Gusset Plate Triage Analysis For Steel Truss Bridges in Washington

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Bellevue, Washington
OUTLINE

• Why?
• Bridge Inventory
• Triage Method
• Triage Example
• Application
• What’s Next
THE MOTIVATION

• Load Rating is a bit of a reaction based program.
  – An engineer is always allowed to check areas of concern. However, tradition and lack of concern has left gusset plates off of the usual list of items to check.
• Minneapolis, 2009 demonstrated a need to analyze quickly a lot of trusses quickly.
WSDOT’S TRUSS INVENTORY

• 130+ steel trusses owned by WSDOT
  – A total of 27.6 miles of truss on WSDOT’s system, and local agencies have more.
  – Sizes range from the very small to the very large.
  – Types range from simple to very complex.
    • Simple span, continuous, drop spans, erection stresses built in.
  – Not every bridge has good plans.

• Modeling
  – Boundary Conditions
    • Global and Local
  – Lane Configuration

• This is a daunting task to evaluate!
THE TRIAGE PLAN

• Identify if a gusset will control a rating.
  • Other methods are available, FHWY, finite element, compare to the current AASHTO Design Code.

• Almost every bridge is deemed okay with the triage method and the rating is not governed by the gussets. We need to identify which ones are not okay, and fast!
SIEVE ANALOGY

• SIEVE 1:
  – With the Triage Method, if the Rating Factors are higher than those currently listed, then the analysis is done.

• SIEVE 2:
  – If the gusset ratings are lower than those currently listed, then the FHWA Method is used.

• SIEVE 3:
  – If RFs are still very low, more detailed analysis tools could be utilized.

• SIEVE 4:
  – If more detailed analysis yields low RFs, then the low RFs are used for rating the bridge.

Most bridges are deemed okay within “Sieve 1.” This takes minimal analysis effort.
DEVELOPMENT OF TRIAGE METHOD

• UW Research
• BPO Involvement
• Standardizing calcs is critical. With so many engineers to do the work, and so few to review, and so few to maintain the load ratings, uniformity is key.
THE TRIAGE METHOD

• Three failure modes considered:
  – Gusset Yielding
  – Gusset Buckling ~ Compression Members Only
  – Rivet Shear
• If the connection is milled to bear, compression on both sides, no evaluation necessary. Tension against Milled to bear requires an evaluation.
• All plates crossing a joint are considered
  – Gussets, Wind Plates, Splice Plates
• Stress reversals require a separate evaluation for each direction.
  – Stress reversal = 2.17 LL > 1.3 DL
THE TRIAGE METHOD

LENGTHS USED FOR AREA CALCS
THE TRIAGE METHOD

LENGTH USED TO DETERMINE PLATE AREA BUCKLING

LENGTH USED TO DETERMINE PLATE AREA FOR YIELDING
MODELING ~ METHODS

• CSI used for analysis
  – Original analysis condition considered.
  – Verified model against original dead loads.
  – Modeled idealized boundary conditions.

• 2D or 3D models used.
  – 2D quicker, 3D more useful later, but rarely.
EXAMPLE ~ VANTAGE BRIDGE

BRIDGE LOCATION

130 mi.
ASTM A-7 ~ fy = 33ksi
ASTM A-242 ~ fy = 50ksi
ASTM A-141 ~ fy = 24-32 ksi

For rivets, fy varies depending upon connection length per the 2011 Interim to the 2010 MBE Article 6A.6.12.5.
TRIAGE EXAMPLE ~ AS-BUILTS

AS-BUILT ~ NODE L4

CONSIDER L4-U5 FOR OUR EXAMPLE
Often times the As-Builts are not correct. For determining exact plate sizes and connection geometry, the shop drawings are the only reliable tool.
MODELING ~ VANTAGE
### MEMBER END FORCES:

<table>
<thead>
<tr>
<th>LANE DISTRIBUTION FACTORS:</th>
<th>LANE 2</th>
<th>LANE 3</th>
<th>LANE 4</th>
<th>TOTAL</th>
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<td>0.75</td>
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### STRESS REVERSAL CONSIDERATION CHECK:

- IF $2.17 \times$ opposing LL $> 1.3 \times$DL, THEN BOTH DIRECTIONS OF LOAD ARE CONSIDERED.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Output</th>
<th>Case</th>
<th>DEAD</th>
<th>UNIT LANE</th>
<th>LANE 2, 3, 4</th>
<th>TRIAGE INPUTS</th>
<th>LEGAL IN LEFT</th>
<th>STRESS REVERSAL CONSIDERATION CHECK</th>
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<tbody>
<tr>
<td></td>
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<td>Controlling HS-20</td>
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## Gusset Plate Inputs & Summary

<table>
<thead>
<tr>
<th>Sheet Information</th>
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<tr>
<td>Rated By</td>
<td>Company</td>
</tr>
<tr>
<td>Patrick Gallagher</td>
<td>WSDOT Bridge</td>
</tr>
</tbody>
</table>

### LL Distribution Factors
- Forces entered into spreadsheet shall be based on a single lane distribution.
- Live load distribution considered in the reactions input below.

#### AASHTO & Legal Trucks
- OL Trucks
- Legal Truck w/OL
- LL Distribution factor for Design & Legal truck shall be based on the number of lanes multiplied by the appropriate reduction factor.
- LL Distribution factor for one OL placed in lane closest to truss multiplied by the appropriate reduction factor.
- LL Distribution factor for Legal Truck w/OL assumes legal loads are placed in lanes adjacent to OL truck multiplied by the appropriate reduction factor.

### LL Input and RF Summary

<table>
<thead>
<tr>
<th>Load Case ID</th>
<th>Truck Type</th>
<th>Overload?</th>
<th>γL</th>
<th>Impact Factor (I)</th>
<th>Rating Method</th>
<th>Minimum RF</th>
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<th>Controlling Resistance Type</th>
<th>Operating RF for LFR only</th>
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<th>Minimum RF</th>
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<td>L4-L3</td>
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<td>2.77</td>
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<td>TYPE 3</td>
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<td>0.0943</td>
<td>LFR</td>
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<td>L4-U4</td>
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<td>TYPE 3S2</td>
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<td>LFR</td>
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<tr>
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<td>Y</td>
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<td>0.2</td>
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</table>

### Plate Material & Dimension Inputs

#### Gusset Plate Properties
- $F_y_{gp}$ (ksi): 50
- Thickness (tgp) (in): 0.625
- Num Plates, np: 2

#### Wind Gusset Plate Properties
- $F_y_{wp}$ (ksi): 33

#### Splice Plate Properties
- $F_y_{sp}$ (ksi): 50

#### Rivet Properties
- $F_u_{r}$ (ksi): 24
### Triage Procedure Connection Inputs

*Rated By: Patrick Gallagher*

#### Connection Information
- **Company**: WSDOT Bridge
- **Date**: 10/5/08

#### Connection Data
- **Connection ID**: Chord or Web? Splice PL's? Wind Bracing GP? Comp. or Tension? Milled to Bear, Y/N?
- **Bridge ID**: 90/180

#### Gusset Plate Connection

<table>
<thead>
<tr>
<th>Wc (in)</th>
<th>9</th>
</tr>
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<tr>
<td>2*Lc tan 30 + Wc</td>
<td>36.71</td>
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</table>

#### Individual Splice Plate Dimensions

<table>
<thead>
<tr>
<th>Splice ID</th>
<th>Wsp (in)</th>
<th>tsp (in)</th>
<th>Brace ID</th>
<th>Wc (in)</th>
<th>Lc (in)</th>
<th>Le (in)</th>
<th>twp (in)</th>
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<td>110</td>
<td>110</td>
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<td>110</td>
<td>110</td>
</tr>
</tbody>
</table>

#### Summary of Yielding Resistance Calculations

- **Agp_wb (in^2)**: 45.89
- **Awp (in^2)**: 0.00
- **Rn (k)**: 1324.8

#### Buckling Resistance Inputs

- **Centroidal Length, L_cent (in)**: 57.00
- **L_Whit45 (in)**: 2.319
- **Ig (in^4)**: 71.25
- **Ag (in^2)**: 1

#### Rating Factors

<table>
<thead>
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<th>Controlling Resistance (k)</th>
<th>Resistance Type</th>
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<td>Rivets</td>
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#### Rating Table

<table>
<thead>
<tr>
<th>Rating Method</th>
<th>Factored DL (k)</th>
<th>Maximum Legal Load</th>
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<tr>
<td>LFR</td>
<td>54.68950305</td>
<td>Maximum force due to legal load based on one lane distribution</td>
</tr>
<tr>
<td>LRFR</td>
<td>409.11</td>
<td>Maximum force due to legal load based on one lane distribution</td>
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</table>

#### Load and Combination of Loads

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Type</th>
<th>Effect</th>
<th>Impact Factor (I)</th>
<th>Rating Method</th>
<th>Member LL (k)</th>
<th>RF</th>
<th>RF</th>
<th>RF</th>
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</thead>
<tbody>
<tr>
<td>HS-20</td>
<td>HS-20</td>
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#### Rivet Input

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<tr>
<th>Rivet Diameter, D_r (in)</th>
<th># of Single Shear Rivets, nss</th>
<th># of Double Shear Rivets, nds</th>
<th>Rn (k)</th>
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<tbody>
<tr>
<td>0.875</td>
<td>72</td>
<td>0</td>
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#### Legal Lane Connection RF Summary

<table>
<thead>
<tr>
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<tbody>
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</tr>
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</table>

#### Dead Load (k)

- **γ_DL**: 1.3
- **γ_DL_C**: 0
- **γ_DL_W**: 0
### SUMMARY OF NODES

<table>
<thead>
<tr>
<th>TRUCK</th>
<th>L0</th>
<th>L2</th>
<th>L4</th>
<th>L6</th>
<th>L8</th>
<th>L10</th>
<th>L12</th>
<th>L14</th>
<th>L15</th>
<th>L16</th>
<th>L17</th>
<th>L18</th>
<th>MIN. RATING FACTORS</th>
<th>MIN. RATING FACTORS</th>
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<td>2.43</td>
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<td>1.89</td>
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### CONTROLLING RF W/O GUSSETS:
- AASHTO 1 = 1.10
- AASHTO 2 = 1.05
- AASHTO 3 = 1.12
- NRL = NA ~ Pre 2011
- Legal Lane = 1.00
- OL1 = 1.08
- OL2 = 0.92
- HS20 Inventory = 0.31
- HS20 Operating = 0.52

Other portions have lower RFS, gussets do not control. Rating complete.
APPLICATION ~ SO WHAT?

• SIEVE 1:
  – If the Rating Factors are higher than those currently listed, then the analysis is done.

• SIEVE 2:
  – If the gusset ratings are lower than those currently listed, then the FHWA Method is used.

• SIEVE 3:
  – If RFs are still very low, more detailed analysis tools could be utilized.

• SIEVE 4:
  – If more detailed analysis yields low RFs, then the low gusset RFs are used for rating the entire bridge.
OTHER FACTORS

• Know the spreadsheet and how it works.
  – Not everything fits into the mold of that spreadsheet.
  • Stacked gussets, varying material strengths, varying rivet diameters, triple shear rivets.

• Know what you’re trying to achieve.
  – Lift span bridges are closed under live load.
  – Understand erection stresses and how they were managed.

• Know how truss bridges function.
  – Truss engineering is a dying art. Learn how they work.
  – If it should be a zero force member, make it one.
  – Hanger members should all have the same loads.
  – Understand drop spans and cantilever spans.
NO AS-BUILTS?
WHAT’S NEXT?

• Once the ratings are updated for gussets, maintaining those records will be ongoing.
• Inspection practices have been adjusted to account for gussets.
• More effort and discussion will be given to bridge maintenance.
• The timeliness is excellent. With a huge design and construction package being completed, maintenance is a natural place to turn efforts towards.
FUTURE OF INSPECTION

• Gusset plates are now their own BMS Element.
• Bridge inspections have been including field verification of gusset thicknesses.
• Truss ratings include gusset ratings.
QUESTIONS:

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