2025 Steel Bridge Design Report

Final

May 6, 2025

TRUSS-TY ENGINEERING

CENE 486

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Abbreviations

AISC .... American Institute for Steel Construction
ASCE .... American Society of Civil Engineers
EIT .... Engineer in Training
HSS .... Hollow structural section
ISWS .... Intermountain Southwest Student Symposium
LRFD .... Load and resistance factor design
SSBC .... Student Steel Bridge Competition

Acknowledgements

The 2025 NAU Steel Bridge team would like to thank the following people and groups for their time and contributions to this project: Sabrina Gibson of Sirius Structures LLC., Dr. Robin Tuchscherer, Mark Lamer, Page Steel, Flagstaff High School, Copper State Nut and Bolt, the NAU ASCE Student Chapter, and our mentees.

Sabrina Gibson served as our technical advisor for this project, guiding us and providing support when the team had questions regarding the design process, including reviewing our RISA models and plan set. We thank you, Sabrina, for making time to share your expertise and help our team engineer this bridge properly.

Mark Lamer acted as the team's grading instructor for the proposal phase and served as the project's client on behalf of ASCE. Mark met with the team regularly at the start of the project to provide insider knowledge about what did and didn't work for previous Steel Bridge competition teams, and he guided us on how to best use our time to ensure that our coordination and fabrication schedule would be as good as possible. Thank you, Mark, for guiding us during our start and motivating us to do well in the competition, and for realizing our potential to work well together as a team.

Dr. Tuchscherer was the team's grading instructor for the technical report part of this project. Dr. Tuchscherer provided his time to us on a regular basis by answering questions and providing feedback on various submittals including the design report and shop drawings. We thank you, Dr. Tuchscherer, for your guidance and sharing your technical expertise this semester.

Page Steel, we want to thank you for your generosity in providing us with the steel needed for our bridge and delivering it to Flagstaff so it was easy for us pick it up. Without this donation, acquiring the materials for and constructing our bridge would've been much more difficult. To Mike Rust and his welding students at Flagstaff High School, we thank you for not only welding our bridge pieces, but also cutting them in rapid time when our access to the farm was delayed so that our construction could remain on schedule. Without help from Flag High, our bridge would be nowhere near as sturdy and professional-looking as it is. Copper State Nut and Bolt, we want to thank you for supplying the nuts and bolts that hold our bridge together. Without this fundamental part of the bridge, we would not have been able to assemble it while also complying with the SSBC Rules. To the ASCE Student Chapter at NAU, thank you for setting up the logistics of our trip and for your financial support so that we could devote our time and attention to making our bridge as great as possible.

To our mentees—Harrison, Trevion, and Larry—we thank you for your interest and enthusiasm in our project and for helping us assemble the bridge at the competition. We wish you all the best in your future Capstone projects, whether Steel Bridge or another one.

Thank you all for making this project possible, and a success

1.0 Project Introduction

1.1 Purpose

Truss-ty Engineering was tasked with designing and constructing a 1:10 scale model of a steel bridge for a hypothetical situation set forth by the American Institute for Steel Construction (AISC) for the Student Steel Bridge Competition (SSBC). The SSBC took place at the American Society of Civil Engineers (ASCE) Intermountain Southwest Student Symposium (ISWS). When designing and constructing the bridge, Truss-ty Engineering had to ensure that all aspects of design and construction complied with the 2025 SSBC Rules [1]. Once designed and constructed the bridge was loaded, judged, and scored based on its performance in a variety of categories such as construction economy, structural efficiency, and overall performance. The bridge was also presented with an accompanying poster explaining the design process at the symposium.

1.2 Project Objectives

Truss-ty Engineering aims to design and construct a bridge to pass the loading tests set by the SSBC Rules and score well within the other competition categories such as aesthetics, cost, and structural efficiency. The team will design and model the bridge per the dimension and connection type constraints and the specified loads within the SSBC Rules. Once the design is complete and the bridge materials have been acquired, welded, and cut, the team will attend the ASCE ISWS conference from April 10th through 12th to compete and test the overall performance of the bridge.

1.3 Relevance

The completion of the design and construction of a steel bridge by Truss-ty Engineering will serve as their capstone experience at Northern Arizona University. This capstone provides the team with an opportunity to use the skills and knowledge that they have acquired in their years as an undergraduate student. The project also gives the team an opportunity to understand the process and technical knowledge needed to complete an engineering design project. The Steel Bridge Capstone specifically gives insight to using modeling software to design and test potential bridge models, understanding materials, creating a usable set of shop drawings, how to work with subcontractors to coordinate fabrication and material acquisition, how to assemble a bridge in a timely manner, and documenting the process in the form of presentations and report submittals. The skills that the team acquires throughout the course of this project will be used during their entire career as practicing engineers.

2.0 Background Research

2.1 Steel Properties and Types

To better understand the material options that could be used for the bridge, the properties and types of steel were researched. This was done using the US Department of Transportation Federal Highway Administration's *Steel Bridge Design Handbook* and the AISC Steel Construction Manual [2,3]. The *Steel Bridge Design Handbook* provided recommendations about which steel shapes are best suited for each of the different parts of a bridge. A summary of these recommendations is shown in Table 2-1, which also has a picture of each steel shape.

Table 2-1: Steel Types and Uses in Bridges

Steel Type	Yield Strength, F_y (ksi) [3]	Ultimate Strength, F_u (ksi) [3]	Steel Image	Typical Bridge Use [2]
Hollow Structural Sections (HSS)	50	62	 [6]	Cross bracing, truss members, and secondary members subject to compression.
Pipes	35	60	 [7]	Tension members
Channels	50	65	 [8]	Stringers
Wide Flange Beams	50	65	 [9]	Truss Chords

Some of the properties of steel were also researched, which included yield stress and ultimate stress. Yield stress is defined as the minimum stress at which a material will experience permanent deformation without a significant increase in the load [4]. Ultimate stress is defined as the maximum stress that a material can experience before breaking [5]. Stronger grades of steel have higher yield and ultimate stresses, which means that they are stronger but may be heavier or more expensive than lower grades [3]. The AISC Steel Construction Manual was also used to determine which grade of steel is recommended for each steel shape so that the appropriate grade could later be used in the RISA-3D models.

2.2 Connection Types

2.2.1 Bolted Connections

There are generally two types of bolt connections: bearing and slip critical. Bearing connections use shear to join two elements, while slip critical connections use friction to join the elements [10].

Failure modes for bolted connections include yielding, bearing, tear out, shear, fatigue and corrosion. Corrosion and fatigue are not concerns for this project and will not be considering when designing the bolted connections. Bolts are considered more economical than welds since less skilled labor is needed for installation. In the context of the Student Steel Bridge Competition, installing a large number of bolts can be considered a drawback, as there is a timed construction portion of the competition and installing more bolts means more construction time which can lead to a lower score. However, bridge members are limited to 42 in. long and 6 in. high, meaning welds will be limited and bolted connections will be a key part of the bridge.

2.2.2 Welded Connections

Welds have key advantages as to why they should be used for connections. This includes their wide range of use and continuous strength. There are different types of welds/joints, which depend on the angle between the two members being joined. Figure 2-1 shows various examples of welded joints and Figure 2-2 shows examples of weld types.

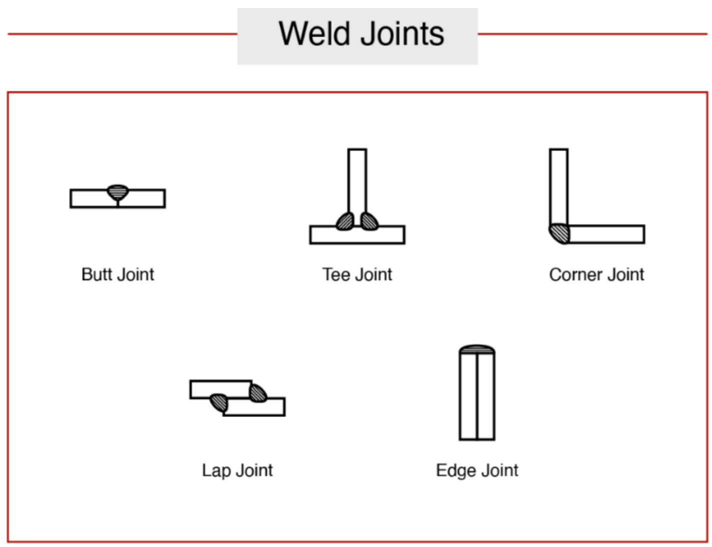


Figure 2-1: Weld Joints [12]

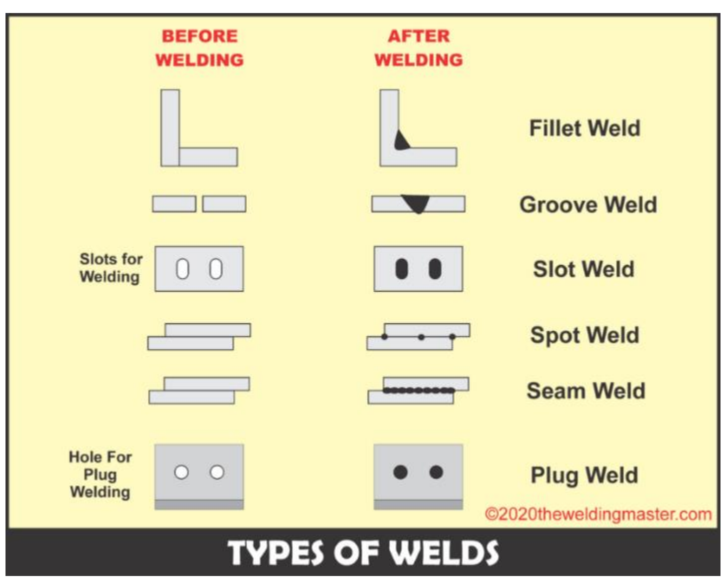


Figure 2-2: Weld Types [13]

While welds are strong, useful connections, they also have disadvantages. These include the expensive skilled labor required to install them, and heat and stress distortions that may occur during the welding process [11]. Specifically related to the SSBC, the sizes of pieces that make up the constructed bridge are limited and must fit into a box that is 42 in. x 4 in. x 6 in.. Due to the size limitations of pieces, the number of welds that can be used in the bridge will be limited, as the whole bridge cannot be welded together as one piece.

2.3 Bridge Types

Before beginning design, the team investigated potential bridge styles that could be used. This information came from general bridge styles found on Google Images, the Steel Bridge Design Manual, as well as previous winners of the SSBC. The primary bridge types that were considered were truss bridges (over or under) and arch bridges. Examples of these bridge types can be found below in Figure 2-3 through Figure 2-5. Underslung trusses were considered to be the most feasible to construct and were therefore more highly considered. Additionally, underslung trusses seemed to be the most commonly used in past Student Steel Bridge competitions.

Figure 2-3: Overslung Truss Bridge Example [14]

Figure 2-4: Underslung Truss Bridge Example [15]

Figure 2-5: Arch Bridge Example [16]

3.0 Design

3.1 Preliminary Sketches

With background research completed, Truss-ty Engineering moved forward with preliminary sketches. Sketches were created by all team members and were done by hand, created in AutoCAD [18], or a combination of the two. There was no limit to the number of sketches, or the style of bridge designed by each team member; however, the team was encouraged to keep the anticipated number of connections and pieces to a minimum, as well as keeping other relevant background research information in mind. Figures 3-1 through 3-3 show a few of the sketches that were created. Figure 3-1 shows a hand drawn sketch depicting a side profile of an over-slung truss bridge. Figure 3-2 shows an AutoCAD drawing of three views of an underslung truss bridge. Figure 3-3 displays a hand drawn sketch for an over-slung truss bridge, designed primarily with aesthetics in mind. Appendix A contains a complete inventory of the sketches that were created by the team.

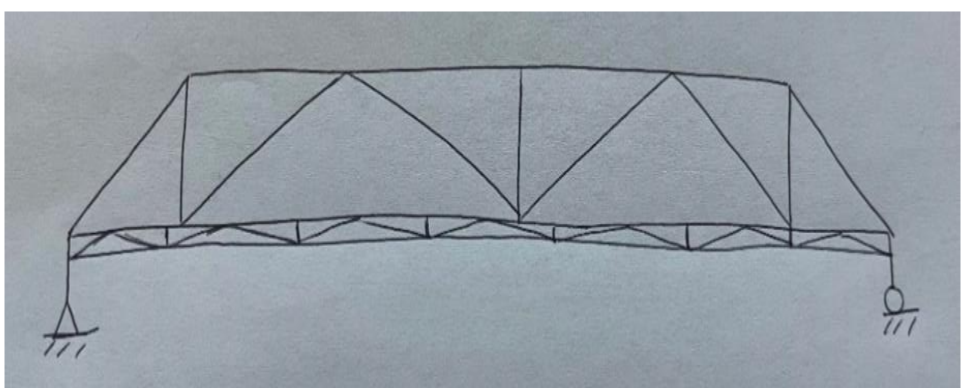


Figure 3-1: Over slung Truss - Hand Drawn Sketch

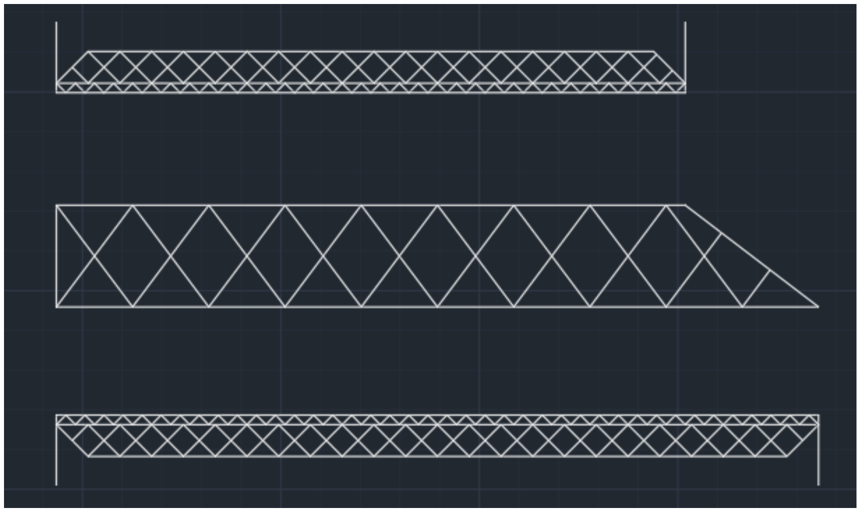


Figure 3-2: Underslung Truss - AutoCAD Sketch

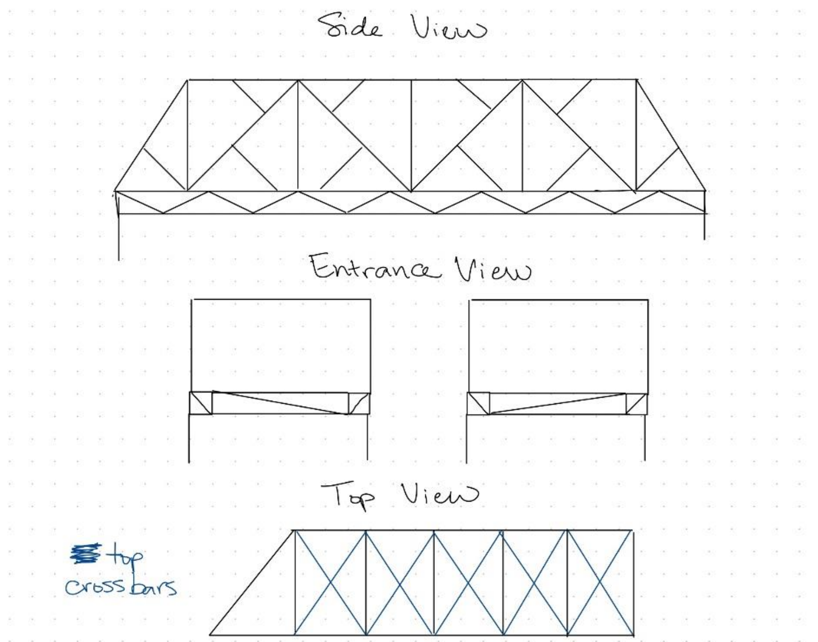


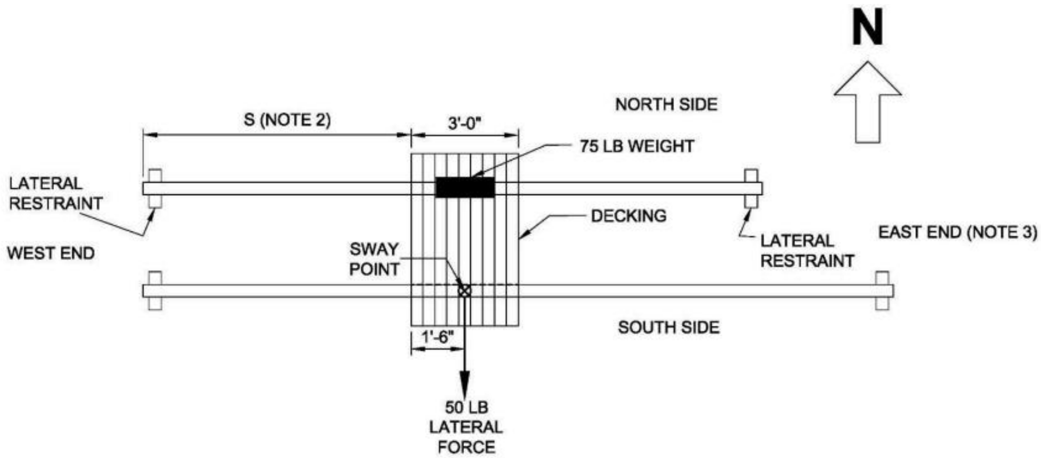
Figure 3-3: Three View Truss - Hand Drawn Sketch

3.2 RISA-3D Models

3.2.1 Load Configuration

With preliminary sketches made, the team moved forward with modeling designs in RISA 3D [19]. Due to time constraints, not all sketches moved to modeling in RISA 3D. The designs that moved forward to RISA were the ones that were visually determined to be most likely to have the fewest connections, lowest predicted weight, and the highest ease of construction based on the number of pieces. Three designs ended up being modeled. The team worked to model each sketch accurately based on the required dimensions and loads as per the SSBC Rules [1].

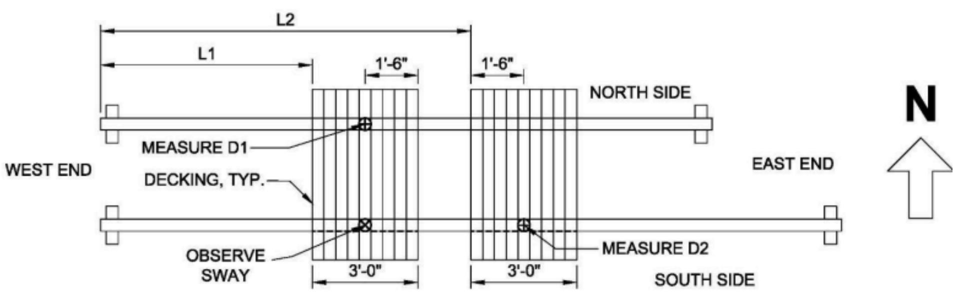
Once the 3D models were created, basic load cases were created to represent each of the possible loading scenarios that the bridge could experience. The amount of loading is the same for all the competing bridges, but the location of where the loads are placed is determined by the dice roll. Within Figure 3-4, the table labeled 'Loading Positions' shows the possible loading positions from the SSBC rules. For loading positions, L1 and L2 are the locations of the applied vertical loads measured from the west end of the north stringer to the west end of the loading deck; S is the location of the applied horizontal load also measured from the west end of the north stringer; and N is the total number rolled by two dice [1]. Figure 3-4 shows where the loading deck will be placed in relation to the bridge for each load test. An elevation view of the vertical load test is shown in Figure 3-5.



LATERAL LOAD DIAGRAM

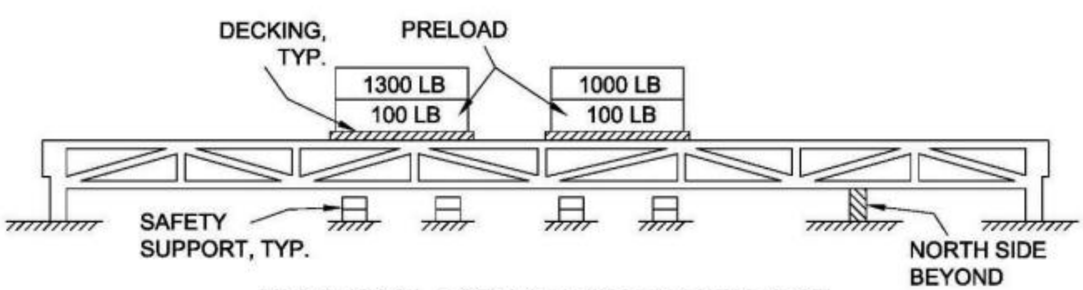
LOADING POSITIONS

N	L1	L2	S
2	3'-0"	8'-6"	7'-0"
3	3'-6"	8'-0"	7'-0"
4	4'-0"	9'-6"	7'-0"
5	4'-6"	9'-0"	7'-0"
6	5'-0"	10'-0"	8'-6"
7	6'-0"	10'-6"	8'-6"
8	10'-0"	5'-0"	8'-6"
9	9'-0"	4'-6"	7'-0"
10	9'-6"	4'-0"	7'-0"
11	8'-0"	3'-6"	7'-0"
12	8'-6"	2'-0"	7'-0"



VERTICAL LOAD DIAGRAM

Figure 3-4: Load Diagrams - Top View [1]



VERTICAL LOAD TEST ELEVATION

Figure 3-5: Vertical Loading Elevation Diagram [1]

To set up for the lateral loading, a 50 lb. piece of decking is placed on the bridge based on the dice roll. A 75 lb. weight is then placed over the north side to prevent uplift. A 50 lb. load is then applied to the south side of the bridge and lateral deflection is observed to see if it is within the allowed limit, which is 0.75 inches. For the vertical load test, a 50 lb. piece of decking is placed at each of the two vertical loading locations, followed by 100 lb. of preload at each location, and then 1300 lb. at location 1 and 1000 lb. at location 2.

The 50 lb. lateral load was modeled as a point load, but all other loads were modeled as distributed loads over the width of the decking units and divided in half to be placed on each stringer. This load modeling process was used for every possible loading scenario. Figure 3-6 shows an example of a lateral loading in RISA, while Figure 3-7 shows a vertical loading example.

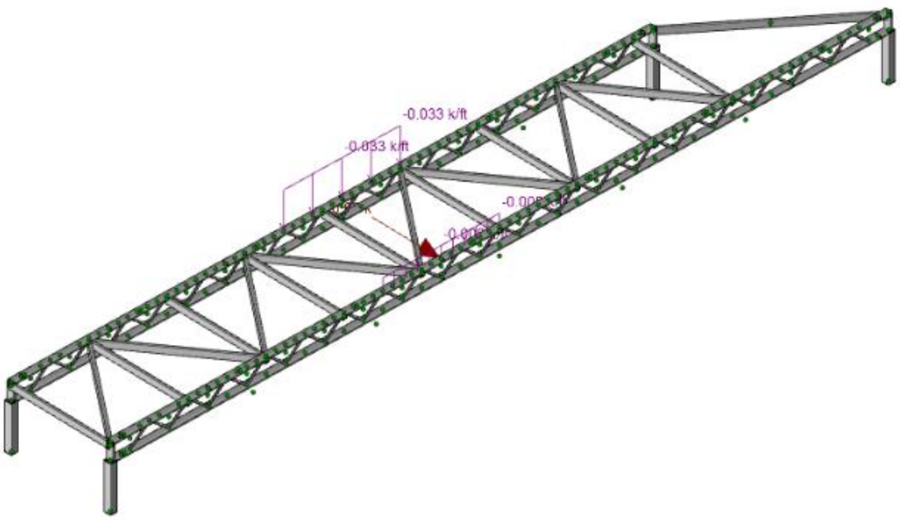


Figure 3-6: Lateral Loading in RISA

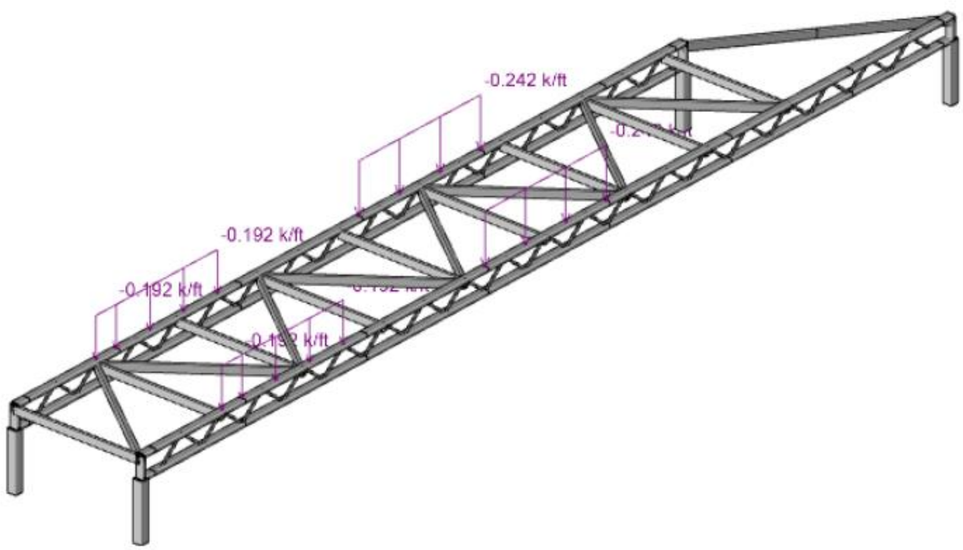


Figure 3-7: Vertical Loading in RISA

3.2.2 Load and Resistance Factor Design (LRFD)

The load and resistance factor (LRFD) design methodology was used, and the load combination of 1.2D+1.6L (written out as 1.2 times the dead load plus 1.6 times the live load, the latter of which is the applied loading specified by the SSBC Rules) was used in conjunction with each of the basic load cases when the models were solved. However, based on feedback from the team's technical advisor, the load combination was eventually modified to be 1.2D+1L. This change arose from the difficulties that one model experienced when trying to comply with the maximum deflection limitations. Since the scope of this project is limited to performing at the competition, the team knows exactly how much loading will be applied to the bridge, so it was deemed acceptable to not apply a factor of safety to the live load. The 1.2 factor on the dead load is still appropriate though because it accounts for some of the components that will be present when the bridge is assembled but are not modeled in RISA, which are plates and bolts.

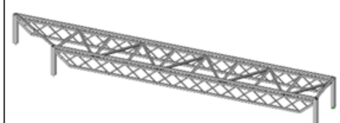
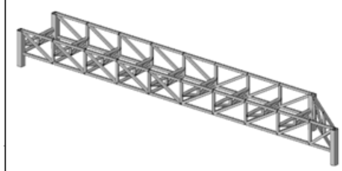
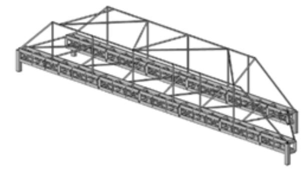
The three bridges were modeled as being simply supported, with the west footings modeled as pins and the east footings modeled as rollers. The pinned footings were allowed to rotate but not move in the X, Y, or Z directions, while the roller footings were allowed to rotate and move along the X-Z plane (i.e. the ground) and could not move vertically in the Y direction. In application, each footing acts as a roller when the bridge is on the ground since it could slide horizontally if pushed with enough force, but it was not feasible to model it this way in RISA because the software would have considered the model unstable and would not have been able to be solved. The use of a simply supported model was also recommended by the team's technical advisor. Additionally, during the lateral load test, an external force would be applied to two of the footers in order to prevent the bridge from slipping during loading. Bolted connections were represented by applying end releases where it was anticipated that bolts would be used. Welded connections were modeled as fixed (i.e. no end releases). Based on the information gained from the *Steel Bridge Design Handbook,* it was decided that HSS members would be used as the stringers, cross bracing, and in some models, the web members of the truss. In some models, pipes were used as the web members instead.

Once the boundary conditions, member properties, end releases, loading, basic load cases, and load combinations had been established for each model, the three models were solved. The absolute maximum horizontal and vertical deflections were noted. Per the SSBC Rules, the maximum allowable horizontal deflection is 0.75 in. and that of the vertical is 3 in., but limiting vertical deflection to 2 in. is preferable because a deflection between 2 in. and 3 in. adds a penalty to the structural efficiency score [1]. The team continued the process of trial and error by modifying aspects of the models to limit the deflections while continuing to follow all dimensional constraints and making the bridge as light as possible.

3.3 Final Design Selection

Once the team had three working models that complied with the deflection requirements, a decision matrix was created to determine which two models would advance to be refined even more in the RISA trial and error process. This decision matrix is shown in Table 3-2 below. Larger pictures of the RISA models for bridges 1, 2, and 3 are shown in Appendix B.

Table 3-2: Decision Matrix (Round 1)

	Bridge Decision Matrix								
	Option 1			Option 2			Option 3		
									
	Actual	**Raw Score**	**Weighted**	**Actual**	**Raw Score**	**Weighted**	**Actual**	**Raw Score**	**Weighted**
Lateral deflection (20%)	0.66 in.	1	0.2	0.27 in.	0.4	0.08	0.38 in.	0.6	0.12
Vertical deflection (15%)	0.43 in.	0.8	0.12	0.42 in.	0.8	0.12	0.55 in.	1	0.15
Weight (30%)	563 lb	0.7	0.21	754 lb	1	0.3	689 lb	0.9	0.27
Constructability (30%)	57 Pieces	0.5	0.15	91 Pieces	0.7	0.21	125 Pieces	1	0.3
Aesthetics (5%)	2	0.6	0.03	1	0.3	0.015	3	1	0.05
Total			**0.71**			**0.725**			**0.89**

Weight and constructability were both weighted the highest in importance at 30% because if the bridge cannot be fully assembled within the time limit, it will not be eligible to compete in either of the load tests and weight adds to the overall structural cost. Additionally, past NAU Steel Bridge teams had difficulty with these aspects of the competition and recommended that these take priority. Lateral deflection was deemed more important than vertical deflection because the bridge must first pass the lateral load test to be eligible to compete in the vertical load test. Aesthetics was deemed the least important because while there is an aesthetics category in the competition, the functionality of the bridge is the primary aspect of the competition.

The 'Actual' column shows the true performance of each bridge in each category. The 'Raw Score' was determined by giving the worst-performing bridge in each category a score of 1, then calculating the other raw scores by dividing the actual values of the other two bridges by the actual score of the poorest performing bridge, shown by Equation 3-1.

Equation 3-1: Raw Score

$$s_r = \frac{n_i}{n_{max}}$$

Where:

$$s_r = raw\ score$$

$$n_i = actual\ value$$

$$n_{max} = maximum\ value\ in\ category$$

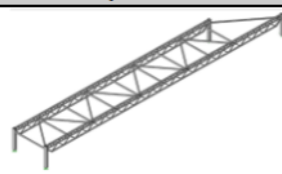
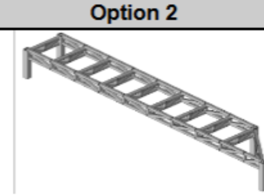
To illustrate the scoring process, the bridge with the largest number of pieces was given a raw score of one (since a large number of pieces is the least desirable), and the bridge with 57 pieces was given a raw score of 57/125=.46, or .5 rounded up. The weighted score was determined by multiplying the raw score by the weight assigned to each category. Lower scores indicate a better-performing and more desirable bridge.

The bridges were assigned an actual aesthetics score of 1, 2, or 3, where 1 indicated the 'best-looking' and 3 the 'least good-looking'. The bridges were judged aesthetically based on the opinions of the team members and an external participant. These scores were then multiplied by the importance factor to determine the weighted score.

The two best-scoring bridge models, 1 and 2, then advanced to be further refined in attempt to reduce the bridge weight while remaining within the deflection limits, in addition to incorporating feedback from the team's technical advisor. The modifications that were made from this feedback included switching the design methodology to LRFD (it was discovered that they had previously been using allowable stress design accidentally), correcting the model to include more member end releases, and reducing member sizes in attempt to get the bridge weight to 300 lbs. or less.

Once the two models had been refined, they were ranked again in a second decision matrix to determine which one would serve as the team's final bridge design. This design would still be subject to further improvements, but it would be the only model that the team would work with moving forward. As shown in the second decision matrix in Table 3-3, Bridge 2 will be the team's final working model. Pictures of Bridges 1 and 2 are shown in Appendix B.

Table 3-3: Decision Matrix (Round Two)

	Bridge Decision Matrix (Round 2)					
	Option 1			Option 2		
						
	Actual	Raw Score	Weighted	Actual	Raw Score	Weighted
Lateral Deflection (20%)	0.59 in.	1.0	0.20	0.40 in.	0.7	0.13
Vertical Deflection (15%)	1.36 in.	1.0	0.15	0.43 in.	0.3	0.05
Weight (30%)	287 lb	0.8	0.24	372 lb	1.0	0.30
Constructability (30%)	49 pieces	0.5	0.15	90 pieces	1.0	0.30
Aesthetics (5%)	1	1.0	0.05	1	1.0	0.05
Total			**0.79**			**0.83**

3.4 Connection Design

3.4.1 SSBC Rules & Identifying Bolted Connections

To design the bridge's connections, the team first consulted the SSBC Connection Safety Examples document [20], which includes the same information as Section 9.5 of the general SSBC Rules except annotated pictures were added to illustrate concepts related to connection design and examples of allowed and prohibited connections. Using this document, the team gained a better understanding of what a faying surface is (the plane along which two members touch) and that there can be a maximum of two at any connection. They also learned that through each faying surface, there must be at least one bolt and nut. An example of one of the figures from the document illustrating this concept is shown in Figure 3-8 below, which is a prohibited connection because it has three faying surfaces.

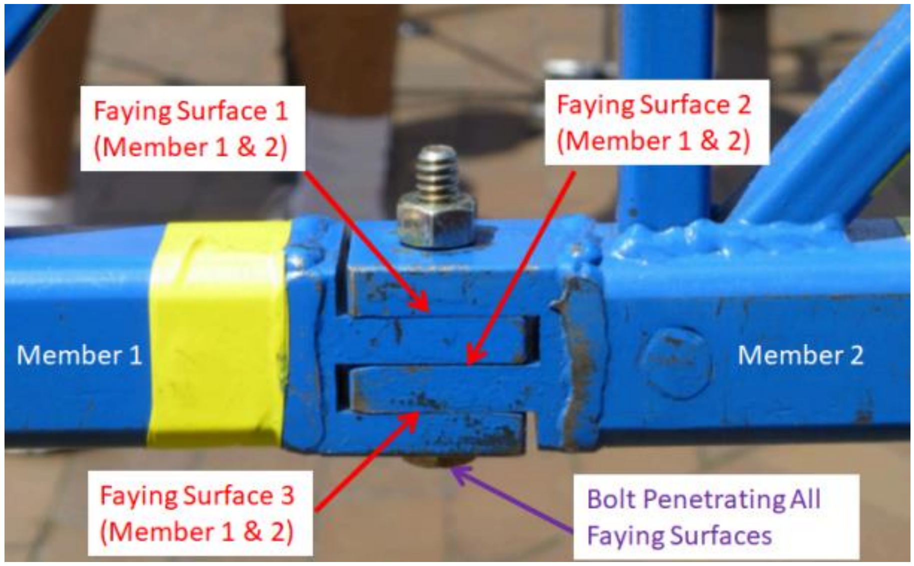


Figure 3-8: Prohibited Connection and Faying Surfaces [20].

Next, the team identified each of the unique types of bolted connections the physical bridge would have. A 'unique' connection type refers to the dimensions and shapes of the members being connected. That is, if there is more than one instance of the same combination of members being joined, in both size and shape, these connections were considered to be of the same 'type'. To identify unique connection types, the team looked at the RISA model in rendered view (a view that shows the bridge as made of the actual steel members it contains instead of a 'stick model') and thought about how the bridge pieces could be bolted together at the locations modeled as 'pins' while keeping the SSBC rules in mind.

3.4.2 Distinct Connection Types

It was determined that the bridge had four distinct bolted connection types, which were eventually named Connections 1, 2, 3, and 4, respectively. The locations of Connections 1 and 2 are shown the bridge drawing in Figure 3-9, and those of Connections 3 and 4 are shown in Figure 3-10.

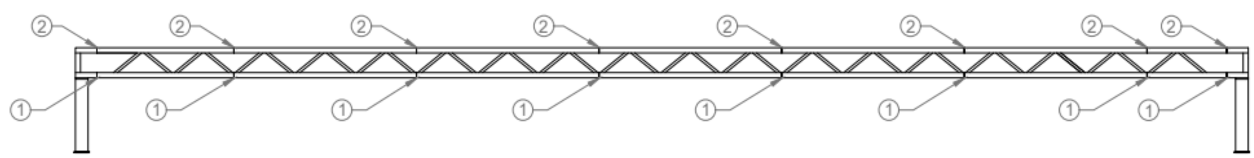


Figure 3-9: Connection Locations - Side View

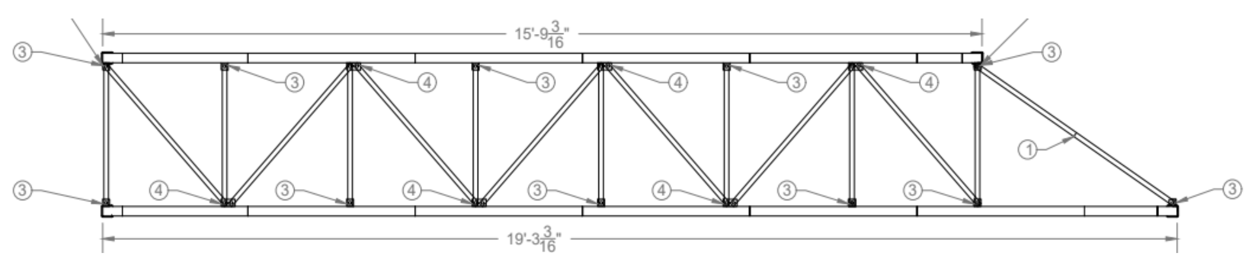


Figure 3-10: Connection Locations - Overhead View

In Connection 1, truss members connect along the bottom stringer by resting on top of two angles with two bolts through. The function of this connection is to primarily resist tension, which is dominant in the bottom truss chord. A picture of Connection 1 is shown in Figure 3-11 below.

Figure 3-11: Connection 1 - Bottom of Truss

Connection 2 secures the top of the truss members together. Since the top chord of the truss is primarily in compression, these members are not as risk of pulling away from each other, so the single bolt at each connection primarily resists shear from the vertical loads. These connections are located on the bottom side of the top stringer to prevent the connection from interfering with the stringer template used for competition. A picture of Connection 2 is shown in Figure 3-12.

Figure 3-12: Connection 2 - Top of Truss

Connection 3 connects the straight (non-diagonal) individual cross braces to the truss pieces. Tabs were welded to the bottom chord of the truss rather than the top chord to allow the stringer template to slide along the top stringers with no obstruction at competition. One bolt is installed at each location to primarily resist shear. A picture of Connection 3 is shown in Figure 3-13.

Figure 3-13: Connection 3 - Straight Cross Bracing

Connection 4 connects the diagonal and non-diagonal cross braces to the truss pieces at the points where three cross braces come together at a tab. A tab with two holes was used to comply with rules regarding faying surfaces. Like Connection 3, the tabs were welded to the bottom chord of the truss to avoid stringer template interference, and bolts are installed vertically to primarily resist shear.

3.4.3 Bolt Calculations

Using the AISC Steel Construction Manual, the number of bolts required for each of the four unique connection types was determined to ensure each connection would be adequate for shear, tension, and bolt bearing, and the base material for tensile yielding, rupture, and block shear. To determine the forces acting on the bolts, all the members in the RISA model that would contain a particular connection type were selected, and the highest internal force value of all those members selected was used to design that connection type, to be conservative. Table 3-4 shows a summary of the limit states checked for each connection and the demand-to-capacity ratio for the worst-case force.

Table 3-4: Bolt Calculation Summary

Connection	Limit States Checked		Controlling D/C Ratio
	Bolt	Base Material	
1	Shear, tension, bearing	Yielding, rupture, block shear	.974 (bolt shear)
2			. 395 (bolt shear)
3			.016 (bolt shear)
4			.016 (bolt shear)

For example, all bridge pieces that contain Connection 1 were selected, and the highest shear value within those members was used in the shear and bearing check, and the highest tension in the tension check, to determine how many bolts were required for Connection 1. Calculations were performed using Microsoft Excel, and a printout of the file is shown in Appendix C.

3.4.4 Welded Connections

To design the welded connections of the bridge, the type of weld joint that would be most appropriate for connecting certain parts of the bridge was identified. For every distinct type of connection modeled as ‘fixed’ in RISA, it was identified whether a tee, corner, lap, edge, or butt weld joint would be most appropriate, since each of these types is best suited for a certain configuration of how the steel members are connected (e.g., a lap joint may be used when two steel members are parallel and stacked on top of each other; see Figure 2-1 for weld joint types). Similar to the bolt design process, a ‘distinct’ or ‘unique’ type of welded connection refers to the types and dimensions of members being joined by the connection. For example, there are four instances where a bridge column (or leg) is welded to the baseplate under it; since the legs and baseplates are the same size and shape between all four instances, they all belong to one type of welded connection.

Using the AISC Steel Construction Manual, the team calculated the available strength of the base material and the required weld size for each distinct connection type. Similar to the bolt calculations, all the bridge members containing a particular type of welded connection were selected, and the highest internal member force within this selection was used to calculate the required weld size to be conservative. The team also verified that the available strength of the base material was greater than the applied force. The AISC Steel Construction Manual states that the size of the weld can be no smaller than the thickness of the base material. Because of this and the conservative approach mentioned previously, the required size of all welds turned out to be 1/8 in., and the weld types were either a fillet weld or butt weld depending on the configuration of the members being joined. Therefore, the welded connections were not numbered like the bolted connections but instead separated out into distinct "types" depending on the members being joined. Table 3-5 shows a summary of the distinct types of welded connections, limit states checked, and worst-case demand to capacity ratio. The weld calculations were performed in Excel, and a printout of the file is shown in Appendix D.

Table 3-5: Weld Calculation Summary

Weld "Type"	Limit States Checked	Controlling D/C Ratio
Truss Web Members to Stringers	Strength of fillet weld, base material yielding, base material rupture	.275 (weld)
Cross-bracing Tabs to Bottom Stringer		.034 (weld)
Vertical Part of Footing to Horizontal Part of Footing		.178 (base material)

4.0 Shop Drawings

The shop drawings that the team created were designed to be used by Flagstaff High School to weld the bridge. For this reason, the shop drawings had to be very thorough and include all necessary views, dimensions, and details so that the bridge could be fabricated exactly how the team had designed it. Table 4-1 shows a summary of sheets. The full shop drawings can be found in Appendix E.

Table 4-1: Shop Drawing Table of Contents

Sheet Number	Title	Description
1	Steel Member Schedule	A list of the quantity and length of all raw materials shown in the shop drawings; quantities of the 5 welded pieces; quantities of the cross-bracing members; quantity of sections containing each connection type; dimensions of plating used at each connection type; general structural notes; and legend
2	Plan and Profile Views with Connection Locations	Plan and profile views of the bridge with where each of the 5 welded section types are located
3	Members by Welded Piece and Section A-A	A list of each of the 5 welded segments and what components they are made of, and the length and quantity of each component. Also, a section view showing the two west footings connected by a cross-brace
4	Welded Member Pieces	Details of each of the 5 welded section types (labeled as A, B, C, D, and E), which are the fundamental “building blocks” of the bridge excluding the cross-bracing
5	Connection Locations	North and South elevation views showing the locations of connections 1 and 2 in the bridge, and a plan view showing the locations of connections 3 and 4 in the bridge
6	Connection Plating Locations	Bridge plan view with dimensions of where plating for connections 2, 3, and 4 should be welded
7	Connection 1 & 2 Details	Top view, side view, and cut view details of connections 1 and 2
8	Connection 3 & 4 Details	Top view and side view details of connections 3 and 4

5.0 Sub-Consultant Coordination and Fabrication

5.1 Coordination with Page Steel

With design and shop drawings complete, the team also created an inventory of the steel needed for bridge construction. The team worked with the previous steel bridge team to obtain a contact at Page Steel. The team then reached out to Page Steel to coordinate ordering and the delivery of the steel. A simplified list of quantities was provided to Page Steel on December 12th, at which point they were able to gather the requested materials. Since the steel was donated, Page Steel delivered the materials to a local welding shop for convenience and cost on their end. Once the materials arrived on January 7th, the team picked them up and moved forward with fabrication.

5.2 Coordination with Flagstaff High School

While the team was still developing shop drawings, the Flagstaff High School (FHS) welding instructor, Mike Rust, was contacted to coordinate a team visit to FHS. On December 12, 2024, the team met Mr. Rust and his group of FHS students that would be welding bridge pieces. A rough draft of the shop drawings was brought to the meeting to give the students a general understanding of the bridge design. The team also described the general competition rules to give the students a general understanding of why the bridge is being constructed. Mr. Rust was also able to provide the team with a preferred timeline for the team to get the final shop drawings and steel to the class, which was before February to allow the welding class to have enough time to also prepare for their Skills USA competition.

With the steel in the possession of the team, the next step was to get the members cut. Originally the team was going to cut the members and deliver the precut pieces to FHS. Due to time constraints FHS offered to cut the members, in addition to welding. The raw steel was then brought to FHS on January 28, along with the final shop drawings. Welding was completed on March 26, where the team then picked up cut and welded members to move forward with final fabrication needs by the team.

5.3 Coordination with Cooper State Nut and Bolt

Prior to receiving the welded portions of the bridge, the team needed nuts and bolts to have ready for when it was time to practice construction. Copper State Nut and Bolt, located in Flagstaff, was contacted and informed of the project and upcoming order. A list was then put together of the quantities and sizes of the materials needed, then taken to Copper State and ordered on February 26th. The materials took approximately one week to arrive and were picked up on March 5th.

5.4 Team Fabrication

Initially, the only team fabrication that was expected to take place was the drilling of bolt holes for Connections 3 and 4 so the team would have more control over the tolerances in these connections. However, upon picking up the finished pieces from Flagstaff High School, it was determined that the placement of Connections 1 and 2 had been switched, requiring the team to perform additional fabrication due to time constraints. The Connection 2 tabs (which were mistakenly welded to the bottom of the truss) were cut off and re-welded to the top of the truss, and Connection 1 was remade as intended per the shop drawings except that 1-inch angles were used in place of tabs. The team purchased these angles from a local hardware store. Bolt holes were then drilled into all applicable members per the shop drawings.

6.0 Competition Preparation

6.1 Practice Bridge Assembly

The team used tape to outline the construction area at the NAU field station exactly as it would be set up at the competition by referencing the dimensioned drawing of the construction area in the SSBC Rules. Figure 6-1 shows the construction area per the rules.

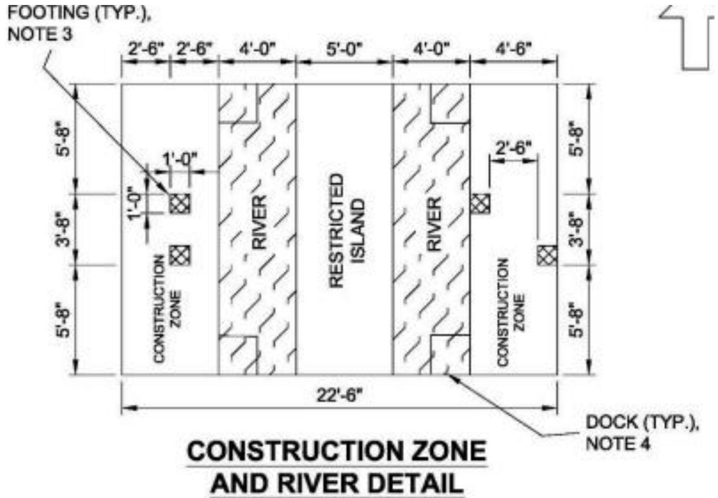


Figure 6-1: Construction Area

The team also marked each bridge piece with a sharpie so the pieces could be easily identified and laid out in order, which would simplify the construction process. During this time, the team decided which pieces should be built in each construction zone. It was first assumed that exactly half of the bridge's pieces for both the north and south sides would be assembled in each zone to distribute the work evenly. However, because no builder can go in the restricted island zone, the team had difficulty connecting the two halves over the island when practicing. During the second practice, it worked better where one construction zone got two thirds of the north side's bridge pieces and the other construction area got two thirds of the south side. The team practiced assembling the bridge while timing themselves a total of two times at the NAU field station, once with four members and once with five (the four team members plus one mentee). During these practice sessions, it was determined that it would be in the team's best interest to use the maximum allowed number of six builders, four team members plus two mentees, to minimize construction time. It was decided that two of the builders would serve as barges, or builders who cannot leave the designated "river zones" at the competition.

6.2 Poster

The requirements for the poster, which was displayed alongside the bridge on Display Day at the competition, are listed in the SSBC Rules. Some of the requirements include providing shear and moment diagrams for one load case of the team's choice; an explanation of why the bridge's connection types were chosen, what analysis was done to ensure the bridge met strength and serviceability requirements, and what limit states were checked in different types of bridge members to prevent failure. The team's poster is shown in Appendix F.

7.0 Competition

7.1 Display Day

The first day of ISWS was display day, where the bridge was assembled and displayed alongside the prepared poster. Each school had their bridge displayed and was able to freely see the other bridges. During the display period, judges viewed the bridge and judged the aesthetics of the bridge. Judges also looked over the poster at the required components. The team's main job was to tend to the display and be prepared to answer questions from either the judges or other participating schools. Figure 7-1 shows team member Alexa Godkin painting an identifying mark on the bridge the morning of display day, and Figure 7-2 shows students from other schools looking at NAU's bridge.

Figure 7-1: Alexa Painting on Display Day

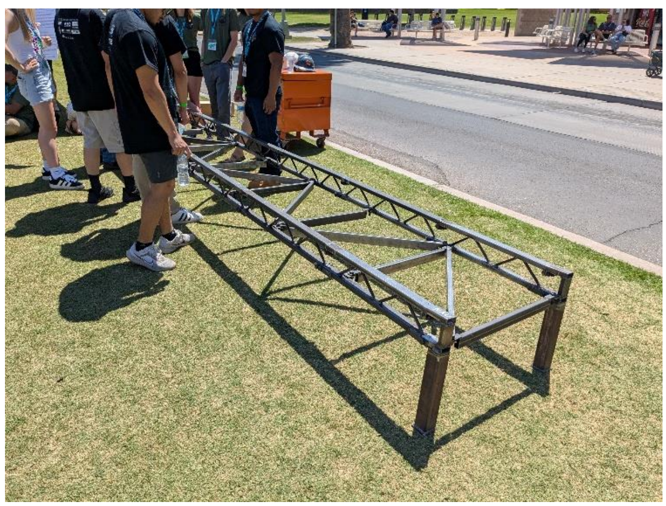


Figure 7-2: Students Looking at NAU Steel Bridge

7.2 Competition Day

The first task on competition day was to set up all materials needed for fabrication within the mapped out staging yard. This included placing and members, tools, bolts, and bolts in the appropriate staging yard. Once the site was set up, the judges began verifying that each member and tool fit into the 42 in. x 6 in. x 4 in. box. During this time, the judges found that the impact drill the team brought did not fit easily in the box. This then led the team to modify it by using an angle grinder to shave down the conflicting edge of the tool. After the alteration, the drill did meet the dimension requirements and was able to be used. During this time, the judges also ran the stringer template over the length of the bridge as well as checked and required dimensions such as clearance from the ground.

The team then proceeded to the timed construction portion. Two people started in each staging area and one person started in each portion of the river, acting as a barge. One person from each staging area acted as a runner, bringing members, tools, and bolts to the person in the construction area. The bridge was assembled by completing the south side first, then north, and finally by installing the cross bracing. The team exceeded 30 minutes of construction time, at which point there were no longer penalties or restrictions related to the build. The team then completed building with a time of 37 minutes and 8 seconds. A picture of the team building the bridge is shown in Figure 7-3 below.

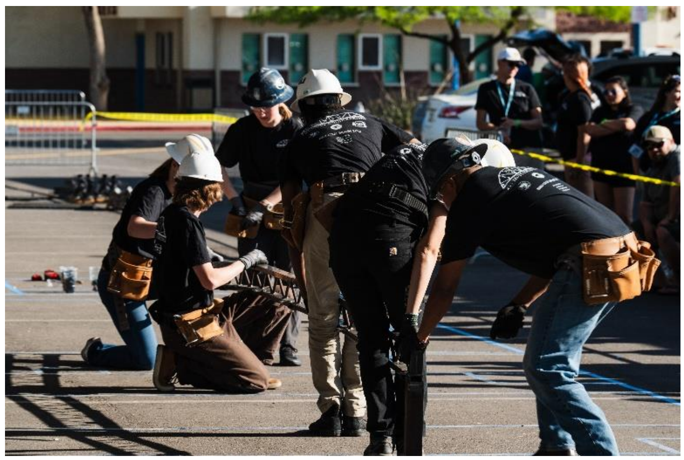


Figure 7-3: Team Building Bridge at Competition

At this point, the judges inspected the bridge for any safety concerns and marked any connections that they deemed could pose a safety risk when the bridge would be loaded. The team was then given two minutes to inspect the marked connections and five minutes to make any final adjustments to the bridge.

The fully constructed bridge was then moved to be weighed prior to loading. The final weight of the bridge was 306 lbs. The judges then rolled the dice to determine which load case the bridge would experience. With all prior steps complete, the bridge was moved to the loading area. The lateral test occurred first, where a 50 lb. load was applied to the south side. A plumb bob was used in conjunction with a target on the ground to determine if the bridge was within the lateral deflection limits. After applying the load, the bridge was within the allowed limits and proceeded to vertical loading.

Vertical loading began by placing two units of decking on the bridge, each 50 lb., followed by 100 lbs. of preload on each. Once the bridge was deemed stable under this load by the judges, the team continued to load the bridge vertically by placing 25 lb. steel angles on it one at a time, first loading the west side decking. Once the team placed the maximum possible load of 56 angles on the west side decking, 1400 lbs. including preload, they began placing angles on the east side decking. When nearing the end of the second load, a connection on the south side of the bridge failed and caused the bridge to deflect the maximum allowable value of 3 inches, at which point the judges stopped more load from being placed on the bridge. The team was able to place 25 of the 44 possible angles on the east side decking, resulting in a total bridge load of 2025 lbs. out of 2500 lbs. possible. Table 7-1 below provides a summary of the competition results. Figure 7-3 shows the team standing by the bridge with the final loading on it.

Table 7-1: Competition Results

Category	Results
Construction Time	37 minutes, 8 seconds
Bridge Weight	306 lb.
Lateral Deflection	Not measured, but within 0.75”
Vertical Deflection	3”
Sustained Vertical Load	2025 lb.

Figure 7-4: Team with Final Load and Bridge

8.0 Summary of Engineering Work

8.1 Design

The team developed three bridge design alternatives in RISA-3D, all of which complied with the SSBC Rules in terms of dimensions and the horizontal and vertical deflection limits, 0.75 in. and 3 in., respectively. The three alternatives were scored in a decision matrix in the categories of lateral deflection, vertical deflection, weight, number of pieces, and aesthetics to determine which two models would be refined further. The two models that advanced were modified to reduce weight and have as few pieces as possible while remaining within the deflection limits. Then, the two bridges were ranked using the same scoring criteria, and the bridge with the best score was selected to move forward with connection design.

The team determined that the bridge would have four unique bolted connection types and three types of welded connections. Once the team verified that their ideas for these connections complied with the SSBC Rules, the bridge's welded and bolted connections were designed using the methodologies in the AISC Steel Construction Manual. A 1/8 in. fillet weld was determined to be adequate for all welded connections, and either one or two 1/2 in. A325 bolts were used at each bolted connection depending on the connection type.

8.2 Material Acquisition

Once the final bridge model was complete and the connections had been designed, the team determined the quantity and type of steel members, nuts, and bolts that were needed to make the bridge a reality. The team provided their subcontractors with the relevant material schedules and obtained the steel members from Page Steel, and the nuts and bolts from Copper State, all of which were donated to this project.

8.3 Fabrication

The team created a set of shop drawings and gave them to Flagstaff High School (FHS). The FHS welding students fabricated most of the bridge by cutting the steel members to the required sizes, welding the designated parts of the bridge, and drilling some of the bolt holes. However, two of the connections were welded in the wrong location, which required the team to cut off and re-weld Connections 1 and 2 of the bridge. Connections 1 and 2 were remade to be the same as shown the shop drawings, except 1-inch angles were used in place of tabs in Connection 1, which the team purchased from a local hardware store. The team also drilled the bolt holes for Connections 3 and 4, which was planned from the beginning.

8.4 Staffing

Over the course of the project there were four roles: Senior Engineer, Engineer, Engineer in Training (EIT), and Drafter. Prior to beginning the project, 710 staffing hours were estimated to be needed to complete this project. Table 8-1 shows the predicted staffing hours by task and position. Updated staffing hours are shown in Table 8-2, which shows the actual staffing hours required for this project, which was a total of 691 hours. A complete staffing table showing hours for each sub task is shown in Appendix G.

Table 8-1: Proposed Staffing Hours

Tasks	SENG	ENG	EIT	DRFT	Task Totals
Task 1: Background Research	5	15	15	5	35
Task 2: Design	15	65	50	30	160
Task 3: Shop Drawings	20	40	25	55	140
Task 4: Sub-Consultant Coordination and Fabrication	20	20	20	10	70
Task 5: Competition Preparation	15	25	25	10	75
Task 6: Competition	20	20	20	0	60
Task 7: Project Management	40	45	30	35	150
Task 8: Project Impacts	5	5	5	0	15
Staff Totals	140	235	190	145	**710**

Table 8-2: Actual Staffing Hours

Tasks	SENG	ENG	EIT	DRFT	Task Totals
Task 1: Background Research	2	13	13	5	33
Task 2: Design	16	68	42	31	157
Task 3: Shop Drawings	17	48	23	69	157
Task 4: Sub-Consultant Coordination and Fabrication	13	30	23	11	77
Task 5: Competition Preparation	8	15	16	6	45
Task 6: Competition	20	20	20	0	60
Task 7: Project Management	35	47	30	36	148
Task 8: Project Impacts	4	5	5	0	14
Staff Totals	115	246	172	158	**691**

As shown by the tables, the proposed hours were slightly higher, by 19 hours. Some key differences in the proposed and actual hours include fewer hours by the Senior Engineer and EIT, and more hours by the Engineer and Drafter. The reduction in hours came mostly from background research and competition preparation, as background research took less time than anticipated and competition preparation was limited due to time constraints related to fabrication. The additional hours primarily came from the additional time required to create shop drawings and the additional fabrication needed to be done by the team.

9.0 Summary of Engineering Costs

A summary of cost was prepared prior to completing the project, as a proposed cost. The cost estimate contained estimated costs for staffing, supplies, subcontracting, and travel. Table 9-1 shows an overview of the proposed cost estimate.

Table 9-1: Proposed Cost

Category	Cost
1.0 Staffing	$ 89,050.00
2.0 Supplies	$ 2,200.00
3.0 Subcontracting	$ 9,000.00
4.0 Travel	$ 2,409.00
Total Cost	$ 102,659.00

After completion of the project, the actual cost was tabulated. The cost was modified based on actual staffing hours, supply costs, and fabrication hours. Travel expenses did not change as those are based on state rates. Table 9-2 shows a summary of the actual project cost. A complete cost estimate can be found in Appendix H.

Table 9-2: Actual Cost

Category	Cost
1.0 Staffing	$ 84,860.00
2.0 Supplies	$ 1,770.45
3.0 Subcontracting	$ 9,360.00
4.0 Travel	$ 2,409.00
Total Cost	$ 98,399.45

As shown by the tables, the actual cost was less than the proposed cost. Overall, the project was $4,259.55 under budget, or about 4% under. Reductions in cost were a result of the estimated staffing hours and materials. Staffing hours were fewer, especially for the Senior Engineer, which reduced cost of staffing. The quantity and price of nuts and bolts were both overestimated, lowering material costs. The same applied to the cost of steel, which was originally estimated at $10.00 per linear foot, but ended up being closer to $7.50 per linear foot.

10.0 Impact Analysis

Table 10-1 compares the positive and negative social, environmental, and economic impacts of a steel bridge and a concrete bridge. Concrete was chosen to compare to the steel bridge because concrete is another common bridge material that could have been used for the hypothetical situation provided in the competition rules. This hypothetical situation was to create a pedestrian bridge to span the Skunk River in Peterson Park, which is located in Iowa.

Table 10-1: Impact Analysis

Impact Analysis				
		People (Social)	**Planet (Environment)**	**Price (Economic)**
Steel Bridge	Positive impacts	Steel structures are more aesthetically pleasing than concrete structures to people passing or using the bridge	Steel has a lower embodied carbon footprint than concrete and generates less waste	Steel Structures generally have lower labor costs due to steel's ability to be prefabricated offsite and brought on site in addition to being lighter weight with an increased ability to span longer lengths, which makes steel more cost effective in the long run, especially for large projects
	Negative Impacts	Steel structures are prone to corrosion, which if not properly maintained could become less aesthetically pleasing to those using and passing the bridge	Steel construction releases more volatile organic compounds (VOCs) and heavy metal emissions than concrete construction does	Steel is generally more expensive up front than concrete and can require more maintenance depending on the project, meaning in the short run a concrete bridge may be more effective than a steel bridge would be
Concrete Bridge	Positive impacts	Concrete is not affected by corrosion and as a result, if the bridge spans over water it is less likely to rust and corrode, making it more appealing to the public	Concrete has the ability to make use of numerous recycled materials compared to steel, which can be beneficial for the environment	Concrete structures are generally cheaper in the short run, purely based on material availability, than steel, making it a better choice for certain projects
	Negative Impacts	Concrete is generally less aesthetically pleasing than steel, making it less appealing for a bridge when compared to a steel bridge	Concrete has a greater embodied carbon footprint than steel and creates more waste than a steel project would, which is detrimental to the environment	Concrete has less ability for prefabrication than steel which can lead to increased construction times which costs more money, making the concrete design less cost effective in the long run than a steel bridge

The table below shows the triple bottom line analysis of a steel bridge and a concrete bridge. Each bridge was ranked on a scale of 1 to 5 for each category, with 1 being the worst and 5 being the best. The '∑' column shows the sum of the bridge's scores in each category. The next column, 'Δ' shows the difference between the highest and lowest scoring values the bridge received. Lastly, the 'SI' column shows the Sustainability Index of each bridge. This is found by subtracting the 'Δ' column from the '∑' column. A higher SI score indicates a more favorable option.

Table 10-2: Sustainability Index (SI)

Triple Bottom Line Analysis						
	People (Social)	Planet (Environmental)	Price (Economic)	Σ	Δ	SI
Steel Bridge	3	4	3	10	1	9
Concrete Bridge	2	3	4	9	2	7

As can be seen in Table 10-2 above, the steel bridge was found to be more favorable than the concrete bridge. This is because it earned a higher sustainability index score. The steel bridge was determined to be more favorable in all three categories: social, environmental, and economic impacts. These scores were determined based on the impact analysis in Table 10-1.

11.0 Conclusion

Although the team did not perform as well as they would have liked at the competition, a lot of lessons were learned about the engineering design and fabrication process. All project objectives were met on time and the team was able to compete in the competition by building the bridge within the required time and loading the bridge.

The team's final RISA model accurately predicted the lateral deflection of the bridge as being within the allowable limit 0.75 in., but the actual vertical deflection of the bridge did not match the model's prediction of around 2 inches. At the end of the vertical load test, the team identified that the cause of the 3-inch deflection was a failure of one of the bottom stringer connections, which broke because one of the bolt holes had been drilled too close to the edge of the tab. The team knew that this might be a risk when they were drilling holes, but due to the fabrication issues with Flagstaff High School and time constraints, they were not able to fix it ahead of time. The ISWS 2025 scoring system did not indicate what place NAU's bridge got in the overall competition since it did not place in the top three schools. However, the bridge was able to withstand about 80% of the required load at 2025 lb.

Truss-ty Engineering is proud of the work that was accomplished and is very thankful to all the people that helped them along the way. The team considers the project a success and is grateful for the opportunity to use their engineering knowledge to make the bridge a reality. At the conclusion of this project, the bridge will be constructed at the home of a team member's uncle where it can be used to cross a small river. The team chose this as the final location of the bridge so that the work can continue to be enjoyed for many years.

12.0 References

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Appendix A: Preliminary Sketches

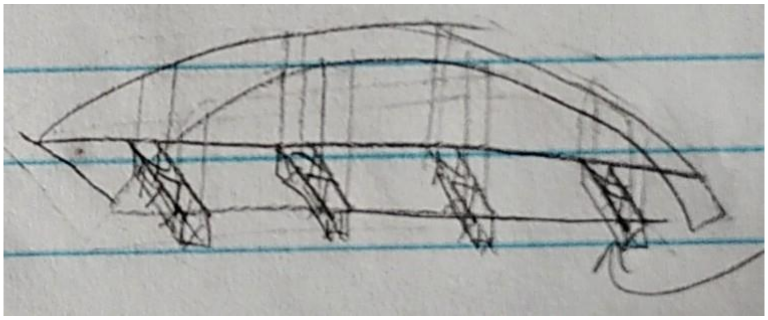


Figure A-1: Hand Drawn Sketch #1

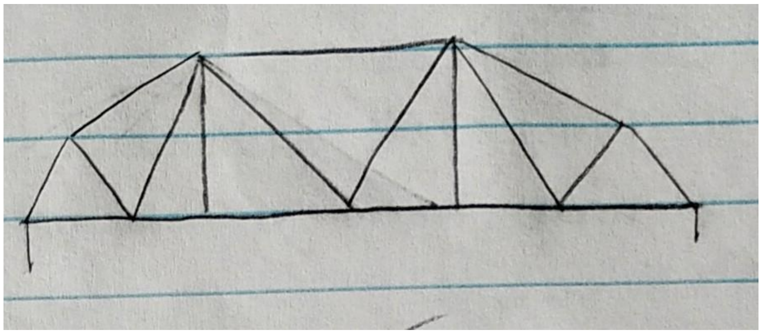


Figure A-2: Hand Drawn Sketch #2

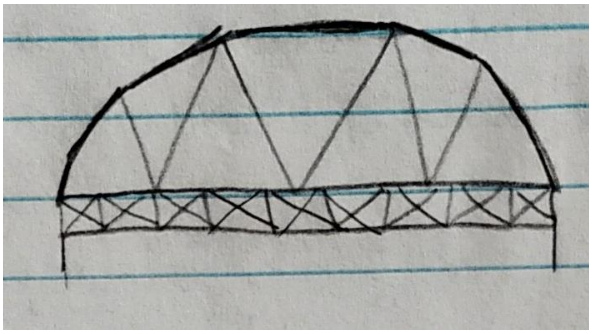


Figure A-3: Hand Drawn Sketch #3

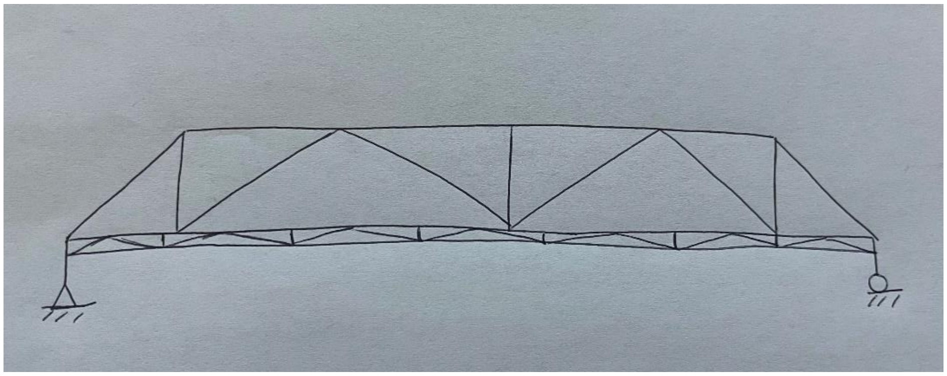


Figure A-4: Hand Drawn Sketch #4

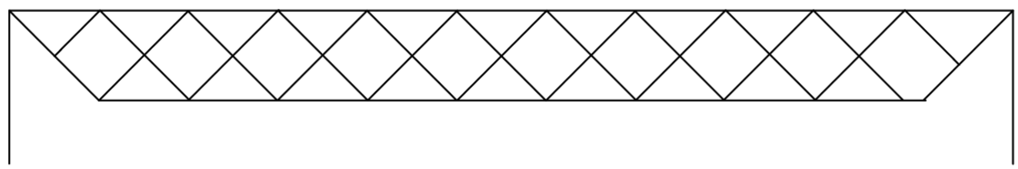


Figure A-5: Hand Drawn Sketch #5

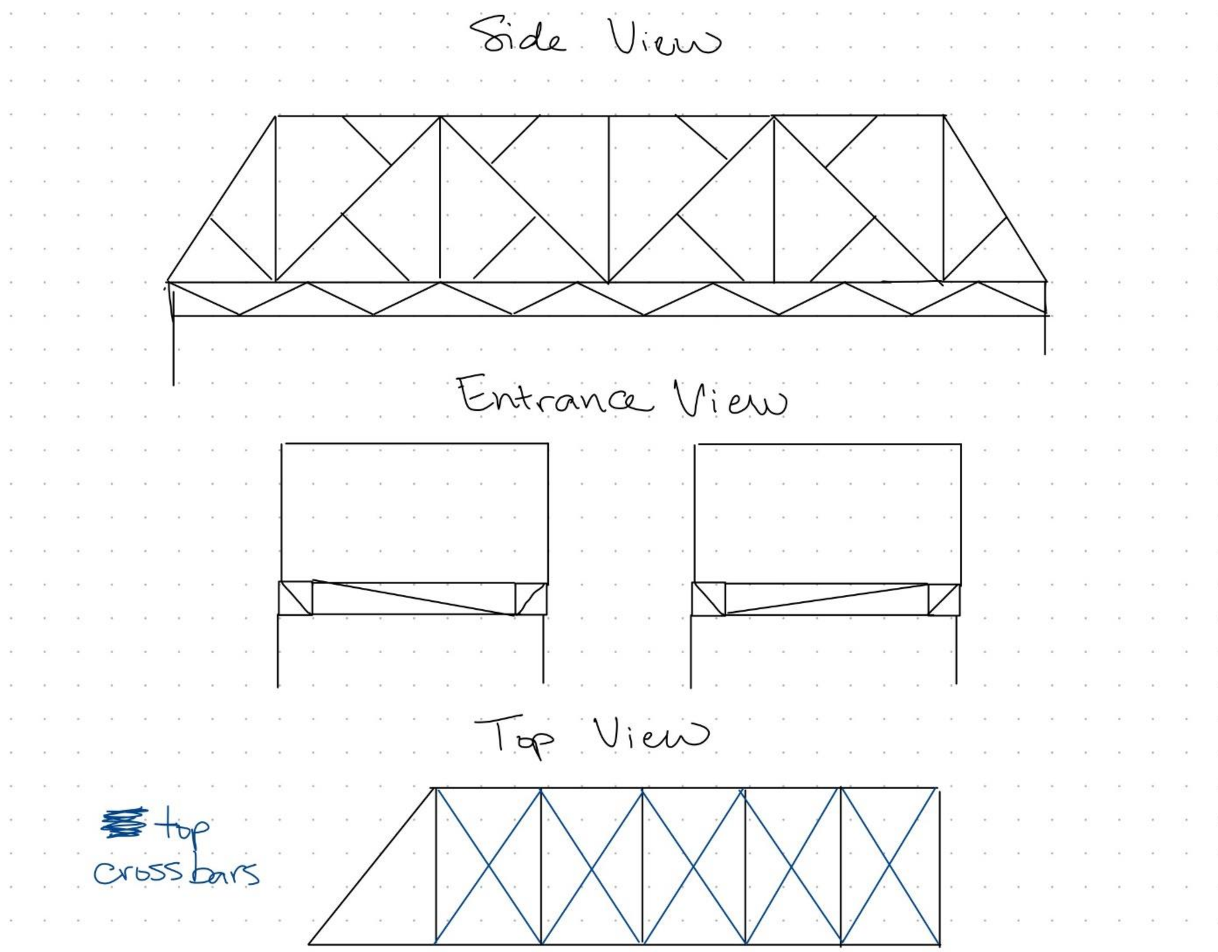


Figure A-6: Hand Drawn Sketch #6

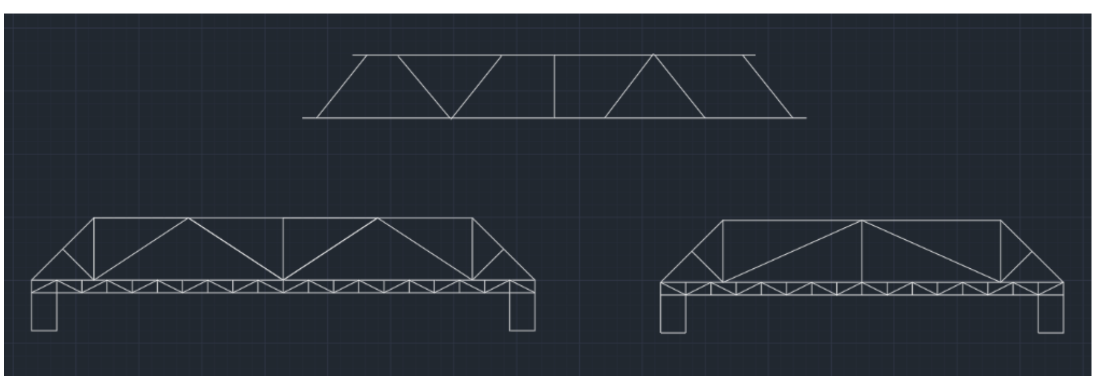


Figure A-7: AutoCAD Sketch #1

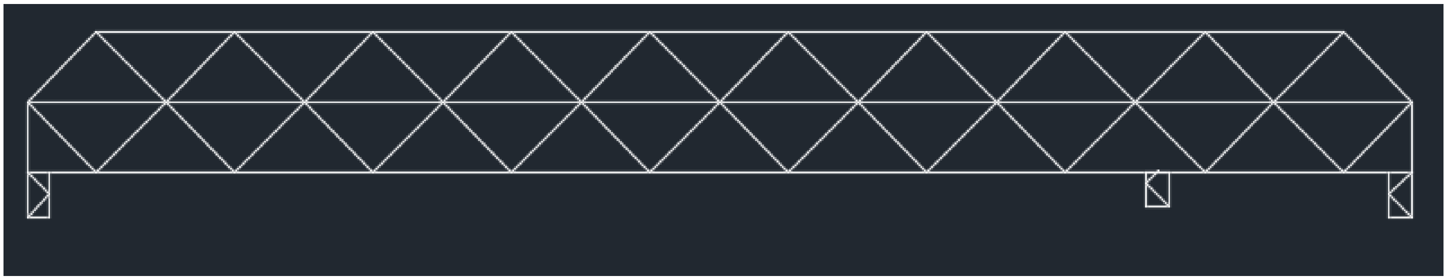


Figure A-8: AutoCAD Sketch #2

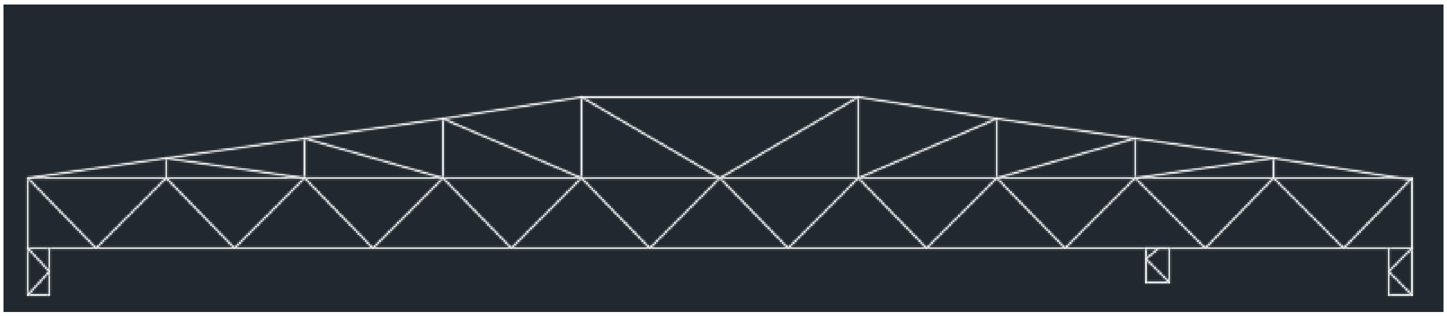


Figure A-9: AutoCAD Sketch #3

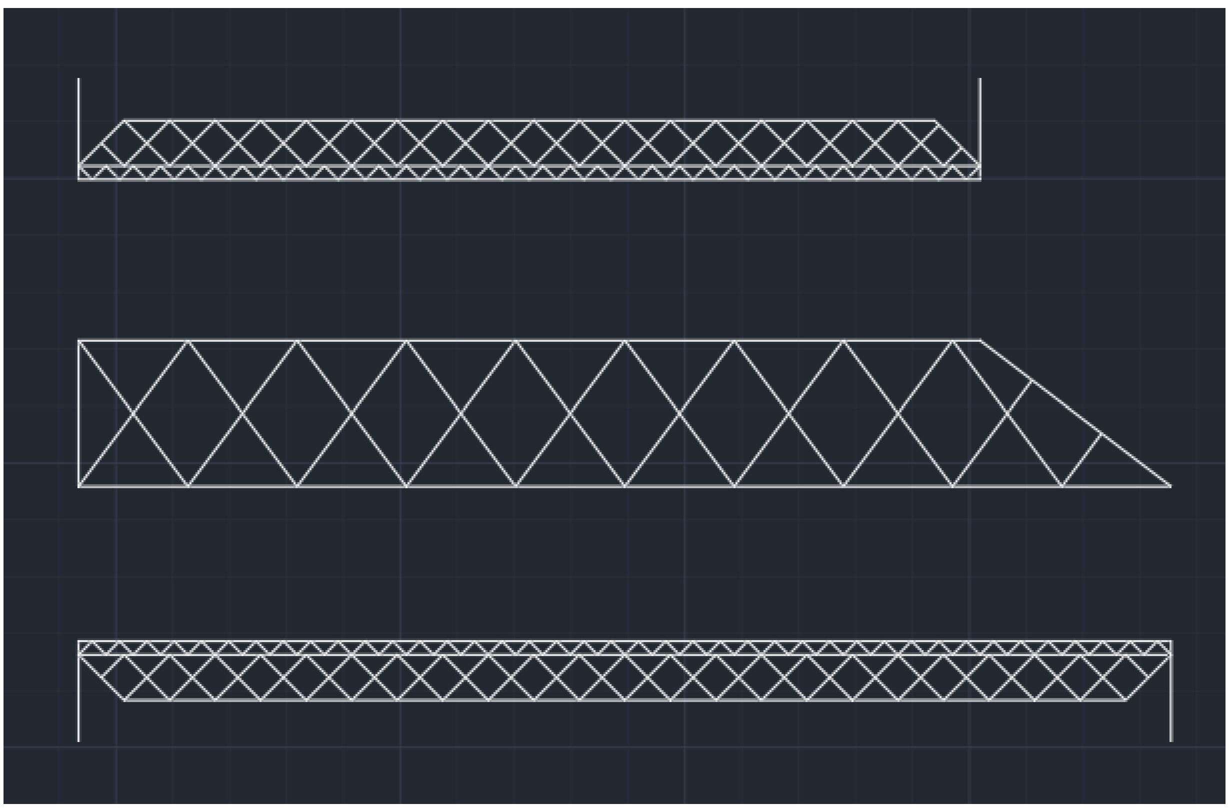


Figure A-10: AutoCAD Sketch #4

Appendix B: RISA Model Pictures

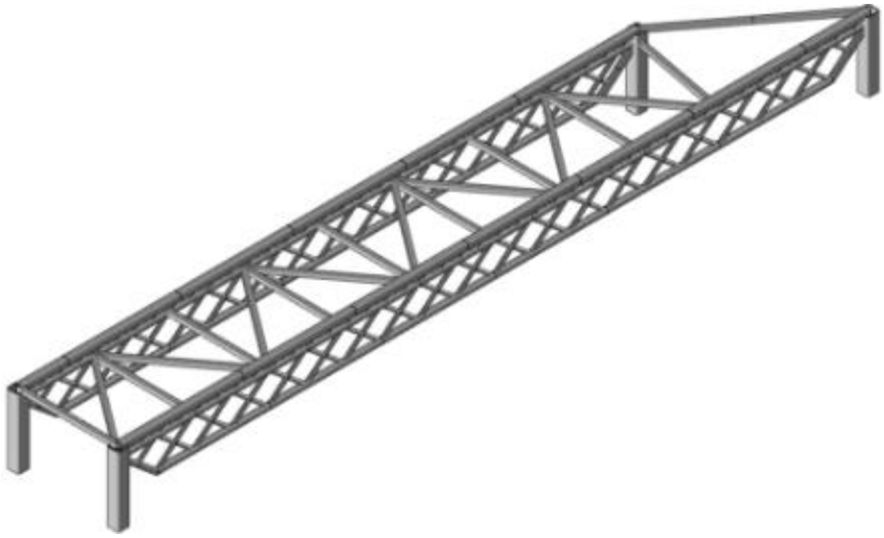


Figure B-1: Bridge 1 for Decision Matrix 1

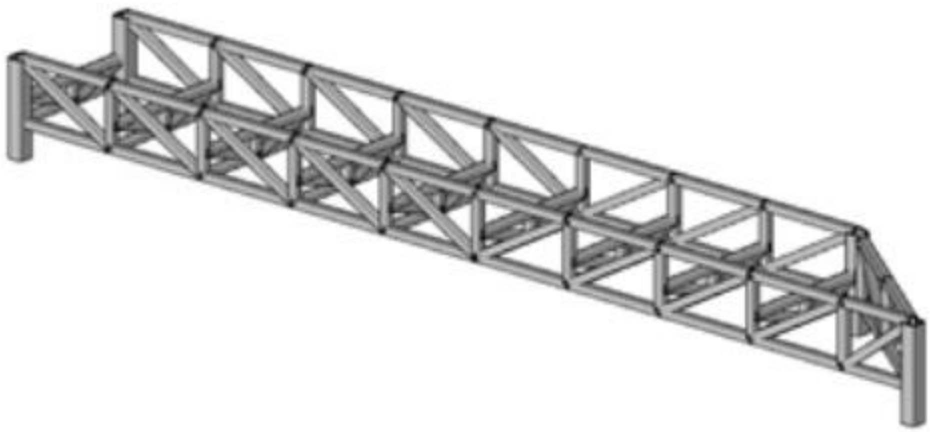


Figure B-2: Bridge 2 for Decision Matrix 1

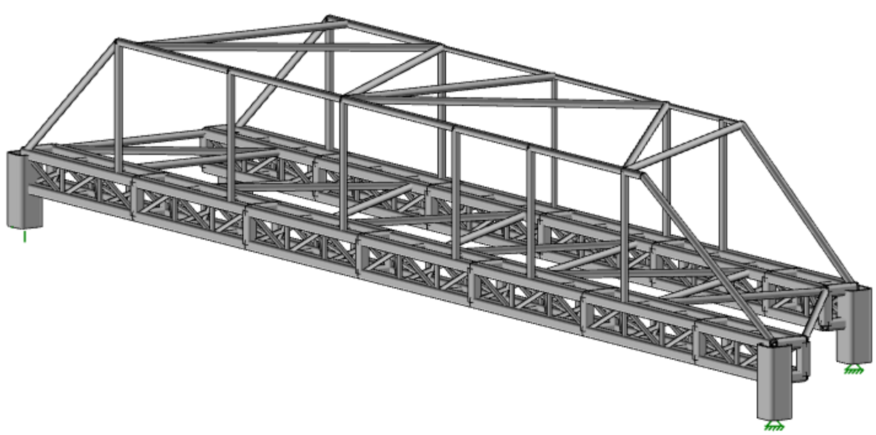


Figure B-3: Bridge 3 for Decision Matrix 1

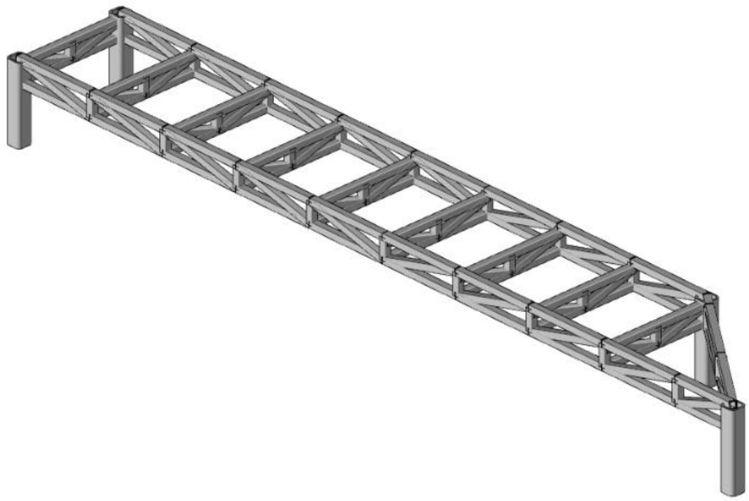


Figure B-4: Bridge 1 for Decision Matrix 2

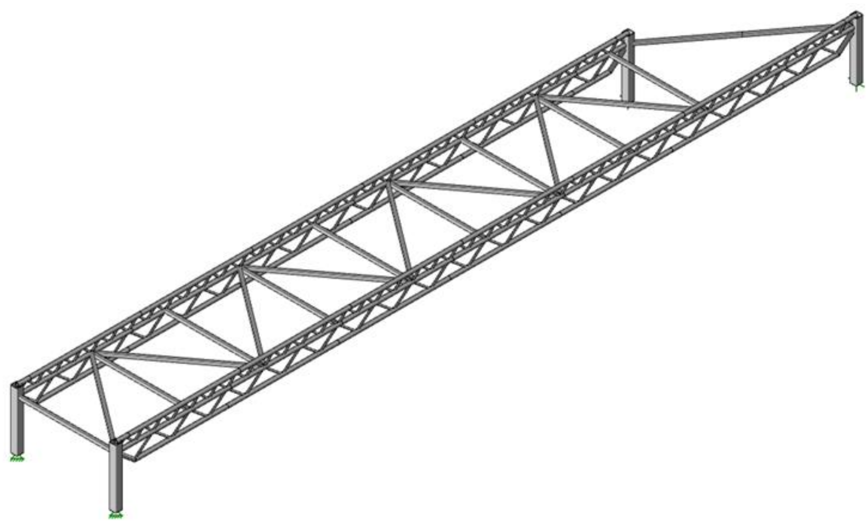


Figure B-5: Bridge 2 for Decision Matrix 2

Appendix C: Bolt Calculations from Excel

C1: Bottom Truss to Bottom Truss

Through-bolting shear check: AISC Part 7, Page 13

R_u	=	15.118	k	*shear from RISA*
n	=	4		*number of bolts*
F_y	=	46	ksi	
d	=	0.5	in	*bolt diameter*
t	=	0.125	in	*thickness of HSS*
ϕR_n	=	15.525	k	

Bolt size OK for shear? OK

Bearing Check: AISC 16.1-109

(combined tension and shear)

F_{nt}	=	90	ksi	*tensile strength from J3.2*
F_{nv}	=	60	ksi	*shear strength from J3.2*
n_{sp}	=	2		*number of shear planes*
f_v	=	9.6244177	ksi	*required shear strength*
F'_{nt}	=	97.751165	ksi	

Is $F'_{nt} < F_{nt}$? No, skip to tension check below

**if bearing applicable* ϕR_n = 14.395047

Bolt size OK for bearing? **if bearing applicable* No

Tension Check: AISC 16.1-108

R_u	=	1.168	k	*tension from RISA*
F_{nt}	=	90	ksi	*tensile strength from J3.2*
A_b	=	0.1963495	in^2	
ϕR_n	=	53.014376		

Bolt size OK for tension? OK

Use: (4) 1/2" A325 bolts

C2: Top Truss to Top Truss

Through-bolting shear check: AISC Part 7, Page 13

R_u	=	1.201	k	*shear from RISA*
n	=	1		*number of bolts*
F_y	=	36	ksi	
d	=	0.5	in	*bolt diameter*
t	=	0.125	in	*thickness of HSS*
ϕR_n	=	3.0375	k	

Bolt size OK for shear? OK

Bearing Check: AISC 16.1-109

(combined tension and shear)

F_{nt}	=	90	ksi	*tensile strength from J3.2*
F_{nv}	=	60	ksi	*shear strength from J3.2*
n_{sp}	=	2		*number of shear planes*
f_v	=	3.0583214	ksi	*required shear strength*
F'_{nt}	=	110.88336	ksi	

Is $F'_{nt} < F_{nt}$? No, skip to tension check below

if bearing applicable* **ϕR_n = 16.328922

Bolt size OK for bearing? OK
**if bearing applicable*

Tension Check: AISC 16.1-108

R_u	=	1.201	k	*tension from RISA*
F_{nt}	=	90	ksi	*tensile strength from J3.2*
A_b	=	0.1963495	in^2	
ϕR_n	=	13.253594		

Bolt size OK for tension? OK

Use: (1) 1/2" A325 bolt

C3 and C4: Cross Bracing to Truss

Shear check: AISC Part 7, Page 13

R_u	=	0.14	k	*shear from RISA*
n	=	1		*number of bolts*
F_{nv}	=	60	ksi	*shear strength from J3.2*
d	=	0.5	in	*bolt diameter*
A_b	=	0.1963495	in^2	
ϕR_n	=	8.8357293	k	

Bolt size OK for shear? OK

Bearing Check: AISC 16.1-109

(combined tension and shear)

F_{nt}	=	90	ksi	*tensile strength from J3.2*
F_{nv}	=	60	ksi	*shear strength from J3.2*
n_{sp}	=	2		*number of shear planes*
f_v	=	1	ksi	*required shear strength*
F'_{nt}	=	115	ksi	

Is $F'_{nt} < F_{nt}$? No, skip to tension check below

**if bearing applicable* ϕR_n = 16.935148

Bolt size OK for bearing? **if bearing applicable* OK

Tension Check: AISC 16.1-108

R_u	=	0.001	k	*tension from RISA*
F_{nt}	=	90	ksi	*tensile strength from J3.2*
A_b	=	0.1963495	in^2	
ϕR_n	=	13.253594		

Bolt size OK for tension? OK

Use: (1) 1/2" A325 bolt

Appendix D: Weld Calculations from Excel

Web Members (small)

Strength of Weld Calc

force Weld needs to resist	=	0.951	kip	
D	=	2	/16"	from table J2.4 min=2/16"
l	=	1.57	"	
Fexx	=	70	ksi	
Φ	=	0.75		
Available strength of Weld	=	4.37124573	kip	

Strength of Base Material Calc

Fbm	=	35	ksi
Abm	=	0.125	in^2
Rn	=	4.375	kip

Available Strength of Connection = 4.371246 kip

GOOD

Use: 1/8" weld all around where specified

Web Members (large)

Strength of Weld Calc

force Weld needs to resist	=	1.201	kip	
D	=	2	/16"	from table J2.4 min=2/16"
l	=	1.57	"	
Fexx	=	70	ksi	
Φ	=	0.75		
Available strength of Weld	=	4.37124573	kip	

Strength of Base Material Calc

Fbm	=	35	ksi
Abm	=	0.125	in^2
Rn	=	4.375	kip

Available Strength of Connection = 4.371246 kip

GOOD

Use: 1/8" weld all around where specified

Tabs for Cross Bracing

Strength of Weld Calc

force Weld needs to resist	=	0.094	kip	
D	=	2	/16"	from table J2.4 min=2/16"
l	=	1	"	
Fexx	=	70	ksi	
Φ	=	0.75		
Available strength of Weld	=	2.78423295	kip	

Strength of Base Material Calc

Fbm	=	35	ksi
Abm	=	0.125	in^2
Rn	=	4.375	kip

Available Strength of Connection = 2.784233 kip

GOOD

Use: 1/8" weld all around where specified

Tabs for Connection 2

Strength of Weld Calc

Demand	=	1.201	kip	
D	=	2	/16"	from table J2.4 min=2/16"
l	=	6	"	
Fexx	=	70	ksi	
Φ	=	0.75		
Available strength of Weld	=	16.7053977	kip	

Strength of Base Material Calc

Fbm	=	35	ksi
Abm	=	0.5	in^2
Rn	=	17.5	kip

Available Strength of Connection = 16.7054 kip

GOOD

Use: 1/8" weld all around where specified

Support Columns to Truss Connection

Strength of Weld Calc

force Weld needs to resist	=	1.46	kip	
D	=	2	/16"	from table J2.4 min=2/16"
l	=	4	"	
Fexx	=	70	ksi	
Φ	=	0.75		
Available strength of Weld	=	11.1369318	kip	

Strength of Base Material Calc

Fbm	=	35	ksi
Abm	=	0.234	in^2
Rn	=	8.19	kip

Available Strength of Connection = 8.19 kip

GOOD

Use: 1/8" weld all around where specified

Base Material Calcs

GSY			GSY		
	ϕ	0.9		ϕ	0.9
	Ag	0.5		Ag	0.25
	Fy	36		Fy	36
	ϕRn	16.2		ϕRn	8.1
NSR			NSR		
	ϕ	0.75		ϕ	0.75
	Ae	0.1875		Ae	0.09375
	Fu	58		Fu	58
	ϕRn	8.15625		ϕRn	4.08
Block Shear			Block Shear		
	ϕ	0.75		ϕ	0.75
	Fu	58		Fu	58
	Fy	36		Fy	36
	U_{BS}	1		U_{BS}	1
	A_{nt}	0.15625		A_{nt}	0.078125
	A_{nv}	0.40625		A_{nv}	0.203125
	A_{gv}	0.875		A_{gv}	0.4375
		23.2			11.6
		27.9625			13.98125
	ϕRn	17.4		ϕRn	8.7

Appendix E: Shop Drawings

2025 NAU ASCE STEEL BRIDGE

TRUSS-TY ENGINEERING

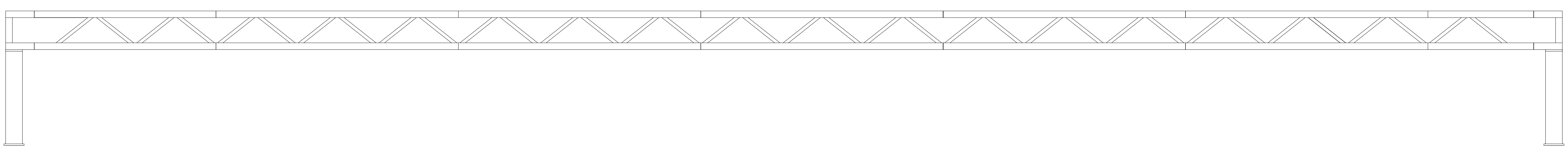
NORTHERN ARIZONA UNIVERSITY
Steve Sanghi College of Engineering

PREPARED BY:

ALEXA GODKIN
SYDNEY JUVE
KYLER WILKENS
LILLY ZELENKA

AHG78@NAU.EDU
(907) 723-5322

REVISION 5
100% PLAN SET



PREPARED FOR:

MARK LAMER
NORTHERN ARIZONA UNIVERSITY
BUILDING 69, ROOM 122M
MARK.LAMER@NAU.EDU

TABLE OF CONTENTS

CUT STEEL MEMBERS SCHEDULE

PIPE $\frac{1}{4}$"	QUANTITY	X65 @ 38°							
	LENGTH	0'-6 1/16"							
HSS 1"X2"X$\frac{1}{8}$"	QUANTITY	X25	X4	X2	X2	X8	x4	X8	X2
	LENGTH	3'-0"	2'-3"	1'-3 3/4"	0'-9 3/4"	0'-4 1/4"	0'-3 3/4"	1'-11 3/4"	2'-0"
HSS 2$\frac{1}{2}$"X2$\frac{1}{2}$"X$\frac{1}{8}$"	QUANTITY	X4							
	LENGTH	1'-1 3/4"							
$\frac{1}{4}$" PLATE	QUANTITY	X32	X30	X6	X11	X32	X4	X4	
	LENGTH	5"X1"	1"X2"	3"X2"	1$\frac{1}{2}$" X 2"	2$\frac{1}{2}$" X 1"	2$\frac{1}{2}$" X 2$\frac{1}{2}$"	3" X 3"	

WELDED PIECE SCHEDULE

A	X 9
B	X 2
C	X 1
D	X 1
E	X 4

LATERAL BRACING SCHEDULE

HSS 1"X2"X$\frac{1}{8}$"X1' 11$\frac{3}{4}$"	X 8
HSS 1"X2"X$\frac{1}{8}$"X3'	X 7
HSS 1"X2"X$\frac{1}{8}$"X2'	X 2

CONNECTION PLATING SCHEDULE

PLATE LENGTH (IN.)	2	2	2 1/2	3	5
PLATE WIDTH (IN.)	1	1 1/2	1	2	1
CONNECTION #					
1					x2
2	x2				
3		X1	VARIES*		
4			X3	X1	

* MAY NEED X1 OR X2 PLATES. SEE PAGE 5 FOR CLARIFICATION

LEGEND

HIDDEN LINE

SECTION CUT NUMBER — X

SECTION CUT PAGE — X

TYPICAL CONNECTION — X TYP.

CONNECTION CALLOUT — X

TYPICAL — TYP.

FILLET WELD CALLOUT — 1/8

CONNECTION SCHEDULE

CONNECTION #	# OF SIMILAR SECTIONS
1	X16
2	X15
3	X11
4	X6

GENERAL STRUCTURAL NOTES

-TOLERANCES AT CONNECTIONS SHOULD BE WITHIN $\frac{1}{16}$" OF SPECIFIED DIMENSIONS

-ALL WELDS ARE $\frac{1}{8}$"

-ALL BOLTS ARE $\frac{1}{2}$"

0 1/4 1/2 1

SCALE: N/A

REVISION NO. 5

PAGE: 1 of 8

DRAWN BY: AG

CHECKED BY: SJ,KW,LZ

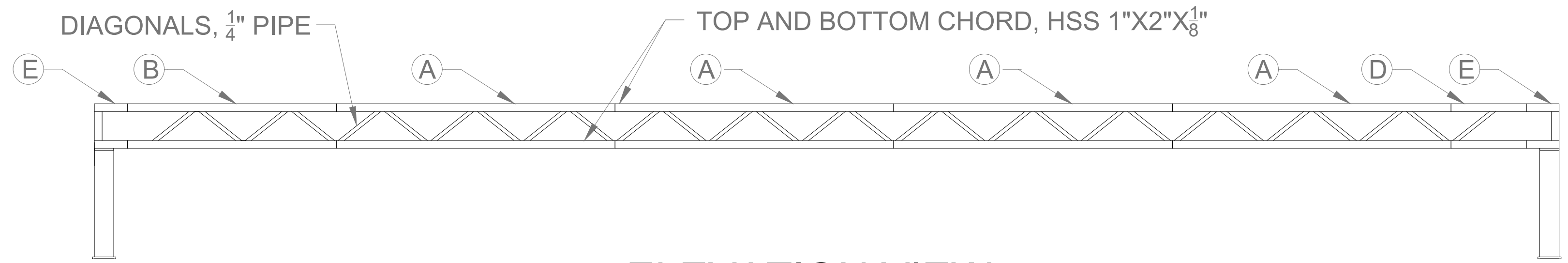
DATE: JANUARY 2025

2025 NAU STEEL BRIDGE

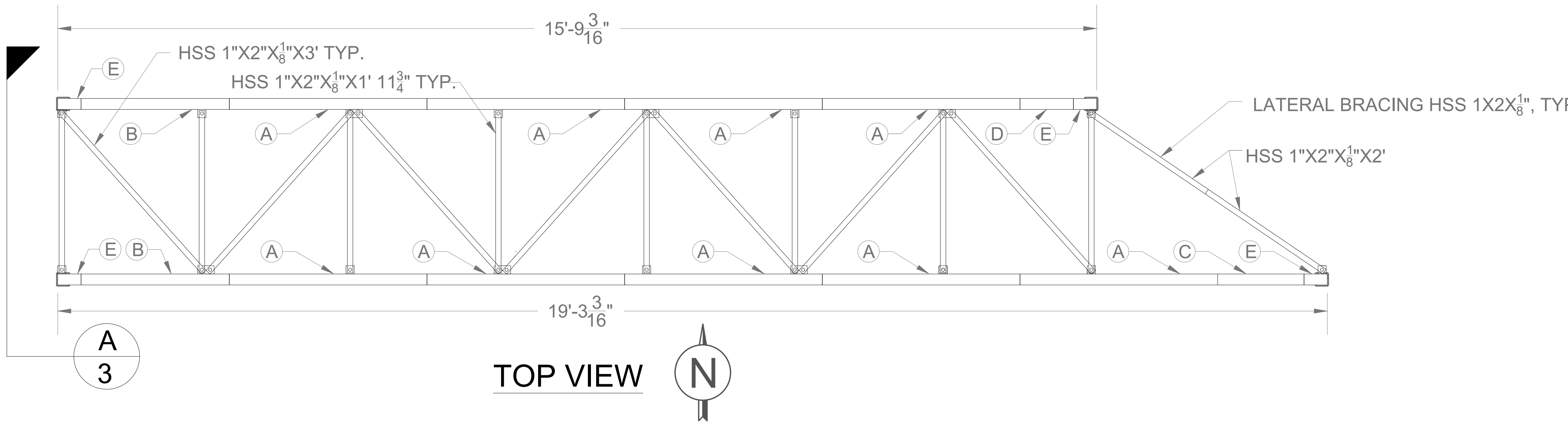
STEEL MEMBER SCHEDULE

TRUSS-TY ENGINEERING

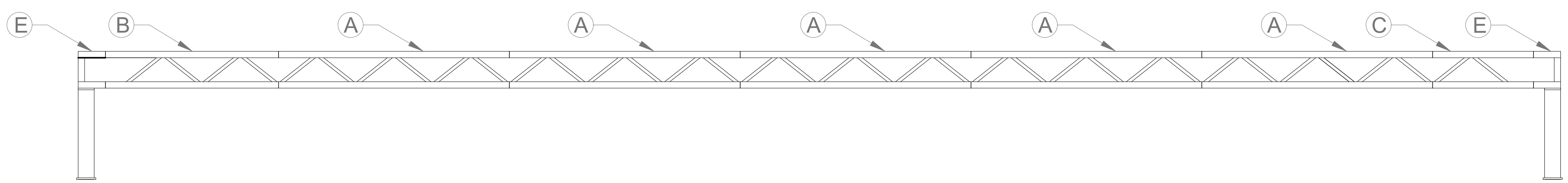
NOTES:
REFER TO SHEETS 3 THRU 4
FOR PART DETAILS



ELEVATION VIEW
(LOOKING SOUTH)



TOP VIEW



ELEVATION VIEW
(LOOKING NORTH)

SCALE: 1/2"=1'
REVISION NO. 5

DRAWN BY: AG
CHECKED BY: SJ,KW,LZ
DATE: JANUARY 2025

2025 NAU STEEL BRIDGE

PLAN & PROFILE VIEWS CONNECTION LOCATIONS

TRUSS-TY ENGINEERING

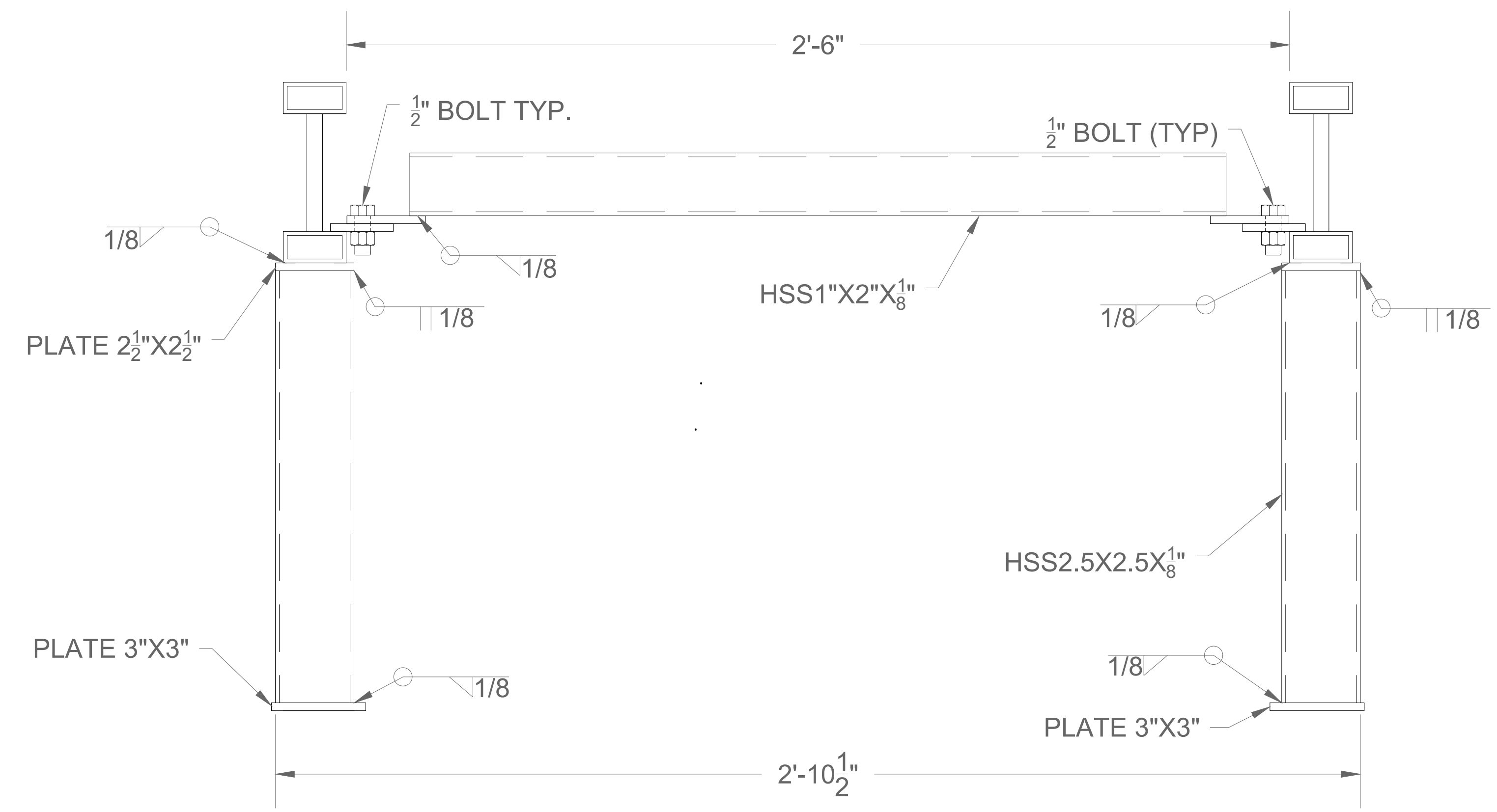
A		
	HSS 1"X2"X$\frac{1}{8}$"	PIPE $\frac{1}{4}$"
LENGTH	3'-0"	0'-6 1/16"
# OF PIECES	2	6

B		
	HSS 1"X2"X$\frac{1}{8}$"	PIPE $\frac{1}{4}$"
LENGTH	2'-3"	0'-6 1/16"
# OF PIECES	2	4

C		
	HSS 1"X2"X$\frac{1}{8}$"	PIPE $\frac{1}{4}$"
LENGTH	1'-3 3/4"	0'-6 1/16"
# OF PIECES	2	2

D		
	HSS 1"X2"X$\frac{1}{8}$"	PIPE $\frac{1}{4}$"
LENGTH	0'-9 3/4"	0'-6 1/16"
# OF PIECES	2	1

E					
	HSS 1"X2"X$\frac{1}{8}$"	HSS 1"X2"X$\frac{1}{8}$"	HSS 2$\frac{1}{2}$X2$\frac{1}{2}$X2	PLATE $\frac{1}{4}$"	PLATE $\frac{1}{4}$"
LENGTH	0'-4 1/4"	0'-3 3/4"	1'-1 3/4"	3"X3"	2$\frac{1}{2}$" X 2$\frac{1}{2}$"
# OF PIECES	2	1	1	1	1



A
3

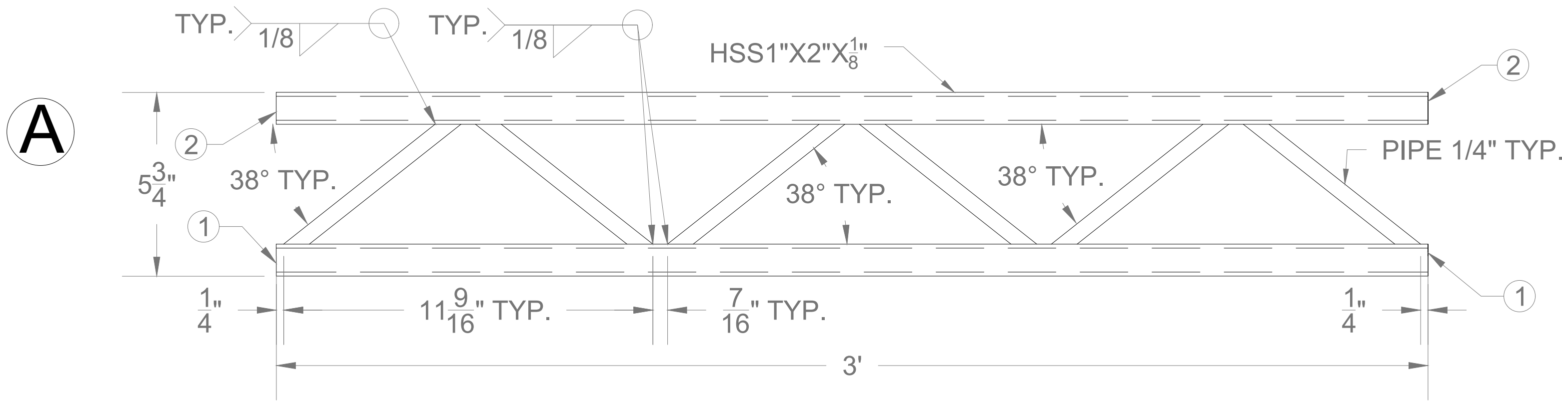
SECTION A-A

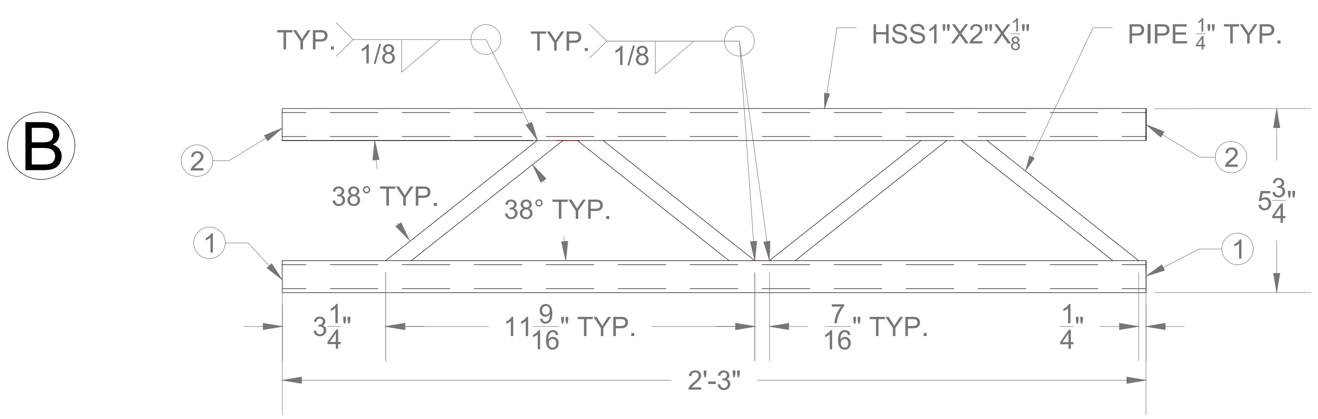
SCALE: 2"=1'
REVISION NO. 5
PAGE: 3 of 8
DRAWN BY: AG
CHECKED BY: SJ,KW,LZ
DATE: JANUARY 2025

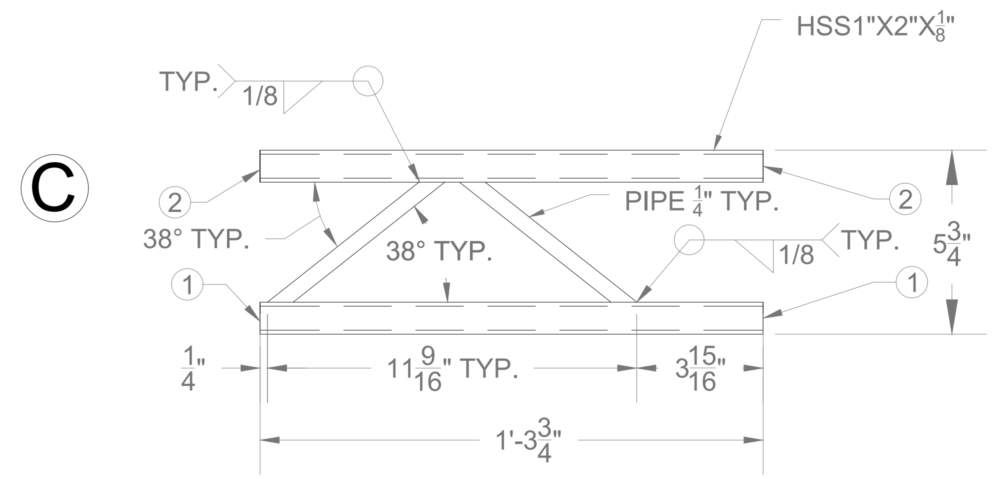
2025 NAU STEEL BRIDGE

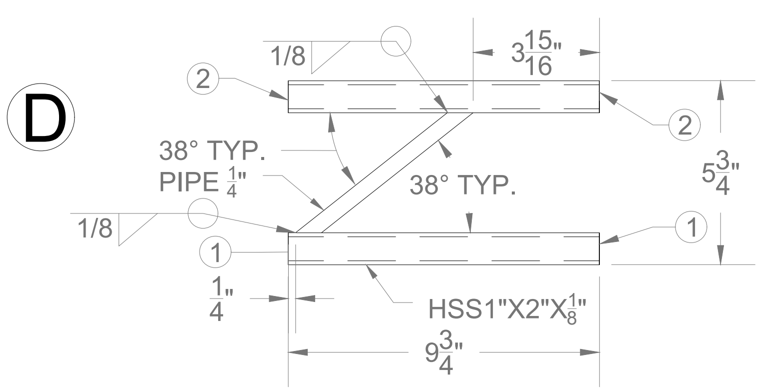
MEMBERS BY WELDED PIECE
SECTION A-A

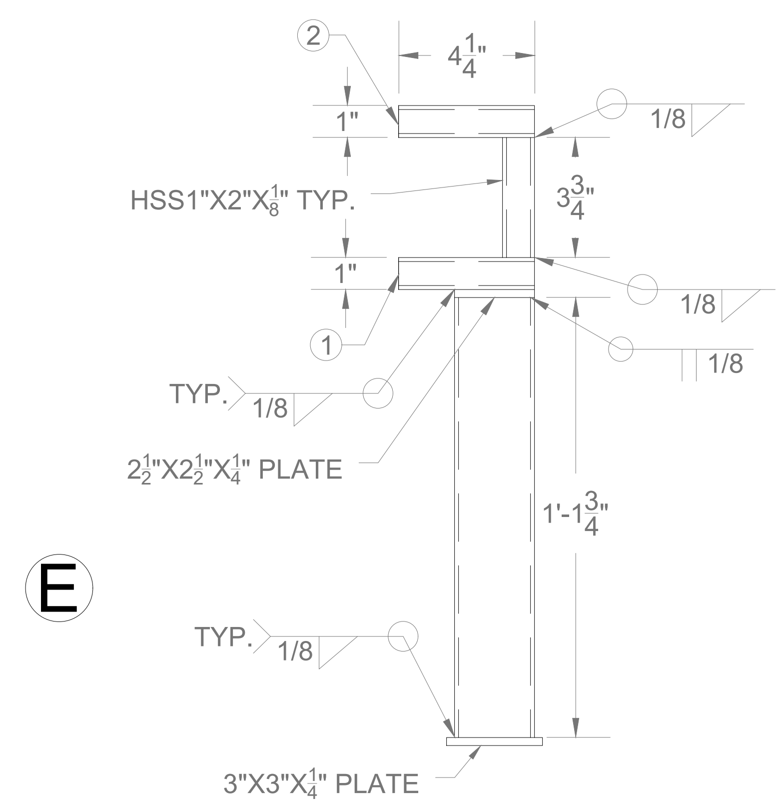
TRUSS-TY ENGINEERING











SCALE: 2"=1'
REVISION NO. 5
PAGE: 4 of 8

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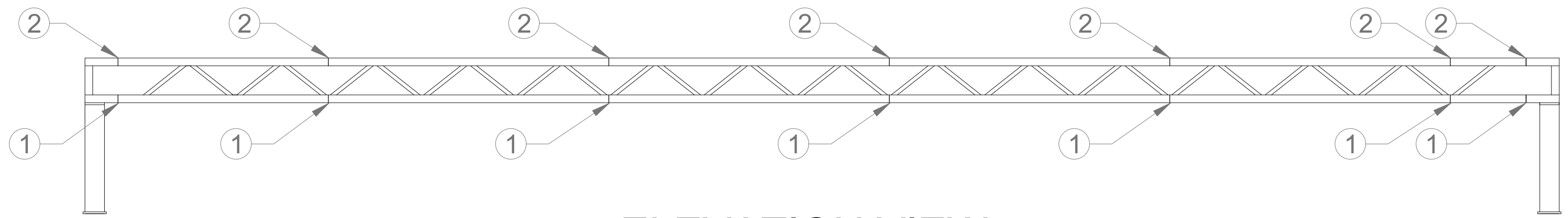
CHECKED BY: SJ,KW,LZ
DATE: JANUARY 2025

2025 NAU STEEL BRIDGE

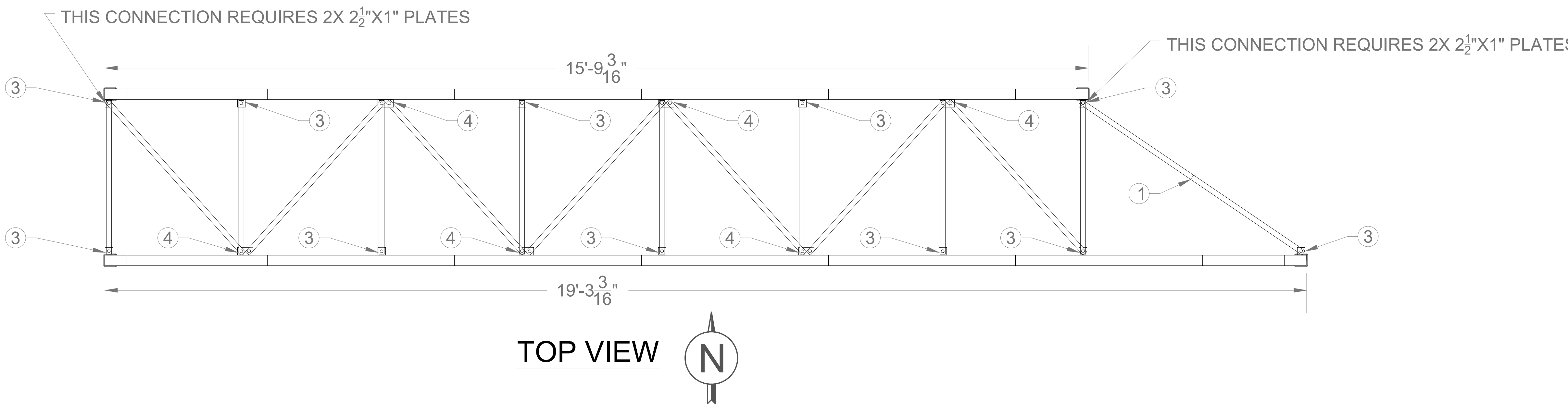
WELDED MEMBER PIECES

TRUSS-TY ENGINEERING

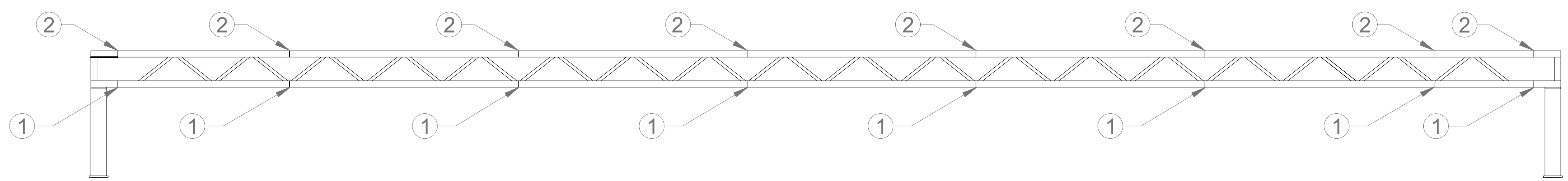
NOTES:
REFER TO SHEETS 6 THRU 8
FOR CONNECTION DETAILS



ELEVATION VIEW
(LOOKING SOUTH)



TOP VIEW

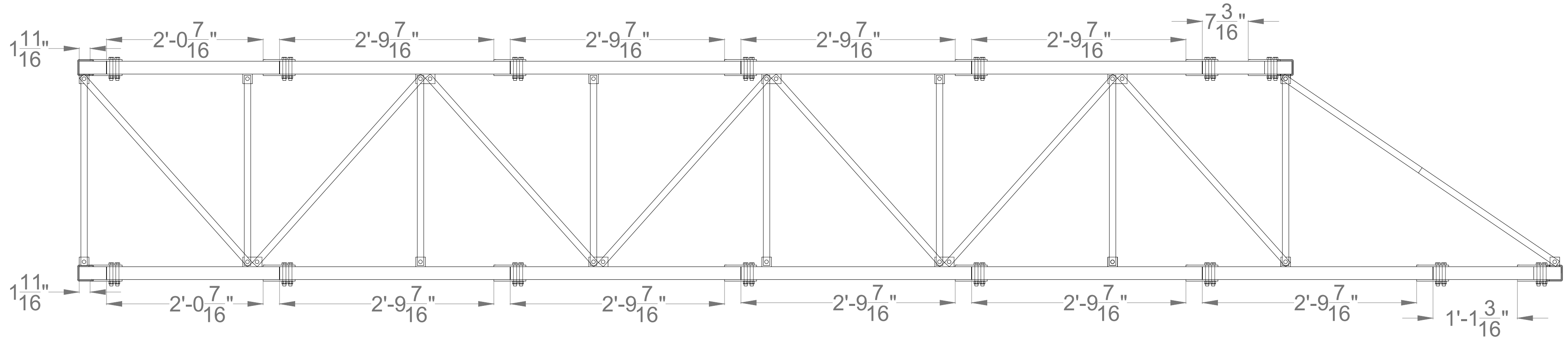


ELEVATION VIEW
(LOOKING NORTH)

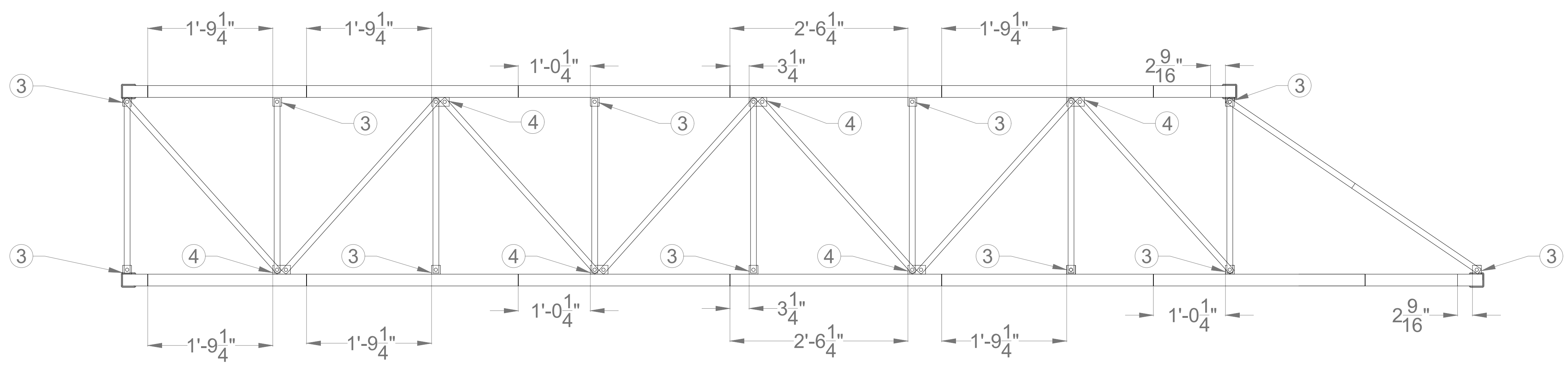
2025 NAU STEEL BRIDGE
CONNECTION LOCATIONS

DRAWN BY: AG
CHECKED BY: SJ,KW,LZ
DATE: JANUARY 2025
SCALE: 1/2"=1'
REVISION NO. 5
PAGE: 5 of 8

TRUSS-TY ENGINEERING



PLATING LOCATION AND ORIENTATION FOR CONNECTION 2



PLATING LOCATIONS FOR CONNECTION 3 & 4

2025 NAU STEEL BRIDGE

CONNECTION PLATING LOCATIONS

DRAWN BY: AG

CHECKED BY: KW,SJ,LZ

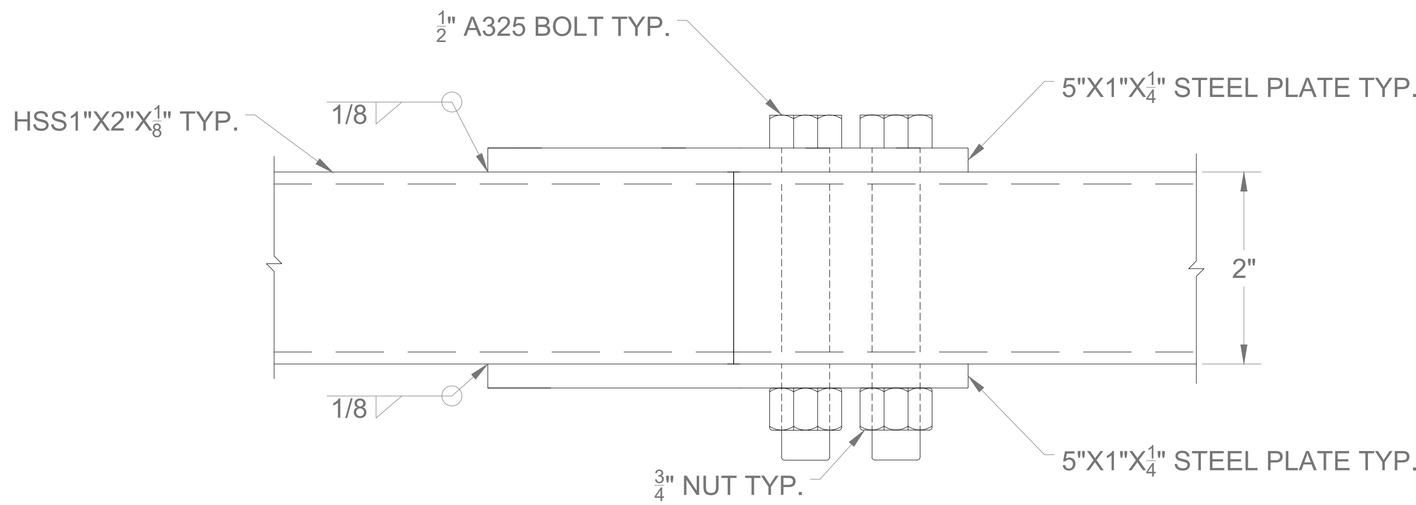
DATE: JANUARY 2025

SCALE: 1/2"=1'

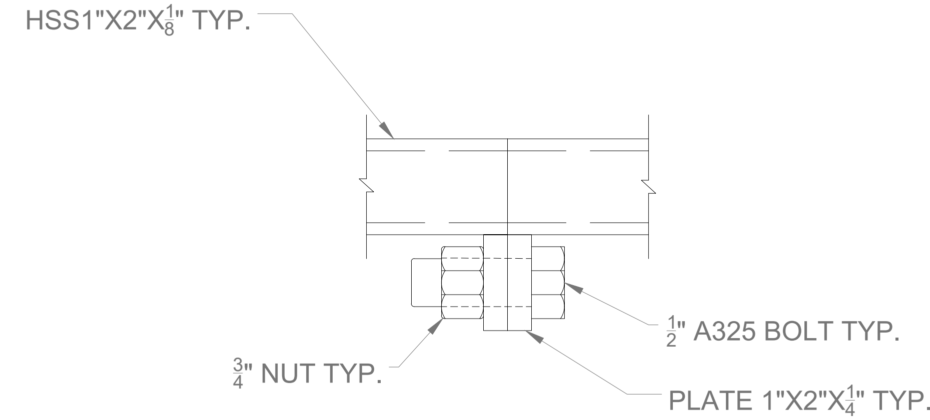
REVISION NO. 5

PAGE: 6 of 8

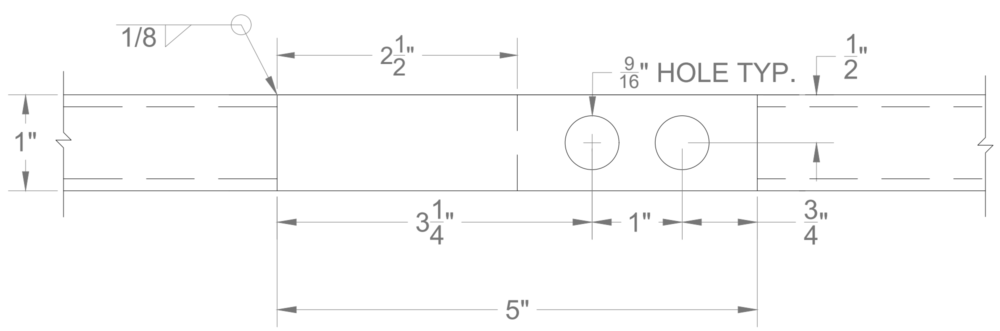
TRUSS-TY ENGINEERING



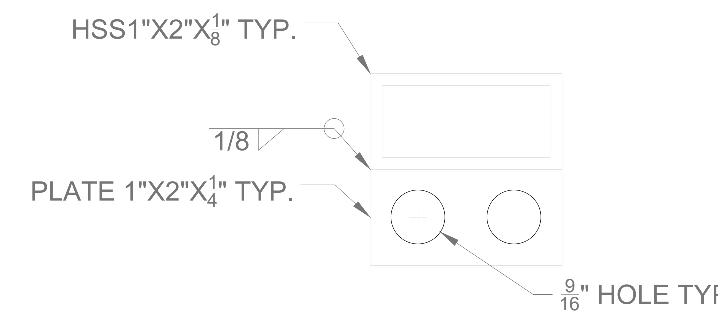
TOP VIEW



SIDE VIEW



SIDE VIEW



CUT VIEW

1 CONNECTION 1 TYPICAL DETAIL

2 CONNECTION 2 TYPICAL DETAIL

0 1/4 1/2 1

SCALE: 6"=1"

REVISION NO. 5

PAGE: 7 of 8

DRAWN BY: LZ

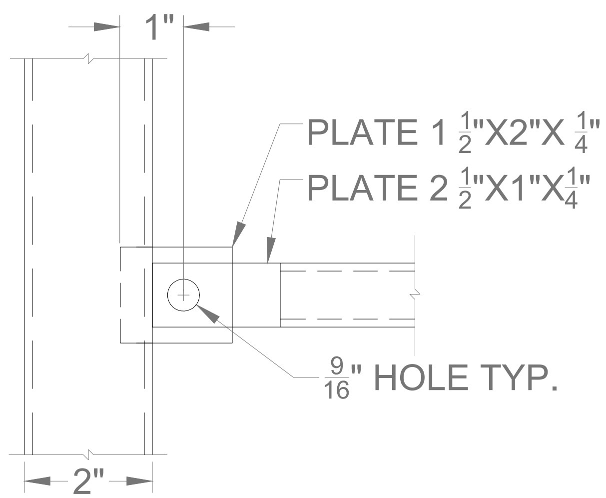
CHECKED BY: AG,SJ,KW

DATE: JANUARY 2025

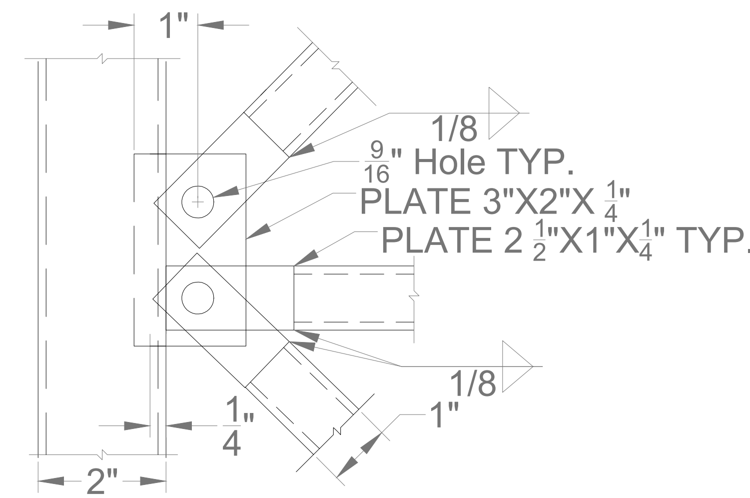
2025 NAU STEEL BRIDGE

CONNECTION 1 & 2 DETAILS

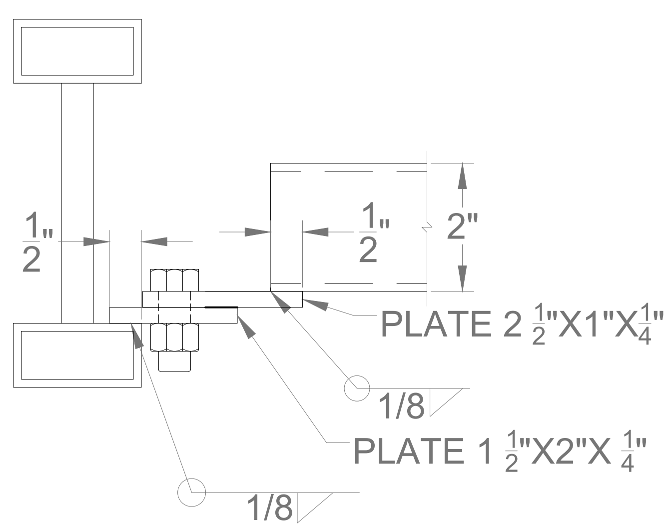
TRUSS-TY ENGINEERING



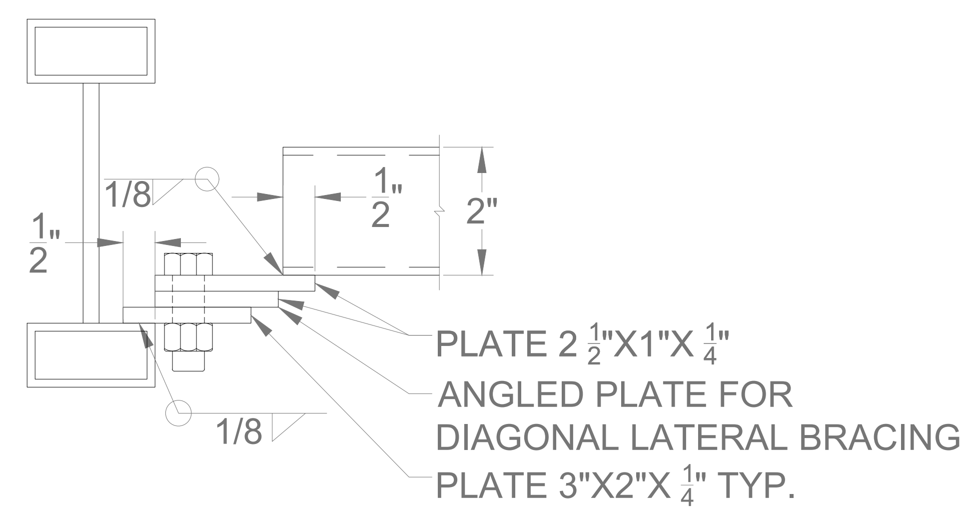
TOP VIEW



TOP VIEW



SIDE VIEW



SIDE VIEW

3 CONNECTION 3 TYPICAL DETAIL

4 CONNECTION 4 TYPICAL DETAIL

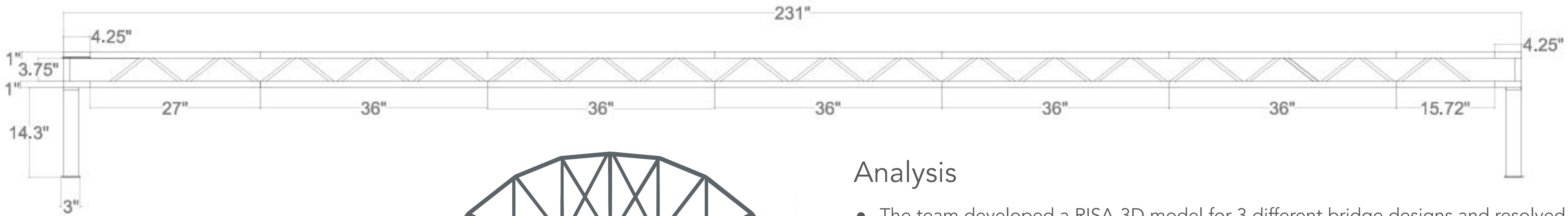
SCALE: 4"=1"
REVISION NO. 5
PAGE: PAGE 8 of 8
DRAWN BY: KW
CHECKED BY: AG,SJ,LZ
DATE: JANUARY 2025

2025 NAU STEEL BRIDGE

CONNECTION 3 & 4 DETAILS

TRUSS-TY ENGINEERING

Appendix F: Poster for Competition

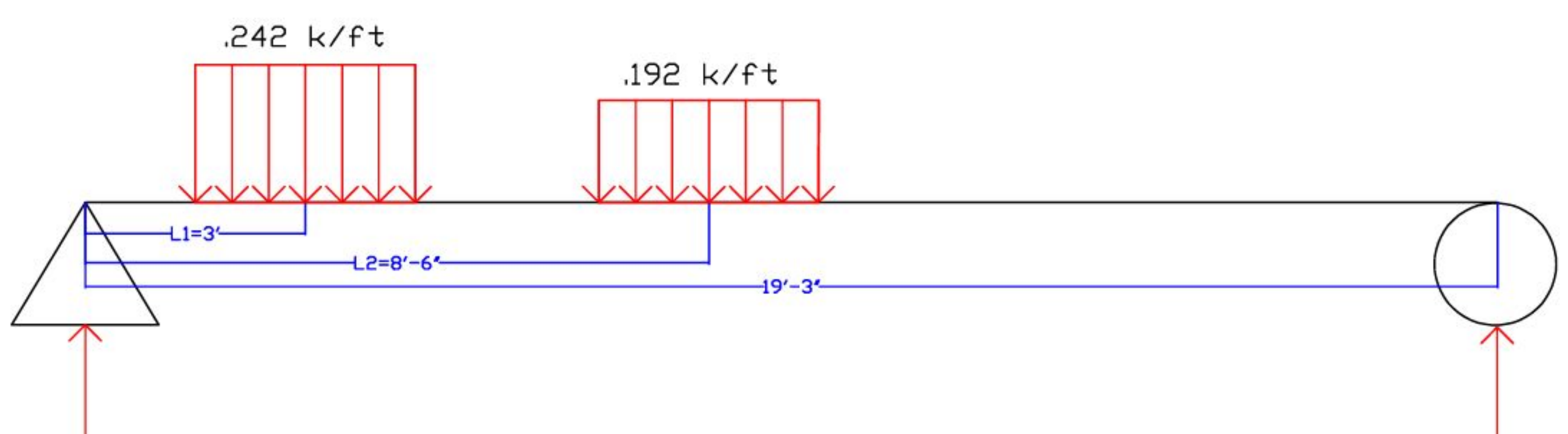


TRUSS-TY ENGINEERING

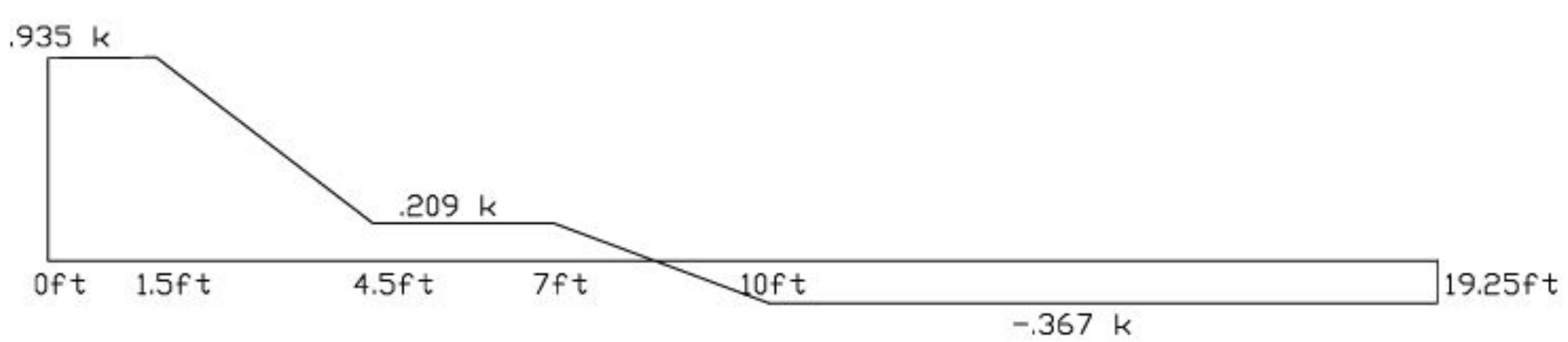
Bridge Design Selection

This bridge design was selected because its RISA-3D model had the fewest pieces and lowest weight compared to the team's other two models that were developed while remaining within the allowable deflection limits. The weight and number of pieces were minimized in order to reduce the amount of materials needed, overall cost, and construction time.

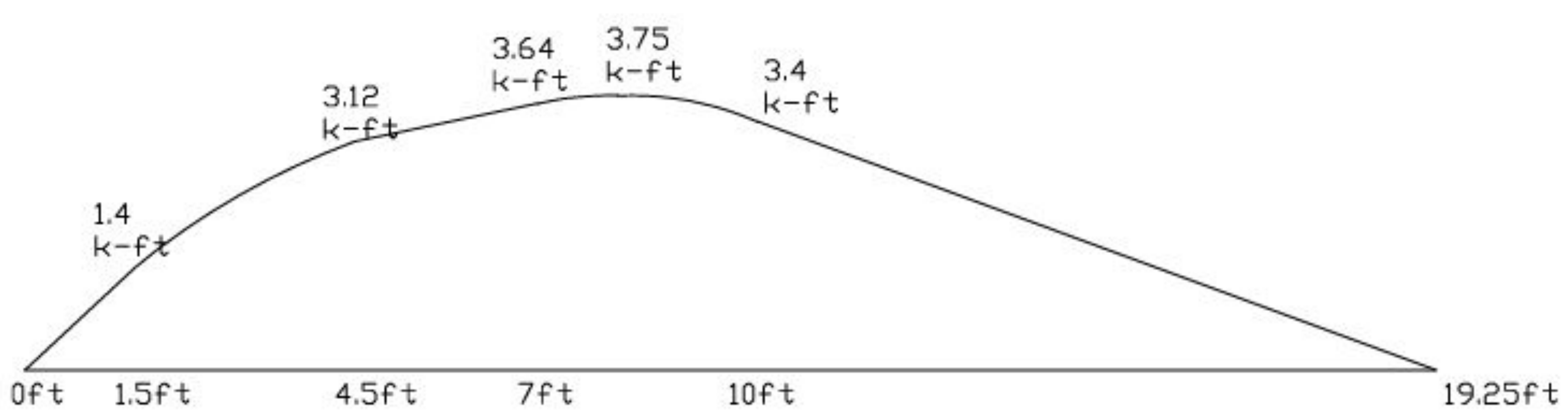
Member	Limit States Checked
Abutment	Tensile & shear yielding and rupture, block shear
Truss	Tensile & shear yielding and rupture, block shear
Cross-brace	Tensile & shear yielding and rupture, block shear



Load Combination N=2, South Stringer

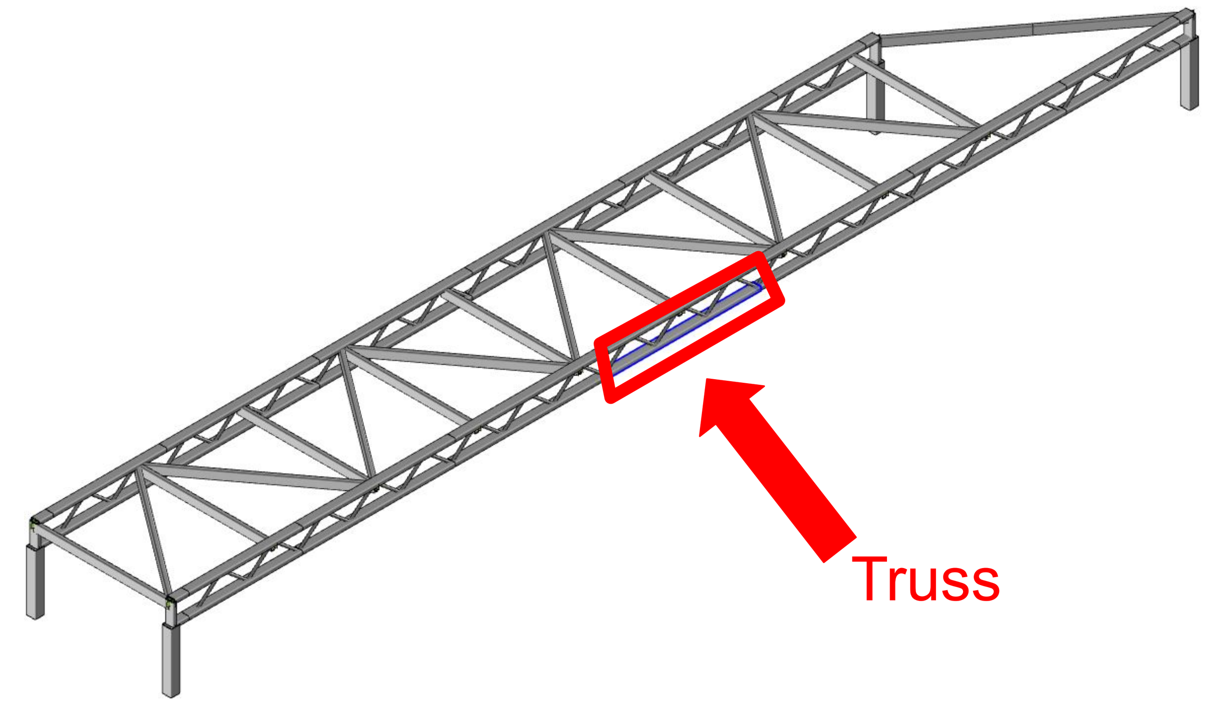


SFD, Load Combination N=2, South Stringer



BMD, Load Combination N=2, South Stringer

Critical Member Calculation Example



Controlling Limit State: Tensile Rupture

$\varphi P_n = .75 F_u A_e = .75(58 \text{ ksi})((.686 \text{ in}^2 - (2)(.125")(9/16")) = 23.7 \text{ k}$

$P_u = 13.7 \text{ k}$

$P_u < \varphi P_n$, 13.7k<23.7k (OK)

Acknowledgements

Mark Lamer, P.E. - grading instructor and advisor
Sabrina Gibson, P.E., S.E. - technical advisor
Robin Tuchscherer, PhD, P.E., S.E. - grading instructor and advisor
Mike Rust & the Flagstaff High School Welding Team - fabrication
Page Steel - donated steel members
Copper State Nut and Bolt - donated nuts and bolts
NAU ASCE Student Chapter - conference trip funding and logistics
AISC/ASCE SSBC - $750 grant for use in this project

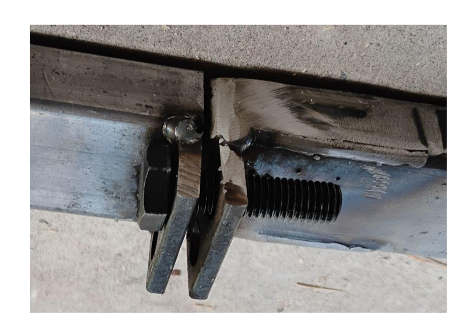
Presented by Alexa Godkin, Sydney Juve, Kyler Wilkens, and Lilly Zelenka

Analysis

- The team developed a RISA-3D model for 3 different bridge designs and resolved any issues that prevented the models from successfully solving (P-delta diverging, model was unstable, etc.)
- Once the three models solved successfully, the team verified that all code checks displayed in the results table were met (i.e. all demand to capacity ratios for all failure modes were less than 1)
- The team then sorted the lateral and vertical deflection values of all locations along the bridge in the results table from absolute maximum to absolute minimum, then noted the largest values and determined whether these were within the allowable deflection limits (.75" lateral and 2" vertical)
- The team continued to refine the three models to make them as light as possible and have as few pieces as possible while remaining within the deflection limits
- Using a decision matrix, the bridge models were scored in categories that were weighted, which were lateral deflection, vertical deflection, bridge weight, and number of pieces to determine which model would be selected for fabrication
- To be conservative, the forces used to design the bridge's welded and bolted connections were taken as the largest internal member forces developed in that connection type (see distinct connection types below) from the final RISA-3D model. That is, each connection is designed to resist that connection type's worst-case force.

Selection of Connections

Connection 1: Truss members connect on the bottom by resting on top of angles with 2 bolts through them to primarily resist tension, which is dominant in the bottom truss chord.



Connection 2: Connects the tops of truss members together. Since the top chord of the truss is primarily in compression, these members are not at risk of pulling away from each other, so the bolts here primarily resist shear from the vertical loads.

Connection 3: Connects the non-diagonal individual cross braces to the truss pieces. Tabs were welded to the bottom chord to prevent stringer template interference. Bolts are installed vertically to primarily resist shear.

Connection 4: Connects the diagonal cross braces to the truss pieces. Tabs were welded to the bottom chord to prevent stringer template interference. Bolts are installed vertically to primarily resist shear.

Appendix G: Staffing Hours

Tasks	SENG	ENG	EIT	DRFT	Task Totals
Task 1: Background Research					
Task 1.1: Steel Properties and Types		3	4		7
Task 1.2: Connection Types	2	5	5	5	17
Task 1.3: Bridge Types		5	4		9
Task 2: Design					
Task 2.1: Preliminary Sketches		5	4		9
Task 2.2: RISA-3D Models	6	29	12	17	64
Task 2.3: Final Design Selection	4	12	8		24
Task 2.4: Connection Design	6	22	18	14	60
Task 3: Develop Shop Drawings					
Task 3.1: Title Block and Cover Sheet			2	4	6
Task 3.2: Required Views	4	14	9	26	53
Task 3.3: Connection Details	5	20	6	19	50
Task 3.4: General Structural Notes	3	3	2	8	16
Task 3.5: Materials Schedule	5	11	4	12	32
Task 4: Sub-Consultant Coordination and Fabrication					
Task 4.1: Coordination with Page Steel	2	4	3		9
Task 4.2: Coordination with Copper State Nut and Bolt	2	4	3		9
Task 4.3: Coordination with Flagstaff High School Welding	4	6	5	11	26
Task 4.4: Team Fabrication	5	16	12		33
Task 5: Competition Preparation					
Task 5.1: Practice Bridge Assembly	6	8	8		22
Task 5.2 Poster	2	7	8	6	23
Task 6: Competition					
Task 6.1: Display Day	10	10	10		30
Task 6.2: Competition Day	10	10	10		30
Task 7: Project Management					
Task 7.1: Deliverables	5	17	10	15	47
Task 7.2: Schedule Management	8	9	5	4	26
Task 7.3: Resource Management	10	6		5	21
Task 7.4: Meetings	12	15	15	12	54
Task 8: Project Impacts	4	5	5		14
Staff Totals	115	246	172	158	691

Appendix H: Project Cost

1.0 Staffing	Description	Quantity	Units	Unit Cost	Cost
	SENG	115	HR	$ 200.00	$ 23,000.00
	ENG	246	HR	$ 150.00	$ 36,900.00
	EIT	172	HR	$ 90.00	$ 15,480.00
	DRFT	158	HR	$ 60.00	$ 9,480.00
			SUBTOTAL		$ 84,860.00
2.0 Supplies	Description	Quantity	Units	Unit Cost	Cost
	Steel	155	FT	$ 7.50	$ 1,162.50
	Nuts	85	EA	$ 0.51	$ 43.35
	Bolts	85	EA	$ 0.76	$ 64.60
	Miscellaneous	1	LS	$ 500.00	$ 500.00
			SUBTOTAL		$ 2,200.00
3.0 Subcontracting	Description	Quantity	Units	Unit Cost	Cost
	Fabrication	104	HR	$ 90.00	$ 9,360.00
			SUBTOTAL		$ 9,360.00
4.0 Travel	Description	Quantity	Units	Unit Cost	Cost
	Rental Van	5	Days	$ 73.54	$ 367.70
	Fuel	530	Miles	$ 0.41	$ 217.30
	Hotel	4	Nights (2 rooms)	$ 120.00	$ 960.00
	Meals and Incidental Expenses	4	People (4 days)	$ 54.00	$ 864.00
			SUBTOTAL		$ 2,409.00
				TOTAL	$ 98,399.45