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. A bridge in PennDOT Engineering District 2-0 has been destroyed by flooding. The bridge is along a heavily traveled road that is also important for Mount Nittany medical center. Therefore, not having this bridge poses severe danger to all resdients of State College.

Objective. A bridge must be designed in an expedited fashion to replace the destroyed one over Spring Creek.

Design Criteria. The replacement bridge has 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 bridge deck elevation shall be set at 20 meters and the deck span shall be exactly 40 meters. Both a Warren through truss bridge and a Howe through truss bridge shall be analyzed.

Technical Approach.

Phase 1: Economic Efficiency. Using Engineering Encounters Bridge Design 2015 software, the plan is to design a Warren and a Howe bridge that support their own weight and the weight of a standard truck loading with as low a cost as possible.

Phase 2: Structural Efficiency. Each design team shall create a prototype of both the Howe and the Warren bridge. They will be made out of a maximum of 60 Popsicle sticks, stuck together with hot and Elmer's glue. These will both be load tested to catastrophic failure. These result will be analyzed to see whether the Howe or the Warren can better dissipate a load. This shall be done by a forensic engineering analysis to determine why each bridge failed.

Results

Phase 1: Economic Efficiency. The results from attachment one were clear cut. The optimum cost for the Howe Bridge came out to be $221,212.23, while the optimum cost for the Warren bridge came out to be $246,128.18. The Howe Truss design was $24915.95 cheaper than the Warren Truss design. This is a statistically significant difference, leading to an advantage in the Howe Design.

Phase 2: Structural Efficiency. The structural efficiency data showed that the Howe and Warren truss bridges had similar structural efficiencies. The Howe truss bridge had an average structural efficiency of about 353, but that of the Warren truss bridge was about 329. The Howe truss bridge average was offset by an outlier that was especially high, whereas there was no outlier for the Warren truss bridge. The geometric mean for the Howe is 318, while it is 306 for the Warren. With and without the outliers taken into consideration, the Howe bridges had a statistically significant better structural efficiency rating.

Best Solution.

Economically and structurally, the Howe truss bridge was better than the Warren truss bridge. Although there was only one set of cost data for the Howe and Warren truss bridges, the Howe bridge was less expensive. The range of cost for the Howe and Warren bridges seemed to be within $20000 out of more than $200000, which meant there was a difference in price but that the cost of both bridges were similar. However, there was a lot of data for the structural efficiency of the Howe and Warren truss bridges and it showed that the Howe truss bridge was more structurally efficient. The structural efficiency of the Warren bridges was about 329, but that of the Howe bridges was about 353. This means that the Howe bridges supported more weight. The data is different enough to draw a strong conclusion even though the structural

efficiency of the Howe is taken down when the high outlier is considered, Regardless of whether economic or structural efficiency is the best measure of which truss bridge type is the best, the Howe bridge was better both economically and structurally. Both the cost data and structural efficiency data was conclusive. The cost data should be viewed more lightly, as it is only the data for one group, not the entire class as a whole.

Conclusions and Recommendations.

In conclusion, the bridge failure is due to bad techniques and lower skills in construction. All bridges have the same popsicle sticks which can be categorized into good and bad sticks. If good techniques and higher skills are used, then the bridge will have better structural efficiency and vice versa. Gluing technique is one of the most important technique in constructing good bridge. Ensure that excessive glue is not applied or else the bridge will have more weight than it should have. The effect will definitely cause the bridge to have low structural efficiency as the weight has increased. However less glue will give effect to the strength of the bridge overall. It cannot bear with the higher weight although supposedly it can. However with less glue used, it cannot perform the best performance. Hence,it is really important to use right gluing technique or otherwise it will effect the bridge overall. Other than that, ensure that the popsicle sticks are all straight and not cracked. It is really important as it will also give effect on how the bridge will perform during the load test.
(i) Howe Bridge is better than Warren bridge as it has higher structural efficiency and better cost compared to Warren Bridge.
(ii) Howe Bridge will be used instead of using Warren Bridge as it has better cost and structural efficiency. Technique in gluing has to be improved in order to accomplish good result in the final design. More attention has to be given to the way it will be built especially, number of popsicle sticks used for struts, top chord and floor beam. Finally,the best bridge will be built after everything has been improved and corrected.

Respectfully,

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ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. Using the EEBD 2015 design software, a design of the Howe Truss Bridge was made and reiterated many times until the most efficient cost was realized. This happened at a cost of $221,212.23. At this cost, the bridge was able to support both the dead load and live load which is the main requirement from PennDOT. Any further actions that lowered the cost of the bridge endangered it's safety as it could no longer support both loads. Therefore, $221,212.23 was decided as the optimum cost of the Howe Truss bridge.

Warren Truss. The cost of the Warren Truss Bridge as calculated by the EEBD 2015 design software was $246,128.18. This was the lowest cost at which the bridge would not fail when a certain load was placed on it. The cost was lowered by strategically using standard grade steel, hollow beams, and thinner members where possible. These parameters were changed until the force and compression limits were almost exceeded but not passed. The cost was the minimum cost at which the bridge could be safe according to PennDOT and the structural capabilities of the bridge.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss

Prototype Bridge. The prototype bridge was created using 60 Popsicle sticks and Elmer's glue. The floor beams were added on using hot glue. The bridge was approximately 13.5 inches in length, 4 inches in height, and 4.5 inches in width. The Popsicle sticks were divided into good, very good, and bad categories. Based on our stress analysis, the very good sticks were placed as members that were subjected to either high compression or high tension. Bad Popsicle sticks were used as members that had low tension or compression.

Load Testing. Our design team had the third worst structural efficiency rating with a score of 265. The average structural efficiency result from all 8 teams was 353. The minimum was 195. The maximum was 603. The range for the Howe data is 408.

Forensic Analysis. The issue with the Howe bridge prototype design was evident at the beginning of its load testing. The structure wobbled as soon as a load was applied to it. As can be seen in the picture, many of the floor beams became disconnected from one side or the other. The main point of failure of the bridge was floor beam C. Not only did the beam get disconnected from one side, but the Popsicle stick snapped. This happened because the load was unevenly distributed to one side of the bridge, and it became too much for the Popsicle stick to handle. The primary reason for the failure of the Howe Truss bridge was not poor design, but instead it was poor construction techniques. the bridge was not level, therefore the load could not be distributed as we had predicted.

Warren Truss

Prototype Bridge.

The prototype bridge used 60 Popsicle sticks connected with Elmer's white glue. Hot glue was used to connect the floor beams and struts to the trusses. The bridge was approximately 13.5 inches in length, 4 inches in height, and 4.5 inches in width.

Load Testing.

Our design team (Team 1) had the second to worst Warren truss bridge structural efficiency with a value of about 207. The other design teams' Warren structural efficiencies

averaged around 329. The minimum structural efficiency was around 203, and the maximum structural efficiency was around 494.

For the Howe bridge, the class average for structural efficiency was about 400, which was about 50 higher than the class average for the Warren bridge.

Forensic Analysis.

Member C3 broke close to, but not at the joint. The member stayed glued at the joint, but snapped. Member D4 broke similarly; it remained intact at a joint but broke right outside of the joint although in a cleaner and less jagged way that member C3 did. Members E7 and B1 broke at the joint, coming unglued from between two other members and leaving a gap in its place. In addition, the floor beams, especially those in the middle, came unglued from the trusses because the area of contact between these members was small.

Overall, the Warren truss bridge failed because of poor construction-it was not completely upright and it started to lean almost immediately after a load was placed. This caused members to fracture and come unglued as the bridge broke in several places.

TABLES

Table 1. Howe Truss Cost Calculation

Material Cost (M)	Carbon Steel Solid Bar (9429.6 kg) x ($4.30 per kg) x (2 Trusses) = $81,094.14
	Carbon Steel Hollow Tube (2676.0 kg) x ($6.30 per kg) x (2 Trusses) = $33,718.09
Connection Cost (C)	(22 Joints) x (500.0 per joint) x (2 Trusses) = $22,000.00
Product Cost (P)	10 - 100x100 mm Carbon Steel Bar (%s per Product) = $1,000.00

	16 - 110x110x5 mm Carbon Steel Tube (%s per Product) = $1,000.00	
	4 - 120x120 mm Carbon Steel Bar (%s per Product) = $1,000.00	
	3 - 120x120x6 mm Carbon Steel Tube (%s per Product) = $1,000.00	
	2 - 130x130x6 mm Carbon Steel Tube (%s per Product) = $1,000.00	
	8 - 140x140 mm Carbon Steel Bar (%s per Product) = $1,000.00	
	2 - 140x140x7 mm Carbon 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 $114,812.23 + $22,000.00 + $7,000.00 + $77,400.00 = $221,212.23	

Table 2. Howe Truss Load Report
Dennis H. Mahan Memorial Bridge
Project ID: 00002A-Sample Design
Designed By: I.M. Bridgemaster

#	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	4.00	0.00	814.24	OK	1416.56	2375.00	OK
2	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1384.67	2375.00	OK
3	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	2011.10	2375.00	OK
4	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1966.38	2375.00	OK
5	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	2149.83	2375.00	OK
6	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	2064.16	2375.00	OK
7	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	2078.92	2375.00	OK

8	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	2138.12	2375.00	OK
9	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1970.11	2375.00	OK
10	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1961.94	2375.00	OK
11	CS	Solid Bar	140x140	4.47	2108.53	2315.16	OK	0.00	4655.00	OK
12	CS	Solid Bar	140x140	4.12	2224.94	2550.11	OK	0.00	4655.00	OK
13	CS	Solid Bar	140x140	4.12	2265.22	2550.11	OK	0.00	4655.00	OK
14	CS	Solid Bar	140x140	4.00	2232.73	2633.62	OK	0.00	4655.00	OK
15	CS	Solid Bar	140x140	4.00	2232.86	2633.62	OK	0.00	4655.00	OK
16	CS	Solid Bar	140x140	4.12	2237.07	2550.11	OK	0.00	4655.00	OK
17	CS	Solid Bar	140x140	4.12	2226.73	2550.11	OK	0.00	4655.00	OK

18	CS	Solid Bar	140x140	4.47	2061.00	2315.16	OK	0.00	4655.00	OK
19	CS	Hollow Tube	110x110x5	3.00	6.56	365.35	OK	0.00	498.75	OK
20	CS	Hollow Tube	110x110x5	5.00	0.00	231.29	OK	496.86	498.75	OK
21	CS	Hollow Tube	110x110x5	6.00	114.31	167.95	OK	39.00	498.75	OK
22	CS	Hollow Tube	110x110x5	7.00	0.00	123.39	OK	466.78	498.75	OK
23	CS	Hollow Tube	110x110x5	7.00	0.00	123.39	OK	441.23	498.75	OK
24	CS	Hollow Tube	110x110x5	6.00	129.79	167.95	OK	35.03	498.75	OK
25	CS	Hollow Tube	110x110x5	5.00	0.00	231.29	OK	478.28	498.75	OK
26	CS	Hollow	110x110x5	3.00	6.56	365.35	OK	0.00	498.75	OK

		Tube								
27	CS	Hollow Tube	140x140x7	6.40	298.53	403.86	OK	239.97	884.45	OK
28	CS	Hollow Tube	140x140x7	6.40	312.14	403.86	OK	205.00	884.45	OK
29	CS	Hollow Tube	120x120x6	8.06	114.84	142.93	OK	347.13	649.80	OK
30	CS	Hollow Tube	120x120x6	8.06	96.48	142.93	OK	426.70	649.80	OK
31	CS	Solid Bar	120x120	2.24	2108.53	2602.05	OK	0.00	3420.00	OK
32	CS	Solid Bar	120x120	2.83	2003.32	2281.28	OK	0.00	3420.00	OK
33	CS	Solid Bar	120x120	2.24	2061.00	2602.05	OK	0.00	3420.00	OK
34	CS	Solid Bar	120x120	2.83	1958.23	2281.28	OK	0.00	3420.00	OK
35	CS	Hollow	130x130x6	2.83	0.00	568.37	OK	663.79	706.80	OK

		Tube								
36	CS	Hollow Tube	130x130x6	2.83	0.00	568.37	OK	648.76	706.80	OK
37	CS	Hollow Tube	110x110x5	6.40	0.00	147.47	OK	354.78	498.75	OK
38	CS	Hollow Tube	110x110x5	7.21	64.71	116.27	OK	173.00	498.75	OK
39	CS	Hollow Tube	110x110x5	6.40	0.00	147.47	OK	370.11	498.75	OK
40	CS	Hollow Tube	110x110x5	7.21	70.44	116.27	OK	150.67	498.75	OK
41	CS	Hollow Tube	110x110x5	8.06	0.00	93.02	OK	344.01	498.75	OK
42	CS	Hollow Tube	110x110x5	8.06	83.87	93.02	OK	179.39	498.75	OK
43	CS	Hollow Tube	110x110x5	8.06	86.35	93.02	OK	208.82	498.75	OK

44	CS	Hollow Tube	110x110x5	8.06	0.00	93.02	OK	314.25	498.75	OK
45	CS	Hollow Tube	120x120x6	7.00	119.39	189.60	OK	52.11	649.80	OK

Member List | Member Details

Member 20

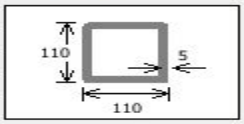
Material Properties:

Material	Carbon Steel
Yield Stress (Fy)	250000 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	110x110x5
Area	0.0021 sq. meters
Moment of Inertia	3.87E-06 meters^4
Member Length	5.00 meters

Section (mm):



Cost:

Unit Cost	$103.86 per meter
Member Cost	$519.28

Strength vs. Length: Graph all tabs Member:

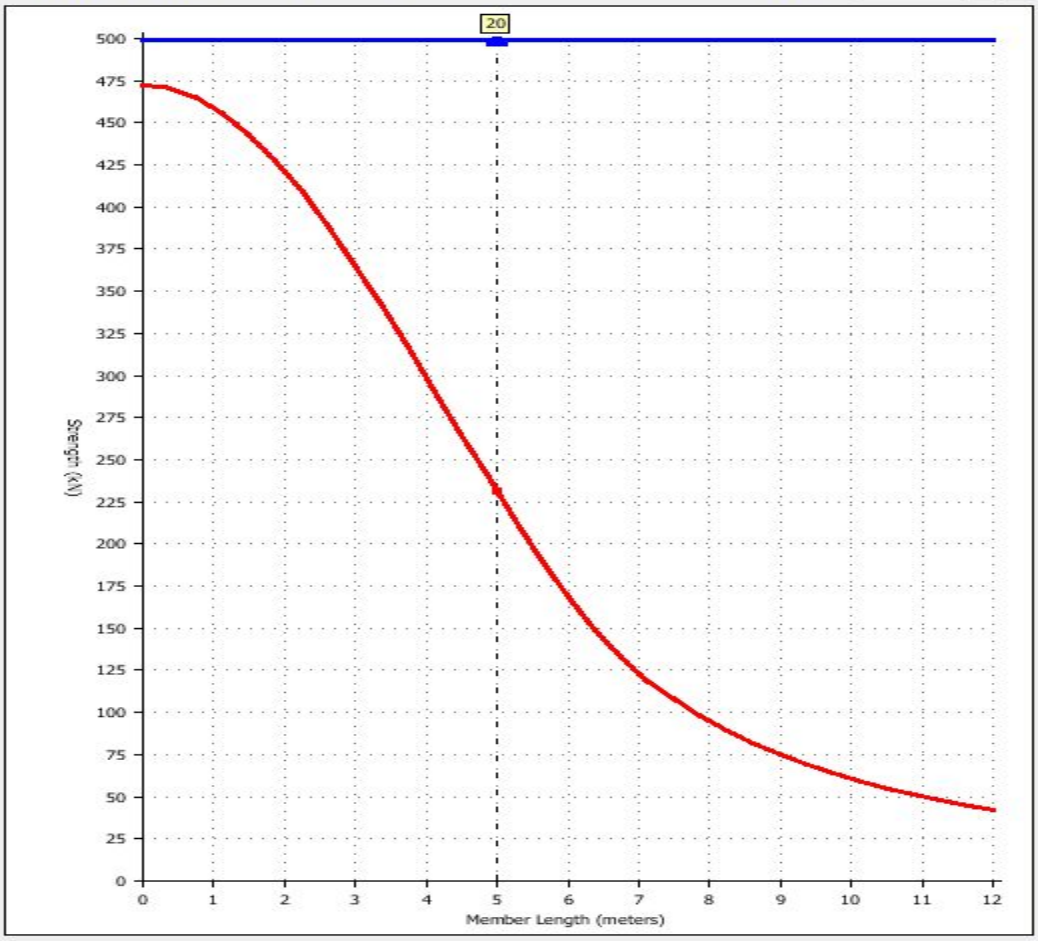


Table 3. Tabulated member detail report for Howe Truss

Table 4: Warren Truss Cost Calculation Report

Material Cost (M) Carbon Steel Solid Bar (12451.5 kg) x ($4.30 per kg) x (2 Trusses) = $107,082.90
Carbon Steel Hollow Tube (1956.0 kg) x ($6.30 per kg) x (2 Trusses) = $24,645.28
Connection Cost (C) (24 Joints) x (500.0 per joint) x (2 Trusses) = $24,000.00
Product Cost (P) 1 - 45x45x2 mm Carbon Steel Tube (%s per Product) = $1,000.00
4 - 80x80x4 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 90x90x4 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 100x100x5 mm Carbon Steel Tube (%s per Product) = $1,000.00
4 - 110x110 mm Carbon Steel Bar (%s per Product) = $1,000.00
6 - 110x110x5 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 120x120 mm Carbon Steel Bar (%s per Product) = $1,000.00
6 - 120x120x6 mm Carbon Steel Tube (%s per Product) = $1,000.00

4 - 130x130 mm Carbon Steel Bar	(%s per Product) = $1,000.00		
2 - 130x130x6 mm Carbon Steel Tube	(%s per Product) = $1,000.00		
6 - 150x150 mm Carbon Steel Bar	(%s per Product) = $1,000.00		
6 - 160x160 mm Carbon Steel Bar	(%s per Product) = $1,000.00		
4 - 160x160x8 mm Carbon 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	$131,728.18 + $24,000.00 + $13,000.00 + $77,400.00 =	$246,128.18

Table 5-Warren Truss Load Test Report
Dennis H. Mahan Memorial Bridge
Project ID: 00002A-Sample Design
Designed By: I. M. Bridgemaster

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	110x110	4.00	0.00	1181.16	OK	2855.06	2873.75	OK
2	CS	Solid Bar	110x110	4.00	0.00	1181.16	OK	2823.32	2873.75	OK
3	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	2883.04	3420.00	OK
4	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3563.19	4013.75	OK
5	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3560.96	4013.75	OK
6	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	2883.04	3420.00	OK
7	CS	Solid Bar	110x110	4.00	0.00	1181.16	OK	2814.87	2873.75	OK
8	CS	Solid Bar	110x110	4.00	0.00	1181.16	OK	2791.29	2873.75	OK
9	CS	Hollow Tube	160x160 x8	4.47	0.00	833.29	OK	539.59	1155.20	OK
10	CS	Hollow Tube	120x120 x6	4.12	114.84	407.77	OK	239.90	649.80	OK
11	CS	Hollow Tube	120x120 x6	4.12	98.55	407.77	OK	279.83	649.80	OK
12	CS	Hollow Tube	160x160 x8	4.47	0.00	833.29	OK	603.71	1155.20	OK
13	CS	Solid Bar	160x160	3.00	3949.72	4613.21	OK	0.00	6080.00	OK

14	CS	Solid Bar	160x160	3.00	3949.72	4613.21	OK	0.00	6080.00	OK
15	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3798.92	4013.75	OK
16	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3757.95	4013.75	OK
17	CS	Solid Bar	160x160	4.47	3192.05	3516.87	OK	0.00	6080.00	OK
18	CS	Hollow Tube	110x110x 5	2.00	0.00	421.47	OK	487.89	498.75	OK
19	CS	Hollow Tube	80x80x 4	4.47	29.77	91.76	OK	233.77	288.80	OK
20	CS	Hollow Tube	110x110x 5	2.00	0.00	421.47	OK	477.23	498.75	OK
21	CS	Solid Bar	160x160	4.47	3120.75	3516.87	OK	0.00	6080.00	OK
22	CS	Solid Bar	150x150	3.16	3119.49	3823.59	OK	0.00	5343.75	OK
23	CS	Solid Bar	150x150	3.16	3209.32	3823.59	OK	0.00	5343.75	OK
24	CS	Solid Bar	150x150	3.16	3104.26	3823.59	OK	0.00	5343.75	OK
25	CS	Solid Bar	150x150	3.16	3131.60	3823.59	OK	0.00	5343.75	OK
26	CS	Hollow Tube	80x80x 4	3.16	92.49	158.62	OK	38.67	288.80	OK
27	CS	Hollow Tube	80x80x 4	3.16	99.23	158.62	OK	36.05	288.80	OK
28	CS	Solid Bar	150x150	3.00	3328.89	3932.43	OK	0.00	5343.75	OK
29	CS	Solid Bar	150x150	3.00	3287.93	3932.43	OK	0.00	5343.75	OK

30	CS	Hollow Tube	160x160 x8	4.47	0.00	833.29	OK	996.95	1155.20	OK
31	CS	Hollow Tube	160x160 x8	4.47	0.00	833.29	OK	961.30	1155.20	OK
32	CS	Solid Bar	160x160	4.00	3589.72	3881.59	OK	0.00	6080.00	OK
33	CS	Solid Bar	160x160	4.00	3567.00	3881.59	OK	0.00	6080.00	OK
34	CS	Hollow Tube	45x45x2	4.00	8.05	10.38	OK	0.00	81.70	OK
35	CS	Hollow Tube	80x80x 4	4.47	52.11	91.76	OK	225.07	288.80	OK
36	CS	Hollow Tube	130x130 x6	4.12	414.91	472.67	OK	0.00	706.80	OK
37	CS	Hollow Tube	130x130 x6	4.12	374.99	472.67	OK	0.00	706.80	OK
38	CS	Hollow Tube	120x120 x6	3.20	411.13	480.22	OK	0.00	649.80	OK
39	CS	Hollow Tube	120x120 x6	3.20	412.00	480.22	OK	0.00	649.80	OK
40	CS	Hollow Tube	110x110x 5	2.50	0.00	395.22	OK	490.98	498.75	OK
41	CS	Hollow Tube	110x110x 5	2.50	0.00	395.22	OK	489.84	498.75	OK
42	CS	Hollow Tube	120x120 x6	3.20	407.75	480.22	OK	0.00	649.80	OK
43	CS	Hollow Tube	120x120 x6	3.20	408.63	480.22	OK	0.00	649.80	OK
44	CS	Hollow Tube	110x110x 5	2.50	0.00	395.22	OK	441.43	498.75	OK
45	CS	Hollow Tube	110x110x 5	2.50	0.00	395.22	OK	442.57	498.75	OK

46	CS	Hollow Tube	90x90x4	4.24	103.23	143.81	OK	190.07	326.80	OK
47	CS	Hollow Tube	90x90x4	4.24	97.36	143.81	OK	205.14	326.80	OK
48	CS	Hollow Tube	100x100x5	5.00	76.94	178.70	OK	446.75	451.25	OK
49	CS	Hollow Tube	100x100x5	5.00	116.80	178.70	OK	406.89		

Member 48

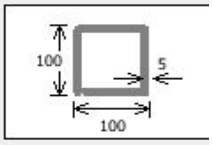
Material Properties:

Material	Carbon Steel
Yield Stress (Fy)	250000 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	100x100x5
Area	0.0019 sq. meters
Moment of Inertia	2.87E-06 meters^4
Member Length	5.00 meters

Section (mm):



Cost:

Unit Cost	$93.96 per meter
Member Cost	$469.82

Strength vs. Length: Graph all tabs Member:

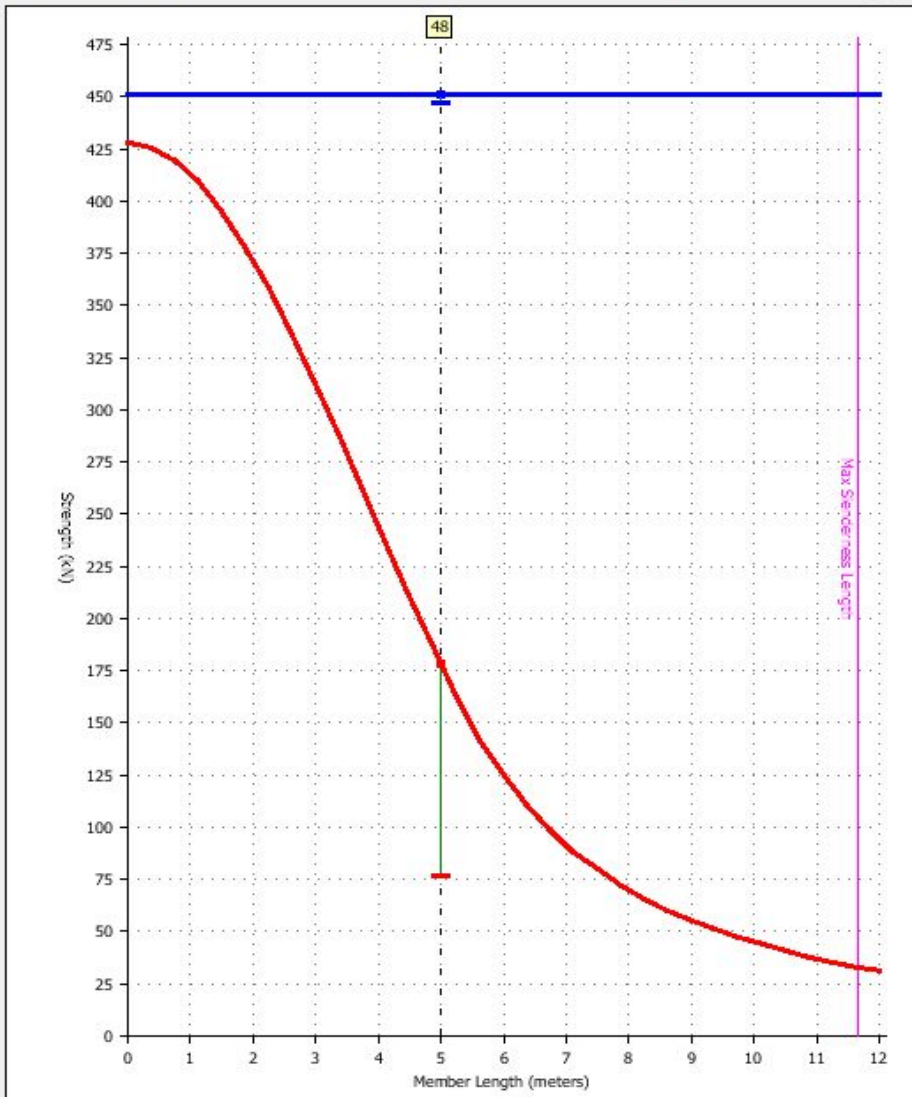


Table 6: Warren Truss Member Detail Report (above)

Table 7. Load at Bridge Failure Data and SE for All Howe Truss Bridges

EDSGN 100 Team	Actual Bridge Weight (g)	Load at Failure (lbs)	SE
1	84.5	49.4	265.1770
2	75.3	34.0	204.8087649
3	81.8	108.8	603.3111
4	78.1	77.9	452.4308
5	81.4	58.3	324.8702
6	85.2	72.1	383.8498
7	79.7	34.3	195.2097
8	80	70.0	396.8937

Table 8: Load at Bridge Failure Data and SE for All Warren Truss Bridges

EDSGN 100 Team	Actual Bridge Weight (g)	Load at Failure (lbs)	SE
1	85.2	39.0	207.6301
2	80.3	55.1	311.2443
3	83.4	90.8	493.8388
4	73.2	32.7	202.6292
5	85.3	60.8	323.3106
6	83.8	70.4	381.0606
7	75.3	55.6	334.036
8	81.9	68.4	378.8241

FIGURES

Figure 1: WPBD 2013 Image of the Howe Truss Bridge Design

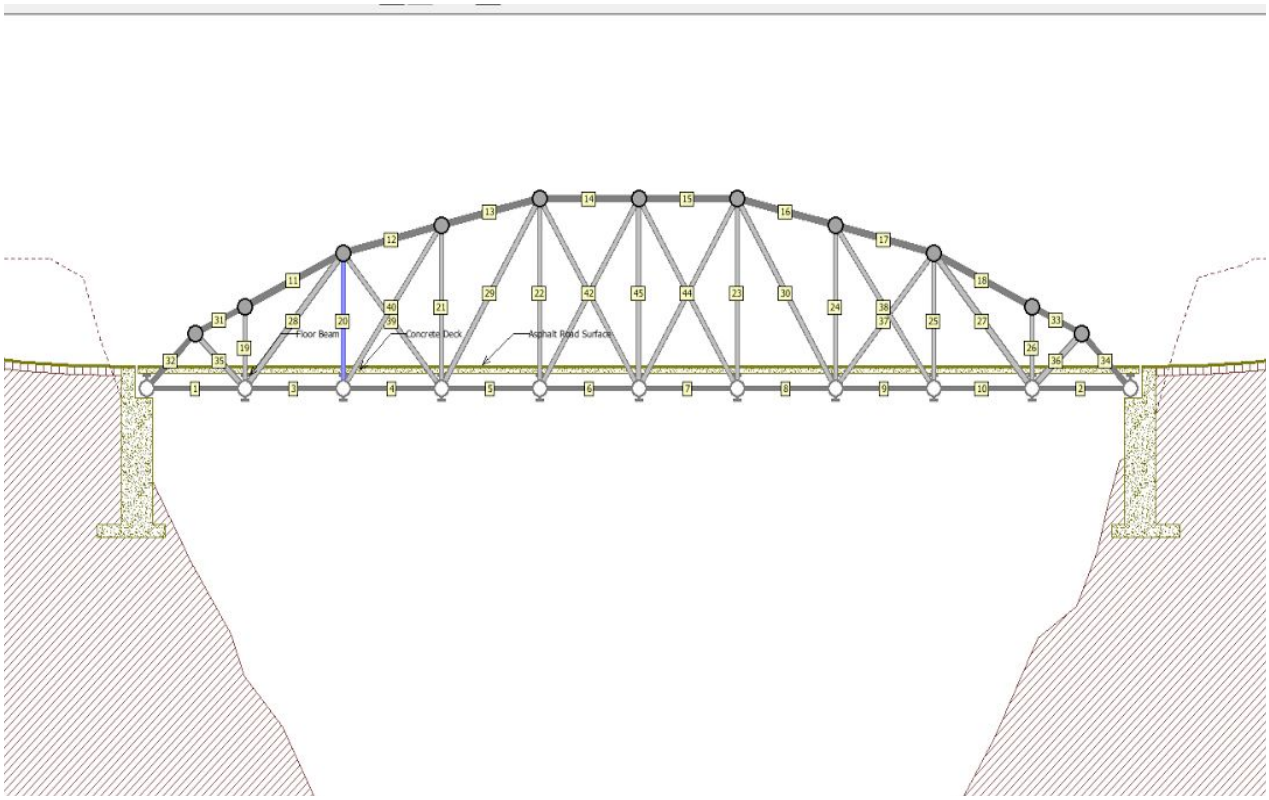


Figure 2: WPBD 2013 Image of the Warren Truss Bridge Design

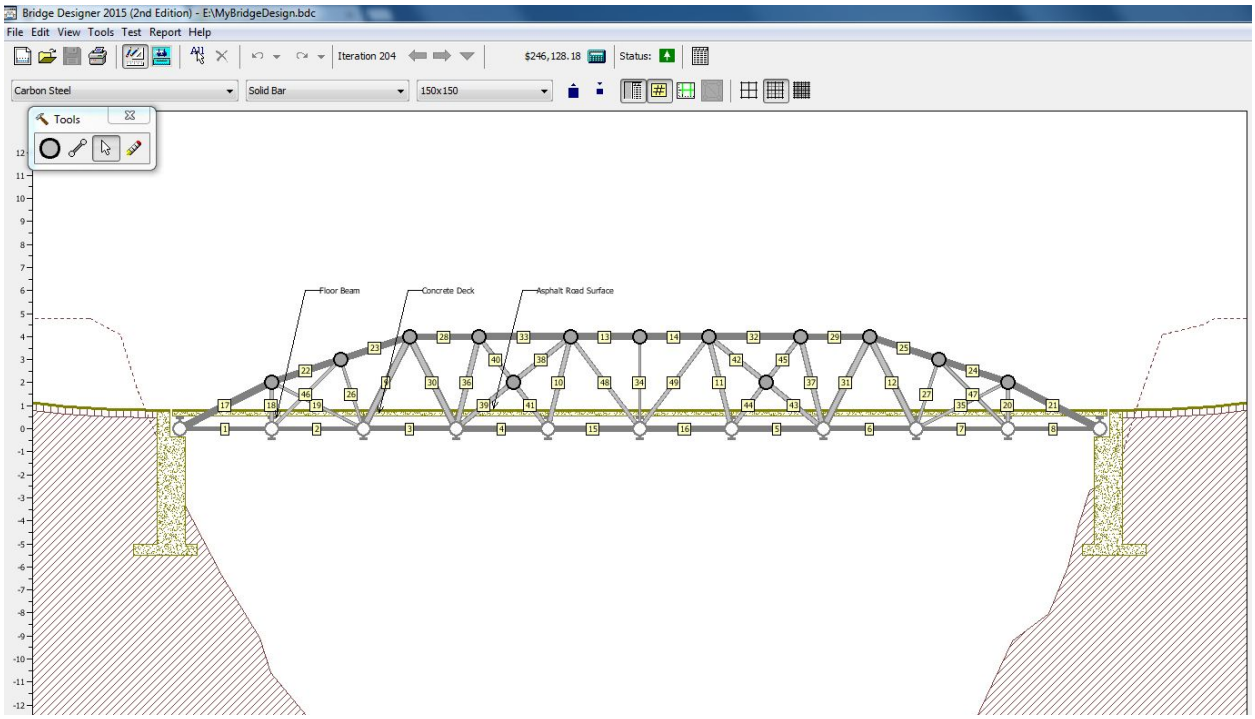


Figure 3: Image of the prototype Howe Bridge Design before load testing

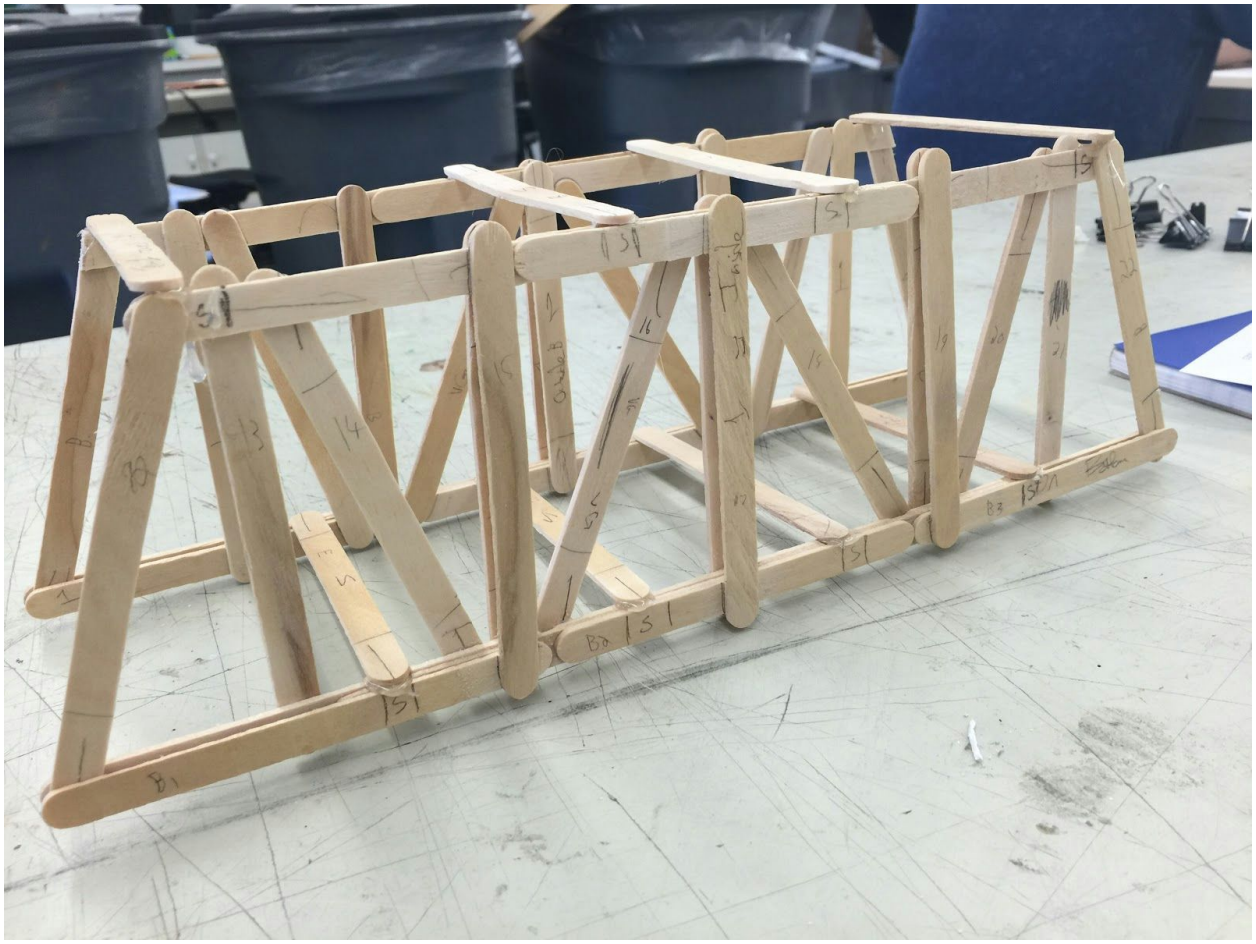


Figure 4

Photo of the Howe Truss bridge AFTER load testing

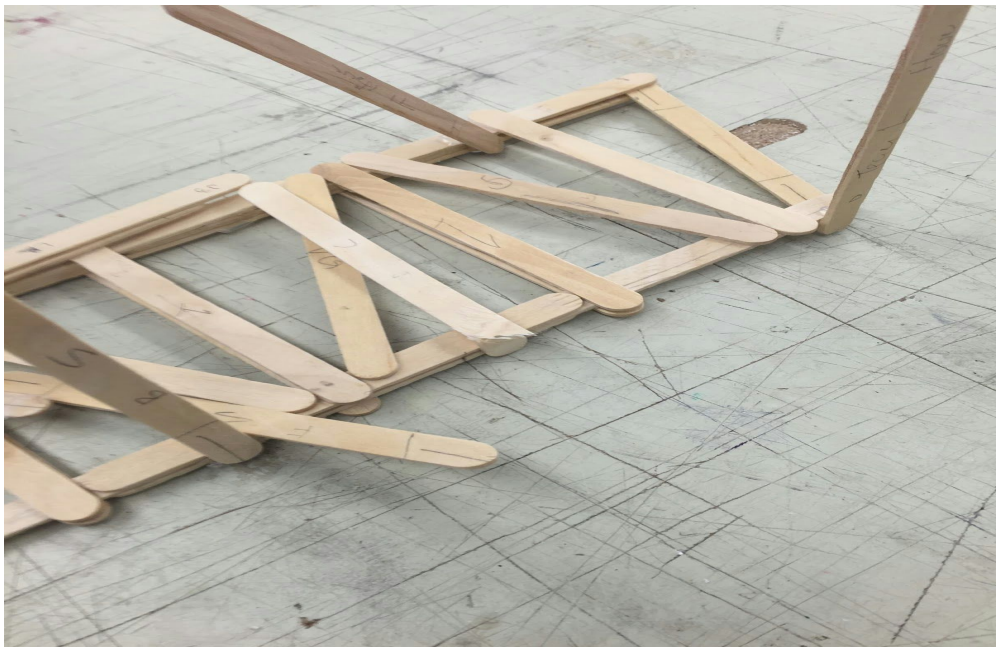


Figure 5

Photo of the prototype Warren Truss bridge BEFORE load testing

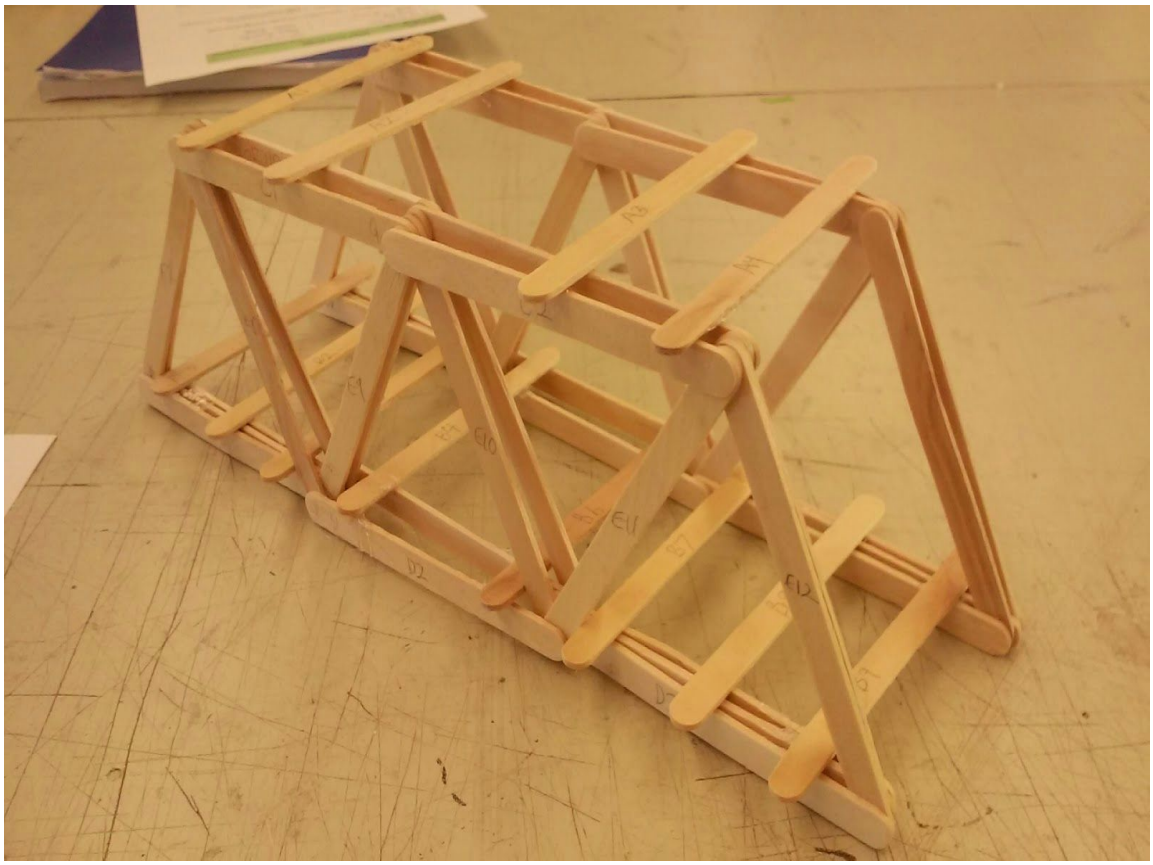


Figure 6 :

Photo of the prototype Warren Truss bridge AFTER failure

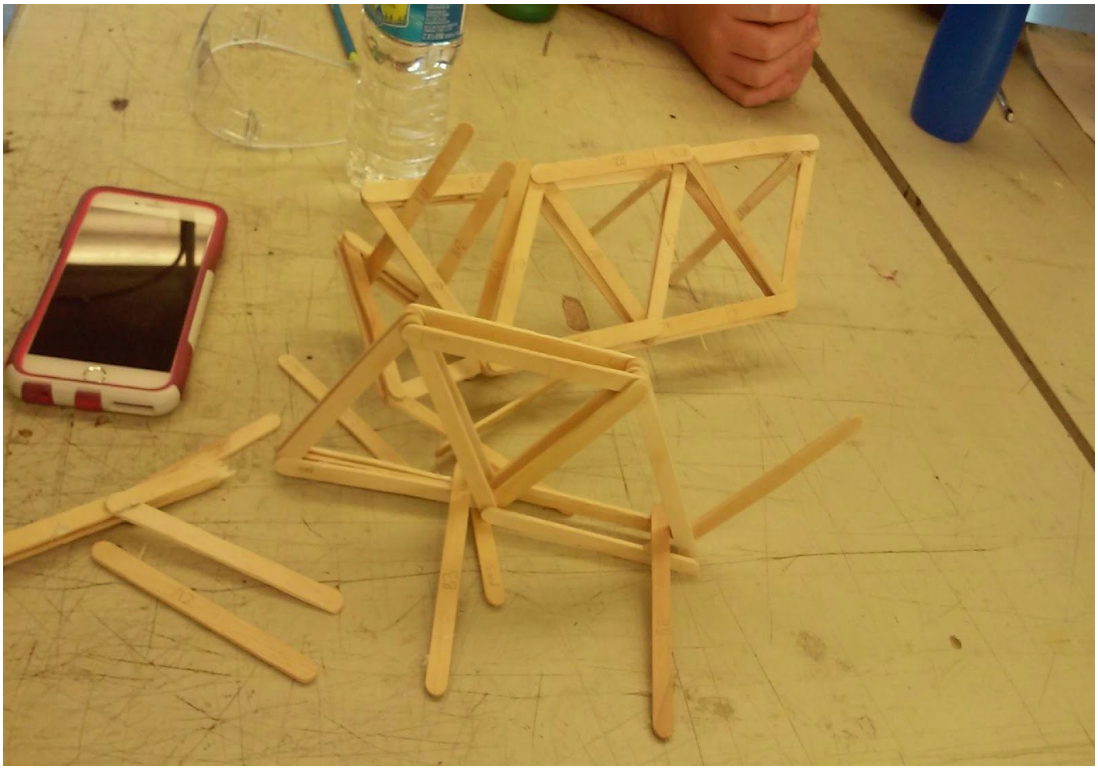


Figure 7. Excel Graph comparing structural efficiency of Howe Truss

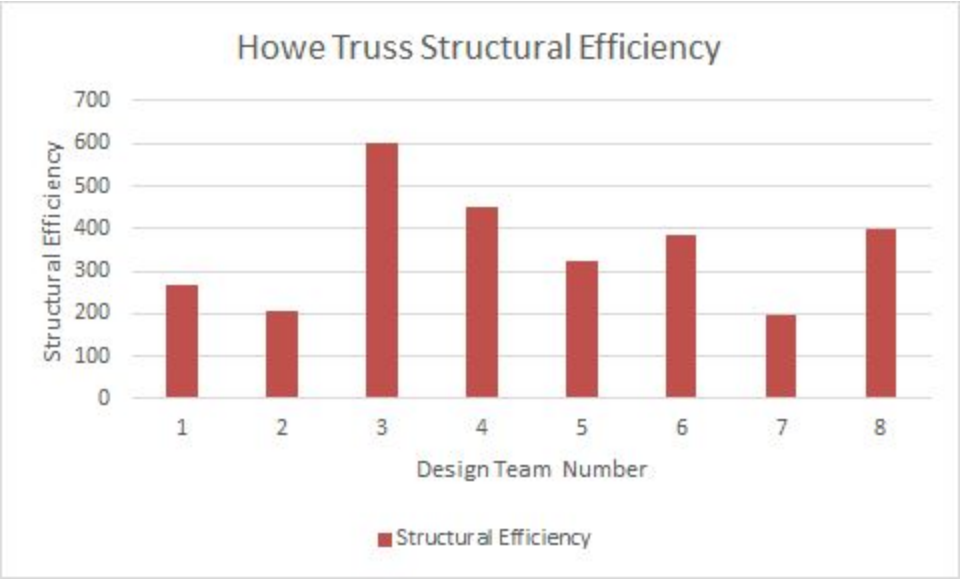
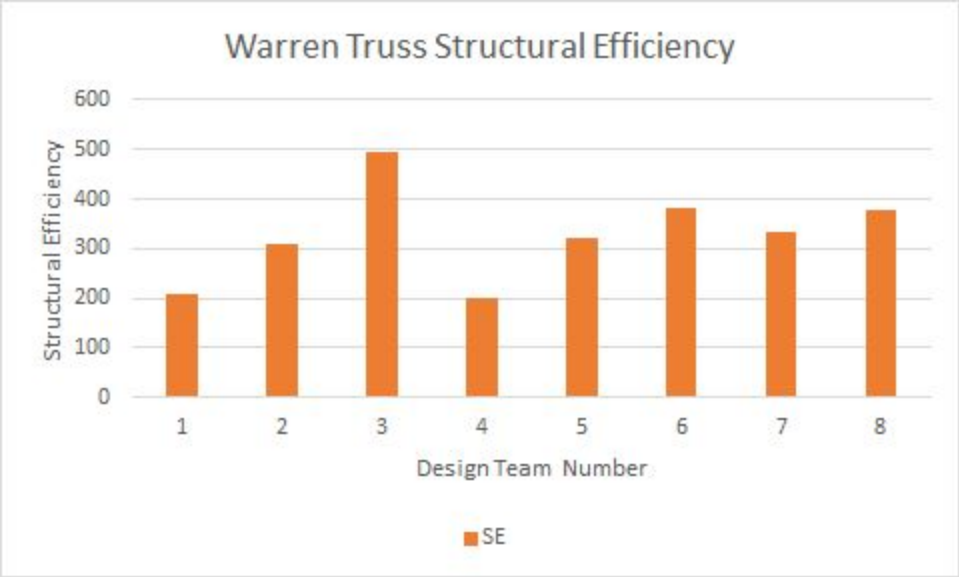



Figure 8: Excel Graph Comparing Structural Efficiency of Warren Truss