Evaluation of Gusset Plate Connections in Steel Truss Bridges

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Presentation Outline

- Introduction
- Motivation
- Scope
- Existing Methods
- Study Phases
  - Development of analytical mode for gusset plate joint
  - Approximate stress distributions at the critical sections on gusset plates
  - Procedure to combine and estimate equivalent stress
  - Application of calculating stresses on gusset plate connections
- Conclusions

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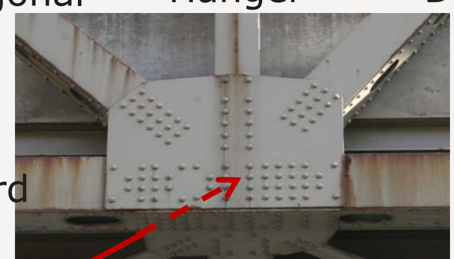
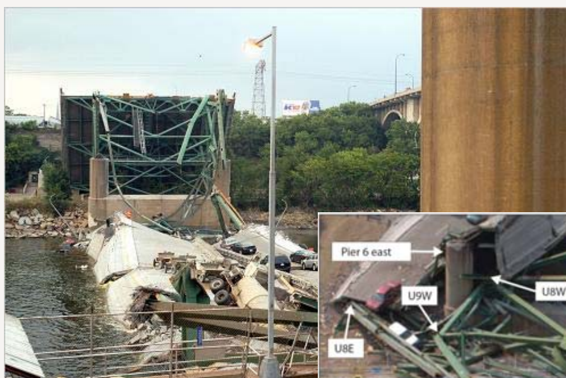
Introduction

- Gusset Plate typically connect diagonals, hanger, and chord in steel truss bridges
- Variety of geometric configurations and load distributions make simple analysis difficult
- The 2007 I-35W Bridge collapse necessitates load rating and prompt the research on gusset plate joints



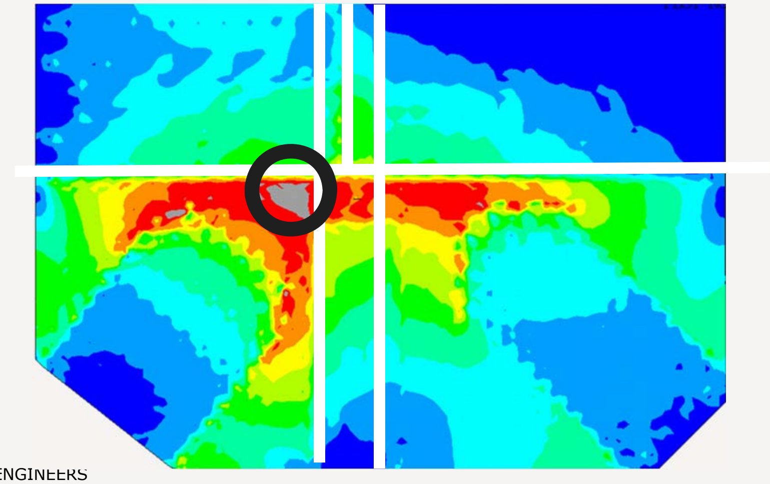
Motivation

- The I-35W Bridge collapsed on August 1st, 2007
- Gusset plates U10 and L11 were investigated, and it was found that they had half the required thickness
- Gusset plate U10 was overstressed and then buckled to cause joint failure



Presentation Scope

- Gusset Plate Elastic Stress Distribution
  - Approximation of stress distribution on the critical sections
  - Procedure to identify the maximum stress and location on gusset plate connection
  - Application of this approach



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Existing Methods

- Only simple approximation is available to estimate gusset plate stress or capacity
  - The Whitmore Method (maximum stress)
  - FHWA Guidance
  - Beam Theory (maximum principal stress)

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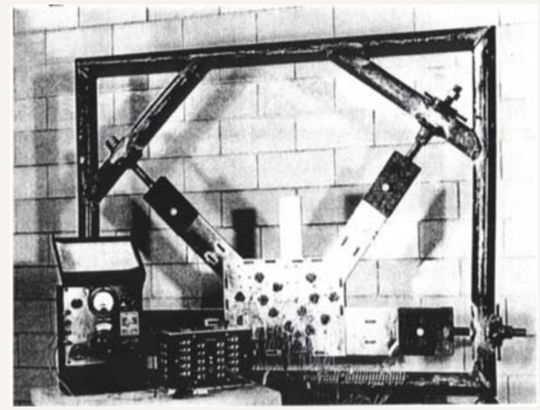
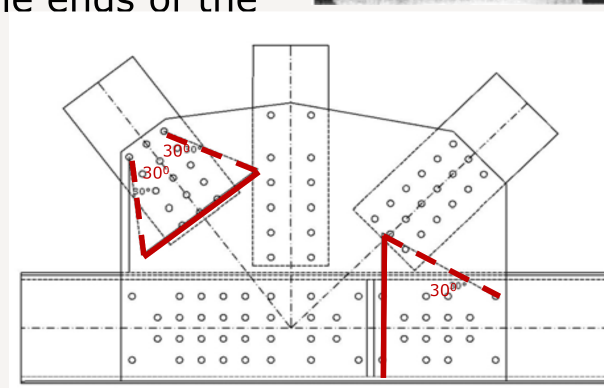
Literature Review for Elastic Stress

- Whitmore (1952)
  - Warren type gusset plate connection was tested
  - High strength aluminum
  - Hanger was neglected and **chord was continuous**
  - **Rectangular bars** were used as truss member
  - 30^0 dispersion angle
  - Maximum principal stresses located at the ends of the diagonals
  - Elastic behavior
- Application today (AASHTO, FHWA):
  - Gross section yield
  - Net section fracture





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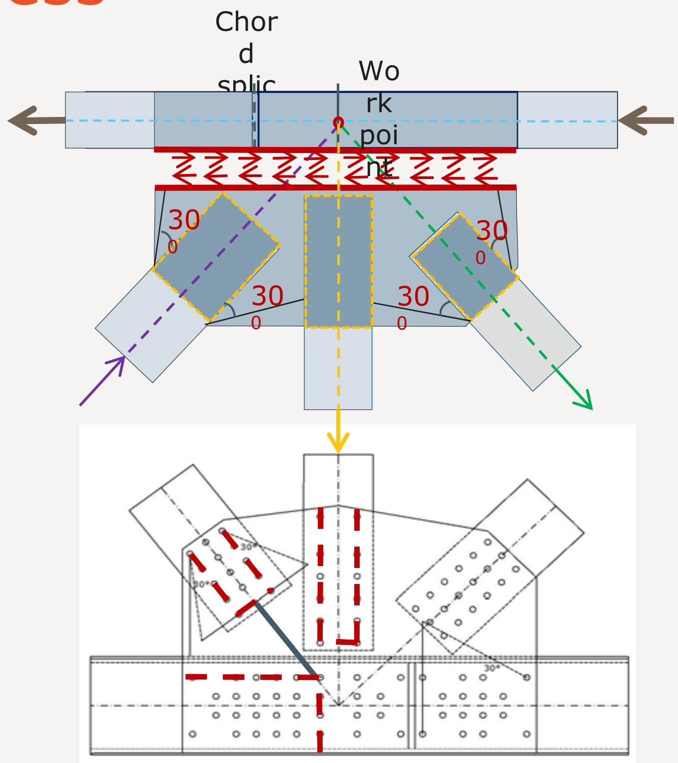
Literature Review for Elastic Stress

- **FHWA: Guidance and Examples for Bolted and Riveted Gusset Plate in Truss Bridge (2009) and AASHTO MBE (2011)**
  - Gusset plate shear resistance
    - Uniform stress Ω=1.0
    - Parabolic stress Ω=0.74
  - Tensile member
    - Block shear
    - Gross yielding, Net section fracture, and using Whitmore’s method



Literature Review for Elastic Stress

- Beam Theory (Section Method)

Stress along section

$$f_a = \frac{P}{A}$$

$$f_b = \frac{M}{S}$$

$$f_{vave} = \frac{V}{A}$$

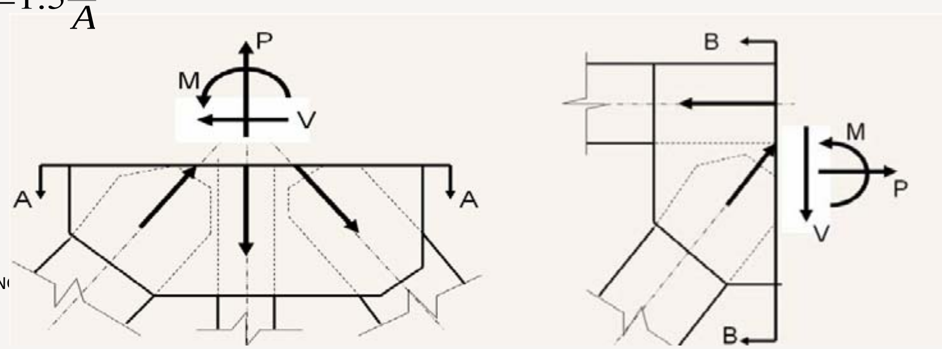
$$f_v = 1.5\frac{V}{A}$$

Principal stress at points of section are

$$R = \sqrt{\frac{(f_a + f_b)^2}{2} + f_v^2}$$

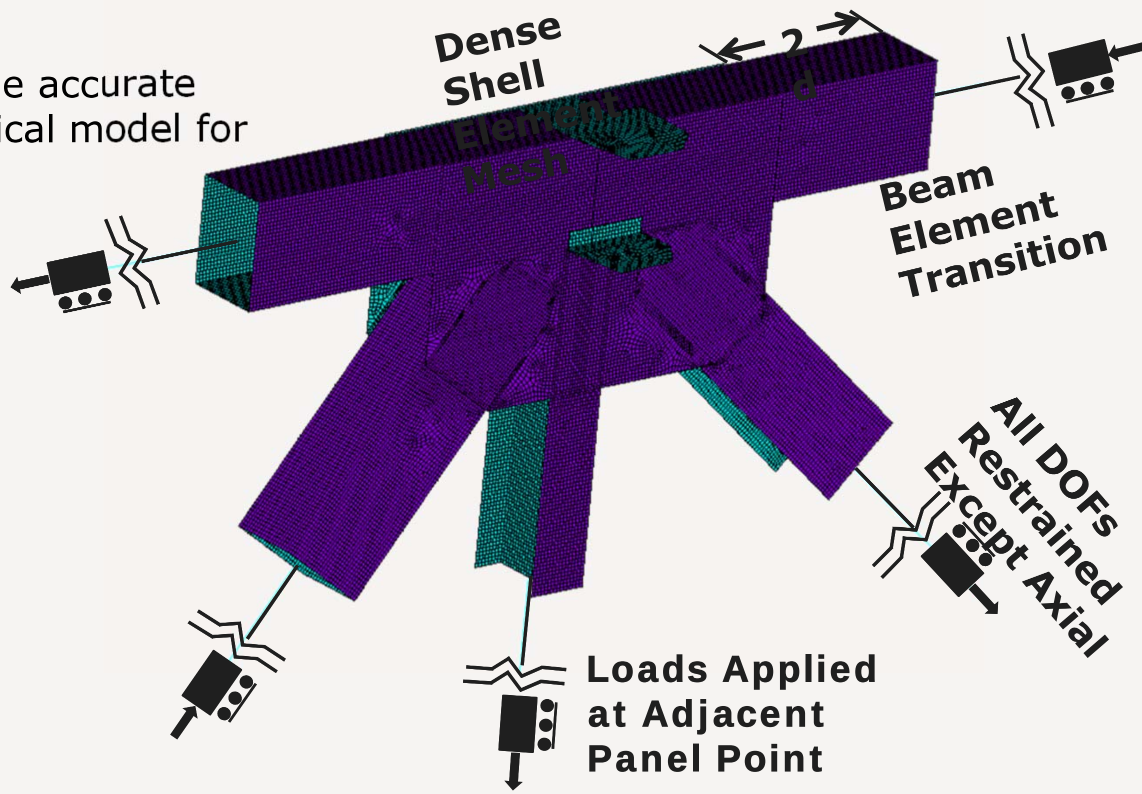
$$f_{tension} = \frac{f_a + f_b}{2} - R$$

$$f_{compresion} = \frac{f_a + f_b}{2} + R$$



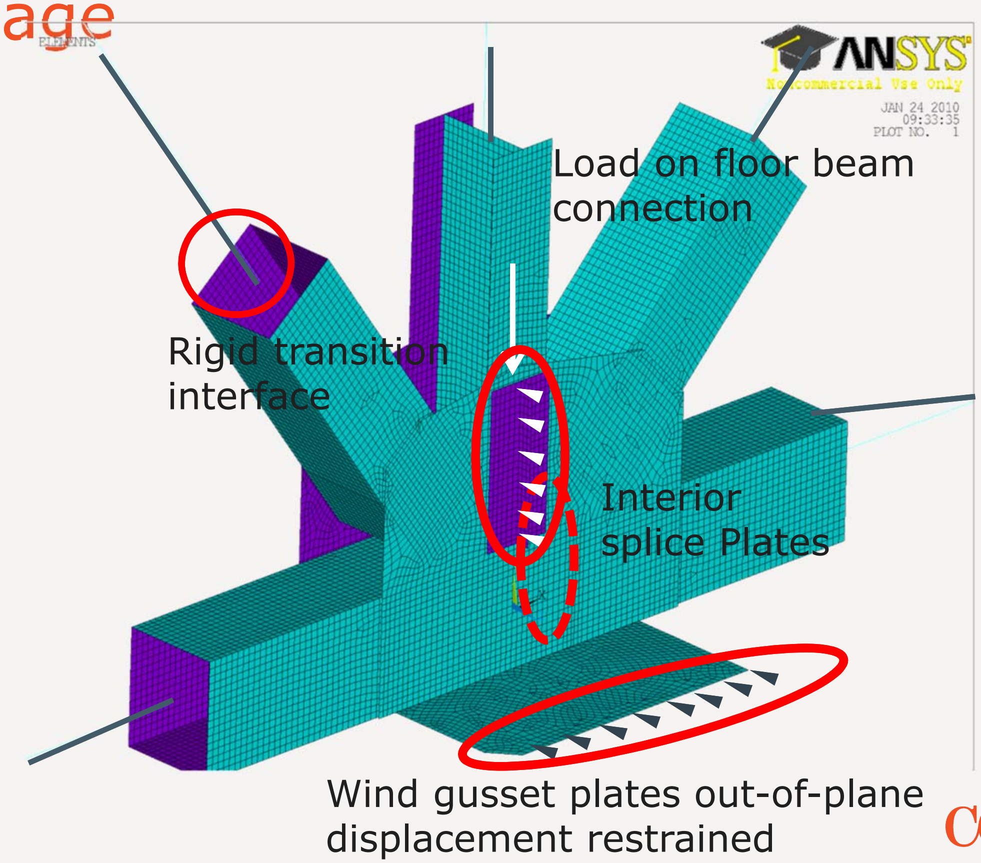
FE Modeling of Joint Subassemblage

› Development of reliable accurate and easily-built analytical model for parametric study



FE Joint Subassemblage

- Rigid transition interface
- Floor beam connection
- Wind gusset plate
- Chord splice plates
- Rivet modeling
- 0.5 in element edge size



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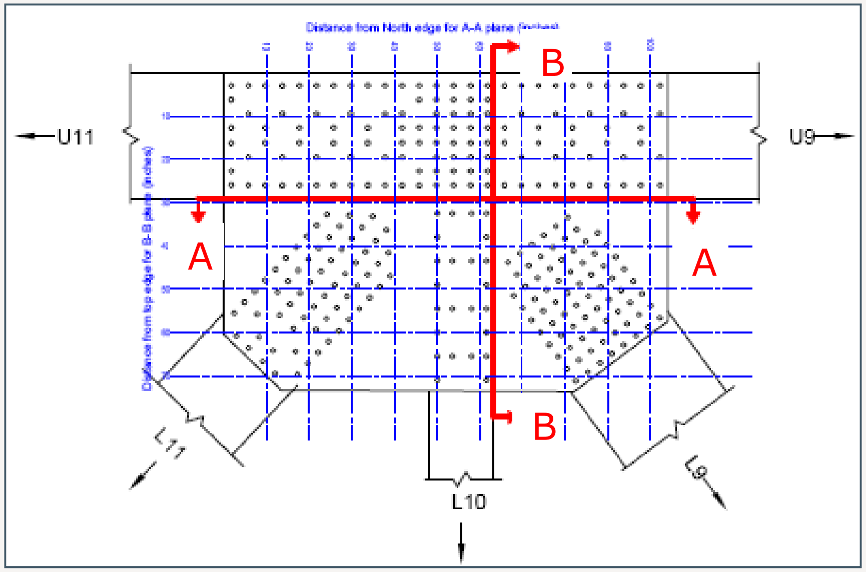
Comparison with FHWA Results

- Examined shear, normal, and Von Mises stresses along A-A and B-B sections and compare with Ocel and Wrights results (FHWA investigation report)



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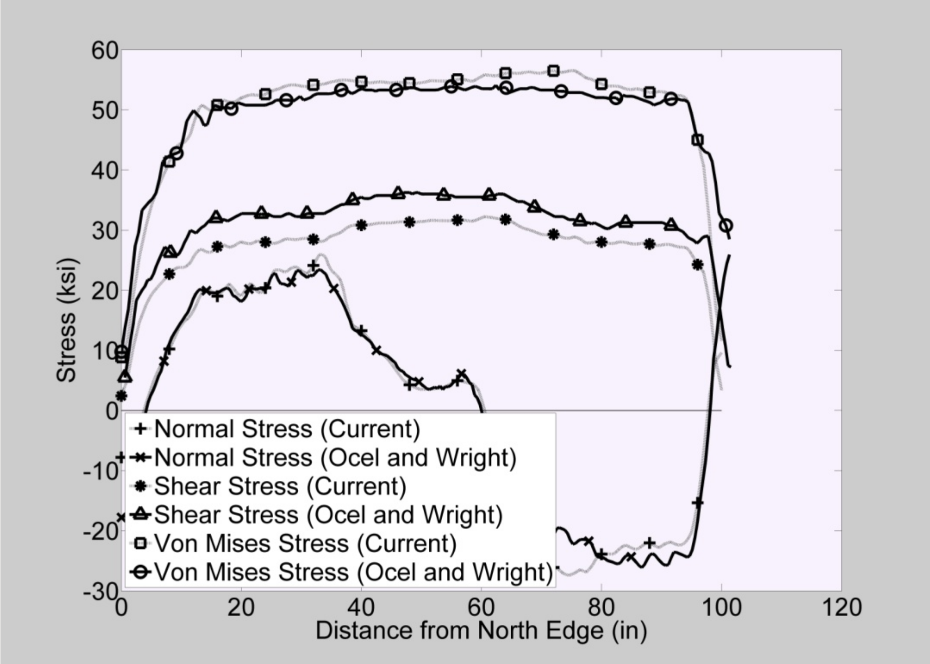
Comparison with FHWA Results

› Along A-A section



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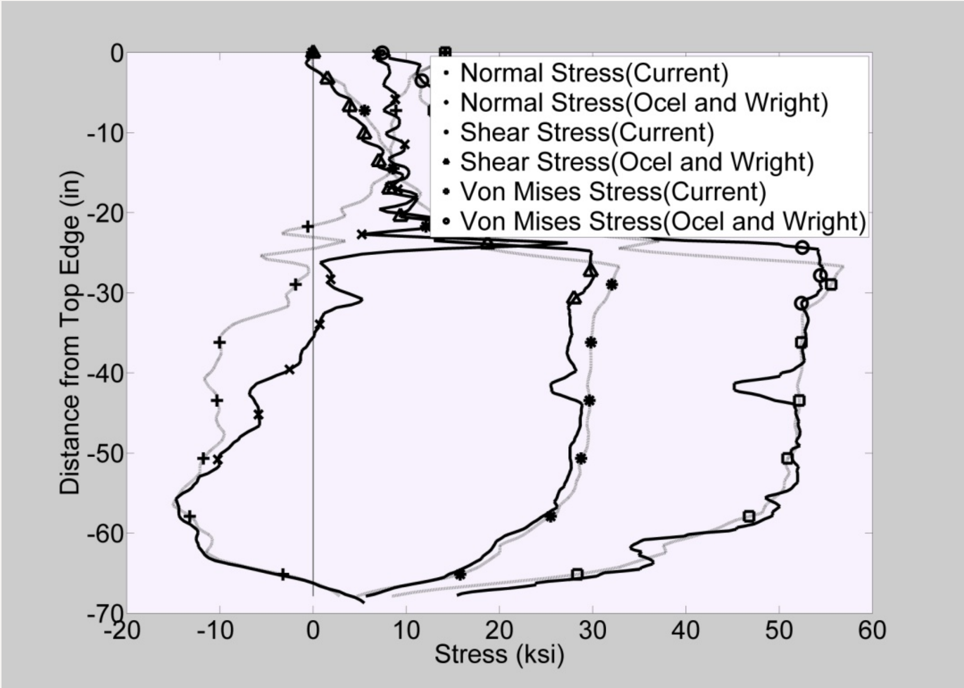
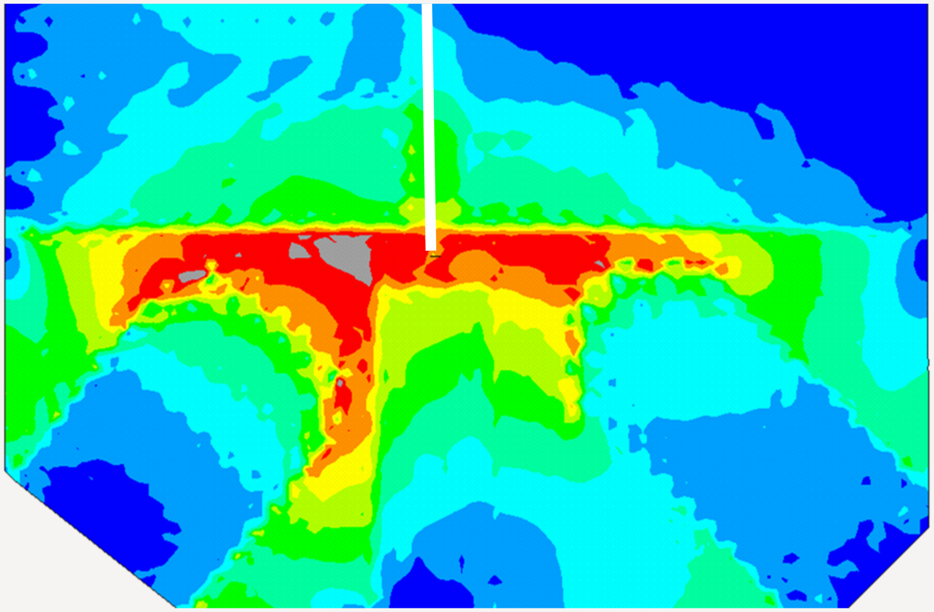
Comparison with FHWA Results

› Along B-B section



Critical Section: Chord Splices



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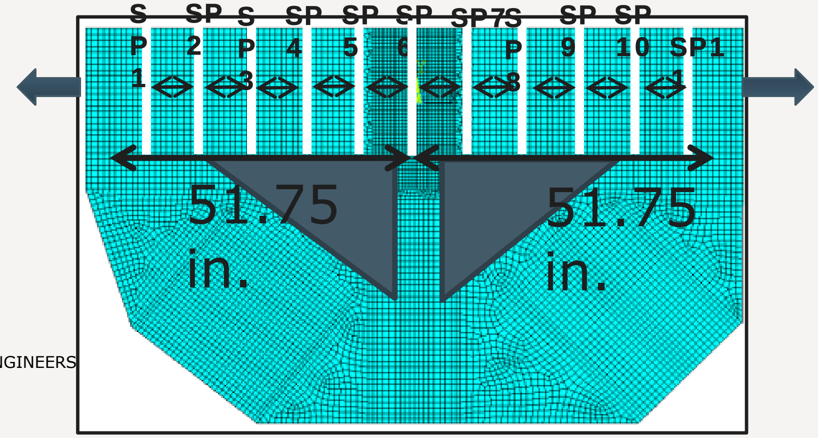
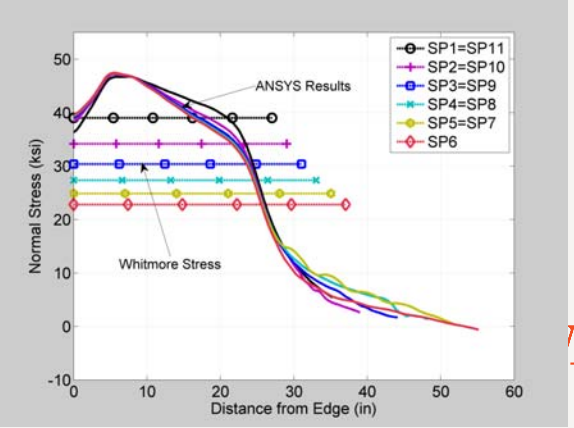
Study of Stresses at the Chord Splice

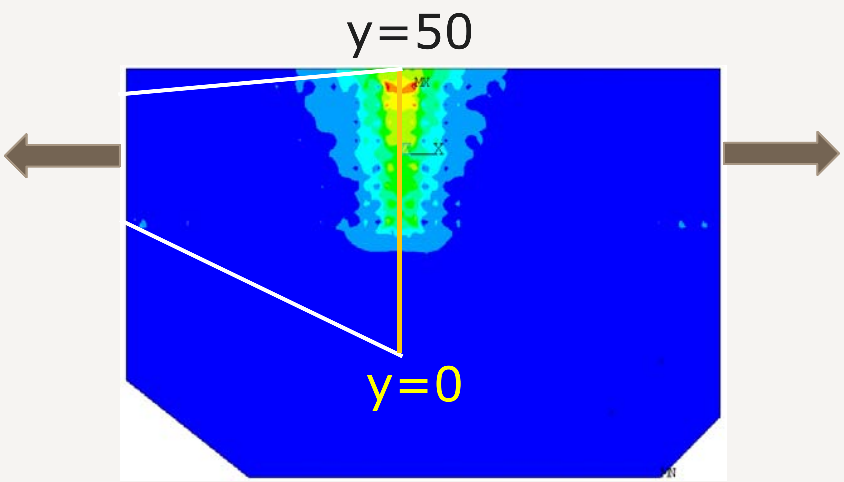
- Lack of verification for the Whitmore's method applied to the chord splice
- Parameters
  - Only chords are loaded with equal and opposite forces
  - Various splice locations considered (7.5 in increments)
- The Whitmore method underestimates the maximum stress
- FEA results shows the stress distribution does not very with splice location

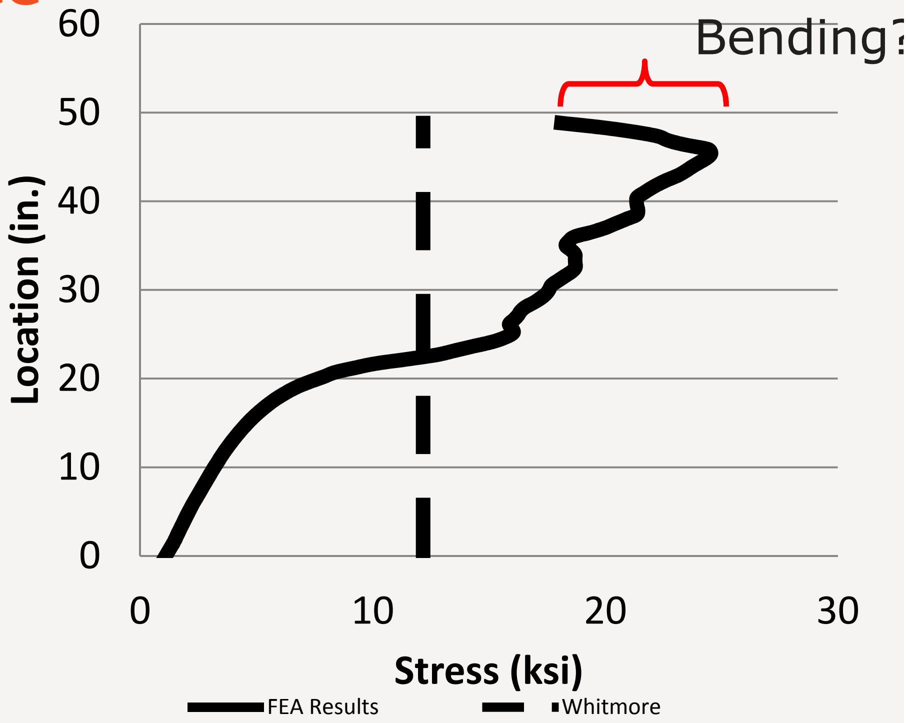




Normal Stress at Chord Splice

› Anti-symmetric geometry





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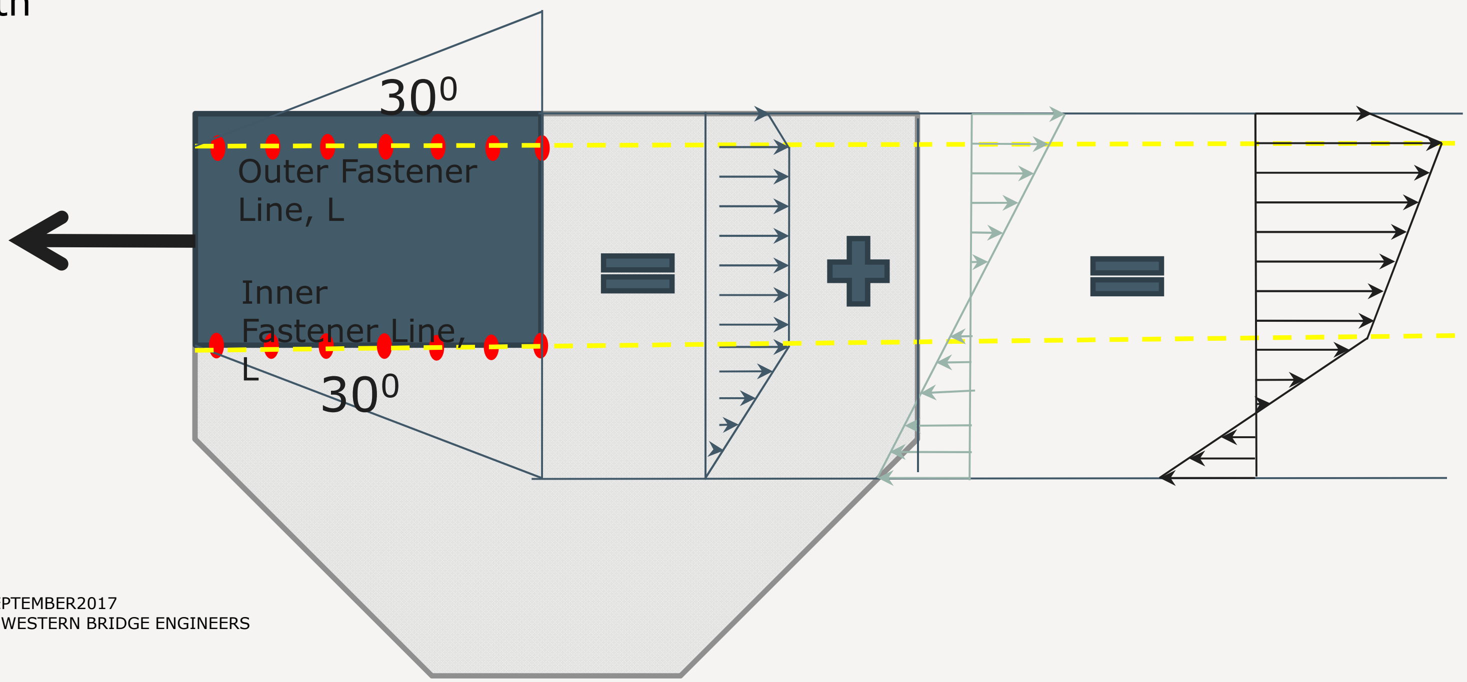
Idealized Approximate Stress Model

› Based on FEA results: Trapezoidal stress distribution + bending effect is used to describe the behavior at the end of chord instead of just using uniform stress over the Whitmore width



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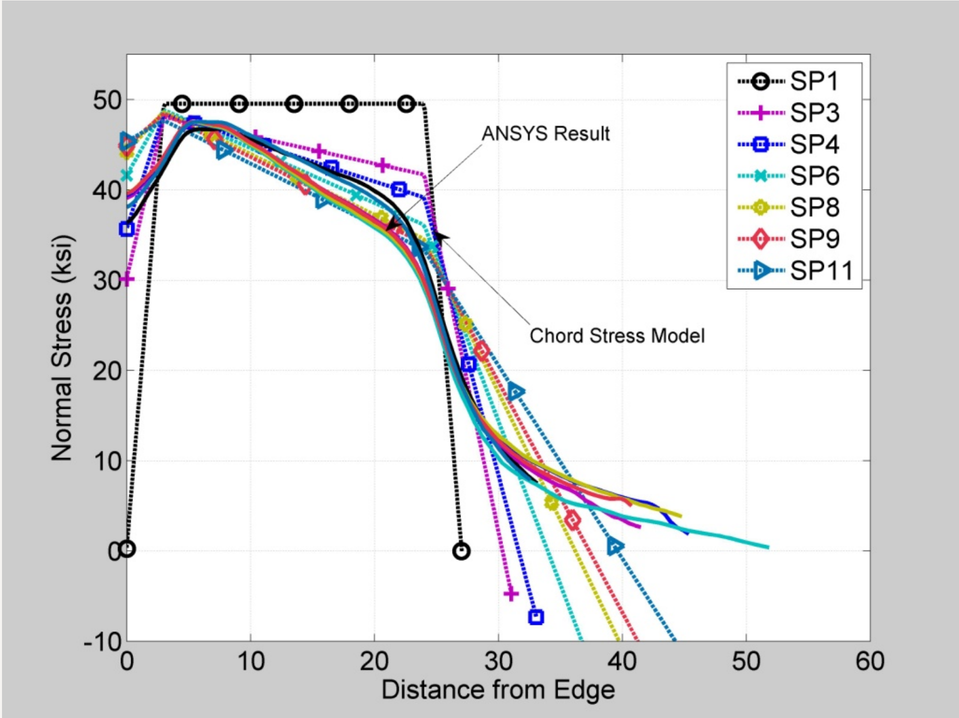
Verification of the Trapezoidal Stress Distribution Model

- Parameters Studied:
  - Gusset plate thickness
  - Deformable fastener
  - Web and flange splice plates
  - Ratio chord connection length to connection width (L/W)
- Conclusion:
  - Works well for only chords loaded



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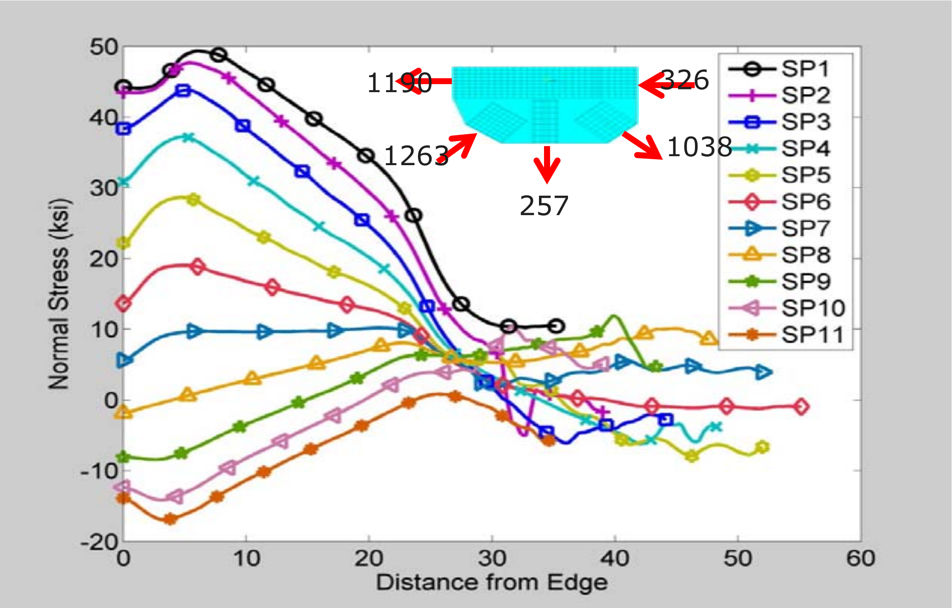
Stress Distribution at the Chord Splice with Full Loads

› Stress at chord splice affected other forces

Need to consider stresses due to loads in other truss members



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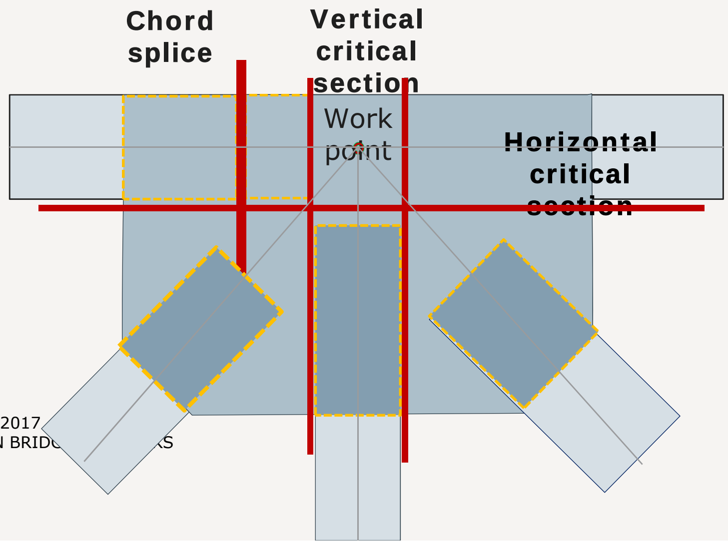
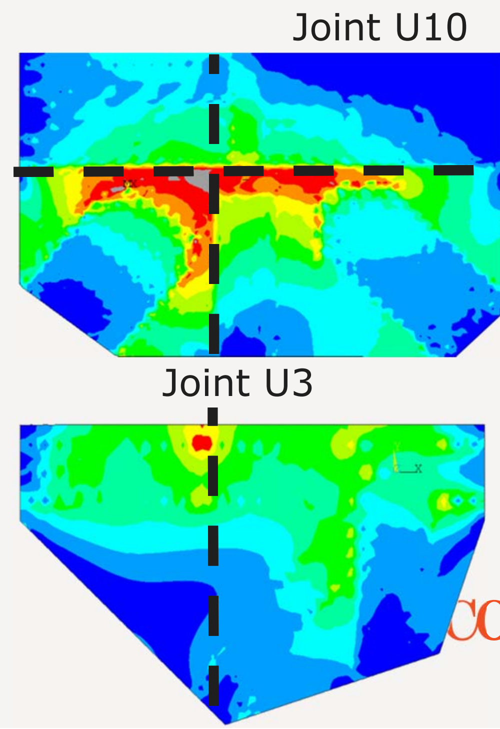
Identification of the Critical Section

- Easiest to consider effect of all elements by looking at stress distribution on critical sections
- Critical sections are found at
  - Horizontal section between chord and diagonals
  - Vertical section between hanger and diagonals
  - Vertical section at chord splice

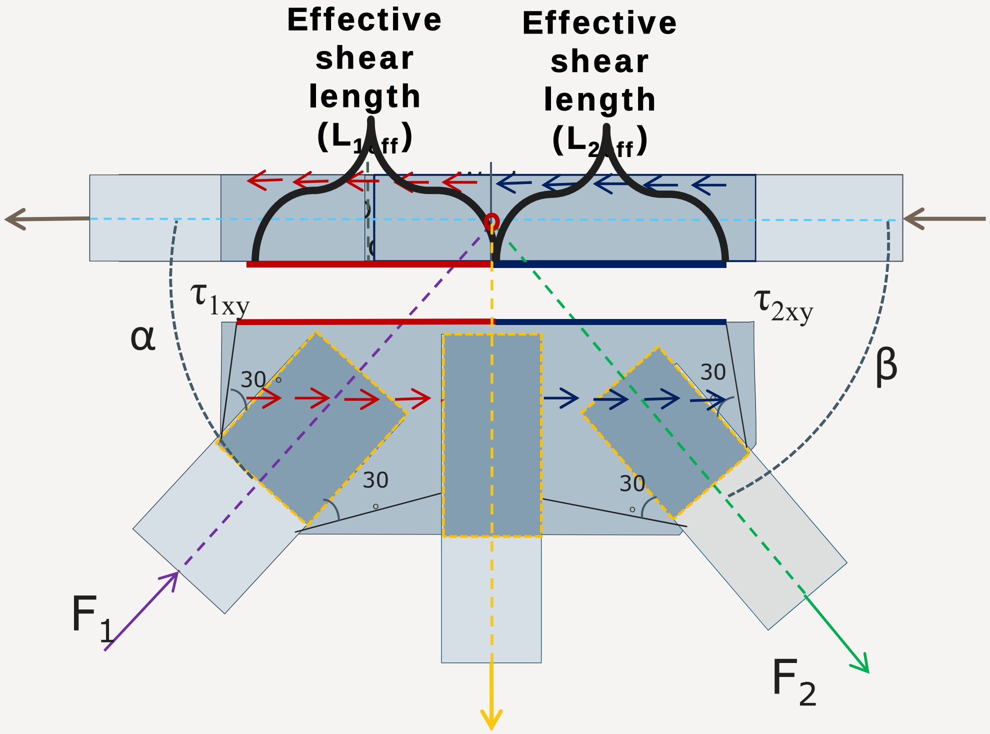


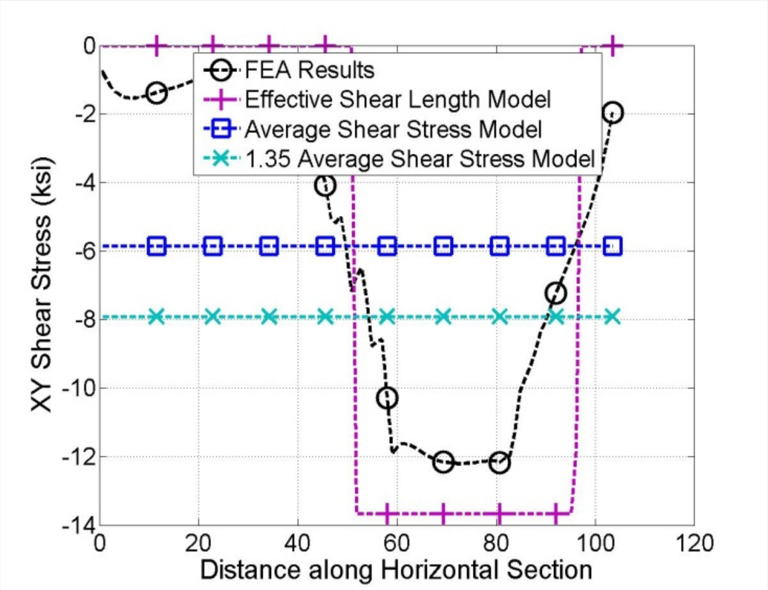


Developing Approximate Stress Distribution at Critical Sections

- Develop loading profiles that highlight one truss member's impact on the stress components at each critical section
- Observe the stress distributions at the critical sections from FEA of U10 for the different loading profiles and chord splice locations
- Develop approximate distributions based on those observations
- Quantify how well the approximations matched FEA results using the error percentage and correlation coefficient
- Combine the stresses using Von Mises at critical locations to determine the maximum gusset plate stress and its location
- Compare results with FEA results for several gusset plate joints

Stress at Horizontal Section





$$\tau_{1xy} = \frac{F_1 \cos\alpha}{2L_{1eff}\,t} \qquad \tau_{2xy} = \frac{F_2 \cos\beta}{2L_{2eff}\,t}$$

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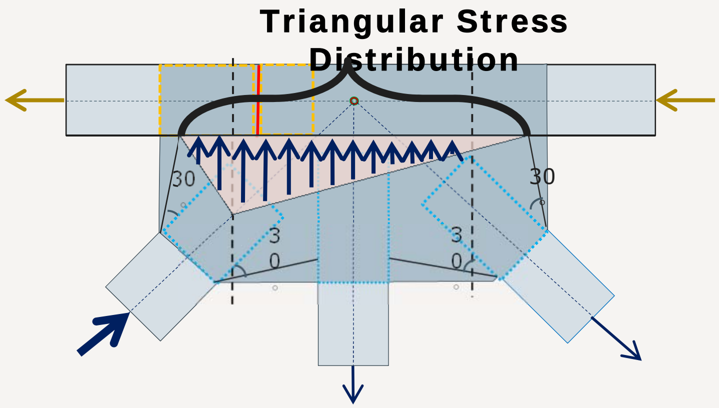
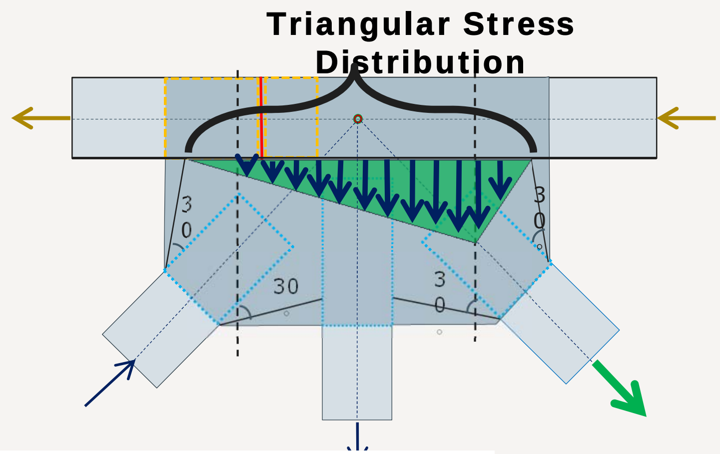
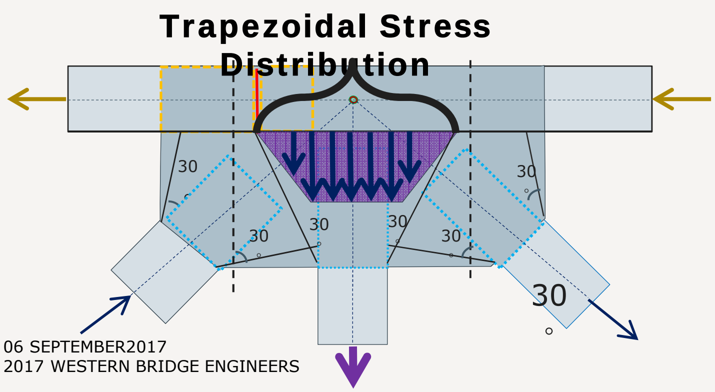
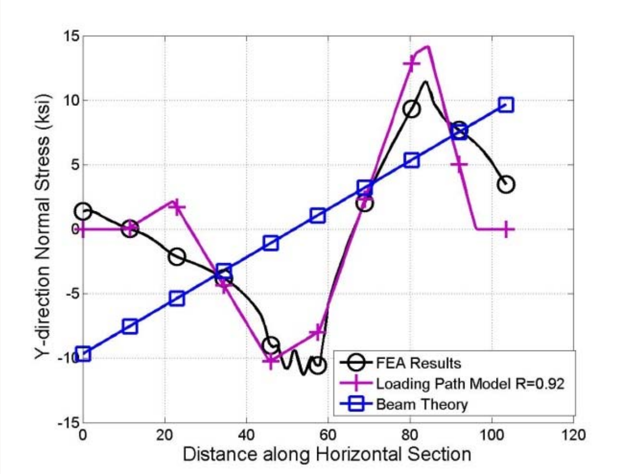
Stress at Horizontal Section









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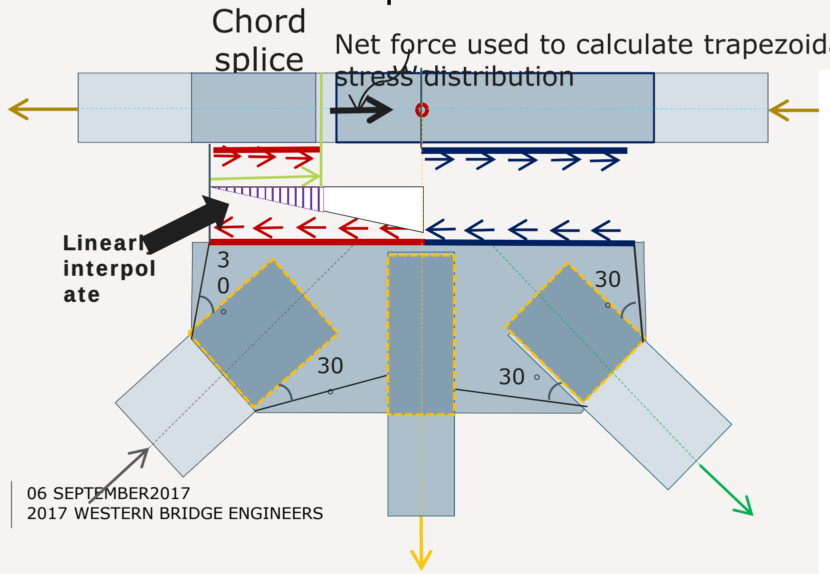
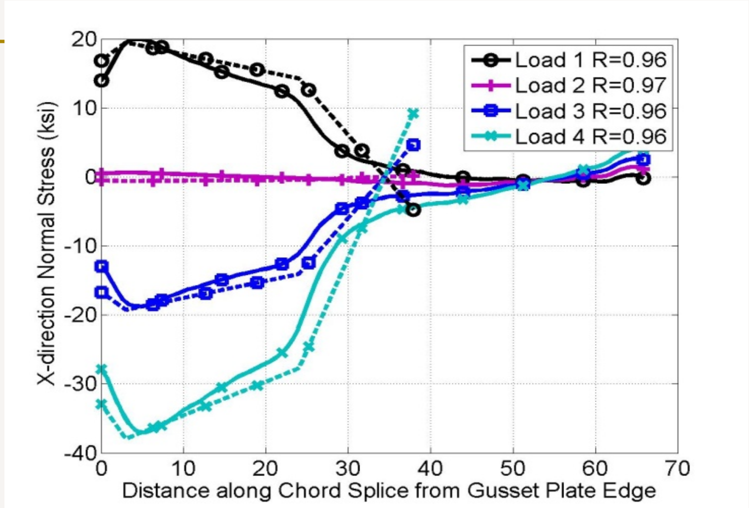
Stress at Chord Splice

- Use net force between chord and horizontal component of the diagonal
  - Linearly interpolate amount of diagonal force based on chord splice location
  - Based on assumption of constant shear stress





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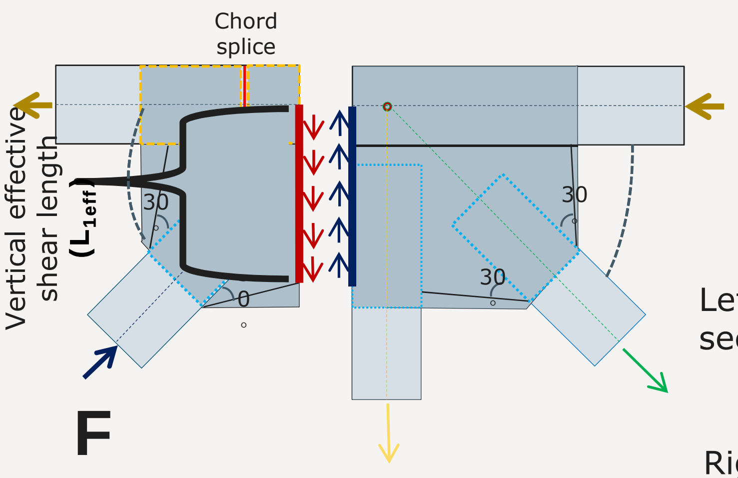
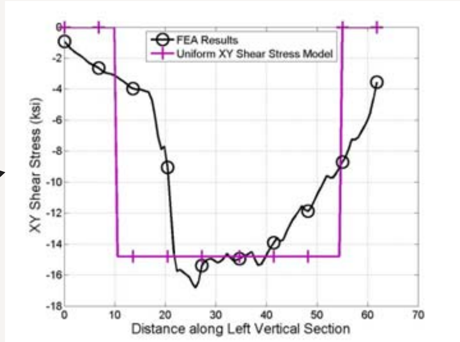
Stress at Vertical Section

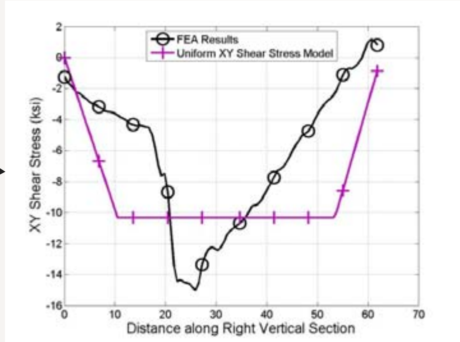


$$\tau_{xy} = \frac{F \sin\alpha}{2L_{eff}t}$$

Left vertical section under



Right vertical section under



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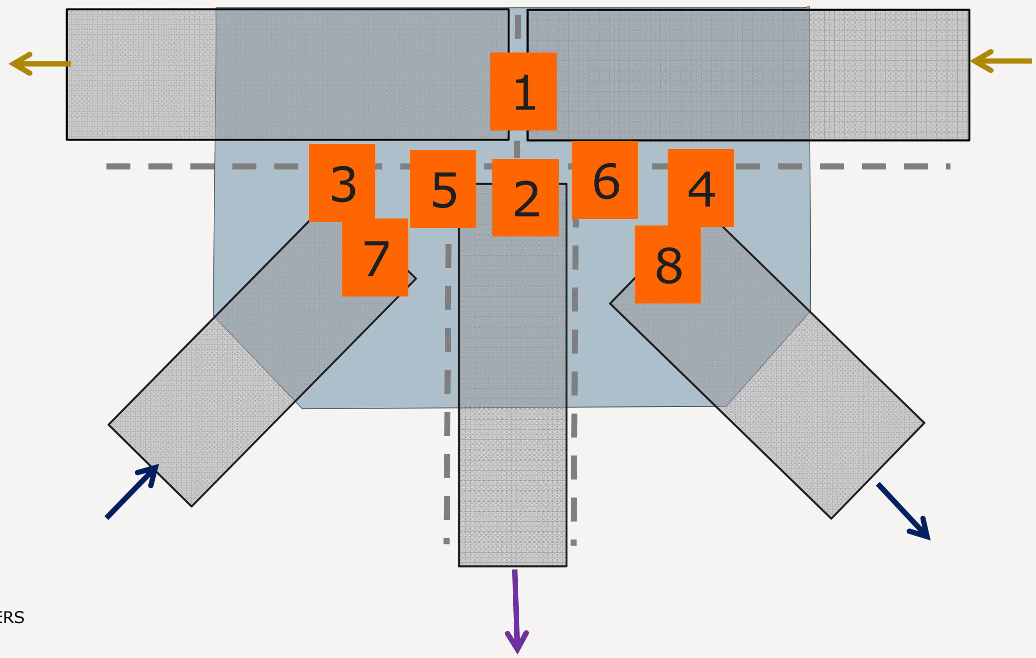
Stress Superposition

- Von Mises stress calculated at locations 1 through 6 using the approximate distributions
- Whitmore stress calculated at locations 2, 7 and 8



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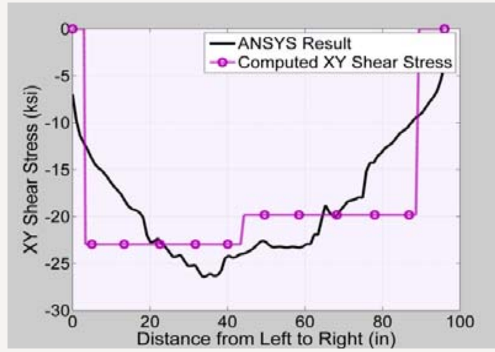
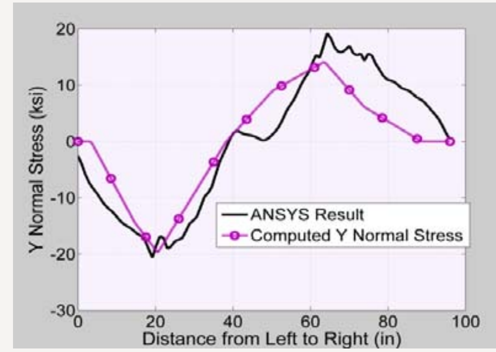
Example- Joint U10

Von Mises Stress (ksi)

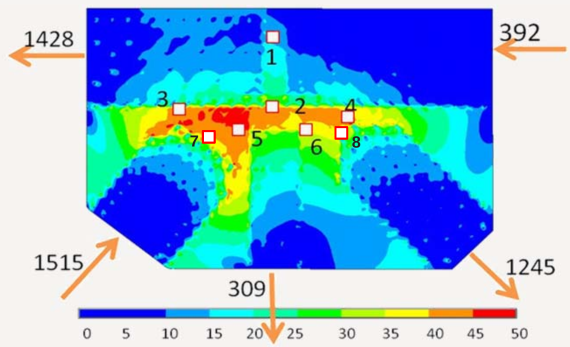
	Predicted	FEA
1	8.3	10-15
2	40.3	40-45
3	44.4	40-45
4	37.1	35-40
5	46.6	45-50
6	36.5	35-40
7	26.1	35-40
8	20.7	30-35

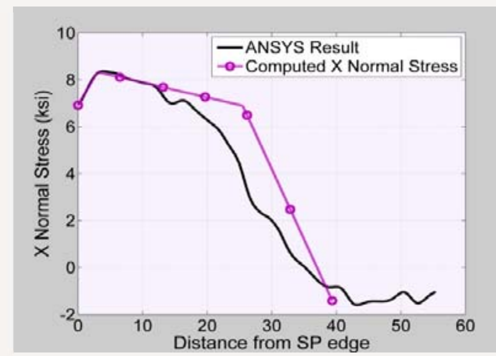
Horizontal section



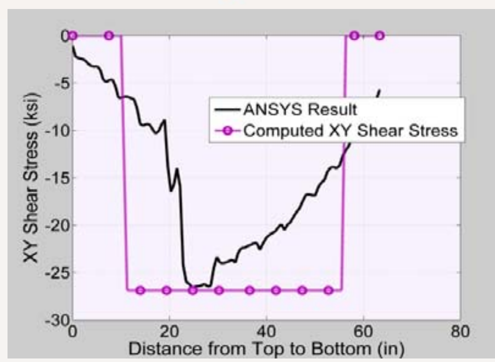


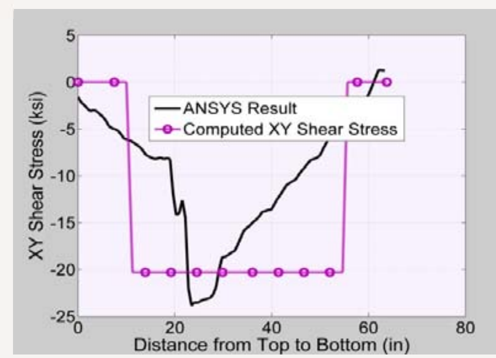
Chord Splice





Vertical section

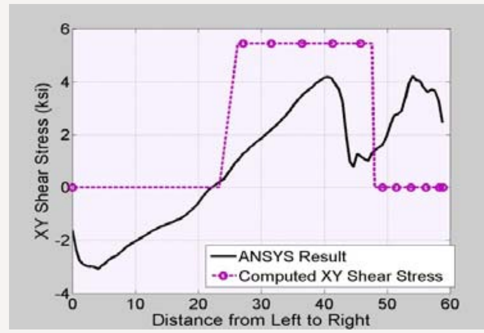


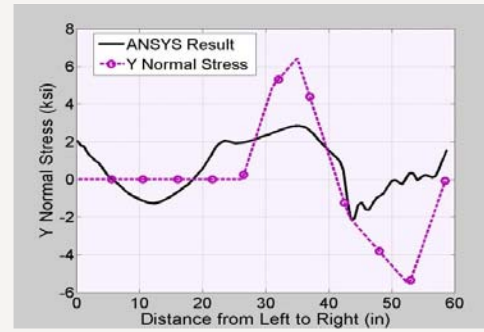


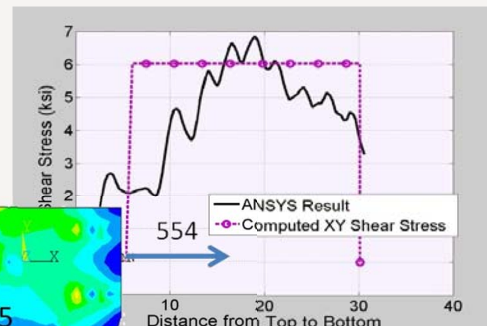
Example-Joint U3

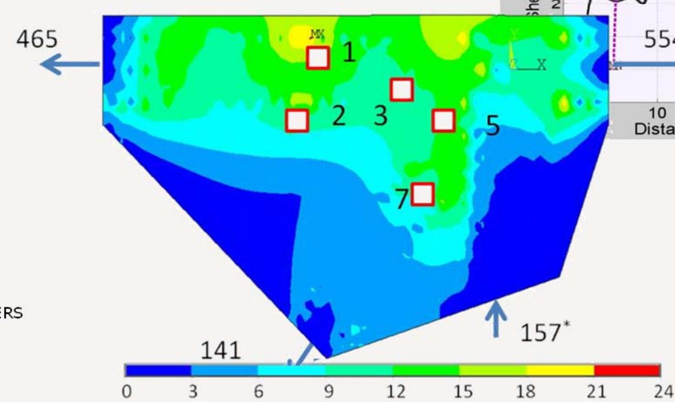
Von Mises Stress (ksi)

	Predicted	FEA
1	20.9	18-21
2	17.7	15-18
3	11.4	9-12
5	10.5	12-15
7	6.6	9-12









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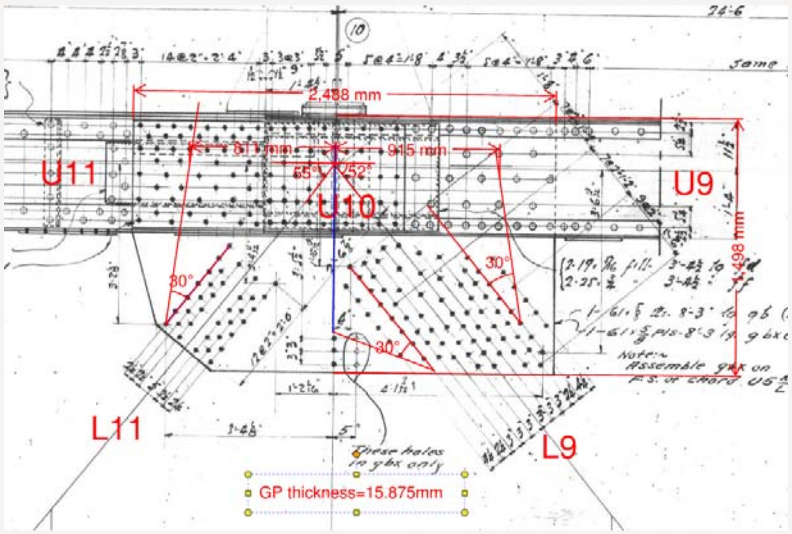
Application of Calculating Stress



- According to FHWA procedure
  - LLFC=0.81 for gross shear yielding along horizontal section
  - LLFC=0.41 for gross shear yielding along vertical section
- Horizontal shear force data
  - U9:Zero force member
  - U11:D1=1902kN, D2=173kN, D3=301kN, PED=138kN, LL=850kN
  - L9:D1=1099kN, D2=101kN, D3=176kN, PED=80kN, LL=495kN
  - L11:D1=799kN, D2=72kN, D3=126kN, PED=65kN, LL=394kN

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Application of Calculating Stress

- Vertical shear forces
  - L9:D1=1347kN, D2=123kN, D3=215kN, PED=99kN, LL=607kN
  - L11:D1=978kN, D2=88kN, D3=154kN, PED=79kN, LL=483kN
- Load factors:
  - $\alpha_{D1} = 1.1$, $\alpha_{D2} = 1.2, \alpha_{D3} = 1.5, \alpha_{ped} = 1.25$, $\alpha_{LL} = 1.7$
- Stresses calculated on the horizontal section
  - L9:τ_{xy} =174MPa, $\sigma_y = 213MPa$ VM=337MPa (@221MPa yield stress)
- Stresses calculated on the vertical section
  - L9:τ_{xy} =180MPa, σ_x=312MPa VM=412MPa (@221MPa yield stress)
- Useful to develop gusset plate strengthening strategy

Conclusions

- Individual stress distribution
  - The shear stress distribution was found to be better represented using individual effective shear lengths for each diagonal
  - The trapezoidal approximate stress distribution at the chord splice better estimates stress than Whitmore's method
- The maximum stress
  - The proposed evaluation procedure is able to estimate the magnitude and location of the maximum stress on the gusset plate

The method of calculating stresses on gusset plate provides a useful tool for designing gusset plate connection strengthening.

Thank You !

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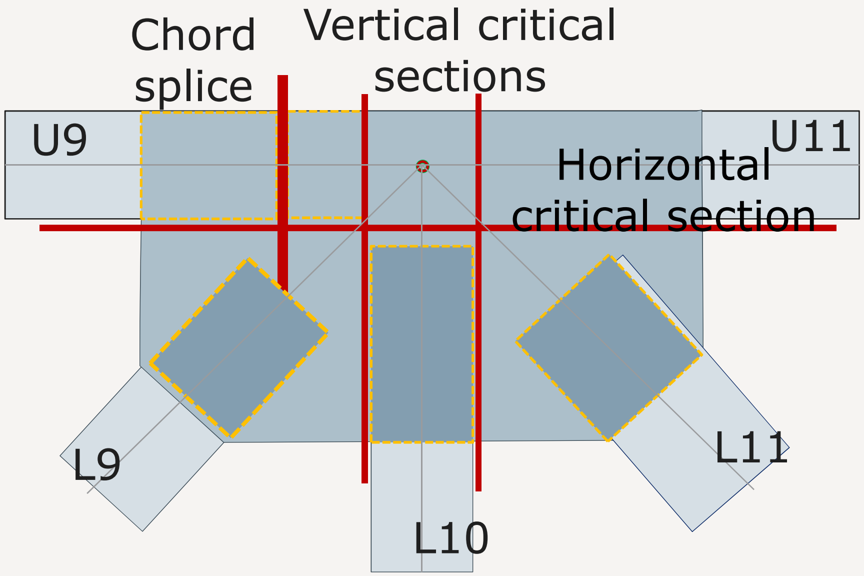
Loading Profiles

Load Profile	Member Forces Varied	Critical Section Stress Studied
I (4 cases)	U9	Chord Splice
II (5 cases)	L9, L11	Chord Splice and Horizontal Section
III (7 cases)	U9/L9	Chord Splice and Horizontal Section
VI (5 cases)	L10, L11, U11	Vertical Section



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