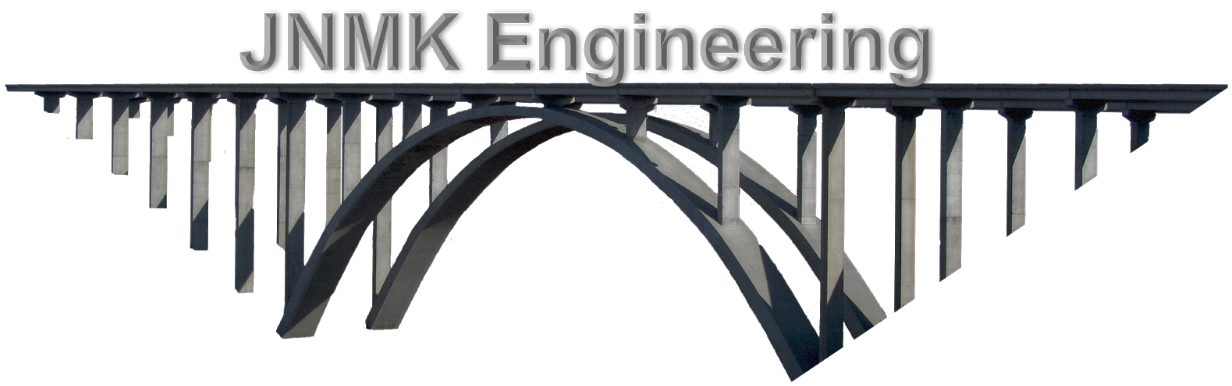
2nd Annual 2019 Delaware Bridge Design Competition

Deck Arch Truss Bridge



Caravel Academy

Team Members: Jeb Williams, Nicholas Sobocinski and Madison Proffitt

Teacher: Allyson Boedeker

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ABSTRACT

The purpose of this project was to design and build a deck arch truss bridge with an optimized strength-to-weight ratio. We started out by creating a timeline to make deadlines for the major checkpoints to ensure that we won't start falling behind. We began by conducting research on deck arch truss bridges and the different ways that they could be made. We each decided what truss we thought would be optimal for the bridge we had to build. After we had enough knowledge about balsa wood and bridges, we decided to build half-scale models of the bridge to see which truss design and deck would work best. Each member of our team created their own unique bridge and each had a different truss design. While building the half-scale model we gained a concept of what challenges we would face when we built our final bridge. After testing our bridges and comparing our results, we started to make slight changes to our bridge to maximize the strength-to-weight ratio. Next, we created a full scale model of our bridge. This model did not do as well as we expected so we decided to go back to the drawing board. Investigating the multiple other forces acting on the bridge, such as compression and tension forces, we concluded that we needed to increase our lateral bracing. We also looked into what truss design was the most efficient by testing many different versions of them in the Model Smart 3D. We created multiple designs in the software and kept trying to optimize the strength-to-weight ratio. Eventually, we found a very strong design that was very light, which therefore would produce a high strength-to-weight ratio. We decided to make this the design for our final, and started to build it right away. The group believes we have made the best possible deck arch truss bridge.

INTRODUCTION

Our team name is JNM Engineering and we go to school at Caravel Academy in Bear, Delaware. Our team consists of three members: Madison Proffitt, Nick Sobocinski, and Jeb Williams. Madison Proffitt is in eleventh grade and has been attending Caravel since fifth grade. She took engineering as an elective to see if it was a career she would like to pursue in the future. The competition was a great experience because it was completely hands on and showed how challenging engineering can be. One of the highlights was getting to talk to experienced civil engineers and receiving advice from them. Nick Sobocinski is a senior and has been attending Caravel since Kindergarten. He took engineering as an elective, because he is going on to study Biomedical Engineering at the University of Delaware this upcoming fall. This class and competition has given him even more insight into what it truly means to be an engineer. Jeb Williams is in eleventh grade and has been attending Caravel since fifth grade. He took engineering as a class during the 2019 spring semester because from a young age he has always said he wanted to be an engineer one day. This competition exposed him to what it would be like to be an engineer in the real world. It also gave him a great appreciation for the work that engineers do.

BODY

The scientific forces that our bridge faced was gravity and sheer force. To counteract the gravity, we built a double laminated arch, with a truss between, to effectively distribute the force from gravity. To counteract the sheer force we built triangles within the bridge to keep the bridge from breaking. While making our bridge we faced a variety of obstacles. The first challenge was simply learning how to construct a balsa wood bridge. We started by first creating half-scale bridges to practice building a bridge and test multiple designs to see which one worked best. Because we knew we had a limited supply of wood for our actual bridge, we borrowed some balsa wood from a science teacher at our school. This supply was only used for the half-scale prototypes.

Another challenge we faced was learning how to use the computer software that was provided to us. A few of the challenges we faced with the Model 3D Software was accurately placing our joints, creating a proper arch, and problems with symmetry. Because of how you must map out and place joints in the software, it was a struggle placing them in the necessary locations, which made creating a symmetrical design difficult. We also encountered problems when we tried to build a smooth arch in the software. Due to the software's limits, it was difficult to create an arch that wasn't rigid. We fixed this problem however, by adding many joints to the arch to make the segments shorter, and as a result, the arch was smoother.

The final challenge our team faced was time. Our class period is only 40 minutes, which was definitely one of the biggest concerns with getting everything done. In addition, we did not have access to either software program outside of class. Therefore, having to work on these in class took away a teammate from building for the majority of the days. We had to use our time wisely every day, getting as much done during the class period as we could. The timeline made beforehand was a huge help with keeping us on track.

While building the bridge, the main challenge was making the bridge level. When the bridge was not level all the load would be forced onto one side of the bridge which resulted in the bridge holding less weight than expected. To fix this we used level to make sure the sides of the bridge were completely level, and we also made exact measurements on the legs of the bridge to make sure that the bridge layed level.

Our designs were tested in two main ways: the Model 3D Software and building half-scale models to break. We began by building both half and full scale bridges that had slightly differing designs. We would test them by hanging a bucket filled with sand by the provided block, which was placed on the bridges deck. Although the bridge designs were all different, the main takeaway from all of them was the importance of making our bridges completely level. This is because in every test our bridges would start to lean and eventually snap, as a result of even a minor flaw in the balance. We then continuously tested our designs in the Model 3D Software. Through many different designs and tests, there were a few main takeaways. The first is that a bridge that has an arch with a truss inside of it is most efficient. Next, we realized that if we laminate the arch pieces, the efficiency sky rockets. This is because it barely increased the bridges weight, but significantly increased the amount of weight the bridge could hold. The final takeaway is that x-shaped cross bracing is not always the most efficient. In many circumstances triangle shaped bracing is lighter and more efficient.

Our deflection test was used to allow us to build our bridges with the correct material in the Model Smart 3D Software. We attached a piece of the balsa wood to a desk, allowing part of it to hang off. We measured the height from the ground of the balsa wood. Next, we attached a 10 gram weight to the end of the balsa wood, and measured the new height. We then took our original height and measured the new recorded height from it, giving us our deflection threshold. This allowed us to know that our material was BalsaD3.

Test Weight (grams)	Deflection Threshold (in.)
10	.50

HALF-SCALE BRIDGE RESULTS

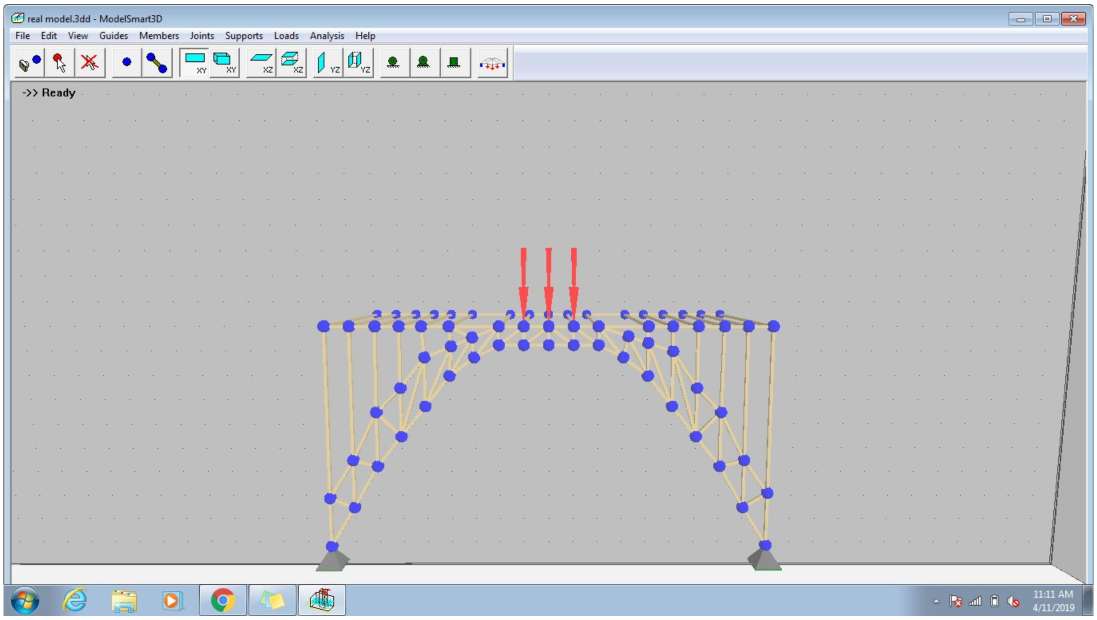
Name	Weight of Bridge	Weight Held	Strength-to-Weight Ratio
Madison (Figure 1)	0.015 kg	2.5 kg	166.7
Jeb (Figure 2)	0.06 kg	0.8 kg	13.3
Nick (Figure 3)	0.015 kg	6.6 kg	440

Figure 1

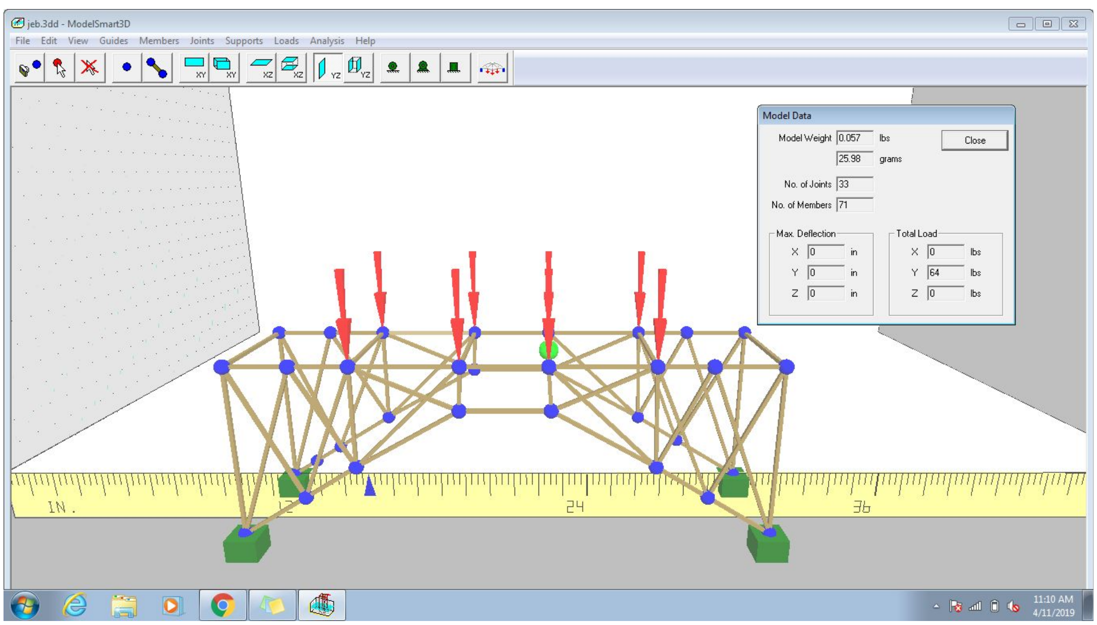
Figure 2

Figure 3

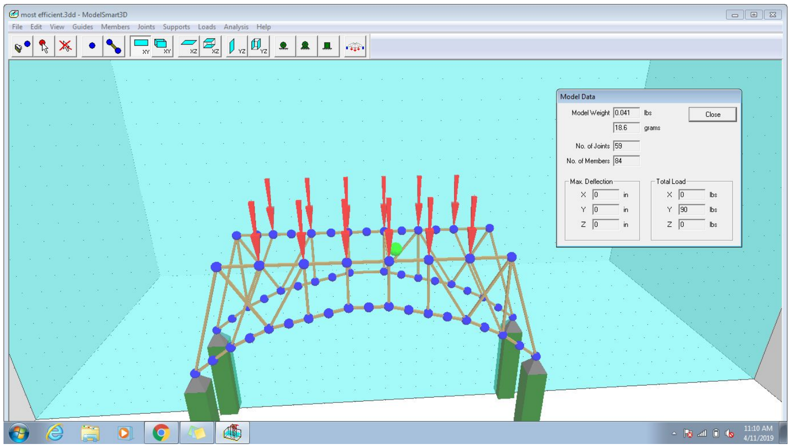
EVOLUTION OF BRIDGE DESIGNS



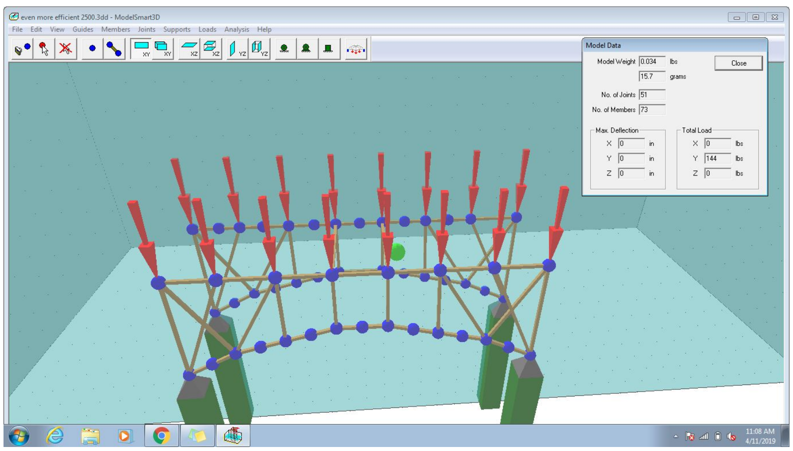
Bridge 1



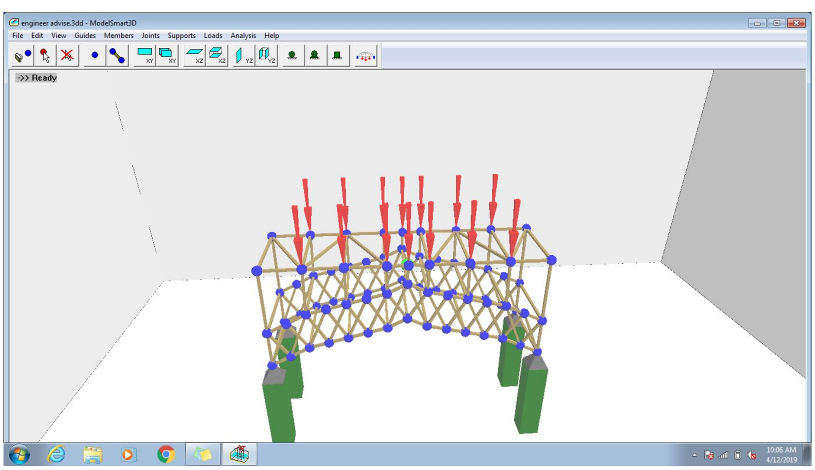
Bridge 2



Bridge 3



Bridge 4

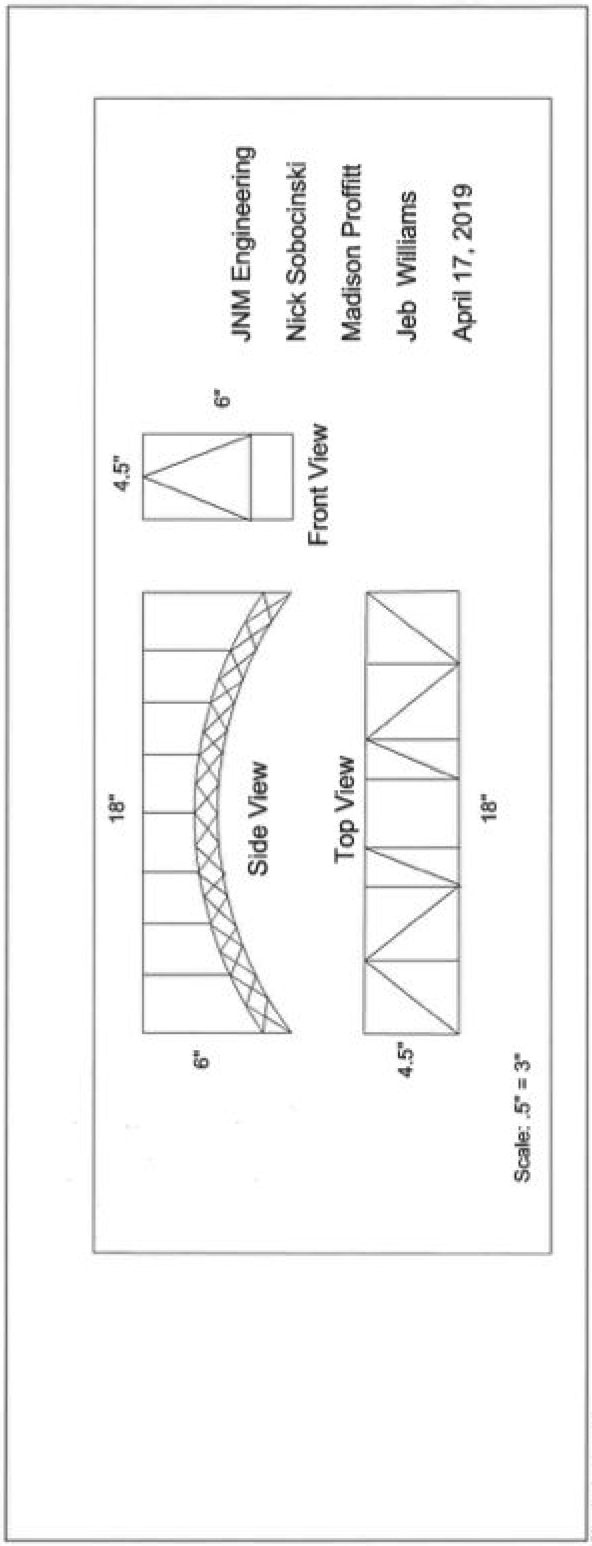


Bridge 5

Bridge Prototype #	Efficiency
Bridge 2	1122
Bridge 3	2195
Bridge 4	4235
Bridge 5	4,564

CONCLUSION

We believe that our project is successful. This is because our bridge may not win the competition, the process and competition has taught us many aspects of what it means to be an engineer. We learned what some daily struggles are that engineers have to deal with, and how projects must be properly planned and executed. These learned lessons, as well as the overall experience, is what truly constitutes our project as a success in our eyes.



JNM Engineering
Nick Sobocinski
Madison Proffitt
Jeb Williams
April 17, 2019
18"
6"
Side View
4.5"
6"
Front View
Top View
18"
4.5"
Scale: .5" = 3"
[Academic use only]

ACKNOWLEDGMENTS

Mrs. Boedeker was the primary adult who assisted this team. She helped our team get started by giving us the most important details of the competition and supervising us as we made our timeline. She always answered any questions that we had when building and gave insight on things we should consider as we modified our designs. Another teacher that assisted us was Mrs. Garrison who was not required to help us, but supplied us with balsa wood to practice with before we started building our bridges for the competition. Lastly, Jonathan Karam and Michael Haddad are two DelDOT engineers who came into our engineering class a few times to answer any questions we had about the structure of our bridge and helped us optimize our designs.

REFERENCES

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"Balsa Wood Bridge- How to Build a Strong Balsa Wood Bridge." *History of Bridges,* History of Bridges, 2019. 15 April 2019.

"Bridge Basics." *PGH Bridges,* Bruce S. Cridlebaugh, 2008. 10 April 2019.

"Bridge Types." *Historic Bridge Foundation,* Historic Bridge Foundation, 2019. 10 April 2019.

"Forces That Act on Bridges." *Garrett's Bridges,* Garrett's Bridges, 2019. 10 April 2019.

"How Do I Find the Optimal Arch Height for a Bridge of a Given Length?" *Quora,* Quora, 9 May 2018. 16 April 2019.

APPENDICES

Appendix A

Timeline

First milestone (February 19)- Discussed how we will split up the work for the project.

Second milestone (February 21)- Started to design and build half scale models of our bridge.

Time between: We continued each day to create our half-scale bridges. During this time we learned how to become efficient at working with balsa wood. It also taught us how long it would take us to build a full scale model of the bridge.

Third milestone (March 19)- Broke the half scale model bridge and we learned that lateral bracing was necessary and that the bridge needed to be level.

Time between: During the half scale model break we learned that the howe truss was the best design. We also realized that lateral bracing was an important aspect of the design to make sure that the weight was equally distributed on both sides.

Fourth milestone (March 22)- Started to create a full scale model of our bridge so that we could test its performance.

Fifth milestone (April 5)- Tested the full scale model and learned that we need to improve on lateral bracing of our bridge, and also really needed to make sure that our bridge was completely level.

Sixth milestone (April 10)- decided on the final design of our bridge. We chose to do two laminated arches on each side of our bridge to hold the most weight.

Seventh milestone (May 1)- Date of the competition

DAILY JOURNALS
Appendix B

February 19
Nick: Helped lead the group in planning out the timeline for the project. Began drawing first prototypes for bridge.
Jeb: Helped plan out the timeline for the project. Helped in assigning roles for the project. Began drawing sketches of the design of the bridge.
Madison: Helped plan out the timeline for the project and created the progress report. Began sketches of the bridge.

February 21
Nick: I made in depth measurements for the pieces of wood that would be used to create the bridge.
Jeb: I created a scaled model of the prototype bridge. Using math calculations to find the lengths of various parts of the bridge (length of the arch, length of trusses).
Madison: I sketched out a model and calculated my measurements for the half scale bridge.

February 22
Nick: Successfully developed the arch for my first balsa wood bridge prototype, using push pins and measurements.
Jeb: Started create the bridge. Focused on the arch of the bridge, got on side of the arch bent into place and stabilized with push pins so it could dry in the givens shape
Madison: Started to form and pin down the arch made of balsa wood for the half scale bridge prototype.

February 25
Nick: Set my first arch down to dry, as well as began to learn the Model Smart 3D software.
Jeb: Created the second arch of the bridge, after than started to learn the Model Smart 3d software and figure of the technology.
Madison: Pinned down my first arch made of balsa wood using push pins and started using the Model Smart 3D software.

February 26
Nick: As a result of finding a flaw in my arch, I created another arch. I also began to develop a model of my half size prototype in the Model Smart 3D software.
Jeb: Worked on Model Smart 3d software to continue making a 3d model of the bridge.
Madison: Pinned down my second arch made of balsa wood for the half model of the bridge and continued making my 3D model on the software.

February 27
Nick: Today I created my second arch and accurately drew my prototype design on graph paper.
Jeb: Today I created a sketch of my bridge on a piece of graph paper so I have a reference to use when building the bridge.
Madison: Cut down my arches to the correct sizes and started a precisely measured sketch on graph paper.

March 4
Nick: I furthered the design of my prototype and began to cute the balsa wood for my bridge.
Jeb: Today I started cutting the truss pieces to length.
Madison: I started cutting the balsa wood for my truss according to my measurements.

March 5
Nick: I worked on developing my bridge in the Bentley software.
Jeb: I started to cut the joints for the trusses and started glueing the joints together
Madison: I continued cutting the balsa wood and started gluing the base pieces of the first arch of my half scale bridge together.

March 6
Nick: I worked on building my truss for my half size bridge model.
Jeb: Continued to cut pieces of my bridge and glued them together as well.
Madison: I glued the diagonal pieces of my half scale bridge to my first arch.

March 7
Nick: Completed my vertical parts of my truss.
Jeb: Started focusing on cutting the vertical and horizontal pieces of my bridge
Madison: I started replicating the first arch of my half scale bridge to make the second.

March 8
Nick: Completed the angled portions of my bridge.
Jeb: Glued the horizontal and vertical pieces to the x joints
Madison: I continued to replicate and build my second arch for my prototype bridge.

March 11
Nick: Had a group meeting discussing further deadlines for the project. Finished first half of my bridge.
Jeb: Had a group meeting and discussed what we could start working on to even out the workload.

Madison: We met as a group and discussed everything that we should be working on and deadlines that it should all be done by. I also finished both truss's for my half scale bridge.

March 12
Nick: Began to build the structure for the other side of my bridge.
Jeb: I finished one side of my bridge. Started laying out the design for the other side.
Madison: I started the deck for my half scale bridge prototype.

March 13
Nick: Started my truss for the second arch.
Jeb: Finished the second side of my bridge and let it dry before continuing.
Madison: I finished the deck for my half scale bridge prototype.

March 14
Nick: Finished the truss on my second bridge
Jeb: Built my deck and added the two sides of the bridge to the deck.
Madison: I put together the two truss's and bridge to complete my half scale bridge.

March 18
Nick: Built my deck and finalized my bridge.
Jeb: Added cross members to my bridge to make it more sturdy.
Madison: I worked on the laptop software to create a duplicate of my half scale bridge.

March 19
Nick: Tested my half scale bridge which broke under minimal weight.
Jeb: Tested my half scale bridge by adding sand to a bucket that was hanging below it.
Madison: I tested my half scale bridge by adding weight to it until it broke.

March 20
Nick: Began to develop our final design in the Model 3D software.
Jeb: Started to layout topics for out presentation, and started to create a design for the team logo
Madison: I started the powerpoint presentation.

March 22
Nick: Continued to finalize our bridge concept in the Model 3D software.
Jeb: Started to make arches for our final bridge and started to make a truss design on paper to reference while building the bridge.
Madison: I started to build arches for our final bridge based off of Jeb's bridge design and drew the deck for the full scale bridge.

March 25

Nick: Finalized the concept on the Model 3D Software and tested it. Our efficiency was 1385.
Jeb: Formed the second arch. Then started to make cuts and layout the pieces for the deck.
Madison: We built the second arch for the full scale bridge and I began the full scale deck duplicated from the sketches.

March 26

Nick: Started fresh on optimizing a new design, based on my last tests, I believe a double arch will be more efficient.
Jeb: Made another arch for the bridge and had a group discussion on how we could make the bridge lighter and optimize the design.
Madison: We continued to make additional arches for a second full scale bridge. We also discussed what changes to make regarding how many X's the truss contained before we began in order to make the weight of the bridge sturdier without adding too much weight.

March 27

Nick: Took what I learned from my final design in Model 3D software and began to create another new design.
Jeb: Worked on the deck of the bridge and decided to move the cross members so that they lay on top of the frame, because we thought it would be a stronger design.
Madison: We finished the full scale deck with minor adjustments of moving the cross pieces from between the edges to on top of the edges.

March 28

Nick: Continued to develop my new design
Jeb: Started to make a full scale sketch of the final bridge with the changes we made to the design so that it would be lighter but still hold enough weight.
Madison: Sketched the full scale bridge truss's with the new changes made to the design.

March 29

Nick: Continuing to develop new design, attempting to lower the weight of the bridge.
Jeb: Started to make cuts for the bridge and lay them out on the full scale sketch to see how everything looked.
Madison: We started the first truss for the full scale bridge based off of Nick's drawings and tests.

April 1

Nick: Continuing to develop new design, attempting to lower the weight of the bridge and increase the weight it can support.
Jeb: Started to make cuts for the bridge and lay them out on the full scale sketch to see how everything looked.
Madison: We completed the first truss for the full scale bridge based off of Nick's drawings and tests and decisions to split the last X into two separate X's.

April 2
Nick: Started to test different truss designs between the arch, should finish it by tomorrow.
Jeb: Started to make an identical truss for the other side of the full scale bridge, using all the same measurements and angles.
Madison: We started duplicating the first truss to make the second one for the full scale bridge prototype to be broken either Thursday or Friday.

April 3
Nick: Came to a conclusion that using an x trust design was most efficient.
Jeb: Completed the second truss and let it dry overnight. Planning on testing it by the end of the week
Madison: We completed all the pieces of the full scale bridge prototype to be put together tomorrow and tested on Friday.

April 4
Nick: Started to develop our final truss design, which is an x design.
Jeb: Glued both sides of the bridge to deck. While gluing we made sure the side were level so that the load would be equally distributed across the bridge. Also added lateral supports to the bridge to ad lateral stabilization
Madison: We glued both the sides of the bridge to the deck, as well as the cross pieces which were put exactly in line with the straight up and down pieces of the truss. It will dry tonight and be broken tomorrow.

April 5
Nick: Started to test the number of verticals that would be needed to be most efficient, connecting the arch to the deck.
Jeb: Tested the bridge today. It held 4.2 Kg and did not do as well as expected. The group came together to discuss what we think went wrong. We believe that there was a problem with the levelness of the bridge and also learned that we need to add better lateral stabilization.

April 8
Nick: Found the optimal amount of verticals to be used to connect the arch to the deck.

Jeb: Today the two guest engineers came and we got to ask them questions. Started to work on the introduction and abstract to our report

April 9
Nick: Began to test new designs for the deck.
Jeb: Worked on powerpoint presentation as well as the proposal.
Madison: I worked on the powerpoint presentation based off of the competition guidelines and cited a few of the sources that we used.

April 10
Nick: An x design for the deck is too inefficient and I began experimenting with triangles.
Jeb: Worked on body, stating what challenge we faced while building the bridge and how we resolved them.
Madison: I completed the acknowledgements section of the final report including Mrs.Boedeker, Mrs.Garrison, and the two guest engineers that came to help us, and cited more sources that were used.

April 11
Nick: Established a final design for the deck, which is using large triangles.
Jeb: I worked on the final report, and started to make a flowchart to show the timeline of our project. I also revised the abstract of the report.
Madison: I worked on the final report, editing what was already done and formatting it all into a professional paper.

April 15
Nick: Made decisions to laminate both aspects of the arch and the support pieces.
Jeb: I started to sketch out the design for the final bridge on a template. Also created the arches for the bridge and glued them together. Started to work on the trusses as well.
Madison: I added data to the final report from our half scale bridges, as well as photos. I also fixed the appendices and added information to the body.

April 16
Nick: Finalized our report and Bentley drawings.
Jeb: I continued to work on the trusses for the bridge and started to sketch the design for the deck of the bridge as well.
Madison: I added more data to the final report from our deflection test. I also fixed minor errors that Mrs. Boedeker found.

Appendix C

Appendix D

Sample Calculations

Deflection Test Example

50 (in.) - 49.5 (in.) = .5 (in.) Deflection Threshold

Original Height - Weighted Height

Efficiency Test Example

144 (lbs) / .034 (lbs) = 4235 Efficiency

Weight supported by bridge / Weight of bridge

Model Height

18 (in.) / 3 = 6 (in.) Height

Bridge Length / 3

"We hereby certify that the majority of the ideas, design, and work was originated and performed by the students, with limited assistance by adults, as described above."

Mrs. Allyson Boedeker

Madison Proffitt

Nick Sobocinski

Jeb Williams