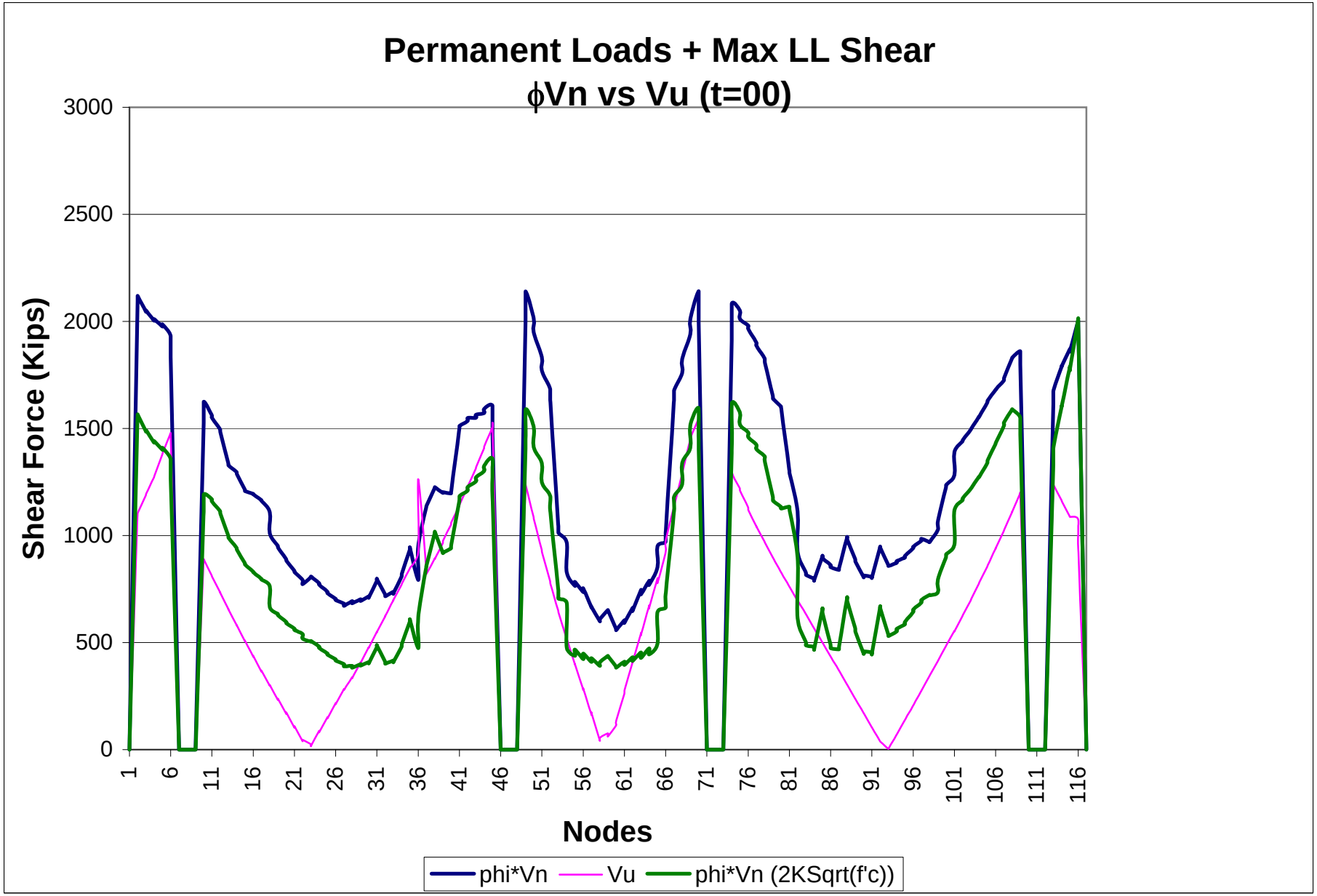
Mainline Segment 3 WB Flexural Demand, M_u

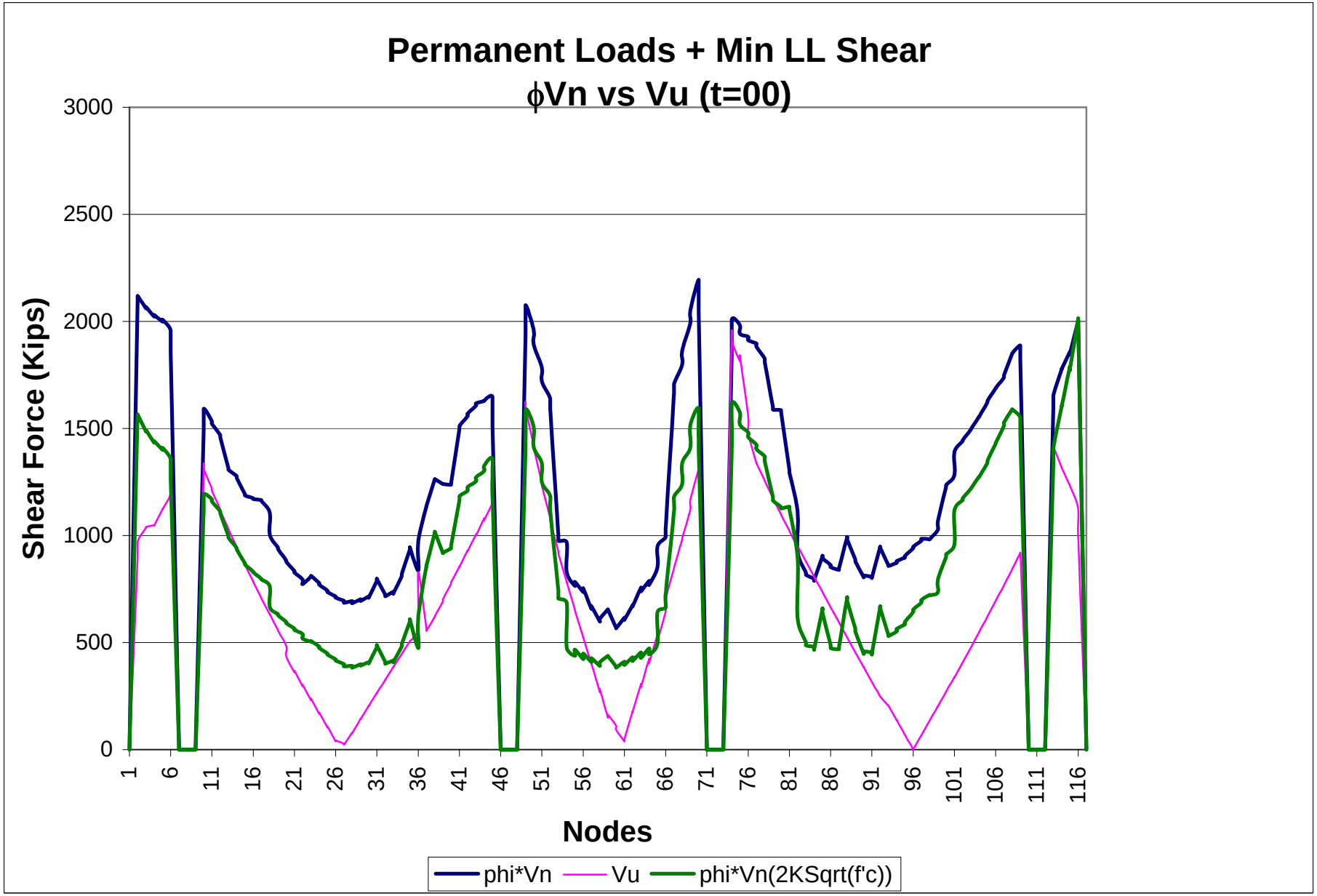


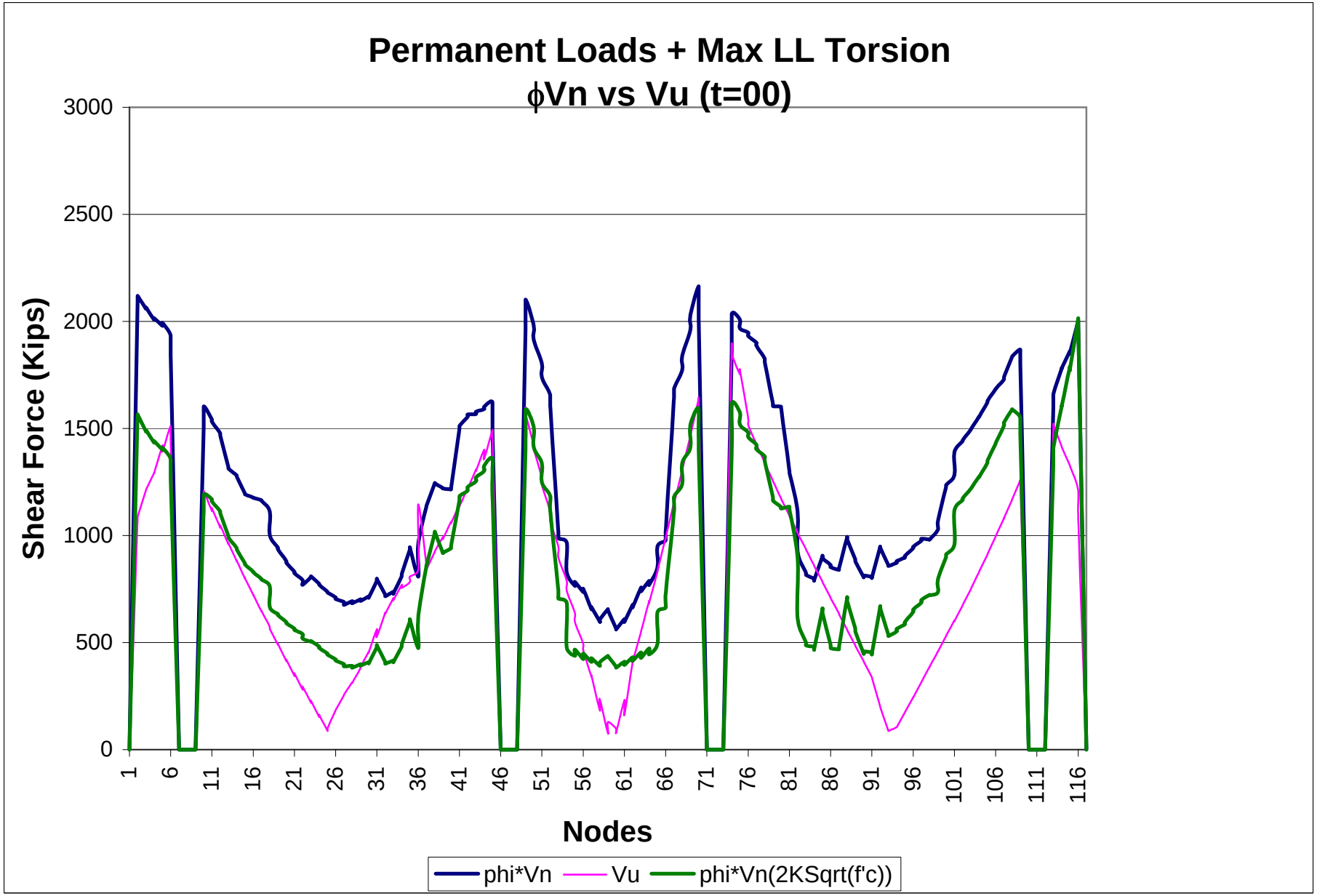
Mainline Segment 3 WB Flexural Strength, ϕM_n

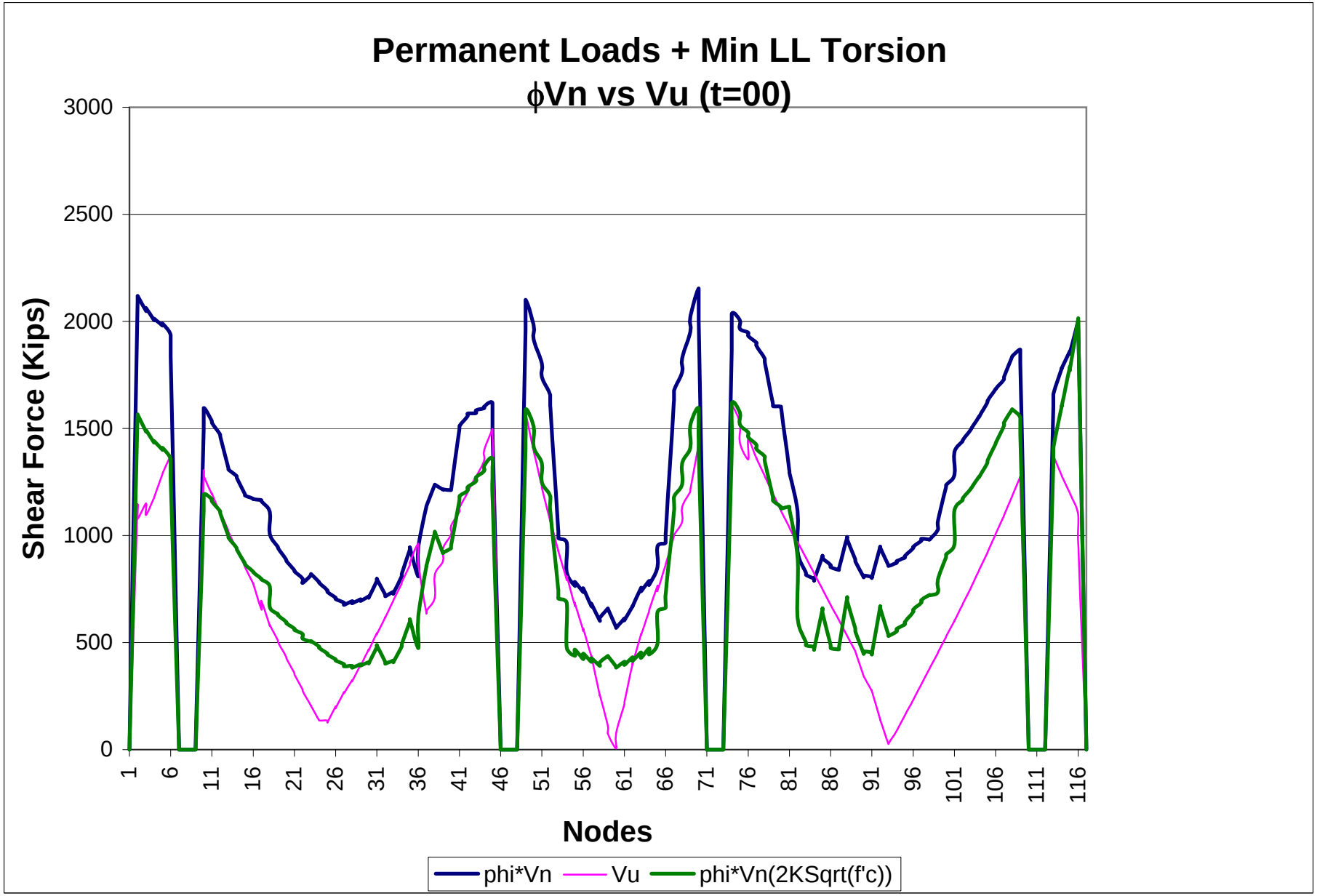


3.8.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
3000
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: RJB
Check: Ind Chk

Page
Date: 10 / 01 / 2009
Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 3 WB\

Node := 36 Position := Ahead $b_{voverride}$:= 14

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = 1370 \cdot kips$	$M_{dc_x} = -57826 \cdot kip \cdot ft$	$T_{dc_x} = -600\, ft \cdot kips$	$N_{dc_x} = -15 \cdot kips$	Dead Load
$V_{dw_x} = 108 \cdot kips$	$M_{dw_x} = -1981 \cdot kip \cdot ft$	$T_{dw_x} = -637 \cdot kip \cdot ft$	$N_{dw_x} = -56 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -234 \cdot kips$	$M_{psec_x} = 29077 \cdot kip \cdot ft$	$T_{psec_x} = 1228 \cdot kip \cdot ft$	$N_{psec_x} = -1113 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -22\, kip$	$M_{crsh_x} = 10644 \cdot kip \cdot ft$	$T_{crsh_x} = 3139 \cdot kip \cdot ft$	$N_{crsh_x} = -273 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 391 \cdot kips$	$M_{LLvmax_x} = 2837 \cdot kip \cdot ft$	$T_{LLvmax_x} = 1290 \cdot kip \cdot ft$	$N_{LLvmax_x} = 54 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -76 \cdot kips$	$M_{LLvmin_x} = 3686 \cdot kip \cdot ft$	$T_{LLvmin_x} = 819 \cdot kip \cdot ft$	$N_{LLvmin_x} = 35 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = 215 \cdot kips$	$M_{LLtmax_x} = 3685 \cdot kip \cdot ft$	$T_{LLtmax_x} = 1953 \cdot kip \cdot ft$	$N_{LLtmax_x} = 51 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = 62 \cdot kips$	$M_{LLtmin_x} = -1015 \cdot kip \cdot ft$	$T_{LLtmin_x} = -1553 \cdot kip \cdot ft$	$N_{LLtmin_x} = -209 \cdot kips$	Min Live Load Torsion

URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Post Tensioning Forces:

$V_{prim_x} = -358 \cdot kips$ Primary PT Shear

$N_{prim_x} = -9234 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 10365 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 542 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -75 \cdot kips$

$M_{tu_x} = 3710 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 138 \cdot kip \cdot ft$

$N_{tu_x} = -218 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 9745 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 22218 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.232 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 124.188 \cdot in$ Height of Box

$y_{bot_x} = 84.787 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.197 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.093 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.147 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.093 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 70.091 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 117 \cdot in$ Depth for Torsion

$A_{s_x} = 7.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 121.938 \cdot in$ Depth of Mild Steel

URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001 Page _____
Design: RJB Date: 10 / 01 / 2009
Check: Ind Chk Date: / /

Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = 2157 \cdot kips$	$T_{uvmax_x} = 2834 \cdot kip \cdot ft$	$M_{uvmax_x} = -37025\, ft \cdot kips$	$N_{uvmax_x} = -1279 \cdot kips$
$V_{uvmin_x} = 1527 \cdot kips$	$T_{uvmin_x} = 2198 \cdot kip \cdot ft$	$M_{uvmin_x} = -35879\, ft \cdot kips$	$N_{uvmin_x} = -1305 \cdot kips$
$V_{utmax_x} = 1920 \cdot kips$	$T_{utmax_x} = 3729 \cdot kip \cdot ft$	$M_{utmax_x} = -35880\, ft \cdot kips$	$N_{utmax_x} = -1283 \cdot kips$
$V_{utmin_x} = 1713 \cdot kips$	$T_{utmin_x} = -1005 \cdot kip \cdot ft$	$M_{utmin_x} = -42225\, ft \cdot kips$	$N_{utmin_x} = -1634 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -1.006\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 5756 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 99.045 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 89.415 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00032$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.871 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.332$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 478.049 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"Yes"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 849.253\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 318.949 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 0.301$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.00036$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.745 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.566$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 495.763 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinShear_x = \text{"Yes"}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 780.247\ kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -86.234 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.338$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.00034$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.809 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.445$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 486.628 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 849.253\,kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 228.429 \cdot kips$

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$$RF_{tpos} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{tpos_{x,1}} = 0.458$$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$$\varepsilon_{stmin} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmin_x} = -0.00032$$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.883 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.31$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 476.421 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"No"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 814.75\,kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = 41.85 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.338}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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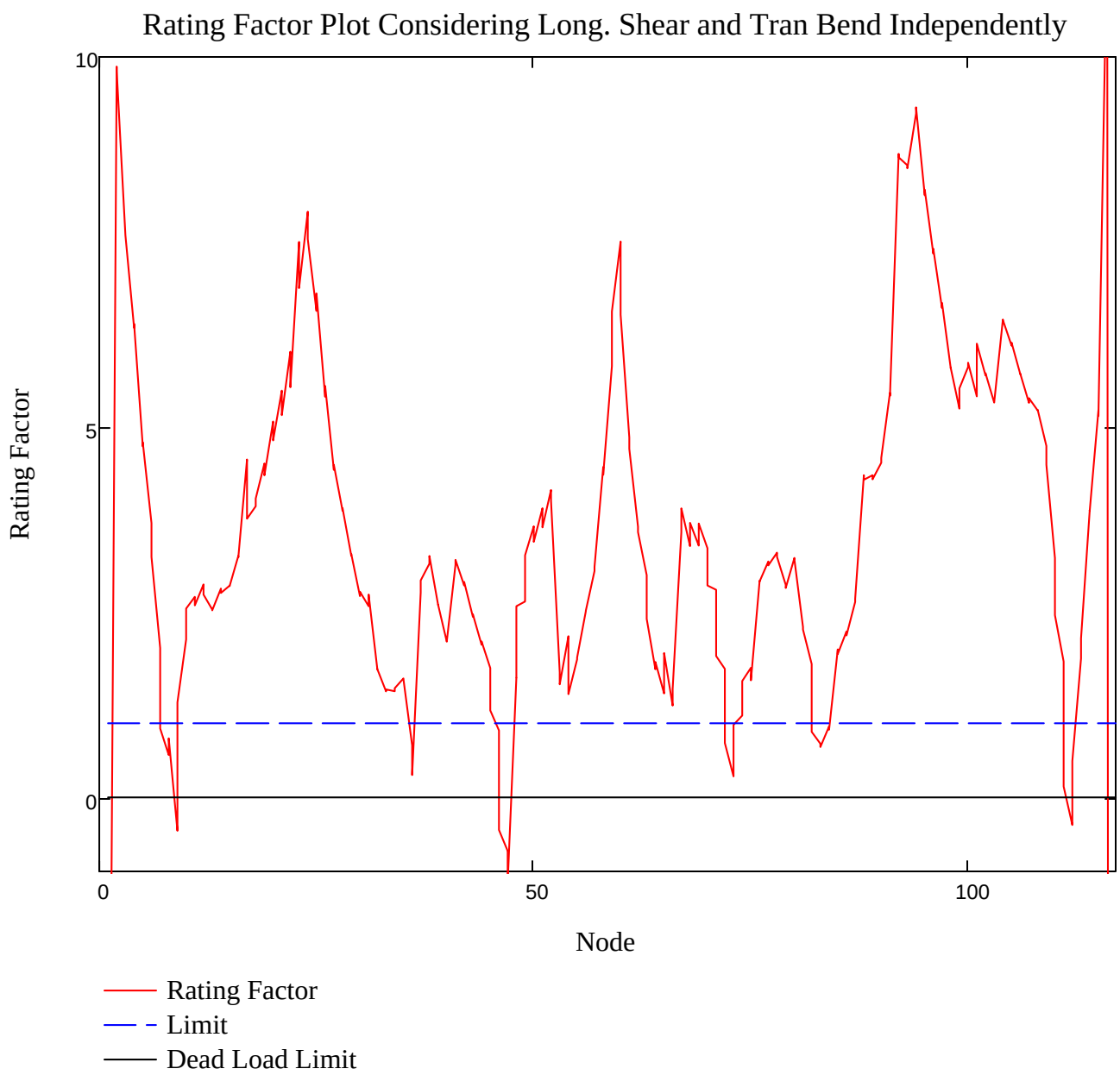

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.301$ at node $minRF_2 = 36$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.418$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 130.544 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 61.806 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.232 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.109 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.521 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 13.95 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 11.008 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 13.95 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 196.558 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 768.247 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.274 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 10.986 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 395.224 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 947.046 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.55 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 11.008 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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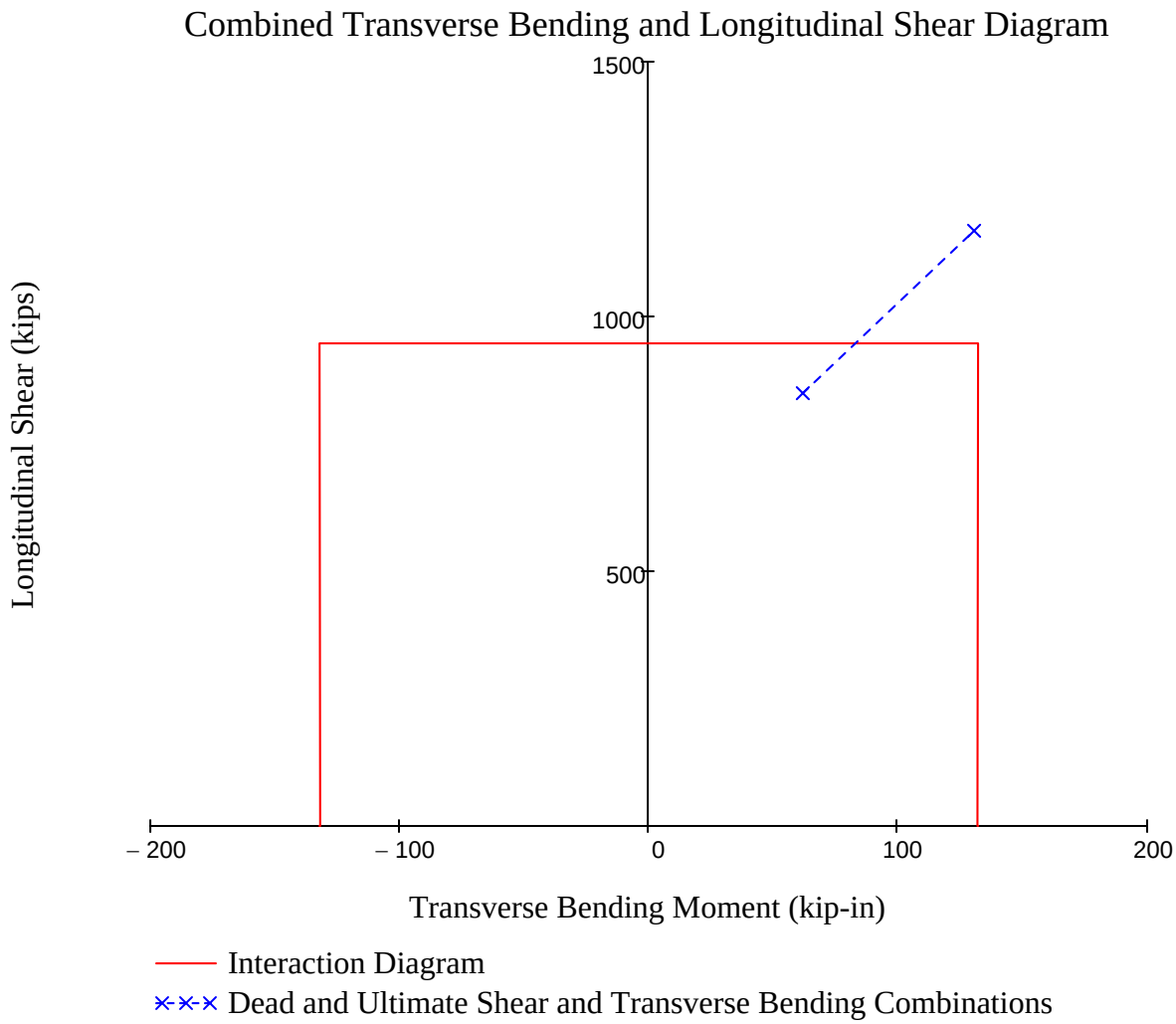


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.023$

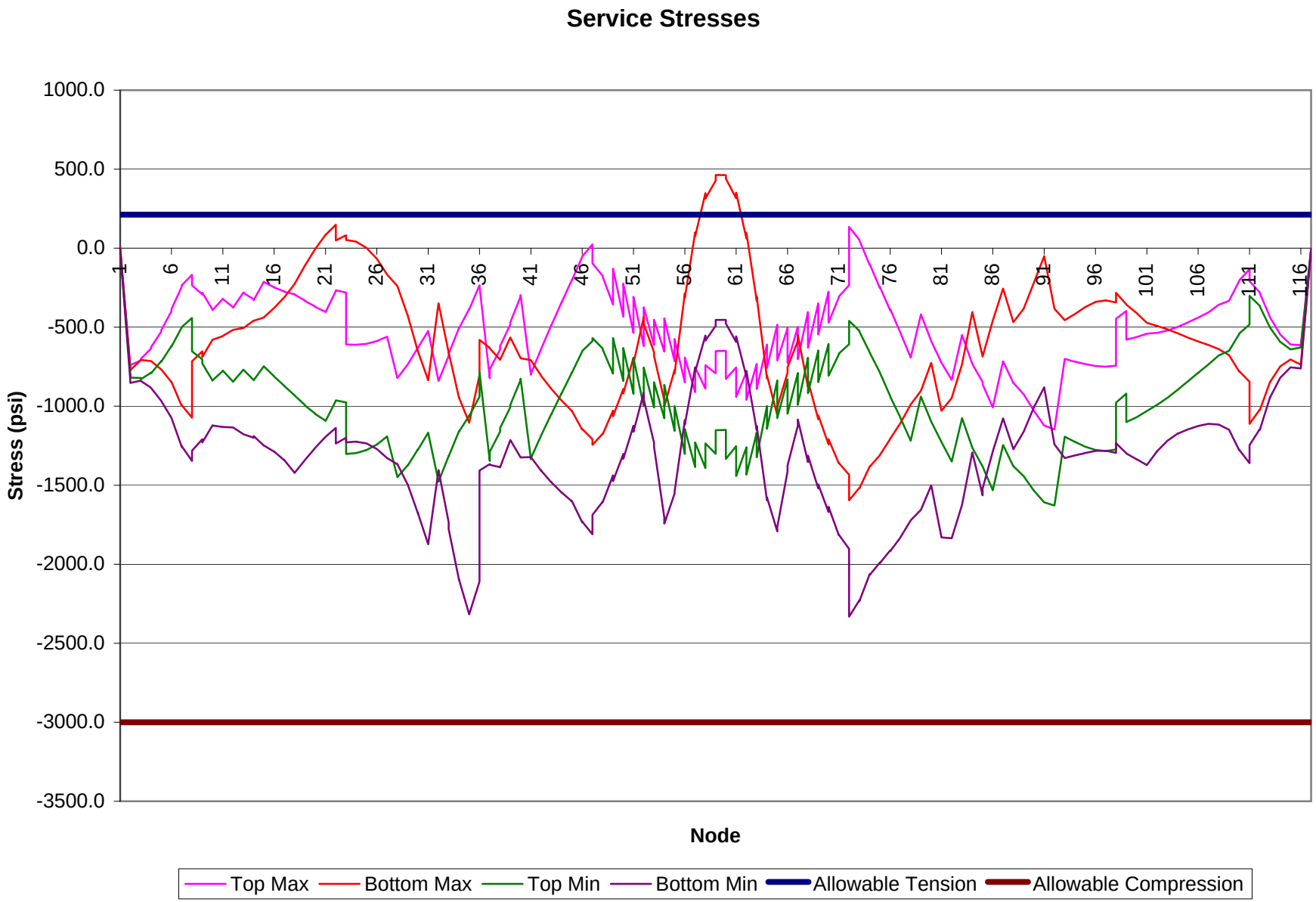
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 0.307$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

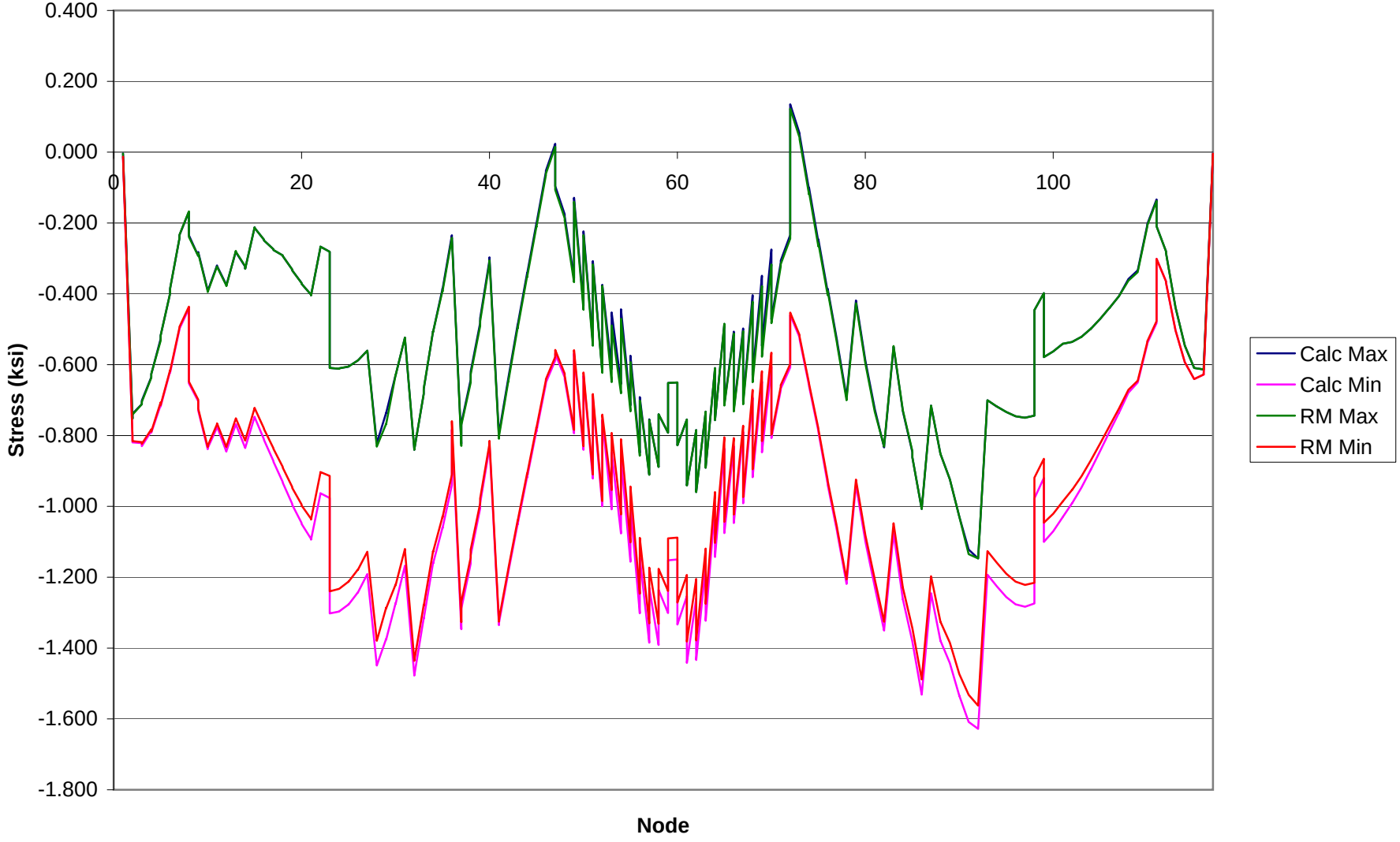
$RF_{torsion} = 0.428$

3.8.4 Service I Flexure (Service Stresses)

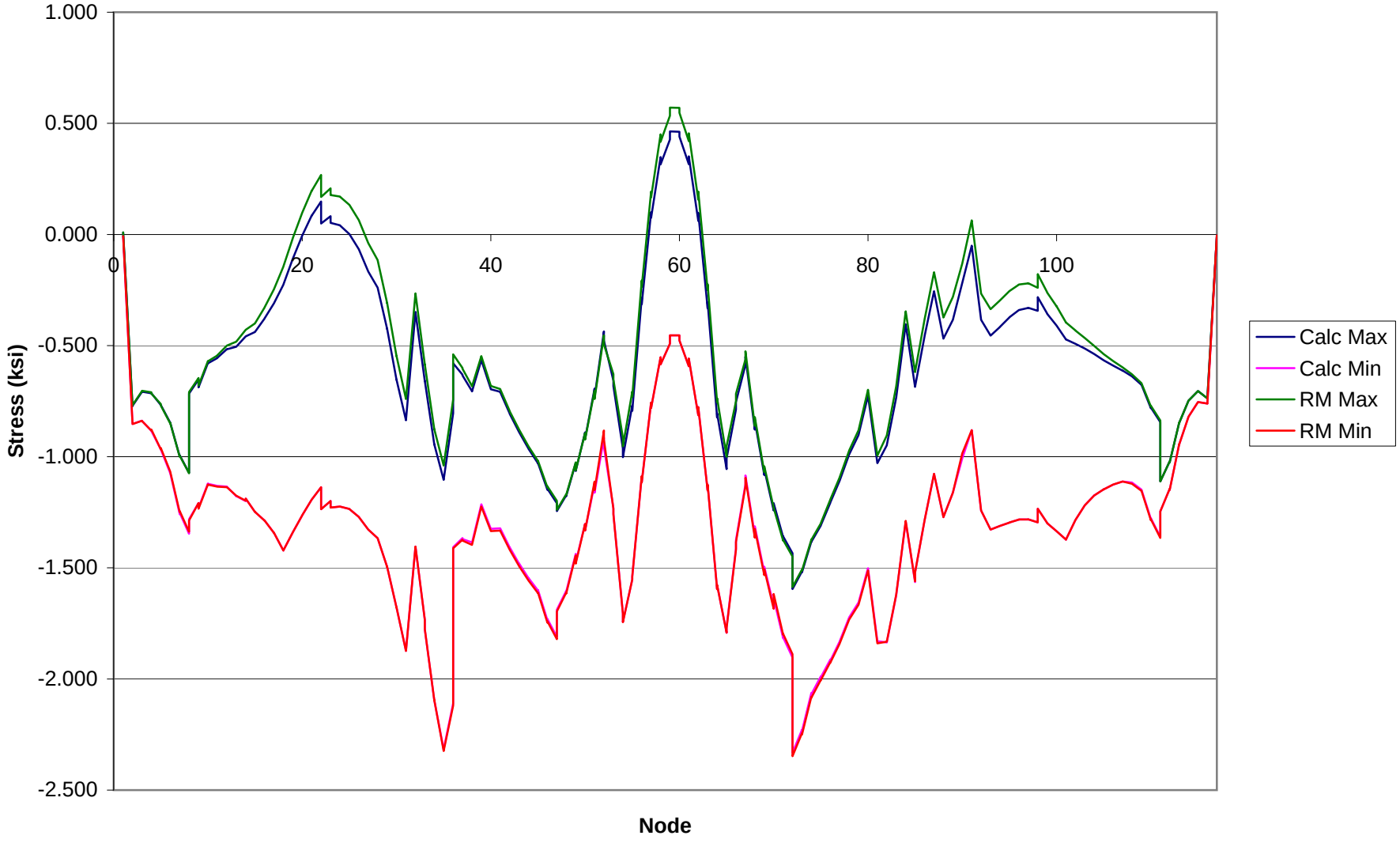

Service Stresses
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression

3.8.4/1

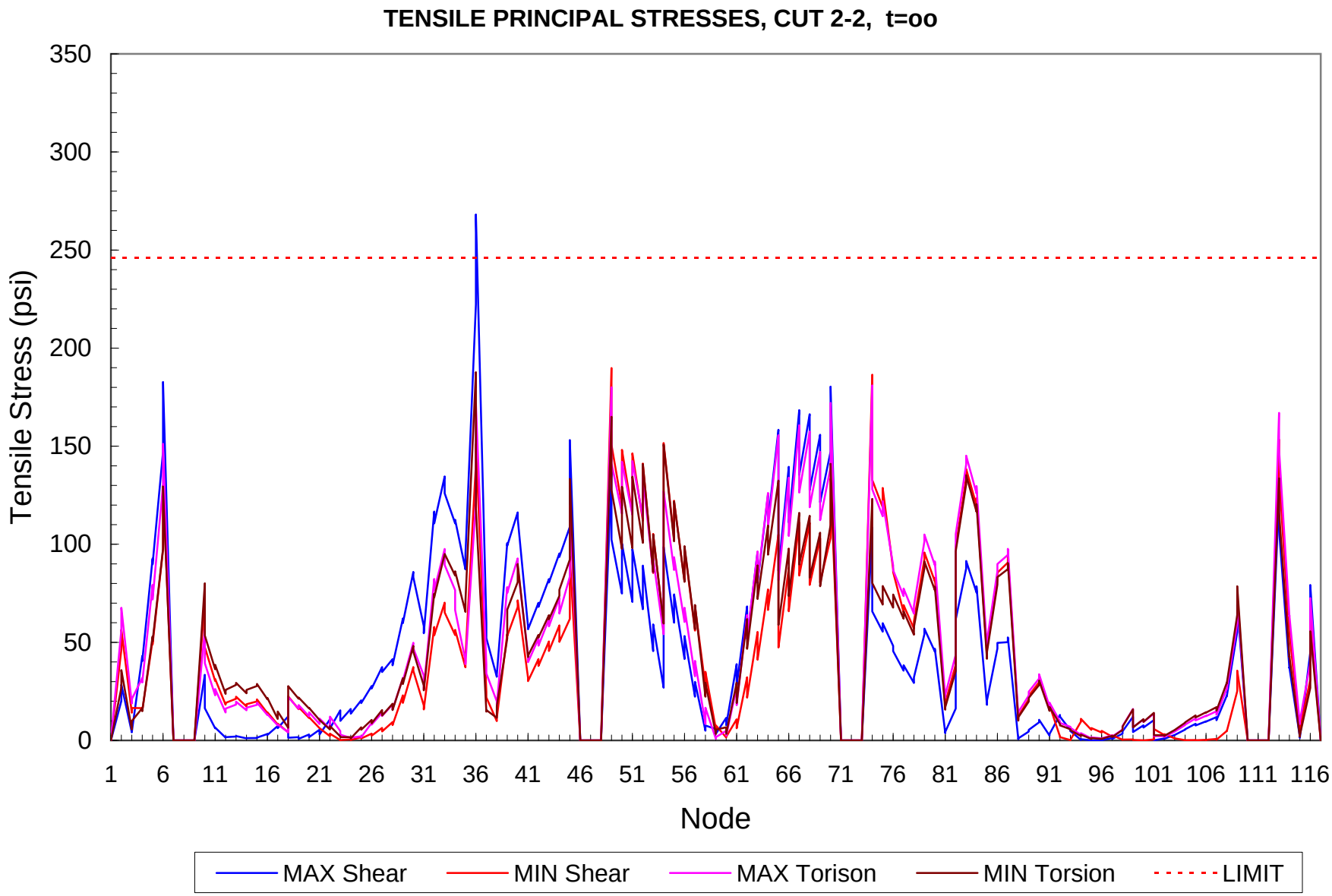
Mainline Segment 3 WB Top Service Stresses



Mainline Segment 3 WB Bottom Service Stresses

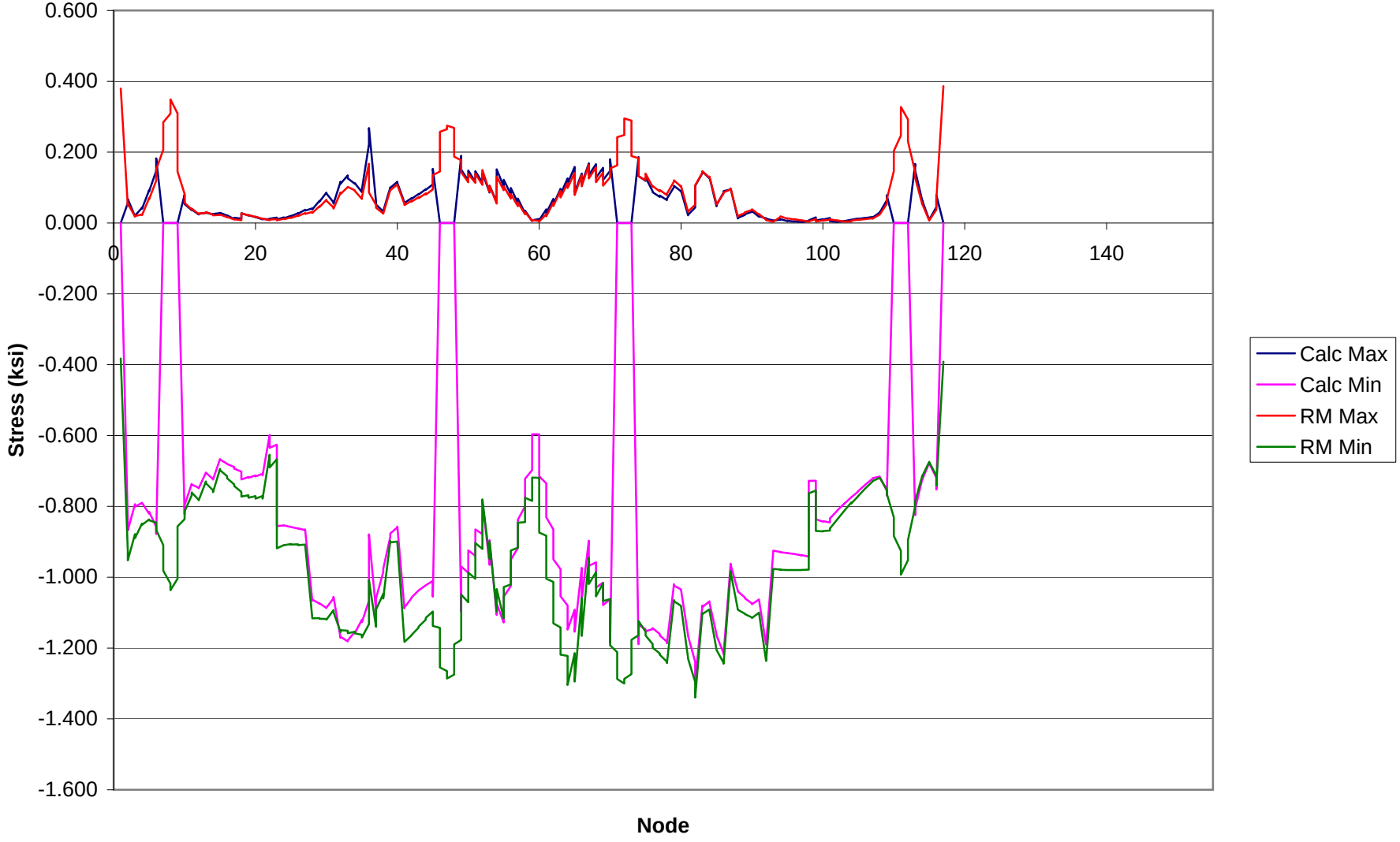


3.8.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.8.5/1

Mainline Segment 3 WB Principal Stresses



3.9 Mainline Segment 4 EB Rating

3.9.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 4 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 4 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.54	2.10	1.46	1.51	1.40	1.61	1.60	1.42	1.44	1.25	1.37	1.19
		Shear	1.40	1.82	1.28	1.29	1.07	1.30	1.29	0.93	0.93	0.84	0.85	0.76
	Service	Flexure	1.24	2.08	1.86	1.91	1.75	1.87	1.85	1.72	1.72	1.58	1.71	1.52
		Principal Stress	1.49	1.34	1.17	1.18	1.00	1.03	1.03	0.86	0.86	0.79	0.76	0.72
Transverse	Strength	Top Slab Centerline	0.86	1.11	1.29	1.35	1.46	1.16	1.13	1.09	1.10	0.98	1.15	1.03
		Top Slab Thickness Change	1.35	1.75	1.78	1.80	1.61	1.54	1.53	1.34	1.36	1.14	1.32	1.14
		Top Slab Webs & Cantilever	1.85	2.40	2.26	2.33	1.97	1.90	1.92	1.67	1.67	1.38	1.58	1.33
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.56	0.57	0.52	0.47	0.47	0.38	0.46	0.38

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	91.20

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 4 EB** CALCS BY: TSP DATE: 10/20/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

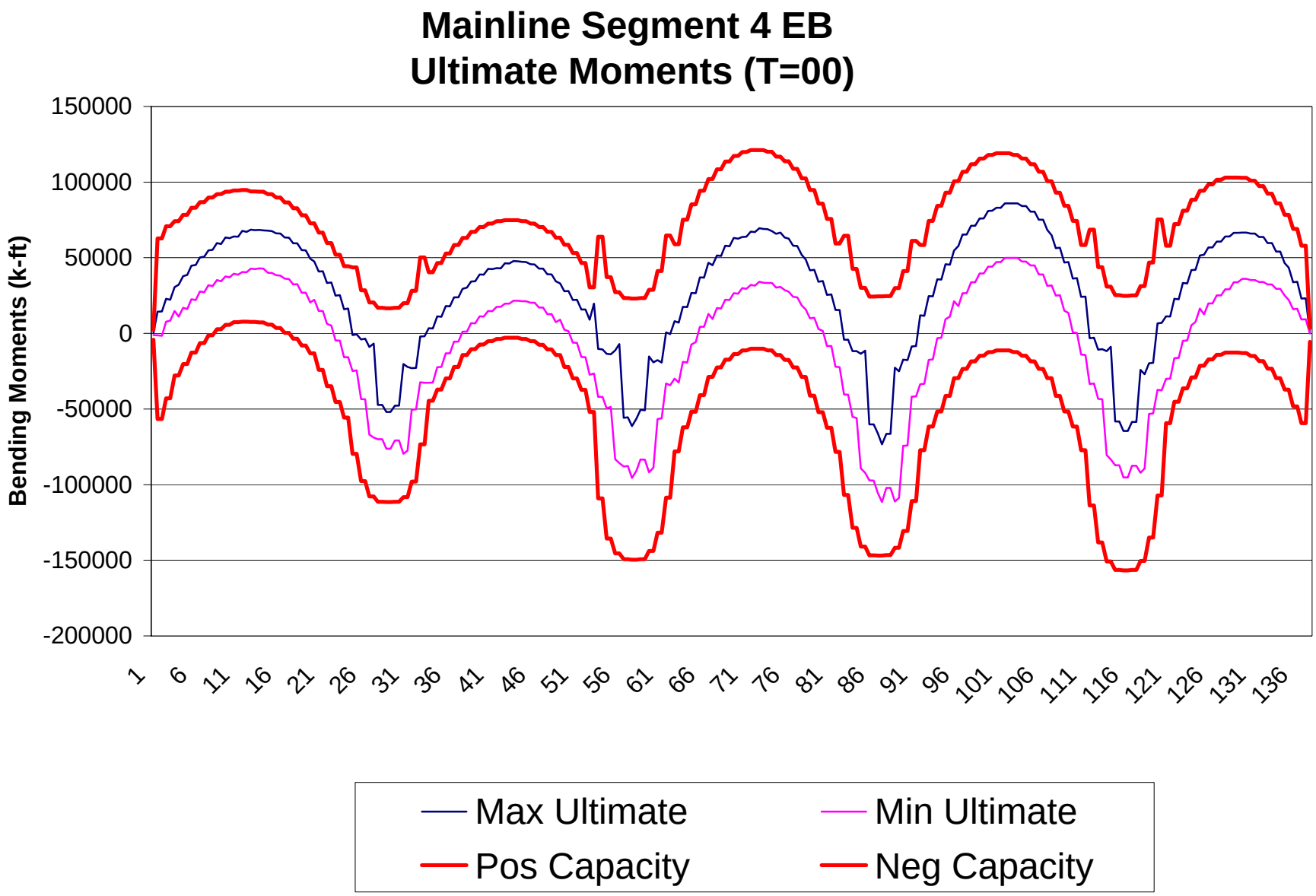
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 4 EB			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.95	2.53										
		Shear	1.54	2.02										
	Service	Flexure	1.47	2.24										
		Principal Stress	1.56	1.59										
Transverse	Strength	Top Slab Centerline	0.86	1.11										
		Top Slab Thickness Change	1.35	1.75										
		Top Slab Webs & Cantilever	1.89	2.45										
		Transverse Web Bending	0.54	0.70										

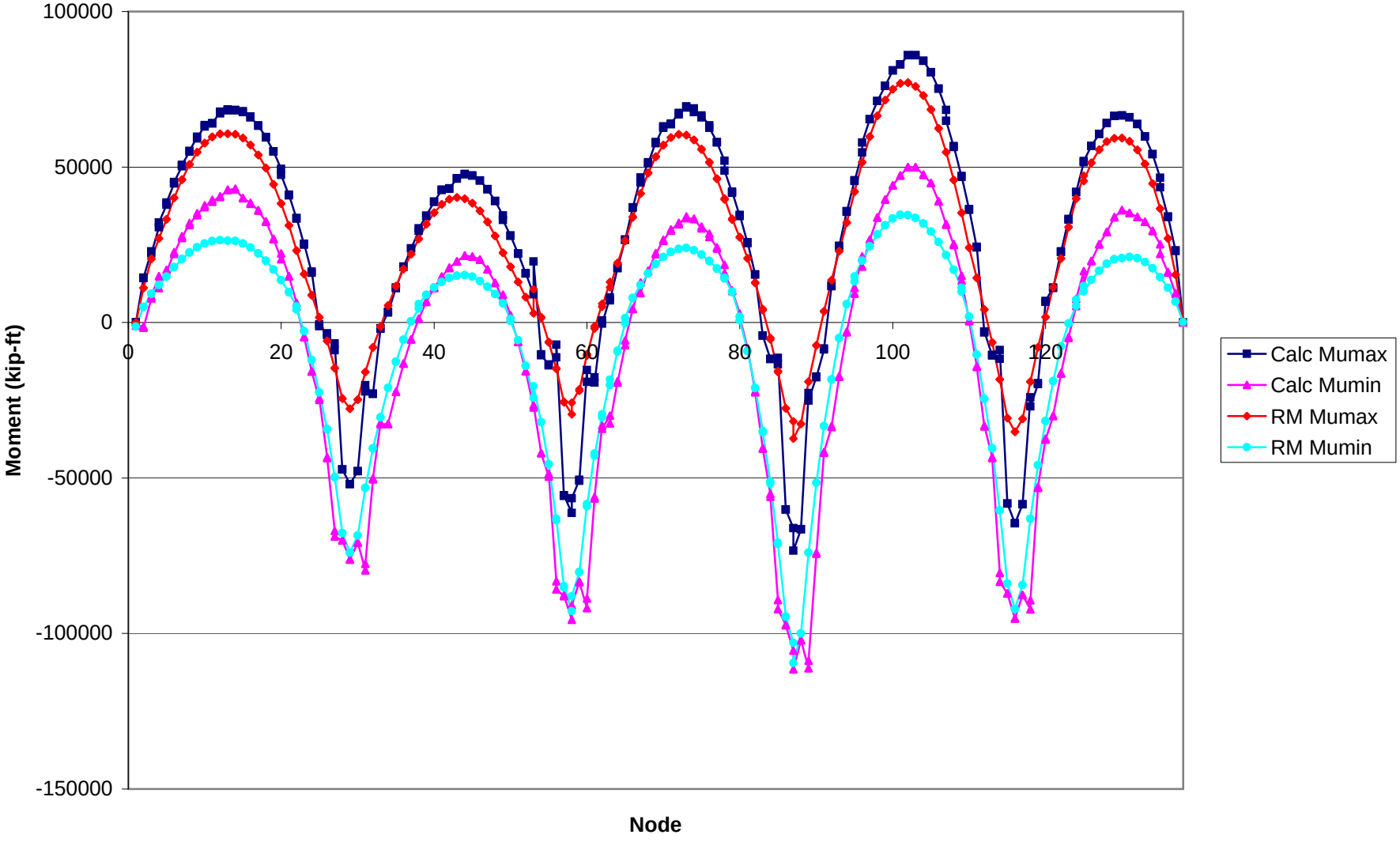
Overall Rating Factor	0.54	0.70	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		25.20	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

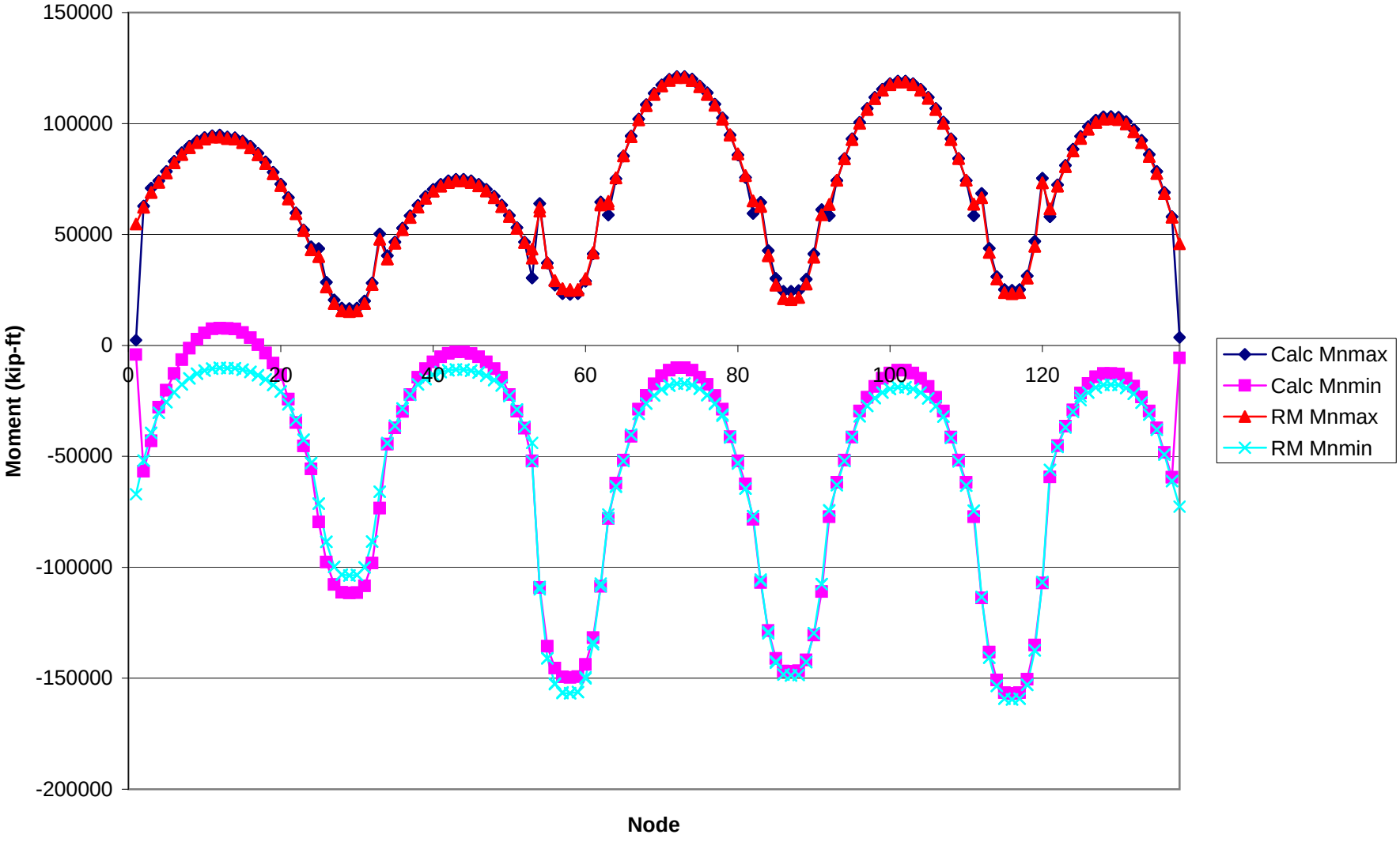
3.9.2 Strength I Flexure


Mainline Segment 4 EB
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

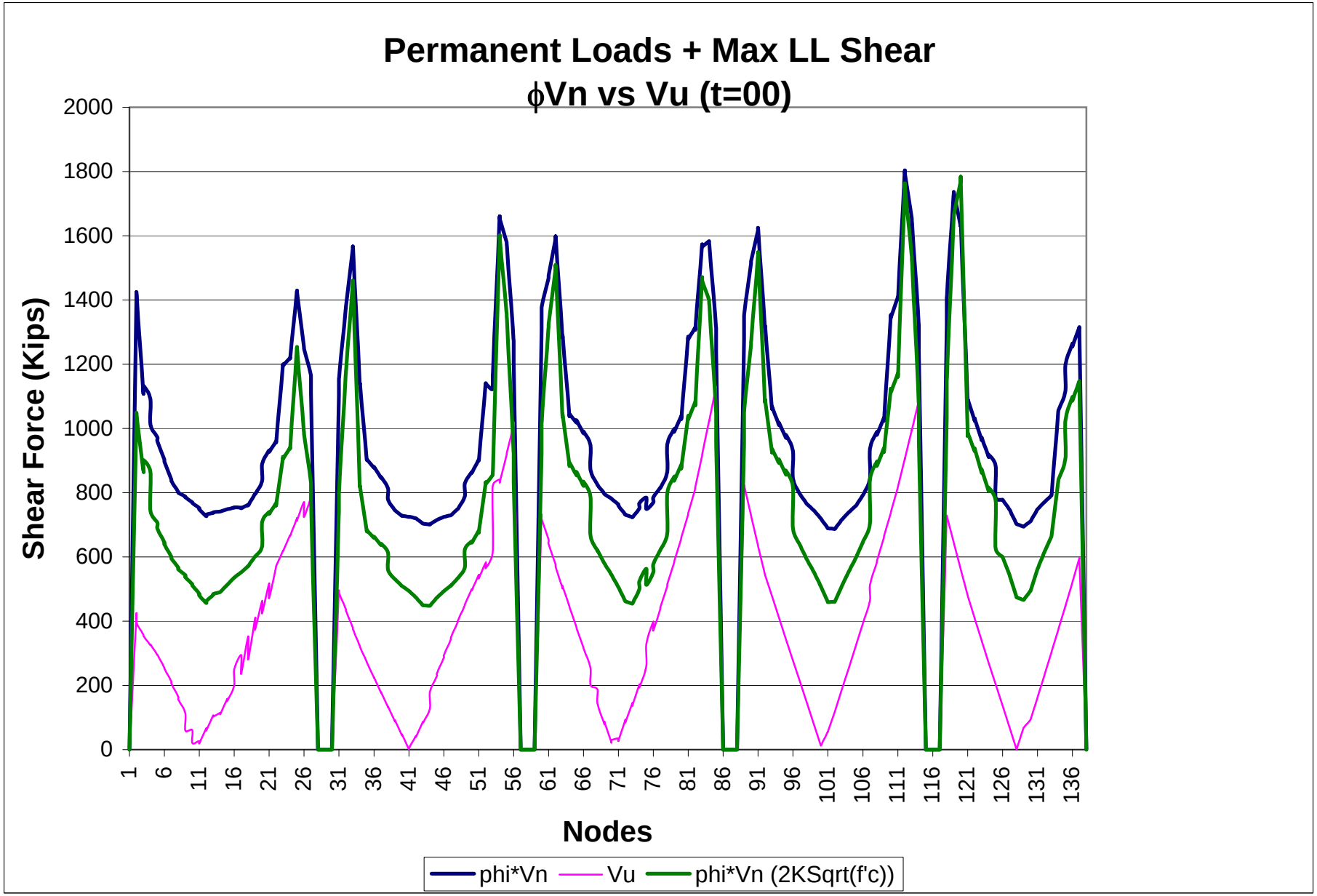
Mainline Segment 4 EB Flexural Demand, M_u

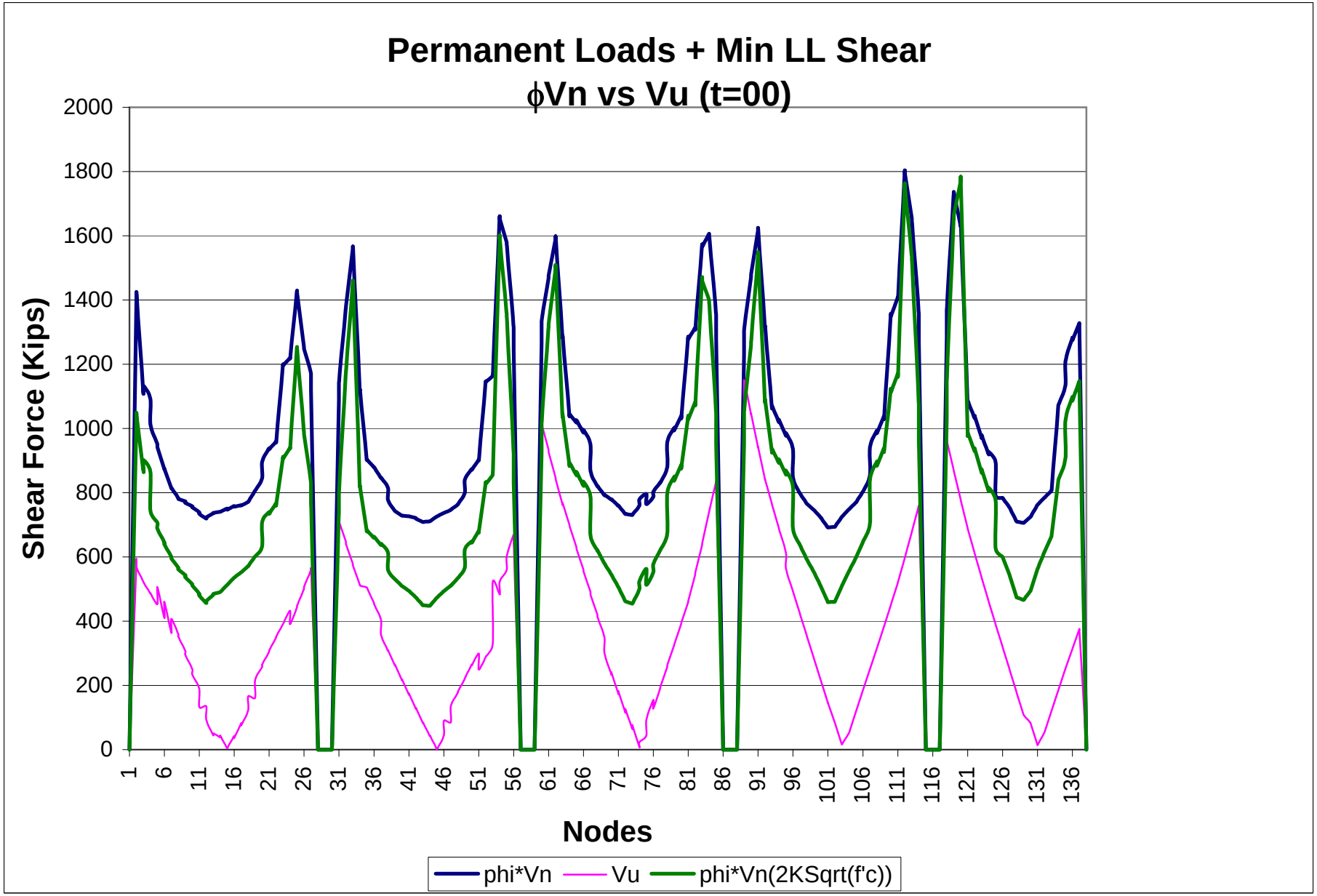


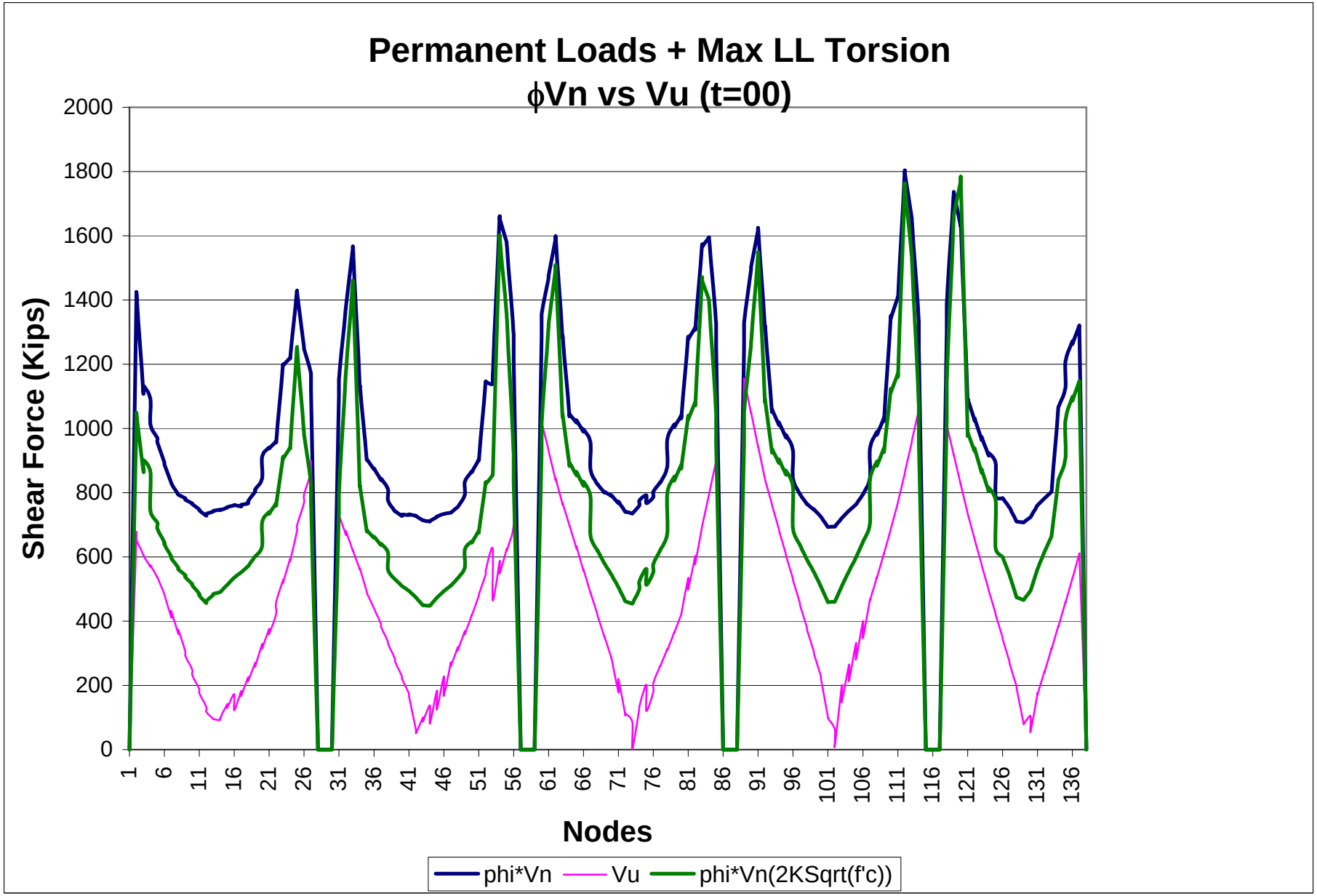
Mainline Segment 4 EB Flexural Strength, ϕM_n

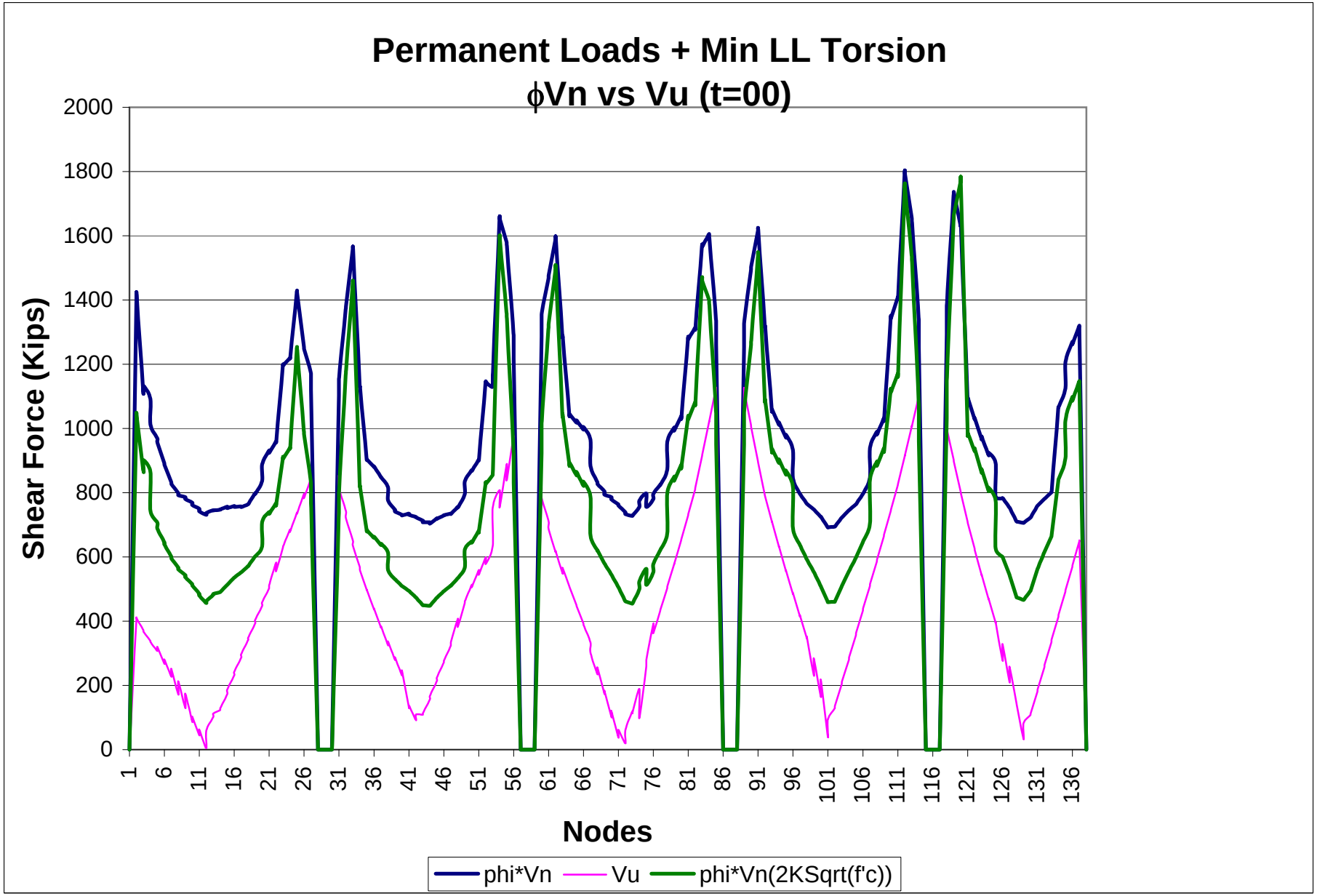


3.9.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 4 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 4 EB\

Node := 89 Position := Back $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -1875 \cdot kips$	$M_{dc_x} = -55442 \cdot kip \cdot ft$	$T_{dc_x} = -198\, ft \cdot kips$	$N_{dc_x} = 0 \cdot kips$	Dead Load
$V_{dw_x} = -196 \cdot kips$	$M_{dw_x} = -5157 \cdot kip \cdot ft$	$T_{dw_x} = -480 \cdot kip \cdot ft$	$N_{dw_x} = 0 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 50 \cdot kips$	$M_{psec_x} = 22491 \cdot kip \cdot ft$	$T_{psec_x} = 1343 \cdot kip \cdot ft$	$N_{psec_x} = -2 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = 35\, kip$	$M_{crsh_x} = 5200 \cdot kip \cdot ft$	$T_{crsh_x} = 346 \cdot kip \cdot ft$	$N_{crsh_x} = 1 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 55 \cdot kips$	$M_{LLvmax_x} = 3175 \cdot kip \cdot ft$	$T_{LLvmax_x} = 0 \cdot kip \cdot ft$	$N_{LLvmax_x} = 0 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -422 \cdot kips$	$M_{LLvmin_x} = -9385 \cdot kip \cdot ft$	$T_{LLvmin_x} = 1295 \cdot kip \cdot ft$	$N_{LLvmin_x} = 0 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -282 \cdot kips$	$M_{LLtmax_x} = -2494 \cdot kip \cdot ft$	$T_{LLtmax_x} = 4677 \cdot kip \cdot ft$	$N_{LLtmax_x} = 0 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -285 \cdot kips$	$M_{LLtmin_x} = -2596 \cdot kip \cdot ft$	$T_{LLtmin_x} = -4288 \cdot kip \cdot ft$	$N_{LLtmin_x} = 0 \cdot kips$	Min Live Load Torsion

URS

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Post Tensioning Forces:

$V_{prim_x} = 792 \cdot kips$ Primary PT Shear

$N_{prim_x} = -13971 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 36670 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1065 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = 8 \cdot kips$

$M_{tu_x} = 1304 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 58 \cdot kip \cdot ft$

$N_{tu_x} = -1 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 18482 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 38773 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.465 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 57.923 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.243 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.143 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 112.84 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 106 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -2496 \cdot kips$	$T_{uvmax_x} = 549 \cdot kip \cdot ft$	$M_{uvmax_x} = -47661\, ft \cdot kips$	$N_{uvmax_x} = -2 \cdot kips$
$V_{uvmin_x} = -3140 \cdot kips$	$T_{uvmin_x} = 2297 \cdot kip \cdot ft$	$M_{uvmin_x} = -64617\, ft \cdot kips$	$N_{uvmin_x} = -2 \cdot kips$
$V_{utmax_x} = -2951 \cdot kips$	$T_{utmax_x} = 6862 \cdot kip \cdot ft$	$M_{utmax_x} = -55314\, ft \cdot kips$	$N_{utmax_x} = -2 \cdot kips$
$V_{utmin_x} = -2955 \cdot kips$	$T_{utmin_x} = -5240 \cdot kip \cdot ft$	$M_{utmin_x} = -55452\, ft \cdot kips$	$N_{utmin_x} = -2 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.698\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 16438 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 89.926 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 80.934 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0003$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.933 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.223$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 460.84 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -856.75\,kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 24.75 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 2.826$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.00023$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 28.201 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 5.791$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 428.871 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -856.75\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -189.9 \cdot kips$

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$$RF_{vneg} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{vneg_{x,1}} = 2.098$$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$$\varepsilon_{stmax} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmax_x} = -0.00027$$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 28.068 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 5.998$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 444.173 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -864.898\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -220.698 \cdot kips$

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$$RF_{tpos} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{tpos_{x,1}} = 1.847$$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$$\varepsilon_{stmin} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmin_x} = -0.00027$$

URS

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 28.07 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 5.994$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 443.926 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -864.898\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -214.247 \cdot kips$

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Project: Cline --Seg 4 EB
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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.901}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

URS

Project: Cline --Seg 4 EB
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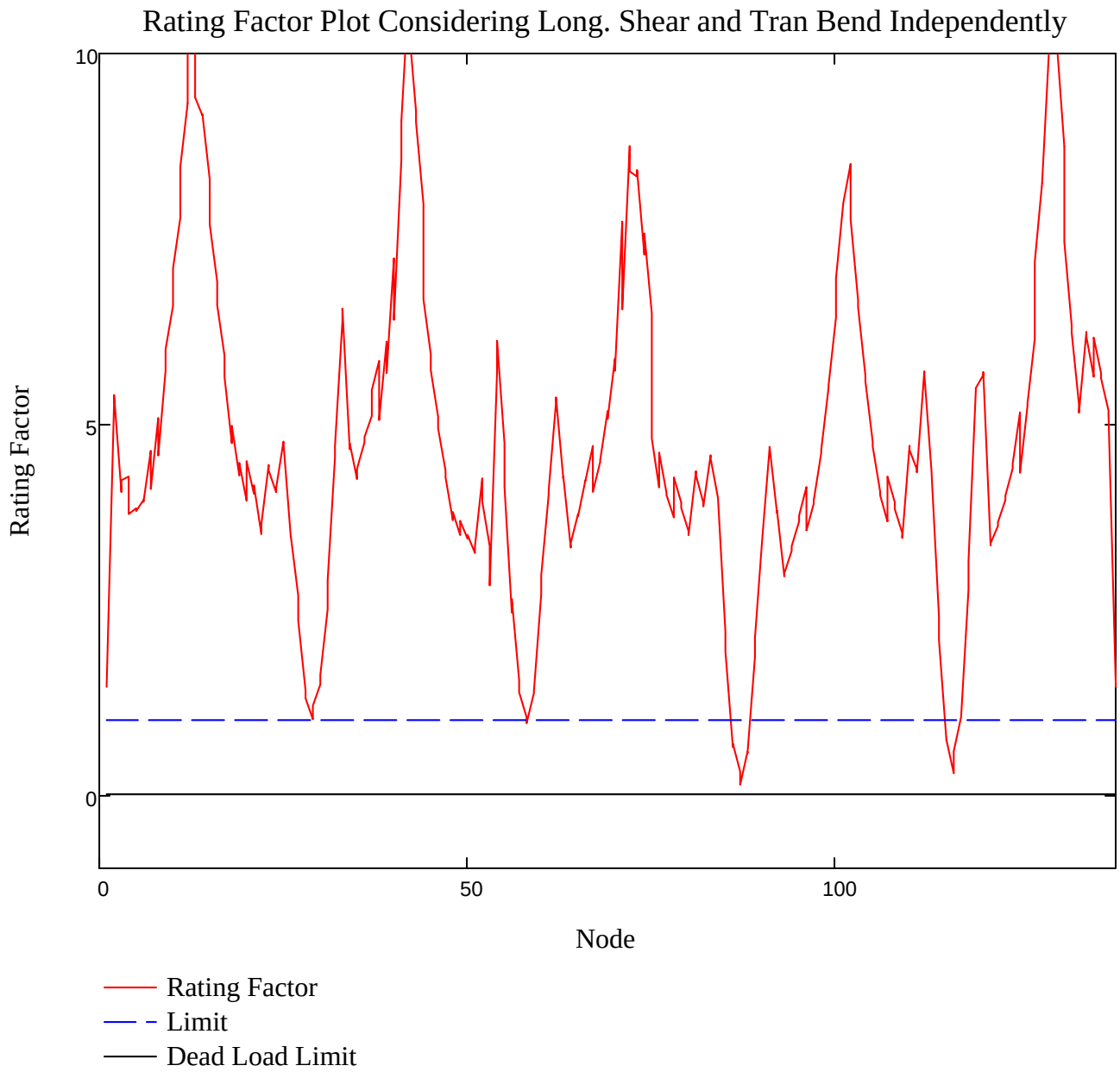

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.847$ at node $minRF_2 = 89$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.528$

URS

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 160.248 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 80.261 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.285 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.142 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.495 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 27.9 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 24.053 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

URS

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 27.9 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 354.897 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 971.764 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.547 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 23.779 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 701.832 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.284 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 1.082 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 24.053 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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Project: Cline --Seg 4 EB
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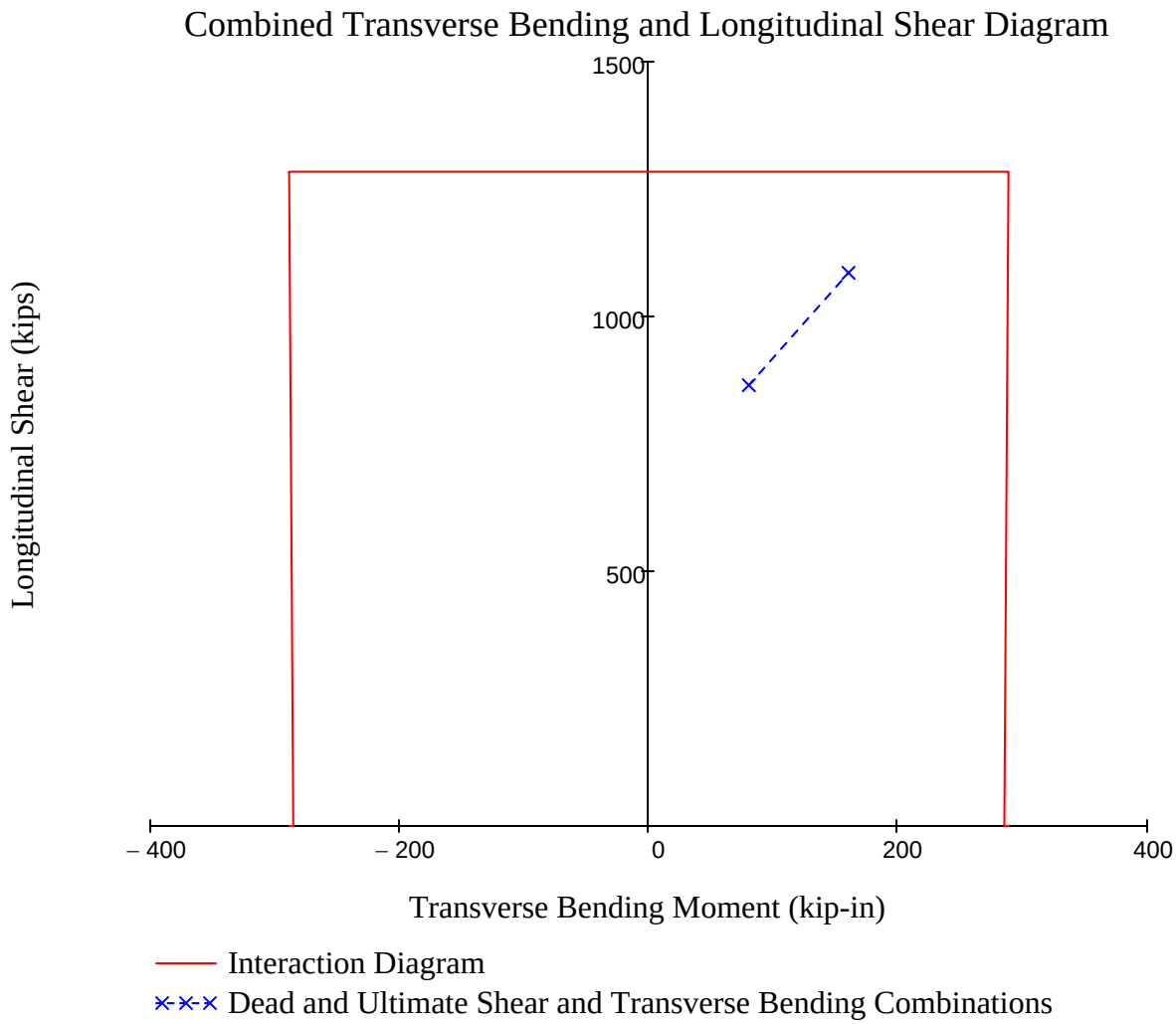


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.605$

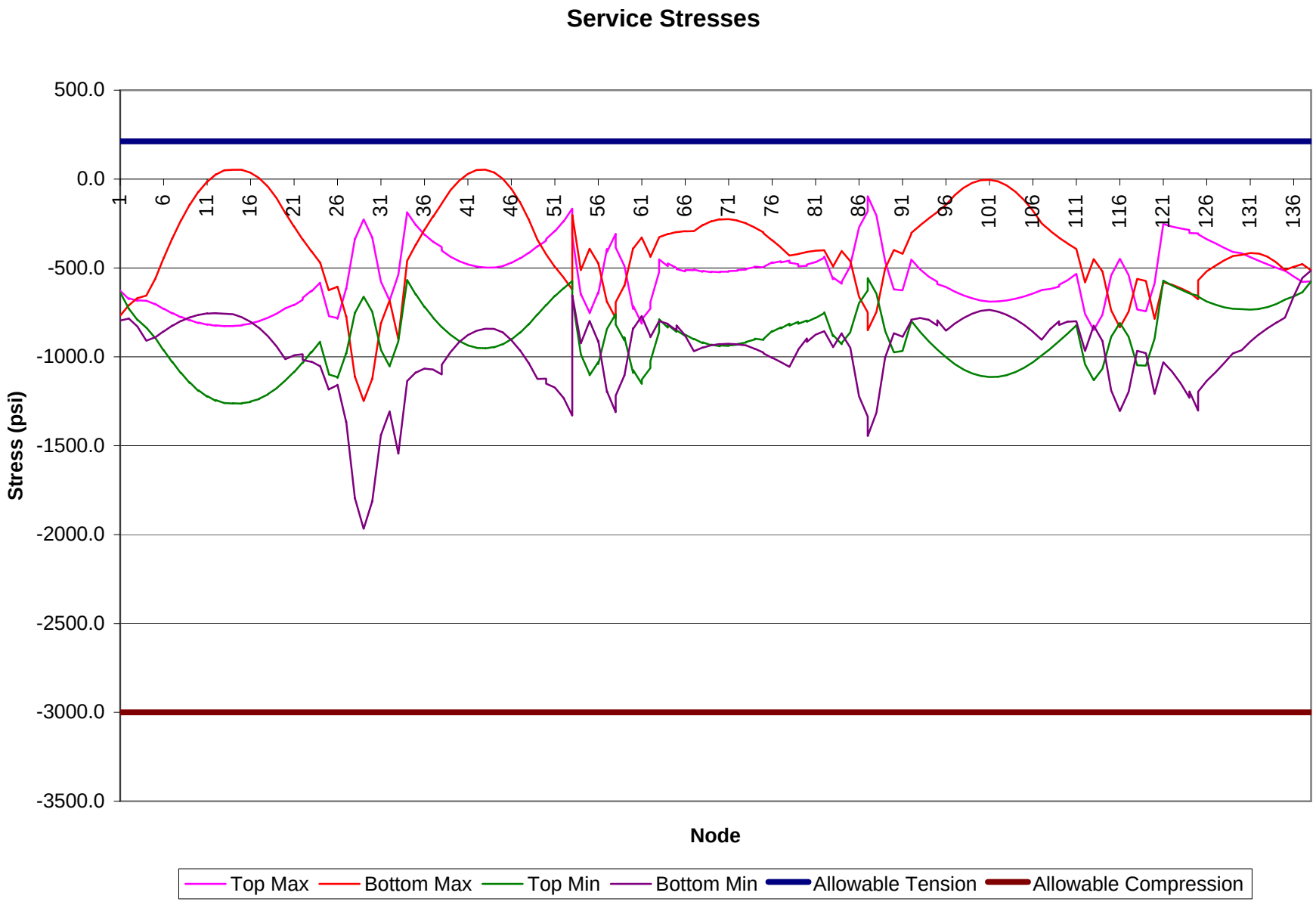
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 2.25$

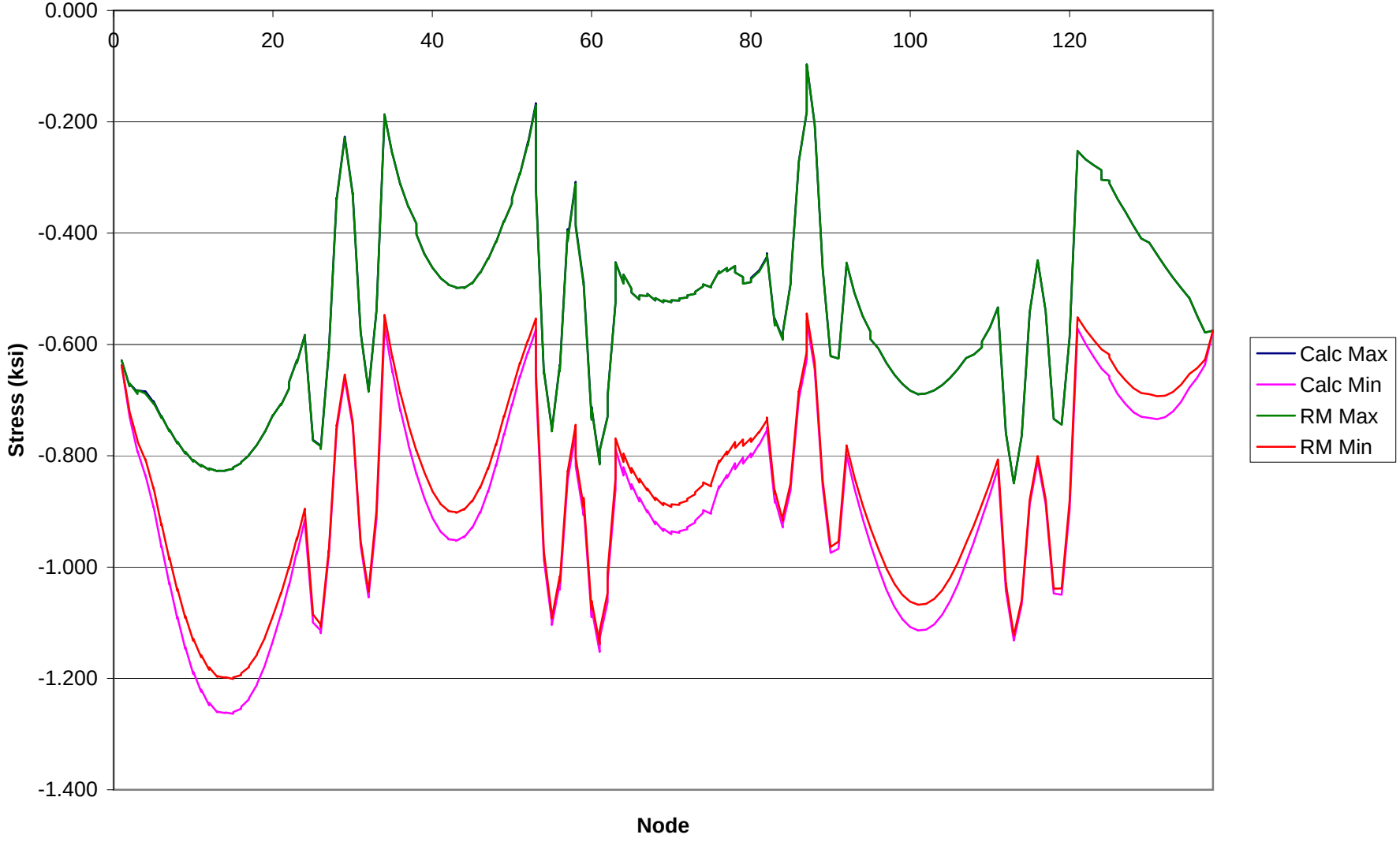
$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 1.899$

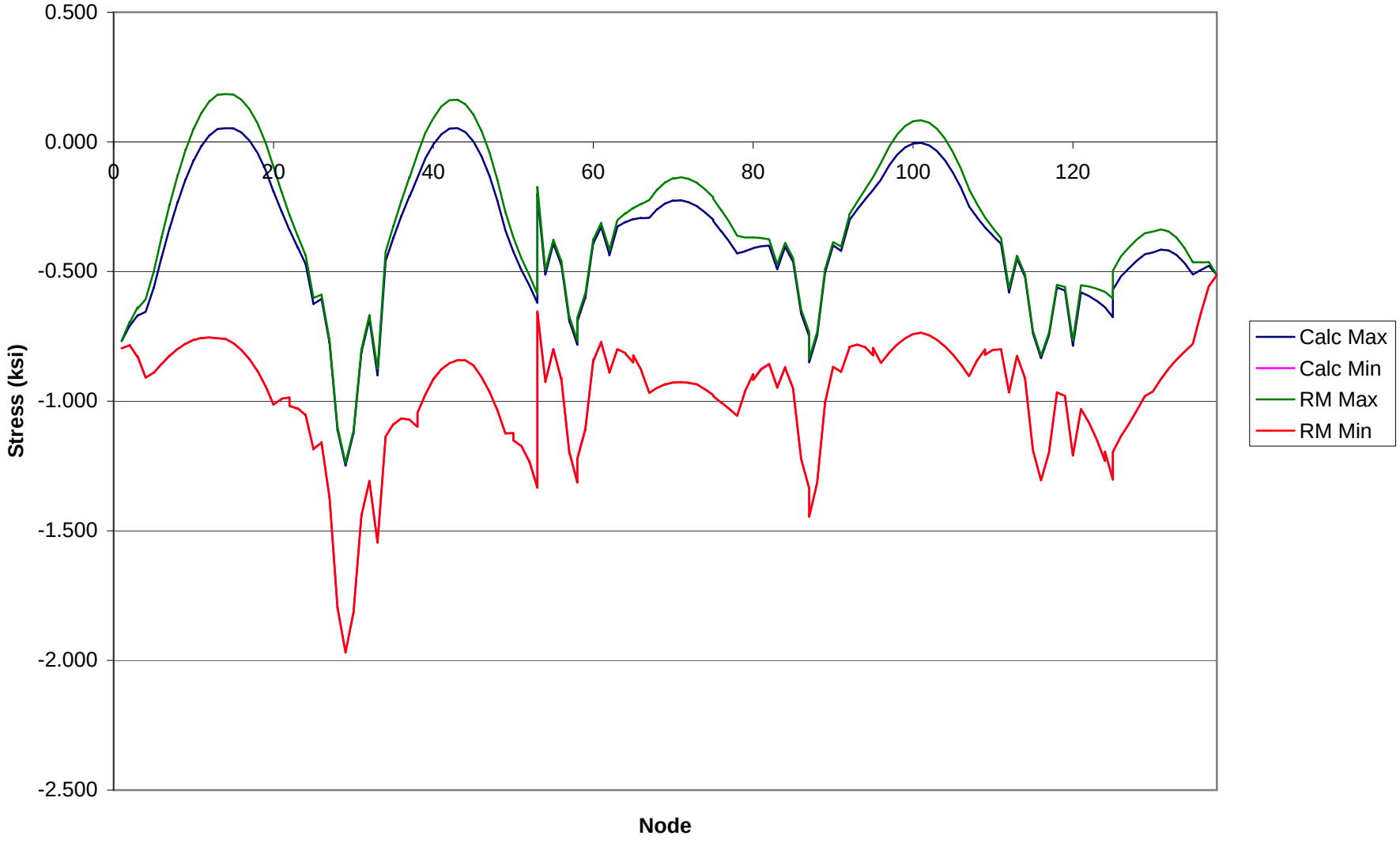
3.9.4 Service I Flexure (Service Stresses)


Service Stresses
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression

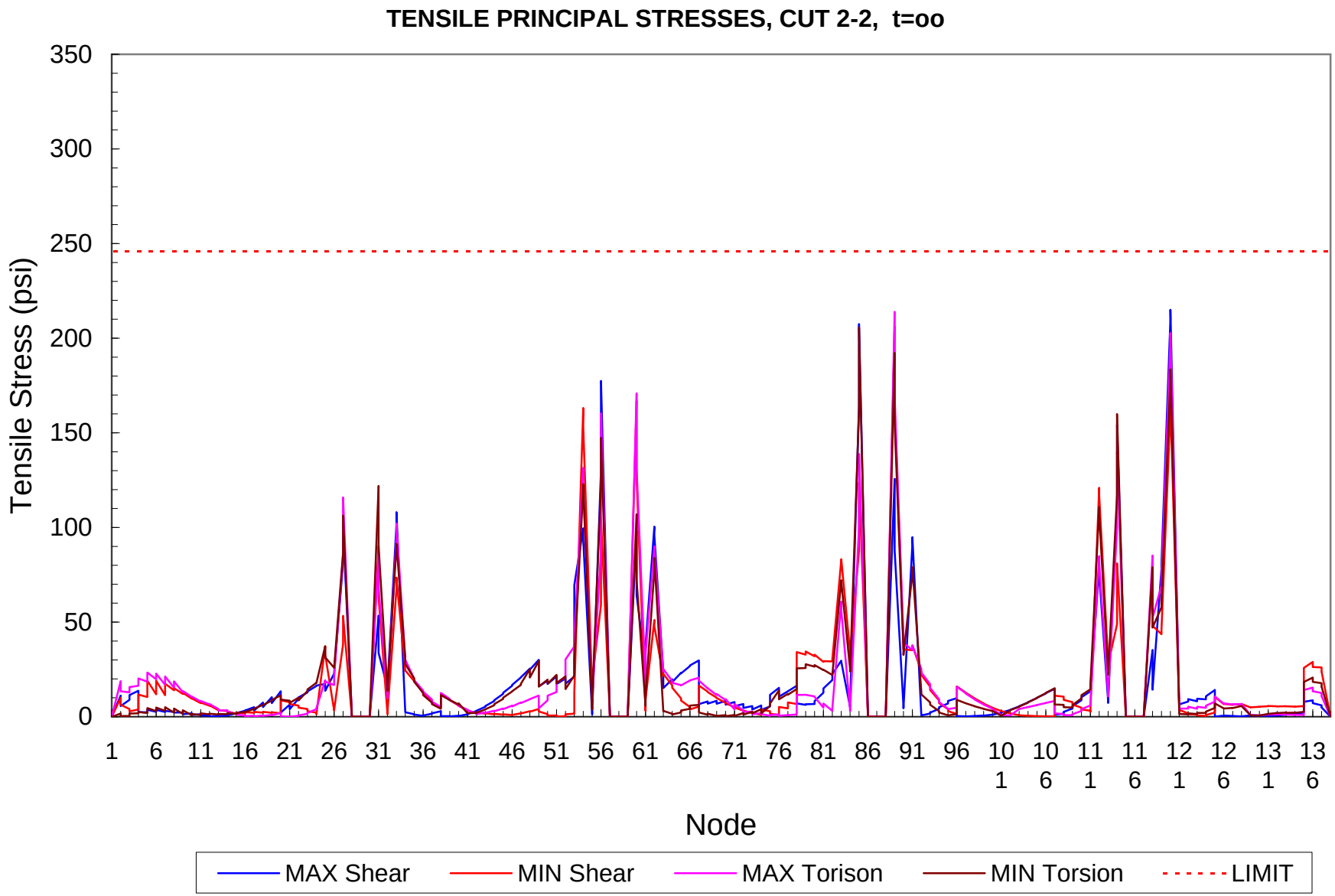
Mainline Segment 4 EB Top Service Stresses



Mainline Segment 4 EB Bottom Service Stresses

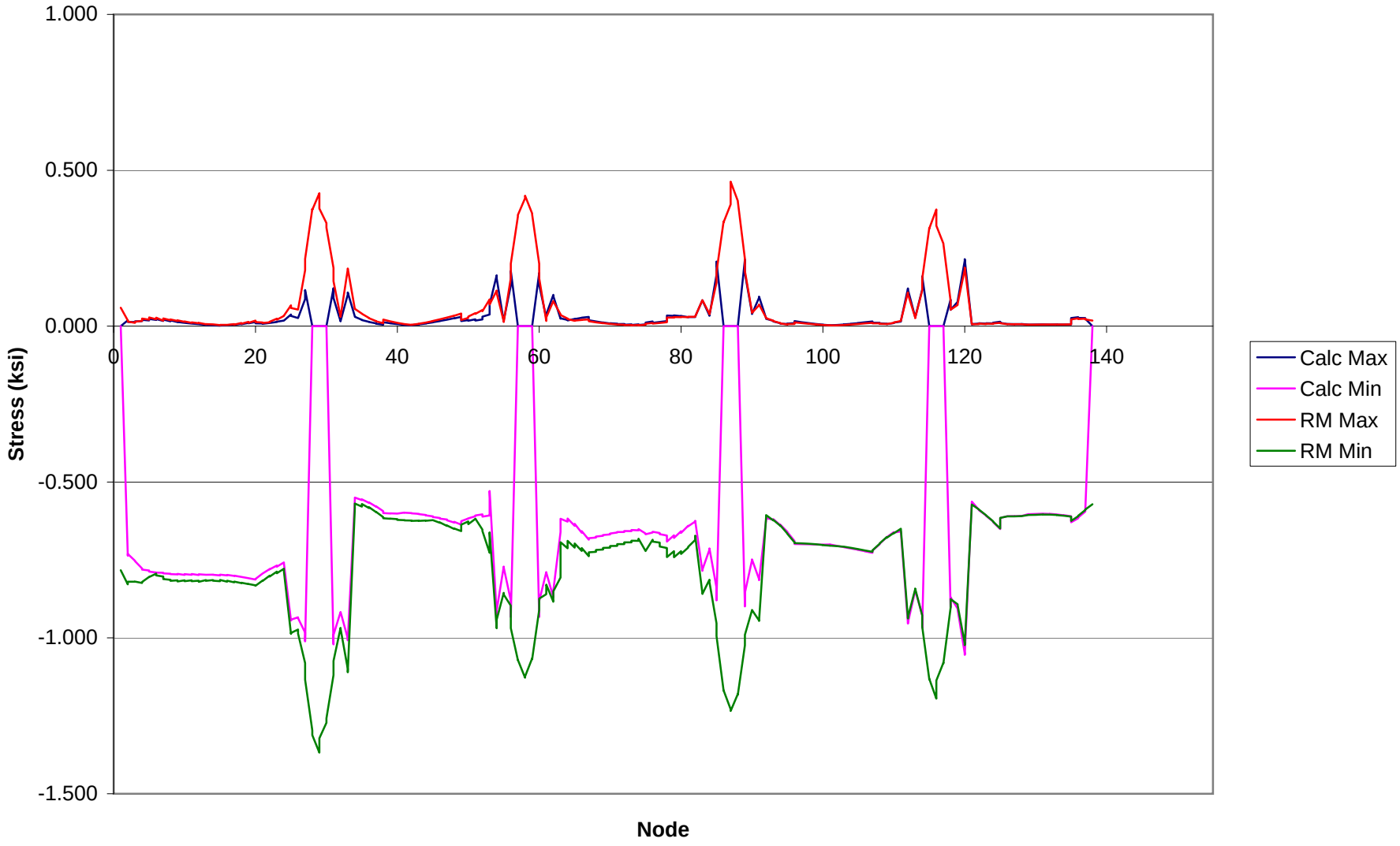


3.9.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.9.5/1

Mainline Segment 4 EB Principal Stresses



3.10 Mainline Segment 4 WB Rating

3.10.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 4 WB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 4 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.80	2.33	1.90	1.93	1.65	2.06	2.05	1.81	1.80	1.65	1.76	1.53
		Shear	0.93	1.21	0.86	0.87	0.72	0.84	0.84	0.62	0.62	0.54	0.47	0.47
	Service	Flexure	1.24	1.97	1.76	1.80	1.61	1.77	1.76	1.61	1.61	1.50	1.60	1.44
		Principal Stress	1.30	1.16	1.03	1.04	0.89	0.91	0.91	0.73	0.73	0.64	0.58	0.58
Transverse	Strength	Top Slab Centerline	1.69	2.19	2.47	2.59	2.76	2.21	2.14	2.12	2.13	1.88	2.17	1.97
		Top Slab Thickness Change	1.78	2.31	2.54	2.59	2.59	2.38	2.41	2.20	2.31	1.84	2.36	1.89
		Top Slab Webs & Cantilever	1.85	2.40	2.36	2.93	2.90	2.85	2.25	2.27	2.32	1.81	2.65	2.00
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 4 WB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

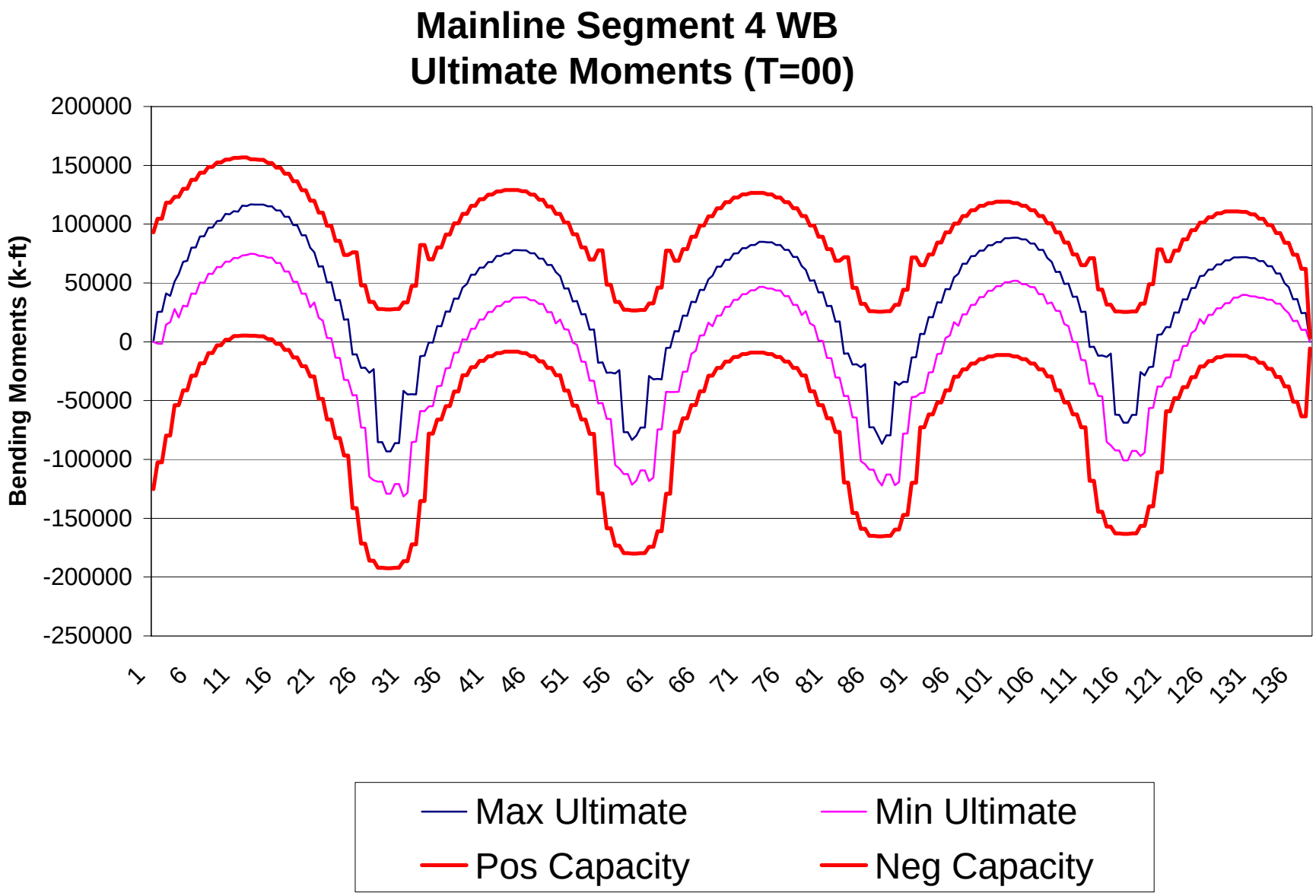
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 4 WB			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.84	2.39										
		Shear	1.00	1.34										
	Service	Flexure	1.26	1.98										
		Principal Stress	1.44	1.46										
Transverse	Strength	Top Slab Centerline	1.69	2.19										
		Top Slab Thickness Change	2.23	2.89										
		Top Slab Webs & Cantilever	3.02	3.92										
		Transverse Web Bending	2.59	3.47										

Overall Rating Factor	1.00	1.34	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		48.24	0.00	0.00

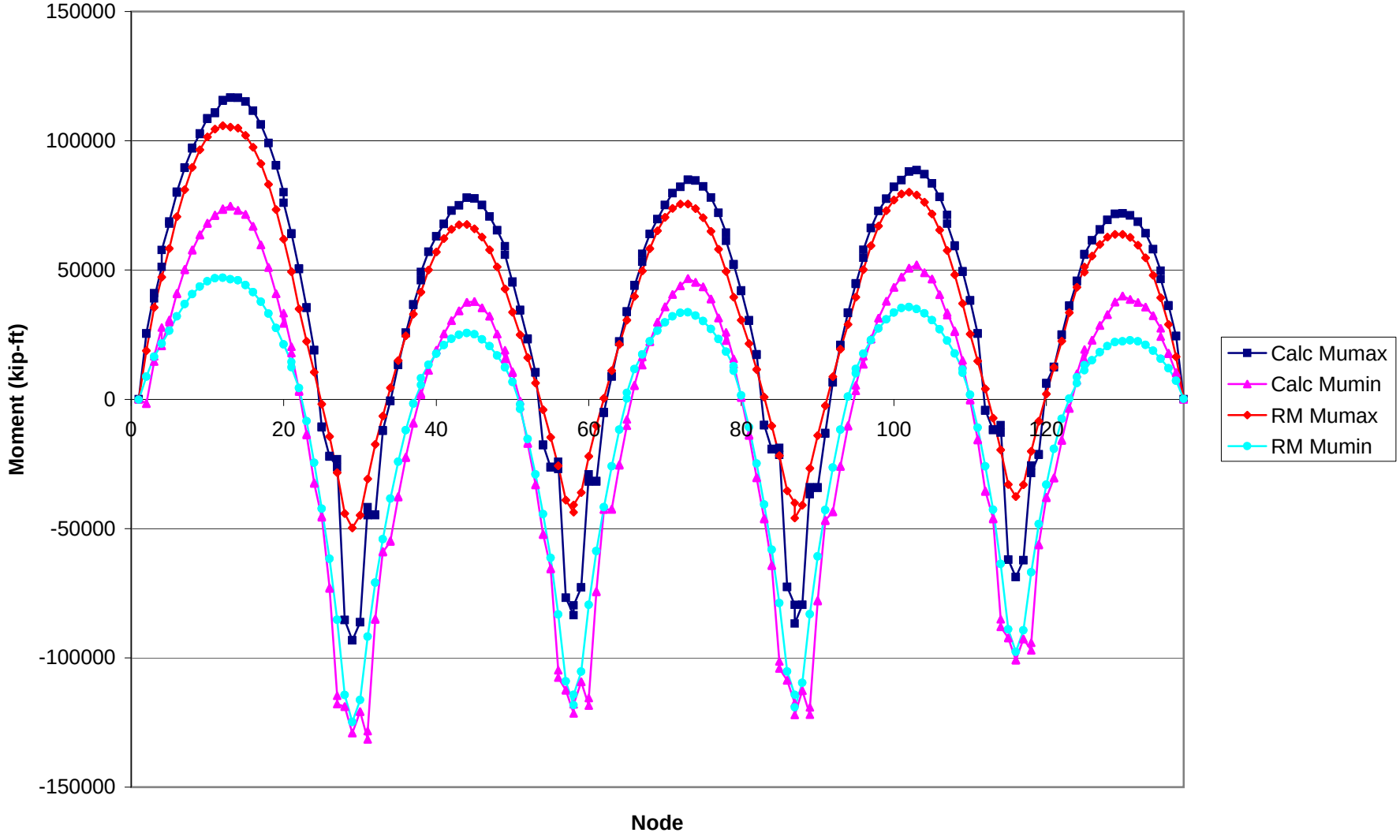
* Max number of lanes loaded = Per AASHTO LRFD

3.10.2 Strength I Flexure

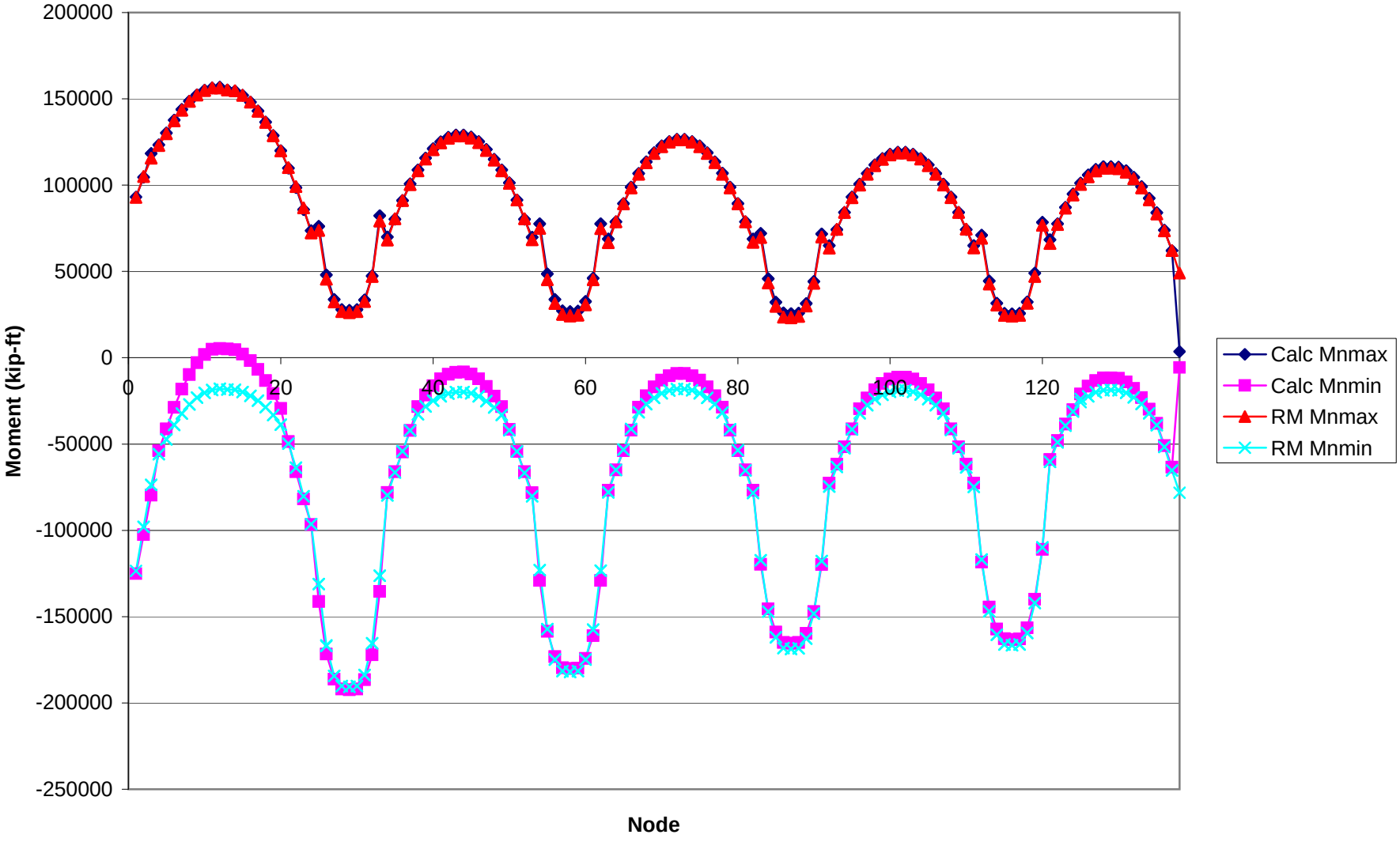

Mainline Segment 4 WB
Ultimate Moments (T=00)
Bending Moments (k-ft)
200000
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

3.10.2/1

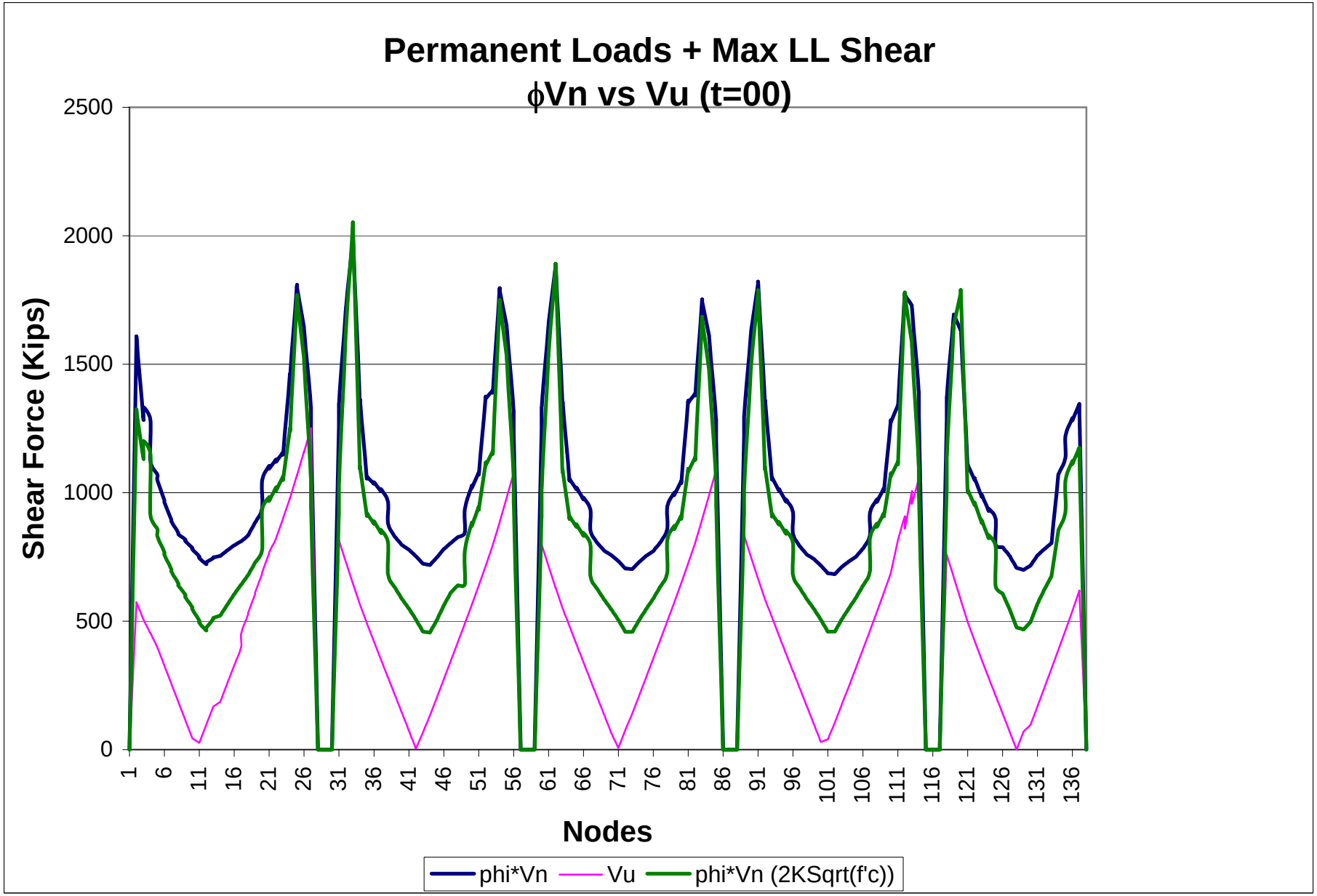
Mainline Segment 4 WB Flexural Demand, M_u

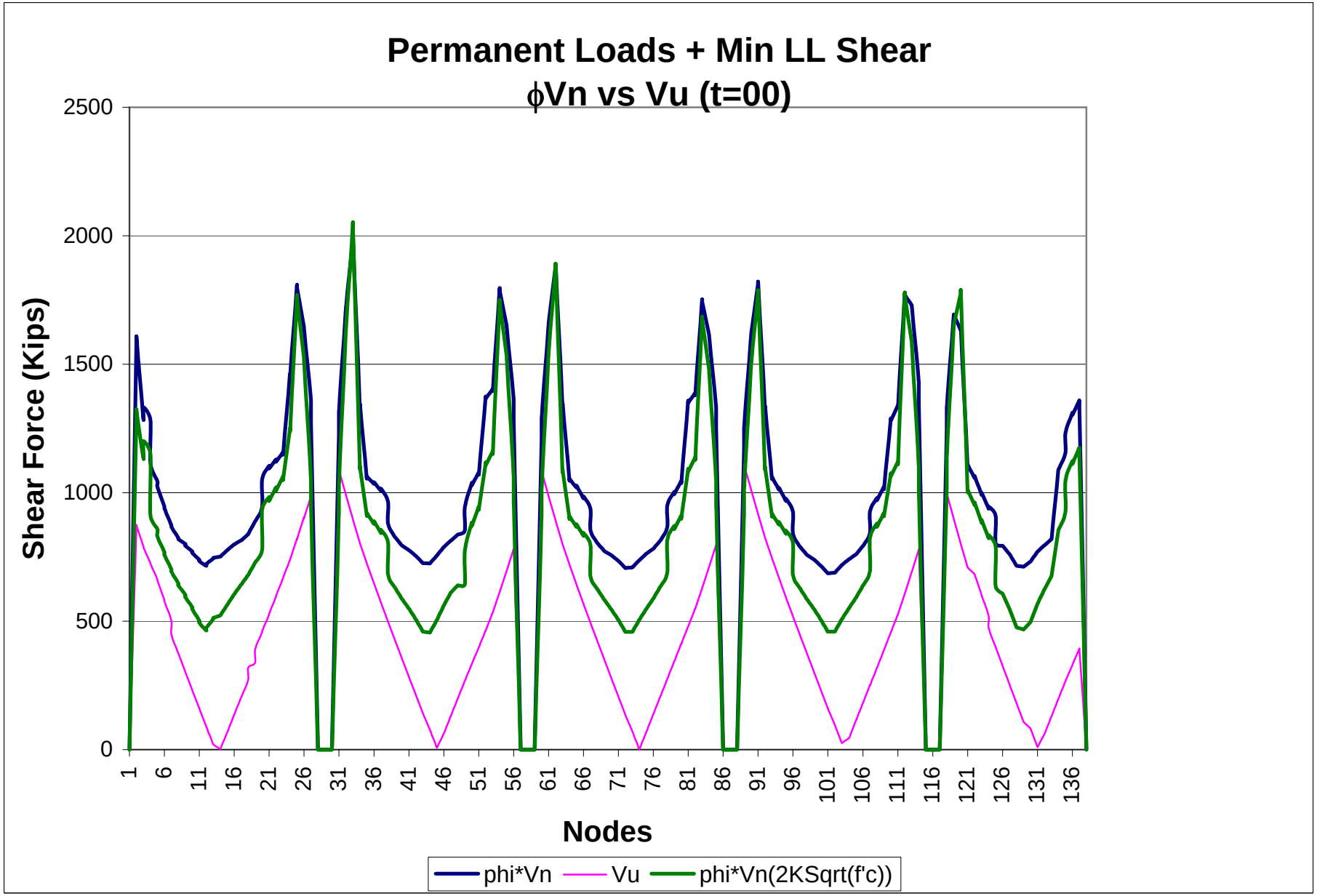


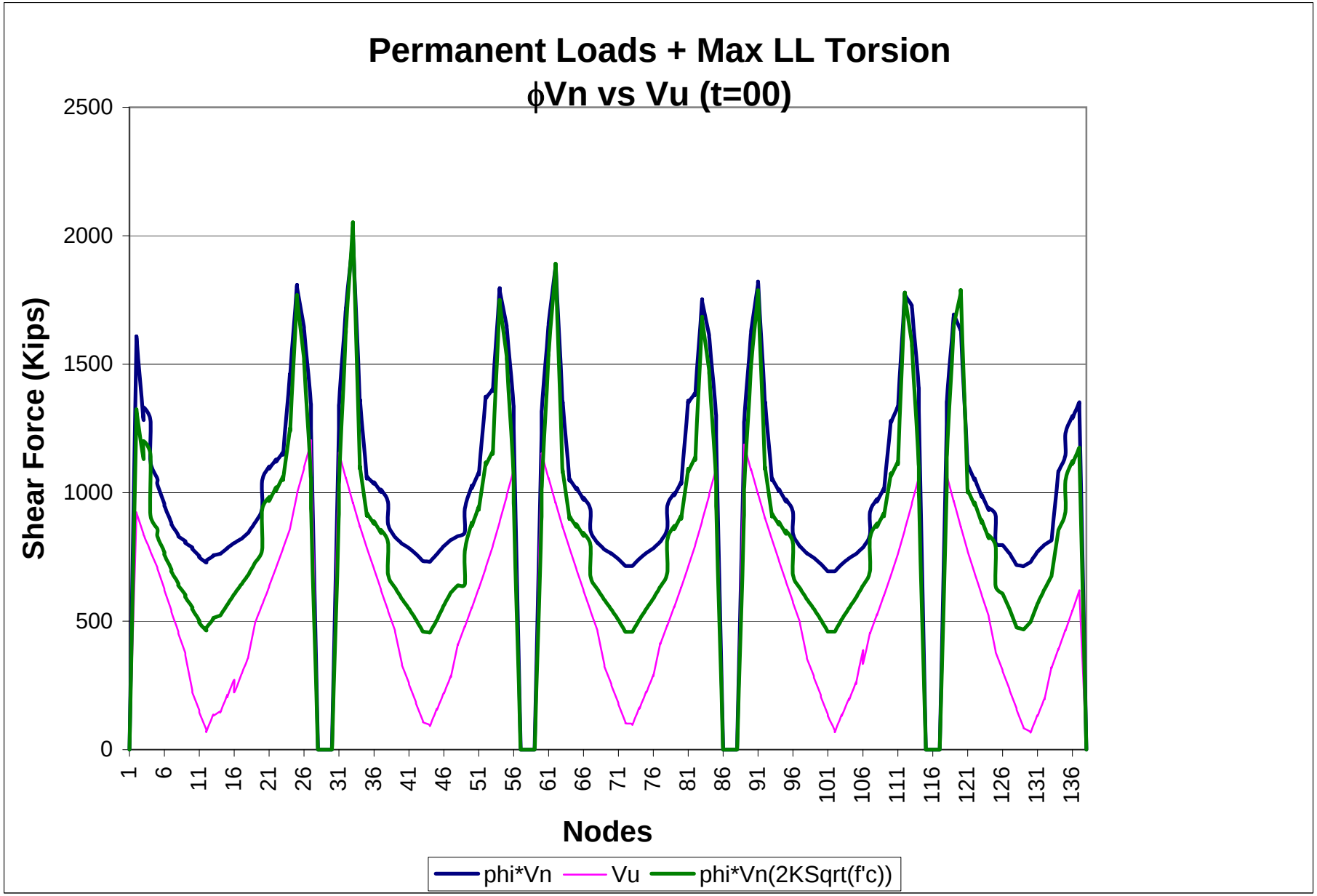
Mainline Segment 4 WB Flexural Strength, ϕM_n

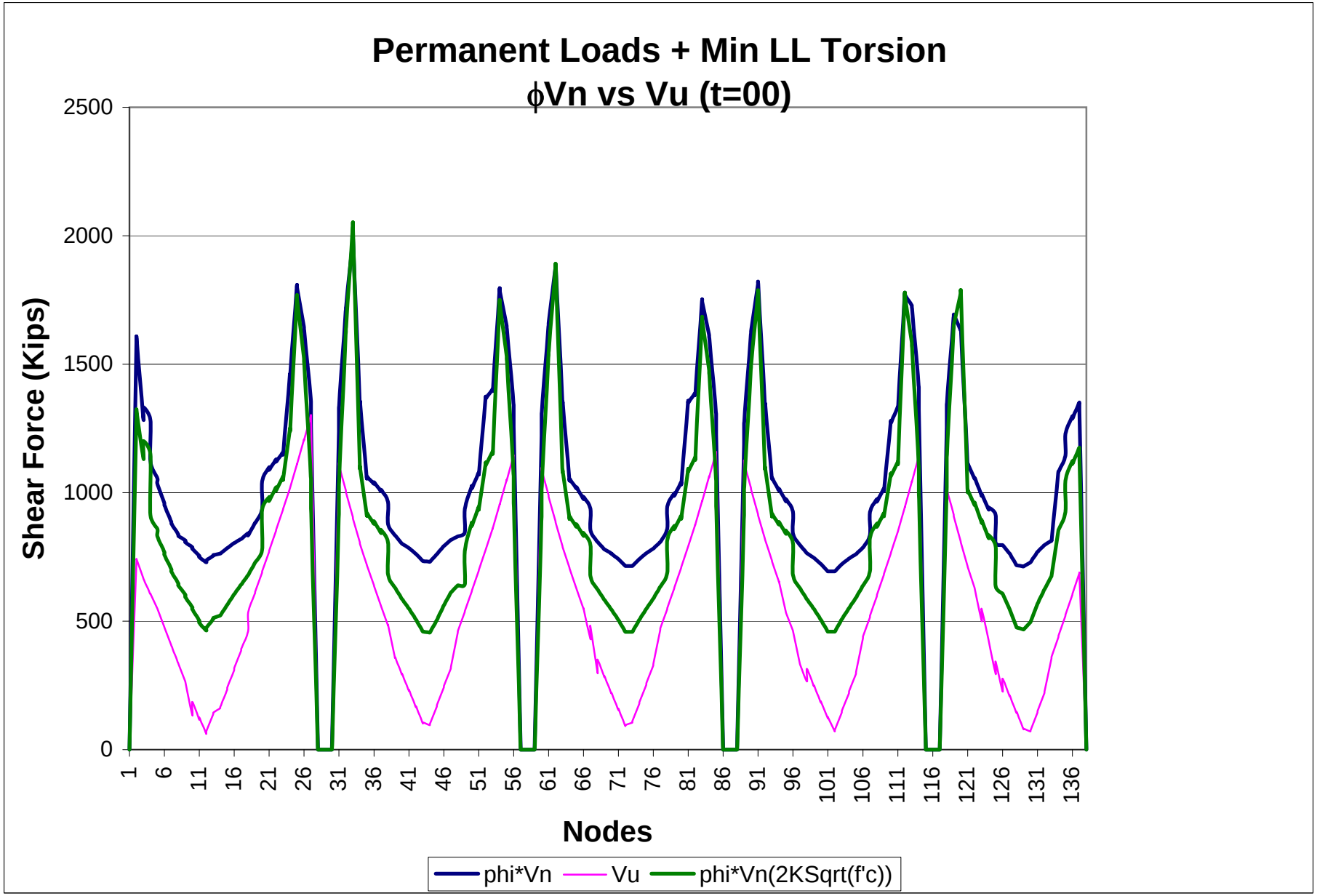


3.10.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
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Node := 27 Position := Ahead $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = 2047 \cdot kips$	$M_{dc_x} = -60947 \cdot kip \cdot ft$	$T_{dc_x} = -775\, ft \cdot kips$	$N_{dc_x} = 0 \cdot kips$	Dead Load
$V_{dw_x} = 247 \cdot kips$	$M_{dw_x} = -7899 \cdot kip \cdot ft$	$T_{dw_x} = -642 \cdot kip \cdot ft$	$N_{dw_x} = 0 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -104 \cdot kips$	$M_{psec_x} = 20516 \cdot kip \cdot ft$	$T_{psec_x} = -1112 \cdot kip \cdot ft$	$N_{psec_x} = 0 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -17\, kip$	$M_{crsh_x} = 3421 \cdot kip \cdot ft$	$T_{crsh_x} = -122 \cdot kip \cdot ft$	$N_{crsh_x} = 0 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 442 \cdot kips$	$M_{LLvmax_x} = -7636 \cdot kip \cdot ft$	$T_{LLvmax_x} = -124 \cdot kip \cdot ft$	$N_{LLvmax_x} = 0 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -11 \cdot kips$	$M_{LLvmin_x} = 2177 \cdot kip \cdot ft$	$T_{LLvmin_x} = -96 \cdot kip \cdot ft$	$N_{LLvmin_x} = 0 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = 336 \cdot kips$	$M_{LLtmax_x} = -5177 \cdot kip \cdot ft$	$T_{LLtmax_x} = 4410 \cdot kip \cdot ft$	$N_{LLtmax_x} = 0 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = 320 \cdot kips$	$M_{LLtmin_x} = -1998 \cdot kip \cdot ft$	$T_{LLtmin_x} = -4867 \cdot kip \cdot ft$	$N_{LLtmin_x} = 0 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = -821 \cdot kips$ Primary PT Shear

$N_{prim_x} = -18476 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 49658 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1885 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = 5 \cdot kips$

$M_{tu_x} = -936 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 97 \cdot kip \cdot ft$

$N_{tu_x} = 0 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 18482 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 38773 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.413 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 57.923 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.243 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.143 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 154.287 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = 3413 \cdot kips$	$T_{uvmax_x} = -3272 \cdot kip \cdot ft$	$M_{uvmax_x} = -76114\, ft \cdot kips$	$N_{uvmax_x} = 0 \cdot kips$
$V_{uvmin_x} = 2802 \cdot kips$	$T_{uvmin_x} = -3234 \cdot kip \cdot ft$	$M_{uvmin_x} = -62867\, ft \cdot kips$	$N_{uvmin_x} = 0 \cdot kips$
$V_{utmax_x} = 3270 \cdot kips$	$T_{utmax_x} = 2849 \cdot kip \cdot ft$	$M_{utmax_x} = -72795\, ft \cdot kips$	$N_{utmax_x} = 0 \cdot kips$
$V_{utmin_x} = 3249 \cdot kips$	$T_{utmin_x} = -9675 \cdot kip \cdot ft$	$M_{utmin_x} = -68503\, ft \cdot kips$	$N_{utmin_x} = 0 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.898\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 16438 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 90.526 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 81.474 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00036$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.731 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.592$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 491.433 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 938.917\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 198.9 \cdot kips$

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$$RF_{vpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{vpos_{x,1}} = 1.64$$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$$\varepsilon_{svmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{svmin_x} = -0.0004$$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 511.213 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 938.917\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -4.95 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 2.402$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.00038$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.679 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.695$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 499.101 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"No"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 938.917\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 151.2 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{tpos_{x,1}} = 2.211$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

ε

$\varepsilon_{stmin_x} = -0.00039$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.625 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.804$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 507.287 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 985.04\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = 241.609 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.229}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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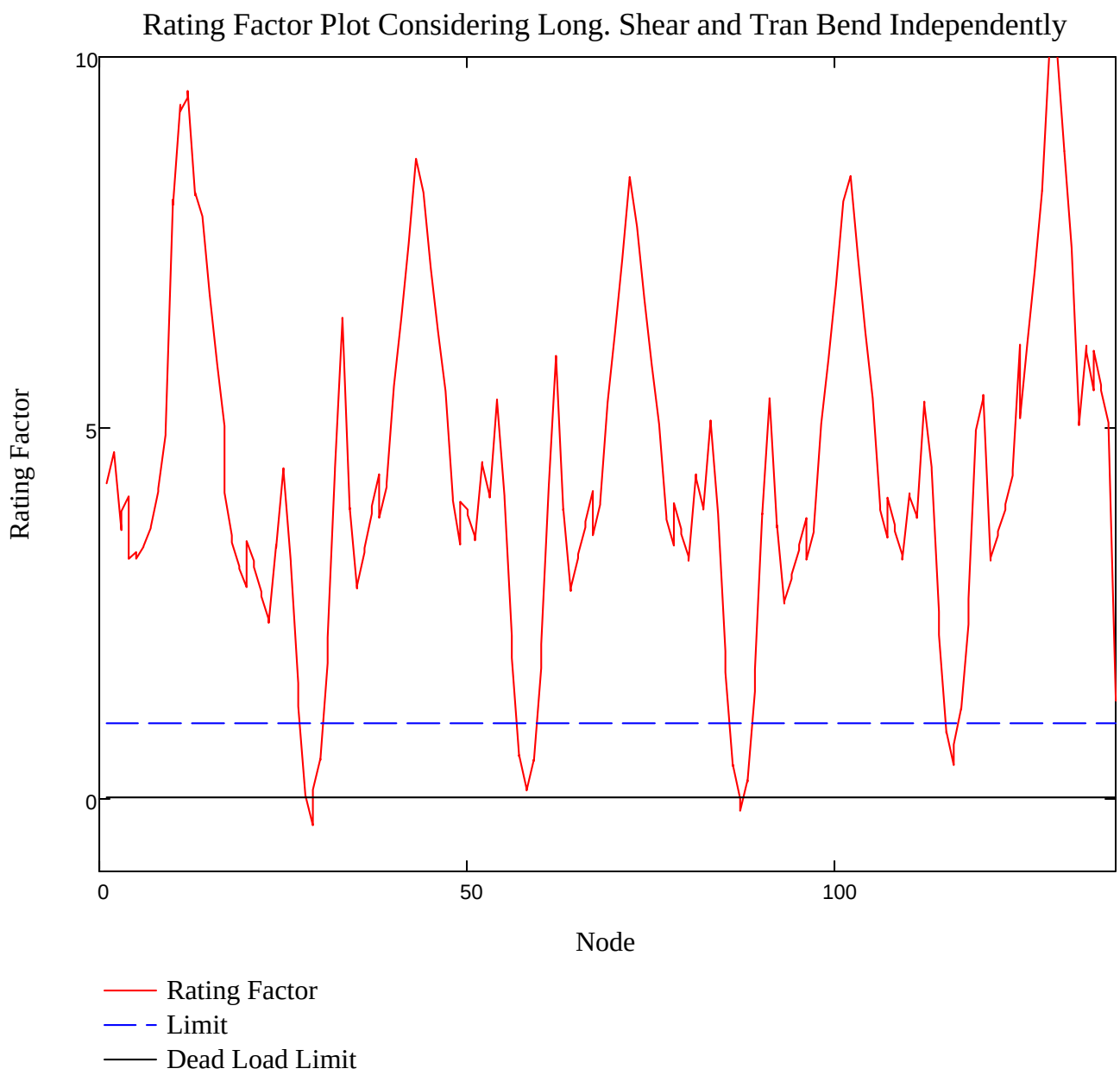

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.229$ at node $minRF_2 = 27$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.705$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 160.248 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 80.261 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.285 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.142 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.495 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 24.8 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 21.38 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 24.8 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 320.287 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 976.848 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.486 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 21.194 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 644.158 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.268 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.978 \cdot in$

$\phi M_{n_3} := \min\left[\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right]\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 21.38 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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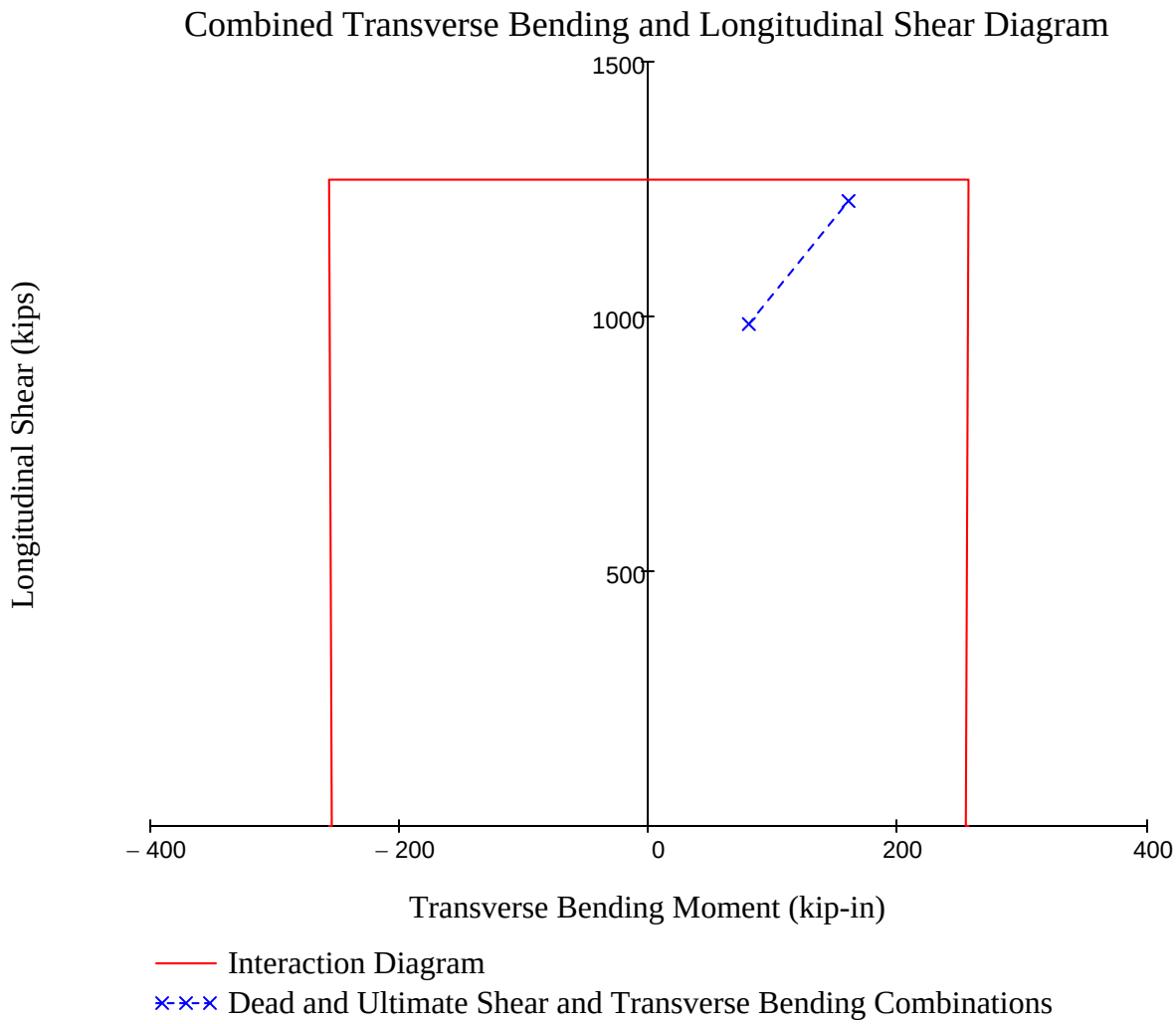


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.204$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

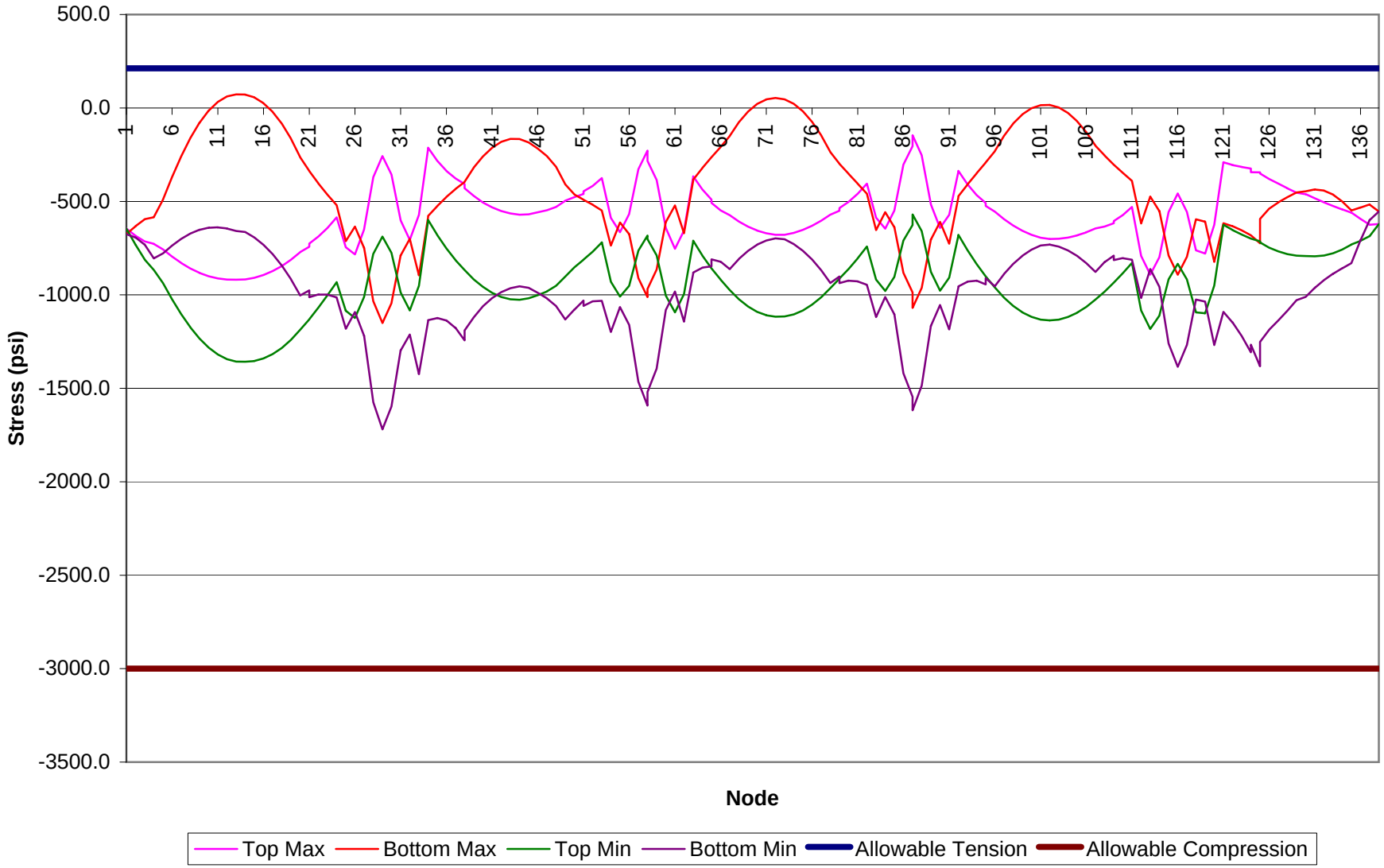
$RF_{shear} = 1.656$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

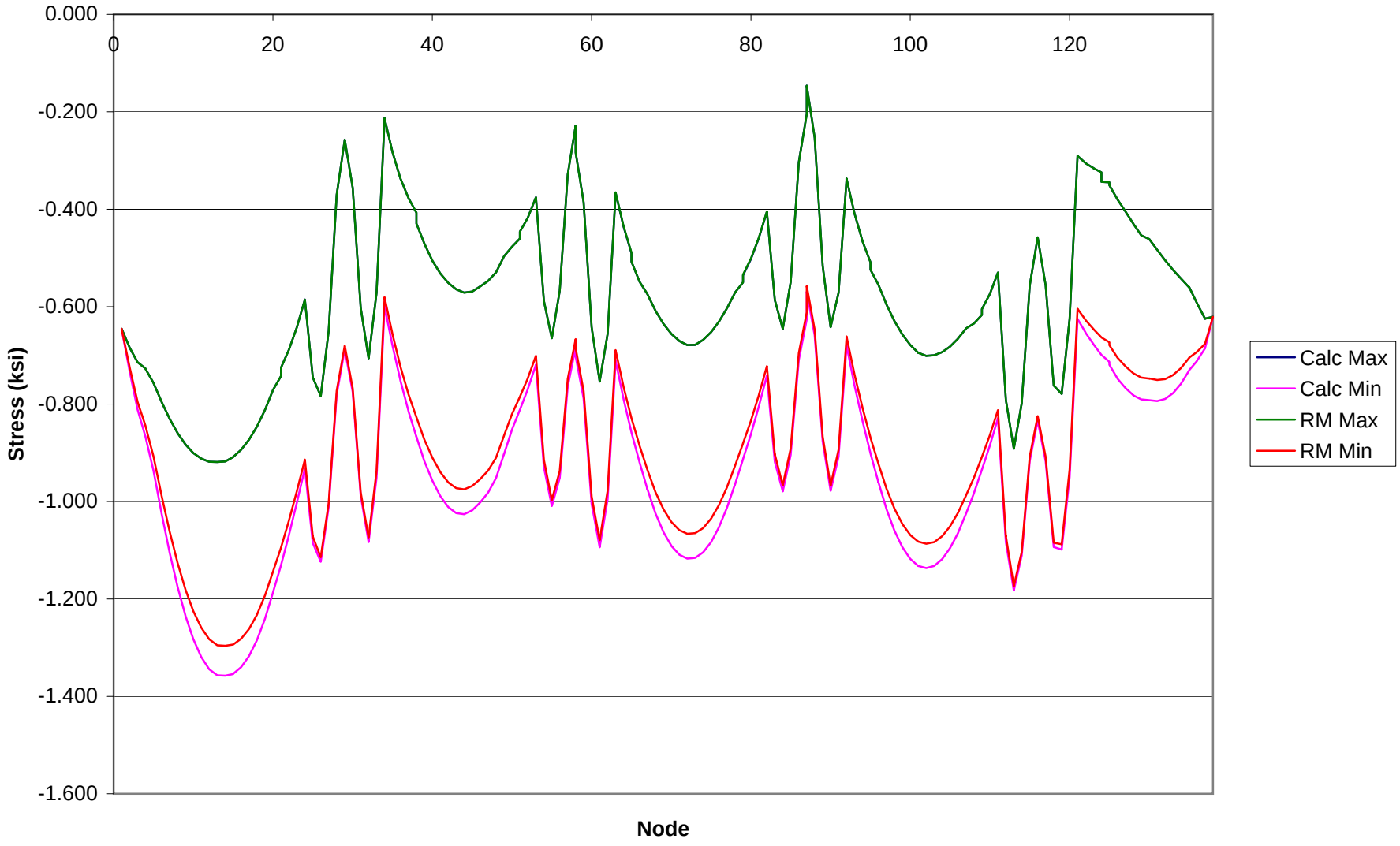
$RF_{torsion} = 1.173$

3.10.4 Service I Flexure (Service Stresses)

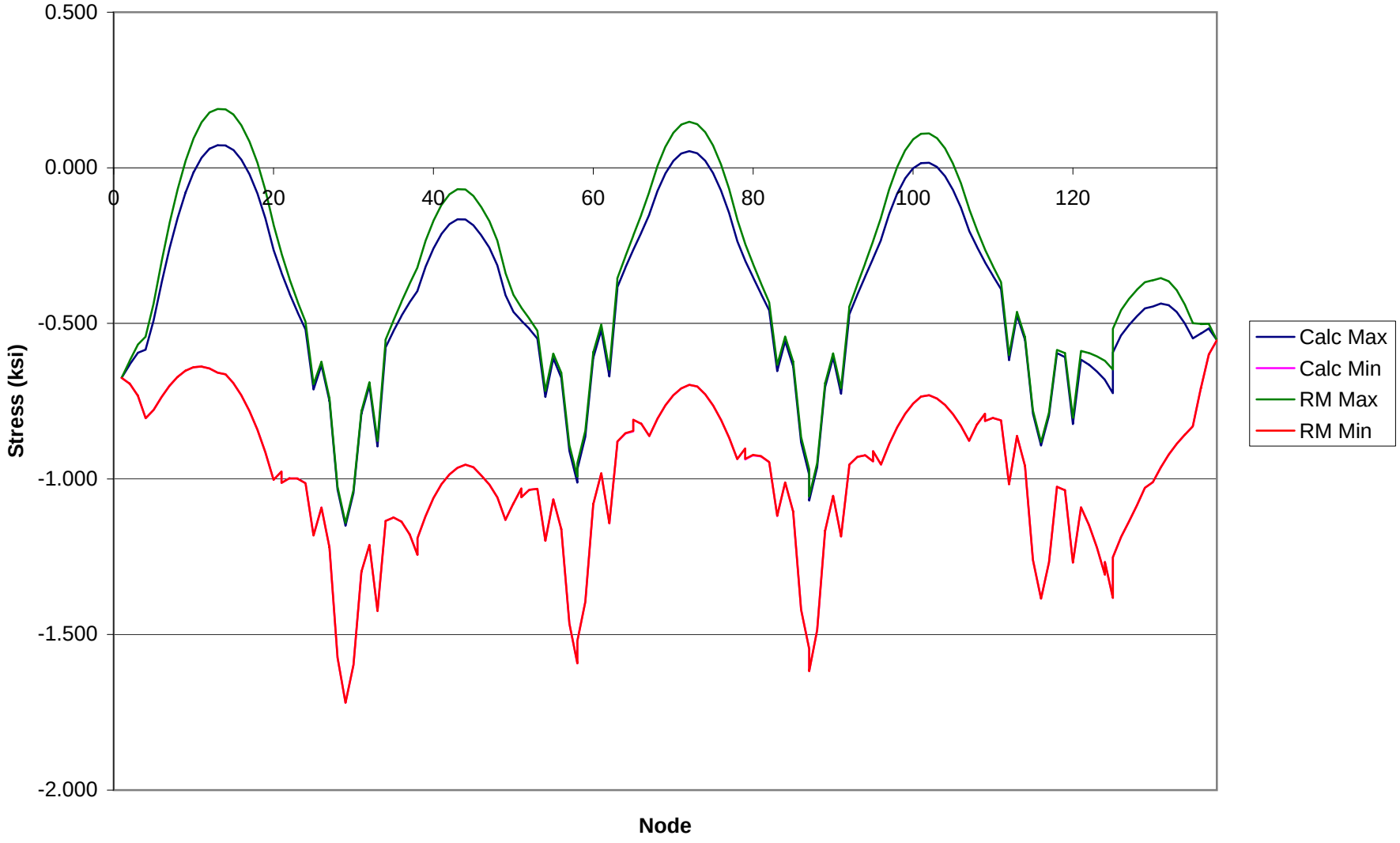
Service Stresses



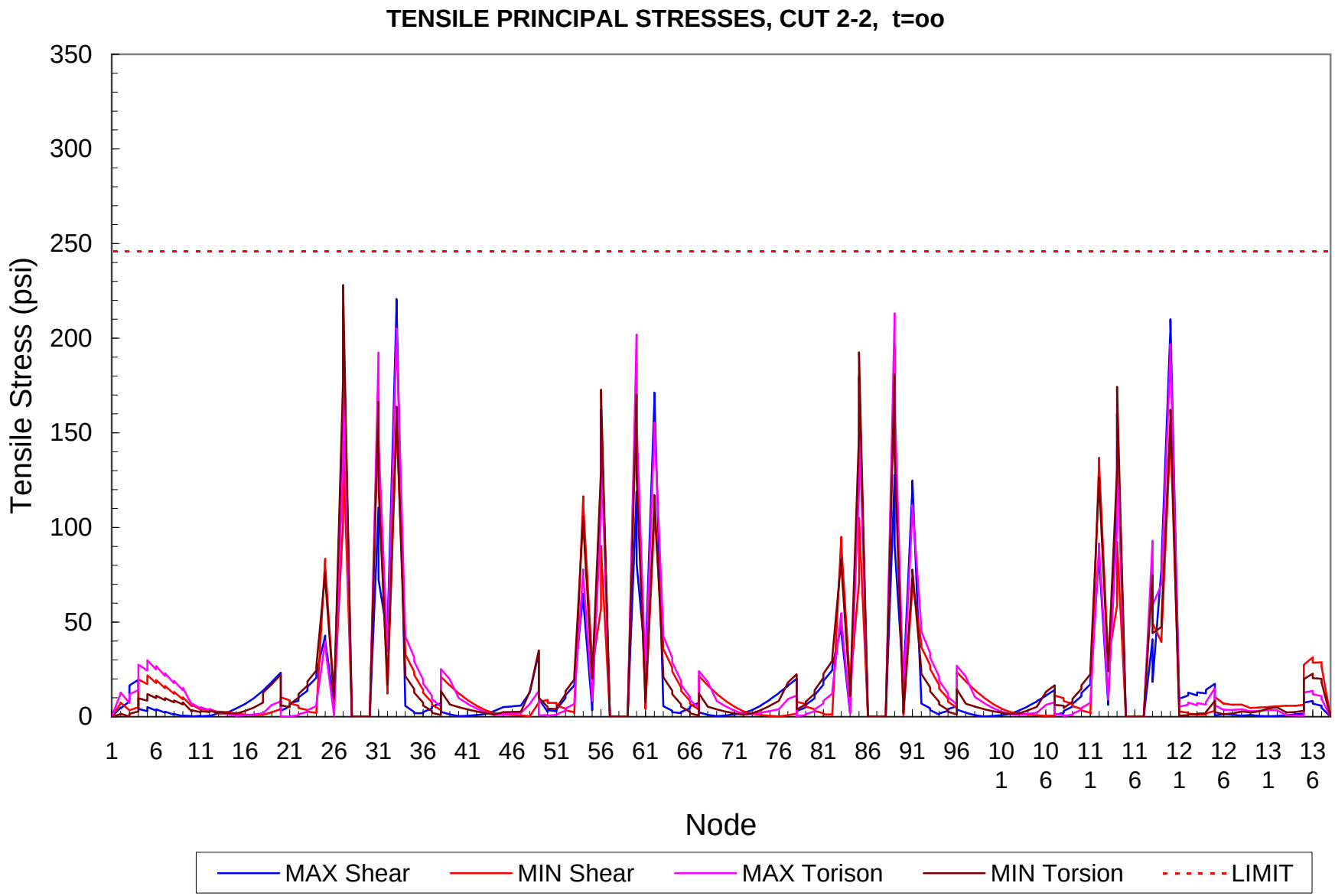
Mainline Segment 4 WB Top Service Stresses



Mainline Segment 4 WB Bottom Service Stresses

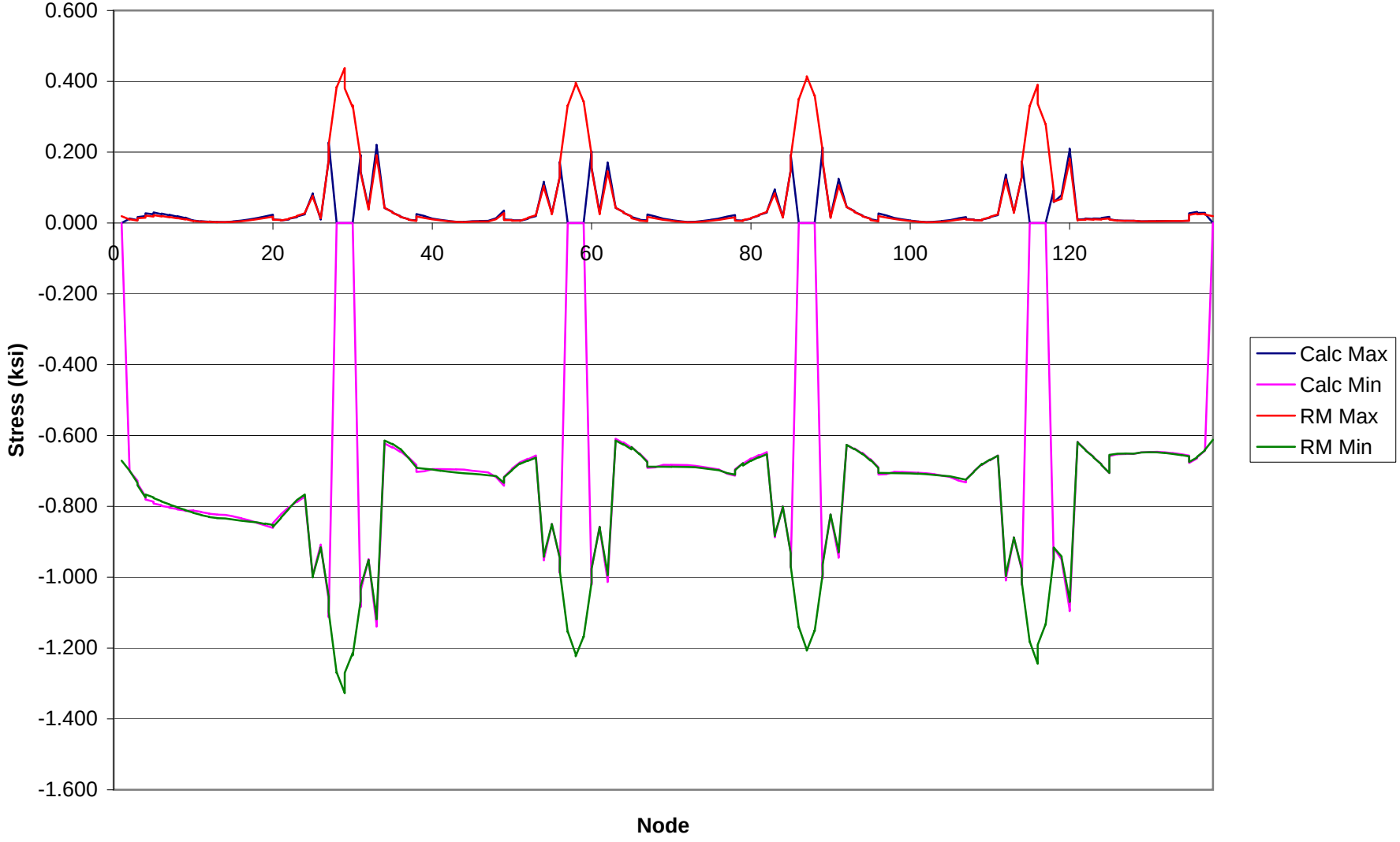


3.10.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.10.5/1

Mainline Segment 4 WB Principal Stresses



3.11 Mainline Segment 5 EB Rating

3.11.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 5 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 5 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.99	2.59	1.83	1.90	1.72	2.26	2.24	2.09	2.10	1.87	2.04	1.83
		Shear	1.26	1.64	1.15	1.16	0.97	1.16	1.16	0.90	0.91	0.81	0.73	0.73
	Service	Flexure	1.04	2.29	2.03	2.07	1.87	2.05	2.03	1.88	1.89	1.70	1.83	1.66
		Principal Stress	1.13	1.04	0.94	1.07	1.19	1.02	1.01	0.87	0.93	0.83	0.87	0.84
Transverse	Strength	Top Slab Centerline	1.69	2.19	2.47	2.59	2.76	2.21	2.14	2.12	2.13	1.88	2.17	1.97
		Top Slab Thickness Change	1.78	2.31	2.54	2.59	2.59	2.38	2.41	2.20	2.31	1.84	2.36	1.89
		Top Slab Webs & Cantilever	1.85	2.40	2.36	2.93	2.90	2.85	2.25	2.27	2.32	1.81	2.65	2.00
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 5 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

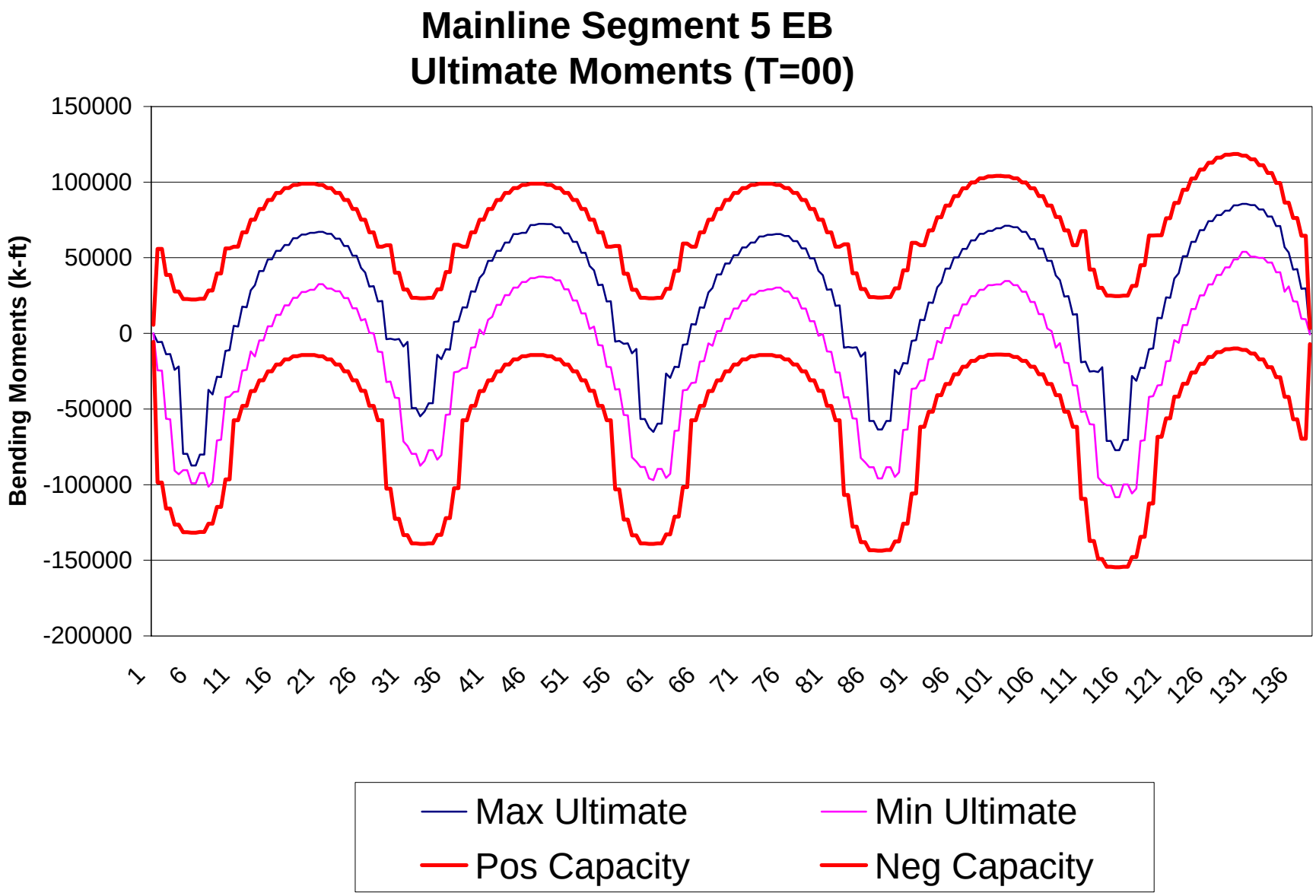
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 5 EB			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	2.03	2.64										
		Shear	1.52	1.93										
	Service	Flexure	1.06	2.29										
		Principal Stress	1.22	1.23										
Transverse	Strength	Top Slab Centerline	1.69	2.19										
		Top Slab Thickness Change	2.23	2.89										
		Top Slab Webs & Cantilever	3.02	3.92										
		Transverse Web Bending	2.59	3.47										

Overall Rating Factor	1.06	1.23	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		44.28	0.00	0.00

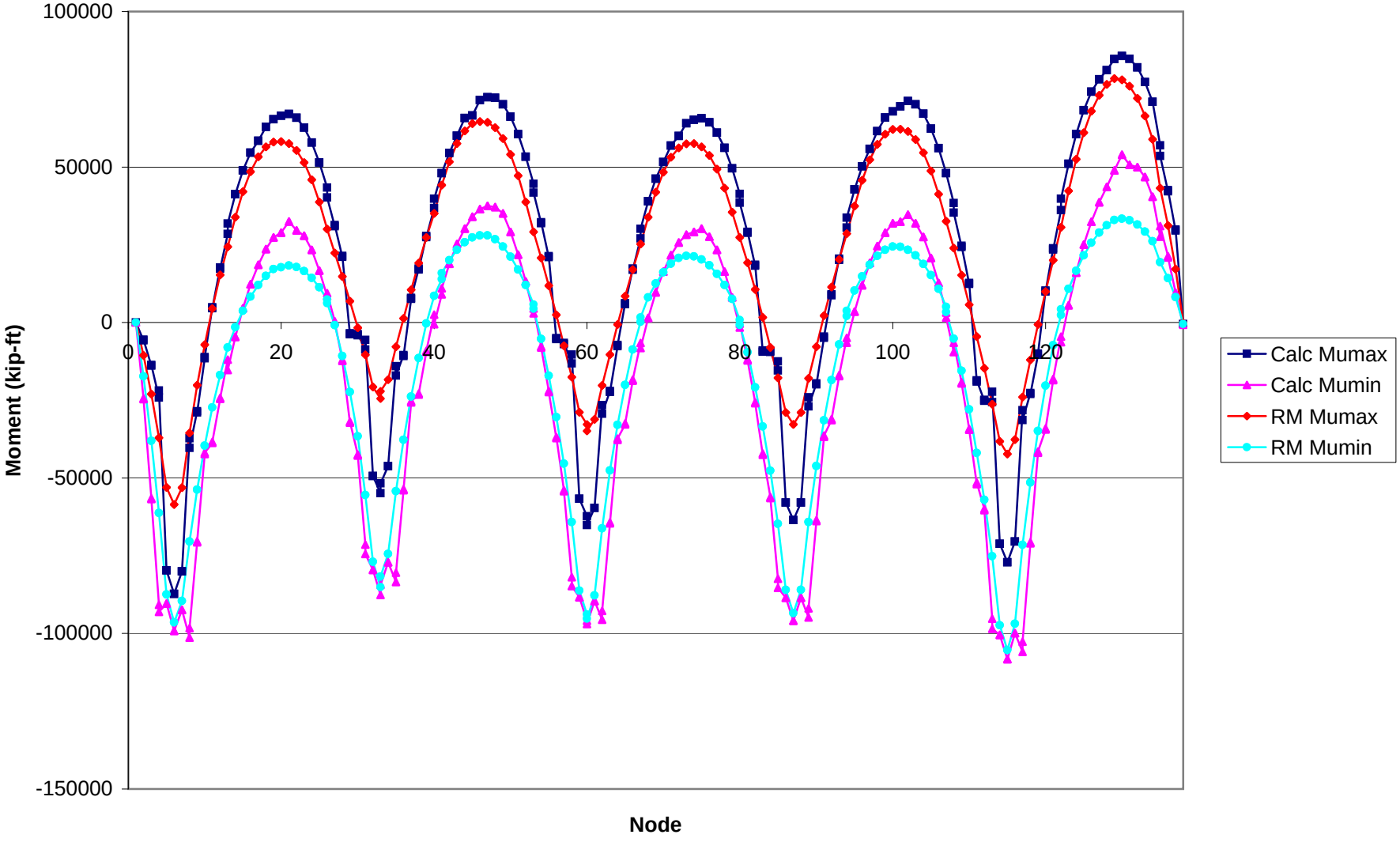
* Max number of lanes loaded = Per AASHTO LRFD

3.11.2 Strength I Flexure

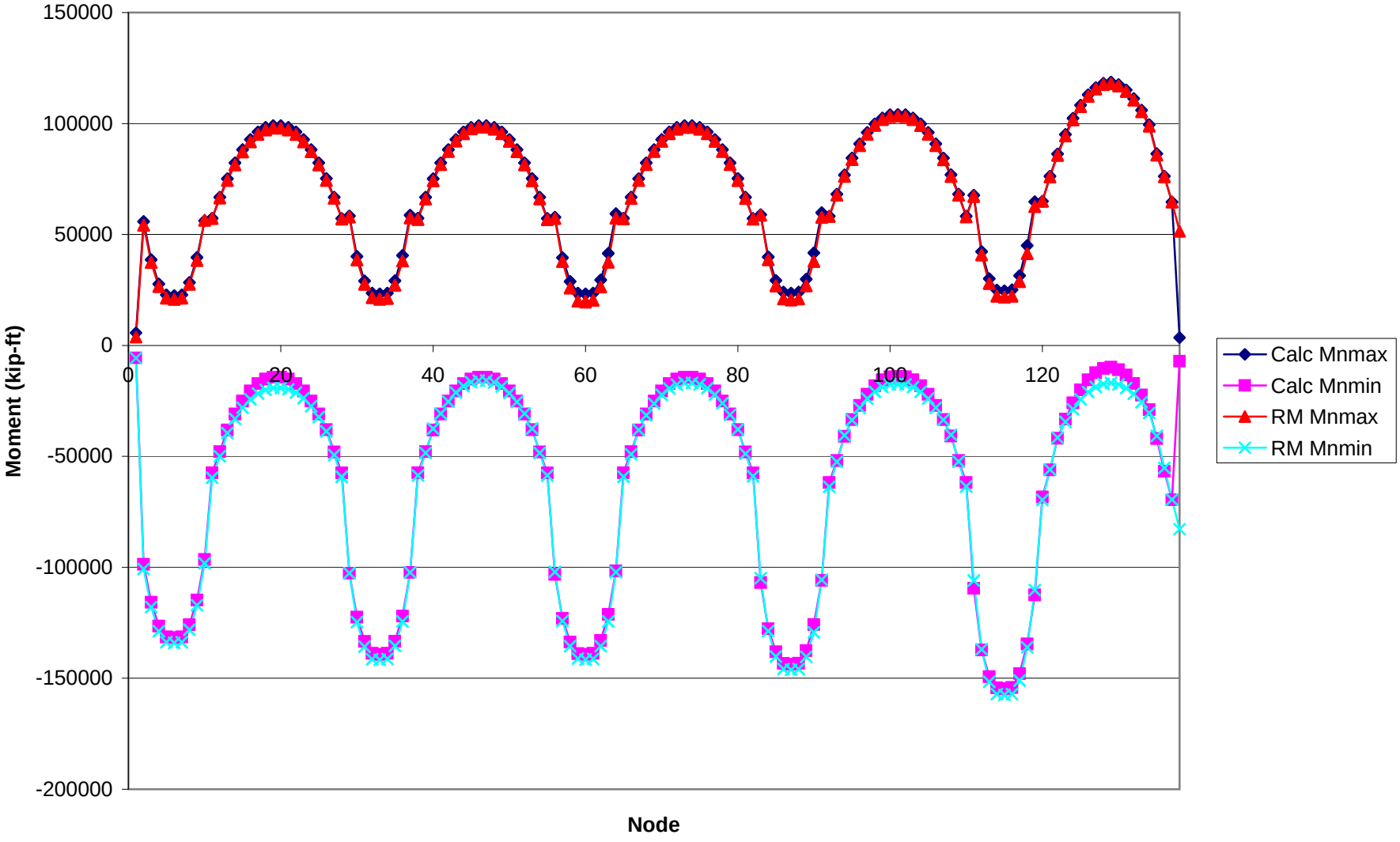

Mainline Segment 5 EB
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

3.11.2/1

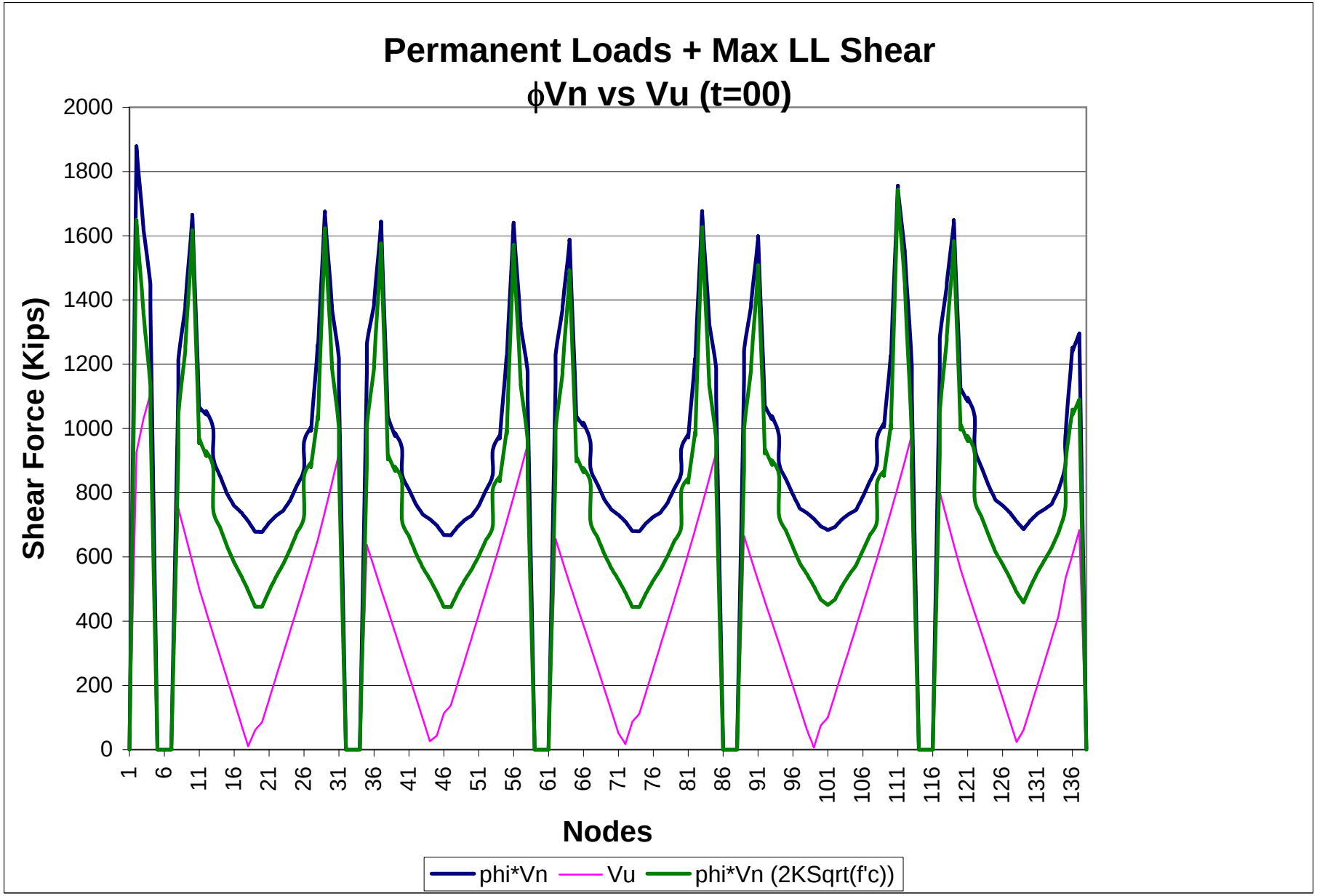
Mainline Segment 5 EB Flexural Demand, M_u

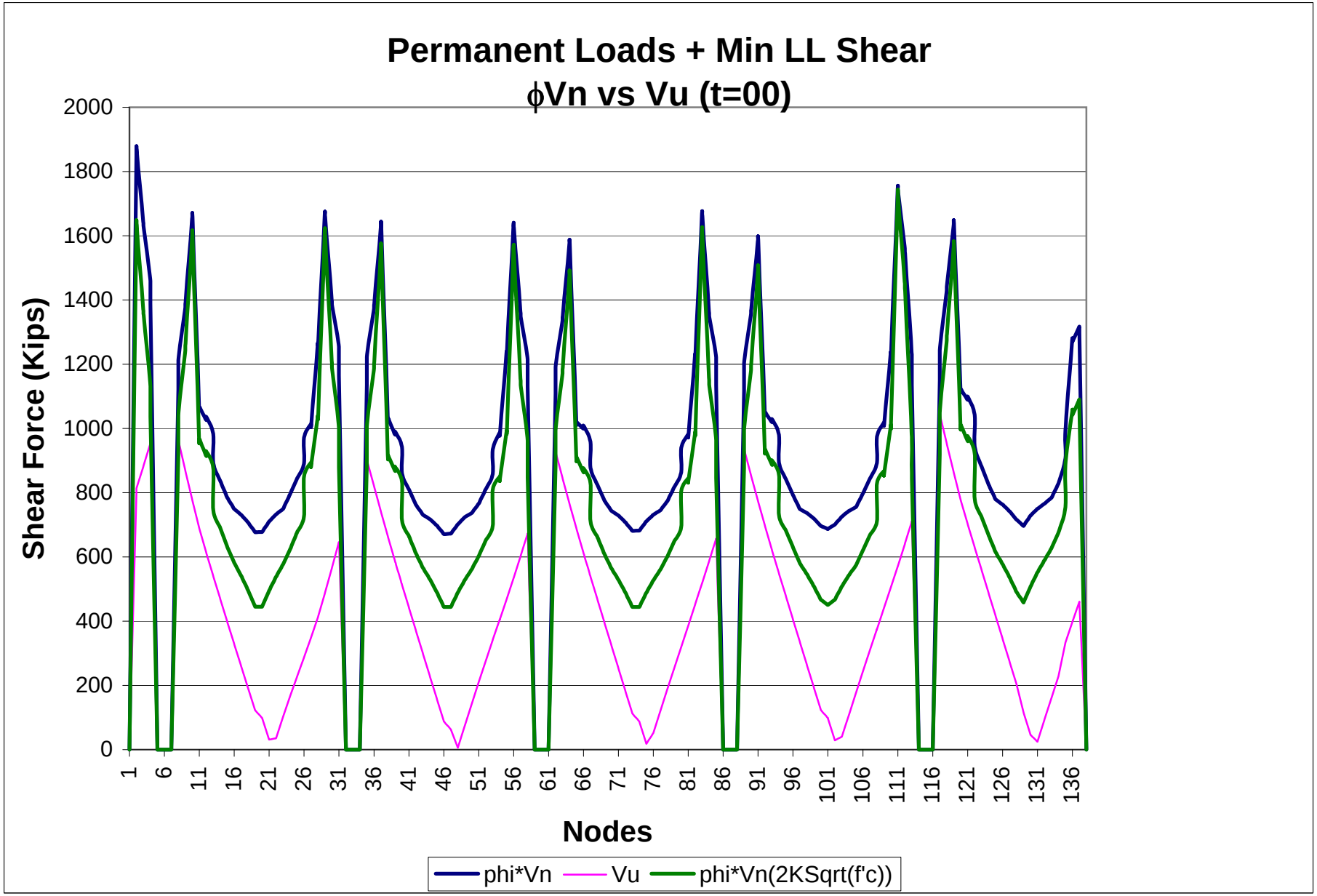


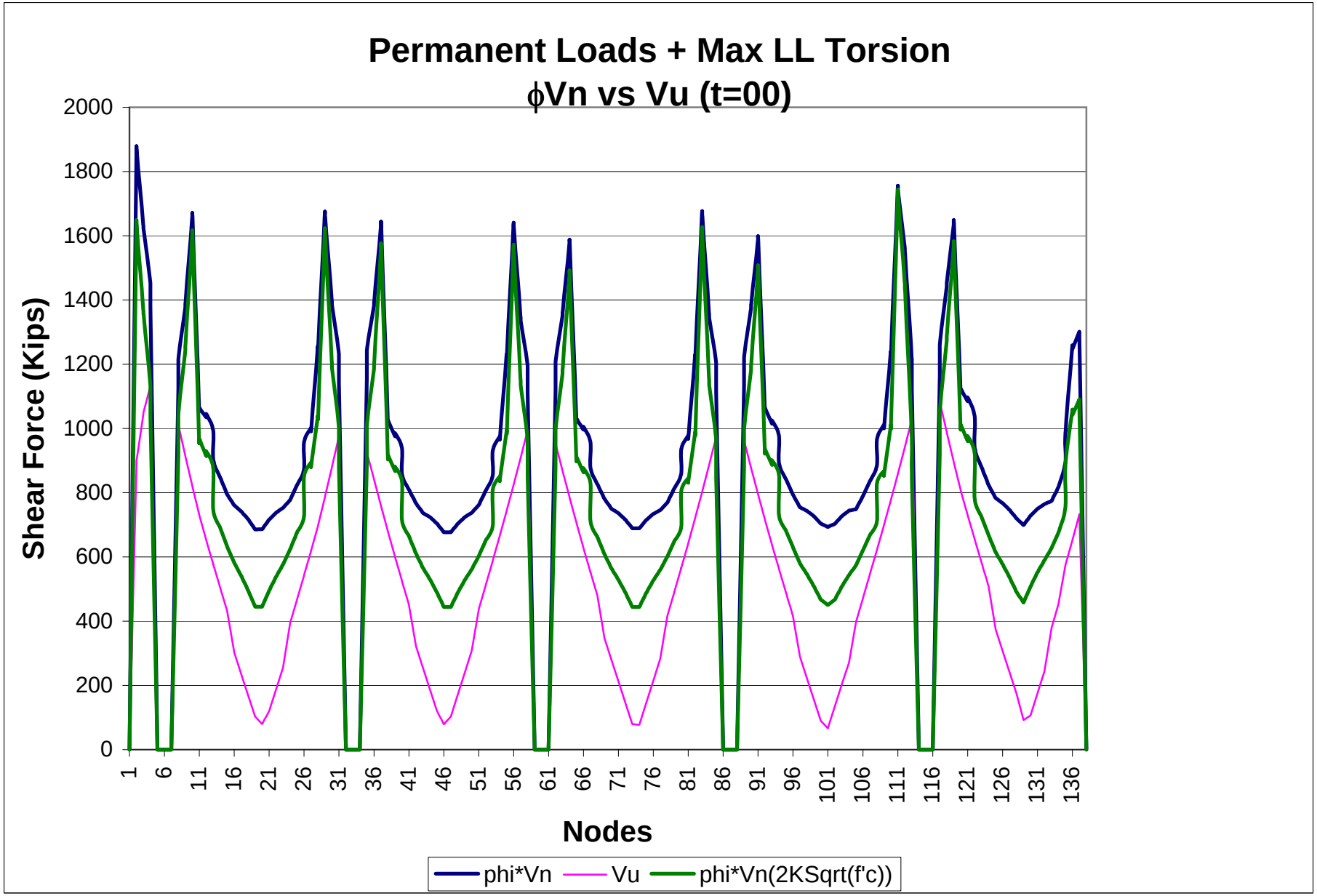
Mainline Segment 5 EB Flexural Strength, ϕM_n

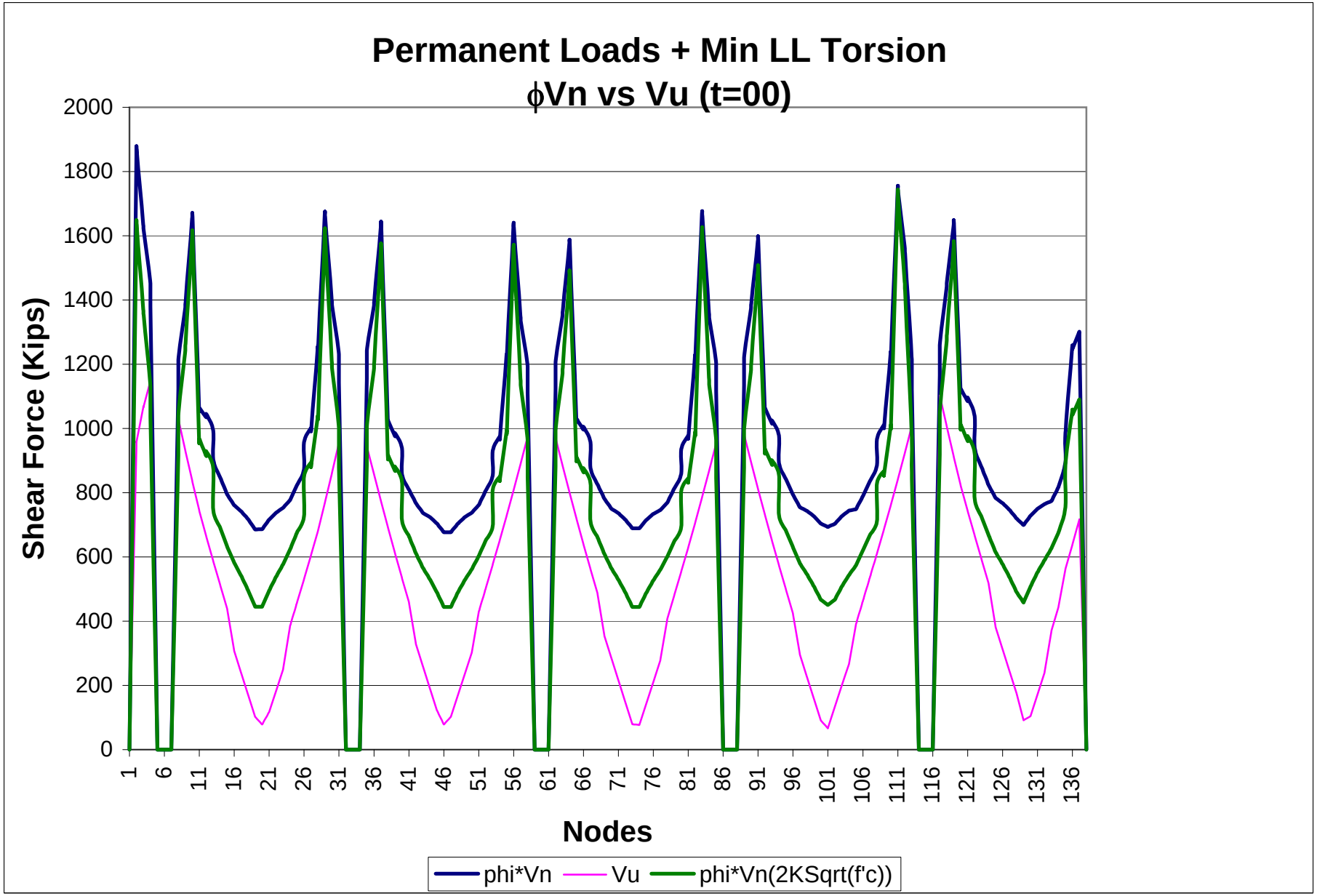


3.11.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

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Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 5 EB\

Node := 117 Position := Back $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -1778 \cdot kips$	$M_{dc_x} = -51071 \cdot kip \cdot ft$	$T_{dc_x} = 16\,ft \cdot kips$	$N_{dc_x} = 0 \cdot kips$	Dead Load
$V_{dw_x} = -212 \cdot kips$	$M_{dw_x} = -5873 \cdot kip \cdot ft$	$T_{dw_x} = -466 \cdot kip \cdot ft$	$N_{dw_x} = 0 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 97 \cdot kips$	$M_{psec_x} = 16530 \cdot kip \cdot ft$	$T_{psec_x} = 4 \cdot kip \cdot ft$	$N_{psec_x} = 0 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = 29\,kip$	$M_{crsh_x} = 4978 \cdot kip \cdot ft$	$T_{crsh_x} = -27 \cdot kip \cdot ft$	$N_{crsh_x} = 0 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 12 \cdot kips$	$M_{LLvmax_x} = 2118 \cdot kip \cdot ft$	$T_{LLvmax_x} = -5 \cdot kip \cdot ft$	$N_{LLvmax_x} = 0 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -404 \cdot kips$	$M_{LLvmin_x} = -6890 \cdot kip \cdot ft$	$T_{LLvmin_x} = -7 \cdot kip \cdot ft$	$N_{LLvmin_x} = 0 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -293 \cdot kips$	$M_{LLtmax_x} = -2413 \cdot kip \cdot ft$	$T_{LLtmax_x} = 4314 \cdot kip \cdot ft$	$N_{LLtmax_x} = 0 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -293 \cdot kips$	$M_{LLtmin_x} = -2401 \cdot kip \cdot ft$	$T_{LLtmin_x} = -4326 \cdot kip \cdot ft$	$N_{LLtmin_x} = 0 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = 878 \cdot kips$ Primary PT Shear

$N_{prim_x} = -14250 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 35268 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1216 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = 0 \cdot kips$

$M_{tu_x} = 18 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = -1 \cdot kip \cdot ft$

$N_{tu_x} = 0 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 17867 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 39103 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 59.366 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.243 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.143 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 119.133 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 106 \cdot in$ Depth of Mild Steel

URS

Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -2413 \cdot kips$	$T_{uvmax_x} = -695 \cdot kip \cdot ft$	$M_{uvmax_x} = -50770\, ft \cdot kips$	$N_{uvmax_x} = 0 \cdot kips$
$V_{uvmin_x} = -2974 \cdot kips$	$T_{uvmin_x} = -698 \cdot kip \cdot ft$	$M_{uvmin_x} = -62931\, ft \cdot kips$	$N_{uvmin_x} = 0 \cdot kips$
$V_{utmax_x} = -2825 \cdot kips$	$T_{utmax_x} = 5135 \cdot kip \cdot ft$	$M_{utmax_x} = -56887\, ft \cdot kips$	$N_{utmax_x} = 0 \cdot kips$
$V_{utmin_x} = -2825 \cdot kips$	$T_{utmin_x} = -6529 \cdot kip \cdot ft$	$M_{utmin_x} = -56871\, ft \cdot kips$	$N_{utmin_x} = 0 \cdot kips$

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Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.73\,ksi$

$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 16578 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \frac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \frac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 89.556 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 80.601 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$

$\varepsilon_{svmax_x} = -0.00033$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.829 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.408$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 472.609 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"No"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -809.667\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 5.4 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 2.062$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.00028$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 28.036 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.05$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 446.193 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -809.667\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -181.8 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.992$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.0003$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.944 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.203$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 457.508 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -819.808\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -217.638 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{tmax_i})}$

$V_p \leftarrow |V_{prim_i}|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{tpos_{x,1}} = 1.673$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004)$ otherwise

ε

$\varepsilon_{stmin_x} = -0.0003$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.944 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.204$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 457.535 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -819.808\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -217.877 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.671}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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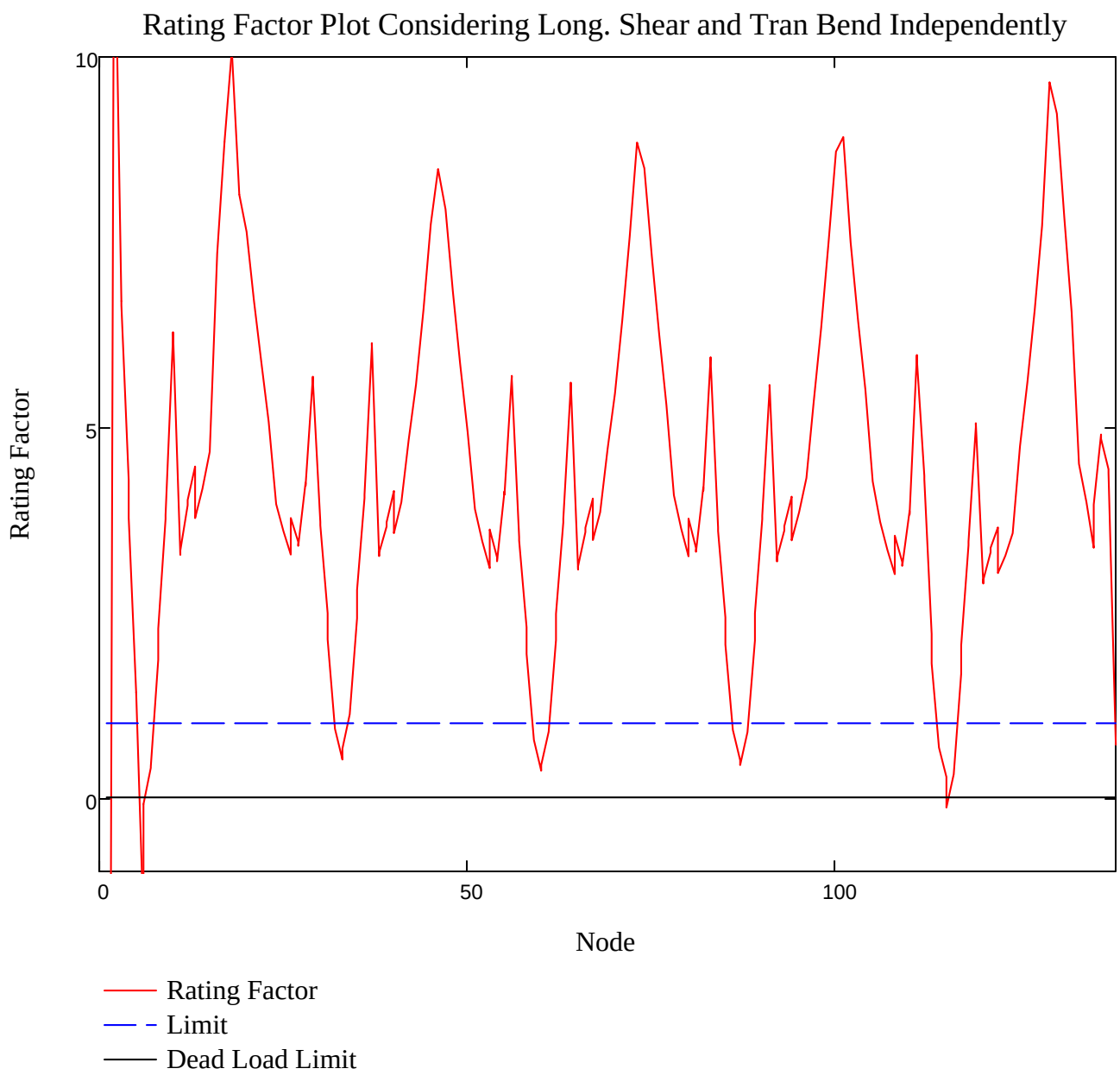

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.671$ at node $minRF_2 = 117$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.705$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 160.248 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 80.261 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.285 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.142 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.495 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 19.242 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 283.995 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 944.343 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 19.115 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 563.054 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.195 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.868 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 19.242 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

URS

Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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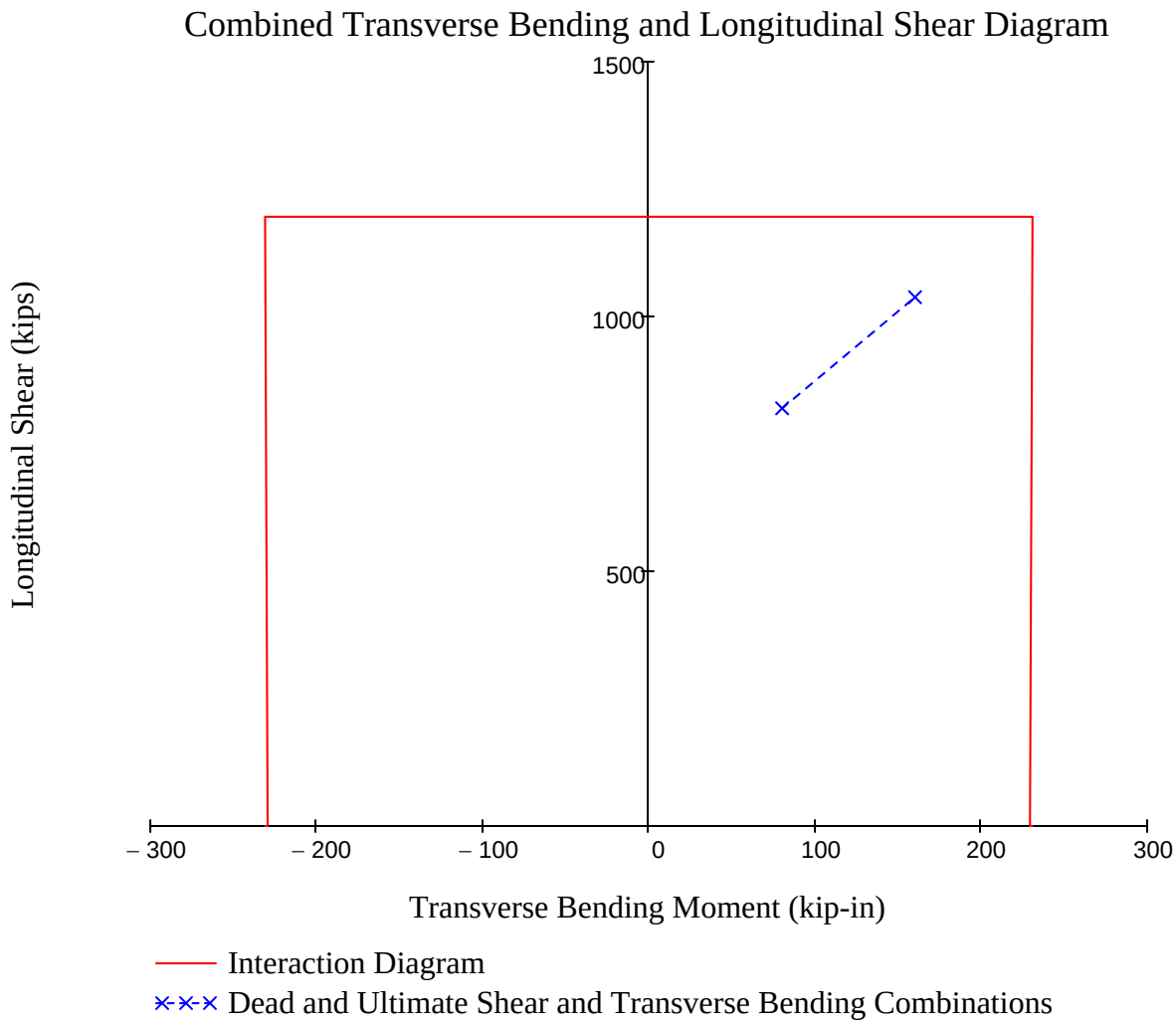


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.883$

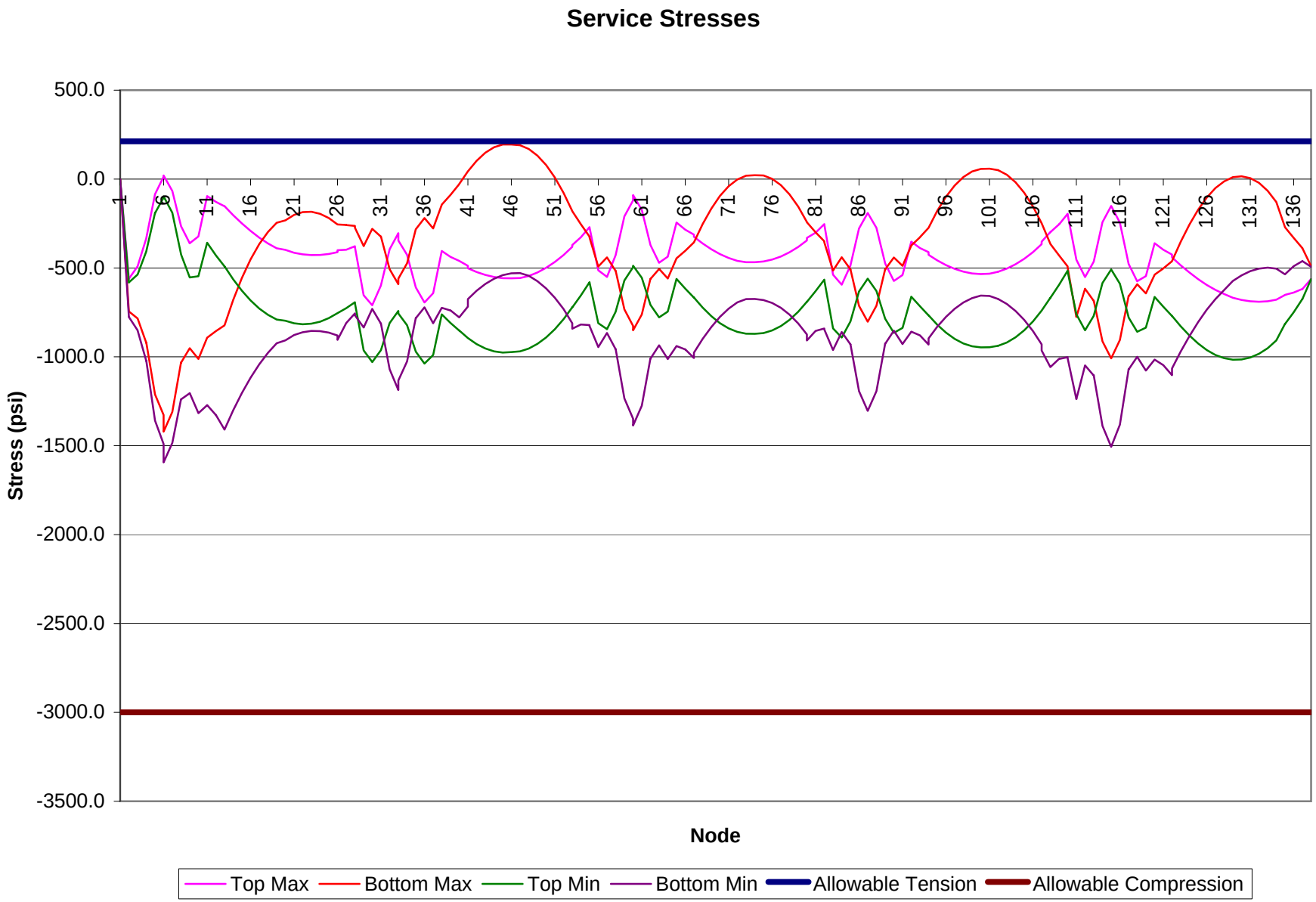
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

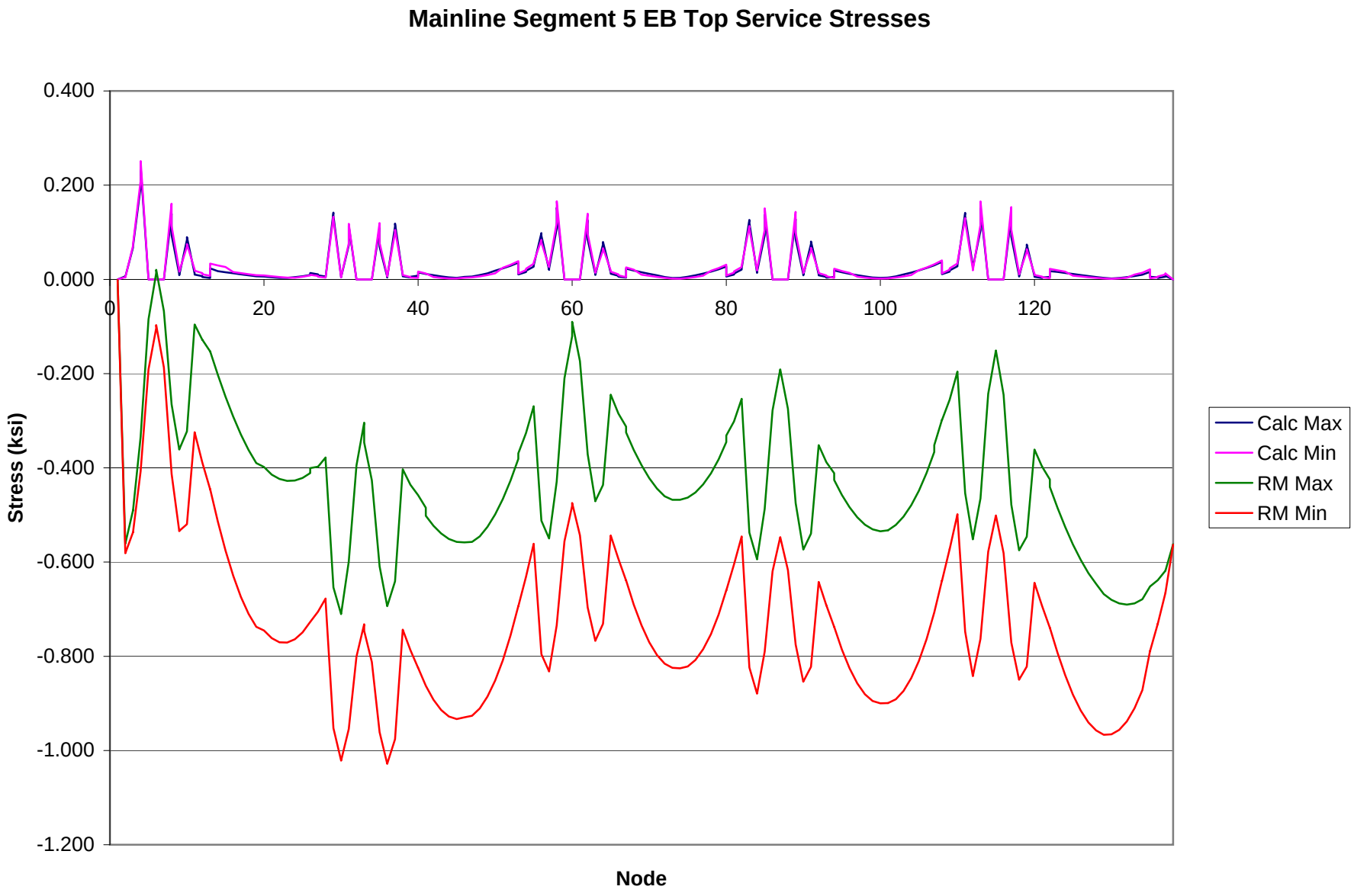
$RF_{shear} = 2.122$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

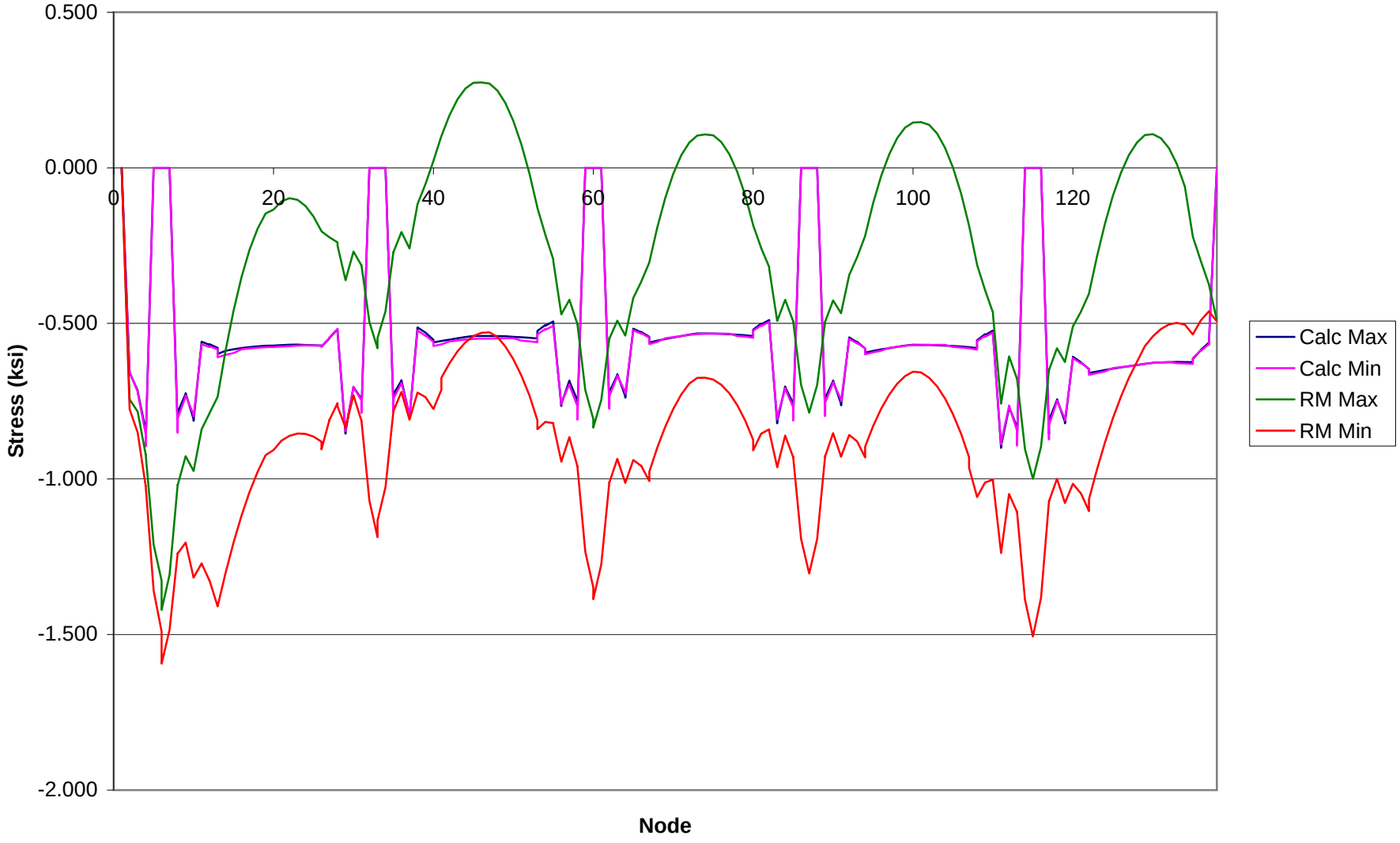
$RF_{torsion} = 1.724$

3.11.4 Service I Flexure (Service Stresses)

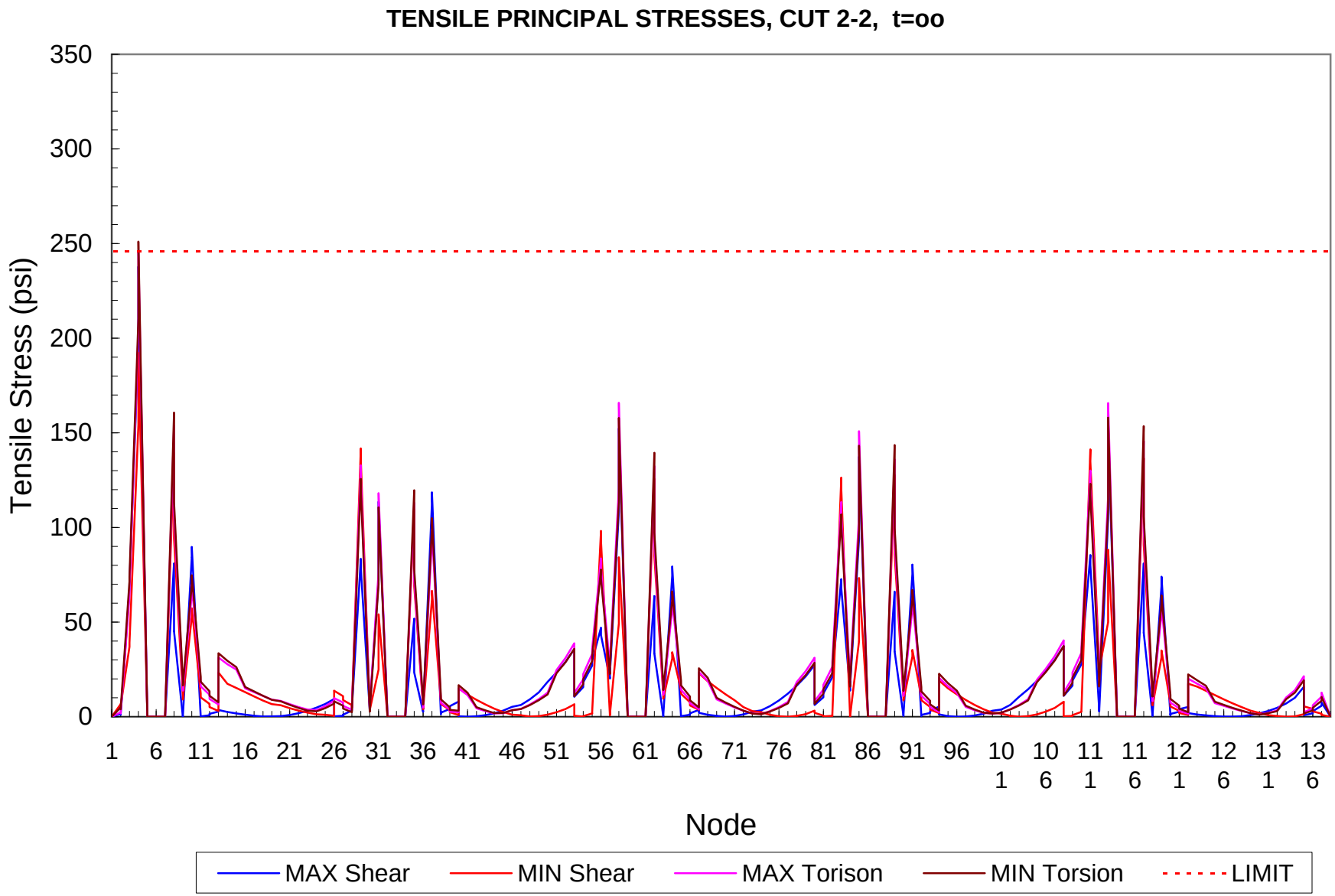

Service Stresses
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
-2500.0
-3000.0
-3500.0
Stress (psi)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
131
136
Node
Top Max
Bottom Max
Top Min
Bottom Min
Allowable Tension
Allowable Compression


Mainline Segment 5 EB Top Service Stresses
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
0
20
40
60
80
100
120
Stress (ksi)
Node
Calc Max
Calc Min
RM Max
RM Min

Mainline Segment 5 EB Bottom Service Stresses

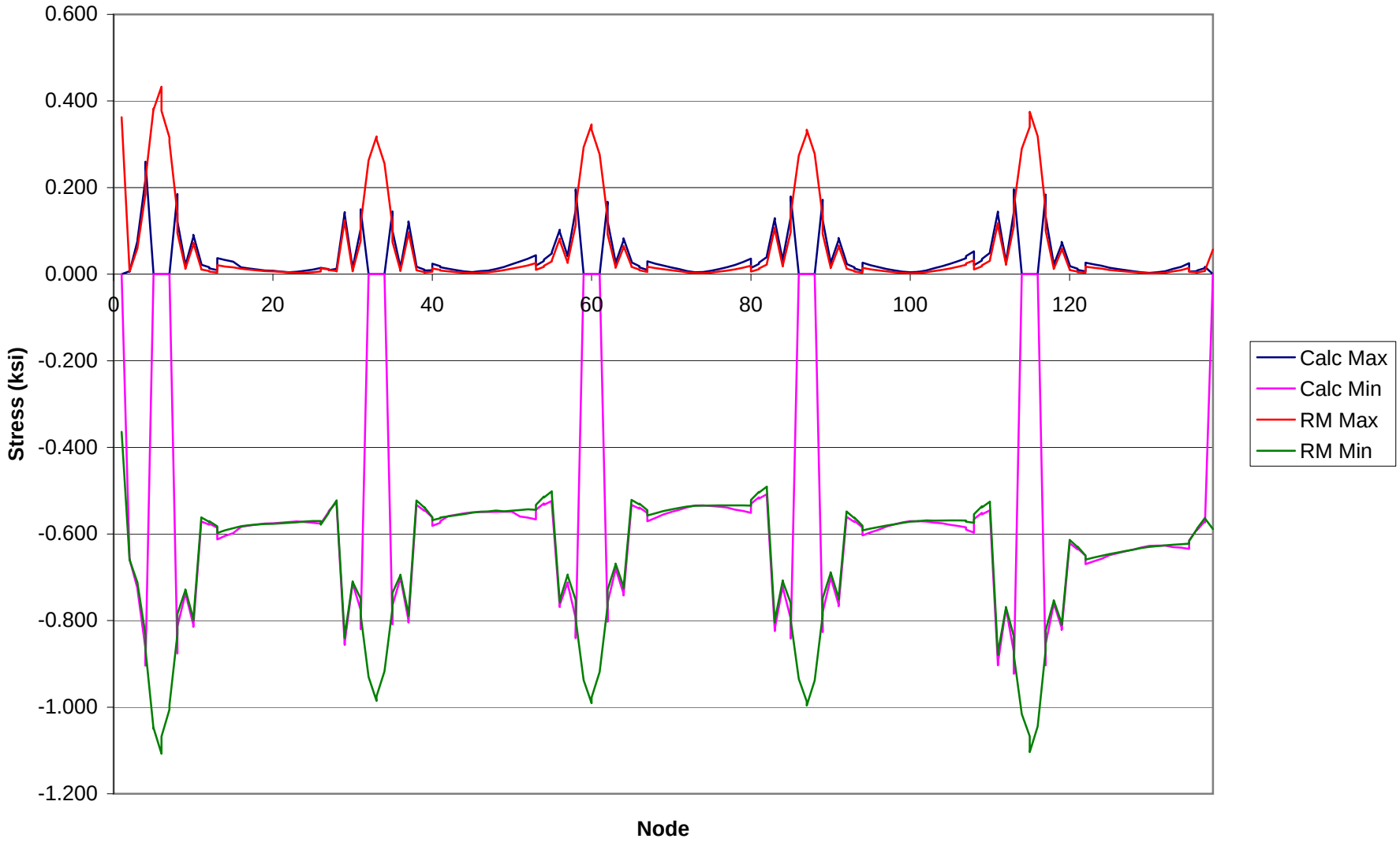


3.11.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.11.5/1

Mainline Segment 5 EB Principal Stresses



3.12 Mainline Segment 5 WB Rating

3.12.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 5 WB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 5 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.67	2.16	1.62	1.74	1.71	2.03	1.99	1.78	1.85	1.68	1.84	1.65
		Shear	1.33	1.73	1.21	1.23	1.06	1.30	1.30	1.06	1.06	0.90	0.82	0.82
	Service	Flexure	0.88	2.22	1.97	2.03	1.85	2.00	1.98	1.85	1.85	1.69	1.83	1.65
		Principal Stress	1.15	1.09	0.99	1.05	1.19	1.07	1.06	0.91	0.98	0.87	0.87	0.87
Transverse	Strength	Top Slab Centerline	1.69	2.19	2.47	2.59	2.76	2.21	2.14	2.12	2.13	1.88	2.17	1.97
		Top Slab Thickness Change	1.78	2.31	2.54	2.59	2.59	2.38	2.41	2.20	2.31	1.84	2.36	1.89
		Top Slab Webs & Cantilever	1.85	2.40	2.36	2.93	2.90	2.85	2.25	2.27	2.32	1.81	2.65	2.00
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.61	0.60	0.52	0.52	0.52	0.38	0.54	0.42

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	66.50

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 5 WB** CALCS BY: TSP DATE: 10/21/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

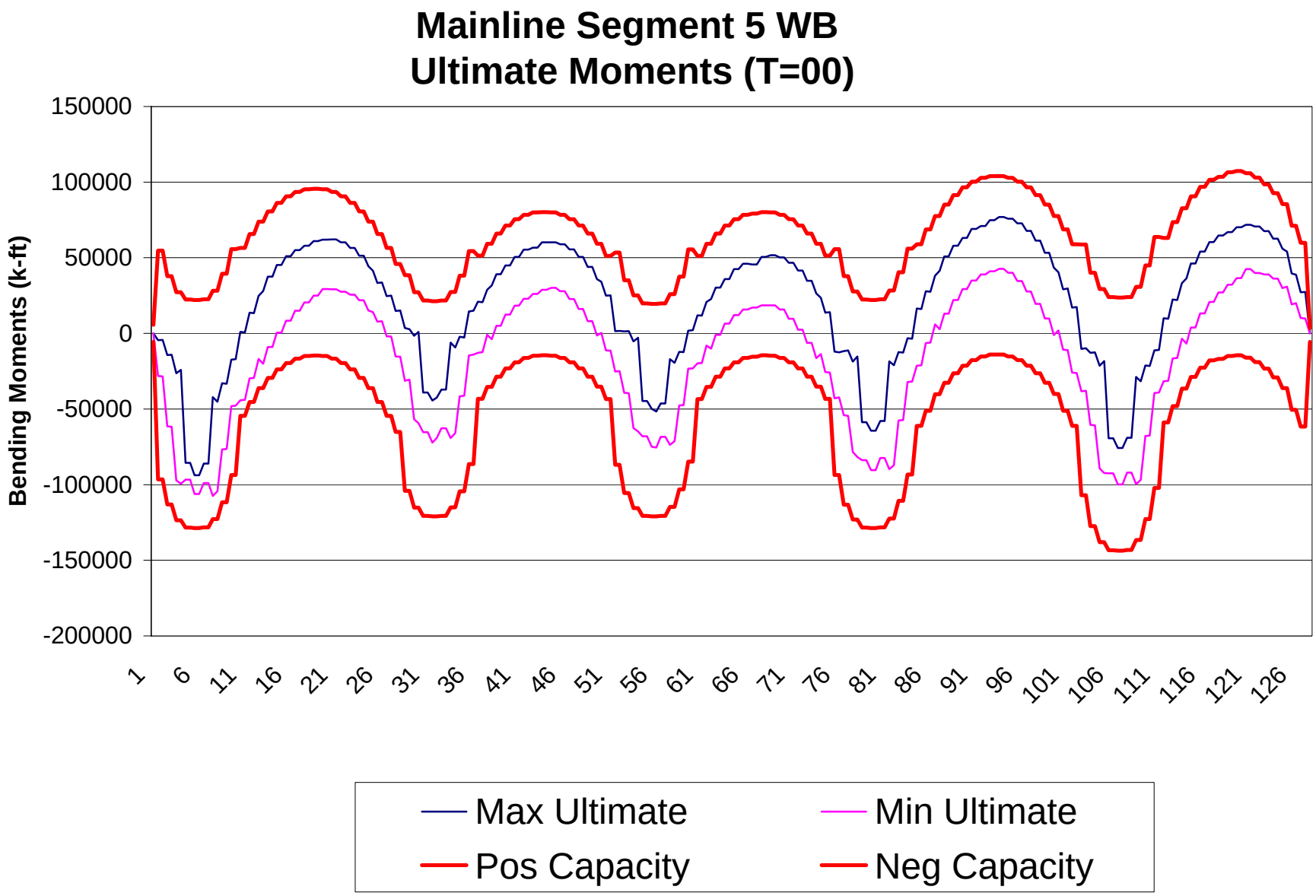
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 5 WB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.70	2.21										
		Shear	1.64	2.09										
	Service	Flexure	0.89	2.22										
		Principal Stress	1.35	1.35										
Transverse	Strength	Top Slab Centerline	1.69	2.19										
		Top Slab Thickness Change	2.23	2.89										
		Top Slab Webs & Cantilever	3.02	3.92										
		Transverse Web Bending	2.59	3.47										

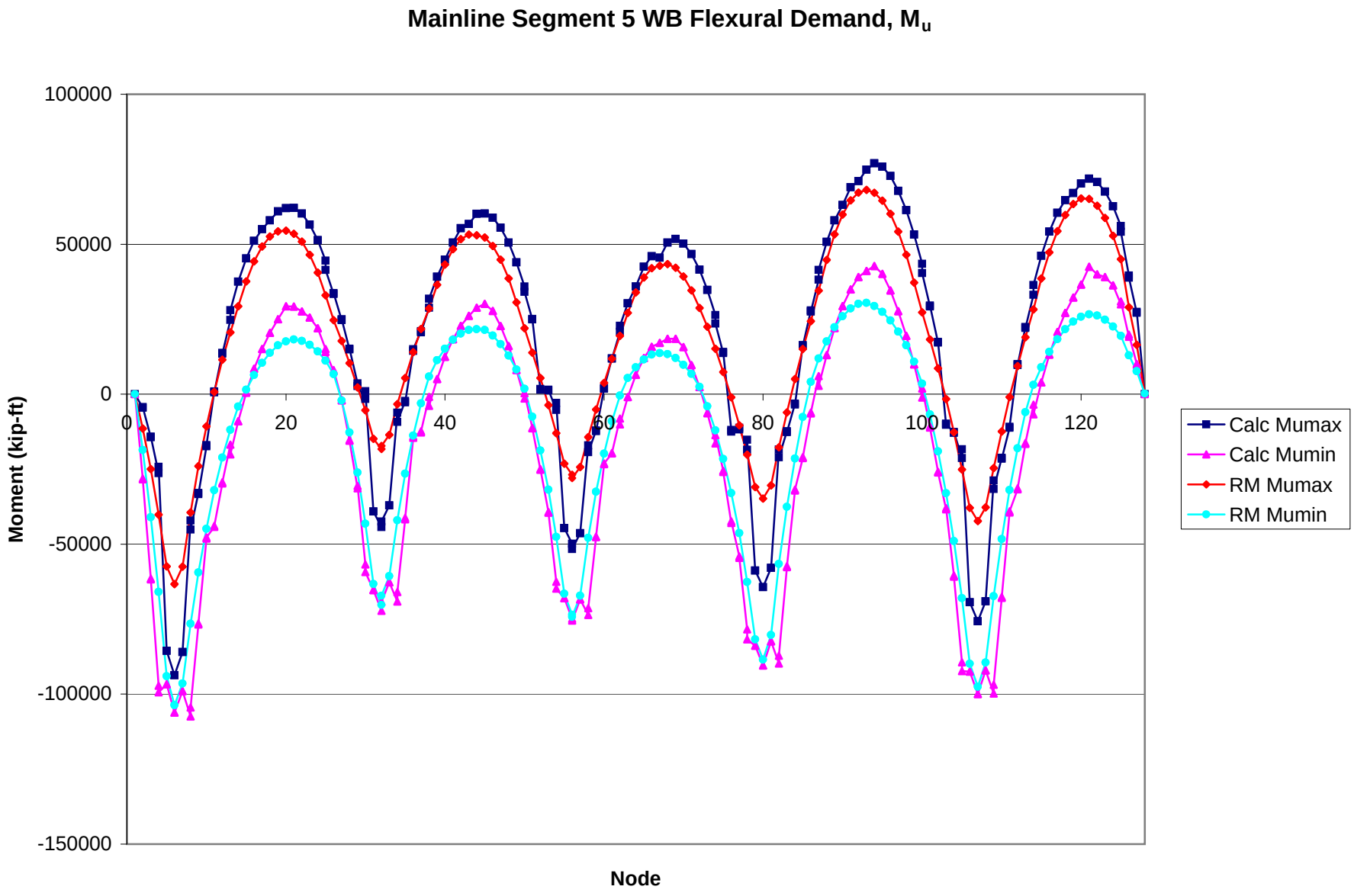
Overall Rating Factor	0.52	0.52	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		18.72	0.00	0.00

* Max number of lanes loaded = Per AASHTO LRFD

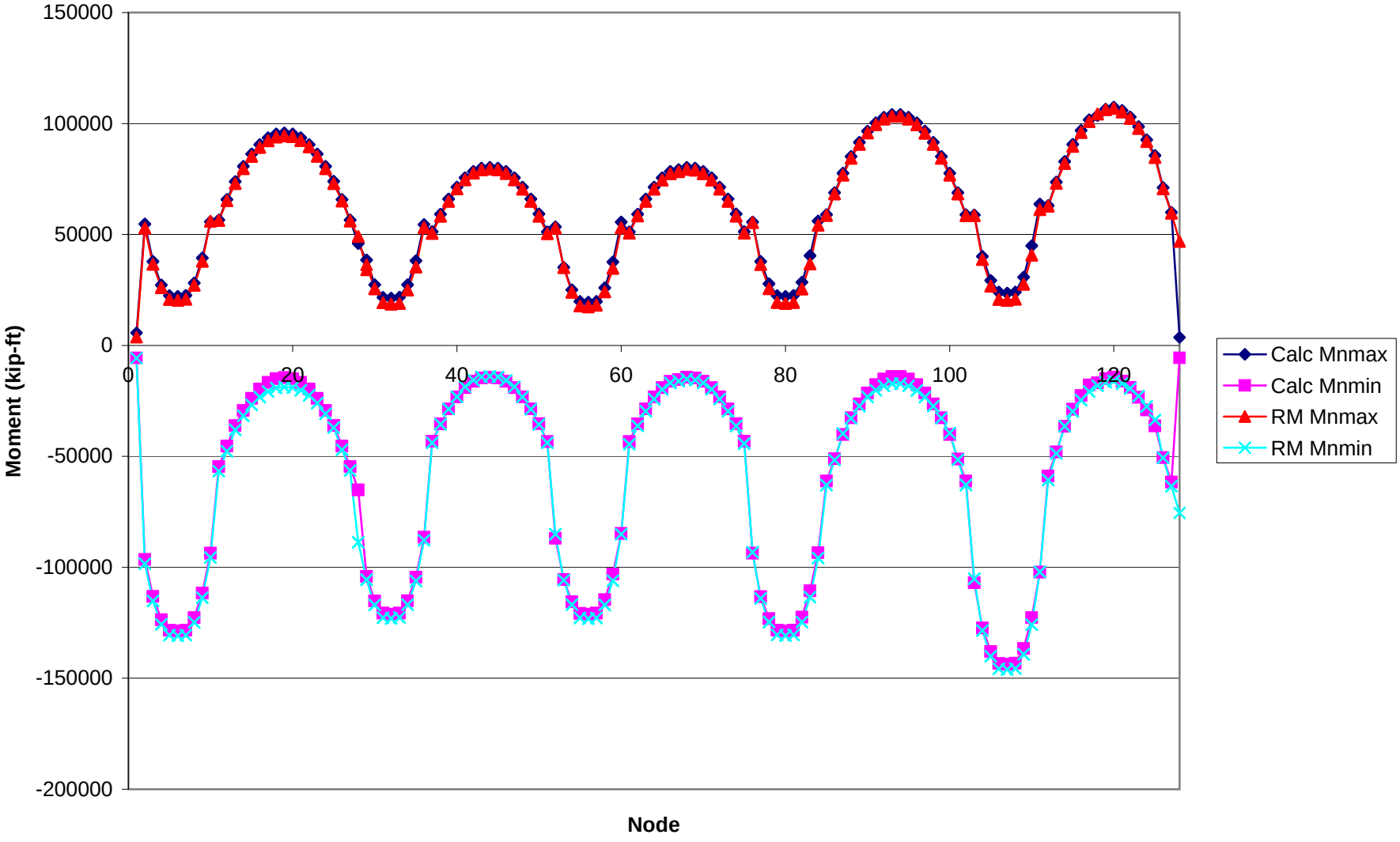
3.12.2 Strength I Flexure


Mainline Segment 5 WB
Ultimate Moments (T=00)
Bending Moments (k-ft)
150000
100000
50000
0
-50000
-100000
-150000
-200000
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

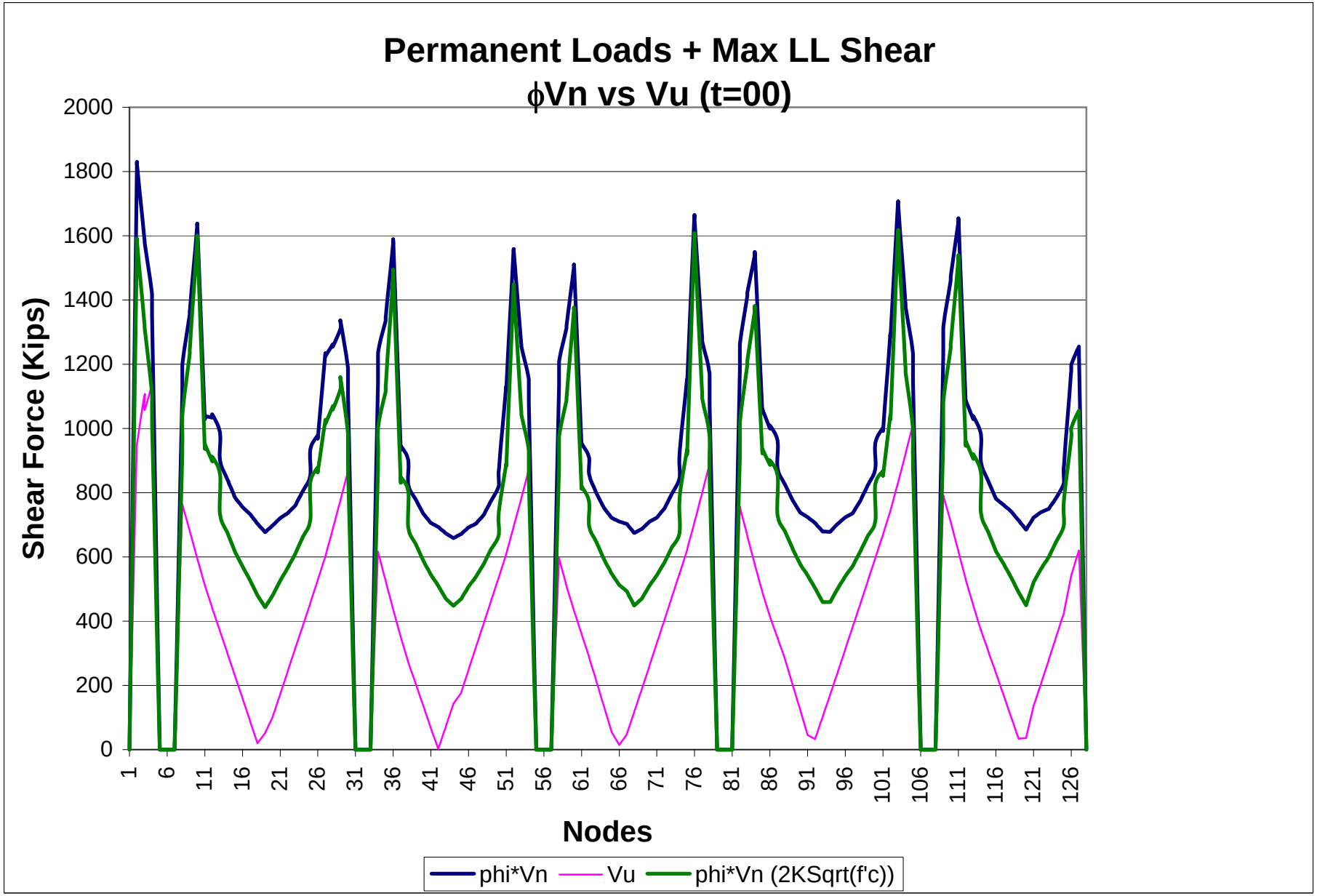
3.12.2/1

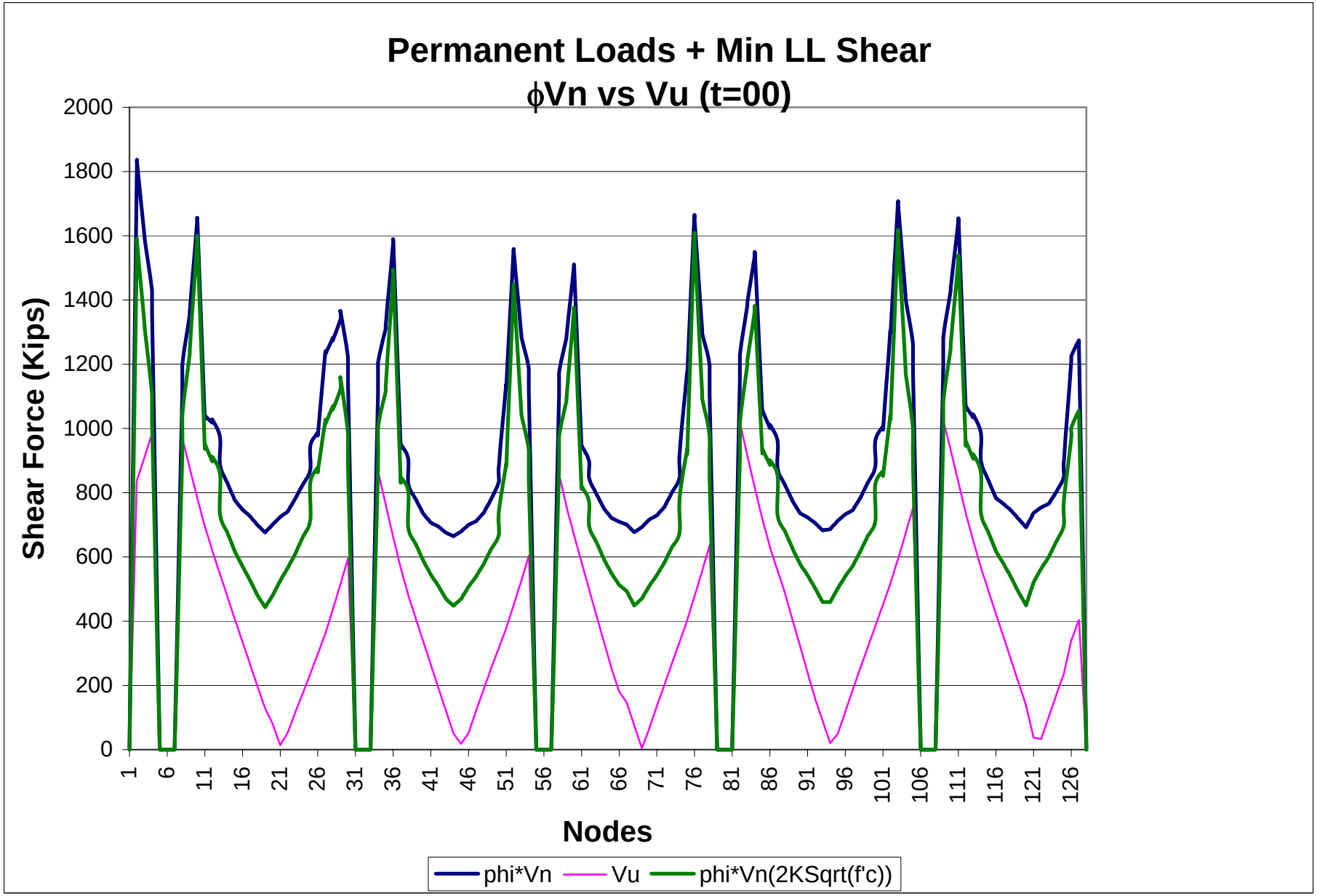

Mainline Segment 5 WB Flexural Demand, M_u
100000
50000
0
-50000
-100000
-150000
Moment (kip-ft)
0
20
40
60
80
100
120
Node
Calc Mumax
Calc Mumin
RM Mumax
RM Mumin

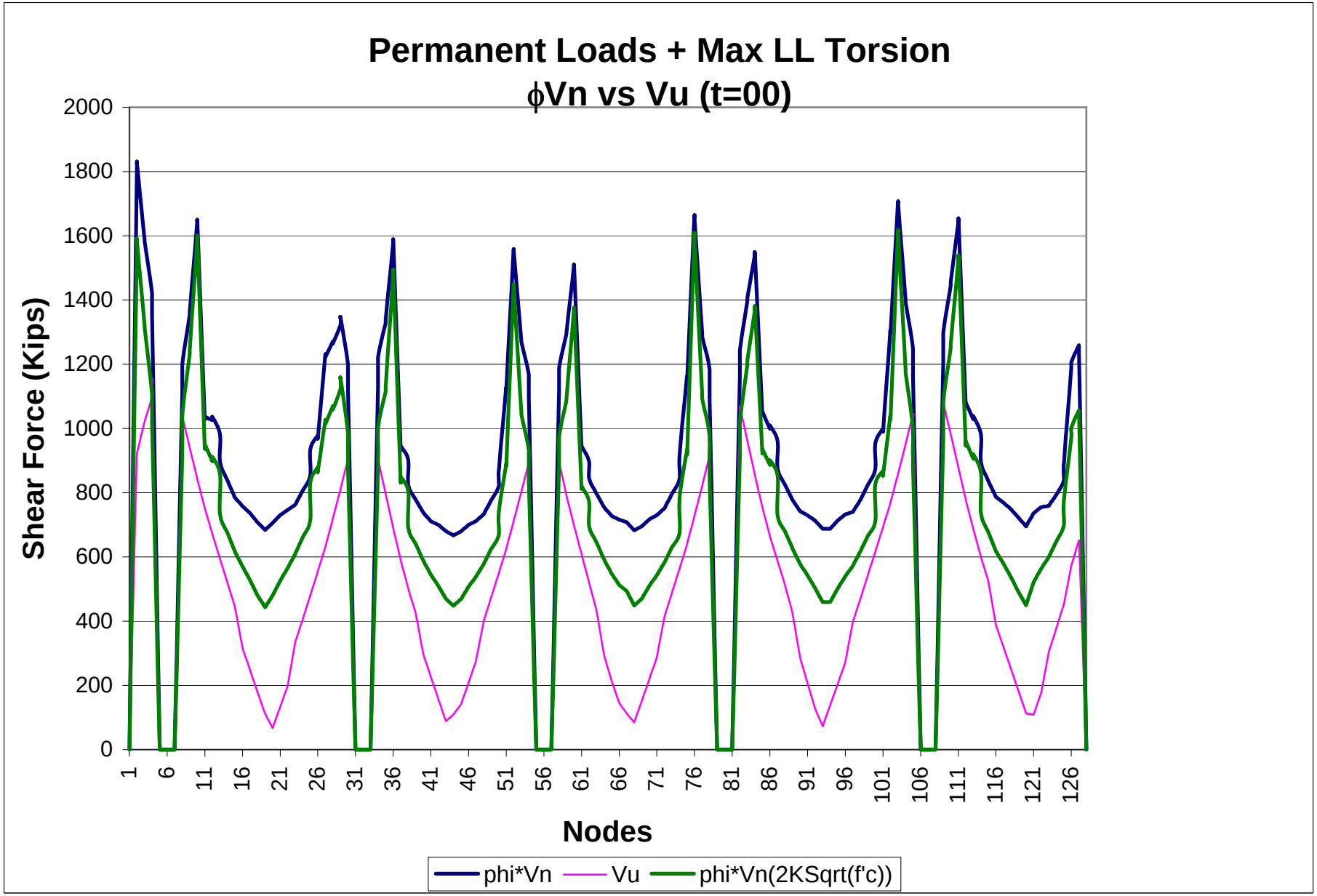
Mainline Segment 5 WB Flexural Strength, ϕM_n

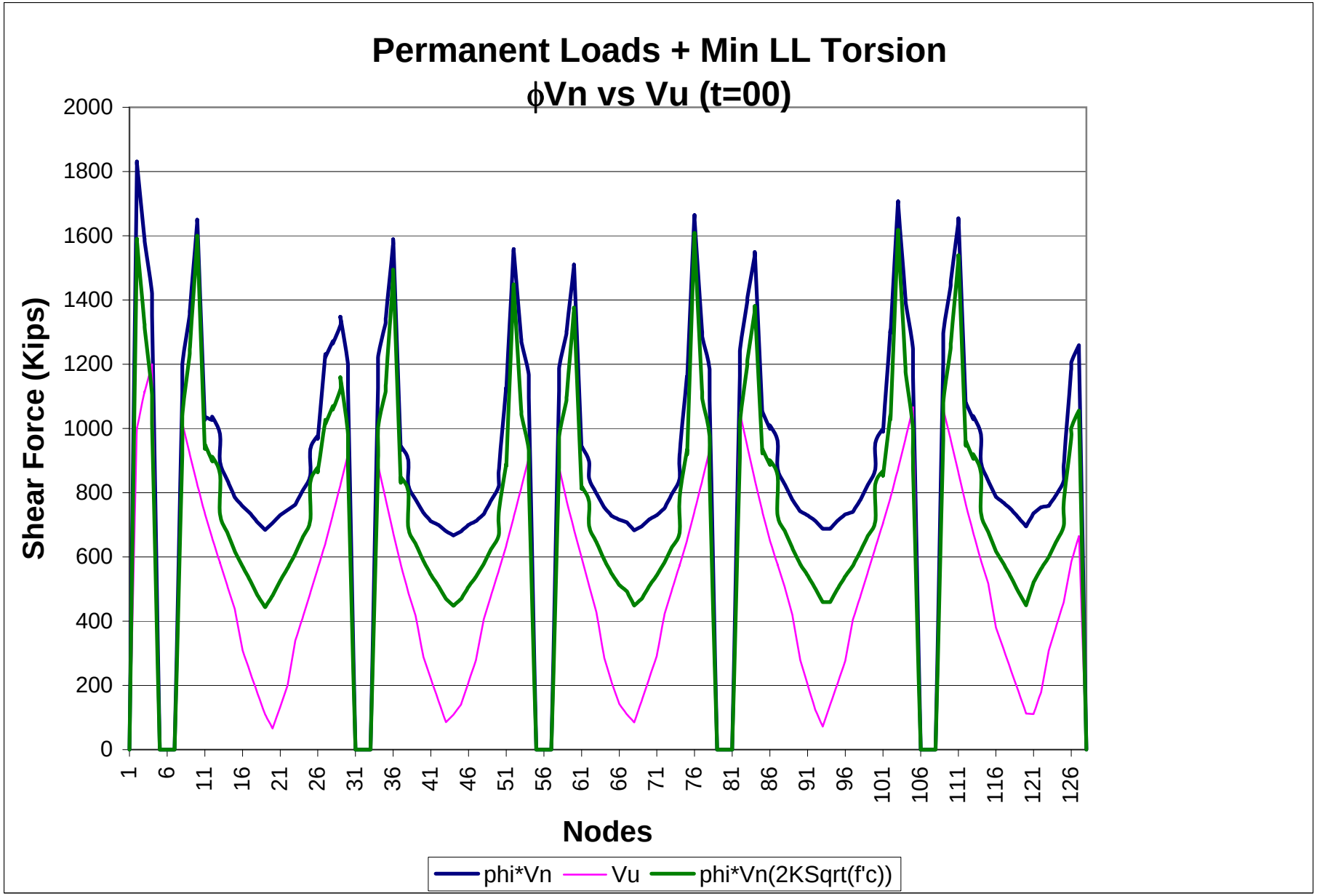


3.12.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
126
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 5 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 5 WB\

Node := 8 Position := Back $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = -1562 \cdot kips$	$M_{dc_x} = -48989 \cdot kip \cdot ft$	$T_{dc_x} = 47\ ft \cdot kips$	$N_{dc_x} = 0 \cdot kips$	Dead Load
$V_{dw_x} = -170 \cdot kips$	$M_{dw_x} = -3519 \cdot kip \cdot ft$	$T_{dw_x} = 416 \cdot kip \cdot ft$	$N_{dw_x} = 0 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = -129 \cdot kips$	$M_{psec_x} = -1483 \cdot kip \cdot ft$	$T_{psec_x} = 17 \cdot kip \cdot ft$	$N_{psec_x} = 0 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -12\ kip$	$M_{crsh_x} = 542 \cdot kip \cdot ft$	$T_{crsh_x} = -24 \cdot kip \cdot ft$	$N_{crsh_x} = 0 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 28 \cdot kips$	$M_{LLvmax_x} = -139 \cdot kip \cdot ft$	$T_{LLvmax_x} = 55 \cdot kip \cdot ft$	$N_{LLvmax_x} = 0 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -325 \cdot kips$	$M_{LLvmin_x} = 2177 \cdot kip \cdot ft$	$T_{LLvmin_x} = -1127 \cdot kip \cdot ft$	$N_{LLvmin_x} = 0 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = -235 \cdot kips$	$M_{LLtmax_x} = 2303 \cdot kip \cdot ft$	$T_{LLtmax_x} = 4228 \cdot kip \cdot ft$	$N_{LLtmax_x} = 0 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -236 \cdot kips$	$M_{LLtmin_x} = 2273 \cdot kip \cdot ft$	$T_{LLtmin_x} = -4226 \cdot kip \cdot ft$	$N_{LLtmin_x} = 0 \cdot kips$	Min Live Load Torsion

URS

Project: Cline --Seg 5 WB
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Post Tensioning Forces:

$V_{prim_x} = 878 \cdot kips$ Primary PT Shear

$N_{prim_x} = -13356 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 32658 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1054 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = -5 \cdot kips$

$M_{tu_x} = 125 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = -1 \cdot kip \cdot ft$

$N_{tu_x} = 0 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 17867 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 39103 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 59.366 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.243 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.143 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.121 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 96.348 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 96 \cdot in$ Depth for Torsion

$A_{s_x} = 11.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

URS

Project: Cline --Seg 5 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Check: Ind Chk Date: / /

Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = -2305 \cdot kips$	$T_{uvmax_x} = 762 \cdot kip \cdot ft$	$M_{uvmax_x} = -67914\, ft \cdot kips$	$N_{uvmax_x} = 0 \cdot kips$
$V_{uvmin_x} = -2781 \cdot kips$	$T_{uvmin_x} = -834 \cdot kip \cdot ft$	$M_{uvmin_x} = -64788\, ft \cdot kips$	$N_{uvmin_x} = 0 \cdot kips$
$V_{utmax_x} = -2660 \cdot kips$	$T_{utmax_x} = 6396 \cdot kip \cdot ft$	$M_{utmax_x} = -64618\, ft \cdot kips$	$N_{utmax_x} = 0 \cdot kips$
$V_{utmin_x} = -2661 \cdot kips$	$T_{utmin_x} = -5017 \cdot kip \cdot ft$	$M_{utmin_x} = -64658\, ft \cdot kips$	$N_{utmin_x} = 0 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.689\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\,rows(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 16578 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 89.315 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 80.383 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00017$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 28.411 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 5.494$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 404.081 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{uvmax_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -780.833\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left| 1.35 \cdot T_{LLvmax_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 12.6 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 2.06$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = -0.00017$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 28.412 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 5.492$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 403.995 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -780.833\,kip$

$V_{LLwebvmin_y} := \dfrac{1.35\,V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -146.25 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 2.06$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = -0.00017$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 28.399 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 5.51$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 405.289 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -790.964\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -189.828 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{tmax_i})}$

$V_p \leftarrow |V_{prim_i}|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{tpos_{x,1}} = 1.765$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004)$ otherwise

ε

$\varepsilon_{stmin_x} = -0.00017$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 28.399 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 5.509$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 405.224 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = -790.964\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -190.238 \cdot kips$

URS

Project: Cline --Seg 5 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.76}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

URS

Project: Cline --Seg 5 WB
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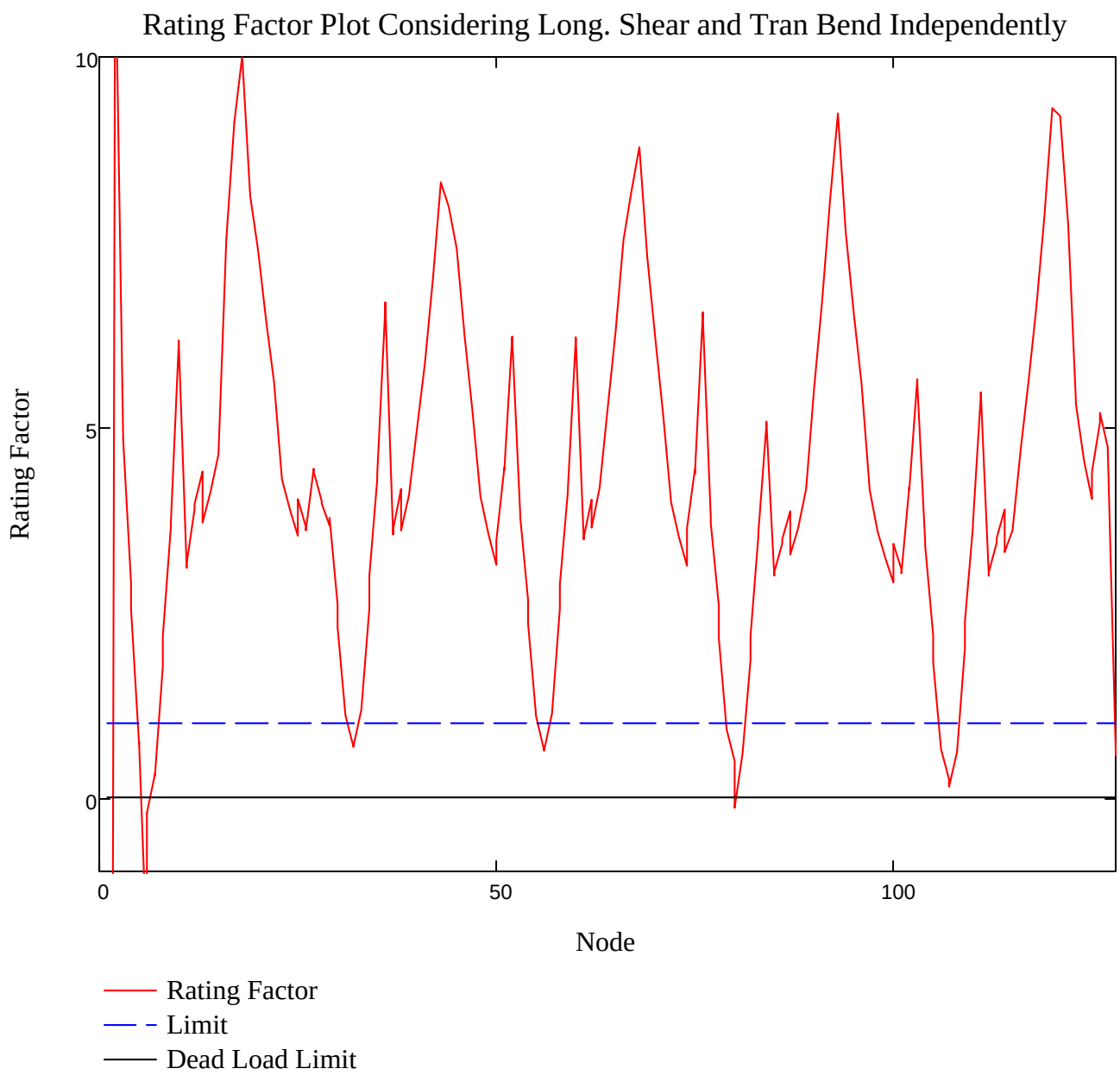

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.76$ at node $minRF_2 = 8$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.704$

URS

Project: Cline --Seg 5 WB
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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 160.379 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 80.327 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.286 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.142 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.495 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 19.242 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 276.394 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 875.828 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 19.115 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 552.769 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.125 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.875 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 19.242 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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Project: Cline --Seg 5 WB
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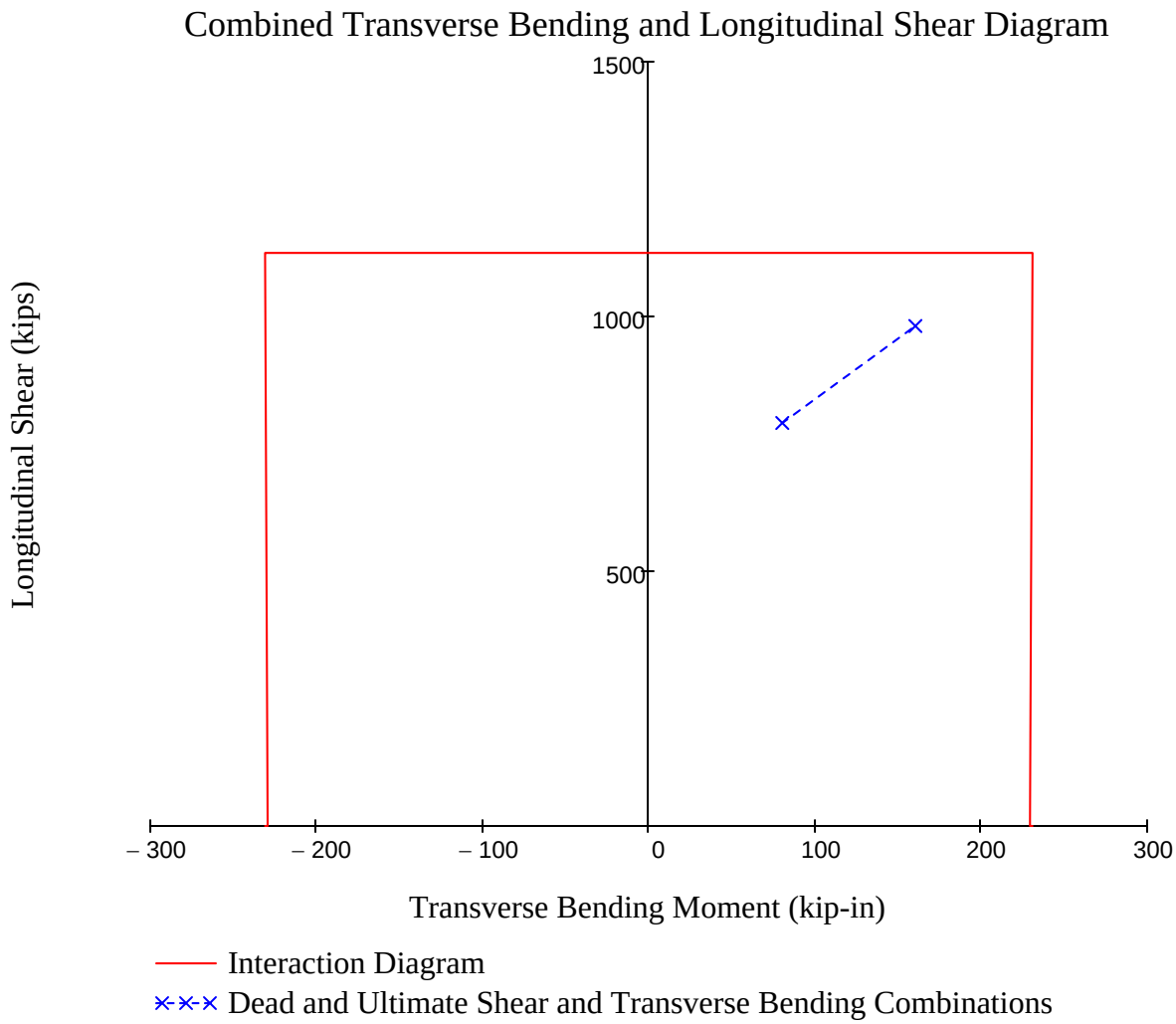


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.881$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

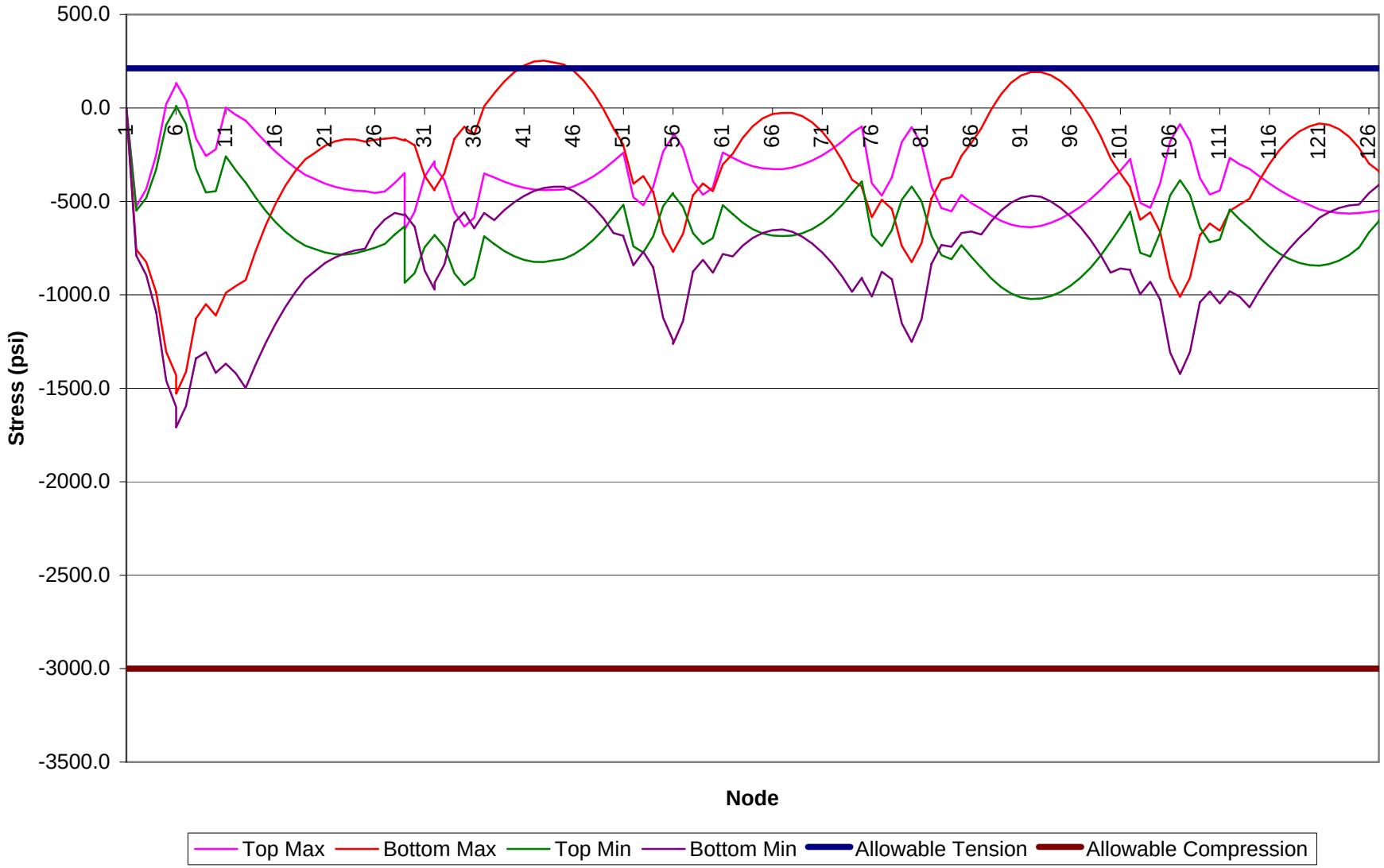
$RF_{shear} = 2.35$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

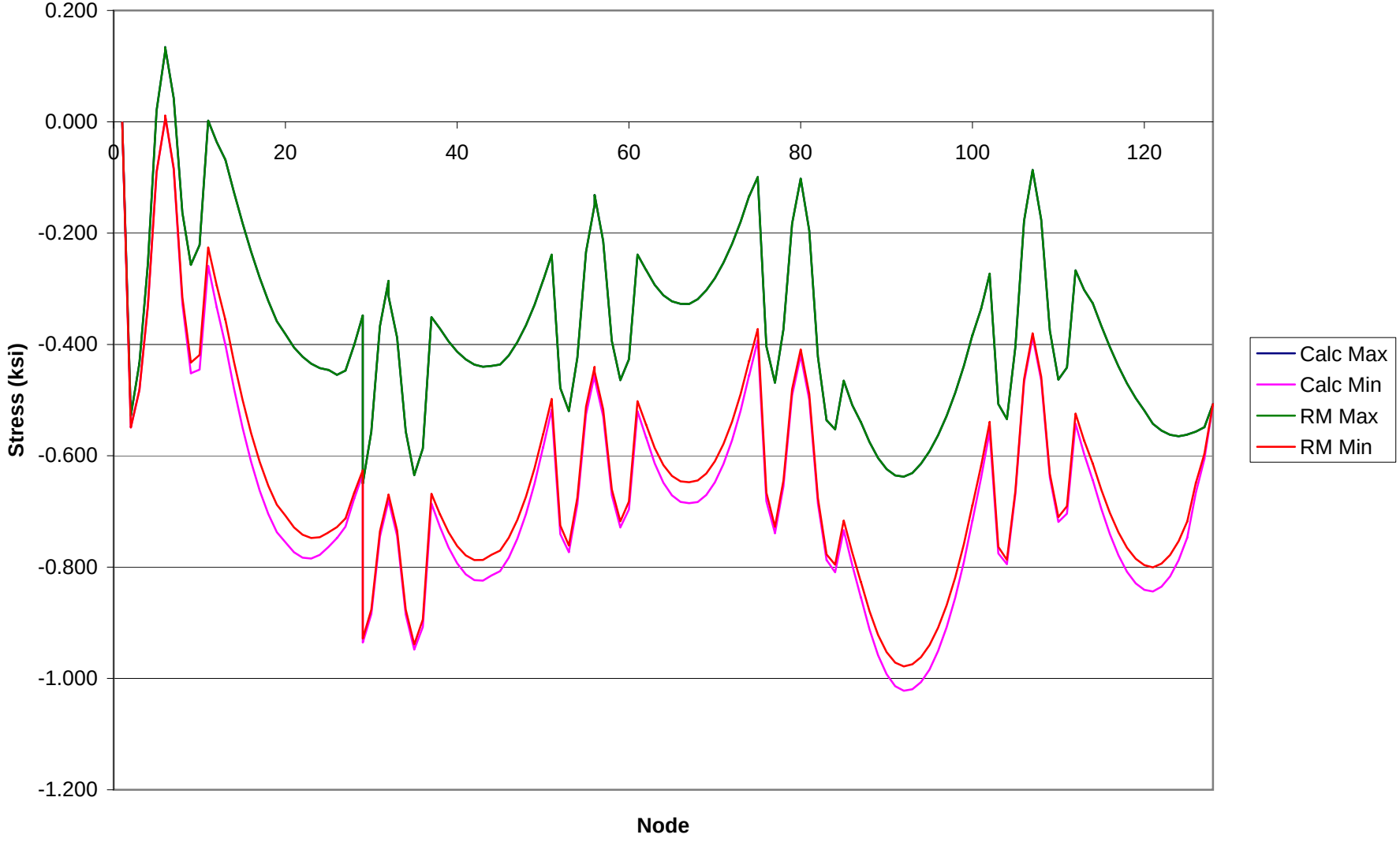
$RF_{torsion} = 1.754$

3.12.4 Service I Flexure (Service Stresses)

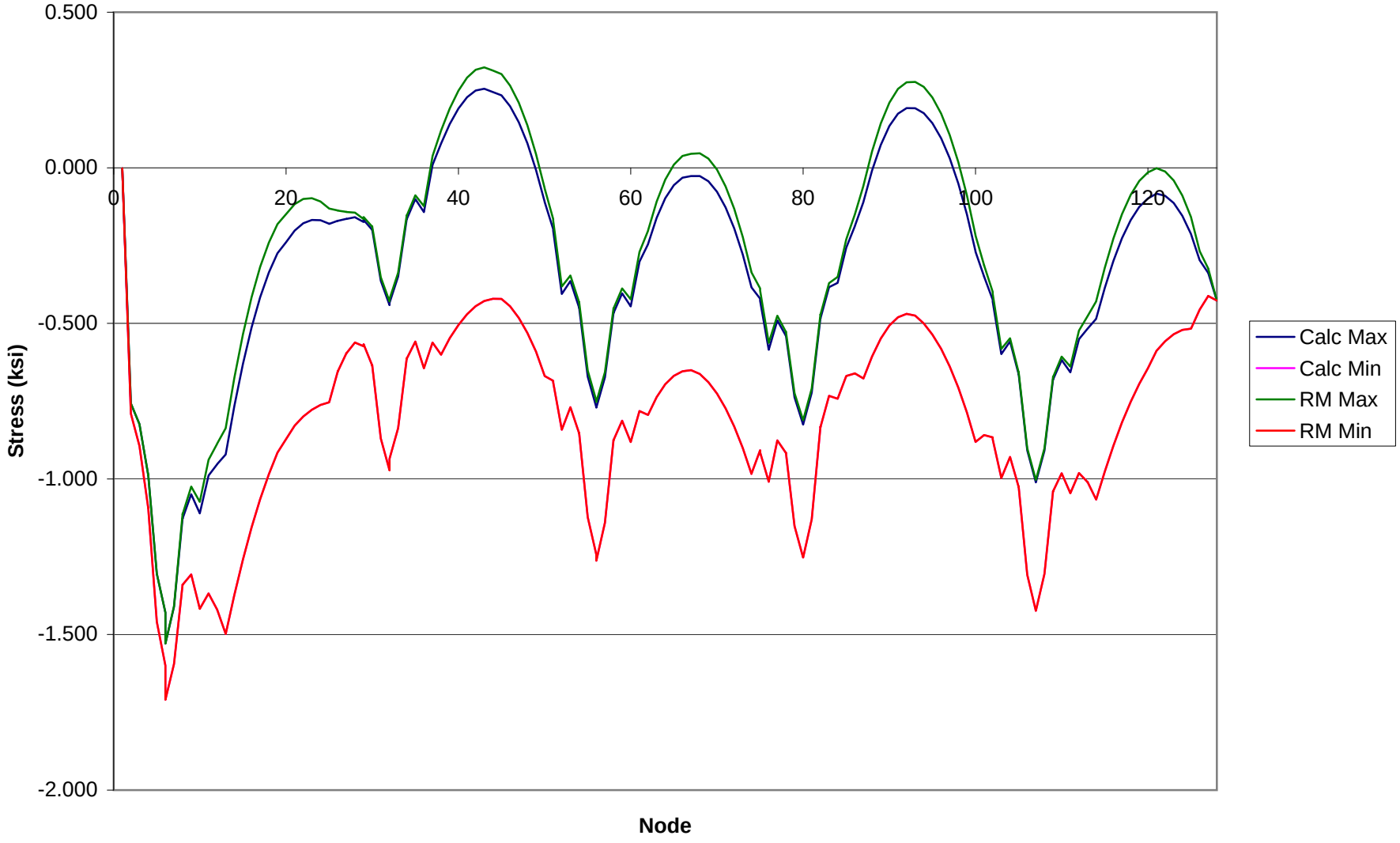
Service Stresses



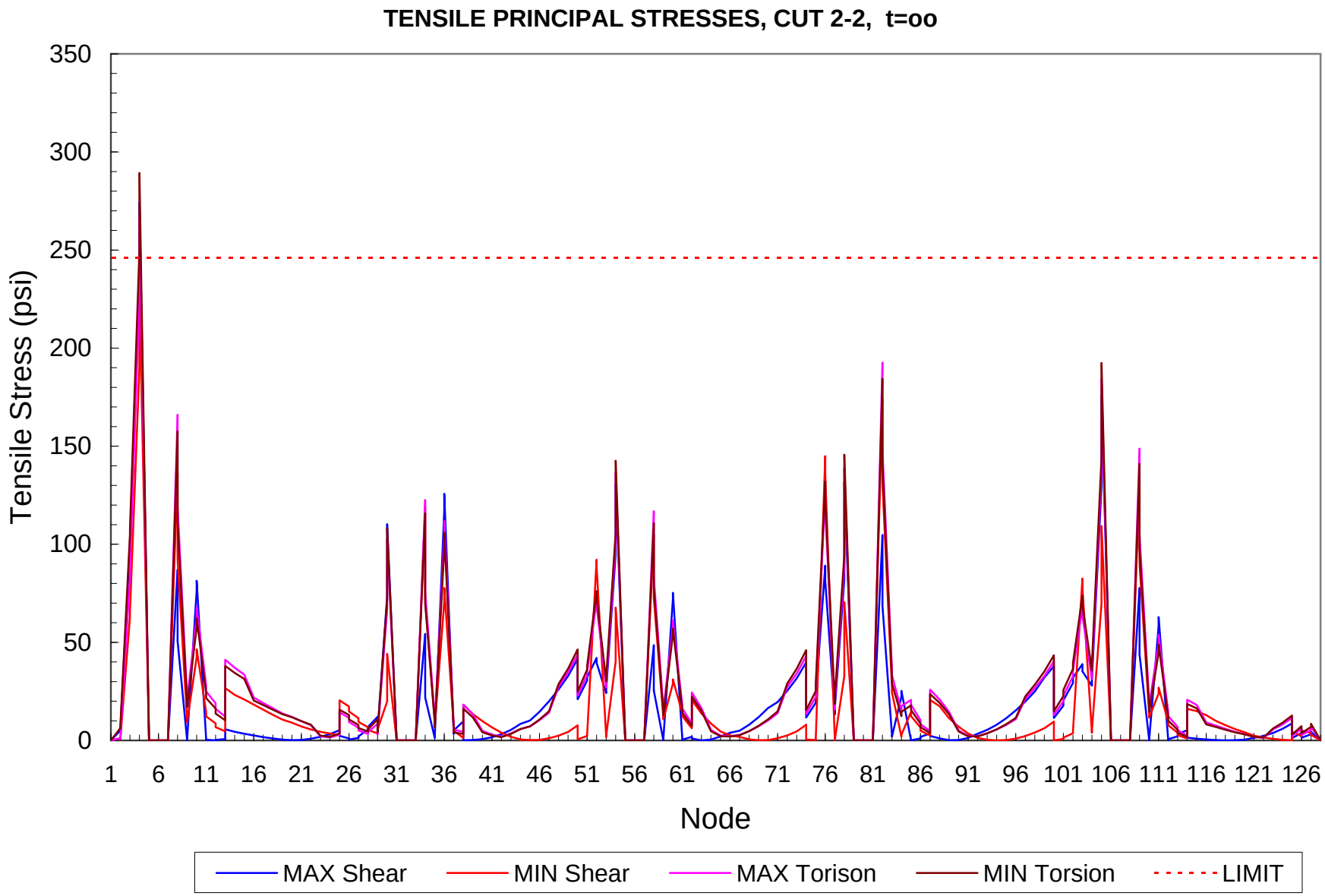
Mainline Segment 5 WB Top Service Stresses



Mainline Segment 5 WB Bottom Service Stresses

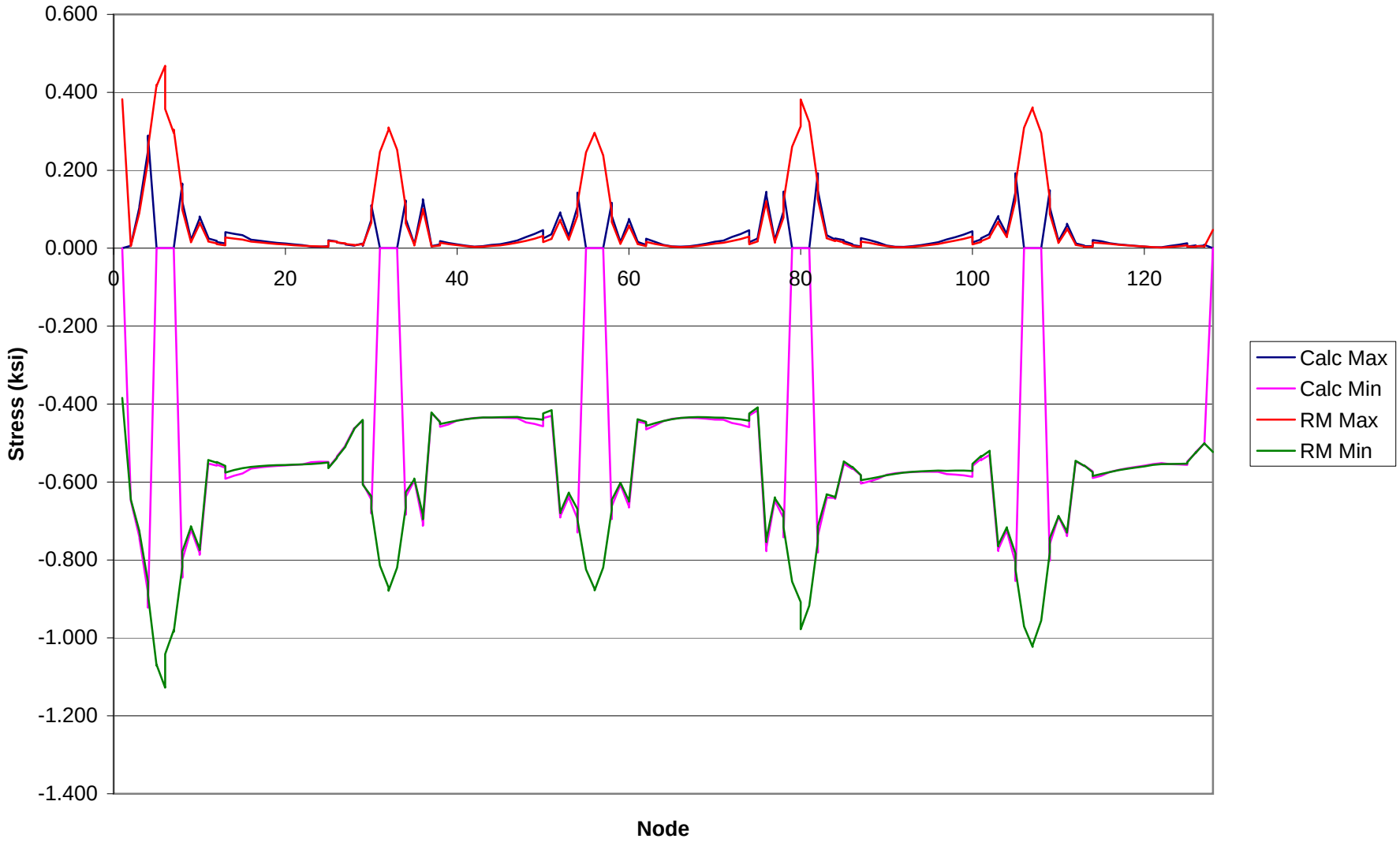


3.12.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.12.5/1

Mainline Segment 5 WB Principal Stresses



3.13 Mainline Segment 6 EB Rating

3.13.1 Rating Summary

URS

PROJECT: **Cline Avenue Mainline Seg 6 EB** CALCS BY: TSP DATE: 10/1/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

AASHTO Lanes

Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 6 EB			Inventory	Operating										
			LFR Design Loads	LFR Design Loads	InDOT Loadings									
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads						
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.72	2.23	1.68	1.79	1.73	1.95	1.95	1.75	1.81	1.66	1.81	1.62
		Shear	0.94	1.22	0.94	0.95	0.81	0.96	0.96	0.74	0.74	0.64	0.58	0.58
	Service	Flexure	1.44	2.38	2.12	2.16	1.92	2.13	2.12	1.95	1.94	1.76	1.89	1.69
		Principal Stress	1.04	1.04	0.94	1.00	1.21	1.02	1.00	0.83	0.91	0.79	0.80	0.80
Transverse	Strength	Top Slab Centerline	1.05	1.36	1.53	1.60	1.68	1.40	1.37	1.30	1.32	1.15	1.37	1.20
		Top Slab Thickness Change	1.60	2.07	2.26	2.31	2.15	2.01	1.95	1.76	1.77	1.50	1.71	1.42
		Top Slab Webs & Cantilever	1.85	2.40	2.26	2.59	2.25	1.94	1.92	1.67	1.67	1.45	1.64	1.40
		Transverse Web Bending	0.49	0.64	0.52	0.61	0.56	0.57	0.52	0.47	0.47	0.38	0.46	0.38

Overall Rating Factor	0.49	0.64	0.52	0.38
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		23.04	23.40	91.20

* Max number of lanes loaded = Per AASHTO LRFD

URS

PROJECT: **Cline Avenue Mainline Seg 6 EB** CALCS BY: TSP DATE: 10/21/09

DESCRIPTION: **Rating Factor Summary** CHECKED BY: DATE:

Striped Lanes

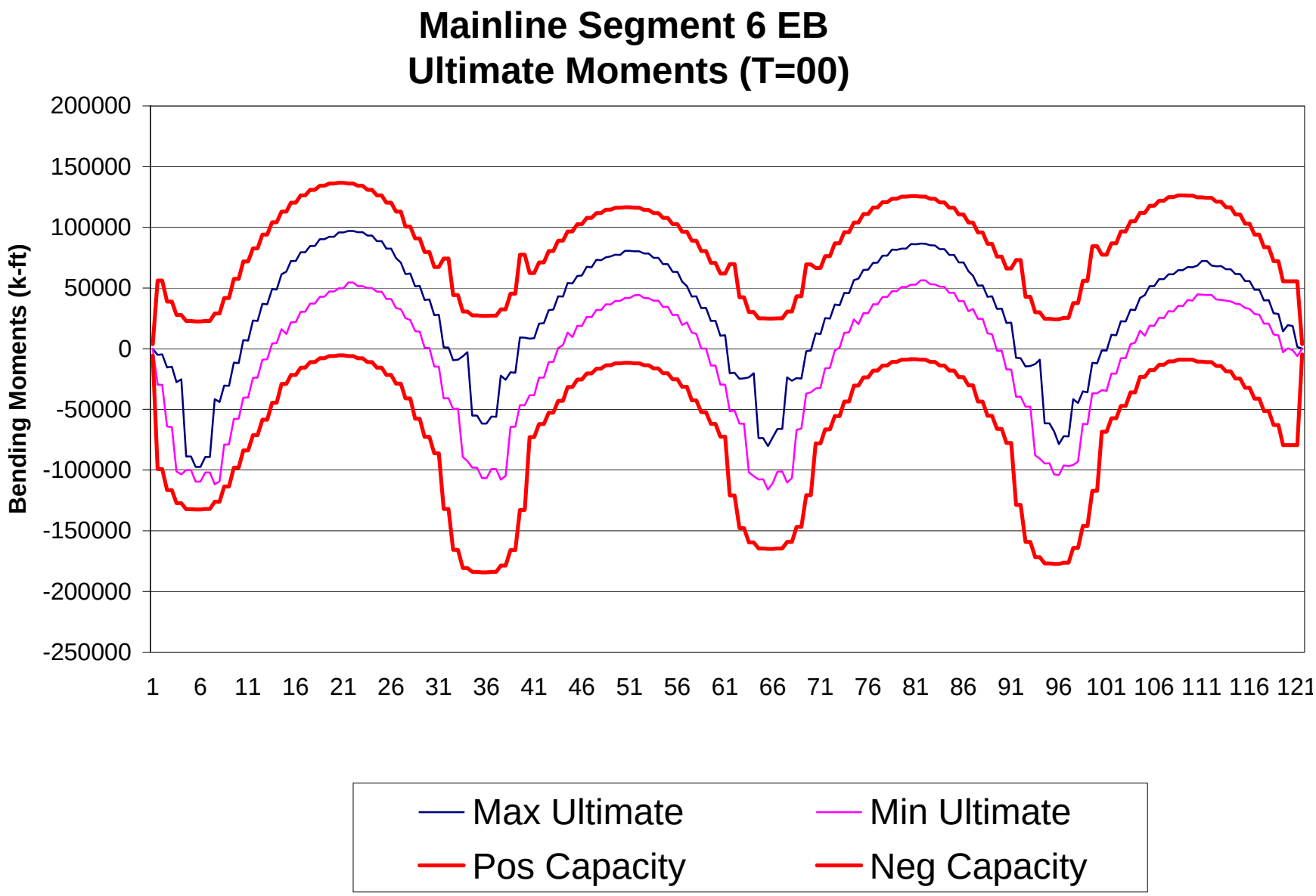
Clear Table | Fill Table | Posting Values

Cline Avenue Load Rating Mainline Segment 6 EB			Inventory	Operating											
			LFR Design Loads	LFR Design Loads	InDOT Loadings										
			HL-93 or Tandem*	HL-93 or Tandem*	InDOT Legal Loads			InDOT Permit Loads							
					R1	R2	R3	R4	R5	S1	S2	S3	S4	S5
Gross Vehicle Weight (tons)			36	36	45	45	63	67	67.1	129	133.5	175	152.5	240
Longitudinal	Strength	Flexure	1.77	2.30										
		Shear	1.11	1.47										
	Service	Flexure	1.47	2.38										
		Principal Stress	1.19	1.19										
Transverse	Strength	Top Slab Centerline	1.05	1.36										
		Top Slab Thickness Change	1.60	2.07										
		Top Slab Webs & Cantilever	1.89	2.45										
		Transverse Web Bending	0.54	0.70										

Overall Rating Factor	0.54	0.70	0.00	0.00
Posting Value (tons) (Controlled by Truck with Lowest Rating Factor)		25.20	0.00	0.00

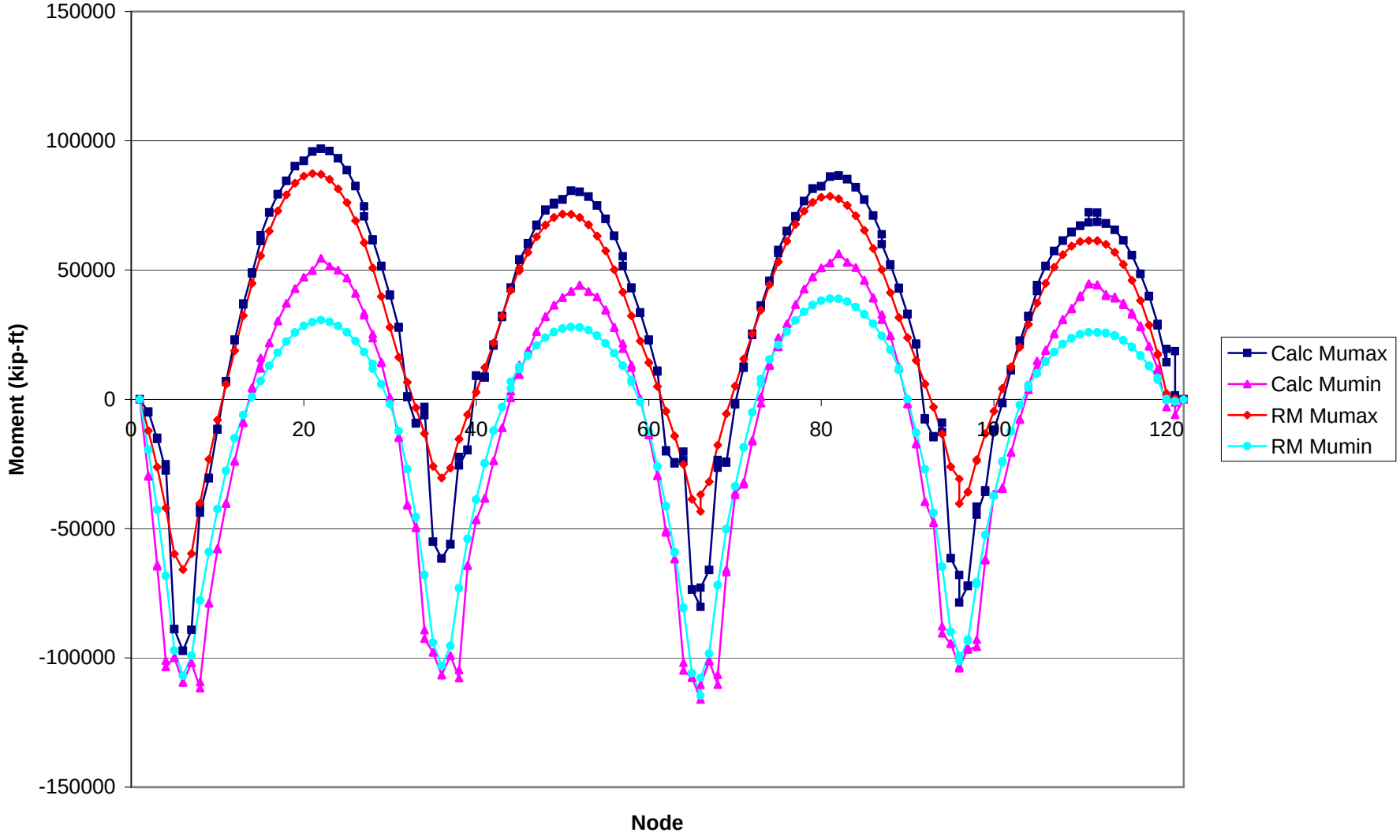
* Max number of lanes loaded = Per AASHTO LRFD

3.13.2 Strength I Flexure

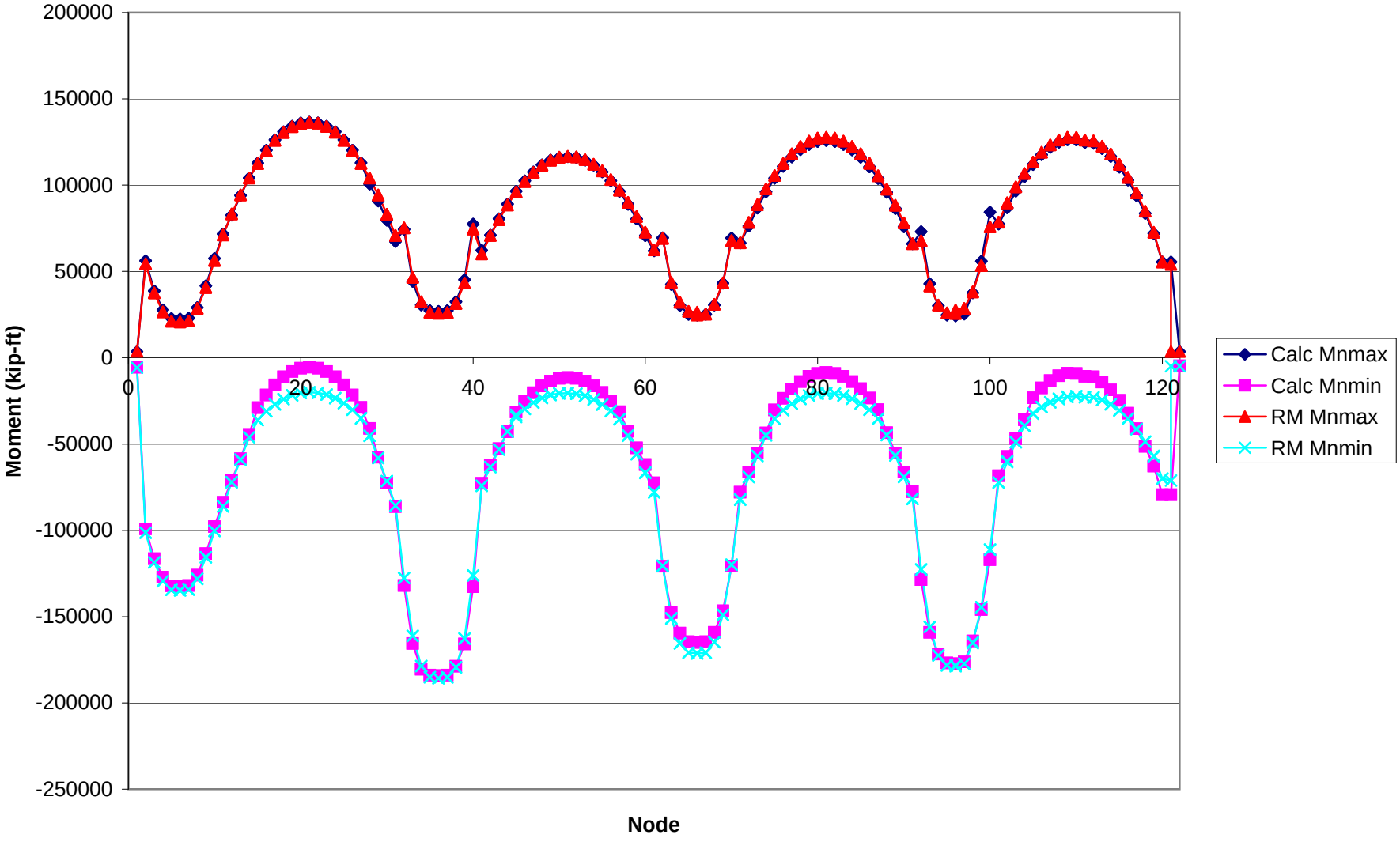

Mainline Segment 6 EB
Ultimate Moments (T=00)
Bending Moments (k-ft)
200000
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121
Max Ultimate
Min Ultimate
Pos Capacity
Neg Capacity

3.13.2/1

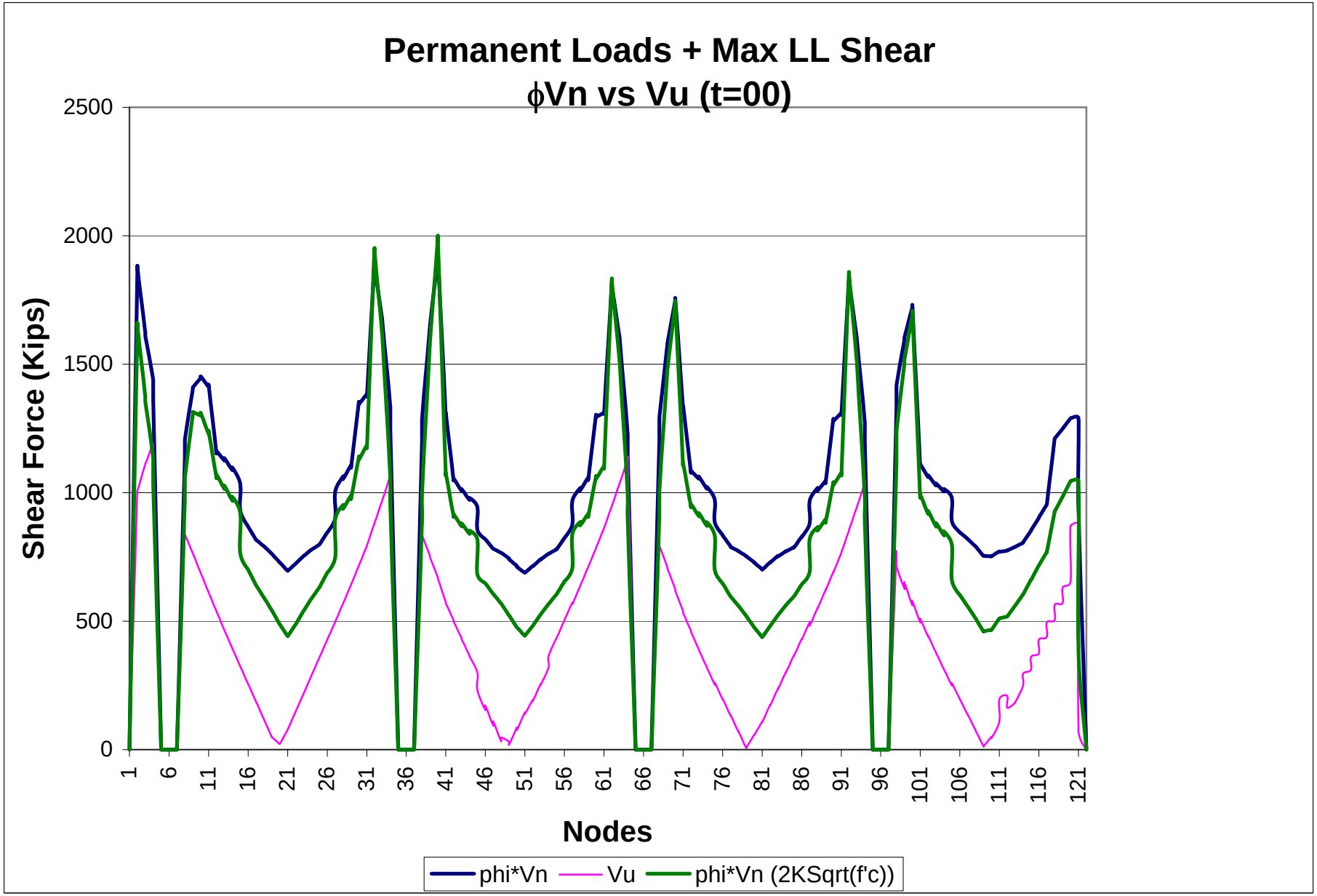
Mainline Segment 6 EB Flexural Demand, M_u

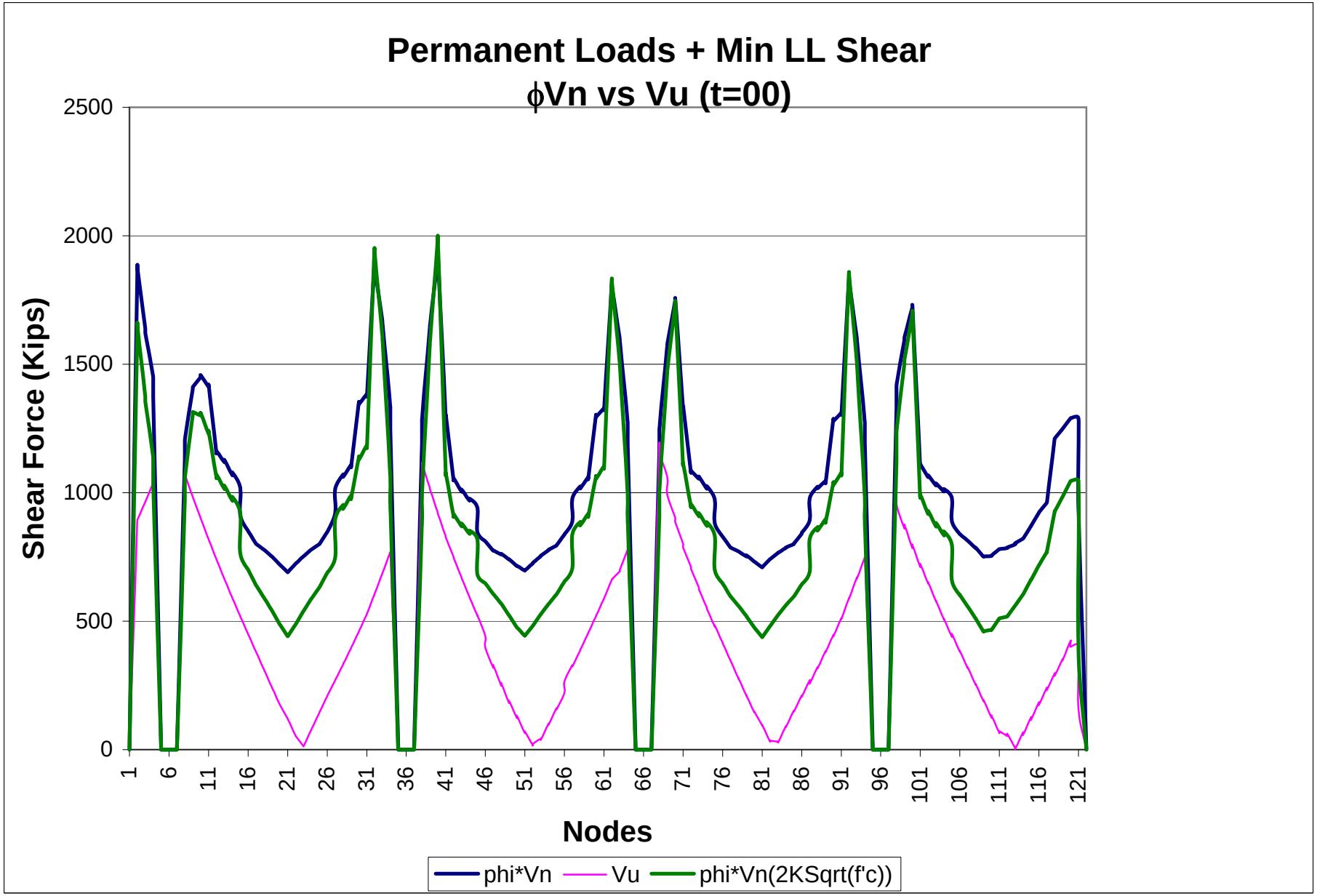


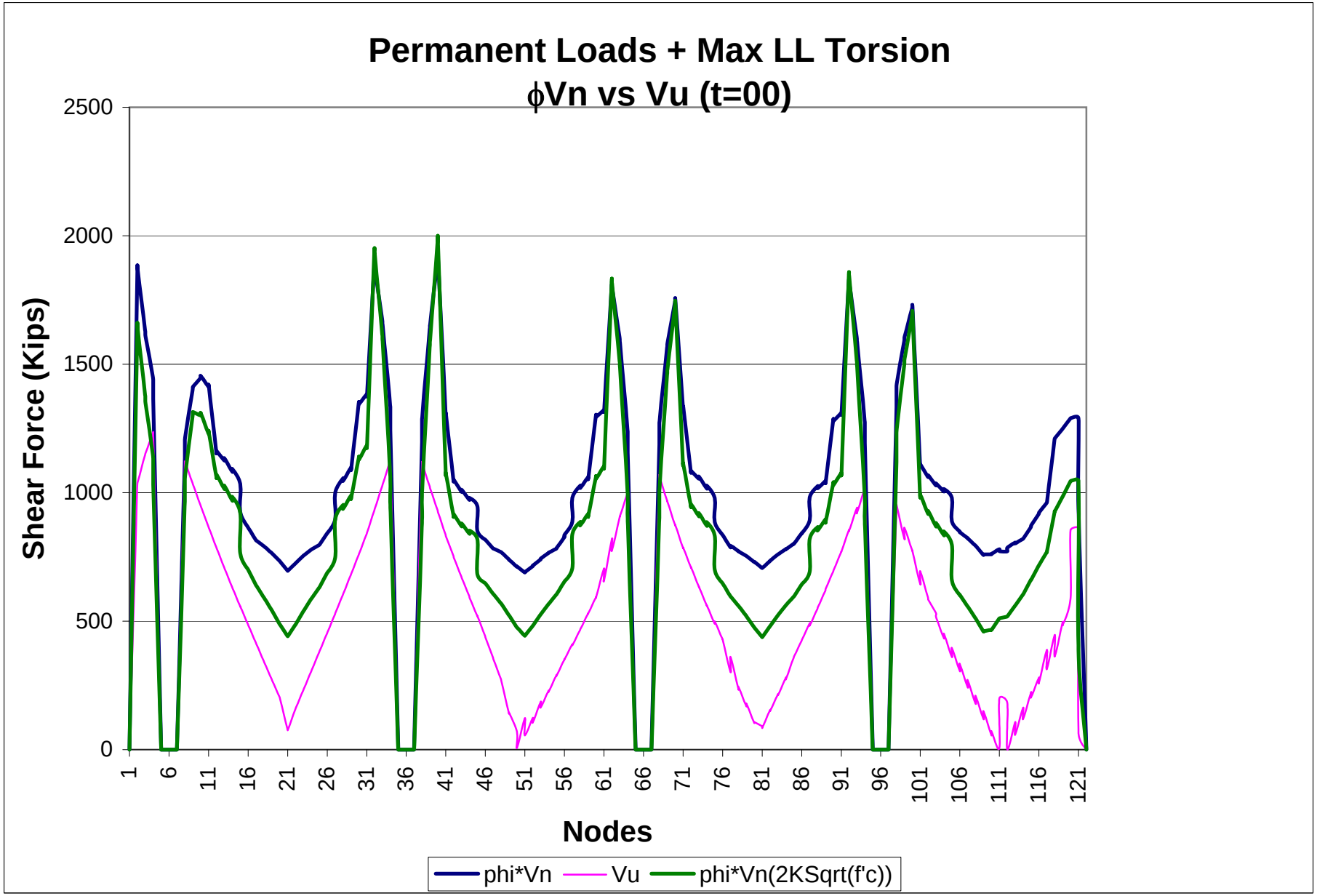
Mainline Segment 6 EB Flexural Strength, ϕM_n

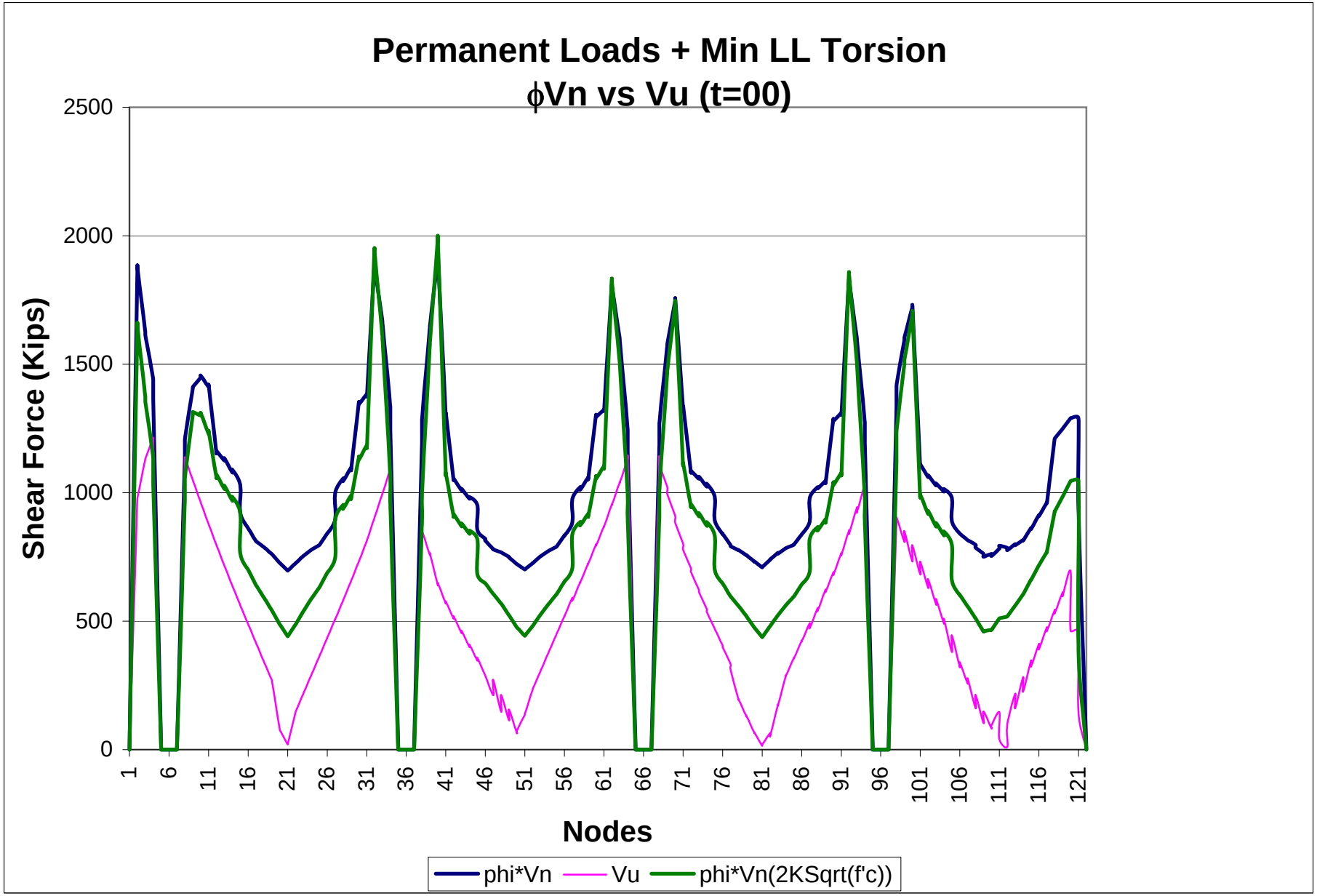


3.13.3 Strength I Shear


Permanent Loads + Max LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
Nodes
phi*Vn
Vu
phi*Vn (2KSqrt(f'c))


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Max LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2500
2000
1500
1000
500
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
121
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

URS

Project: Cline --Seg 6 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 6 EB\

Node := 121 Position := Back $b_{voverride}$:= 15

Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

General Information

Permanant Loads:

$V_{dc_x} = 874 \cdot kips$	$M_{dc_x} = -23 \cdot kip \cdot ft$	$T_{dc_x} = -73\, ft \cdot kips$	$N_{dc_x} = 1 \cdot kips$	Dead Load
$V_{dw_x} = 105 \cdot kips$	$M_{dw_x} = 14 \cdot kip \cdot ft$	$T_{dw_x} = 101 \cdot kip \cdot ft$	$N_{dw_x} = 1 \cdot kips$	Superimposed Dead Load
$V_{psec_x} = 117 \cdot kips$	$M_{psec_x} = 0 \cdot kip \cdot ft$	$T_{psec_x} = -688 \cdot kip \cdot ft$	$N_{psec_x} = 0 \cdot kips$	Secondary PT
$V_{ptls_x} = 0 \cdot kips$	$M_{ptls_x} = 0 \cdot kip \cdot ft$	$T_{ptls_x} = 0 \cdot kip \cdot ft$	$N_{ptls_x} = 0 \cdot kips$	Secondary Loss PT
$V_{crsh_x} = -108\, kip$	$M_{crsh_x} = -160 \cdot kip \cdot ft$	$T_{crsh_x} = -911 \cdot kip \cdot ft$	$N_{crsh_x} = 97 \cdot kips$	Creep & Shrinkage

Live Loads (HL-93):

$V_{LLvmax_x} = 633 \cdot kips$	$M_{LLvmax_x} = -259 \cdot kip \cdot ft$	$T_{LLvmax_x} = 3356 \cdot kip \cdot ft$	$N_{LLvmax_x} = -3 \cdot kips$	Max Live Load Shear
$V_{LLvmin_x} = -153 \cdot kips$	$M_{LLvmin_x} = 132 \cdot kip \cdot ft$	$T_{LLvmin_x} = -1584 \cdot kip \cdot ft$	$N_{LLvmin_x} = 2 \cdot kips$	Min Live Load Shear
$V_{LLtmax_x} = 585 \cdot kips$	$M_{LLtmax_x} = -268 \cdot kip \cdot ft$	$T_{LLtmax_x} = 3723 \cdot kip \cdot ft$	$N_{LLtmax_x} = -2 \cdot kips$	Max Live Load Torsion
$V_{LLtmin_x} = -70 \cdot kips$	$M_{LLtmin_x} = 149 \cdot kip \cdot ft$	$T_{LLtmin_x} = -1932 \cdot kip \cdot ft$	$N_{LLtmin_x} = 2 \cdot kips$	Min Live Load Torsion

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Post Tensioning Forces:

$V_{prim_x} = -1175 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10777 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 25 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1226 \cdot kips$ Primary PT Axial Force

Temperature/Transient Loads:

$V_{tu_x} = 92 \cdot kips$

$M_{tu_x} = -139 \cdot kip \cdot ft$

Temperature/Transient Loads:

$T_{tu_x} = 4679 \cdot kip \cdot ft$

$N_{tu_x} = 46 \cdot kips$ Uniform Temperature

Girder Properties / Reinforcement:

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 13174 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 40905 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 67.433 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 12.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.271 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.257 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 0 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 101 \cdot in$ Depth for Torsion

$A_{s_x} = 9.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 106 \cdot in$ Depth of Mild Steel

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Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

Operating Load Combinations:

Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left| V_{tu_y} \right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left| T_{tu_y} \right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left| M_{tu_y} \right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left| N_{tu_y} \right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

$V_{uvmax_x} = 2168 \cdot kips$	$T_{uvmax_x} = 3447 \cdot kip \cdot ft$	$M_{uvmax_x} = -437\, ft \cdot kips$	$N_{uvmax_x} = 47 \cdot kips$
$V_{uvmin_x} = 1106 \cdot kips$	$T_{uvmin_x} = -3222 \cdot kip \cdot ft$	$M_{uvmin_x} = 90\, ft \cdot kips$	$N_{uvmin_x} = 54 \cdot kips$
$V_{utmax_x} = 2103 \cdot kips$	$T_{utmax_x} = 3943 \cdot kip \cdot ft$	$M_{utmax_x} = -450\, ft \cdot kips$	$N_{utmax_x} = 49 \cdot kips$
$V_{utmin_x} = 1219 \cdot kips$	$T_{utmin_x} = -3691 \cdot kip \cdot ft$	$M_{utmin_x} = 113\, ft \cdot kips$	$N_{utmin_x} = 54 \cdot kips$

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Calculate Variables Used for All Live Load Conditions:

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.725\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 10598 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 106 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 95.4 \cdot in$

Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = 0.00401$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 43.052 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 1.197$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 104.463 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxShear_x = \text{"Yes"}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 453.715\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 351.97 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vpos_{x,1}} = 0.951$

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$\varepsilon_{svmin} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left|\left|V_{uvmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{svmin_x} = 0.0004$

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$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 30.402 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 3.691$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 322.194 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinShear_x = \text{"Yes"}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 421.619\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -100.53 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)}$

$V_p \leftarrow \left|V_{prim_i}\right|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.737$

Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right)$ otherwise

ε

$\varepsilon_{stmax_x} = 0.00378$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 42.231 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 1.252$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 109.256 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 453.715\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 337.71 \cdot kips$

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$RF_{tpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)}$$

$$V_p \leftarrow \left|V_{prim_i}\right|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{tpos_{x,1}} = 1.033$

Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear

$\varepsilon_{stmin} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise}$$

ε

$\varepsilon_{stmin_x} = 0.00032$

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$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 30.112 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 3.877$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 338.405 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 421.619\, kip$

$V_{LLwebtmin_y} := \dfrac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{ll} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = -70.14 \cdot kips$

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$RF_{tneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{tmin_i})}$

$V_p \leftarrow |V_{prim_i}|$

$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}}$

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{tneg_{x,1}} = 1.737$

$RF_{all} :=$ for $i \in y$

$RF_{i,1} \leftarrow \min(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}})$

$RF_{i,2} \leftarrow \min(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}})$

$RF_{i,3} \leftarrow \min(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}})$

RF

$Limit :=$ for $i \in y$

$L_i \leftarrow 1$

L

$DLLimit :=$ for $i \in y$

$D_i \leftarrow 0$

D

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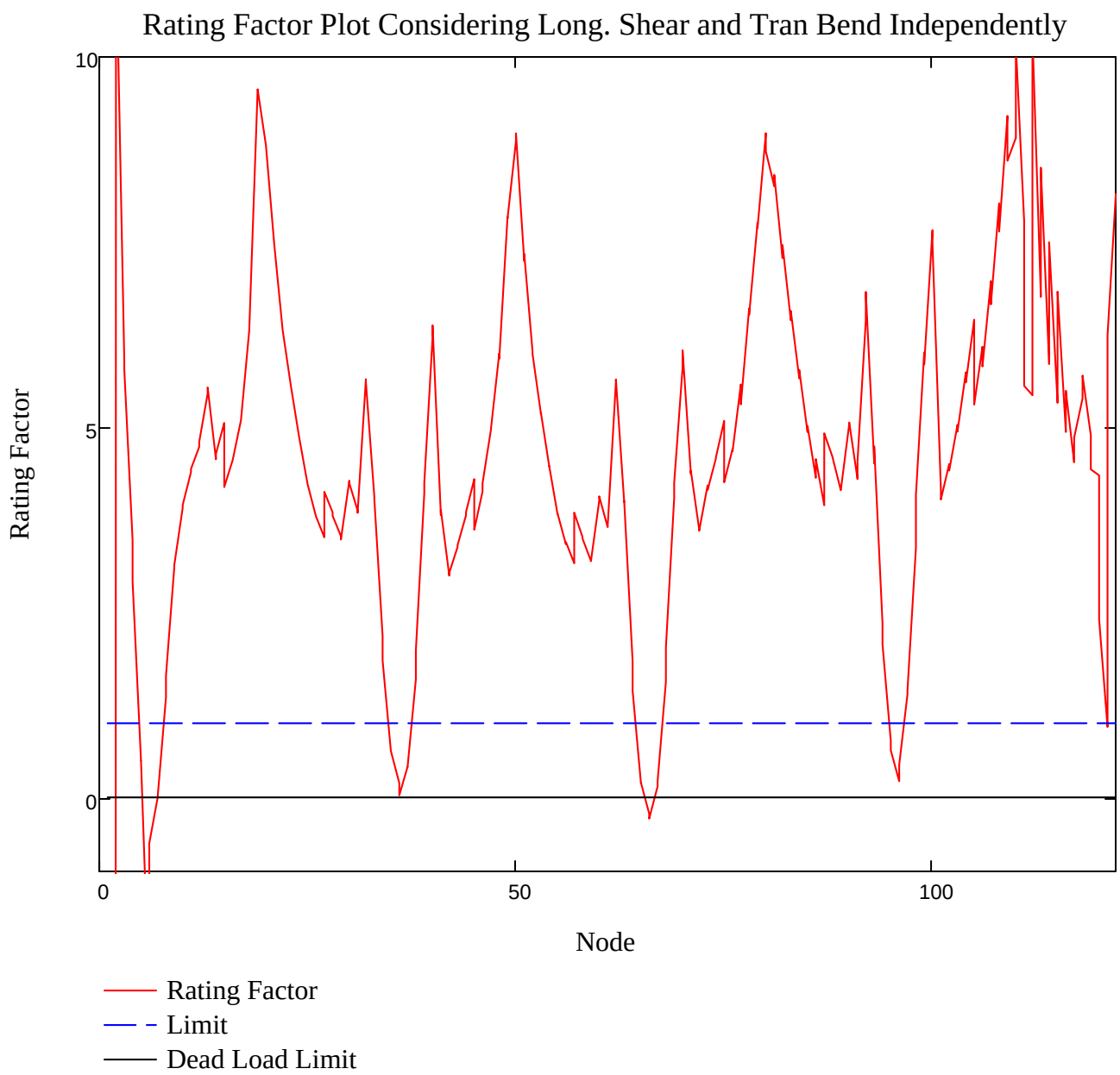

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.951$ at node $minRF_2 = 121$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.528$

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Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left(d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 178.893 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left(d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $V_{p_x} = -391.667\, kip$ $m_{rd_x} = 89.239 \cdot kip \cdot in$

$V_{prim_x} = -1.175 \times 10^3\, kip$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 10.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[0.85 - 0.05 \cdot \left(\frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.319 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.158 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.478 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 19.214 \cdot kip \cdot ft$

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$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $V_{s2_x} = 189.939 \cdot kips$

$\phi V_{n2_y} := \phi \cdot (V_{cvmax_y} + V_{s2_y} + |V_{p_y}|)$ $\phi V_{n2_x} = 617.462 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\phi M_{n_2} = 19.115 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $V_{s3_x} = 604.834 \cdot kips$

$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\phi V_{n_3} = 990.867 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $b_{wreq3_x} = 1.394 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\phi M_{n_3} = 19.214 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad V_{n_i} \leftarrow \phi V_{n_i} \\ \quad V_{n_{7-i}} \leftarrow \phi V \\ V_n \end{array} \right. \quad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad M_{n_i} \leftarrow \phi M_{n_i} \\ \quad M_{n_{7-i}} \leftarrow -\phi M_{n_i} \\ M_n \end{array} \right. \quad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad M_{u_i} \leftarrow m_{rd_x} \\ \quad M_{u_{i+1}} \leftarrow m_{r_x} \\ M_u \end{array} \right. \quad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad V_{u_i} \leftarrow |V_d| \\ \quad V_{u_{i+1}} \leftarrow |V_d + V_{LL}| \\ V_u \end{array} \right.$$

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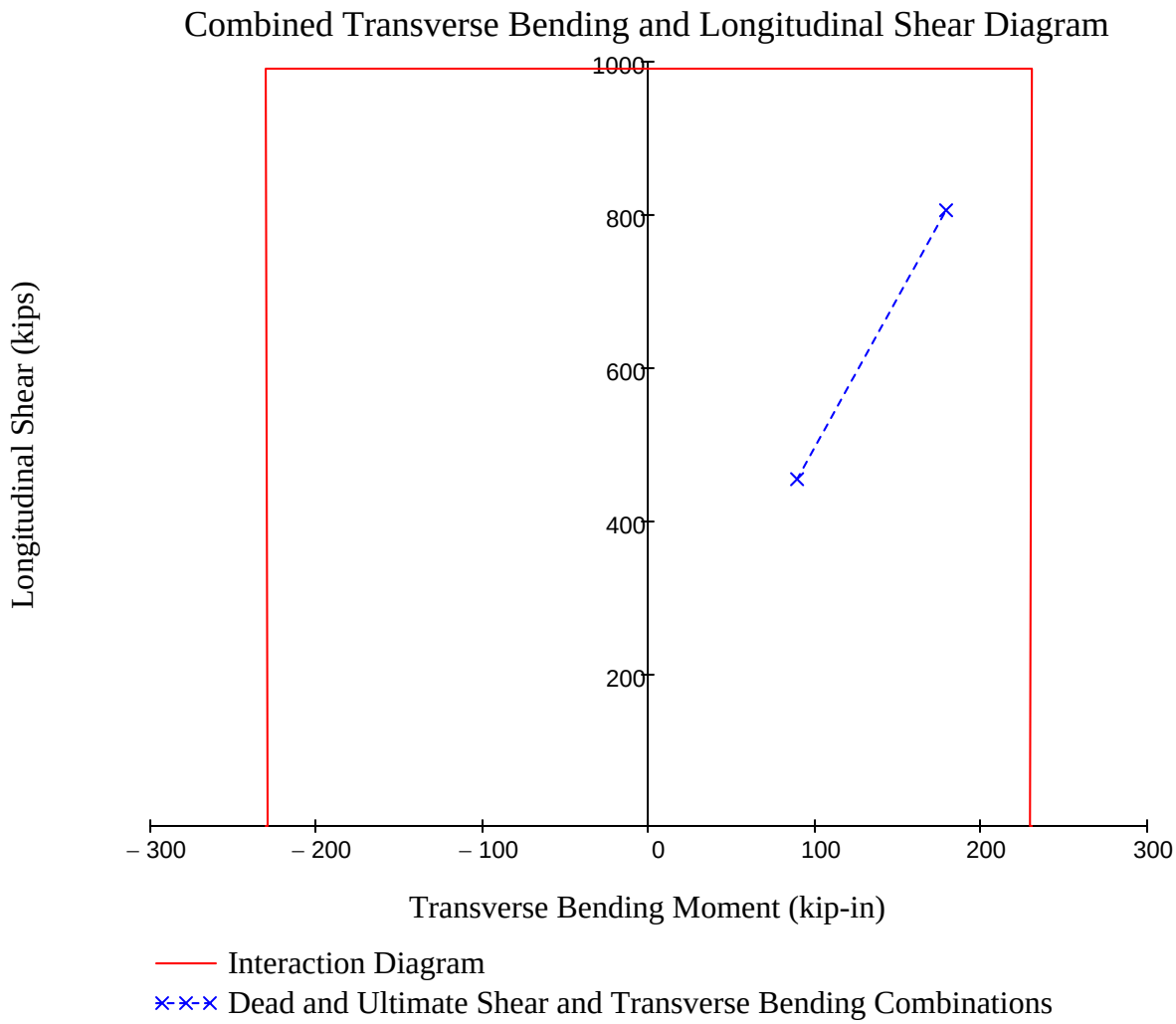


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.576$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

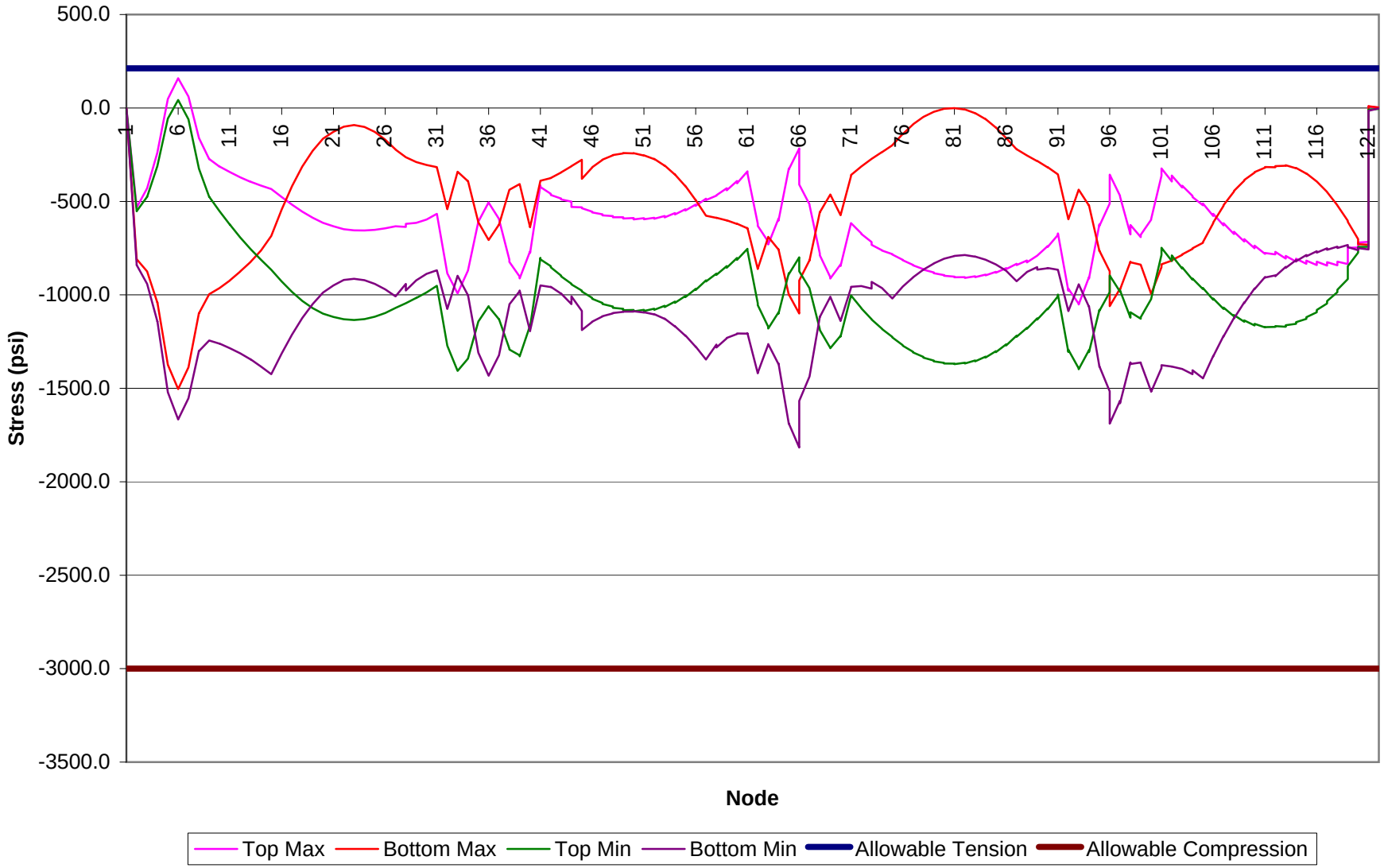
$RF_{shear} = 1.526$

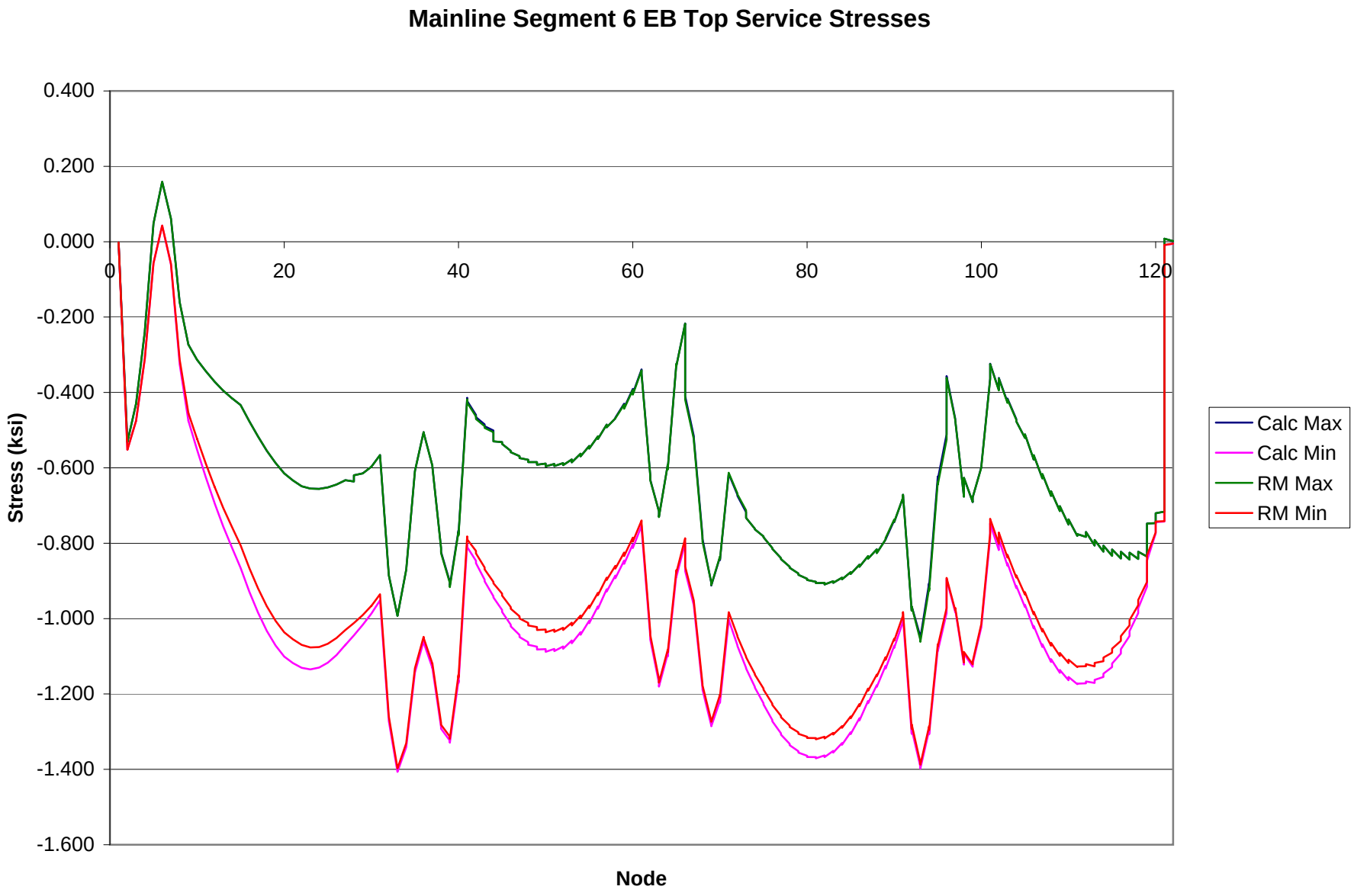
$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 1.591$

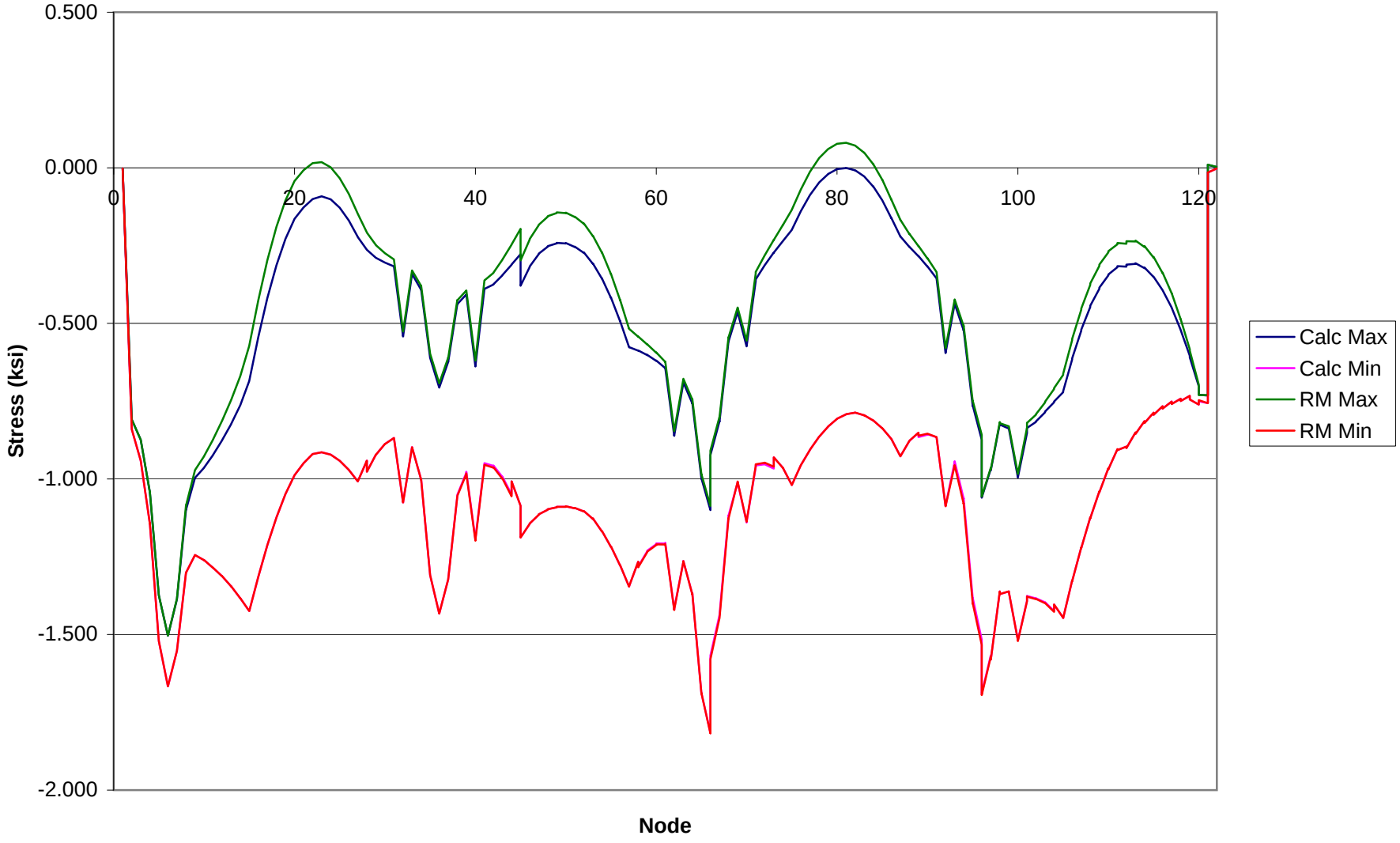
3.13.4 Service I Flexure (Service Stresses)

Service Stresses

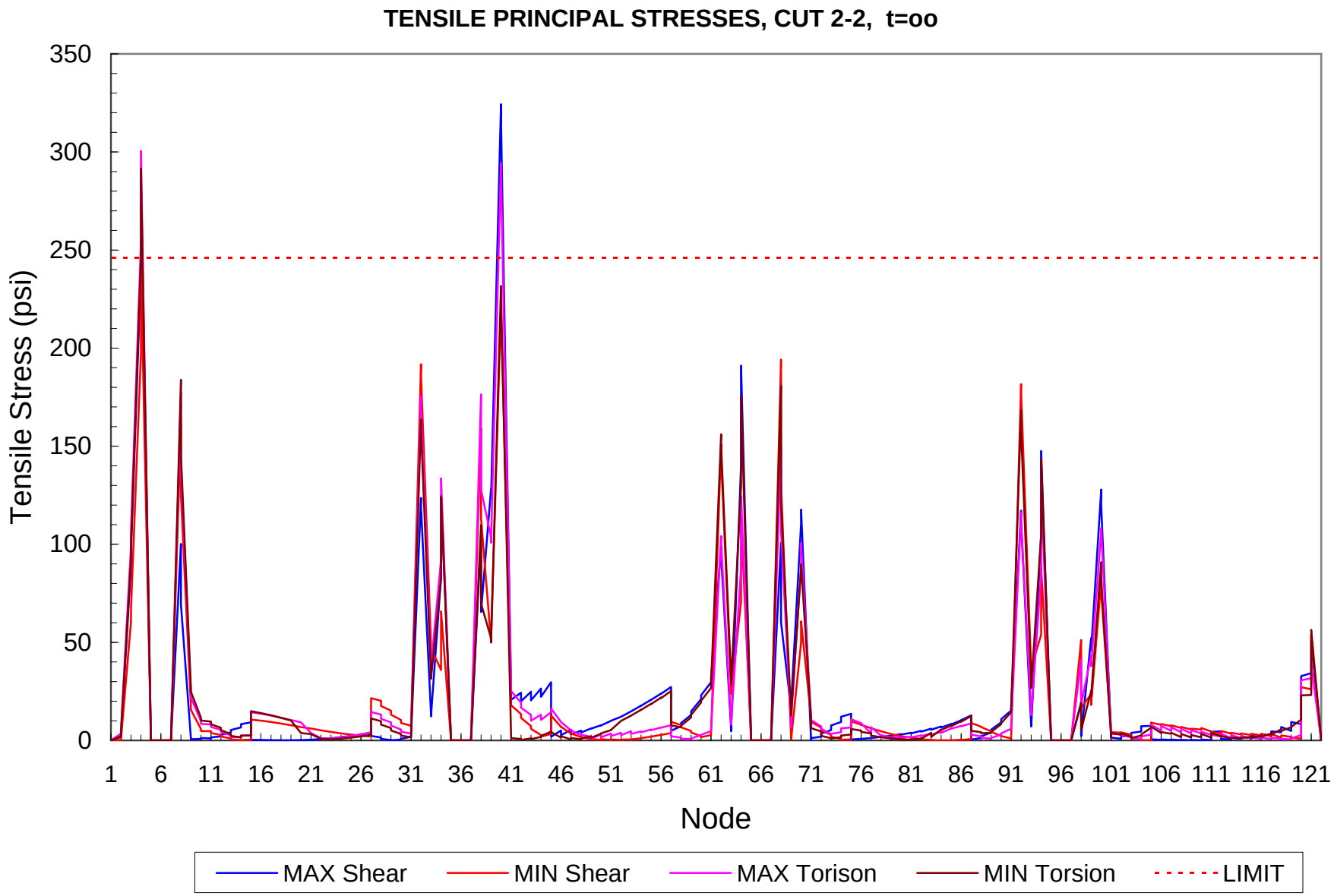


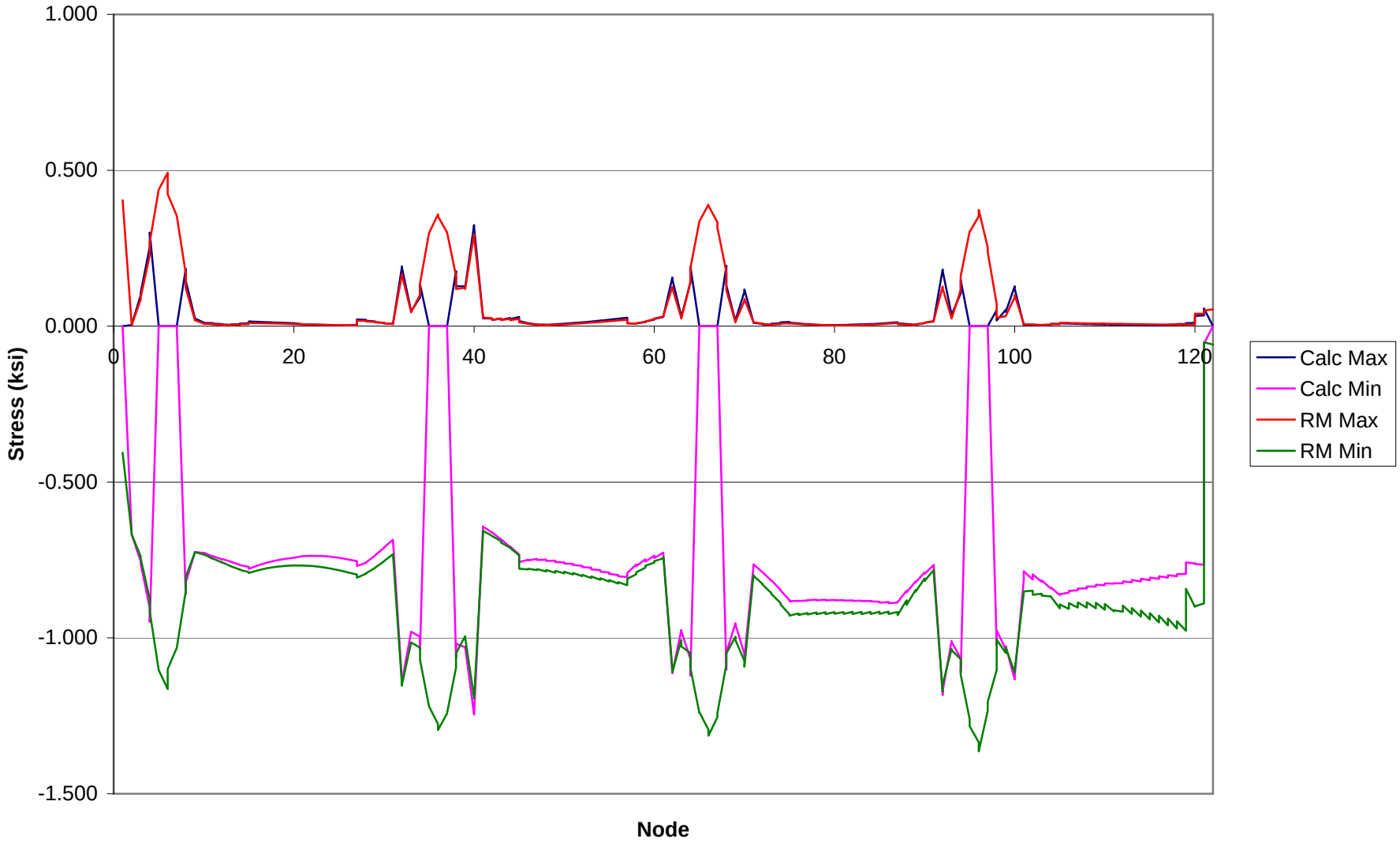

Mainline Segment 6 EB Top Service Stresses
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-1.400
-1.600
0
20
40
60
80
100
120
Stress (ksi)
Node
Calc Max
Calc Min
RM Max
RM Min

Mainline Segment 6 EB Bottom Service Stresses



3.13.5 Service I Principal Stresses


TENSILE PRINCIPAL STRESSES, CUT 2-2, t=oo
Tensile Stress (psi)
350
300
250
200
150
100
50
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121
Node
MAX Shear
MIN Shear
MAX Torison
MIN Torsion
LIMIT

3.13.5/1

Mainline Segment 6 EB Principal Stresses