PENNSTATE

School of Engineering Design, Technology and Professional Programs
213 Hammond Building
University Park, PA 16802-2701

October 30, 2015

Kevin R. Kline, PE, District Executive
PennDOT Engineering District 2-0
1924 Daisy Street - P.O. Box 342
Clearfield County, PA 16830

Dear Mr. Kline:

Reference. PennDOT Engineering District 2-0, Statement of Work, Subj: Concept Design for Vehicle Bridge over Spring Creek along Puddintown Road in College Township, Centre County, PA, dated September 11, 2015.

Statement of Problem. Due to flooding the previous bridge located over Spring Creek along Puddintown Road has become structurally unstable and caused it to be destroyed. Since the bridge is heavily traveled and connects the residence and emergency vehicles to the Medical Center it has become a vital lifeline. Without a bridge there is a 10 mile detour that cuts off College Township from the rest of the region.

Objective. To create a well-designed replacement Vehicle Bridge that will expand over Spring Creek and will be both structurally sound and cost efficient.

Design Criteria. The replacement bridge design must be both structurally and cost efficient. The bridge can be either a Warren or Howe truss bridge that is made from 60 popsicle sticks. Of those 60 popsicle sticks eight must be used for the floor beams and struts. PVA white glue was the bonding agent for the structural members of the bridge and hot glue was used to connect the floor beams and struts.

Technical Approach.

Phase 1: Economic Efficiency. To determine the economic efficiency of our bridges our design team referenced the estimated cost of each type of truss bridge we had designed on Bridge Designer. When we designed the bridge we had to make sure the bridge was stable and capable of supporting its own weight plus the weight of a standard truck load. For each component and part of the bridge our design team considered the material being used and decided the best material depending on tension and compression in each member. We also made sure to use uniform members wherever possible, shortened the length of each individual member, and lastly made sure that all strains of tension and compression was as close to 1.

Phase 2: Structural Efficiency. To determine the structural efficiency our design team built a small scale prototype of a Howe and Warren through truss bridge. As described previously the prototypes should be made using 60 popsicle sticks, eight of which will be used for floor beams and struts, PVA white glue, and hot glue to connect the main structure with the floor beams and struts. Once our bridges were created we load tested them in the lab. Load testing is when an item undergoes large amounts of weight, for our load testing a block was placed on top of the bridge and a bucket hung from below. The bucket was then filled with sand and various weighted items until the bridge ultimately failed. The structural efficiency of the bridge is then determined by dividing the load the bridge supports at failure by the weight of the prototype bridge.

Results.

Phase 1: Economic Efficiency. Comparing the results of both the Howe and Warren truss bridges our design team found that the Warren truss was less expensive than the Howe truss. Our Warren truss was about $248,000 and our Howe truss was about $281,000. The Warren truss required a smaller amount of material to be used thus leading to a lower overall cost on the bridge. A more detailed paragraph describing the results of the economic efficiency of our bridges in located in Attachment 1.

Phase 2: Structural Efficiency. Again when comparing the Howe and Warren truss bridges our design team found that one bridge performed better than the other. In structural efficiency the Howe truss was determined to be able to hold a greater amount of weight then the Warren truss. Our Howe truss bridge was one of the top structurally efficient bridges amongst the other design teams. The Howe truss bridge had a structural efficiency of 475 and our Warren truss had a structural efficiency of 382. More information about the structural efficiency results can be found in Attachment 2.

Best Solution. The best solution really depends on what aspect of the bridge is more important to the client. The bridge that was more economically efficient was the Warren truss. The Warren truss bridge has an estimated total cost of $248,000 a whole $33,000 cheaper than the Howe truss bridge. These values discussed can be found in Tables 1 and 4. In terms of the bridge that is more structurally efficient that is the Howe truss bridge. As you'll see in Tables 7 and 8 the Howe truss prototype load tested with a larger weight than that of the Warren truss. The overall structurally efficiency of the Howe truss was about 476 and the structural efficiency of the Warren truss was about 381. Either bridge is a viable option the decision it really depends on what aspect is more important to the client. Our design team decided that the Howe truss bridge would be the best solution. Even though the bridge would cost more money the Howe truss has a better structural efficient design then that of the Warren. Investing the extra money to build the Howe truss bridge will be beneficial because you won't have to replace later down the road.

Conclusions and Recommendations. Our design team came to the conclusion that the Warren truss would be more economically efficient and that the Howe truss would be more structurally efficient. When comparing the two our team decided that the Howe truss would be a smarter decision for the replacement bridge. We think that investing the extra money into this bridge will be more beneficial because you'd be investing in a more structurally efficient design so the likelihood of having to replace the bridge is not high.

Now as for recommendations to move on to the final design processes. After both the Warren and Howe truss bridges were load tested our design team concluded that both bridges failed at the floor beams and struts. A recommendation that we have to offer for the replacement bridge is to make sure that the struts and floor beams are strong. With stronger struts and floor beams the bridge will be able to support the forces that will push down on them and will better hold the weight of the bridge. To move on into the final design phase of the replacement bridge find a stronger material that will be able to withstand large amounts of weight. Also it would help to rebuild the prototype with stronger floor beams and struts and then load test to see if the new bridge has a better structural efficiency.

Respectfully,

Jessica Mongeluzi
Engineering Student
EDSGN100 Section 002
Design Team 6
Design Team: You Can't Sit With Us
College of Engineering
Penn State University

Breanna Lee
Engineering Student
EDSGN100 Section 002
Design Team 6
Design Team: You Can't Sit With Us
College of Engineering
Penn State University

Matt Huggler
Engineering Student
EDSGN100 Section 002
Design Team 6
Design Team: You Can't Sit With Us
College of Engineering
Penn State University

Austin Ruggiero
Engineering Student
EDSGN100 Section 002
Design Team 6
Design Team: You Can't Sit With Us
College of Engineering
Penn State University

ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. Out of our teams two bridges the Howe truss proved to be a pain in reducing the price and cost. The final cost of the Howe truss was $281,471.29. This number along with the detailed cost calculation report can be found in Table 1. The item we spent the most money on were Carbon Steel bars, about $133,000. The Howe truss is more money because it has more joints and more parts that attach together so that the bridge can be structurally sound. The Howe Bridge required 22 joints multiplied by two trusses to equal $22,000 and a total of 43 connection bars/ tubes (Table 2).

As you can see in Table 3 the member that had the highest compression was member 33 one of the inner diagonals and the member that had the highest tension was member nine which was the first bar in the bottom chord. Member 33 was a 75 mm Carbon Steel bar and member nine was 80 mm Carbon Steel bar. The materials used for each diagonal, vertical, floor beam, etc. is located in Table 2.

A picture of our Howe truss that was built in Bridge Designer is located below as Figure 1.

Warren Truss. When designing the Warren truss bridge on the Bridge Designer software our design team was able to build a bridge that was capable of holding a standard truck load of weight and had a low cost to it. The final cost of the Warren truss bridge was $248,155.25. This number along with a detailed cost calculation report can be found as Table 4. The majority of the bridge was made with High- Strength Low- Alloy Steel which was an expensive material but proved to work best (Table 5). Since this material was expensive these tubes and bars were where majority of the total cost comes from, about $143,700. This type of truss bridge required less joints and diagonal bars/ tubes, but it wasn't that off from the Howe truss. The amount of joints was 21 totaling at $21,000 and the number of diagonals was 39 (Table 5).

In Table 6 the member that had the highest compression was member 39 which was the furthest right diagonal and the highest tension was member 2 which the second member in of the bottom chord. Member 39 was made with High-Strength Low Alloy tube and member 2 was made with High- Strength Low Alloy bar. With our Warren truss we made sure that each similar member was made with the same material and was the same length to keep overall costs low. A report of each member of our bridge is located below as Table 5.

A picture of our Warren truss that was built in Bridge Designer is located below as Figure 2.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss. The overall structural efficiency of the Howe truss bridge was what our design team had expected. The Howe truss we built was sturdy and was able to hold a large amount of weight. Since it had a well-designed structure the bridge then tested with a high structural efficiency. The structural efficiency of the bridge is then determined by dividing the load the bridge supports at failure by the weight of the prototype bridge.

Prototype Bridge. For the creation of our prototype bridge our group was given 60 popsicle sticks, PVA white glue, hot glue, and binder clip clamps. Of the 60 popsicle sticks given our group used all of them to build the Howe truss, eight of the popsicle sticks were used for the floor beams and struts and the remaining 52 sticks were used for the actual structure. As stated before PVA white glue was used to connecting the sticks together for the structure and hot glue was used to connect the floor beams and struts. As for the method of building the bridge we glued the verticals, diagonals, top chord, and the bottom chord all together of the table and then placed binder clip clamps on the joints so that when they were drying the joints did not move. Once all the glue used for the bridge had dried/ cured we hot glued the struts and floors beams. A picture from before load testing is down below as Figure 3.

Load Testing. In comparison to the other design teams our Howe truss bridge was one of the top three best. Our bridge failed at a load weight of 84.2 lbs. For the Howe truss bridge the average load weight at failure load amongst the design teams was 65.8 lbs. Now when comparing the structural efficiency of each design team's bridge ours is still in the top three. Our bridge had the second best failure load weight and the second highest structural efficiency. The maximum structural efficiency is 569.6 and the minimum is 238.4. That makes the range of the structural efficiency 332 and our bridge's structural efficiency was 475. These values are located below in Table 7.

Forensic Analysis. Our design teams Howe truss bridge failed at a load of 84.2 lbs. (numbers located in Table 7). Our bridge ultimately failed at the floor beams and struts. In Figure 4 you'll be able to see that the first two floor beam completely fell off of our bridge. As for the failing struts the two in the middle stayed attached at one end of the stick and then got dislocated on the other end. Our design team believes that our bridge failed because the placement of our floor beams and struts were not in a location that could hold a lot of weight. Now the structure of our bridge did stay intact which leads our group to believe that if we placed the failing beams and struts in a different locations and used stronger popsicle sticks in those places our bridge could have held more weight.

Results. A graph comparing the structural efficiencies of each of the design teams Howe truss bridges is located below as Figure 7.

Warren Truss. Our estimated load weight at failure was a little high, but our design team had confidence that our bridge could stand up to a weight somewhat close to that. In comparison to the Howe truss the Warren weighed more and had a sturdy structure as well. As stated above the structural efficiency of the bridge is then determined by dividing the load the bridge supports at failure by the weight of the prototype bridge.

Prototype Bridge. Like the Howe truss bridge our design team was given 60 popsicle sticks, PVA white glue, hot glue, and binder clip clamps. Of the 60 popsicle sticks given the Warren truss bridge only used 50 sticks for the structure and eight for the floor beams and struts, leaving two sticks left over. When building this bridge our team used the same method as the Howe bridge. We first white glued the parts for our bottom chords, top chords and then glued the parts for our diagonals, to make sure the popsicle sticks didn't move we placed binder clip clamps on the ends. Once the PVA glue had dried/ cured we attached all of the parts to create the main structure, again once those joints dried we hot glued the floor beams and struts. Our design team for both bridges decided to use a lot of PVA glue to strengthen the joints and the overall structure of the bridge. A picture from before load testing is down below as Figure 5.

Load Testing. Unlike the Howe truss our Warren truss bridge did not withstand as much weight when load tested. The Warren truss bridge failed at a load weight of 75.8 lbs. Like our Howe truss the Warren truss fell within the top three best bridges in terms of the highest load weight at failure compared to other design teams. For the Warren truss bridge the average load weight at failure was 64.9 lbs. When compared with the other design team our Warren truss was the third most structurally efficient. The maximum structural efficiency was 579.3 and the minimum was 199.4. These values makes the range of the structural efficiency 380 and our bridges structural efficiency was 381. The values discussed above can be found below in Table 8.

Forensic Analysis. The forensic analysis of the Warren truss is really similar to the forensic analysis of our Howe truss. The Warren truss bridge failed at a load of 75.8 lbs. (numbers located in Table 8). Like our Howe truss bridge the Warren truss failed at the struts and floor beams. As you can see in Figure 6 below the strut the failed was one of the inner ones and then the floor beams on the far left snapped off or in half. You can also see in Figure 6 that one of the popsicle sticks located on the bottom chord popped away from the hot glue used to hold it in place. Same as the Howe truss our design team believes that the floor beams and the struts failed because they were not in the correct location and the popsicle sticks used were weak and could not hold the weight of the load. Besides the failing struts and floor beams the actual structure did stay intact which leads our group to believe that if we used stronger popsicle sticks and placed the struts and floor beams in better locations on the top and bottom chords our bridge could have held more weight and have a better structural efficiency

Results. A graph comparing the structural efficiencies of each of the design teams Warren truss bridges is located below as Figure 8.

TABLES

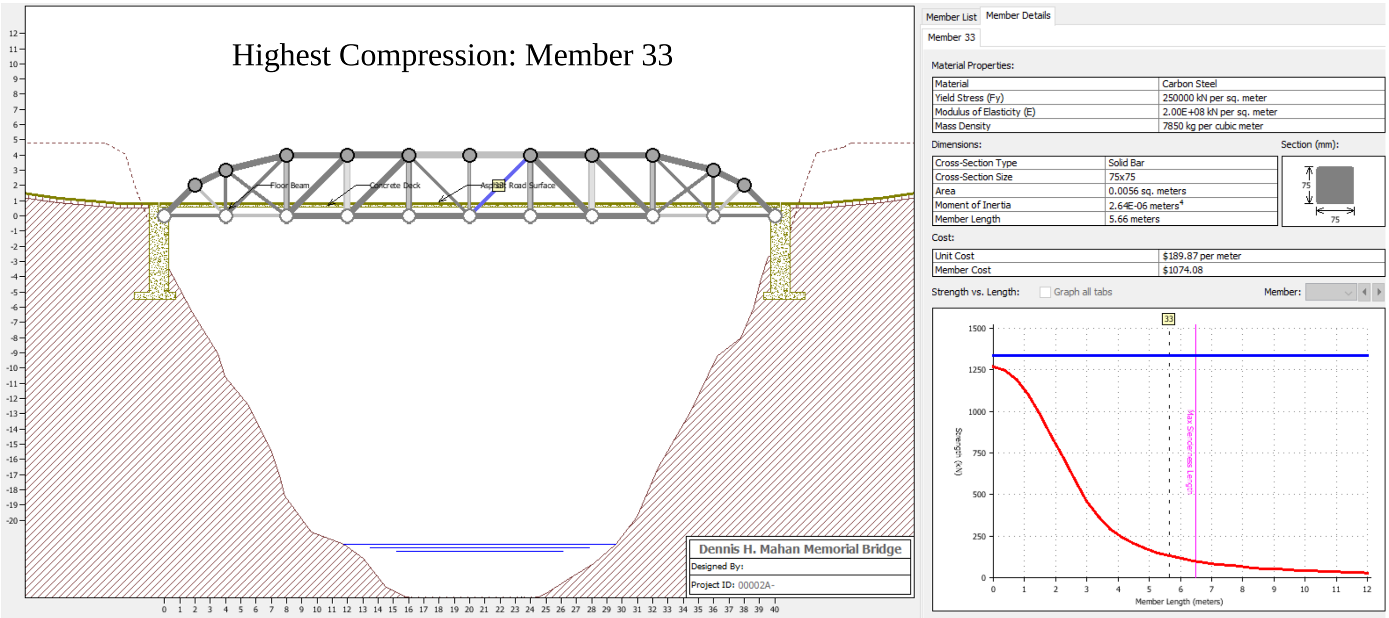
Table 1
Howe Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Economic Efficiency (Howe Truss)			
Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(15483.4 kg) x ($4.30 per kg) x (2 Trusses) =	$133,157.58
	Carbon Steel Hollow Tube	(505.9 kg) x ($6.30 per kg) x (2 Trusses) =	$6,374.55
	Quenched & Tempered Steel Solid Bar	(2293.8 kg) x ($6.00 per kg) x (2 Trusses) =	$27,525.60
	Quenched & Tempered Steel Hollow Tube	(325.6 kg) x ($7.70 per kg) x (2 Trusses) =	$5,013.55
Connection Cost (C)		(22 Joints) x (500.0 per joint) x (2 Trusses) =	$22,000.00
Product Cost (P)	2 - 75x75 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	8 - 80x80 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	1 - 80x80x4 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 80x80 mm Quenched & Tempered Steel Bar	(%s per Product) =	$1,000.00
	14 - 140x140 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	4 - 140x140x7 mm Carbon Steel Tube	(%s per Product) =	$1,000.00
	4 - 150x150 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 160x160 mm Carbon Steel Bar	(%s per Product) =	$1,000.00
	2 - 160x160 mm Quenched & Tempered Steel Bar	(%s per Product) =	$1,000.00
	2 - 170x170x8 mm Quenched & Tempered Steel Tube	(%s per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =	$19,900.00
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =	$10,500.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	M + C + P + S	$172,071.29 + $22,000.00 + $10,000.00 + $77,400.00 =	$281,471.29

Table 2
Howe Truss Bridge
Load Test Results Report from Bridge Designer 2015

					Load Test Results		
#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	CS	Bar	150	4.12	95.22	0.86	0.00
2	CS	Bar	150	4.00	92.38	0.80	0.00
3	CS	Bar	160	4.00	86.60	0.88	0.00
4	QTS	Bar	160	4.00	86.60	0.78	0.00
5	QTS	Bar	160	4.00	86.60	0.78	0.00
6	CS	Bar	160	4.00	86.60	0.87	0.00
7	CS	Bar	150	4.00	92.38	0.78	0.00
8	CS	Bar	150	4.12	95.22	0.85	0.00
9	CS	Bar	80	4.00	173.21	0.00	0.96
10	QTS	Bar	80	4.00	173.21	0.00	0.62
11	CS	Bar	140	4.00	98.97	0.00	0.73
12	CS	Bar	140	4.00	98.97	0.00	0.83
13	CS	Bar	140	4.00	98.97	0.00	0.83
14	CS	Bar	140	4.00	98.97	0.00	0.83
15	CS	Bar	140	4.00	98.97	0.00	0.83
16	CS	Bar	140	4.00	98.97	0.00	0.72
17	QTS	Bar	80	4.00	173.21	0.00	0.62
18	CS	Bar	80	4.00	173.21	0.00	0.94
19	CS	Bar	140	5.66	139.97	0.83	0.00
20	CS	Bar	140	5.66	139.97	0.58	0.00
21	CS	Bar	140	5.66	139.97	0.55	0.00
22	CS	Bar	140	5.66	139.97	0.80	0.00
23	CS	Bar	80	3.00	129.90	0.49	0.00
24	CS	Tube	140	4.00	73.57	0.00	0.67
25	QTS	Tube	170	4.00	60.41	0.00	0.36
26	CS	Tube	140	4.00	73.57	0.00	0.71
27	CS	Tube	80	4.00	128.74	0.10	0.00
28	CS	Tube	140	4.00	73.57	0.00	0.71
29	QTS	Tube	170	4.00	60.41	0.00	0.38
30	CS	Tube	140	4.00	73.57	0.00	0.69
31	CS	Bar	80	3.00	129.90	0.50	0.00
32	CS	Bar	75	5.66	261.28	0.64	0.38
33	CS	Bar	75	5.66	261.28	0.99	0.35
34	CS	Bar	140	2.83	69.99	0.61	0.00
35	CS	Bar	140	2.24	55.33	0.58	0.00
36	CS	Bar	140	2.24	55.33	0.57	0.00
37	CS	Bar	140	2.83	69.99	0.59	0.00
38	QTS	Bar	80	2.83	122.47	0.00	0.23
39	QTS	Bar	80	2.83	122.47	0.00	0.23
40	CS	Bar	80	5.66	244.95	0.00	0.17
41	CS	Bar	80	5.66	244.95	0.00	0.17
42	CS	Bar	80	5.00	216.51	0.00	0.62
43	CS	Bar	80	5.00	216.51	0.00	0.61

Table 3
Howe Truss Bridge
Member Details Report from Bridge Designer 2015
Member with the Highest Compression (or Tension) Force/Strength Ratio



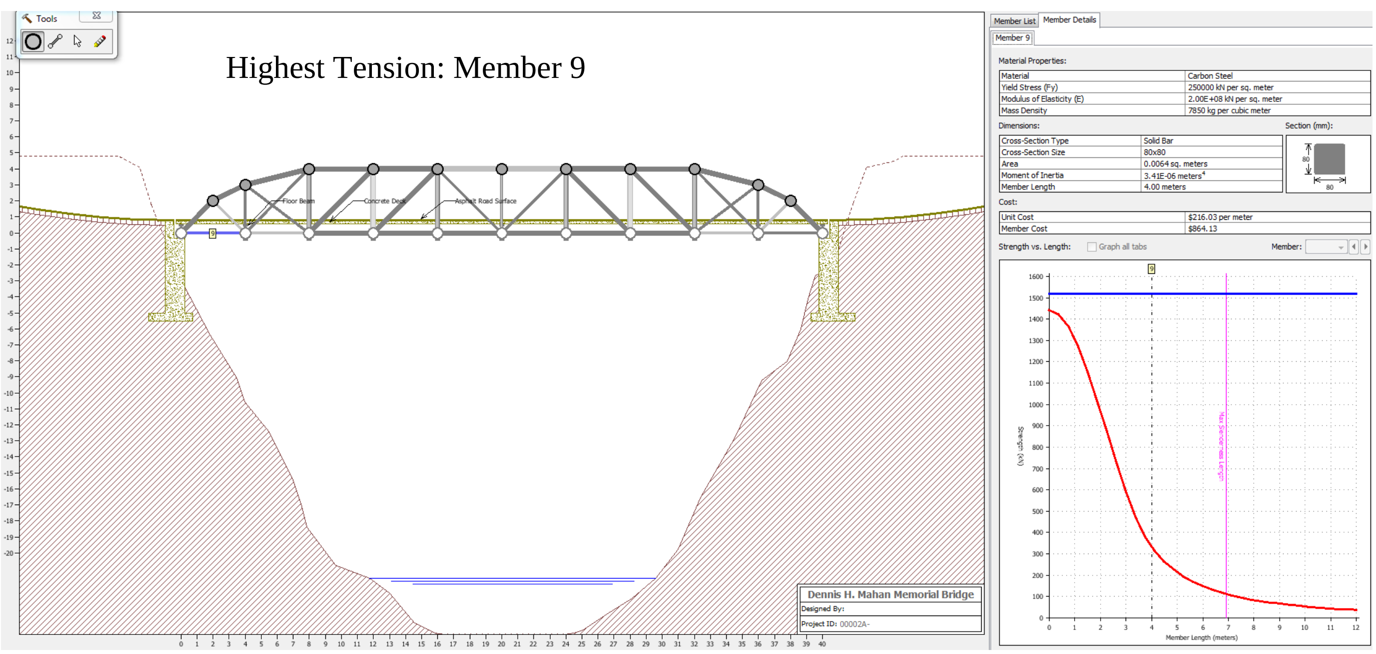


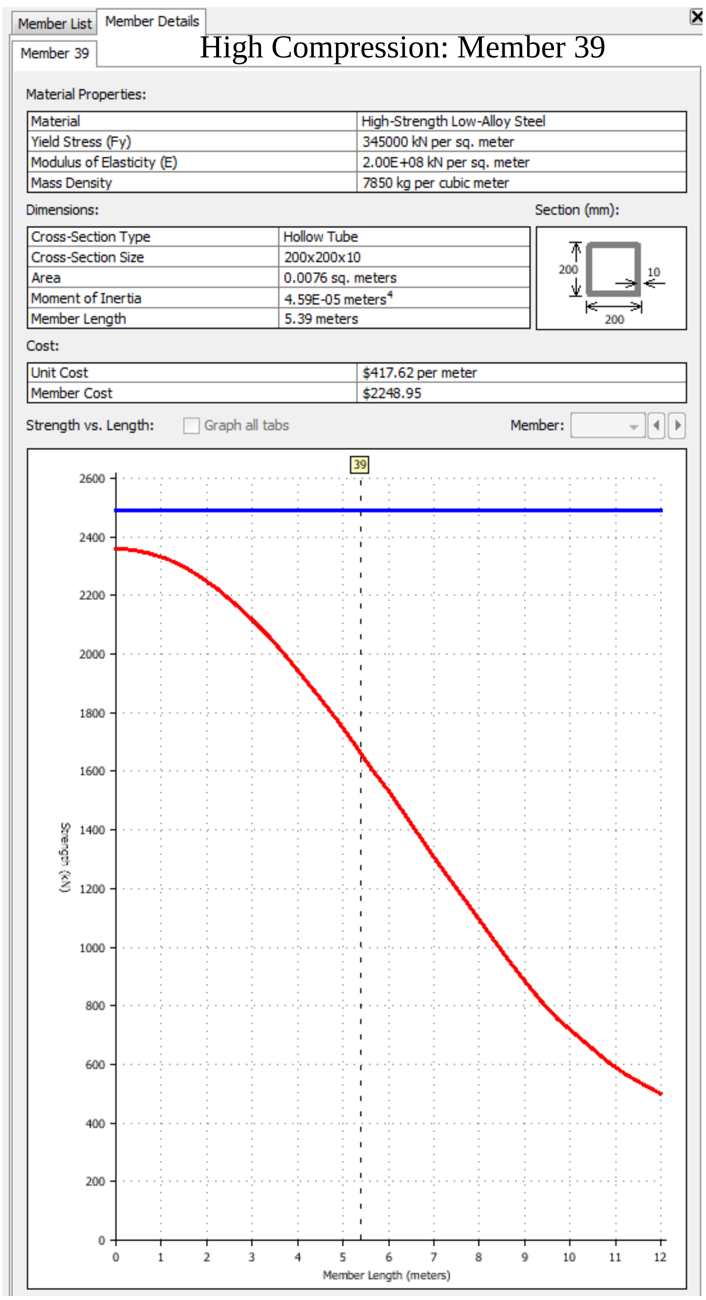
Table 4
Warren Truss Bridge
Cost Calculation Report from Bridge Designer 2015

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	High-Strength Low-Alloy Steel Solid Bar	(5002.0 kg) x ($5.60 per kg) x (2 Trusses) =	$56,022.78
	High-Strength Low-Alloy Steel Hollow Tube	(6266.6 kg) x ($7.00 per kg) x (2 Trusses) =	$87,732.47
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses) =	$21,000.00
Product Cost (P)	12 - 70x70 mm High-Strength Low-Alloy Steel Bar	($1,000.00 per Product) =	$1,000.00
	8 - 100x100 mm High-Strength Low-Alloy Steel Bar	($1,000.00 per Product) =	$1,000.00
	2 - 120x120x6 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	8 - 200x200x10 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	6 - 240x240x12 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
	3 - 280x280x14 mm High-Strength Low-Alloy Steel Tube	($1,000.00 per Product) =	$1,000.00
Site Cost (S)	Deck Cost	(10 4-meter panels) x ($4,700.00 per panel) =	$47,000.00
	Excavation Cost	(19,900 cubic meters) x ($1.00 per cubic meter) =	$19,900.00
	Abutment Cost	(2 standard abutments) x ($5,250.00 per abutment) =	$10,500.00
	Pier Cost	No pier =	$0.00
	Cable Anchorage Cost	No anchorages =	$0.00
Total Cost	**M + C + P + S**	**$143,755.25 + $21,000.00 + $6,000.00 + $77,400.00 =**	**$248,155.25**

Table 5
Warren Truss Bridge
Load Test Results Report from Bridge Designer 2015

						Load Test Results	
#	Material Type	Cross Section	Size (mm)	Length (m)	Slender-ness	Compression Force/Strength	Tension Force/Strength
1	HSS	Bar	70	4.00	197.95	0.00	0.35
2	HSS	Bar	70	4.00	197.95	0.00	0.96
3	HSS	Bar	100	4.00	138.56	0.00	0.69
4	HSS	Bar	100	4.00	138.56	0.00	0.84
5	HSS	Bar	100	4.00	138.56	0.00	0.92
6	HSS	Bar	100	4.00	138.56	0.00	0.92
7	HSS	Bar	100	4.00	138.56	0.00	0.85
8	HSS	Bar	100	4.00	138.56	0.00	0.69
9	HSS	Bar	70	4.00	197.95	0.00	0.95
10	HSS	Bar	70	4.00	197.95	0.00	0.34
11	HSS	Tube	280	4.00	36.78	0.74	0.00
12	HSS	Tube	280	4.00	36.78	0.71	0.00
13	HSS	Tube	280	4.00	36.78	0.72	0.00
14	HSS	Tube	240	4.00	42.91	0.88	0.00
15	HSS	Tube	240	4.00	42.91	0.67	0.00
16	HSS	Tube	240	4.00	42.91	0.38	0.00
17	HSS	Tube	240	4.00	42.91	0.87	0.00
18	HSS	Tube	240	4.00	42.91	0.66	0.00
19	HSS	Tube	240	4.00	42.91	0.37	0.00
20	HSS	Tube	120	5.39	115.55	0.22	0.42
21	HSS	Tube	120	5.39	115.55	0.33	0.38
22	HSS	Bar	70	5.39	266.50	0.00	0.41
23	HSS	Bar	70	5.39	266.50	0.00	0.59
24	HSS	Bar	70	5.39	266.50	0.00	0.77
25	HSS	Bar	70	5.39	266.50	0.00	0.94
26	HSS	Bar	70	5.39	266.50	0.00	0.39
27	HSS	Bar	70	5.39	266.50	0.00	0.57
28	HSS	Bar	70	5.39	266.50	0.00	0.75
29	HSS	Bar	70	5.39	266.50	0.00	0.92
30	HSS	Tube	200	5.39	69.33	0.91	0.00
31	HSS	Tube	200	5.39	69.33	0.75	0.00
32	HSS	Tube	200	5.39	69.33	0.58	0.00
33	HSS	Tube	200	5.39	69.33	0.41	0.00
34	HSS	Bar	100	5.39	186.55	0.87	0.02
35	HSS	Bar	100	5.39	186.55	0.79	0.03
36	HSS	Tube	200	5.39	69.33	0.39	0.00
37	HSS	Tube	200	5.39	69.33	0.56	0.00
38	HSS	Tube	200	5.39	69.33	0.73	0.00
39	HSS	Tube	200	5.39	69.33	0.89	0.00

Table 6
Warren Truss Bridge
Member Details Report from Bridge Designer 2015
Member with the Highest Tension (or Compression) Force/Strength Ratio


High Compression: Member 39

Member List | Member Details | Member 39

Material Properties:

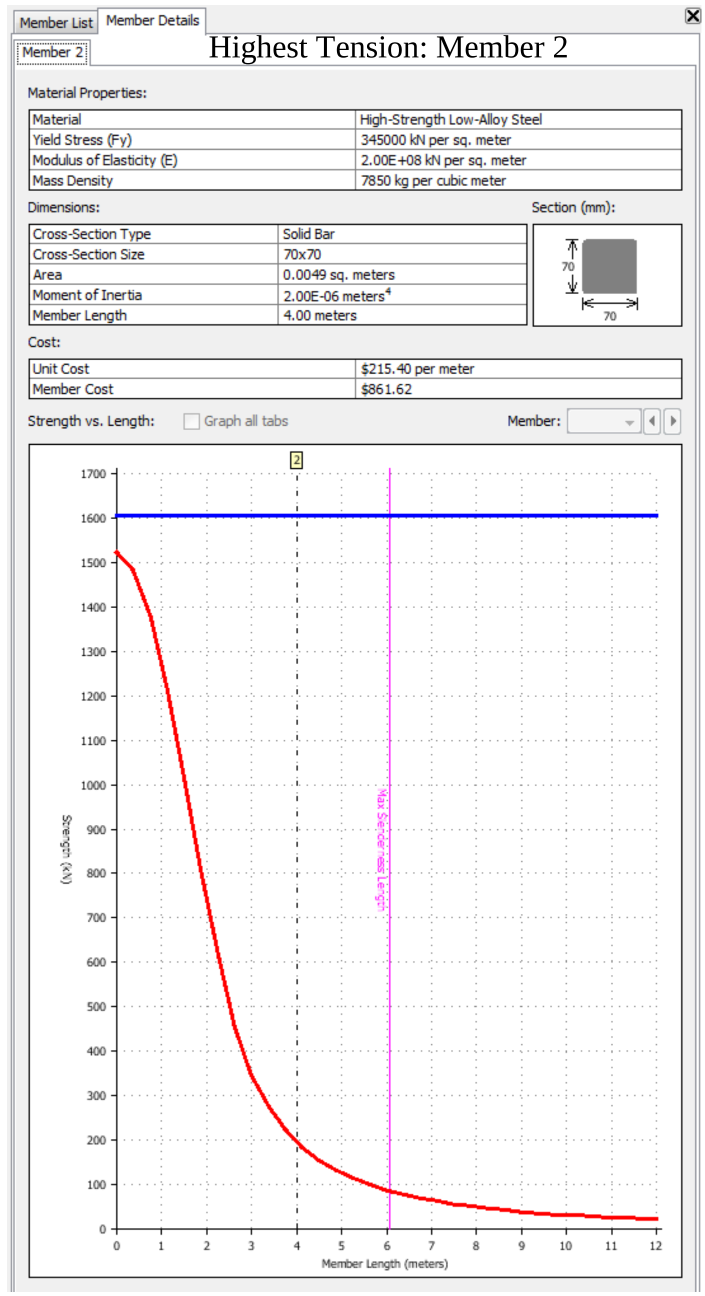
Material	High-Strength Low-Alloy Steel
Yield Stress (Fy)	345000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Dimensions:

Cross-Section Type	Hollow Tube
Cross-Section Size	200x200x10
Area	0.0076 sq. meters
Moment of Inertia	4.59E-05 meters^4
Member Length	5.39 meters

Cost:

Unit Cost	$417.62 per meter
Member Cost	$2248.95


Highest Tension: Member 2

Member List | Member Details | Member 2

Material Properties:

Material	High-Strength Low-Alloy Steel
Yield Stress (Fy)	345000 kN per sq. meter
Modulus of Elasticity (E)	2.00E+08 kN per sq. meter
Mass Density	7850 kg per cubic meter

Dimensions:

Cross-Section Type	Solid Bar
Cross-Section Size	70x70
Area	0.0049 sq. meters
Moment of Inertia	2.00E-06 meters^4
Member Length	4.00 meters

Cost:

Unit Cost	$215.40 per meter
Member Cost	$861.62

Table 7
Howe Truss Bridge
Load Testing Results

Howe Bridge				
Design Team	Actual Bridge Weight (grams)	Estimated Load at Failure (lbs)	Load at Failure (lbs.)	Structural Efficiency
1	81.3	74.23	69.78	389.3200
2	64.3	20	33.8	238.4361
3	95.8	50	59.6	282.1935
4	78.5	30	65.4	377.8978
5	79.4	42	99.7	569.5619
6	80.4	94	84.2	475.0314
7	84.7	20	71	380.2255
8	82.6	50	44.3	243.2708

Minimum: 238
Maximum: 570
Range: 332
Mean: 369

Table 8
Warren Truss Bridge
Load Testing Results

Warren Bridge				
Design Team	Actual Bridge Weight (grams)	Estimated Load at Failure (lbs.)	Load at Failure (lbs.	Structural Efficiency
1	81.9	69	104.6	579.3140
2	77.1	20	33.9	199.4397
3	74.9	30	50.8	307.6438
4	75.7	30	38.2	228.8936
5	80.9	60	55.4	310.6186
6	90.1	97	75.8	381.6020
7	87.0	30	70.9	369.6522
8	83.6	31	90.3	489.9455

Minimum: 199
Maximum: 579
Range: 380
Median: 358

FIGURE

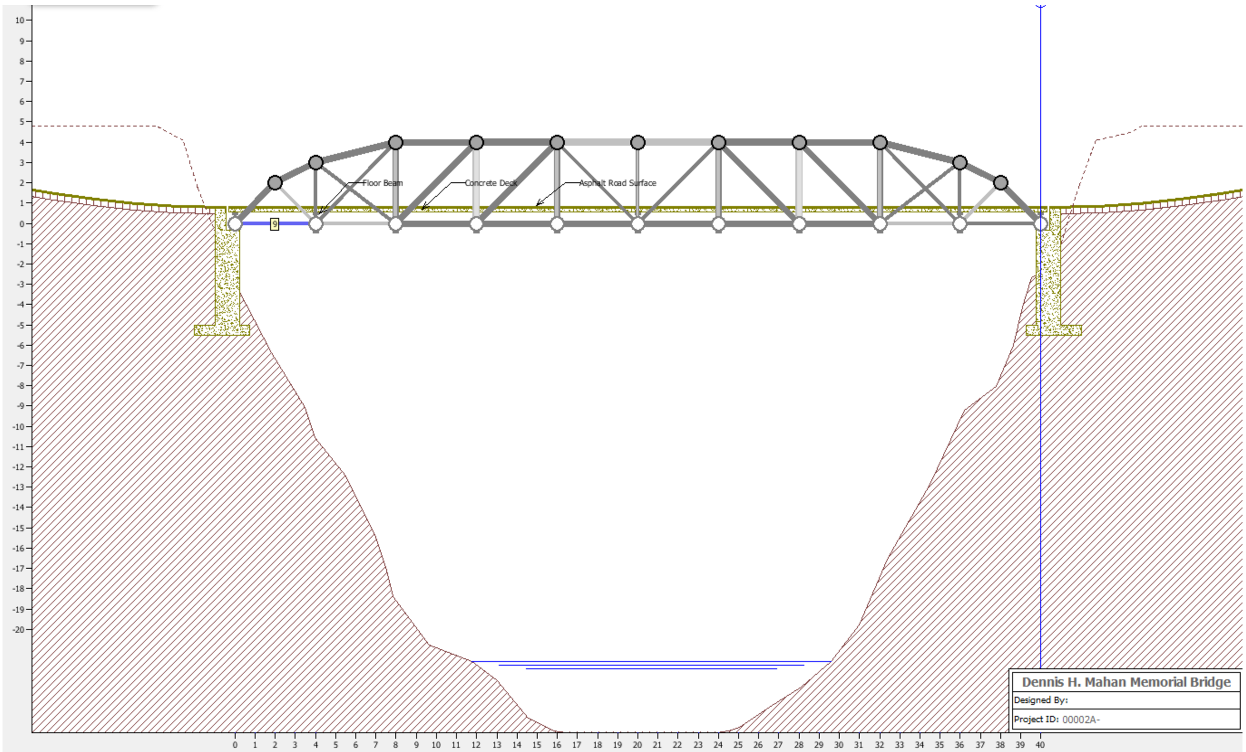


Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

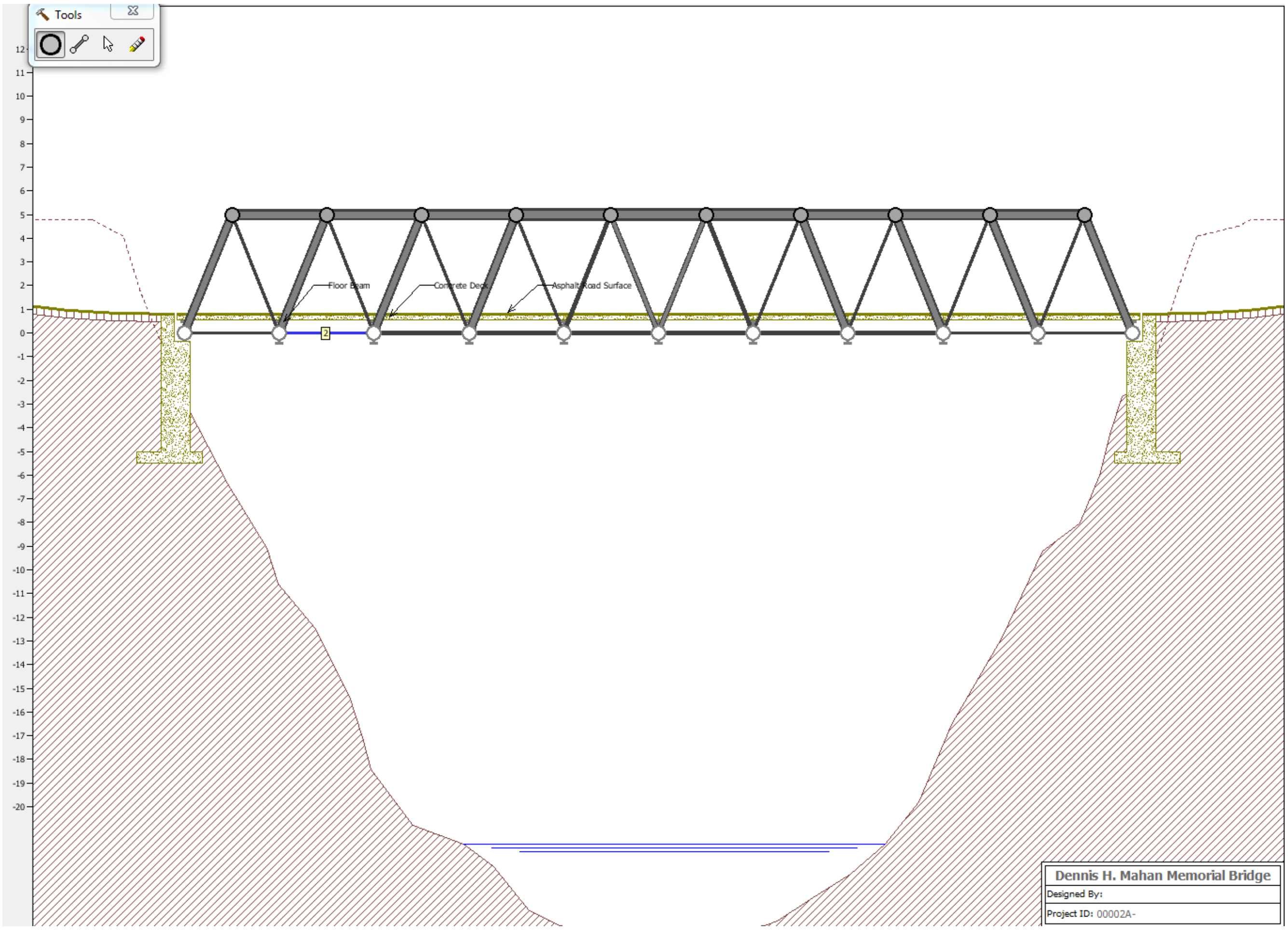


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

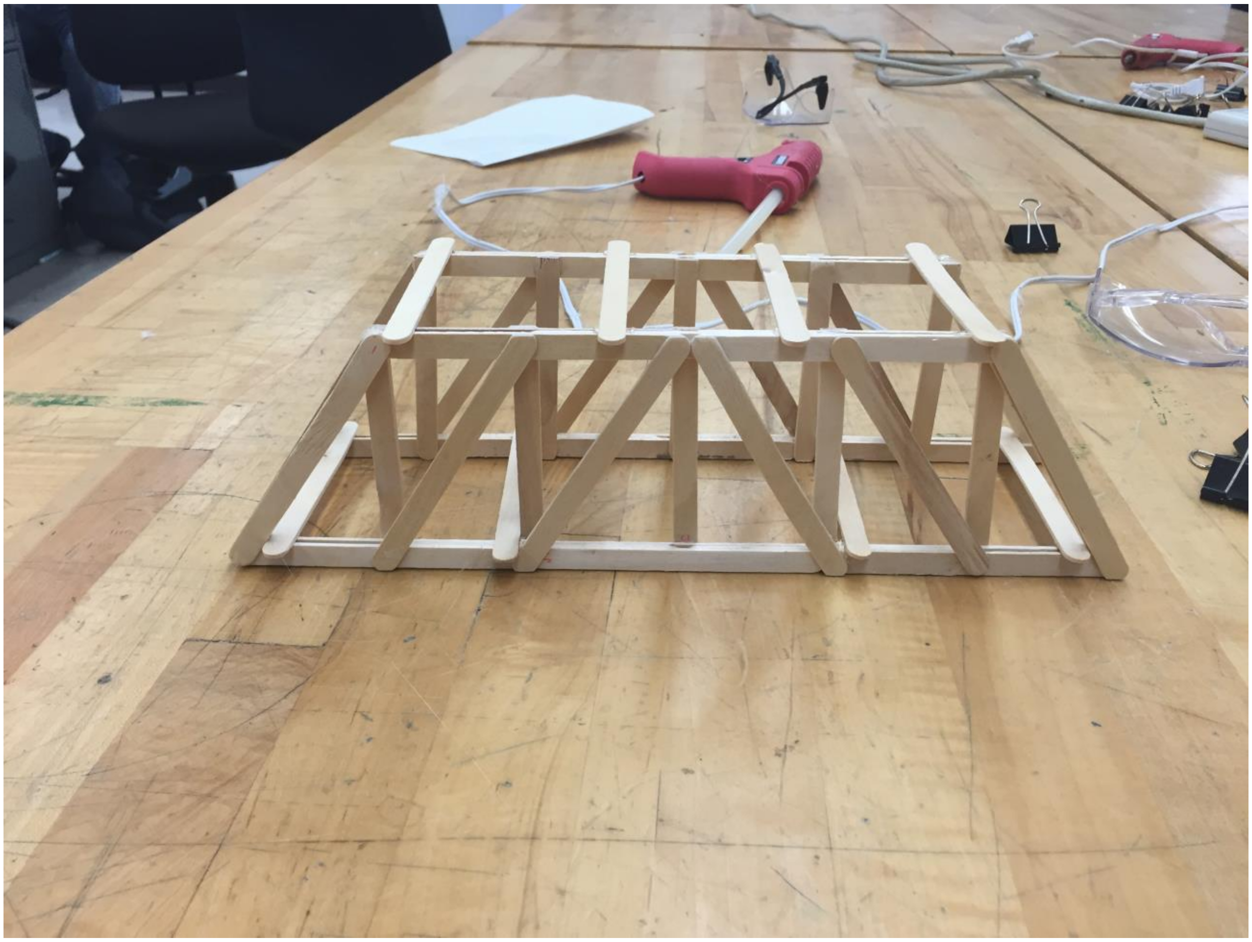


Figure 3. Howe Truss Bridge Prototype before Load Testing

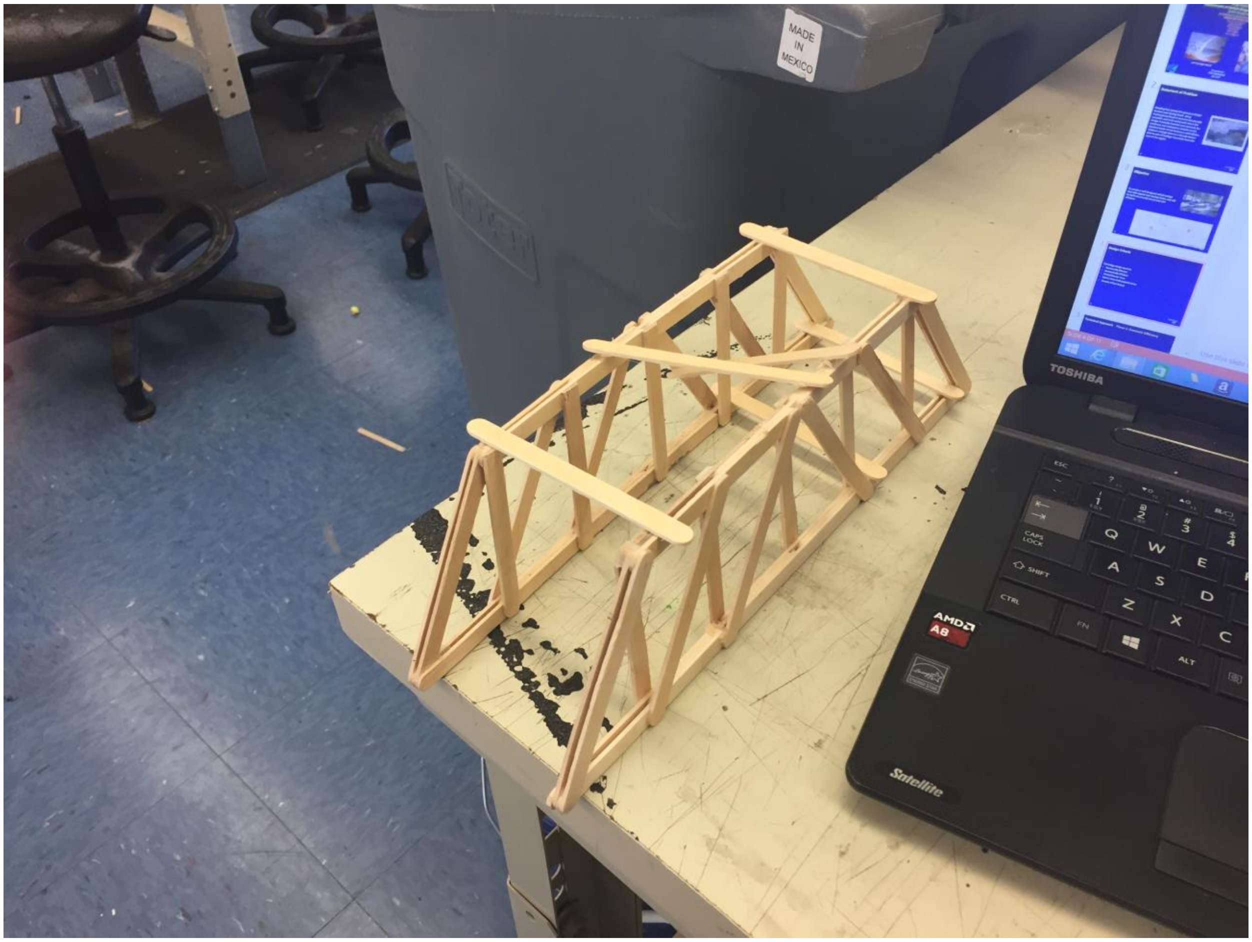


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

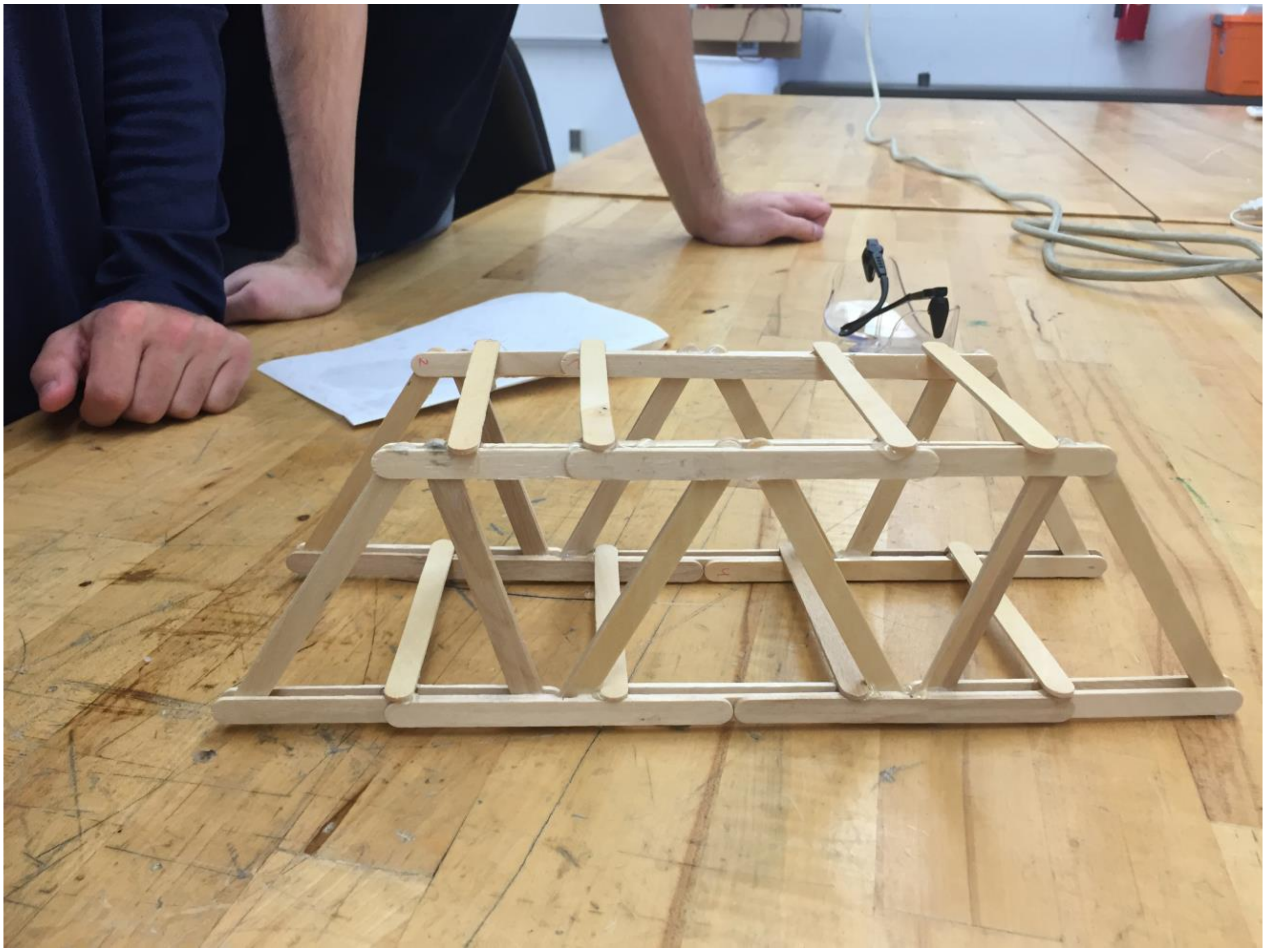


Figure 5. Warren Truss Bridge Prototype before Load Testing

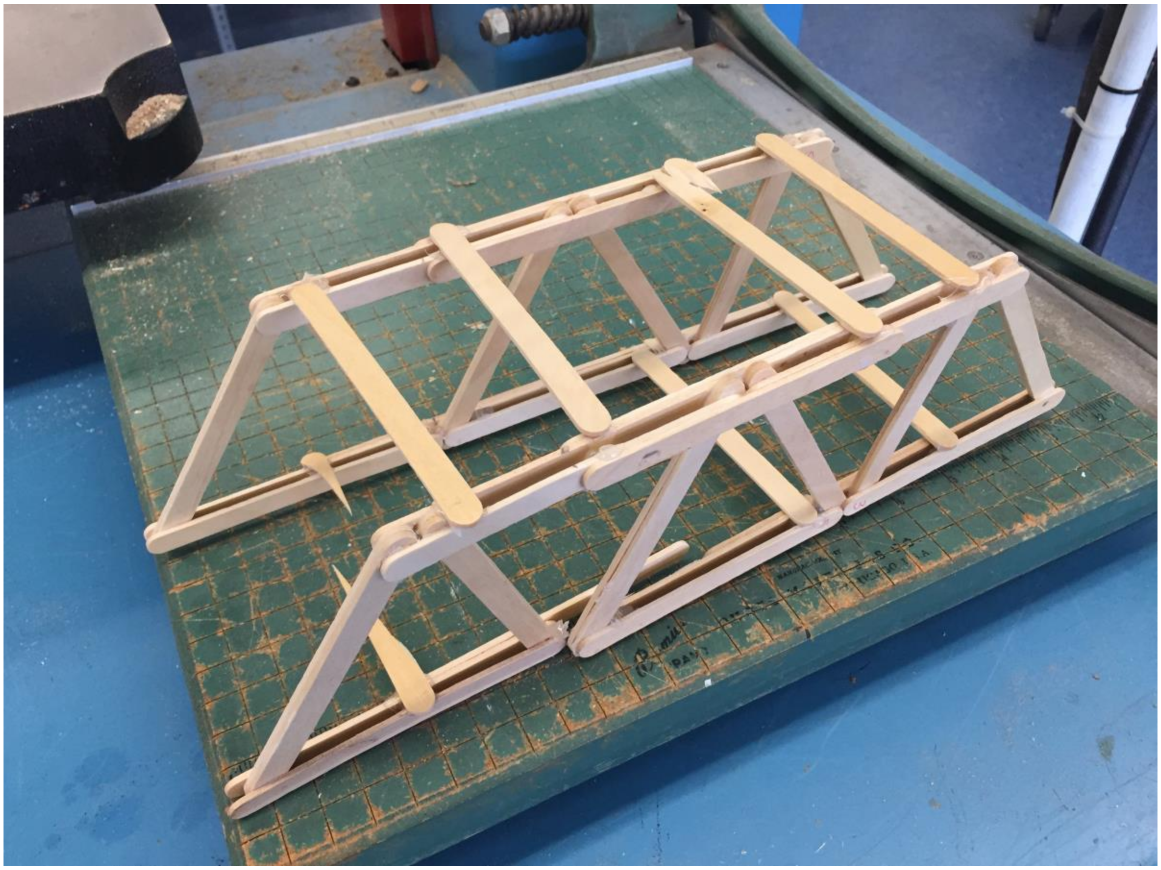


Figure 6. Warren Truss Bridge Prototype Failure after Load Testing

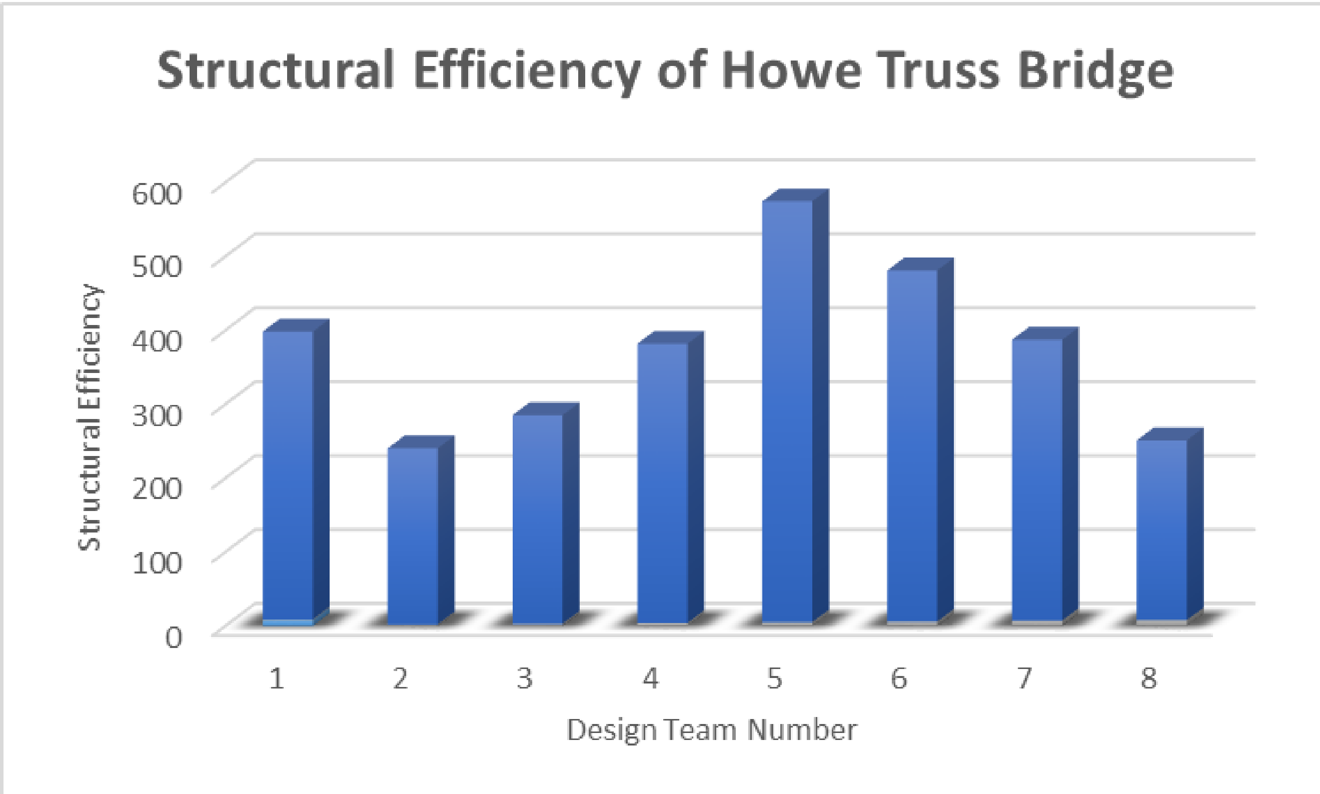


Figure 7. Howe Truss Bridge Structural Efficiencies

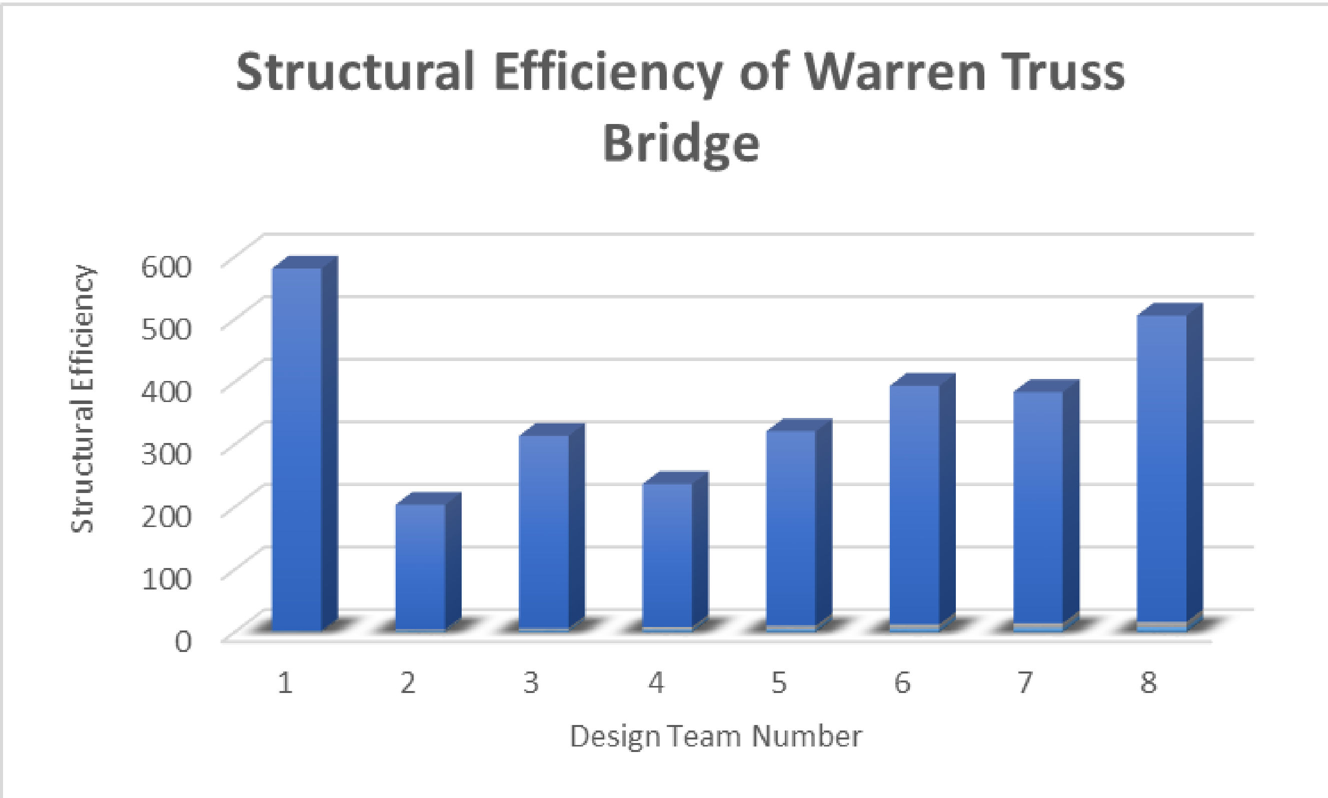


Figure 8. Warren Truss Bridge Structural Efficiencies