PENNSTATE

School of Engineering Design, Technology and Professional Programs
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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 a 100 year flooding event, the bridge over Spring Creek on Puddintown Road catastrophically failed. The bridge is vital to the town's commerce as traffic is now diverted 10 miles away.

Objective. The objective is to design a truss bridge that can span the gap and last for a very long time as well as look visually appealing.

Design Criteria. The bridge must be 20 meters above the creek and the bridge span is to be 40 meters. The bridge is all one span, without any cable anchorages. The deck is made from .23 meter thick medium strength concrete. The bridge should be designed to support two 225 kN trucks with one in each traffic lane.

Technical Approach.

Phase 1: Economic Efficiency. To get the total cost of the bridge, Bridge Designer 2015 was used to design and build the bridge

Phase 2: Structural Efficiency. To find the structural efficiency of the bridge, a small model was made from Popsicle sticks

Results.

Phase 1: Economic Efficiency. The Howe truss bridge beat out the Warren truss bridge by about $2500. As seen in attachment 1, the Howe is less expensive, but only slightly.

Phase 2: Structural Efficiency. As seen by the structural efficiencies listed in the Attachment 2, the Warren truss bridge is vastly more structurally efficient than the Howe truss bridge.

Best Solution. Although the economic efficiency of the Howe Truss Bridge is better than the economic efficiency of the Warren Truss Bridge, the difference in the costs of the two is not that great to really know which is better by this factor alone. Therefore, the structural efficiency must be taken into account. The structural efficiency of the Warren is almost double that of the Howe. Therefore the best option is the Warren Truss Bridge is the obvious choice.

Conclusions and Recommendations. Overall, the Warren truss bridge types provide a better structure for around the same cost of the Howe truss bridge. The next step in the design would be to make a simulation model with steel that would be to a scale of what would be expected of the actual bridge.

Respectfully,

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ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss. As evidenced by Table 1, the total cost of the bridge is $241,952.54. The low cost can be attributed to the fact that there are many hollow bars used in this design. This allows the design to deal with compressive forces better which are more apparent in Howe Truss bridges. Table 2 shows the load test report of this bridge, which shows that the bridge is up to speculations and basic loading requirements. Table 3 shows all the different members along with their thicknesses and strength. This shows how the bridge is mostly consistent of hollow tubes, which allows for it to better handle compressive forces due to the Howe Truss design having verticals under compression. The member detail in figure 1 shows member number , which is a highly stressed member in this design. However, it is evident that even it meets specifications.

Warren Truss. As evidenced by Table 4, the total cost of the bridge is $244,520.72. The higher cost can be attributed to the fact that there are many solid bars used in this design. . This allows the design to deal with compressive forces better which are more apparent in Howe Truss bridges. Table 5 shows the load test report of this bridge, which shows that the bridge is up to speculations and basic loading requirements. Table 6 shows all the different members along with their thicknesses and strength. This shows how the bridge is mostly consistent of solid bars, which allows for it to better handle tensile forces due to the Warren Truss design having many members under tension. The member detail in figure 2 shows member number , which is a highly stressed member in this design. However, it is evident that even it meets specifications.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss. The Howe truss design as previously stated, is the cheaper of the two designs. This section will discuss the load testing results of this particular type of bridge and the methods used to make the model.

Prototype Bridge. The materials that were used to build the prototype bridge were Popsicle sticks, the bridge was made up of 60 Popsicle sticks, the length of the bridge was 31.5 cm long, and the height and width were 10.5 cm. These methods of construction can be seen in Figure 3.

Load Testing. Compared to the other Howe Truss bridges made, the bridge designed by team 8 had a relatively low structural efficiency. It was the second lowest structural efficiency of the whole testing group. The average for all of the Howe bridges was 369.44. The minimum was 238.44 and the maximum was 569.56, giving it a range of 331.12. Table 7 shows all of the calculations of how these numbers were found as well as all other team's Howe Truss bridge loading data.

Forensic Analysis. The Howe Truss Bridge, when placed under load, failed at the strut and the end post. This is most likely due to the glue joints at these two places. The failed strut is likely the result of hot glue being used instead of white glue. Unlike white glue, which hardens, hot glue is flexible, and bends easily. If placed in harmonic motion, the glue can flex, which will lead to breaking.

Results. As a final result, the Howe scored very low in comparison with the other Howe Truss Bridges in the class, and even lower than the Warren Truss Bridge did. The results are shown in Figure 5.

Warren Truss. The Warren truss design as previously stated, is the costlier of the two designs. This section will discuss the load testing results of this particular type of bridge and the methods used to make the model.

Prototype Bridge. The mock up bridge was made with standard sized popsicle sticks and white glue. The bridge spans 31 cm long, 11 cm wide and 10 cm high. A picture of this can be seen in figure 6.

Load Testing. Compared to the other Warren Truss bridges made, the bridge designed by team 8 had a relatively high structural efficiency. It was the second highest structural efficiency of the whole testing group. The average for all of the Warren bridges was 358.59. The minimum was 228.89 and the maximum was 579.31, giving it a range of 350.42. Table 8 shows all of the calculations of how these numbers were found as well as all other team's Warren Truss bridge loading data.

Forensic Analysis. The Warren Truss Bridge, when placed under load, failed at the struts and the floor beams. This was because hot glue was used to attach these to the sides

instead of white glue. Hot glue has a tendency to flex, so when the load would swing, the bridge would lean with it. This leaning weakened the glue joints to the point of failure. The bridge then fell sideways and snapped the trusses of one side apart. Figure 7 shows the bridge after load testing.

Results. Overall, the team 8 Warren Bridge did very well in comparison with the rest of the class. The bar graph in figure 8 shows the comparison.

Table 1

Dennis H. Mahan Memorial Bridge
Project ID: 00002A-
Iteration #207 (Fri, 18 Sep 2015, 11:56:17)

Type of Cost Item Cost Calculation Cost

Material Cost (M) Carbon Steel Solid Bar (3027.0 kg) x ($4.30 per kg) x (2 Trusses) = $26,031.86
Carbon Steel Hollow Tube (2214.1 kg) x ($6.30 per kg) x (2 Trusses) = $27,897.78
High-Strength Low-Alloy Steel Hollow Tube (3364.6 kg) x ($7.00 per kg) x (2 Trusses) = $47,104.47
Quenched & Tempered Steel Hollow Tube (1851.8 kg) x ($7.70 per kg) x (2 Trusses) = $28,518.43

Connection Cost (C) (20 Joints) x (500.0 per joint) x (2 Trusses) = $20,000.00

Product Cost (P) 2 - 120x120 mm Carbon Steel Bar (%s per Product) = $1,000.00
3 - 120x120x6 mm Carbon Steel Tube (%s per Product) = $1,000.00
4 - 130x130 mm Carbon Steel Bar (%s per Product) = $1,000.00
3 - 140x140x7 mm Carbon Steel Tube (%s per Product) = $1,000.00
1 - 150x150x7 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 160x160x8 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 160x160x8 mm High-Strength Low-Alloy Steel Tube (%s per Product) = $1,000.00
2 - 170x170x8 mm High-Strength Low-Alloy Steel Tube (%s per Product) = $1,000.00
2 - 180x180x9 mm Carbon Steel Tube (%s per Product) = $1,000.00
2 - 180x180x9 mm High-Strength Low-Alloy Steel Tube (%s per Product) = $1,000.00
2 - 190x190x9 mm High-Strength Low-Alloy Steel Tube (%s per Product) = $1,000.00
2 - 200x200x10 mm Quenched & Tempered Steel Tube (%s per Product) = $1,000.00
4 - 220x220x11 mm High-Strength Low-Alloy Steel Tube (%s per Product) = $1,000.00
2 - 240x240x12 mm Carbon Steel Tube (%s per Product) = $1,000.00
4 - 240x240x12 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 $129,552.54 + $20,000.00 + $15,000.00 + $77,400.00 = $241,952.54

Table 2

Dennis H. Mahan Memorial Bridge
Project ID: 00002A-
Designed By:

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	HSS	Hollow Tube	220x220x11	5.66	1988.58	2076.87	OK	0.00	3013.99	OK
2	CS	Hollow Tube	180x180x9	4.00	0.00	1165.88	OK	1400.88	1462.05	OK
3	HSS	Hollow Tube	160x160x8	4.00	0.00	1117.80	OK	1406.14	1594.18	OK
4	CS	Hollow Tube	240x240x12	4.00	0.00	2234.95	OK	2499.56	2599.20	OK
5	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3278.02	3420.00	OK
6	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3740.94	4013.75	OK
7	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3888.25	4013.75	OK
8	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3888.25	4013.75	OK
9	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3720.39	4013.75	OK
10	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	3237.01	3420.00	OK
11	CS	Hollow Tube	240x240x12	4.00	0.00	2234.95	OK	2438.08	2599.20	OK
12	HSS	Hollow Tube	160x160x8	4.00	0.00	1117.80	OK	1374.24	1594.18	OK
13	HSS	Hollow Tube	180x180x9	4.00	1406.14	1506.95	OK	0.00	2017.63	OK
14	QTS	Hollow Tube	200x200x10	4.00	2499.56	2530.55	OK	0.00	3501.70	OK
15	QTS	Hollow Tube	240x240x12	4.00	3278.02	3958.27	OK	0.00	5042.45	OK
16	QTS	Hollow Tube	240x240x12	4.00	3740.94	3958.27	OK	0.00	5042.45	OK
17	QTS	Hollow Tube	240x240x12	4.00	3720.39	3958.27	OK	0.00	5042.45	OK
18	QTS	Hollow Tube	240x240x12	4.00	3237.01	3958.27	OK	0.00	5042.45	OK

TABLE 3

19	QTS	Hollow Tube	200x200x10	4.00	2438.08	2530.55	OK	0.00	3501.70	OK	
20	HSS	Hollow Tube	180x180x9	4.00	1374.24	1506.95	OK	0.00	2017.63	OK	
21	HSS	Hollow Tube	220x220x11	5.66	1620.39	2076.87	OK	0.00	3013.99	OK	
22	CS	Hollow Tube	160x160x8	4.00	0.00	879.98	OK	1139.21	1155.20	OK	
23	HSS	Hollow Tube	190x190x9	5.66	1249.03	1323.29	OK	0.00	2135.62	OK	
24	CS	Hollow Tube	140x140x7	4.00	0.00	630.23	OK	876.65	884.45	OK	
25	HSS	Hollow Tube	170x170x8	5.66	876.85	947.42	OK	0.00	1699.06	OK	
26	CS	Hollow Tube	120x120x6	4.00	0.00	417.77	OK	613.38	649.80	OK	
27	CS	Hollow Tube	150x150x7	5.66	504.58	550.30	OK	87.91	950.95	OK	
28	CS	Hollow Tube	120x120x6	4.00	0.00	417.77	OK	624.33	649.80	OK	
29	CS	Hollow Tube	120x120x6	4.00	0.00	417.77	OK	581.48	649.80	OK	
30	HSS	Hollow Tube	170x170x8	5.66	831.73	947.42	OK	0.00	1699.06	OK	
31	CS	Hollow Tube	140x140x7	4.00	0.00	630.23	OK	844.75	884.45	OK	
32	HSS	Hollow Tube	190x190x9	5.66	1203.91	1323.29	OK	0.00	2135.62	OK	
33	CS	Hollow Tube	160x160x8	4.00	0.00	879.98	OK	1107.31	1155.20	OK	
34	HSS	Hollow Tube	220x220x11	5.66	1575.27	2076.87	OK	0.00	3013.99	OK	
35	CS	Hollow Tube	180x180x9	4.00	0.00	1165.88	OK	1368.98	1462.05	OK	
36	HSS	Hollow Tube	220x220x11	5.66	1943.47	2076.87	OK	0.00	3013.99	OK	
37	CS	Hollow Tube	140x140x7	5.66	459.57	474.03	OK	132.91	884.45	OK	

TABLE 4

Dennis H. Mahan Memorial Bridge

Project ID: 00002A-

Iteration #145 (Fri, 18 Sep 2015, 11:54:40)

Iteration #145 (Fri, 18 Sep 2015, 11:54:40)

Type of Cost Item Cost Calculation Cost

Material Cost (M) Carbon Steel Solid Bar (13008.2 kg) x ($4.30 per kg) x (2 Trusses) = $111,870.51

Carbon Steel Hollow Tube (1845.3 kg) x ($6.30 per kg) x (2 Trusses) = $23,250.21

Connection Cost (C) (21 Joints) x (500.0 per joint) x (2 Trusses) = $21,000.00

Product Cost (P) 6 - 75x75 mm Carbon Steel Bar (%s per Product) = $1,000.00

2 - 100x100 mm Carbon Steel Bar (%s per Product) = $1,000.00

2 - 100x100x5 mm Carbon Steel Tube (%s per Product) = $1,000.00

2 - 110x110 mm Carbon Steel Bar (%s per Product) = $1,000.00

4 - 120x120 mm Carbon Steel Bar (%s per Product) = $1,000.00

8 - 130x130 mm Carbon Steel Bar (%s per Product) = $1,000.00

4 - 130x130x6 mm Carbon Steel Tube (%s per Product) = $1,000.00

2 - 140x140 mm Carbon Steel Bar (%s per Product) = $1,000.00

4 - 160x160 mm Carbon Steel Bar (%s per Product) = $1,000.00

4 - 160x160x8 mm Carbon Steel Tube (%s per Product) = $1,000.00

1 - 320x320x16 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 $135,120.72 + $21,000.00 + $11,000.00 + $77,400.00 = $244,520.72

Table 5
Dennis H. Mahan Memorial Bridge
Project ID: 00002A-
Designed By: Scott Foley & Logan Smith

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	75x75	4.00	0.00	257.63	OK	1195.29	1335.94	OK
2	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1965.07	2375.00	OK
3	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	2892.04	3420.00	OK
4	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3495.71	4013.75	OK
5	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3803.15	4013.75	OK
6	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3819.10	4013.75	OK
7	CS	Solid Bar	130x130	4.00	0.00	2091.29	OK	3516.19	4013.75	OK
8	CS	Solid Bar	120x120	4.00	0.00	1606.24	OK	2892.04	3420.00	OK
9	CS	Solid Bar	100x100	4.00	0.00	814.24	OK	1944.58	2375.00	OK
10	CS	Solid Bar	75x75	4.00	0.00	257.63	OK	1168.72	1335.94	OK
11	CS	Solid Bar	130x130	3.91	1867.10	2150.73	OK	0.00	4013.75	OK
12	CS	Solid Bar	75x75	3.35	0.00	366.41	OK	1061.66	1335.94	OK
13	CS	Solid Bar	130x130	3.64	1736.91	2317.62	OK	0.00	4013.75	OK
14	CS	Solid Bar	110x110	4.47	796.23	953.71	OK	0.00	2873.75	OK
15	CS	Solid Bar	75x75	4.47	0.00	206.11	OK	1297.47	1335.94	OK
16	CS	Solid Bar	120x120	4.47	1009.52	1347.81	OK	0.00	3420.00	OK
17	CS	Solid Bar	140x140	4.00	2545.31	2633.62	OK	0.00	4655.00	OK
18	CS	Hollow Tube	160x160x8	4.47	0.00	833.29	OK	994.01	1155.20	OK
19	CS	Hollow Tube	160x160x8	4.47	707.13	833.29	OK	0.00	1155.20	OK

Table 6

20	CS	Solid Bar	160x160	4.00	3336.58	3881.59	OK	0.00	6080.00	OK	
21	CS	Hollow Tube	130x130x6	4.47	0.00	444.49	OK	693.20	706.80	OK	
22	CS	Hollow Tube	130x130x6	4.47	406.72	444.49	OK	61.68	706.80	OK	
23	CS	Solid Bar	160x160	4.00	3805.72	3881.59	OK	0.00	6080.00	OK	
24	CS	Hollow Tube	320x320x16	4.00	3954.77	4145.34	OK	0.00	4620.80	OK	
25	CS	Hollow Tube	100x100x5	4.47	73.42	212.76	OK	394.98	451.25	OK	
26	CS	Hollow Tube	100x100x5	4.47	109.07	212.76	OK	359.33	451.25	OK	
27	CS	Hollow Tube	130x130x6	4.47	371.07	444.49	OK	97.33	706.80	OK	
28	CS	Hollow Tube	130x130x6	4.47	0.00	444.49	OK	657.55	706.80	OK	
29	CS	Solid Bar	160x160	4.00	3785.23	3881.59	OK	0.00	6080.00	OK	
30	CS	Hollow Tube	160x160x8	4.47	671.48	833.29	OK	0.00	1155.20	OK	
31	CS	Hollow Tube	160x160x8	4.47	0.00	833.29	OK	958.36	1155.20	OK	
32	CS	Solid Bar	160x160	4.00	3295.61	3881.59	OK	0.00	6080.00	OK	
33	CS	Solid Bar	120x120	4.47	973.87	1347.81	OK	0.00	3420.00	OK	
34	CS	Solid Bar	140x140	4.00	2483.86	2633.62	OK	0.00	4655.00	OK	
35	CS	Solid Bar	75x75	4.47	0.00	206.11	OK	1261.81	1335.94	OK	
36	CS	Solid Bar	110x110	4.47	772.46	953.71	OK	0.00	2873.75	OK	
37	CS	Solid Bar	75x75	3.35	0.00	366.41	OK	1037.89	1335.94	OK	
38	CS	Solid Bar	130x130	3.91	1825.59	2150.73	OK	0.00	4013.75	OK	
39	CS	Solid Bar	130x130	3.64	1698.22	2317.62	OK	0.00	4013.75	OK	

Table 7 Howe Truss

Team Number	Actual Bridge Weight (grams)	Bridge Weight (lbs)	Load at Failure (lbs)	Structural Efficiency
1	81.3	0.179235606	69.7	388.8736259
2	64.3	0.141757066	33.8	238.4360861
3	95.8	0.211202596	59.6	282.1935011
4	78.5	0.17306267	65.4	377.897787
5	79.4	0.175046828	99.7	569.5618775
6	80.4	0.177251448	84.2	475.0313803
7	84.7	0.186731314	71	380.2254613
8	82.6	0.182101612	44.3	243.2707735

Table 8 Warren Truss

Team Number	Actual Bridge Weight (grams)	Bridge Weight (lbs)	Load at Failure (lbs)	Structural Efficiency
1	81.9	0.180558378	104.6	579.3140211
2	77.1	0.169976202	33.9	199.4396839
3	74.9	0.165126038	50.8	307.643789
4	75.7	0.166889734	38.2	228.8936478
5	80.9	0.178353758	55.4	310.6186302
6	90.1	0.198636262	75.8	381.6020259
7	87	0.19180194	70.9	369.6521526
8	83.6	0.184306232	90.3	489.9454512

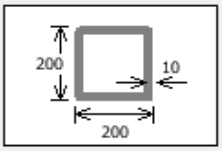
Material Properties:

Material	Quenched & Tempered Steel
Yield Stress (Fy)	485000 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	4.00 meters

Section (mm):



Cost:

Unit Cost	$459.38 per meter
Member Cost	$1837.53

Strength vs. Length: Graph all tabs Member:

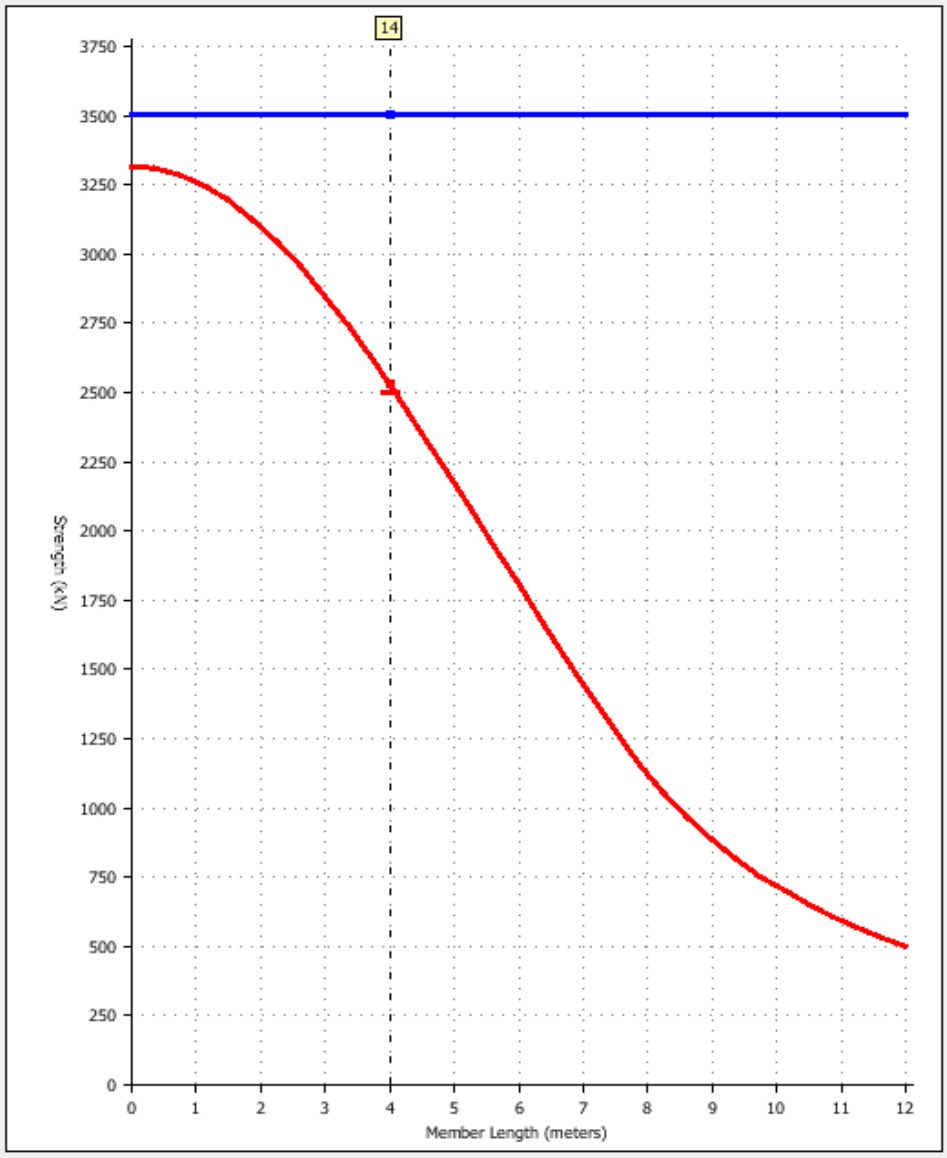


Figure 1

Figure 2

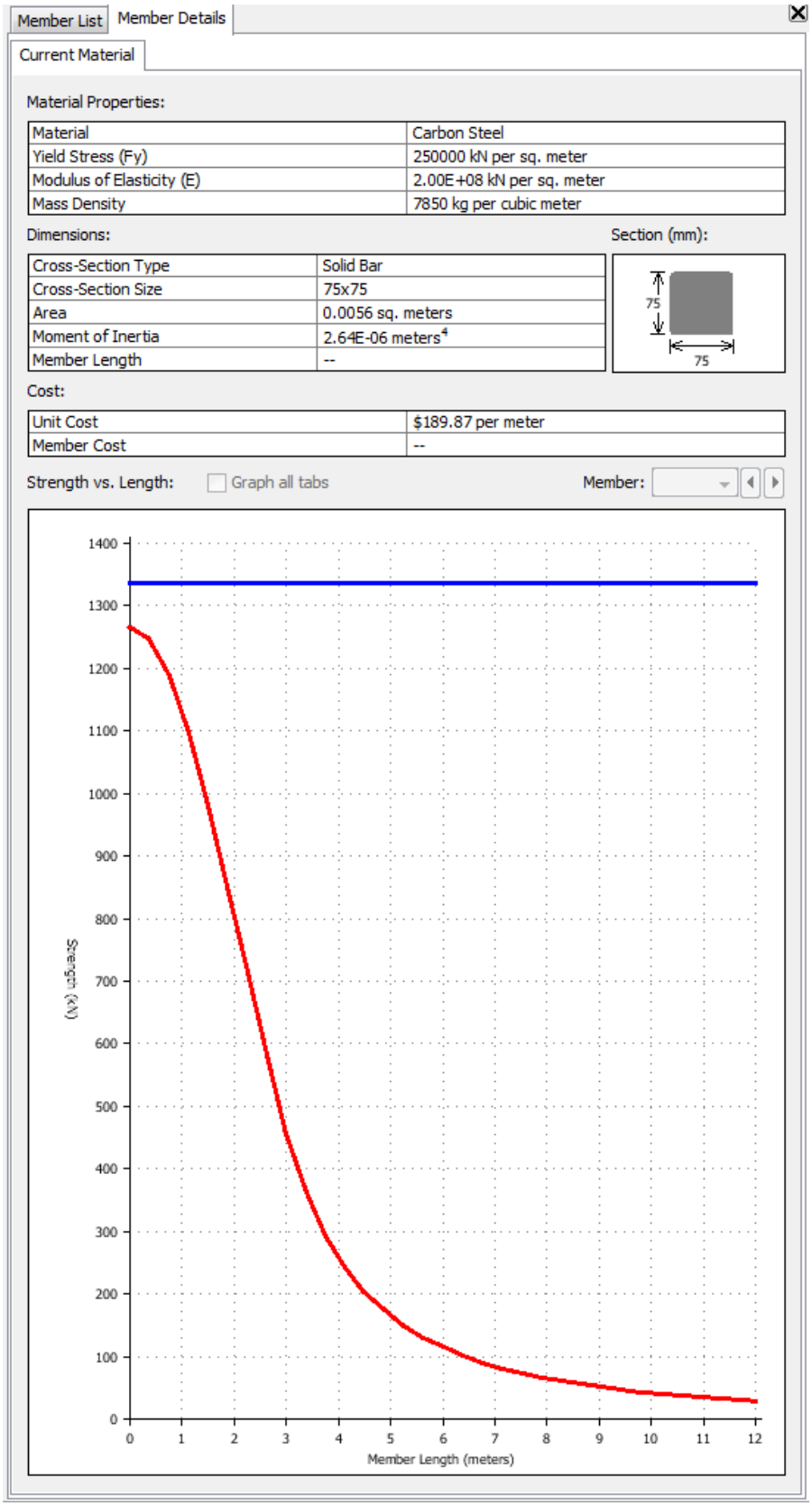

Member List
Member Details
Current Material
Material Properties:
Material | Carbon Steel
Yield Stress (Fy) | 250000 kN per sq. meter
Modulus of Elasticity (E) | 2.00E+08 kN per sq. meter
Mass Density | 7850 kg per cubic meter
Dimensions:
Section (mm):
Cross-Section Type | Solid Bar
Cross-Section Size | 75x75
Area | 0.0056 sq. meters
Moment of Inertia | 2.64E-06 meters4
Member Length | --
75
75
Cost:
Unit Cost | $189.87 per meter
Member Cost | --
Strength vs. Length:
Graph all tabs
Member:
Strength (kN)
Member Length (meters)

Figure 3

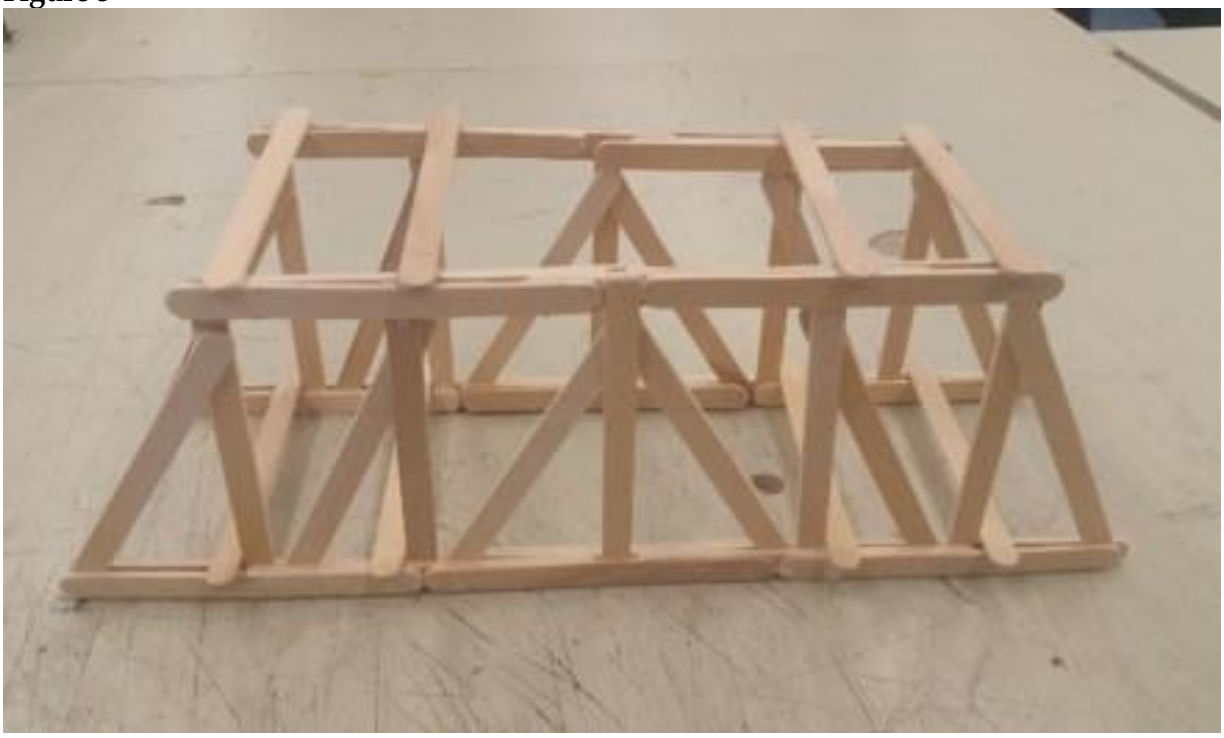


Figure 4

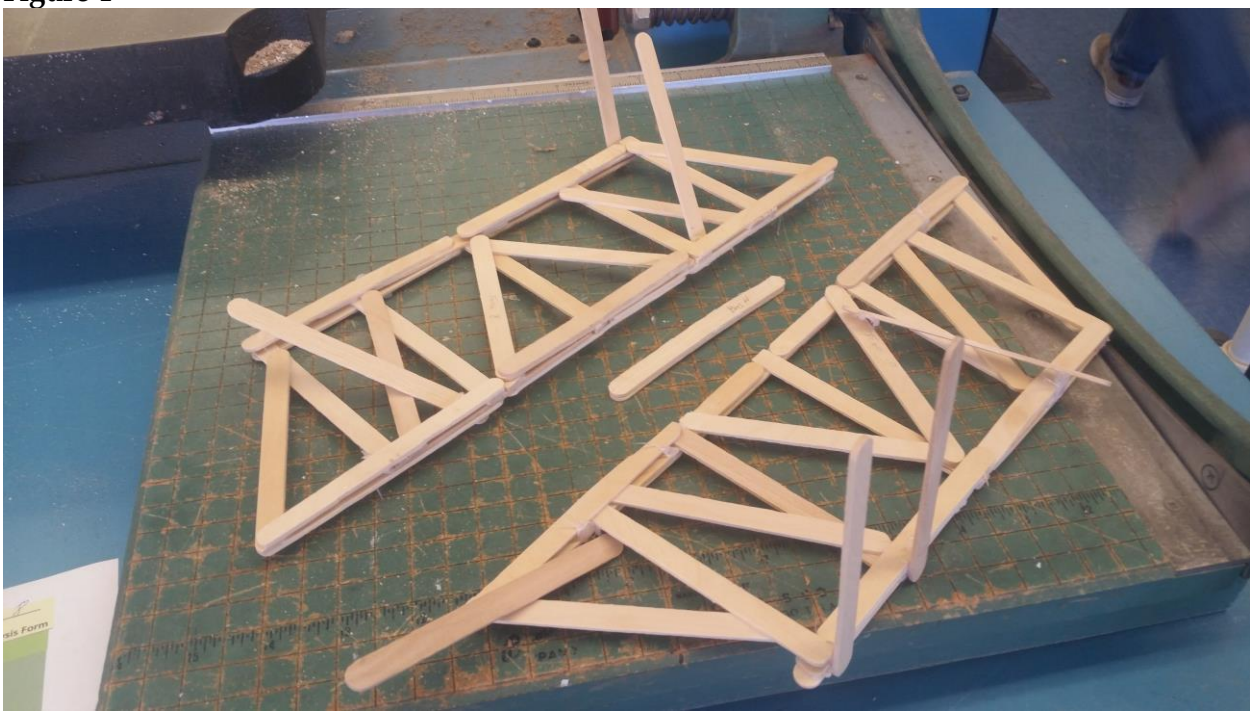


Figure 5

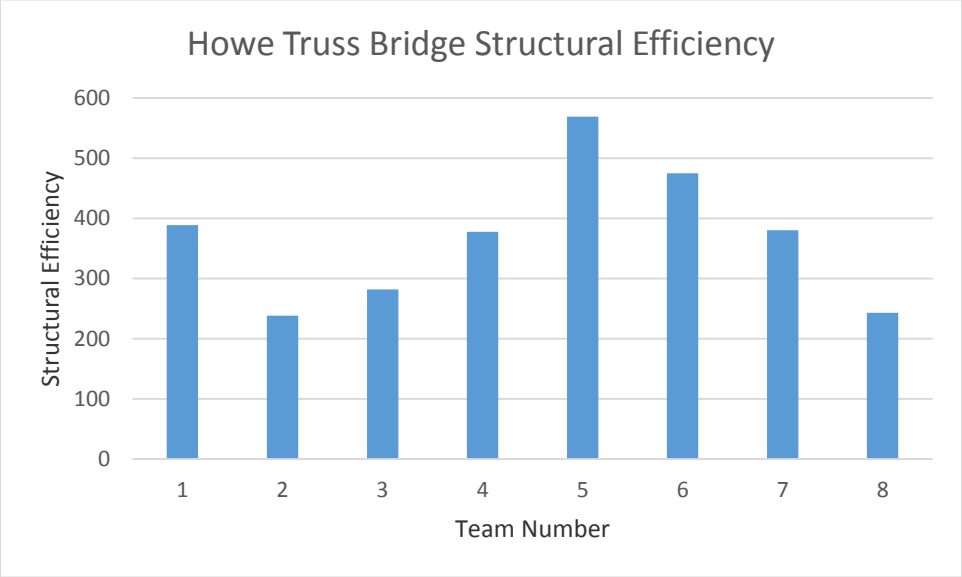

Howe Truss Bridge Structural Efficiency
Structural Efficiency
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
Team Number

Figure 6

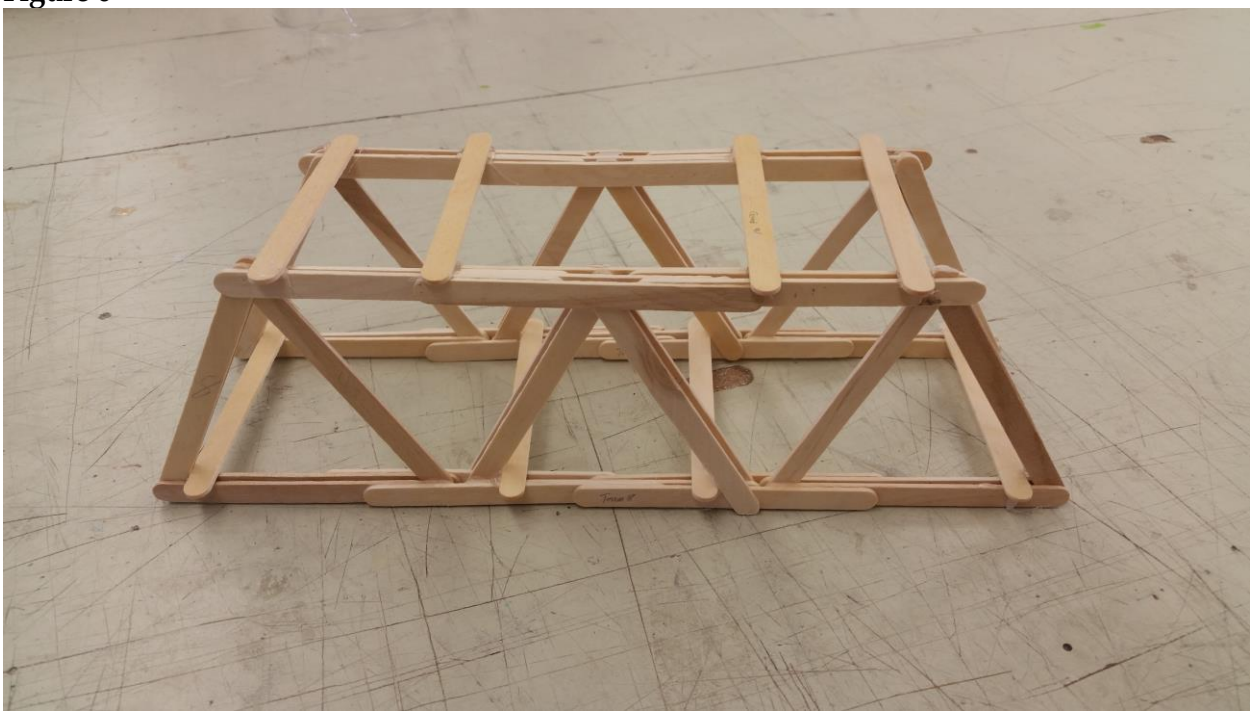


Figure 7

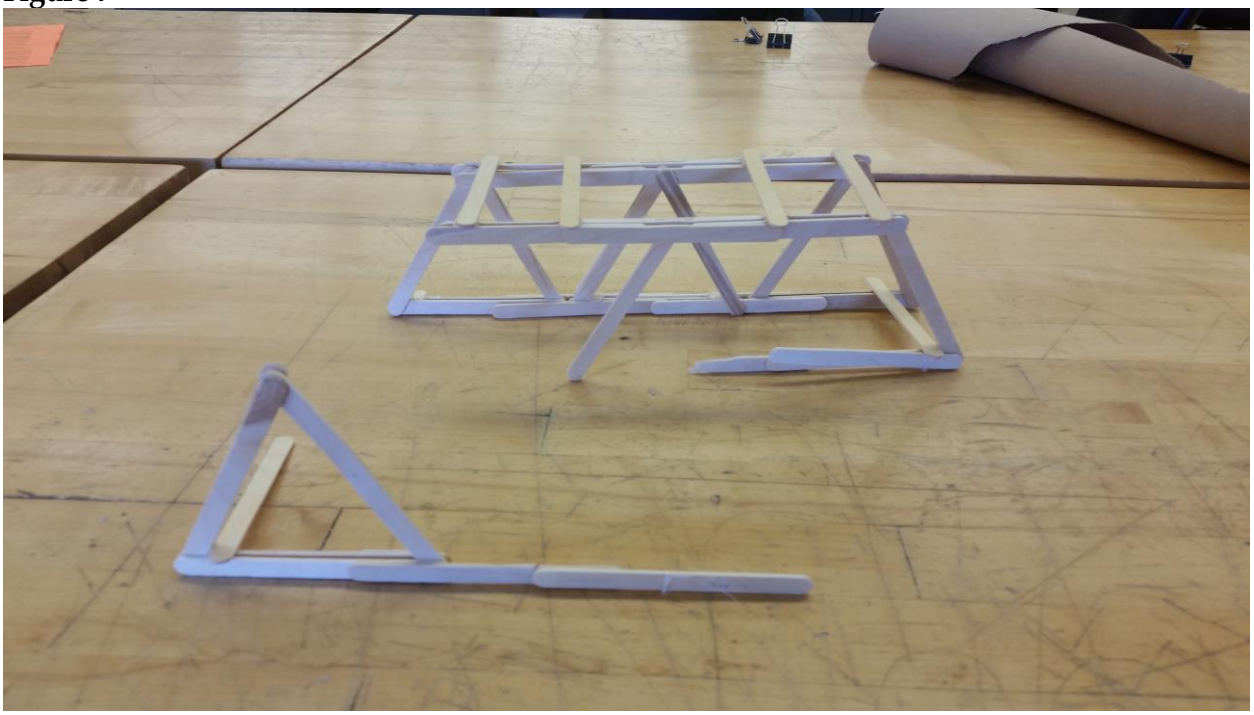
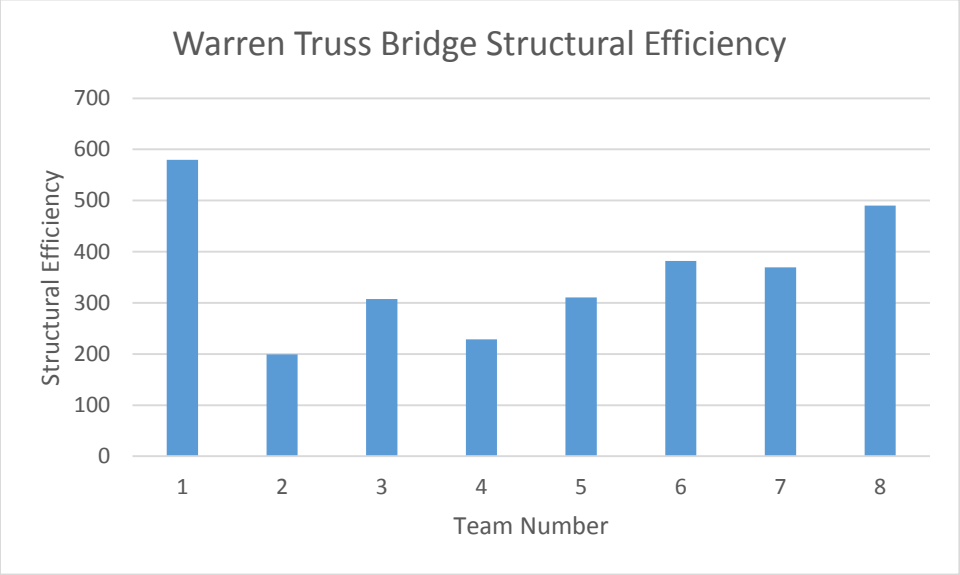


Figure 8


Warren Truss Bridge Structural Efficiency
Structural Efficiency
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
Team Number