APPENDIX K. DESIGN EXAMPLES BASED ON DRAFT SPECIFICATION

Three connections were selected from different bridges referred to in Appendix A to demonstrate the application of the proposed rating specifications. These connections were rated using the existing LRFR checks from the FHWA Guide, as well as, the proposed LRFR and LFR specification for the MBE found in Appendix J. A summary of the rating factors for each joint are reflected in Table K1 through K3. The reader should be aware of three caveats when comparing all the rating factors from the tables below:

1. The checks focus on the gusset plate limit-states only, hence limit-states associated with fasteners were not performed.

2. No condition factors were used in any of the LRFR calculations.

3. When evaluating LRFR with the FHWA Guide, the system factor was not used. A system factor of 0.90 was assumed in the LRFR checks with the proposed specification because it is recommended this be mandatory. Therefore, a true comparison between the LRFR specifications should consider an additional 0.90 reduction on the values calculated with the FHWA Guide.

It is expected that there will be differences in rating factors calculated from the three methods, though these three example may shed some light on the magnitude of the differences. Overall, there is little change between the LRFR ratings attained from the FHWA Guide, the LRFR proposed specifications, and the LFR proposed specifications at the Inventory level. At the Operating level, the proposed LFR specifications consistently produced more favorable ratings than the two LRFR approaches.

Detailed rating calculations for each joint can be found on the pages following Table K3.

Table K1. Rating Factors for I-35W L1 Joint

	Inventory Level			Operating Level		
	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification
Member 1	1.25 buckling	2.85 buckling	2.40 buckling	1.62 buckling	3.69 buckling	4.01 buckling
Member 2	3.26 buckling	3.35 buckling	2.69 buckling	4.23 buckling	4.35 buckling	4.49 buckling
Member 3	2.02 buckling	1.08 PPSY	1.03 PPSY	2.62 buckling	1.40 PPSY	1.72 PPSY
Member 4	3.70 buckling	1.26 chord splice	1.46 chord splice	4.79 buckling	1.63 chord splice	2.43 chord splice
Vertical Shear 1	3.46 yielding	3.99 yielding	3.65 yielding	4.49 yielding	5.17 yielding	6.1 yielding
Vertical Shear 2	4.59 yielding	5.25 yielding	4.84 yielding	5.96 yielding	6.80 yielding	8.09 yielding
Controlling Rating Factor	1.25	1.08	1.03	1.62	1.40	1.72
PPSY = Partial Plane Shear Yield						

Table K2. Rating Factors for I-80 L3 Joint

	Inventory Level			Operating Level		
	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification
Member 1	2.38 buckling	NA	NA	3.09 buckling	NA	NA
Member 2	7.25 block shear	6.71 yielding	6.26 block shear	9.40 block shear	8.70 yielding	10.45 block shear
Member 3	9.24 buckling	10.14 buckling	8.32 buckling	11.98 buckling	13.15 buckling	13.89 buckling
Member 4	6.55 buckling	2.51 PPSY	2.53 PPSY	8.50 buckling	3.26 PPSY	4.22 PPSY
Member 5	6.36 buckling	NA	NA	8.25 buckling	NA	NA
Chord Splice	NA	5.55	6.42	NA	7.19	10.72
Horizontal Shear	4.04 yielding	4.53 yielding	4.46 yielding	5.23 yielding	5.87 yielding	7.44 yielding
Controlling Rating Factor	2.38	2.51	2.53	3.09	3.26	4.22
N/A = Not Applicable PPSY = Partial Plane Shear Yield						

Table K3. Rating Factors for I-64 U5

	Inventory Level			Operating Level		
	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification	FHWA Guidance (LRFR)	Proposed LRFR Specification	Proposed LFR Specification
Member 1	3.20 buckling	NA	NA	4.15 buckling	NA	NA
Member 2	12.77 buckling	14.23 buckling	11.8 buckling	16.56 buckling	18.44 buckling	19.7 buckling
Member 3	8.45 block shear	9.31 block shear	7.27 block shear	10.95 block shear	12.07 block shear	12.14 block shear
Member 4	2.86 buckling	NA	NA	3.71 buckling	NA	NA
Chord Splice	NA	3.67	4.84	NA	4.76	8.07
Horizontal Shear	16.72 fracture	14.39 fracture	14.36 fracture	21.67 fracture	18.66 fracture	23.96 fracture
Controlling Rating Factor	3.20	3.67	4.84	3.71	4.76	8.07

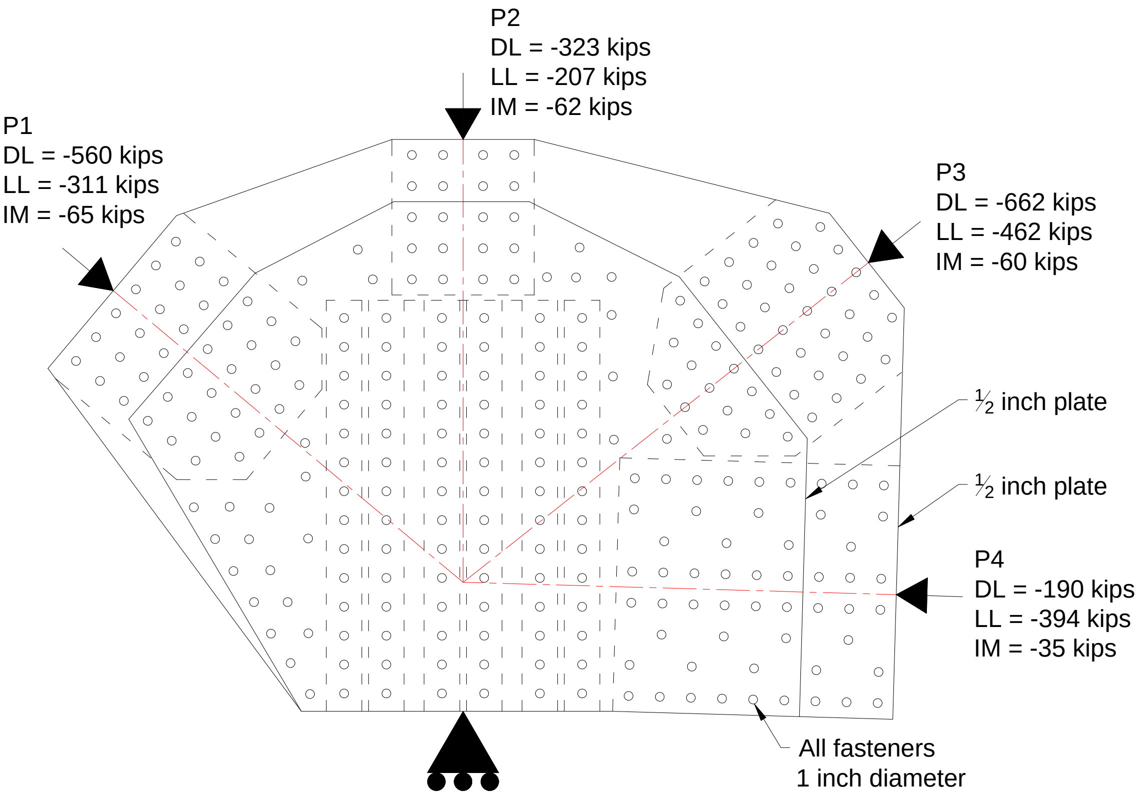
N/A = Not Applicable
PPSY = Partial Plane Shear Yield

I-35W GUSSET PLATE CHECKS

All Units: kip, in

These checks will make comparisions between the existing FHWA Guidance, the new proposed LRFR MBE specification, and the new proposed LFR MBE provisions. Fastener checks will also not be provided. Condition factors are assumed to be 1.00.

TRUSS JOINT L1



Note this joint has a bearing reaction on the bottom and the built-up multi-cell box section beneath the vertical member is extremely stiff and negates checking some limit states. This multi-celled section should be checked for compression resistance from the bearing reaction, but will not be done in this example

$F_y := 50\text{ksi}$

$F_u := 70\text{ksi}$ *Material Properties*

$E := 29000\text{ksi}$

$t_g := \frac{1}{2}\text{in}$ *Gusset and Shingle Plate Thickness*

Existing FHWA Guide Resistance Factors

$\phi_y := 0.95$ $\phi_c := 0.9$

$\phi_u := 0.80$ $\phi_{vy} := 0.95$

$\phi_{bs} := 0.80$ $\phi_{vu} := 0.80$

$\Omega := 0.74$

Proposed Resistance Factors

$\phi_{bs\_new} := 1.00$ $\phi_{c\_new} := 0.95$

$\phi_{vg} := 1.00$ $\phi_{cs} := 0.85$

$\Omega_{new} := 0.88$

Load Factors

$\gamma_{LL} := 1.75$ $\gamma_{LL\_LFR} := 2.17$

$\gamma_{DL} := 1.25$ $\gamma_{DL\_LFR} := 1.3$

System Factor

$\phi_s := 0.90$ *assumes it's a bolted truss, proposed as mandatory for LRFR under MBE Article 6A.6.12.6. The system factor will not be used in calculations using the existing FHWA Guidance*

Member Forces For One Gusset Plate

$P_{1DL} := \frac{560}{2} kip$ $P_{1LL} := \frac{311 + 65}{2} kip$ *Compression*

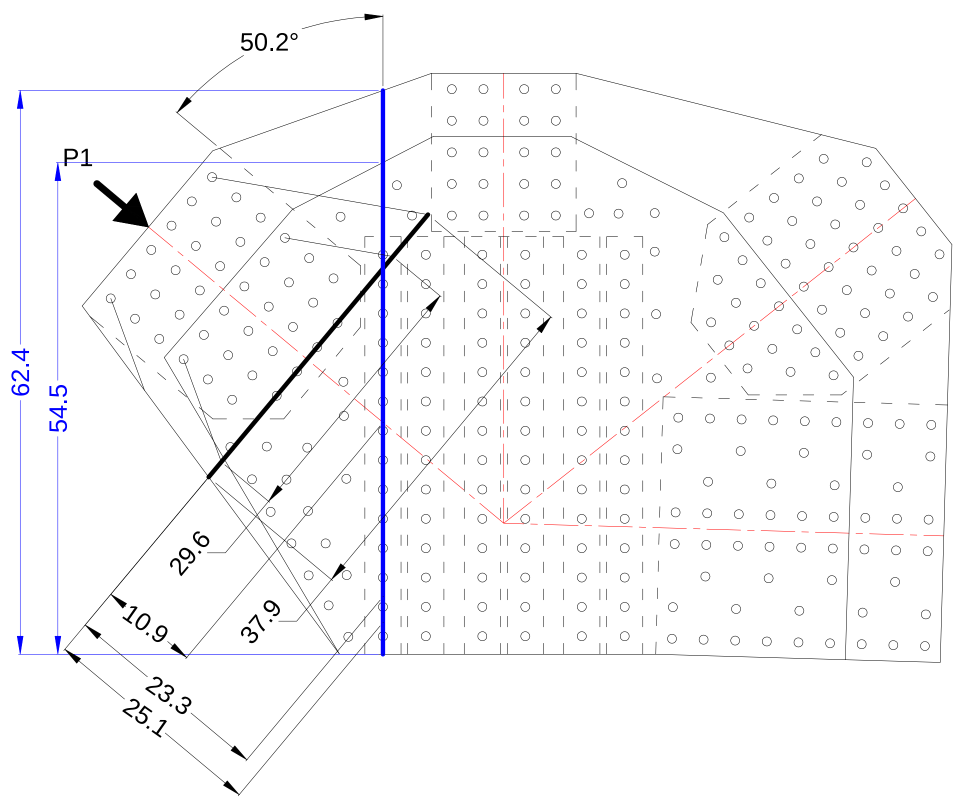
$P_{2DL} := \frac{323}{2} kip$ $P_{2LL} := \frac{207 + 62}{2} kip$ Compression

$P_{3DL} := \frac{662}{2} kip$ $P_{3LL} := \frac{462 + 60}{2} kip$ *Compression*

$P_{4DL} := \frac{190}{2} kip$ $P_{4LL} := \frac{394 + 35}{2} kip$ *Compression*

MEMBER 1

Compression Member - Need to check Whitmore buckling and partial plane shear yielding



$L_{avg1} := \frac{0in + 10.9in + 25.1in}{3}$

$L_{avg2} := \frac{0in + 10.9in + 23.3in}{3}$

$L_{mid} := 10.9in$

$r_s := \frac{t_g}{\sqrt{12}}$

$A_{s1} := 37.9in \cdot t_g$

$A_{s2} := 29.6in \cdot t_g$

Calculate LRFR rating factors using existing FHWA Guidance method

$$K := 1.2$$

Calculate the compression capacity of the primary gusset plate

$$\lambda_1 := \left(\frac{K \cdot L_{avg1}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_1 = 1.74$$

$$C_1 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_1} \cdot F_y \cdot A_{s1}\right) & \text{if } \lambda_1 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s1}}{\lambda_1} & \text{otherwise} \end{cases} \qquad C_1 = 414.05 \cdot kip$$

Calculate the compression capacity of the shingled plate

$$\lambda_2 := \left(\frac{K \cdot L_{avg2}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_2 = 1.57$$

$$C_2 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_2} \cdot F_y \cdot A_{s2}\right) & \text{if } \lambda_2 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s2}}{\lambda_2} & \text{otherwise} \end{cases} \qquad C_2 = 346.97 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{\left(C_1 + C_2\right) - \gamma_{DL} \cdot P_{1DL}}{\gamma_{LL} \cdot P_{1LL}} = 1.25}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 1.62}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.1

$$\frac{P_{1DL}}{P_{1LL}} = 1.49$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.49 - 1}{5}\right) \qquad R_{DL\_LL} = 0.99$$

calculate the factored Whitmore buckling strength.

$$P_{e1} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s1} = 3804.43 \cdot kip \qquad P_{e2} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s2} = 2971.27 \cdot kip$$

$$P_{o1} := F_y \cdot A_{s1} = 947.5 \cdot kip \qquad P_{o2} := F_y \cdot A_{s2} = 740 \cdot kip$$

$$Whit_1 := \phi_{c\_new} \cdot \begin{cases} \left(0.658^{\frac{P_{o1}}{P_{e1}}} \cdot P_{o1} \right) & \text{if } \frac{P_{e1}}{P_{o1}} \geq 0.44 \\ 0.877 \cdot P_{e1} & \text{otherwise} \end{cases} = 811.02 \cdot kip$$

$$Whit_2 := \phi_{c\_new} \cdot \begin{cases} \left(0.658^{\frac{P_{o2}}{P_{e2}}} \cdot P_{o2} \right) & \text{if } \frac{P_{e2}}{P_{o2}} \geq 0.44 \\ 0.877 \cdot P_{e2} & \text{otherwise} \end{cases} = 633.41 \cdot kip$$

calculate the partial plane shear yield check

$$PS_1 := \phi_{vg} \cdot \frac{\Omega_{new} \cdot (0.58 \cdot F_y) \cdot (62.4in) \cdot t_g}{\cos(50.2deg)} = 1243.89 \cdot kip$$

$$PS_2 := \phi_{vg} \cdot \frac{\Omega_{new} \cdot (0.58 \cdot F_y) \cdot (54.5in) \cdot t_g}{\cos(50.2deg)} = 1086.41 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LRFR} := \min(Whit_1 + Whit_2, PS_1 + PS_2)$$

$$RF_{LRFRinv} := \frac{R_{DL\_LL} \cdot \phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{1DL}}{\gamma_{LL} \cdot P_{1LL}} = 2.85$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$RF_{LRFRopr} = 3.69$$

Calculate the proposed LFR rating factors (minimum of Whitmore buckling and partial plane shear)

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y \cdot \left[1 - \frac{F_y}{4 \cdot \pi^2 E} \left(\frac{K \cdot L_{mid}}{r_s} \right)^2 \right] & \text{if } \frac{K \cdot L_{mid}}{r_s} \leq \sqrt{\frac{2 \cdot \pi^2 \cdot E}{F_y}} \\ \frac{\pi^2 \cdot E}{\left(\frac{K \cdot L_{mid}}{r_s} \right)^2} & \text{otherwise} \end{cases} = 46.89 \cdot ksi$$

$$Whit := 0.85 \cdot (A_{s1} + A_{s2}) \cdot F_{cr} = 1345.06 \cdot kip$$

calculate the partial plane shear yield check

$$PS := \frac{\Omega_{new} \cdot (0.58 \cdot F_y) \cdot (62.4in + 54.5in) \cdot t_g}{\cos(50.2deg)} = 2330.29 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LFR} := \min(Whit, PS) = 1345.06 \cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{1DL}}{\gamma_{LL\_LFR} \cdot P_{1LL}} = 2.4}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

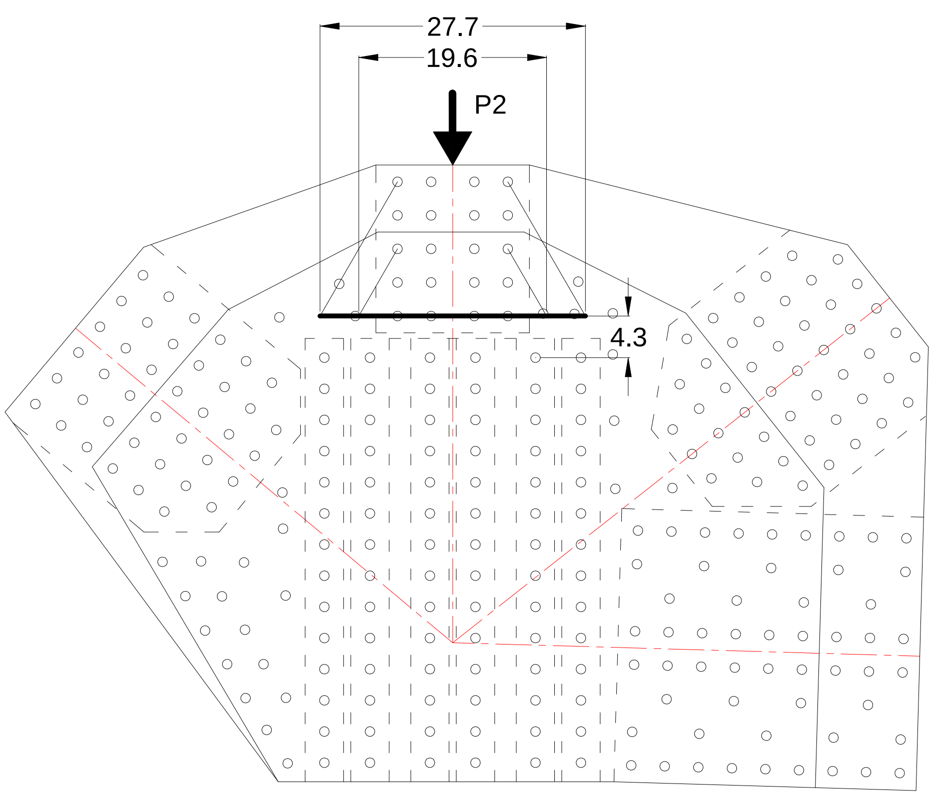
$$\boxed{RF_{LFRopr} = 4.01}$$

Summarize Rating Factors Using the Three Methods for Member 1

	Inventory	**Operating**
Existing FHWA LRFR Method	$RF_{FHWAinv} = 1.25$	$RF_{FHWAopr} = 1.62$
Proposed LRFR Method	$RF_{LRFRinv} = 2.85$	$RF_{LRFRopr} = 3.69$
Proposed LFR Method	$RF_{LFRinv} = 2.4$	$RF_{LFRopr} = 4.01$

MEMBER 2

Compression Member - Need to check Whitmore buckling



$$L_{avg1} := \frac{4.3in + 4.3in + 4.3in}{3}$$

$$L_{avg2} := \frac{4.3in + 4.3in + 4.3in}{3}$$

$$L_{mid} := 4.3in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_{s1} := 27.7in \cdot t_g$$

$$A_{s2} := 19.6in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

$K := 1.2$

Calculate the compression capacity of the primary gusset plate

$$\lambda_1 := \left(\frac{K \cdot L_{avg1}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_1 = 0.22$$

$$C_1 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_1} \cdot F_y \cdot A_{s1}\right) & \text{if } \lambda_1 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s1}}{\lambda_1} & \text{otherwise} \end{cases} \qquad C_1 = 568.03 \cdot kip$$

Calculate the compression capacity of the shingled plate

$$\lambda_2 := \left(\frac{K \cdot L_{avg2}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_2 = 0.22$$

$$C_2 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_2} \cdot F_y \cdot A_{s2}\right) & \text{if } \lambda_2 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s2}}{\lambda_2} & \text{otherwise} \end{cases} \qquad C_2 = 401.93 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{\left(C_1 + C_2\right) - \gamma_{DL} \cdot P_{2DL}}{\gamma_{LL} \cdot P_{2LL}} = 3.26}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 4.23}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.1

$$\frac{P_{2DL}}{P_{2LL}} = 1.2$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.18 - 1}{5}\right) \qquad R_{DL\_LL} = 1$$

calculate the factored Whitmore buckling strength. Sum together the individual components of the gusset and shingle plate.

$$P_{e1} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s1} = 17866.8 \cdot kip \qquad P_{e2} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s2} = 12642.21 \cdot kip$$

$$P_{o1} := F_y \cdot A_{s1} = 692.5 \cdot kip \qquad P_{o2} := F_y \cdot A_{s2} = 490 \cdot kip$$

$$\text{Whit}_1 := \phi_{c\_new}\cdot \begin{cases} \left(0.658^{\frac{P_{o1}}{P_{e1}}}\cdot P_{o1}\right) & \text{if } \dfrac{P_{e1}}{P_{o1}} \ge 0.44 \\ 0.877\cdot P_{e1} & \text{otherwise} \end{cases} = 647.29\cdot \text{kip}$$

$$\text{Whit}_2 := \phi_{c\_new}\cdot \begin{cases} \left(0.658^{\frac{P_{o2}}{P_{e2}}}\cdot P_{o2}\right) & \text{if } \dfrac{P_{e2}}{P_{o2}} \ge 0.44 \\ 0.877\cdot P_{e2} & \text{otherwise} \end{cases} = 458.01\cdot \text{kip}$$

calculate the partial plane shear yield check

This check is not relavent to this vertical member because there is no partial plane that can shear and reduce the out-of-plane stiffness of the member

therefore the capacity is only detemined from the sum of the Whitmore buckling strength from the primary gusset and shingle

$$C_{LRFR} := \text{Whit}_1 + \text{Whit}_2 = 1105.3\cdot \text{kip}$$

$$\boxed{RF_{LRFRinv} := \frac{R_{DL\_LL}\cdot \phi_s\cdot C_{LRFR} - \gamma_{DL}\cdot P_{2DL}}{\gamma_{LL}\cdot P_{2LL}} = 3.35}$$

$$RF_{LRFRopr} := RF_{LRFRinv}\cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 4.35}$$

Calculate the proposed LFR rating factors

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y\cdot\left[1 - \dfrac{F_y}{4\cdot\pi^2 E}\left(\dfrac{K\cdot L_{mid}}{r_s}\right)^2\right] & \text{if } \dfrac{K\cdot L_{mid}}{r_s} \le \sqrt{\dfrac{2\cdot\pi^2\cdot E}{F_y}} \\ \dfrac{\pi^2\cdot E}{\left(\dfrac{K\cdot L_{mid}}{r_s}\right)^2} & \text{otherwise} \end{cases} = 49.52\cdot \text{ksi}$$

$$\text{Whit} := 0.85\cdot\left(A_{s1} + A_{s2}\right)\cdot F_{cr} = 995.39\cdot \text{kip}$$

calculate the partial plane shear yield check

This check is not relavent to this vertical member because there is no partial plane that can shear and reduce the out-of-plane stiffness of the member

therefore the capacity is only detemined from the sum of the Whitmore buckling strength from the primary gusset and shingle

$$C_{LFR} := \text{Whit} = 995.39\cdot \text{kip}$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{2DL}}{\gamma_{LL\_LFR} \cdot P_{2LL}} = 2.69}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

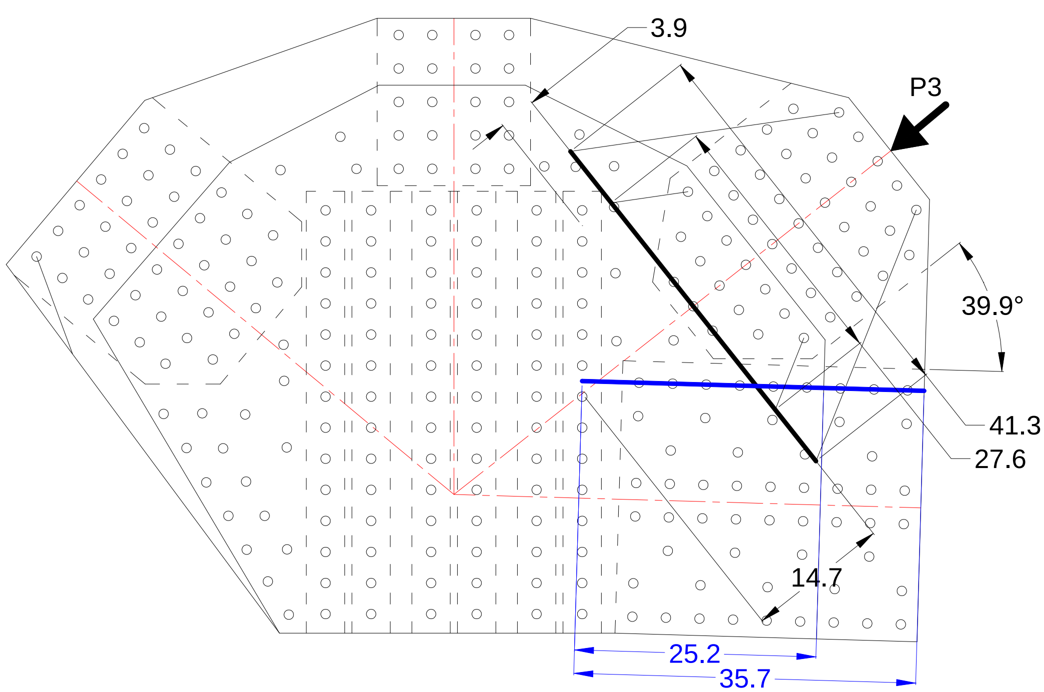
$$\boxed{RF_{LFRopr} = 4.49}$$

Summarize Rating Factors Using the Three Methods for Member 2

	Inventory	**Operating**
Existing FHWA LRFR Method	$RF_{FHWAinv} = 3.26$	$RF_{FHWAopr} = 4.23$
Proposed LRFR Method	$RF_{LRFRinv} = 3.35$	$RF_{LRFRopr} = 4.35$
Proposed LFR Method	$RF_{LFRinv} = 2.69$	$RF_{LFRopr} = 4.49$

MEMBER 3

Compression Member - Need to check Whitmore buckling and partial plane shear yielding



$$L_{avg1} := \frac{0in + 14.7in + 0in}{3}$$

$$L_{avg2} := \frac{3.9in + 14.7in + 0in}{3}$$

$$L_{mid} := 14.7in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_{s1} := 41.3in \cdot t_g$$

$$A_{s2} := 27.6in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

$K := 1.2$

Calculate the compression capacity of the primary gusset plate

$$\lambda_1 := \left(\frac{K \cdot L_{avg1}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_1 = 0.29$$

$$C_1 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_1} \cdot F_y \cdot A_{s1}\right) & \text{if } \lambda_1 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s1}}{\lambda_1} & \text{otherwise} \end{cases} \qquad C_1 = 823.79 \cdot kip$$

Calculate the compression capacity of the shingled plate

$$\lambda_2 := \left(\frac{K \cdot L_{avg2}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_2 = 0.46$$

$$C_2 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_2} \cdot F_y \cdot A_{s2}\right) & \text{if } \lambda_2 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s2}}{\lambda_2} & \text{otherwise} \end{cases} \qquad C_2 = 512.07 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{\left(C_1 + C_2\right) - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 2.02}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 2.62}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.1

$$\frac{P_{3DL}}{P_{3LL}} = 1.27$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.27 - 1}{5}\right) \qquad R_{DL\_LL} = 0.99$$

Calculate the factored Whitmore buckling strength.

$$P_{e1} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s1} = 2279.39 \cdot kip \qquad P_{e2} := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_{s2} = 1523.28 \cdot kip$$

$$P_{o1} := F_y \cdot A_{s1} = 1032.5 \cdot kip \qquad P_{o2} := F_y \cdot A_{s2} = 690 \cdot kip$$

$$Whit_1 := \phi_{c\_new} \cdot \begin{cases} \left(0.658^{\frac{P_{o1}}{P_{e1}}} \cdot P_{o1}\right) & \text{if } \frac{P_{e1}}{P_{o1}} \geq 0.44 \\ 0.877 \cdot P_{e1} & \text{otherwise} \end{cases} = 811.48 \cdot kip$$

$$Whit_2 := \phi_{c\_new} \cdot \begin{cases} \left(0.658^{\frac{P_{o2}}{P_{e2}}} \cdot P_{o2}\right) & \text{if } \frac{P_{e2}}{P_{o2}} \geq 0.44 \\ 0.877 \cdot P_{e2} & \text{otherwise} \end{cases} = 542.29 \cdot kip$$

Calculate the partial plane shear yield check

$$PS_1 := \phi_{vg} \cdot \frac{\Omega_{new} \cdot \left(0.58 \cdot F_y\right) \cdot (35.7in) \cdot t_g}{\cos(39.9deg)} = 593.79 \cdot kip$$

$$PS_2 := \phi_{vg} \cdot \frac{\Omega_{new} \cdot \left(0.58 \cdot F_y\right) \cdot (25.2in) \cdot t_g}{\cos(39.9deg)} = 419.14 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LRFR} := \min\left(Whit_1 + Whit_2, PS_1 + PS_2\right)$$

$$\boxed{RF_{LRFRinv} := \frac{R_{DL\_LL} \cdot \phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 1.08}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 1.4}$$

Calculate the proposed LFR rating factors

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y \cdot \left[1 - \frac{F_y}{4 \cdot \pi^2 E} \left(\frac{K \cdot L_{mid}}{r_s}\right)^2\right] & \text{if } \frac{K \cdot L_{mid}}{r_s} \leq \sqrt{\frac{2 \cdot \pi^2 \cdot E}{F_y}} \\ \frac{\pi^2 \cdot E}{\left(\frac{K \cdot L_{mid}}{r_s}\right)^2} & \text{otherwise} \end{cases} = 44.34 \cdot ksi$$

$$Whit := 0.85 \cdot \left(A_{s1} + A_{s2}\right) \cdot F_{cr} = 1298.32 \cdot kip$$

calculate the partial plane shear yield check

$$PS := \frac{\Omega_{new} \cdot (0.58 \cdot F_y) \cdot (35.7in + 25.2in) \cdot t_g}{\cos(39.9deg)} = 1012.93 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LFR} := \min(Whit, PS) = 1012.93 \cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{3DL}}{\gamma_{LL\_LFR} \cdot P_{3LL}} = 1.03}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

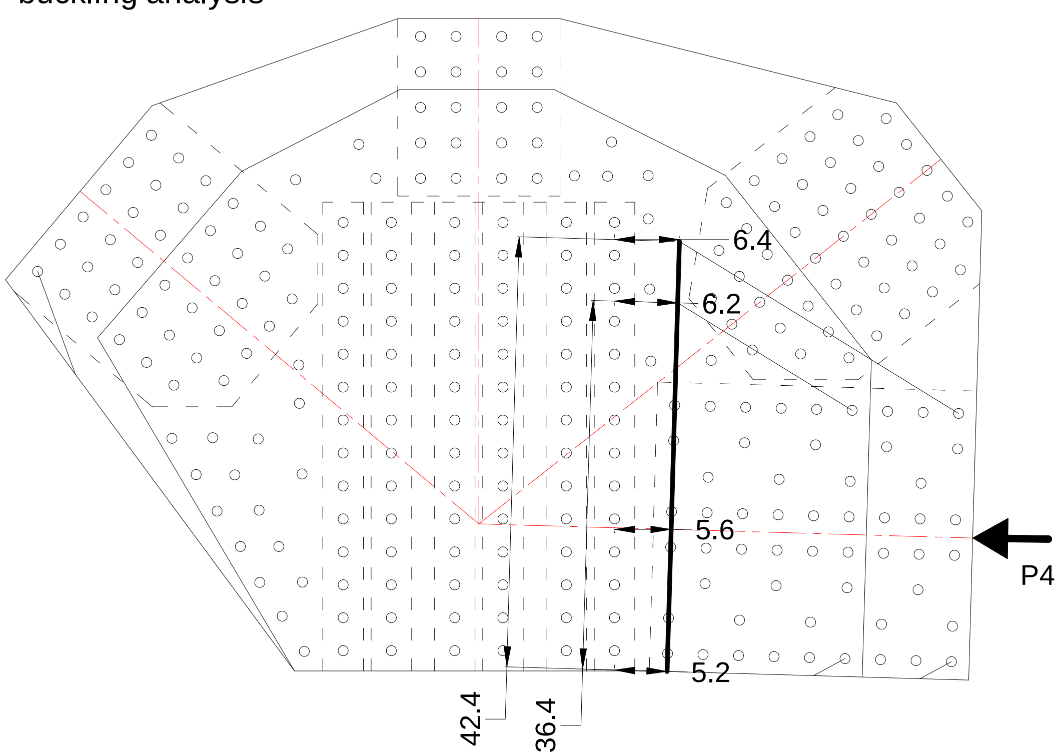
$$\boxed{RF_{LFRopr} = 1.72}$$

Summarize Rating Factors Using the Three Methods for Member 3

	Inventory	**Operating**
Existing FHWA LRFR Method	$RF_{FHWAinv} = 2.02$	$RF_{FHWAopr} = 2.62$
Proposed LRFR Method	$RF_{LRFRinv} = 1.08$	$RF_{LRFRopr} = 1.4$
Proposed LFR Method	$RF_{LFRinv} = 1.03$	$RF_{LFRopr} = 1.72$

MEMBER 4

Calculate LRFR rating factors using existing FHWA Guidance method that suggests a Whitmore buckling analysis



$$L_{avg1} := \frac{6.4in + 5.6in + 5.2in}{3}$$

$$L_{avg2} := \frac{6.2in + 5.6in + 5.2in}{3}$$

$$L_{mid} := 5.6in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_{s1} := 42.4in \cdot t_g$$

$$A_{s2} := 36.4in \cdot t_g$$

$$K := 1.2$$

Calculate the compression capacity of the primary gusset plate

$$\lambda_1 := \left(\frac{K \cdot L_{avg1}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_1 = 0.4$$

$$C_1 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_1} \cdot F_y \cdot A_{s1}\right) & \text{if } \lambda_1 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s1}}{\lambda_1} & \text{otherwise} \end{cases} \qquad C_1 = 808.95 \cdot kip$$

Calculate the compression capacity of the shingled plate

$$\lambda_2 := \left(\frac{K \cdot L_{avg2}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda_2 = 0.39$$

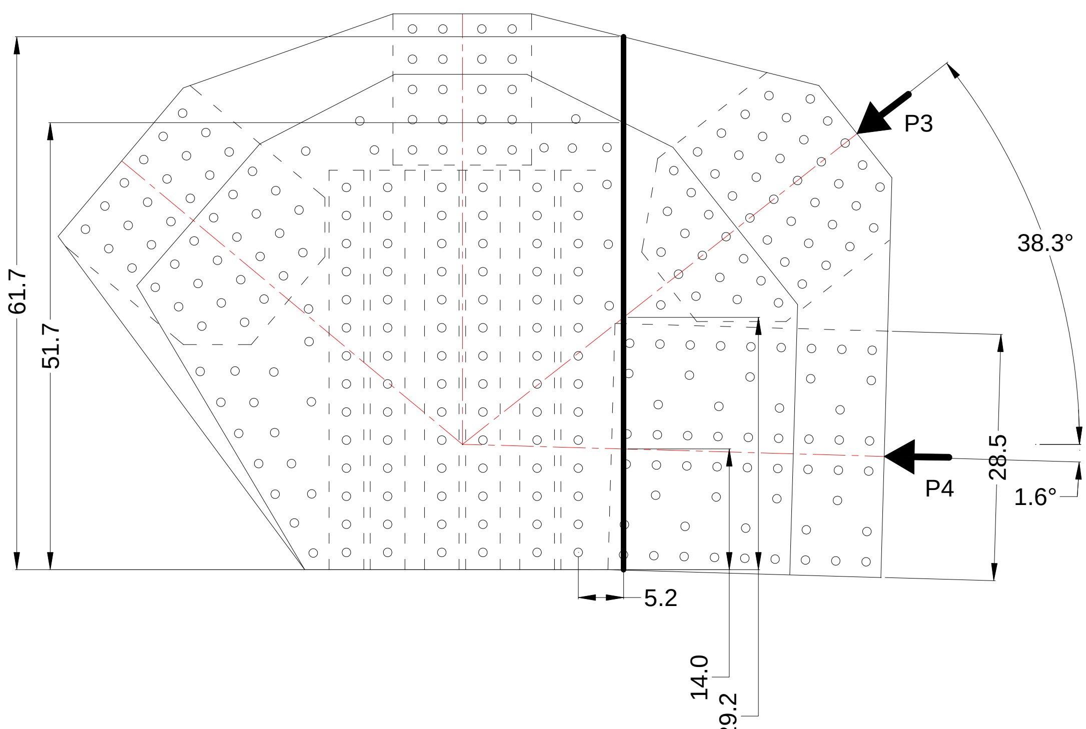
$$C_2 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda_2} \cdot F_y \cdot A_{s2}\right) & \text{if } \lambda_2 \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s2}}{\lambda_2} & \text{otherwise} \end{cases} \qquad C_2 = 697.13 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{\left(C_1 + C_2\right) - \gamma_{DL} \cdot P_{4DL}}{\gamma_{LL} \cdot P_{4LL}} = 3.7}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 4.79}$$

Calculate the proposed LRFR rating factors. Check the member as if it was a chord splice to ensure the section won't yeild under the eccentric loading, this would consider the load from both the P3 and P4 members.



$$K := 0.5 \qquad L_{splice} := 5.2in \qquad \frac{K \cdot L_{splice} \cdot \sqrt{12}}{2 \cdot t_g} = 9.01$$

Since KL/r of the free plate between chords is less than 25, Fcr equals Fy (MBE Equation 6A.6.12.6.8-2)

$$F_{cr} := F_y$$

Calculate the height (h1) of the P3 and P4 force resultant, use the factored loads

$$P3 := 2 \cdot \gamma_{LL} \cdot P_{3LL} + 2 \cdot \gamma_{DL} \cdot P_{3DL} \qquad P3 = 1741 \cdot kip$$

$$P4 := 2 \cdot \gamma_{LL} \cdot P_{4LL} + 2 \cdot \gamma_{DL} \cdot P_{4DL} \qquad P4 = 988.25 \cdot kip$$

$$h_1 := \frac{P4 \cdot \cos(1.6deg) \cdot (14.0in) + P3 \cdot \cos(38.3deg) \cdot (29.2in)}{P4 \cdot \cos(1.6deg) + P3 \cdot \cos(38.3deg)} \qquad h_1 = 22.82\ in$$

Calculate the gross area of the combined gusset and shingle plate cross-section

$$A_g := 2 \cdot t_g \cdot (61.7in) + 2 \cdot t_g \cdot (51.7in) = 113.4\ in^2$$

Calculate the height of the centroid of the combined gusset and shingle plate cross-section

$$h_2 := \frac{2 \cdot t_g \cdot (61.7in) \cdot \left(\frac{61.7}{2} in\right) + 2 \cdot t_g \cdot (51.7in) \cdot \left(\frac{51.7}{2} in\right)}{A_g} \qquad h_2 = 28.57\ in$$

Calculate the eccentricity between the force resultant and the centroid of the cross-section

$$e_p := h_2 - h_1 \qquad e_p = 5.75\ in$$

Since the centroid of the force is below the centroid of the cross-section, the maximum axial+bending stress will be at the bottom of the plate. Now calculate the section modulus to the bottom of the cross-section

$$I_g := 2 \cdot \left[\frac{(61.7in)^3 \cdot t_g}{12} + (61.7in) \cdot t_g \cdot \left(\frac{61.7}{2} in - h_2\right)^2 + \frac{(51.7in)^3 \cdot t_g}{12} + (51.7in) \cdot t_g \cdot \left(\frac{51.7}{2} in - h_2\right)^2\right]$$

$$S_g := \frac{I_g}{h_2} \qquad S_g = 1112.78 \cdot in^3$$

Calculate the capacity of the section assuming it occurs at first yield using beam bending theory (MBE Eqn. 6A.6.12.6.8-1)

$$C_{LRFR} := \phi_{cs} \cdot F_{cr} \cdot \left(\frac{S_g \cdot A_g}{S_g + e_p \cdot A_g}\right) = 3039.09 \cdot kip$$

Calculate the DL/LL reduction factor

$$\frac{\left(P_{4DL}\cdot\cos(1.6deg) + P_{3DL}\cdot\cos(38.3deg)\right)}{\left(P_{4LL}\cdot\cos(1.6deg) + P_{3LL}\cdot\cos(38.3deg)\right)} = 0.85$$

*** The DL/LL ratio is less than 1.0, so no DL/LL reduction is necessary ***

$$R_{DL\_LL} := 1$$

Calculate the LRFR Inventory rating factor

$$RF_{LRFRinv} := \frac{\phi_s\cdot R_{DL\_LL}\cdot C_{LRFR} - 2\cdot\gamma_{DL}\cdot\left(P_{4DL}\cdot\cos(1.6deg) + P_{3DL}\cdot\cos(38.3deg)\right)}{2\cdot\gamma_{LL}\cdot\left(P_{4LL}\cdot\cos(1.6deg) + P_{3LL}\cdot\cos(38.3deg)\right)}$$

*** dead and live loads were doubled because ealier in the sheet they were halved so resistance checks could be made per gusset plate, which doesn't apply to the chord splice ***

$$\boxed{RF_{LRFRinv} = 1.26}$$

$$RF_{LRFRopr} := RF_{LRFRinv}\cdot\frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 1.63}$$

Calculate the proposed LFR rating factors

The capacity calculation is no different in LFR

$$C_{LFR} := \frac{C_{LRFR}}{\phi_{cs}} = 3575.4\cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - 2\cdot\gamma_{DL\_LFR}\cdot\left(P_{4DL}\cdot\cos(1.6deg) + P_{3DL}\cdot\cos(38.3deg)\right)}{2\cdot\gamma_{LL\_LFR}\cdot\left(P_{4LL}\cdot\cos(1.6deg) + P_{3LL}\cdot\cos(38.3deg)\right)} = 1.46}$$

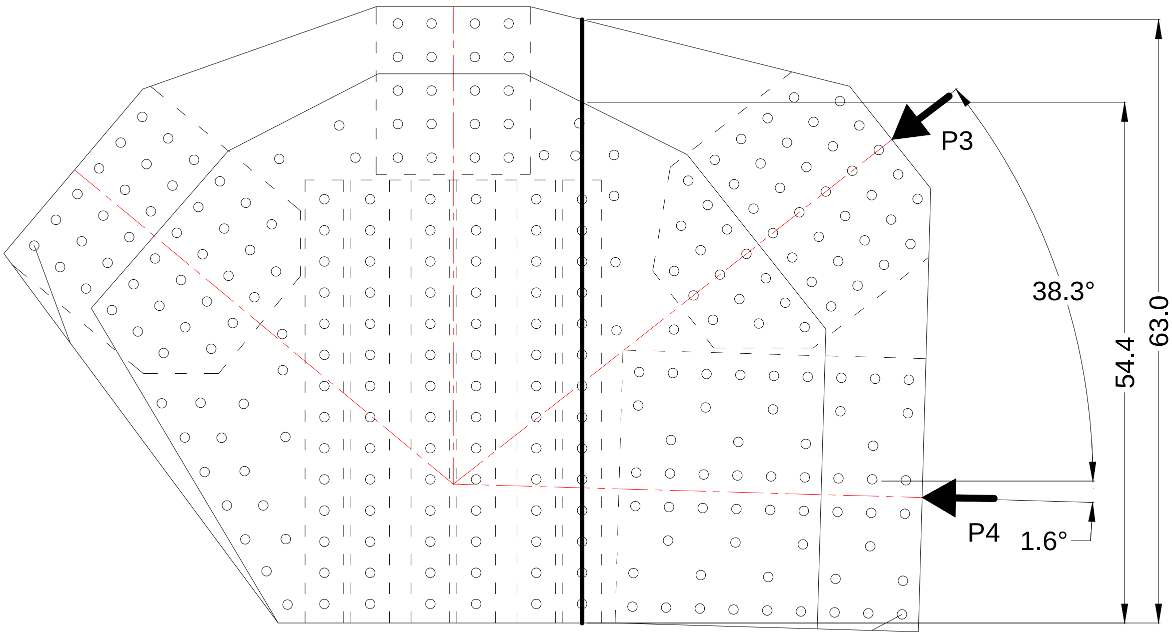
$$RF_{LFRopr} := RF_{LFRinv}\cdot\frac{2.17}{1.3}$$

$$\boxed{RF_{LFRopr} = 2.43}$$

Summarize Rating Factors Using the Three Methods for Member 4

	Inventory	**Operating**
Existing FHWA LRFR Method	$RF_{FHWAinv} = 3.7$	$RF_{FHWAopr} = 4.79$
Proposed LRFR Method	$RF_{LRFRinv} = 1.26$	$RF_{LRFRopr} = 1.63$
Proposed LFR Method	$RF_{LFRinv} = 1.46$	$RF_{LFRopr} = 2.43$

Vertical Plane 1 Shear Check



$$P_{3VDL} := P_{3DL} \cdot \sin(38.3deg) \qquad P_{4VDL} := P_{4DL} \cdot \sin(1.6deg)$$

$$P_{3VLL} := P_{3LL} \cdot \sin(38.3deg) \qquad P_{4VLL} := P_{4LL} \cdot \sin(1.6deg)$$

$$P_{VDL} := P_{3VDL} - P_{4VDL} = 202 \cdot kip$$

$$P_{VLL} := P_{3VLL} - P_{4VLL} = 156 \cdot kip$$

Calculate LRFR rating factors using existing FHWA Guidance method

Gross Yielding

$$V_{ny} := \phi_{vy} \cdot \left(0.58 \cdot F_y\right) \cdot (54.4in + 63.0in) \cdot t_g \cdot \Omega = 1197 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot \left(0.58 \cdot F_u\right) \cdot \left[54.4 + 63.0 - 16 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 1614 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{FHWA} := \min\left(V_{ny}, V_{nu}\right) = 1196.72 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{VDL}}{\gamma_{LL} \cdot P_{VLL}} = 3.46}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 4.49}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.1

$$\frac{P_{VDL}}{P_{VLL}} = 1.3$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.30 - 1}{5}\right) \qquad R_{DL\_LL} = 0.99$$

Gross Yielding

$$V_{ny} := \phi_{vg} \cdot (0.58 \cdot F_y) \cdot (54.4\text{in} + 63.0\text{in}) \cdot t_g \cdot \Omega_{new} = 1498 \cdot \text{kip}$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot (0.58 \cdot F_u) \cdot \left[54.4 + 63.0 - 16 \cdot \left(1 + \frac{1}{8}\right)\right] \text{in} \cdot t_g = 1614 \cdot \text{kip}$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LRFR} := \min(V_{ny}, V_{nu}) = 1498.02 \cdot \text{kip}$$

$$\boxed{RF_{LRFRinv} := \frac{R_{DL\_LL} \cdot \phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{VDL}}{\gamma_{LL} \cdot P_{VLL}} = 3.99}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 5.17}$$

Calculate the proposed LFR rating factors

Gross Yielding

$$V_{ny} := (0.58 \cdot F_y) \cdot (54.4\text{in} + 63.0\text{in}) \cdot t_g \cdot \Omega_{new} = 1498 \cdot \text{kip}$$

Shear Fracture

$$V_{nu} := 0.85(0.58 \cdot F_u) \cdot \left[54.4 + 63.0 - 26 \cdot \left(1 + \frac{1}{8}\right)\right] \text{in} \cdot t_g = 1521 \cdot \text{kip}$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LFR} := \min(V_{ny}, V_{nu}) = 1498.02 \cdot \text{kip}$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{VDL}}{\gamma_{LL\_LFR} \cdot P_{VLL}} = 3.65}$$

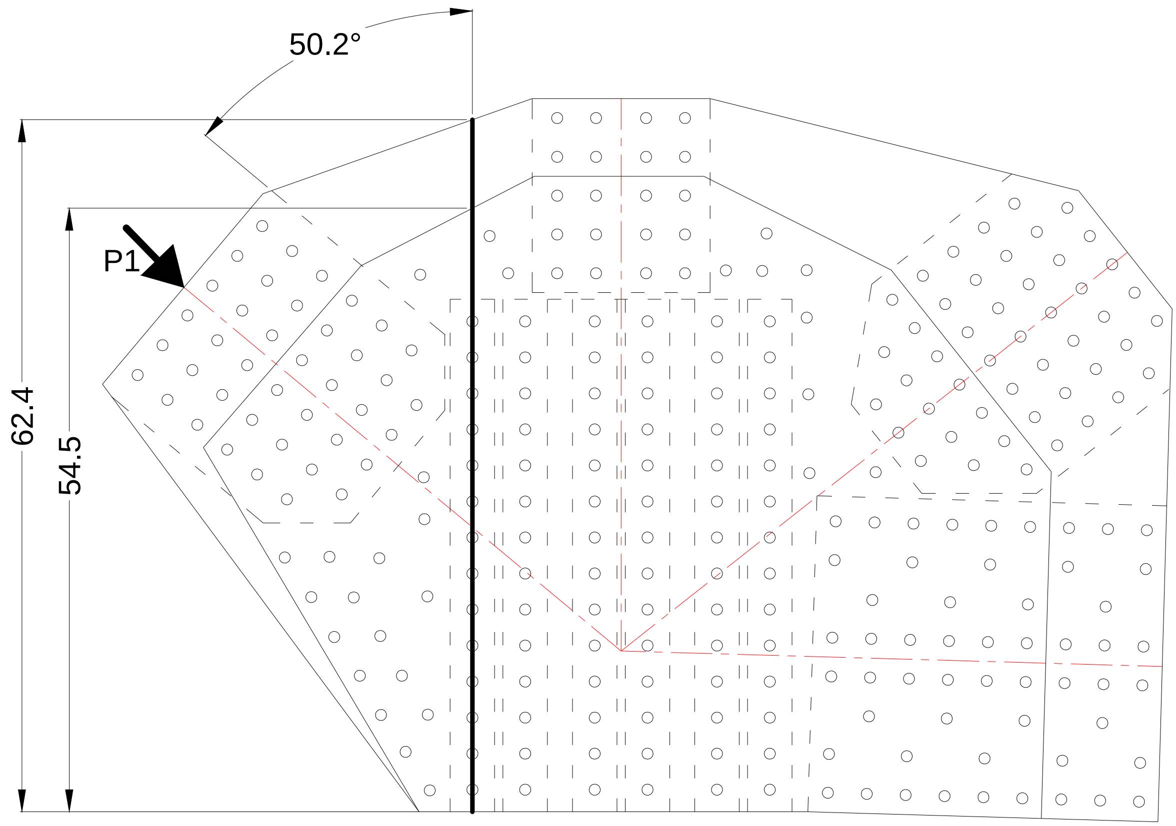
$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

$$\boxed{RF_{LFRopr} = 6.1}$$

Summarize Rating Factors Using the Three Methods for Vertical Plane 1 Shear

	Inventory	Operating
Existing FHWA LRFR Method	$RF_{FHWAinv} = 3.46$	$RF_{FHWAopr} = 4.49$
Proposed LRFR Method	$RF_{LRFRinv} = 3.99$	$RF_{LRFRopr} = 5.17$
Proposed LFR Method	$RF_{LFRinv} = 3.65$	$RF_{LFRopr} = 6.1$

Vertical Plane 2 Shear Check



$$P_{VDL} := P_{1DL} \cdot \cos(50.2deg) = 179 \cdot kip$$

$$P_{VLL} := P_{1LL} \cdot \cos(50.2deg) = 120 \cdot kip$$

Calculate LRFR rating factors using existing FHWA Guidance method

Gross Yielding

$$V_{ny} := \phi_{vy} \cdot \left(0.58 \cdot F_y\right) \cdot (54.5in + 62.4in) \cdot t_g \cdot \Omega = 1192 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot \left(0.58 \cdot F_u\right) \cdot \left[54.5 + 62.4 - 14 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 1643 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{FHWA} := \min\left(V_{ny}, V_{nu}\right) = 1191.62 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{VDL}}{\gamma_{LL} \cdot P_{VLL}} = 4.59}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 5.96}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.1

$$\frac{P_{VDL}}{P_{VLL}} = 1.49$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.49 - 1}{5}\right) = 0.99$$

Gross Yielding

$$V_{ny} := \phi_{vg} \cdot \left(0.58 \cdot F_y\right) \cdot (54.5in + 62.4in) \cdot t_g \cdot \Omega_{new} = 1492 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot \left(0.58 \cdot F_u\right) \cdot \left[54.5 + 62.4 - 14 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 1643 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LRFR} := \min\left(V_{ny}, V_{nu}\right) = 1491.64 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{R_{DL\_LL} \cdot \phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{VDL}}{\gamma_{LL} \cdot P_{VLL}} = 5.25}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 6.8}$$

Calculate the proposed LFR rating factors

Gross Yielding

$$V_{ny} := \left(0.58 \cdot F_y\right) \cdot (54.4in + 63.0in) \cdot t_g \cdot \Omega_{new} = 1498 \cdot kip$$

Shear Fracture

$$V_{nu} := 0.85\left(0.58 \cdot F_u\right) \cdot \left[54.4 + 63.0 - 26 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 1521 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LFR} := \min(V_{ny}, V_{nu}) = 1498.02 \cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{VDL}}{\gamma_{LL\_LFR} \cdot P_{VLL}} = 4.84}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

$$\boxed{RF_{LFRopr} = 8.09}$$

Summarize Rating Factors Using the Three Methods for Vertical Plane 2 Shear

	Inventory	Operating
Existing FHWA LRFR Method	$RF_{FHWAinv} = 4.59$	$RF_{FHWAopr} = 5.96$
Proposed LRFR Method	$RF_{LRFRinv} = 5.25$	$RF_{LRFRopr} = 6.8$
Proposed LFR Method	$RF_{LFRinv} = 4.84$	$RF_{LFRopr} = 8.09$

Horizontal Plane Shear Check

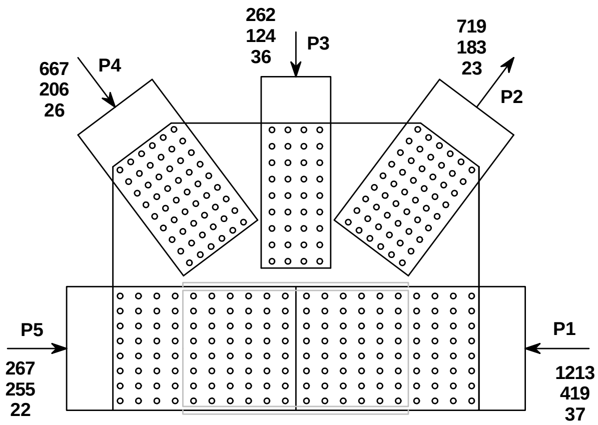
the only valid plane would have to pass through the multi-celled box above the bearing thus requiring alot of area to shear that cannot occur.

I-80 GUSSET PLATE CHECKS

All Units: kip, in

These checks will make comparisions between the existing FHWA Guidance and new proposed MBE specification. Since the final report clearly outlined that Whitmore compression checks of chord splices do not provide value, they will not be reported. Fastner checks will also not be provided. Condition factors are assumed to be 1.00.

TRUSS JOINT L3



Plates: Gusset 3/4
Side Splice 1 30 x 1/2
Side Splice 2 16 x 7/16
Top Splice 24 x 3/8
Bottom Splice 18 x 3/8

$F_y := 50ksi$

$F_u := 70ksi$ *Material Properties*

$E := 29000ksi$

$t_g := 0.75in$ *Gusset Thickness*

$A_{TCS} := \left(\frac{3}{8}in\right)\cdot 24in$ $A_{TCS} = 9\,in^2$

$A_{BCS} := \left(\frac{3}{8}in\right)\cdot 18in$ $A_{BCS} = 6.75in^2$ *Splice Plate Areas*

$A_{SCS} := \left(\frac{4}{8}in\right)\cdot 30in + \left(\frac{7}{16}in\right)\cdot 16in$ $A_{SCS} = 22\,in^2$

Existing FHWA Guide Resistance Factors

$\phi_y := 0.95$ $\phi_c := 0.9$

$\phi_u := 0.80$ $\phi_{vy} := 0.95$

$\phi_{bs} := 0.80$ $\phi_{vu} := 0.80$

$\Omega := 0.74$

Proposed Resistance Factors

$\phi_{bs\_new} := 1.00$ $\phi_{c\_new} := 0.95$

$\phi_{vg} := 1.00$ $\phi_{cs} := 0.85$

$\Omega_{new} := 0.88$

Load Factors

$\gamma_{LL} := 1.75$ $\gamma_{LL\_LFR} := 2.17$

$\gamma_{DL} := 1.25$ $\gamma_{DL\_LFR} := 1.3$

System Factor

$\phi_s := 0.90$ *assumes it's a bolted truss, proposed as mandatory for LRFR under MBE Article 6A.6.12.6. The system factor will not be used in calculations using the existing FHWA Guidance*

Member Forces For One Gusset Plate

$P_{1DL} := \frac{1213}{2} kip$ $P_{1LL} := \frac{419 + 37}{2} kip$ *Compression*

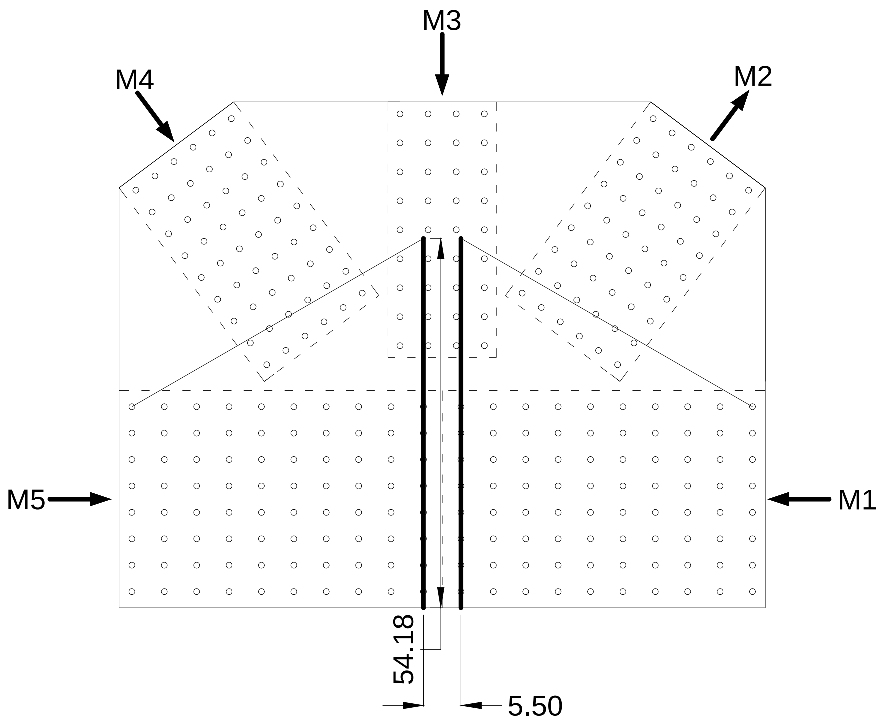
$P_{2DL} := \frac{719}{2} kip$ $P_{2LL} := \frac{183 + 23}{2} kip$ *Tension*

$P_{3DL} := \frac{262}{2} kip$ $P_{3LL} := \frac{124 + 36}{2} kip$ *Compression*

$P_{4DL} := \frac{667}{2} kip$ $P_{4LL} := \frac{206 + 26}{2} kip$ *Compression*

$P_{5DL} := \frac{267}{2} kip$ $P_{5LL} := \frac{255 + 22}{2} kip$ *Compression*

MEMBERS 1 and 5



$$L_{avg} := \frac{5.5in + 5.5in + 5.5in}{3}$$

$$L_{mid} := 5.5in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_s := 54.18in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

$$K := 1.2$$

Calculate the compression capacity of the primary gusset plate

$$\lambda := \left(\frac{K \cdot L_{avg}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda = 0.16$$

$$C := \phi_c \cdot \begin{cases} \left(0.66^{\lambda} \cdot F_y \cdot A_s\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_s}{\lambda} & \text{otherwise} \end{cases} \qquad C = 1709.3 \cdot kip$$

Calculate the rating factors for Member 1

$$\boxed{RF_{FHWAinv} := \frac{C - \gamma_{DL} \cdot P_{1DL}}{\gamma_{LL} \cdot P_{1LL}} = 2.38}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 3.09}$$

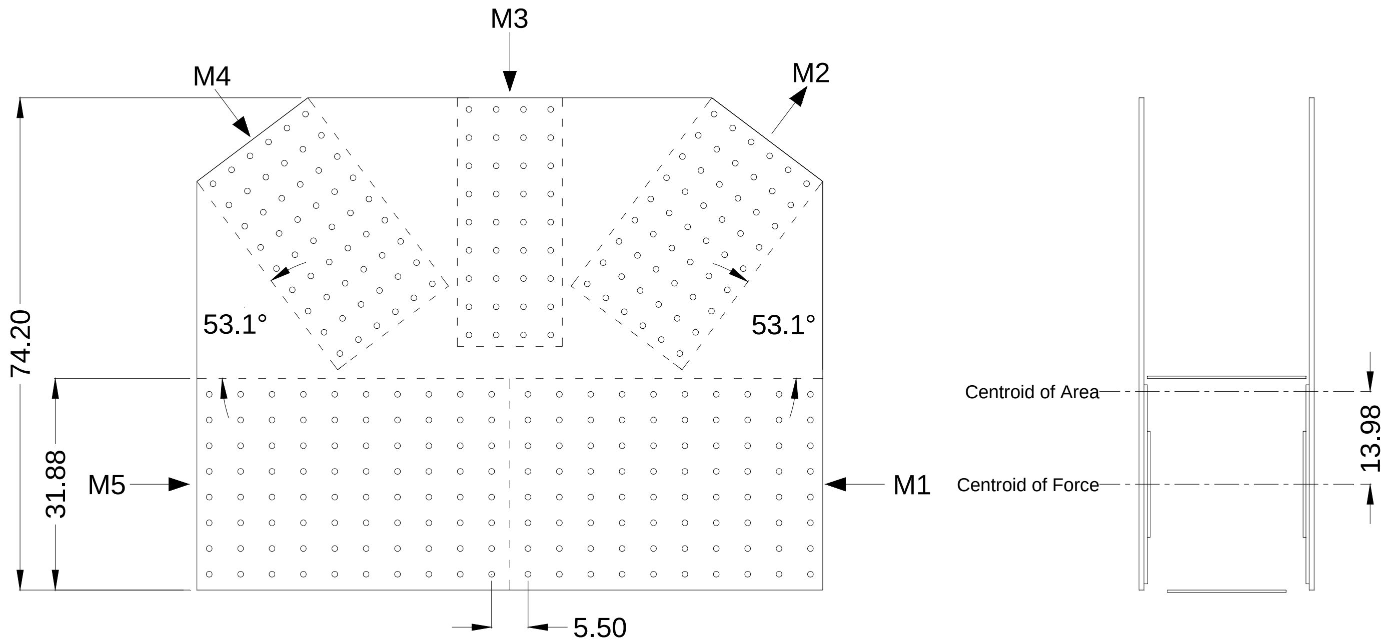
Calculate the rating factors for Member 5

$$\boxed{RF_{FHWAinv} := \frac{C - \gamma_{DL} \cdot P_{5DL}}{\gamma_{LL} \cdot P_{5LL}} = 6.36}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 8.25}$$

Calculate the proposed LRFR rating factors. In the proposed method, both members are evaluated as part of a chord splice check.



Start by calculating the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6. Look at loads on both sides of the splice and use the worst case.

left side

$$F_{left} := \gamma_{DL} \cdot \left(P_{5DL} + P_{4DL} \cdot \cos(53.1deg)\right) + \gamma_{LL} \cdot \left(P_{5LL} + P_{4LL} \cdot \cos(53.1deg)\right) = 781.44 \cdot kip$$

right side

$$F_{right} := \gamma_{DL} \cdot \left(P_{1DL} - P_{2DL} \cdot \cos(53.1deg)\right) + \gamma_{LL} \cdot \left(P_{1LL} - P_{2LL} \cdot \cos(53.1deg)\right) = 779.09 \cdot kip$$

since the loads are very similar, calulate the DL/LL reduction for each set of loads to consider the worst case loading

$$\frac{\left(P_{5DL} + P_{4DL} \cdot \cos(53.1deg)\right)}{\left(P_{5LL} + P_{4LL} \cdot \cos(53.1deg)\right)} = 1.6 \qquad \frac{\left(P_{1DL} - P_{2DL} \cdot \cos(53.1deg)\right)}{\left(P_{1LL} - P_{2LL} \cdot \cos(53.1deg)\right)} = 2.35$$

$$R_{DL\_LLleft} := 1 - 0.1 \cdot \left(\frac{1.6 - 1}{5}\right) = 0.99 \qquad R_{DL\_LLright} := 1 - 0.1 \cdot \left(\frac{2.35 - 1}{5}\right) = 0.97$$

The loads on the right side would be more sever, so base the chord splice capacity on the of the right side of the connection

Determine the height (h1) of the M1 and M2 force resultant, using the factored loads. Since both members share a common workpoint that is on the spliced plane, h1 is simply half the depth of the chord.

$$h_1 := 31.88 \frac{in}{2} \qquad h_1 = 15.94\,in$$

Calculate the gross area of the combined gusset and shingle plate cross-section

$$A_g := 2 \cdot t_g \cdot (74.20in) + A_{TCS} + A_{BCS} + 2 \cdot A_{SCS} = 171.05\,in^2$$

The other cross-sectional properties of the combined section were determined using a CAD program.

$e_p := 13.98in$ is the eccentricity between the force resultant and the centroid of the combined plate area.

$I_g := 74126in^4$ is the moment of inertia of the gross spliced section, calculated with a CAD program

Since the centroid of the force is below the centroid of the cross-section, the maximum axial+bending stress will be at the bottom of the plate. Now calculate the section modulus to the bottom of the cross-section

$$S_g := \frac{I_g}{h_1} \qquad S_g = 4650.31 \cdot in^3$$

Determine if the chord splice is compact

$$K := 0.5 \qquad L_{splice} := 5.5in \qquad \frac{K \cdot L_{splice} \cdot \sqrt{12}}{t_g} = 12.7$$

Since KL/r of the free plate between chords is less than 25, Fcr equals Fy

$$F_{cr} := F_y$$

Calculate the capacity of the section assuming it occurs at first yield using beam bending theory

$$C_{LRFR} := \phi_{cs} \cdot F_{cr} \cdot \left(\frac{S_g \cdot A_g}{S_g + e_p \cdot A_g} \right) = 4800.91 \cdot kip$$

Calculate the rating factor

$$RF_{LRFRinv} := \frac{\phi_s \cdot R_{DL\_LLright} \cdot C_{LRFR} - 2 \cdot \gamma_{DL} \cdot \left(P_{1DL} - P_{2DL} \cdot \cos(53.1deg) \right)}{2 \cdot \gamma_{LL} \cdot \left(P_{1LL} - P_{2LL} \cdot \cos(53.1deg) \right)}$$

$$\boxed{RF_{LRFRinv} = 5.55}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 7.19}$$

Calculate the proposed LFR rating factors

The capacity calculation is the same, though there is a difference in the resistance factors.

$$C_{LFR} := \frac{C_{LRFR}}{\phi_{cs}} = 5648.13 \cdot kip$$

Calculate the rating factor

$$RF_{LFRinv} := \frac{C_{LFR} - 2 \cdot \gamma_{DL\_LFR} \cdot \left(P_{1DL} - P_{2DL} \cdot \cos(53.1deg)\right)}{2 \cdot \gamma_{LL\_LFR} \cdot \left(P_{1LL} - P_{2LL} \cdot \cos(53.1deg)\right)}$$

$$\boxed{RF_{LFRinv} = 6.42}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

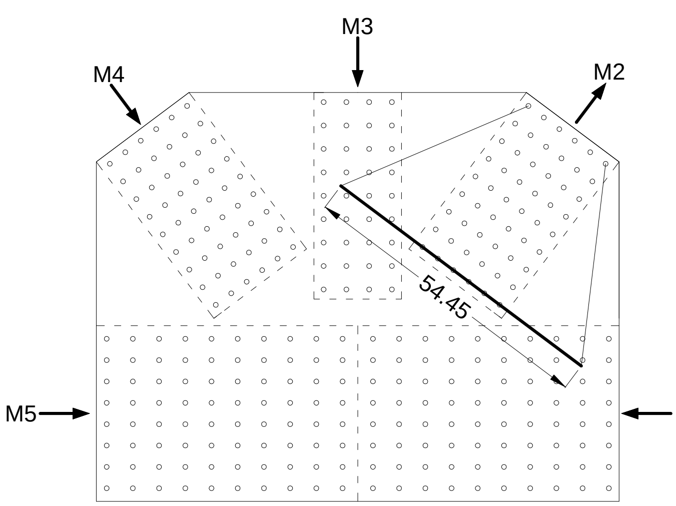
$$\boxed{RF_{LFRopr} = 10.72}$$

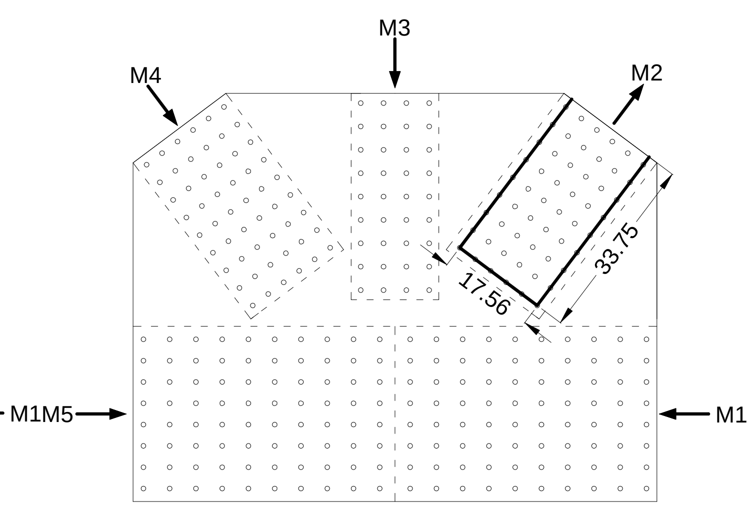
Summarize Rating Factors Using the Three Methods for the Chord Splice

	Inventory	**Operating**
Existing FHWA Method	not applicable	not applicable
Proposed LRFR Method	$RF_{LRFRinv} = 5.55$	$RF_{LRFRopr} = 7.19$
Proposed LFR Method	$RF_{LFRinv} = 6.42$	$RF_{LFRopr} = 10.72$

MEMBER 2

Tension member - Need to check gross/net section checks on Whitmore section, and block shear





define the gross and net section areas on Whitmore section

$$A_g := 54.45in \cdot t_g = 40.84\ in^2$$

$$A_n := \left[54.45in - 6 \cdot \left(\frac{7}{8} + \frac{1}{8}\right)in\right] \cdot t_g = 36.34\ in^2$$

define the gross and net sections for block shear check

$$A_{tg} := 17.56in \cdot t_g = 13.17\ in^2$$

$$A_{vg} := (2 \cdot 33.75in) \cdot t_g = 50.62\ in^2$$

$$A_{tn} := A_{tg} - 5 \cdot \left(\frac{7}{8} + \frac{1}{8}\right) in \cdot t_g = 9.42\ in^2$$

$$A_{vn} := A_{vg} - 17 \cdot \left(\frac{7}{8} + \frac{1}{8}\right) in \cdot t_g = 37.88\ in^2$$

Calculate LRFR rating factors using existing FHWA Guidance method

calculate yield on gross and fracture on net for the Whitmore plane

$$P_y := \phi_y \cdot F_y \cdot A_g = 1940 \cdot kip$$

$$P_n := \phi_u \cdot F_u \cdot A_n = 2034.9 \cdot kip$$

calculate block shear resistance

$$P_{bs} := \begin{cases} \left[\phi_{bs} \cdot \left(0.58 \cdot F_y \cdot A_{vg} + F_u \cdot A_{tn}\right)\right] & \text{if } A_{tn} \ge 0.58 \cdot A_{vn} \\ \left[\phi_{bs} \cdot \left(0.58 \cdot F_u \cdot A_{vn} + F_y \cdot A_{tg}\right)\right] & \text{otherwise} \end{cases} = 1756.98 \cdot kip$$

the capacity is based on the minimum of block shear, yield on Whitmore, and fracture on Whitmore

$$C_{FHWA} := \min\left(P_y, P_n, P_{bs}\right) = 1756.98 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{2DL}}{\gamma_{LL} \cdot P_{2LL}} = 7.25}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 9.4}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.

$$\frac{P_{2DL}}{P_{2LL}} = 3.49$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{3.49 - 1}{5}\right) = 0.95$$

calculate yield on gross for the Whitmore plane

$$P_y := \phi_y \cdot F_y \cdot A_g \cdot R_{DL\_LL} = 1843 \cdot kip$$

$$P_n := \phi_u \cdot F_u \cdot A_n \cdot R_{DL\_LL} = 1933.56 \cdot kip$$

calculate the block shear resistance

$$P_{bs} := \begin{cases} \phi_{bs\_new} \cdot \left(0.58 \cdot F_u \cdot A_{vn} + F_u \cdot A_{tn}\right) \cdot R_{DL\_LL} & \text{if } F_u \cdot A_{vn} \le F_y \cdot A_{vg} \\ \phi_{bs\_new} \cdot \left(0.58 \cdot F_y \cdot A_{vg} + F_u \cdot A_{tn}\right) \cdot R_{DL\_LL} & \text{otherwise} \end{cases} = 2021.57 \cdot kip$$

the resistance is the minimum of the Whitmore yield on gross, Whitmore fracture on net, and block shear

$$C_{LRFR} := \min\left(P_y, P_n, P_{bs}\right) = 1843.18 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{2DL}}{\gamma_{LL} \cdot P_{2LL}} = 6.71}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 8.7}$$

Calculate the proposed LFR rating factors

calculate yield on effective Whitmore plan

$$\beta := 0.15$$

$$A_e := \begin{cases} A_n + \beta \cdot A_g & \text{if } A_n + \beta \cdot A_g \le A_g \\ A_g & \text{otherwise} \end{cases} = 40.84\, in^2$$

$$P_y := F_y \cdot A_e = 2042 \cdot kip$$

calculate block shear resistance

$$P_{bs} := \begin{cases} \left[0.85 \cdot \left(0.58 \cdot F_y \cdot A_{vg} + F_u \cdot A_{tn}\right)\right] & \text{if } A_{tn} \ge 0.58 \cdot A_{vn} \\ \left[0.85 \cdot \left(0.58 \cdot F_u \cdot A_{vn} + F_y \cdot A_{tg}\right)\right] & \text{otherwise} \end{cases} = 1866.79 \cdot kip$$

the capacity is the minimum of the yield on effective Whitmore area or block shear

$$C_{LFR} := \min\left(P_y, P_{bs}\right) = 1866.79 \cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{2DL}}{\gamma_{LL\_LFR} \cdot P_{2LL}} = 6.26}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

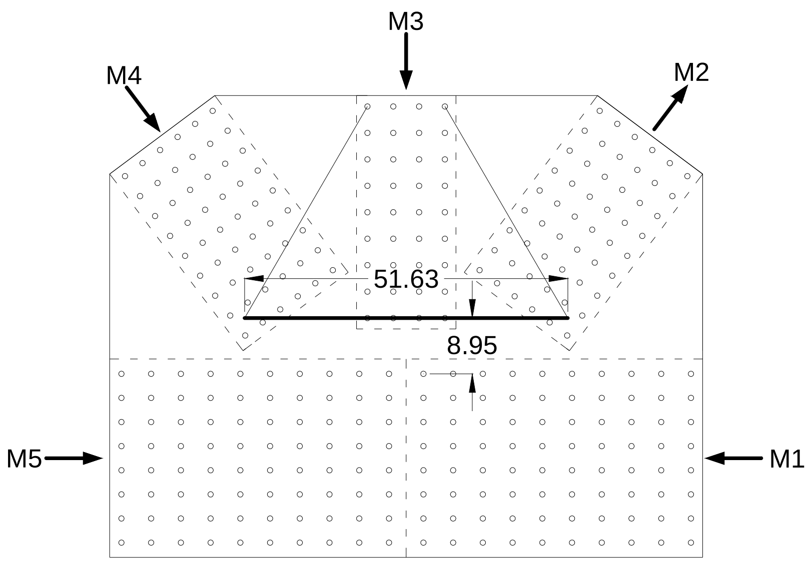
$$\boxed{RF_{LFRopr} = 10.45}$$

<u>Summarize Rating Factors Using the Three Methods for Member 2</u>

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 7.25$	$RF_{FHWAopr} = 9.4$
Proposed LRFR Method	$RF_{LRFRinv} = 6.71$	$RF_{LRFRopr} = 8.7$
Proposed LFR Method	$RF_{LFRinv} = 6.26$	$RF_{LFRopr} = 10.45$

MEMBER 3

Compression Member - Need to check Whitmore buckling and partial plane shear yielding



$$L_{avg} := \frac{3 \cdot 8.95in}{3}$$

$$L_{mid} := 8.95in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_s := 51.63in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

Calculate the compression capacity of the primary gusset plate

$$K := 1.2$$

$$\lambda := \left(\frac{K \cdot L_{avg}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) = 0.43$$

$$C_{FHWA} := \phi_c \cdot \begin{cases} \left(0.66^{\lambda} \cdot F_y \cdot A_s\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_s}{\lambda} & \text{otherwise} \end{cases} = 1457.48 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 9.24}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 11.98}$$

Calculate the proposed LRFR rating factors (minimum of Whitmore buckling and partial plane shear)

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6

$$\frac{P_{3DL}}{P_{3LL}} = 1.64$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{1.64 - 1}{5}\right) \qquad R_{DL\_LL} = 0.99$$

calculate the factored Whitmore buckling strength.

$$P_e := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_s = 25943.81 \cdot kip$$

$$P_o := F_y \cdot A_s = 1936.12 \cdot kip$$

$$Whit := \phi_{c\_new} \cdot R_{DL\_LL} \cdot \begin{cases} \left(0.658^{\frac{P_o}{P_e}} \cdot P_o\right) & \text{if } \frac{P_e}{P_o} \geq 0.44 \\ 0.877 \cdot P_e & \text{otherwise} \end{cases} = 1759.94 \cdot kip$$

calculate the partial plane shear yield check

there is no valid partial plane shear plane for this vertical member and this does not need to be checked

the buckling strength is the Whitmore buckling strength

$$C_{LRFR} := Whit = 1759.94 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 10.14}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 13.15}$$

Calculate the proposed LFR rating factors (minimum of Whitmore buckling and partial plane shear)

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y \cdot \left[1 - \dfrac{F_y}{4\cdot\pi^2 E}\left(\dfrac{K\cdot L_{mid}}{r_s}\right)^2\right] & \text{if } \dfrac{K\cdot L_{mid}}{r_s} \le \sqrt{\dfrac{2\cdot\pi^2\cdot E}{F_y}} \\ \dfrac{\pi^2\cdot E}{\left(\dfrac{K\cdot L_{mid}}{r_s}\right)^2} & \text{otherwise} \end{cases} = 49.07\cdot ksi$$

$$Whit := 0.85\cdot A_s\cdot F_{cr} = 1615\cdot kip$$

calculate the partial plane shear yield check

there is no valid partial plane shear plane for this vertical member and this does not need to be checked

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LFR} := Whit = 1615\cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR}\cdot P_{3DL}}{\gamma_{LL\_LFR}\cdot P_{3LL}} = 8.32}$$

$$RF_{LFRopr} := RF_{LFRinv}\cdot\frac{2.17}{1.3}$$

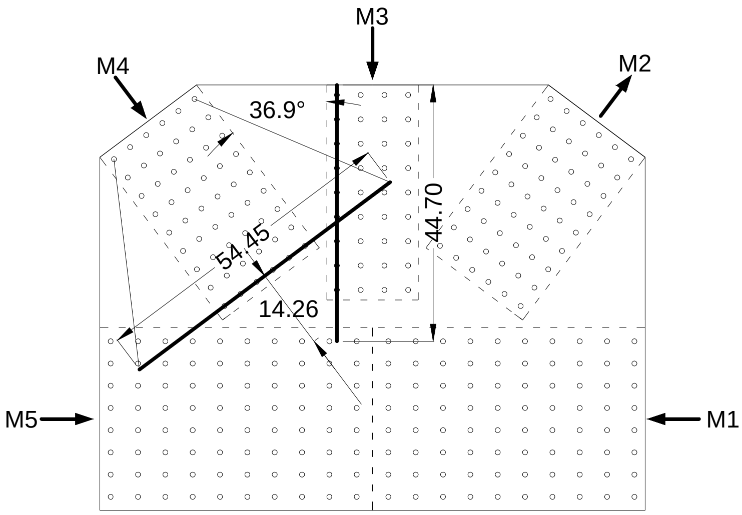
$$\boxed{RF_{LFRopr} = 13.89}$$

<u>Summarize Rating Factors Using the Three Methods for Member 3</u>

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 9.24$	$RF_{FHWAopr} = 11.98$
Proposed LRFR Method	$RF_{LRFRinv} = 10.14$	$RF_{LRFRopr} = 13.15$
Proposed LFR Method	$RF_{LFRinv} = 8.32$	$RF_{LFRopr} = 13.89$

MEMBER 4

Compression Member - Need to check Whitmore buckling and partial plane shear yielding



$$K := 1.2$$

$$L_{avg} := \frac{0in + 14.26in + 0in}{3}$$

$$L_{mid} := 14.26in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_s := 54.45in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

Calculate the compression capacity of the primary gusset plate

$$K := 1.2$$

$$\lambda := \left(\frac{K \cdot L_{avg}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) = 0.12$$

$$C_{FHWA} := \phi_c \cdot \begin{cases} \left(0.66^{\lambda} \cdot F_y \cdot A_s\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_s}{\lambda} & \text{otherwise} \end{cases} = 1747.39 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{4DL}}{\gamma_{LL} \cdot P_{4LL}} = 6.55}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 8.5}$$

Calculate the proposed LRFR rating factors (minimum of Whitmore buckling and partial plane shear)

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6

$$\frac{P_{4DL}}{P_{4LL}} = 2.88$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{2.88 - 1}{5}\right) \qquad R_{DL\_LL} = 0.96$$

calculate the factored Whitmore buckling strength.

$$P_e := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_s = 10777.96 \cdot kip$$

$$P_o := F_y \cdot A_s = 2041.87 \cdot kip$$

$$Whit := \phi_{c\_new} \cdot R_{DL\_LL} \cdot \begin{cases} \left(0.658^{\frac{P_o}{P_e}} \cdot P_o\right) & \text{if } \frac{P_e}{P_o} \geq 0.44 \\ 0.877 \cdot P_e & \text{otherwise} \end{cases} = 1724.53 \cdot kip$$

calculate the partial plane shear yield check

$$PS := \phi_{vg} \cdot \frac{\Omega_{new} \cdot (0.58 \cdot F_y) \cdot (44.7in) \cdot t_g \cdot R_{DL\_LL}}{\cos(36.9deg)} = 1029.64 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LRFR} := \min(Whit, PS) = 1029.64 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{4DL}}{\gamma_{LL} \cdot P_{4LL}} = 2.51}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 3.26}$$

Calculate the proposed LFR rating factors (minimum of Whitmore buckling and partial plane shear)

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y \cdot \left[1 - \frac{F_y}{4 \cdot \pi^2 E} \left(\frac{K \cdot L_{mid}}{r_s}\right)^2\right] & \text{if } \frac{K \cdot L_{mid}}{r_s} \leq \sqrt{\frac{2 \cdot \pi^2 \cdot E}{F_y}} \\ \frac{\pi^2 \cdot E}{\left(\frac{K \cdot L_{mid}}{r_s}\right)^2} & \text{otherwise} \end{cases} = 47.63 \cdot ksi$$

$$Whit := 0.85 \cdot A_s \cdot F_{cr} = 1653.39 \cdot kip$$

calculate the partial plane shear yield check

$$PS := \frac{\Omega_{new} \cdot \left(0.58 \cdot F_y\right) \cdot (44.7in) \cdot t_g}{\cos(36.9deg)} = 1069.87 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LFR} := \min(Whit, PS) = 1069.87 \cdot kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{4DL}}{\gamma_{LL\_LFR} \cdot P_{4LL}} = 2.53}$$

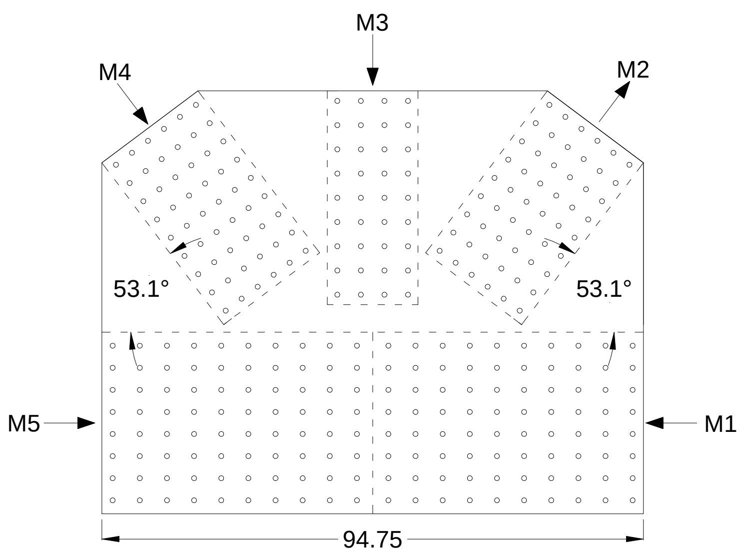
$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

$$\boxed{RF_{LFRopr} = 4.22}$$

Summarize Rating Factors Using the Three Methods for Member 4

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 6.55$	$RF_{FHWAopr} = 8.5$
Proposed LRFR Method	$RF_{LRFRinv} = 2.51$	$RF_{LRFRopr} = 3.26$
Proposed LFR Method	$RF_{LFRinv} = 2.53$	$RF_{LFRopr} = 4.22$

Horizontal Plane Shear



$$P_{2HDL} := P_{2DL} \cdot \cos(53.1deg) = 216 \cdot kip$$

$$P_{2HLL} := P_{2LL} \cdot \cos(53.1deg) = 62 \cdot kip$$

$$P_{4HDL} := P_{4DL} \cdot \cos(53.1deg) = 200 \cdot kip$$

$$P_{4HLL} := P_{4LL} \cdot \cos(53.1deg) = 70 \cdot kip$$

$$P_{HDL} := P_{4HDL} + P_{2HDL} = 416 \cdot kip$$

$$P_{HLL} := P_{4HLL} + P_{2HLL} = 131 \cdot kip$$

Calculate LRFR rating factors using existing FHWA Guidance method

Gross Yielding

$$V_{ny} := \phi_{vy} \cdot (0.58 \cdot F_y) \cdot 94.75\,in \cdot t_g \cdot \Omega = 1449 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot (0.58 \cdot F_u) \cdot \left[94.75 - 20 \cdot \left(\frac{7}{8} + \frac{1}{8}\right)\right] in \cdot t_g = 1821 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{FHWA} := \min(V_{ny}, V_{nu})$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{HDL}}{\gamma_{LL} \cdot P_{HLL}} = 4.04}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 5.23}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.

$$\frac{P_{HDL}}{P_{HLL}} = 3.16$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{3.16 - 1}{5}\right) = 0.96$$

Gross Yielding

$$V_{ny} := \phi_{vg} \cdot (0.58 \cdot F_y) \cdot 94.75\,in \cdot t_g \cdot \Omega_{new} \cdot R_{DL\_LL} = 1735 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot (0.58 \cdot F_u) \cdot \left[94.75 - 20 \cdot \left(\frac{7}{8} + \frac{1}{8}\right)\right] in \cdot t_g \cdot R_{DL\_LL} = 1742 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LRFR} := \min(V_{ny}, V_{nu}) = 1735.17 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{HDL}}{\gamma_{LL} \cdot P_{HLL}} = 4.53}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 5.87}$$

Calculate the proposed LFR rating factors

Gross Yielding

$$V_{ny} := \left(0.58 \cdot F_y\right) \cdot 94.75 in \cdot t_g \cdot \Omega_{new} = 1814 \cdot kip$$

Shear Fracture

$$V_{nu} := 0.85 \cdot \left(0.58 \cdot F_u\right) \cdot \left[94.75 - 20 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 1870 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LFR} := \min\left(V_{ny}, V_{nu}\right) = 1813.51\ kip$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{HDL}}{\gamma_{LL\_LFR} \cdot P_{HLL}} = 4.46}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

$$\boxed{RF_{LFRopr} = 7.44}$$

<u>Summarize Rating Factors Using the Three Methods for Horizontal Shear</u>

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 4.04$	$RF_{FHWAopr} = 5.23$
Proposed LRFR Method	$RF_{LRFRinv} = 4.53$	$RF_{LRFRopr} = 5.87$
Proposed LFR Method	$RF_{LFRinv} = 4.46$	$RF_{LFRopr} = 7.44$

Vertical Plane Stress Check

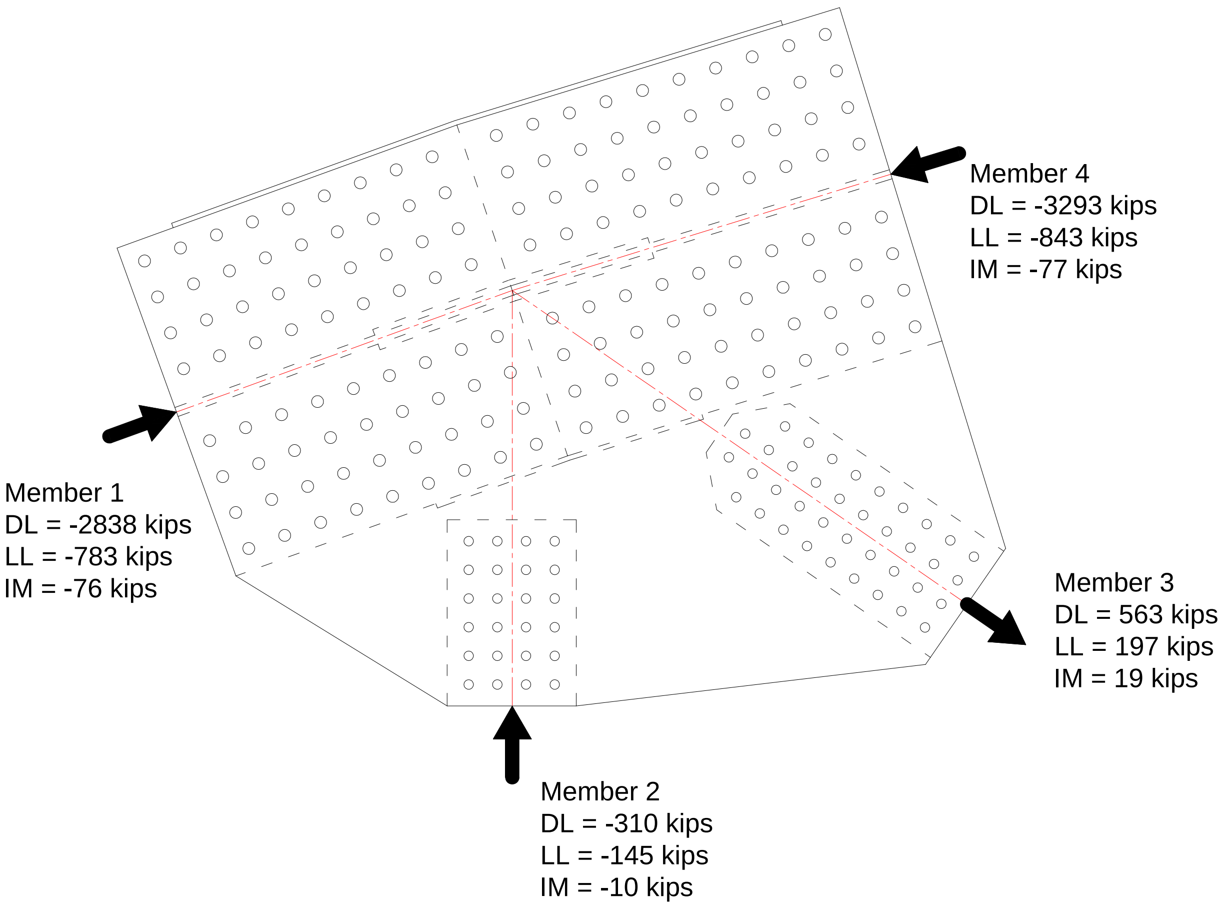
unnesseccary as plate cannot mobilize through chord splice

I-64 GUSSET PLATE CHECKS

All Units: kip, in

These checks will make comparisions between the existing FHWA Guidance, the new proposed LRFR MBE specification, and the new proposed LFR MBE provisions. Since the final report clearly outlined that Whitmore compression checks of chord splices do not provide value, they will not be reported. Fastener checks will also not be provided. Condition factors are assumed to be 1.00.

TRUSS JOINT U5



$F_y := 100\text{ksi}$

$F_u := 110\text{ksi}$ *Material Properties*

$E := 29000\text{ksi}$

$t_g := 1\text{in}$ *Gusset Thickness*

$A_{TCS} := \left(\frac{1}{2}\text{in}\right)\cdot 26\text{in}$ $A_{TCS} = 13\,\text{in}^2$

$A_{BCS} := \left(\frac{1}{2}\text{in}\right)\cdot 26\text{in}$ $A_{BCS} = 13\,\text{in}^2$ *Splice Plate Areas*

$A_{MCS} := 2\cdot\left(\frac{5}{8}\text{in}\right)\cdot 26\text{in}$ $A_{MCS} = 32.5\,\text{in}^2$

Existing FHWA Guide Resistance Factors

$\phi_y := 0.95$ $\phi_c := 0.9$

$\phi_u := 0.80$ $\phi_{vy} := 0.95$

$\phi_{bs} := 0.80$ $\phi_{vu} := 0.80$

$\Omega := 0.74$

Proposed MBE Resistance Factors

$\phi_{bs\_new} := 1.00$ $\phi_{c\_new} := 0.95$

$\phi_{vg} := 1.00$ $\phi_{cs} := 0.85$

$\Omega_{new} := 0.88$

Load Factors

$\gamma_{LL} := 1.75$ $\gamma_{LL\_LFR} := 2.17$

$\gamma_{DL} := 1.25$ $\gamma_{DL\_LFR} := 1.3$

System Factor

$\phi_s := 0.90$ *assumes it's a bolted truss, proposed as mandatory for LRFR under proposed MBE Article 6A.6.12.6. The system factor will not be used in calculations using the existing FHWA Guidance.*

Member Forces For One Gusset Plate

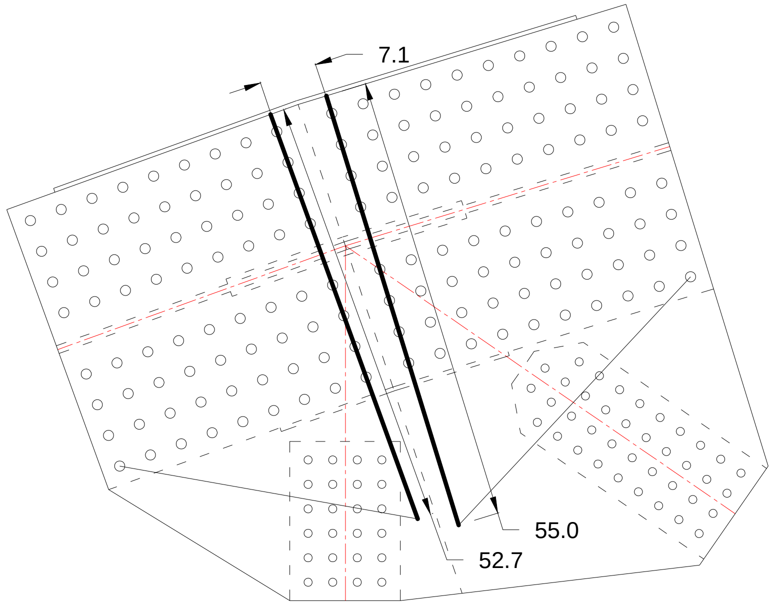
$P_{1DL} := \frac{2838}{2}\,kip$ $P_{1LL} := \frac{783 + 76}{2}\,kip$ *Compression*

$P_{2DL} := \frac{310}{2}\,kip$ $P_{2LL} := \frac{145 + 10}{2}\,kip$ Compression

$P_{3DL} := \frac{563}{2}\,kip$ $P_{3LL} := \frac{197 + 19}{2}\,kip$ Tension

$P_{4DL} := \frac{3293}{2}\,kip$ $P_{4LL} := \frac{843 + 77}{2}\,kip$ *Compression*

MEMBERS 1 and 4



$$L_{avg} := \frac{7.1in + 7.1in + 7.1in}{3}$$

$$L_{mid} := 7.1in$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_{s1} := 52.7in \cdot t_g$$

$$A_{s4} := 55.0in \cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

$$K := 1.2$$

Calculate the compression capacity of the primary gusset plate

$$\lambda := \left(\frac{K \cdot L_{avg}}{r_s \cdot \pi}\right)^2 \cdot \left(\frac{F_y}{E}\right) \qquad \lambda = 0.3$$

$$C_1 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda} \cdot F_y \cdot A_{s1}\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s1}}{\lambda} & \text{otherwise} \end{cases} \qquad C_1 = 4179.58 \cdot kip$$

$$C_4 := \phi_c \cdot \begin{cases} \left(0.66^{\lambda} \cdot F_y \cdot A_{s4}\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88 \cdot F_y \cdot A_{s4}}{\lambda} & \text{otherwise} \end{cases} \qquad C_4 = 4361.99 \cdot kip$$

Calculate the rating factors for Member 1

$$\boxed{RF_{FHWAinv} := \frac{C_1 - \gamma_{DL} \cdot P_{1DL}}{\gamma_{LL} \cdot P_{1LL}} = 3.2}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 4.15}$$

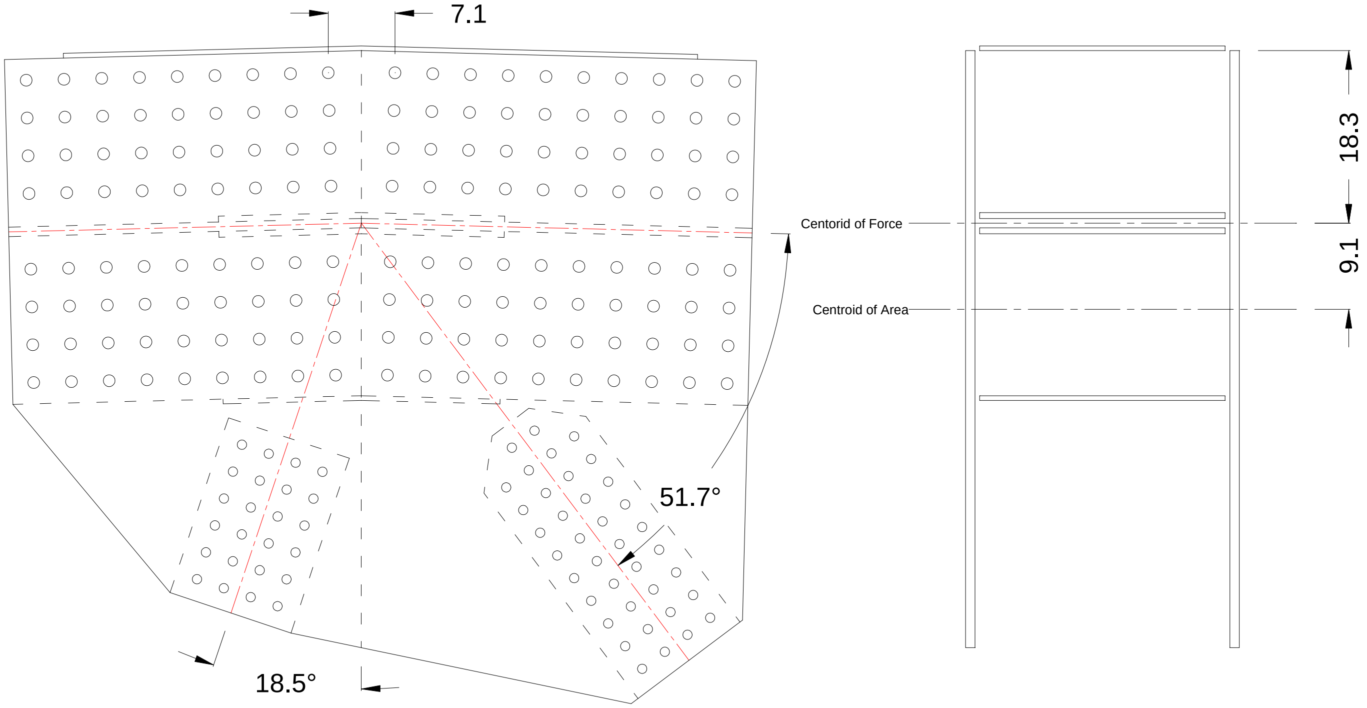
Calculate the rating factors for Member 4

$$RF_{FHWAinv} := \frac{C_4 - \gamma_{DL} \cdot P_{4DL}}{\gamma_{LL} \cdot P_{4LL}} = 2.86$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$RF_{FHWAopr} = 3.71$$

Calculate the proposed LRFR rating factors. In this case both members 1 and 4 are considered part c the chord splice check.



Start by calculating the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6. Look at loads on both sides of the splice and use the worst case.

left side

$$F_{left} := \gamma_{DL} \cdot \left(P_{1DL} + P_{2DL} \cdot \sin(18.5deg)\right) + \gamma_{LL} \cdot \left(P_{1LL} + P_{2LL} \cdot \sin(18.5deg)\right) = 2629.89 \cdot kip$$

right side

$$F_{right} := \gamma_{DL} \cdot \left(P_{4DL} - P_{3DL} \cdot \cos(51.7deg)\right) + \gamma_{LL} \cdot \left(P_{4LL} - P_{3LL} \cdot \cos(51.7deg)\right) = 2527.9 \cdot ki$$

since the loads are very similar, calulate the DL/LL reduction for each set of loads to consider the worst case loading

$$\frac{\left(P_{1DL} + P_{2DL} \cdot \sin(18.5deg)\right)}{\left(P_{1LL} + P_{2LL} \cdot \sin(18.5deg)\right)} = 3.23 \qquad \frac{\left(P_{4DL} - P_{3DL} \cdot \cos(51.7deg)\right)}{\left(P_{4LL} - P_{3LL} \cdot \cos(51.7deg)\right)} = 3.75$$

$$R_{DL\_LLleft} := 1 - 0.1 \cdot \left(\frac{3.23 - 1}{5}\right) = 0.96 \qquad R_{DL\_LLright} := 1 - 0.1 \cdot \left(\frac{3.75 - 1}{5}\right) = 0.95$$

The loads on the right side would be more sever, so base the chord splice capacity on the of the right side of the connection

The other cross-sectional properties of the combined section were determined using a CAD program.

$A_g := 184.8\text{in}^2$ is the gross area of all gusset and splice plates.

$e_p := 9.10\text{in}$ is the eccentricity between the force resultant and the centroid of the combined plate area.

$I_g := 58049\text{in}^4$ is the moment of inertia of the gross spliced section.

Since the centroid of the force is above the centroid of the cross-section, the maximum axial+bending stress will be at the top of the plate. Now calculate the section modulus to the top of the cross-section

$$S_g := \frac{I_g}{18.3\text{in}} \qquad S_g = 3172.08 \cdot \text{in}^3$$

Determine if the chord splice is compact

$$K := 0.5 \qquad L_{splice} := 7.1\text{in} \qquad \frac{K \cdot L_{splice} \cdot \sqrt{12}}{t_g} = 12.3$$

Since KL/r of the free plate between chords is less than 25, Fcr equals Fy

$$F_{cr} := F_y$$

Calculate the capacity of the section assuming it occurs at first yield using beam bending theory

$$C_{LRFR} := \phi_{cs} \cdot F_{cr} \cdot \left(\frac{S_g \cdot A_g}{S_g + e_p \cdot A_g} \right) = 10265.65 \cdot \text{kip}$$

Calculate the rating factor

$$RF_{LRFRinv} := \frac{\phi_s \cdot R_{DL\_LLright} \cdot C_{LRFR} - 2 \cdot \gamma_{DL} \cdot \left(P_{4DL} - P_{3DL} \cdot \cos(51.7\text{deg})\right)}{2 \cdot \gamma_{LL} \cdot \left(P_{4LL} - P_{3LL} \cdot \cos(51.7\text{deg})\right)}$$

*** dead and live loads were doubled because ealier in the sheet they were halved so resistance checks could be made per gusset plate, which doesn't apply to the chord splice ***

$$\boxed{RF_{LRFRinv} = 3.67}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 4.76}$$

Calculate the proposed LFR rating factors

only the capacity calculation changes because the resistance factor is 1.00. Still calculate the splice capacity for each side

$$C_{LFR} := \frac{C_{LRFR}}{\phi_{cs}} = 12077.24 \cdot kip$$

the minimum rating factor using left and right loads will controll the rating

$$RF_{LFRinv} := \frac{C_{LFR} - 2 \cdot \gamma_{DL\_LFR} \cdot \left(P_{4DL} - P_{3DL} \cdot \cos(51.7deg)\right)}{2 \cdot \gamma_{LL\_LFR} \cdot \left(P_{4LL} - P_{3LL} \cdot \cos(51.7deg)\right)}$$

$$\boxed{RF_{LFRinv} = 4.84}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

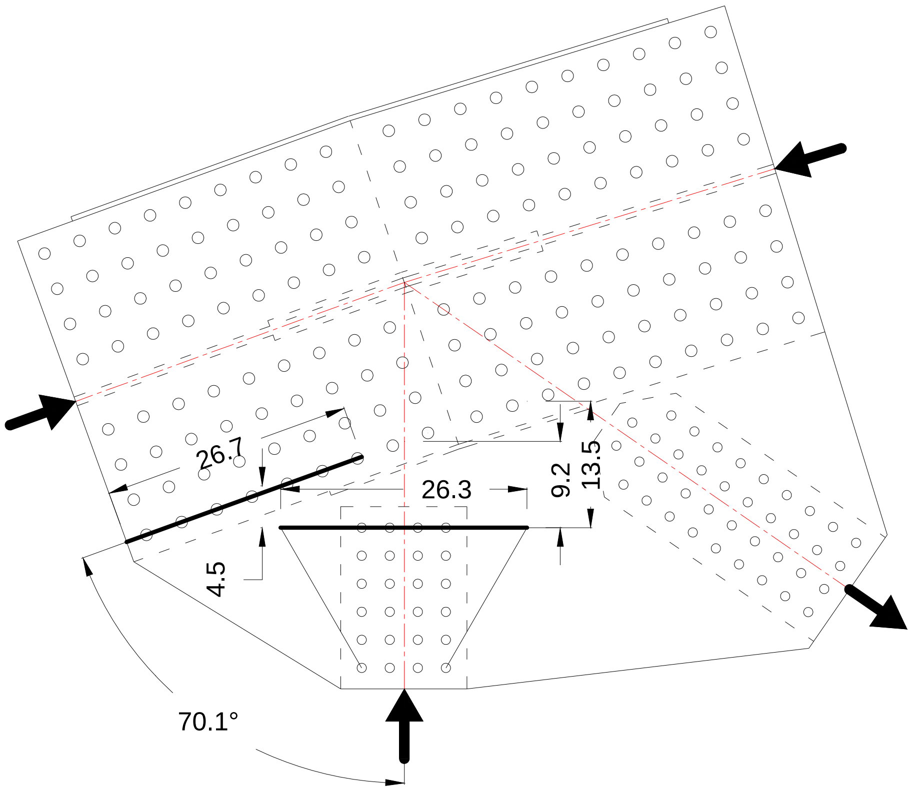
$$\boxed{RF_{LFRopr} = 8.07}$$

<u>Summarize Rating Factors Using the Three Methods for the Chord Splice</u>

	Inventory	**Operating**
Existing FHWA Method	not applicable	not applicable
Proposed LRFR Method	$RF_{LRFRinv} = 3.67$	$RF_{LRFRopr} = 4.76$
Proposed LFR Method	$RF_{LFRinv} = 4.84$	$RF_{LFRopr} = 8.07$

MEMBER 2

Compression Member



$$L_{avg} := \frac{(4.5 + 9.2 + 13.5)\text{in}}{3}$$

$$L_{mid} := 9.2\text{in}$$

$$r_s := \frac{t_g}{\sqrt{12}}$$

$$A_s := 26.3\text{in}\cdot t_g$$

Calculate LRFR rating factors using existing FHWA Guidance method

Calculate the compression capacity of one gusset plate

$$K := 1.2$$

$$\lambda := \left(\frac{K\cdot L_{avg}}{r_s\cdot\pi}\right)^2\cdot\left(\frac{F_y}{E}\right) = 0.5$$

$$C := \phi_c\cdot\begin{cases}\left(0.66^{\lambda}\cdot F_y\cdot A_s\right) & \text{if } \lambda \le 2.25 \\ \dfrac{0.88\cdot F_y\cdot A_s}{\lambda} & \text{otherwise}\end{cases} = 1925.92\cdot\text{kip}$$

$$\boxed{RF_{FHWAinv} := \frac{C - \gamma_{DL}\cdot P_{2DL}}{\gamma_{LL}\cdot P_{2LL}} = 12.77}$$

$$RF_{FHWAopr} := RF_{FHWAinv}\cdot\frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 16.56}$$

Calculate the proposed LRFR rating factors (minimum of Whitmore buckling and partial plane shear)

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6

$$\frac{P_{2DL}}{P_{2LL}} = 2$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{2-1}{5}\right) \qquad R_{DL\_LL} = 0.98$$

calculate the factored Whitmore buckling strength.

$$P_e := \frac{3.29 \cdot E}{\left(\frac{L_{mid}}{t_g}\right)^2} \cdot A_s = 29646.54 \cdot kip$$

$$P_o := F_y \cdot A_s = 2630 \cdot kip$$

$$Whit := \phi_{c\_new} \cdot R_{DL\_LL} \cdot \begin{cases} \left(0.658^{\frac{P_o}{P_e}} \cdot P_o\right) & \text{if } \frac{P_e}{P_o} \geq 0.44 \\ 0.877 \cdot P_e & \text{otherwise} \end{cases} = 2359.28 \cdot kip$$

calculate the partial plane shear yield check

$$PS := \phi_{vg} \cdot \frac{\Omega_{new} \cdot \left(0.58 \cdot F_y\right) \cdot (26.7in) \cdot t_g \cdot R_{DL\_LL}}{\cos(70.1deg)} = 3923.6 \cdot kip$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C := \min(Whit, PS) = 2359.28 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C - \gamma_{DL} \cdot P_{2DL}}{\gamma_{LL} \cdot P_{2LL}} = 14.23}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 18.44}$$

Calculate the proposed LFR rating factors (minimum of Whitmore buckling and partial plane shear)

calculate the factored Whitmore buckling strength

$$K := 0.5$$

$$F_{cr} := \begin{cases} F_y \cdot \left[1 - \dfrac{F_y}{4 \cdot \pi^2 E}\left(\dfrac{K \cdot L_{mid}}{r_s}\right)^2\right] & \text{if } \dfrac{K \cdot L_{mid}}{r_s} \le \sqrt{\dfrac{2 \cdot \pi^2 \cdot E}{F_y}} \\ \dfrac{\pi^2 \cdot E}{\left(\dfrac{K \cdot L_{mid}}{r_s}\right)^2} & \text{otherwise} \end{cases} = 97.78 \cdot \text{ksi}$$

$$Whit := 0.85 \cdot A_s \cdot F_{cr} = 2185.92 \cdot \text{kip}$$

calculate the partial plane shear yield check

$$PS := \frac{\Omega_{new} \cdot \left(0.58 \cdot F_y\right) \cdot (26.7\text{in}) \cdot t_g}{\cos(70.1\text{deg})} = 4003.67 \cdot \text{kip}$$

the buckling strength will be controleld by the minimum of the Whitmore buckling strength and partial plane shear yield criteria

$$C_{LFR} := \min(Whit, PS) = 2185.92 \cdot \text{kip}$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{2DL}}{\gamma_{LL\_LFR} \cdot P_{2LL}} = 11.8}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.3}$$

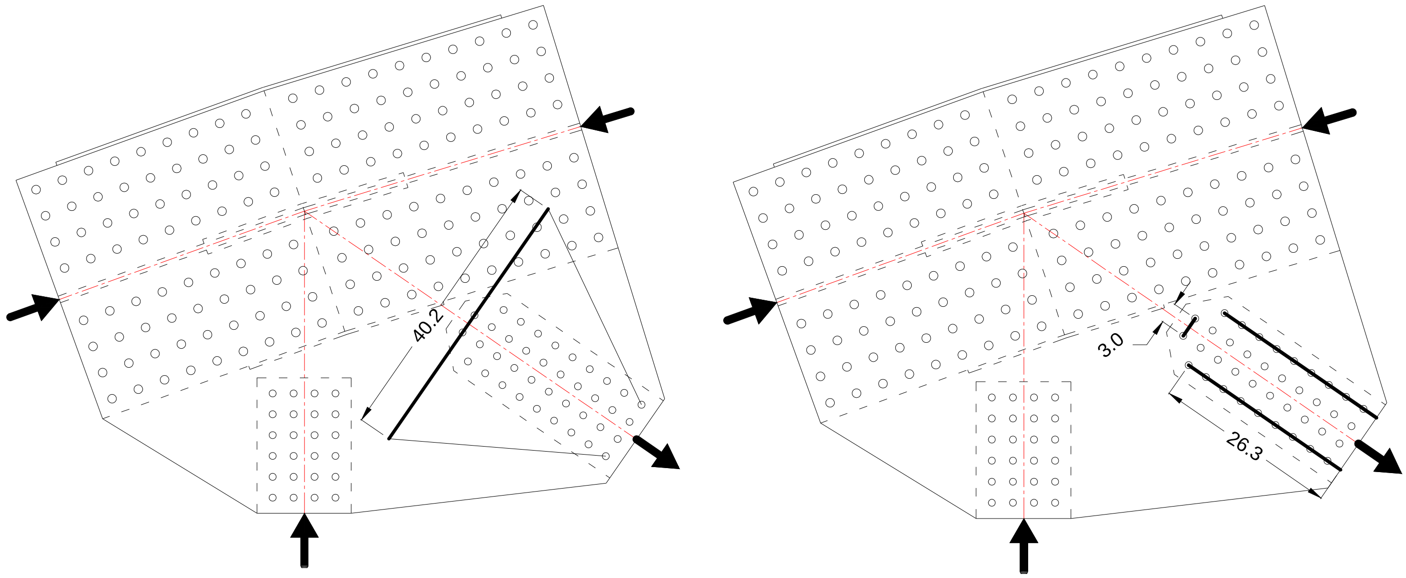
$$\boxed{RF_{LFRopr} = 19.7}$$

<u>Summarize Rating Factors Using the Three Methods for Member 2</u>

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 12.77$	$RF_{FHWAopr} = 16.56$
Proposed LRFR Method	$RF_{LRFRinv} = 14.23$	$RF_{LRFRopr} = 18.44$
Proposed LFR Method	$RF_{LFRinv} = 11.8$	$RF_{LFRopr} = 19.7$

MEMBER 3

Tension member - Need to check gross/net section checks on Whitmore section, and block shear



define the gross and net section areas on Whitmore section

$$A_g := 40.2in \cdot t_g = 40.2\ in^2$$

$$A_n := \left[40.2in - 2 \cdot \left(1 + \frac{1}{8}\right) in\right] \cdot t_g = 37.95\ in^2$$

define the gross and net sections for block shear check

$$A_{tg} := 3in \cdot t_g = 3\ in^2$$

$$A_{vg} := (2 \cdot 26.3in) \cdot t_g = 52.6\ in^2$$

$$A_{tn} := A_{tg} - 1 \cdot \left(1 + \frac{1}{8}\right) in \cdot t_g + \frac{3^2}{4 \cdot 3} in \cdot t_g = 2.62\ in^2$$

$$A_{vn} := A_{vg} - 17 \cdot \left(1 + \frac{1}{8}\right) in \cdot t_g = 33.47\ in^2$$

Calculate LRFR rating factors using existing FHWA Guidance method

calculate yield on gross and fracture on net for the Whitmore plane

$$P_y := \phi_y \cdot F_y \cdot A_g = 3819 \cdot kip$$

$$P_n := \phi_u \cdot F_u \cdot A_n = 3339.6 \cdot kip$$

calculate block shear resistance

$$P_{bs} := \begin{vmatrix} \left[\phi_{bs} \cdot \left(0.58 \cdot F_y \cdot A_{vg} + F_u \cdot A_{tn}\right)\right] & \text{if } A_{tn} \geq 0.58 \cdot A_{vn} \\ \left[\phi_{bs} \cdot \left(0.58 \cdot F_u \cdot A_{vn} + F_y \cdot A_{tg}\right)\right] & \text{otherwise} \end{vmatrix} = 1948.56 \cdot kip$$

the capacity is based on the minimum of block shear, yield on Whitmore, and fracture on Whitmore

$$C_{FHWA} := \min\left(P_y, P_n, P_{bs}\right) = 1948.56 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 8.45}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 10.95}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.

$$\frac{P_{3DL}}{P_{3LL}} = 2.61$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{2.61 - 1}{5}\right) = 0.97$$

calculate yield on gross for the Whitmore plane

$$P_y := \phi_y \cdot F_y \cdot A_g \cdot R_{DL\_LL} = 3696 \cdot kip$$

$$P_n := \phi_u \cdot F_u \cdot A_n \cdot R_{DL\_LL} = 3232.06 \cdot kip$$

calculate the block shear resistance

$$P_{bs} := \begin{cases} \phi_{bs\_new} \cdot \left(0.58 \cdot F_u \cdot A_{vn} + F_u \cdot A_{tn}\right) \cdot R_{DL\_LL} & \text{if } F_u \cdot A_{vn} \le F_y \cdot A_{vg} \\ \phi_{bs\_new} \cdot \left(0.58 \cdot F_y \cdot A_{vg} + F_u \cdot A_{tn}\right) \cdot R_{DL\_LL} & \text{otherwise} \end{cases} = 2346.39 \cdot kip$$

the resistance is the minimum of the Whitmore yield on gross, Whitmore fracture on net, and block shear

$$C_{LRFR} := \min\left(P_y, P_n, P_{bs}\right) = 2346.39 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{3DL}}{\gamma_{LL} \cdot P_{3LL}} = 9.31}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 12.07}$$

Calculate the proposed LFR rating factors

calculate yield on effective Whitmore plane

$$\beta := 0.15$$

$$A_e := \begin{cases} A_n + \beta \cdot A_g & \text{if } A_n + \beta \cdot A_g \le A_g \\ A_g & \text{otherwise} \end{cases} = 40.2\, in^2$$

$$P_y := F_y \cdot A_e = 4020 \cdot kip$$

calculate block shear resistance

$$P_{bs} := \begin{cases} \left[0.85\cdot\left(0.58\cdot F_y\cdot A_{vg} + F_u\cdot A_{tn}\right)\right] & \text{if } A_{tn} \geq 0.58\cdot A_{vn} \\ \left[0.85\cdot\left(0.58\cdot F_u\cdot A_{vn} + F_y\cdot A_{tg}\right)\right] & \text{otherwise} \end{cases} = 2070.35\cdot\text{kip}$$

the capacity is the minimum of the yield on effective Whitmore area or block shear

$$C_{LFR} := \min\left(P_y, P_{bs}\right) = 2070.35\cdot\text{kip}$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR}\cdot P_{3DL}}{\gamma_{LL\_LFR}\cdot P_{3LL}} = 7.27}$$

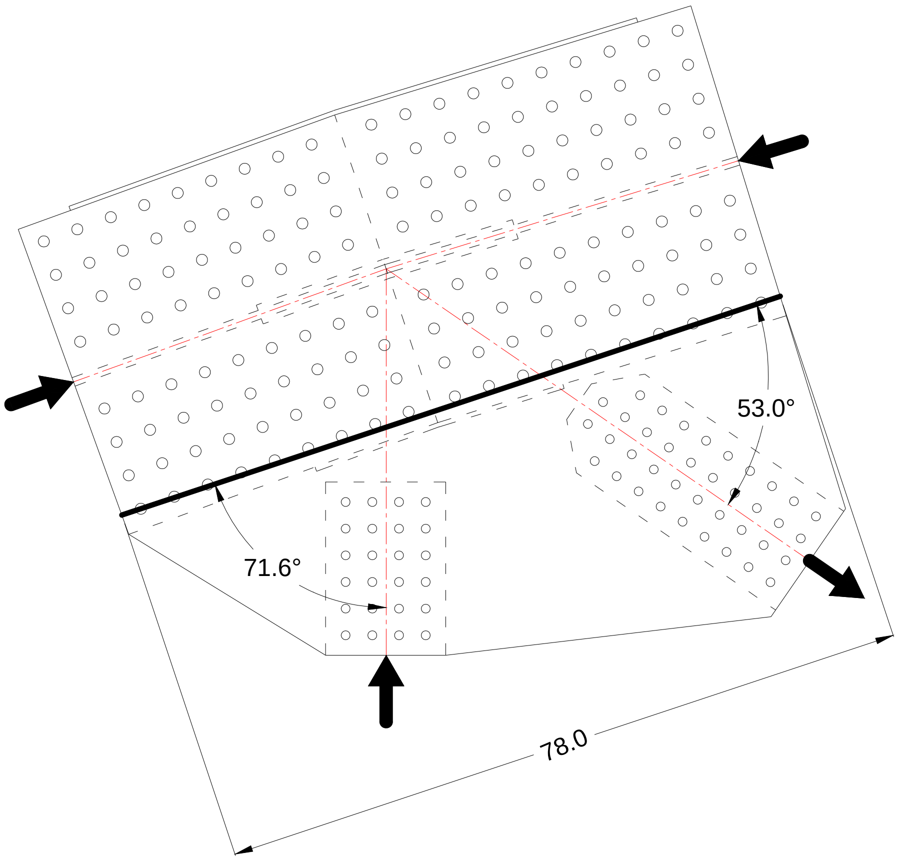
$$RF_{LFRopr} := RF_{LFRinv}\cdot\frac{2.17}{1.3}$$

$$\boxed{RF_{LFRopr} = 12.14}$$

<u>Summarize Rating Factors Using the Three Methods for Member 3</u>

	Inventory	**Operating**
Existing FHWA Method	$RF_{FHWAinv} = 8.45$	$RF_{FHWAopr} = 10.95$
Proposed LRFR Method	$RF_{LRFRinv} = 9.31$	$RF_{LRFRopr} = 12.07$
Proposed LFR Method	$RF_{LFRinv} = 7.27$	$RF_{LFRopr} = 12.14$

Horizontal Plane Shear



$$P_{2HDL} := P_{2DL} \cdot \cos(71.6deg) = 49 \cdot kip$$

$$P_{2HLL} := P_{2LL} \cdot \cos(71.6deg) = 24 \cdot kip$$

$$P_{3HDL} := P_{3DL} \cdot \cos(53.0deg) = 169 \cdot kip$$

$$P_{3HLL} := P_{3LL} \cdot \cos(53.0deg) = 65 \cdot kip$$

$$P_{HDL} := P_{2HDL} + P_{3HDL} = 218 \cdot kip$$

$$P_{HLL} := P_{2HLL} + P_{3HLL} = 89 \cdot kip$$

Calculate LRFR rating factors using existing FHWA Guidance method

Gross Yielding

$$V_{ny} := \phi_{vy} \cdot \left(0.58 \cdot F_y\right) \cdot 78.0in \cdot t_g \cdot \Omega = 3180 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot \left(0.58 \cdot F_u\right) \cdot \left[78.0 - 19 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 2890 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{FHWA} := \min\left(V_{ny}, V_{nu}\right) = 2890.14 \cdot kip$$

$$\boxed{RF_{FHWAinv} := \frac{C_{FHWA} - \gamma_{DL} \cdot P_{HDL}}{\gamma_{LL} \cdot P_{HLL}} = 16.72}$$

$$RF_{FHWAopr} := RF_{FHWAinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{FHWAopr} = 21.67}$$

Calculate the proposed LRFR rating factors

Calculate the DL/LL ratio for this limit state to account for further reduction according to MBE Article 6A.6.12.6.

$$\frac{P_{HDL}}{P_{HLL}} = 2.44$$

$$R_{DL\_LL} := 1 - 0.1 \cdot \left(\frac{2.44 - 1}{5}\right) = 0.97$$

Gross Yielding

$$V_{ny} := \phi_{vg} \cdot (0.58 \cdot F_y) \cdot 78.0in \cdot t_g \cdot \Omega_{new} \cdot R_{DL\_LL} = 3866 \cdot kip$$

Shear Fracture

$$V_{nu} := \phi_{vu} \cdot (0.58 \cdot F_u) \cdot \left[78.0 - 19 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g \cdot R_{DL\_LL} = 2807 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LRFR} := \min(V_{ny}, V_{nu}) = 2806.9 \cdot kip$$

$$\boxed{RF_{LRFRinv} := \frac{\phi_s \cdot C_{LRFR} - \gamma_{DL} \cdot P_{HDL}}{\gamma_{LL} \cdot P_{HLL}} = 14.39}$$

$$RF_{LRFRopr} := RF_{LRFRinv} \cdot \frac{1.75}{1.35}$$

$$\boxed{RF_{LRFRopr} = 18.66}$$

Calculate the proposed LFR rating factors

Gross Yielding

$$V_{ny} := (0.58 \cdot F_y) \cdot 78.0in \cdot t_g \cdot \Omega_{new} = 3981 \cdot kip$$

Shear Fracture

$$V_{nu} := 0.85(0.58 \cdot F_u) \cdot \left[78.0 - 19 \cdot \left(1 + \frac{1}{8}\right)\right] in \cdot t_g = 3071 \cdot kip$$

The capacity is the minimum resistance between shear yielding and fracture

$$C_{LFR} := \min(V_{ny}, V_{nu})$$

$$\boxed{RF_{LFRinv} := \frac{C_{LFR} - \gamma_{DL\_LFR} \cdot P_{HDL}}{\gamma_{LL\_LFR} \cdot P_{HLL}} = 14.36}$$

$$RF_{LFRopr} := RF_{LFRinv} \cdot \frac{2.17}{1.30}$$

$$\boxed{RF_{LFRopr} = 23.96}$$

Summarize Rating Factors Using the Three Methods for Horizontal Shear

	Inventory	Operating
Existing FHWA Method	$RF_{FHWAinv} = 16.72$	$RF_{FHWAopr} = 21.67$
Proposed LRFR Method	$RF_{LRFRinv} = 14.39$	$RF_{LRFRopr} = 18.66$
Proposed LFR Method	$RF_{LFRinv} = 14.36$	$RF_{LFRopr} = 23.96$

Vertical Plane Stress Check

unnesseccary as plate cannot mobilize through chord splice