DelDOT Bridge Design Competition 2019

Deck Arch Truss Bridge

The Powerpuff Girls

MOT Charter High School

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Mr. Brendan Murphy

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Abstract

The team is tasked to construct a deck arch truss bridge that carries a high load capacity relative to the bridge weight. The team first conducted initial research on bridges, forces and other scientific principles. Challenges were experienced during designing and building, but several preliminary designs were created and tested with the ModelSmart3D software to create a final design using Bentley Microstation Powerdraft. Throughout the process, data tables representing numbers were collected regarding ratios and weight. Also, a project plan was made in the form of a calendar that displays upcoming tasks, goals, and milestones, a work log was made to track tasks completed throughout the time period given to complete this project, and photographs were taken of competitors working on the project. As a group, we came to a final decision to build a warren deck arch truss bridge through the research conducted and digital bridge testing processes. Because of this project, we've developed and improved upon skills that are not only technical and computer-based, but surround the essential ideas of time management, communication, collaboration, and teamwork.

Introduction

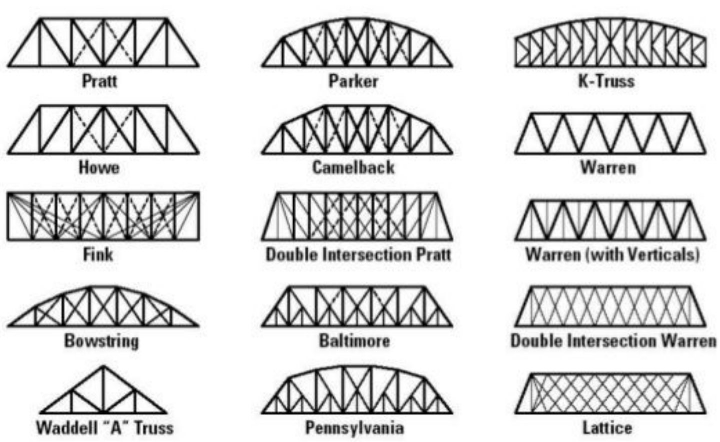
The Powerpuff Girls is composed of Angela Abad, Sierra Szper, and Cynthia Wang, who attend MOT Charter High School. Angela and Sierra are both Engineering majors who played for the school's Varsity Volleyball Team and currently participate in travel volleyball clubs. Cynthia is a Computer Science major, and she participates in TSA along with Angela. They're both part of the club's Chapter Officer Team: Cynthia is the Treasurer and Angela is the Secretary. Cynthia also participates in Science Olympiad, Math League, and Math Modeling and is planning on studying Biomedical Engineering in the future. Sierra, along with volleyball, is also working and volunteering outside of school. She wants to study in nursing to gain her masters degree then continue on that path to become a nurse anaesthetist. Angela is constantly active in community service outside of school and is interested in taking on Statistics and art fields in college and her career. All three members are in the same Advanced Engineering & Design III class, have known one another since freshman year, and are all proud members of MOT Charter's National Honors Society.

Body

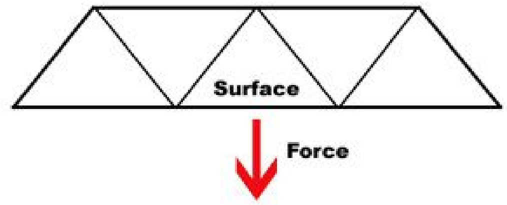
Scientific Principles

Creating the Bridge: The process of building the bridge begins with a design. Placing wax paper over the design, and the design over a piece of cardboard, allows the glue to not stick to the wax paper and helps with removing the frame from the wax paper without any paper coming off with it. Next, cutting smaller pieces in the shape that is needed to create the frame of the bridge. Gluing it together ensures that the pieces stick together and are strong. Pins are used to hold the pieces into place while they are being glued together. Different devices can be used to test the bridge in the end.

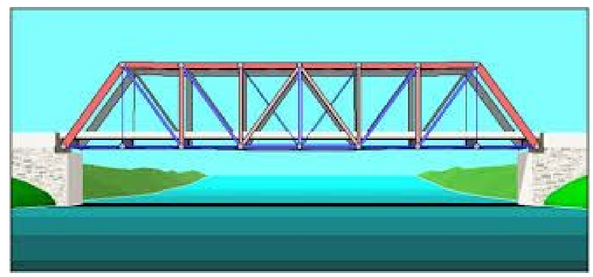
Shapes and Forces: Triangles are the strongest and most stable shape that a bridge can have. The triangle has the ability to evenly distribute its weight without changing the actual shape that it is in. On the bridge, compression and tension will be forced onto it to see how sturdy the bridge is. Compression a force that causes the bridge to push against itself. In the end, this will lead to buckling of the bridge and eventually it will snap. Tension on the bridge is a force that wants to rip the bridge apart and make it snap while more and more weight is added on.

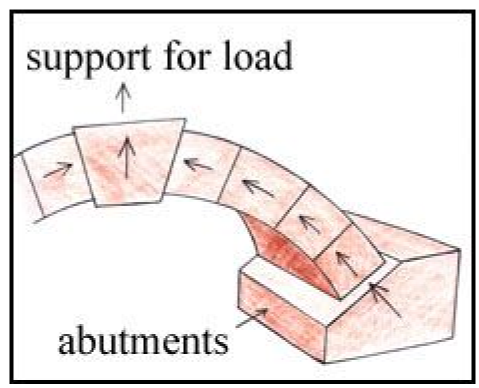


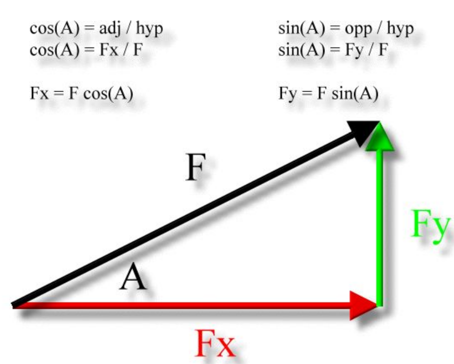
Truss bridges are composed of a structure of connected elements. They often contain triangular shapes in them due to the ability of the triangle to distribute forces without changing shape. Common types of trusses are shown in the image above. The Warren Truss bridge is the simplest form of the truss bridge. It is made of equilateral triangles. However, the Warren Truss bridge is not very versatile because forces move substantially across the bridge as the placement of weight changes. An alternative is the Pratt Truss (bottom right), which distributes its force more effectively. Diagonals point towards the center of the bridge, so forces do not change substantially as weight placement changes. In an arch bridge, instead of having forces go straight down, the forces are distributed along the curve of the arch to supports at the end, called abutments. The force along the arch is compression force.



Warren Truss Bridge







In a simple bridge with only horizontal and vertical members, the forces on each vertical member can be determined directly by dividing the total force among the members of the bridge. To calculate the vertical and horizontal force for forces at an angle, trigonometry can be used. The angle and direction of the force can be used to find the magnitude and direction of vertical and horizontal forces using sine (vertical) and cosine (horizontal).

Bridges are categorized by travel surface configurations. In deck bridges, the travel surface is the top of the bridge. In a pony bridge, vehicles travel through parallel vertical superstructures that are not connected at the top. In a through bridge, vehicles travel through a structure that is braced at the top and bottom. A deck arch truss bridge combines the elements of a truss bridge and arch bridge, with a deck travel surface configuration.

Strength to Weight Ratio: The strength to weight ratio relates to the mass of the material to its ability to withstand permanent deformation or fracture under pressure. In other words, this is essential for the bridge competition because it shows how much force the structure can take in relation to its weight. To calculate this ratio, the maximum load criteria provided must be divided by the weight of the designed bridge in grams.

CAD: Computer Aided Drafting (CAD) is used to convey an engineer's
plan to stakeholders in order to produce safe, efficient, and cost effective projects. CAD Softwares display designs digitally, programmed by the designers themselves to effectively show the structure in all angles and to a certain magnification.

Challenges Encountered in Designing

When designing the bridge, initially we came across the challenge that everyone had different ideas. Sometimes it was hard to try and pick a design that everyone would agree on. To solve this issue, we explained to each other why a design might be better than another and then voted as a team to determine which design to use. We also tested multiple designs to determine which one was the most efficient.

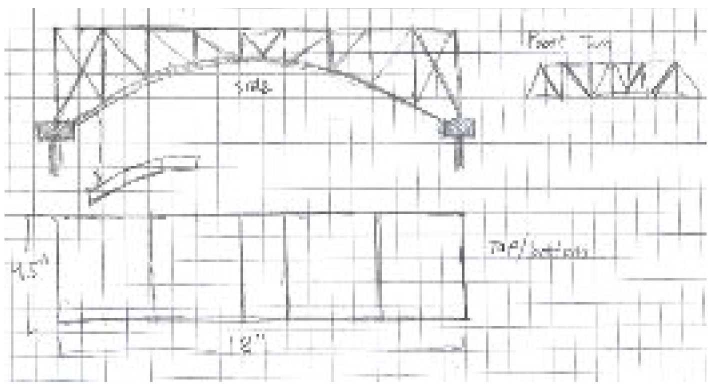
The criteria and constraints in the project brief (listed below) led to some challenges in the design of the bridge. For example, we had to construct a deck arch truss bridge, which required us to determine how to angle the members and how many members to use in the arch part of the bridge. We solved this issue by making a fixed horizontal interval for each member, and decreasing the vertical interval by 0.25 inches for each member as they reached the center of the arch. This created a smooth curvature. The method of testing the bridge at the competition also posed a challenge because we had to design a stable method to rest the bridge on top of the tester supports to maximize the forces the bridge can withstand. We solved this problem by designing the bottom corners of the bridge angled inward so that the arch can be compressed horizontally (resting on sides of supports) and the vertical end members can be compressed vertically (resting on top of supports).

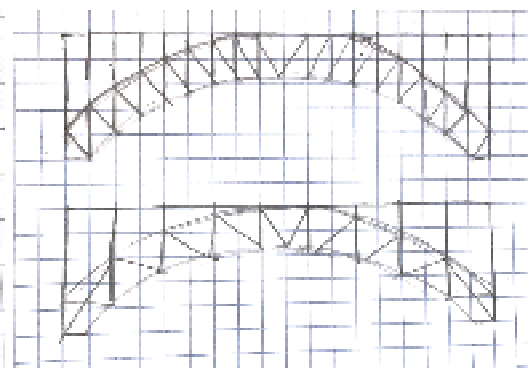
Criteria	**Constraints**
- A block of wood with dimensions 16” by 2” by 1” must be able to be pushed across the bridge deck - A ¾” hole mid-span on the bridge is required for a ⅝” testing rod to pass through - Bridge must be a deck arch truss bridge	- Must be made out of the materials given only - Length of bridge must be 18” - The maximum width of the bridge is 4.5” - The bridge can only touch the top and interior side of the Tester Supports

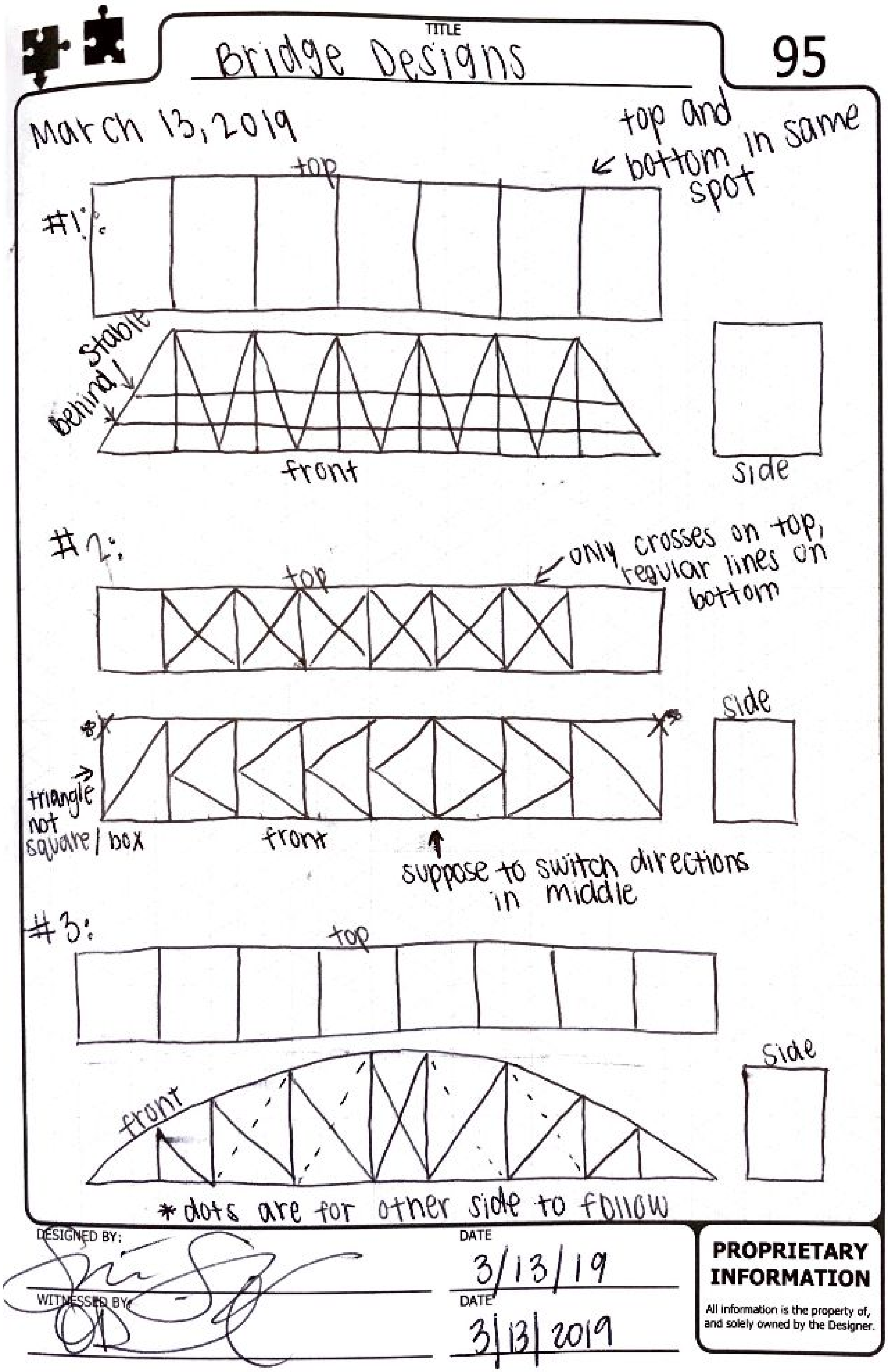
Another challenge we had was using Microstation Powerdraft to make a scaled drawing. We had never used it before, so it was a new experience to us and we had to go through a learning curve. We were able to allocate some more time for using the software, since we had some extra time in the project plan, and we were able to learn how to use the software by reading instructions and watching video tutorials.

Preliminary Designs

We each brainstormed to come up with possible solution bridges based on our research.






TITLE
Bridge Designs
95
March 13, 2019
top and bottom in same spot
#1:
top
stable behind
front
side
#2:
only crosses on top, regular lines on bottom
top
side
triangle not square / box
front
suppose to switch directions in middle
#3:
top
side
front
* dots are for other side to follow
DESIGNED BY:
DATE
3/13/19
WITNESSED BY:
DATE
3/13/2019
PROPRIETARY INFORMATION
All information is the property of, and solely owned by the Designer.

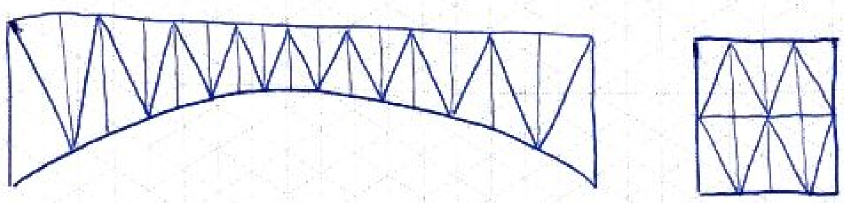
TITLE
BRIDGE CAPSTONE PROJECT

BRIDGE CAPSTONE BRAINSTORMING

3-22-19

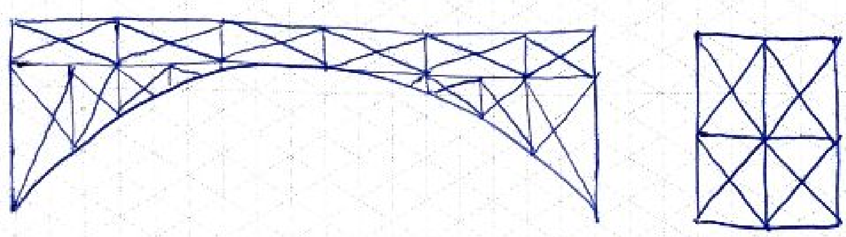
→ Design #1

Warren (with verticles)



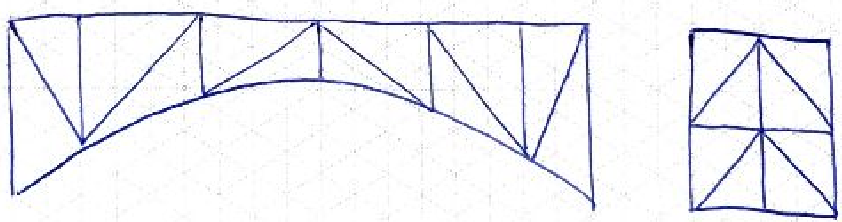
→ Design #2

Bowstring



→ Design #3

Howe

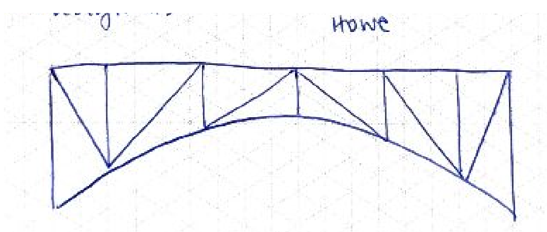
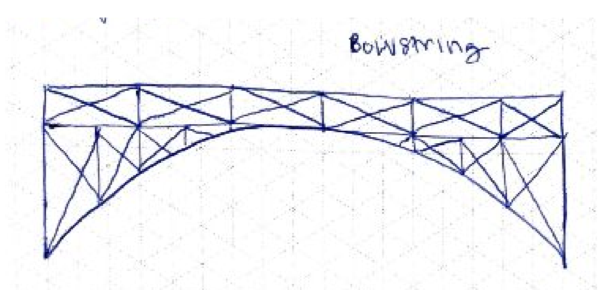


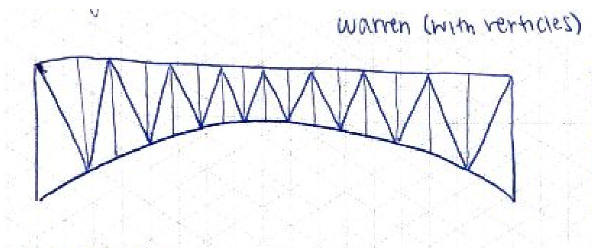
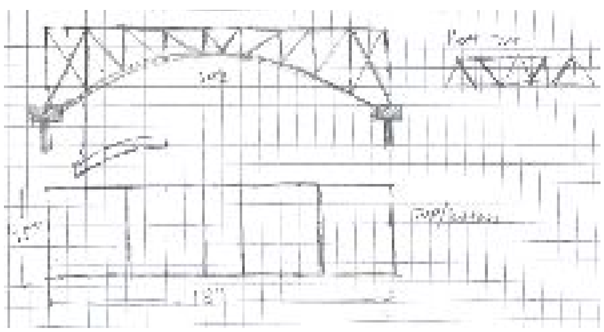
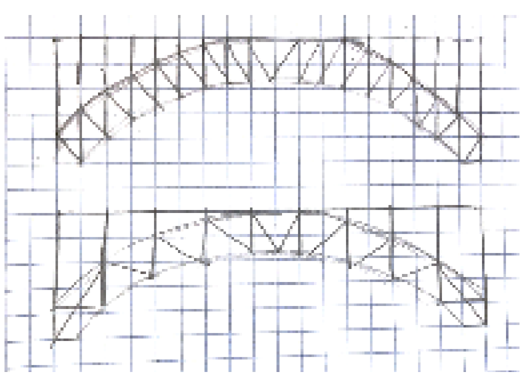
DESIGNED BY: [signature] DATE 3-22-19

WITNESSED BY: [signature] DATE 3-22-19

SWOT Analysis

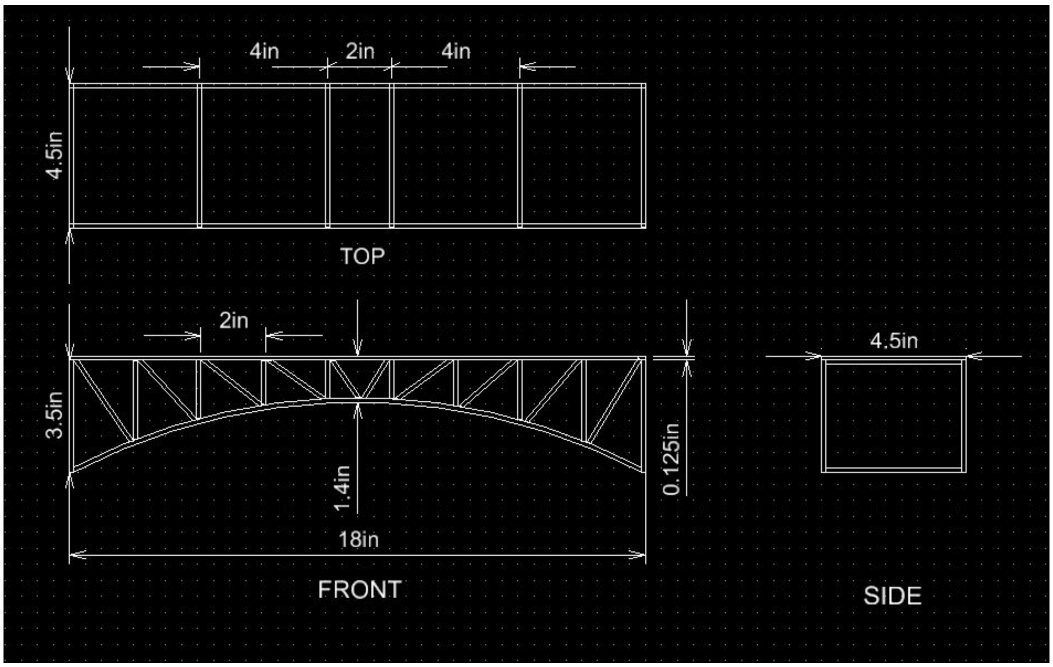
The truss bridges and arch truss bridges (not deck arch truss bridge) were removed from possible solutions because they did not fit the requirement of a deck arch truss bridge. For the rest of the bridges, a SWOT Analysis was performed, which involved identifying and comparing strengths, weaknesses, opportunities, and threats of the designs to determine the most desireable one.

	**Strengths:** Low material cost (lower weight) Suitable for longer spans. **Weaknesses:** Compressive forces are on longer diagonal members and tension forces are on shorter vertical members, which is disadvantageous for wood because wood is stronger in tension (parallel to grain) **Opportunities:** Easy to construct Comparatively less stress on top and bottom chord members, so those members may be designed with slightly lighter build. **Threats:** Fewer supports/members could cause bridge to fail more easily.
	**Strengths:** Uses triangular structures for better support **Weaknesses:** Unconnected distribution of forces **Opportunities:** Two layers allows for easy adjustment of bridge height. **Threats:** Difficult to construct; more complicated

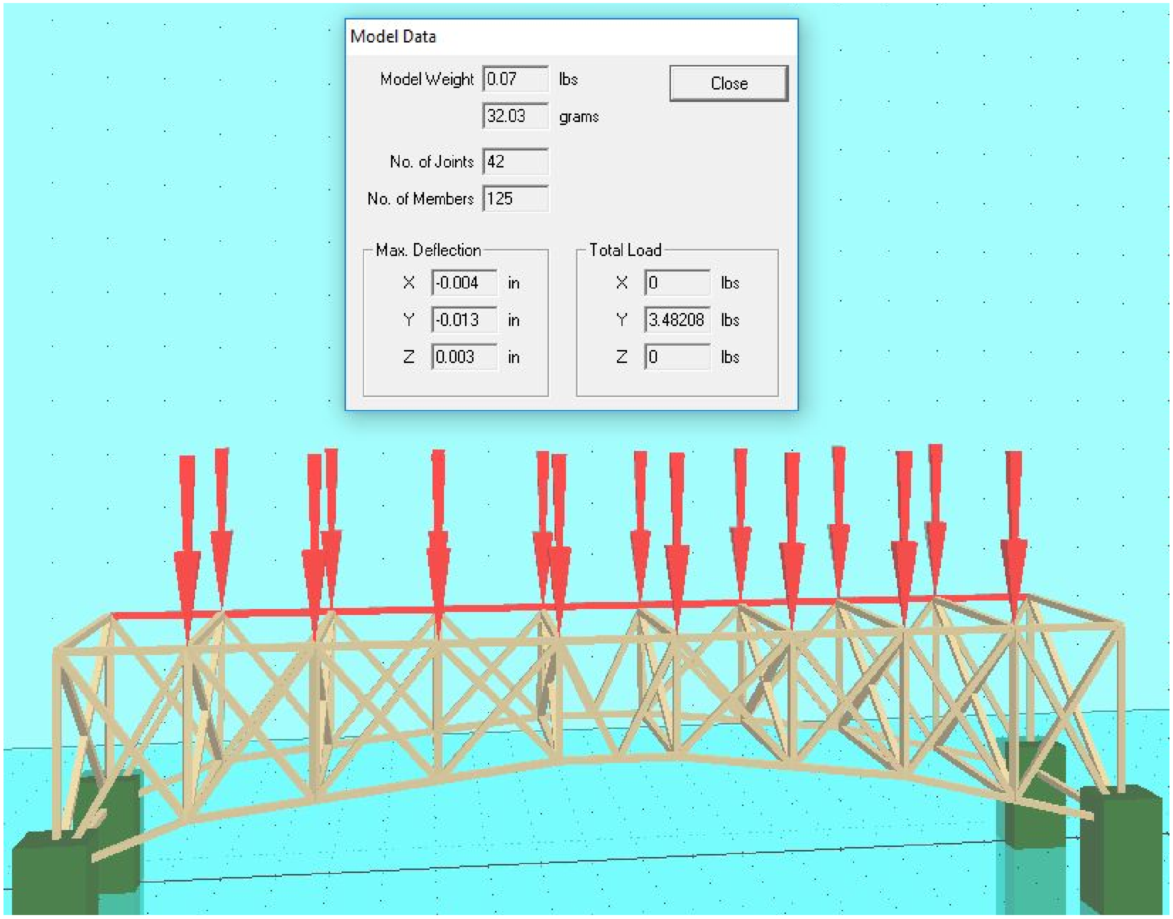
	**Strengths:** Relatively low material cost (lower weight) Both vertical and diagonal members, spreads load fairly evenly between members **Weaknesses:** Uses more materials than Howe and Pratt designs due to diagonals in both directions **Opportunities:** Relatively simple to construct **Threats:** Different angles that may be difficult to construct
	**Strengths:** Compression on shorter vertical members and tension on longer diagonal members, which is advantageous for wood. Pratt truss design is good for vertical forces Relatively low weight **Weaknesses:** Not suitable for very long spans. **Opportunities:** Comparatively simple to build **Threats:** Comparatively larger stress on top and bottom chord members, so larger section members are required for top and bottom.
	**Strengths:** Compression on shorter vertical members and tension on longer diagonal members, which is advantageous for wood. **Weaknesses:** Vertical members without triangular support can fail more easily **Opportunities:** Vertical members connect at joints, which can distribute force well. **Threats:** Difficult to construct; more complicated

Testing the Design

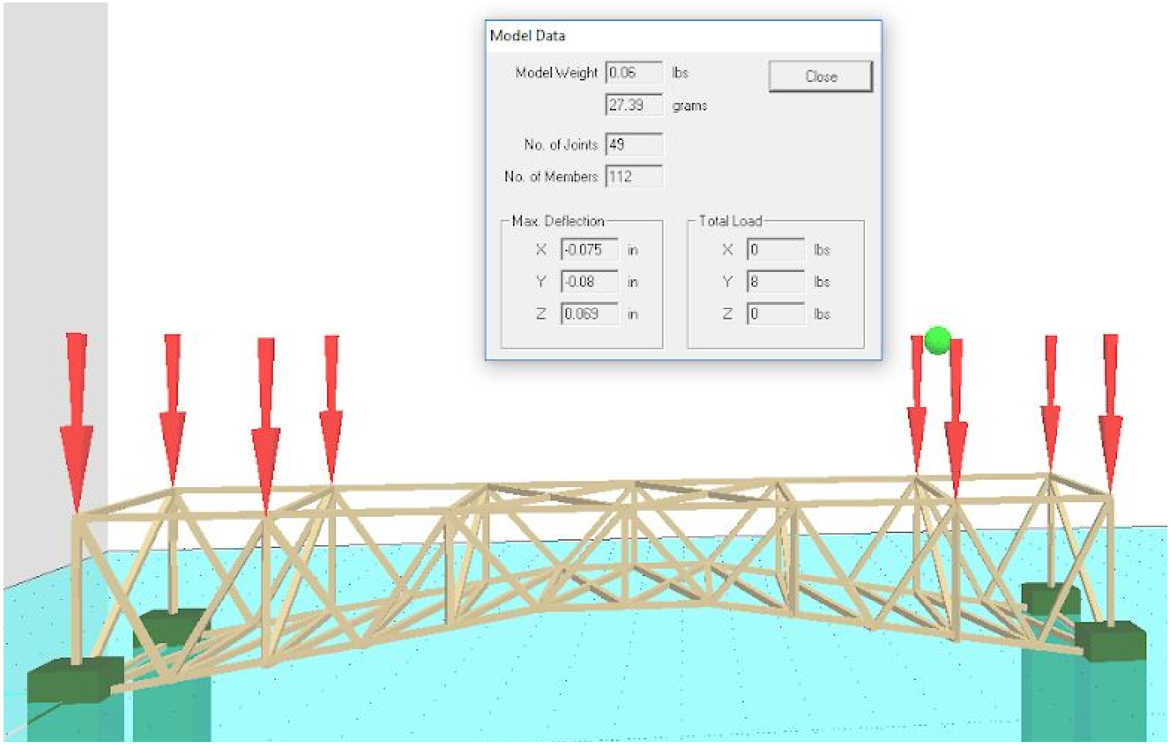
Based on the SWOT analysis, the pratt-truss based design was chosen to be tested. It had a large amount of strengths and opportunities and a low amount of weaknesses and threats compared to other designs. We used Microstation PowerDraft to make a 2D orthographic model of the bridge design to finalize the dimensions and structure.



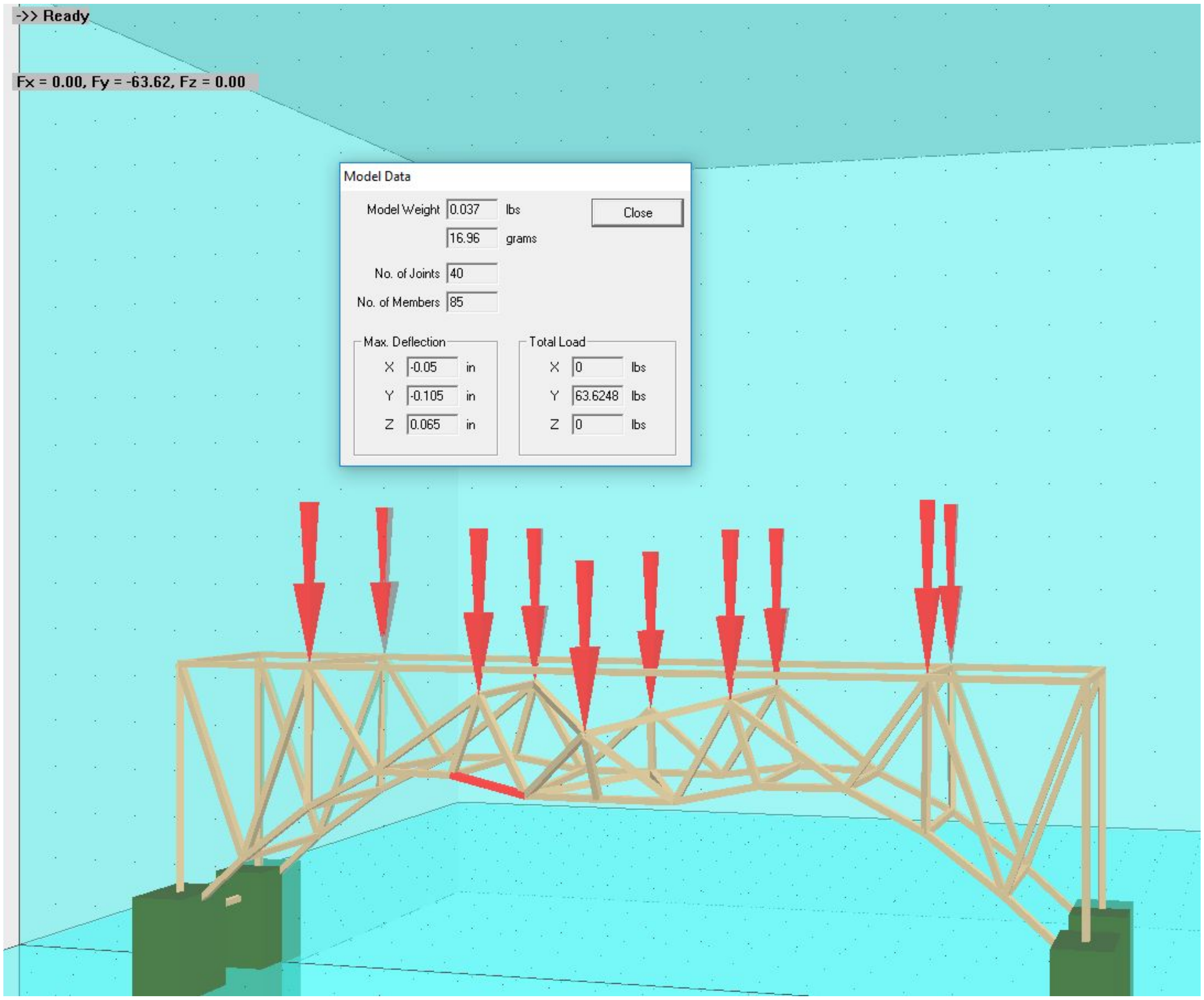
Then, we made a 3D model of the bridge in ModelSmart3D to test it. The bridge, even with additional members for support, was not able to hold four pounds. The maximum load was 3.38 pounds, and the bridge had a weight of 32.03 grams.



As a result, we decided to try the warren truss design with the same overall dimensions as the pratt-truss design. It was able to hold four pounds. We also tried adjusting the distribution of forces and found that it was able to hold up to eight pounds near the ends of the bridge with extra members for support, but not near the center where the block of would would be placed.



To improve the design, we decided to try increasing the radius of the arch and increasing the height of the bridge, while keeping the warren truss design. We also reduced the width of the bridge to 2 inches because the wooden block used for testing would only be 2 inches wide, and it is ideal to place forces on the joints of the bridge. This design was able to hold up to 63.6248 pounds based on the ModelSmart3D software, even without the extra members that were added for support in previous designs.

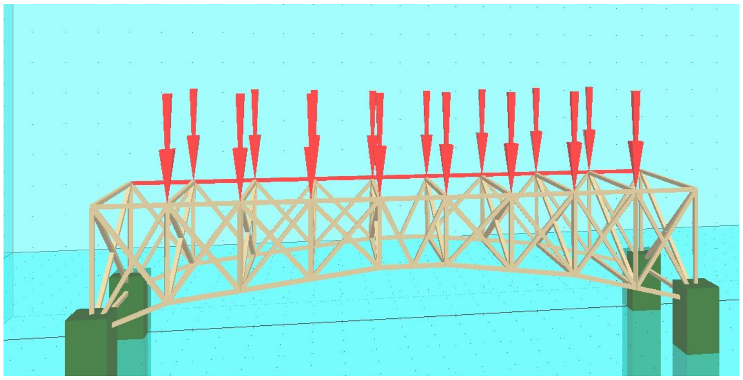


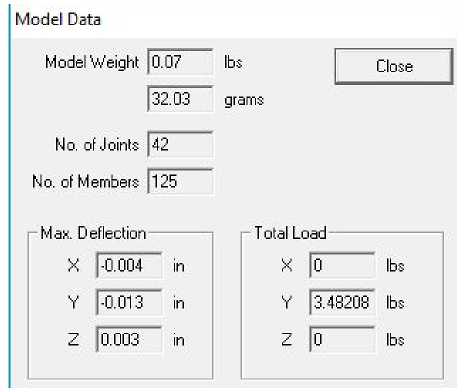
->> Ready
Fx = 0.00, Fy = -63.62, Fz = 0.00
Model Data
Model Weight 0.037 lbs
16.96 grams
Close
No. of Joints 40
No. of Members 85
Max. Deflection
X -0.05 in
Y -0.105 in
Z 0.065 in
Total Load
X 0 lbs
Y 63.6248 lbs
Z 0 lbs

Data, Graphics and Calculations

Initial Solution
(pratt-truss based)

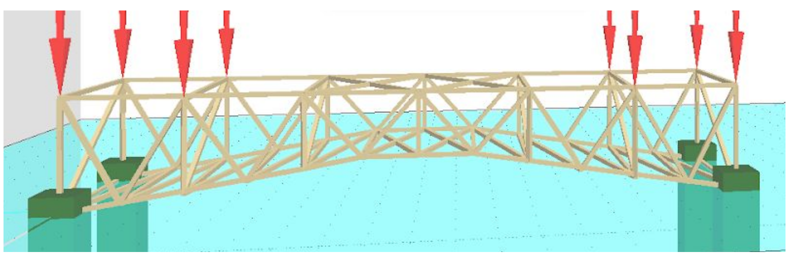
Maximum downward force (3.48208 lbs):

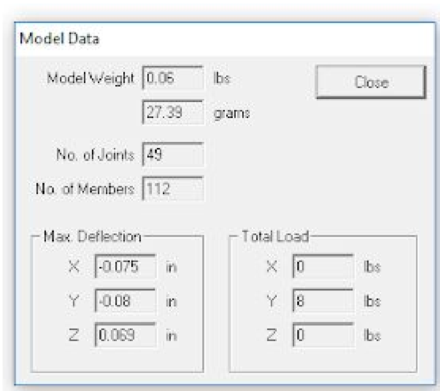




After Modifications
(warren-truss based)

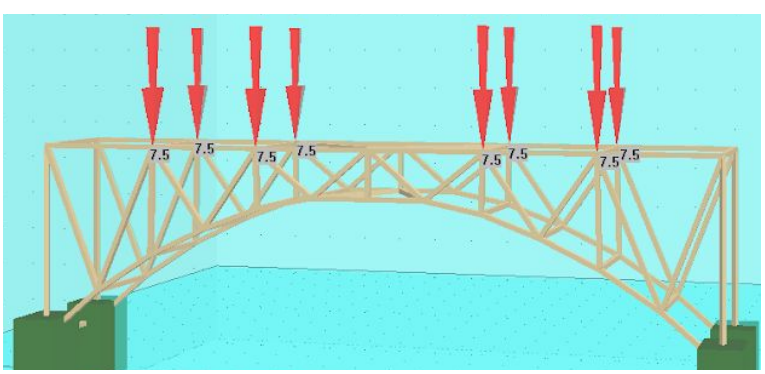
Maximum downward force (8lbs):

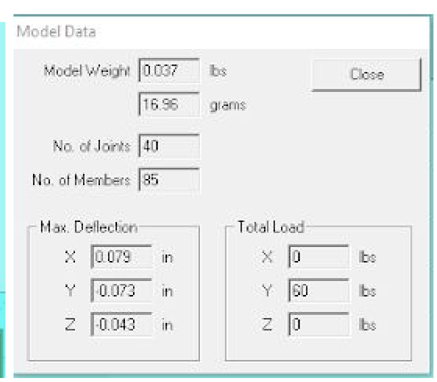




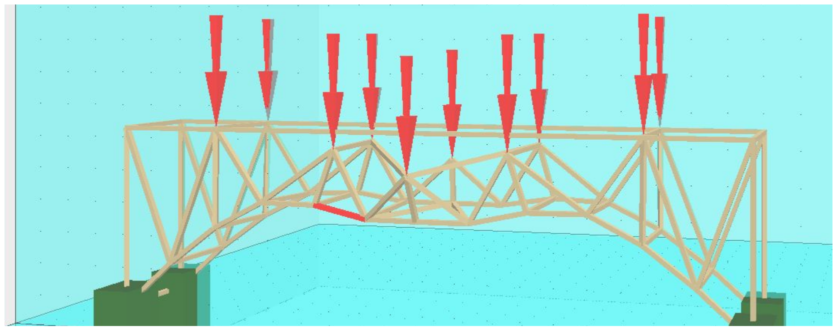
Final Solution
(warren-truss based with modifications)

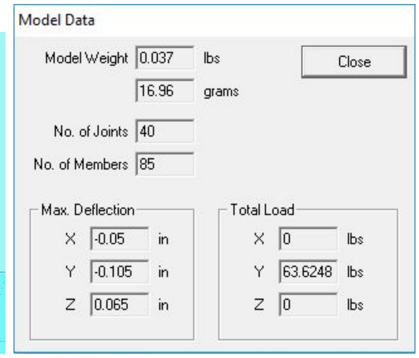
With 60 pounds of downward force:





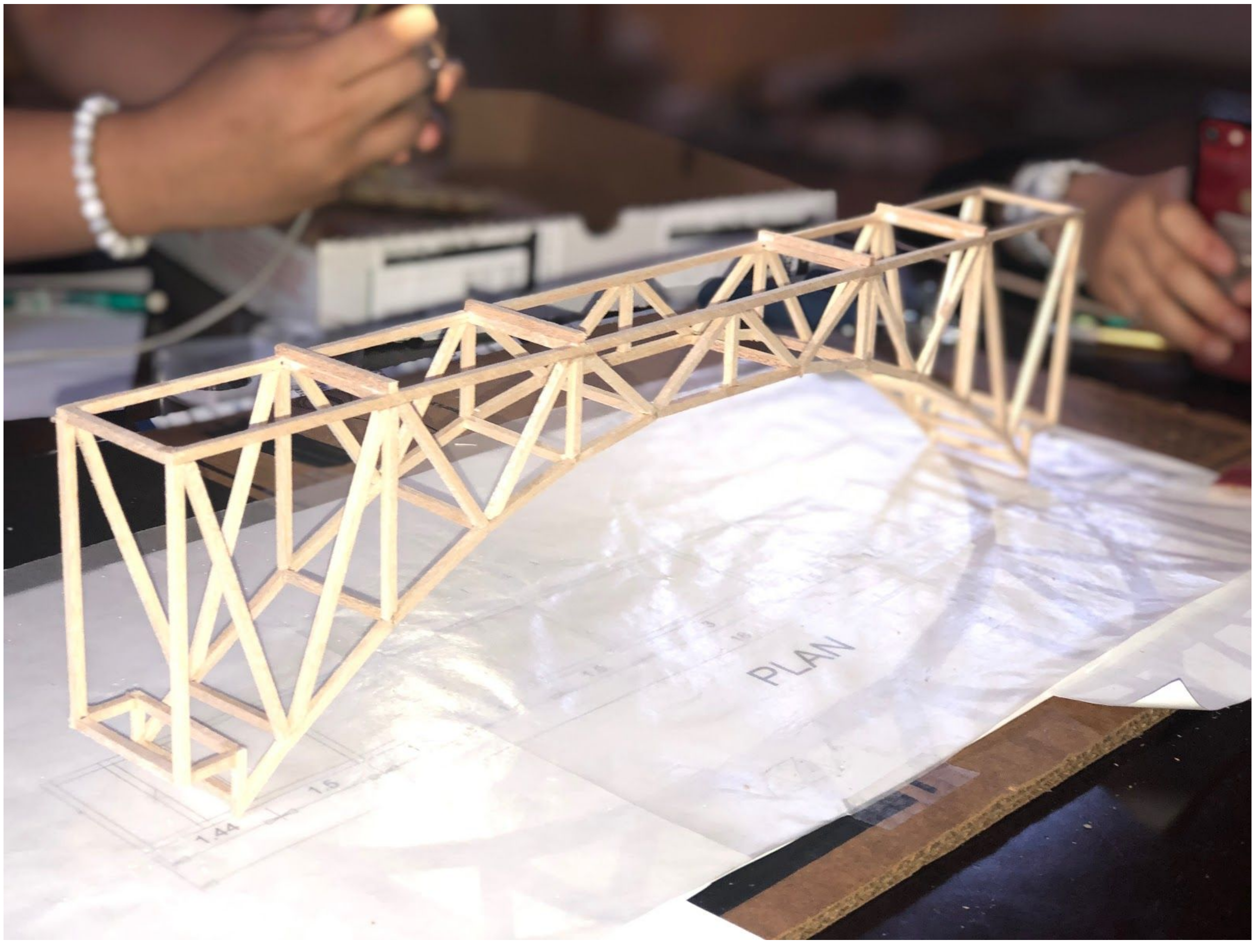
Maximum downward force (63.6248 lbs):



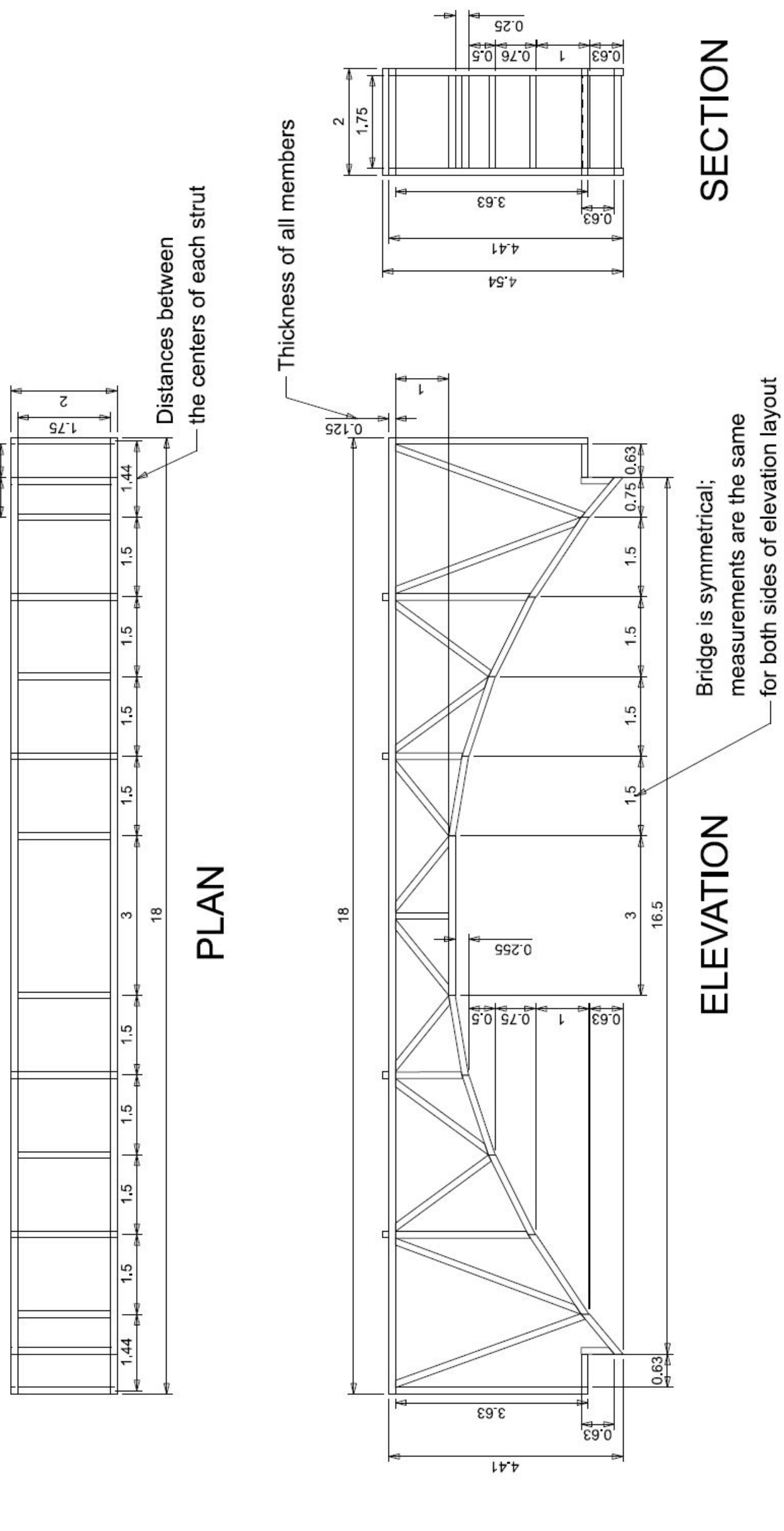


Strength-to-Weight Ratios (data from ModelSmart3D software)			
Parameter	**Initial Solution (pratt-truss based)**	**After Modifications (warren-truss based)**	**Final Solution (warren-truss based with modifications)**
Maximum load (lbs)	$3.38\ lbs$	$8\ lbs$	$63.6248\ lbs$
Maximum load (g)	$3.38\ lbs \times \frac{454g}{lb} = 1534g$	$8\ lbs \times \frac{454g}{lb} = 3632g$	$63.6248\ lbs \times \frac{454g}{lb} = 28885.7g$
Bridge weight (g)	$32.03\ g$	$27.39\ g$	$16.96\ g$
Strength-to-Weight Ratio	$\frac{1534g}{32.03g} = 47.91$	$\frac{3632g}{27.39\ g} = 132.6$	$\frac{28885.7g}{16.96\ g} = 1703.16$

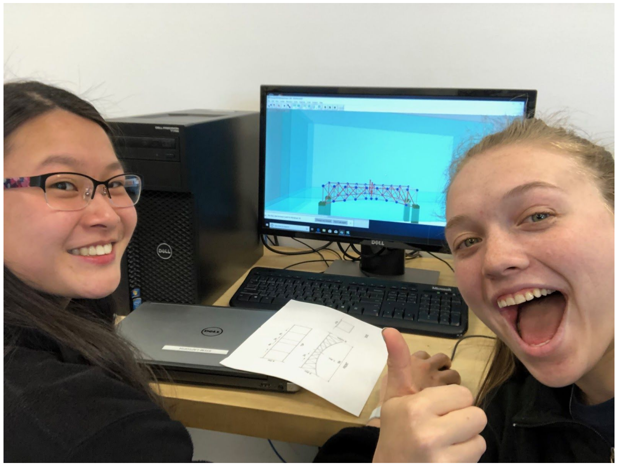
Final Bridge Solution

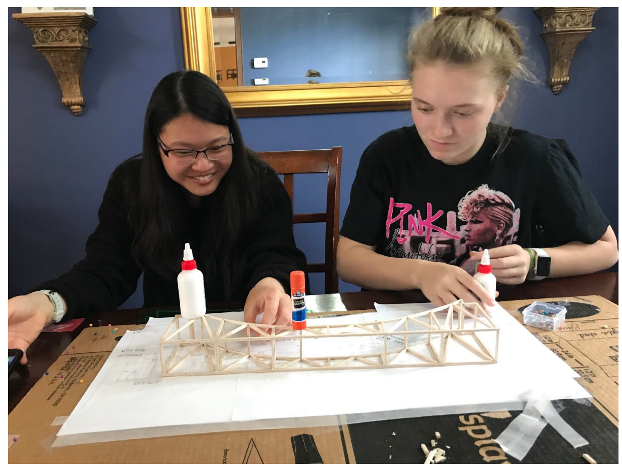


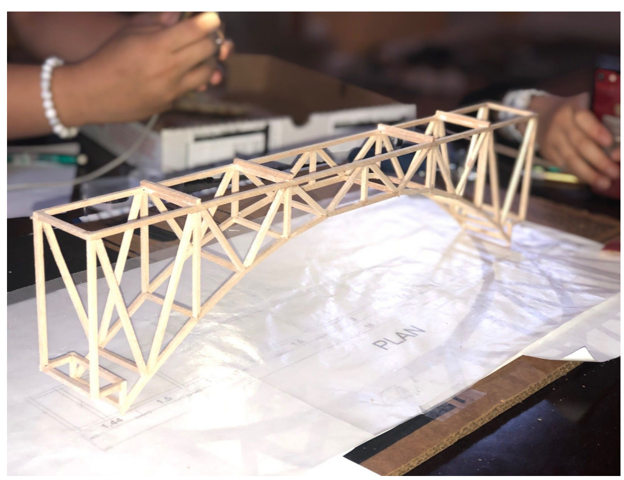
The picture above shows the completed bridge structure. It was built based on the design shown on the following page (dimensions shown in inches), which was based on the Warren-truss based design that could hold more than 60 pounds when tested on the ModelSmart3D software. The only change that was made in the final design was bottom corners that are angled inward. This allows the bridge to rest on the tester supports and use the supports to help with compression force. The vertical end members will have downward force on them, and the support will be able to provide opposite upward force. The arched bottom members will have sideways forces running down them, which can be supported by the side of the top of the tester supports.


PLAN
Distances between the centers of each strut
ELEVATION
Thickness of all members
Bridge is symmetrical; measurements are the same for both sides of elevation layout
SECTION
18
16.5
4.41
4.54
3.63
0.63
0.125
0.255
0.25
1.75
2
1.44
1.5
3
0.75
0.76
0.5
1

Photos





Challenges in Building

One of the major problems we had was losing a team member. Sometimes one of the team members had to leave school for personal problems which left the group without a team member. That really hurt the team when trying to decide on a design or finish something in time. We solved the problem by modifying the project plan. During the project, Sierra also sprained her ankle making it difficult to stay after school when other members could because the transportation. We solved this issue by distributing work that could be done at home to her (such as the proposal) and building the bridge at places closer to her house.

We were able to solve this problem by printing out the full-scale 2D plan to be able to measure and line up each member accurately. We also created multiple copies of each member at a time (since each side of the bridge is symmetrical and the two sides are the same) to increase efficiency and ease of making the exact angles.

We also had to be sure to follow safety precautions when building the bridge to prevent ourselves from getting injured. We made sure to keep our fingers at least an inch away from the cutter blade. We also wore safety glasses, kept long hair tied back, and refrained from wearing baggy clothes.

While making the design, we had to construct the bridge accurately and symmetrically to maximize the forces it can hold. We decided to construct each side of the bridge first, using the 2D full scale design as a template. We also needed to keep pieces in place as we cut and glued them. We solved this challenge by using pins to pin down the structure. To prevent the glue from sticking to the design, we placed a piece of semi-transparent wax paper between the structure and the design.

Conclusion

This project was successful. The team was able to improve the design substantially, from a bridge that could only hold around 3 pounds to more than 60 pounds. The team was also able to finish all components on time, completely, and with great effort. Through this project, we as a group has learned and gained a variety of information, skills, and lessons. The research portion of this proposal allowed us to understand the basic and in-depth information about bridges, the different types of structural designs, effectiveness of various kinds of bridges, and the concepts of force and load. As we were introduced to a new CAD software to virtually build our bridge design, we gained additional technical, programming, and problem solving skills while using these essential softwares. Most importantly, we as a group have learned the significance of teamwork, communication, and hard work. Our team faced different challenges along the way but in the end we were a team. We created a bridge together and became closer than before. We recommend to continue this project next year due to the invaluable experiences we have earned through it.

Acknowledgments

"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 below."

- ★ Brendan Murphy assisted us by introducing us to the project, advising us, and supervising us.

  X____________________ Date: 4/17/19

- ★ Roger Seedorf assisted us by giving us advice and suggestions for ways to test the bridge.

  X____________________ Date: 4/17/19

- ★ Emily Bush assisted us by helping us install the necessary software to virtually build and test our bridge design.

  X____________________ Date: 4/17/19

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Appendices

i. Scheduling and Accomplishments

During the Bridge Competition, we were also working on another project for the class called the Drought Time project. We made sure to balance the time for both projects in our project plan so that we would be able to complete both efficiently, and we checked the project plan periodically to make sure we were staying on task. We also had status reports to make sure we were not falling behind and to receive guidance from mentors. Overall, we were able to complete most of the items as scheduled, but we did have to push some tasks back, such as building the bridge, because some members were not able to make it to school.

DelDOT Bridge Competition & Drought Time Project Plan

Holidays
School Functions
Drought Time Events
Bridge Capstone Events

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
February	**10**	**11**	**12**	**13**	**Valentine's Day 14**	**15**	**16**
	17	**18**	**19**	**Research Assignment 3 Due 20**	**21**	**Research Assignment 1 and 2 Due 22**	**23**
	24	**Materials Arrived; Design Paths and vehicle 25**	**26**	***Checkpoint 1; Status Report 1*** **27**	**28**	**Work on Slides 1**	**Contact all panel members by this date 2**
March	**3**	**Map out three locations for drop off research: geography & current transportation**	**Complete Research 5**	**Create account for software; Project plan due 6**	**cyber day 7**	**Write explanation for vehicle subsystems no school 8**	**9**

		4					
	daylight savings 10	Finish up checkpoint #2: due 03/13 begin to work on the final prototype, due 03/27 11	12	Checkpoint 2 3 Design ideas from each member due 13	14	15	16
	St. Patrick's Day 17	Start Presentation 18	19	Final prototype SKETCH: done 3D model: start working; Begin to describe each subsystem 20	21	Calculate Vehicle Costs 22	23
	24	Finish up everything for checkpoint #3 for 03/27; final prototype & sub-system explanation 25	26	SAT's 27	28	Work on written proposal Get familiar with software 29	Work on written proposal 30
April	Work on written proposal 31	Issues & tradeoffs; total cost; final prototype; final presentation Checkpoint 3 1	Test each design with software; calculate strength:weight ratios; Finalize initial solution design 2	Checkpoint 4 3	Test each design with software; calculate strength:weight ratios; Finalize initial solution design 4	Test each design with software; calculate strength:weight ratios; Finalize initial solution design 5	6
	7	Build bridge Meet with Cpt. Seedorf Team Status Report 2 8	Build bridge 9	Drought Time Presentations 10	Build bridge 11	Build bridge 12	Work on written proposal 13
	Work on written proposal 14	Work on written proposal Build bridge 15	Work on written proposal 16	Finalize written proposal Proposals Due by 5PM 17	18	Spring Break 19	Create on-site presentation slides Spring Break 20

	Create on-site presentation slides **Spring Break** **21**	**Spring Break** **22**	**Spring Break** **23**	**Practice presentation** **Spring Break** **24**	**Spring Break** **25**	**Spring Break** **26**	**Spring Break** **27**
May	**Finalize presentation** **Spring Break** **28**	**Team Status Report 3; PowerPoint Presentation due** **29**	**30**	***Competition @ Polytech Adult Education Center*** **1**	**2**	**3**	**4**

Meeting records:

Status Report 1 (February 27): We talked to Mr. Murphy about tasks we have already finished, including going over the project, creating a project plan, and starting research. We also talked about our next plans, which were to finish research, familiarize ourselves with the software, and create preliminary designs. We went over some concerns about the project, such as being able to have transportation to the competition and having time to work on the project since we also have to work on the Drought Time project. Mr. Murphy agreed to extend the Drought Time project and give us class time to work on the DelDOT Bridge Competition

Status Report 2 (April 8): We talked to Captain Seedorf about our status. We are finished with most of the proposal and need to finish building the bridge by the proposal due date. After that, we only need to work on the presentation and practice it. We talked about what we learned from the project and why it would be good to continue the project in the future.

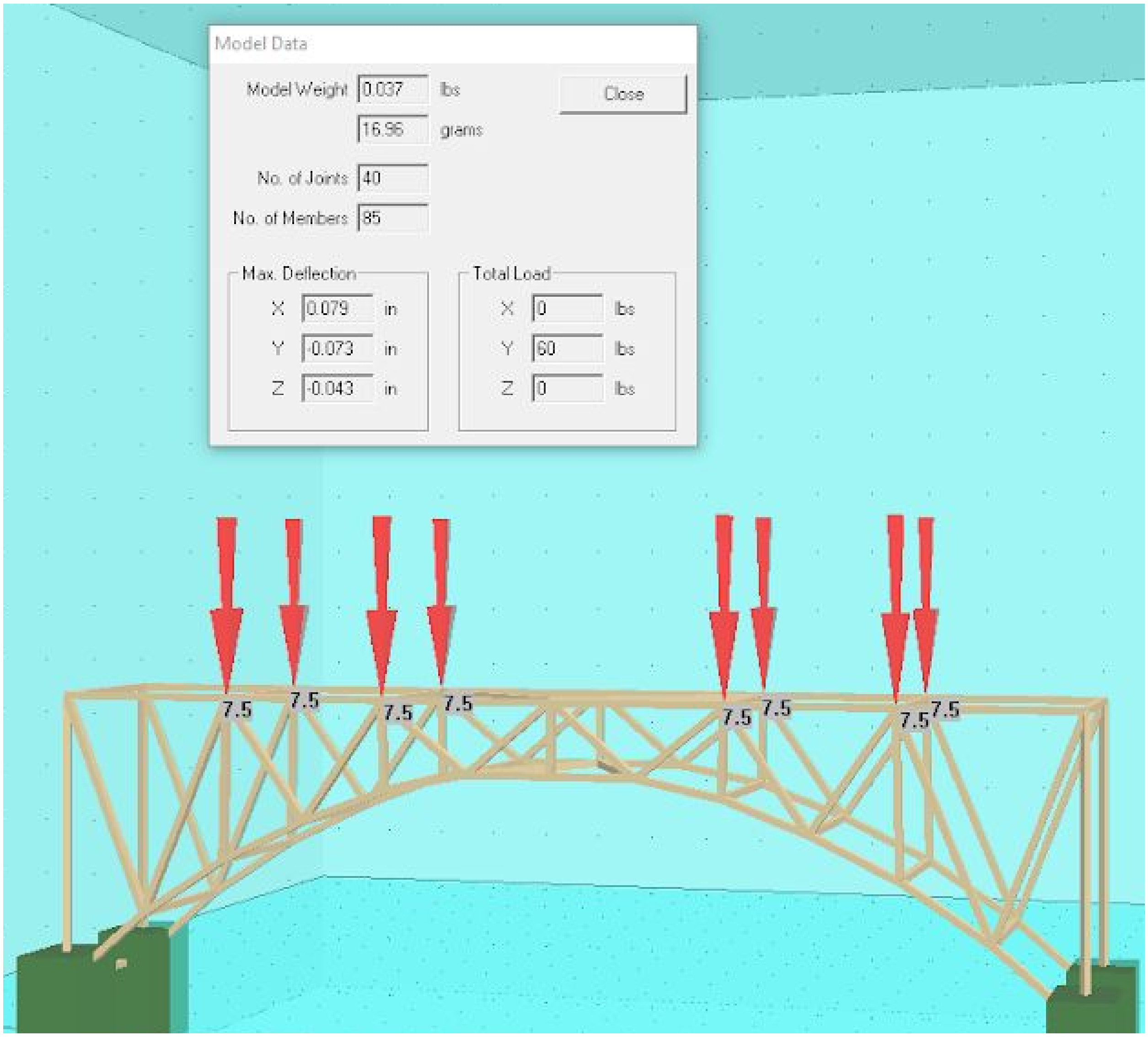
ii. Daily Journals

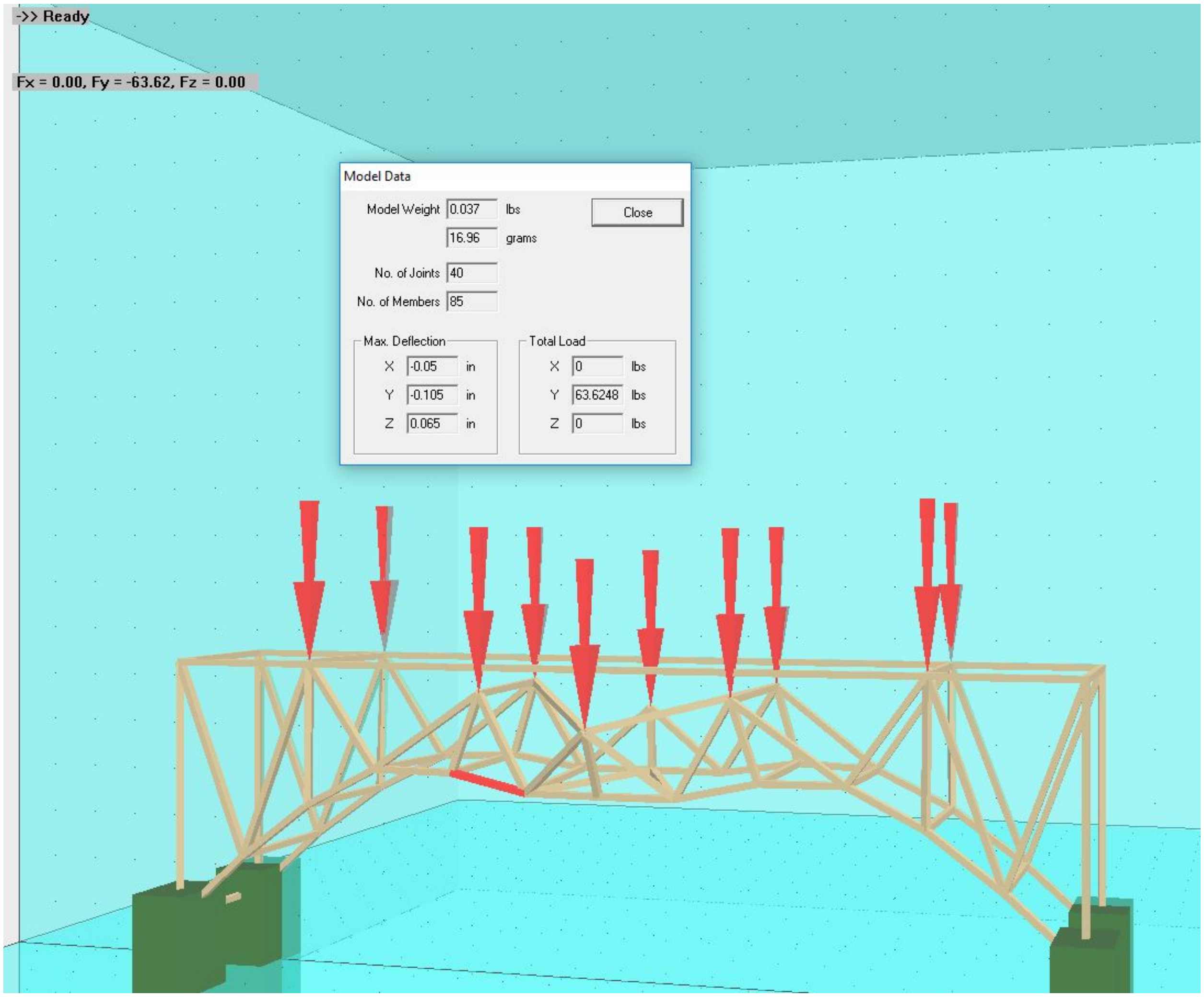
Date	Notes
2/8	The team looked over individual roles and each member created logos for the team. We also went over the rules and guidelines, along with that started creating a proposal document.
2/22	The team completed the introduction paragraph on each of us, chose a final logo, and finalized it.
2/25	Today we received our materials and went over everything that is required for the project and presentation. We also downloaded the software that is required for the project onto the school laptops. No individual work was done; all work was done together.
3/4	Today we learned about the software. There was something else that needed to be downloaded and we are going to try and download it onto our personal laptops by following the paper provided for us. A group member was also missing today which means we are going to meet with our mentor on Wednesday.
3/6	Today we met with our mentor and discussed everything that we needed to complete the project. He gave us some resources that we could use in our research and building the bridge. We also completed our research on the bridge today.

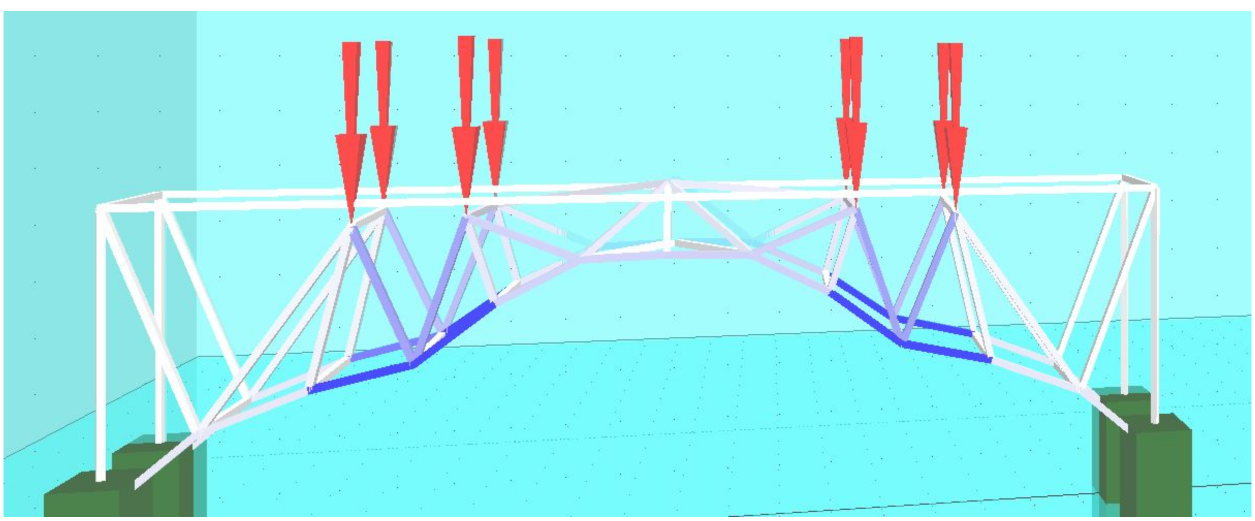
3/13	Today we went over our researched and started to create some designs that we could test on the software. Hopefully, we can get the software at home and we can work on it at home. Today Sierra finished her three designs from each team member.
3/18	Cynthia is working on her designs and downloaded the software on our personal laptops. The presentation is also starting to be put together today. Along with starting the presentation, we also made modifications to our project plans.
3/22	Angela created her designs and Cynthia finished up hers. All research was placed into the proposal. Sierra also worked on the proposal and the group started to get familiar with the software. They also started to perform SWOT analysis with the bridges to find the best one.
3/29	Today Cynthia finally got to work on the software and build our first bridge. Angela corrected the written proposal to fit the formatting and information that was missing. Sierra changed and improved the project plan along with the the status report that is due on April 5. Sierra also worked on the written proposal. Angela and Sierra both helped Cynthia with the software if help was needed.
4/2	Cynthia and Sierra stayed after school today and tested out their first bridge design on the software (Pratt). It was a fail, since the bridge was only able to hold around 3 pounds. They started a new design (Warren) to try and hold more weight.

4/8	Cynthia worked on the software and tried modifying the design to make it more efficient. She was able to increase the curvature of the arch to make it smoother, allowing the bridge to hold more than 60 pounds. Cynthia, Angela, and Sierra also worked on the Bentley Microstation Powerdraft software to create a drawing of the final design.
4/10	Cynthia finished the final design. Cynthia and Sierra worked on building the bridge with a full-scale printed version of the design. They were able to finish one side of the bridge. Next week they are planning on finishing the bridge.
4/13-4/15	Cynthia, Sierra, and Angela worked on the proposal.
4/15	Sierra, Cynthia, and Angela met with their mentor and had their second team status report to make sure they were on track with what they are doing. After the status report, we continued to build our bridge. We finished one side of the bridge and cut all the pieces for the top and bottom connectors in class. We went to Angela's house to continue building and finish the bridge.
4/16	Sierra, Cynthia, and Angela finished the rest of the proposal except for the bibliography.
4/17	Sierra and Cynthia are finishing the bibliography and sending the proposal in to be looked at before 5pm.

iii. Design Software




->> Ready
Fx = 0.00, Fy = -63.62, Fz = 0.00
Model Data
Model Weight 0.037 lbs
16.96 grams
Close
No. of Joints 40
No. of Members 85
Max. Deflection
X -0.05 in
Y -0.105 in
Z 0.065 in
Total Load
X 0 lbs
Y 63.6248 lbs
Z 0 lbs



iv. Photos