University of Southern Indiana
Pott College of Science, Engineering, and Education
Department of Engineering

8600 University Blvd
Evansville, IN 47712

AISC Student Steel Bridge Competition

Design, Fabrication, and Construction

Eric Espino, Maria Lopez
ENGR 491 – Senior Design
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Approved by: ____
Faculty Advisor: Kerry Hall, Ph.D.   Date:

Approved by: ____
Department Chair: Paul Kuban, Ph.D.   Date

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ABSTRACT

The purpose of this project was to plan, design, and execute the fabrication of a scale-model steel bridge for the 2024 competition sponsored by the American Institute of Steel Construction. This bridge had to meet all requirements established by AISC such as spanning twenty-one feet, carrying 2,500 pounds without exceeding a deflection of three inches, and passing a lateral load test with a ¾-inch sway limit. Utilizing advanced structural analysis software such as RISA 2D and RISA 3D was of importance to evaluate design parameters and do proper connection calculations for all members of the bridge using steel design codes. The fabrication process involved getting welding experience to fabricate all members and becoming familiar with steel-cutting equipment accessible at the university. Since evaluation was based on structural efficiency, a strength-to-weight ratio had to be prioritized by properly sizing all members to achieve the lightest bridge possible. The steel bridge was successfully constructed, and load tested at the ASCE IN-KY Symposium at Purdue Northwest on April 12th, 2024, in Hammond, IN.

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1 BACKGROUND

1.1 AISC STUDENT STEEL BRIDGE COMPETITION

The Student Steel Bridge Competition is an annual competition sponsored by the American Institute of Steel Construction where students from different institutions are challenged to use their engineering skills learned throughout college to build a bridge. A theoretical problem statement was provided by AISC where a new bridge addition in Lincoln Parish Park is needed. This park would be located in Ruston, Louisiana and considered one of the most popular parks in America due to its several miles of amenities like disc golf courses, bike trails, and a lake for fishing activities called Hoogland Lake.

Since the park is considering a new addition to the disc golf course, using the existing lake and ponds as obstacles, a new bridge would be an excellent idea for all players and visitors to cross the lake and continue their leisure activities. A feasibility study at the competition is done by AISC to identify the best design for this project, which should not only meet certain requirements such as supporting a certain weight, but also be aesthetically pleasing to all visitors to the park. Although certain tests for stability, strength, and serviceability will be done to determine the best bridge, other aspects such as the structural cost, construction cost, and build duration will also be considered. Tests for serviceability include lateral and vertical load tests.

Figure 1. 2019 AISC National Steel Bridge Competition

1.2- PROJECT SCOPE

The 2024 USI Steel Bridge team set out with three key goals driving the completion of the project. Outlining project objectives is a vital part of any project, so the first goal was creating a bridge design that stood out among other teams during the competition. This involved not just meeting the basic requirements but going beyond to create something innovative, aesthetically pleasing, and structurally efficient. The second goal was prioritizing structural efficiency in the design process. This meant maximizing the bridge's performance while minimizing material usage and construction costs. By focusing on efficiency, the team could focus on creating a bridge that could withstand various load conditions without excess weight or unnecessary complexity.

Finally, captains and team members were committed to enhancing fabrication skills throughout this project. This involved hands-on learning and practical application of fabrication techniques, tools, and methodologies at the USI Applied Engineering Center. Actively engaging in the fabrication processes was an opportunity for the team to gain valuable experience that would have not only benefitted this project but also contributed to the overall growth as engineers and designers. These three goals together form the backbone of the project.

1.3- PROJECT TEAMWORK

Although two captains led the design process, there was a team of approximately six other students who volunteered to help with fabrication and construction of the bridge before, during, and after fabrication. All the tasks were distributed among these members with four of them having core positions within the competition team. These individuals, including team captains, are to build the bride at the competition, while the others hold builder positions and run miscellaneous activities like sorting and transportation of bridge members. *Figure 2* shows an organizational structure created to visualize the team. Team captains are at the center of the chart.

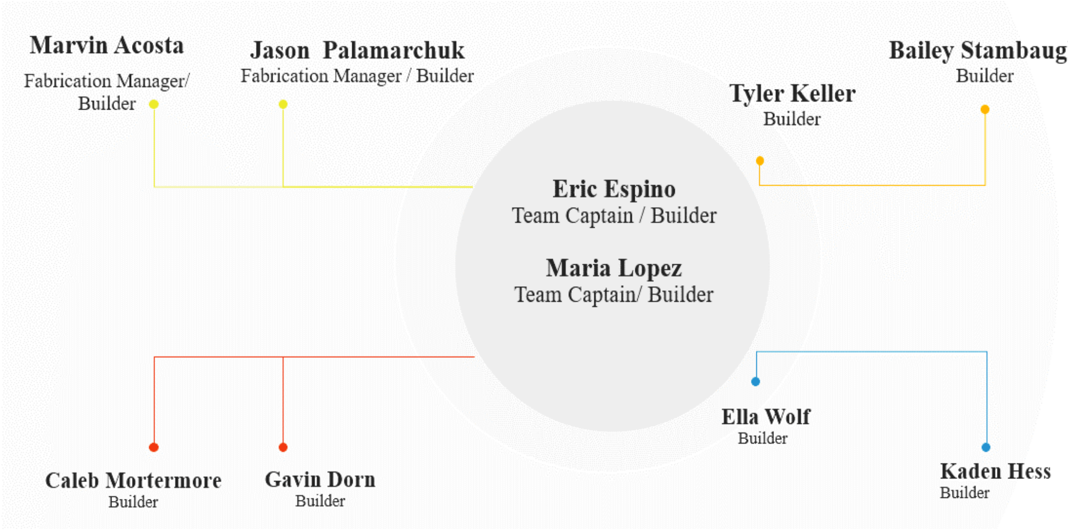


Figure 2 Steel Bridge Proposed Team Organizational Chart

1.4- PROPOSED PROJECT TIMELINE

Figure 3 shows the detailed timeline of the Steel Bridge for the University of Southern Indiana, and it represents the sequence of the events that the team went through to accomplish the steel bridge project, from the proposal to final execution of the bridge. This timeline is categorized into four phases, such as phase 0, phase 1, phase 2 and phase 3, all of which occurred between 2023 and 2024. Phase 0 is the initiation phase where we presented our proposal to pre senior class in December 2023. Next, Phase 1 is the planning phase and we started brainstorming designs which were designed in RISA2D, RISA3D, and AUTOCAD. Phase 2, execution phase, we utilized various equipment available at the Applied Engineering Center. Finally, the closing phase, Phase 3, which is when the team had the final product, and only competition requirements had to be met.

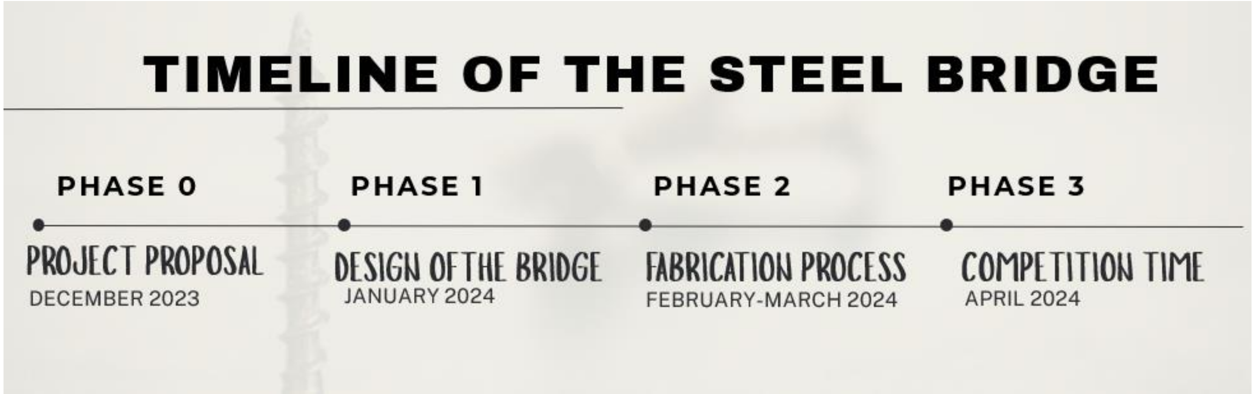


Figure 3 Steel Bridge Timeline

2 COMPETITION INFORMATION

2.1 BRIDGE PARAMETERS

2.1.1 FRONT SIDE BRIDGE ENVELOPE

For competitors to be eligible for the competition, the ASCE, 2024 Steel Bridge Competition stipulated a set of requirements for the bridge. The bridge should be between twenty and twenty-one feet long, with a maximum height of two feet and six inches, each footing should be one foot wide, and a maximum height of one foot and eleven inches for the two stringers. There are also other details listed in the bridge envelope, including a five-inch gap between the ground and the bottom of the bridge (*Figure 4*).

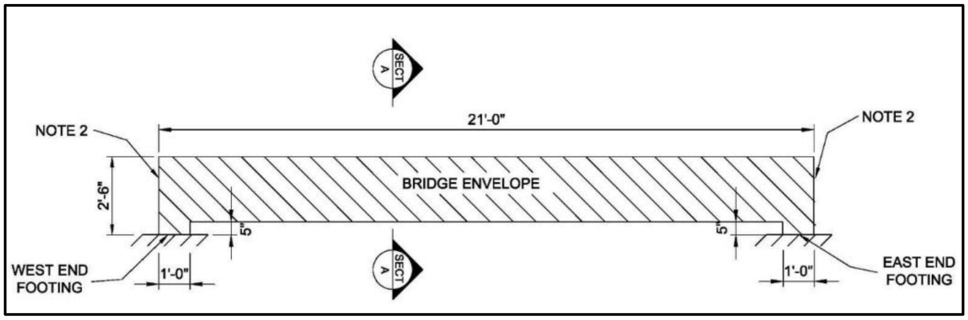
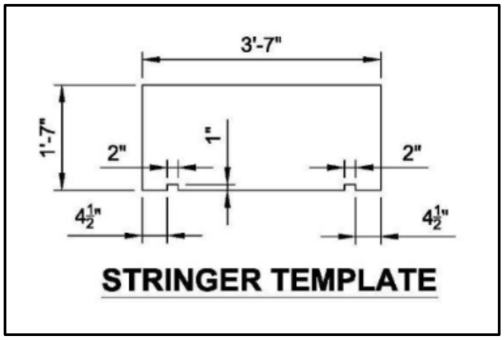


Figure 4. Front Side Bridge Envelope

2.1.2 SIDE BRIDGE ENVELOPE

The bridge should have a width of five feet and a height of two feet and six inches, fitting inside the bridge envelope. The side bridge's top stringer has a critical dimension as well and its maximum height is one foot and eleven inches, and its minimum height is one foot and seven inches (*Figure 5*). The stringer template is an essential component of the bridge's construction and design. It measures three feet and seven inches in width, one foot and seven inches in height, and has two stringers measuring two inches by one inch, spaced four feet and one and a half apart from the bottom corners on each end (*Figure 6*).



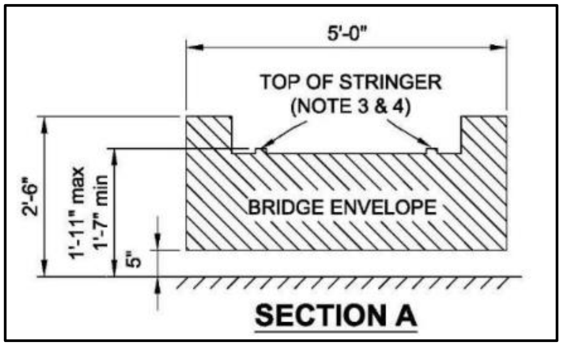


Figure 5. Side Bridge Envelope

Figure 6. Stringer Template

2.1.3 BOX

The wood box is another crucial part for this competition since all the steel members that the competitors will use in the competition should fit in this box (*Figure 7*). The dimension of this box is 3'-6" x 6" x 4" and the hosts of the competition would provide this box so that the competitors could make sure that their steel members complied with the requirements of the competition (*Figure 8*).

Figure 7. Judges Using Wood Box

Figure 8. Wood Box

2.2 CONSTRUCTION SITE LAYOUT

The construction site plan has a total length of sixty-five feet which is divided into five sections, and it has a width of fifteen feet as it is shown in *Figure 9*. This is the place where the competition will assembly the bridge with fabricated steel members during the competition.

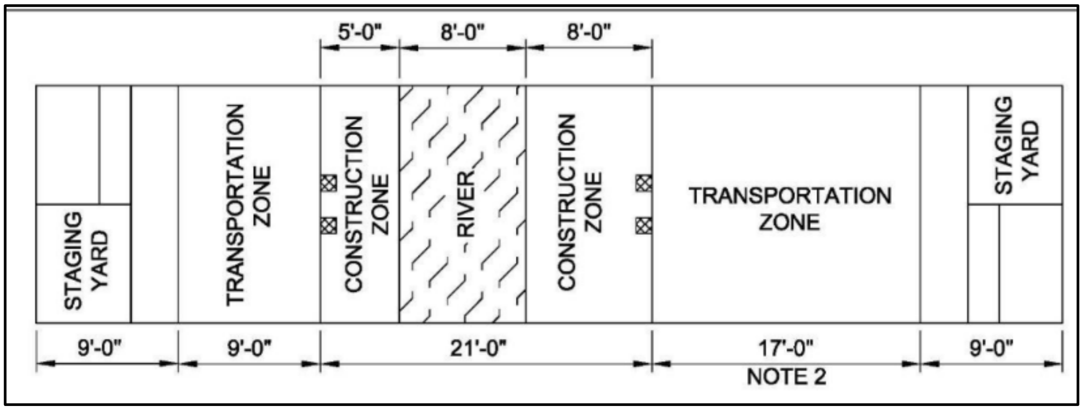


Figure 9. Construction Site Layout

2.2.1 TWO STAGING YARDS

As depicted in *Figure 10*, this is the area of the construction site where builders, tools, bolts, and nuts are located at the beginning and end of timed construction. It is forbidden to add or remove tools or components from the construction site after the staging inspection is complete. The members are placed in a box measuring six feet by seven feet and six inches, the tools are placed in a box measuring four feet by seven feet and six inches, the nuts and bolts are placed in a box measuring two feet by seven and six inches, and the builders are placed in the final box, measuring three feet by fifteen feet, according to the construction plan's staging yard dimensions.

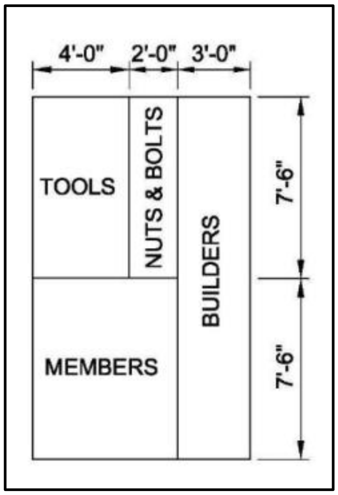


Figure 10. Staging Yards

2.2.1 TWO TRANSPORTATION ZONES

A section of the construction site where builders transport members, tools, nuts, and bolts, and it is situated between the construction zone and staging yards. This portion measures 9 feet long by 15 feet wide on one side, and 17 feet long by 15 wide on the other. This was the only section where builders could pass tools and members to other builders. See (*Figure 11 & 12*) for detailed plans.

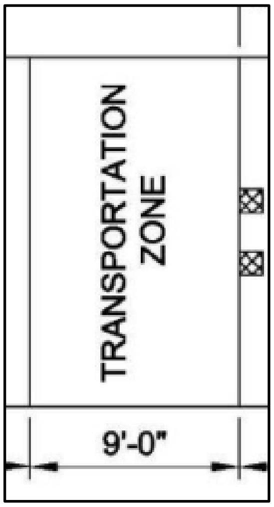


Figure 11. Right Transportation Zone

Figure 12. Left Transportation Zone

2.2.2 TWO CONSTRUCTION ZONES AND THE RIVER

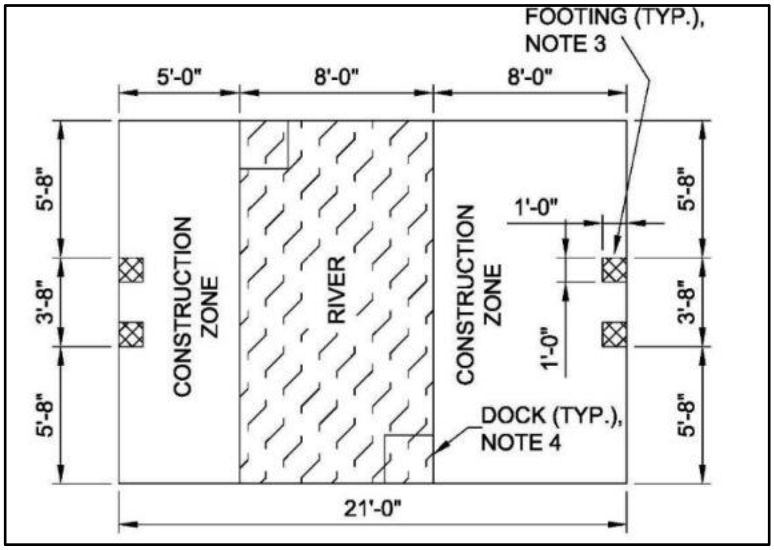


Figure 13. Construction Zones and The River

This was the location in the construction site where builders put the members together to construct the bridge. The dimensions of these two boxes are five feet long by fifteen feet wide on one side, eight feet by fifteen feet wide in the other. The river is another important feature of this competition because the main builders are not allowed to cross from the ground on one side of the transportation zone to the ground on the other side: however, this year the competition allows at least two barges who are included in the total count of the six builders, and they must remain in the river throughout timed construction. This river will be eight feet long by fifteen feet wide as it is shown in the *Figure 13*.

2.3 LATERAL LOAD TEST

The lateral load test was the first test of the competition, and it involved applying seventy-five pounds vertically on the stringers, and fifty pounds of lateral load placed a certain distance from the east end of the bridge as it is shown in *figure 14*. Distance "S" is the distance from the west end of the bridge where this load would be applied. It is important to consider that the sway could not exceed a limit of ¾ inches, and if exceeded, the bridge was not eligible to go into the vertical load test, which was the following step within the competition.

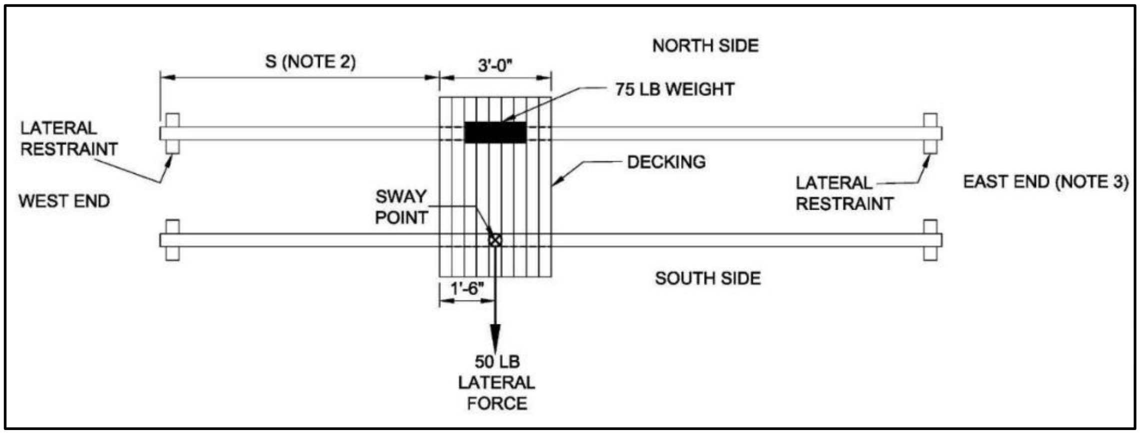


Figure 14. Lateral Load Test

2.4 *VERTICAL LOAD TEST*

The vertical load testing was a fundamental part for this competition as it evaluated the structural integrity of the bridge. This competition had various cases of vertical loads to make sure all students involved in the design process understood the importance of assessing the ability of the bridges to support the assigned loads without experiencing deflection or failure. *Figure 15* shows the different cases of vertical load that AISC had proposed, one of them being selected on a dice roll by the judges.

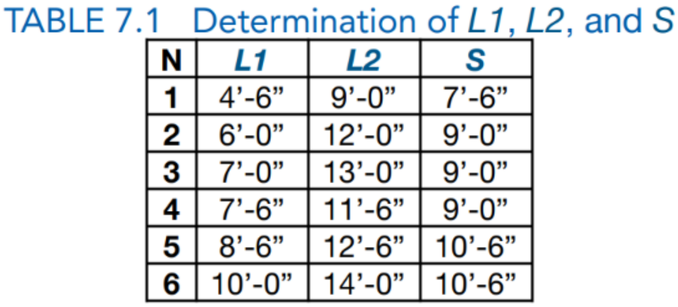


TABLE 7.1 Determination of *L1*, *L2*, and *S*

N	*L1*	*L2*	*S*
1	4'-6"	9'-0"	7'-6"
2	6'-0"	12'-0"	9'-0"
3	7'-0"	13'-0"	9'-0"
4	7'-6"	11'-6"	9'-0"
5	8'-6"	12'-6"	10'-6"
6	10'-0"	14'-0"	10'-6"

Figure 15. Load Cases

Two decking units that are three feet long in the longitudinal direction of the bridge were to be placed centered between the stringers of the bridge, and each of them weighed around fifty pounds. These decking units consisted of a bar grating identified as W-19-4 (1" x 1/8") which is approximately 3'-6"x 3'-0" x 1" (*Figure 16*). The competition organizers decided to use this type of decking in the competition due to its significant bending strength, ideal to support a heavy load. These units were to be placed perpendicular to the bridge stringers, as it is the best way to distribute the load along the entire span of the bridge.

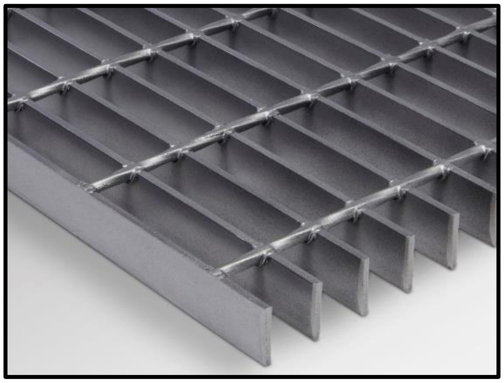


Figure 16. Decking Units

The first decking unit would be placed at a distance L1, as it is shown in picture 17, from the west end of the bridge and it is measured from the top of the north side stringer while the second decking unit was to be placed a distance L2 from the west end of the bridge. Competition staff would place 1400 pounds of additional load on the decking that is placed at L1 and nine hundred pounds of additional load on the unit that is at L2 as shown in *figure 18*. Dimensions D1 and D2 mean the location where the vertical deflection is measured during vertical load testing. D1 is centered on the north side of the decking unit positioned at L1, and D2 is centered on the south side of the decking unit positioned at L2.

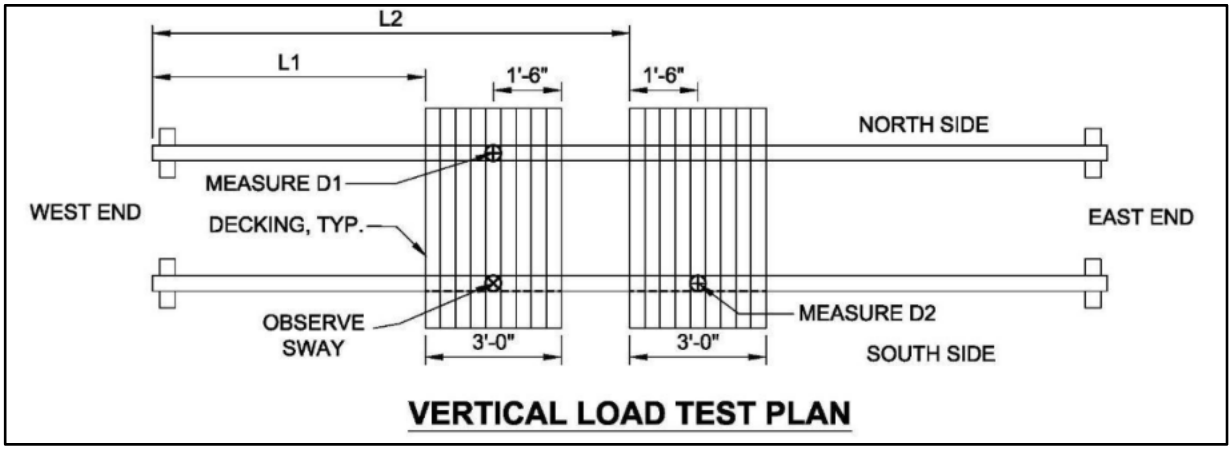


Figure 17. Vertical Load Test L1 and L2

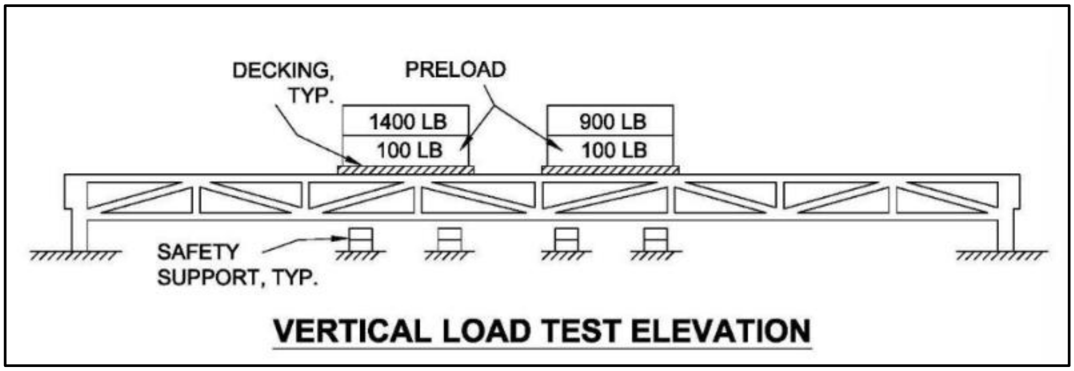


Figure 18. Location of the Loads for the Vertical Load Test

3 BRIDGE DESIGN SELECTION

3.1 PRELIMINARY DESIGNS

RISA 2D was a valuable tool for the steel bridge selection process because it helped the team to select the optimal design which means a stiff design and smallest deflection. As a team, we began with the simplest design as it is shown in the figure below. However, we decided to change the design a little bit to see the impact of the design, and it was visible that the weight increased, and the deflection also increase in design 2. Then, we did design number three which is a combination of design 1 and 2. This led to a reduction in weight, but the deflection was not appropriate. Finally, we did design four, where we combined design two and design three, and this design ended up having the best deflection of 0.26 inches and a weight of 260 lb.

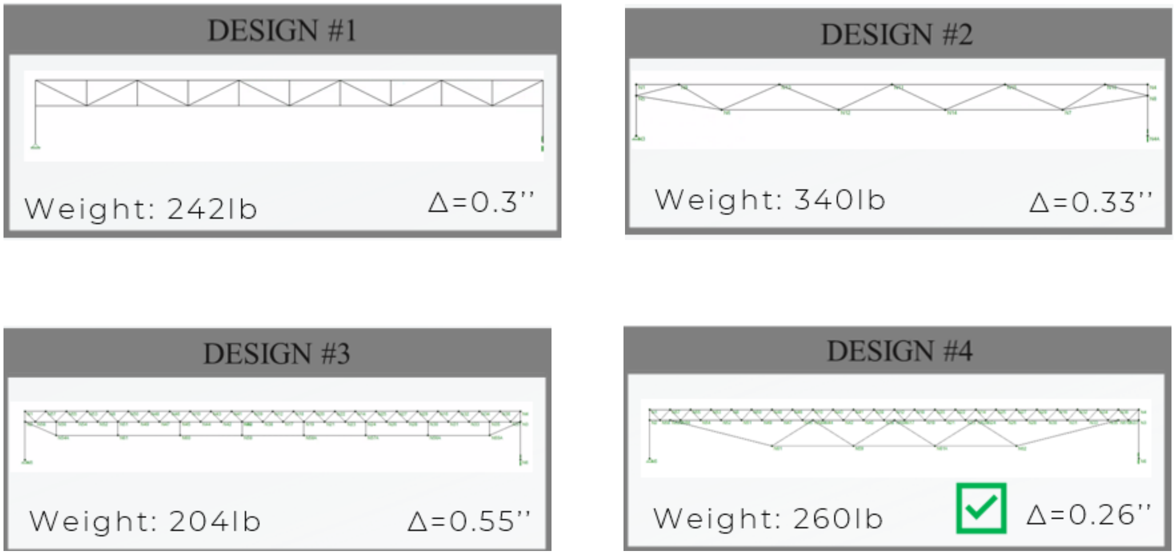


Figure 19. Preliminary Desings

3.2 STRUCTURAL ANALYSIS

All the modeling and structural analysis for the 2024 USI Steel Bridge were carried out using RISA 3D. This software helped team captains design and evaluated bridge components and overall structure, ensuring that it meets safety standards by AISC. By utilizing RISA 3D, the team was able to accurately simulate the behavior of the bridge under different scenarios, allowing us to make informed decisions and optimize its design for performance and durability. The main approach was to input all load case scenarios given in the rules into RISA 3D, to finally obtain an envelope solution that included the worst-case values for vertical deflection and sway. The option to apply area loads to the RISA 3D model provided a way to obtain more accurate results, compared to just applying point loads or distributed loads along the stringers. *Figure 20* shows the isometric view of the model where one of the load scenarios was applied using the area loads option.

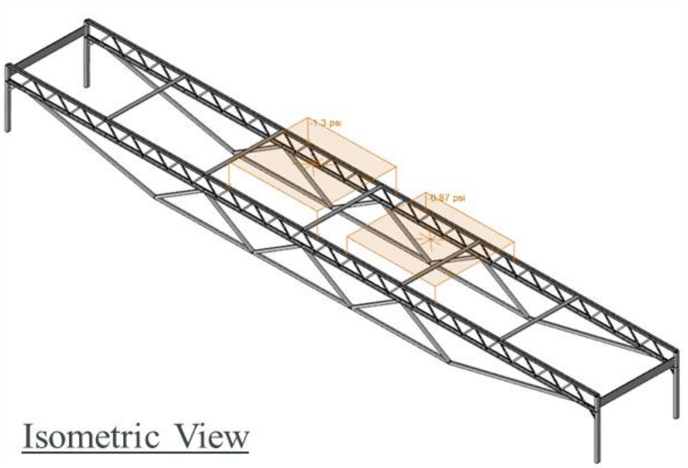


Figure 20. Bridge Isometric View, Loads Applied

An important part of the model had to do with setting the correct unbraced lengths Lc to get accurate results. The team captains decided to split all joist members into several sizes for transportation and assembly purposes. The joists, which were also the stringers of the bridge for this specific design were split as shown in Table 1, where the unbraced length was set to the same length as the joist.

Table 1. Joist Stringer Length

Joist Stringer Lengths		
Lc (in)	Quantity	Total Inches
5	2	10
25	2	50
30	2	60
40	3	120
Total (in)		240
Total (ft)		20

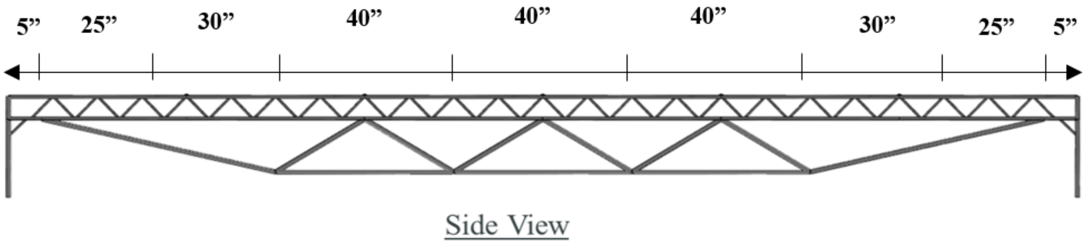


Figure 21. Side View of the Bridge

Table 1 shows the lengths for each of the joist members, multiplied by the number of specific joists that would be part of the stringers. This results in a total of 240 inches along the span of the bridge, which equates to twenty feet when converted. This was the total span desired for the bridge to fit perfectly within the proposed layout by AISC (*Figure 21*).

3.3 AISC STRUCTURAL CODE

RISA 3D also had the option to do a combined compression and bending check to the bridge. This is also referred to as a unity check where all members of the bridge are analyzed. This check considers a ratio of all the applied loads, which can be forces and moments, to the member's capacity, which depends on the materials used and the code. In this case, the LRFD code was used for analysis, which stands for load and resistance factor design. A unity check ratio less than one meant that a member was safe, while a unity check ratio greater than one meant that a member was overstressed and therefore needed to be redesigned.

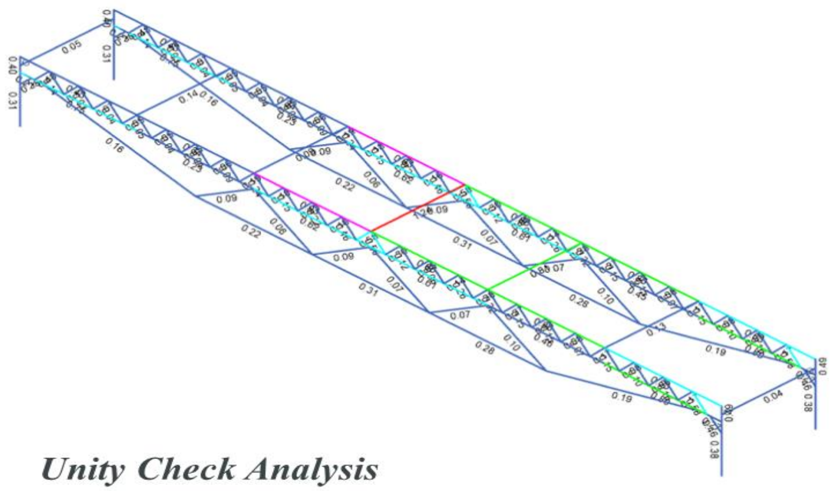


Figure 22. Unity Check Analysis Diagram

Figure 22 shows a preliminary analysis for the steel bridge where RISA 3D had the option to color-code all members depending on the resulting ratios for each member. The member in the middle of the lateral system is shown a red, meaning that there was an issue with the member that needed to be addressed. This member had a unity check ratio of 1.20, therefore the team had to go back and evaluate if the member size was the issue, or if the boundary conditions were not set properly. The team decided to change the member size to a 1"x1" HSS to fix the issue.

4 MATERIAL AND COMPONENT SPECIFICATIONS

The primary material used for this competition was steel, and all the specifications provided by the Student Steel Bridge Competition had to be met. First, all the steel used had to be magnetically attractive to ensure proper strength and high performance was performed. If any competitors did not follow these constraints, their respective bridges would be disqualified from the competition since there would be unfair advantages. The components of the bridge are steel members which correspond to ASTM Grade 36 and Grade 50, steel plates, nuts, and bolts which were commercially available for purchase (*figure 23*).

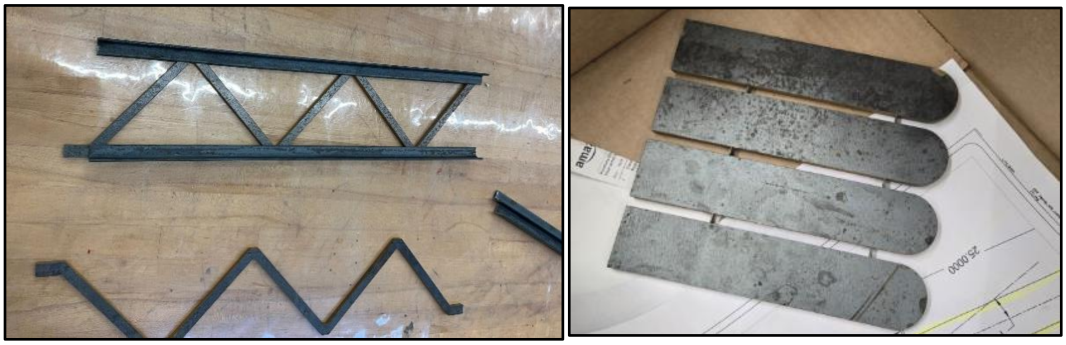
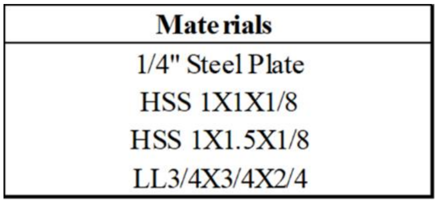


Figure 23. 1/4" Steel Plates and Double Angles

4.1. STEEL

Grade 36 was the predominant steel used in the fabrication process because it is low carbon steel, easy to weld and form, and the cheapest grade of steel available. The following table provides a summary of all the steel sections used for various parts of the bridge.

Table 2. List of Steel



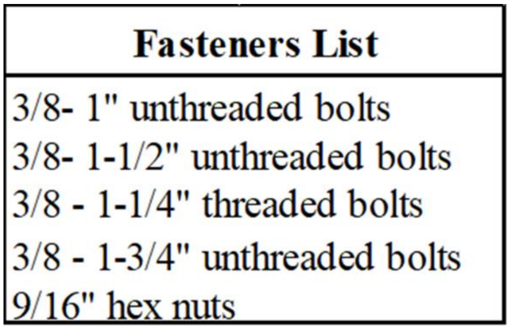
Materials
1/4" Steel Plate
HSS 1X1X1/8
HSS 1X1.5X1/8
LL3/4X3/4X2/4

Table 2 shows that there were four types of steel sections involved in the construction of the bridge. The first one was ¼" steel plates that were used to create the webbing for the joists. These were designed by team captains but cut using the waterjet by Lab Manager Justin Amos. Two sizes of hollow steel sections or HSS were used to create the under truss, lateral system, and columns. The biggest HSS size was used for the columns to help with the lateral stability of the bridge. 3/4x3/4x2/4 double angles were also used to create the top and bottom part of the joists which were purposely considered bridge stringers.

4.2 FASTENERS

Loose bolts and nuts were also eligible for connection design; however, some of the bolts were selected so that part of its entire length was unthreaded. Loose bolts could not be mechanically altered and needed to have a nominal length that should not exceed three inches measured from the bottom of the head to the end. If threading was chosen, it had to extend along the entire circumference of the bolt. The following table shows all bolt sizes and specifications used for the diverse types of connections.

Table 3. List of Fasteners



Fasteners List
3/8- 1" unthreaded bolts
3/8- 1-1/2" unthreaded bolts
3/8 - 1-1/4" threaded bolts
3/8 - 1-3/4" unthreaded bolts
9/16" hex nuts

All the bolt sizes reported in *Table 3* correspond to connections between joists, under truss, and lateral system. The first two sizes were used for connections between the top and bottom chords of the joists respectively, while the third size was used to connect the long plates to the columns for lateral stability. The biggest bolt size was used for all connections between under truss members, which were bigger than the rest of the members. Therefore, a bigger bolt was going to be enough for this cross section. More details about connections are provided in Section 5, where drawing and cross sections are provided for each type of connection.

5 BOLTED CONNECTION DESIGN

5.1. AUTOCAD DRAWINGS

The figure below shows a summary of the AUTOCAD drawings that were designed for the steel bridge. At the top, there are three types of connections, and those have the purpose of connecting the joists with the under truss. This image also reflects the final product which is a twenty feet long bridge, 2' 6" tall, and it also has a gap between the ground to the bottom part of the bridge of 6".

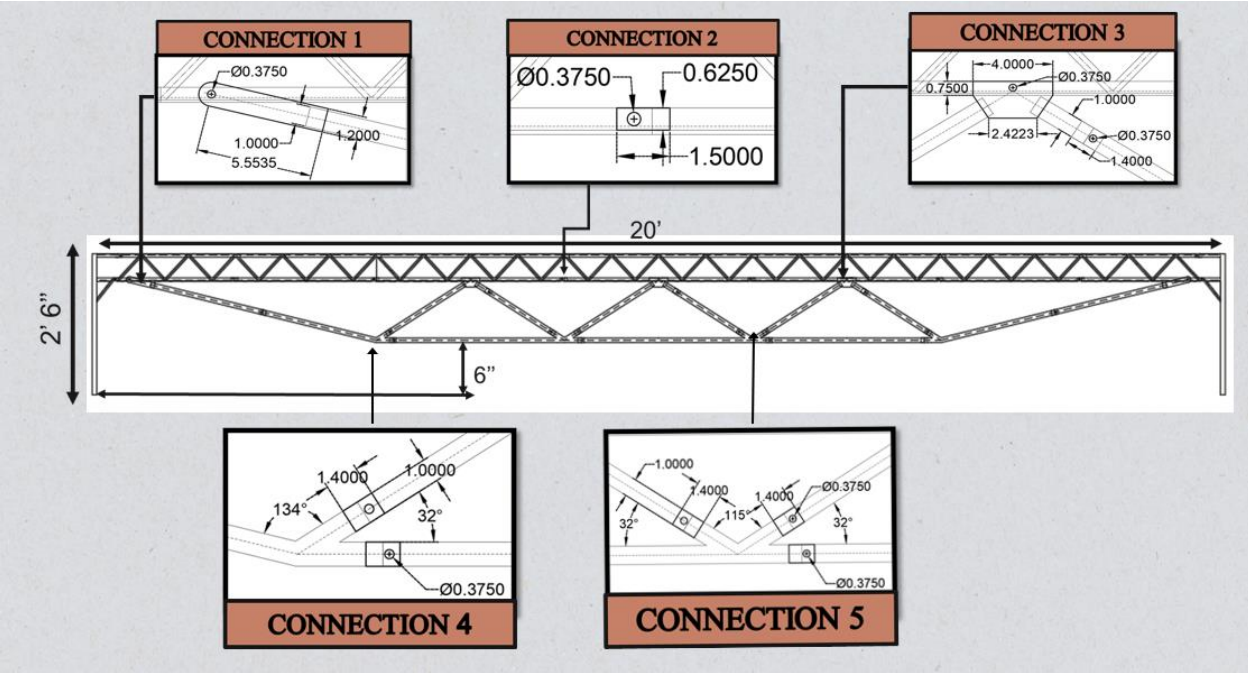


Figure 24. AutoCAD Drawing for Connections

5.2. BOLTED CONNECTIONS

5.2.1. TOP CHORD CONNECTION

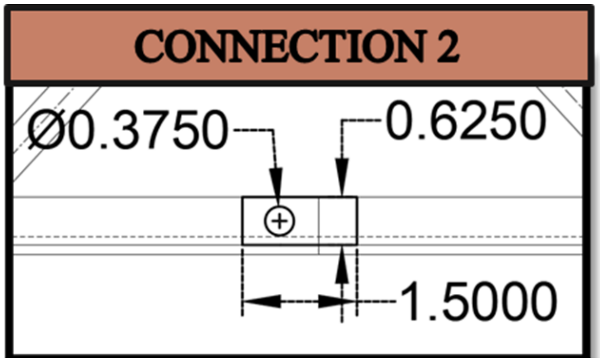


Figure 25. Connection 2

Figure 25 shows the type of connection used for the joist top chord and part of the bottom chord. These were mainly plate connections with the dimension described that stuck over each of the joists to be connected to the next one using the bolts described in Section 4. This type of connection was essential for our design since it took the least time to assemble and fasten. A total of sixteen connections like this one were used along the entire span of each of the stringers/joists.

5.2.2. BOTTOM CHORD CONNECTION

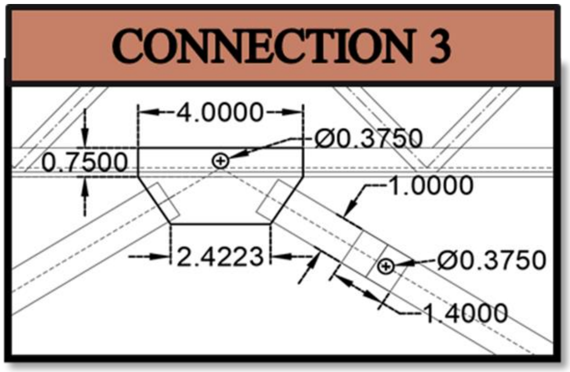


Figure 26. Connection 3

Figure 26 shows the plate connections used to connect the bottom chord of the joists with the top part of the under truss. These connections were designed so that part of the plate welded to the HSS could slide in between the double angles that made up the joist chords, to then be bolted. These connections were efficient in terms of construction time and strength since the bolt was double shear.

5.2.3. TRANSVERSAL CONNECTION

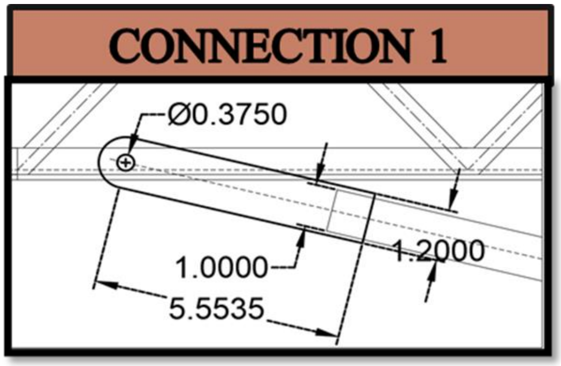


Figure 27. Connection 1

The transversal connections shown in *Figure 27* were used to ends of the under truss. This term was proposed by team captains because of the way the connection had to be bolted to the bottom chord of the joists. This type of connection also involved welding a plate to the HSS to be able to connect it in between the double angles existing in the joists. There were two of these connections on each side of the bridge.

5.2.4. COLUMN CONNECTION

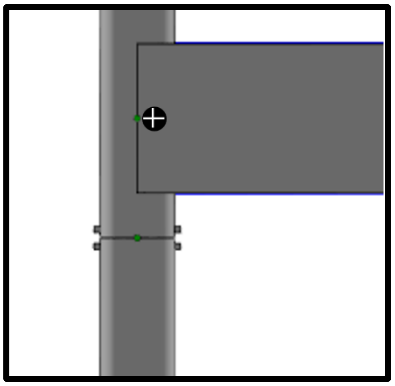


Figure 28. Column Connection

Column connections as shown in *Figure 28* were done with a straightforward yet effective method. Bolts were used to secure a plate laterally to the columns. This plate serves as a crucial link, connecting the columns horizontally. By fastening the bolts through the columns and into the plate, a stable connection is achieved. This arrangement ensures that the columns are firmly joined together, providing lateral support to the bridge structure.

5.2.5 UNDERTRUSS CONNECTIONS

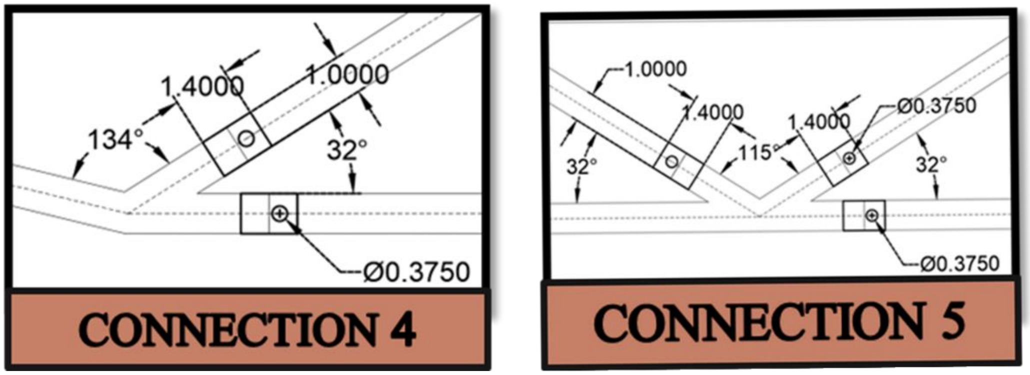


Figure 29. Undertruss Connections

All connections of the under truss were done using 1”x1.4” plates on both sides of the members. This meant that all connections were in double shear as well. *Figure 29* show the specific dimensions for these connections and the arrangement selected to connect every member of the under truss.

5.2.5 TEAROUT AND RUPTURE CONNECTION CHECKS

The connections were one, if not the most important part of the bridge since failure usually occurs at the connections. Tearout and rupture formulas provided in the AISC Manual of Steel Construction to meticulously calculate the clear distances and maximum strength of the connections were utilized. These formulas, grounded in the principles of structural engineering, were especially important in ensuring the integrity and stability of this bridge design. By applying these calculations, the team was able to determine the structural capacity of each connection point as well as bolt clear distances, safeguarding against potential failures and optimizing the overall performance of the bridge.

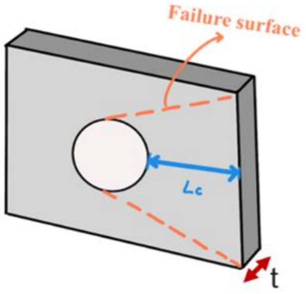


Figure 30. Tearout Calculations Diagram

Figure 30 shows the purpose of Tearout calculations. This type of failure occurs along the surface indicated above, parallel to the direction of the force. The main purpose of this calculation was to determine the clear distance Lc between the end of every plate connection to where the bolt hole should start. This clear distance ensures tearout does not occur. All these calculations were used using the following formula.

$$\varphi Rn = \varphi 1.2 t l_c F_u \qquad \text{Equation 1}$$

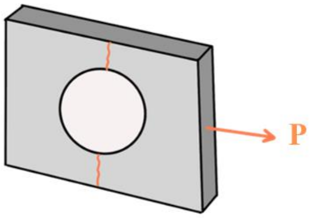
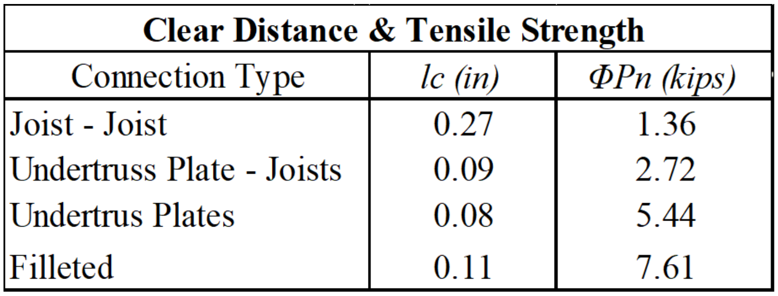


Figure 31. Rupture Failure

Figure 31 then shows the case for rupture failure. This type of failure occurs perpendicular to the direction of the force. The main purpose of these calculations was to determine the maximum axial forces the connection could hold. The input for these calculations were obtained from the RISA 3D model, where the team was able to get axial force diagrams and values to determine the maximum forces transmitted through all the members. The formula used for this calculation was the following.

$$\varphi Rn = F_y\, A_g \qquad \textit{Equation 2}$$

The results for every connection are summarized in the following *figure*. These results include calculations for every type of connection for the bridge including stringers and under truss.



Clear Distance & Tensile Strength		
Connection Type	*lc (in)*	*ΦPn (kips)*
Joist - Joist	0.27	1.36
Undertruss Plate - Joists	0.09	2.72
Undertrus Plates	0.08	5.44
Filleted	0.11	7.61

Figure 32. Clear Distance & Tensile Strength

It is worth noting that all these results included a Φ (phi) factor of safety that accounted for uncertainties in the material and codes. In this case, the team used the LRFD code which stands for Load and Resistance Factor Design. All calculations for the results tabulated are located in Appendix **B.**

6 STEEL BRIDGE FABRICATION

In order to complete the whole bridge, we had to go through four important processes. The first one was the cutting phase where we used five machines to cut all the steel that was donated from Metal Fabrication LLC. Then, we had the fabrication of jigs because we needed to weld and do the hole in the bridge, and jigs are crucial tool to maintain the steel members in place at the moment of welding or drilling. For the steel bridge, we decided to create three types of jigs, and those were for the joists, columns and under truss. The next process was the MIG welding and as a team, we had to learn how to weld. The last process was painting, assembling, and practice time. These three parts of this phase were important because the bridge had to go through an aesthetic judgement.

6.1 CUTTING

The first machine used was the waterjet, and we used it to cut the 1/4" steel plate. Then, the chop saw was used to cut all the HSS because the original pieces were too long. After we cut the HSS with the chop saw, we decided to use the shear machine in order to cut the steel member even shorter. The next machine was the horizontal band saw which was used to cut the necessary angles in the HSS. Finally, we used the mill machine to do all the necessary holes in the steel members (*figure 33).*

Figure 33. Cutting Process

6.2 JIGS

Since we knew that we were going to be welding the whole time, and we wanted to be precise with the steel members, so we decided to design three types of jigs. The first jig was for the joists, and we had to create this one because we had two single angles, one HSS, and steel plate. The following jig was for the column, and we made sure that it complied with the requirements given by the competition. Then, we decided to make another jig for the under truss because we had three types of angles, so we wanted to be precise. Finally, all these jigs were made of wood and screws that were available at the Applied Engineering Center (*figure 34*).

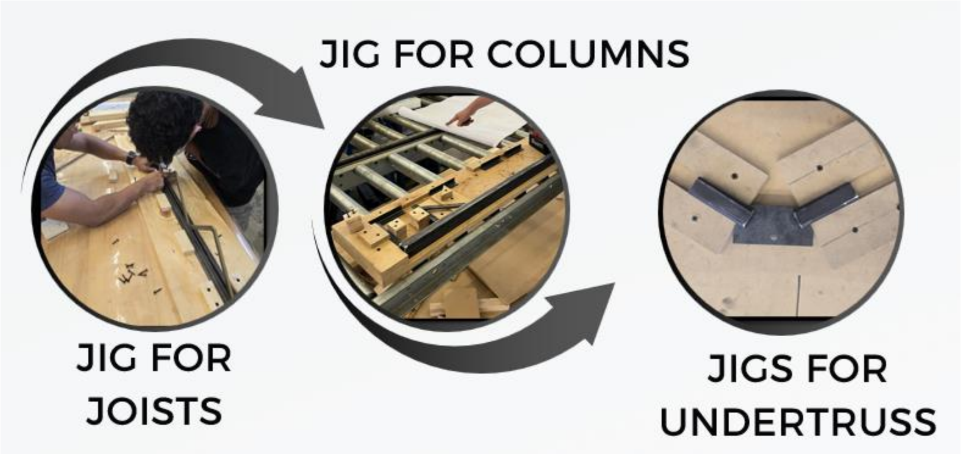


Figure 34. Jigs

6.3 MIG WELDING PROCESS

After the jigs were done, the team was ready to start the welding training sessions. This was the first step in this process and the sessions took about an hour. After that, the grinding process started by making sure that all the pieces were the correct size and matched the specifications provided in the plans. After that, most of the parts were welded, this was the part of the process with team members devoting over three hundred hours to the MIG welding portion of the project. Finally, assembly sessions and practices were done to make sure that all the steel members were aligned. All of this process if shown in *Figure 35*.

Figure 35. MIG Welding Process

6.4. PAINTING, ASSEMBLING, AND PRACTICE PROCESS

This is the process of the steel bridge execution, so we started mimicking the layout the competition because we wanted to have a strategy to build our bridge during the competition. Then, we did five practices session where we had the opportunity to take the time construction and assemble the bridge many times. Finally, the competition has a category for aesthetic, so we decided to paint our bridge (*figure 36*). This painting session were done outside of the Applied Engineering Center, and we decided to paint it white and gold which inspired us to call the bridge as the Southern Indiana Starlight.

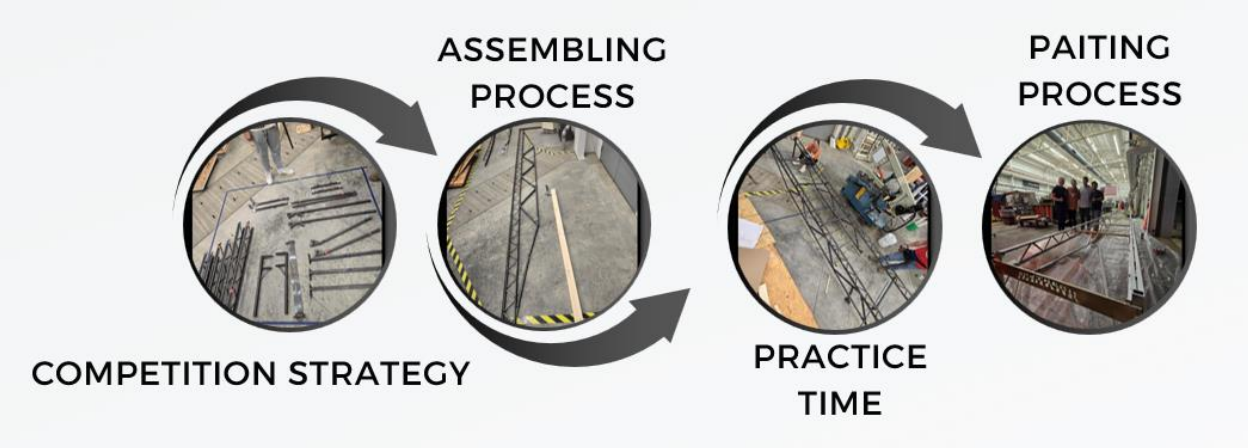


Figure 36.8 Painting, Assembling and Practice Process

7 PHASE 3: COMPETITION

The 2024 IN-KY Student Steel Bridge competition took place on Saturday, April 13 at Purdue Northwest. This campus is located in Hammond, IN, but the competition took place in the Purdue Northwest Gym from 8 AM to 3PM. A total of seven schools were participating in the competition including schools such as Trine University, Purdue University West Lafayette, and Western Kentucky University.

7.1. FINAL PRODUCT

The following three pictures show the final product of the bridge. During the competition, there were seven bridges, and they all had to be assembled the night before the competition because the aesthetic judgement was going to be early in the morning. After that, timed build and other aspects of the competition would start.

7.1.1 TOP VIEW

Figure 37. Top View of the Bridge

The top view of the bridge shown in *Figure 37* portrays how the lateral system was built. The lateral system was composed of a total of six 1”x1” hollow steel sections and two steel plates where the Southern Indiana logo was cut out using the water jet as shown in *Figure 38*.

7.1.2 SIDE VIEW

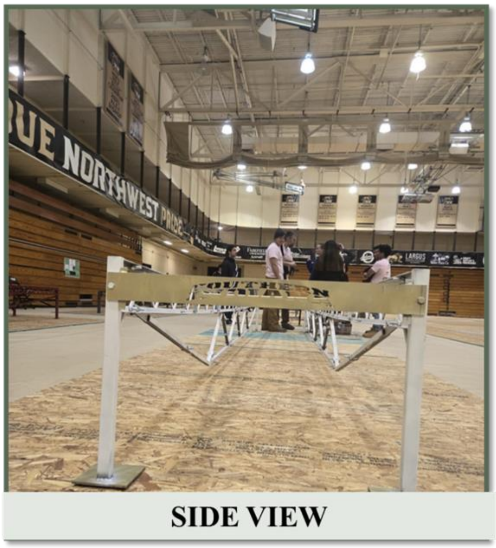


Figure 38. Side View of the Bridge

This side view also shows the detailed column connections. These connections had the end plates connected to the columns as specified in Section 5. Rectangular plates were welded to the column's footings for lateral stability and to prevent sway in any direction.

7.1.3. FRONT VIEW

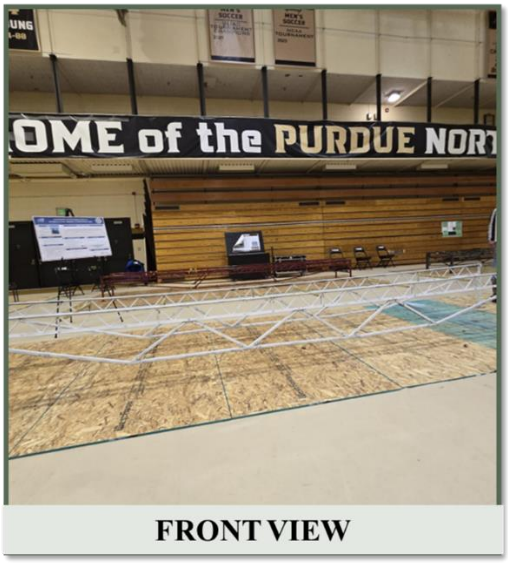


Figure 39. Front View of the Bridge

Figure 39 shows the joists and the under truss which were a very important part of the bridge. The under truss was the component of the bridge that took the longest to be built due to its intricate connections that had to match perfectly. A certain pattern for the under-truss assembly had to be followed for the connections to match.

7.2 CHALLENGES

During the development of the last phases of the bridge, the team encountered some challenges regarding the connections and alignment of the structure. Despite careful planning and attention to detail, issues arose that required careful troubleshooting and finding solutions. From problems in alignment to unexpected complications with connections, these issues demanded teamwork, and required all members to use all problem-solving skills. The issues that we had to fix are thoroughly explained as follows.

7.2.1 DECKING

Figure 40. Decking Issues

Stringers were not aligned at certain sections of the bridge as shown in *Figure 40*. There was a requirement that every stringer needed to have a width of less than two inches, but the stringer template was not sliding properly along the entire span of the stringers. Since some of the bolts connecting the joists and lateral system were also sticking out of the interior flange of the double angles, this prevented the bridge from not exceeding the two-inch width limit. This was not, however, an issue that could disqualify the bridge but would add a penalty to the score.

7.2.2 LATERAL SYSTEM

Figure 41. Lateral System Issues

The issue shown in *Figure 41* has to do with the lateral stability of the lateral system connections. The results obtained from the RISA 3D were results where assumptions regarding rigid connections were made. However, the connections once the bridge was built were not as rigid as expected. This caused the bridge to laterally deflect more than expected, therefore exceeding the ¾” sway limit provided in the rules.

7.3. COST ANALYSIS

Every project should have a cost analysis to know if it is worth undertaking a task. The following three table shows the process of cost analysis for the steel bridge, but this is an approximate cost analysis in real life because we used Davis Bacon Wages in order to know the salary per hour of each other people in charge of the project (Table 7). We just included the labor costs since the steel was donated by Metal Fabricator LLC.

7.3.1 WORK BREAKDOWN STRUCTURE

The table below shows the Work Breakdown Structure which is list of processes and tasks that we did to complete the bridge.

Table 4 Work Breakdown Structure

<table>
<tr><th colspan="6">Work Breakdown Sequence (WBS)</th></tr>
<tr><th colspan="6">STEEL BRIDGE</th></tr>
<tr><th>1. INITIATION</th><th>2. MISC.</th><th>3. FABRICATION PROCESS</th><th>4 PAINTS</th><th>5. COMPETITION</th><th>6. DISPOSAL</th></tr>
<tr><td>1.1 Do the design in RISA 2D</td><td>2.1 Provide plans from AUTOCAD and RISA 3D</td><td>3.1 Cut the steel members</td><td>4.1 Prepare the surface</td><td>5.1 Transport the members</td><td>6.1. Dispose the construction waste</td></tr>
<tr><td>1.2 Do the design in RISA 3D</td><td>2.2 Make quotes</td><td>3.2. Grind the steel member</td><td>4.2 Prime the surface</td><td>5.2 Assemble the bridge</td><td>6.2. Donate the usable items</td></tr>
<tr><td>1.3 Do the connection design in AUTOCAD</td><td>2.3. Order materials</td><td>3.3. Weld the steel members</td><td>4.3. Choose the color</td><td>5.3. Build the bridge</td><td>6.3 Recycle the items</td></tr>
<tr><td>1.4 Schedule safety training</td><td>2.4 Pickup materials</td><td>3.4. Create jigs</td><td>4.4 Paint the bridge</td><td></td><td>6.4 Rent Dumpsters and cleaning items</td></tr>
<tr><td>1.5 Schedule welding training</td><td></td><td>3.5 Assemble the steel members</td><td>4.5. Apply additional coats</td><td></td><td></td></tr>
<tr><td>1.6. Read all the competition rules</td><td></td><td>3.6. Do the hole in the steel members</td><td>4.6. Touch up and clean up</td><td></td><td></td></tr>
<tr><td>1.7 Prepare a timeline for the project</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

7.3.2 RESOURCE MATRIX

The table below shows the Resource Matrix which is the table that shows the responsible people for tasks that were assigned in the Work Breakdown Structure.

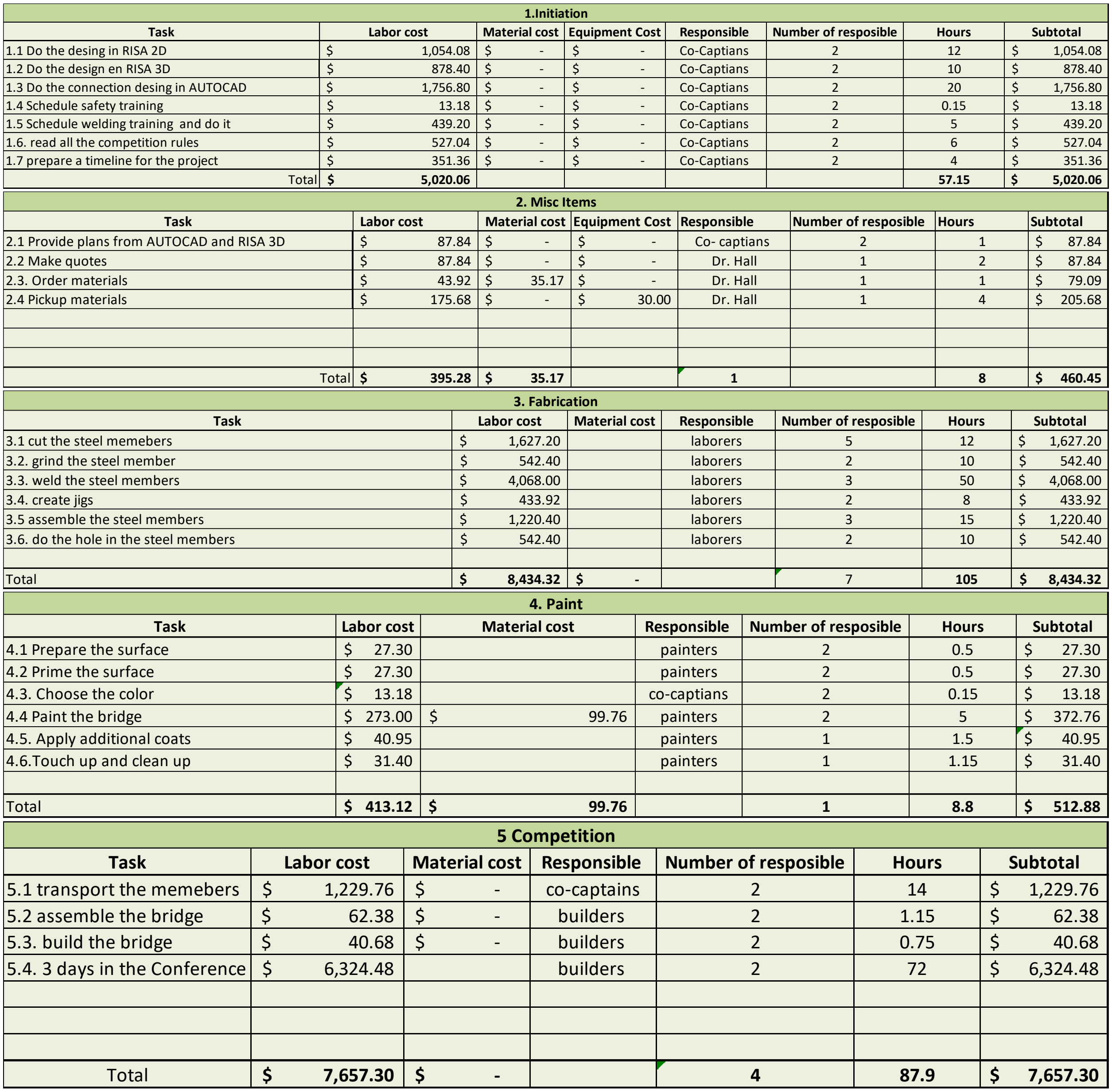
Table 5. Resource Availability Matrix

Resource Availability Matrix											
Steel Bridge											
1. Initiation		**2. Misc.**		**3. fabrication process**		**4. Paint**		**5. competition**		**7. Disposal**	
Task	Responsible	Task	Responsible	Task	Responsible	Task	Responsible	Task	Responsible	Task	Responsible
1.1 Do the design in RISA 2D	**Co-Captains**	2.1 Provide plans from AUTOCAD and RISA 3D	**Co-captains**	3.1 cut the steel members	**laborers**	4.1 Prepare the surface	**painters**	5.1 transport the members	**co-captains**	7.1. Dispose the construction waste	**Laborers**
1.2 Do the design in RISA 3D	**Co-Captains**	2.2 Make quotes	**Dr. Hall**	3.2. grind the steel member	**laborers**	4.2 Prime the surface	**painters**	5.2 assemble the bridge	**builders**	7.2. Donate the usable items	**co-captains**
1.3 Do the connection design in AUTOCAD	**Co-Captains**	2.3. Order materials	**Dr. Hall**	3.3. weld the steel members	**laborers**	4.3. Choose the color	**co-captains**	5.3. build the bridge	**builders**	7.3 Recycle the items	**Laborers**
1.4 Schedule safety training	**Co-Captains**	2.4 Pickup materials	**Dr. Hall**	3.4. create jigs	**laborers**	4.4 Paint the bridge	**painters**			7.4 Rent Dumpsters and cleaning items	**co-captains**
1.5 Schedule wilding training	**Co-Captains**			3.5 assemble the steel members	**laborers**	4.5. Apply additional coats	**painters**				
1.6. read all the	**Co-Captains**			3.6. do the	**laborers**	4.6. Touch up	**painters**				

7.3.3 BUDGET

The following table shows the budget of the project based on the Davis Bacon Wages of Vanderburgh, Indiana.

Table 6 Budget



1.Initiation

Task	Labor cost	Material cost	Equipment Cost	Responsible	Number of resposible	Hours	Subtotal
1.1 Do the desing in RISA 2D	$ 1,054.08	$ -	$ -	Co-Captians	2	12	$ 1,054.08
1.2 Do the design en RISA 3D	$ 878.40	$ -	$ -	Co-Captians	2	10	$ 878.40
1.3 Do the connection desing in AUTOCAD	$ 1,756.80	$ -	$ -	Co-Captians	2	20	$ 1,756.80
1.4 Schedule safety training	$ 13.18	$ -	$ -	Co-Captians	2	0.15	$ 13.18
1.5 Schedule welding training and do it	$ 439.20	$ -	$ -	Co-Captians	2	5	$ 439.20
1.6. read all the competition rules	$ 527.04	$ -	$ -	Co-Captians	2	6	$ 527.04
1.7 prepare a timeline for the project	$ 351.36	$ -	$ -	Co-Captians	2	4	$ 351.36
Total	**$ 5,020.06**					**57.15**	**$ 5,020.06**

2. Misc Items

Task	Labor cost	Material cost	Equipment Cost	Responsible	Number of resposible	Hours	Subtotal
2.1 Provide plans from AUTOCAD and RISA 3D	$ 87.84	$ -	$ -	Co- captians	2	1	$ 87.84
2.2 Make quotes	$ 87.84	$ -	$ -	Dr. Hall	1	2	$ 87.84
2.3. Order materials	$ 43.92	$ 35.17	$ -	Dr. Hall	1	1	$ 79.09
2.4 Pickup materials	$ 175.68	$ -	$ 30.00	Dr. Hall	1	4	$ 205.68
Total	**$ 395.28**	**$ 35.17**		**1**		**8**	**$ 460.45**

3. Fabrication

Task	Labor cost	Material cost	Responsible	Number of resposible	Hours	Subtotal
3.1 cut the steel memebers	$ 1,627.20		laborers	5	12	$ 1,627.20
3.2. grind the steel member	$ 542.40		laborers	2	10	$ 542.40
3.3. weld the steel members	$ 4,068.00		laborers	3	50	$ 4,068.00
3.4. create jigs	$ 433.92		laborers	2	8	$ 433.92
3.5 assemble the steel members	$ 1,220.40		laborers	3	15	$ 1,220.40
3.6. do the hole in the steel members	$ 542.40		laborers	2	10	$ 542.40
Total	**$ 8,434.32**	**$ -**		7	**105**	**$ 8,434.32**

4. Paint

Task	Labor cost	Material cost	Responsible	Number of resposible	Hours	Subtotal
4.1 Prepare the surface	$ 27.30		painters	2	0.5	$ 27.30
4.2 Prime the surface	$ 27.30		painters	2	0.5	$ 27.30
4.3. Choose the color	$ 13.18		co-captians	2	0.15	$ 13.18
4.4 Paint the bridge	$ 273.00	$ 99.76	painters	2	5	$ 372.76
4.5. Apply additional coats	$ 40.95		painters	1	1.5	$ 40.95
4.6.Touch up and clean up	$ 31.40		painters	1	1.15	$ 31.40
Total	**$ 413.12**	**$ 99.76**		**1**	**8.8**	**$ 512.88**

5 Competition

Task	Labor cost	Material cost	Responsible	Number of resposible	Hours	Subtotal
5.1 transport the memebers	$ 1,229.76	$ -	co-captains	2	14	$ 1,229.76
5.2 assemble the bridge	$ 62.38	$ -	builders	2	1.15	$ 62.38
5.3. build the bridge	$ 40.68	$ -	builders	2	0.75	$ 40.68
5.4. 3 days in the Conference	$ 6,324.48		builders	2	72	$ 6,324.48
Total	**$ 7,657.30**	**$ -**		**4**	**87.9**	**$ 7,657.30**

7. Disposal						
Task	Labor cost	Material cost	Responsible	Number of resposible	Hours	Subtotal
7.1. Dispose the construction waste	$ 271.20	$ 19.98	Laborers	2	5	$ 291.18
7.2. Donate the usable items	$ 50.51	$ -	co-captains	1	1.15	$ 50.51
7.3 Recycle the items	$ 81.36	$ -	Laborers	2	1.5	$ 81.36
7.4 Clean everything	$ 263.52		co-captains	2	3	$ 263.52
Total	**$ 403.07**	**$ 19.98**		**3**	**7.65**	**$ 686.57**

Total of hours for the project	274.5
Number of workers	8
Material cost	$ 154.91
Labor cost	$ 22,323.14
Total cost of project	**$ 22,478.05**

Table 7. Davis Bacon Wages

Davis Bacon Wages			
Job Title	Rate	Fringes	Total Labor Cost
Laborer	$ 27.12	$ 18.10	$ 45.22
Painter	$ 27.30	$ 18.19	$ 45.49
Project Manager			$ 43.92

9. CONCLUSION

9.1. FINAL THOUGHTS

The Steel Bridge that we designed followed all the rules given by America Institute of Steel Construction, and we also followed all the technical requirements for the competition, such as, site layout, box, stringers, length, height, and width. Another important part of our project was Structural analysis software because it helped us to choose the best design and make changes if we needed to. It was a project that took around 300 hours, and it was rewarding seeing the results after all the hours that we spent designing and fabricating it. After all, bridges are infrastructures that provides strength and durability because it ensures the connectivity of places in our daily lives, facilitating economic growth and safety. As civil engineering students interested in structural design, this project was challenging but it was worth it to see the result.

9.2 REFLECTION

Participating in the AISC Steel Bridge Competition presented a significant opportunity for all team members to grow professionally in various ways. First, the competition provided a platform for hands-on application of theoretical knowledge gained in classes, allowing team members to bridge the gap between academic learning and practical implementation. Additionally, the competition fostered teamwork, communication, and leadership skills as team members collaborated to design, fabricate, and construct the bridge under strict guidelines and deadlines.

The nature of the competition itself encouraged problem-solving and critical thinking as the team faced several challenges along the way. Overall, the 2024 AISC Steel Bridge Competition served as a transformative learning experience, pushing team members to develop both technical expertise and learn skills essential for success in professional settings.

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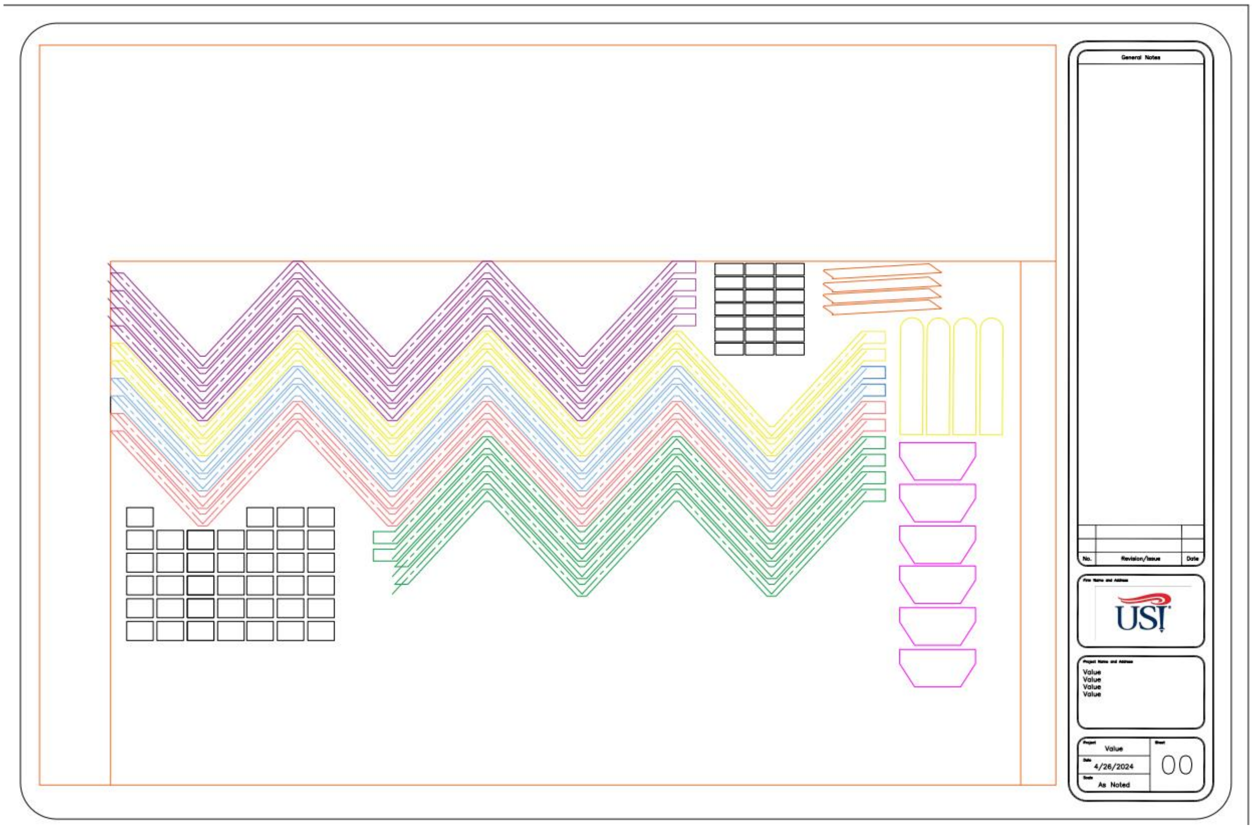
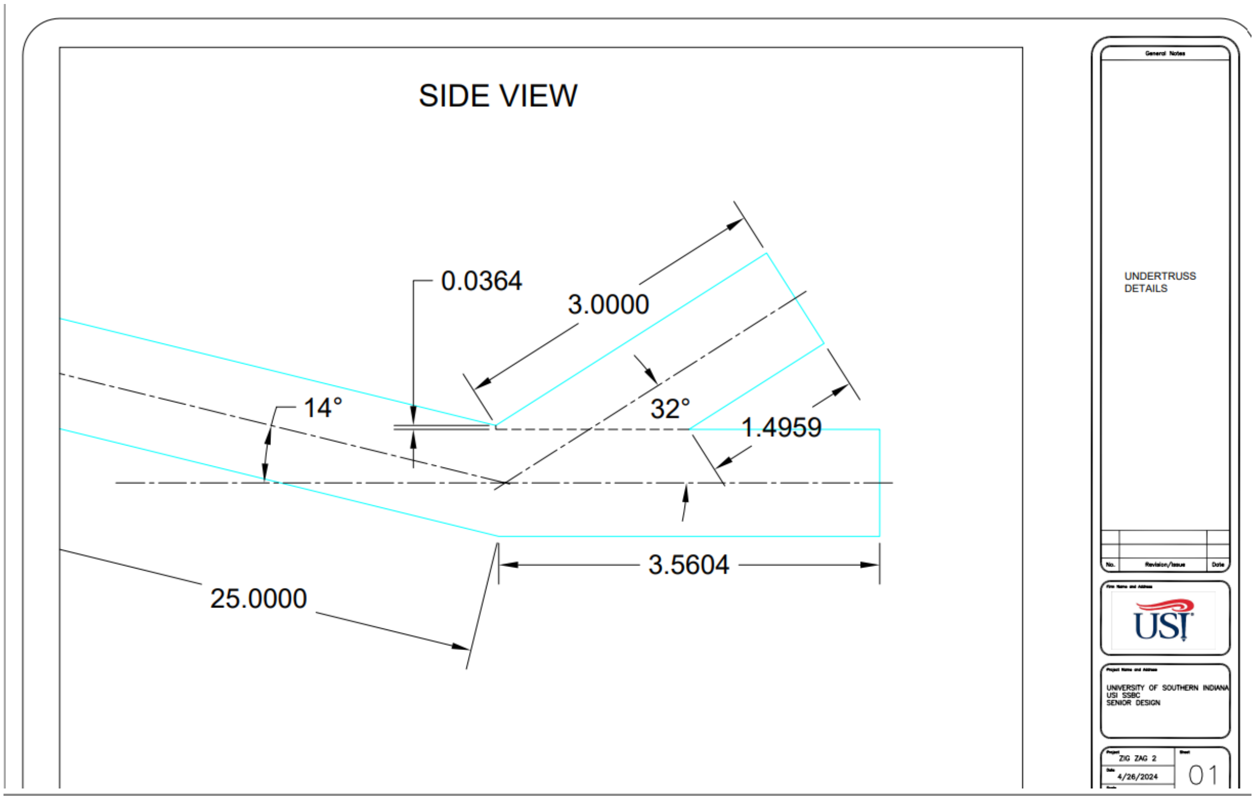
11. APPENDIX

11.1. APPENDIX A: PLANS

- Waterjet Drawings

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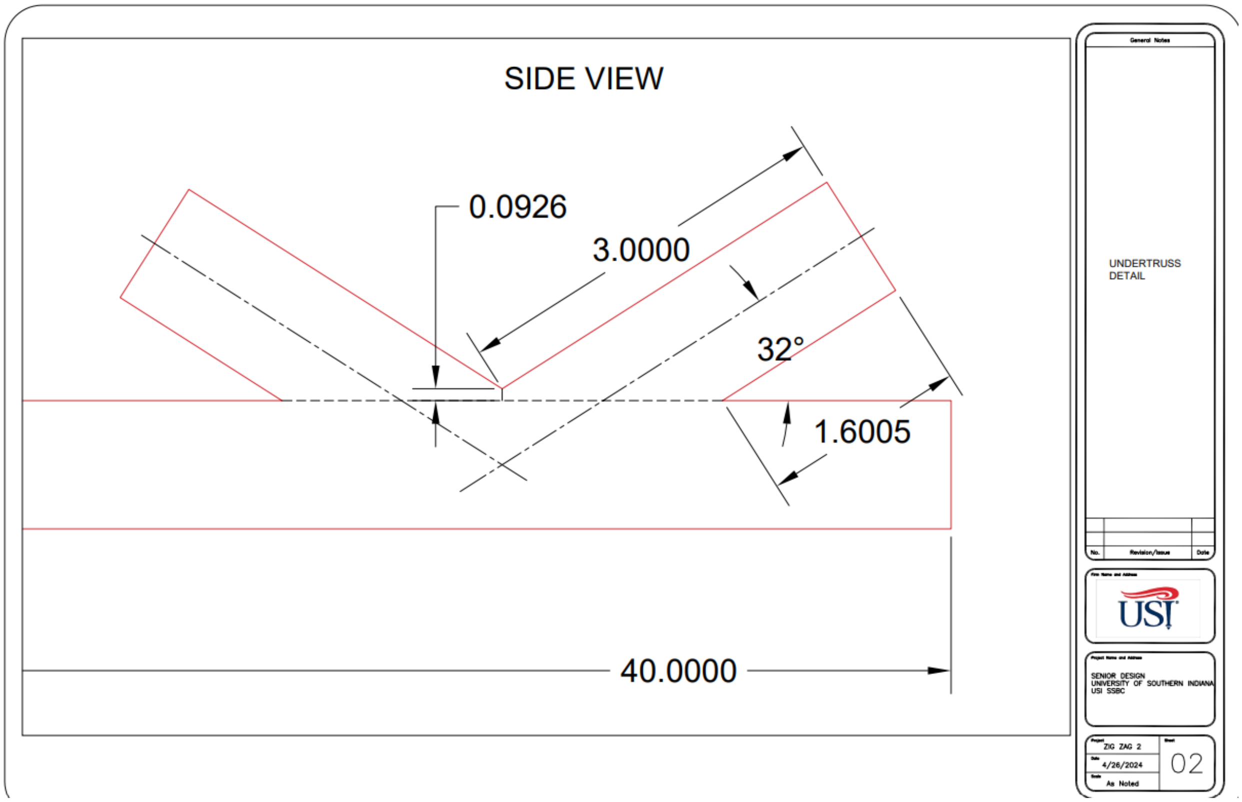
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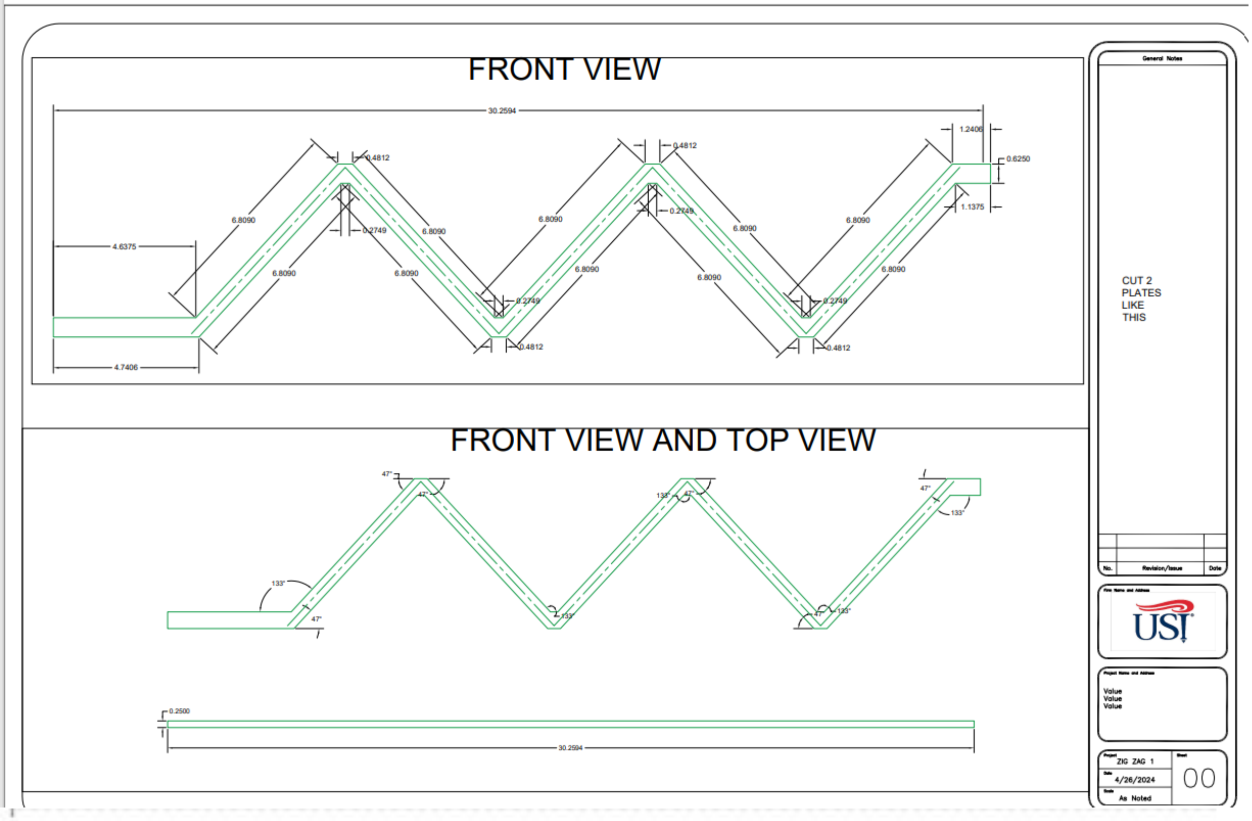
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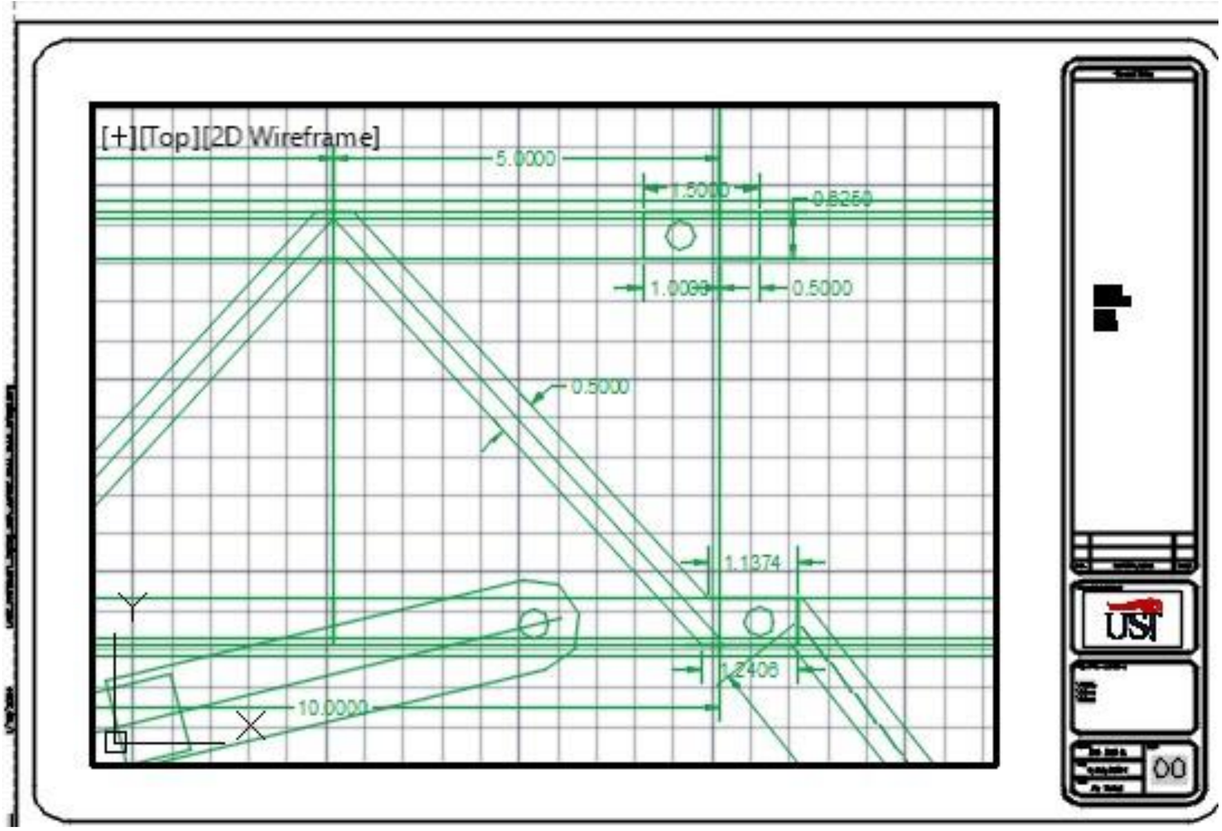
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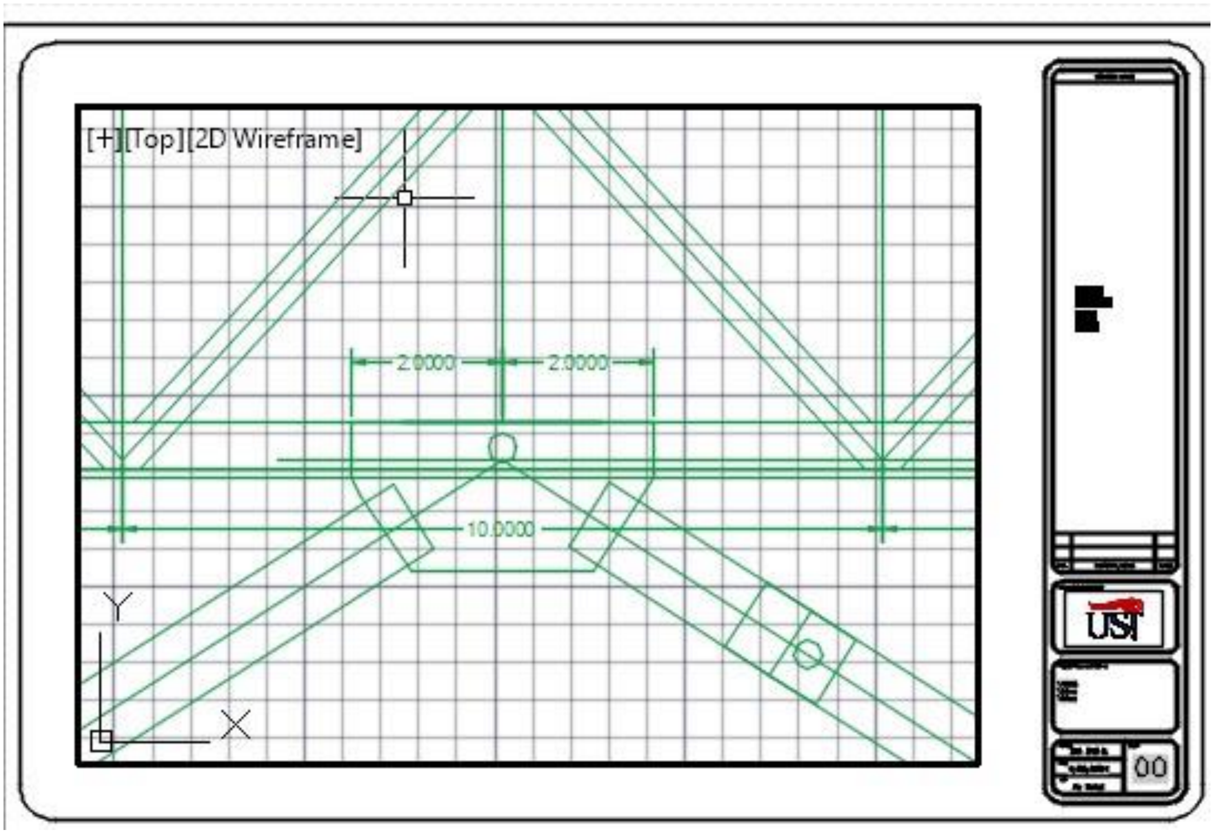
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11.2. APPENDIX B: ***STEEL BRIDGE CONNECTION CALCULATIONS***

TEAROUT

Note: All Rn values were obtained from the RISA 3D Model by choosing the biggest axial member force being transmitted through each of the nodes. These values were also rounded to the nearest hundredth.

Webbing-Double Angle	
Rn (k)	3.5
Coefficient - Deformation Considered	1.2
Fu (ksi)	43.5
t (in)	0.25
lc (in)	**0.27**

Undertruss Plate - Joists	
Rn (k)	1.2
Coefficient - Deformation Considered	1.2
Fu (ksi)	43.5
t (in)	0.25
lc (in)	**0.09**

Undertruss HSS	
Rn (k)	1
Coefficient - Deformation Considered	1.2
Fu (ksi)	43.5
t (in)	0.25
lc (in)	**0.08**

Round Plate - Joist	
Rn (k)	1.4
Coefficient - Deformation Considered	1.2
Fu (ksi)	43.5
t (in)	0.25
lc (in)	**0.11**

All calculations are done per the AISC Manual of Steel Construction. Deformation at the bolt hole was a design consideration.

RUPTURE CALCULATIONS

Joist Bottom Chord Plates	
Fu (ksi)	58
Ag (in2)	0.15625
Ae (in2) = An*U	0.03125
An (in2)	0.03125
ΦPn (kips)	**1.36**
ΦPn (lbs)	1359.375

Undertruss Filleted Plates	
Fu (ksi)	58
Ag (in2)	0.3
Ae (in2) = An*U	0.175
An (in2)	0.175
ΦPn (kips)	**7.61**
ΦPn (lbs)	7612.5

Undertruss Connections	
Fu (ksi)	58
Ag (in2)	0.25
Ae (in2) = An*U	0.125
An (in2)	0.125
ΦPn (kips)	**5.44**
ΦPn (lbs)	5437.5

Joist Connections	
Fu (ksi)	58
Ag (in2)	0.1875
Ae (in2) = An*U	0.0625
An (in2)	0.0625
ΦPn (kips)	**2.72**
ΦPn (lbs)	2718.75

A U value of 1.0 was considered for rupture calculations.

11.3 APPENDIX C

DESIGN FACTORS CONSIDERED

- ***PUBLIC HEALTH SAFETY, AND WELFARE***

The steel bridge will not serve the public because it is a competition between colleges, but in general, steel bridges should be safe infrastructures and provide convenient transportation routes. These infrastructures should promote connectivity within states, which can have indirect effect on public health by providing access to healthcare facilities and emergency service. Even though our senior project is a competition, these types of competitions can influence other bridge designers by improving their real-world designs with modern designs and construction methods.

The student steel bridge competition has a list of safety rules that all the participants must follow so that they can be safe during the competition. Some of those safety rules are basic shop attire, housekeeping, storage, welding, abrasive cutting and right-angles grinders, drill presses and milling machines, and loading. The basic shop attire consists of wearing safety glasses, long pants, rugged leather shoes or boots, long hair should be tied back in a tight bun, and hearing protection.

Regarding housekeeping, all the students should maintain a clear area with tools organized and avoid routing cords on the floor. Storage is also a fundamental part of this competition because all the containers should be labeled to avoid confusion during the competition. Another important safety part of this project is welding because all the students have to create their parts from scratch, so they need to wear all the clothing necessary to fabricate those bridge parts.

Abrasive cutting and right angles grinders is another crucial safety part of the projects, and the students should comply with a series of rules such as having their work area clean, wearing full-face shields, wearing hearing protection, wearing gloves and full skin protection. Next, drill presses and milling machines is also important part for the safety of this project because students should know a few things, such as they should never touch a moving spindle, the workpiece should be firmly clamped in place, emergency shut-off switches should be located for quickest possible emergency use and disconnect and be in control of the power before setting up the machine or changing bits. Finally, Loading the bridge should be perform carefully, and they students should ensure that the load test is blocked to prevent large lateral movements.

- ***GLOBAL***

The competition is primarily regional because it will be done in the north side of Indiana, however using steel can have a global impact because steelmaking is one of the most carbon-intensive manufacturing process that produces a lot of carbon dioxide emission globally. Nevertheless, recycled steel will be used in this project because we want to make it more sustainable and environmentally eco-friendly.

- ***CULTURAL***

The steel bridge competition can also have a cultural importance since it brings together students with diverse backgrounds, such as diverse cultures and experiences. By doing this competition, all the students are exchanging ideas, which enhance the understanding and respect within students and professors.

- ***SOCIAL***

Since this competition is among college students, it has a huge social importance. This type of competition gathers students from different colleges with the purpose of helping them to learn how to work as a team. Moreover, it encourages students to push their limits and showcase their talents along with the importance of gaining skills, such as problem solving and engineering skills. Also, the steel bridge competition is a fundamental activity because students can expand their network and they can learn from each other. Overall, the steel bridge competition will help students to develop leadership, teamwork, and communication, which are important skills that students need for their educational and social growth.

- ***ENVIRONMENTAL***

Steel production is one of the major contributors to global warming in the world, and it is important to acknowledge that by using this material, it will cause environmental consequences. However, these consequences will be reduced by using recycled steel, optimizing transportation organization, and minimizing waste. In general, the strategies that will be used during this competition to reduce the Carbone dioxide can be seen by future engineers, and they will be able to create sustainable and ecofriendly structures.

- ***ECONOMIC***

When it comes to economic factors in construction of a steel bridge, there are a couple of things to consider. First, the recycled steel will reduce the total cost of the bridge because it reduced the cost of getting new steel. Next, all the parts will be fabricated in the Applied Engineering Center, so the university will not spend money on the fabrication of the steel bridge parts in a metal company, which is expensive. Finally, by participating in this competition, it can generate economic benefits for the university that is hosting the competition, and it can attract sponsors that are going to support future competitions.

- ***ETHICAL & PROFESSIONAL***

Building a steel bridge from scratch has so many things related to it that we need to know, and there are going to be more other things that we will need to learn during this project. One of the crucial things that we will have to learn is welding because the design should be unique, and it has a series of rules that need to be followed in the competition. The welding training will help us grow professional because most of the engineers in the field just know the organizational part of the project, but the real-life construction.

Choosing the correct materials and bolts for this bridge will also require an extensive investigation because we do not have that experience of working with steel, so we are planning to search on different metal shop online and going to different metal companies around Evansville to have a better understanding of this material. Also, our advisor has a lot of experience with this material, so we are going to consult with him about which steel is the best for this competition. Also, we would have to use the Steel Code which will help us to be more ethical in our project because there is a way to prove our calculations for the bridge.

As students, we have knowledge about using computer aided design software such as AUTOCAD and RISA 2D, but designing this type of bridge on this type of software will require a deep understanding of this software. Then, our knowledge about structural engineering principal such as load combinations, structural analysis, bearing design, and deflection increased after this project.

- ***REFERENCE FOR STANDARDS***

For our steel project, we used a series of codes that helped us to support our calculations, and one of them is the Steel Construction Manual. By using this code, we gain learning experience because those are the type of books that engineers are going to use in the field of Civil Engineering. Moreover, RISA2D and RISA3D used the LRFD code in their calculation and we considered that it was a fundamental part of our learning process because that it the most common code that must be used in construction sector.