



October 21, 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.

Local flooding has eventually destroyed a structurally deficient bridge over Spring Creek along Puddintown Road in College Township, Centre County, PA. The bridge was heavily travelled and a main entrance road to get to the Mount Nittany Medical Center in State College, PA. The bridge needs to be replaced to withstand the heavy traffic.

Objective.

Pennsylvania Department of Transportation of Engineering District 2-0 has initiated an emergency, fast-track project to expedite the design a new vehicle bridge over Spring Creek to replace the bridge destroyed by the recent extreme flood event. The new bridge must be as structurally and economically efficient as possible.

Design Criteria.

PennDOT District 2-0 set the design criteria of the new bridge to include: standard abutments, no piers (one span), deck material shall be medium strength concrete (0.23 meters thick), no cable anchorages and designed for the load of two AASHTO H20-44 trucks (225kN) with one in each traffic lane. The deck of the bridge needs to be 20 meters high and the deck will span 40 meters.

Technical Approach.

Phase 1: Economic Efficiency.

To minimize cost while still meeting the criteria, we used the Engineering Encounters Bridge Design 2015 (EEBD 2015) software. We used the criteria given, to test a Howe Truss and a Warren Truss while minimizing costs. With each bridge, we made sure it would support its dead weight, along with the live load of traffic. We tested different materials and different types of members to maintain efficiency and minimize cost the best way possible.

Phase 2: Structural Efficiency.

The truss bridge type that exhibits the best structural efficiency when tested to failure in prototype shall be determined. Structural efficiency is the ability of the truss bridge to safely dissipate live loads. Structural Efficiency (SE) is calculated by dividing the load the bridge supports at failure by the weight of the prototype bridge. The design objective is to determine and report which prototype through truss bridge design is more effective at dissipating the force of a load, a Howe through truss bridge or the Warren through truss bridge.

Results.

Phase 1: Economic Efficiency

Both the Warren and Howe Truss bridges were designed in Engineering Encounters Bridge Design software. After cost optimization, the Warren design cost \$245,317.43. The Howe design cost \$243,361.04, which is \$1,956.39 less; therefore the Howe design is more economically efficient. See Attachment 1: Phase 1 for additional details about cost optimization and load testing.

Phase 2: Structural Efficiency.

Structural efficiency was measured by the live load divided by the weight of the bridge. As seen below in attachment 2, the Howe Truss Bridge was more structurally efficient. The Howe's efficiency was 383.9, while the Warren's efficiency was 381.1. Both bridges performed well over the averages and were very efficient.

Best Solution.

The best solution is to build a Howe Truss Bridge. The Howe proved to be the better of the two bridges in both the Bridge Designer 2015 program, and also in the prototype. In Bridge Designer 2015, both bridges supported the live load along with their dead weight. The Howe Bridge ended up costing around \$2,000 less than the Warren did. The prototypes were very similar in performance, but the Howe's structural efficiency was 2 points higher than the Warren Bridge. The Warren did use 2 less popsicle sticks, but that weight difference did not compare to the difference in overall efficiency.

Conclusions and Recommendations.

The truss bridge that will be used to replace the bridge that was destroyed is the Howe Truss Bridge. The Howe outperformed the Warren Truss Bridge in both structural efficiency and in cost. As determined in the Bridge Builder 2015 program, the cost for the Howe is approximately \$2,000 less than the Warren. When testing the prototypes, the structural efficiency of the Howe was 383.9, while the Warren was only 381.1. The clear choice to use it the Howe because it outperforms on both major components needed in a replacement bridge.

Respectfully,

Tyler Snyder

Engineering Student

EDSGN100 Section 1

Design Team 6

Design Team Sean's Favorite Team

College of Engineering

Penn State University

Sonny Albright

Engineering Student

EDSGN100 Section 1

Design Team 6

Design Team Sean's Favorite Team

College of Engineering

Penn State University

Stan Pinchuk

Engineering Student

EDSGN100 Section 1

Design Team 6

Design Team Sean's Favorite Team

College of Engineering

Penn State University

Flynn Munroe

Engineering Student

EDSGN100 Section 1

Design Team 6

Design Team Sean's Favorite Team

College of Engineering

Penn State University

ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss.

View the Howe Truss bridge design in Figure 1. The economic efficiency of the bridge was determined by the cost of the bridge. When designing the bridge, the cost was systematically minimized by testing different types of material, thickness of members, and type of member (whether it be solid bar or hollow tube). The total projected cost found in the EEBD 2015 was \$243,361.04 (see Table 1). That price was found by tweaking each structural member and analyzing the possible changes that could reduce the cost, while maintaining the structural efficiency of the bridge. Different members on the bridge have different forces acting upon them. Some encounter tension forces while others encounter compression forces (see Table 2). The type of member can be changed depending on these forces acting on each member, e.g. hollow tubes handle tension forces relatively better than solid bars. Also, members under less force were able to be demoted to a weaker, cheaper material and/or a lower thickness. The bridge member with the highest force to strength ration was member number 11. Member 11 maxed out with a compression rate of 4400kN and a tension rate of 6850kN (see Table 3). That member could support the most force for its size and type of member.

Warren Truss.

View the Warren Truss bridge design in Figure 2. To design the Warren Truss Bridge with the best economic efficiency, a similar process to the Howe design was put into place. The goal of the design was to limit costs, while maximizing structural efficiency. The total cost of the Warren Truss Bridge that was originally designed in the EEBD 2015 was \$245,317.43 (see Table 4). The information found in examining the forces generated by EEBD load tests determined what type of material was used for each member. The maximum load for the bridge at the minimum cost was found by limiting the costs until the bridge reached its maximum load capacity, then going through all the other members and repeating. Table 5 shows the strength of each member at it's minimum cost while still supporting its own dead weight and the weight of the load. Table 6 shows a tabulated member detail report and also documents the member that held the strongest force to strength ratio. Member 37 supports up to 4550kN in compression, and 6850kN in tension.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss.

Prototype Bridge.

See Figure 3. The Howe Truss bridge prototype was built entirely of wooden popsicle sticks and two types of glue, normal PVA-based synthetic glue and hot-melt adhesive. After sketching and drafting the design and deciding how to distribute the limited supply of members, construction took place over four weeks time which allowed joints sufficient curing time. All 60 Popsicle sticks were used in the prototype and its final dimensions were 13.5 by 4.25 by 3.75 (L by W by H).

Load Testing.

Table 7 shows the results and data collected from all of the Howe Bridges tested by all 8 groups. The arithmetic mean for structural efficiency, which is defined as maximum load divided by total dead load, was 353.3, and the geometric mean was 330.8 (arithmetic is a little higher because of a greater influence of outliers on the calculation). Design team 6 had the fourth highest place with 383.9 efficiency, which is above both the arithmetic and geometric means. Design Team 7 had the lowest structural efficiency of 195.2 and Team 3 had the highest of 603.3.

Forensic Analysis.

The Howe Truss Bridge failed because of limited materials and means of construction. One side of the bridge remained fully intact, leading to the belief that the bridge could have been better balanced and straightened. The prototype could have supported more weight if better construction techniques could have been employed, such as leveling members and checking for plumb. One also could have wet the joints before gluing to try to draw the glue polymers farther into the wood. The bridge failed near the center of one side near the center joints of members 2 and 16 after skewing towards that side quite a bit. See Figure 4 for a post-fail graphic.

Results.

The Howe Truss Bridge was in all more structurally efficient than the Warren. The bridge was well over the averages of all the groups, and did not fail from a design error. A few simple changes in the construction could have helped the bridge perform better in the test.

Warren Truss.

Prototype Bridge.

The Warren Truss Bridge prototype was designed by using just popsicle sticks and glue. The designed used, bases on the most efficient design made in Bridge Designer 2015, consisted of 58 popsicle sticks. The members were glued together with PVA-based synthetic glue. Of the 58 popsicle sticks, only 25 were used for each side of the bridge. The two sides of the bridge were connected by the last 8 popsicle sticks, 4 on top of the bridge and 4 on the deck, with a hot-melt adhesive. Each side of the bridge was created and glues together with that glue. The overall construction time for designing and building the prototype was 4 weeks. The first weeks were used to put together each side, to give proper time to dry, and the last was to attach the two sides together. The final dimensions of the bridge were 12.5 inches in length, 4 inches high and 4.25 inches wide. These observations can be seen in Figure 5 (below).

Load Testing.

Table 8 shows the results and data collected from all of the Warren Bridges tested by all 8 groups. The arithmetic means for structural efficiency, which is the maximum load divided by the dead weight of the bridge is 329.1. The geometric means are 316.5. Design team 2 had the lowest structural efficiency of 202.6. Design team 3 had the highest structural efficiency of 493.8. Design team 6 came in second with a structural efficiency of 381.1.

Forensic Analysis.

The design of the Warren Truss Bridge was successful, but the construction of the bridge is what caused its failure. The two sides of the bridge were not parallel with each other, nor were they perpendicular to the ground. The slight tilt in the bridge caused it to lean over once the load reached a certain weight. No parts of the bridge broke until it tipped completely over and hit the ground area. At that time, the glue holding members 13 and 14 failed, along with the 8th cross member to snap. The photo of the bridge after failure can be seen in Figure 6.

Results.

The Warren Truss Bridge was not the best solution out of the two, but in comparison to the other groups, it outperformed all other bridges but 1. The bridge was well over the averages of all the groups, and did not fail from a design error. A simple change in the construction could have helped the bridge perform better in the test.

TABLES

Howe Truss Bridge

Table 1: Bridge Designer 2015 Cost Calculations Report

Howe Truss Bridge Cost Efficiency Report			
Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	$(13842.9 \text{ kg}) \times (\$4.30 \text{ per kg}) \times (2 \text{ Trusses}) =$	\$119,048.86
	Carbon Steel Hollow Tube	$(1501.0 \text{ kg}) \times (\$6.30 \text{ per kg}) \times (2 \text{ Trusses}) =$	\$18,912.18
Connection Cost (C)		$(20 \text{ Joints}) \times (500.0 \text{ per joint}) \times (2 \text{ Trusses}) =$	\$20,000.00
Product Cost (P)	6 - 90x90x4 mm Carbon Steel Tube	$(\% \text{ s per Product}) =$	\$1,000.00
	2 - 100x100x5 mm Carbon Steel Tube	$(\% \text{ s per Product}) =$	\$1,000.00
	4 - 120x120 mm Carbon Steel Bar	$(\% \text{ s per Product}) =$	\$1,000.00
	6 - 130x130 mm Carbon Steel Bar	$(\% \text{ s per Product}) =$	\$1,000.00
	8 - 130x130x6 mm Carbon Steel Tube	$(\% \text{ s per Product}) =$	\$1,000.00
	1 - 140x140x7 mm Carbon Steel Tube	$(\% \text{ s per Product}) =$	\$1,000.00
	5 - 160x160 mm Carbon Steel Bar	$(\% \text{ s per Product}) =$	\$1,000.00
	5 - 170x170 mm Carbon Steel Bar	$(\% \text{ s per Product}) =$	\$1,000.00
Site Cost (S)	Deck Cost	$(10 \text{ 4-meter panels}) \times (\$4,700.00 \text{ per panel}) =$	\$47,000.00
	Excavation Cost	$(19,900 \text{ cubic meters}) \times (\$1.00 \text{ per cubic meter}) =$	\$19,900.00
	Abutment Cost	$(2 \text{ standard abutments}) \times (\$5,250.00 \text{ per abutment}) =$	\$10,500.00
	Pier Cost	No pier =	\$0.00
	Cable Anchorage Cost	No anchorages =	\$0.00
Total Cost	M + C + P + S	$\$137,961.04 + \$20,000.00 + \$8,000.00 + \$77,400.00 =$	\$243,361.04

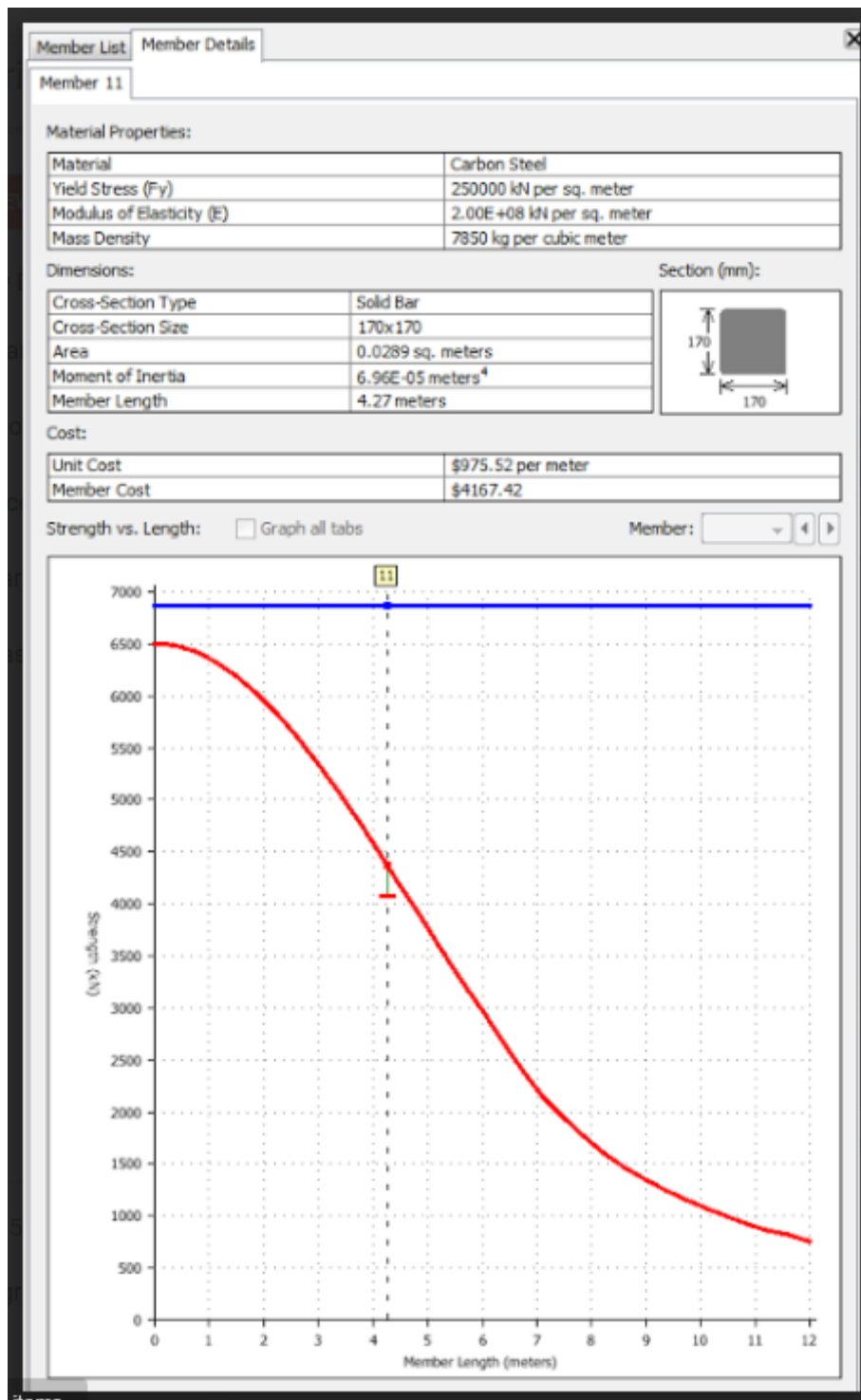
Howe Truss Bridge

Table 2: Bridge Designer 2015 Load Test Report

Howe Truss Bridge Load Test Report										
#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	130x130	4	0	2091.29	OK	3733.75	4013.75	OK
2	CS	Solid Bar	130x130	4	0	2091.29	OK	3609.54	4013.75	OK
3	CS	Solid Bar	130x130	4	0	2091.29	OK	3511.28	4013.75	OK
4	CS	Solid Bar	120x120	4	0	1606.24	OK	3361.94	3420	OK
5	CS	Solid Bar	120x120	4	0	1606.24	OK	3328.71	3420	OK
6	CS	Solid Bar	120x120	4	0	1606.24	OK	3328.71	3420	OK
7	CS	Solid Bar	120x120	4	0	1606.24	OK	3380.68	3420	OK
8	CS	Solid Bar	130x130	4	0	2091.29	OK	3556.24	4013.75	OK
9	CS	Solid Bar	130x130	4	0	2091.29	OK	3700.48	4013.75	OK
10	CS	Solid Bar	130x130	4	0	2091.29	OK	3819.96	4013.75	OK
11	CS	Solid Bar	170x170	4.27	4079.72	4364.04	OK	0	6863.75	OK
12	CS	Solid Bar	170x170	4.19	4002.14	4430.09	OK	0	6863.75	OK
13	CS	Solid Bar	170x170	4.12	3814.37	4484.88	OK	0	6863.75	OK
14	CS	Solid Bar	160x160	4.07	3618.22	3828.1	OK	0	6080	OK
15	CS	Solid Bar	160x160	4.01	3387.27	3875.61	OK	0	6080	OK
16	CS	Solid Bar	160x160	4.01	3368.5	3875.61	OK	0	6080	OK
17	CS	Solid Bar	160x160	4.07	3572.47	3828.1	OK	0	6080	OK
18	CS	Solid Bar	160x160	4.12	3720.63	3787.01	OK	0	6080	OK
19	CS	Solid Bar	170x170	4.19	3911.81	4430.09	OK	0	6863.75	OK
20	CS	Solid Bar	170x170	4.27	3987.65	4364.04	OK	0	6863.75	OK
21	CS	Hollow Tube	90x90x4	1.5	0	281.3	OK	220.54	326.8	OK
22	CS	Hollow Tube	140x140x7	4.85	14.63	550.85	OK	728.3	884.45	OK
23	CS	Hollow Tube	90x90x4	2.75	50.46	224.33	OK	216.99	326.8	OK
24	CS	Hollow Tube	130x130x6	5.48	0	361.69	OK	670.67	706.8	OK
25	CS	Hollow Tube	90x90x4	3.75	153.38	170.07	OK	203.2	326.8	OK
26	CS	Hollow Tube	130x130x6	6.02	0	318.62	OK	645.19	706.8	OK
27	CS	Hollow Tube	100x100x5	4.5	28.64	210.91	OK	378.8	451.25	OK
28	CS	Hollow Tube	130x130x6	6.21	176.78	303.88	OK	393.92	706.8	OK
29	CS	Hollow Tube	130x130x6	4.75	0	421.76	OK	623.45	706.8	OK
30	CS	Hollow Tube	100x100x5	4.5	0	210.91	OK	402.97	451.25	OK
31	CS	Hollow Tube	90x90x4	3.75	100.95	170.07	OK	215.12	326.8	OK
32	CS	Hollow Tube	90x90x4	1.5	0	281.3	OK	225.93	326.8	OK
33	CS	Hollow Tube	130x130x6	4.85	24.47	413.2	OK	703.73	706.8	OK
34	CS	Hollow Tube	90x90x4	2.75	28.39	224.33	OK	225.41	326.8	OK
35	CS	Hollow Tube	130x130x6	5.48	11.12	361.69	OK	583.96	706.8	OK
36	CS	Hollow Tube	130x130x6	6.02	0	318.62	OK	547.65	706.8	OK
37	CS	Hollow Tube	130x130x6	6.21	208.39	303.88	OK	339.15	706.8	OK

Howe Truss Bridge

Table 3: Bridge Designer 2015 Member Detail Graph



Howe Truss Bridge

Table 7: Structural Efficiency Compared to Other Groups

HOWE Truss Bridge				
Design Team No.	Actual Bridge Weight (grams)	Actual Bridge Weight(lbs)	LOAD at Failure (lbs)	Structural Efficiency
1	84.5	0.18629039	49.4	265.2
2	75.3	0.166007886	34	204.8
3	81.8	0.180337916	108.8	603.3
4	78.1	0.172180822	77.9	452.4
5	81.4	0.179456068	58.3	324.9
6	85.2	0.187833624	72.1	383.9
7	79.7	0.175708214	34.3	195.2
8	80	0.1763696	70	396.9

Warren Truss Bridge

Table 4: Bridge Designer 2015 Cost Calculations Report

Dennis H. Mahan Memorial Bridge			
Project ID: 00002A-			
Iteration #174 (Wed, 28 Oct 2015, 20:53:24)			
Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	$(16036.9 \text{ kg}) \times (\$4.30 \text{ per kg}) \times (2 \text{ Trusses}) =$	\$137,917.43
Connection Cost (C)		$(21 \text{ Joints}) \times (500.0 \text{ per joint}) \times (2 \text{ Trusses}) =$	\$21,000.00
Product Cost (P)	7 - 70x70 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	2 - 75x75 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	7 - 80x80 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	4 - 100x100 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	4 - 120x120 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	6 - 130x130 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	2 - 150x150 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	3 - 160x160 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
	4 - 170x170 mm Carbon Steel Bar	$(\%s \text{ per Product}) =$	\$1,000.00
Site Cost (S)	Deck Cost	$(10 \text{ 4-meter panels}) \times (\$4,700.00 \text{ per panel}) =$	\$47,000.00
	Excavation Cost	$(19,900 \text{ cubic meters}) \times (\$1.00 \text{ per cubic meter}) =$	\$19,900.00
	Abutment Cost	$(2 \text{ standard abutments}) \times (\$5,250.00 \text{ per abutment}) =$	\$10,500.00
	Pier Cost	No pier =	\$0.00
	Cable Anchorage Cost	No anchorages =	\$0.00
Total Cost	M + C + P + S	$\$137,917.43 + \$21,000.00 + \$9,000.00 + \$77,400.00 =$	\$245,317.43

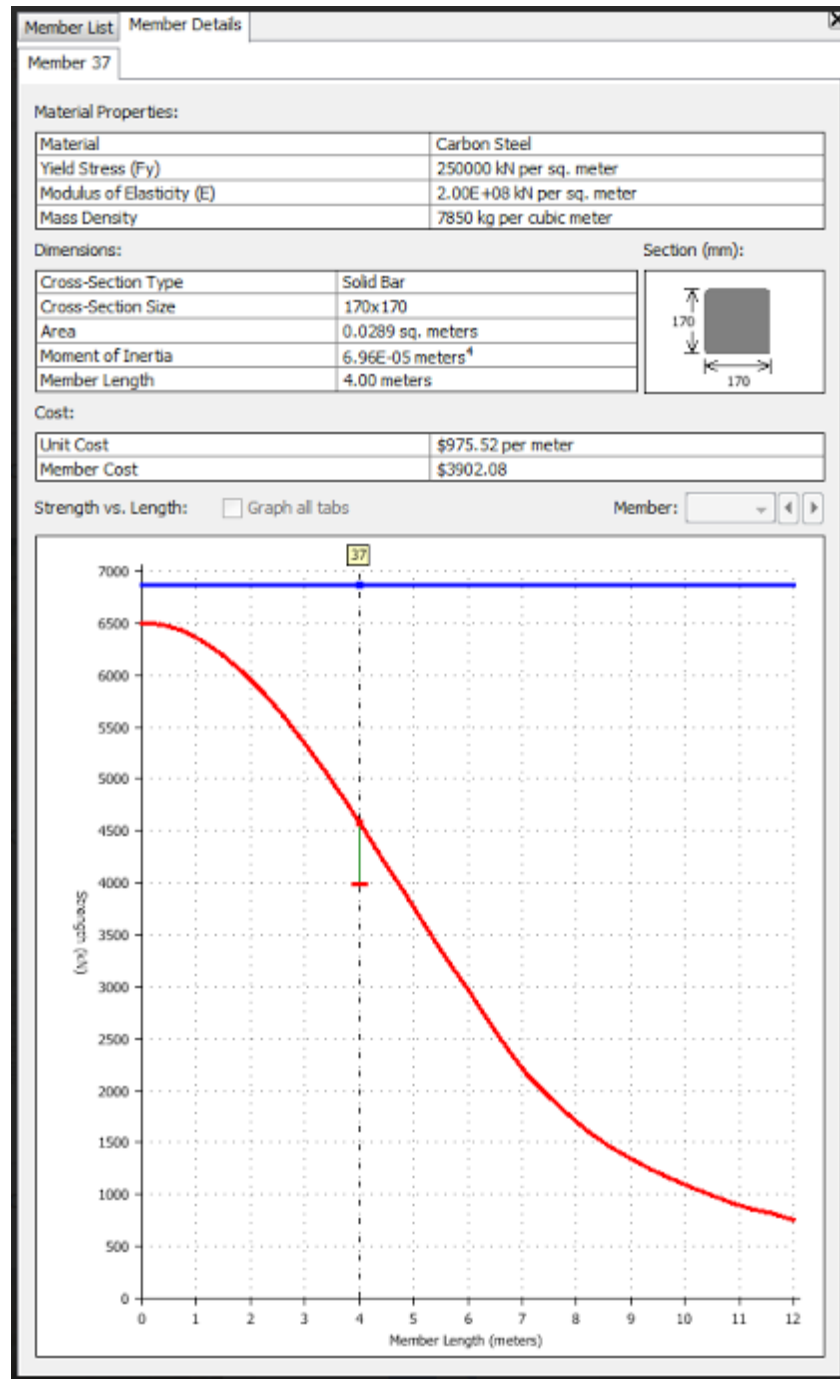
Warren Truss Bridge

Table 5: Bridge Designer 2015 Load Test Report

#	Material Type	Cross Section	Size (mm)	Length(m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	100x100	4	0	814.24	OK	1924.25	2375	OK
2	CS	Solid Bar	120x120	4	0	1606.24	OK	3163.52	3420	OK
3	CS	Solid Bar	130x130	4	0	2091.29	OK	3583.78	4013.75	OK
4	CS	Solid Bar	130x130	4	0	2091.29	OK	3758.21	4013.75	OK
5	CS	Solid Bar	130x130	4	0	2091.29	OK	3835.19	4013.75	OK
6	CS	Solid Bar	130x130	4	0	2091.29	OK	3850.47	4013.75	OK
7	CS	Solid Bar	130x130	4	0	2091.29	OK	3778.11	4013.75	OK
8	CS	Solid Bar	130x130	4	0	2091.29	OK	3581.57	4013.75	OK
9	CS	Solid Bar	120x120	4	0	1606.24	OK	3129.02	3420	OK
10	CS	Solid Bar	100x100	4	0	814.24	OK	1880.78	2375	OK
11	CS	Solid Bar	120x120	2.5	2405.32	2463.25	OK	0	3420	OK
12	CS	Solid Bar	80x80	2.5	0	777.2	OK	1193.25	1520	OK
13	CS	Solid Bar	160x160	4.07	3536.18	3828.1	OK	0	6080	OK
14	CS	Solid Bar	150x150	4.12	2900.24	3141.57	OK	0	5343.75	OK
15	CS	Solid Bar	80x80	3.82	317.49	366.44	OK	147.76	1520	OK
16	CS	Solid Bar	75x75	3.82	0	283.06	OK	489.91	1335.94	OK
17	CS	Solid Bar	80x80	4.25	206.6	295.43	OK	250.87	1520	OK
18	CS	Solid Bar	80x80	4.25	8.46	295.43	OK	427.89	1520	OK
19	CS	Solid Bar	70x70	4.47	149.44	156.4	OK	318.79	1163.75	OK
20	CS	Solid Bar	70x70	4.47	73.38	156.4	OK	395.02	1163.75	OK
21	CS	Solid Bar	70x70	4.47	107.55	156.4	OK	360.85	1163.75	OK
22	CS	Solid Bar	70x70	4.47	124.57	156.4	OK	366.67	1163.75	OK
23	CS	Solid Bar	70x70	4.25	57.36	173.18	OK	402.3	1163.75	OK
24	CS	Solid Bar	80x80	4.25	186.22	295.43	OK	322.89	1520	OK
25	CS	Solid Bar	75x75	3.82	0	283.06	OK	468.78	1335.94	OK
26	CS	Solid Bar	80x80	3.82	299.18	366.44	OK	225.54	1520	OK
27	CS	Solid Bar	70x70	3.2	0	305.17	OK	619.68	1163.75	OK
28	CS	Solid Bar	100x100	3.2	602.46	1177.78	OK	0	2375	OK
29	CS	Solid Bar	80x80	2.5	0	777.2	OK	1166.08	1520	OK
30	CS	Solid Bar	120x120	2.5	2350.97	2463.25	OK	0	3420	OK
31	CS	Solid Bar	150x150	4.12	2967.46	3141.57	OK	0	5343.75	OK
32	CS	Solid Bar	100x100	3.2	623.34	1177.78	OK	0	2375	OK
33	CS	Solid Bar	70x70	3.2	0	305.17	OK	639.65	1163.75	OK
34	CS	Solid Bar	160x160	4.07	3625.19	3828.1	OK	0	6080	OK
35	CS	Solid Bar	170x170	4.03	3870.42	4558.99	OK	0	6863.75	OK
36	CS	Solid Bar	170x170	4.01	3967.3	4577.7	OK	0	6863.75	OK
37	CS	Solid Bar	170x170	4	3986.83	4583.96	OK	0	6863.75	OK
38	CS	Solid Bar	170x170	4.01	3944.74	4577.7	OK	0	6863.75	OK
39	CS	Solid Bar	160x160	4.03	3821.16	3857.73	OK	0	6080	OK

Warren Truss Bridge

Table 6: Bridge Designer 2015 Member Detail Graph



Warren Truss Bridge

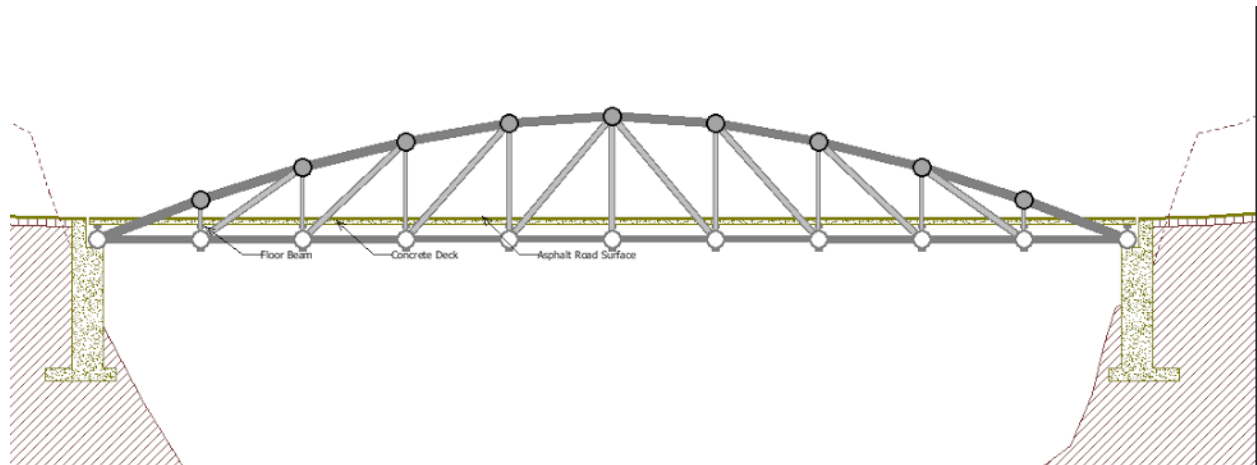
Table 8: Structural Efficiency Compared to Other Groups

WARREN Truss Bridge				
Design Team No.	Actual Bridge Weight (grams)	Actual Bridge Weight (lbs)	LOAD at Failure (lbs)	Structural Efficiency
1	85.2	0.187833624	39	207.6
2	80.3	0.177030986	55.1	311.2
3	83.4	0.183865308	90.8	493.8
4	73.2	0.161378184	32.7	202.6
5	85.3	0.188054086	60.8	323.3
6	83.8	0.184747156	70.4	381.1
7	75.5	0.16644881	55.6	334.0
8	81.9	0.180558378	68.4	378.8

FIGURES

Howe Truss Bridge

Figure 1: Bridge Designer 2015 Images of Bridge Design



Howe Truss Bridge

Figure 3: Photograph of the Prototype before Load Testing



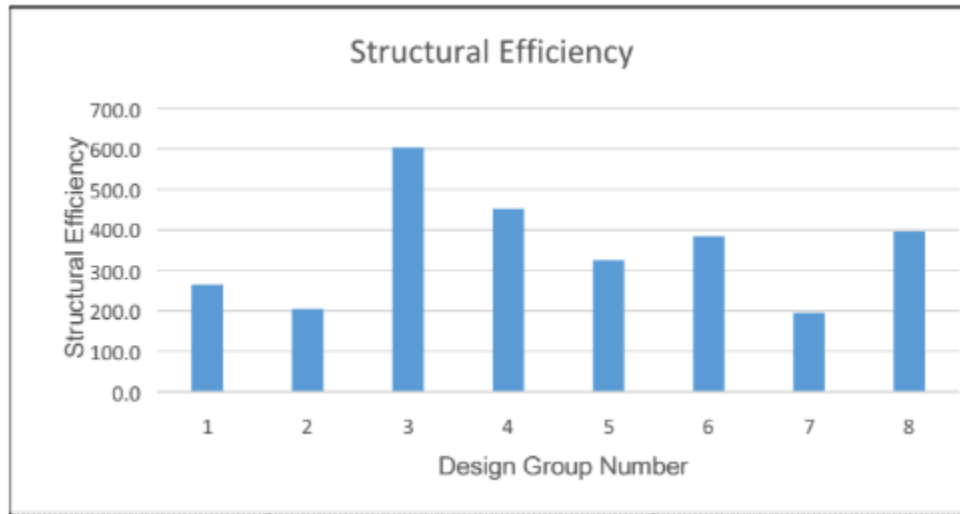
Howe Truss Bridge

Figure 4: Photograph of the prototype after failure



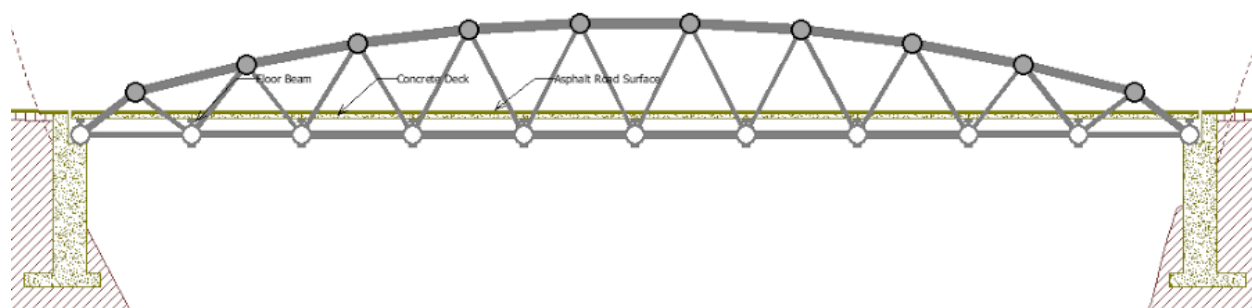
Howe Truss Bridge

Figure 7: Comparing Structural Efficiencies from Table 7 (above)



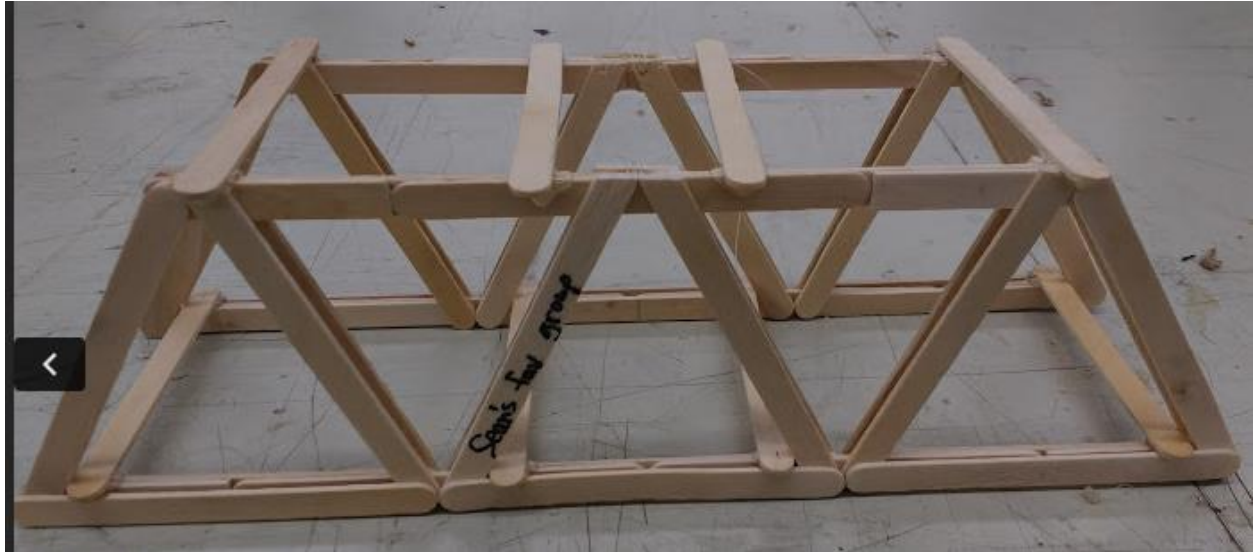
Warren Truss Bridge

Figure 2: Bridge Designer 2015 Images of Bridge Design



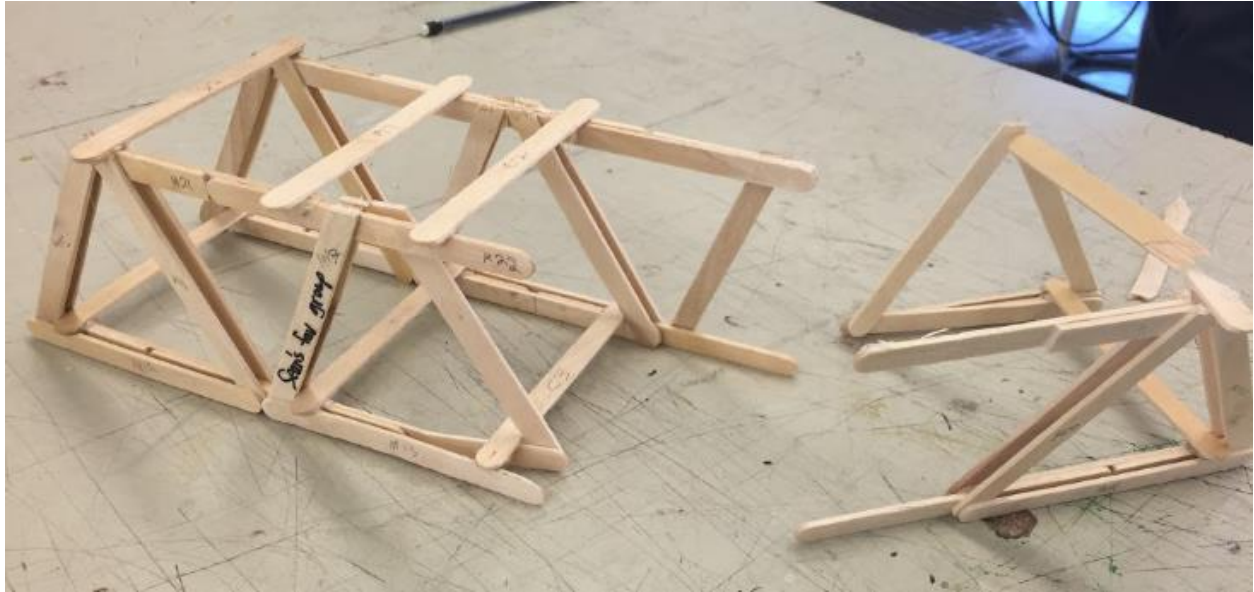
Warren Truss Bridge

Figure 5: Photograph of the Prototype before Load Testing



Warren Truss Bridge

Figure 6: Photograph of the prototype after failure



Warren Truss Bridge

Figure 8: Comparing Structural Efficiencies from Table 8 (above)

