'20-'21

NAU Steel Bridge Team

CENE 486C
April 16, 2021

Members: Tatianna Smith, Emma Keiser, M Eric Barton, Joshua Lamphier, and Aadil Farried

Client: Mark Lamer

Introduction - Last Team's Bridge: A Baseline

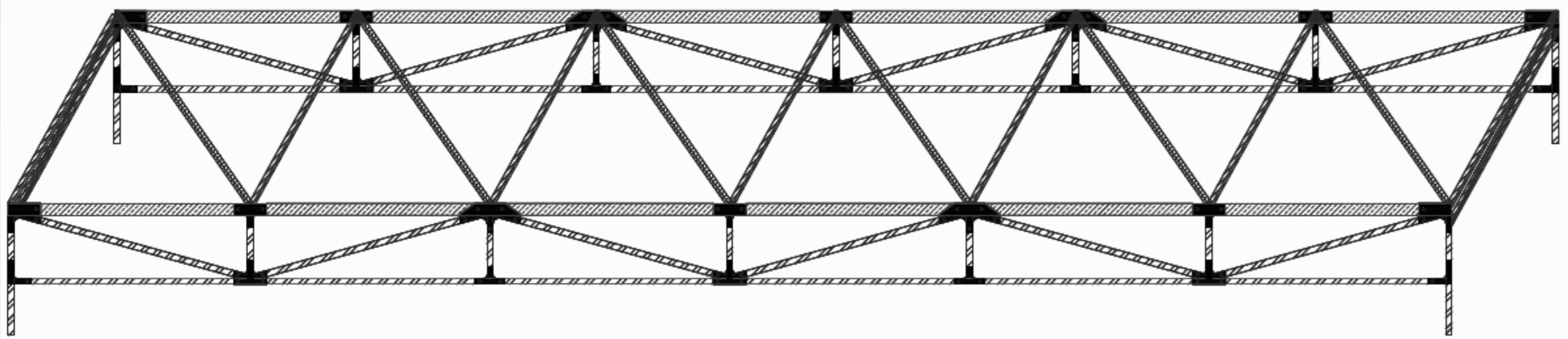


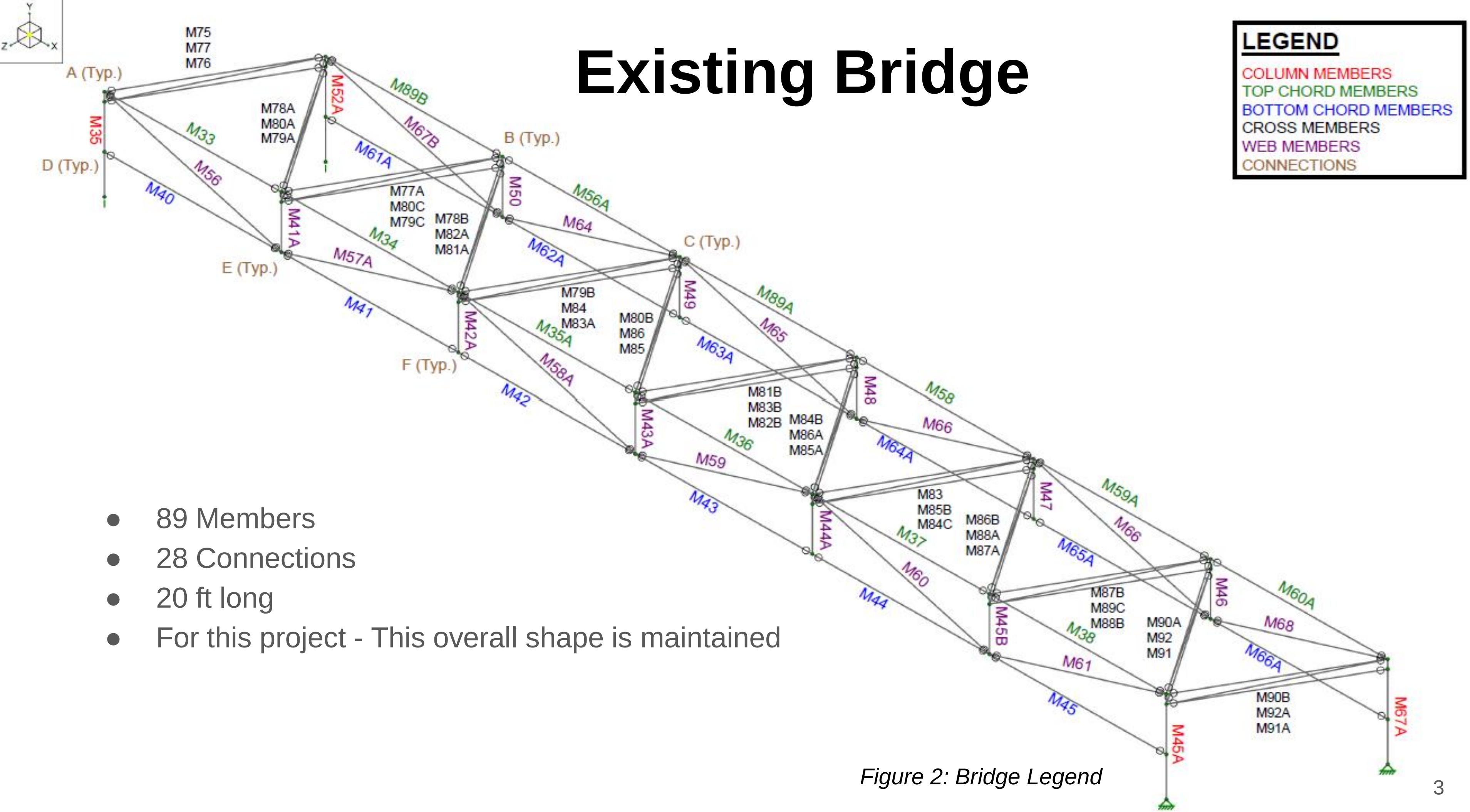
Figure 1: Bridge Overview

- Determined maximum load capacities of the existing bridge
- Used these capacities as a baseline for improvement for this year
- Maintained previous year's bridge shape
- Designed NEW connections to increase overall bridge capacity
    - Focused on industry standards for steel design and manufacturing
- Analyzed new connections
- Predicted new bridge weak points
- Fabricated new bridge design

End goals:

- **Increase load capacity**
- **Create predicted vs. actual performance report**

Existing Bridge



- 89 Members
- 28 Connections
- 20 ft long
- For this project - This overall shape is maintained

Figure 2: Bridge Legend

Existing Connections

- Designed to cut down assembly time
- These were analyzed and redesigned to improve the overall bridge capacity
- The redesigned connections focus on steel design principles

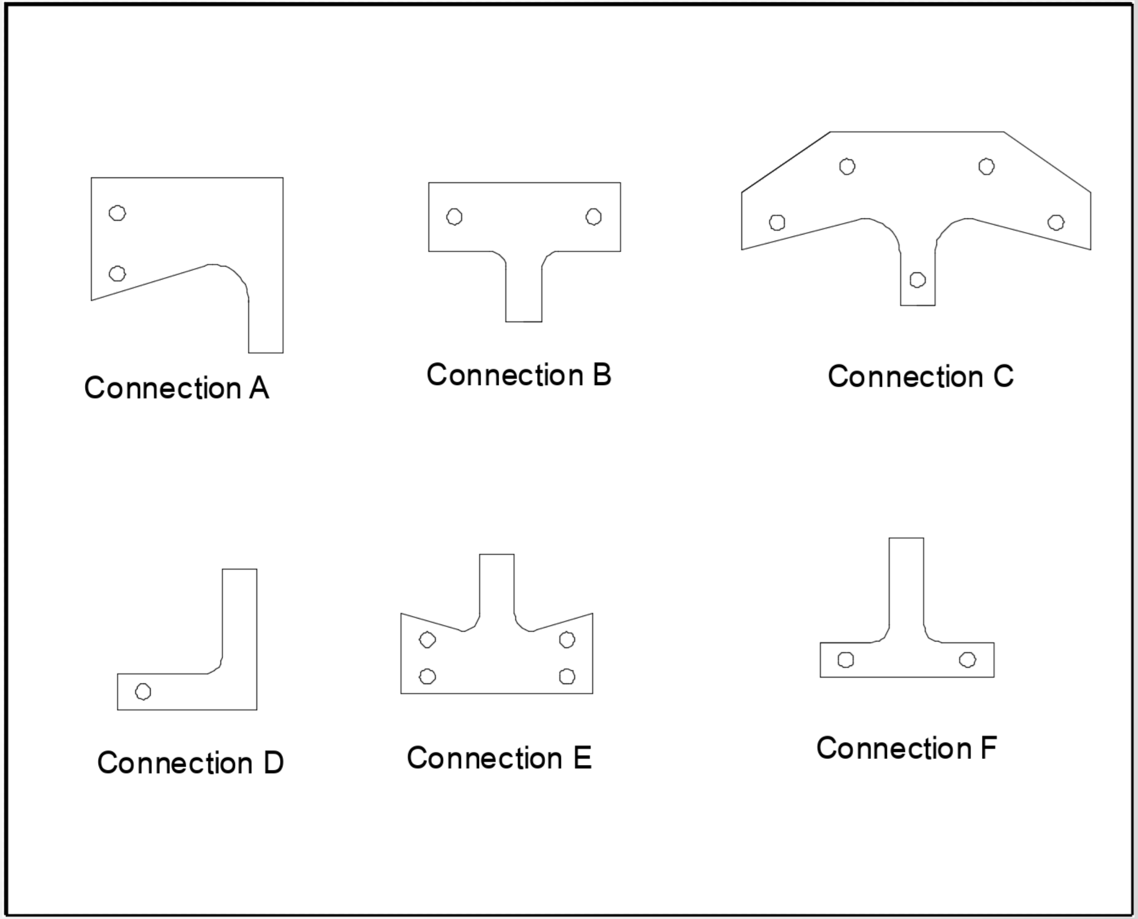


Figure 3: Existing Connections

Capacity Calculations for Existing Connections

- Controlling Capacities
  - Tensile Fracture
  - Bolt Hole Tearout
- Other Capacities Checked
  - Tensile Yielding
  - Bolt Hole Bearing Strength
  - Tensile Strength of Bolts
  - Shear Strength of Bolts

Table 1 : Equations Used to Determine Connection Capacities

Fracture Limit Strength	$\varphi_t P_n = (0.75) F_u A_e$
Tearout Strength At Each Bolt Hole Connection	$\varphi_t R_n = (0.75)\, 1.5 l_c t F_u$

A_e = *Effective net area, in*^{2}

t = *Thickness of connected material, in*

F_u = *Specified minimum tensile strength of the connected material, ksi*

l_c = *Clear distance, in direction of force, between the edge of the hole and the edge of the material*

Figure 4: AISC Steel Construction Manual Logo

Initial Connection Capacities

- Calculated connection capacities for each model and respective bolt hole

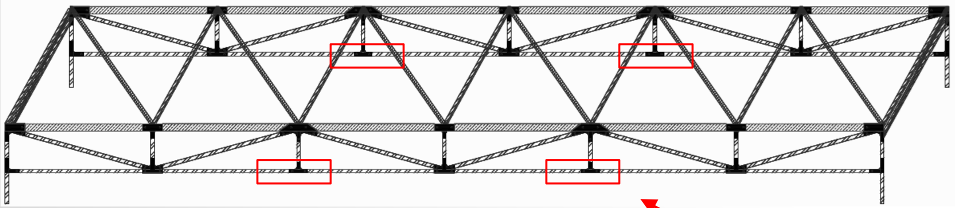


Figure 5: Connection F Locations

Table 2: Existing Connection Capacities

Connection	Controlling Strength Capacity, kips	Description
A1 (top hole)	8.96	Bolt hole tearout
A2 (bottom hole)	8.96	Bolt hole tearout
B	8.96	Bolt hole tearout
C1 (top hole)	12.66	Bolt hole tearout
C2 (middle hole)	8.44	Bolt hole tearout
C3 (bottom hole)	8.96	Bolt hole tearout
D	5.625	Tensile Fracture
E1 (top hole)	10.02	Bolt hole tearout
E2 (bottom hole)	8.96	Bolt hole tearout
F	5.625	Tensile Fracture

Six Different Load Cases Analyzed

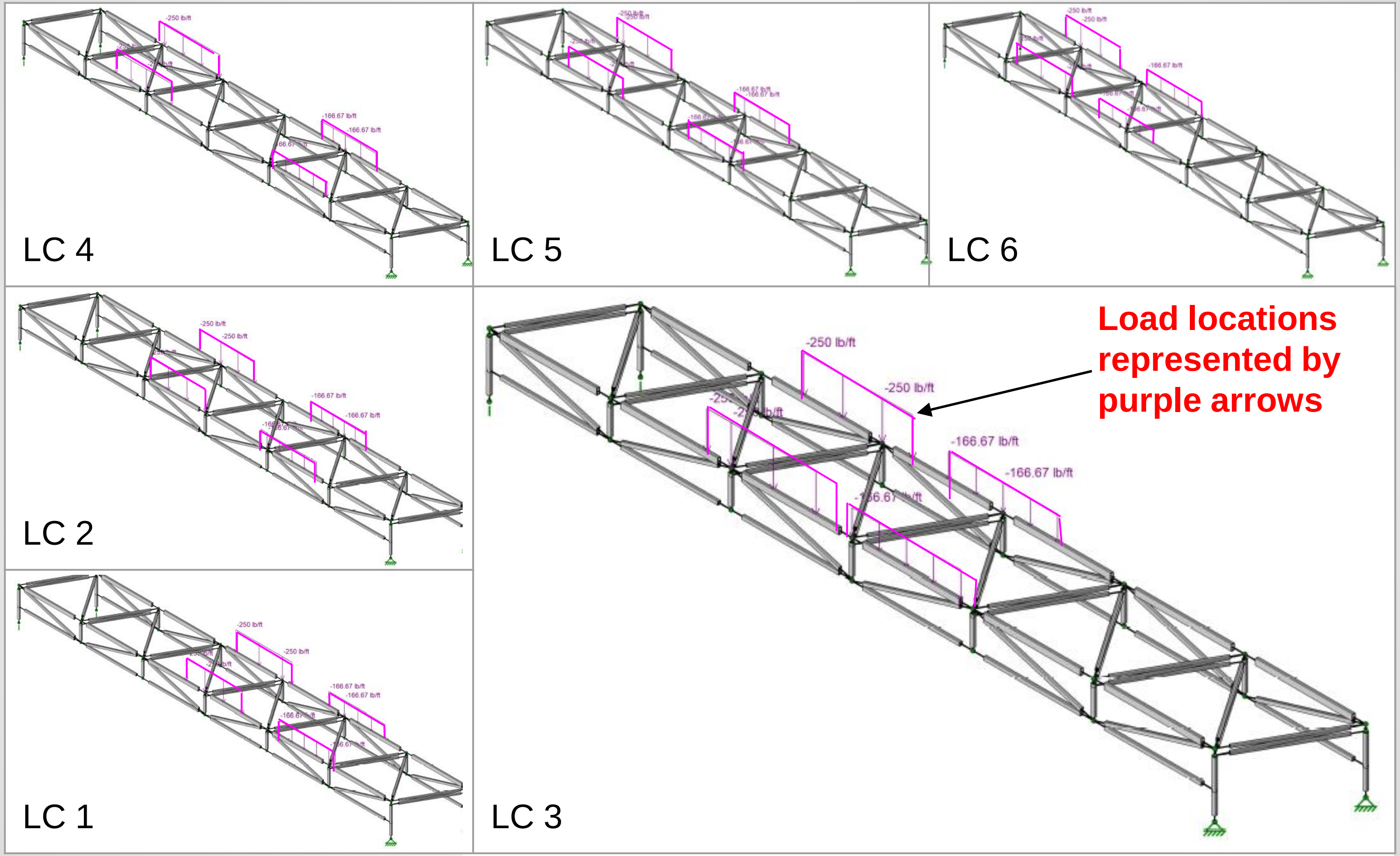


Figure 6: Load Case Models

Internal Axial Forces from RISA

- RISA Modeling
  - Load placed on bridge
  - Internal axial forces returned from RISA
  - Axial forces compared to connection capacities
  - Demand ÷ Capacity shows the % each connection is loaded

Table 3: Capacity Calculations Legend

Legend	
Axial [lb] Column Color Scheme [+] : Compression *(this column only)* [-] : Tension *(this column only)*	Bottom 50% of Force Distribution Values
	Median Values [negligible axial force]
	Top 50% of Force Distribution Values
Demand vs Capacity Column Color Scheme Demonstrates % Loaded for each connection in terms of capacity	Top 50% of Values [Farthest from Failure]
	Median Values [Not Predicted to Fail]
	Bottom 50% of Values [Closest to Failure]
Plan Set ID Color Scheme	Top Chord Members
	Bottom Chord Members
	Vertical Columns at Bridge Ends
	Web Members

Table 4: Capacity Calculations

RISA Label	Plan Set ID	Axial[lb]	Axial[kip]	Connection 1	Connection 2	Connection 1 Capacity, kips	Connection 2 Capacity, kips	Controlling Capacity	% Loaded
M56A	BC	2588.774	-2.59	B	C1	8.96	12.66	8.96	-28.89%
M58	BC	6453.102	-6.45	B	C1	8.96	12.66	8.96	-72.02%
M59A	BC	3053.647	-3.05	B	C1	8.96	12.66	8.96	-34.08%
M60A	AB	3040.53	-3.04	A1	B	8.96	8.96	8.96	-33.93%
M62A	EF	-5072.81	5.07	E2	F	8.96	5.625	5.625	90.18%
M63A	EF	-5055.19	5.06	E2	F	8.96	5.625	5.625	89.87%
M64A	EF	-5598.41	5.60	E2	F	8.96	5.625	5.625	99.53%
M65A	EF	-5563.79	5.56	E2	F	8.96	5.625	5.625	98.91%
M66A	AC	-22.743	0.02	D	E2	5.625	8.96	5.625	0.40%
M67A	AA	929.108	-0.93	A2	A2	8.96	8.96	8.96	-10.37%
M35	AA	645.508	-0.65	A2	D	8.96	5.625	5.625	-11.48%
M33	AB	2120.753	-2.12	A1	B	8.96	8.96	8.96	-23.67%
M34	BC	2142.072	-2.14	B	C1	8.96	12.66	8.96	-23.91%

Goal: Increase These Values

Overall Bridge Capacity - Initial Conditions

Table 5: Calculated Max Load Capacity for Each Load Scenario

Load Case	Bridge Load Capacity, lbs	Governing Connection
LC1	3200	F
LC2	3125	F
LC3	2875	F
LC4	3500	F
LC5	3250	F
LC6	3075	F

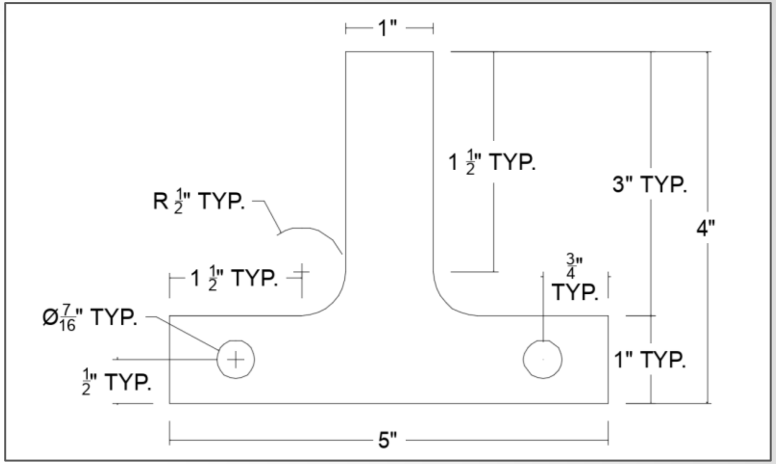


Figure 7: Connection F

Table 6: Connection F Capacity

Capacity of Connection F	
5.625 kips	Breaks due to Tensile Fracture

New Connection Designs

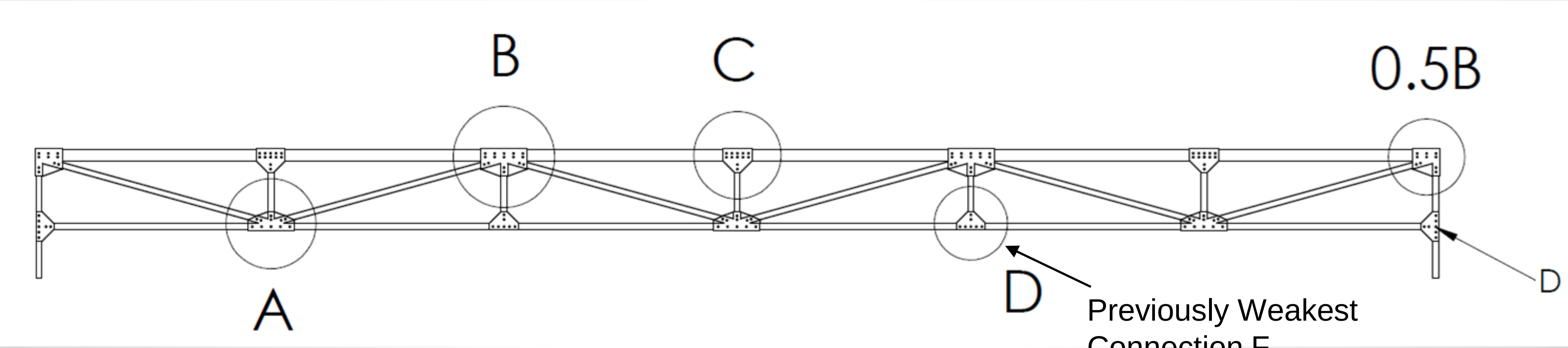


Figure 8: New Design Detail Locations

Previously Weakest Connection F

- All connections were redesigned for design repeatability & constructability

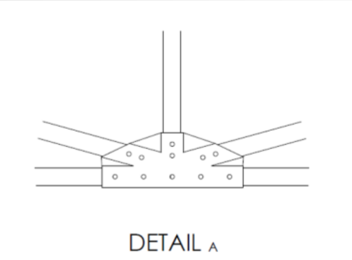


Figure 9: Detail A

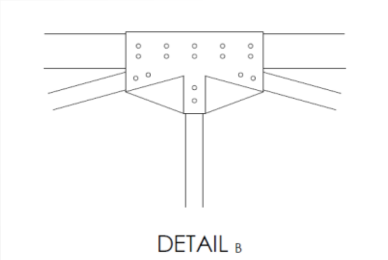


Figure 10: Detail B

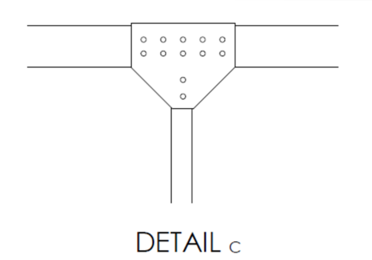


Figure 11: Detail C

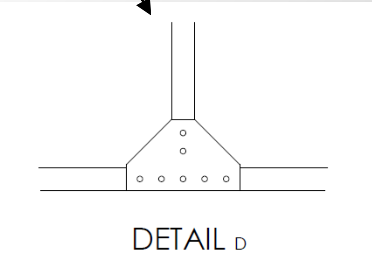


Figure 12: Detail D

Design Features Focused on Industry Steel Design Practices

- Increased amount of bolt holes
- Decreased bolt hole sizes
- Increased cross-sectional area and gusseting
- Increased clear distance between bolt holes and edges

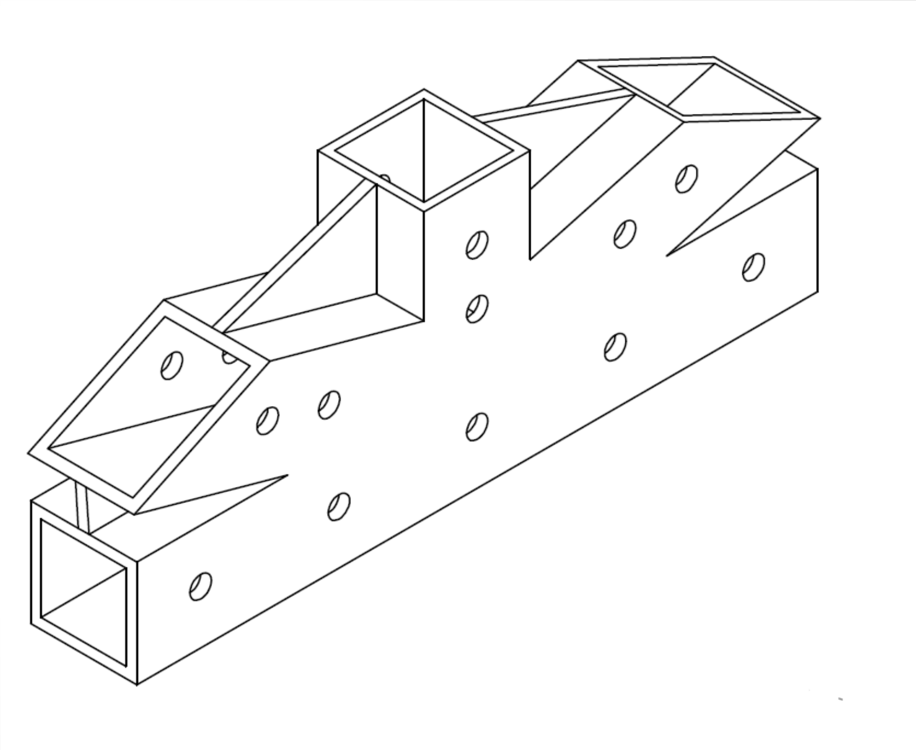


Figure 13: SolidWorks Model for Detail A Connection

New Bridge - Kept Chords as Continuous Members

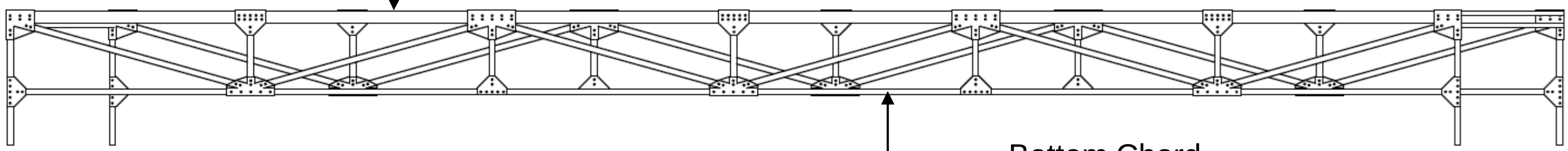


Figure 14: New Bridge Profile (Side) View

- Redistributes the major tensile forces exerted on the top and bottom chords of the bridge
- Instead, the bottom and top chords experience bending moment
- Load path changes - capacity is less dependant on connection strength

Revision 1 Connections - SOLIDWORKS

- Dimensional compatibility checked
- Design feasibility checked
- Fully dimensioned plan sets created

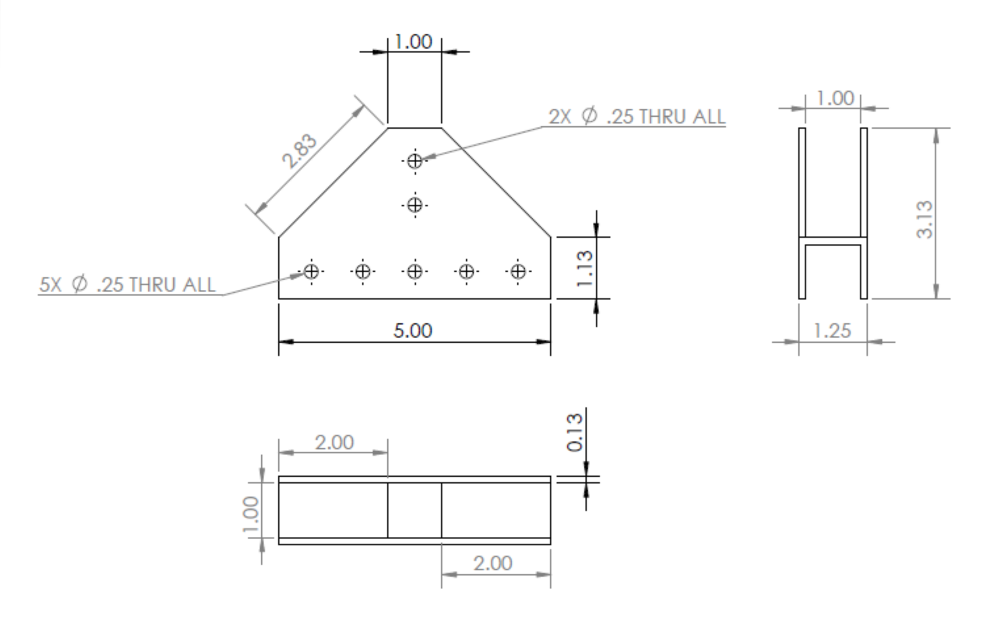


Figure 16: SolidWorks Dimensioned Plan Set for Detail D Connection

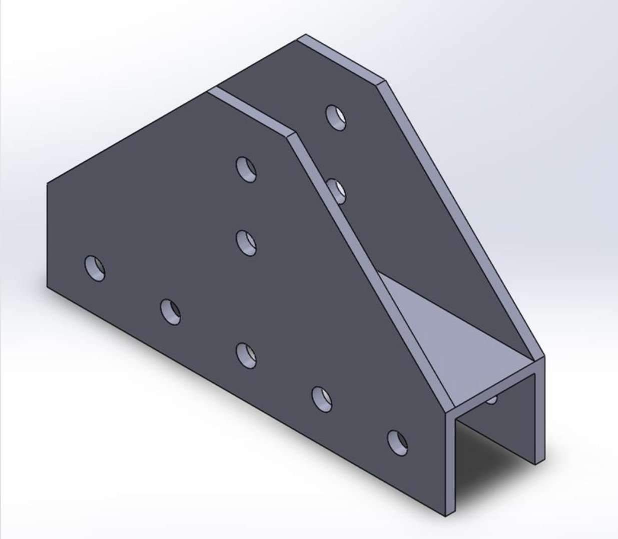


Figure 15: SolidWorks Model for Detail D Connection

Revision 2 Connection Design - For Ease of Manufacturing and Design Feasibility

- Three-Plate Interlocking Design
  - Cost of Manufacturing and Fabrication ↓
  - Cost of Materials ↓
  - Strength ↓ (for A and B only!)
    - Strength is decreased only in non-critical areas (angled truss web members)
    - Strength is still increased and maintained in critical areas (Connections C and D)

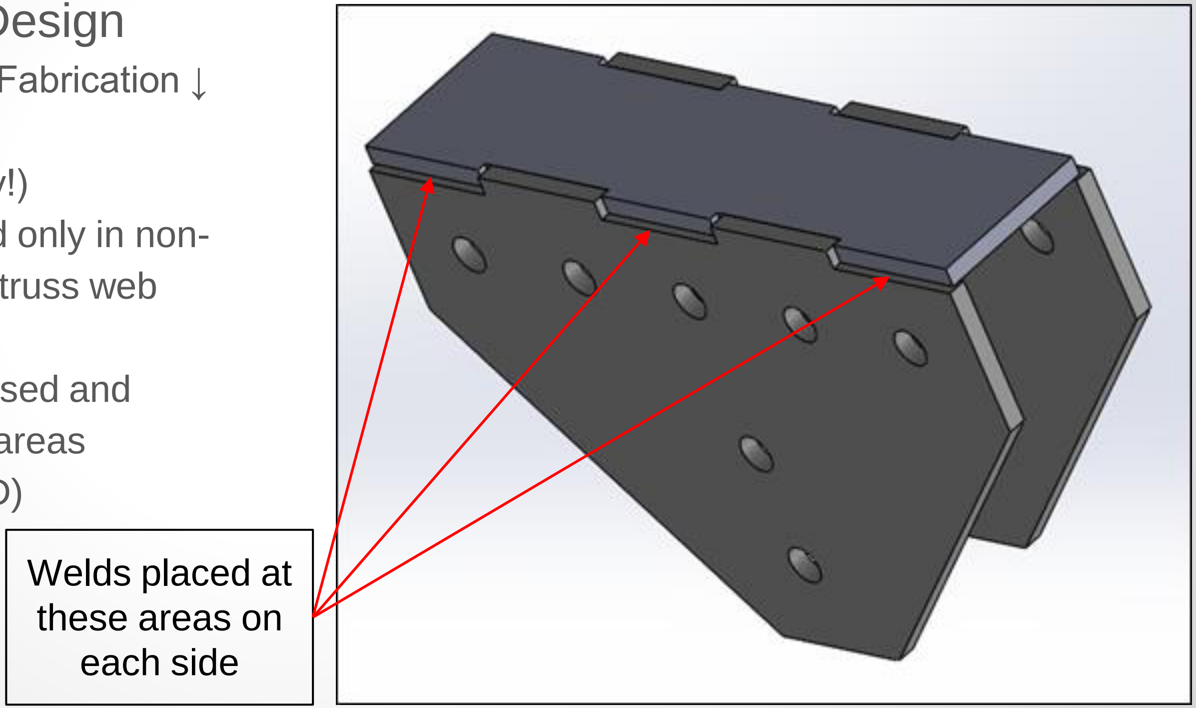


Figure 17: Connection D - Revision 2 Assembly

Controlling Capacity of the New Connections

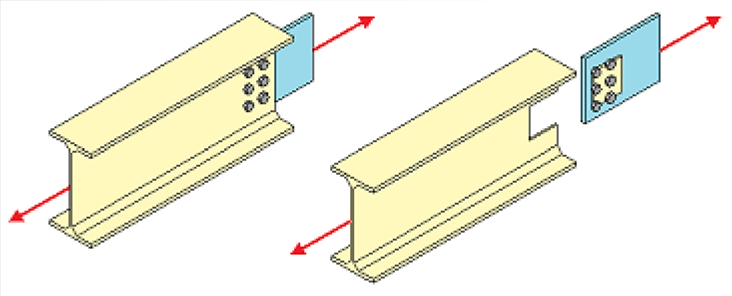


Figure 18: Block Shear Illustration

Block Shear: A "block" of the material shears off around the bolted area

$$\phi R_n = 0.60 F_u A_{nv} + U_{bs} F_u A_{nt}$$

F_u= Material tensile strength, 60 ksi
A_{nv}= Net area subject to shear, in^2
U_{bs}= Uniform tension stress factor
A_{nt}= Net area subject to tension, in^2

Calculated Capacities for the New Connections

Old Connection Name	New Connection Name	Old Capacity, kip	Revision 1 Capacity, kip	Revision 1 % Stronger	Revision 2 Capacity, kip	Revision 2 % Stronger
E2	A1	10.02	20.6	105.59%	3.87	-61.38%
E1	A2	8.96	11.67	30.25%	3.87	-56.81%
E2	A3	10.02	NA		NA	
C1	B1	8.96	10.86	21.21%	9.46	5.58%
C2	B2	8.44	13.39	58.65%	3.87	-54.15%
C3	B3	12.66	NA		NA	
B	C1	8.96	NA		NA	
B	C2	8.96	NA		NA	
F	D1	5.625	21.94	290.04%	21.94	290.04%
F	D2	5.625	NA		NA	

Rev. 1 not kept for final design

- Capacity Increased
- Eliminated Failure Path

Critical amount of force is applied to this connection

Table 6: Comparison of Old vs New Connections

Predictions for New Overall Bridge Capacity

- Based on capacities of new connections
- In all cases, the ultimate load capacity was increased - **Project Goal Met!**

Load Case	Old Ultimate Load Capacity, lbs	New Ultimate Load Capacity, lbs	Connected Member	Governing Connection	% Increase in Strength Over Existing Bridge
LC1	**3200**	**3569**	M61	A2	42.75%
LC2	**3125**	**4021**	M61	A2	60.82%
LC3	**2875**	**3568**	M67B	A2	42.71%
LC4	**3500**	**3723**	M67B	A2	48.94%
LC5	**3250**	**3378**	M67B	A2	35.13%
LC6	**3075**	**3161**	M67B	A2	26.46%

Table 7: Calculated Load Capacities for New Bridge

*Capacity Increased

Performance Comparison - Load Case 2

Old Conditions:

- Deflection before yielding: 0.936 in

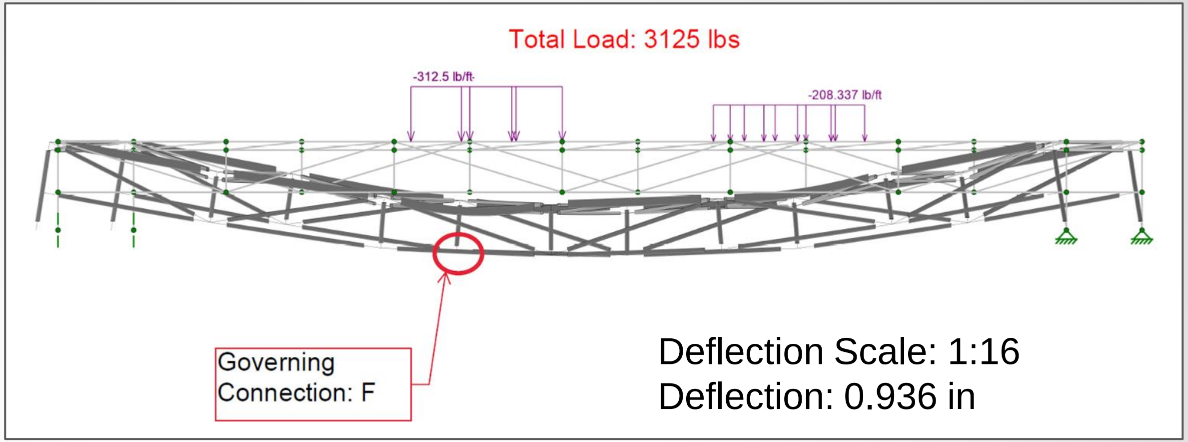


Figure 19: Load Case 2 - Old Design Performance

New Conditions:

- Deflection before yielding: 1.193 in
    - 27% Increase

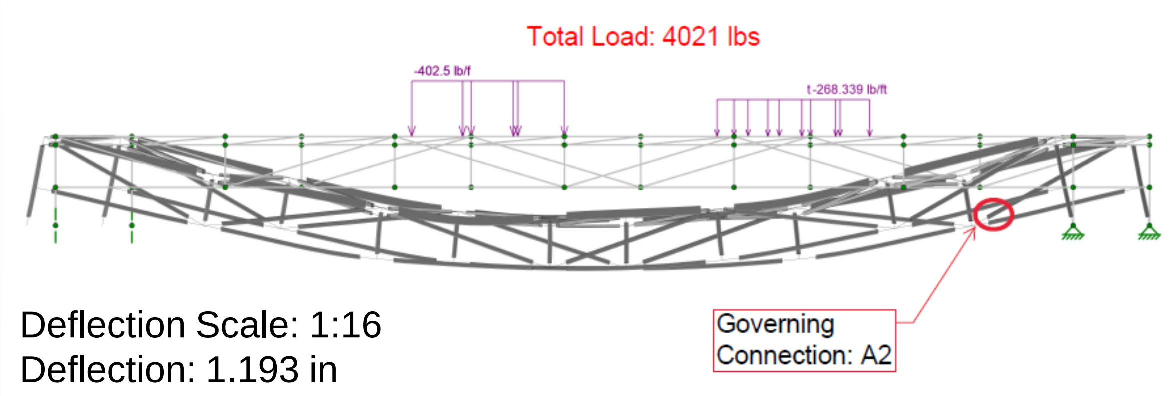


Figure 20: Load Case 2 - New Design Performance

Materials

- Grade A500 Square tubing
- 11 Gauge ASTM 1011 Grade 50 Sheet Steel
- Grade 8 Zinc Plated Half Threaded ¼” - 2” Bolts (Not Pictured)
- Grade 8 ¼” Nuts (Not Pictured)

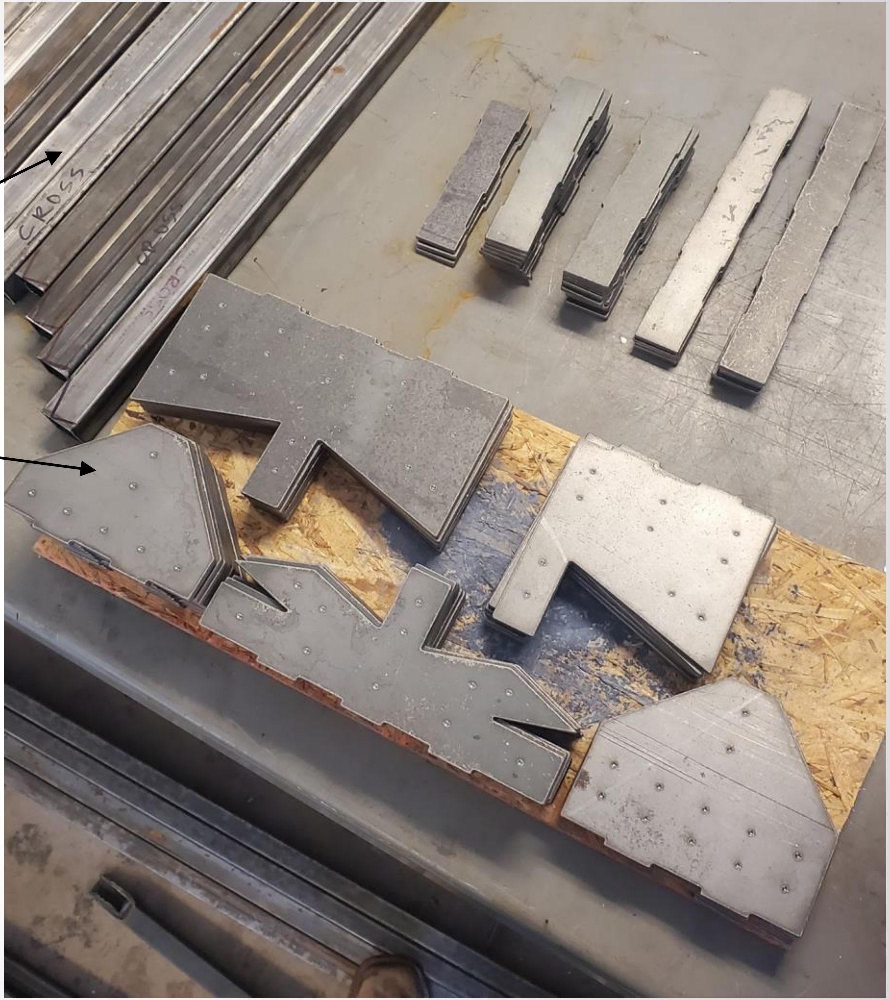


Figure 21: Steel Materials Provided by Page Steel

Outsourced Fabrication - Plasma Cutting

- Connection plates
  - Completed by Mingus Welding
  - Cut on a plasma table
  - Center holes marked with plasma table for later drilling

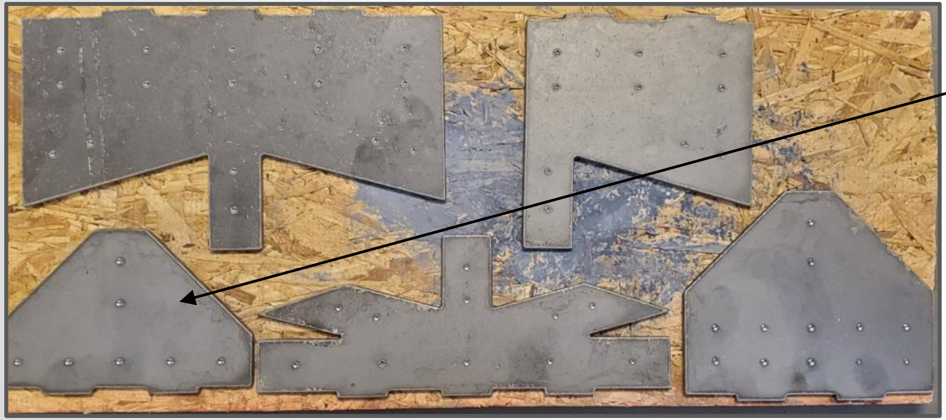


Figure 22: Plasma Cut Plate Connections

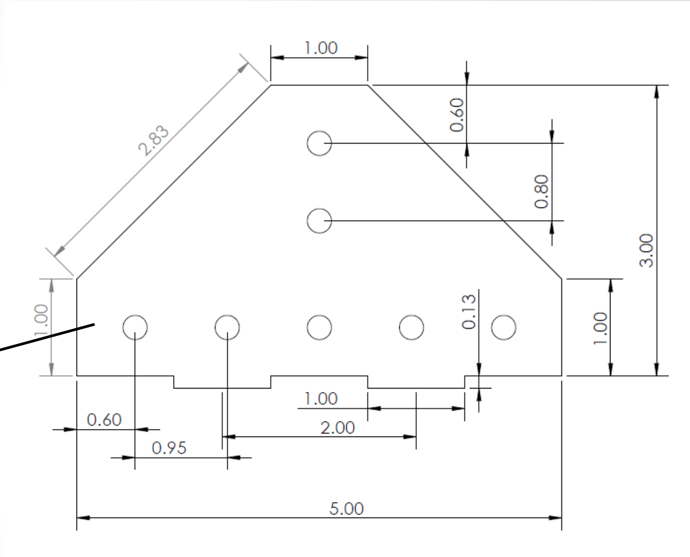


Figure 23: Manufacturing Drawings for Connection D

In-House Fabrication

- Cutting, drilling, and deburring done in-house
- Welding done by guest Eddie Byron and EK

Figure 28: Eric B. Cutting

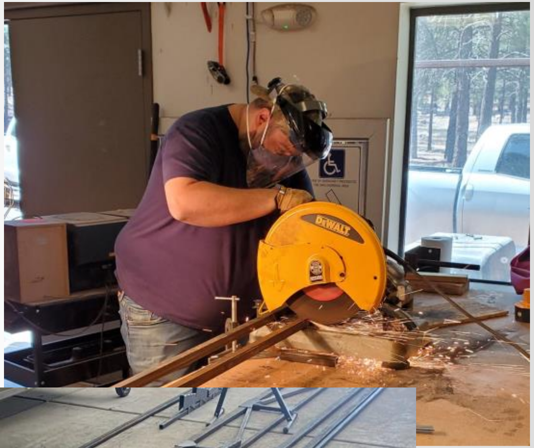


Figure 25: Emma K. Welding

Figure 26: Josh L. Drilling

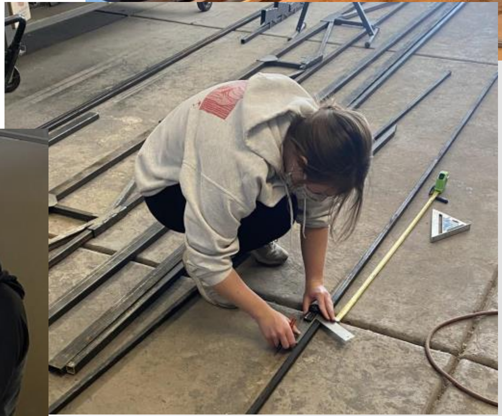


Figure 27: Tatianna S. Measuring

Figure 24: Aadil F. Deburring

Assembling the Bridge

- Currently 100% complete in fabrication

Figure 29: Final Assembled Bridge

Figure 30: Final Assembled Top Web Connection

Loading the Bridge!

- April 22nd

Figure 31: Bridge Loaded to Failure

- Weight: 6188 lbs
- Deflection 5”

Figure 32: Failure Location - Block Shear at A2

References

[1] Steel Construction Manual, 15th ed. 2017.

[2] M. C. H. Yam and J. J. R. Cheng, “Behavior and design of gusset plate connections in compression,” *Journal of Constructional Steel Research*, vol. 58, no. 5-8, pp. 1143–1159, Jan. 2002.

Thank You For Listening!

Any Questions?