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 collapsed that spanned Spring Creek along Puddington Road in College Township, Centre Township. This vehicular bridge is critical to the Mount Nittany Medical Center as it is a commonly used route for ambulances and the closing of this bridge has led to a detour that is very inconvenient.

Objective.
A project has been initiated by PennDOT District 2-0 to design and build a new bridge spanning over Spring Creek to replace the bridge destroyed by the recent flood event.

Design Criteria.
PennDot District 2-0 has created a list of requirements for the bridge to have: 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 elevation of bridge deck 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. All other design criteria, such as: steel member type, steel cross section type, and steel member size shall be selected by the design team.

Technical Approach.

Phase 1: Economic Efficiency.

The Economic Efficiency is to be determined by designing and testing a bridge using the Engineering Encounters Bridge Design 2015 (EEBD 2015) software that meets all the design criteria and bridge restraints. Also, the objective is to use EEBD 2015 to create and analyze both a Warren and Howe through truss bridge that is not only supportive, but also functional. Then, the bridges must be analyzed to be the most cost-effective while also supporting its own weight (dead load) and a standard truck weight (live load).

Phase 2: Structural Efficiency.

A prototype is designed for both a Warren through truss and Howe through truss bridge, and they will be tested to catastrophic failure. The structural efficiency of a bridge is the ability of the truss bridge to safely dissipate loads, and it is calculated by dividing the load the bridge supports by the weight of the prototype bridge. Bridges were designed with a maximum of 60 popsicle sticks and white glue, and hot glue only to connect the 8 floor beams/struts. After the load test is performed, a forensic engineering investigation should be initiated and should include why, where, and how did it fail. The investigation should be supported and documented with photographs, sketches, measurements, and analyses. Prior to the load test the bridges should be markes therefore the type of failure can be determined. Load testing the bridges and conducting an investigation is essential to determining the structural efficiency.

Results.

Phase 1: Economic Efficiency.

By using all Carbon Steel beams, the Howe Truss Bridge was able to support the live and dead loads while also being economically efficient. Out of the 37 members that made up the Howe Truss Bridge, 27 were hollow while only 10 were solid bars. By increasing the size of the hollow tubes, which are inherently less expensive than the bars, and only using steel bars where it was absolutely necessary, the Howe Truss Bridge designed was on cost-friendly and strong bridge. After being constantly analyzed and improved while also occasionally failing after it became too weak after different adjustments, the final Howe Truss Bridge successfully held both loads while only costing $222,757.74.

The Warren Truss Bridge was similarly created and analyzed to the Howe Truss. By constantly making changes to the design and placement of the members, the member size, and member type, the Warren Truss Bridge came out to be a very stable and efficient bridge. Each improvement in the design led to a more cost-effective bridge than the previous design while still effectively transporting the truck across the bridge. By using only Carbon Steel Bars and Hollow Tubes, the Warren Truss Bridge came out to a price of $225,595.93 and successfully held both

loads.

Phase 2: Structural Efficiency.

The Warren Truss Bridge and the Howe Truss Bridge were tested to catastrophic failure. Both sides of the bridges were built from 60 standard popsicle sticks and was held together by Elmer's glue. Hot glue was used for the struts/floor beams to connect the two adjacent truss sides. The dimensions for each bridge design is to be approximately 13.5 inches in length, 4 inches in height, and 4.5 inches in width.

Warren Truss Bridge: The Warren through bride weighed 83.4g including all the members and glue used. This bridge design held 90.8 lbs.

Howe Truss Bridge: The Howe bridge weighed 82.536g which included all the members and the glue used. This bridge was tested to failure and held 108.8 lbs.

Best Solution.

To clearly find the best solution, the economic efficiencies of each bridge determined from data used from EEBD 2015, and the structural efficiencies of both bridge types the were built and tested to catastrophic failure determined from data recorded in class are both highly considered in the process of determining PennDot's new bridge.

The Howe Truss Bridge is slightly yet clearly more economically efficient. Costing just under $3,000 less than the Warren Truss, the Howe Bridge successfully holds both live and dead loads. By being less expensive, albeit not by much, the Howe Truss Bridge is definitively more economically efficient. If the best solution was chosen based on economic efficiency, the Howe Bridge would be selected as the replacement for PennDot. However, the structural efficiency of both bridges needs to be taken highly into consideration when selecting the best solution.

Structural Efficiency is the determination of how much weight one bridge can support related to how much the bridge itself weighs. For the Howe Truss Bridge, it had a lower minimum (195), higher maximum (603), bigger range (408), and larger mean (353) than the Warren Truss Bridge for all Design Teams. This shows that the Howe Truss Bridge for each design team varies greater than the Warren Truss Bridge. However, based on the average, the Howe Truss Bridge is more structurally efficient than the Warren Truss Bridge.

Considering both the economic and structural efficiencies of the Howe and Warren Truss Bridges, the best solution is a Howe Truss Bridge. It will save the most money while also being the most efficient at holding the live and dead loads.

Conclusions and Recommendations.

PennDot, to solve its problem and help alleviate unnecessary stress on local drivers, should build a Howe Truss Bridge to replace its fallen bridge over Spring Creek. It clearly is the most cost-efficient and structural-efficient option. Therefore, PennDot needs to take the necessary steps to advance the project further and assure the completion and success of the project. The next step for PennDot is to review the design and prototype for any mistakes. Then,

they must make any improvements on the design or prototype to make sure the best possible bridge replaces the fallen one. From there, the project will go into the Final Design.

Respectfully,

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ATTACHMENT 1

Phase 1: Economic Efficiency

Howe Truss.

The Howe bridge had a total cost of $222,757.74. This total cost included: the material cost, connection cost, product cost, site cost, excavation cost, deck cost, and abutment cost. The entire Howe bridge was designed from carbon steel members with the majority of the Members being hollow tubes as compared to the solid bars. Carbon steel is the cheapest material out of them all which kept material cost lower, also the hollow tubes were cheaper than the solid bars. The total material cost is $116,357.74 of which the hollow tubes account for $91,298.03 of that cost.Although the hollow tubes account for much more of the material cost there still cheaper than if they were solid bars. This allowed the cost of the bridge to be drastically cut. All these members had to be connected together and that caused a cost of $20,000. Product cost was worth $9,000. Before the any of the steel members can be placed the site has to excavated to allow room for these members. This excavation had a total cost of $19,900. At the site there must be abutments placed to help support the bridge. These abutments cost a total of $10,500. To complete the bridge there has to be a deck spanning across it. The deck for this bridge cost $47,000. There were no cost for piers and anchorages. The carbon steel member 14 had the highest compression force/strength ratio

14	CS	Hollow Tube	240x240x12	4.12	2217.76	2221.46	OK	0	2599.2	OK

out of any other steel member in the bridge.

Warren Truss.

The Warren Truss bridge had a total cost of $225,595.93. This total cost included: the material cost, connection cost, product cost, site cost, excavation cost, deck cost, and abutment cost. The entire Warren Truss bridge was designed from carbon steel members. Carbon steel is the cheapest material out of all possible choices which kept material cost low. Along with the solid bars used, the bridge also included hollow tubes to maintain a cheaper cost. The total material cost is $111,195.93 of which the hollow tubes account for $34,633.12 of that cost. All these members had to be connected together and that caused a cost of $21,000. Product cost was worth $13,000. Before the any of the steel members can be placed the site has to excavated to allow room for these members. This excavation had a total cost of $19,900. At the site there must be abutments placed to help support the bridge. These abutments cost a total of $10,500. To complete the bridge there has to be a deck spanning across it. The deck for this bridge cost $47,000. There were no cost for piers and anchorages. The carbon steel member 37 had the highest

37	CS	Solid Bar	90x90	4	0	534.22	OK	1864.39	1923.75	OK

Tension force/strength ratio out of any other steel member in the bridge.

ATTACHMENT 2

Phase 2: Structural Efficiency

Howe Truss.

The Howe truss bridge prototype designed held the most weight of 108.8 pounds over the other prototypes and therefore was very structurally efficient. The value for structural efficiency of the Howe truss was 603, the higher the number the more structurally efficient the bridge is. The lowest structural efficiency number for the Howe truss bridges was 195 which was relatively low compared to the other values. Typically if a bridge is light and can hold the most weight it should generally be structurally efficient. There was a .3 load weight difference between two bridges that should hardly affect the structural efficiency of the bridge, but since one bridge was lighter than the other the SE number was 205 compared to the heavier bridge at 105. In order to have a successful bridge it must hold a significant live load and be cheap to build.

Prototype Bridge.

Initially a top and bottom of one side of the bridge was designed to use the least amount of popsicle sticks but to have a structurally sound design. The popsicle stick concentration was heavier towards the middle of the top and bottom of the bridge because it was known that most of the load would be on the center. All 60 popsicle sticks were used in the Howe truss bridge design and 4 were cut at the end to provide reinforcement. To glue the bridge together, it was essential to smooth out the glue with a q-tip so it would dry quicker and be lighter. The design of the bridge prototype had the verticals of the truss glued on one side of the bridge and the diagonals on the opposite to distribute the load weight evenly. Attention was paid to critical members and joint and were reinforced accordingly to provide the most structurally efficient design.

Load Testing.

The average structural efficiency number for the Howe truss bridges was approximately 318, our design team built a bridge prototype with a structural efficiency number of 603. The SE number of 603 was an outlier in the set of data received for the structural efficiency of each design team. 603 deviates from the average SE number. The lowest SE number was 195 while 603 was the highest. Relatively the low of 195 was not an outlier because the second lowest was 205. Generally if a bridge had a relatively high load weight and it was light than its SE number was average. The range of the SE number was 408 which can be considered a large range for popsicle stick bridges that were constructed from the same materials. Since each bridge was built from the same raw materials, it is evident that the design of the bridge was principal, not considering any major defects in individual bridges.

Forensic Analysis.

The Howe Truss Bridge failed after it supported 108.8 pounds. The top and bottom of both sides of the bridge remained strong throughout. But when the bridge failed, it failed because a popsicle stick that was being used as diagonal snapped and flew out off of the bridge. This then immediately let the bridge to collapse. Since this member was no longer able to support the necessary weight, the Howe Truss Bridge crumbled. After reviewing a slow motion video as the bridge collapsed, this was proven to be true. The diagonal snapped and exploded off the bridge. Then immediately, the bridge caved in where that diagonal was. However, it was clear in the video that the diagonal member broke not at the joint but rather

fractured near the middle of the popsicle stick. This means that the joint and glue held steady but the weight was too much for the flimsy popsicle stick.

Results. The result from the load testing of the Howe truss bridge was successful with a maximum weight of 108.8 pounds held, the highest amongst the other bridge prototypes. From the load testing, structurally efficiency of the bridge could be calculated using the load weight and the weight of the bridge, which gave a SE number of 603, also the highest amongst the other bridge prototypes. The bridge was the most structurally efficient compared to the rest of the Howe truss bridges.

Warren Truss.

In the Warren truss bridge category, the bridge prototype designed by our design team held 90.8 pounds, the most weight held by a Warren truss prototype compared to the other bridges. The bridge resulted in having a structural efficiency number of 494, the highest value, which could be considered an outlier compared to the other values. The attention to design of the bridge ultimately contributed to the high value of structural efficiency of the bridge. The lowest structural efficiency number for the Howe truss bridges was 203 which was relatively average compared to the other values. Typically if a bridge is light and can hold the most weight it should generally be structurally efficient.

Prototype Bridge.

The Warren truss bridge design is composed of strictly triangles and no verticals. The prototype designed included a total of 7 triangles which was typically the max for the span of the bridge. The top and bottom of the bridge were carefully designed similarly to the Howe with more popsicle stick concentration towards the center because tha primarily where the load would be. When connecting the members to form the triangles, generally they were on the same side with only a few on the opposite side to distribute the weight. Member were also cut to fit properly on the bridge. Attention was also paid to critical joints and members. The same method of gluing was used with a q-tip to minimize weight and maximize drying. All 60 popsicle sticks were utilized in the bridge to maximize strength. Also a new method was introduced in this bridge and not in the Howe, sanding. members were sanded to increase the glue strength between popsicle sticks as it would increase the likelihood that the glue would bond with the wood.

Load Testing.

The average structural efficiency number for the Warren truss bridges was approximately 306, our design team built a bridge prototype with a structural efficiency number of 494. The SE number of 494 could potentially be considered an outlier in the set of data received for the structural efficiency of each design team. The lowest SE number was 203 while 494 was the highest. Relatively the low of 203 was not an outlier because the second lowest was 208. Generally if a bridge had a relatively high load weight and it was light than its SE number was average. The range of the SE number was 291 which can be considered an average range for popsicle stick bridges that were constructed from the same materials. Compared to the Howe truss bridge range of 408, the range of the Warren truss bridges were much more average because it didn’t have a significant outlier.

Forensic Analysis.

The Warren Truss bridge was able to hold 90.8lbs before failure. Due to the high amount stress being put onto the bridge by the weights, a diagonal member (popsicle stick 27) fractured off the structure, which

caused the collapse of the bridge. The glue for this member was secure and did not fail. Once this popsicle stick broke, it caused other supports at the end of the bridge to fail as well. These factors all help lead to the complete collapse of the Warren Truss bridge. To improve this Warren Truss design, there would need to be additional bracing placed at the point of failure (popsicle stick 27) and at the ends of the bridge.

Results.

The result from the load testing of the Warren truss bridge was successful with a maximum weight of 90.8 pounds held, the highest amongst the other Warren truss bridge prototypes. From the load testing, structurally efficiency of the bridge could be calculated using the load weight and the weight of the bridge, which gave a SE number of 494, also the highest amongst the other bridge prototypes. The bridge was the most structurally efficient compared to the rest of the Warren truss bridges.

TABLES

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

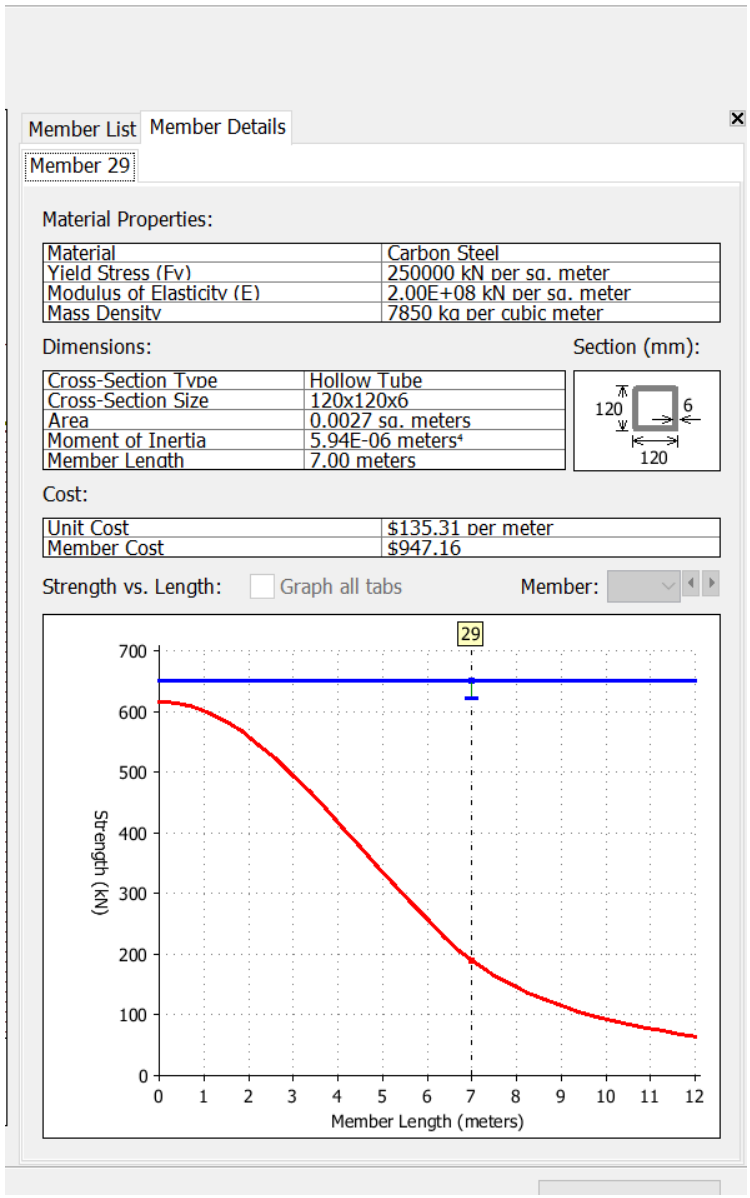
Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(2913.9 kg) x ($4.30 per kg) x (2 Trusses)	$25,059.71
	Carbon Steel Hollow Tube	(7245.9 kg) x ($6.30 per kg) x (2 Trusses)	$91,298.03
Connection Cost (C)		(20 Joints) x (500.0 per joint) x (2 Trusses)	$20,000.00
Product Cost (P)	8 - 100x100 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	2 - 80x80 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	2 - 110x110x5 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	7 - 120x120x6 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	3 - 160x160x8 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	3 - 170x170x8 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	9 - 240x240x12 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	2 - 200x200x10 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	1 - 260x260x13 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	
Total Cost	**M + C + P + S**	**$116,357.74 + $20,000.00 + $9,000.00 + $77,400.00**	**$222,757.74**

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

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	80x80	4	0	333.51	OK	1404.3	1520	OK
2	CS	Solid Bar	100x100	4	0	814.24	OK	1994.97	2375	OK
3	CS	Solid Bar	100x100	4	0	814.24	OK	2179.37	2375	OK
4	CS	Solid Bar	100x100	4	0	814.24	OK	2131.74	2375	OK
5	CS	Solid Bar	100x100	4	0	814.24	OK	2215.71	2375	OK
6	CS	Solid Bar	100x100	4	0	814.24	OK	2215.71	2375	OK
7	CS	Solid Bar	100x100	4	0	814.24	OK	2119.7	2375	OK
8	CS	Solid Bar	100x100	4	0	814.24	OK	2151.54	2375	OK
9	CS	Solid Bar	100x100	4	0	814.24	OK	1945.37	2375	OK
10	CS	Solid Bar	80x80	4	0	333.51	OK	1372.08	1520	OK
11	CS	Hollow Tube	240x240x12	4.24	1940.42	2208.04	OK	0	2599.2	OK
12	CS	Hollow Tube	240x240x12	5.39	1736.57	2065.71	OK	0	2599.2	OK
13	CS	Hollow Tube	240x240x12	4.12	2005.25	2221.46	OK	0	2599.2	OK
14	CS	Hollow Tube	240x240x12	4.12	2217.76	2221.46	OK	0	2599.2	OK
15	CS	Hollow Tube	240x240x12	4	2119.7	2234.95	OK	0	2599.2	OK
16	CS	Hollow Tube	240x240x12	4	2131.74	2234.95	OK	0	2599.2	OK
17	CS	Hollow Tube	260x260x13	4.12	2246.44	2647.14	OK	0	3050.45	OK
18	CS	Hollow Tube	240x240x12	4.12	2056.3	2221.46	OK	0	2599.2	OK

					6					
19	CS	Hollow Tube	240x240x12	5.39	1777.38	2065.71	OK	0	2599.2	OK
20	CS	Hollow Tube	240x240x12	4.24	1985.98	2208.04	OK	0	2599.2	OK
21	CS	Hollow Tube	170x170x8	3.16	0	1034.48	OK	777.78	1231.2	OK
22	CS	Hollow Tube	200x200x10	6.4	650.43	1195.87	OK	0	1805	OK
23	CS	Hollow Tube	120x120x6	5	0	335.92	OK	635.97	649.8	OK
24	CS	Hollow Tube	170x170x8	7.21	483.49	624.88	OK	0	1231.2	OK
25	CS	Hollow Tube	110x110x5	6	0	167.95	OK	327.54	498.75	OK
26	CS	Hollow Tube	120x120x6	8.06	115.11	142.93	OK	346.86	649.8	OK
27	CS	Hollow Tube	120x120x6	7	0	189.6	OK	611.44	649.8	OK
28	CS	Hollow Tube	160x160x8	8.06	410.51	451.28	OK	72.02	1155.2	OK
29	CS	Hollow Tube	120x120x6	7	0	189.6	OK	621.88	649.8	OK
30	CS	Hollow Tube	160x160x8	8.06	374.46	451.28	OK	108.06	1155.2	OK
31	CS	Hollow Tube	120x120x6	7	0	189.6	OK	580.14	649.8	OK
32	CS	Hollow Tube	120x120x6	8.06	97.11	142.93	OK	426.08	649.8	OK
33	CS	Hollow Tube	110x110x5	6	55.06	167.95	OK	311.91	498.75	OK
34	CS	Hollow Tube	170x170x8	7.21	460.35	624.88	OK	68.9	1231.2	OK
35	CS	Hollow Tube	120x120x6	5	0	335.92	OK	616.72	649.8	OK
36	CS	Hollow Tube	200x200x10	6.4	628.71	1195.87	OK	0	1805	OK
37	CS	Hollow Tube	160x160x8	3.16	0	954.96	OK	759.85	1155.2	OK

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



Member List | Member Details

Member 29

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	120x120x6
Area	0.0027 sq. meters
Moment of Inertia	5.94E-06 meters⁴
Member Length	7.00 meters

Section (mm):

Cost:

Unit Cost	$135.31 per meter
Member Cost	$947.16

Strength vs. Length: Graph all tabs Member:

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

Type of Cost	Item	Cost Calculation	Cost
Material Cost (M)	Carbon Steel Solid Bar	(9251.5 kg) x ($4.30 per kg) x (2 Trusses)	$79,562.81
	Carbon Steel Hollow Tube	(2748.7 kg) x ($6.30 per kg) x (2 Trusses)	$34,633.12
Connection Cost (C)		(21 Joints) x (500.0 per joint) x (2 Trusses)	$21,000.00
Product Cost (P)	2 - 70x70 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	4 - 80x80 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	2 - 90x90 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	6 - 90x90x4 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	4 - 100x100 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	4 - 100x100x5 mm Carbon Steel Tube	(%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
	4 - 130x130 mm Carbon Steel Bar	(%s per Product)	$1,000.00
	2 - 130x130x6 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	5 - 140x140 mm Carbon Steel Bar	(%s per Product)	$1,000.00

	2 - 150x150x7 mm Carbon Steel Tube	(%s per Product)	$1,000.00
	2 - 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	
Total Cost	**M + C + P + S**	**$114,195.93 + $21,000.00 + $13,000.00 + $77,400.00**	**$225,595.93**

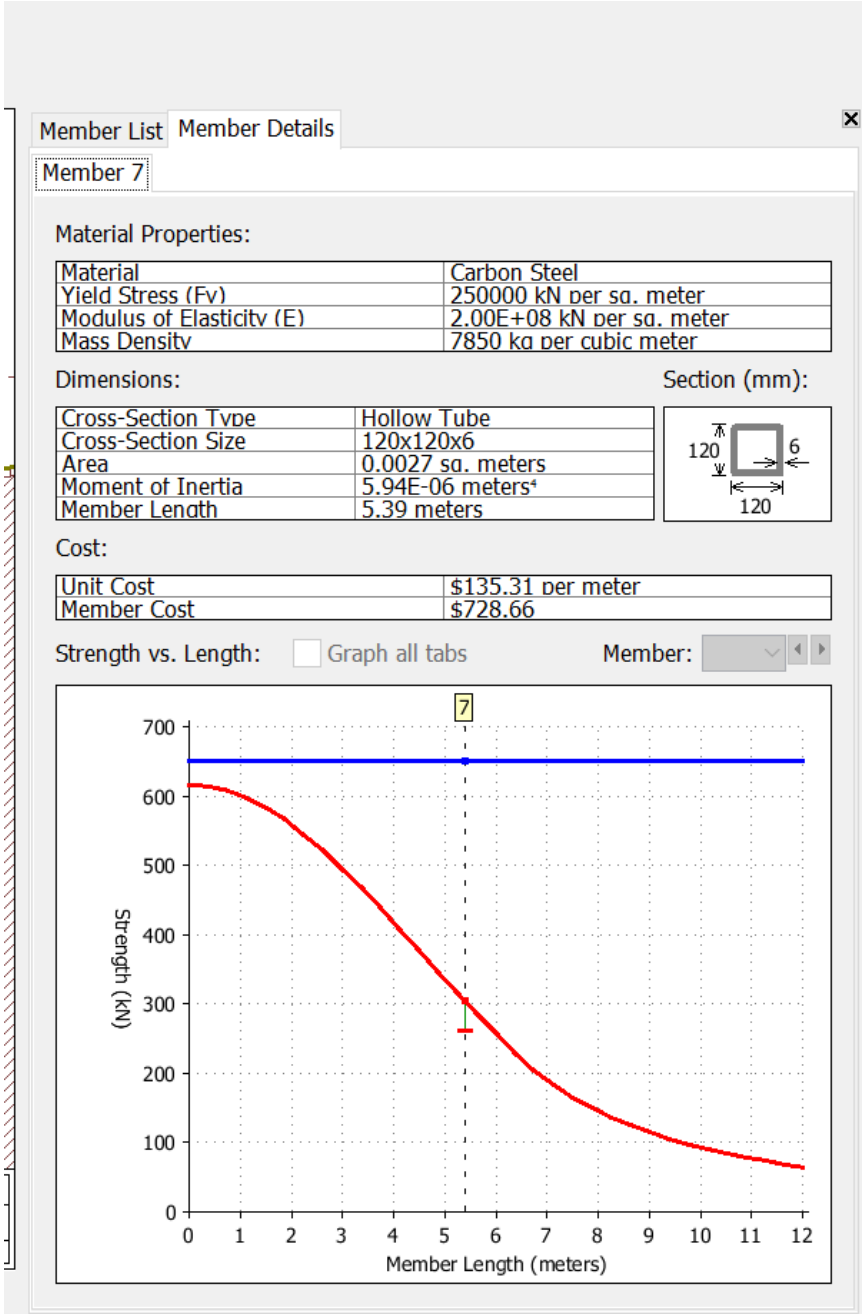
Table 5
Warren Truss Bridge
Load Test Results Report from Bridge Designer 2015

#	Material Type	Cross Section	Size (mm)	Length (m)	Compression Force	Compression Strength	Compression Status	Tension Force	Tension Strength	Tension Status
1	CS	Solid Bar	150x150	4.47	1643.71	2887.87	OK	0	5343.75	OK
2	CS	Solid Bar	150x150	4.47	1606.21	2887.87	OK	0	5343.75	OK
3	CS	Solid Bar	100x100	4.47	0	651.39	OK	790.49	2375	OK
4	CS	Hollow Tube	120x120x6	5.39	261.18	304.89	OK	0	649.8	OK
5	CS	Solid Bar	120x120	6.32	338.03	675.37	OK	34.91	3420	OK
6	CS	Solid Bar	120x120	6.32	322	675.37	OK	84.55	3420	OK
7	CS	Hollow Tube	120x120x6	5.39	260.96	304.89	OK	0	649.8	OK
8	CS	Solid Bar	100x100	4.47	0	651.39	OK	774.7	2375	OK
9	CS	Solid Bar	140x140	4.12	1785.4	2550.11	OK	0	4655	OK
10	CS	Solid Bar	140x140	4.12	2031.93	2550.11	OK	0	4655	OK
11	CS	Solid Bar	140x140	4.12	2200.47	2550.11	OK	0	4655	OK
12	CS	Solid Bar	140x140	4.12	2150.75	2550.11	OK	0	4655	OK
13	CS	Solid Bar	140x140	4	2032.25	2633.62	OK	0	4655	OK
14	CS	Solid Bar	140x140	4.12	2137.94	2550.11	OK	0	4655	OK

15	CS	Solid Bar	140x140	4.12	2144.86	2550.11	OK	0	4655	OK
16	CS	Solid Bar	140x140	4.12	1999.77	2550.11	OK	0	4655	OK
17	CS	Solid Bar	140x140	4.12	1766.93	2550.11	OK	0	4655	OK
18	CS	Solid Bar	75x75	4	0	257.63	OK	735.09	1335.94	OK
19	CS	Solid Bar	90x90	4	0	534.22	OK	1122.36	1923.75	OK
20	CS	Solid Bar	90x90	4	0	534.22	OK	718.32	1923.75	OK
21	CS	Solid Bar	90x90	7.21	0	164.38	OK	970.22	1923.75	OK
22	CS	Hollow Tube	110x110x5	7.81	0	99.12	OK	206.91	498.75	OK
23	CS	Solid Bar	100x100	8.49	64.24	180.94	OK	205.27	2375	OK
24	CS	Solid Bar	90x90	7.21	0	164.38	OK	913.47	1923.75	OK
25	CS	Hollow Tube	110x110x5	7.81	0	99.12	OK	200.37	498.75	OK
26	CS	Hollow Tube	100x100x5	8.49	26.66	62.23	OK	79.16	451.25	OK
27	CS	Solid Bar	110x110	8.25	0	280.5	OK	560.17	2873.75	OK
28	CS	Hollow Tube	110x110x5	8.25	66.39	88.92	OK	365.46	498.75	OK
29	CS	Solid Bar	110x110	8.25	98.55	280.5	OK	333.29	2873.75	OK
30	CS	Solid Bar	110x110	8.25	0	280.5	OK	613.82	2873.75	OK
31	CS	Hollow Tube	75x75x3	5.39	0.99	40.31	OK	61.19	205.2	OK
32	CS	Solid Bar	75x75	6.32	0	103.05	OK	213.23	1335.94	OK

33	CS	Hollow Tube	75x75x3	5.39	10.27	40.31	OK	52.45	205.2	OK
34	CS	Solid Bar	75x75	6.32	64.01	103.05	OK	195.35	1335.94	OK
35	CS	Solid Bar	90x90	4	0	534.22	OK	1864.05	1923.75	OK
36	CS	Solid Bar	90x90	4	0	534.22	OK	1067.64	1923.75	OK
37	CS	Solid Bar	90x90	4	0	534.22	OK	1864.39	1923.75	OK
38	CS	Solid Bar	110x110	4	0	1181.16	OK	2006.58	2873.75	OK
39	CS	Solid Bar	110x110	4	0	1181.16	OK	1956.13	2873.75	OK
40	CS	Solid Bar	110x110	4	0	1181.16	OK	1963.93	2873.75	OK
41	CS	Solid Bar	110x110	4	0	1181.16	OK	2027.32	2873.75	OK
42	CS	Solid Bar	110x110	7.28	0	359.89	OK	305.2	2873.75	OK
43	CS	Solid Bar	110x110	7.28	281.55	359.89	OK	0	2873.75	OK
44	CS	Solid Bar	110x110	7.28	303.69	359.89	OK	47.02	2873.75	OK
45	CS	Solid Bar	110x110	7.28	73.92	359.89	OK	330.75	2873.75	OK

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



Member List | Member Details

Member 7

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	120x120x6
Area	0.0027 sq. meters
Moment of Inertia	5.94E-06 meters⁴
Member Length	5.39 meters

Section (mm):

Cost:

Unit Cost	$135.31 per meter
Member Cost	$728.66

Strength vs. Length: Graph all tabs Member:

Table 7
Howe Truss Bridge
Load Testing Results

Design Team #	Howe Truss Bridge Weight (grams)	Bridge Weight (lbs.)	Load at Failure (lbs.)	Structural Efficiency
1	84.5	0.1863	49.4	265
2	75.3	0.1660	34.0	205
3	81.8	0.1803	108.8	603
4	78.1	0.1722	77.9	452
5	81.4	0.1795	58.3	325
6	85.2	0.1878	72.1	384
7	79.7	0.1757	34.3	195
8	80.0	0.1764	70.0	397

Minimum: 195
Maximum: 603
Range: 408
Mean: 353

Table 8
Warren Truss Bridge
Load Testing Results

Design Team #	Warren Truss Bridge Weight (grams)	Bridge Weight (lbs.)	Load at Failure (lbs.)	Structural Efficiency
1	85.2	0.1878	39.0	208
2	80.3	0.1770	55.1	311
3	83.4	0.1839	90.8	494
4	73.2	0.1614	32.7	203
5	85.3	0.1881	60.8	323
6	83.8	0.1847	70.4	381
7	75.5	0.1664	55.6	334
8	81.9	0.1806	68.4	379

Minimum: 203
Maximum: 494
Range: 291
Mean: 329

FIGURES

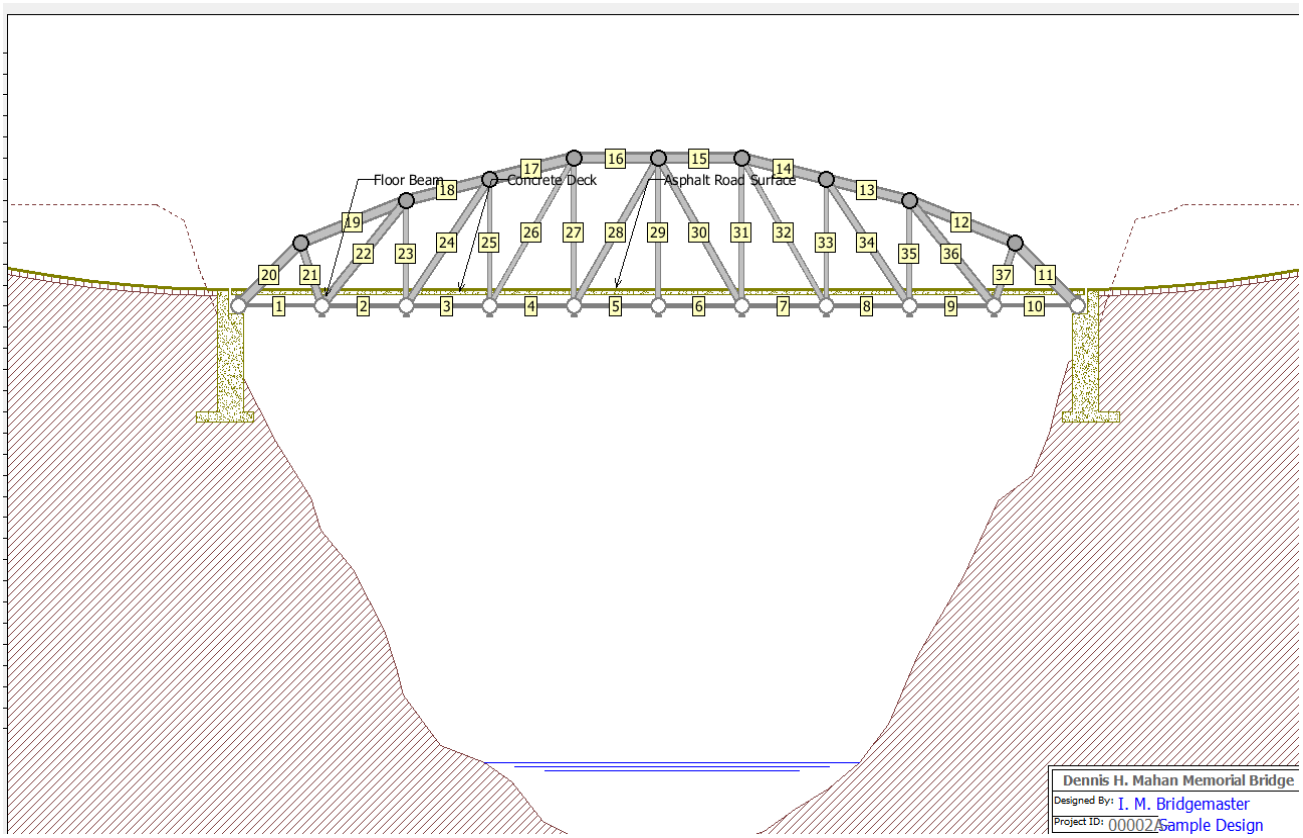


Figure 1. Howe Truss Bridge Model from Bridge Designer 2015

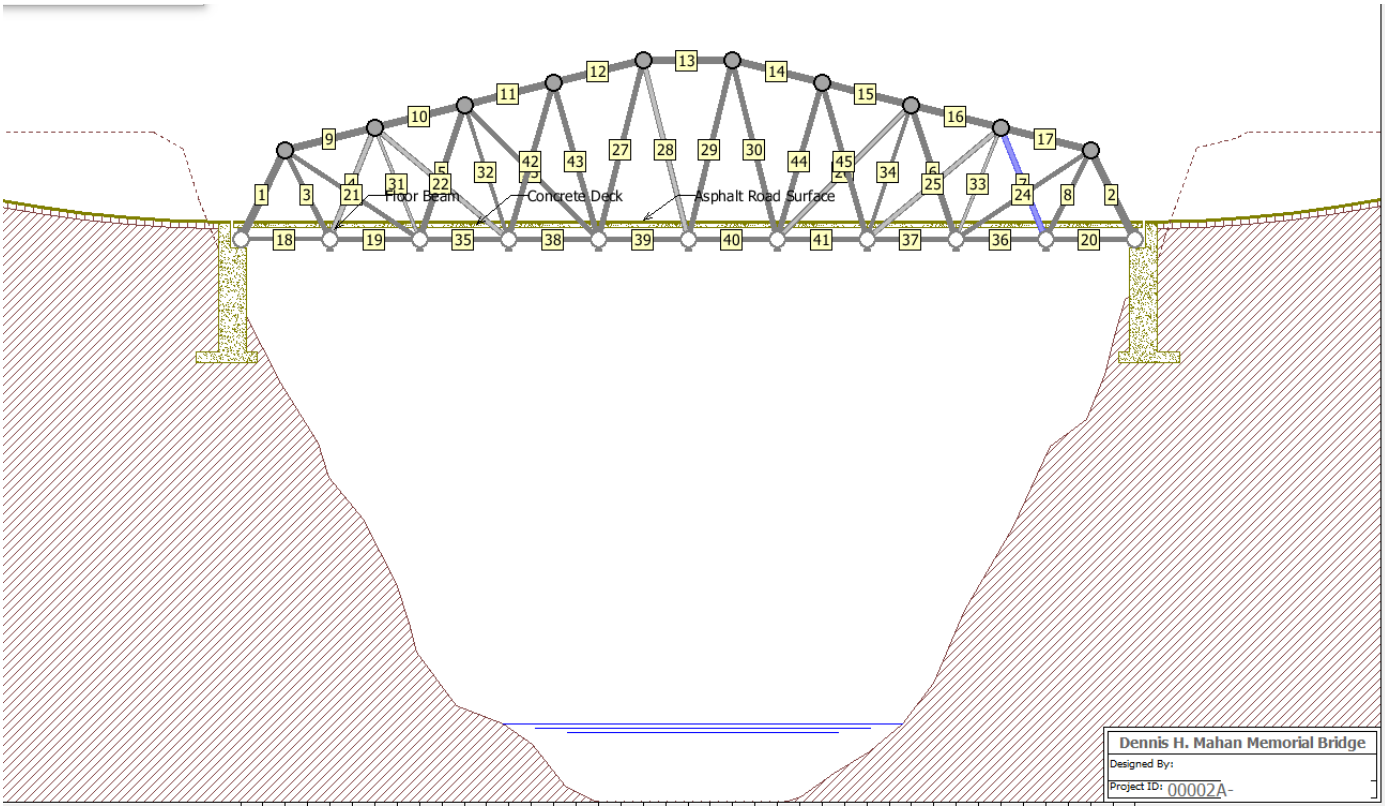


Figure 2. Warren Truss Bridge Model from Bridge Designer 2015

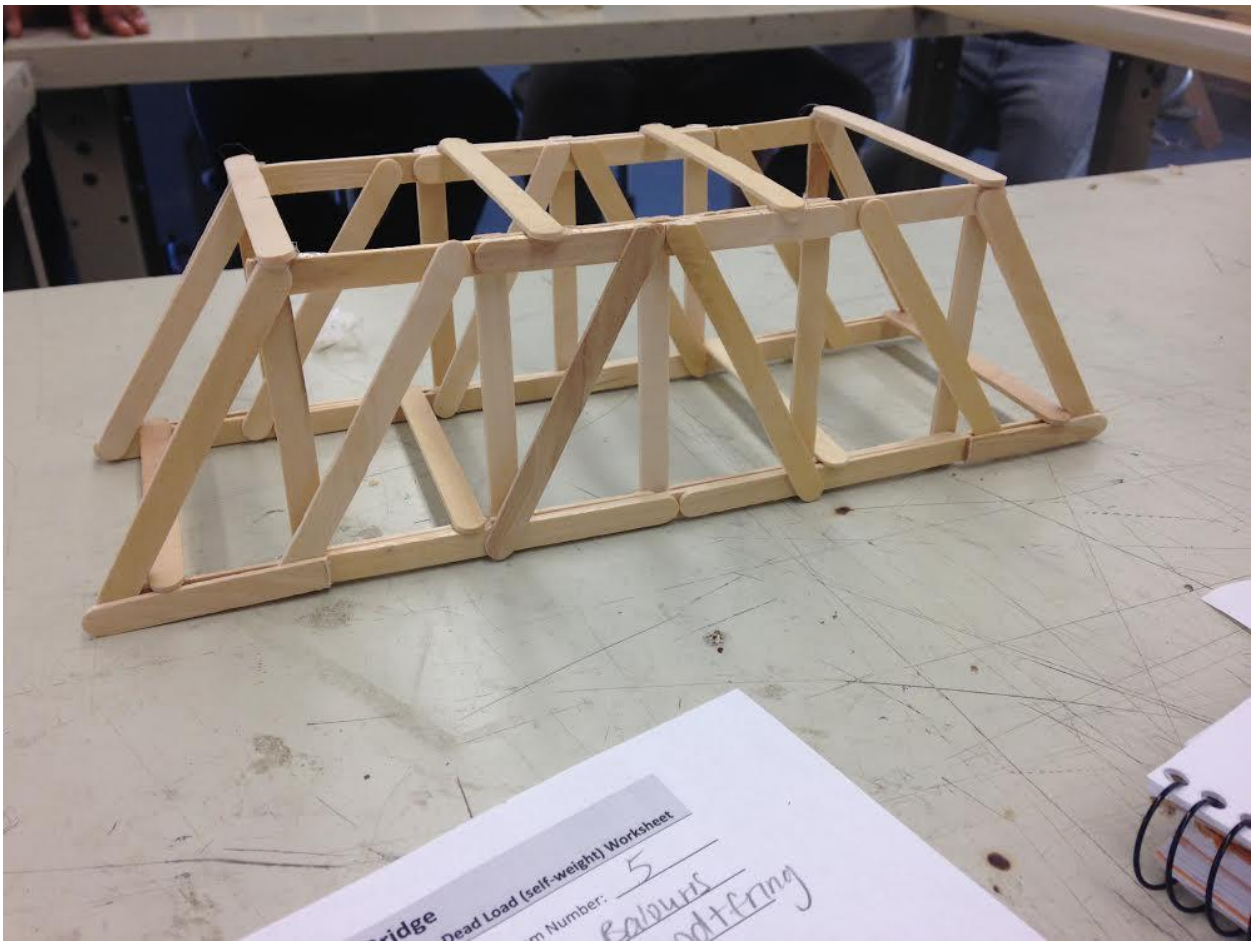


Figure 3. Howe Truss Bridge Prototype before Load Testing

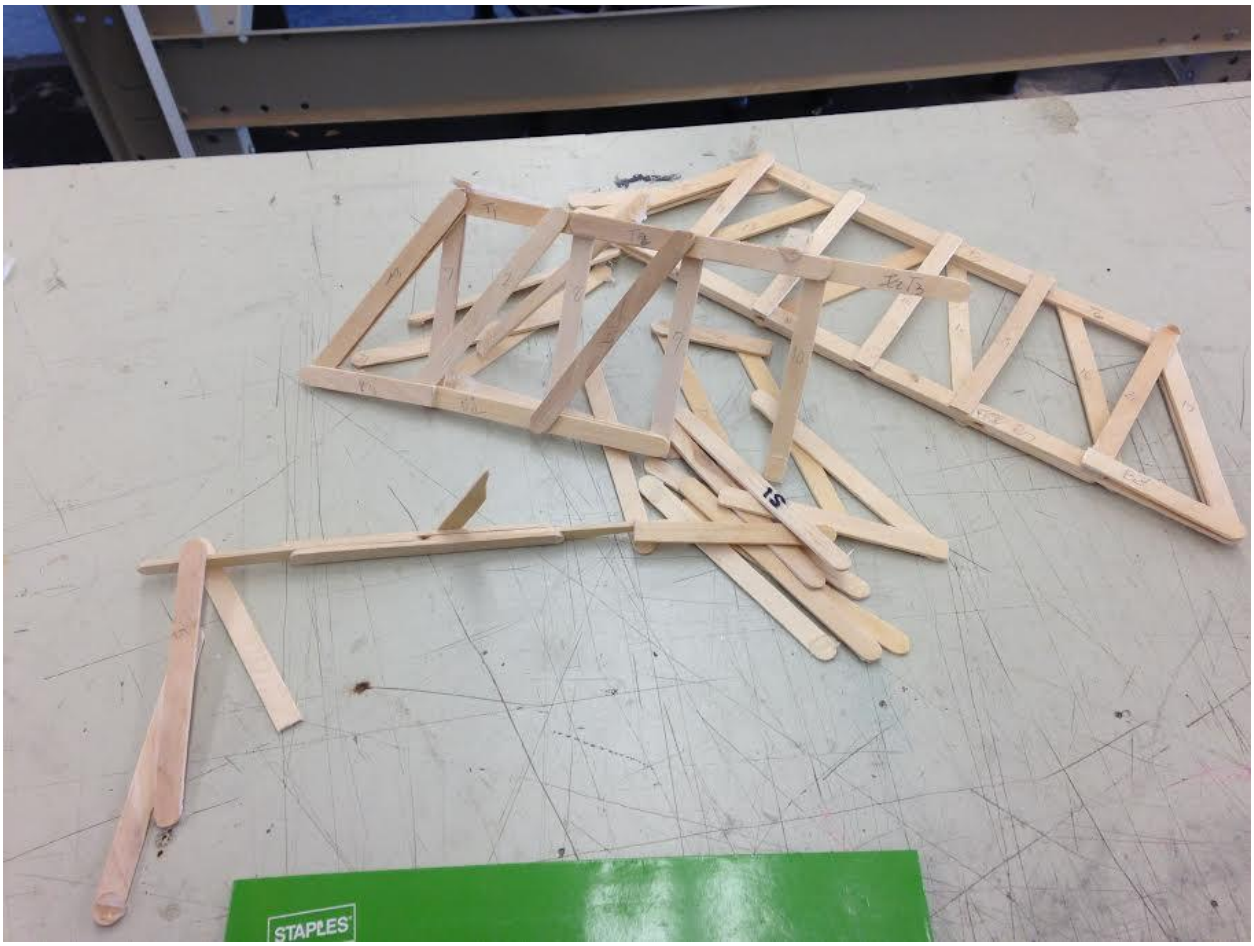


Figure 4. Howe Truss Bridge Prototype Failure after Load Testing

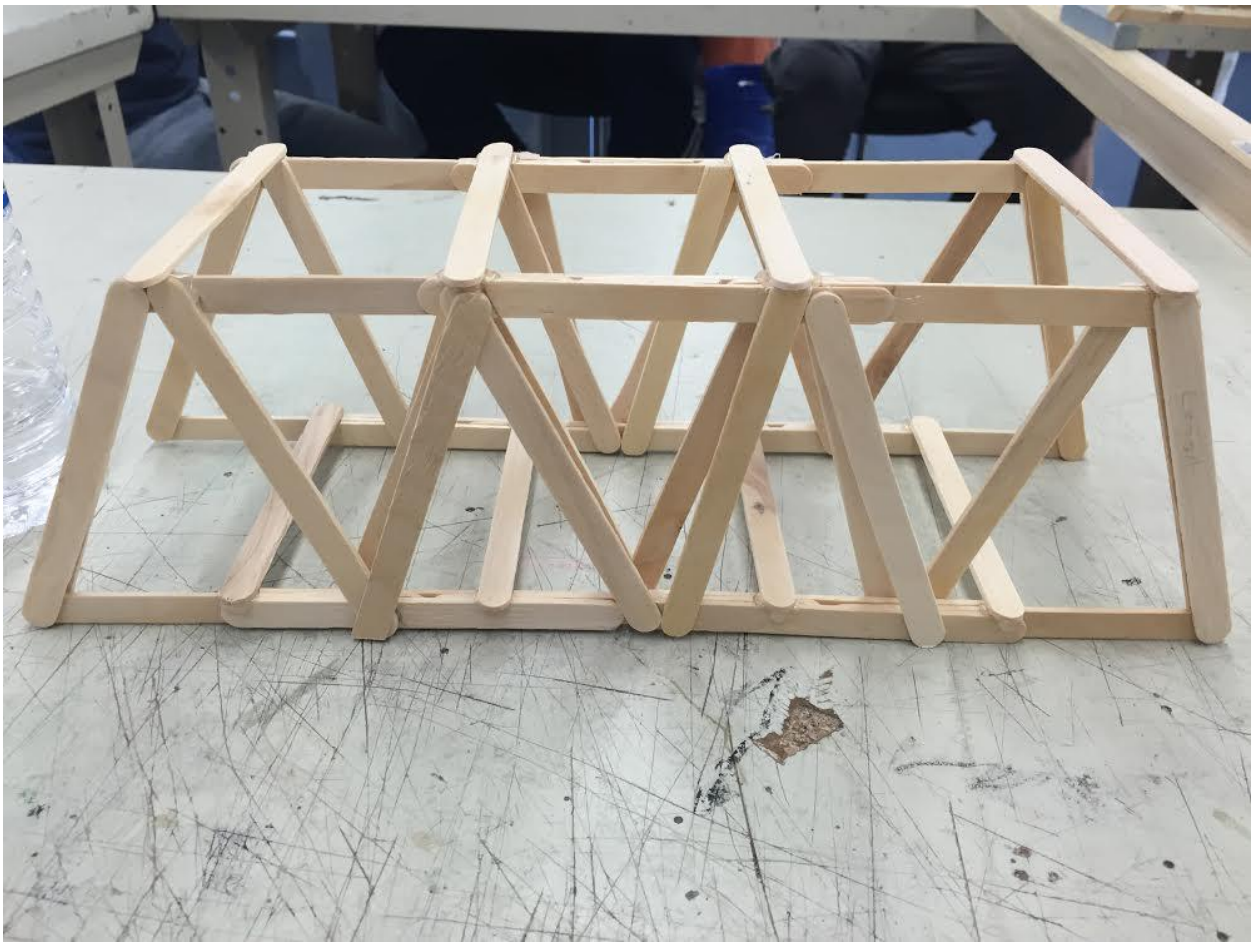


Figure 5. Warren Truss Bridge Prototype before Load Testing

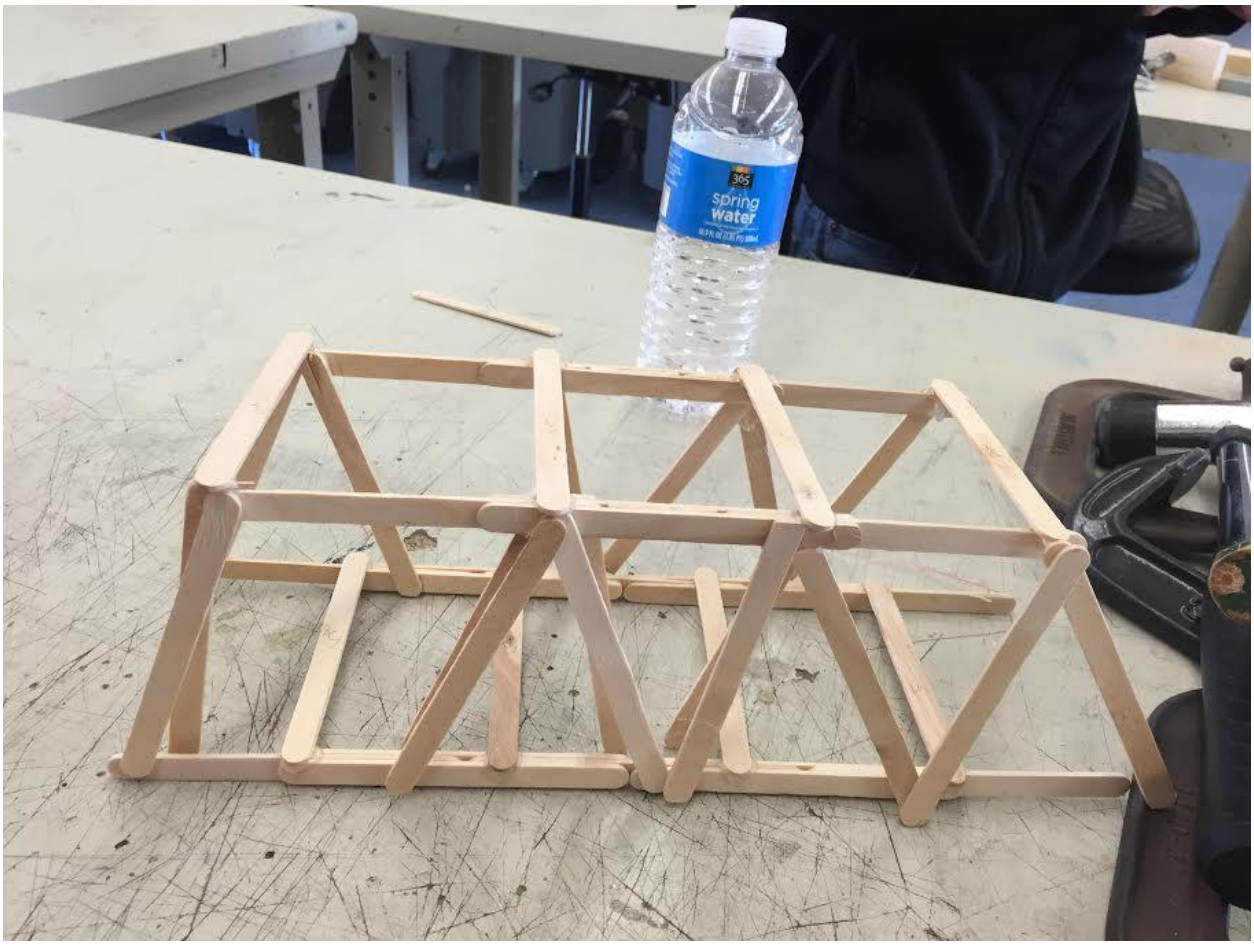


Figure 6. Warren Truss Bridge Prototype Failure after Load Testing

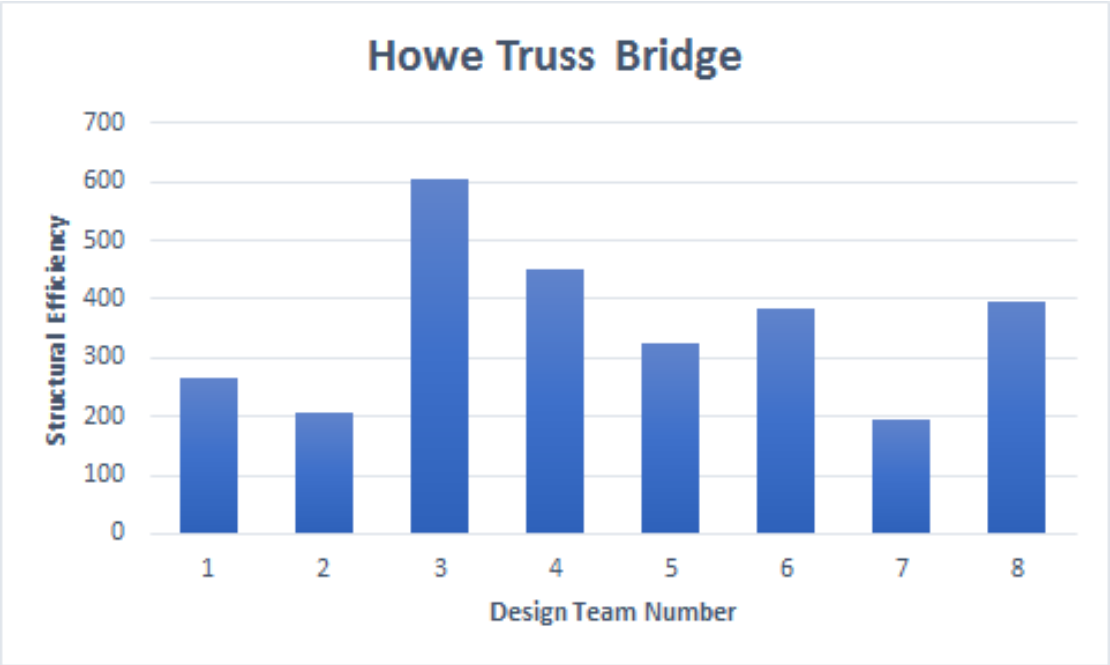


Figure 7. Howe Truss Bridge Structural Efficiencies

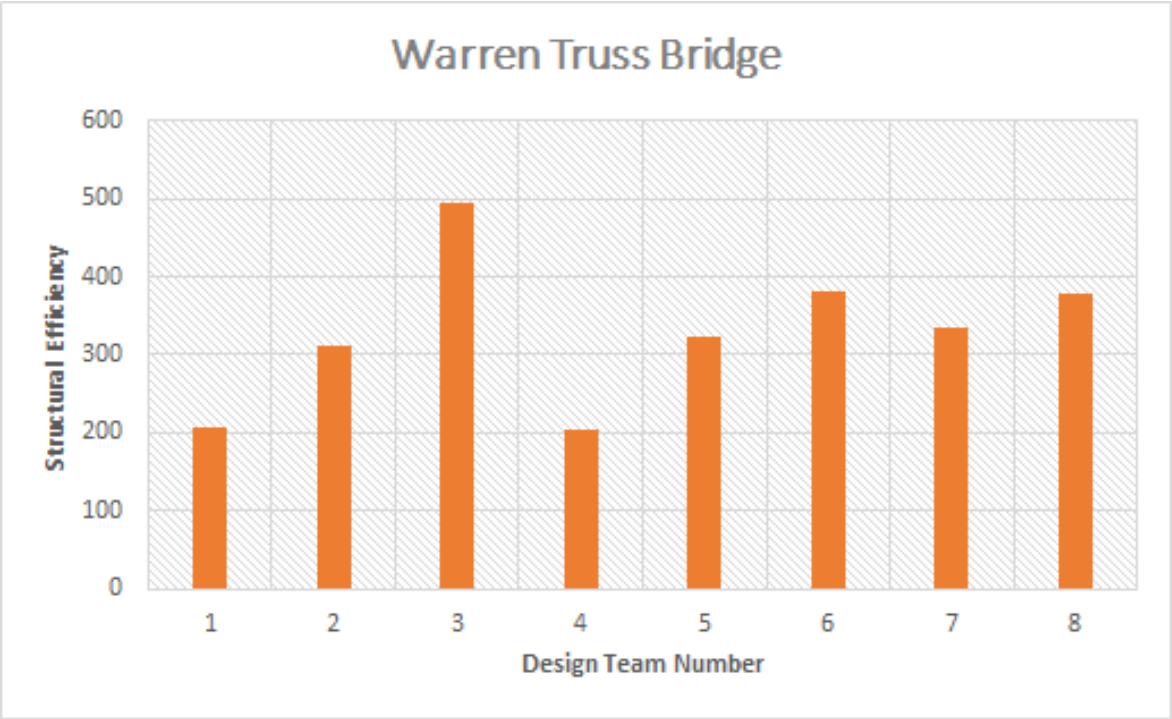


Figure 8. Warren Truss Bridge Structural Efficiencies