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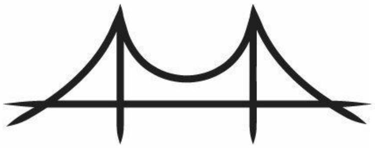

100% Design Report

To
CENE 486C Grading Instructor:
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List of Equations

Equation 1.3.1:

$$C_c = \text{Total Time (minutes)} \times \text{Number of Builders (persons)} \times 50{,}000\ (\$/\text{person-minute})$$
$$+\$30000\ \text{(If temporary pier is staged for construction)}$$
$$+\ \text{Load Test Penalties}\ (\$)$$

Equation 1.3.2:

(weight ≤ 400 lbs)

$$C_s = \text{Total Weight (Pounds)} \times 10{,}000\ (\$/\text{Pound}) +$$
$$\text{Aggregate Deflection (Inches)} \times 1{,}000{,}000\ (\$/\text{Inch}) + \text{Load Test Penalties}\ (\$)$$

Equation 1.3.3:

(weight > 400 lbs)

$$C_s = [\text{Total Weight (Pounds)}]^2 \times 25\ (\$/\text{Pound}^2) +$$
$$\text{Aggregate deflection (Inches)} \times 1{,}000{,}000\ (\$/\text{Inch}) + \text{Load test penalties}\ (\$)$$

Acknowledgements

The Northern Arizona University Steel Bridge Team would like to thank several people for their donations of both time and money. The team would like to thank Southwest Waterjet and Laser, Copper State Nut and Bolt Company, Agate Steel, and Eagar Welding for their help with the fabrication of the bridge. The team would also like to thank Mark Lamer and Thomas Nelson for their help and guidance throughout the entire project. Lastly, the team would like to thank all family and friends who have donated money to help with fabrication of the bridge.

1.0 Project Description [1]

1.1 Project Purpose

The objective of the steel bridge project is to design, analyze, fabricate, and construct a 1:10 scale model of a steel bridge. This bridge design and model will represent Northern Arizona University (NAU) at the 2016 American Society of Civil Engineers (ASCE) Pacific Southwest Conference (PSWC). This conference is a sponsored event by the American Institute of Steel Construction (AISC) and ASCE, and a set of provided rules and regulations for this competition are found on the AISC website. All bridges are evaluated for construction speed, weight, aesthetics, economy, and strength. The client and technical advisor on this project have been chosen, and through meetings with these two parties, project expectations and standards are set forward and made clear. It is the goal of the Steel Bridge Team to pass loading in order to be applicable for final judging at the 2016 PSWC.

1.2 Technical Considerations

There are several types of technical work that must be considered to successfully complete this project by passing load testing. The two areas that require technical consideration in the project are the design and fabrication phases. The design will require a fair amount of technical consideration to be successful such as choosing the best design out of three candidates, deciding which material properties to use to make the bridge an efficient design, and deciding which construction sequence will yield the fastest construction time. Extensive design work is necessary to account for potential failures that could occur throughout the bridge. A poor design can cause the fabrication and construction to essentially be a waste of time.

The design portion is critical to the project, but fabrication also requires significant technical consideration. Fabricating each steel member to match what the team designed requires a great amount of expertise. This includes cutting, drilling, welding, and grinding each member. All of the fabricated members have to be similar so they can all be compatible and work together to create a strong section. Previous competitions have had great designs that failed due to a fault in the fabrication process.

1.3 Project Evaluation

1.3.1 Member Constraints

The bridge can only be constructed with members, loose bolts, and nuts made of steel. Each member is limited to dimensions of three feet by six inches by four inches and each bolt must not exceed three inches in length. The members of the bridge must retain their shape, dimensions, and rigidity during timed construction and load testing.

1.3.2 Bridge Construction Constraints

Construction speed is the time it takes to construct the bridge model, with the addition of time penalties accrued during construction. Time penalties are added to the overall construction time each time equipment or a bridge member touch the river, the ground outside the staging area, or the ground inside or outside the construction area. The time to construct the bridge must be less than forty-five minutes, but anytime over thirty minutes will result in a total construction time of 180 minutes. Construction will be halted after 45 minutes regardless of build completion and inspected for safety. If the bridge is deemed unsafe, the bridge will be disqualified from the competition.

1.3.3 Bridge Competition Evaluation

Construction economy (C_c) determines the design cost and is calculated using Equation 1.3.1. There is a maximum of six builders allowed for construction, and a temporary pier is allowed to help span the river. Both factor into the construction costs and can vary depending on the team needs. Penalties can be added to the construction economy for every instance a builder or a part of their clothing touches the river or ground outside the construction area. The penalty will be recorded as an additional builder. The structural efficiency (C_s) is used to judge the structural design. Equation 1.3.2 or Equation 1.3.3 are used to calculate the structural efficiency, depending on the overall weight of the bridge. The overall performance of the bridge will be judged on the combination of the construction economy and the structural efficiency. The team with the lowest score is deemed the winner of the competition.

1.4 Stakeholders

This project is for the AISC and ASCE Student Steel Bridge Competition, and for this reason, the stakeholders are divided amongst two primary groups. The first group involves the people of Impecunia, for whom this model bridge is being designed and built for. The main client within this group of stakeholders is ImpDOT, who has requested this generic model in order to replace numerous deficient bridges around Impecunia. Since the bridge with the best overall strength, ease of construction, stability, and serviceability will be chosen to be constructed, all citizens of Impecunia are stakeholders for this project. The second group includes all people affiliated with Northern Arizona University including: the client, Mark Lamer, technical advisor, Thomas Nelson, Northern Arizona University, NAU CECMEE department, and the NAU ASCE Student Chapter. Other potential stakeholders include the donors of labor, design programs, and materials contributing to the Steel Bridge design and construction. From the competitiveness of the competition, the Steel Bridge Team will represent these stakeholders.

2.0 Technical Sections

2.1 Background Research

2.1.1 Competition Rules

Competition rules and design specifications were provided by the American Institute of Steel Construction (AISC). All rules and specifications were used as considerations for the design, fabrication, and construction of the bridge.

2.1.2 Bridge Designs

Different bridge designs were researched to determine the type of bridge that the team could design for this project. Bridge designs researched include different truss designs, such as the Warren and Pratt trusses, a beam bridge, and a suspension bridge.

2.1.3 Connections and Weld Types

Different weld types were researched including metal inert gas (MIG) welding, tungsten inert gas (TIG) welding, arc welding, and oxy acetylene welding. The team also discussed different types of connections for bridge members including tension connections and shear connections.

2.1.4 Materials and Member Types

Types of steel were researched such as alloy steel, carbon steel, and stainless steel, and the team discussed considerations for member strength, size, and shape.

2.2 Design

2.2.1 Preliminary Design

For this project the Steel Bridge Team analyzed three preliminary design options: a Warren truss, a beam bridge, and a bowstring truss after conduction background research. Each of the three designs were moderately designed in RISA 3D to get an idea of preliminary deflection results. All three designs were put into a decision matrix and were evaluated based on the following criteria: stiffness, efficiency, economy, construction speed, constructability, usability, and aesthetics. The team chose weighted percentages for each criterion based on the competition rules. The team decided that stiffness, efficiency, and economy were the most important criteria to meet with the final design of the bridge with twenty percent each of the overall score. These were ranked as the most important criteria in the decision matrix due to their importance in the actual bridge competition. Stiffness, efficiency, and economy are weighted the highest in the actual competition; therefore, it is fair that they were weighted the highest when choosing a final design. The decision matrix can be found in Appendix A.

Based on the preliminary RISA 3D analysis and the decision matrix, the team determined that the beam bridge was the best option for the final design. Although the Warren truss had a close overall score, the team used engineering judgment to choose the beam bridge because it would require less members when building and would ultimately result in a lower construction time.

2.2.2 Final Design

The beam bridge design was fully analyzed in RISA 3D to get optimal vertical and horizontal deflections. To optimize the vertical and horizontal deflections of the bridge, iterations were done and subsequent save files were made in case an iteration did not work and the team needed to go back to an older version. Six different load cases were implemented in RISA 3D to simulate all possible load combinations that could occur on the day of the competition. The RISA 3D software runs an analysis to calculate the worst possible deflection on the bridge based on the different applied load cases. The team then determined different member sizes, dimensions, and configurations that would produce the least amount of deflection by analyzing the forces in each individual member. The team chose to use three different member sizes for the bridge including a 3/4in HSS square tube, a 1/2in HSS square tube, and a 1/4in solid round rod.

The RISA 3D model produced the following deflection results using the chosen member sizes. With a lateral load of 50lbs, the final design has an overall projected lateral deflection of .149in, which is less than the allowable deflection of one inch. With a vertical load of 1400lbs in the center of the bridge and an offset vertical load of 1000lbs, the final design has an overall projected vertical deflection of 0.681in, which is less than the allowable deflection of three inches. The RISA 3D design results are shown in Appendix B.

After the RISA 3D analysis was completed, the team conducted separate hand calculations to ensure that the member strength was sufficient to support the applied loads. The team also checked the strength of a selected bolt size of 1/4in with a 5/16in bolt hole. Calculations were also done for the pullout strength of a 10ga plate that would be used for connections on the bridge, as well as the edge distance required for the placement of a bolt within the plates. The strength calculations are shown in Appendix C.

2.2.3 Bridge Design Plans

After completing the design analysis for the bridge, the team completed a full set of construction plans drawn in AutoCAD. In this phase of the design, the team determined the overall configurations of each member of the bridge as well as the plate detailing. The team had several different plan submittals including 30% drawings, 60% drawings, 90% drawings, and 100% drawings. Each set of plans were reviewed by our technical advisor, who provided redlines on each draft of plans. The team was able to develop a full set of quality construction plans after all submittals were reviewed. The overall construction plans include member details and weld details for each build assembly, as well as material lists which list the required materials with specified dimensions for each build assembly. Also included are overall elevation and plan views of the bridge. The full set of design plans are shown in Appendix D.

2.3 Fabrication

When the bridge design plans were completed, the team began the fabrication phase of the project. The team received all materials at the beginning of the spring semester from Agate Steel in Phoenix, Arizona. Shortly after, the team prepared the material for fabrication by cleaning and organizing different member sizes. The team then cut each member to the length specified in the design plans and drilled bolt holes at the specified locations. Following member cutting and drilling, the team worked with Eagar Welding in Flagstaff, Arizona to complete the welding portion of the fabrication phase. Eagar Welding developed various welding jigs that allowed for easier assembly of welded members, such as the three dimensional truss used for the top cord of the bridge. Each weld assembly was tack welded first to ensure that everything lined up correctly and that everything was in the correct place. Then, Eagar Welding staff applied full welds to the entire bridge. Once welding was finished, the team spent time reaming out bolt holes to allow bolts to fit easier in each connection. The team also grinded each member and plate to apply a shiny finish, which helped with overall aesthetics.

2.4 Construction Practice

During this phase of the project, the team used the construction envelope provided in the 2016 AISC Student Steel Bridge Competition Rules. The team practiced a total of 11 times before the actual day of the bridge construction competition. The first build time was at approximately one hour, with many equipment drops and connection issues. By the third construction of the bridge, the build time had been decreased by approximately half to a time of thirty-two minutes, with less equipment drops and connections went together much easier. The night before the competition, the team practiced for the last time, which resulted in the best construction practice build time of 26 minutes. Since this build time was below the specified build time of thirty minutes which resulted in better scores in the competition, the team felt confident that we would perform well in the actual time construction.

2.5 Pacific Southwest Conference

From March 31st through April 2nd, the Steel Bridge Team attended the 2016 ASCE Pacific Southwest Conference at California State University of Long Beach in Long Beach, California. At the conference, the team participated in Display Day, where the team put the bridge on display with the display board and judges observed the bridge for overall aesthetics. The biggest events took place on the day of the Steel Bridge Competition. On this day, the team competed in timed construction with a maximum time limit of forty-five minutes. The team then competed in the loading competition, where the bridge was loaded laterally and vertically.

2.5.1 Display Day

The first day of the Pacific Southwest Conference is the Display Day for each team’s steel bridge design. A display board was made showing the name of the university, why the bridge design was chosen, a scaled side view of the bridge, a free-body diagram for one of the six load cases, shear and moment diagrams for the chosen free-body diagram, provisions for Accelerated Bridge Construction (ABC), and acknowledgement of all sponsors and donors who helped in any way throughout the entire bridge design build process. An award is given for display and is judged on the following criteria: appearance including balance, proportion, elegance and finish, and permanent identification of the bridge showing the university name exactly as shown on the ASCE student web page.

2.5.2 Off-Center Load Case Location Determination

Before conference, every team was given six different load cases to design for. The night before the Steel Bridge Competition, all conference captains met with the head judge to ask any final questions. Also at this meeting, a die was rolled to determine the location of the off-center load.

The off-center load was determined to be Load Case 4, which placed the off-center load of 1,000 pounds at 12’-0” from the right side of the bridge. All teams at the competition were subjected to this loading condition as well as the load of 1,400 pounds at the approximate center of the bridge (8’-9” from the right side).

2.5.3 Timed Construction

The day of the competition, all teams were required to build their designed bridge in a timed fashion. Before starting, all bridge members, fasteners, a temporary pier, and tools were staged and inspected by the judges. The build team split into two separate groups, building the bridge from both sides. On one side of the build envelope, Team 1 built two bays of the bridge. On the other side of the build envelope, Team 2 built four bays of the bridge away from the river. Once finished with their side, Team 2 rotated the bridge to connect with the Team 1 between the fourth and fifth bays. Team 1 then completed the construction process of connecting the bridge. When the team determined that the bridge was fully constructed, each team member ran back to the staging yards and the team captain told the judges we were finished. The judges then assessed the safety of the bridge and determined if there were any dimensional violations. The team was able to successfully construct the bridge within the specified time limits and go on to the loading portion of the competition.

2.5.4 Loading and Weight

After timed construction was completed, the team moved the bridge to the loading area. The judge decided an “A” side of the bridge by a random process and the other side was determined as the “B” side. The decking units were then placed; one at 8’-9” from the right side and the other at the location of the load of Load Case 4, 12’-0” (specified as distance “D”) from the right side. Three vertical deflection gauges are placed, one on the “A” side at a distance D + 3’-0” from the right end of the decking unit, and two on the “B” side: one at a distance D + 1’-6” from the right end of the decking unit and the other at a distance 10’-3” from the right end of the decking unit.

Lateral loading was tested first and seventy-five pounds was placed on the “B” side of the bridge to help restrain the bearing surfaces of the bridge from uplifting. Then, fifty pounds of lateral load was placed as close to the decking unit as possible. One inch of sway was allowed for the bridge to pass lateral loading. The bridge successfully passed the lateral load test and the team was able to continue on to the vertical load test.

The next loading condition was the vertical load test. Approximately fifty pounds of pre-load was evenly distributed across the decking units. From there, 1,000 pounds of additional load was placed on the off-center decking units and 1,400 pounds of additional load was placed on the center-decking unit. All loads were placed in a manner of individual twenty-five pound pieces of angle iron. Three inches of aggregate deflection was allowed for the bridge to pass vertical loading. The bridge must not deflect past three inches for the entire loading process, including the time when the load is being removed from the bridge. Fortunately, the bridge successfully passed the vertical load test, which allowed the bridge to be included in overall judging of all competition criteria, rather than a disqualification.

After the bridge passed both the lateral and vertical load tests, the bridge was moved to be weighed. Four scales were used to weigh the bridge, one for each foot of the bridge. The weights displayed on each scale were added together to determine the total weight of the bridge.

3.0 Competition Results

After the Steel Bridge Competition was complete, the bridge was judged against all other bridges that were not disqualified for the following criteria: stiffness, construction speed, weight, economy, efficiency, display, and overall product.

3.1 Stiffness

The stiffness category was based on bridge deflections due to the lateral and vertical load tests. For the lateral load test, the bridge deflected a total of 0.25 inches. For the vertical load test, the bridge deflected a total of 2.1 inches. The total aggregate deflection, which is the sum of each deflection gage that was on the bridge, came to a total of 4.97 inches.

3.2 Construction Speed

During the construction portion of the competition, the team was given an overall time of construction. The construction speed also includes time penalties for any equipment drops that occur during construction. The team had a total of six drop penalties during construction, which added 75 seconds to our overall build time (15 seconds for each drop). With penalties included, the construction speed for the bridge was at a time of 25 minutes and 16 seconds.

3.3 Weight

The weight of the bridge was determined after loading was completed. The weight included the total weight of the bridge, plus weight penalties for any dimensional violations that were present. Our bridge had one dimensional violation less than ¼", which resulted in a weight penalty of 20 pounds. Adding this to the weight measured by the four scales resulted in a total weight of 273 pounds.

3.4 Economy

The bridge economy determines the construction cost, based on how many builders are used during construction as well as if a temporary pier was used and the construction speed, as shown in Equation 1.3.1. The team used six builders to construct the bridge and a temporary pier was used, which added a cost of $30,000 to the economy equation. The equation also includes load test penalties if the vertical deflection is more than two inches. Since the vertical deflection of our bridge was at 2.1 inches, $8,000,000 was added to the bridge economy cost. Using all components applied to the economy equation, the total economic cost was $15,610,000.

3.5 Efficiency

The structural efficiency is based on the effectiveness of the structural design, and includes aggregate deflection and weight of the bridge. Equations 1.3.2 and 1.3.3 are used based on whether or not the bridge is under 400 pounds or over 400 pounds. Since our bridge weighed 273 pounds, Equation 1.3.2 was used to determine the efficiency. Load penalties were also included for a vertical deflection that was greater than two inches, which added $20,000,000 to the efficiency score. With all components considered, the total structural efficiency was at a cost of $27,695,000.

3.6 Display

From Display Day, the bridge was judged for aesthetics as well as for the display board that was shown along with the bridge. The team placed third for display out of seventeen schools.

3.7 Overall Product

The overall score was based on the individual scores for each criterion. Out of a total of seventeen schools that participated in the Steel Bridge Competition, the Northern Arizona University Steel Bridge Team achieved sixth place.

4.0 Project Management

4.1 Scheduling

A schedule was created to stay on track during the course of the project. Each major task was listed on the schedule with approximate start and finish dates, along with subtasks that were included as a part of the critical path.

4.2 Budget

A budget was created based on the amount of time needed to complete the project, as well as the resources required. This included the personnel and materials that were necessary for the completion of the project. The budget also took into account any donations that were received to help fund the project.

4.3 Fundraising and Donations

The team contacted different resources in the hopes of acquiring donated materials or funds. For any donated materials, the team was in contact with vendors throughout the course of the design phase of the project. This helped ensure that all materials used for the final bridge design were readily available when the fabrication phase began.

5.0 Discussion and Recommendations

5.1 Bridge Design

The team has provided a RISA 3D design of a 20’-9’’ beam bridge for future teams to review and improve upon. The RISA 3D design has six applied load cases for the vertical load test as well as one load case for the lateral load test, as specified in the AISC Steel Bridge Competition Rules. In future years, the RISA 3D design loads and bridge overall dimensions will need to be changed per the AISC competition rules and specifications. The bridge dimensions can be changed by scaling the node coordinates in the X, Y, and Z directions. For example, if next year's bridge is three-quarters of the length of the previous bridge designed in RISA 3D, the new designers of the bridge should apply a 0.75 scale factor to all nodes for the x-coordinates of the nodes. This can be done in a similar fashion for the width (z-axis) and height (y-axis) of the bridge. It is important to understand that node to node dimensions might change to an undesirable length, such as dimensions with decimal places to 1/100th of an inch. Discussions amongst the bridge team should be made to account for any dimensional issues in RISA 3D. It is highly recommended that future design teams use the previous RISA 3D design, making minor changes to the design, which will ultimately save time during the design phase of the project. The design of the bridge in RISA 3D must be completely thought out before using the design results to choose material section sets for the bridge. This means that if a RISA 3D design has a node or member constraint that is not applied during construction, the bridge is more likely to fail. Be sure to only include node constraints (i.e M-XX or M-ZZ reactions) that will be constructed.

The future bridge teams should use alternate design methods to ensure the bridge members are stable, and provide sufficient service values for the bridge competition. This means that all loads should be factored by a 1.1 or 1.2 load factor. Also, members in compression should only be stressed to 80% of the allowable design value. If a member in compression is stressed to its ultimate load, this could cause the member to have complete buckling failure. It is recommended that the future bridge team use the Microsoft Excel calculations provided by the 2016 Steel Bridge Team to check if each bridge section set has sufficient capacity. The Excel calculations provided will check local buckling for members in compression, as well as yielding and rupture for members in tension. The steel bridge competition is a balance between strength and service for each member of the bridge. This means that if every member of the bridge is stressed to 99% tension or compression capacity, the bridge will most likely deflect more than desired, or even possibly fail. The final recommendation for the future bridge design would be to focus on limiting the overall deflection of the bridge. The penalty for having a high deflection during loading is more significant than having a bridge that weighs more than 200 pounds. Limiting the deflection can be mitigated by ensuring each member of the bridge is at 80% stressed or less, as well as using a 1.2 load factor. The connection design of the bridge can also influence the deflection of the bridge. The 2016 Steel Bridge Team made the mistake of not accounting for the "slop" in each plate connection. For the construction of the bridge, the team used a bolt-hole diameter that was 1/16 inch to 1/8 inch larger than the bolt diameter. This slop in the connection caused each plate to move roughly 1/16' inch during loading. The result of this mistake was that the bridge deflected twice the amount that the RISA 3D design predicted. This slop can be mitigated by changing the connection design of the bolts so that the bolts are in tension, rather than shear. Future teams can also use other software programs, such as ANSYS, which can help with connection design.

The Steel Bridge Team spent more time on the design of the bridge than expected, primarily due to the fact that the team had to build the design from scratch. Fortunately, future teams will have a good RISA 3D design to utilize and hopefully improve upon, cutting down the time needed for design drastically. If the design is completed on time early in the first semester, there should be plenty of time for future teams to fabricate and complete the bridge before the competition.

5.2 Material Selection

The Steel Bridge Team used 33 kips per square inch (ksi) steel donated from Agate Steel for the design, which was sufficient for strength, but not for serviceability. This was because of the low ultimate strength; the team needed more area of steel to decrease deflection. If the team had a higher yield strength steel, less of the material would be needed to stiffen the design. To be more competitive in the competition, the Steel Bridge Team recommends that future teams contact material sponsors earlier to try to get A513 steel, which has a yield strength of approximately 90 ksi. With the A513 steel, the team could have a lighter design and can stress the members more, eliminating a lot of the bridge members from the 2016 Steel Bridge Design.

5.3 Fabrication and Construction

The team obtained material from Agate Steel. It is recommended for future teams that they request Agate Steel to cut the steel members prior to picking up the material. Once the team obtained the material, the team began to cut the members to the correct length. The cutting of the steel involved using the band saw and angle grinder. The team then drilled all of the holes in the steel members at the appropriate locations. While the team was working on the steel members, Southwest Water Jet cut all of the 10 gage plates for the bridge. This allowed the team to have the bridge plates cut to a tolerance of 0.001’’. It is recommended that future bridge teams sub-contract all plate manufacturing for ease of fabrication. Once the steel members and plates were cut, the team assembled all of the “welded assemblies” for the sub-contracting of the welding. The total cost of the welding by Eagar Welding was estimated to be $1200.00. The team spent approximately three weeks welding all of the members together. It is highly recommended that future teams sub-contract the welding portion of the bridge. This will ensure that the bridge is welded correctly. Professional welding will ensure that all of the bridge welds will be developed to the compression or tension capacity of each member.

The team had a total of 11 practices before the steel bridge competition and got their best practice time down to 26 minutes. This was a great improvement to last year when the 2014-2015 Steel Bridge Team barely made it to 45 minutes the night before competition. The team attributes this to the beam bridge design, which is easier to construct than a Warren Truss. With getting the design and fabrication done earlier, the next Steel Bridge Teams can get more practices in earlier. By doing this, future teams can optimize their construction times by practicing and experimenting with different construction methods.

5.4 ASCE Competition

The Steel Bridge Team had one big issue during the Steel Bridge competition. Unfortunately, the team missed placement of a bolt in one of the bolt holes during construction. The team has some recommendations to avoid this issue for future teams. First, the conference captain should look over the bridge while the judges are checking it to ensure everything is in place. The team also recommends the possibility of painting around the holes of the plates with a bright color. Painting around the bolt holes would help the team catch any missed bolts because the bolt would normally cover the paint, but if one was missing it would be highly visible.

5.5 Final Recommendations

To design and construct the steel bridge successfully, future steel bridge teams must stay on schedule. This means that the bridge design, both RISA 3D and AutoCAD designs, must be completed during CENE 476 in the fall semester, preferably before Winter Break. Materials for the steel bridge must be ordered before winter break, so that they are ready to be picked up by the time the spring semester begins. Finally, the fabrication of the bridge will take majority of the time between January and March. If funding is available, sub-contract as much work out as possible to ensure the bridge is fabricated correctly and efficiently.

6.0 References

[1] 2016 ASCE Steel Bridge Team, "*2015-2016 ASCE Steel Bridge Project Proposal*." CENE 476. Fall 2015.

[2] Aisc.org., *"Student Steel Bridge Competition Rules*", 2015. [Online]. Available: https://www.aisc.org/WorkArea/showcontent.aspx?id=21576. [Accessed: 30- Sep- 2015]

Appendix A: Decision Matrix

Scale: 1 = worst score, 5 = best score

	Beam	**Bowstring**	**Warren**
Constructability (10%)	5	2	3
Usability (10%)	3	3	3
Stiffness (20%)	2	5	4
Construction Speed (15%)	5	2	2
Efficiency (20%)	2	3	5
Economy (20%)	4	2	2
Aesthetics (5%)	3	5	3
TOTAL WEIGHTED SCORE	**3.3**	**3.05**	**3.25**

Appendix B: RISA 3D Design Results

Appendix C: Strength Calculations

Appendix D: Design Plans