



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.

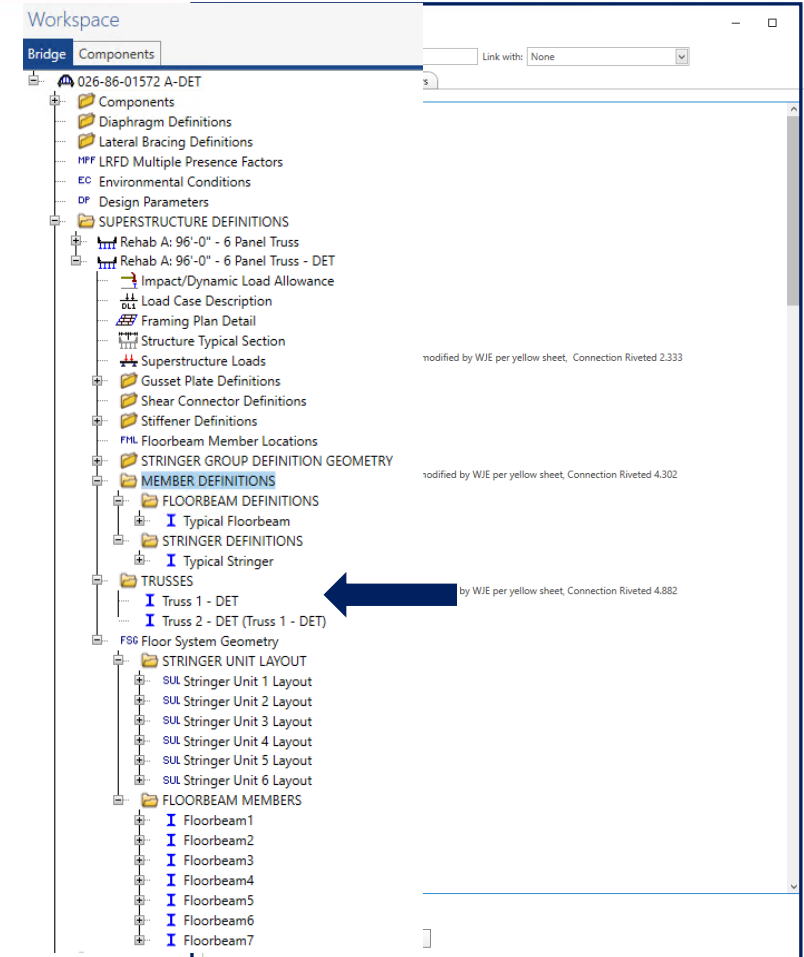


Overview of Truss and Gusset Plate Model Structure in BrDR

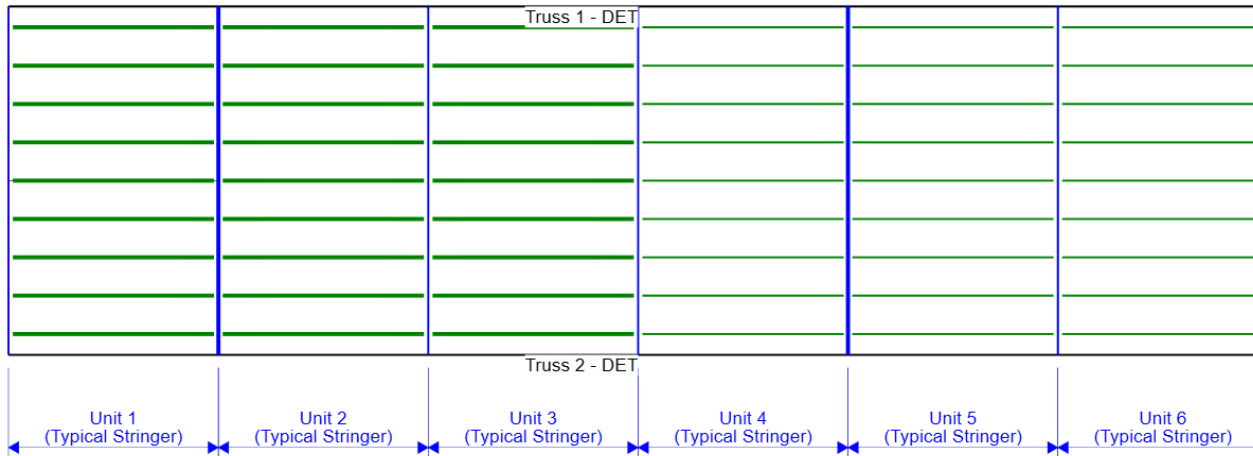
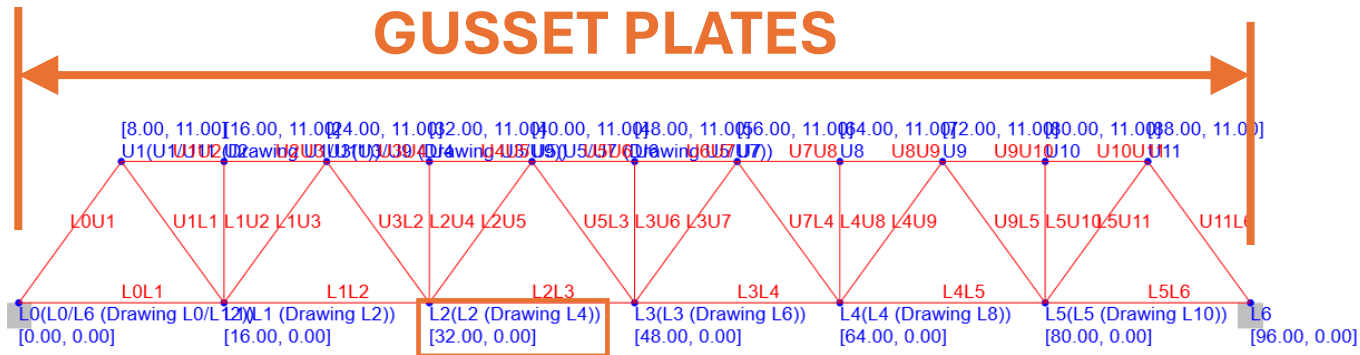
TRUSS MEMBERS

Diagram illustrating a truss structure with 12 joints (U0 to U11) and 16 members (L0 to L6). The joints are located at the top (U) and bottom (L) of the truss. The members are labeled L0 to L6 and U0 to U11. The diagram shows a series of triangles forming a truss. The joints are located at the top (U) and bottom (L) of the triangles. The members are the lines connecting the joints. The diagram is titled 'TRUSS MEMBERS'.

Member	Joint 1	Joint 2	Length (m)	Angle (°)
L0	U0	L0	8.00	45
L1	U1	L1	8.00	45
L2	U2	L2	8.00	45
L3	U3	L3	8.00	45
L4	U4	L4	8.00	45
L5	U5	L5	8.00	45
L6	U6	L6	8.00	45
U0	U0	U1	16.00	0
U1	U1	U2	16.00	0
U2	U2	U3	16.00	0
U3	U3	U4	16.00	0
U4	U4	U5	16.00	0
U5	U5	U6	16.00	0
U6	U6	U7	16.00	0
U7	U7	U8	16.00	0
U8	U8	U9	16.00	0
U9	U9	U10	16.00	0
U10	U10	U11	16.00	0
U11	U11	U12	16.00	0



Model Overview: Gusset Plates



Workspace

Bridge Components

- 026-86-01572 A-DET
 - Components
 - Diaphragm Definitions
 - Lateral Bracing Definition
 - LRFD Multiple Presence
 - Environmental Condition
 - Design Parameters
 - SUPERSTRUCTURE DEFINITION
 - Rehab A: 96'-0" - 6 Panel Truss - DET
 - Impact/Dynamic Load Allowance
 - Load Case Description
 - Framing Plan Detail
 - Structure Typical Section
 - Superstructure Loads
 - Gusset Plate Definitions
 - L1 (Drawing L2)
 - L2 (Drawing L4)**
 - L3 (Drawing L6)
 - L0/L6 (Drawing L0/L12)
 - U1/U11 (Drawing U1/U11)
 - U3/U9 (Drawing U3/U9)
 - U5/U7 (Drawing U5/U7)
 - L4 (Drawing L8)
 - L5 (Drawing L10)

Rehab A: 96'-0" - 6 Panel Truss - DET

Impact/Dynamic Load Allowance

Load Case Description

Framing Plan Detail

Structure Typical Section

Superstructure Loads

Gusset Plate Definitions

L1 (Drawing L2)

L2 (Drawing L4)

L3 (Drawing L6)

L0/L6 (Drawing L0/L12)

U1/U11 (Drawing U1/U11)

U3/U9 (Drawing U3/U9)

U5/U7 (Drawing U5/U7)

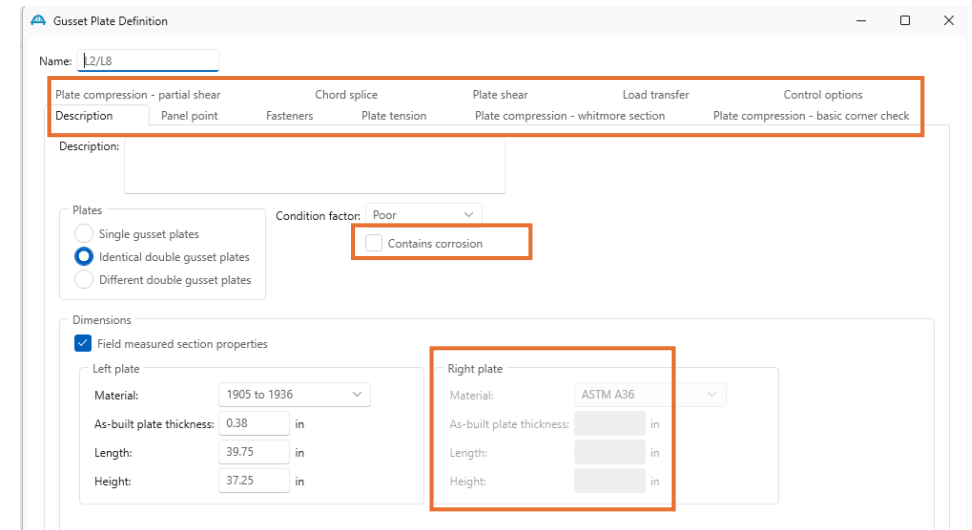
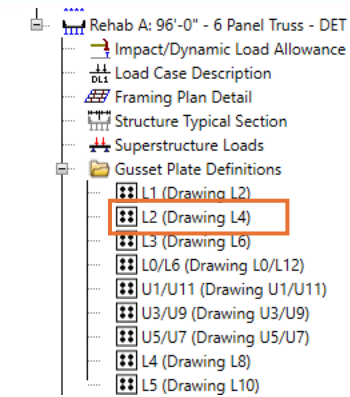
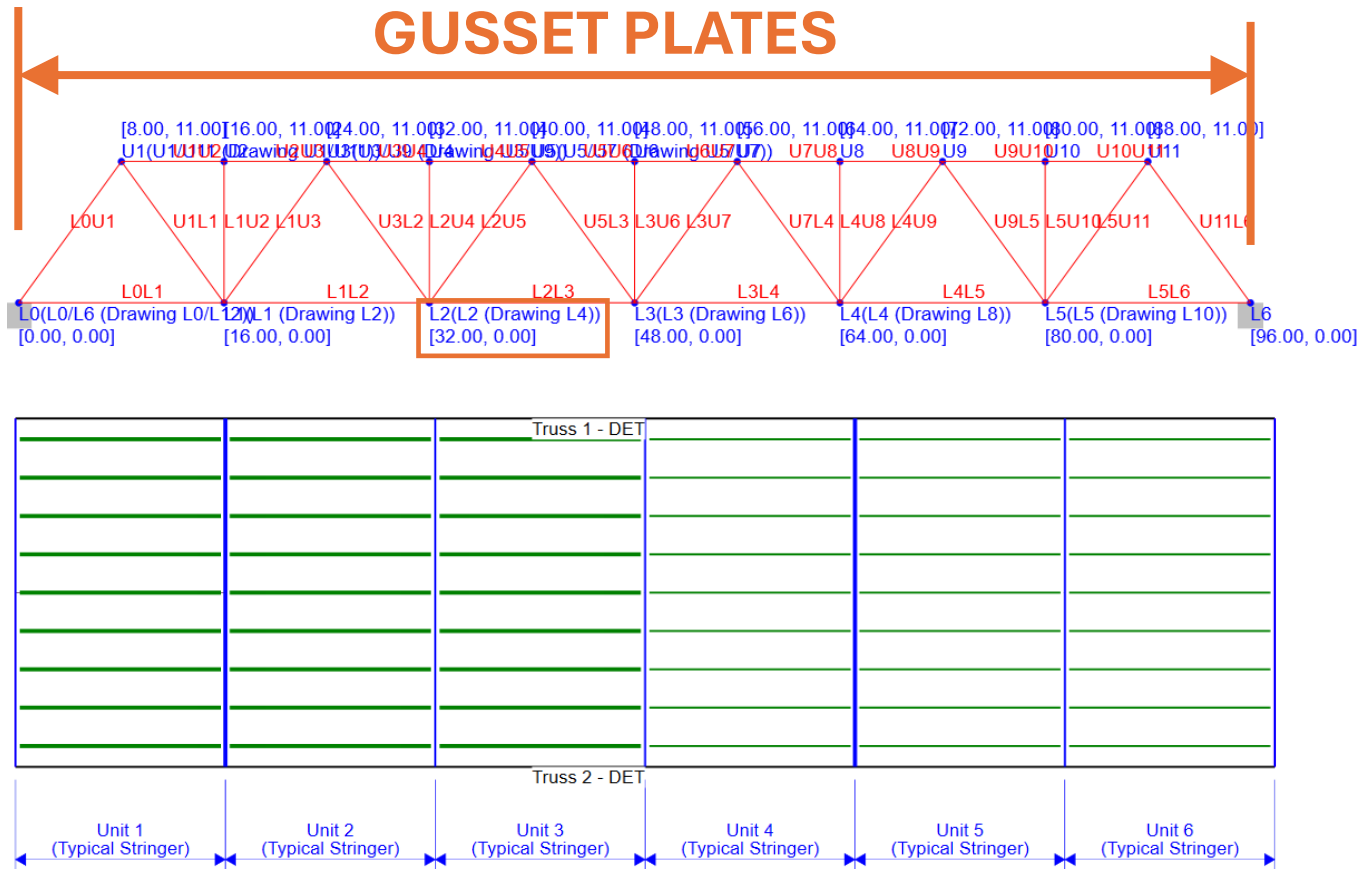
L4 (Drawing L8)

L5 (Drawing L10)

Description Gusset plates Specs Factors

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

Gusset Plate Definition

Name: L2/L8

Plate compression - partial shear | Chord splice | **Plate shear** | Load transfer | Control options

Description: [Empty text box]

Plates: ☐ Single gusset plates ☒ Identical double gusset plates ☐ Different double gusset plates

Condition factor: Poor ☐ Contains corrosion

Dimensions: ☒ Field measured section properties

Left plate

Material: 1905 to 1936

As-built plate thickness: 0.38 in

Length: 39.75 in

Height: 37.25 in

Right plate

Material: ASTM A36

As-built plate thickness: [Empty] in

Length: [Empty] in

Height: [Empty] in

Gusset Plate Definition

Name: L2/L8

Description: Plate compression - partial shear | Panel point | Fasteners | Plate tension | **Plate shear** | Plate compression - whitmore section | Load transfer | Plate compression - basic corner check | Control options

Shear reduction factor: 0.88

Left plate

Shear plane	Length (in)	Thickness (in)	Number holes	Hole diameter (in)	Override angle	Override angle (Degrees)	Override member selection	Member Selection							
								1	2	3	4	5	6	7	8
> Vertical	37.25		12.00	0.94	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐
Horizontal	39.75		5.00	0.94	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐

Right plate

☒ Same as left plate

Shear plane	Length (in)	Thickness (in)	Number holes	Hole diameter (in)	Override angle	Override angle (Degrees)	Override member selection	Member Selection							
								1	2	3	4	5	6	7	8
> Vertical					☐		☐	☐	☐	☐	☐	☐	☐	☐	☐
Horizontal					☐		☐	☐	☐	☐	☐	☐	☐	☐	☐



Load Distribution between Gusset Plates

Load Distribution

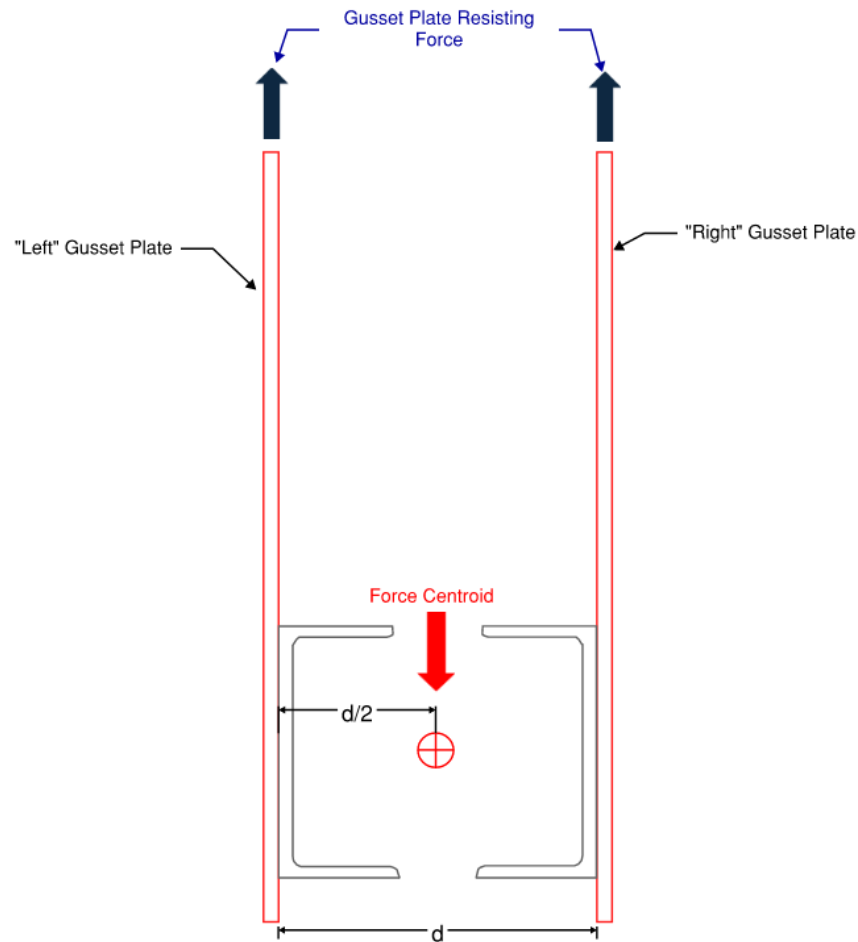


Common practice to sum plate capacities for connection resistance, which is reasonable when plate capacities are similar (BrDR).

- **BUT....**

- Deterioration profiles are rarely the same on any plate at a shared joint.
- Connection plates oftentimes are asymmetric.

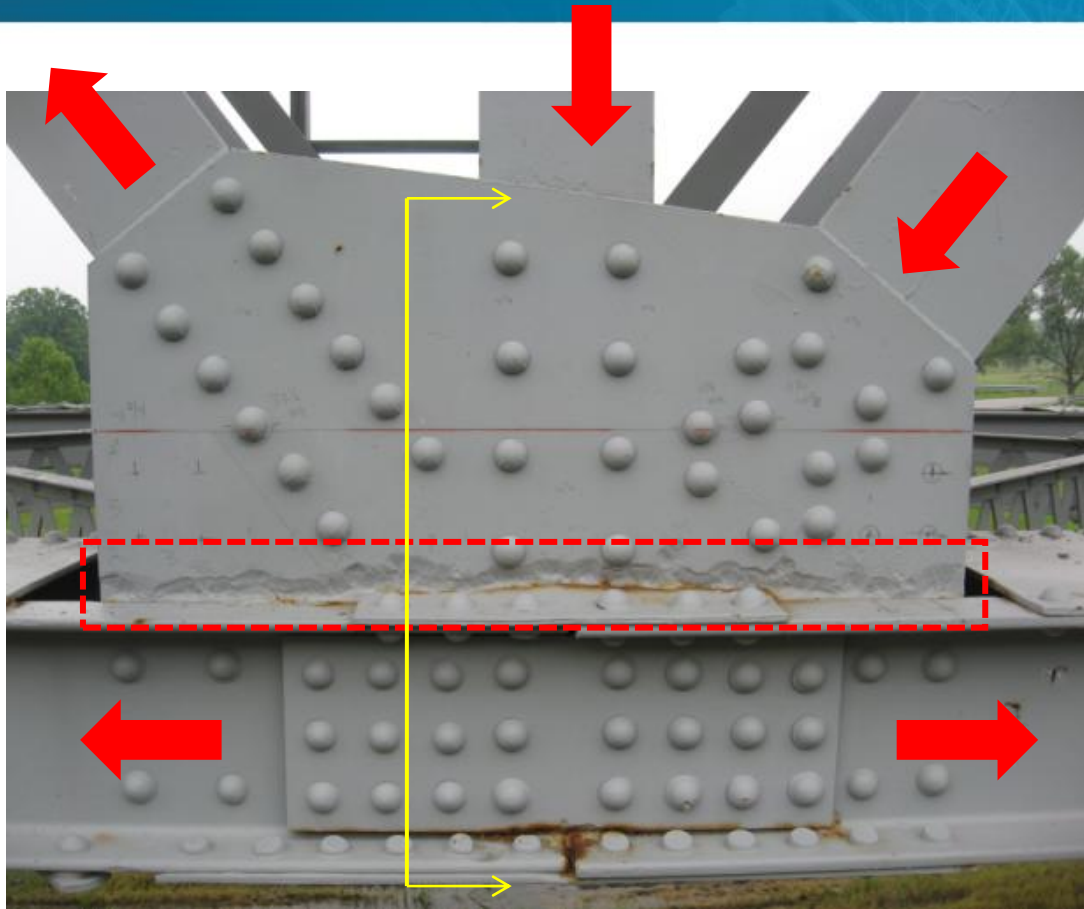
Load Distribution



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

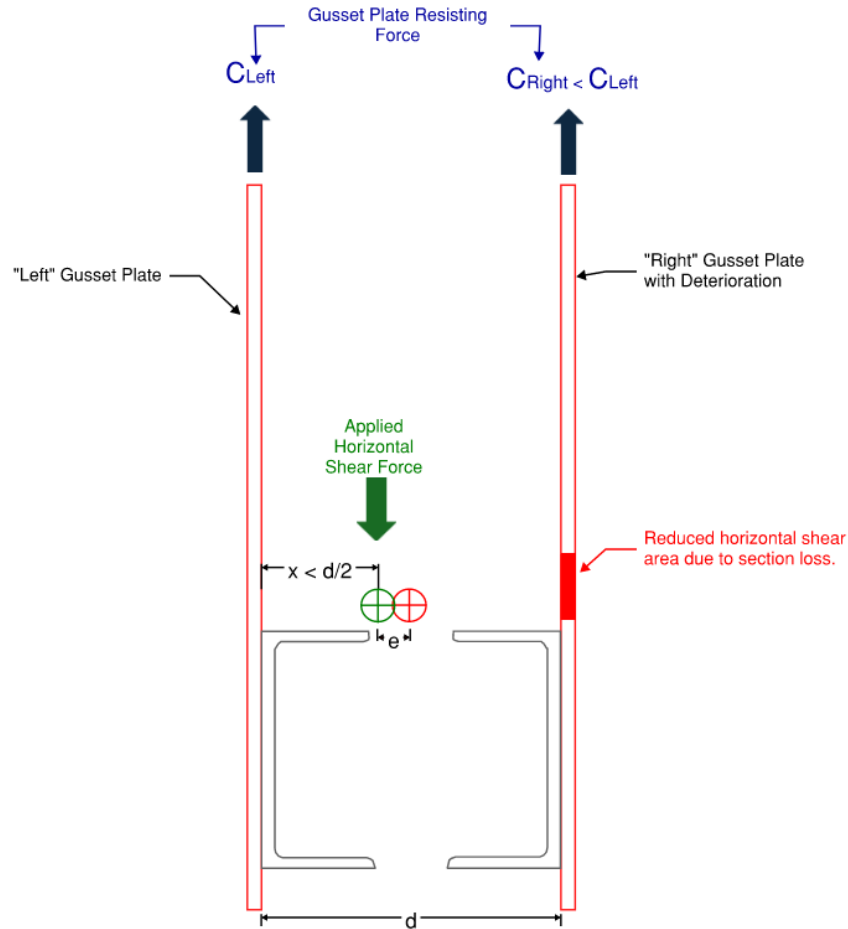
- Member forces are resolved near the midpoint between the gusset plates.
- No moment introduced into the connection.
- $C_{PP} = C_{Left} + C_{Right}$ is reasonable.

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:

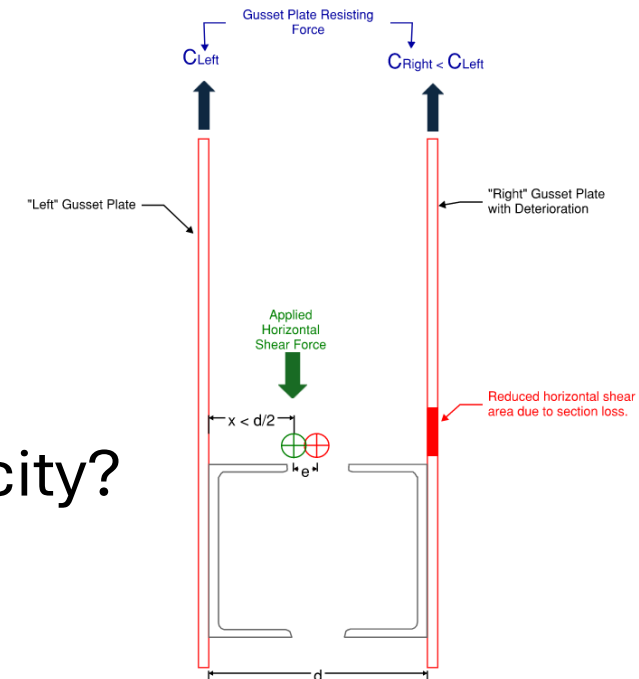
- Member forces are no longer resolved at the midpoint of the gusset plates.
- A portion of the member forces will redistribute from the weaker gusset plate to the stronger gusset plate.
- $C_{PP} = C_{Left} + C_{Right}$ **may be** reasonable depending on the magnitude of disparity between C_{Left} and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

Load Distribution

- For ductile materials such as steel, loads will re-distribute; however...
- As C_{Left} or $C_{\text{Right}} \rightarrow 0$, 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

Name: L100E DET

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

Shear reduction factor: 0.88

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

Heavy section loss on left plate.

Right plate

☐ Same as 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	0.50	17.00	0.94

Full thickness remains on right plate.

Horizontal Shear Resistance:

Gusset Plate Left:

Avg: 12.303 (in²)

Resistance:

$C_{Yield} = \Phi V_Y * 0.58 * F_y * A_{vg} * \Omega$

$C_{YieldLeft} = 282.564$ (kip)

Avn: 9.274 (in²)

Resistance:

$C_{Rupture} = \Phi V_U * 0.58 * F_u * A_{vn}$

$C_{RuptureLeft} = 320.059$ (kip)

Gusset Plate Right:

Avg: 32.375 (in²)

Resistance:

$C_{Yield} = \Phi V_Y * 0.58 * F_y * A_{vg} * \Omega$

$C_{YieldRight} = 743.589$ (kip)

Avn: 24.406 (in²)

Resistance:

$C_{Rupture} = \Phi V_U * 0.58 * F_u * A_{vn}$

$C_{RuptureRight} = 842.260$ (kip)

Individual capacities summed for typical rating:

Total Resistance (Horizontal):

$C_{Yield} = 1026.153$ (kip)

$C_{Rupture} = 1162.319$ (kip)

C: 1026.153 (kip)

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 --		RF	Capacity (Ton)
			A1	A2		
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

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

Horizontal Shear Resistance:

Gusset Plate Left:

Avg: 12.303 (in²)

Resistance:

$C_{Yield} = \Phi_t V_Y * 0.58 * F_y * Avg * \Omega$

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

LFR Rating Factor – Left Plate Only

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

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

...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 $\rightarrow \phi R_n (\text{BrR}) = \phi R_n (\text{Hand Calculations})$

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

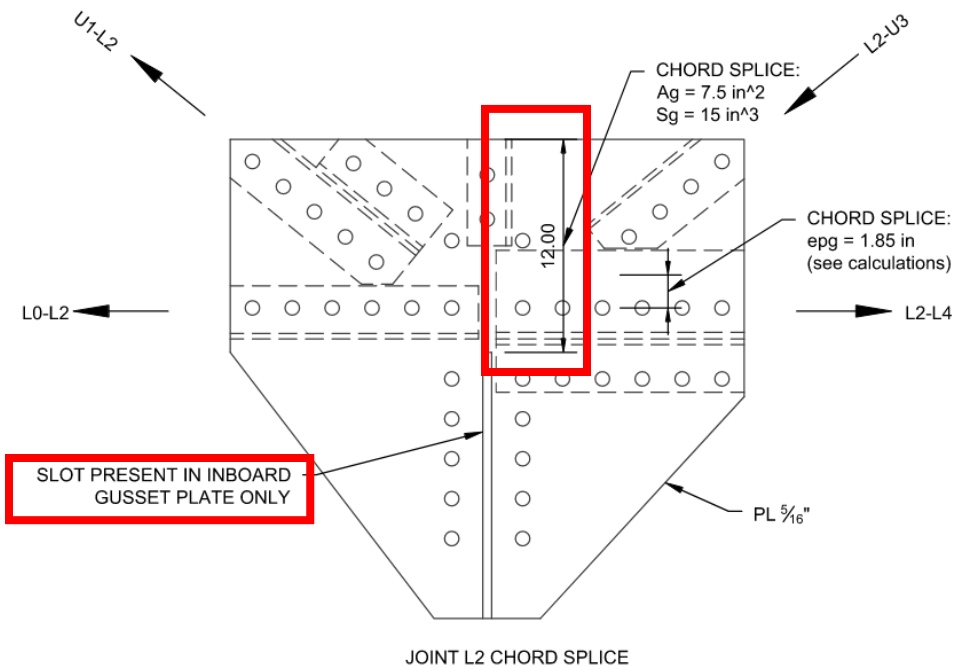


**Inside Plate Slotted
for Floor Beam**



Load Distribution: Modelling using BrDR, Option 2

- Chord Splice Evaluation



35% Load → Slotted Inside PL

65% Load → Outside PL

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

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

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

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

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

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

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

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:

- $A_g = 7.5 \text{ in}^2$
- $S_g = 15 \text{ in}^3$

Effective eccentricity

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

BrR Input

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

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

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).

BrR Spec Check

Gusset Plate Definition

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 in²

Gross section modulus: 15.000 in³

epg: 1.850 in

SUMMARY:

Yield Capacity $C = \phi_{cs} \cdot F_y \left[\frac{S_g \cdot A_g}{S_g + eA_g} \right]$

where
 $F_y = \min(F_{y_Left}, F_{y_Right})$

Fracture Capacity $C = \phi_{cs} \cdot F_u \left[\frac{S_n \cdot A_n}{S_n + eA_n} \right]$

where
 $F_u = \min(F_{u_Left}, F_{u_Right})$

Tensile Yield: 116.88 (kip)

Tensile Fracture: 116.13 (kip)

Tensile Resistance = Min(Yield, Fracture) = 116.13 (kip)



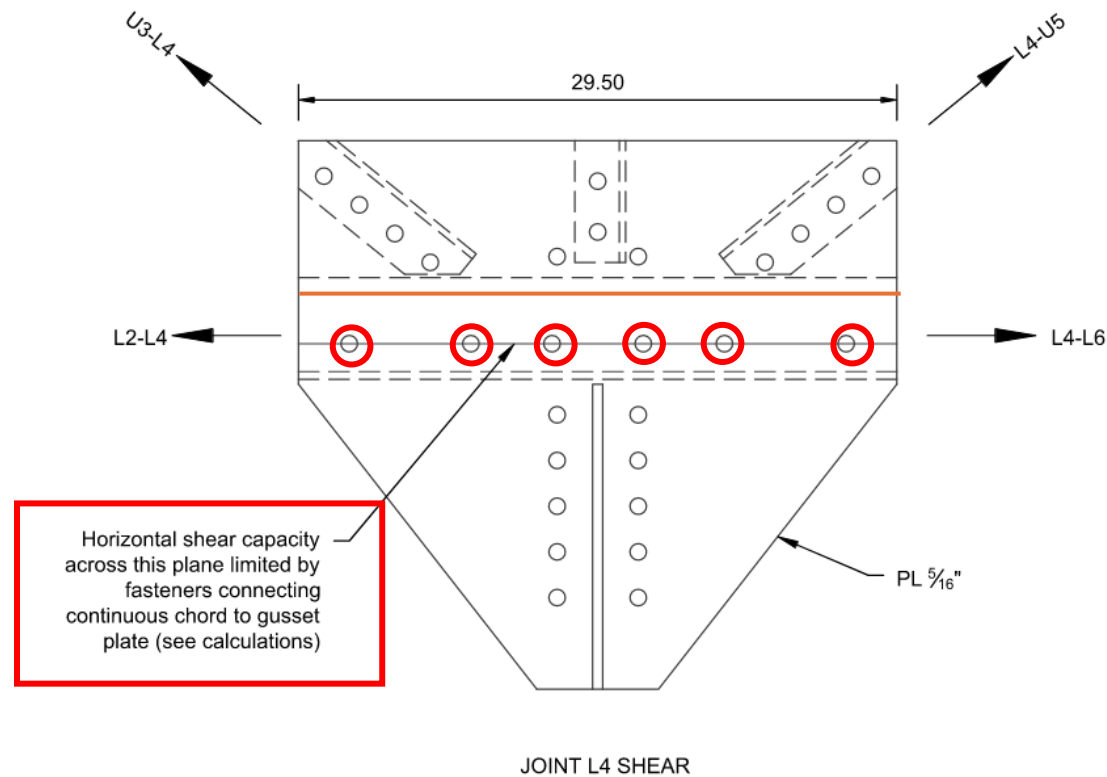
Fastener Capacity and Effect On Other Limit States

Limiting Fastener Resistance



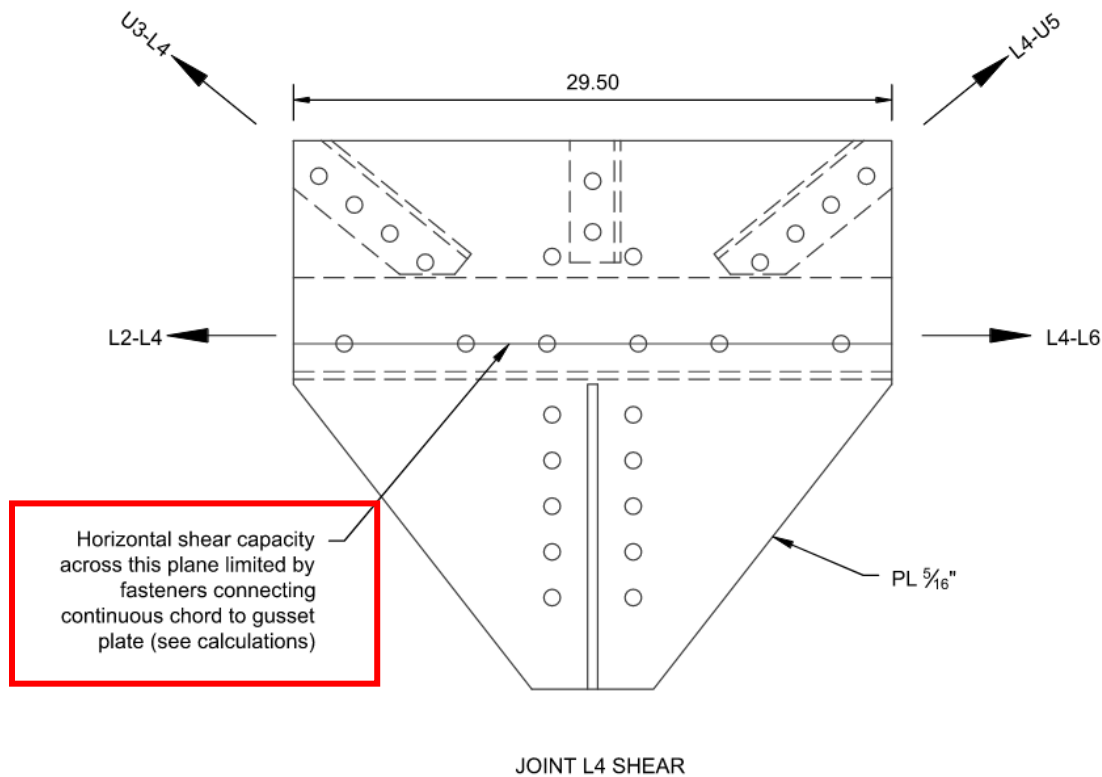
**Horizontal Shear at
Gusset Plate L4**

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



$$V_y := 1.00 \cdot (0.58) \cdot F_y \cdot A_g \cdot \Omega = 141.2 \cdot \text{kip}$$

Shear yield strength

$$V_r := 0.85 \cdot (0.58) \cdot F_u \cdot A_n = 227.6 \cdot \text{kip}$$

Shear rupture strength

$$6 \cdot \phi R_{\text{bolt}} = 33.1 \cdot \text{kip}$$

Capacity of 6 bolts connecting continuous chord to gusset plate, significantly lower than gusset plate shear strength.

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

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

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

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

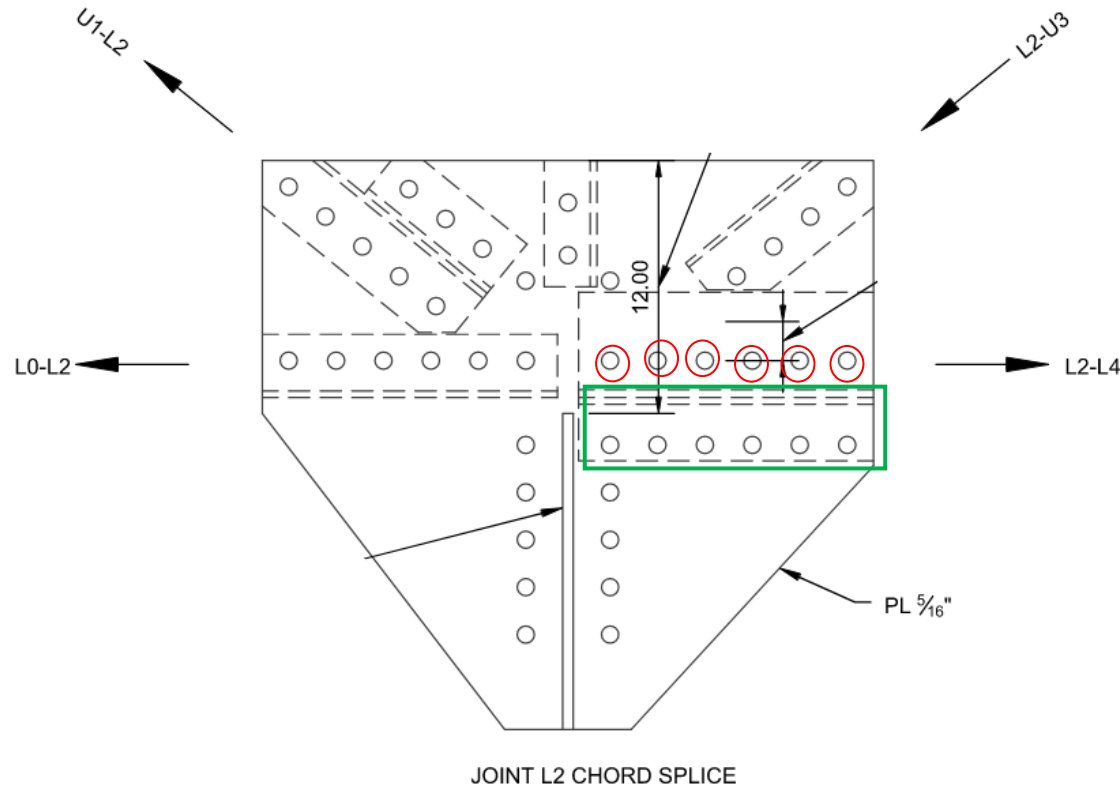
Always limited by the load transferred by the fasteners.

Extra Fasteners



**Fastener Strength at
Gusset Plate L2**

Extra Fasteners



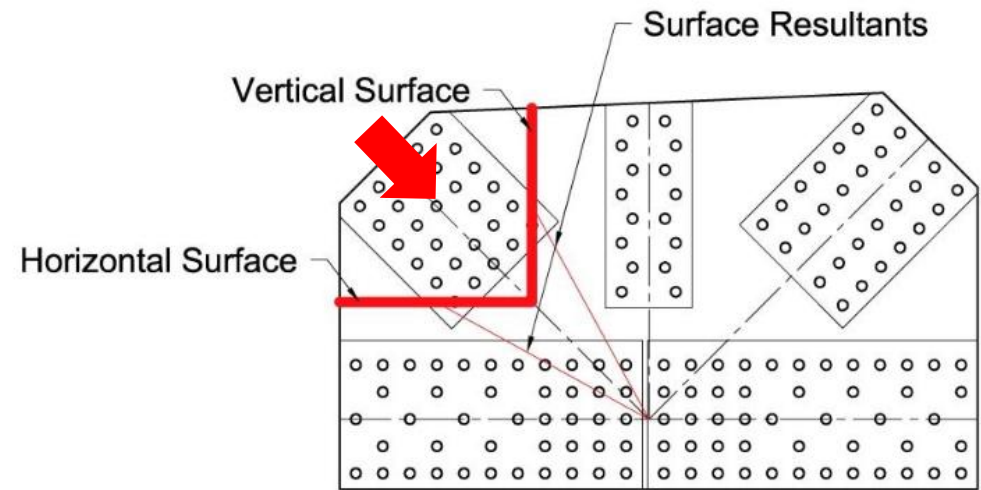
Check Fastener Strength:

- 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

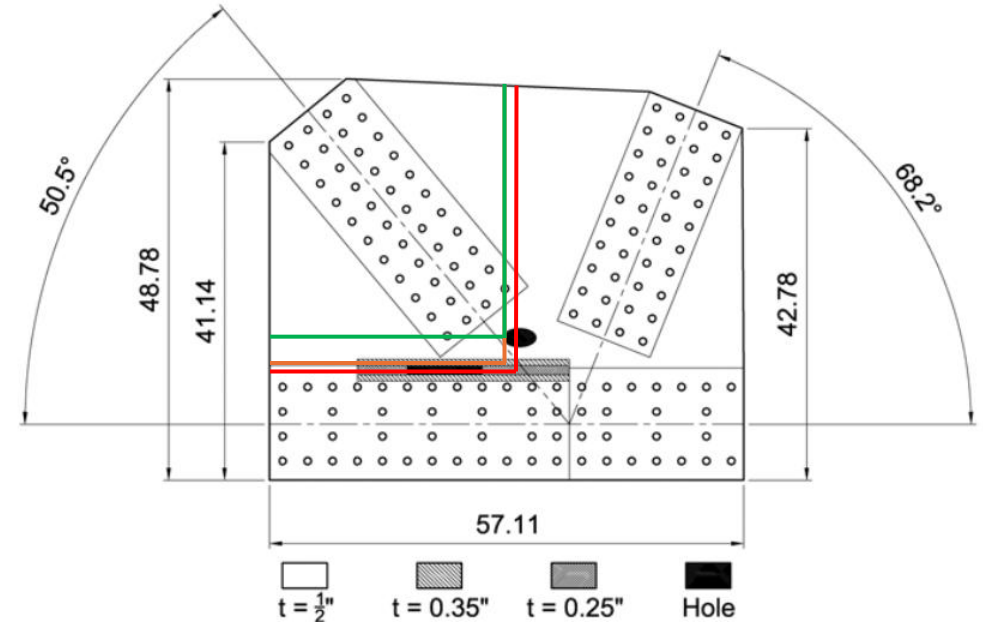
Other Considerations: Corner Checks with Deterioration

- 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 $P_{br} > [P_u - \min(\frac{1}{2}P_u , \frac{1}{2}\phi P_n)]$
 - 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

 Gusset Plate Definition

Name: L2/L2' 1/2" PL

Description	Panel point	Fasteners	Plate tension	Plate compression	Plate shear	Chord splice	Load transfer
		% Load transfer via fasteners (%)		% Load transfer			
Member 1							
Member 2							
Member 3							
Member 7							
Member 8							

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} .

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

Gusset Plate Definition

Name: U3/U15

Description Panel point Fasteners Plate tension Plate compression - whitmore section Plate compression - basic corner check Plate compression - partial shear Chord splice

☒ Consider chord splice
☐ Continuous chord members

Gross area: 68.82 in²
Gross section modulus: 508.500 in³
epg: 11.820 in

Compression splice

Lsplice: 3.500 in
K: 0.50
Gusset plate thickness: 0.750 in
Computed slenderness ratio: 8.08
Fcr: 33.000 ksi

Tension splice

Net area: 57.66 in²
Net section modulus: 383.000 in³
epn: 13.350 in

Compute slenderness ratio

Other Considerations: Compression Chord Splices

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

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

Gusset Plate Definition

Name: U3/U15

Description Panel point Fasteners Plate tension Plate compression - whitmore section Plate compression - basic corner check Plate compression - partial shear Chord splice

☒ Consider chord splice
☐ Continuous chord members

Gross area: 68.82 in²
Gross section modulus: 508.500 in³
epg: 11.820 in

Compression splice

Lsplice: 15.000 in

K: 0.50

Gusset plate thickness: 0.750 in

Computed slenderness ratio: 34.64

Fcr: 33.000 ksi

Compute slenderness ratio

Tension splice

Net area: 57.66 in²
Net section modulus: 383.000 in³
epn: 13.350 in

Other Considerations: Compression Chord Splices

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

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

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} :

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

$$KL_{splice} / r_s = 34.64$$

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

$$F_o = F_y = 33 \text{ ksi}$$

$$F_o / F_e = 0.138 < 2.25$$

$$F_{cr} = [0.658^{0.138}] * 33 \text{ ksi} \\ = 31.14 \text{ ksi}$$

Gusset Plate Definition

Name: U3/U15

Description Panel point Fasteners Plate tension Plate compression - whitmore section Plate compression - basic corner check Plate compression - partial shear Chord splice

☒ Consider chord splice
☐ Continuous chord members

Gross area: 68.82 in²
Gross section modulus: 508.500 in³
epg: 11.820 in

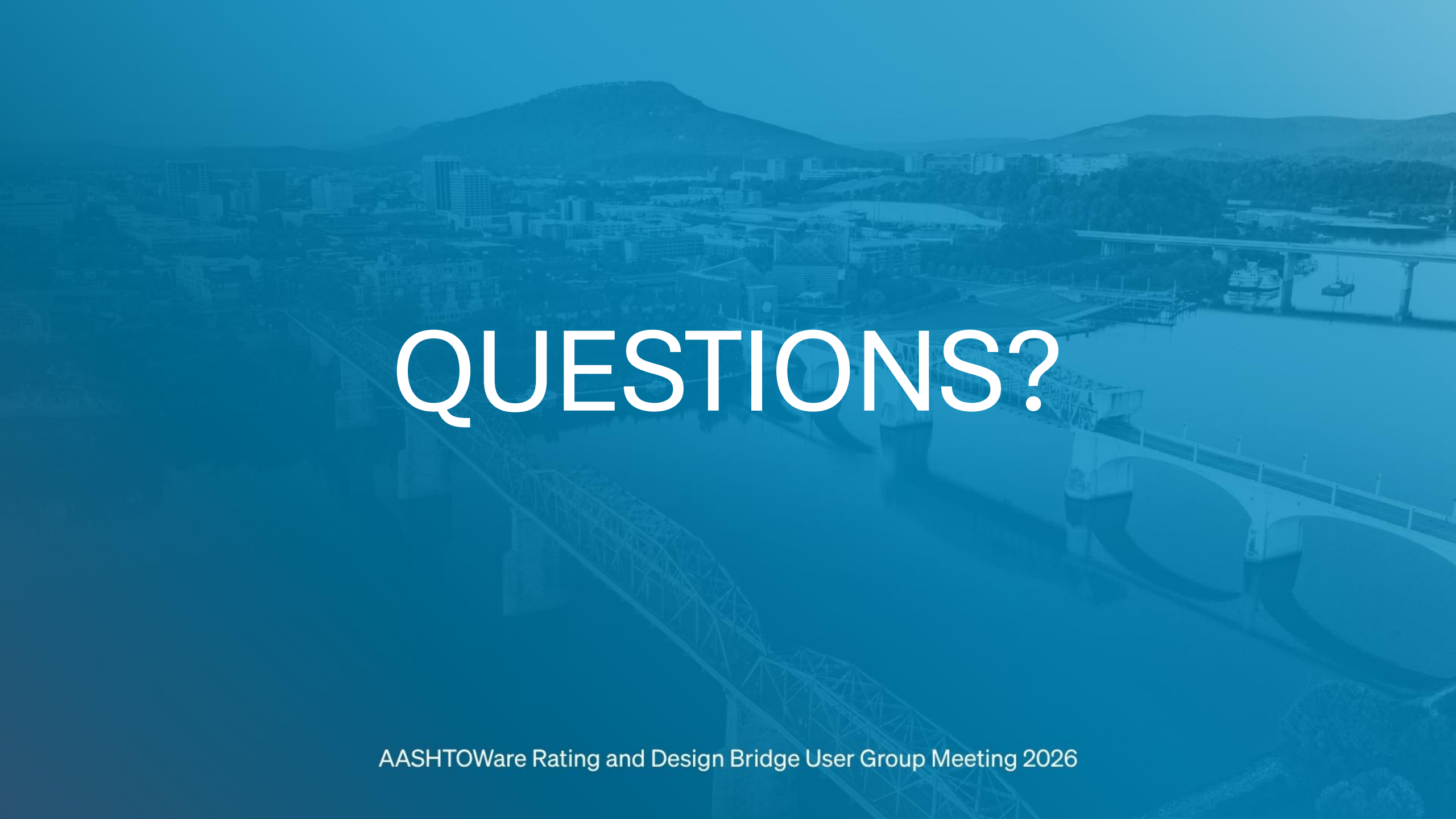
Compression splice

Lsplice: 15.000 in
K: 0.50
Gusset plate thickness: 0.750 in
Computed slenderness ratio: 34.64
Fcr: 31.14 ksi

Tension splice

Net area: 57.66 in²
Net section modulus: 382.860 in³
epn: 13.350 in

Compute slenderness ratio

An aerial photograph of a city, likely Pittsburgh, featuring a river with several bridges. A large mountain is visible in the background. The entire image is covered with a semi-transparent blue filter. The word "QUESTIONS?" is written in large, white, sans-serif capital letters across the center of the image.

QUESTIONS?

AASHTOWare Rating and Design Bridge User Group Meeting 2026