CENE 486C:
STUDENT STEEL BRIDGE

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5/9/2023

STUDENT STEEL BRIDGE COMPETITION

- Purpose:
  - Design 24 ft. long, 1:10 scale bridge model
  - Fabricate the model
  - Assemble the bridge for competition
- Competiton held April 13th and 14th, 2023 in Reno, Nevada
- Client: Mark Lamer

Figure 1.0: Competition Day

BRIDGE DIMENSIONS

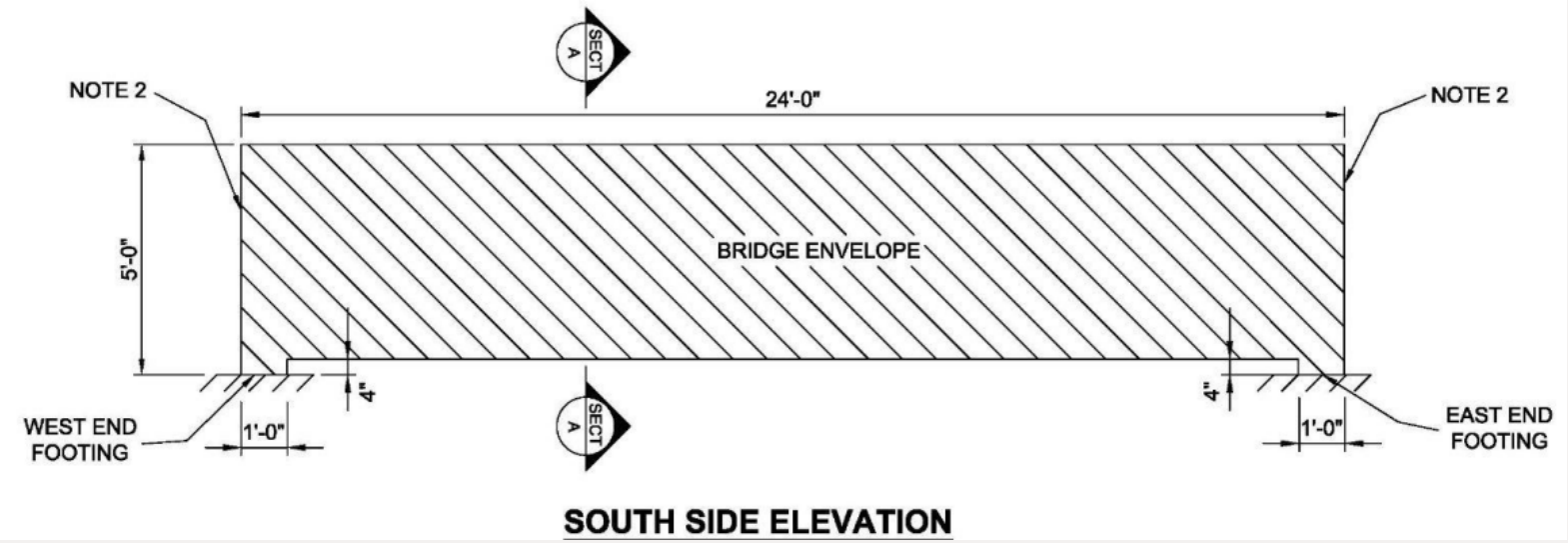


Figure 2.0: South Elevation of Bridge Envelope

- Max height: 5 feet
- Max width: 5 feet
- Stringer template must slide across bridge length
- Maximum member size is 42"x6"x4"

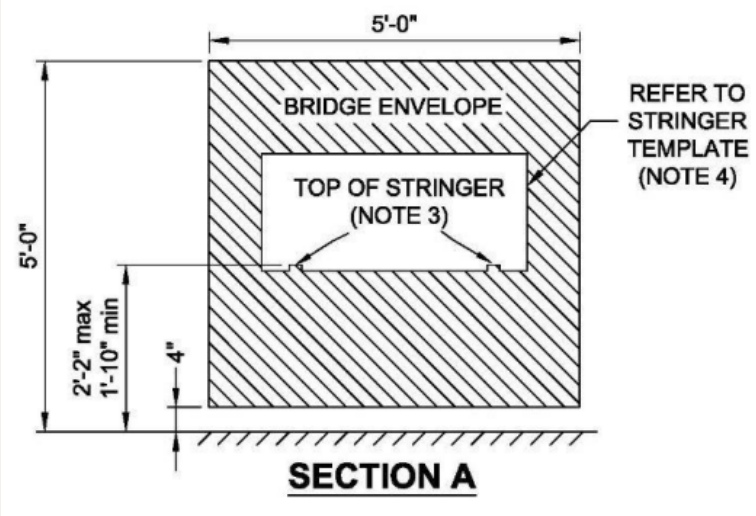


Figure 3.0: Section A of Bridge Envelope

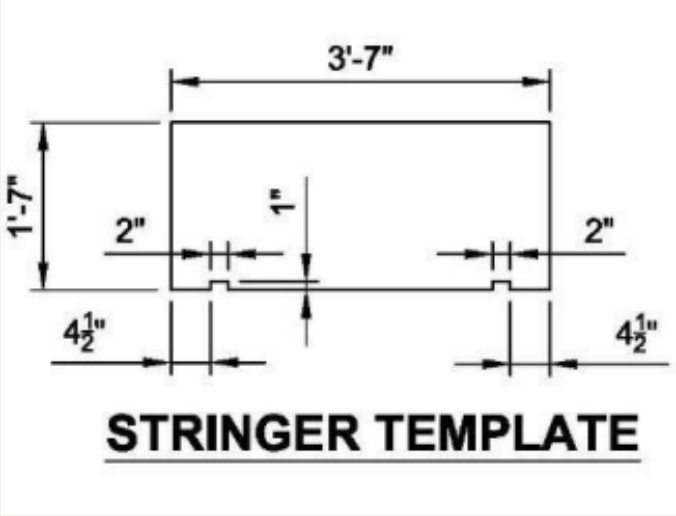


Figure 4.0: Stringer Template

COMPETITION CONSTRAINTS

- Vertical Load Test
  - 100-pound pre-load at locations L1 and L2,
  - 1,300 pounds added to location L1, 1,000 pounds added to L2
  - 50-pound sway load at location S
- For the competition, N3 was chosen.

Table 1.0: Determination of L1, L2, and S

N	L1	L2	S
1	4’-0”	7’-6”	7’-0”
2	4’-6”	8’-6”	7’-0”
3	7’-0”	13’-0”	10’-0”
4	8’-6”	13’-6”	13’-0”
5	10’-0”	15’-0”	10’-0”
6	11’-6”	16’-0”	13’-0”

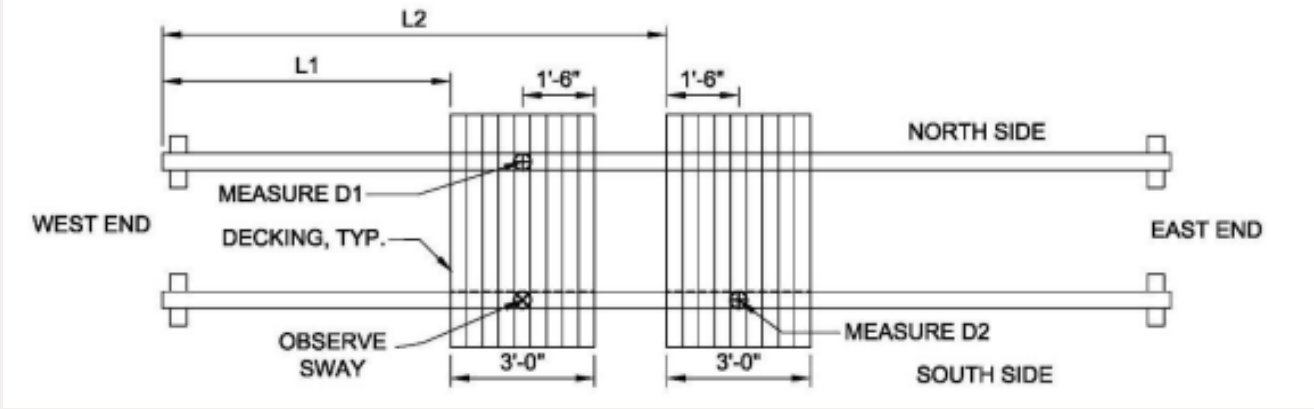


Figure 5.0: Vertical Testing

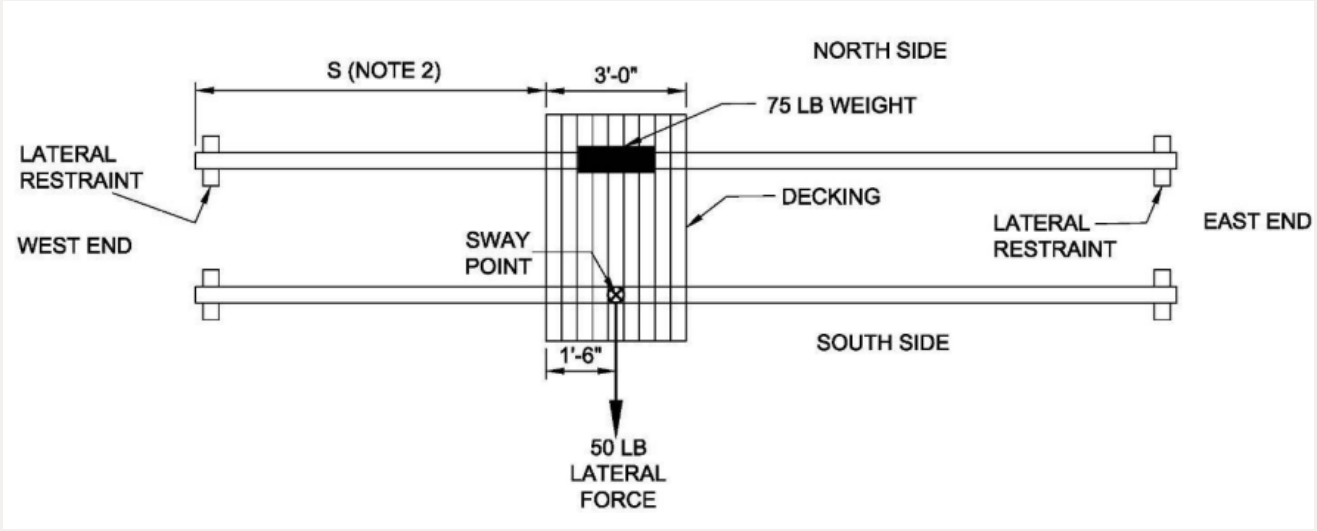


Figure 6.0: Lateral Testing

COMPETITION SCORING

- **Construction Economy**
  - Construction Speed
- **Structural Efficiency**
  - Lightness
  - Stiffness
- **Overall Performance**
- **Cost Estimation**
- **Aesthetics**
  - If a given team is DQ'd for any reason, this is the only category where an award can be received

$$C_c = \textit{Construction time}\ (\text{minutes}) \times \text{number of } \textit{builders}\ (\text{persons}) \times 100{,}000\ (\$/\text{person-minute}) + (\textit{Total time} - \textit{Construction time}) \times 250{,}000\ (\$/\text{minute}) + \textit{load}\ \text{test penalties}\ (\$).$$

Figure 7.0: Construction Economy Equation

$$C_s = [\textit{Measured weight}\ (\text{pounds})]^{1.85} \times 45\ (\$/\text{pound}^{1.85}) + (\textit{Total weight} - \textit{Measured weight})\ (\text{pounds}) \times 2{,}500\ (\$/\text{pound}) + \textit{Aggregate deflection}\ (\text{inches}) \times 2{,}750{,}000\ (\$/\text{inch}) + \textit{Load}\ \text{test penalties}\ (\$).$$

Figure 8.0: Structural Efficiency Equation

PRELIMINARY DESIGN

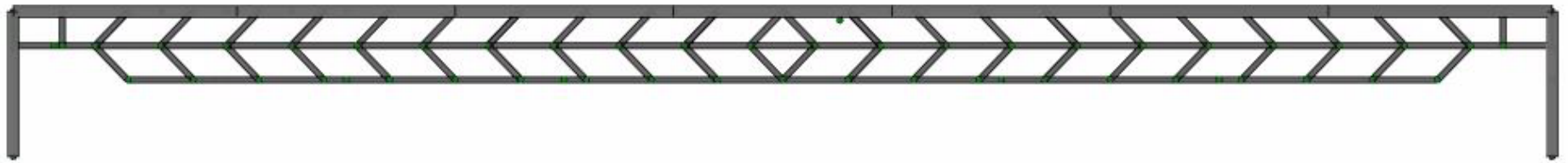


Figure 9.0: Deck/Beam Bridge

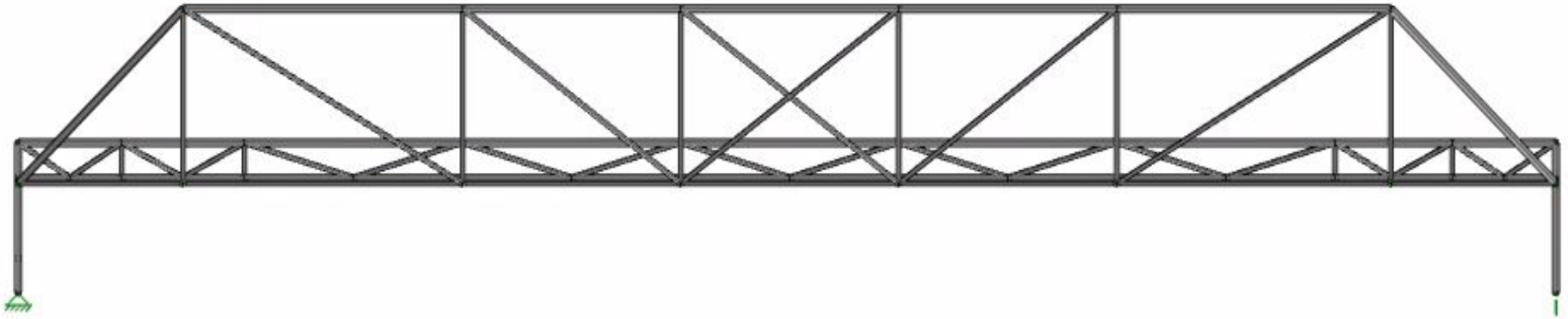


Figure 10.0: Truss Bridge

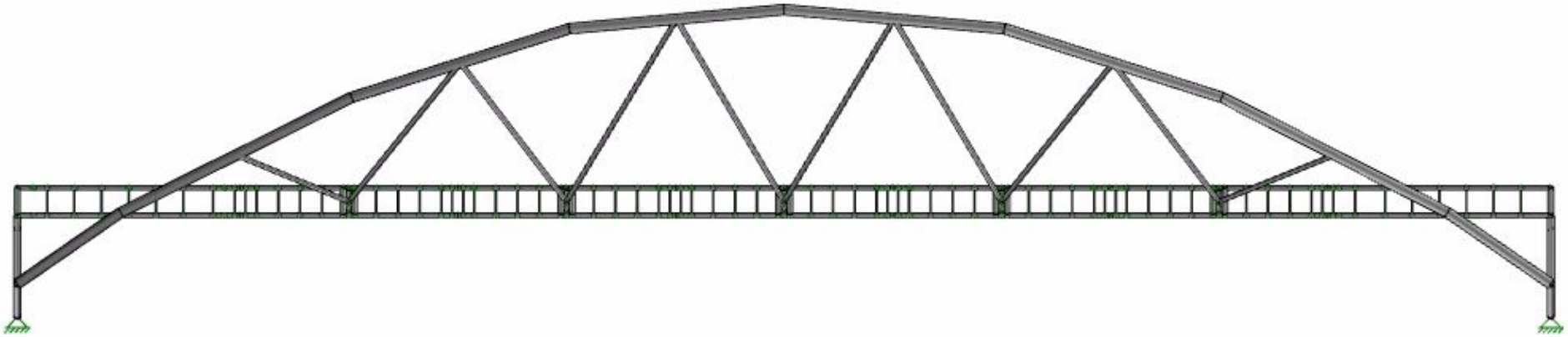


Figure 11.0: Arch Bridge

PRELIMINARY BRIDGE SELECTION

Table 2.0: Bridge Type Selection

Bridge Type	Pros	Cons
Arch	• Low deflection • Potentially lightest • Potentially lower build times	• Angles critical to performance • Difficult fabrication process • Hard to analyze
Truss	• Low deflection • Reasonable analysis	• Potentially heavy • Complex fabrication process • Long assembly time
Beam	• Easy analysis • Simple fabrication process • Quick assembly	• Heavy • Lacking support at middle span

BRIDGE SELECTION

Table 3.0: Bridge Type Decision Matrix

Bridge Type Selection			
Criteria	**Beam**	**Truss**	**Arch**
Complexity (15%)	3	2	1
Aesthetics (5%)	1	3	3
Lightness (20%)	1	2	3
Stiffness (25%)	1	3	3
Fabrication (20%)	3	1	2
Construction (15%)	3	1	2
Total	2.0	2.0	2.4

**Criteria is evaluated on a scale from 1 to 3, 1 being not ideal and 3 being ideal*

STRUCTURAL ANALYSIS

- RISA 3D to analyze each of the given six load cases
- Vertical Deflection
- Lateral Deflection
- Overall stresses
- Shear and moment values used for connection design

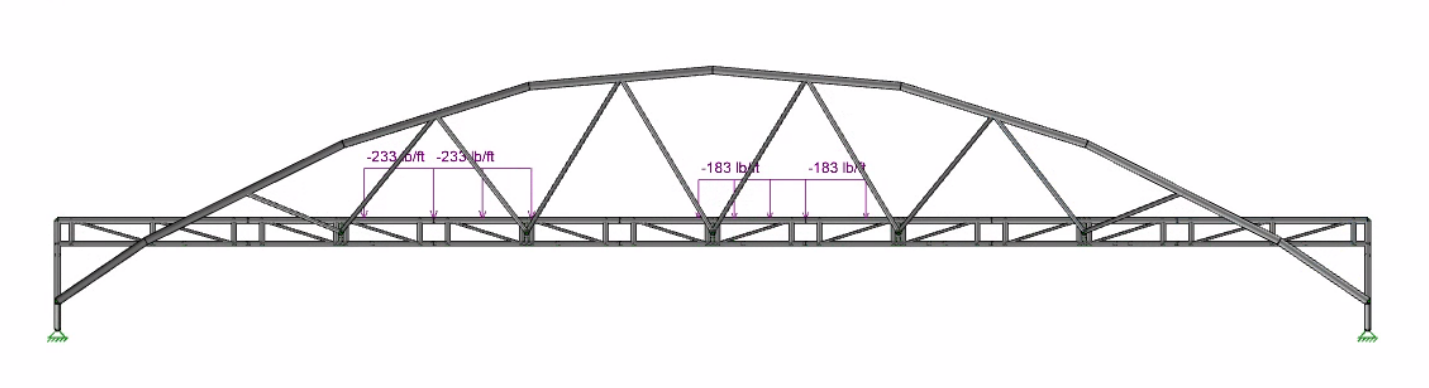


Figure 12.0: RISA Load Case 3

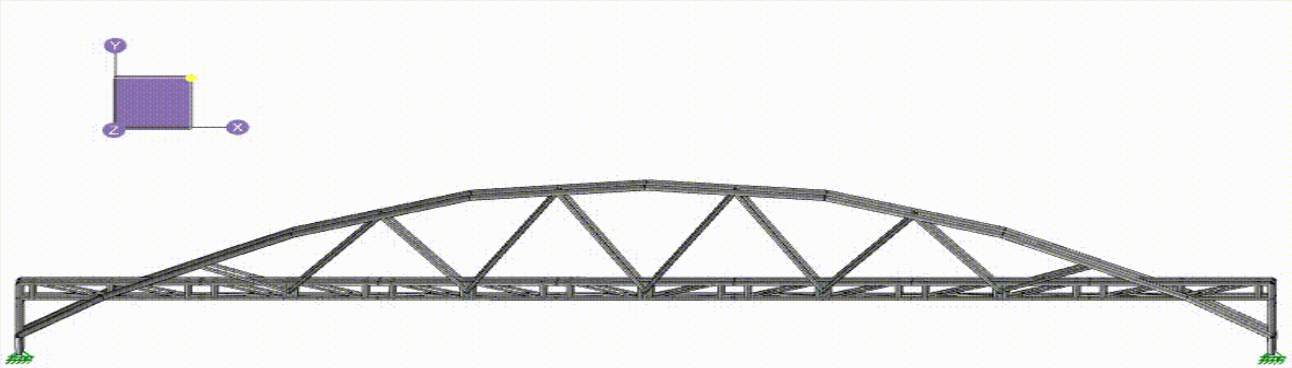


Figure 13.0: RISA Load Case 3 Deflection (8x exaggeration)

DESIGN PROCESS

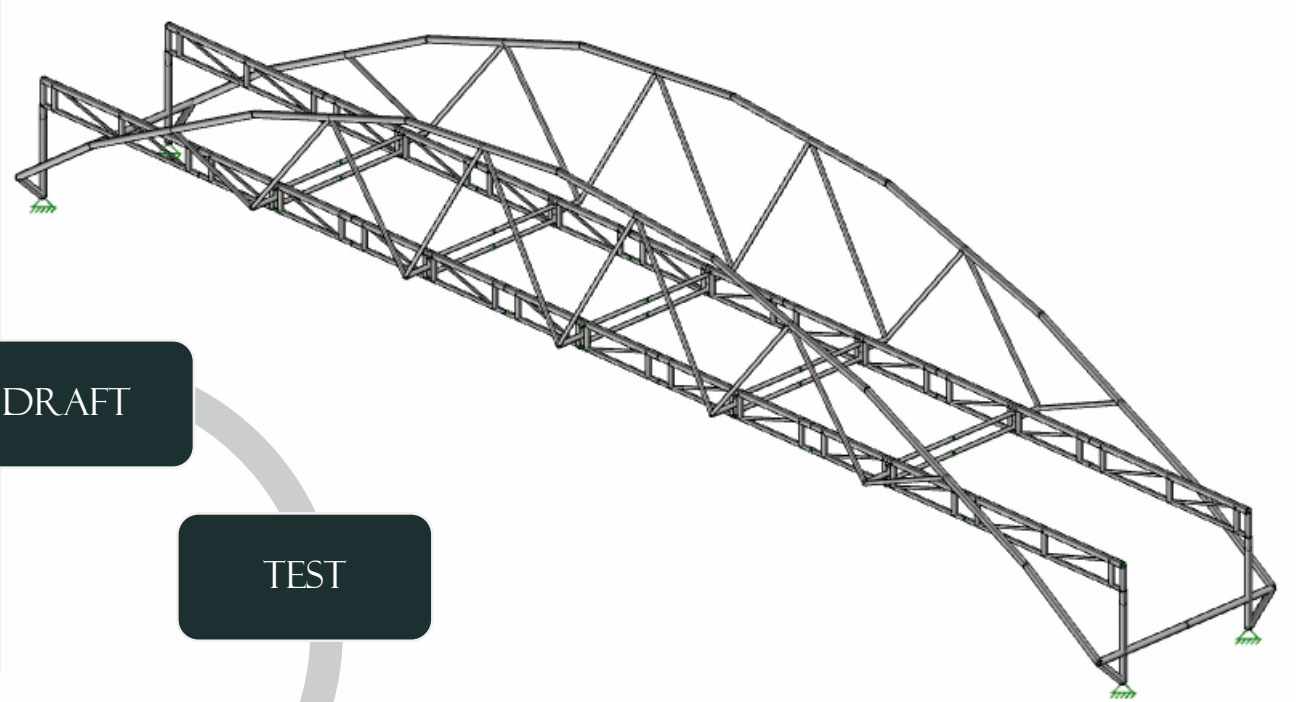
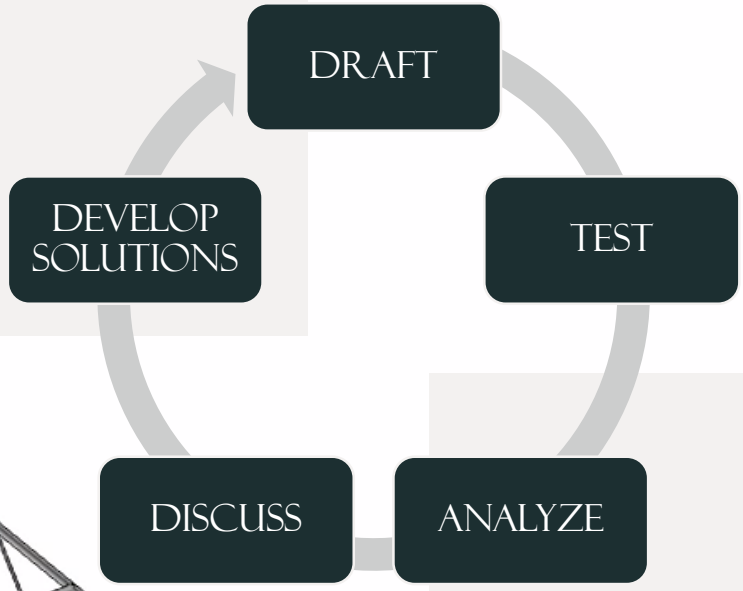


Figure 15.0: Intermediate Design



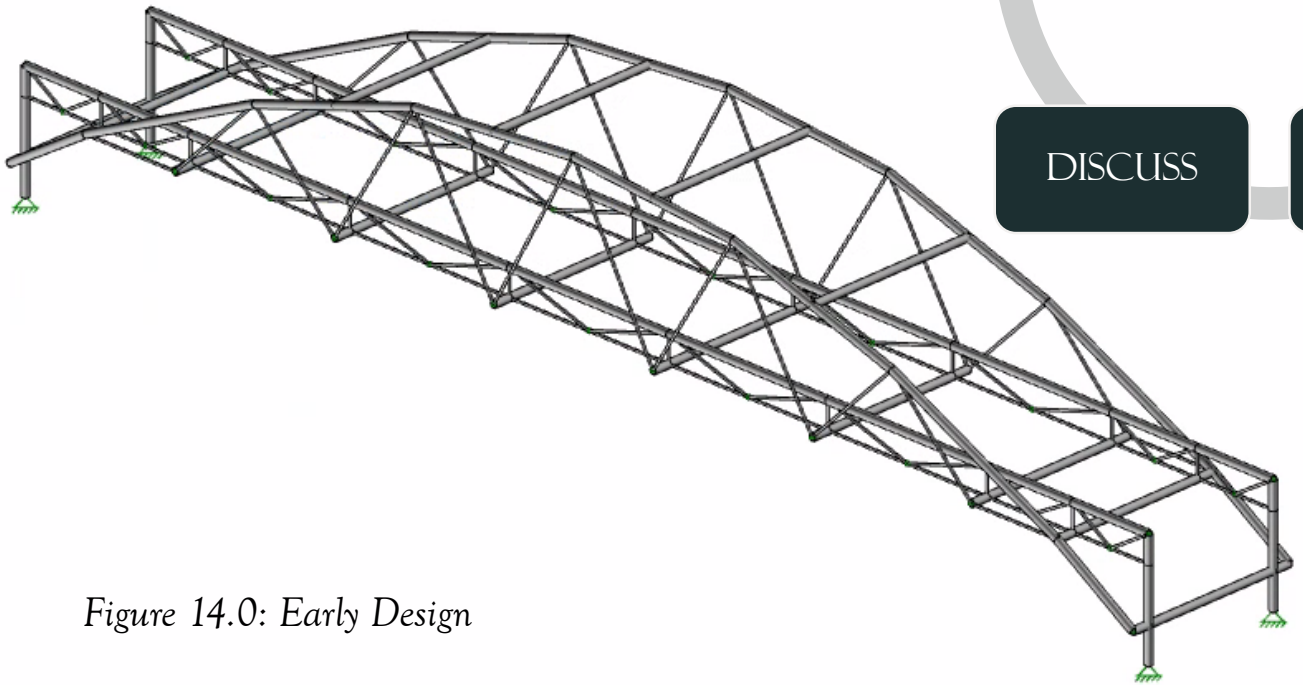


Figure 14.0: Early Design

ANALYSIS METHODOLOGY

- Load Factor Resistance Design (LRFD)
  - Reduce member strength, increase load demand
- Flexure (M)
- Shear (V)
- Axial (P)
  - Tension/Compression
- RISA Code Check
  - Ensure capacity is greater than demand

Figure 16.0: Structural Model

AISC 15th (360-16): LRFD Code Check

Limit State	Required	Available	Unity Check	Result
Applied Loading - Bending/Axial				
Applied Loading - Shear + Torsion	-	-	-	-
Axial Tension Analysis	0.000 lb	17728.201 lb	-	-
Axial Compression Analysis	1899.829 lb	10174.394 lb	-	-
Flexural Analysis	21.898 lb-ft	557.55 lb-ft	-	-
Shear Analysis	740.564 lb	5318.46 lb	0.139	Pass
Bending & Axial Interaction Check (UC Bending Max)	-	-	0.187	Pass
Torsional Analysis	0.000 lb-ft	522.188 lb-ft	0.000	Pass

Figure 17.0: RISA 3D Code Check

FINAL DESIGN

- Through-Arch Bridge
- Truss to Transfer Load to Arch
- Vertical Braces on Stringers
  - Used to Distribute stress among top and bottom chord of stringer
- Horizontal Braces on Arch and Stringers
  - Reduction of Horizontal Sway

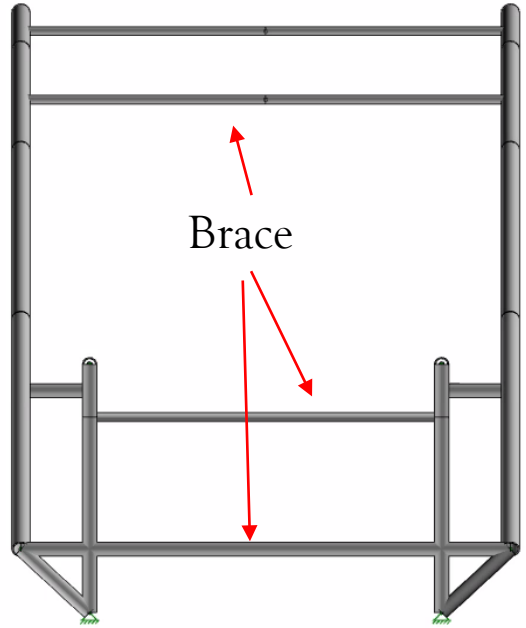


Figure 19.0: Side View

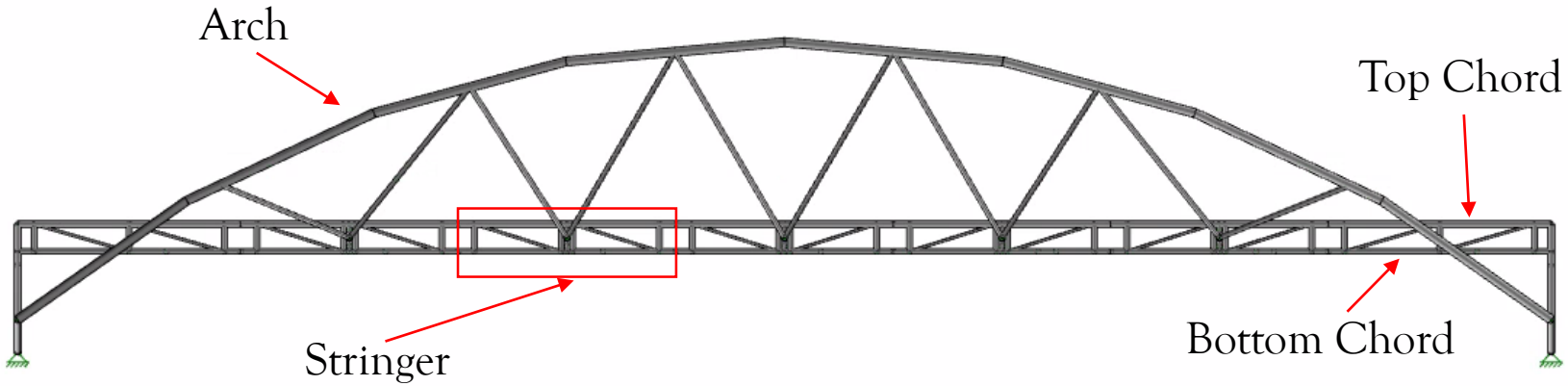


Figure 18.0: Elevation View

FINAL DESIGN - CONNECTIONS

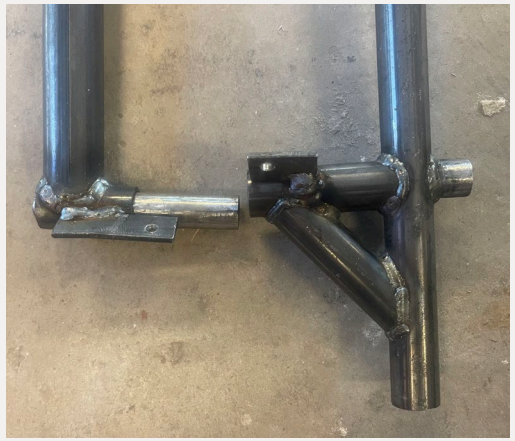
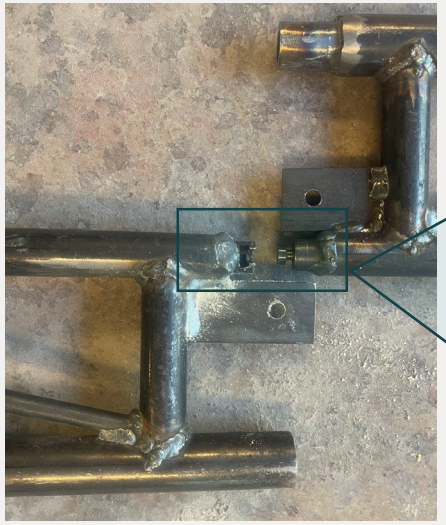


Figure 20.0: Footings (8)



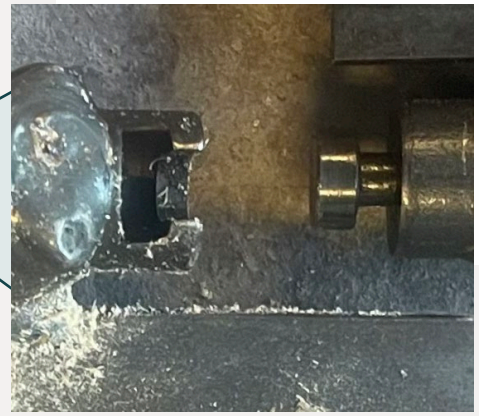


Figure 21.0: Stringers (3)

Figure 22.0: Side View

Figure 23.0: Elbows (9)

Figure 24.0: Braces (5, 6)

CONNECTION ANALYSIS

AISC Steel Manual

- Tensile and shear strength for bolts
- Bearing strength at bolt holes
- Tensile strength of plates

NOMINAL DIA OF PRODUCTS AND THREADS PERINCH	SAE GRADE 8	
	PROOF LOAD, LB.	TENSILE STRENGTH MIN, LB.
1/4 - 20	3,800	4,750
5/16 - 18	6,300	7,850
3/8 - 16	9,300	11,600
7/16 - 14	12,800	15,900
1/2 - 13	17,000	21,300
9/16 - 12	21,800	27,300
5/8 - 11	27,100	33,900
3/4 - 10	40,100	50,100
7/8 - 9	55,400	69,300
1 - 8	72,700	90,900
1-1/8 - 7	91,600	114,400
1-1/4 - 7	116,300	145,400
1-3/8 - 6	138,600	173,200
1-1/2 - 6	168,600	210,800

Figure 25.0: SAE Grade 8

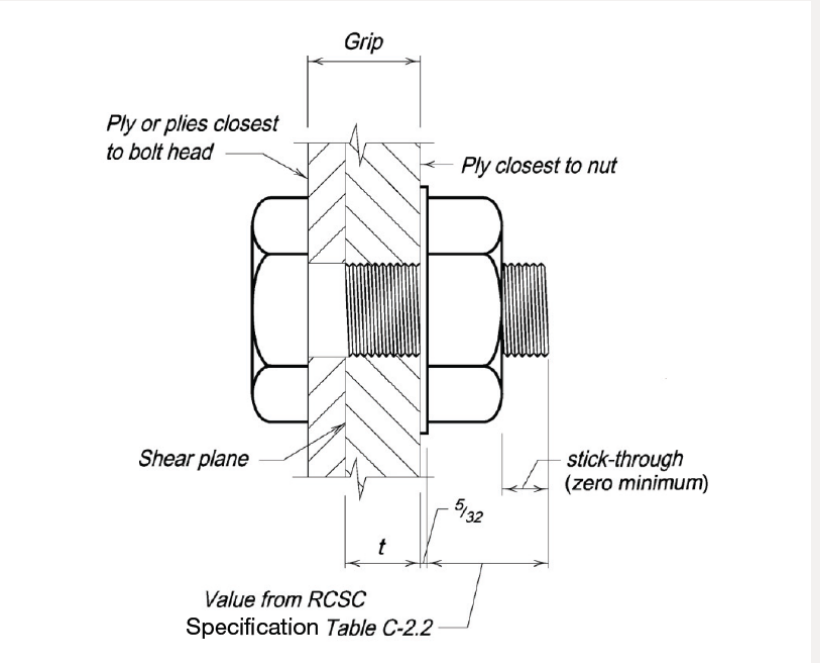


Figure 26.0: Bolt Side View

FABRICATION

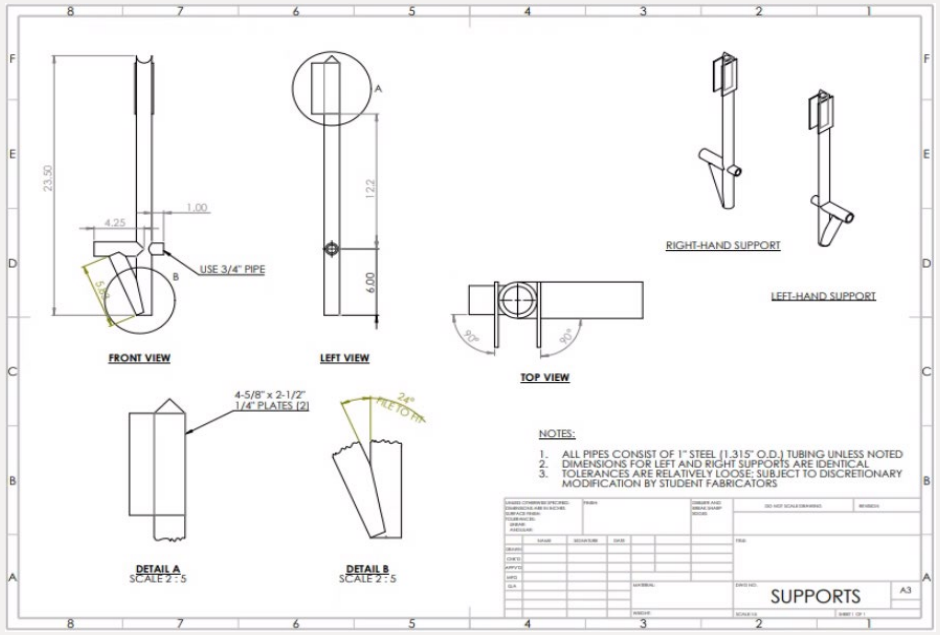


Figure 27.0: Footing blueprint

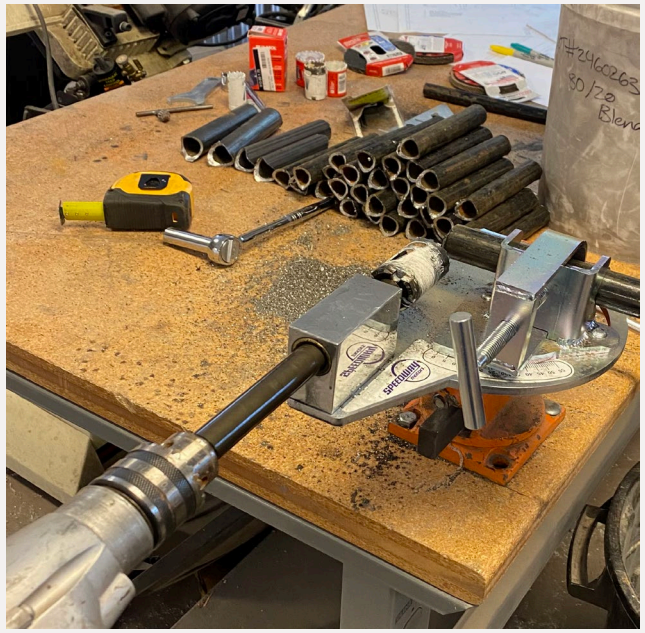


Figure 28.0: Notched Pipe

Figure 29.0: Welding Sample

FABRICATION – COMPLETED

Figure 30.0: Completed Stringers

Figure 31.0: Completed Fabrication

FABRICATION CHALLENGES

- 1.25" and 1" pipe
  - Discrepancy between expected and delivered pipe dimensions
  - Correct angles difficult to produce
- Arch exceeded height envelope by 8"
  - Required modification to achieve height under maximum 60"
- Hand fitting required to achieve acceptable dimensions and usable connections
  - Parts not interchangeable, which would have been the "ideal"

Figure 32.0: Design Arch

DESIGN AS BUILT

Design Changes:

- Replaced several elbow joints with straight connections at several points
- Two arch-cross-braces instead of 4

RISA Modeling:

- Predicted vertical deflection of 0.974"
- Lateral sway of 0.253"

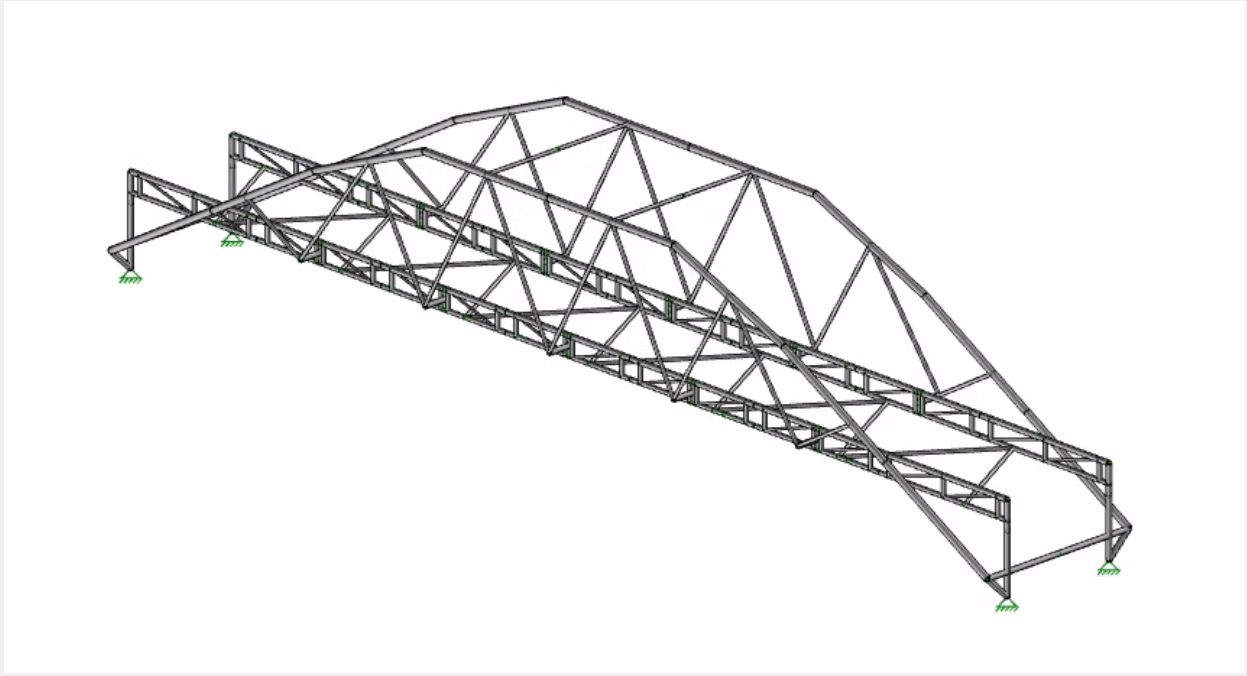


Figure 33.0: As-Built Iso-View

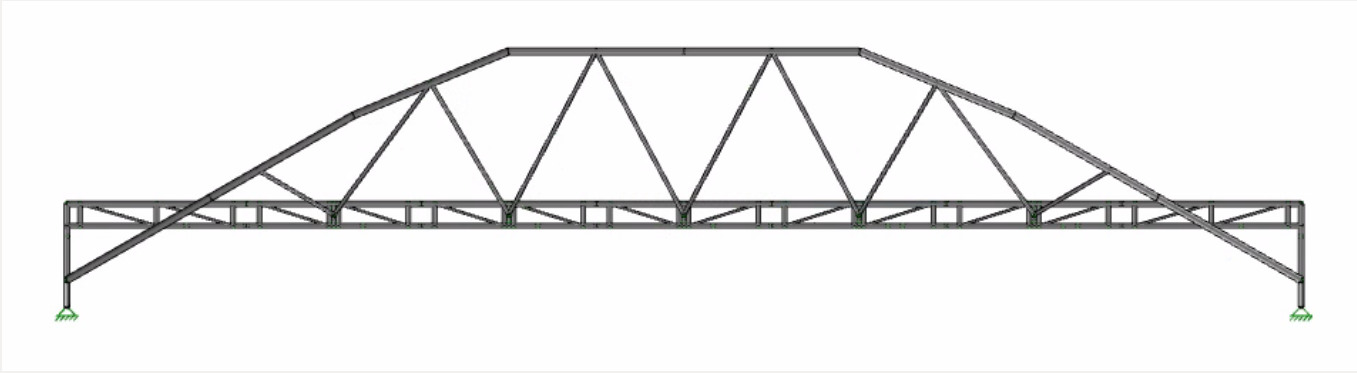


Figure 34.0: As-Built Elevation View

CONFERENCE - DISPLAY

- Fabrication was completed prior to display time
- Bridge was prepped and labeled for construction
  - Colored stickers and numbers for aiding construction speed and efficiency
- Here is where bridges were judged for the Aesthetics category

Figure 35.0: Final Design in Display

CONFERENCE - COMPETITION

Figure 36.0: Applying Load to Bridge

- Construction time
  - <45 mins
- Lateral loading test:
  - 50 lbs. at 10 ft.
  - Deflection of less than a 1/10th of an inch
  - Pass
- Vertical loading test:
  - 1,400 lbs. at 7 ft. and 1,100 lbs. at 13 ft.
  - Disqualified for exceeding 1 in. of sway when L1 carried 1,400 lbs. and L2 carried 500 lbs.

COMPETITION RESULTS

Table 4.0: Competition Results

Results	Deflection (in)	Build Time (min:sec)	Weight (lbs.)	Aesthetics (1-10)
Anticipated:	0.95	20:00	500.0	9.995 +/- 0.005
Actual:	1.65	43:19	511.3	8.5

Table 5.0: Competition Results (Aesthetics)

Rank	Full Name	Score
1	Northern Arizona University	12.83
2	Utah Valley University	12.17
3	Boise State University	12.00

IMPACTS AND TAKEAWAYS

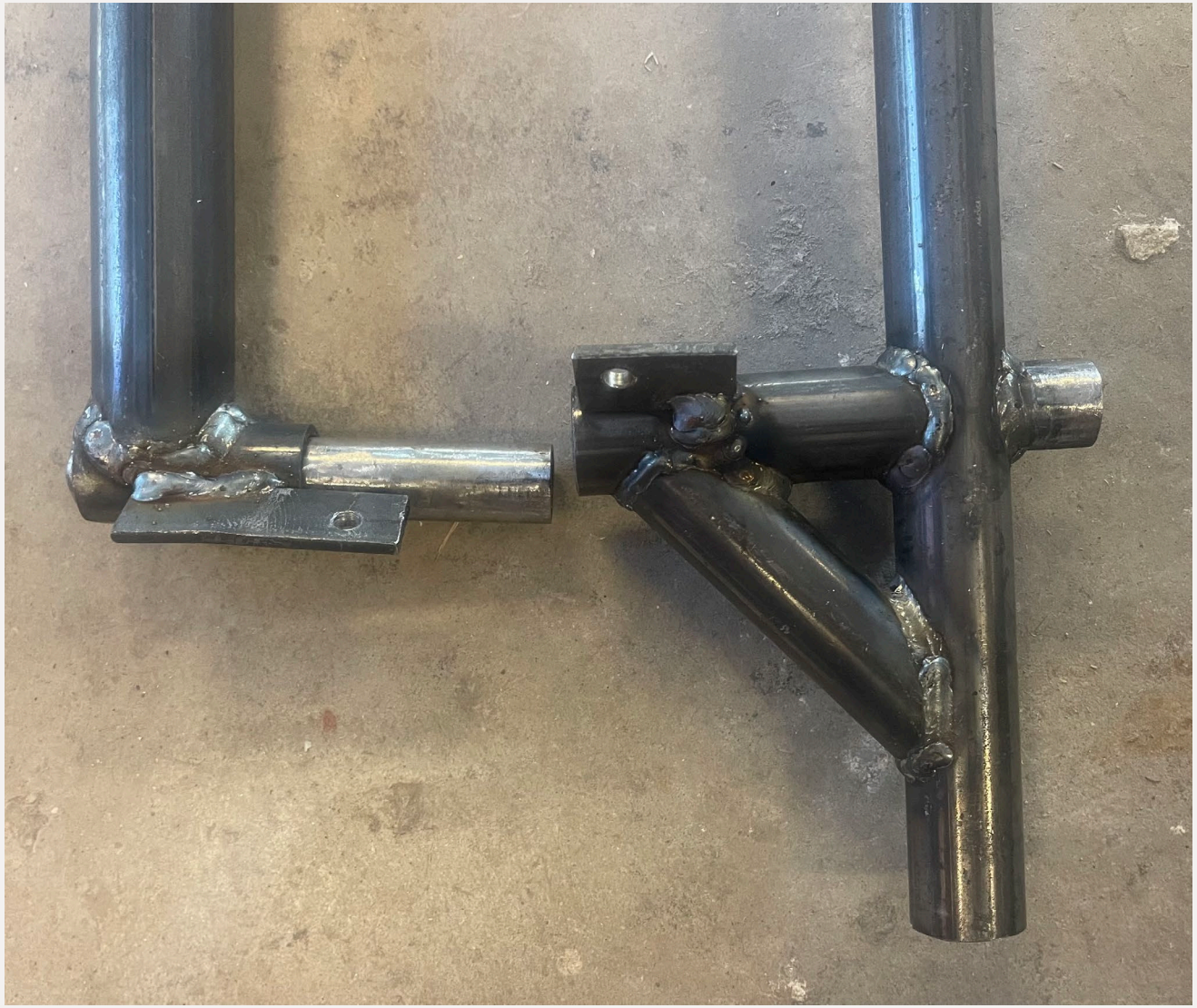
- Social
  - Connected Arizona fabricators with local students for a regional competition, creating a sense of pride for those involved
- Environmental
  - Utilized recycled steel parts to reduce overall waste
  - Recycling finished product to also reduce overall waste
- Economic
  - Utilized steel distributor and donations to reduce overall cost

- Takeaways
  - Exposure to structural steel design and fabrication
  - Usage of structural analysis programs
  - Coordination with various groups and sponsors for material and labor

ANY QUESTIONS?

THANK YOU!

FOOTINGS



ARCH ELBOWS

STRINGER - BRACES

STRINGER