AASHTOWare™ BRIDGE DESIGN AND RATING

Considerations when Modelling Deteriorated Gusset Plates using BrDR

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Purpose and Outline

PURPOSE:

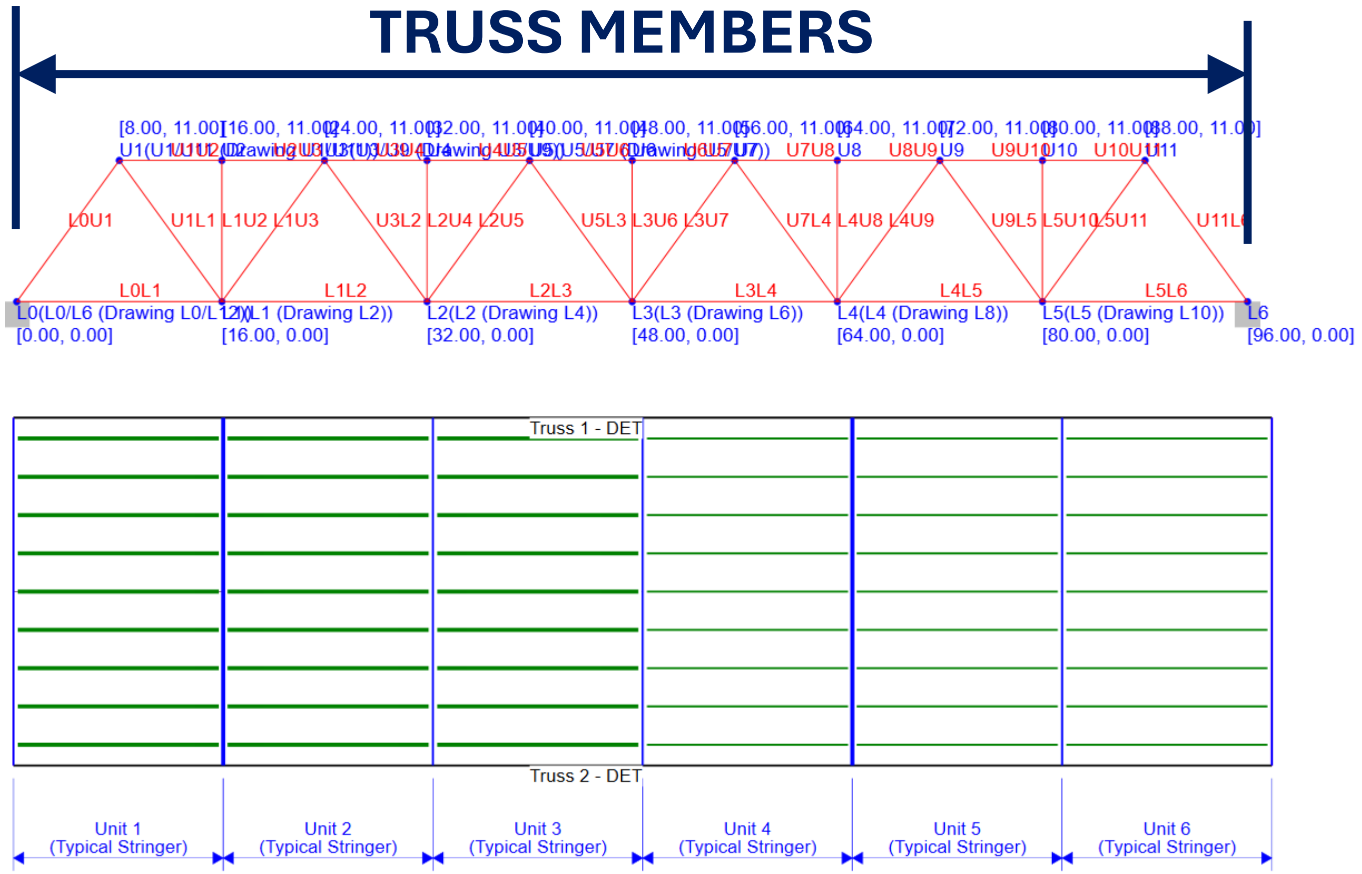
Discuss gusset plate modelling using BrDR and additional considerations when encountering deterioration and/or unique conditions.

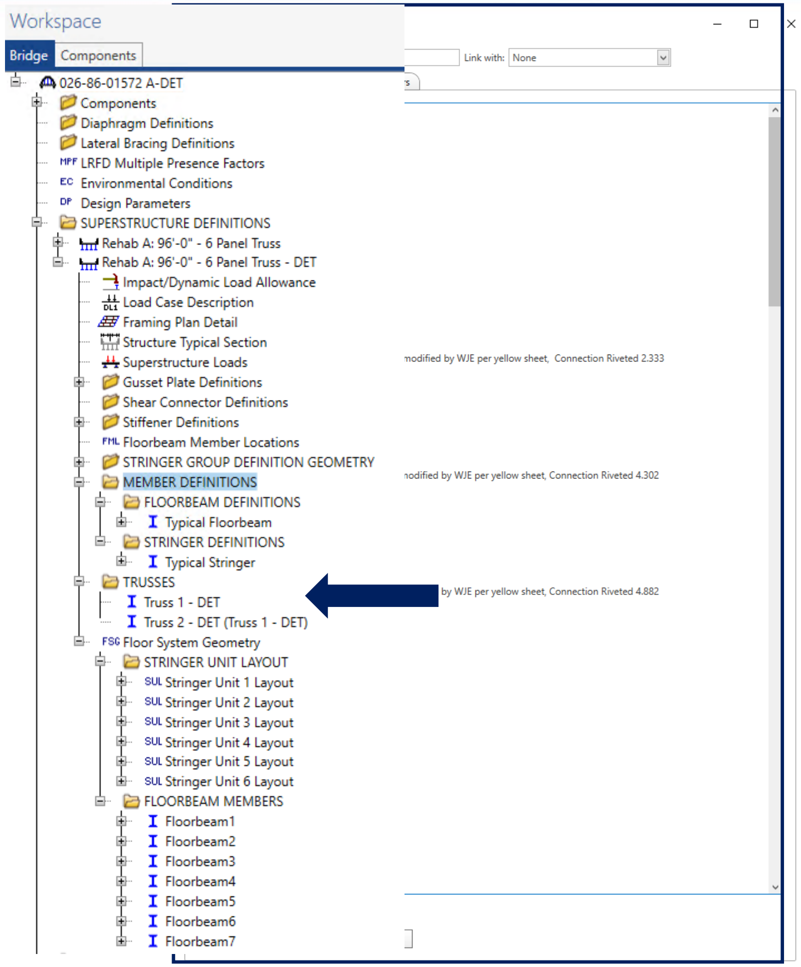
OUTLINE:

- Brief overview of gusset plate modelling using BrDR.
- Load distribution between gusset plates.
  - Discuss how BrDR evaluates gusset plates (i.e., as a panel point or as individual plates).
  - Discuss methods to calculate rating factors using BrDR when gusset plate capacities are severely dissimilar.
- Fastener capacity and effect on other limit states.
- Corner checks with deterioration.
- Compression chord splice refinements.

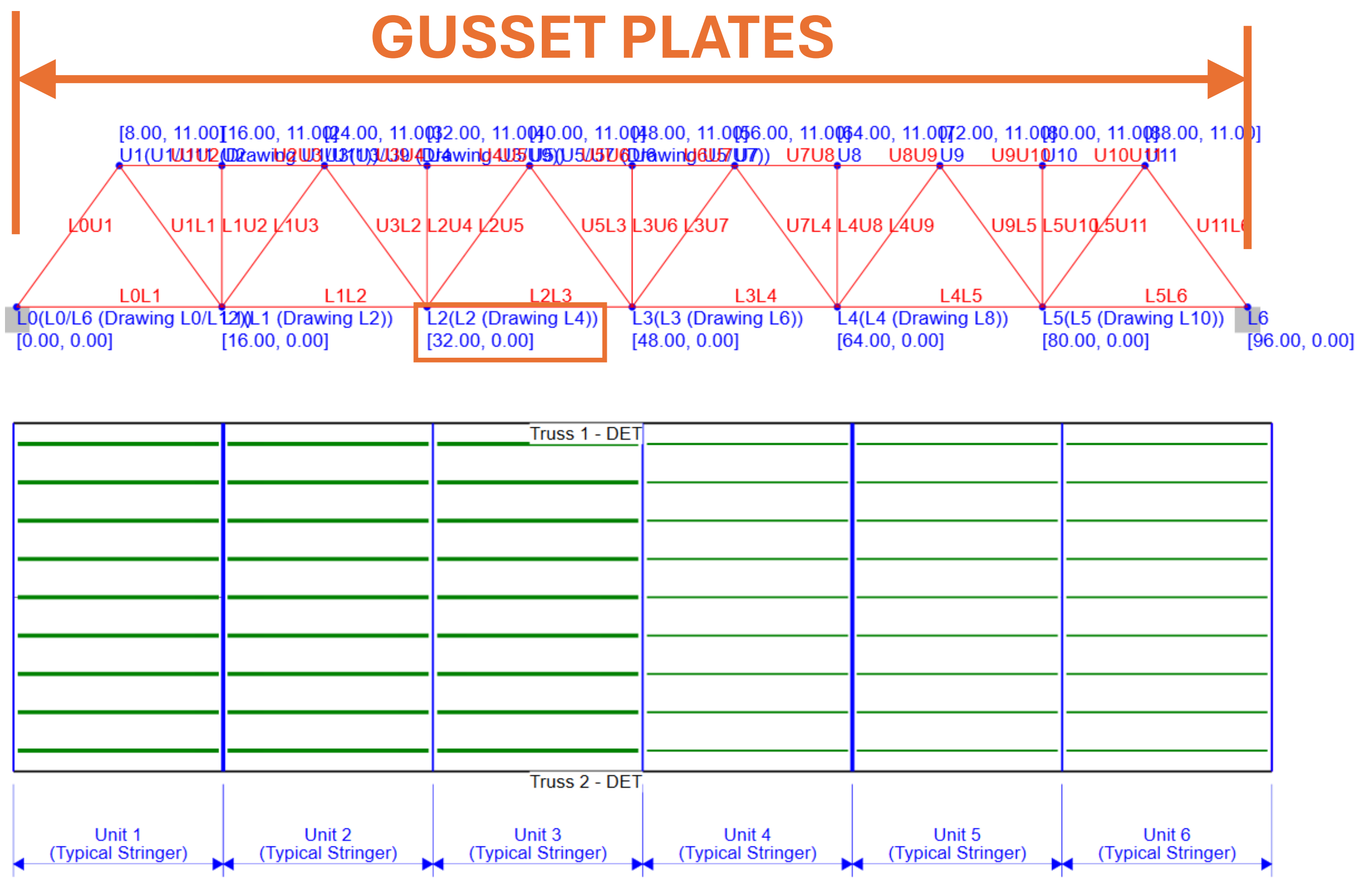
Overview of Truss and Gusset Plate Model Structure in BrDR

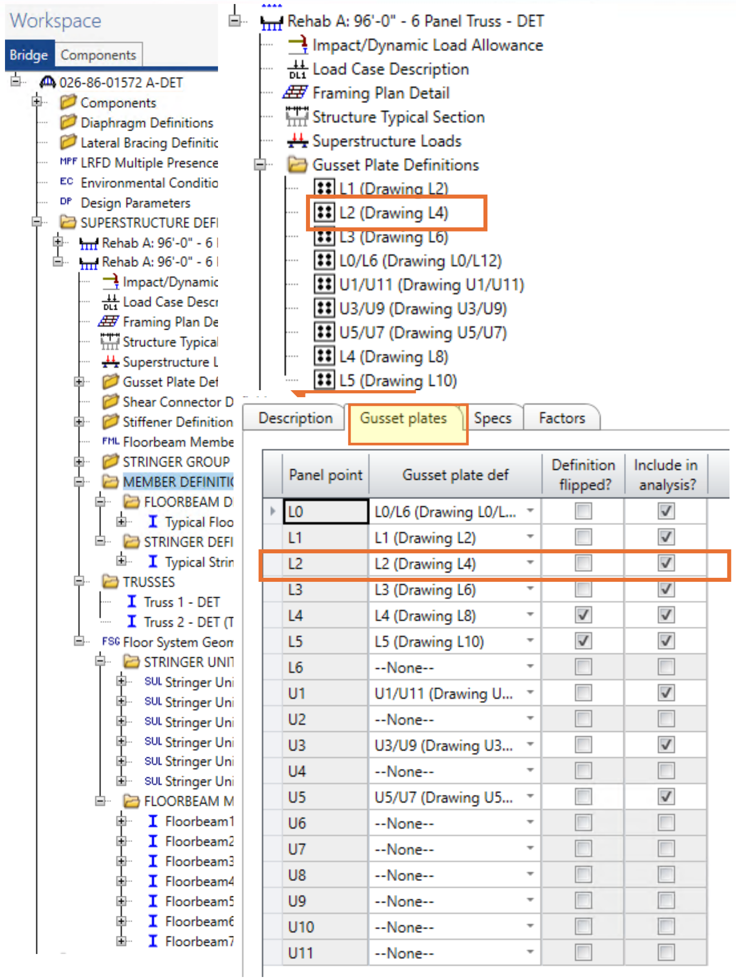
Model Overview: Truss Members





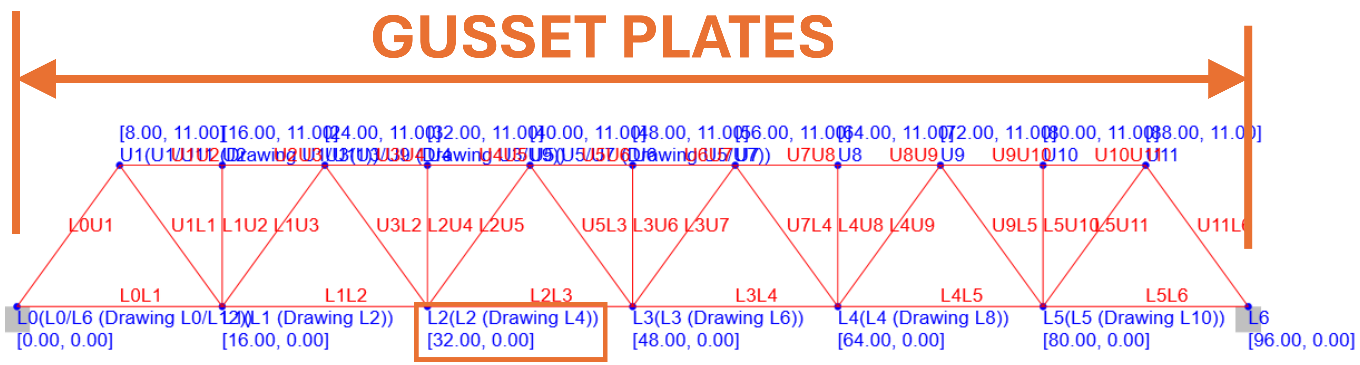
Model Overview: Gusset Plates

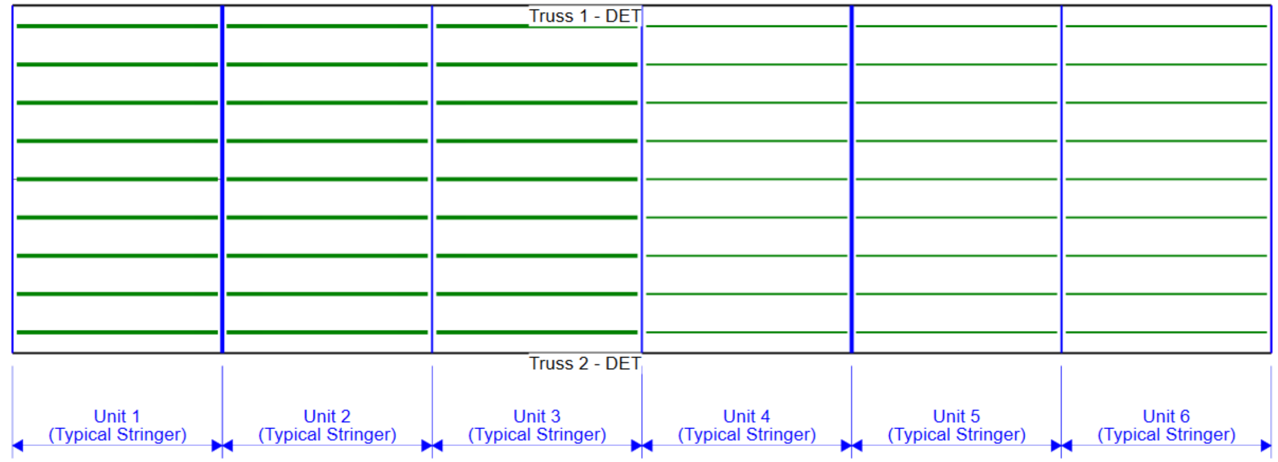


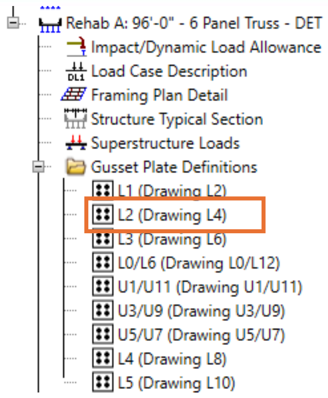


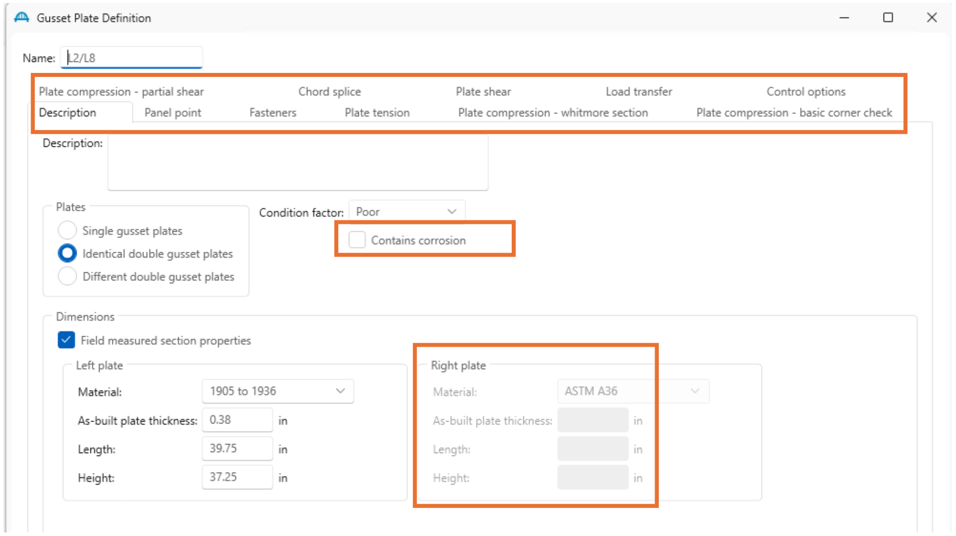
Panel point	Gusset plate def	Definition flipped?	Include in analysis?
L0	L0/L6 (Drawing L0/L...	☐	☑
L1	L1 (Drawing L2)	☐	☑
L2	L2 (Drawing L4)	☐	☑
L3	L3 (Drawing L6)	☐	☑
L4	L4 (Drawing L8)	☑	☑
L5	L5 (Drawing L10)	☑	☑
L6	--None--	☐	☐
U1	U1/U11 (Drawing U...	☐	☑
U2	--None--	☐	☐
U3	U3/U9 (Drawing U3...	☐	☑
U4	--None--	☐	☐
U5	U5/U7 (Drawing U5...	☐	☑
U6	--None--	☐	☐
U7	--None--	☐	☐
U8	--None--	☐	☐
U9	--None--	☐	☐
U10	--None--	☐	☐
U11	--None--	☐	☐

Model Overview: Gusset Plates

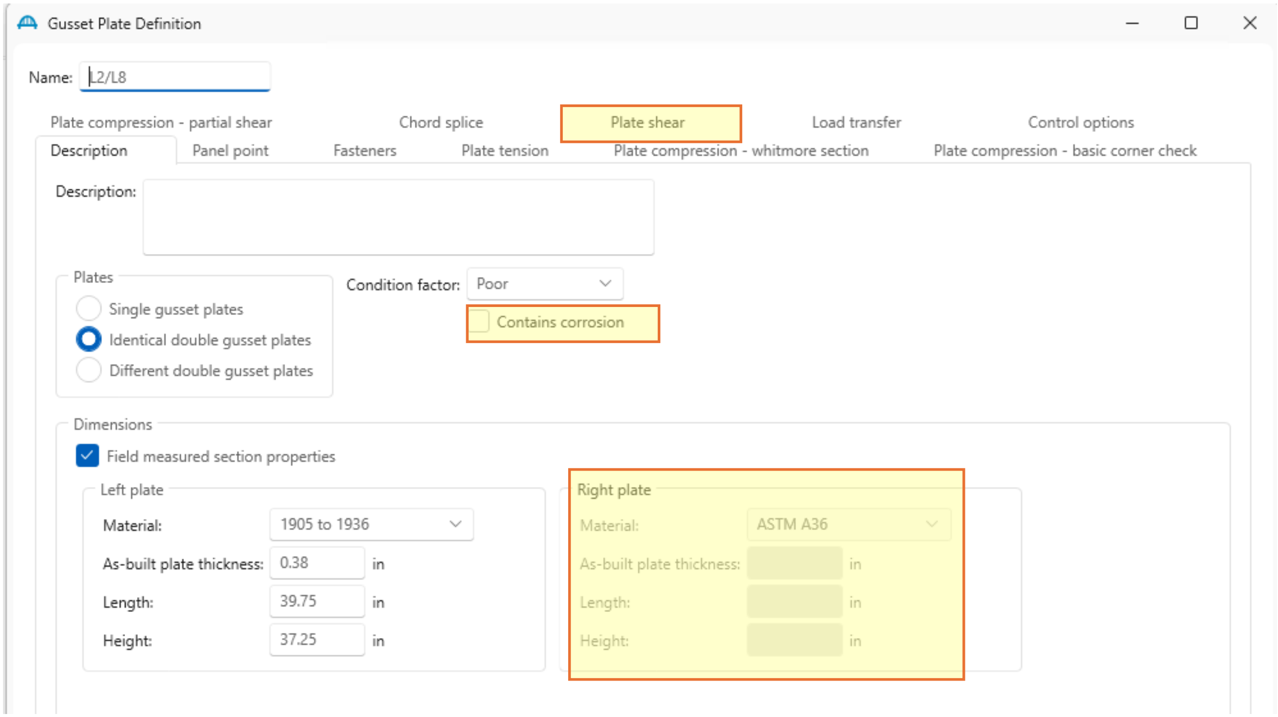


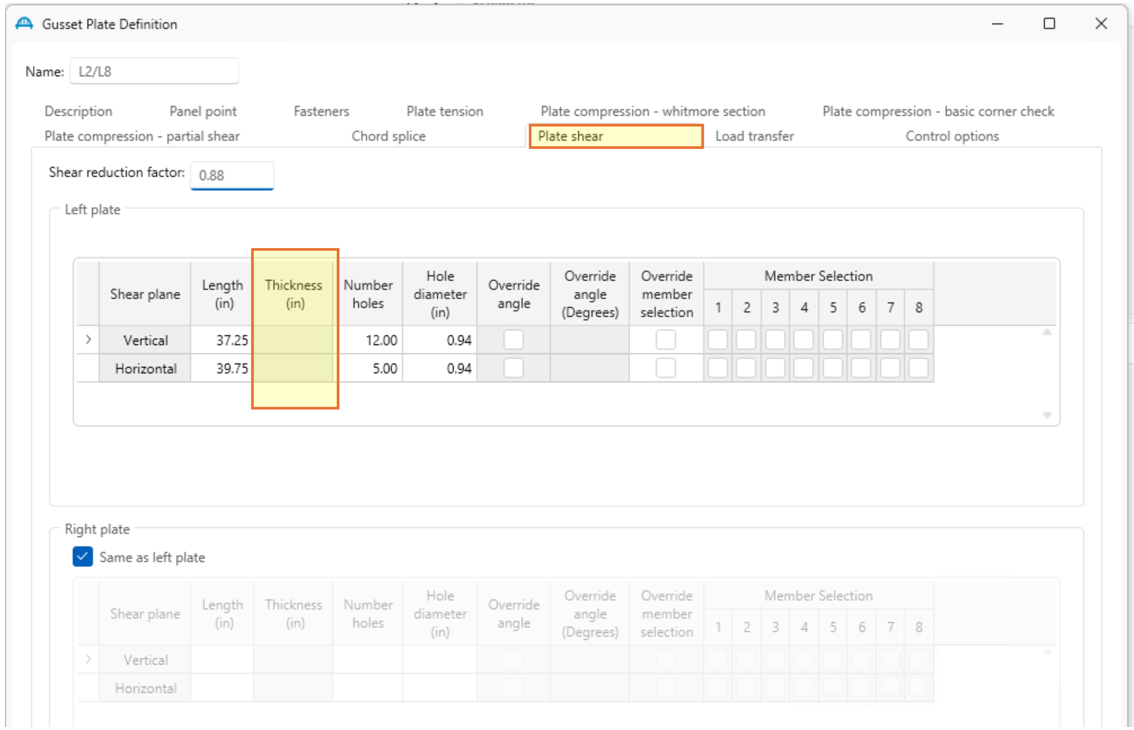






Model Overview: Gusset Plates





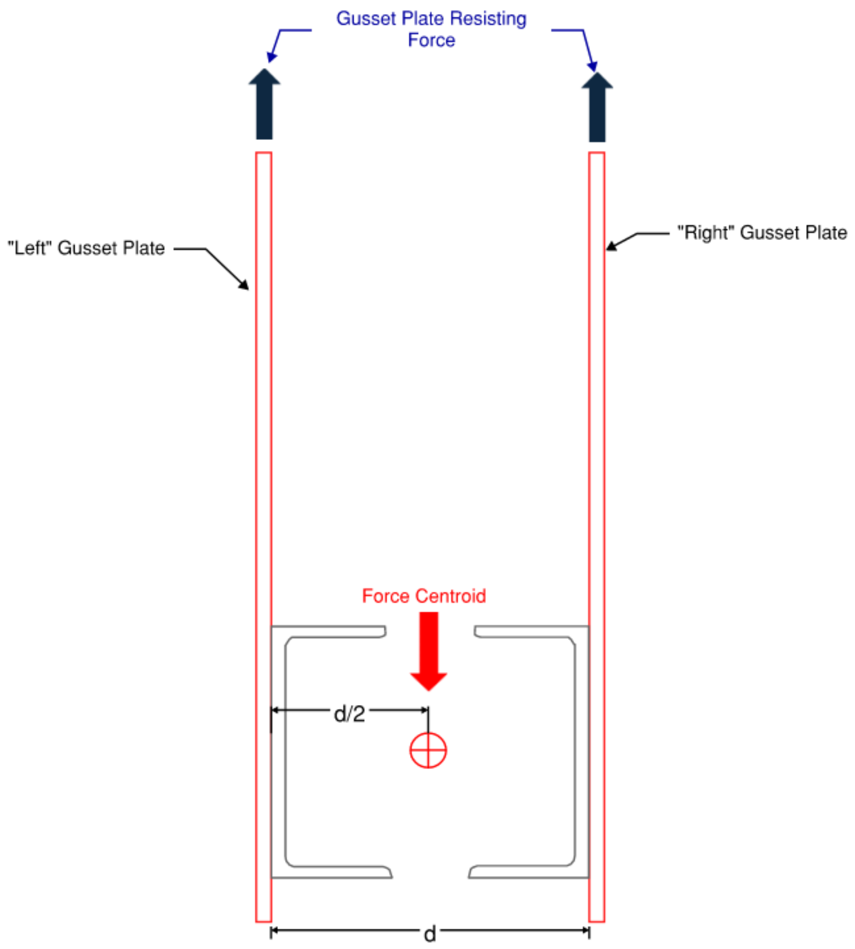
Load Distribution between Gusset Plates

Load Distribution

Common practice to sum plate capacities for connection resistance, which is reasonable when plate capacities are similar (BrDR).

- **<u>BUT….</u>**
  - Deterioration profiles are rarely the same on any plate at a shared joint.
  - Connection plates oftentimes are asymmetric.

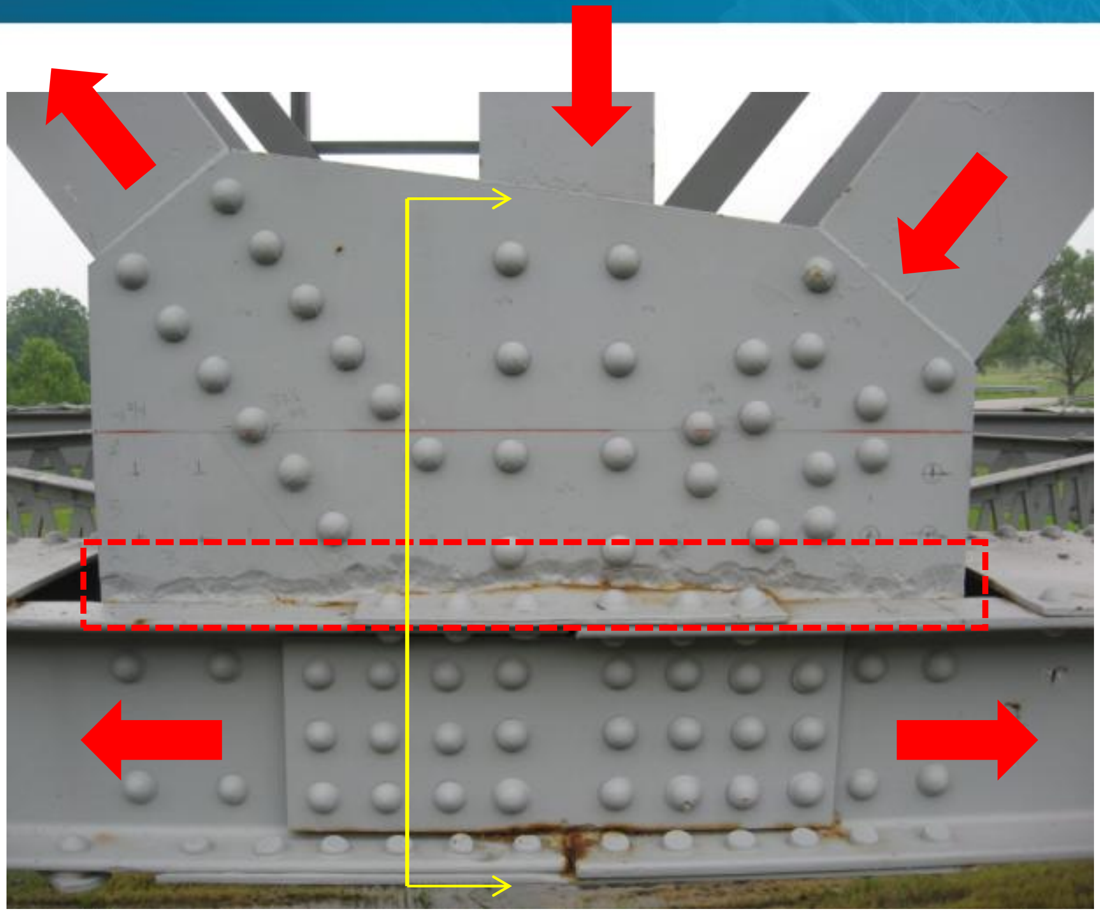
Load Distribution



For panel points ***with little or no deterioration and similar gusset plate geometries***:

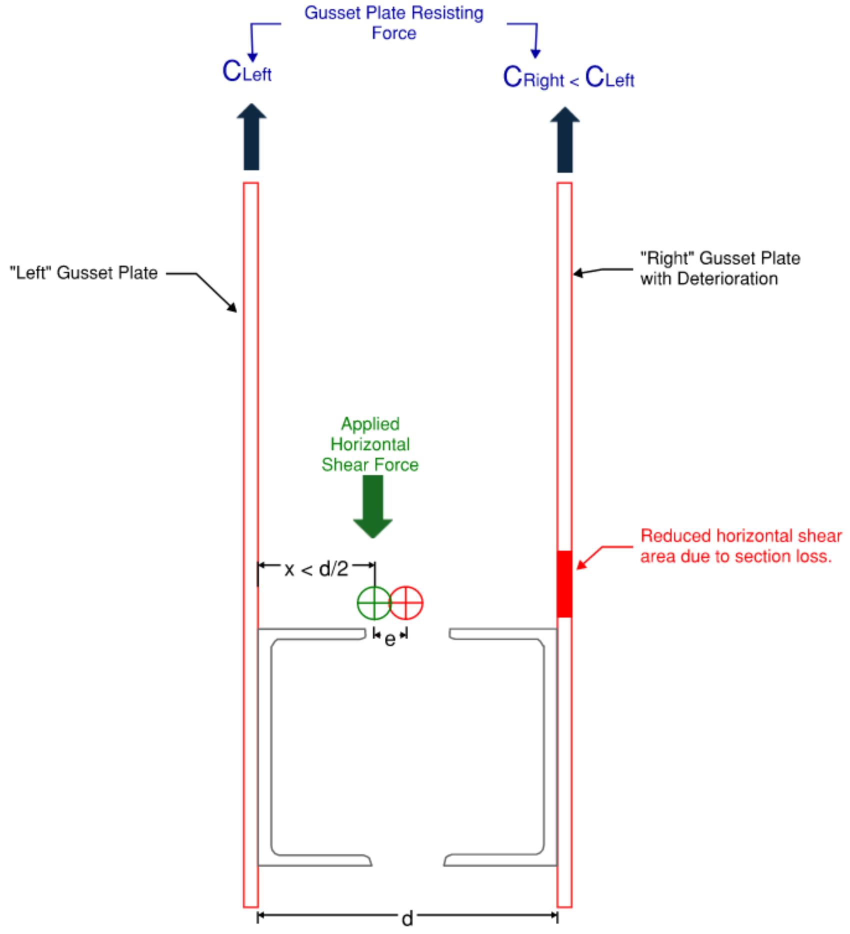
- Member forces are resolved near the midpoint between the gusset plates.
- No moment introduced into the connection.
- $C_{PP} = C_{Left} + C_{Right}$ is reasonable.

Load Distribution



- What about when one plate has measurably more deterioration than the other?
- Applies to all gusset plate limit states (i.e., fasteners, shear, tension, compression, chord splice)
- Consider horizontal shear along the top of the bottom chord.

Load Distribution

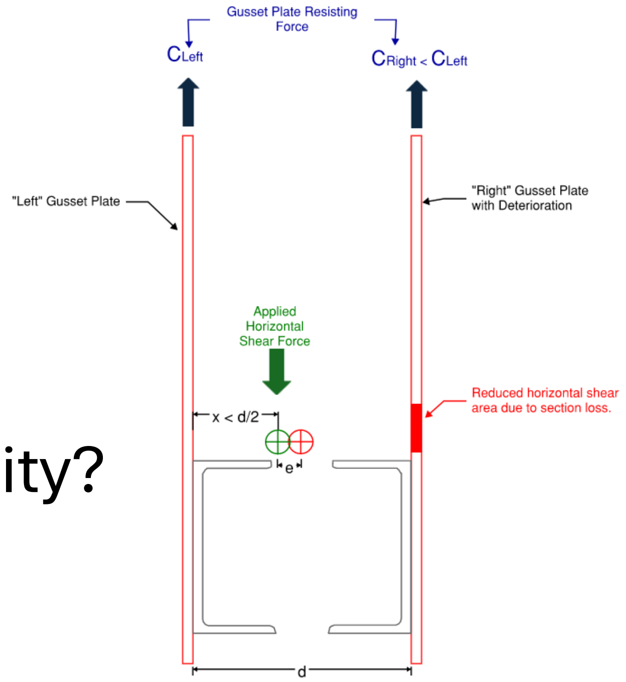


For panel points with ***different deterioration profiles***:

- Member forces are no longer resolved at the midpoint of the gusset plates.
- A portion of the member forces will redistribute from the weaker gusset plate to the stronger gusset plate.
- $C_{PP} = C_{Left} + C_{Right}$ **may be** reasonable depending on the magnitude of disparity between C_{Left} and C_{Right}.

Load Distribution

- For ductile materials such as steel, loads will re-distribute; however…
- As C_{Left} or C_{Right} → 0, eccentricity approaches d/2.
  - Bending moment introduced into the connection.



KEY QUESTION:

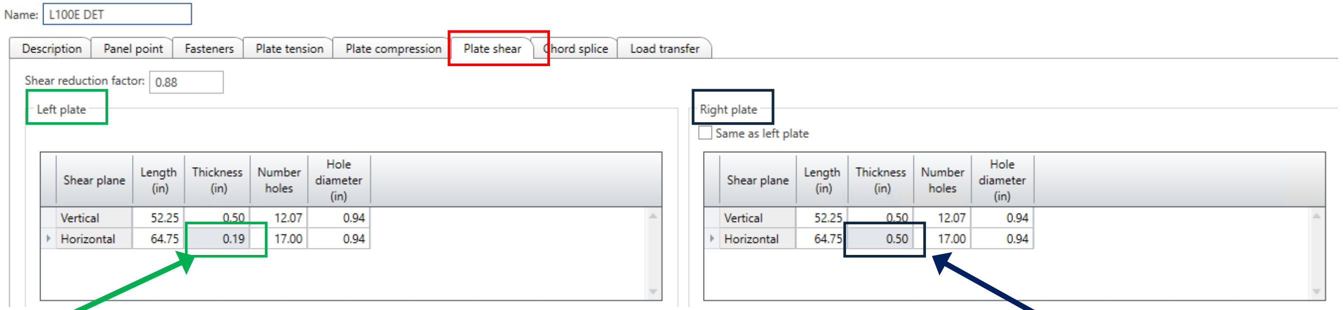
- What are reasonable limits on the connection eccentricity?
  - Illinois Department of Transportation considers a maximum distribution of 65% / 35% (IDOT *Structural Services Manual)*.
  - Moments in the connection can be ignored if the gusset plates are evaluated within these limits.

Load Distribution: Modelling using BrDR

- BrDR currently evaluates the panel points as the **sum** of gusset plate capacities ($C_{PP} = C_{Left}+C_{Right}$).
- When (i) the applicable distribution limits of 65% / 35% are exceeded and (ii) if the load rater does not wish to consider bending moment in the connection, there are two options for modelling using BrDR:
  1. Hand-calculate rating factors for the gusset plates **individually** using demands and plate capacities from BrDR.
  2. Hand-calculate capacities, then input effective parameters into BrDR, then allow the engine to generate equivalent rating factors.
  - For both options, the stronger gusset plate receives 65% of the member load. Weak gusset plate receives 35% of the member load.

Load Distribution: Modelling using BrDR, Option 1

- Option 1: Calculate Rating Factors Outside of BrR



Left plate:

Shear plane	Length (in)	Thickness (in)	Number holes	Hole diameter (in)
Vertical	52.25	0.50	12.07	0.94
Horizontal	64.75	0.19	17.00	0.94

Right plate:

Shear plane	Length (in)	Thickness (in)	Number holes	Hole diameter (in)
Vertical	52.25	0.50	12.07	0.94
Horizontal	64.75	0.50	17.00	0.94

Heavy section loss on left plate.

Full thickness remains on right plate.

```
Horizontal Shear Resistance:

Gusset Plate Left:
Avg:                         12.303 (in^2)

Resistance:
CYield = PhiVY * 0.58 * Fy * Avg * Omega
CYieldLeft:                 282.564 (kip)

Avn:                          9.274 (in^2)

Resistance:
CRupture = PhiVU * 0.58 * Fu * Avn
CRuptureLeft:               320.059 (kip)

Gusset Plate Right:
Avg:                         32.375 (in^2)

Resistance:
CYield = PhiVY * 0.58 * Fy * Avg * Omega
CYieldRight:                743.589 (kip)

Avn:                         24.406 (in^2)

Resistance:
CRupture = PhiVU * 0.58 * Fu * Avn
CRuptureRight:              842.260 (kip)

Total Resistance (Horizontal):
CYield:                    1026.153 (kip)
CRupture:                  1162.319 (kip)
C:                         1026.153 (kip)
```

Individual capacities summed for typical rating:

Load Distribution: Modelling using BrDR, Option 1

- Option 1: Calculate Rating Factors Outside BrR

HORIZONTAL SHEAR RATING FACTOR CALCULATIONS

C = 1026.153 (kip)

VDL Top = 332.592 (kip)
VDL Bot = 0.000 (kip)

A1 = Dead Load Factor
A2 = Live Load Factor

Top Side:

Rating Level	Vehicle	VLL(1+I) (kip)	-- Load Factors -- A1	A2	RF	Capacity (Ton)
Inv	1	170.93	1.30	2.17	1.600	57.60
Inv	1	176.14	1.30	2.17	1.553	55.90
Inv	2	93.23	1.30	2.17	2.934	105.61
Inv	2	93.23	1.30	2.17	2.934	105.61

Total Resistance (Horizontal):
CYield: 1026.153 (kip)
CRupture: 1162.319 (kip)
C: 1026.153 (kip)

Individual capacities summed for typical rating:

RF > 1.0.....GREAT!!

... NOT SO FAST...

Load Distribution: Modelling using BrDR, Option 1

- ***<u>When rating gusset plates, the load rater should consider checking plates individually when section loss is measurably different.</u>***

```
Horizontal Shear Resistance:

Gusset Plate Left:
Avg:                     12.303  (in^2)

Resistance:
CYield = PhiVY * 0.58 * Fy * Avg * Omega
CYieldLeft:                282.564  (kip)

VDL Top =     332.592  (kip)
VDL Bot =       0.000  (kip)

A1 = Dead Load Factor
A2 = Live Load Factor

Top Side:
--------
```

Rating Level	Vehicle	VLL(1+I) (kip)
Inv	1	170.93
Inv	1	176.14
Inv	2	93.23
Inv	2	93.23

<u>LFR Rating Factor – Left Plate Only</u>

- V_{hn} = 282.6 kip
- V_{DL} = 332.6 kip
- V_{LL} = 176.1 kip (Including IM)
- Assign *DIST*=35% of total load to plate with heavy sxl (**<u>minimum</u>**)

$$RF = \frac{V_{hn} - (1.3 * V_{DL} * DIST)}{(2.17 * V_{LL} * DIST)} = 0.98$$

…compared to *RF=1.55* when capacities are summed

Level	Vehicle	(kip)	A1	A2	RF	(Ton)
Inv	1	170.93	1.30	2.17	1.600	57.60
Inv	1	176.14	1.30	2.17	1.553	55.90

Load Distribution: Modelling using BrDR, Option 2

- Option 2: Hand-Calculate Capacities and BrR Effective Inputs
  - BrR Input → ϕR_n (BrR) = ϕR_n (Hand Calculations)

Load Distribution: Modelling using BrDR, Option 2

Chord Splice at Gusset Plate L2

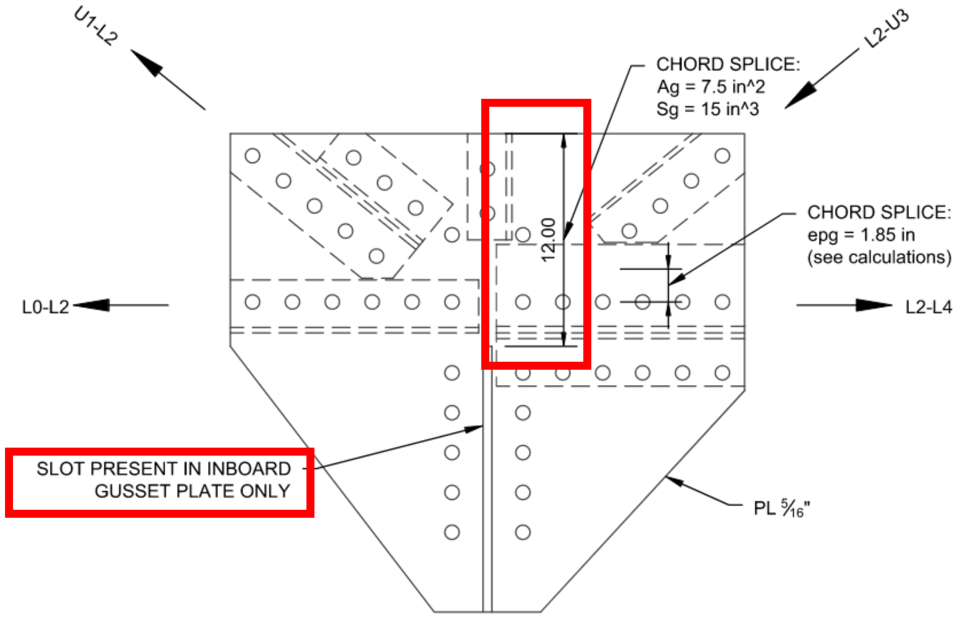
Load Distribution: Modelling using BrDR, Option 2

Bottom Chord Spliced at L2

Inside Plate Slotted for Floor Beam

Load Distribution: Modelling using BrDR, Option 2

- Chord Splice Evaluation



JOINT L2 CHORD SPLICE

35% Load → Slotted Inside PL

65% Load → Outside PL

$\phi P_1 := 1.00 \cdot F_y \cdot \left(\frac{S_{p1} \cdot A_{p1}}{S_{p1} + e_{p1} \cdot A_{p1}} \right) = 178.12 \cdot kip$

Factored chord splice compression resistance (MBE Eqn. L6B.2.6.6-1) for outbard gusset plate.

$\phi P_2 := 1.00 \cdot F_y \cdot \left(\frac{S_{p2} \cdot A_{p2}}{S_{p2} + e_{p2} \cdot A_{p2}} \right) = 40.91 \cdot kip$

Factored chord splice compression resistance (MBE Eqn. L6B.2.6.6-1) for outbard gusset plate.

$\frac{\phi P_2}{35\%} = 116.9 \cdot kip \quad < \quad \frac{\phi P_1}{65\%} = 274 \cdot kip$

Capacity limited by inboard gusset plate, considering 65% / 35% load distribution

$\phi P_{cs} := \frac{\phi P_2}{35\%} = 116.9 \cdot kip$

Capacity of chord splice group considering 65% of force distributed to outboard gusset plate and 35% of force distributed to inboard gusset plate

Load Distribution: Modelling using BrDR, Option 2

- Compute Effective Eccentricity for BrR Input Assuming:
  - $A_g = 7.5\ in^2$
  - $S_g = 15\ in^3$

BrR Input

Effective eccentricity

$$e_{eff} := \frac{\dfrac{1.00 \cdot F_y \cdot (S_g \cdot A_g)}{\phi P_{cs}} - S_g}{A_g} = 1.85 \cdot in$$

Effective eccentricity for BrR input to generate chord splice resistance calculated above considering 65% / 35% force distribution

$$1.00 \cdot F_y \cdot \left(\frac{S_g \cdot A_g}{S_g + e_{eff} \cdot A_g}\right) = 116.9 \cdot kip \quad = \quad \phi P_{cs} = 116.9 \cdot kip$$

Resulting strength utilized by BrR when effective eccentricity is input. This capacity accounts for 65% of the member's loads carried by the outboard gusset plate (without a slot for the floor beam) and 35% of the member's loads carried by the inboard gusset plate (where the presence of the slot limits the chord splice resistance).

Gusset Plate Definiton

Name: L2

Description | Panel point | Fasteners | Plate tension | Plate compression | Plate shear | Chord splice | Load transfer

☑ Consider chord splice

☐ Continuous chord members

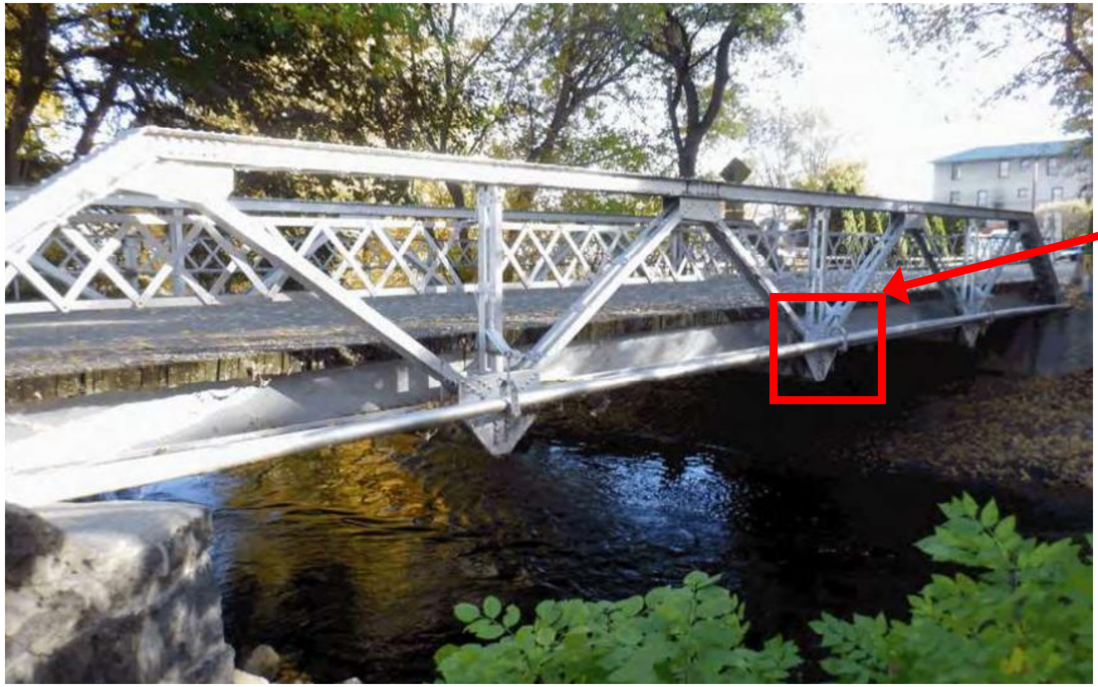
Gross area:	7.50	in^2
Gross section modulus:	15.000	in^3
epg:	1.850	in

```
SUMMARY:

                                          _             _
                                         |    Sg * Ag    |
Yield Capacity C = phi_cs * Fy |  -----------  |
                                         |_   Sg + eAg  _|
   where
   Fy = min(Fy_Left, Fy_Right)

                                           _             _
                                          |    Sn * An    |
Fracture Capacity C = phi_cs * Fu |  -----------  |
                                          |_   Sn + eAn  _|
   where
   Fu = min(Fu_Left, Fu_Right)

Tensile Yield:             116.88 (kip)
Tensile Fracture:          116.13 (kip)
Tensile Resistance = Min(Yield, Fracture) = 116.13 (kip)
```

BrR Spec Check

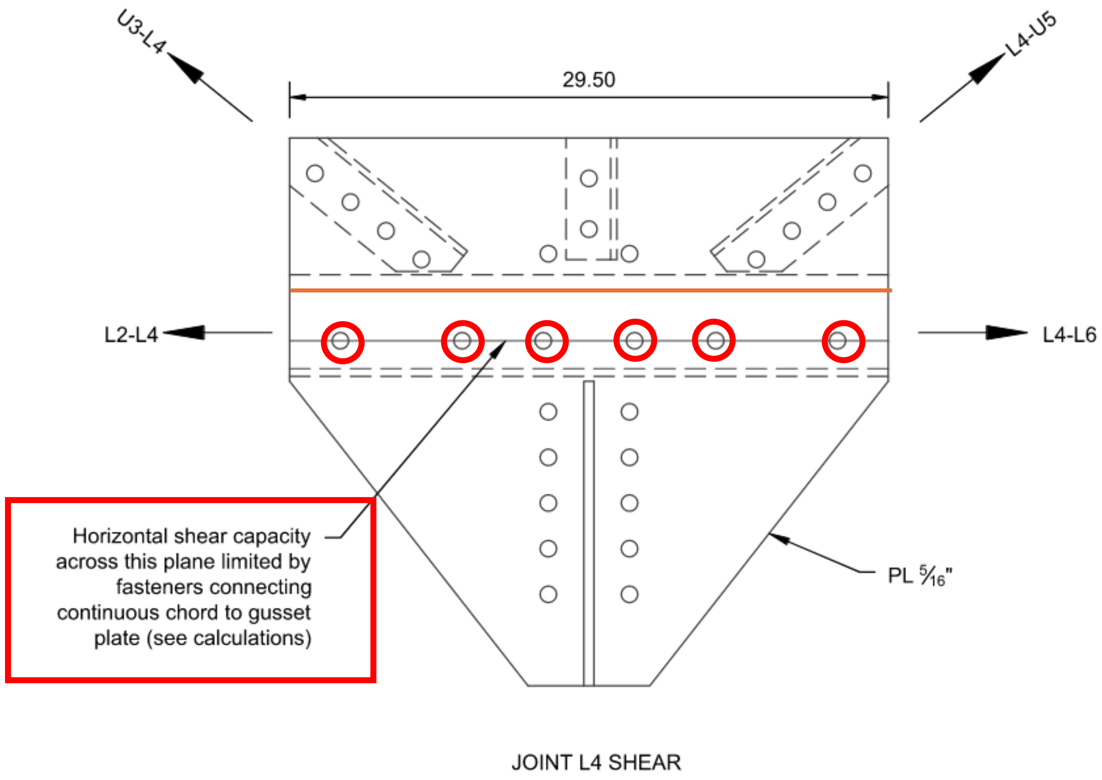
Fastener Capacity and Effect On Other Limit States

Limiting Fastener Resistance



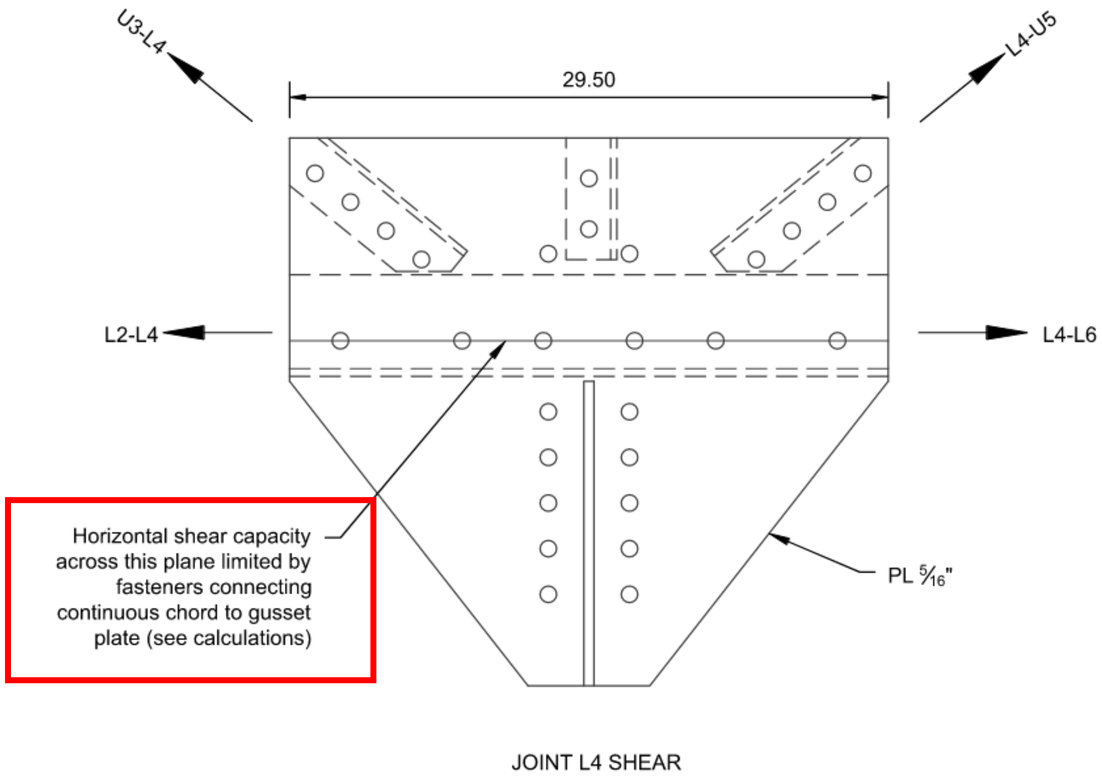
Horizontal Shear at Gusset Plate L4

Limiting Fastener Resistance



- Bottom chord continuous
- Check horizontal shear
  - Only 6 fasteners provided for chord connection.
  - Horizontal shear capacity limited by fastener strength.

Limiting Fastener Resistance



$V_y := 1.00\cdot(0.58)\cdot F_y\cdot A_g\cdot\Omega = 141.2\cdot kip$ — Shear yield strength

$V_r := 0.85\cdot(0.58)\cdot F_u\cdot A_n = 227.6\cdot kip$ — Shear rupture strength

$6\cdot\phi R_{bolt} = 33.1\cdot kip$ — Capacity of 6 bolts connecting continuous chord to gusset plate, significantly lower than gusset plate shear strength.

$$L_{eff} := \frac{6\cdot\phi R_{bolt}}{1.00\cdot(0.58)\cdot F_y\cdot\left(\frac{5}{16}in\right)\cdot\Omega} = 6.92\cdot in$$

Effective shear length to input for horizontal shear in BrR to reflect fastener shear capacity. Since shear yield controls, input 0 holes.

$$V_{y\_eff} := 1.00\cdot(0.58)\cdot F_y\cdot\left(\frac{5}{16}in\right)\cdot L_{eff}\cdot\Omega = 33.1\cdot kip$$

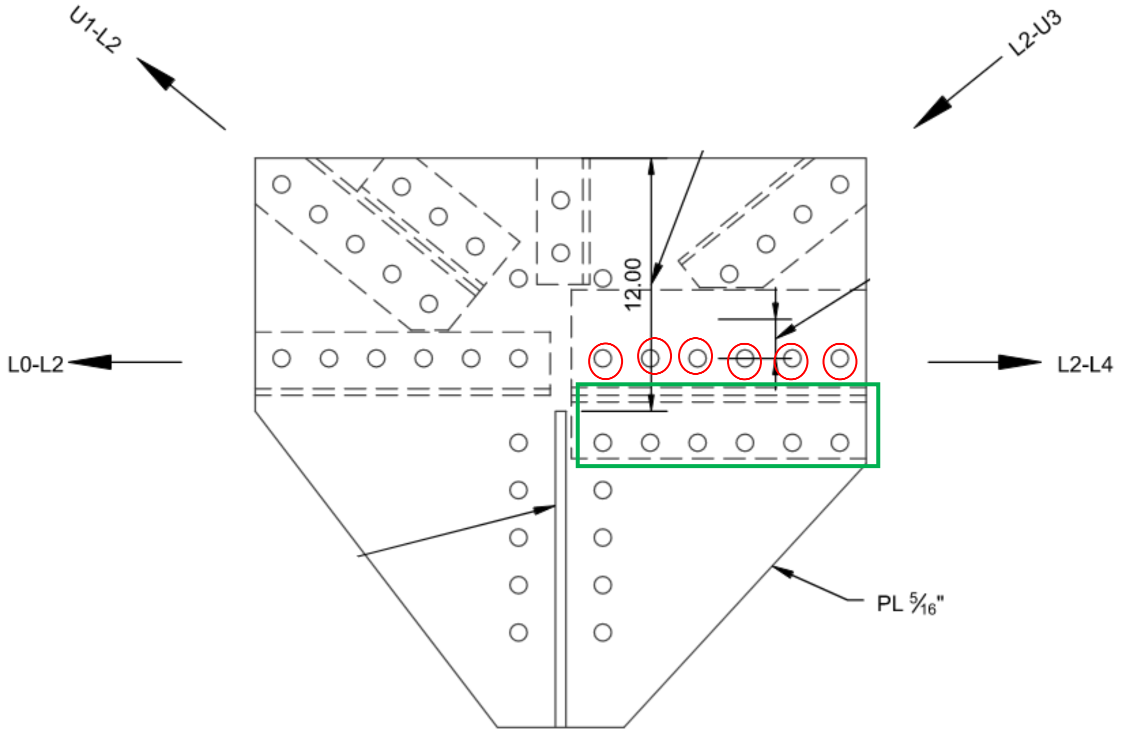
Shear yield strength of one gusset plate in BrR, reflecting capacity limited by fasteners.

Always limited by the load transferred by the fasteners.

Extra Fasteners

Fastener Strength at Gusset Plate L2

Extra Fasteners



JOINT L2 CHORD SPLICE

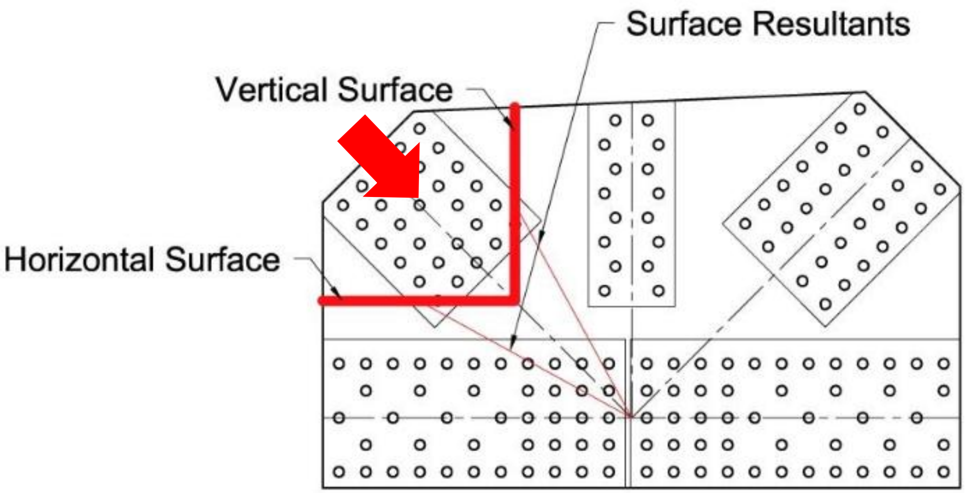
Check Fastener Strength:

- L2-L4 vertical leg connected to GP with 6 fasteners, which may be insufficient for fastener shear…
- L2-L4 horizontal leg connected to angle.
- Check if connection angle can develop extra fasteners to resist force in L2-L4. Fastener rating factors increase.

Other Considerations

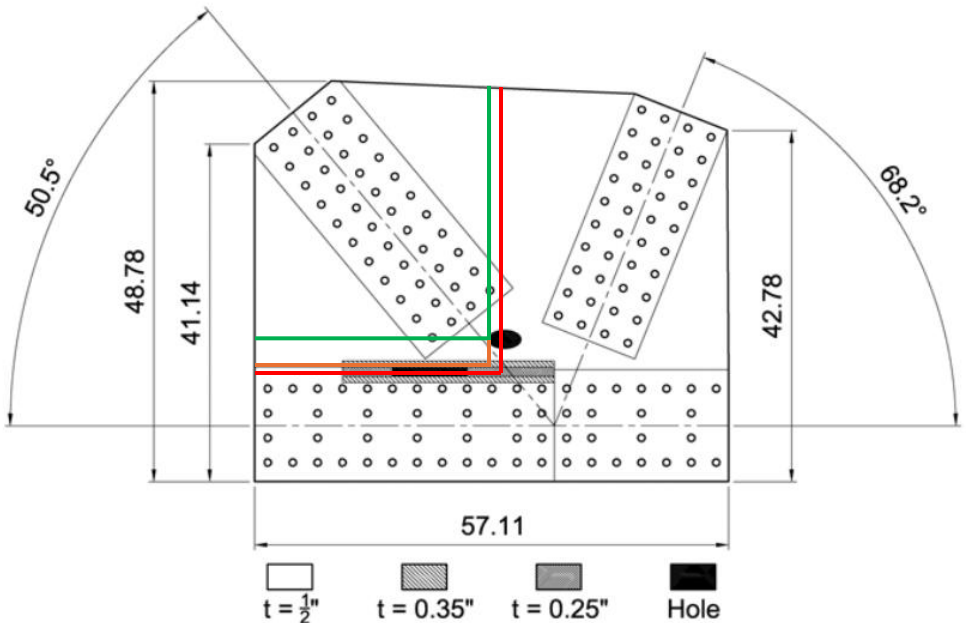
Other Considerations: Corner Checks with Deterioration

- Corner Check: Evaluation of combined shear and normal stresses on a “Corner” section of gusset plates resisting compression in web members.
- *IDOT Gusset Plate Evaluation Guide* (2014)
- Anticipated to be incorporated into the 4th Edition of the *Manual for Bridge Evaluation*.
- Basic Corner Check (BCC) incorporated into version 7.7 of AASHTOWare BrDR.



Other Considerations: Corner Checks with Deterioration

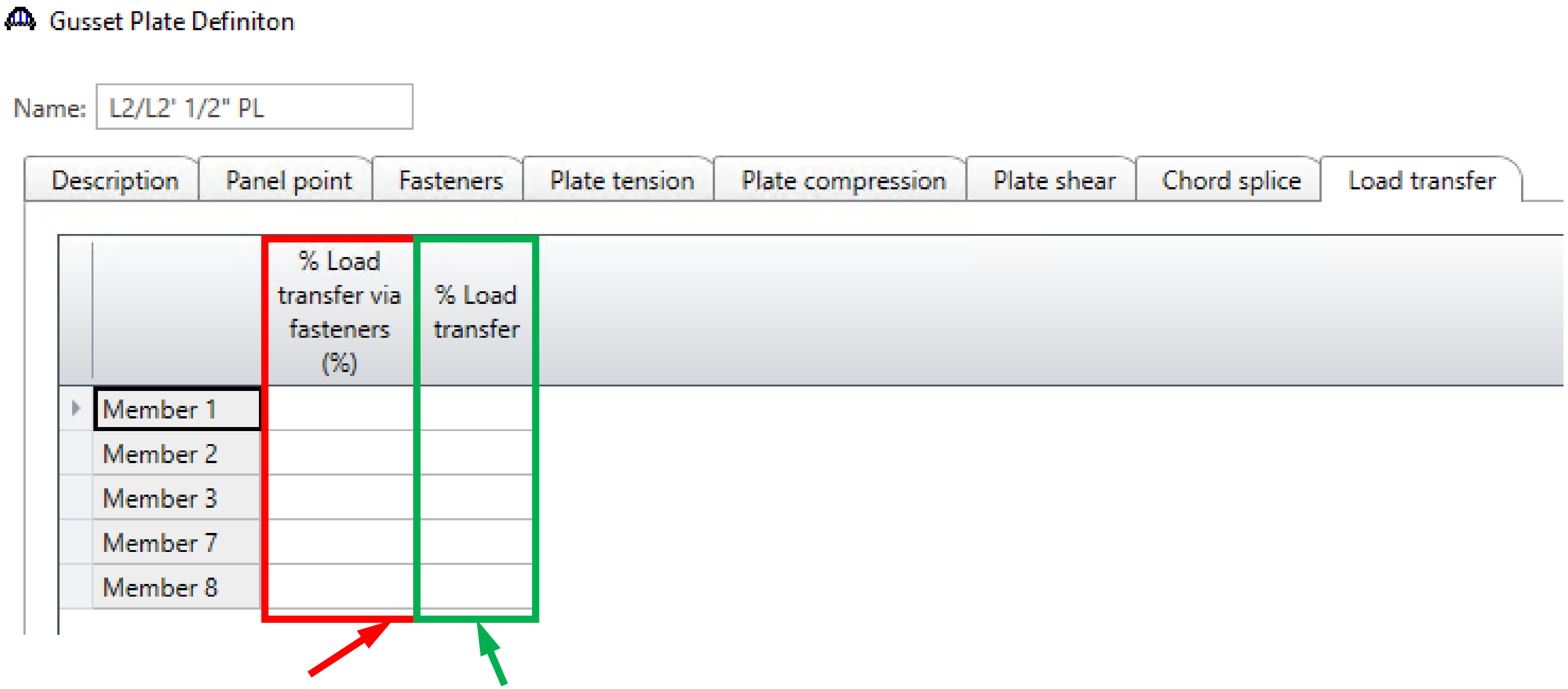
- For GPs **without** deterioration, the controlling corner section typically intersects the corner fasteners of the web member being checked.
- For GPs **with** deterioration, the controlling corner section depends on the profile and magnitude of the deterioration.
- Multiple corner sections may need to be checked to determine the controlling corner section capacity.



Other Considerations: Compression Chord Splices

- Milled Ends at Compression Chord Splices
  - Reduce compression chord splice loads for ends that are milled to bear.
  - Faces must be in full contact.
  - Check chord splice resistance, P_{rcs}, against 50% of factored load, P_u, or 50% of factored strength, φP_n (LRFD 6.13.6.1.2 and LRFD 6.14.2.8.6).
  - Hand-calculate bearing resistance, $P_{br} = 1.4A_{pn}F_y$ (LRFD 6.10.11.2.3).
  - Check $P_{br} > [\, P_u - \min(\frac{1}{2}P_u \;, \frac{1}{2} fP_n)\,]$
  - Bearing checks must be made outside of BrDR.
  - Could use load transfer tab in BrDR to evaluate chord splice for reduced loads.

Other Considerations: Compression Chord Splices



Percent of Member Load used to check fastener shear/bearing.

- **Default = 100%**

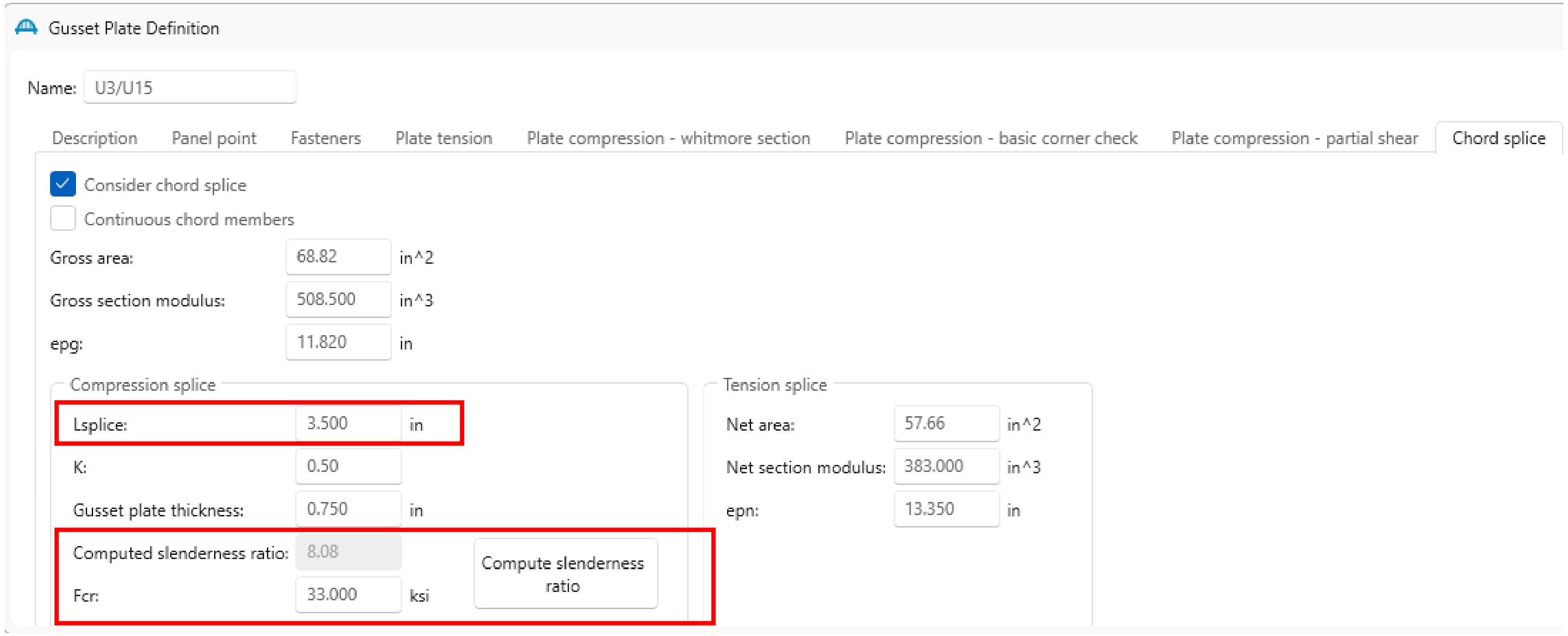
Percent of Member Load used to check Whitmore, Block Shear, Partial Shear, Horizontal/Vertical Shear, and Chord Splices.

- **Default = 100%**

Other Considerations: Compression Chord Splices

- Critical buckling stress in spliced section, F_{cr}.

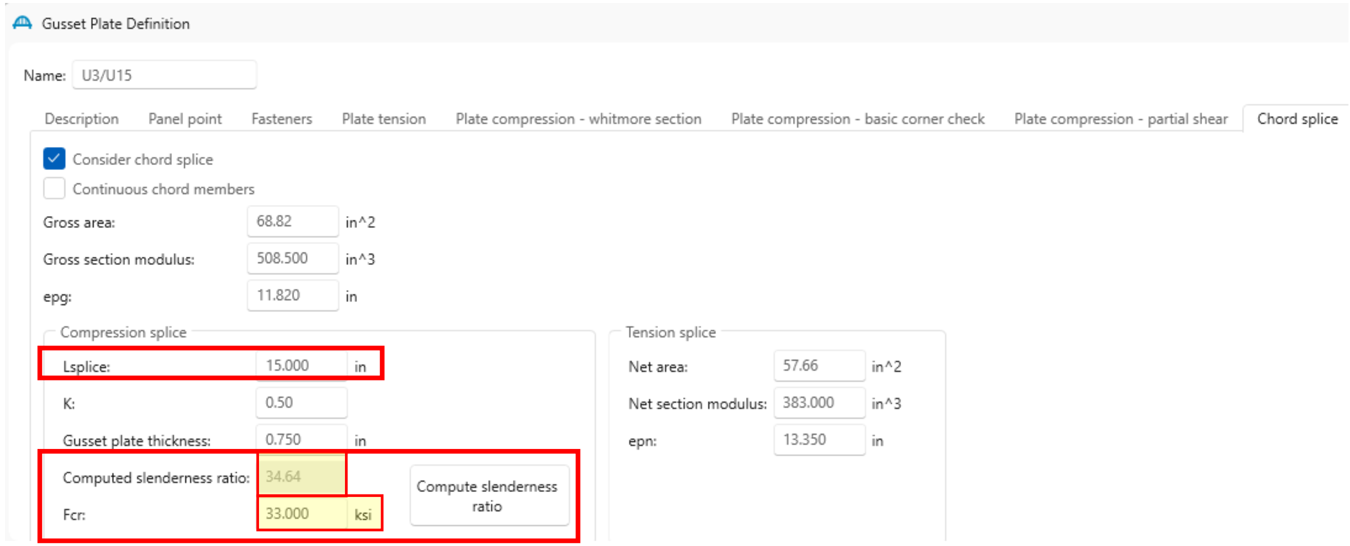
$$\boxed{\frac{KL_{\text{splice}}\sqrt{12}}{t_g} < 25}$$



Other Considerations: Compression Chord Splices

- Critical buckling stress in spliced section, F_{cr}.

$$\boxed{\cancel{\frac{KL_{\text{splice}}\sqrt{12}}{t_g} < 25}}$$



Other Considerations: Compression Chord Splices

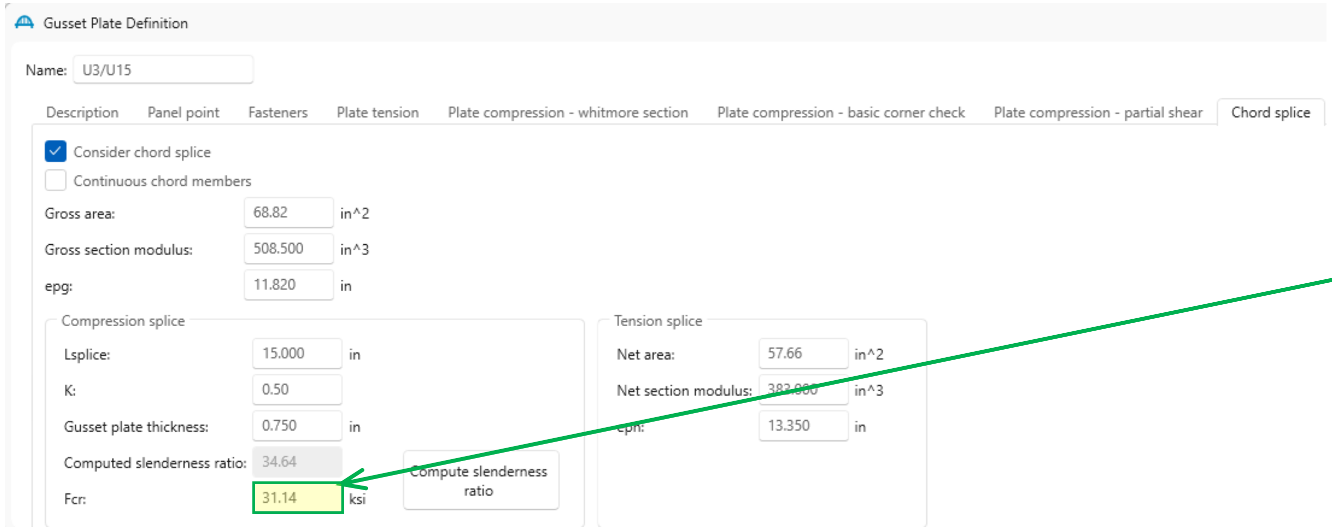
- Critical buckling stress in spliced section, F_{cr}.

$$\cancel{\boxed{\frac{KL_{splice}\sqrt{12}}{t_g} < 25}}$$

MBE Commentary:

"If not, the Engineer will need to derive a reduced value of F_{cr} to account for possible elastic buckling of the gusset plate within the splice."

Elastic Flexural Buckling ***Compression Resistance***



Calculate F_{cr}:

$r_s = t_g/\sqrt{(12)} = 0.217$ in

$KL_{splice} / r_s = 34.64$

$F_e = \pi^2 E / (34.64)^2 = 238.5$ ksi

$F_o = F_y = 33$ksi

$F_o / F_e = 0.138 < 2.25$

$$\boxed{\begin{aligned} F_{cr} &= [0.658^{0.138}] * 33\text{ksi} \\ &= 31.14\text{ksi} \end{aligned}}$$

QUESTIONS?