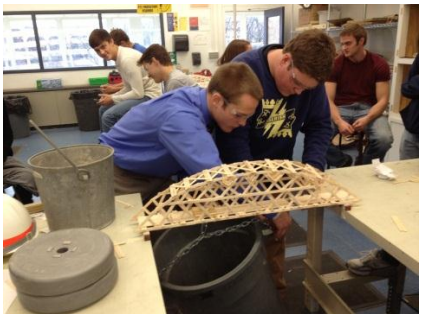
EDSGN100 Truss Bridge Design
Final Design Report

Introduction to Engineering Design
EDGSN 100 Section 11

Team 7
#7

Alexander Bellows, personal.psu.edu/aqb5335, aqb5335@psu.edu
Ian Whitehead-Scanlon, personal.psu.edu/iaw5023, iaw5023@psu.edu
Kevin Rold, personal.psu.edu/kar5627, kar5627@psu.edu
Jason Lewis, personal.psu.edu/jtl5212, jtl5212@psu.edu



Alex Bellows
Ian Whitehead-Scanlon
Kevin Rold
Jason Lewis

Submitted to: Prof. Berezniak

Date: 11/16/12

EDSGN100 Bridge Design

EDSGN100 Truss Bridge Design
Final Design Report

Table of Contents

Executive Summary

1.0 Introduction…… Page 4
2.0 General Factors for Design…… Page 4
2.1 Structural Constraints…… Page 4
2.2 Construction Constraints…… Page 4
2.3 Quality Control Testing…… Page 5
2.4 Aesthetics…… Page 7
2.5 Economics …… Page 7
3.0 Consideration of Design Alternatives…… Page 7
4.0 Selection of Bridge Design…… Page 7
5.0 Prototype Construction…… Page 8
6.0 Estimated Load Capacity…… Page 8
7.0 Prototype Load Testing…… Page 9
8.0 Prototype Performance and Forensic Analysis…… Page 9
9.0 Final Design Performance…… Page10
10.0 Refine the Design…… Page11
11.0 Conclusions and Recommendations…… Page11
12.0 References…… Page12

List of Tables

Table 1 Quality Control Testing…… Page 5
Table 2 Costs…… Page10
Table 3 Failure Load to Bridge Weight Ratio…… Page10
Table 4 Bridge Aesthetics…… Page11
Table 5 Truss Bridge Competition…… Page11

List of Figures

Figure 1 Unglued Sticks…… Page 3
Figure 2 Glued Sticks (Glue Wet)…… Page 3
Figure 3 Glued Sticks (Glue Dry)…… Page 3
Figure 4 Final Bridge Design…… Page 7
Figure 5 Bridge Concept Drawing…… Page 8
Figure 6 Fractured Bridge…… Page 9

EDSGN100 Truss Bridge Design
Final Design Report

Executive Summary

Our task was to design a bridge to cross a gap of 29 inches. There were many other structural constraints as well that limited our design. The bridge could not exceed 400g and 34 inches in total length. Also, the bridge could not exceed 10 inches above the end supports or 3 inches below the end supports. There are more specifications discussed later on in the report. There were constructional constraints as well as structural that had to be followed. Some of these include having no gaps in the roadway except where the load testing device was placed. Also, no more than 50% of any popsicle stick could be glued to another popsicle stick. These constraints significantly impacted our design.

Before each group created their design, quality control testing was done. Each stick was weighed dry, with glue, and dry with glue. This was done for groups of 2,4,6,8...which gave each group a basis for how many sticks they would be able to use in order to not exceed the maximum weight of the bridge. Our group used these results to determine the maximum number of sticks and glue that we could use without exceeding our limit. The QCT results are shown later in the report.

Aesthetics was one of the judging categories for the bridge design contest. So, we ensured that our design provided an aesthetically pleasing bridge that also would be able to support a great amount of weight. We decided on an arched truss for our final design.

Economics played an equally important role in our bridge design. We had to create bridge that would look appealing, while remaining strong, while also minimizing our cost. Overall, the construction of our bridge cost $675,000. This was slightly more than the cost should have been due to our overestimate on the amount of glue we needed. Had we determined the correct amount of glue, the bridge would have cost around $500,000.

We had a few other bridge designs that were created, but our arched bridge design was the most appealing, while also holding the most weight per its cost. We estimated that it would take about 270-280 sticks to build our bridge, which it did. After weight testing, our bridge weighed in at 346.8g, which was well below the 400g maximum weight.

Load testing was performed by attaching chain to a block placed inside our bridge. The chain was then attached to a large garbage can. Weights were placed in until nearing the breaking point. Once it neared breaking or when there were no more weights, sand was dumped in to the garbage can until the bridges failed. Our bridge failed after holding 104.2 lbs. During the creation of our bridge, the way the sides dried due to gravity caused them to warp, which made our bridge crooked. If we were able to create the bridge straight, we believe it would have held more than 115 lbs.

Compared to the other design groups, our bridge was pretty successful. It held the 4th greatest amount of weight. It was ranked 4th best for aesthetics, despite it being crooked. It also had the 4th best failure weight to bridge weight ratio. Our cost came in ranked 7th compared to the other groups because of our severe miscalculation for how much glue we would need. Besides our cost, our bridge was about average compared to the other design teams.

If we were to design this bridge again, we would change some things in the design to allow it to hold more weight. First, we would add more members to the second tier on our bridge to give more overall support to the frame. Second, we would build the road perpendicular to the path of

the bridge instead of parallel. Lastly, we would ensure that the bridge was not built crooked because of faulty gluing. If these changes were made in a future design, our bridge would be more appealing while holding much larger amounts of weight.

1.0. Introduction.

We were given the task of designing a bridge to cross a canyon. We produced a concept design that was both cost efficient as well as incredibly sturdy. Overall, we had to abide by many structural and construction restraints that required us to change our design slightly. We also attempted to make our bridge aesthetically pleasing, while ensuring that the bridge will remain structurally sound. We considered some other bridge designs, however, we chose the arched type design because it held the most weight and was the most appealing bridge.

2.0 General Factors for Design.

2.1 Structural Constraints.

No part of the bridge may exceed 10-inches above the end supports or 3-inches below the end supports. The bridge must have a roadway that can accommodate a 4-inch high by 4-inch wide vehicle. The total outside width of the bridge must be 5-inches or less. The length of the bridge must be greater or equal to 30-inches in length, but may not exceed 34-inches in total overall length.

Weight: The total bridge must weigh 400 grams or less at the time of loading.

For our bridge, we chose an through truss bridge that resembled a bowstring truss bridge type.

2.2 Construction Constraints.

Roadway: The roadway must be constructed as if wheeled traffic were to cross over its span. The roadway must be continuous along its width over the entire distance between the supports (except for a gap exactly 10-inches from where the bridge end supports would be located, assuming a 29-inch clear span.). No gaps shall exist in the roadway except where natural warping has occurred after construction of the bridge. The roadway is the portion of bridge to be loaded. If you have bridge structure over the roadway, an opening must be maintained above the loading area on the roadway to allow the bridge to be loaded. The roadway must be constructed to accommodate a 4-inch high, 4-inch wide vehicle. No part of the roadway may be greater than 6-inches above or less than 2-inches above the top of the end supports.

Connections: Not more than 50% of any plan surface of any member may be laminated. (50% Rule) Each member consists of two plan surfaces (the two larger sides unless all sides are equal then all sides must comply with the 50% rule). A maximum of 6 sticks may be stacked at any joint. There must be at least a 1-inch clear gap between any two stacks.

For load testing, the bridge will set on supports that will be provided by the Instructor. No special supports may be used. The end supports will have the dimensions of: 3/4-inches wide x 3/4-inches high x 5-inches long. The end supports will be placed 29-inches apart (center-to-center). Mark where the end supports should come in contact with your bridge. A 'simple connection' shall only be used to connect the bridge to the loading supports. The bridge may not exert any horizontal loads on the supports, other than friction.

The bridge will be loaded on the roadway 10-inches from one of the ends. The loaded end will be determined by the Instructor on bridge loading day. The load will be applied on a 3-inch square loading plate with the center of the plate placed exactly 10-inches from one end of the bridge on the roadway (deck). A 3x3-inch square will be drawn on your bridge at the contest. The load will be applied from weight applied below the roadway. The bridge must be constructed to allow a steel cable or chain to be suspended vertically from the 3-inch square loading plate and hang below the deck.

2.3 Quality Control Testing.

In order to make an accurate bridge design with weight taken into account, we had to weigh our popsicle sticks in three different categories: wet with glue. dry with glue, and dry before glue. The following tables and graphs show the results of the weighing procedures which let us calculate the maximum amount of popsicle sticks and glue that our bridge could use.

EDSGN100.011						
No. of sticks	Unglued Weight (grams)	Estimated Weight per Stick (grams)	Glued Weight WET (grams)	Estimated Weight per Stick (grams)	Glued Weight DRY (grams)	Estimated Weight per Stick (grams)
2	2.6	1.300	2.6	1.300	2.6	1.300
4	5.4	1.350	5.5	1.375	5.5	1.375
6	8.0	1.333	8.2	1.367	8.1	1.350
8	11.0	1.375	11.2	1.400	11.1	1.388
10	13.7	1.370	13.9	1.390	13.8	1.380
12	16.5	1.375	16.8	1.400	16.7	1.392
14	19.1	1.364	19.5	1.393	19.4	1.386
16	21.7	1.356	22.1	1.381	22.0	1.375
18	24.4	1.356	24.8	1.378	24.7	1.372
20	27.1	1.355	27.6	1.380	27.4	1.370
WEIGHTS	minimum	1.3000	minimum	1.3000	minimum	1.3000
	maximum	1.3750	maximum	1.4000	maximum	1.3917
	average	1.3534	average	1.3764	average	1.3687
No. STICKS	minimum	308	minimum	308	minimum	308
	maximum	291	maximum	286	maximum	287
	average	296	average	291	average	292

Table 1

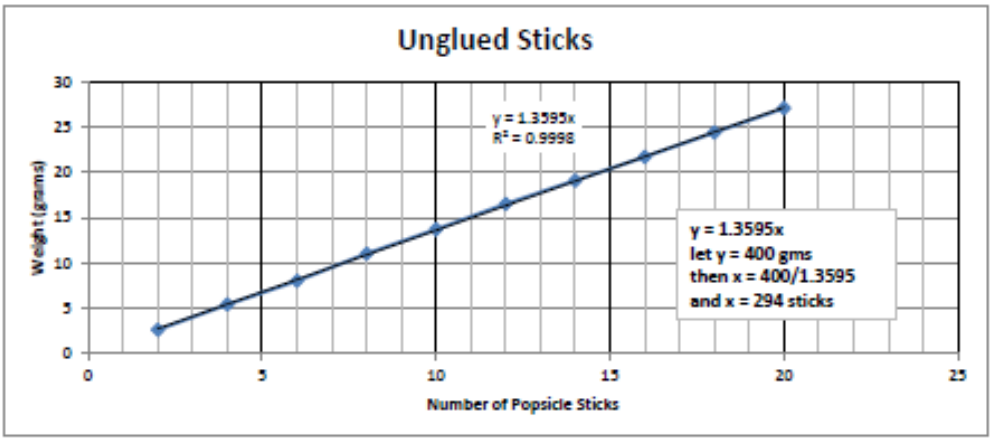


Figure 1

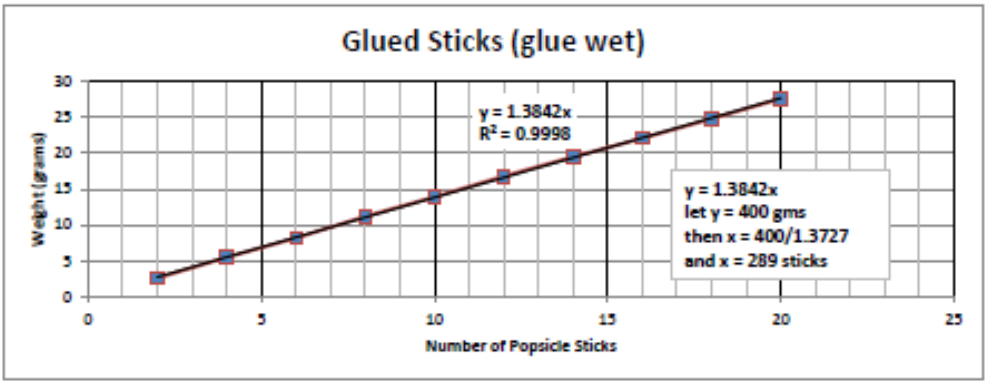


Figure 2

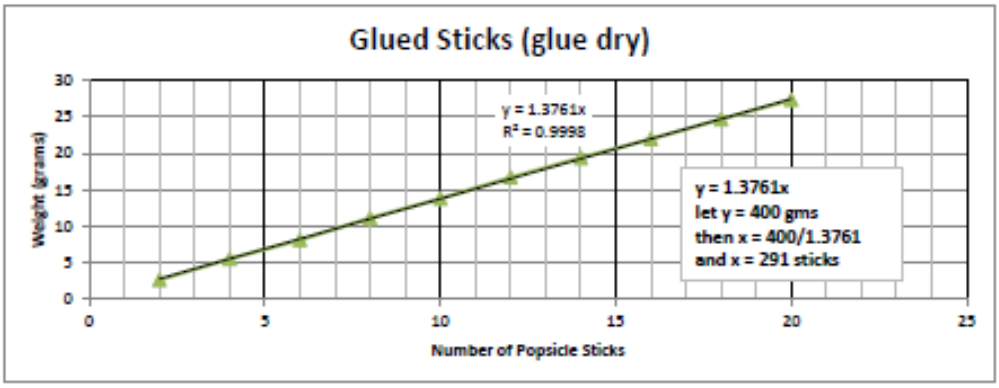


Figure 3

2.4 Aesthetics.

Our bridge featured pleasing aesthetics. The arched bridge design has always been an appealing one. Unfortunately, the way our glue dried, our bridge turned out to be a little crooked. However, when all 8 bridges were ranked by a previous class, we still managed to get a rank of 4. Had our bridge not been crooked we would have managed 1 or 2. Our bridge had two layers of bracings on the sides as well.

2.5 Economics.

With this bridge design, cost was a major factor. Each popsicle stick cost $1000 to simulate a real world price. Glue cost $5000 dollars per gram. We had to make careful estimations on how much supplies we originally purchased. We had a good estimate for the amount of popsicle sticks needed. We bid for 300 sticks and used about 280 of them. The remaining 20 sticks were sticks that were warped that we would have rather not used. We bid for 75 grams of glue. This was an extreme over estimation. We figured we would use a lot more glue since we had 300 sticks, however, we didn't use as much as we thought we would. We only used 28.1 grams of glue. The cost of the bridge would have been significantly less had we estimated the amount of glue correctly. Labor was also a factor which raised our cost. It was $100/hr.

3.0 Consideration of Design Alternatives.

We had a few other designs that we could choose from for our final design. None of them were as strong as the final bridge we chose. We designed a typical pratt through truss bridge that was cost efficient, but it lacked the strength needed. We also had another arched bridge design that included a under carriage with extra support underneath. This bridge had too many members and would have been difficult to build. With all of these factors taken into account, we decided on the final design as seen below.

Figure 4

4.0 Selection of Bridge Design.

When we considered our bridge design, we had many factors to account for such as bridge weight, strength, ease of construction, cost, and labor. The arched bridge that we chose had the best strength compared to the other two bridge designs. It was slightly more difficult to build since it had a complex arch design, however, the strength paid off the extra work. It was slightly

more expensive compared to our other bridges, but the slight increase in cost was well worth the increased strength achieved. Overall, the arched bridge was our best design for success.

5.0 Prototype Construction.

When constructing our bridge, we had many factors to account for, such as number of sticks needed to build the bridge and how much glue we would need. After creating a drawing of our bridge, we believed that we would need between 270-280 sticks. So, we bought 300 since we didn't want to include any warped sticks and we figured there would be a decent amount of them, which there were. After viewing our bridge design, we knew that it wouldn't exceed 400g, so we weren't too worried about the weight. Our constructed bridge weighed in at 346.8g. We figured that it would take about 8 total hours of build time. After building the bridge in completion, it was pretty close to this amount of time. Below is the original sketch of our bridge.

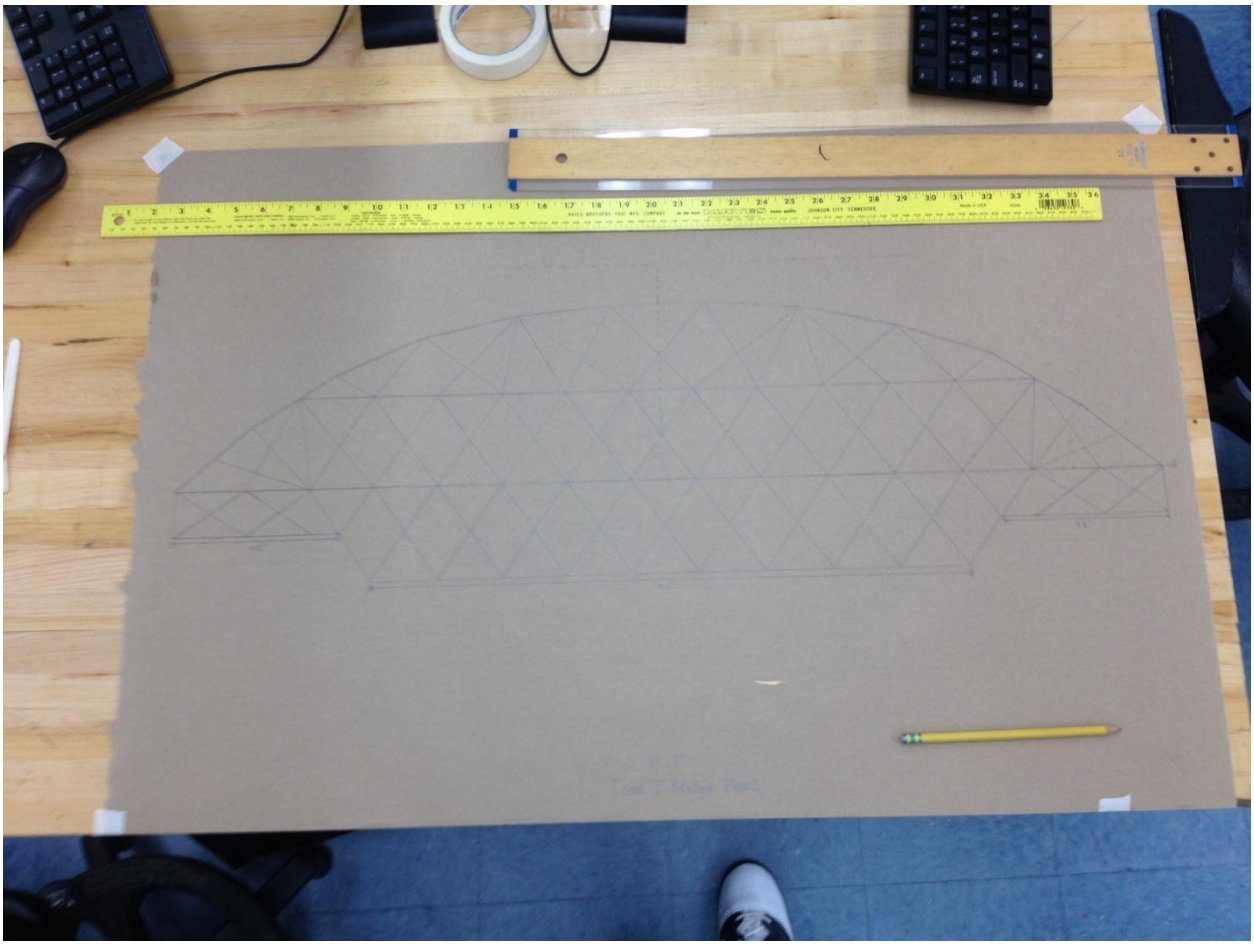


Figure 5

6.0 Estimated Load Capacity.

During the time where we estimated our load capacity, we joked about how we thought our bridge would be able to hold one "Ian" which is about 230 pounds. That was what we wrote down on the estimation sheet. However, if we provided an accurate estimate, we would have said

about 115 pounds. After testing, our bridge held 104.2 lbs. So, we would have been very close with our estimation. Compared to our original 230 lb estimation, it was very far off.

7.0 Prototype Load Testing.

For load testing, the bridge will set on supports that will be provided by the Instructor. No special supports may be used. The end supports will have the dimensions of: 3/4-inches wide x 3/4-inches high x 5-inches long. The end supports will be placed 29-inches apart (center-to-center). Mark where the end supports should come in contact with your bridge. A 'simple connection' shall only be used to connect the bridge to the loading supports. The bridge may not exert any horizontal loads on the supports, other than friction.

The bridge will be loaded on the roadway 10-inches from one of the ends. The loaded end will be determined by the Instructor on bridge loading day. The load will be applied on a 3-inch square loading plate with the center of the plate placed exactly 10-inches from one end of the bridge on the roadway (deck). A 3x3-inch square will be drawn on your bridge at the contest. The load will be applied from weight applied below the roadway. The bridge must be constructed to allow a steel cable or chain to be suspended vertically from the 3-inch square loading plate and hang below the deck. The bridge will be continually loaded until catastrophic failure, meaning the bridge could no longer function as safe, useable bridge.

8.0 Prototype Performance and Forensic Analysis.

The Bridge failed on the left side of the base (roadway). It failed in this spot because it was not sturdy enough or well-supported. Parts of the bridge did not function as intended because the efficiency of popsicle sticks and Elmer's Glue cannot be relied on. There could have been a slight miscalculation in the placement of the sticks, or as stated before, they simply were just not supported enough. The Arc in our bridge was very strong, although slightly slanted. The weakest part of the bridge, and where we could have improved, was our road. We did not support the road well enough in order to hold our guessed weight. Our two design flaws were the bridge being slanted, and the road not being aligned or supported correctly. Our failing mechanism and where the bridge failed was in the road. We experienced a catastrophic collapse when our bridge finally failed, holding a total 104.6 lbs.

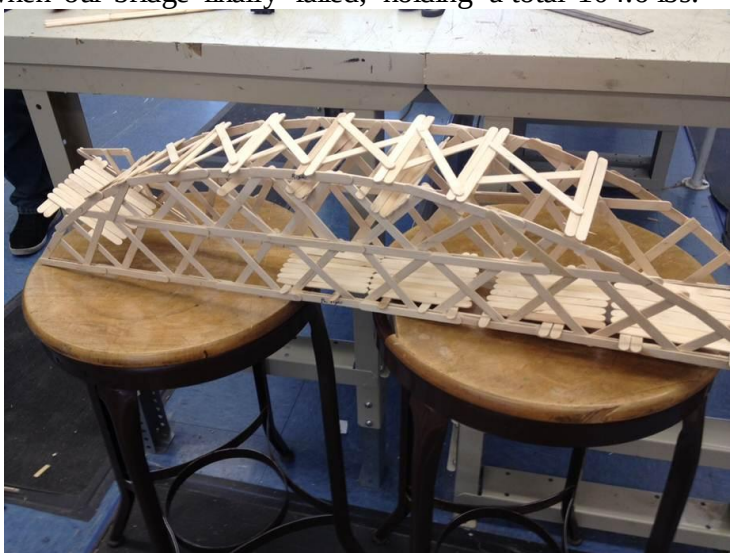


Figure 6

9.0 Final Design Performance.

Overall, our bridge came in fourth place out of all 8 bridge design groups. We had the 2nd most expensive bridge, but that was only because we overestimated the amount of glue that we were going to use. Had we not overestimated, our rankings would have been much higher. For bridge aesthetics, an outside class was allowed to come in our judge our bridges based on appearance. Even though our bridge was bent, we still managed to bring in 4th place for most appealing. Had we not made it bent, it would have been 1st or 2nd we believe. We had the 4th best failure to load to bridge weight ratio. We believe we could have improved this ranking as well if it had not been crooked. We obtained 5th place for BELC, with a 54.7%. Overall, our bridge was ranked sixth, because of its extreme cost. Had we estimated our costs better, we would have been around 4th or 3rd place. The following tables show all 8 groups ranking and stats for the areas that were judged for the competition.

Costs		
Design Team	Total Cost (Materials)	Rank
1	$530,000.00	6
2	$350,000.00	1
3	$500,000.00	3
4	$525,000.00	5
5	$450,000.00	2
6	$500,000.00	3
7	$675,000.00	7
8	$805,000.00	8

Table 2

Failure Load to Bridge Weight Ratio					
Design Team	Bridge Weight (grams)	Failure Load (lbs)	Failure Load (grams)	Ratio FL/BW	Rank
1	264.4	73.9	33520.5	127	5
2	310.6	31.8	14424.2	46	8
3	401.4	56.0	25401.2	63	7
4	354.1	146.2	66315.2	187	1
5	344.5	122.5	55565.1	161	2
6	294.5	45.5	20638.5	70	6
7	346.8	104.2	47264.3	136	4
8	391.8	131.0	59420.6	152	3

Table 3

Bridge Aesthetics								
Team #	1	2	3	4	5	6	7	8
rank	1	8	7	5	5	2	4	3
sum	44	136	135	123	123	104	120	111

Table 4

EDSGN 100 Truss Bridge Competition										
Design Team	Bridge Weight (grams)	Est. Load (lbs)	Actual Load (lbs)	BELC %	BELC Rank	Load Rank	Aesthetics Rank	Cost Rank	Overall Score	Overall Rank
1	264.4	85.0	73.9	13.1%	1	5	1	6	13	1
2	310.6	70.0	31.8	54.6%	4	8	8	1	21	7
3	401.4	460.0	56.0	87.8%	6	6	7	3	22	8
4	354.1	75.0	146.2	94.9%	7	1	5	5	18	4
5	344.5	40.0	122.5	206.3%	8	3	5	2	18	4
6	294.5	40.0	45.5	13.8%	2	7	2	3	14	2
7	346.8	230.0	104.2	54.7%	5	4	4	7	20	6
8	391.8	94.8	131.0	38.2%	3	2	3	8	16	3

Table 5

10.0 Refine the Design.

Our bridge held up pretty well. We could have improved the design though. Instead of having the road created using sticks parallel to the road, we could have glued them horizontally while connecting them to the support members running along the sides of the bridge. This would have given the bridge extra stability and strength. Also, next time we should ensure that the bridge gets glued straight without the top being crooked. Unfortunately, letting part of the bridge dry on its side caused gravity to warp the connected sticks into a bent shape. When connecting the two sides of the bridge, the pieces didn't connect perfectly. So, to refine the design, we would ensure that we properly allowed the sides to dry. Another thing we could have done was to support the second tier of our bridge with slightly more members. Other than these changes, we would build the bridge again in a similar way, as it produced good load testing results considering its fallbacks.

11.0 Conclusions and Recommendations.

Overall, we believed that this bridge design process was a success. We met all the requirements specified in previous sections of the report, while designing and constructing a bridge that was aesthetically pleasing as well as very strong. Compared with the other design groups, our bridge held the 4th most weight, even with the bridge being crooked. We very strongly believe that if the bridge had not been crooked, it would have held about 10-15 lbs more weight. The bridge was cost efficient, however, we overestimated how much glue we would need to construct the bridge. For future design projects, we will be sure to correctly estimate our materials in order to minimize the cost the most. For a re-design, we believe that the road should

be constructed with sticks perpendicular to the direction of the road for the most strength. More support members should be added to the second tier as well. We are happy with the results of this bridge design project.

12.0 References.

12.1 ANGEL/Lessons/Design Project #1/Final Design Report/EDSGN100_Bridge Building_SOW_F2012+.doc.

12.2 ANGEL/Lessons/Design Project #1/Final Design Report/EDSGN100_Bridge Building_Specifications_F2012+.doc.

12.3 ANGEL/Lessons/Design Project #1/Final Design Report/EDSGN100_Stick Weights_F2012+.xlsx.

12.4 ANGEL/Lessons/Design Project #1/Final Design Report/EDSGN100_Bridge Competition_F2012+.xlsx.

12.5 West Point Bridge Designer (2011). Developed by Colonel Stephen Ressler, Department of Civil and Mechanical Engineering, U.S. Military Academy, West Point, NY <http://bridgecontest.usma.edu/download2011.htm>.

12.6 Virtual Laboratory: Bridge Designer. Johns Hopkins University, Baltimore, MD <http://www.jhu.edu/virtlab/bridge/bridge.htm>.