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

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

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:

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

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

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

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

$V_{uvmax_x} = 2168 \cdot kips$	$T_{uvmax_x} = 3447 \cdot kip \cdot ft$	$M_{uvmax_x} = -437\, ft \cdot kips$	$N_{uvmax_x} = 47 \cdot kips$
$V_{uvmin_x} = 1106 \cdot kips$	$T_{uvmin_x} = -3222 \cdot kip \cdot ft$	$M_{uvmin_x} = 90\, ft \cdot kips$	$N_{uvmin_x} = 54 \cdot kips$
$V_{utmax_x} = 2103 \cdot kips$	$T_{utmax_x} = 3943 \cdot kip \cdot ft$	$M_{utmax_x} = -450\, ft \cdot kips$	$N_{utmax_x} = 49 \cdot kips$
$V_{utmin_x} = 1219 \cdot kips$	$T_{utmin_x} = -3691 \cdot kip \cdot ft$	$M_{utmin_x} = 113\, ft \cdot kips$	$N_{utmin_x} = 54 \cdot kips$

Calculate Variables Used for All Live Load Conditions:

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

$f_{pc_x} = -0.725\,ksi$

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

$K_x = 2$

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

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

$T_{cr_x} = 10598 \cdot kip \cdot ft$

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

$d_{e_x} = 106 \cdot in$

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

$d_{v_x} = 95.4 \cdot in$

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

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

$\varepsilon_{svmax_x} = 0.00401$

$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 43.052 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 1.197$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 104.463 \cdot kips$

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

$UseTorsionMaxShear_x = \text{"Yes"}$

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

$V_{dwebvmax_x} = 453.715\,kip$

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

$V_{LLwebvmax_x} = 351.97 \cdot kips$

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

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

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

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

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

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

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

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

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

RF

$RF_{vpos_{x,1}} = 0.951$

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

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

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

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

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

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

ε

$\varepsilon_{svmin_x} = 0.0004$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 30.402 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 3.691$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 322.194 \cdot kips$

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

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

$V_{dwebvmin_x} = 421.619\, kip$

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

$V_{LLwebvmin_x} = -100.53 \cdot kips$

$RF_{vneg} :=$ 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

$\varepsilon_{stmax_x} = 0.00378$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 42.231 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 1.252$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 109.256 \cdot kips$

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

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

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

$V_{dwebtmax_x} = 453.715\, kip$

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

$V_{LLwebtmax_x} = 337.71 \cdot kips$

$RF_{tpos} :=$ 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

$\varepsilon_{stmin_x} = 0.00032$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 30.112 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 3.877$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 338.405 \cdot kips$

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

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

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

$V_{dwebtmin_x} = 421.619\, kip$

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

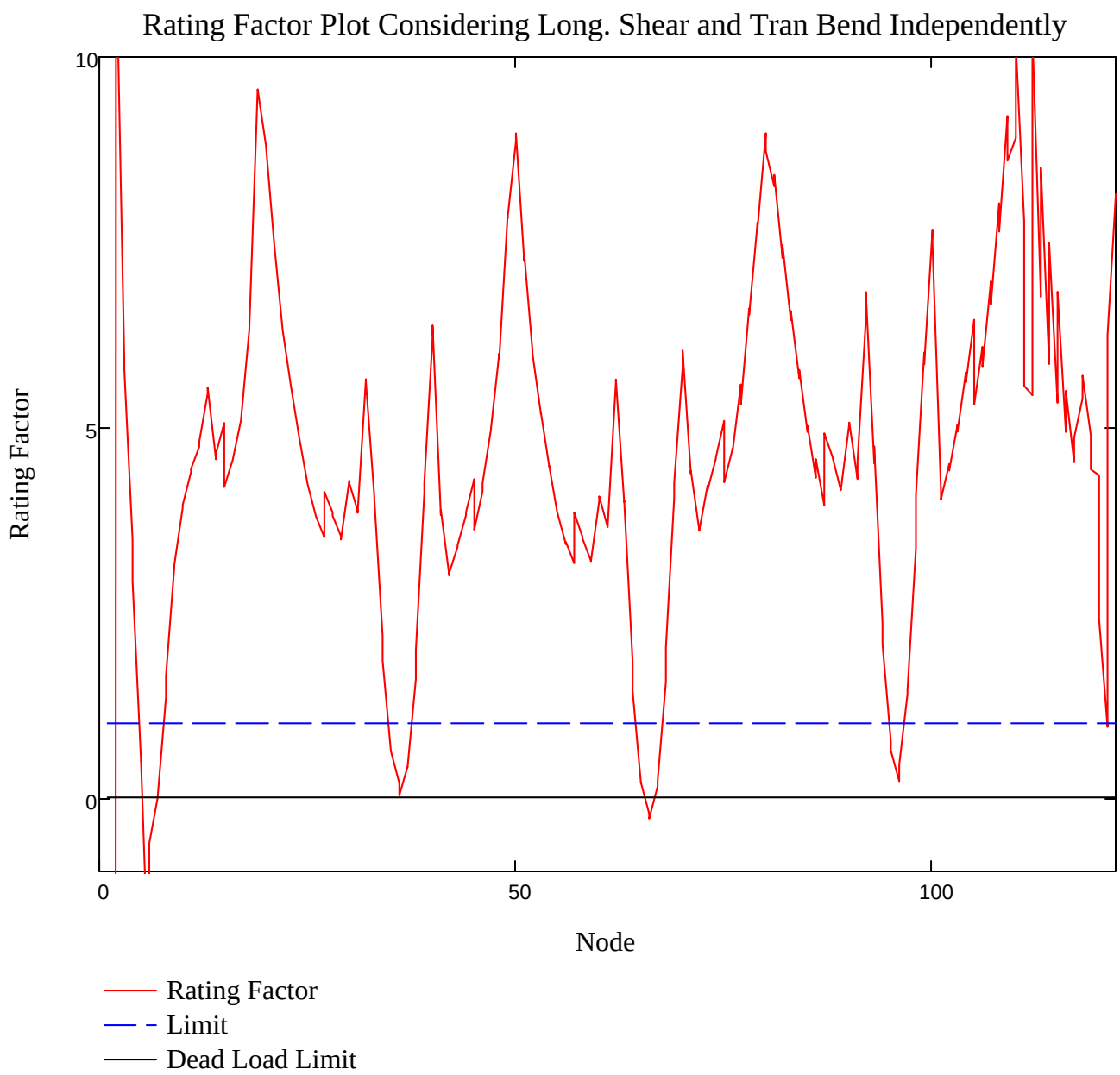
$V_{LLwebtmin_x} = -70.14 \cdot kips$

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

$RF_{tneg_{x,1}} = 1.737$

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

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



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 $minRF_3 = 0.528$

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

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 11.478 \cdot in$

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

$\phi M_{n_1} := \phi \cdot \left(F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 19.214 \cdot kip \cdot ft$

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

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

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $V_{s3_x} = 604.834 \cdot kips$

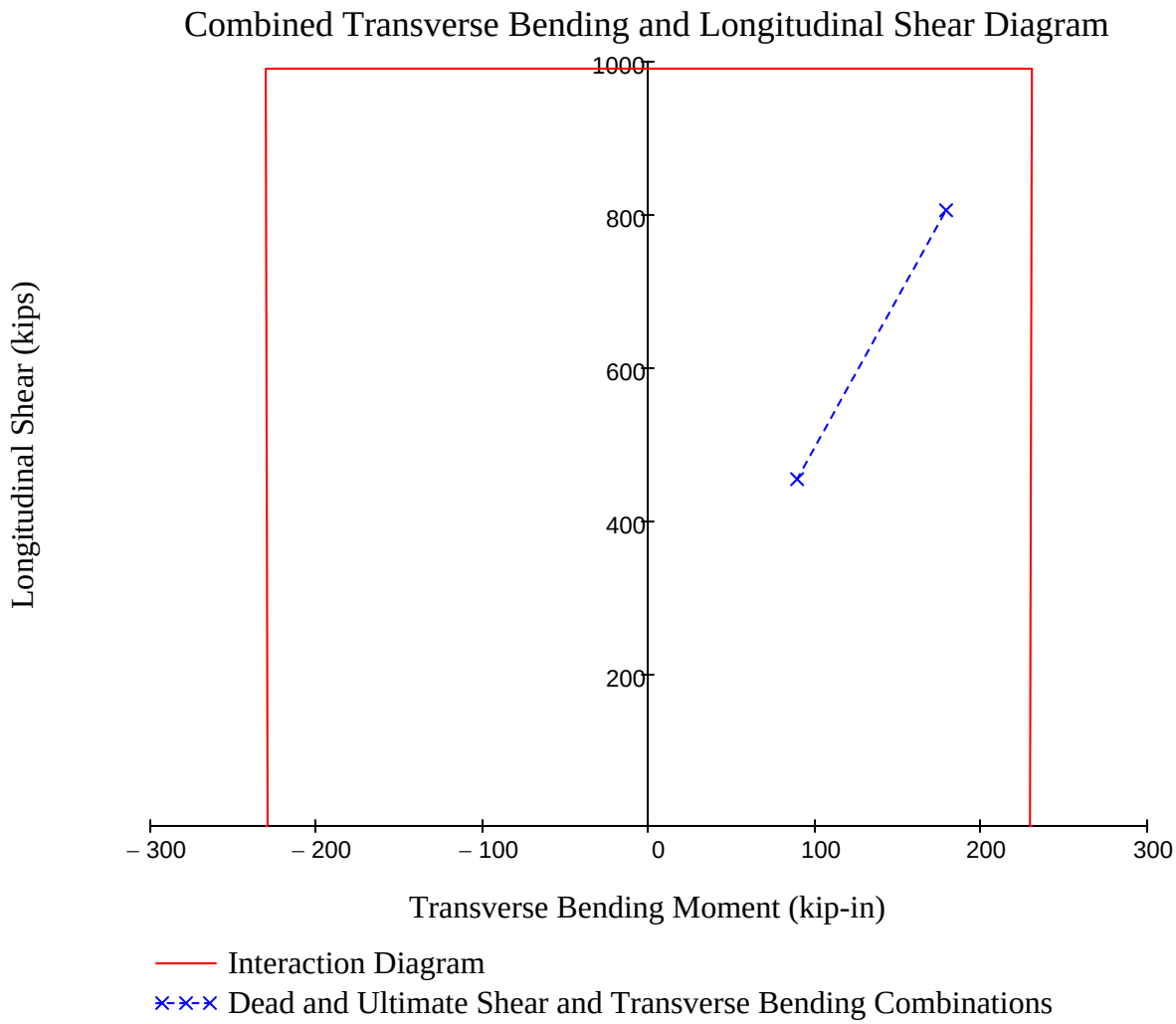
$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\phi V_{n_3} = 990.867 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $b_{wreq3_x} = 1.394 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\phi M_{n_3} = 19.214 \cdot kip \cdot ft$

Derive the Interaction Diagram:

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



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.

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

$RF_{bend} = 1.576$

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

$RF_{shear} = 1.526$

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

$RF_{torsion} = 1.591$