50% Report for

ASCE Steel Bridge Competition

Prepared for:

CENE 486C: Spring 2014

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February 27, 2014

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Acknowledgements

Donors & Donations

Agate Inc.

Special Thanks to: Jim Uhl & Les McCauley

About Agate:

Founded in 1973 by President and CEO Jim Uhl, Agate provides general building and general engineering projects to meet the needs of a wide variety of clients. Additionally Agate fabricates structural steel, manufactures pre-engineered metal buildings and flight line canopies and operates an 8-acre Steel Service Center.

Contribution: 36 ksi Grade Hallow Structural Section Steel tubing

Quantity: 500 ft.

Copper State

Special Thanks to: Bruce MacKenzie

About Copper State:

Copper State Bolt & Nut Co. has proudly served the southwestern U.S. for more than 40 years. Founded in 1972 with six employees in a 6,000 square foot warehouse, the company now supports more than 15,000 customers through 450 employees in 21 locations. Rooted in the principles of quality and customer service, Copper State provides a wide product offering of fasteners, construction products, industrial supplies, power tools & accessories, fluid sealing products, customer specific kits, and specially manufactured items. Our products and services support customers in the mining, construction, steel fabrication, renewable energy, municipality, OEM/MRO, fluid sealing, and wholesale/retail industry sectors. In every one of our locations Copper State is proud to support the very smallest of customers, the very largest of customers, and everyone in between.

Contribution: Grade 8 1-½ in. Bolts along with ¼ in. Nuts

Quantity: 300 each

Schuff Steel

Special Thanks to: Pat Denbo,

About Schuff Steel:

Founded in 1976, Schuff Steel is now the nation's largest and most experienced structural steel fabricator and erector, ranked by ENR as the top Steel Erector and in the top 10 specialty contractors overall. With ten fabrication plants located in California, Arizona, Texas, Kansas, Georgia and Florida, Schuff Steel is uniquely positioned to service our customers anywhere in the country – and beyond. From our in-house design-assist/design-build preconstruction engineering services through erection, our innovative approach to project execution has placed us at the head of the class. Our in-house engineering department uses the latest tools and design techniques to deliver the most efficient steel design possible, providing preconstruction budgeting along the way.

Contribution: 36 ksi. Grade Structural Steel Plates

Quantity: 9 sq ft.

Northern Arizona University Welding Shop

Special Thanks to: Gregory Hahn

About NAU's Welding Shop:

Located just south of Northern Arizona University, a welding shop provides students and faculty with high quality welding for various projects. This shop allows individuals, associated with NAU, access to welding and other fabrication techniques for their group or community projects. The primary focus of this shop is to assist engineering capstone groups with the development of their physical deliverables.

Contribution: M.I.G. Welding techniques

Quantity: 10 Hours

Northern Arizona University Engineering Fabrication Shop

Special Thanks to: Perry Wood

About the Engineering Fabrication Shop:

Engineering Fabrication Shop in the College of Engineering, Forestry, and Natural Sciences (Building 98C) is primarily a student shop. Our focus is on teaching students to run basic machine shop equipment in a safe environment.

Contribution: Access to all shop equipment

Quantity: 15 Hours

Northern Arizona University Construction Management Branch

Special Thanks to: Rob Bruner, MAdmin

About the Construction Management Branch:

The Construction Management program is designed to prepare students for immediate employment as quantity surveyors, estimators, coordinators, project engineers, and supervisors. The program intends to provide well rounded individuals with skills in AutoCAD, Primavera, and other industry standard software.

Contribution: Personal protective equipment (hard hats)

Quantity: 6

The American Institute of Steel Construction

Special Thanks to: President, Roger E. Ferch

About The American Institute of Steel Construction:

The American Institute of Steel Construction (AISC), headquartered in Chicago, is a not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities, including: specification and code development, research, education, technical assistance, quality certification, standardization, and market development. AISC has a long tradition of service to the steel construction industry providing timely and reliable information.

Contribution: Monetary Donation

Quantity: $400

Norfab Steel and Fabrication

Special Thanks to: David Novak (Owner) and Jay Neis (Sales, Estimating, Engineering)

About Norfab Steel and Fabrication:

Norfab Steel and Fabrication is a steel fabrication company that serves the southwest US. This company was established in 1987 and operates only in Flagstaff, AZ. They generally service cement, lime, and power generation industries. The objective for steel fabrication is to provide their customers with exceptional service and quality products at a competitive price. Norfab's goal for long-term relationships with clients is to provide the best service possible and services needed for all of your plant needs. They have over 40 years of experience and are a respectable company in the Flagstaff area.

Contribution: 1"x1"x1/8" Angled Iron and 1"x3/16" Flat Bar

Quantity: 80 ft of each shape

Eagar Welding

Special Thanks to: Brent Eagar, Owner/Operator

About Eagar Welding:

Eagar Welding is a welding company that has been serving Flagstaff, AZ since 1999. Everyone on staff has widespread knowledge of the welding profession. This company's mission is to keep a standard of excellence. Based on this standard, this company chooses only the best quality of material to use. This company takes pride in their product due to their acute attention to craftsmanship. The high ethics of this company governs the relationship between employees and clients.

Contribution: Laser cut plate that displays the school name

Quantity: 1

Technical Assistance

Thomas Nelson, M.S., E.I.T.

Mark Lamer, PE

Robin Tuchscherer, PhD, PE

John Tingerthal, MSCE, EdD, PE

1. Project Description

The American Society of Civil Engineers (ASCE) Student Steel Bridge Competition consists of designing a 1:10 scale bridge that will be constructed during a competition using Accelerated Bridge Construction (ABC) methods and then will be loaded with a given weight. The competition is called the ASCE Pacific Southwest Conference and will be held during April 2014 in San Diego, California. The purpose of the competition is to give students experience with civil design though fabrication, erection, and testing. This project also increases student's awareness of spatial constraints, material properties, strength, serviceability, fabrication and erection processes, safety, aesthetics, project management, and cost. This project not only gives students practice with engineering principles, but with managing effective teamwork as well.

The bridge will be judged in various categories, such as durability, constructability, usability, stiffness, construction speed, efficiency, economy, and attractiveness. During competition the bridge will be loaded in a specific arena area with various sections marked off with duct tape. This can be seen in Figure 2.1 on the following page. There are six different load cases that the bridge must be designed for. The load case used in competition will be decided during at competition by rolling a dice. The following table, Table 2.1, shows that various load cases. M1 and M2 are the locations for the loads, L1 and L2. S represents the number that may be rolled with the dice. M1 and M2 are shown in Figure 2.1 on the following page.

Load Cases				
S	**M1**	**M2**	**L1 (lb)**	**L2 (lb)**
1	6'-6"	3'-0"	1400	1000
2	9'-1"	5'-11"	1200	1200
3	9'-1"	5'-11"	1400	1000
4	10'-0"	5'-6"	1200	1200
5	10'-6"	4'-6"	1400	1000
6	10'-6"	4'-6"	1200	1200

Table 1.1

In addition to the conference, the project also entails fishing deliverables for a capstone class at Northern Arizona University. The progress of the project will be represented in biweekly presentation, a 50% report, a final report, and a website. The website will be constantly updated throughout the semester and can be found at http://www.public.asu.edu/~ajshafi/index.html.

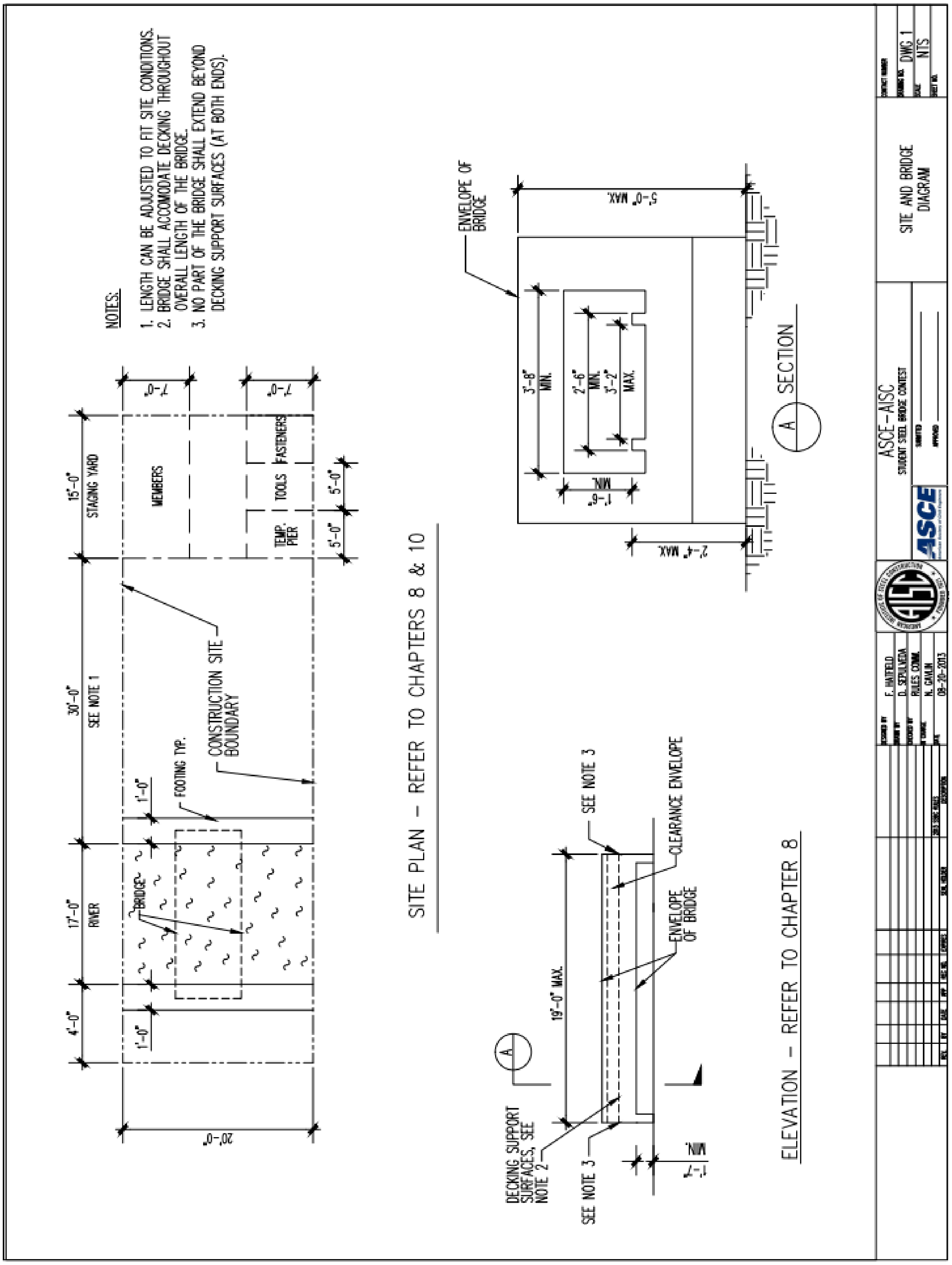

NOTES:
1. LENGTH CAN BE ADJUSTED TO FIT SITE CONDITIONS.
2. BRIDGE SHALL ACCOMODATE DECKING THROUGHOUT OVERALL LENGTH OF THE BRIDGE.
3. NO PART OF THE BRIDGE SHALL EXTEND BEYOND DECKING SUPPORT SURFACES (AT BOTH ENDS).
4'-0"
17'-0"
RIVER
30'-0"
SEE NOTE 1
15'-0"
STAGING YARD
1'-0"
BRIDGE
FOOTING TYP.
CONSTRUCTION SITE BOUNDARY
MEMBERS
TEMP. PIER
TOOLS
FASTENERS
7'-0"
5'-0"
20'-0"
SITE PLAN – REFER TO CHAPTERS 8 & 10
ENVELOPE OF BRIDGE
5'-0" MAX.
3'-8" MIN.
2'-6" MIN.
3'-2" MAX.
1'-6" MIN.
2'-4" MAX.
A SECTION
DECKING SUPPORT SURFACES, SEE NOTE 2
SEE NOTE 3
19'-0" MAX.
CLEARANCE ENVELOPE
ENVELOPE OF BRIDGE
1'-7" MIN.
ELEVATION – REFER TO CHAPTER 8
ASCE-AISC
STUDENT STEEL BRIDGE CONTEST
F. HATFIELD
D. SEPULVEDA
RULES COMM.
N. GAVLIN
09-20-2013
SITE AND BRIDGE DIAGRAM
DWG 1
NTS

Figure 1.1

2. Project Constraints

Designing a bridge that will be successful in all of the necessary categories is challenging because of all the constraints listed in the Student Steel Bridge Competition 2014 Rules book. Another major constraint for the Northern Arizona University steel bridge team is that there is a very small budget for the team, therefore most of the material is what companies are willing to donate. The rules for the project can be found at the website, http://www.aisc.org/WorkArea/showcontent.aspx?id=21576. The rule book has various constraints and limitations such as:

Functionality

1. The bridge must span a 17 ft wide "river."

Usability

(Reference Figure 2.1)

2. The bridge shall not exceed a length of 19 ft.
3. The bridge shall not exceed a height of 5 ft.
4. The minimum height between the bottom of the bridge and the ground is 1 ft 7 in.
5. A box that is 1 ft 6 in tall by 3 ft 8 in wide must be able to slide through the middle of the bridge.
6. The outer edges of the two decking supports shall be no less that 2 ft 6 in apart, and the inner edges shall be no more than 3 ft 2 in apart.
7. The decking support surfaces shall be no more than 2 ft 4 in above the surface of the river or ground.

Note: If the bridge dimensions are violated, the following weights will be added to the bridges overall weight depending on the size of the dimension violation:

(1) 50 lbs for a dimensional violation of ½ in or less
(2) 150 lbs for a violation greater than ½ in but less than 1 in
(3) 300 lbs for a violation greater than 1 in but less than 2 in
(4) Greater than 2 in will cause the bridge to not be eligible for awards in any category

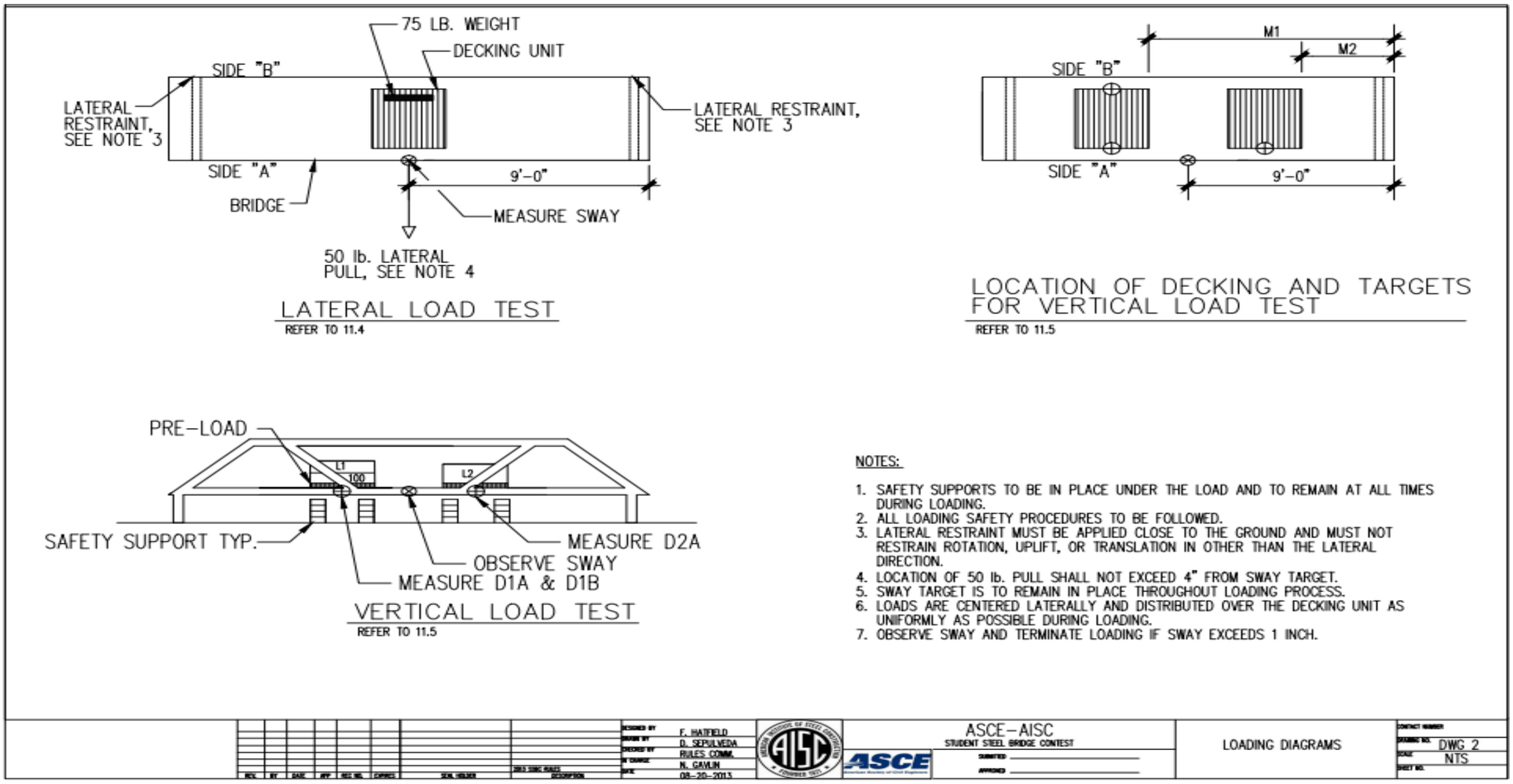


Figure 2.1

Structural Efficiency

8. The bridge shall weigh less than 400 lbs to get the best score for structural efficiency:

   For a bridge that weights 400 lbs or less,

   C_s = Total weight (lb) x 20,000 ($/lb) + Aggregate deflection (in) x 1,000,000 ($/in) + Load test penalties ($)

   For a bridge that weights more than 400 lbs,

   C_s = [Total weight (lb)]^2 x 50 ($/lb^2) + Aggregate deflection (in) x 1,000,000 ($/in) + Load test penalties ($)

Member-to-Member Connections

9. Every contact surface shall be continuous, planar, smooth, and free of protrusions.
10. Every contact surface shall be penetrated by one or more fasteners.
11. Bolts shall fully engage the threads or the nut, such that the bolt extends beyond or is flush with the outer face of the nut.

    Note: For every non-compliant fastener or member, a weight of 25 lbs will be added to the bridges total weight.

Safety

12. A member shall not weigh more than 20 lbs.

13. A bridge shall not incorporate an electric, electronic, fluidic, or other non-mechanical sensor or control system.

Durability and Constructability

14. A member must not exceed overall dimensions of 3 ft x 6 in x 4 in.
15. A bolt must have a minimum diameter of 3/8 in and no more than 1 1/2 in nominal length.
16. Bolt heads and nuts shall have a hexagonal shape.

Note: For every non-compliant fastener or member, a weight of 25 lbs will be added to the bridges total weight.

Construction Regulations

17. A temporary pier shall not exceed 1 ft 6 in in any horizontal dimension.
18. The bridge must be able to be constructed within 45 minutes.

3. Background

To prepare for the steel bridge project, the ASCE steel bridge team had taken structural and steel classes at Northern Arizona University to attain knowledge necessary for steel bridge design. The structural class helped to understand how to do structural analysis and design. The steel class taught methods of design for tension, compression and flexural members. The RISA program has been taught in classes, which can be used to set up a bridge model and run analysis. Once the model has been set up, the results of tension, compression, flexural forces and the deflection of the bridge will be listed.

Analysis must be conducted on the bridge materials, connections, and members. The American Institute of Steel Construction (AISC) Steel Construction Manual 14th edition was used as reference during the bridge analysis. Load and Factored Resistance Design (LRFD) will be used for all of the bridge analysis equations. Factors for dead and live loads are 1.2 and 1.6 respectively. Dead load is the weight of the bridge and live loads is the weight placed on the bridge during competition. The results from the analysis influences design choices. Material analysis will determine member sizing based upon a load and moment envelope determined for the possible loading configurations from the rules. Connection analysis will be done to find connections that will decrease construction time during the competition. Structural analysis will be done to minimize deflections vertically and laterally.

Another resource used for the steel bridge design is the Student Steel Bridge Competition 2014 Rules because it provides various constraints that will determine which design alternatives are chosen. The detailed rule book can be found at http://www.aisc.org/WorkArea/showcontent.aspx?id=21576.

4. Design Alternatives

4.1 Truss Type Alternatives

Howe Truss

This truss design includes diagonal members that slant away from the center of the bridge which causes the vertical members to be in tension (See Figure 4.1).

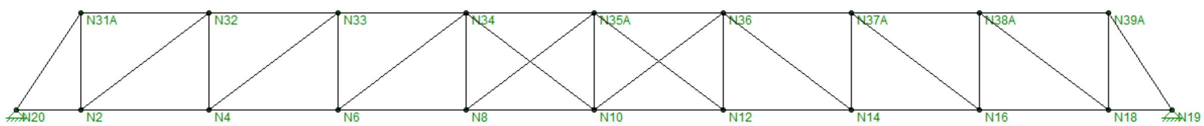


Figure 4.1

Consideration Justifications

- This truss design uses less steel members than other designs while providing the required strength.
- This design has a mild aesthetic appeal; however, this design is more used with wood designs.
- Because there are less members within this design, the construction of this bridge will be faster compared to a design with more members.

Double Warren Truss

This truss design includes only diagonal members that form diamond-shaped structure across the bridge. This design causes the top chord to be in compression and the bottom chord to be in tension (See Figure 4.2).

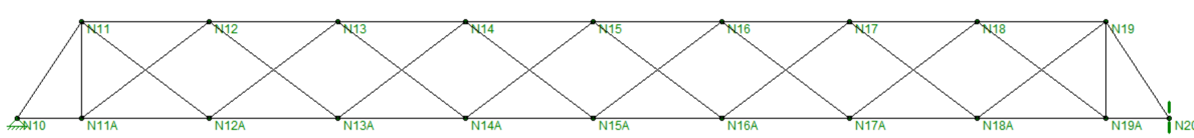


Figure 4.2

Consideration Justifications

- Very simple design
- The diagonals both carry a portion of the compression and tension stress.
- This design focuses on members; as long as the members are strong enough to take the compressive/tensile stress, this design works better than most truss types.

Pratt Truss

This truss design is similar to the Howe truss except the diagonals slant towards the center of the bridge which causes the vertical members to be in compression (See Figure 4.3).

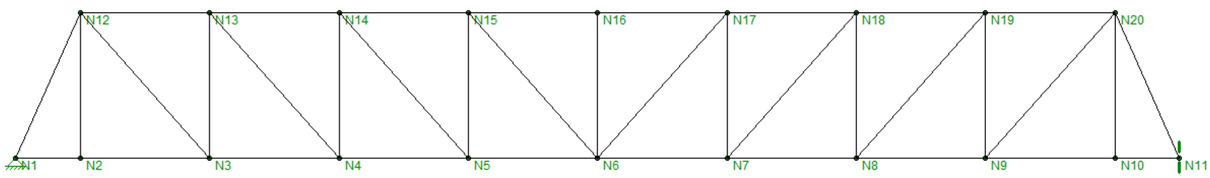


Figure 4.3

Consideration Justifications

- Steel is stronger in tension than compression; the diagonals in this design are in tension.
- Like the Howe truss design, this design has mild aesthetic appeal, uses less members with the same overall strength, and good construction speed.

Baltimore Truss

This truss design is a variation of the Pratt truss design that adds bracing to prevent buckling (See Figure 4.4).

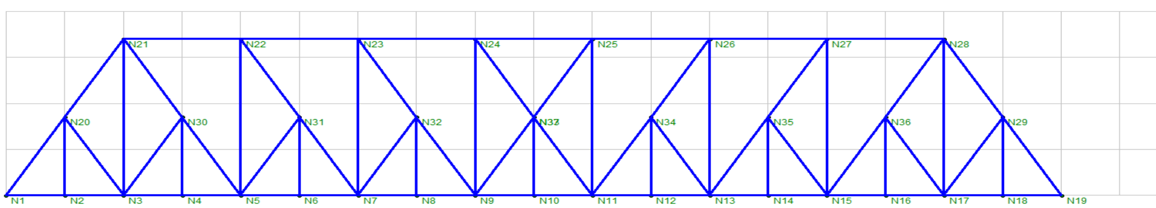


Figure 4.4

Consideration Justifications

- Very aesthetically pleasing
- This design is meant to reduce deflections that the original Pratt truss has.
- Less stress in each individual member due to more members to spread out the stresses within the design.

4.2 <u>Member shape</u>

One type of member shape is a solid steel bar which is a round piece of steel that has material over the entire cross section. Advantages of a solid bar is that it has increased stiffness in tension and compression, but a disadvantage of a solid bar is that there is significantly more weight than a hollow section.

Another type of member is steel tubing which is considered a Hollow Structural Section (HSS). Benefits of HSS sections are a high strength to weight ratio, fabrication flexibility, and manufacturing it is fairly uniformly. A disadvantage of HSS sections is that smaller section sizes are not very abundant and larger sizes would have to be used increasing overall weight of the bridge with unnecessary strength.

Galvanized steel is steel that has a zinc coating that protects the metal from oxidation. The shape considered by team is a Furring Channel. Advantages of this section are that it has high strength while being lightweight. A disadvantage of cold rolled steel is that it suffers from local buckling, which means it is hard to analysis by model program.

4.3 <u>Connection Design</u>

Member to member connections are considered as an important part for the construction of steel bridge. The connections are designed to have minimal eccentricity to minimize the effects of moment in the connections and members. Since the rules say that every touch surface must has a plate to connect. There are two types of connections are focused.

The first option is to weld two plates on the end of each member. The two plates will be placed over an HSS section at the connections and will have a bolt going all the way through the two plates and the member. The space between two members would be 1/8 in. This connection is shown in Figure 4.5. The benefits of this type of connection is that the fabrication is easy and straight forward. The issue with this connection would be that the bolts may not be long enough to go through two plates and a 1 in by 1 in HSS member, or that the plates would buckle under compression.

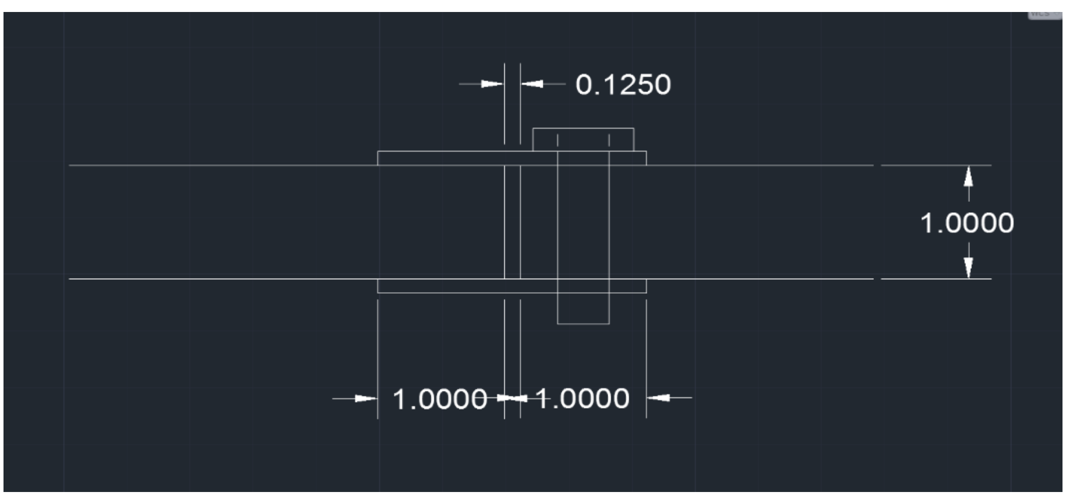


Figure 4.5

The second option is similar to the first one, except that there are two plates on the inside of the members. The plates are necessary to obey the rule that a bolt must go through every two touching surfaces. The design has a bolt will go through the two plates welded to the inside of the HSS members. The space between the two members totals 1/4 in, 1/8 in on each side. The benefit of this member connection is that it allows for a shorted bolt, compaired to option one and there is much less of a chance that the plates would buckle under compression. The disadvantages of this connection is that it is harder to manufacture and it will not hold up well when a moment is placed at the connection.

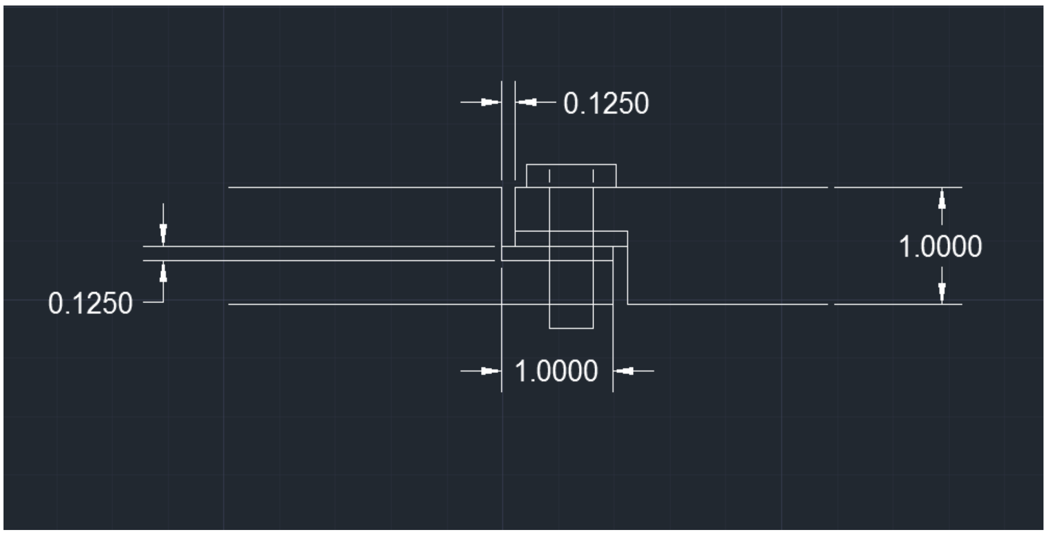


Figure 4.6

5. Analysis

5.1 Plate Analysis

The following plate dimensions, shown in Figure 5.1, were used in the analysis for the plates because it is the most typical plate that will be used in most of the spots of the bridge. The locations for this plate can be seen in the set of plans, in the appendices. The following five calculations were:

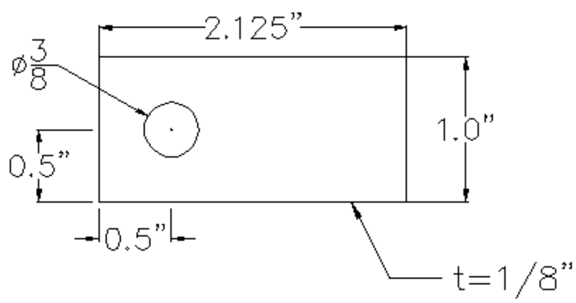


Figure 5. 1

Compression Capacity

$\phi_c p_n = \phi_c A_g F_{cr}$ [AISC Equation E4-1]

$F_e = \frac{\pi^2 E}{(\frac{KL}{r})^2}$ [AISC Equation E3-4]

Since $\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$

$F_{cr} = 0.877F_e$ [AISC Equation E3-3]

Result: $\phi_c p_n = 2.65$ kip

The most that would be compressed on a plate would be 1.4 kip the fact that one plate can withstand buckling under 2.65 kips means that it is strong enough and does not need to be stiffened. At every spot where a plate is located there are actually two plates, so ideally the connection will be twice as strong. This type of connection is shown in Figure 4.5.

Plate Yield Limit State (YLS)

$\phi_t P_n = 0.9A_g F_y$ [AISC Equation D2-1]

Result: $\phi_t P_n = 4.65$ kip (tension)

The maximum tension at any spot on the bridge is 4.61 kip and the plate can withstand not yielding for up to 4.65 kip. There will also be two plates at each location, as discussed above, so yielding will not be an issue. This is important because if the connections yield they will increase the deflection greatly. The 4.65 kips of tension was found using RISA and looking at the maximum tension in any given member under any of the six load cases.

Plate Fracture Limit State (FLS)

$\phi_t P_n = 0.75 A_e F_u$ [AISC Equation D2-2]

$A_e = A_n U$ [AISC Equation D3-1]

Result: $\phi_t P_n$ = 3.4 kip (tension)

The fracture limit state is very important because it is the amount of load that the plate can handle when it is initially loaded. The maximum tension at any member, shown by RISA, is 4.1 kip which is above the facture limit state of 3.4 kip. This would be an issue if there was only one plate at each connection, but there are two at each connection so ideally the strength will be twice as great, 6.8 kip, and will not be an issue.

Bearing Strength

$\phi_b R_n = 0.75(2.4 d t F_u)$ [AISC Equation J3-6a]

Result: $\phi_b R_n$ =4.9 kip

The bearing strength refers to the strength of the plate around the bolt hole. The bearing strength is important so the hole does not stretch and increase deflections of the bridge. The forces on the bridge are all much less than 5 kip so the bearing strength of the plates is more than satisfactory.

Shear Strength

$\phi_v F_{nv} = 0.75 f_{nv} A_b$

Result: $\phi_v F_{nv}$ =2.23kip

The largest shear on the bridge would be located at the bottom cross members which would have the weight directly loaded on them. The largest load at any spot is 1.4 kip and there for the greatest shear at any spot is 0.7 kip. The shear strength of the plates are well above the shear at any point on the bridge so shear failure will not be an issue.

5.2 <u>Bridge Supports</u>

The supports are to be constructed by welding multiple columns that are the same dimensions as the members to plates on the top and bottom. A single column were analyzed to determine the compression capacity. This is important because the column must be able to hold the compressive weight of the bridge without flexural buckling. The thickness of the plates needed to resist the moment (Heffelfinger, Nelson, & Strain, 2009) caused by the column loads was determined as well. This is important because the plate cannot deform or cause a tip over of the entire support.

Column Compression Capacity

In order to use the formulas listed below, several parameters had to be determined. The effective length factor (K) within the member slenderness parameter $\left(\frac{KL}{r}\right)$ was determined to be 2.1 because of the end conditions of the columns. It was presumed that the bottom of the column should act as fixed in both rotation and translation; the top would be free in both rotation and translation. The radius of gyration (r) of the cross-section is equal to 0.361 in and was determined by the equation $r = \sqrt{\frac{I}{A}}$ where I is moment of inertia and A is the gross cross-sectional area. The rest of the parameters are decided by the steel material properties and design decisions.

$\phi_c p_n = \phi_c A_g F_{cr}$ [AISC Equation E4-1]

$F_e = \frac{\pi^2 E}{(\frac{KL}{r})^2}$ [AISC Equation E3-4]

Since $\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$

$F_{cr} = 0.877F_e$ [AISC Equation E3-3]

Result: $\phi_c p_n$ = 13.8 kips

This result is very promising; the highest load that our columns would have to hold is 1.3 kips so the columns are proficient in compression capacity.

Plate Thickness

To determine the minimum plate thickness needed for the support, the following equation was used: $\phi M_n = \phi F_y Z = \phi F_y \frac{bt^2}{4}$. To determine the plate capacity(ϕM_n), a free body diagram of the plate and columns were constructed and the moment at the edge of the plate was calculated. Once the moment capacity was calculated, the other parameters were determined by the steel material properties and design decisions.

Result: t = 0.304 in

This result raises some serious questions; the way that the analysis was done was to assume that the point loads are all co-linear. Two point loads are co-linear and one is not. The analysis may have been overestimated to the point where it is unreasonable. However, this is the best way of calculating a good estimate of the plate thickness needed for the support.

5.3 <u>RISA Analysis</u>

For this project, RISA 2D and RISA 3D programs was used for various design decisions. The RISA 2D program was used to determine the deflection and maximum strength parameters for the truss type decision matrix. The RISA 3D program was used for a model representation of our final design for theoretical load testing.

RISA 2D Analysis

The first step in this analysis is to build the four truss type models. The model had to have the exact material and shape to accurately analyze each model (Figure 5.2). The material and shape that was used for this analysis is A36 1”-1”-1/8” Hollow Structural Steel (HSS). Since the shape was not available by default settings, a custom shape had to be created (See Figure 5.3). The following figure shows the screen on which the material and shape is inputted.

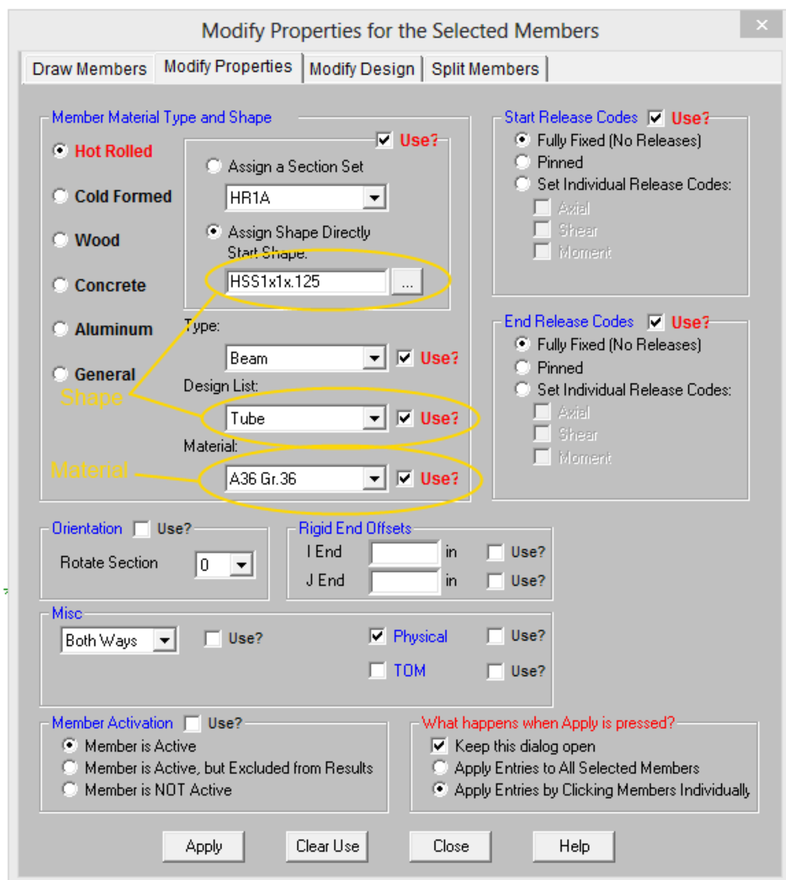


Figure 5. 2

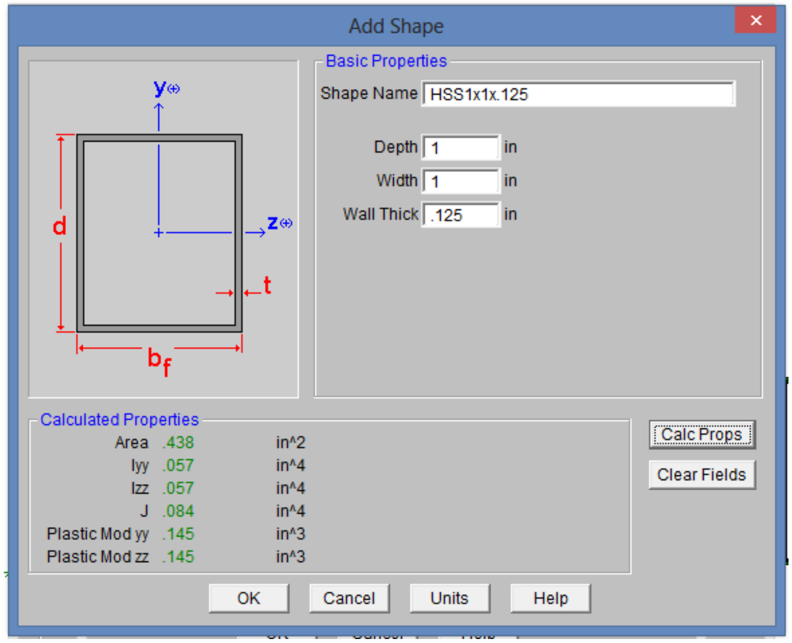


Figure 5. 3

The next step is to build the four models so that they both have the same height and length. It was decided to use a truss that was 18 feet long and 1.5 feet tall. After this step, the load cases had to be implemented in such a way that it would be similar to how the whole entire bridge would carry the load. In order to do this, it was decided to install point loads on the joints that would carry the load by ratio. For example, Figure 5.4 below shows how the Howe truss was loaded with the fourth load case. Based on Section 12.2 in the rulebook, the decking unit is 3 feet wide. The decking unit is the platform in which the load will be on. The decking unit on the rightmost side only spans over one joint on the truss. Therefore, half of the load at that spot theoretically will land on that joint based on tributary area. The same logic is used for the other unit, but the unit spans on two joints.

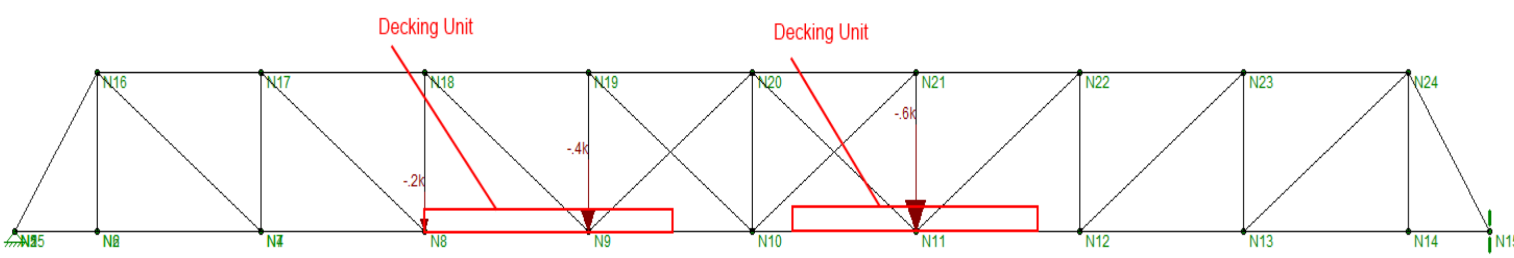


Figure 5. 4

After building all of the models with all of the load cases, the next step is to run the analysis on the models to come up with the highest deflection, compressive stress within the members, and tensile stress within the members. The RISA 2D program has a result tab that has all of the categories that is needed to acquire the data needed.

RISA 3D Model

The RISA 3D program was useful in displaying the most accurate display of what the bridge would look like. The same process to build the model in the 2D program is the same for the 3D program. The selected truss design for the bridge was used for the 3D model, along with spanning, rail, and lateral bracing member.

6. Selected Design

6.1 Truss Type

The four truss types mentioned above in design alternatives were analyzed in RISA and were rated in a decision matrix, Table 6.1. The scoring for the decision matrix is based on a scale from 1-5, 1 being bad and 5 being great.

- The lightness was based on the total member lengths for each bridge. The Baltimore had the greatest totaling member length of 111ft, and the Pratt and Howe had the lowest totaling member length of 76 ft.
- Deflection was found using RISA. The maximum deflection was the Baltimore truss with a magnitude of 0.158 in and the minimum deflection was for the Double Warren truss with a magnitude of 0.131 in.
- Aesthetic scores were based on the steel bridge team's opinion.
- Time was based on the number of joints because this affects how many connections will have to be put together during competition.
- The maximum strength of the bridge was determined by using RISA to find the maximum compression and tension of any member in the bridge. All six load cases were considered in finding the maximum values.

	Weight Factor	Pratt	Howe	D. Warren	Baltimore
Lightness	2	6	6	4	2
Deflection	3	6	6	9	3
Aesthetics	1	2	2	3	5
Time	3	6	6	6	3
Maximum Strength	2	6	4	2	2
Total		26	24	24	15

Table 6.1

6.2 Member Shape

Member shapes were compared in three categories within a decision matrix shown on Table 6.2. The categories are: weight, ultimate tensile strength [UTS], yield strength and flexibility of fabrication.

- Weight has 30% of the total points, since light weight is an important part in competition. The square tube has the largest weight of 1.35 lb/ft, and the Galvanized steel furring channel has the smallest weight of 0.5 lb/ft.

- Ultimate Tensile Strength has 10% of the total points, since all alternative designs chosen is good. The 0.5x0.5 hot rolled steel square bar has the largest tensile strength of 60ksi, and the Galvanized steel furring channel has the lowest strength of 49ksi.
- Yield strength has also 10% of the total points. The square Tube has the largest yield strength of 46ksi, and the Galvanized steel furring channel has the lowest strength of 43.5ksi.
- Flexibility of fabrication has 50% of the total points. It is because when design a steel bridge, how to connect the members is the most important part. The square tube and galvanized steel furring channel have the highest point of 4, and the steel square bar has the lowest point of 2.
- The member shape that had the best score was the HSS Shape with dimensions of 1 in by 1 in with thickness of 1/8 in. Therefore this is the member shape that we will use for our entire bridge.

	Weight Factor	Square Tube (HSS 1X1X0.125)	Galvanized steel Furring Channel (PB129)	0.5x0.5Hot Rolled Steel Square Bar
Weight (lb/ft)	0.3	0.405	0.15	0.255
Ultimate Tensile Strength (ksi)	0.1	5.8	4.9	6.0
Yield Strength (ksi)	0.1	4.6	4.35	3.6
Flexibility of Fabrication	0.5	2	2	1
final points		12.805	11.4	10.855

Table 6.2

The truss type that scored the highest in the decision matrix, shown above in the analysis section, was the Pratt truss. It had a good strength to weight ratio, so it was the truss that was chosen for the final design.

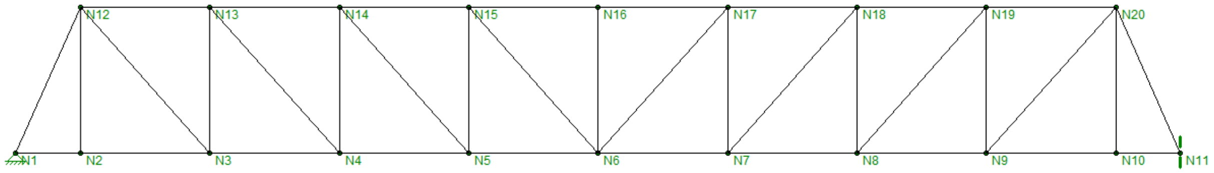
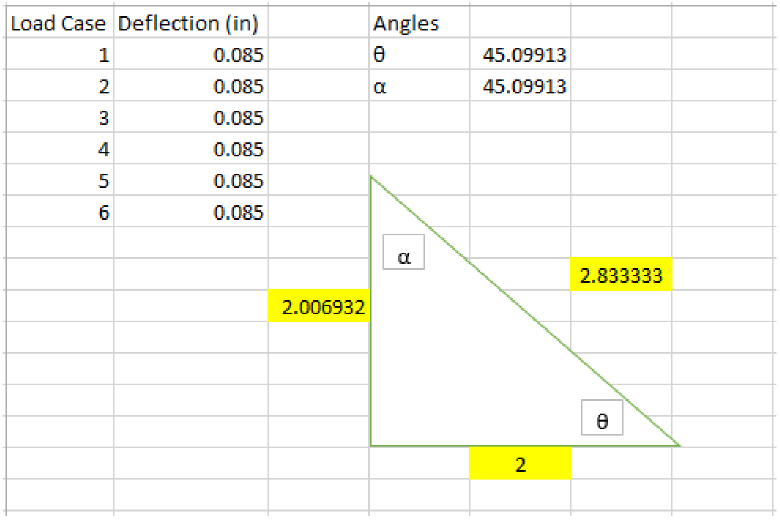


Figure 6.1

After deciding on the Pratt truss, the bridge had to be optimized. This was done by using constraints given by the rule book and by looking at minimum deflections based on RISA. The results of the best option for dimensions is shown below in Figure 6.2.



Load Case	Deflection (in)		Angles	
1	0.085		θ	45.09913
2	0.085		α	45.09913
3	0.085			
4	0.085			
5	0.085			
6	0.085			

Figure 6.2

6.3 <u>Bolt Grade</u>

Steel bolts come in many different grades of steel. Grade 8 bolts were chosen because they have the highest strength of common commercially available bolts. The bolts are 1.5 in thick from the bottom of the head to the bottom of the bolt. The diameter of the bolts are 3/8 in in diameter.

6.4 <u>Plate Design</u>

The plates on the bridge are all $\frac{1}{8}$ in thick except for the support plates which are ¼ in thick. The plates are $\frac{1}{8}$ in thick so that there is enough room to put the bolt through the member and two plates and then put the nut on. The support plates are thicker in order to add weight to the supports and prevent them from tipping over.

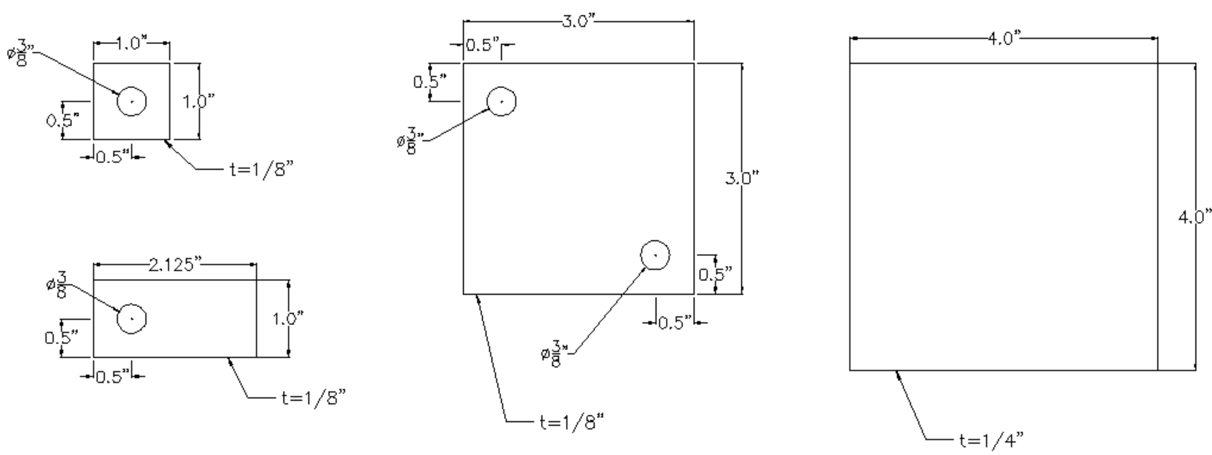


Figure 6.3

- The 1 in by 1 in plates are for the connection on the cross members at the top of the bridge.

- The $2\frac{1}{8}$ in by 1 in plates are for all of the connections on the sides of the bridges and the bottom cross members.
- The 3 in by 3 in plates are for the rails to connect to the cross members on the bottom of the bridge.
- The 4 in by 4 in plates are for the supports.

6.5 Connection Design

After finding out that the bolts would be 1½ in long and after doing plate analysis showing that a $\frac{1}{8}$ in plate would not buckle, the connection of two plates on the outside of the HSS is going to be used. This can be seen in more detail on the set of plans that will be attached to this document.

6.6 Support Design

The supports are composed of two plates that are each ¼ in thick and three vertical HSS members that are 22 in tall. The supports can be seen with more detail in the set of plans which will be attached to this document.

7. Final Design

The final design is shown in the set of plans that will be attached to this document. The final plans will be included in the final report at the end of the semester. Also, the complete RISA report will be available in the final report.

7.1 Truss Type

The truss type that scored the highest in the decision matrix, shown above in the analysis section, was the Pratt truss. It had a good strength to weight ratio, so it was the truss that was chosen for the final design.

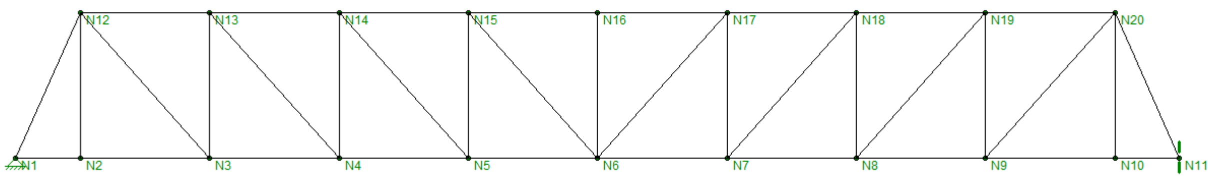


Figure 7.1

7.2 Member Shape

The member shape that had the best score in Table 5.2 above was the HSS Shape with dimensions of 1 in by 1 in with thickness of 1/8 in. Therefore this is the member shape that we will use for our entire bridge.

7.3 Bolt Grade

Steel bolts come in many different grades of steel. Grade 8 bolts were chosen because they have the highest strength of common commercially available bolts. The bolts are 1.5 in thick from the bottom of the head to the bottom of the bolt. The diameter of the bolts are 3/8 in in diameter.

7.4 Plate Design

The plates on the bridge are all $\frac{1}{8}$ in thick except for the support plates which are ¼ in thick. The plates are $\frac{1}{8}$ in thick so that there is enough room to put the bolt through the member and two plates and then put the nut on. The support plates are thicker in order to add weight to the supports and prevent them from tipping over.

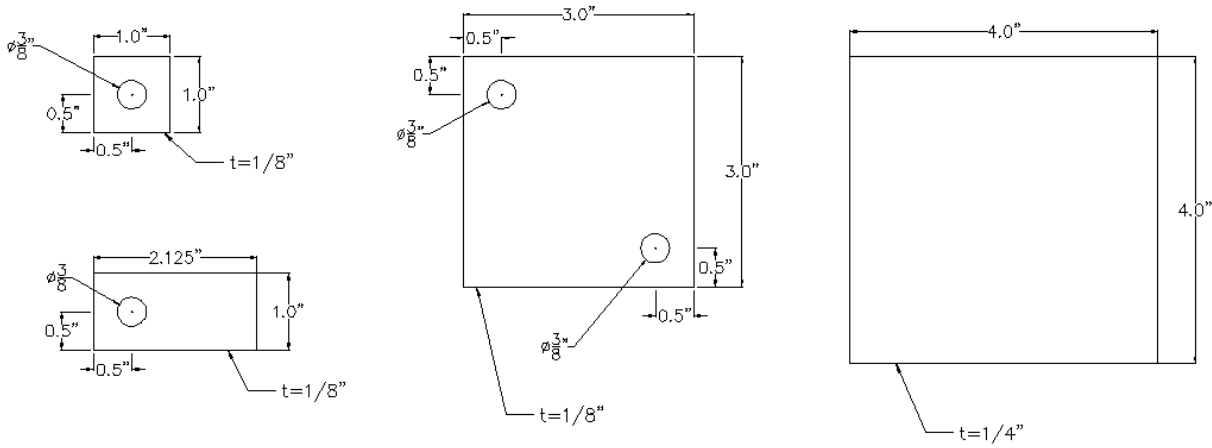


Figure 7.2

- The 1 in by 1 in plates are for the connection on the cross members at the top of the bridge.
- The $2\frac{1}{8}$ in by 1 in plates are for all of the connections on the sides of the bridges and the bottom cross members.
- The 3 in by 3 in plates are for the rails to connect to the cross members on the bottom of the bridge.
- The 4 in by 4 in plates are for the supports.

7.5 <u>Connection Design</u>

After finding out that the bolts would be 1½ in long and after doing plate analysis showing that a $\frac{1}{8}$ in plate would not buckle, the connection of two plates on the outside of the HSS is going to be used. This connection is shown in the following figure.

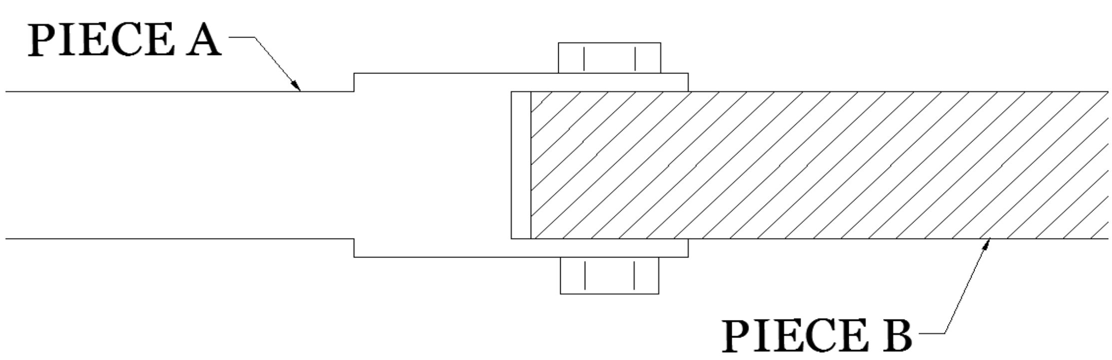


Figure 7.3

7.6 Support Design

The supports are composed of two plates that are each ¼ in thick and three vertical HSS members that are 22 in tall. The supports can be seen with more detail in the set of plans which will be attached to this document.

7.7 Rail and Span Members

The rail and span members are all HSS members; the rail member is composed of one HSS member and 2 1 by 1 in. plates, and these two plates are welded at the end of each HSS member side with 7/16 in. diameter hole to go through the bolts. The span member is composed of one HSS member, a 3 by 3in. plate is welded on the middle top of the span member with two 7/16in. diameter holes are at corner of the plate. The connection detail can be seen in Figure 7.5.

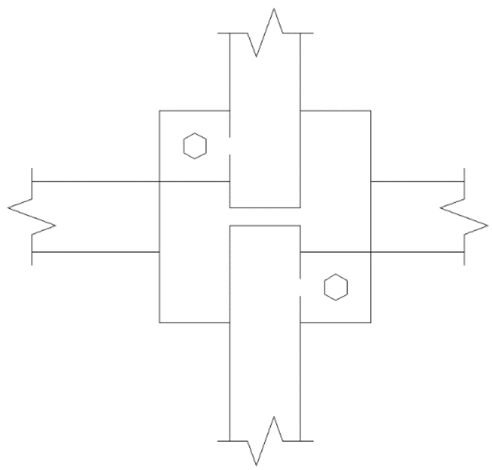


Figure 7.5

7.8 Angle Iron Cross Bracing

We used angle iron members as our cross bracing because it is lightweight and the dimensional constraints for members. The red members on Figure 7.6 below represents how the lateral design that was used. We used two bolts to connect the members because two bolts can reduce more moments than using one bolt.

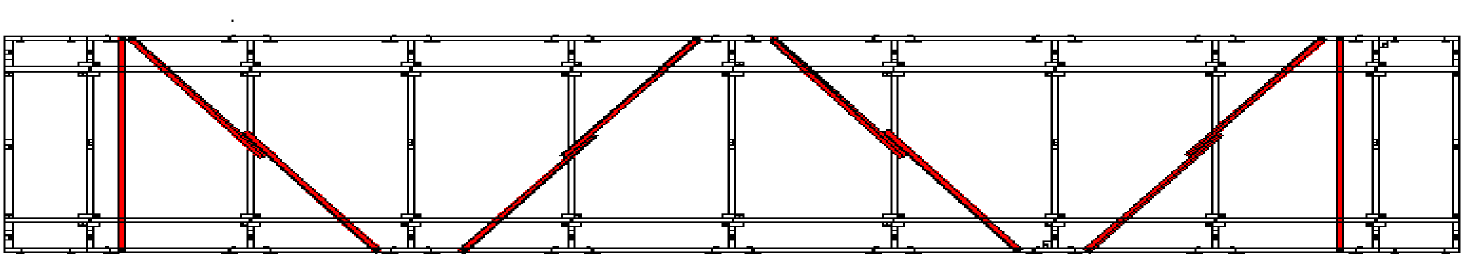


Figure 7.6

7.9 Impacts

This project has three major impacts: social and economic and environmental. For social impact, our steel bridge team can compete to other universities' teams and we can offer design ideas to the future students. Also, it is a good chance to work face to face with companies to ask for donating. For economic impact, our team paved the way for future students. For environmental impact, the steel usually has been recycled properly to be used later. However since our bridge did well, we can display our bridge somewhere in the building for students to see.

7.10 Final Product

The bridge was decided to be named Lumberjacked based on our school color paint theme that was implemented. The final product of our bridge is shown at the figure below.

Figure 7.7

8. Design and Fabrication Costs

The following cost include the cost for all of the hours put into the project and the cost of travel. The hours spent on the project consisted of doing design using hand calculations and computer analysis, reviewing the design and calculations, fabricating the bridge parts, painting the bridge, and practicing bridge construction. The travel costs include going to meetings such as dropping off or picking up materials and going to conference.

Predicted Cost

Personnel (Including OH)			
Person	**Hours**	**Rate, $/hr**	**Cost, $**
SENG	25	210	5250.00
ENG	250	68	17000.00
LAB	150	46	6900.00
FAB	500	18	9000.00
CON	30	25	750.00
Travel			
Locations	**Distance (Round Trip)**	**Cost/Mil**	**Cost, $**
Agate Inc.	1mtg*308mil	$0.05/mi	154.00
Schuff Steel	1mtg*26mil	$0.05/mil	13.00
Copper State	1mtg*5mil	$0.05/mil	2.50
SDSU	1mtg*966mil	$0.05/mil	483.00
TOTAL=			**$39,552.50**

Table 8. 1

Actual Cost

Personnel (Including OH)			
Person	**Hours**	**Rate, $/hr**	**Cost, $**
SENG	25	210	5250.00
ENG	340	68	23120.00
LAB	120	46	5520.00
FAB	1100	18	19800.00
CON	90	25	2250.00
Travel			
Locations	**Distance (Round Trip)**	**Cost/Mil**	**Cost, $**
Agate Inc.	1mtg*308mil	$0.05/mi	154.00
Schuff Steel	1mtg*26mil	$0.05/mil	13.00
Copper State	2mtg*5mil	$0.05/mil	5.00
SDSU	1mtg*966mil	$0.05/mil	483.00
TOTAL=			**$56,595.00**

Table 8. 2

All of the hours were underestimated, except for the amount of time for lab hours. Lab hours consisted of doing RISA 2D and 3D analysis. The total amount of hours that was predicted for this project was 955 and the actual amount of hours spent on the project was 1,475. The task that had the largest discrepancy between predicted and actual hours was the fabrication. We thought that it would take about 400 hours but it actually took about 1100 hours. Our team members ended up doing a lot more fabrication then we planned on doing. Since, our team thought that the fabrication would be done on a larger scale at a large company which would not have taken as long as it did. There were some setbacks such as drilling holes ourselves, which took a very long time. The construction time was also underestimated by quite a large amount because it was assumed that each practice would take about 30 to 60 minutes, there would be about 5 to 10 practices held, and 6 people doing the construction. The number of practices and construction members predicted was correct, but the amount of time spent at each practice was underestimated. Unpacking and setting everything up before doing the actual timed practice was much more time consuming than expected.

Project Costs

The following costs consist of what our group would have spent on materials for the project. These materials are for the 1:10 scale model that was built. This is not the cost for the full scale bridge materials. Although there were over $3000 worth of material costs, monetary and material donations covered all of the costs for the project.

Materials	Cost, $
Sharpi Markers (2 Packs)	8.62
Cleaning Supplies	12.56
Bins / Containers	22.21
Norfab Steel	65.00
Clamps	8.25
7/16 Drill Bit	16.00
Sockets / Mallets	42.33
Center Punch	7.58
Tool Bag	20.00
Tool Belt	28.65
Parking Passes	9.00
Paint, Knee Pads, Eye Levels, Masking Tape	141.90
Machine Shop Labor	150.00
Paint	115.00
HSS Tubing 1”x1”x1/8” (500ft)	500.00
1/8” Plates (2-1/8” long, 300)	300.00
Welding Labor	1600.00
Bridge Sing	70.00
Angle Iron	70.00
Nuts & Bolts (350 Ea.)	60.00
Total=	**$3247.10**

Table 8. 3

References

[1] American Institute of Steel Construction, *Steel Construction Manual*, 14th Edition

[2] Heffelfinger, S., Nelson, T., & Strain, S. (2009). *Final Design Report: 2008-2009 ASCE Student Steel Bridge.* Flagstaff.