Investigation of Prefabricated Steel Truss Bridge Deck Systems

Final Presentation and Implementation Meeting

Damon Fick          Tyler Kuehl

October 26, 2017
Presentation Outline

• Background
• Literature Review
• Preliminary Evaluation, 148 ft. span, Cooper Creek
  • Distribution factors
  • Fatigue
  • Materials and fabrication costs
• Proposed Hybrid Truss Evaluation, 205 ft span
  • 3D model
  • Connections and splices
  • Materials and fabrication costs
  • Erection
• Conclusions
Background

Three preliminary bridge designs were proposed by Allied Steel (Lewistown, Montana).

All connections welded – constructed with an integral concrete deck.

<table>
<thead>
<tr>
<th>Option</th>
<th>Span</th>
<th>Deck Thickness</th>
<th>Top Chord Member</th>
<th>Bottom Chord Member</th>
<th>Vertical Member</th>
<th>Diagonal Member</th>
<th>Steel Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>148 ft.</td>
<td>7 in.</td>
<td>WT12x38</td>
<td>WT18x97 / WT20x147</td>
<td>HSS6x6 / HSS5x5</td>
<td>LL5x3 / LL6x3 / LL7x4</td>
<td>29,100 lbs.</td>
</tr>
<tr>
<td>2</td>
<td>148 ft.</td>
<td>7 in.</td>
<td>WT12x38</td>
<td>WT18x97 / WT20x147</td>
<td>W8x15-31</td>
<td>W6x16 / W8x21-28</td>
<td>28,000 lbs.</td>
</tr>
<tr>
<td>3</td>
<td>108 ft.</td>
<td>8-1/4 in.</td>
<td>PL3/4x12</td>
<td>PL1-3/4x12 / PL2x6</td>
<td>W8x18-24</td>
<td>PL1x6</td>
<td>18,080 lbs.</td>
</tr>
</tbody>
</table>

Lighter weight, longer spans, improved construction safety, and accelerated construction potential.
Research Question

Are steel truss/integrated concrete deck bridge systems a viable construction alternative for Montana?

Research Plan

Task 1 = Literature Review
Task 2 = Analytical Evaluation
Task 3 = Analysis of Results
Task 4 = Final Report, Presentation, and implementation meeting
Literature Review

• The most common application for modular prefabricated steel truss systems has been for temporary bridge crossings.

Acrow Bridge, Acrow Corporation of America 2015
• Two cases of permanent welded truss bridge replacement projects were implemented with shorter spans and low traffic volumes and were significantly more economical than traditional solutions.

Crosier Bottom Crossing (McConahy 2004)
• Measured fatigue stresses for a connection configuration similar to one of the proposed welded connections by Allied steel were consistent with the AASHTO Fatigue Detail Category E.

Double angle connection, Battistini et al. 2014
• Full-scale experimental investigations of two steel truss bridges resulted in different conclusions related to the degree of rotational restraint provided by the truss connections.

Partial fixity of joints not significant

Joint restraint should be considered

Full-Scale Bailey Bridge Model (King et al. 2013)

Hillsville Truss (Hickey et al. 2009)
## Analytical Evaluation

### Proposed Truss Designs by Allied Steel, Inc.

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<td>W8x18-24</td>
<td>PL1x6</td>
<td>18,080 lbs.</td>
</tr>
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</table>

Option 1 was selected for preliminary analysis
Bridge Geometry

(a) Cross-Section
- 7 in. concrete deck
- prefabricated segment
- bolted bridging connection
- longitudinal joints
- 7'-0" typical

(b) Elevation
- 7 in. concrete deck
- prefabricated segment
- bolted splice connection
- 8'-0" typical
- 148'-0"
2D Finite Element Model (SAP 2000)

Lever Rule Distribution Factors

= 0.79 for Strength I

= 0.57 for Fatigue I
Fatigue Thresholds

Connection Examples of Detail Category E for Longitudinally Loaded Welded Attachments (AASHTO, 2012 Table 6.6.1.2.3-1)

Fatigue I = 4.5 ksi (infinite life)

Fatigue II = 6.4 ksi (75-year life)
Strength I Load Combination

Axial Stress (ksi)

Truss Member

HL-93M
HL-93K

Design Yield Stress = 34.2 ksi (Diagonals)
Design Yield Stress = 47.5 ksi (Chords)
Fatigue I Load Combination

The figure shows the axial stress for each truss member under Fatigue I load combination. The stress values range from 4 ksi to 12 ksi. A red horizontal line indicates the Fatigue I threshold of 4.5 ksi.
Fatigue II Load Combination

Graph showing axial stress (ksi) for truss members 1 to 12. The threshold for Fatigue II is indicated as 6.4 ksi.
Materials and Fabrication Cost

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
<th>Plate Girder</th>
<th>% Difference (minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVEVA</td>
<td>$45,950</td>
<td>$43,210</td>
<td>$48,120</td>
<td>5</td>
</tr>
<tr>
<td>RTI Fabrication</td>
<td>$40,740</td>
<td>$40,320</td>
<td>$51,190</td>
<td>20</td>
</tr>
<tr>
<td>Allied Steel</td>
<td>$42,210</td>
<td>$42,210</td>
<td>$49,660</td>
<td>15</td>
</tr>
</tbody>
</table>

Observations:

- Competitive with plate girder
- Undesirable 75-year design life limitation
Proposed Hybrid Truss

• Bolted connections between diagonal members and top and bottom chords:

Diagonal Member Connection Examples of Detail Category B for Longitudinally Loaded Bolted Attachments (AASHTO Table 6.6.1.2.3-1)

Fatigue I = 16.0 ksi (infinite life)
Welded Vertical Member Connections

Example of Detail Category C’ for Longitudinally Loaded Bottom Chord with Transverse Welded Attachments (AASHTO Table 6.6.1.2.3-1)

Fatigue I = 12.0 ksi (infinite life)
Wide Flange Vertical Members

Heavier than HSS verticals, but less expensive per pound
Increased Span Length
## Selected Geometry

<table>
<thead>
<tr>
<th>Span</th>
<th>Deck Thickness</th>
<th>Top Chord Member</th>
<th>Bottom Chord Member</th>
<th>Vertical Member</th>
<th>Diagonal Member</th>
<th>Steel Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>205 ft</td>
<td>8 in.</td>
<td>WT16.5x65</td>
<td>WT20x162 / WT16.5x193.5</td>
<td>W10x39</td>
<td>MC10x33.6 / MC10x25 / MC8x18.7</td>
<td>69,000 lbs.</td>
</tr>
</tbody>
</table>

8 in. concrete deck x 8.75 ft. wide

Comparable to Swan River plate project, designed by MDT
Preliminary Connection Configuration
Fatigue I (infinite life) Results
(distribution factor = 0.93)
Preliminary Results

• Hybrid truss is 24% lighter than Swan River plate girder

• Fatigue threshold stresses are 3.5 times larger for AASHTO Detail Category B (4.5 ksi vs. 16 ksi)

• Conservative distribution factor (0.93) calculated using lever rule
Proposed Hybrid Truss

• Create a 3D finite element model to evaluate distribution factors calculated using lever rule (0.93)

• Investigate two truss configurations for conventional and accelerated construction alternatives

• Evaluate material and fabrication costs in addition to shipping and erection considerations
3D Finite Element Model
# Load Distribution Analysis

## Hybrid Truss

<table>
<thead>
<tr>
<th>Loading</th>
<th>Maximum Tension (+) / Compression (-) Forces (kips)</th>
<th>2D Model</th>
<th>3D Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane</td>
<td>-66</td>
<td>104</td>
<td>431</td>
</tr>
<tr>
<td>Truck</td>
<td>-66</td>
<td>107</td>
<td>437</td>
</tr>
<tr>
<td>Lane + Truck</td>
<td>-132</td>
<td>211</td>
<td>868</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Swan River Plate Girder

<table>
<thead>
<tr>
<th>Loading</th>
<th>Mid-span Bending Moment (kip-ft.)</th>
<th>2D Model</th>
<th>3D Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane</td>
<td>3364</td>
<td>1716</td>
<td></td>
</tr>
<tr>
<td>Truck</td>
<td>4537</td>
<td>2428</td>
<td></td>
</tr>
<tr>
<td>Lane + Truck</td>
<td>7901</td>
<td>4144</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>
## Distribution Factors

<table>
<thead>
<tr>
<th>Steel system</th>
<th>Distribution factors</th>
<th>3D/2D ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moment</td>
<td>Shear</td>
</tr>
<tr>
<td>Swan River plate girder</td>
<td>0.67</td>
<td>0.87</td>
</tr>
<tr>
<td>Hybrid steel truss</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Select a distribution factor of 0.75
- Approximately centered between 0.93 and 0.5
- Approximately centered between 0.67 and 0.87

More representative comparison to Swan River plate girder
Bolted Connections

12 bolt, 8 bolt, and 6 bolt connections were designed.
Construction Configurations Considered

(a) Plate Girder

(b) Truss 1

(c) Truss 2

Conventional construction

Accelerated construction
# Truss Member Sizes

## Truss 1 (1 splice)

<table>
<thead>
<tr>
<th>Span</th>
<th>Deck Thickness</th>
<th>Top Chord Member</th>
<th>Bottom Chord Member</th>
<th>Vertical Member</th>
<th>Diagonal Member</th>
<th>Steel Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>205 ft</td>
<td>8 in.</td>
<td>WT18x116 / WT18x128</td>
<td>WT20x162 / WT18x181</td>
<td>W10x39</td>
<td>MC10x28.5 / MC10x22 / MC8x18.7</td>
<td>80 kips</td>
</tr>
</tbody>
</table>

15% reduction in steel weight from plate girder

## Truss 2 (2 splice)

<table>
<thead>
<tr>
<th>Span</th>
<th>Deck Thickness</th>
<th>Top Chord Member</th>
<th>Bottom Chord Member</th>
<th>Vertical Member</th>
<th>Diagonal Member</th>
<th>Steel Weight</th>
</tr>
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<tbody>
<tr>
<td>205 ft</td>
<td>8 in.</td>
<td>WT16.5x65</td>
<td>WT20x162 / WT18x181</td>
<td>W10x39</td>
<td>MC10x28.5 / MC10x22 / MC8x18.7</td>
<td>68 kips</td>
</tr>
</tbody>
</table>

28% reduction in steel weight from plate girder
Splice Connections

Truss 1 (single splice)

- Side PLs $1\frac{1}{2} \times 14\frac{1}{2} \times 2'\cdot8''$ w/ 40 - $\frac{7}{8}''$ Diameter A490 Bolt

- Bot. PL $1\frac{1}{2} \times 16 \times 3'\cdot2''$ w/ 24 - $\frac{7}{8}''$ Diameter A490 Bolt

(a) Top Chord

(b) Bottom Chord

Truss 2 (two splices)

- Side PLs $1\frac{1}{2} \times 14\frac{1}{2} \times 2'\cdot2''$ w/ 32 - $\frac{7}{8}''$ Diameter A490 Bolt

- Bot. PL $1\frac{1}{2} \times 14\frac{1}{2} \times 2'\cdot8''$ w/ 20 - $\frac{7}{8}''$ Diameter A490 Bolt

(a) Top Chord

(b) Bottom Chord

224 bolts for two chord splices compared with 552 bolts for two plate girder splices

560 total bolts in Truss 2
Materials and Fabrication Cost

<table>
<thead>
<tr>
<th></th>
<th>Plate Girder</th>
<th>Truss 1</th>
<th>Truss 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allied Steel</td>
<td>$135,000</td>
<td>$105,000</td>
<td>$94,000</td>
</tr>
<tr>
<td>AVEVA</td>
<td>$95,000</td>
<td>$103,000</td>
<td>$85,000</td>
</tr>
<tr>
<td>RTI Fabrication</td>
<td>$126,000</td>
<td>$112,000</td>
<td>$84,000</td>
</tr>
<tr>
<td>Average</td>
<td>$119,000</td>
<td>$107,000</td>
<td>$88,000</td>
</tr>
</tbody>
</table>

Cost savings: 10% 26%

Other potential savings

- Bolted diagonal member connections less expensive than welded connections
- Camber could be built in to bolted and welded connections (heat curving not required)
- Inspections not required for vertical member fillet welds
# Shipping Considerations

<table>
<thead>
<tr>
<th>Member Lengths (ft.)</th>
<th>Approximate Weight (kips)</th>
<th>Steel</th>
<th>Concrete Deck</th>
<th>Total Lift Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate Girder (2 splices)</td>
<td>62.5 / 80 / 62.5</td>
<td>27 / 37 / 27</td>
<td>-</td>
<td>27 / 37 / 27</td>
</tr>
<tr>
<td>Truss 1 (conventional construction, 1 splice)</td>
<td>108 / 97</td>
<td></td>
<td>42 / 38</td>
<td></td>
</tr>
<tr>
<td>Truss 2 (accelerated construction, 2 splices)</td>
<td>66.7 / 71.8 / 66.7</td>
<td>22 / 24 / 22</td>
<td>58 / 63 / 58</td>
<td>80 / 87 / 80</td>
</tr>
</tbody>
</table>

- 3 trusses delivered on single truck without permit
- 1 truss with concrete deck delivered on single truck without permit

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**Shipping Guidelines for Montana, MDT, 2006**

<table>
<thead>
<tr>
<th>Gross Legal Load</th>
<th>Up to 120,000 lbs., depending on trailer/axle combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flag Vehicle Requirements</td>
<td>One flag vehicle for loads &gt; 120 ft. on interstate One flag vehicle for loads &gt; 110 ft. on non-interstate</td>
</tr>
<tr>
<td>Permit Requirements</td>
<td>Lengths over 75 ft.</td>
</tr>
</tbody>
</table>
Erection Considerations

• Many variables to consider
  • site access and available staging
  • bridge replacement or new alignment?

• Sletten Construction preferred Truss 1 (single splice)
  • lighter weight
  • only one temporary support required
Erection Considerations

• Dick Anderson Construction preferred Truss 2 (two splices)
  • shorter members provide easier transportation, site access, unloading and staging
  • accelerated construction alternative could be an alternative to precast decked bulb tee systems

• Decked Bulb Tee Systems
  • capable of spanning up to 160 ft, but length and weight creates transportation and site access issues
Conclusions

• The bolted member end connections meet Detail Category B requirements from AASHTO and have a threshold fatigue stress that is approximately 3.5 times greater than the welded connection Detail Category E. The bolted connections are able to meet design requirements for an infinite life design using the Fatigue I load combination.
Conclusions

• A 3D analysis of the steel truss using geometry from the plate girder bridge over the Swan River reduced the loads to the truss members by approximately 50%. For the bridge geometry and loading considered, a distribution factor of 0.75 was selected as a representative value between the conservative lever rule and more sophisticated 3D analysis.
Conclusions

• Significantly larger top chord members were required for the conventional construction method to support the construction loads required for casting the deck after erection. The total steel weight of the truss using the larger top chord member increased by 18% (80k for conventional construction, 68k for accelerated (precast deck)).
Conclusions

• The steel weight of the bolted and welded steel trusses assuming conventional and accelerated construction were 15% and 28% less than the steel weight of the Swan River plate girders. Materials and fabrication prices suggest a reduction in cost of up to 10% and 26% for the two construction alternatives, respectively.
Conclusions

• A single splice across the bridge span and two splices for accelerated construction methods were considered. Input from erection and construction professionals indicate preferred splice locations is largely dependent on site and construction conditions.
Questions?
Implementation Recommendations

1. Meet with Allied Steel and Dick Anderson Construction to discuss potential bridge crossing sites and truss geometry for successful implementation of either conventional or accelerated construction methods.

2. Evaluate the performance of the Maxwell Coulee bridge (22 miles E. of Jordan, MT) for joint performance and concrete deck condition.
Implementation Recommendations

3. Complete a final design of the steel truss for a selected bridge crossing with input from erector, fabricator, and Maxwell Coulee observations.

4. Implement a monitoring and evaluation program for constructed hybrid steel truss bridge.