Investigation of Prefabricated Steel Truss Bridge Deck Systems

Final Presentation and Implementation Meeting

Damon Fick Tyler Kuehl

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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.

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

- 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.

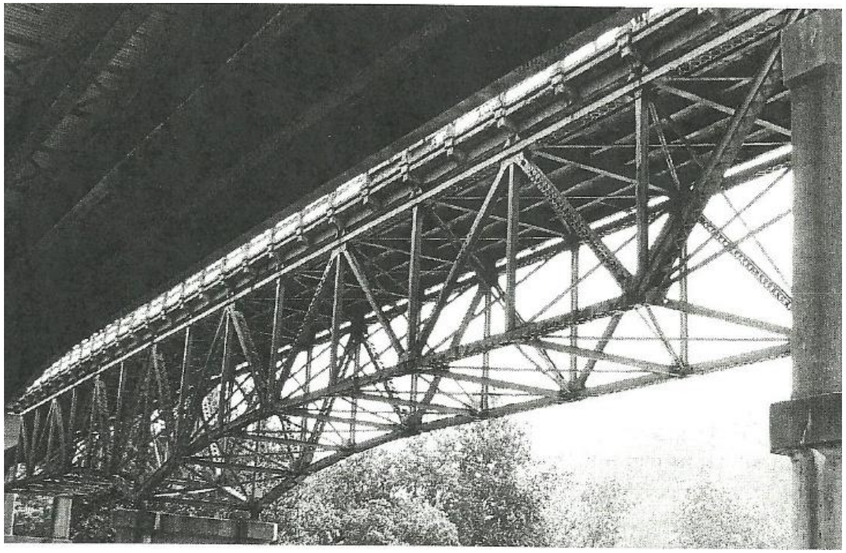
Double angle connection, Battistini et al. 2014

- 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

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

Joint restraint should be considered



Hillsville Truss (Hickey et al. 2009)

Analytical Evaluation

Proposed Truss Designs by Allied Steel, Inc.

Option	Span	Deck Thickness	Top Chord Member	Bottom Chord Member	Vertical Member	Diagonal Member	Steel Weight
1	148 ft.	7 in.	WT12x38	WT18x97 / WT20x147	HSS6x6 / HSS5x5	LL5x3 / LL6x3 / LL7x4	29,100 lbs.
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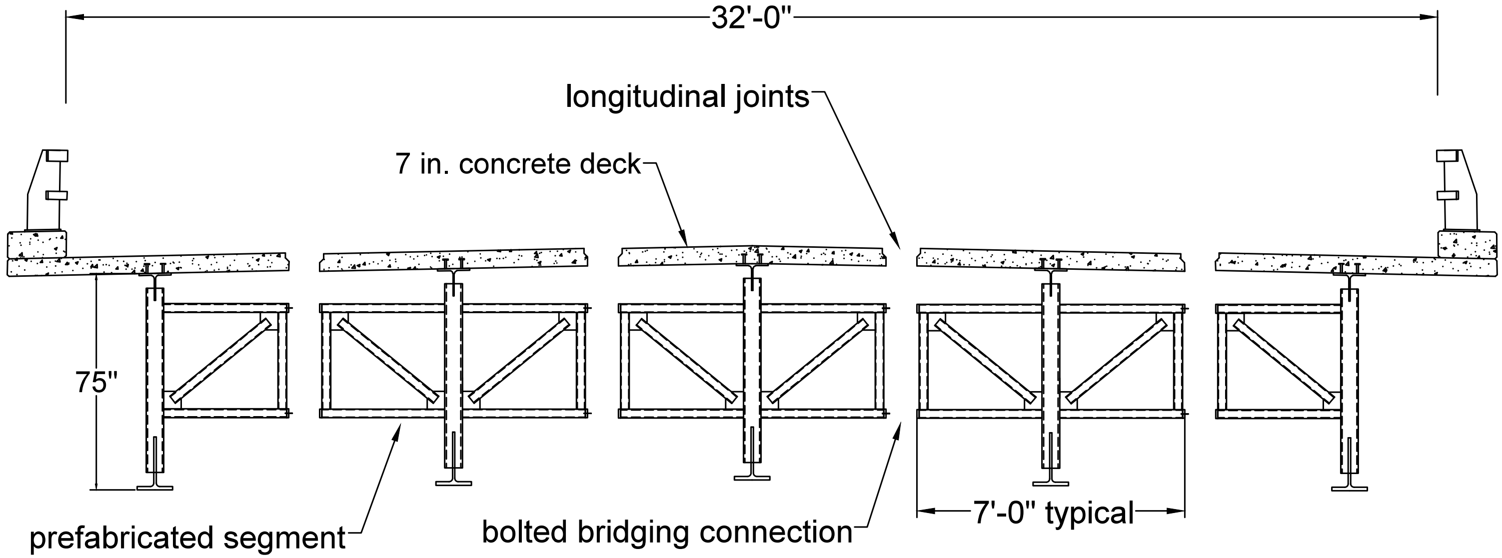
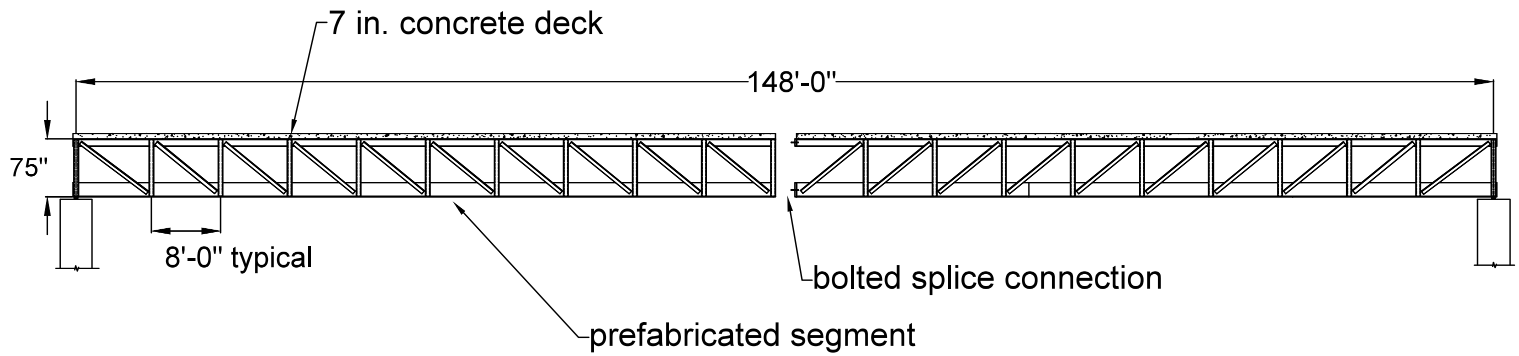
3	108 ft.	8-1/4 in.	PL3/4x12	PL1-3/4x12 / PL2x6	W8x18-24	PL1x6	18,080 lbs.

Option 1 was selected for preliminary analysis

Bridge Geometry

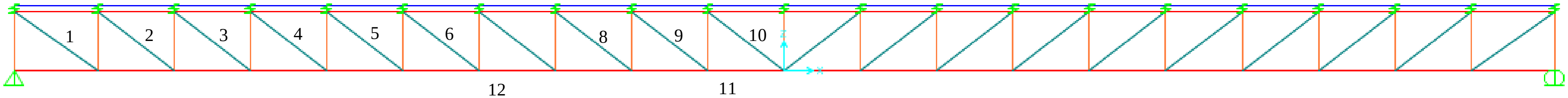


(a) Cross-Section



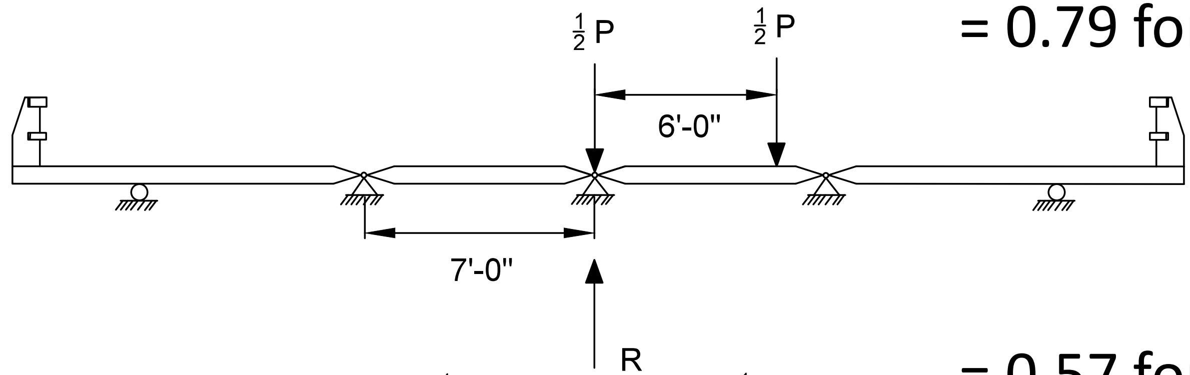
(b) Elevation

2D Finite Element Model (SAP 2000)

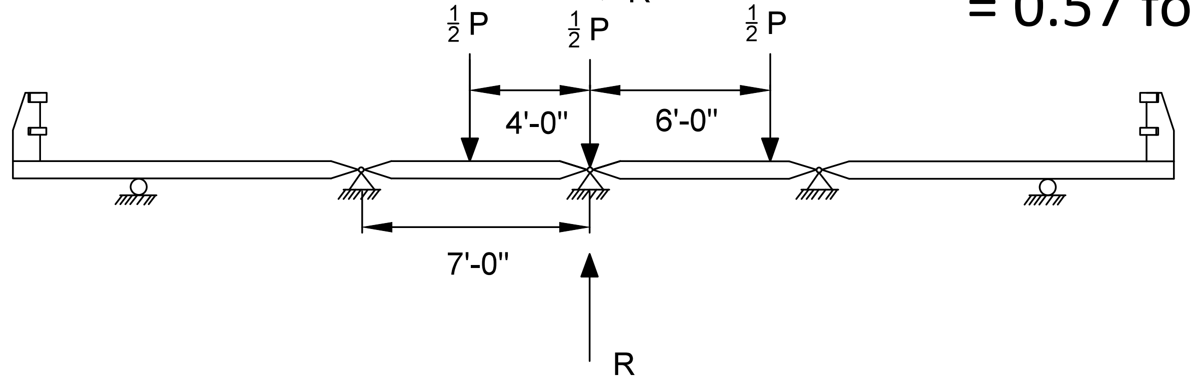


Lever Rule Distribution Factors

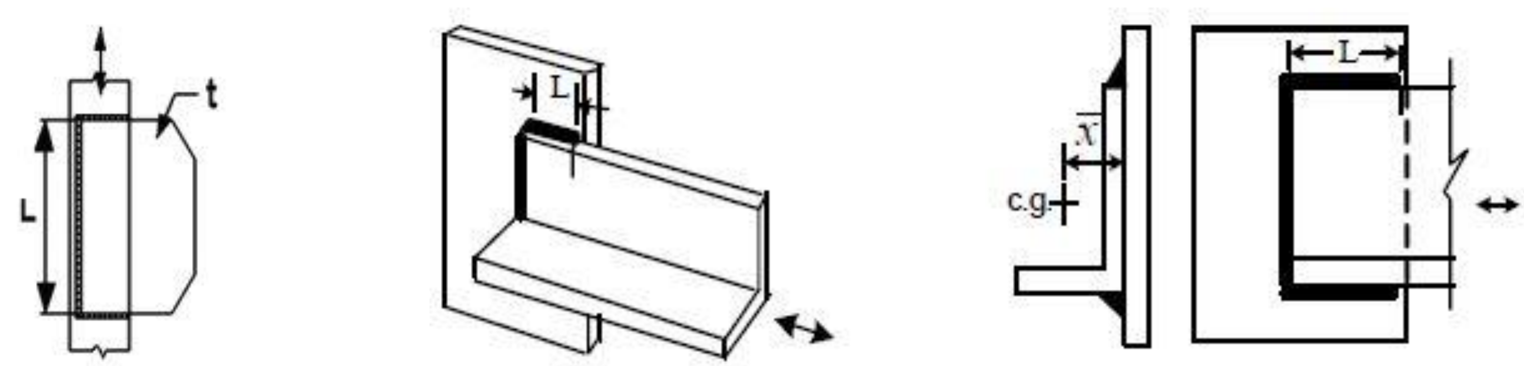
= 0.79 for Strength I



= 0.57 for Fatigue I



Fatigue Thresholds



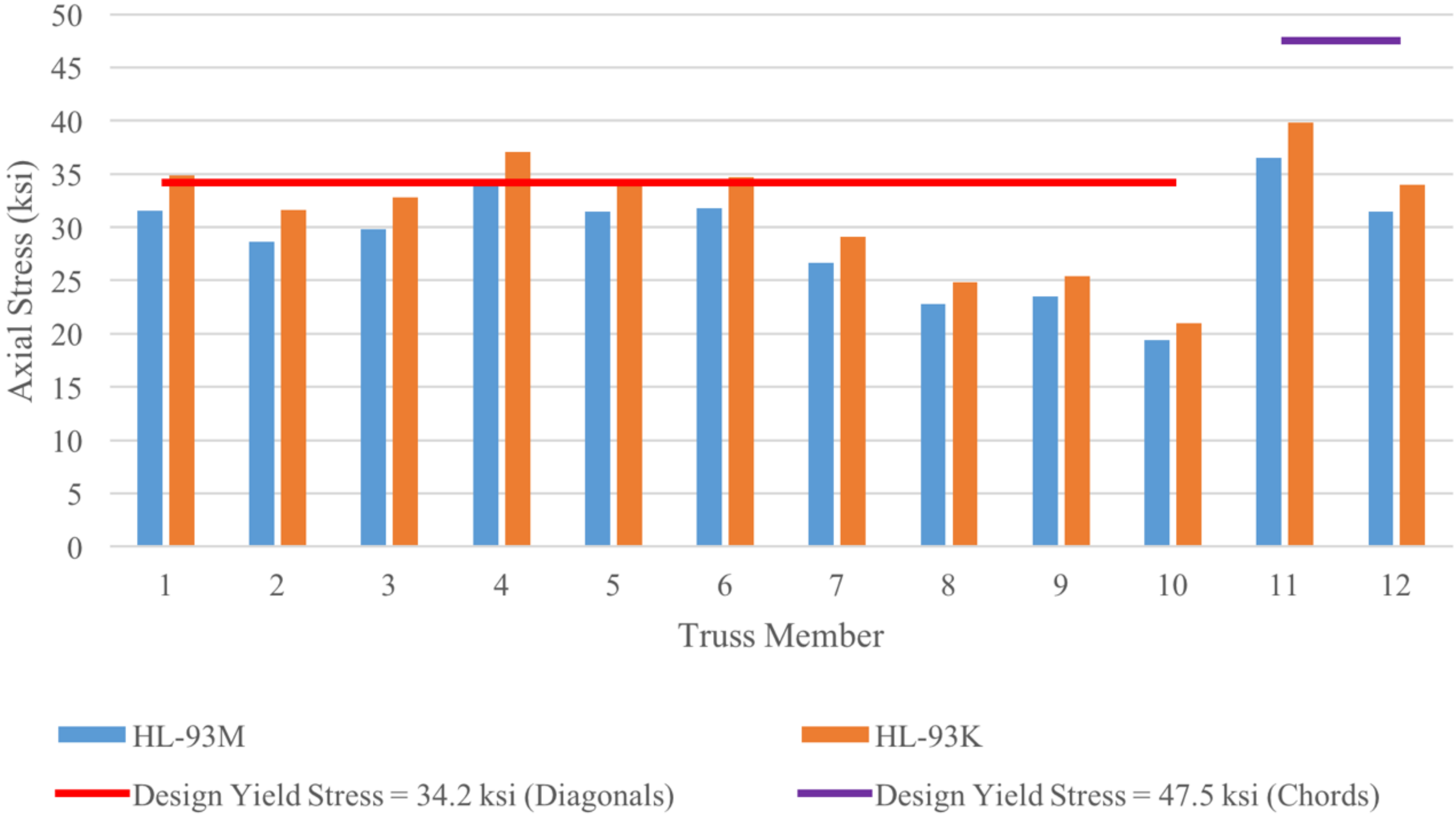
(a) (b)

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

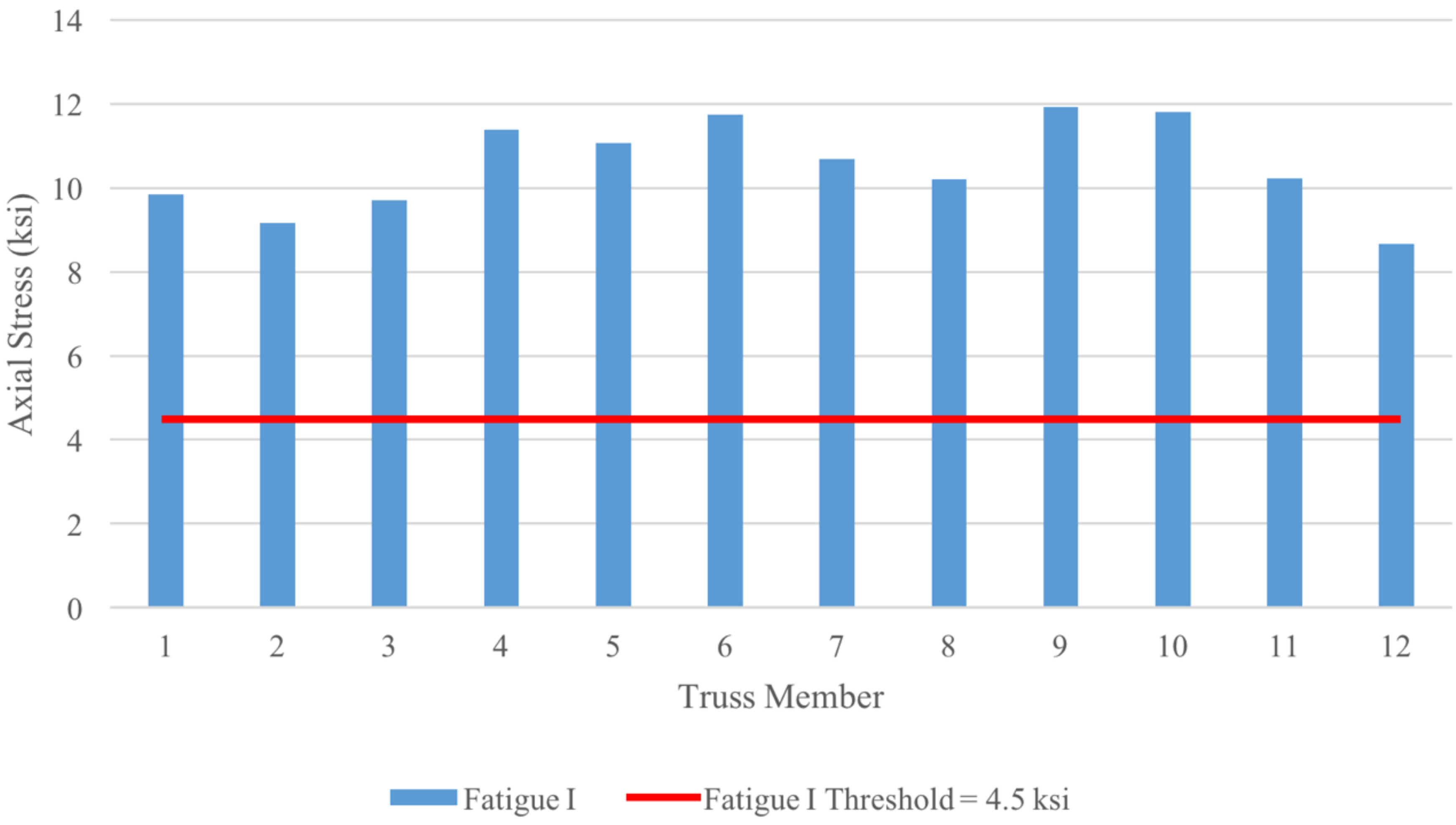
Fatigue I = 4.5 ksi (infinite life)

Fatigue II = 6.4 ksi (75-year life)

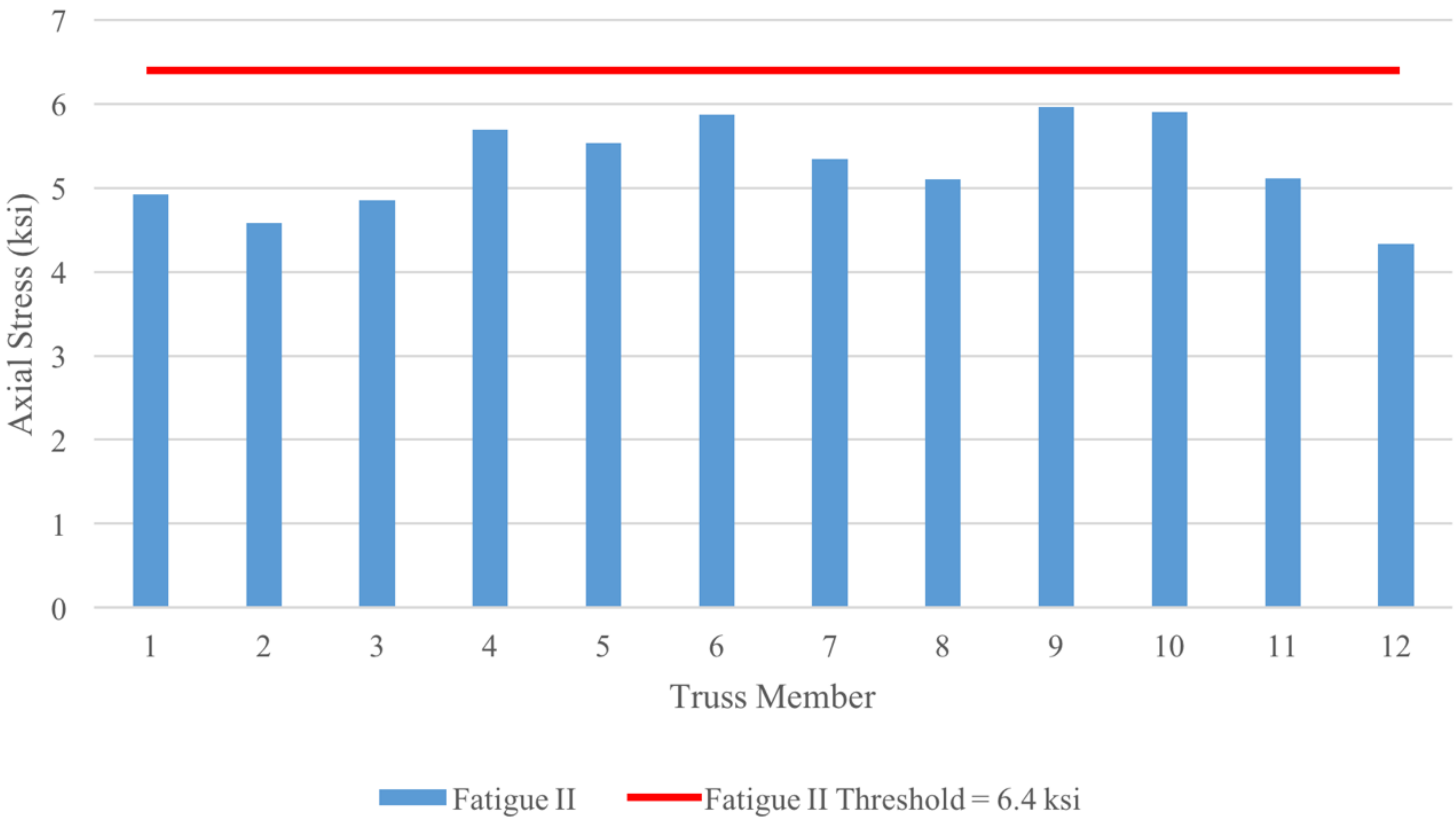
Strength I Load Combination



Fatigue I Load Combination



Fatigue II Load Combination



Materials and Fabrication Cost

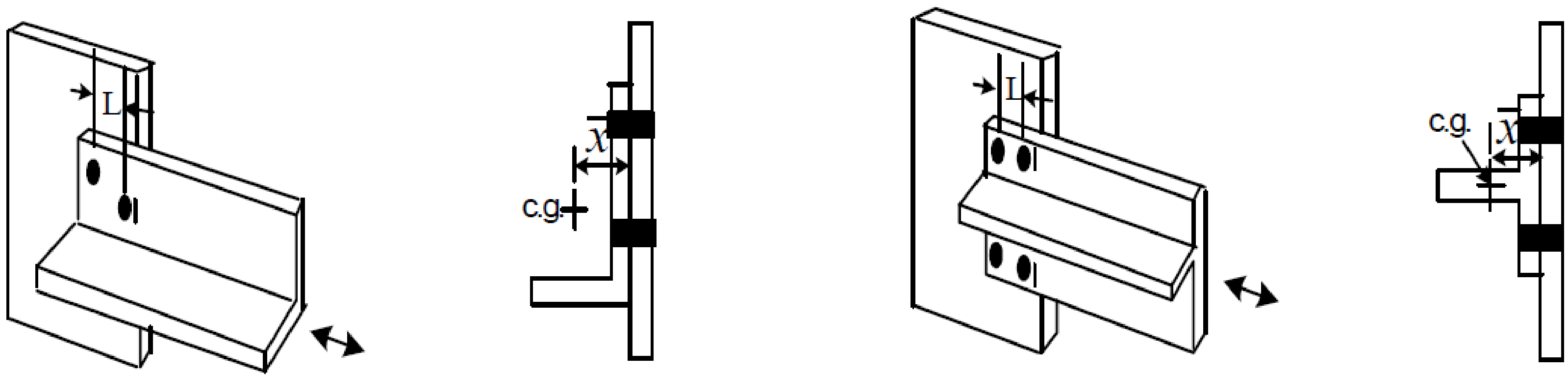
	Option 1	Option 2	Plate Girder	% Difference (minimum)
AVEVA	$45,950	$43,210	$48,120	5
RTI Fabrication	$40,740	$40,320	$51,190	20
Allied Steel	$42,210	$42,210	$49,660	15

Observations:

- Competitive with plate girder
- Undesirable 75-year design life limitation

Proposed Hybrid Truss

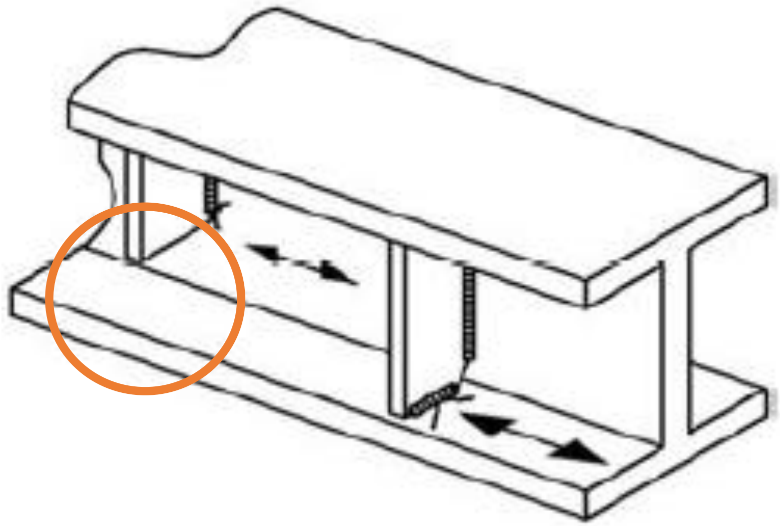
- Bolted connections between diagonal members and top and bottom chords:



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)

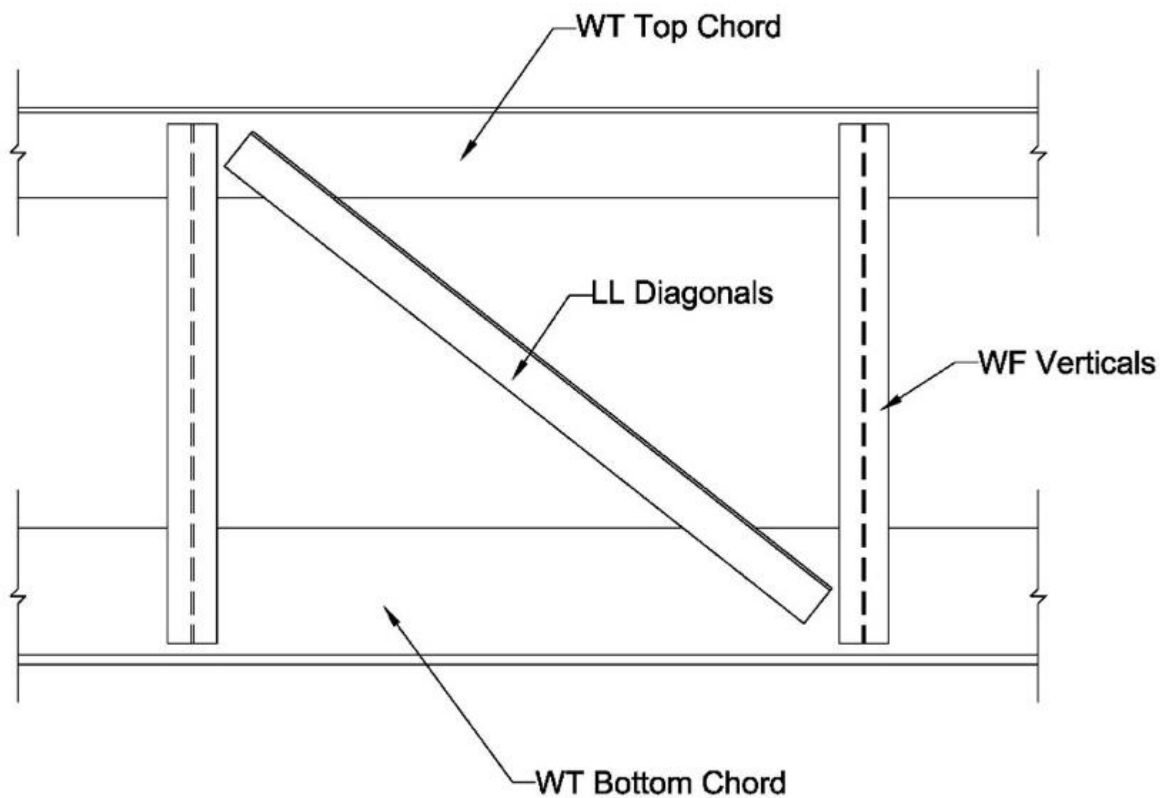
Welded Vertical Member Connections



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

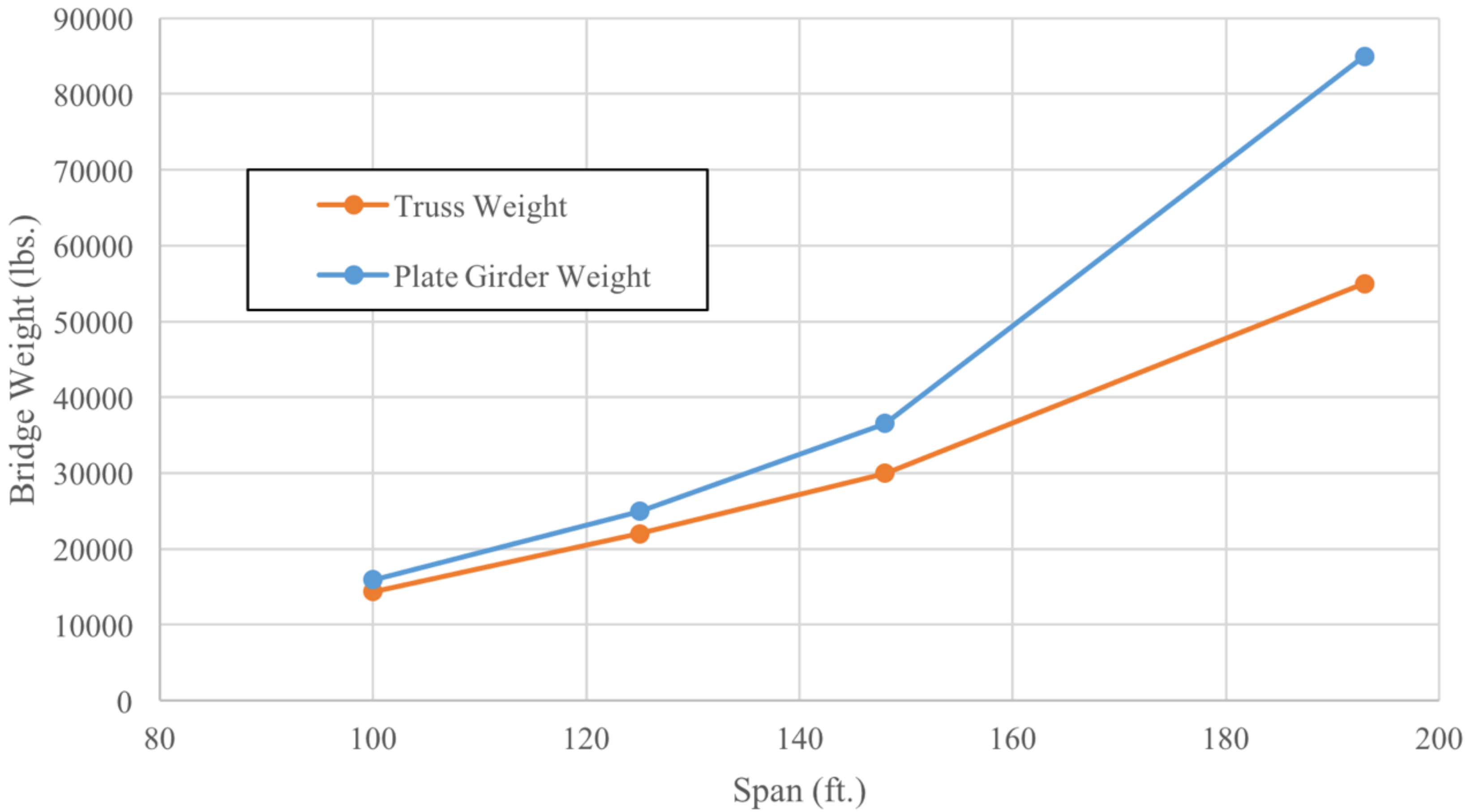
Fatigue I = 12.0 ksi (infinite life)

Wide Flange Vertical Members



Heavier than HSS verticals, but less expensive per pound

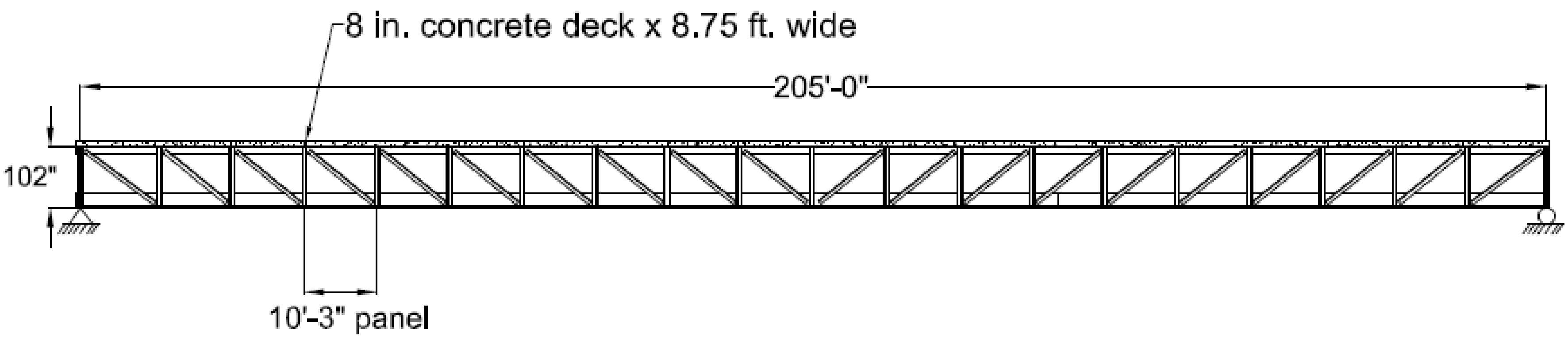
Increased Span Length



Selected Geometry

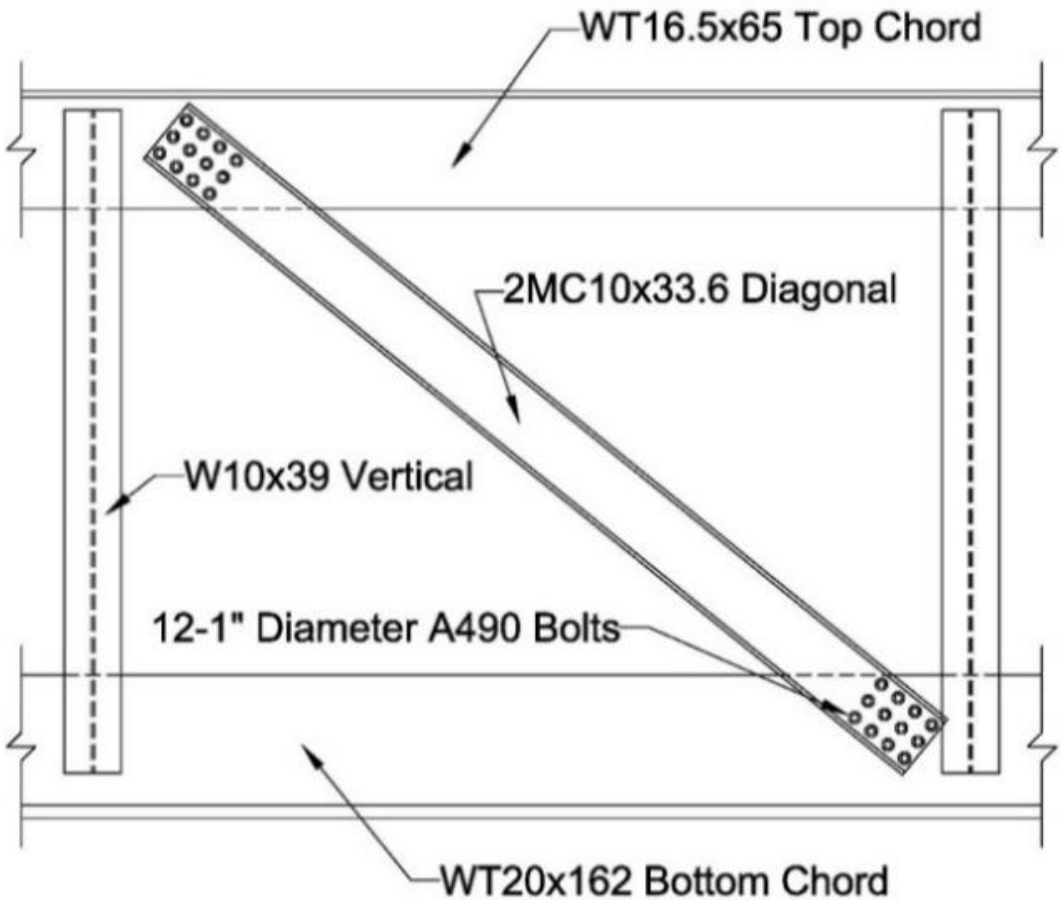
Span	Deck Thickness	Top Chord Member	Bottom Chord Member	Vertical Member	Diagonal Member	Steel Weight
205 ft.	8 in.	WT16.5x65	WT20x162 / WT16.5x193.5	W10x39	MC10x33.6 / MC10x25 / MC8x18.7	69,000 lbs.

?

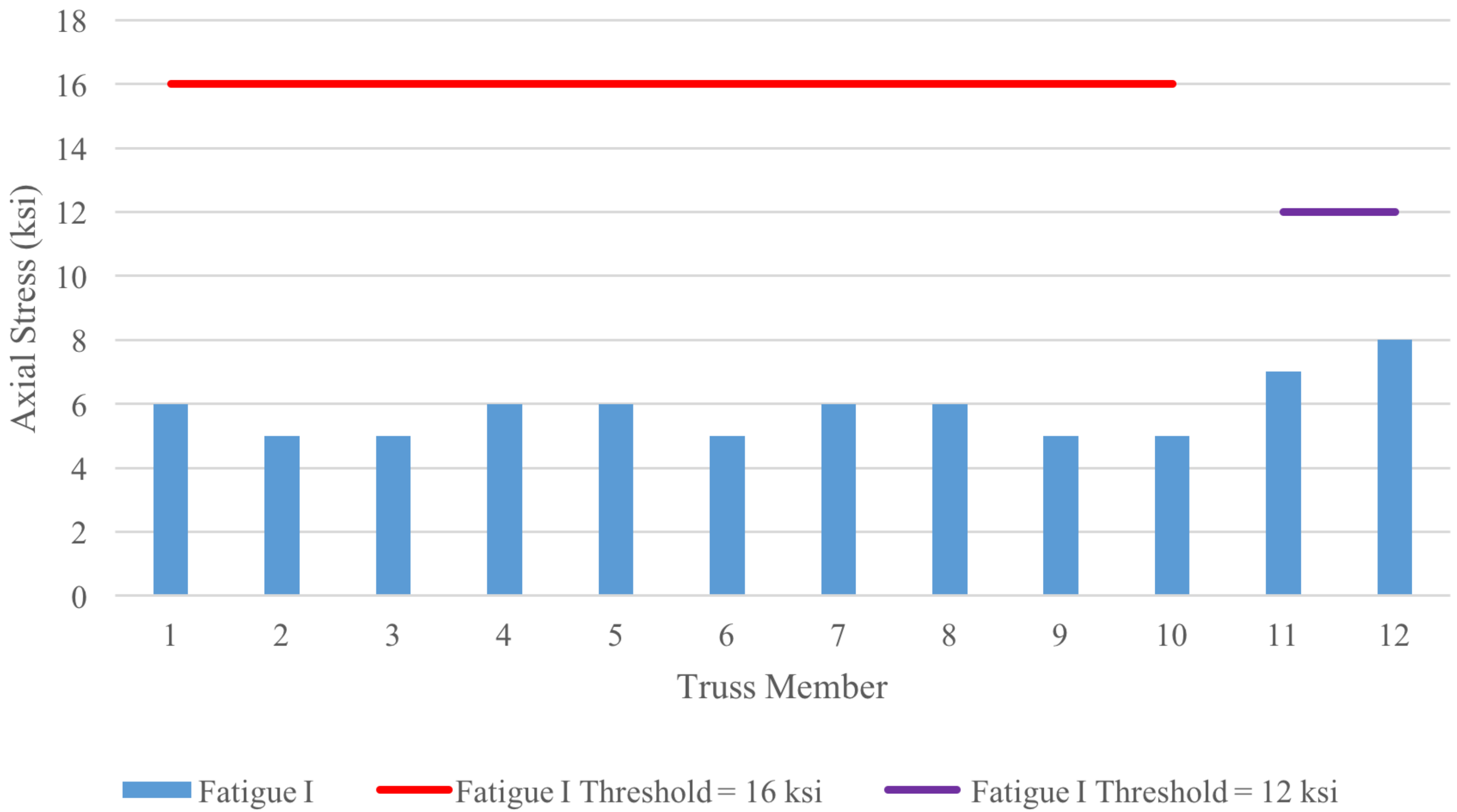


Comparable to Swan River plate project, designed by MDT

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

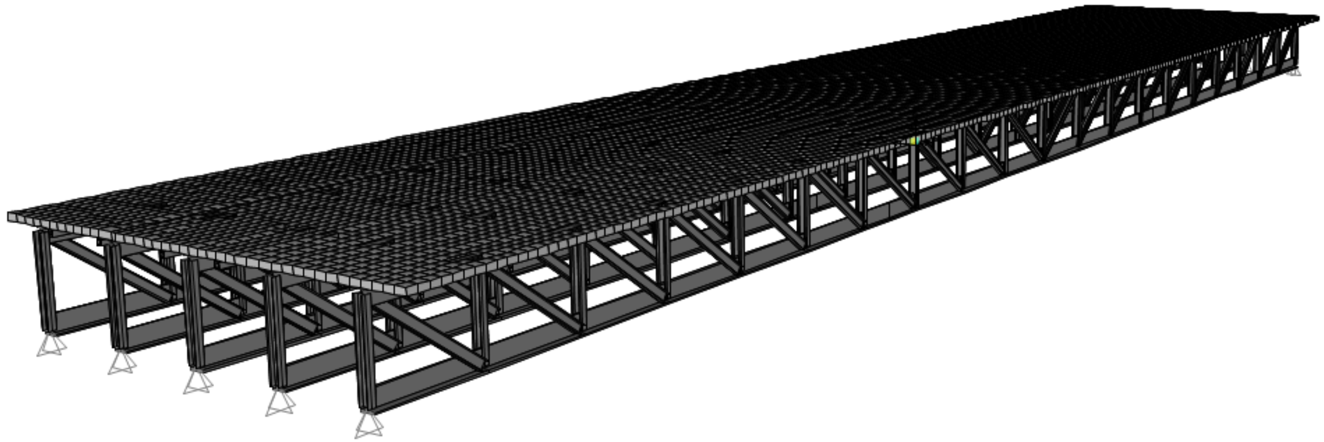
Proposed Hybrid Truss

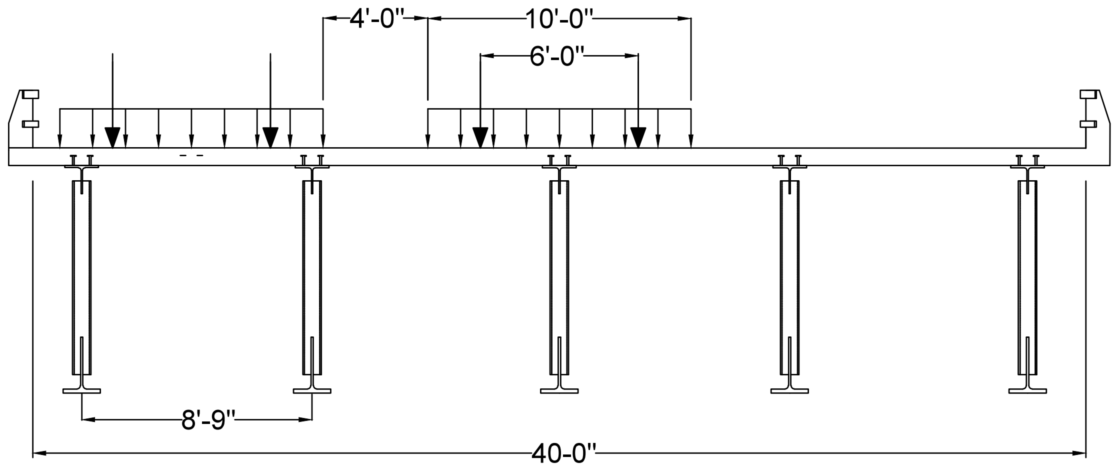
- Create a 3D finite element model to evaluate distribution factors calculated using lever rule (0.93)

- 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

Loading	Maximum Tension (+) / Compression (-) Forces (kips)					
	2D Model			3D Model		
	Vertical	Diagonal	Bot. Chord	Vertical	Diagonal	Bot. Chord
Lane	-66	104	431	-37	56	273
Truck	-66	107	437	-36	52	172
Lane + Truck	-132	211	868	73	108	445
			3D / 2D Ratio	0.55	0.51	0.51

Swan River Plate Girder

Loading	Mid-span Bending Moment (kip-ft.)	
	2D Model	3D Model
Lane	3364	1716
Truck	4537	2428
Lane + Truck	7901	4144
	3D / 2D Ratio	0.52

Distribution Factors

Steel system	Distribution factors			3D/2D ratio
	Moment	Shear	Lever rule	
Swan River plate girder	0.67	0.87	-	0.52
Hybrid steel truss			0.93	0.51 - 0.55

Select a distribution factor of 0.75

- Approximately centered between 0.93 and 0.5
- Approximately centered between 0.67 and 0.87

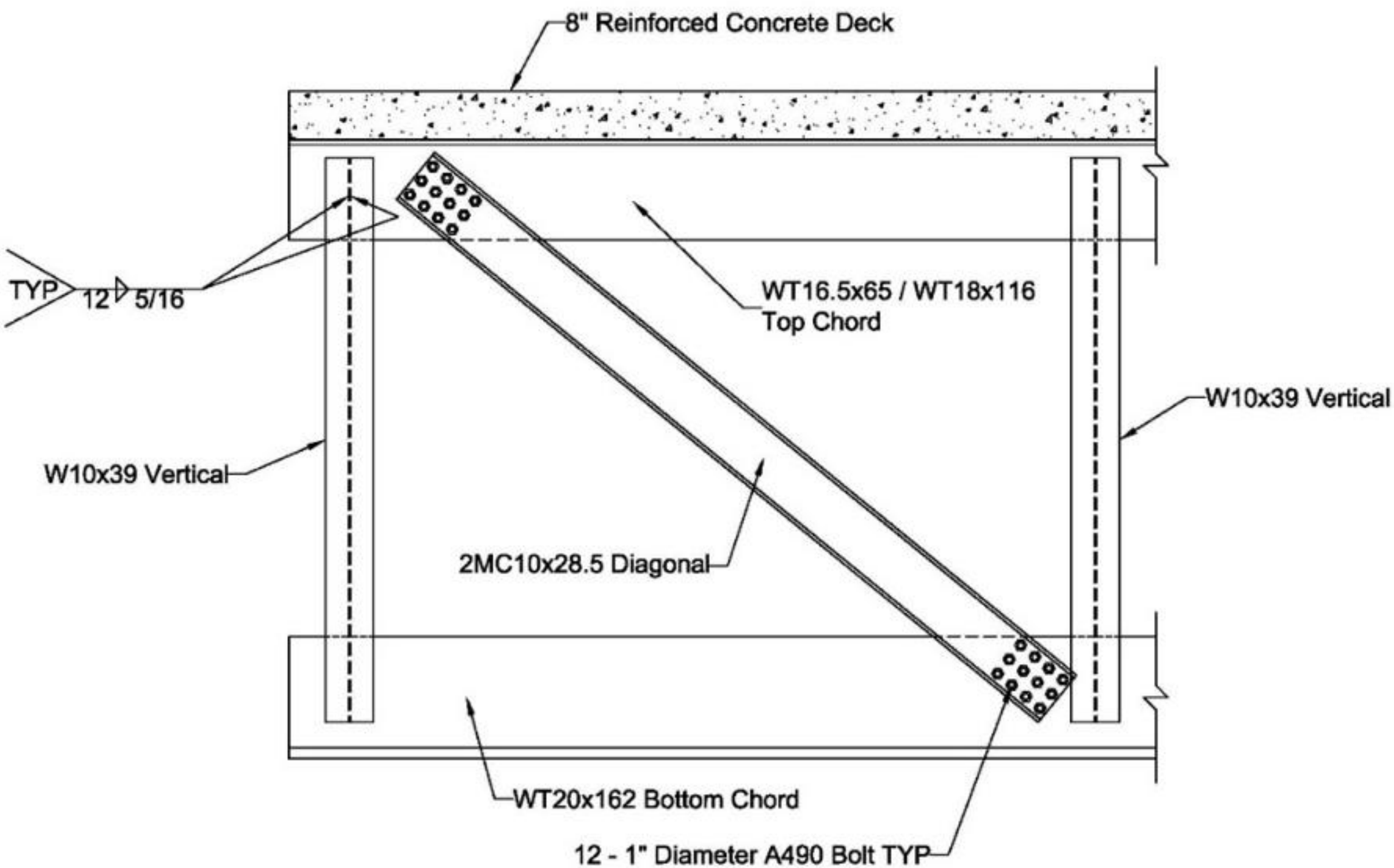
More representative comparison to Swan River plate girder

Bolted Connections

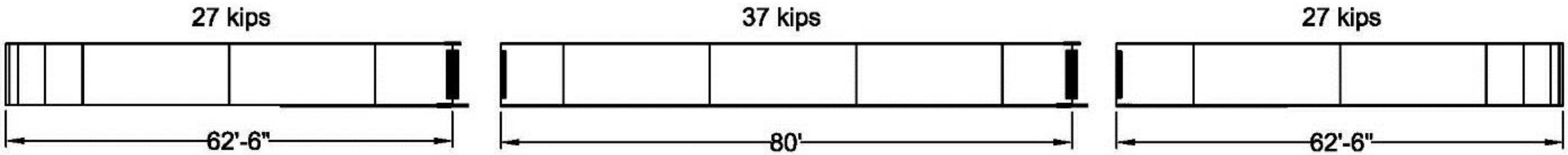
support

midspan

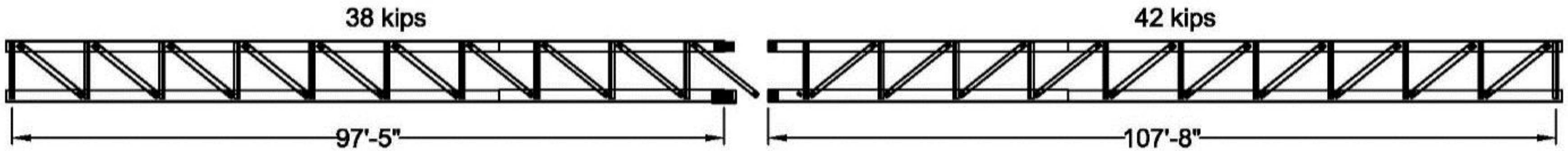
12 bolt, 8 bolt, and 6 bolt connections were designed



Construction Configurations Considered

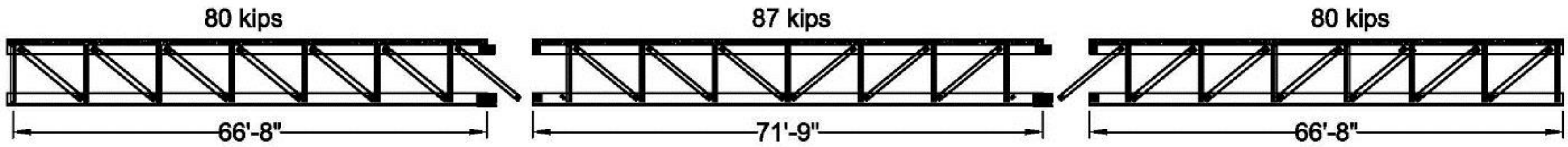


(a) Plate Girder



(b) Truss 1

Conventional construction



(c) Truss 2

Accelerated construction

Truss Member Sizes

Truss 1 (1 splice)

Span	Deck Thickness	Top Chord Member	Bottom Chord Member	Vertical Member	Diagonal Member	Steel Weight
205 ft.	8 in.	WT18x116 / WT18x128	WT20x162 / WT18x181	W10x39	MC10x28.5 / MC10x22 / MC8x18.7	80 kips

15% reduction in steel weight from plate girder

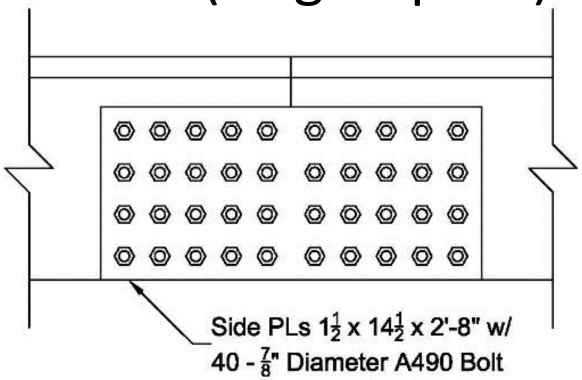
Truss 2 (2 splice)

Span	Deck Thickness	Top Chord Member	Bottom Chord Member	Vertical Member	Diagonal Member	Steel Weight
205 ft.	8 in.	WT16.5x65	WT20x162 / WT18x181	W10x39	MC10x28.5 / MC10x22 / MC8x18.7	68 kips

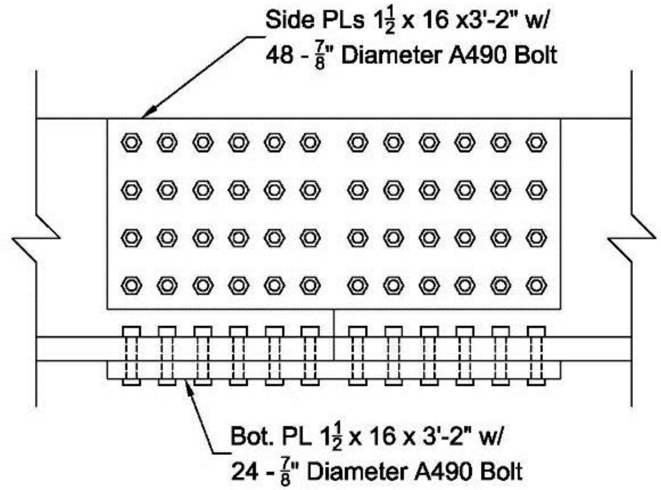
28% reduction in steel weight from plate girder

Splice Connections

Truss 1 (single splice)

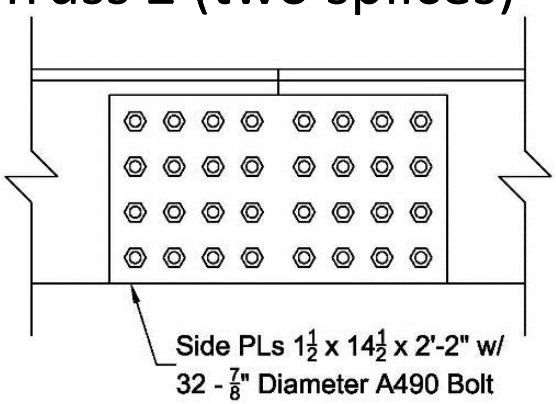


(a) Top Chord

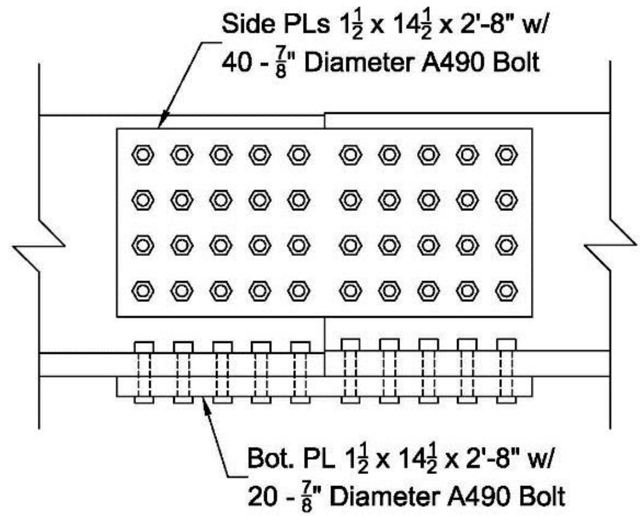


(b) Bottom Chord

Truss 2 (two splices)



(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

	Plate Girder	Truss 1	Truss 2
Allied Steel	$135,000	$105,000	$94,000
AVEVA	$95,000	$103,000	$85,000
RTI Fabrication	$126,000	$112,000	$84,000
Average	$119,000	$107,000	$88,000

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

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

3 trusses delivered on single truck without permit

1 truss with concrete deck delivered on single truck without permit

Shipping Guidelines for Montana, MDT, 2006

Gross Legal Load	Up to 120,000 lbs., depending on trailer/axle combination
Flag Vehicle Requirements	One flag vehicle for loads > 120 ft. on interstate One flag vehicle for loads > 110 ft. on non-interstate
Permit Requirements	Lengths over 75 ft.

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.